Adam M. Stuart

CCD Astrophotography

High-Quality Imaging from the Suburbs

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Adam M. Stuart, M.D.

With 201 figures, 142 in full color.

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Adam M. Stuart, M.D.
Physician Offices of Florida City
Florida City, Florida
amstuart@bellsouth.net

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My intellectual *past* was shaped by two visionary and brilliant giants of the twentieth century, the late Dr. Carl Sagan and Sir Arthur C. Clarke, who were instrumental in kindling a life-long interest in science and cultivating an appreciation for the greatest science fiction writing of all time. My greatest love, my children Lauren and Rachel, are my ambassadors to the *future* and are destined to be stellar in whatever they do.

Technical Innovations 6-ft (1.8-m) Home-Dome. Looking southwest in author's backyard. Royal Palm trees further west impede the view for the first 35° in altitude.

Preface

When I was a little boy I wanted to be an astronaut or a dinosaur hunter. I was 5 or 6 years old when I received my first telescope in the late 1960s, a 60-mm (2.4-in.) Tasco refractor. This white-and-black metal tube put me on a course to develop a life-long interest in astronomy, and science in general. I never became an astronaut (or a dinosaur hunter for that matter!), but I promised myself many years ago that when I got older and could afford some decent equipment, I would buy a telescope to rival that first 60-mm (2.4-in.) refractor.

Three short years ago I purchased a Meade 10-in. (25-cm) LX200 Schmidt-Cassegrain telescope. The Meade Telescope catalog had gorgeous images obtained with this telescope and a special camera: I had never heard of a CCD imager (charged-coupled device), but I knew I had to have one. A computerized GO TO telescope is not necessarily the suggested first "real" telescope to own, but I had my sights set on imaging and enough people in this wonderful hobby confided that Meade's was an adequate platform from which to image.

Did I mention that I live in Miami, Florida? Over the last 2 years, trading stories on the Internet, seeking advice and answers to my never-ending questions, I have learned that there is special recognition for those who image under the light-polluted skies of the world. Miami, like London, is right up there with some of the toughest skies under which to image. On the Bortle Scale, my imaging site rates an 8–9 on most nights (limiting magnitude 3 or 4: "most people don't look up"). Skyglow makes it difficult to collect data that are mired in the muck: Expose for too long and many astronomical targets of interest are barely discernible above the background "noise"; expose for too short an integration and the target of interest cannot register enough photons to adequately produce an image. My typical sky glows a hazy orange, extending a full 60° or more in some directions above my local horizon.

After a few weeks, the weight of my telescope and set up/break down time became a burden: I was at risk for joining the club of newcomers to this hobby who use their big, expensive telescopes as a living room ornament or as a hat rack after being in the field a few times with their equipment. A permanent set up in a fiberglass dome would be perfect! I dug a hole to China, bolted a steel pier to an isolated concrete pad, and assembled a fiberglass observatory on a concrete foundation to enclose everything. The purchase of my first CCD camera was my final ticket to entering the world of CCD astrophotography. Wiring the dome, a computer and the telescope for control from my house was a dream realized for a man whose first gaze upon our wonderful universe was through 60-mm (2.4-in.) of aperture, many moons ago. OakRidge Observatory saw first light September 1, 2002.

This book is a synopsis of my experiences, from the planning stages of building an observatory and making a laundry list of equipment and accessories, to finally obtaining and processing the various images contained in this book. I am humbled when I see the outstanding images obtained by my colleagues, many with less expensive equipment and portable set ups. Many readers of popular magazines such as *Sky & Telescope* and *Astronomy* might be left with the impression that high-quality images require a large telescope and dark skies. Not true! My determination in obtaining astrophotos under difficult imaging sky conditions has rewarded me with more than a degree of self-satisfaction. All those photons, teeming across space at mind-boggling speed for unimaginable eons, only to find my detector positioned just right to record the event. Few imagers have not heard people comment "Why take these photos of outer space? I can go online and find any picture I want!" This book cannot answer that question, but for those of us who have spent countless hours "doing what we love in the dark," each of us has a very personal reason for taking these images.

The inclusion of a few photos in both *Astronomy* and *Sky & Telescope* in 2004, as well as an invitation to submit two of my astrophotos to forthcoming astronomy publications, is flattering. Most recently, in September 2004 I was chosen as a Featured Observer in the ongoing Amateur Astronomy program at the Smithsonian National Air and Space Museum.

There are many people I need to thank. The many friendships that have been cultivated on the various Internet groups are a big part of the enjoyment that is derived from this hobby. The many brains that I have picked are numerous: There are some very knowledgeable, dedicated, and talented astroimagers out there, setting the bar higher and higher. I want to thank the publishers Harry Blom, Christopher Coughlin, and John Watson for their insightful discussions during manuscript preparation, as well as Lesley Poliner, Senior Production Editor at Springer.

Finally, my warmest appreciation goes to my wife Debi and daughters Lauren and Rachel: many, many nights have I said "I'm going into the dome," and what I got in return were smiles of encouragement. "Priceless."

Adam M. Stuart, M.D.
Miami, Florida
October 2004

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Introduction

Another CCD (charge-coupled device) imaging book? Bear with me as I explain why I think there will be support for yet another book on this topic. I have not seen a CCD imaging book written for beginners, by a beginner, documenting what can be captured under challenging skies. I own many books written by authoritative imagers, most all of which contain stunning photos taken under near-perfect conditions. If you are a beginner like me, you might be inspired and will strive to become better, or be intimidated and pursue another interest. I thought it would be instructive to publish my imaging experience because most of us with permanent imaging setups do not have the opportunity to throw our equipment into the car in search of pristine skies.

There are so many facets to this wonderful hobby of ours. Some of us love the beauty and mystery of the universe and do not own *any* astroimaging equipment. These people are content to view the work of others. Some of us have portable set ups; others have permanent imaging observatories. Some of us prefer to learn and enjoy astroimaging from the comfort of our favorite armchair, by reading books or magazines on the subject. Some of us prefer to return frequently to our favorite online websites, many of which whose owners have beautifully documented their journey in astroimaging. There are local astronomy clubs, planetariums, star parties, observing and imaging groups, and even astronomy imaging camps. You get the picture. Whether you are an absolute novice or a respected master of his craft, this hobby can be approached from many different directions if you delight in looking at images of the universe.

Be prepared to spend some money if you are interested in taking part in *gathering* those photons. Entry-level setups, ranging from portable telescopes with piggybacked 35-mm cameras, to gorgeous Ritchey-Chretien optical systems and professional-grade CCD cameras costing as much as a small house are available. Do your homework, take notes, and take note of your wallet before deciding on whether you are just putting a toe in the water or jumping in with both feet.

I was introduced to the gorgeous images of Jason Ware, Phillip Perkins, Jack Newton, Thierry Legault, Don Parker, and Ian King in Meade Instruments' 2000–2001 General Catalog and decided to wade into the water. I have never looked back. Our hobby is addictive and provides instant feedback as we watch our raw images download on a computer.

Finally, I am reminded that once in a while it is worthwhile to exchange the camera and CCD chip for an eyepiece. Time to "stop and smell the roses." When I am alone in my observatory and staring through an eyepiece at a distant target, or staring at a recently downloaded image on my computer monitor, you do not have to be spiritual to be moved by the grandeur of it all. The dimensions of our canvas are beyond comprehension. Who has not thought about the meaning of it all, beyond the pretty picture aspect?

CHAPTER ONE

The Challenge of Imaging Under a Light-Polluted Sky

Light pollution is the bane of amateur astronomers, whether your interest is in observing or imaging. Regardless of the quality of your local skies at your imaging site, the requirement to produce good charge-coupled device (CCD) images is the same. We want to maximize signal and minimize noise. This signal-to-noise ratio, known as S/N or SNR, is the holy grail of astroimagers. Signal (both good and bad) is the light that is recorded by the CCD chip, such as from a galaxy or globular star cluster, along with at least one type of unwanted light (skyglow). The exact unwanted signal cannot easily be known with certainty, but the goal is to separate out this unwanted signal.

Light pollution and other atmospheric factors contribute to the brightness of the sky background. Skyglow, one form of light pollution, is a key determinant in the ability to image extended, deep sky objects. The problem is that signal, both good and bad, builds linearly. If your mount is adequate and/or your imaging setup is equipped for guiding, extended integrations are possible. Unwanted skyglow, however, builds in tandem with your extended integrations. Image a galaxy for 30 s and your raw frame has both a dim galaxy image (hopefully, at least a dim image!) and possibly an overwhelming background glow. There are some extended objects that will be out of the reach of your CCD chip: Despite all of your best efforts and despite optimizing your system, skyglow will dominate your wanted signal, making your raw frames unusable. Solar system objects, such as the moon and bright planets, are not difficult CCD targets because integration times are short and wanted signal is easy to capture.

Sky brightness is measured in magnitudes per square arc-second. Because the brightness difference on the magnitude scale is a factor of 2.5 between each value, a magnitude 16 sky background requires 2.5 times longer integration time than when imaging under a magnitude 17 sky background, all other things being equal. If imaging a galaxy using 300-s integrations is achievable with your set up, a magnitude worsening of 1 in your sky brightness background now requires 750 s to image that same galaxy. Again, as mentioned earlier, some targets might need to be crossed off your wish list if longer integration times are prohibitive due to mount issues or due to background skyglow overwhelming wanted signal.

Fully two-thirds of Americans and Europeans can no longer discern our own Milky Way galaxy with the naked eye, and of the 2500 individual stars that should be visible under pristine, dark skies, closer to 200 stars are visible under a typical suburban sky (*Sky & Telescope* press release, October 11, 2002). "Take back the night sky" is a cry heard around the world by many of us who image under less-than-ideal, dark skies. Several states and European countries have enacted legislation to address wasteful light that ruins our night skies. The International Dark Sky Association (IDA), a nonprofit organization, has a website tool, DarkSky, that allows one to input their observing site coordinates (latitude and longitude, to four decimal places) and subsequently view the zenithal naked eye limiting magnitude. The limiting magnitude is only approximate and assumes perfect conditions, but the skies above my backyard observatory have a value of 3 to 5, depending on weather conditions and other factors. There are plenty of nights when the sky is cloudless, the humidity low, and the skyglow is similar to when we are near Full Moon.

All skies, even your favorite dark sky observing/imaging site, have a minimal background glow, produced from various sources. A typical suburban sky at night, however, is almost 5–10 times brighter at the zenith than the natural dark

Figure 1.1. Steve Albers has compiled an image of the United States that models light pollution. The Zenithal Limiting Magnitude for areas in red are less than 4.75 and is considered the worst on the scale. (Used with permission, Steve Albers, NOAA.)

sky. If you have had an opportunity to look skyward while walking down the streets of a populated city in the United Kingdom or in America, the sky is anything but dark, and the stars are anything but obvious in all directions. Inefficient lighting sources and particulate matter that is suspended in the air, such as smog and dust, contribute to this skyglow (see Figs. 1.1 and 1.2). Moisture in the air also contributes a bit. Many of us who have chosen to migrate to the suburbs, on

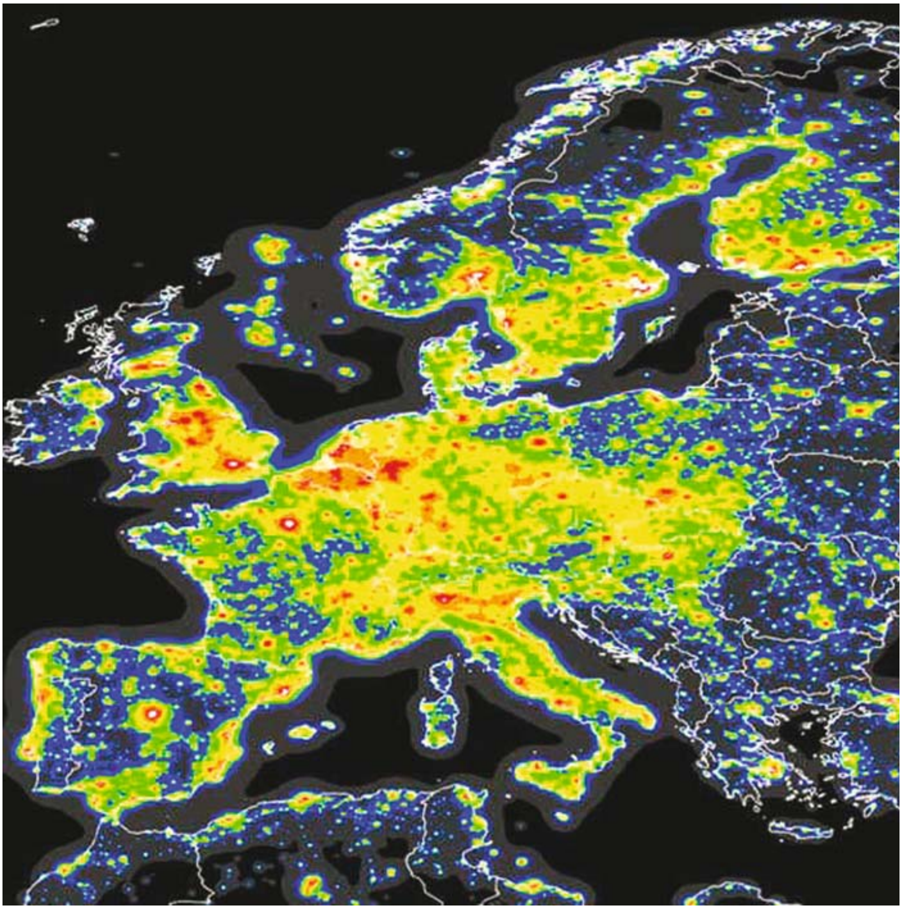


Figure 1.2. This map of Europe shows levels of light pollution in the atmosphere. The orange level indicates areas where the Milky Way is invisible; red areas indicate zones where approximately one-hundredth of stars are visible over 30° of elevation; blue borders indicate artificial sky brightness more than 10% that of the natural brightness, which is the definition of a "light-polluted sky." Yellow indicates an artificial sky brightness double that of the natural sky background. [Used with permission; Credit: P. Cinzano, F. Falchi (University of Padova), C. D. Elvidge (NOAA National Geophysical Data Center, Boulder). Copyright Royal Astronomical Society. Reproduced from the *Monthly Notices of the RAS* by permission of Blackwell Science.]

the outskirts of populated cities, live under a night sky that is likewise anything but dark. The orange glow that stretches from my local horizon upwards through 60+° in some directions is a combination of mall parking lights, unshielded or poorly aligned light fixtures, inefficient lamp sources, and security lighting that is unshielded. Mercury street lamps, outdoor sodium vapor lamps, and neon advertising signs limit the length of individual exposures that you can take. Without a compass, I can easily discern which direction downtown Miami is, almost 25 miles (42 km) distant, because the signature glow is strongest in one direction (see Fig. 1.3).

There are several ways to deal with artificial sky brightness. If you have a portable set up, nothing beats driving to a darker observing and imaging site. For those of us with permanent setups, there are several workarounds. Imaging late in the evening or early morning, when skyglow is diminished, is an effective but constraining solution for those of us who must work for a living. ("early to bed, early to rise" is the unfortunate mantra of many.) Imaging in a direction less affected by skyglow, because most skyglow is not uniform, or waiting for a target to climb higher in the sky and out of the glow are easy to accomplish. All successful imagers will agree that waiting for a target to approach its zenith, or transit, is the optimum time to image anyway. Select a target that you are interested in and use a planetarium software program (such as TheSky, Software Bisque) and time-

Figure 1.3. The orange glow of downtown Miami is unmistakable, looking North from the author's observatory. Polaris, the North star, is just visible in the original image.

skip the object until you find the transit time and date that meet your needs. The amount of atmosphere that you are imaging through is less the higher the object is in the sky. The reality is that although some targets never set and are always above the local horizon, they nevertheless hug the horizon, never getting above the glow. A few targets, such as M81 and M82, are bathed in an orange glow at my imaging location year-round. Imaging on dark (New Moon) and transparent nights, or when humidity is less, are further ways to combat skyglow. Direct glare, different than skyglow, can be blocked by erecting portable partitions to shield the telescope and camera from line-of-site intrusion.

Many astroimagers employ light-pollution-rejection filters in their imaging train. Meade, Celestron, Lumicon, and Hutech are a few of the many companies that manufacture these special filters. These glass filters have special coatings that reject sodium, incandescent, and mercury vapor, reflecting those wavelengths away from the CCD chip. There is no light amplification involved; the filter transmits the desired light of the object in which you are interested. Unfortunately, these filters do not work on all objects. Because the wavelength of starlight from galaxies and globular star clusters is similar to the rejected and unwanted light, imaging these targets with a light-pollution filter in the imaging train has diminishing returns. The goal of this filter is to transmit wanted signal

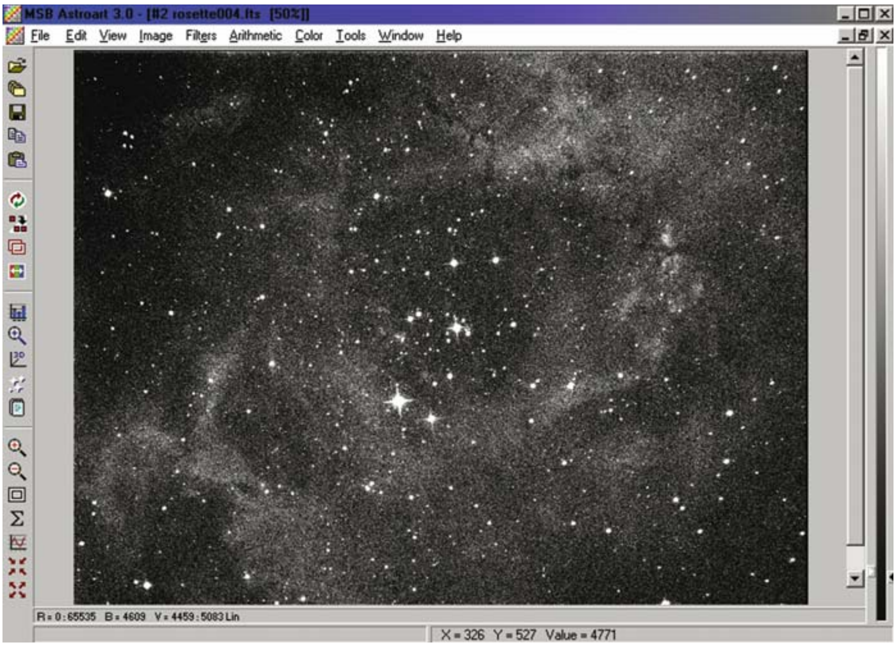


Figure 1.4. Astroart 3.0 screen capture. Single 300-s integration raw frame of the Rosette Nebula showing good nebulosity, captured with Astronomik 13-nm Ha filter. Diffraction spikes are artificial. Note the grainy background, indicative of noise, which can be removed with image processing. (Used with permission, MSB Software, Inc.)

and maintain proper color balance. Different manufacturers approach this issue differently, rejecting/transmitting light at slightly different wavelengths. The average price for a decent filter approximates the cost of a quality eyepiece. One downside to using a light-pollution filter is the requirement for longer integrations. Some of the blocked light is the desired light from the target you are imaging.

The luminous haze limits one's ability to see the stars and photograph what we see with our naked eye or through a lens. The extended deep sky objects that we cannot see, but that our favorite planetarium software shows us are there, are even more challenging to filter out of the mire. Light pollution adversely affects the ability of a CCD camera to record deep sky objects, but, fortunately, a CCD camera can integrate longer exposures to overcome light pollution to some extent.

Light pollution adds additional background signal to individual raw images, which must be subtracted out. Longer integration times on individual exposures (see Fig. 1.4) and taking more exposures in order to bring out the object of interest are further requirements. When you combine images, the SNR is improved because signal increases faster than noise. Signal increases in a linear fashion with

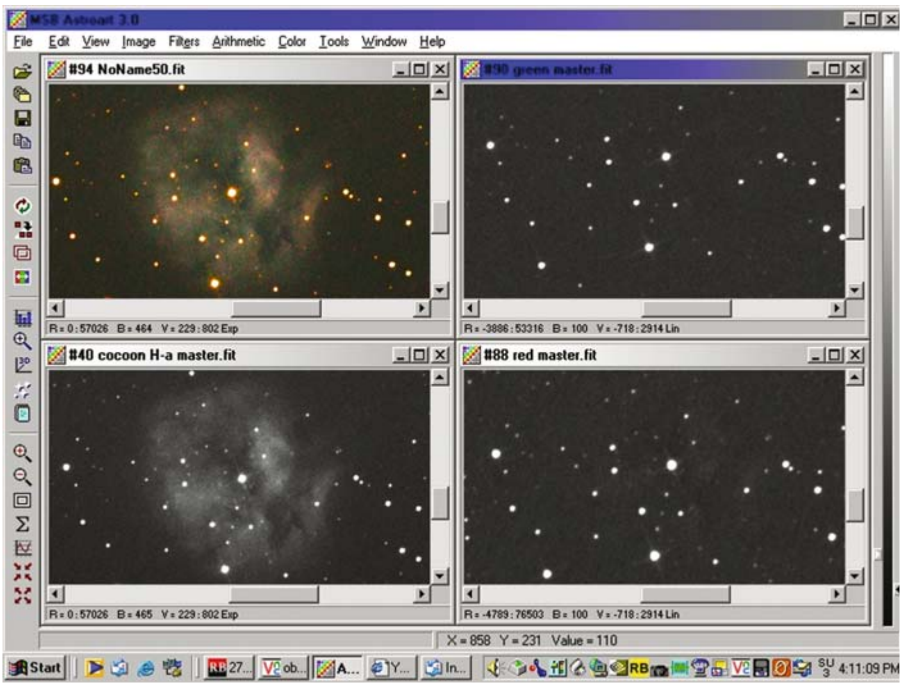


Figure 1.5. Astroart 3.0 screen capture. The Cocoon Nebula, even with 600-s integrations and an Ha filter, is still a dim target under my skies. The upper left panel shows a combined (Ha) RGB composite image. Representative channels show good signal in the Ha and barely discernible signal in the Red and Green channels. (Used with permission, MSB Software, Inc.)

each additional exposure, but noise increases as the square root of the number of images. Some imagers adjust their histograms by raising the black point high enough to hide any gradient that is present, but at the expense of losing faint detail in portions of the image. Light-pollution gradients should be dealt with first, allowing you to adjust the image histogram, which leaves a more pleasing display of the data. See Chapter IV, Processing Astrophotos Made Simple, for additional discussion about histograms.

If light pollution is severe or the object is too faint, the CCD chip will be saturated before a meaningful signal is recorded (see Fig 1.5). Additionally, light pollution is not uniform in images obtained with red, green, and blue (RGB) filters. If light pollution is not uniform, the resulting gradient must also be removed postprocessing.

Another possible work-around is to use a hydrogen alpha (Ha) filter. This type of filter is considered a narrow-bandpass filter due to selectively capturing the 656-nm Ha light that is emitted from emission nebulae. The filter allows this bandpass through and blocks most other light, including skyglow. High signal can be built with extended integrations. I use an Astronomik 13-nm Ha filter (Astronomik, Inc.) with a minimum of 300-s integrations (see Fig. 1.6).

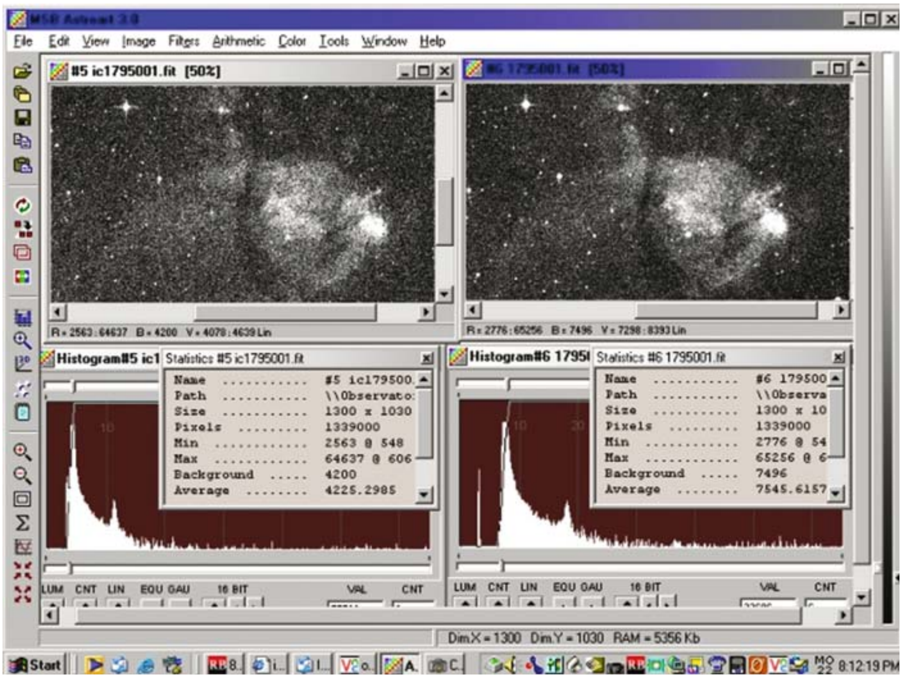


Figure 1.6. Astroart 3.0 screen capture. Emission Nebula IC1795 is shown as a raw, unstretched 600-s integration on the left and as a 900-s integration on the right. Five additional minutes yields less noise and more detail, as seen in the raw image. (Used with permission, MSB Software, Inc.)

CHAPTER TWO

Equipment Inventory

If boating on the ocean or on your local waterways is one of your hobbies, you might have heard the analogy that a person's boat is like a bottomless hole in the water: There is a never-ending list of must-have items and the hobby can be expensive. I was reminded that the universe, which is our bottomless hole, is likewise enormous and that I might need to hold my wallet tight and keep things in perspective as I assembled a list of "must-have" items.

A huge building with the word Tasco on it used to adorn the Miami skyline until a few years ago. Tasco has since purchased all of the major stock of Celestron International, and Tasco has since moved from the huge South Florida location, but whenever I drove past the building on State Route 826, I was gently nudged that I was "supposed to" buy that telescope that I always wanted. Tasco's product line was appealing to me as a child, when my needs were simple: visual observation, easy set up, an instrument with good optical quality. Celestron's and Meade's product line, however, both supported a higher performance for specialized use. When Meade's Telescope Catalog arrived in the mail in 2001, I was amazed at the size of some of the telescopes that amateur astronomers could purchase. It is a good thing that the catalog did not have any prices in it: I wanted the 16-in. (41-cm) Polar mounted LX200 at first sight!

Like most people who come to this hobby (or who come back to this hobby, as was my case), I thought magnification is king. The more obvious advertisements on most toy telescope boxes are that the optics will deliver 675× magnifications! We have all seen this type of advertisement. Most hobbyists will agree that a practical upper limit of magnification is 30–50× per inch of aperture. I quickly learned that it is the collection of light and a telescope's ability to resolve an image (how much detail can be observed through a given telescope), that are paramount. The larger the lens or mirror, the more light that can be collected, revealing brighter and sharper images. I knew I wanted a telescope for astronomical purposes (as opposed to terrestrial observing) and I knew I should purchase a telescope that I would not quickly outgrow. I settled on the 10-in. (25-cm) LX200 f/10 classic and was determined to be the "uncommon observer who requires a telescope of larger than 8-in. (20-cm) aperture for any astronomical (studies)" (Meade Catalog, 2000).

What was the size of my budget? Well, I did not have a formal spending limit, but I allowed myself a reasonable amount given the cost of the telescope and mount. The Meade 10-in. (25-cm) LX200 Schmidt–Cassegrain telescope is advertised as one of the "largest-selling serious telescopes in the world," with the ability to locate more than 64,000 celestial objects at the push of a button (see Fig. 2.1). I decided that because I was not purchasing a toy, but a real scientific instrument, I would call Meade and a few telescope dealers/distributors that I saw advertised in the print media. I put together my laundry list of accessories to go along with the big-ticket purchase (the telescope) and I additionally purchased what I could afford. Ironically, it turned out that there was no money left over for a CCD camera!

Figure 2.1. Meade 10-in. LX200 Schmidt–Cassegrain telescope, on a tripod. (Used with permission, Meade Telescope Instruments, Inc.)

My initial list of items had a staggering bottom line of several thousand dollars. I chose the Oceanside Photo and Telescope (OPT) dealership in California (USA) after faxing my list back and forth with a handful of dealerships in the eastern United States. I was comfortable with the company's promise and written policy of standing behind my purchase, even though the main purchase, the telescope, was really coming from the Meade factory. I also sought the personal experience of several colleagues on the Internet. OPT exchanged several smaller accessories without charging me a restocking fee, as well as allowed me to test-drive Meade Instrument's Pictor software before deciding on Software Bisque's TheSky.

Setting up each twilight in my backyard, without knowing the luxury of a permanently housed observatory, was fun and an adventure at first, but the finicky weather often put a damper on my observing intentions. I learned the mechanics of the telescope and was forced to learn to navigate the sky because I did not own a portable computer that could be linked to the telescope.

The decision to build a permanent setup was made for me: Too many promising observing nights turned into dreary, cloud-covered evenings and began to put a dent in my enthusiasm. What used to be fun (planning the evening observing session while at work on my computer, while no one was looking, and racing home to set up the telescope to do a two-star alignment) was now becoming "pointless" as clear skies gave way to clouds and rain. I searched the World Wide Web for statistics to support my observations: The seasonal average humidity is 73% for Miami; the average number of rainy days is 130; the average annual monthly maximum is 83°F (28°C); the annual average monthly temperature overall is 76°F (25°C). At night, more times than not, the weather pattern brings clouds in from the east (the Atlantic) and can easily end an imaging session in a matter of minutes. I reasoned that if one-third of my days were going to be rained out, and additional nights clouded out, I estimated that due to other constraints (family and work) I might have 5–10 evenings per month of observing and imaging. I might as well optimize my time when the seeing was good and not spend time and energy when the seeing was lousy. If the seeing conditions deteriorated, it was a matter of a few minutes to shut down the observatory and hope for a better night "tomorrow."

The following pages deal with my equipment in greater detail. I do not attempt to compete with the necessary and excellent reading material that is available in the numerous books and Internet articles, which the reader is encouraged to pursue. On the subject of the LX200 telescope, for example, one only needs to do a GOOGLE search on R. A. Greiner (Doc G.), a living legend, who has greatly facilitated the astronomy community over the years. His knowledge and expertise on many subjects astronomical, including the LX200, are unsurpassed. The level of detail that is available for the electronic components alone for this telescope can fill an entire book. The focus of this book is to allow the interested reader to learn how one amateur brought everything to fruition in order to produce astroimages under suburban light-pollution conditions. I certainly do not bring a sense of authority to any subject in this writing. What I can offer are insightful tips and perhaps provide some inspiration to other amateur imagers who are just starting out.

A. Telescopes

1. 10-in. (25-cm) LX200 f/10 Classic

The concept of "how fast" an imaging system I should get eluded me when I placed an order for my main observing and tracking telescope. Speaking in terms of speed sounds funny at first when discussing optical systems, but the native f/10 system is "slower" than a wider-field f/6.3 system. Given two extended targets in the night sky, I would theoretically be able to gather an image in less time with an f/6.3 system than with the f/10 system that I purchased. There were work-arounds to change the f/-ratio of my system, so I figured I could barlow (magnify) my system for enhanced planetary views, and I could add a focal reducer/field flattener to grab wider-field views quicker. Purchasing an f/10 system would be a good compromise to be able to do both planetary imaging and deep-space imaging.

The 10-in. (25-cm) aperture LX200 Schmidt–Cassegrain telescope (SCT, Classic, 3.34 ROM software) is a catadioptric (mirror–lens) design, compact in size but with a long focal length. The worm-gear motor-drive system has enough precision to enable long-exposure guided photography. Theoretical pointing accuracy is 0.333 arc-seconds (1 arc-second is 1/3,600 of a degree). With the motor engaged, the telescope tracks at a precise sidereal rate required to track the stars across the sky. The electronics of the LX200 are integrated in the fork-mount design, and "observatory-level" precision in tracking, guiding, and slewing are claimed by Meade.

P.E.C. training (correcting periodic error due to imperfections in the right ascension (R.A.) drive worm gear) is mandatory. This greatly enhances the east–west drift accuracy of the LX200. Declination drift can also be corrected, but an accurate polar alignment is an absolute must. Phillip Perkins has an excellent tutorial on polar aligning the LX200 (see Chapter VIII). Polar alignment refers to aligning the rotational axis of the telescope mount with the rotational axis of the Earth by adjusting the equatorial wedge to which the telescope is mounted. We forget that we are imaging from a rotating Earth: Long exposures will show star trailing if the telescope's drive did not track at sidereal rate or if the R.A. axis were not properly aligned. On a permanent pier, doing a good polar alignment once will retain its alignment for many months. Periodic maintenance on the alignment can be checked with yet another routine called the Drift Method, which is also referenced in Chapter VIII. I like Chuck Vaughn's easy-to-understand treatment of this topic.

Collimation is also a requirement of this telescope design. This term refers to optically aligning the two mirrors. On a permanent pier, the alignment can hold for many months but should be checked before critical high-resolution imaging of the planets. Any maladjustment of the imaging train will diminish the quality of the images.

Because the telescope is permanently mounted, each imaging session begins easily enough with making sure that the time and date are accurately set in the keypad, confirming that the keypad selection is set for the telescope being in polar alignment mode, and then synchronizing on a known star that is visible.

This is all that it takes for the telescope's computer to know where I am in the world and where every cataloged object in the computer's memory is in relation to my observatory site. Pretty awesome. In a later section, I discuss available software that allows integration of the telescope with a much expanded catalog of asteroids, comets, and extended targets.

The keypad allows access to an enormous library of targets in the night sky. Messier objects, planets, galaxies, distant nebulae, and tens of thousands of stars are available from several popular catalogs. Enter the name, coordinate, or designation of an intended target, press a button, and the telescope slews to the object at up to 8° per second. Depending on the quality of one's telescope, the object, if not centered in the field of view (FOV), is within the field each time.

The mirror–lens design is a bit problematic when focusing. The focus knob controls the position of a primary mirror as it moves along a greased baffle. Due to the lateral movement of the mirror when focusing, an object that is initially centered in the FOV will sometimes fly out of the field with a change in focus position, something Meade does not advertise. Meade jumped on the bandwagon of aftermarket electric focusers and now includes both their microfocuser and mirror-lock design on their new and improved GPS LX200 units. I chose a JMI NGF-S electric focuser (Jim's Mobile, Inc.), which, instead of moving the primary mirror of the telescope to achieve focus, moves the eyepiece (or camera) draw tube, which leaves objects centered in the eyepiece or on a CCD chip despite a change in focus. The aftermarket purchase of an electric focuser, which does not attach to the telescope's focus knob, is an important accessory to purchase if you own an SCT telescope, whether observing or CCD astrophotography is your interest.

Another useful aftermarket design for the LX200 classic, since incorporated in the newer GPS unit, is a mirror-lock bolt, which allows the primary mirror to be safely "locked down" after achieving rough focus. Tweaking fine focus is achieved by use of the JMI focuser, in my case.

Rod Mollise's *Choosing and Using a Schmidt–Cassegrain Telescope* (Springer, 2002) is a must-have reference that goes into great detail about all aspects of SCT design and use, including the LX200.

2. Stellarvue® Nighthawk with Crayford Focuser (Formerly Known as SV 78-S Refractor)

A piggybacked refractor telescope is a necessary purchase for several reasons when the primary telescope is a long-focal-length LX200 (see Fig. 2.2). A refractor can provide wide-field images while guiding through the LX200, and guiding through the refractor is possible when imaging through the LX200. Wide-field images reveal sweeping views and place objects in context, but there might be little detail revealed. Some of the galaxy images in Chapter V, for example, are interesting because of their size contrasted against the enormity of the stellar background. In both cases, the LX200 provides a reasonable tracking mount. The Stellarvue® line of achromats is very popular in the astronomy community. Stellarvue® specializes in making hand-crafted refractors with excellent optical

Figure 2.2. Piggybacked Stellarvue Nighthawk and Meade LX200. The large blue metal dew shield on the LX200 almost extends out of the observatory. The blue attachments are infrared detectors, part of the Dome-Works™ system. A small Meade guide scope is to the left of the refractor. Black heating straps circle the dew shields of both telescopes and are part of the Kendrick Dew Heater system. (Used with permission, Stellarvue® Telescopes, Meade Instruments, Technical Innovations, and Kendrick Astro Instruments, respectively.)

quality. The company has a reputation for delivering quality products and has excellent customer service. The Stellarvue® Internet user group is one of the most mild-mannered groups out there, with *never* a sour note aimed at the manufacturer or product line. I cannot think of another group or product line that is in the same company.

The Stellarvue® Nighthawk is a pearl-white achromat that includes a 2-in. (5-cm) JMI Crayford focuser as an upgrade (see Figs. 2.3 and 2.4). A Crayford focuser is a type of telescope focuser in which the focus tube is moved by a roller. It is noted for smooth, slack-free motion and for precisely adjustable friction. The aperture is 80-mm and it has a fast f/6 design. Color correction is considered "good." The biggest drawback with most any achromat is the way the telescope focuses blue light in a plane different from where red and green are brought to focus. This leads to some "blue bloat," which describes stars that are fat and less than pinpoint. This phenomenon is discussed in a later section.

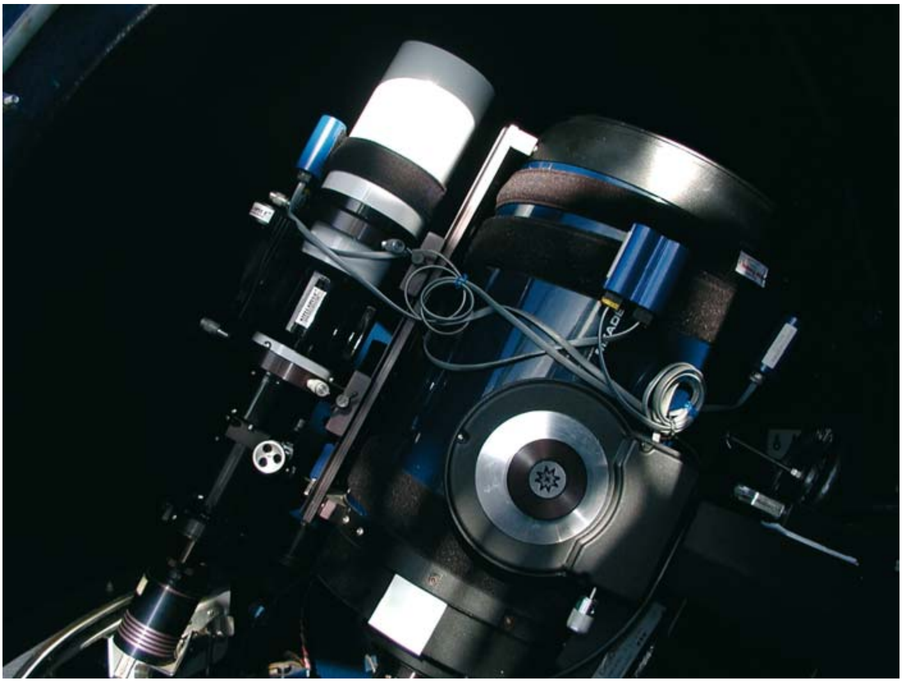


Figure 2.3. Stellarvue Nighthawk mounted on Losmandy dovetail plate and DR 125-mm rings, all secured to LX200. The Starlight Xpress™ HX916 camera and Astronomik filter drawer are seen at the lower left. (Used with permission, Stellarvue® Telescopes, Losmandy Astronomical Products, Meade Instruments, and Astronomik, Inc., respectively.)

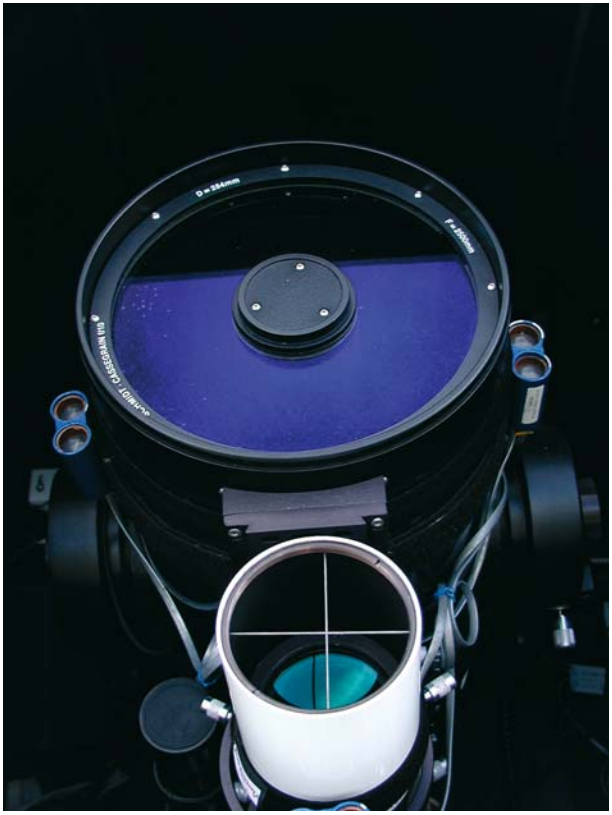


Figure 2.4. The business end of the Meade LX200 and Stellarvue Nighthawk refractor. Corrector plate glass with central secondary mirror housing is shown on the LX200. The three round screws are used to collimate the mirrors. The Stellarvue Nighthawk has two perpendicular metal wires just inside the dew shield lip, which are used to create artificial diffraction spikes to assist in focusing. Infrared detectors, part of Technical Innovations' Dome-Trak™ system, can be seen on each side of the LX200. (Used with permission, Meade Instruments, Inc., Stellarvue Telescopes, Inc. and Technical Innovations, Inc., respectively.)

3. Takahashi FS 60-C

I had the pleasure of owning my first apochromatic telescope (albeit, sporting only 60-mm of glass aperture) for a few months. The Takahashi refractor is a fluorite apochromatic refractor and the Takahashi line is considered one of the finest in the industry. I purchased the Takahashi FS 60-C intending to use it as a wide-field imaging scope and found it almost completely free of chromatic aberrations, with little color focus shift when using my Astronomik Type II filters. I found a slight bit of blue misfocus, which required the use of a Schuler–VIR filter, similar to when imaging through the Stellarvue Nighthawk. The FOV is extremely wide when used with the Starlight Xpress™ HX916 camera (a whopping 67×85 arc-minutes) and provides for nice framing of large nebulae regions and open star clusters.

B. Superwedge and Pier

When it comes to astrophotography, the altitude/azimuth mount becomes a shortcoming due to field rotation. To do proper astrophotography with a fork-mounted telescope, you need to tilt the forks to your latitude. The best way to do this is with a wedge (see Fig. 2.5). When the telescope is turned on, assuming an accurate polar alignment, objects will stay in the FOV because the mount is tracking at a sidereal rate (one Earth revolution per 24 h). By turning in R.A. (from east to west) the telescope drive counters the turning Earth.

The Meade Superwedge is both a godsend and a curse. This very heavy apparatus [25 lbs (11 kg)] sits on top of the Astro Pier™ (see Fig. 2.6). The problem with the Superwedge out of the box is that there is sloppiness in both the R.A. and azimuth adjustment. The Mitty, Milburn, and a few other wedges are more precisely engineered than the Superwedge. In my opinion, this only makes a difference when *adjusting* the wedge. Once the wedge is permanently mounted and precisely aligned, the Superwedge is a stable platform. The problems with the Meade Superwedge involve making fine adjustments rather than a lack of stability. A few modifications to the Meade wedge will make it more adjustable as well. These modifications are described in the Meade Advanced Product User Group (MAPUG) archives (which can be found online, see Chapter VIII) in great detail. For a permanent installation, and if you have the patience to set it up carefully, the Meade Superwedge is fine.

