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Potentially Habitable Kepler Planets

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Abstract: ***The basic understanding of life on exoplanets must be based on what we know about life on Earth. Liquid water is the main element that indicates life may exist and is the common requirement for life on mother earth. Temperature is the second parameter to consider, because it influences liquid water and because it can be estimated from climate models of exoplanets. Life exists at temperatures less than -15^{0}C and, as high as 122^{0}C. Deserts have shown the potential that even a little water can be enough to sustain life. Studies conducted in deserts have shown that life exists even in extreme regions with less rainfall, snow, fog, and adequate humidity giving slight chance for photosynthe- sis, resulting in microbial life. Only a small amount of light is required for photosynthesis. Some nitrogen must be present for life and the presence of oxygen would be a good indicator of photosyn- thesis and possibly complex life. All these show even in harsh conditions, they are chances to find life.***

Keywords: Goldilocks Zone, Host Star, Habitable Planets, Enrico Fermi, Paradox, Extra-Terrestrial Intelligence, SETI (Search for Extra Terrestrial Intelligence), Civilizations, Orbits, Main Sequence Stars, Red Dwarfs, Kepler space telescope, Kepler Planets, Interstellar, Potential Life Conditions.

That is a big question we all have: are we alone in the universe? And exoplanets confirm the suspicion that planets are not rare

- Neil DeGrasse Tyson

1. Introduction

Plenty of questions remain unanswered, numerous mysteries unresolved, yet we have reached this far understanding the cosmos and pushing our limits, to finally understand Our Place in The Universe, its existence, and the beginning. Once we started understanding the diversity of our universe, A question popped in our curious minds “Are we alone?”. Our approach towards this is a modern astronomical approach, which comes through something called the Drake Equation. [10]

$$N = R\ast \cdot f_P \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

It was first introduced when people began to search for extra-terrestrial intelligence through Radio Waves back in the early 60’s. The number of stars in our galaxy is the first factor that would go into the Drake Equation, and when we deal with the first factor which is really a question of how many stars are there? also tells us how often do they form? and how long does a star exist. The next factor would be, the number of planets revolving around those stars leading to the question of origin of life. This makes it crystal clear that no planet is equal to no evidence of life. The next factor is crucial for our search, what is the fraction of habitable planets revolving around these stars. Once we have found planets in the habitable zone, we have reached a step forward, but the question is are they in a place where it is possible for water to exist as liquid on their surface. These two factors combined define habitability. The next factor is the fraction of planets that show potential for forming life. Where we need to ask ourselves if all the planets so called Habitable form life or they consist of all elements required for life, yet there is no origin. The search for exoplanets has been phenomenal for the last 25 years. Since, the Greek the question was if planets revolved around stars, and it was unanswered till 1995 or 1996, but now we know. And after we did look into this question, we had to frame a new one: The Question of Life?

Before that we need to first understand how nature enables for life to exist in our galaxy. The conditions required for all aspects to unravel the mysteries of origin of life. But it’s not so easy, Individual planets may be difficult to spot for purposes like direct imaging. Trying to look at a planet around a star, is like trying to look at a firefly around a huge white light in the dark of the streets. Planets shine due to the reflection of star light, but they are dim compared to the star they are orbiting. We start to get to the bottom of it, by looking into their time period to orbit their star, which also tells us how far they are from the star. That also tells us the amount of sunlight they receive, though which we could interpret its temperature. Also, by directly measuring their mass and radius, we would be able to figure out its density. If the density is much like a rock, then it’s a terrestrial planet. If the density is much like gas, then it’s a gas giant or ice giant. Life do not form on gas giants, whereas there is possibility that it would form on the moons of gas giants. We also measure the presence of atmosphere and get the sense of its composition. When it is found that oxygen is one of its components, it shows that life has forged and it is growing. These planets should exist in orbits where the temperature exactly holds good for the water to stay as liquid, instead of getting frozen or evaporated. That’s why we call them Habitable zone or the Goldilocks zone. So how many planets are found in the habitable zone? as of June 2013, it was estimated that 64% of stars have planets revolving around them. And as of January 2014, scientific report stated that there is about 22% of sun like stars have Earth-sized planets in its habitable zone. We know that, billions and billions of Life Potential Planets exist out there and we need to grasp its aspects of sustaining life. With the discoveries of Kepler Telescope which was a satellite to find planets via the transit method, our understanding has grown and has began the procedure of deciphering the code of life. [12]

According to 2015, the most life sustainable Kepler planets are Kepler-62f, Kepler-186f, Kepler- 442b. Kepler-62e and Kepler-1229b have also showed potential for life.

