Implications of the Copernican principle for our future prospects

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Making only the assumption that you are a random intelligent observer, limits for the total longevity of our species of 0.2 million to 8 million years can be derived at the 95% confidence level. Further consideration indicates that we are unlikely to colonize the Galaxy, and that we are likely to have a higher population than the median for intelligent species.

THE Copernican revolution taught us that it was a mistake to assume, without sufficient reason, that we occupy a privileged position in the Universe. Darwin showed that, in terms of origin, we are not privileged above other species. Our position around an ordinary star in an ordinary galaxy in an ordinary supercluster continues to look less and less special. The idea that we are not located in a special spatial location has been crucial in cosmology, leading directly to the homogeneous and isotropic Friedmann cosmological models in general relativity theory which have been remarkably successful in predicting[1,2] the existence and spectrum of the cosmic microwave background radiation[3,4]. In astronomy, the Copernican principle works because, of all the places for intelligent observers to be, there are by definition only a few special places and many nonspecial places, so you are likely to be in a nonspecial place. This idea can be used to estimate the likely future longevities of various observables, including that of our own species. I will discuss its implications for the far future, for the Search for Extraterrestrial Intelligence (SETI) and for space travel.

Delta *t* argument

Assuming that whatever we are measuring can be observed only in the interval between times t_{begin} and t_{end}, if there is nothing special about t_{now} we expect t_{now} to be located randomly in this interval. The estimate $t_{\text{future}} = (t_{\text{end}} - t_{\text{now}}) = t_{\text{past}} = (t_{\text{now}} - t_{\text{begin}})$ will overestimate t_{future} half the time and will underestimate it half the time. If $r_1 = (t_{\text{now}} - t_{\text{begin}})/(t_{\text{end}} - t_{\text{begin}})$ is a random number uniformly distributed between 0 and 1, there is a probability $P = 0.95$ that $0.025 < r_1 < 0.975$, or equivalently

$$\tfrac{1}{39} t_{\text{past}} < t_{\text{future}} < 39 t_{\text{past}} \quad \text{(95\% confidence level)} \qquad (1)$$

Similarly,

$$\tfrac{1}{3} t_{\text{past}} < t_{\text{future}} < 3 t_{\text{past}} \quad \text{(50\% confidence level)} \qquad (2)$$

Equation (1) tells us that the length of time something has been observable in the past is a rough measure of its robustness not only against the calamities of the past, but also against whatever calamities may affect its observability in the future, because all that is required for equation (1) to work is that in the end *your* position as an observer turns out not to have been special. Just to illustrate, in 1969 I saw for the first time Stonehenge ($t_{\text{past}} \approx 3{,}868$ years) and the Berlin Wall ($t_{\text{past}} = 8$ years). Assuming that I am a random observer of the Wall, I expect to be located randomly in time between t_{begin} and t_{end} (t_{end} occurs when the Wall is destroyed or there are no longer any visitors left to observe it, whichever comes first). The Wall fell 20 years later giving $t_{\text{future}} = 2.5 t_{\text{past}}$, within the 95% confidence limits predicted by equation (1). Applying the ($P = 0.95$) delta t argument also correctly predicts that Stonehenge should still be observable today, 24 years later (as $t_{\text{future}} > 99$ years, from equation (1)). In 1977 I visited the U.S.S.R. ($t_{\text{past}} = 55$ years). Although at that time its existence into the indefinite future was generally assumed, it ended only 14 years later ($t_{\text{future}} = 0.25 t_{\text{past}}$, consistent with the limits in equation (1)). Equation (1) was satisfied not because my visit somehow caused the demise of the U.S.S.R. but simply because in hindsight we can now see that the timing of my visit was unremarkable. *Nature* has been published for 123 years; the delta t argument predicts ($P = 0.95$) its future publication will last more than 3.15 years but less than 4,800 years.

