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# The 'Great Silence': the Controversy Concerning Extraterrestrial Intelligent Life

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SUMMARY

Recent discussions concerning the likelihood of encountering extraterrestrial technological civilizations have run into an apparent paradox. If, as many now contend, interstellar exploration and settlement is possible at non-relativistic speeds, then reasonable calculations suggest that space-faring species, or their machine surrogates, should pervade the Galaxy. The apparent absence of evidence for extraterrestrial civilizations, herein called 'the Great Silence' places severe burdens on present models.

Many of the current difficulties are due to inadequate exploration of the parameters of the problem. A review of the topic shows that present approaches may be simplistic.

## INTRODUCTION

The possibility of intelligent life beyond Earth has left the realm of abstract speculation and entered the arena of public policy debate. Late in 1981 the modest federal funds allocated for SETI (the radio Search for Extra-Terrestrial Intelligence), roughly $2 million, were excised in the US Congress. Chief antagonist Senator William Proxmire cited an article in *Physics Today* (1) expressing the belief of some scientists that advanced extraterrestrial technological species cannot exist.

Few important subjects are so data-poor, so subject to unwarranted and biased extrapolations – and so caught up in mankind's ultimate destiny – as is this one. Ornstein *et al.* (2), Crick & Orgel (3), Sagan (4), and many other prominent scientists, have been drawn into a debate which has, with few exceptions, fallen into a confusion of ill-matched arguments and *non-sequitur*.

Philosophical battle lines have been drawn between those who might be called 'Contact Optimists' – who contend that simple reasoning indicates a Universe in which life and intelligence must be relatively common – and proponents of the 'Uniqueness Hypothesis', who suggest that Earth is probably the first and only abode of technical civilization in our Galaxy.

Most of those denying the existence of extra-terrestrial intelligent species (ETIS) base their arguments on the increasingly accepted notion that space habitats and interstellar spaceflight are at least conceptually possible (**2, 3, 4, 5, 6, 7, 7a, b**), and might be achieved by humanity within a few centuries. They calculate that even one prior technological species that possessed both the means and desire could and would have colonized the entire Galaxy within approximately $10^8$ yr (**1, 8, 9**). Tipler, taking the vanguard of the Uniqueness

Hypothesis (**1, 2, 10, 11**) has advanced a version of John von Neuman's self-reproducing robots to suggest that auto-replicating machine surrogates could pervade the Milky Way within about $10^6$ yr, subject to none of the biological restraints on living travellers.

This chain of logic, plus the apparent absence of evidence for extraterrestrials in the vicinity of Earth at any time in the recent past, leads people such as Hart (**9**), Tipler, Jones (**8**), and Bond (**12**), to conclude that such prior expansionist ETIS never existed. They attack the blithe assumption that we have neighbours in space.

In responses, 'Contact Optimists' such as Carl Sagan generally attempt to assign extraterrestrial motivations to explain why they might refrain from colonizing, or even exploring or communicating with their neighbours (**4, 9, 13, 14, 15, 61**).

'Xenology' is not a field conducive to philosophical rigour. Positions have been taken based upon frankly admitted personal bias. In this article I will attempt to break the question of alien intelligence into encompassing logical elements, which can be considered one at a time.

## THE QUANDARY OF THE 'GREAT SILENCE'

Between the late 1950s and early 1970s most discussions of the SETI question revolved around a single assumption – that intelligent life evolves at isolated sites distributed widely and randomly about the Galaxy . . . sites that remain isolated forever thereafter. Interstellar travel was assumed virtually impossible. The 'islands' of intelligence would only come into contact with each other via electromagnetic signals (**16, 17**). This chain of logic gave rise to OZMA, CYCLOPS, SETI and CETI, projects to discover radio traffic from nearby inhabited star systems.

Although Western and Soviet efforts have come up with nothing in almost 20 years, supporters of SETI until recently saw no reason to be discouraged. Little time or money had been spent, and, according to the 'islands' logic there was every reason to expect the search to take decades, anyway.

Today, however, with the 'islands' model no longer well accepted, such patience has begun to fade. In its place has developed a quandary which might be called the 'Mystery of the Great Silence'.

The centrepiece of xenological discussion has been, and remains today, the 'Drake equation', first put forward by Frank Drake of Cornell University (**17b**). A once useful tool, it is now clearly insufficient to encompass the subject.

The 'Drake equation'

$$E = R f_g n_e f_l f_i f_c L \tag{1}$$

where $E$ = the expected number of sites in the Galaxy, at any given time, at which technological civilization has evolved and exists at present. Here $R$ = the average galactic rate of star production; $f_g$ = the fraction which are 'good' stable dwarf stars accompanied by planets; $n_e$ = the number of 'candidate' planets per system (upon which the requisite conditions for life occur); $f_l$ = the fraction of said planets upon which life arises; $f_i$ = the

fraction of the latter upon which intelligence evolves; $f_c$ = the fraction of intelligent species which develop detectable technologies; and $L$ = the average lifespan of such a technological culture.

Both sides of the present debate accept this equation as the primary working tool for the field. Their disagreement is primarily over the values to be assigned the factors defined above. For instance, Contact Optimists such as Sagan suggest that the results of equation (1) are only moderately affected by order of magnitude variations in the fractional factors. Using logic that went virtually unchallenged through the 1960s, they chose to assign values between 0·001 and 1·0 to each fraction (**16, 17**). The controlling factor would then be $L$, the average lifespan of extraterrestrial intelligent species. If $L$ is large, there should be many sites of spontaneous appearance of ETIS (**14, 16**). If $L$ is very small then $E$ is small, and the separation between sites is immense.

Uniqueness advocates such as Jones also use the Drake equation. Starting with the presumption that the apparent absence of ETIS implies that $E$ is very small, they go on to propose that some of the fractional factors are actually miniscule. Numbers as small as $10^{-18}$ have been suggested for $f_l$ and $f_i$ (**2, 12, 18**), indicating the belief of Leonard Ornstein and others that either life, or intelligence, or both, are extremely unlikely occurrences.

Part of the problem today rests in the incompleteness of the Drake equation. As currently written, equation (1) merely speaks of the number of sites at which ETIS *spontaneously arise*. It says nothing directly about the contact cross-section between an ETIS and contemporary human society. It predicts no observable event. Nor does it take into account the paradigm revolution caused by the growing acceptance of the concept of non-relativistic interstellar spaceflight.

A modified formulation would solve these problems. Let $C$ = the likelihood of verifiable contact between twentieth century humankind and extraterrestrial technological species.

$$C = (1/N^*)\sum_{j=1}^{E} A_j(n_j+1). \tag{2}$$

$E$ is the total number of sites of *spontaneous* evolution of technological culture, as described by the Drake equation. Here it is used as the limit in a summation. Each '$j$th' site of evolved technological civilization will have settled in – or sent von Neuman robot surrogates to – $n_j$ neighbouring systems at the time of the sampling (where $n_j$ can be zero as determined in equation (3). When $n_j = 0$ only the planet of origin is occupied). The sum of all settled sites in the sampling space, divided by the total number of stars sampled, $N^*$, is a rough but useful measure of the likelihood of contact.

(To make this expression more useful we redefine $N^*$ to be the number of 'candidate' stars, excluding short-lived giants, close binaries, unstable stars, and all others excluded from reasonable SETI scenarios.)

$A_j$ is humankind's 'contact cross-section' with each expanding civilization, encompassing such factors as motivations to initiate/avoid contact, life-style variations, abandonment of radio for hypothetical 'advanced technologies',

and anything else which might cause a nearby site of ETIS to be more or less observable. For example, an ETIS whose expansion was solely intellectual, via von Neuman/Tipler robot surrogates, might have a lower cross-section for contact/detectability, $A_j$, than an ETIS which settles neighbouring sites in person, invading biospheres with expanding populations of alien life-forms and filling the airwaves with commercial radio traffic. (When $n_j = 0$ and $A_j = 1$ for all $j$, this equation simply reduces to the Drake equation.)

