WHERE ARE THEY?

WHY I HOPE THE SEARCH FOR EXTRATERRESTRIAL LIFE FINDS NOTHING

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When water was discovered on Mars, people got very excited. Where there is water, there may be life. Scientists are planning new missions to study the planet up close. NASA's next Mars rover is scheduled to arrive in 2010. In the decade following, a Mars Sample Return mission might be launched, which would use robotic systems to collect samples of Martian rocks, soils, and atmosphere, and return them to Earth. We could then analyze the sample to see if it contains any traces of life, whether extinct or still active. Such a discovery would be of tremendous scientific significance. What could be more fascinating than discovering life that had evolved entirely independently of life here on Earth? Many people would also find it heartening to learn that we are not entirely alone in this vast cold cosmos.

But I hope that our Mars probes will discover nothing. It would be good news if we find Mars to be completely sterile. Dead rocks and lifeless sands would lift my spirit.

Conversely, if we discovered traces of some simple extinct life form—some bacteria, some algae—it would be bad news. If we found fossils of something more advanced, perhaps something looking like the remnants of a trilobite or even the skeleton of a small mammal, it would be *very* bad news. The more complex the life we found, the more depressing the news of its existence would be. Scientifically interesting, certainly, but a bad omen for the future of the human race.

How do I arrive at this conclusion? I begin by reflecting on a well-known fact. UFO-spotters, Raelian cultists, and self-certified alien abductees notwithstanding, humans have, to date, seen no sign of any extraterrestrial intelligent civilization. We have not received any visitors from space, nor have our radio telescopes detected any signals transmitted by any extraterrestrial civilization. The Search for Extra-Terrestrial Intelligent Life (SETI) has been going for nearly fifty years, employing increasingly powerful telescopes and data mining techniques, and has so far consistently corroborated the null hypothesis. As best we have been able to determine, the night sky is empty and silent—the question "Where are they?" thus being at least as pertinent today as it was when Enrico Fermi first posed it during a lunch discussion with some of his physicist colleagues back in 1950.

Here is another fact: There are on the order of 100 billion stars in our galaxy alone, and the observable universe contains on the order of 100 billion galaxies. In the last couple of decades, we have learnt that many of these stars have planets circling around them. By now, several hundred exoplanets we have discovered. Most of these are gigantic, but this is due to a selection effect: It is very difficult to detect smaller exoplanets with current observation methods. (In most cases, the planets cannot be directly observed. Their existence is inferred from their gravitational influence on their parent sun, which wobbles slightly when pulled towards a large orbiting planet; or alternatively by a slight fluctuation in their sun's perceived luminosity which occurs when it is partially eclipsed by the exoplanet.) We have every reason to believe that the observable universe contains vast numbers of solar systems, including many that have planets that are Earth-like at least in the sense of having a mass and temperature similar to those of our own orb. We also know that many of these solar systems are much older than ours.

From these two facts it follows that there exists a "Great Filter".[1] The Great Filter can be thought of as a probability barrier. It consists of one or more *highly improbable* evolutionary transitions or steps whose occurrence is required in order for an Earth-like planet to produce an intelligent civilization of a type that would be visible to us with our current observation technology. You start with billions and billions of potential germination points for life, and you end up with a sum total of zero extraterrestrial civilizations that we can observe. The Great Filter must therefore be powerful enough—which is to say, the critical steps must be improbable enough—that even with many billions rolls of the dice, one ends up with nothing: no aliens, no spacecraft, no signals, at least none that we can detect in our neck of the woods.

Now, an important question for us is, just where might this Great Filter be located? There are two basic possibilities: It might be behind us, somewhere in our distant past. Or it might be ahead of us, somewhere in the millennia or decades to come. Let us ponder these possibilities in turn.

Consider first the possibility that the filter is in our past. This would mean that there is some extremely improbable step in the sequence of events whereby an Earth-like planet gives rise to an intelligent life form comparable in its technological sophistication to our

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[1] I borrow this term from Robin Hanson's "The Great Filter—Are We Almost Past It?" (http://hanson.gmu.edu/greatfilter.html), a paper which presents an argument similar to the one expounded here.

contemporary human civilization. Some people seem to take it for granted that evolution of intelligent life on this planet was straightforward—lengthy, yes, complex, sure, yet ultimately inevitable or nearly so. Carl Sagan appears to have held this view; he once wrote that "the origin of life must be a highly probable circumstance; as soon as conditions permit, up it pops!"[2] But this view might well be completely mistaken. There is at any rate hardly any evidence to support it. Evolutionary biology, at the moment, does not enable us to calculate from first principles how probable or improbable the evolution of intelligent life on Earth was. Moreover, if we look back at the history of life on this planet, we can identify a number of evolutionary transitions each one of which is a plausible candidate Great Filter.

