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THE SEARCH FOR LIFE IN THE UNIVERSE:

A HUMANISTIC PERSPECTIVE*

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1 The Last Frontier

Astronomy has come a long way since the first humans peered at the night sky. The universe was a cozy place to ancient cultures, a tented canopy to the Egyptians, crystalline spheres wheeling overhead to the Greeks. Modern cosmology presents a more austere vision. A census of the visible universe reveals about 10^{80} particles, the vast majority of which are hydrogen and helium atoms. These particles are clumped by gravity into about 10^{20} stars, which are contained in roughly 10^{11} galaxies of different shapes and sizes. This summation ignores the contribution of the ubiquitous dark matter, which may compose 90% of the mass of the universe (but that is another story...). The material content of the universe is dwarfed by an even larger amount of radiation, some 10^{88} photons. Most of these photons have very low energy, so the patterns we see are dictated by the long reach of gravity.

Modern cosmology supposes an origin event some 12 billion years ago. The universal expansion we see today began with a state of enormously high temperature and density, the big bang [1]. In this cauldron of careening photons and particles, all the forces of nature were initially equal in strength. After 300,000 years, when stable atoms formed, gravity was free to exert its attractive pull. Gradually, it sculpted the ripples in the early universe into structures on all scales. This process was influenced by the large amount of unseen dark matter [2]. One billion years after the Big Bang, enormous gas clouds collapsed into galaxies with great voids between them. Within them, legions of stars collapsed and switched on for the first time. Stars have followed a pattern of birth and death for 10-11 billion years. Most stars die a quiet death, as slowly fading embers called white dwarfs. The massive ones explode as supernovae, and seed the space between stars with heavy elements. Many stars are surrounded by the debris of their own creation. On a rocky fragment of one such star, life evolved out of a watery, organic broth. Four and a half billion years later, warmed by a middle-aged star and bathed in the microwave afterglow of the creation event, humans point their telescopes at the skies and ponder the meaning of it all.

The search for life in the universe is perhaps the last and most exciting frontier in astronomy. We have an excellent theory of gravity, general relativity, which has been subjected to and passed numerous observational tests [3]. We have adequate models for the birth and death of stars, including a detailed understanding of the processes that create heavy elements in the

cores of stars, and an emerging understanding of how planets might form as a natural byproduct of star formation [4]. We have a successful model for the expanding universe, the hot big bang. Although there are major debates concerning the early history, rate of expansion and curvature of the universe, and the nature and space distribution of dark matter, the big bang model itself has strong support from observations of the microwave background and the products of primordial nucleosynthesis [5]. Yet we have almost no idea of the prevalence of one of the most remarkable features of the universe: life.

SETI, or the Search for Extraterrestrial Intelligence, has predominantly been the domain of astronomers, mathematicians, and engineers [6]. Occasionally, biologists, chemists and geneticists have weighed in on the probability that life will evolve given simple chemical constituents [7]. Yet it is clear that understanding the role of life in the universe is an interdisciplinary intellectual adventure. Paleontologists, anthropologists, linguists, psychologists, and sociologists have a role to play in the debate. The insights of poets, philosophers and artists are relevant. There is no subject in science more appropriate for a humanistic perspective.

2 A Brief History of SETI

Speculations concerning the existence of extraterrestrial life date back to the earliest philosophers. Aristotle believed that the Moon was inhabited, and Democritus postulated an infinite number of worlds distributed through space, some of which might harbor life. In the hands of Lucretius, this belief in the plurality of worlds was highly developed, with diverse races of beasts and men on other worlds, which arose by chance and evolved according to the dictates of natural selection in diverse environments. Throughout history, the debate has been colored by teleology, the doctrine that living creatures have been designed with a purpose (for a brief history, see [8]). After Copernicus had displaced the Earth from the center of the natural order, it became part of Christian theology to suppose that distant worlds might support life. All of this speculation ocurred in the absence of any data.

Practitioners of SETI have taken the pragmatic attitude that we will never know whether we are alone or not without trying to communicate. In 1820, the great mathematician Karl Gauss proposed seeding tracts of Siberia with wheat and trees in a vast geometric representation of the Pythagorean

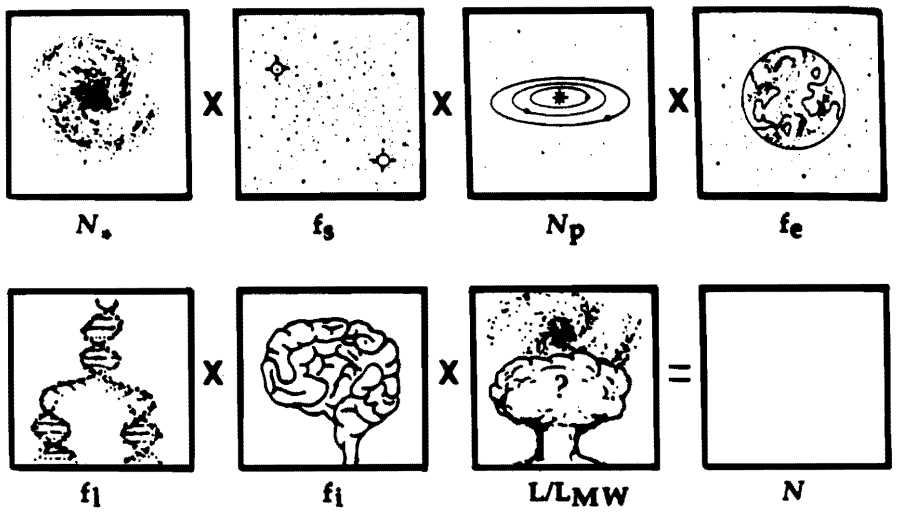

Figure 1: A pictorial version of the Drake equation, represented as the product of a number of factors, the product of which is N, the number of intelligent, communicable civilizations (Goldsmith and Owen 1992)

theorem. Later that century, Joseph von Littrow proposed filling trenches full of burning kerosene in the Sahara desert to outline geometric shapes, and Charles Cros suggested setting up patterns of large mirrors distributed across Europe. All of these efforts were directed towards communication with other inhabitants of the solar system, and none of them were funded. Tesla and Marconi attempted to receive messages from space, using the new technology of radio communications. For detailed accounts of the early days of SETI research, see [9].

