AstroTalk: Behind the news headlines of December 2011

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Searching for planets like the Earth: why do we care?

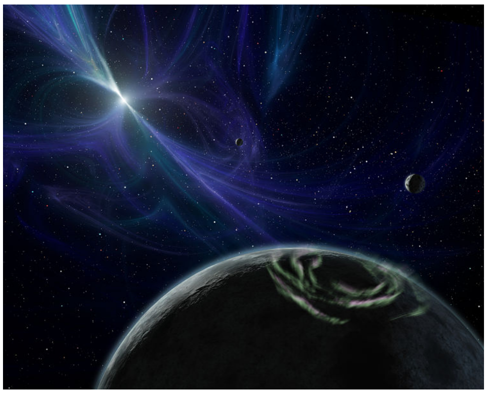
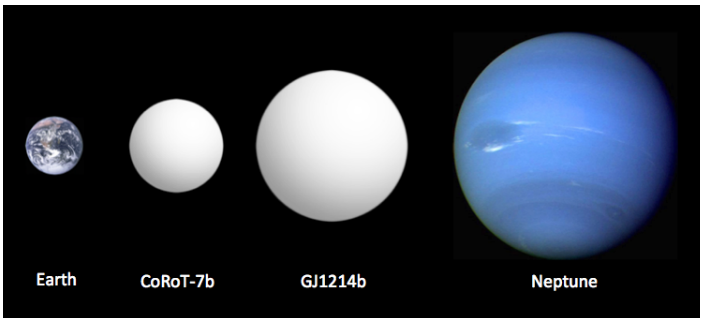


Figure 1: Artist's impression of exoplanets in the PSR 1257+12 system. *(Credit: NASA/JPL-Caltech/R. Hurt, Spitzer Science Center)*

At the end of December 2011, the online *Extrasolar Planets Encyclopaedia* (http://exoplanet.eu) included 716 candidate exoplanets; that is, planets orbiting stars other than our own Sun. We have come a very long way from the early days of planet hunting, when the discovery of every new exoplanet was frontpage news: new discoveries are now reported routinely and they usually don't really cause much excitement anymore. The first confirmed detection of four planets with masses similar to that of the Earth orbiting a "pulsar" – a rapidly rotating neutron star that emits a beam of highly energetic radiation – was reported in 1992. The first exoplanet discovery linked to a "normal" star was announced in 1995, when two independent teams of scientists concluded that a giant planet in a four-day orbit around the star 51 Pegasi was responsible for variations in its intensity.

Since then, the main focus of planet hunters has been on discovering Earth-like planets, and particularly terrestrial planets orbiting their parent stars in what is called the "Goldilocks" zone, where such planets might be habitable. This name has its origins in *The Story of the Three Bears* (1837) by British author and poet Robert Southey, in which a small girl, Goldilocks (referring to the colour of her hair), has to choose from sets of three items. She ignores items that are too extreme and settles on those in the middle, which are "just right". Similarly, a planet following this Goldilocks Principle is neither too close nor too far from its parent star to rule out liquid water on its surface. Finding Earth-like planets, in particular if they orbit stars that are similar to our Sun, opens up exciting prospects for explorations as to whether they might be suitable to sustain "life" as we know it. Establishing whether those requirements are met is, however, extremely difficult and riddled with uncertainties.



Following the original discovery of four terrestrial planets in orbit around the pulsar PSR B1257+12, scientists have since been looking for more benign environments that might be conducive to development of life. In February 2009, this led to the discovery by a team using the French/European Space Agency observatory *CoRoT* (Convection, Rotation and planetary Transits) of the first "rocky" planet outside our solar system, CoRoT-7b, at a distance of approximately 489 lightyears from Earth and similar in density as the solar system's rocky planets, Mercury, Venus, the Earth and Mars. Until the discovery of Kepler-10b in January 2011, CoRoT-7b was the smallest exoplanet known, with a radius of just 1.58 times that of the Earth. However, it is unlikely to harbour life: with an orbital period of only 20½ hours, it whizzes around its parent star at just a fraction of the Sun–Earth distance. This small distance from its star is probably the main obstacle to the development of life as we know it: while the temperature on the planet at the side facing its parent star, a so-called yellow dwarf, is about 2000°C, it drops to –200°C at the opposite side… That's quite a bit more extreme than the difference between winter and summer temperatures in Beijing! Subsequent research has revealed that CoRoT-7b may be more like Mercury than to Earth, giving it a rocky surface but a large iron core, and a total mass of around eight times that of the Earth. You would feel pretty heavy if you could be walking around on its surface!