$E$ is derived from a modified Drake equation. $A_j$ is affected by various hypotheses which will be discussed later. What remains needed is $n_j$, the number of sites settled or explored by a particular ETIS. We define,

$$n_j = Bf_g\, n_e\, 4(\pi) \,.\int_0^{R(j)} r^2\, e^{-(R-r)/vL'} dr \qquad (3)$$

where $B$ is the number density of stars, $R(j)$ is the radius (assuming spherical symmetry) of the volume into which the species '$j$' has expanded.

The effective expansion velocity, $v$, is discussed by von Hoerner (19), Jones (8), Hart (9), Kuiper & Morris (6), and Newman & Sagan (4). It represents a combination of ship speed – generally assumed to be limited to below $0{\cdot}1c$ – and the recovery time required to regenerate populations and industry at each settlement site before the next phase of expansion can be launched. The same logic applies whether discussing sophont populations on a colonized planet, or robot probes which mine asteroids to make duplicates of themselves to launch toward further stars.

$L'$ represents the characteristic survival time of ETIS at each colonized site. It is obviously related to, but not necessarily the same as, $L$ in (1). $L'$ portrays how long an average site remains occupied after it is settled. Integration of (3) gives the number of active sites within each sphere of settlement/exploration.

Since what we seek are upper bounds to (2) (upper limits to the number of detectable ETIS) we shall, for simplicity, assume the separate spheres being summed do not overlap. We implicitly assume a freeze-frame sampling at a time when some state of quasi-equilibrium has been reached.

With only (1) to consider, we had six unknowns (assuming modern astronomical theory gives a reliable rate of star formation within two orders of magnitude). By including (2) and (3) we expand the suite of variables to nine – plus possible phase factors if quasi-equilibrium must be abandoned.

The added complexity is more than made up for by two features of the new model. First, as we shall see, the factors in (1)–(3) now encompass all the concepts currently discussed in the literature, whereas (1) alone did not. Secondly, (2) makes testable predictions.

The factors to consider are: $f_g$, $n_e$, $f_l$, $f_i$, $f_c$, $L$, $A$, $v$, and $L'$. Having thus set up a list of morphological pieces to the puzzle, we may begin cataloguing the possibilities.

## PHILOSOPHICAL CONSIDERATIONS

The SETI debate is unique. To no other subject do modern scientists bring a more eclectic array of speculations, combining biology, chemistry,

sociology and astrophysics. In no other area do philosophical issues butt heads so dramatically.

For instance, the Cosmological Principle, or 'assumption of mediocrity', is taught as almost religious canon to students of astronomy (**21**). Since Copernicus removed the Earth from the centre of the cosmos, astronomers have come to hold in suspicion any theory that proposes that our time and place is anything but mundane and mediocre. Again and again, as our conception of the Universe has expanded, this principle has proved rewarding.

It seemed natural to exobiologists of the 1960s to extend the concept of mediocrity from purely physical situations to evolution here on Earth . . . the implication being that the local occurrence of life, and even intelligence, must be merely a typical case of a common phenomenon.

(Had the *Viking* mission verified even modest Martian micro-organisms deriving from an independent genetic heritage, SETI proponents would have had cause for encouragement. The mediocrity argument would have gained support. But it is impossible to extrapolate from a single data point.)

The philosophical counter to the principle of mediocrity is the 'Anthropic Principle', which proposes that it is possible, even in a great and diverse Universe, for an observer to witness a special place and time, especially if the special attribute is required for there to be an observer in the first place. To illustrate the point, Brandon Carter has paraphrased Descartes (**21, 21b**): 'Cogito ergo mundas talis est'. ('I think, therefore such is the world.') Uniqueness advocates see nothing wrong with the proposal that the intelligent life we have on Earth is rare.

Equilibrium is another concept which weaves through the new SETI debate almost without acknowledgment. It is generally considered sound scientific practice to assume a state of quasi-equilibrium when beginning to explore a previously undeveloped field of knowledge, since most natural phenomena with long time-scales can be modelled as perturbations of an equilibrium state. Secular changes are generally slow, and the Universe tends to look pretty much the same from year to year, or even from galactic revolution to galactic revolution.

Yet when Sagan and others attempt to explain the absence of ETIS by suggesting that they simply 'have not arrived yet' (**4, 14**), they imply a situation of profound disequilibrium.

Tipler, Jones, and others suggest that the Galaxy is about to depart from one equilibrium state – virtual emptiness of intelligent life – to another state, one in which humanity will expand to crowd the stars with traffic and adventure.

To those given above we are tempted to add one more, rather tentative, 'principle' . . . a 'Principle of Non-exclusiveness', which states that diversity will tend to prevail unless there exists a mechanism to enforce conformity. This idea will be discussed in more detail later. We will see that in discussing ETIS and the Great Silence it will be the exceptions that make the rules.

None of these 'principles' is as persuasive as a single observable, however. Consider $C$, the likelihood of contact with ETIS by contemporary human

culture. Clearly the vast majority of humans is unaware of any such contact at this time. That is our one fact. If we define $N^*$ as the total number of spectral class F, G or K stable dwarfs sampled, and define ETIS as species which use technologies that can be detected over a multi-parsec range, then we can begin by setting an upper limit to $C$.

Although SETI efforts have been extremely modest, so far, the project has at least eliminated the nearest dozen or so candidate stars, including tau Ceti, epsilon Eridani, and alpha Centauri (**22**). We therefore set an upper limit of $C$ less than 0·01–0·1.

The original SETI proposals never claimed that anyone would be so close. The traditional estimated range to the nearest ETIS civilisation was 200 light years (**19, 16, 17**), 10 times the radius of the globe so far studied. Without the new and numerous starship concepts (**23, 7**) – suggesting various methods from antimatter propulsion to laser-driven lightsails and generation ships to cross interstellar space – there would be no quandary yet. However, with the growing acceptance that surrogate robots, at least, could travel among the stars, programmed to communicate with local intelligent life (**5, 1, 10, 11**), a low value for $C$ places severe burdens on the SETI's basic assumption – that life should be common, and intelligence not be rare.

The apparent absence of strong evidence for prior alien colonies on the Earth (**25**), suggests that $C$ has been small for quite a long time, at least the last 50 Myr or so. Furthermore, recent studies of reflectance spectra of asteroids (**25b**) indicate that most appear to occupy orbits which are primordial. By implication these asteroids have apparently never been subjected to the sort of major modifications (**7b, 16**, p. 469) which might be made by space-dwelling ETIS, and which we may soon initiate ourselves.

The apparent failure of Venus and Mars to have been terraformed (**16**, p. 467) at any time in the past 2–4 Byr, especially when both are thought to have had considerably more water in their younger days (**26**), causes the burden on the contact optimists to begin to appear overwhelming.

The most powerful indictment of the old SETI logic is found in the sedimentary layers of Earth rocks, as we shall see.

## THE FACTORS CONTROLLING CONTACT

We can eliminate two factors in (1) from this discussion fairly quickly. While it is possible that something will change our minds next year, there is general agreement today that $f_g$ and $n_e$ are fairly large numbers. Even most Uniqueness advocates are willing to posit this.

Almost all of the angular momentum of the Solar System is contained in the planets, particularly Jupiter. The Sun retains less than 1 per cent, although it comprises 99·9 per cent of the mass of the Solar System. Since almost all stable solitary dwarf stars seem to rotate about as slowly as our Sun, most astronomers today believe that planets are the rule for small stars (**27, 28**). (Some proper motion observations of Barnard's Star, 61 Cygni, and other nearby stars (**30**) appear to support this idea, though some doubt has recently been cast on some of the published claims.) It seems reasonably conservative, in any event, to assign $f_g$ a value of one-tenth (**11, 28**).

The average number of 'suitable' planets in such a system – rocky worlds with secondary (volcanic) water-rich atmospheres, rather than primary (hydrogen) atmospheres, and which are also of acceptable size and orbital distance from their primaries (**29**) – is represented by $n_e$.

With a few cavils (**31**), uniqueness proponents generally do not dispute the SETI proposal that $n_e$ be assigned a value around one-tenth (**8, 17**). Stephen Dole's models (**32**) of condensing new-born star systems seem to suggest that this number is conservative.

