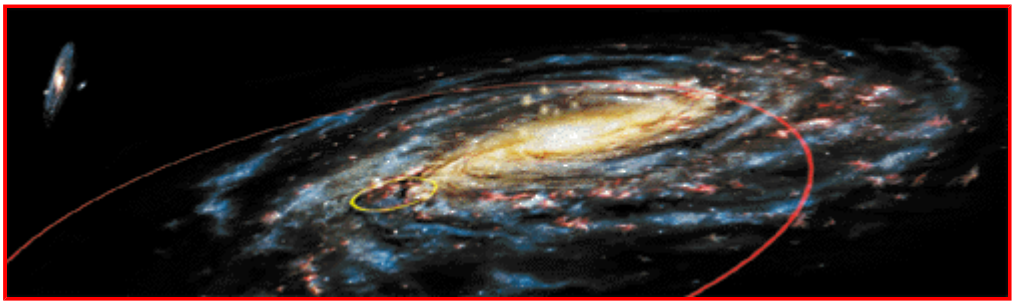
SEARCHING FOR EXTRATERRESTRIALS

Where Are They?



Maybe we are alone in the galaxy after all

by Ian Crawford

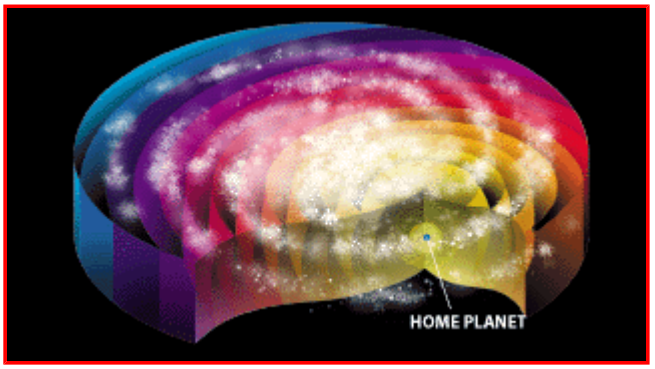
How common are other civilizations in the universe? This question has fascinated humanity for centuries, and although we still have no definitive answer, a number of recent developments have brought it once again to the fore. Chief among these is the confirmation, after a long wait and several false starts, that planets exist outside our solar system.

Over the past five years more than three dozen stars like the sun have been found to have Jupiter-mass planets. And even though astronomers have found no Earth-like planets so far, we can now be fairly confident that they also will be plentiful. To the extent that planets are necessary for the origin and evolution of life, these exciting discoveries certainly augur well for the widely held view that life pervades the universe. This view is supported by advances in our understanding of the history of life on Earth, which have highlighted the speed with which life became established on this planet. The oldest direct evidence we have for life on Earth consists of fossilized bacteria in 3.5- billion-year-old rocks from Western Australia, announced in 1993 by J. William Schopf of the University of California at Los Angeles. These organisms were already quite advanced and must themselves have had a long evolutionary history. Thus, the actual origin of life, assuming it to be indigenous to Earth, must have occurred closer to four billion years ago.

Earth itself is only 4.6 billion years old, and the fact that life appeared so quickly in geologic time--probably as soon as conditions had stabilized sufficiently to make it possible--suggests that this step was relatively easy for nature to achieve. Nobel prize winning biochemist Christian de Duve has gone so far as to conclude,

"Life is almost bound to arise ... wherever physical conditions are similar to those that prevailed on our planet some four billion years ago." So there is every reason to believe that the galaxy is teeming with living things.

Does it follow that technological civilizations are abundant as well? Many people have argued that once primitive life has evolved, natural selection will inevitably cause it to advance toward intelligence and technology. But is this necessarily so? That there might be something wrong with this argument was famously articulated by nuclear physicist Enrico Fermi in 1950. If extraterrestrials are commonplace, he asked, where are they? Should their presence not be obvious? This question has become known as the Fermi Paradox.



COLONIZATION OF THE GALAXY

This problem really has two aspects: the failure of search for extraterrestrial intelligence (SETI) programs to detect radio transmissions from other civilizations, and the lack of evidence that extraterrestrials have ever visited Earth. The possibility of searching for ETs by radio astronomy was first seriously discussed by physicists Giuseppe Cocconi and Philip Morrison in a famous paper published in the journal *Nature* in 1959. This was followed the next year by the first actual search, Project Ozma, in which Frank D. Drake and his colleagues at the National Radio Astronomy Observatory in Green Bank, W.Va., listened for signals from two nearby stars. Since then, many other SETI experiments have been performed, and a number of sophisticated searches, both all-sky surveys and targeted searches of hundreds of individual stars, are currently in progress [see "The Search for Extraterrestrial Intelligence," by Carl Sagan and Frank Drake; SCIENTIFIC AMERICAN, May 1975; "Is There Intelligent Life Out There?" by Guillermo A. Lemarchand; SCIENTIFIC AMERICAN PRESENTS: *Exploring Intelligence*, Winter 1998]. In spite of all this activity, however, researchers have made no positive detections of extraterrestrial signals.

