High precision photometric follow-ups of transiting exoplanets: towards transit timing variation

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Abstract: Transiting exoplanets are of great importance for the astrophysics of extrasolar planetary systems. High-precision photometric follow-ups allow to refine planetary and stellar parameters. Such observations may also lead to discoveries of additional bodies if transit time variations are detected. Effects of dark spots on a surface of a host star and signs of non-strictly periodic transits are illustrated by sub-millimagnitude-precision transit light curves obtained for WASP-10 b and WASP-12 b.

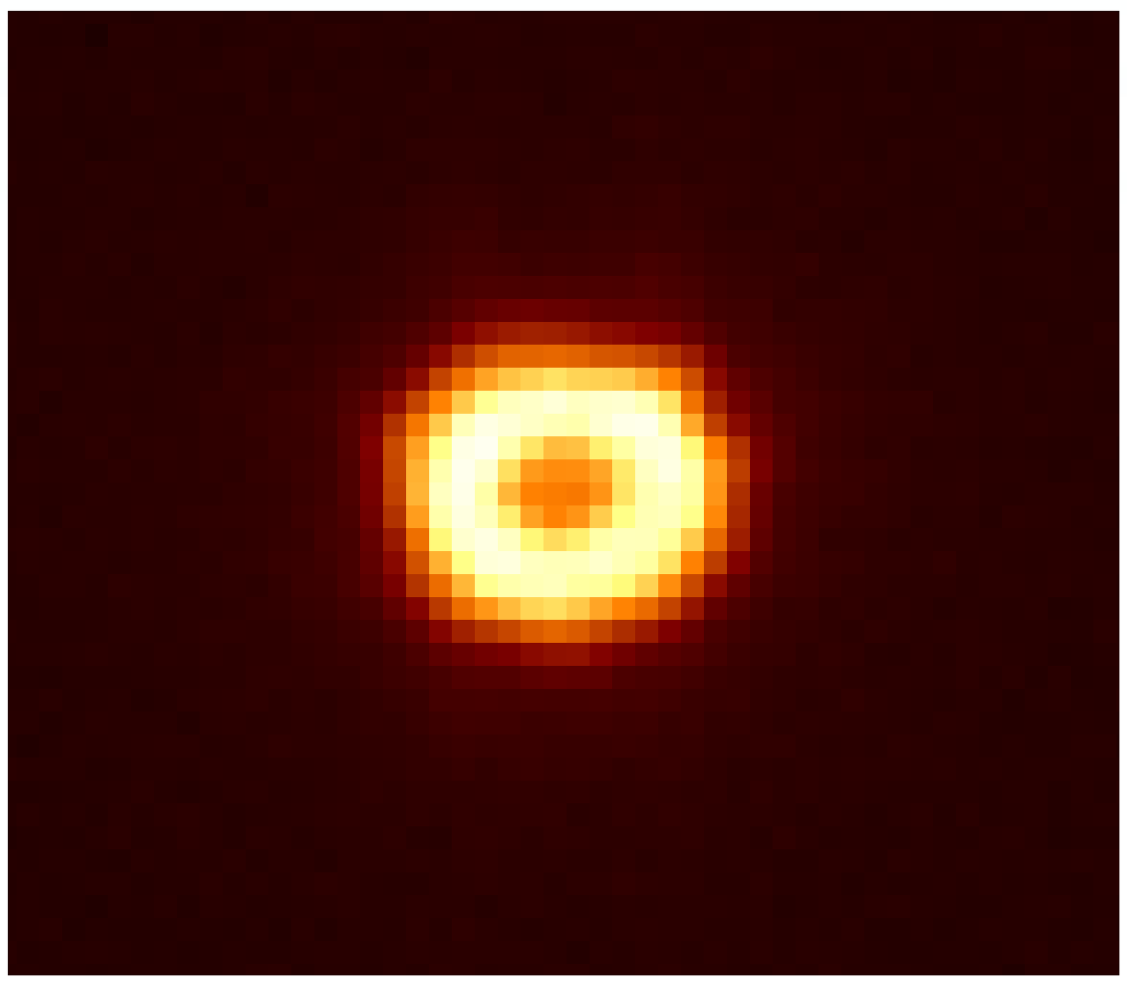

Figure 1: A donut-like shape of stellar PSF after telescope defocusing. One pixel in the image translates to ~0.5 arcsec in the sky.

