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Introduction

The fact that no evidence of alien civilisations has been discovered does not preclude the possibility that they in fact exist. The Fermi Paradox is the contradiction between the high probability of the existence of intelligent alien life in the galaxy versus the fact that we have yet to encounter any signs of this life, has fascinated scientists and philosophers. Indeed, while it has been observed on Earth that life flourishes in extreme conditions and while *Homo sapiens* are the species with the highest level of intelligence, a number of other species have also evolved to a reasonable level of intelligence (e.g. dolphins, crows, monkeys), and perhaps will continue to evolve. This leads to the conclusion, that provided the correct conditions are met, the same process of evolution should occur on other planets. So the question remains, as posed by Enrico Fermi (JonesWeb), "Where is everybody?". In examining various theories that seek to explain the Fermi Paradox, this essay first establishes the nature of life as we know it and what defines intelligence, as well as the requirements and constraints for interstellar colonisation and communication, and finally identifies the most likely explanation of why we have not yet observed signs of alien existence.

What is the Fermi Paradox?

A paradox is a statement or group of statements, where by logically analysing the statements, they prove to be contradictory. The liar's paradox, commonly attributed to Eubulides of Miletus, illustrates this concept, "A man says that he is lying; is what he says true or false?". If the man is telling the truth, he cannot be lying, and the statement is wrong. If he is lying, then the statement cannot be true, and is therefore wrong, resulting in a contradiction (Webb, 2002).

Similarly, the Fermi Paradox refers to the contradiction between the high probability of the existence of other intelligent life in the galaxy, and the lack of evidence for this existence. The Fermi Paradox was inspired by a discussion amongst Enrico Fermi, Edward Teller, Herbert York and Emil Konopinski during a lunch in the summer of 1950 (JonesWeb). Fermi made a passing joke linking the recent disappearance of public trash cans with visiting alien life. This lead to a spirited discussion on whether aliens existed and if they had discovered how to travel faster than the speed of light and so on in this vein. After discussing this for a while, they moved on to other topics. Then out of the blue, Fermi posed the question, "Where is everybody?". Fermi then made some quick calculations and came to the conclusion, due partly to the size and age of the galaxy, that we should have been visited by aliens long ago and numerous times (JonesWeb).

The Fermi Paradox states that, if life is common throughout the galaxy, several species should have already colonised the galaxy, and we should see evidence of this. (Davies, 2010) The main assumptions for the Fermi Paradox include the following:

- Life is common in the galaxy
- Civilisations will tend to migrate and colonize stars

What is Life?

The general consensus on the definition of life, based on observations on Earth, which constitutes our only observable source life, includes the following (Cleland & Chyba, 2002; MullenWeb) :

- Reproduction: Living organisms reproduce. They either reproduce sexually, whereby a parent creates a new single cell organism that grows into a new adult, or asexually, where the parents splits in two to form two adults.
- Metabolism : Life requires energy to survive, either via processing materials or energy directly (such as photosynthesis).
- Stimuli : Organisms react to outside stimuli, such as a chemical, heat, light or even simple prodding. Multicellular animals may have more complicated reactions.
- Evolution : A living organism can mutate. New generations will be different to previous generations over a large enough sample size.
- Homeostasis : An organism tries to maintain its' internal environment at an equal temperature.

On Earth life can survive in extreme conditions. Almost everywhere where there is liquid water, there is life. Under the Taylor Glacier, microbes have been found that survive with no heat, light or oxygen. These microbes recycle sulphates for energy. If these microbes were transported to another planet with a source of sulphates and liquid water, they would survive (Bidle, Lee, Marchant, & Falkowski, 2007). In the reactor of Chernobyl, some forms of fungi have developed, that use the radiation remaining in the reactor as their energy source (CosmosWeb). A more advanced form of multicellular life that does not require oxygen to survive has recently been discovered beneath the seabed of the Mediterranean (Danovaro et al. 2010). Tardigrades, also known as water bears, have been taken up into space, released into vacuum and have been known to survive, albeit not reproduce (Jönsson, et al. 2008). These examples show that life flourishes even in extreme conditions on Earth, adapting to whatever resources are available to survive. On Earth, life is common. Although evidence of life, even microbial life, has not been found on another body in the Solar System, it is likely that eventually we will discover life elsewhere, since numerous bodies contain liquid water. Thus, if life can be found elsewhere in the Solar System, this will prove the first of the Fermi Paradox assumptions, that life is common in the galaxy, as if life has developed independently of Earth, it should develop elsewhere in the galaxy.

