*Q. Jl R. astr. Soc.* (1983) **24**, 113–121

# The Solipsist Approach to Extraterrestrial Intelligence

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(Received 1982 October 30)

One of the distinctions and triumphs of the advance of science has been the deprovincialization of our world view. In the sixteenth century there were battles over whether the Earth is at the centre of the Solar System; in the seventeenth century about whether the stars are other suns; in the nineteenth century, about whether the Earth is much older than real or mythical human history; in the eighteenth to twentieth centuries about whether the spiral nebulae are other galaxies something like the Milky Way, and about whether the Sun is at the centre of the Milky Way; and in the nineteenth and twentieth centuries about whether human beings have arisen and evolved as an integral part of the biological world, and whether there are privileged dynamical frames of reference. These deep questions have generated some of the major scientific advances since the Renaissance. Every one of them has been settled decisively in favour of the proposition that there is nothing special about us: we are not at the centre of the Solar System; our planet is one of many; it is vastly older than the human species; the Sun is just another star, obscurely located, one among some 400 billion others in the Milky Way, which in turn is one galaxy among perhaps hundreds of billions. We humans have emerged from a common evolutionary process with all the other plants and animals on Earth. We do not possess any uniquely valid locale, epoch, velocity, acceleration, or means of measuring space and time.

The latest issue in this long series of controversies on our place in the Universe properly concerns the existence of extraterrestrial intelligence. Despite the utter mediocrity of our position in space and time, it is occasionally asserted, with no sense of irony, that our intelligence and technology are unparalleled in the history of the cosmos. It seems to us more likely that this is merely the latest in the long series of anthropocentric and self-congratulatory pronouncements on scientific issues that dates back to well before the time of Claudius Ptolemy. The history of deprovincialization of course does not *demonstrate* that there are intelligent beings elsewhere. But, at the very least, it urges great caution in accepting the arguments of those who assert that no extraterrestrial intelligence exists. The only valid approach to this question is experimental.

The most elaborate recent exposition of the solipsist world view is that of Tipler (1980, 1981abc, 1982abc). Seeking, in effect, a universal principle to explain the apparent absence of extraterrestrial beings on Earth, he contends that if extraterrestrial intelligent beings exist, their manifestations will be obvious; conversely, since there is no evidence of their presence, they do not exist. But absence of evidence is not evidence of absence. Because some experts in artificial intelligence propose that general purpose self-replicating robots will be devised on Earth within a century, Tipler concludes that any extraterrestrial civilization, only a little more advanced than we, will necessarily infest the Galaxy in a few million years with exponentiating devices. Adopting a conservative assumption on velocity of $3\times10^{-4}$ light yr $\mathrm{yr}^{-1}$, Tipler deduces a replication time for his 'von Neumann machines' $\sim10^4$ yr. In several places in his discussion he imagines that a von Neumann machine, landing on a virgin world, makes no more than a few copies of itself. The reason for such reproductive restraint is never mentioned. With the implacable dedication to self-replication with which these machines are supposedly endowed, thousands or millions of replications per world seems much more likely. However, with any plausible initial mass for such a device, and with even one copy per reproductive event, the entire mass of the Galaxy would be converted into von Neumann machines within a few million years of their invention. (Stars are, after all, excellent sources of the $^3$He that Tipler imagines the von Neumann machines to hunger for.) For example, with a modest mass $\sim10^9$ g per von Neumann machine they will consume $10^9\,2^r$ g in $r$ generations. If $r\sim150$, this is $\sim10^{54}$ g $\gg$ the mass of any known galaxy. The conversion will take $<1{\cdot}5\times10^6$ yr. These considerations apply equally to other galaxies, none of which appears to have been converted into von Neumann machines. Thus we can derive a still stronger consequence from these dubious arguments than Tipler does: if there is anywhere an intelligence more advanced than ours, then substantial volumes of the Universe will have been fundamentally reworked, in apparent contradiction to observation. It follows that ours is the most advanced civilization not merely in our Galaxy, but in the cosmos; of all the $\sim10^{23}$ planets which are implicit in Tipler's arguments, and in the $\sim$ 15 billion year history of the Universe, ours is the only world on which an advanced technology has evolved. This naturally raises a question. Considering the history of solipsist argument, which is more likely: that in a 15 billion-year-old contest with $10^{23}$ entrants, we happen, by accident, to be first or that there is some flaw in Tipler's argument?