We are left with seven highly controversial factors. We shall see that hypotheses have been proposed which cause each factor in turn to be reduced, in order to give a miniscule value for $C$ – a value small enough to explain the apparent absence of extraterrestrials from the Earth for millions of years. Until now these proposals have never been categorized in this way, but have been presented individually and uncorrelated. The difference between the Uniqueness and Contact forces turns out to be strictly a function of the factors each concentrates upon. Each of the ideas presented below has been advanced vociferously and in isolation by some respected scientist as the sole reason for the Great Silence.

*The incidence of life – factor* '$f_l$'. The first two controversial factors, $f_l$ and $f_i$, are the most complex and have suffered the most debate. All of the arguments presented cannot be covered in a brief review. We will attempt only to touch upon the main points.

Since the famous experiments of Miller & Urey (**33**), it has been accepted that the precursors of life might be produced under mundane and non-biotic conditions. Aqueous mixtures of simple reducing gases have been subjected to electrical discharges and UV radiation, producing aldehydes, carboxylic acids, and amino acids. Polymerization of aqueous mixtures of HCN, followed by simple photochemistry, have given rise to nitrogenous bases such as adenine (**40**).

With the discovery of interstellar molecular clouds of simple organic compounds, of amino acids in meteorites, and the smog-like atmosphere of Titan, few dispute that the Universe might be a virtual 'soup' of pre-biotic organic chemicals.

(We speak here only of 'life' such as it appears here on Earth, and shall continue to do so as a limiting case.)

Beyond this point, however, debates begin. Tipler (**10, 11**) lists many of the recent statistical arguments which hold that the leap from organic soup to membrane-moderated, self-replicating DNA-based structures is a long one.

The 'statistical rebuttal' has received generous exposure in the press. At the recent Little Rock Arkansas 'Scopes-II trial', in which a law requiring the teaching of creationist alternatives to the theory of evolution was tested in the courts, Chandra Wickramasinghe of University College of Wales suggested that the probability of the chance assembly of genes of the approximately 2000 enzymes characteristic of life was one in ten to the power of 40 000. He concluded that life must have resulted from intervention by a creator (**34**).

There are more objections to the one-time presumption that life is an easy step from an amino acid soup. Since the Oparin–Haldane debates, a chicken-

and-the-egg controversy has raged over which came first, the membranes or the nucleic acids, enzymes or DNA, the proto-cell or the naked gene. Candidates for an intermediate step to the cell include the coacervate – a polymer-rich colloidal droplet suspended in water – and 'thermal proteinoid' droplets.

Varieties of candidate precursors to the cell have been investigated for decades (35). Yet progress at replicating more complex, cell-mimicking forms has been notably lacking.

Going to the opposite extreme, Sir Fred Hoyle has suggested (24) that life may arise spontaneously in temporary liquid-filled chambers within water-ice comets . . . resulting in viral forms which could, from time to time, invade the Earth. Hoyle & Wickramasinghe have also proposed (36, 36b) the controversial (37) theory that the 3–9 $\mu$m infrared signatures of interstellar dust are perfectly matched by the transmission spectra of freeze-dried *E coli* bacteria – implying that space might be filled with unicellular organisms adapted to life in deep vacuum!

It is not the purpose of this paper to go into detail on a subject as complex as the origin of life, or note every obscure hypothesis. However it should be pointed out that the statistical arguments suffer from the supposition that the interactions of pre-biotic molecules in an aqueous medium, such as the Earth's early seas, were random, requiring aeons before happenstance brought about just the right complex ancestor to DNA.

There are two replies to this, one frequently mentioned and one seldom, if at all.

First, it seems clear from the geological record that biological activity on Earth began within 700–900 Myr after the planet formed (38, 38b, 39), just after many believe the surface had barely cooled sufficiently to allow the occurrence. This suggests a rapid process.

Furthermore, the molecular interactions would not necessarily have been random. The prominent evolutionary biologist T.Dobzhansky has written (39, p. 359):

> 'For practical purposes, the probability of creating any average protein from a prebiotic supply of amino acids by random processes is as remote as the probability of a monkey typing (the first sentence of *Origin of Species*). . . . Selection must have been involved.'

Stanley Miller has said of the basic pre-biotic reactions (22); 'You don't get a bit of everything. You tend to concentrate on (compounds) that are prominent in living organisms.'

There may have been, in the 'soup', a molecular driver which biased the early reactions in a direction leading almost inevitably to our form of life. This biasing agent may have been *adenine*.

Of all the purines, adenine is the one most prolifically produced in Miller/Urey/Orgel-type experiments involving hydrogen cyanide. Adenine has been claimed to have been found, along with guanine, in the Orgueil chondrite (41, 41b). The only one of the DNA/RNA bases which pairs with two partners, adenine is a very stable compound. The energy economy of all living cells is controlled by adenosine phosphates.

Recent experiments have suggested that micas and clays might have played a major rôle by providing, in interplane interstices, ionic catalysis sites. For instance, certain clays seem to concentrate and catalyze the polymerization of adenylate esters of amino acids and adenosine monophosphate. These adenylates are, in turn, the precursors of protein synthesis in all living things (**40**).

Of the thousands of possible amino acids, only about 300 occur naturally, and only 20 are coded for protein synthesis by all living things on Earth. Is this narrow assemblage a product of a single, unlikely event? Or was it the inevitable result of simple pre-biotic processes? Weber and Miller (**41c**) contend, using abundance and stability arguments, that 'If life were to arise on another planet, we would expect that the catalysts would be poly alpha amino acids, and that about 75% of the amino acids would be the same as on the Earth.'

It would seem, then, that attempts to derive Earthly biology from random organic reactions are unnecessarily conservative by many orders of magnitude.

On another tack, much has been made of the levo *v.* dextro argument by Ornstein (**2**). All 20 amino acid isomers used by life on Earth are levo. Miller & Orgel (**40b**) suggest reasons why it might be advantageous for a primitive organism to stick to only one orientation. Cox (**41d**) points out that if this were not true, and the all-one-way system on Earth were an accident, then the odds against the same biochemistry occurring on another planet would be 2 to the power of 20, assuming all the basic amino acids were the same. (This might not cause life to be rare, but might put a crimp in colonization efforts.)

In any event, there is a growing consensus that the fact that all life on Earth is of one orientation does not at all imply that a solitary pre-biotic miracle was responsible.

Completely apart from the statistical arguments are suggestions that the Earth relies on a delicate balance which might have been easily upset in the past. Why did our world not go the way of Venus, our sister world, down the road toward greenhouse catastrophe (**31**)? Might a weaker geomagnetic field have resulted in an ultraviolet holocaust making life on the land impossible (**42**)? Are the 'life-zones' around those numerous dwarf stars less massive than the Sun is too narrow (**42b**) to support a large population of habitable worlds?

Is it a combination of fortuitous circumstances that life on Earth was able to assist in extracting carbon from the atmosphere, adapt to the self-made change from a reducing to oxidizing atmosphere, and develop the delicate gas and radiation balance that today keeps the seas liquid and air sweet? The predominating opinion appears to be that all of these effects were relatively easy evolutionary adaptations to changing circumstances (**39**). Yet this belief is without firm evidence. If, at any one of these points, the success of Earth really was 'miraculous' a great many other worlds might have faced similar tests and failed.

Even a brief survey of the subject should include 'panspermia'. First suggested by Svante Arrhenius in 1908, the idea that life on Earth was

originally seeded, either accidentally (24) or by design (3, 35), is fascinating. It is also untestable.

The 1·5 Byr or more after life appeared, but before eukaryotic organisms showed up, argues strongly against any scenario of outside intervention. 1·5 Byr is a wide temporal window during which more advanced 'seeds' could have, but did not, invade the Earth. It is hard to believe that intelligent beings casting spores through space would have limited themselves to crude prokaryotic forms.

Certainly any visiting crew of star travellers who were careless with their garbage would have changed the entire course of the Precambrian.

Nothing definite can be derived from all of the controversy over $f_l$. Certainly the argument will go on, and in far more detail than we can go into here. The SETI forces assign $f_l$ – the likelihood that a candidate planet will develop life – a value of 0·1–1·0. Uniqueness proponents are split on the issue. But new discoveries seem year by year to support the tentative belief that life – indeed life very much as we know it – should be quite common in the Universe.

