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COMUNICACIÓN DE TRABAJO – CONTRIBUTED PAPER

Millimagnitude photometry for OGLE transiting extrasolar planetary candidates

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Abstract. VLT images in the V-band are used to make light curves of transits of candidate OGLE planets. The data for some of the targets are complemented with NTT K-band images. Using difference image photometry, we are able to achieve milli-mag errors in the individual datapoints. Here we discuss the observations, and data reductions. We also present the preliminary results for OGLE-TR-109, arguing that it is likely to be a new transiting planet.

Resumen. Usamos imágenes del VLT en la banda V para obtener curvas de luz de tránsitos planetarios de OGLE. Algunos candidatos son complementados con imágenes del NTT en la banda K. Obtenemos errores de milimagnitudes en los puntos individuales usando fotometría diferencial de imágenes. Aquí discutimos las observaciones y reducciones de datos. Además, presentamos resultados preliminares para OGLE-TR-109, argumentando que es un nuevo tránsito planetario.

1. Introduction

We started a program to monitor photometrically the confirmed OGLE transiting planets. The main aim of this program is to improve upon the planetary parameters: the planetary radii are measured to about 10% by OGLE (Udalski et al. 2003). With millimagnitude photometry during transits we expect to halve this uncertainty as done by Moutou et al. (2005). Additional but not less

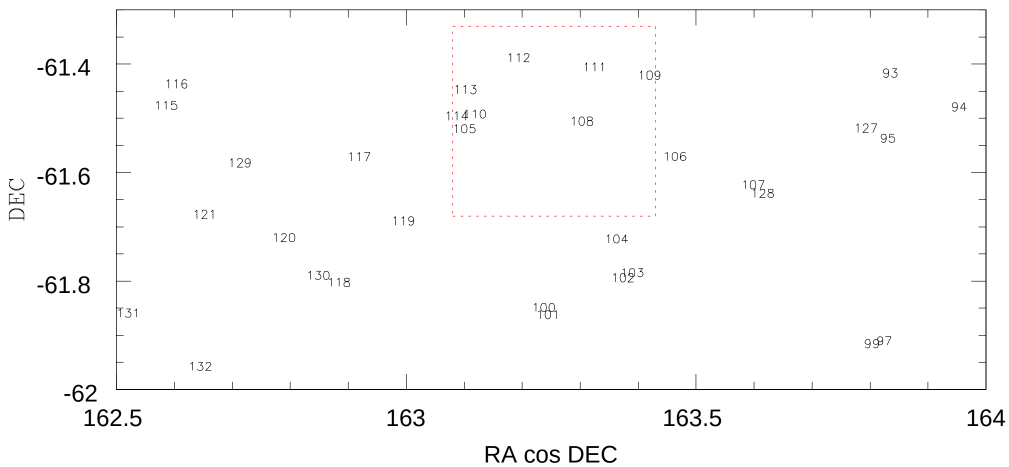

Figure 1. Map of OGLE transit candidates in the Carina field.

interesting goals are to search for long time trends in the mean transit times in order to constrain the presence of other planets in these systems (Holman & Murray 2005, Agol et al. 2005), and to search for planetary satellites (Sartoretti & Schneider 1999), and star spots (Silva 2003). In this paper we describe the observations and reductions, and present some of the results obtained.

2. Observations

The photometric observations were taken with VIMOS at the Unit Telescope 4 (UT4) of the European Southern Observatory Very Large Telescope (ESO VLT) at Paranal Observatory during the nights of April 9 to 12, 2005. VIMOS is an imager and multi-object spectrograph. Its field of view consists of four 7×8 armin fields covered by the four CCDs arranged in a square pattern with a separation gap of 2 arcmin. In preparation for the run a selection of fields was made based mostly on maximizing the number of interesting OGLE transiting candidates to be monitored simultaneously (Figure 1), and computed the expected transit ephemerides during the 4 nights of observations for all targets within the field of view (Figure 2). Because of the large effective field of view of 14×16 arcmin, that allows to monitor several transit candidates simultaneously, VIMOS is one of the most efficient instruments in the world for our project.

