How common are technological civilizations?

Ian Crawford highlights the absence of evidence for intelligent technological civilizations elsewhere in the galaxy.

The possible evidence for past life on Mars (McKay *et al.* 1996; Grady *et al.* 1997) has rekindled the age-old debate about life in the universe. Certainly, if the conclusions drawn from the analysis of the Martian meteorite ALH84001 stand up to more detailed scrutiny, and life did indeed evolve independently on Mars, then it seems safe to conclude that it will also have arisen on just about every suitable planet in the galaxy. Given the rate at which planetary systems are being discovered around other sun-like stars (e.g. Mayor and Queloz 1995; Butler and Marcy 1996; also Schneider 1996), this would imply that the universe is teeming with living things.

Does it follow that "advanced" life, and therefore technological civilizations, are also abundant? There is an argument that once "primitive" life has evolved, natural selection will "inevitably" direct it towards intelligence and technology. I shall argue here that this is not necessarily the case and that extra-terrestrial technological civilizations are probably very rare in the galaxy. For the purpose of this article I will take a "technological civilization" to be a civilization having a technological base sufficient to develop the means of communicating and/or travelling across interstellar distances, whether or not it chooses to do so.

The conclusion that such civilizations are rare is based on two independent lines of argument: the absence of evidence of extra-terrestrial (ET) civilizations (the so-called Fermi Paradox), and the history of biological evolution on our planet. Neither argument is original, but as their strength appears not to be widely appreciated, and recent events have renewed interest in the subject, a brief review seems appropriate.

Absence of evidence

The "absence of evidence" argument has two aspects: first, the failure of the Search for Extraterrestrial Intelligence (SETI) programmes to detect radio transmissions from planets around other stars; second, the lack of evidence for ET civilizations ever having visited Earth.

The first of these is still a relatively weak argument because SETI has so far explored only a small fraction of the total parameter space (defined by the number of target stars, radio frequencies observed and receiver sensitivity; Tarter 1985, 1992). But initial results are already beginning to place some interesting upper limits on the prevalence of radio-transmitting civilizations in the galaxy. For example, Horowitz and Sagan (1993), reporting the results of a five year all-sky survey, concluded that there are no Kardashev (1964) Type I civilizations (isotropically transmitting $\approx 10^{13}$ W) within 25 light-years of the Sun, and no Type II civilizations (isotropically transmitting $\approx 10^{26}$ W) within 2500 light-years. Much more sensitive searches are now in progress (e.g. McDonough 1996), and these limits should be tightened considerably in the next few years.

Arguments that the absence of evidence of extra-terrestrial civilizations amounts to evidence for their absence are reviewed and found logically compelling. This implies that such civilizations are very rare; I argue that this conclusion is supported by what we know of biological evolution on our own planet. Thus humanity may possess one of the very few technological civilizations to have arisen in the Milky Way galaxy.

The second argument, which was first put forward by Hart (1975) then extended by Tipler (1980), is of greater weight. Hart took as his starting point the fact that we see no evidence for ETs ever having visited the Earth in the historical or the geological past. In particular, we can be certain that the Earth has never been "taken over" by an ET civilization, as this would have put an end to our own evolution.

There are four possible ways of reconciling the lack of evidence with the widely-held view that ET civilizations are common in the galaxy:

- interstellar spaceflight is physically impossible, in which case "they" could never have come here even if they had wanted to;
- interstellar travel is possible, but ET civilizations either have no interest in making use of it or destroy themselves before they get a chance;
- ET civilizations are indeed actively exploring and/or colonizing the galaxy, but space is so big that they haven't reached us yet;
- ETs have been, or still are, active near Earth, but sociological, cultural or ethical factors prevented them from interfering with us.

If we can eliminate each of these explanations for the absence of evidence, we must face the fact that we are probably alone in the galaxy.

Interstellar space travel

There is no reason to believe that interstellar spaceflight will be impossible for a sufficiently advanced technology. Even today we can envisage propulsion strategies (e.g. nuclear rockets, antimatter rockets and laser-pushed light sails) that might make it possible for a starship to reach 10 to 20% of the speed of light, thereby permitting travel between nearby stars in a matter of decades (for reviews see Mallove and Matloff 1989; Crawford 1990). Also, although our current understanding of physics is doubtless incomplete, it is important to realize that future discoveries can only ease the problem of interstellar space travel – they cannot detract from what we already know to be physically possible.

