Beacon of Exoplanets—Light of Life?

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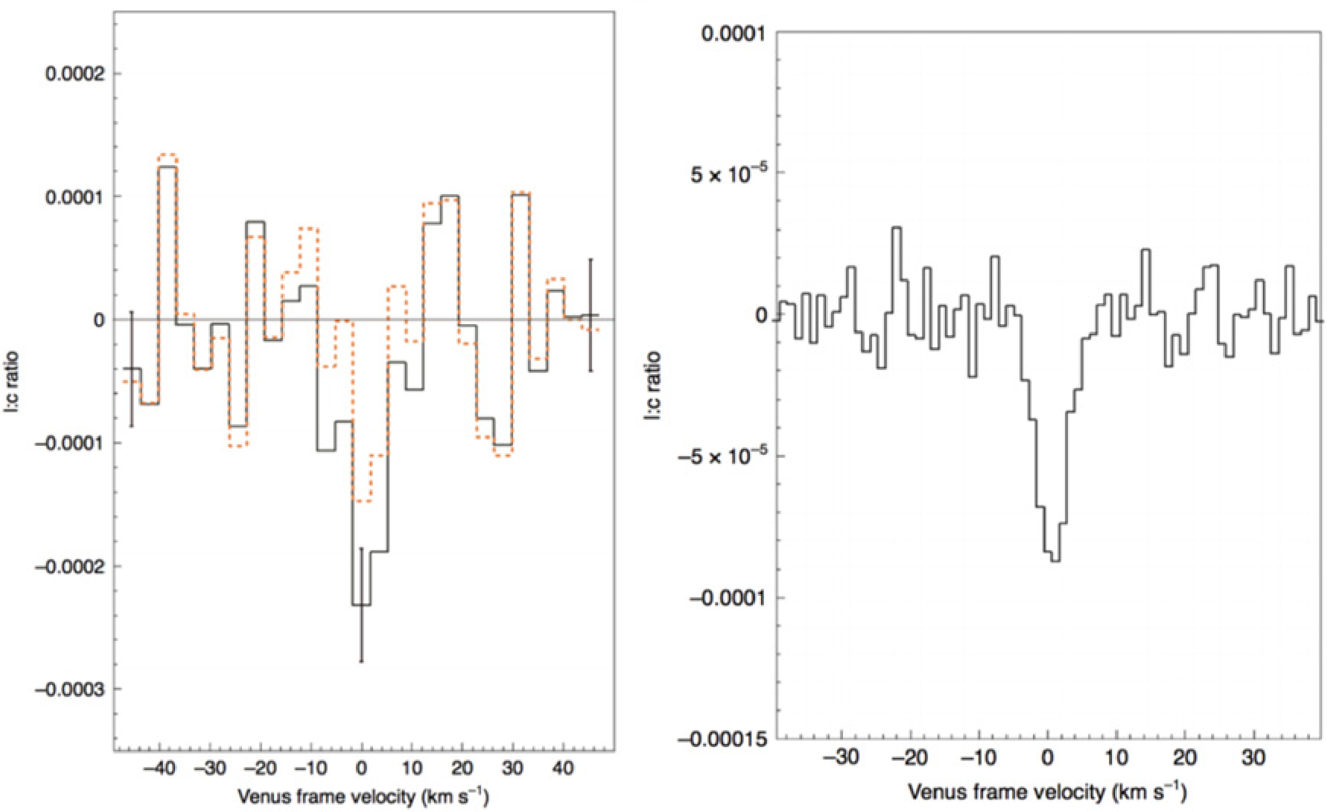
In 1979, while writing about the possibility of balloon-like creatures existing in the clouds of Venus, Carl Sagan popularised the concept of ECREE—acronym for "Extraordinary Claims Require Extraordinary Evidence". The aphorism is as old as the 18th Century and has been used by many thinkers—from English philosopher David Hume (1711–1776) in his essay "On Miracles" to the French Mathematician Pierre-Simon, marquis de Laplace (1749–1827). The principle states that "the weight of evidence for an extraordinary claim must be proportioned to its strangeness". ECREE, which decrees that the more unlikely a scientific claim is against the existing evidence, the more stringent the standard of proof that is required to establish it, has remained a gold standard for the scientific method and critical thinking ever since. A piece of such an "extraordinary evidence" was obtained by scientists in September 2020 from the noxious clouds of Venus again, hinting at the possibility of life there.