Our future longevity

Suppose, consistent with the findings of Carter[5], intelligent species are currently being formed in the Universe at a uniform rate. By 'intelligent' species we mean one that is self-conscious and has the cognitive abilities to reason abstractly, think about the future, create art and so forth. So far, on Earth, we, *homo sapiens*, are the only species to fit this description[6]. Assume that these intelligent species are subject to some unknown extinction rate λ_0. The distribution of ages t_p of the N_{total} intelligent species alive today is

$$N(t_p)\, dt_p = N_{\text{total}} \lambda_0 \exp(-\lambda_0 t_p)\, dt_p \qquad (3)$$

as only a fraction $f = \exp(-\lambda_0 t_p)$ of those species born at an epoch t_p ago survive today. Species alive today are subject to the extinction rate λ_0 so the number of these species becoming extinct as a function of time t_f in the future is

$$N(t_f)\, dt_f = N_{\text{total}} \lambda_0 \exp(-\lambda_0 t_f)\, dt_f \qquad (4)$$

Let r_1 and r_2 be independent random numbers each distributed uniformly over the interval [0, 1]. For a given species alive today

$$t_p = -(\lambda_0)^{-1} \ln r_1$$
$$t_f = -(\lambda_0)^{-1} \ln r_2 \qquad (5)$$
$$r_1^{(t_f/t_p)} = r_2$$

Let $Y > 0$ be a constant

$$P([t_f/t_p] > Y) = \int_0^1 r_1^Y\, dr_1 = 1/(Y+1) \qquad (6)$$

The above probability distribution for the ratio of t_f/t_p is exactly that found earlier through what I have called the delta t argument: 50% of the time $t_f > t_p$ ($P = 0.5$ for $Y = 1$), 50% of the time $\frac{1}{3} t_p < t_f < 3 t_p$ ($P = 0.25$ for $Y = 3$ and $P = 0.75$ for $Y = \frac{1}{3}$), and 95% of the time $\frac{1}{39} t_p < t_f < 39 t_p$ ($P = 0.025$ for $Y = 39$ and $P = 0.975$ for $Y = \frac{1}{39}$); see Fig. 1.

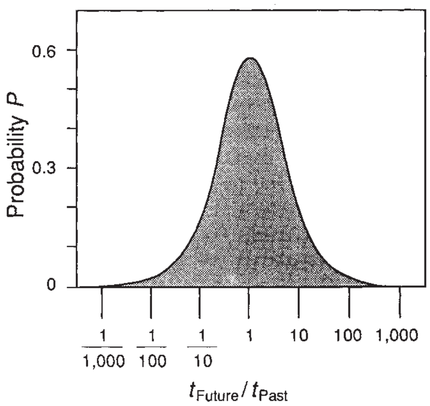

FIG. 1 Probability per unit logarithmic interval (base 10) of finding a given ratio $t_{\text{future}}/t_{\text{past}}$ for an observable from the delta t argument. The probability that $t_{\text{future}}/t_{\text{past}}$ is greater than Y is $1/(Y+1)$ [see equation (6)]. There is a 95% probability that $t_{\text{future}}/t_{\text{past}}$ lies between (1/39) and 39.

Our species, *homo sapiens*, is roughly $t_p \approx 200{,}000$ years old. (This is conservative, as recent estimates include >100,000 years[7], >150,000 years[8], 200,000 years[9] and 250,000 years[6]; if improved estimates become available they can be substituted in an obvious way). Clearly, t_p is much less than the age of the Universe, $t_0 \approx 13 \times 10^9$ years. Using equations (1) or (6), the estimate for the future lifetime of our species is

$$5{,}100 \text{ years} < t_f < 7.8 \times 10^6 \text{ years} \quad (95\% \text{ confidence limits}) \qquad (7)$$

This gives our species a total longevity between 0.205 million and 8 million years.

The average longevity for most species is between 1 and 11 million years[10-12], and for mammals it is 2 million years[13]. Our direct ancestor *homo erectus* lasted only about 1.4 million years and our near relatives, the Neanderthals, flourished for roughly 200,000 years. There is thus an order-of-magnitude coincidence between the range of total legevity of our species as predicted by the delta t argument and the observed longevity of other species, particularly species like ours. Thus we should not assume that our intelligence is likely to increase our longevity vastly above that of other species.