Of course, we are still in the early days of SETI, and the lack of success to date cannot be used to infer that ET civilizations do not exist. The searches have so far covered only a small fraction of the total "parameter space"--that is, the combination of target stars, radio frequencies, power levels and temporal coverage that observers must scan before drawing a definitive conclusion. Nevertheless, initial results are already beginning to place some interesting limits on the prevalence of radio-transmitting civilizations in the galaxy *[see box on next page]*.

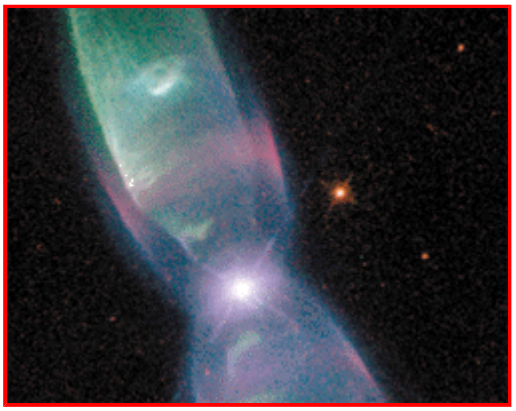
The Fermi Paradox becomes evident when one examines some of the assumptions underlying SETI, especially the total number of galactic civilizations, both extant and extinct, that it implicitly assumes. One of the current leaders of the field, Paul Horowitz of Harvard University, has stated that he expects at least one radio-transmitting civilization to reside within 1,000 light-years of the sun, a volume of

space that contains roughly a million solar-type stars. If so, something like 1,000 civilizations should inhabit the galaxy as a whole.

This is rather a large number, and unless these civilizations are very long-lived, it implies that a truly enormous number must have risen and fallen over the course of galactic history. (If they are indeed long-lived--if they manage to avoid natural or self-induced catastrophes and to remain detectable with our instruments--that raises other problems, as discussed below.) Statistically, the number of civilizations present at any one time is equal to their rate of formation multiplied by their mean lifetime. One can approximate the formation rate as the total number that have ever appeared divided by the age of the galaxy, roughly 12 billion years. If civilizations form at a constant rate and live an average of 1,000 years each, a total of 12 billion or so technological civilizations must have existed over the history of the galaxy for 1,000 to be extant today. Different assumptions for the formation rate and average lifetime yield different estimates of the number of civilizations, but all are very large numbers. This is what makes the Fermi Paradox so poignant. Would none of these billions of civilizations, not even a single one, have left any evidence of their existence?

Extraterrestrial Migration

This problem was first discussed in detail by astronomer Michael H. Hart and engineer David Viewing in independent papers, both published in 1975. It was later extended by various researchers, most notably physicist Frank J. Tipler and radio astronomer Ronald N. Bracewell. All have taken as their starting point the lack of clear evidence for extraterrestrial visits to Earth. Whatever one thinks about UFOs, we can be sure that Earth has not been taken over by an extraterrestrial civilization, as this would have put an end to our own evolution and we would not be here today.



STELLAR CORPSES

There are only four conceivable ways of reconciling the absence of ETs with the widely held view that advanced civilizations are common. Perhaps interstellar spaceflight is infeasible, in which case ETs could never have come here even if they had wanted to. Perhaps ET civilizations are indeed actively exploring the galaxy but have not reached us yet. Perhaps interstellar travel is feasible, but ETs choose not to undertake it. Or perhaps ETs have been, or still are, active in Earth vicinity but have decided not to interfere with us. If we can eliminate each of these explanations of the Fermi Paradox, we will have to face the possibility that we are the most advanced life-forms in the galaxy.

The first explanation clearly fails. No known principle of physics or engineering rules out interstellar spaceflight. Even in these early days of the space age,

engineers have envisaged propulsion strategies that might reach 10 to 20 percent of the speed of light, thereby permitting travel to nearby stars in a matter of decades [see "Reaching for the Stars," by Stephanie D. Leifer; SCIENTIFIC AMERICAN, February 1999].