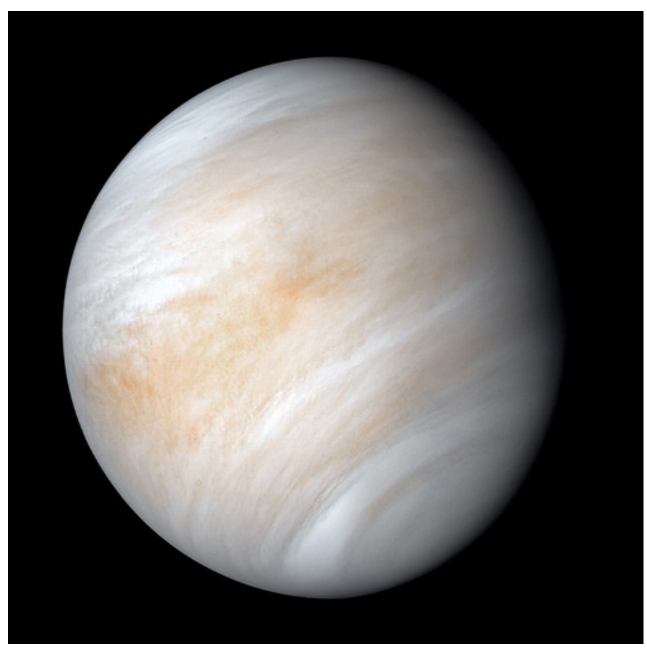
The detection of PH3 towards the entire planet of Venus. The left is the detection with JCMT and right is with ALMA. The x-axis is labelled 'Venus frame velocity' because the observed spectra need to be corrected for the velocity at which Venus is spinning. V=0 on the x-axis corresponds to the frequency at which PH3 emits. On the y-axis, l:c stands for line: continuum ratio. Continuum can be thought of as the background and the line corresponds to the PH3 detection. Any value away from zero means that there is flux at that frequency. Bumps and wiggles are normal and are called 'noise'. The authors are able to determine the significance of the detection based on the depth of the line compared to the noise (plus some other fancy statistics).
Source: Nature Astronomy, https://astrobites.org/2020/09/21/phosphine-in-venus/, accessed 15/09/2020.

Though the brightest star in the night sky, Venus has always been overlooked as a possible candidate for the existence of extra-terrestrial life as life is thought to be impossible in a planet roasting at hundreds of degrees and surrounded by clouds of carbon-di-oxide and corrosive sulfuric acid. However, on September 14, an international team led by Jane Greaves of Cardiff University in Wales detected signs of phosphine (PH_3)—a molecule of phosphorus and oxygen, in Venus' clouds by using two different telescopes - the James Clerk Maxwell Telescope in Hawaii and the powerful ALMA Telescope Array in Chile. Instead of visible light, these telescopes work with millimetre-wave radiations lying between the infrared and the radio wavelengths. Molecules in Venus's toxic hot atmosphere give out quite a bit of radiation at these wavelengths which can be detected from their absorption spectra which is produced when the molecules in the cooler air above the atmosphere absorb some of these radiations while moving out into space. The specific wavelengths absorbed depend on the absorbing molecules, and the spectrum shows a dip at the corresponding wavelength, revealing a chemical present in the atmosphere of the planet. Phosphine showed up as a dip in Venus' spectrum at about 1.12 mm.