2. The Search for Extra-Terrestrial Life

2.1 Fermi Paradox: The Beginning

If even a very small fraction of the hundred billion stars in the Milky Way are home to civilizations with advanced technology which colonize other star systems, the entire galaxy could be completely colonized in just few million years. After billions of years, the absence of such extraterrestrial civilizations visiting Earth is the Fermi paradox.

Using the assumption direct interstellar colonization is feasible, A model for interstellar colonization is proposed. Due to the time lag involved in interstellar travel, it is assumed that a colony established will rapidly develop a culture independent of the civilization that originally settled it.

Any given colony will have a probability P of developing a colonizing civilization, and a probability (1-P) that it will develop a non-colonizing civilization.

The galaxy contains roughly a hundred billion stars, there must be a very large number of such civilizations. If any of these civilizations have the capability to colonize over interstellar distances, even at half way the speed of light, they should have colonized the entire galaxy in just millions of years. Now the galaxy is billions of years old, Earth should have been visited and colonized long ago. Martin J. Fogg suggests that this should have taken place before life emerged from water. The absence of any evidence for such visits is the Fermi paradox or Fermi-Hart paradox, as Fermi was first to ask the question, Hart was the first to do a analysis showing that the problem is important, publishing his results. [18] [9]

Why haven't we met them? Solutions
Along the years, many solutions to Fermi paradox have been proposed, but unsatisfactory in one or the other way. [7]

The Rare Earth Theory
We are the only Intelligent life in the Universe

The universe is fundamentally hostile to complex life. While microbial life may be common in the universe, complex intelligent multi-cellular life required an exceptionally unlikely set of circum- stances, and therefore complex life is likely to be extremely rare. The essential criteria for complex life on a planet are a terrestrial planet with plate tectonics, sufficient oxygen supply, a large moon affecting the planet's tilt, magnetic field, a gas giant like Jupiter for protection from asteroids and an orbit in the habitable zone of the perfect star. This also includes geological events during the past such as Snowball Earth, the Cambrian Explosion, and the various mass extinction events such as

- Ordovician-silurian Extinction: 440 million years ago.
- Devonian Extinction: 365 million years ago.
- Permian-triassic Extinction: 250 million years ago.
- Triassic-jurassic Extinction: 210 million years ago.
- Cretaceous-tertiary Extinction: 65 Million Years Ago.

That nearly destroyed life on Earth arguably make the existence and survival of complex life rare and it has taken million of years to evolve, unlike bacteria, which were the first life to appear on Earth, prone to becoming extinct within a short period of time as it is extremely fragile to severe changes in the environment.

The Great Filter Theory
Other Intelligent Alien Race died in mass extinction and we might be next.

The right star system→ Self Replicating Patterns (RNA) → Simple (prokaryotic) unicellular life → Complex (archaeatic & eukaryotic) unicellular life → Sexual reproduction and Multi-cellular life →Tool-using animals →Industrial to Information Revolution → Where we are now! → Colonization explosion. According to this theory, Civilizations follow a evolutionary path that finally they are brilliant enough, that a mass explosion takes place and the civilization ends. This shows that something is present at the end that makes the galactic civilization impossible or extremely hard.

This is "Great Filter". This final stage leads to two scenarios.

Scenario 1: The Filter is Behind us, which means we already crossed it and are the first ones to accomplish it. the question is what was it? It could be Life itself or development of Multi-cellular life which was rare and happened only once, a primitive hunter cell swallowed another cell leading to further developments of complex life.

Scenario 2: The Filter is ahead of us, Major Extinctions have already caused a lot of deaths, but the order of magnitude always rises. Even if we encounter another major disaster and few survived, we could still get back, even if it takes million years. This is not Great Filter and its just a roadblock to Galactic Civilization. A Great Filter is so powerful that killed all advanced civilizations. This is most likely to happen when the civilization takes control of it's own planet. It could be either Nuclear War or Nano-Technology that goes out of control. Technology may be a way to achieve this. We can already see the competitive nature of species fighting for resources.