The modern era of SETI began with the first quantitative study of the suitability of radio signals for interstellar communication [11], and with the first search performed using radio telescopes, *Project Ozma* in 1960 [12]. Since then, most astronomers have assumed that low energy electromagnetic waves are the most efficient means for modulating and transmitting a signal over large distances. Radio telescopes have been used as ears and voices, to both send and recieve messages that could not have a natural astronomical origin. Strategy is driven by the need to sample the "cosmic haystack", the

enormous range of fequency and signal strength that must be probed for a wide variety of targets. Luckily, SETI has ridden the wave of innovations in computers and electronics. The recently begun High Resolution Microwave Survey can duplicate in less than a millisecond what took *Project Ozma* over 200 hours.

Traditionally, SETI has worked in the context of the Drake equation (Figure 1). This multiplicative combination of factors, that range from the astronomical to the sociological, is designed to provide a crude estimate of N, the number of intelligent, communicable civilizations in our galaxy at any time. N_* is the number of stars in the Milky Way, f_s is the fraction of sunlike stars, N_p is the average number of planets per star, f_e is the fraction of planets suitable for life, f_l is the fraction of those planets where life actually develops, f_i is the fraction of planets with life where intelligent civilizations arise, and L/L_{MW} is the communicable timespan as a fraction of the age of the Milky Way. Even SETI practitioners admit that the Drake equation is more of a way of organizing ignorance than of defining a scientific methodology.

3 Assumptions in the Search

Many aspects of the search for extraterrestrial life, and in particular the search for intelligent life, involve assumptions that are worth a closer examination. Most researchers go far beyond the simple notion of the existence of life elsewhere, assuming that there are long-lived civilizations of intelligent lifeforms that have both the capability and the inclination for electromagnetic communication.

The first is the assumption of *mediocrity*, an extension of the Copernican principle to the universe beyond the solar system. Our cosmic census has revealed an enormous number of potential sites for life, the temperate zones surrounding some 10^{20} stars. The context for the SETI debate is biochemical life, which cannot function either within stars or in the frigid low density regions between stars. Even if we rule out binaries and single stars that are unsuitable, either because they are too massive and therefore transient, or because they are too small and therefore have a slender habitable zone, there are millions of suitable sites in the Milky Way alone. The assumption of mediocrity rests on the theoretical expectation that planets will naturally form by accretion of the debris left over from star formation.

No planet has yet been detected around a solar-type star. Infrared observations have revealed cases of a flattened dust cloud out of which planets *may* form. Exquisitely accurate Doppler measurements can be used to detect the subtle reflex motions of stars with orbiting Jupiter-mass bodies; however, early evidence for planets has not been confirmed with larger datasets [13]. It is disconcerting for the presumption of planets around solar-type stars that the first clearly detected extra-solar planets were found in a most unlikely place: in orbit around a pulsar [14]. Proposed and planned ground-based and orbiting telescopes will use a combination of high resolution and great sensitivity to isolate planets from the glare of their neighboring stars [15]. This research is likely to settle the issue of the ubiquity of planets within one or two decades.

The second assumption involves the ***inevitability*** of the evolution of biochemical life, given a suitable site and cosmic chemistry. This argument is bolstered by the fact that the neccesary elements – hydrogen, nitrogen, carbon, and oxygen – are widely distributed through space. Over 40 years ago, Stanley Miller and Harold Urey showed that amino acids could form out of simple molecules under primordial conditions. Since then, theories on the composition of the prebiotic atmosphere have changed, but various formulations of the Miller-Urey experiments have succeeded in synthesizing 18 of the 20 amino acids needed for life [16]. Progress has even been made on the dimly understood evolution from macromolecules to simple cells. Proteins can fashion themselves into objects called microspheres; protocells with membrane walls that can generate and store molecular information. The early history of the Earth provides additional support for this assumption. Traces of life date back to 3.8 billion years ago, only 700 million years after the Earth formed [17]. Life formed almost as soon as it possibly could, after the crust cooled and the oceans formed. There is also evidence that life had several false starts, perhaps being eradicated in the early period of heavy bombardment [18]. All life today may have descended from just one of the origination events.

The ground becomes less firm in the assumption that alien lifeforms be ***intelligent***, or that they will have the ***technology*** to communicate using electromagnetic radiation. Direct communication is painfully slow given present technology. The Pioneer 10 spacecraft became the first human artifact to leave the solar system, some 12 years after launch. However, if we imagine the Sun as a grapefruit, and the next nearest star as another grapefruit over

a thousand miles away, space probes can only cover the distance between them at the rate that grass grows. Radio waves offer the means of sending a large amount of information, with very low energy cost, and at a speed that makes two-way communication possible within a human lifetime.

Although SETI has dedicated itself to this strategy, it does not follow that the premise that underlies it is valid. Astronomers and physicists are usually sanguine about the likelihood that life will evolve intelligence and the capability to harness technology. For physical scientists, who often incline towards determinism, the enormous number of potential life "experiments" means that even improbable events have occured many times. By contrast, biologists and paleontologists are accustomed to the capricious and irregular process of evolution by natural selection. Social and life scientists often argue that evolution of advanced species with technology might well be unique to the Earth (for a juxtaposition of these points of view, see [7]).

The last issue concerns *methodology*. The uncertainty in N, the number of intelligent, communicable civilizations in the galaxy at any time given by the Drake equation, is dictated by the *most* uncertain factor. Since the cultural and sociological factors are essentially indeterminate, so is the resulting estimate of N, regardless of how well we know the astronomical factors. Second, we do not know how improbable intelligent life really is. For example, there is a tiny but finite probability that every atom in a brick could change its energy simultaneously in the same direction, raising the brick spontaneously off the ground. The probability is 10^{-100}, so low that such an event will not happen, even when we consider the entire contents and history of the universe. Despite over 10^{20} potential sites, it is possible that the conditions leading to technological civilizations were not duplicated on any other planet in the universe. With only ourselves to put under the microscope, we cannot use the standard inductive method of science. The terrestrial experience will never be able to tell us about the attributes of life *in general*.

