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Finding earths

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On the 23 July 2015, NASA announced the discovery of Kepler-452b, the first exoplanet similar in size to our own planet (about 60% larger than Earth), orbiting around a star similar to our Sun (Kepler 452 is a G2V-type star) at about the same distance between Earth and Sun, within the habitable zone of this star. From these, other similarities extend: this exoplanet takes 385 Earth days to orbit its star, its probable mass is calculated to be about five times that of the Earth, and its surface gravity is twice of Earth's.

The discovery of exoplanets has intensified interest in the search for extraterrestrial life, particularly for those that orbit in the host star's habitable zone, where it is possible for liquid water to exist on the surface. Nonetheless, the suitability of a planet for hosting life, as we know it, must consider a wide range of other factors.

If Kepler-452b has a composition similar to Earth, that is made primarily of silicate rocks or metals, then it would have a solid surface with many active volcanoes and its atmosphere would be similar to that of Venus, with plenty of thick and misty clouds generating a runaway greenhouse effect. At this point in its star's evolution, Kepler-452b is receiving 10% more energy from its parent star than Earth is currently receiving from the Sun.

For centuries, philosophers and scientists supposed that exoplanets existed; yet, finding them was considered technically unattainable, if not impossible. The Italian philosopher Giordano Bruno in the sixteenth century put forward the view that the fixed stars seen at night were similar to the Sun and were likewise accompanied by planets. Isaac Newton also considered this a possibility in his Principia. Yet, various detection claims made in the nineteenth century were rejected by astronomers.

In 24 July 1952, Ukranian-American astronomer Otto Struve pointed out that exoplanets could be much closer to their parent star than is the case in the Solar System, and proposed Doppler spectroscopy and the transit method to detect super-Jupiters in short orbits. Four decades later, on 9 January 1992, the first confirmed detection of an exoplanet came with the discovery of several terrestrial-mass planets orbiting the pulsar PSR B1257+12, a surprising finding since a pulsar is the cadaver of a massive star that exploded as a supernova, therefore it was unexpected that a planet would either survive such event or form after it. The first confirmation of an exoplanet orbiting a main sequence star was made on 6 October 1995, when a giant planet was found in a four-day orbit around the nearby star 51 Pegasi, the kind of super-Jupiter Struve had predicted.

A planet reflects very little light from what its host star emits; this makes it extremely difficult to detect it from the star's glare, reason for which very few exoplanets have been observed directly and fewer have been resolved from the host star. Instead, astronomers have resorted to indirect methods to find them including detecting variations in radial velocities, observed brightness, polarization of the light, or timing of periodical phenomena associated to the exoplanetary system.

The vast majority of exoplanets have been discovered by the radial velocity method. A star with a planet will move in its own small orbit in response to the planet's gravity; this leads to variations in the radial velocity of the star with respect to Earth, which can be observed through the Doppler effect. The velocity of the star around the system's center of mass is much smaller than that of the planet; however, velocity variations down to 1 m/s or even less can be detected with modern

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spectrometers. This method is distance independent, but requires high signal-to-noise ratios to achieve high precision, so is used only for relatively nearby stars. It easily finds massive planets that are close to stars, planets around low-mass stars, or planets with orbits of low inclinations to the line of sight from Earth. Magnetic fields, certain types of stellar activity, or multiple planets can give false signals, though. The eccentricity of the planet's orbit can be measured directly, but it can only estimate the planet's minimum mass.

The transit method was the one used to find Kepler-452b. If a planet crosses or transits in front of its parent star's disk, then the observed visual brightness of the star drops a small amount. The amount the star dims depends on the relative sizes of the star and the planet; therefore, this method can determine the radius of the planet. Generally, such variations are of the order of several millionths of the star's measured brightness, which can be detected by monitoring the target star continuously for a very long time (months), better if from space to avoid the Earth's atmosphere blurring.

Such transits are only observable for planets whose orbits happen to be perfectly aligned from the Earth's vantage point; it is estimated that about 10% of planets with small orbits have such alignment, and the fraction decreases for planets with larger orbits. However, by scanning large areas of the sky containing thousands or even hundreds of thousands of stars at once, transit surveys can find extrasolar planets at a rate that exceeds that of the radial velocity method. This is what NASA's Kepler mission is doing, by observing and monitoring subtle brightness variations in about 150,000 main sequence preselected stars in the constellations of Cygnus, Lyra, and Draco, which are roughly the same distance from the galactic center as the Solar System, and also close to the galactic plane. This fact is important if position in the galaxy is related to habitability.

