FONTANA

Messages from the Stars

Ian Ridpath

COMMUNICATION & CONTACT WITH EXTRA-TERRESTRIAL LIFE: A SCIENTIFIC VIEW

MESSAGES FROM THE STARS

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Communication and contact with extra-terrestrial life

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To Carl Sagan

All the night
I heard the thin gnat voices cry
Star to faint star across the sky

Rupert Brooke
The Jolly Company

PREFACE

Does life exist elsewhere in space? This is the single most important scientific question which we are currently capable of answering, and certainly the most exciting. *Messages from the Stars* is an attempt to tell the story of the search for life in space, a story which should appeal to every human being and particularly to those millions who buy science fiction either in the form of self-confessed adventure stories or in the guise of speculative fact as purveyed by writers on UFOs and ancient astronauts.

Messages from the Stars begins by looking at the scientific basis for the belief in life elsewhere in space, and at the attempts by scientists to find such life, either by sending spacecraft such as Viking in search of lowly lifeforms on the planets of our own solar system, or by listening with radio telescopes for signals from advanced civilizations on planets circling other stars. The book also considers how we might colonize space and travel to the stars, as well as speculating upon the consequences of such actions. It ends with a critical examination of the claims by those such as Erich von Daniken and writers on UFOs that we already have been, or are being, visited by extraterrestrials, and I attempt to place these fantastic claims in perspective against the results of the scientific search for extraterrestrial life.

When I put the finishing touches to my first book on this subject, *Worlds Beyond*, at the end of 1974, I did not suspect that two years later I would have embarked on a sequel. But such has been the pace of advance that this sequel has become necessary. The scientific search for extraterrestrial life has become a boom subject. It has grown from the part-time concern of a few enthusiasts to the stage at which NASA has put its authority and facilities behind plans for two major new searches. Within the next five to ten years we should either have detected messages from the stars, or if not we will at least have placed severe constraints upon the likelihood of their existence. Whether we find messages or not, I strongly suggest in Chapter 8 of this book that we should also consider whether to begin radiating deliberate signals of our own.

If a sense of puzzlement, even of paradox, emerges part-way through the book, it is an accurate reflection of the reaction of many people, myself included, to the fact that, while life *ought* to be abundant throughout space, we have as yet found no clear sign of it. As of now, it must be admitted that we do not know that there is life out there to be detected. But I for one would like to know whether or not there is life elsewhere in space, and it will certainly be exciting to try to find out. The discovery that we are not alone would rival major landmarks in our civilization's development, such as the release of atomic power and the first landing on the Moon, and I believe it would eventually come to dominate them in importance. For both author and reader, the search for extraterrestrial life is the biggest science story of our day.

Since the subject is so big, it is not surprising that it takes more than one average-sized book to do it justice. Although *Messages from the Stars* is designed to be read and understood on its own, readers interested in more background information on some of the topics covered will find this in its predecessor, *Worlds Beyond* (Wildwood House, London; Harper & Row, New York). The two books are intended to be complementary.

As before, I must thank the scientists and other thinkers who have made this subject so rich in activity and insight; without them there would be no book to write. They are credited individually throughout the book wherever their results or ideas appear. I must also thank Graham Massey and Peter Spry-Leverton of BBC-TV, producer and researcher respectively of the *Horizon* special on ancient astronauts, for help with the last section of the book, particularly Chapters 11 and 12. And to Andrew Best, Bob Woodings, and Helen Fraser, who believe in giving readers facts, not fantasy.

IAN RIDPATH

I

ARE WE ALONE?

In 1976, the United States landed two automatic biology laboratories on the surface of the planet Mars – a billion-dollar commitment to the possibility that life has arisen on another planet in space.

In 1974, a radio message announcing the existence of human life on Earth was beamed from the giant Arecibo radio telescope in Puerto Rico towards a cluster of 300,000 stars in the constellation Hercules. At present, the Pioneer 10 and 11 spacecraft are heading through the solar system before leaving the Sun's environment entirely and drifting out towards the stars, carrying plaques engraved with a message to other civilizations that might intercept them deep in the Galaxy.

By 1980, America's National Aeronautics and Space Administration hopes to begin a large-scale search for possible interstellar radio messages, building on the experience of several pilot projects by radio astronomers in recent years. The Soviet Union in 1974 announced two five-year plans of its own to detect messages from the stars.

Astronomers with large telescopes are currently scanning nearby stars for the existence of planets, potential habitats of life elsewhere in the Galaxy. A group of British engineers and physicists is outlining the design for a nuclear-powered starship that could reach the nearest of these planetary systems.

Against the backdrop of this scientific investigation, many citizens of Earth are prepared to believe that other civilizations in space are also undertaking similar projects – with us as a target. Optimists have placed bets with Ladbroke's, the London bookmakers, that a UFO will land or crash on Earth with alien life on board. A lady named Ruth Norman from El Cajon, California, who claims to have been in touch with extraterrestrials, regularly renews her bet on this proposition; so far she has staked a total of several thousand pounds.*

The scientific investment in the search for extraterrestrial life is also, in its own way, a gamble, since no one has any real proof that such life will be found. But the scientific gamble is sure of at least some return, for the investigation will clarify understanding of the formation of stars, planets – and of life itself.

The popular belief in life beyond Earth frequently manifests itself as a kind of space-age religion, such as in the form of flying saucer cults. In contrast, the scientists' belief is based on a more rational assessment of the Universe around us.

As long ago as 1961, a group of highly qualified American scientists held a symposium at the National Radio Astronomy Observatory, Green Bank, to estimate the possibility of extraterrestrial life. In the Soviet Union, similar informal discussions were also underway. The two sides met for an international scientific summit in 1971 at the Byurakan Astrophysical Observatory in Soviet Armenia, where they concluded that as many as one million civilizations capable of interstellar communication may exist in our Galaxy.

To arrive at their conclusion, the scientists discussed what is known as the Drake equation, named after the American radio astronomer Frank Drake who first put it forward at the Green Bank conference in 1961. Drake is also famous as the progenitor of Project Ozma, the first attempt to listen for messages from the stars. The Drake equation allows scientists to calculate the number of civilizations in space from an assessment of the various unknowns involved in the origin and evolution of extraterrestrial life. Unfortunately, the estimates for most of the unknowns are little more than educated guesses,

* But UFO sceptic Philip Klass of Washington, D.C., has risked 10,000 dollars that such an event will not happen. See Chapter 13.

and the final conclusion is correspondingly uncertain. Improving our understanding of the various factors in the Drake equation is one of the main tasks in the search for life beyond Earth.

The Drake equation multiplies together the following factors: the rate of star formation at the time the Sun was born; the fraction of those stars with planets; the number of planets in each system that are suitable for life; the fraction on which life actually does arise; the likelihood that such life will develop to the stage of intelligence; the desire among that life-form to communicate; and the longevity of the civilization. This simple formulation has been the jumping-off point for much speculation about life in space.

Each of the factors seems innocent enough in itself, but each conceals a morass of assumption and speculation. One factor that we can assess with reasonable accuracy is the first: the rate at which stars were formed when the Sun itself came into being. Stars are glowing balls of gas, and the Sun is an average example. If we could get as close to the other stars in the sky as we are to the Sun, then we would see that all stars are incandescent spheres, some larger and hotter than the Sun, others smaller and cooler, but all emitting their own light and heat.

Because of their extreme distance we are unable to examine stars in the same detail as we study the Sun, but astronomers can sort stars into broad classes of size and temperature by analysing their light in spectroscopes attached to telescopes. In this way the full range of star types from blazing supergiants to feeble dwarfs has been listed, and with the help of theorists a consistent picture of their birth, evolution, and death has been pieced together. Fortunately for us, it turns out that the Sun is a relatively long-lived star, in stable middle age, and certain to go on shining steadily for thousands of millions of years yet.

All the stars we see in the sky are part of a Catherine-wheel-shaped aggregation known as the Galaxy. The Sun lies about two-thirds of the way to the edge of this stellar congregation, in the galactic suburbs. The nearest stars to us appear scattered over the night sky, forming the familiar shapes of the constellations. The more distant stars of the Galaxy cannot be seen individually, but form the faint, hazy band around the sky known as the Milky Way. The name Milky Way is often used as a synonym for our Galaxy.

Astronomers estimate that there are 100,000 million stars or more in our Galaxy. The whole Galaxy is so large that it would take a beam of light 100,000 years to cross from one side to the other. In the jargon of astronomy, the Galaxy is therefore said to be 100,000 light years in diameter. The distances between individual stars are of the order of a few light years. For instance, Alpha Centauri, the nearest other star to the Sun, lies 4.3 light years away.*

The Galaxy in its early days, 10,000 million or so years ago, consisted mostly of hydrogen gas from which stars were forming. As the amount of gas declined, so did the rate of star formation. The Sun is believed to have formed about 4600 million years ago, when the Galaxy was approximately half its present age, so the rate of star formation at that time was probably the average of that over the entire history of the Galaxy. Production of 100,000 million stars over a 10,000-million-year span means an average birth rate of 10 stars a year. We have therefore estimated the first factor in the Drake equation.

The second factor, the existence of planets, is more problematic. Planets are non-luminous bodies smaller than stars; a total of nine planets, including the Earth, orbit the Sun. The Sun and planets are believed to have come into being together from the same cloud of dust and gas in the Galaxy, a process which theory suggests

* Strictly, Alpha Centauri is a group of three stars linked by gravity. The name when used without further qualification is taken to mean all three stars.

should happen around many other stars. Spotting planets around other stars is difficult, and not one other planetary system has been identified with complete certainty. However, astronomers are stepping up their search to clarify this vital factor (see Chapter 2). For the moment, it seems reasonable to suppose that at least one star in ten may have planets.

How many planets in each planetary system will possess the right conditions for life? At least one such planet exists in our own solar system – the Earth. Probably the number would be the same in other systems. But the very existence of a suitable planet is no guarantee that life really will arise – Mars seems to be an example of a planet with the right ingredients for life, but on which life never gained a foothold. With no firm knowledge to go on, we have no clear idea of how likely or unlikely the emergence of life is.

My own suspicion is that, while plant life is easily formed, the emergence of major forms of animal life is the most difficult evolutionary step of all. A typical example of extraterrestrial life could be a forest of trees or a meadow of tall grass. Plant life is probably dominant throughout space; it certainly dominated the existence of life in this planet, up till 600 million years ago when the first sea creatures crawled on to land.

Some scientists believe the emergence of life is very likely on suitable planets, while others think it could be rare. Similar disputes occur in estimating how frequently life will become intelligent and develop the ability and desire to communicate with other beings. Perhaps life is commonplace, but only rarely does it become able and willing to communicate. Or perhaps life is infrequent, but the evolutionary advantage of intelligence is so great and the desire to inquire is such an inescapable aspect of intelligence, that life will nearly always develop to an advanced state.

Whatever the truth, the general conclusion from these discussions among scientists is that the Drake equation can be boiled down to the statement that the number of advanced civilizations in the Galaxy at the moment is 1/10 L, where L is the lifetime of each civilization – the one factor we have not so far taken into account. Without worrying about L for the moment, the conclusion means that one technological civilization like our own comes into being in the Galaxy every ten years or so. This figure could, however, be badly in error because of the uncertainties in estimating each of the individual factors.

The lifetime, L, of each civilization is important because not all the civilizations formed in the past will still be with us: many, or all, may already have died out, which would leave us with no one to talk to. If the lifetime of each civilization is short, then our contemporaries in the Galaxy are likely to be so thinly spread that we will have to search a long way off in order to find them. But if lifetimes are long, then we could be lucky enough to have intelligent neighbours around some of the closest stars. Therefore, to complete our calculation of the total number of our contemporaries in the Galaxy, we must estimate the average lifetime of all advanced civilizations.

But here we are stuck, because we have absolutely no evidence to go on. Our own civilization has reached the advanced stage of being able to communicate with the stars in only the past decade or so. We have no way of knowing whether the mistakes of this faltering young civilization will wipe it out within the next few centuries, or whether we shall transcend our present difficulties of population, food, energy, pollution, and unruly behaviour towards one another, and emerge on to the stable plateau of maturity and genuinely cosmic wisdom.

One widely canvassed view is that there are two types of civilization: the overwhelming majority which rise and then subside precipitously in only a few generations; and those that come through their bad patch to live for thousands of millions of years, which are the minority. (If all civilizations reached this stage then the Galaxy would be swarming with intelligent creatures, which we don't see.)

Optimists hope that we on Earth belong to the latter category rather than the former, but it's touch and go. Perhaps there is some subtle flaw in evolution which makes intelligent creatures so competitive that they eventually destroy themselves as well as their adversaries. The overkill capacity of nuclear weapons is the prime example of this, although a more futuristic idea was presented at the 1971 Byurakan conference by Soviet mathematician M. Y. Marov who visualized a society of robots among whom a certain elite were given to dismantling and reassembling others in order to preserve their own power. There is no reason to suppose that intelligent robots or even advanced computers will not have the same shortcomings as mankind: ambition, greed and envy.

Assuming that the lifetime of advanced civilizations, averaged over both long-lived and short-lived types, is 10 million years, then the number of civilizations like ourselves or more advanced in the Galaxy is one million. This works out at one civilization between every 100,000 stars, and indicates that our nearest neighbours with whom we may communicate are several hundred light years away.

Another complicating aspect is the different lifeforms one might expect to find throughout the Galaxy. Noted astronomer Sir Fred Hoyle rekindled visions of his black cloud science-fiction concept in a recent paper with N. C. Wickramasinghe of University College, Cardiff. Hoyle and Wickramasinghe propose that the complex molecules of life can be made in the dust and gas clouds between the stars. The possibility here is that the cloud as a whole might eventually act as an advanced form of life, with implications that are beyond the realm of scientific speculation at present.

One limiting factor on the origin and development of advanced lifeforms may be the occurrence of the stellar cataclysms known as supernovae. As a giant star flares up in a supernova explosion, it throws off its shattered outer layers and sends beams of dangerous radiation flying through space. A supernova is expected within 50 light years or so of the Earth every few hundred million years. Its consequences, as astrophysicist Malvin Ruderman of Columbia University, New York, has calculated, would be drastic for life on Earth.

Dr Ruderman finds that radiation from the supernova could strip away the layer of ozone in our upper atmosphere that keeps out the Sun's ultraviolet light. This shielding layer could be destroyed for up to a century. Although radiation from the supernova itself need not reach the ground, the vast increase in ultraviolet light from the Sun reaching Earth would cause death of simple organisms, skin cancer in humans and animals, possible poisoning by overproduction of vitamin D in our bodies, and an epidemic of mutations. Such a catastrophe may well have happened several times in the history of the Earth. Perhaps we have been lucky to have survived so far.

Whether there is anyone around for us to talk to or not, throughout the Galaxy there must be many extinct civilizations and planets inhabited by intelligent creatures who have not developed high technology. The few civilizations that rise to the level of interstellar spaceflight will thus become the biologists and archaeologists of the Galaxy, studying the various primitive lifeforms and remains of bygone ages on the surfaces of other planets around distant stars – the role envisaged in space fiction stories such as the *Star Trek* series.

This aspect has been investigated by space scientists J. Freeman and M. Lampton of the University of California at Berkeley. 'Throughout cosmic time the Galaxy may have harboured several hundred million technically advanced civilizations, and thousands of millions of intelligent species,' they said, adding that these conclusions do not depend on the disputed conjectures about the average lifetimes of advanced civilizations.

From a modified form of the Drake equation, Freeman and Lampton calculated that the number of advanced (i.e. communicative) civilizations that have evolved so far in the history of the Galaxy is 250 million, and that the number of planets housing intelligent creatures without contact capacity has totalled ten times as many (assuming that only one in ten intelligent civilizations rises to the communicative level). Whereas we have no idea about the lifetime of an advanced civilization, we do have one very good example of the lifetime of an intelligent but non-communicative family – our ancestors. Anthropologists say that our evolution from the stage of ape-men to the present day has taken at least three million years. Inserted into the Drake equation, this longevity implies that there are three million planets inhabited by creatures of at least ape-like intelligence at present – one around every 300,000 stars, giving a distance of perhaps 150 light years to the nearest.

Freeman and Lampton's treatment leads to the result that there are a total of 2500 million stars around which intelligent life once existed, making the nearest 18 light years away; and that the remains of extinct advanced civilizations will be found around 250 million stars, meaning that we would have to search out to 40 light years to find the nearest.

Would-be galactic archaeologists and biologists will have to wait a few centuries until interstellar travel is developed to take them on their field trips. But there is plenty to interest the rest of us in the meantime. Already we have the ability to exchange radio messages with any advanced beings that may exist around other stars, and the apparently optimistic results of the Drake equation have prompted the first brief searches for interstellar signals (see Chapter 7).

Some problems in this field, stemming from the various likely lifetimes of advanced civilizations, have been considered by Gerrit Verschuur of the Fiske Planetarium in Boulder, Colorado. Verschuur is a former radio astronomer who made one of the earliest searches for signals from the stars. Now, in effect, he admits he may have wasted his time.

If the average lifetime of a civilization really is only a century or two, then the Drake equation predicts that there can be no more than 10 or 20 of them around in the Galaxy at present, making the nearest about 2000 or more light years distant. Even if we could find this nearest civilization among the tens of millions of stars within this radius, the travel time for a radio message each way would be 2000 years (radio waves travel at the same speed as light), and the round-trip for an exchange of greetings would be 4000 years. But such a two-way conversation could never take place, because the lifetime of each civilization is too short – the line would go dead before the reply could be received. Therefore, says Verschuur, for a short lifetime 'we are effectively alone in the Galaxy.'

If it seems impossible for short-lived civilizations to contact each other, how much do things improve for a longer average lifetime? Verschuur is pessimistic. An average lifetime of 10 million years means a typical separation between communicative societies of 100 light years or so, thus giving an approximate round-trip time of 200 years for messages. In a long-lived and stable society, two centuries would not be a particularly long time; such societies would seem well suited to undertaking long-term projects of that sort which daunt us and our short-term mentalities.

Yet Verschuur sees difficulties, among them being the fact that two societies are unlikely to reach the same stage of development simultaneously. He illustrates his point by reference to apes: if, in thousands or millions of years, they develop the ability to talk as we do at present, the chances are that we would still be unable to exchange ideas or discuss concepts with them because our own evolution would have progressed.

'It is simply unrealistic to believe that society on this planet, or any other planet, will be remotely similar for a thousand years – let alone a million or billion years,' he declares. 'The inevitable conclusion that evolution never stops leads to the assumption that L [the average lifetime of civilizations with whom we may communicate] is a small number.'

This seemingly powerful analogy is weakened by many factors. Prominent among them is the fact that we already can communicate in simple form with chimps: the famous chimp Washoe was taught sign language used by the deaf and dumb, and another chimp, Sarah, was taught a language using coloured plastic shapes for words. The language abilities of dolphins may be even greater, but communication here is hampered by the creatures' lack of manipulative ability – perhaps the main reason why we, not they, developed technology.

Any highly advanced civilization will realize the problems of interstellar discourse and so, if it wishes to talk with as many people as possible, it will use the simplest possible method for establishing that all-important first contact. The main interest of an old and advanced civilization may be in the developing creatures of the Galaxy, as the anthropologists of the western world are increasingly fascinated by the stone-age societies that remain on Earth.

An altogether more optimistic outlook was presented in 1975 by Bernard Oliver of the Hewlett-Packard electronics company of Palo Alto, California. Oliver's treatment of the Drake equation and the factors affecting interstellar communication is probably the most thorough yet made, and is worth relating in detail.

Oliver draws attention to a factor previously overlooked: that communication might begin between civilizations that were coincidentally close together, and then spread outwards to more isolated communities. He notes that the older stars near the Galaxy's centre are two or three times closer together than the younger stars in the Sun's vicinity, so that interstellar communication is most likely to have begun long ago in these dense central regions.

Stars are moving through space at different speeds as they orbit the Galaxy. Therefore, a star's closest neighbours are continually changing, so that stars undergo a general mixing which can only increase the number of encounters between civilizations. Additionally, Oliver points to some theoretical predictions that planets could also exist in systems where two stars orbit each other; this factor is not normally taken into account in the Drake equation, which instead concentrates on single stars only. Stable orbits for planets are theoretically possible around twin stars at 2½ times or more the stars' separation; in other words, the planet would orbit around the outside of both stars. In such a situation the planet would probably be too far away from the stars to be warm enough for life. But things improve if the two members of a double-star system are sufficiently wide apart for planets to exist around each individual star. Stable orbits are possible around the more massive component at up to one-half of the stars' separation, while around the smaller component planets could orbit safely at up to one-quarter the stars' separation. Examples of both types of orbit are provided in the solar system: if Jupiter is regarded as a dark companion of the Sun, then the outer planets beyond Jupiter can be said to orbit both the Sun and Jupiter, while the inner planets and the satellites of Jupiter follow stable orbits around each individual component.

Observations by astronomers tend to confirm these theoretical speculations about the possible existence of planets in double-star systems (see Chapter 2). Since double stars far outnumber single stars, even though only a fraction of them will be suitable for life, Oliver estimates that this modification of the Drake equation leads to a tripling of the number of possible civilizations in the Galaxy.

Occasionally life would arise on planets orbiting both components of a double-star system. Since both members of a double-star system are of similar age, this tends to synchronize the emergence of life in their vicinity. If the average lifetime of civilizations is 10 million years, Oliver suggests that something like 100,000 such civilizations will have arisen within the same double-star system, and one million within a distance of 10 light years of each other. 'Interstellar communication will have been established independently countless times,' he asserts.

Over the millennia, such contacts will have profoundly modified the science, philosophy, and destinies of the races in contact. Additionally, his figures suggest that there have been approximately 40 million cases where a space voyage by an advanced culture around one component of a double-star system has found either simple life or the remnants of a long-dead advanced civilization on the planets of the other component star.

Even if the lifetimes of civilizations are far shorter than the 10 million years assumed here, and there is little direct effort at sending messages to other stars, one civilization could still detect another from the radio noise accidentally leaking into space from its domestic transmissions. 'For a cost less than that of space programmes we have already undertaken, we could construct a receiving system that would detect the presence of signals like our own UHF television at a 50-light-year range,' he said. He was here referring to the Project Cyclops plan for a giant radio receiving array, described in Chapter 8.

We have been radiating UHF TV signals for 15 years, and are likely to continue doing so for at least another 35 years. Even if a civilization radiates such leakage signals for only 50 years, Oliver estimates that up to 500 civilizations could have come within a 50-light-year eavesdropping range of their neighbours over the Galaxy's history.

Once such evidence of another civilization came to light, Oliver envisages, the eavesdropping society would be encouraged to search deeper into space for further signs of life and also to radiate a beacon that would attract others. With a deliberate beacon operating in the Galaxy, the possibility of interstellar contact brightens enormously. Explains Oliver: 'The same system that could detect leakage radiation at 50 light years could detect a 250-megawatt beacon at 500 light years and thus reach one thousand times as many stars.

'The number of close civilizations, although uncertain, seems large enough to support the hypothesis that an intercommunicating galactic community of advanced cultures already exists.'

Oliver's work, like that of many before him, emphasizes above all that the only way to find out for sure whether or not there are messages from the stars to be intercepted is to listen for them. This point was first made in 1959 by physicists Philip Morrison and Guiseppe Cocconi in a paper which first openly suggested a search by radio astronomers for interstellar messages, and thus brought the subject out into the light; the point remains as strong today as ever. The Drake equation cannot give us final answers, but it can act as a guide. Its most valuable contribution is that it gives us a rational basis for the hope that we are not alone in space. And, of course, any other intelligent civilization can make a similar calculation that will reveal to them both the prospects and the problems of interstellar communication. If they are by nature pessimists, they may abandon the project immediately; or, as one hopes, they will be optimistic enough to make allowances for the problems and proceed with the business of getting in touch with whoever may be around.

There may be humane reasons why advanced beings should wish to attract the attention of other civilizations in space. If it is true that the majority of cultures live for only a short time, there may come a take-off point at which a civilization lives just long enough to exchange messages with beings elsewhere. This exchange could provide the spur that a civilization needs to enter the long-lasting phase of its evolution. Our work today on interstellar communication could be our life insurance for the future.

Ultimately, the value of our present discussions about interstellar communication may be philosophical, rather than scientific. In debating the possible lifetimes of civilizations, we become more aware of our own mortality. We should therefore strive to ensure that we are the one civilization in a hundred – or the first one ever – that survives for millions of years.

And if we are the first, we inherit a responsibility that goes far beyond the bounds of tiny Earth. For if no one before has reached the plateau of cosmic maturity, our radio call signs in the future may be the lifeline that pulls other developing civilizations in space out of the despair of their own isolation.

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2

STARS AND PLANETS

Every star in the sky is a sun – a potential centre for life in space. Stars are born from giant clouds of gas and dust, like the famous nebula in the constellation Orion. Gravity compresses parts of the clouds into tiny spinning gas blobs called protostars, at whose centres nuclear reactions begin to flare, making the object a true star. These nuclear reactions in the star's interior produce heat and light so that the star shines. Starlight is intimately linked with life in space.

The heat and light from the Sun is the basic source of energy that sustains life on Earth: plants use sunlight for photosynthesis, the process in which they break down carbon dioxide from the atmosphere, taking in carbon for their bodies and releasing oxygen for us to breathe. Plant life, such as plankton at sea or grass on land, provides the first link in the food chain that leads eventually to man. Whereas an advanced technological society could provide its own energy sources and inhabit the most inhospitable depths of space, the inert chemicals from which life formed on Earth 3500 million or so years ago had no such ability. They had to rely on the energy of sunlight to assemble them into the first living things, which themselves continued to rely on solar energy for photosynthesis. It is difficult indeed to imagine how life could emerge and develop without the natural energy source of a nearby star.

The Sun is an ideal star to nourish life, for it is not so hot as to produce searing amounts of dangerous short-wavelength radiation, nor is it so faint that it has little warming effect on the surrounding planets. Its surface temperature is 5800°K, which places it just below midway in the range from the coolest known stars to the hottest. In colour, the Sun appears yellowish, whereas the hottest stars are blue and the coolest are red. The Sun is a stable-burning star, not given to unpredictable changes in energy output, and it is also fairly long-lived – its total predicted lifetime is about 10,000 million years, of which it has completed approximately half.

A star's lifetime depends on its mass: the heaviest stars burn the brightest, using up their nuclear fuel in the shortest time. For instance, if the Sun had only 25 per cent more mass, it would already have burned out. A star such as the white-coloured Sirius, with a surface temperature of about 10,000°K, is more than twice as massive as the Sun and thus is expected to live for perhaps one tenth the total time. This is not long enough for life to develop on any planets it may have, if the pace of evolution on our own Earth is typical. By contrast, a red dwarf star such as Barnard's star, with a surface temperature only about 2800°K and a mass perhaps one tenth that of the Sun, could live for 100,000 million years or more, at least ten times as long as the Sun.

Therefore the hottest stars, with their intense radiation and short lifetimes, seem the least likely centres of extraterrestrial life, whereas the dimmest stars, despite their glow-worm output, have the advantage of longevity to compensate. We live around a star which seems to have a good compromise between the conflicting requirements of luminosity and longevity. Over 5 per cent of the stars in the Galaxy have roughly the same mass and temperature as the Sun; the most abundant stars of all are the red dwarfs, which are 10 times as frequent as Sun-type stars.

But the existence of a suitable star is not by itself sufficient for the origin of life. Astronomers have found that the gas clouds around forming stars are rich in the chemicals that go to form life – simple substances such as carbon, nitrogen, and water. What is needed are places where these chemicals could become concentrated, and give life its first footing. Planets can act as rendezvous points for the chemicals of life. Planets provide an atmosphere which traps heat, supplies chemicals, and provides pressure which keeps substances such as water in liquid form. Therefore, if we want to find potential homes of life in space, we should look for planets. So how many stars have planetary systems?

The majority of stars in the sky seem to come in groups of two, three, or even more. For example, the nearest star of all, Alpha Centauri, is actually triple, and the bright star Castor in Gemini is a system of six stars, although in both cases only one star is visible to the naked eye. A major lesson from contemporary astrophysics is that stars never seem to come into being singly; the formation of stars from clouds of gas and dust in the Galaxy seems to lead naturally to the formation of multiple stars, or of a star with planets, like the Sun and its solar system of which we are a part. Therefore planets could, in theory, be as numerous in the Galaxy as are stars. But the problem is that no planets of other stars are directly visible from Earth. Since planets, by their nature, are cold nonluminous objects that shine only by reflecting sunlight and give out no light of their own, they are too faint to be seen by existing methods. Even from the nearest star, our own solar system would be invisible through an ordinary telescope.

Astronomers Helmut Abt and Saul Levy of the Kitt Peak Observatory in Arizona have attempted to estimate the number of planet-bearing stars from a study of a number of double and multiple stars near the Sun. Their work, published in 1976, is a major advance in our understanding of the formation of stars and planetary systems, and is worth reporting in detail.

Abt and Levy examined 123 bright stars near the Sun with masses ranging from the same as the Sun to 50 per cent greater – in other words, stars as bright and as hot as the Sun or slightly above. In addition to 69 stars already known to be double or multiple, they found another 25 hitherto unrecognized double stars. These discoveries were made by studying the visible stars' light. Regular variations in the wavelength of light from a star reveals that it is moving round in orbit with another star too close to be seen separately; a system of this kind is known as a *spectroscopic binary*.

The Kitt Peak astronomers made allowances for possible companion stars that they may have missed detecting. For instance, if the two stars orbit each other in a plane perpendicular to our line of sight, so that they do not move alternately towards and away from us, then there will be no wavelength change in the spectrum and their binary nature will escape detection; equally, the companion star may be of such low mass that it scarcely has any effect on the movement of the visible star. Other, more distant, companion stars which ought in theory to be seen separately may also have been missed because they are too faint to pick out from the mass of background stars.

Abt and Levy made the important discovery that double-star systems fall into two distinct classes: those with orbital periods of more than about 100 years, and those which orbit more quickly. The period of a binary star's orbit, like the period of a planet around the Sun, depends on the separation of the two objects, with the widest pairs having the longest periods.

In the short-period binaries one finds progressively fewer pairs as one looks for companions with progressively smaller masses than the primary; but in the long-period systems, there are progressively more pairs as one moves to companions of decreasing mass. Abt and Levy believe that this distinction arises from the different ways in which wide-separation and close binaries are formed. Probably, the close binaries were formed when a condensing protostar split in two because it was spinning too quickly for stability; the tendency is for a protostar to split into two equal halves. The wide binaries arise where two stars were born from independent protostars but were then captured by each other's gravity. There is no preference for equal-sized partners in this group; rather, it reflects the increased abundance of smaller stars.

The orbital period of roughly 100 years which divides these two classes of binary corresponds to a separation between the stars about equal to the distance of the planet Neptune from the Sun, which is probably the characteristic size at which a shrinking protostar begins to divide. A mass of 2.4 Suns spread over this diameter gives a density of gas similar to that assumed for the gas cloud around the Sun from which our own planetary system formed. This fits in well with theories of planetary formation, according to which the solar system formed from a small fraction of the so-called solar nebula surrounding the Sun, the unused remainder being lost into space. Abt and Levy therefore speculate that the formation of a planetary system is one result of the splitting of a protostar.

Such a view is backed up by the fact that the gas in protostellar blobs is observed to be moving at about 1 km/sec; but as the protostar gets smaller it spins faster. By the time the blob has condensed to the size of a star, its rotation will have speeded up so that it should in theory be spinning at up to 1000 km/sec, which is too high for stability. In fact, the observed rotation speeds of stars are about 1 to 10 km/sec. So what has happened to the lost rotation? In typical binary systems, between one hundred and one thousand times as much rotational energy is contained in the stars' orbital motions as in their axial spin; equally, most of the rotational energy in the solar system seems to be contained in the orbital motions of the planets rather than in the spin of the Sun. This suggests that, to get rid of their surplus spin, all condensing protostars split to form either a double star or a star with planets.

Abt and Levy found that two-thirds of the stars they studied have short-period stellar companions. The other one third of stars had no detectable stellar companions. If this remaining one-third of the stars sampled were also formed by shrinking and splitting gas blobs, then they too should have companions – but these companions would be too small to be visible stars.

This brings up the interesting question of what constitutes a true star. According to calculations by the University of Virginia astrophysicist Shiv Kumar, the smallest mass at which a protostar can turn on nuclear reactions to become a genuine star is 0.07 times that of the Sun, or about 70 times the mass of Jupiter. Then there comes a transition region between true stars and planets. A shrinking gas blob with a mass in this region will glow from the energy of its contraction before finally fading to become a black dwarf, sometimes termed a degenerate star. Even our own Jupiter is giving out a vestige of internal heat, one cause of which might be a slight shrinkage; Jupiter has been termed the star that failed.*

According to Abt and Levy's calculations, 15 per cent of their sample stars should be accompanied by degenerate stars and 20 per cent by planets, thus underlining the theoretical speculation that no star ever forms alone. In fact, if astronomers are right in their understanding of how stars form, each shrinking blob *has* to split into two because of its high speed of rotation. Abt and Levy also find that 72 per cent of the stars in their sample are wide binaries – that is, with companions that orbit in more than 100 years. Each member of a wide binary should itself have a close twin, thus producing a quadruple system.

* The stars of smallest mass were once believed to be the components of the binary star UV Ceti (also catalogued as L 726-8), each of which was estimated to have a mass 0.04 that of the Sun; this would have meant that they were still contracting before fading out to become black dwarfs. However, more recent work (Harrington and Behall, *Astronomical Journal*, vol. 78, p. 1096, 1973) gives a more accurate figure of 0.1 solar mass for each object, thus making them true stars. The stars now of smallest known mass are the two components of Wolf 424, and the smaller component of the double star Ross 614; in each case the estimated mass is 0.06 that of the Sun, thus placing them on the theoretical borderline between real and degenerate stars.

These conclusions have deep implications for our understanding of stars and their formation. From such a limited sample, it is difficult to be certain to how many stars Abt and Levy's findings apply. But it seems that they should hold for all stars of suitably long lifetimes for life to develop – that is, of 1.5 solar masses and smaller. Therefore, around all stars in this range that are not close binaries, including the individual members of wide double-star systems, we should expect to find planets on which life might conceivably form.

The conclusion helps clarify a long-standing disagreement about whether or not planets would be expected in multiple-star systems. Some astronomers, such as Tom Heppenheimer of the Max-Planck-Institut für Kernphysik in West Germany have argued that the presence of a degenerate star would prevent the formation of terrestrial-type planets. Robert Hohlfeld and Yervant Terzian of Cornell University have suggested that the difficulties in the formation of planets in a double-star system should lead to a reduction by a factor of 50 in the number of civilizations predicted by the Drake equation.

But theoretical work indicates that planets, if they can form, should be able to survive around the components of a double star, as long as the components were sufficiently separated; there is an analogy in the solar system, where Jupiter is sufficiently far from the Sun to possess a family of moons like a small-scale solar system. If the component stars are too close, any planets would be forced out of the system or into one of the stars by gravitational effects; the analogy in the solar system is Mercury and Venus, neither of which can possess moons.

The stability of planetary orbits in a binary system has been examined most recently by Robert S. Harrington of the US Naval Observatory, Washington. He has affirmed that planets can exist if they are sufficiently close to the individual members of a binary or if they are sufficiently distant that they orbit around the outside of both stars (the analogy here is Uranus, Neptune, and

Pluto, which can be said to orbit around the Sun-Jupiter double system).

Harrington mathematically tested known binaries to see if planets could exist in them. He found that planets are stable as long as the outer body (be it a star or planet) comes no closer than three to four times the separation of the two inner objects. Additionally, the region of planetary stability for most known binaries includes the area in which conditions on the planets would be suitable for life. Interestingly, Harrington found that if the Sun were replaced by a close binary of two 0.5 solar-mass stars, or if Jupiter were replaced by a 1-solar-mass star, the Earth's orbit would remain stable and temperatures on Earth would not be significantly different from today.

Alpha Centauri could be an excellent example of a multiple-star system with planets. The two main stars of Alpha Centauri are both similar in nature to the Sun, and orbit each other every 80 years; presumably they are the two halves of a protostar that split. But a third member of the Alpha Centauri system is a faint red dwarf named Proxima Centauri, which is marginally the closest of the three to the Sun. Proxima Centauri is so far separated from the two main members of the Alpha Centauri system that it must take about a million years to orbit them. It was presumably captured by the other two stars, and is certainly far enough from them to possess a planetary system. Unfortunately, it has not been studied for any evidence of planets.

Richard Isaacman and Carl Sagan of Cornell University have simulated on a computer the formation of planets from a nebula around a star. Their results broadly support the observations of Abt and Levy, in that they find either the production of a multiple-star system or of a planetary system around the parent star. By varying the mass of the original cloud and the conditions within it, Isaacman and Sagan created a whole range of possible outcomes, from multiple stars with planets to a single star with a large family of asteroids. In many cases recognizable planetary systems were formed, with an average of about 10 planets. Isaacman and Sagan conclude that planetary systems are most likely widespread throughout the Galaxy, although their appearances are quite diverse – many of them will not look like our solar system.

Astronomers are now finding what they believe to be examples of planetary formation in action. In 1975, University of Minnesota astronomer Edward Ney reported an hourglass-shaped blob of gas in the constellation Cygnus, dubbed the Egg nebula. Its shape is apparently caused by a ring of dark dust around the nebula's central star, which absorbs its light to produce the dark 'neck' of the hourglass, and re-radiates the star's energy at infrared wavelengths. One possibility is that the ring of obscuring dust is similar to the dense disk around the young Sun from which our own planetary system is believed to have formed 4600 million years ago. In 1977 astronomers from the University of Arizona led by Rodger I. Thompson announced the discovery of a forming star in Cygnus, designated MWC 349, surrounded by a flat disk from which planets may be forming.

Other examples of stars surrounded by obscuring rings of material include the so-called double-fan nebula in northeastern Orion; the two bright 'fans' are caused by a young star illuminating a surrounding cloud of gas, with a dark lane between them which is apparently the shadow of a disk of dust around the star's equator.

Lick Observatory astronomer George Herbig has been foremost in examining young stars, known as T Tauri stars after their prototype, which still seem to be settling down after their recent birth from gas blobs. T Tauri-type stars appear to be ejecting vast amounts of matter, as is believed to have happened when the remaining nebula around the young Sun was swept away, leaving only the planets. T Tauri stars should provide considerable information about planetary formation in action, and a group of Swedish astronomers, led by G. F. Gahm of Stockholm Observatory, believe they have found just such an example of a forming planetary system round the star known as RU Lupi, in the southern hemisphere constellation of Lupus, the wolf. Observing from the European Southern Observatory in Chile, the Swedish astronomers found that the star's brightness rises and falls every few days, apparently due to the passage of obscuring material across the star's face. They calculate that these obscuring bodies are actually dust clouds with the mass of asteroids and moving at planetary distances – in other words, mini planets in the process of formation. This fits very well with the assumptions of theorists that the disk of dust around the Sun first built up asteroid-sized bodies which then aggregated into planets. Remnants from this sweeping-up process are the meteorites that occasionally hit the Earth.

A rather different example of possible planetary formation is provided by the star Epsilon Aurigae, which is eclipsed every 27 years by an invisible companion that blocks off half its light. Observations of the eclipse indicate that the obscuring body cannot be rounded, like a star, but must be a flattened disk. According to a recent analysis by mathematicians Michael Handbury and Iwan Williams of Queen Mary College, London, this secondary body is actually a protostar surrounded by a disk of dust in which planets may be forming. Thus Epsilon Aurigae helps provide support for the supposition that planets can arise in a binary system if the stars are far enough apart – in this case, about 3500 million km, or midway between the distances of Uranus and Neptune from the Sun.

Are there any signs of planets that have already formed – solar systems like our own? Since planets around other stars cannot yet be seen directly, astronomers have to use indirect methods of detecting them. One such method is to search for the gravitational effect that an invisible star or planet has on the motion of its visible parent star.