For the same reason, the second explanation is problematic as well. Any civilization with advanced rocket technology would be able to colonize the entire galaxy on a cosmically short timescale. For example, consider a civilization that sends colonists to a few of the planetary systems closest to it. After those colonies have established themselves, they send out secondary colonies of their own, and so on. The number of colonies grows exponentially. A colonization wave front will move outward with a speed determined by the speed of the starships and by the time required by each colony to establish itself. New settlements will quickly fill in the volume of space behind this wave front *[see illustration on next page].*

Assuming a typical colony spacing of 10 light-years, a ship speed of 10 percent that of light, and a period of 400 years between the foundation of a colony and its sending out colonies of its own, the colonization wave front will expand at an average speed of 0.02 light-year a year. As the galaxy is 100,000 light-years across, it takes no more than about five million years to colonize it completely. Though a long time in human terms, this is only 0.05 percent of the age of the galaxy. Compared with the other relevant astronomical and biological timescales, it is essentially instantaneous. The greatest uncertainty is the time required for a colony to establish itself and spawn new settlements. A reasonable upper limit might be 5,000 years, the time it has taken human civilization to develop from the earliest cities to spaceflight. In that case, full galactic colonization would take about 50 million years.

The implication is clear: the first technological civilization with the ability and the inclination to colonize the galaxy could have done so before any competitors even had a chance to evolve. In principle, this could have happened billions of years ago, when Earth was inhabited solely by microorganisms and was wide open to interference from outside. Yet no physical artifact, no chemical traces, no obvious biological influence indicates that it has ever been intruded upon. Even if Earth was deliberately seeded with life, as some scientists have speculated, it has been left alone since then.

It follows that any attempt to resolve the Fermi Paradox must rely on assumptions about the behavior of other civilizations. For example, they might destroy themselves first, they might have no interest in colonizing the galaxy, or they might have strong ethical codes against interfering with primitive life-forms. Many SETI researchers, as well as others who are convinced that ET civilizations must be common, tend to dismiss the implications of the Fermi Paradox by an uncritical appeal to one or more of these sociological considerations.

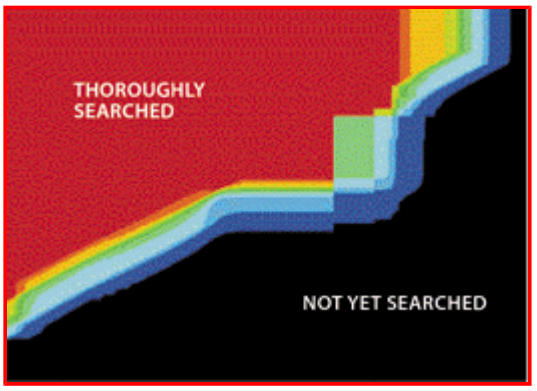
But they face a fundamental problem. These attempted explanations are plausible only if the number of extraterrestrial civilizations is small. If the galaxy has contained millions or billions of technological civilizations, it seems very unlikely that they would all destroy themselves, be content with a sedentary existence, or agree on the same set of ethical rules for the treatment of less developed forms of

life. It would take only one technological civilization to embark, for whatever reason, on a program of galactic colonization. Indeed, the only technological civilization we actually know anything about--namely, our own--has yet to self-destruct, shows every sign of being expansionist, and is not especially reticent about interfering with other living things.

Despite the vastness of the endeavor, I think we can identify a number of reasons why a program of interstellar colonization is actually quite likely. For one, a species with a propensity to colonize would enjoy evolutionary advantages on its home planet, and it is not difficult to imagine this biological inheritance being carried over into a space-age culture. Moreover, colonization might be undertaken for political, religious or scientific reasons. The last seems especially probable if we consider that the first civilization to evolve would, by definition, be alone in the galaxy. All its SETI searches would prove negative, and it might initiate a program of systematic interstellar exploration to find out why.

Resolving the Paradox?

Furthermore, no matter how peaceable, sedentary or uninquisitive most ET civilizations may be, ultimately they will all have a motive for interstellar migration, because no star lasts forever. Over the history of the galaxy, hundreds of millions of solar-type stars have run out of hydrogen fuel and ended their days as red giants and white dwarfs. If civilizations were common around such stars, where have they gone? Did they all just allow themselves to become extinct?



