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Extraterrestrial Intelligent Beings do not Exist*

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SUMMARY

It is argued that if extraterrestrial intelligent beings exist, then their spaceships must already be present in our solar system.

I INTRODUCTION TO THE ARGUMENT

One of the most interesting scientific questions is whether or not extraterrestrial intelligent beings exist. This question is not new; in one form or another it has been debated for thousands of years (1). The contemporary advocates for the existence of such beings seem to be primarily astronomers and physicists, such as Sagan (2), Drake (3), and Morrison (4), while most leading experts in evolutionary biology, such as Dobzhansky (5), Simpson (6), Francois (7), Ayala *et al.* (8) and Mayr (9), contend that the Earth is probably unique in harbouring intelligence, at least amongst the planets of our Galaxy. The biologists argue that the number of evolutionary pathways leading from one-celled organisms to intelligent beings is minuscule when compared with the total number of evolutionary pathways, and thus even if we grant the existence of life on 10^9 to 10^{10} planets in our Galaxy, the probability that intelligence has arisen in our Galaxy on any planet but our own is still very small. I agree with the biologists; I shall argue in this paper that the probability of the evolution of creatures with the technological capability of interstellar communication within five billion years after the development of life on an Earth-like planet is less than 10^{-10}, and thus we are the only intelligent species now existing in this Galaxy. The basic idea of my argument is straightforward and indeed has led other authors, such as Fermi (10), Dyson (11), Hart (12), Simpson (6), and Kuiper & Morris (13), to conclude that extraterrestrial intelligent beings do not exist: if they did exist and possessed the technology for interstellar communication, they would also have developed interstellar travel and thus would already be present in our solar system. Since they are not here (14,15), it follows that they do not exist. Although this argument has been expressed before, its force does not seem to have been appreciated. I shall try to rectify this situation by showing that an intelligent species with the technology for interstellar communication would necessarily develop the technology for interstellar travel, and this would automatically lead to the exploration and/or colonization of the Galaxy in less than 300 million years.

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To begin with, we must assume that any intelligent species which develops the technology for interstellar communication must also have (or will develop in a few centuries) technology which is at least comparable to our present-day technology in other fields, particularly rocketry. This is actually a consequence of the principle of mediocrity (**16**) (that our own evolution is typical), which is usually invoked in analyses of interstellar communication. However, this assumption is also an essential one to make if interstellar communication via radio is to be regarded as likely. If we do not assume that an advanced species knows at least what we know, then we have no reason to believe an advanced species would use radio waves, for they may never have discovered such things. In the case of rocket technology, the human species developed rockets some 600 years before it was even aware of the existence of radio waves, and present-day chemical rockets can be regarded as logical extensions of early rocket technology.

In addition to a rocket technology comparable to our own, it seems likely that a species engaging in interstellar communication would possess a fairly sophisticated computer technology. In fact, Sagan has asserted (**17**) that 'Communication with extraterrestrial intelligence . . . will require . . . , if our experience in radio astronomy is any guide, computer-actuated machines with abilities approaching what we might call intelligence'. Furthermore, the Cyclops (**18**) and SETI (**19**) proposals for radio telescopes to search for artificial extraterrestrial radio signals have required some fairly advanced data-processing equipment. I shall therefore assume that any species engaging in interstellar communication will have a computer technology which is not only comparable to our present-day technology, but which is comparable to the level of technology which we know is possible, which we are now spending billions of dollars a year to develop, and which a majority of computer experts believe we will actually possess within a century. That is, I shall assume that such a species will eventually develop a self-replicating universal constructor with intelligence comparable to the human level – such a machine should be developed within a century, according to the experts (**20,21,22**) – and such a machine combined with present-day rocket technology would make it possible to explore and/or colonize the Galaxy in less than 300 million years, for an initial investment less than the cost of operating a 10 MW microwave beacon for several hundred years, as proposed in SETI (**19**). It is a deficiency in computer technology, not rocket technology, which prevents us from beginning the exploration of the Galaxy tomorrow.

