THE SEARCH FOR EXTRATE

Scientific Quest or

A DEBATE BETWEEN ERNST MAYR AND CARL SAGAN

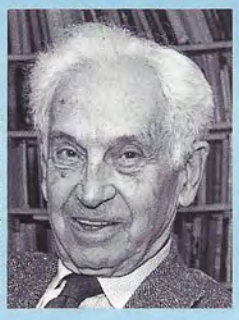


Photo: Jane Reed/Harvard News Office

Ernst Mayr –"Darwin's current bulldog" is how Scientific American describes Ernst Mayr, recalling Thomas Huxley, the 19th-century scientist who is remembered largely because of his vociferous defense of the theory of evolution. Mayr will be remembered for championing evolution as well as for his many achievements in the field of biology. In systematics, ornithology, evolutionary biology and the history of science, he stands as a giant of the 20th century. He has been awarded the National Medal of Science, the Balzan Prize for his contributions to evolutionary biology and the Sarton Medal for his work in the history of science. As the Alexander Agassiz Professor of Zoology, Emeritus, of Harvard University, the 91-year-old Mayr still works every day, tackling challenging subjects, such as the Search for Extraterrestrial Intelligence.

Since humans first looked up, they have seen in the skies the phantoms of their wondering minds. If there is one thread that links the ancient Greek philosophers to modern space scientists, it is the uncertainty about the plurality of worlds. Vast and ancient beyond ordinary human understanding, the universe leaves us pondering the ultimate significance, if any, of our tiny but exquisite life-bearing blue planet.

With the development of technology and our present understanding of the laws of nature, the human species is now in a position where the possibility of extraterrestrial civilizations can be verified by experiment. But because we have yet to find a single piece of concrete evidence of alien intelligence, a philosophical battle has arisen between those who might be called contact optimists–who generally embrace SETI–and the proponents of the uniqueness hypothesis, which suggests that Earth is the only technical civilization in our galaxy.

In these pages, we present both sides of this philosophical and scientific battle. Which view is more palatable to you? Read on and decide for yourself. –Guillermo A. Lemarchand

This debate between two of the most prominent scientists of the 20th century first appeared in *The Bioastronomy News*, a special-interest newsletter published by The Planetary Society. The debate was conceived by newsletter editor Guillermo A. Lemarchand, a researcher at the Argentine Institute of Radio Astronomy and a leader in the Society's META II project.

THE IMPROBABILITY OF SUCCESS

by Ernst Mayr

What is the chance of success in the Search for Extraterrestrial Intelligence? The answer to this question depends on a series of probabilities. I have attempted to make a detailed analysis of this problem in a German publication (Mayr, 1992) and shall attempt here to present in English the essential findings of this investigation. My methodology consists in asking a series of questions that narrow down the probability of success.

How Probable Is It That Life Exists Somewhere Else in the Universe?

Even most skeptics of the SETI project will answer this question optimistically. Molecules that are necessary for the origin of life, such as amino acids and nucleic acids, have been identified in cosmic dust, together with other macromolecules, and so it would seem quite conceivable that life could originate elsewhere in the universe.

Some of the modern scenarios of the origin of life start out with even simpler molecules—a beginning that makes an independent origin of life even more probable. Such an independent origin of life, however, would presumably result in living entities that are drastically different from life on Earth.

RRESTRIAL INTELLIGENCE:
Hopeful Folly?

Photo: Andy Levin/Parade

Carl Sagan – Carl Sagan is the David Duncan Professor of Astronomy and Space Science and Director of the Laboratory for Planetary Studies at Cornell University; Distinguished Visiting Scientist at the Jet Propulsion Laboratory of the California Institute of Technology; and cofounder and President of The Planetary Society. He is one of the few astronomers with a background in biology: research assistant to Nobel laureate geneticist H.J. Muller at Indiana University, Visiting Assistant Professor of Genetics at the Stanford University Medical School and author of the article "Life" in the Encyclopaedia Britannica. He is coauthor, with I.S. Shklovskii, of the classic SETI text, Intelligent Life in the Universe, and has made many research contributions to the study of the prebiological organic chemistry on Earth and in the outer solar system and of the origin of life.

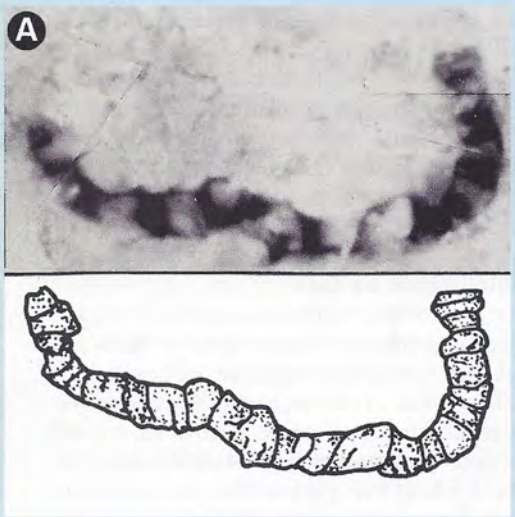
Where Can One Expect to Find Such Life?