Let us for the moment set aside any doubts about whether von Neumann machines of the sort Tipler describes are technologically feasible or will have their development supported by any advanced society. Either there are entirely reliable restraints on their rates and sites of replication, or there are not. In the former case, our Solar System may have been intentionally bypassed because of the evolution of intelligence here, or for many other possible reasons, and the problem Tipler poses vanishes. In the latter case, these implacable replicators will not stop until the entire Universe has been converted into $\sim10^{47}$ von Neumann machines, which then presumably cannibalize each other. If anything like this were a real danger, an emerging interstellar civilization would be wise, as a matter of self-preservation, to take steps to prevent it. No civilization could be sure of the ultimate fidelity over $> 10^6$ yr of the self-replication programs of the von Neumann machines, and whether they ultimately might pose as grave a threat to the planets of their builders as to any other world. Tipler's assurance that the problem is comparable to, and as easily remedied as, that posed by recombinant DNA is unconvincing. In our problem there is no host specificity: the von Neumann machines are imagined able to enter any random planetary system and set about reproducing themselves in less than the transit time. Thus, the prudent policy of any technical civilization must be, with very high reliability, to prevent the construction of interstellar von Neumann machines and to circumscribe severely their domestic use. If we accept Tipler's arguments, the entire Universe is endangered by such an invention; controlling and destroying interstellar von Neumann machines is then something to which every civilization – especially the most advanced – would be likely to devote some attention. If the first galactic civilizations were not so careless as to have overlooked the cosmic danger that Tipler has called to our attention, it seems that we can safely dismiss the spectre of exponentiating machines that eat stars and worlds, and consider what other principles with some claim to universality might explain the apparent absence of extraterrestrials on Earth.

Thus, we return to the more 'conventional' scenarios of biological and mechanical beings, replicating together, slowly expanding in an irregular propagation wavefront to explore and possibly colonize other worlds, a circumstance we have discussed in some detail elsewhere (Newman & Sagan 1981, henceforth, Paper I). In order to model galactic colonization, it is convenient to develop a colonization strategy that is applicable generally and in which differences in strategy are described through choices of numerical parameters. Once such a formulation is complete, mathematical techniques can be employed to transform this microscopic description into a macroscopic one describing colonization on a galactic scale. The search strategy we employ in Paper I is characterized by three assumptions that we believe to be plausible:

(1) colonization ventures are more likely to be launched from worlds with substantial populations, rather than from fledgling, newly established colonies;

(2) colonies are more likely to be established on unpopulated or sparsely populated worlds than on well-developed, pre-existing colonies or planets with advanced indigenous organisms; and

(3) colonization drives will be mounted towards the nearest available colonization sites, not toward very remote worlds which would be rendered less attractive by economic constraints and by motivational questions.

Taken together with a population dynamic representation for *in situ* population growth and saturation, we constructed a mathematical description of this colonization strategy. Jones (1978) earlier developed a Monte Carlo computer code for such a colonization strategy. Our treatment is a rigorous analytic description of the problem, applicable to a very wide range of parameter selections, that reproduces Jones' results for his choice of parameters. Our preferred parameterization employs numerical values consistent with long-term human history, while, in our opinion, Jones' preferred values invoke atypically high values of the population growth and emigration rates. We discuss this point further below. On a microscopic level, our strategy corresponds to a Markov process. When the emigration time-scale is long relative to the *e*-folding time for population growth, the mathematical description must be retained in discrete form – as was the case for some of our models and for all of Jones'. But when the emigration time-scale is short relative to the population growth time, the description can be reduced to a non-linear partial differential equation – as was the case for another subset of our models. Both cases represent a directed form of Brownian motion on a microscopic scale, and to non-linear diffusion on a macroscopic scale. We refer to these two cases of our multiplicative diffusion model as the discrete and continuous limits, respectively. There are important differences that render the behaviour of our model very different from the usual attributes of a diffusive process.

