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12

Why are we so lonely?

Chris Impey
Steward Observatory, The University of Arizona

Abstract. We are currently facing the prospect of a new stage in the Copernican revolution – the demonstration that we live in a biological universe, where the chemical processes that lead to life have played out in many other cosmic settings. Yet astronomers have also been carrying out a much more difficult and quixotic experiment – the search for signals from intelligent, technological civilizations. This talk will look at the cultural backdrop for SETI, which has primed all of us, scientists included, to anticipate the existence of communicable aliens. It will be argued that we might reasonably be optimistic about the existence of life beyond Earth but pessimistic about direct communication. The conditioning of our own history might also be limiting us in considering the full range of cosmic life processes.

Introduction

Whether life exists beyond Earth is one of the most profound questions we can ask about our place in the universe. As the designer and visionary Buckminster Fuller once said, 'We are alone in the universe, or we are not. Either way, the implications are staggering'.

Modern telescopes have given us a clear sense of our place in the universe of galaxies.[1] There are roughly 60 billion galaxies to the limit of view of the Hubble Space Telescope, giving a total of 100 billion billion stars. Not only do we orbit an unremarkable star, which itself orbits in an unremarkable galaxy, but we have recently learned that we are not made of the stuff that most of the universe is made of. The baryons contained within normal atoms are out-weighed by a factor of 20-30 by dark matter,

[1] D. Overbye, *Lonely Hearts of the Cosmos* (New York: Little, Brown, 1992).

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and by a factor of 60-80 by dark energy.[2] The fundamental nature of both dark matter and dark energy is still mysterious.

Since the universe spent its first few billion years expanding faster than the speed of light, the hot Big Bang model contains the implication that the physical universe – all that there is – is larger than the observable universe – all that we can see. The flatness and smoothness of the universe on large scales is best explained if it underwent a period of inflation in the first tiny fraction of a second after the Big Bang, ballooning in size by many orders of magnitude.[3] This leads to the concept of the 'multiverse', where our universe is just one of a potentially vast number of disconnected regions of space-time, each of which may have different physical properties.[4]

Perhaps the final step in the Copernican revolution would be the discovery that we live in a biological universe, that the processes that led to life on Earth are not unique. Speculations about life in the universe have been kicked into high gear by the routine discovery of extrasolar planets.[5] However, the debate about the nature of life beyond Earth is framed by assumptions and expectations that are not purely scientific. This paper will summarize the status of our search for life in the universe and will end by placing it in the context of human culture.

What We Know

We now know that planet formation is a natural by-product of star formation. In the solar system, the Sun contains 99.9% of the mass – all nine planets plus all of the moons, asteroids and comets form a minute rocky residue of the material that collapsed to form the central star. After centuries of speculation, astronomers made a breakthrough in 1995 using the indirect technique of radial velocity shifts. Any massive planet induces a reflex motion in the star it orbits, so an unseen planet can be detected by the periodic motion of the star that it orbits. As Jupiter orbits the Sun, it tugs the Sun so that it pivots around one edge. This motion is

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[2] M. Bartusiak, *Through a Universe Darkly* (New York: Harper Collins, 1993); R. Kirshner, *The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Cosmos* (Princeton, NJ: Princeton University Press, 2002).
[3] A. H. Guth and A. P. Lightman, *The Inflationary Universe: The Quest for a New Theory of Cosmic Origins* (New York: Perseus, 1998).
[4] M. J. Rees, *Before the Beginning: Our Universe and Others* (New York: Perseus, 1998).
[5] M. Mayor and P.-Y Frei, *New Worlds in the Cosmos: The Discovery of Exo-Planets* (Cambridge: Cambridge University Press, 2003).

too subtle to see directly, but the wobble creates a variation of Doppler shift in the Sun's radial velocity of only 13 meters per second with a twelve year period.[6]

The direct method of detection by imaging is beyond current technology. To see why, recall that the Earth only intercepts a billionth of the Sun's light. Jupiter is a hundred times bigger, but is also five times farther away, so the net gain is only a factor of four in reflected light. As seen from afar, Jupiter would be swamped by the Sun's light, and at the distance of nearby stars, it would be hopelessly buried in the wings of the image of the Sun. This situation may change when large ground-based telescopes are fitted out with adaptive optics systems that can remove the blurring caused by the Earth's atmosphere. Alternatively, upcoming space missions may yield sharp enough images for direct planet detection.