Method

We use two-meter-class telescopes to acquire high-precision light curves of exoplanetary transits. As our targets are relatively bright ($10 < V < 13$ mag), we significantly defocus instruments to spread light over a ring of about a dozen arcsec in a diameter. This method is expected to minimise random and flat-fielding errors. It also enables long exposure times (up to 60 s) that shortens the total overhead time during an observing run. As it is illustrated in Fig. 1 and 2, stellar profiles exhibit donut shape. In practice, it is possible to collect up to 5×10^4 counts per second of exposure that results in 3×10^6 counts for a target in a single 60-s exposure.

Data presented in this work were obtained with the 2.2-m telescope at the Calar Alto Observatory (Spain). The Calar Alto Faint Object Spectrograph (CAFOS) was used as a detector. Light curves were acquired in the Johnson R-band filter which guarantees the highest efficiency of the set-up. The differential aperture photometry was used to derive magnitudes. In the photometric weather conditions, precision of 0.6 mmag (rms per point) is achieved for a 12-mag star and 60-s exposures. That assures timing errors of ~10 s.

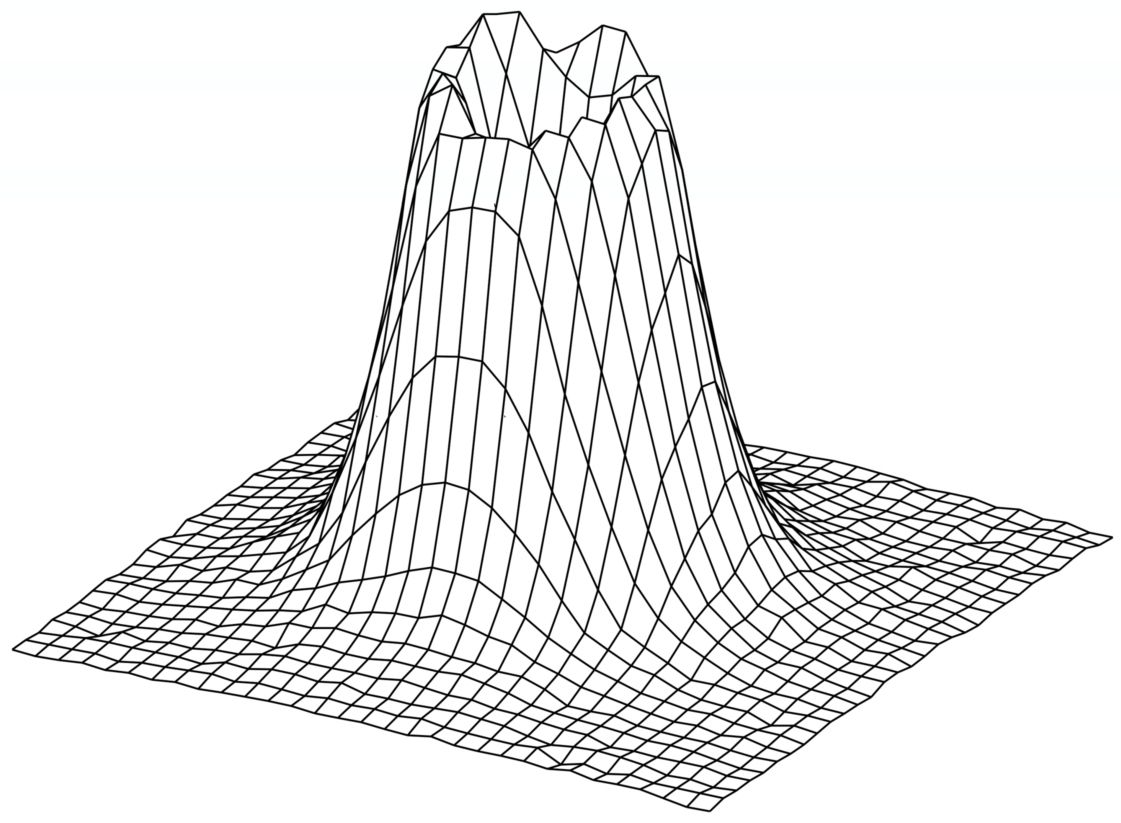

Figure 2: The three-dimensional flux distribution of the stellar profile. The logarithmic vertical scale was used for better contrast. The 30×30 pixel fragment corresponds to 15.9×15.9 arcsec on the sky. Data were extracted from a typical 50-s exposure.

