Abstract:

We attempt to determine the probability of an Earth-like clone planet with similar properties as the Earth with the assumption that such a planet would have a high probability of life formation. Using variables that the Earth possesses, which include; being within a spiral galaxy, being in the galactic habitable zone, solitary G-type star, Solar system with large Jupiter type planet, planet that is within 20% of Earth’s size and location within the solar system habitable zone with a similar orbit, a large moon and a magnetosphere. Using these requirements, the known universe would have 11 billion such Earth-like clones whereas each spiral galaxy would have approximately 1.12 such planets. Thus, the probability of Earth-like clone planets in the Universe is high but on a galactic scale, these numbers are quite low.

Introduction:

The expectations that life exists elsewhere in the Galaxy and Universe have been debated since man walked the planet. Why are here? Are we alone? Questions that have plagued philosophers and poets alike. Here we delve into the probability of the existence of life in our galaxy and universe based strictly on Earth being the standard. Many articles have been written on the subject of life in the universe but often the variables are expanded to include planets significantly different than Earth or with suns different than ours. What we currently know is that the Earth is the only place where life is known to exist and it is the only basis for life that we can speculate on. It is of course speculation when we only have a sample size of one but if another planet exists with all the attributes that make our Earth unique, then it is quite probable that life would develop and exist on that similar planet. In this analysis, we have decided to use these unique attributes that the Earth possesses to determine the number of Earth like clones. It is not known if all of these attributes are required as a basis for the production of life but we are using attributes that have been suggested by others as potentially essential. This is a big assumption, but at this time, we know of no other planet that harbors life and given that, we must assume that not only does life require these qualities to develop, but if they are present, that life will develop naturally given the same variables. Obviously, life could exist outside of these boundaries but we know of none and that is the reason for this analysis. For this analysis the following variables have been considered essential as being unique to the Earth and these variables are; Spiral galaxy, star in the galactic habitable zone, solitary G-type star, Jupiter type planet, Earth-sized planet in the habitable zone with a similar orbit, a large moon and a magnetosphere. If an Earth-like clone were to have these variables then given a period of one billion years, life could naturally form as it did here on Earth.

Methods:

What are the unique characteristics of the Earth that make life possible? These are obviously debatable within the scientific community and there are many but we tried to focus on the big picture and thus we assumed for the sake of this article that the prementioned variables would make a planet that has these similar attributes viable for developing life. The assumption is that an Earth-like clone would develop life naturally as did the Earth and that life is the natural order of things. This assumption, eliminates unique events that could be required to formulate life that are unknown to us. Obviously, an Earth clone could have all these attributes and not develop life. Thus, for our analysis, life is the assumed end result of any planet that has our suggested attributes since a clone of the Earth should result in another potential Earth. For simplicity, we delve into the attributes from the large to the small and thus we start with galaxies and move inward. Every calculation will be based on the Earth as the standard requirement for life as best that can be determined given the information available at this time. If there is variation in the data, we tried to get the variable to within 20% of the Earth as best possible.