If $\lambda_0 \ll (200{,}000 \text{ years})^{-1}$, only a tiny fraction $f < 200{,}000 \text{ years} \times \lambda_0 \ll 1$ of all intelligent observers alive at present would observe $t_p \leq 200{,}000$ years, and you would be unlikely to be among them. In the limit where we expect our species to live forever, λ_0 goes to 0 and $P(t_p \leq 200{,}000 \text{ years})$ goes to 0. What we would expect to observe in the limit as λ_0 goes to 0 is that the value of t_0 we observe goes to infinity, $t_p \approx t_0$ and $(t_0 - t_p) \ll t_0$. These would be the telltale signs that we might survive into the indefinite future. In fact we see exactly the opposite: $t_p \ll t_0$, and $(t_0 - t_p) \approx t_0$. These are the telltale signs that we can expect to last only a short time into the future $t_f \approx t_p(\times 39^{\pm 1})$.

Replace the words 'intelligent species' with intelligent genus, intelligent family, intelligent order or intelligent class, and the argument remains the same. So the estimates of t_f that I have derived apply not only to us but to any (by an argument analogous to the delta t argument there are not likely to be many) intelligent species (including intelligent machine species) descended from us.

Gould[6] called $t_p \ll t_0$ "geology's most frightening fact", because "If humanity arose just yesterday as a small branch on a flourishing tree, then life may not in a genuine sense, exist for us or because of us. Perhaps we are only an afterthought, a kind of cosmic accident, just one bauble on the Christmas tree of evolution." I find it frightening too, but for a different reason: if $t_p \ll t_0$ then the delta t argument suggests $t_f \approx t_p(\times 39^{\pm 1})$ and thus $t_f \ll t_0$, meaning that on astronomical timescales, we and our intelligent descendants probably will not be around very long.

Population effects. When you evaluate your observations of the Universe you must take account of the selection effects associated with the fact that you are an intelligent observer. For example, the places and times that intelligent observers are born may be limited by the laws of physics[14]. This is the weak anthropic principle as formulated by Carter[15] and is basically just a self-consistency argument. It has had notable success in cosmology[16,17], giving us our best explanation of the Dirac large-numbers coincidence[14]. Carter[5] has pointed out that there is a remarkable order-of-magnitude coincidence between the time required to develop intelligent life on the Earth, $t_l = 4.5 \times 10^9$ yr measured from the formation of the Solar System, and the future main-sequence lifetime of the Sun $t_{fms} \approx 6 \times 10^9$ yr. Carter uses this fact and an ingenious argument to deduce that there must be of the order of 1 improbable event required for the formation of intelligent life. I agree; further, this coincidence is just what one would expect from the delta t argument if the intelligent life is simply formed at some random time during the main-sequence lifetime of the star. Interestingly, Carter's argument depends implicitly on the idea presented formally here: that according to the Copernican principle, among all intelligent observers (including those yet to be born) you should not be special.

Let us formalize this as the 'Copernican anthropic principle': that the location of your birth in space and time in the Universe is privileged (or special) only to the extent implied by the fact that you are an intelligent observer, that your location among intelligent observers is not special but rather picked at random. Knowing only that you are an intelligent observer, you should consider yourself picked at random from the set of all intelligent observers (past, present and future) any one of whom you could have been.

Assume therefore that you are located randomly on the chronological list of human beings. If the total number of intelligent individuals in the species is a positive integer $N_{tot} = N_{past} + 1 + N_{future}$ where N_{past} is the number of intelligent individuals in the species born before a particular intelligent observer and N_{future} is the number born after, then we expect N_{past} to be the integer part of the number $r_1 N_{tot}$ where r_1 is a random number uniformly distributed between 0 and 1. Thus:

$$(1/39)N_{past} - 1 < N_{future} < 39(N_{past} + 1) \quad (95\% \text{ confidence level}) \qquad (8)$$

and if $N_{past} \gg 1$

$$(1/39)N_{past} \leq N_{future} \leq 39 N_{past} \quad (95\% \text{ confidence level}) \qquad (9)$$

The number of human beings born so far is of the order of 70 billion (refs 18–20). By equation (9) the number of human beings yet to be born is expected to be

$$1.8 \text{ billion} < N_{future} < 2.7 \text{ trillion} \quad (95\% \text{ confidence level}) \qquad (10)$$

