Aliens must have almost certainly visited our Solar System

180201222
June 7, 2024

In late October 2017, an interstellar visitor was detected in our Solar System for the first time. Catching the public eye, ideas of a cosmic tour-bus, or a scout from a nearby alien race, or an interstellar warship, were conjured up. *Oumuamua* exhibited unusual characteristics - a peculiar morphology, strange orbital mechanics, and mysterious composition [1]. Taken from the Hawaiian "a messenger from afar, arriving first", Oumuamua sparked renewed worldwide interest in the plausibility of aliens visiting our planet [2]. But could this visitor from afar really have been the work of an alien civilisation?

1 INTRODUCTION

The idea of alien visitors has been prevalent in science fiction and popular culture for a long time. Movies such as 'Independence Day', 'Signs' and 'The Worlds End' depict the arrival of another intelligent species from beyond our own star. But, with how much confidence can we truly say that "aliens must have almost certainly visited our Solar System"? In this context, the 'aliens' are not from any body in our Solar System. For these beings to have 'visited', only an intentional ('conscious'?) effort to travel to our Solar System is considered. The motivation behind the voyage may be ambiguous, and there is consideration later in the essay as to why a civilisation may be compelled to visit our Solar System. Finally, many popular stories of visiting aliens consider what would happen if they visited us *today*. The Solar System formed some 4.5 billion years ago, providing a time-frame in which we consider the possibility of alien visitors. By making the statement "aliens must have almost certainly visited our Solar System", a series of assumptions are automatically being made about the development of life, and its ability and capability to make contact with our home.

The first assumption one might make is that life must be everywhere. The sum total of all life in the vast Universe cannot be solely constrained to a single speck of dust in some unremarkable corner of the cosmos. With abundant intelligent life on Earth, it seems inevitable that in the vastness of space and time, we cannot be alone. Yet, despite the seeming inevitability of there existing another species beyond our own star, no convincing evidence exists. Perhaps other civilisations conceal their existence, out of respect or out of fear. Perhaps we are too primitive to detect them, or they are too primitive to reach us. Perhaps every other species has had its day and become extinct before humanity began. Perhaps we are the first, or only species even capable of pondering this.

This essay is a response to the title statement. The implied assumptions of this statement are explored by answering a series of questions relating to the feasibility of another civilisation visiting our Solar System. Does other life exist? Does other complex and intelligent life exist? Does another technological civilisation exist? How might such a civilisation reach our Solar System? Why have we never seen an alien?

2 LIFE SHOULD BE EVERYWHERE

The first question to ask is "does other life exist outside of the Solar System?". In this section, the origin of life on Earth is briefly covered before discussing the size of the Universe.

The origin of life

On the surface, the question "what is life?" seems fairly straightforward to answer. When you take a walk through the park, there is life everywhere you look. Trees harvest sunlight, and their acorns sustain squirrels. Birds feed on insects and plants to gain energy. All of these organisms are clearly *alive*. But what does that actually mean? Whether other organisms, such as viruses, are living is not as clear cut.

Life may be defined using *entropy*. Put simply, entropy is a measure of the level of disorder in an isolated system. For example, adding milk to a cup of tea causes the milk and 'tea' molecules to mix. The system in the cup becomes more disordered as the two liquids mix and reach thermal equilibrium (see Fig. 1). Living organisms can decrease their entropy by turning many simple molecules into fewer complex molecules (e.g. eating food and making amino acids/proteins. Ultimately, growing.)[1]. Furthermore, they are also out of thermal equilibrium with their surroundings (homeostasis). Life may therefore be defined as the ability to decrease internal disorder and remain out of thermal equilibrium with its environment, using external energy sources[2]. The origin of life is widely studied, but not entirely understood.

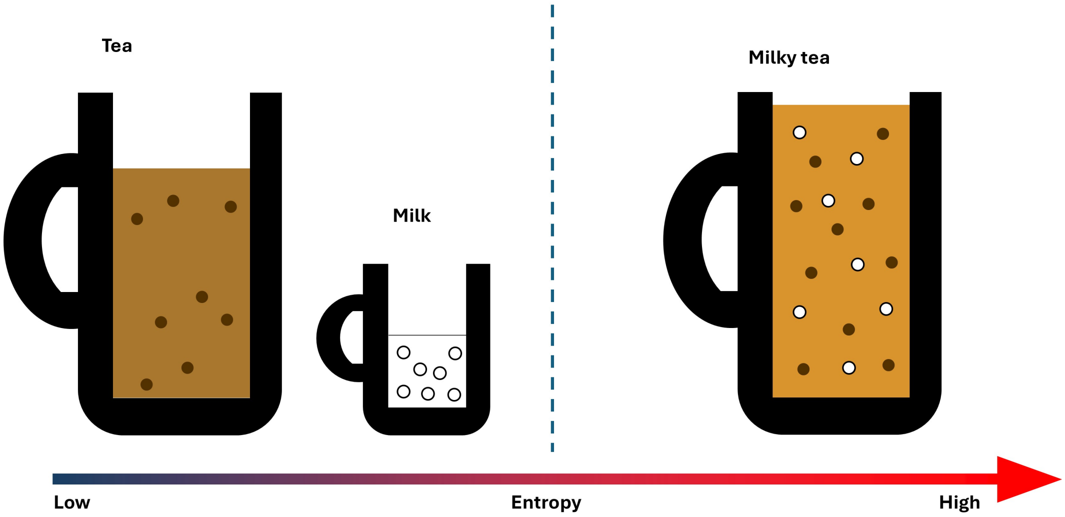

Figure 1: The entropy of a cup of tea. *Left:* the tea and milk are separate, and the molecules ordered. The system has low entropy. *Right:* after the milk is added to the cup, the milk and tea molecules mix together, increasing the disorder of the system and therefore its entropy.

It can be said for certain that life on Earth developed quickly. The first life was in the form of simple *prokaryotic* cells, basically genetic material and protein-assembling molecules held inside a cell membrane. These cells certainly existed over 3500 million years ago (mya). Some more tentative evidence even traces this life as far back as 4400 mya[3].

Life was formed from some of the most common elements in the Universe. The 'molecules of life' (e.g. CH_4, H_2O, NH_3) are made of the elements carbon, hydrogen, oxygen and nitrogen[4]. By harnessing the energy of the Sun, *autotrophs* became able to fix carbon, removing it from inorganic molecules and creating organic molecules. A famous example of this is photosynthesis in plants, which takes carbon from the air and creates glucose. Organisms unable to fix carbon themselves, *heterotrophs*, consume organic molecules.

Eventually, from the combination of biochemistry and freely available energy arose the first life. The temperature in which these biochemicals existed must have been warm enough that liquids were available and reactions could take place, but cool enough that they could remain stable and molecular. This gives a rough temperature range of $100 < T < 400$ K[5].