All four nights were clear throughout, with sub-arcsecond seeing during most of the time. The VIMOS pixel scale is 0.205 arcsec/pixel, and no images were undersampled during this run. No standard stars were observed, because we will perform difference photometry.

We monitored nightly two fields, one of which contained OGLE-TR-109. The two fields were observed alternatively, with three consecutive 15 second images acquired per field before offsetting to the other field. The observing sequence was then F1-F1-F1-F2-F2-F2-F1-F1-F1-F2-F2-F2- etc. For this to work, we

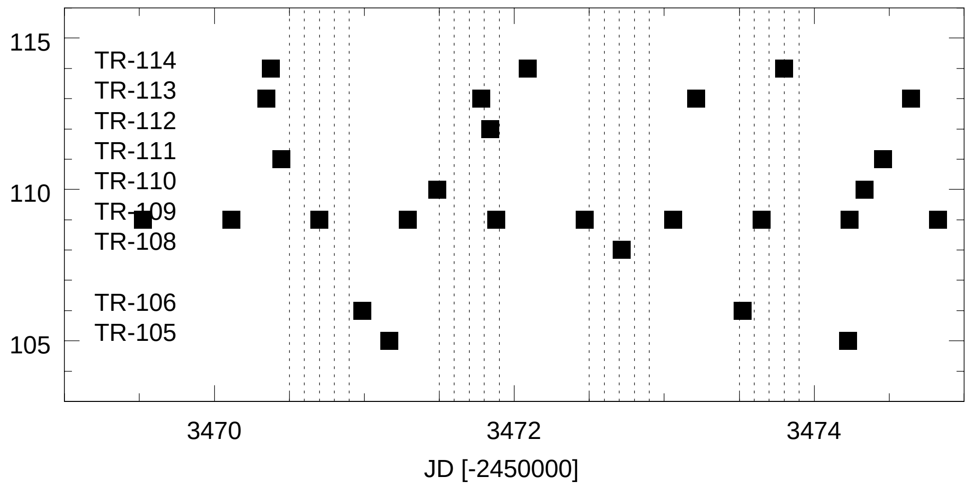

Figure 2. Computed transit times of the OGLE candidates monitored during the 4 nights of the VIMOS observing run in April 2005.

had to reduce the overheads (the mirror active configuration, the telescope moving, the acquisition, etc.), doing a record number of presets through the whole nights. According to the VIMOS Users Manual there was going to be a 9 minute overhead in between two field exposures, which was clearly inefficient for our purposes. Even though the transit time of OGLE-TR-109 lasts ~2 hours according to the light curve presented by Udalski et al. (2003), the ingress and egress times, where most of the transit information is contained, lasts of the order of 20 minutes. We aimed to have several photometric points during these short phases of the light curve. With the help of the ESO Paranal staff, we managed to reduce the nominal 9 minute overhead between two different field exposures, to 90 seconds. This ensured adequate sampling of the transit ingress and egress, while providing ~ 30 datapoints within a single transit, from which a very precise transit amplitude and duration can be measured. Typically 150 points per night were obtained in the field of OGLE-TR-109, resulting in well sampled transits. The observations lasted for about 9 hours per night, until the field went below 3 airmasses. Figure 3 shows an example of our best images taken near the zenith.

The filter used was the V_{bess}, with $\lambda_0 = 5460\AA$, $FWHM = 890\AA$. We choose the V-band in order to complement the OGLE I-band light curves. Note that the desired sampling rate did not allow us to use two different filters, unless we were willing to sacrifice the observations of the second field. One of the main objectives of this work was to discard blends and binary stars present among the transit candidates. For this, light curves measured in the V-band can be compared with the OGLE light curves in the I-band, and non-planetary eclipses can be discarded when very different amplitudes are measured, for example. In addition, while the I-band filter is more efficient for transit searches, the V-band shows better the effects of limb darkening during the transit, and is adequate for the modelling of the transit parameters.