Stars near the Sun show a systematic drift in position over the years, termed *proper motion*, which results from their rotation around the Galaxy. Like cars on a giant racetrack some stars move ahead of the Sun, while others fall behind. A star's proper motion is imperceptible to the naked eye, but it can be detected on large-scale photographs taken with long-focus telescopes. A single star should move in a straight line; but if the star is double or if it has planets, then its motion will be unbalanced. It will therefore show a slight wave-like wobble in its path as it swings around in orbit with its invisible companion. The amount of wobble, and its frequency, reveals the mass and orbital period of the invisible companion. A detailed study of the motions of nearby stars, captured on photographic plates taken over the past 40 years, has rewarded astronomers with the discovery of at least one possible planetary system, as well as many previously unknown low-mass stars.

Peter van de Kamp of the Sproul Observatory, Pennsylvania, began a regular photographic survey of the stars within 30 to 40 light years of the Sun in 1937, using the observatory's 61 cm refractor.* In 1963, van de Kamp announced that the red dwarf Barnard's star, the second closest star to the Sun, had a possible planetary system. Barnard's star, lying 6 light years away in the constellation Ophiuchus, has a mass of 0.14 that of the Sun and gives out 0.00044 the Sun's light – too faint to be seen without a telescope. The wobble of Barnard's star on the Sproul photographs indicated the presence of a planet roughly 1½ times the mass of Jupiter, orbiting every 24 years. Six years after his first announcement, van de Kamp raised the possibility that not one planet existed around Barnard's star but two, with masses similar to Jupiter and periods of 26 and 12 years. Other astronomers suggested that even more planets might be present.

But it was later found that a spurious kink in the observed motion of Barnard's star had been caused in 1949 when the Sproul telescope's lens was placed in a new retaining cell made of cast iron, instead of the old

* The 100,000th photographic plate in the programme was taken on March 1, 1974.

aluminium one. This kink meant that previous interpretations of the movement of Barnard's star had to be modified, although the existence of a planetary system was not disproved.

The high-quality Sproul observations from 1950 onwards have confirmed that the star's motion does waver. Using the accurate new data, Peter van de Kamp in 1975 published a new analysis of the motion of Barnard's star in which he concluded that the existence of at least one planet 'appears to be well established'. The existence of a second planet was, he said, 'admittedly marginal', but helped satisfy the observations. He also noted that photographs of Barnard's star taken at the Allegheny and Van Vleck observatories contained evidence for a wobble in the star's motion caused by at least one planet.

From data extending into 1976 Dr van de Kamp has calculated the probable masses of the Barnard's star planets to be 0.9 and 0.4 times that of Jupiter, with periods of 11.7 and 18.5 years, orbiting at distances of 410 million km and 560 million km. Planets like the Earth might also orbit Barnard's star, but their effects would be too small to be detected.

A second star with a possible planetary system or degenerate stellar companion found by van de Kamp is Epsilon Eridani, one of the nearby stars most like the Sun. Epsilon Eridani, 10.7 light years away, is slightly cooler than the Sun, with three-quarters the Sun's mass and giving out one-third the light. Van de Kamp first proposed a massive planet-like companion for Epsilon Eridani in 1973. Using data into 1976, he finds that this companion has a period of 26 years and a distance from Epsilon Eridani of 1200 million km. The estimated mass is at least 6 times that of Jupiter, large by solar system standards but well below the minimum mass for a true star.

Other stars being tracked at Sproul for possible planetary systems are EV Lacertae (also catalogued as BD +43°4305) and BD +5°1668, both red dwarfs of about one-quarter the Sun's mass, 16 and 12 light years away respectively. The red dwarf star Lalande 21185, 8.1 light years away in the constellation Ursa Major, was once credited with a planetary companion about 10 times the mass of Jupiter, but follow-up studies have failed to confirm this. Other possible wobbles quoted in the past have turned out to be false alarms, although one star, 61 Cygni, remains controversial. It is a double star, the components having slightly over one-half the Sun's mass and orbiting each other every 720 years. The slightly larger and brighter star of the two, 61 Cygni A, was once suspected of having a planetary companion with a mass of about eight times that of Jupiter, but more recently it was crossed off the list.

Then, in 1977, two Soviet astronomers from Pulkovo Observatory, A. N. Deutsch and O. N. Orlova, reported the possible existence of three companions to 61 Cygni, with masses of seven, six, and 11 times that of Jupiter and periods of six, seven, and 12 years respectively. There is some indication, the astronomers reported, that the two largest planets orbit one component of 61 Cygni, while the smallest planet orbits the other star. When their own data from Pulkovo was combined with more extensive data from Sproul, the calculated masses of the planets were halved.

The star has also been under survey by Murray Fletcher at the Dominion Astrophysical Observatory in Canada. He has used a sensitive spectroscopic method to search for the approximately five-year period of the planet around 61 Cygni A reported some years ago. In 1977, after five years of observations, he reported results which showed that if any planet exists around 61 Cygni A it must have a mass smaller than 10 solar masses. It seems that the case with regard to 61 Cygni is too uncertain to draw any firm conclusions at present.

Photographic materials, plate-measuring techniques, and data-analysis have all improved greatly since van de Kamp began his search in the 1930s. Astronomers can now track the tiny wavers in a star's motion with less effort and greater accuracy than ever before, thereby increasing the number of stars around which they might find planetary systems. A new search has in fact been started at the University of Pittsburgh's Allegheny Observatory by a young astronomer, George Gatewood, who has assumed van de Kamp's mantle as a planet-hunter.

The detectability of a planet depends on its mass, the mass of its parent star, and the star's distance from Earth. Gatewood estimates that planets the mass of Jupiter would be detectable with the Allegheny Observatory's 76 cm refractor around 10 or more of the Sun's neighbour stars (see table). All these stars are red dwarfs,

Stars around which Jupiter-like planets are detectable (in approximate order of detectability)

Star	*Distance* (light years)	*Mass* (Suns)
Proxima Centauri	4.3	0.11
Barnard's star	6.0	0.14
Wolf 359	7.6	0.10
G 51-15	12.0	0.09
Ross 154	9.5	0.15
Ross 248	10.3	0.13
L 789-6	10.7	0.15
Ross 128	10.8	0.15
Groombridge 34B	11.6	0.15
Kruger 60B	12.9	0.13
G 158-27	14.6	0.10

although planets larger than Jupiter could be detected around more massive stars. Answers are not expected for decades. Gatewood's search, like that of van de Kamp before him, may need to continue for a lifetime to be sure of the minute effects that are searched for. The slow pace of this research is dictated by the long times that planets take to go around their orbits – the largest planets of our solar system, Jupiter and Saturn, have orbital periods of 11.9 and 29.5 years respectively.

One strong ray of hope for the future comes from the plans for large telescopes in space, which will enable astronomers to plot star positions with far greater accuracy than is currently possible through the dense, turbulent blanket of the Earth's atmosphere. NASA's 2.4 m space telescope, due for launch by the Space Shuttle in the 1980s, is expected to improve position-measuring accuracy ten times.

There has been an explosion of late in the number of feasible planet-spotting techniques being suggested. One method now being introduced is a sensitive refinement of the technique for finding spectroscopic binary stars. The technique involves measuring slight changes in wavelength of light from a visible star as it swings around in orbit with its invisible companions. This wavelength change is known as the Doppler effect, and occurs in light from all moving bodies.

At the University of Arizona's Lunar and Planetary Laboratory, astronomer Kristopher Serkowski is monitoring the spectra of bright Sun-like stars for such tiny wavelength changes, using the Laboratory's 155 cm reflector in the Santa Catalina mountains outside Tucson. He began by artificially polarizing different wavelengths of light from the star to assist in measuring any slight wavelength changes, but in 1976 switched to a device known as a Fabry-Perot interferometer which transmits only certain very narrow wavelength intervals. Any slight wavelength changes are registered by a detector.

Serkowski hopes to be able to measure star motions as small as 5 metres a second, which would be sufficient to reveal the existence of planets the size of Jupiter around his target stars. In our own solar system, the Sun is slightly unbalanced by the presence of Jupiter, which is the only planet that matters, since it is 2½ times the mass of all the other planets put together. The Sun and Jupiter act like the two halves of a very uneven double star. Although it is true for most practical purposes to say that Jupiter orbits the Sun, when dealing with precision astronomical measurements one must also take into account the fact that the Sun moves around the centre of gravity of the Sun-Jupiter system at about

12.7 m/sec. Therefore, a distant observer would see a cyclical change in the wavelength of light from the Sun of the type that Serkowski is seeking. This is in fact another, more sensitive, way of finding the same star wobbles as sought by photography. Unlike the photographic technique, it is not restricted to the nearest stars.

For his study, Serkowski has selected 25 stars similar to the Sun. All are brighter than magnitude 6, appear nearly overhead at Tucson, and have no known stellar companions. In addition, he is extending the work of Abt and Levy by observing the 52 stars for which they found no detectable companion. Each star needs to be observed on at least four nights a year to obtain the desired accuracy of 5 m/sec in its motion. Serkowski estimates that the programme will take a decade to complete.

A similar project is planned by Dr George Isaak of Birmingham University, who has developed a system that accurately compares specific wavelengths in a star's spectrum with a wavelength standard on Earth. In trials of this system, Isaak and his team have found what they claim to be regular oscillations of about 10 km in the outer layers of the Sun.

Another sophisticated approach has been suggested by Harold McAlister of Kitt Peak Observatory. He has noted that it should be possible to detect the presence of any planets in binary star systems by the technique known as speckle interferometry, which unscrambles the blurring caused by the Earth's atmosphere to give the accurate relative positions and orientations of the members of close double stars. Plants themselves could not be seen directly with this technique, but speckle interferometry promises to give star positions in binaries at least 15 times as accurately as with direct photography, thereby allowing astronomers to search for slight wobbles in the paths of the components of double stars caused by the presence of planets.

In 1976 a team of astronomers and engineers met for a summer study on planetary detection at NASA's Ames Research Center in California. During the study, called

Project Orion, they came up with a proposal for a so-called imaging interferometer, a twin telescope whose two views of a star field are combined to give more accurate positions of stars than are possible with a single telescope alone. Such a twin telescope, either on the Earth or in space, could detect the wobbles in star motions that would reveal the existence of Earth-sized planets around 400 stars out to a distance of 32 light years, or Jupiter-sized planets around most stars out to 150 light years, which is vastly better than the single-telescope astrometric studies being made by van de Kamp and Gatewood.

But what are the chances of seeing planets of other stars directly? The problem is that the faint light from planets is swamped by the light, often 1000 million times brighter, of their parent stars. Even space telescopes, such as the 2.4 m reflector due to be launched by the Shuttle, will not be able to resolve planets on its own. But Charles KenKnight of the Lunar and Planetary Laboratory at the University of Arizona has pointed out that special optical systems can be devised to cut down the amount of light from parent stars, thus revealing images of any bright accompanying planets from among the glare. He believes that a 2 m telescope in Earth orbit equipped with suitable optics could see planets like Jupiter or even Venus (because of its brightness) around nearby stars.

As the results from these searches come in over the next decade, astronomers will for the first time have observational evidence to back up their theoretical speculation that planets are common in space. For the moment, though, only one star is known with certainty to have planets – the Sun.

Ironically, although stars provide the heat and light to nourish any life around them, they also drive that life away when they die. About 5000 million years from now, the Sun will begin to heat up at the centre. It will slowly swell to a red giant star, 100 times its present diameter, engulfing the planets Mercury, Venus, and perhaps even the Earth. Then it will puff off its outer layers into space, leaving its hot core as a slowly cooling white dwarf.

Long before that happens, of course, all remaining life on Earth will have been incinerated. Once the Sun starts to heat up it will cause widespread changes in the Earth's climate, a melting of the polar caps, and consequent flooding of lowland areas. Then the seas will evaporate, leaving the Earth as a parched and bare cinder. Any distant descendants of ours will have left the Earth in search of another home around a younger star. Other civilizations, if any exist, may already have been through this enforced emigration from their home star.

Once a star starts to die, the existence of planets around other suns becomes more than a matter of academic curiosity. It is a matter of life or death.

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3

LIFE IN THE SOLAR SYSTEM

The nine planets and associated debris of our solar system provide a vast range of conditions, from searing heat to near-absolute cold, from total vacuum to dense gas, from zero gravity to many times Earth gravity, and from arid sterility to a seething soup of organic chemicals. If, as seems probable, there are other planetary systems in space, there is likely to be something of these conditions in every one of them. By studying our solar system, we should gain clues to the possible niches in which life may form in space. This study will illuminate the third unknown in the Drake equation – the number of habitable planets in each solar system.

Mercury, the closest known planet to the Sun (there may be some smaller asteroids closer still) is probably typical of the smaller planets in space, at least on its outside. Internally, it is remarkable in having a giant iron core, comprising about four-fifths its total diameter; the core is made from the heavy elements that remained closest to the Sun in the cloud from which the planets formed.

Mercury's rocky surface, first shown in detail in 1974 by the Mariner 10 spacecraft, has been badly battered by impacts from debris left over after the formation of the solar system. Mercury's craters, basins, and lava plains are very reminiscent of the Moon – not surprisingly so, for Mercury's diameter of 4880 km is only 50 per cent larger than our Moon; some of the satellites of the outer planets are larger than Mercury. The Moon and Mercury do not have sufficient gravity to hold an atmosphere that would shield them from meteorites.

Mercury turns on its axis once every 59 days, two-thirds of the time it takes to orbit the Sun. The remarkable consequence of this is that from one Mercurian noon to the next takes 176 days; during this time, the planet has orbited the Sun twice and spun three times on its axis. Mercury's rotation has been braked by the gravitational pull of the Sun.

Standing among the lunar-like craters on the dayside of Mercury, you would see the sun 2½ times larger than it appears from Earth. Without the filtering effect of an atmospheric blanket, you would be bathed in deadly levels of short-wavelength radiation as the Sun heated surface rocks to 400°C or more at maximum, hot enough to melt tin and lead. But during the three-month Mercurian night, the temperature of the surface rocks around you would drop to – 170°C.

Mercury is simply too close to the Sun for life to exist on its surface. If the Sun were slightly cooler, a planet with an atmosphere at Mercury's distance would be at the right temperature for life. But around the smallest and coolest stars of all, red dwarfs like Barnard's star, a planet would have to be even closer than Mercury to be kept warm enough for life – so close that its axial spin would be locked by gravity so that it kept one face forever turned towards the star, like the Moon keeps one face turned to the Earth. Life on a planet with permanent day in one hemisphere and eternal night on the other would be a little monotonous, but not necessarily impossible.

How near to a star or how far from it must a planet be to support life? Each star is surrounded by a habitably warm zone known as its ecosphere in which, like around a bonfire, temperatures are neither uncomfortably hot nor uncomfortably cold. The size of a star's life zone depends on the star's temperature: the coolest stars, like faintly glimmering bonfires, warm only a small area, whereas the hottest stars spread heat and light over a much larger area. Our Earth, not surprisingly, is at the very centre of the Sun's life zone. Venus, the second planet from the Sun, is just at the inner edge of the habitable zone, and it is instructive to compare the differences between Venus and Earth to see how finely the scales are balanced between an uninhabitable planet and one that teems with life.

On the face of it, Venus and Earth appear very similar. Venus is only slightly smaller than Earth (12,104 km diameter, as against 12,756 km), and they come closer together (within 41 million km) than any other two planets. Both Venus and Earth have copious atmospheres. A long-standing nickname for Venus was Earth's twin. But the results of space-probe research have shown what a devilish misnomer this is. For Venus has more in common with Hell than our own Earthly paradise.

Venus appears brighter in the sky than any other planet, because sunlight is reflected strongly from the dense clouds that obscure the planet's surface from the prying eyes of astronomers. Only radar can see through the clouds, to produce crude maps of the surface which show Venus to be peppered with craters, cut by canyons, layered with lava flows, and crested by mountains that look suspiciously similar to the giant volcanoes of Mars. Apparently Venus has had an active geological history.

One distinct curiosity about the planet is that it rotates on its axis every 243 days from east to west, instead of the usual west to east, longer than the 225 days it takes to orbit the Sun. From Venus, therefore, the Sun would appear to rise in the west and set in the east, taking 117 days to go once around the sky (half Venus's year). The rogue back-to-front rotation of Venus is a major puzzle, but it may somehow be connected with the combined gravitational pulls of the Sun and Earth.

The clouds themselves are now believed to be composed of a strong solution of sulphuric acid, in about 80 per cent concentration. The cloud tops visible in telescopes are at a height of 60 km above the planet, and according to spacecraft measurements extend down to 35 km from the surface. Below that is a thick atmosphere of almost pure carbon dioxide, which reaches a pressure of 90 Earth atmospheres at the surface – equivalent to the pressure half a mile under the ocean on Earth, sufficient to crush a submarine like tinfoil.

Not surprisingly, the first Soviet probes to parachute into Venus's atmosphere were destroyed before they ever reached the ground. Only in 1970 were the first signals received from the surface of Venus, transmitted by the probe Venus 7 which had been specially strengthened to withstand the forces that had crushed its predecessors. Subsequent probes have sent back data indicating that the rocks on Venus are similar to granite and basalt on Earth, and have taken photographs of the rocky surface which show that as much light penetrates the clouds as does on a cloudy summer's day on Earth.

These probes have confirmed previous findings that the temperature at the surface of Venus, on both day and night hemispheres, is a furnace-like 475°C. A luckless astronaut who crash-landed on Venus would thus be simultaneously crushed, roasted, and suffocated.

Two planets, similar in size, in the same part of the solar system and apparently of similar composition – why should Earth and Venus today have such startlingly different conditions? Venus, by virtue of its proximity to the Sun, receives nearly twice as much solar radiation as the Earth; but 80 per cent of this is reflected by the clouds, so the surface temperature should be comfortably warm. Why, then, is Venus so roastingly hot? And where has its water gone?

One point of similarity between Venus and Earth, not obvious at first glance, is that both planets have comparable amounts of carbon dioxide; on Earth, though, most of this is locked up in limestone sediments, a result both of natural chemical processes and of the action of sea creatures in the past. Carbon dioxide traps heat very efficiently, in a process known as the greenhouse effect (indeed, one of the fears on Earth is that the extra carbon dioxide being released into the atmosphere by the burning of fossil fuels may cause drastic changes in our climate). Sunlight can warm Venus in the normal way but the presence of so much carbon dioxide in the atmosphere prevents the heat from escaping again, thus building up the planet's high temperature.

Both Venus and the Earth are believed to have obtained their present atmospheres from gases released from their interiors, particularly through the mouths of volcanoes. The volcanoes broke through the crust as the interiors of the planets heated up from the decay of radioactive atoms; bodies such as Mercury and the Moon would have been too small to heat up sufficiently, which is why they have no large volcanoes.

This degassing through volcanoes would presumably have produced similar gases on both planets – mostly water vapour, carbon dioxide, and nitrogen. But already the evolution of the two planets' atmospheres was being altered by their different temperatures. Venus, being closer to the Sun, would have been hotter than Earth to start with, and this higher surface temperature would have affected the chemical reaction that binds up carbon dioxide in the planet's crust. While chemical reactions on Earth removed carbon dioxide from the atmosphere and kept the planet down to a reasonable temperature for life to form, on Venus this process would not have occurred. The carbon dioxide would thus have built up in the Venus atmosphere, making the planet still hotter, and leading to the oven-like temperatures of today.

What of the water on Venus? The main product of volcanoes on Earth is water vapour, which has condensed to fill our oceans. But water on Venus today is almost non-existent. The reason seems to be quite straightforward. Since Venus is so hot, its water would have remained as vapour in its atmosphere, where it would be broken up by sunlight. This process, called photodissociation, splits water into its component hydrogen and oxygen atoms. The hydrogen, being lightweight, would be lost into space, while the oxygen could both combine in chemical reactions with the crust and help to make the sulphuric acid clouds. Water vapour in the atmosphere would have worked with the carbon dioxide to block the loss of heat from Venus, thus leading to a runaway greenhouse effect that quickly produced the hot, arid, sterile planet we see today.

It is possible that, in the past, Venus had oceans. Theories of stellar evolution indicate that the Sun would have been slightly cooler thousands of millions of years ago, so that the greenhouse effect on Venus may not then have got underway. Venus, in fact, may once have been quite Earthlike, with volcanoes belching gases into the sky and cooling streams running over the faces of continents to fill the oceans. In those oceans, fed by a rain of organic molecules from the planet's chemically rich atmosphere, life could have begun to evolve at the same time as it did on Earth, nearly 4000 million years ago. But eventually, after perhaps 3000 million years, the warming Sun would have snuffed out that life as the planet's climate changed catastrophically. The fossils of dead sea creatures may lie in the rocks of the deep basins on Venus, mute testimony to a planet that, a few million kilometres farther from the Sun, could have been as fertile as the Earth.

One day, the Earth will become like Venus. As the Sun swells into a red giant star at the end of its life, in thousands of millions of years' time, it will begin to heat up the Earth. As the Earth gets hotter, the carbon dioxide will be liberated from the rocks in which it is chemically trapped. Water will evaporate from the seas, be broken up by sunlight, and be lost. The runaway greenhouse effect will take charge in the predominantly carbon dioxide atmosphere, and Earth will become a burning Hell.

The strong sulphuric acid clouds of Venus and the lack of water (no more than one part per thousand, possibly one hundred times less) seem to rule out the suggestion made some years ago that Venus could be made habitable by seeding its atmosphere with algae that would break down the carbon dioxide to release oxygen. The situation might be saved if we could arrange to import more water – perhaps by diverting an icy comet into the clouds of Venus.

Liquid water is the one factor which selects Earth as the most favourable planet in the solar system for life.

Water itself is not lacking in the solar system; its simple combination of two hydrogen atoms with one of oxygen is plentiful, particularly on the giant outer planets. But there it is either frozen as ice or in droplets as water vapour. On Earth it is abundant as a liquid because our planet lies in the middle of the Sun's life zone – that celestial green belt in which we expect to find a star's life-bearing planets.

Water is the liquid of life. It acts as a solvent in which chemicals can come together and react; as far as we know, life originated in or around the oceans of the early Earth. Water is also the major component of living things; about 90 per cent in the case of many vegetables (think of dried potato powder or packet soup), and two-thirds in the case of human beings. Without water, organisms cannot live.

According to the theories of the origin of life, basic organic chemicals which comprise proteins and nucleic acids were made easily in the atmosphere of the primitive Earth – many of those organic chemicals have been produced in experiments that simulate conditions 4000 million years ago. And those component chemicals are the same in the proteins and nucleic acids of every form of life on Earth – only their arrangement is different, like different shapes made from the same set of building blocks. Such similarity at the microscopic level gives a truly breathtaking glimpse of the basic unity of all life on this planet, from microbes to man.

Proteins are the structural material of life, whereas the nucleic acids, DNA and RNA, guide reproduction and growth (the genetic code). Cells are, at their most basic, a shell of protein wrapping nucleic acids. How the first proteins and nucleic acids were built, and how they came together in cells to form the first living organisms, are unsolved problems that remain at the forefront of biochemical research.

Chemical fragments of proteins and nucleic acids seem to have helped in each other's mutual development, a two-way process which eventually built up today's fullsized proteins and nucleic acids. Proteins and nucleic acids still bear the imprint of their intimate evolutionary relationship, as shown by the model-building experiments of American biologists Charles Carter and Joseph Kraut, who found that twisted chains of protein wrap neatly around the famous double-helix spirals of nucleic acid.

Leslie Orgel and his colleague Andre Brack at the Salk Institute in California concluded that the first protein would most likely be made of alternating chains of the amino-acid chemicals glycine and alanine, which are the most abundant amino acids formed in simulations of conditions on the primitive Earth. The genetic code for this protein would require a chain of alternating nucleic acids, as observed in the nucleic acids of today. Thus the genetic code would have originated by interactions between the first simple proteins and the first simple chains of nucleic acids.

The vast complexity of the origin of life has been amply depicted by organic chemist Dr Peter Molton in an outline of 18 major steps to the formation of a cell, involving the synthesis and amalgamation of chemical units that developed separately in the pre-biotic soup of the Earth's young oceans. Each of those first chemical units was probably the barest arrangement capable of doing the job; they were improved by later additions, producing the highly complex molecules we see today. Some cells incorporated a unit that allowed them to use carbon dioxide as food – the reaction known as photosynthesis. Thus came the division of life into plant cells (the photosynthesizers) and animal cells (those that preyed on the plant cells, and on each other). Eventually, co-operation between cells produced the astounding multi-cellular organisms that dominate the Earth.

Fred Hoyle and Chandra Wickramasinghe in their 'black cloud' paper of 1977 joined the ranks of those who propose that the Earth may have been seeded by life from outer space. Astronomers know that the dark clouds in space contain microscopic graphite and silicate dust, and about 40 molecules of varying complexity. Hoyle and

Wickramasinghe quoted evidence from the absorption of life at ultraviolet wavelengths by dust in space that even more complex molecules, including the molecules of life, can be built up on the surfaces of the dust grains in clouds such as the Orion nebula. Rocky meteorites, such as that which landed at Murchison, Australia, in 1969, have been found to contain quite complex organic molecules, including amino acids, apparently formed in space under the conditions that Hoyle and Wickramasinghe describe.

Later in 1977, Hoyle and Wickramasinghe noted that the absorption of light by dust clouds in space at certain infra-red wavelengths reveals the apparent existence of cellulose in space, formed from stable rings of the organic molecule formaldehyde (H_2CO) which is already known to be abundant. Cellulose, of course, is the structural material of plant cell walls.

Hoyle and Wickramasinghe propose that the clumping and breaking up of dust grains in the interstellar clouds could eventually produce simple forms of living organism, trapped and preserved inside grain clumps and feeding off the nutrient of the surrounding gas. These organisms would divide and grow like any normal biological system as the grain clumps split and recombine, except that once a grain clump and its kernel of organic material is isolated from the surrounding cloud it becomes biologically inert, rather like a spore. Such a spore, if it became included in a meteorite, would remain in a state of suspended animation until released in a suitable planetary atmosphere, when it would spring back into life and begin to evolve in its new environment.

More recently, Hoyle and Wickramasinghe have argued that comets are the favoured sites for the origin of life, and that not only may life have been started by an impact of a comet with Earth, but that encounters with micrometeorites from comets in modern times are responsible for delivering periodic waves of disease to Earth. On this basis, life would be expected to be frequent throughout the Galaxy, and also to be built on similar biochemical lines to ourselves.

Most biologists remain sceptical of the view that the Earth was seeded with life from space – they feel that conditions were far more conducive for life to have evolved on Earth in the first place. Also, no 'living' spores have been detected in meteorites, and the failure to detect life on Mars seems to argue against the proposal.

Despite these advances in unravelling many of the steps to life, no scientist is anywhere near being able to create life in the laboratory. Until that can be accomplished – and it may eventually happen – the origin of life remains a mystery. And while it remains so, the corresponding factor in the Drake equation is totally uncertain.

It has traditionally been assumed that life might arise on one planet in ten with suitable conditions. But this is nothing more than an assumption – an expression of faith, some might call it. This is why the hunt for traces of life on another planet assumes such overriding importance. Evidence that life has arisen spontaneously on another body in space would place our existence in perspective more sharply than any other discovery we could make. It would, in the words of physicist Philip Morrison, turn the origin of life from a miracle into a statistic. One point of optimism is that traces of the earliest, single-celled organisms on Earth extend back 3500 million years or possibly longer, thus indicating that life, however caused, did not take long to get going.

Two other factors in the Drake equation – the probability of intelligence and the frequency of technological civilization – are as uncertain as the origin of life. Intelligence took much longer to develop on this planet than life itself. Only during the past few million years have beings of the *Homo* lineage been present on Earth; latest discoveries of fossil man place the split of true man from the ape-men at 3 to 4 million years ago. By contrast, our development from the use of stone tools to the level of high technology has been the fastest stage of all in our evolution. Some biologists believe that high intelligence is such an advantage that it is almost certain to develop, given time. And the inquisitive, dexterous nature of highly intelligent beings is bound to make them into a technological civilization that starts to question and examine its surroundings, probing even for evidence of other beings elsewhere in space. But further discussion of these matters is for anthropologists and sociologists, and we must return to the solar system.

Throughout this century the planet Mars, next past the Earth, has seemed the most likely place to find evidence of other life in space. In the popular vision, constructed by astronomers such as Percival Lowell at the turn of the century and eagerly supported by science fiction writers since, Mars was a dying world whose inhabitants were fighting a losing battle against the planet's parched deserts. Their technology had produced artifacts visible clear across the multi-million-kilometre gap to Earth: irrigation canals for channelling melted water from the polar caps to their crops near the equator. Lowell and his followers drew an intricate network of canals, interspersed with dark patches they termed oases, and charted what appeared to be vast areas of crops which varied seasonally in extent and coloration.

The large dark markings were real enough; moderate-sized amateur telescopes will show the largest of them, and they have been captured clearly on photographs. But what of the canals? They first came to prominence after the close approach between Mars and Earth in 1877 (the same occasion, incidentally, on which the two moons of Mars were discovered). The Italian astronomer Giovanni Schiaparelli drew a series of linear markings on the planet which he termed channels. Schiaparelli always kept an open mind about their true nature; but, for the American astronomer Percival Lowell, they were clear signs of an advanced technological civilization on the planet.

Lowell, a member of a famous New England family, built his own observatory in the dry, clear air of northern Arizona to study Mars*. During the years following the observatory's opening in 1894, Lowell and his collaborator Earl C. Slipher charted an increasingly complex network of canals. These findings, coupled with Lowell's romantic visions of the decaying civilization on Mars, fired the public's imagination – despite the fact that most other observers failed to see the canals, and denied their existence.

After Lowell's death in 1916 the debate rumbled on, with most astronomers regarding Lowell's claims with increasing scepticism. The dispute was finally laid to rest in 1965 with the arrival of the Mariner 4 spacecraft, which radioed back to Earth a string of photographs as it sped past Mars. The photographs showed a cratered surface that looked more like the Moon than the Earth. Of the canals – or of life – there was no sign. The Mariner 6 and 7 craft which photographed more of Mars in 1969 were no more encouraging, indicating that Mars was a dry, frigid, and near-airless world.

But a full photographic survey had to wait until 1971-72, when the Mariner 9 reconnaissance probe went into orbit around Mars. As expected, the large dark and light patches noted by Earth-based observers were found to correlate with areas of darker and lighter rock or dust on the planet. But where were the fine, straight lines drawn by the canal observers? Cornell University astronomers Carl Sagan and Paul Fox overlaid Earl C. Slipher's definitive map of the canals on to a mosaic of Mariner 9 pictures. In only a few cases did the 'canals' correlate with real surface features, such as a chain of craters or a dark surface streak, and in many instances there were topographic features or markings which showed no sign of having been recorded by Slipher despite the fact that

* The Lowell Observatory at Flagstaff, Arizona, is today one of the foremost centres of planetary research. The astronomers there now seem a little embarrassed about the observatory's sensational early history.

they are much wider than many of the supposed 'canals' which he drew. Basically, therefore, it seems that most of the canals are unexplained. Sagan and Fox characterized the canals as monuments to the imprecision of human observers under difficult conditions.

Any hope of finding patches of vegetation on the surface of Mars were finally dashed by the Mariner 9 pictures. The changes in shape and intensity of the dark markings are caused by dust being blown around by seasonal winds, not growing vegetation.

But the space probes did not completely rule out the possibility of life on Mars. In fact, they discovered one critical factor which made it more likely: Mars has volcanoes, and spectacular ones, too. The main volcanic mountain on Mars, Mount Olympus, is the largest known volcano in the solar system, dwarfing even the volcanic Hawaiian islands on Earth. Volcanoes on Mars opened the prospect of water on the planet – and Mariner 9 photographed numerous examples of what looked suspiciously like dried-up Martian rivers, which presumably flowed during more clement times in the planet's history.

The present atmosphere of Mars is scanty. It is made mostly of carbon dioxide gas, as thin as the Earth's air at a height of 32 km. Consequently, temperatures on Mars are well below freezing, but the Mariner 9 findings held out hope that Mars may have had a denser atmosphere in the past, particularly at the time when the volcanoes were active. With a denser atmosphere, Mars would also have been warmer. Had Mars been a slightly larger planet – it is half the diameter of the Earth – it would have become hotter inside and degassed more, building up a substantial atmosphere that could have kept it comfortably warm for life. On this view, the Earth at the distance of Mars could still be a habitable planet.

Even so, Earth-type organisms could just about cling to survival under present-day Martian conditions. Optimistic biologists believed that life might once have arisen on the planet, and that traces of it might still be found in the Martian soil. The two American Viking probes were designed to find out. Their results are described in the next chapter.

Beyond Mars, the solar system grows colder. This is the realm of the giant planets – and none is larger than Jupiter, king of our solar system, containing over twice as much mass as all the other planets wrapped up together. In contrast to the four small, solid bodies of the inner solar system, the four giant planets of the outer reaches are mostly made of gas, similar in composition to the Sun. Jupiter, in particular, is like a star that failed. It still releases a pale warmth of its own, possibly caused by a continual overall shrinkage of about 1 millimetre a year.

When we look at the outer planets, all we see is a cloudy atmosphere. The thick cloak of gases around each of these planets is a remnant of the cloud around the Sun from which the solar system first formed. Similar primitive atmospheres may also have surrounded the inner planets shortly after their birth, later being blown away by solar radiation. By contrast, the giant planets, being larger and cooler, retained the gases of their primitive atmospheres. The main components of Jupiter, as of all the outer planets, are hydrogen and helium, the two lightest and most abundant substances in the Universe. Small percentages of other substances, in a body the size of Jupiter, provide plenty of molecules for chemical reactions. Since helium is chemically unreactive, the most abundant reactive materials on Jupiter are hydrogen, methane, ammonia, and water – those same constituents from which life formed in the Earth's early atmosphere. Jupiter is thus a kind of space fossil. When we look at it we are viewing conditions on our Earth 4000 million years ago.

Simulations of Jupiter's atmosphere, like the simulations of the primitive Earth, have shown that organic molecules are plentifully formed from the gases by the action of ultraviolet light, electric sparks, and shock waves. The atmosphere of Jupiter provides 1000 times the volume for organic synthesis than the atmosphere of Earth. Many of the resulting molecules are highly coloured, from red (azobenzene, the starting point of many organic dyes) to blue (azulene), which can help explain the welter of transitory colour seen in the clouds of Jupiter. Evidently, organic synthesis in Jupiter's atmosphere continues today, and traces of such molecules should be detected by the infra-red spectrometers being carried by the Voyager 1 and 2 probes, due to reach the planet in March and July 1979.

But the presence of organic molecules, formed by simple chemistry, does not of itself imply the existence of life. The white cloud tops of Jupiter are made of frozen ammonia at a temperature of – 120°C; this is not a likely habitat for life. Slightly below the clouds, however, temperatures may be warm enough for liquid ammonia droplets, which raises the question of alternative biochemistries to those we know on Earth. A plausible arrangement for life is to use liquid ammonia as a solvent instead of water, and it may be that the atmospheres of the outer planets provide the ideal conditions for a liquid-ammonia lifeform.

The ammonia clouds form Jupiter's turbulent weather layer, responsible for the continual changes in the planet's appearance visible in telescopes. Below this is a much more stable region where temperatures lie between the freezing and boiling point of water, at pressures that increase with depth from five to ten times the Earth's atmospheric pressure. Here, about 80 km below the visible cloud tops, clouds of water vapour form, making this the most promising locale for Jovian life. Lower still, temperatures and pressures increase rapidly until the hydrogen of which the planet is predominantly made is compressed first into a liquid, and then into a super-dense state with the properties of a metal. Jupiter has no solid surface as we know it on Earth; any biology must therefore be restricted to its clouds.

Carl Sagan has joined with Cornell University colleague E. E. Salpeter, an astrophysicist, to examine the possible ecologies of Jupiter's atmosphere, concluding that there is an 'abundant biota' in the Jovian clouds. They compare the warm, wet cloud layers with the seas of Earth which have simple photosynthetic plankton at the top level, fish at lower levels which feed off these creatures, and marine predators which hunt the fish. The hypothetical Jovian equivalents of these organisms are respectively termed sinkers, floaters, and hunters.

The sinkers will drift downwards from just below the level of the visible clouds into the deeper atmosphere of Jupiter, eventually being burned up by the planet's internal heat. Before then, they must have reproduced in order to maintain a steady-state population.

As the sinkers drift downwards, they provide food that is mopped up by the floaters. Organisms that can propel themselves around to coalesce with other bodies in the clouds of Jupiter are the hunters. The approach and coalescence of two organisms serves to exchange genetic material – the same function as mating. Some highly evolved Jovian organisms may include aspects of all three life styles in their life cycles.

The creatures that Sagan and Salpeter envisage are gas-bags that move by pumping out helium, retaining the hydrogen for balloon-like buoyancy. Hunters in the clouds of Jupiter could grow to be many kilometres across, within the resolution of the cameras carried by the Voyager 1 and 2 probes.

If Sagan and Salpeter are right, we may already have visible evidence of life in Jupiter's clouds: they say the clue lies in the red coloration so frequently seen on the planet. Their estimates show that the direct action of sunlight does not seem to provide adequate supplies of red-coloured molecules at the right levels in the atmosphere, below the white ammonia clouds. Instead, they claim that sufficient red coloration can come as a result of biological activity by Jovian organisms capable of photosynthesis, like simple algae on Earth. In other words, Jovian organisms are themselves red, like certain coloured plankton on Earth that give the Red Sea its name. The great red spot, an updraught of heated air with prominent coloration, may thus be particularly favoured for life.*

Sagan and Salpeter do not speculate on how life may have arisen on Jupiter in the first place. One possibility is that, on a planet with no solid surface, organic molecules may join together into forms of life on the surfaces of tiny particles, both liquid and solid, floating in the atmosphere. While the basis of Jovian life will probably be carbon, which is contained in such substances as methane, ethane, and acetylene in the planet's atmosphere, other details of Jovian biochemistry are completely uncertain. As Sagan and Salpeter say, it is possible there exists a variety of different paths to the origin of life, some of which favour the Earth while others favour Jupiter.

An entry probe into Jupiter's atmosphere carrying sensitive instruments could detect the level of organic molecules predicted by the biological hypothesis of Sagan and Salpeter. The current Voyager spacecraft will not enter the atmosphere of Jupiter; that will be left for a planned orbiter/entry mission in 1982. Voyagers 1 and 2 will photograph Jupiter as they fly past before proceeding to the ringed planet Saturn, which they will reach in November 1980 and August 1981.

Saturn, like Jupiter, is mostly made of hydrogen and helium, and also seems to have an internal heat source. Saturn has dusky brown and yellow bands between white belts of ammonia clouds, but the markings on Saturn are less prominent and less variable than the turbulent clouds of Jupiter. Also present in the atmosphere is a small percentage of methane, from which the action of sunlight builds up traces of other hydrocarbons such as ethane, ethylene, and acetylene. More complex organic molecules are also likely on Saturn. The similarity between Saturn's and Jupiter's atmospheres leads Sagan and Salpeter to propose possible airborne organisms in the clouds of Saturn,

* Conventional astronomy attributes the spot's colour to red phosphorus.

although with less certainty.

Some of the satellites of the giant planets are possible sites for synthesis of organic molecules, notably Saturn's largest satellite, Titan, which has an appreciable atmosphere. But if there is no life on the far more Earth-like surface of Mars, there is unlikely to be life of any kind on these small bodies.

Our knowledge of conditions on the planets beyond Saturn is woefully slight, but what we do know is not promising for life. The outer gas giants, Uranus and Neptune, show virtually no features in their greenish methane atmospheres thereby indicating an almost total absence of the turbulent mixing that makes Jupiter's clouds so chemically complex.

There may be seas of liquid methane deeper under these clouds, where low-temperature life might survive, but sunlight at these distances is so weak that the synthesis of complex organic compounds or the origin of photosynthetic organisms must be considered highly unlikely. There is a hint that Neptune, like Jupiter, produces it own internal heat, which may improve matters slightly. But overall these remote, frigid bodies seem forbidding to life.