Modification examples include replacing all of the bearings with special bushings and nylon washers, replacing all of the hex socket screws with T-bolts, and replacing the azimuth threaded dog (the metal piece that locates in the slot and

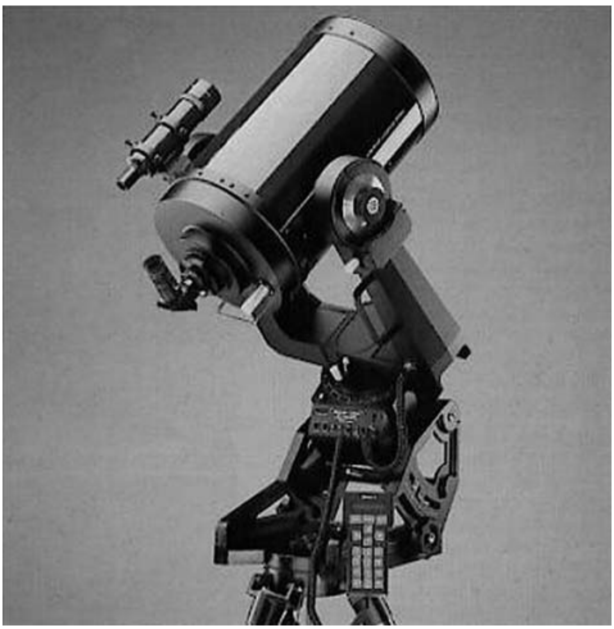


Figure 2.5. Meade 10-in. LX200 f/10 Classic, mounted on Meade Superwedge and tripod. (Used with permission, Meade Instruments, Inc.)

Figure 2.6. LX200 drive base attached to Superwedge and Astro Pier™. Take note of the angle at which the drive base is attached to the wedge tilt-plate (26° for my latitude).

pushes the wedge side to side) with a longer one with a closer fitting thread so that it does not "twist" (a fault contributing to backlash). Any and all of these modifications are reported to make a significant improvement in the ease and reliability of accurately setting up. On a modified Superwedge, turning either the altizmuth or azimuth knob results in a smooth and precise movement of the star in an eyepiece. There is no backlash. This is how the factory version should work, but does not. Again, however, a polar mounted telescope once adjusted needs tweaking only rarely and the solid mount that it is makes the Superwedge a great piece of equipment to have.

My Le Sueur Astro Pier™ (Le Sueur Manufacturing Company, Inc.) eliminates the task of having to level the telescope and line up on North before each observing session (see Fig. 2.7). It offers excellent rigidity to virtually eliminate vibration

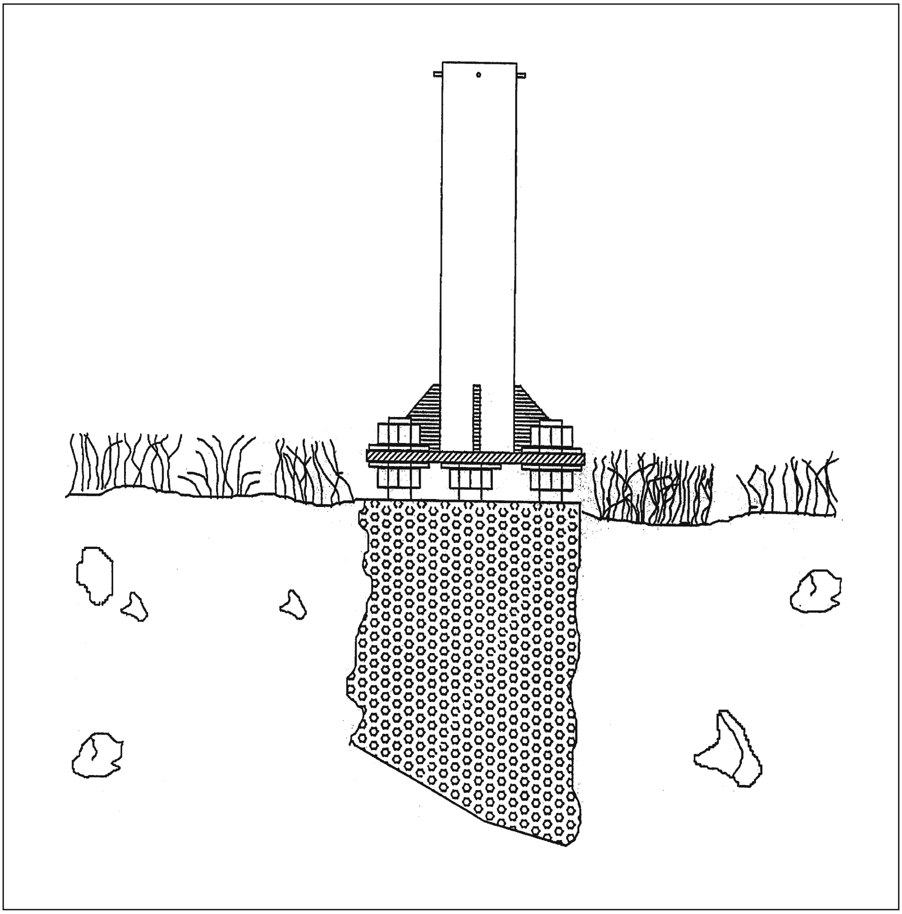


Figure 2.7. Schematic of Le Sueur Astro Pier, with mounting J-bolts depicted as having been set in concrete. (Used with permission, Le Sueur Manufacturing Co., Inc.)

from accidental jarring, which makes it an excellent choice for precision guiding. Whether you have the need for precision astrophotography or just like to sit down for a few hours of visual observation, a permanent-mounting pier is the perfect choice. The Aurora model Astro Pier is manufactured to accommodate larger fork-mounted telescopes. Being of industrial quality, this pier has the rigidity demanded by larger telescopes and those that have a high-use application. The rigidity ensures that for a given force, vibration dies out quickly. Bolt holes in the pier's base allow for leveling of the entire pier and mount by simply adjusting the nuts on the mounting bolts.

The pier is isolated on a concrete pad from the observatory floor with 0.5-in. (1.3-cm) thick felt pads on all four sides. Manufactured of steel with fully welded seams, the Astro Pier is rugged and durable. Four coats of white Rustoleum Industrial Enamel™ are applied, so the finish is pretty and durable for weather resistance. The vertical tube has an outside diameter of 6-in. (15-cm) and a wall thickness of 0.25-in. (0.6-cm). The pier base plate is 0.5-in. (1.3-cm) thick and 14-in. (36-cm) in diameter.

My finished pier is 30-in. (76-cm) tall and is mounted slightly off center, just north of the dome's center. The mounting plate has a bolt pattern that matches the bottom of the Superwedge. A mounting bolt kit contains all the necessary installation hardware, as well as a template for the installation of the pier. Le Sueur ships the kit in advance of the pier so that the concrete footing and J-mounting bolts can be prepared in advance, cured and ready to accept the pier. I dug an 18-in.-wide × 36-in. deep (46-cm-wide × 91-cm-deep) hole in order to pour the concrete footing (see Fig. 2.8).

I ordered an electrical outlet installed on the pier, as well as an accessory shelf. I had to hand-tap the holes for the machine screws in order to mount the shelf, but the convenience of having a shelf was worth it.

C. CCD Camera

A little history first. The CCD camera was developed at Bell Laboratories more than 30 years ago. CCDs have the ability to record objects too faint for the eye to see. The CCD is a silicon chip recessed behind a clear optical window. The rest of the camera comprises electronics to record and digitize the signal, plus a cooling system. There is no viewfinder! The *Voyager* spacecraft, which lifted off from Earth 28 years ago, the current *Cassini* spacecraft orbiting Saturn and its moons, and the two rovers currently on the surface of Mars—all of the stunning pictures that have been transmitted back to Earth have been imaged with a CCD camera.

The basic design consists of an array or matrix of light-sensitive regions called pixels (1 pixel = 1/1000-mm, or about 4 ten-thousandths of an inch). The light from distant objects, after teeming across time and space, is recorded on the detector as electronic signals at each pixel element site. A computer that the camera is connected to subsequently counts the electrons and processes the data as an image of light and dark regions.

The CCD cameras have several advantages over traditional film cameras, the most important of which is a greater sensitivity over film emulsion. The almost

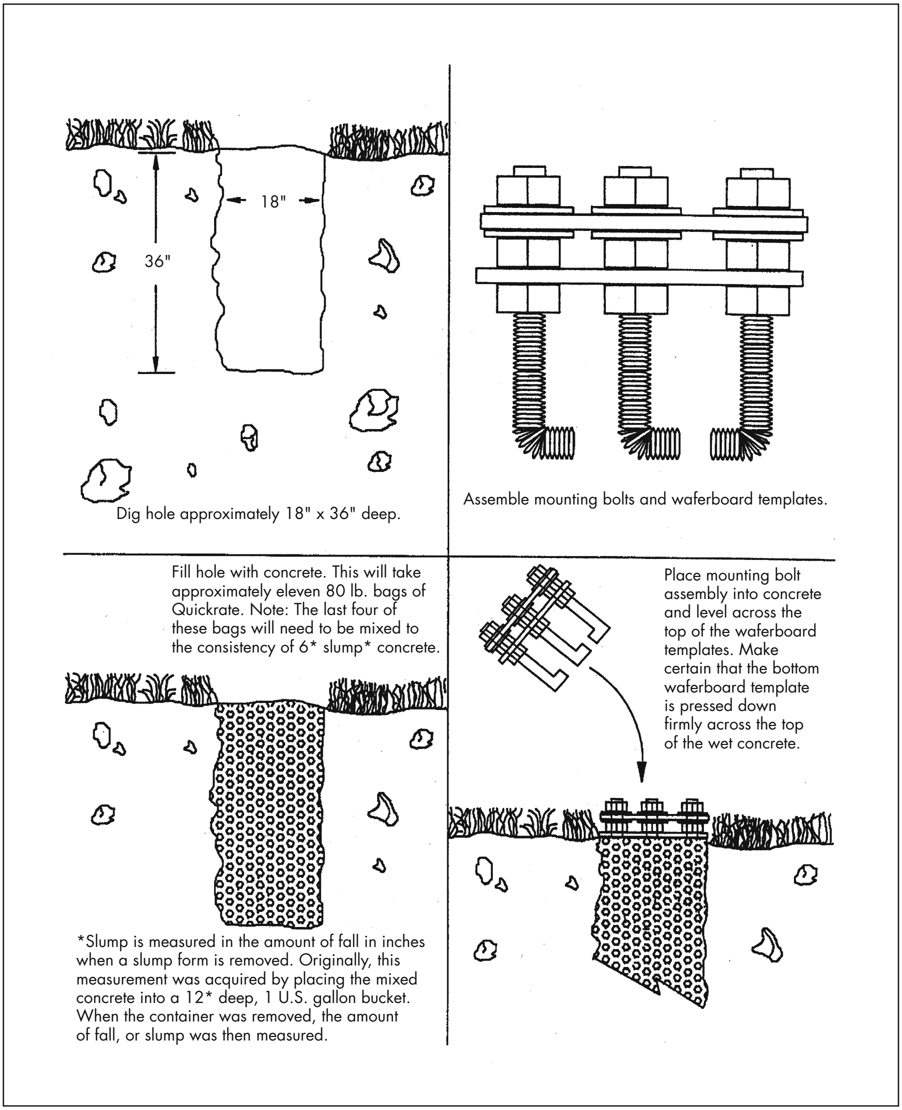


Figure 2.8. Schematic of mounting template that supports a Le Sueur Astro Pier. (Used with permission, Le Sueur Manufacturing Co., Inc.)

instantaneous display of one's images on a computer screen after downloading from the camera means that no film needs to be dropped off for processing.

A Starlight Xpress™ HX916 camera was my first CCD camera purchase (see Fig. 2.9). When this camera was first introduced, it was advertised as the world's first megapixel CCD camera, with a fast USB connection. The HX916 is a high-resolution monochrome camera that comes with proprietary software for image

Figure 2.9. Starlight Xpress HX916 camera and USB control box. The USB control box is attached with Velcro to the west fork arm of the LX200. (Used with permission, Starlight Xpress™.)

acquisition and minimal image processing. The USB connection is approximately three times faster than a parallel port connection, and download times for unbinned 1×1 images are on the order of 11 s. Unbinned images are a large 1300 × 1030 pixels, and each pixel is 6.7-μm on a side (1-μm = 1/1000-mm). The camera is fairly light, a mere 4-in. (10-cm) long, and just over 2.3-in. (6-cm) wide. The CCD array is a Sony ICX085AL chip that has a spectral response curve typical of most amateur CCD chips: it peaks in the visible range (roughly 400–600-nm wavelengths) with some sensitivity in both tails (ultraviolet in the left tail, infrared in the right tail). Sensitivity in infrared (IR) (~700–900-nm wavelengths) is the reason that many imagers employ an IR-blocking filter when doing trichrome imaging with an achromatic refractor. (see Fig. 2.10).

Software driver installation for the camera is not necessarily straightforward or user-friendly. The installation sequence is supposed to complete with minimal user interference, but installing the software on a computer running Windows XP home edition or on a computer running Windows Me was a several-day chore. Soliciting opinions on the Internet, I found many people with the same installation issues. Device Manager conflicts, hex file incompatibilities, and Block I/O issues are some of the sticking points during installation. Terry Platt from

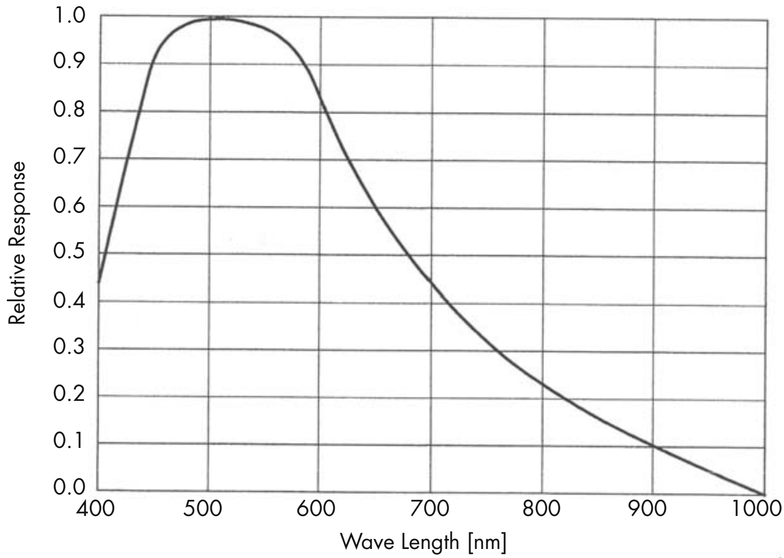


Figure 2.10. Spectral response curve of the Sony ICX085AL chip. The profile displays the fairly typical peak response in the visible range of 400–600-nm wavelengths. (Courtesy of Sony Electronics, Inc.)

Starlight Xpress provided decent support in a timely fashion via email, and the Internet user group for Starlight cameras was also a tremendous help.

The quality of the downloaded images is impressive because of good quantum efficiency (QE), which describes a camera's response to different wavelengths of light. An ideal QE of 100% would mean that the conversion of photons to electrons was complete. The QE of the Sony chip in the Starlight Xpress HX916 camera peaks at 48% in the green. Depending on local imaging conditions, matching dark frames are rarely needed, but a bias frame is recommended. Both types of images are discussed later.

Matching a CCD camera to a telescope is important in order to optimize the resolution that your optics can deliver. You still need to take into account your local seeing conditions. Table 2.1 illustrates the LX200 and Stellarvue refractor in various configurations with the CCD camera (Table 2.1). Unbinned images with the LX200 are practical only when used with the Meade 3.3 focal reducer. When the image scale is less than 1 arc-second/pixel, images are said to be oversampled (i.e., the pixels are too small for the optical configuration). When the scale is too large (say, very much larger than 4–5 arc-seconds/pixel), the image is said to be undersampled and stars can appear square and blocky.

Table 2.1. LX200 and Stellarvue Nighthawk in Various Configurations with a CCD Camera

Telescope	Chip Array (pixels) SX HX916 camera	Pixel Size (microns)	Field of View (arc-minutes)	Image Scale (arc-sec/pixel) Unbinned 1×1	Binned 2×2
10″ LX200 f/10	1300 × 1030	6.7	9.5 × 12	.55	1.1
10″ LX200 f/6.3	1300 × 1030	6.7	15 × 19	0.88	1.75
10″ LX200 f/3.3	1300 × 1030	6.7	28 × 36	1.67	3.34
80mm SV Nighthawk	1300 × 1030	6.7	49 × 62	2.88	5.75

D. Observatory and Creature Comforts

The purpose of an observatory is to protect the equipment from the elements, provide a place of comfort for the observer, and allow efficient use of the equipment by not having to spend a lot of time setting up for a night of imaging or observing. Amateur astronomers dream of having their own observatory, a site with dark skies and good seeing. One out of three was in the cards for me. I spent a lot of time designing my observatory (or as my kids called it, a la-BOR-atory, such as they hear the cartoon character Dexter pronounce it). I did a GOOGLE Internet search for amateur observatories and saw a multitude of design choices, both prefabricated and do-it-yourself. Did I want a roll-off roof design? Did I want a square building similar to a converted tool shed? Did I want a dome shutter that opened outward, on a hinge? Nah! I wanted a white, fiberglass observatory with round walls, a dome top, and a real working electric shutter because this design looked absolutely cool! This is the traditional observatory design that most people envision when you mention that you have an observatory. Mt. Palomar, on an affordable scale, in my backyard.

Technical Innovations, Inc. was founded by John and Meg Menke more than a decade ago, a delightful husband and wife team who made the entire selection process a breeze. I found their company advertised in the pages of *Sky & Telescope* and also found their website on the Internet. Jerry Smith, who is molded from the same character as the Menkes, has since taken the reins of the company. The structure is a fiberglass product designed with the budget of amateur astronomers in mind. Several diameters are available, from 6-ft (1.8-m) to 15-ft (4.5-m), as well as the ability to customize colors, add cubbyholes built directly into the circular wall, add extensions to increase the height of the walls, automate the dome, and so on. A very detailed *At Home in a Dome* handbook (Technical Innovations, Inc., 1996) is available on the Technical Innovations website, and I was able to read the basics of observatory design, form, and function before placing an order. I selected the 6-ft (1.8-m) Home Dome with one PC computer cubby. A cubby is 30-in. wide, 16-in. deep, and 40-in. high (76.2-cm wide, 40.6-cm deep, 102-cm high) and increases the dome

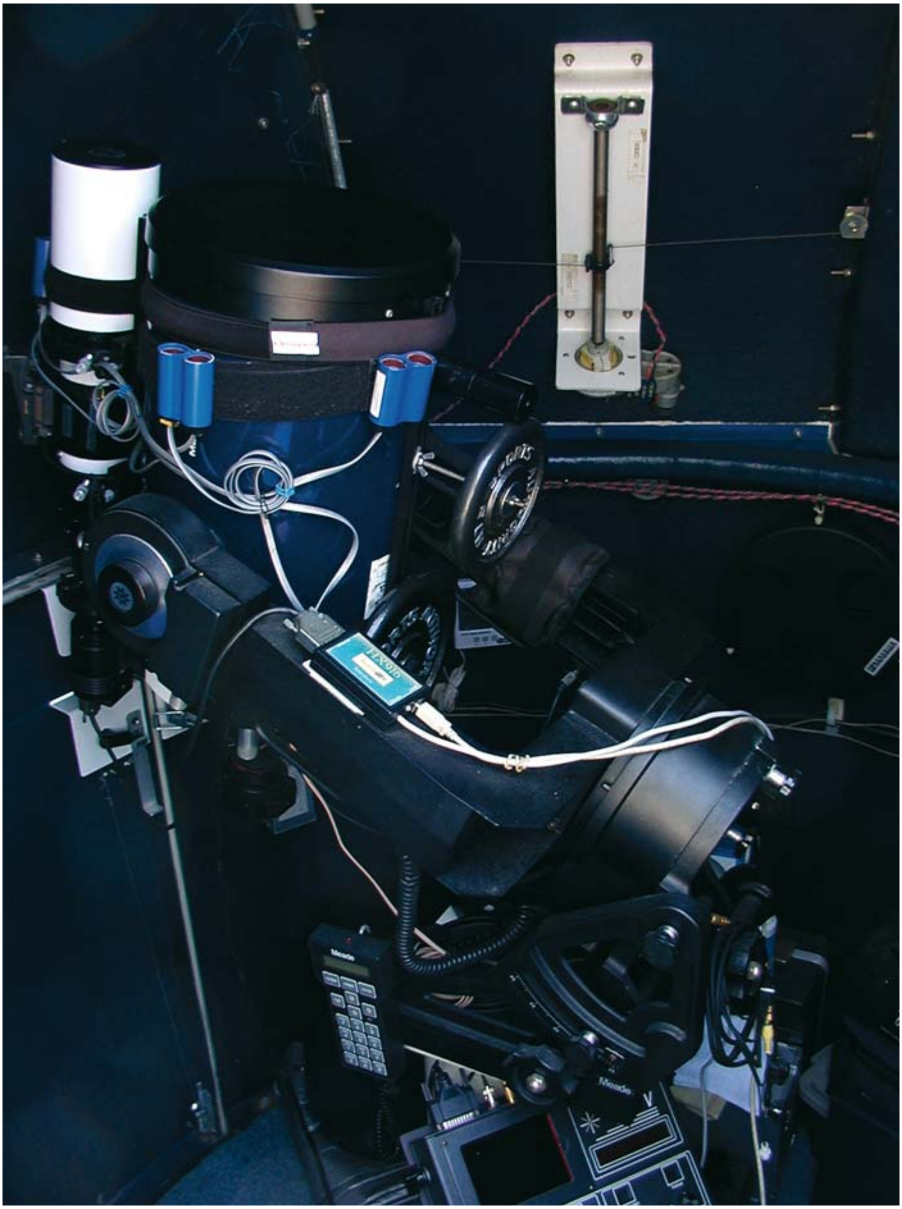


Figure 2.11. Windlass and steel cable on rear cover of shutter (Technical Innovations, Inc.) Weight plates on bottom of the LX200 balance the telescopes and camera. Notice the 5-lb (2.3 kg) strap weight attached to the LX200 east fork-arm, which assists in tracking across the sky.

floor area by providing a recess in the wall. The walls of the dome are 45-in. high (1.1-m).

An Astro Pier is installed slightly off-center in the north direction. An SCT telescope in equatorial configuration on a Meade Superwedge and I easily fit within

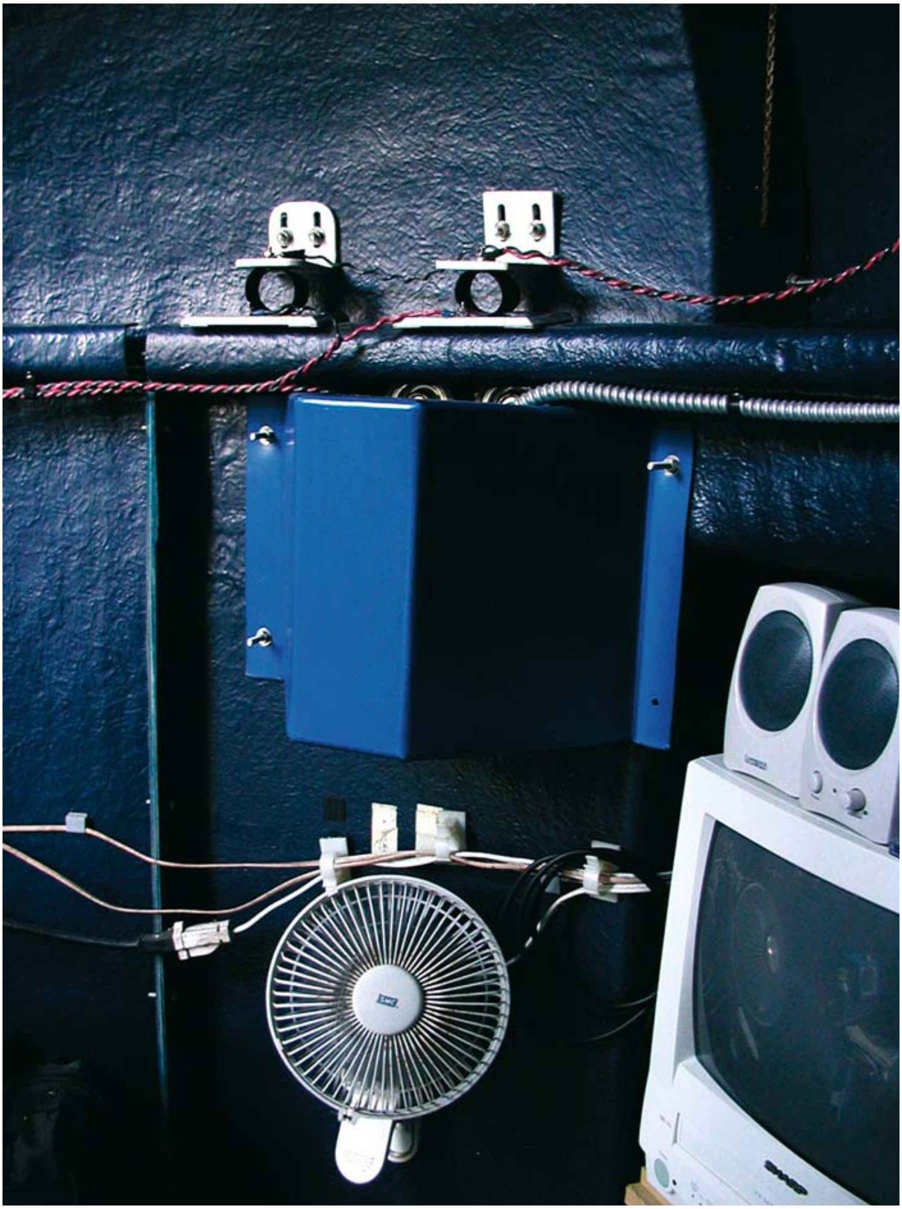


Figure 2.12. Plastic cover that dampens the sound of the dome rotation motors when they are engaged. The wires are attached to copper contacts and allow the motorized shutter to operate only when the dome has rotated to the neutral or home position. (Used with permission, Technical Innovations, Inc.)

the more than 32-ft^2 (2.9-m^2) of floor space. I decided to motorize the dome shutter, which consists of three panels, two of which move up and over, automatically disengaging during opening to nest together at the rear of the dome when opened. A 12-V DC motor controls the shutter windlass and stainless-steel cable system (see Fig. 2.11). The shutter width is 30-in. (76-cm) and the slot opens 10-in. (25-cm) past the zenith. Dome rotation is accomplished with two 12-V DC motor drive systems, each fitted with a plastic sound-suppression cover. The covers were an afterthought and hide the unsightly motors, in addition to suppressing their noise. (see Fig. 2.12). Dome-Trak™ is a proprietary system that links the telescope and dome slot position via infrared technology. Infrared sensors placed on the telescope tube allow the slot opening to frame the front of the telescope aperture. The power supply is a 12-V 10-A system with a built-in key switch and two toggle switches for dome rotation and shutter operation (see Fig. 2.13). Dome-Dial™ is another electronic system that monitors and displays the azimuth direction of the observatory dome (see Fig. 2.14). A sensing wheel detects movement of the dome and reads the position relative to the starting, or home, position. With the slot aimed North, the azimuth position is 0. Communication between the observatory computer and telescope is accomplished via Ethernet cable from my house.

Choosing a location for the observatory on my builder's half-acre (0.2 ha) lot was an important first step. I live in a residential community bound by the rules

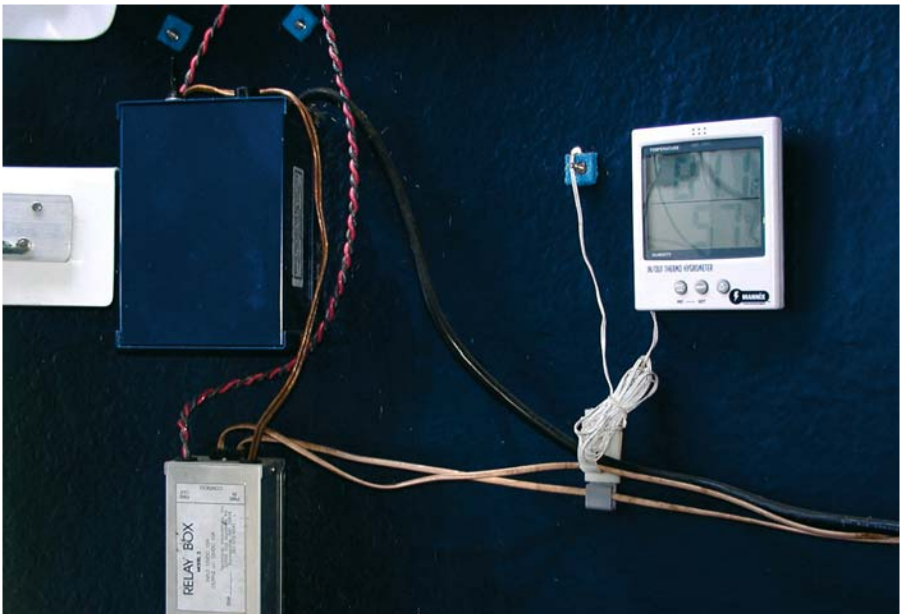


Figure 2.13. Technical Innovations power supply box, relay box, and a wall-mounted hygrometer.

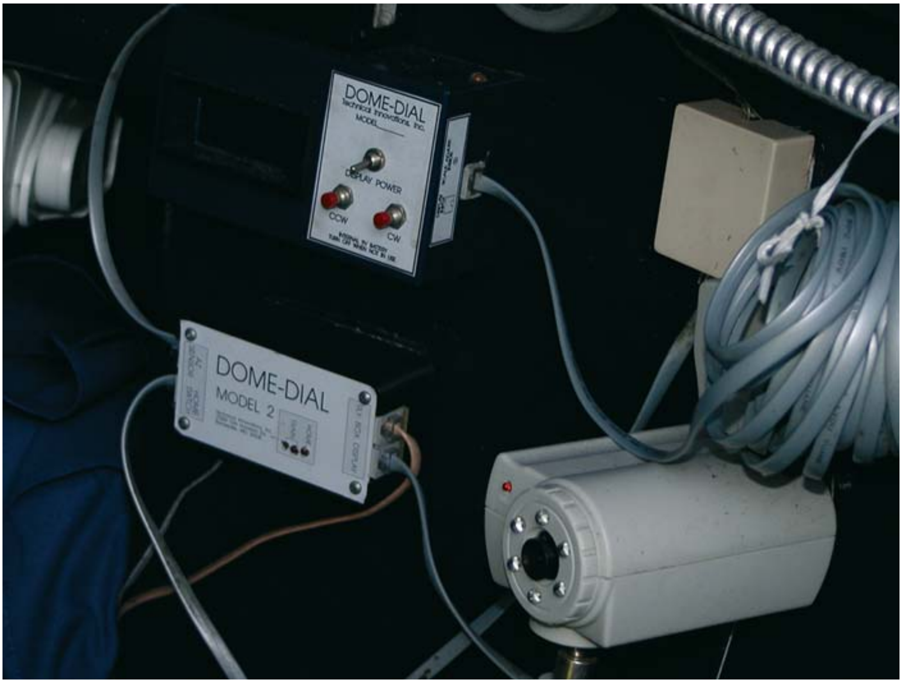


Figure 2.14. Dome-Dial display unit and relay box, mounted on observatory wall. Black-and-white security camera is also shown. (Used with permission, Technical Innovations, Inc.)

of a homeowner's association board: I wanted the dome set back far enough from fence lines [6-ft (1.8-m) minimum] so as not to cause any easement problems, and I chose the planting location of all of our palm trees so as not to impact the view to the east or north. I additionally had to apply for a building and electrical permit. Constructing an observatory as an accessory building on a concrete pad was an easy building permit to get.

Polaris, the North Star, is visible from my yard in a few unobstructed locations, and the southwest corner of the yard is where everything came together for the right reasons (see figs. 2.15 and 2.16). Unfortunately, this meant digging a 150-ft (45-m) trench, by hand, from my home office (the control room) to the observatory for the electrical and cable! I marked the footprint of the observatory in the grass, hand-excavated a 16-ft^3 (0.5-m^3) hole for the pier's footing, and poured the concrete for the J-bolts of my pier. The concrete footing thus directly contacts the soil supporting the entire pad. The hole was dug 36-in. (91-cm) deep and improved the resistance of the pier to side motion and vibration. The relative effect of the "off-balance" equatorial mount is reduced by the mass and size of the concrete footing [roughly 2400 pounds (1090 kg)]. Additionally, vibrations transmitted through the soil cannot move the large mass of the pier footing to any significant degree.

Figure 2.15. Technical Innovations 6-ft (1.8-m) Home-Dome, looking east in author's backyard. Alexander Palm fronds extending above the shutter in the photo are 20-ft (6-m) away and impede the view for the first 20+° in altitude.

For several weeks, the odd-looking white pier stood waiting to be enclosed by a dome, but the birds found another use for it. I laid and braced separate runs of polyvinyl chloride (PVC) conduit for my electrical and cable from my house to the observatory site. Cat 5e Ethernet cable would network my home office personal computer (PC) with the observatory's PC, and I left room in the conduit for a run of video cable. The observatory pad would be 12-in. (30.4-cm) larger on all sides than the observatory structure in order to protect the fiberglass from lawn mowers striking the walls. The soil under the pad was firmly compacted (hand-tamped) and leveled. I distributed a layer of crushed stone over the dirt to promote better drainage and then laid a sheet of polyethylene plastic as a moisture barrier between the soil and concrete foundation. After firmly bracing wood planking at 12-in. (30.4-cm) intervals with metal stakes, in the outline of the footprint of my observatory walls and cubbyhole, I added plenty of rebar and coordinated the delivery of a cement mixer to deliver the concrete. I had to wheelbarrow the concrete to the observatory site because the truck would not fit through my gate. Delivery of concrete for the intended purpose was a first for the company: The driver got a big kick out of finishing the concrete surface for me "just right." I removed the wood planking forms after 12 h and beveled the edge of the concrete where it met the forms in order to promote water drainage off the pad. I

Figure 2.16. Technical Innovations 6-ft (1.8-m) Home-Dome, looking north in author's backyard. Various palm trees and a distant Rainbow eucalyptus impede the view for the first 20+° in altitude.

covered the concrete with plastic sheets for a few days in order to retain moisture and not cause rapid drying of the surface. When a concrete surface dries too quickly, the result is excessive concrete dust.

A month later, the fiberglass observatory arrived by freight and was soundly packed in a large wooden crate. The estimated weight of the crate was close to 700-lbs (318-kg). Shipping within the United States is via a freight carrier with "tailgate" service. This service entails gently placing the 700-lb (318-kg) crate on the tailgate of the truck and it is up to the owner to arrange for the crate to travel from the tailgate to the garage floor, for example. International shipping is also available and can be arranged by Technical Innovations, Inc. for either air or ocean shipping. Unfortunately, additional duty and taxes must be shouldered by international customers. I was at work when the delivery truck arrived at my door; for $50.00 (27£) additional, I told my wife to make sure the delivery man found a way to get the crate safely into my garage, where it sat unopened for a few days because I did not own a crowbar!

The unassembled fiberglass observatory consists of two dome halves, a rear cover and shutters, dome support rings, three-piece 45-in. (114-cm) high walls, three-piece base ring, a molded full-height entrance door, and all hardware, caulk, and a detailed instruction manual. The manual comes in a three-ring binder and is written in standard English with numerous supporting photographs and schematics of the observatory construction.

The walls were assembled first and thankfully fit on the concrete foundation as measured. Assembled, it looked like a hot tub from a distance. This lessened the chance for raised eyebrows from the neighborhood patrol. The dome walls have a reverse flange that was secured to the foundation with lag bolts and concrete anchors. I used a 0.5-in. (1.3-cm) masonry bit and some elbow grease. I drilled small pilot holes first to maximize the location of the hole. I also injected expanding foam under the base ring in order to better achieve a watertight seal with the observatory walls and foundation. The walls as anchored to the foundation do not support a significant weight from above, but the structure has to resist lateral forces due to wind and rainstorms. Dome construction was a two-person job, but it was easily managed. The center height of the dome and walls is 82-in. (2-m), requiring several ladders and two people to assemble. Indoor/outdoor carpet installation completed the floor, which I wanted to both cushion my feet and cushion the accidental impact of any dropped eyepieces. I hired a carpet installer for this small 32-ft^2 (2.9-m^2) job but had to purchase a minimum amount of carpet from the manufacturer.

A certified electrician utilized available breakers in my house electrical panel and extended electrical runs 150-ft (45-m) in buried conduit to my observatory, giving me a separate three-breaker panel in the dome. One hundred ten-volt power cables were placed in one PVC conduit, and signal wires were placed in another to avoid cross-talk as a potential source of noise. I had a light socket wired into the wall of the dome so a red light could be installed, which preserves night vision. Sound-suppression covers were installed over each of the two dome rotation motors, and a hygrometer was installed, with a probe extending through a small hole drilled in the observatory wall. A 30-day memory keeps a record of inside and outside extremes in humidity and temperature. With the Meade Superwedge in place atop the Astro Pier, my LX200 was set in place and the drive base awaited connection to my Gateway desktop computer.

Creature comforts include an AM/FM/CD radio and a color television/VCR and player. Listening to music from Carl Sagan's *Cosmos* series might seem hokey to some, but it certainly sets the mood when you are alone in the observatory, under a starry night. Electrical interference is a possibility in a small, enclosed location, so electrical equipment is divided and plugged into three separate grounded sockets. I use a Belkin APC Battery Backup that is rated at 650 VA. It provides adequate surge protection, eight back-up outlets, RJ-11 ports, and video/telephone line protection.

A few words about lightning protection are in order. You must remember that lightning is not only an electrical charge with a magnetic component but it is also a plasma. It can jump to and from nongrounded to grounded objects at will. The type of soil your observatory sits on plays the biggest part in good lightning protection. It is best to put the protection (i.e., lightning rods) away from the structure that you are trying to protect. The electricity coming into the observatory through PVC conduit is itself routed through insulated flex tube, and each of three receptacles in the observatory are GFI protected. The observatory is grounded to Earth at two locations around the perimeter. To avoid equipment damage through any electrical ground, I unplug all of the interconnecting cables and electrical equipment when not in use. A direct lightning strike in my backyard in 2004 could not have been better prepared for, but there is no design or surge protection equipment that can protect from a direct strike. A typical lightning strike contains 1 billion volts and contains between 10,000 and 200,000 *a* of current. I lost my LX200 mother board, RS-232 port, and a serial port on my computer. As a result of this expensive learning experience, the electrical equipment remains unplugged in my observatory when not in use.

Meade Instrument Corporation was contacted after my lightning strike and their company policy requires the entire telescope to be returned for repair. I did not want to ship the almost 90-lb. (40 kg) telescope (in its shipping container) to California from Florida, so I sought the advice of some colleagues on the MAPUG and LX200 Internet groups for an alternative solution. Tim Prowten at TelescopeService.com can repair most electronic problems with the LX200 telescope. When the components are returned, he gives you a full description of the problems found, the repair that was carried out, and documents the final test to ensure complete functionality. Whenever possible, you can send the electronics only, not the whole scope. There are some things Tim will not do, namely replace components that are the intellectual property (IP) of Meade Instrument Corporation. These include the CNGC Library chips. If Tim finds a problem with these parts, he will inform you before repairing anything else. Tim provides disassembly instructions and packaging instructions and contacts you when your package arrives in good order. I spent a little over $125 (68£) and had my LX200 up and running within 5 business days of my damaged parts being shipped to Tim.

E. Computer and Cables

I chose a Gateway Pentium 4 desktop PC running Windows XP home edition as my observatory computer (see Fig. 2.17). The observatory is watertight, and although the humidity and temperature can rise during a prolonged, hot summer day, a hygrometer with memory that I installed inside the dome rarely recorded temperatures exceeding 95°F (35°C) and 80% humidity. These extremes are within the design capabilities of the electronics of the computer. The processor is a fast 2.6-GHz Pentium 4 and the 40-GB hard drive has adequate temporary storage for image files. I eventually transfer all files to CD-R disks, which is explained in a later section.

An RS-232 cable connects the LX200 drive base to the computer, which allows communication between my observing program (TheSky version 5, Level 4; Software Bisque, Inc.) and the telescope. A floating cross-hair display on the computer's virtual sky allows point-and-click slewing of the telescope to any target in the evening sky. I use a USB hub to connect a Philips ToUcam Pro PCV740K camcorder and an SBIG STV camera. There are no hardware conflicts at all.

Communication between my observatory PC and my home office PC is established via an Ethernet cable network. My host operating system is Windows ME, and again there are no conflicts. I ran Cat 5e cable over a 150-ft (45-m) distance, buried in PVC conduit 9-in. (23-cm) in the ground. I do not have a frost line to

Figure 2.17. Gateway Pentium 4 computer, 15-in. (38-cm) monitor, and television monitor. Monitors and CD/radio are located in a recessed cubbyhole, so floor space remains uncluttered.

contend with, but the variety of palm trees that are planted on my property have mature, spreading surface roots, so I wanted to stay below their reach. The Ethernet cable runs in a separate conduit from the electrical cable, about 6-in. (15-cm) apart. I use a Netgear® four-port hub (Netgear®, Inc.). When the panel bulbs lit green for the first time, indicating an intact physical network, I was thrilled!

F. Software for Observing and Telescope Control

I purchased TheSky version 5 Level 4 (Software Bisque, Inc.) for my observing routine, which is considered one of the premiere pieces of software to own for observing and planning an evening under the stars. TheSky allows the user to display a virtual night sky on the PC desktop, and the viewer's location can be customized to include the local horizon and physical obstacles (i.e., trees, buildings). The LX200 can be fully controlled, as well as the ability to print star charts and watch time-lapse events such as eclipses, and updated TLEs (two-line elements) for satellites can easily be downloaded to command the telescope to find these targets. These are the same TLEs that are used by NASA and NORAD. Ephemeris positions for asteroids and comets can be downloaded from several Internet websites so that these deep sky objects can similarly be tracked and imaged with a telescope.

TheSky displays real-time cross-hairs on the computer screen to show exactly where the telescope is pointing (see Fig. 2.18). Many telescope functions are available, including slewing, jogging, centering, or focusing a star.

I found a great freeware utility called RealVNC viewer, which allows my home computer to take control of my observatory PC. RealVNC is a UK company founded in 2002 by a team from the world-leading AT&T Laboratories in Cambridge. RealVNC (Virtual Network Computing) software makes it possible to view and fully interact with one computer from any other computer or mobile device anywhere on the Internet. RealVNC software is cross-platform, allowing remote control between different types of computers. For ultimate simplicity, there is even a Java (a programming language designed for use on the Internet) viewer, so that any desktop can be controlled remotely from within a browser without having to install software.

I can run the telescope and CCD camera from my house, comfortable in the air conditioning and not have to battle the mosquitoes. I have a manual filter holder, however, which necessitates going outside to change filters. My wife is not quite ready to grant me this last bit of automation by allowing me to purchase a motorized filter wheel: "You can walk to the observatory for free" she reminds me.

