Is the orbital period of WASP-12 b constant?

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Abstract: The exoplanet WASP-12 b is one of the most intensely irradiated planets. Some preliminary signs of transit timing variation have been detected that makes WASP-12 b an attractive target for follow-up observations. We present light curves of complete transits observed by us with the >1-m telescopes in the 2010/2011 observational season. We show that new mid-transit times seem to confirm a departure from a linear ephemeris.

1. WASP-12 system

WASP-12 b is a transiting exoplanet which 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 (Hebb et al. 2009). The high effective temperature of the central star (~6300 K) and short orbital period make WASP-12 b one of the most intensely irradiated exoplanets. This results in a high equilibrium temperature of ~2500 K. The orbit of such a close planet is expected to be circularised on short time scales, but surprisingly the orbital eccentricity of WASP-12 b was initially found to be nonzero. Further observations showed that WASP-12 b's orbit is rather highly circular (e.g. Husnoo et al. 2011). Li et al. (2010) predict that the planet may be losing mass at a rate of $\sim 10^{-7}$ M_J yr^{-1} by exceeding its Roche lobe. The planetary gas is expected to fall towards the host star through Lagrangian point L_1 and form an optically thin accretion disk. Using spectropolarimetric observations, Fossati et al. (2010) find some hints of atmospheric pollution in the photosphere of the host star. Ibgui et al. (2010) suggest that the planet is even being disrupted by tidal forces. These findings make WASP-12 b an attractive target for follow-up observations.

