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SEARCHING FOR EXTRASOLAR PLANETS VIA THE MICROLENSING TECHNIQUE: DISCOVERIES AND IMPLICATIONS FOR PLANET ABUNDANCE

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Abstract. Microlensing has recently proven to be a valuable tool to search for extrasolar planets of Neptune- to super-Earth-mass planets at orbits of few AU. Since planetary signals are of very short duration, an intense and continuous monitoring is required, which is achieved by ground-based network of telescopes, once the microlensing nature of an object has been identified by single dedicated telescopes. Up to now (July 2007) the detections of extrasolar planets amount to four, one of them being OGLE 2005-BLG-390Lb, a planet of only $\sim 5.5\,M_\oplus$ orbiting its M-dwarf host star at ~ 2.6 AU. For non-planetary microlensing events observed from 1995 to 2006, we compute detection efficiency diagrams which can then be used to derive an estimate of the limit on the Galactic abundance of sub-Jupiter-mass planets, as well as relative abundance of Neptune-like planets.

1 Introduction

A Galactic microlensing event occurs when a massive compact intervening object (the lens) deflects the light coming from a more distant background star (the source). It leads to the apparent magnification of the source star. In a typical scenario, the source belongs to the Galactic Bulge, while the lens can be part either of the Bulge (2/3 of the events) or the Disk (1/3 of the events) population. Mao & Paczynski (1991) were the first to suggest that microlensing could provide a powerful tool to search for extrasolar planets at distances of a few kpc, provided a continuous monitoring of Bulge stars. The detection of exoplanets through microlensing does not rely on observing the light from their host stars, but the stellar mass function implies that they are preferably M-dwarfs.

Due to the relative motion between source, lens and observer, the magnification factor varies with time (e.g. Kubas et al. 2005), and its duration is given by $t_{\rm E} \simeq 40 \times \sqrt{M_*/M_\odot}$ days assuming a source and lens distance of respectively 8.5 and 6.5 kpc and a relative motion between source, lens and observer of $15\,\mu$as/day. The duration of the planetary light curve signal then scales as $t_{\rm p} \approx 2\sqrt{q} \times t_{\rm E}$, where q is the planet-to-star mass ratio, which means only few hours for Neptune- to Earth-mass planets.

2 The 1995-2006 PLANET campaigns

Since its pilot season in 1995, the PLANET (Probing Lensing Anomalies NETwork) collaboration has been active in monitoring Galactic microlensing events in order to detect exoplanets and put limits on their abundance. With the round-the-clock coverage provided by its telescope network (in Chile, South Africa, Australia and Tasmania), PLANET currently has unequaled capability for covering microlensing events at its disposal, which minimizes data gaps in which planetary signatures could hide.

While the microlensing surveys (OGLE & MOA) currently monitor more than $\sim 10^8$ Galactic Bulge stars on a daily basis, the small field-of-view of PLANET telescopes (usually a single ongoing microlensing event per exposure) forces us to select our targets with the goal to maximize the planet detection efficiency.

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3 Detection of a $\sim 5.5\,M_\oplus$ planet on a ~ 2.6 AU orbit

The microlensing method probes a domain in the planet mass-orbit diagram that is out of reach of other techniques, for it is mainly sensitive to Jovian- down to Earth-mass planets (e.g. Bennett & Rhie 2002) with orbits of $\sim 1-10$ AU, at several kpc.

