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The universe and the possibility of life existing outside the Earth

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Abstract
This paper explores the nature of the universe and its existence as it examines the possibility of life existing beyond Earth. It starts by outlining how the formation of matter is necessary for life, subsequently on how planets, moons, and other celestial bodies could harbor the requirements for life to develop. This study contemplates both the scientific approaches used for exploring extraterrestrial life, such as chemical analyses, telescopic observations, and space missions, and the reasons scientists believe life may exist elsewhere, such as the presence of water, essential molecules, and energy sources. By evaluating current scientific theories, the suggestions of the Fermi Paradox and expedition efforts, this study underlines both the possibility and the uncertainty of finding life outside our planet. While Earth seems to be the only acknowledged planet to sustain life, the immensity and age of the universe raise the possibility that life may have emerged either on Earth or elsewhere. In addition, this paper describes philosophical and scientific implications of humanity potentially being one of the first, or only advanced civilizations in the universe, raising questions about our existence in cosmic history and in the future, and how we may be exceptionally rare as an intelligent life form.

Keywords: life, Earth, planets, moons, celestial bodies, universe

1. Introduction

For many centuries, humans have looked at the stars and wondered whether extraterrestrial life exists, or if we are alone in this universe. Due to the huge, and possibly infinite amount of space, the idea that life may exist outside Earth has attracted scientists, philosophers, and the public [1]. The observable universe has approximately two trillion galaxies with 1 septillion (10^{24}) stars and planets [2, 3, 4, 5]. The discovery of thousands of exoplanets, also known as extrasolar planets, throughout the past few decades, especially those that have habitable zones, has only increased the question of whether life exists beyond Earth. Tools such as the Kepler and James Webb Space Telescopes (JWST) have been able to help researchers to expand their ability to detect potentially habitable worlds, while missions to Mars, Europa (moon to Jupiter), and Enceladus (moon to Saturn) may seek biosignatures across our solar system [6, 7].

As scientists continue to prospect the universe, the search for extraterrestrial civilizations not only challenges our understanding of planetary and biological science but also changes our perspective about the cosmos. This exploration is deeply connected to how the universe originated itself. Several theories such as the Steady state theory and Eternal inflation theory provide scientific frameworks for how stars, galaxies, and eventually planets formed [5, 8]. So far, the Big Bang Theory is one of the most widely accepted [5, 9]. As we try to uncover life outside the Earth, we also seek clues about how everything began, what we may discover, and what the implications are for our future existence.

2. The scale and structure of the universe: How did it all begin?

It is believed that the universe contains everything, that is, it has all matters and energy as well as space and time. In 1927, Georges Lemaitre developed the Big Bang Theory, in which it is stated that the universe was formed approximately 14 billion years ago [10]. The universe started as a small hot region (known as aa 'primeval atom') that was very dense, after which was an explosion known as the Big Bang, allowing the universe to expand from a single point. As time passes, the density and temperature have slowly decreased. Thus, the universe is expanding (this is observed through galaxies moving away from one another, and at a faster rate when they are further away). This was also supported by Edwin Hubble as he observed the galaxies [11]. As mentioned earlier, this theory appears to be mostly accurate as there are several pieces of evidence that support this theory. The first is where light spectrums from supernovae are observed, where further galaxies are receding faster than nearby galaxies and light from the spectrum is galactic red-shifted, proving that the universe is expanding. The second is the existence of the cosmic microwave background (CMB) as electromagnetic (EM) radiation, which formed starting from the early stages of the Universe. The CMB is known as a fossil remnant and was made from high energy radiation that has redshifted for more than billions of years. The radiation of CMB started off as a hot body that cools down over a very long time [12, 13].

It is believed that this universe as a closed system follows laws of thermodynamics as the energy changes its forms and the system becomes disordered, thus there is an increase in entropy. This happens as energy moves from a hotter substance to a cooler substance. One example includes a cup of hot coffee placed at room temperature that cools down and reaches its room temperature. The internal heat of the universe and its disorder increase, which eventually reaches a point of maximum disorder where everything will have the same temperature. This concept is known as heat death of the universe as the temperature would be at absolute value with low motion (known as 'thermodynamic equilibrium') and basically reaching the end of existence. At this point there would be no order or very low entropy, and life would not be sustained [9, 14, 15].

