Why don't we see robotic civilizations rapidly expanding across the universe?

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The central region of the Milky Way, also known as the Zone of Avoidance. Credit: ESO/S. Brunier

In 1950, while sitting down to lunch with colleagues at the Los Alamos Laboratory, famed physicist and nuclear scientist Enrico Fermi asked his famous question: "Where is everybody?" In short, Fermi was addressing the all-important question that has plagued human minds since they first realized planet Earth was merely a speck in an infinite universe. Given the size and age of the universe and the way the ingredients for life are seemingly everywhere in abundance, why haven't we found any evidence of intelligent life beyond Earth?

This question has spawned countless proposed resolutions since Fermi's time, including the infamous Hart-Tipler Conjecture (i.e., they don't exist). Other interpretations emphasize how space travel is hard and extremely time and energy-consuming, which is why species are likely to settle in clusters (rather than a galactic empire) and how we are more likely to find examples of their technology (probes and AI) rather than a species itself. In a recent study, available as an OSF preprint, mathematician Daniel Vallstrom examined how artificial intelligence might be similarly motivated to avoid spreading across the galaxy, thus explaining why we haven't seen them either.

The Hart-Tipler Conjecture originated in 1975 when astronomer (and white nationalist) Michael Jart wrote a paper titled "An Explanation for the Absence of Extraterrestrials on Earth." At the core of Hart's argument is the notion that any ETC that arose in the Milky Way in the past would have had ample time to develop interstellar travel and establish outposts of its civilization in other star systems. These outposts would eventually send their own ships outward, leading to the creation of a Galactic civilization that covered the majority of the Milky Way.

Where is everybody?

Based on his calculations, Tipler determined that a civilization limited to a modest fraction of the speed of light (10%) could accomplish this within just 650,000 years—long before life and human civilization arose on Earth. Given the fact that no evidence of any civilization existed (what Hart called "Fact A") means that there were no ETCs and humanity was alone in the universe. In 1980, physicist and cosmologist Frank Tipler took things further in his paper "Extraterrestrial Intelligent Beings Do Not Exist," where he employed refined calculations and the

Copernican Principle.

Also known as the Cosmological Principle, this axiom states that neither Earth nor humanity are in a privileged or unique position to view the universe. In other words, our planet, our system, and our species are representative of the norm. In this vein, Tipler theorized that an ETC would be assisted by self-replicating robotic explorers (von Neumann probes) that would spread from system to system, facilitating the arrival of settlers later. As he wrote:

"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… I shall therefore assume that such a species will eventually develop a self-replicating universal constructor with intelligence comparable to the human level… 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."

No organics, robots

The idea that humanity is not likely to come into contact with an alien species but could learn of their existence through their robotic emissaries is a foregone conclusion among many SETI researchers. And it certainly makes sense. Why send a crewed mission on a multi-generational interstellar voyage fraught with hazards and no guarantee of success when you can send self-replicating robots? In addition to not being vulnerable to cosmic radiation, these probes could expand outwards ad infinitum, carrying messages of greetings to anyone they encounter.

Far from being a matter of theory, proponents of this idea point toward our own history of launching probes into deep space. Since 1972, humanity has sent five probes that are currently (or destined to be) in interstellar space: Pioneer 10 and 11, Voyager 1 and 2, and New Horizons. The possibility that extraterrestrials may someday intercept these deep-space missions was strongly considered, leading to the creation of the Pioneer Plaque and the Voyager Golden Record. Per the Copernican Principle, the fact that humanity has sent five probes destined for interstellar space in just fifty years means it is likely that other species have been doing the same for much longer.

Avi Loeb, the Frank B. Baird Jr. Professor of Science at Harvard University and founder of the Galileo Project, advanced this very argument in his recent book "Interstellar: The Search for Extraterrestrial Life and Our Future in the Stars."

"SETI's traditional approach, however, remains the equivalent of waiting for your phone to ring. To receive an electromagnetic signal, we need the sender to transmit it exactly a light-travel-time ago with similar communication technologies to those we developed over the past century. The odds of this happening are mind-bogglingly long... The longer we persist, the more often we are likely to send craft out into interstellar space. And the opposite logic holds true: any civilization similar to ours that managed to last for millions of years could well have sent out billions of such craft. It is high time scientists looked deliberately for them."

Of course, this raises the question: if we're likely to find bits of an intelligent civilization's technology rather than members of a civilization itself, why haven't we?

It ain't easy being Type III

Addressing Hart's "Fact A," many proposed resolutions to the Fermi Paradox questioned the notion that extraterrestrial civilizations would attempt to spread across our galaxy—something the Hart-Tipler

Conjecture treats as a foregone conclusion. This includes "Percolation Theory," which Geoffrey A. Landis presented in a 1993 paper where he argued that the laws of physics would impose limits on the extent of a species' interstellar expansion. Instead of a uniformity of expansion, species would be more likely to "percolate" outward, which would be subject to expansion and contraction.

A key point in Landis' study is that there would be no "uniformity of motive" among extraterrestrial civilizations, with some choosing to venture out and others opting to "stay at home." Another proposed resolution was advanced by Serbian astronomer and astrophysicist Milan M. Cirkovic in his 2008 study, "Against the Empire." Using two models for determining the behaviors of an extraterrestrial civilization—what he called the "Empire-State" or the "City-State" model—Cirkovic questioned whether a species would invariably be expansion-driven or optimization-driven.