4 Catastrophes and Contingency

Cosmic intruders have been decisive in the history of life on Earth. The first wave of comet and asteroid impacts 4.5 billion years ago brought substantial amounts of gases and organic materials that were essential to life. Since then, the much rarer large impacts have been catastrophic (the scarred surface of

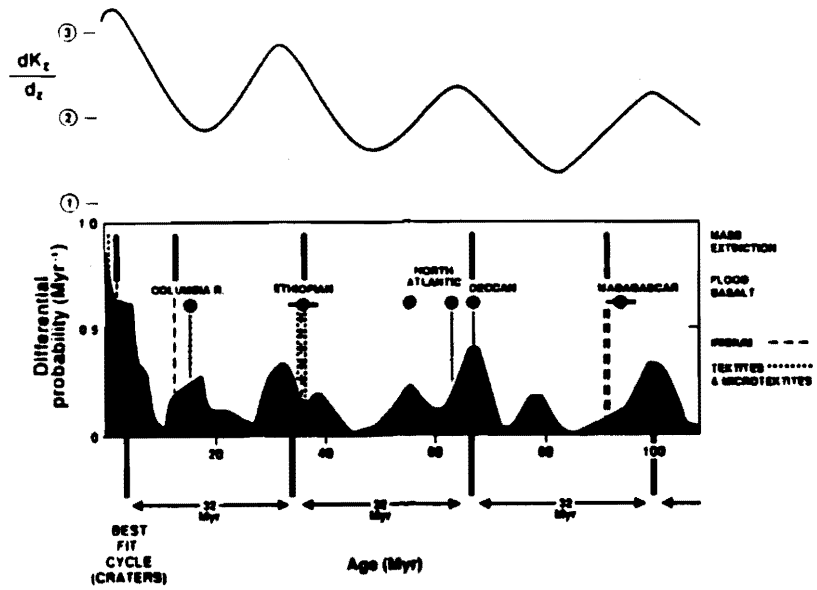

Figure 2: A number of terrestrial anomalies are correlated with the passage of the solar system through the plane of the Milky Way, where the maximum tidal influence is given by the peaks of dK_z/dz. Catastrophic events that occur quasi-periodically include impact craters, flood basalts, irridium enhancements and microtektite layers (Rampino and Caldeira 1993)

the Moon testifies to the cratering history of the Earth). An asteroid impact 65 million years ago may have caused the mass extinction between the Cretaceous and Tertiary periods [19]. Impacts have been proposed as the dominant trigger for other "punctuated equilibrium" changes in the evolution of species [20]. Catastrophic impacts are extremely rare, occuring only once every 10^8 years or so [21]. However, pulses of impacts can be induced by external events, such as the explosion of a nearby supernova. Alternatively, the passage of a star near to the Sun can perturb the orbits of distant comets and send swarms of them into planet-crossing orbits. Figure 2, based on data from Rampino and Caldeira, shows a clear relationship between mass extinctions, large craters,. global climate change, the deposition of microtektites caused by an impactor, and the periodic passage of the solar system through the plane of the Milky Way.

Even if the external environment is ignored, the evolution of complex life

on Earth is characterized more by contingency than inevitability [23]. Despite a rapid start, it took 3 billion years for the first multicelled organisms to appear. Recent calculations indicate that in only 1.1 billion more years, the luminosity of the Sun will increase enough to initiate a runaway greenhouse effect on Earth, boiling off all the oceans and destroying life as we know it. If evolution had been only 30% slower on Earth, the endpoint and pinnacle of life would have been the humble algae or plankton. While we might imagine that intelligence conveys some adaptive advantage, this does not mean that evolution towards music appreciation is inevitable. Pond scum (blue-green cyanobacteria) has not changed for 1 billion years. This primitive organism is the perfect ecological generalist, able to adapt to a wide range of environments and changing conditions. It took 99.99% of the time since life began to develop a human level of intelligence. If we compare the timeline of the Earth to a cosmic "year", we have had technology for only a blink of the eye in the long span since the motor of life first turned over. Also, 99.8% of the 500 million species of animal and plant life in Earth's history are extinct. Our confidence in the superiority and inevitability of intelligence must be tempered by that fact. If humans disappeared, another intelligent species might evolve, but we cannot be sure.

A close look at the history of life on Earth shows how unpredictable and opportunistic evolution really is. The story of life features long periods of inaction, mixed with bursts of development, cosmic catastrophes, mass extinctions, experimentation and strange ecological niches [24]. It defies any attempt to impose an orderly progression, and it is *not* deterministic.

5 How Strange Can Life Be?

Exobiology, the speculation about life beyond the Earth, is heavily tainted by anthropomorphism. The images might raise a smile, but we are heavily conditioned by our popular culture with visions of aliens as bipedal, oxygen breathing humanoids. We need to start by asking how strange can life be?

Terrestrial species occupy a remarkable range of evolutionary niches. Nature has rolled the dice over billions of years, and culled the results based on the ability to survive in a changing environment. Oceanographers have discovered communities of sea life clustered in the darkness near seafloor volcanos; the entire food web is based on bacteria that utilize volcanic heat and

metabolize hydrogen sulfide [25]. The seafloor temperature of 520 K (482° F) and pressure of 250 atmospheres represent conditions as severe as those on Venus. Plants, bacteria, and even some insects can survive down to 10% of normal atmospheric pressure [26]. It would therefore be rash to close the door entirely on the possibility of life elsewhere in the solar system. Primitive lifeforms have radiated into an amazing variety of harsh environments on Earth. On the other hand, advanced species tend to be fragile; humans can only tolerate a 3% variation in body temperature. Feathers and fur and sex and symphonies may be the products of Earth only.