A group of American scientists, led by biologist Lynn Margulis of Boston University, reported in 1977 that the probability of a terrestrial organism being able to survive in the atmosphere of Uranus or Neptune is nil. There seem formidable barriers to the growth of Earth organisms even in the more hospitable atmosphere of Titan. Therefore, the chances of life having arisen under these conditions must also be zero.

If the two Voyager probes to Jupiter and Saturn are successful, the second will be sent on to examine Uranus, arriving there by January 1986. We should then learn more about the prospect of life in the outer reaches of the solar system.

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4

WHAT VIKING FOUND ON MARS

America's Viking 1 space probe landed on Mars on 20 July, 1976, in the most difficult technical achievement in the history of the space age. Its landing site was the flat lowland known as Chryse, the plain of Gold. Its mission, and that of its sister craft Viking 2 which landed on September 3 was to answer the question: Is there life on Mars?

Each Viking lander carried a tiny biological laboratory to analyse Martian soil collected by the craft's remote-controlled sampling arm. By incubating the soil in three different ways and seeing if anything grew, the biologists hoped they would find whether or not there was any life on the Martian surface. One experiment, called the gas-exchange experiment, assumed that Martian organisms, like terrestrial organisms, would respond to the addition of water and a rich mixture of nutrients. It simply attempted to detect changes in the gases above a sample of Martian soil which was fed with this nutrient solution, colloquially termed 'chicken soup'; proportions of various gases would be expected to change as any Martian bugs breathed, ate, grew, and reproduced.

Two other experiments looked for the release or uptake of carbon by Martian micro-organisms. One of these, the labelled-release experiment, fed a Martian soil sample with a nutrient solution containing radioactively labelled carbon; any carbon dioxide or other carbon-containing gas released by the sample would be detected by radioactive counters. The other experiment, the pyrolitic-release experiment, looked for evidence of photosynthesis in the soil, as would be expected if plant-like organisms existed there. In photosynthesis, carbon is taken from the atmosphere, which on Mars consists mostly of carbon dioxide (a trace of carbon monoxide also exists). In the pyrolitic-release experiment, soil samples were incubated under an artificial Martian atmosphere of carbon dioxide and carbon monoxide which had been labelled with radioactive carbon; the soil was then heated (pyrolysed) to drive off any carbon that may have been taken up by micro-organisms and the resulting gases were again analysed by radioactive counters.

Working alongside these three strictly biological experiments was a fourth, closely related experiment which analysed the surface soil with a device known as a gas chromatograph mass spectrometer (GCMS for short). This heated a Martian soil sample to drive off gases, and the gases were sorted according to weight for identification by the mass spectrometer. Its purpose was to detect whatever compounds, particularly organic ones, there might be in the Martian soil.

And of course there were the television cameras aboard each lander, which were capable of making the simplest and most positive identification of Martian life – by photographing whatever was growing or moving on the surface.

The Viking missions got under way from Cape Canaveral, Florida, when a Titan-Centaur rocket boosted Viking 1 into space on 20 August, 1975. Viking 2 followed on September 9. Both Vikings were identical, and each came in two halves: an orbiter with cameras and other instruments to survey the planet from above, and the all-important lander, sterilized and hermetically sealed in a shell to prevent contamination by terrestrial organisms before launch.

A series of landing sites had been selected by scientists from the Mariner 9 survey of Mars in 1971-2. These sites had to be lowlands, so that the landing parachutes could give the maximum braking effect, and also because the warmest temperatures and the maximum amount of water were likely to be found in lowland areas. But the landing sites had also to be as flat and smooth as possible, because rocky terrain or steep slopes could tip the tiny lander over. Therefore the Vikings took a further close look at the target sites from orbit before releasing their lander craft.

After its 10-month voyage, Viking 1 went into orbit around Mars on June 19 and immediately began surveying its projected landing site in an area known as Chryse (rhymes with 'icy'). Chryse was a lowland drainage basin into which water was believed to have flooded during the wet times on Mars. Viking's first photographs from orbit, more detailed than those of Mariner 9, confirmed that water had indeed flowed over the Chryse area, but they also showed that the intended landing site was far rougher than had been anticipated, with many tiny craters and eroded channels not seen on the Mariner 9 photographs. Scientists cancelled the landing, originally planned for 4 July, the bicentennial of the United States, and began to search for a smoother, safer location.

An alternative site, northwest of the original target area, was tentatively selected, but radar reflections from Earth showed that this was also too rough for safety (reflections of radar beams can reveal the texture of a surface on a scale too small for the orbiter's cameras to see). Eventually a site was chosen farther northwest, about 900 km from the original target area but still in the Chryse basin. Viking 1's lander touched down successfully at 22.27°N, 47.94°W, on 20 July, 1976, seven years to the day after the first manned landing on the Moon.

Viking 1's orbiter had also begun to scan the intended landing area for Viking 2, which was then approaching Mars. It found that the intended site was again dangerously rough. On August 7 Viking 2 joined its predecessor in orbit around Mars, and together the two probes sought out a safe new landing area. Mission scientists decided on a basin known as Utopia, lower even than Chryse but farther north, in an area covered by frosts during the winter. Viking 2's lander touched down here successfully on September 3, at 47.67°N, 225.71°W – almost exactly on the opposite side of the planet from the Viking 1 lander. Two craft were on Mars, making the first on-the-spot search for life on another planet.

One important clue to the possible existence of life on Mars came within hours of touchdown from the instruments that analysed the composition of the planet's atmosphere. In addition to the 95 per cent carbon dioxide already known to exist, the Viking landers detected 2½ per cent nitrogen in the atmosphere of Mars; the remaining few per cent is made up of traces of argon, oxygen, carbon monoxide, and one or two other gases. This was the first time that nitrogen had been identified in the Martian atmosphere, and it meant that, along with carbon and water, all the basic ingredients for life had been found to exist on the planet. Added to the fact that the Martian atmosphere seems to have been denser in the past, when the volcanoes erupted and water flowed, prospects for Martian biology looked better than ever.

What was there to see on Mars? Viking lander 1 began to survey its surroundings within minutes of touchdown. After transmitting a picture of one of its footpads resting gently on the stony surface, the lander looked up towards the horizon, about 3 km away. The scene, consisting of scattered rocks and sand dunes, resembled nothing so much as one of the stony deserts in the southwest United States. Colour photos from the Viking landers confirmed that Mars is indeed a very red planet. Not only are the surface rocks rust-red, a result of the large amounts of iron oxide they contain, but the sky itself is pink, because of fine dust caught up by winds and suspended in the atmosphere. Yet of life there was no sign.

I, for one, was disappointed not to see a Saguaro cactus or two dotting the landscape, along with an occasional Martian equivalent of a Joshua tree. Optimistic biologists had suggested before the mission that organisms large enough to be easily visible by the lander cameras might exist on the surface of Mars. These organisms, the speculation ran, would obtain water that was trapped in the rocks, or they would melt frost; even a thin nightly layer of frost would contain enough water to support a cover of moss or lichen over much of the surface. Large organisms would keep warm more easily in the freezing temperatures than small organisms. One suggested possibility was that the Martian plants might have developed deep roots down to the permafrost layer below the topsoil, and have silica domes like sunshades to ward off the Sun's ultraviolet light. Shells from dead organisms, or their fossils, would have remained visible to the lander cameras even if such life had died out. Alas, the first photographs disproved these daring speculations.

Some indication of the harsh conditions that any Martian creatures would have to withstand was provided by Viking's meteorology instruments, which measured a maximum air temperature in Chryse of −29°C in the mid-afternoon, falling to a minimum of −85°C at dawn – and this in the Martian summer! Temperatures were similar at the Viking 2 site, but as winter advanced during 1977 at this northern site temperatures fell to −123°C, so low that carbon dioxide frost began to form on the ground around the lander. Atmospheric pressure at both sites was around 7.5 millibars, equivalent to the pressure at a height of about 35 km above Earth. At neither Viking site does the ground temperature rise above 0°C at any time of the year.

Viking's cameras photographed the rising and setting of the Sun every Martian day, or Sol, which lasts about 40 minutes longer than our own 24-hour day. On Sol 8, Viking lander 1 reached out its soil-sampling arm to scoop up the first handful of Martian surface material and tipped it into the experimental apparatus on board for analysis. One non-biological experiment was designed to analyse the composition of the surface material, which it found to contain about 13 per cent of iron, agreeing with the supposition that the red colour of the rocks is caused by iron oxide. But, inevitably, most interest centred on the results from the three biology experiments.

What do they tell us about life on Mars? First, let's look at the gas-exchange experiment, the one that fed the soil with 'chicken soup' nutrient in the hope that Martian bugs would respond to the same kind of nutrients as terrestrial organisms; its results are the easiest to interpret and, as it turned out, are the least interesting from the point of view of Martian biology. The gas-exchange experiment worked in two stages: in stage one, a few drops of the nutrient solution were added to the test chamber, just enough to dampen the atmosphere, on the assumption that the soil already contained sufficient nutrients to support life. The reaction of Martian soil to this breath of water vapour was then measured. In stage two, sufficient nutrients were added to enrich the soil and the resulting gases were again analysed.

When the experiment was run on Viking lander 1, things began to happen immediately the soil same into contact with water vapour in the first stage of the test. Dramatic increases in the amounts of carbon dioxide and oxygen were recorded in the test chamber; there were fluctuations in the amount of nitrogen recorded. Scientists already realized that any sudden and dramatic response would be a sign of soil chemistry, not life, and so it proved: the reactions levelled off after the initial five-fold increase in carbon dioxide and an astounding 200 times increase in the amount of oxygen.

A better clue to the existence of life would be given by the second stage of the experiment, in which more nutrient was poured in to soak the soil; reduction or elimination of the reaction would confirm that chemistry was responsible, whereas a repeat of the reaction would have argued for biology. In fact, only carbon dioxide was given off in stage two, and at a reduced rate; the amount of oxygen present in the chamber declined. Similar results were obtained from the gas-exchange experiment at the Viking 2 Utopia site, although rather less gas was given off.

Vance I. Oyama of NASA's Ames Research Center in California, the leader of the gas-exchange team, was quick to interpret the results from this experiment in terms of soil chemistry. Since Mars is a very dry world, the surface material in the test chamber was meeting copious water vapour for the first time in at least millions of years. Probably the water vapour was displacing carbon dioxide gas that had collected on the surface of the soil particles, thereby explaining the initial surge of carbon dioxide in stage one of the experiment. The oxygen production requires another explanation, involving the chemical nature of the soil. Evidently the surface of Mars is highly oxidized, and this abundant oxygen was being released in chemical reactions on contact with the water vapour during stage one: the decomposition of peroxides by water is known to proceed well in the presence of iron compounds, and there is plenty of iron oxide on Mars to catalyse such a reaction. The lower response of the soil at the Utopia site is presumably because there already exists about 2½ times as much water vapour in the atmosphere there than at Chryse.

In the second part of the test, when the soil was soaked with nutrient, the resulting depletion of oxygen was probably due to chemical recombination of the oxygen with ascorbic acid (vitamin C) in the nutrient. The continued production of carbon dioxide in stage two can be explained by further displacement of the gas from between the soil particles, or by oxidation of the carbon compounds in the nutrient by the highly oxidized Martian soil. The changes in nitrogen abundance can also be explained by chemical reactions. Therefore, the gas-exchange experiment tells us nothing about life on Mars, but it does provide important clues to the chemical nature of the Martian surface, and it also aids understanding of the results from the second experiment we shall discuss, the labelled-release experiment.

The labelled-release experiment also assumed that Martian organisms need the addition of moisture and some nutrients to aid their growth. A solution of seven simple organic substances, including the amino acids glycine and alanine, was injected into the Martian soil in the test cell. The carbon in the nutrients was radioactively labelled, and the gas above the soil sample was periodically monitored in the hope that any Martian bugs feeding off the nutrient solution would give themselves away by realeasing gas containing the radioactively-labelled carbon.

As with the gas-exchange experiment, results were immediate and electrifying: on injection of the nutrient into the first Chryse sample, there was a sudden and definite emission of radioactive gas into the chamber, resembling that displayed by biologically poor but nonetheless life-bearing terrestrial soils from the Antarctic. However, within a day the increase slowed down and then levelled out, remaining almost constant for five sols. Seven sols after the first injection of nutrient, a second dose was added. The overall effect was a drop in radioactive gas in the chamber, which then slowly climbed again. Could this be the first definite sign of life on Mars? One way to find out was to run the experiment again with a control sample that had been heat-sterilized to kill any organisms that might be present. So the test cell was cleaned out and a second sample introduced, which was heated to 160°C for three hours. Injection of nutrients into this heat-sterilized sample produced an entirely different response from before, one like that which had been obtained from sterile lunar soils in preflight tests on Earth: after a small initial peak, radioactivity fell away to the level of background noise, and even a second injection of nutrient failed to provoke a response. Whatever was causing the reaction had therefore been eliminated by the heat treatment.

This looked very good for Martian biology, although chemical reactions were by no means ruled out. A third trial run remained to be done to clinch the matter: if, over a long period of incubation, radioactive gas continued to be produced at an increasing rate, this would argue for the growth of Martian micro-organisms. Gas production from a chemical reaction, on the other hand, would tend to flatten out with time. A third soil sample was therefore tested at the Chryse site in the labelled-release experiment. This sample behaved similarly to the first sample after its first and second injections of nutrients;

then a third dose was added, and experimenters sat back to watch the results. Again, the addition of more nutrient led to a drop in radioactive gas, which then began to climb.

After a total incubation time of 60 sols, the radioactive gas had returned to its former level, where it seemed to remain constant. There was no sign of the hoped-for increasing rate of gas evolution that would have been a tell-tale sign of Martian life.

Two samples tested at the second landing site, Utopia, showed similar responses to the first and third Chryse samples. At Utopia, a sample was also subjected to heat treatment before incubation, but this time only to 50°C – not enough to kill all organisms had it been a sample of terrestrial soil, but vastly greater than anything that Martian bugs ever encounter. This so-called 'cold' sterilization led to a reduction by about half in the output of radioactive gas.

So what can we conclude from this experiment? Experimenters Gilbert Levin and Patricia Ann Straat noted that the results of the labelled-release experiment are consistent with a biological interpretation, although they also discussed possible chemical explanations. We must remember the similar sudden response of the gas-exchange experiment to the introduction of water and nutrient. Biologist Cyril Ponnamperuma of the University of Maryland was quick to point out a possible chemical explanation for the results of both gas-exchange and labelled-release tests, resulting from the highly oxidized state of the Martian soil; both experiments were probably measuring different aspects of the same chemical reactions between the injected nutrient and the Martian surface.

Probably what was happening in the labelled-release experiment was that formic acid (chemical formula HCOOH) in the solution was reacting with the hydrogen peroxide in the soil to produce carbon dioxide, which was the gas being detected by the radioactive counters, and water, which contained no radioactive carbon and thus went undetected. The drop in gas after subsequent injections of nutrient is explained by absorption of the carbon dioxide in the moist nutrient. It should be remembered that the reaction was not eliminated by heat treatment at 50°C as would have been expected if Martian bugs were the cause of the gas production – Martian organisms would not previously have encountered such a high temperature and should presumably have been damaged or killed by it, unless they are highly resistant to sudden elevated temperatures as well as to continual sub-zero ones. Therefore, although it must be admitted that the results of the labelled-release experiment are ambiguous, it seems that they can be adequately explained by chemical reactions, without recourse to the supposition of Martian micro-life.

Biology test three, the pyrolitic-release experiment, was designed to operate under conditions closely matching those on Mars, and thus might have been expected to give the most reliable clues to the existence of Martian biology. In fact, its results are the most complex and most difficult of all to explain in terms of chemistry. Nevertheless, it seems that these results are still not due to Martian biology.

In this experiment, also known as the carbon-assimilation experiment, a sample of Martian atmosphere was trapped above the soil sample in the test chamber. To this genuine atmosphere was added some radioactively-labelled carbon dioxide and carbon monoxide; any carbon from the atmosphere taken up by the soil, for instance by living beings, would be detected by its radioactivity. A lamp illuminated the test chamber with simulated sunlight; small amounts of moisture could be added to the soil if required, but no nutrients, thereby keeping conditions in the test chamber as Mars-like as possible. The main departure from conditions on the surface was that heat from the spacecraft kept the soil sample around terrestrial room temperature, considerably warmer than the sub-zero ground temperatures normally experienced.

The soil sample was incubated under simulated Martian conditions for 120 hours, then the soil was heated to drive off any carbon-containing compounds which would be detected by a radioactive detector. The first test at the Chryse site gave a positive response – not as strong as that from terrestrial soils, but positive nonetheless. Something in the Martian soil was fixing radioactive carbon from the atmosphere. A control test was then run, sterilizing the soil at 175°C for three hours before beginning incubation. Any living organisms in the soil should have been completely destroyed by this heat treatment; but the uptake of radioactive carbon did not completely cease. It sank to 10 per cent of its previous level, significantly higher than expected from a sterile soil. Whatever was causing the reaction was clearly affected by heat, but not so much as one would have expected for biological organisms.

A third test run at Chryse showed another positive result, although less pronounced than on the first run; the first Chryse sample turned out to have produced the greatest response of all the Viking pyrolitic-release tests at either site. One contributory factor might have been the ground temperature: the first Chryse sample was collected at 7 a.m. local time, as against 11.20 a.m. for the third sample when the ground temperature was 60°C higher.

In all, six pyrolitic-release tests were conducted at the Chryse site. Chryse sample four produced a response slightly higher than that of sample three. Sample five was heat treated to 90°C for two hours before incubation, which should have been sufficient to kill off any micro-organisms in the soil; but the carbon uptake of the soil was unaffected. Chryse sample six had water vapour added, but produced a similar level of carbon uptake to samples four and five.

At Utopia three pyrolitic-release tests were successfully conducted, two being performed without the light source switched on; one of these runs in the dark gave a positive result, showing that the existence of light is not essential for the reaction to occur. The second Utopia sample to be incubated in dark, dry conditions was taken from underneath a rock, and did not absorb carbon. One Utopia sample was incubated in the light with added water, but for some reason produced virtually zero response.

So what is the explanation here? According to pyrolitic-release experimenter Norman Horowitz and his colleagues, the fact that uptake of carbon by Chryse sample five was undiminished by heat treatment at 90°C, and the failure of sterilizing at 175°C to completely eliminate the reaction in sample two, argues strongly against a biological explanation. Differences in response between different unsterilized samples are probably due to differences in their composition. One significant factor may be their history of exposure at the surface: perhaps only surface material recently exposed to solar radiation can fix carbon from the atmosphere. Even so, as of early 1978 a convincing chemical explanation for the reactions had not emerged, although attempts were being made to simulate the pyrolitic-release results with synthetic Martian soils.

In discussing the possibility of life on Mars, we must take into account the results from a fourth Viking experiment which, while not strictly concerned with biology, is an important adjunct to the three biology experiments. This is the gas chromatograph mass spectrometer (GCMS) which analysed the soil for the presence of organic compounds – that is, compounds containing carbon, the basic constituent of life as we know it. The search for organic molecules is important because it provides information on the composition of Martian organisms, their food, and the products of their decay.

A total of four soil samples was studied by this instrument, two at each site. Each sample was heated to drive off gases, which were analysed according to their weight. On heating to 200°C, carbon dioxide was given off; with further heating to 500°C, oxygen was given off as well. No organic compounds from the soil were detected at either site.

This failure to detect organic material on Mars has caused considerable surprise. Tests with an identical GCMS on Earth showed that it is sensitive enough to detect organic material in soils from the Antarctic, and even the traces of organic compounds present in meteorites. Since meteorites regularly land on Mars, many scientists had expected that traces of organic molecules from these would have shown up in the GCMS results. The answer seems to be that the organic matter from meteorites is so thoroughly mixed up in the Martian soil that it becomes too diluted to be detected by the GCMS.

Organic compounds would also be expected to be synthesized on Mars from the carbon of its atmosphere by the action of ultraviolet light. But ultraviolet light can break up molecules as well as produce them, particularly in the presence of oxides like those on the Martian surface. The results from the GCMS show that, if organic compounds are produced at all on the surface of Mars, they must be broken up just as quickly as they are formed.

Although the GCMS is sensitive, a small population of Martian micro-organisms could still exist in the soil and go undetected – for instance, the amount of carbon fixed by the pyrolitic-release experiment, enough to support a few hundred bacteria, would be below the level of sensitivity of the GCMS. But pre-flight tests with samples of biologically poor Antarctic soil have shown that there is 10,000 times as much organic matter in the form of debris in the soil than there is in the bodies of organisms that live in the soil. This debris provides food for the organisms and consists of the remains of dead bodies. But the negative results from the GCMS show that no such level of organic debris exists in the soil of Mars. Therefore, GCMS experimenter Klaus Biemann and his team conclude that organisms based on terrestrial biochemistry are unlikely to exist on Mars unless they are *very* much more efficient at scavenging organic debris than organisms on Earth.

The GCMS results help underline the message of the Viking biology experiments: Mars is not teeming with life. In all, a total of 26 experimental tests were carried out on Mars by the two Viking landers, twice as many as anticipated, in an attempt to clarify the problem of whether or not there is life on Mars. The red planet turns out to be frustrating for biologists – it is so nearly favourable for life, but not quite. I am reminded of an old cartoon depicting the return to Earth of the first astronaut to visit Mars. He is besieged by reporters clamouring to know: 'Is there any life on Mars?' He replies: 'There's a little on Saturday night, but it's pretty dull for the rest of the week.' Likewise, Viking is telling us that, from the point of view of life, Mars is pretty dull right now.

Although it is fair to say that Viking did not discover life on Mars, the possibility of Martian biology cannot yet be completely ruled out. For one thing, the Viking biology experiments were limited in scope; a small population of lifeforms might exist that did not respond to the Viking biology experiments. As Viking chief biologist Harold Klein has put it, looking for life on Mars is like fishing in an unknown lake with several different types of bait; perhaps Viking used the wrong bait. Alternatively, a much larger population of organisms might exist at more favoured locations, such as around the polar caps. Whatever the case, it is certainly true that Mars does not contain an abundant terrestrial-type biota at the Viking landing sites in Chryse and Utopia.

What of the future? A number of plans have been suggested for future exploration of Mars, although nothing has been decided as of this writing. The simplest plan, a straight repeat of Viking with new biology experiments, does not find much favour. A better idea might be a Mars rover, similar to Viking but on caterpillar tracks so that it can be steered around on Mars in search of the most interesting sites to examine. Another suggestion is the Mars surface penetrator, a long and pointed instrumented package that parachutes to the surface of Mars at high speed, burying itself several metres into the ground to analyse the subsurface composition and to sense Marsquakes. Such a surface penetrator would probably be dropped from a Mars orbiter.

Most exciting of all, though, is a Mars sample return mission – actually bringing back soil from Mars by an automatic vehicle like the Soviet lunar landers which have automatically returned samples of Moon soil. Perhaps only in this way can we finally answer the question about life on Mars. A modified Viking could be sent to the surface of Mars, scoop up a sample of surface material, and feed it into a return capsule which blasts off for the journey back to Earth. Such a mission was strongly favoured by a US National Academy of Sciences report on post-Viking biological investigation of Mars published in 1977. Although technically possible, a Mars sample return is unlikely to take place until 1990 at the earliest.

And even if there is no life on Mars today, we will eventually put life on the planet. Men will one day stand on Mars, although that is going to be such a difficult and expensive undertaking that no one can tell when it is likely to happen – certainly not before the turn of the century. A summer study at NASA's Ames Research Center in 1975 considered the possibility of making Mars fit for human habitation – that is, engineering the planet so that it had free oxygen, water, and a bearable climate.

Such an adventurous piece of planetary engineering could be accomplished by seeding the planet with ultraviolet-resistant bugs which would break down the carbon dioxide atmosphere to produce free oxygen. But it would take 100,000 years to make Mars habitable in this way. An alternative is to warm Mars up by increasing its absorption of sunlight. This can be done by decreasing the reflectance of its polar caps, either by planting vegetation on them or by sprinkling dark dust over them. The extra heat absorbed as a result of this treatment would vaporize the polar caps, increasing the density of the atmosphere, melting the permafrost under the surface of Mars, and producing a habitable environment. Even so, this new climate might still not become stable for 10,000 to 100,000 years. We might reduce this timescale by bioengineering a super-microbe capable of a vastly improved rate of photosynthesis, and we could artificially pump more heat into the polar caps to increase their rate of evaporation.

But that is far into the future. In the meantime, let us turn towards some more readily attainable goals.

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5

LIVING OUT THERE

Colonies in space have been a dream of mankind since the time of the Soviet space prophet Konstantin Tsiolkovsky, who in an 1895 science fiction story, 'Dreams of Earth and Heaven', visualized what we would now term a space station orbiting the Earth. Tsiolkovsky went further in his 1903 book *The Rocket into Cosmic Space*, introducing the idea of spinning the station to provide artificial gravity, and using sunlight for power. He and his readers felt the lure of living in space, and recognized the promise of new freedom that it afforded. Now, we are ready to take those first few steps that may lead to mankind's eventual colonization of the Galaxy.

Since Tsiolkovsky's work was little known outside Russia, impetus for space-station studies in Europe came from the German spaceflight pioneer Hermann Oberth who in his small but influential book *The Rocket into Interplanetary Space* published in 1923 envisaged the use of manned stations for observing the Earth and heavens, as well as bases for constructing and refuelling a spacecraft in orbit. Hermann Noordung (the pen-name of an Austrian army captain named Potocnik) in 1929 proposed a wheel-shaped station spinning to provide gravity, an idea which sounds very familiar today. Noordung's wheel was 100 ft in diameter and carried large mirrors to focus sunlight to provide power. In 1951, Wernher von Braun designed a larger wheel-shaped station built in orbit from prefabricated sections. This concept was widely publicized, and from then on the whole idea was up for graps.

For instance, Dandridge Cole in 1963 envisaged hollowing out an asteroid to create living space. Arthur C. Clarke in *A Fall of Moondust*, 1961, pointed out the advantages of the gravitationally stable Lagrangian points in the Moon's orbit as locations for space stations. The idea of building giant cylinders in space, 1 km long and 300 m in diameter, to provide living space for up to 20,000 people, was broached in a daring 1956 proposal by Darrell Romick.

These speculations lay around like prefabricated components awaiting assembly into a coherent whole when in 1969 Princeton physicist Gerard K. O'Neill realized that not only was space colonization technically feasible within our lifetimes, but that it had strong merits which made it highly worthwhile. Since then, colonies in space have beckoned as the next major goal once the Space Shuttle transportation system is in operation. Beyond that, space colonization (or, as O'Neill terms it, the 'humanization' of space) has major implications for interstellar travel and communications – both by us and by any other civilizations that may exist. In looking at space colonies we may be seeing the genesis of manned starships and of space communication bases.

O'Neill's interest in space colonization began by chance at a seminar for a first-year Princeton physics class. O'Neill is a high-energy physicist, noted for his invention of the storage ring technique for increasing the collision energies of atomic beams from particle accelerators. His imagination had already been caught by the opportunities of space – in 1966 he applied as a scientist-astronaut for the continuing programme of space science that NASA was then planning. But that programme was cut back in 1967 just before the final intake of new astronauts was selected, and O'Neill remained at Princeton. There are no regrets, as he explained to me in an interview for *New Scientist*: 'I don't think that any of the things I could have done as a scientist-astronaut would have made nearly as much of a contribution as I can hope to make with the humanization of space.'

His attempt to make physics relevant on a wider scale in the face of the apparent disillusionment with science in the late 1960s led to that 1969 physics seminar at which he set his class the question: Is a planetary surface the right place for an expanding technological civilization?

The answer, it soon emerged, was No. The surface areas of the Moon and Mars, for instance, would no more than double the available land area of Earth, and of course their environments would need to be radically engineered to be suitable for life. These limitations do not apply to an enclosed colony in free space.

There are three basic shapes for a colony rotating to provide gravity: a wheel, a sphere, or a cylinder. O'Neill's group felt that a wheel was more appropriate for a space station than the mini-worlds of which they were thinking. This left the cylinder as the best choice, for it has the maximum inner surface at full artificial gravity – in the sphere, gravity falls off as the sphere curves in towards its rotation axis. Rough calculations of mechanical strengths soon showed that cylindrical colonies could be built with diameters of several kilometres, offering enough land area to support millions of people. The colonies would be constructed of materials mined from the Moon. They would be heated and illuminated by sunlight reflected in through large windows by mirrors on the outside. Eventually, using the asteroids for new building material, it would be possible to construct enough colonies to provide for 20,000 times the Earth's current population.

Fascinated by now, O'Neill continued the study in his spare time. He quickly saw the possibilities of providing pleasant living conditions without the problems of pollution, overcrowding, food shortages, and energy crisis that mar our technological age on Earth. Immediately, the stifling Limits to Growth philosophy, which predicted gloom and doom for our technological future, was seen to be undermined by the opportunities of space – the very enterprise which many Limits to Growth supporters criticized as the most wasteful and irrelevant of all.

These utopian possibilities quickly attracted a following on the college circuit as O'Neill lectured about his ideas. With some supporters, he held a modest conference at Princeton on space colonization in May 1974. In September 1974, the magazine *Physics Today* published an article by O'Neill outlining his proposals which other magazines had dismissed as little short of science fiction. The response from scientists and public alike was immediate and positive.

It became apparent from that first Princeton conference that there were no insuperable technological obstacles to building the colonies, if we so wished, by the turn of the century; all that was needed was a commitment. But why should we build space communities? What would be the economic return that would make investment in them worthwhile?

At the end of 1974, with the feasibility of the space-colony concept secure, O'Neill began to consider the possibility of using his colonies as construction bases for the satellite solar power stations proposed several years earlier by Dr Peter Glaser of the Arthur D. Little company of Cambridge, Massachusetts. Each solar power satellite would produce 10,000 megawatts, enough to power a city. In geostationary orbit around the Earth, these satellites would collect sunlight via solar panels, turn it into microwaves (short-wavelength radio waves) and beam it back to receivers on Earth where it would be converted into electricity. In an experiment to test this technique, a bank of 17 lamps was lit by a microwave beam of 30 kilowatts power transmitted across one mile from the 26 m NASA tracking dish at Goldstone, California.

An alternative to collecting sunlight with solar cells is the approach of Gordon Woodcock and Daniel Gregory of the Boeing Aerospace Co., who have considered using sunlight as a heat source to drive gas turbines, which generate the power that is beamed back to Earth in the form of microwaves. A turbine-powered satellite may be more readily constructed than the version using solar cells envisaged by Peter Glaser, because the silicon crystals of solar cells are both expensive and intricate to make – that's why they have not already displaced traditional power sources on Earth. Cheaper and simpler solar cells are on the way, but they may never be competitive with turbine-generated electricity, either on Earth or in space.

The advantage of placing solar power collectors in orbit is that sunlight in space is at least four times as plentiful as at the sunniest places on Earth. In space, the Sun never sets, and there are no interruptions due to bad weather. Sunlight seems the ideal energy source, because it is clean, endless, and free – apart, that is, from the cost of harnessing it. Solar power satellites have the drawback that they are large and heavy, which would make them expensive to launch from Earth. But with an O'Neill colony there are no launch costs, because the space colonists build the power stations in space using the same techniques as they used to build the colonies themselves. They then sell the electricity to Earth.

The whole economics of satellite solar power stations is therefore transformed, as O'Neill reported in the magazine *Science* in December 1975. He noted the enormous potential market for electricity in the US, where it is estimated that around 100,000 megawatts a year of new generating capacity will be needed by the year 2000. Building power stations on Earth to meet such demand will require investment of several hundred thousand million dollars, and the environmental threat from such a profusion of new power plant, coal-fired or nuclear, is itself alarming. Solar power from orbit not only has environmental advantages, in the long run it will be cheaper than building power stations on Earth.

A rough estimate of the total outlay to produce the first space colony which will start building power satellites is 100,000 million dollars. That first colony will be under construction for six years or so, and the first 10,000 megawatt power satellite will come into operation one to two years later. More colonies will then be built, which will produce their own power satellites, so that the enterprise becomes self-perpetuating without further help from Earth. Thirteen years after the start of the project, the power satellites could be supplying sufficient energy to meet the US annual need for new generating capacity.

To ensure market penetration, the electricity must be competitively priced. O'Neill assumes a starting price of

1.5 cents per kilowatt hour, equivalent to the lowest-cost electricity currently available in the US, which comes from nuclear reactors. This price would be progressively dropped so that solar power satellite electricity was by far the cheapest available. Even at these low rates, after 24 years the whole project will have paid itself back, and be returning handsome profits.

Solar power from space thus appears to be an attainable and desirable solution to our energy crisis. If the economic and technical arguments stand up to scrutiny, then the colonies will certainly be built. Once the colonies are in existence, of course, their other advantages such as sites for materials processing and space industrialization, as a jumping-off place for the rest of the solar system, as an astronomy platform, and simply as a desirable place to live, would come as an added bonus. NASA has been sufficiently impressed to fund O'Neill's research since 1975.

O'Neill originally envisaged his first colonies as small cylinders, 1 km long and 200 m wide, spinning three times a minute to provide Earth-normal gravity. For stability, the cylinders would be linked in pairs, rotating in opposite directions: they must be kept with their long axes oriented towards the Sun. As many as 10,000 people could be housed in the first colony. Once this is set up, its occupants provide the workforce for building new and larger models, pairs of cylinders up to 32 km long and 6.4 km in diameter, with space for millions of people. O'Neill foresaw that the colonies would be established at the gravitationally stable Lagrangian points of the Moon's orbit. As seen from Earth, these lie 60° ahead of land behind the Moon, and are known as L4 and L5 respectively. These are the points at which the gravitational effects of the Earth and Moon exactly cancel, as calculated in 1772 by the French mathematician Joseph Louis Lagrange. Highly complex calculations performed by computer in 1968 showed that the additional gravitational effects of the Sun destroyed the stability of these theoretical points, but replaced them with something at least as good: stable kidney-shaped orbits centred on L4 and L5, along which a colony would take 89 days to travel. There is room on each orbit for thousands of colonies, so the situation is actually better than if we were stuck with L4 and L5 alone.*

Apart from their stability, the areas at L4 and L5 have the advantage that they are seldom eclipsed by the Earth, and they are easily reached from the Moon's surface, which is where the construction material will be mined. The vital knowledge, without which the colonization concept could not have got underway, was the chemical composition of the Moon, as revealed by the samples brought back from the Apollo missions. It turned out that the Moon is surprisingly rich in aluminium, titanium, and iron; it is from these metals that the colonies will be built. There is also plentiful silicon, which will be used for the glass of the colonies' windows, and abundant oxygen, which will serve both to make an atmosphere and also as a rocket fuel. Lacking in Moon rock is carbon, nitrogen, and hydrogen, which will initially need to be brought from Earth, but will eventually be obtained from asteroids.

A mining team of perhaps 150 men will be located on the Moon with bulldozers and scoops, probably on the south-eastern Mare Tranquillitatis, where they will scrape up and shoot into space a million tons of lunar topsoil a year. Even a generation of digging will not produce a crater large enough to be seen from Earth. It is not a rocket that propels the lunar material into space, but a device called the mass driver, which uses the technology developed for magnetically levitated trains. Parcels of lunar soil are fitted into so-called buckets, which are then accelerated along a guideway by magnetic fields at 100 g to the escape velocity of the Moon, 2.4 km/sec. The bucket shoots out from the end of the track and is in free flight, where its trajectory is checked by laser beams

* There are three other Lagrangian points, one behind the Moon as seen from Earth, one between Moon and Earth, and one on the opposite side of Earth from the Moon.

and is corrected if necessary by magnetic impulses. Then the bucket enters another section of track where it is rapidly decelerated, allowing the payload to shoot out into space. As the payload curves away from the Moon the bucket is ferried back to the starting point many kilometres away for reloading. A model mass driver with an acceleration of 35 gravities was demonstrated at the third Princeton conference on space manufacturing in May 1977; models with greater performance have since been developed.

Two payloads will be launched each second. After two days' flight through space they will reach L2, the Lagrangian point 64,000 km beyond the Moon as seen from Earth. Here the parcels of Moonstuff will be caught by a rotating bag made of Kevlar fabric, the synthetic material used for bullet-proof vests. When full, the catcher moves off to the colony site where the ore processing plant is waiting to reduce the precious lunar material into metal and glass for construction.

In addition to O'Neill's yearly Princeton conferences, NASA has held a number of summer studies at the Ames Research Center, California, to examine the space colonization concept. At the second of these, in 1976, it was realized that the L4 and L5 Lagrangian points might not after all be the best locations for the first colonies. A high Earth orbit, two-thirds of the way from the Earth to the Moon, now seems as good a location as any; it is easier than L4 and L5 to reach both from L2 and the Earth, and it would also be easier to deliver power satellites from there to geostationary orbit. This discovery was somewhat embarrassing, for the L5 location in particular had become closely associated with O'Neill's vision – a grassroots organization formed to support O'Neill's space colonization aims has styled itself the L5 Society. But the large, primarily residential colonies foreseen by O'Neill may yet be stationed at L4 and L5.

The first NASA summer study, in 1975, had also led to a revision of ideas about the shape of that first colony. Whereas O'Neill had been thinking in terms of small cylinders that would need to rotate three times a minute to provide Earth-normal gravity, a medical student named Larry Winkler maintained that such a speed of rotation would produce motion sickness in the occupants; a rotation rate of one revolution per minute was the maximum he considered allowable. A cylinder shape was still acceptable for the largest colonies, capable of housing millions of people, because they would need to rotate at only 1 r.p.m. or less to simulate Earth gravity. But in the case of the small first colonies, the occupants would either have to be specially selected to withstand motion sickness, or they would have to put up with a slower spin that gave them less than Earth gravity. Or the colony would need to be redesigned.

The greater the diameter of a colony, the slower it need spin to simulate Earth gravity, so the 1975 summer study participants looked again at wheel-shaped designs and came up with a concept that was dubbed the Stanford torus. This was a ring like a bicycle tyre, 1.8 km in diameter; the tyre tube itself, inside which the 10,000 colonists live, is 130 metres across. The torus rotates once a minute to provide Earth-normal gravity on the inside surface of the tyre rim. Docking ports for arriving spacecraft are situated at the station's hub, from where passengers transfer to the outer ring along spoke-like corridors. At the hub, gravity is virtually non-existent because the rotational forces are so low. Here would be the station's main recreational area, in which the inhabitants could experience the delights of low-gravity living, including human-powered flight. Attached to the hub by transfer tubes are the manufacturing areas of the colony, where space freighters will unload their cargoes of lunar materials to be processed into the metal tubes, girders, and panels for building the power satellites that govern the colony's economy.

Unlike an O'Neill cylinder, whose rotation axis is aligned towards the Sun, the axis of the Stanford torus points at right angles to the Sun. Above the colony, opposite the manufacturing areas, hovers a giant mirror a kilometre or so across, angled at 45° to reflect sunlight down on to the colony. A second set of mirrors around the hub reflects the light into the torus; tilting these mirrors up and down produces the effect of day and night. To the inhabitants of the colony, who would have their feet on the outer rim of the torus, sunlight would appear to come from overhead.

O'Neill, though, preferred to forge a compromise between the lower recommended rotation rate and his favoured colony shape. He rejected the Stanford torus design; for the 10,000-inhabitant Island One, as it became called, he suggested instead a 460 m diameter sphere, rotating twice a minute to give Earth-normal gravity at its equator. This is the design that has been widely illustrated and is sometimes referred to as a Bernal sphere, after the Irish scientist J. D. Bernal who foresaw the construction of 'space arks' for space colonization. Gravity on the inner surface of a spinning sphere falls off towards the axis of rotation, so most of the human habitation will be in the equatorial region. Soil from the Moon will coat the inner surface of the colony. Around the equator, a river may meander.