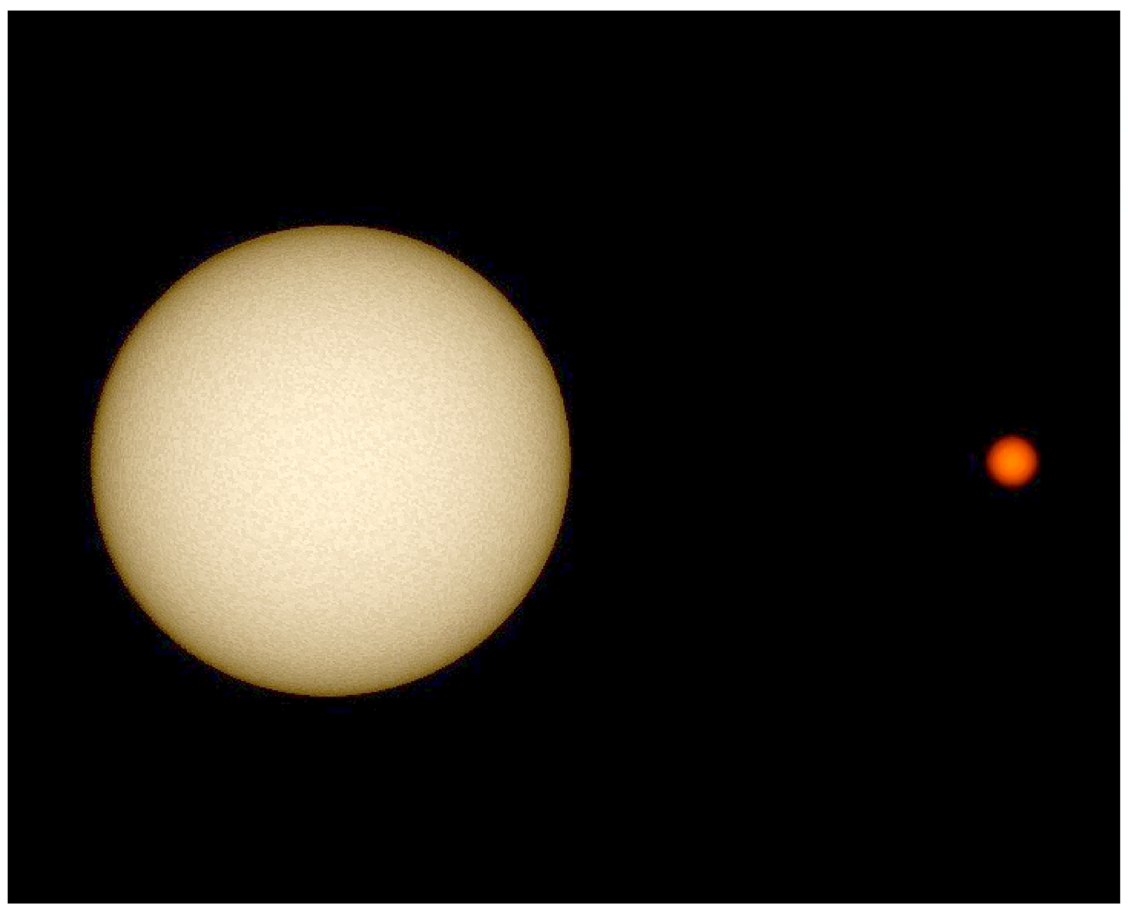

Figure 1: *An artist conception of the WASP-12 system in quadrature. The host star is an F8 dwarf (Hebb et al. 2009) and its radius is* $1.63 \pm 0.08\,R_\odot$ *(Maciejewski et al. 2011). The planet is eight times smaller with a radius of ~1.8* R_J *and has a mass of ~1.4* M_J*. The body moves in tight orbit with a semi-major axis of* 0.023 *AU.*

2. Our previous contribution

WASP-12 b has been a target of our transit-timing-variation (TTV) campaign since 2009 January (Maciejewski et al., in prep.). We found that WASP-12b's transit timing cannot be explained by a constant period but high-quality data were desired to confirm this finding. In early 2010 we got 8 nights at the 2.2-m telescope at the Calar Alto Observatory (Spain) but we managed to collect valuable data during 2 nights only due to bad weather conditions in remaining nights. The telescope was significantly defocused to minimise random and flat-fielding errors and reduce overhead time. The sub-millimag precision was achieved with timing errors of 10–12 s. The redetermined physical parameters of the system agree with previous studies within one sigma. Interestingly, the observation minus calculation (O–C) diagram for transit timing clearly shows a deviation in our mid-transit times from the linear ephemeris. The amplitude of the possible TTV has been found to be 73 s between 22 epochs at the level of 3.4σ. Our numerical simulations show that this transit timing variation could be caused by an additional terrestrial-type planet if both planets are close to orbital resonances (see Maciejewski et al. 2011 for details).