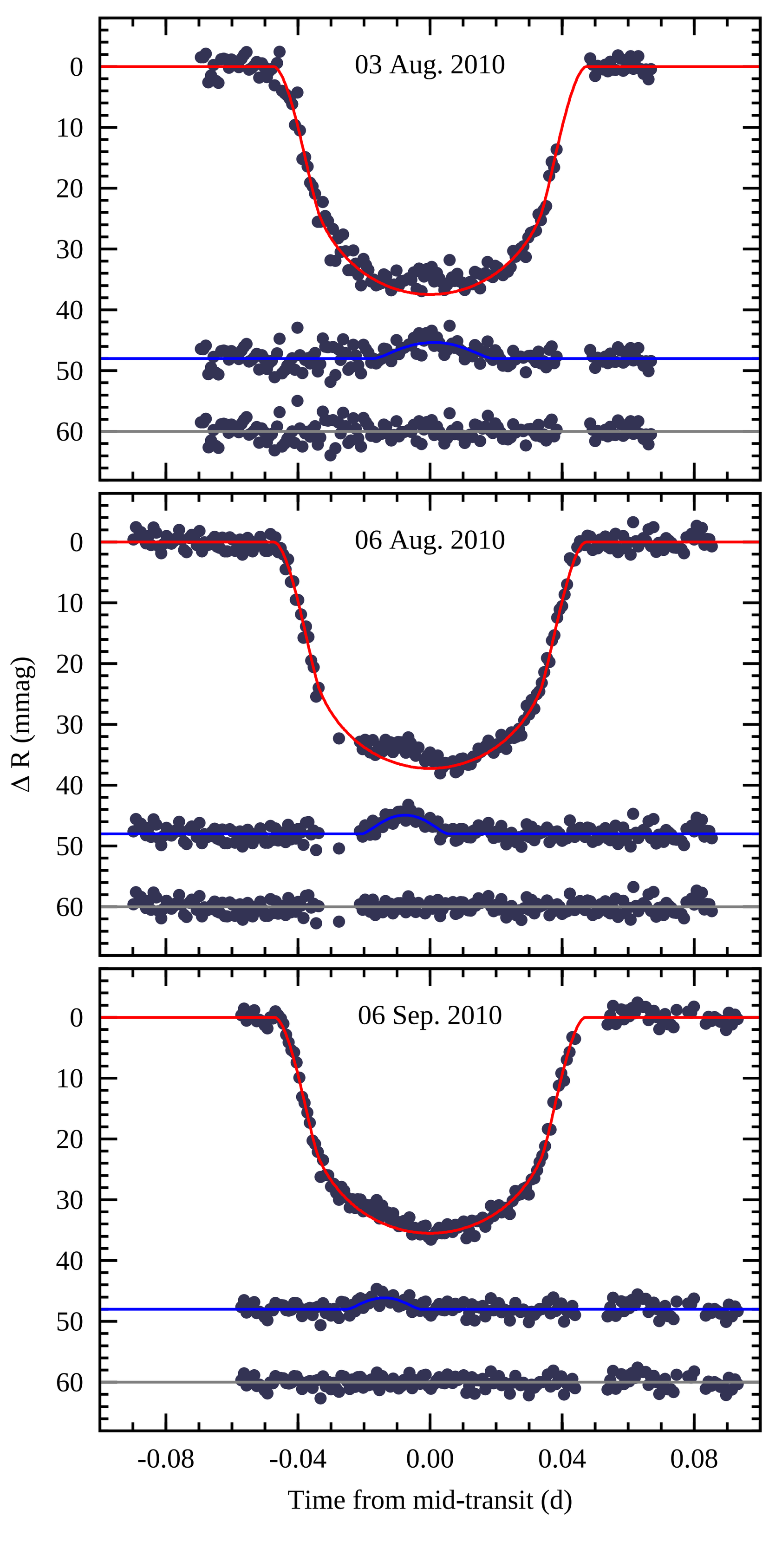

Figure 3: Light curves for three transits of WASP-10 b with individually fitted model light curves (red lines) after rejecting data points affected by stellar spots. The residuals, plotted in middle graphs, allowed us to distil starspot features which were approximated with the spot occultation models (blue lines). The final residuals are plotted in bottom graphs.

WASP-10 b

The WASP-10 planetary system has been found to be intriguing due to properties of the transiting exoplanet it contains. The host star exhibits activity which is manifested in photometric variability caused by the rotational modulation due to spots. Different values of a planet-to-star radius ratio are reported for the system. Moreover, a sinusoidal component was discovered in planet's transit timing what could be a sight of an additional planet which perturbs the orbital motion of WASP-10 b.

We acquired high-precision light curves for four transits of WASP-10 b in 2010. Three of them exhibit signatures of dark-spot occultations during planet's passage across the stellar disk (Fig. 3). These brightness bumps were modelled with a simplified transit-like model assuming a flux bump instead of a flux drop. The height of these features was found to be in a range between 2 and 3 mmag. The duration of two events was found to be ~40 minutes, i.e. comparable with the total duration of transit ingress and egress. One event lasted longer indicating the occultation of a starspot complex.

The influence of stellar activity was estimated and taken into account while determining system parameters. Assuming various limb-darkening laws, we generated best-fitting models and redetermined parameters of the system. The prayer-bead method and Monte Carlo simulations were used to derive error estimates. We found that the radius of WASP-10 b is not greater than $1.022^{+0.072}_{-0.043}$ Jupiter radii, a value significantly smaller than most of previous studies indicated (Maciejewski et al. 2011a, in prep.).