Given that interstellar space travel is possible, it can be shown that any civilization with this technology would be able to colonize the entire galaxy on a cosmically short timescale if it really wished to do so. We will discuss possible motivations below. For the moment, consider a civilization that embarks on a programme of interstellar colonization by sending colonists to a few of the planetary systems closest to it. Then, after they have established themselves, suppose that these colonies send out secondary colonies of their own, and so on. The number of colonizing missions will then grow exponentially (roughly as n^R, where n is the number of new colonies sent out by each established colony, and R is the radial distance from the starting point). However, the number of colonizable planetary systems will (for a flat galactic disk) only grow as R^2. This implies that the vicinity of the home star will quickly saturate with colonies and a colonization wavefront will move outwards with a speed v_{col}, given (e.g. Newman and Sagan 1985) by

$v_{col} = D/(t_{travel} + t_{con})$, where D is the average spacing between colonies, t_{travel} is the travel time between colonies ($t_{travel} = D/v_s$, where v_s is the ship speed) and t_{con} is the consolidation time that each colony requires before it can establish colonies of its own. Because of the exponential growth in colony numbers, the volume interior to the colonization wavefront will remain saturated (i.e. no star within this volume is likely to be missed).

In general, v_{col} will be much less than v_s owing to the need for each colony to become established before sending out colonies of its own. For D=10 light-years, $v_s = 0.1c$ (certainly physically possible) and $t_{con} = 400$ years (which doesn't seem unreasonable given what we know of human history) we obtain $v_{col} = 0.02$ light-years/year. As the galaxy is 100 000 light-years across, this results in a galactic colonization timescale of 5 million years. Although a long time in human terms, this is essentially instantaneous compared with relevant astronomical and biological timescales. Moreover, the conclusion is not affected significantly even if we have underestimated t_{con} by an order of magnitude: $t_{con} = 5000$ years (equal to the period of human history from the Sumerian city states to the present) gives a galactic colonization timescale of 50 million years, still only 0.5% of the age of the galaxy.

The conclusion appears inescapable: 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 (Bracewell 1982). In principle, this could have happened billions of years ago, when the Earth was inhabited solely by single-celled micro-organisms and was wide open to interference from outside. Yet there is no evidence for any ET civilization near Earth, and considerable evidence (the unbroken thread of terrestrial biological evolution) that our planet has never been colonized.

Sociological explanations

Any attempt to reconcile the absence of evidence with a galaxy full of technological civilizations must rely on the other explanations identified by Hart (1975). These are essentially "sociological"; they rest on assumptions about social and cultural factors affecting the behaviour of ET civilizations. Most important are:

- ET civilizations destroy themselves before developing technology for interstellar travel;
- "they" do not want to colonize the galaxy;
- those that do explore the galaxy have strong ethical codes that prevent them from interfering with primitive life forms.

The problem with all of these explanations is that they are plausible only if the number of ET civilizations is quite small. For example, if only half a dozen technological civilizations arose in the galaxy, we could imagine that two of them might have aspired to interstellar travel but, being inherently aggressive, destroyed themselves before getting the chance; three of them might have developed high technology, but never had the sociocultural motivations for interstellar space flight; and one might have explored/colonized the whole galaxy but, being a highly ethical species, never interfered with inhabited planets. However, if the galaxy contains millions of technological civilizations (as SETI optimists often suppose), it seems unlikely that they would all destroy themselves, or be content with a sedentary existence, or agree on the same set of ethical rules for the treatment of less-developed forms of life. The implausibility of such a view appears particularly great if we consider that the only civilization we actually know anything about, namely our own, has not destroyed itself, shows every sign of being expansionist and is not especially ethical in its treatment of other living things.

Of course, the argument that the absence of evidence amounts to evidence of absence rests on the assumption that at least some ET civilizations would *want* to go gallivanting about the galaxy. Despite the vastness of the undertaking, I think we can identify a number of reasons why at least a subset of technological civilizations might become engaged in interstellar colonization. For one thing, there would seem to be a Darwinian bias in its favour. It is true that the behaviour of a technological civilization is more likely to be dominated by cultural considerations than by natural selection. However, culture is rooted in biology (e.g. Bonner 1980) and, given the evolutionary advantages likely to have been enjoyed by a colonizing species on its home planet, it is not difficult to imagine this biological inheritance being carried over into a space-age culture. Moreover, colonization could be initiated for purely ideological (e.g. political or religious) reasons, quite unrelated to biology. Once under way, it might then continue as a result of tradition and social inertia. Indeed, there are several examples in human history (reviewed by Gamble 1993) of colonization undertaken for just such socio-ideological reasons, apparently unconnected with economics or survival. Perhaps the most interesting here is the Polynesian colonization of the Pacific, consideration of which led Gamble (1993 p233) to suggest that "ideology provides the only sufficient reason for voyaging and its cessation".

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The Helix Nebula. Planetary nebulae result when solar-type stars leave the main-sequence. If such stars ever had civilizations, where have they gone?