Some readers of our paper (e.g. Tang 1982) have assumed, despite our lengthy elaboration of the differences between linear and non-linear diffusion models, that our results are prone to the anomalies inherent in the former. Since the model incorporates an increased likelihood of a colony being launched from a well-populated world to an unpopulated one, the propagation is directed away from population centres to virgin worlds (a mechanism called 'directed motion' by Gurney & Nisbet 1975 in application to comparable terrestrial biological problems). The directivity imparted by the model into the emergent population flow produces a *nonrandom dispersal.* Spatial and temporal variability in the habitability of worlds emerges in the form of strong fluctuations in the effective diffusion coefficient and provides for substantial *anisotropy* in the resulting distribution of colonies. Our model, therefore, describes all but the mathematically most catastrophic situations, and different colonization scenarios are reduced to the selection of numerical parameters.

Tipler claims that our mathematical development, although appropriate to animal populations, is inappropriate to humans. He guesses that the colonization of North America proceeded at a velocity, $v \cong 6$ miles yr$^{-1}$. The corresponding step size, $\Delta x$, scales as

$$\Delta x = v(t_{\mathrm{travel}} + t_{\mathrm{growth}}) \qquad (1)$$

(*cf.* equation 71, Paper I). Here $t_{\mathrm{travel}}$ is a measure of the travel time from a settlement to a new colonization site, a matter of only a few decades at $v \sim 0{\cdot}1\,c$. On the other hand, $t_{\mathrm{growth}}$ is a measure of the time-scale for population increase due to the combined influence of natural population growth (i.e. the excess of births over deaths) and of immigration. (Since $t_{\mathrm{growth}} \gg t_{\mathrm{travel}}$, we can safely ignore the latter.) Much of our paper (including the appendix) dealt with the computational details of establishing $t_{\mathrm{growth}}$ from the associated population growth rate $\gamma$ and the specific emigration rate $\psi$. In assessing probable values of $\gamma$ and $\psi$ for interstellar colonization, we examined the historical record. The values we chose corresponded to colonization as a means of exploration, as an outlet for national or religious zeal, as a tool for plunder, but not as a means of relieving the burdens posed by excess population in the source nation. The remarkable early growth in the population of the United States was the direct consequence of the overwhelming number of exiles who came to America seeking relief from an overcrowded, chaotic and hungry Europe following the Industrial Revolution. Our interstellar choices for $\gamma$ and $\psi$ do not describe and were not meant to describe this mass exodus. Our objective was to select values of $\gamma$ and $\psi$ appropriate to the age of exploration on Earth and, by inference, to the colonization of the stars.

Adopting numerical values for $\psi$ and $\gamma$ appropriate to the age of exploration prior to the demographic transition, and with his assumed value $v = 6$ miles yr$^{-1}$, Tipler obtains a time-scale $\sim$ 1000 yr, and $\Delta x \sim 10\,000$ miles, which he describes, correctly, as 'ridiculous'. But this value of $t_{\text{growth}}$ is inappropriate to post-1750 America (as we have seen) and the value of $v$ chosen, although quite reasonable after the American Revolution, is a tremendous overestimate for the United States prior to 1750. If $v \sim 6$ miles yr$^{-1}$ were appropriate during the preceding 250 years, a coastal strip of depth $250 \times 6 = 1500$ miles would have been inhabited at or near the population saturation density. In contrast, the original 13 colonies, occupying a very narrow coastal strip, had a population under two million in 1750 (McEvedy & Jones 1978). Tipler's attempt to demonstrate a *reductio ad absurdum* in our non-linear diffusion model fails.

