Are We Alone?

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Are we alone in the Universe? Is there someone watching us from space? Is there life beyond Earth? To explore answers to these questions, we first need to understand three mysteries: what defines life, what the pre-requisites for life are and finally, how life has evolved and survived on Earth in the first place.

What really are the defining features of 'life'? Looking around, we can identify several characteristics of life - life grows, life replicates, life metabolises, life manipulates the environment for energy and sustenance, life displays a level of complexity that distinguishes it from non-life. Life has a sophisticated system for storing, processing and transmitting information to the next generation. Life adapts and evolves. But there is hardly any characteristic that is not shared by non-life. Crystals of salt grow on their own, computer programs can replicate and evolve, and computers possess highly sophisticated system of storage and sharing of information. Fire metabolises, releasing energy by burning. Weather exhibits incredibly complex behaviour. So none of these characteristics is unique to life.

Gerald Joyce, a NASA scientist, gave a simple definition of life as a self-sustaining chemical system capable of Darwinian evolution. But as Carol Cleland, a philosophy professor said, we are perhaps yet to develop a proper language of natural sciences to be able to define life, just like a proper definition of water needed our understanding of molecular chemistry. However, the 'most accepted working definition of life' is that living forms are those that use energy to build molecular structures and replicate themselves following a specific set of instructions embedded within themselves.

Scientists generally agree that for life to evolve and thrive anywhere, there are certain prerequisites, the most important of which is the presence of water. Further, there has to be a 'habitable zone' conducive to life, that is, a planet at an appropriate distance from the parent star on which water can exist in liquid state under ordinary temperatures and pressures.[2] There also has to be abundance of organic elements necessary for making the complex organic molecules required to capture and reflect the complexity of life. Ninety nine percent of all living materials on Earth are composed of only six elements - carbon, hydrogen, nitrogen, oxygen, phosphorus and sulphur (CHNOPS). All metabolizing organisms contain organic molecules of these elements dispersed in water which provides an ideal environment in which chemical interaction between these molecules can take place.

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[2] This habitable zone called the circumstellar habitable zone (CHZ) is also known as Goldilocks zone, from the fairy tale of Goldilocks and the Three Bears, in which a little girl chooses one that is "just right" from various items, ignoring the ones too large or too small or too extreme.

Water has some unique properties unlike any other liquid. Due to the strong chemical bond between hydrogen and oxygen, liquid water remains stable over a wide range of temperatures. Further, ice, being less dense, floats on water- it also means that oceans that harbour life freeze from the top when temperature drops and the top layer of white ice insulates the bottom layers of water protecting living forms below. Ammonia, in contrast, which remains a liquid from -78^{o} to -33^{o} Celsius, would solidify upwards from the ocean floor, freezing all living forms to death. Other liquids may not be as conducive to life as water.

Apart from the presence of liquid water, other conditions necessary for life include a steady source of energy, like sunlight, for metabolism, which a star can supply. Such energy could also come from chemical reactions; that makes it possible, at least in theory, for life to evolve in sub-surface environments. A renewable supply of organic elements along with a stable interface between solids, liquids and gases as on land or ocean-surface are other prerequisites for life.

How did life evolve on earth? As J E Lovelock said in his book "*Gaia: A New Look at Life on Earth"*- Life was "an utterly improbable event with almost infinite opportunities of happening." Life on Earth evolved possibly as an accident, a random event that was the result of sundry combinations of chemicals taking place in the primeval oceans over billions of years of change and transformation that ultimately resulted in the formation of a molecule capable of replicating itself. From its cradle in the blue green waters of the primeval ocean where life probably evolved, it grew most luxuriantly through billions of years of trials and tribulations, taking myriad shapes and forms through endless chains of transformations.

The same process could also have happened in the interstellar clouds of gas and dust where the simple molecules and elements were present and chemical reactions among them could have been triggered by the energy of a nearby star. Indeed, ammonia and water vapour were discovered in interstellar space in 1968 through radio-astronomical observations in microwaves. In 1969, formaldehyde, another organic molecule, was discovered in the interstellar clouds of gas and dust. Obviously, if life processes could start on Earth out of chemical reactions after only 800 million years of its existence, the same processes would have a greater probability of occurring in the interstellar clouds, which are several billion years older. These processes could also have been triggered inside the nucleus of a comet, where heat provided by the decay of radioactive elements could have easily formed the 'warm little ponds' as on Earth.