In 2019, Prof. Adam Frank and colleagues from NASA's Nexus for Exoplanetary Systems Science (NExSS) released a study where they argued that settlement of the galaxy would also occur in clusters because of inhospitable environments. Named in honor of the novel "Aurora" by Kim Stanley Robinson, Frank and his colleagues simulated how a civilization's expansion across the galaxy would be limited by the "Aurora effect"—where habitable planets are not hospitable due to the presence of indigenous species.

However, for his study, Vallstrom emphasized another source of motivation for robotic explorers: morality. Not morality in the traditional sense, mind you, but in the sense of decisions that ensure long-term survival. As he explained:

"With an evolutionary approach, the basis of morality can be explained as adaptations to problems of cooperation. With 'evolution' taken in a broad sense, evolving AIs that satisfy the conditions for evolution to apply will be subject to the same cooperative evolutionary pressure as biological entities… Diminishing beneficial returns from increased access to material resources also suggests the possibility that, on the whole, there will be no incentive to colonize entire galaxies, thus providing a possible explanation of the Fermi paradox."

Central to Vallstrom's study is the notion that advanced societies will eventually give rise to super-AIs as a function of evolution—as they ought to be safer, more efficient, more flexible, and fitter. This is especially true where space exploration is concerned, which entails considerable hazards for biological entities. He further argues that the Fermi Paradox is only paradoxical if one assumes that societies and super-AIs are "exhaustively expansive," which is debatable for three reasons. The first has to do with material resource utilization, beyond which accumulating more will offer diminishing returns.

This diminishing effect, says Vallstrom, will eventually lead societies to adopt cooperation in the form of trade, collaboration, and redistribution. Taking this a step further, Vallstrom argues that cooperative societies and super-AIs would need a good reason to pursue exponential growth and settle an entire galaxy, eventually culminating in a Kardashev type III society. In addition, he posits that evolution would not necessarily favor rapid or exponential reproduction, as evidenced by three points. First, there is how entities living on a surface can only spread so fast as a function of time for mathematical reasons, as each entity takes up a certain amount of space, and others must travel farther to find more.

Second, Vallstrom argues how biological evolution emphasizes "fitness," where species continue to evolve to adapt to (and fill niches) in their environment. This does not necessarily favor very fast reproduction, which can be maladaptive when numbers outstrip resources. Third, there are cultural evolution and other changes to consider, as exemplified by human fertility rates. "[T]he number of births peaked in 2012 and is projected to continue to get smaller," he writes, "hence the number of children peaked in 2017 and is projected to continue to get smaller, and (hence) human population is projected to decrease within a few generations."

So where are all the robots?

Lastly, there is the question of where we should look for super-AIs or robotic space explorers. First, Vallstrom states plainly that advanced civilizations and super-AIs would not be likely to contact us since they would be unlikely to benefit from it. Simply put, a highly advanced species would have little reason to contact a less advanced species, not unless the cost of doing so was small or there was mutual benefit to be had. "For example, we probably wouldn't fault old societies or super-AIs for not helping, say, the dinosaurs or the Neanderthals," he writes.

So, if we assume we will not hear from them anytime soon, how could humanity search for evidence of advanced intelligence and its AI progeny? This is where the question of motivations and morality really comes into play. Suppose we also accept that advanced civilizations and super-AI are not motivated by the desire for exponential growth, eventually leading to a Kardashev type III society. In that case, we must consider other, more pragmatic concerns. For example, Vallstrom ventures that super-AIs might be concerned about the eventual fate of the universe, known as the "heat death" scenario.

According to the predominant cosmological model—the lambda cold dark matter (LCDM) model—the universe will eventually expand to the point that the cosmic microwave background (CMB) will recede into the radio end of the spectrum and that anything beyond our galaxy will be beyond the event horizon (and therefore, invisible). Therefore, Super-AIs may be motivated to prepare for this eventuality (since it will also mean their death) by grouping galaxy clusters together and extending the life of their stars. As Vallstrom wrote, this represents a prediction that may one day be testable for SETI researchers:

"It would, possibly, be better to have fewer and larger clusters rather than more and smaller clusters, all other things being equal… [A]s a hypothetical example, if we observe configurations—at lower redshifts, but not at very high ones—that in the far future will result in useful clusters, and to a larger extent than what we would otherwise expect, then perhaps we might consider the possibility that those observations could be signs of super-AI actions. Further, if super-AIs will succumb to heat death, then possibly they could try to reduce entropy waste, e.g. maybe by affecting star formation."

For decades, the Search for Extraterrestrial Intelligence (SETI) has been guided by a handful of established principles. These include the notion that intelligent life will be subject to the same physics and technological principles as humanity (the Copernican Principle), subject to a spectrum of motivations, and likely be older and more advanced than humanity. After sixty years of surveys, two things remain unchanged: one, we haven't found any evidence that we are not alone in the universe, and two, we have barely scratched the surface.

In the meantime, coming up with testable predictions and ideas that challenge old assumptions gives us something to look forward to. And thanks to next-generation telescopes, advanced analytics, and growing support for SETI projects, we may finally get a chance to test them all.

More information: Daniel Vallstrom, Cooperative Evolutionary Pressure and Diminishing Returns Might Explain the Fermi Paradox: On What Super-AIs Are Like and Why We Don't See Them (2022). DOI: 10.31219/osf.io/bq438

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