Consider the following toy model. Suppose the birth rate b is a constant and that the death rate has the constant value $d_1 < b$ before time t_{max} and the constant value $d_2 > b$ after time t_{max}. The population $p(t)$ will thus have a rate of increase $= b - d_1 = t_1^{-1}$ before time t_{max} and a rate of decrease $= d_2 - b = t_2^{-1}$ after t_{max}. The number of people born as a function of time is thus

$$\begin{aligned} N_B(t)\,dt &= bp(t)\,dt \\ &= bN_{max} \exp([t - t_{max}]/t_1)\,dt \\ &\quad \text{for } t < t_{max} \\ N_B(t)\,dt &= bp(t)\,dt \\ &= bN_{max} \exp([t_{max} - t]/t_2)\,dt \\ &\quad \text{for } t > t_{max} \end{aligned} \qquad (11)$$

Regardless of the values of t_1 and t_2, 50% of observers are born at times when the population $p(t)$ is within a factor of 2 of its maximum value of N_{max} (and 95% of observers are born when the population is within a factor of 20 of N_{max}). It is thus interesting that the current population of the Earth is over 5 billion and many projections of future growth show the population topping out at ~8 to 12 billion[21-23]. Estimates of the theoretical maximum population for the Earth include 20 billion[21] and 40 billion[24]. Exponential growth and decline is common in biological systems, so you should not be surprised to be born in an epoch with problems of overpopulation. The total number of people born before t_{max} is $N_1 = bN_{max}t_1$ and the number of people born after t_{max} is $N_2 = bN_{max}t_2$, so $N_1/N_2 = t_1/t_2$. In the limit where t_2 goes to infinity, this model crudely follows a logistic curve, a period of exponential growth followed by a long period of equilibrium where the birth and death rates are equal. But this is not allowed because if you find yourself on the rising exponential you are a member of the set N_1, and we require that $N_2 < 39N_1$ in order that your good luck should not be more spectacular than 2.5%; this means that $t_2 < 39t_1$, and as you are likely to be born near t_{max}, that $t_f \leq 39t_p$ (just as in the delta t argument). But the set N_2 to which you do not belong can be as small as 0, which means that the only lower limit on t_2 is 0. In the limit $t_2 = 0$ (sudden extinction) you are likely ($P = 0.95$) to be born between 3.7 and 0.025 e-folding times (t_1) of the end, giving a lower limit of $t_f > 0.025t_1 \approx t_p/40 \ln(N_{max})$.

We might reasonably expect, as a first guess, that an eventual population crash would roughly mirror its rise but perhaps be multiplied by a scale factor in time. In this case we would still expect the 95% confidence level upper limit on t_f to be $\sim 39t_p$ just as in the delta t argument (because if the fall mirrored the rise but was stretched out by a factor of 39 in time, then 39/40 of the people would be born on the declining portion of the curve). The 95%-confidence-level lower limit on t_f can be calculated directly by noting that the 95%-confidence-level lower limit on the number of future human births is 1.8 billion (equation (10)). At current rates[25] it will take only about 12 years for another 1.8 billion people to be born (assuming births continue without abatement before a sudden extinction). This extremely pessimistic lower limit would need a double dose of bad luck, bad luck at the 2.5% level coupled with an instantaneous extinction. The number of years is so short because a reasonable fraction, 7.7%, of all the people who have ever lived are alive today[18–20,25]. This is a dangerous situation. Thus, including population effects,

$$12 \text{ years} < t_f < 7.8 \text{ million years} \quad (95\% \text{ confidence level}) \qquad (12)$$

Disturbingly, even extraordinarily low values of t_f cannot be confidently excluded ($P = 0.95$) but high values of t_f, such as many billion years, which we might hope for, can be.