The possibility of *intelligence without technology* must be considered. Dolphins are land mammals that returned to the oceans millions of years ago. They have a similar brain-to-body weight ratio to humans, and a complex language that is still imperfectly understood by us. They show evidence of self-awareness and the ability to communicate by the manipulation of abstract symbols [27]. Chimpanzees display cognitive strategies that indicate an ability to model the mental experience of others [28]. Among the order of mammals, both primates and cetacea are believed to have some level of abstract reasoning ability. But only humans have created telescopes and wondered whether thay are alone in the universe.

Equally important is the possibility of *technology without intelligence.* Humans have created machines to do our bidding, and we have exerted a large degree of control over the natural environment. However, Raup [29] has pointed out that adaption through natural selection is a highly effective scheme for finding optimum solutions to engineering problems. Insects escape predators by adaptive mimicry, and insect societies involving bees, ants and termites are capable of impressive feats of engineering. In no case is the individual organism intelligent. Migratory birds and other animals and marine organisms developed navigational systems by the biological synthesis of the mineral magnetite, which allows the detection of magnetic fields [30]. A number of species have evolved the ability to hunt and communicate using sonar or electric fields. Nonintelligent species have also used chemical means to solve the problem of high speed communication. Pheromones can easily transmit 100 bits per second or the equivalent of 20 words of English text per second, and the capacity scales up with the number of distinct pheromones [31]. It should also be noted that the Earth has leaked a sphere of radio signals into space that is now 80 light years across, encompassing hundreds of stars, yet these emissions were intended for terrestrial communications,

rather than for communication with alien species.

Finally, we should remove our biochemical blinders. Artificial life is an emerging discipline which involves collaborations between computer scientists, biologists, physicists, and chemists [32]. The elevated expectations aroused by early research on artificial intelligence tend to make us forget how far computers have actually progressed. Computers are close to meeting the challenge of the Turing test, whereby a human interrogator cannot tell the difference between a human and a machine, and a computer program recently accomplished what only five years ago would have been considered unthinkable, the defeat of world chess champion Gary Kasparov. Most spectacular computer achievements are the result of no more than simple algorithms run at blinding speed. However, computers program are being developed which simulate life in two important ways: by the interconnected storage of vast amounts of information, and by the ability for self-organization.

The "weak" form of artificial life simulates various attributes of biochemical life in ways that allow the programmer to vary the experimental conditions. Some of these simulations are striking. Computer scientists at Thinking Machines in Cambridge, Mass. have designed an evolutionary system where virtual creatures resembling robots reproduce and compete for resources in a three-dimensional arena. Over hundreds of generations, these creatures reproduce, evolve new capabilities, compete, and learn new strategies for controlling resources.

In the "strong" form of artificial life, computer programs mimic the basic attributes of life without any reference to biological organisms. The first essential requirement is *information storage*, a task which can be carried out as well in silicon as it can in the complex folds and chains of proteins and DNA. The second requirement is *complexity*. Even though the number of algorithms may be limited, when a computational system has sufficient complexity, the outputs are no longer predictable. By moving beyond the deterministic limitations of a simple machine, computers are able to achieve a degree of self-organization, to *evolve*. We have no idea whether or not life in the universe has evolved independent of carbon chemistry, but the possibility must be taken seriously.

6 Where Are They?

It has proved almost impossible to excise anthropocentric thinking from the debate over life in the universe. For simple logical reasons, the terrestrial experience cannot be used to make general statements about exobiology. We know neither the neccesary nor the sufficient conditions for life. Ironically, SETI enthusiasts have embraced these anthropocentric limitations in a self-effacing way; many popular talks on the subject are filled with anecdotes about the Pioneer plaque and nods in the direction of *Star Trek* and *2001: A Space Odyssey.*

Accept for a moment the presumption that biochemical life is widespread, that the progression towards intelligence is mandated by evolution, and that a significant number of civilizations have the capability for electromagnetic communications. There remains the problem that civilizations are isolated in time and space. An optimistic application of the Drake Equation produces $N = L$, where the number of intelligent communicable civilizations roughly equals the lifetime of the civilization in the communicable phase. If the average civilization lasts about 3500 years or less, then the average distance between such civilizations spread through the Milky Way is so large that they could not even exchange one message at the speed of light before one of the civilizations disappears [10]. This is already an extrapolation by a factor of 100 over our current timespan of conducting SETI experiments. Even if gulfs of time and space are not an issue, synchrony is. Imagine two identical Earth-like planets, warmed by identical yellow Suns. With a mismatch of only 10% in the evolutionary clocks, driven perhaps by a 5% difference in the Earth-Sun distance, one planet will harbor humans, but life will not have emerged from the oceans of the other. With a mismatch of 30% in the other directions, one planet will harbor humans, but the other will have been engulfed by its bloated and dying star.

Over fifty years ago, Enrico Fermi asked the pointed question "Where are They?" Influenced by the large number of potential civilizations, he interpreted the fact that we have not been visited by aliens as evidence that they do not exist. This idea has been embraced and embellished by others [44]. It is pointed out that with a modest extrapolation of current technology, space probes could be designed that would fan out to neighboring stars, mine asteroids or planets to replicate themselves, and continue to propagate through the galaxy. Since a single civilization could do this in a million

years or so, and since it has (apparently) not happened, we must be alone. However there are many reasons why we may not know of the existence of other civilizations (we discount the possibility that aliens *have* already visited: UFOs are real and claims of ancient astronauts should be taken at face value). They may not exist. They may not manifest their presence (the "zoo" hypothesis). They may be so advanced as to be unrecognizable. They may not have chosen to colonize or communicate (space exploration may be a cultural activity rather than a biological imperative). The logical quandary is evident: absence of evidence is not evidence of absence.

