Frontline

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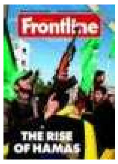

SCIENCE

A celestial surprise

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The discovery of an earth-size extra-solar planet close to the centre of the Milky Way appears to support the theory of planetary formation based on the model of the solar system.

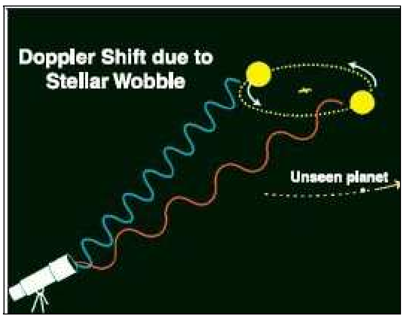
An artist's impression of the exoplanet discovered recently, with its "sun" in the background.

TEN years ago, astronomers made the first discovery of a planet orbiting a normal star other than the sun - an `extra-solar' planet or `exoplanet'. Since then the number of exoplanets discovered has grown rapidly and till date 170 of them, associated with 147 planetary systems, are known. But the discovery announced on January 25 in the journal *Nature* is significant for several reasons. It is probably the smallest planet found so far, with a mass of only about 5.5 times that of the earth. It is also perhaps the most distant planet discovered so far. But, more important, it is the first exoplanet that appears to conform to the theory of planetary evolution formulated on the basis of the generally accepted model of the solar system. The international collaboration that made the discovery includes 73 scientists from 32 institutions.

Designated as OGLE-2005-BLG-390Lb, the new planet orbits a `red dwarf' that is five time less massive than the sun. Red dwarfs are stars that are smaller and cooler, and hence dimmer, than the sun - the cooler a star, the redder it is, just as a dying ember fades from yellow-orange to cherry-red - and these are the most common stars of our galaxy. In the close vicinity of the sun, for example, there are 10 times more red dwarfs than sun-like stars. This particular parent star is, however, distant. It lies close to the centre of the Milky Way in the constellation of Sagittarius about 20,000 light years away (one light year is about 10 trillion kilometres).

The new planet is about three times farther from the host star than the earth is from the sun - the earth-sun distance is termed as one Astronomical Unit (A.U.). In the solar system, one finds an asteroid belt at about this distance. But, since the parent star is of a lower mass, the planet takes about 11 years to complete an orbit compared to five years by the asteroids.

Although the discovery marks a significant progress in the detection of `habitable' earth-like planets in other planetary systems, this particular one cannot be harbouring any life on it. For, the likely surface temperature on the planet has been estimated to be an icy 220{+0} Celsius below zero. This is because of the relatively cool and faint parent star and the large distance of the planet from it. At such low temperatures water, necessary for life, cannot remain in liquid form. According to the scientists of the collaboration, like the earth, the planet is likely to have a thin atmosphere but its rocky interior is probably buried deep underneath the icy layers. It, therefore, more closely resembles a more massive version of Pluto, rather than the rocky inner planets of the solar system such as the earth and Venus.



When the star moves towards the observer, the frequency of the emitted light increases (blue), and the frequency decreases

(red) when it moves away.

The masses of the exoplanets discovered so far range from below the mass of Neptune to several times the mass of Jupiter, the largest planet of the solar system. Some are bound tightly to their parent stars, completing a circular orbit in just over a day while others have very elongated orbits, the farthest distance from the parent star being 10 times the smallest distance. However, the giant planets that were discovered with masses several times the mass of Jupiter seem to be moving in orbits much closer to the parent star than what is observed in the solar system. Thus, all these exoplanets do not seem to fit into the scheme based on our understanding of how the solar system itself came into being. This had led to postulating mechanisms, such as `orbital migration', that alter the conventional course of planetary evolution.

