# New photometric observations of transiting extrasolar planet TrES-3b

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**Abstract:** We present the new transit observations of transiting exoplanet TrES-3b. The orbital parameters of the system were re-determined and the new linear ephemeris was calculated. We found discrepancy between parameters presented here and already published. This differences are described below. We performed numerical simulation for studying the stability of orbits.

## The observations and data reduction

- All observations presented here were carried out at the several observatories: Stara Lesná (Slovakia), Torun Center for Astronomy (Poland), Michael Adrian Observatory (Germany), University Observatory Jena (Germany) and Vihorlat Observatory (Slovakia).
- We have used telescopes with diameter of primary mirrors in the range 30 – 120 cm and optical CCD-cameras (*RI*-bands).
- Our observations were calibrated by standard way (bias, dark and flat correction) using IRAF procedures[1], C-munipack software package[2] and Mira Pro 7 software[3]
- Subsequently, in all cases the aperture photometry was performed.

*[1] http://iraf.noao.edu/*
*[2] http://c-munipack.sourceforge.net/*
*[3] http://www.mirametrics.com/mira_pro.htm*

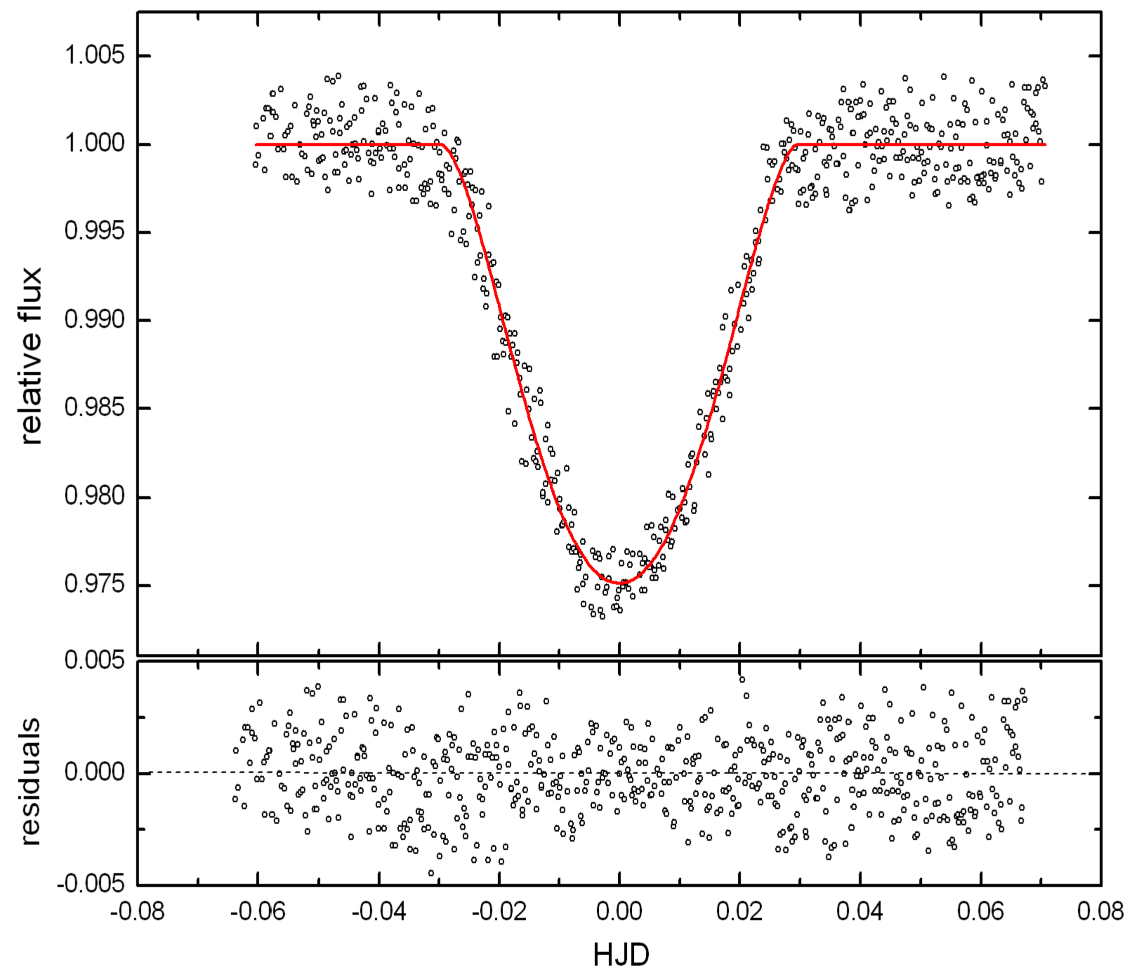


**Fig. 1. Top:** *Composition of 560 data points from the two nights: 13/07/10 and 20/08/10 (dd/mm/yy) of the exoplanetary system TrES-3b. The observations were made in filter R (UBVRI Bessel system) using 1.2m Cassegrain telecope and SBIG STL-6303E CCD camera at Michael Adrian Observatory in Trebur (Germany).* **Bottom:** *Residuals from the best fit model.*

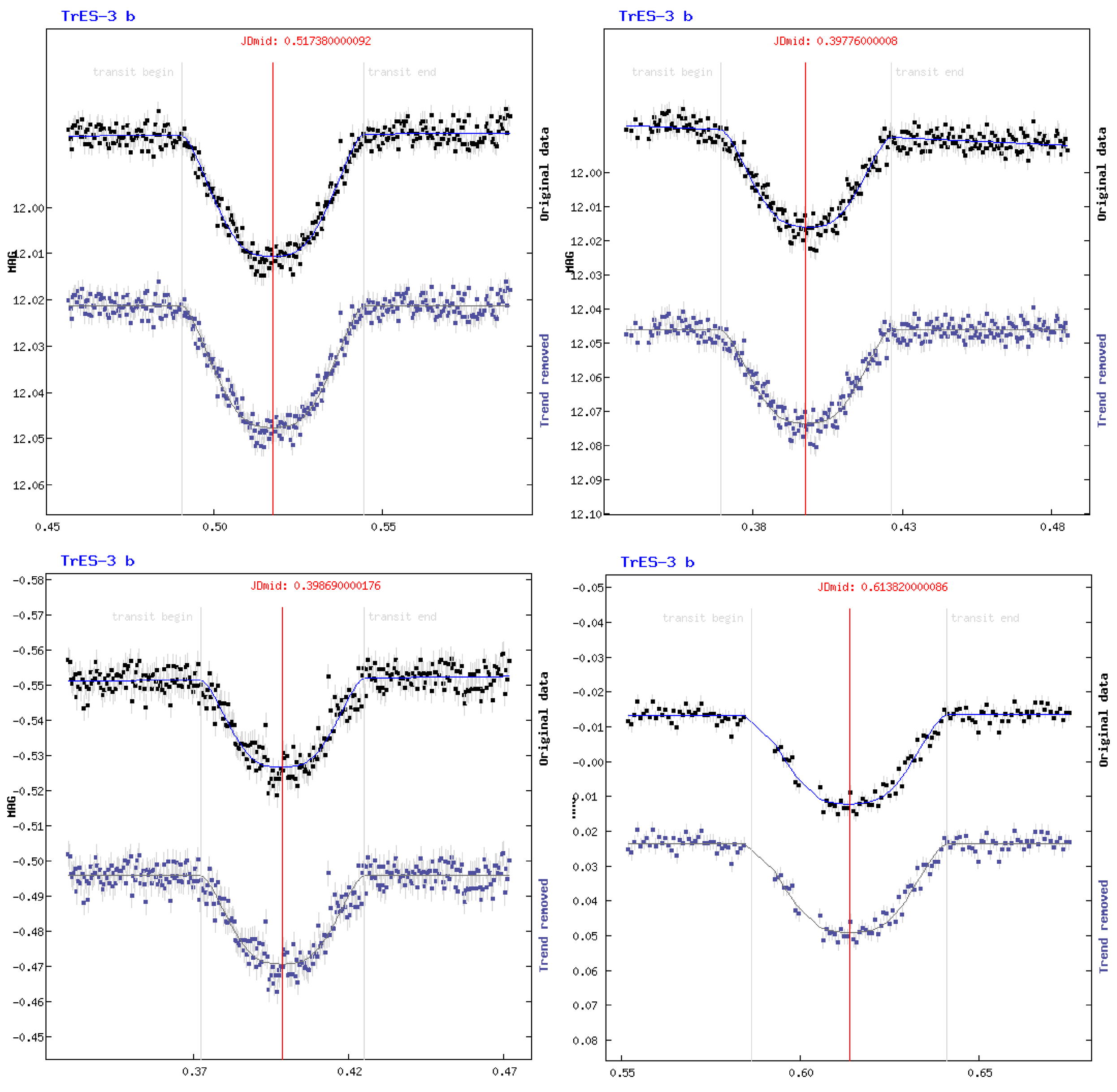


**Fig. 3** *An example of light curves of TrES-3b obtained at other observatories during the last two years. Based on the HJD mid transits we determined the linear ephemeris of the system*

