Photometric follow-ups of transiting exoplanets WASP-3 b, WASP-10 b, and WASP-12 b

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Abstract: Transiting exoplanets are of great importance for the astrophysics of extrasolar planetary systems. The high-precision photometric follow-ups allow us to refine planetary and stellar parameters. Such observations may also lead to discoveries of additional bodies if transit time variation is detected. We present results obtained for three transiting exoplanets for which deviations from linear ephemerides were reported in the literature.

WASP-3 b

In a single-transiting-planet system, transits happen strictly periodic. If there is another (not necessarily transiting) planet in the system, it interacts gravitationally with the transiting planet and may perturb significantly the orbital motion of the latter one. These perturbations result in a quasi-periodic signal in an observations minus calculations (O–C) diagram for a transit timing. The transit time variation (TTV) method has already been used to confirm the planetary nature of systems with multiple transiting planets (e.g. Holman et al. 2010, Science, 330, 51) and to discover an additional planetary companion which cannot be detected with other techniques (e.g. Ballard et al. 2011, ApJ, 743, 200). All these discoveries are based on data acquired with the Kepler space telescope and to our knowledge no confirmed TTV signal has been detected from the ground so far.

The planet around the main sequence star WASP-3 is a strongly irradiated gas giant which revolves its host star in ~44 h on a circular orbit (Pollacco et al. 2008, MNRAS, 385, 1576). It was postulated that the observed transit timing of this planet cannot be explained by a constant period but by a periodic variation in the O–C diagram (Maciejewski et al. 2010, MNRAS, 407, 2625). The configuration with the hypothetical second planet of the mass of ~14 Earth masses, located close to the outer 2:1 commensurability, was found to reproduce the observed variations for the timing residuals.

In 2010 we acquired high-precision light curves for 4 transits of WASP-3 b with the 2.2-m telescope at the Calar Alto Observatory (Spain). Our goal was to confirm the postulated TTV signal and refine its amplitude and periodicity. The host star is relatively bright ($V = 11.6$ mag), so the telescope was significantly defocused to allow 30-s long exposures to be taken. Derived mid-transit times will be combined with additional observations gathered within the framework of the Young Exoplanet Transit Initiative (YETI, Neuhäuser et al. 2011, AN, 332, 547) to study the postulated TTV signal.