A more nearly correct determination of $\Delta x$ can be accomplished by the use of appropriate parameters. We consider post-1750 America and compare it with Ireland around 1850. With the dramatic decline in the death rate precipitated by advances in public health and nutrition, the population growth rate in Ireland had risen to 0·01 yr$^{-1}$ (Davis 1974). The Irish potato blight of the 1840s caused widespread famine and produced a flood of immigrants to the US. Indeed, $\psi$ actually exceeded $\gamma$, and the overall population of Ireland experienced a continuous decline (although it was the only European country to do so). The natural population growth rate $\gamma$ of eighteenth century America was 0·03 yr$^{-1}$ (McEvedy & Jones 1978). As this unprecedented growth diminished in the early nineteenth century, the slack was taken up by the exodus from Ireland and elsewhere. As a consequence, the growth of America's population due to a combination of natural growth and immigration continued at the phenomenal rate of 0·03 yr$^{-1}$ until this century, when it declined by a factor of 2. An aggregate population growth rate for the period 1700 to 1950 is slightly in excess of 0·02 yr$^{-1}$, implying a value for $t_{\text{growth}}$ of $\lesssim$ 50 yr. The corresponding value of $\Delta x$, a measure of the width of the colonization front in our multiplicative diffusion model, is therefore $\sim$ 6 miles yr$^{-1}$/0·02 yr$^{-1}$ = 300 miles. It is not coincidental that this length scale is of the same order as the distance between major population centres in the continental United States.

Finally, Tipler indicates (without explanation) his dissatisfaction with our choice of what he calls $t_{\text{const}}$ (the time-scale for a new colony to become sufficiently large to support a colonization venture of its own). This time-scale, as explained in Paper I, scales as

$$t_{\text{const}} \sim (\ln \alpha)/\gamma \tag{2}$$

where $\alpha$ is the ratio of the population at the time of launching a new colony of generation $n+1$ to the population of the source colony of generation $n$. (Implicitly, this expression assumes exponential population growth at a rate $\gamma$.) Since the logarithmic factor is $\cong 10$, our disagreement focuses on the choice of $\gamma$. We prefer $\gamma \sim 6\times 10^{-4}\ \mathrm{yr}^{-1}$, a value that describes the growth of the human population since the dawn of civilization to the middle of the eighteenth century; it corresponds to $t_{\mathrm{const}} \sim 2\times 10^4$ yr (not $10^5$ yr as Tipler claims). Tipler would prefer to use a substantially higher value for $\gamma$, perhaps one more representative of the recent global growth rate of $0{\cdot}02\ \mathrm{yr}^{-1}$ (which demographers regard as aberrational). We have pointed out that at that level of fecundity, a hypothetical Adam and Eve could populate an Earth-like planet to its carrying capacity in a little over 1000 yr. Historical precedent argues strongly for much lower values of $\gamma$.

For our values of $\gamma$ and $\psi$, it follows (equation 84, Paper I) that the time for a colonization wave to cross the Galaxy, allowing for discretization ($\bar{\nu} \sim 30$) in the solution to our equations, is $7{\cdot}5\times 10^8$ yr; or, with no allowance for discretization ($\bar{\nu} \sim 2$), $\sim 10^{10}$ yr. (We stress again that spacecraft velocities have little bearing on the solution to this problem.) The times would be several orders of magnitude longer if the colonizing societies adopted zero population growth. The galaxy-crossing time is proportional to $(\psi\gamma)^{-1/2}$, so our results are not very sensitive to the values of growth and emigration rates. It might be argued that the values of $\psi$ chosen are improbably *large*. In this case the galaxy-crossing time will be longer still. But it is difficult to be certain about what progress in interstellar spaceflight will be exhibited by civilizations a million years, say, in our technological future. Even with the numbers selected, the galaxy-crossing times calculated with and without discretization correspond, respectively, to three galactic rotations and to the age of the Milky Way Galaxy itself. We believe that these are the most likely values of the time-scale required, in the absence of impediments from other civilizations, to populate every habitable world and to establish a full galactic empire.