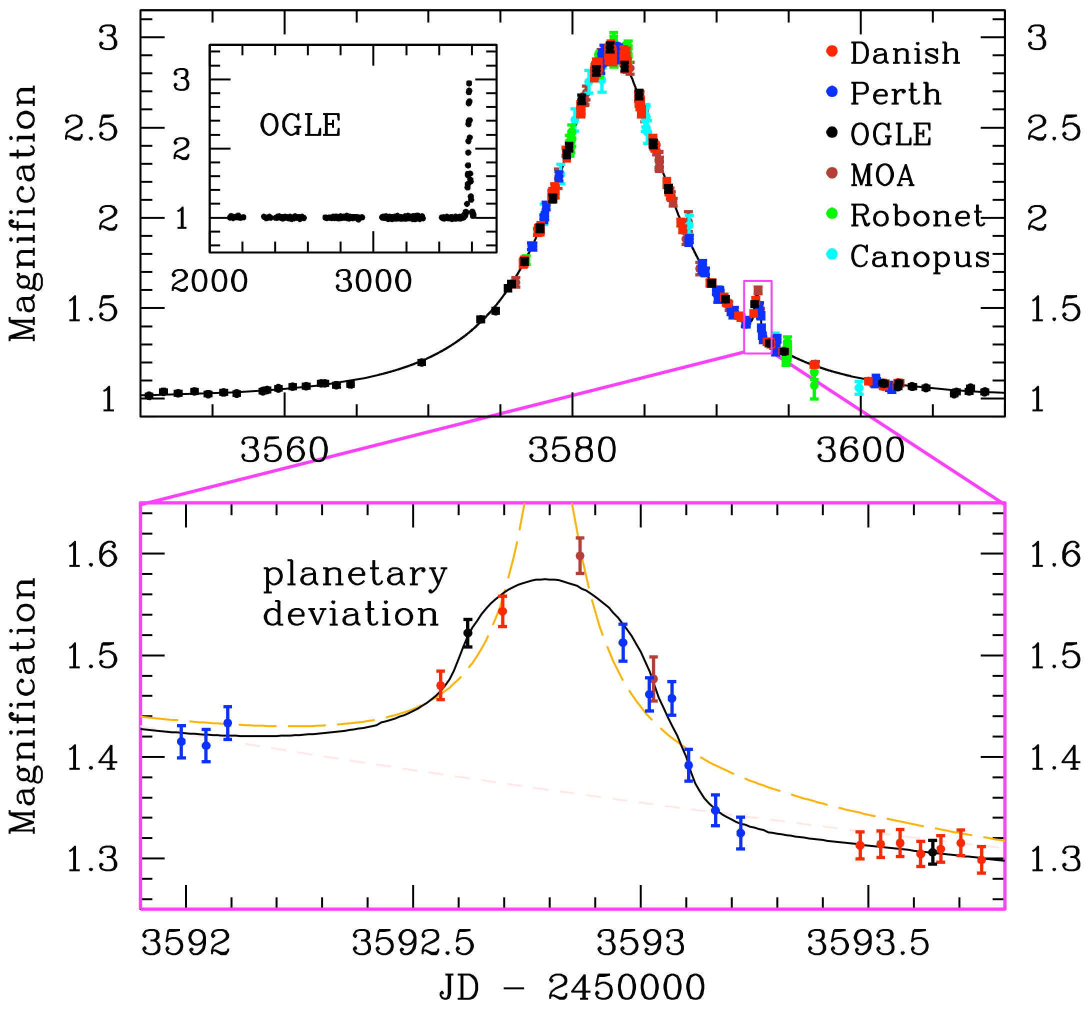

Fig. 1. The light curve of OGLE 2005-BLG-390, showing the planetary signal of a $\sim 5.5\,M_\oplus$ planet with an ~ 2.6 AU orbit.

Some promising detections have recently been made, with the discoveries of two gas giants of a few Jupiter masses, MOA 2003-BLG-53Lb (Bond et al. 2004) and OGLE 2005-BLG-071Lb (Udalski et al. 2005), as well as a Neptune-mass planet OGLE 2005-BLG-169Lb (Gould et al. 2006) and OGLE 2005-BLG-390Lb (Beaulieu et al. 2006), a $\sim 5.5\,M_\oplus$ planet on an ~ 2.6 AU orbit. The latter was discovered by PLANET. The planetary light curve signal was confirmed by four observing sites and three different collaborations (see Figure 1). Since a microlensing event does not repeat, such independent confirmations are important for the robustness of detections. This first detection of a cool rocky/icy sub-Neptune mass planet has thus opened a new observing window for the exoplanet field.

4 Probing the multiplicity of discovered planetary systems

Microlensing allows the direct detection of a multi-planetary system, as well as circum-binary systems, however the system configuration may not be suitable to make such a detection ; no such observation has been made yet, however a candidate is under consideration.

Nevertheless, the method makes it possible to put limits on the presence of further planets in the a microlensing event where a planet has been proven to exist. The constrains one may derive are stronger for higher peak magnifications events. In the case of OGLE 2005-BLG-390L (Figure 2), we find (Kubas et al., 2007, submitted) that more than 50% of potential planets with a mass in excess of 1 M_J between 1.1 and 2.3 AU would have revealed their existence, which was however not observed. For gas giant planets above 3 M_J in orbits between 1.5 and 2.2 AU, the detection efficiency exceeds 70%. Our photometric microlensing data therefore do not contradict the existence of gas giant planets at any separation orbiting OGLE 2005-BLG-390L. Furthermore we find a detection probability for an OGLE-2005-BLG-390Lb-like planet, given an idealization of the microlensing technique, to be around 3%. In agreement with current planet formation theories this quantitatively supports the prediction that sub-Neptune mass planets are common around low mass stars.