To understand how life could arise elsewhere in the universe, we must first understand how matter forms, since life cannot exist without matter. In the earliest moments after the Big Bang, the universe existed in an extremely hot, dense state of pure energy, with low entropy and uniform temperature. As the universe expanded and cooled, energy condensed into fundamental subatomic particles such as quarks and neutrinos. Quarks combine to form protons and neutrons, while electrons emerge separately [16, 17]. Eventually, these particles formed the first atoms, primarily hydrogen (H_2) and helium (He). Atoms constitute elements, and as the universe continued to evolve, these elements began to bond, forming molecules and compounds. Over time, this led to the emergence of complex matter, anything with mass and volume. It is from this matter that stars, planets, and ultimately life arose.

The order: *Subatomic particles → atoms → elements → molecules → matter → life* [17, 18]

H_2 is considered the first element to appear in which other elements such as He originated from it [19]. Several of these elements where there was mostly H_2, assembled into a large cloud which eventually coalesced through gravity, thus creating galaxies and stars. Our galaxy, known as the Milky Way Galaxy, originated approximately 1 billion years later after the universe started to exist, and eventually many more galaxies were made. Our solar system appeared in the center of our galaxy after 8.4 to 5.4 billion years where the sun is the center for the planets to orbit. While our galaxy has billions of stars, our solar system has planets that orbit in a disk within the sun being the center. The sun, known as G-2 type star, along with other stars generate huge amounts of energy because of nuclear fusion (this enables H_2 to convert into He, thus all the stars spread out energy). More elements starting from He up till Iron (Fe) were also generated. When stars would run out of fuel and cannot resist gravity, they would explode in supernovae, generating heavier elements such as Uranium (U) and Gold (Ag) because stars, like organisms, have a life cycle i.e. they are born and then age and eventually they die. In other words, it is believed that all elements are generated through stars and were scattered through explosions as Carl Sagan stated: *'We are made of star stuff.'* It took the universe billions of years to enrich itself [20]. Planets were made from a cloud of gas (mostly H_2 and He) and dust called solar nebulae along with heavier elements [21].

Eventually dwarf planets, moons and the smaller solar system bodies (SSSBs) (this includes 3900 comets, planetoids, centaurs, and 1.3 million asteroids) were made from heavier elements. Moons (so called natural satellites) are used to orbit the planets (Venus is the exception), possibly hundreds of dwarf planets, and SSSBs. So far, life is discovered only on our planet even though scientists are looking for civilizations on other planets, as well as moons, dwarf planets, and SSSBs by using spacecraft missions, telescopes, and biosignatures for sustaining life [22].

In our galaxy, there are 8 known planets that are divided into two groups: inner-terrestrial planets (our planets, Mercury, Mars, Venus) and outer giant planets (Jupiter and Saturn as gas planets and Uranus, and Neptune as ice planets). Even though there are many dwarf planets, only 5 of them are recognized such as Eris, Pluto, Haumea, Ceres, and Makemake. From March 25, 2025 there are approximately more than 891 discovered moons so far (as Earth has 1 moon, Mars has 2 moons (Phobos and Deimos), Jupiter has 95 moons, Saturn has 274 moons with Titan as the second largest moon in our solar system, Uranus has 27 moons that are mostly icy, and Neptun has 14 moons in which dwarf planets has possibly dozens of moons [23]. Our planet is around 4.6 billion years old and the only planet in our solar system that has a biosphere with suitable conditions for life [22]. Apart from not knowing whether there is extraterrestrial life or not, it is also not even clear how life appeared on Earth or whether it initially started to appear outside the Earth and then spread through Earth [24].

3. Search for life outside the Earth: Challenges and Paradoxes

The fact that extraterrestrial presence may exist is considered more fictional as it's difficult to find evidence that there is life beyond Earth and that so-called alien life has ever visited our planet. Even though the National Aeronautics and Space Administration (NASA) is used for exploring our galaxy and outside galaxies, extraterrestrial life was still not found [25]. The concept of Fermi paradox was introduced by Enrico Fermi in 1950 and suggests that there we might be truly alone in this universe as humans have tried to detect signals since the mid-20s and that no advanced civilization tried to contact us. This concept was documented by Hart in 1975 along with other researchers [26]. It is confirmed that it took billions of years to form 118 known elements in the universe may also mean that we may be one of the first civilizations, and many other planets are still becoming more chemically ready to form life [27].