7 Message in a Bottle

The impatience of the SETI enthusiasts is understandable; we will never know unless we try. Over the past twenty years, messages have been placed in bottles and tossed out into the inky void. The most famous is the plaque attached to the leg of the Pioneer 10 spacecraft (Figure 3), launched in 1971 and now nearly 4 billion miles from Earth and drifting towards nearby stars, a journey that will take tens of thousands of years. The history of the plaque is an amusing tale of terrestrial politics. NASA was chastised for sending smut into space, the faces of the figures had to be modified to be more ethnically diverse, women's groups questioned why only the man's hand should be raised in greeting, student groups thought that the couple was too "straight," foreign governments complained that they had not been consulted, the public pointed out that since parts of the message were unintelligible to them it was unlikely to be understood by aliens, and so on.

In 1977, these issues were revisited with the launch of two Voyager spacecraft. Attached to each was a gold-plated phonographic record, containing digitized versions of the sights and sounds of Earth [33]. The images form a sweeping vision of the home planet, its topography and species, its culture and civilization. The message is upbeat; representations of death or war are not included. The music section is admirably eclectic, with a short selections of classical music, jazz, rock and roll, folk music, and tribal music from all parts of the world. The Voyager record has severe shortcomings as a scientific experiment. There are serious questions as to how it could be interpreted, and it is ironic that the technology used for the message is already obsolete here on Earth. It is difficult not to see it as more of a message to ourselves

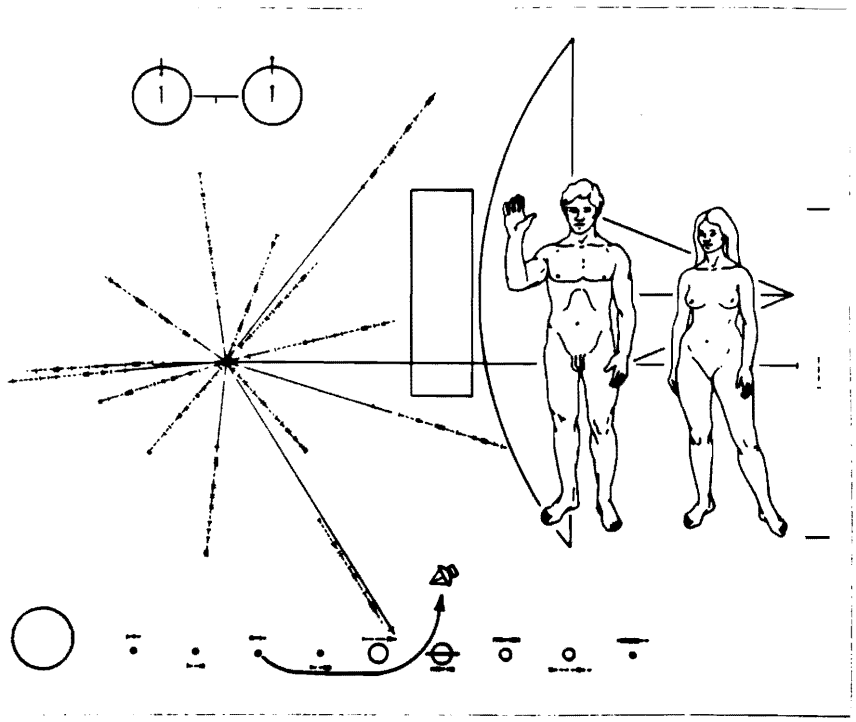

Figure 3: The plaque carried aboard the Pioneer 10 and 11 spacecraft. Two humans in scale with the spacecraft are shown on the right. On the left, the solar system is identified by triangulation with respect to luminous pulsars, whose periods are represented in binary along each line of sight (NASA).

than an attempt to communicate with an intelligence of arbitrary function and form.

Since then, the paradigm for interstellar communication has been coded and pulsed electromagnetic waves, primarily at long radio wavelengths. One famous early message consisted of a string of 1679 "on" and "off" radio pulses, beamed towards the globular cluster M13 in Hercules. Rearranged into the product of two prime numbers, 23 and 73, and coded into a visual field by replacing on with black and off with white, a complex pattern is revealed (Figure 4). To those who can decipher it, the message is a curious mixture of pictograms and binary representations of abstract quantities. Either way, humans should not hold their collective breath. A return message from M13 travelling at the speed of light would take at least 52,000 years.

The design of modern SETI experiments requires the talents of com-

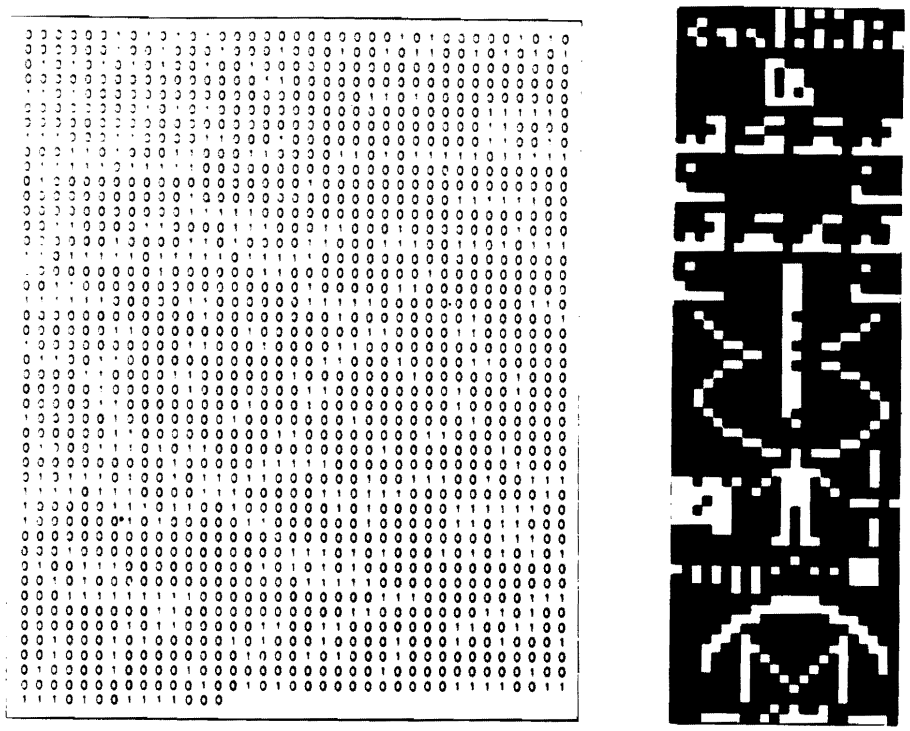

Figure 4: The sequence of 1679 bits of information sent towards the globular cluster M13 in the form of on/off radio signals (left) Rearranged into a grid of 23 × 73, and coded by on=white, off=black (right), the picture is revealed as a mixture of pictograms and binary representations of geological, chemical and biological information (NASA).