On 28 September 1969, a large meteorite struck at a place called Murchinson in Australia. Among the debris were traces of five amino acids – glycine, alamine, glutamine, valine and proline, which were not of biogenic origin. In fact, they could be direct chemical precursors to organic evolution. Seeds of life could thus have been carried to Earth from the outer space, an extraterrestrial planet, by meteorites or other objects that bombarded the earth incessantly during its initial formative eons; they could also have come to earth through solar or stellar winds. But in whatever form the original living molecules existed in the beginning and wherever they came from, they were still far from becoming the kind of life we are familiar with. That would still take billion years of evolution. Consciousness and intelligence would still take many more million years to evolve.

By all accounts, life was an early feature of Earth - primitive life appeared almost as soon as the Earth's crust had solidified. The strip of land stretching from Greenland to Canada called the North Atlantic Craton has some of the most ancient rocks formed on this planet, dating back to nearly 3.8 billion years ago. Isua supracrustal belt is one such place in the interior of Greenland, where sedimentary rocks have been buried long and become metamorphosed. These rocks have been found to contain mineral graphite - a form of carbon which can come only from two sources: primordial inorganic carbon released during volcanic eruptions or organic carbon from buried remains of organic matter on the ocean floor. Carbon has two stable isotopes, with atomic weights 12 and 13 (C^{12} and C^{13}). Living organisms tend to contain a little more C^{12} than C^{13}in their tissues, as C^{12} is more reactive than C^{13}. The graphite in Isua was found to be richer in C^{12} by about 2 percent, indicating its organic origin from marine microbes which must have died and got buried in the sediments, subsequently becoming compressed and metamorphosed into graphite as old as these sediments. The origin of life thus dates almost back to the unremembered beginning of this planet, less than 800 million years since this rocky planet had come into existence.

The Sun was about a quarter less luminous then as its fusion reactions were far from consummate. It produced less energy and consequently the Earth also received less. But for the greenhouse gases carbon-di-oxide and methane which were abundant in the atmosphere of the nascent earth and partly neutralised the faint young Sun, the Earth would have been a frozen planet, with all its surface transformed into permafrost conditions unsuitable for evolution of life. Further, oceans that covered most of the Earth's surface, being dark, absorbed sunlight, while icecaps on mountains that reflected sunlight back into space were few. A temperature balance was thus maintained which was crucial to the evolution of life.

By 2.8 billion years ago, most of Earth's crust had already been formed and continents had started to emerge along with the development of large shelf areas around them. Weathering of these areas led to concentration of nutrients in the oceans, resulting in significant increases in the population of microscopic organisms. Till late in the Archean era, around 2.5 billion years ago, the atmosphere was primarily composed of methane, with less than one part per million of molecular oxygen. Oxygenation of its atmosphere – the so-called Great Oxidation Event - would occur in steps, first 2.4 billion years ago, taking the oxygen level to about 2 percent, then 750 million years ago, increasing the level of atmospheric oxygen to 3 percent, and finally about 580 million years ago, raising the oxygen content in the atmosphere to above 10 percent. This oxygenation was caused primarily by the evolution of photosynthetic oxygen-producing bacteria in the surface of oceans, an ancestor to the blue-green 'cyanobacteria' that today swarm in the lakes and oceans of Earth. The surge in oxygen would naturally lead to development of complex 'aerobic' or oxygen-breathing organisms.

Till then, life forms could only exist by breaking the complex substances and using the energy released. These complex substances, food for the primitive micro-organisms, were rebuilt from their simpler constituents by the action of ultraviolet light on oceans. But once oxygen was formed in the atmosphere, oxygen molecules split by sunlight into oxygen atoms combined with other molecules of oxygen to yield ozone. The released ozone formed the ozone layer above the atmosphere, shielding the Earth from ultraviolet rays from the Sun. While the ozone layer protected life from the destructive ultraviolet rays which it still does, it also hastened the pace of evolution of life by cutting off ultraviolet light that was making food for the molecules of life. Replenishment of the chemical food supply thus no longer being possible, an acute competition now set off among the living molecules for food. As the primordial chemical soup was neared exhaustion in the oceans, organisms capable of synthesising their own food had to evolve, and the only energy available was that from sunlight. Organisms that could use this low-energy light to manufacture their own food had to learn to trap this energy. They were some mitochondria-like substances containing chlorophyll – the blue-green algae. These sea-dwelling microbes were probably the first cells, very simple 'prokaryotes', the ancestors to modern 'chloroplasts' - the sub-cellular bodies containing chlorophyll within plant cells where photosynthesis takes place.