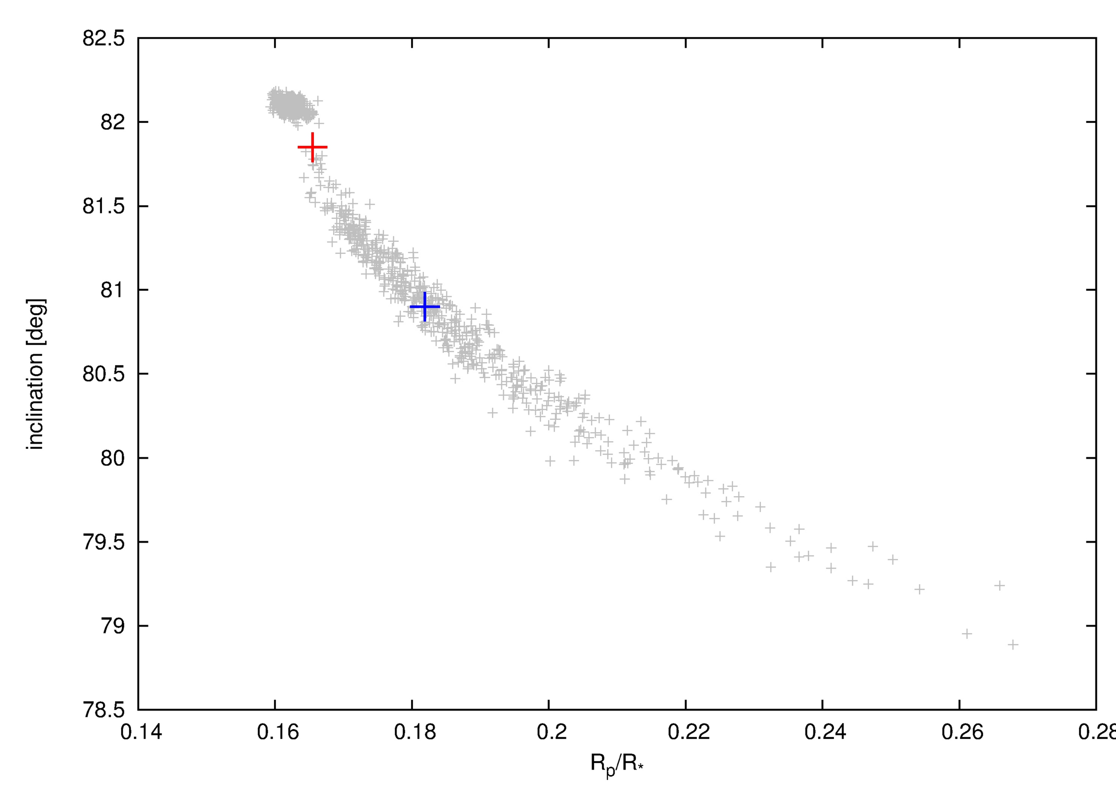


**Fig. 2:** *Dependence of the inclination on the planet to star radius ratio. Red cross represents the solution of Sozzetti et al.(2009). Blue cross is our solution. Our solution is very different from that of Sozzetti et al. (2009). Small grey crosses are individual solutions of the synthetic data sets. They demonstrate an obvious degeneracy between the inclination and the planet radius. At the same time this cloud of points demonstrates the error or uncertainty of these parameters which may be larger then originally thought. This is also the reason why our solution is not in agreement with Sozzetti.*

