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"Where is Everybody?" An Analysis of Our Search for Extraterrestrial Life

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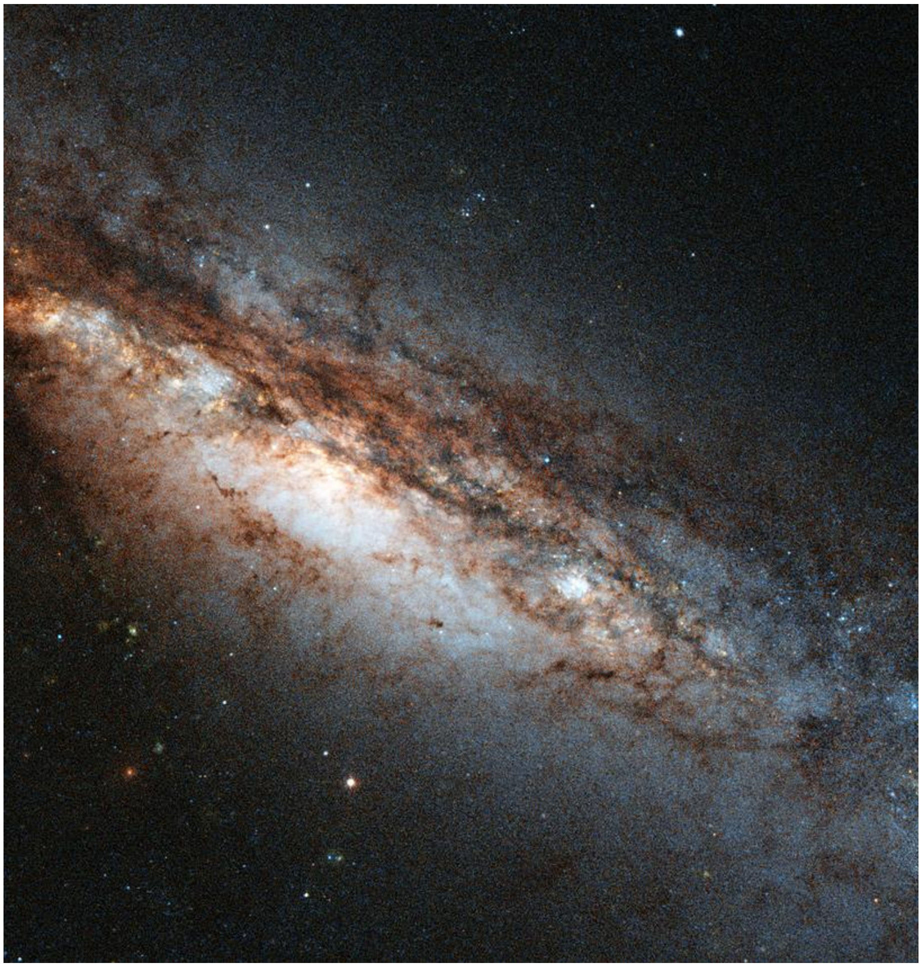

“Where is Everybody?”

AN ANALYSIS OF OUR SEARCH FOR EXTRATERRESTRIAL LIFE

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Abstract

In this paper, I will explore the historical context of our search for extraterrestrial life. Along with this, I will include our current knowledge of the universe, putting emphasis on new discoveries in the field of astrobiology made in the last decade, as well as some expert positions on the possibility of extraterrestrial life being discovered in our future. My exploration includes unpacking and examining the Drake Equation and the Fermi Paradox, along with the implications that they have for each other. I will also include my own version of the Drake Equation and my opinion of the Fermi paradox and a few of its various solutions.