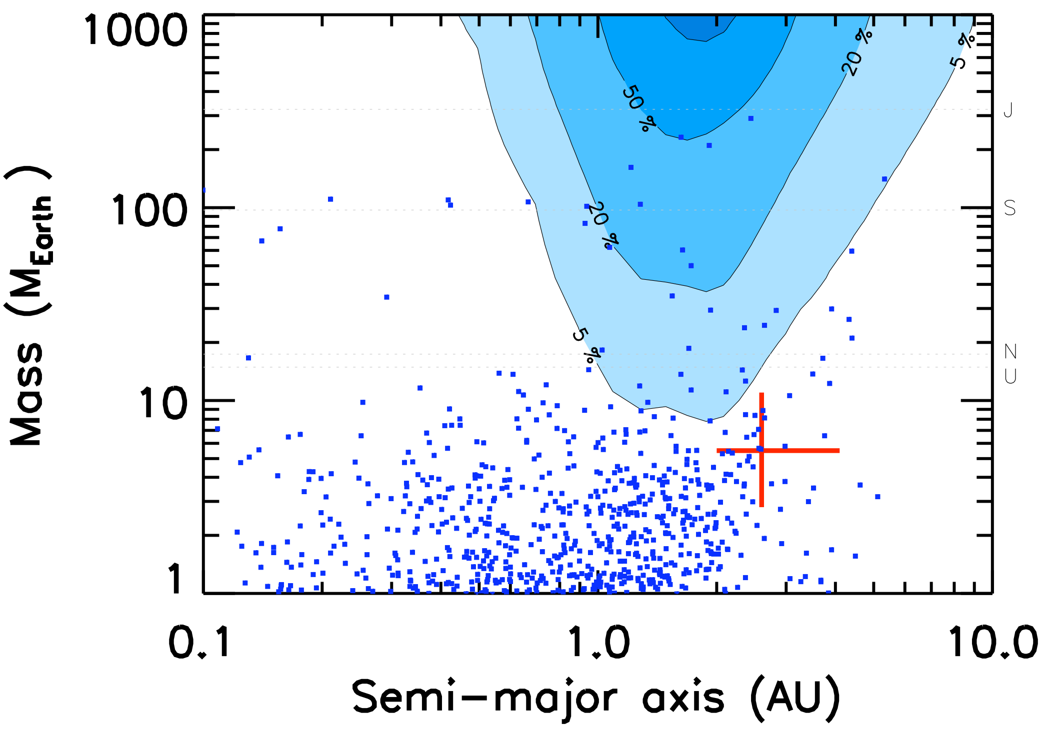

Fig. 2. Detection efficiency for an additional planets orbiting OGLE-2005-BLG-390L as a function of its orbital separation and mass, with drawn contours of 5%, 20%, 50% and 70% are shown. The cross marks the median values for the properties of OGLE 2005-BLG- 390Lb along with 1 σ confidence intervals and the dashed horizontal lines mark the masses of Jupiter (J), Saturn (S), Neptune (N) and Uranus (U) for comparison. The blue dots represent the predicted final distribution of a seed of 2×10^4 planetary cores around an M-dwarf of 0.2 $M_\odot$ resulting from a core-accretion model assuming inefficient migration (taken from Fig. 9b of Ida & Lin (2005)).

5 Detection efficiency and Galactic abundance of planets

As a further goal, PLANET's intense monitoring programme allows to obtain a planet detection efficiency from which conclusions about the planet abundance can be drawn, rather than just hunting for detections without having a sufficient statistical basis for determining how common these planets are.

¿From 42 events densely monitored between 1997 and 1999, PLANET was able to provide the first significant upper abundancy limit of Jupiter- and Saturn-mass planets around M-dwarfs resulting from any technique, namely that less than 1/3 of the lens stars have Jupiter-mass companions at orbital radii between 1.5 and 4 AU, and less than 2/3 have Saturn-mass companions for the same range of orbital radii, assuming circular orbits (Gaudi et al. 2002).