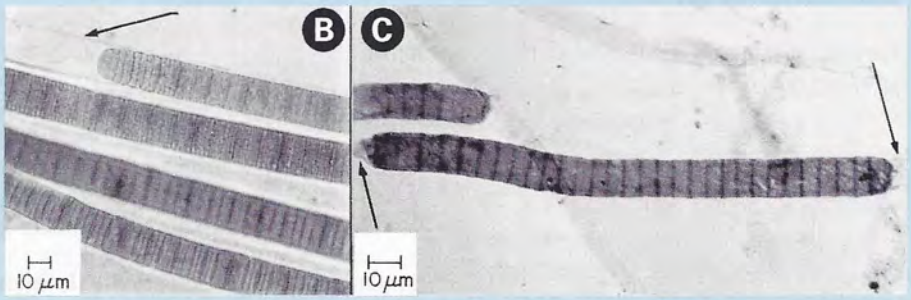
Obviously, only on planets. Even though we have up to now secure knowledge only of the nine planets of our solar system, there is no reason to doubt that in all galaxies there must be millions if not billions of planets. The exact figure, for instance, for our own galaxy can only be guessed.

How Many of These Planets Would Have Been Suitable for the Origin of Life?

There are evidently rather narrow constraints for the possibility of the origin and maintenance of life on a planet. There has to be a favorable average temperature; the seasonal variation should not be too extreme; the planet must have a suitable distance from its sun; it must have the appropriate mass so that its gravity can hold an atmosphere; this atmosphere must have the right chemical composition to support early life; it must have the necessary consistency to protect the new life against ultraviolet and other harmful radiations; and there must be water on such a planet. In other words, all environmental conditions must be suitable for the origin and maintenance of life.

One of the nine planets of our solar system had the right





Perhaps as early as 3.8 billion years ago, life appeared on Earth. The earliest fossils are of prokaryotic ("before a nucleus") organisms, such as cyanobacteria, also called blue-green algae. To the left (A) is an example of one of the filamentous forms, dated at 3.465 billion years old, with an interpretive drawing beneath. Such organisms were stupendously successful and, in fact, dominated Earth for the first 2 to 3 billion years that life existed. The forms of cyanobacteria have remained remarkably constant. (B) above is a living form, while (C) is the fossil of a similar organism about 950 million years old.

Photos: J. William Schopf

kind of mixture of these factors. This, surely, was a matter of chance. What fraction of planets in other solar systems will have an equally suitable combination of environmental factors? Would it be one in 10, or one in 100, or one in 1,000,000? Which figure you choose depends on your optimism. It is always difficult to extrapolate from a single instance. This figure, however, is of some importance when you are dealing with the limited number of planets that can be reached by any of the SETI projects.

What Percentage of Planets on Which Life Has Originated Will Produce Intelligent Life?

Physicists, on the whole, will give a different answer to this question than biologists. Physicists still tend to think more deterministically than biologists. They tend to say that if life has originated somewhere, it will also develop intelligence in due time. The biologist, on the other hand, is impressed by the improbability of such a development.

Life originated on Earth about 3.8 billion years ago, but high intelligence did not develop until about half a million years ago. If Earth had been temporarily cooled down or heated up too much during these 3.8 billion years, intelligence would have never originated.

Conditions According to Mayr That Must Be Met for the Success of SETI

Condition	Likelihood
1 Extraterrestrial life must be able to originate repeatedly.	Probable
2 Other habitable planets similar to Earth must be available.	Probable
3 The planet must have conditions that enable the development of intelligent life.	Improbable
4 Extraterrestrial life must adapt "toward" high intelligence.	Highly improbable
5 The extraterrestrial life-forms must grow intelligent enough to found a civilization.	Improbable
6 The extraterrestrial civilization must be able to send and receive signals.	Improbable
7 The life-forms' sense organs must be adapted to receive electronic signals.	Improbable
8 The civilization must be long-lived and sending signals for a long time.	Improbable

When answering this question, one must be aware of the fact that evolution never moves in a straight line toward an objective ("intelligence"), as happens during a chemical process or as a result of a law of physics. Evolutionary pathways are highly complex and resemble more a tree with all of its branches and twigs.

After the origin of life—that is, 3.8 billion years ago—life on Earth consisted for 2 billion years only of simple prokaryotes, cells without an organized nucleus. These bacteria and their relatives developed surely 50 to 100 different (some perhaps very different) lineages, but, in this enormously long time, none of them led to intelligence. Owing to an astonishing, unique event that is even today only partially explained, about 1,800 million years ago the first eukaryote originated, a creature with a well-organized nucleus and the other characteristics of "higher" organisms. From the rich world of the protists (consisting of only a single cell), there eventually originated three groups of multicellular organisms: fungi, plants and animals. But none of the millions of species of fungi and plants was able to produce intelligence.

The animals (Metazoa) branched out in the Precambrian and Cambrian time periods to about 60 to 80 lineages (phyla). Only a single one of them, that of the chordates, led eventually to genuine intelligence. The chordates are an old and well-diversified group, but only one of its numerous lineages, that of the vertebrates, eventually produced intelligence. Among the vertebrates, a whole series of groups evolved—types of fishes, amphibians, reptiles, birds and mammals. Again, only a single lineage, that of the mammals, led to high intelligence. The mammals had a long evolutionary history which began in the Triassic Period, more than 200 million years ago, but only in the latter part of the Tertiary Period—that is, some 15 to 20 million years ago—did higher intelligence originate in one of the circa 24 orders of mammals.

The elaboration of the brain of the hominids began less than 3 million years ago, and that of the cortex of *Homo sapiens* occurred only about 300,000 years ago. Nothing demonstrates the improbability of the origin of high intelligence better than the millions of phyletic lineages that failed to achieve it.

How many species have existed since the origin of life? This figure is as much a matter of speculation as the number of planets in our galaxy. But if there are 30 million living species, and if the average life expectancy of a species is about 100,000 years, then one can postulate that there have been billions, perhaps as many as 50 billion species since the origin of life. Only one of these achieved the kind of intelligence needed to establish a civilization.