Now, the question is, is life so rare in the universe? Possibly not, as Carl Sagan stated: The *universe is a pretty big place. If it is just us, it appears to be an awful waste of space.* 'From his statement, it seems that the universe does not mean that it is lifeless as its visible regions are estimated to be approximately 46 billion light years away and there are so many things undiscovered [28, 29]. Another theory is based on The Rare Earth Hypothesis which claims that terrestrial planets like Earth are needed for life to arise. Also, there was discovery of extremophiles showing that these types of organisms can survive and adapt in extreme environments which are mostly harsh and lethal for many organisms on Earth. This may indicate that life may exist in environments vastly different from Earth's, giving out the possibility that habitable conditions can be more common than what the Rare Earth Hypothesis suggested [30]. To prove that complex organisms can survive outer space, a Russian experiment was conducted on the International Space Station (ISS). They used seeds, insect larva, Crustacean Eggs, Bacteria, fungi, and several types of plants (tomato, leaf mustard, radish, red mustard, rice, barley) that were sealed inside Biorisk containers and were put to the outside walls of the ISS. After 7-13 months, it was found that most of them survived and were able to produce [31].

For life there to exist, there must be several suitable basic conditions to sustain life as each organism has two basic goals, i.e. to survive and reproduce. To detect the possibility of life, scientists look for signs including water, basic essential elements including Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, and Sulfur (CHONPS), suitable temperature and atmospheric conditions. These essential elements are abundant in the Galactic disc, meaning we can find life signs somewhere else. Sun is needed for organisms to obtain energy in the form of light and to maintain redox reactions. On the other hand, Earth is unique due to its carbon cycle being tightly connected with life and climate regulation, as it enables suitable conditions for organisms over geologic time [32]. However, even though Earth life is carbon-based, scientists are also considering that there may be life forms which are radically different, such as silicon-based life or that they do not rely on water (even it is argued that organisms cannot live without water) [33, 34]. This unpredictability makes it challenging to recognize life when scientists manage to find it, and not know what they are looking for, making it tough to formulate effective approaches for detection.

Another factor is that our technology is not well advanced to detect civilizations outside our planet even though some technologies were able to detect many things as there are enormous distances between stars and galaxies. The Search for Extraterrestrial Intelligence (SETI) is mostly used for finding radio signals, but these signals could be too weak, too far away, or may be unrecognizable with current technology [35].

A critical element in this search is the Drake Equation, formulated in 1961 by Frank Drake, that's used for estimating the number of technologically advanced societies in the galaxy and for those that can communicate in space. In this equation several factors including the rate of star formation, the number of stars with planets, and the probability of life developing are considered. His goal was to estimate the probability of finding extraterrestrial life, and he introduced this equation while having a meeting based on SETI at Green Bank Observatory, West Virginia.

The formula of Drake Equation:

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

where:

- N represents the number of extraterrestrial civilizations in our galaxy that can communicate with our planet
- R* represents the average amount of new stars generated each year in our galaxy
- fp represents the fraction of these stars with planetary systems
- ne represents the average amount of planets for each star that can sustain life
- fl represents the fraction of these planets which are capable of developing life
- fi represents the fraction of these planets which already have advanced extraterrestrial life
- fc represents the fraction of extraterrestrial societies with developed technology which can release signals of their existence into space
- L represent the time length of these extraterrestrial societies communicate

The values are given as : R* = 1 (as in 1 star formed per year), fp = 0.2-0.5, ne = 1-5, fl = 1 (100% of these planets will have a life), fi = 1 (100% of these planets will have extraterrestrial intelligent life), fc = 0.1-0.2(10–20% of them can communicate) and L = a value in between 1000 and 100,000,000 years.