*The odds of life evolving intelligence – factor* '$f_i$'. A majority of uniqueness advocates seem willing to accept a fairly large value for $f_l$. Of the factors in (1), they address most of their attention to $f_i$, the fraction of life-worlds upon which intelligence evolves.

What do we mean by 'intelligence'? We can only discuss what we can imaginatively extrapolate from our own experience, so we shall limit our discussion to realms of consciousness comprehendible by man. Consider active, mobile creatures, possessed of time-sense, discursive ability, curiosity and powers of comparison and self-appraisal. Is the existence of such creatures here on Earth an evolutionary fluke, or merely a manifestation of an ecological niche that sooner or later must be filled? To many, the question revolves around 'convergence', where species from wholly unrelated taxa may independently evolve similar morphologies or behaviour-suites.

Is 'intelligence' selectively advantageous? Is it accessible in stages via selection of mutant traits? If so, is it reasonable to suppose that the same adaptive solution can crop up in many different places? Along many different paths? The contact optimists have blithely assumed that the answers to all three questions are 'yes'. In assigning $f_i$ values from 0·01 to 1·0, they took convergence to be given. Phillip Morrison (43) suggested that, should mankind ever destroy the other primates, and then himself, the racoon might replace us within a few million years.

Proponents point to homeomorphic development of the shapes of dolphins, tuna and the extinct icthyosaurs as one example of convergence (44). The independent development of very similar lens eyes by vertebrates and cephalopod molluscs is another frequently cited case.

But there are anti-convergence voices, as well. Attempts have been made to explain both the dolphin's shape and the gel-lens eye (2) as resurrection, through recapitulation, of attributes of distant common ancestors.

The paradigm seems to be tipping strongly in favour of convergence. For example, the polyphyly of Arthropoda is of great interest to taxonomists

right now (45, 46). According to Dobzhansky,

> 'A large body of evidence supports the view that the phylum Arthropoda is polyphyletic. Between two and four separate lineages of annelid-like worms have each undergone arthropodization to produce an assemblage of characters that represents the arthropod ground plan' (39, p. 326).

Cases of strikingly similar morphology emerging from unrelated lines include the two unrelated species of extinct marsupial wolves which evolved independently in Australia and South America, both closely resembling the placental wolf of the northern hemisphere, to which neither was closer related than to a tree shrew. More examples include the North American flying squirrel and the phalanger of Australia; the porcupine and the echidna; humming birds and humming moths (which are almost indistinguishable when they feed on nectar at dusk); and many others (47, 51). There are exceptions, of course. In the niche filled elsewhere by grazing ungulates, the marsupials of Australia substitute the great kangaroo. But similar niches seem often to call up duplications of the same adaptation.

Convergence does not mean identity. Blum (48) has suggested that an average of 1000 discrete mutations separates phylogenically neighbouring species. With a million species known on Earth, Blum suggests odds of greater than a billion to one against our present ecosystem. Ornstein (2) gives odds of $10^{-18}$ against duplication of mankind by random mutation.

But duplication of mankind is not required by SETI. The presumption is that there are many paths to the same end.

Can mankind's intelligence be considered simply the most advanced version of something that is accessible, to a lesser degree, to other higher mammals?

It has been suggested that the primary feature distinguishing man is his emphasis on extragenetic transmission and absorption of information. Human beings clearly have the least 'hard-wired' set of behaviour patterns, to use computer analogies. Instead, each generation programs much of its own 'software' during a very extended childhood.

But to a lesser extent apes and cetaceans also nurture their young for many years. Chimpanzees (49) and rough-toothed dolphins (50) have recently been shown to possess the ability to respond accurately to complex four or five element 'sentences'. The work with dolphins, in particular, is intriguing, narrowing for the first time the broad range of levels of competency many have claimed for Cetacea. There is no longer much doubt that the higher Cetacea are as bright as apes, and far more like human beings in their sense of curiousity and eagerness to communicate (50).

The dolphin is also clearly not our peer when it comes to 'intelligence' as we arbitrarily defined it, above.

Can the apparent convergence of two diverse orders – Cetacea and Primates – to similar levels of 'threshold' intelligence, be used to argue that true intelligence is a natural stage of development?

On the basis of morphological features, taxonomists have placed *Homo sapiens* alone, not only in his own genus but in an isolated family (Hominidae) in the primate order. Yet analysis of the enzyme chemistry of man and chimp

(52) has shown that the two are as near biochemically as any two closely related but distinct species. The consensus explanation (52, 39) is that the great morphological differences are functions of the *regulation* of expression of alleles.

In the 1930s Aldous Huxley whimsically suggested that the great difference between man and ape was that man was a 'neotenous' – perpetually undeveloped – ape. Today the idea is widespread that a minor regulatory shift keeps humans in a 'child-ape' condition, hairless and insatiably curious, throughout their lives.

If this is so, then chimpanzees (and perhaps dolphins) might be only a few minor 'quantum' regulatory steps away from some indisputible degree of intelligence. The implication for the expected value of $f_i$ is enormous (52b, 52c), for then there would at last be more than one data point on the curve.

For completeness we should touch upon a few other scenarios which might lead to low values for $f_i$.

Bond (12) has proposed that the step from higher mammals to intelligence might be relatively easy, but that the intermediate leap to the complexity of the mammalian way of life might be the anomalous event. He suggests that the size of genome is the major correlate with the level of advancement of a species (though both salamanders and wheat both have larger genomes than man). He also states that the only practical way to enlarge the genome is via the rare doubling mechanism of polyploidy. If genome doublings occur at most every few hundred million years, the mammalian genome has a probability of less than $10^{-14}$ or so.

But polyploidy is almost universally fatal to vertebrates. Colchicine-induced polyploidy amongst plants generally results in asexual apomixis (loss of sexual reproduction ability). In any event, the genome need not double in order to enlarge gradually (39). Translocation, inversion, and fusion of chromosomes will accomplish that end much more simply.

One more reason why nascent intelligent life might be rare is intervention by outside forces. Pre-sentient life-forms might be interfered with by star-travelling races, either intentionally or as innocent victims of ecosphere takeovers by technological species. *Homo sapiens* has come close to doing this to the great cetaceans and great apes. This idea will be discussed further later on, but its potential effect on $f_i$ is unquestionable.

(The opposite effect has also been proposed. More advanced space-faring races might intervene to 'uplift' local presentients via bioengineering (53). The excesses of Erich von Daniken and others (25) should not deter contemplation of an essentially plausible idea. However, any effect that tends to raise, rather than lower, a factor in (2) is of little interest in this discussion.)

I am of the opinion that the Uniqueness proponents who argue for extremely small values of $f_l$ and $f_i$ have presented a poor case. (Others reading the references cited herein may come to different conclusions.) This does not mean that the Uniqueness advocates are wrong in their basic conclusion – that we are alone in the Galaxy. The low value of '*C*' in (2) is a fact. From here we proceed to examine the other factors and discuss other possible explanations for the apparent absence of extraterrestrial civilizations.

*The emergence of a technological culture – factor* '$f_c$'. There have been many suggested scenarios describing how an 'intelligent' species might fail to develop a technological culture. For instance, even if there were selective advantages to developing the hunter-gatherer-farmer way of life, with language and tool-use, there is no obvious explanation for the overshoot to what mankind has become in a mere 5000 yr – a space-faring race capable of inhabiting vacuum. Other species might achieve speech, agriculture, even analytical ability sufficient to dominate their environments, and never need or acquire the vigorous imagination that drives us so.

Water covers over 70 per cent of the Earth's surface. Yet perhaps the Earth is towards the *dry* end of the habitable class of worlds. A much smaller land area, or lack of any dry land at all, would afford little opportunity for the evolution of tool-using species. Most intelligent species in the Universe might possess the outlook of whales, and never conceive of radio, or travel to the stars.

Again, intervention by transient space-farers can also affect $f_c$, up or down.