3. New high-quality data

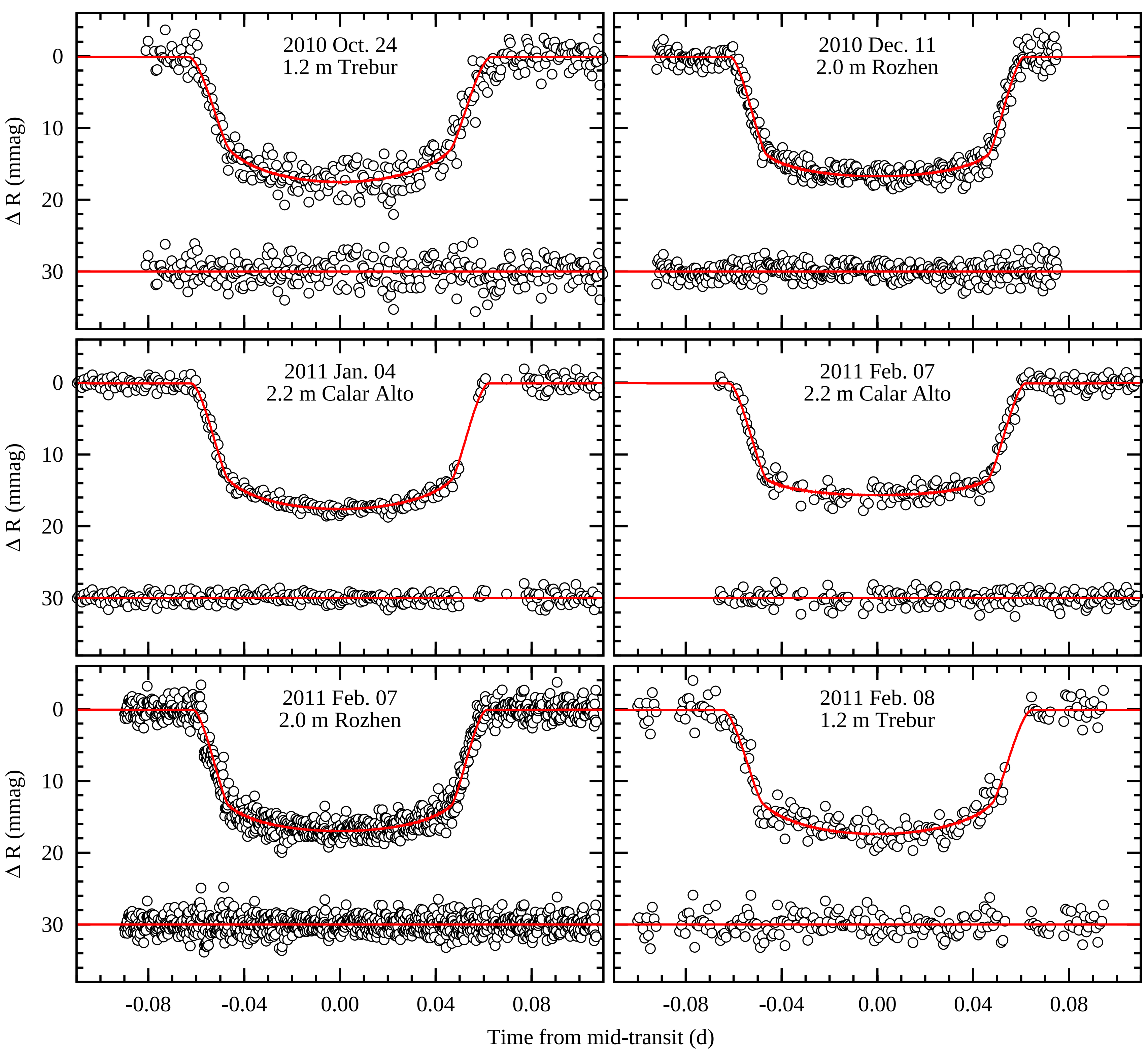

Figure 2: *The R-band light curves of WASP-12 b's transits observed by us with the >1-m telescopes in the 2010/2011 season. The JKTEBOP code (Southworth et al. 2004) was used for data modelling. The rms between 0.67 and 1.65 mmag per point was achieved. Timing errors are between 14 and 44 s and were determined with the prayer-bead method.*

We collected 6 high-quality light curves for 5 transits of WASP-12 b in the 2010/2011 season. The event on 2011 February 7 was observed with two instruments to verify timing accuracy which was found to be well within 1σ error bars. The difference in both mid-transit times is only 7 s. The following >1-m telescopes were used in the campaign:

- The 2.2-m telescope at the Calar Alto Observatory (Spain). The Calar Alto Faint Object Spectrograph (CAFOS) in imaging mode was used as a detector. The telescope was significantly defocused and stellar profiles exhibited a donut-like shape.
- The 2.0-m Ritchey-Chrétien telescope at the National Astronomical Observatory at Rozhen (Bulgaria), equipped with the PI VersArray:1300B CCD camera.
- The 1.2-m Cassegrain telescope at the Michael Adrian Observatory in Trebur (Germany), coupled with the SBIG STL-6303 CCD Camera.