Our expansive home

The chemicals of life are common in the Universe. Hydrogen is by far the most abundant element, comprising three quarters of baryonic matter. It was formed as a consequence of the Big Bang. Oxygen, nitrogen and carbon formed later from the fusion of elements in stars, or during the explosive deaths of massive stars. The shock waves and winds of these events distribute material throughout galaxies, making it common in the giant clouds which collapse to form stars like our Sun. Does this happen in all other galaxies in our universe?

[1] Note that by taking energy from the surrounding environment, the entropy of the Universe is ultimately increasing, satisfying the second law of thermodynamics.

[2] This is not a complete definition. Some crystals are able to decrease their entropy, for example.

[3] This figure comes from the study of *zircons* - minerals containing ^{235}U and ^{238}U with half-lives of 700 and 4500 million years respectively, providing a "double-check" method for isotope dating.

[4] Sulphur and phosphorus are also useful molecules for life.

[5] Kelvin is the degree centigrade scale but with a minimum point of absolute zero such that 0 K = -273 °C.

One of the fundamental aspects of cosmology (the study of the Universe) is that the Universe is homogeneous and isotropic. That is, on large enough scales it is the same everywhere. This is the 'Extended Copernican Principle' (ECP). Through the astrobiologist's lens, the ECP states that our location in the Universe is not special in any way. The implication of the ECP is that nothing about the conditions in which life began on Earth is particularly unique. Hence, these conditions are commonplace throughout the Universe.

The scale of the Universe is incomprehensible (see [3]). Our Sun is a relatively small star which could comfortably fit 1000 Earths inside of it. The Milky Way contains around 400 billion stars. Galaxies are populous in the Universe. In the early 2000s, the Hubble Space Telescope was pointed for an extended period at a small, dark patch of sky. The Ultra Deep Field (HUDF, see Fig. 2) shows over 10,000 galaxies in this region, the reddest of which were seen as they were when the Universe was in its infancy[6]. The result of the HUDF, along with the ECP imply that trillions of galaxies inhabit the observable Universe - many of which formed during its infancy.

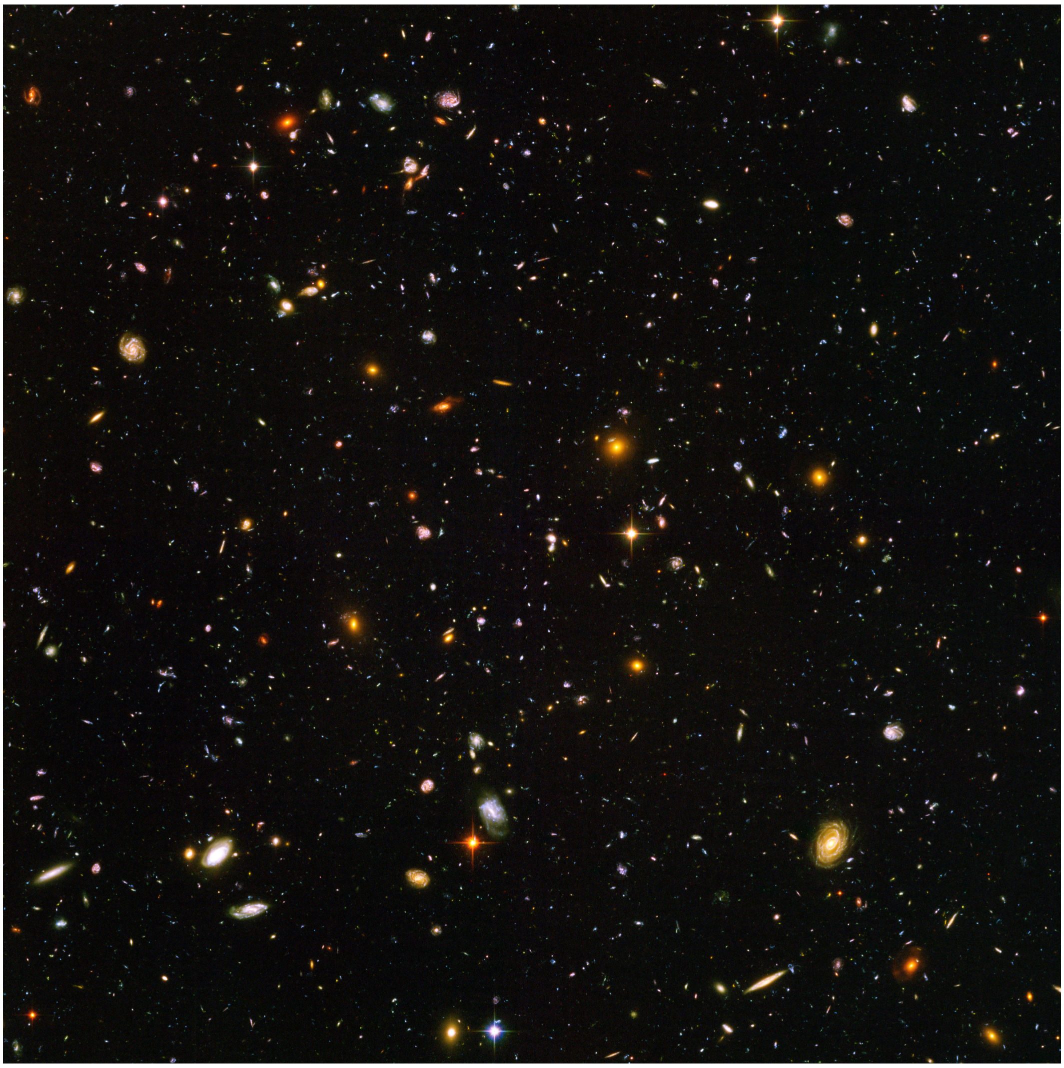

Figure 2: The Hubble ultra deep field shows almost 10,000 galaxies in a patch of sky less than one tenth the size of the full Moon. The oldest (and reddest) galaxies are seen as they were when the Universe was just 800 million years old. Credit: ESA/Hubble

In just the Milky Way alone, there is an abundance of stars and the chemicals of life. It is believed that around most, if not all, of these stars are planets. Given the abundance of material and energy, there may be around 20 billion planets with the conditions to potentially host life [4]. But how much time does this life require to develop past a primordial soup? The Milky Way was formed in the infancy of the Universe (see Fig. 3). Just as complex life has existed for a fraction of the age of the Solar System, the Solar System is young in comparison our host galaxy. The Milky Way is 10-12 billion years old, giving a significant amount of time for life to develop on a life-favouring planet.