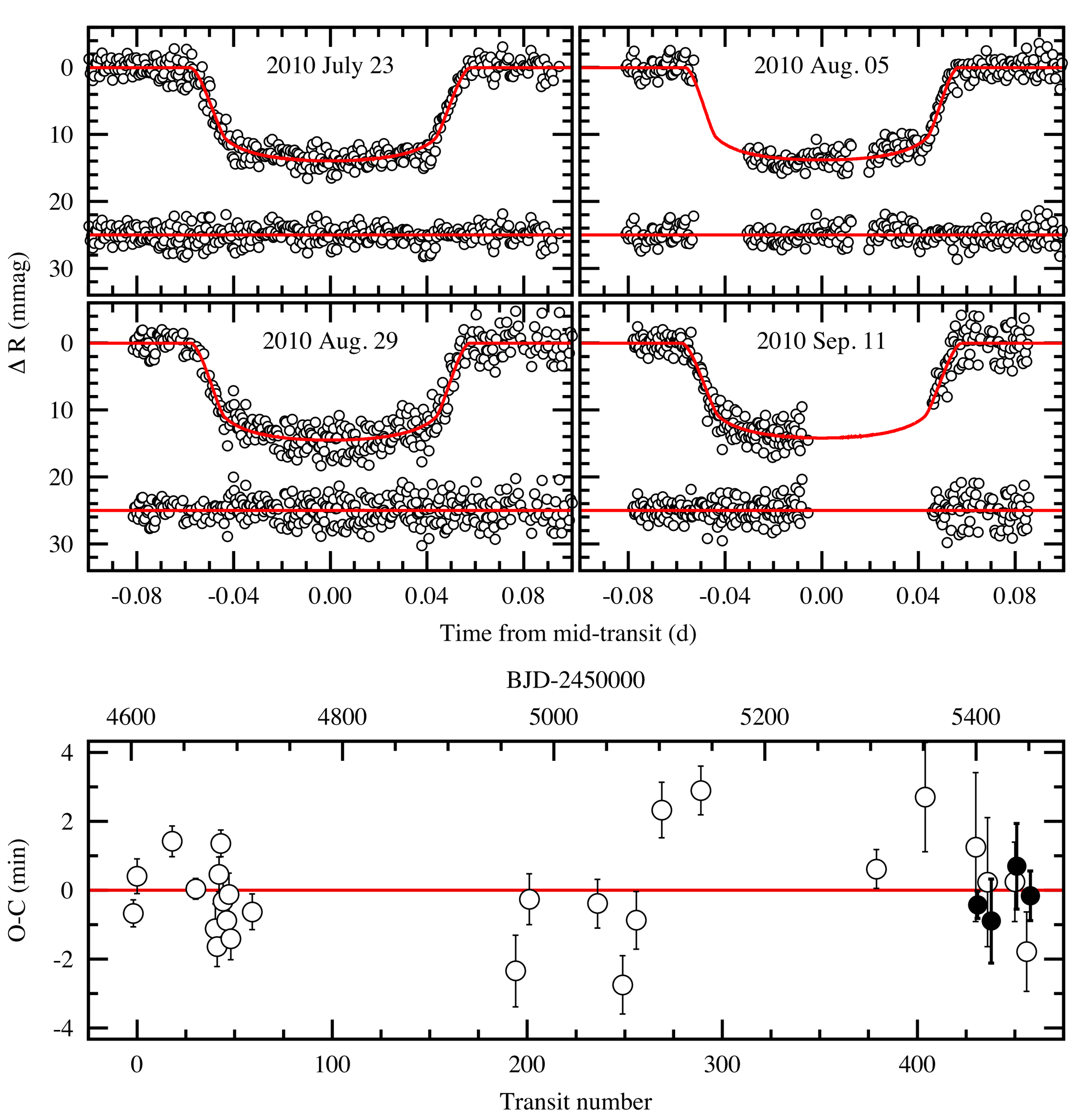

Figure 1: *Light curves for four transits of WASP-3 b, observed by us with the 2.2-m telescope at Calar Alto. The data were modelled with the JKTEBOP code (Southworth 2004, MNRAS, 349, 547; Southworth 2004, MNRAS, 351, 1277). The bottom panel shows the timing residuals from a refined linear ephemeris (open and filled symbols denote the literature and our new mid-transit times, respectively).*

WASP-10 b

The WASP-10 planetary system has been found to be intriguing due to properties of its transiting exoplanet (Christian et al. 2009, MNRAS, 392, 1585). The host star exhibits activity which is manifested in photometric variability caused by the rotational modulation due to spots. The signatures of spot occultations during transits are also observed (Maciejewski et al. 2011, A&A, 535, A7). The radius of WASP-10 b is close to Jupiter radius while the mass is 3 times greater. The high mean density of the planet indicates a significant fraction of heavy elements in the planetary interior. A sinusoidal variation was discovered in the planet's transit timing that could be a sign of an additional planet which perturbs the orbital motion of WASP-10 b (Maciejewski et al. 2011, MNRAS, 411, 1204).

We observed 10 transits in 2011 with the 2.2-m telescope at Calar Alto. The transit on 2011 Oct. 10 was observed in R and B bands to model properties of an active region occulted by the planetary disk. We acquired additional 7 mid-transit times through the YETI collaboration. The data will be thoroughly analysed in terms of the influence of the stellar activity on the transit timing.