Furthermore, no matter how sedentary and peaceable most ET civilizations might be, ultimately they would all have a motive for interstellar colonization because no star lasts for ever. Recall that just about every planetary nebula and white dwarf in the sky was once a solar-type star that has evolved off the main-sequence and that, over the history of the galaxy, tens of millions of similar stars have suffered the same fate. If civilizations were common around such stars, we have to ask where they all went. Of course, one might hope that, finding itself threatened by the death of its home star, a mature, ecologically responsible civilization would just pack its bags, move to a nearby uninhabited planetary system and stay there. In this case the exponential growth of colonies described above would not occur, but it would still be necessary to suppose that *every* threatened civilization would adopt this minimalist survival strategy.

There is one remaining way of reconciling the absence of evidence with the view that ET civilizations are common, and this is the "zoo hypothesis" advanced by Ball (1973; cf. Shklovskii and Sagan 1966). This postulates that there already exist one or more ET civilizations, but that these are keeping themselves hidden from us (i.e. we are in the zoo). At first sight this is an attractive way of explaining the absence of evidence, but it is not as strong as it appears. For one thing, like all the other attempted explanations, it only works if the number of ET civilizations is quite small, it being inconceivable that a large number of independently evolved civilizations, all with different ethical viewpoints and/or political ideologies, would agree on the same set of rules for the zoo. The only way out of this objection is to assume that the first civilization to break out into the galaxy (i.e. Bracewell's [1982] pre-emptive civilization) was both highly ethical, and did not itself interfere with primitive worlds, and powerful enough to enforce its ethical viewpoint on everyone else. However, considering that the zoo would have to be maintained over spatial scales of thousands of light-years, and last for billions of years (i.e. the time over which an Earth-like planet must be protected if its biosphere is to be permitted to evolve independently), this does not seem very plausible either. I have speculated elsewhere (Crawford 1995) that an advanced civilization might be able to overcome the communication problem if it could travel faster than the speed of light. However, even if this turns out to be physically possible, we are still left with the apparently insuperable problem of maintaining a secure zoo for billions of years.

To reiterate: it would take only one, not-especially ethical, civilization to embark on a programme of galactic colonization to put an end to indigenous biological evolution on every planet it encounters. Earth has been exposed to the possibility of such interference for thousands of millions of years, yet there is no evidence that it has ever been intruded upon (I am here ignoring the possibility that Earth was deliberately seeded with life at the beginning of its history because, even if it was, the fact that it has been left alone since then leaves the basic argument unchanged). It follows that either there are no ET civilizations, as argued by Hart (1975) and Tipler (1980), or that they are sufficiently rare for some combination of "sociological" explanations to account plausibly for the lack of evidence.

The history of life on Earth

As it happens, this conclusion is supported by what we know of the history of biological evolution on our own planet. The earliest unambiguous evidence that we have for life on Earth comes from fossilized bacteria 3.5 billion years old (Schopf 1993). As these organisms are already quite complicated, and as the Earth is only 4.5 billion years old, the origin of life (assuming it to be indigenous to Earth) must have occurred close to 4 billion years ago. The fact that life appeared so quickly, probably almost as soon as conditions on the early Earth had stabilized sufficiently (Maher and Stevenson 1988), seems to indicate that this step was relatively easy. This view is supported by some recent biochemical thinking on the origin of life, which suggests that "life is almost bound to arise...wherever physical conditions are similar to those that prevailed on our planet some 4 billion years ago" (de Duve 1995).

At first sight this seems encouraging for the prospects of life in the universe, and contrary to the "absence of evidence" argument outlined above. However, while the rapid appearance of life on Earth does indeed augur well for the prospects of simple life in the universe, subsequent evolutionary history actually leads us to expect that more complicated forms of life will be quite rare. This is because multicellular life did not appear on Earth until about 0.7 billion years ago (for reviews see Gould 1989; de Duve 1995): for more than 3 billion years the Earth was inhabited solely by single-celled micro-organisms. This is a vast stretch of time and, in contrast with the rapidity with which the first bacteria appeared, may imply that the evolution of anything more complicated than a single cell is extremely difficult. Indeed, Carter (1983) has already pointed out that this timescale, comparable to the main-sequence life of the Sun, implies that at least one step must have had a very low probability.

It is true that important biological developments (notably the evolution of the eukaryotic cell and the accumulation of atmospheric oxygen from bacterial photosynthesis) did occur during life's first 3 billion years, and that these laid the foundations for the eventual appearance of multicelled animals. However, it is probably a mistake to see anything inevitable about this process. For example, the development of the eukaryotic cell, on which all multicellular life depends, seems to have relied on the symbiotic incorporation of once free-living bacteria within an ancestral host cell (e.g. Margulis 1993). Furthermore, multicelled plants and animals may themselves be the result of symbiotic associations of once free-living cells. We do not know the circumstances under which such symbiotic relationships are established, but it seems quite possible that they result from chance events outside the usual scope of Darwinian natural selection. This would make them prime candidates for the kind of evolutionary bottleneck identified by Carter (1983), and would imply that the transition to multicellular animals might occur on only a tiny fraction of the millions of planets likely to harbour single-celled organisms.