The Universe is massive and we really don’t know the size of it. The known Universe is 93 billion light years across and over nearly 14 billion years old. The Universe is comprised of galaxies. Galaxies are defined based on the Hubble Sequence1. The Hubble sequence splits galaxies into three categories; Ellipticals, Lenticulars and Spirals. These are fairly straightforward with Ellipticals being round conglomerations of stars grouped into a sphere-like shape, Spirals galaxies being those appearing disc shaped with spiral arms and Lenticular being somewhere between the two with a central bulge and disc but without spiral arms. Hubble believed that Lenticular galaxies were the stage between Elliptical and Spiral but it wasn’t until better telescopes that this was truly deemed a classification2. The Earth exists in a typical Spiral Galaxy called the Milky Way. Are spiral galaxies required for life? Obviously, this is not known but since the Earth exists in a spiral galaxy, and we are duplicating the qualities of the Earth, we will assume that this is a requirement for the existence of life. Fortunately, 60% of galaxies are spiral in nature3. Spiral galaxies tend to be not to be in the center of galaxy clusters and are in low density regions which might aid to the stability and the formation of life. If these spiral galaxies are the eventual progression of elliptical galaxies and lenticular galaxies then it would imply that they are older. Older galaxies would also possess more of the heavier elements required for life such as carbon and iron. Our nearest neighbor, Andromeda is also a spiral galaxy and the two will eventually merge together forming one large spiral galaxy. The number of spiral galaxies in the Universe depends on the size of the Universe. As stated previously, the visible Universe which is 96 billion light years in diameter4. Beyond that, we are not certain of the size of the universe. It could be endless or not. As stated in our hypothesis, we are basing our decisions on that which is known and therefore we are using the visible universe for calculations. In the known visible Universe, there are estimated to be between 100 to 200 billion galaxies with some speculating up to two trillion galaxies5. These Galaxies range in size from small, one-million-star systems to massive galaxies that are multitudes larger than the Milky Way, but our galaxy appears to be the average size. We will use the average of 100 to 200 billion galaxies which is 150 billion as the number of galaxies in the Universe. Thus, 60% of 150 billion is 90 billion spiral or possible inhabitable galaxies in the universe.

At the galaxy level, each galaxy has probable habitable regions. This is referred to as the galactic habitable zone (GHZ). It is assumed that the galactic core has too much radiation and stellar activity for life and the further out regions might not have enough heavy elements. The GHZ is in one of the middle spiral arms of the spiral galaxy. The Milky Way is an average sized spiral galaxy in the universe with an estimated number of 250 billion stars with a range of 100 to 400 billion stars and approximately 300 million of these stars in the Milky Way are in the GHZ6. Based on the average of 250 billion stars for the Milky Way, which is an average spiral galaxy, and with 300 million of these stars being in the GHZ, this results in 0.0012 or 0.12% of the stars of a spiral galaxy being in the GHZ. Of these stars in the GHZ, 85% are red dwarfs, which are smaller than our Sun, which are too small for our consideration for an Earth like clone7. Our Sun is a G-type star which represents 7% or 28 billon of the stars in the Milky Way8. 7% of the 300 million GHZ stars is 21,000,000 G type stars (21 million stars). Thus, if 0.0012 of the stars are in the GHZ and 7% of these are G-type stars, then 0.000084 (0.0084%) stars in the Milky Way are G-type stars in the Galactic Habitable Zone. Of these G-type stars, approximately 1/3 of them are in solitary systems while 2/3 are in binary or more systems9. This then implies that of the stars in a typical spiral galaxy only 0.000084 of these stars are G-type stars in the GHZ, and only 0.000028 or 0.0028% are solitary G-type stars in the GHZ. Of interest, 75% of the stars in the Galactic Habitable Zone are older than the Sun and thus if live occurred with any of these stars, then they would be further along in their life cycle than our solar system and they may have even completed their life cycles. This also implies that only 25% of the stars in our GHZ would be in the process of developing new life.

To compute our analysis of galactic requirement for an Earth like clone, if there are approximately 150 billion galaxies in the universe and 60% of them are spiral galaxies, thus there are 90,000,000,000 spiral galaxies. Using the data above, the calculation for Earth-like star systems is 90 billion x 250,000,000,000 (average number of stars in spiral galaxy) x 0.0012 (number of stars in GHZ) x 0.07 (number of G-type stars) x 0.33 (solitary stars) = 62,300,000,000,000,000,000 or 6.23 x 1017 potential inhabitable stars in the known universe based on Earth’s solar system location as the standard. For the Milky Way Galaxy the approximate number is 250,000,000,000 (stars in the Milky Way) times the above-mentioned variables which offers 6,930,000 potentially viable stars in our Galaxy. Thus, on a star level, there are numerous stars that would be potentially compatible with life given Earth as the standard.