The observatory PC is set up as the host and the office PC is set up as the client. Once installed, which was effortless, RealVNC is opened on the host computer and then subsequently opened on the client PC. A successful link displays the desktop of the observatory PC on the office PC desktop, virtually in real time. If TheSky is opened on the observatory PC, or the STV camera/guiding console

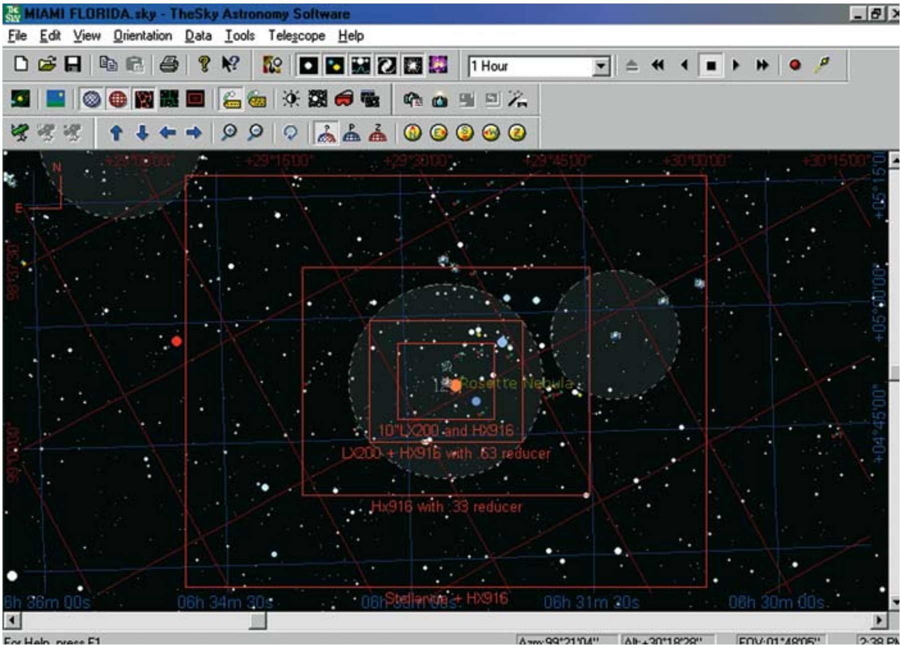


Figure 2.18. TheSky version 5, Level 4 screen capture. Rectangles depict FOV for various configurations with the LX200 and Stellarvue refractor. The gray circle for the Rosette Nebula denotes the approximate filamentous extensions of the nebula. (Used with permission, Software Bisque, Inc.)

(STV Remote) is opened, the software is controlled from inside the house. Pointing and clicking anywhere on the virtual sky commands the telescope to move. Guiding parameters from the STV Remote console can be monitored and changed from inside. I can safely make small moves and slew to new targets; I can use the mouse to control the JMI focuser if the focus position changes during the night. There are several out-of-bound positions of the telescope where it might hit the mount, depending on the length of the imaging train, so movements are small and at slow speed. I installed a wireless video camera mounted on the observatory wall to monitor telescope slews from my home office.

G. Software for Image Processing

Astroart 2.0 (MSB Software, Inc.) was my first purchase for both image acquisition and preliminary image processing. There are many software utilities and suites from which to choose. The two gold standards (Maxim DL, Diffraction Limited and Adobe Photoshop; Adobe Systems) demand a higher level of understanding and skill and the willingness to fork over several hundred dollars.

Astroart, since upgraded to version 3.0, provides a beginner like me with a fully functional and fairly user-friendly camera control and image processing program. One improvement in version 3.0 is the ability to fully process in 32-bit floating-point math. The software fully supports 32-bit flexible image transport system (FITS) images. This means that key parts of an image, which are combined as a straight addition, are not necessarily saturated due to pixel values reaching 65,534 analog-to-digital units (ADUs) (images reaching higher SNRs).

Astroart supports several file formats including the industry standard FITS format as well as Joint Photographic Expert Group (JPEG) and bit-map graphic format (BMP). Numerous functions, including image editing, image analysis, various math functions, processing filters, and photometry and astrometry are available. Four new algorithms (one star, two stars, planet, and correlation) permit alignment and addition of every kind of image. The astrometric and photometric calibration is a main feature of Astroart. It is carried out with an integrated star atlas (18 million stars, up to 15th magnitude based on the Guide Star Catalog (GSC). With just a few mouse clicks, it is possible to assign the reference stars of the image for the subsequent reduction. Many amateur astronomers use Astroart for photometry and astrometry on comets, minor planets and super novae. After measuring the R.A., declination (Dec.) and magnitude of a minor planet or comet, Astroart automatically creates a correctly formatted report from your measurements that can be sent to the Minor Planet Center (MPC).

The *Handbook of Astronomical Image Processing* (HAIP) and its integral AIP for Windows (AIP4WIN) processing software (Willmann-Bell, Inc.) is a second program that I use for certain parts of my processing routine and is covered in a later chapter (see Fig. 2.19). The software comes with a several-hundred-page hard-cover textbook that is a thorough discussion of the theory and math behind image processing. Several image processing tutorials are included on a CD-ROM.

H. SBIG STV Camera and Autoguider

The STV camera (Santa Barbara Instrument Group, SBIG) is a sensitive, cooled, digital video camera that can autoguide and image without the need for a computer (see Fig. 2.20). Why autoguide? The longest unguided exposure that you can take varies with the declination of the object being imaged, and the closer to the celestial equator, the greater the drift that results from a less-than-perfect polar alignment. Autoguiding helps level the playing field by directing the telescope and mount to track a guide star as it moves, monitoring and adjusting your mount during an imaging session. It has been called a hybrid design because of its dual functionality. SBIG is a recognized industry leader and the STV unit is regarded as a premium autoguider. The STV uses a TC 237 CCD chip with 656 × 480 pixels and has various binning modes. The single-stage thermoelectric cooling can effectively take the camera down –25°C (–13°F) from ambient.

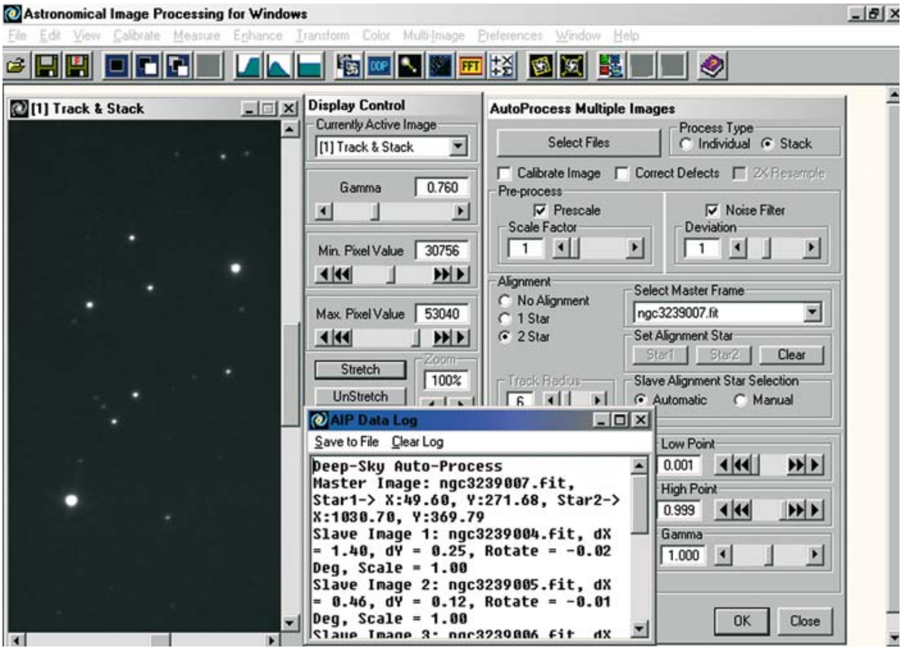


Figure 2.19. AIP4WIN screen capture. During a multi-image processing session, the software saves all image steps in a Data Log for subsequent review. (Used with permission, Wilmann-Bell, Inc.)

Figure 2.20. STV Deluxe camera and control box. (Used with permission, Santa Barbara Instrument Group, Inc.)

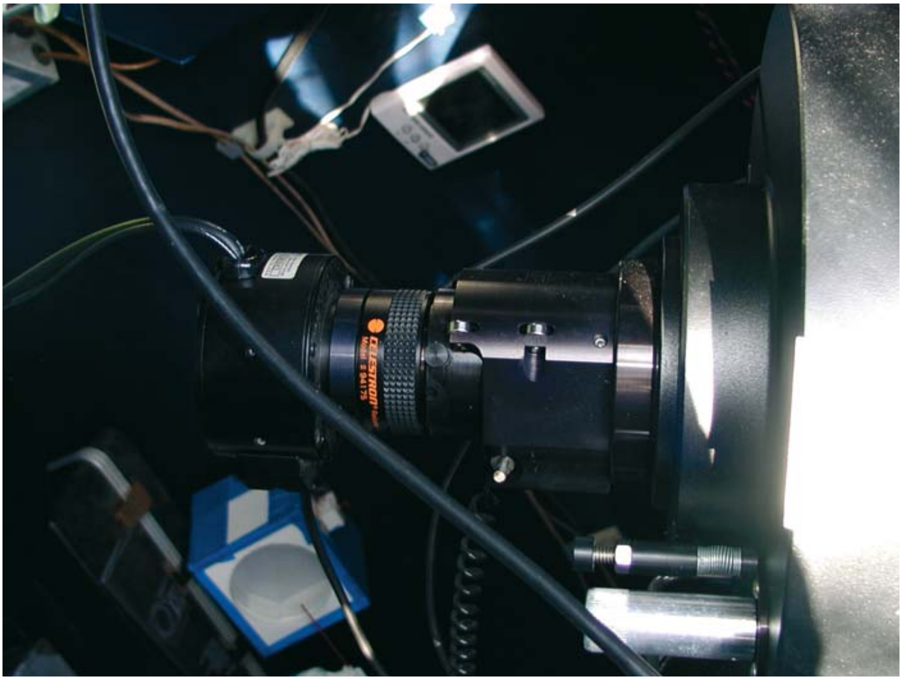


Figure 2.21. SBIG STV camera head attached to Celestron f/6.3 focal reducer and field flattener, followed by JMI NGF-S focuser and Meade LX200. The reducer allows guiding through the LX200 at a manageable 1575-mm effective focal length. (Used with permission, Santa Barbara Instrument Group, Celestron, Inc., Jim's Mobile, Inc, and Meade Instruments, Inc., respectively).

Exposures from 1/1000 s to 600 s are possible. Two major components are the camera head [1 lb (0.4 kg)] and a control box (see Fig. 2.21). The camera nosepiece fits a standard 1.25-in. (3.2-cm) focuser. The STV control box is mounted to a pier shelf, which was custom-made by Greg Mueller (Mueller's Atomics) (see Figs. 2.22 and 2.23).

The video output is seen on a built-in 5-in. (13-cm) LCD screen of the unit or can be cabled to a video monitor (I use a television monitor on the auxiliary setting) (see Fig. 2.24). The LCD monitor provides an image of the guide star as well as a real-time graph of the last several minutes of guiding corrections in both axes. I use the STV primarily as an autoguider, with calibrate and track modes. As a stand-alone video camera, it will store 2 Mbytes of digital images in its on-board memory just like a digital camera. The images can be downloaded to a computer at a later time or downloaded after each image is obtained if the STV is directly connected to a PC at the time of imaging (see Fig. 2.25).

The STV automatically calculates exposure time and estimates the amount of move to make, moves the mount in each of four directions, and measures the results. The STV marks as many stars (up to eight) that it can detect. *Calibration*

Figure 2.22. SBIG STV Deluxe camera control box mounted on pier shelf. Meade Superwedge is above, and three-breaker panel is below the STV display box. (Used with permission, Santa Barbara Instruments Group and Meade Instruments, respectively).

Figure 2.23. Greg Mueller (Mueller's Atomics) fabricated an SBIG STV control box bracket that allows the unit to fit nicely between the Meade Superwedge above and the circuit breaker panel below. White switch box controls a red bulb in the observatory, which preserves night vision.

Figure 2.24. STV Deluxe video output can be viewed on built-in 5-in. LCD screen or on a television monitor via video cable. (Used with permission, Santa Barbara Instruments Group).

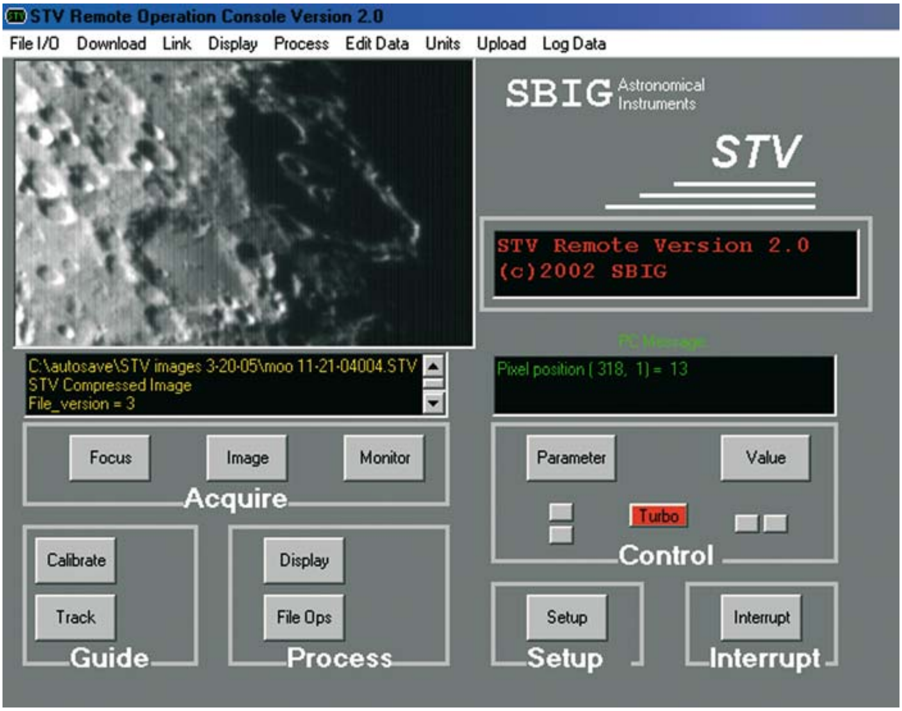


Figure 2.25. STV Deluxe screen capture. Using STV Remote version 2.0 software, an image of the moon has been captured and downloaded to the observatory computer, where it can be saved and further processed. (Used with permission, Santa Barbara Instruments Group).

is the process whereby the STV camera learns how much and in what direction it should move the telescope to correct for drift of a guide star that it is tracking.

During *tracking*, in Auto mode, the STV will find a suitable guide star after a successful calibration, setting the proper exposure time. You can override Auto by selecting Manual mode and adjust all guiding parameters.

When imaging through the piggybacked refractor, I guide through the LX200 with a Meade 3.3 focal reducer in place, which effectively reduces the focal length to a less demanding 833-mm and a pixel scale of 3.4 arc-second/pixel. I typically guide 5–15-min subexposures for extended targets without any major tracking issues.

When I swap the camera for the guider, I guide through the refractor and image through the LX200. This is the more challenging setup of the two because the image scale increases and it is more demanding to image at higher resolution. The seeing conditions rarely allow imaging at f/10 (2500-mm focal length); I usually attach a 6.3 focal reducer and image at 1575-mm.

I. Accessories

Meade Instruments Corporation had a great introductory offer when I purchased my telescope a few years ago: a complete Series 4000 Plössl eyepiece set for $99.00 (53£). The range of eyepieces included 6.2-mm through 32-mm, and I additionally purchased a 24.5-mm super wide-field eyepiece and a Series 4000 8–24-mm zoom eyepiece. These high-quality eyepieces are associated with low astigmatism and off-axis color and provide high contrast and sharpness. Each eyepiece has a soft rubber eye guard for maximizing comfort. The zoom eyepiece has smooth movement and maintains optical collimation at all settings. Plössl eyepieces are very popular for amateurs. The edge of field sharpness across the entire range of focal lengths is well known.

A Barlow lens is an eyepiece amplifier. It effectively doubles the magnification of the eyepiece and doubles the focal length of your system. I have a 2× shorty (Parks Optical, Inc.) and an off-brand 3× Barlow. Barlow lenses are great for improving planetary views and lunar views when seeing conditions support the higher magnification. A Barlow lens can be placed between a star diagonal and eyepiece to yield 2× magnification, and between a star diagonal and focuser to achieve nearly 3× magnification.

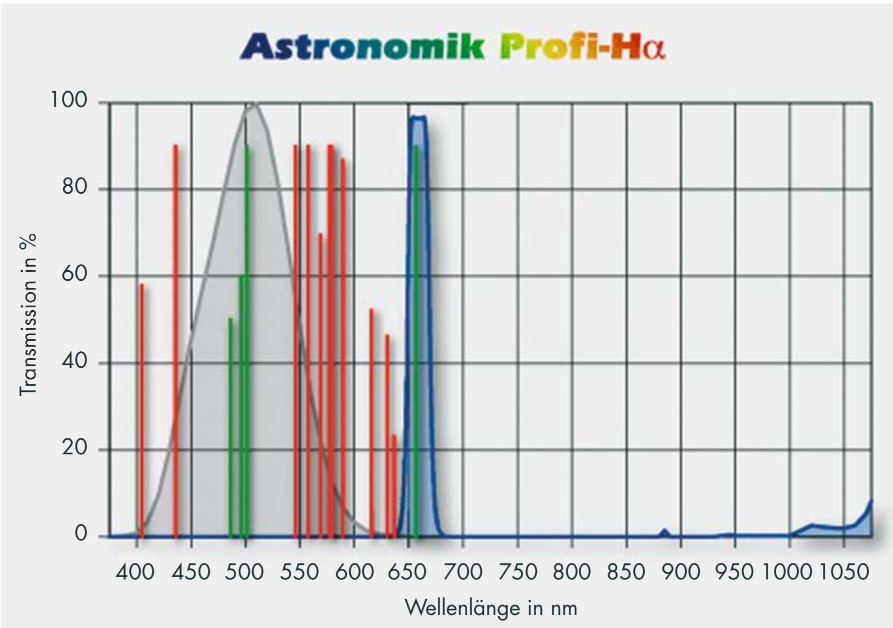


Figure 2.26. Astronomik Ha filter, 13-nm bandpass. The red lines are the most important lines from artificial light pollution. The green lines are the most prominent emission lines for nebulas. The gray curve is the human eye´s night sensitivity. The blue line is the transmission curve of the filter at 656 nm bandpass. (Used with permission, Gerd Neumann, Jr.'s Astronomik, Inc.)

Various filters are used for visual use or imaging use. An ND-96 moon filter (Meade Instrument Corporation) is used for contrast enhancement and reduction of moon glare. A Lumicon Deep Sky Filter (Lumicon, Inc.) is used as a light-pollution-suppression filter, and narrow-band imaging is through a Lumicon OIII (Lumicon, Inc.) or Astronomik 13-nm Ha filter (Astronomik, Inc.). (see Fig. 2.26). A complete set of Astronomik Type II IR blocked LRGB filters (Astronomik, Inc.) are my main imaging filters (see Fig. 2.27.) These filters are optimized for CCD astroimaging and are 1.25-in. (3.2-cm) in size. All four filters are used with a manual Astronomik filter drawer (Astronomik, Inc.) (see Fig. 2.28). The filter drawer, precision machined to maintain parfocal distances, holds 1.25-in. (3.2-cm) filters and is made of aluminum and brass. All parts are black anodized and all surfaces are blackened to prevent infrared reflection. Blocking infrared is often desirable on refractors to reduce the star bloating due to chromatic shift (inability of all colors to be brought to the same focus point).

A Losmandy ring and dovetail set (Losmandy Astronomical Products, Inc.) attach my piggybacked refractor to the LX200. A two dimensional (2-D) balance system is used on a rail system attached to the underside of the LX200. Fifteen-pound (6.8-kg) flat weights slide on rails and are used to balance the imaging setup depending on configuration.

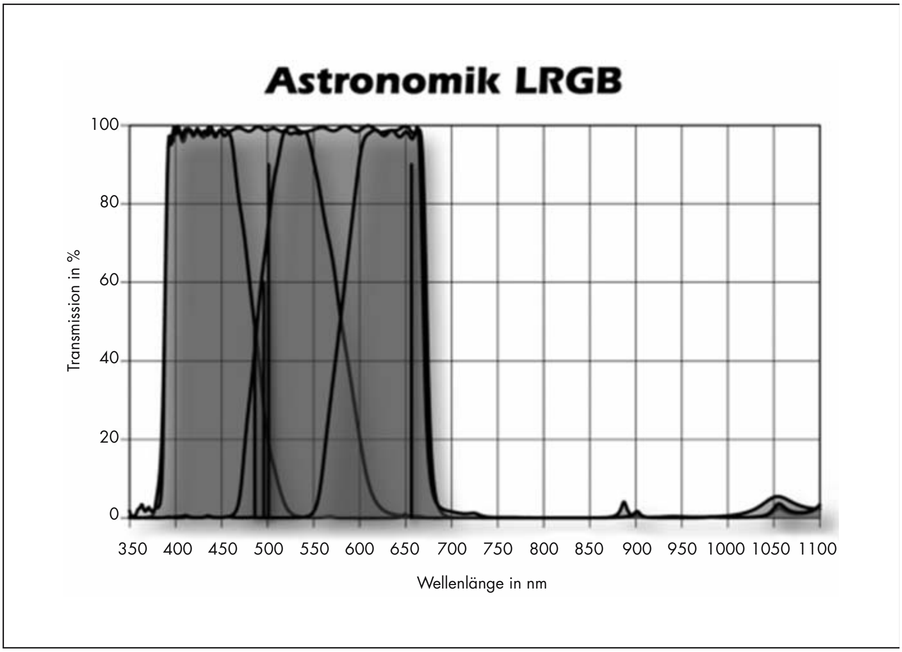


Figure 2.27. The transmission curves of the Astronomik Type II RGB filters are optimized for CCD astronomy. Continuum radiators like stars and galaxies as well as objects that shine only in single lines (e.g., planetary nebulas) are reproduced in their true colors. Each filter blocks infrared wavelengths. (Used with permission, Gerd Neumann, Jr.'s Astronomik, Inc.)

Figure 2.28. Crayford focuser at top, followed by Astronomik filter drawer, Meade Instruments adapter, and Starlight Xpress HX916 camera. (Used with permission, Stellarvue Telescopes, Astronomik, and Starlight Xpress, respectively).

All eyepieces are kept in an aluminum Orion accessory case (Orion Telescopes and Binoculars, Inc.), which has padded bins for eight standard 1.25-in. (3.2-cm) eyepieces and room for additional sundry accessories (see Fig. 2.29). I keep packets of silica gel in the case to help combat humidity in the dome.

A JMI NGF-S electric focuser (Jim's Mobile, Inc.) can be controlled from a hand paddle or from a computer when plugged into the drive base of the LX200. The focuser is designed for fine-focus control and allows only 0.5-in. (1.3-cm) of total travel of the focus tube. The motor provides a level of control from either a hand paddle plugged directly into the focuser or from software such as TheSky when the focuser is plugged directly into the LX200 mount.

A Kendrick dew heater and controller (Kendrick Astro Instruments, Inc.) are used to keep the telescope glass dew-free. Dew will sneak up on you at night as the temperature falls and moisture condenses on the lens optics. The humidity is typically high most of the year in Miami, Florida. My dew heater gets turned on most imaging sessions. I do not see any degradation of image due to use of the heating elements. I use a heating element wrapped around the corrector plate of the LX200 and wrapped around the objective of the Stellarvue refractor. The Kendrick system does an excellent job of keeping the glass free of dew and moisture by providing a low-voltage heater coil. I use a Pyramid Model PS-9KX 12-V,

Figure 2.29. Orion Telescopes and Binoculars case. Foam cutouts allow various telescope eyepieces, filter boxes, and assorted imaging accessories to be conveniently located. (Used with permission, Orion Telescopes and Binoculars, Inc.)

5-a regulated power supply (Pyramid, Inc.) to control the Kendrick controller, which is attached by Velcro to the LX200 fork arm (see Figs. 2.30 and 2.31). The Pyramid controller has electronic overload protection and short-circuit and thermal protection.

A standard metal First Aid box is attached to my observatory wall and provides spacious 10-in. × 10-in. × 4-in. (25-cm × 25-cm × 10-cm) of convenient storage for various items that I want quick access to in an organized fashion. The hinged lid doubles as a handy shelf to temporarily place something on when opened (see Fig. 2.32).

A metal Hartmann focus mask (with three holes) (Kendrick Astro Instruments, Inc.) fits over the end of the LX200 and can be used to refine the focus (see Fig. 2.33). The out-of-focus image generated by each hole merges when the telescope is in focus. The device goes by two different names, with Hartmann mask describing a mask with multiple holes and Scheiner disk describing a mask with two holes. Two wooden dowels placed over the end of the optical tube assembly (OTA) serve a similar function. I like the dowels better. A Meade metal blue dew shield for the LX200 (Meade Instrument Corporation) does not see much use, as the observatory walls and dome provide adequate protection of both telescopes from stray/off-axis light. Depending on direction being imaged, if stray light is

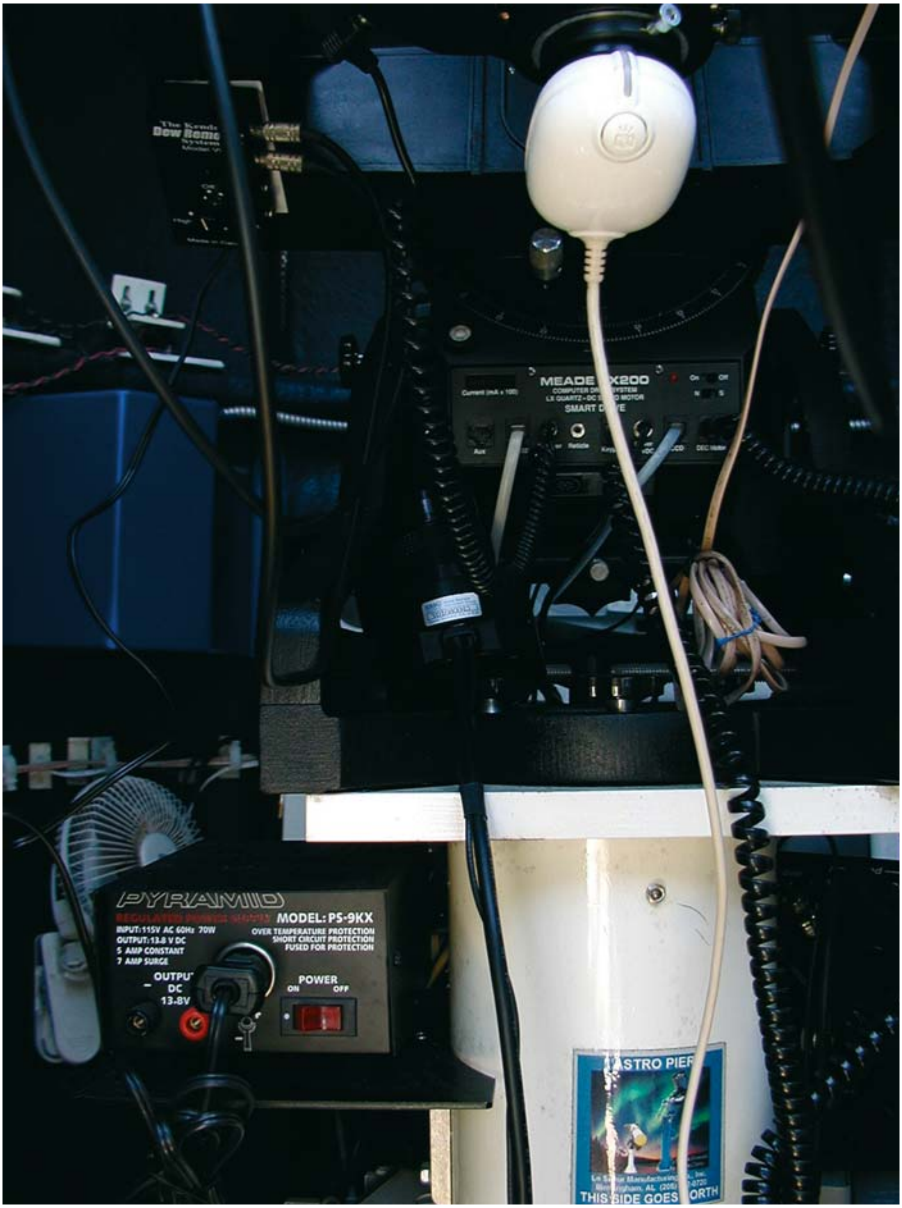


Figure 2.30. Pyramid 12-v controller (Pyramid, Inc.), which powers the Kendrick Astro Instruments Dew Remover system. Dew Remover controller is seen at the upper left, with the black rotary knob. Phillips ToUcam Pro PCVC740K camcorder is shown inserted in the LX200 1.25-in. (3.2-cm) adapter. (Used with permission, Kendrick Astro Instruments, Inc. and Koninklijke Philips Electronics N.V.)

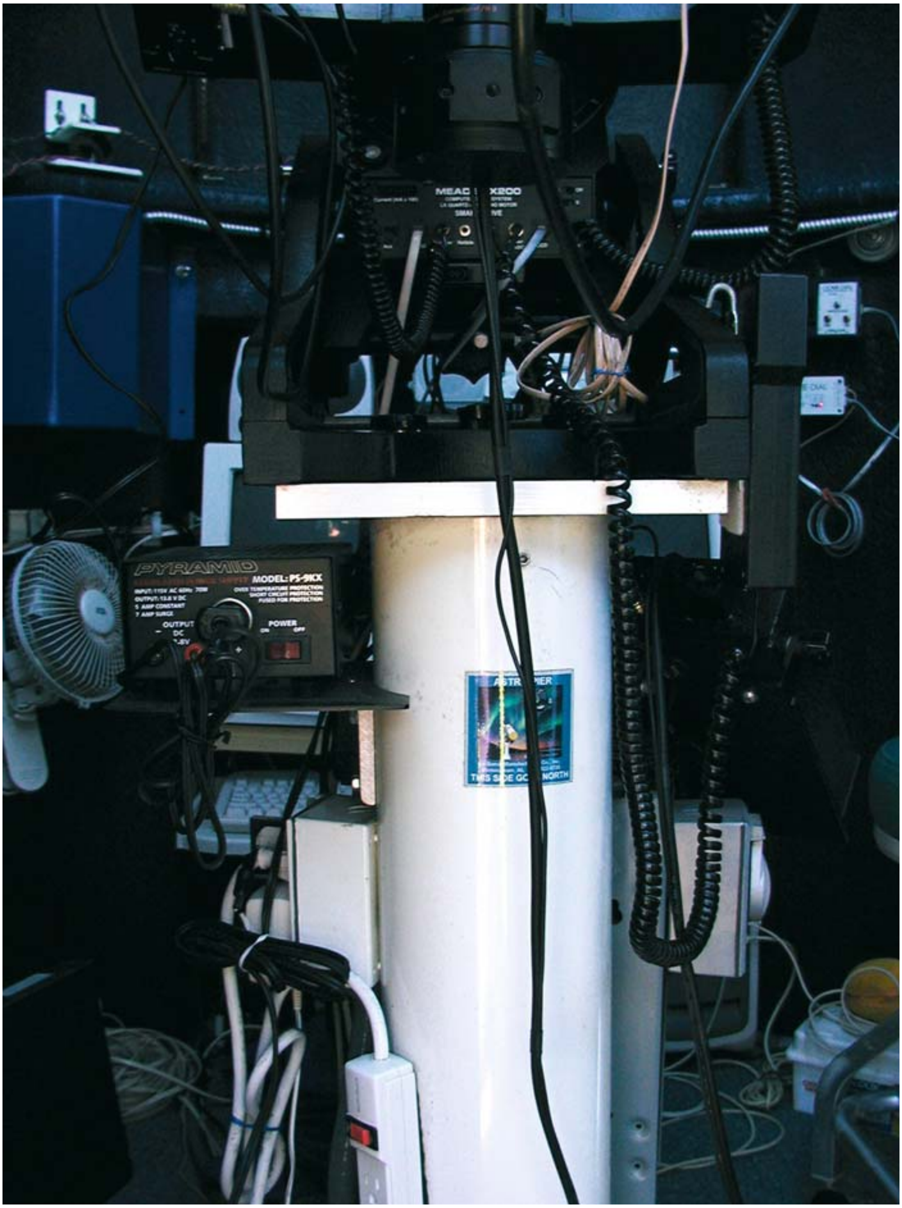


Figure 2.31. Pyramid 12-v controller (Pyramid, Inc.), which powers the Kendrick Astro Instruments Dew Remover system. An electrical outlet strip can be seen attached to Le Sueur Astro Pier. (Used with permission, Le Sueur Manufacturing Co, Inc.)

Figure 2.32. Accessory case mounted to observatory wall. Cover opens down and acts like a shelf.

pronounced, I will use the shield and need to rebalance the imaging setup because the dew shield weighs about 2 lbs (900 g).

I use a home-built aperture mask made of Baader Mylar that fits over the end of my 10-in. (254-mm) LX200. The solar material allows safe viewing and imaging of the sun. I spent about $20.00 (11£) on the material in order to fashion a full-aperture mask. Sunspots look reasonable as does the Sun's surface granularity, but this is not a prominence filter (everyone would love to be able to view solar prominences if these filters were not so expensive!), so I do not spend much time solar observing.

A Series 4000 corded 9-mm (0.4-in.) reticle (Meade Instrument Corporation) is used for refining polar alignment. Micrometric *x-y* positioning controls facilitate locking onto a guide star, and the reticle pattern (double crossline with two concentric circles) can be placed anywhere in the field. The brightness control and pulse control of the light can be adjusted.

I use a Meade 3.3 focal reducer/field flattener (Meade Instrument Corporation) and a Celestron 6.3 reducer/field flattener (Celestron, Inc.). Both accessories convert a native LX200 f/10 or Stellarvue f/6 telescope to a faster imaging platform. This accessory makes it possible to have a dual focal ratio instrument, without sacrificing image quality. It offers wide FOVs with any Schmidt–Cassegrain telescope. Used for astrophotography, it reduces exposure

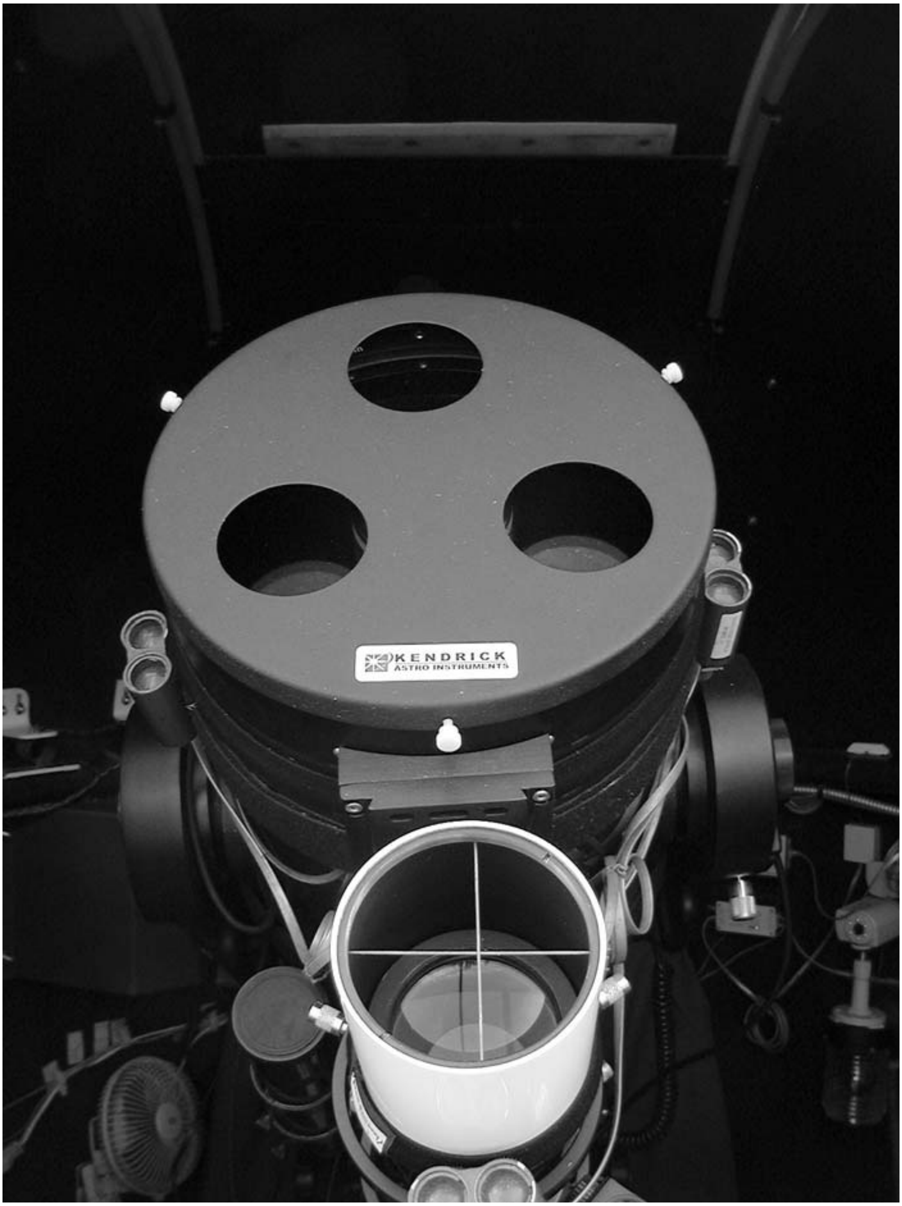


Figure 2.33. Hartmann mask on the Meade LX200. A Hartmann mask with three holes is a focusing aide. See text for explanation. (Used with permission, Kendrick Astro Instruments, Inc.)

time by a factor of 3. Focal reducers are the opposite of a Barlow lens, shortening the telescope's focal length and reducing the magnification. Most reducers suffer some form of vignetting when used with an SCT: The FOV gets cut off at the edges, which can be corrected by using flat fields (discussed in Chapters III and IV).

I keep a small vacuum cleaner in the observatory (I am a neat freak!) and use carpet fresh deodorizer with baking soda a few times a year. Ant bait traps are spread around the perimeter of the dome base and are changed every few months. There is only so much you can do to thwart minor infestations, however. Because the dome is not 100% impervious to the outside elements, once in a while a wasp takes up refuge on the ceiling and I have a rude awakening when I open the dome after a prolonged absence to find that an entire nest has formed.

J. ToUcam Camcorder

The ToUcam Pro PCVC740K camcorder (Philips, Inc.) is one of many popular camcorders that has revolutionized the ability to capture magnificent images of solar system objects (planets, Moon, Sun) and, with camera modifications, extended deep space objects. For less than $100.00 (54£) out of the box, this camera can easily be attached to a telescope (in place of an eyepiece) and wonderful images can be downloaded and displayed on a PC monitor in real time. The CCD chip is 640 × 480 pixels and produces satisfying results at 5–10 frames per second. The camera weighs a mere 100 g (4 oz.) and is powered via a USB cable. Camera adjustment parameters include frame rate, contrast, gamma, brightness, white balance, exposure control, and backlight compensation.

I like to take 45–60 s worth of images with the ToUcam attached to my LX200 typically with a 2× or 3× Barlow lens [effective focal length of 5000 or 7500-mm (197-in. or 295-in.) respectively]. If the seeing conditions permit, the number of frames that capture good detail can be numerous. Software packages can stack these frames to produce a smooth and detailed image.

There is an entire online community (QCUIAG, Quickcam and Unconventional Imaging Astronomy Group) devoted to discussing these cameras, as well as video surveillance and digital cameras. Modifying these cameras so that they perform much like a dedicated cooled CCD camera has a large and popular following in the astroimaging community.

I use the software that came with the camera in order to capture images, but another popular capture and initial processing program is Peter Katreniak's K3CCD Tools program. Video is memory-intensive. Each second of captured Audio Video Interleave (AVI) file is approximately 1 MB in size, so a hard drive can fill up quickly.

One neat feature of using a camcorder and the telescope is the sweeping vistas of the Moon that can be viewed in real time. Using the LX200 keypad, the surface of the Moon can be panned over as if you are in orbit, looking for a favorable landing site! A future cable run from my observatory will allow me to download the images to a wide-screen high definition television (HDTV) in the family room, which should give an impressive view of the Moon and planets in real time.

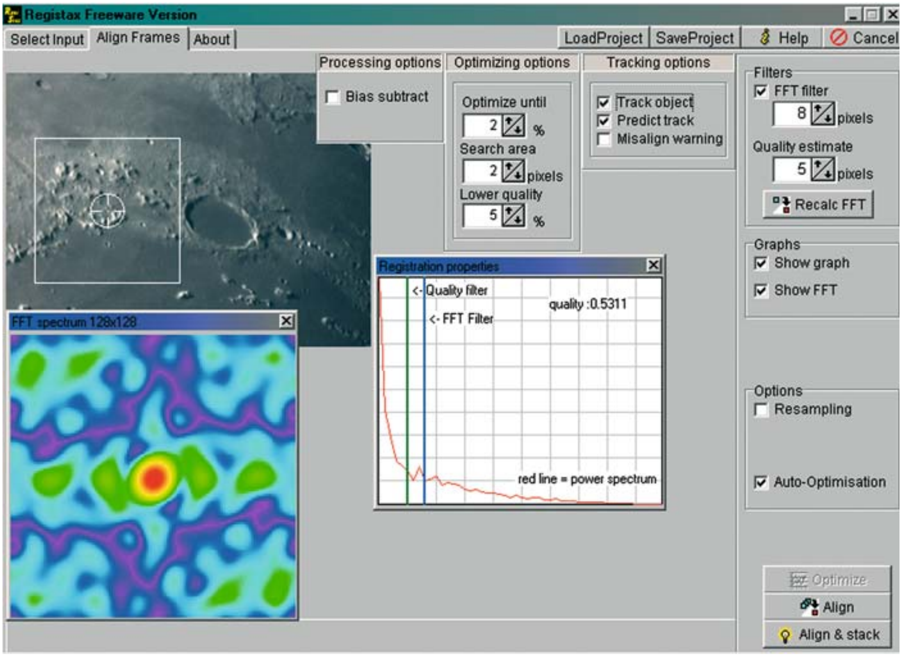


Figure 2.34. Registax version 2.1.13 screen capture. Single frame of a 300 frame AVI file, showing Moon crater Plato and selection box with crosshairs. All frames will be aligned and stacked, based on various quality parameters that the user can define. (Used with permission, Cor Berrevoets' RegiStax Version 2.1.13 Beta.)

Cor Berrevoets and his development team are the software authors of the famous RegiStax program, which is now in its third version as of January 2005. This freeware allows hundreds of frames of an AVI film, downloaded from a camcorder, for example, to be aligned and stacked utilizing a very user-friendly interface. Processing options and wavelet filters make this program a necessary addition to your imaging and processing program (see Figs. 2.34 and 2.35).

I also installed a wireless black-and-white video surveillance camera and keep a small monitor in my home office. When I am remotely operating an imaging session, I like to see the interior of the observatory and visually confirm telescope slews if the movement across the sky is extended. I also like to monitor the telescope during a slew to prevent any potential cable wrap. When doing a large slew or when imaging near the zenith, the camera swings very close to the Superwedge, so I like to monitor this.

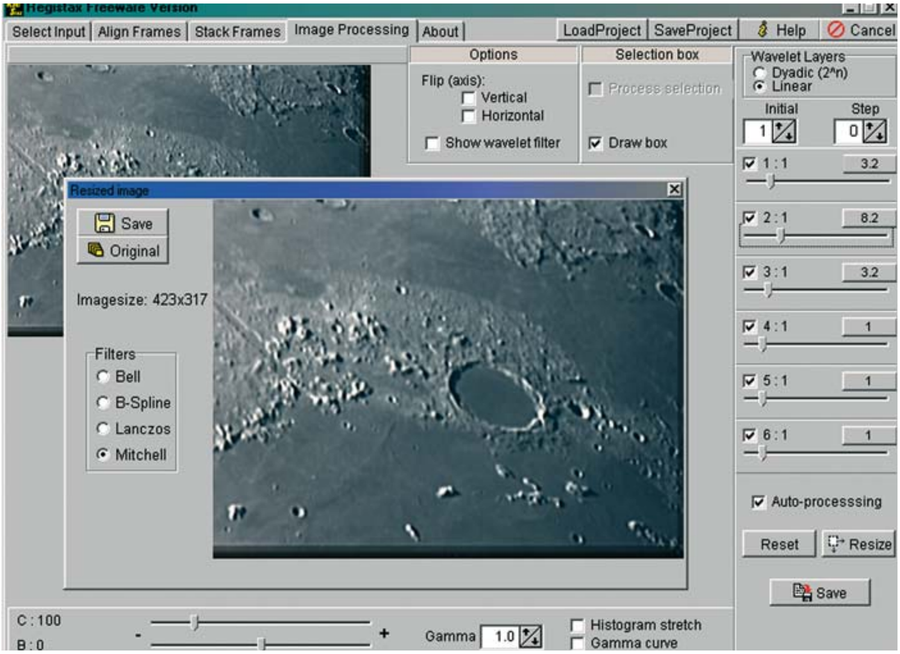


Figure 2.35. Registax version 2.1.13 screen capture. Aligned and stacked AVI file of Moon crater Plato. Image can be resampled and saved in several formats for subsequent processing. (Used with permission, Cor Berrevoets' RegiStax Version 2.1.13 Beta.)