For example, perhaps it is very, very improbable that even simple self-replicators should emerge on any given Earth-like planet. Attempts to create life in the laboratory by mixing water and gases believed to have existed in the early atmosphere on Earth have failed to get much beyond the synthesis of a few simple amino acids. No instance of abiogenesis has ever been observed.

The oldest confirmed microfossils date from approximately 3,500 million years ago, and there is tentative evidence that life might have existed a few hundred million years prior to that date, but no evidence of life before 3,800 million years ago. Life might well have arisen considerably earlier than that without leaving any traces. There are very few preserved rock formations this old and such as have survived have undergone major remolding over the eons. Nevertheless, there is a period lasting several hundreds of millions of years between the formation of Earth and the first known life. The evidence is thus consistent with the hypothesis that the emergence of life required an extremely improbable set of coincidences, and that it took hundreds of millions of years of trial-and-error, of molecules and surface structures randomly interacting, before something capable of self-replication happened to appear by a stroke of astronomical luck. For aught we know, this first critical step could be a Great Filter.

Since we cannot rerun the history of life multiple times to obtain rigorous statistics, it is difficult to determine conclusively the "difficulty" of any given evolutionary development. There are, however, some criteria that we can use to identify evolutionary transitions that are at least good candidates for being a Great Filter, i.e. that are both extremely improbable and practically necessary for the eventual emergence of intelligent technological civilization. One criterion is that the transition should have occurred only once. Flight, sight, photosynthesis, and limbs have all evolved several times here on Earth, and are thus ruled out. Another indication that an evolutionary step was very improbable is that it took a very long time for it to occur even after its prerequisites were

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[2] Sagan, C. (1995). "The abundance of life-bearing planets." *Bioastronomy News* 7(4): 1–4.

in place. A long delay suggests that a vastly many random recombinations had to be tried before one was found that worked. Perhaps several improbable mutations had to occur all at once in order to leap from one local fitness peak to another: the mutations might individually be deleterious and only fitness-enhancing when they occur together. (The evolution of Homo sapiens from one of our recent hominid ancestors, such as Homo erectus, happened rather quickly on geological timescales, so this step would be a relatively weak candidate for a Great Filter.)

The original emergence of life appears to meet these two criteria. As far as we know, it might have occurred only once and it might have taken hundreds of millions of years for it to happen even after the planet had cooled down sufficiently to enable a wide range of organic molecules to be stable. Later evolutionary history offers additional candidates for the Great Filter. For example, it took some 1.8 billion years for prokaryotes (the most basic type of single-cell organism) to evolve into eukaryotes (a more complex kind of cell with a membrane-enclosed nucleus). 1.8 billion years is a long time, and as far as we know eukaryotes evolved only once, making this transition an excellent possible Great Filter. Other strong candidates include the rise of multi-cellular organisms and sexual reproduction.

So one possibility is that the Great Filter is behind us. This would explain the absence of observable aliens. Why? Because if the rise of intelligent life on any one planet is sufficiently improbable, then it follows that we are most likely the only such civilization in our galaxy or even in the entire observable universe. (The observable universe contains approximately 10^{22} stars. The universe might well extend infinitely far beyond the part that is observable by us, and may contain infinitely many stars. If so, then it is virtually certain that there exists an infinite number of intelligent extraterrestrial species, no matter how improbable their evolution on any given planet. However, cosmological theory implies that, due to the expansion of the universe, any life outside the observable universe is and will forever remain causally disconnected from us: it can never visit us, communicate with us, or be seen by us or our descendants.)

The other possibility is that the Great Filter is after us, in our future. This would mean that there is some great improbability that prevents almost all technological civilizations at our current human stage of development from progressing to the point where they engage in large-scale space-colonization and make their presence known to other technological civilizations. For example, it might be that any sufficiently technologically advanced civilization discovers some technology—perhaps some very powerful weapons technology—that causes its extinction.

