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Where Are They?

Why I hope the search for extraterrestrial life finds nothing.

By Nick Bostrom

People got very excited in 2004 when NASA's rover *Opportunity* discovered evidence that Mars had once been wet. Where there is water, there may be life. After more than 40 years of human exploration, culminating in the ongoing Mars Exploration Rover mission, scientists are planning still more missions to study the planet. The Phoenix, an interagency scientific probe led by the Lunar and Planetary Laboratory at the University of Arizona, is scheduled to land in late May on Mars's frigid northern arctic, where it will search for soils and ice that might be suitable for microbial life *(see "Mission to Mars (http://www.technologyreview.com/Energy/19502/?a=f) ," November/December 2007)*. The next decade might see a Mars Sample Return mission, which would use robotic systems to collect samples of Martian rocks, soils, and atmosphere and return them to Earth. We could then analyze the samples to see if they contain 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 discover nothing. It would be good news if we find Mars to be 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 that looked 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-form we found, the more depressing the news would be. I would find it 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, Raëlian cultists, and self-certified alien abductees notwithstanding, humans have, to date, seen no sign of any extraterrestrial 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 Intelligence (SETI) has been going for nearly half a century, employing increasingly powerful telescopes and data-mining techniques; so far, it has 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?" is thus at least as pertinent today as it was when the physicist Enrico Fermi first posed it during a lunch discussion with some of his colleagues at the Los Alamos National Laboratory back in 1950.

Here is another fact: the observable universe contains on the order of 100 billion galaxies, and there are on the order of 100 billion stars in our galaxy alone. In the last couple of decades, we have learned that many of these stars have planets circling them; several hundred such "exoplanets" have been discovered to date. Most of these are gigantic, since it is very difficult to detect smaller exoplanets using current methods. (In most cases, the planets cannot be directly observed. Their existence is inferred from their gravitational influence on their parent suns, which wobble slightly when pulled toward large orbiting planets, or from slight fluctuations in luminosity when the planets partially eclipse their suns.) We have every reason to believe that the observable universe contains vast numbers of solar systems, including many with planets that are Earth-like, at least in the sense of having masses and temperatures similar to those of our own orb. We also know that many of these solar systems are older than ours.

From these two facts it follows that the evolutionary path to life-forms capable of space colonization leads through a "Great Filter," which can be thought of as a probability barrier. (I borrow this term from Robin Hanson, an economist at George Mason University.) The filter consists of one or more evolutionary transitions or steps that must be traversed at great odds in order for an Earth-like planet to produce a civilization capable of exploring distant solar systems. 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 sufficiently powerful--which is to say, passing the critical points must be sufficiently improbable--that even with many billions of 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, just where might this Great Filter be located? There are two possibilities: It might be behind us, somewhere in our distant past. Or it might be ahead of us, somewhere in the decades, centuries, or millennia to come. Let us ponder these possibilities in turn.

If the filter is in our past, there must be some extremely improbable step in the sequence of events whereby an Earth-like planet gives rise to an intelligent species comparable in its technological sophistication to our contemporary human civilization. Some people seem to take the evolution of intelligent life on Earth for granted: a lengthy process, yes; complicated, sure; yet ultimately inevitable, or nearly so. 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 emergence of intelligent life on Earth was. Moreover, if we look back at our evolutionary history, we can identify a number of transitions any one of which could plausibly be the Great Filter.

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

The oldest confirmed microfossils date from approximately 3.5 billion years ago, and there is tentative evidence that life might have existed a few hundred million years before that; but there is no evidence of life before 3.8 billion years ago. Life might have arisen considerably earlier than that without leaving any traces: there are very few preserved rock formations that old, and such as have survived have undergone major remolding over the eons. Nevertheless, several hundred million years elapsed between the formation of Earth and the appearance of the first known life-forms. 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.