This tells us that finding bacteria or small micro organisms in other planets or galactic bodies could be bad, and ruins of ancient civilization could be horrible. [5]

The Great Silence Theory
Other Aliens are too intelligent and we are not worth their time.

From late 1950's to early 1970's, most of the discussions of SETI were related to questions which lead to an assumption - that complex life evolves at isolated sites of the interstellar, randomly distributed throughout. However, today this 'island' model is no longer accepted, and it's replaced by

'Mystery of the Great Silence' or the 'The Great Silence Theory'. The centerpiece of this theory has been the 'Drake equation'.

Where,

$N = R* \cdot fP \cdot ne \cdot fl \cdot fi \cdot fc \cdot L$

- N = The expected number of sites in the Galaxy, at which technological civilization has evolved.
- $R*$= Number of stars in the Galaxy
- fP = Fraction of stars which have planets orbiting them
- ne = Fraction of planets which are found in Goldilocks Zone, and can sustain Life.
- fl = Fraction of habitable planets in which intelligent life has evolved
- fi = Fraction of Intelligent life which have advanced technology
- fc = Fraction of those life forms which might be listening to us at any given moment
- L = How long the Intelligent species might be around at all (Controlling Factor).

The equation is completely statistical. One can estimate the values or parameters by using sta- tistical methods. It is statistically consistent, but there is a lack of evidence which is known as Fermi paradox. It's a fact that science always takes time. Encountering with any kind of extraterrestrial life also would take time. Statistically, we get N as Billions now and we haven't found any evidence yet. This provoke the Great Silence Theory, which concluded that Other Civilizations were too intelligent that they kept ignoring us as if we don't exist. [3] [2]

Early Bird Theory
Life Began First on Earth, We're the most advanced beings.

Different Kind of Life
They are not carbon based like us

For life on earth, Biochemical reactions take place in water, which acts as a solvent. Sufficient quantities of carbon and other elements, along with water, might enable the formation of living organisms on terrestrial planets and temperature range similar to that of Earth. Life based on ammonia has been suggested as an alternative, though this solvent appears less suitable than water. Also, There are forms of life whose solvent is a liquid hydrocarbon, such as methane, ethane or propane. [6]

In a Far Away Galaxy
They're are too far and out of our reach

The galaxies in the interstellar medium, beyond our solar system are moving away from us, and the ones that are farthest are moving the fastest. This means all the galaxies are moving away from each other. They are moving in space, because space is also moving. In other words, the universe has no center; everything is moving away from everything else.

One famous analogy to explain the expanding universe, which i find fascinating is imagining the universe to be a loaf of bread dough with raisins. As the bread rises while heating and expands, the raisins move far away from each other, but they are still stuck in the bread. Similarly in the universe, there may be planets out there that we can't see any more because they have moved away so far and fast that their light never reached Earth. The current width of the observable universe is about 90 billion light-years. But beyond that boundary, there's a bunch of other random stars and galaxies, whose existence we will never know. [4] [8]

2.3 Conclusion

With so many theories proposed as solutions and no evidence for extra terrestrial intelligence, we need to assume that we are the only conscious minds in the universe and it is our sole purpose, to keep this civilization going, to continue the Human Race and become the first Galactic Civilization. Otherwise, if we end as the only civilization to ever exist, there would be no meaning left to observe our universe.

For this to happen, we need to start finding Life Potential Exoplanets, so that we can start spreading to these planets starting colonies and colonizing most of our galaxy. Around 400 million years ago, life dared to leave the ocean. Now, it dares to leave the Earth.

3. Finding another Earth

The planets beyond our solar system are called "exoplanets"

What are the characteristics which make Earth a heaven of Life? How would we find these characteristics on a planet situated hundreds or thousands of light-years away? Once a upon a time, Earth was uninhabitable for millions of years, and it took billions to develop complex life.