[6]Due to the finite speed of light, light from more distant objects takes longer to reach us. The expansion of the Universe also stretches this light as it travels towards us, a phenomenon known as redshift.

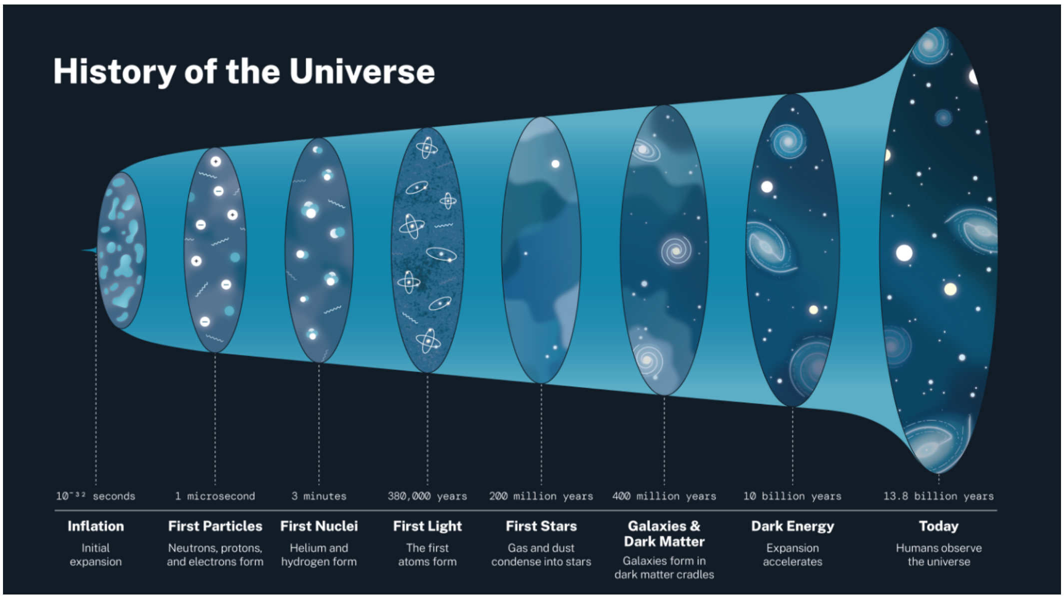

Figure 3: The epochs of the Universe. The first galaxies were formed as early as 400 million years after the Big Bang. The Solar System has only existed for the final 4.5 billion years of the history of the Universe. Credit: NASA [5]

3 COMPLEX AND INTELLIGENT LIFE SHOULD BE EVERYWHERE

Having established that simple life forms quickly from abundant elements, the next question to ask is "how likely is complex life to emerge?". In this section, the emergence of complex and intelligent life is discussed.

Complex life

Complex life arose around 2100 mya when single-celled organisms merged to form a new cell which contained specialised parts known as 'organelles'. These *eukaryotic* cells were fundamental for multicellular life to develop. Also around this time was the 'great oxygenation event', where the oxygen sinks on Earth were filled, and the poisonous gas began to pollute the atmosphere. This was a mass extinction event, earning the alternative name 'the oxygen catastrophe'. Around 1200 mya, multicellular life emerged from the unity of eukaryotic cells. Around this time, sexual reproduction had developed, rapidly speeding up evolution.

Only 550 mya there was a second major event in the history of life on Earth, the Cambrian explosion (see Fig. 4). At this time, there was an explosion in the diversity of organisms. In particular, body sizes increased dramatically, biomineralisation emerged (the formation of skeletons and exoskeletons) and animals first appeared. In this time, the level of oxygen in the atmosphere rose from 1 – 15%. This allowed for aerobic respiration, which mitigated this increase in size.

Do these events imply that there are certain requirements for life to progress and develop? The introduction and increase in atmospheric oxygenation appears to have aided the development of life twice in Earth's history. Other significant changes may also have played roles. The break-up of land masses, such as Pangaea around the Triassic and Jurassic periods (Fig. 4), may have increased the availability of nutrients by kicking up inorganic material from the ocean. New habitats are also formed from this break-up, particularly in shallow waters. We are currently exiting an ice-age, with global temperatures cooler than average over the Earth's lifetime. Two of these 'snowball Earths' coincided with the two most important events in the development of life on Earth.

Are events like these necessary for the development of life? The Cambrian explosion marked the rapid evolution from single celled organisms to large, complex animals over just a few hundred million years. Could it be the case that without the oxygenation of the atmosphere due to early carbon fixing life, life would not have had the chance to become large enough before the extinction of the Sun, roughly 10 billion years after the formation of the Solar System? Was the Cambrian explosion necessary for life to develop quickly enough to become intelligent before the Earth becomes uninhabitable?