What is an Intelligent Species?

The assumption that life is common across the galaxy poses the question on whether intelligent life eventually evolves. The following are the main characteristics that separate *Homo sapiens* from other animals (Webb, 2002):

- Use of tools
- Language
- Problem solving

Use of tools means using items to solve problems. Language is the ability of the entire species to learn from one another and share new skills. Finally through problem solving, new skills will be developed. Apart from *Homo sapiens*, there is a number of other species on Earth that have evolved, albeit to a lesser degree. Assuming that every species on Earth evolved from the same pool of single cell organisms, and that every creature shares a common ancestor, a similar process of evolution could occur on other planets, provided that life elsewhere in the galaxy also followed a similar path of evolving from a carbon based single cell organism (Theobald, 2010). The New Caledonian crow has been shown to use tools to solve problems. Notably, a crow bent a piece of wire into a hook, in order to fetch food out of a tube (Weir, Chappell, & Kacelnik, 2002). The crows also seem to communicate with a very basic form of language. Dolphins are another species that has learnt to use tools. They communicate amongst themselves, and teach each other new tricks that they have discovered or learnt. In the wild they have been observed to place sponges on their noses, in order to protect themselves from the spiny bodies of some prey. This is an example of tool use. In captivity, a dolphin was trained that by trading litter with her trainer she would receive a fish. Consequently, she then learnt, by herself, that if she hid the paper, and tore off strips, she could get more fish. Later she then caught a gull and traded that for more fish. She decided to keep a fish left over to catch gulls to trade for fish. She then proceeded to teach the other dolphins this use of tools and problem solving. This is a fairly advanced form of problem solving, and is similar to what a human toddler can accomplish (DolphinWeb). Finally, an extinct intelligent species, that possibly branched relatively recently from the ancestry of *Homo sapiens,* and is considered to have possessed a high degree of intelligence was Neanderthal Man (NeanderthalWeb). It is unknown whether any of these extant species will eventually evolve to the point of being able to build an interstellar communication system. However, assuming that *Homo sapiens* evolved from the same distant ancestor, it is possible that one of these species, or even another species, will eventually gain intelligence on a similar level. Thus, if numerous species can evolve to a high degree of intelligence on Earth, this does show that, given sufficient time and correct conditions, the same situation is likely to occur on other worlds.

The Drake Equation

During the 1961 conference on the search for extraterrestrial intelligence at Green bank, radio astronomer Frank Drake presented The Drake Equation. This equation seeks to determine the specific factors that are required for intelligent life to develop to the point where it can communicate via interstellar space (SetiWeb).

$$N = R \times fp \times ne \times fl \times fi \times fc \times L$$

N = Number of civilisations capable of interstellar communication in the Galaxy

R = The rate on which stars form per year

fp = The fraction of stars that have a planetary system

ne = The number of planets, per solar system, suitable for life

fl = The fraction of planets where life develops

fi = The fraction of planets with life, where intelligent life develops

fc = The fraction of intelligent life planets that develop interstellar communication

L = The time in years a culture will be able to broadcast into space

One of the current theories states the number of stars created in the Milky Way each year is 7 (MilkyWayWeb). This number may have been different in the past.

The fraction of stars that have a planetary system is currently estimated at 50% (Cowen, 2009). With current detection methods only able to detect planets with masses of at least 3-4 times that of Earth, more stars might have planets.

The number of planets which may be suitable for life is partly based on the habitable zone (HZ) within the star system. The habitable zone refers to the range from a star where a planet can support life. This zone moves as the star ages. When a star is newly born, it generates less light and heat. Therefore, the HZ will be closer to the star. As the star becomes older and generates more heat, the HZ will drift outwards. Thus, over the majority of the life cycle of the star, there exists an area, called the continuously habitable zone, that can support life (Ward & Brownlee, 2003). Therefore, if it takes too long for life, intelligent or otherwise, to develop, the planet may move out of the HZ.