Mars, once which had life sustaining conditions, now dry and absence of atmosphere, which we believe might reveal evidence of past life. A life-sustaining rock might also be a moon of gas giants or covered with ice layers. Jupiter's moon, Europa, and Saturn's Enceladus, are two moons which show conditions suitable for life, both hide oceans beneath the icy surface sheets. Titan, which is also a moon of saturn is the only other solar system body with rain, rivers and lakes. But instead of water it is hydrocarbons methane and ethane which could give rise to different form of life. Venus also is a twin planet to earth, which shows suitable conditions for life on the clouds. By studying our own solar system furthermore, we could understand the qualities we require to search for a perfect planet. [15]

Detection Method
It all began around 1995 or 1996, when it was impossible to directly detect an exoplanet. But indirectly, we started using techniques to identify exoplanets with the help of their host stars, The shadows of planets, hundreds of light-years away as they crossed the faces of their host star. It is called the 'Transit' Method. Kepler Space Telescope, and it's successor, TESS, Transiting Ex- oplanets Survey Satellite were assigned to find these shadows. With this we started initiating the next step, to study the atmosphere of these planets. "Every new telescope that gets launched gives us a totally new way of looking at the universe'. Hubble and Spitzer space telescopes observed the atmospheres of these

planets, capturing evidence of the gases present. Life can be inferred by the presence of atmospheric biosignature gases, produced by life that can accumulate to detectable levels in an exoplanet atmosphere. Many other techniques have been implemented, and new tools are added to the new satellites, which provide them to detect the doppler shift of the stars, from the light that travels to us, caused by the mass of planets revolving closely around them, which can be invisible to the other telescopes. Also, called the Radiation Velocity Technique.

NASA's James Webb Telescope is first of the Newest Generation. It will be able to capture starlight shining through the atmospheres of exoplanets. Certain bars will be blocked in the spectrum of the starlight by the gases in the atmosphere of these planets, in a way that scientists can read like a bar code, a method known as spectroscopy. The path to assess life beyond the solar system is being established. According to NASA, so far we have confirmed more than 4000 exoplanets.[14]

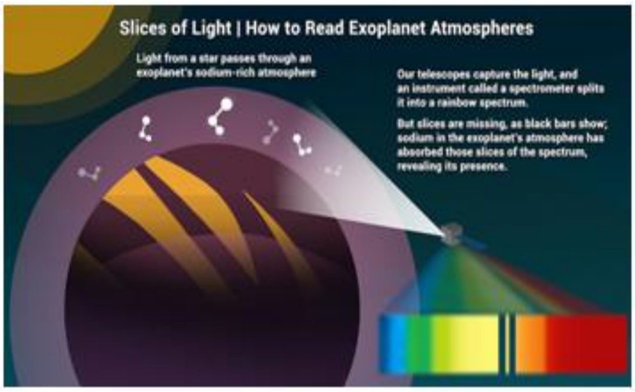

Figure 1: Reading Technique of the Atmosphere. Image credit: NASA/JPL-Caltech

Types of Exoplanets

Our nearest star is Proxima Centauri which is about 4 light-years away, 40 trillion Km. It is found to consist at least two or more rocky planets, which could probably sustain life. Rest all the other exoplanet detections are millions and billions of life years away, and we could never reach them with our latest technology. The farthest we have ever travelled in space is 22,827,565,000 Km or 153 AU by Voyager 1 which has successfully entered the interplanetary space.

In Terms of Mass

- *Mesoplanet*: A planetary body with a size smaller than Mercury, but larger than Ceres.
- *Sub-Earths*: Planets less massive than that of Venus.
- *Super-Earths*: terrestrial and ocean planets with masses around 5 to 10 times the size of Earth, less massive than the ice giants of our solar system.
- *Mega-Earths*: A massive terrestrial exoplanet that is at least ten times the mass of Earth. Mega-Earths are more massive than Super-Earths.
- *Mini-Neptune*: A gas dwarf or transitional planet, whose mass ranges from 10 times the size of Earth to Uranus and Neptune. Mini-Neptunes have thick hydrogen–helium atmospheres, with liquid or layers of ice on it's surface.
- *Super-Jupiter*: Planets or Interstellar bodies massive than that of Jupiter.

In Terms of Composition

- *Chthonian Planet*: Chthonian planets are gas giants that had their hydrogen or helium at- mospheres stripped away, leaving their cores.
- *Gas Dwarfs*: Low-Mass Planets mainly composed of Hydrogen or Helium.
- *Gas Giants*: Massive Planets composed of Hydrogen or Helium.
- *Ice Giants*: Massive Planets composed of icy substances heavier than helium or hydrogen, like water, methane or ethane.
- *Terrestrial Planet*: A rocky planet made of carbonaceous or silicate rocks or metals.