As chloroplasts multiplied in the ancient seas, the blue green algae started using carbon dioxide in the atmosphere to produce molecular oxygen through the process of photosynthesis, gradually transforming the terrestrial atmosphere. Lime secreted by these algae would collect in the shallow oceans that received sunlight, forming the first life-created structures called stromatolites. Bubbles containing oxygen would form on these stromatolites by photosynthesis, then rise slowly to the surface of the sun-blanched oceans and detach themselves from water, freeing their oxygen into the atmosphere. Once the atmosphere was oxygenated and ozone layer was completely formed, it was safe for organisms to dwell on the surface of oceans and eventually to come to land from their watery abode, heralding the evolution of aerobic creatures. From now on, the evolution of life forms would proceed along two distinct directions – one developing into the oxygen-breathers and rapid-movers, evolved from the aerobic living forms, and the other evolving into the immobile plant kingdom, the breathers of carbon dioxide. These two forms would have a complementary and symbiotic relationship with each other. The change in environment brought about by the release of oxygen was thus the most significant event in the history of life. Gradually, from the simple prokaryotes, 'eukaryotes'- organisms with cell-nuclei would evolve. Subsequent advent of sexual reproduction would accelerate the pace of biological evolution manifold, making the process of evolution of life almost uncontrollable and leading to speciation, formation of new species, bringing myriads of forms and irrepressible diversity of life on Earth.

Fossil and other evidences establish that life had been remarkably resilient on Earth, holding onto the most extreme environments. In 2113, a microbe was retrieved from Lake Whillans, almost a kilometer underneath the Antarctic ice. Colony of microbes has thrived even in toxic environments of carbon monoxide and hydrogen sulphide 50 feet underground in a cave in Mexico. Superheated hydrothermal vents on ocean floors have been found to harbour a rich ecosystem of bacteria. Life, in fact, has been found to survive and proliferate in almost every extreme environment, in hot springs and frigid lakes deep below the Earth's surface, in highly acidic, alkaline or radioactive sites – almost everywhere in every inconceivable environment. This only confirms that it can evolve and grow anywhere in the galaxies.

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Let us now look beyond our planet. There may be any number of Earth-like rocky planets within the habitable zone in other stellar systems within and outside our galaxy that may nurture life. Scientists have discovered nearly 3400 such planets, called ‘exoplanets’, beyond our Solar System, but so far, haven’t had any evidence of extra-terrestrial. Exoplanets are detected indirectly from stellar properties like brightness, position etc. which are affected by the presence of planets - by tracking the motion of a star across the sky, by measuring Doppler shift of the stellar spectra or periodical decrease in starlight due to the movement of a planet across its face or by a technique called micro-lensing, using the bending of light beams by the star’s gravity. They can also be detected by direct observations made by telescopes in space, like Hubble Space Telescope (2001), Spitzer Space Telescope (2003), Corot (2006) and Kepler Space Telescope (2009).[3]

Once an exoplanet is discovered, scientists look for bio-signatures of life in it. The planet’s visible or infrared spectrum may reveal the presence of oxygen or methane, two gases produced by life through photosynthetic or other biological processes. They may look for the evidence liquid water which is essential for life. Ozone will provide another bio-signature as also compounds of organic sulphur or carbon-di-oxide. However, some of these gases and compounds may even be produced by abiotic processes; there also remains the possibility that even when no bio-signature is detected, some form of life can still be ebbing and flowing beneath the surface of the planets – in subsurface oceans of water or organic compounds like methane or ammonia.

Scientists have identified nine bodies inside the solar system where life might exist in subsurface oceans of water or other organic liquids like methane or ammonia: Mars, Ceres, the largest asteroid, Europa, Ganymede and Calisto - all moons of Jupiter, Enceladus and Titan, moons of Saturn, Triton, the largest moon of Neptune and Pluto. Mars once had free flowing water on its surface – some of it may still be flowing underground. Europa has a cracked surface covered with vast ice sheets covering oceans of liquid water underground - due to the internal heat generated by tidal forces of Jupiter’s other moons; it may also have hydrothermal vents in its ocean floor like the Earth. Enceladus contain underground water and Titan has huge oceans and lakes of methane and ethane. Right now, Pluto is under close observation by the New Horizons spacecraft of NASA that has detected vast frozen, craterless, young plains in the northern icy mountainous region of Pluto, named "Tombaugh Region", after Clyde Tombaugh, who discovered the planet in 1930. But so far there was nothing to suggest that life did or could exist on the planet.