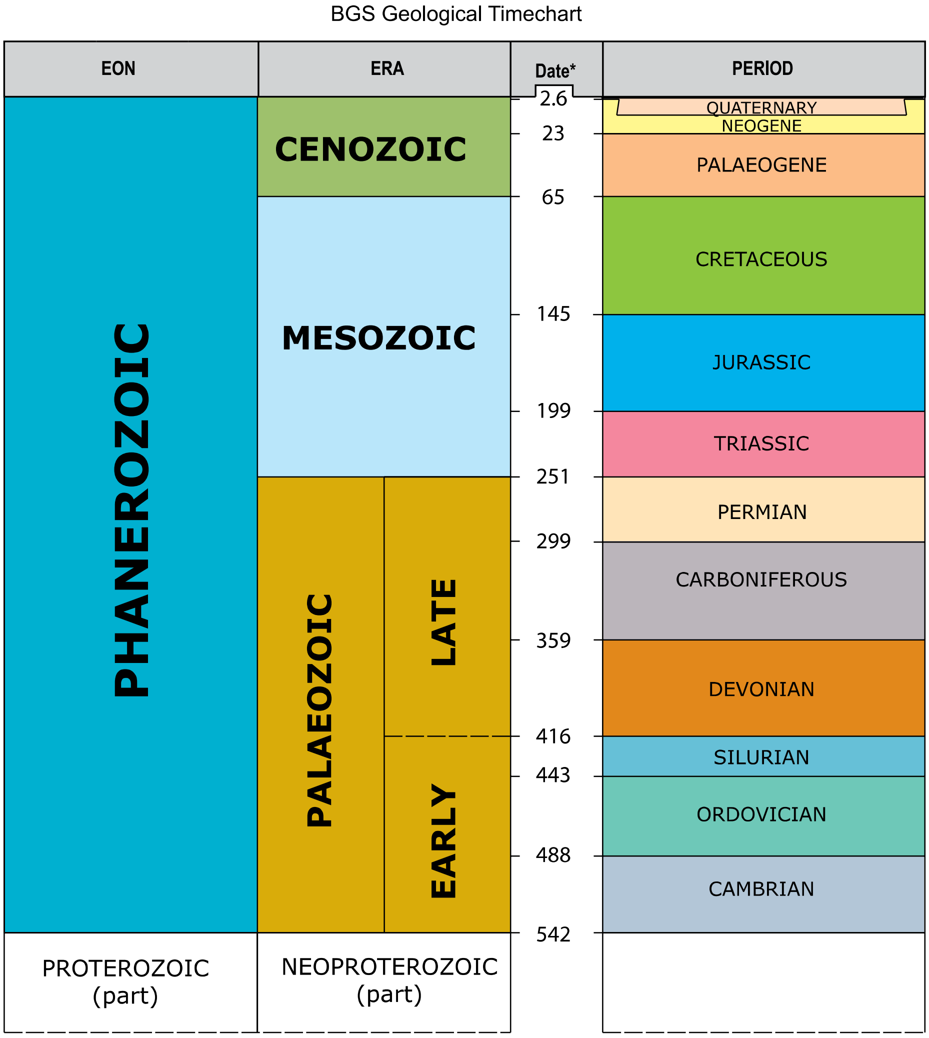

Figure 4: The periods of Earth's history since the Cambrian explosion. The numbers in the date column are in millions of years. Not included in this diagram are fateful encounter (1200 mya) the great oxygenation event (2100 mya). Credit: British Geological Survey

Intelligent life

The existence of brains only came about after the Cambrian explosion. Today, there are countless species which are able to think and comprehend the world thanks to information processors inside their heads. Intelligence and consciousness likely evolved as a survival mechanism - being able to think allows greater adaptation. The size, density of neurons and relative proportions of parts of the brain varies between species. So too do levels of intelligence and consciousness.

Consciousness may be defined as the awareness of ones inner self, famously put by Descartes "Cognito, ergo sum" [6]. Intelligent species are those with the ability to problem-solve and learn[7]. It took around four billion years for these traits to develop on Earth, perhaps vitally due to specific events in Earth's history acting as a catalyst for evolution. It appears that with complex life comes intelligence, as brains evolve. However, the timescale of this development is unclear. Were the explosive developments in life necessary for intelligence to arise on Earth as soon as it did? As far as scientists can tell, the transition from prokaryotic to eukaryotic cells only happened once in the Earth's history. Whether this happened early, late or as expected is impossible to tell with a sample size of only one. How long would life have taken to develop brains without such events? Could life survive long enough to do this?

[7] As with life, both consciousness and intelligence are very difficult to define, and there is no consensus on exact definitions.

4 TECHNOLOGICAL CIVILISATIONS MUST OCCASIONALLY ARISE

The Search for ExtraTerrestrial Intelligence (SETI) is an effort to find alien technological civilisations (ATCs) (e.g. [7]). An ATC is defined as an intelligent technological civilisation (ITC) capable of producing detectable electromagnetic signals. Interestingly, humanity would not qualify under SETIs definition, as an ATC is required to be deliberately broadcasting its existence into space. Humanity theoretically has the capability to do this, but currently does not[8].

Recent history is evidence that technology develops extremely rapidly. The most powerful telescopes in the world at the beginning of the 20th century were 1-m class reflectors in the US. By the 1990s, the 2.4-m Hubble Space Telescope was launched into space. It might be reasonable to assume then that if technology does emerge, it will develop rapidly. Are humans the only species capable of technology? Once more, the answer to this question depends on an incomplete definition. Many animals have been observed using tools and medicine, as humans did at the dawn of humanity. Chimpanzees use rocks to crack open nuts, orangutans have been observed using medicinal balms to heal wounds, and crows have used pebbles to displace water in order to drink it from a tube (see [8]). But at what point do tools become technology? Perhaps then one day, these animals will too develop their own technology. Is it an inevitability that, given enough time, intelligent beings like the great apes will develop their own technology?

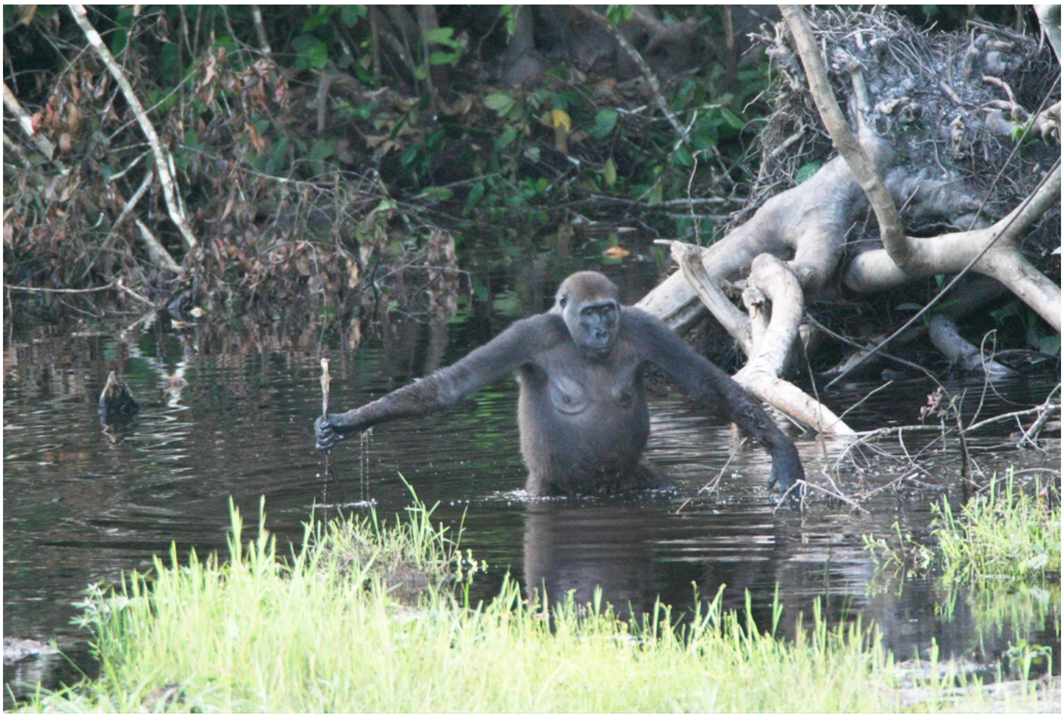

Figure 5: A gorilla uses a stick possibly as a tool to measure the depth of the water. Could this be the first step towards gorilla technology? Credit: T Breuer [9]

There are four factors to consider when determining whether technology is an inevitable consequence of life. Firstly, the species must survive for long enough to develop. Life on Earth has undergone several mass extinction events in its history. Furthermore, the lifetime of the Sun set a timeframe of 8 – 10 billion years for life to develop before the planet becomes uninhabitable. Are events like the Cambrian explosion required to develop complex life in time for intelligence to arise? Is intelligence actually common? There is plenty of evidence of intelligent life on Earth, but Earth is our only case study. Finally, how likely are intelligent species to develop their own technology? Again, there is only one definite example of a species developing its own technology, humans. However, the use of tools by other animals (see Fig. 5) implies that perhaps eventually, a chimpanzee, raven or even dolphin technological civilisation is possible.