We will not list all possible suppressions of $f_c$ here for two reasons. First, these explanations are excessively speculative. Furthermore, no-one contends that $f_c$ could be so small as to have a crucial effect on (1). If only 1 in 1000 intelligent species develops radio/space-travel, that is enough to set off the Contact Scenario. The principle of non-exclusion applies here. It will be the exceptions that make the rules.

*The (homeworld) lifespan of technological species – factor* 'L'. The SETI scenario of the late 1960s was optimistic regarding the first six factors of the Drake equation (1). 'Xenologists' of the SETI school – Sagan, Morrison, etc. – believed that the last factor, '*L*', was crucial (**16, 17**). von Hoerner approached the matter differently but came to the same conclusion (**19**). The mean lifetime of technological species is crucial in determining the cross-section of interaction with them. von Hoerner demonstrated that if only one in a hundred ETIS survive an initial 'crisis of survival' and settled down into a long maturity, the population of the Galaxy at equilibrium would be dominated by such older races.

We might explain the apparent lack of extraterrestrial sophonts by postulating that $L$ is catastrophically low. A common suggestion is that technological species necessarily pass through a crisis of survival upon the discovery of nuclear power (**16, 17**). Self-destruction is a very real possibility for mankind. Is this a pattern for all who pass this way?

This is a difficult premise to support. There is no mechanism put forward – other than an amorphous 'aggressive instinct' – that generalizes convincingly beyond the Earth. We appear to face fairly even odds of surviving another hundred years as a technologically sophisticated species. If the chances of survival are as high for other fledgling ETIS, the losses would hardly be noticeable in (2).

Other scenarios include *Resource Exhaustion* – in which a high consumption phase is rapidly replaced by a decline into soft technologies or barbarism –

and *Transcendance* – which suggests, as did Arthur C.Clarke in his novel, *Childhood's End*, that we shall soon encounter realms of adventure and understanding that will cause us to abandon technology as we know it, the way a child abandons toys it has outgrown.

Non-exclusiveness would seem to apply to *Resource Exhaustion*. Even if some ETIS were wastrels, at least a few others would see the crunch coming and plan for it.

To *Transcendance* there is no ready answer, except a willingness to watch for signs of an upcoming Parousia. The hypothesis should be catalogued and noted, but at this point it cannot be grappled with.

To overcome non-exclusivity we need a mechanism which might affect $f_c$ systematically, so that there are few if any exceptions to slip away and fill the Galaxy with the commerce we do not observe.

Consider the von Neuman/Bracewell/Tipler probes we discussed earlier. Tipler (1) states that self-replicating surrogate robots would be a way by which an ETIS could simply and economically send out explorers and messengers to the stars. There might be some argument over even 'slowboat' interstellar travel by organisms, but with few exceptions (2) there is little dispute that this scenario with robots could take place, if not in one locale then in another.

Now, it has been proposed that such probes would benignly seek out new life, contact new civilizations, and boldly lend assistance to emergent space-farers such as ourselves. This might have a dramatically positive effect upon the lifespan of our own techno-species – much the effect the SETI people hoped would come from receiving radio messages from ETIS.

This is the logic which places the greatest burden upon (2). By Tipler's reasoning it should take less than 5 Myr to fill the Galaxy with such robot envoys. Yet we have not met any probes. The final test will come as we begin to explore the Solar System in detail.

One version of the robot-surrogate idea might explain the Great Silence by *reducing L* – it is called 'the Deadly Probes Scenario'. Its logic is compellingly self-consistent.

Let us say many advanced ETIS get the robot-emissary idea, and ship out first-generation probes as Tipler suggests, to replicate and fill the void with messages of brotherhood. Then suppose that for every 100 or 1000 or 10 000 'sane' ETIS, there is one that is xenophobic, paranoid even. Such a race might programme its self-replicating emissaries to add powerful bombs to their repertoire, and command them to home in on any unrecognized source of modulated electromagnetic radiation.

Science fiction author Fred Saberhagen broached a related idea in his novel *Berserker*. Gregory Benford has refined this scenario of malignity much further. The frightening thing about 'Deadly Probes' is that it is consistent with all of the facts and philosophical principles described in the first part of this article. There is no need to struggle to suppress the elements of the Drake equation in order to explain the Great Silence, nor need we suggest that no ETIS anywhere would bear the cost of interstellar travel.

It need only happen once for the results of this scenario to become the equilibrium condition in the Galaxy. We would not have detected extra-terrestrial radio traffic – nor would any ETIS have ever settled on Earth – because all were killed shortly after discovering radio.

The effect of 'Deadly Probes' on $L$ is profound. And 'I Love Lucy' has spread well past tau Ceti by now.

*Star travel – factor* 'v'. Speculations on interstellar settlement usually begin with an implicit series of limiting assumptions. For instance, while it is posited that older extraterrestrial civilizations might achieve technological skills that would seem 'magical' to us (Clarke's Law), it is also generally assumed that the Einsteinian travel restrictions will remain in effect. Insisting that the limits of Special Relativity still hold for advanced species does not imply an absolutely rigid rejection of the remote possibility of Faster Than Light Travel (FTLT). The restriction is made because there is little to be learned from a thought-experiment in which FTLT has a part. Xenological speculation is useful only in exploring low upper-bounds to diffusion of extraterrestrial civilizations, not the high lower-limits approach FTLT implies.

Further assumptions suggest why a species that attains interstellar flight capability might choose to exercise the privilege. Migration by space-faring species has been modelled both from a diffusion approach by Newman & Sagan (**4**) and via Monte Carlo iteration by Jones (**8**). These discussions assume that colonized areas will expand under the population pressure to fill available living sites (presumably including not only habitable and 'Terra-formed' worlds, but also space habitats converted from planetoids orbiting near sources of solar power and volatile gases).

For an initial period after colonization of a virgin world, a space-faring race is assumed to engage in exploitation and population expansion. This period is taken to be as short as decades (**9**) and as long as hundreds of thousands of years (**4**). When industrial capacity has risen sufficiently, and when per capita resources fall below some desired level, the effort of exploration and emigration once again becomes worth the cost. Enterprising colonists, seeking better lives for themselves and their offspring, depart then for fresher horizons. This cycle of settlement, development, saturation, and further exploration is assumed to continue at each site along the expanding zone of colonization.

Analyses include assumptions regarding the likely distribution of usable sites near stable stars, population growth rates, and emigration rates once each colonization phase begins. These mathematical studies, with few exceptions (**4**), suggest that, even if starships are restricted to velocities well below $0{\cdot}1c$, and to ranges less than 5 pc, a star-faring race should be able to expand to fill a galaxy like the Milky Way within approximately 60 Myr (**9**).

Including settlement pauses, Kuiper & Morris (**6**) calculated an expansion velocity, $v$, of about $0{\cdot}016c$, not too dissimilar from the results of Jones and of von Hoerner (**19**). This value is virtually independent of ship speed, meaning that almost any scenario for interstellar travel (light-sail, asteroid ark, suspended animation, etc. (**23**)) is relevant.

Those who insist that interstellar travel is impossible (54) will not be convinced by the sources cited here. If their case can be demonstrated, the central point of Tipler and others will be repudiated, and SETI will return to the situation of the late 1960s. This author believes that the case for some version of slow interstellar travel is growing stronger yearly.

Assuming star-travel is physically possible, are there any other ways in which $v$ might systematically be reduced below the values estimated above?

Newman & Sagan (4) have suggested that population pressure is not the driving force behind the expansion, and that dispersal might therefore be slower. But this conclusion is weak. Explorations undertaken out of curiosity would cover far greater distances than those motivated by mere practicality. When colonies are established as side effects from such expeditions, these will serve as nuclei for further migration. Instead of a growing sphere we would then see multiple 'infections' all over the Galaxy. The population pressure hypothesis, though itself simplistic, is preferred because it can be modelled on real examples from Earth, and also because it offers low upper limits on settlement diffusion rates.