Ehrlich and Ehrlich[24] propose three possible future population scenarios for the human race: (1) topping out at 10 billion in the next century and then dying out; (2) topping out at 10 billion in the next century and then collapsing to a few hundred thousand people eking out a livelihood on an impoverished planet for the next 4 million years; and (3) a sustainble stable population of 1 billion for the next 4 million years. The number of future births implied by these scenarios are roughly (1) 10 billion, (2) 30 billion and (3) 40×10^{12}. Unfortunately, only the two pessimistic cases (1) and (2) are within the limits in equation (10) (see Fig. 2). Combining $N_{\text{future}} < 2.7 \times 10^{12}$ (equation (10)) with the current rate of 145 million births per year[25] we find $t_f < 19{,}000$ years unless the rate of births drops. If we wish to stretch our survival out to the upper limit of 7.8 million years (from equation (12)) we require the average rate of births to drop by a factor of more than 400. Although an optimist might hope for this to be produced by extraordinary means such as genetic engineering producing a greatly increased human lifetime, a pessimist would note that any civilization potent enough to produce a large linear increase in its life expectancy would be potent enough to produce an exponential increase in its numbers as well, and argue that such a drop could be more easily produced simply by a population crash.

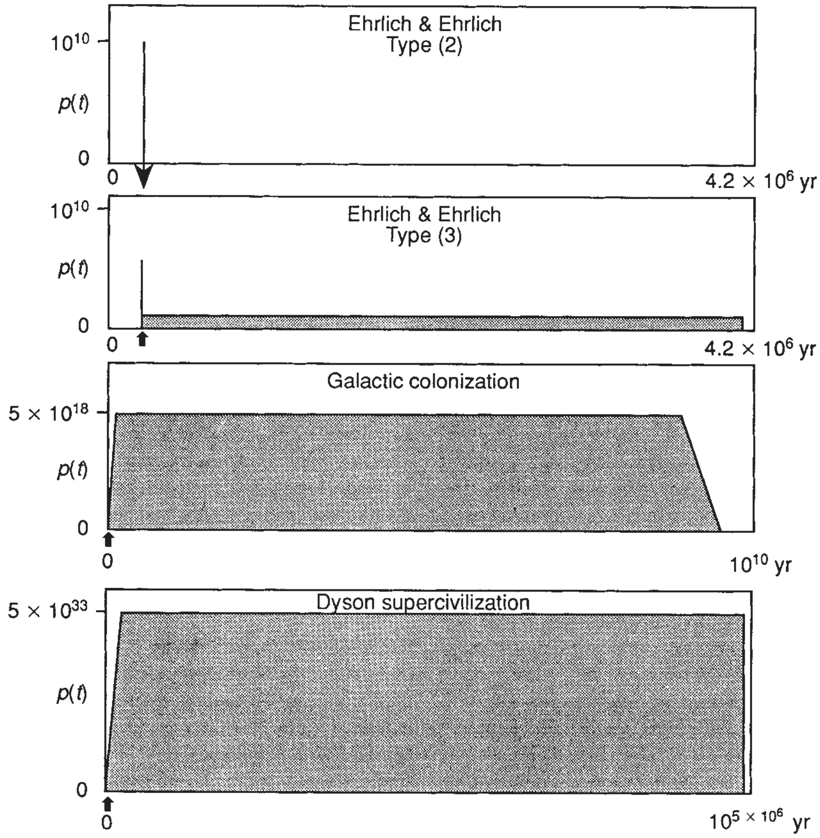

FIG. 2 Population against time for various scenarios discussed in the text shown on linear scales. In the pessimistic Ehrlich & Ehrlich Type (2) scenario, the population reaches 10 billion in the next century and then collapses to a few hundred thousand for the next 4 million years; on this scale, only the population spike near the present is visible. In all but the Type (2) scenario your position (black arrow) turns out to be extraordinarily lucky to be in the first tiny fraction of the intelligent observers in our lineage.

Equation (9) claims that it is likely that you are not in either the first 2.5% or the last 2.5% of the chronological list of human beings. Can you avoid this conclusion by arguing that you occupy a special position on the list because you are born into an epoch where the level of sophistication is great enough to know equation (9)? Well, if you are now over 12 years old, more than 1.8 billion people have already been born after you, so you already know that you are not in the last 2.5% of the chronological list. In another 12 years, with the current rate of births, everyone alive today will be off the last 2.5% of the chronological list. So bad luck is required for you to be on the last 2.5% of the list. If you are an optimist and believe that civilization will go onward and upward from here, then any future humans should live in a civilization advanced enough to remember or rederive equation (9); so of all those observers who live in epochs sophisticated enough to apply equation (9), less than 2.5% of them can be in the first 2.5% of the entire chronological list (because they occupy all of the chronological list except for a segment at the beginning).