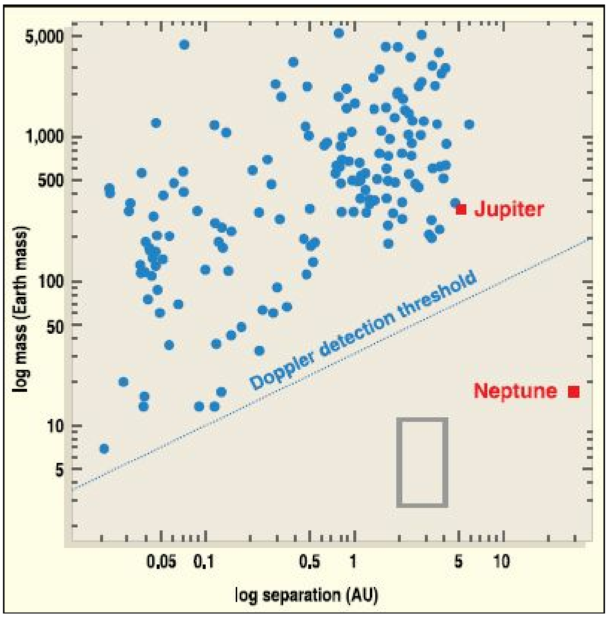
According to the popular `core-accretion model' of planetary system formation, solid `planetisimals' aggregate from the remnants of a new-born star to form planetary cores. If these are sufficiently massive, they then accrete gas from the debris to form giant planets. Around red dwarfs, this model predicts the formation of planets with masses between the earth and Neptune at distances of 1-10 A.U. from the parent star. The model also predicts that such stars would be more common than Jupiter-mass planets. "This planet is actually the first and only planet that has been discovered so far that is in agreement with the theories for how our solar system formed," says Uffe Grae Jorgensen, a member of the team from Niels Bohr Institute, Copenhagen.

The ability to find an earth-size planet around such a star implies that many more such planets should show up soon, scientists believe. "Our detection suggests that such cool, sub-Neptune-mass planets may be more than gas giants, as predicted by the core-accretion theory," the authors of the discovery wrote in their paper. And this detection ability comes from employing a relatively new technique for planetary searches, known as `gravitational microlensing'. This is the third discovery of a planet using `microlensing' and the first one of an earth-size planet. "The other two microlensing planets have masses of a few times that of Jupiter, but the discovery of a five-earth-mass planet is a strong hint that these objects are very common," says Jean-Philippe Beaulieu of the Astrophysics Institute of Paris, the lead author of the paper.

The planet's name comes from the acronym of an international collaboration project called Optical Gravitational Lensing Experiment (OGLE), which led the discovery in association with other similar international astronomy projects, PLANET (Probing Lensing Anomalies NETwork), MOA (Microlensing Observations in Astrophysics) and MPS (Microlensing Planet Search).

More than 150 of the known exoplanets were found by an indirect method wherein the variation in the stellar radial velocity, or the `wobble', caused by the gravitational force of the orbiting planet, is measured. As the planet orbits, it causes the central star to move a little back and forth when observed from the earth. The wobble makes the light from the star change its frequency owing to the Doppler Effect, the principle that makes the pitch of a train whistle increase or decrease respectively as it approaches or moves away.

The wobble and the corresponding frequency shift are, however, tiny. The heavier the planet, the greater the change. But even for a planet of Jupiter's size, the variation is only about 10 metre per second. Until recently the best telescopes could measure the Doppler Effect with an accuracy of about 100 m/s. But more advanced instruments such as the High Accuracy Radial Velocity Planet Searcher (HARPS) Spectrograph at the 3.6 m telescope of the European Southern Observatory (ESO) at La Silla, Chile, can measure changes in the stellar motions with an accuracy of about 1 m/s and has been able to detect several exoplanets, including the first rocky planet, having a mass 13 times the earth's mass. However, the technique works for relatively nearby stars up to about 160 light years because it requires the stars to be bright. Also, while it can detect planets that are close to the stars, it is not good for planets orbiting at great distances.



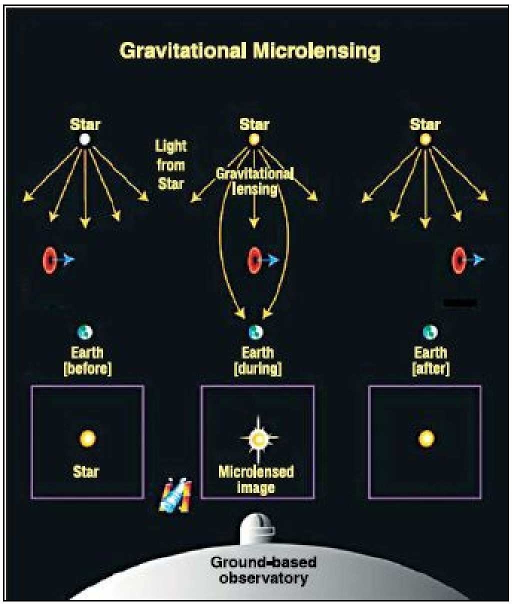
The blue dots indicate the masses of the extra-solar planets found so far using the Doppler technique, plotted against the separation from their stars. High-mass planets on short orbits cause the greatest deflection in their star, and are therefore easier to identify. But there is a detection threshold for Doppler surveys (blue line) below which no planet can be found. The gray rectangle indicates the region including uncertainties of the new planet found by gravitational microlensing, which is wellbelow the Doppler sensitivity threshold. Jupiter and Neptune are shown for comparison.