[8]Would you wager that every civilisation out there is peaceful?

How likely is another technological civilisation?

So far the origins and development of life on Earth have been outlined, and the likelihood of each stage of progress discussed. The rapid emergence of life on Earth from common materials suggests that in the vast cosmos, simple life is everywhere. The emergence of complex and advanced life on Earth coincided with the great oxygenation event and Cambrian explosion. Both how necessary and rare these events are makes determining the likelihood of complex life existing outside of our Solar System extremely difficult. The variety of conscious and intelligent species on Earth suggests that these traits are perhaps inevitable in advanced life, given enough time to develop.

5 HOW MIGHT ANOTHER CIVILISATION REACH US?

The next section speculates how ATCs might look, and the means by which one might visit our Solar System.

What are aliens like?

The means by which an ATC might visit our Solar System depends on several factors. What is their biology and technology like? How do they think? Assuming that a civilisation develops similarly to humanity, an older ITC would have more advanced technology (and may be wiser), and may therefore use different means to travel to Earth.

Presented below are three case studies of civilisations older than humanity.

A few thousand years ahead of us

Four thousand years ago, the great pyramids of Giza were being built as tombs for fallen Pharaohs. These buildings are so breathtaking that even today there are conspiracies of lost ancient technologies which were used to build them. In reality of course, technology was far less advanced then, so much so that everyday items as simple as a wristwatch would be striking. Show an ancient Egyptian a smartphone and it would be considered magic[9]. However, in astronomical terms, the great pyramids have existed for the blink of an eye. If the age of the Milky Way was condensed into a single day, the pyramids would have been built less than one thirty-fourth of a second ago.

The point of this analogy is that on cosmic timescales, technology advances extremely quickly. A civilisation which formed at almost the exact same time as humanity could have technology which would look like magic to us. Imagine humanity in a few thousand years. Given the current efforts to colonise the Moon and Mars, we might have spread throughout the Solar System, with colonies on or orbiting every major body and its satellites. Beyond the Solar System, humanity will perhaps have sent probes or people[10] to nearby stars.

A few million years ahead of us

Given the 'magical' nature of technology just a few thousand years more advanced than our own, it is reasonable to assume that a civilisation with millions of years head start would have simply incomprehensible technology. This civilisation might have advanced to our current technology when dinosaurs still roamed the Earth. In our cosmic day, this civilisation still formed less than 10 minutes ago. As well as its technology, the species itself would have evolved. Could evolution be 'helped along' to produce enhanced biologies, capable of withstanding long journeys, high quantities of information and the varying conditions of multiple planets? For life such as this, it may be possible for biological organisms to embark on interstellar voyages 'in person'. Over this time, a species' brain would also continue to evolve. What level of consciousness and intelligence might it possess?

Ancient civilisations

Even older civilisations have enough time in the cosmic day to develop. Such civilisations would be completely incomprehensible to us, and humanity would have no chance of noticing them without their permission. If such civilisations exist, their choice to remain hidden may be interpreted in multiple ways - some more optimistic than others, but all slightly uncomfortable (see Section 6).

[9] In the words of Arthur C. Clarke, "Any sufficiently advanced technology is indistinguishable from magic".

[10] Unless close to light speed travel is developed, this would likely involve 'generation ships', enhanced biologies or stasis.

Non-biological visitors

Another possibility is that instead of visiting the Solar System 'in person', a probe is sent instead. The idea of this probe is to visit the Solar System and relay information back home, avoiding the additional challenges of sending biological life across long distances[11]. Von Neumann probes (VNPs) are hypothetical examples of probes which could be used to explore the galaxy.

Von Neumann probes (VNPs)

A VNP is a 'smart-probe' with the capability to travel to a star, self-replicate, then scout the star system, sending information back to its home planet. Self-replication may be achieved by building copies of itself using materials from the outer star system. If a VNP was programmed to construct three versions of itself before exploring the stellar neighbourhood, then there would be enough VNPs to visit every star in the Milky Way in 30 generations. How long would this take? It takes light 4.2 years to reach the nearest star to Earth, Proxima Centauri. On average, the distance between stars in the Milky Way is around 5 light-years. At 1% of the speed of light, it would take a VNP 500 years on average to travel between stars. Given another 500 years to replicate, the total 'mission time' is around 1,000 years. In 30 generations time, the VNPs could spread to every star in the Milky Way in 5 – 10 million years (around a minute in our cosmic day).

There are three main reasons an ATC might deploy a VNP: exploration, colonisation and competition. The drive to explore is engrained in the human psyche. Perhaps humans in a few hundred or thousand years will sent our own VNPs out into the galaxy, motivated by curiosity and wonder. VNPs could be used for the purpose of colonisation in two ways. Scouting a star system for a potentially habitable planet to live on is known as *active* colonisation, and is a very popular topic in sci-fi. Another method of colonisation is by *seeding*. Panspermia is the process of introducing life to a planet, either by chance (e.g. prokaryotes on an asteroid) or deliberately[12]. Competition between multiple advanced life-forms could bring about the need for 'hunter-killers' which seek out and destroy other VNPs. Alternatively, they could target life forms and wipe out any civilisation which could potentially be a threat[13]. Finally, they may be in place to target their own kind, a sort of galactic population control.

6 WHY DON'T WE SEE THEM? - THE FERMI PROBLEM

In Sections 2, 3 and 4, the likelihood of simple, intelligent and technological life existing outside of our Solar System was discussed. Simple life appears to be easy to develop, with complex life proving far less likely to occur. However, given the vast scale of the Milky Way and the Universe, the odds of another technological civilisation increase. It was argued that for another potential ATC to have significantly more advanced technology than our own requires very little time on a cosmic scale. Furthermore, with relatively modest technology (VNPs), every star in our galaxy could be visited in the blink of a cosmic eye. From the arguments presented in this essay so far, it might seem fair to say that aliens have almost certainly visited our Solar System. But if this is true, why have we never seen them? This question is the Fermi problem (e.g. [10]). There are two answers to this question, they either do not exist, or they do exist but we cannot see them (see [11]).