CHAPTER THREE

A Night of Imaging Under the Stars (and Clouds)

One of the great things about having all of my imaging equipment securely housed in an observatory is the quick setup routine to power-up and power-down for the evening. When the weather changes in a heartbeat, it is less of a physical drain to call it a night and close up shop. When the weatherman fails to accurately forecast the night's weather and the clouds part above my backyard, it is just as easy to turn the key and open the observatory for the evening. I can set up in less than 10 min and close up in less than 5 min.

I do an accurate polar alignment at least twice a year. My pier is not subject to any movement due to frost lines or soil shifts, but I do a *drift alignment* in order to eliminate any declination drift. Drift alignment is a technique used to get the polar axis of your telescope parallel with the polar axis of the Earth. It is done by watching selected stars "drift" in declination while viewing them. For an easy-to-understand approach, see Chuck Vaughn's treatment referenced in Chapter VIII. From the type of declination drift, we can determine which way our scope is mis-aligned and can correct it accordingly. Thus, the name "drift align."

During the work week, I keep track of my local weather with a live radar Doppler loop feed, displayed on my computer with a Java applet. Many local television news agencies in the United States that have an Internet site have a local online forecast, updated several times during the day, if not a direct link to live Doppler radar. Another great Internet site used for planning is the Clear Sky Clock at www.cleardarksky.com. At a glance, it shows when it will be cloudy or clear for up to the next 2 days. It is a prediction of when your site and the surrounding 10 miles (17 km) will have good weather for astronomical observing. The forecast data comes from the Canadian Meteorological Center, which is unique because the forecasts are specifically designed for astronomers. There are clocks for 2292 locations.

What conditions make for a good or great night of imaging? Two items come to mind. First, equipment needs to be optimized. It is important to match the telescope's focal ratio to the camera in order to maximize resolving power of the CCD-telescope combination. Nyquist sampling theory requires two pixels for each unit of resolving power. For example, if your telescope/camera can resolve 1 arc-second/pixel, you should ideally choose a configuration that ensures two pixels per arc-second in order to maximize the resolution. *Binning* refers to the ability to combine pixels. A CCD chip is an array of rectangular light detecting regions (pixels). Sometimes images can be taken by combining the information in adjacent pixels and make them one effective superpixel. The advantage of binning is that there is a reduction in noise and the camera sensitivity is improved, both at the cost of lower resolution. When one pixel in the camera maps to one pixel in the image, the camera is said to be at its highest resolution.

Image scale describes how much sky each pixel covers. Imaging conditions will impact the theoretical limit of your equipment's resolution on any given night. My Stellarvue refractor and HX916 camera image with a resolution of just less than 2.8 arc-seconds/pixel. The LX200 reduced to 1575 mm (62 in.) focal length and HX916 camera image with a resolution less than 1 arc-second/pixel; this is very difficult to do given my imaging conditions. The weather is the second determinant that impacts a good night of imaging. A few weather-related terms as they are used in astronomy should be discussed. *Cloud cover* is obvious and refers to total cloud cover over an extended area. Local forecasts might miss low clouds and afternoon thunderstorms however. *Transparency* refers to the total transparency of the atmosphere from ground to space and is calculated from the total amount of water vapor in the air. Above-average transparency is necessary for good observation of low-contrast objects like galaxies and nebulae. Deep sky imaging is best done on nights of high atmospheric transparency. Cold fronts that move through your area usually help by bringing in cold, dry, clean air and washing out pollutants and dust. However, open star clusters and planetary nebulae are quite observable in below-average transparency. Large globular star clusters and planets can be observed in poor transparency.

Excellent *seeing* means that at high magnification you will see fine detail on planets. In bad seeing, planets might look fuzzy and lack detail at any magnification, but the view of galaxies and open star clusters is probably undiminished. Bad seeing is caused by turbulence combined with temperature differences in the atmosphere. Daytime heating contributes to nighttime seeing, especially if you image over a large concrete or asphalt area. Some people observe worse seeing though their telescope than what a perfect seeing forecast would predict because of tube currents.

Darkness is not a weather term but it tells you when the sky will be dark, assuming no light pollution and a clear sky. It takes into account the Sun's and Moon's position, moon phase, and solar cycle. It does not consider light pollution, dust, clouds, snow cover or the observer's visual acuity. Thus, your actual limiting magnitude might be different.

Some imagers need to know about *wind speed*. The wind forecast will not necessarily determine whether or not you can observe, but it will probably affect your ability to image. In particular, long-focal-length astrophotography or observing with large dobsonians require light wind conditions. Large dew shields, which act like sails, might be impossible to use in windy conditions. Having a telescope protected by observatory walls allows for imaging in otherwise poor conditions due to light winds and can help block out line-of-sight stray light (glare).

Humidity variations will not determine whether you can observe, but it might affect observer comfort and can indicate the likelihood of dewing. However, dewing is not simply correlated to relative humidity. Dewing tends to happen when the sky is clear, the temperature is dropping, and there is not much wind. A forecast of 95% humidity under a darkening sky is a pretty good clue that the dome should remain closed: It is about to rain!

Temperature near the ground is often reported. Although temperature variations will not determine if you can observe, the forecast can be handy for choosing clothing for cold observing conditions. Observers with thick primary mirrors should take note of falling temperature conditions because their mirrors might require additional cooling to reach equilibrium and thus prevent tube currents.

It is a short walk to the observatory. I turn a key and throw a toggle switch, and the electric shutter opens. A wall-mounted hygrometer tells me that the current temperature inside the observatory is within a few degrees of outside temperature, so it does not take long for all of the equipment to reach thermoequilibrium (usually within 15–20 min). My Gateway desktop computer is already on and in hibernate mode, so after "waking up," I confirm that the local network is intact and then plug in the CCD camera and STV autoguider unit. I turn on the Kendrick dew heater, which keeps the LX200 corrector plate and refractor objective glass free of dew. Some nights I image unguided if integrations are less than 180 s, but I set up the autoguider nevertheless, because the camera will be nice and chilled should I decide to image with extended integrations. Finally, I turn on the LX200 and hear the familiar "beep." The initialize routine on the LX200 paddle (version 3.4 firmware) is effortless for a permanently mounted telescope. The hand-paddle menu will have a checkmark next to Polar Mode and all you have to do is hit ENTER.

With the computer on, I open the various programs that I will use on the observatory desktop. TheSky (Software Bisque, Inc.) is my planetarium and telescope-control software. I select a bright star in the sky (during twilight) that I can visually see and can identify, place the mouse cursor on the same star in the virtual sky, and synchronize on it. Now, the telescope and computer are synchronized in terms of location. I use a freeware program called Atomic Clock Sync (v2.6) (www.worldtimeserver.com) to synchronize my PC clock with a time server. When I update the time clock in TheSky, the signal updates the LX200 hand paddle and now the telescope, PC, and software are all synchronized.

I load the freeware program RealVNC Viewer, which makes it possible to view and fully interact with one computer from any other computer on the local network. My office desktop PC, 150 ft (45 m) away, can control the telescope and any opened software program on the observatory PC desktop. The observatory PC acts as the host and the office PC is the client. I also open Astroart 3.0 to control the camera and STV Remote to control/monitor the autoguider.

The STV autoguider must be initialized with the correct time and date, and you must verify that the telescope parameters are correct (aperture, focal length, type of telescope you are guiding through, etc). I usually guide with a Meade 3.3 focal reducer or a Celestron 6.3 focal reducer. The effective focal length becomes 825 mm (32 in.) and 1575 mm (62 in.), respectively, from a native 2500 mm (98 in.) at f/10.

The STV autoguider takes exposures of a small part of the sky. A guide star is chosen, and after each exposure in two positions along each axis, guiding software measures the drift of the star and directs the mount to move in order to return the star to the same starting location. The STV can make measurements as accurate as 1/30 of a pixel. The precision that is required for successful guiding is measured in arc-seconds, or 1/3600 of a degree. The R.A. axis is always moving during a guided exposure, and the autoguider tries to keep up with the apparent motion of the slowly rotating Earth. The declination axis is stationary unless a correction is made.

I manually slew the telescope while looking through the 8 × 50-mm finder scope until I spot a relatively bright star. Because I am synchronized with TheSky, I could also point and click with the mouse on the virtual sky and slew to a star. My LX200 GOTO accuracy is fairly good in most parts of the sky, so I would come close to the intended target if using TheSky. Either way works fine. The finder scope, piggybacked Stellarvue refractor, and LX200 are optically aligned along the same axis, so the guide star is also visible on the LCD screen of the STV. I go through the Calibrate routine in the STV to ensure that the LX200 mount properly tracks along all four axes. When each axis receives a “Pass” message, you are ready to Track. Calibration allows the STV camera control software to model the LX200’s behavior during guiding corrections. Some imagers recalibrate when declination changes by 10° or more or when imaging in a part of the sky very different from where the initial calibration took place.

I own a manual Astronomik filter holder (Astronomik, Inc.), which attaches between the telescope and camera. Whether I am imaging in monochrome or contemplating trichrome color imaging, my Astronomik filter set is *almost* parfocal and very little focus adjustment is necessary if I need to change filters during an evening’s imaging session. Whether you can afford a more expensive motorized filter wheel or a more affordable filter holder, the requirement is the same: You do not want to touch the telescope or change the camera orientation in any way.

Astroart 3.0 is initialized and the first order of business is to go through the focus routine, which is iterative. Although a star is a point source, you cannot shrink a star’s image to a point regardless of how perfect your focus is. The sequence is straightforward. I take a short exposure of a star (simultaneously present on the STV LCD screen and in the finder scope), and after it is downloaded to the desktop (11 s when binning 1×1, approximately 3 s when binning 2×2), I draw a selection box around the star. The size of the selection box is sensitive and will determine whether you see a scintillating star within a small focus box (see Fig. 3.1), in real-time on your desktop, or whether you see random noise (see Fig. 3.2). Typical settings for the focus routine are 0.3-s integrations, unbinned 1×1. Fabio Cavicchio at MSB Software, Inc. suggests that the focus box need not be constrained in size, but in practice, any box larger than 30+ pixels on a side does not initialize the focusing routine.

I manually tweak the knob of the Crayford focuser on the Stellarvue refractor (my JMI electric focuser is attached to the LX200) until the star pattern in the focus window is a tight cluster of pixels. Stars do not focus to a true point, but usually a small pixelated cross-pattern is attained. The idea is to get the Fwhm_X and Fwhm_Y values as small as possible and the total star count (expressed in ADU values) as high as possible. Fwhm refers to full-width half-maximum, which better reflects the approximate size of the star's image as seen by the eye. It is the width across a Gaussian profile of the star's light when it drops to half of its peak, or maximum, value. It is a simple and well-defined number that can be used to compare the quality of images obtained under different observing conditions. On a steady night of imaging, a magnitude 6 star typically yields both Fwhm_X and Fwhm_Y values under 1.5 with my setup. The better the focus, the brighter the pixel values because the star light is concentrated into a tighter image area. Atmospheric turbulence will scatter light and cause the star to dance around a bit. I have two 0.0625-in.-diameter (1.5-mm) lengths of wire perpendicular to each other just inside the threaded lip of my refractor dew shield. These wires produce an artificial diffraction spike pattern by partially blocking the light and this makes it easier to appreciate perfect focus during the focus routine. I lock down the draw tube to keep the camera and filter holder at perfect focus. Take the time to perfect your focusing routine: Nothing else that you do tonight will have as dramatic effect on the quality of your images. Sitting down with your images,

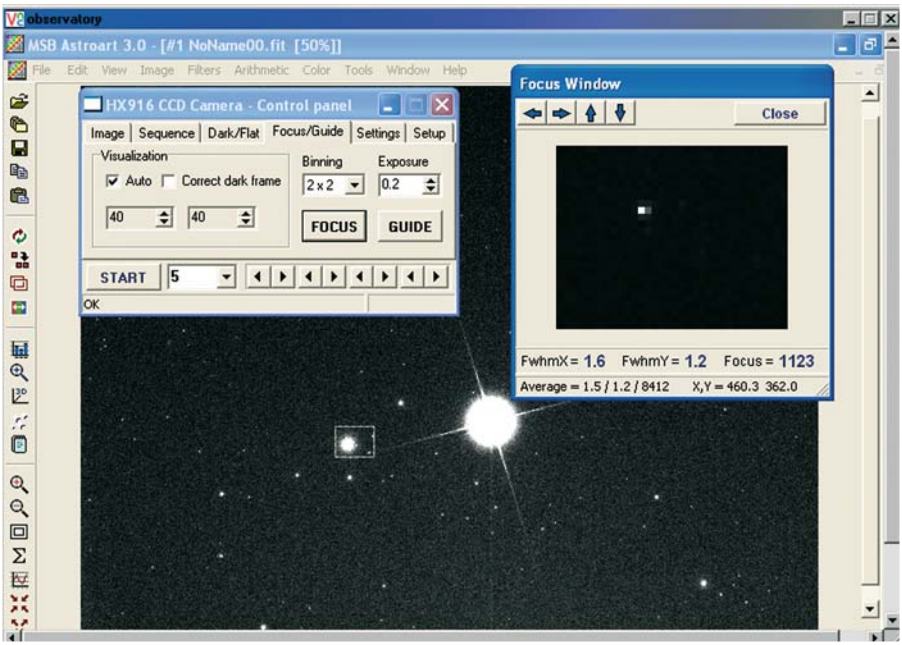


Figure 3.1. Astroart 3.0 screen capture. Selection box has been drawn around a magnitude 4 star, to the left of bright Procyon (magnitude 0.5). Diffraction spikes are artificial. Focus window reveals good focus for image: Fwhm_X and Fwhm_Y values are unchanging and a Focus value of 1123 is maximum. (Used with permission, MSB Software, Inc.).

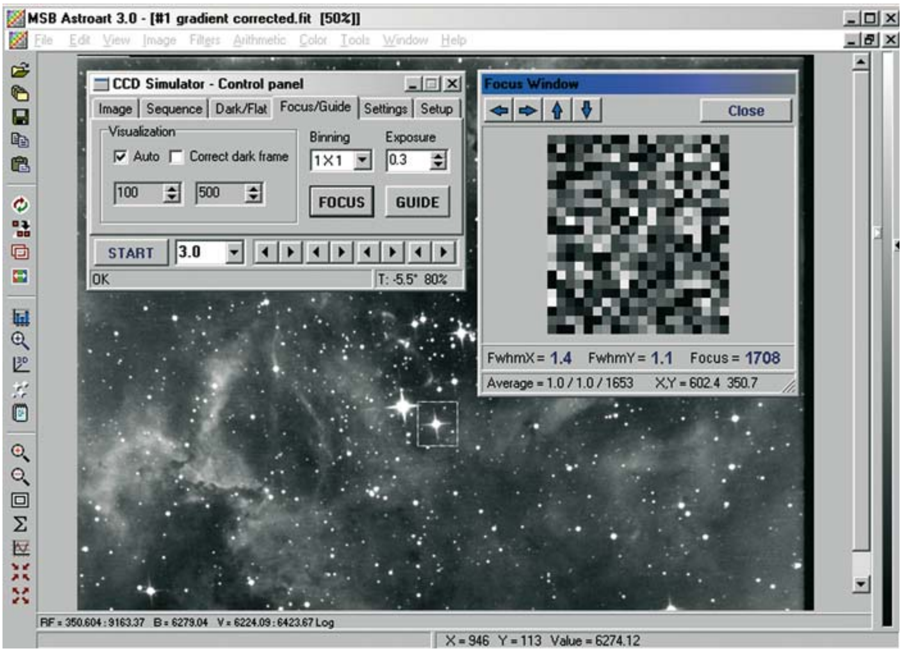


Figure 3.2. Astroart 3.0 screen capture. Selection box has been drawn around a star in the Rosette Nebula. Diffraction spikes are artificial. Focus window reveals good focus for image: $Fwhm_X$ and $Fwhm_Y$ values are unchanging and a Focus value of 1708 is maximum, but the focus window does not show star. This is a known bug with the software and the Windows operating system. (Used with permission, MSB Software).

hours after acquiring them, only to find fuzzy donuts instead of crisp stars is an eye-opening experience, not to be repeated.

Now the autoguider is calibrated; the camera is cooled and focused, the planetarium software, computer, and LX200 are time-synchronized, and the office PC is client-enabled and can control the host PC in the observatory. There is only one thing left to do: select a target to image! Ideally, target selection should be made in advance of beginning your imaging session. As alluded to previously, it is desirous to image a target as it is transiting or approaching culmination (i.e., its highest point in the sky). Sometimes, depending on scheduling, I have no idea what “is up” and I scan the local meridian for any objects that happen to be transiting at the particular time that I am imaging. I place the telescope mouse cursor in TheSky on the local meridian and slew through safe declination limits of the telescope, scanning the FOV display and looking for an interesting target (see Fig. 3.3).

A target is selected and a test exposure is made. Individual frames should have as long an integration as possible without saturating key parts of the image that you are trying to make. In the real world, this will depend on the quality of your mount without getting star trailing, how long you can go before skyglow domi-

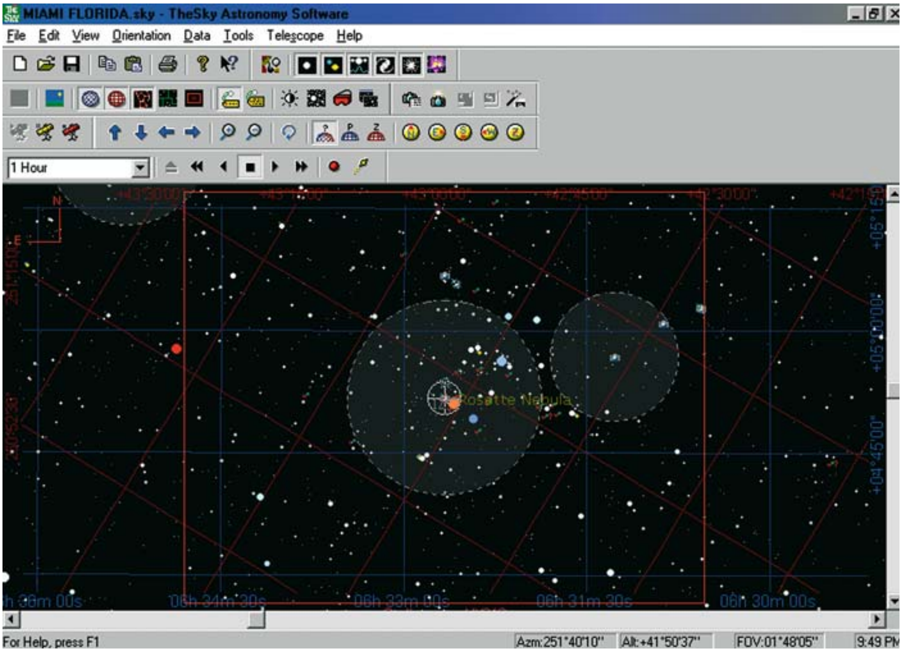


Figure 3.3. TheSky version 5, Level 4 screen capture. Rectangle depicts FOV of Starlight Xpress HX916 camera and Stellarvue® Nighthawk refractor, an impressive 49 × 62 arc-minutes. The gray circles denote the approximate filamentous extensions of the nebulae. Orientation of the field has been matched to camera orientation: note the N and E (for North and East, respectively) in the upper left corner. (Used with permission, Software Bisque, Inc.)

nates the image, and so forth. I rotate the virtual sky's FOV so North is up (and East is to the left) and this matches my camera orientation, which is orthogonal to the telescope's R.A. and Dec. axes. I am looking at a few things when I shoot my test exposure. First, I want to be able to see the object and not have it overwhelmed by background skyglow. I typically image anywhere from 120 to 600 s. If an extended deep-space object is in a dense star field with bright stars, for aesthetic reasons I might plan ahead and take 30–60 s images in order to capture the star field without having unacceptable star bloat or saturation. I then take deeper integrations in order to record the extended object. Processing routines (discussed later) allow combining both integrations in order to showcase a pleasing star field and deep extended object.

I engage the autoguider and hope that there is an adequate star in the field to use as a guide. Sometimes this is the trickiest part of trying to begin an imaging session. I can say from experience that this is where skyglow has an immediate impact on an imaging session. Magnitude 6+ stars that are good to guide on are sometimes unavailable in the field that is being imaged. The STV guider can be tweaked by increasing the integration time of the camera, but the goal with my LX200 mount is to guide with less than 2–4-s exposures, trying to get star ADU counts of less than 2500 units. The longer the integration used for guiding, the greater the likelihood of recording a guide star at the expense of poor mount performance. A 1–3-s exposure is usually just right. Too short of an exposure and the guider will be guiding more on seeing than on a star and be correcting all over the place. Too long an integration and the mount might wander too much during the exposure, and you will have large correction swings. The only rule of thumb is "the shorter the better," but depending on seeing, the value might change night to night.

Aggressiveness on the autoguider can also be changed. A setting of 1 on the STV means that the guider will make the full correction it calculates it needs to make. So, if the guide star is 0.4 pixels off in R.A., for example, it will try to move 0.4 pixels with a setting of 1. The aggressiveness is balanced by the Max Correction, which is the maximum pixel distance the STV will try to move the telescope for any one correction. So, if the STV determines that the guide star is 0.4 pixels off in R.A. but the Max Correction is set to 0.5, the calculated move will be 0.2 pixels, and after another guide exposure, the remaining error might be corrected (as long as the mount does not add more error in the meantime!) You want to keep oscillations to a minimum and produce less erratic and smoother corrections. The aggressiveness, Max Correction, and averaging of calculated movements before a correction is made can be adjusted in real time, so all is not lost if guide exposure integration times cannot be held to less than approximately 2 s.

The Technical Innovations Home-Dome design of the 6-ft (1.83-m) dome does not have a split front door. This means that the opened dome slot must be in the home position in order to enter or exit the dome. The door and supporting dome ring must be aligned in the home position for the door to open. This is fine if you only want to image on the local meridian (R.A. = 0, any Dec. within the telescope's safe slewing limits) or if you do not mind staying inside the dome during an entire imaging session. Because my goal during most imaging sessions is to go inside my house and monitor/control the session from my office computer, I needed a way to get out of the dome. Jerry Smith at Technical Innovations helped me modify the front door and latch system. I can now enter and exit the dome regardless of the orientation of the dome slot and telescope (see Fig. 3.4).

When a test exposure is adequate, I sync the artificial telescope cursor in TheSky with the target as it appears in the virtual sky. The Astroart 3.0 camera control software allows for several items to be selected: exposure length, number of exposures, binning mode, and a file name and directory location in which all images will be saved.

I engage the IR detectors that are attached to the LX200 and piggybacked refractor: These sensors keep track of the dome slot opening, and during an extended imaging session, they automatically direct two dome motors to rotate the dome counterclockwise in R.A., always keeping the dome slot opening in front of the telescope. I engage the STV autoguider, begin the camera integrations, and exit the dome. On my office PC desktop, the STV autoguider window, planetarium software, and camera control window are all available during the remote imaging session. Figure 3.5 shows a RealVNC screen shot on my control room computer, with the STVRemote program open on the desktop.

Noise, which shows up as graininess in an image, is approached with specialized imaging frames. In addition to light frames, other images need to be taken

Figure 3.4. Technical Innovations Home-Dome with a modified front door and latch system. Entry and exit can take place regardless of the position of the dome slot. (Used with permission).

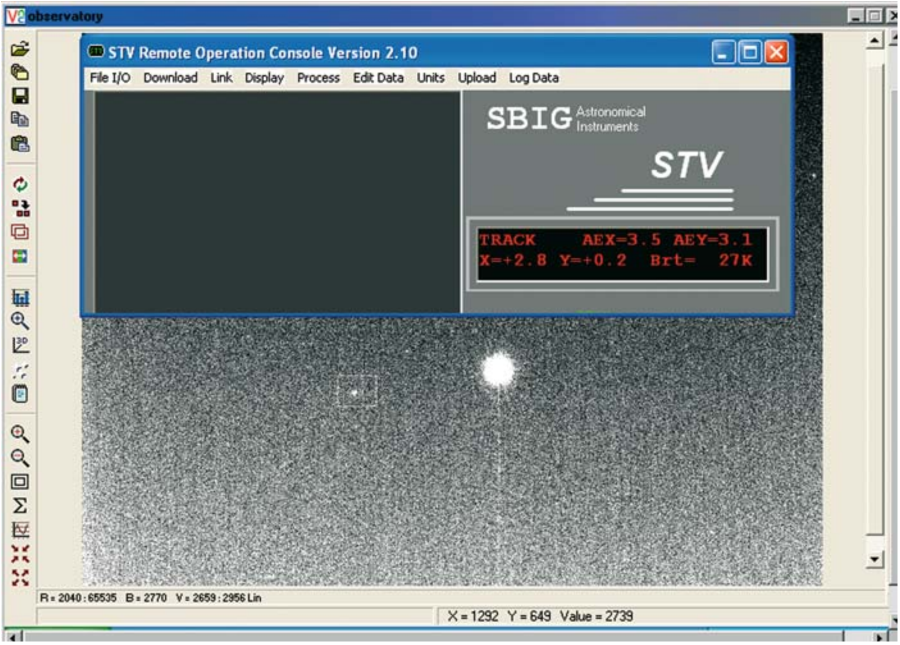


Figure 3.5. RealVNC software screen capture on control room computer. An image of a star (with selection box) has been captured by a Starlight Xpress HX916 camera and downloaded to the observatory computer. The same star is being tracked by the STV camera, and instantaneous X and Y pixel movements are shown in the window. AEX and AEY values represent average moves made over the preceding 16 corrections, made in both R.A and Dec., respectively. (Used with permission, Santa Barbara Instruments Group).

(in groups of 5–10, or more) that will be used during image processing. These other types of image are bias frames, dark frames, and flat-field frames. When the exposure time is close to zero (1 ms is the shortest exposure on my HX916), we would expect pixel values to be close to zero-brightness. A *bias* frame represents the pixel brightness values recorded by the CCD detector at almost zero exposure time, with the lens cap on. It represents residual system noise that is always present, regardless of the duration of an exposure. The noise is typically so low in the bias frame that many imagers do not bother incorporating them in their data reduction routine. If your dark frame and light frame images have the same exposure time, you do not have to take bias frames.

Dark frames represent the thermal noise present on the CCD chip when no light strikes the CCD detector. Each dark frame represents reproducible noise on a CCD chip for a specified integration time and temperature. The greater the cooling in the camera, the lower the thermal noise. Dark frame images are taken with the same integration time as a light frame. Thermal noise varies from image to image, but if the temperature remains fairly constant, the dark frame will be fairly consistent (see Fig. 3.6). Incorporating dark frames during image reduction

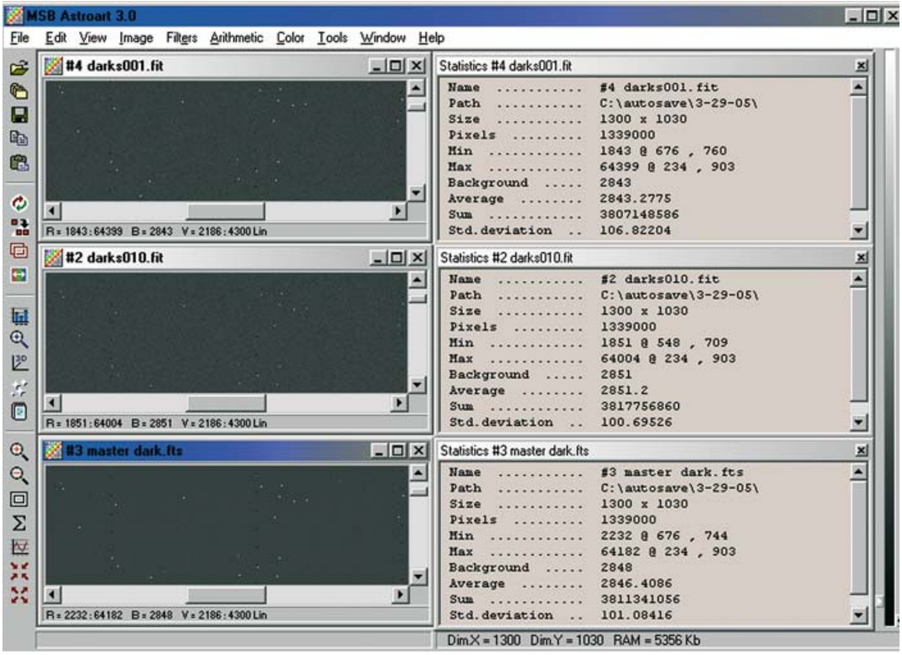


Figure 3.6. Astroart 3.0 screen capture. Dark frame image comparison. Dark frames 001 and 010 are each of 180-s duration, taken 32 min apart factoring in the 11-s USB download time for each. The Starlight Xpress HX916 camera does a good job at keeping the camera CCD chip cooled, as the average ADU count and standard deviation are in good agreement. Observatory conditions at the time of exposure were 85°F (29°C) and 80% humidity. The master dark frame is a median combine of the 10 images. (Used with permission, MSB Software, Inc.).

additionally eliminates cosmic ray hits. The idea is to subtract the dark frame from the light frame in order to leave an accurate and clean record of the light that the CCD detector recorded, eliminating artifacts such as hot pixels and cosmic ray hits.

Flat-field frames are taken to record the variations in brightness, reflections, and optical artifacts (dust motes, lint) located anywhere in the imaging train. The visual impact of dust varies with its distance from the CCD chip (the focal plane). Flat fields will help correct uneven backgrounds due to vignetting when a focal reducer is used. To create the flat field, what you want to do is take an image of a very evenly illuminated surface. This is not as easy as it might sound because an evenly illuminated surface presenting itself square to the CCD chip's surface is required. Learn a technique, any technique, and you will appreciate the big difference in the appearance of your images. Flat-field techniques include stretching a white tee-shirt over the telescope tube opening, taking an image of the sky at twilight (with hopefully none to few stars present), taking an image of a sky that is clouded over, or using a light box. Regardless of the technique that you use, you

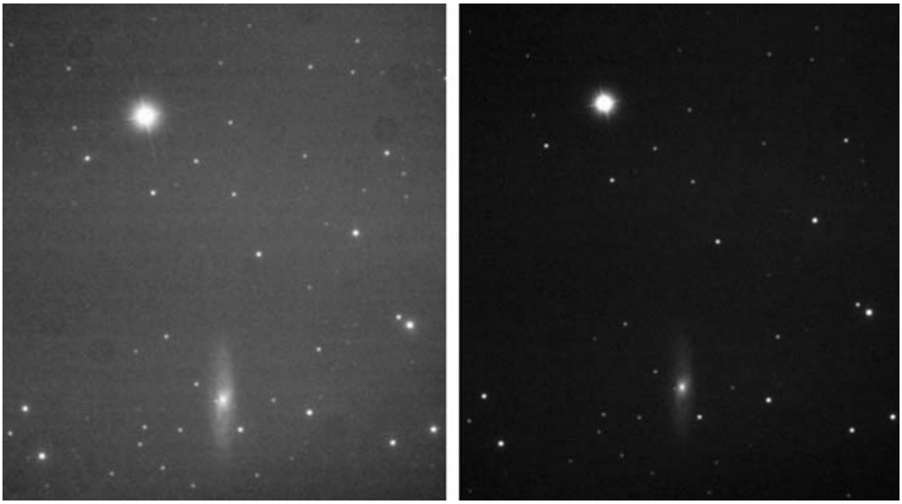


Figure 3.7. Dark frame-reduced (left) and dark- and flat-field-reduced (right) image of spiral galaxy M65.

must not rotate the camera, change focus, add (or remove) a dew shield, or change a filter. The focus position cannot change because the shadows created by the dust motes will change in size on the image. You are trying to capture an image of your optical system in the same arrangement as the light images were taken. See Fig. 3.7 for an example of dark frame and flat-field image reduction on spiral galaxy M65.

There are a few considerations to keep in mind. Flat fields are difficult to take during a bright Moon or if there is a nearby bright light because of the resulting gradient that will most certainly show up. Off-axis (oblique) lighting can also cause problems because of the uneven illumination that will fall on the CCD chip. A gradient that is created on your flat-field frames makes it more difficult to process out, but it is not impossible. If you are doing trichrome imaging, the gradients that are created in a less-than-ideal flat and even background can cause wild color variations among the red, green, and blue frames.

Building a light box will allow you to control the flat-field process (see Fig. 3.8). No longer do you have to worry about extraneous or off-axis light. A light box is constructed large enough to fit snuggly over the end of your telescope tube. There are several plans available on the Internet to construct a sturdy, inexpensive box. My box is made of foam board and clear plastic. I used a glue gun to attach the sides of the box. Four incandescent white bulbs provide the internal illumination, which is filtered through a sheet of drafter's vellum (some people use milk plastic) before illuminating the CCD chip. I use an AC/DC regulator and dimmer switch so that I do not go through too many 9-V batteries. I use an integration time so that ADU counts are roughly 40–60% of the CCD chip's saturation level (two-thirds well capacity for my HX916). For the HX916, I usually get counts of 26,000 to 40,000 ADU.

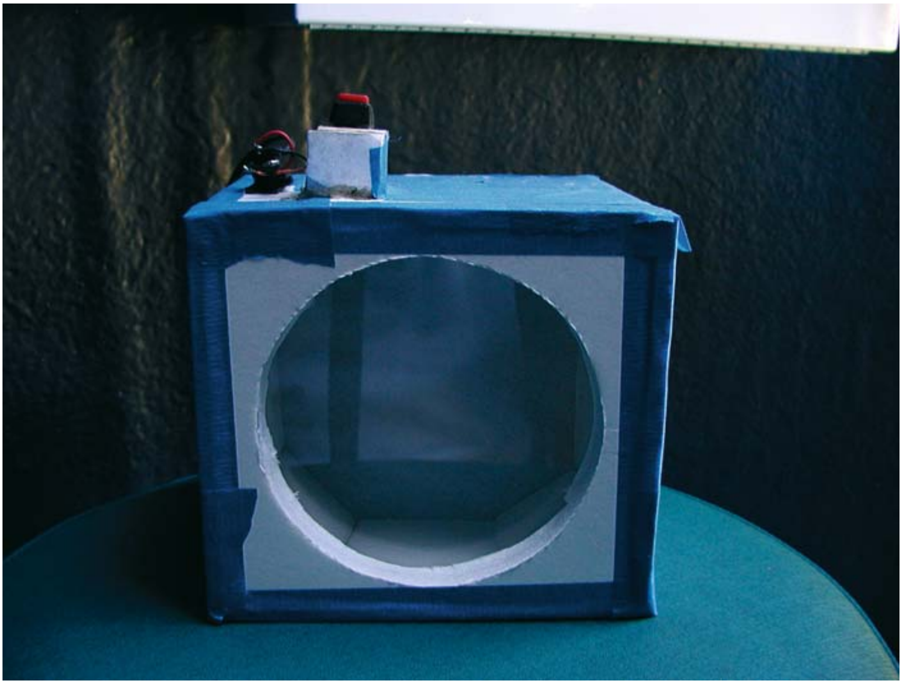


Figure 3.8. Light box for flat-field images, constructed of foamcore board and clear plastic. The round circle just fits the dew shield of the Stellarvue refractor (80 mm). Black and red switch for use with the AC/DC regulator is at the top of the box.

CHAPTER FOUR

Processing Astrophotos Made Simple

Well, let us cut to the chase: There really is nothing "simple" about processing astrophotos. Oh, how I wish it were simple! The good news is that there are many talented imagers out there who have paved the way for the likes of us newcomers. If your favorite image processing software has a less-than reader-friendly manual, there is a good chance that several people are online, on any of several Internet groups, at any hour of the day, anywhere in the world, willing and eager to answer your questions. Processing your images, however, is not a one-size-fits-all endeavor. When I started image processing in early 2002, I was dismayed that there was no single book, reference sheet, or manual that explained what to do, in easy-to-understand language.

To be sure, there are *lots* of good books on the subject, *lots* of software to select from to accomplish your goals, and *plenty* of knowledgeable and friendly imagers out there willing to assist you. Like everything else in life, it takes some effort to get good at something meaningful. Read and assimilate whatever you can get your hands on and put what you learn to use during an image processing session by practicing different techniques. This chapter is intended to describe in some detail what is involved in image processing, from a beginner's perspective. All one needs to do is skim the several-hundred-page book by Ron Wodaski (*The New CCD Astronomy*, The New Astronomy Press, 2002) to appreciate that my approach and treatment of the subject merely glosses over the fundamentals. After reading this chapter, you will not be magically transformed into a Robert Gendler, a Tony Hallas, a David Malin, or a Dennis di Cicco. You might not be *any* further along the learning curve. However, this is the approach that works for me after a few years of trial and error. Hopefully, you might pick up a pearl or two.

The Internet makes it possible to quickly see the images of our colleagues around the world. We can read about their setups and study their equipment,

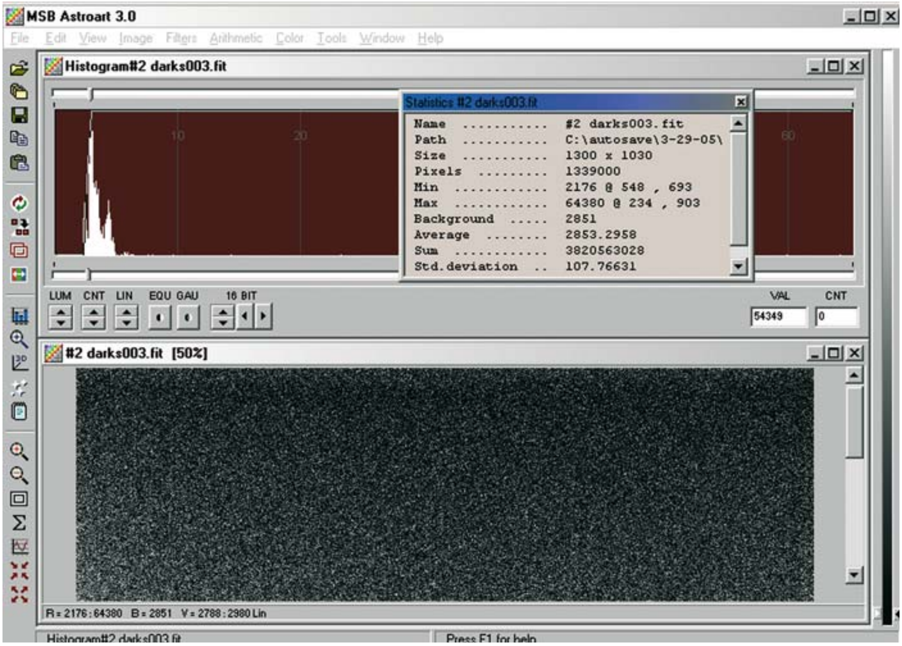


Figure 4.1. Astroart 3.0 screen capture. Single 180-s-integration raw dark frame. Range of pixel values is 2176 to 64380, with the histogram showing the majority clustered at around 3000 ADU counts. (Used with permission, MSB Software, Inc.)

compare image resolution, and get a hint of imaging sky conditions and local weather. Many imagers are natural teachers: Their websites not only proudly display their images, but many imagers are eager to share their processing skills and techniques and invite others to email them with questions. “See one, do one, teach one.”

The best CCD images have a good SNR. To get the highest possible ratio when imaging under light-polluted skies, we should take the longest possible exposures and combine multiple images. Image processing ultimately begins at the telescope, because proper planning involves taking critically focused light images and matching dark frames, and taking flat-field images. Many images of long-enough duration need to be available for stacking when you sit down to process them in order to combine them into a high-quality image.

Thus, the imaging session has come to an end, and it is either late at night or early the next morning. You have accumulated your raw images and matching-integration dark frames (see Fig. 4.1), flat-field images (see Fig. 4.2) and their matching dark frames, and bias frames (see Fig. 4.3) have been taken. If you are doing trichrome imaging, each filter should ideally have a set of flats and matching darks for the flats. The first thing I do is transfer the contents of the folder that all of the images are saved in to a folder on my office PC. I transfer across the local network, which takes several minutes. I leave the computer in hibernate

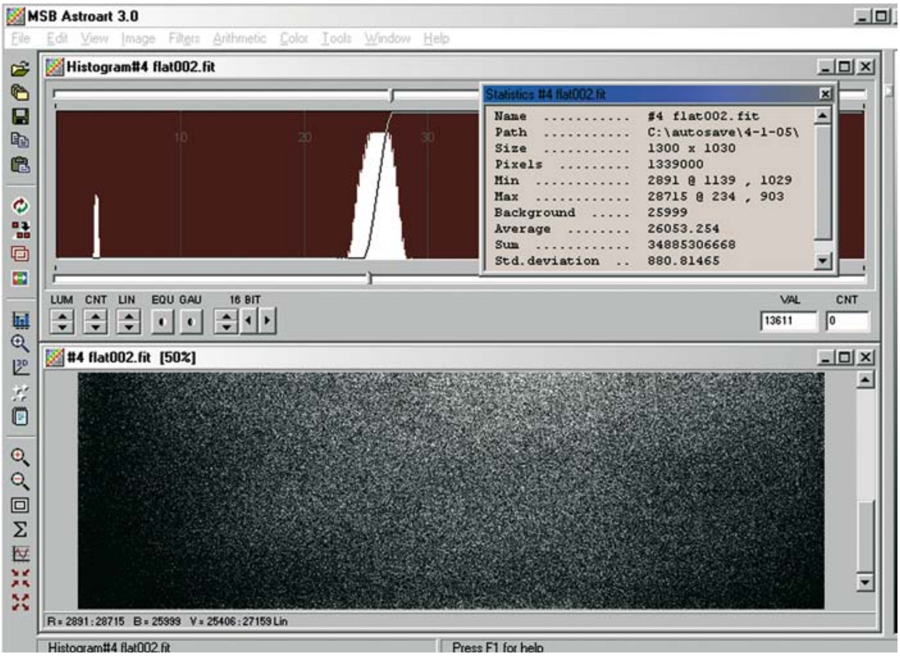


Figure 4.2. Astroart 3.0 screen capture. Single 0.5-s flat-field frame, raw image. Notice the dark black corners at the bottom left and right of image. This represents optical vignetting. A flat field will correct the same dark black corners of the image frames. (Used with permission, MSB Software, Inc.)

mode and close down the observatory, covering the telescope and unplugging the telescope and cameras. Depending on the time (and whether you have to work the next day), there is now a folder of images sitting on the office computer's hard drive, ready to be processed. This folder contains the fruits of our labor, what we worked so hard to obtain.

Image reduction (or *calibration*) refers to cleaning up your images in order to reveal the wanted data in the best possible light (pun intended). We want to correct defects in the image-taking process and remove some of the noise that is random and unpredictable (variations in brightness levels among and between multiple exposures), as well as some of the *system noise*, which is inherent in the equipment. When the camera is cooled, for example, the CCD detector has less noise and you will be closer to a higher-quality raw image. Like focusing, image processing rewards begin with optimizing all conditions at the telescope. Noise and unwanted artifacts that we can do something about include optical dust, background noise (skyglow), and internal reflections in the optical train.