From the perspective of life, these new planets are a disappointment. Just as we would be very surprised if there was life in the cool atmosphere of a gas giant like Jupiter, extra-solar planets seem to be very inhospitable for biological life. On the other hand, the game is now on. Planets have been found around 10-20% of solar-type stars. In the planetary system we know best, our own, there are five bodies (three planets and two moons) where life of some kind might exist or might have existed – Earth, Mars, Venus, Titan and Europa.[7] With a hundred billion billion stars in all the galaxies in the observable universe, there are a phenomenal number of potential sites for life.[8]

What We Can Infer

The argument for the cosmic 'inevitability' of biochemical life starts with the fact that the essential elements are widely distributed through space. Massive stars have been creating carbon, nitrogen and oxygen and ejecting it into the interstellar medium for over ten billion years. Updated versions of the classic Miller-Urey experiments have shown that simple molecules can interact in the liquid medium, with the addition of energy, to synthesize 18 of the 20 amino acids needed for life. Although the progression from macromolecules to simple cells is not well understood,

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[6] Mayor and Frei, *New Worlds in the Cosmos: The Discovery of Exo-Planets*.

[7] B. Jakosky, *The Search for Life on Other Planets* (Cambridge: Cambridge University Press, 1998).

[8] J. Bennett, S. Shostak, and B. Jakosky, *Life in the Universe* (San Francisco, CA: Addison Wesley, 2003).

proteins can fashion themselves into microspheres – protocells with membrane walls that can generate and store molecular information.

The earliest reliable traces of life date back to 3.8 billion years ago, and there is more controversial evidence from chemical biomarkers for life 4 billion years ago, only 500 million years after the Earth formed. Life formed very soon after the crust cooled and the oceans formed, when the Earth was geologically very active. There is even evidence that life had several false starts, since the Earth may have been sterilized during the period of heavy bombardment. All life today may have descended from just one of the origination events.[9]

Life formed almost as soon as it possibly could on the primitive Earth, and it radiated into every conceivable evolutionary niche. Oceanographers have discovered communities of sea life clustered in the darkness near deep-sea vents; the entire food web is based on bacteria that utilize volcanic heat and metabolize hydrogen sulfide. The seafloor temperature of 480 degrees F and pressure of 250 atmospheres represent conditions as severe as those on Venus. Plants, bacteria, and some insects can survive down to 10% of normal atmospheric pressure. Microbes have been found that can exist deep with rock, hibernate for a million years or more, and thrive in environments that range from pure base to pure acid.[10]

Even if microbial life started quite readily, subsequent evolution has had many twists and turns. Life quickly attained a high level of biochemical complexity, but transition from simple cells to cells with nuclei took over two billion years. 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 and experimentation, cosmic catastrophes, and mass extinctions. It defies any attempt to impose an orderly progression, and it is not deterministic.[11]

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 billions of 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

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[9] F. Dyson, *The Origin of Life* (New York: Cambridge University Press, 1987); S. J. Gould, ed., *The Book of Life* (New York: Norton, 1993).

[10] Jakosky, *The Search for Life on Other Planets*.

[11] S. J. Gould, *Wonderful Life* (New York: Norton, 1989).

human level of intelligence. We have had technology and the capability for astronomy 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 now 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.

What We Do Not Know

It would be rash to close the door entirely the possibility of life elsewhere in the solar system. Three billion years ago, Mars was warmer and wetter and Venus was cooler than it is now, and both may have been hospitable to simple life forms that could possibly still endure under the surface soil layers. Jupiter's moon Europa has an ice pack with water underneath that might be kept warm by mild geological activity, and Saturn's moon Titan probably has liquid ethane-methane oceans where biochemistry could operate. Thus, there are five plausible sites for life in the solar system – three planets and two moons. As for what lies beyond, we can only speculate.

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 occurred 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. In addition, the argument has been advanced that Earth-like planets with stable and hospitable conditions might be extremely rare.[12]

The traditional framework for thinking about life in the universe is the Drake equation. This multiplicative set of factors, ranging 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. The factors are the number of stars in the Milky Way, the fraction of Sun-like stars, the average number of planets per star, the fraction of planets suitable for life, the fraction of those planets where life actually develops, the fraction of planets with life where intelligent

[12] P. D. Ward and D. Brownlee, *Rare Earth: Why Complex Life is Uncommon in the Universe* (New York: Copernicus, 2000).

civilizations arise, and the communicable time span as a fraction of the age of the Milky Way. Remember that there are numerous galaxies beyond the Milky Way that might harbor life, but communication with those life forms would take millions of years or more. Astrobiologists admit that the Drake equation is more a way of organizing ignorance than a way of defining a scientific.[13]

The uncertainty in the number of intelligent, communicable civilizations 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. It is consistent with current knowledge that microbial life is widely spread through the cosmos but intelligent life is very rare. It is logically possible that the conditions leading to technological civilizations have not been 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.