Newman & Sagan (4) have also suggested that ETIS are out there, but have simply not arrived here yet – it taking a very large time, perhaps 2 Byr, using their population parameters, for civilization to diffuse across the Galaxy. Jones (8, 55) has pointed out, however, that even Newman & Sagan's extremely conservative growth rates could fill the Galaxy within half a billion years, as the differential galactic rotation smears the expansion zone into a spiral of high surface area. In any event, what Newman & Sagan suggest is a non-equilibrium situation, which thus starts off with one strike against it.

Suppression of factor $v$ is a favourite method of contact optimists to explain the Great Silence, but generally their arguments seem weak. Those who examine the references cited herein may come to another conclusion, but it would seem that relief must be sought elsewhere.

*Approach and avoidance – factor* 'A'. Contact optimists are not unanimous about which factor in (2) is responsible for the apparently low value of $C$. As we have seen, some assail the logic of interstellar travel. Others try to explain why ETIS might *choose* not to contact us. The factor that represents the latter hypotheses is '$A$', the 'approach/avoidance' cross-section in (2). Here we will briefly list references to a few of the various ideas offered.

(1) *Avoidance*. (a) Kuiper & Morris (6) have suggested that members of a galactic radio club might choose not to contact 'beginners', because this would vitiate the novices' usefulness as eventual members of the network. Making us information *consumers* too early would spoil us as information *providers*, whose unique experience would add richness to galactic culture.

(b) If the 'Deadly Probes' scenario has even a grain of truth in it, knowledgeable ETIS would be cautious about leaking too much electromagnetic radiation into their skies. They would be selective about who they would contact, whether in person or by radio. And they might be particularly cautious with surrogate probes. Benford (2) has suggested that self-replicating probes can mutate, much as organisms do, and, after many generations,

become a hazard to the creator species. Realising this, ETIS might be conservative in sending out such surrogates.

Saunders (56) has listed more reasons why initiating contact might be advantageous or disadvantageous to a technological species.

(2) '*Bad search strategies*.' 'They' might very well be all over the place, but we have been looking in the wrong way. Much of the SETI debate has been over which radio frequencies would be used by an ETIS radio hotline (43, 22, 16, 17). Still, the consensus regarding the 'water hole' frequencies (43) might be in error (6). Traffic carried by narrow coherent beams might be undetectable from Earth, for instance.

Sagan (14) explains the apparent absence of insterstellar radio traffic by pointing out how New Guinea natives once communicated across large valleys with tom-toms while totally unaware of radio waves filling the air around them. His point is that sufficiently advanced species might use unknown means of communication more efficient than radio. But this strongly implies that the FTL option should be reinstated, as long as we are discussing 'magic'. It also suggests that the New Guineans would not recognize the sounds of a rock band on a passing passenger liner as having intelligent origin.

In human society, whenever new channels of communication have opened, the older basic channels were not abandoned, but rather were more extensively used than ever.

ETIS may transmit only at intervals or at narrow angles. If so, astronomical events might serve as *markers* to them, supernovae in the time-domain (57), or flare stars in spatial orientation (58), suggesting that there might be some special search strategy for SETI to use, if we can only figure it out.

Tipler's argument against SETI (1) rests on the idea that self-replicating surrogate probes would have settled into place in the Solar System by now, and made contact upon detecting radio flux from our new civilization. With the exception of some strange 'echoes' detected in the 1920s and 1930s (22) (the zeta Reticuli mystery), there have been no traces to indicate such probes are here. Still, such probes may not be programmed the way Tipler expects. Only detailed exploration of the Solar System will show if robots are out there now, quietly awaiting us (59).

(3) '*Quarantine*.' *Purposeful isolation of the Earth*. Ball (61) has suggested a simple version of an idea long discussed in science fiction. He explains the Great Silence by suggesting that the Solar System is (a) kept as a 'zoo'.

Alternatively (b), Kuiper & Morris suggest benevolent species might want to let worlds such as Earth lie fallow for long periods, to let new sentience nurture (6).

Related hypotheses are that observers are (c) awaiting mankind's social maturity, or have (d) quarantined us as dangerous.

Extraterrestrials may even be in secret contact with governments or individuals on Earth (e). (Aversion to an idea, simply because of its long association with crackpots, gives crackpots altogether too much influence. All options should be listed.)

A problem with 'Quarantine' is the Galaxy's differential rotation. If our neighbours during one epoch are environmentalists, 10 Myr later our Sun could enter the demesne of a less scrupulous race. The Quarantine hypothesis appears to call for some degree of cultural homogeneity across space. How such homogeneity could be enforced in an Einsteinian galaxy is hard to imagine.

(4) *Macrolife. The abandonment of planet-dwelling as a lifestyle.* Consider an expanding sphere of colonized stellar systems, as suggested by Jones, Sagan, and many others. Expansion will generally come from those colony worlds most recently settled. There would be a tremendous selective process in this case, favouring those most suited to living in starships. One can imagine a very rapid social (and maybe physical) adaptation to where planet-bound existence is spurned in favour of space habitats throughout all but the innermost part of the sphere of settlement **(60)**. This might result in either of two disparate behaviours, each compatible with the Great Silence. Truly space-born sophonts might greedily fragment terrestroid planets for building material and volatiles, leading to disastrous suppression of $n_e$, $f_l$ and $f_i$. Or they might cherish Nursery Worlds for what they are, and protect them as in option 'Quarantine', without any conflict of interest or desire to use high gravity real estate.

(5) *'Seniors only.' More alternate lifestyles.* It is often suggested that space-faring sophonts might 'graduate' to other interests after a reasonable time. This would set a limit to the period of expansion though not, perhaps, to exploration. It is difficult to imagine any such scenario prevailing for *all* older sapient species.

Discovery of life extension techniques could tend to promote conservatism, ecological sensitivity, and an avertion to the dangers of spaceflight **(4)**. Self-surgery to suppress residual territoriality instincts is another option suggested by Sagan **(4)** although he may be confused between 'territoriality' and a healthy imperative towards 'dispersal'. The latter drive is an element of speciation, and does not become irrelevant with the invention of culture.

(6) *'Low rent.' Earth is inaccessible or undesirable.* (a) The one technique for travelling faster than light (FTL) which has drawn some support from a few in the physics community has been via 'geometrodynamics'. Solutions to Einstein's field equations of general relativity include those which relate to black holes either with net charge or which rotate. These solutions may be analytically continued through the interior of the black hole in a time-like direction into a succession of asymptotically flat space-time regions far removed from the original region of space. (Some physicists now claim that such 'wormhole' tunnels are smashed by unbounded blueshift effects within the singularity. Others are less sure **(62, 63)**.)

If such a version of FTL travel were convenient and efficient, one might expect galactic civilization to cluster around entry and exit points. The expensive and slow technologies for 'slowboat' travel would languish. The fact that astronomers have observed no nearby black holes, then, may be a manifestation of the Anthropic Principle. If a 'usable' black hole were closer, the Earth would have already been settled, an ecological holocaust would

likely have ensued (see next chapter), and we would not exist to observe the black hole. Thus the fact that we are here is consistent with a failure to observe nearby black holes.

Author Hal Clement's 'red empire' concept was similar, suggesting that the very numerous and long-lived red dwarf stars may be the true centres of civilization. ETIS may generally shun hotter stars such as our Sun.

(b) Another systematic effect that might make for periods of inaccessibility is the migration of the Sun around the centre of the Galaxy. We are currently on our way out of a gas- and dust-rich spiral arm. In a few million years the Sun will be in an 'open' area, where there are few bright, younger stars, or dense interstellar hydrogen clouds. These clouds may be required to run Bussard ramscoop starships (**64**) but they might also be considered hazards to other forms of travel.

(c) Earth lifeforms rely almost totally on the left-handed isomers of amino acids. This might not be the case elsewhere. Should 'dextro-' life dominate everywhere else we might find Earth systematically avoided because there would be nothing here for prospective settlers to eat.

The variety of scenarios which might have kept alien beings from contacting us has only been touched upon by this listing. There are many other possibilities (**65**). Unfortunately, almost all of these suggestions fall prey, again, to the non-exclusivity rule. So far we have uncovered few explanations which would *systematically* prevent any contact at all over the immense time period we have discussed.