It is understood that our best chances of detecting extra-terrestrial life would come from an alien civilization that is intelligent – at least as intelligent as us - and communicative too. In 1961, Frank Drake, a young radio astronomer, had formulated an equation that has since been known as the Drake Equation for estimating the number of alien civilizations that can be detected from the earth.

[3] In January 2015, Kepler had discovered an earth-like exoplanet in our galaxy which has since been named as Kepler 452b, also known as 'Earth 2.0'. Three more Earth-like rocky exoplanets were discovered in July 2015 in the constellation Cassiopeia, only 21 light-years away from Earth.

The Drake equation runs like this:

$$N = R^{*}.\ f_p.\ n_e.\ f_l.\ f_i.\ f_c.\ L, \text{ where}$$

N = number of civilizations in the Milky Way Galaxy whose electromagnetic emissions are detectable;

R* = rate of formation of stars suitable for the development of intelligent life;

f_p = fraction of those stars with planetary systems;

n_e = number of planets, per solar system, with an environment suitable for life;

f_l = fraction of suitable planets on which life actually appears;

f_i = fraction of life bearing planets on which intelligent life emerges;

f_c = fraction of civilizations that develop a technology that releases detectable signs of their existence into space; and finally

L = life time of such civilizations.

Except the rate of formation of stars suitable for life, all other factors still remain highly speculative. Even then, in 1961, Drake had estimated about 10000 such communicative civilizations in our galaxy. The Drake equation is a simple, fascinating equation that suggests that life being the end product of a natural, cosmic evolution, may not be unique and that we may not occupy any special position in this Universe in that sense, even though so far ours is the only kind of life known.

The Search for Extraterrestrial Intelligence (SETI) is the name for collective scientific investigations undertaken to search for intelligent extraterrestrial life. The search began in 1957 with the Lovell Radio Telescope mounted in Manchester, UK, to detect radio signals from intelligent civilizations. The SETI Institute was established in 1984 to "explore, understand and explain the origin, nature and prevalence of life in the universe" and which today comprises the largest distributed array of radio telescopes across the world. With increasingly high-powered of radio-telescopes now being deployed, searches have become much broader and deeper, but we have not yet succeeded in detecting any intelligent life elsewhere. And that is an enigma.

After all, our Earth is only a 4.6 billion years old planet orbiting a star that is too young in the Universe; there are stars in our galaxy itself that are twice as old. If life was a random event, it must have arisen in the galaxy long before it did on Earth. By now, those civilizations would have mastered the technology of space travel or even time travel, and possibly even to travel at superluminal speeds. They should have colonized the galaxy by now. Such colonization would have been a necessity for their survival, because energy is the driver of all civilizations and they would have exhausted their planetary or even stellar supply of energy long back and thus would be forced to seek it elsewhere. Then why haven't we found any of them so far? Why haven't they discovered us? Why haven't they intercepted and responded to the several radio messages we have sent into space? This is the fundamental question Enrico Fermi asked in 1950, known as Fermi Paradox.

Maybe, we are truly alone in this vast Universe, making us a rarity and our Earth a 'Rare Earth' that shelters the only life in this Universe, in which case at least one factor in Drake's equation will have to be vanishingly small. Or maybe, they do not need to colonize the galaxy, having solved the energy problem by the use of advanced technology. But these answers look rather improbable, given that vastness of the universe and the deepness of time through which it has evolved. Another possibility is that they have already destroyed themselves through an Armageddon-type nuclear war; in fact, we in Earth had come very close to this in the last century.

There is of course another possibility - maybe they have indeed found us and are just watching us from space, refusing to communicate. A civilization that has the technological prowess to explore the galaxies must be a very mature civilization, and must have already conquered hunger, poverty, sickness, maybe even physical death. Conflicts and wars between their people must have been a thing of antiquity, as must have been hatred and jealousy, bigotry and social cleavage, while we are as yet far from conquering these evils. Our ways on this earth, where we constantly fight, bleed, kill and inflict unspeakable atrocities upon our fellow beings must seem extremely repulsive to an advanced, intelligent and sophisticated intergalactic civilization. We cannot blame them for hiding from us, rather we should be ashamed of ourselves.

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