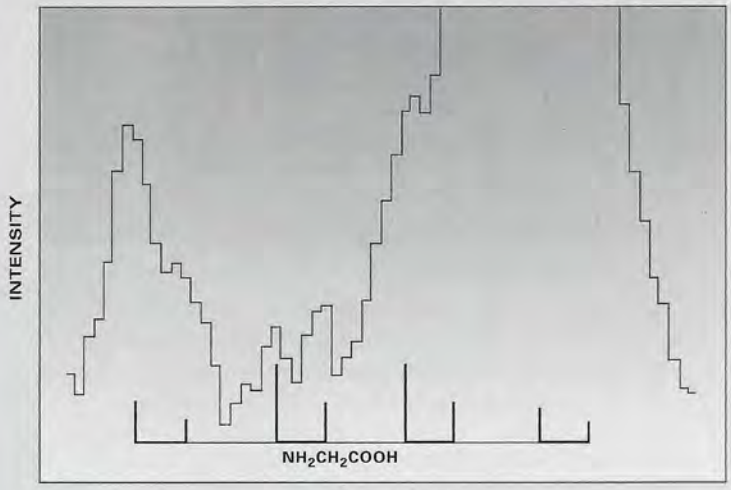
To provide exact figures is difficult because the range of variation both in the origination of species and in their life expectancy is so enormous. The widespread, populous species of long geological duration (millions of years), usually encountered by the paleontologist, are probably exceptional rather than typical.

Why Is High Intelligence So Rare?

Adaptations that are favored by selection, such as eyes or bioluminescence, originate in evolution scores of times independently. High intelligence has originated only once, in human beings. I can think of only two possible reasons for this rarity. One is that high intelligence is not at all favored by natural selection, contrary to what we would expect. In fact, all the other kinds of living organisms, millions of species, get along fine without high intelligence.

The other possible reason for the rarity of intelligence is that it is extraordinarily difficult to acquire. Some grade of intelligence is found only among warm-blooded animals (birds and mammals), not surprisingly so because brains have extremely high energy requirements. But it is still a very big step from "some intelligence" to "high intelligence."

The hominid lineage separated from the chimpanzee lineage about 5 million years ago, but the big brain of modern man was acquired less than 300,000 years ago. As one scientist has suggested (Stanley, 1992), it required complete emancipation from arboreal life to make the arms of the mothers available to carry the helpless babies during the final stages of brain growth. Thus, a large brain, permitting high intelligence, developed in less than the last 6 percent of the life on the hominid line. It seems that it requires a complex combination of rare, favorable circumstances to produce high intelligence (Mayr, 1994).



The building blocks of life may even be found in interstellar space. This spectrum of a molecular cloud near our galactic center shows peaks at some of the frequencies expected for the glycine molecule (NH_2CH_2COOH), one of the amino acids upon which earthly life is based.
Chart: Lewis E. Snyder; redrawn by B.S. Smith

How Much Intelligence Is Necessary to Produce a Civilization?

As stated, rudiments of intelligence are found already among birds (ravens, parrots) and among non-hominid mammals (carnivores, porpoises, monkeys, apes and so forth), but none of these instances of intelligence has been sufficient to found a civilization.

Is Every Civilization Able to Send Signals Into Space and to Receive Them?

The answer quite clearly is no. In the last 10,000 years, there have been at least 20 civilizations on Earth, from the Indus, the Sumerian and other Near Eastern civilizations, to Egypt, Greece and the whole series of European civilizations, to the Mayas, Aztecs and Incas, and to the various Chinese and Indian civilizations. Only one of these reached a level of technology that has enabled it to send signals into space and to receive them.

Would the Sense Organs of Extraterrestrial Beings Be Adapted to Receive Our Electronic Signals?

This is by no means certain. Even on Earth, many groups of animals are specialized for olfactory or other chemical stimuli and would not react to electronic signals. Neither plants nor fungi are able to receive electronic signals. Even if there were higher organisms on some planet, it would be rather improbable that they would have developed the same sense organs that we have.

How Long Is a Civilization Able to Receive Signals?

All civilizations have only a short duration. I will try to emphasize the importance of this point by telling a little fable.

Let us assume that there were really intelligent beings on another planet in our galaxy. A billion years ago, their astronomers discovered Earth and reached the conclusion that this planet might have the proper conditions to produce intelligence. To test this, they sent signals to Earth for a billion years without ever getting an answer. Finally, in the year 1800 (of our calendar) they decided they would send signals only for another 100 years. By the year 1900, no answer had been received, so they concluded that surely there was no intelligent life on Earth.

This shows that even if there were thousands of civilizations in the universe, the probability of a successful communication would be extremely slight because of the short duration of the "open window."

One must not forget that the range of SETI systems is very limited, reaching only part of our galaxy. The fact that there are a near infinite number of additional galaxies in the universe is irrelevant as far as SETI projects are concerned.

SETI Success: An Improbability of Astronomic Dimensions

What conclusions must we draw from these considerations? No less than six of the eight conditions to be met for SETI success are improbable. When one multiplies these six improbabilities with each other, one reaches an improbability of astronomic dimensions.

Why are there nevertheless still proponents of SETI? When one looks at their qualifications, one finds that they are almost exclusively astronomers, physicists and engineers. They are simply unaware of the fact that the success of any SETI effort is not a matter of physical laws and engineering capabilities but essentially a matter of biological and sociological factors. These, quite obviously, have been entirely left out of the calculations of the possible success of any SETI project.

