Where is Everybody?

An Exploration of the Drake Equation and Fermi Paradox

Written by Keegan Selby, November 2014

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In a universe with billions of galaxies like our own Milky Way, one intelligent species has struggled to explain the galactic loneliness of life on Earth. While the vast majority of the world looked to the heavens for an answer, an astronomer and astrophysicist by the name of Frank Drake devised a probabilistic argument encapsulating all of the relevant variables for contemplating the existence of extraterrestrial life. Drake estimated that even with conservative figures, there must be at least 1,000 actively radio-communicating alien civilizations in our galaxy. As the lack of evidence for these civilizations contradicted the high estimates for the probability of their existence, a variety of theories have been proposed to solve the paradox. Earth's greatest scientific minds continue to speculate whether intelligent life is a product of improbable coincidences and conditions unique to Earth or a natural result that should be replicated on Earth-like planets throughout the universe.

In the year 1961, Frank Drake was about to lead the world's first Search for Extra-Terrestrial Intelligence (SETI) meeting in Green Bank, West Virginia. Realizing that he would need an agenda for the meeting, Drake devised an equation to estimate the number of actively radio-communicating civilizations in the Milky Way Galaxy. In the previous year, Drake headed the first attempt, dubbed Project Ozma, to detect radio signals from intelligent life using the telescopes at the National Radio Astronomy Observatory. For four months, these highly sensitive telescopes listened for signals from nearby solar systems but found nothing. In order to stimulate a scientific dialogue regarding these results and the probability of detecting ET life with this method in the future, Drake identified seven relevant variables. The first of these factors collectively identify the rate at which candidate civilizations are being created in our galaxy and the last term is used to compute the average length of time that these civilizations would be broadcasting detectable radio signals (The Drake Equation).

The first variable of the equation estimates the rate of formation of suitable stars in the Milky Way. It is important to note that the term suitable is used to describe stars that have a long enough average lifespan to support the evolution of life and are appropriately sized so that the star provides warmth for its host planets without scorching them. While estimates for the total number of stars in our galaxy range from 100 to 400 billion, Drake used a formation rate of one star per year in his calculation, which was considered conservative. NASA's latest calculation puts the formation rate at seven stars per year (The Drake Equation).

As life (as we know it) cannot exist in the extreme conditions found on Sun-like stars, Drake estimated the fraction of these stars that had orbiting planets. At the time, the only planets that were known to exist were the original nine in our solar system. Drake successfully predicted the discovery of extrasolar planets and approximated that the fraction of stars with planets is ½. Modern estimates place this fraction closer to one as recent microlensing surveys support the cosmological rule that all stable stars are orbited by one or more planets (The Drake Equation).

Drake's next step was to estimate the average number of habitable planets per suitable star using two criteria. The first factor in determining whether a planet is habitable is the chemical composition of the solar nebula that created the planet. This parameter would identify planets that featured sufficient quantities of the key elements to life. The second criterion for a suitable planet involves the idea of a star's habitable zone. As liquid water is considered an essential ingredient for life, the range of orbital distances that allow water to exist in liquid form is often referred to as the "habitable zone." Drake presumed that every solar system would feature two habitable planets. While NASA estimates that there may be 100 billion earth-like planets orbiting the habitable zones of stars in the Milky Way, the limitations of even the most modern instruments add significant uncertainty to any "educated guess." While arriving at a number for this variable inherently involves a considerable degree of speculation, the absolute unknown nature of the next variable makes it a true wildcard (Kasting).

Once Drake arrived at an estimate for the number of planets that have conditions hospitable to life and orbit the habitable zones of suitable stars, he needed to address the likelihood of life actually emerging. Since there is only one known example of planetary life in the entire universe, it is exceedingly difficult to put a number on the probability of life emerging, even given the right environmental conditions. However, many geologists suggest that the fraction of suitable planets where life emerges could be relatively high. There is significant geological evidence that links the beginning of hospitable conditions for life on Earth to the same period that life began. Around 3.5 billion years ago, our solar system stabilized and the Earth was no longer subject to the constant bombardment of space debris that is typical in newborn galaxies. The oldest evidence of life, fossils of cyanobacteria discovered in northwestern Australia, is also dated at 3.5 billion years (Wallenhorst). This suggests that abiogenesis, the natural process of life emerging from non-living matter such as organic compounds, could be relatively common under the right environmental circumstances (Intelligent Life in the Universe). However, skeptics of this extrapolation contend that the anthropic bias of the evidence (only one sample planet chosen non-randomly by its own inhabitants) do not permit a valid estimate.