They do not exist

Rare Earth

One of the assumptions made when arguing about the probability of life outside the Solar System was that our place in the Universe is not special - the ECP [12]. The 'rare Earth' argument proposes the opposite to the ECP, suggesting that the formation of life and technology on Earth was due to a set of inconceivably 'lucky' circumstances. There are several events involving the origin of life which suggest the circumstances of Earth are extremely unlikely.

[11] Non-biological life (artificial intelligence) could also achieve this, but the motivation for a freely thinking non-biological being to visit a star system is difficult to decipher.

[12] Perhaps the "rise of the eukaryotes" was a deliberate attempt to create complex life on Earth by a civilisation far more advanced than our own.

[13] Are any of these headed our way?

The Sun is a fairly common star. Most Sun-like stars form in groups of two or more. Interactions in these groups can eject stars from their systems. Our Sun is a lone star. However, the relatively even orbits of the Solar System bodies suggests that it has experienced no major interactions with other stars. Forming in isolation is less common. Another feature of the Sun is that it is relatively 'quiet'. This lack of Solar activity likely allowed life on Earth time to develop without experiencing significant extinction events related to the Sun.

Migration is where bodies in the Solar System change orbits to closer or further distances to the Sun. During the evolution of the Solar System there were several major incidences of migration, particularly from the gas giants Jupiter and Saturn. The migration of the planets in the Solar System are described by the Grand Tack, and Nice models (see Fig. 6). The presence of volatiles such as water could potentially be attributed to the inward migration of the massive planets in the early Solar System. In the Grand Tack and Nice models, volatiles are introduced to the inner Solar System at different times. It is unclear if other mechanisms of introducing volatiles to the inner Solar System exist, or whether similar migration events are required in all potentially habitable star systems.

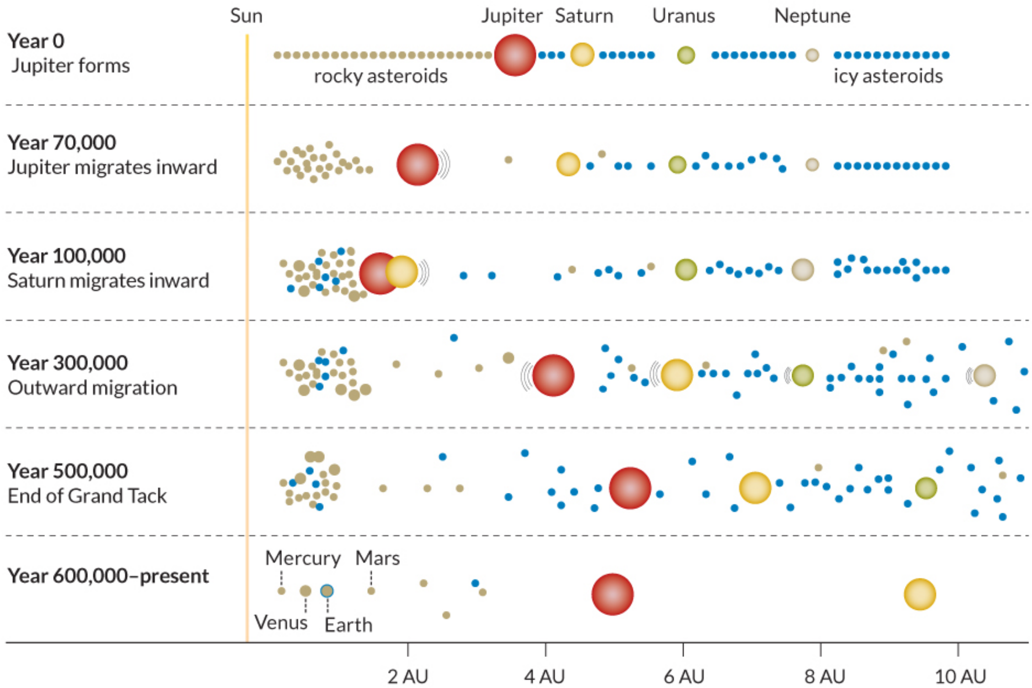

Figure 6: The Grand Tack model. The inward migration of Jupiter and Saturn bring volatiles into the inner Solar System, where the terrestrial (rocky) planets reside. This migration happens quickly, occuring in less than a million years. Credit: Center for Planetary Origin

The Moon is believed to have formed during a collision between Earth and another Mars-sized body[14]. Its size relative to Earth is far larger than any other moon (relative to its planet) in the Solar System. Due to this, the Moon strongly affects the climate on Earth. The tides, which would have been stronger in the early Solar System than today, pull the oceans over rocky sediment and churn up molecules. They also induced volcanic activity by pulling on Earth's liquid mantle, which is close to the surface thanks to Earth's thin crust - possibly another consequence of the Moon's violent formation. Finally, the Earth may have enjoyed greater protection from collisions with asteroids and other objects thanks to the Moon's larger mass. However, this is not certain.

The Earth's thin crust and liquid water allows for plate tectonics, which play a vital role in the carbon cycle. Briefly, volcanic activity induced by the shifting of tectonic plates releases carbon into the atmosphere in the form of CO_2. This CO_2 is absorbed in "sinks", mainly in silicate rock and the oceans. The subduction of an oceanic plate transfers carbon into the Earth's mantle. This is when the collision of a continental and oceanic plate causes the latter to slide underneath, melting into the hot mantle. Another important factor in the carbon cycle is the Earth's size. Our planet owes the retention of its atmosphere to its size. The gravitational attraction due to its mass keeps gas stuck to its surface and its liquid iron core acts as a dynamo, which generates a magnetic field strong

[14]This body was named 'Theia' after the ancient Greek Titan, who gave birth to Selene - the Goddess of the Moon.

enough to stop the atmosphere from being stripped away by solar winds[15] [13]. The Earth is also small enough to allow land to rise above the oceans, allowing erosion to occur.

Before the two most significant events in the development of life, the emergence of eukaryotes and Cambrian explosions, the Earth experienced snowball phases (ice ages). Whether the coincidence of these events is just that is unclear. However, if a snowball Earth provides the boost required for life to develop then these events would need to happen on every potentially habitable planet to produce complex and intelligent life.

Another potentially significant argument for the rare Earth includes our Sun's position in the galaxy. Our orbital velocity around the centre of the Milky Way has kept us away from its vibrant spiral arms, which contain activity such as supernovae that could have potentially spelt disaster for life on Earth.

Timescales

A theory which does consider the ECP considers the significant age of the Universe. The Universe is more than old enough for an ATC to have emerged exactly as humanity did, and then died off again before the dawn of humanity. One theory suggests that humanity is the only ITC right now. In this model, ITCs come and go like fireworks. Due to the immense age of the Universe, the rise and fall of these ITCs do not overlap. This leaves just a single civilisation alone in the Universe for the duration of their existence. For this theory to hold, there must be something which causes species to collapse before they can become multi-planetary, and spread across multiple homes. These barriers are known as "great filters".