References

Ernst Mayr, "Lohnt sich die Suche nach extraterrestrischer Intelligenz [Is It Worthwhile to Search for Extraterrestrial Intelligence?]," *Naturwissenschaftliche Rundschau,* vol. 45, no. 7, 1992, pp. 264–266.

Ernst Mayr, "Does It Pay to Acquire High Intelligence?" *Perspectives in Biology and Medicine,* 1994, pp. 150–154.

S. Stanley, "An Ecological Theory for the Origin of *Homo*," *Paleobiology*, vol. 18, 1992, pp. 237–257.

→

THE ABUNDANCE OF LIFE-BEARING PLANETS

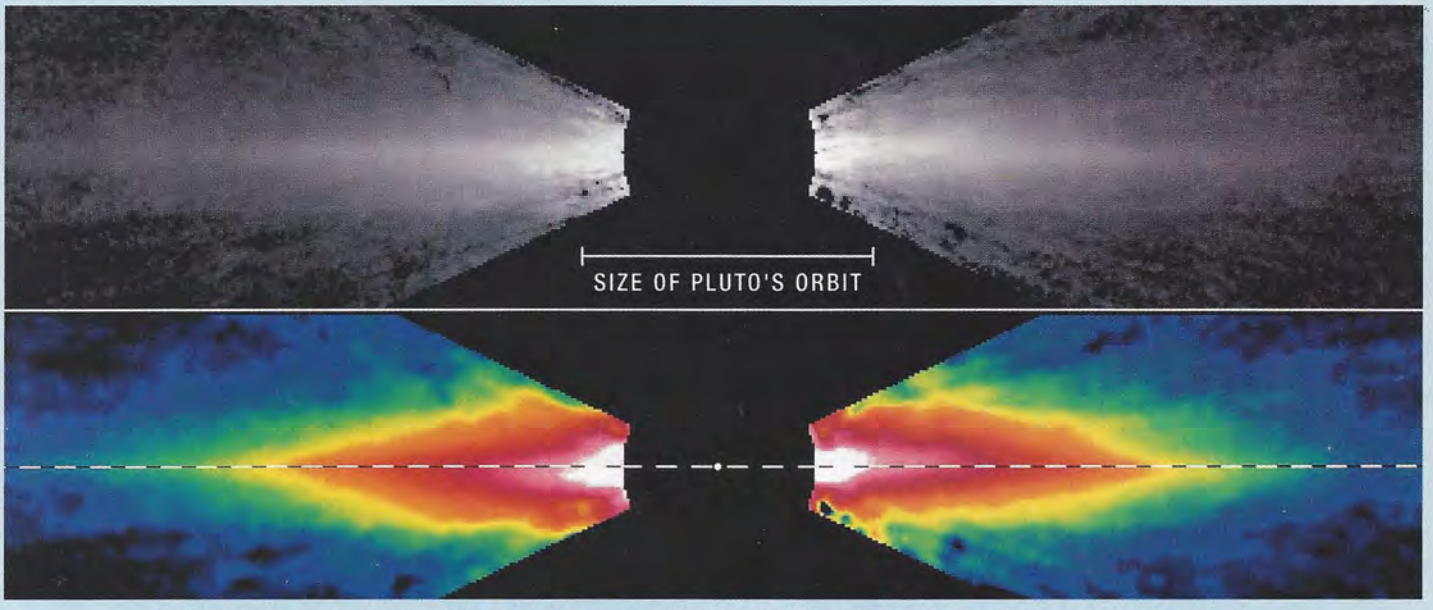
by Carl Sagan

We live in an age of remarkable exploration and discovery. Fully half of the nearby Sun-like stars have circumstellar disks of gas and dust like the solar nebula out of which our planets formed 4.6 billion years ago. By a most unexpected technique—radio timing residuals—we have discovered two Earth-mass planets around the pulsar B1257+12. Apparent jovian planets have been detected around the stars 51 Pegasi, 70 Virginis and 47 Ursae Majoris. A range of new Earth-based and spaceborne techniques—including astrometry, spectrophotometry, radial velocity measurements, adaptive optics and interferometry—all seem to be on the verge of being able to detect jovian-type planets, if they exist, around the nearest stars. At least one proposal (The FRESIP [Frequency of Earth-Sized Inner Planets] Project, a spaceborne spectrophotometric system) holds the promise of detecting terrestrial planets more readily than jovian ones. If there is not a sudden cutoff in support, we are likely entering a golden age in the study of the planets of other stars in the Milky Way galaxy.

Once you have found another planet of Earth-like mass, however, it of course does not follow that it is an Earth-like world. Consider Venus. But there are means by which, even from the vantage point of Earth, we can investigate this question. We can look for the spectral signature of enough water to be consistent with oceans. We can look for oxygen and ozone in the planet's atmosphere. We can seek molecules like methane, in such wild thermodynamic disequilibrium with the oxygen that it can only be produced by life. (In fact, all of these tests for life were successfully performed by the *Galileo* spacecraft in its close approaches to Earth in 1990 and 1992 as it wended its way to Jupiter [Sagan et al., 1993].)

The best current estimates of the number and spacing of Earth-mass planets in newly forming planetary systems (as George Wetherill reported at the first international conference on circumstellar habitable zones [Doyle, 1996]) combined with the best current estimates of the long-term stability of oceans on a variety of planets (as James Kasting reported at that same meeting [Doyle, 1996]) suggest one to two blue worlds around every Sun-like star. Stars much more massive than the Sun are comparatively rare and age quickly. Stars comparatively less massive than the Sun are expected to have Earth-like planets, but the planets that are warm enough for life are probably tidally locked so that one side always faces the local sun. However, winds may redistribute heat from one hemisphere to another on such worlds, and there has been very little work on their potential habitability.