In such an optimistic scenario if $N_{\text{future}} > 2.7 \times 10^{12}$, you would have to ask yourself why, of all the more than 2.7×10^{12} humans who will live in epochs where equation (9) or its variants are known, you are so lucky ($P < 0.002$) as to be among the 5.4 billion people alive when it is discovered. For example, you live in an epoch where Copernicus's theory is known, but you were not lucky enough to have been around when it was discovered, and in such an optimistic scheme it would be likely for you to be in the same position with respect to equation (9). The only hope to force you into the first 2.5% of the chronological list is to live in a type (2) scenario where civilization collapses in the near future and we return just as before to a hunter-gatherer phase (which forgets the equation and is not sophisticated enough to rederive it) which one might hope would last a long time. But this will not work either, because without civilization we would lose our possibility of being especially protected against extinction and we should at that point have an expected future longevity of about 2 million years or less, like other hominid species. The population in the final hunter-gatherer phase should be low so that future births should be of order 30 billion (consistent with equation (9)). (In such a situation, the civilization, by Carter's[5] argument, should form at some random time during the lifetime of the species and the delta t argument should apply). Being in the first 2.5% of the chronological list requires at least good luck at the 2.5% level in all these cases.

Any biases due to the fact that we live in a technological civilization we expect to be small in any case, because populations are so high during technological civilizations that we expect a substantial fraction of all intelligent observers to be born into them.

Prospects for the far future

The probability that we will colonize the Galaxy (increasing our population by a factor of at least 10^9) is of order $P \leq 10^{-9}$, as in such a situation we expect $N_{\text{future}} > 10^9 N_{\text{past}}$ and $P(N_{\text{future}} > 10^9 N_{\text{past}}) \leq 10^{-9}$. (Seeding other worlds with microorganisms[26] might be possible, but by Carter's[5] argument only a small fraction would ever develop intelligent life. Even if one entertained the notion that life on Earth was seeded in this way[26-28], the typical delay of several billion years to evolve intelligent life when it does occur guarantees that the number of direct 'ancestor' civilizations in our lineage must be at most a few, and, using an argument similar to the delta t argument, the number of our 'descendant' intelligent species is also not likely to be large). The probability that we will build a Dyson[29] sphere of O'Neill[30] solar-powered space colonies surrounding the Sun (using all the Sun's radiant energy and multiplying our population by a factor of at least 10^8) is of order $P \leq 10^{-8}$. The probability of our establishing a Kardashev type III civilization, defined as one that uses the energy output of its entire galaxy by placing a Dyson sphere around each star (multiplying our population by a factor of at least 10^{17}) is of order $P \leq 10^{-17}$.

Dyson[31] showed that operating at lower and lower temperatures as the Universe expands (thinking ever more slowly, and interspersing periods of hibernation), intelligent life could in principle continue forever, having an infinite number of thoughts on only a finite amount of energy. As an example, consider Linde's[32] chaotic inflationary[33] cosmology where our Universe may continue its normal expansion for $\sim 10^{5\times10^6}$ years. The amount of effective conscious time elapsed would be $10^{1.25\times10^6}$ years because of the slow thinking and hibernation. Because the mass within the horizon grows linearly with time in the Linde model up to $10^{5\times10^6}$ years, even with an extremely pessimistic probability for the formation of intelligent life on a habitable planet (say $10^{-4,000}$) there would still be of the order of $10^{5\times10^6}$ intelligent civilizations in our entire inflationary domain that would eventually become visible. Intelligent observers with life-expectancies longer than 10^2 conscious years must not be sufficiently common to dominate the total, otherwise you would be likely to be one. Elimination of all current causes of death other than murder and suicide would only increase life-expectancies to 10^4 years and even extraordinary increases in lifespans (of up to say 10^{100} conscious years) would still require the Dyson supercivilization to have over time of order $10^{1.25\times10^6}$ individuals and our probability of becoming a Dyson supercivilization would be less than of order $10^{-1.25\times10^6}$; still there could be as many as $\sim 10^{3.75\times10^6}$ Dyson supercivilizations in the Universe. So some intelligent life may last into the far future; it is just not likely to be us or our descendants.