puter scientists, mathematicians and cryptologists. The basic problem is to detect a signal of artificial origin in the presence of noise [34]. The radio noise can be due to terrestrial interference, the solar wind interacting with the atmosphere, or to a variety of cosmic sources beyond the solar system. Sophistocated fourier algorithms are used to separate periodic and stochastic signals. Since we cannot say what an intelligent message will look like, the strategy involves filtering out naturally occuring signals. This supposes that we have an encompassing knowledge of all astrophysical phenomena that can produce nonrandom radio signals. As a cautionary note, recall that the first pulsars were designated LGM1, LGM2 etc in 1967 ("Little Green Men") because it was considered unlikely that stellar physics could produce such a rapidly repeating signature.

The current wave of SETI experiments uses a network of radio telescope around the world to listen on millions of narrow radio channels simultaneously. Two survey strategies are employed. The first targets a set of about 100 nearby solar-type stars, the second scans larger regions of the sky to look for rarer signals from much larger volumes. It is a classic "needle in a haystack" experiment, without the benefit of a metal detector, and without knowing whether or not there is a needle to be found! Regardless of our concious efforts to listen, we have been inadvertently betraying our presence for several decades. Starting with the advent of radio communications, a bubble of electromagnetic signals has been moving out from the Earth and is now some 80 light years across. Over 500 stars have heard a Caruso aria, over 200 stars have witnessed the *I Love Lucy* show. Unfortunately, it is much easier to decide that a signal is nonrandom than it is to decode the information [35]. Even if the assumption of electromagnetic communication is granted, interpretation requires the resolution of a series of imponderables involving sensory apparatus, language and syntax. As an example, consider the gulf between human senses. An olfactory creature could represent an apple by a coded and digitized version of the shapes of the molecules that give the apple a particular scent. Could this be understood by a creature with only the visual sense? Despite a few brave attempts [36], efforts to develop a universal language are still in their infancy.

This pessimism can be tempered by lessons from our emerging technology that make interstellar communication more feasible. Travel between stars has been considered futile because of the phenomenal energy cost of accelerating a modest payload to a significant fraction of the speed of light. Recent aeronautics design has come up with mechanisms to harness radiation pressure in space with enormous "sails," and launch a spacecraft stuffed with microelectronics from near Earth orbit. With an energy budget equal to the annual consumption of a small city, a payload the size of a baseball can be accelerated to 30,000 kms^{-1}, or 1/10 of the speed of light. At this speed, direct communication using sentient probes becomes a possibility.

Another insight comes from computer networks. Point to point communications across the Milky Way are neccesarily time-consuming, taking tens of thousands of years at the speed of light. However, with a grid of information storage automata, the communication time is reduced to the light travel time to the nearest node of the network [37]. This collective network could store the accumulated and evolving knowledge of all civilizations in the

galaxy, independent of the fate of any particular species. A final option is to transmit the information of the organism rather than the organism itself. A generous estimate of the information content of the synapses and neurones of the human brain is 10^{17} bits, corresponding to less than 1 erg or energy [38]. There is no theoretical objection to "teleportation," in the sense that exact replicas of the quantum state of an object can be transmitted and replicated [39], however many might find the mechanistic implications of this argument distasteful!

We come back to Earth with a bump by recalling the untested assumptions that underlie the prediction of intelligent civilizations beyond the solar system. It is in fact far more likely that we will detect life *of some kind* rather than intelligent life. NASA has recognized this with its ambitious program called TOPS, *Toward Other Planetary Systems* [15]. The large telescopes and space-based interferometers that can be used for detecting extrasolar planets can also be used to carry out spectroscopy of distant planetary atmospheres. As the Galileo probe headed towards Jupiter, it looked back toward the Earth and was able to detect evidence of life from the large amount of oxygen and other molecules that were severely out of equilibrium [40]. For over 2 billion years, the oxygen in the Earth's atmosphere has betrayed the presence of biochemical life. Independent of technology, we might detect other planetary systems where the chemistry has been altered by a primitive metabolism.

8 Myths and Aliens

It is almost irresistible for humans to believe that they have a special place in the scheme of things. This is the simplest reason for the dominance of Aristotle's geocentric cosmology for nearly two thousands years. The natural theology of Christianity embraced the geocentric cosmos, and cemented it into a static heirarchy called the "Chain of Being," where humans stand at the pinnacle of creation, ranged below the perfection of the heavenly realm [41]. The idea of the plurality of worlds was condemned by Saint Augustine, and was formally declared heretical in the eleventh century.