Introduction

One of the defining traits of humanity is our innate curiosity. Throughout history we have pushed the boundaries of the unknown so that we might ultimately learn to know it. From decoding the human genome to splitting the atom to exploring new frontiers on land and in the ocean, we have always strived to expand our knowledge of ourselves and our place in the universe. The new frontier for human knowledge now lies in space. People have been looking up to the stars for eons, giving them names and slowly but surely uncovering secrets of our planet, our solar system, and the universe. Now, one of the explosive discoveries we're searching for is extraterrestrial life. We look up at the stars and wonder, "are we alone"? For the past 60 years, many scientists have been exploring this question in the hopes that we are not alone in the universe, but that we are a part of something bigger. They have been using various statistical methods to aid in their search and have run into certain problems as well, mainly the fact that we have yet to find any trace of extraterrestrial life. In this paper, I plan to explore one of these statistical methods, the Drake equation, and the main dilemma of this search, the Fermi paradox. Rarely are they analyzed in conjunction with each other, despite the fact that they are greatly intertwined by nature. I hope to remedy this by giving backgrounds on both, explaining how they work, discussing how they influence each other, and then providing my own opinions on the implications that they raise.

The Drake Equation

Frank Drake created the Drake equation in 1961 in order to have a way to evaluate the number of transmitting extraterrestrial civilizations in our galaxy. He started down this path in

1959, when physicists Giuseppe Cocconi and Philip Morrison published an article in *Nature* about "Searching for Interstellar Communications". They thought that our radio telescopes had become sensitive enough to pick up transmission sent by civilizations on other planets. They posited that we should focus our efforts on the wavelength 21 centimeters (1,420.4 megahertz) because this is the emission of neutral hydrogen, the most common element in the universe. They felt that other civilizations would view this as a logical landmark in the electromagnetic spectrum where people like us could find it. Frank Drake took this information and became the first person to start a systematic search for extraterrestrial transmissions. His project was called the Ozma experiment, and he used the dish at the National Radio Astronomy Observatory to scan this frequency six hours a day from April to July in 1960. After the experiment in 1961, Drake organized a meeting with fellow enthusiastic scientists to discuss the prospects of the search for extraterrestrial life (SETI). Astrophysicist Carl Sagan and Nobel Prize-winning chemist Melvin Calvin both attended (Schilling and MacRobert 2013). In preparing for this meeting he came up with the Drake Equation, which is as follows:

$$N = R \times f_p \times n_h \times f_L \times f_i \times f_c \times L$$

R is the rate that stars form in our galaxy. f_p is the fraction of those stars that have planets. n_h is the average number of planets per planetary system that are habitable. f_L is the fraction of those planets that had life form and evolve. f_i is the fraction of inhabited planets that then also developed intelligent life. f_c is the fraction of those worlds with intelligent life that then went on to develop civilizations that are capable of interstellar communication. L is the lifetime of those communicating civilizations. Multiply all of these variables together and you get N, the number of extraterrestrial civilizations capable of transmitting in our galaxy (Catling 2013).

Table 1

Variable	Description
N	the number of extraterrestrial civilizations capable of transmitting in our galaxy
R	the rate that stars form in our galaxy
f_p	the fraction of those stars that have planets
n_h	the average number of planets per planetary system that are habitable
f_L	the fraction of those planets that had life form and evolve
f_i	is the fraction of inhabited planets that then also developed intelligent life
f_c	the fraction of those worlds with intelligent life that then went on to develop civilizations that are capable of interstellar communication
L	is the lifetime of those communicating civilizations

This straightforward equation breaks down a large unknown into smaller variables that are addressable, though not quantifiable with any certainty (Table 1). It has allowed the SETI project to become a tangible effort and gave a scientific basis to the question of alien life. Astronomers, biologists and other scientists have been trying to "solve" the equation ever since, and while the premise of it is straightforward, the actual application of it is very theoretical. Some of the variables have been researched and elaborated on in the last few decades, but some of them will remain speculative until the time life on other planets is discovered, if it ever is discovered (Schilling and MacRobert 2013).