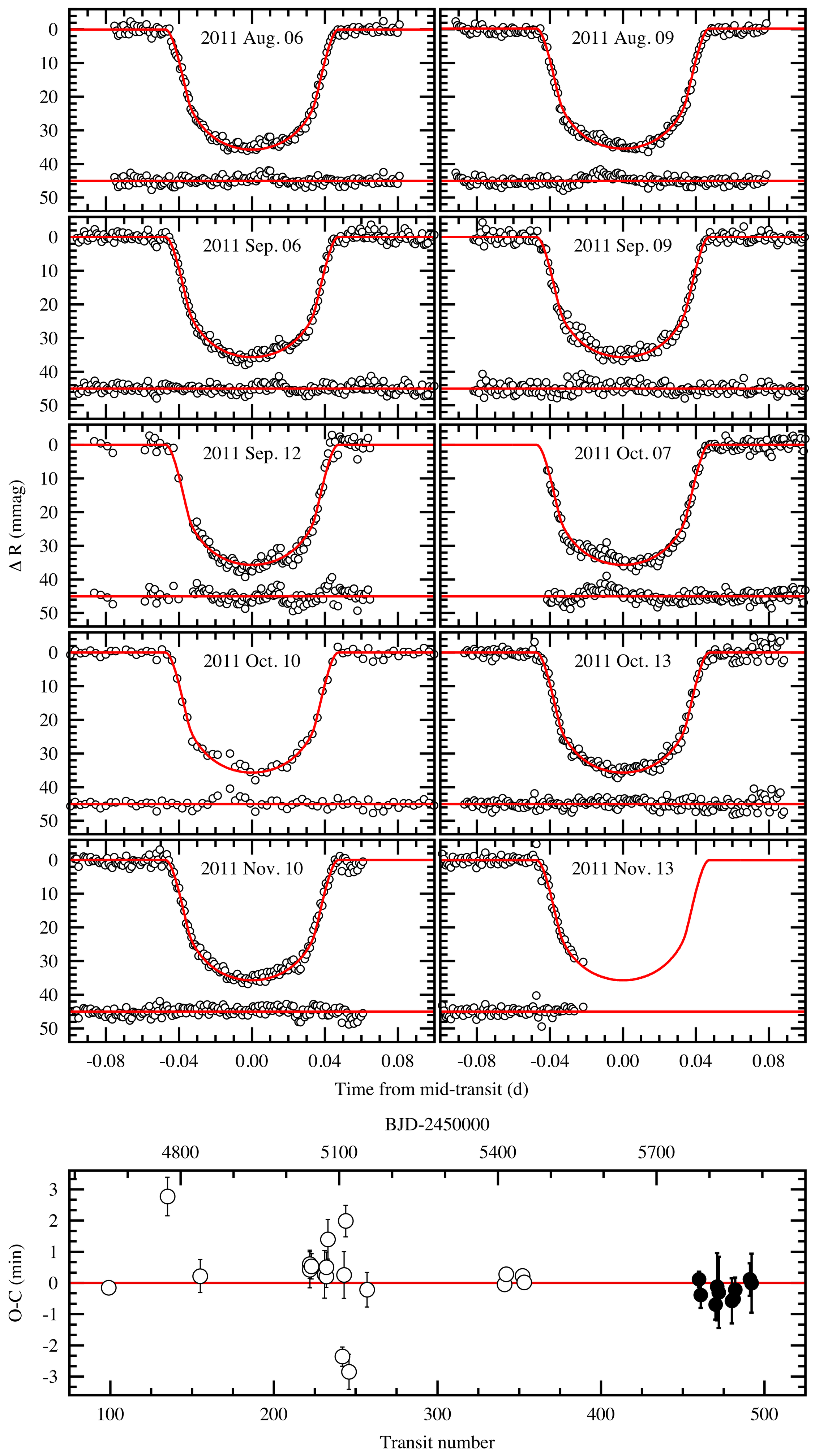

Figure 2: *New light curves for WASP-10 b transits observed by us with the 2.2-m telescope at Calar Alto. The shape of individual light curves is affected by spot occultations. The best fitting models obtained with the JKTEBOP code are drawn with red lines. The bottom panel shows the timing residuals from a refined linear ephemeris (designations as in Fig. 1).*

WASP-12 b

The transiting extrasolar planet WASP-12 b was found to be one of the most intensely irradiated planets orbiting its G-type host star every 1.09 d (Hebb et al. 2009, ApJ, 693, 1920) and thus became a subject of numerous studies on its atmosphere (e.g. Li et al. 2010, Nature, 463, 1054; Crossfield et al. 2012, ApJ, 746, 46). In the discovery paper, the planet was found to have the mass $M_{\mathrm{b}} = 1.41 \pm 0.10\ M_{\mathrm{Jup}}$ and the unexpectedly large radius $R_{\mathrm{b}} = 1.79 \pm 0.09\ R_{\mathrm{Jup}}$. Results of the further follow-ups, based on high-precision photometric observations, confirmed the large planetary radius (Maciejewski et al. 2011, A&A, 528, A65; Chan et al. 2011, AJ, 141, 179).

Our previous observations from the 2009/2010 observing season allowed us to conclude that there is a sign of a short-period TTV signal. Since the number of observed transits was small at that time, we could only put upper constraints on the mass of a possible perturber. In the next two seasons (2010/2011 and 2011/2012) we acquired complete or partial light curves for 20 transits with the 2.2-m telescope at Calar Alto and 2.6-m Nordic Optical Telescope (NOT). The TTV signal with a period of ~500 epochs and peak-to-peak amplitude of ~ 2 min has been detected. The planetary configurations which reproduce the postulated timing variation have been identified by numeric simulations and verified by radial velocities (Maciejewski et al., in prep.).