At present this estimate is difficult to calculate. NASA's Kepler mission (NASAKeplerWeb) is currently searching for habitable planets. If it does find habitable planets, this factor of the Drake Equation will be easier to estimate. For the moment, since we have detected 200 planetary systems, and the only other candidate for a habitable planet is Gilese 581 (von Bloh et al, 2008), we can estimate this as 2 (Earth and Gilese 581) out of 200.

As Earth is the only example where evidence of life currently exists, the fraction of planets where life develops is difficult to estimate. Assuming life will evolve on all planets that can support life, and that it took Earth roughly a billion years to develop life, the estimate would be roughly 0.13 (Lineweaver & Davis, 2002).

It is even more difficult to estimate what fraction of planets have the potential to develop intelligent life. Currently, out of the billions of species that have existed on Earth, only one has proven to have advanced intelligence. Even if the previously discussed examples of crows, dolphins and Neanderthal man are included, the count will go up to four out of billions. However, the question is whether any species, provided that it does not experience extinction, will eventually evolve into an intelligent, tool using species that can communicate through interstellar space. Therefore, the pessimistic view is one in a billion, and the optimistic view is that all species will eventually evolve into intelligent species, and thus the odds are 100%.

Developing interstellar communication is another factor that lacks hard data. For example, suppose an intelligent species develops in the oceans on the moon Europa. The ocean of this moon is covered by a thick crust of ice. The species could have developed without knowing that there are stars and planets above the crust, and thus not researched into astronomy, let alone an interstellar communication system. Furthermore, their planet could be like Venus (though more hospitable) with a thick cloud cover that does not allow them to see the outside universe either. Thus, at a best guess estimate, it can be assumed that 50% will develop interstellar communication in their lifetime.

Intelligent species may only have a short life span, relative to the age of the galaxy. The Earth has gone through several mass extinction events, such as the meteor strike that resulted in the extinction of the dinosaurs (Schulte et al. 2010). However, it is hard to think of any event, apart from the destruction of the Sun, that has the potential to destroy all of Earth's civilisation. Davies (2010) has a theory that once a civilisation hits a certain point of technological advancement, its' total destruction is extremely difficult. While several events could occur that would destroy over 99% of life on Earth, some form of human civilisation would still exist, and would likely recover fairly quickly. According to the the pessimistic view, a technologically advanced civilisation could last 10,000 years. Optimistically, it could be billions of years. This essay will take 2 million years for the optimistic view. Lawton and May (1995) calculated the average lifespan of species as 5 million years, with mammals only surviving for 1 million years.

Inserting these calculations into The Drake Equation:

N	**R**	**fp**	**ne**	**fl**	**fi**	**fc**	**L**
45500	7	0.5	0.01	0.13	1 (optimistic)	0.5	1 x 10^7 (optimistic)
2.275x10^-7	7	0.5	0.01	0.13	1 x 10^-9 (pessimistic)	0.5	1 x 10^5 (pessimistic)

It is evident that, assuming life is plentiful in the universe, and it will evolve into intelligent species that wish to communicate across interstellar space, the galaxy should be full of alien civilisations. If some of these factors are extremely rare, then it is much less likely, and we could be the only intelligent species in the galaxy. However, due to the likelihood of development of intelligent species and the length of time a civilisation lasts for, it is highly possible that we are not alone in the galaxy.

Colonisation

The Fermi Paradox assumes that civilisations tend to migrate and colonise, and that eventually this process will result in the colonisation of numerous stars. At present it seems unlikely that humanity will colonise the stars in the foreseeable future, as demonstrated by the following calculations.

Voyager 1, designed and built using 30 year old technology, is travelling at roughly 0.005% of the speed of light (VoyagerWeb). Assuming that within the next 50 years humanity can build a space faring vessel that is able to travel at a maximum speed of 100 times faster, or at 0.5% the speed of light . Assuming that the average distance between stars is roughly 4.5 light years (BerkeleyWeb). This would mean it would take roughly 900 years to travel between the stars.