2 THE GENERAL THEORY OF SPACE EXPLORATION AND COLONIZATION

In space exploration (or colonization), one chooses a strategy which maximizes the probable rate of information gained (or regions colonized) and minimizes the cost of the information, subject to the constraints imposed by the level of technology. Costs may be minimized in two ways: first, 'off-the-shelf' technology is to be used as far as possible to reduce the research research and development costs; second, resources which could be used for no other purpose should be utilized as far as possible. The resources available in uninhabited stellar systems cannot be utilized for any human purpose unless a space vehicle is first sent; therefore, any optimal exploration strategy must utilize the material available in the other stellar system as far as possible. With present-day technology, such utilization could not be very extensive, but with the level of computer technology assumed in the previous section, these otherwise useless resources can be made to pay for virtually the entire cost of the exploration program.

What one needs is a self-reproducing universal constructor, which is a machine capable of making any device, given the construction materials and a construction program. In particular, it is capable of making a copy of itself. Von Neumann has shown (**23,24**) that such a machine is theoretically possible, and in fact a human being is a universal constructor specialized to perform on the surface of the Earth. (Thus the manned space exploration [and colonization] program outlined in (**11,12,13**) is just a special case of the exploration strategy discussed below.)

The payload of a probe to another stellar system would be a self-reproducing universal constructor with human level intelligence (hereafter called a von Neumann machine) together with an engine for slowing down once the other stellar system is reached, and an engine for travelling from one place to another within the target stellar system – the latter could be an electric propulsion system (**25**), or a solar sail (**26**). This machine would be instructed to search out construction material with which to make several copies of itself and the original probe rocket engines. Judging from observations of our own solar system (**27**), what observations we have of other stellar systems (**28**), and the vast majority of contemporary solar system formation theories (**29**), such materials should be readily available in virtually any stellar system – including binary star systems – in the form of meteors, asteroids, comets, and other débris from the formation of the stellar system. Whatever elements are necessary to reproduce the von Neumann machine, they should be available from one source or another. For example, the material in the asteroids is highly differentiated; many asteroids are largely nickel-iron, while others contain large amounts of hydrocarbons (**27**).

As the copies of the space probe were made, they would be launched at the stars nearest the target star. When these probes reached these stars, the process would be repeated, and so on until the probes had covered all the stars of the Galaxy. Once a sufficient number of copies had been made, the von Neumann machine would be programmed to explore the stellar system in which it finds itself, and relay the information gained back to the original solar system from which the exploration began. In addition, the von Neumann machine could be programmed to use the resources of the stellar system to conduct scientific research which would be too expensive to conduct in the original solar system.

It would also be possible to use the von Neumann machine to colonize the stellar system. Even if there were no planets in the stellar system – the system could be a binary star system with asteroid-like débris – the von Neumann machine could be programmed to turn some of this material into an O'Neill colony (**30**). As to getting the inhabitants for the colony, it should be recalled that all the information needed to manufacture a human being is contained in the genes of a single human cell. Thus if an extraterrestrial intelligent species possessed the knowledge to synthesize a living cell – and some experts assert (**31,32**) the human race could develop such knowledge within 30 years – they could program a von Neumann machine to synthesize a fertilized egg cell of their species. If they also possessed artificial womb technology – and such technology is in the beginning stages of being developed on Earth (**33**) – then they could program the von Neumann machine to synthesize members of their species in the other stellar system. As suggested by Eiseley (**34**), these beings could be raised to adulthood by robots in the O'Neill colony, after which they would be free to develop their own civilization in the other stellar system.

Suggestions have occasionally been made (**35**) that other solar systems could be colonized by sending frozen cells via space probes to the stars. However, it has not yet been shown (**36–39**) that such cells would remain viable over the long periods required to cross interstellar distances. This difficulty does not exist in the above-outlined colonization strategy; the computer memory of the von Neumann machine can be made so that it is essentially stable over long periods of time. If it is felt that the information required to synthesize an egg cell would tax the memory storage space of the original space probe, the information could be transmitted via microwave to the von Neumann machine once it has had time to construct additional storage capacity in the other solar system. The key point is that once a von Neumann machine has been sent to another solar system, the entire resources of that solar system become available to the intelligent species which controls the von Neumann machine; all sorts of otherwise-too-expensive projects become possible. It would even be possible to program the von Neumann machine to construct a very powerful radio beacon with which to signal other intelligent species!