*Settled spheres – factor* 'L'. Many have estimated the rate at which a technological species might expand through interstellar space, once it attains the capability (**1, 4, 8, 9**). Ship speed is generally assumed high enough to make migration practical, yet low enough that colonists would choose to settle the first suitable site. Thus diffusion of an ETIS would likely be spherical until the thickness of the galactic lens was traversed, then proceed as an expanding disc. In these studies the main interest has been the leading edge of the populated zone, the wavefront determining how far an expanding race might spread in a given time.

If population pressure is the primary driver, however, one wonders about the fate of the long-occupied worlds deep in the interior of the settled sphere. The words 'population pressure' suggest the likely fate of these communities.

Consider the settlement of Polynesia, from roughly 1500 BC to about AD 800 (**66**). The island-hopping analogy to interstellar exploration and colonization is apt. Jones has used archaeological demographies of the Polynesian expansion to suggest growth and emigration rates for his model of interstellar settlement. He sees the intrepid Polynesians as testimony to the likely success of 'star-hopping' colonization ventures (**8**).

The history of Polynesia may be analogous to interstellar settlement, but perhaps in more of a sanguinary than a sanguine sense. The Hollywood image of island life is paradisical, but Polynesian cultures were subject to regular cycles of extreme overpopulation controlled by bloody culling of the adult male population, in war or ritual. There are many stories of islands whose men were almost entirely wiped out – sometimes by internal strife, and sometimes by invading males from other islands (**67**).

Introduction of domestic and parasitic animals disrupted island ecosystems. Many native plant and animal species were extinguished.

The most severe case was the island of Rapa Nui, also known as Easter Island. Isolated thousands of miles from its nearest neighbours, it was as much like an interstellar colony as any place in human history, when settled around AD 800.

The Polynesian inhabitants utterly destroyed the virgin ecosystem of Rapa Nui within a few generations, completely ravaging the native forests. Without wood for houses or boats, they had to abandon the sea and its resources, along with all possibility of escape or trade. What remained was native rock – which they carved into hauntingly desolate images – and warfare. When Europeans arrived, the natives of Rapa Nui had just about annihilated themselves (**68, 69**).

(Alfred Crosby has shown that such disasters are commonplace side-effects of colonization (**70**).)

If Polynesia is to be used as an analogy of interstellar migration, it might be best to consider not only the great feats of navigation but the rest of the story as well, extrapolated to a technological setting.

Assume a settled sphere of ETIS expansion. What of the inner systems? The Polynesian example leads us to picture increasing competition for dwindling resources, with no escape valve for excess population, since all surrounding systems are in similar straits.

Stull (**71**) has suggested that depredations by inner systems, on outer shell settlements, might slow the rate of exploration and expansion. But interstellar imperialism without FTLT seems preposterous. Conflict arising from population pressure is far more likely to take the form of struggles for resources within each planetary system.

In a long settled system, available asteroids would have early been turned into habitats. Safe inner orbits with unhindered access to solar power would be at a premium. Under such circumstances one might see a profound cultural split between those living upon planetary surfaces and those living in space. Even the most efficient space structures would require frequent replenishment of volatiles, for instance. Comets might supply part of this, and asteroids which were once cometary nuclei (**72**), but terrestroid planets would be closer, and rich in desired elements.

From their position atop a gravity well, the space dwellers might bully their planet-bound cousins, bombarding their cities with redirected asteroids until civilization was obliterated. The space-born, long divorced from any sense of attachment to planetary life, might even see a terrestroid planet as a likely source of building materials. It would not be beyond the abilities of an advanced technology to pulverize a world such as the Earth by arranging planetary collisions. It is an idea less remote than FTL transport or communications modalities that bypass electromagnetism. The effect that waves of such events might have on the terms of Drake's formula, particularly $n_e$, is severe.

'*Nursery Worlds.*' There is a large body of literature suggesting that modern society is exhausting or degrading Earthly resources at a greater rate than

they can be naturally replenished (73, 74, 75, 80). Suppose a planetary system can support a high-pressure technological culture for only a certain characteristic period. This lifetime would vary from site to site, culture to culture, but within each species' expansion sphere it might be assigned a characteristic value $L'$. A survival factor $S(t) = \exp(-t/L')$ can be assigned to a site occupied for time $t$.

Assume an ETIS expands from the system where it evolved, at average effective velocity $v$ pc yr$^{-1}$ (combining ship speed with delay to develop the forwardmost settlements at range limit $R$). Then for a site at distance $r$ from the centre, $S(r) = \exp(-(R-r)/vL')$. The number of surviving sites within the settled sphere, as calculated in equation (3), is

$$n_j = Bf_g\, n_e\, 4(\pi)\,.\int_0^R r^2\, e^{-(R-r)/vL'}\, dr. \qquad (3)$$

We have seen that many authors believe $n_j$ to be relatively insensitive to expansion velocity, $v$. But it certainly depends heavily on $L'$. If settled biospheres can maintain technological civilizations for a long time, $n_j$ goes up as the cube of the radius reached. If $L'$ is very small, however, sites in the interior die off rapidly, the outermost shell dominates, and the number of sites expands only as the square. When one introduces the finite disc shape of the Galaxy, $n_i$ soon has to rise linearly, and eventually decline, as a grass fire burns itself out for lack of fuel.

Like the scorched ground where a brush fire has swept by, the Galaxy may eventually rebound with other ventures in 'intelligent' activity. But how quick would be such a response? Consider the life cycle of a 'Nursery World', a planet with an equable biosphere, upon which the long, slow evolution to intelligence can take place.

On Earth, much has happened since the Cretaceous–Tertiary Catastrophe, approximately 65 Myr ago – a disaster which wiped out, over a brief period, nearly every land animal species whose adult form massed more than 25 kg (76). The creatures whose descendants went on to dominate the planet were the early equivalents of mice, lemurs, and tree shrews. These humble animals expanded and diversified to fill the ecological niches left vacant by the demise of the large reptiles. We are among their descendants.

Would the sudden extinction of this planet's present technological race finish off the Earth as a nursery? Perhaps not. If 'mice' did it once, they could presumably do it again.

It is suggested that suitable worlds must pass through long, initial fallow periods before attaining a biological sophistication – a complexity of genome perhaps – ripe for intelligence. Afterwards they should be able to produce sophont species at fairly short intervals, depending upon the time needed to recover from the depredations of the previous sentient race. The interval between the Cretaceous Catastrophe and the present is a reasonable estimate for the time involved, once small creatures have reached a high level of sophistication.

Now consider cyclical waves of migration and colonization by spacefarers. We assume that planets are settled, exploited, and then for one reason

or another abandoned. Unless tenant sophonts leave large parts of their worlds fallow, or engage in 'uplift' bio-engineering of local higher animals, their mere presence is likely to prevent the appearance of indigenous sentient species. The cycle of production of intelligent species on a planet is probably delayed indefinitely by an active technological settlement.

When the settlers finally do vacate (or die off), the recovery time required before another generation of tool-users evolves will depend on the way the former tenants treated their adopted world. The more extensive their exploitation, the more severe the winnowing of the local biosphere. Our own technological civilization has markedly simplified ecological networks on Earth, even where efforts have been made to preserve wilderness. 'Higher' life forms have proved particularly delicate and dependent upon complex eco-networks.

This is a major consideration, in regard to interstellar migration, that has largely been overlooked. When settlers finally do step aside, by attrition, self-immolation, exodus or some sort of transcendental dissipation, ecological recycling can resume, but recovery and regeneration of sapiency will be delayed for a long time after a technological race has occupied the planet. Therefore population pressure affects not only factor $L'$, but factor $f_i$ in equation (1) as well.

There is no clear evidence that Earth was ever settled by an ETIS. The most recent event with faint possibilities is the Cretaceous Catastrophe, which featured not only the demise of the dinosaurs, but the virtually instant extinction of the majority of taxa of siliceous and calcareous phytoplankton and many other marine micro-organisms (77).

Recently thin layers of clay rich in iridium (up to $150\times$ normal abundance) were found at sediment levels associated with the end of the Cretaceous. Discoveries in 25 locations such as Italy (78) and New Mexico (79) seem to correlate a sudden intrusion of anomalous dust with the great demise. A reasonable hypothesis is that a major meteorite impact caused both events by severely modifying weather patterns, reducing insolation, and cutting off photosynthesis for as long as three months.