Calibration refers to what we need to do first, which is remove the noise from our images. AIP4WIN software (Willmann-Bell, Inc.) is the first program that I open. This software has a Calibrate routine which allows the master dark frames and dark-frame corrected flat fields to be stored in a memory buffer. See Fig. 4.4

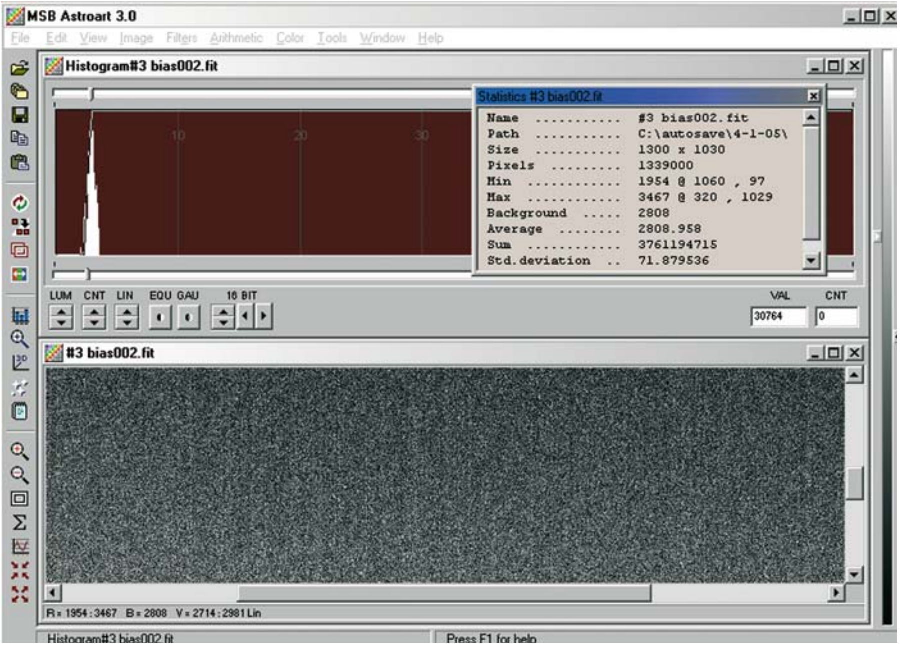


Figure 4.3. Astroart 3.0 screen capture. Single bias frame, 1-ms integration, telescope capped. Notice that there are still pixel counts, ranging from 1954 to 3467, even with no light hitting the CCD detector. (Used with permission, MSB Software, Inc.)

for a screen capture of AIP4Win's Calibrate window. Let us say that I took 10 dark frames, each 300-s and *unbinned* 1×1 to match the 300-s *unbinned* 1×1 light frames. I median combine all 10 dark frames and store the master dark frame in memory. Next, I median combine all flat field images into a master flat-field, median combine all flat-field dark frames, and subtract the master flat-field dark from the master flat field. Bias frames are similarly median combined and saved in the memory buffer. These images comprise a *reduction group* and will be applied to the light frames, a process called image (or data) reduction, in order to yield a pleasing image that reveals as much data as possible.

A few words about stacking/combining methods. There are four choices: *summing*, *average* combining, *median* combining, and *sigma combining*. Summing is not available in all software programs, usually for a good reason; namely software that does not do the addition in floating-point math will saturate the image once values go above 65,535 ADU counts. The information will be lost and can never be recovered. Adding using 16-bit integers leads to this information loss. Astroart 3.0, which I also use for image processing, allows summing in floating-point math. When averaging subexposures, the amount of signal in the final image is equivalent to the length of just one subexposure. For example, 60, 1-min subexposures averaged are equivalent to a 1-min total exposure in terms of the amount of actual signal (while noise is significantly reduced by the $\sqrt{[n]}$,

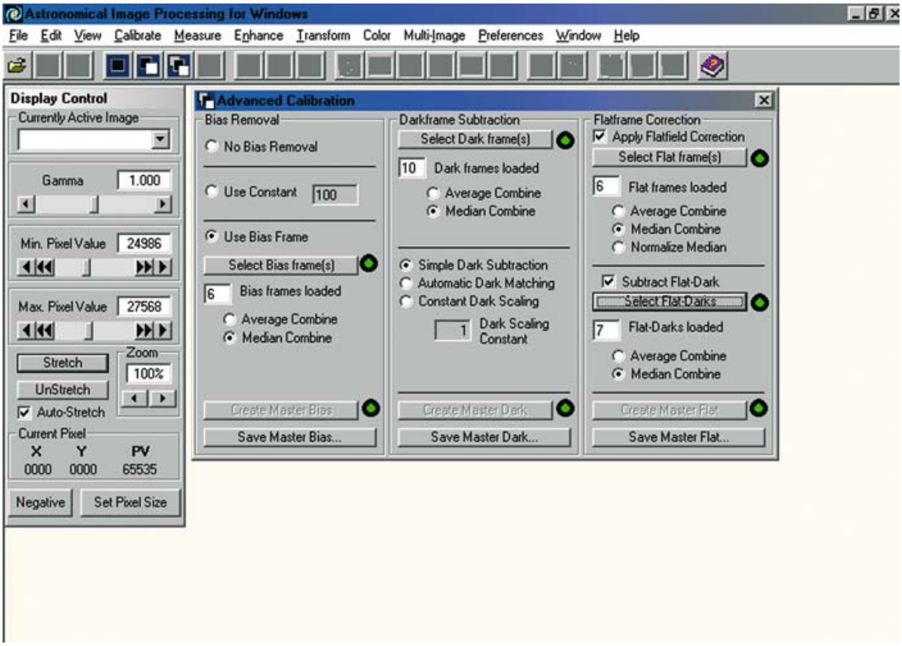


Figure 4.4. AIP4WIN screen capture. Advanced Calibration routine allows all reduction group images (bias frames, dark frames, flat field, and flat-field dark frames) to be loaded into AIP4WIN's memory buffer. Multi-image processing can then begin. (Used with permission, Wilmann-Bell, Inc.)

where [n] is the number of averaged subexposures). If you had added the subframes instead of averaging, then the total amount of signal in the combined image would be the sum of all the subexposures. Adding 60, 1-min subexposures will result in the amount of signal equivalent to a single 60-min exposure. The main consideration, however, is not the total signal itself but rather the SNR. Adding and averaging provide the best SNR and produce very similar results as long as floating-point math is used.

Median combining is useful for stacking images that might have artifacts, such as airplane or satellite trails or cosmic ray hits. Median combining is useful when compositing many dark frames because pixel values that are high or low are canceled out, and the middle value of each pixel is assigned. Cosmic ray hits are eliminated. You have to have a minimum of three images to use this combination method.

Ray Gralak's Sigma pre-beta 11 freeware program (and Astroart 3.0's Sigma combine routine) provide a fourth way to combine images. The Sigma combine routine further reduces noise in your images compared to using a simple average/mean combine. Sigma has two algorithms to reduce noise when combining images. Images must be aligned and coregistered before using this program. Darks and flats do not need to be registered nor should they. Also, the more

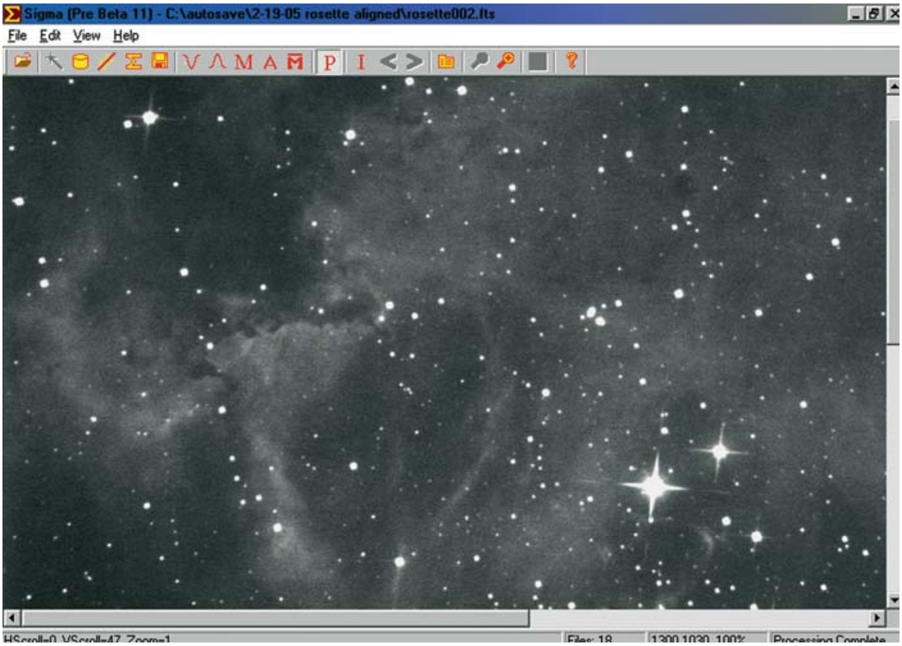


Figure 4.5. Sigma Combine Pre-beta 11 screen capture. Small area of Rosette Nebula shown after combining 15 previously aligned and coregistered frames. No dark frames or bias frames were applied. Image is smooth and free of any hot pixels or other artifacts. (Used with permission, Ray Gralak's Sigma Combine Pre-beta-11).

images you combine, the better Sigma will work. To truly see the best results, you should combine at least 10 darks, flats, or light images (see Fig. 4.5).

AIP4WIN is still open on my desktop, and all of the master reduction group images are stored in the memory buffer. I open the Multi-Image Processing routine and select all of the light frame images (highlight the first image in the folder, press SHIFT, and select the last image in the folder. All images will be highlighted). The light frame images must be aligned, pixel for pixel, before stacking to yield a higher-quality image. With the Align and Calibration buttons bulleted, the light frames are loaded and two reference stars are selected on one of the images to allow the software to align and coregister all of the images using these two stars as a reference. Both AIP4WIN and Astroart 3.0 use two star centroids to shift and rotate images into alignment. When tracking with the STV goes great, my mount still experiences a drift in declination and right ascension of 5–10 pixels over a 2–3-h period. I attribute this drift to a less-than-perfect polar alignment. When I image unguided, my drift is worse. The point is that software brings things under control by allowing all elements of each image to nicely align with each other.

I used to calibrate, align, and stack the result in AIP4WIN until I was introduced to the Sigma combine algorithm. Now, I calibrate and align the images in

AIP4WIN, save the images to another folder that I name "Aligned," and run these images through Ray Gralak's Sigma pre-beta 11. Actually, I review each image before stacking to make sure that there are no outliers (i.e., trailed star or major artifact). If so, the image is discarded.

The routine in the Sigma combine program can take several minutes to complete. Sixty images unbinned 1×1 are 1300 × 1030 pixels each. The combine routine is memory-intensive even on my operating system (Windows-based, 2.6-GHz processor, 512 MB RAM). Once the stacking is done, the unfiltered image is retained as a FITS image and opened in Astroart 3.0. Why three separate imaging programs so far? Well, for me, each program has its strengths and weaknesses. Although Astroart 3.0 has incorporated a Sigma combine routine, for example, the parameters for the combine algorithm cannot be changed, so I use Gralak's program. AIP4WIN has a greater ability to control the alignment and coregister routine than Astroart 3.0. Astroart 3.0 has more intuitive controls for image processing once an image is aligned and stacked. Again, after 3 years of image processing, this is my educated opinion: "Your mileage may vary."

Astroart 3.0 has an automatic screen stretch. When the Sigma combine image is opened on the desktop, it is typically dark black with a few scattered white dots. It is impossible to tell that the image is an astrophoto. At this stage, I used to panic when I first started image processing! I usually select View Range = "Auto" and Transfer Function = "Auto" in order to inspect the image. A typical CCD image has 65,000 brightness levels, the overwhelming majority of which the human eye cannot distinguish. The histogram of the image, a visual graph of the brightness levels in an image, can be adjusted in order to adjust the information that is displayed (or hidden) in an image (see Fig. 4.6). Any unacceptable artifacts (i.e., hot pixels) that remain at this stage are eliminated before any image processing begins. If there is a gradient in the image after flat-fielding, I remove the gradient with an Astroart Gradient Removal plug-in. The software does a respectable job of correcting the gradient(s). The easiest gradient to fix is one that shows a change in one direction only. Each Astroart 3.0 plug-in is an external Dynamic Link Library (DLL) software module. DLL's are executable functions that can be used by a windows-based application. The gradient filter corrects vignetting and sky background gradients, and it is possible to create a synthetic flat field from the image.

Next, I apply a minimum DDP (Digital Development Process) filter using Astroart's default settings. DDP filtering sharpens images and stretches faint portions of an image. I use the default settings for initial filter runs on an image, but the parameters of the filter can be changed to experiment with the results. The screen display is again changed (which does not alter the data, only the way they are displayed) in order to scrutinize the results. Histogram shaping and stretching the image are additional tools that change brightness and contrast values in an image. At this point, the *art* of image processing rears its head. No two imagers will process the same data in the same way. Finding images on the Internet or in reference books will also show that there is no "standard" to which to compare one's image. This is more apparent when doing trichrome imaging. For monochrome processing (or luminance processing), we are only interested in image detail, not color. Filters for sharpening and smoothing can be applied next. An excellent signal in an image is a requirement when using a sharpening filter.

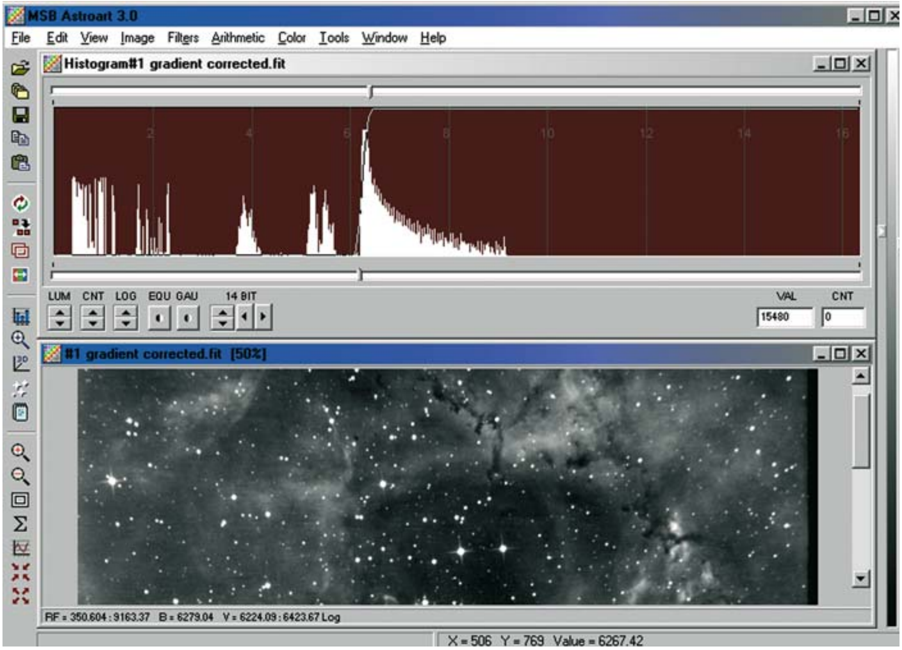


Figure 4.6. Astroart 3.0 screen capture. This FITS image of the Rosette Nebula has been aligned, coregistered, and stacked and is ready for postprocessing. The histogram above shows the pixel distribution based on intensity and number of pixels. (Used with permission, MSB Software, Inc.)

Sharpening tends to highlight or enhance noise if the signal in your image is fair or marginal. Deconvolution is a special sharpening filter that uses the point-spread function (PSF) of a chosen star. Images are sharpened by removing any blurring effects that are present. Noisy images are not good candidates for this filter. The dark halo effect shows up when you are too aggressive with either the PSF that is chosen or the number of iterations that the filter is used on the image. In Astroart 3.0, Lucy-Richardson and Maximum Entropy are two deconvolution (sharpening) filters that, when properly applied, can enhance an image. I usually apply minimum sharpening features in Astroart 3.0 and then save the image as both a FITS file and export a bitmap (BMP) copy to yet another program, Corel Photo Paint (Corel, Inc.). Many imagers continue postprocessing in a graphics package rather than in one of the astronomy software programs. The final image should have a sky background that is a very dark gray (not black). I use the gamma control in Corel to control this, usually starting with a value of 0.9. Additionally, a powerful image processing tool, Levels and Curves, is also found in Corel, and when properly mastered, it can be used to mine more data from your image. I also crop the image to a desired field and resample the image down from its native almost 12 in. × 16 in (30 cm × 41 cm). The reason for resampling is that I want the image to fit on a computer screen when I eventually upload the image to my website; it is cumbersome and less pleasing on the eye to have to scroll around the field to take everything in.

Color composite imaging (trichrome imaging) is another entirely different ballgame. Color images can be gorgeous, aesthetically pleasing, totally scientifically inaccurate, and open to a wide variety of interpretations when you decide on final image presentation. The HX916 camera, like most imaging CCD cameras, is a monochrome camera. Colored images are obtained by placing colored filters in front of the camera, one at a time, and later combined with special software. If you have a full set of hair and are just starting out in astroimaging and processing, get set for some hair pulling. I cut my teeth on Astroart 2.0 and have since moved up to Astroart 3.0 exclusively when I process my images. I learned how to do luminance layering (also known as LRGB processing), which aims to produce a high-quality color image by processing separate monochrome, red-, green-, and blue-filtered images. The eye judges sharpness and contrast in the luminance layer, so the goal is to take as long an exposure as possible and/or combine multiple exposures to make the luminance image as smooth and pleasing as possible. All histogram changes should be done on the luminance image so as not to disturb color balance in the filtered images. Some successful imagers do RGB (red, green, blue) color imaging, depending on the target being imaged. Some targets, such as globular star clusters and open star fields, do well imaged with a green filter in place to both record the luminance frames and the green images. Stars are tight and the luminance image is as pleasing as if a separate clear, IR blocking filter was in place. Still other imagers use the stacked RGB frames as the luminance channel image during LRGB color compositing.

One of the benefits of LRGB processing is that if a high-quality luminance image is taken, unbinned 1×1, and processed as well as possible, the RGB-filtered images at the telescope can be taken unbinned 2×2, saving time during each integration. Additionally, the quality of the RGB frames *does not have* to be spot-on because the higher-quality luminance image layered on top will mask the RGB frames to some extent. I think of this LRGB technique as allowing the luminance channel to represent the detail of the image, letting the RGB frames "bleed through" to reveal their color contribution.

Personally, I take all of my frames unbinned 1×1 and take the time to get as high-quality frames as I can regardless of whether my clear, red, green, or blue filter is in the optical train. I think processing is easier and more forgiving when the quality of the images is better to start with. I do not care much about reducing the time at the telescope because I do not mind returning to a target on a subsequent night to complete my filtered images. Additionally, the length of each subexposure is the same regardless of which filter is in place.

A few words about "returning" to a target on a subsequent night of imaging. First, think about how fortunate we are that the extended objects that we image are so unimaginably far away and so unimaginably large. Eons can pass and these objects never change, never alter their appearance. On a subsequent night of imaging, I open a raw image on my desktop in the observatory, from the previous imaging session, and then slew the telescope (using TheSky) to get in the general vicinity of the intended target. I take a few test images and use the cursor in Astroart 3.0 to mouse-over a few obvious stars that are present in both images. I take note of the X,Y pixel coordinates of the previous night's image and use the Guide speed control on the LX200 paddle to iteratively move the telescope and camera until a downloaded test image has the star's pixel coordinates matching the coordinates on the raw image from the previous night.

The first step in creating a composite image is to approach the luminance and filtered images as separate routines done in parallel. At the end of the overall routine, the master LRGB frames are layered on each other to produce a color image. The luminance processing was covered previously when I discussed monochrome imaging, so let us start with the RGB frames. Exactly like the luminance image, a master red frame is obtained by first aligning and registering the calibrated frames (remember that the filtered images have their own dark frames, flat-field frames, and flat-field dark frames; I use the same bias frames used with the luminance images) and then Sigma combine the images in Gralak's program. This is repeated for the green and blue images.

In Astroart 3.0, the LRGB master images need to be aligned and coregistered with each other. This means, for example, that a star in the luminance frame at pixel position (X = 32, Y = 465) needs to be at the exact same position (*x*-*y* coordinate) in the red, green, and blue frames. Otherwise, compositing the individual master frames will not produce pinpoint stars. Astroart has a two-star align/coregister function that is pretty good at giving consistent results.

A few words on color balancing. Lazy imagers assume that their RGB imaging filters are close to a 1:1:1 ratio. Astronomik Type II filters are close to this ratio, but your system (filters and imaging equipment) will yield unique color balancing factors that will be used during processing. Sun-like (G2V) star data are utilized to achieve true color balance and apply atmospheric extinction coefficients to each filtered image. It sounds messy, but it is straightforward. Previously, a G2V-type star was imaged through each of red, green, and blue filters. AIP4WIN has a G2V photometry algorithm that allows you to find the correct coefficient multipliers to use with your CCD camera/telescope combination in order to process the sun like star. In Astroart 3.0, G2V ratios obtained from AIP4WIN are applied as divisors. For my Astronomik Type II IR-blocked filters, when I image with my Stellarvue refractor and a Schuler -VIR filter (Schuler, Inc.), my ratios are Red = 0.731, Green = 1.00, and Blue = 0.508. With the LX200 at f/6.3, my ratios are Red = 0.750, Green = 1.00, Blue = 0.485. The goal is to get the correct color balance (a white star) so that all of your images, regardless of the target, will have a correct color balance. No guesswork should be involved. Never having heard about G2V color balancing, I used to play with the brightness and contrast settings in Astroart when I first started out in this hobby. It was a nightmare to achieve any semblance of correct color balance. See Al Kelly's important paper on this subject, referenced in Chapter VIII.

Correcting for atmospheric extinction refers to using mathematical factors to lessen the impact that the atmosphere has on true color balance. The lower the target that is being imaged is to the horizon (the further the image is away from the zenith), the more impact that the factor has on achieving correct color balance.

Now that each master image is color balanced (color multiplier applied to the master image, extinction coefficient divisor applied to the master image), sky background color needs to be neutralized. Skyglow is different when viewed through each color filter. Because I have light pollution to contend with, it is usually greener. When I take separate RGB exposures, each channel will contain some amount of background sky that will be different from the other channels. If you look at the histograms before setting the visualization ranges to the same values in each RGB master, they all look different. If you were to combine them without making the adjustments, you will get wildly mismatched colors, with the color starting furthest from the left dominating, and the color frame that starts closest to the left being almost invisible. Normalizing the background involves subtracting a constant value from each channel so that the histograms start to rise at about the same distance from the left.

I open the red, green, and blue master images and look at the "background" levels in each image's histogram. I use the "arithmetic," "add offset" function to subtract from each frame a value that will leave the background at 500 ADU. For example, if the background is 1500, I subtract 1000. Next, I increase the white point slider, using linear scaling, until the object begins to show fairly well in the green filtered image. Now I look at the visualization minimum and maximum on the green frame's histogram and set the same visualization numbers on the red and blue images, using the "view range" and "user defined" function. If you do not set each frame to the same white and blackpoint visualization numbers, the color balance will be affected.

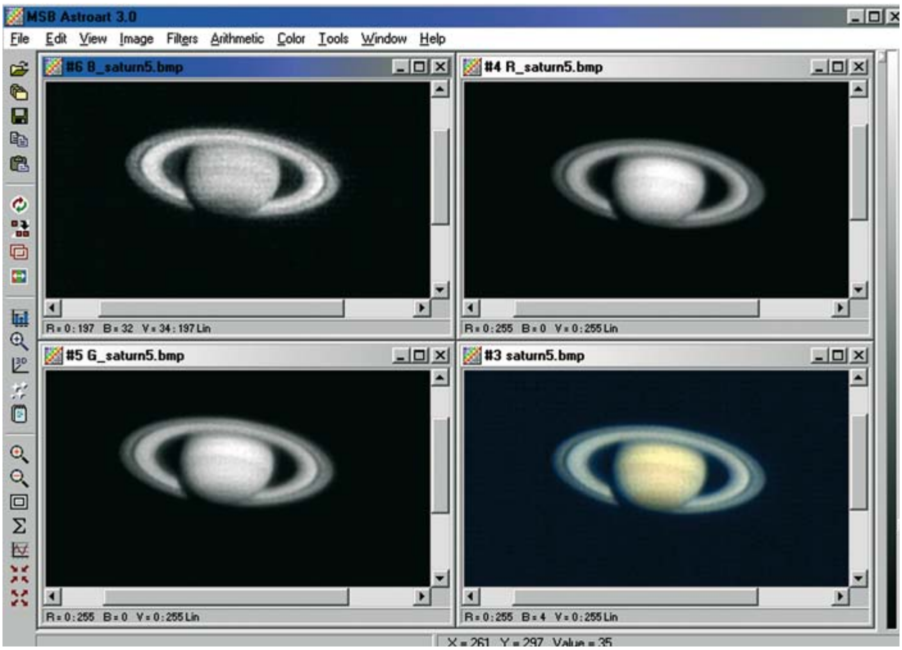


Figure 4.7. Astroart 3.0 screen capture. An aligned and stacked image of the planet Saturn is shown in its separate red, green, and blue channels. (Used with permission, MSB Software, Inc.)

Select the "color" button on the Astroart 3.0 menu and select "trichromy." Use the defaults and select "okay." The resulting image is a synthesized RGB image. The background color should be gray. Adjust the bottom sliders on the color balance menu until the background meets your satisfaction. The image will look dim but should not affect the LRGB. To make the LRGB composite, again select the "color" tab on the Astroart menu and select LRGB synthesis (see Fig. 4.7). Select your luminance image and select "okay," and your LRGB image will be created. The colors might look dull or washed out. If so, select "Color" and then "Saturation" on the drop-down menu. Increase the saturation to your liking. Are you done at this point? Are you ever done? Probably not. Further touch-ups, such as tweaking the color balance, gamma adjustments, and so forth, can be done in your favorite graphics software program. I save the LRGB image as both a FITS file and as a bitmap image so that I can further process the image in Corel (see Fig. 4.8). When I have finished processing the final product (for the time being!), I save the image as a least-loss JPEG image so that the image remains small and of high quality for uploading to my website for display.

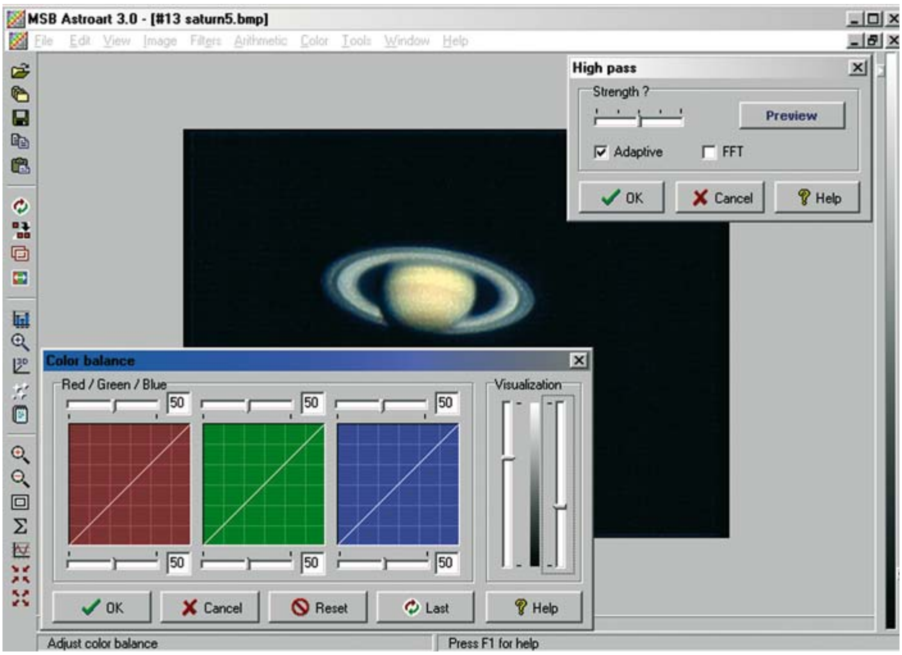


Figure 4.8. Astroart 3.0 screen capture. An aligned and stacked image of the planet Saturn is shown, with the color balance selection and high-pass filter windows open. (Used with permission, MSB Software, Inc.)

CHAPTER FIVE

A Collection of Astrophotos

All images were taken by the author. Celestial North is up and East is to the left in each image. After initial processing, each FITS image was saved as a BMP file and additional processing was done in Corel Photo Paint-8 (version 8.369). Images were resampled and printed on a Hewlett Packard hp Photosmart 1115 Inkjet printer, using the following settings: print quality: Best; photo paper: HP Premium Plus Photo Paper, Glossy; Automatic Image Enhancement (Photo-Ret), which selects the best combination of print speed and quality. Each image was saved as a high-resolution BMP image and provided on CD-R to the Publisher.

The following Image Gallery is organized into the following categories: Solar System, Nebulae, Globular Star Clusters, Galaxies, and Open Star Clusters.

A. Solar System

Figure 5.1. Cyrillus and Theophilus, LX200 @ f/50. Cyrillus is 62 miles (104 km) in diameter; Theophilus is 67 miles (100 km) in diameter and has a few prominent mountain peaks rising from the crater floor.

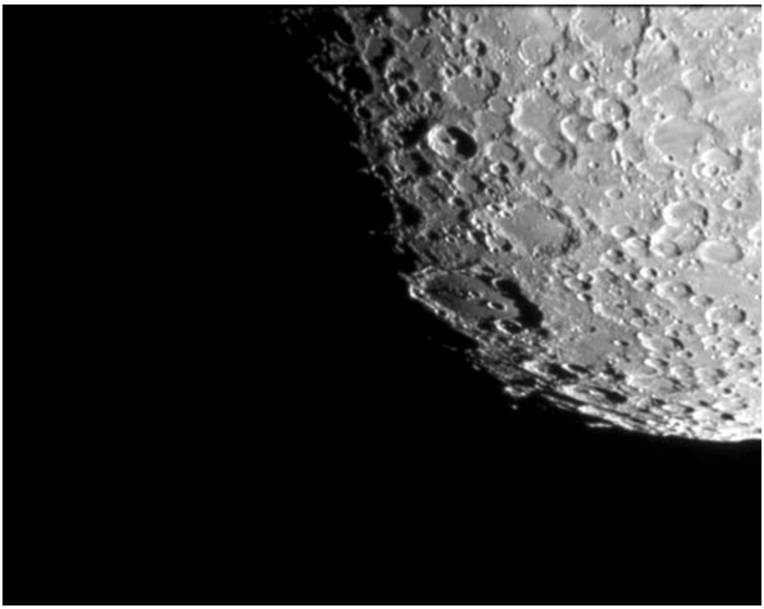


Figure 5.2. Lunar terminator passing near Clavius, LX200 @ f/10.

Figure 5.3. Gibbous Moon, Stellarvue Nighthawk @ f/3.6.

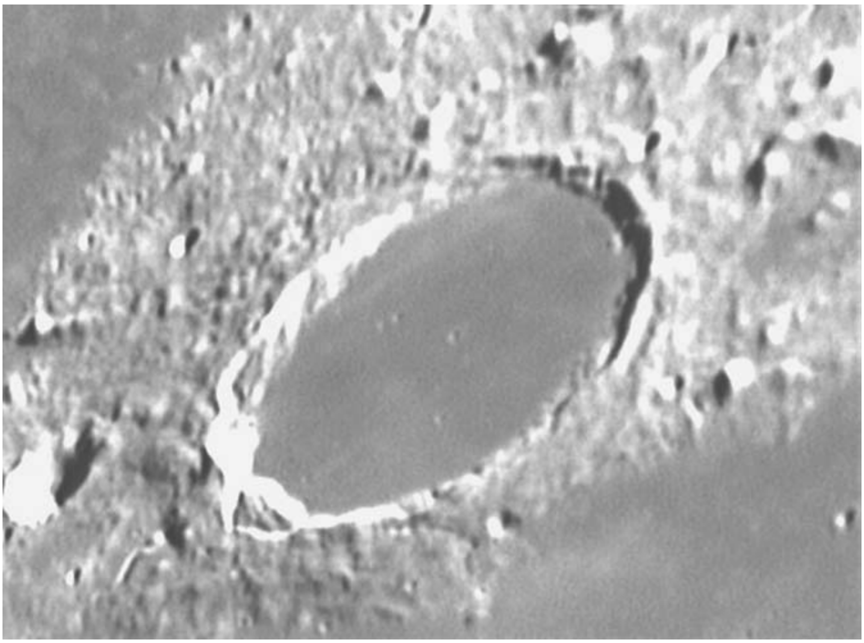


Figure 5.4. Plato, LX200 @ f/50. This crater is used to test the resolution of one's optics. Lunar orbiter images reveal more than 100 craterlets on the floor of Plato.

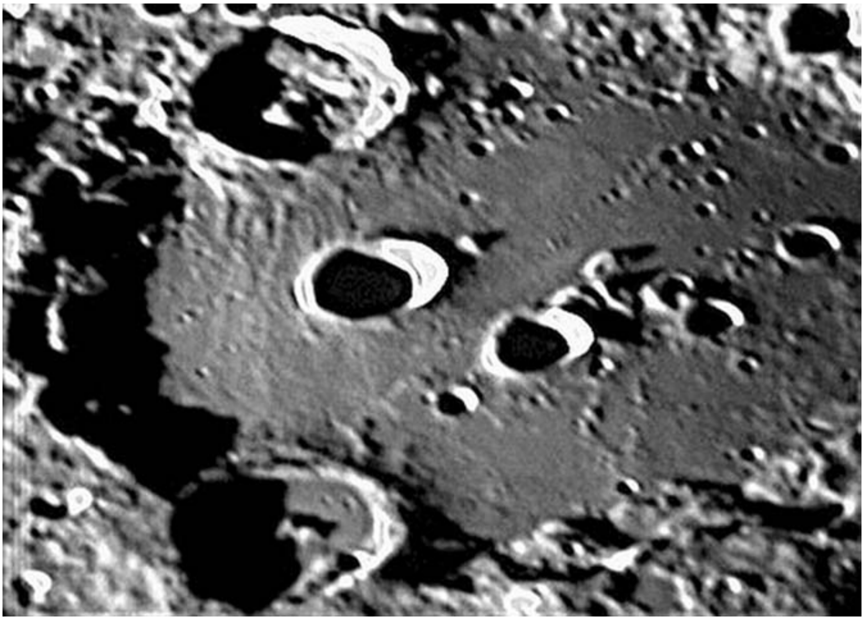


Figure 5.5. Crater Clavius, LX200 @ f/50.

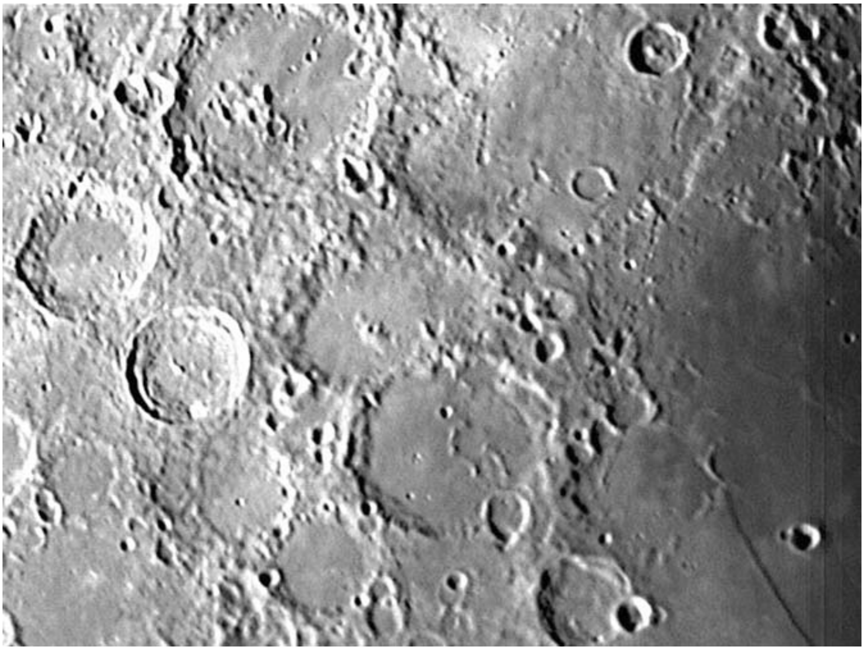


Figure 5.6. Craters, LX200 @ f/10. Panning over the surface of the Moon at any phase is never disappointing.

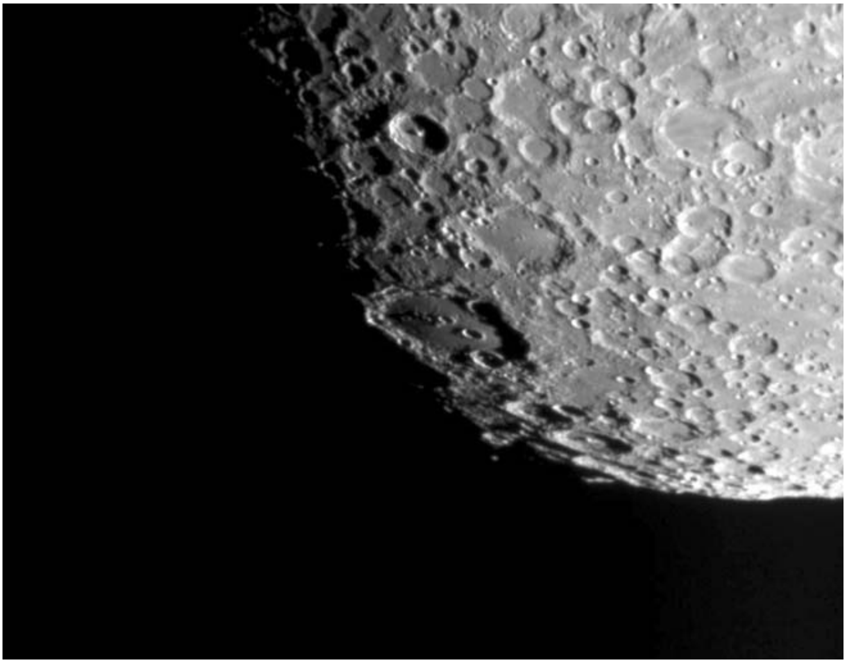


Figure 5.7. Lunar terminator, passing through Clavius, LX200 @ f/20.

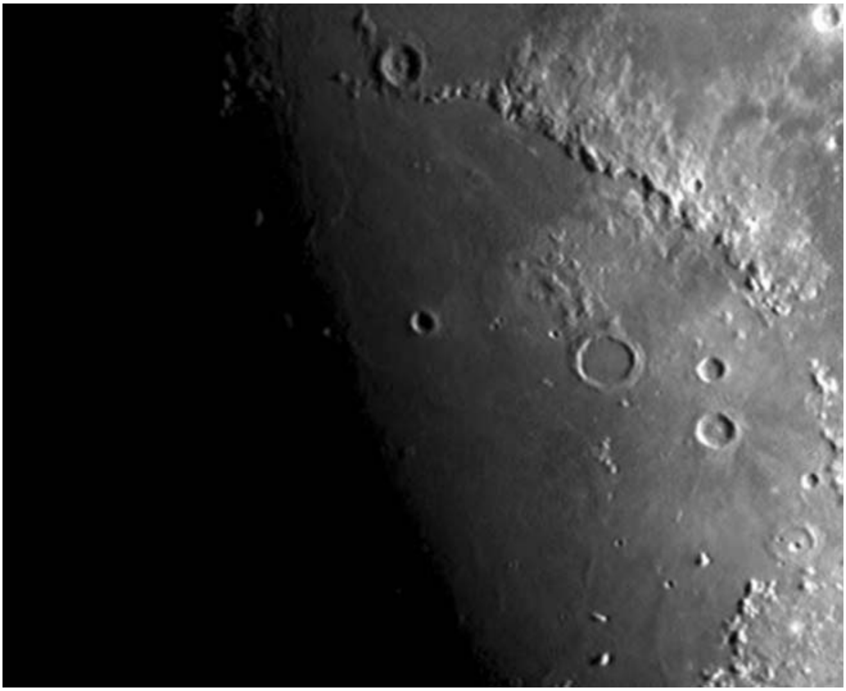


Figure 5.8. Alps and Caucasus mountains, LX200 @ f/10. Caucasus mountains rise to a height of 7.5 miles (12.5 km).

Figure 5.9. Hesiodus and Hesiodus Rima, LX200 @ f/20, diameter 28 miles (47 km). There is an obvious gap in the crater wall.

Figure 5.10. Full Moon, Stellarvue Nighthawk @ f/4. Our nearest neighbor, 225,000 miles away (375750 km). A 3-day trip by rocket.

Figure 5.11. Mare Nectaris, southwest limb. LX200 @ f/10.

Figure 5.12. Rimae Hippalus and Campanus, LX200 @ f/20. Hippalus is a rile 145 miles (247 km) long and is a straight valley with deep walls, probably formed as an open channel in a lava flow.

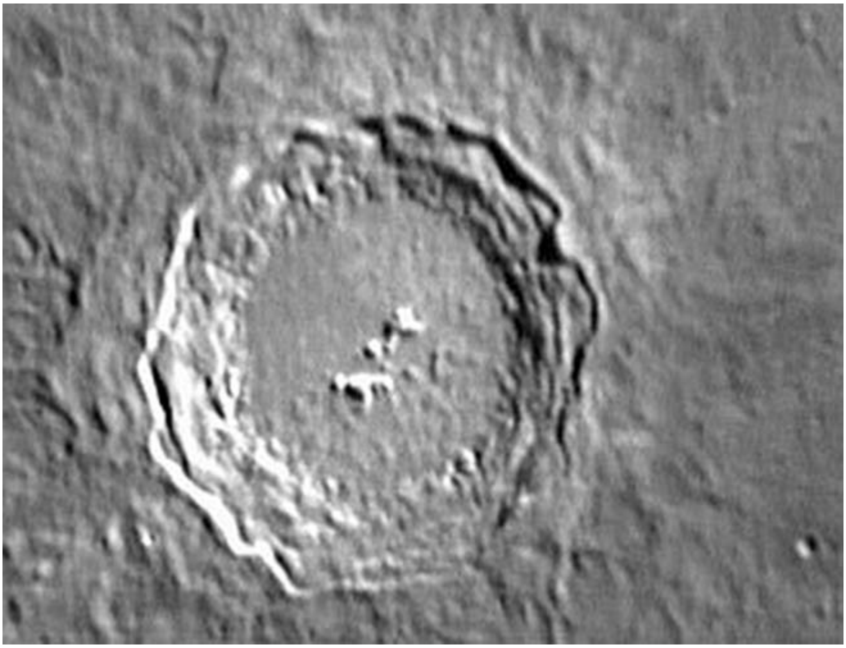


Figure 5.13. Copernicus, LX200 @ f/50, diameter 56 miles (93 km). Three central mountain peaks are evident.

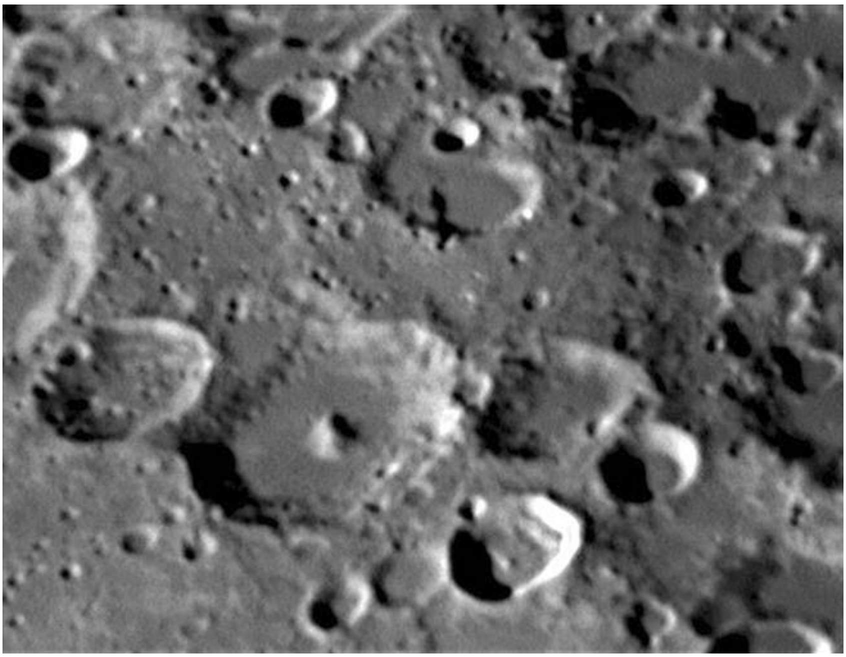


Figure 5.14. Lilius, LX200 @ f/20, diameter 32 miles (93 km). Central mountain peak is prominent.