Thus the problem of interstellar travel has been reduced to the problem of transporting a von Neumann machine to another stellar system. This can be done even with present-day rocket technology. For example, Hunter (**40,41**) has pointed out that by using a Jupiter swingby to approach the Sun and then giving a velocity boost at perihelion, a solar system escape velocity v_{es} of about 90 km s^{-1} ($\sim 3 \times 10^{-4}$c) is possible with present-day chemical rockets, even assuming the launch is made from the surface of the Earth. As discussed in references (**28**) and (**29**), most other stars should have planets (or companion stars) with characteristics sufficiently close to those of the Jupiter–Sun system to use this launch strategy in reverse to slow down in the other solar system. The mass ratio μ (the ratio of the payload mass to the initial launch mass) for the initial acceleration would be 10^3, so the total trip would require $\mu < 10^6$ (less than, since the 10^3 number assumed an Earth-surface launch), quite high, but still feasible. With Jupiter swingby only, the escape velocity would be $\sim 1{\cdot}5 \times 10^{-4}$c with $\mu = 10^3$. The *Voyager* spacecraft will have (**42**) a solar escape velocity of about $0{\cdot}6 \times 10^{-4}$c with $\mu = 850$.

It thus seems reasonable to assume that any intelligent species would develop at least the rocket technology capable of a one-way trip with deceleration at the other stellar system, and with a travel velocity v_{es} of 3×10^{-4}c.

At this velocity the travel time to the nearest stars would be between 10^4 and 10^5 years. This long travel time would necessitate a highly developed self-repair capacity, but this should be possible with the level of computer technology assumed for the payload (43). Nuclear power-sources could be developed which would supply power for that length of time. However, nuclear power is not really necessary. If power utilization during the free-fall period was very low, even chemical reactions could be used to supply the power. As v_{es} is of the same order as the stellar random motion velocities, very sensitive guidance would be required, but this does not seem to be an insuperable problem with the assumed level of computer technology.

Because of the very long travel times, it is often argued (44) that interstellar probes would be obsolete before they arrived. However, in a fundamental sense a von Neumann machine cannot become obsolete. The von Neumann machine can be instructed by radio to make the latest devices after it arrives at the destination star.

Restricting consideration to present-day rocket technology is probably too conservative. It is likely that an advanced intelligent species would eventually develop rocket technology at least to the limit which we regard as technically feasible today. For example, the nuclear pulse rocket of the Orion Project pictured (45) a solar escape velocity v_{es} of 3×10^{-2}c with $\mu = 36$ for a one-way trip and deceleration at the target star. The cost of the probe would be \$$3 \times 10^{12}$ in 1979 prices, almost all of the money being for the deuterium fuel. This is about the present GNP of the United States. Project Daedalus (43), the interstellar probe study of the British Interplanetary Society, envisaged a stellar fly-by via nuclear pulse rocket (no slow-down at the target star), with $v_{es} = 1{\cdot}6 \times 10^{-1}$c, $\mu = 150$, and a cost of \$$9 \times 10^{11}$. As before, almost all the cost is for the helium-3 fuel (at 1960 prices). With slow-down at the target star, $\mu = 2 \times 10^4$, the cost would be \$$1{\cdot}4 \times 10^{14}$, or almost 100 times the United States GNP, and it would require centuries to extract the necessary helium-3 from the helium source in the Daedalus study, the Jovian atmosphere.

