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A stellar flare during the transit of the extrasolar planet OGLE-TR-10b[★] (Research Note)

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ABSTRACT

We report a stellar flare occurring during a transit of the exoplanet OGLE-TR-10b, an event not previously reported in the literature. This reduces the observed transit depth, particularly in the u' -band, but flaring could also be significant in other bands and could lead to incorrect planetary parameters. We suggest that OGLE-TR-10a is an active planet-hosting star and has an unusually high X-ray luminosity.

Key words. stars: individual: OGLE-TR-10 – stars: planetary systems – stars: flare – stars: activity

1. Introduction

The radii of transiting extrasolar planets are determined from the transit depth. However, the transit lightcurve can be affected by star spots (Rabus et al. 2009) or by intrinsic stellar variability (Boisse et al. 2008). There have been five different published transit depths of OGLE-TR-10, which has resulted in some uncertainty in the value of the radius of OGLE-TR-10b. Transit depths range from $\sim 0.99\%$ (Holman et al. 2007) to $\sim 2.20\%$ (Udalski et al. 2002). This relatively large range of transit depths has been attributed to photometric errors associated with overcrowding in the OGLE-TR-10 field (Pont et al. 2007). Uncertainties in the spectral model of the host star have also lead to a range of stellar, and hence planetary radius, estimates (Ammler von Eiff et al. 2008).

In this paper we report a flare during a transit of OGLE-TR-10b, which affects the observed transit depth, particularly in the u' -band. We also discuss whether OGLE-TR-10a is an active star.

2. Observations, analysis and results

Observations were made with ULTRACAM (Dhillon et al. 2007) on the VLT UT3 (Melipal) telescope on June 10th 2007. ULTRACAM is a triple-beam CCD camera that obtains simultaneous images in SDSS u' , g' and i' filters; each detector consists of a 1024×1024 pixel, back-illuminated, thinned, Marconi 47-20 frame-transfer CCD, with a platescale of $0.15'' \text{pixel}^{-1}$. We acquired 2100 exposures over a period of 6 h, with

exposure times of 9.5 s per frame for the i' and g' -band frames and 70.6 s per frame for the u' -band frames. The observing conditions were good throughout. The data were reduced using ISIS (Alard 1998), using the reduction strategies of Hartman et al. (2004).

The lightcurves (Fig. 1) are contaminated by a flare during mid-transit between at least MJD = 2 454 262.31 and 2 454 262.34. The relative brightness of the flare increases from the i' -band to the u' -band, as expected for a small intensity flare (Tovmassian et al. 2003).

We used the Markhov-Chain Monte Carlo (MCMC) technique to estimate parameters of the system from the i' and g' -band lightcurves (we did not model the u' -band lightcurve since the lightcurve is dominated by the flare). We follow the general description given in Holman et al. (2007) using the analytical lightcurve modelling of Mandel & Agol (2002). The free parameters in our fit are the radius ratio R_p/R_* , impact parameter b , time of central transit T_0 , transit phase duration R_*/a_p and u_1 and u_2 , the non-linear limb-darkening coefficients (R_p , R_* and a_p are the planetary radius, stellar radius and semi-major planetary orbital axis, respectively). We estimated our errors by using the scatter about the fit between the model and data, excluding the data points containing the flare. We fixed the period to $P = 3.10129$ days, as given by Pont et al. (2007). To determine the effect of the flare on the transit depth, we computed fits both with and without the region of the lightcurve (HJD = 2 454 262.81 to 2 454 262.84) containing the flare.

The results of our MCMC fit are shown in Table 1 and the lightcurves in Fig. 1. In the i' -band the R_p/R_* is the same ($R_p/R_* = 0.106^{+0.002}_{-0.003}$) regardless of whether the flare is excluded. In the g' -band the measured R_p/R_* is slightly greater when excluding the flare region ($R_p/R_* = 0.099^{+0.008}_{-0.006}$), than when including it ($R_p/R_* = 0.093^{+0.005}_{-0.009}$).

[★] Table 2 contains the u' , g' and i' -band lightcurve data and is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/505/901>

