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# BROWN DWARFS DETECTIONS THROUGH MICROLENSING

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**Abstract.** Gravitational microlensing is known to be a powerful method to hunt for extrasolar planets and brown dwarfs. Recently, several brown dwarfs companions to stars have been detected through microlensing, as well as brown dwarfs binaries. We present the discovery of a new $\sim 40\,M_{\rm J}$ brown dwarf orbiting a K-dwarf at $\sim 4\,$AU, located at $\sim 4\,$kpc from the Earth. Besides using the standard photometric light curves gathered from different round-the-world observatories, its characterization involved high-resolution adaptative optics measurements from NaCo at VLT which allowed to break the degeneracies between the physical parameters and provide the exact mass and projected separation of the system.

Keywords: Gravitational lensing: micro - Brown dwarfs - Planets and satellites: detection.

## 1 Introduction

Gravitational microlensing is a powerful technique to detect extrasolar planets (Mao & Paczynski 1991), and holds great promises in detecting populations of brown dwarfs companions to stars. Compared to other detection techniques, microlensing provides unique information on the population of exoplanets, because it allows the detection of very low-mass planets (down to the mass of the Earth) at large orbital distances from their star (0.5 to 10 AU). It is also the only technique that allows the discovery of planets at distances from Earth greater than a few kiloparsecs, up to the bulge of the Galaxy.

Milestone discoveries include detections such as the detection of the first cool super-Earth OGLE-BLG-2005-390Lb (Beaulieu et al. 2006), a frozen super-Earth orbiting a star at the bottom of the main sequence (Kubas et al. 2012) or the detection of a population of free-floating planets located at Galactic distances (Sumi et al. 2011). So far 31 planets have been published, but several more are currently being analyzed. Detections and non-detections inform us on the abundance of planets as a function of planetary mass. Recent microlensing studies imply that low-mass planets, in particular super-Earths, are far more abundant than giant planets, and reveal that there are, on average, one or more bound planets per Milky Way star (Cassan et al. 2012).

Brown dwarfs, on the other hand, have found to be intrinsically rare. While a number of brown dwarfs companions to stars have been detected by other methods, there are still few detections by microlensing, mainly because until now, observing priority has been given to low-mass objets. New advances in using networks of robotic telescopes are today changing the situation, many more detections are to be expected in a near future. With these detections, microlensing should provide a unique view of brown dwarfs around low-mass stars (M dwarfs), which will complement the currently available sample which contains mainly solar-type stars. These expected detections will help to understand the current lack of brown dwarf around 40-50 Jupiter masses at short orbital distances (the "brown dwarf desert" in Marcy & Butler 2000), and explore more precisely the population of objects in the mass range 10-80 $M_{\rm J}$ at orbital distances of 0.5-10 AU.

## 2 Brown dwarfs detections by microlensing

Gould et al. (2009) announced the first detection of a $0.056 \pm 0.004\ M_{\odot}$ field brown dwarf located in the thick-disk of the Milky Way using a terrestrial parallax signature in the light curve of OGLE-2007-BLG-224. After an advanced analysis of the event OGLE-2008-BLG-510/MOA-2008-BLG-369 including the effects of systematics on the lens properties, Bozza et al. (2012) showed that both binary-lens and binary-source models

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are compatible with the data, including a lens consisting of an M-dwarf orbited by a strong brown dwarf, solution also proposed by Shin et al. (2012a). After a full analysis of microlensing events characterized by a low mass ratio, Shin et al. (2012b) identified two brown dwarfs among seven good candidates: OGLE-2011-BLG-0172/MOA 2011-BLG-104 is due to a $0.02 \pm 0.01\,M_{\odot}$ brown dwarf orbiting a low-mass M-dwarf, while MOA 2011-BLG-149 is due to a lens composed of a $0.019 \pm 0.002\,M_{\odot}$ brown dwarf orbiting a low-mass M-dwarf as well. Another detection of a $0.05\,M_{\odot}$ brown dwarf orbiting an M-star was reported by Bachelet et al. (2012) who derived the physical properties of the lens using Galactic models. In the analysis of the anomalous microlensing event MOA-2010-BLG-073 involving a source star previously known to be photometrically variable and irregular, Street et al. (2013) found the lens to be composed of a $11.0 \pm 2.0\,M_{\rm J}$ substellar companion at the planet/brown dwarf boundary orbiting a $0.16 \pm 0.03\,M_{\odot}$ M-star. Finally, Jung et al. (2014) reported the discovery of a $0.013 \pm 0.002\,M_{\rm J}$ brown dwarf orbiting a very low mass star, both objects being close to the boundary between planet/brown dwarf on the one hand and brown dwarf/star on the other hand.