There are a multitude of scenarios for the equation. One version of the equation comes from physicist Stephen Webb. He sets R = 1 (a rate of star formation in the galaxy as one star per year), $f_p = 0.5$ (half the stars have planets), $n_h = 2$ (stars with planets on average each have two planets with environments conducive to live), $f_L = 1$ (every planet that can develop life will develop life), $f_i = 1$ (once life develops, intelligent life certainly will follow), $f_c = 0.1$ (one in ten intelligent life-forms will develop a civilization capable of communication), and $L = 10^6$ (civilizations remain in the communication phase for about one million years). This gives $N = 10^6$, or one million civilizations in our galaxy are currently capable of communication with us (Webb 2002).

A more recent view comes from astrobiologist David Catling. He sets R = 10 (astronomers are currently observing ten new stars per year of class G, M, and K types), $f_p = 2/3$ (current exoplanet searches suggest that at least this many stars have planets), $n_h = 1/100$ (data from the Kepler mission to survey the Milky Way are still being analyzed, but it seems like this is a likely number for habitable planets), $f_L = 0.5$ (life developed rapidly on earth, so it's likely that life originates on half of habitable planets), $f_i = 1/8$ (the fraction of biospheres that develop intelligent life), $f_c = 0.1$ (one in ten intelligent biospheres is capable of interstellar transmissions), L = 10,000 (sociological speculation, but we'll assume that the lifetime of communicating civilizations is 10,000 years). This gives N = 4, or there are four currently communicating civilizations in our galaxy (Catling 2013). It is important to note that while the Drake equation is a strong theoretical exercise that allows scientists to hone in on certain areas of astrobiology that needed to be further explored, it is also inherently filled with uncertainty. In science, statistical significance is required to accept any findings as correct, but due to the large knowledge gaps in the variables of the equation, no statistical significance can be determined with any certainty. Thus, the Drake Equation remains an effective mental exercise, but the outputs should never be taken as solid facts.

Implications of New Research for the Drake Equation

New research being conducted could potentially assist in making some of the variables in this equation more accurate in order to ensure a more realistic output. Exoplanet studies and the search for life in our own solar system will help fine tune the number of potentially habitable planets that reside around each star. NASA's Kepler mission is currently surveying and cataloguing the Milky Way in an attempt to identify and map habitable exoplanets. In our own solar system, scientists are relatively optimistic that there might be at least microbial extraterrestrial life. Discoveries of extremophiles on earth have opened possibilities of habitability that we hadn't considered before: thermophiles live deep in Earth's crust, in hot springs at Yellowstone National Park, and by hydrothermal vents deep in the Antarctic Ocean. Some locations in the solar system that scientists are searching for life are in a potential subsurface ocean on the Ceres asteroid, a subsurface ocean on Europa (large, icy moon of Jupiter), lakes of methane on the surface of Titan (largest moon of Saturn), and a potential subsurface ocean of Enceladus (icy moon of Saturn) which also has a presence of organics (Catling 2013).

The other variables can't be nailed down for sure, but scientists can use available information to try and fine tune them as much as possible. For example, the parameters set for the variables influence how you would interpret them. In the case of f_i (the likelihood of intelligent life developing), it would be prudent to define what intelligence means, and by doing so determine how common it occurs on earth. Multiple species capable of intelligence on earth versus just humans being capable of intelligence would have different implications on the application of that variable in the Drake equation. Should intelligent life be common on Earth, our only guide to life in the universe, it should be safe to assume that intelligent life would be common on any other planets. The opposite would be true if intelligent life is uncommon on earth, as we could assume that intelligent life on other planets would be less common as well. I would argue that there is no one good definition of intelligence, and that it depends entirely on the context of what you're trying to determine: is Mozart more intelligent than Einstein or vice versa? Because of this, I will proceed using the generic definition of intelligence given by the Merriam-Webster dictionary: “the ability to learn or understand or to deal with new or trying situations, the ability to apply knowledge to manipulate one’s environment or to think abstractly as measured by objective criteria (such as tests)”. Using this definition, it becomes apparent that much of life on earth is intelligent, not just humans.