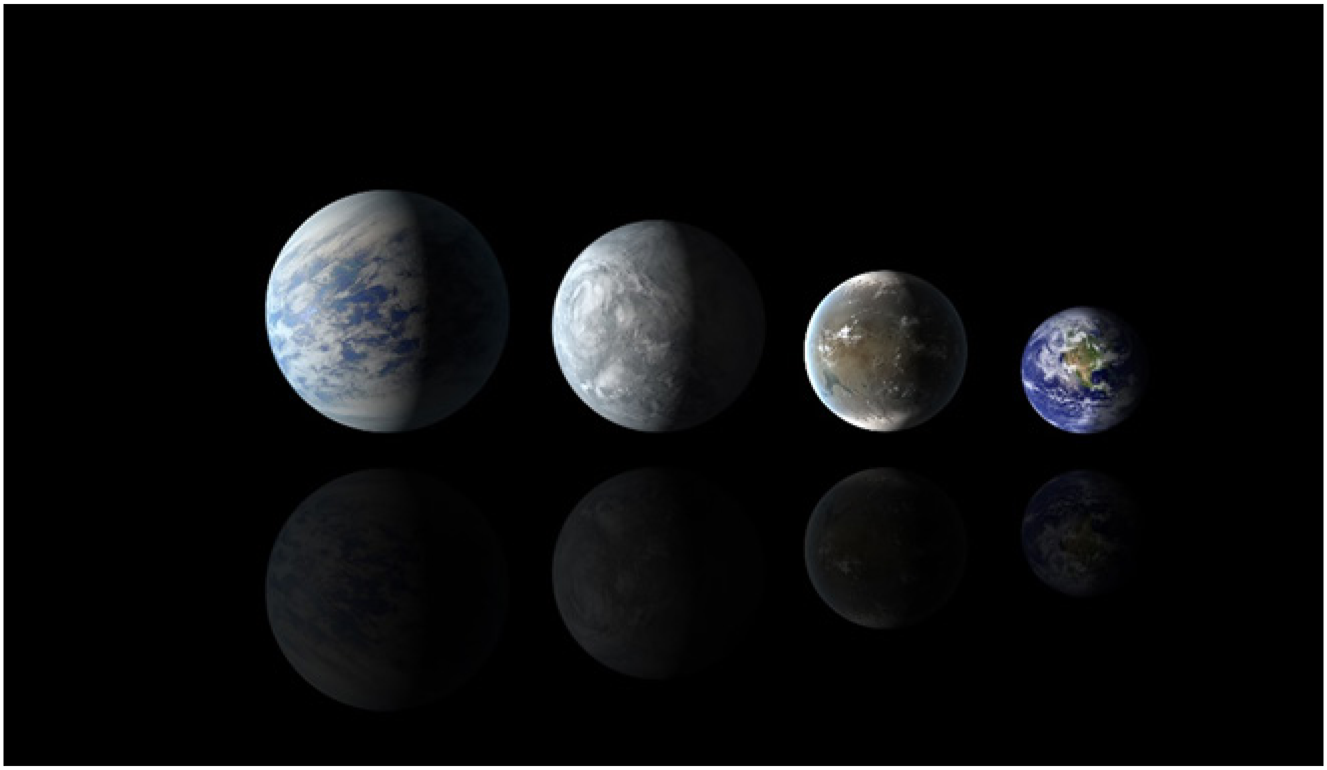
Bacteria on Earth make phosphine from the phosphate of minerals or biological material and hydrogen. Being a gas produced by non-oxygen-using life, it can therefore be used as a biomarker to indicate the possibility of existence of life on planets around other stars. But the discovery of phosphine in Venus's clouds indeed comes as a huge surprise, because such a molecule is thought unlikely to survive in the highly corrosive, carbonated and acidic atmosphere of Venus—because chemistry would destroy it as soon as it is formed. To account for its observed incidence of about 20 parts per billion in Venus's atmosphere, something else must be producing it at the same rate as atmospheric chemistry destroys it. That something could only be a living organism - a microbe.