Enter the technique of gravitational microlensing. It is based on a concept first discussed by Albert Einstein in 1915, according to which the light from a distant star is bent by the gravity of the objects (stars, nebulae, dark matter or black hole) it passes on its way to the earth. This prediction was observationally confirmed in 1919 when a solar eclipse allowed the study of stars close to the line of sight of the sun. Accurate positional measurement showed that the sun's gravitational field bent the light from remote stars.

This bending effect can, in fact, make gravity of the intervening object act as a lens and magnify the distant star even when great distances separate the source star and the intervening object. This is known as gravitational lensing. When the lensing is effected by extended, very heavy clusters of galaxies, the source or the `lensed' star may appear as large, spectacular arcs and well-separated multiple images. Objects much less massive than a galaxy (such as faint low-mass stars), however, produce a much less striking lensing effect and the image extensions are too small to be distinguished directly. Even though present-day telescopes cannot resolve the details of the magnified image, the rise and fall in the brightness, as the lens passes across the line of sight, can be measured. Such an effect, where the actual image distortion is itself too small to be measurable, is called `microlensing'.

Thus, microlensing occurs when a compact body (usually a low-mass Milky Way star moving in a galactic orbit) passes almost directly between the earth and the source (also usually a star). The plot of the observed light intensity is referred to as the `light curve'. In most cases, especially in crowded sky regions in which there are many bright stars, the lens itself cannot be directly observed. However, if the geometrical alignment between the source, the lens and the observer is precise, the gravity of a low-mass object is sufficient to produce a measurable `microlensing' effect. This makes the technique quite powerful and particularly important for detecting objects that cannot be directly seen, such as `dark matter'.

If the lensing star also happens to have an orbiting planet, the planet's gravitational effect causes perturbations, which show up as `wiggles' or `blips' in the light curve. "This small defect in the brightening reveals the existence of a planet around the lens star. We don't see the planet, or even the star that it is orbiting; we just see the effect of their gravity," explains Andrew Williams of Perth Observatory, a member of the team. The characteristic brightening due to the intervening star lasts for about a month. The additional signal superposed on it owing to any orbiting exoplanet can last for days for giant planets down to hours for earth-size planets.

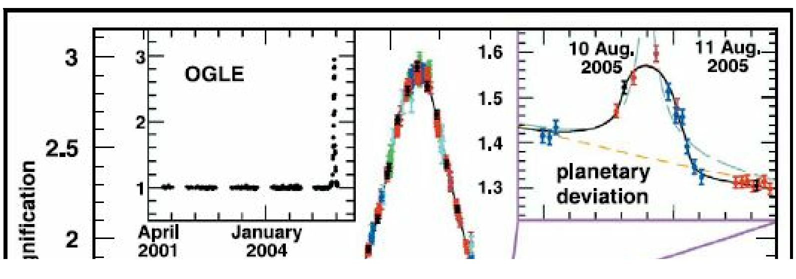


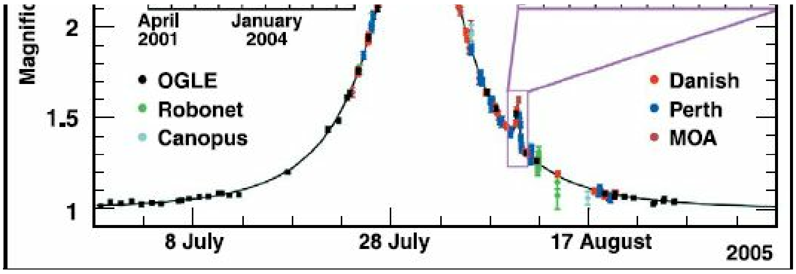
The geometrical alignment for microlensing to occur, however, happens only rarely. Says Andrzej Udalski of Warsaw University, leader of the OGLE team: "The probability that a given star undergoes a microlensing event at a given time is only about one in a million. However, with more than 100 million stars being routinely monitored by OGLE, we can provide the scientific community with about 120 ongoing events and nearly 1,000 events a year". Indeed, in the past few years, it has been possible to detect a fair number of microlensing events. In fact, the number 390 in the new planet's name refers to the 390th microlensing event detected by OGLE in 2005 and BLG refers to the event taking place in the galactic bulge.