For example, dolphins are capable of problem-solving. Dolphins hunt fish, though often schools of fish are elusive due to their quick nature and therefore escape predation. However, some dolphin pods in Florida have been seen utilizing a unique hunting strategy to get around this problem that includes individual role specializations. This strategy is called “mud-ringing”. One dolphin will beat their tail against the ground in increasingly smaller circles around a shoal of fish, creating a mud barrier that the fish need to jump over to escape. When the fish jump over the mud barrier, they jump right into the waiting dolphins’ mouths (Gazda et al. 2005). This type of role specialization and unique hunting strategy shows an ability in dolphins to recognize an obstacle and then find a way around that obstacle in an efficient and effective manner.

Another example of animal intelligence involves primates and their ability to learn rudimentary language and understand abstract ideas. A chimpanzee named Washoe was taught how to sign and communicate in ASL (over 350 signs). She had previously been pregnant twice, and had lost both of the babies. In 1989, research assistant Kat Beach became pregnant, and when she walked in to the rooms with Washoe, the chimp would sign “baby” at Kat’s belly repeatedly. Kat ended up having a miscarriage, and decided to tell Washoe about it, and so when she returned to work she signed “my baby died” to Washoe. The chimp signed back “cry” and touched her cheek below her eye, and when Kat left for the day, Washoe signed “please person hug” (Safina 2015). This shows a capacity in chimpanzees for practical and emotional intelligence, and certainly is included the dictionary definition of intelligence.

My Equation

Using this definition for intelligence and the new discoveries of extremophiles and exoplanets, I’ve formed my own version of the Drake equation. I will set $R = 10$, as this is the current rate of star formation as determined by astronomers. I will set $f_p = 2/3$, which based on current exoplanet searches, like that of Kepler, is the number of stars in the galaxy that have planets. I will set n_h = 1/10 and say that one in ten planets are habitable, not just those located in the Goldilocks zone, due to the discovery of extremophiles and current searches for life in our solar system. I will set f_L = 1 under the assumption that if a planet it habitable, it will have enough resources that life will then develop. I will set f_i = 3/4 by using earth as a model. Since intelligent life seems to be so abundant on earth (primates, dolphins and a multitude of other animals), I will assume that the majority of planets with life will most likely develop some form of intelligent life as well. I will set f_c = 1/100 due to the fact that despite Earth having so much intelligent life (humans and animals included), only humans have become capable of interstellar communication. Because of this, I will posit that a lot of intelligent alien life may not become capable of communication or space travel as well. I will set L = 200,000 because this variable is pure sociological speculation, so I arbitrarily will pick the current length of time modern humans have been on the planet. This gives me N = 1000, or there are currently one thousand communicating extraterrestrial civilizations in the Milky Way. However, regardless of if the Drake equation tells us there's a million planets, a thousand planets, or four planets trying to communicate with us in our galaxy, the dilemma remains the same: in over 50 years of the SETI project, no extraterrestrial life has been found. This is the heart of the Fermi paradox.

The Fermi Paradox

Enrico Fermi was a renowned physicist in both the experimental and theoretical fields. He analyzed the behavior of the fundamental particles that make up matter: protons, neutrons, and electrons. He also came up with the modern theory of beta decay, which is a form of radioactivity. He won a Nobel Prize for physics in 1938 for his technique used to probe atomic nuclei that led to more than 40 artificial radioisotopes, and his discovery on how to make neutrons move slowly, which is used in the operation of nuclear reactors. Fermi came to America from Italy during the reign of Mussolini to help his Jewish wife escape persecution. He then started working on nuclear fission research commissioned by President Roosevelt. His group achieved the first self-sustaining nuclear reaction and he also estimated the energy output of bombs that were being tested in the Manhattan Project. He died in 1954 at the age of 53 from stomach cancer.