As the equation goes on, the skepticism surrounding the reliability of its estimate increases. Ernst Mayr, a leading evolutionary biologist, points to the fact that out of the billions of species that have existed on Earth, only one has evolved to the intelligence necessary to develop radio-communication technology. While life emerged relatively soon after the formation of the Earth, it remained very simple until about 542 million years ago when a period labeled the Cambrian explosion saw an exponential acceleration of the diversification of life (The Drake Equation). Some use this event as evidence of special Earthly conditions that gave life a rare kick-start on a long evolutionary path to intelligence. It is difficult to say whether our own civilization would be capable of interstellar communication if not for the electromagnetic work of a few uniquely brilliant individuals such as Michael Faraday in the last century of human history. In another highly speculative guess, Drake included the estimate that one of every ten intelligent civilizations will release detectable radio signals into space. In 1964, Drake and Carl Sagan wrote and broadcasted the Arecibo message, which contains several pieces of information about DNA, the appearance of our species, and a graphic of our solar system (Ward). The message will take 25,000 years to reach its destination of globular star cluster M13 (which will not be there by the time the message arrives). According to a *Cornell News* press release, the message "served more as a demonstration of human technological achievement than an attempt to start a conversation with extraterrestrials."

The final variable of the Drake Equation accounts for the expected lifetime of a radio-communicative civilization during the period that it is broadcasting across interstellar space. David Grinspoon, the Principal Scientist at the Planetary Science Institute, has argued that a civilization developing at the rate of ours will eventually overcome all threats to its existence and survive indefinitely (Intelligent Life in the Universe). In this case, the variable would simply be the age of the civilization's interstellar radio technology. Astronomers, astrophysicists, cosmologists and curious minds from across the world have used the Drake Equation to obtain a wide range of guesstimates for the number of active communicating civilizations out there. Ranging from 1 (only us) to the hundreds of millions, the results yielded from the Drake Equation can be used to estimate the density of these civilizations throughout the 100,000 light-year diameter of our Milky Way. This information can be used to infer an average distance between civilizations and thus determine how long ago the civilization must have sent a signal in order for it to be detectable. For example, if there are 23 actively communicating civilizations, it is possible to assume that they will be separated by a distance of 20,000 light years on average. Under these circumstances, any civilization that hasn't been broadcasting for 20,000 years (like those on Earth) will not yet be detectable.

It is important to remember that the equation was not proposed to accurately quantify alien civilizations, but to open a dialogue on the relevant concepts that scientists must consider when questioning the existence of life elsewhere. The scientific community places the value of the Drake Equation not in its numerical result, but in its role in stimulating intellectual curiosity about our universe and the planet that we call home. After 50 years of searching the night sky for a sign, the Search for Extra-Terrestrial Life has returned absolutely nothing, that is, with the exception of one mysterious sign: the Wow Signal. On a summer night in 1977, Jerry Ehman was scanning deep space for interstellar radio waves when suddenly the measurements of the Big Ear telescope spiked. He detected a strong signal in the protected spectrum (a frequency forbidden from use by terrestrial transmitters) that bore all the hallmarks of an extra-terrestrial origin. The signal lasted for the entire length of the 72-second window that the instrument was able to observe it and was never detected again. Despite numerous searches and investigations, the solitary signal remains an unexplainable mystery and a tantalizing taste of what contact from intelligent extraterrestrial life might look like. As the source of the Wow Signal has not been confirmed, Drake's high estimates for the number of intelligent communicating alien civilizations are met without the slightest evidence of a single ET life form in the more than 80 billion galaxies in our observable universe (Webb). If even one of these expected civilizations has been around for more than tens of millions of years (less than a thousandth of the age of the universe), it would have been able to colonize the entire galaxy by now, even with our relatively slow speeds of space travel. This overwhelming paradox led Italian physicist Enrico Fermi to question, "Where is everybody?" (Landis).