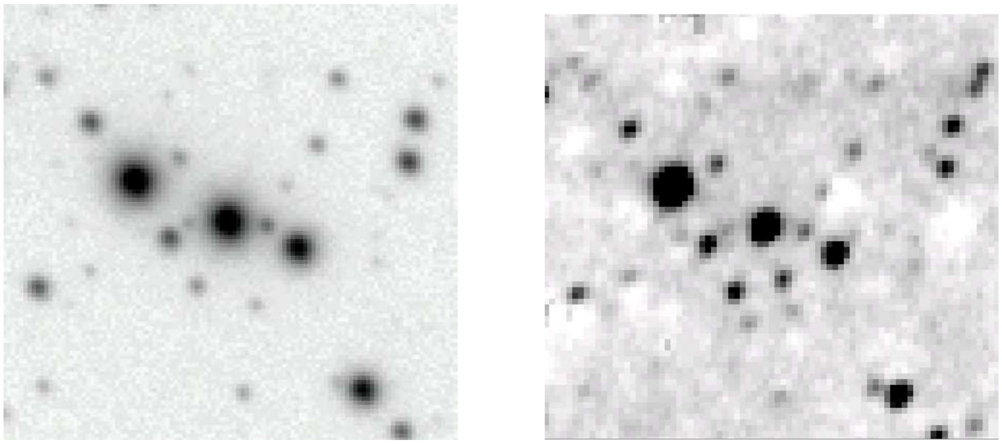

Figure 3. Reduced VIMOS V-band image (left) and SOFI K-band image (right) centered on OGLE-TR-109 ($V = 15.8$). The images cover 10×10 arcsec, and represent the best FWHM obtained ($0.5''$). The faintest stars detected in our images have $V \sim 24$ and $K \sim 21$.

3. Data analysis

The bulk of the data acquired with VIMOS amounts to 82 Gb. In order to reduce the analysis time, here we decided to process images around the transit candidates rather than the whole images. The future processing of the whole images is nevertheless a gold mine to identify additional hot Jupiters around stars with $16 < V < 20$, and even hot Neptunes around stars with $16 < V < 18$, complementing the OGLE search. We estimate that the whole images contain > 10000 stars with $15 < V < 19$ for which light curves can be obtained with individual photometric errors < 0.01 mag. The images of the transit candidates analyzed here are 400×400 pix, or 80 arcsec on a side. Each of these small images contains about 500 stars with $15 < V < 24$ that can be used in the difference images, and light curve analysis. The 7 best seeing images for each candidate were selected, and a master image was made for each night, which serves as reference for the difference image analysis (see Alard 2000).
The difference image photometry was performed in the individual raw and reduced frames. We obtained basically the same results, and we found that the raw images showed less photometric scatter. We note that the shear size of the telescope minimizes scintillation effects. Extensive tests with the difference image photometry were performed, varying different photometric parameters, and choosing different sets of reference stars. In addition, the seeing, position of the stars, peak counts, and sky counts were monitored. The individual light curves were checked against these parameters in search for systematic effects.

4. The transits of OGLE-TR-109

The shortest period planets known are OGLE-TR-56, and OGLE-TR-113 (Udalski et al. 2002, Konacki et al. 2003, Bouchy et al. 2004, Konacki et al. 2004).