Great filters

As I write this essay, a superheavy rocket with the ultimate goal of transporting humans to Mars is completing its first successful test flight. With this in mind, it seems that planetary colonisation and the spread of humanity to other planets is closer every day. When exactly this will be achieved is yet to be seen, however, if civilisations do poke in and out of existence before achieving multi-planetary habitation, then the end of humanity is nigh. Humanity has the capability to wipe itself from existence. If such a catastrophic event as a nuclear disaster were to occur in such a way that the entire population of Earth was eradicated, this could be considered a 'great filter' through which our species could not pass.

A slightly more optimistic great filter is that of an ageing Sun. As the Sun ages, it becomes more luminous. A result of this is that the Earth would heat to the point where it becomes uninhabitable. Surviving that, at the end of its life, the Sun would expand into a red giant, engulfing the Earth[16].

Not all great filters are necessarily in the future however. The "fateful encounter hypothesis" suggests that life on Earth has already passed through a significant great filter. This is the emergence of eukaryotic cells, which were formed from the fusion of separate cells. As was mentioned in Section 3, this occurrence is believed to have only happened once in the history of life on Earth. This fateful encounter was the catalyst for the progression of life from primordial soup to complex life. If such an event is so unlikely to happen, then it would make the complex and intelligent life on Earth extremely rare in the galaxy, and possibly the Universe. Could it be that the snowball Earth was the reason for this fateful encounter? This would suggest, as per the rare Earth argument, that conditions on Earth were specifically needed for life to form.

They do exist

ATCs are too advanced

The other possibility is that there is life beyond our Solar System, but we cannot see it. As mentioned in Section 4, an ATC with as little as a few thousand years head-start on humanity may have technology that is inconceivable today. Perhaps then there is life everywhere, but it is so far ahead of our own technology that we simply cannot detect any evidence of their presence. Furthermore, if there are VNPs in our Solar System, they would likely be on the very outskirts and far too difficult to detect or distinguish from other objects.

[15] The interaction between Earth's magnetic field and solar winds produces the Aurora Borealis (the northern lights).

[16] *The Wandering Earth* by Cixin Liu is an excellent short story about humanity attempting to escape this.

Space is big

Perhaps instead, the opposite is true. Our galaxy alone takes more than 60,000 years for light to cross. If there are ATCs in the Milky Way, it might simply be that they have not come across our Solar System yet. This problem is solved by sending out self-replicating 'smart-probes' (see Section 5), however. It could be the case that an ATC detected life on Earth, or maybe even Venus or Mars[17], and there is *someone* on the way to see us. One possibility could be that there is an ATC in the Milky Way which has detected human life on Earth, however the reward of travelling to Earth to meet us is not worth the effort of the project. Perhaps it is too risky to give away the existence of your species to one as volatile as the human race.

The dark forest hypothesis

On the topic of concealing ones existence, the dark forest hypothesis suggests that the ATCs in existence are deliberately masking their position in space. The reasons for this may vary. Perhaps not every ATC is friendly, it is better to hide your position from everyone than take the risk and be proven wrong. They could be afraid of us, and our weapons of mass destruction. They could be far more advanced than us, and simply following the 'Prime Directive' from Star Trek by not interfering with our progress before we are ready.

The cosmic zoo

The cosmic zoo leans into the idea that humans are too primitive a species to know about other ATCs. In this scenario, far more advanced civilisations are able to observe us at will, without our knowledge. Perhaps one day we are able to leave the cage, and meet the zookeepers.

Why visit our Solar System?

The cosmic zoo hypothesis suggests that alien civilisations would *want* to observe humanity and our Solar System. What benefit would this bring to a far superior species than our own? Perhaps this is entirely out of curiosity. Given the knowledge that an ATC exists and the technology to visit them, there is no doubt that humanity would immediately begin training astronauts for the first interstellar mission. It cannot be assumed that another species would think similarly to us however. As a Vulcan, Commander Spock would only think logically about a decision to visit another life-bearing Solar System.

Given the enormity of the challenge of interstellar travel, is it unlikely that an in-person visit to our Solar System would be worth the effort. Our Solar System is made of very common elements, centred on a very ordinary star. The life on planet Earth makes the Solar System 'special', whether it is rare or not. For an ATC which already knows of our existence, a visit to our Solar System would simply be illogical.

7 CONCLUSIONS

This essay has discussed the likelihood of intelligent technological civilisations existing outside of our Solar System, the means by which such a species may visit, and some of the reasons behind the lack of evidence for ATCs.

There are many chances for life to emerge. We live in an old universe and galaxy. In our cosmic day, the rise of the eukaryotes - the so called fateful encounter - happened just four hours ago. On top of this, the Universe is vast. The most common elements within this expanse are those which are fundamental for life, and it appears that life gets started almost as soon as it can. The transition from simple to complex life is perhaps the most difficult great filter that life on Earth has overcome. This could stall most, if not all other life in the Milky Way. If this is the case, then one would expect that a large proportion of alien life in the Universe is simple prokaryotic cells. If life does develop past this stage, it would perhaps require a second 'boost' similar to the Cambrian explosion. Given the variety of species with evolved brains on todays Earth, it may be reasonable to assume that intelligence and maybe technology will inevitably develop, given enough time.

[17] A reminder that due to the finite speed of light, the greater the distance to an object, the further back in time you see it. This applies to aliens looking at our Solar System too, an alien 55 light years away with a powerful enough telescope could watch the Moon landings. Could an observer much further away have seen life on Venus? [14]

The fact remains, however, that these arguments are based on a sample size of one. The arguments presented in this essay are ultimately built upon speculation. We have to say that the Earth has ideal conditions for life because we exist. Similarly, just because life on Earth developed in a certain way does not mean that all other life has to[18].

For an ATC to visit our Solar System requires both the means and the motivation. An ATC would only need to have developed a fraction sooner than humanity in order to have technology beyond our comprehension. However, to travel here involves both risk and effort, which may outweigh any benefits beyond curiosity. There has never been any substantial evidence to suggest that ATCs do exist, or have travelled to our Solar System. Perhaps these species do exist, but are concealing their existence to protect themselves, or to allow us to progress. Perhaps other species have existed before, but no civilisation can survive long enough to meet one another. Or perhaps life is simply too rare, and life on Earth is all there is.

Are we alone?

In short, the response to the phrase "aliens must have almost certainly visited our Solar System" is that we cannot know for sure. In fact, we cannot yet say for certain if any life at all exists beyond even our own planet. If ITCs are extremely rare, we could be the only one in the Milky Way. Does this mean if we were to ever encounter an ATC, it would be from beyond our own galaxy? Would we even be able to understand them?