Figure 5.15. Craters, LX200 @ f/10.

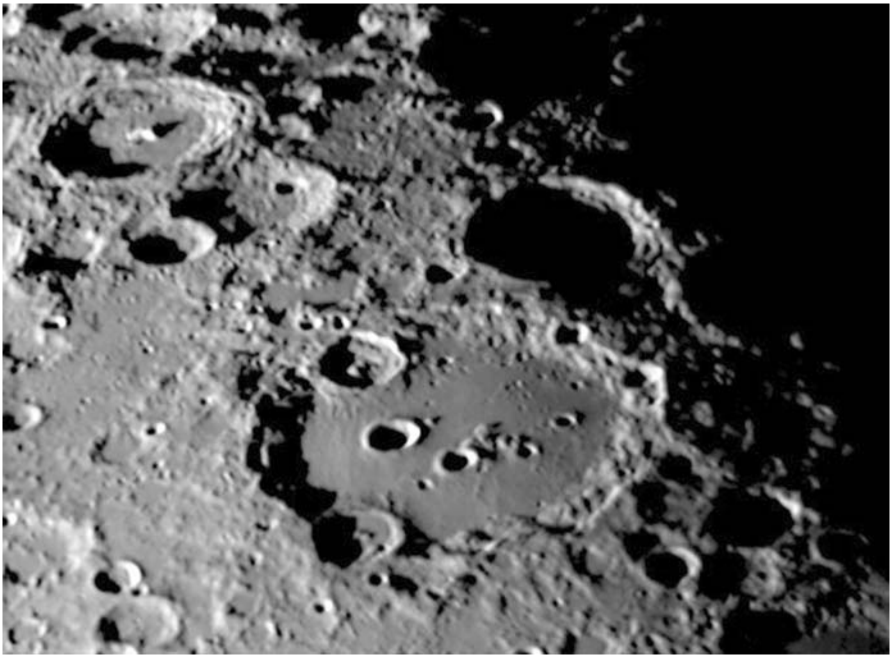


Figure 5.16. Clavius, LX200 @ f/20. Sir Arthur C. Clarke's black monolith of *2001: A Space Odyssey* fame was dug up here.

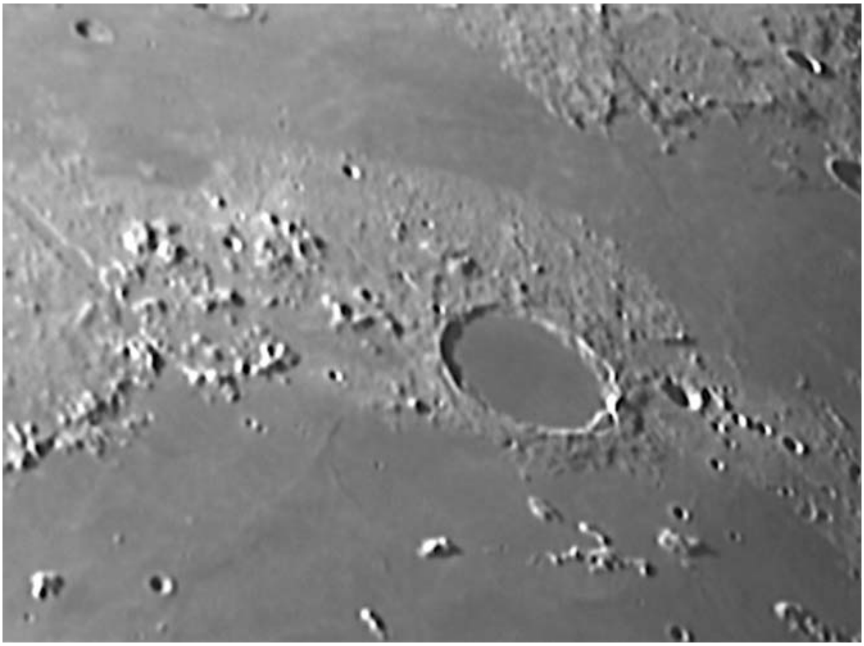


Figure 5.17. Plato and Vallis Alpes, a rectilinear fault 700 m wide. LX200 @ f/10.

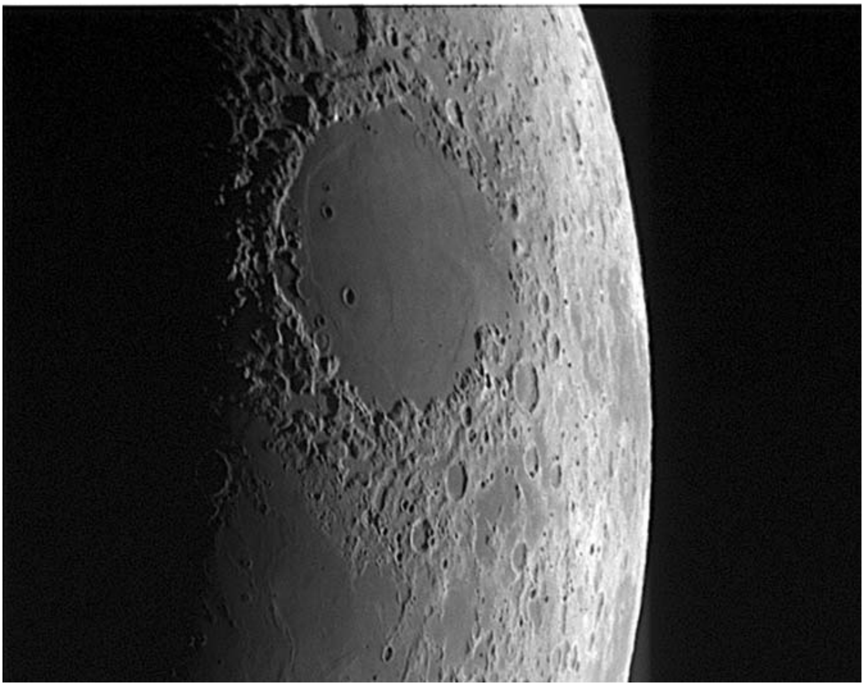


Figure 5.18. Mare Crisium, LX200 @ f/10, diameter 350 miles (585 km). Site of a large mason, a gravitational anomaly due to the asteroid impact that created the mare basin.

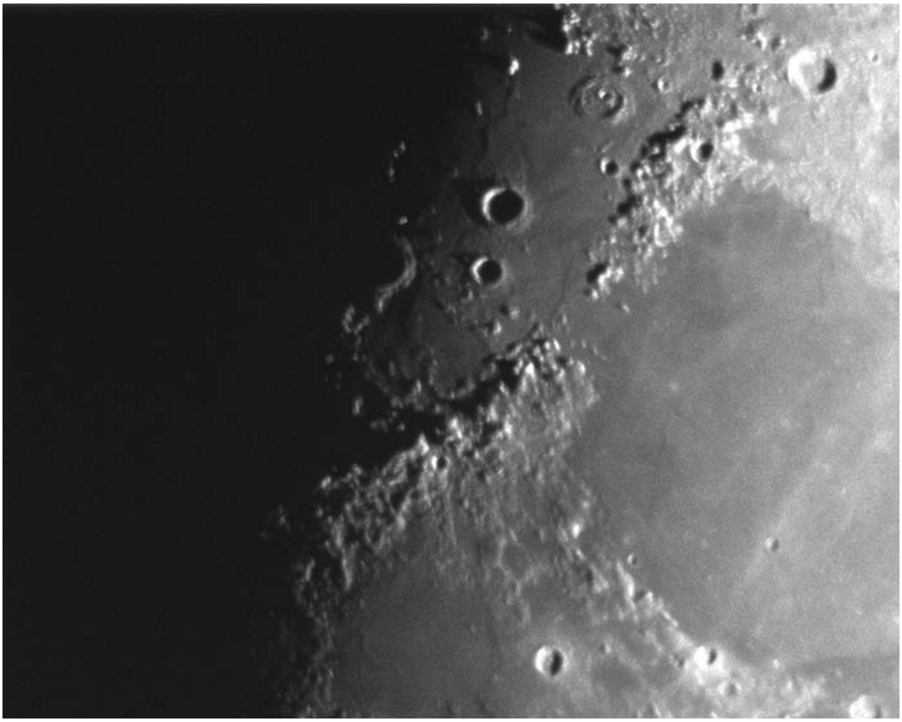


Figure 5.19. Apennine and Caucasus mountains, LX200 @ f/10. The Apennine range stretches 360 miles (600 km) along Mare Imbrium.

Figure 5.20. Jupiter, LX200 @ f/20. Colorful wind-driven cloud bands are seen as blue, tan, and brown, with lighter colored areas called zones.

Figure 5.21. Jupiter, Io and, Ganymede, LX200 @ f/30. Jupiter is 400 million miles (650 million km) from Earth. Io and Ganymede are 2 of 28 moons of Jupiter; Io has extensive volcanism.

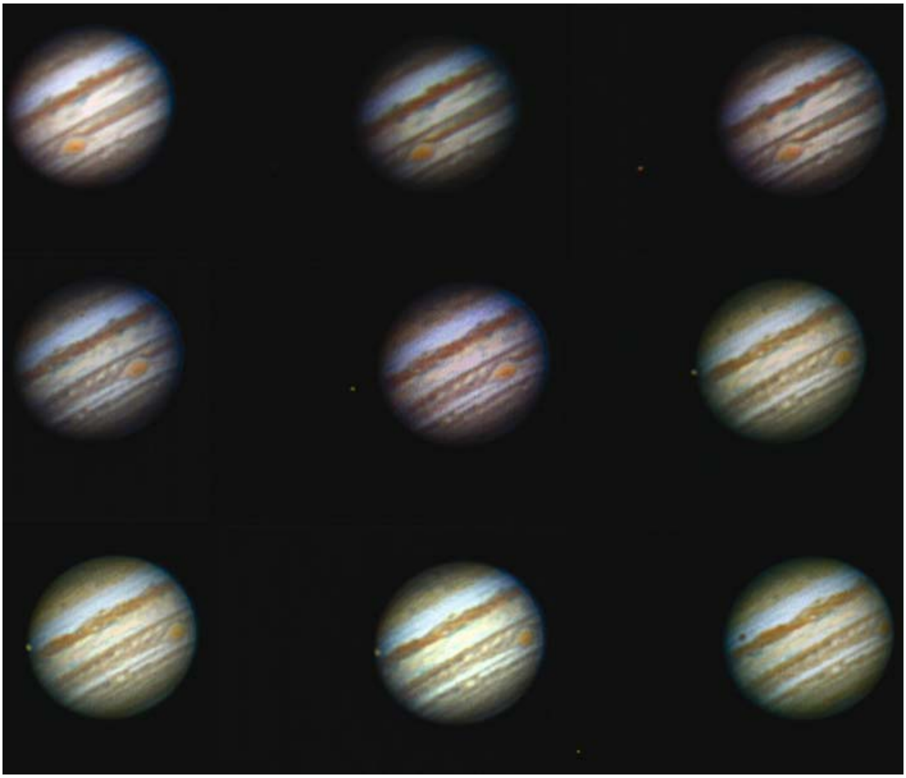
Figure 5.22. Jupiter and Great Red Spot, with Io off limb, LX200 @ f/20.

Figure 5.23. Jupiter and Great Red Spot, with Io off limb and Ganymede's shadow transiting, LX200 @ f/20.

Figure 5.24. Jupiter and Great Red Spot, with Io off limb and Ganymede's shadow transiting, LX200 @ f/20.

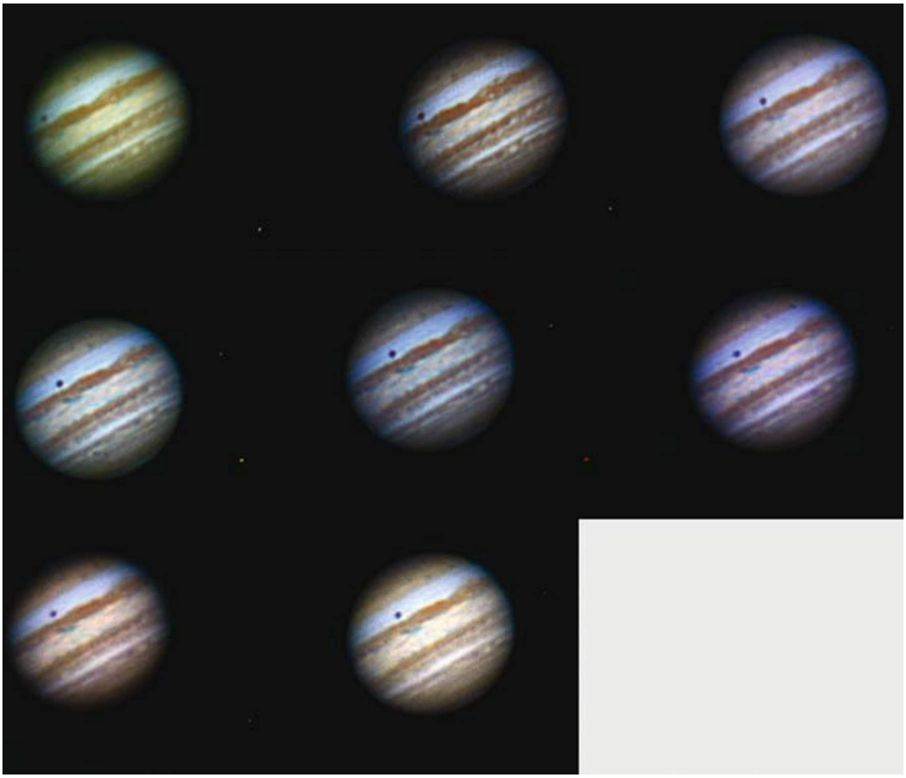
Figure 5.25. Jupiter and Great Red Spot, with Io off limb and Ganymede's shadow transiting, LX200 @ f/20.

Figure 5.26. Jupiter and Io. Great Red Spot transiting near western limb, LX200 @ f/20.



a

Figure 5.27. (a + b) Jupiter and satellites montage. Left-to-right on each row, 17 images capture the transit of Ganymede, Io, and, finally, Europa as they move east to west (left to right) in image sequence, taken 3/21/2004 from 1233 UT to 0341 UT. Images taken with ToUcam Pro Philips ToUcam Pro PCVC740K webcam (Koninklijke Philips Electronics N.V.) and LX200 at f/30. Registered and stacked in Cor Berrevoets' RegiStax version 2.1.13 Beta.



b

Figure 5.27. Continued

Figure 5.28. Jupiter, Io and Great Red Spot. Note blue-green festoons, LX200 @ f/20.

Figure 5.29. Jupiter with blue/green festoons, LX200 @ f/20.

Figure 5.30. Saturn, LX200 @ f/20. Eight hundred million miles (1.3 billion km) from Earth; it takes 30 years to orbit the Sun.

Figure 5.31. Saturn, LX200 @ f/20.

Figure 5.32. Saturn, LX200 @ f/30.

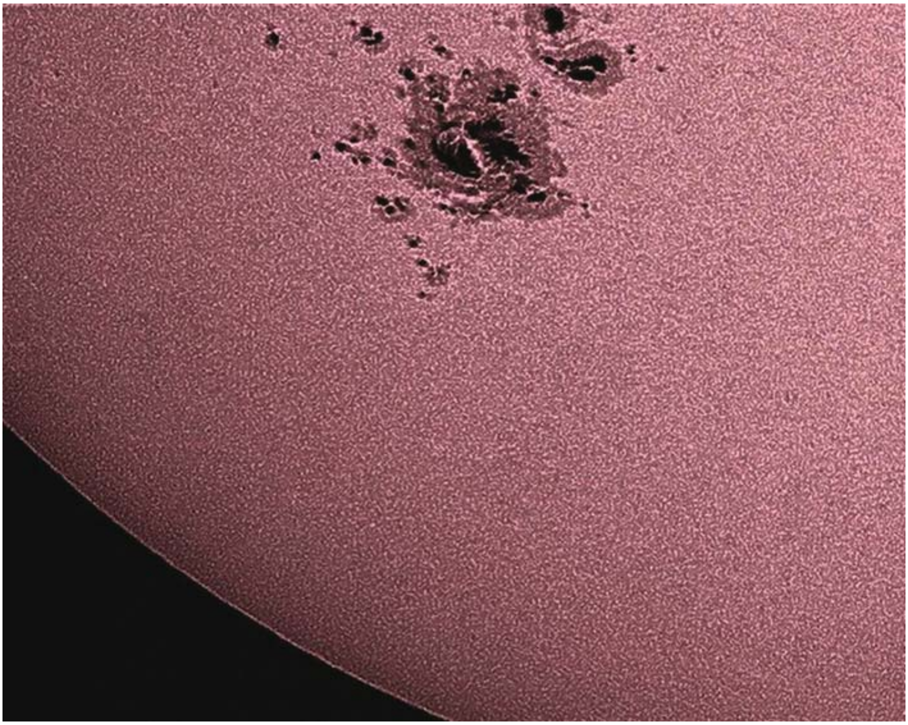


Figure 5.33. Sunspot Complex 484, LX200 @ f/20. This complex appeared in October 2003. It is approximately 87,000 miles (137,000 km) in diameter. Sunspots are concentrations of magnetic flux and are dark due to their cooler temperatures compared to the surrounding photosphere.

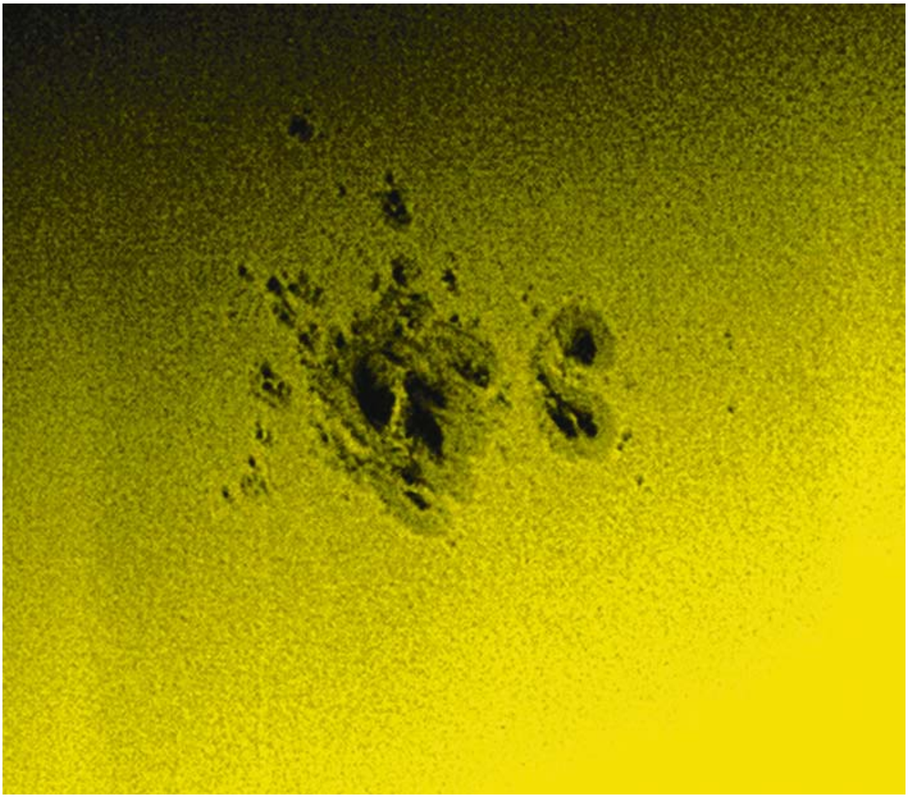


Figure 5.34. Sunspot Complex 484, LX200 @ f/20. Meade Series 4000 #12 Yellow filter used. This complex appeared in October 2003. It is approximately 87,000 miles (137,000 km) in diameter. Sunspots are concentrations of magnetic flux, and are dark due to their cooler temperatures compared to the surrounding photosphere.

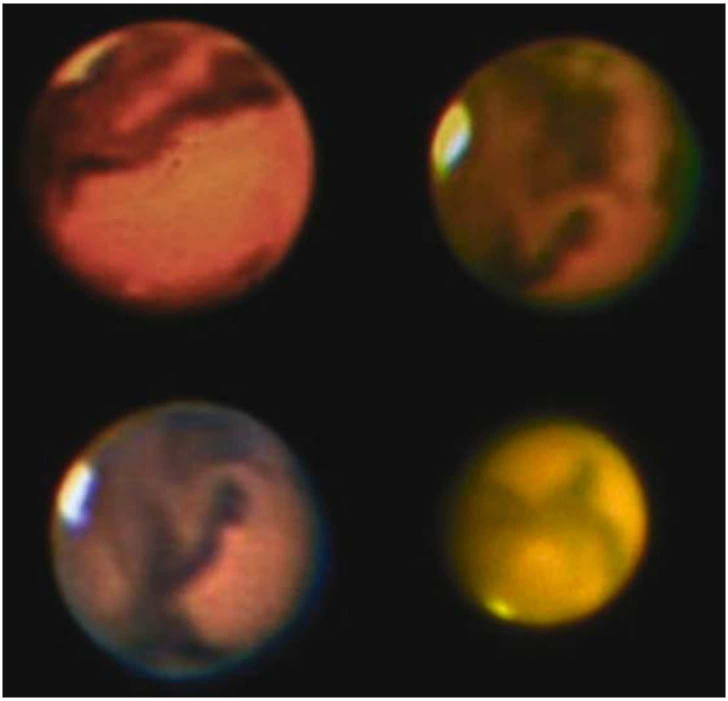


Figure 5.35. Mars montage. Top left: image taken August 18, 2003; top right: image taken August 26, 2003; bottom left: image taken August 30, 2003; bottom right: image taken August 31, 2003. The closest approach of Mars occurred on August 27 (09:51:14 UT) at a distance of 55.758 million km, or 34,646,418 miles. At this distance, Mars appeared larger than at any previous time, 25.11 arc-seconds in diameter, and this was the planet's closest approach in 59,619 years. Images taken with ToUcam Pro PCVC740K webcam (Koninklijke Philips Electronics N.V.) and LX200 at f/50. Registered and stacked in Cor Berrevoets' RegiStax (version 2.1.13 Beta.)

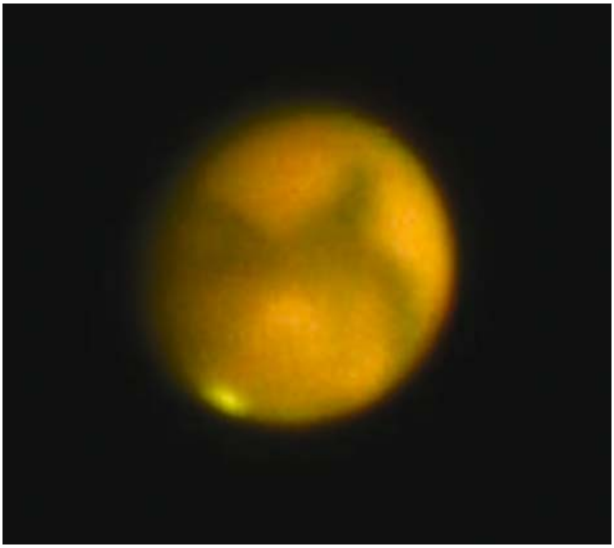


Figure 5.36. Mars, LX200 @ f/30. Note polar Cap at bottom of image.

Figure 5.37. Comet C/2004 F4 Bradfield, Stellarvue Nighthawk @ f/6. A nice tail is seen extending from the nucleus towards the upper right.

Figure 5.38. Comet C/2004 Q2, Stellarvue Nighthawk @ f/6; also known as comet Machholz, discovered in 2004. A nice jet is seen to the left, extending from the bright nucleus.

Figure 5.39. Comet C/2001 Q4, Stellarvue Nighthawk @ f/6; also known as comet NEAT, discovered in 2001 by the NEAT Survey. Camera tracked the comet nucleus during integration, so stars appear red, green and blue when composited.

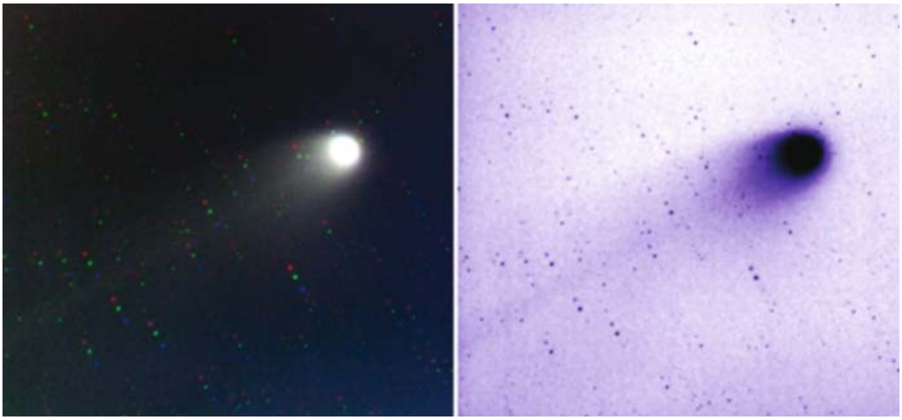


Figure 5.40. Comet C/2001 Q4, Stellarvue Nighthawk @ f/6; also known as comet NEAT, discovered in 2001 by the NEAT Survey. Image on right is a negative, used to enhance any detail in the comet's tail.

Figure 5.41. Asteroid 71 Niobe, Stellarvue Nighthawk @ f/6. Moving against the backdrop of the stars, this 56-mile-diameter (83-km) rock appears as a small streak in the center of this image.

B. Nebulae

Figure 5.42. Horsehead Nebula (B33/IC 434) and Flame Nebula (NGC 2024), Ha image. Takahashi FS 60-C @ f/6. One of the prettiest and more famous compositions that all astroimagers strive to obtain each season.

Figure 5.43. Horsehead Nebula (B33/IC 434) and Flame Nebula (NGC 2024), Takahashi FS 60-C @ f/6. One of the prettiest and more famous compositions that all astroimagers strive to obtain each season.

Figure 5.44. Rosette Nebula (NGC 2237), Takahashi FS 60-C @ f/6. Inside the nebula lies an open cluster of bright young stars that formed about 4 million years ago. The nebular material and their stellar winds are clearing a hole in the nebula's center, insulated by a layer of dust and hot gas.

Figure 5.45. Flaming Star Nebula (IC 405), Takahashi FS 60-C @ f/6. Ha image. The nebula is being illuminated by the high-energy star AE Aurigae (embedded in the nebula, center of image) and is actually moving through the nebula at this time.

Figure 5.46. Cone Nebula and Christmas Tree Cluster (NGC 2264), Takahashi FS 60-C @ f/6. Ha image. Many stellar nurseries are found within this massive region. Clouds of gas and dust are buffeted by energetic winds from newborn stars.

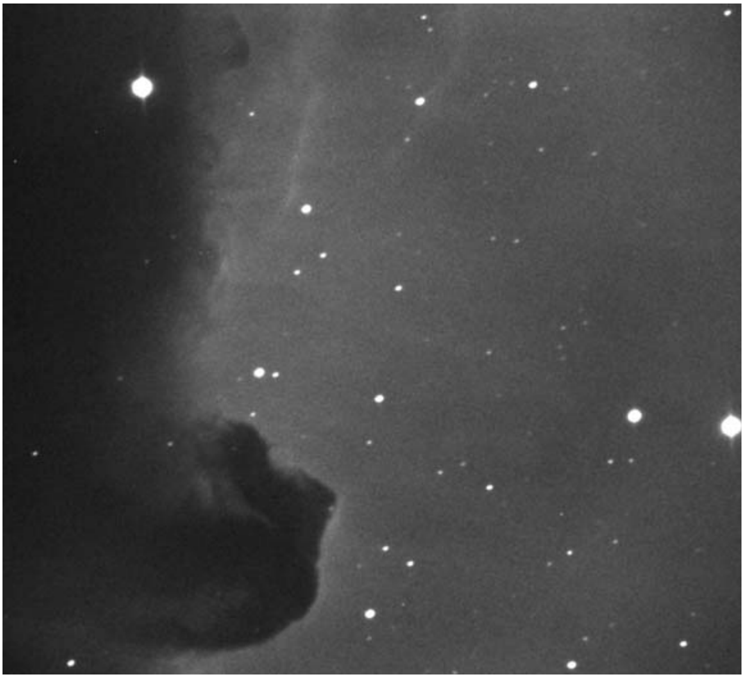


Figure 5.47. Horsehead Nebula (B33), LX200 @ f/6.3, Ha image. Shaped like a chess knight, this dark cloud of gas and dust shows up in extended integrations but not in an eyepiece.

Figure 5.48. Emission Nebula IC410, Takahashi FS 60-C @ f/6. Ha image. Diffuse wreath-shaped emission nebula in Auriga. It resembles a small Rosette. It lies about 2° southwest of IC 405 (Flaming Star Nebula).

Figure 5.49. Emission Nebula IC410, Takahashi FS 60-C @ f/6. Diffuse wreath-shaped emission nebula in Auriga. It resembles a small Rosette. It lies about 2° southwest of IC 405 (Flaming Star Nebula).

Figure 5.50. Cone Nebula and Christmas Tree Cluster (NGC 2264), Takahashi FS 60-C @ f/6. Many stellar nurseries are found within this massive region. Clouds of gas and dust are buffeted by energetic winds from newborn stars.

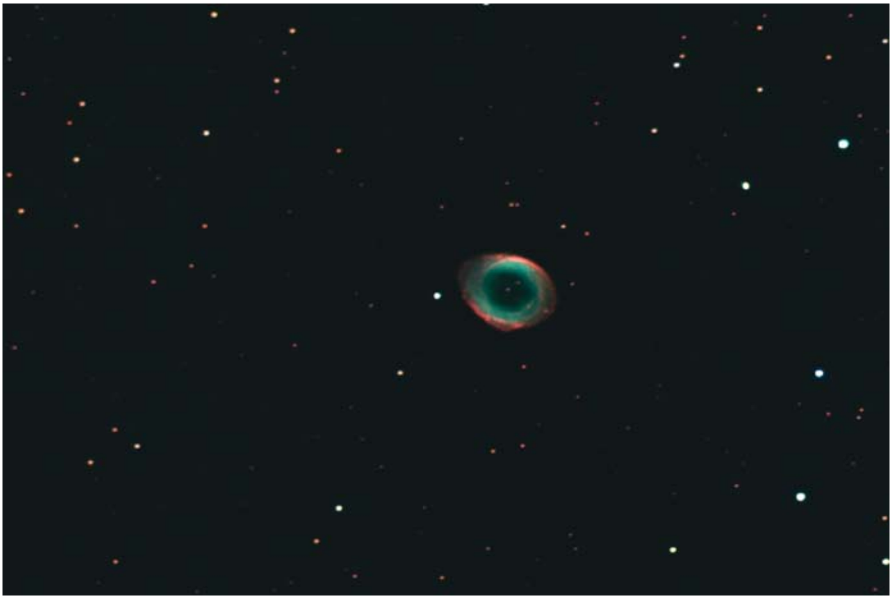


Figure 5.51. Ring Nebula (M57), LX200 @ f/6.3. The famous ring nebula is often regarded as the prototype of a planetary nebulae, and recent research has confirmed that it is actually a ring (torus) of bright light-emitting material surrounding its central star.

Figure 5.52. Dumbbell Nebula (M27), Stellarvue Nighthawk @ f/4.9. This was the first planetary nebula discovered by Charles Messier.

Figure 5.53. Dumbbell Nebula (M27), Stellarvue Nighthawk @ f/4.9. Ha image. This was the first planetary nebula discovered by Charles Messier.

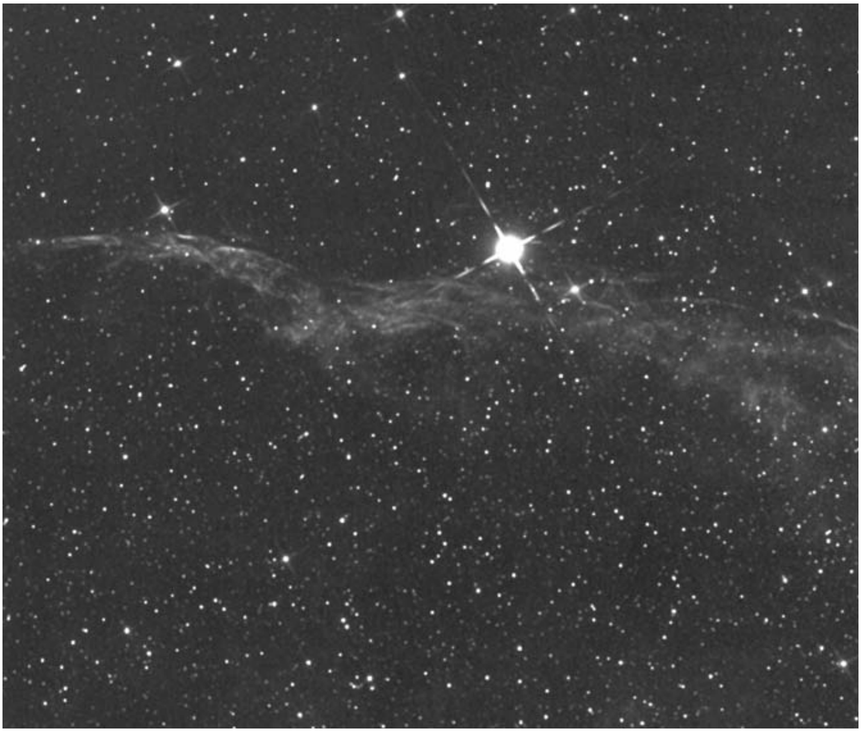


Figure 5.54. Pickerings Triangular Wisp (Veil Complex NGC 6960), Stellarvue Nighthawk @ f/6. Ha image. The Bridal Veil nebula is a large, complex nebula that spans over 3° and is the expelled remnants of a supernova.

Figure 5.55. Cocoon Nebula (IC 5146), Stellarvue Nighthawk @ f/6. Ha image. This nebula is located about 4000 light-years away toward the constellation of Cygnus. Inside the Cocoon is a newly developing open cluster of stars. Like other stellar nurseries, the Cocoon Nebula is an emission nebula, a reflection nebula, and an absorption nebula. Recent measurements suggest that the massive star in the center of the image opened a hole in an existing molecular cloud and now provides the energy source for much of the emitted and reflected light from this nebula.

Figure 5.56. Cocoon Nebula (IC 5146), Stellarvue Nighthawk @ f/6. Ha image. Resampled 150%. This nebula is located about 4000 light-years away toward the constellation of Cygnus. Inside the Cocoon is a newly developing open cluster of stars. Like other stellar nurseries, the Cocoon Nebula is an emission nebula, a reflection nebula, and an absorption nebula. Recent measurements suggest that the massive star in the center of the image opened a hole in an existing molecular cloud and now provides the energy source for much of the emitted and reflected light from this nebula.

Figure 5.57. North American Nebula (NGC 7000) and Pelican Nebula (IC5067-70) composite image, Stellarvue Nighthawk @ f/4.9. Ha image. Only a portion of NGC 7000 is shown. On a dark night under a clear and transparent sky, the North American Nebula can be seen with the unaided eye as a bright patch in the Cygnus Milky Way. The Pelican Nebula lies about 2000 light-years away in the constellation of Cygnus, the Swan. The two glowing nebulae appear separated from our vantage point by a large obscuring dust cloud.

Figure 5.58. Horsehead Nebula (B33), Stellarvue Nighthawk @ f/4.9. Ha image. Shaped like a chess knight, this dark cloud of gas and dust shows up in extended integrations but not in an eyepiece.

Figure 5.59. Open Star Cluster NGC 6910, Sadr, and surrounding nebulae, Stellarvue Nighthawk @ f/6. Ha image. The third brightest star of Cygnus, called Gamma Cygni or Sadr (the bright star right of center of the photograph), is surrounded by a huge complex of emission nebulosity. The nebula, which extends well beyond the borders of this image, is excited by young, hot blue-white stars and separated by dark nebulae into at least five major parts.

Figure 5.60. Great Nebula in Orion (M42). Stellarvue Nighthawk @ f/6.0. Ha composite image. Immense cloud of gas is 1500 light-years away. It can be seen with the naked eye at dark sites. The trapezium is at the center of the nebula and requires shorter integrations due to the brighter stars located here.

Figure 5.61. Network Nebula (NGC6992). Stellarvue Nighthawk @ f/6. Ha image.

Figure 5.62. Pac Man Nebula (NGC 281), Stellarvue Nighthawk @ f/4.9. Ha image. Busy area of intense star formation. Dark Bok globules, black blobs visible against the brighter nebulosity, are areas of intense star formation.

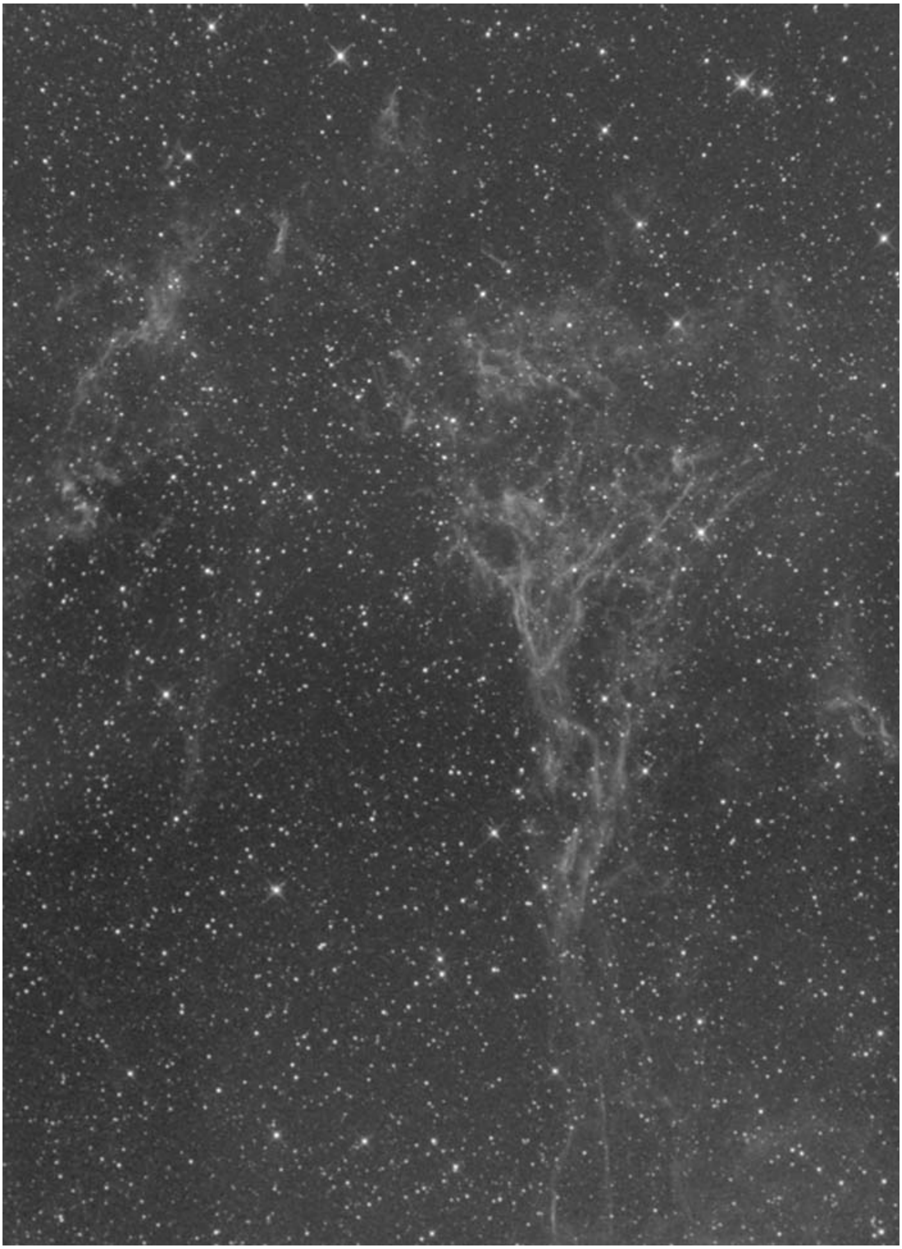


Figure 5.63. Lace-Work Nebula and Cirrus Nebula NW Part. Stellarvue Nighthawk @ f/6. Ha image. The Bridal Veil nebula is a large, complex nebula that spans over 3° and is the expelled remnants of a supernova.

Figure 5.64. Bubble Nebula (NGC 7635), Stellarvue Nighthawk @ f/6. Ha image. As fast moving gas expands from a nearby star, it pushes the surrounding gas into a shell. The energetic starlight then ionizes the shell, causing it to glow.

Figure 5.65. Nebula Complex IC 1396 and surroundings, Stellarvue Nighthawk @ f/4.9. Ha image. One of the largest emission nebulae in the universe, it spans 3°. The Elephant Trunk can be seen in the lower right of this image.

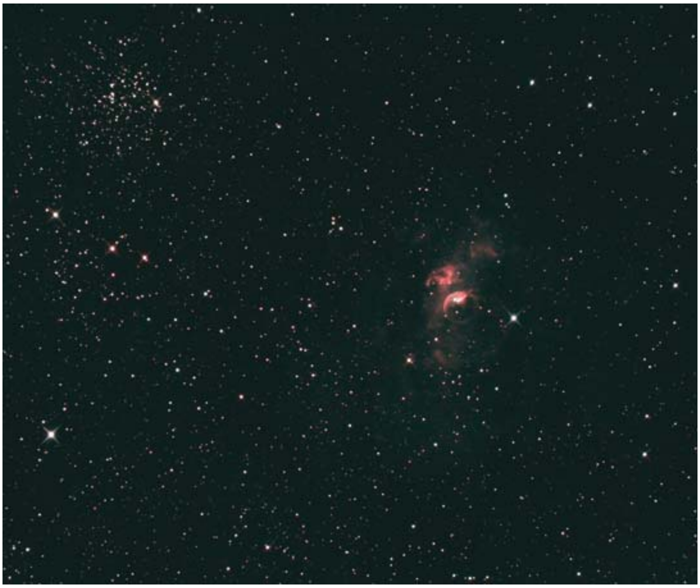


Figure 5.66. Open Star Cluster M52 and Bubble Nebula (NGC 7635), Stellarvue Nighthawk @ f/6. As fast-moving gas expands from a nearby star, it pushes the surrounding gas into a shell. The energetic starlight then ionizes the shell, causing it to glow.

Figure 5.67. Bubble Nebula (NGC 7635), Stellarvue Nighthawk @ f/6, cropped. As fast-moving gas expands from a nearby star, it pushes the surrounding gas into a shell. The energetic starlight then ionizes the shell, causing it to glow.

Figure 5.68. Emission Nebula NGC 1893, Stellarvue Nighthawk @ f/6. Ha image.

Figure 5.69. Emission Nebula IC1795, Stellarvue Nighthawk @ f/6. Ha image. Very dim emission nebula with dark dust lanes.

Figure 5.70. Flame Nebula (NGC 2024), Stellarvue Nighthawk @ f/6. Ha image. Bright star Alnitak, easternmost star in Orion's Belt, lights up the Flame Nebula.