The cost of such probes is far beyond present-day civilization. However, note that almost all the cost is for the rocket fuel. Building the probe itself and testing it would cost relatively little. A possible interstellar exploration strategy would be to design a probe capable of $v_{es} = 0{\cdot}1$ c, record the construction details in a von Neumann machine, launch the machine via a chemical rocket at 3×10^{-4}c to a nearby stellar system, and program the machine to construct and *fuel* several high velocity (0·1 c) probes with von Neumann payloads in the other system. When these probes reach their target stars, they would be programmed to build high velocity probes, and so on. In this way the investment on interstellar probes by the intelligent species is reduced to a minimum while maximizing the rate at which the Galaxy is explored. (The von Neumann machines could conceivably be programmed to develop the necessary technology in the other system. This would reduce the initial investment even further.) The disadvantage, of course, is the fact that for 10^4 years, there is no information on other stellar systems reaching the original solar system. There is a trade-off between the cost of the first probe and the time interval the intelligent species must wait before receiving any information on other stellar systems. But with second generation probes with $v_{es} = 0{\cdot}1$ c, new solar systems could be explored at the rate of several per year by 10^5 years after the original launch. The intelligent species need only be patient and launch a sufficient number of initial probes at $v_{es} = 3 \times 10^{-4}$c so that at least one succeeds in reproducing itself (or in making a high velocity probe) several times. This number will depend on the failure rate. Project Daedalus (43) aimed at a mission failure rate of 10^{-4}, and the designers argued that such a failure rate was feasible with on-board repair. If we adopt this failure rate and assume failures to be statistically independent, then only three probes need be launched to reduce the failure probability to 10^{-12}. Judging by contemporary rocket technology, the cost of the initial low velocity probes would be less than $\$1 \times 10^9$ each, since von Neumann probes would make themselves and the original R & D costs would be small – von Neumann machines would originally be developed for other purposes (46). Thus the exploration of the Galaxy would cost about 3 billion dollars, about one-tenth the cost of the *Apollo* program.

To maximize the speed of exploration and/or colonization, one must minimize $[d_{av}/v_{es}) + t_{const}]$, where d_{av} is the average distance between stars and t_{const} is the time needed for the von Neumann machine to reproduce itself and the space probe. The time t_{const} will be much larger for $v_{es} = 0{\cdot}1$ c probes than for 10^{-4}c probes. I would guess the minimum to be obtained for $v_{es} = 5 \times 10^{-2}$c and $t_{const} = 100$ years. With $d_{av} = 5$ light years, this gives a rate of expansion of $2{\cdot}5 \times 10^{-2}$ly/yr, and thus the Galaxy could be explored in 4 million years. For the purposes of this article I shall assume only present-day rocket technology, which would give an expansion rate of 3×10^{-4}ly/yr, and the exploration of the Galaxy in 3×10^8 years (with $t_{const} < 10^3$ yr).

Once the exploration and/or colonization of the Galaxy has begun, it can be modelled quite closely by the mathematical theory of island colonization – a theory developed fairly extensively by MacArthur & Wilson (47,48) – since the islands in the ocean are closely analogous to stars in the heaven, and the von Neumann machines are even more closely analogous to biological species. There are several general conclusions applicable to interstellar exploration and/or colonization which follow from this theory. First, there are two basic behavioural strategies, the *r*-strategy and the *K*-strategy, which would be adopted in different phases of the colonization. Here is the net reproductive rate, and *K* is the carrying capacity of the environment. The *r*-strategy is one of rapid reproduction at the expense of all else, and it would be followed in the early stages of the colonization, while the *K*-strategy has a much smaller *r* and emphasis on securing the ecological niche in the target stellar system. The *K*-strategy would be adopted after the solar system had been colonized for some time, and would result in fewer probes being sent to other stars. In the past few centuries Western society has been an *r*-strategist, but as the carrying capacity of the environment is approached, it is beginning to adopt a *K*-strategy. Second, the MacArthur–Wilson theory suggests (49) that the fraction of probes reaching a distance *d* from the system of launch is $\sqrt{2/\pi}\,[\exp(-d^2/2)]/d$, which could result in an exploration rate of up to twice the value of $2{\cdot}5 \times 10^{-2}$ ly/yr with $v_{es} = 5 \times 10^{-2}$c probes.