In order to be able to catch and characterise such planetary microlensing signals, a round-the-clock high-precision monitoring of the ongoing microlensing events is achieved through the PLANET/RoboNet network of 1 m class telescopes around the world. The network consists of the Danish 1.54 m ESO telescope at La Silla, the 1.0 m telescope at Canopus Observatory in Hobart and the 0.6 m telescope at Perth in Australia, the Boyden 1.5 m telescope and the 1.0 m SAAO telescope at Sutherland in South Africa. Since 2005, this network has also included RoboNet comprising the fully robotic 2.0 m telescope at Liverpool in the U.K. and the Faulkes telescope in Hawaii.

The OGLE team, led by Udalski, detected the event OGLE-2005-BLG-390 on July 11, 2005. OGLE immediately alerted fellow astronomers around the world, thus triggering the PLANET network to train its telescopes on to the event. Very soon the data revealed a light curve, consistent with the microlensing due to a single lens star with an amplification factor of three. This was observed, from July 31, 2005, until August 10, 2005, when the Danish 1.54 m telescope picked up the planetary blip sitting on it. Lasting for about half a day, this planetary deviation was confirmed by OGLE as well as the Perth astronomers. The MOA collaboration was later able to identify the star on its images, which enabled the estimation of the various parameters associated with the lensing event and the deduction of the characteristics of the orbiting exoplanet.

The fact that this new exoplanet was discovered using the microlensing technique also explains why it is also the farthest found. The OGLE monitors the region towards the centre of the Milky Way where many stars are present thus increasing the probability of such an event. The parent star in this case lies close to the centre and is therefore more than 20,000 light years away.





Data obtained by PLANET/RoboNet, OGLE, and MOA on the microlensing event OGLE-2005-BLG-390 together with a model light curve, showing the planetary deviation on its falling part, lasting about a day. The regular cycle of colours shows how the task of observing is taken over by the next telescope in turn as the night ends at each site. An enlargement of the planetary deviation is inset.

As mentioned earlier, OGLE-2005-BLG-390Lb is the third exoplanet detected by microlensing, the other two having masses three to five times that of Jupiter. Thus, Jupiter- or Saturn-like gas giant planets, which are much more likely to be detected because of their larger gravitational pull on the lensing star, appear to be rare around red dwarfs. Since microlensing relies on the gravity of the lensing star, and red dwarfs are abundant, the detection of a third rocky/icy earth-size planet suggests that such planets are more common than gas giants, which is in qualitative agreement with theories of planet formation. "Indeed, if Jupiter-like planets were as widespread, the microlensing method should have found dozens of them by now," points out David Bennett of Notre Dame University, a PLANET team member.

Scientists of the discovery team believe that microlensing is most probably the only technique currently capable of detecting planets similar to the earth. However, recently Indian astronomers Sujan Kumar Sengupta and Malay Maiti of the Indian Institute of Astrophysics in Bangalore suggested another, more versatile, method that is based on measurement of the linear polarisation of scattered starlight from orbiting exoplanets. The time variation - corresponding to the orbital motion of the exoplanet - of the polarisation effect is a distinct signature for the presence of a planet, they have argued in their recent paper, which is due to be published in *The Astrophysical Journal*.

They find that polarisation is significant in starlight scattered from optically thin earth-like atmospheres. The more oblate the planet and greater the ellipticity of its orbit, higher the polarisation, according to the scientists. But, most significantly, this effect is independent of the mass or size of the planet. So it is an ideal method for detecting exoplanets that other techniques are likely to miss, in particular earth-size planets. It also does not depend on chance like the microlensing event, points out Sengupta. In addition, the time dependence also provides information on the planet's orbital period, the eccentricity and inclination of its orbit and even its mass. So, the technique can be particularly useful for investigating the details of already known exoplanets as well. However, since the effect is small - polarisation being about 10,000ths of a per cent - the technique would need high-precision polarimetry.

The method has apparently been picked up by NASA, which will be flying a polarimeter in its Terrestrial Planet Finder mission, Sengupta says. "We do not have many people working in this field in our country. To use this technique with terrestrial telescopes, we need a very sensitive polarimeter, which we lack," he says. "However, with satellite astronomy missions now on the anvil, I plan to propose flying a polarimeter on one of these missions," he adds.