Figure 5.71. California Nebula (NGC1499). Portion taken with Stellarvue Nighthawk @ f/6. Ha image.

Figure 5.72. Heart of Rosette Nebula (NGC 2237), Stellarvue Nighthawk @ f/6. Ha image. Inside the nebula lies an open cluster of bright young stars that formed about 4 million years ago. The nebular material and their stellar winds are clearing a hole in the nebula's center, insulated by a layer of dust and hot gas.

Figure 5.73. Open Star Cluster M52 and Bubble Nebula (NGC 7635), Stellarvue Nighthawk @ f/6. Ha image. As fast-moving gas expands from a nearby star, it pushes the surrounding gas into a shell. The energetic starlight then ionizes the shell, causing it to glow.

Figure 5.74. California Nebula (NGC 1499), Takahashi FS 60-C @ f/6. Ha image. The California Nebula gets its name from its resemblance to the United States' most populous state and is located 1000 light-years from our solar system. It is believed to be illuminated by the star Xi Persei, the fourth-magnitude star at the top of the image. Although large in size, this nebula has a low surface brightness, which makes it difficult to detect visually.

Figure 5.75. Crescent Nebula (NGC 6888), Stellarvue Nighthawk @ f/6. Ha image. This nebula is about 25 light-years across and was created by winds from the bright star seen near the center of the nebula. NGC 6888's central star should ultimately go out with a bang, creating a supernova explosion in 100,000 years.

Figure 5.76. Horsehead Nebula (B33), LX200 @ f/6.3.

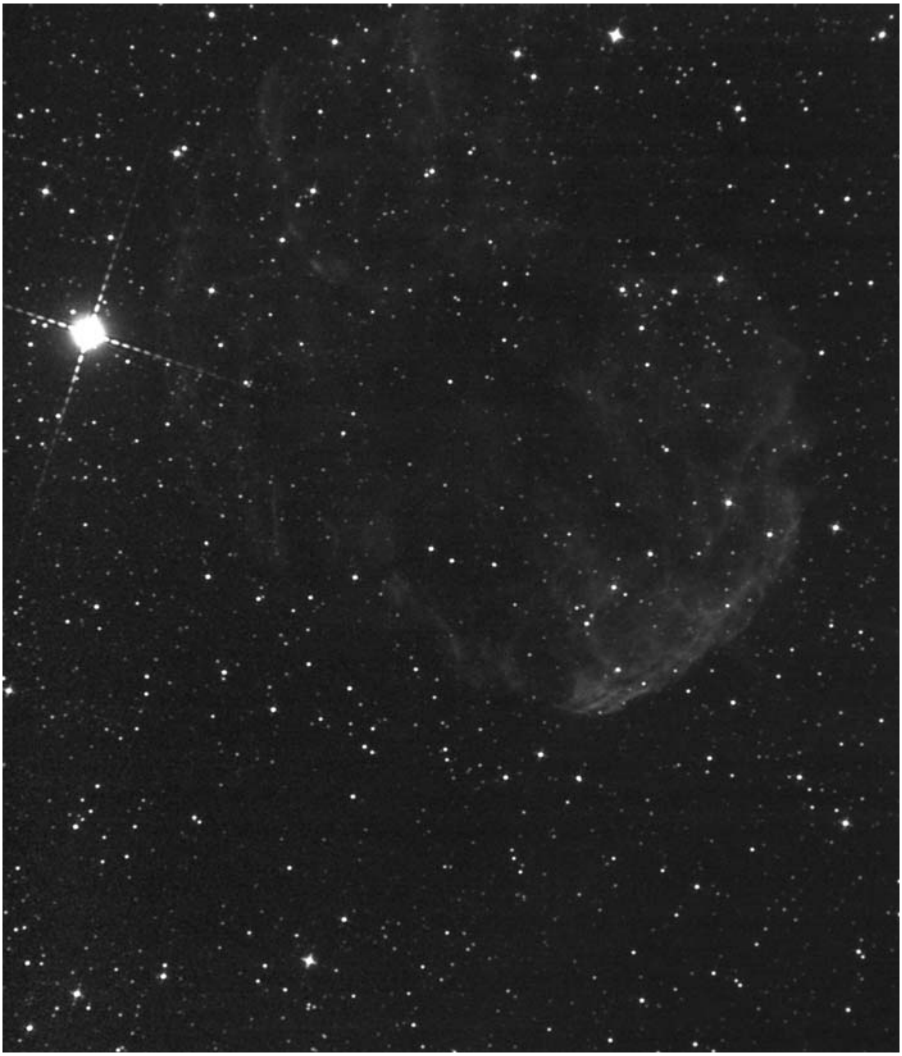


Figure 5.77. Emission Nebula IC443, Takahashi FS 60-C @ f/6. Ha image. Supernova remnant, looks to many like a jellyfish. A neutron star is buried deep within this nebula.

Figure 5.78. Flaming Star Nebula (IC 405), Takahashi FS 60-C @ f/6. The nebula is being illuminated by the high-energy star AE Aurigae (embedded in the nebula, center of image) and is actually moving through the nebula at this time.

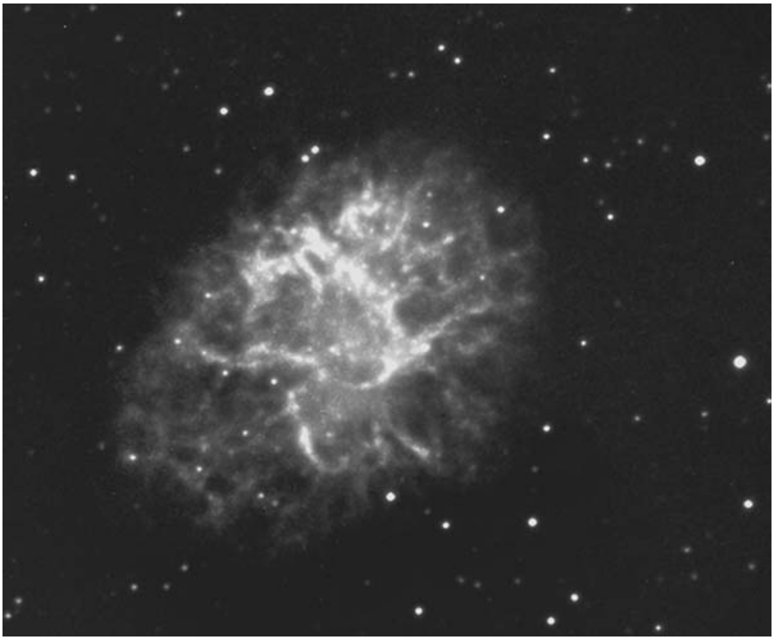


Figure 5.79. Crab Nebula (M1), LX200 @ f/6.3. Ha image. Supernova remnant of a star that exploded in AD 1054. A pulsar is at the center of the envelope of tendrils.

Figure 5.80. Dumbbell Nebula (M27), LX200 @ f/6.3. Ha image. This was the first planetary nebula discovered by Charles Messier.

Figure 5.81. Dumbbell Nebula (M27), Stellarvue Nighthawk @ f/4.9. Ha image. This was the first planetary nebula discovered by Charles Messier.

Figure 5.82. Great Orion Nebula (M42) and Running Man Nebula (NGC 1977), Stellarvue Nighthawk @ f/6. NGC 1977 is a reflection nebula and appears blue because the blue light from the neighboring stars scatters more efficiently from nebula gas than does red light.

Figure 5.83. Great Nebula in Orion (M42). Takahashi FS 60-C @ f/6. Immense cloud of gas 1500 light-years away. It can be seen with the naked eye at dark sites. The trapezium is at the center of the nebula and requires shorter integrations due to the brighter stars located here.

Figure 5.84. Ring Nebula (M57), Stellarvue Nighthawk @ f/6. The famous ring nebula is often regarded as the prototype of a planetary nebulae, and recent research has confirmed that it is actually a ring (torus) of bright light-emitting material surrounding its central star. A wide-field image places the nebula in context against the vastness of space.

C. Globular Star Clusters

Figure 5.85. Globular Star Cluster M71, LX200 @ f/3.3. A very loose globular star cluster that is a part of a small and unique group of globulars with metal-rich stars.

Figure 5.86. Globular Star Cluster M5, Stellarvue Nighthawk @ f/6. M5, located in the constellation of Serpens Caput, is one of the three great globulars, ranking with M13 and M3.

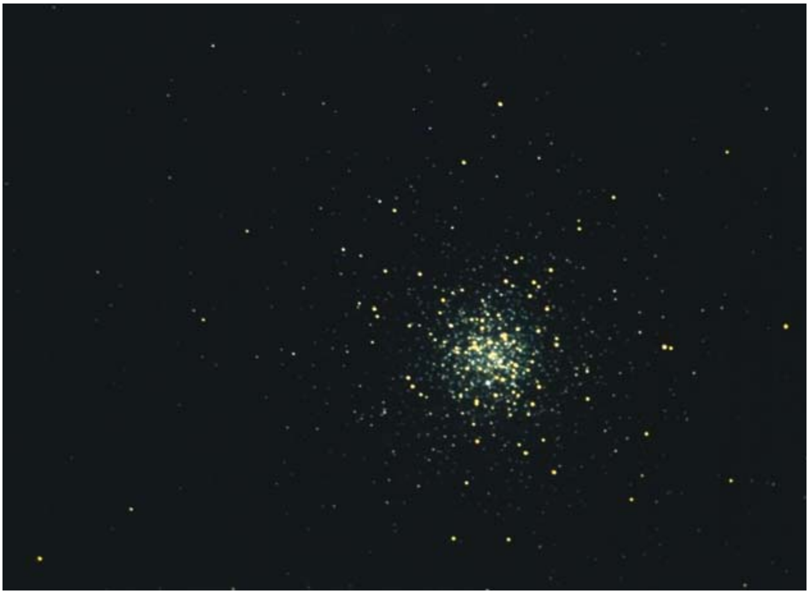


Figure 5.87. Globular Star Cluster M3. Stellarvue Nighthawk @ f/6. Like all globulars, this huge ball of stars predates our Sun. Long before our Earth existed, ancient globs of stars condensed and orbited a young Milky Way Galaxy. Of the 250 or so globular clusters that survive today, M3 is one of the largest and brightest.

Figure 5.88. Hercules Globular Star Cluster M13, LX200 @ f/6.3. One of the brightest and largest globulars visible to northern hemisphere observers.

Figure 5.89. Hercules Globular Star Cluster M13, Stellarvue Nighthawk @ f/4. One of the brightest and largest globulars visible to northern hemisphere observers.

Figure 5.90. Hercules Globular Star Cluster M13, Stellarvue Nighthawk @ f/6. Cropped.

Figure 5.91. Globular Star Cluster M22, LX200 @ f.6.3.

Figure 5.92. Globular Star Cluster M3, LX200 @ f/6.3. Like all globulars, this huge ball of stars predates our Sun. Long before our Earth existed, ancient globs of stars condensed and orbited a young Milky Way Galaxy. Of the 250 or so globular clusters that survive today, M3 is one of the largest and brightest.

D. Galaxies

Figure 5.93. Spiral Galaxy M33, Stellarvue Nighthawk @ f/6. The Triangulum galaxy M33 is a prominent member of the Local Group of galaxies. Several knots in the spiral arms of M33 have been assigned their own NGC catalog numbers.

Figure 5.94. Spiral Galaxy M106, Stellarvue Nighthawk @ f/6. This galaxy is distinguished by arms, or jets, seen curving outward through the disk in optical emission lines. Recent measurements near the nucleus suggest a supermassive dark object (a black hole candidate with mass on the order of 100 million solar masses) at the center of this galaxy.

Figure 5.95. The Great Andromeda Galaxy M31, Stellarvue Nighthawk @ f/6. This is a portion of the Andromeda Galaxy, the nearest major galaxy to our own Milky Way Galaxy. Our Galaxy is thought to look much like Andromeda. Together these two galaxies dominate the Local Group of galaxies. The diffuse light from Andromeda is caused by the hundreds of billions of stars that comprise it.

Figure 5.96. Spiral Galaxy NGC 2543, Stellarvue Nighthawk @ f/6, cropped.

Figure 5.97. Spiral Galaxy NGC 2903, Stellarvue Nighthawk @ f/6. This barred spiral galaxy is estimated to be 20 million light-years away. This is one of the objects Messier missed for some reason—its magnitude of 9.6 is in the brightness range of other Messier galaxies. NGC-2903 is also known as a "starburst galaxy" and has been the subject of Hubble Space Telescope studies.

Figure 5.98. Spiral Galaxy UGC 3587, Stellarvue Nighthawk @ f/6.

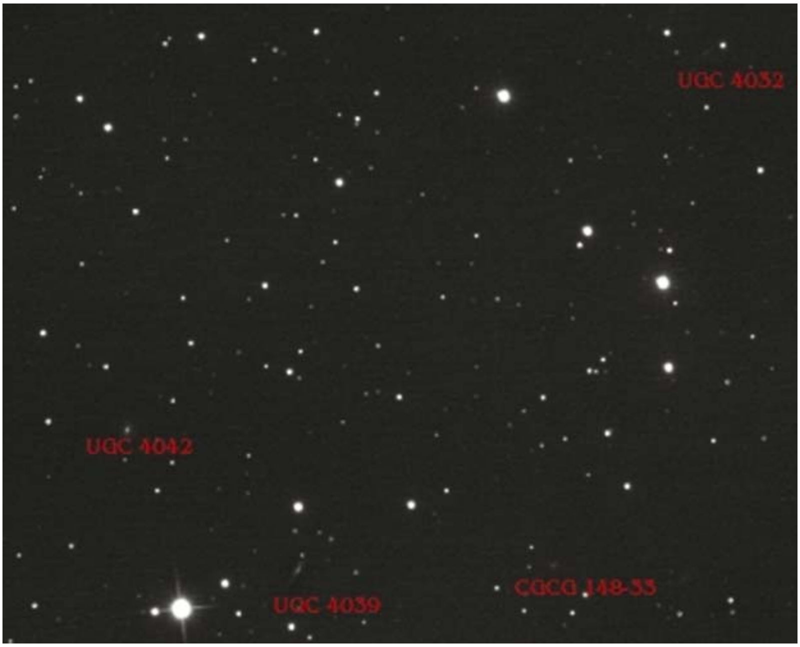


Figure 5.99. Galaxies UGC 4042, UGC 4039, CGCG 148-33, and UGC 4032, Stellarvue Nighthawk @ f/6.

Figure 5.100. Galaxies NGC 3185, NGC 3189, NGC 3187, and MCG4-24-22, Stellarvue Nighthawk @ f/6. The central three galaxies are part of the Hickson 44 Group in the constellation Leo.

Figure 5.101. Barred spiral galaxy NGC 3432, Stellarvue Nighthawk @ f/6. NGC 3432 is interacting with a faint nearby galaxy PGC 32617 located between the tic marks.

Figure 5.102. Spiral Galaxies NGC 2968 and NGC 2964, Stellarvue Nighthawk @ f/6.

Figure 5.103. Spiral Galaxy NGC 2862, Stellarvue Nighthawk @ f/6.

Figure 5.104. Blackeye Galaxy (M64), Stellarvue Nighthawk @ f/6. Known for its dark arc-shaped dust region.

Figure 5.105. Sombrero Galaxy (M104), Stellarvue Nighthawk @ f/6. Well-known dust lane. Disk and bulge have a mass of several billion Suns.

Figure 5.106. Spiral Galaxy M74 (NGC 628), Stellarvue Nighthawk @ f/6. This spiral galaxy is an island universe of about 100 billion stars, 30 million light-years away toward the constellation Pisces. M74 presents a gorgeous face-on view and is similar in many respects to our own Milky Way Galaxy.

Figure 5.107. Edge-on Spiral Galaxy NGC 891, Stellarvue Nighthawk @ f/6. The galaxy's disk is so thin that the spiral galaxy appears edge-on. The dark band across the middle is a lane of dust that absorbs light.

Figure 5.108. Edge-on Spiral Galaxy NGC 891, cropped. Stellarvue Nighthawk @ f/6. The galaxy's disk is so thin that the spiral galaxy appears edge-on. The dark band across the middle is a lane of dust that absorbs light. Cropped.

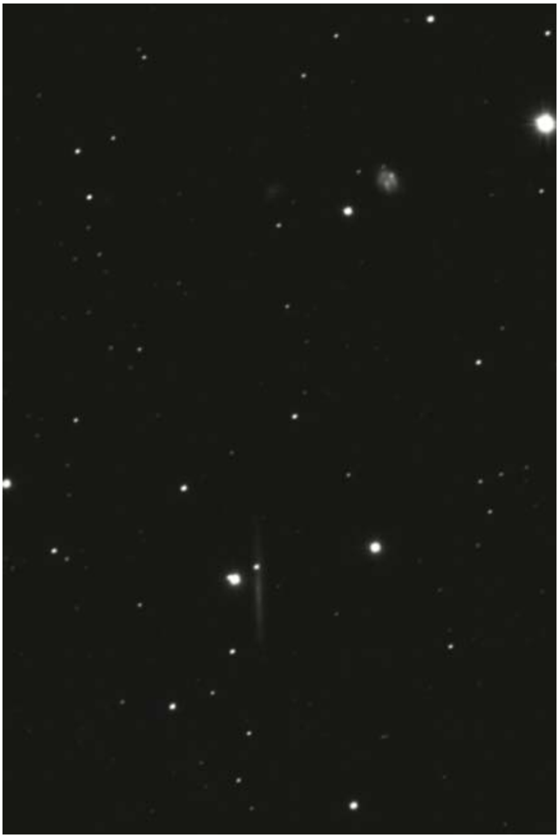


Figure 5.109. Edge-on (Needle) Galaxy IC2233, Bear Paw Galaxy (NGC 2537) and Spiral Galaxy NGC 2537A, Stellarvue Nighthawk @ f/6.

Figure 5.110. Leo Triplet Galaxies M65, M66, and NGC 3628, Stellarvue Nighthawk @ f/6. All are part of the same group of galaxies at a distance of 65 million light-years from Earth.

Figure 5.111. Whirlpool Galaxy (M51), LX200 @ f/6.3.

Figure 5.112. Whirlpool Galaxy (M51), Stellarvue Nighthawk @ f/6.

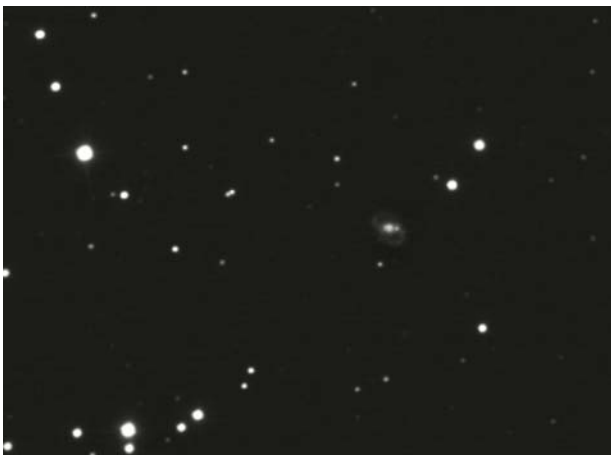


Figure 5.113. Spiral Galaxy NGC 2543, Stellarvue Nighthawk @ f/6.

Figure 5.114. Sculptor Galaxy (NGC 253), Stellarvue Nighthawk @ f/6. Largest member of Sculptor Group of Local Galaxies, nearest group to our own Milky Way Group.

E. Open Star Clusters

Figure 5.115. Open Star Cluster NGC 6705, Stellarvue Nighthawk @ f/6. Also known as the Wild Duck Cluster, it is one of the richest and most compact known open clusters, with an estimated 2900 stars.

Figure 5.116. Open Star Clusters NGC 869 and NGC 884, Stellarvue Nighthawk @ f/6. Also known as the Double Cluster in Perseus, this unusual cluster is bright enough to be seen from a dark location without binoculars.

Figure 5.117. Open Star Cluster M103, Stellarvue Nighthawk @ f/6. Bright blue stars highlight the open cluster known as M103. The gas clouds from which these stars condensed has long dispersed. Of the stars that were formed, the brightest, bluest, and most massive have already used up their nuclear fuel and self-destructed in supernova explosions.

Figure 5.118. Open Star Cluster NGC 1528, Stellarvue Nighthawk @ f/6. Open star cluster in Perseus.

Figure 5.119. Open Star Cluster NGC 663, Stellarvue Nighthawk @ f/6. Open star cluster in Cassiopeia.

Figure 5.120. Open Star Cluster NGC 743, Stellarvue Nighthawk @ f/6. Only 15 stars to this group, with the center clear of stars.

Figure 5.121. Open Star Cluster NGC 1582. Stellarvue Nighthawk @ f/6.

Figure 5.122. Open Star Cluster NGC 6819, Stellarvue Nighthawk @ f/6. Also known as The Foxhead star cluster in Cygnus.

Figure 5.123. Open Star Cluster M34, Stellarvue Nighthawk @ f/6. This intermediate-aged open cluster of about 100 stars lies about 1400 light-years distant and is scattered over 35 arc-minutes, more than the diameter of the Full Moon.

Figure 5.124. Open Star Clusters M35 and NGC 2158, Stellarvue Nighthawk @ f/6. Open star cluster M35 consists of several hundred stars and is scattered over the area covered by the Full Moon (30 arc-minutes).

Figure 5.125. Open Star Cluster M36 (NGC 1960), Stellarvue Nighthawk @ f/6. Considered one of the youngest open star clusters at 20 million years of age.

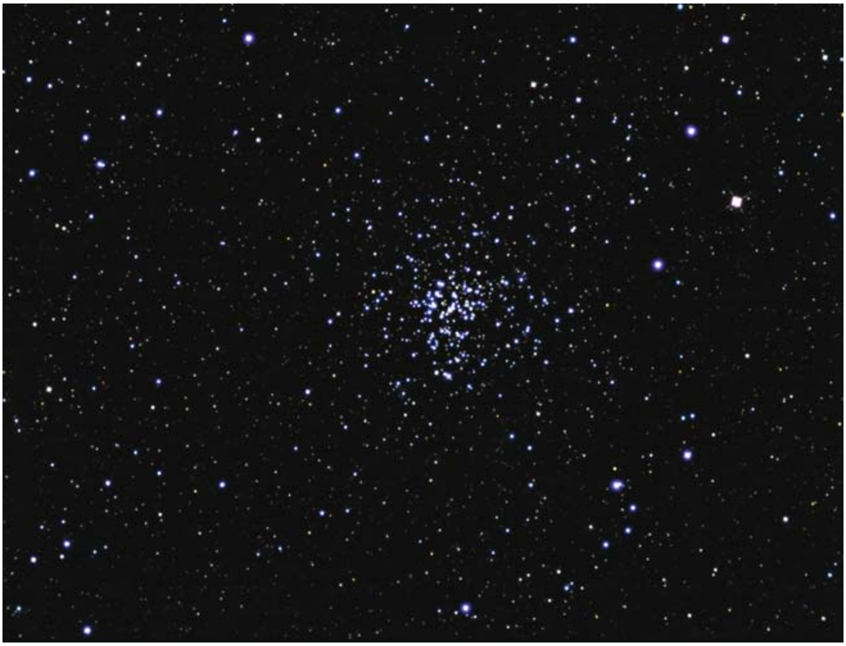


Figure 5.126. Open Star Cluster M37, Takahashi FS 60-C @ f/6. M37 is the brightest of the three open clusters in southern Auriga.

Figure 5.127. Open Star Clusters M38 and NGC 1907, Takahashi FS 60-C @ f/6. M38's brightest stars form a pattern resembling the Greek letter pi.

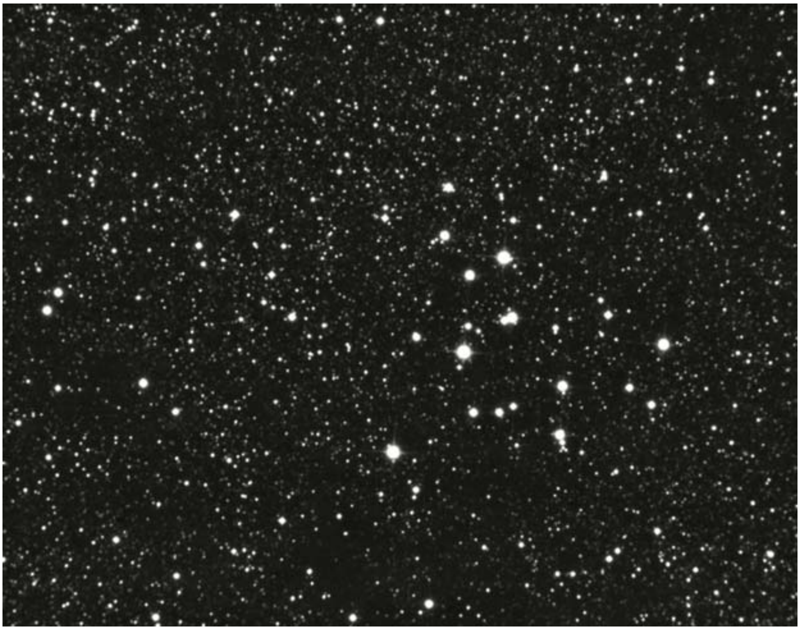


Figure 5.128. Open Star Cluster M39, Stellarvue Nighthawk @ f/6. M39 is a very large and very loose open cluster, only 800 light-years distant. Thirty stars are proven members.

Figure 5.129. Open Star Cluster M44, Stellarvue Nighthawk @ f/6. Also called Praesepe (Latin for "manger"), or the Beehive cluster. It is one of the open star clusters easily visible to the naked eye and thus known since prehistoric times.

Figure 5.130. Open Star Cluster M46 with Planetary Nebula NGC 2438, Stellarvue Nighthawk @ f/6. The cluster is very rich, with 150 stars. A famous feature is planetary nebula NGC 2438, appearing within the apparent borders of M46. This object appears to lie near the northern fringes of the cluster, but is a passing guest.

Figure 5.131. Open Star Clusters M47 and NGC 2423, Stellarvue Nighthawk @ f/6. Open cluster M47 is a bright cluster that can be glimpsed with the naked eye under good conditions as a dim nebulosity. It is a coarse cluster of approximately 50 bright stars.

Figure 5.132. Open Star Cluster M50, Takahashi FS 60-C @ f/6. Open cluster M50 is probably about 3200 light-years distant and has an estimated population of about 200 stars in the main body.

Figure 5.133. Open Star Cluster M67, Takahashi FS 60-C @ f/6. M67 is one of the oldest known open star clusters at 3.2 billion years which is much less than the age of our Solar System.

Figure 5.134. Open Star Clusters NGC 869 and NGC 884, Stellarvue Nighthawk @ f/6. Also known as the Double Cluster in Perseus, this unusual cluster is bright enough to be seen from a dark location without binoculars. Luminance imaged through green filter.

Figure 5.135. Open Star Cluster/Nebulosity NGC 1931, Stellarvue Nighthawk @ f/6. NGC 1931 is a tiny little cluster of stars embedded in nebulosity . At the heart of the cluster lies a tiny version of the famous Trapezium in M42; four stars that make a rough trapezoid.

Figure 5.136. Open Star Cluster NGC 457, Stellarvue Nighthawk @ f/6. This open star cluster, also known as the ET Cluster, lies in the constellation Cassiopeia. It contains more than 100 stars and lies at a distance over 9000 light-years away.

Figure 5.137. Open Star Cluster NGC 7209. Stellarvue Nighthawk @ f/6.

Figure 5.138. Open Star Cluster NGC 663, Stellarvue Nighthawk @ f/6. Open star cluster in Cassiopeia. Luminance imaged through green filter.

CHAPTER SIX

What to Do with All Those Astrophotos

Many of us who take astrophotos want to share them with anyone who is interested. My children are 11 years old. I must admit that after 3 years of trying to achieve higher-quality images and trying to improve my image processing skills, I *think* they are warming to the idea that astrophotos can be interesting to look at. My wife is supportive, but she is quick to ask me "haven't you imaged this before?" when I show her a new image. "Once an open star cluster always an open star cluster" is her mantra. Well, you get the picture. Unless you share the passion for this hobby of ours, I guess the 100th open star cluster or wide-field galaxy imaged at 2.84-arc-seconds/pixel resolution begins to look the same. For me, a wide-angle image that captures a galaxy that is only 2 arc-minutes in longest dimension against the backdrop of enormous blackness and sprinkled stars—there is majesty in this image. I like the context that such an image conveys. I have tried to explain to my kids that the fuzzy blob they were staring at in an image was so unimaginably big and yet so far away despite its apparent size on the image. They could not comprehend that a few hundred *billion* stars were contained in that ovoid smudge in the image. How many people can?

There are several storage media to choose from so that your hard drive does not fill to capacity too quickly. Each night's imaging session gets recorded to a CD-R disk (capacity 750 MB). When I do tricolor imaging, an evening's session can easily fill several disks. Additionally, many imagers save several iterations during the processing routine. After trying a particular filter or processing step, the intermediate image is saved so it can easily be revisited.

Some imagers save their final images in JPEG or BMP format and burn them to a CD-R so the images can be hand-delivered to a photo processing place. You might be dismayed at the overall color of your images when you get them printed by a 1-h photo store or lab. Sky backgrounds in the images can be wild, spanning the colors of the rainbow. Why don't the prints look like the pictures in the magazines and on the Web? There are a variety of reasons that the sky background can be different colors. A likely one is that the sky really does have some color from man-made light pollution, but the overriding cause is that the automatic printing machine and operator at the photo lab just do not know what to do with an astronomy picture. Our images can contain lots of blackness or be almost completely blank except for some dots (stars). Try to work with the actual person who does the printing at the 1-h lab. See how much control the operator has and if they are interested in helping you.

When your images are digitized, you can adjust them yourself and then print them on your inkjet printer or laser printer. I bought a Hewlett Packard high-end inkjet printer and have had some success printing lunar and planetary images. One of the proprietary software programs that came bundled with the printer allows a lot of image manipulation in a real-time window, which looks very similar to the printed image. However, open star clusters and nebulae with wispy elements do not print well on my inkjet printer.

Computer monitor calibration is extremely important, not only for viewing true fidelity of your color and monochrome images but also to preview your image for eventual printing. There are devices and bundled software that can accomplish this, as well as Internet websites that have special gray scales and color bars that the user can reference as his or her monitor is adjusted. Unfortunately, not all imagers keep their monitors calibrated, and if you like to post your images to a website or view the images of others, you need to keep this in mind when scrutinizing images.

If you decide to print your own images, the printer is the ultimate decision-maker when it comes to the quality of your printed photos. Your Printer's Device Options will allow you to change your printer's ability to produce great printed photos. The important settings to look for are: print quality settings and paper type. You should set the print quality to the highest setting and select the correct paper type. If you select the "Plain Paper" setting but print on premium photo paper, the results will be less than optimal. *Consumer Reports*, here in the United States, reviewed photo paper for inkjet printers (*Consumer Reports*, January, 2005) and came to the following conclusions: Generic photo glossy paper [100 sheets for $15.00 (8.10£)] is not worth the time or expense. The results were extremely poor. Professional Grade photo paper is recommended and the added expense is worth the results.

I was introduced to online photo printing by a fellow astroimager. I have used iphotoshop.com for almost 2 years and have had the good fortune of only having the postal service ruin my printed images once. The company now uses sturdy photo mailing tubes to return photos regardless of the size of your order. This service allows you to digitally upload your highest-quality formatted image using three different methods: an FTP (File Transfer Protocol) server, a traditional website, or uploading after installing a company freeware utility called a print wizard. With FTP uploading, you organize your images into a folder on your local computer and either drag the folder to a window on the company's website or directly FTP transfer. This service uploads faster than standard Web upload and uses the optimum file resolution for the selected print size. Web uploads allow all of your photos (regardless of print size desired) to be uploaded using a file upload interface. (Depending on your browser version, you can either "drag and drop" your files all at once or browse for them individually). When the upload is complete, you will see a thumbnail preview of each image. You can now select the print size and quantity for each image. Finally, the Print Wizard is a free application that gets installed onto your system to help you process online digital print orders quickly and easily. Uploads are faster than standard Web upload and FTP, which is great for users with slower connections and/or users uploading a large order.

A handful of quality lunar images taken at f/30 with the LX200 and ToUcam camera looked so good on my monitor that I uploaded them to iphotoshop.com and had several poster-size images printed with a matte finish. Behind nonglare glass, matted and framed, this collection of lunar landscapes usually draw comments from guests to my house, incredulous that they were not beamed back from one of the lunar orbiters! I have also used the online photo service for resampling some of my open star clusters and colorful nebulae shots to a reasonable 16-in. × 20-in. (41-cm × 51-cm) or 24-in. × 30-in. (61-cm × 76-cm) image. There is some cost savings realized by getting photo mounting spray glue and mounting and framing the images yourself.

Designing a website can be as simple as uploading JPEG photos to an image-hosting site or spending lots of money for a fully functional Web portal where you control everything. There are also choices in between the extremes. I am computer-savvy but do not know anything about Web Page construction and design. I chose PBase galleries to host my JPEG images because for a nominal fee of around $20 (10.80£) annual, I have unlimited storage and ease of use. The great thing about having your own website is the instantaneous ability to share images by clicking and pointing. I designed a site that organizes my images into folders (galaxies, nebulae, solar system, and so forth) and have thumbnails for quick reference.

Sky & Telescope and *Astronomy* are two magazines that many of us subscribe to that encourage readers to send in our best images for consideration in their Gallery section. If one of your images does not make it into the Gallery section, many photos taken by amateurs also make it into the body of an article, or if a special feature that is discussed needs a photo of the Moon or Jupiter, for example, one of our prize images is substituted for a stock photo. It is nice to recognize familiar names in print of imagers with whom we might correspond on any of the Internet groups.

CHAPTER SEVEN

An Introduction to Minor Body Astrometry

On February 17, 2005 OakRidge Observatory was given an official observatory designation (H76). An observatory code is assigned by the Minor Planet Center (MPC) upon receipt of acceptable observations of minor bodies (asteroids and comets). This is a pretty exciting honor. The MPC is responsible for the designation of minor bodies in the solar system: minor planets, comets, and natural satellites. The MPC is also responsible for the efficient collection, computation, checking, and dissemination of astrometric observations and orbits for minor planets and comets. Several publications, such as the *Minor Planet Circulars*, are issued throughout the year in print and electronic format.

Astrometry is the precise measurement of the position and motion of astronomical objects, with respect to standard star catalogs. Newcomers to astrometric observing are required to observe a number of low-numbered, known minor planets each on pairs of nearby nights. If weather interferes, the two observing nights can be nonconsecutive. After reporting two or three observations of each object from each night, a specially formatted MPC Report is submitted and the positions are checked against known astrometric solutions. The quality of the observations, measured in arc-seconds, is reported back to the observer. An observatory code is assigned upon acceptance of an initial submitted batch of observations.

It is expected that an observer can produce good astrometry of known objects before beginning to discover new objects. It is important that observers can consistently produce observations with an accuracy of less than 1 arc-second for observations using the same comparison stars, and the night-to-night consistency should be limited only by the comparison star catalog. (One arc-second refers to a measurement within a 1-arc-second circle of the predicted asteroid position.)

Through April 2005 I have logged 40 total observations (residuals) on 6 known minor bodies, with 36 astrometric solutions having an accuracy less than 2 arc-seconds (90%). My R.A. error is +0.05 ± 0.99 and my Dec. error is +0.10 ± 0.83. Not bad for having one of the smallest, if not *the* smallest, aperture telescopes (78 mm) being used of all the reporting observatories in the world. There are 1160 listed observatory codes, updated nightly, though April 13, 2005.

One problem with looking for minor planets under a light-polluted sky is the ability to discern these small rocks at much beyond magnitude 17 or 18. My approach thus far to recording known minor planets on CCD images is to use TheSky to search for extended minor planets at a specific area of the sky, near my local zenith, where it is darker. I frame an area with the FOV indicator, orient the view in the virtual sky to match my camera, and look for suitable targets. I can slew with the LX200, take a few test images, and match apparent asterisms (or patterns; you typically cannot see the minor body even with a dramatic screen stretch). With the STV guider tracking through the LX200, I can snap an image of 180–300 s integration every 15 min for up to 1 h or so; during the 15-min inter-

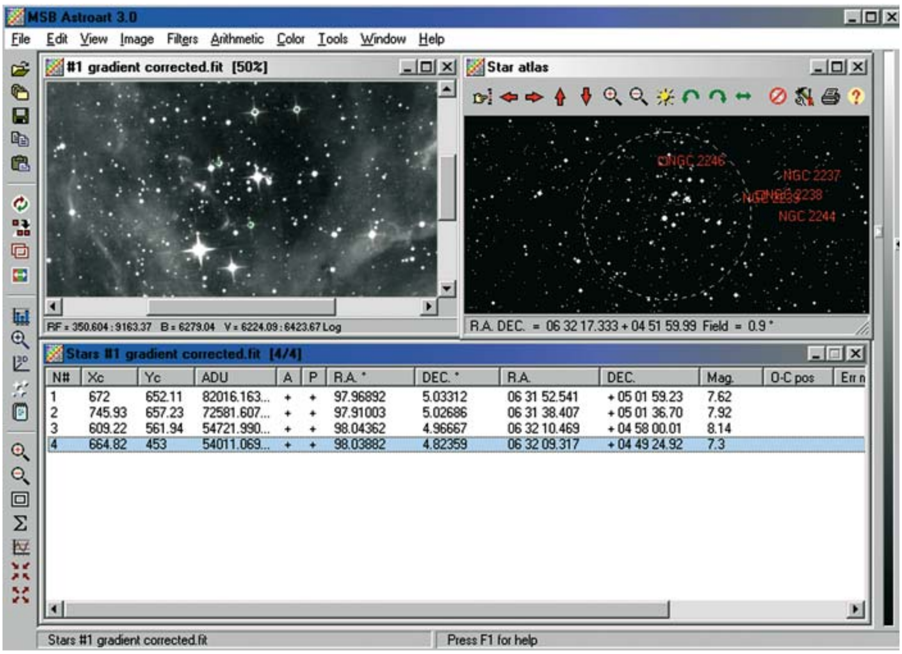


Figure 7.1. Astroart 3.0 screen capture. Astrometry is the precise measurement of the position and motion of astronomical objects, with respect to standard star catalogs such as the Guide Star Catalog (GSC) that Astroart uses. A portion of the Rosette Nebula (NGC 2246) is shown on the left, with four small circles marking the position of four known stars, as shown in the Star Atlas at right. The window at bottom shows the R.A. and Dec coordinates, as well as the stellar magnitude, of these four stars. (Used with permission, MSB Software, Inc.)

lude the minor planet moves against the backdrop of the "fixed" stars, and when I subsequently align the images on the stars, there should be one minor planet (or more) moving between image frames.

Astroart 3.0 has a "blink" function that allows each image to be compared to the other at various speeds in order to best spot the moving body against the fixed background. I can also use AIP4WIN to make an AVI loop, replaying the small movie of several frames. If I spot the known minor planet where it should be (TheSky shows minor planet positions for any time and any time interval), I can easily mark the FITS image with a centroid marker. Astroart 3.0 has both an astrometric and photometric tool, but the software and creation of an MPC Report is unstable with my Windows operating system (see Fig. 7.1).

Instead, I use Software Bisque's CCDSoft and TheSky to perform an astrometric solution on my images, whether I can see the minor planet or not. (Sometimes, even with a dramatic screen stretch, the minor planet that is *supposed* to be there, right next to an obvious star, is just not there. Chalk it up to light pollution.) An inventory of every star from your CCD image is created (see Fig. 7.2). Using the approximate equatorial coordinates from the FITS image's header (which is copied from the Astroart 3.0 FITS header because the camera

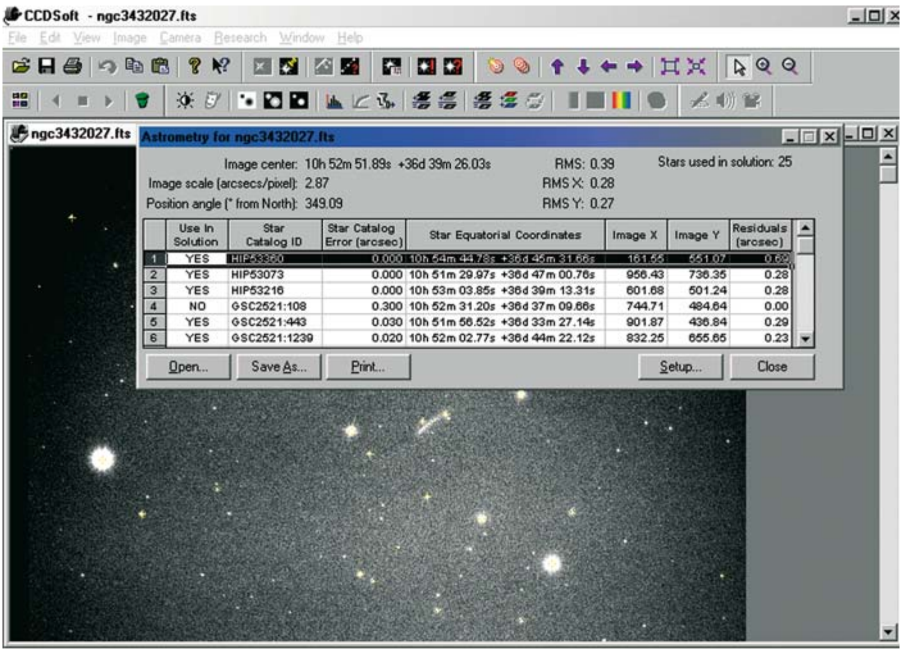


Figure 7.2. CCDSoft version 5 screen capture. Raw image of galaxy NGC3432 has been opened and astrometric solution completed. Twenty-five stars were used in the solution, marked with yellow crosses in original. RMS, RMS X and RMS Y values are all very good. Image scale is 2.87 arc-seconds/pixel. White streak at center is galaxy NGC3432, stretched. (Used with permission, Software Bisque, Inc.)

that I use is a non-SBIG camera: otherwise, it is automatically supplied by TheSky when the image was taken if using an SBIG camera), Image Link pattern recognition then determines the stars from your image that match stars from the Guide Star Catalog and/or the stars from the Hipparcos/Tycho stellar catalog.

Accurate star centroids are computed for each star, and a six-coefficient linear plate solution (astrometric solution) is computed using all available stars (see Figs. 7.3 and 7.4). The Astrometry dialog box is presented, showing the precise right ascension and declination of the center of the image, the image scale in arc-seconds/pixel, the image's position angle, the overall root mean square (RMS) value, as well as astrometric data for each individual star used in the solution. Computed residual error, measured in arc-seconds, is the amount by which the star's position varies from the catalog position.