The revolutionary Copernicus struck a major blow against the Christian idea that the universe is a cozy affair between God and man. However, even he was unwilling to take the next step, and propose that humans occupy a modest position in an enormous, and perhaps limitless, universe of

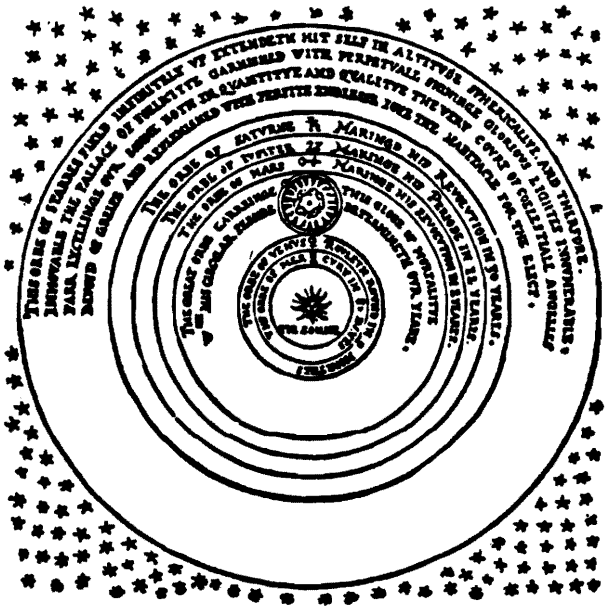

Figure 5: The infinite universe of Thomas Digges, a modification of the Copernican system, published in *A Perfect Description of the Celestial Orbes* in 1576.

planets and stars [42]. In 1576, Thomas Digges published a map of the Copernican unverse where the stars spill out into infinite space (Figure 5). Giordano Bruno went further, by explicitly postulating the existence of stars distributed through infinite space, and the presence of varied lifeforms on planets circling those farflung stars. Bruno suffered for his extravagant claims by being burned at the stake in 1600, but by the eighteenth century the belief in the plurality of worlds was commonplace.

The possibility of large numbers of potential sites for life can no longer be refuted. While the materialistic tendencies of scientists should be tempered with our profound ignorance of the life process, we must consider the possibility of intelligent life beyond the Earth. The theological implications of this are profound, and they have been barely discussed. Put simply, what does it imply for Christianity if the incarnation of Christ were only terrestrial while there are unredeemable souls elsewhere in the universe? In the absence of a scholarly debate, the field has been left to the broad brush strokes of popular culture. Science fiction books and movies have often presented the

God-as-alien metaphor. In the hugely popular film by Stephen Speilberg, *ET – The Extraterrestrial*, the representation is explicit. The alien is possessed of miraculous powers, which are only manifested to those without power or authority. After persecuation, the alien dies, is reborn, and ascends back into "heaven". This representation has its antecedents in classic science fiction films of the 1950s, such as *The Day the Earth Stood Still*, and earlier work such as Fritz Lang's *Metropolis*, which elevates science to a religion [43].

Myths and aliens combine to illuminate the human condition. The messages we send into space are shaped more by our self-image than by any likely or plausible configuration of alien intelligence. Religion and science fiction are both filled with a pantheon of benevolent and malevolent extraterrestrial beings, designed to help us come to terms with our bizarre position as sentient observers of the universe.

9 The Anthropic Trap

The Anthropic Principle is an ambitious attempt to turn the progression started by Copernicus on its head. It has been the subject of dense and scholarly attention [45], [46]. In its weak form, the Anthropic Principle states that people can only observe a universe that is capable of allowing observers to exist. This is essentially a tautology: true, but boring. In its strong form, the Anthropic Principle states that the universe *had* to evolve in a way that would ultimately allow observers to exist. Essentially, the universe was made for us. This is an incredible statement.

The Anthropic Principle seeks to *explain* the physical properties of the universe. Nature exhibits some remarkable coincidences [47]. If the mass ratio of the proton to neutron was not close to unity, there would be no stable nucleides, and no chemistry or biology. If the electromagnetic force was slightly weaker or stronger, stars would either evolve too fast or be too cold to nurture life on their surrounding planets. If the strong nuclear force was a few percent weaker or stronger, stellar fusion would be impossible or stable atoms would not form. If the weak nuclear force was much weaker or stronger, no hydrogen would be formed or stable stars would be rare because the big bang had already converted all the hydrogen into helium. It is striking that the values of fundamental physical parameters happen to be propitious for life. A multitude of possible universes can be imagined

where the parameters are different. Each would operate rationally according to physical laws, but almost none of them would be capable of supporting biochemical life.

If the epistemological basis for the weak Anthropic Principle is self-evident, the epitemological basis for the strong Anthropic Principle is weak. Philosophers have now weighed in with their opinions. William Craig has made the distinction between the proposition that (1) people should not be surprised that they do *not* observe features of the universe which are *incompatible* with their own existence, and the proposition that (2) people should not be surprised that they *do* observe features of the universe that are *compatible* with their own existence. Logically, (1) is true, but (2) does not follow from it. Imagine you face a firing squad of 50 highly trained sharpshooters. They all miss. Clearly, you should not be surprised that you do not observe that you are dead! On the other hand, you should be surprised that you do observe that you are alive. Fifty marksmen missed, and that is surprising! The Anthropic argument would be that they missed for a reason, but this explanation is entirely post hoc and cannot be used to *predict* any feature of the universe.

Alternatively, you could imagine that there are very many firing squads, and that you are one of the very rare survivors. This statistical argument has its parallel in cosmology. We should not be surprised that the universe is as large and old as it is. If the density was much lower, stars would not have condensed out of the expanding gas. If the density was much higher, the universe would have recollapsed without creating many of the heavy elements that are byproducts of stellar evolution. The universe is close to the critical density required for long-lived universe, which is just what is required for carbon-based lifeforms. Chaotic inflation allows the possibility of many universes forming out of a quantum space-time "foam" [48]. Most of these universes would be still-born, in the sense that the physical properties would not permit an expansion. Of those that could inflate, only a tiny fraction could harbor life.