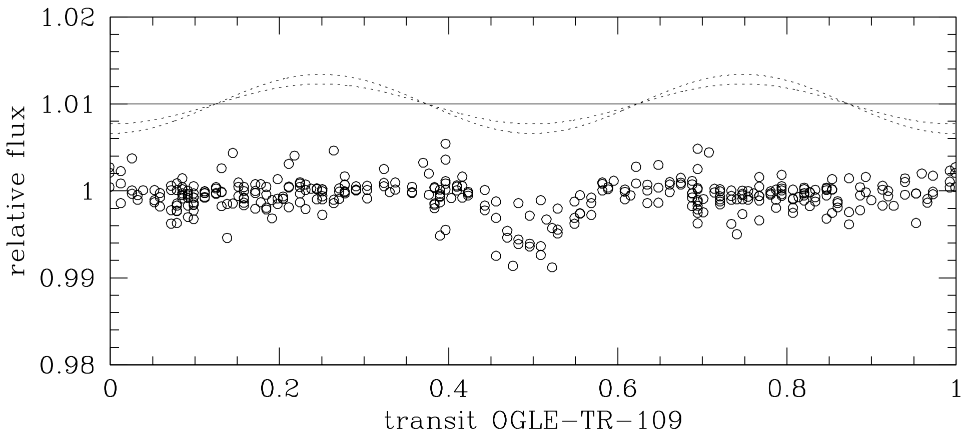

Figure 4. Phased light curve of OGLE-TR-109. For comparison, the expected ellipsoidal modulation corresponding to a companion with $M = 0.08$ and $0.045\ M_{\odot}$ are shown with the dashed lines above the light curve, with amplitudes 0.0034 and 0.0023 mag, respectively. The fact that no such light modulations are seen allows to constrain the mass of the companion.

With $P = 1.2\ d$, and $P = 1.4\ d$, their orbital periods more than double that of OGLE-TR-109. If this is a planetary transit, it would be the shortest period planet known so far, around the hottest star measured. Unfortunately, the star is rapidly rotating, with $V = 35.4 \pm 1.8$ km/s, which makes the measurement of precise velocities very difficult (Pont et al. 2005). Therefore, in this (and other similar cases that might arise), it is rather important to find other means of establishing the presence of a planet that do not require the measurement of $M_p\ sin\ i$ by radial velocities.

One such possibility is to place limits to the ellipsoidal modulation of the light curve due to tidal effects, as discussed by Drake (2003) and Sirko & Paczynski (2003). A short period massive companion would induce a detectable photometric signature in the light curve of the primary star, with a periodicity of half the orbital period. Sirko & Paczynski (2003) measure for OGLE-TR-109 one of the light curves with least modulations. No ellipsoidal modulation with $P = 0.3\ days$ is detected in our light curve for OGLE-TR-109 larger than ~ 0.001 mag (Figure 4), supporting their conclusions.

Drake (2003) studied the expected amplitudes of the modulation due to ellipsoidal effects for main sequence stars of different spectral types as function of their companion mass. The effect is larger for early type main sequence stars, because their surface gravity is lower than that of a solar-type star, for example. He considered a single period of 2 days, but the modulation increases with decreasing period as P^{-2}, and one would expect for his models to provide a strong upper limit for the case of OGLE-TR-109 with $P = 0.589$ days. In fact, the effect in the light curve amplitudes for this star should be more than 11 times that shown in Figure 1 of Drake (2003). For example, an F0V star with

a 0.1 $M_\odot$ companion would exhibit a modulation with amplitude of 0.4 $mmag$ if the orbital period is $P = 2$ $days$. For an orbital period of $P = 0.589$ $days$, this amplitude would be about 4.5 $mmag$, certainly not observed in the light curve of OGLE-TR-109. Figure 4 shows the phased light curve of OGLE-TR-109 for nights 2, 3, and 4, along with the expected modulation corresponding to a companion with $M = 0.080$ $M_\odot$ (the brown dwarf limit), and 0.045 $M_\odot$ (the radial velocity limit of Pont et al. 2005). These modulations, with amplitudes 0.0034 and 0.0023 mag, respectively, are not seen in our light curve (Figure 4), indicating that the companion mass is smaller than these limits.
The OGLE light curve provides an even more stringent limit to the mass. Using the amplitude measured by Sirko & Paczynski (2003) $a_{c2} = 0.61 \pm 0.33$ mmag to extrapolate in Figure 1 of Drake (2003) for an F-type main sequence star yields an upper limit of $M = 0.014 \pm 0.008$ $M_\odot$ for the companion mass. This rules out a low mass star or brown dwarf, and leaves the possibility of a transiting giant planet. Note that this constraint from the ellipsoidal modulation agrees with the maximum mass limit $M_{max} = 0.045$ $M_\odot$ established for the companion by Pont et al. (2005) using radial velocities.
In conclusion, we argue that OGLE-TR-109 is likely to be a new transiting planet. The only other alternative would be a triplet, i.e. an FOV star blended with a background eclipsing binary. We consider this possibility rather unlikely because of the absence of near-IR excess, of centroid shifts, and of ellipsoidal modulation.

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