Moving inward, our solar system also has unique attributes that we will assume are required for life for this analysis. These include a large Jupiter type planet, an Earth sized planet in the Habitual Zone (HZ) with a similar orbit, a large moon and a magnetosphere. An excellent paper was written by Erik Petigura Et. Al and much of the data comes from that paper. Using our solar system as the standard, an Earth-like clone must have a large gaseous planet, like Jupiter, that might help eliminate the amount of late term bombardments on the Earth10. The probability of Jupiter sized planets associated with Sun like stars is 1.6% of such stars harbor such a planet. Thus, a large Jupiter type planet is uncommon but not exceptional.

Similar to the galactic level, the solar system has a habitable zone (HZ) which is based on sunlight levels that allow for fluid water to exist. According to Petigura, 22% of Sun like stars harbor an Earth like plant that is 1 to 2 times the size of the Earth and receives similar sunlight levels. The numbers in this study were extrapolated to include potentially missed planets based on abnormal inclinations of orbits and a fudge (completeness) factor was used to include these potentially missed planets. Again, using Earth as an example and assuming that an Earth-like clone requires a uniform solar disc with planets not excessively inclined, we will use their detected amount, excluding their completeness factor. The same article gives the number of 5.5% for Earthlike planets detected (no completeness factor) with a planet size of 1-1.4 the size of Earth in their specified HZ. Using their estimate of 5.5% which includes planets within 40% of the Earth’s size (1 to 1.4 Earth sizes) and reducing that by half to include only planets within 20% of Earth’s size, this number is now 2.75% of planets. This is a reasonable adjustment since their data reveals a linear distribution of planet sizes. Their article has a HZ that is based on a planet existing between 0.5 and 2 AU (astrological units). This AU definition would include both Venus (0.7 AU) and Mars (1.5 AU) if it was used and thus is not acceptable for our study since neither of these planets harbor life nor possess liquid water. Since Venus is only 0.3 AU different from the Earth, we will use 0.2 AU (or 20%) as the cutoff for a planet’s HZ. Assuming a linear distribution of planets, using 1 AU +/- 0.2 as our habitual zone, similar planets need to exist within 20% or 18.6 million miles of the orbit size of the Earth. This would reduce the number of planets in the mentioned article’s HZ (prior HZ zone 1.5 AU to 0.2 AU) by a factor of 74% to 26% of planets. This results in 0.72% of solar systems have an Earth sized planet in their HZ since 2.75 x 0.26 = 0.72. We also want an orbit that is at least 100 days or 1/3 of our current year to allow for seasonal change. Finding planets with long orbital periods is more difficult than those with rapid transitions and larger planets tend to have longer orbital periods. The mentioned study only revealed four Earth sized planets with orbital periods greater than 100 days. This begs the question as to whether longer orbital periods are uncommon or is it that much more difficult to locate long orbital period planets with our current technology. Their study appears to show a linear distribution for the orbital periods from 0 to 100 days. Thus, for our calculations, we will assume that a similar number of planets have longer orbits as those with shorter orbits and thus no change is applied to our results. This assumption could be significantly incorrect though, but given the lack of data we will assume that the straight-line distribution the research reveals for 0-to-100-day orbits continues onwards for up to 400 days.

The uniqueness of Earth includes a multitude of factors, some of which we are probably not even aware of, but for our study, we will try to limit our calculations to obvious features such as a magnetosphere and a large Moon and exclude items such as water which will assume is prevalent throughout the universe in the above defined HZ regions of space. Starting with the Moon, it is 25% the diameter of the Earth. No other planet in our solar system has such a large moon compared to its own size. None of the other terrestrial planets have moons with the exception of Mars having two small probably captured asteroids as moons. How did the Moon form? It has been speculated that the moon formed due to a large impact between two proto-planet-sized objects11. This has been suggested based on the fact that isotopes from moon rocks are similar to those from the mantle of the Earth. In such an impact, the angle and mass of the two objects must be within a certain margin or a moon will not form. The Moon has been suggested as being a stabilizing factor on our planet by keeping the Earth from wobbling, allowing for tides, and even possibly decreasing earth-asteroid impacts. Since our moon is so unusual amongst our own solar system, we must assume it is possibly essential for an Earth-like clone, but how common are such large moons? A study by Gorlova at Caltech, implies that large moons are uncommon in the universe12. Their study found one out of 400 suns observed had tell-tale signs of dust from such a large impact. Extrapolating the data to account for how long the tell-tale dust would stick around and the time period for such impacts, their estimate was that at most 5-10% of systems have large Earth-Moon sized planets. Since this number is an extrapolation, for our study, we will use their lower number of 5% since only 1 out of 400 or 0.25% suns in their study even revealed such tell-tale dusts from an impact and therefore their extrapolation of 5% might be unusually high but that is the number we will use for calculations.