Unfortunately, this attractive notion contains a logical flaw, which philosopher Ian Hacking has called the inverse gambler's fallacy. If you roll a pair of dice, you are much more likely to throw a double-six in a long run of throws than if you roll them once. This does not mean, that after a long run of throws in which no double-six has appeared, that the probability of a double-six on the next throw is any more than 1 in 36. To believe that

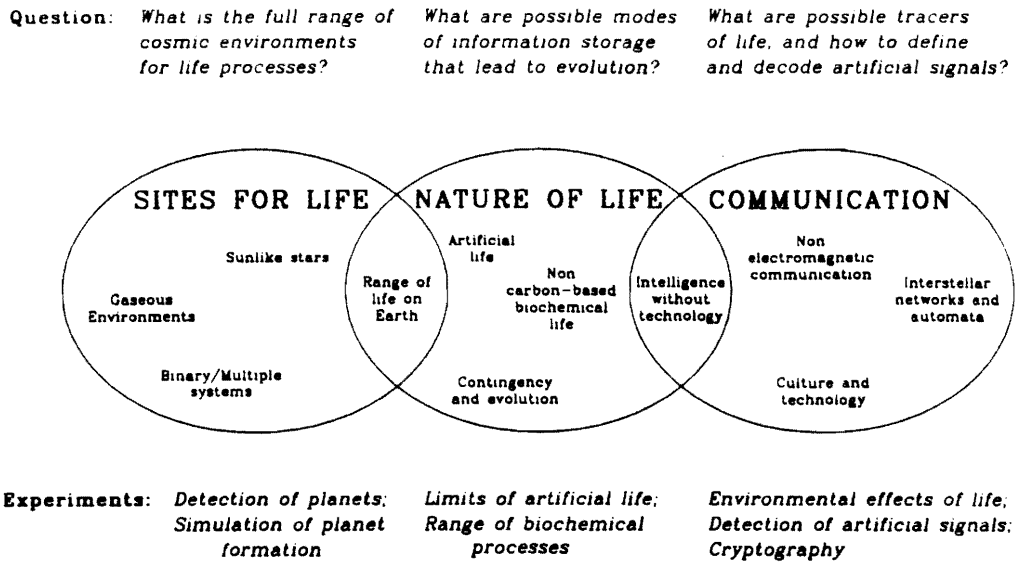

Figure 6: An inductive schema for considering life in the universe, framing the most general possible questions that are still amenable to observational or experimental tests. A distinction is made between the nature and detection of life, and successful communication with intelligent lifeforms.

repeated failure brings success closer is the gambler's fallacy. The inverse gambler's fallacy states that it is just as fallacious to infer that many throws have taken place from the fact that a double-six has just been thrown. A double-six always has a probability of 1 in 36, the supposition doesn't explain it. Similarly, the idea that there have been many randomly different universes does not make this universe any less probable, and so does not explain it. The constants of nature certainly warrant a physical explanation, but it will require a more profound theoretical framework than any we have available to us now.

A hundred years after forceful critiques by Hume and Russell, the argument from design has raised its head in a new form. Apart from its logical problems, and its lack of predictive power, the Anthropic Principle is based on an unduly anthropocentric view of an observer. Does life need heavy elements and stars, or just thermal disequilibrium? Seekers of deep truths about life in the universe will have to look elsewhere.

10 Extraterrestrial Muse

Life in the universe is ripe for creative thinking. Recent surveys of the subject are almost disappointing, as experts plough the narrow and well-worn troughs of their own disciplines [49]. One modest step might be to consider a broader paradigm. The Drake equation is deductive. The result is the contingent product of a number of factors, and so it is limited by the most uncertain factor, and it is shaped by the assumptions involved in each factor. Figure 6 shows an alternative inductive framework. It is shaped by the distinction between the existence of life *of any kind*, and the much more uncertain existence of potential penpals.

Like it or not, the debate over life in the universe occupies a large cultural arena. Federal funding for SETI has run into continuing problems in Congress, even though the program consumes less than 0.1% of the NASA budget. Politicians can score easy points with their constituents by mocking the aspirations of scientists to find aliens. The public, on the other hand, is broadly supportive, although this is more due to a widespread folk belief in the existence of UFOs than to an understanding of the scientific issues involved [50]. Arts and Humanities can bridge the gap between knowledge and ignorance. At its best, science fiction has been amazingly prescient. The imagined worlds of writers and painters and poets can enrich the discussion [51], [52]. Diane Ackerman's poem "Ode to the Alien" [53] amply demonstrates that life in the universe is as much the domain of poets as of scientists.

> Beast, I've known you
> in all love's countries, in a baby's face
> knotted like walnut meat,
> in the crippled obbligato
> of a polio-stricken friend,
> in my father's eyes
> pouchy as two marsupials,
> in the grizzly radiance
> of a winter sunset, in my lover's arm
> veined like the blue-ridge mountains.
> To me, you are beautiful
> until proven ugly.

Anyway, I'm no cosmic royalty
either: I'm a bastard of matter
descended from countless rapes
and invasions
of cell upon cell upon cell.
I crawled out of slime;
I swung through the jungles
of Madagascar;
I drew wildebeest on the caves at Lascaux;
I lived a grim live
hunting peccary and maize
in some godforsaken mudhole in the veldt.

I may squeal
from the pointy terror of a wasp,
or shun the breezy rhetoric
of a fire;
but, whatever your form, gait, or healing,
you are no beast to me,
I who am less than a heart-flutter
from the brute,
I who have been beastly so long.
Like me, you are that pool
of quicksilver in the mist,
fluid, shimmery, fleeing, called life.

And life, full of pratfall and poise,
life where a bit of frost
one morning can turn barbed wire
into a string of stars,
life aromatic with red-hot pizzazz
drumming ha-cha-cha
through every blurt, nub, sag,
pang, twitch, war, bloom of it,
life as unlikely as a pelican, or a thunderclap,
life's our tour of duty

on our far-flung planets,
our cage, our dole, our reverie.

Have you arts?
Do waves dash over your brain
like tide rip along a rocky coast?
Does your moon slide
into the night's back pocket,
just full when it begins to wane,
so that all joy seems interim?
Are you flummoxed by that millpond,
deep within the atom, rippling out to every star?
Even if your blood is quarried,
I pray you well,
and hope my prayer your tonic.

I sit at my desk now
like a tiny proprietor,
a cottage industry in every cell.
Diversity is my middle name.
My blood runs laps;
I doubt yours does,
but we share an abstract fever
called thought,
a common swelter of a sun.
So, Beast, pause a moment,
you are welcome here.
I am life, and life loves life.

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