I will return to this scenario shortly, but first I shall say a few words about another theoretical possibility: that the extraterrestrials are out there, in abundance but hidden from our view. I think this is unlikely, because if extraterrestrials do exist in any numbers, it's reasonable to think at least one species would have already expanded throughout the galaxy, or beyond. Yet we have met no one.

Various schemes have been proposed for how an intelligent species might colonize space. They might send out "manned" space ships, which would establish colonies and "terraform" new planets, beginning with worlds in their own solar system before moving on to more distant destinations. But much more likely, in my view, would be colonization by means of so-called "von Neumann probes", named after the Hungarian-born prodigy John von Neumann, who included among his many mathematical and scientific achievements the development of the concept of a universal constructor. A von Neumann probe would be an unmanned self-replicating spacecraft, controlled by artificial intelligence, capable of interstellar travel. A probe would land on a planet (or a moon or asteroid), where it would mine raw materials to create multiple replicas of itself, perhaps using advanced forms of nanotechnology. These replicas would then be launched in various directions, thus setting in motion a multiplying colonization wave.[3] Our galaxy is about 100,000 light years across. If a probe were capable of travelling at one-tenth of the speed of light, every planet in the galaxy could thus be colonized within a couple of million years (allowing some time for the bootstrapping process that needs to take place between a probe's landing on a resource site, setting up the necessary infrastructure, and producing daughter probes). If travel speed were limited to 1% of light speed, colonization might take twenty million years instead. The exact numbers do not matter much because they are at any rate very short compared to the astronomical time scales involved in the evolution of intelligent life from scratch (billions of years).

If building a von Neumann probe seems like a very difficult thing to do—well, surely it is, but we are not talking about a proposal for something that NASA or the European Space Agency should get to work on today. Rather, we are considering what would be accomplish with some future very advanced technology. We ourselves might build Neumann probes in decades, centuries, or millennia—intervals that are mere blips compared to the lifespan of a planet. Considering that space travel was science fiction a mere half century ago, we should, I think, be extremely reluctant to proclaim something forever technologically infeasible unless it conflicts with some hard physical constraint. Our early space probes are already out there: Voyager 1, for example, is now beyond our solar system.

Even if an advanced technological civilization could spread throughout the galaxy in a relatively short period of time (and thereafter spread to neighboring galaxies), one might still wonder whether it would opt to do so. Perhaps it would rather choose to stay at home and live in harmony with nature. However, there are a number of considerations that make this a less plausible explanation of the great silence. First, we observe that life

[3] This scenario was developed by Frank Tipler in 1981.

here on Earth manifests a very strong tendency to spread wherever it can. On our planet, life has spread to every nook and cranny that can sustain it: East, West, North, and South; land, water, and air; desert, tropic, and arctic ice; underground rocks, hydrothermal vents, and radioactive waste dumps; there are even living beings inside the bodies of other living beings. This empirical finding is of course entirely consonant with what one would expect on the basis of elementary evolutionary theory. Second, if we consider our own species in particular, we also find that it has spread to every part of the planet, and we even have even established a presence in space, at vast expense, with the international space station. Third, there is an obvious reason for an advanced civilization that has the technology to go into space relatively cheaply to do so: namely, that's where most of the resources are. Land, minerals, energy, negentropy, matter: all abundant out there yet limited on any one home planet. These resources could be used to support a growing population and to construct giant temples or supercomputers or whatever structures a civilization values. Fourth, even if some advanced civilization were non-expansionary to begin with, it might change its mind after a hundred years or fifty thousand years—a delay too short to matter. Fifth, even if some advanced civilization chose to remain non-expansionist forever, it would still not make any difference if there were at least one other civilization out there that at some point opted to launch a colonization process: that expansionary civilization would then be the one whose probes, colonies, or descendants would fill the galaxy. It takes but one match to start a fire; only one expansionist civilization to launch the colonization of the universe.

For all these reasons it seems unlikely that the galaxy is teeming with intelligent life and that the reason we haven't seen any of them is that they all confine themselves to their home planets. Now, it is possible to concoct scenarios in which the universe is swarming with advanced civilizations every one of which chooses to keep itself well hidden from our view. Maybe there is a secret society of advanced civilizations that know about us but have decided not to contact us until we're mature enough to be admitted into their club. Perhaps they're observing us, like animals in a zoo. I don't see how we can conclusively rule out this possibility. But I will set it aside for the remainder of this essay in order to concentrate what to me appears to be more plausible answers to Fermi's question.