Let's assume that roughly every 1000 years, each colonised planets would launch their own colony missions, and each colony launches 2 missions. Therefore, in the 1st generation, 2 missions will be launched. In the 2nd generation, 4 missions will be launched. In the 3rd generation, 8 missions will be launched, the 4th generation 16, and so on.

Number of stars colonised = number of colony launches^generation number

After 10 generations, roughly 20,000 years, there would be 1024 stars colonised.

After 50 generations, roughly 100,000, there would be 1 x 10^15 stars colonised.

Assuming there being 1 x 10^11 stars in the Milky Way, in a little under 37 generations, or 74,000 years, every star in the galaxy would be colonised, and, as discussed previously, only half those stars will have planets.

If the number of colonies launched every cycle is higher, the time taken becomes even lower. If each generation colonised 5 planets, for example, it would only take a little under 16 generations, or 32,000 years.

Therefore, given a thousand more years for technology to develop, and perhaps even with today's current technological level, humanity could colonise the stars. The question remains as to why haven't humans or any other species attempted to colonise the galaxy?

No drive for colonisation

In 1969, man walked on the moon for the first time. The last time man walked on the moon was in 1972 (MoonWalkWeb). For the short period of 3 years, humanity had manned exploration of other planetary bodies. In the 1960's people dreamt that by the 21st Century there would be colonies on the Moon and Mars, and that space travel would be as cheap and available as air travel. So why has space colonisation not become more common?

One reason is the cost. When humans colonised different continents, it was relatively cheap to migrate to those areas. Moreover, migration to new continents was immediately beneficial and provided an opportunity to improve one's social position, to gain wealth or land quickly, as well as a chance to explore new cultures, discover new flora and fauna or experience better climate. The migration to the stars would not be cheap, nor provide immediate benefits. Furthermore, the likelihood of the planet having an atmosphere similar to that of Earth to allow easy colonisation would also be fairly low. Therefore the colonists would need to live indoors, unless the planet's atmosphere could be transformed to support human life, a process could take centuries to accomplish. In addition, not taking into account the time needed to colonise the planet, travelling to a relatively close star would be time consuming. As mentioned previously, with current or near future technology, this would take 900 years. Colonists who started on the mission, would not be alive to land on the planet, and only their descendants would. The likelihood of knowledge lost between the continuing generations is very high. Whether any generation would survive long enough to reach the planet is also an unknown. The colony vessel would need to support a very large population, and also have an almost zero net gain in population to overcrowd the vessel and deplete its resources. It would also be fairly difficult to obtain a competent crew of people willing to leave behind everything on Earth to colonise a new planet, especially since it would be numerous generations before the benefits were gained. While it is easy enough to obtain volunteers for missions in isolations lasting 3-4 years, such as the Mars isolation test (MarsWeb), acquiring a large crew of willing colonists, who are willing to also commit their descendants to the mission will prove much more difficult.

As a result, in order for humanity to be motivated to colonise the stars, either cheap, faster than light travel or the motivation to leave Earth are required. Considering current or near future technology levels, where colonisation would prove to be a viable option, would be the avoidance of event that would completely, or almost completely, destroy the Earth. However, this event would have to be detected early enough to develop and build space colonisation vessels. It would be easier to stop certain extinction level events, such as a meteor colliding with Earth, than colonising the stars. Even with faster than light travel, with relativistic time dilation, time will pass much quicker on Earth relative to the space vessel. While a journey to the nearest star may only take 2 years, centuries may pass on Earth.