Drake's original approximation seems optimistic, indicating that there might be 10-10,000 intelligent alien societies in our galaxy [36]. However, there are limitations in these equations as some of these variables (f*i*, L, and f*l*) are poorly speculative. Even though the equation points out that life may be common in the universe, we still did not find definitive proof of it. Our present knowledge is reduced to our Solar System, where Earth represents the only example of life. Current missions to Mars, Europa, and Enceladus as well as detecting biosignatures in exoplanets may help us to widen the knowledge for this equation. Also, estimating how long civilizations can communicate remains uncertain, considering that there are possible threats such as ecological failure, nuclear war, or technological displacement from detectable communication. Another problem is that the equation is mainly based on how each term is independent, and interdependence seems to be neglected. It also does not account for the fact that civilizations do not rise synchronously; they could arise starting from today 10 million years after. Not to mention that some of these civilizations may use different forms of communication that may be unfamiliar to us and difficult to detect, such as neutrino-based communication as this equation was mainly based on radio communication. Some civilizations may choose not to communicate and limit to following patterns that have Earth-like conditions. Also, this equation basically ignores Fermi paradox as it does not resolve the discrepancy between the high chance of extraterrestrial civilizations existence and the absence of observable evidence [37, 38].

The Great Filter Hypothesis, proposed by Robin Hanson in 1996, states that there are major obstacles or ″filters‶ that prevent life from becoming more advanced so it could travel through space and associate with other civilizations. Like the Fermi paradox, it explains why despite the immensity of the universe and the high chance of extraterrestrial intelligence being emerged, no signs of it have been detected [39].

Finally, the discovery of 5500 exo-planets, planets that orbit stars out of our solar system, has broadened our understanding of the possibility for life outside the Earth [40]. Many of them are considered to have ‘habitable zones’ with their stars and possibly liquid water existing, but it is not clear whether life will emerge, or it has already emerged. Seager Equation, developed by Sara Seager in 1999, is based on estimating the number of planets with detectable biosignature gases and substances that may indicate the presence of life.

$H = \mu g/kT$,

where:

- H: Atmospheric scale height (in meters)
- k: Boltzmann constant
- T: Atmospheric temperature (Kelvin)
- μ: Mean molecular weight of the atmosphere (in atomic mass units)
- g: Surface gravity of the planet (m/s^2)

In her equation, she focused mostly on M stars as they are the most common stars in our solar system and less luminous than the star as it is based on finding detectable signs of life (e.g. biosignature gases), instead of finding intelligent civilizations trying to communicate. Her approach may be more practical as it helps to find traces of biomarkers including Oxygen (O_2), Ozone (O_3), Methane (CH_4) and Nitrous oxide (N_2O) [41, 42].

4. Possible signs of Life

To detect life, scientists are looking for possible signatures. There have been multiple missions launched to other planets and other locations as well. Since 1846, there were 9 recognized planets as Pluto was also classified as a planet but in 2006 Pluto was demoted as it is considered a dwarf planet [43]. To search for any aliens lurking in our solar system, probes were sent to some planets and satellites. From 2021, JWST started to give first glimpses: the combination of gases in the earth-like atmospheres of exoplanets giving out a strong indication of possible life. In the future, more advanced telescopes may pick up more signs such as photosynthesis or atmospheric pollution created by possibly intelligent, technological life. There is a possibility to find life near planets and moons such as Mars, Venetian clouds and Jupiter. Starting from Mercury, it is found to be hostile towards life and has a temperature of 400 °C during the day and −180 °C at nighttime as it has no atmosphere to trap the heat to circulate air and water [44]. It is the first planet in our solar system but not the hottest planet, and it is a heavy planet as it has more than 70% metal (mostly Fe and silica) [22, 45]. Venus has an average temperature of 464 °C because of the greenhouse effect as its atmosphere is composed of 96% carbon dioxide (CO_2) and 3.5% nitrogen (N_2). It does not have water remaining on the surface as it is dissolved in H_2 because of ultraviolet (UV) radiation. However, there is potential that life could exist as there is sulfuric acid which is suitable for thermoacidophilic microorganisms (as these organisms can live in this type of environment on Earth). Also, data obtained from the Venus Express probe launched in 2005, shows that there might have been oceans on Venus's billions of years ago, back then when the Sun was cooler and possibly, life could have formed and evolved. Two other compounds were detected: carbonyl sulfide (COS) was detected and cannot be easily reproduced without the presence of life and phosphine (PH_3), discovered in the cloud of Venus 4 years ago. These compounds represent a biomarker [44]. It is argued by scientists that Venus may be also too hostile for life considering its thick atmosphere of CO_2, intense magnetic pressure, and its surface hot enough to melt lead (Pb). But some scientists believe that there may be life in Venetian cloud as there might be ammonia (NH_3), molecular oxygen and CH_4 present (but not yet confirmed) despite having sulfuric acid (H_2SO_4) as anaerobic bacteria are found to produce PH_3 and CH_4 [46].