Moreover, a new population of low mass brown dwarfs hosting planets in a very tight orbit was proposed by Choi et al. (2013) from the analysis of the events OGLE-209-BLG151/MOA-2009-BLG232 and OGLE-2011-BLG-0420. These two systems consist in two super-Jupiter of $0.0075 \pm 0.0003\ M_{\odot}$ and $0.0094 \pm 0.0005\ M_{\odot}$ orbiting a $0.018 \pm 0.001\ M_{\odot}$ and a $0.025 \pm 0.001\ M_{\odot}$ brown dwarf respectively, with a projected separation lower than 0.4 AU in both cases. Similarly, Han et al. (2013) reported another $0.022 \pm 0.002\ M_{\odot}$ field brown dwarf hosting a $1.9 \pm 0.2\ M_{\rm J}$ planet in a tight system.

If gravitational microlensing is usually promoted cause its unique sensitivity to low mass planets, these recent discoveries confirmed the ability of microlensing to detect brown dwarfs in very different contexts, from solitary objects to brown dwarfs orbiting low mass stars, including brown dwarfs hosting planets. This method is also well suited to explore the transition between super-Jupiters and brown dwarfs, without little bias in brightness and in distance in the Milky Way when using direct imaging (Close et al. 2003). The brown dwarfs detected so far by microlensing constitute approximately a third of the planets detected and published using this method. Five companion brown dwarfs have been clearly identified and published among 2009 to 2013 observing seasons. We report the temporary first results revealing a sixth brown dwarf detected in 2007.

## 3 The event MOA 2007-BLG-197

During a gravitational microlensing event, the light from a distant star (called the source) in the Galactic bulge is deflected due to a space-time curvature in the vicinity of a planetary system called the lens, resulting in multiple images of the source. These images can't be resolved by a single telescope, but an amplification of the flux from the source may be detected, and its time dependance strongly depends on the mass distribution on the lens plane. This is why this method is that sensitive to the low mass ratio binary systems.

The event MOA 2007-BLG-197 was first detected by MOA collaboration in May 2007, and was fully followed by PLANET/RoboNet and $\mu$FUN collaborations (six telescopes) as soon as a single-lens model, *i.e.* a single lens star, obviously failed to describe the observations. The light curve of this event presented in Fig. 1, exhibits features specific to binary systems. The caustic exit is particularly noteworthy and was densely followed, but the analysis of the light curve suffers from the missing caustic entry that could give crucial constraints. Additional NaCo high-resolution images were obtained at the Very Large Telescope and balanced this lack of information.

Since the light curve exhibits caustic-crossing features, we take into account finite-source effects on the models. The measurements are fitted by eleven parameters. The different parameters are added successively starting with a static model, so that the most subtle effects are sought step by step, and the degeneracies explored thanks to a Markov Chain Monte Carlo algorithm. As there is no shared calibration between all the telescopes, two additional parameters per observatory are required: the flux from the source, and the blending.

As expected for long timescale events (several months), annual parallax features have been detected in the light curve, as well as the orbital motion of the lens, breaking model degeneracies, and thus providing a measurement of the lens mass, distance, and transverse velocity. However, the dynamic of the caustic seems very slow, and parallax remains partly degenerated with orbital motion cause lack of constraints during the caustic entry.