In Terms of Orbital Position

- *Jovian Planet*: The planet that orbits its star in an eccentric orbit.
- *Goldilocks Planet*: A exoplanet that falls in the planet's Habitable zone, where Water is said to be in Liquid State.
- *Hot Jupiter*: Extrasolar planets similar to Jupiter, but that have high surface temperatures because they orbit very close to it's host star.
- *Pulsar Planet*: An astronomical body which orbits a rapidly rotating neutron star.
- *Rogue Planets*: An interstellar body, with no host star and orbits the galaxy itself directly
- *Trojan Planets*: A planet co-orbiting with another planet.

This way discoveries of the past few decades have been classified for better understanding and also to distinguish between the discovered exoplanets. [16]

Kepler Planet Candidates

During 9.6 years in orbit, Kepler led to the discovery of more than 2,600 planets by observing more than half a million stars.

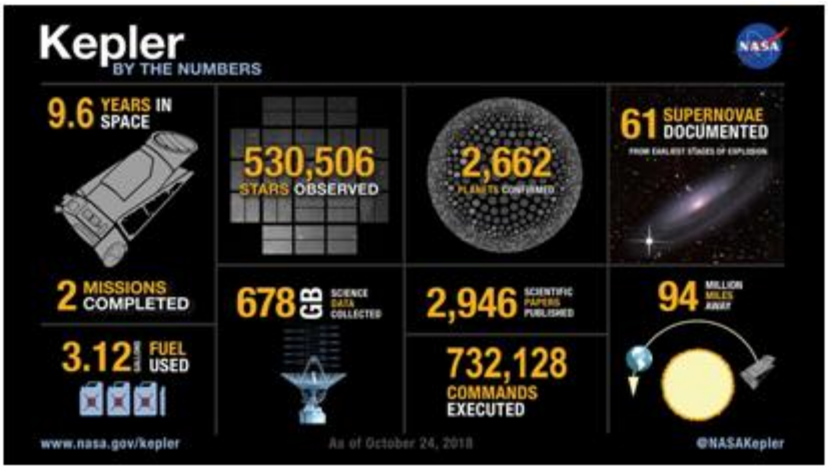

Figure 2: Kepler Satellite's Legacy. Image credit: NASA

According to the data from Planetary Habitability Laboratory, we have found 60 habitable planets in total, of which, 1 is Sub-Terran (Mars Size), 23 is Terran (Earth's Size) and 36 is Super- Terran (Super-Earth or Mini-Neptune). Which mostly ranges from 4.2 Light Years to 1194 Light Years. Due to Distance and travelling constraints, considering that it is not too far, there are only five Kepler planets in the list. Here, is a list of the exoplanets that are more likely to have a rocky composition and maintain surface liquid water (i.e. 0.5 < Planet Radius ≤ 1.5 Earth radii or 0.1 < Planet Minimum Mass ≤ 5 Earth masses).