The origin of the Fermi paradox has often been traced back to a 1950 lunch in Los Alamos. During that spring and summer in New York, there were widespread disappearances of public trashcans, the same year as a spike in flying saucer reports. This led to *The New Yorker* publishing a cartoon that connected the two, implying the Martians were taking them. This led to Fermi, who was in New York for a meeting at the time, discussing the logistics of flying saucers with Edward Teller, Herbert York, and Emil Konopinski. They were pondering if it was possible for the saucers to exceed the speed of light. After this discussion, he reportedly asked "where is everybody?", which ultimately led to the creation of the Fermi paradox. The Drake equation had set up a precedent that there could potentially be intelligent civilizations out there. Assuming that those civilizations are long-lived and technologically advanced, we could reasonably expect them to colonize the galaxy, especially since we're expanding into space as well. The paradox is that we don't see these alien civilizations when we might expect to, and so they must not exist (Webb 2002). Some even go farther and say that since some solar systems in the Milky Way are 9 billion years old and Earth is only 4.5 billion years old, if intelligent life is common many civilizations should have arisen long before us humans (Catling 2013).

It is important to note that the Fermi paradox is not actually the creation of Fermi. When he asked, "where is everybody?", he was asking it in response to whether or not interstellar travel is feasible, but he wasn't implying that alien life doesn't exist anywhere, as Fermi actually believed in the existence of extraterrestrials. The official paradox of "they're not here, therefore they don't exist" was published by Michael Hart in a 1975 paper. This paper influenced policy in Congress, convincing them of the futility of using resources to search for the electromagnetic spectrum for alien transmissions, and so they defunded NASA's SETI program. The program still exists, it is just privately funded instead of funded by the government. Frank Tipler extended the paradox in his 1981 paper to include not just the galaxy, but the whole universe, positing that humans are the only intelligent species in the universe (Gray 2015).

The Drake equation has implications for the Fermi paradox. No matter if you look at the optimistic or pessimistic scenario of the paradox, any scenario that gives a number of communicating civilizations above zero makes the paradox stronger. If there are communicating civilizations in our galaxy, it makes it more probable that we should have encountered them. The more optimistic scenarios are damning, because they make it more difficult to justify why we haven't encountered aliens yet. Recently, Frank and Sullivan introduced a modified Drake equation that strengthens the Fermi paradox even further. Rather than asking how many communicating civilizations exist now, they're asking if we're the only communicating species that has ever arisen. Their equation goes as follows:

$$A = N_{ast} \times f_{bt}$$

A is the number of technological species that have formed over the history of the observable universe. N_{ast} is the number of habitable planets in a given volume of the universe. f_{bt} is the likelihood of a technological species arising on one of these planets (Table 2). Frank and Sullivan applied new exoplanet data to the 2×10^{22} stars and found that human civilization is likely to be unique in the universe only if the odds of another civilization developing on a different habitable planet are less than one in 10 billion trillion. The odds of another technological species not evolving in our Milky Way are less than one chance in 60 billion (Sierra 2016). However, this doesn't mean they're still around today, as only the original Drake equation calculated the odds of current civilizations. With the odds stacked so firmly in the favor of extraterrestrial life, it's even more striking that we haven't seen any signs of alien life.

Table 2

Variable	Description
A	the number of technological species that have formed over the history of the observable universe
N_{ast}	the number of habitable planets in a given volume of the universe
f_{bt}	the likelihood of a technological species arising on one of these planets

Solutions to the Fermi Paradox

Ever since the Fermi paradox has been introduced, there has been a multitude of solutions introduced that would solve the paradox, ranging from ones given by experts to outlandish theories thought up for fun by regular citizens. I will present a few of the more common and fleshed out solutions, and break them up into two categories: aliens don't exist, and aliens do exist (Table 3). To give a basis for some of these theories, astrophysicist Nikolai Kardashev created the Kardashev scale to assist in the consideration of technological advancements by developing civilizations capable of interstellar travel. The scale measures a civilization's technological advancement based on how much energy it is able to utilize for communication. A Type I civilization, or a planetary civilization, is able to harness all of the energy that reaches their home planet from their parent star. Humans are close to achieving this, especially with the rise of renewable energies, but we're not there yet. A Type II civilization, or a stellar civilization, has figured out how to harness all of the energy of their home star. One of the most popular concepts for this is a Dyson sphere, which is a device that would surround the star and transfer all of its energy back to the home planet. A Type III civilization, or a galactic civilization, has harnessed all of the available energy in their galaxy (Kardashev 1964).