The transit method suffers from a high rate of false detections though, as transit signals are hard to separate from the starlight own periodic pulsations if it happens to be variable or has substantial chromospheric activity. A star with a single transit detection requires additional confirmation, typically from the radial velocity method. When both methods are combined, the mass and density of the planet can be determined, and hence we can learn something about the planet's physical structure.

The transit method also makes it possible to study the atmosphere of the transiting planet; as light from the star passes through the upper atmosphere of the planet, high-resolution spectra can be used to detect elements in the planet's atmosphere. A planet and/or its atmosphere could also be detected by measuring the polarization of the starlight as it is reflected off or passed through the planet's atmosphere. If the star's brightness during the secondary eclipse (when the planet is blocked by its star) is subtracted from its brightness before or after, only the signal caused by the planet remains. It is then possible to measure the planet's temperature and even detect possible signs of cloud formations on it.

As of August 2015, there have been found close to 2,000 planets, of which about 500 belong to multiple planetary systems. About 10% of discovered exoplanets have been found by the transit method, 1% by gravitational microlensing, 1% by timing methods, 1% have been imaged directly, and the rest vast majority have been found by radial velocity. The radial velocity method is biased to find large planets in nearby orbits (i.e. hot Jupiters); the transit method tends to find planets even closer to their host stars, while those imaged directly are located far away from their star.

Our Solar System seems to be a rather unique planetary system when compared to what we have found so far in the exoplanets jungle. Nonetheless, all finding methods suffer from stringent biases that prevent us from finding more terrestrial planets out there. In any case, stars like our Sun are quite common in our galaxy, and galaxies like the Milky Way are very common as well in the universe; therefore, it should not be unexpected that many Earth-like planets exist. What about life?

Astronomy has proven that chemistry in other places in and out the Milky Way seems to be about the same. Hydrogen and Helium are the most abundant elements everywhere; Carbon, Nitrogen, and Oxygen are produced mostly within massive stars that later on in their lives deliver these elements to the interstellar medium through mechanisms like supernova explosions or strong stellar winds that expel the stars' outer layers forming the so-called planetary nebulas (a misnomer since these have nothing to do with planets, but they look round, like planets, when observed in optical telescopes). This enriched gas is recycled into new generations of stars, which in their formation process can generate a debris disk that later on transforms into one or more planets. Our Sun is in fact a second- or third-generation star and one of the current holy grails of Astronomy is to find the primordial stars that had no more than Hydrogen, Helium, and some Lithium in them; the least massive ones should still be living on today, quietly fusing Hydrogen into Helium.

In the mean time, Carbon-based life, like the one we know on Earth, has plenty of raw materials in the universe to start on. As for conditions for it to start or keep going and evolve, it seems life can actually resist and even thrive in harsh environments; extremophiles found on Earth can tolerate very low or high temperatures, pressures, oxygen content, radiation exposure, and so on. It has been proposed that life may have spread for example within our Solar System trough *panspermia*, where comets and asteroids serve as transports of microbial life that later on develop on an appropriate surface.

If water is needed for life, then the Oort Cloud, a large reservoir of comets outside the Solar System, is possibly an important reservoir of frozen water in the Solar System. The Oort Cloud and the Kuiper Belt objects (i.e. Pluto and all the other dwarf planets beyond Neptune) are the leftover debris of the Solar System formation. It is believed that comets impacting on Earth in the early periods of our planetary system, when collisions were more frequent, were the main the source of water that exists now in liquid form on Earth's surface. Such debris disks have also been found around other stars. In any case, for RNA- or DNA-based life or any other kind, the sky is literally the limit.

What is clear now is that there are many other kinds of planets, small and large, solid or gaseous, nearby or far from their host stars, in circular or highly eccentric orbits, around single or multiple stars, which can be young or old and evolved. These apparently odd planetary systems can exist, evolve, and survive long enough to be observed and could possibly develop life of some form. Also, some planets can be kicked out of their birthplace and had been in fact found flying solo in space, as true vagabonds that fulfill the original meaning of the word *planetes*, in Greek, a wanderer celestial body.

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