But while the meteorite seems clearly to have been responsible for the marine extinctions, it could only have been the last straw for the great reptiles. After roughly $10^8$ yr of great stability, the dinosaurs had begun dying some time *before* the final catastrophe.

The sequence of extinctions somewhat resembles the ecological story of African fauna at the hands of the recent technological inhabitants, white and black men. And the catastrophic conclusion of the age of dinosaurs is not inconsistent with the violent end of an epoch of settlement, a final war perhaps, fought with asteroids, in which extraterrestrial settlers cleaned the Earth's surface of higher forms, returning it unintentionally to nursery status.

Papagiannis (59) has suggested that the asteroids might hold remnants of visits to our star by ETIS. Might we find the remains of gigantic populations, killed off, perhaps, in desperate retaliation by the Earth-dwelling cousins they had annihilated? The settlement of Earth by an ETIS about 70 Myr ago offers one more (admittedly tenuous) explanation for the destruction of

the higher terrestroid life forms and many marine taxa over a brief period. Even assuming the settler cities are now under astroblemes, it is hard to support this idea. Flowering plants did make their appearance about this time, a major evolutionary discontinuity, but there is no real evidence of introduction by outside agencies.

I put no great emphasis on this explanation for the Cretaceous mystery. Indeed, the farther back in time we push failure of the Earth to have been colonized, the more strongly we must consider some of the alternative explanations for the Great Silence suggested herein. It is interesting to note, however, that the fallow period since that catastrophe – an interval which included the development of *Homo sapiens*, is the same 60 Myr suggested by Jones (**8**) for the optimum galaxy-filling time by a technological race.

In fact, the Cretaceous–Tertiary event was not the only one of its kind. At least four other major mass extinctions are found in the sedimentary record, including one at the end of the Devonian and another at the Permian–Triassic boundary, approximately 225 Myr ago. (The latter sediments also feature an anomalous clay boundary about 1 cm thick.) It may not be preposterous to compare the rough $10^7$–$10^8$ yr intervals seen with those suggested by Newman and Sagan for galaxy filling by space-travelling species.

If the ecological holocaust of the Cretaceous was a local manifestation of the death spasm of a prior space-faring race whose overpopulated sphere of settlement spoiled as the shell of 'civilization' passed outward, Earth may be the first nursery world in the vicinity to have recovered sufficiently to develop a species with technology. This offers a mechanism that the 'Uniqueness' hypothesis has so far lacked. It offers an explanation as to why our region of space might be in a disequilibrium state of emptiness.

What of our own future then? If we survive our current crisis of survival, and initiate an era of interstellar travel of our own, will we find all around us the sad remains of an earlier epoch? We might then learn a lesson. But with the ever-present opportunities for expansion, those human cultures that exercise self-restraint and environmental sensitivity upon their adopted worlds will not be able to force this tradition upon those who travel far away to establish newer colonies. A nucleus of selfishness is likely to expand faster than a centre of more rational colonization. There may be zones where sensitive settlers preserve and protect local ecospheres, aware of their long-range potential. Others will be rapacious. Non-exclusivity cuts both ways.

Jones (**55**) has suggested that if the interiors of settled spheres fail, in either catastrophy or a milder form of resource-degradation exhaustion (preventing further space travel), the inner worlds might be targets of colonial ventures from the still-vital outermost shell. This would result in a 'counter-flow' of civilization. The problem with this idea is the recovery time required before a biosphere regains its attractiveness (**73, 74, 75**). And even if this happened, this does nothing for the higher animal forms driven extinct on ravaged nursery worlds. The next generation of ETIS has still been wiped out.

Is the Great Silence the sound of sands drifting up against monuments? The absence of extraterrestrials may be a quiet testament to the fate of the

TABLE I

*Chart of suggested causes of the apparent absence of extraterrestrials*

| Factors from equations (1–4) | $n_e$: number of useful planets per star | $f_l$: percentage develop life | $f_i$: percentage of $f_l$ that gain intelligence | $f_c$: percentage of $f_i$ that attain technology | $L$: span of isolated ETI | $L_c$: characteristic ETI colony lifespan | $v$: effective settlement expansion velocity | $A_v$: approach/avoidance factor |
|---|---|---|---|---|---|---|---|---|
| ***Solitude*** | | | | | | | | |
| (a) Habitable planets are rare (1, 3) | (−,t) | | | | | | | |
| (b) Life needs a 'spark' (1, 16, 17) | | (−,t) | | | | | | |
| (c) Intelligence needs a 'spark' (1, 6) | | | (−) | | | | | |
| (d) Deadly probes | | | | | (−) | ? | | |
| (e) 'Inevitable' self-destruction (12) | | | | | (−) | (−) | | |
| ***Migrational holocaust*** | | | (−) | (−) | | (−) | +? | |
| ***Prevalence of water worlds suppresses technology*** | | | −? | (−) | | | | |
| ***Quarantine*** | | | | | | | | |
| (a) Fallow preserve | | | | | | | | (−) |
| (b) Meddling in secret | | | ? | ? | ? | ? | | (−) |
| (c) Awaiting 'maturity' (27, 31) | | | | | | | | (−, t) |
| (d) Not interested in us (5) | | | | | | | | (−, t) |
| (e) Secret contact | | | | ? | ? | | | (−, t) |
| (f) Friendly probes (24, 26) | | | | | (+) | | | (+, t) |
| ***Macrolife*** | | | | | | | | |
| (a) Greedy breakup of 'nurseries' | (−) | (−) | | | | | | |
| (b) Inability to adapt to space-life | | | | | | | (−) | (+) |
| (c) Tolerance of 'nurseries' | | | (+) | | | | | (−) |
| ***Seniors only*** | | | | | | | | |
| (a) Lose interest in spaceflight (5) | | | | | | | (−) | (−) |
| (b) Immortality conservatism (5) | | | | | | | (−) | (−) |
| ***Low rent*** | | | | | | | | |
| (a) FTL selection (e.g. black holes) | | | | | | | (−) | (−) |
| (b) Galactic drift | | | | | | | (+) | (−) |
| (c) Biological incompatibility (17, 32) | | | | | | | | |
| (d) . . . . . . . . ?? | | | | | | | | |

(−) means the effect is expected to be negative on one of the factors in equations (1–4)
(+) where it may be positive
(t) indicates where the author thinks the option might be testable.

pre-sapient victims of star-travelling species which allow 'population pressure' to be their motivation for the stars.

## CONCLUSION

The quandary of the Great Silence gives the infant study of xenology its first traumatic struggle, between those who seek optimistic excuses for the apparent absence of sentient neighbours and those who enthusiastically accept the Silence as evidence for humanity's isolation in an open frontier.

Both approaches suffer greatly from personal bias, and from lack of detailed comparative study. In this article we have attempted to deal with a subject that, for all of its great importance, is almost ghostly in its intangibility. We have broken the subject into its logical elements and attempted a morphological discussion of the possibilities. Table I presents an overview of many of the ideas discussed here and their respective effects on the factors in equations (1–3). It is up to the interested reader to look up the references cited and come to his/her own conclusions.

Some of the branch lines discussed here serve the optimists, while others seem pessimistic to an unprecedented degree. We have laid out only the outline of a full analysis of the problem. Further work should consider every experimental test that could be applied to this fundamental question of humanity's uniqueness.

This survey demonstrates that the Universe has many more ways to be nasty than previously discussed. Indeed, the only hypotheses proposed which appear to be wholly consistent with observation and with non-exclusivity – 'Deadly Probes' and 'Ecological Holocaust' – are depressing to consider.

Still, while the author does not accept that elder species will necessarily be wiser than contemporary humanity, such noble races might have appeared. If such a culture lived long, and retained much of the vigour of youth, it might have instilled a tradition of respect for the hidden potential of life in subsequent space-faring species.

It might turn out that the Great Silence is like that of a child's nursery, wherein adults speak softly, lest they disturb the infant's extravagant and colourful time of dreaming.

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