Table 3

Type of Theory	Solution
Aliens Don't Exist	Rare Earth Hypothesis
Aliens Don't Exist	The Great Filter
Aliens Do Exist	Visited Earth Before Intelligent Life
Aliens Do Exist	Earth is on Edge of Colonized Space
Aliens Do Exist	Aliens Live in a Utopia
Aliens Do Exist	Super-Intelligent Predatory Species
Aliens Do Exist	Zoo Hypothesis
Aliens Do Exist	Sustainability Hypothesis
Aliens Do Exist	Aliens Are Here and We've Seen Them
Aliens Do Exist	We Don't Recognize the Signals
Aliens Do Exist	We Haven't Been Listening Long Enough

Aliens Don't Exist

There are prevalent solutions to the Fermi paradox that posit that aliens either never existed, or don't exist right now. One of them is the Rare Earth Hypothesis, which posits that circumstances that led to life on earth are so uncommon that life (especially intelligent life) won't exist anywhere else. This includes the earth being in the right place in the galaxy, Jupiter capturing and diverting destructive comets, plate tectonics, and a moon to stabilize Earth's axial tilt and climate (Catling 2013). The second solution is called the Great Filter. The idea is that before a civilization can make it through the Kardashev Scale, it hits and obstacle or filter that causes it to die off. There are three subsections to this theory. One is that humans have already made it past the Great Filter. Perhaps the filter is the likelihood that life begins in the first place, or maybe it's the jump from single cells to complex ones, or it could even be the transition from semi-intelligence (apes) to complex intelligence (humans). The Great Filter could also still be ahead of us and humans are doomed. It could be a cataclysmic natural disaster like an asteroid or gamma ray burst, nuclear war, disease, overpopulation, or it could be a super-advanced technology that we built that ends up destroying us (Miller and Felton 2017).

However, it could also be argued that the Great Filter is still ahead of us but humans are one of the first, if not the first species that has a shot of making it past. It could be that we're in the right place at the right time. Perhaps the filter is relatively easy to get past, but conditions in our universe only just became good enough to support the type of intelligent life that makes it to the other side. It could even be argued that we could use the paradox to our own benefit. Maybe civilizations are common in the universe but they die off before they're able to complete interstellar communication and travel. As time goes on, this paradox becomes more paradoxical, because the greater the age of the universe, the more surprising it is that we haven't seen or been contacted by extraterrestrials. This strengthening of the paradox is to our advantage because if there is a "filter" that is taking out civilizations between the splitting of the atom and colonizing other star systems, we're more likely to discover what it is than our predecessors. The Fermi paradox points us towards prioritizing the gathering of astronomical data that would not have been available to past civilizations at our same level of development. We could then use this data to attempt to mitigate existential risks and formulate solutions (Miller and Felton 2017).

Aliens Do Exist

Other Femi paradox solutions involve the assertion that aliens are out there in space currently. They could have visited Earth before intelligent life existed here. Modern humans have only been around for 200,000 years of Earth's 4.5-billion-year lifespan. Aliens could have appeared here when the planet was still a ball of molten lava, or a ball of ice. Maybe our galaxy is colonized, but Earth is on the edge of colonized space so aliens haven't yet traveled far enough to reach us. When Europeans were colonizing the world, and landed in the Americas, it took them a while to run into all of the Native American tribes. There are also native tribes residing in the Amazon that we know next to nothing about. It could be that other civilizations live in a sort of utopia and therefore feel no need to colonize space. They could have downloaded their minds into self-sustaining virtual realities where they have no reason to look for outside resources or even energy.