If Island One is made of an aluminium shell, the thickness of the sphere will vary from a maximum of about 18 cm at the equator to 5 cm near the rotational axis. Since the gravitational stresses are least near the axis, that will be the best place for the windows. There will be a ring of windows around the axis at each end of the sphere, but they will not look out directly into space; instead, they will be surrounded by a circular mirror which deflects sunlight inside.

Agriculture is carried on in areas at the ends of the sphere, surrounding the docking ports on the axis of rotation, while the industrial regions are entirely separate, reached by commuter ships. All power for the colony is supplied by an on-board solar power station.

Whatever the shape of Island One, or wherever it is eventually located, one thing is clear: construction will not begin until considerable experience has been gained in living and working in space via the Space Shuttle, the re-usable space transportation system due to come into full-time operation in 1980. According to current NASA plans, the Shuttle will probably be used in the mid-1980s to establish a full-scale space station, far more impressive than the makeshift Skylab of 1973-4. Although it is too early to be sure exactly what such an interim station would look like, it will probably be made from individual units that plug together, and could house up to 200 people. The experience in space industrialization gained through such a station would be an essential stepping stone to O'Neill's space colonies, which could begin to dot the sky like faint new stars between the years 1990 and 2000.

Even 200 men, though, will not be enough to build the first space colonies. Before Island One can begin to take shape, we would need to set up an industrial facility, colloquially termed the construction shack, containing a workforce of perhaps 2000, who would process the lunar ores fired into space. For the workers in the construction shack and the lunar colony, life will be rather like that on an offshore oil rig: hard and monotonous, and perhaps hazardous. Room will be at a premium, for these initial structures will need to be delivered into space from Earth. One proposed design foresees the shack as a sphere 100 m in diameter. It would need to contain rolling mills and casting beds to produce the metal sheets and cables required for the construction of Island One and the first satellite power station. Its total weight might be 10,000 tons; a similar weight of material might need to be delivered to the lunar surface to set up the first mining base. In addition to these materials, there will also be many thousands of colonists requiring transport into space.

Even the modern Space Shuttle is too small and too expensive to cope without adding considerably to the space colonization budget. What is needed is a still larger and more economical launcher, termed the Heavy Lift Launch Vehicle (HLLV). Various studies based on an extension of the current Shuttle system or even a re-usable version of the Saturn V first stage show that although such launchers may take several billion dollars to develop they will still be worth it: launch costs make up the major part (perhaps 60 per cent) of the 100 billion dollars estimated for the total colonization scheme, which is about three times the cost of project Apollo at current prices. Without the new vehicles, the colonization cost will be almost doubled. Nevertheless, the need to develop them so soon after the introduction of the Shuttle may be a political stumbling block to space colonization. So would the frequency of launches: one a day for several years, which is considerable for a spaceport although trivial in comparison with aircraft movements.

One of the dangers to the workers in the construction shack will be radiation damage. The walls of the shack can be shielded to exclude most cosmic rays, but every so often flares erupt on the surface of the Sun, spewing out beams of radiation strong enough to kill a man. The construction shack workers will then have to retreat to lead-lined flare shelters for a day or so until the danger is past. But what about the colonies themselves? Many people assume that long-term exposure to radiation and the chances of meteorite impact will make living in space unacceptably hazardous.

It turns out that radiation can easily be screened out, by surrounding the colonies with soil two metres thick. For the Stanford torus, 10 million tons of shielding will be required; the Bernal sphere has a much smaller surface area and would require only one third as much shielding mass, which is another reason for favouring it. These figures compare with a mass of half a million tons for the colony structure itself. In either case, the shielding will be nothing more glamorous than the slag left over from industrial processing of the lunar soil, and so will not require to be sent up specially from the Moon. Only the window openings present a problem; they must be shielded from a direct view of space by the angled mirrors that reflect light into them. In the case of the largest colonies, the giant cylinders of O'Neill's grandest vision, the thickness of the cylinder structure and the depth of atmosphere will be sufficient in themselves to absorb cosmic ray particles without further shielding. Thus, space colonists in all sizes of habitat can live as safe from radiation as people on Earth.

Meteoroid damage will be more of a problem, but it will not be the catastrophe one might instinctively guess. Most meteoroids are so small that they would have little more than a gentle sandblasting effect on the outer skin of the colony, while many of the larger ones are so fragile that they would break up on impact like clods of soil – most of the meteorites that encounter the Earth never survive the passage through the atmosphere. The thick cosmic-ray shielding of the early colonies will also serve to absorb meteorite impacts. In the largest colonies, which will have plentiful window areas, glass panels will probably be broken every few years by meteorites of around 100 grams weight. Since the panes of glass will be similar in size to those in domestic windows, leakage will be slight: loss of one window panel in a large colony will lead to complete decompression over many years, which gives repair teams plenty of time to patch the leak. Meteorites weighing a ton or more, capable of punching a large hole in the shell, will be encountered every few million years, so that space colonization will be less hazardous than most other forms of human activity.

Everything about a space colony will be exotic, including its interior. O'Neill imagines that Island One might be given a tropical climate like that of Hawaii – colonies can control their temperature by regulating the amount of sunlight they allow inside. Tests on Moonsoil have shown that plants grow very well in it, with the addition of water and nitrates, so there would be plentiful vegetation in the colonies – trees, bushes, and attractive flowers. Gardeners will not be troubled by weeds or pests because these will be left behind. Strict regulations will prevent the import of undesirable parasites and diseases.

Despite the projected population for Island One, the inside area of the sphere is so great that there will be ample room for everyone. Building materials will be bricks cast from slag, metal extracted from lunar soil and glass made from the silicon which is abundant in the lunar crust. Therefore apartments and houses in the colonies will consist of much the same materials as in modern buildings on Earth.

Occupants looking out from their apartment or garden in Island One will see the sphere curving away on all sides. Trees, buildings, and people would jut out at the horizontal up the sides of the sphere and appear to hang upside down on the opposite side of the sphere, 460 metres overhead. As you walked uphill to the rotation axis, you would feel lighter as the effect of artificial gravity diminished. At the axis itself you would be weightless; here would be the low-gravity swimming pool, and from here the high-fliers of the colony would launch themselves into the air to attain man's dream of human-powered flight.

Atmosphere, water, and food are the prime requirements of any colony. Many people assume that the colonies must be regularly supplied with consumables from Earth, but this is not so. Each colony will be a mini-Earth, with its own closed ecological system. Wastes must be recycled while plants will remove carbon dioxide and replenish oxygen; other air-freshening will use the same techniques as in submarines. Water will at first be made by combining hydrogen brought from Earth with oxygen released from the Moon's crust, but eventually other sources of hydrogen will be found – notably the asteroids. Since most of the Earth's atmosphere is nitrogen which is not important for our breathing, atmospheric pressure in the colonies can be reduced without danger. Apollo astronauts, for instance, breathed pure oxygen at a pressure one-third that at sea level. In the colonies, some nitrogen will be mixed with the oxygen to bring up atmospheric pressure to half that at sea level on Earth.

Agriculture in the colonies will actually be easier than on Earth. Farm areas will be kept separate from the living areas, so that their conditions can be tailored to the crops being grown. Since the climate can be controlled, the growing season would be continuous. One estimate is that a colony of 10,000 people can be supplied amply by 100 acres of agricultural area. There will be cereals, fruit, and vegetables. Goats will provide milk, and for meat the most efficient source would be rabbits and chickens. Fish should also be easy to rear in space. Steak will literally be rare at first in the colonies, because cattle are both heavy and inefficient at using feedstuffs. Eventually, though, popular pressure will lead to the introduction of a wider selection of farm animals.

Good though the living will be in Island One, and its sister worlds in space, it will still fall short of the ultimate possibilities of the largest colonies. Once the return from the power satellites has put space colonization on an economic footing early next century, attention will be turned towards building the second-generation colonies. Various nations may wish to design and place orders for their own versions. Plausible designs would be a larger Bernal sphere, 1800 m in diameter, or a cylinder 3.2 km long and 640 m diameter, both capable of housing over 100,000 people. By the middle of next century the time may be right for Island Three, the very largest colonies of all, housing millions of people in cylinders 32 km long and 6.4 km in diameter spinning every two minutes (the largest cylinders that could be built within the physical strength of materials are 120 km long and 24 km in diameter, but it is unlikely that the engineers would want to go so far). With colonies the size of Island Three it would be possible to provide new living area at a rate faster than the growth of population on Earth.

Down the length of each cylinder would run three strips of land, alternating with three strips of window. Opposite each land strip would be a window, through which sunlight would be reflected by a longitudinal mirror outside the colony. Tilting and turning these mirrors will give reassuringly familiar impressions of sunrise and sunset during each day. Even more Earthlike, in cylinders of such size the sky appears blue, and clouds form at around 1000 m altitude. There will be rainstorms and a small but definite variety of weather from day to day.

Whereas the first colonies would serve primarily as bases for power satellite construction workers and for scientists, the larger colonies are seen as permanent habitats for humans. Whole families will move permanently to the colonies in search of new opportunities, like the flood of immigrants to America in the last century. Not only will the colonies offer high living standards in an attractive, pollution-free environment; they will also offer freedom.

Residential colonies will demand a much greater variety of foodstuffs than would be available in Island One. O'Neill suggests that there should be a ring of smaller agricultural cylinders which can be adapted to provide abundant food of all kinds. Unless diseases unexpectedly invade agricultural cylinders (in which case the cylinder will be closed and sterilized) there will be no chance of crop failure, so that food will be more abundant than on Earth.

Of course, we must expect problems. Will the moisture in the atmosphere condense on the colony windows? What unexpected ecological effects will arise in the artificial biosphere? Will there be corrosion and fatigue like in bridges and aircraft? What will be the political relationship between the colonies and Earth as they become increasingly independent? What, above all, will be people's response to living in an enclosed environment? Space living may suit only a small proportion of humanity.

As the number of larger colonies grows, the smaller ones may be refurbished for special uses. For instance, they might be occupied by scientists carrying out dangerous experiments such as in genetics that require total isolation; or social groups may take colonies over for experiments in community living. Zero-gravity laboratories at the axes of the colonies could make astounding developments in physics, medicine, or metallurgy, generating further valued income for the colonies. Space colonies are likely to become the scientific mecca of the next century. Astronomers will be fighting to set up large telescopes in the colonies to observe the Universe free of the blurring effects of the Earth's atmosphere. One colony, equipped with giant radio telescopes, may become the headquarters of the search for messages from the stars. Another might be adapted as an interstellar spacecraft.

We need not despoil the Moon to build these additional colonies. We can instead use the raw materials contained in asteroids, many of which are believed to offer the hydrogen, nitrogen, and carbon that is missing on the Moon. Although it would require considerable energy to bring back an asteroid from the main belt between Mars and Jupiter, a select group of asteroids have orbits that bring them close to Earth. There may be 100,000 asteroids larger than 100 m diameter that pass suitably close to Earth. Astronomer Brian O'Leary of Princeton has calculated that an Earth-approaching asteroid 200 m across weighing 10 million tons, containing enough material to build 10 satellite solar power stations, could be retrieved at a cost no more than half, and perhaps as little as one-tenth, that of bringing the same mass up from the Moon. Many asteroids – the carbonaceous chondrites – are rich in complex hydrocarbons, which the space industrialists can use to make plastics. Eventually, the major manufacturing industries of Earth will be forced to move out into space where raw materials are so much more plentiful.

It will not be many decades before colonies are set up elsewhere in the solar system. With a suitably modified mirror system, O'Neill colonies could function on incident sunlight out to the orbit of Pluto. Beyond about three light days from the Sun, the light becomes too weak to use without impracticably large mirrors. But with a nuclear power system on board, the colonies could travel through space as self-sufficient interstellar arks.

This is the real, long-term significance of the space colonization programme. Not many years after the first colonies have been set up they will be totally independent of Earth. Even if some disaster should totally eradicate life on Earth, they would be able to carry on. The colonies thus act as a lifeboat for humanity, effectively making mankind as a species immortal. And once mankind has made this first breakout into space, interstellar travel – even colonization of the Galaxy – follows naturally.

The question is: since that first breakout into space can occur so readily, with even our relatively primitive level of technology, has it happened elsewhere? And if so, where are they?

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6

OUR FIRST SHIP TO THE STARS

Less than twenty years after the orbiting of the first Sputnik, four probes to the outer planets had been launched – Pioneers 10 and 11, and Voyagers 1 and 2 – that will eventually leave the solar system and drift dead and dark among the stars millions of years hence. They each carry messages for any civilization that may intercept them – see Chapter 8. Therefore we already have the ability to reach the stars, albeit slowly. When the Pioneer and Voyager probes leave the solar system they will be travelling at 17 km/sec, faster than any object before them. But even at that speed they would still take the best part of 80,000 years to reach Alpha Centauri.

The O'Neill colonies described in the previous chapter could act as habitats for long-duration manned interstellar missions, like the space arks of science fiction. But they, too, would provide a very slow boat to the stars. Can we hope to reach the stars inside a human lifetime? And, if so, when might it be possible?

These questions have been addressed by a 12-man, and one-woman, team of engineers, physicists, and astronomers from the British Interplanetary Society in a design study called Project Daedalus. Their aim was to design an unmanned craft, based on the technology likely to be available by the turn of the century, that could fly to Barnard's star within about fifty years. Barnard's star was chosen as a target because of its high probability of having planets, although there is nothing to stop the probe being sent instead to other nearby stars. In fact, there could be a whole fleet of Daedalus craft built to examine the Sun's stellar neighbourhood. The four-year Project Daedalus design study, which terminated after more than 10,000 man-hours of work in April 1977, proved that it would theoretically be possible to send unmanned probes to the nearest stars, and get back information, within the next century.

Because stars are so far apart, it is a basic fact of the Universe that interstellar missions must always last longer than missions to the planets of our own solar system. Even if our own probes could travel at the speed of light, which theory says is impossible, we on Earth would still need to wait twelve years to receive results from Barnard's star – six years for the journey and another six years for the radio message to come back. In practice, interstellar journeys would be undertaken at considerably less than the speed of light, and so would take several tens of years to complete. Judged in this light, Daedalus is a very impressive prototype starship.

Daedalus makes no appeal to the mythical space warps or other inventions of science fiction to propel it across the yawning gulf to the stars. Rather, it uses the most powerful energy source currently available to man – hydrogen fusion, as in a nuclear bomb. If we can control fusion power, we have the practical answer to interstellar travel. At the moment, our only way of using such power for space travel is in a nuclear pulse rocket, which is the technique adopted for Daedalus, although future developments in fusion reactors may give us improved engines for starships.

Daedalus is a two-stage craft of enormous proportions, 230 metres long and 200 metres across at its widest, weighing 53,200 tons, all but a few thousand tons of which is propellants – bombs in the form of small spheres a few centimetres in diameter. For comparison, the Saturn V Moon rocket stood 111 m tall and weighed 3000 tons fully fuelled. Daedalus carries a very substantial payload, 450 tons, which is six times the weight of Skylab, the largest and heaviest spacecraft so far launched. Over half the Daedalus payload is taken up by 23 smaller sub-probes designed to examine the Barnard's star system and interstellar space en route.

Daedalus will not be built and launched from Earth, but will be constructed in space by the same industrial facilities as used for O'Neill's colonies described in the previous chapter. Daedalus's structural materials will be mostly aluminium, titanium and nickel.

The Daedalus team, led by Alan Bond and Anthony Martin of Culham Laboratories, Oxfordshire (working in their spare time, not in an official capacity) decided from the outset that of the possible nuclear reactions which could power the vehicle, the fusion of deuterium and helium-3 was the most favourable, because it releases considerable energy but unlike reactions between pure deuterium, or between deuterium and tritium, it does not yield neutrons which would otherwise have to be screened from the rest of the craft by heavy shielding. However, subsidiary reactions in the starship exhaust do produce neutrons – enough for anyone within 400,000 km to receive in excess of the safe human dose. Daedalus will therefore be taken a long way from the Earth before its engine is ignited.

One problem is that there is not enough helium-3 on Earth to make the 30,000 million tiny spherical bombs that would be needed – but there is sufficient helium-3 in the gaseous atmosphere of Jupiter to fuel millions of Daedalus starships. The Daedalus team foresee sifting the required 30,000 tons of helium-3 (a light isotope of helium) and 20,000 tons of deuterium (a heavy isotope of hydrogen) from the atmosphere of Jupiter using separation plants floated beneath balloons. Again, this would be within the capability of space industrialization next century, although it demonstrates that only a civilization with a solar-system-wide economy like that which follows establishment of the O'Neill colonies is likely to build and launch starships. A civilization begins interstellar travel once it has colonized its own solar system – by which time it will already be sending out messages to the stars (see Chapter 8).

Propellant bombs for the first stage of Daedalus are stored in six spherical tanks arranged in a ring around the vehicle's central core. The bombs are injected one at a time by a magnetic gun into the first-stage reaction chamber, a hemisphere 100 metres in diameter. Each bomb, a deuterium honeycomb filled with helium-3, is coated with a superconducting shell so that it can be shot into the reaction chamber by a magnetic wave travelling along a coil, which makes up the injection gun. To traverse the 50 m gap to the firing point in the correct time, the bombs are injected at a velocity of 13.75 km/sec, faster than the escape velocity from Earth.

At the ignition point in the reaction chamber the bomb is hit by high-energy beams of electrons fired from electron guns around the chamber rim. These heat and compress the bomb so that fusion reactions can occur, producing helium-4 and protons, and releasing energy equivalent to the explosion of 90 tons of TNT. Techniques like those envisaged for the Daedalus propulsion system are under development in laboratory experiments by fusion engineers, and the Daedalus designers are confident that electron-triggered fusion will be a practical source of power by the turn of the century.

Inside the reaction chamber is a conically shaped magnetic field set up by four superconducting coils around the chamber. The expanding fireball from each bomb momentarily squashes this magnetic field against the magnetically conducting shell of the reaction chamber, made of very thin molybdenum. The hot plasma from the explosion is then ejected by the magnetic field out of the reaction chamber, giving an exhaust velocity of 10,000 km/sec, several hundred times that of even the most advanced ion rockets currently under test.

A thrust structure transmits the propulsive force of each explosion from the reaction chamber to the rest of the craft. Around the reaction chamber's exit is an induction coil which extracts energy from the outgoing exhaust; this energy is then used to inject and ignite the subsequent bomb. Subsidiary power on board the probe, such as for cooling purposes and communications, is provided by four fission reactors of conventional type.

Although the 90-ton blast of each bomb would be considerable on Earth, when it comes to moving a large spacecraft like Daedalus it is nothing more than a pin-prick. Bombs are injected and exploded at a rate of 250 every second to accelerate Daedalus on its mission to the stars. Daedalus will thankfully be well clear of the Earth, probably out near Jupiter, before that nuclear pulse engine starts up.

The first stage of Daedalus is under power for two years, the fuel tanks dropping off as they are emptied. Eventually, the entire first stage is discarded and the second stage takes over. This operates in a similar way except that its reaction chamber is only 44 metres in diameter. After another 1.8 years the second-stage engine shuts down, and Daedalus begins its coast towards Barnard's star at 12.2 per cent of the velocity of light – over 130 million km/h. One of the second stage's five fuel tanks remains attached to the vehicle for any necessary midcourse corrections.

From engine ignition to encounter with Barnard's star takes 49.2 years. Once on its way, Daedalus is entirely independent of Earth, and controls itself by a powerful computer housed in a central core running through the payload. This computer will have to think for itself, navigating the craft across interstellar space, planning the encounter with Barnard's star, checking that everything is satisfactory on board, and finally communicating the results back to Earth. One important realization from the Daedalus study has been that much interstellar exploration will be done not by biological creatures but by intelligent machines.

During its cruise, Daedalus navigates by reference to the stars, notably Alpha Centauri which will appear to change in position by 60° between the Sun and Barnard's star. With suitable midcourse corrections, the navigation team hope to be able to aim Daedalus to within one astronomical unit (the distance between the Earth and Sun).

Impacts by tiny dust particles in space threaten the safety of the high-speed probe. At the front of its payload it carries a beryllium shield, 55 metres in diameter, to protect it in interstellar space, but once it enters the Barnard's star system even that will not be sufficient to ward off impacts from meteorites. The designers now envisage spraying a protective screen of fine particles 200 km ahead of Daedalus as it approaches Barnard's star. Erosion looks like being one of the major drawbacks to ultra-high-speed interstellar flight, and so many missions are likely to be restricted to speeds similar to those of Daedalus.

What of the massive payload that Daedalus is carrying towards Barnard's star? Included are five sub-probes that will be released and recovered again along the way to study conditions in the space between stars. But probably the greatest interest is in the 18 probes intended to examine the planetary system of Barnard's star, as well as the star itself. A typical probe is 20 m long and weighs 10 tons, which makes it more like a manned space station than the planetary probes we are used to in the solar system. Inside it is packed a wide range of instruments to survey the targets in wavelengths ranging from infra-red to ultraviolet, and to take detailed photographs. Special instrumented packages may be ejected to perform specific duties such as atmospheric entry and examination of satellites.

Daedalus carries two telescopes of 5 m (200 inch) aperture, the same size as the Mount Palomar reflector, with which it begins to survey the Barnard's star system ten years before encounter. Such large telescopes are necessary because the planets would appear so faint in the weak light from their red dwarf parent. Seven years before encounter, the first set of probes is dispatched on courses that will take them to intercept the largest, Jupiter-like planets of the star. As Daedalus gets closer its telescopes will be able to distinguish any Earth-like planets that exist around Barnard's star, and it will deploy probes to examine these planets, as well as Barnard's star itself, up to one year prior to encounter. Each sub-probe has a nuclear-electric propulsion system for final manoeuvres.

Since Daedalus does not decelerate, it and its array of sub-probes will pass through the entire Barnard's star system in only a few hours; the encounter time of any one probe with a planet is only a few minutes. Yet during this brief period the Daedalus mission may be grabbing many thousands of photographs to give us our first close-up look at another planetary system in space. It will take several years to return this data to earth.

Each sub-probe will dispatch its data to the mother ship, which is the top stage of the craft that left our solar system 50 years previously. The unwanted reaction chamber of the second-stage engine, which would long since have shut down and cooled, can be used as a giant radio telescope for communication with Earth. Down this radio link to large receivers on or near Earth will come the photographs and data from our first interstellar mission.

Although Daedalus has been designed with existing or attainable technology in mind, such a mission could still not come about overnight. Once the go-ahead had been given, detailed design, manufacture, and vehicle checkout with trial flights to the edge of the solar system and back would involve about 20 years, followed by 50 years' flight time and six to nine years for transmission of data to Earth. Therefore, the Daedalus team conclude, it appears that even the simplest interstellar missions will require a funding commitment lasting 75 to 80 years.

What would such a mission cost? One estimate from the Daedalus team is that it would cost something like 100,000 million dollars, or more than the United States has spent on space since the launching of its first satellite. Curiously, however, this happens to be exactly one year's defence spending by the United States. Therefore, if we forewent defence spending for one year, we could go to the stars.

In practice, of course, we could not attempt it today; but next century it would be possible, and I believe we will do it then. What better way to celebrate the 100th anniversary of the space age in 2057 than by launching our first ship to the stars?

Gregory Matloff of New York University's division of applied science has considered the possibility of attaching a Daedalus-type engine to an O'Neill-type colony. Such a combination ought to achieve a cruise velocity of one or two hundredths the speed of light, giving journey times of 400, 600 and 1100 years to Alpha Centauri, Barnard's star, and Tau Ceti respectively.

As long ago as 1964, Robert D. Enzmann of the Raytheon Corporation proposed an interstellar ark driven by eight nuclear pulse rockets. The living quarters of the starship, habitable by 200 people but with room for growth, would be in three modules interlinked into a cylinder 300 m long and 100 m diameter. Like the O'Neill colonies, this cylinder would spin to provide gravity. At the head of the starship would be a sphere 300 m across filled with 12 million tons of frozen deuterium, which acts as the starship's fuel and also incidentally serves as a forward shield for the living quarters during the journey. Fuel is channelled from this giant snowball-on-a-stick through a central load-bearing core to the eight engines at the rear of the ship. Abundant neutrons are liberated in a deuterium-deuterium reaction, so that thick shielding will be needed around the engines to prevent danger to the crew.

Enzmann foresaw a fleet of three to ten such starships setting out together for their stellar destination, which they would reach at a speed of about 0.1 that of light. The modular construction of the vehicle means that even if one section is completely destroyed, it can be discarded while the other two carry on; in the event of a total catastrophe, the remaining crew can bail out into another member of the fleet, which will have spare room for them.

An adventurous 50-year crash programme leading to manned interstellar exploration has been proposed by Robert L. Forward of Hughes Research Laboratories in Malibu, California. On Forward's timescale, the first target would be to launch robot probes to the stars by the end of the century. The programme would start with 15 years of design and research into critical areas of technology, such as fusion drives. Funding during this stage would be limited to a modest few million dollars a year, but would climb to several billion dollars a year as the building and test flying of small prototype starships began, peaking around the year 2000 as the first full-scale probes are launched to Alpha Centauri, Barnard's star, and other likely nearby targets. Development work on manned versions of the craft would continue during the following 20 years while the probes, travelling at one-third the speed of light, reached their targets and sent back data. Once assured that all was well by the success of the robot pathfinders, manned missions would leave around the year 2025, reaching Alpha Centauri in 10 to 20 years.

One must admire Forward's optimism, while admitting that his timescale is somewhat compressed. Perhaps if everything were stretched out four times in length, it might bear some relation to reality. Can we really consider flight to the stars before men have landed on Mars? Do we even want to send men to the stars when intelligent machines can do the job for us? These are questions that different societies might answer in different ways – and which we ourselves might view differently in decades to come.

One well-known starship design is the so-called interstellar ramjet, a device which in theory would scoop in fuel from the hydrogen clouds in space and burn this in a reactor to create thrust. The ramjet design, first suggested in 1960 by Robert Bussard, has the apparent advantage that it need carry no fuel and would gather in more hydrogen from space the farther and faster it went, making it seemingly ideal for long-distance, high-velocity voyages that would be necessary to reach distant parts of the Galaxy. But is it feasible?

Bussard himself realized that such a design was beyond the reach of contemporary technology, but nuclear physicist Tom Heppenheimer of the Max-Planck-Institut in Heidelberg now claims that the interstellar ramjet would never work successfully, even in theory. It would be quicker to get out and push.

A ramjet would have to operate by fusion of deuterium (heavy hydrogen) from among the hydrogen clouds of space. Energy generation as in the Sun, by the fusion of protons (hydrogen nuclei), would release energy at a far slower rate – so slowly that in terms of power-to-weight ratio a galley full of Roman slaves would be more efficient; one could get more energy from the slaves' body heat while they were asleep, Heppenheimer notes puckishly. Even so, there are problems with the deuterium-deuterium reaction.

If the gas in the reaction chamber is not dense enough, it will radiate away more energy than it releases – at least 1000 million times as much as can be produced by the fusion reactions, according to Heppenheimer. The answer, it would seem, is to collect more gas and make it denser. This would require a ramscoop an astounding half-light-year in diameter. But even so, hydrogen is so thinly spread in space that more energy is required to compress it sufficiently than can be recovered from the subsequent fusion reactions. In either case, we lose more than we gain. Heppenheimer therefore concludes that the interstellar ramjet is infeasible for propulsion, but that it dissipates energy so successfully that it would make a successful brake – an effect that one day may prove useful, even if it is the reverse of the application that the ramjet advocates have had in mind.

By contrast, a device such as Daedalus carrying its own propellants emerges successfully from the analysis by Heppenheimer, who proposes that fusion engineers and starship designers should join forces to advance each other's art. A bomb-powered spacecraft may not seem the most elegant of engineering solutions, so perhaps things can be improved by further advances in fusion technology during the coming decades.

Looking into the realms of the fantastic, perhaps the ultimate form of propulsion one can envisage is the photon rocket, in which matter and antimatter annihilate each other to produce pure energy. This process is over one hundred times as efficient as hydrogen fusion, in which only a fraction of a per cent of the mass is turned into energy, but it suffers from some astounding engineering problems, not least being to produce and store sufficient antimatter and then to generate thrust from the photons so produced. Even if these details can be accommodated, not many starship captains would, I suspect, be happy with the thought of a craft containing a propellant that promised to annihilate any part of the ship it came into contact with. An accident in a starship whose antimatter fuel broke out of confinement would be marked by a flareup like the nova explosion of a star.

One intriguing possibility that I expect the science-fiction writers will soon be on to is to capture a mini black hole for use as a starship power source. Work by theorists such as Stephen Hawking of Cambridge has shown that black holes can actually radiate energy, and that small black holes, containing the mass of a mountain squashed into a space the size of an atomic particle, radiate thousands of megawatts. Such mini black holes could have been formed in the conditions of extreme temperature and pressure shortly after the Big Bang explosion believed to have marked the beginning of the Universe, and if it is possible to find and harness these compact energy sources then one of the biggest problems of starflight will have been solved.

For the foreseeable future, though, we are stuck with the energy of nuclear fusion, as utilized by the Daedalus designers, which should be adequate for our purposes. The importance of the Daedalus study, the first detailed design for an interstellar mission, is that even if it bears no relation to starships as eventually built, it will still have served its purpose by showing how we *might* build our first ship to the stars. Although we are, for the moment, restricted to making plans on paper, other civilizations more advanced than ourselves may have already put those plans into practice. If there are starships of other civilizations in space, could we expect to see them?

The possible detection of starships has been discussed by David Viewing of the British Interplanetary Society, with colleagues C. J. Horswell and E. W. Palmer. Firstly, the authors believe that slow, unpowered starships like the Pioneer and Voyager craft will be most abundant, because they are so much cheaper than the high-powered Daedalus kind and they will eventually return just as much data if we are willing to wait long enough. Sufficiently reliable electronic systems to last the journey should be feasible. Probes like this would be virtually undetectable unless someone possessed an intensely powerful interstellar early-warning radar for spotting stray bodies in space. Beams from such a radar should be detectable on Earth, although radio astronomers have to date found no sign of any artificial interstellar transmissions. But what about larger probes with high-energy propulsion systems, like the fusion drive of Daedalus?

Daedalus itself is not designed to have its engine firing as it flies past its target star. It would be invisible by reflected sunlight as it passed through our solar system even on photographs taken with large telescopes, because it is too small and is moving too quickly. A large enough craft might reveal itself briefly by blocking out light as it passed in front of stars, but the chances of detection in this way are extremely slim. Viewing and his colleagues examined the possibility of a net of sentry probes around the Sun designed to detect itinerant starships, and found that a ring of approximately 1000 probes would be needed to be sure of spotting any alien Daedalus-like craft that flew between them.

'Daedalus probes could arrive at our system at hourly intervals completely unnoticed by terrestrial civilization,' conclude the authors. 'No matter how awesome the starship might be in a terrestrial context, in its own environment – interstellar space – it is virtually invisible.'

Starships with more advanced capabilities than Daedalus hold out more hope of detection, because the emissions from their engines would give them away. 'It seems probable that the radiation and particle fluxes generated in the engines of starships are, even at this moment, falling upon the Earth,' say Viewing and his colleagues. The problem is separating this influx from the natural cosmic ray background. 'The fires of starship engines are lost at present in galactic noise.'

A starship would be easily distinguished from a normal cosmic-ray source because of its high-velocity motion which may also allow us to trace back its path to the star of origin. A starship's engine will also be a point source, far smaller than any natural galactic source, and in the case of a Daedalus-type engine the emissions will be rapidly pulsed. Although a starship's engine might be shut down for the coast between stars, it would light up again when manoeuvring into or out of a solar system. We might hope to spot a starship manoeuvring in our own solar system.

Fusion explosions in a Daedalus-type starship engine give out X-rays, and neutrons are produced from subsidiary reactions in the exhaust. From these emissions, the second stage of Daedalus could be detected by instruments like those in satellites and on Earth today at distances of 60 to 70 million km – in other words, from Earth it could be detected beyond the orbit of Venus almost out to the orbit of Mars. Daedalus's exhaust consists of highly ionized hydrogen, deuterium, and helium, which would produce a glow of light in the far ultraviolet that could be seen by suitable instruments at more than 100 million km, the distance of Saturn.

Viewing and his colleagues note that throughout Earth history, less advanced civilizations have usually first detected the more advanced varieties by observation of their vehicles – first sailing ships, and now aircraft. Even the most remote tribe on Earth could not by now have failed to see an aircraft or a satellite. We, so far, have failed to detect even one interstellar spacecraft, although we could certainly expect to have done so had there been any manoeuvring among the inner planets of the solar system

The fact that we have made no such observations of starships near the Earth is one argument against the proposition that we are currently being visited by extraterrestrial space travellers. Other objections are given in Chapter 13.

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7

MESSAGES FROM THE STARS

Eventually we will send probes to the stars in searc of life, but at the moment our space-probe exploration i confined to our own solar system. Even if there is lif in the solar system – and in the wake of Viking tha does seem improbable – it will be only of the most lowl kind. If we want to find signs of advanced technologica life, like ourselves or more advanced, we must listen fo messages from the stars. Several pilot listening pro grammes have been undertaken by individual radio astro nomers; now, both NASA and the Soviet Academy o Sciences are embarking on official and ambitious signa searches.

In January 1900 the radio pioneer Nikola Tesla describe strange signals he had received on his own radio equip ment the previous year: 'The changes I noted were takin place periodically, and with such a clear suggestion o number and order that they were not traceable to an cause then known to me . . . It was some time afterwar when the thought flashed upon my mind that the disturb ances I had observed might be due to intelligent control This was the first suggestion that radio communicatio between worlds in space might be taking place. Bearin in mind the low sensitivity and the long operating wav length of Tesla's equipment it seems unlikely that h could have been detecting an interstellar message, bu the exact nature of the disturbance he recorded was neve clarified because he refused to give further details aft his speculations about interstellar radio communicatio had been harshly criticized.*

Nowadays, the idea of interstellar radio communic

* Tesla's 'extraterrestrial signal' is reported by Leland Anderson in *Nature*, vol. 190, p. 374, 1961.

tion has become widely accepted. With modern radio telescopes we could make our presence known by signalling to nearby stars, so naturally the question arises: Are other civilizations trying to contact us? We could easily pick up their transmissions with existing radio telescopes, if any such transmissions exist. But there are two main problems: Where to look? And at which wavelength?

Imagine not being able to pick up a radio station on a domestic receiver unless the aerial were pointed directly at the transmitter, and having to tune through all the bands to find the right channel. That's the problem faced by radio astronomers, with the added disadvantage that it may take several minutes' listening at each wavelength to pick out the faint signal from the background noise. Fortunately, we can make a few assumptions that simplify the problem.

As noted in Chapter 2, astronomers believe that stars similar to the Sun are the most likely to harbour advanced extraterrestrial life because they are hot enough to warm any planets that may orbit them (unlike smaller, fainter stars) and they keep up their stable light output long enough for advanced lifeforms to develop (unlike larger, hotter stars which burn out too quickly). Therefore, the signal-searchers have concentrated on Sun-like stars, plus some nearby red dwarfs like Barnard's star, with the emphasis on single stars because of the doubts about the existence of planets in double-star systems.

The first serious attempt at detecting messages from the stars was Frank Drake's now-classic Project Ozma in 1960, during which he listened fruitlessly for 150 hours to the Sun-like stars Tau Ceti and Epsilon Eridani with the 26 m dish at the National Radio Astronomy Observatory, Green Bank. Drake listened at a wavelength of 21 centimetres, which is naturally emitted by hydrogen in space (21 cm radiation is equivalent to a frequency of 1420 megaHertz). Since hydrogen is the most abundant substance in the Universe, its 21 cm line will be known about by radio astronomers everywhere who will be regularly tuned to it, and so it would make a good band for interstellar signalling.

The idea of listening for messages from the stars at 21 cm wavelength, first suggested in 1959 by the physicists Giuseppe Cocconi and Philip Morrison, has been widely adopted by subsequent signal searchers. In 1972 radio astronomer Gerrit Verschuur at the National Radio Astronomy Observatory updated and extended the Project Ozma search by listening at 21 cm wavelength with the Green Bank 43 m and 91 m telescopes to ten nearby stars, although again with negative results.

The most comprehensive search undertaken to date was completed in 1976 at Green Bank by Benjamin Zuckerman and Patrick Palmer. During the previous four years they had surveyed at 21 cm wavelength the 659 stars most likely to harbour life from 6 to 76 light years from the Sun, using the Green Bank 91 m and 43 m dishes. Zuckerman and Palmer estimated that, with the vastly increased sensitivity of their equipment over the original Ozma experiment, they could have detected a 40 MW transmitter beaming through a 100 m dish (a technical capability equivalent to our own) around any of the target stars. They listened to each star for four minutes at a time, reobserving them six or seven times in all.

Ten stars which had shown 'glitches' (i.e. unexplained spikes of energy) were carefully resurveyed. Several of the glitches were traced to terrestrial sources of interference, such as aircraft, while others remained a mystery; however, since none of the spikes were repeatable, they are unlikely to be due to beacon transmissions from other civilizations.

Another extensive search, still under way, is being undertaken by Robert S. Dixon at the Ohio State University radio observatory. Dixon is concentrating on the 21 cm hydrogen line, but with a slight difference. Because all stars are moving in orbits around the Galaxy, their motions cause a slight wavelength change, known as the Doppler shift, in any signals transmitted or received from them. Therefore, a signal transmitted at 21 cm wavelength by another civilization would be received at a slightly different wavelength depending on whether we were moving towards or away from them. The only way to avoid this problem, thinks Dixon, is if both the receiving and the transmitting civilizations correct for their own motion around the galactic centre, so that any signal would be received at a constant wavelength, as though it were being transmitted from a stationary aerial at the centre of the Galaxy.

Rather than concentrate on specific targets, Dixon is scanning the entire sky from 63° north to 36° south visible with the radio telescope originally used to compile the Ohio Sky Survey, a famous radio astronomy catalogue. This telescope consists of an antenna 100 metres long and 30 metres high, whose collecting area is equivalent to that of a 53 m circular dish. Dixon began his search with his detector centred on the frequency that would be received from a 21 cm transmitter at the centre of the Galaxy, in December 1973, running 24 hours a day, 365 days a year. He estimates that out to a distance of 1000 light years his telescope beam covers an average of three stars like the Sun, or slightly hotter or cooler than the Sun, at all times. Such an all-sky search has the added advantage that it would detect messages coming from space between stars, such as might be transmitted from an interstellar probe or a space colony.

By the end of 1977, Dixon and his assistant Dennis M. Cole had covered the northern sky from declinations +48° to +14° and declinations −33° to −23° in the southern sky without detecting any apparently artificial signals. Dixon plans to continue his search indefinitely, continually improving the sensitivity of his receiver to pick up ever-fainter signals. By the time the first search is completed the improvements in sensitivity will make it worthwhile beginning another search.

Frank Drake and Carl Sagan of Cornell University have used the largest single radio dish in the world, the 305 m dish at Arecibo, Puerto Rico, to listen for messages coming from possible super-civilizations in nearby galaxies. Although a civilization so advanced as to be able to make itself heard over intergalactic, rather than interstellar distances would be rare, the advantage of looking at a complete galaxy is that it brings thousands of millions of stars into view at once. Beginning in 1975, Drake and Sagan scanned four nearby galaxies at wavelengths of 21, 18, and 12.6 cm without detecting any suspicious signals.

Their choice of reception wavelengths was governed by the equipment available at the radio telescope, a common limitation in radio astronomy. The 12.6 cm wavelength is used by the Arecibo dish for interplanetary radar bounces, but the 18 cm line is more interesting. It is the wavelength emitted by the molecular grouping known as hydroxyl, or OH, which is water lacking one hydrogen atom. The 18 cm and 21 cm wavelengths of OH and H stand like gateposts either side of an area of the radio spectrum commonly termed the water hole. Many radio astronomers are beginning to regard the water hole as the preferable slot for interstellar transmissions, for two reasons: it coincides with a natural minimum in the background noise from space; and because of the importance of water to all life as we know it. In recognition of this, Robert S. Dixon has now incorporated a receiver to scan the area around the 18 cm OH line in addition to his 21 cm search at Ohio State University radio observatory.

