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PLANET FREQUENCY FROM MICROLENSING OBSERVATIONS

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Abstract. Galactic gravitational microlensing is a very efficient technique to detect brown dwarfs and extrasolar planets at large orbital distances from their stars, and down to Earth-mass planets. More than 50 planets have been discovered so far, with 31 already published. Recent statistical results on the frequency of exoplanets based on several years of microlensing observations find that planets should be the rule rather than the exception, and confirm that super-Earth are much more frequent that giant planets in the Galaxy.

Keywords: Gravitational microlensing - Extrasolar planets - Planets and satellites: detection.

1 Detections

Galactic gravitational microlensing was proposed twenty years ago as a very promising method to detect extrasolar planets (Mao & Paczynski 1991) located at great distances from Earth ($1 - 10$ kpc). In 2003, after a decade of monitoring marked by great technical improvements, the MOA and OGLE collaborations discovered the first microlensing exoplanets (Bond et al. 2004). Since then, microlensing has contributed major exoplanet discoveries, such as the first cool super-Earth OGLE-BLG-2005-390Lb (Beaulieu et al. 2006; Kubas et al. 2008), a frozen super-Earth orbiting a star at the bottom of the main sequence (Kubas et al. 2012) or free-floating planets (Sumi et al. 2011). So far 31 planets have been published (Fig. 1), 20 more are now confirmed, and ongoing 2014 season has already revealed several new candidates.

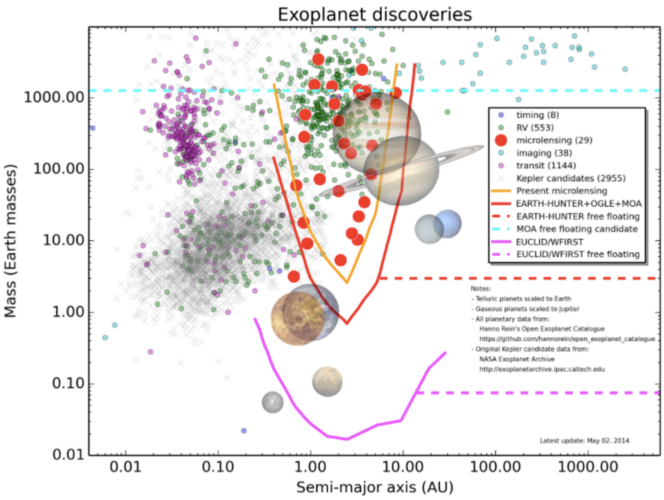

Fig. 1. Exoplanet discoveries, as a function of planetary mass and semi-major axis. Red dots mark microlensing planets, while solid lines encompass the core microlensing sensitivity using ground-based telescopes (red and orange) or a spacecraft (pink). The dashed lines indicate the typical minimum masses of free-floating planets detectable with microlensing (figure: courtesy J.-B. Marquette).

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Amongst the different methods to search for exoplanets, gravitational microlensing is up to now the only method able to detect low-mass planets (Neptunes, super-Earths) at large orbits (several astronomical units). The search for extrasolar planets using microlensing is right now in great expansion in terms of observing facilities, thanks to the development of networks of robotic telescopes.

2 Statistics, PLANET data 2002-07

We have conducted a statistical analysis (Cassan et al. 2012) that involves six years of microlensing observations gathered between 2002-07 by the PLANET and OGLE collaborations (Fig. 2). From these data combined with results from previous independent microlensing studies, we estimated the frequency of cool extrasolar planets with masses ranging from 5 Earths to 10 Jupiters and orbits between $0.5 - 10$ AU. We found an average of 1.6 planet per star, which suggests that planets around Milky Way stars are the rule, rather than the exception.