As discussed, unless we have a cheap form of fast interstellar travel, widespread colonisation is unlikely. However, Miguel Alcubierre (1994) has devised a theoretically possible faster than light drive, commonly known as the Alcubierre drive. This drive operates within the known framework of general relativity. The benefits of the drive, apart from the faster than light speed, also mean that some relativistic effects such as time dilation will not apply. Therefore, time will travel at the same speed on the space vessel as back on Earth. This means that we could visit close stars within days, and only days will pass on Earth. Were such a drive developed, it is likely that, despite the cost, considering humanity's drive for exploration, most of the nearby stars would soon be visited and colonised. Consequently, if the Alcubierre drive was possible, it would massively reduce the time factor in colonisation formula, ensuring that the stars are colonised at a much quicker rate, as fast as 5 new star systems at a rate of under 100 years, more likely much faster, even as fast as every 20 years. As previously discussed, this would only take 16 generations, or 1600 years. A mere blink in the age of the Milky Way. Provided a drive similar to the Alcubierre drive was possible and we were not alone in the galaxy, it poses the question of why we have not seen any evidence of alien life.

Earth is Unique

Perhaps the answer to the Fermi Paradox is a simple one: planets that can support and develop life, such as Earth, are very rare in the universe and we are in fact alone in the Milky Way galaxy. As discussed previously, a planet needs to be within a Habitable Zone of a star system to sustain life. Earth has been in the correct position during its entire lifetime. Mars may have been within the Habitable Zone at some point, but not currently, and we are yet to detect any form of life on Mars. Furthermore, the star itself also needs to be within the Galactic Habitable Zone (Ward & Brownlee, 2003). Stars near the centre of the Milky Way galaxy are tightly clumped together, and are impacted by supernova's that emit harmful, sterilising gamma rays more frequently. Thus, the number of viable stars that could support life could be reduced.

Additionally, the presence of the gas giant Jupiter also protects Earth from frequent meteor strikes (Ward & Brownlee, 2003). Without its' existence, Earth would be bombarded by meteors. While there are theories that life and water on Earth may have come from comet strikes (Napier et al. 2007), if the strikes were too frequent, they could destroy the advanced life that had developed on the planet.

Plate tectonics, the large scale movement of the lithosphere (the crust and upper mantle), are also thought to be needed to support life. The movement of these plates results in changes to the environment on the planet, thus increasing the probability life developing. With different environments, the likelihood of different species developing is increased. Subsequently, with numerous different species, the likelihood for one of these species developing intelligence is also increased. Finally, active volcanism is also needed to prevent a complete decrease of CO_2 in the atmosphere. Active volcanoes keep the plate tectonics moving. If the plates stop, the continents will eventually be worn away by erosion, resulting in an ocean planet. With an ocean planet, via weathering, CO_2 will be dissolved in the oceans, creating a frozen planet (Ward & Brownlee, 2003).

Since no definite evidence of life, microbial or otherwise, has been found on other planets within the Solar System, it may be the the conditions for life to develop are rarer than we have previously thought. However, considering the number of stars in the galaxy, the possibility of another planet with similar conditions to Earth is fairly high.

They exist, but we have not recognised the signs

Another reason why we have not encountered any signs of alien life may be down to the fact due to the current technology level on Earth, we can not interpret the signals. There are various SETI (Search for Extra-Terrestrial Intelligence) projects that are active on Earth, such as the SETI@home projects which use volunteer computing power to search IR, visible and radio wavelengths (SetiPulseWeb), although the signals it searches for are fairly narrow (Anderson et al. 2002). For example, radio waves have been used for a little over 100 years on Earth, and analogue broadcasting is in the process of being changed to digital broadcasting. Another 100 years will perhaps see a change to yet another form of communication, which means that the window for detecting a broadcast from an alien species at a similar technology level to that of Earth, is extremely small and highly unlikely to ever overlap. Davies (2010) compares the odds to a street of 100 houses. Every night one house turns their light on at a random time for a couple of seconds. Another house then does the same. The chances of both houses having their lights on at the same time, and noticing their neighbour with the lights on are very low. Since SETI@home covers less than 50% of the night sky, signals might have already been missed.

Ball (BallWeb) believes that alien civilisations use gamma ray bursts to communicate. While this is unlikely, as naturally occurring sources for both short and long gamma ray bursts have been discovered, some form of advanced communication could be taking place in the universe, but as yet we do not have the technology to detect it, or we have not been looking in the correct place.

Perhaps, just like Earth, other civilisations are just listening for signals, and not making a concentrated effort to broadcast, and just like Earth, perhaps they are listening on a different frequency than what others are broadcasting on.