In December 2009, the "super-Earth" GJ1214b was discovered by a team of astronomers using the Fred Lawrence Whipple Observatory at Mount Hopkins in Arizona (USA). Although it is significantly larger than CoRoT-7b and much more massive than Earth, the planet is noteworthy because it was only the second exoplanet known to be much smaller than the well-known and routinely discovered gas giants (like Jupiter and Saturn in our solar system) and of relatively low density. Detailed modelling led to the exciting conclusion that GJ1214b could be a rocky planet with an atmosphere composed predominantly of hydrogen, a mini-Neptune, or – perhaps most exciting – an ocean planet, like a bigger and hotter version of Jupiter's Galilean moons.

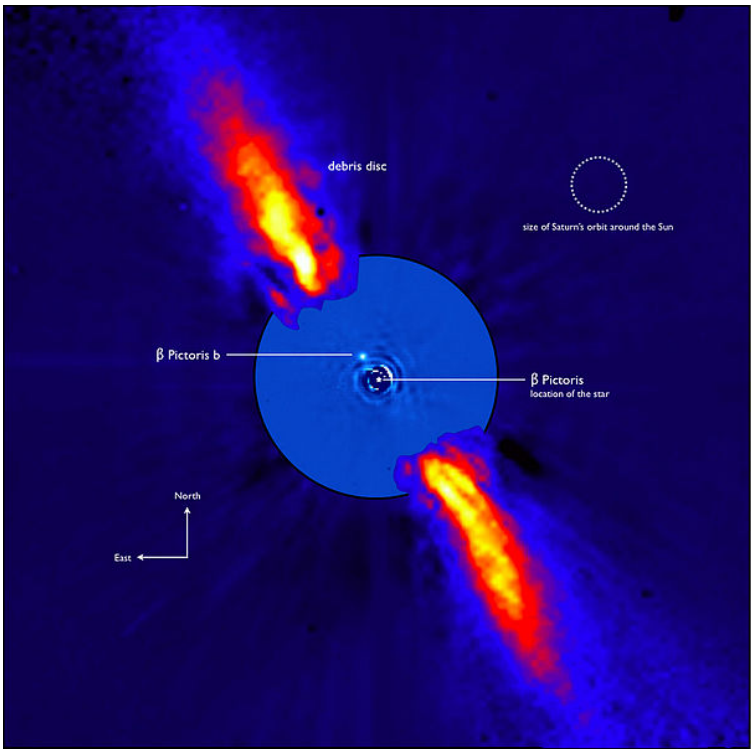


Figure 3: β Pictoris b discovery image. This very faint environment is revealed after a careful subtraction of the much brighter stellar light contribution. The outer part of the image shows the star's light reflected by the dust disk; the inner part is the innermost part of the system, as seen at a wavelength of 3.6 microns. β Pictoris b is more than 1000 times fainter than its parent star, aligned with the disk, at a projected distance of eight times the Earth–Sun distance. *(Credit: ESO)*

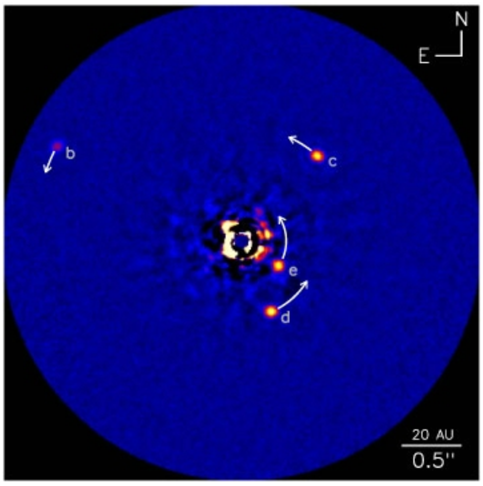


Figure 2: The HR 8799 planetary system. The light of the central star has been masked out. *(Credit: Ben Zuckerman/Wkimedia Commons)*

Direct detection of exoplanets has proven difficult. It is easiest to obtain images when the planet is especially large (considerably larger than Jupiter), widely separated from its parent star and hot, so that it emits intense infrared radiation, although more sophisticated methods for direct imaging of more regular planets have recently been developed. Among the first directly detected exoplanets were β Pictoris b and Fomalhaut b. The latter was found using *Hubble Space Telescope* images taken eight years apart. It has a mass that is approximately three times that of Jupiter, which is usually used as comparison object. Around the same time of the Fomalhaut b detection, in November 2008, planet hunters using the Keck and Gemini telescopes on Hawai'i imaged the first multiplanet system, HR 8799, hosting planets with masses of 10, 10 and 7 times the mass of Jupiter.