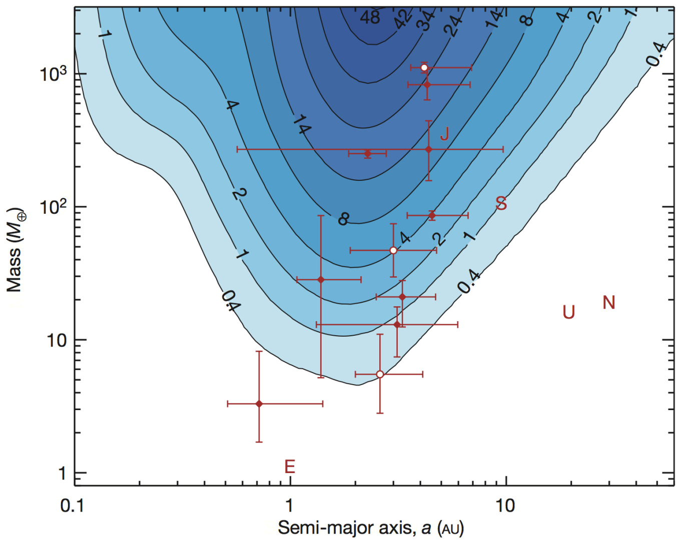

Fig. 2. Detection sensitivity diagram of PLANET 2002-07 data, as a function of planet mass and semi-major axis. Blue contours show the expected number of detections from the survey if all lens stars have exactly one planet with orbit size a and mass M. Red points with error bars mark all microlensing planet detections between 2002-07, while white dots further signal data consistent with PLANET detection efficiency (figure from Cassan et al. 2012).

3 Planet frequency

Microlensing surveys confirm that low-mass planets, such as super-Earth, are more frequently found around stars than giant planets. The mass function derived from microlensing data (Cassan et al. 2012) predicts slightly more planets than other techniques, as seen in Fig. 3. These methods, however, probe a different range in host star masses and orbital separations, in particular, most microlensing planets are located beyond the snow line.

4 The Future : networks of robotic telescopes and space-based observatories

During the last decade, microlensing has slowly evolved from a strategy of manual follow-up of selected microlensing targets to a more automated survey, mainly due to the development of robotic telescopes with wide-field cameras. With 700 alerts per year in 2009 to about 2500 in 2011, the OGLE collaboration has already quadrupled its number of alerted microlensing events, leading to a leap forward in the number of targets. The RoboNet collaboration (Tsapras et al. 2009) has been operating first generation robotic telescopes for more than ten years. A highly valuable experience has been gathered to prepare the upcoming new generation microlensing surveys. Today, the network has reached the required degree of efficiency to open a new window for microlensing searches. In parallel, many progresses have been made in terms of modeling algorithms, in particular for automated online modeling (Cassan et al. 2010; Cassan 2008; Kains et al. 2012). Future satellite

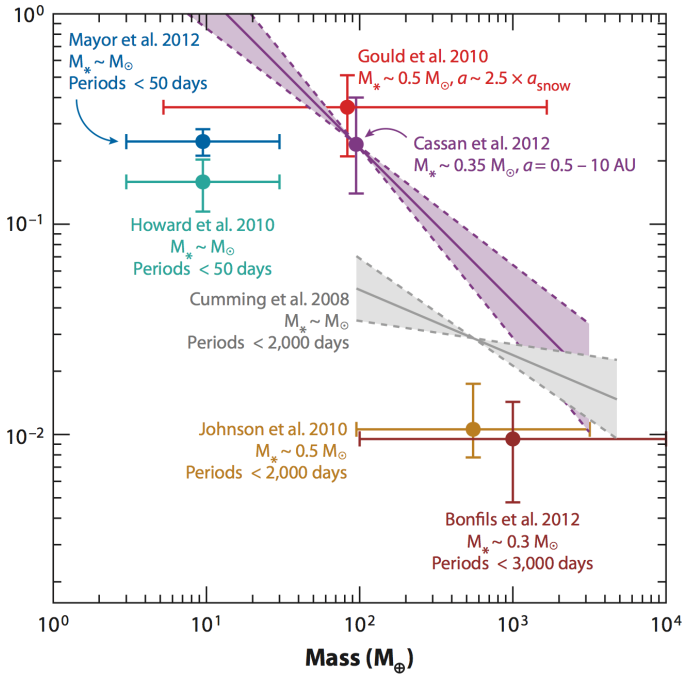

Fig. 3. Comparison of different planetary mass functions versus planetary mass, as derived from microlensing (violet, red) and Doppler (other colours) surveys. For each measurement, typical host star masses and orbit size ranges are indicated (figure from Gaudi 2012).

missions (possibly onboard Euclid or WFIRST) should also detect a large number of planets and free-floating planets (Penny et al. 2013), and constrain the planetary mass functions down the mass of Mars.

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