Nevertheless, the bulk of the current evidence suggests a vast number of planets distributed through the Milky Way with abundant liquid water stable over lifetimes of billions of years. Some will be suitable for life—our kind of carbon and water life—for billions of years less than Earth, some for billions of years more. And, of course, the Milky Way is one of an enormous number, perhaps a hundred billion, other galaxies.



In 1984, astronomers Brad Smith and Rich Terrile discovered a disk of dust 200 billion kilometers (about 120 billion miles) wide surrounding the star Beta Pictoris. This was exactly what was predicted by theories of planetary formation. The innermost region was clear of dust, as if planets orbiting there had swept it up, but there was little else to suggest that there might be planets orbiting that star—until the Hubble Space Telescope returned the images seen here. They reveal that the inner dust disk is warped. This is indirect evidence that a planet roughly Jupiter's size is orbiting the star at a distance that falls within the range found for planets in our solar system. (The dark region in the center of both images is caused by an occulting disk in the telescope.) ***Images: Chris Burrows, ESA and NASA***

Need Intelligence Evolve on an Inhabited World?

We know from lunar cratering statistics, calibrated by returned *Apollo* samples, that Earth was under hellish bombardment by small and large worlds from space until around 4 billion years ago. This pummeling was sufficiently severe to drive entire atmospheres and oceans into space. Earlier, the entire crust of Earth was a magma ocean. Clearly, this was no breeding ground for life.

Yet, shortly thereafter—Mayr adopts the number 3.8 billion years ago—some early organisms arose (according to the fossil evidence). Presumably the origin of life had to have occupied some time before that. As soon as conditions were favorable, life began amazingly fast on our planet. I have used this fact (Sagan, 1974) to argue that the origin of life must be a highly probable circumstance; as soon as conditions permit, up it pops!

Now, I recognize that this is at best a plausibility argument and little more than an extrapolation from a single example. But we are data constrained; it's the best we can do.

Does a similar analysis apply to the evolution of intelligence? Here you have a planet burgeoning with life, profoundly changing the physical environment, generating an oxygen atmosphere 2 billion years ago, going through the elegant diversification that Mayr briefly summarized—and not for almost 4 billion years does anything remotely resembling a technical civilization emerge.

In the early days of such debates (for example, G.G. Simpson's "The Non-prevalence of Humanoids"), writers argued that an enormous number of individually unlikely steps were required to produce something very like a human being, a "humanoid"; that the chances of such a precise repetition occurring on another planet were nil; and therefore that the chance of extraterrestrial intelligence was nil. But clearly when we're talking about extraterrestrial intelligence, we are not talking—despite *Star Trek*—of humans or humanoids. We are talking about the functional equivalent of humans—say, any creatures able to build and operate radio telescopes. They may live on the land or in the sea or in the air. They may have unimaginable chemistries, shapes, sizes, colors, appendages and opinions. We are not requiring that they follow the particular route that led to the evolution of humans. There may be many different evolutionary pathways, each unlikely, but the sum of the number of pathways to intelligence may nevertheless be quite substantial.

In Mayr's current presentation, there is still an echo of "the non-prevalence of humanoids." But the basic argument is, I think, acceptable to all of us. Evolution is opportunistic and not foresighted. It does not "plan" to develop intelligent life a few billion years into the future. It responds to short-term contingencies. And yet, other things being equal, it is better to be smart than to be stupid, and an overall trend toward intelligence can be perceived in the fossil record. On some worlds, the selection pressure for intelligence may be higher; on others, lower.

If we consider the statistics of one, our own case—and take a typical time from the origin of a planetary system to the development of a technical civilization to be 4.6 billion years—what follows? We would not expect civilizations on different worlds to evolve in lockstep. Some would reach technical intelligence more quickly, some more slowly, and—doubtless—some never. But the Milky Way is filled with second- and third-generation stars (that is, those with heavy elements) as old as 10 billion years.

So let's imagine two curves: The first is the probable timescale to the evolution of technical intelligence. It starts out very low; by a few billion years it may have a noticeable value; by 5 billion years, it's something like 50 percent; by 10 billion years, maybe it's approaching 100 percent. The second curve is the ages of Sun-like stars, some of which are very young—they're being born right now—some of which are as old as the Sun, some of which are 10 billion years old. If we convolve these two curves, we find there's a chance of technical civilizations on planets of stars of many different ages—not much in the very young ones, more and more for the older ones. The most likely case is that we will hear from a civilization considerably more advanced than ours. For each of those technical civilizations, there will have been tens of billions or more other species. The number of unlikely events that had to be concatenated to evolve a technical species is enormous, and perhaps there are members of each of those species who pride themselves on being uniquely intelligent in all the universe.

Need Civilizations Develop the Technology for SETI?

It is perfectly possible to imagine civilizations of poets or (perhaps) Bronze Age warriors who never stumble on James Clerk Maxwell's equations and radio receivers. But they are removed by natural selection. The Earth is surrounded by a population of asteroids and comets, such that occasionally the planet is struck by one large enough to do substantial damage.

From what was probably a single progenitor, life on Earth has adapted and evolved into a bewildering variety of forms, with astonishing behaviors that enable these teeming organisms to survive. Consider the sponge: For most of its life, this animal sits attached to one place, sifting its food from seawater flowing through its many cavities. It is not a lifestyle that requires intelligence. But the sponge does possess one remarkable trait. If a sponge is forced through a fine mesh, breaking it into single cells or clumps of cells, the cells will reassemble themselves into another sponge.