3 ASTROPHYSICAL CONSTRAINTS ON THE EVOLUTION OF INTELLIGENT SPECIES

The probability that intelligent life which eventually attempts interstellar communication will evolve in a star system is usually expressed by the Drake equation:

$$p = f_p n_e f_l f_i f_c$$

where f_p is the probability that a given star system will have planets, n_e is the number of habitable planets in a solar system that has planets, f_l is the probability that life evolves on a habitable planet, f_i is the probability that intelligent life evolves on a planet with life, and f_c is the probability that an intelligent species will attempt interstellar communication within 5 billion years after the formation of the planet on which it evolved. The time limit in f_c is tacit in most discussions of extraterrestrial intelligence. Some time period of approximately 5 billion years must be assumed in order to use the Drake equation to estimate the number of existing civilizations. If for example f_c were a Gaussian distribution with maximum at $t = 30$ billion years and $\sigma = 1$ billion years, then we would be the only civilization in the galaxy. The probability estimates made below will hold if it is assumed that f_c is either sharply peaked at 5 billion years after planetary formation or a Gaussian distribution with $t_{\text{peak}} < 6$ billion years and $\sigma > 1$ billion years.

The problem with the Drake equation is that only f_p – and to a lesser degree n_e – is subject to experimental determination. In order to measure a probability with a high degree of confidence, one must have a fairly large sample; for f_l, f_i, and f_c we have only one obvious case, the Earth. However, if one accepts the argument of the previous sections that any intelligent species which attempts interstellar communication will begin the galactic exploration program outlined within 100 years after developing the technology for interstellar communication, then the sample size is enlarged to include all those stellar systems older than $t_{\text{age}} = 5$ billion years $+ t_{\text{ex}}$, where $t_{\text{ex}} \leqslant 300$ million years is the time needed to expand throughout the Galaxy. That is, the Drake probability p is less than or equal to $1/N$, where N is the number of stellar systems older than t_{age}, because all of these stars were, under the assumptions underlying the Drake equation, potential candidates to evolve communicating intelligent species, yet they failed to do so – had such species evolved on planets surrounding these stars within 5 billion years after star formation, their probes would already be present in the solar system, and these probes are not here (**14,15**). Since f_p and n_e can in principle be determined by direct astrophysical measurement, the fact that extraterrestrial intelligent beings are not present in our solar system permits us to obtain a direct astrophysical measurement of an upper bound to the product $f_l f_i f_c$, which depends only on biological and sociological factors.

This argument assumes that the five probabilities of the Drake equation do not vary rapidly with galactic age. The available astrophysical evidence and most theories of the formation of solar systems indicate that this assumption is valid. The formation of solar systems requires that the interstellar gas be sufficiently enriched by 'metals' (those elements heavier than helium). Most experts (**29,51–53**) agree that a substantial fraction of existing metals were formed in massive stars very early in galactic history – during the first 100 million years of the galaxy's existence – and the metal abundance has changed by at most a factor of about two since then. The evidence (**54,55**) gives a galactic age between 11 and 18 billion years, and it is generally assumed (**52**) that the rate of star formation has been decreasing exponentially ever since the initial burst of heavy element formation. Existing stellar formation theory is unable to decide definitely if the so-called initial mass function – the number of stars formed per unit time with masses between m and $m+\Delta m$ – changes with time after the initial burst of massive stars (**51**). Furthermore, it is not clear to what extent the earthlike planet formation rate depends on the metal abundance (**56,57**). However, the observational evidence (**51**) (such as it is) does not indicate a large variation of the initial mass function or the earthlike planet formation rate with time. I shall thus assume that these are roughly constant, and most discussions of extraterrestrial intelligence make the same assumption (**58,59**). The factors f_l, f_i, f_c should not depend strongly on the evolution of the Galaxy as a whole (see however (**60–62**), and so can be regarded as constants. Since the Galaxy is between 11 and 18 billion years old, the number N of stars older than 5·3 billion years is about twice the number of stars formed after the Sun, and thus is approximately equal to the number of stars in the Galaxy, 10^{11}. Thus $p \leqslant 10^{-11}$. If we accept the usual values of $f_p = 0{\cdot}1$ to 1 and $n_e = 1$ found in most discussions of interstellar communication (**2,18**), then $f_l f_i f_c \leqslant 10^{-10}$. The number of communicating civilizations now existing in our Galaxy is less than or equal to $p \times$ (number of stars in galaxy) $= 1$; that is to say, us.