For convenience, we refer to our value for the galaxy-crossing time as 'one billion years'. The establishment of galactic hegemony requires a perseverance to the task for a period of a billion years. The steadfastness of such a commitment seems remarkable. Given a doubling time of some technological figure of merit of, say, 30 yr – a rough index for the present epoch – the technology will advance in a thousand years by a factor of $10^9$. With modest allowances for the nature of the technological advance in a thousand years – much less a billion – we can well imagine much more exciting and fulfilling objectives for an advanced civilization than strip-mining or colonizing every planet in sight. One of us proposed many years ago (Sagan 1973) that civilizations only a thousand years in our technological future become disinterested even in communicating with civilizations as backward as ours. A society thousands or millions of years more advanced than we are, beneficiaries of an exponentiating technology over all those intervening millenia, will not be engaged in a simple extrapolation of our activities, or be driven by our motives. It seems to us quite unlikely that an advanced technological civilization, undergoing continued biological and psychological as well as scientific development, will persevere in such imperialist designs for a billion years. Some hint of the possible concerns and enterprises of a very advanced society have recently been mentioned by Frautschi (1982). The idea that there will be no new and more compelling challenges for such civilizations than relentless galactic colonization represents a serious failure of the imagination – although it is a natural enough notion were we to extrapolate carelessly from recent human history.

But the colonization of our region of the Galaxy does not require that every advanced galactic civilization colonizes; only that one does. If there are abundant civilizations in the Galaxy, their absence on Earth requires a principle of universality so compelling as to admit essentially no exceptions. It is possible that the enormously greater challenges that are likely to be uncovered by an advanced technological civilization in less than the galaxy-crossing time provide a sufficient principle of universality. But there are a number of other candidate principles summarized in Paper I, one of which we wish to stress: the intrinsic instability of societies devoted to an aggressive galactic imperialism. (A culture that gave a wide berth to planetary systems in which life is evolving would, of course, pose no contradictions to the apparent absence of extraterrestrials in the Solar System; such a civilization could have occupied all the remaining planetary systems in our spiral arm and we would be none the wiser.) We need not speculate on the nature of future societies or extrapolate into the indefinite future in order to see why such societies might be self-limiting. We need only look around us. Since 1945 there has been a steep and monotonic increase in the number of nuclear weapons and the efficacy of their delivery systems. The present global arsenal of some 50 000 nuclear weapons of all types and more than 17 000 targeted strategic weapons (Sivard 1982) is more than adequate to destroy our technical civilization and perhaps (although this is not essential to our argument), through synergistic effects, to destroy our species as well. There are at present at least six nations possessing nuclear weapons and their delivery systems and three or four commonly mentioned additional candidate states. Because of the widespread availability of weapons-grade fissionable materials and increasing world-wide competence in the relevant technology, the number of nations with nuclear weapons should increase sharply in the next few decades, if no new and major precautionary steps are taken. It is widely speculated that it is only a matter of time before small groups acquire nuclear weapons; and, we suppose, only a few decades later before individuals of great wealth and power can, if they so choose, be 'armed' with nuclear weapons. These circumstances are generally recognized as unstable.

We may, of course, destroy ourselves. Alternatively, it is possible that we will make fundamental changes in the way we manage the planet, in the way we organize our society, in what passes for conventional political, economic, social and ethical judgements so as to ensure *with extremely high reliability* that nuclear weapons do not pose a significant threat to the human species. The suggestion that such fundamental changes can be instituted is often considered 'Utopian', and different people have different estimates of how difficult it would really be – given the alternative – to make such changes. In a widely quoted remark, Einstein said that the advent of nuclear weapons has changed everything except our way of thinking, when it is precisely our way of thinking that must change if we are to survive nuclear weapons. It seems very plausible that, if we do not change our way of thinking, the lifetime of our technical civilization will be short.