A disconcerting hypothesis is that the Great Filter consists in some destructive tendency common to virtually all sufficiently advanced technological civilizations. Throughout history, great civilizations on Earth have imploded—the Roman Empire, the Mayan civilization that once flourished in Central America, and many others. However, the kind of societal collapse that merely delays the eventual emergence of a space-colonizing civilization by a few hundred or a few thousand years would not help explain why no such civilization has visited us from another planet. A thousand years may seem a long time to an individual, but in this context it's a sneeze. There are planets that are billions of years older than Earth. Any intelligent species on those planets would have had ample time to recover from repeated social or ecological collapses. Even if they failed a thousand times before they succeeded, they could still have arrived here hundreds of millions of years ago.

To constitute an effective Great Filter, we hypothesize a terminal global cataclysm: an existential catastrophe. An existential risk is one where an adverse outcome would annihilate Earth-originating intelligent life or permanently and drastically curtail its potential for future development. We can identify a number of potential existential risks: nuclear war fought with stockpiles much greater than those that exist today (maybe resulting from future arms races); a genetically engineered superbug; environmental disaster; asteroid impact; wars or terrorists act committed with powerful future weapons, perhaps based on advanced forms of nanotechnology; superintelligent general artificial intelligence with destructive goals; high-energy physics experiments; a permanent global Brave-New-World-like totalitarian regime protected from revolution by new surveillance and mind control technologies. These are just some of the existential risks that have been discussed in the literature, and considering that many of these have been conceptualized only in recent decades, it is plausible to assume that there are further existential risks that we have not yet thought of.

The study of existential risks is an extremely important albeit rather neglected field of inquiry. But here we must limit ourselves to making just one point. In order for some existential risk to constitute a plausible Great Filter, it is not sufficient that we judge it to have a significant subjective probability of destroying humanity. Rather, it must be of a kind that could with some plausibility be postulated to destroy virtually all sufficiently advanced civilizations. For instance, stochastic natural disasters such as asteroid hits and super-volcanic eruptions are unlikely Great Filter candidates, because even if they destroyed a significant number of civilizations we would expect some civilizations to get lucky and escape disaster; and some of these civilizations could then go on to colonize the universe. Perhaps the most likely type of existential risks that could constitute a Great Filter are those that arise from technological discovery. It is not farfetched to suppose that there might be some possible technology which is such that (a) virtually all sufficiently advanced civilizations eventually discover it and (b) its discovery leads almost universally to existential disaster.

So where is the Great Filter? Behind us, or not behind us?

If the Great Filter is ahead of us, we have still to confront it. If it is true that almost all intelligent species go extinct before they master the technology for space colonization, then we must expect that our own species, too, will go extinct before reaching technological maturity, since we have no reason to think that we will be any luckier than most other species at our stage of development. If the Great Filter is ahead of us, we must relinquish all hope of ever colonizing the galaxy; and we must fear that our adventure will end soon, or at any rate, prematurely. Therefore, we better hope that the Great Filter is behind us.

What has all this got to do with finding life on Mars? Consider the implications of discovering that life had evolved independently on Mars (or some other planet in our solar system). That discovery would suggest that the emergence of life is not a very improbable event. If it happened independently twice here in our own back yard, it must surely have happened millions times across the galaxy. This would mean that the Great Filter is less likely to occur in the early life of planets and is therefore more likely still to come.

If we discovered some very simple life forms on Mars in its soil or under the ice at the polar caps, it would show that the Great Filter must exist somewhere after that period in evolution. This would be disturbing, but we might still hope that the Great Filter was located in our past. If we discovered a more advanced life-form, such as some kind of multi-cellular organism, that would eliminate a much larger stretch of potential locations where the Great Filter could be. The effect would be to shift the probability more strongly to the hypothesis that the Great Filter is ahead of us, not behind us. And if we discovered the fossils of some very complex life form, such as of some vertebrate-like creature, we would have to conclude that the probability is very great that the bulk of the Great Filter is ahead of us. Such a discovery would be a crushing blow. It would be by far the worst news ever printed on a newspaper cover.

Yet most people reading the about the discovery would be thrilled. They would not understand the implications. If the Great Filter is not behind us, it is ahead of us.

So this is why I'm hoping that our space probes will discover dead rocks and lifeless sands on Mars, on Jupiter's moon Europa, and everywhere else our astronomers look. It would keep alive the hope for a great future for humanity.