There are certain limits on the observable radio window. At wavelengths longer than about 30 cm, background noise from our galaxy becomes a problem. At wavelengths shorter than about 3 cm, noise from our atmosphere, particularly water vapour, becomes obtrusive. Water emits strong signals at a wavelength of 1.35 cm, and thus defines another possible line for interstellar communication which, to some astronomers, seems as appealing as the 21 cm line. Two Canadian radio astronomers, Paul Feldman and Alan Bridle, began a search for possible interstellar messages at the 1.35 cm water wavelength in 1974, using the 46 m dish of the Algonquin radio observatory in Ontario. Their plan is to examine around 500 likely stars, but the project has been severely hampered by equipment failures and has not so far progressed beyond surveying about 70 stars.

Some scientists involved in the search for extraterrestrial intelligence (SETI*) do not even think that radio is the mostly likely mode of communication. An American engineer, Herbert Wischnia, has argued that lasers sending beams of ultraviolet light are a likely means of interstellar communication. Since stars like the Sun radiate relatively little energy in the ultraviolet, the laser beam would not be swamped by natural stellar radiation. Ultraviolet light is absorbed by the Earth's atmosphere, so the only way to check this speculation is by satellite, and Wischnia obtained observing time in late 1974 on NASA's OAO-3 satellite, also known as Copernicus, which has an 81 cm telescope on board for examining ultraviolet radiation from stars. With this observatory satellite, Wischnia looked at Epsilon Eridani, Tau Ceti, and Epsilon Indi, but found no ultraviolet laser emissions.

Cambridge astronomer Andy Fabian has made the somewhat tongue-in-cheek suggestion that advanced civilizations might attempt to attract our attention by dropping matter on to neutron stars to produce bursts of X-rays. A 1 km chunk of rock dropped on to a neutron star would produce a flash of X-rays detectable throughout the Galaxy. However, there is no indication that any of the X-ray sources observed by satellites are actually interstellar signals.

Some civilizations might go so far as to vary the light output of a star, like a galactic Aldis lamp. Many stars are now being discovered to exhibit fractional fluctuations in light output, detectable only by sensitive instruments. One suggestion is that these light changes are caused by slight oscillations in size of the star. An advanced civilization could set an entire star 'ringing' to

* NASA now prefers this acronym to the previous CETI (communication with e.t.i.) because of the erroneous impression of a two-way link given by the word communication'.

produce such brightness fluctuations by impacting material such as comets on to the star's surface; they might even modulate a coherent message on the fluctuations.

While most astronomers strongly favour radio communication as the best way of establishing contact between stars, the idea of using the 21 cm hydrogen line has come under increasing attack, both because any signal would tend to be swamped by the background noise of natural hydrogen radiation, and also because a powerful 21 cm transmitter would jam all local receivers. This second disadvantage, at least, is avoided by Robert S. Dixon's strategy of applying a frequency correction in all directions at the transmitter and receiver to compensate for the parent star's rotation around the Galaxy.

Some astronomers have proposed using harmonics, or multiples, of the 21 cm line, but these could be mistaken for natural emissions. A more intriguing idea has been proposed by P. V. Makovetskii of the Leningrad Institute of Aviation Instrument Manufacture. He agrees with Cocconi and Morrison that the 21 cm line of hydrogen will be universally known to astronomers, but he also notes that certain mathematical constants, such as π. and $\sqrt{2}$, should also be universally recognized, His proposal for a clearly recognizable artificial signal is to beam radio transmissions at a specific wavelength defined by a combination of these physical and mathematical constants. He regards the six most probable wavelengths as being the 21 cm hydrogen line alternately multiplied and divided by π, 2π, and $\sqrt{2}$. The resultant wavelengths, 3.3 cm, 6.7 cm, 15 cm, 30 cm, 66 cm, and 132 cm, will be precisely defined, and would be immediately identified as artificial.

A precisely defined wavelength is an advantage, because the narrower the bandwidth of a signal (that is, the smaller the spread of frequencies) the more powerful the signal will be for a given transmitter output, and therefore the greater its range. The disadvantage, from the point of view of radio astronomers, is that their receivers are tuned to accept a fairly wide band of frequencies, usually several kilohertz, which reduces their sensitivity to narrow-band signals – the wider a receiving channel, the more difficult it is to pick out a signal from the noise of surrounding frequencies, which is perhaps one reason why messages from the stars have not yet been detected during normal radio-astronomy observations. And conversely, the narrower a receiver channel, the more time it takes to scan a given region of the spectrum, such as the water hole, or the more receivers operating in parallel that are needed to cover the same frequency range simultaneously.

Another 'fundamental' frequency has been proposed by radio astronomers T. B. H. Kuiper and M. Morris, based on the speed of light and certain properties of the electron; the resulting frequency is equivalent to a wavelength of 11.7 cm. Kuiper and Morris have also discussed possible search strategies, arguing that messages would most probably be coming from nearby rather than far off, if they are coming to us at all. The reasoning behind this claim is that, if there are many civilizations out there which are millions of years in advance of us, then they will most likely have already colonized the Galaxy (see also Chapter 11). We might therefore come under the aegis of one local area of this galactic empire, whose role would be to attract our attention when they thought we were ready. Therefore, argue Kuiper and Morris, if we are being signalled to at all, then the message is probably coming from no farther away than 10 light years or so.

In the wake of the Zuckerman-Palmer and Dixon searches, new SETI projects have been springing up in the United States. Radio astronomers from the University of California at Berkeley have begun a SETI programme with the 26 m dish of the Hat Creek radio observatory. The search is not aimed at specific targets, but runs in conjunction with normal radio-astronomical work being done at the observatory. The wavelengths under scrutiny are 21 cm, 16 cm, and 32 cm.

In 1976 and 1977, a combined team from NASA's Ames

Research Center and Goddard Space Flight Center used the Green Bank 43 m and 91 m telescopes for narrow-band examination of 200 stars, including those which showed glitches in the Zuckerman and Palmer search, at wavelengths of 18 cm and 35 cm. Their receiver, which has a bandwidth of 5 Hz, better than anything used previously for SETI, was designed for particularly high-resolution radio astronomy work. At Arecibo, Frank Drake has also begun examination of several likely stars at 18 cm wavelength with a receiver of even narrower bandwidth.

These latter two narrow-band schemes are predecessors of even more ambitious plans officially backed by NASA, and announced in 1977. On one thing the NASA searchers seem agreed: the incoming signals are likely to be of very narrow bandwidth, so that special receivers are required. However, since there now seems no reason to choose any particular wavelength, the searchers are intending to scan as much of the radio spectrum as possible, particularly in the water hole.

To speed up the search, which would otherwise be prohibitively long, NASA's Ames Research Center and Jet Propulsion Laboratory, both in California, are co-operating on the development of a device known as a Multi-Channel Spectral Analyser (MCSA) which will be able to survey a wide range of radio frequencies simultaneously. The MCSA under design will have one million channels, so that it can survey a 300 MHz band (the width of the water hole) with a resolution of 300 Hz per channel. Alternatively, it can be used to survey a smaller slice of the radio spectrum with resolutions of only a few Hertz per channel. Eventually there might come a thousand-million channel MCSA, capable of scanning the entire water hole at a time with 0.3 Hz resolution. Such a staggering increase in capability over existing receivers is due largely to vast improvements in microelectronics, which can now cram such a powerful package into a manageably small size.

The MCSA will feature in a 5-year SETI plan being embarked upon jointly by the Ames Research Center and the Jet Propulsion Laboratory. Both the Ames and the JPL searches will have greater sensitivity than their predecessors. The Ames team will be using the Arecibo dish and two other radio telescopes, one in the northern hemisphere and one in the south, to scan the water hole in the direction of at least several hundred selected stars within 1000 light years, with resolutions of a few Hertz. According to astronomer David Black of the Ames team, this programme will take only a few per cent of the observing time on each telescope, and has an anticipated cost of six million dollars, most of which is accounted for by the MCSA and equipment to analyse the signals for possible message content.

The JPL team are making even fewer assumptions, intending to scan the entire sky between 30 cm and 1.2 cm wavelength with 300 Hz resolution, using an identical MCSA attached to the Goldstone 26-m tracking dish, plus a network of smaller horn antennas. According to the manager of the JPL project, Robert E. Edelson, the Goldstone dish will be able to cover about 80 per cent of the sky. The 26-m dish is used about 40 hours a week for deep-space tracking, but for the rest of the time, about 16 hours a day, it will be available for the automated SETI programme. The cost of the JPL programme is estimated to be 14 million dollars, bringing the combined outlay for both searches to 20 million dollars – equivalent to the cost of the movie *Close Encounters of the Third Kind*. Subject to budgetary approval, building of the MCSAs was due to begin in October 1978, with field tests in mid-1979. On this schedule, the 5-year programme of SETI observations will begin in 1980.

Even if neither project detects messages from the stars, the surveys will produce considerable new astronomical information so that the effort will not be wasted. Only such a co-ordinated programme, rather than the piecemeal attempts made to date, will provide firm evidence about the existence of communicative civilizations elsewhere in space. 'Within a few decades, mankind will either have discovered the presence of extraterrestrial intelligence, or will have placed very severe constraints on the likelihood that such intelligence exists,' says David Black.

American astronomers are not alone in their SETI efforts. Soviet radio astronomers have been making attemps to detect messages from the stars since 1968. Unlike their American counterparts, the Soviet astronomers have tended to use modest receivers in the hope of detecting highly powerful transmissions from super civilizations, with the receivers spread out across the USSR to pinpoint the source of any strange signals received. In 1973 the group led by Dr Nikolai Kardashev were reported as having picked up coded signals which they believed might be from extraterrestrials. But, according to a 1977 report by the Soviet science journalist Boris Belitsky, subsequent work showed the signals to have come from Earth satellites.

Although these initial Soviet attempts were modest, an altogether more ambitious 10-to 15-year CETI programme was approved in 1974 by the Soviet Academy of Sciences. The CETI programme is split into two parts: CETI 1, from 1975 to 1985, and an overlapping CETI 2 from 1980 to 1990. The proposals for CETI 1 include all-sky monitoring from eight ground stations, with associated antennae for continuously surveying nearby galaxies; this is an extension of existing Soviet CETI work. Additionally, two space stations with large antennae are visualized to augment the all-sky search. Features of CETI 2 are enlargement of the space station antennae, and introduction of a widely spaced pair of dishes of collecting area one square kilometre for examining specific objects.

The CETI programme recommends searching radio and infra-red frequencies from 0.3 cm to 30 cm, but with special emphasis on molecular lines such as 21 cm, 18 cm, and 1.35 cm. The new RATAN 600 radio telescope, consisting of a group of 900 collector plates arranged in a ring 600 metres in diameter, is planned to cover the wavelengths from 21 cm to 0.8 cm, while a millimetre-wave telescope is under development at Gorki for even shorter-wavelength studies. As well as searches of globular clusters and the dense star fields at the centre of the Galaxy (both locations of old stars where we might find highly advanced civilizations), and galaxies of the local group, the Soviet CETI plans recommend monitoring 'all appropriate stars' up to 100 light years distance, and eventually to 1000 light years. In future, Soviet researchers foresee automated probes being sent to investigate likely targets.

It's difficult to know how much of the programme will actually be achieved, as it seems more of a statement of desirable aims rather than an instruction to be followed to the letter. But it does at least seem clear that Soviet scientists are taking the CETI search seriously, and that it is becoming an adjunct of normal astronomical investigation.

What of the future? If the existing searches fail to detect signs of messages from the stars, we may have to consider new approaches to the problem, particularly casting our net as widely as possible and attempting to monitor the whole sky continuously. To assist with all-sky monitoring, Hendrik J. Gerritsen and Sean J. McKenna of the physics and astronomy department at Brown University in Rhode Island have proposed using a device known as a Luneberg lens, named after R. K. Luneberg who invented it in 1944; with this device, say Gerritsen and McKenna, we can simultaneously monitor 'a huge number of stars'. A Luneberg lens is a large sphere filled with a suitable medium which refracts radio waves on to its inside back surface, thus forming an image of the radio sky. One Luneberg lens can image a hemisphere, so that two could cover the entire sky. The Luneberg lens is the receiving equivalent of an omnidirectional beacon.

Signals from each of the many star images focused on its periphery are collected by an equally large number of microwave horns and guided to an amplifier. Experimental spheres made of lightweight polystyrene foam have been constructed. According to Gerritsen and McKenna, a Luneberg lens of given diameter performs as well, if not better, than a dish reflector of the same aperture up to 70 m across, when performance of the Luneberg lens falls off due to losses from absorption of microwaves in the sphere.

Gerritsen and McKenna conclude that a Luneberg lens would be best placed on the Moon or in space for a SETI programme which they term Project Argus. Assuming that other civilizations are already listening with a Luneberg lens, the Brown University scientists believe we should begin a programme of short transmissions to the nearest stars, and then begin listening for replies. At the moment, though, the idea of the Luneberg lens for CETI seems to have met with little response.

NASA has studied the possibility of building several advanced systems for detecting messages from the stars, either on the Earth, the Moon, or in space; such systems will be necessary if signals turn out to be excessively faint, or distant, or both. Most famous of these is the Cyclops project, an array of 1000 or more dishes each of 100 m aperture; together these would equal the performance of a single dish 3 km in diameter, sufficient to detect a 1000 megawatt omnidirectional beacon with 0.1 Hz bandwidth at distances of 500 light years, an area that includes several hundred thousand stars of interest. Transmissions of only a few megawatts strength could be detected from much closer stars, such as Tau Ceti and Epsilon Eridani, including leakage from domestic TV or radio broadcasts not even intended as interstellar signals.

A study group from the Stanford Research Institute, acting on a NASA contract, has compared an Earth-based Cyclops with other systems in space or on the Moon.* A lunar system would have the advantage that, on the Moon's far side, it is shielded from the radio noise of Earth; the lower lunar gravity is also an advantage when building large dishes. But of course costs would be enormous.

* Parametric Study of Interstellar Search Systems by R. P. Basler, G. L. Johnson, and R. R. Vondrak, Stanford Research Institute Project 4359, August 1976. See also *Radio Science*, vol. 12, p. 845, 1977.

The Stanford team looked at the possibilities of building a lunar Cyclops with steerable dishes, and even a lunar Arecibo. Whereas the Arecibo dish on Earth is suspended in a natural hollow between mountains, the Stanford team envisaged hundreds of similar dishes suspended from the rims of small bowl-shaped lunar craters. A comparable multi-dish Arecibo array on Earth would be hampered by lack of suitable mountain hollows in which to hang the reflectors.

Although an array of Arecibo-type reflectors on the Moon works out at about half the cost of a lunar Cyclops, the dishes are unsteerable and can only sweep a limited range of sky so that they would require a larger collecting area and would have to search out to greater distances to have the same chance of detecting a message. It will be far cheaper to build and operate large radio-astronomy arrays on the Moon once lunar industrial bases are established, such as for building the O'Neill colonies (Chapter 5). In that case, the cost of a lunar Arecibo array would be similar to that of an Earth-based Cyclops.

The Stanford group also looked at large space antennae, possibly to be situated at the L3 Lagrangian point of the Earth-Moon system which is on the opposite side of the Earth from the Moon. But any of the Lagrangian points, including the L4 and L5 positions suggested for the O'Neill colonies, could be used. The 'cup' antenna would be backed by a 'saucer' to shield it from terrestrial radio noise. Because of their potential for complete sky coverage, the ability to track a source continually should a message be discovered, and their simplicity of construction, space systems are immediately attractive.

Collectors in space with areas of up to a few square kilometres, capable of probing several hundred light years, would cost two or three times as much as an equivalent Earth-based system. But one surprise from the Stanford study was that a space system might be the cheapest of all at the very large collector sizes, 5 km or so in diameter, that would be needed to push the search for a 1000 megawatt omnidirectional beacon out to 1000 light years. Costs would be cheaper still following establishment of an O'Neill-type space manufacturing facility, which could turn out antennae of 2.5 km diameter for just over 200 million dollars each, according to O'Neill's estimates.

The Stanford study concluded that Moon-based systems are the least cost-effective of all three options, but that the cost-effectiveness of Earth-based Cyclops or space systems depended on the number of civilizations in the Galaxy and thus the size of collector needed to detect messages from them. Overall costs are difficult to assess accurately, but the total Cyclops system is likely to cost at least 10,000 million dollars, or a substantial proportion of the cost of the Apollo Moon project.

A NASA committee on the search for extraterrestrial intelligence, chaired by Frank Drake, met in May 1976 to discuss the relative merits of these advanced proposals, without coming to any firm conclusion. In any case, even if such systems were approved, they would be unlikely to begin construction until the 1990s. The SETI committee did, however, focus attention on the increasing use by terrestrial radars and satellites of the microwave radio region, particularly around the water hole. If such interference continues to grow, then there will be no alternative but a space or Moon-based SETI system.

But behind all this technological wizardry, what exactly is it that they hope to hear? What would a message from the stars sound like? According to communications specialists, the most efficient way to transmit information is to spread it out as widely in frequency as possible. Anyone overhearing such a transmission would not understand it unless they knew the code to extract the message that was being carried; otherwise the signal would sound like random noise. But if someone were deliberately trying to attract attention, they would presumably send a signal that was unmistakable – one confined to as narrow a bandwidth as possible, say 1 Hz of frequency or even less. And this clearly artificial narrow-band transmission would be the carrier for a message that would be encoded on it, in some easily recognizable form, either as pulses or in the form of alternate left and right hand polarization.

What would the message contain? It could be very complex, perhaps divided into three overlapping parts. One part might be a regularly repeated introductory passage, perhaps with a translation guide to assist comprehension of the rest. In between this could be a longer and continually updated message containing current information on the planet, its population, and technological level – a kind of travelogue-cum-documentary. The third part of the message may be a continuing story of the history of the planet and the development of its people – a celestial slide show of anthropology, art, and culture.

Or the CETI signal might be the simplest one capable of unambiguously announcing the transmitting civilization's presence – a steady narrow-band signal. To get a better idea of the type of signals that we might expect to receive, let's take a look at our own first attempts at interstellar signalling, and what we might do in the future.

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8

HOW WE COULD TALK TO THE STARS

At 17.00 GMT on 16 November, 1974, mankind's first deliberate radio message to the stars was transmitted from the 305-meter-diameter radio telescope at Arecibo, Puerto Rico. It was a three-minute signal, sent just once towards a group of stars 24,000 light years away – hardly a serious attempt at interstellar communication. But it was a demonstration of what might be possible on a wider scale in the future, as well as a pointer to what we might discover coming from other civilizations in the Galaxy.

The Arecibo message was transmitted as part of the reinauguration of the radio telescope after it had been resurfaced and new equipment installed. The Arecibo telescope's maximum power in any one direction is now equivalent to that of an omnidirectional antenna blasting out 20 million megawatts in all directions, ten times the generating capacity of all electric power stations on Earth. This upgrading of the instrument means that with a bandwidth of 1 Hz or less its signal can be detected by similar radio telescopes throughout the Milky Way. As the first use of this new facility, the staff thought it 'highly appropriate' to send a simple and brief signal to the fringes of the Galaxy announcing our existence.

The Arecibo message was concocted by staff members of the National Astronomy and Ionosphere Center headquartered at Cornell University, which operates the radio telescope; primarily concerned were Frank Drake, Richard Isaacman, Linda May, and James C. G. Walker, with assistance from others, notably Carl Sagan. Their message consists of a string of 1679 pulses, which can be arranged into a grid of 23 characters by 73, forming a dot picture that reveals details about humankind which might be of interest to extraterrestrials. The idea of sending streams of on-off pulses which can be arranged to give a picture is widely favoured for interstellar communication, because of its essential simplicity, and because picture communication overcomes all language barriers. Pulse trains can also convey complex mathematical concepts: computers use the same kind of on-off pulse system, known as the binary code. Many scientists involved in the search for messages from the stars expect that beacon signals from extraterrestrials will be pulsed.

Once the pulses of the Arecibo message are correctly assembled, they portray the following: a counting scheme, five biologically significant atoms (hydrogen, carbon, oxygen, nitrogen, and phosphorus), the component parts of DNA, a schematic view of the DNA double helix, and representations of a human being, the solar system, and the Arecibo dish itself.

The target for the message was a globular cluster of about 300,000 stars called M 13, in the constellation Hercules. Since the cluster is about 24,000 light years away, no rapid reply is expected, even if anyone happens to pick up the transmission. M 13 is just the right size to fill the Arecibo telescope's beam, so that all 300,000 stars were covered simultaneously. The signal was transmitted at the rate of 10 pulses per second on 12.6 cm wavelength (2380 MHz), with a bandwidth of 10 Hz. The chosen wavelength is used by astronomers for radar studies of the solar system, and is not one of the wavelengths particularly favoured for interstellar communication. However, as noted in the previous chapter, signal searchers are now abandoning the idea of special CETI wavelengths and are instead attempting to scan as much of the radio spectrum as possible; presumably aliens listening out for us would also be covering all options in the same way.

The Arecibo message is believed to have been the strongest signal yet radiated by mankind, equivalent to an omnidirectional beacon of 3 million megawatts. In the words of the Arecibo staff, it was intended as 'a concrete demonstration that terrestrial radio astronomy has now reached a level of advance entirely adequate for interstellar radio communication over immense distances'. They added, though, that more extensive attempts at interstellar signalling should not be made until after international consultation, as was agreed by representatives from the US, USSR, and other countries at an international conference on extraterrestrial communications held in Byurakan, Soviet Armenia, during September 1971. Even so, there were criticisms that the Arecibo message had been sent without prior warning to the signatories of the Byurakan agreement.

The Arecibo signal was not the first message for other civilizations to leave the Earth. In March 1972 and April 1973 two spacecraft, Pioneer 10 and Pioneer 11, were launched on deep-space missions to the planet Jupiter, after passing which they would drift out of the solar system towards the stars. Pioneer 11 was later retargeted to look at Saturn, which it was scheduled to reach in 1979, but eventually it too will follow Pioneer 10 out into the Galaxy. Of course, both probes will long have stopped transmitting before they reach any stars – even if they were aimed at the nearest star, and they are not, they would take 80,000 years to get there. (The Arecibo radio message, travelling at the speed of light, overtook the Pioneer probes about an hour after it was transmitted.) But on the off-chance that the probes may one day swim into the ken of some advanced galactic civilization who will retrieve them, both Pioneers carry identical engraved plaques telling something of their place of origin and the people who sent them.

One main part of the Pioneer plaque shows the position of the Sun relative to 14 pulsars. Since any civilization advanced enough to retrieve a space probe will know about pulsars, they will be able to reconstruct the approximate position of the Sun in the Galaxy. The periods of the pulsars are indicated in binary notation; since pulsars run down with age, by comparing the observed frequency of each pulsar with the frequency indicated on the plaque, the receiving civilization will also be able to work out roughly when the probes were sent. Another part of the engraving shows the solar system, with the path of the Pioneers past Jupiter.

But most puzzling of all may be the representations of human beings. What will other creatures make of these? Much debate has been occasioned by the fact that the man has one hand raised in what is alleged to be the universal gesture of greeting and friendship. But it would be foolish to imagine that it would be interpreted so everywhere in the Galaxy; to some other civilization it could be extremely rude. I once encountered a cageful of Rhesus monkeys, who are not too far removed on the family tree from man, and I decided to try them out: I raised my hand to the side of their cage in the universal gesture of greeting and friendship. And they attacked me.

In August and September 1977, the Pioneer probes were joined in space by two probes carrying messages of a different kind: sounds of the Earth on a 12-inch long-playing record. The probes were Voyagers 1 and 2, bound initially for the outer planets but eventually destined, like the Pioneers before them, to leave the solar system and drift forever among the stars.

As with the Pioneer plaques, the man behind the scheme was galactic guru Carl Sagan of Cornell University. His colleagues involved were Frank Drake, Alastair Cameron, Philip Morrison, Bernard Oliver, and Leslie Orgel, in addition to musicians and artists. A record was chosen both because it can contain more information than a simple engraved plaque, and also to commemorate the 100th anniversary of Edison's invention of the phonograph.

Each record, made of copper and placed in an aluminium protective jacket to protect it for over a billion years in space, contains instructions on how it is to be played with the cartridge and needle provided. At their playing speed of 16⅔ rpm, the records last for nearly two hours. On them are spoken messages in 55 languages, samples of Earth sounds, and a selection of music.

The recordings begin with 115 pictures which are encoded electronically into the grooves. Included among the pictures are views of our solar system, diagrams of human anatomy, landscapes of Earth, pictures of various human activities, and examples of human technology such as aircraft, radio telescopes, and space vehicles. Also electronically encoded is a written message from President Carter. Then follow the spoken greetings from around the world and what is described as a 'sound essay' on the evolution of the planet Earth, from the sounds of volcanoes, rain, and surf (all important factors in the formation of life) to animal noises, the emergence of humans (denoted by footsteps and heartbeats), and ending with sounds of technology from the Morse code to launch of a Saturn 5 and the beat of a pulsar. Most of each record is taken up with 90 minutes of music in 27 excerpts ranging from Pan-pipes, a Navajo Indian night chant, and an Australian horn and totem song, through Bach, Beethoven, and Stravinsky, to Louis Armstrong and Chuck Berry. The result should intrigue, or baffle, civilizations throughout the Galaxy in millions of years to come.

The Voyagers are not scheduled to leave the solar system until 1990, travelling at 17 km/sec; ground controllers anticipate that they should still be able to communicate with the probes, if they remain operational, until about 2007, when they will be 15,000 million km distant.

One day we might intercept a similar probe-borne culture capsule from another civilization, and hear what another planet sounds like, or gaze upon pictures of its inhabitants going about their everyday lives. The Pioneer plaques and the Voyager records, like the Arecibo message, are best seen as examples of what might be coming our way, rather than serious attempts at making our presence known to extraterrestrials, for the chances of their being picked up are almost unimaginably slight.

If the Cyclops radio telescope array described in the previous chapter is ever built, we would have a marvellous instrument for signalling to the stars, as well as listening. And in fact, it has been suggested that the forest of 1000 or more giant antennae making up Cyclops be used to beam out messages in between listening projects, each individual antenna being aimed at a separate target. A one-megawatt beacon beaming through one of the 100 m diameter Cyclops dishes with 1 Hz bandwidth could be detected by the 76 m radio telescope at Jodrell Bank over 150 light years away – *if* it were listening in the right direction at the right time on the right frequency. At 0.1 Hz bandwidth the range increases to 500 light years, whereas another Cyclops could detect the 1 Hz beacon at an astounding 8000 light years.

If the entire 1000-dish Cyclops were used en masse to beam a beacon at one star, assuming a total power of 1000 Mw at 1 Hz, its signal could be detected by a suitably tuned omnidirectional antenna at over 150 light years. Thus Cyclops could be picked up at considerable distances by antennae that were not even aimed at it. The Soviet CETI searchers are using just such omnidirectional antennae to listen for incoming beacon signals, and so they stand a chance of success if there are any Cyclops-like transmitters pointed our way.

Britain's Astronomer Royal, the radio astronomer Professor Sir Martin Ryle, in 1976 joined those who warn against the possible dangers of signalling to the stars. Yet there is no way in which we can keep our existence secret from those who are determined to overhear us. Since the 1940s, powerful microwave beams from radar and television transmitters have been leaking out into space. This leakage noise is already slowly washing over the nearest stars like a tide of electromagnetic flotsam. Anyone listening to the right wavelengths with a sufficiently sensitive receiver within a range of about 40 light years will already know that we are here, and would now presumably be flagging for our attention. In the past decade or more, usage of the radio spectrum has moved to ever-higher frequencies (UHF TV wavelengths range from about 70 cm to 35 cm) and to greater powers, so that we have certainly given ourselves away, and will continue to do so for at least the foreseeable future. No one can be sure how long such profligate transmissions will continue, but probably they will eventually be replaced by the more economical direct transmissions from satellites with consequent reductions in leakage.

TV and radio masts do not transmit omnidirectionally. Rather, they are constructed so that their beam is concentrated horizontally, where it is needed; therefore, it goes much further for a given transmitter power. The signals received by extraterrestrials from domestic leakage will be fragmentary, since the rotation of the Earth will regularly sweep the transmitter beam across the extraterrestrial receiving antenna for perhaps only 20 minutes twice a day. But a typical 50 kw TV transmitter could be detected by a Cyclops system, or its equivalent such as a large space antenna, at a distance of about 50 light years; since the same TV channels are shared by several transmitters around the world, the total power being leaked to space increases and the range of likely detection is correspondingly extended to perhaps 100 light years.

Although it is unlikely that anyone will be able to decode our TV programmes, the aliens will at least get an insight into how we split up the radio spectrum for domestic broadcasting and they will also be able to judge our level of military activity from the extent of our radar surveillance. Perhaps the most powerful regular transmitters on Earth are those employed by the military of both West and East. Scottish science writer Duncan Lunan has suggested that some form of message to extraterrestrials could be superimposed on the radar beams. Wider radar coverage of the sky is given by the Space Detection and Tracking system of NORAD (North American Air Defense Command), which keeps track of all objects orbiting the Earth.

Even without a deliberate message embodied on it, radio and TV leakage will reveal the approximate technological level of our civilization. The discovery of d mestic transmissions also solves the wavelength problem for the other civilization: they simply beam in to us at the wavelengths already being used. In 1977, hoaxers broke into a news programme from Southern Television in England with a 'space message' purporting to come from an interstellar craft circling Earth. One day, such a message may be received that is not a hoax.

In some ways, we have more chance of being detected by our leakage radiation than from the occasional transmission bursts suggested for the Cyclops array, because our domestic broadcasts are continuous. Professor David Bates of Queen's University, Belfast, a leading critic of CETI, has shown quite convincingly that flashing a message in turn at each of a large number of stars in the hope that someone is simultaneously listening in our direction leads to impossibly long times before contact is established – perhaps 10 million years or more. The problem is to get the transmitting and receiving antennae pointing in the same direction at the same time.

Radio astronomers Gordon W. Pace and James C. G. Walker have introduced the idea of time markers for interstellar communication – preset instants when transmitter and receiver can simultaneously be turned towards each other. Since there can be no prior consultation between the transmitting and receiving civilizations, a time marker needs to be some event clearly observable to both parties, and Pace and Walker note that just such events occur in binary star orbits when the two stars are at their nearest to each other or farthest apart. The radio astronomers therefore suggest that civilizations orbiting a star in a binary system would choose to transmit at the moments when their parent stars were nearest together or farthest apart, and that we should accordingly listen or transmit to binary stars at those observed times.

As another solution to the problem of when and where to send signals, an American astronomer, William I. McLaughlin, and a Soviet scientist, P. V. Makovetskii, have independently suggested using a starburst like a bright nova as a time marker for interstellar transmissions. As an example, they cite Nova Cygni, the brightest stellar outburst for 33 years, which we on Earth saw in 1975. If other civilizations began to transmit signals as soon as they saw the nova, we can predict when their messages should arrive at the Earth.

On this assumption, signals from Barnard's star would have begun to arrive on September 15, 1978. Signals from a star very similar to the Sun, known variously by its catalogue numbers of Gliese 788, DM +66 1281, or GC 28252, and lying 48.7 light years away in the constellation Draco, would have been expected to arrive beginning August 1978. Signals from Lalande 21185 would be expected in March 1984, from Tau Ceti in January 1987, and from Epsilon Eridani in June 1988. NASA's SETI project could be beginning at a very propitious time.

To ensure that contact is made in the shortest possible time, it seems clear that full-time transmissions to all stars of interest coupled with a large-scale listening project is necessary. One suggested mode of transmission is to have 1000 or so individual aerials, perhaps like the Cyclops array, trained full time on each of the 1000 most likely target stars. But this seems to me an inefficient and wasteful system. A large and expensive array (or, rather, two for we would need one on each side of the Earth to keep track of each star for 24 hours a day) would be devoted entirely to a very limited task, with no guarantee that the right stars had actually been selected. I cannot see us, or any other civilization, using such a system for a long-duration signalling project.

The only way to be sure of covering every possible target is to signal omnidirectionally. It is usually assumed in the CETI literature that some highly advanced civilization is transmitting with an omnidirectional antenna of enormous power, 1000 megawatts or more. But as we have seen, it would take a complete Cyclops system to detect such a beacon at distances out to 500 light years, even with the quite narrow bandwidth of 0.1 Hz. What happens if civilizations are farther apart than this? With a 100 m receiver, the range is only a pathetic 25 light years. Therefore, with current radio astronomy equipment, a 1000 megawatt omnidirectional beacon is undetectable at the likely distances of other civilizations.

Since the intensity of a radio beam falls off with the square root of the distance, to increase the range ten times means increasing the power 100 times, in this case to 100,000 megawatts. Again, I do not foresee that anyone would be using such an immensely powerful omnidirectional beacon, for quite practical reasons: no antenna would be able to withstand the immense voltages involved. It would rapidly break down and put itself out of action.

My argument is that omnidirectional beacons of practicable power are probably not detectable over the kind of distances that separate civilizations; they are certainly not detectable with our level of technology. Therefore, if we do detect a CETI signal, or if we construct a practicable beacon ourselves, it will employ a different strategy altogether – one so far not seriously considered by signal searchers. I believe there is a more efficient CETI strategy than either the fixed-dish or omnidirectional systems which, in a limited form, we could begin today. In fact, I suggest that it may actually be easier to transmit CETI signals to most stars in the Galaxy than it is to receive them, thus placing the onus for advanced technology on the receiving civilization rather than the transmitting one, which is an interesting inversion of the usual assumption.

Should the current searches for messages from the stars described in Chapter 7 draw a blank, I believe that we should consider setting up a long-range transmission system ourselves, on the assumption that someone is waiting for a lead from us. Interstellar communication can never succeed if everyone listens and no one transmits! My own feeling is that the lack of signs of any other life in the Galaxy to date indicates that other civilizations, if they exist, are sparsely spread and that we may need to make ourselves heard over thousands of light years. Perhaps we will never be accepted into galactic culture until we choose to announce our existence. Our first message to the stars will be like the first cry of a baby, announcing our birth.

Nature has simplified the transmitting problem for us because most of the stars in which we are interested lie in the narrow band of the Milky Way, which is centred on the plane of the Galaxy. Therefore we could transmit to most of the stars in the Galaxy by sweeping a radio beam along the Milky Way like a lighthouse beam, and this is the essence of the strategy which I am proposing. To cover nearby stars which lie out of the galactic plane and which would otherwise be missed by such a lighthouse-beam system, we could use some other strategy, such as two relatively low-powered omnidirectional antennas in space, shielded from Earth.

How would we go about setting up such a system with current technology? To begin with, we would call for four radio telescopes, each of the order of Jodrell Bank size; we know that such dishes, with suitable transmitter power, can be detected by their identical twin at several hundred light years' distance. Two of the dishes we set up in one hemisphere. One points at the galactic plane rising at the eastern horizon, while the other points to the galactic plane setting on the western horizon. But we can see only half of the sky from any one point on Earth, so on the other side of the world the other two dishes are similarly poised.

Each dish starts to sweep along the galactic plane from one horizon to the other. Having completed their scan in a few minutes, they begin to swing back. The stars on the galactic plane will therefore be swept by one telescope beam every few minutes. (Using two dishes in each hemisphere keeps the tracking speed down to reasonable proportions while ensuring that each star is swept within a reasonable listening time.) Since the signal will flash across each star briefly, for perhaps a few seconds in each scan, we should probably want to transmit it in the quietest region of the radio spectrum, which is the so-called water hole between 21 cm and 18 cm wavelength mentioned in Chapter 7.

Anyone within range who is patient enough to listen to us for 1000 seconds or so – typically the exposure time discussed for CETI searches – would therefore know we are here. Once they have detected the first flash of our radio beam, they will be able to discover our strategy by listening for further flashes. We could if we wanted modulate a message on our transmissions so that eventually the receiving civilization could extract as much information as though the beam had been continuous. But the basic aim of CETI is initially to make our presence known at the receiving end, and this lighthouse-beam system seems the most efficient strategy for doing so.

Of course, one aerial would cover only a fraction of a degree strip of sky. To cover the full thickness of the Milky Way – about 20° – we would need to build up a system with more dishes. Such a system would look like the aperture-synthesis type of radio telescope as pioneered at the University of Cambridge by radio astronomers under Sir Martin Ryle. In an aperture-synthesis instrument, radio dishes are arranged in a line to synthesize the view of the sky that would be obtained by one large dish whose diameter is equal to the total length of the line. The main difference of the CETI system is that its dishes would be lined up north-south instead of the east-west used for most aperture synthesis telescopes. In this way, the CETI instrument would form what is known as a transit instrument. Such a transit instrument could have powerful astronomical uses; it could also be used to sweep for incoming CETI signals. Since each dish is confined to sweeping the galactic plane, it need not be fully steerable, thus saving costs.

If we assume a beam width of one-tenth of a degree per dish, then a line of 200 dishes is needed to cover the 20° width of the Milky Way. We can therefore signal to the majority of stars in the Galaxy with fewer dishes than proposed for the more limited strategy of using Cyclops as a transmitter. Given that we use two lines of dishes at each station, then with the same 1000 Mw total power as envisaged for an omnidirectional beacon, each dish is fed with 2.5 Mw. As our technology improves we can increase the power, thereby sending the signal ever-deeper into the Galaxy.

Scanning the galactic plane would continue endlessly. Each dish would be rolled into a maintenance shed periodically for overhaul, its place in line being taken by a fresh aerial. One can perhaps compare the construction effort with that of the Very Large Array, the world's largest radio telescope on the plains of New Mexico, which consists of 27 aerials of 25 m aperture arranged along arms 21 km long. During regular observing the 27 antennae are removed one at a time along railway tracks to a central station for maintenance, being replaced by a spare aerial.

For the CETI project, if we wished to encourage international co-operation any number of countries could set up their own dishes to sweep an agreed band of sky. To cut down the number of dishes needed at the start, we might spread the beam out wider in the hope that there is a Cyclops-type collector available to detect us.

By trading off a small amount of time, and not being greedy in the amount of sky that we attempt to cover, we can therefore signal to the stars with almost as much chance of being detected as with continuous all-sky coverage and without recourse to implausibly high-powered omnidirectional beacons.

The drawbacks with such a ground-based system are the mechanical problems involved with continually driving radio dishes along the galactic plane, and also the power needed – although this latter problem is shared by all CETI systems. Both these problems are solved by transferring the lighthouse-beam system into space.

The idea of a spinning CETI beacon in space makes particular sense because once an object in space has been set spinning, it continues unhindered. In space, the entire sky is visible from one spot, which avoids the need for duplicating the system as is necessary in each hemisphere on Earth; and of course there is plentiful free power from the Sun. Construction of a CETI beacon seems an ideal task for the O'Neill colonies.

The beacon would consist of a row of antennae studded along the outside of a spinning cylinder. Since the cylinder is not intended to be inhabited, except perhaps for a residential scientific team or occasional maintenance crews, its diameter can be as small as practicable – say 100 m wide. A cylinder of such small diameter spinning once every few minutes generates only a fraction of Earth gravity, so the antennae can be lighter and simpler than in a comparable Earth-based system. The cylinder's axis will be aligned on the galactic poles, so that the beam from the transmitting dishes sweeps the Milky Way on each rotation. If we assume, as before, 200 dishes of 100 m aperture each, the total length of the cylinder required is 20 km, less than the Island Three design of O'Neill.

The power station for the CETI cylinder will be similar to that used in the solar power satellites supplying energy to the Earth. The 10,000 megawatt total output of such a station, divided between 200 antennae gives 50 megawatts per dish, sufficient for the transmissions to be picked up by a Cyclops at the galactic centre. A CETI colony would be best sited as far away from the Earth as possible, both to reduce interference on Earth and to prevent the Earth from blocking the beam from part of the sky. Probably the best place would be on the opposite side of the Earth's orbit, behind the Sun.