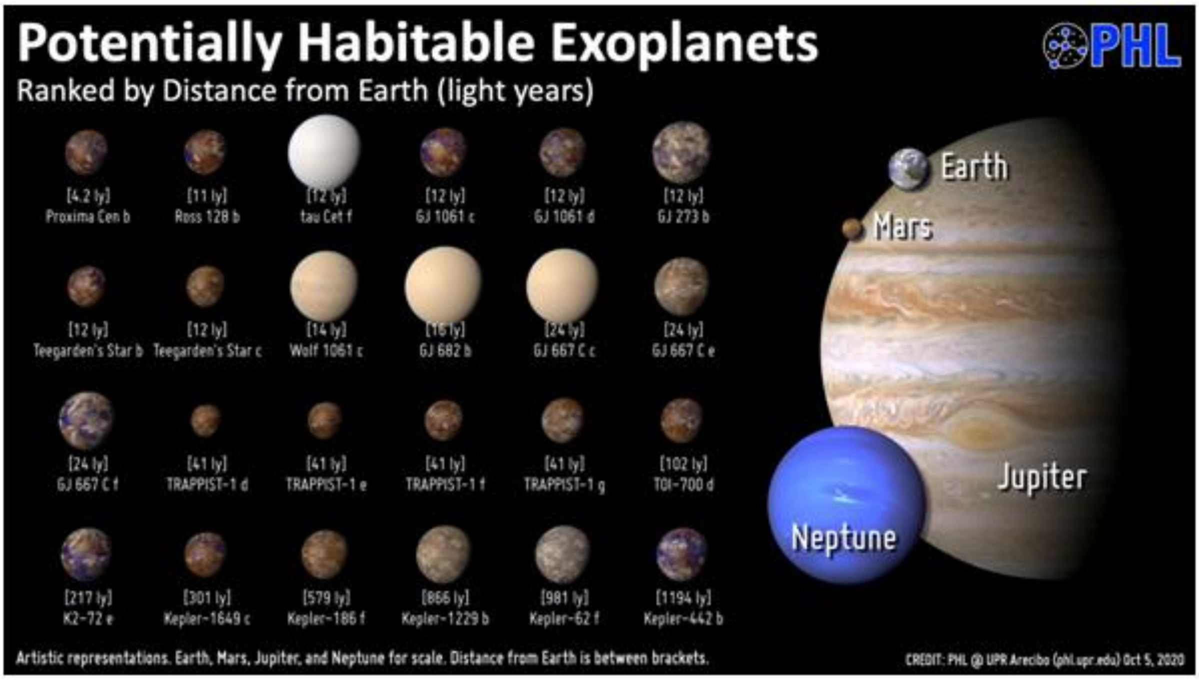

Figure 3: List of Potentially Habitable Exoplanets. Image credit: PHL @ UPR Arecibo

With respect to the distance, The Five Potential Kepler Exoplanets are:

- Kepler 1649c (301 Light Years From Earth)
- Kepler 186f (579 Light Years From Earth)
- Kepler 1229b (866 Light Years From Earth)
- Kepler 62f (981 Light Years From Earth)
- Kepler 442b (1194 Light Years From Earth)

Kepler 1649c

Figure 4: Kepler 1649c. Image credit: NASA, Ames Research Center

Earth-sized Habitable planet found in the Goldilocks zone of the Kepler-1649, Red Dwarf Star System. This planet is 300 light years from earth. It is just 1.06 times the size of our earth, and estimated to also have similar temperature, as it receives 75% of sunlight received by the earth. One year on Kepler-1649c is just 19.5 Earth Days. Equilibrium Temperature (K) = 234 20. The Financial Express wrote about Kepler 1649c's "proximity to the life conditions on the Earth" and that "there is no exoplanet that is closer to Earth in size and temperature and which also lies in the habitable zone".

Kepler-1649c was originally classified as a false positive by the Kepler pipeline, but was rescued as part of a systematic visual inspection of all automatically dispositioned Kepler false positives. The Kepler space telescope observed the earth-sized Kepler-1649 for a total of 756 days between 2010 and 2013. Kepler 1649c experiences a very different environment from planets in our own solar system. Kepler 1649c orbits a star with only 20% mass and 0.5% brightness of the Sun. Such characteristics for the planet's host star keeps Kepler-1649c outside of the ultraviolet habitable zone. A planet to be habitable, should be present in both liquid water habitable zone and ultraviolet habitable zone, but Kepler-1649c does not follow the ultraviolet habitable zone and instead is present outside it. Kepler 1649c orbit will be tidally locked, as it is close to it's host star, which means that one hemisphere of Kepler 1649c will permanently face its star, and will be very hot while the other hemisphere will be extremely cold. This also implies that any surface water on hot hemisphere will be transported to its cold hemisphere where it will remain permanently frozen. [17]