Photo: Brian Parker, Tom Stack & Associates

The most famous is the K-T event (the massive near-Earth-object impact that occurred at the end of the Cretaceous Period and start of the Tertiary) of 65 million years ago that extinguished the dinosaurs and most other species of life on Earth. But the chance is something like one in 2,000 that a civilization-destroying impact will occur in the next century.

It is already clear that we need elaborate means for detecting and tracking near-Earth objects and the means for their interception and destruction. If we fail to do so, we will simply be destroyed. The Indus Valley, Sumerian, Egyptian, Greek and other civilizations did not have to face this crisis because they did not live long enough. Any long-lived civilization, terrestrial or extraterrestrial, must come to grips with this hazard. Other solar systems will have greater or lesser asteroidal and cometary fluxes, but in almost all cases the dangers should be substantial.

Radiotelemetry, radar monitoring of asteroids, and the entire concept of the electromagnetic spectrum are part and parcel of any early technology needed to deal with such a threat. Thus, any long-lived civilization will be forced by natural selection to develop the technology of SETI. (And there is no need to have sense organs that "see" in the radio region. Physics is enough.)

Since perturbation and collision in the asteroid and comet belts are perpetual, the asteroid and comet threat is likewise perpetual, and there is no time when the technology can be retired. Also, SETI itself is a small fraction of the cost of dealing with the asteroid and comet threat.

(Incidentally, it is by no means true that SETI is "very limited, reaching only part of our galaxy." If there were sufficiently powerful transmitters, we could use SETI to explore distant galaxies; because the most likely transmitters are ancient, we can expect them to be powerful. This is one of the strategies of the Megachannel Extraterrestrial Assay [META].)

Is SETI a Fantasy of Physical Scientists?

Mayr has repeatedly suggested that proponents of SETI are almost exclusively physical scientists and that biologists know better. Since the relevant technologies involve the physical sciences, it is reasonable that astronomers, physicists and engineers play a leading role in SETI.

But in 1982, when I put together a petition published in *Science* urging the scientific respectability of SETI, I had no difficulty getting a range of distinguished biologists and biochemists to sign, including David Baltimore, Melvin Calvin, Francis Crick, Manfred Eigen, Thomas Eisner, Stephen Jay Gould, Matthew Meselson, Linus Pauling, David Raup and Edward O. Wilson. In my early speculations on these matters, I was much encouraged by the strong support from my mentor in biology, H.J. Muller, a Nobel laureate in genetics.

The petition proposed that, instead of arguing the issue, we look: "We are unanimous in our conviction that the only significant test of the existence of extraterrestrial intelligence is an experimental one. No a priori arguments on this subject can be compelling or should be used as a substitute for an observational program."

Many civilizations have risen and fallen on Earth, but only one has developed the technology to communicate over interstellar distances. The Mayans, for example, were expert astronomers,

To get a handle on the myriad living things that share this planet, humans name and classify every distinct form they identify. They then clump the life-forms into groups. In one system, there are three main branches of life: the eubacteria, the archebacteria and the eukaryota. The eukaryota are divided into four kingdoms—Protista (single-celled or colonial forms), Animalia (our kingdom), Plantae (plants) and Fungi. This last group is highly successful, but its members are not the sort of life-forms that might evolve intelligence. They are, however, relatively close relations of ours; our evolutionary paths diverged a little more than a billion years ago.

Photo: David M. Dennis, Tom Stack & Associates

References

L.R. Doyle, ed., *Circumstellar Habitable Zones: Proceedings of the First International Conference,* Travis House Publications, Menlo Park, California, 1996.

Carl Sagan, "The Origin of Life in a Cosmic Context," *Origins of Life,* vol. 5, 1974, pp. 497–505.

Carl Sagan and Ann Druyan, *Shadows of Forgotten Ancestors: A Search for Who We Are,* Random House, New York, 1992.

Carl Sagan et al., "A Search for Life on Earth From the *Galileo* Spacecraft," *Nature,* vol. 365, 1993, pp. 715–721.

Carl Sagan, *Pale Blue Dot: A Vision of the Human Future in Space,* Random House, New York, 1994.

I.S. Shklovskii and Carl Sagan, *Intelligent Life in the Universe,* Holden-Day, San Francisco, 1966.

G.G. Simpson, "The Non-prevalence of Humanoids," *Science,* vol. 143, 1964, pp. 769–775.

using the motion of the heavens as a clockwork for many aspects of their lives. But this knowledge did not save the culture, whose abandoned monuments were swallowed by the jungle life-forms. The Pyramid of the Magician in Uxmal, Mexico, shown here, is a reminder of the short life-times of earthly civilizations. Photo: David L. Brown, Tom Stack & Associates

Ernst Mayr Responds:

I fully appreciate that the nature of our subject permits only probabilistic estimates. There is no argument between Carl Sagan and myself as to the probability of life elsewhere in the universe and the existence of large numbers of planets in our and other nearby galaxies. The issue, as correctly emphasized by Sagan, is the probability of the evolution of high intelligence and an electronic civilization on an inhabited world.

Once we have life (and almost surely it will be very different from life on Earth), what is the probability of its developing a lineage with high intelligence? On Earth, among millions of lineages of organisms and perhaps 50 billion speciation events, only one led to high intelligence; this makes me believe in its utter improbability.

Sagan adopts the principle "it is better to be smart than to be stupid," but life on Earth refutes this claim. Among all the forms of life, neither the prokaryotes nor protists, fungi or plants have evolved smartness, as they should have if they were "better." In the 28-plus phyla of animals, intelligence evolved in only one (chordates) and doubtfully also in the cephalopods. And in the thousands of subdivisions of the chordates, high intelligence developed in only one, the primates, and even there only in one small subdivision. So much for the putative inevitability of the development of high intelligence because "it is better to be smart."