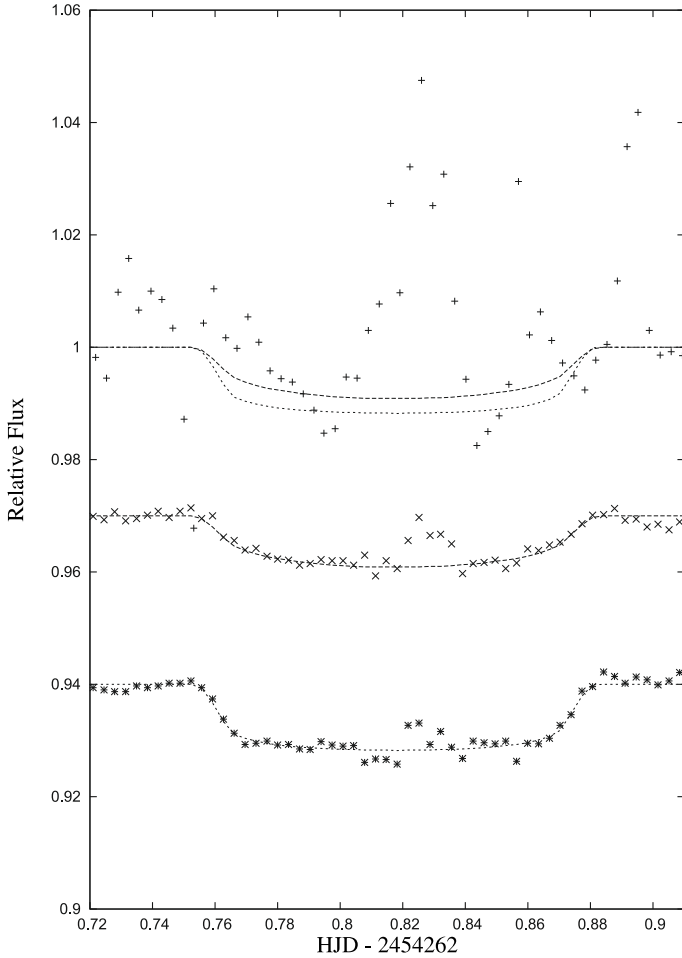


Fig. 1. Lightcurves, in 5 min bins, of the transit of OGLE-TR-10 in the *u'*-band (top), *g'*-band (middle, offset by 0.03) and *i'*-band (bottom, offset by 0.06). The *i'* and *g'*-band lightcurves have the best-fitting transit overplotted; these fits are also overplotted in the *u'*-band transit.

Table 1. MCMC-estimated parameters for the *i'*-band and *g'*-band lightcurves.

Parameter	<i>i'</i> band value	<i>g'</i> band value
T_0 (HJD)	$2454262.8175^{+0.0003}_{-0.0003}$	$2454262.8180^{+0.0040}_{-0.0013}$
R_p/R_*	$0.106^{+0.002}_{-0.003}$	$0.093^{+0.005}_{-0.009}$
b	0.53 ± 0.16	0.83 ± 0.15
R_s/a	$0.133^{+0.022}_{-0.017}$	$0.185^{+0.058}_{-0.073}$
u_1	0.2491 ± 0.0100	0.6435 ± 0.0050
u_2	0.3204 ± 0.0100	0.1839 ± 0.0050

3. Discussion

3.1. The radius ratio

There has been much disagreement in the literature over the reported R_p/R_* of OGLE-TR-10; published R_p/R_* values include the original OGLE measurement of 0.148 (Udalski et al. 2002), 0.129 ± 0.003 (Bouchy et al. 2005), 0.127 ± 0.017 (Konacki et al. 2005) and 0.099 ± 0.002 (Holman et al. 2007). Attempting to solve this discrepancy, Pont et al. (2007) concluded that systematic noise was affecting the R_p/R_* measurement of Udalski et al. (2002) and Holman et al. (2007). Reporting new VLT data, Pont et al. (2007) argued for a radius ratio of $R_p/R_* = 0.110 \pm 0.002$. There appears to be no obvious signs of flares in any of the aforementioned authors' lightcurves.

Our *i'*-band R_p/R_* is compatible with the value of Pont et al. (2007). Our *g'*-band R_p/R_* , however, is the shallowest yet reported for OGLE-TR-10, which could result from contamination by the flare. Our *u'*-band lightcurve shows a transit that is nearly entirely filled in by the flare.

The variation of R_p/R_* in each band is too large to be due to wavelength-dependant absorption in the atmosphere of OGLE-TR-10b. In the *i'* bandpass there is expected to be strong molecular absorption in the atmosphere of OGLE-TR-10b, although this will change the relative transit depth by no more than 10^{-4} (Carter et al. 2009).

3.2. The activity of OGLE-TR-10a

Stellar X-ray emission is associated with stellar activity and planet-harboured stars are found to be more X-ray active than non-planet-harboured stars by a factor of ~ 4 (Kashyap et al. 2008). Kashyap et al. (2008) also found that OGLE-TR-10a is among the most X-ray luminous planet-hosting stars with an X-ray luminosity of $\log L_X = 30.34 \pm 0.25 \text{ erg s}^{-1}$ which is unusually high for a G-dwarf (for the Sun, $28 > \log L_X > 27 \text{ erg s}^{-1}$). Furthermore, OGLE-TR-10a has an L_X similar to RS CVn stars, which supports the notion that OGLE-TR-10a is an active star (Holmberg et al. 2008).

The estimated brightness of the flare is $55.24 \pm 3.50 \text{ mmag}$ for the *u'*-band (using the *i'*-band transit depth as an out-of-flare flux reference point), $5.45 \pm 1.50 \text{ mmag}$ for the *g'*-band and $2.34 \pm 2.00 \text{ mmag}$ for the *i'*-band, which are low amplitudes compared to other small flare events reported in the literature (e.g. Ventura et al. 1995). By estimating the quiescent luminosity of OGLE-TR-10a and the increase in magnitude we used the relations discussed in Gershberg & Shakhovskaya (1983) to estimate the energy of the flare to be $E \approx (1 \pm 0.1) \times 10^{32} \text{ erg s}^{-1}$. Compared to solar activity, this is an energetic event, equivalent to an X13 class solar flare.

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