However, most exoplanets are discovered by careful analysis of the intensity variations of their parent stars: if a planet (which does not radiate itself but only reflects light from its star) passes in front of or behind the star, the overall brightness of the system will show a dip in its "light curve" (a diagram showing the total intensity over a period of time). Detailed modelling of the system can then give us a good idea as to the size and mass of the planet – or planetary system – orbiting the star. This is the basic principle of how the *Kepler* space telescope (a joint venture of NASA and the European Space Agency) works and goes about detecting exoplanets. In fact, since the launch of the *Kepler* telescope in March 2009, planet hunters have enjoyed a tremendous bonanza of new planetary candidates.

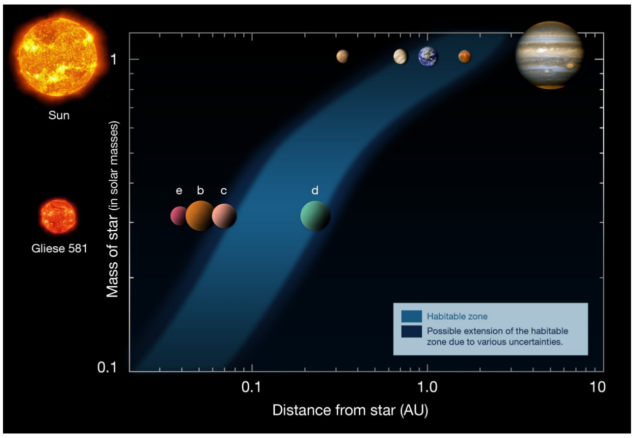
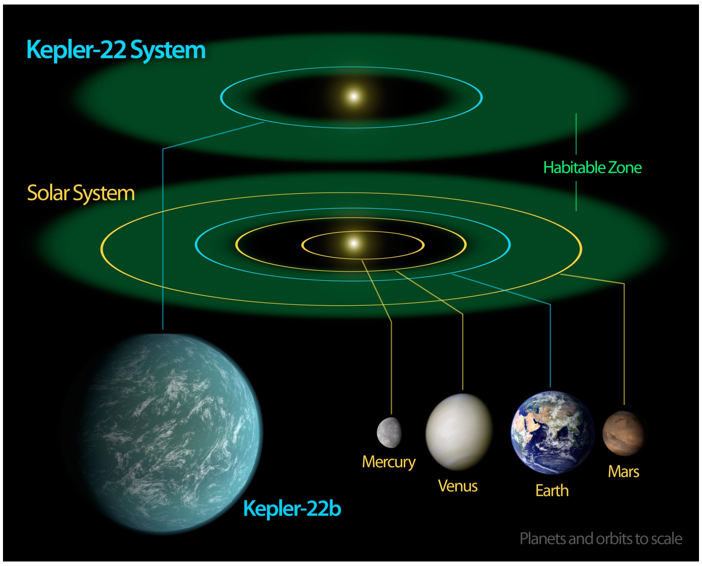


Figure 5: Distances of planets in our solar system compared to those in the Gliese 581 system. (Credit: http://www.hellofromearth.com)

This month has proven to be one of the most fruitful periods in the hunt for Earth-like planets to date. In fact, scientists at the University of Puerto Rico announced publication of a new catalogue in which exoplanets (and even exomoons!) are ranked by their potential ability to sustain life, the *Habitable Exoplanets Catalog*. In essence, the ranking criteria are based on a planet's similarities with Earth at any time during its evolution and its location with respect to the Goldilocks zone of the parent star. At present, only the planets Gliese 581d and HD 85512b meet the catalogue's habitability criteria, while 15 additional exoplanets and 30 exomoons are listed as "potentially habitable". Don't pack your suitcase just yet, however: the disappointing bottom line is that we need more observations to confirm the suitability for life of these rocky bodies…