Sagan applies physicalist thinking to this problem. He constructs two linear curves, both based on strictly deterministic thinking. Such thinking is often quite legitimate for physical phenomena, but is quite inappropriate for evolutionary events or social processes such as the origin of civilizations. The argument that extraterrestrials, if belonging to a long-lived civilization, will be forced by selection to develop an electronic know-how to meet the peril of asteroid impacts is totally unrealistic. How would the survivors of earlier impacts be selected to develop the electronic know-how? Also, the case of Earth shows how impossible the origin of any civilization is unless high intelligence develops first. Earth furthermore shows that civilizations inevitably are short-lived.

It is only a matter of common sense that the existence of extraterrestrial intelligence cannot be established by a priori arguments. But this does not justify SETI projects, since it can be shown that the success of an observational program is so totally improbable that it can, for all practical purposes, be considered zero.

All in all, I do not have the impression that Sagan's rebuttal has weakened in any way the force of my arguments.

Carl Sagan Responds:

The gist of Professor Mayr's argument is essentially to run through the various factors in the Drake equation (see Shklovskii and Sagan, 1966) and attach qualitative values to each. He and I agree that the probabilities concerning the →

THE DRAKE EQUATION

With only one example of a technical civilization in front of us, how can we estimate how many such civilizations might exist in our galaxy? In the early 1960s, astronomer Frank Drake took a run at the problem and produced an equation that became famous in SETI circles. The Drake equation attempts to derive *N*, the number of detectable civilizations around other stars. The equation takes into consideration the following items:

- N_* — the number of stars in the Milky Way galaxy
- f_p — the fraction of stars that have planetary systems
- n_e — the number of planets in a given system that are ecologically suitable for life
- f_l — the fraction of otherwise suitable planets on which life actually arises
- f_i — the fraction of inhabited planets on which an intelligent life-form evolves
- f_c — the fraction of the planets inhabited by intelligent beings on which a communicative technical civilization develops
- f_L — the fraction of a planetary lifetime graced by a technical civilization

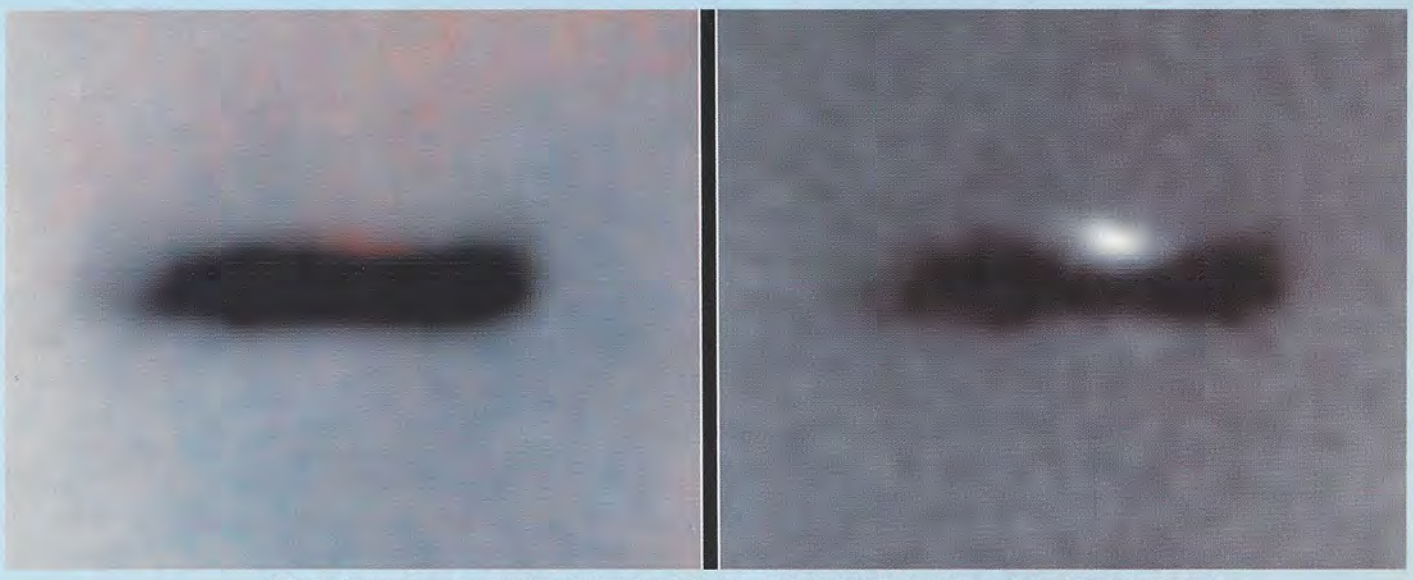
Written out, the equation reads:

$$N = N_* f_p n_e f_l f_i f_c f_L$$

All the *f*'s are fractions with values between 0 and 1. The values assigned to these elements depend on the presuppositions and assumptions of the person doing the calculation. As you'll note after reading the accompanying debate, for some, *N* will equal 1; for others, it could be a sizable number.

—*Charlene M. Anderson*

abundance of planets and the origins of life are likely to be high. (I stress again that the latest results [Doyle, 1996] suggest one or even two Earth-like planets with abundant surface liquid water in each planetary system. The conclusion is of course highly tentative, but it encourages optimism.) Where Mayr and I disagree is in the later factors in the Drake equation, especially those concerning the likelihood of the evolution of intelligence and technical civilizations.