A fully rotating 360° lighthouse beam in space would produce flashes like a slow pulsar. Next century, we could be operating such a beacon, and it does not seem implausible to imagine that civilizations only slightly more advanced than ourselves are already employing such a system. Civilizations of equivalent technical level to our own could already be using the Earth-based version. I therefore conclude that interstellar signalling is possible for civilizations at our level of technical development, which considerably increases the number of potential messages from the stars.

An understanding of the likely strategy of a transmitting civilization gives us a better idea of what to listen out for in our own searches. Although I believe that many civilizations like our own lying in the galactic plane could be using such a system at this moment, their outputs would be more difficult to detect than is normally anticipated for interstellar transmissions, which helps reconcile the fact that no such transmissions have yet been discovered, either by deliberate attempt or accidentally.

However, we can detect these signals once we know what to listen for. We should therefore organize an international radio sky-survey project, like the Carte du Ciel of optical astronomy last century, with each nation allotted an area of sky whose solar-type stars they should survey at likely wavelengths for 1000 seconds or so (15 to 20 minutes) at a time. They should be on the lookout for spikes of energy every few minutes as the lighthouse-beam illuminates us briefly. After rechecking on each star for between six months to a year, to take account of possible eclipse of the transmitting planet by its parent star, we would know whether there were any beacon signals to be picked up. The searchers should be encouraged in their task by the fact that the requirements of interstellar signalling are clearly not as extreme as some pessimists have declared.

There may be many weak radio pulsars with periods of a few minutes that are actually lighthouse CETI beacons being transmitted from O'Neill type colonies around other stars, but they would have gone unnoticed to date because radio observatories do not scan for pulsar periods longer than a few seconds. If such transmissions were detected their artificiality would be immediately evident, both because natural pulsars do not transmit that slowly, and also because of the very narrow bandwidth of the beam.

All CETI projects are based on the faith that communicative civilizations exist simultaneously in the Galaxy. We must proceed on this faith, or not proceed at all. While our efforts are confined to simple listening projects there is no great commitment, but once a civilization begins a signalling project it is committing itself to an essentially open-ended task. Not only must we face the prospect of signalling endlessly, but we must also listen endlessly, too, in case our efforts have triggered a return message. At least the listening can be sporadic, since a reply is likely to be beamed full-time at us for a long period. Once the target has been singled out, all available power can be devoted to sending a complex message of the type described at the end of the last chapter.

An endless CETI commitment may sound daunting at first, but it is no different from many of the other commitments inherent in our society. For instance, public utility companies such as electricity authorities face the fact that their task will continue endlessly, generation after generation, century after century. When we invest with a bank we assume (I hope rightly!) that we are dealing with a permanent institution. Many such businesses are commitments to the permanence of civilization.

A CETI signalling project is a statement of faith not only in the permanence of our own civilization, but also in the permanence of others.

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9

MESSENGER PROBES

Somewhere in space, a message from the stars may be on its way towards us in the electronic brain of a messenger probe sent by another civilization. This is the visualization of Stanford University radio astronomer Ronald Bracewell, who believes that space probes are better under certain circumstances for initiating interstellar communication than a radio beacon.

His argument runs as follows. If life is plentiful – hundreds of millions of civilizations throughout the Galaxy (call this Case I) – then there is no problem in establishing first contact by radio, because civilizations would be no more than 30 light years apart and would each need to scan only about 50 stars before they found evidence of the other's existence. Unless we have been particularly unlucky so far in our listening projects, there seem to be no civilizations this close to the Sun, and we can conclude that the Universe is not inhabited to such a high density.

Therefore we must be dealing with civilizations that are, at best, sparsely distributed in the Galaxy: say, from 30 to 300 light years apart. This, in Bracewell's analysis, corresponds to Case II, where there are perhaps 10 million civilizations in the Galaxy. Case III, where life is rare (only a few thousand civilizations), means that civilizations are so far apart they hardly ever live long enough to exchange a message – although some distant race might occasionally emit a swan song to which it expects no reply.

If Bracewell's Case II corresponds to reality, then a direct radio message is not necessarily the best way of setting up communication. Beyond the 30-light-year range the number of potential targets increases dauntingly, such that there are 1000 within 100-light-years' range, and

10,000 within 300 light years. The implications of these figures apply to all forms of signalling and reception, and are worth considering in detail.

For two civilizations to make contact, one must be listening at the same time as the other is transmitting. This part of the problem can be solved if the transmitting civilization aims to cover all likely target stars with either a permanent beam or a rapidly repeating signal that will be picked up with only a few minutes' listening, as discussed in the previous chapters. Oddly enough, our receipt of a beacon signal would put us at an advantage over the senders: we know where they are, but they do not know where we are. Should we decide to reply, our message of acknowledgement will be arriving at a time unknown to them, from a direction that they are equally unable to predict. Therefore, they must put as much effort into listening for a reply as they do into sending the initial signal – an effort that could last centuries at the very least.

Even assuming that the transmitting civilization is prepared to undertake such an open-ended project, there would be political problems at our end. If the civilization is, say, 100 light years away, two centuries will elapse before we know whether our reply has been picked up: our message, the equivalent of 'Hello, how are you?' will take 100 years to cross the gap, while the other civilization's rejoinder, perhaps something like 'Good to hear you, I'm fine,' will take another 100 years to arrive. In the meantime, we might as well transmit something along the lines of 'Let me tell you more about myself' while we are waiting. But a major project of this sort that will tie up a large radio telescope and considerable amounts of power for centuries on end may not commend itself to legislators on Earth. Clearly, the whole process of establishing radio communication over distances of hundreds of light years is somewhat cumbersome, and is open to pitfalls on both sides.

Bracewell believes that these problems can be avoided by the use of intelligent automated probes as intermediaries in establishing first contact. In principle, it is possible to pack an enormous amount of information into an interstellar probe and send it out towards a likely star. When such a robot messenger encountered another civilization it would be able to converse with them while it relayed news of its discovery across the 100 light years or so to its parent planet. The probe would tell the receiving civilization where to point its radio telescopes so that both civilizations could enter into direct contact with the minimum of wasted effort.

The sending civilization, which Bracewell terms Superon, would naturally need to be patient while its probes reached their targets and awaited the emergence of communicative life. And there would need to be as many probes as there are target stars – up to 10,000 of them within a 300-light-year limit. In the long run, though, it might be more economical to follow this scheme than to squander endless power on an unheard beacon and waste unaccountable hours on searches for a nonexistent answer.

Possibly, Bracewell hazards, our nearest galactic neighbour is already sending out messenger probes, with the Sun as one of its targets. However, if no contact has been established by the time we begin to explore the stars, then it will be our turn to assume the more active role.

Let us follow the fortunes of one probe, sent to investigate a star 100 light years or so from Superon. We assume that its propulsion unit is similar to that of the Daedalus starship described in Chapter 6, so that it travels at one-tenth the speed of light and has a journey time of 1000 years. When the probe arrives at the star, it will swing into orbit within the star's habitable zone. Once there, its instruments may be able to distinguish the most likely planet to support life. Drawing its power from the light of the alien sun, the probe will settle down to listen for the awakening of technological civilization on that planet. The simplest way of detecting technological life on a planet is to listen for leakage radiation from its domestic broadcasts. These would be too faint to be detected by radio telescopes over distances of several hundred light years, but an on-the-spot probe would pick the noise up easily. Of course, even if the planetary system proves sterile the probe will not have been wasted, as its instruments can make scientific observations like those planned for Daedalus.

On arrival the probe sends back its preliminary report on the alien solar system to Superon. Then follows silence from the probe, possibly broken every century or so with a progress report and telemetry on the state of its on-board systems.

But one day, the probe's ever-listening radio ear detects a stirring in the electromagnetic spectrum on the planet within the life zone. This is the sign it has been waiting for. The probe begins to activate its dormant circuits, updates its view of its surroundings, and attentively studies the first chirps of this fledgling civilization.

The first sounds come only sporadically, and at the long-wavelength end of the radio spectrum. But the probe can afford to be patient a few more years yet. Soon, regular broadcasts can be heard weakly filtering their way into space. And then comes a major advance: the transmissions, now much stronger, move into the high-frequency region of the spectrum. Sudden bursts of high power and complex signals carried on very high frequency bands indicate that the civilization is developing radar and TV. It is time for the probe to move into action. How ought it to respond?

Here, the frequency selection problem is simple. The probe simply beams out a signal on one or more of the frequencies that it knows are already in use on the planet below. Somewhere there must be a receiver already tuned to those transmissions. Possibly, the probe's transmissions would be received on domestic radio and TV sets.

What would be the nature of the probe's transmissions? It could beam pure interference, a kind of jamming signal that is bound to be noticed but which would cause inconvenience, consternation, and not a little panic as radio engineers quickly traced the signal to a source in space not far from their home planet. Ronald Bracewell, though, suggests another strategy. Rather than interrupt the transmissions, why not amplify and relay them, thus giving an echo effect? Receivers on the planet would pick up first the direct transmissions, and then the signal retransmitted from the probe, the delay time being seconds or minutes depending on the probe's distance. Such a scheme would not only appear more friendly than an indiscriminate jamming, it would also indicate that the probe is prepared to interact with our transmissions, thus providing a basis for two-way communication.

Once the probe's existence is clear and its position in space has been located, radio engineers on the planet below can begin to converse with it. Firstly, they must change the character of the transmissions which the probe is echoing, so that the probe knows it has been spotted. This would probably happen by sending short radio bursts towards the probe, interspersed with pauses in which it can make its reply. After a short to-and-fro exchange of transmission and echoes, it should be clear to the probe that is has caught somebody's attention.

Next the probe will want to know more about the civilization's technical capabilities. By progressively weakening the strength of its echo, and noting when the civilization ceases to respond, the probe can deduce the sensitivity of the equipment it is dealing with. It can also slowly begin to change the frequency of its transmissions, and see how long the civilization can follow it. By slowly changing the frequency of their own responses, the civilization can guide the probe on to the wavelength that is most convenient for them, allowing the domestic radio channels to return to their normal business. By then, of course, the probe will already have gained a fair insight into the technological level of the civilization it is dealing with, and it will have begun to flash news of its discovery back to the Superon Space Agency, which will be alert for such stop-press news from any of its messenger probes.

Now comes the time for the probe to unfold the messages that it has carried in its computer brain across the

100-light-year gap from Superon. Even without knowing the recipients' language, the messenger probe can put across plentiful information about its home and its creators in the form of pictures. The first interstellar message will therefore come in the form of television, a universal sign language. The probe will either play over a test card until it receives an acknowledgement that the signal is being successfully reconstructed below, or it might obligingly encode its transmissions so that they fit in with the existing TV systems.

Bracewell speculates that the first picture from the probe will be of a constellation of stars that will be familiar to the receiving civilization, followed by a zooming in on the home star. This is the crucial part of the message: it directs attention to the source of future radio transmissions. Another important part of the probe's message would be the correct wavelength and strength of the interstellar signal to be sent by Superon. Of course, no transmissions will be sent until Superon knows that the probe has found life, but the recipient civilization will know how long they have to wait by measuring the distance to the probe's home star. In the meantime, the civilization can develop the technology they will need, or even flash messages of their own.

As the probe's fantastic TV travelogue continues, the home star will become visible as a disk, perhaps with starspots. Around it a family of planets will swing into view until at last the picture zooms in on Superon, the home planet itself. What follows is restricted only by the imaginations of the probe's senders, and the ingenuity of the recipients in reconstructing it. Perhaps the message might include digitized holograms, reconstructable like pictures received from our own space probes, which will give a 3-D picture of the Superonians, their dwellings, examples of their technology, and their works of art. Alternatively, actual holograms may be carried aboard the probe; part of its message may be an invitation to retrieve it from orbit to obtain artifacts stored on board.

The probe's memory banks may contain a simple pictorial dictionary to help us learn Superese, the language of its makers, and to aid it in translating our language. Says Bracewell: 'Knowledge of our language will enable the probe to tell us many fascinating things: the physics and chemistry of the next 100 years, wonders of astrophysics yet unknown to man, beautiful mathematics. After a while it may supply us with astounding breakthroughs in biology and medicine. But first we will have to tell it a lot about our biological make-up. Perhaps it will write poetry or discuss philosophy. Perhaps the messenger knows how the Universe started, whether it will end, and what will happen then. Maybe the probe knows what it all means, but I wonder . . . I think that is why Superon wants to consult us!'

The probe's ability to react quickly to the situation below will help circumvent any political disputes that its presence might spark off. For instance, some governments might wish to keep the probe's information to themselves, and jam the signal if they thought rival governments were likely to gain its secrets. A dumb radio message arriving from afar would be open to such treatment. But the probe knows better. Firstly, it can select who it talks to by dropping its power to such a level that only an international organization such as the deep-space tracking network of NASA could keep in contact with it. Secondly, it can move frequencies to prevent jamming. And it can, if it wants, initiate communications with any transmitting station on the planet. The circumvention of rivalries between nations would be uppermost in the probe's pre-programmed strategy.

The messenger probe scheme clearly overcomes the problem of putting two civilizations in contact. A civilization contacted by a probe can be fairly sure that any response it makes to the home star will be picked up; and it will know that, once the probe's positive report has reached home, there will be more transmissions on the way. What's more, Superon is unlikely to be the only advanced civilization within our range; the probe may tip us off about a number of other communications centres with which we may swap messages. 'There will likely be a galactic club, whose members are experienced at finding developing communities such as ours and inducting them into the galactic community,' declares Bracewell.

Unlike a radio-beacon signal, the probe scheme can be tailored to fit the prevailing economic climate on Superon. Only one probe a year or even less need be sent; the entire programme can be stopped temporarily without upsetting the eventual chance of success, as long as there is always a monitoring station in operation to pick up reports from the probes as they reach their destination. The one drawback is the long time before Superon completes its project; the first report will not come back for centuries, and the final probe will not be launched for millennia. But of course a radio-beacon project must also be measured in centuries or millennia. This is not a criticism, but a fact of life; an interstellar culture must inevitably think in far longer timescales than we are presently used to on Earth. Bracewell's point is that the probe strategy should in the long run be more successful than sending radio beacons *if* life is reasonably frequent throughout the Galaxy.

Is it possible that such a probe entered our solar system long ago, and has been orbiting silently ever since between Venus and Mars? The existence of such a probe, should we ever find it, would be mute but incontrovertible evidence of other beings in space. If there are artifacts on board, designed to survive long after the probe's electronic systems have decayed, we may still learn much about Superon and its inhabitants. Were the Superonians merely keen on spreading life around the Galaxy, they would have crashed the probe on the most habitable-seeming planet (presumably Earth) and released a wide variety of biological samples in the hope that some would take root. There is no evidence of any alien life-forms on Earth.

But could there be a probe out there today, not dead but very much alive and trying to contact us?

One interesting case concerns a US TV station KLEE, channel 2 in Houston, the test card of which was allegedly received on TV sets in England in 1953, years before the advent of communications satellites or even the first Sputnik. What made the achievement even more remarkable was the fact that KLEE-TV had changed hands three years previously, and was by 1953 transmitting under a different call sign, KPRC.

This fascinating case has been thoroughly investigated by radio astronomer Frank Drake, and the explanation is quite clear: it was a hoax which backfired. The hoaxers were two English businessmen who were demonstrating TV sets which they claimed could pick up overseas TV. Strangely, all that ever showed up were call signs – no programmes or moving pictures at all. The hoaxers encouraged gullible witnesses to photograph the signs, including one supposedly from Moscow written in English, and send the photographs to the TV stations for confirmation. Many examples of these photographs are in the possession of station KPRC in Houston, along with considerable correspondence on the matter. The photographs reveal the call signs to be poor forgeries; presumably the call signs were projected inside the actual sets by the hoaxers. When the hoaxers made the mistake of projecting an out-of-date call sign their deception should have been immediately exposed. Instead, it provided another UFO-type mystery for the gullible.

A far better example of the possible 'echo' effect of a messenger probe, and one quoted by Bracewell himself, was the series of curious radio pulses picked up in the late 1920s during early experiments on long-distance radio propagation. In particular, several remarkable sequences of echoes were recorded in October and November 1928 from transmissions made by station PCJJ Eindhoven in the Netherlands. Echoes of varying delay, from three to thirty seconds, were picked up in Oslo, London, and Eindhoven itself. On the face of it, there seemed no explanation for echoes of such long delay – even a reflection from the Moon would have given a delay of only 2.5 seconds, and the echoes would have been far weaker than those actually recorded. One of the remarkable facts about the long-delayed echoes, or LDEs as they came to be called, was that they did not get fainter with delay time, as would have been expected with a simple reflection effect. So whatever was delaying them was also amplifying them.

Since then, radio operators have continued to pick up LDEs sporadically, and the phenomenon has become known as radio's flying saucer effect. Explanations centred around plasma effects in the ionosphere.

Then, in 1972, a Scottish writer, Duncan Lunan, decided to take Bracewell's space-probe suggestions more seriously. When he plotted a series of LDE pulses from Eindhoven transmissions recorded by Jorgen Hals and Carl Stormer in Oslo on 11 October, 1928, he found what appeared to be a star map of the constellation Boötes, the herdsman, with particular attention drawn to the star Epsilon Boötis. Lunan tentatively concluded that the LDEs were being sent by a probe which had come from Epsilon Boötis and which now lay at one of the gravitationally stable Lagrangian points of the Moon's orbit; analysis of LDE events showed that they occurred most often when the Lagrangian points were high in the observer's sky.

This interpretation created considerable interest when published in the magazine *Spaceflight* in 1973. The following year Lunan published interpretations of further LDE 'dot pictures' dating from 1928 and 1929 in his book *Man and the Stars*, supporting the idea that the probe was sent by inhabitants of a planet around Epsilon Boötis.

Epsilon Boötis is a double star, the brighter component of which is an orange giant, swelling up at the end of its life. On Lunan's scenario, the probe was one of many that had been sent out as a last dying gasp by the inhabitants of Epsilon Boötis in search of a new home. However, Lunan later abandoned this interpretation when it became clear that Epsilon Boötis was approximately twice as far as previously believed, which meant that the component stars were both bigger and brighter than previously assumed, and thus too short-lived for life to have arisen in their vicinity. Abandoning Epsilon Boötis as the theoretical star of origin also invalidated the other dot picture interpretations. Lunan has not tried to reinterpret these.

Instead, he has since claimed that Epsilon Boötis would be a prime navigational reference for a starflight from Tau Ceti to the Sun; as seen from Tau Ceti, our Sun would lie in Boötes. In 1975 a Russian astronomer, A. V. Shpilevski, published an alternative interpretation of the 11 October, 1928, LDEs in the Polish magazine *Urania*. By plotting the same dot series in a different way he found a star map of the constellation Cetus, with the star Tau Ceti indicated as the star of origin. Thus, if the star map has any reality, it shows us that the probe came from the nearby star Tau Ceti, from which no radio noise has ever been detected. However, when the same data can be used to 'prove' two mutually exclusive interpretations, this indicates that both results are illusory.

Further problems for the space-probe theory came when Tony Lawton, an English electronics engineer, traced records of LDEs from the Eindhoven transmissions made by Edward Appleton and his colleague R. L. A. Borrow at King's College, London, in November 1928 and February 1929. The Appleton-Borrow LDEs do not yield a star map. It became clear from these records that not every transmitted pulse produced an LDE, whereas some pulses produced a train of LDEs; if the LDEs received on 11 October, 1928, in Norway were not a continuous sequence but had followed a similarly fragmentary pattern, this would be sufficient to destroy the star-map plot. What's more, the LDEs Appleton and Borrow received were a mixture of clear and blurred echoes, which does not sound like the deliberate transmissions of a probe, but could well be the result of natural effects.

Lawton conducted a search for LDEs during 1974 and 1975 with a colleague, Sidney Newton. Most of their work was confined to listening for echoes of existing transmissions, but they also undertook six sending attempts of their own, three using Morse signals and three by transmitting a two-tone frequency that would have been unmistakable had it been echoed. They found that LDEs are very rare; they did not receive one certain LDE during their entire vigil. If long LDE sequences exist like those of 1928-9, they are swamped by other transmissions that flood the airwaves today.

Lawton and Newton developed a natural explanation for LDEs. They propose that LDEs are caused by plasma effects not only in the ionosphere but also in regions around the Lagrangian points, which can occasionally fill with dust and ionized gas; visual observations of faint glows around the Lagrange point areas have been reported. With such a mechanism, the radio waves would pass right out of the ionosphere and into the gas around the Lagrange-point areas (the Trojan ionosphere, as they term it) before being reflected. Effects in the plasma would account both for the delay times and the amplification of the signals. This would also explain the association of LDEs with the position of the Lagrangian points in the observer's sky.

Although Lunan himself now doubts the probe's existence, he has not altogether given up hope. He maintains that the only conclusive test is to retransmit the star-map pattern to the Lagrangian points of the Moon's orbit, which ought to reactivate the probe if it genuinely exists. Accordingly, with colleagues in ASTRA (the Association in Scotland to Research into Astronautics), he plans just such a decisive transmission – 'If only,' as he says, 'to bring the speculation to a close.' But even by the beginning of 1978, these transmissions had not taken place.

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10

CONSEQUENCES OF CONTACT

Humanity may be united by the receipt of that first message from the stars, or it may be irrevocably split. Or, more likely, it will carry on much as before. Over the centuries, civilizations have developed a remarkable resilience to new ideas. Copernicus in 1543 produced the major bombshell of the Renaissance when he asserted that the Earth was not the centre of the Universe, but was instead an ordinary planet orbiting the Sun; this was confirmed by the calculations of Johannes Kepler and the observations of Galileo Galilei. Intellectuals and Churchmen were thrown into a turmoil, but normal everyday life, as far as can be determined, continued unaffected. Last century, the evolutionary ideas of Charles Darwin created a scandal in high society, but were soon assimilated into mainstream thought. In the 1920s, perhaps the most astounding astronomical discoveries of all – that ours was but one Galaxy in a Universe full of other galaxies, and that the Universe as a whole was expanding – passed almost without a ripple. Nowadays, people are actually bored with the idea of men walking on the Moon.

There has been so much cultural conditioning that if extraterrestrial life were eventually discovered it would come as an anti-climax rather than a shock. It is the unknown and the unexpected that cause the greatest surprise, and extraterrestrial contact is not unexpected. Extraterrestrial beings already exist, at least in many people's minds. People seem eager to grasp the concept of extraterrestrials, as though the possibility of mankind being alone has now become the more frightening alternative.

I recall joining an audience of several hundred people at Caxton Hall, London, in 1973 to hear Duncan Lunan describe what he believed might be a radio message from an alien space probe (see previous chapter). The scene reminded me of nothing so much as Professor Challenger's public address on his return from the Lost World, in Conan Doyle's book of the same name. The press had heard of Lunan's ideas, and the meeting had been widely publicized. But there was no panic: no hordes tried to force their way in, and the audience remained calm throughout. A similar religious orderliness prevails at UFO group meetings. From this I can only conclude that people are either thoroughly prepared to meet extraterrestrials, or that they don't believe what they are being told!

When we are faced with incontrovertible evidence of extraterrestrial contact, of course, the situation may be different.

We must distinguish between indirect contact, such as by radio, and direct physical contact, for we react to these differently. A long-distance radio message from the stars would seem relatively innocuous. We are accustomed to receiving graphic new cultural and intellectual inputs via TV and cinema – views of far-off lands, strange people, and curious customs – but are very little affected by them. Personal contact is something different altogether. In 1938 the famous Orson Welles broadcast of *The War of the Worlds* created panic because it seemed as though a physical contact with extraterrestrials was occurring, and a hostile one at that; people perceived an immediate threat, which is not so apparent in a message. In a way, we have already experienced one personal contact which has radically changed the Western world: the arrival of Jesus Christ. His philosophy had more impact *at the time* than the more slowly assimilated ideas from Copernicus and Galileo onwards that have re-cast our views of the Universe (Jesus did not teach any astronomy, incidentally).

Whereas one would expect hordes of sensation seekers besieging the radio observatories at which searches for interstellar signals are being made, there is an almost total lack of curiosity. Perhaps people fear that science facts would spoil their fantasies.

What would astronomers do if they intercepted that first message from the stars? I have quizzed several signal-searchers, and their replies reveal a surprising divergence of opinion. Benjamin Zuckerman and Patrick Palmer, who have used the Green Bank telescopes for the major survey to date, said that they did not initially put a lot of thought into what they would do if a message had been discovered (an admission that they were not expecting to succeed?). Zuckerman says: 'I think that we would try to confirm beyond a doubt that it was a CETI signal before we let the world know about it. I would also think very hard about replying to "them" before we made our results public.'

Patrick Palmer says: 'My desire has always been to handle it as a normal scientific discovery. Our greatest interest would be in understanding the message and communicating, and we would certainly need the aid of many other scientists to do this as efficiently as possible. I believe that it is essentially always wrong to try to withhold basic scientific information.' He dismisses as 'science fiction' any suggestion of government attempts to suppress positive results, noting that in three years of work on signal searching there had been no contact from any governmental agency. 'Since we use a national facility [the National Radio Astronomy Observatory at Green Bank is open to qualified investigators from many sources] rather than our own observatory, keeping something secret is very difficult because of the sheer number of people passing through and the openness of the observatory operation.'

Canadian signal-searchers Paul Feldman and Alan Bridle say they feel the release of CETI information 'depends very much on the apparent content of the message' – an indication of the worries that some scientists feel about the implications of interstellar contact. Carl Sagan, by contrast, says that his first response would be to ask for confirmation of the signal from other observatories, to establish its reality. 'It would be very hard to hide the existence of a message.'

Bernard Oliver has pointed out that dangers do not arise with the detection of a signal, only our response. Before we answer a CETI message or radiate a beacon of our own, he said 'the question of potential risks should be debated and resolved at national or international level.' This echoes the guidelines laid down at the 1971 Soviet-American conference at Byurakan, Armenia, where the participants declared: 'It seems to us appropriate that the search for extraterrestrial intelligence should be made by representatives of the whole of mankind.' By extension, this implies that any conscious signal transmitted should also be the subject of international agreement and co-operation, which was not the case with the Arecibo message (Chapter 8).

Free and orderly dissemination of information about an extraterrestrial contact will be vital to prevent undue confusion and alarm. A fine example of how to handle a potentially explosive situation was provided in 1957 by the Smithsonian Astrophysical Observatory after the surprise launching by the Soviet Union of the first Sputnik. Smithsonian scientists decided to tell the public all that was known; they set up an information centre which held regular press conferences and where experts were able to help newsmen sort out fact from fiction, truth from rumour. This open approach helped dispel much of the fear that the surprise launching inevitably aroused. The need to set up such a reliable information source should messages from the stars be intercepted is paramount.

In 1967, radio astronomers at Cambridge, England, were faced with a similar situation when they detected the flashing radio sources known as pulsars which they at first thought might be interstellar beacons. But the astronomers did not make an announcement until they had studied the objects further and determined their true nature.* A bodged announcement would have caused considerable misunderstanding, as happened in 1973 when

* The Cambridge astronomers were still discussing what to do when it was proved that the signals had a natural origin.

Soviet astronomers revealed that they were picking up signals that might be from extraterrestrials (Chapter 7). Western newsmen and scientists had difficulty in finding out more following this preliminary announcement, which is now believed to have been due to a misinterpretation of natural signals and satellite transmissions. Such a false alarm and the subsequent apparent clamp-down on information do not inspire confidence in the abilities of some nations to handle events should they be the first to detect a message from the stars.

There would doubtless be a wide range of reactions to the discovery of extraterrestrial life. Scientists will regard it as the greatest discovery ever made, outstripping in importance the release of atomic power and the landing of the first men on the Moon, two events whose implications are even now not fully realized. Discovery of lowly lifeforms, such as were thought to exist on Mars, would seem comparatively innocuous; but what about evidence of advanced technological lifeforms?

A radio message, for instance, will have its impact affected by the speed with which the signal is confirmed and decoded. A simple message could be understood immediately, so that the scientists could announce receipt of the first message from the stars and at the same time tell us what it said. But a more complex message would take months or years to decipher; we will first be told that an extraterrestrial message has been received, but only slowly will we learn of its contents as it is decoded and interpreted like an ancient script. This second chain of events would considerably cushion the blow.

Those with the most dogmatic beliefs will be most affected by news of intelligent extraterrestrial signals. Flying saucer cultists would claim it as final confirmation of their unsubstantiated myths – yet it will be nothing of the kind, for visitors do not telephone long-distance if they are already dropping in in person. If we were visited in person, it would allow us to compare real extraterrestrials and their genuine interstellar craft with the shimmering visions of the UFO evangelists. First contact with extraterrestrials may be to the UFO cults what Earth satellites were to the Flat Earthers.

But the profoundest response of all will be religious. People will take new stock of the world and their relation to it, as they had to after the realization in the seventeenth century that the Earth was not the centre of the Universe. Whereas we know that the Earth has no privileged position in space, we do not as yet know that there are beings superior to us anywhere in the Universe; thus, we tend to regard ourselves, albeit subconsciously, as the pinnacle of creation. Discovery of superior extraterrestrials would dent our ego, and we might react out of sheer annoyance at their existence. We would want to try to assert our imagined superiority over the extraterrestrials, particularly if they visited us in person.

Traditional religions will need to re-examine their assumptions. Western religions, in particular, with their focus on Jesus Christ, may be in the biggest trouble of all. Perhaps the major outcome will be a further demystifying of religion, a move from the spiritual to the more material, a weakening of the concept of God in favour of an emphasis on humanism. A man of the cloth sitting next to me in a radio discussion on extraterrestrial life confessed that his main concern was with the quality of alien life – that is, whether the beings were good or evil. But these are human concepts; such ideas might have no meaning to an extraterrestrial, and we must guard against judging the aliens by our own standards. This is particularly true in physical and social terms: a major shock could be something about their appearance or their behaviour (a cannibalistic society, for instance) which is unacceptable or repugnant to us. We all have preconceived notions about the 'right' behaviour which are often shattered by contact with other cultures on Earth. How much greater will the contrast be with aliens? Cultures are shaped by their environment: so other environments, other cultures.

It seems that interstellar signalling is the best way of initiating relations, because it removes the physical threat to both groups of beings. We are, for instance, suspicious of the uninvited caller, whereas one who phones first is more readily accepted. But we have no guarantee that this is how contact will be established. Instead, our first brush with extraterrestrials may be an unexpected visit, and this is where the danger lies. The surprise encounter may come with the unintentional crash-landing of an alien ship or an accidental meeting with a survey team.

Certain of the dangers of a visit from extraterrestrials have been exaggerated, such as the possibility that they would carry us off for food. Anyone embarking on an interstellar mission would be sure to grow their own appetizing food on board, like in the O'Neill colonies, rather than rely on the off-chance of finding something palatable at their destination. In fact, in view of the probable differences in biochemistry on different planets, one good rule would be not to eat anything on an alien planet. To avoid misunderstanding with the natives, another good rule would be not to go prospecting for natural resources in inhabited solar systems. But in any case I cannot see the value of prospecting the Moon, say, for shipment to Alpha Centauri or beyond; advanced civilizations will get their raw materials much nearer home.

One real danger, albeit unintentional, will be that of disease. On Earth, isolated communities have been decimated by relatively innocuous diseases such as influenza introduced by visitors; how much greater might the health danger be from visitors from other planets. For their own safety as well as ours, alien visitors are unlikely to walk around on Earth without spacesuits, or allow us into their craft without similar precautions to prevent the exchange of germs.

One way in which visitors could meet us on more equal terms would be by making contact with a Moon base or space colony. That way, they could be sure of meeting a select, science-oriented group with similar experience of the space environment. With so much in common, rational communication would be eased, and conditions for an in-person meeting would be better than on Earth for representatives of both groups could meet in spacesuits in the neutral territory of space or the lunar surface. Off-Earth contact would help buffer the shock of that first alien encounter, as long as it was carefully handled. Members of a Moon post might feel more apprehensive of the aliens, because of their isolation. Back on Earth, the reaction could be greater because of uncertainty about what was happening, which might lead to a well-intentioned but clumsy 'rescue' expedition that could create unwanted confrontation.

We must assume that anyone who makes such an approach must be friendly, since ill-intentioned visitors would swamp us without introducing themselves, and there is nothing we could do about it. It would need just one spacecraft to poison the atmosphere and the seas to kill or immobilize all life on Earth. Invasion from space is one of those theoretical hazards of life, like possible extinction of living organisms by the supernova explosion of a nearby star.

Some people have urged that we should not transmit radio messages to the stars for fear that this would give our existence away to possibly aggressive extraterrestrials. But an interstellar King Herod, who was intent on stamping out the newborn of the Galaxy, would find us soon enough anyway. Since apes in a recognizably protohuman state were around at least three million years ago, it is reassuring that we have been allowed to progress this far without interference.

I therefore assume that any contact in which we are allowed freedom of action will be a peaceful contact, and it will be up to us to ensure that the contact continues peacefully. The difficulties are immense – imagine, for instance, the alarm of an alien crew surrounded by eager pressmen with popping flashbulbs.

Anthropologists will be the most important intermediaries in a peaceful contact. They will need to explain our culture to the visitors, and discover more about the behaviour and ethics of the visitors, so that neither group offends the other by some unintended rudeness or sacrilege. If nothing else, it will be illuminating to see ourselves as others see us; we may get a few tips on how to improve our social behaviour. Our first attempt at explaining terrestrial culture is contained in the recordings aboard the Voyager probes (Chapter 8). Exchange of such a culture capsule could be a good way of initiating relations with aliens.

But there are more serious problems in the long-term aspects of contact with extraterrestrials. Will contact lead to trade? Or war? Or interrogation? Any form of trade, apart from swapping souvenirs, seems unlikely because of the long distances between stars; freight rates would be too high. War is possible if we perceive some deliberate threat, or if our visitors wilfully ignore our legitimate rights. Living things of all kinds on this planet regard territorial rights particularly dearly; visitors would realize that violating territorial rights is asking for trouble. They would do well to make it clear that they are purely tourists on a temporary visit.

Can two widely dissimilar societies come to a stable and lasting relationship? This is a question which I do not believe it is possible to answer without knowledge of contacts elsewhere in space. On Earth, the evidence is depressing: advanced societies have always swamped the less fortunate. In many cases, such as with the American Indian, cultures have been destroyed, and new forms of government imposed. I do not relish the prospect of our becoming a mere outpost of a galactic empire, ruled from afar like the nations conquered by Rome. We must make it clear from the start that, while we are happy to engage in a limited cultural and intellectual exchange, we do not wish to be colonized – and then hope. Because, in the final analysis, any contacted planet will be at the mercy of its visitors.

Although I have looked at the problem so far as though we were on the receiving end of a visitation, the truth of the matter is that if we do not find evidence of advanced extraterrestrials despite serious efforts at picking up messages from the stars, then first contact will probably be the other way around. As we have seen, in only a few centuries starships could be leaving Earth for Alpha Centauri and all points beyond. In the near future, therefore, *we* will be the Little Green Men entering other people's skies. Looking at the problem this way round gives a better idea of how visitors ought to behave, and what a civilization's response to them might be.

Firstly, we should examine our moral obligations towards any extraterrestrials. Perhaps the first is that we should not attempt to contaminate them with any of our preconceived notions: there should be no interstellar evangelism, but we must accept them as they are. Many cultures on Earth have been destroyed by attempts to 'civilize' the natives to Western standards.

Robert A. Freitas has discussed the basic principles of metalaw, the legal rules which we should apply to our dealings with alien races. Both contactor and contacted will benefit from such a procedural outline. The need to guarantee physical security is the first of these requirements. A second is that we should be careful of contacting another culture that might be unable to cope with the shock of meeting us – the so-called principle of non-interference. Above all, there is the Golden Rule, or the theory of reciprocity: treat others as you would want them to treat you. But is this such a good idea as it seems? Andrew G. Haley, widely regarded as the father of metalaw, thought not, because it implies that our wishes would also be those of aliens, which is not necessarily so. Instead, we must take their wishes into account. So, Haley says, the rule should be: Do unto others as they would have you do unto them.

Austrian legalist Ernst Fasan has formulated eleven rules of metalaw to regulate conduct between aliens. The rules state the rights and obligations of civilizations, including the doctrines that no partners may demand or be required to perform impossible or harmful acts, that civilizations have the rights to their own living space and self-determination, that preservation has precedence over development, and that all societies have the right to defend themselves against the harmful acts of others.

Anthropologist Barbra Moskowitz has also been concerned with our moral obligations towards extraterrestrials. She notes it is essential to practise the doctrine of free choice: that any society must have the right to freely accept or reject any suggestions or advances we may make to them. We must accept their decisions as final. We must observe any civilizations first before we make physical contact with them, so that we know the best way to deal with them and what their reaction to us is likely to be. She terms anthropologists 'cultural interpreters' who will help explain our intentions to the visited group, and defend the aliens by ensuring that we adequately understand their viewpoint. If they consider us a threat, she says, they will send a war leader, or if they consider us a supernatural occurrence they will send a religious leader. 'We must accept the leadership of those designated to deal with us.'

So how do we go about establishing contact? I believe that interstellar signalling is not only the best way of initiating relations with other technical civilizations, but also that it is the most likely, because unless we find some way of cracking the light barrier it will always be easier to send and receive signals than to travel physically between stars. This exchange of messages, which will take centuries or millennia, will give both sides ample time to size each other up. Exchanges at first should be restricted to intellectual matters, such as science and mathematics, but eventually cultural and physical details must follow – these will be both the most difficult to understand and in many ways the most disturbing. We could well find ourselves talking to a computer.

With the directives of metalaw in mind, only when one side clearly indicates that it wishes to meet should there be any physical contact. Therefore, long-range interstellar travel should be undertaken only as an adjunct of interstellar signalling. Anyone out there may be standing off from Earth until they get a come-on signal from us. If so, then they have the same attitude to metalaw as we do.

But of course there are likely to be many inhabited planets around the Galaxy whose citizens do not have the technological ability either to receive our signals or to tell us to come on down. What should we do if we discover these on our interstellar explorations? The principle of non-interference says we should tiptoe away again, for even the most passing contact with aliens is certain to change the entire development of a primitive race. Yet scientific curiosity is sure to be aroused by such a discovery. The social anthropologists will have a field day – new forms of art and expression, new forms of government and personal freedom, all providing a perspective on our own way of life. Perhaps a limited and circumspect survey-cum-contact will be made, but if so it is almost certain to leave no trace. Therefore, if the Earth has been visited in the past, we should not expect to find any sign of it.

For our own safety, we might not want to make personal contact with every new species that we discover. One suggestion, by anthropologist Shirley Ann Varughese, is that we should grade alien societies according to their levels of social and technical development. For instance, we can compare the time it takes for a civilization to reach certain stages of technical development (the technical quotient) with the time it took to reach the same stage on Earth; we can do the same thing for social development (the social quotient). A comparison of their technical and social quotients will give an assessment of their culture. We might choose to steer clear of a society with a high technical quotient (i.e. rapid technical advance) and low social quotient (i.e. slow social advance) – but they will probably be on the way to self-destruction anyway. Fortunately, I believe we will be more likely to find aliens with high social development but low technical development, as in many remote tribes on Earth.

Being the superior civilization in any contact is reassuring, because members of Western civilization, at least, are used to having the upper hand in dealing with people on Earth. We have the luxury of knowing that the maximum freedom of action is ours, and the excitement of knowing that we will have a major influence in what goes on in the Galaxy in future. But such a situation will happen only if advanced technical life is rare in the Galaxy. We may indeed turn out to be masters of all we survey, but we do not yet know that. In fact, the debates about extraterrestrial life and the attempts to detect messages from the stars have assumed the opposite. We may yet find that we are humble in the family of galactic life.

Being on the receiving end of an encounter with life-forms more advanced than ourselves I find somewhat unappealing. Certainly there will be many things we can learn from our superiors, even by radio, but there is a danger that we might be told too much, too quickly. Civilization has progressed by the desire to find its own answers; knowledge that ready-made answers are there for the taking may stifle our own development rather than aid it.