4. Transit timing

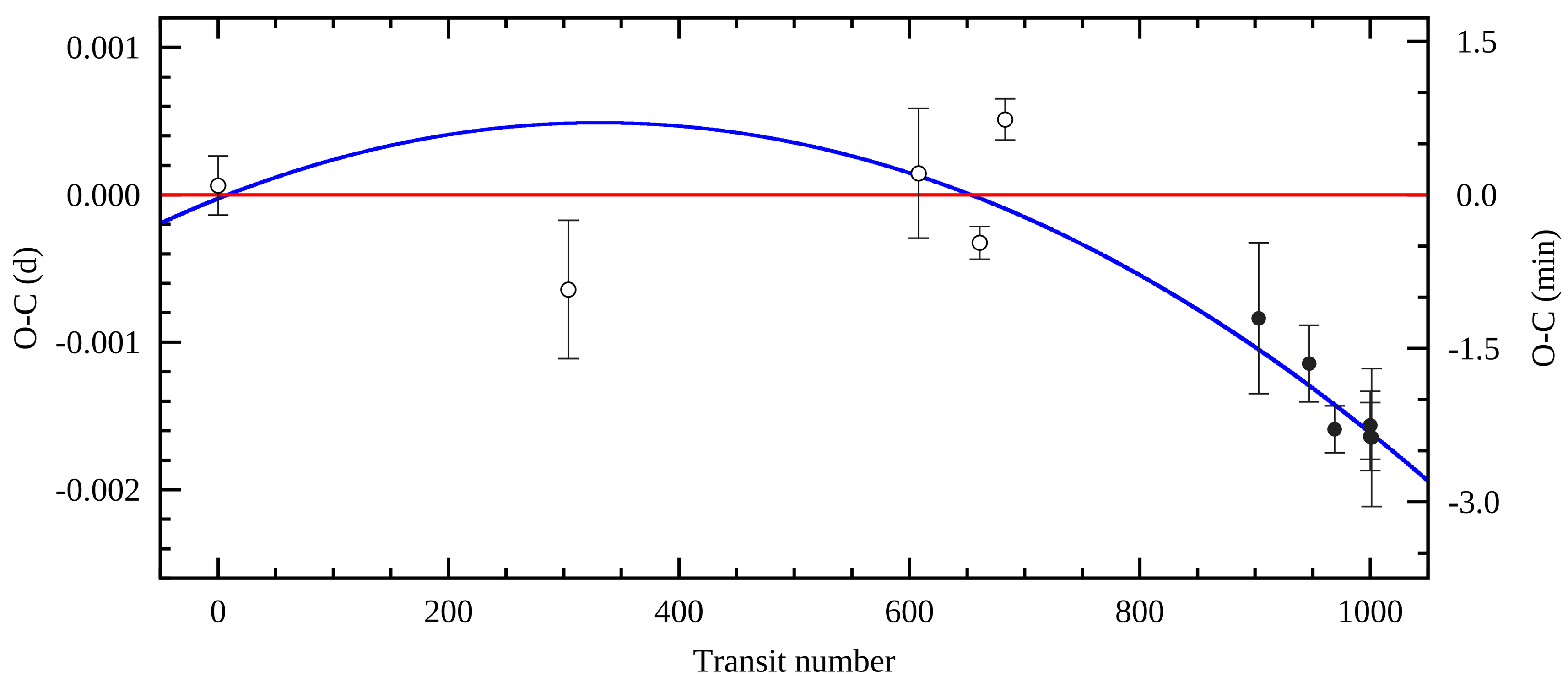

Figure 3: *The O–C diagram for WASP-12 b generated for the linear ephemeris from Maciejewski et al. (2011), sketched with a red line. Open symbols denotes literature data from Hebb et al. (2009), Chan et al. (2011), and Maciejewski et al. (2011). Filled symbols mark new mid-transit times determined in this work. A blue line shows an ephemeris with a quadratic term.*

The observed transits happened up to ~2 min earlier than the linear ephemeris by Maciejewski et al. (2011) predicts. The observed departure from the linear ephemeris, if real, may be a part of a long-time-scale signal, e.g. caused by a stellar companion in a wide orbit. It can also be a sign of WASP-12 b's orbital decay being a result of planet-star tidal interactions. We notice that an ephemeris with a quadratic term results in a better fit than a constant-period ephemeris. Using mid-transit time errors as weights, we derived a new ephemeris as a function of epoch (transit number) E:

$$T(E)\ (\mathrm{BJD_{TDB}}) = 2454508.9768(2) + 1.0914256(7) \times \mathrm{E} - 4.7(6) \times 10^{-9} \times \mathrm{E}^2$$

with the reduced $\chi^2_{\mathrm{quad}} = 4.8$ which is much smaller (by a factor of 2.5) than $\chi^2_{\mathrm{lin}} = 11.8$ for a linear ephemeris. Interestingly, the data still do not exclude a short-time timing variation. Assuming that the orbital period P decreases at a constant rate, we derive $\dot{P} = -3.1(4) \times 10^{-6}$ days yr^{-1}. This rate is four times greater than a possible orbital period decay postulated for OGLE-TR-113 b by Adams et al. (2010). Observations in the 2011/2012 season are expected to shed new light on the period change of WASP-12 b.

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