RESULTS OF SETI PROGRAMS

The apparent rarity of technological civilizations begs for an explanation. One possibility arises from considering the chemical enrichment of the galaxy. All life on Earth, and indeed any conceivable extraterrestrial biochemistry, depends on elements heavier than hydrogen and helium--principally, carbon, nitrogen and oxygen. These elements, produced by nuclear reactions in stars, have gradually accumulated in the interstellar medium from which new stars and planets form. In the past the concentrations of these elements were lower--possibly too low to permit life to arise. Among stars in our part of the galaxy, the sun has a relatively high abundance of these elements for its age. Perhaps our solar system had a fortuitous head start in the origins and evolution of life.

But this argument is not as compelling as it may at first appear. For one, researchers do not know the critical threshold of heavy-element abundances that life requires. If abundances as low as a tenth of the solar value suffice, as seems plausible, then life could have arisen around much older stars. And although the sun does have a relatively high abundance of heavy elements for its age, it is certainly not unique [see "Here Come the Suns," by George Musser; SCIENTIFIC

AMERICAN, May 1999]. Consider the nearby sunlike star 47 Ursae Majoris, one of the stars around which a Jupiter-mass planet has recently been discovered. This star has the same element abundances as the sun, but its estimated age is seven billion years. Any life that may have arisen in its planetary system should have had a 2.5-billion-year head start on us. Many millions of similarly old and chemically rich stars populate the galaxy, especially toward the center. Thus, the chemical evolution of the galaxy is almost certainly not able to fully account for the Fermi Paradox.

To my mind, the history of life on Earth suggests a more convincing explanation. Living things have existed here almost from the beginning, but multicellular animal life did not appear until about 700 million years ago. For more than three billion years, Earth was inhabited solely by single-celled microorganisms. This time lag seems to imply that the evolution of anything more complicated than a single cell is unlikely. Thus, the transition to multicelled animals might occur on only a tiny fraction of the millions of planets that are inhabited by single-celled organisms.

It could be argued that the long solitude of the bacteria was simply a necessary precursor to the eventual appearance of animal life on Earth. Perhaps it took this long--and will take a comparable length of time on other inhabited planets--for bacterial photosynthesis to produce the quantities of atmospheric oxygen required by more complex forms of life. But even if multicelled life-forms do eventually arise on all life-bearing planets, it still does not follow that these will inevitably lead to intelligent creatures, still less to technological civilizations. As pointed out by Stephen Jay Gould in his book *Wonderful Life*, the evolution of intelligent life depends on a host of essentially random environmental influences.

This contingency is illustrated most clearly by the fate of the dinosaurs. They dominated this planet for 140 million years yet never developed a technological civilization. Without their extinction, the result of a chance event, evolutionary history would have been very different. The evolution of intelligent life on Earth has rested on a large number of chance events, at least some of which had a very low probability. In 1983 physicist Brandon Carter concluded that "civilizations comparable with our own are likely to be exceedingly rare, even if locations as favorable as our own are of common occurrence in the galaxy."

Of course, all these arguments, though in my view persuasive, may turn out to be wide of the mark. In 1853 William Whewell, a prominent protagonist in the extraterrestrial-life debate, observed, "The discussions in which we are engaged belong to the very boundary regions of science, to the frontier where knowledge ... ends and ignorance begins." In spite of all the advances since Whewell s day, we are in basically the same position today. And the only way to lessen our ignorance is to explore our cosmic surroundings in greater detail.

That means we should continue the SETI programs until either we detect signals or, more likely in my view, we can place tight limits on the number of radio-transmitting civilizations that may have escaped our attention. We should pursue a rigorous program of Mars exploration with the aim of determining whether or not life ever evolved on that planet and, if not, why not. We should press ahead with

the development of large space-based instruments capable of detecting Earth-size planets around nearby stars and making spectroscopic searches for signs of life in their atmospheres. And eventually we should develop technologies for interstellar space probes to study the planets around nearby stars.

Only by undertaking such an energetic program of exploration will we reach a fuller understanding of our place in the cosmic scheme of things. If we find no evidence for other technological civilizations, it may become our destiny to embark on the exploration and colonization of the galaxy.

The Author

IAN CRAWFORD is an astronomer in the department of physics and astronomy at University College London. His research interests mostly concern the study of interstellar and circumstellar environments, including circumstellar disks thought to be forming planets. He believes that the cosmic perspective provided by the exploration of the universe argues for the political unification of our world. He explains: "This perspective is already apparent in images of Earth taken from space, which emphasize the cosmic insignificance of our entire planet, never mind the national boundaries we have drawn upon its surface. And if we do ever meet other intelligent species out there among the stars, would it not be best for humanity to speak with a united voice?"