Thinking Outside The Box

Ignorance is confining but it can also be liberating. It is usually assumed that the best place to look for life is the habitable zone of a terrestrial planet – defined by the range of distances in a nearly circular orbit where surface water will remain liquid. But a sufficiently large planet or moon can generate energy by geological activity, and we know that life exists on Earth's sea floor, independent of the Sun's energy. Moreover, a small moon in a tight elliptical orbit of a massive planet can generate heat by tidal flexing. The range of life sites may be much wider than we had imagined.

‘Life is digital information’. So said James Watson, co-discoverer of the DNA double helix as the blueprint for life. Two essential ingredients for terrestrial life are carbon and water, both of which are abundant throughout the cosmos. Carbon is without peer in facilitating the growth of long chain molecules, which provide a means for storing genetic information. Water is an excellent solvent and a perfect medium for permitting chemical reactions. Computer simulations show that feedback in autocatalytic networks accelerates the growth of chemical complexity. Although it cannot yet be demonstrated in the lab, this is presumably the

[13] T. Ferris, *Life Beyond Earth* (New York: Simon and Schuster, 2001).

key to the generation of a multi-billion chain molecule, and the rebuttal to the combinatory argument of cosmologist Fred Hoyle, who said that the creation of DNA from simple ingredients was as unlikely as a tornado putting together a jumbo jet by whipping through a junk yard.

The ability to sequence DNA in a variety of organisms sheds new light on the history of life on Earth. In terms of the information storage of DNA, life attained a high degree of complexity within the first billion years, when creatures were still microscopic. Humans and all animals represent one of twenty families of life, most of which are micro-organisms with chemical and metabolic processes that are not well understood (usually because they cannot be cultured in the lab). It turns out that there is more DNA in a teaspoon of seawater than in the entire human genome. Rather than being a sturdy branch at the top of the tree, homo sapiens are a mere twig in the tree of life. In terms of nucleic acids, we share over 50% of our DNA with yeast.

If large brains and intelligence are contingent outcomes of evolution, and if their development only involves a minor articulation of the complexity of the underlying genetic code, then what does that imply about life based on a molecule other than DNA, or life where DNA has had ten billion years to develop possibilities, rather than four billion? Stephen Jay Gould posed the question about contingency in an interesting way.[14] Given a hundred or a thousand Earths, with identical conditions just after their formation, on how many would you expect to return after 4.5 billion years and find apes or humans or even mammals?

The logical next step is to question whether life needs biochemistry at all. It is not wild-eyed science fiction but well-motivated induction to speculate about life based on organizing structures as varied as crystal lattices or magnetic fields. As a minimum requirement, life needs thermal disequilibrium and a mechanism for storing and transmitting information. Carbon chemistry may not be the only (or even the best!) way to accomplish that task. This premise is the basis for artificial life, an emerging discipline involving collaborations between computer scientists, biologists, physicists, and chemists.[15]

There are two useful ways to think of computation in the context of life. The first uses computers to simulate life processes, either to mimic what may have occurred on early Earth or to explore other possible realizations of biochemical processes. Artificial life can contain analogs

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14 Gould, *Wonderful Life*.

15 S. Levy, *Artificial Life* (New York: Pantheon, 1992).

of both the genotype – the genetic information that is transmitted to future generations, and the phenotype – the instructions that must be executed to produce an organism. These genetic 'algorithms' display periods of stasis broken by phases of rapid evolution, which is the punctuated equilibrium well known to population biologists. The genetic makeup of the population evolves even during the periods of equilibrium. When the presence of a gene that conveys enhanced adaptation to the environment reaches a critical level, the rate of evolution surges. This work may shed light on the biological problem of epistasis: organs that convey adaptive advantage, such as eyes and ears, contain the morphological expression of many genes.

Computer algorithms are also capable of mimicking life processes at a more fundamental level, without any reference to biological organisms. The basic requirements are (1) information storage, which can be carried out as well in silicon as it can in the complex folds and chains of proteins and DNA, (2) complexity, where beyond a certain level of complexity, computational outputs are no longer predictable and self-organization and evolution are possible, and (3) a set of directions for self-adaptation and modification. Life is a profound example of the creation of order, denoted by information content, in the face of disorder, represented by the global tendency towards increased entropy. Non-linear dynamical systems (biochemical networks are just one example) can generate complexity and store information.[16]

This experimentation has been taken the farthest with the simplest form of computational machines. Cellular automata are one-dimensional algorithms to propagate cells that each carry one bit of information, i.e., coded black or white. The application of simple rules can lead to patterns, randomness and surprising complexity.[17] Different cellar automata have been used to generate prime numbers, solutions to differential equations, Turing machines (i.e., universal computers), and complete axiom systems beyond standard mathematics. Complexity based on recursion is not solely a property of cellular automata. The same behavior is seen if the system is extended to more than one dimension, if the fixed grid is replaced by a flexible network, or if information is propagated according to constraints rather than rules.