Mars, known as the red planet, may have had life in the past considering that photographs from the Mars Global Surveyor show rivers and saltwater during the summer [44]. There are suggestions that life initially started on Mars via abiogenesis (a Martian "organic soup") and eventually spread to Earth approximately 4 billion years ago. Scientists argue that due to the complexity of Deoxyribonucleic acid (DNA) as genetic material for the cells, abiogenesis may not be likely for it to occur in outer space [47]. However, according to directed Panspermia theory proposed by Francis Crick, suggesting that an advanced civilization seeded life on Earth as well as on other planets [48]. These organisms may be in a state of dormancy, frozen in ice, hidden deep within the core of a titanic, mineral rich meteorite, or encased in a bubble of NH_3, CH_4, and subjecting to planets and moons for contamination and interplanetary cross fertilization [47]. It seems possible that outer organisms may have DNA, and the nature of their DNA is to produce diversity and more complex living things such that DNA keeps evolving in a similar manner. Also, our genome may have traces of alien DNA incorporated; however, there is no evidence to support this theory [48, 49]. However, there is evidence to support that portions of genes transfer between several different organisms through a process called horizontal gene transfer (HGT) and one example is that the virus remnants are incorporated in our DNA as viruses invade our cells to replicate and use our genetic material [50, 51]. Further, DNA is a very stable molecule and it is found to remain virtually the same for millions of years [52]. It is possible that DNA may come from viruses according to the Ribonucleic acid (RNA) world theory as viruses initially had RNA molecules and since RNA molecules are labile, they had evolved to transit into DNA forms to evade host defenses more effectively [53]. Life may be repeatedly transferred between Mars and Earth and other planets. The Great Oxidation Event may took around 2 billion years ago on Mars, and Earth, and then to the evolution of organisms similar to terrestrial Acritarchs, tube worms, sponges, Ediacaran and legless eye-less metazoans; all of which are fossilized and found in several regions including the dried lake beds of Gale Crater [47]. Further, during ancient Martian life, it is believed that several types of microorganisms including cyanobacteria and green algae may have also lived in the oceans of Mars as they are also found in Gale Crater [54]. Also, scientists are trying to find biomarkers in the Atacama Desert, located in Northern Chile, which is one of the driest places on our planet, and it thereby makes a good Mars analogy. The environment is similar to having extreme aridity, a lot of UV radiation, and soils with high salt content. So far, photosynthetic bacteria, eukaryotes, and archaea were found to adapt in this extreme environment with low content water suggesting that they might be life on Mars [55]. Some of our dwarf planets, including Ceres and Pluto, were explored to see if there is life. Ceres is found to have water underground and may not have enough internal heat. On the other hand, it has carbon and H_2 molecules which can sustain life but there's no evidence [44]. Pluto also has frozen water but a weak atmosphere with CH_4 and N_2. It has organic compounds, but its surface temperature (-225 °C) may be too cold to support life but perhaps the interior part may support it [44, 56].

Jupiter, known as the failed star, has an atmosphere made of 90% H_2 and 10% He with an average mean temperature of -110 °C [44, 57]. Due to its extreme storm (the most famous is a swirling anticyclonic storm known as Great Red Spot), extreme atmosphere pressure that decreases drastically going down the planet hydrogen gas is compressed into a liquid forming the largest ocean in our solar system and powerful magnetic field (which is 20,000 times stronger than our planet and powerful enough to destroy an aircraft), it is not possible to support life [57, 58, 59]. Three out of 95 Jupiter moons (Europa, Ganymede and Callisto) may have the potential to support life. Europa has a saline ocean beneath its thick ice crust allowing hydrothermal activity which is like Earth's hydrothermal vents (but the ocean is twice the Earth's ocean) [60, 61]. The ocean is warm due to tidal heating and has several essential compounds such as water and CO_2 [60]. Ganymede also has a 100 km deep ocean that is larger than Earth's ocean and located. So, it is the only moon known to have its own magnetic field (generated by movement of saltwater and the metallic nucleus) which is rare for celestial satellites [44, 62, 63]. This means it may provide protection from Jupiter's intense radiation [64]. However, it is argued that it may be not able to support life as it has a thin amount of O_2 in the atmosphere as it is not breathable [63]. It probably comes from a process known as radiolysis, where charged particles from Jupiter's magnetosphere strike the icy surface of Ganymede, dividing water molecules (H_2O) into H_2 and O_2. The lighter forms H_2 escapes into space, and the O_2 is left behind [44, 65]. In terms of cratering, Callisto is the heaviest one and it has a thin atmosphere made of CO_2 and molecular O_2. It may have extraterrestrial life located in a salty ocean beneath its surface, but conditions seem to be less favorable compared to Europa. The two main reasons are: no contact with rock material and the lower heat transfer from its interior surface [44].