This conclusion that we are the only technical civilization now existing in the Galaxy does not depend on any biological or sociological arguments except for the assumption that a communicating species would eventually begin interstellar travel; nor does it depend on f_p or n_e. It follows from just the interstellar travel assumption, the assumption that the galactic environment has not changed by more than a factor of five during the history of the Galaxy, and the fact (?) that extraterrestrial probes are not present in our solar system.

4 MOTIVATIONS FOR INTERSTELLAR COMMUNICATION AND EXPLORATION

It is difficult to construct a plausible scenario whereby an intelligent species develops and retains for centuries an interest in interstellar communication together with the technology to engage in it, and yet does not attempt interstellar travel. Even if we adopt the pessimistic point of view that all intelligent species cease communication efforts before developing von Neumann machines, either because of a loss of interest or because they blow themselves to bits in a nuclear war, the conclusion that we are the only intelligent species in the Galaxy with interest in interstellar communication is not changed. For in this case, the longevity L of a communicating civilization is less than or equal to 100 years (using our computer experts' opinions for the time needed to develop von Neumann machines), and since the Drake equation gives $n = R_* pL$ for the number of communicating civilizations in the galaxy, we obtain $n = 10$, even if we use Sagan's optimistic estimate[2] of $R_*p = 1/10$. (The number R_* is the average rate of star formation.) This value of n is essentially the same as $n \sim 1$ obtained in the previous section, and in any case such short-lived civilizations would on the average be too far apart and exist for too short a time to engage in interstellar communication. If $L \geqslant 100$ years so that the species has time to develop probe technology, the value of L is irrelevant to the calculation of the number p. Once the probes have been launched, they will explore the Galaxy automatically; the death of the civilization that launched them would not stop them. We are thus left with the possibility that for some reason, intelligent beings with the technology and desire for radio communication do not use the exploration strategy because they *choose* not to do so, not because they are incapable of developing the technology.

There is no good reason for believing this. Virtually any reason for engaging in interstellar radio communication provides an even stronger argument for the exploration of the Galaxy. For example, if the motivation for communication is to exchange information with another intelligent species, then as Bracewell (**63,64**) has pointed out, contact via space probe has several advantages over radio waves. One does not have to guess the frequency used by the other species, for instance. In fact, if the probe has a von Neumann machine payload, then the machine could construct an artifact in the solar system of the species to be contacted, an artifact so noticeable that it could not possibly be overlooked. If nothing else, the machine could construct a 'Drink Coca-Cola' sign a thousand miles across and put it in orbit around the planet of the other species. Once the existence of the probe has been noted by the species to be contacted, information exchange can begin in a variety of ways. Using a von Neumann machine as a payload obviates the main objection (**65**) to interstellar probes as a method of contact, namely the expense of putting a probe around each of an enormous number of stars. One need only construct a few probes, enough to make sure that at least one will succeed in making copies of itself in another solar system. Probes will then be sent to the other stars of the galaxy automatically, with no further expense to the original species.

Morrison has expressed the opinion (**4**): '. . . once there is really interstellar communication, it may be followed by a ceremonial interstellar voyage of some special kind, which will not be taken for the sake of the information gained, or the chances for trade . . . , but simply to be able to do it, for one special case, where there is a known destination. That's possible, one can imagine it being done – but it is very unlikely as a search procedure'. However, if it is granted that a *single* probe is launched, for *any* reason, then with a von Neumann machine payload, the same probe can be used to start the galactic expansion program outlined in Section 2. While *en route* to a solar system known to be inhabited, the probe could make a stop-over at a stellar system along the way, make several copies of itself, refuel and then proceed on its way (or send one of the copies to the inhabited system). If the inhabited system is farther than 100 light years, and if $v_{es} \leqslant 0{\cdot}1$ c and $t_{const} \leqslant 100$ years, then the time needed to reach the inhabited system is increased by less than 10 per cent, and one obtains the exploration and/or colonization of the entire Galaxy as a free bonus. Furthermore, because the inhabited system is so far away, *any* probe sent would have to be autonomous, which would mean a computer with a human-level intelligence, and capable of self-repair – which means that it would essentially be a von Neumann machine. Since its instrumentation makes *any* interstellar probe capable of galactic exploration, why not use it for that?