Now, it might be thought an amazing coincidence if Earth were the only planet in the galaxy on which intelligent life evolved. If it happened here—the one planet we have studied closely—surely one would expect it to have happened on a lot of other planets in the galaxy also, which we have not yet had the chance to examine? This objection, however, rests on a fallacy: It overlooks what is known as an "observation selection effect." Whether intelligent life is common or rare, every observer is guaranteed to find themselves originating from a place where intelligent life did, indeed, arise. Since only the successes give rise to observers who can wonder about their existence, it would be a mistake to regard our planet as a randomly-selected sample from all planets. (It would be closer to the mark to regard our planet as though it were a random sample from the subset of planets that did engender intelligent life: this being a crude formulation of one of the sane elements extractable from the motley ore of ideas referred to as the "anthropic principle".)

Since this point confuses many, it is worth expounding it slightly. Consider two different hypotheses. One says that the evolution of intelligent life is fairly easy and happens on a significant fraction of all suitable planets. The other hypothesis says that the evolution of intelligent life is extremely difficult and happens perhaps only on one out of a million billions planets. To evaluate their plausibility in light of your evidence, you must ask yourself, "What do these hypotheses predict that I should observe?" If you think about it, it is clear that both hypotheses predict that you should observe that your civilization originated in places where intelligent life evolved. All observers will observe precisely that, whether the evolution of intelligent life happened on a large or a small fraction of all planets. An observation selection effect guarantees that whatever planet we call "ours" was a success story. And as long as the total number of planets in the universe is large enough to compensate for the low probability of any given one of them giving rise to intelligent life, it is not a surprise that a few success stories exist.

If—as I hope is the case—we are the only intelligent species that has ever evolved in our galaxy, and perhaps in the entire observable universe, it does not follow that our survival is not in danger. Nothing in the above reasoning precludes the Great Filter from being located both behind us *and* ahead of us. It might both be extremely improbable that intelligent life should arise on any given planet, and very improbable that intelligent life, once evolved, should succeed in becoming advanced enough to colonize space.

But we would have some grounds for hope that all or most of the Great Filter is in our past if Mars is indeed found to be barren. In that case, we may have a significant chance of one day growing into something almost unimaginably greater than we are today.

In this scenario, the entire history of humankind to date is a mere instant compared to the eons of history that lie still before us. All the triumphs and tribulations of the millions of peoples the have walked the Earth since the ancient civilization of Mesopotamia would be like mere birth pangs in the delivery of a kind of life that hasn't really begun yet. For surely it would be the height of naiveté to think that with the transformative technologies already in sight—genetics, nanotechnology and so on—and with thousands of millennia still ahead of us to perfect and apply these technologies and others that we haven't yet conceived of, human nature and the human condition will remain unchanged for all future. Instead, if we survive and prosper, we will presumably develop into some kind of posthuman existence.

So this is why I conclude that the silence of the night sky is golden, and why, in the search for extraterrestrial life, no news is good news. It promises a potentially great future for humanity.

None of this means that we ought to cancel our plans to have a closer look at Mars. If the red planet ever harbored life, we might as well find out about it. It might be bad news, but it would tell us something about our place in the universe, our future technological prospects, the existential risks confronting us, the possibilities for human transformation: issues of considerable importance.

It is impossible to know in advance what insights might be gleaned by applying the kind of careful and systematic study to such big questions that we apply every day to smaller and less consequential technological and scientific problems. There may be surprising arguments and ideas out there merely waiting to be discovered. Some of these might even turn out to have practical ramifications of such importance as to change our whole scheme of priorities. Perhaps the greatest benefit from the SETI program will result if it prompts thinking about these larger matters.

Theoretically, smart ambitious scholars could start thinking without waiting for such prompts. Expensive instruments, however, have a way of lending scientific status and respectability to a field of inquiry. Academics are keen to put as much distance as possible between themselves and the kooks and cranks that flock to these big questions. If large telescopes, NASA satellites, and complicated mathematical data analysis are involved, it becomes harder for outside observers to mistake the work for the ramblings of UFO-nuts and other crackpots. There may be no signals from space, yet those with their antennas tuned to more anthropomorphic wavelengths are sure to pick up a buzz of social signaling in people's attitudes towards the search for extraterrestrial beings. Such social background noise might in fact be one of the main obstacles to intellectual progress on many big picture topics.

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