In the limit where (cosmology permitting) a supercivilization is able to accumulate an infinite amount of elapsed conscious time and an infinite number of intelligent observers (N_{tot}), the fraction of ordinary civilizations such as ours that will develop into such a supercivilization must go to zero so that the set of observers born on the original home planet is not an infinitesimal minority of all intelligent observers.

Implications for SETI

Colonization is not important in the sense that galactic colonists and their descendants must not dominate the numbers of intelligent observers in the Universe (otherwise you would be likely to be one). Significantly[34], this explains why we should not be surprised that we have not been colonized by extraterrestrials. Assume 10^9 habitable planets in the Galaxy (surely optimistic). Carter's[5] argument shows that the fraction of these that will develop intelligent life is at least an order of magnitude and perhaps many orders of magnitude less than 1. As the main-sequence lifetime of their star t_{ms} is of the order of 10^{10} years, the rate at which intelligent civilizations are forming in the Galaxy is $\eta < 0.01\ \text{yr}^{-1}$. If the average longevity of these civilizations for radio-transmission is $\langle L \rangle$ then (as colonization is not important) by the Drake equation[35,36] we expect to be able to observe within our Galaxy $N_0 = \eta \langle L \rangle < 0.01\ \text{yr}^{-1} \langle L \rangle$ civilizations transmitting now. You are born into a radio-transmitting civilization, so you should be picked at random from the set of observers in radio-transmitting civilizations. Assume our radio transmission longevity is L_j (radio transmission may end because we become extinct, technological civilization comes to an end, or we simply move on to a different method of communication). Then by the delta t argument we know that $L_p = r_1 L_j$ where $L_p = 105$ years is the past longevity of radio transmission on Earth, and r_1 is a random number uniformly distributed between 0 and 1. Arrange all N radio-transmitting civilizations in a catalogue in order of their radio longevity so that for all i, $L_i \leq L_{i+1}$. Assume that the number of intelligent observers in a radio-transmitting civilization is proportional to L (equivalent to assuming a civilization's rate of births is not correlated with L; if it were positively correlated, which might seem natural, then the limits would be even stronger). As you are randomly located on the list of observers in the catalogue

$$\sum_{i=1}^{j} L_i = r_2 \sum_{i=1}^{N} L_i = r_2 \langle L \rangle N \leq j L_j \leq N L_j = N L_p / r_1 \quad (13)$$

where r_2 is a random number uniformly distributed between 0 and 1. Thus

$$\langle L \rangle \leq L_p / (r_1 r_2) \quad (14)$$

The probability $P = 0.95$ that $(r_1 r_2) > 0.0087$ so

$$\langle L \rangle < 12{,}100 \text{ years}, \quad N_0 < 121 \quad \text{(95\% confidence level)} \quad (15)$$

independent of the form of the distribution of the Ls, and considerably lower than Cameron's[37] estimate of $\langle L \rangle = 10^6$ years.

Thus there is some possibility that a radio search for other civilizations in our Galaxy or others could be successful, but a targeted radio search of 1,000 nearby stars is not likely to succeed. The upper limit on N_0 is generous because Carter's[5] argument implies that the probability of forming an intelligent species on a habitable planet around a given star during its main-sequence lifetime may be many orders of magnitude below unity rather than the optimistic one order of magnitude below unity that we adopted.

As a human being today the probability is large ($P = 0.97$) that you were born in a country with a population of more than the median value of 6.3 million[25]. For the same reason, if there is a large spread in the populations of intelligent species, which we would expect for noninteracting opportunistic species, then it is likely that you, as a random intelligent observer, would find yourself in an intelligent species with a population larger than the median. (In the canonical $a = 0.2$ lognormal distribution which best fits a wide variety of observed species-abundance curves, 98.6% of all individuals come from species having populations above the median value)[38-42]. Civilizations significantly larger than our own must be sufficiently rare that their individuals do not dominate the total. Thus, we do not expect to see a Dyson sphere civilization within our Galaxy, or a Karadashev type III civilization within the current observable horizon.