It is always problematic to interpret scientific data from the space with any certainty, as we had learnt from our 2015 BICEP3 experiment that generated great excitement about the detection of the gravitational waves. Especially when trying to detect a tiny amount of gas in another planet's atmosphere, the observed dip attributed to phosphine could have been caused by other sources which could be anything—from the Earth's thick atmosphere to the inner workings of the telescope itself that produce wriggles that scientists call "noise". Any particular dip could just be a random, extra-large wiggle. The intrinsic brightness of Venus may also introduce such wriggles. The standard practice is to write an equation of the wriggle and subtract it from the observed data. The equation is generally expressed by a polynomial - the team used a twelfth-order polynomial, that is, an equation with twelve variables (the simplest second order polynomial is: $ax - y + b = 0$, where x, y are variables and a, b are constants) to describe the noise in their ALMA data, but other astrophysicists found "no statistically significant sign of phosphine" in the ALMA data. Obviously many more confirmations will be necessary before accepting or rejecting the possibility of life in Venus—an extraordinary claim. The next mission to Venus from the Earth should give us enough time to design an appropriate experiment for this, and it will be sent by none other than India: the Shukrayaan-1 orbiter is currently scheduled for launch in 2023.

For life to evolve and thrive anywhere, a set of conditions needs to be satisfied, the most important of which is the presence of water. Further, there has to be a 'habitable zone' conducive to life, the so-called Circumstellar Habitable Zone (CHZ), also known as the 'Goldilocks Zone'. This means that a candidate planet has to be at an appropriate distance from the parent star on which water can exist in liquid state under ordinary temperature and pressure. There also has to be an abundance of organic elements necessary for making the complex organic molecules to capture and reflect the complexity of life—99



Venus (Source: NASA/JPL-Caltech)



Artists' depictions of the newly discovered super habitable planets and Earth. Left to right: Kepler-69c, Kepler-62e, Kepler-62f and Earth (Source: NASA/Ames/JPL-Caltech)

percent of all living forms on Earth are composed only of six elements—carbon, hydrogen, nitrogen, oxygen, phosphorus and sulphur (CHNOPS). Organic molecules of these elements dispersed in water provide an ideal environment for chemical interaction between these molecules which forms the basis of all metabolising mechanisms on Earth.

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 flowing on its surface—some of it may still be flowing underground. Life has so far been ruled out in Venus which once lay within the Goldilocks Zone. But the Goldilocks Zone also changes its boundaries due to the brightening of the Sun over the past billions of years. On Venus, it triggered a "runaway greenhouse effect" which boiled its seas away, driving any living microbes which existed on its surface waters into the Venus skies, where the temperature remains bearable and water even now remains liquid in droplets. Beyond our Solar System, scientists have discovered nearly 3400 Earth-like rocky planets within the Goldilocks Zone in other stellar systems within and outside our galaxy capable of nurturing life, though without any evidence of life so far. Such planets, called 'exoplanets' are detected indirectly from the stellar properties like brightness, position, etc. or by direct observations made by telescopes in space, like Hubble, Spitzer, Corot or Kepler Space Telescopes.

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 evidence of liquid water which is essential for life. Ozone will provide another bio-signature as also the 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, though less likely.