On the darker side, it has been suggested that super-intelligent civilizations prey on lesser civilizations like ours. Other civilizations could either be wiped out before they can communicate with us, or no one else is broadcasting in order to try and avoid predation by the killer civilization (Webb 2002). Darwin's theory of natural selection and evolution favors species that adapt to survive. Colonizing nearby planets or a galaxy could be a means to gain much needed resources, or a form of self-defense. By killing off other species, an alien civilization might be ensuring that a rival species doesn't use up valuable resources, or pose a direct physical threat (Miller and Felton 2017). Another popular, yet ultimately unlikely, theory is the Zoo hypothesis. Proponents for this theory believe that Earth has been singled out as an exhibit for alien tourists or sociologists, and that they watch us through some sophisticated type on one-way mirror (SETI Institute 2017).

A relatively new theory, called the Sustainability Hypothesis, has been gaining traction in some scientific circles. The hypothesis states that "the absence of extraterrestrial observation can be explained by the possibility that exponential or other faster-growth is not a sustainable development pattern for intelligent civilizations". If exponential growth and expansion is unsustainable, then we wouldn't necessarily expect to see extraterrestrials yet as it would take longer to colonize. Scientists look to human populations as a model for this theory. The rate of growth of the global human population is currently decreasing. Humanity could potentially be transitioning towards a stable, sustainable development pattern. In all of human history, exponentially expansive growth has been unsustainable: you can't consume more resources than can be produced over the long-term. Resource depletion and degradation caused by human activities has led to violent conflicts and collapses of human populations. On Easter Island, it is believed that the major population decline was caused by major resource depletion. Many experts believe that if humans keep consuming resources at the level of unsustainability that we currently do, it will lead to a global population collapse, which would make us unable to colonize the galaxy (Haqq-Misra and Baum 2009).

There is another popular solution to the Fermi paradox that almost one-half of the US population believes in: aliens have already been to Earth and we've seen them. Thousands of sightings of unidentified flying objects (UFOs) are reported annually. However, despite the multitude of alien sightings throughout history, virtually all have been debunked, and rely solely on witness testimony without any hard, physical evidence needed to prove them scientifically (SETI Institute 2017). A couple of the more famous sightings include Tunguska and Roswell. In 1908, there was an explosion in Tunguska that felled acres of trees across the Siberian taiga. Researchers found no debris that would indicate and asteroid impact. After WWII, many people believed that it could have been due to a nuclear blast from a spaceship. However, scientists found no evidence of radioactivity at the site. It was eventually determined that the blast was due to a stony meteoroid that exploded in the atmosphere (Webb 2002). In 1947, there was a crash on a ranch in Roswell, New Mexico. Witnesses claimed to have seen a "flying disc" and some even claimed to have seen alien bodies on the crash site. US military claimed that it was a weather balloon. However, this turned out to be a coverup for Project Mogul, and the craft that crashed was actually a nuclear surveillance balloon commissioned by the US Air Force (Olmsted 2011).

More likely than little green men are the theories that aliens are broadcasting, but we either don't recognize their signals or we just haven't been listening long enough. We could potentially be focusing on the wrong frequencies, or maybe we don't have the right technologies yet, or other life forms communicate in different ways like telepathy. Most of the current SETI projects focus on the waterhole region, which is a quiet band of the electromagnetic spectrum with wavelengths of 21 and 18 centimeters. Widespread interstellar gas occurs at these wavelengths, with hydroxyl radicals at 18 and hydrogen at 21. Their presence absorbs radio noise, creating a "quiet" channel. Bernard Oliver theorized this would allow for an obvious band of communication with extraterrestrials and coined the phrase "water hole", which is a reference to watering holes, common places to meet and talk (Ross 2009). We also haven't been actively performing widespread searches for signals for very long: SETI was founded in 1984. Extraterrestrials could be communicating with each other or with us and we just haven't heard it yet. If that communication is in bursts instead of a continuous beacon, it would be even more difficult to detect. The Arecibo telescope (used for SETI) would need to be pointed in the exact right position of space, one of millions, and it would need to be at the exact right time (Webb 2002). It seems to me that we owe ourselves and any potential extraterrestrials a little patience.