Implications for space travel

Why is our probability of colonizing the Galaxy so low given that it would be very good for our survival prospects to expand our habitat vastly and that we already know how to travel in space? Although we have been around for 200,000 years or so, civilization (with cities and writing) has only been around for 5,500 years and technological civilization sophisticated enough to engage in space travel for only 32 years. But the delta t argument tells us that the capacity and motivation to engage in space travel may be with us for only of the order of another 32 years ($\times 39^{\pm 1}$). The Cold War which was responsible for the space race in the first place is now over. Human flights to the Moon lasted for only four years, and human activity in space has unfortunately retreated at present to low Earth orbit. The delta t argument suggests that there may be only a brief window of opportunity for space travel during which we will in principle have the capability to establish colonies (which could in turn establish further colonies). If we let that opportunity pass without taking advantage of it we will be doomed to remain on the Earth where we will eventually go extinct. So far, not a single human being has been born outside the gravitational potential well of the Earth.

The methods that I have used here are very conservative; if the results are dramatic it is only because the facts are dramatic ($t_p \ll t_0$). This paper only points out and defends the hypothesis that you are a random intelligent observer. Sometimes we say that the future is unpredictable. Another way to look at this is to say that at birth you have no information on where fractionally in the chronological list of human beings you will in the end turn out to be. You are no more likely eventually to turn out to be in the first 2.5% of the chronological list of human beings than you are to be in the first 2.5% of the alphabetical list of human beings in your home town's telephone book. Short of having actual data on the longevities of other intelligent species, this hypothesis is arguably the best we can make. At present we have no data sufficient to reject this hypothesis and it does explain a number of facts: that you were born during a period of high population and that the Earth has not been previously colonized by extraterrestrials. Like any good scientific hypothesis, this hypothesis is falsifiable, either immediately by discovery of intelligent radio signals from a civilization around a nearby star; or eventually, if more than 2.7×10^{12} more human beings are born. If you believe that our intelligent descendants will last 10 billion years and colonize the Galaxy, you must believe that you will, in the end, turn out to have been very lucky to have been in the first tiny fraction of the members of our intelligent lineage (see Fig. 2). If you were not lucky enough to find yourself on the first page of the phone book or were not even born on January 1, can you feel comfortable assuming that you will turn out to be even luckier in the ultimate chronological list? You should be suspicious of any claim that future events will conspire to make you *in the end* turn out to be exceptionally lucky, like the claim that you will win the lottery tomorrow or get rich by participating in a chain letter you have received.

What about the future of all life on Earth? Darwin[43] said "And of the species now living very few will transmit progeny of any kind to a far distant futurity.... As all the living forms of life are the lineal descendants of those which lived long before the Silurian epoch, we may feel certain that the ordinary succession of generations has never once been broken, and that no cataclysm has desolated the whole world. Hence we may look forward with some confidence to a secure future of *equally* inappreciable length" [italics mine]. This is essentially the delta t argument applied to our position among all living things on earth. If our species does become extinct sometime within the next few million years, and we do not colonize space and are not potent enough to destroy all life on Earth either, then we will indeed be like other species (albeit especially interesting) and we might indeed be expected to occupy a random position in the history of life on earth. Life on Earth began over 3.6 billion years ago, and we might expect it to last another 6 billion years until the Sun becomes a red giant, in agreement with equation (1) and Darwin's prediction.

The odds are against our colonizing the Galaxy and surviving to the far future, not because these things are intrinsically beyond our capabilities, but because living things usually do not live up to their maximum potential. Intelligence is a capability which gives us in principle a vast potential if we could only use it to its maximum capacity, but so does the ability to lay 30 million eggs as the ocean sunfish does[44]. We should know that to succeed the way we would like, we will have to do something truly remarkable (such as colonizing space), something which most intelligent species do not do.

After completing this paper, I have learned that ideas on future human population similar to some of those presented here were discussed by Brandon Carter in a 1983 talk, although never in print (see treatment by Leslie[45–47]), as well as independently proposed by Nielson[48]. □

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