Consider the search strategy adopted by the *first* species interested in interstellar communication to arise in our Galaxy. Most likely it would be thousands or even millions of years before another such species arose. Even if another species arose simultaneously, the probability is only about 10^{-6} that it would be within 100 light years of the other species. Therefore, when the first species begins to signal, it will probably get no answer for thousands or millions of years. During this time it will be receiving no information on other stellar systems for its investment. If there remains strong interest in interstellar communication during this period, why should it not also launch a few probes? *Some* information on other systems would be guaranteed in 100 to 10^4 years, even if other intelligent beings are not discovered. Also, if there are other intelligent beings in the Galaxy, the von Neumann probes will eventually find them, even if they are intelligent beings who would never develop on their own an interest in interstellar communication. With radio waves and a null result, there is always the possibility that the wrong frequency has been chosen, that some other means than radio waves has been used by the other species, etc. There is no such problem with probes.

If human history is any guide, this first species will launch a probe rather than make radio beacons in the first place. In the early part of this century, when Lowell had convinced many that there were intelligent beings on Mars, but when interplanetary rocket probes were regarded as a ridiculous fantasy, the Harvard astronomer W.H.Pickering pointed out **(66)** that communication with these beings was possible with a mirror one-half square mile in area: '[it] would be dazzlingly conspicuous to Martian observers, if they were intellectually and physically our equals'. If we were content to use such a device to learn about Mars from these hypothetical Martians, we would still know little about Mars. Instead, we sent probes, and Sagan's recent proposals **(67)** for advanced Mars probes are robots with manipulative ability and a considerable degree of artificial intelligence – they are a step in the direction of a von Neumann machine.

If we assume that a behaviour pattern which is typical not only of *Homo sapiens* but also of all other living things on our planet would also be adopted by any intelligent species (to deny this would be to deny the assumption of mediocrity), then we would conclude that a sufficiently advanced intelligent species would launch von Neumann probes. All living things have a dispersal phase **(68)**, in which they tend to expand into new environments, for the dispersal behaviour pattern is obviously selected by natural selection. The expansion is generally carried out to the limit imposed by their genetic constitution. In intelligent species, this limit would be imposed by the level of technology **(69,70)**, and we would expect the dispersal behaviour pattern to be present in at least some groups of an intelligent species. We should therefore expect that at least some groups of the species would attempt an expansion into the galaxy, and the construction of only one successful von

Neumann probe would be sufficient for this. By launching such a probe and using it to colonize the stars, a species increases the probability that it will survive the death of its star, nuclear war, etc. Note that it need not take territory away from another species (intelligent or not) to accomplish this purpose. The species could, for example, restrict itself to the construction of O'Neill colonies around stars with no living things on their planets.