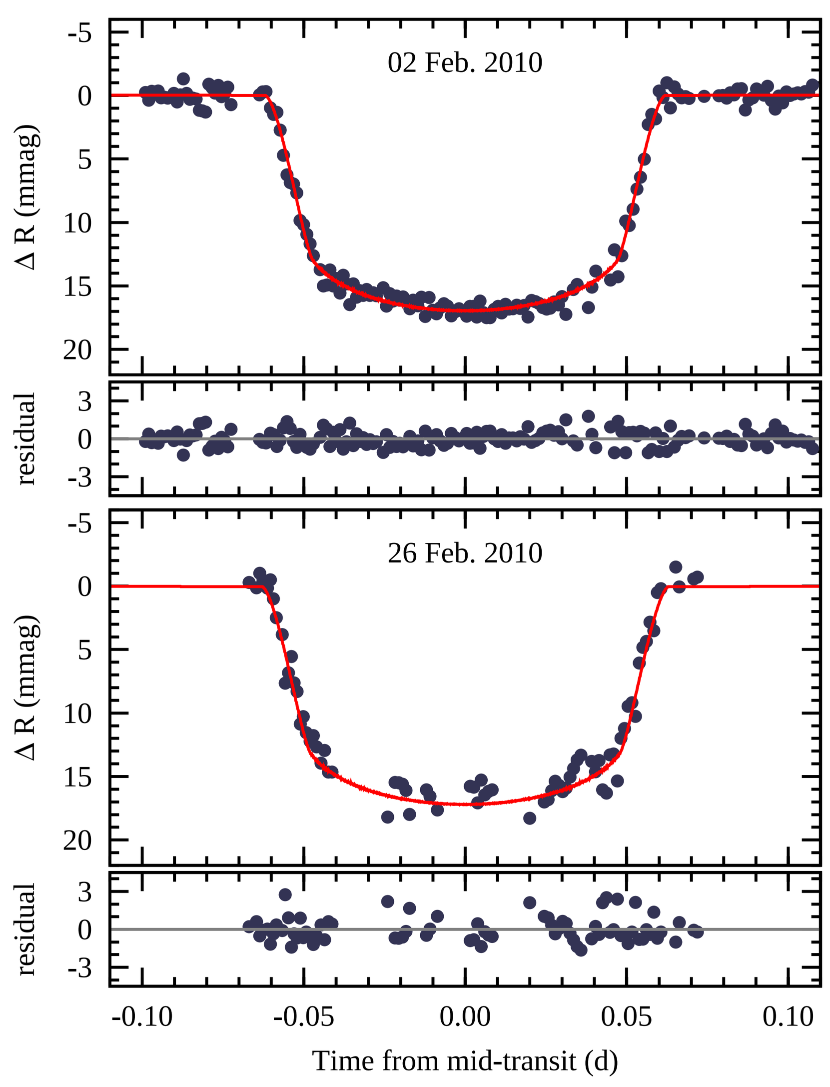

Figure 4: Light curves for two transits of WASP-12 b with best-fitting models, based on the square-root limb darkening law, are plotted with red lines. The residuals are shown in the bottom panels.

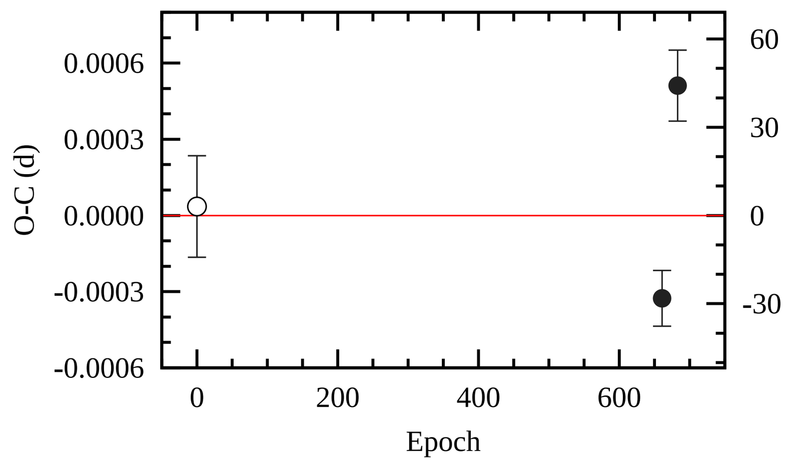

Figure 5: The O–C diagram for WASP-12 b. The open symbol is from the literature and the filled ones are our mid-transit times.

WASP-12 b

The transiting extrasolar planet WASP-12 b was found to be one of the most intensely irradiated exoplanets (Hebb et al. 2009, ApJ, 693, 1920). It orbits the host star with a period of about 1.09 day causing transits with a depth of 14 milli-mag (mmag) and duration of 2.7 hours. It is an unexpectedly bloated Jupiter-mass planet which is losing mass that may accrete into the host star. Our aim is to refine the parameters of this intriguing system and search for signs of transit timing variations (TTVs).

We gathered high-precision light curves for two transits of WASP-12 b in 2010 (Fig. 4). System parameters obtained by us are found to agree with previous studies within one sigma. Use of the non-linear limb-darkening laws results in the best-fitting models. With two new mid-transit times, the ephemeris was refined that resulted in the initial mid-transit time of $2454508.97682 \pm 0.00020$ $\mathrm{BJD_{TDB}}$ and orbital period of $1.09142245 \pm 0.00000033$ d.

Interestingly, the observed transit timing suggests there is a short-time TTV at the level of 3.4σ (Fig. 5). Such a TTV signal can be induced by an additional planet in the system. Simplified numerical simulations shows that a perturber could be a terrestrial-type planet if both planets are in a low-order orbital resonance (see Maciejewski et al. 2011b, astroph/1102.2421). Such a planet would be in practice undetectable with modern state-of-the-art instruments for radial velocity measurements. This finding makes WASP-12 b an attractive target for the TTV follow-up which is carried out in the 2010/2011 season.

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