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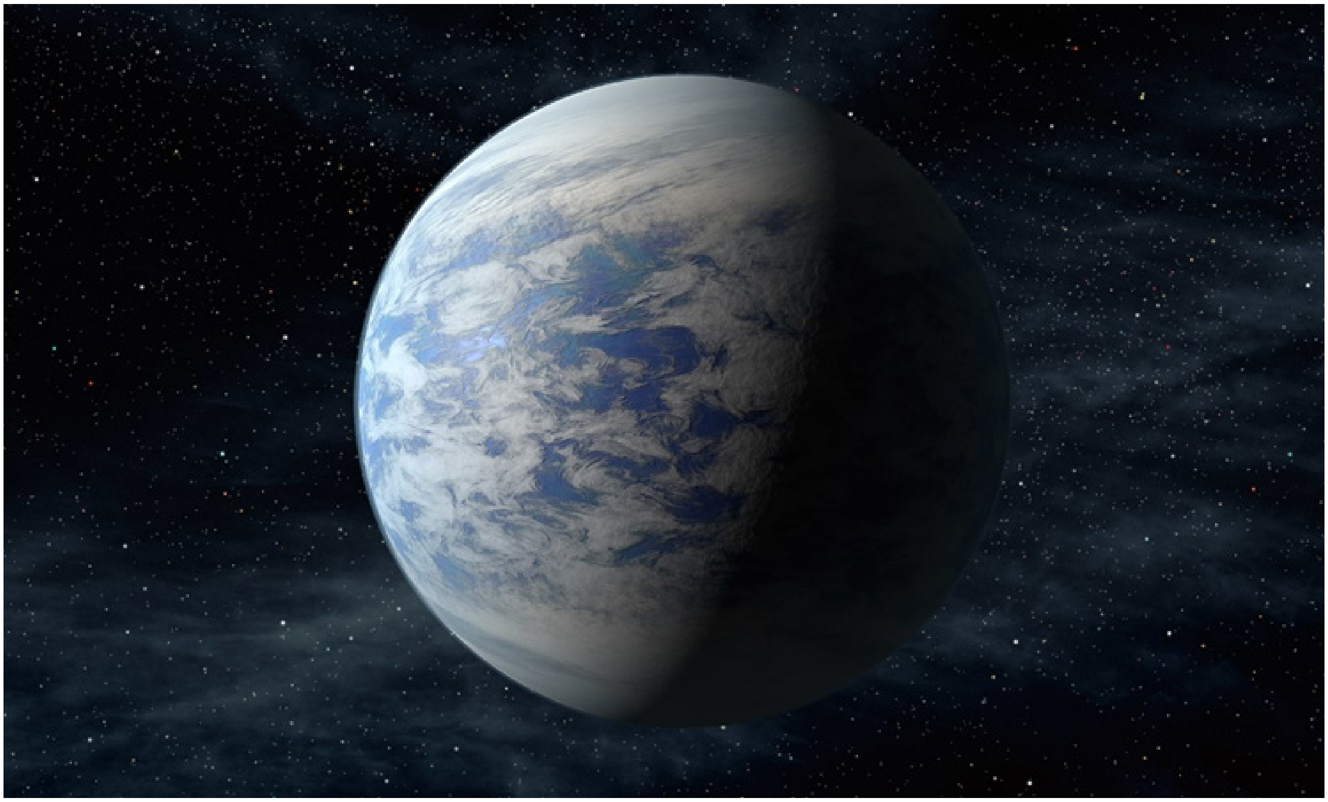
Given that vastness of the universe and the immensity of time through which it has evolved, it is unlikely that a single planet like our Earth in this Universe only



Kepler-69c: Super-Venus (Source: NASA Ames/JPL-Caltech)

harbours life, where in fact it has been proved to exist and proliferate under the most extreme conditions, in highly acidic, alkaline or radioactive environments, in hot springs and frigid lakes deep below the surface. In September 2020, in a research paper titled "In Search for a Planet Better than Earth: Top Contenders for a Super-habitable World"1 astrophysicists Dirk Schulze-Makuch, René Heller and Edward Guinan from Washington State University have identified the conditions that will make a exoplanet habitable—in fact more habitable than our Mother Earth. These demand that it should be about 5–8 billion years old and up to 1.5 times heavier and 10 percent larger than the Earth, with mean surface temperature about 5°C higher. It must also have a large moon with up to 10 percent of planetary mass at a moderate distance of 10–100 planetary radii, with plate tectonics or similar geological and geochemical recycling mechanism as well as a strong protective geomagnetic field. Further, it must be orbiting around a K-type dwarf star with surface temperature lower than the Sun which is a G-type dwarf star. The Sun, in fact, has a relatively short lifespan of 10 billion years. Since it took some 4 billion years for complex life to emerge on Earth since its formation, it is likely that many stars like the Sun would live out their lives before complex life—unlike simple microbial life—could evolve upon them. K-type dwarf stars, being smaller, cooler and less bright than the G-stars, can shine for 20 to 70 billion years—time enough for complex life to evolve. Further, planets tend to get cooled due to the exhaustion of their internal heat-generating mechanisms once they grow older which affect their environment and temperature, making them less suitable for life. Earth is about 4.5 billion years' old and from probabilistic calculations, researchers estimated between 5 billion and 8 billion years as the optimal age of a planet to harbour complex life.

