ASTRONOMY

Bound and unbound planets abound

Two teams searching for extrasolar planets have jointly discovered a new population of objects: ten Jupiter-mass planets far from their host stars, or perhaps even floating freely through the Milky Way. SEE LETTER P.349

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Two decades ago, we had no idea whether planets orbiting stars other than the Sun existed at all. Today, more than 500 exoplanets have been discovered, and the field of exoplanet research has advanced to become one of the most captivating branches of astronomy. Observational techniques now aim to address questions such as what the atmosphere and weather are like on some of these planets, and to determine their global statistical properties. On page 349 of this issue, the MOA and OGLE research teams[1] provide an exciting result for exoplanetary science: the discovery of a population of planets that have roughly the mass of Jupiter and separations from their putative host stars of at least ten times Earth's distance to the Sun.

The teams' finding[1] is based on gravitational microlensing, an established technique for detecting exoplanets that is well placed for statistical studies of exoplanets. There are two particularly exciting aspects to the discovery of this new exoplanetary population. The first is the authors' conclusion that, on average, there is more than one Jupiter-mass planet per Milky Way star. The second is the evidence that these planetary-mass objects could be at great distances from their host stars. Some of them could even be floating freely through the Milky Way — that is, they might not be gravitationally bound to any star at all.

Gravitational microlensing is one of a suite of planet-search techniques. The methods are truly complementary to one another, each probing different planetary properties and having its own particular strengths[2]. But most of them detect and explore nearby exoplanets. By contrast, microlensing probes more distant planets, using the host star–planet system as a magnifying glass. When a foreground star (the lens) passes in front of a distant, background star, the latter is magnified and displays a characteristic 'light curve'[3]. The two observables that characterize such a microlensing event are the height of the light curve's magnification peak and the duration of the magnification, which depends, among other parameters, on the mass of the lens: the lower the mass, the shorter the duration. Originally proposed as a way of searching for dark matter, it soon became clear that microlensing could also be used to detect planetary systems[4]: a planet orbiting the foreground star would produce a secondary peak in the light curve (Fig. 1).

Microlensing offers two advantages over other methods: it has the potential to yield the most representative statistical sample of Milky Way planets and it is, in principle, sensitive enough to detect Earth-mass objects[5,6] with current technology. However, the downside is that microlensing events are rare: fewer than one in a million stars in the central part of the Milky Way are microlensed at any given time by a foreground lensing star. And even if every such lensing star had a Jupiter-mass planet at a few times the Earth–Sun distance, only about 1% of these planets would be detected owing to the exact geometric alignment required between the background star, the planetary system and an observer on Earth. So discovering such microlensing events is akin to finding a needle in a haystack.

To tackle these statistical challenges, a handful of independent research teams have developed advanced techniques to monitor the brightness of about 100 million Milky Way stars every few days. These techniques have allowed the teams to routinely find about