Saturn is a gaseous planet also made of H_2 and He along with traces NH_3 and CH_4, with the largest and most visible rings in our solar system [56]. These rings were probably formed when a moon or comet was too close and was torn apart by Saturn's gravity through a process known as Roche limit disruption. The rings therefore consist of billions of particles, mostly water ice, with some rocky dust, reflecting sunlight making them look bright but cannot support life as they have no atmosphere and temperature is around -200 °C [66]. This planet does not have a surface and has extreme conditions (intense pressure and radiation as well as extreme cold temperature) that's not suitable for life [67]. 2 out of 274 known Saturn moons, Titan and Enceladus, are so-called prime candidates for future exploration for extraterrestrial search as well as providing a similar environment towards the environment of exoplanets and other moons [68]. Titan is the only moon to have a substantial atmosphere with mostly N_2 and water on the surface, including clouds, river, rains and traces of liquid form hydrocarbons (Ethane (C_2H_6) and CH_4). According to Cassini spacecraft, it is revealed that this moon is covered with an ocean of liquid water (probably mixed with salts and NH_3) along with organic molecules may be useful to study prebiotic chemistry of life [68, 69]. Enceladus, known to have an icy world orbit around Saturn between two other Saturn moons; Mimas and Tethys [70]. Obtaining data from Cassini mission, it is revealed that on the south polar there is a process called active cryovolcanism, that is used for ejecting water vapor, ice particles, and organic compounds. Also, a subsurface ocean is in contact with a rocky core, providing conditions like Earth's hydrothermal vents [68].

Uranus and Neptune have similar atmospheric compositions just like Saturn's atmosphere and have volatile conditions for life to adapt [61, 71]. This is because of very cold temperatures that's approximately -200 °C, extreme pressure of 8–11 million bar, higher proportions of heavier metals compared to Jupiter as well as H_2O, NH_3 and CH_4 exist in volatile forms as inside these planets they are in supercritical state due to heat and intense pressure [72, 73]. Despite this, several of their moons may have potential for habitable environments. According to Voyager 2 flyby, new data was obtained from the magnetosphere of Uranus recently showing that moons are within the magnetic field along with ionized gases and some of them (Titania, Ariel, Oberon and Miranda) may have subsurface oceans [74]. Among all Neptune moons, Triton is so far the best candidate for habitable life as it may have a subsurface ocean beneath its shell that is protected from harsh outer space radiation. The water is kept liquid because of the internal heating and tidal forces occurring (due to its orbital interactions) as well as radioactive decay. It is also revealed that there is active cryovolcanism that spews off N_2 gas along with other organic compounds making this place geologically alive [75]. It is believed that this moon is a captured Kuiper Belt Object that's like Pluto composition and rich in volatile compounds [75, 76]. Pluto and among these potential planets may represent analogs for exoplanets or exomoons in similar extreme cold conditions for detecting life. However, more missions are needed to find evidence of extraterrestrial life. For instance, Nasa's Uranus probe is expected to arrive by 2045 [74].

Considering that there have been habitable exoplanets discovered in the last three decades. Before that, it was not known that exoplanets existed or planets that orbit other stars as it was difficult to discover. This gives scientist's hope as it brings us closer to answering one of the most profound questions. According to the NASA Exoplanet Archive, there have been estimated 24 extrasolar planets with ideal environments out of 5500 extrasolar planets via NASA missions including the Hubble Space Telescope, Kepler Space Telescope, and the Transiting Exoplanet Space Telescope (TESS), as well as terrestrial observations [6, 40, 77]. Data collected from Spitzer Space Telescope, Transiting Planets and Planetesimals Small Telescope-South 1 (TRAPPIST-1) system is group a 7 Earth-sized terrestrial planets where they have similar composition (they have same ratio of several materials such as Fe, O_2, and magnesium (Mg)) are involved single stellar system of red dwarf star called TRAPPIST-1(40 light-years from Earth) [78]. Also, the study done by Pichierri in 2024 also proposes that the TRAPPIST-1 system formed in compact order through two stages: inner planets first migrated inward, then the outer planets came later while the disk's inner edge subsided. This suggests that these planets were probably formed beyond the ice line, making them rich in water and volatile substances. Thereby, these planets stand out to be promising candidates [79].