Moreover, even if multicelled life forms do eventually arise, it does not follow that these will inevitably lead to intelligent creatures, and still less to technological civilizations. While it will be admitted that the potential for biological complexity, and with it intelligence, is greatly enhanced by the appearance of multicellular life, the realization of this potential remains contingent on a host of essentially random environmental influences (Gould 1989). This is perhaps illustrated most clearly by the fate of the dinosaurs. These creatures were the dominant life forms on this planet for some 180 million years, during which time there is no convincing evidence for the evolution of intelligence, and certainly not a technological civilization. Their extinction, 65 million years ago, left the way open for a flowering of mammalian evolution and thus, in the fullness of time, to our appearance on this planet. But the extinction of the dinosaurs was quite possibly the result of a chance event, without which subsequent history would have been very different and Earth would probably not now host a technological civilization.

The fact is, evolution of intelligent life on Earth rested on many chance events, at least some of which had a very low probability. As Carter (1983) pointed out, this implies that "civilizations comparable with our own are likely to be exceedingly rare, even if locations as favourable as our own are common in the galaxy".

Conclusion

Two independent lines of argument, based on the "absence of evidence" and the history of life on Earth, lead to the same conclusion: life may be common in the galaxy, but "advanced" multicellular life forms, and thus technological civilizations, are probably extremely rare. There is an interesting corollary to this, already pointed out by Bracewell (1982): it may be *our* destiny to embark on the exploration and colonization of the galaxy. I have argued elsewhere (Crawford 1993) that this would bring significant scientific and cultural advantages for humanity. But it is also clear that, on a social and ethical level, human civilization is far from ready for such an undertaking. Given that we may have produced one of the very few technological civilizations in the history of the galaxy, and that within a century or so we may ourselves achieve interstellar space-flight, it is not too soon to start developing the ethical framework and the political institutions appropriate for the cosmic responsibility that this implies. ●

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References

Ball J A 1973 *Icarus* **19** 347.
Bonner J T 1980 *The Evolution of Culture in Animals* (Princeton U P).
Bracewell R N 1982 *Extraterrestrials: Where are They?* eds M H Hart and B Zuckerman (Pergamon, New York) p34.
Butler R P and **Marcy G W** 1996 *Ap. J.* **464** L153.
Carter B 1983 *Phil. Trans. R. Soc. Lond.* **A310** 347.
Crawford I A 1990 *QJRAS* **31** 377.
Crawford I A 1993 *JBIS* **46** 415.
Crawford I A 1995 *QJRAS* **36** 205.
de Duve C 1995 *Vital Dust* (Basic Books, New York).
Gamble C 1993 *Timewalkers: the Prehistory of Global Colonisation* (Alan Sutton, Stroud).
Gould S J 1989 *Wonderful Life* (Penguin, London).
Grady M M *et al.* 1997 *A&G* **38(1)** 26.
Hart M H 1975 *QJRAS* **16** 128.
Horowitz P and **Sagan C** 1993 *Ap. J.* **415** 218.
Kardashev N S 1964 *Sov. Astron. A.J.* **8** 217.
Maher K A and **Stevenson D J** 1988 *Nature* **331** 612.
Mallove E F and **Matloff G L** 1989 *The Starflight Handbook* (John Wiley, New York).
Margulis L 1993 *Symbiosis in Cell Evolution* 2nd edn (Freeman NY).
Mayor M and **Queloz D** 1995 *Nature* **378** 355.
McDonough T R 1996 *Planetary Report* **XVI(2)** 4.
McKay D S *et al.* 1996 *Science* **273** 924.
Newman W I and **Sagan C** 1985 *Interstellar Migration and the Human Experience* eds B R Finney *et al.* (University of California Press, Berkeley) p302.
Schneider J 1996 *The Extrasolar Planets Encyclopedia* "http://www.obspm.fr/departement/darc/planets/encycl.html".
Schopf J W 1993 *Science* **260** 640.
Shklovskii I S and **Sagan C** 1966 *Intelligent Life in the Universe*, (Holden-Day, San Francisco) p451.
Tarter J C 1985 *Interstellar Migration and the Human Experience* eds B R Finney *et al.* (University of California Press, Berkeley) p314.
Tarter J C 1992 *Frontiers of Life* eds J Tran Thanh Van *et al.* (Editions Frontieres, Gif-sur-Yvette) p351.
Tipler F J 1980 *QJRAS* **21** 267.