Conclusively determining the probability of any given evolutionary development is difficult, since we cannot rerun the history of life multiple times. What we can do, however, is attempt to identify evolutionary transitions that are at least good candidates for being a Great Filter--transitions that are both extremely improbable and practically necessary for the emergence of intelligent technological civilization. One criterion for any likely candidate is that it 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 to occur even after its prerequisites were in place. A long delay suggests that vastly many random recombinations occurred before one worked. Perhaps several improbable mutations had to occur all at once in order for an organism to leap from one local fitness peak to another: individually deleterious mutations might be fitness enhancing only when they occur together. (The evolution of *Homo sapiens* from our recent hominid ancestors, such as *Homo erectus*, happened rather quickly on the geological timescale, so these steps would be relatively weak candidates 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 enough for a wide range of organic molecules to be stable. Later evolutionary history offers additional possible Great Filters. For example, it took some 1.8 billion years for prokaryotes (the most basic type of single-celled organism) to evolve into eukaryotes (a more complex kind of cell with a membrane-enclosed nucleus). That is a long time, making this transition an excellent candidate. Others include the emergence of multicellular organisms and of sexual reproduction.

If the Great Filter is indeed behind us, meaning that the rise of intelligent life on any one planet is extremely improbable, then it follows that we are most likely the only technologically advanced 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 it may contain infinitely many stars. If so, then it is virtually certain that an infinite number of intelligent extraterrestrial species exist, no matter how improbable their evolution on any given planet. However, cosmological theory implies that because the universe is expanding, any living creatures outside the observable universe are and will forever remain causally disconnected from us: they can never visit us, communicate with us, or be seen by us or our descendants.)

The other possibility is that the Great Filter is still ahead of us. This would mean that some great improbability prevents almost all civilizations at our current stage of technological development from progressing to the point where they engage in large-scale space colonization. For example, it might be that any sufficiently 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 extraterrestrials are out there in abundance but hidden from our view. I think that this is unlikely, because if extraterrestrials do exist in any numbers, 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 intelligent species might colonize space. They might send out "manned" spaceships, which would establish colonies and "terraform" new planets, beginning with worlds in their own solar systems 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, among whose many mathematical and scientific achievements was the concept of a "universal constructor," or a self-replicating machine. A von Neumann probe would be an unmanned self-replicating spacecraft, controlled by artificial intelligence and 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. In a scenario proposed by Frank Tipler in 1981, replicas would then be launched in various directions, setting in motion a multiplying colonization wave. Our galaxy is about 100,000 light-years across. If a probe were capable of traveling at one-tenth the speed of light, every planet in the galaxy could thus be colonized within a couple of million years (allowing some time for each probe that lands on a resource site to set up the necessary infrastructure and produce daughter probes). If travel speed were limited to 1 percent of light speed, colonization might take 20 million years instead. The exact numbers do not matter much, because the timescales are at any rate very short compared with the astronomical ones on which the evolution of intelligent life occurs.

If building a von Neumann probe seems very difficult--well, surely it is, but we are not talking about something we should begin work on today. Rather, we are considering what would be accomplished with some very advanced technology of the future. We might build von Neumann probes in centuries or millennia--intervals that are mere blips compared with the life span 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 at the edge of 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 choose to do so. Perhaps it would prefer to stay at home and live in harmony with nature. However, a number of considerations make this explanation of the great silence less than plausible. First, we observe that life has here on Earth manifested a very strong tendency to spread wherever it can. It has populated 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 find that it has spread to every part of the planet, and we have even established a presence in space, at vast expense, with the International Space Station. Third, if an advanced civilization has the technology to go into space relatively cheaply, it has an obvious reason to do so: namely, that's where most of the resources are. Land, minerals, energy: all are 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 most advanced civilizations chose to remain nonexpansionist forever, it wouldn't make any difference as long as there was one other civilization that opted to launch the colonization process: that expansionary civilization would 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 begin colonizing the universe.

For all these reasons, it seems unlikely that the galaxy is teeming with intelligent beings that voluntarily 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 as if we were animals in a zoo. I don't see how we can conclusively rule out this possibility. But I will set it aside in order to concentrate on what to me appear more plausible answers to Fermi's question.