The best-fitting light curve points out that blending dominates, suggesting that NaCo images and CMD constrain the lens spectral type rather the source. The high-resolution adaptative optics (AO) images provide measurements of near $J$, $H$ and $K_s$ colors of the event. The combination of the high-resolution images, the CMD and the best-fitting set of parameters in a Bayesian framework led to balanced the not well constrained parallax and orbital motion. The preliminary resulting model gives a lens composed by a $36\,M_{\rm J}$ brown dwarf

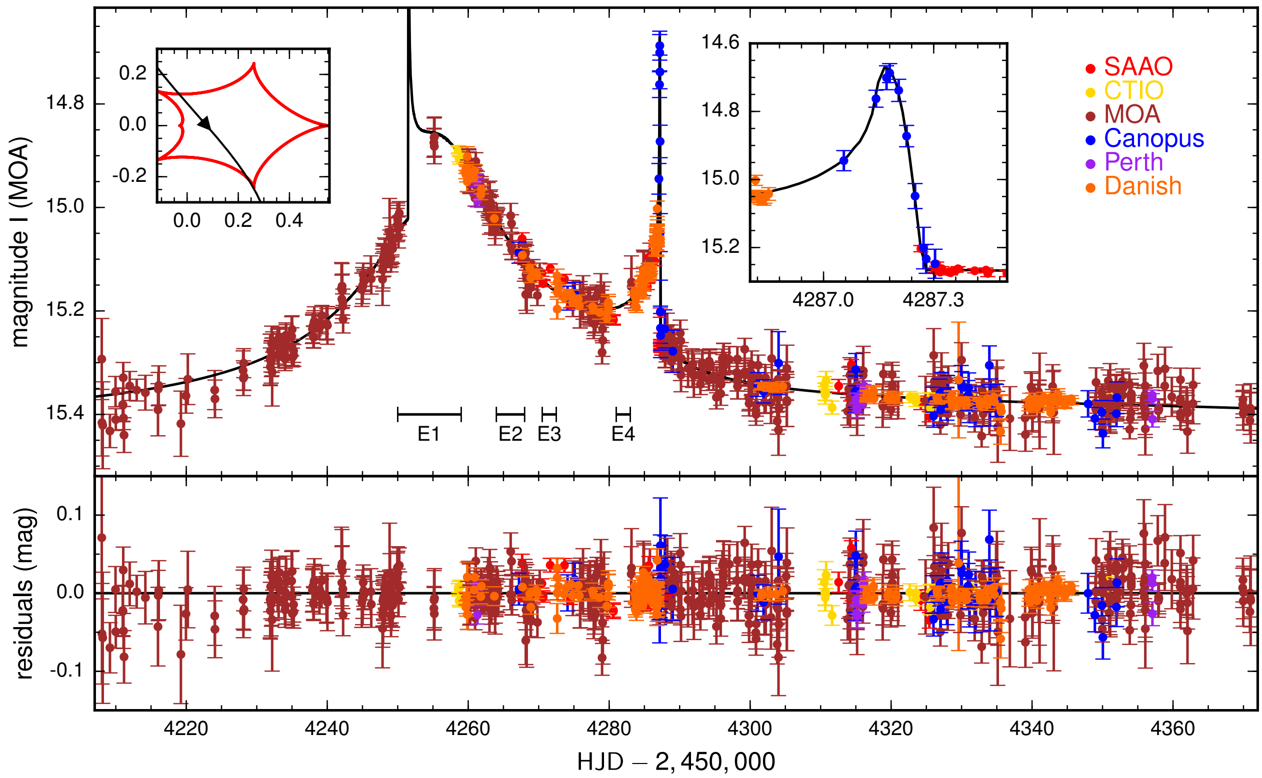


**Fig. 1.** In the upper panel, the light curve of MOA 2007-BLG-197 and the best-fitting model (solide line) are plotted. On the left-hand side, the caustic structure at the time of closest approach is drawn in red, and the trajectory of the source relative to the caustic is shown in black (Einstein units). In the lower panel, the residuals are reported. In both panels, the color refers to the observatory which performed the measurements. Adapted from Ranc *et al.*, in prep.

orbiting a Main Sequence star at 4 AU, this system being located at 3.7 kpc from the Earth (Ranc *et al.*, in prep.).

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