If every civilization that invents weapons of mass destruction must deal with comparable problems, then we have an additional principle of universal applicability. Weapons of mass destruction force upon every emerging society a behavioural discontinuity: if they were not aggressive they probably would not have developed such weapons; if they do not quickly learn how to control that aggression they rapidly self-destruct. Those civilizations devoted to territoriality and aggression and violent settlement of disputes do not long survive after the development of apocalyptic weapons. Long before they are able to make any significant colonization of the Milky Way they are gone from the galactic stage. Civilizations that do not self-destruct are pre-adapted to live with other groups in mutual respect. This adaptation must apply not only to the average state or individual, but, with very high precision, to every state and every individual within the civilization. Because we are so newly faced with this difficult alternative, because we can so easily feel our own predispositions to territoriality and aggression, and because our culture provides so little encouragement to a planetary perspective, such an alternative organization, especially for a highly technological society, might seem to us at first unlikely. The required changes might take thousands of years or more, if the society does not destroy itself first. They might involve major new departures in rearing the young, in education, in the structuring of adult society, or even in prosthetic or biological intervention. Perhaps – although we consider this unlikely – very few societies succeed in such a programme. In any case, the result is that the only societies long-lived enough to perform significant colonization of the Galaxy are precisely those least likely to engage in aggressive galactic imperialism.

We think it possible that the Milky Way Galaxy is teeming with civilizations as far beyond our level of advance as we are beyond the ants, and paying us about as much attention as we pay to the ants. Some subset of moderately advanced civilizations may be engaged in the exploration and colonization of other planetary systems; however, their mere existence makes it highly likely that their intentions are benign and their sensitivities about societies at our level of technological adolescence delicate. This self-sorting of the civilizations in the Galaxy necessarily operates on time-scales $\gg 10^9$ yr. Thus, any interstellar civilization with a lifetime approaching the galaxy-crossing time will have long before selected itself away from aggressive designs. We believe that the apparent difficulties posed by the 'Where are they?' question derive partly from a conceptual model of interstellar colonization that is in poor accord with long-term human history, and that ignores the differences between the exploration of the Earth and the exploration of the Galaxy; and partly from an inappropriate and self-contradictory application of recent human history to the circumstances which prevail after the invention of weapons of mass destruction.

Since Tipler refers repeatedly to *Intelligent Life in the Universe*, perhaps we may be excused for quoting a passage from it:

> 'Finding life beyond the Earth – particularly intelligent life . . . – wrenches at our secret hope that Man is the pinnacle of creation, a contention which no other species on our planet can now challenge . . . The discovery of life on some other world will, among many things, be for us a humbling experience . . . In assessing evidence for extraterrestrial life, and in evaluating statistical estimates of the likelihood of extraterrestrial intelligence, we may be at the mercy of our prejudices. At the present time, there is no unambiguous evidence for even simple varieties of extraterrestrial life, although the situation may change in the coming years. There are unconscious factors operating, in the present arguments of both proponents and opponents of extraterrestrial life.'

(Shklovskii & Sagan 1966, p. 22). This is an issue of some importance. Many people have an emotional investment in the outcome. The question touches on religious and political matters where predispositions have traditionally played important rôles. But it is abundantly clear from the history of science that no convincing resolution of this issue is likely to come from protracted debates carried on with great passion and sparse data. We have an alternative denied to the medieval scholastics: we are able to experiment. We can organize a scientifically rigorous systematic search for extraterrestrial intelligence using the technology of modern radioastronomy. That is where the energies should be focused of those concerned with the great issue of the existence of other technical civilizations in the cosmos.

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