The more 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 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 probably 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 still could have arrived here hundreds of millions of years ago.

The Great Filter, then, would have to be something more dramatic than run-of-the mill societal collapse: it would have to be a terminal global cataclysm, an existential catastrophe. An existential risk is one that threatens to annihilate intelligent life or permanently and drastically curtail its potential for future development. In our own case, we can identify a number of potential existential risks: a nuclear war fought with arms stockpiles much larger than today's (perhaps resulting from future arms races); a genetically engineered superbug; environmental disaster; an asteroid impact; wars or terrorist acts committed with powerful future weapons; superintelligent general artificial intelligence with destructive goals; or high-energy physics experiments. These are just some of the existential risks that have been discussed in the literature, and considering that many of these have been proposed only in recent decades, it is plausible to assume that there are further existential risks we have not yet thought of.

The study of existential risks is an extremely important, albeit rather neglected, field of inquiry. But in order for an existential risk to constitute a plausible Great Filter, it must be of a kind that could destroy virtually any sufficiently advanced civilization. For instance, random natural disasters such as asteroid hits and supervolcanic eruptions are poor Great Filter candidates, because even if they destroyed a significant number of civilizations, we would expect some civilizations to get lucky; and some of these civilizations could then go on to colonize the universe. Perhaps the existential risks that are most likely to constitute a Great Filter are those that arise from technological discovery. It is not far-fetched to imagine some possible technology such that, first, virtually all sufficiently advanced civilizations eventually discover it, and second, 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 will, too, since we have no reason to think that we will be any luckier than other species. 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 had 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 very improbable. If it happened independently twice here in our own backyard, it must surely have happened millions of times across the galaxy. This would mean that the Great Filter is less likely to be confronted during the early life of planets and therefore, for us, 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 come 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 multicellular organism, that would eliminate a much larger set of evolutionary transitions from consideration as the Great Filter. The effect would be to shift the probability more strongly against the hypothesis that the Great Filter is behind us. And if we discovered the fossils of some very complex life-form, such as a vertebrate-like creature, we would have to conclude that this hypothesis is very improbable indeed. It would be by far the worst news ever printed.

Yet most people reading about the discovery would be thrilled. They would not understand the implications. For if the Great Filter is not behind us, it is ahead of us. And that's a terrifying prospect.

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 of 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--planets 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 originate from a place where intelligent life did, in fact, 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 a random sample from the subset of planets that did engender intelligent life, this being a crude formulation of one of the saner ideas extractable from the motley ore referred to as the "anthropic principle.")

Since this point confuses many, it is worth expanding on it slightly. Consider two different hypotheses. One says that the evolution of intelligent life is a fairly straightforward process that happens on a significant fraction of all suitable planets. The other hypothesis says that the evolution of intelligent life is extremely complicated and happens perhaps on only one out of a million billion planets. To evaluate their plausibility in light of your evidence, you must ask yourself, "What do these hypotheses predict I should observe?" If you think about it, both hypotheses clearly predict that you should observe that your civilization originated in places where intelligent life evolved. All observers will share that observation, 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 preceding reasoning precludes there being steps in the Great Filter both behind us and ahead of us. It might be extremely improbable both that intelligent life should arise on any given planet and 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 found to be barren. In that case, we may have a significant chance of one day growing into something greater than we are now.

In this scenario, the entire history of humankind to date is a mere instant compared with the eons that still lie before us. All the triumphs and tribulations of the millions of people who 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 yet begun. For surely it would be the height of naïveté to think that with the transformative technologies already in sight--genetics, nanotechnology, and so on--and with thousands of millennia still ahead of us in which to perfect and apply these technologies and others of which we haven't yet conceived, human nature and the human condition will remain unchanged. Instead, if we survive and prosper, we will presumably develop some kind of posthuman existence.

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, and the possibilities for human transformation--issues of considerable importance.

But in the absence of any such evidence, I conclude that the silence of the night sky is golden, and that in the search for extraterrestrial life, no news is good news.

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