On 6 December, excitement reached a temporary climax when news media across the world reported confirmation of the first Earth-like planet orbiting another star, Kepler-22b. This newly discovered planet, dubbed "Earth 2.0", is located at a distance of approximately 600 lightyears. Preliminary models suggest that it is about 2.4 times the size of Earth and has a temperature of approximately 22°C. Kepler-22b lies 15% closer to its parent star than the Earth is to our Sun, and its year takes some 290 days. However, the planet's parent star emits approximately 25% less light, keeping the planet at a balmy temperature that would support the existence of liquid water. However, before you pack your bags to set off to this target, I note that the *Kepler* scientists have so far been unable to decide whether the planet's surface is composed of rock, gas or liquid… In fact, in the *Habitable Exoplanets Catalog* Kepler-22b is not even listed as a promising candidate to harbour life: the pleasant temperature of 22°C would only be achieved if it had an Earth-like atmosphere and a similar composition to our own planet. Planetary scientist Abel Mendez from the University of Puerto Rico says the most optimistic habitable scenario would be if Kepler-22b were an ocean planet, with a global ocean and some clouds. But even that is only marginally life-friendly, he notes. It is more likely that the planet is host to a massive atmosphere and very serious greenhouse effects, resulting in conditions that may be too hot for comfort… This uncertainty strikes at the heart of the scientific debate: we don't really know what "habitable" is. But it is the right question to be asking.

The announcement of the discovery of Kepler-22b almost completely drowned out another important result from the *Kepler* mission: scientists announced detections of 1094 new candidate planets, bring the spacecraft's overall haul to 2326, of which some 207 are roughly Earth-sized and smaller! Clearly, these are wonderful targets for the SETI (Search for Extraterrestrial Intelligence) Institute's efforts to pick up signal from life forms "out there" using the newly restarted Allen Telescope Array, composed of a series of radio antennas at Hat Creek Observatory in California (USA). Intriguingly, a team led by scientists at the University of Birmingham (UK) also announced that 50 of the stars that *Kepler* identified as hosts to exoplanetary systems show clear evidence of oscillations. These lead to “pulses” (changes in brightness) and are caused by sound trapped inside the stars which, in turn, makes the stars “ring” or vibrate like musical instruments. By analysing the oscillations, scientists can measure the properties of the stars very accurately and probe their interiors, constrain the sizes and ages of the candidate exoplanets and determine whether they might lie in the Goldilocks or habitable zones of their parent stars.

Towards the end of the month, the announcement of the discovery of two Earth-like rocky planets orbiting a Sun-like star caused even more excitement, among both scientists and the news media. They were billed as the most important planets ever discovered outside our solar system. The planets, Kepler-20e and Kepler-20f, may – at some point in their distant past – have been able to support life and one of them may have had conditions similar to those on Earth, but they now lie outside their star’s habitable zone. The planets were once further from their star and likely cool enough for liquid water to exist on their surfaces, which is a necessary condition for life as we know it. They are the smallest exoplanets ever discovered to be orbiting a Sun-like star. Kepler-20f is almost exactly the size of the Earth, while Kepler-20e is slightly smaller at 0.87 times the radius of Earth. It is also closer to its parent star than 20f. “The primary goal of the *Kepler* mission is to find Earth-sized planets in the habitable zone,” said Francois Fressin of the Harvard-Smithsonian Center for Astrophysics (USA), lead author of a new study published in the journal *Nature*. “This discovery demonstrates for the first time that Earth-sized planets exist that orbit other stars, and that we are able to detect them.”

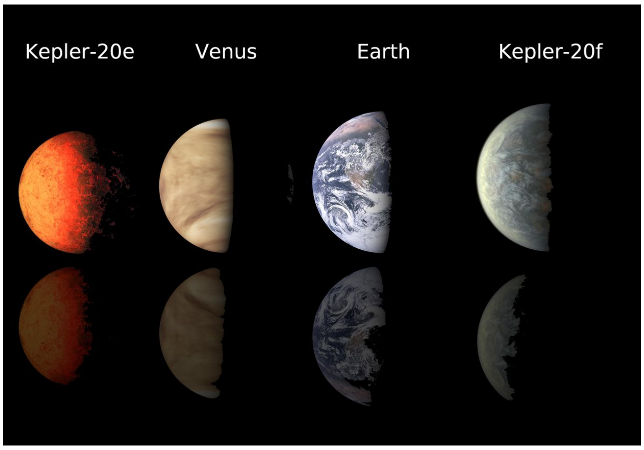


Figure 7: Size comparisons of Kepler-20e and Kepler-20f with Venus and the Earth.

Kepler’s impact continued to amaze the public and scientists alike this month, with the additional discovery of two Earth-like planets orbiting a red giant star, a star in the final stages of its life. When stars reach the red giant phase of their evolution, they swell up to many times their “usual” size, and any planets that orbit too closely to their parent star are engulfed in the expansion. Scientists used to think that this would lead to the complete annihilation of any such planets, but the discovery of objects KOI 55.01 and KOI 55.02, which orbit their parent star extremely closely, may require us to rethink our theories. Perhaps this is the key lesson to learn from all these exciting discoveries. New discoveries may require us to let go of any pre-existing assumptions and adjust our view of the natural world.