A team of scientists in Cambridge were studying the atmosphere of planet K2-18b that's 124 years light away and they detected 650 trace molecules (e.g. Dimethyl sulfide (DMS), Dimethyl disulfide (DMDS), NH_3, Hydrogen sulfide (H_2S), PH_3, or nitrous oxide (N_2O)) that are only produced by simple organisms. This planet is not found in our solar system, and it is so called a mini version of Neptune as using JWST, scientists detected CH_4 and CO_2 in its atmosphere [80, 81].

In addition to the K2-18b planet and TRAPPIST-1 system, several other exoplanets are also promising candidates for their Earth-like characteristics. The closest known extrasolar planet is called Proxima Centauri b which orbits within its M dwarf star and known as 'super Earth' as it may support surface water with suitable atmospheric conditions [82]. A recent study done by Bohl in 2024 where there were 174 rocky exoplanets (e.g., LHS 1140 b, Teegarden's Star b, Ross 128 b, and Wolf 1061 c) compiled obtaining data from NASA. These planets were selected with radii that's either less than or equal to match the 1.6 Earth radii. They analyzed all these planets and calculated each planet's position and equilibrium temperatures assuming Earth-like conditions. They found that 67 of them are rocky planets in the habitable zone while 38 of them are identified as being in a refined habitable zone defined by a 3D climate model (this means that complex atmospheric and planetary dynamics are involved) [83].

5. What If We Do Find Extraterrestrial Life?

As Arthur C. Clarke famously stated in his book: *'There are two possibilities. We are alone in the Universe or we are not. Both are shocking*' [84]. Many things are possible on what would happen after scientists manage to successfully discover even the smallest percentage of terrestrial life as it represents one of the most profound moments in humanity. If it were to happen, then the Fermi paradox would be incorrect and therefore life would not be considered unique to Earth [85]. The Earth would no longer be the center planet of life in the universe, and even our galaxy may not be the center of the universe [44]. Of course, it would have a societal, ethical, and psychological impact on humanity as some of us may want to interact with extraterrestrial civilizations. This may also reshape our understanding of the universe and religious beliefs. As the authors Anton, Elliott, and Schetsche argue, preparing for contact isn't just a scientific challenge but also a social one [85]. Also, it may give us new insights into how life originated and evolved, potentially revolutionizing exobiology. There may be ethical considerations as there would be theological and philosophical questions which need to be addressed, such as how to treat outer space life and what kind of moral status it should have [86]. Not to mention, there would have been a huge impact on the economy and politics as there may be supply and demand for space exploration and tourism. Also, scientists may discover extraterrestrial life that poses a potential threat towards our society, requiring us to enable new defense strategies and technologies [87]. According to the study done by Kwon in 2018, a survey has been conducted on more than 500 people using Linguistic Inquiry and Word Count (LIWC) text analysis software and people were asked how they would react if there were a hypothetical announcement based on discovery of extraterrestrial microbial life. Most of the responses were optimistic and enthusiastic as many seem very excited about the potential discovery. These findings indicate that people perceive discovery as an exciting advancement in science rather than something terrified of [88]. However, regardless of what happens in the future, whether microbial or intelligent life is discovered, it would mark a pivotal moment towards our curiosity [89, 90].

6. Conclusion

As our technological advances and knowledge of the entire universe expands, our perspective based on finding extraterrestrial life continues to evolve. Over many years, a lot of hypotheses, equations, and concepts have been used to solve this cosmic question. While there is no direct evidence of extraterrestrial life, the ongoing research through astrobiology, astronomy, and planetology continues to expand our understanding of how and where life might originate. As our technology develops and progresses, the search for biosignatures and habitable environments may get us closer to answering one of humanity's most profound questions: Are we alone in the universe?

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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