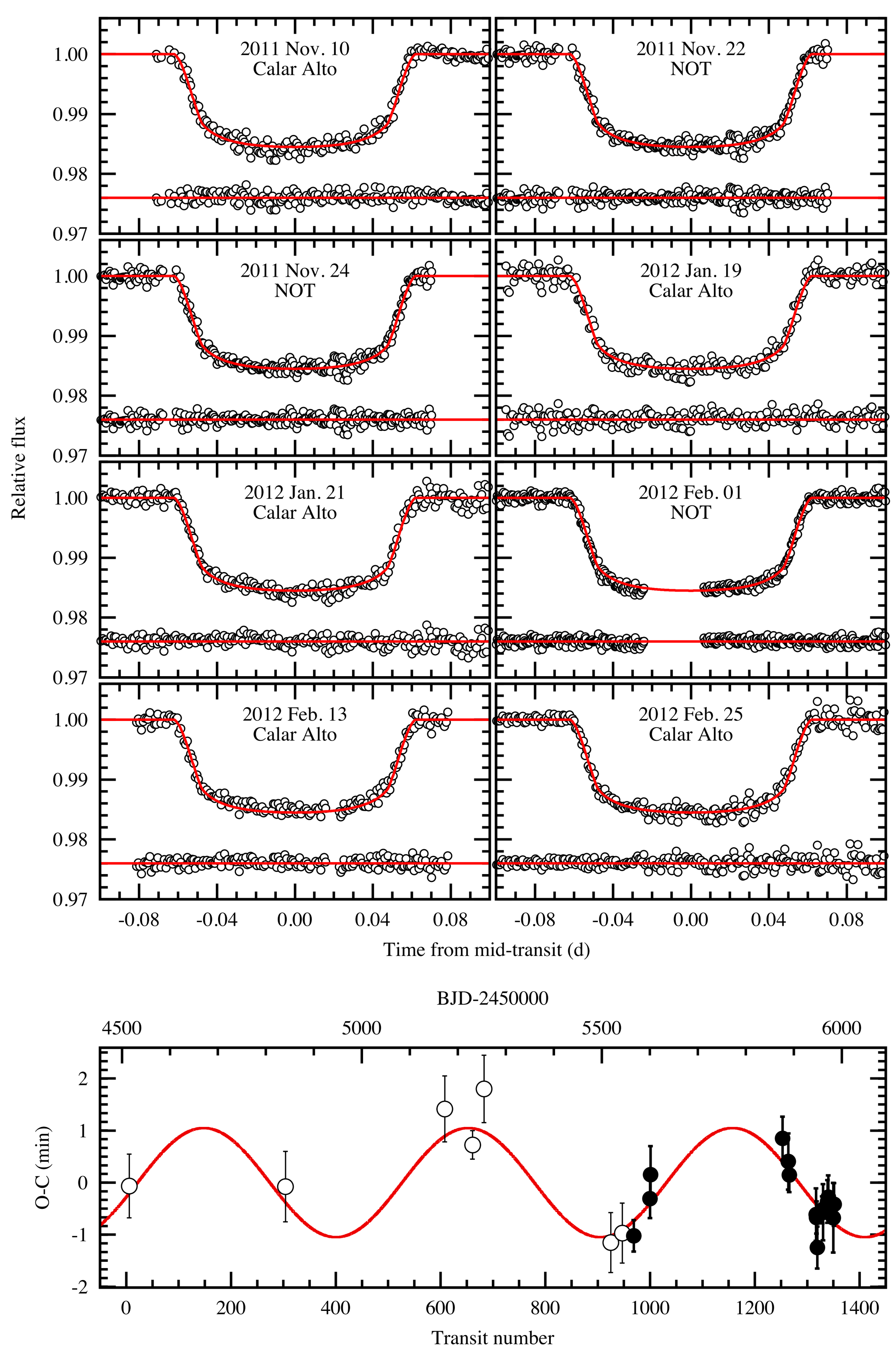

Figure 3: *A sample of WASP-12 b transits observed by us with the 2.2-m telescope at Calar Alto and NOT. The light curves were modelled with the Transit Analysis Package (Gazak et al. 2011, arXiv:1102.1036). The bottom panel shows the timing residuals from a linear ephemeris. Open symbols denote literature mid-transit times while the dots mark our new determinations from observations of complete transits. The red sinusoid sketches the postulated TTV signal of the planetary origin.*

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