It is possible that an intelligent species which develops a level of technology capable of interstellar communication would decide not to build von Neumann machines because they would be afraid that they would lose control of the machines. Since no reproduction can be perfect, it is possible that the program which keeps the von Neumann probes under the control of the intelligent species could accidentally be omitted during the reproduction process, with the result that the copy goes into business for itself. This problem can be avoided in three ways. First, the program which keeps the probe under control can be so integrated with the total program that its omission would cause the probe to fail to work at all. This is analogous to the constraints imposed on the cells used in recombinant DNA technology. Second, the intelligent species could program the probes to form colonies of the intelligent species in the stellar system reached by the probes. These colonies would be able to destroy any probes which slipped out of control. Third, the intelligent species might not care if the von Neumann machines slipped out of control. After all, a von Neumann machine would be an intelligent being in its own right, an intelligent being made of metal rather than flesh and blood. The rise of human civilization has been marked by a decline in racism, and an extension of human rights – which include freedom – to a wider and wider class of people. If this trend continues and occurs in the cultures of all civilized beings, it seems likely that von Neumann machines would be recognized as fellow intelligent beings, beings which are the heirs to the civilization of the naturally evolved species that invented them, and with the right to the freedom possessed by the inventing species. If on the other hand, the intelligent species retained their racism, it seems likely that they would regard other 'flesh and blood' intelligent species as 'non-people'. If so, then they would either wish to avoid communication altogether (lest it 'pollute' their culture with alien ideas), or else launch von Neumann machines to either colonize the Galaxy for themselves (lest it be done by 'non-people' who would crowd them out) or to destroy these other intelligent species. For example, this colonization or destruction would be their best strategy if they believed that the biological 'exclusion principle', which says **(71,72)** two species cannot occupy the same ecological niche in the same territory, applies to intelligent species. With the advent of the O'Neill colony, the ecological niche occupied by an intelligent species would consist of the entire material resources of a solar system. The ecological niches of two intelligent species would have to overlap. In any case, the von Neumann probes would be launched. If a species was not afraid of alien ideas itself, but was reluctant to contaminate the culture of another species with its own culture, then it should not attempt radio contact. However, with probes it would be possible to study an alien species without it becoming aware of the species which was studying it.

A final possibility to be considered is what I have hitherto denied, namely that perhaps the von Neumann probes of an extraterrestrial intelligent species *are* present in our solar system. If a probe had just arrived, there would as yet be no evidence for its presence. The probability that a probe arrived for the first time within the past 20 years is 10^{-9} (= 20/[age of Galaxy]). Thus the probability that extraterrestrial intelligent beings exist but their probes have just arrived is actually greater than the calculated probability $f_l f_i f_c$ that they evolve. Another possibility would be that they are here but have decided for some reason not to make their presence known; this is the so-called zoo hypothesis (**73**). Kuiper and Morris (**13**) have proposed testing this hypothesis by attempting to intercept radio communications between beings in our solar system and the parent stars. Another possible test would be to search for the construction activities of a von Neumann machine in our solar system. For example, one could look for the waste heat from such activities. As Dyson has pointed out (**11,74**), this heat would give rise to an infrared excess, and the most likely place to look for a von Neumann probe would be the asteroid belt where material is most readily available. (It is amusing that infrared radiation of astronomical origin does come from the asteroid belt (**75**).) If such a von Neumann probe were present in the solar system and if a large number of mutually intercommunicating intelligent species existed who were interested in studying us, we would expect the von Neumann machine to construct members of each of these species, together with spaceships, one appropriate type for each of the species. We would thus expect to see a wide variety of species and spaceships on earth studying us (**76**). But no extraterrestrial ships of any type are seen (**14,15**). Furthermore, if intelligent beings existed, it is likely that their probes would have arrived a billion years ago when there was nothing on earth but one-celled organisms, and hence they would have no reason to hide their technology. The entire asteroid belt would be artifacts by now. Thus the evidence is enormous that extraterrestrial intelligent beings do not exist.

But the evidence is not utterly conclusive; beings with extremely advanced technology could be present in our solar system and make their presence undetectable should they wish to do so. The point is that a belief in the existence of extraterrestrial intelligent beings anywhere in the galaxy is not significantly different from the widespread belief that UFOs are extraterrestrial spaceships. In fact, I strongly suspect the psychological motivation of both beliefs to be the same, namely 'The expection that we are going to be saved from ourselves by some miraculous interstellar intervention . . . ' (quoted from (**77**), page 272).

As discussed in ref. (**1**), the belief in extraterrestrial intelligent beings is associated with a belief in the immensity of the Cosmos: if there is a huge number of habitable planets, is it plausible that there is only one inhabited planet? I would contend the answer is yet. Wheeler has argued (**78**) that if the Universe were much smaller than it is, it would terminate in a final singularity before intelligent life would have time to evolve. This is an example of an 'Anthropic Principle' argument. The Anthropic Principle (**79–81**) states that many aspects of the Universe are determined by the requirement that intelligent life exists in it. Thus the Universe must contain 10^{20} stars in order to contain a single intelligent species. We should not therefore be surprised if indeed it contains only one.

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