During a casual lunch break in 1950, Fermi was having an informal discussion with three of his colleagues at Los Alamos National Laboratory. They were discussing a span of recent UFO reports when Fermi began rattling off estimates very similar to those of the Drake Equation for the probabilities of earthlike planets, intelligent life, and advanced technology in other solar systems. He suggested that even with very conservative calculations, Earth should have been visited by ET life long ago and several times over (Webb). The Fermi Paradox has been the subject of extensive scholarly debate and theoretical speculation. The debate is generally divided into two arguments. Some seek to explain why the apparent absence of evidence for ET life confirms its non-existence while others offer explanations for why life may exist elsewhere without are ability to detect it.

The most common argument of those who accept our galactic loneliness is the Rare Earth hypothesis. This argument contends that life on Earth arose from an improbable set of coincidences and rare conditions unique to our planet. The presence of our moon, which not only stabilizes Earth's rotation but also results in the tidal plains that allowed life to evolve from the ocean to land, is the result of a random astronomical collision. This collision is also believed to be the cause of Earth's molten iron core, which creates the Van Allen radiation belts that protect our atmosphere from being removed by solar wind. Proponents of the Rare Earth hypothesis suggest that the initial abiogenesis (birth of life from non-living matter) may be the most perplexing of these coincidences. While Earth-like planets may not be exceedingly rare, the existence of a complex collection of molecules that spontaneously begin reproducing, extracting fundamental ingredients from the environment, and harnessing energy to sustain the reaction, might, at least for now, be a universal anomaly (Ward). While the improbability of this event alone could explain our galactic solitude, life has subsequently endured more than 3.5 billion years of evolutionary history during which 99% of all species that have ever lived have met extinction. Despite this loss of biodiversity, Earth's ecosystems are still teeming with 9 million beautifully unique species (Wallenhorst). Life has transitioned from single to eukaryotic cells, migrated from sea to land, and survived five mass extinctions. Regardless of the infinitesimally low probabilities tied to each of these events, our presence is a testament to life's ability to always find a way. Whether our evolutionary meandering was too random to be reproduced is a question that cannot be answered with certainty-- at least not yet.

On the other side of the aisle, sit those who believe that the Earth is not a special case and that there should be billions of other similar planets harboring life in our galaxy. The Mediocrity Principle, which refutes the Rare Earth hypothesis, suggests that our planet, civilization, and intelligence are not unusual in the universe. Consistent with this notion, Stephen Hawking proposed, "The human race is just a chemical scum on a moderate-sized planet, orbiting around an average star in the outer suburb of one among a hundred billion galaxies." As Earth was born from the same nursery nebula that the rest of the Milky Way originated from, mathematical models similar to that of the Drake Equation suggest that it is highly unlikely for our planet to be a single rare breed in the cosmos. In November of 2013, astronomers reported that data from the Kepler Space Mission evidenced the existence of as many as 11 billion Earth-sized planets in the habitable zones of sun-like stars (Intelligent Life in the Universe).

There are several assumptions as to why intelligent civilizations might exist on many extrasolar planets but remain silent. Of these attempts to solve the Fermi Paradox, the most logical involve problems of scale or incompatible technologies. Electromagnetic signals can only travel as fast as the speed of light; therefore, even if another actively communicating civilization exists in our galaxy, a relatively small separation of a few thousand light-years would cause a delay of thousands of years between the emission and reception of a signal (Webb). This distance would render conversation impossible for all practical means. As the expansion of the universe is constantly accelerating galaxies away from us, our signals will never reach civilizations that our beyond our cosmic horizon (approximately 10 billion light-years). To complicate the situation further, alien emissions may come from such foreign technology that we are unable to detect them. Our search for extraterrestrial radio communication may be as effective as attempting to receive an email with a walkie-talkie. Just as various life forms on Earth exist in relatively close proximity to one another without ever sensing the other's existence, alien life may pass us by without ever attempting to introduce themselves, similar to our own habits when in the presence of microscopic bacteria. However, as our ability to observe and explore our galaxy increases at an exponential rate, our generation may be the first to solve Fermi's Paradox.