As far as humans were concerned, protoplanetary disks once existed only in the hypotheses of physicists trying to work out how our solar system formed. But with technological devices like the Hubble Space Telescope, these disks have graduated from the realm of hypothesis to fact. This embryonic solar system, seen edge on, resides around a newborn star in the Orion nebula. On the left, the disk stands out distinctly from the nebula. On the right, seen through different filters, the edges are not so distinct, but we can see a faint glow from the hidden central star. Our solar system may have looked something like this 4.5 billion years ago. *Images: Mark McCaughrean, C. Robert O'Dell and NASA*

Mayr argues that prokaryotes and protista have not "evolved smartness." Despite the great respect in which I hold Professor Mayr, I must demur: Prokaryotes and protista are our ancestors. They *have* evolved smartness, along with most of the rest of the gorgeous diversity of life on Earth.

On the one hand, when he notes the small fraction of species that have technological intelligence, Mayr argues for the relevance of life on Earth to the problem of extraterrestrial intelligence. But on the other hand, he neglects the example of life on Earth when he ignores the fact that intelligence has arisen here when our planet has another 5 billion years more evolution ahead of it. If it were legitimate to extrapolate from the one example of planetary life we have before us, it would follow that

1. There are enormous numbers of Earth-like planets, each stocked with enormous numbers of species, and
2. In much less than the stellar evolutionary lifetime of each planetary system, at least one of those species will develop high intelligence and technology.

Alternatively, we could argue that it is improper to extrapolate from a single example. But then Mayr's one-in-50 billion argument collapses. It seems to me he cannot have it both ways.

On the evolution of technology, I note that chimpanzees and bonobos have culture and technology. They not only use tools but also purposely manufacture them for future use (cf. Sagan and Druyan, 1992). In fact, the bonobo Kanzi has discovered how to manufacture stone tools.

It is true, as Mayr notes, that of the major human civilizations, only one has developed radio technology. But this says almost nothing about the probability of a human civilization developing such technology. That civilization with radio telescopes has also been at the forefront of weapons technology. If, for example, Western European civilization had not utterly destroyed Aztec civilization, would the Aztecs eventually—in centuries or millennia—have developed radio telescopes? They already had a superior astronomical calendar to that of the *conquistadores*. Slightly more capable species and civilizations may be able to eliminate the competition. But this does not mean that the competition would not eventually have developed comparable capabilities if they had been left alone.

Mayr asserts that plants do not receive "electronic" signals. By this I assume he means "electromagnetic" signals. But plants *do*. Their fundamental existence depends on receiving electromagnetic radiation from the Sun. Photosynthesis and phototropism can be found not only in the simplest plants but also in protista.

All stars emit visible light, and Sun-like stars emit most of their electromagnetic radiation in the visible part of the spectrum. Sensing light is a much more effective way of understanding the environment at some distance; certainly much more powerful than olfactory cues. It's hard to imagine a competent technical civilization that does not devote major attention to its primary means of probing the outside world. Even if they were mainly to use visible, ultraviolet or infrared light, the physics is exactly the same for radio waves; the difference is merely a matter of wavelength.

I do not insist that the above arguments are compelling, but neither are the contrary ones. We have not witnessed the evolution of biospheres on a wide range of planets. We have not observed many cases of what is possible and

what is not. Until we have had such an experience—or detected extraterrestrial intelligence—we will of course be enveloped in uncertainty.

The notion that we can, by a priori arguments, exclude the possibility of intelligent life on the possible planets of the 400 billion stars in the Milky Way has to my ears an odd ring. It reminds me of the long series of human conceits that held us to be at the center of the universe, or different not just in degree but in kind from the rest of life on Earth, or even contended that the universe was made for our benefit (Sagan, 1994). Beginning with Copernicus, every one of these conceits has been shown to be without merit.

In the case of extraterrestrial intelligence, let us admit our ignorance, put aside a priori arguments and use the technology we are fortunate enough to have developed to try and actually find out the answer. That is, I think, what Charles Darwin—who was converted from orthodox religion to evolutionary biology by the weight of observational evidence—would have advocated.

Ernst Mayr Responds:

Since all we deal with are probabilities, most of them extrapolated from a sample of one, let me make a few observations in response to Carl Sagan: (1) We have no evidence that of the enormous number of Earth-like planets "each [is] stocked with enormous numbers of species." (2) There is a world of difference between plants photosynthesizing and a civilization developing the necessary theories and instrumentation for electronic communication. (3) Sagan states, "We have not witnessed the evolution of biospheres on a wide range of planets." The truth is, we have not witnessed it on a single planet outside Earth. (4) I am not talking about the possibility of extraterrestrial intelligence; I am talking about the probability of establishing it with the available means. None of Sagan's arguments has weakened my argument that it is virtually zero. This is not a conceit but a sober calculation of probabilities. The negative answer we are bound to receive will not tell us anything about the actual possibility of some extraterrestrial intelligence somewhere.

Carl Sagan Responds:

I draw the tentative conclusion that other Earth-like planets have millions of species of life on them from the same data set that leads Professor Mayr to conclude that there are no extraterrestrial technical civilizations. Mayr now concedes (observation number 4 above) that there may be extraterrestrial intelligence. (Maybe even large numbers of planets inhabited by intelligent life?) But he is dubious about whether this intelligence will have developed the means for interstellar radio communication. As I have stressed, there is absolutely no compelling way to evaluate this question except by looking for interstellar radio transmissions. That is what we are doing. ■

One of our interplanetary spacecraft, Galileo, did detect evidence of life on one planet it explored.

Image: JPL/NASA