All species end up extinct

Another explanation is that all species end up extinct. Historically, the average lifespan of a species on Earth is between 5 – 10 million years (Lawton & May, 1995). For mammals, the average lifespan is as low as 1 million years. One cause of species extinction is mass extinction events. For example, the asteroid that hit the Earth, causing the mass extinction of the dinosaurs (Schulte, et al. 2010). While if detected early enough, with our current technology, we could deflect an asteroid

(NEOWeb), there are other mass extinction events the galaxy can throw at us.

A gamma ray burst, caused by a nearby star (within 30 light years) going supernova would send enough gamma radiation at Earth to sterilise most of the planet (Webb, 2002). We have also detected long gamma ray bursts (LGRB), thought to be caused by hypernovae, a star collapsing into a black hole. A LGRB could be powerful enough to sterilize an entire galaxy. On average we detect a LGRB at a rate of 1 per day via the Compton Gamma Ray Observatory(Webb, 2002). This covers about one third of the sky. If we estimate that there are 10^11 galaxies in the universe, that would average out to 10^-8 LGRB's per galaxy per year, or every galaxy will have a LGRB every 100 million years. Coincidently, this figure matches the gap between mass extinction events on earth, which has been estimated to once every 100 million years (Webb, 2002). This gamma radiation would sterilize the planet of most higher forms of life. There are also some theories that when the galaxy was younger, LGRB's occurred more frequently (Webb, 2002). Now that the rate has slowed down, perhaps life has had time to evolve into sentient, technologically advanced species. Thus, one solution to the Fermi Paradox is that we are one of the first species to develop after the last mass extinction event of the galaxy.

Another factor is the possibility of humanity itself causing mass extinction events, such as nuclear war and global warming. Furthermore, Earth could be destroyed through a highly unlikely event of creating a black hole that destroys the planet, via an experiment like the Large Hadron Collider. Thus, perhaps all intelligent species eventually destroy themselves through war or misuse of the planets resources.

Zoo Scenario

Another theory explaining why we have not encountered alien life is the “Zoo Scenario”, proposed by John Ball in 1973 (Webb, 2002). Much like the Brazilian government leaves some uncontacted tribes in the Amazonian rainforest alone (AmazonianWeb), perhaps other alien civilisations have set up a no contact zone around Earth. The main argument against this theory, apart from it not yielding to tests, is the proposition that we would have observed some evidence of alien existence even if we were in a no contact zone. Even the lost tribes of the Amazon have occasionally seen a helicopter or plane overhead.

Stephen Baxter proposed a modification of the Zoo Scenario, called the Planetarium Hypothesis (Webb, 2002). According to this hypothesis, an alien civilisation, whose level of technology exceeds our own and possessing the technology to harness the energy output of entire stars, has set up a holographic style simulation around the edge of our Solar System. This simulation stops us seeing any evidence of their existence, while still exploring, at least visually, the galaxy. It would also allow them to look in and observe us, if they so chose. This hypothesis had recently gained some very minor support when Voyager 2 suddenly started sending back garbled communications. Some people saw it as aliens attempting to communicate with us, while others believed that Voyager had broken through the planetarium. The truth was a little more mundane, as the 30 year old hardware had a single flipped bit of memory (NASAGlitchWeb).

While the Zoo scenario has the potential to explain the Fermi Paradox, its fundamental issues is its inability to be tested and thus proved right or wrong. Furthermore, even if there was a quarantine zone, there is a strong possibility that one curious alien would break it, much like the occasional reporter breaking the zone around the lost tribes of the Amazon.

Homo Sapiens are the first Intelligent Species in the Galaxy

Perhaps we are the first intelligent species in the galaxy. As mentioned previous, the Habitable Zone for a planet is rather narrow, and a planet needs to remain in this zone long enough for intelligent life to develop. In our Solar System, we still have not found definite proof of even microbial life (Ward & Brownlee, 2003). If we take the assumption, and past evidence of mass extinction events, maybe we are the first civilisations to reach a reasonably advanced stage of technology in the 100 million year cycle within the Milky Way.