If we do pick up a message from the stars, we must decide whether to respond to it, and how. Who will make these decisions? Perhaps they should be debated publicly, like the issue of genetic engineering. Once radio contact has been made, there is the possibility of personal contact to follow. We must decide whether we want this.

Eventually, although I confess it is impossible to see clearly this far into the future, we will be absorbed into a galactic culture, hopefully to the benefit of mankind. In fact, there seems little point in setting up such a system unless it *is* beneficial: galactic conflict will do no one any good (we would surely have seen clear signs of it by now), and an interstellar empire would be too difficult to administer, if only because of the time taken to send directives.

Whichever way round contact occurs, I believe that, if extraterrestrials exist, contact with them is inevitable. Whatever our misgivings, we must be ready to face the existence of other beings in space. First contact will be the end of our isolation, and it will also be the end of our innocence.

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11

THE CASE OF THE ANCIENT ASTRONAUTS

If there are advanced, star-faring civilizations out in the Galaxy, where are they? The apparently innocuous observation that there are no extraterrestrials on Earth has been turned to make a telling point against those who profess that advanced life is prevalent throughout space. If such beings existed, the argument runs, they would have explored and colonized the Galaxy as we have explored and colonized the Earth.

This line of argument was developed by Michael Hart of the Goddard Space Flight Center in a paper which has caused considerable consternation in the exobiology community – and the gravity of the paradox he points to has been underlined in an independent analysis by David Viewing of the British Interplanetary Society. Hart imagines that we might in the future send colonizing expeditions to all the nearest likely stars – say, those within 20 light years. We would be hopping into space like the Polynesians spreading from island to island in the Pacific. Each of our colonies would eventually send out their own expeditions, which would in turn give rise to more, and so on, creating an ever-increasing cascade of humanity that would spread across the Galaxy like ink over blotting paper.

Assuming that we used starships capable of travelling at one-tenth the velocity of light, as the Daedalus probe described in Chapter 6 is designed to do, the frontier of space exploration would advance on a sphere whose radius increased at one-tenth the speed of light. At that rate, most of our Galaxy would have been colonized in 650,000 years. Even if we slowed things down by assuming that the time between voyages is roughly the same as the duration of a single voyage, say 50 years, then the

Galaxy would still be spanned in less than 2 million years.

The spread of a civilization into the Galaxy has been modelled on a computer by Eric M. Jones of the University of California's Los Alamos Laboratory, building in additional controls on population growth and levels of immigration that a civilization might impose. Even with these restrictions, the results showed that the Galaxy would still be colonized in 5 million years. This seems to indicate that, while it will not take us long to spread throughout the Galaxy, we must be the first (or almost the first) to try it.

A further hint that we may be near the forefront of galactic development comes in a study by an American computer scientist, James R. Wertz, who divided the growth and spread of civilization across the Galaxy into three stages: a slow evolutionary phase; a rapid colonization era; and a period of slow growth or decline as the Galaxy becomes fully inhabited. His suggestion is that the Galaxy is now near the transition between phases I and II. If so, we could soon be leading the spread of life into space.

To the question Where is everyone? Wertz answers: 'Everybody is still at home, looking at the stars and wondering where *we* are.' But N. H. Langton of Robert Gordon's Institute of Technology in Aberdeen is one who feels driven to the dismal conclusion that there can be no other civilizations in the Galaxy at present. The reason, he believes, is that life is so unlikely to reach an advanced stage on two planets at the same time that technological civilizations never coexist; each will have died out by the time the next arises.

It seems to be a widespread assumption that most civilizations have a limited lifespan – they live for perhaps a few thousand or a few million years. Perhaps some reach a plateau where they abandon science and technology in favour of sitting at home uncommunicatively to meditate (or vegetate). Others die out altogether. I find this gloomy assumption difficult to accept. Even the dinosaurs reigned supreme for hundreds of millions of years. Why should advanced civilizations die out? What kills them off? This almost passive acceptance of a cosmic Armageddon seems to deny the natural instinct for self-preservation. Once a civilization has begun to colonize space, does this not insure the civilization against localized catastrophes? On the face of it, there seems no reason why humanity should not exist for ever. Or is there some fatal flaw in evolution that has already condemned us irrevocably to eventual extinction? Biologist Peter Molton has spoken of what he terms Nature's joke on mankind: given no new frontiers, the aggressiveness that gave us civilization will turn inwards to violence and war, a tendency which is perhaps already becoming visible today.

As discussed in Chapter 1, a long average lifetime for civilizations implies that there should be many civilizations around at the moment, and therefore numerous potential interstellar travellers. One line of explanation frequently offered for the absence of extraterrestrials on Earth is that they have chosen not to come here for some sociological reason – either they are keeping the Earth as a space wilderness area or zoo, or they have no interest in space exploration, or their civilization was wiped out before it reached us. But all such attempted explanations must apply to *every* civilization *all* the time – an implausible uniformity in a Universe of such variety. Thus we are led into what we might term Hart's paradox: one cannot have abundant extraterrestrials without abundant evidence for them on Earth.

While the paradox doesn't rule out the existence of simpler forms of life on other planets, it does imply that the factors in the Drake equation governing emergence of advanced technological life have been overestimated. But the conclusion that we are alone or among the first advanced civilizations to arise in the Galaxy is not yet inescapable: a paradox can reveal as well as refute. The famous paradoxes of Zeno and Olbers were resolved by factors not even dimly perceived at the time they were advanced. What Hart's paradox may reveal is that our perception of the problem is far too naïve.

For instance, even if there are one million civilizations like us or more advanced throughout the Galaxy, as the standard calculations suggest, the nearest would still be several hundred light years away. They may never reach here in manned craft because the time involved dissuades them from journeying in person beyond a few tens of light years of home. There may of course be exceptions to this rule, but they will be affected by other factors described below. In any case, interstellar travel is certainly more difficult than sending radio messages. Therefore it should still be worth searching for messages from the stars, even though the chance of a personal visit from the extraterrestrials is very slim.

Would civilizations indiscriminately send manned expeditions to colonize the stars as Hart supposes? The cost and use of materials for space purposes must be justified by any civilization against competition from its other needs. Most likely, the first stages of interstellar exploration will involve unmanned pathfinder probes, like Daedalus or Bracewell's messengers. Only then would manned missions follow, one at a time, to selected targets. Each new colony would not send out its own explorers until it, too, had scouted carefully ahead with unmanned probes – a survey which might take 1000 years or more. At this rate, it would take many times longer than the age of the Galaxy to complete the spread of colonizers, assuming they wanted to saturate the Galaxy, which I doubt.

I presume that any manned interstellar expeditions will not be colonists but observers, like the crew of the USS Enterprise in TV's famous *Star Trek* series. Any colonies that are set up may only be temporary, with the starfarers choosing not to despoil but instead moving on like nomads of the stars.

There may be strong effects of natural selection which mean that nomads are preferred to habitual colonizers: civilizations that do not realize the importance of severely limiting their own numbers soon suffer a population crash, and possibly extinction. Occasionally, civilizations will be forced to move on because of the impending demise of their own star. But there is no reason why they should choose more than a handful of nearby sites to move to, around stars with long-term prospects.

Expansionism need not be the only philosophy for technological life. The lemming-like rush to expand that is current among mankind today is a result of our relatively primitive stage of technological development, although already there are signs of a change. In general, living things on Earth are in balance with their environment, as indeed were the hunting bands of early men on the plains of Africa. A better clue to the true nature of spacefarers may be the stable populations of bushmen and nomadic tribes. Even a civilization that grows only slowly will eventually have to stop once it has colonized the entire Galaxy. But long before that stage is reached it will have made its decision to stabilize.

Finding a suitable new world and setting up a colony there may be far more difficult than we suppose, particularly since the most welcoming planets are likely to be inhabited. In search of a solution to Hart's paradox, astronomer Laurence Cox of the Hatfield Polytechnic Observatory has pointed out that our bodies need 20 specific amino acids, not all of which might be available on other planets. Hart's argument assumes that our biochemistry is typical of living things throughout the Galaxy, yet such a requirement would by itself severely limit the number of likely civilizations in space. Unless there is some reason why our biochemical make-up should be favoured, alien plants or animals will likely have little food value to us, or will be poisonous. Another problem is the danger of disease from micro-organisms in air or water. Even subtle matters such as the percentage of oxygen in the atmosphere would affect our physical efficiency. The product of billions of years of evolution on one planet is entitled to feel ill at ease if transferred to an alien biosphere. Establishing artificial biospheres on sterile planets or in space arks would be a solution, but would add greatly to the difficulty of setting up home around a new star.

In a direct answer to Hart's paradox, Cox notes that a population growing at our current rate would soon outstrip the rate at which it could colonize new planets. For us to populate one planet around each star in the Galaxy to the current density on Earth in the 650,000 years envisaged by Hart would require that our population double in not less than 20,000 years, as against 30 years now. Cox concludes that by the time any society reaches the stage of interstellar travel it will already have had to stabilize its population, and the paradox, which assumes continued expansion, is avoided.

Further considerations have been voiced by David Stephenson of the Institute of Space and Atmospheric Studies of the University of Saskatchewan, who notes that the timescale of millions of years required to colonize the Galaxy is also the timescale of evolution. Over the course of galactic colonization, one would expect strong evolutionary effects to become noticeable – think, for instance, of the evolutionary changes in man over the past few million years. It is probable, says Stephenson, that the inhabitants of a starfaring vessel will be adapted to deep space travel. The resulting creatures will be physically very different from ourselves, and would actually find planetary living uncomfortable or even hostile. Although the space creatures may pay temporary visits, they would be unlikely to colonize.

Furthermore, the limited space and consumables on interstellar ships means that such travellers would need total control over reproduction – they would, in fact, be conditioned to living in an environment of zero population growth. Starfarers will not only be physically different from us, but also culturally so: their motivation is purely one of curiosity, not of expansion and demand for new resources that has so far governed human spread on Earth.

As elaborated in previous chapters, it is more likely that intelligent machines will undertake interstellar exploration rather than humans. Such an intelligent visitor could be living in the solar system now – and, being a machine, it would survive happily in space without the need to colonize a planet. Perhaps the whole Galaxy has by now been scouted by intelligent machines, and only in a few instances have biological creatures followed.

My conclusion, then, is optimistic. I do not think that the absence of extraterrestrials on Earth today is proof of their total absence in the Galaxy. Rather, I would interpret it as supporting evidence that civilizations stabilize their growth and do not colonize.

Conceivably we have been visited once or many times in the past by interstellar nomads, none of whom chose to stop. If, by chance or design, we were visited relatively recently, the signs of the visit might still be evident in artifacts and legends. Some writers claim that such evidence exists. Others maintain that the extraterrestrials are here today, and we see them (or their craft) in the form of UFOs. This means that we have tangible messages of other civilizations from the stars. We shall examine these popular assumptions in this and following chapters.

Best-known evangelist for the belief in visits from ancient astronauts is Swiss author Erich von Daniken, whose books on the subject have consistently outsold all other authors on the same theme. Von Daniken's thesis, nowhere better exposed than at the end of his fourth book, *In Search of Ancient Gods*, is that the emergence of true man, genus *Homo*, from the apes occurred with the help of genetic manipulation by aliens. He speaks of a 'sudden' advance in intelligence.

Actually, fossil evidence reveals that the earliest known members of *Homo* lived at least 3 million years ago. Yet, according to von Daniken, Earthlings of only a few thousand years ago were still so dim that they needed alien help to build the Pyramids and the Inca cities. Apparently another round of genetic improvement was called for at that time. But there is no evidence of any changes in man's physical or mental capabilities for at least 10,000 years, since the time of the Neolithic revolution; the only changes have been cultural ones. Even put at its clearest, von Daniken's theory is confusing and contradictory.

Von Daniken's success is due not to any originality of evidence, since all the authors in this field cite much the same examples (mostly quoting each other). Rather, it is due to his highly effective style of writing (or rather that of his rewrite man, Wilhelm Roggersdorf). One feels that this tendentious style would have made him a fearsome advocate in court had he taken to the legal profession.* And it is on a courtroom analogy that his work is best judged. When all the evidence is taken into account, does he prove his case beyond a reasonable doubt?

Avid von Daniken readers will have spotted many examples of his persuasive style by which, without saying anything wrong or making a definite statement, he nevertheless draws you, the jury, to the conclusion he wants – usually by means of the rhetorical question. I shall cite one example, from *Chariots of the Gods*:

> 'Various people knew the technique of embalming corpses, and archaeological finds favour the supposition that prehistoric beings believed in return to a second life, i.e. a corporeal return. Drawings and sagas actually indicated that the "gods" promised to return from the stars in order to awaken the well-preserved bodies to new life. Who put the idea of corporeal rebirth into the heads of the heathen? And whence came the first audacious idea that the cells of the body had to be preserved so that the corpse, preserved in a very secure place, could be awakened to a new life after thousands of years?'

Overlooking the pejorative term 'heathen' here, let's

* Alas, this talent did not prevent his conviction in 1970 for embezzlement, fraud and forgery.

look at the technique used by the Egyptians for mummification. First, the brain was pulled out through the nostrils by tweezers. Then the skull was filled with resin. The vital organs were removed, and the body coated with embalming fluid which solidified so that it would later have to be chipped away by hammer and chisel, or heated to 500°C to melt. To borrow von Daniken's rhetorical technique: does this sound like the preparation for the reawakening of the dead?

There are many examples of religious drawings and stylized wall paintings or sculptures shown by von Daniken that seem to depict astronauts in spacecraft and spacesuits. Of all these, perhaps the best known is the so-called Great Martian God, a cave drawing discovered in 1956 by the Frenchman Henri Lhote at Tassili in the Sahara. Lhote described the figures as dressed in a ritual mask and costume, part of an artistic tradition known as the period of the round heads. But in the 'ancient astronaut' books the expert witness is not called to give evidence that puts the drawing into context, and it becomes a mysterious portrayal that can only be of a man in a space helmet.

Perhaps the 'Martian god' is not very convincing; neither is the 'Palenque astronaut', an engraving on the lid of a tomb that contained the bones of the Mayan king Pacal. Altogether more impressive is the famous Piri Re'is map. This is a map of the Atlantic Ocean and its surrounding continents, which belonged to the 16th-century Turkish admiral Piri Re'is, and was discovered in the Topkapu Palace, Istanbul, in 1929. Von Daniken claims that the coasts of North and South America and even the contours of the Antarctic are 'precisely delineated' on this map. His theory: that the map was drawn from aerial photographs taken by a spaceship hovering above Cairo.

The truth is a little more mundane. According to expert cartographer Charles Hapgood, large sections of the South American coastline on the Piri Re'is map are missing. Hapgood does not have a very high opinion of the accuracy of the map, and certainly does not suggest it was made from aerial photographs, although von Daniken gives exactly the opposite impression in *Chariots of the Gods*. The moral here is – always check with the original source.

Careful comparison of this exhibit with modern maps reveals other embarrassing discrepancies. Cuba is misshapen and misplaced; it is impossible to confidently identify the Amazon or the River Plate; and Antarctica does not even appear. Instead, the coast of South America meanders across the bottom of the map as though the cartographer had lost his bearings. For the result of a space-borne survey, it is feeble – although as an example of the work of early navigators it is impressive.

In fact, the Piri Re'is map looks remarkably like other charts of the time known as portolans, which were made from compass bearings and distance estimates. As on other portolans, the Piri Re'is chart contains two mother compasses, plus several smaller ones, for picking off magnetic headings. The chart naturally becomes distorted down the coast of South America because of the increasing angle of divergence between the magnetic and geographic poles, and the mariner's uncertainty of his actual distance travelled. The Piri Re'is chart is dated 1513, and is a compilation of several earlier maps going back to Columbus. In 1569 Gerhardus Mercator invented his famous Mercator projection, and considerably better charts were soon being produced. But no one suggests that these were the work of extraterrestrial visitors.

The ancient 'batteries' found near Baghdad that von Daniken marvels over may be examples of very primitive electrical cells, possibly used for electroplating at about the time of Christ. A replica was tested in 1960 and produced half a volt of electricity for 18 days – impressive for 2000 years ago, but hardly of use to advanced space voyagers.

The lens from 700 B.C. in the British Museum which von Daniken says in *Chariots of the Gods* needed 'a highly sophisticated mathematical formula' to grind is in fact a piece of natural crystal polished around the edges.

The rustproof pillar near Delphi which von Daniken says is made of 'welded parts' and of an 'unknown alloy' is actually a single piece of pure iron – the result of advanced, but nevertheless terrestrial, metallurgy of about A.D. 500. In an interview with *Playboy* magazine in 1974, von Daniken admitted that new investigations had made him change his mind – 'so we can forget about this iron thing'.

Von Daniken's vivid imagination plays freely over Mayan drawings and carvings. As he so rightly says in *In Search of Ancient Gods*: 'So far only a minimum number of the Mayan picture writings has been deciphered, so there is plenty of scope for my assumptions.' This is the whole problem: too much fantasy, too few facts. Never has von Daniken given the game away so clearly.

Von Daniken makes accurate statements and then contradicts them, as in this example from Chapter 6 of *Gold of the Gods*: 'The oldest demonstrable remains of forms of life on Earth were discovered in 3.5-billion-year-old sedimentary rock in the Transvaal, South Africa [true]. Their stage of development corresponds to that of the blue algae living today [true]. But 3.5 million years ago there was no kind of organic life on our planet' [contradiction].

In *Chariots of the Gods* he notes correctly that the Pyramids were apparently aligned on astronomical objects and that the Egyptians had an accurate calendar based on the rising of the sky's brightest star, Sirius. Then he claims in contradiction that we have 'very little evidence of an early Egvptian astronomy' and wonders why they were interested in Sirius! (For another hypothesis concerning Sirius see Chapter 12).

He does not suggest extraterrestrial influence on the building of Stonehenge and other megalithic monuments which are aligned astronomically and actually predate the Pyramids; evidently he accepts the Europeans were advanced enough to understand astronomy, while the Egvptians were not. This highlights a curious bias in von Daniken's world coverage: European examples are missing. They're too familiar. The omission is strange, for the achievements of European cultures as for instance documented by Colin Renfrew in his book *Before Civilization* were in many cases more advanced for their time than any of the examples von Daniken quotes.

In *Chariots of the Gods* von Daniken scoffs at archaeologists who claim that the Pyramid builders pulled their stone blocks by ropes over wooden rollers, both of which he asserts were 'non-existent'. But friezes of the period show . . . Pyramid builders pulling stone blocks over wooden rollers. Ropes have been found in the quarries from which the Pyramid stones came, and the Egyptian trade in cedar logs from the Lebanon is well documented.

Von Daniken overlooks the fact that the building of the Pyramids was no overnight affair, but was a slow process developed over many centuries. The first Pyramid, that of Zoser, was built in a step shape. The second was built at too steep an angle and collapsed, so the third, which was under construction at the time, had its angle of slope changed, producing the celebrated Bent Pyramid. Such disastrous mistakes do not seem the work of highly advanced 'gods' from space.

Skipping continents and coming 3000 years forward in time, von Daniken draws attention to the precision jointing of stone walls built by the Incas in South America. But equally fine stonework, such as the Colosseum in Rome or the Parthenon in Athens, was being undertaken in Europe over a thousand years before the Inca cities were built. The medieval cathedrals of Europe with their astounding stonework are contemporary with Inca civilization, and what's more they contain soaring arches which von Daniken's 'gods' never taught the Incas. Von Daniken omits dates, confuses cultures, and deliberately underestimates the abilities of ancient peoples, particularly those who seem strange and remote to us.

Another example of von Daniken's cavalier treatment of the facts concerns the markings on the plain of Nazca in Peru. The marks have been made simply by removing the brown stony surface of the plain to reveal the lighter-coloured soil underneath. Though no one (except von Daniken) seems quite sure of their purpose, archaeologist Maria Reiche who has made a lifelong study of them is convinced that astronomical alignments, like those of the earlier European megaliths, are at least partly involved. Many of the figures drawn on the plains are representations of animals, apparently portrayals of constellation figures that played important parts in Inca mythology. Yet von Daniken interprets the markings as aircraft runways and landing bays. Why advanced spacemen with technology far in advance of that which set our own Lunar Module on the Moon should need gigantic markers and aircraft runways eight miles long is left unexplained. But what is clear is that no aircraft, or any other craft, ever set down here. Had it done so, it would have left its own indelible markings in the loose desert surface, like the tracks left by vehicle tyres today.

Perhaps von Daniken's most outrageous misrepresentation is if the work of Thor Heyerdahl on the Easter Island statues. To von Daniken, these gigantic statues carved out of volcanic rock could only have been the work of spacemen, blatantly ignoring the fact that Heyerdahl had filmed the entire process of cutting and erecting a statue, which proved that it could be done by the existing population of the island without outside help. Heyerdahl long remained silent, in the belief that, as he says, 'anyone stupid enough to take this kind of hoax seriously deserves to be cheated'. But in a recent critique of the works of Erich von Daniken by Ronald Story, *The Space Gods Revealed*, he published an open attack on what he termed the 'entertaining fiction' of von Daniken:

> 'The general reader who cares to know has the right to be informed that there is not the slightest base of fact in what von Daniken writes concerning the origin of the giant statues on Easter Island. We know exactly how they were carved, where they were carved, why they were carved, and when they were carved. To

gether with my colleagues I am to blame for not promptly having used the modern mass media for telling the public not to take his references to Easter Island seriously.'

Jetting around the world in search of archaeological mysteries, or scampering after celebrities to snatch a tape-recorded interview, von Daniken presents an engaging naïvety that has undoubtedly contributed considerably to his popular success. His audience, no more able to test his theories than he is, doubtless admire his brazenness in stepping so firmly on so many toes – and there is, of course, an overwhelming reaction that anything expressed so confidently in print *must* be right. But, in omitting so much of the evidence, he does not give his readers a chance to judge for themselves how accurate or plausible his assertions are. Unless his audience is willing to become experts on archaeology and astronomy, they must take von Daniken's views on trust: counsel for the prosecution, without one for the defence.

Von Daniken's most celebrated case is that of the mysterious underground tunnels with glazed walls in Ecuador containing golden treasure, which he describes in *The Gold of the Gods*. Von Daniken vividly recounts his descent into the caves, led by his Ecuadorian guide Juan Moricz who, says von Daniken, stopped him from taking photographs. Therefore we never actually see the supposed treasure hoard; and the pictures of the tunnels reproduced in the book are apparently someone else's. But this does not seem to matter, because von Daniken next shows photographs of this 'Inca treasure' in the possession of Father Carlo Crespi, a Catholic priest of the Church of Maria Auxiliadora in Cuenca. According to von Daniken, the Indians bring to Father Crespi the most valuable gold, silver, and metal objects from their hiding places, and have done so for decades. These ought to be of the greatest archaeological importance, for they contain a previously unknown Inca script. So what's wrong here?

The German news magazine *Der Spiegel* tracked down

Juan Moricz, the Ecuadorian who, von Daniken claimed, had personally conducted him through the caves on his purported visit so vividly described. But Moricz denied that von Daniken had ever been in the caves.* Instead, Moricz said he had only taken von Daniken to a blocked side entrance. There Moricz was pumped for all the information he had, which von Daniken later passed off in loving detail as his own experiences. Von Daniken admitted his lie on a BBC television documentary in the *Horizon* series, broadcast in November 1977. He said that his invention of the story was 'not important' and appealed to artistic licence. Yet this story is contained in a book which begins: 'It could easily have come straight from the realms of science fiction if I had not seen and photographed the incredible truth in person.'

Of course, if von Daniken had real evidence he would not need to hoodwink the public.

I have been in similar caves: gigantic halls that stretch far underground, with shiny walls so smooth that they could never have been polished by the primitive men that lived in them. They have an eerie ventilation system that keeps the temperature remarkably constant all year round, like the controlled environment of an underground shelter. Strange, glazed shapes decorate the walls, ceiling, and floor as though carved from the very rock by processes that we could not imitate with our technology today.

The caves are at Cheddar Gorge and Wookey Hole in England. They were formed by the natural action of water, as were the glazed walls and the stalactites and stalagmites that adorn them. According to the BBC *Horizon* programme, a British expedition to the Ecuadorian caves in 1976 found them to be natural in origin, with no sign of any gold valuables.

Archaeologist Pino Turolla of Miami, Florida, has reported that the 'gold treasure' of Father Crespi is crude

*The exposé was featured on the front cover of *Der Spiegel* as 'Der Daniken Schwindel', which scarcely needs translation.

metalwork made from tin and brass by the local Ecuadorian natives, who trade it to him in return for food and clothes. Crespi, although lovable, is a somewhat eccentric and unreliable old man. Turolla says he has seen a copper toilet-cistern float among Crespi's 'gold of the gods'.

The 'Inca writings' on these cheap imitations are present-day doodles. Von Daniken reproduces in his book one embossed metal plate showing an Egyptian-style pyramid attended by two elephants which, as he rightly says, 'the artists could not possibly have seen in South America around 12,000 B.C.'. As with the KLEE-TV hoax reported in Chapter 11, such a glaring anomaly should immediately have revealed the truth. But instead, it is presented as an added 'puzzle' to impress the credulous.

Von Daniken, who cheerfully describes himself as a 'Sunday archaeologist', presented further exhibits from Peru on a BBC television programme, *Tonight*, in 1976. He showed slides of small carved stones, apparently predating the Incas, which depict advanced surgical knowledge, including heart transplants and blood transfusions, being performed under anaesthesia. The Museum at Ica in Peru contains thousands of these stones which, surprisingly for such valuable archaeological specimens, are also on sale in unending supply to tourists.

The BBC *Horizon* investigation the following year cleared up the mystery. These again are modern artifacts made by the locals. A local stoneworker admitted he had made all the carvings, taking his ideas from newspapers and magazines. He carved a 'heart transplant' design for the cameras. The dark weathered look of the stones is obtained by baking them in donkey dung and blacking them with boot polish. The *Horizon* team took a stone from the Museum along with their specially made 'heart transplant' stone for analysis at the Institute of Geological Sciences in London. Scientists there confirmed that the sharpness of the etched grooves and the lack of weathering on the stone from the Inca Museum meant that it had been carved recently, and was the same as the 'fake' stone carved for the cameras.

It seems pointless to continue.

'Von Daniken's books are not written to persuade the informed reader. They are a romanticist's fiction,' notes Stanford University radio astronomer Ronald Bracewell. 'Von Daniken's books tell us not about the ostensible subject matter but about the society which buys them so eagerly. For those who need certainty and stability in a world of jolting change and ambiguity the attractions of von Daniken's books are that they are understandable and are presented vividly with firm conviction. They represent a substitution of faith for reason. Unfortunately, they can offer only a brief haven as they are so vulnerable to criticism.'

One of the major problems faced by exobiologists is to understand how creatures became highly intelligent and technologically advanced. Ascribing it to the influence of ancient astronauts is no solution; that simply transfers the problem elsewhere. The 'gods from space' approach hinders understanding of human development rather than helps it.

One point is clear. The stonework of South America, the Easter Island statues, the Pyramids, or even Stonehenge, while impressive structures, are all state-of-the-art technology for the human civilizations that built them. Visiting spacemen or 'gods' do not work in stone. They use metals and plastics.

For an extraterrestrial artifact to be convincing, it must be clearly out of place – for instance, a transistor radio embedded in a block of clear plastic, which examination would show was beyond even 20th-century technology. The existence of remarkable stone structures on Earth proves nothing about the existence of extraterrestrials. But perhaps far better clues than these to possible visitations in the past are to be found in ancient legends of various peoples – and it is one such suggestion that we turn to next.

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12

THE AMPHIBIANS OF SIRIUS

Amphibious beings from the star Sirius, 8.7 light years away, visited the Earth 5000 or more years ago, leaving advanced astronomical knowledge that is still possessed by a remote African tribe. That is the startling essence of perhaps the most puzzling of all ancient astronaut stories, first popularized by writer and orientalist Robert Temple in his 1976 book *The Sirius Mystery* and since adopted by Erich von Daniken. At the centre of the mystery are the Dogon people living near Bandiagara, about 300 km south of Timbuktu in Mali, west Africa, knowledge of whose customs and beliefs we owe to the French anthropologists Marcel Griaule and Germaine Dieterlen, who worked among the Dogon from 1931 to 1952.

Between 1946 and 1950 the Dogon head tribesmen unfolded to Griaule and Dieterlen the innermost secrets of their knowledge of astronomy, which is shared by the neighbouring peoples the Bambara and the Bozo. Much of this secret lore is complex and obscure, as befits ancient legends, but there are certain specific facts which stand out. For instance, the Dogon know that Jupiter has four moons, that Saturn has rings, and that there are endless stars in the sky. They know that the Earth spins on its axis and that it, along with the other planets, orbits the Sun. Motions of objects in the sky are likened by the Dogon to the circulation of the blood, about which they also seem to have remarkably detailed knowledge – including references to the process of respiration and digestion and of red and white blood cells.

But their most remarkable knowledge concerns the star Sirius, with which their religion and culture is deeply concerned. In their information imparted to the French anthropologists, the Dogon refer to a small and superdense companion of the star Sirius, made of matter heavier than anything on Earth, and moving in a 50-year elliptical orbit around its parent star. Sirius does indeed have a companion star answering this description: a white dwarf invisible without a telescope. The white dwarf companion of Sirius was not seen until 1862 when the American optician Alvan Graham Clark spotted it while testing a new telescope. But the Dogon tradition concerning a companion of Sirius indubitably extends back thousands of years, well before any terrestrial astronomer could have known of its existence, let alone its composition and orbital details. How can we account for the remarkable accordance between the ancient Dogon legends and modern astronomical fact?

A Dogon legend, similar to many other tales by primitive people of visits from the sky, speaks of an 'ark' descending to the ground amid a great wind. Robert Temple interprets this as the landing of a rocket-powered spacecraft bringing beings from the star Sirius. According to Dogon legend, the descent of the ark brought to Earth an amphibious being, or group of beings, known as the Nommo. 'Nommo is the collective name for the great culture-hero and founder of civilization who came from the Sirius system to set up society on the Earth,' explains Temple. Why should the Nommo be amphibians? He notes that amphibious beings would have an advantage on a planet around a hot star like Sirius, because the water would keep them cool and also because water absorbs the dangerous short-wavelength radiation that hot stars like Sirius emit more strongly than the Sun.

Temple equates the mythical Nommo with the fish-god Oannes whom the Babylonians credit with the founding of their civilization. This similarity between Dogon traditions and those of Middle Eastern or Mediterranean civilizations is no surprise, as the Dogon share common cultural and physical roots with those peoples. The ancient Egyptians were also preoccupied with Sirius; they even based their calendar on its yearly motion around the sky. That fact is easily explained without recourse to ancient astronauts, because Sirius is the brightest star in the entire sky, easily visible from Mediterranean regions. The first observable rising of Sirius before the Sun (termed the heliacal rising) marked the beginning and end of each Egyptian year; it also coincided with the agriculturally all-important flooding of the Nile. No wonder that the Egyptians accorded Sirius such respect, regarded it as re-vitalizing life on Earth, and embodied it in their legends. Sirius would be assured of this honoured place in Egyptian and Dogon belief irrespective of Temple's ancient astronaut theory. So is there any independent evidence of life around Sirius to back up Temple's interpretation of the Dogon legends?

First, let's look at Sirius and its companion star, based on what we have already said about stars and planets in this book, to see if it is at least theoretically plausible that advanced life might have arisen in the Sirius system. Sirius A, the bright white star we see from Earth, has a mass 2.35 times that of the Sun. Its white dwarf companion, Sirius B, has a mass of 0.99 Suns. Stellar evolutionary theory tells us that the most massive stars burn out the quickest, so that originally Sirius B must have been the more massive star, before burning out to become a white dwarf. Probably Sirius B spilled over some of its gas on to Sirius A during its ageing process, so that the original masses of the two stars were approximately the reverse of what we see today.

Let us assume that Sirius B initially had a mass at least twice that of the Sun (it could have been more), while Sirius A had about one solar mass (the sum of their masses must have been at least 3.35 Suns, which is their mass total today). A star with twice the Sun's mass lives for no more than about 1000 million years before swelling up into a red giant, as the Sun will do at the end of its life; this does not seem long enough for advanced life to develop. Even if life had evolved, the red giant stage of Sirius B would have led to its disappearance. As the star swelled up there would be changes in climate on any nearby planet, followed by a stellar gale between the two stars as hot gas streamed from Sirius B on to Sirius A. Theorists calculate that during this mass transfer the two stars would have moved apart, so that they were originally much closer than we see them today.

Astronomer Stephen Maran of NASA's Goddard Space Flight Center has reviewed information on Sirius, and finds from spectroscopic observations that the surface layers of Sirius A do indeed seem to have been contaminated with material from Sirius B. Perhaps Sirius B lost more than half its original mass. Some of its gas would have been lost for ever into space, but much of it would have been claimed by Sirius A, roughly doubling that star's mass and leaving the core of Sirius B as the burned-out white dwarf we see today.

There is an interesting additional problem here. Astronomers of Ptolemy's time, 2000 years ago, referred to Sirius as red, when we know it to be almost pure white. Is it possible that they were seeing the end of Sirius B's red giant phase? And it is possible even that the Oannes/Nommo creatures came to Earth many thousands of years ago to escape the impending doom of their home star? Alas, this charming speculation is not supported by facts. For one thing, theorists calculate that the mass-transfer phase between the two stars would have lasted at least 100,000 years, and could have taken millions of years. The most reliable observations of the size and temperature of Sirius B, analysed by theorist H. L. Shipman of the University of Delaware, show that it must have been a cooling-down white dwarf for at least 30 million years. Probably the Greeks described Sirius as red because they observed it close to the horizon, where atmospheric effects make it glint red.

If we are to take the Dogon legend at face value, it seems that the Nommo visited Earth after Sirius B became a white dwarf. But it is even less likely that life could have arisen in the Sirius system since that time. Sirius A can only live for a few hundred million years in its present form before it, too, burns out (and its own red-giant death will be a spectacular thing to see from Earth).

There has not been time for life to arise in the Sirius system since Sirius B became a white dwarf. In any case, life there now would not be too healthy, for Dutch X-ray astronomers have found that the Sirius system emits soft X-rays, which H. L. Shipman has demonstrated must originate from deep in the layers of hot gas around Sirius B. And to cap it all, Robert S. Harrington of the US Naval Observatory has shown that habitable planets cannot exist in stable orbits in the Sirius system.

In short, astronomical evidence argues strongly against Temple's ancient astronaut theory.

With this information in mind, let's now look in more detail at the Dogon legend. Immediately, we encounter a surprise: Dogon legend maintains that Sirius has *two* companions. This belief comes not from astronomy but from an important concept of twinning which the Dogon and their related peoples apply to many objects, not just to Sirius. According to the twinning concept, two companions representing the male and female sexes accompany Sirius like the two horns either side of the head of an animal. On the BBC-TV *Horizon* documentary on ancient astronauts Madame Dieterlen showed centuries-old Dogon ritual masks to illustrate this concept. The masks consist of a head with horns, the head representing Sirius and the horns the two companions. Also on the masks are symbols representing Sirius and its two companions, one either side.

The companion identified as Sirius B is called *po tolo*, which the French anthropologists Griaule and Dieterlen term the Digitaria star (*tolo* means star, and *po* is the Dogon name for a cereal seed which is known botanically as *Digitaria exilis*). The second star is *emme ya*, Sorghum-female, which according to Griaule and Dieterlen is the seat of the female souls of all living or future beings. Digitaria assumes the greater importance of the two Sirius companions because it has a symbolic association with the male circumcision ceremony. As in so many cultures, the complex Dogon mythology is largely concerned with male-female sexuality (witness the attributes of Digitaria and *emme ya*) and of fertility. Sirius has been associated with creation and revitalization since the time of the ancient Egyptians, so that these attributes are scarcely mysterious.

Is there any astronomical evidence for a third star in the Sirius system? Several astronomers in the 1920s and 1930s suggested the existence of a possible third star because of an apparent wobble in the measured orbits of Sirius A and B. The American astronomer Philip Fox believed he had seen a close companion of Sirius B in 1921 at Dearborn Observatory, and further sightings of this supposed Sirius C came a few years later from observers in South Africa. No one else managed to see it, though. In 1965 Irving W. Lindenblad at the US Naval Observatory, Washington DC, began a series of photographic observations of Sirius A and B to solve the problem. Lindenblad reported in 1973 that his observations, more accurate than any before, showed no evidence of a close companion to either Sirius A or B.*

Since this point is so important I wrote to Dr Lindenblad for additional confirmation. He replied: 'My work disproved ideas that had persisted for years, namely that analysis of the visual observations made since the discovery of Sirius B gave evidence of a perturbation caused by some third body. The possibility of a *very distant* third body cannot be ruled out theoretically as being physically impossible but there is absolutely no evidence for such a body.'

What do the Dogon say about their imaginary third member of the Sirius system, which they call *emme ya*? There are two sources of information. One is an article entitled 'A Sudanese Sirius System' published by Griaule and Dieterlen in 1950. The second is a book by the two

* Temple wrongly claimed that the first photograph of Sirius B was taken by Lindenblad in 1970. In fact, photographs of Sirius B were taken by G. B. van Albada at the Bosscha Observatory in Indonesia in 1955 onwards, and also at Sproul Observatory from 1964.

called *Le Renard Pâle* published in 1965, which gives a more detailed description of Dogon astronomy.

According to Griaule and Dieterlen, the Dogon describe *emme ya* as larger than Digitaria, but four times as light in weight, a description which is consistent with a red dwarf. Yet such a body anywhere near Sirius A and B would have shown up in Lindenblad's observations. In the Sudanese Sirius System article, Griaule and Dieterlen report that *emme ya* supposedly travels along a greater trajectory than Digitaria, but in the same time. This is a physical impossibility. According to Kepler's laws, the larger an orbit, the longer an object takes to go around it. So here the legend is astronomically wrong.