## Data analysis

- To obtain an analytical transit LC we used the formulae from Mandel & Agol (2002) assuming the quadratic limb darkening in the from:

$$I(\mu)/I(1) = 1 - c_1(1-\mu) - c_2(1-\mu)^2,$$

- The limb darkening coeff. $c_1$ and $c_2$ were linearly interpolated from Claret (2000) for the following star parameters: $T_{eff}$ = 5650 K, *log (g)* = 4.4 and *[Fe/H]* = -0.19 (based on the results of Sozzetti et al. 2009). For subsequent analysis we combined observations of two transit in the highest quality into a single light curve. This final composition is displayed in the Fig. 1 and consists of 560 individual CCD exposures.
- To obtain the best fit parameters we found the minimal value of the $\chi^2$ function given by:

$$\chi^2 = \sum_{i=1}^{N} \left( \frac{m_i - d_i}{\sigma_i} \right)^2,$$

- Where $m_i$ is the model value and $d_i$ is the measured value of the flux, both for $i^{th}$ measured value; $\sigma_i$ is the uncertainty for the i$^{th}$ measurement.
- For the minimization procedure, the downhill simplex method was used (Press et al. 1992). We search for the optimal values of the parameters described in the Table 1.
- To estimate the uncertainties of parameters we have used the Monte Carlo simulation method (Press et al. 1992). We produced 1000 synthetic data sets with the same probability distribution as the residuals of the fit in Figure 1. From each synthetic data set obtained in this way we estimated the synthetic transit parameters. Subsequently, we determined the uncertainties of the real parameters from the distribution of synthetic parameters.

**Tab. 1:** Parameters of the extrasolar system TrES-3 from this work compared with the results from Sozzetti et al. (2009) and Christiansen et al. (2011). $P_{orb}$ is the orbital period, $R_p/R_*$ is the planet to star radius ratio, $R_*/a$ is the star radius to semimajor axis ratio, $i$ is the inclination of the orbit, $R_*$ is the host star radius, $b \equiv a \cos i/R_*$ is the impact parameter, $R_p$ is the planet radius and $T_D$ is the transit duration assuming the semimajor axis $a = 0.02282^{+0.00023}_{-0.00040}$ AU (Sozzetti et al. 2009).

| Parameter | This work | (Sozzetti et al. 2009) | (Christiansen et al. 2011) |
|---|---|---|---|
| $P_{orb}$ [days] | $1.30618595 \pm 1 \times 15^{-8}$ | $1.30618581 \pm 1 \times 51^{-8}$ | $1.30618608 \pm 1 \times 38^{-8}$ |
| $R_p/R_*$ | $0.1819 \pm 0.0020$ | $0.1655 \pm 0.0020$ | $0.1661 \pm 0.0343$ |
| $R_*/a$ | $0.1785 \pm 0.0070$ | $0.1687^{+0.0140}_{-0.0410}$ | $0.1664 \pm 0.0204$ |
| $i$ [deg] | $80.9 \pm 0.7$ | $81.85 \pm 0.16$ | $81.99 \pm 0.30$ |
| $R_*$ [$R_\odot$] | $0.876^{+0.008}_{-0.016}$ | $0.829^{+0.015}_{-0.022}$ | $0.817 \pm 0.022$ |
| $b \equiv a \cos i/R_*$ | $0.886 \pm 0.015$ | $0.840 \pm 0.010$ | — |
| $R_p$ [$R_J$] | $1.551^{+0.014}_{-0.028}$ | $1.336^{+0.031}_{-0.037}$ | $1.320 \pm 0.057$ |
| $T_D$ [hours] | $1.320 \pm 0.017$ | — | $1.365 \pm 0.018$ |

## Constraints on the presence of an additional planet

- Gibson et al. 2009 claimed that their data are sufficiently sensitive to have probed small mass planets initially on circular orbits near 2:1 resonances with Tres3-b but there is no conclusive evidence for their presence.
- In this work, we investigate the gravitational influence of Tres3-b on a potential second planet in the system not only near the 2:1 resonance but covering the whole phase-space of orbital elements of potential planet. Studying the evolution of orbits, we can identify the zones of the stability, where the possible additional planet can be detected.
- We perform numerical simulation for studying the stability of orbits. For checking the chaotic behavior of orbits we are using the well-known tools - the method of Maximum Eccentricity (ME) and the Lyapunov characteristic indicator (LCI).
- Because of studying the stability maps of very small planets (Earth-like) in this system we can approximate these planets by massless particles, in our simulations. To study the evolution of orbits we generated 10000 massless particles. The results of this theoretical part of study will be presented in the conference proceeding.

## References:

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