Kepler 186f

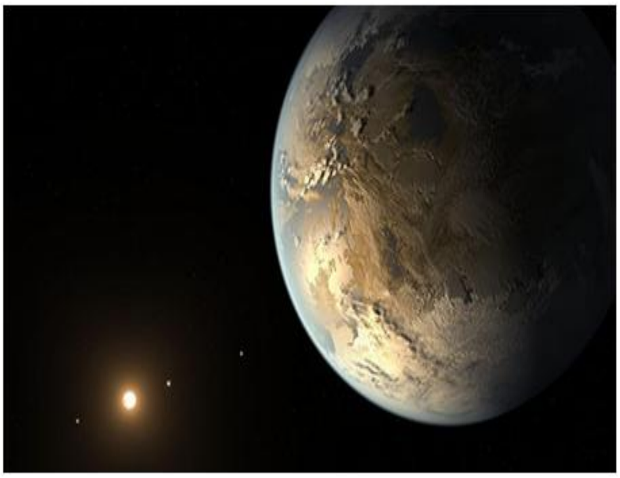

Figure 5: Kepler 186f. Image credit: NASA

It is the first Earth-sized Goldilocks planet found by Kepler Space Telescope. It revolves in an orbit about Kepler-186, which is also a red dwarf star. This planet is in direction of constellation cygnus, about 570 light years away. Previously, a small number of Earth-sized planets, such as Kepler-20e, have been discovered, but they orbit close to their star, making them too hot, due to which chances of life are impossible. Few other planets have been found to orbit in their star's habitable zone, like Kepler-22b and Kepler-62f, but these are Super-Earths and have thick atmosphere similar to Jupiter or Neptune, instead of any solid surface. Kepler-186f is the first habitable planet, with the right size and right distance from its host star, It also is rocky just like earth and has atmosphere suitable to support life, which helps water to remain in liquid state. It is one of the best candidates of Kepler planets for showing potential in sustaining life. [13]

Kepler 1229b

Figure 6: Kepler 1229b. Image credit: MarioProtIV - Space Engine

Kepler 1229b is a Super-Earth which orbits a Red Dwarf, Kepler 1229, which is 860 light years away. It's 2.54 times massive than the earth. Kepler-1229b is the most unexpected planet in this list of potentially habitable planets since no previous study pointed to this planet as a potentially interesting and habitable one. It takes 86.88 earth days to revolve around its host star. It is also present in the habitable zone of Kepler-1229, where liquid water can exist on the surface. The atmospheric conditions also appear to be suitable for life, as it's at the right place.

This planet is also tidally locked to its star, and one side is super hot, whereas the other side faces eternal darkness and is very cold. However, between these two intense areas, there would be a silver of habitability called the terminator line, where it is suitable for liquid water to exist with temperature of about 273K or 0°celsius. There are chances for a much larger portion of the planet to be suitable for life if it supports a thick enough atmosphere to transfer heat to the side facing away from the star. [11]

Kepler-62f

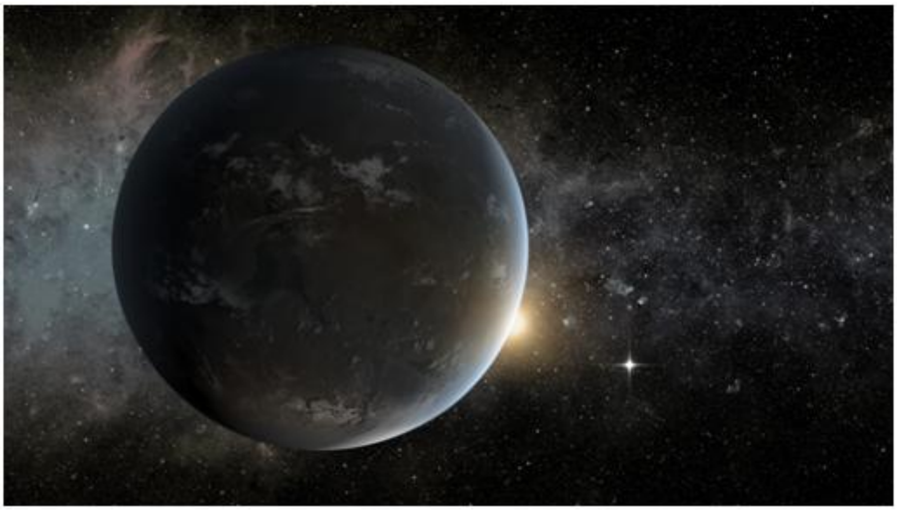

Figure 7: Kepler 62f. Image credit: NASA/JPL-Caltech

Kepler-62f is also super-earth sized planet about 981 light-years from our planet. The planet is only 1.4 times bigger than Earth and is in orbit around a star that is somewhat dimmer and smaller than the sun. It is in the habitable region of its host star. Kepler-62f's newfound neighbor, Kepler-62e, is just 1.6 times the size of the earth. Both are among the smallest exoplanets found in Kepler-62's habitable zone. These two are assumed to be water worlds which are the closest analogs to earth yet found. Kepler-62f is in a 262 Earth Days Orbit and it is about 40% the size of earth.