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[16] P. Bak, *How Nature Works: The Science of Self-Organized Criticality* (New York: Springer-Verlag, 1996).
[17] S. Wolfram, *A New Kind of Science* (Champaign, IL: Wolfram Media, 2002).

What does this imply about life? It implies that biochemical life is just one example of a broad array of computationally equivalent processes. It may be that more than one physical process has led to self-organization and complexity. It may be that biochemistry is a stage in the evolution of life, with mechanical organisms and artificial intelligence as outcomes that go beyond the constraints of cells and DNA.[18] We may currently be witnessing the first tentative steps on this road, as nano-technology seeks to replace our body parts from within and as the processing power and information storage of computers approaches the level of the human brain. As much as it might disturb us to consider this prospect on Earth, it must be contemplated within huge confines of the universe.

Where Are They?

Over fifty years ago, Enrico Fermi asked the question: 'Where are They?'. Keying off the enormous number of potential sites for life, he wondered if the absence of contact might indicate that intelligent life in the universe is rare. Regardless of the scientific case for or against the ubiquity of intelligent life, there are several enormous practical challenges to communication.

The first is isolation in space and time. If an average civilization lasts 3500 years or less, the average distance between civilizations is so large that they could not exchange messages before one of the civilizations disappears. The second is synchrony. Our ability to communicate through space is recent, a tiny fraction of the span of human existence. A timing argument would say that any civilization that we encounter is likely to be unimaginably more advanced than we are. Last is communication itself. It is much easier to decide that a signal is nonrandom than to decode the information. We must assume electromagnetic, sensory apparatus, culture and language.[19] Plus, recall that we cannot communicate with species on this planet with whom we share 99% of our DNA.

There are a number of possible answers to Fermi's question, with no logical or epistemological way to decide between them (we discount the possibility that UFOs are real and aliens have actually visited). They may not exist. They may not manifest their presence (the 'zoo' hypothesis).

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[18] S. Nolfi and D. Floreano, *Evolutionary Robotics* (Cambridge, MA: MIT Press, 2000).

[19] C. Sagan, *Murmurs of Earth* (New York: Random House, 1978); H. Freudenthal, *LINCOS: Design for a Language of Cosmic Intercourse* (Amsterdam: North-Holland, 1960).

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). More significantly, the fact that we know of no alien visitation or artifact is a weak constraint.[20] Only a tiny fraction of the Earth's surface and environment has been under surveillance since humans first appeared. The logical quandary is evident: absence of evidence is not evidence of absence.

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. Yet the progress of astrobiology may force us to face the implications of being alone or not being alone. Within a decade, astronomers will be able to take spectra of planets around other stars and look for tracers of metabolic processes and life: oxygen, ozone, and chlorophyll. Our own solar system may still yield evidence of biology beyond the Earth. And of course the current wave of SETI experiments could yield the detection of an intelligent signal at any time. The universe seems amazingly fine-tuned for the presence of life,[21] yet we must not overplay the anthropic argument since we would not be here to observe the universe unless it were this way.[22]

Meanwhile, scientific ideas about life in the universe exist within a swirl of popular culture. Science fiction books and movies have often presented the God-as-alien metaphor.[23] For example, in *E.T.*, the popular film by Stephen Spielberg, the representation is explicit. The alien is possessed of miraculous powers, which are only manifested to those without power or authority. After persecution, the alien dies, is reborn, and ascends back into 'heaven'. This representation has antecedents in classic science fiction films of the 1950s, such as *The Day the Earth Stood Still*. Science fiction has also been prescient in its discussion of non-biological life processes and sentient computers.

Myths and aliens combine to illuminate the human condition. The unknown form of extraterrestrial intelligence is an empty vessel into

[20] S. Webb, *Where is Everyone?* (New York: Copernicus, 2002).
[21] J. D. Barrow and F. J. Tipler, *The Anthropic Cosmological Principle* (Oxford: Clarendon Press, 1986).
[22] N. Bostrom, *Anthropic Bias* (New York: Routledge, 2002).
[23] R. Lambourne et al., *Close Encounters? Science and Science Fiction* (Bristol: Adam Hilger, 1990).

which we pour our hopes and fears and aspirations. The messages we have sent into space are shaped more by our self-image than by any likely or plausible configuration of alien intelligence. Both religion and science fiction are filled with a pantheon of benevolent and malevolent extraterrestrial beings, designed to help us come to terms with our position as sentient observers of the universe. With this as a backdrop, the scientific study of life in the universe is only just beginning. Rather than 'Are We Alone', we might redirect to the more cultural question: 'Why Are We So Lonely?'.