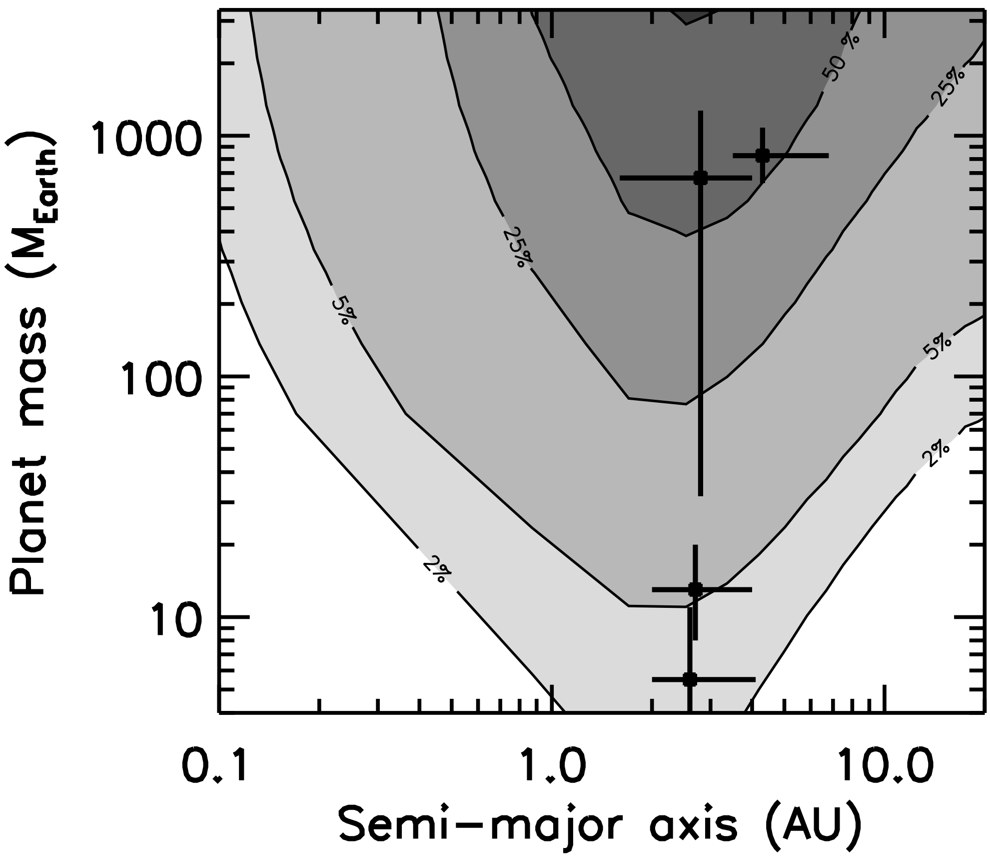

Fig. 3. PLANET detection efficiency from the 2004 season (preliminary diagram), as a function of planet mass and orbital separation. The crosses are the detected planets with their parameter error bars.

By using an adequate Galactic model for the distribution of lens masses and velocities, we aim to pursue and improve the study, moreover taking into account more than ten years of observations (Cassan et al. 2007, in preparation). The Figure 3 shows a preliminary planet detection efficiency diagram, computed from well-covered events of the 2004 season. Convolved with the probability distributions from the Galactic model, one can derive an estimate of the frequency of Jupiter-like planets, as well as the relative abundance of Jovian and Neptunian planets.

6 Conclusions

Microlensing was proposed as a technique to hunt for extrasolar planets few years before the first detection of an extrasolar planet, about a decade ago. However it has taken a longer time to give its first results, microlensing is operational now: four strong detections were made since 2003, with the particularity all detected planets are situated at few AU from their parent star. These detections include the lightest planet discovered so far, OGLE 2005-BLG-390Lb, that has a mass of only $\sim 5.5\,M_{\oplus}$. New detections have been made during the 2007 season, which will be presented in forthcoming papers.

By probing the presence of planets around stars passing in the same line of sight of other stars, the method by essence probes all kind of host stars: their mass and not their luminosity matters for microlensing. Two main consequences follow: (1) microlensing can probe very distance stars that are out of reach of any other technique, and (2) there is almost no bias toward larger mass stars, so the whole mass spectrum of stars is probed. Finally and as a corollary, microlensing might be one the best suited method for statistical studies of planet abundance, since with time not only accuracy but completeness may be achieved by conducing a dense and continuous monitoring in the coming years. We have started such a statistical analysis, that makes a basis for further observations.

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