If life on Earth is truly the only life in the galaxy, or even the Universe, then it bears the enormous responsibility of being the only matter capable of comprehending it. A universe without life simply exists, but without any *meaning*. Humanity has the potential to remove meaning from a significant corner of the Universe. Perhaps in preventing this from happening, we prove our species worthy of expanding across the stars.

[18] For example, just because you do not have an allergy to peanuts, you cannot assume that no one else on the plane does either.

Reading list

An introduction to astrobiology - Rothery, Gilmour & Sephton [15]
This text book was used in multiple sections in this essay. Chapter 1 (pp. 1–41) contains useful information on the origin of life on Earth and the transition to complex life. Chapter 9 (pp. 281-302) contains more detail on extraterrestrial intelligence and SETI.

Life on a young planet - Andrew Knoll [16]
This book contains information used in the sections outlining the origins of life (chapter 5, pp. 72), the oxygen revolution (chapter 6, pp.89), eukaryotic cells (chapter 8, pp. 122) and the emergence of animals (chapter 10, pp. 161).

Astrobiology: An evolutionary approach - Vera Kolb [17]
This textbook contains information on the origin of the CHON elements and formation of the Solar System (chapter 2, pp. 19 - Ken Rice). There is also interesting material on viruses in astrobiology which was not touched upon in this essay.

Astrobiology: A multidisciplinary approach - Lunine [18]
This textbook contains highly useful information on the scaling of the Universe, the creation of the CHON elements and a discussion on whether the Universe is tuned for life (not touched upon in this essay).The evolution of life and the Solar System is discussed, along with the evolution of intelligence and the persistence of civilisations.

References

[1] A. Loeb, "6 Strange Facts about the Interstellar Visitor 'Oumuamua."

[2] M. T. Bannister, A. Bhandare, P. A. Dybczyński, A. Fitzsimmons, A. Guilbert-Lepoutre, R. Jedicke, M. M. Knight, K. J. Meech, A. McNeill, S. Pfalzner, S. N. Raymond, C. Snodgrass, D. E. Trilling, Q. Ye, and The 'Oumuamua ISSI Team, "The natural history of 'Oumuamua," *Nature Astronomy*, vol. 3, pp. 594–602, July 2019.

[3] BBC, "Our Universe is SO big, it's mindblowing! BBC," Nov. 2021.

[4] S. Bryson, M. Kunimoto, R. K. Kopparapu, J. L. Coughlin, W. J. Borucki, D. Koch, V. S. Aguirre, C. Allen, G. Barentsen, N. M. Batalha, T. Berger, A. Boss, L. A. Buchhave, C. J. Burke, D. A. Caldwell, J. R. Campbell, J. Catanzarite, H. Chandrasekharan, W. J. Chaplin, J. L. Christiansen, J. Christensen-Dalsgaard, D. R. Ciardi, B. D. Clarke, W. D. Cochran, J. L. Dotson, L. R. Doyle, E. S. Duarte, E. W. Dunham, A. K. Dupree, M. Endl, J. L. Fanson, E. B. Ford, M. Fujieh, T. N. Gautier III, J. C. Geary, R. L. Gilliland, F. R. Girouard, A. Gould, M. R. Haas, C. E. Henze, M. J. Holman, A. Howard, S. B. Howell, D. Huber, R. C. Hunter, J. M. Jenkins, H. Kjeldsen, J. Kolodziejczak, K. Larson, D. W. Latham, J. Li, S. Mathur, S. Meibom, C. Middour, R. L. Morris, T. D. Morton, F. Mullally, S. E. Mullally, D. Pletcher, A. Prsa, S. N. Quinn, E. V. Quintana, D. Ragozzine, S. V. Ramirez, D. T. Sanderfer, D. Sasselov, S. E. Seader, M. Shabram, A. Shporer, J. C. Smith, J. H. Steffen, M. Still, G. Torres, J. Troeltzsch, J. D. Twicken, A. K. Uddin, J. E. Van Cleve, J. Voss, L. Weiss, W. F. Welsh, B. Wohler, and K. A. Zamudio, "The Occurrence of Rocky Habitable Zone Planets Around Solar-Like Stars from Kepler Data," *The Astronomical Journal*, vol. 161, p. 36, Jan. 2021.

[5] "Overview - NASA Science."

[6] J. Locke, *An Essay Concerning Human Understanding*. Kay & Troutman, 1847.

[7] I. Crawford, "The science and culture of SETI: Life On Other Worlds: The 20th-Century Life Debate by Stephen J Dick, Cambridge University Press, 1998, ISBN 0 521 62012 0, £17.95 (hbk)," *Astronomy & geophysics : the journal of the Royal Astronomical Society*, vol. 40, no. 3, pp. 3.34–3.34, 1999.

[8] The New York Times, "How Smart Are Crows? | ScienceTake | The New York Times," Apr. 2014.

[9] Breuer, "Wild Gorillas Handy with a Stick," *PLOS Biology*, vol. 3, p. e385, Oct. 2005.

[10] D. Dunér, “On the Plausibility of Intelligent Life on Other Worlds: A Cognitive-Semiotic Assessment of fi · fc · L,” *Environmental humanities*, vol. 9, no. 2, pp. 433–453, 2017.

[11] TED-Ed, “Why Can’t We See Evidence of Alien Life?,” Mar. 2012.

[12] P. D. Ward, D. Brownlee, and L. Krauss, “Rare Earth: Why Complex Life Is Uncommon in the Universe,” *Physics today*, vol. 53, no. 9, pp. 62–63, 2000.

[13] “Earth’s Magnetosphere: Protecting Our Planet from Harmful Space Energy - NASA Science.”

[14] A. Mann, “Venus Might Host Life, New Discovery Suggests,” Dec. 2020.

[15] D. A. Rothery, I. Gilmour, M. A. Sephton, A. Conway, and Open University, *An Introduction to Astrobiology.* Cambridge: University Press, rev. ed. / edited by david a. rothery, iain gilmour and mark a. sephton ; authors, andrew conway ... [et al.]. ed., 2011.

[16] A. H. Knoll, *Life on a Young Planet: The First Three Billion Years of Evolution on Earth*. Princeton Science Library, Princeton: University Press, new princeton science library paperback edition. ed., 2015.

[17] V. M. Kolb, *Astrobiology: An Evolutionary Approach*. Boca Raton, Boca Raton, Fla. ; London: CRC Press, 2015.

[18] J. I. Lunine, *Astrobiology: A Multidisciplinary Approach*. San Franciso: Pearson Addison Wesley, 2005.