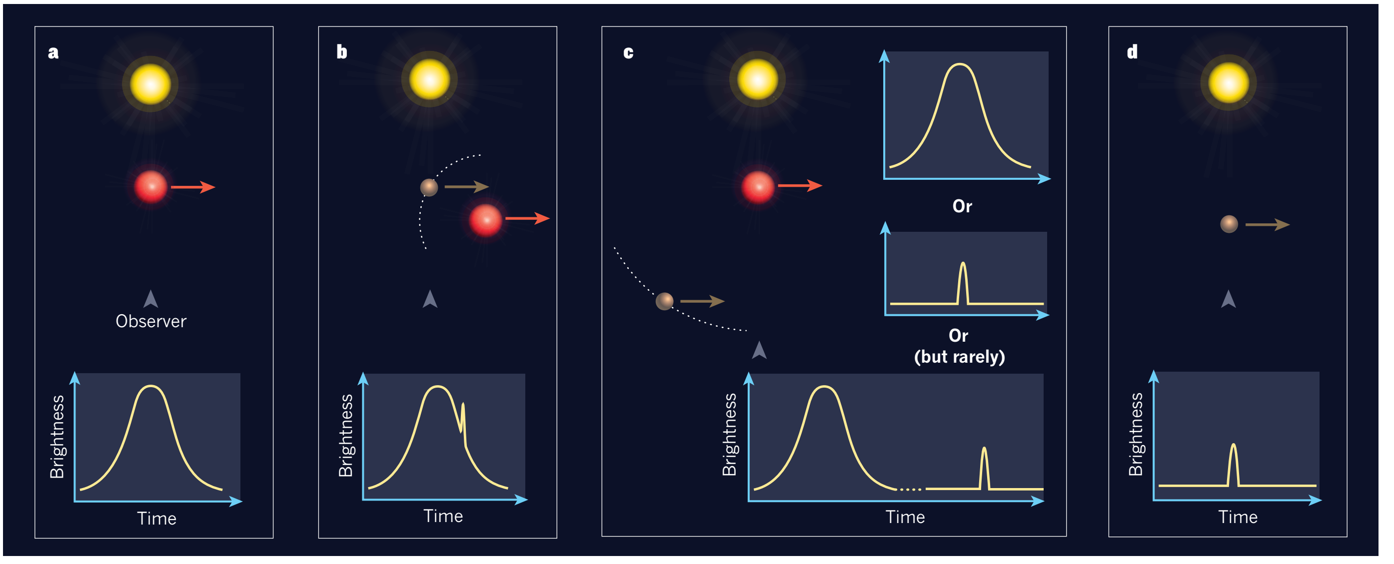

Figure 1 | Planet microlensing. **a**, When a foreground star (red) passes in front of a distant, background star (yellow), it bends the background star's light and causes it to brighten and fade with a characteristic 'light curve'. **b,** For a foreground system composed of a star and an orbiting planet (brown) that are close to each other, the brightening and fading can be accompanied by a sharp secondary peak due to the planet. **c,** If the host star and planet are far apart, most observed light curves will display either the broad peak associated with the star or the sharp peak associated with the planet; very rarely will the alignment between the background star, the foreground planetary system and the observer on Earth be such that both peaks are observed (the two observations can be years apart). **d,** For an isolated planet without a host star, the observed light curve will always display a single, short-duration peak.

1,000 (stellar) microlensing events per year. So far, however, only about a dozen exoplanets have been detected by microlensing. Nevertheless, impressive results have been derived on the abundance of planets in the Milky Way: planetary systems similar to our own are expected around one sixth of all stars[7], and cold Neptune-mass planets are common[8].

In a specially designed study, the MOA (Microlensing Observations in Astrophysics) team[9] monitored 50 million Milky Way stars for about two years, each at least once per hour. In this way, they were able to detect microlensing events of very short duration. In a careful analysis of the data — which excludes all known sources of contamination — the team has now discovered[1] 474 individual microlensing events, ten of which lasted for less than two days. The researchers then added independent data obtained by the OGLE (Optical Gravitational Lensing Experiment) team[10], to substantiate their original conclusions that there are many more short-duration microlensing events than expected from the known population of stars and brown dwarfs in the Milky Way. The authors[1] interpret this over-abundance of short events as being produced by a thus far unknown population of Jupiter-mass objects.

Because the observed light curves for the ten very short-duration microlensing events do not show any signature of a possible host star, the authors[1] conclude that these Jupiter-mass objects must be located at distances from their host stars of at least ten times the Earth–Sun distance. When comparing their derived abundance of Jupiter-mass objects with upper limits on abundances of wide-separation exoplanets from direct detections, they[1] argue that it is very likely that most of their newly discovered planetary-mass objects are unbound. These conclusions prompt at least two questions.

To be or not to be called a planet — that is the first (linguistic) question. After the first discovery, about a decade ago, of isolated low-mass objects in young star-forming regions[11], a heated discussion ignited over what to call these entities. Among the contending denominations were 'free-floating planets', 'isolated planetary-mass objects', 'objects formerly called planets' and 'rogue planets'. One of the contentious issues is whether the mass and the dynamic state of the objects concerned alone should determine their class name, or whether their formation history should also be considered. The International Astronomical Union (IAU) succeeded, in 2006, in re-defining what a planet is. But it postponed the definition of an exoplanet. In light of the discovery of a probable new class of objects[1], it may now be worthwhile to reconsider these definitions[12,13].

To be or not to be a bound planet — that is the second (astronomical) question. If these objects do turn out to be unbound, we want to understand how they reached this state. The MOA and OGLE teams provide[1] plausible arguments, but various hypotheses for the formation and dynamic state of the objects seem possible, and certainly deserve further investigation. Ultimately, the question of whether these objects are bound to stars or freely floating through the Milky Way will be answered through astronomical observations. In the former case, the relative motion between the background star and the foreground star–planet system will occasionally be oriented such that the background star will be magnified a second time by the focusing effect of the planet's host star[14]. This second (broader) peak may well happen a few years after (or before) the planetary blip in the light curve. Another signature of a bound planet, known as astrometric microlensing, is a minute change in the position of the background star during the magnification[15].

The implications of this discovery[1] are profound. We have a first glimpse of a new population of planetary-mass objects in our Galaxy. Now we need to explore their properties, distribution, dynamic states and history. A continuation of high-cadence ground-based microlensing observations will surely shed some further light on these objects. But dedicated observations by satellite telescopes with large viewing angles will be pivotal for a full understanding of this population. Well-developed concepts for such projects[16–18] on both sides of the Atlantic guarantee a head start. Exploring unbound (former) satellites of stars with bound (future) satellite telescopes of planet Earth will open up a new chapter in the history of the Milky Way. ■

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