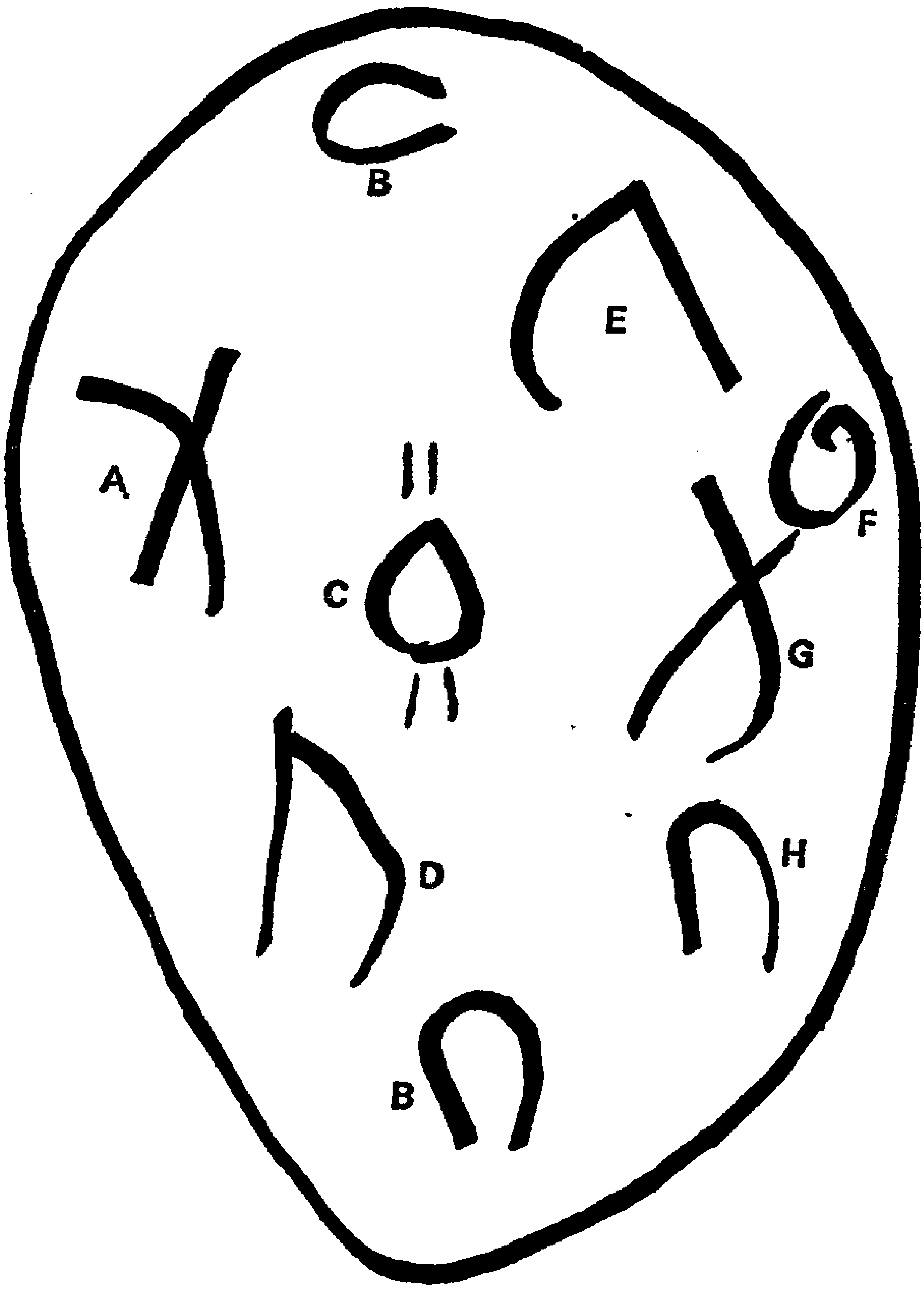
But contradictorily, in *Le Renard Pâle* it is said that the orbital period of *emme ya* is 32 years, shorter than the 50-year period of Digitaria, which would mean that *emme ya*'s orbit is smaller than that of Digitaria, not greater. Temple has recently suggested that the figure of 32 years actually refers to close approaches between *emme ya* and Digitaria, which would occur every 32 years if *emme ya* moved along a larger orbit every 100 years in the opposite direction to Digitaria in its 50-year orbit. But this introduces another conflict, because the legend specifically says that the two bodies travel in the same direction. The respective positions of Digitaria and *emme ya* are said in one part of Griaule and Dieterlen's writings to be at right angles, and elsewhere as in a line. Where the legend is not at variance with fact, it is self-contradictory. On this evidence, the Sirius mystery is intractable.

If the Dogon knowledge of Sirius C is unreliable, what do they say about Sirius B (Digitaria)? It is described as being the smallest and heaviest star, consisting of a heavy metal known as *sagala*. It was certainly the smallest and heaviest star known in the 1920s, when the superdense nature of white dwarfs was becoming understood; the material of which white dwarfs are made is indeed compressed more densely than metal. But since then many other white dwarfs have been found, not to mention neutron stars which are far smaller and denser. Any visiting spaceman would certainly have known about these as well as black holes; he would also have known that Jupiter has more than four moons.

The Dogon are supposed to know that Sirius B orbits every 50 years. But what do they actually say? Griaule and Dieterlen put it as follows: 'The period of the orbit is counted double, that is, one hundred years, because the Siguis are convened in pairs of 'twins', so as to insist on the basic principle of twinness.' Temple emphasizes that the number fifty appears regularly in ancient myths, such as the 50 companions of Gilgamesh, but it is difficult to see what this has to do with the Dogon. The Sigui ceremony referred to above is a ceremony of the renovation of the world that is celebrated every 60 years (originally it was celebrated every 7 years). Griaule and Dieterlen admit that the 60-year recurrence of the Sigui ceremony is inconsistent with the 50-year orbit of Sirius B.

The Dogon are also supposed to know that Sirius B orbits Sirius A in an ellipse, which they draw. Where does this information come from? Actually, it comes from Robert Temple. At a yearly ceremony known as the *bado*, the Dogon make a sand drawing of the Sirius system. This time they place *emme ya*, 'the sun of women', at the centre. Around it in the diagram are marked Sirius, represented by a cross; Digitaria, shown in two positions, drawn as a horseshoe-shape to indicate its nature as a collector and distributor of matter placed in it by the Creator; and five other signs representing different objects, one of them the Nommo. Drawn around these symbols is an oval, the egg of the world. This oval is a device which the Dogon use to enclose other diagrams, not just of Sirius.

This Dogon sand diagram of the complete Sirius system is shown in the illustration. Its description, as given by Griaule and Dieterlen, contains clear elements of male-female sexuality; it is symbolic. Temple chooses to interpret it literally. On pages 23 and 25 of his book he gives his own modified version of this diagram. Temple retains



Dogon sand drawing of the complete Sirius system, after Marcel Griaule and Germaine Dieterlen. A, Sirius; B, Digitaria, shown in two positions; C, *emme ya,* the sun of women; D, the Nommo; E, the Yourougou, a mythical male figure whose destiny is to pursue his female twin; F, the star of women, a satellite of *emme ya*; G, the sign of women; H, the sex of women, represented by a womb shape. The whole system is enclosed in an oval, representing the egg of the world.

the symbol for Sirius, plus one of the positions of Digitaria, and the surrounding oval; all the other symbols that fill the oval he omits. He then interprets the 'egg of the world' oval as the orbital path of Sirius B around Sirius A, even though Digitaria is drawn as lying within it, not on it. This, then, is the basis for saying that the Dogon 'know' the orbit of Sirius B around Sirius A to be an ellipse.

Of course, the most crucial factor of all for the ancient astronaut theory is that the Dogon say the Nommo came from Sirius. Where do they say this? Again, Temple says it for them. On page 217 of his book, he reports that the Dogon say that '*po tolo* and Sirius were once where the Sun now is'. This ambiguous statement is the only quotation he offers throughout the entire 290-page book to substantiate this most vital claim. He shows four designs, looking like Cleopatra's needle, found on Dogon masks and speculates: 'Maybe the Dogon have actually drawn a rocket ship.' In fact, the pencil-shaped structures, over 7 times as tall as they are broad, would be too unstable for a landing craft. Nowhere does the Dogon legend specifically state that the Nommo came from Sirius.

And what of the nature of the Nommo itself (or themselves)? The Nommo is a spiritual being, associated with the life-giving rains that are vital in this arid part of the world. An interesting sidelight here is that the neighbouring Bozo people, who share much of the Sirius mythology, believe that the lungfish which lives in the mud of the River Niger 'falls from heaven with the first rainstorm of the season'. This sounds to me a lot like the Nommo, but not like an extraterrestrial visitation. The obsession with fish-like creatures is no surprise, since fishing on the River Niger is a major industry hereabouts; the town of Mopti on the Niger, about 50 km from Bandiagara, is the area's commercial centre.

Looked at in this light, Temple's ancient astronaut theory for the Sirius mystery is no more solid than his assumptions and interpretations of the Dogon legend – a legend which, as we have seen, is riddled with contradictions, at least when one attempts to interpret it in terms of the real world.

In his book, Temple makes one prediction which allows a test of his theory. He asks: 'What if this is proven by our detecting on our radio telescopes actual traces of local radio communications?' I asked two astronomers engaged in the search for extraterrestrial radio messages, Paul Feldman at Algonquin and Robert Dixon at Ohio, to help (they would otherwise have paid no attention to Sirius because of its extreme unlikelihood of supporting life). Feldman's search was filmed by BBC-TV for the *Horizon* documentary on ancient astronauts. In April 1977 Feldman listened to Sirius with the Algonquin dish for three ten-minute periods; no signal was detected. Simultaneously with Feldman's search, but at a different wavelength, Robert Dixon in Ohio listened to Sirius for one-minute intervals on each of thirteen days in April 1977; again no signals were detected. So two independent tests of Temple's hypothesis have drawn a blank. It is difficult to resist the conclusion that there is no life in the Sirius system, nor has there ever been.

The true test of a good extraterrestrial story is that it should tell us something we don't already know. The Dogon legend only tells us what we know already; and some of what it does tell us is wrong.

It is all too easy for Westerners to think of African tribes as isolated, ignorant, and uneducated. If the Dogon have their roots in Greek and Egyptian civilization, as seems to be the case, then they are certainly not ignorant. Neither are they isolated nor uneducated. The Dogon live near an overland trade route, as well as close to the southern banks of the Niger river, which is another channel of trade. Any number of travellers could have passed through their midst, or Dogon tribesmen could themselves have journeyed far, possibly meeting astronomically informed seamen on the coast. The Dogon have been in contact with Europeans since at least the late nineteenth century. It is even said that members of the Dogon fought for the French in the trenches during the First World War.

Astronomers Peter and Roland Pesch of the Warner and Swasey Observatory in Ohio have pointed out that French schools have existed in the Dogon area since 1907, including geography and natural history in their curricula. Dogon members wishing to pursue higher education have been able to do so in nearby towns. There are also Islamic schools, and the Dogon have apparently incorporated aspects of Islamic ritual and culture into their own culture.

Then there are missionaries, who would naturally be closely interested in the legends of the natives. I confirmed with the London headquarters of the White Fathers, a Catholic group who have been very active in this part of Africa, that missionaries from their sect had made contact with the Dogon in the 1920s. It is tempting to speculate that certain of the more specific details about Sirius B were grafted on to the existing Sirius legend at that time because it was about then that astronomers had just discovered the true nature of Sirius B as a tiny, superdense star, and white dwarfs were being accorded the same kind of publicity as attends black holes today. Alas, there is no mention in the missionaries' summary reports of their activities that they discussed Sirius with the Dogon, although if more detailed notes were published they might add significantly to our understanding of the origins of Dogon knowledge.

The point is that there are any number of channels by which the Dogon could have received western knowledge long before they were visited by Griaule and Dieterlen. Dogon knowledge of the moons of Jupiter, the rings of Saturn, and the circulation of the blood confirm that some such influx of information has taken place. Although Dogon Sirius mythology, particularly the story of Nommo and the concept of twinning, is admittedly both ancient and profound, is it not at least possible that some of the more superficial resemblances with astronomical fact are trimmings added this century?

'This full cycle return of a myth to its culture of origin through an unwary anthropologist might sound unlikely if there were not so many examples of it in anthropological lore,' says Carl Sagan. He recounts the true story of an anthropologist who was investigating the traditions of American Indians early this century. The anthropologist asked one of the local elders about rituals and ceremonies concerning childbirth, puberty, marriage, and death. Each time, the elderly informant retreated into his hogan before emerging with the answer. Could he, the anthropologist wondered, be consulting an even more aged Indian who lived within? In fact, it turned out that he was reading up the answers in the *Dictionary of American Ethnography*.

Perhaps of more relevance to the Sirius case are two examples concerning the physician Dr Carleton Gajdusek, who in 1976 shared the Nobel Prize for Medicine. In 1957 Dr Gajdusek and some companions travelled into New Guinea, where they stayed briefly with some of the native inhabitants. One night, the native hosts sang some of their traditional songs, and in return Gajdusek's party sang some traditional Russian songs, including *Ochichornia*, of which the natives requested many repetitions. Several years later, while engaged in collecting traditional songs in a nearby region of New Guinea, Gajdusek was amazed to hear a slightly altered but still recognizable version of *Ochichornia*, which had by then become accepted as a traditional native song.

Shortly thereafter, Gajdusek was visited by an Australian physician who had found that some New Guinea natives believed that a certain disease was transmitted in the form of an invisible spirit that entered the skin of a patient. The native informant had sketched with a stick in the sand a circle outside which, he explained, was black, and inside which was light. Within the circle the informant drew a squiggly line to represent the appearance of these invisible malevolent spirits. How did they get such an astounding insight into the transmission of disease by microbe? Years earlier, Gajdusek had shown the natives the appearance of a disease-causing germ through his microscope, and the sand drawing was simply the natives' recollection of this deeply impressive sight.

'All three of these stories underline the almost inevitable problems encountered in trying to extract from a "primitive" people their ancient legends,' notes Sagan. 'Can you be sure others have not come before you and destroyed the pristine state of the native myth?'

In view of the Dogon fixation with Sirius it would surely be more surprising if they had *not* grafted on to their existing legend some new astronomical information gained from Europeans, picking what fitted their purpose and ignoring the rest. We may never be able to reconstruct the exact route by which the Dogon received their current knowledge, but out of the confusion one thing at least is clear: they were not told by beings from the star Sirius.

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13

VISITORS FROM WHERE?

In recent years, the belief that UFOs represent extraterrestrial spacecraft has grown from a minor cult obsession into widespread folk-knowledge. Although the term UFO (unidentified flying object) was introduced as a noncommittal alternative to the colloquial term 'flying saucer' in a vain attempt at scientific respectability, the two terms have by popular usage become interchangeable and I have seen no point in trying to distinguish between them. It is a measure of the assumptions inherent in this field that for many people the term 'unidentified' is now synonymous with 'extraterrestrial spacecraft'.

If we were indeed being visited by aliens it would obviously be an important and exciting discovery, particularly in view of the difficulty of finding signs of extraterrestrial life by our own efforts. In principle there is nothing absurd about the idea; but does the suggested evidence stand up to critical analysis? In the last two chapters I have examined several suggested examples of extraterrestrial visitation in the past and found the evidence to be very weak. But whether or not we were visited in the past, is it possible that we are being visited today? Are UFOs indeed the most obvious of all messages from the stars – personal visits by aliens?

That UFOs exist, in the sense that people see things in the sky that they cannot identify, is incontrovertible. Sightings of strange aerial objects go back to the most ancient times, except that then they were described in terms of angels riding celestial chariots. In the 1890s came a rash of sightings of unidentified airships, and nowadays of course they are described as spaceships. The interpretations seem to depend on the state of terrestrial technology. What will they be termed next century?

The modern era of UFOlogy began over 30 years ago, on

24 June, 1947, when Kenneth Arnold, a 32-year-old businessman piloting a private aircraft saw what he described as a chain of nine 'saucer-like' objects that were flying from north to south near Mt Rainier in Washington State. The Press eagerly coined the name flying saucer for these objects; although no one realized it at the time, this emotive label was to kindle a new mythology. Arnold's report was followed by a flood of other flying saucer sightings that continues to this day.

Under pressure to explain the apparent invasion of domestic airspace, the perplexed US Air Force set up a series of investigations, the first of which, known as Project Sign, was initiated in 1948. Project Grudge followed in 1949, and in 1952 began the famous Project Blue Book, which was closed in 1969. The Air Force also contracted with the private RAND Corporation for an independent study of the saucer phenomenon.

All the investigations reached essentially the same conclusion: that the so-called saucers presented no threat to national security, that the reports were most probably misinterpretations or fabrications, and that there was no evidence that saucers were extraterrestrial vehicles.

These conclusions did not satisfy committed saucer watchers such as UFO writer Donald Keyhoe, who claimed in the 1950s and 1960s that the Air Force was not telling all it knew. But the official documents, now declassified, reveal that the Air Force knew no more than anyone else. A declassified CIA report of the same period, the Robertson Panel Report of 1953, yields no further support for the once-popular 'cover-up' theory. UFOlogists pricked up their ears again in April 1977 when the *US News and World Report* promised that the saucer-sensitive Carter government would release restricted CIA information by the end of that year. But hopes were soon dashed when it was realized that the report was based on a misunderstanding. President Carter's science adviser Frank Press had asked both the CIA and the Air Force if they still retained UFO information. The answer was No. Carter's next move was to ask NASA if it would be prepared to undertake a new

UFO study, a request which the space administration rejected as 'wasteful and probably unproductive'.

The Air Force explained the Kenneth Arnold sighting as mirages due to a temperature inversion. Arnold had reported that the air at his flying height of 9500 ft was clear and still – characteristic of such an inversion. The Air Force files also pointed out inconsistencies in Arnold's estimates of the probable sizes and distances of the objects: his attention was drawn to the objects by a series of flashes, but the chances are very slight that a moving object would continually reflect sunlight in a series of flashes to an observer 20 to 25 miles away, which is the range Arnold estimated for the objects. Also, at that distance the saucers would have been at least 2000 ft long and moving at supersonic speed to fit his description of their apparent size and motion. The objects, if they were real, were probably smaller, much closer to him, and slower-moving than he proposed. Inconsistencies in a report can indicate that the sighting is a misperception, as was apparently the case here.

An altogether more spectacular case the year following Arnold's sighting sparked off a new sensationalist line: UFOs are hostile. On 7 January, 1948, Air Force captain Thomas Mantell was killed while climbing to intercept a high-flying UFO reported by ground control at Godman Field, Kentucky. The position of the reported UFO fits that of the planet Venus, but a Navy Skyhook balloon released that morning was also in the area. These balloons fly at altitudes of 60,000 ft or more, well above the operating height of Mantell's plane, which had no oxygen equipment. Mantell described the object as 'metallic, of tremendous size'; his last words, at 15,000 ft altitude were: 'I'm trying to close in for a better look.' His crashed plane was subsequently found 5 miles south-west of Franklin, Kentucky. The Air Force conclusion was that Mantell had blacked out from oxygen starvation during his climb, and the uncontrolled aircraft had spiralled into the ground.

The CIA entered the UFO field at this point, because it was they who were developing the Skyhook programme for photo-reconnaissance of the Soviet Union. They were both embarrassed that their secret should get out, and they were also worried that some UFO cases might actually be sightings of similar Soviet balloons sent to spy on the United States.

In the 1950s came the famous hoax by George Adamski, who claimed he had met extraterrestrial beings from Venus, Mars, and Saturn who had given him rides in their spacecraft to see people living on the far side of the Moon. Adamski's photographs of the reputed flying saucer that picked him up are among the most blatantly fraudulent ever produced, even in a field that has become notorious for trickery: one can even see the multiple reflections from the artificial lights used to illuminate the saucer model. These excesses gave UFOlogists at least one clear lesson: never trust a flying saucer photograph.

Adamski and his like brought the flying saucer field into ridicule. But it was soon revived by the birth of the Space Age, first with the launch of Sputnik 1 in 1957 and then Yuri Gagarin's pioneer manned flight in 1961. Here was a practical demonstration that beings can travel through space in rocket ships. Naturally, it also brought reports that astronauts had encountered UFOs, beginning with the 'fireflies' seen by John Glenn. These were simple flakes of paint or liquid droplets from the craft itself, but others proved more puzzling.

Astronaut UFOs have recently been investigated by James Oberg of NASA's Johnson Space Center in Houston, Texas. By reference to original NASA photo files, Oberg was able to explain several UFO photographs as long-range views of rocket stages, in one case tracking lights on a rocket stage seen on the night side of Earth, several examples of lens flare, and even a deliberate forgery by a UFO hoaxer who had airbrushed out part of a Gemini spacecraft, leaving two reflections of sunlight from thrusters on the spacecraft's nose appearing like mysterious lights in space.

In 1975, the UFO group NICAP selected a photograph taken by Gemini 4 astronaut James McDivitt as one of the 'four best' UFO photographs ever. But they ignored the fact that McDivitt himself explained that the image, a hazy blob with a long tail, was caused by sunlight reflected off a metal bolt on to the dirty window. McDivitt did report seeing in orbit a cylindrical object with an arm, which Air Defense computers could not identify with the known position of any existing satellite. But actually, reports Oberg, the object was the upper stage of the booster which placed Gemini 4 into orbit, with a strap hanging from it. The computer did not take Gemini 4's own booster into account when trying to identify the mystery object.

There are other examples of sightings (and photographs) of satellites and space debris seen either in orbit or, in the case of Apollo 12, on the way to the Moon (these were panels jettisoned from around the Lunar Module), but there are no signs of any alien spacecraft. The only 'evidence' is within the minds of the UFOlogists who, unlike Oberg, have not had the opportunity to check the data for themselves.

Recently there have been suggestions that there are aliens on the Moon, and that NASA has photographic evidence that it is keeping quiet. I was vaguely aware of these rumours but had not paid them much attention until I received some unsolicited information in June 1977 from a religious group in London, quoting a story from a Canadian newspaper. I was surprised to find that their main piece of 'evidence' was ten years old. It was a photograph taken by the American probe Lunar Orbiter 5 in 1967, which I well remember from my days in lunar research at the University of London Observatory. The photograph shows rocks rolling down the central peak of the lunar crater Vitello, although the UFO group claimed that these were mining machines and that the photograph was still on the secret list. In fact, it was published on page 217 of the October 1967 issue of the world's leading astronomy magazine *Sky & Telescope*.

Rather than being kept secret, the photograph is listed in the current NASA catalogue – order photograph number 67-H-1135. As further 'evidence', the UFOlogists claimed that Apollo V (presumably meaning Apollo 5) had photographed mining machines on the far side of the Moon in January 1969. Actually, Apollo 5 was launched in January 1968, not 1969; it was an unmanned test flight into Earth orbit, and never went anywhere near the Moon. Of course, Apollo 11 landed on the Moon in 1969, but that was in July. In January 1969 there were no Apollo or Lunar Orbiter craft around the Moon.

Now that scientists have become so interested in the possibility of extraterrestrial life, UFO events are being subjected to far more rigorous examination – with the result that many of the most cherished cases are crashing to the ground. Technical journalist Philip Klass of *Aviation Week and Space Technology* magazine has disposed of most of the classic cases of UFOlogy. Among them is the celebrated 'landing' at Socorro, New Mexico, in April 1964, which UFOlogists once voted the most impressive case on record. According to the story, patrolman Lonnie Zamora was chasing a speeding motorist towards the edge of town when his attention was drawn by a roaring sound and a bright flame in the desert three-quarters of a mile away. Abandoning his chase, Zamora drove over to what was apparently a landed spacecraft, with two white-clad figures standing nearby. As he approached, the craft took off and disappeared over the nearby mountains. At the site of the purported landing were four pad prints.

Klass found numerous inconsistencies in this story. Despite the loud noise and brilliant flame which Zamora said drew his attention, a couple living a few hundred yards from the site had noticed nothing unusual. Photographs show that despite the reported 'intense flame' under the craft, there was no more singeing of a bush and a clump of grass than could have been produced with a cigarette lighter. The reputed pad prints were spaced irregularly; one looked as though it had been formed by moving a rock, while another appeared to have been dug by a small shovel. No one other than Zamora noticed the noisy, flaming craft depart over US Highway 60, although a gas station attendant reported that a customer told him he had seen a police car going out after a flying craft that was coming in to land. But Zamora said he did not see the craft until it was already on the ground.

Such blatant inconsistencies point not merely to a misconception, but to a hoax. Klass noted that, by curious coincidence, the local mayor, who is also the town banker, happened to own the site on which the alleged UFO landed. Socorro gained considerable publicity from the case, with an inevitable improvement in the tourist trade.

Socorro has been superseded as the most celebrated UFO case of all by the so-called interrupted journey of an American couple, Barney and Betty Hill, who one evening in 1961 were returning to their home in Portsmouth, New Hampshire, after a holiday in Canada. Betty became troubled by what she thought was a strange light in the sky following their car as they passed through the White Mountains in the north of the State. Barney did not at first think that the light was anything unusual, until convinced by the prompting of Betty who had been watching it for half an hour. Alarmed, the couple took to some back roads to 'escape' the UFO, arriving home two hours later than anticipated.

That was all. What happened subsequently is an example of how a UFO story can grow from the simplest of beginnings. Various aspects of this exceptional case have been thoroughly investigated by Robert Sheaffer, an astronomer and computer systems analyst.

Firstly, what was the light that sparked off the whole case? Betty Hill said she saw two bright objects near the Moon that night; she made a drawing, labelling one of these objects a star, and the other she called the UFO. Sheaffer knew that there were only two bright objects near the Moon at that time: Jupiter and Saturn. Betty Hill's sketch showed the 'star' close to the actual position of Saturn, while her 'UFO' corresponded to Jupiter. Had there been a real UFO present, she should have seen three bright lights near the Moon. In other words, Betty and Barney Hill's UFO was a misidentification of the bright planet Jupiter which, along with Venus, is a frequent offender in these matters.

Of course, if this were all there was to it, the story would soon have died, like most other UFO cases. But the incident clearly preyed on Betty Hill's mind, and she began reading UFO books. Over a week after the event, she began to have a recurrent dream that she and Barney had not escaped from the UFO after all, but on the back roads they had been abducted by aliens. Eventually, the couple sought psychiatric help. Under hypnosis, Betty Hill described how she had been taken aboard the UFO by aliens for medical examination. And it is this amazing tale as revealed under hypnosis that has made the case so famous.

But the Hills' psychiatrist, Dr Benjamin Simon, concluded that Betty was simply retelling her dreams under hypnosis, and that the alleged abduction had never taken place. Needless to say, UFOlogists do not represent the case in this way.

When NBC television in the United States screened a two-hour programme on the Hill case in 1975, Philip Klass wrote an article predicting that it would inspire imitators. Within weeks came the story of the alleged abduction of an Arizona woodcutter, Travis Walton, who disappeared for five days after his colleagues claimed to have seen him taken aboard a flying saucer.

Klass found that the woodcutting team of which Walton was a member were in danger of incurring a financial penalty for failing to complete a woodcutting contract on schedule, and they apparently staged the 'abduction' as an 'act of God' excuse for not meeting the contract deadline. A leading polygraph examiner who tested Walton within a week of the incident concluded that Walton was 'attempting to perpetrate a UFO hoax, and that he has not been on any spacecraft'.

No more reliable is the case of two shipyard workers at Pascagoula, Mississippi, who claimed in 1973 to have been abducted by UFO occupants with lobsterlike claws while fishing from a pier in the Pascagoula river. I have seen that pier, which is only a few hundred yards from the busy US Highway 90 between Mobile and New Orleans, and can confirm that no glowing UFO could have landed without being seen by passing motorists. Yet there were no other reported sightings of this UFO. Klass found that a lie-detector test, the only independent support for the fantastic story, was administered by an unqualified operator under uncontrolled conditions.

Some astounding experiments, reported in 1977, throw a harsh new light on the analysis of such 'contactee' cases. The Pascagoula shipyard workers were examined under hypnosis, a technique used increasingly to extract details of UFO encounters, as happened with the Betty Hill and Travis Walton cases. UFO researchers term such abductions close encounters of the third kind, a classification originated by astronomers J. Allen Hynek and since adopted as the title of a famous film. Some people regard hypnosis as a truth test in itself; alas, experiments by Professor Alvin H. Lawson of California State University, Long Beach, reveal that this is not so.

I received a copy of Professor Lawson's report after an article of mine criticizing UFOlogists had appeared in *New Scientist*; at the time of writing, the report remains unpublished. With the help of Dr William C. McCall, a highly experienced medical hypnotist who has hypnotically examined about 20 people supposedly involved in close encounters of the third kind, a group of test subjects were hypnotized and asked to describe imaginary UFO abductions. The subjects had been specially chosen because they had no particular knowledge of the UFO field, nor had they been involved in any UFO cases. Yet the details they related under hypnosis correlated closely with those described by 'real' UFO abductees.

In particular, the test subjects recounted how they were taken on board the UFO, examined by strange creatures, and then released unharmed. References to bright lights inside the UFO, strange writing on the wall, uncomfortably cold temperatures, telepathic communication with the humanoid UFOnauts, and subsequent amnesia or even time lapse, are all familiar themes in UFO abduction cases. Lawson concluded that the details given by alleged UFO abductees comes not from reality but from the witnesses' imaginations. Therefore it seems that we can sweep away all close encounters of the third kind.

Professor Lawson left open the question of what stimulates the abduction fantasy. But, by reference to well-known cases we can conclude that, in the language of psychology, UFO fantasies are projections on to normal objects which have been misperceived. As so many cases have shown, once witnesses believe they have spotted a UFO their imagination runs riot. An extreme case is the Interrupted Journey, in which a misperception of the planet Jupiter apparently triggered an abduction fantasy. Some cases, by contrast, have no specific stimulus – they are deliberate hoaxes. But even these will seem convincing under hypnosis, as Lawson's experiments show. UCLA psychologist Ronald K. Seigel noted in an article in the October 1977 *Scientific American* that similar hallucinations can occur in different people. The psychologist Carl Gustav Jung also drew attention to the similarity between UFOs and dream images and even UFO images in modern paintings.

Although there is clearly a strong psychological component in many UFO cases, it would be wrong to dismiss all sightings as products of the imagination. The bulk of the UFO problem consists of cases far less spectacular than close encounters of the third kind.

In 1973 J. Allen Hynek, former astronomical consultant to Project Blue Book, set up the Center for UFO Studies in Evanston, Illinois, to co-ordinate scientific investigation of UFO reports. UFO cases are phoned in to the Center from police departments and other official agencies over a toll-free hot line, which is manned 24 hours a day. In November 1976 the Center began publishing a monthly bulletin, the *International UFO Reporter*, which reports on investigation of cases notified to the Center and selects an occasional monthly case of notable merit. The bulletin was perhaps a little unlucky in the choice of its first high-merit case, a silver saucer reportedly seen by 14 boys during a hike at summer camp near Winsted, Connecticut. Alas, there were no independent reports of the object, and a letter in the local paper the following week purporting to come from four of the campers confessed it to be a hoax. Nonetheless, the UFO Center rated its chances of being a 'genuine UFO' as 50 per cent.

In a typical month, March 1977, the Center received 82 reports at an average of 2.6 per day. Of these reports, 95 per cent, or 78 cases, were identified, the main culprits being bright stars and planets, aircraft, meteors, and satellites. The remaining four sightings were classified as UFOs of limited merit, which means that they remained unidentified after preliminary investigation, but for various reasons were not considered sufficiently reliable to warrant further scrutiny (here the term 'unidentified' really does mean what it says!). There was no case of outstanding merit that month.

It hardly needs to be emphasized that throughout the 30 years or more of UFO investigation no one has yet come up with one confirmed case of extraterrestrial visitation – we would certainly have heard all about it if they had! There are many tall tales that would be of great importance if they were true – but investigation has shown that they are not. After 12 years of fairly consistent interest in this field, I do not know of one UFO report that has been identified as an extraterrestrial spacecraft – although I know of many reports that have been identified as natural or man-made objects.

When something unexpected but undeniably real does occur, there is usually no shortage of witnesses or confirming evidence. For instance, on the afternoon of 10 August, 1972, a gigantic fireball streaked through the atmosphere, missing the Earth's surface by 40 miles before speeding on out into space again. Such an event is exceptionally unlikely, but nevertheless it was seen by thousands of eye witnesses, including a meteor expert, and was extensively photographed, even though it passed over one of the most sparsely inhabited regions of North America, from Utah to Alberta. It was also detected by a US Air Force surveillance satellite.*

As another example, a bright meteor that split into two as it entered the atmosphere over California on 22 March, 1977, produced reports to the Center for UFO Studies from six sheriffs' departments, eight police officers, and nine pilots at three separate airports, even though the event occurred at 3.30 a.m. On 21 December, 1968, I well remember seeing a peculiar, starlike object in the western sky surrounded by a fuzzy glow – a 'classic' UFO. Telephone calls quickly confirmed that many amateur astronomers in Britain had spotted it, too; several of them photographed it. The effect we were watching was caused by a fuel dump from the third stage of the rocket that had boosted Apollo 8 towards the Moon earlier that day.

Going back even farther, a ball of fire streaked to Earth in the valley of the Stony Tunguska river, Siberia, in 1908, exploding violently and devastating a wide area. Some speculative writers suggested that the Tunguska body was a nuclear-powered spacecraft, but no strange radiation was found by scientific expeditions to the site in the early 1960s, although scientists specifically checked on this point. Rather, study of the object's orbit around the Sun and comparison with a similar object that broke up over Canada in 1965 suggested that the Tunguska body was a comet of carbonaceous chondrite composition. Clinching evidence for this view came in 1977 when Soviet scientists announced discovery of particles of carbonaceous chondrite material, evidently from the shattered comet's head, in the 1908 peat layers at the Tunguska site. (See also Ian Ridpath, *Mercury*, September/October 1977, p. 2; and *New*

* For photographs and further details of this remarkable event, see *Sky & Telescope*, July 1974.

Scientist, vol. 75, p. 346, 1977).

Most UFO reports (although not all) are made by people who are unfamiliar with the sky, and are genuinely baffled by something they are unable to identify. Even Jimmy Carter's famous UFO sighting, made in 1969 but not revealed until he was running for President, turned out to have been a misidentification of the planet Venus. Unlike the cases of unexpected but actual effects reported above which were widely sighted, a disproportionate number of UFO reports seem to have limited witnesses (often only one) and no reliable photographic evidence. Such UFOs seem to be ephemeral: they can apparently materialize and dematerialize at will, and have a wide range of abilities such as sudden turns and acceleration and supersonic travel without a sonic boom. It seems, in fact, that UFOs have whatever attributes we wish to assign them, including the ability to avoid conclusive detection. UFO sceptic Robert Sheaffer has noted that theories about such dubious phenomena are set up so that they can never be refuted, no matter how often they fail. Since these theories forbid nothing, they tell us nothing, and hence have no scientific value.

From this I deduce what I term the UFO Uncertainty Principle: one cannot have a UFO sighting which is both highly reliable and highly specific. By a reliable sighting I mean one with many independent witnesses who all agree on what they have seen – when these occur, the object is either something like an unspecified light in the sky, or it is rapidly identifiable, as in the cases mentioned above. By a highly specific sighting I mean one which speaks of such things as silvery craft and alien occupants – but these seem to occur only to isolated individuals or small groups, and are highly unreliable, as in the Betty Hill, Socorro and Pascagoula cases.

Mathematician Paul Davies of King's College, London, notes that over the past 50 years a new category of event called ball lightning has emerged from reports of strange aerial phenomena. Reports by the public and scientists of luminous objects that move erratically and disappear by exploding are now categorized by this name, even though its true nature is not understood. Davies argues, reasonably enough, that among UFO reports may be evidence of other, still unknown atmospheric phenomena. But if a previously unexpected phenomenon such as ball lightning can be identified and become accepted, why cannot an expected phenomenon like alien spacecraft? One compelling answer is that such craft do not exist. Indeed, there are so many stimuli, natural and man-made, in the sky that we do not even need the extra hypothesis of alien visitation to explain UFO reports.

This should not be surprising, since the scientific assessment of extraterrestrial life discussed in this book implies that not one of the hundreds of thousands of UFO reports on file throughout the world represents an extraterrestrial visitation. Whereas UFOlogists have always argued that once the obviously erroneous sightings have been weeded out there remains a so-called residue of apparently baffling cases, the dedicated researches by modern UFO investigators have shown that even the supposedly 'best' of these cases is soluble.

I believe that investigation of UFO reports should continue, at least for a while, because to the general public and the credulous UFOlogists every sighting that remains unexplained becomes one more example of extraterrestrial visitation. I am concerned that the wide sensationalism of UFO stories by the media is leading to a public hysteria in which fantasized details are projected on to ordinary objects such as planets that have been misperceived, and that even entire encounters are being fantasized. With ever-more alleged cases, and ever-more amateur UFO research groups being formed to look into them, UFOlogy is facing a crunch of having to deliver the goods.

CNES, the French space agency, began an official UFO study in 1977, the same year that NASA rejected President Carter's request to begin a study of its own to supersede the controversial Condon Report of 1969. Only a study which solicits the views of believers and sceptics alike will command the respect of all. Once it has swept aside the smokescreen of misinformation that cloaks this whole subject, I doubt that such a study will reach a different conclusion from those before it. But this time everyone will have to accept it.

I have argued, in Chapter 10, that the best way of making first contact is by radio, and so far there has been no sign of any such radio signals. The detection of real starships was discussed at the end of Chapter 6; so far, no starships answering to those descriptions have been observed. Yet, according to what I read from UFOlogists, we are under continuous, exhaustive survey by many types of craft and, seemingly, many different beings, from some unspecified base or bases. The purpose of this scrutiny is not clear, nor is the need for such frequent visits. Such a belief builds on the basic fallacy that we are important enough for other people to be deeply interested in us. If there are a lot of other civilizations out there, then we certainly are *not* important. And if there are not a lot of civilizations out there, where are all these visitors coming from?

The UFOnauts described in so many flying saucer stories seem to be incredibly dumb for creatures apparenly capable of interstellar travel – witness their numerous reported landing goofs, their clumsy medical examinations that seem to be fashionable for all contactees, and their general inability to communicate with people. No Earth society would keenly fund such an inefficient bunch of space explorers.

Imagine that we discovered life on another planet. We would either land and make our presence known, or we would observe circumspectly, from a distance, so that no one would know we were there. Unless interstellar travel is *much* easier than we have imagined, we would not keep making frequent visits. We might resurvey the planet every few centuries, but in between we would leave a machine to keep watch for us like the Bracewell probes described in Chapter 9.

An increasingly popular theory is that UFOs are not spacecraft from other worlds, but visitors from another dimension – perhaps time travellers. But changing the theory does not change the lack of factual evidence. Despite more than 30 years of study, the field of UFOlogy has failed to produce *one* concrete example of visitation, from any dimension. Most scientists would draw their own conclusions from such an abject lack of results, but they do not have the indefatigable optimism of committed UFOlogists for whom the Perfect Case, like the Second Coming, is an article of faith.

The basic appeal of UFOlogy for the masses is that it is a belief system, rather than a field of scientific investigation. This explains why scientists engaged in the search for extraterrestrial life are not besieged by the millions of readers of UFO books. People prefer their dreams. UFOlogy loses its value as an escape mechanism when examined too closely.

In August 1977 the Committee for the Scientific Investigation of Claims of the Paranormal in the US attacked the media for its growing uncritical coverage of parascience. If similar distorted treatment were given to politics or history there would be a major outcry. While some newspapers and TV companies lay out considerable sums on credulous items about UFOlogy and related topics of parascience, similar interest is not shown in reporting rational solutions to mysteries or investigative journalism, of the We Name The Guilty Men variety, to expose the hoaxes and fraudsters.

The power of the media in promoting misinformation in this field is not to be underestimated. As an April Fool's joke in 1977, Anglia TV in the UK broadcast a widely publicized spoof documentary which invented a fantastic story about a space 'cover-up' and a secret US-Soviet manned landing on Mars. In this case, no blame attaches to the TV company, who were quite open about their leg-pull and even dated the programme credits 1 April.*

* Erich von Daniken, incidentally, claims that *New Scientist*

Yet I still found myself arguing months later with members of a UFO group who told me that TV companies wouldn't have gone to those lengths unless there was 'something in it'. The documentary was a telling example that no matter how absurd your tale or however unconvincingly it is presented, there will always be a small percentage of people who believe it.

By the same token, many people believe that there would not be such a fuss about UFOs unless there were 'something in it'. For those who wish to cash in on their belief, I mentioned Ladbroke's UFO bet in Chapter I. In the United States, the sensationalist *National Enquirer* newspaper has upped its reward for proof that UFOs come from outer space and are not natural phenomena from 100,000 dollars to one million dollars, with a 10,000 dollar prize for each year's best UFO story (perhaps this is one reason why the number of elaborate hoaxes is on the increase).

UFO sceptic Philip Klass has demonstrated his own confidence that there are no spaceships from other worlds in our skies with what is known as his 10,000 dollar offer. According to the terms of the offer, Klass agrees to pay 10,000 dollars to the other party to the offer should one of three events occur: when a spacecraft or fragment is found that is clearly of extraterrestrial origin, in the opinion of the US National Academy of Sciences; when the National Academy of Sciences announces other information which it believes constitutes proof of extraterrestrial visitation in the twentieth century; or when the first alien visitor appears before the United Nations or on a national TV programme. The other signatory to this offer undertakes to pay Klass 100 dollars per year for ten years, at which point his payments cease although Klass's obligations remain in force until the death of either of the parties. Also, should any of the events specified in this agreement come

magazine supports his ancient astronauts viewpoint, citing an article in that magazine which was deliberately published on 1 April . . .

to pass, Klass has offered to refund the purchase price of his book *UFOs Explained* to all those disgruntled readers who return their copies to him.

The day that Klass, the *Enquirer*, or Ladbroke's pay out, I will be happy to admit that the first extraterrestrial visit has finally occurred.

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