Earth is unusual amongst our terrestrial planets because we possess a magnetosphere. Mercury, Venus and Mars do not have a real magnetosphere and do not protect the planet from solar radiation. A magnetosphere has been considered essential for life since the solar radiation would decay DNA that our life depends on. As for a magnetosphere, a paper by Susan McIntyre of the 2018 European Planetary Science Congress found that magnetospheres of any sized terrestrial (rocky) planets that were equal to or stronger than Earth’s magnetic dipole moment only accounted for 21 of 725 detected planets13. They found only 4 of these planets were within the HZ of their system. Using their data, which is the only data on this subject available, we must conclude that 21 out of 725, or 3% of planets would harbor a magnetosphere large enough to protect the planet from harmful radiation that would destroy life as we know it. We could utilize the data of the planets that were only within the HZ which would then be 4 out of 725 or 0.5% but given the small amount of data we decided to utilize the larger variable even though it also includes planets of any size. Thus, this 3% is not just Earth-sized planets but any planet that was observed.

A variable that we did not include is plate tectonics. Plate tectonics allows the constant recycling of the earth’s crust, control of internal heat and possible maintaining of the magnetosphere and is unique among the terrestrial planets14. There is much debate as to whether or not plate tectonics is essential for the emergence of life. It is suggested that plate tectonics is required for long term sustained life but possibly not for the initial emergence of life15. A paper by Robert Stern and Taras Gerya suggests that plate tectonics involved a long transition from the Mesoproterozoic active single lid which occurred from 1.6 to 1 Ga to modern plate tectonics that occurred in the Neoproterozoic era 1 to .5 Ga which was associated with the time period that there was a rapid acceleration of complex life16. If this is true, then plate tectonics occurred after simple bacteria existed on the Earth and was not required for the formation of life. They also state that the existence of plate tectonics might only be present on 0.003% of planets. Thus, since plate tectonics occurs later in the evolution of our planet than the first 1 billion years during which life forms, for our analysis, we did not include plate tectonics as an essential variable for the existence of an Earth-like clone but plate tectonics is probably required for sustaining life long-term and some might consider it a variable as well.

Results:

Using the Earth as the basis for life, life formed naturally here after approximately one billion years post the formation of the planet. Thus, we assume that an Earth-like clone would naturally produce single cell organisms or life if given 1 billion years of stability. Using our seven variables that include; spiral galaxy, star within the galaxy habitable zone, solitary G-type star, Solar system with large planet like Jupiter, planet similar in size to Earth in the solar habitable zone with similar orbit, large moon and a magnetosphere, we can determine the probability of an Earth-like clone being present in the Universe. Using the known visible Universe being 96 billion light years across and possessing approximately 150 billion galaxies we can use the above-mentioned data to determine an Earth-like clone planet. Of these 150 billion galaxies, 60% are spiral, like our Milky Way. Of the stars in these galaxies, of which the Milky Way is a typical sized spiral galaxy, 300,000,000 stars are within the GHZ. Of our Milky Way galaxy, which again is a typical spiral galaxy, 7% of the stars are G-type stars like our Sun, and 1/3 of these being solidary. In these extrinsic solar systems, it appears that a large Jupiter type planet is uncommon and amounts to 1.6% of solar systems. Of these extrinsic solar systems, 2.75% have planets that are within 20% of the size of the Earth with similar orbits. Of these planets, 0.72% would be within their solar system habitable zone based on a habitable zone that is within 20% of our Earth. Such a habitable zone would exclude planets similar to Mars (1.5 Au) or Venus (0.7 Au), which are both inhospitable to life as we know it. A large moon similar to ours is considered an uncommon event with it occurring at most 5% of the time in such systems. Finaly, a magnetosphere occurs in around 3% of all planets in these studied extrinsic systems.