Exoplanets can not only be habitable but 'super-habitable' if they are also larger, heavier, warmer, and wetter compared to Earth. Heavier planets with larger surface areas would feature stronger gravity to support and retain atmosphere, provide more space to support "more biomass and a higher biodiversity", besides adequate plate tectonics to form large landmasses like continents as on earth and strong protective geomagnetic shields. However, there is a fine trade-off—too large a planetary mass might make the planet evolve into a "gas giant or mini-Neptune retaining the light gases such as hydrogen or being an undifferentiated iron-rich body". A planet with sufficient water content in the form of moisture would guarantee sufficient humidity, clouds, rainfall and tropical forests; it should have oxygen content between 25 and 30 percent compared to Earth's 21 percent, and should be warmer than the Earth so that with the additional moisture it can generate vast tropical areas with fewer regions of extreme climate. A large moon at a moderate distance would impart stability to its orbital motion and ensure stable seasons like the Earth.

Based on the above criteria, the team identified some 24 super-habitable planets out of some 4500 candidate exoplanets that could support life better than on earth, even though none of course could be found to satisfy all the criteria; the most that any exoplanet could meet were three, as in the case of exoplanet designated KOI 5715.01. Our current technology is also unable to measure many of the parameters, like atmospheric oxygen, plate tectonics, geomagnetism and natural moons, etc., on extra-terrestrial planets. However, only two of them—Kepler 1126 b and Kepler-69c, have been designated as "statistically validated planets", the rest being only "unconfirmed Kepler Objects of Interest". The upcoming probe tools like NASA's James Webb Space Telescope, LUVIOR Space Observatory, ESA's space telescope and the other new generation telescopes and radio telescopes might help bring more clarity on this aspect. But time to pack our bags will be long as all these 24 exoplanets are more than 100 light years away, a distance we still do not know how to negotiate. Kepler-69c for example lies at a distance of 2000 light years—too far away even for a target to be investigated by telescopes. It also does not imply that we should pack our spaceship with deadly missiles to face any possible existential threats from creatures living there—being super-habitable does not automatically mean that intelligent life actually exists on these remote worlds.

But in the end, we may not have to leave the world and search for a new Earth after all. Old and exploited though the Earth is, it now looks as if she might just able to support her 8 billion human children. A study of population trends in 195 countries by the University of Washington's "Institute for Health Metrics and Evaluation" published in the reputed medical journal, The Lancet, in July 2020 projected the world population to reach its peak at 9.73 billion in 2064 and then gradually to decline to 8.79 billion in 2100, as against the current world population of around 8 billion. Stability of population is defined by the Total Fertility Rate (TFR) which is the average number of children per woman. A TFR of 2.1 just replaces the current population. The Lancet study estimated that

the TFR in 183 of the 195 countries will fall below the replacement level, with the global TFR declining from 2.37 in 2017 to 1.66 in 2100. Population will shrink by more than 50 per cent in 23 countries including Japan, Thailand, Italy and Spain. With lesser population, environment and climate will become sustainable and with appropriate global regulation on conspicuous consumption, the planetary carbon footprints can also be brought within manageable levels. Progress in technology will ensure adequate food production for the current level of population well into the future and even to meet their future energy demand. We won't have to explore other planets for energy or for setting up extra-terrestrial human colonies at immense expenditure and risk to human lives. After all, can there be another planet for us humans like the mother Earth, where we live and love, learn and grow, and help and harm each other, but which still remains to all humans as dear as life. ◆

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1. https://doi.org/10.1089/ast.2019.2161

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