There Is No Fermi Paradox

While the Fermi paradox and its solutions are a popular hallmark of the search for alien life and astrobiology, there are some that say no solutions are needed to solve the paradox because there is no paradox. Robert Freitas claims that the paradox is actually an unsound argument with evidentiary flaws, and set up the argument in syllogistic form to prove it.

1. If ETI exist, then ETI will come here
2. If ETI come here, then we will observe them
3. We have not observed them

Therefore, they have not come here

Therefore, ETI don't exist

The first and second premises cannot be determined as certainly true, so the argument for the paradox may be valid, but it is ultimately unsound and therefore useless. Premise 3 is only true for what we've seen in evidence so far, but it is not necessarily true that we will never observe them, just that we haven't observed them yet. To give some context on just how little of space we've actually searched, a good observational search limit for an extraterrestrial messenger probe could have a size as small as 1-10 meters. This has been derived from SETI search statistics, radar and infrared detectability, and assumptions on the purpose of said spacecraft (Freitas 1985). For reference, the Voyager 1 spacecraft is about 13 meters in length (Williams 2017). Our current technology is unable to detect 1-10 meter objects more than 1 au (astronomical unit, which is 93 million miles approximately, or the distance between the earth and the sun) away from Earth. This means that heliocentric orbital space is 99.99% unexplored for this size foreign objects, 99.96% of the surface area of the solar system is unexamined, and the rest of space as well. Objects that are buried or submerged on planets or moons would also be undetectable to us (Freitas 1985).

While some of this may be outdated information, especially for our solar system (our technology is better and we've explored farther and more completely in the last 30 years), the fact remains that the vast majority of space remains unexplored, and we've only just begun. The Voyager missions are our first missions intended for exploration and contact of extraterrestrial life specifically meant to search in interstellar space. Voyager 1 carries a Golden

Record of earth sounds, pictures, and messages. It has only been on its mission for 40 years (1977-2017), and it only entered interstellar space in 2012, the first spacecraft to have done so. It won't be near another star for 40,000 years (Northon 2017). This is a blip in the time scale of the universe and in the vastness of space, and it would be irresponsible to say that just because we haven't had contact yet means we never will.

Conclusions

My personal take on the Fermi paradox is that it is not a true paradox. I agree with Freitas that it's unsound and ultimately useless to make such grandiose assumptions about extraterrestrial civilizations. Since virtually everything about the search for extraterrestrial life is speculative at this point, making sweeping claims about the lack of existence of alien civilizations seems to be extremely premature. Even though I place stock in the Fermi paradox, I still agree with people that posit that we're either too primitive to recognize alien broadcasting signals, or that we haven't been listening long enough. Voyager 1 has a record on it that we wanted to use to teach potential aliens about Earth culture, but most of the world doesn't even use records anymore, instead opting for online music sites like Spotify. It took less than 40 years for that technology to become obsolete, and we haven't even started colonizing other planets like Mars yet, let alone anywhere outside of our solar system or galaxy. The notion that we'd be able to recognize alien communication becomes rather flimsy when put in that context. And as stated before, humans have only been on Earth for roughly 200,000 years, and have only had widespread efforts to search for extraterrestrial life for little over 40 years. We've been using government funding to search for the cure for cancer in roughly the same amount of time. We've made incredible strides, increasing the childhood cancer survivorship rate from 50% to 80%, but we have yet to find a widespread and effective cure (Park 2011). If we gave up now and said that what we have is as good as it's ever going to get, it would be an incredibly foolish thing to do. Of course, we know that science and medicine are always evolving, and that the chances of us finding a cure for cancer get better every day due to new research in epigenetics methods like gene therapy. The same could be said for the search for extraterrestrial life. We know so little about the universe that it would be naïve to believe that we have it all figured out. Thus, I wholeheartedly support the continued search for extraterrestrial life.

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