It could be Ice-Ball from pole to pole, unless the atmosphere is compact with carbon enough to heat the planet. Kepler-62f is the farthest known planet in its system and may require atmosphere and clouds to insulate the planet and keep water from freezing to ice. If this did happen, it would be a beautiful planet of ocean with a bright star. There may be chances of evolution of life there, but a life of technology in a water-world is seemingly impossible as they would not have much of access to metals, electricity or fire. But, we do know that life on earth also evolved from water. So, this Kepler candidate shows greater potential in possessing suitable conditions for life. [1]

Kepler-442b

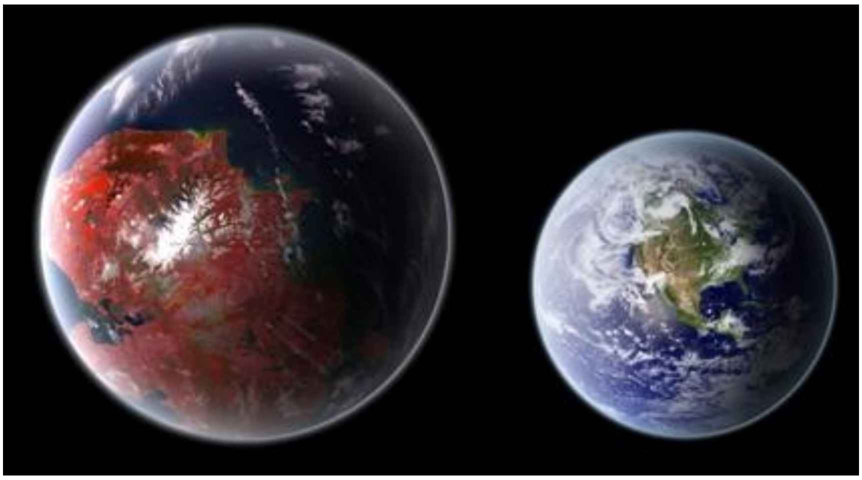

Figure 8: Kepler 442b. Image credit: Wikimedia Cosmos

Kepler-442b is Super-Earth which revolves around a main sequence star, Kepler-442b. Kepler- 442b is a K-type Main Sequence Star, about 1200 light years away. The planet is 2.6 times the size of earth. The planet is almost close as mercury to its host star. It is just outside the region to be tidally locked to Kepler-442. Though it is so close, it receives just 70% sunlight received by earth. The orbital period of Kepler-442b is roughly 112 days. It is in the Habitable zone of the star, where liquid water exist in liquid form. Therefore, As of July 2018, Kepler-442b was considered the most-habitable non-tidally locked exoplanet to be discovered by Kepler Space Telescope. [11]

Reflections

Fermi estimated that for any reasonable set of assumptions, a technological civilization would have reached every corner of the entire Milky Way within a time much shorter than the age of the solar system. Although many potential solutions to the so-called Fermi paradox have been suggested over the years—the first detailed examination was by astrophysicist Michael Hart in 1975. Hence, it was called Fermi-Hart Paradox. The key point is that in human history for the first time, we are perhaps only a few years away from being able to finally arrive at an answer for Fermi's question. And, not finding an answer can teach us our speciality in the cosmos.

SETI Institute's Allen Telescope Array in northern California has been observing all scientifically reported Kepler candidate exoplanets in search of signals from extraterrestrial technological civiliza- tions. It looks for patterns in frequency and time that could indicate an signal which was engineered specifically for sending a message rather than natural radio emissions. With so many developments in the field, including the James Webb Space Telescope soon in space, and future telescopes, our understanding of the cosmos and along with exoplanetary sciences, will take a step towards reaching the dream of a second home.

"The cosmos is all that is or ever was or ever will be. Our feeblest contemplations of the Cosmos stir us—there is a tingling in the spine, a catch in the voice, a faint sensation, as if a distant memory, or falling from a height. We know we are approaching the greatest of mysteries." - Carl Sagan, Astronomer

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