In 2018, NASA's James Webb Space Telescope (JWST) will launch into orbit with the mission of studying the formation of stars and galaxies as well as continuing the search for signs of alien life. At nearly 100 times the strength of the Hubble Space Telescope, JWST will become the new premier observatory of the coming decade. JWST's sophisticated infrared instruments will be able to analyze the molecular composition of distant planetary atmospheres in search for biological byproducts. The detection of appropriate levels of oxygen or carbon dioxide in the atmospheres of Earth-sized planets would be convincing evidence for the presence of extraterrestrial life (James Webb). As humankind's next step in unlocking the secrets of our universe, JWST is one of the most anticipated technological advances of the coming decade. With the ability to survey much deeper into space and identify likely ET civilization, several have questioned if revealing our presence will ultimately prove to be a wise decision for humanity. Even believers in the altruistic nature of highly intelligent civilizations such as Carl Sagan, have deemed the idea of "shouting into an unknown jungle that we do not understand" as "unwise and immature." As the discovery of North America by European explorers did not boast well for its natives, Nick Bostrom of Oxford University suggests that no news might be good news (Intelligent Life in the Universe).

As our search radius for extra-terrestrial signals currently covers about .1% of our galaxy, it is still too early to discredit the existence of extraterrestrial life based on absent evidence. While our species may be the subject of a "Zoo Hypothesis", forbidden from interacting with more intelligent civilizations like that of an uncontacted Amazonian tribe, there are an infinite number of theoretical suppositions that could explain our current seclusion. While the numbers suggest that it is highly unlikely for us to be alone in the universe, the Search for Extra-Terrestrial Intelligence has only confirmed that if aliens do exist in our detectable range, they have not been actively radio-broadcasting for long enough to be detected on Earth. In a field shrouded with uncertainty, we have eliminated that unknown, an accomplishment that couldn't be claimed a short century ago. As we continue our search for signs of life throughout this cold seemingly desolate galaxy, we're reminded of the spectacular beauty in our own cosmic evolution and the possibility that we may be the first beings to ever ask the question, where is everybody?

Works Cited

Baxter, S. "The Planetarium Hypothesis - A Resolution of the Fermi Paradox." *The Planetarium Hypothesis - A Resolution of the Fermi Paradox*. The Smithsonian/NASA Astrophysics Data System, n.d. Web. 07 Nov. 2014.

"The Drake Equation." *SETI Institute*. N.p., n.d. Web. 07 Nov. 2014.
"Intelligent Life in the Universe." *Intelligent Life in the Universe*. N.p., n.d. Web. 07 Nov. 2014.

"The James Webb Space Telescope." *The James Webb Space Telescope*. N.p., n.d. Web. 06 Nov. 2014.

Kasting, James. "Habitable Zones Around Low Mass Stars and the Search for Extraterrestrial Life - Springer." *Habitable Zones Around Low Mass Stars and the Search for Extraterrestrial Life - Springer*. N.p., n.d. Web. 07 Nov. 2014.

Landis, Geoffrey. "The Fermi Paradox: An Approach Based on Percolation Theory : Landis, Geoffrey A : Free Download & Streaming : Internet Archive." *Internet Archive*. NASA, n.d. Web. 07 Nov. 2014.

Wallenhorst, Steven. "The Drake Equation Re-examined." *1981QJRAS..22..380W Page 380*. Carnegie Institute of Washington, n.d. Web. 07 Nov. 2014.
Ward, Peter. "Rare Earth - Springer." *Rare Earth - Springer*. N.p., n.d. Web. 07 Nov. 2014.

Webb, Stephen. *If the Universe Is Teeming with Aliens ... Where Is Everybody?: Fifty Solutions to the Fermi Paradox and the Problem of Extraterrestrial Life*. New York: Copernicus in Association with Praxis Pub., 2002. Web.

Illustration of Universe, Man, and Dog - Artist Unknown