Technology has an upper limit

While technology like the Alcubierre drive may be theoretically possible, it might not be achievable in reality, as there might exist a limit to technology. If faster than light travel where relativistic time dilation does not occur is not achievable, it will limit the possibility of interstellar travel. For example, Moore's law states that every 2 years the number of transistors of circuit doubles. The doubling of the number of transistors has resulted in a doubling of computing power as well. However, this process will stop, when a transistor is on the atomic level and can not be any smaller (MooreWeb). Perhaps another form of computing power will be developed, such as quantum computing, which will continue the trend. Only time will tell, but it is unlikely that technology will continue to double without limit, otherwise we again need to ask why we have not seen any evidence of an alien civilisation. If technology keeps improving, interstellar travel would eventually become so cheap, that sooner or later some curious alien would visit Earth. Certain theoretical technologies, such as faster than light travel, might also prove to be impossible. The speed of light in a vacuum, which is currently believed to be as fast as anything can travel, may well be the fastest speed anything can travel.

Von Neumann Probe

A Von Neumann Probe, is a self replicating space vessel, that is designed to replicate itself using resources found in its travels, and to explore the galaxy, sending back information that it gathers (Freitas, 1980). A modification of the Von Neumann Probe, is the Bracewell Probe. This is a probe with a degree of artificial intelligence, that will attempt to communicate with any species that it discovers (Freitas, 1980). While self replicating machines may seem futuristic, current 3d-printers are almost at the level where they can build copies of themselves, for example the RepRap 3d-printer can currently print a majority of its own parts, apart from the electronics (RepRapWeb, 2010). With sufficient technology levels, and a little base investment, a probe could be created to constantly replicate itself and explore the stars.

Once again, the fact that this technology is almost within the reach of humanity raises the question of why have we not seen any evidence of other civilisations. The answer is twofold, for one we could be the first intelligent species in the galaxy and while we are almost there in technology, the last 10% of any new technology often proves to be the most difficult to accomplish. Also an alien civilisation could have sent out a Von Neumann Probe, designed just to observe, with the probe designed to be “cloaked” from our current level of technology, similar to how the B-2 Stealth Bomber is cloaked from radar detection.

Conclusion

The two main assumptions in the Fermi Paradox are that life is common in the universe, and that intelligent life will colonise the stars.

Currently, we have not found evidence of life, even microbial life, elsewhere in the Solar System. However, from what we have observed of life on Earth, wherever there is liquid water, there is life, and life does thrive in unusual and extreme conditions. As liquid water is believed to have once been present on Mars, and exists on the moons Europa, Enceladus and Ganymede amongst others, it is likely that there is microbial life elsewhere in the Solar System, apart from Earth. Once this is confirmed, the first assumption of the Fermi Paradox can be proved within reason.

The second assumption, that civilisations will colonise the stars, might prove harder to validate. After the 1960's, while space exploration has progressed to a certain degree, colonisation of even the relatively close Moon has stalled. Unless there is sufficient cause to drive interstellar colonisation it may not happen. In the past, cheap and available technology has driven various technological revolutions, such as the printing press, air travel and recently computers. If a cost effective form of cheap and quick interstellar travel becomes available, then yes, humanity would quickly colonise the stars. However, if there is no way to create a faster than light drive that avoids the negatives of relativistic time dilation, there is no immediate, or even medium term benefit from travelling between the stars. As mentioned previously, it would take 900 years to reach even the closest star, but due to time dilation, an even longer period of time will pass on Earth. Currently it is difficult for society to invest in relatively short term projects, such as stopping climate change. This long term investment may prove to be impossible.

One of the most plausible solutions to the Fermi Paradox is that intelligent life is rare in the galaxy. And that humanity is perhaps one of just a handful of intelligent species, if not the only one. If you combine this with the possible limitations of technology and lack of need and drive to colonise the stars, this will answer the paradox.

However, while we may be alone in the Milky Way, the universe contains at least 125 billion galaxies, each which billions of stars (GalaxyWeb). It is almost impossible that we are the only intelligent species in the universe, though we may never encounter another species due to the limitations of technology and the laws of physics.

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