Amateur astronomers often contribute to activities such as helping to track asteroids and observing occultations to determine both the shape of asteroids and the shape of the terrain on the edge of the Moon. In the past, amateur astronomers have also played a major role in discovering new comets. Recently,

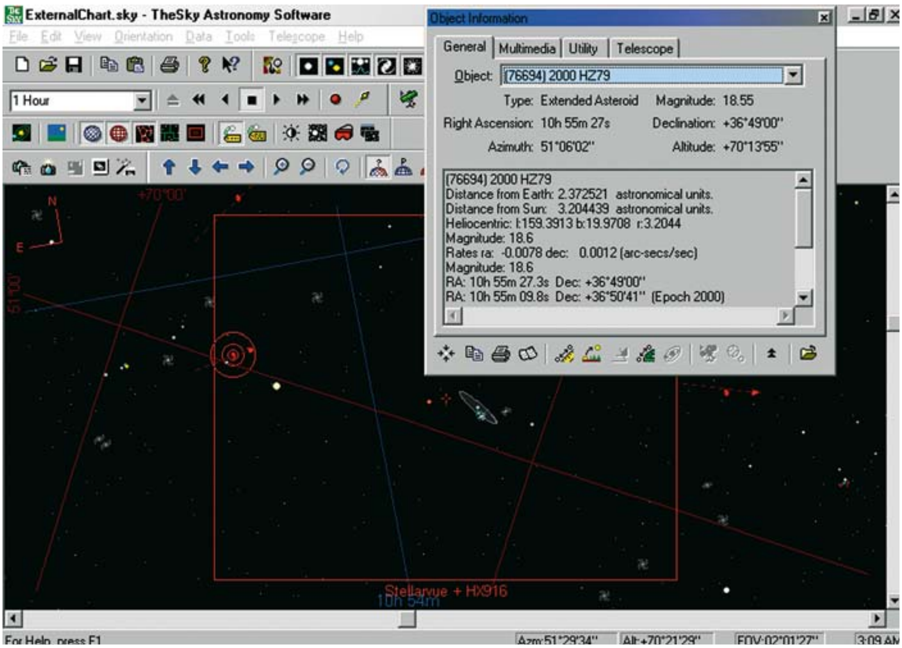


Figure 7.3. TheSky version 5, Level 4 screen capture. CCDSoft has completed a successful astrometric solution and has successfully linked the image with TheSky. The rectangle frames the FOV of the telescope and CCD camera and shows galaxy NGC3432 at center. Asteroid 76694, a magnitude 18.55 extended minor planet moving at 0.0012 arc-seconds/s, is seen at left of FOV. During a 300-s integration, the asteroid will have moved approximately 0.12 pixels. Circle with arrowed vector denotes direction and movement over ensuing 24 h. (Used with permission, Software Bisque, Inc.)

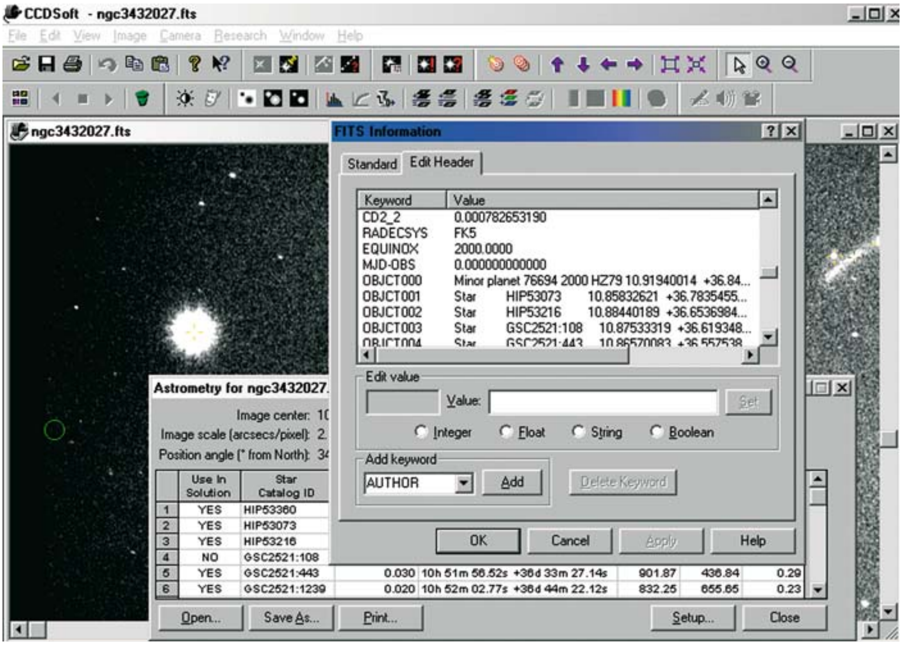


Figure 7.4. CCDSoft version 5 screen capture. Raw image of galaxy NGC3432 has been opened and astrometric solution completed. "Insert Minor Planets" command has been selected and a circle (green in original) has marked the location of the only known minor planet in the FOV at the time of image capture. The FITS header has been opened to show the detected body is minor planet 76694. Streak at right of FITS information box is galaxy NGC3432. (Used with permission, Software Bisque, Inc.)

however, funding of projects such as the Lincoln Near-Earth Asteroid Research and Near Earth Asteroid Tracking projects has meant that *most* comets and asteroids are now discovered by automated systems, long before it is possible for amateurs to see them.

Just locating an asteroid is an achievement! Well, software certainly makes things easier, but the observer can still prepare for a night of imaging asteroids. Armed with an ephemeris (table of predicted positions), a star chart, and software, the problem is greatly reduced. Plotting the position on the star chart will enable you to recognize the brighter asteroids immediately or else to narrow the search down to a few possible stars. Final recognition depends on determining which "star" is moving. Over the period of an hour, most asteroids will reveal their identity against the background. Having found a moving body on your CCD images, what do you do? Well, you can prepare an MPC Report and wait for confirmation of a minor body having been captured by your CCD camera or you can first use software, such as Find Orb, to first test the quality of your astrometric observations. Let us say that you record the position of a moving body several times and feed the results to Find Orb. If you see that their positions line up nicely on an orbit with residuals of around 1 arc-second, you will start to feel much better about the quality of your astrometry.

Even relatively simple observations can be instructive. Photometry, the measurement of apparent magnitudes of astronomical objects, can also be conducted. Does the apparent brightness of a moving body change during the course of an evening as the asteroid spins on its axis? Some elongated asteroids have large amplitudes. By estimating the brightness at regular intervals over two or three nights it is possible to derive an axial rotation period very accurately. Even if the brightness does not appear to change during the course of a night, it will change as the distance from the Earth changes, brightening as opposition approaches and fading as the Earth draws ahead after opposition.

Although amateur observers still contribute many valuable Near Earth Orbit (NEO) observations, their most significant contributions have evolved away from NEO discovery toward astrometric follow-up (observations to help refine the orbits of new NEOs discovered by the professional surveys) and valuable physical studies to help better characterize the physical nature of these planetary projectiles.

Recording *known* asteroids on CCD detectors is fun but not necessarily challenging. A small investment in time is all that is necessary, as you typically need to record three or four images, spaced 15–20 min apart, on two separate nights. I usually plan a deep sky imaging session with this time commitment in mind. That is for *known* asteroids. The real fun is the prospect that on any (and maybe all) of your deep sky images lurks a moving body that might be an undiscovered asteroid! During a 3-h imaging session, I might align and coregister three images (first, middle sequence, and end) in Astroart 3.0 and manually blink the images. Three images might represent Time_0, $\text{Time}_{+90\text{ min}}$, and $\text{Time}_{+180\text{ min}}$. You can play with the screen stretch to best visualize the background of your images. What appears to be a moving object might very well be a group of hot pixels, dust mote artifact, or maybe an asteroid! To better visualize the movement of the object over the entire 3 h of imaging, I align and coregister the images in AIP4WIN after dark-frame subtracting and flat-fielding and then load the calibrated images into an AVI file. You can watch a time-compressed loop over and over, looking for the moving object against the background. If the motion is obviously impossible (i.e., the object has retrograde motion or flies out of the frame at an acute angle), you have just wasted an hour: You have not recorded an asteroid. You can also do an astrometric solution on a few frames in CCDSoft and TheSky, generate an MPC Report, and run a few observations through the Find Orb software.

No other branch of science allows the naming of new worlds by the discoverer. The discoverer of a new asteroid has the privilege of suggesting a name to the 15-member Committee for Small-Body Nomenclature of the International Astronomical Union, which judges its suitability. This committee is composed of professional astronomers (with research interests connected with minor planets and/or comets) from around the world. The assignment of a particular name to a particular minor planet is the end of a long process that can take many years. This would be a nice way for someone to leave their mark on astronomy.

CHAPTER EIGHT

Invaluable Contacts and Links

There are so many dedicated imagers out there who have helped me immensely over the last 3 years. I have saved much of the "important" email correspondence over the years (the Pearls of Wisdom) in a binder with tabbed dividers, which has made the job of organizing this book easier. Special thanks must go out to Jon Talbot, Alan Chen, Al Kelly, Paul LeFevre, Paul Kane, Terry Platt, Daniel Bisque, Rod Mollise, Al Testani, Bob Holzer, Michael Downing, Fabio Cavicchio, R.A. Greiner (Doc G.), Ron Wodaski, Charlie Warren, and the late Bruce Johnston. These guys patiently (I hope) answered many of my questions; many continue to do so. I am sure I have forgotten several others. If my imaging results fall short of the reader's expectations, the fault is all mine! Please do a GOOGLE search on any of these imagers and see what quality astroimaging is all about.

"Acquiring and Processing Astronomical CCD Images"	http://www.ghg.net/akelly/procccd.htm
Adirondack Video Astronomy	http://www.astrovid.com
Amateur Astronomy Feature at the National Air and Space Museum	http://www.nasm.si.edu/exhibitions/gal111/universe/firstlight/observers.cfm
Astroart User Group	http://groups.yahoo.com/group/AstroArt
AIP4WIN User Group	http://groups.yahoo.com/group/AIP4WIN
Anacortes Telescope and Wild Bird	http://www.buytelescopes.com/default.asp
Art and Science of CCD Astronomy	Ratledge, David (Ed). Springer, 1996
Astroart 3.0 User Group	http://groups.yahoo.com/group/AA3Plugins
Astromart	http://www.astromart.com/default.asp?

Astronomik	http://www.astronomik.com/english/eng_contact.html
Astronomy magazine	http://www.astronomy.com
"At Home in a Dome"	http://www.homedome.com/online.htm
Atomic Clock Sync	http://www.worldtimeserver.com/atomic-clock
Backyard Astronomer's Guide	Dickinson, Terrance and Alan Dyer. Firefly Books, LTD, 2002
Belkin Corporation	http://world.belkin.com
Choosing and Using a Schmidt–Cassegrain Telescope	Mollise, Rod. Springer, 2001
Clear Sky clock online	http://cleardarksky.com
Consolidated Lunar Atlas	http://www.lpi.usra.edu/resources/cla/
Corel Photo Paint	http://www.corel.com
"Drift Method of Polar Alignment"	http://www.aa6g.org/Astronomy/articles.html
Ephemeris Generator	http://ssd.jpl.nasa.gov/cgi-bin/eph
Ephemeris Time Spans	http://ssd.jpl.nasa.gov/eph_spans.html
Find Orb	http://www.projectpluto.com/find_orb.htm
FRcalc.exe software	http://www.aquest-inc.com/downloads.htm
Gateway computers	http://gateway.com
"G2V Color CCD Balancing"	http://www.ghg.net/akelly/artdraf7.htm
The Handbook of Astronomical Image Processing (AIP4WIN)	http://www.willbell.com/AIP/Index.htm
Heavens-Above	http://www.heavens-above.com
High Resolution CCD Imaging	http://legault.club.fr/index.html
Interactive NGC Catalog	http://www.seds.org/~spider/ngc/ngc.html
International Dark Sky Association	http://www.darksky.org
iphotoshop	http://www.iphotoshop.com
Jerry Lodriguss Image Index	http://www.astropix.com/HTML/K_MISC/TOC_DEX.HTM
Jim's Mobile, Inc.	http://www.jimsmobile.com/index.htm
K3CCD Software	http://www.pk3.org/Astro
Kendrick Astro Instruments	http://www.kendrickastro.com/astro/index.html
Le Sueur Manufacturing Company	http://www.astropier.com
Light Pollution in Europe	www.inquinamentoluminoso.it/dmsp
Losmandy Astronomical Products	http://www.losmandy.com
Lumicon	http://www.lumicon.com
"LX200 Polar Alignment"	http://www.astrocruise.com/polarnew.htm
LX200 User Group	http://groups.yahoo.com/group/LX200
MAPUG	http://www.mapug.com/index.htm
MEADE Instruments	http://www.meade.com
Meade Uncensored User Group	http://groups.yahoo.com/group/Meade-Uncensored
Messier Catalog	http://seds.lpl.arizona.edu/messier/xtra/history/m-cat.html

Minor Planet Center	http://cfa-www.harvard.edu/cfa/ps/mpc.html
Moon and Sun Rise/Set tables online	http://aa.usno.navy.mil/data/docs/RS_OneYear.html
Moon-"light" Atlas online	http://www.astrosurf.com/cidadao/moonlight.htm
MSB Astroart 3.0 software	http://www.msb-astroart.com
Mueller's Atomics	http://www.muellersatomics.com
The New CCD Astronomy	Wodaski, Ron. The New Astronomy Press, 2002
National Optical Astronomy Observatory Image Gallery	http://www.noao.edu/image_gallery
National Service Radar	http://www.srh.noaa.gov/radar/latest
The NGC/IC Project	http://www.ngcic.org
Night Sky magazine	http://nightskymag.com
Observatories User Group	http://groups.yahoo.com/group/Observatories
Oceanside Photo and Telescope	http://www.optcorp.com/default.aspx
Orion Telescopes and Binoculars	http://www.telescope.com
Parks Optical	http://www.parksoptical.com
PBase.com	http://www.pbase.com
Philips	http://www.pc-cameras.philips.com
QCUIAG User Group	http://groups.yahoo.com/group/QCUIAG
RealVNC Software	http://www.realvnc.com
Registax software	http://registax.astronomy.net
SBIG Santa Barbara	http://sbig.com
SBIG STV User Group	http://groups.yahoo.com/group/SBIGSTV
ScopeStuff	http://www.scopestuff.com
SCT User Group	http://groups.yahoo.com/group/sct-user
Sigma Combine	http://www.gralak.com/Sigma/index.html
Sky & Telescope magazine	http://skyandtelescope.com
Sloan Digital Sky Survey	http://www.sdss.org
SoftBisq User Group	http://groups.yahoo.com/group/SoftBisqUser
Software Bisque	http://www.bisque.com
Spaceweather.com	http://spaceweather.com
Starlight Xpress™	http://www.starlight-xpress.co.uk
Starlight Xpress™ User Group	http://groups.yahoo.com/group/starlightxpress
Stars	http://www.astro.uiuc.edu/~kaler/sow/class-g.html
Stellarvue® Telescopes	http://www.stellarvue.com
Stellarvue® User Group	http://groups.yahoo.com/group/Stellarvue
Adam Stuart's Gallery	http://www.pbase.com/adamstuart
Takahashi America	http://www.takahashiamerica.com
TelescopeService	http://www.telescopeservice.com/services.htm
The STScI Digitized Sky Survey	http://stdatu.stsci.edu/cgi-bin/dss_form

Technical Innovations	http://www.homedome.com
“What is Drift Alignment?”	http://members.aol.com/ccdastro/drift-align.htm

Glossary

Achromat A type of refractor whose objective is made from lenses of different materials, selected to bring two colors of light (usually blue and yellow) to the same focal point. The rest of the colors of visible light are brought *almost* to the same focal point, but because they all do not arrive at the same focal point or plane, there is some color distortion around bright point sources.

ADU Value Analog-to-Digital Units. These are the raw numbers that emerge from a CCD camera and represent the counts per pixel read out from a CCD.

Aggressiveness Term used when making guiding adjustments. An aggressiveness setting of 1 means that the SBIG STV guider will make the full correction that it calculates it needs to make; a setting of 0.5 means that it will make half the calculated move. Setting a number to less than 1 helps reduce oscillation or overshoot.

Altizmuth/Azimuth Mount Short for Altitude–Azimuth (also called Alt-Az). Telescopes that are mounted so that they move up-down and left-right (as opposed to equatorially) are called Alt-Az. This is a typical configuration for visual use on a traditional tripod.

Aperture The term as used with a telescope refers to the opening at the front of the tube that allows light through; the diameter of the objective of a telescope.

Apochromat A type of telescope that lacks both spherical and chromatic aberration.

Astigmatism An optical defect in which star images are elongated into ovals that change from a radial orientation (pointing toward the center of the field) to a tangential one (at right angles to the center) as the telescope focuser is moved from one side of best focus to the other.

Asterism Pattern of apparently neighbored, but physically unrelated stars, formed by a chance alignment of the stars at different distances that happen to be situated in about the same direction. A famous asterism is the Big Dipper.

Astrometry The precise measurement of the position and motion of astronomical objects, such as asteroids and comets, with respect to standard star catalogs.

Atmospheric Extinction Coefficient Imaging a target other than near the zenith, its light travels a longer distance through the Earth's atmosphere before it can reach you. A coefficient is determined for each colored filter and imaging setup that is used to color-correct for those photons that are absorbed and scattered by the atmosphere at nonzenith angles.

Autoguider A CCD that is attached to a guide scope and electronically attached to the control of the telescope mount. It monitors the position of a guide star on the CCD chip and adjusts the telescope's drives to keep the star in the same position. This enables long-exposure astrophotography by correcting for drive errors and polar alignment errors.

AVI Loop An AVI file video format that can be played on popular computer software. A loop means that the small file is played continuously, restarting after the video file ends.

Backlash Term describing the amount of play between gears. Use of zero-image-shift Crayford focusers, modifying the Meade Superwedge, and P.E.C. training the LX200 are examples of trying to improve or eliminate backlash.

Barlow Lens Barlow is a negative (diverging) lens that is placed between the objective lens (or primary mirror) and the eyepiece of a telescope. It increases the effective focal length of an objective lens, thereby increasing the magnification. Assuming that the Barlow is a good lens, the only disadvantage is a slight loss of light that hits your retina or CCD chip.

Bias Frame An image of almost zero exposure time, with no light reaching the CCD detector.

Binning Binning involves combining pixels on a CCD chip to create larger pixels. For example, one pixel that is binned becomes a 2×2 square of pixels and creates one pixel that is twice the width and four times the area of the original pixel. This is done to increase sensitivity or to match a long-focal-length telescope to a CCD camera with small pixels. Unbinned is also written as 1×1 binning.

Black Point A histogram adjustment that will determine the amount of shadow detail in an image. It is considered proper to set the black point so that the darkest part of an image will just have zero detail.

Blue Bloat Refers to an RGB (red, green, blue) image acquired with an achromat that has blue channel bloating. The stars in the image will appear to have blue halos because of the blue bloat.

Bortle Scale To help observers judge the true darkness of a site, John Bortle created a nine-level scale based on nearly 50 years of observing experience. The scale goes much beyond estimating one's limiting magnitude.

CCD Charge-coupled device. A type of image sensor used in some astronomical cameras. When a picture is taken, the CCD is struck by light coming through the telescope lens to which the camera is attached. Each of the thousands or millions of tiny pixels that make up the CCD converts this light into electrons. The number of electrons are measured and then converted to a digital value, which is recorded by a computer that is attached to the camera.

Centroid As used in image processing, refers to the X,Y-coordinate of a star's center position, usually compared to the expected position as determined from a reference stellar catalog.

Chromatic Aberration In a refractor, light passes through a lens and is bent to reach a focus point. Each wavelength of light is bent differently, so they do not all meet at the same point of focus. The result is an out-of-focus glow, usually purple or blue in color because the violet light is least likely to meet focus with the other colors. Some refractors are specially corrected for this aberration. CCD cameras are far more sensitive to ultraviolet and infrared light than the human eye, so only the very best refractors are suitable for high-resolution CCD imaging. My Stellarvue Nighthawk is an achromat.

Collimation The process of aligning the elements of an optical system. Collimation is routinely needed in SCTs and requires simple adjustments of the secondary mirror on the Meade LX200 by turning three screws.

Coregister Term used in image processing. Refers to aligning images, regardless of orientation or telescope-CCD camera configuration used to take the image, so all stars and extended objects line up pixel for pixel.

Corrector Plate The glass lens on the front of an SCT. Because an SCT uses spherical mirrors that suffer from spherical aberration, the corrector plate is used to eliminate this aberration.

Cosmic Ray Hits Charged particles moving at nearly the speed of light that reach the Earth from space and hit the CCD detector. These events are recorded on the CCD image as small streaks and need to be processed out.

Crayford Focuser A type of telescope focuser in which the focus tube is moved by a roller. These focusers are known for smooth, slack-free motion and for precisely adjustable friction.

Dark Current Astronomical CCDs can detect electronic noise generated by the CCD chip itself. The amount of noise created by the CCD chip is known as dark current. Dark current is a function of temperature, and cooling the CCD chip can remove much of the noise. The remaining noise is eliminated with dark frames.

Dark Frame A dark frame is a CCD image taken with the lens cap on the telescope, of the same duration as the light image. This image detects noise generated by dark current. Using image processing software to subtract the dark frame from the raw image leaves only the object. The dark noise is eliminated.

DDP Filter DDP stands for Digital Development Processing. This an image processing routine used in many software programs. DDP processing allows both bright and dim parts of an astronomical object to be displayed at the same time. DDP essentially compresses washed-out regions of an object into a range that the computer can display.

Declination (Dec.) Declination is one of the coordinates in a system used by astronomers to locate celestial bodies in the sky. Declination is measured in degrees and refers to how far above the imaginary "celestial equator" an object is. It is similar to latitude on the Earth. Declination is measured as 0° at the celestial equator, +90° at the North Pole, and –90° at the South Pole.

Declination Drift Even if the seeing is excellent, if a telescope's mount is not polar aligned with good accuracy, there will be a slow north or south drift in declination (i.e., the star will slowly drift from its original location). Drift polar aligning is accomplished by monitoring the declination drift of a star at high power in the eyepiece and adjusting the polar axis of the mount based on the direction of drift. See Chuck Vaughn's treatment of this referenced in Chapter VIII.

Device Manager A tool that is included with the Microsoft Windows operating system; it can display and control the hardware that is attached to a computer running MS Windows. When a piece of hardware (i.e., a CCD camera) is not working properly, the offending hardware is highlighted in yellow and the user can attempt to troubleshoot the conflict.

Download time As used with a CCD camera attached to a computer, it is a measure of the time it takes for images to appear on the computer monitor after an exposure ends. USB download connections are faster than parallel port, and binned images download faster than unbinned images.

Ephemeris The coordinates of a planet, sun, comet, or moon given at regular intervals of time. The standard format can be downloaded to popular planetarium programs (such as Software Bisque's TheSky) to locate these celestial bodies in real time or to plan for an upcoming observing or imaging session.

Equatorial Mount An equatorial wedge is used for imaging with a fork-mounted telescope. An equatorial wedge mounts between the telescope and pier to allow the forks to be aimed toward Polaris so that the telescope can track in just one axis, eliminating field rotation.

Ethernet The most widely installed local area network (LAN) technology. The most commonly installed Ethernet system is called 10BASE-T and provides transmission speeds up to 10 Mbps, allowing several computers to transfer data over a communications cable.

Extended Deep Sky Object Deep sky objects (DSOs) include the enormous variety of nebulae, star clusters, and galaxies beyond our solar system. DSOs appear extended: They have a visible size, rather than just being a single pinpoint of light like an individual star.

Extended Minor Planet Term as used in Software Bisque's TheSky. It refers to minor planets that can exceed 30,000 objects in inventory and are computed for a given instant in time and remain visible on the Virtual Sky for only a specified period.

Field of View (FOV) The two dimensional area that can be seen through the telescope and CCD imaging system. It is expressed in arc-minutes or degrees, depending on how small (or large) the CCD chip is when used with a given optical system.

Field Rotation If the mount is not polar aligned correctly, field rotation will result. This refers to stars at the edge of the image frame appearing to rotate around the guide star.

FITS Standard Stands for Flexible Image Transport System. A file written in this standard format conforms to the specifications and endorsement of the IAU (International Astronomical Union) for transfer of astronomical data.

Flat Field Out-of-focus dust particles in the optical system and vignetting can lead to an unevenly illuminated CCD chip. By taking an image of an evenly illuminated source (such as the evening sky after sunset or the inside of an observatory dome), the differences in illumination across the field of view can be removed using image processing software.

Focal Ratio (f/ratio) The f/ratio of a telescope is determined by dividing the focal length of the primary lens or mirror by the aperture (the diameter of that same lens or mirror). This number tells us several important things about a telescope. The lower the f/ratio the faster the telescope is said to be; that basically means that it provides a brighter image than a similar sized telescope with a higher f/ratio. Telescopes with low f/ratios give wide-field images with bright star fields; they are good for viewing star clusters and faint nebulae. Telescopes with high f/ratios do not deliver views as bright but yield higher magnifications with narrower fields of view. They are ideal for planet viewing.

Focal Reducer A focal reducer is used to reduce the focal length of a telescope objective. It is a converging lens and helps to increase the "speed" of the telescope.

FWHM Full-width-at-half-maximum. This numeric value reflects the approximate size of a star's image as seen by the eye. It is shaped like a Gaussian curve and is the width across the profile when it drops to half of its peak, or maximum, value. It is a well-defined number that can be used to compare the quality of images obtained under different observing conditions.

G2V Star A term that refers to a spectral type of star. The Sun is a G2V star, meaning that it is a "G" star, subclass 2, and of luminosity class V, signifying Main Sequence. G2V stars are considered known white-source stars and are used for calibrating filters used for trichrome imaging.

Galaxy A system of about 100 billion stars. Our Sun is a member of the Milky Way Galaxy. There are billions of galaxies in the observable universe.

Globular Star Cluster A spherical cluster of thousands and thousands of stars, formed at the same time billions of years ago. Globular clusters usually have a size of 50–150 light-years.

GPS Telescope Global Positioning System. A system of relay satellites sends information to a receiving device on a telescope and computes the position of the observer on the Earth. It eliminates the need with computer-controlled telescopes to go through the alignment routine when setting up. This type of telescope is probably more meaningful to someone who does not have a permanent setup.

Gradient The departure from an even background in an image. It is usually seen when tangential light enters the telescope optics and is recorded by the CCD chip as a nonuniform grade.

GSC Catalog The Guide Star Catalog I (GSC I) is an all-sky catalog of positions and magnitudes of approximately 19 million stars and other objects in the 6th to 15th magnitude range. The GSC 1 catalog is used for the control and target selection of the Hubble Space Telescope. GSC 2.2 contains almost 450 million objects.

Guiding No telescope mount can track perfectly. For CCD imaging, it is necessary to very accurately track the object being imaged. This is done by guiding on a star and making small mount corrections as the star is followed. This makes up for any errors in the telescope's drive system. Guiding can be done manually by watching a star through a crosshair eyepiece or by using an autoguider such as the SBIG STV.

Hartmann Mask A full aperture mask with two or three holes cut in it. When placed over the front of a telescope, it causes multiple images of a star when the star is out of focus. When in focus, the star's images converge to become one.

Hipparcos Catalog The Hipparcos star catalog contains 118,218 stars. The Hipparcos Catalog is one of the primary products of the European Space Agency's astrometric mission, Hipparcos, which operated from 1989 to 1993, returning high-quality data.

Histogram A histogram is a graph of the number of pixels versus pixel values in an astronomical image. Pixel values run from lowest (displayed as black, to the left on the graph) to highest (displayed as white, to the right on the graph). A bar is plotted for each pixel value showing the number of pixels in the image with that value. An astronomical image typically has more pixels toward the lower end of the histogram because most astroimages contain large amounts of dark sky.

Host/Client The Local Network is comprised of the observatory computer (Host) and control room computer (Client). The Host computer provides Client users with services such as database access and typically has the software on it on which the Client computers depend.

Hydrogen-alpha Filter This is a filter that is designed for CCD imaging of gas and planetary nebulae. Due to the narrow bandpass of the H-alpha line at 656 nm, the filter provides maximal increase in contrast even under poor observing conditions. The 13-nm bandwidth of the Astronomik H-alpha filter allows transmission as high as 97%.

Image Calibration/Reduction Refers to modifying the raw CCD data after it is obtained. This is where dark frames, flat fields, and bias frames (and their matching dark frames) are applied.

IR-Blocked Digital sensors are infrared (IR) sensitive. IR-blocking filters are used to block spurious responses from color filters when doing trichromy.

Light Box An internally illuminated box that uses indirectly placed light sources to evenly illuminate a translucent diffuser screen (milk plastic or vellum) on one side of the container. The screen is sized to cover the entire aperture of the telescope so that accurate flat-field frames can be made.

Light-Pollution-Rejection Filter These filters generally work by blocking wavelengths of light that interfere with the object you are trying to view or image. Light-pollution filters work by blocking the scattered light from mercury vapor lights and other terrestrial light sources.

Light-Year The distance that light, moving at a constant speed of 186,000 miles per second (300,000 km per second), travels in 1 year. One light-year is about 6 trillion miles, or 10 trillion km.

Limiting Magnitude The magnitude of the dimmest star that you can see at the zenith (overhead). It is determined by weather, local light-pollution, and viewing techniques.

LRGB Images taken with a black-and-white CCD camera through red, green, and blue filters are combined to make RGB images. We get most of the spatial information about an image from the brightness, or luminance, portion of the image, not from the color, or hue, portion. This means that it is possible to take a lower-resolution color image and combine it with a high-resolution black-and-white image to make an LRGB image (the L stands for luminance). As long as the low-resolution color image is combined with a high-resolution luminance image, the full resolution is maintained and the total exposure time is decreased.

Luminance The monochrome (high-resolution) portion of an image.

Magnitude Scale A system of ranking stars by apparent brightness. The brightest stars in the sky are categorized as being of first magnitude, and the faintest stars visible to the naked eye are classified as sixth magnitude. The scheme extends to cover stars and galaxies too faint to be seen by the unaided eye. Increasing magnitude means fainter stars, and a difference of five magnitudes corresponds to a factor of 100 in apparent brightness. The brightest star visible with the naked eye is over 600 times brighter than the faintest one. The Sun is over 6 trillion times brighter than the faintest star visible to the naked eye.

Median Combine Noisy images can be smoothed to some extent by taking the median value of all the pixels in the images when image processing. Median combining requires that there be an odd number of images (e.g., you can median combine 9 images, but not 10).

Memory Buffer Also called a memory cache, it is a portion of computer memory made of high-speed Static Random Access Memory (SRAM) instead of the slower and less expensive dynamic RAM (DRAM) used for main memory. Memory caching is effective because most programs access the same data or instructions over and over. By keeping as much of this information as possible in SRAM, the computer avoids accessing the slower DRAM.

Meridian Transit This is the passage of a celestial body across the observer's meridian, coincident with the time when the object reaches its highest point in the sky. The meridian is an imaginary great circle projected on the sky, passing through the North and South poles at right angles to the equator.

Messier Objects The original 110 objects are a set of astronomical objects (galaxies, nebulae, open star clusters, and globular star clusters) cataloged by Charles Messier in his catalog of nebulae and star clusters, first published in 1774. The original motivation behind the catalog was that Messier was a comet hunter and was frustrated by objects that resembled but were not comets.

Micron The length of one-millionth of a meter, or 1/1000000 m (~ 1/25,000 in.) This length is also referred to as a micrometer.

Mirror-Lock The LX200 Classic design is prone to image shift when focusing. A primary mirror-lock completely cancels any residual image shift while focusing during CCD imaging when using a Crayford-style focuser, which moves the eyepiece holder and not the telescope mirror once locked.

Mirror Slop Refers to the focus shift that is caused by the primary mirror when it slides on the baffle tube (all moving-mirror Cassegrains have some mirror slop).

Monochrome Refers to having a single color, typically referring to a black-and-white image.

MPC Report Astrometric observations of comets, minor planets, and natural satellites are submitted for publication in the Minor Planet Circulars (MPC), Minor Planet Electronic Circulars and IAU Circulars, and are represented by

80-column records. The format differs depending on whether the observation is optical (photographic, CCD, or visual), radar, or satellite based.

Nebula A diffuse mass of interstellar dust and gas.

Network A connection of two or more computers that can share resources.

Noise Unwanted, random variations in brightness or color that is always present to some extent within any signal. The information captured by a CCD sensor contains both image data and noise.

Nyquist Sampling Theorem The law that is the basis for sampling continuous information. It states that the frequency of data sampling should be at least twice the maximum frequency at which the information might vary. Applied to CCD imaging, if we want to accurately reproduce a telescope image, the resolution of the CCD should be twice the resolution of the telescope.

Open Star Cluster A cluster of stars usually containing several hundred members packed into a region usually less than 20 light-years in size. They are normally found near regions of star formation in the spiral arms of galaxies.

Opposition The position of a planet when it is exactly opposite the Sun as seen from Earth. A planet at opposition is at its closest approach to the Earth.

Oversampled If too many pixels are gathered by a CCD camera, no additional information is afforded, and the image is said to have been oversampled. The extra pixels do not theoretically contribute to improving the spatial resolution.

Parallel Port A port on the computer that is faster than a serial port but slower than USB. Often used by printers and flash card readers.

Parfocal A term that refers to both eyepieces and filters. With eyepieces, a change in magnification maintains an image that remains in focus. With filters, the claim means that an object being imaged remains in focus despite a change in filter. My Astronomik Type II filters are advertised as parfocal and they are *close*, but the focus still needs adjustment with an achromat refractor and the LX200.

P.E.C. Training Every set of drive gears has some inherent inconsistencies that will manifest as a time-varying tracking rate. In the case of the LX200's right ascension (R.A.) gears these errors repeat every 8 min. The Smart Drive function of Meade's LX200 telescope allows one to train the computer to compensate for periodic errors in the drive's R.A. gears. This is more commonly known as periodic error correction, or PEC. Training the Smart Drive of your LX200, similar to doing an accurate polar alignment, is one of the best ways to improve the quality of your photographs.

Photometry Photometry is the measurement of apparent magnitudes of astronomical objects, like stars or asteroids.

Photon Visible light behaves like a wave phenomenon, but in other respects it acts like a stream of high-speed, submicroscopic particles arranged in discrete packets. These high-energy packets travel through empty space at a speed of approximately 186,000 miles (300,000 km) per second.

Pixel Pixel is short for picture element and describes the tiny squares that make up a CCD image. Pixels can also refer to the individual squares in an image or the actual light-sensitive squares on a CCD chip (also called photosites).

Planetary Nebula As a star collapses, the outer gaseous layers are ejected into space and resemble a planet like ball of gas.

Plate Solution Another term for object's solution, which is the precise measurement of an astronomical objects position and motion.

Polar Alignment "Equatorial" telescope mountings have two axes (a polar axis and a declination axis) to help compensate for the Earth's rotation and aim at objects in different parts of the sky. The polar axis of an equatorial mount should point at the north celestial pole and the process of accomplishing this is called "polar aligning." This means making the polar axis of the mount parallel to the Earth's axis of rotation. This greatly simplifies the tracking of a celestial object across the sky, requiring only the motion of the telescope's mount in right ascension. For long-exposure deep sky astrophotography, polar alignment is critical.

Quantum Efficiency (QE) As photons of light hit a CCD chip, they are converted into electrons that are stored and then read out at the end of the exposure. Not every photon that hits the chip is converted into an electron. How many photons are converted depends on the camera's QE. QE is expressed as a percentage of the number of photons converted. If all the photons produced electrons, the QE would be 100%. Most amateur CCD cameras have QEs in the range 25–50. Film has a typical QE of around 2%.

Raw Frame The downloaded, unprocessed FITS image that the CCD camera produces.

Refractor This is what most people think of as a traditional telescope: It has a lens at one end and you look straight through the other. This is sometimes referred to as a "Galilean" telescope, as it is of the same design that Galileo used.

Residuals Used in astrometry, this term describes the observed position of a celestial body compared to the predicted position. A residual of 0 would imply precise location. Low residuals are an indication of quality data.

Resolution The ability of a telescope to measure the angular separation of objects in an image that are close together. Also, it refers to the level of detail that a CCD camera can capture, usually expressed in arc-seconds per pixel. Smaller pixels produce a higher resolution, meaning that smaller details can be seen.

Reticle A system of lines and/or concentric circles incorporated into an eyepiece, used for positioning or guiding the telescope, or polar-aligning an equatorial mount. The Meade 9mm reticle is illuminated in order to render the lines visible against a dark background sky.

Right Ascension (R.A.) Right ascension is one of the coordinates in a system used by astronomers to locate celestial bodies in the sky. It is similar to longitude on the Earth. Right ascension is measured in hours of time, from 0 to 24.

RMS Value This is a complicated mathematical term—the square root of the average of the squares (root mean square) of the instantaneous values. It is the square root of the arithmetical mean of the squares. For our purposes, it refers to overall RMS (root mean square) error of an astrometric solution. Values under 0.50 indicate a very good solution.

Schmidt-Cassegrain (SCT) A classic wide-field telescope. The first optical element is a Schmidt corrector plate. The plate is produced by placing a vacuum on one side and grinding the exact correction required to correct the spherical aberration caused by the primary mirror. It is placed in front of the mirror and intercepts the light as it enters the telescope. The Schmidt corrector is thicker in the middle and the edge. This corrects the light paths so that light reflected from the outer part of the mirror focuses at the same point as light reflected from the inner portion of the mirror.

Sidereal Rate Time measured relative to the fixed stars. The sidereal day is the period during which the Earth completes one rotation on its axis. Because the Earth moves in its orbit about the Sun, the sidereal day is about 4 min shorter than the solar day and a given star will appear to rise 4 min earlier each night, so that different stars are visible at different times of the year.

Sigma Combine Sigma is a type of mathematical averaging used in image processing routines with automatic rejection of bright and dark pixels, much more powerful than the simple median combine, with a better SNR ratio.

Signal-to-Noise Ratio (SNR) For our purposes, it is the ratio between the magnitude of a light signal (meaningful information) and the magnitude of background noise. SNR is the true test of a CCD camera's detection capability. All scientific CCD camera manufacturers attempt to maximize the signal (the number of available full-well electrons) and minimize the noise (electrical and thermal) in order improve the camera's performance.

Slew This term refers to moving the LX200 telescope with the hand paddle or using the artificial crosshair cursor in TheSky to point and select a target. You can then command the telescope to slew, or move, to the intended target.

Software Driver A program that interacts with a particular device or special (frequently optional) kind of software. The driver contains special knowledge of the device or special software interface that programs using the driver do not have.

Star Bloat This term refers to the appearance of brighter stars in an image during extended integrations. You can tame star bloat by shortening integration times and possibly perform some image processing to further reduce the bloat.

Star Diagonal A telescope accessory that contains a mirror or prism that redirects a beam of light upward for more convenient viewing. A star diagonal typically fits into a focuser, has an eyepiece fitted into it, and bends the light path through a right angle. Some imagers use a CCD camera in place of the eyepiece in order to control camera orientation.

Summing Images Because astronomical objects tend to be faint, it is often desirable to add CCD images together to increase the detail visible in the image. This process is known as summing. Summing images will also increase the noise in the image, but not at the same rate that signal builds.

Two-Line Element (TLE) Orbital data for any satellite tracking program, such as contained in Software Bisque's TheSky, are referred as two-line elements. They are updated regularly by CelesTrak and can be downloaded in specially formatted files from the Internet directly into a software program.

Tracking Mount The stars appear to move because of the motion of the Earth. If you are using a telescope for astro imaging, you will need to have a telescope with a clock drive that "follows" them. The quartz clock moves the mount and telescope at a sidereal rate.

Trichrome Color Imaging Most astronomical CCD cameras are inherently black-and-white. To take color images, red, green, and blue filters are placed in the imaging train in order to isolate each color. Each image is then subsequently combined using image processing software to create a color image.

Two-Star Alignment Built-in procedure in the LX200 computer that allows the user to align the telescope with the sky by first selecting two stars, approximately 50–90° apart. This initializes the telescope when in altizmuth/azimuth configuration.

Tycho Catalog Another stellar catalog, Tycho is complete to magnitude 10.5 and contains almost 3 million stars.

Undersampled If too few pixels are utilized when imaging, then all of the spatial details comprising the image will not be present in the final image.

USB A serial connection technology that is almost universally available in current computers. Version 1.x allowed for 12-Mbps transfer rates, and this was boosted to 480-Mbps for USB 2.0.

Vignetting Vignetting is a darkening of the corners of an image, usually caused by light falling off toward the edge of the CCD chip due to the optical system. It is typically seen with an SCT and a focal reducer and is often removed by using a flat field.

Virtual Sky Software Bisque's TheSky graphically represents the night sky and telescope position with a virtual sky. It is the main window that shows the stars, planets, galaxies, and other celestial objects.

White Point A histogram adjustment that will determine the amount of highlight detail in an image. It is considered proper to set the white point so that the lightest part of an image will just have zero detail.

Zenith The point that is directly above the observer on the imaginary sphere against which celestial bodies appear to be projected.

Formulas

1. **f/ratio of optical system**

$$f/ratio = FL/aperture$$

where FL = focal length.

2. **Focal length of system**

$$FL = (\text{pixel size} \times 206)/\text{resolution}$$

where pixel size is in microns and resolution is in arc-seconds/pixel.

3. **Limiting visual magnitude**

$$m = 6.5 - 5 \log \text{Delta} + 5 \log D = 2.7 + 5 \log D$$

(assuming transparent dark sky conditions), where *m* is the approximate limiting visual magnitude, Delta is the pupillary diameter (in mm) (accepted value 7.5), and *D* is the diameter of the objective (in mm).

4. **Dawes limit (smallest resolvable angle)**

$$\text{Theta} = 115.8/D$$

where Theta is the smallest resolvable angle (in seconds) and *D* is the diameter of the objective (in mm). Atmospheric conditions seldom permit Theta < 0.5 arc-seconds.

5. **Resolution of lunar features**

Resolution = [2 × (Dawes limit × 3476)/1800]
Dawes Limit = 115.8/*D*

where Resolution is the smallest resolvable lunar feature (in km), *D* is the diameter of the objective (in mm), 2 × Dawes limit is the Airy disk (a more practical working value is twice this); 1800 is the angular size of the moon (in seconds), and 3476 is the diameter of the Moon (in km).

6. **Magnification of optical system**

$$m = FL_{OTA}/FL_{ep}$$

where *m* is magnification, FL is focal length, OTA is the optical tube assembly of the telescope, and ep is eyepiece.

7. **Maximum allowable tracking error**

$$S \sim 8250/(F \times E)$$

where S is the error ("slop") (in arc-seconds), F is the focal length (in mm), and E is the amount of enlargement of the image.

8. **Apparent angular size of an object**

$$\text{Theta} = (h/D) \times k$$

where Theta is the object's apparent angular size (in units corresponding to k), h is the linear height of the object (in units corresponding to D), D is the distance of the object (in units corresponding to h), Theta is the object's angular height (angle of view) (in units corresponding to k), k is a constant with a value of 57.3 for Theta (in degrees), 3438 (in minutes of arc), or 206,265 in [seconds of arc (the number of the respective units in a radian)].

9. **Range of useful magnification of a telescope**

Minimum useful magnification	$0.13 \times D$
Best visual acuity	$0.25 \times D$
Wide views	$0.4 \times D$
Lowest power to see all detail (resolution of eye matches resolution of telescope)	$0.5 \times D$
Planets, Messier objects, general viewing	$0.8 \times D$
Normal high-power, double stars	$1.2 \times D$ to $1.6 \times D$
Maximum useful magnification	$2.0 \times D$
Close doubles	$2.35 \times D$
Limit imposed by atmospheric turbulence	$500\times$

where D is the diameter of the telescope's aperture (in mm).

10. **Angular size units**

$1° = 60$ arc-minutes, denoted $60'$
$1' = 60$ arc-seconds, denoted $60''$
1 radian $= 57.2957795$ deg
$= 3437.74677'$
$= 206264.806''$

11. **Speed of light**

186,000 miles per second (300,000 km/s) = 6 trillion miles per year traveled (9.6 trillion km)

12. **Solar System distances from Earth (average)**

Sun	93 million miles (150 million km)
Moon	253,000 miles (405,000 km)
Mars	50 million miles (75 million km)
Jupiter	400 million miles (650 million km)

Saturn	800 million miles (1.3 billion km)
Ceres	160 million miles (256 million km)
International Space Station	240 miles (380 km)

13. **How far can you see?**
Because light travels 6 trillion miles (9.6 trillion km) each year [= 1 light-year (LY)], get your calculator out for these objects.

The Pleiades M45	380 LYs
The Dumbbell Nebula M27	1250 LYs
The Orion Nebula M42, M43	1600 LYs
The Ring Nebula M57	2300 LYs
The Crab Nebula M1	6300 LYs
Globular Star Cluster M13	25,000 LYs
The Andromeda Galaxy M31	2.9 million LYs
The Whirlpool Galaxy M51	37 million LYs
Stars within the Milky Way Galaxy	Thousands of LYs
Messier objects	The most distant Messier objects = 60 million LYs
Other galaxies	Hundreds of millions of LYs

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