Therefore, using the data aforementioned, the probability of a Earth like clone planet in the Universe is: (Number of galaxies) x (percent that are spiral galaxies) x (number of stars in typical spiral galaxy) x (percent of stars in the galactic habitable zone) x (percent of stars that are G-type stars) x (number of G-type stars that are singular) x (probability of Jupiter like planet) x (probability of Earth sized planet within 20% of Earth’s size with similar orbit) x (planet being in the solar system habitable zone) x (probability of a large moon) x (probability of a magnetosphere) which results in 150,000,000,000 galaxies x 0.6 (spiral galaxies) x 250,000,000,000 (stars in typical spiral galaxy) x 0.0012 (stars in GHZ) x 0.07 (G-type stars) x 0.33 (solitary stars) x 0.016 (Jupiter type planets) x 0.0275 (Earth sized planets with similar orbits) x 0.26 (planets in HZ) x 0.05 (Large moon) x 0.03 (magnetosphere) = 107,026,920,000. Thus, in the universe there should be nearly 110 billion Earth-like clones. This would imply that over half of the galaxies in the known Universe, could have an Earth-like clone planet. For the Milky Way Galaxy, or a typical spiral galaxy, the calculation would be the above without multiplying the number of spiral galaxies. Thus, the calculation would be 250,000,000,000 x 0.0012 x 0.07 x 0.33 x 0.016 x 0.0275 x 0.26 x 0.05 x 0.03 = 1.2. Thus, at the galactic level, Earth-like clone planets would be exceptional.

Discussion:

In this study we attempted to use our criteria that make the planet Earth unique to determine the probability of an Earth-like clone planet. We are assuming that if you have an Earth-like clone planet elsewhere in the Universe, that the probability of life developing would be high since this clone would have similar properties to the Earth and thus life should naturally form there as it did here. Our criteria for an Earth-like clone include a spiral galaxy like the Milky Way, a star in the galactic habitable zone, that star being a solitary G-type star like our Sun, a solar system with large Jupiter sized planet, an Earth sized planet in the habitable zone that is within 20% of Earth’s size with a similar orbit, a large moon and finally a magnetosphere. Even though plate tectonics are probably essential for life’s long-term survival, it has been determined that they are not required for the development of simple life and are therefore excluded from our study. Using these aforementioned variables, the results based on the known visible Universe results in just under 11 billion possible Earth-like clones in the Universe. For any typical spiral galaxy like the Milky Way, the number of Earth-like clone planets would be 1.12 per spiral galaxy. Thus Earth-like clone planets would be common within the Universe but would be rare at the galactic level. This doesn’t imply that every spiral galaxy has just one Earth-like clone since some could have zero and others could have multiples but what this data does imply is that planets similar to the Earth are quite common in the Universe but quite rare at the local galaxy level. If one was to assume that plate tectonics was also essential for life or an Earth-like clone then the 1.12 Earth-like clones would decrease to 1.12 x 0.00003 = 3.6 x 10-5.

Conclusion

Using common variables that have been used in the past to define a planet that might harbor life, we fine-tuned those variables to create an Earth-like clone with a limit being within 20% of Earth’s size and 20% similar orbit within the solar habitable zone leads to only 1.12 such Earth-like clones per galaxy but nearly 11 billion such planets in the known Universe. Thus, Earth-like clones are quite common in the Universe.

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