

Observations of planetary transits at the University Observatory Jena



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Abstract

We have started high precision photometric monitoring observations at the University Observatory Jena in fall 2006. Therefore, we use a 25 cm Cassegrain telescope equipped with an optical CCD-camera mounted picky-pack on a 90 cm telescope. To test the obtainable photometric precision, we observed stars with known transiting planets. We paid special attention to the accurate determination of transit times in order to identify precise transit timing variations that would be indicative of perturbations from additional bodies and to refine the orbital parameters of the systems. Here, we present results for three transiting planets: XO-1b, TrES-1 and TrES-2. Our transit observations provide anchors for future searches for transit time variations.

Instruments and Observations

We have three telescopes available, a 90 cm reflector, a 20 cm refractor and a 25 cm Cassegrain telescope (see box on the right side).

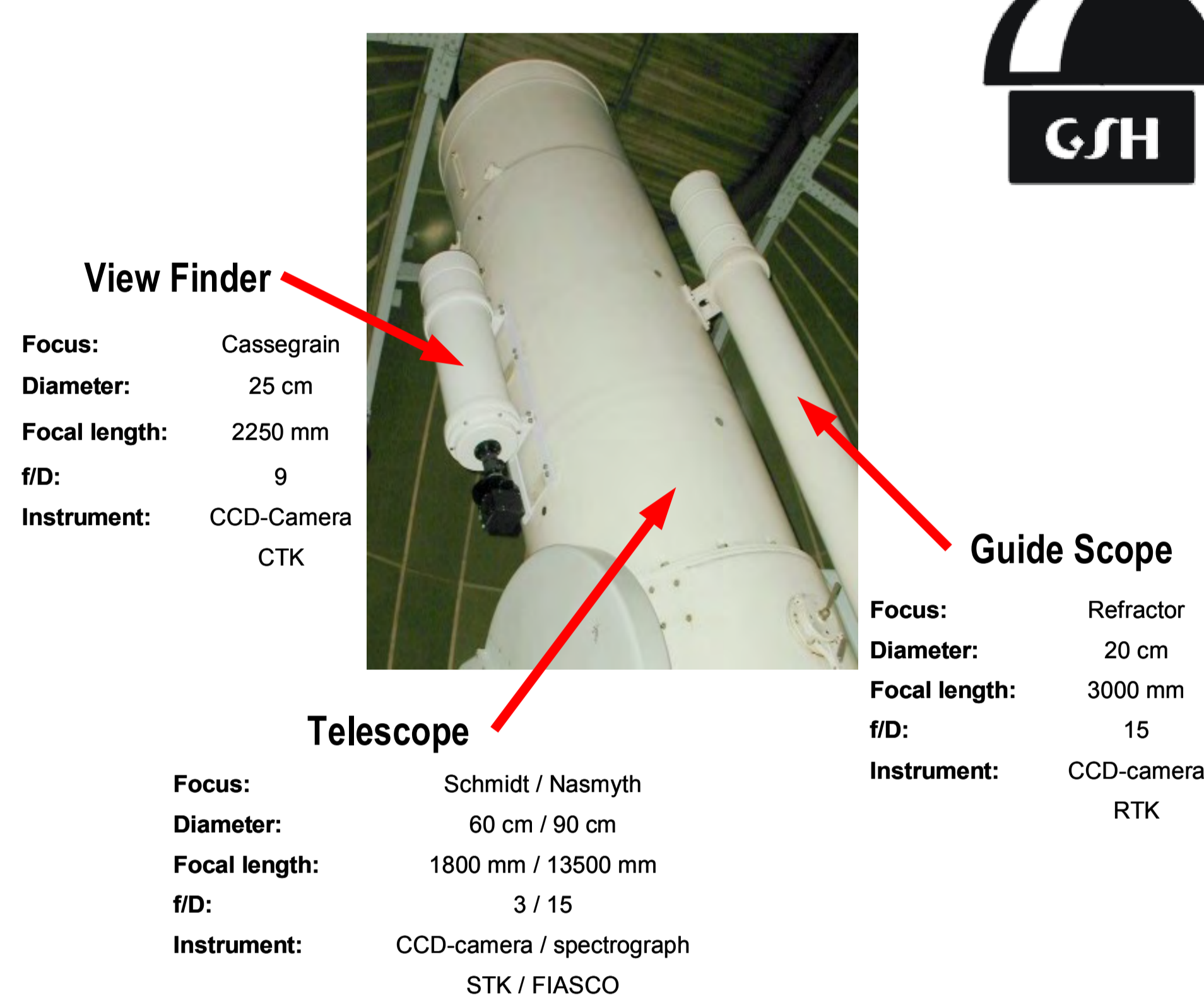
For our transit observations we use the 25 cm Cassegrain view finder mounted picky-pack on the tube of a 90 cm telescope equipped with the optical CCD-camera CTK (*Cassegrain Teleskop Kamera*, see camera information box).

In the course of the year 2006 we started our continuous observations. Between March 2007 and January 2009, we used 53 clear nights for our transit observations. Part of the time we observed stars with known transiting planets in *R* and *I* band.

Methods

- A differential photometry algorithm by Broeg et al. (2005) was used to determine the differential magnitudes.
- A detrending algorithm called "Sys-Rem" (Tamuz, Mazeh & Zucker 2005, implemented by Johannes Koppenhöfer) was used to remove systematic effects
- The System parameters by Holman et al. (2006) and Winn, Holman & Roussanova (2007) was used to fit the light curves of XO-1 and TrES-1
- An analytic light curve taking limb darkening into account was applied to fit the data of TrES-2

The Telescopes



Since 1962 the Friedrich-Schiller-University Jena operates an observatory. It is about 10 km to the west of Jena on a plateau (close to the small village Großschwabhausen) and offers for its location in Central Europe decent conditions for optical astronomy.

CTK - *Cassegrain-Teleskop CCD-Kamera*

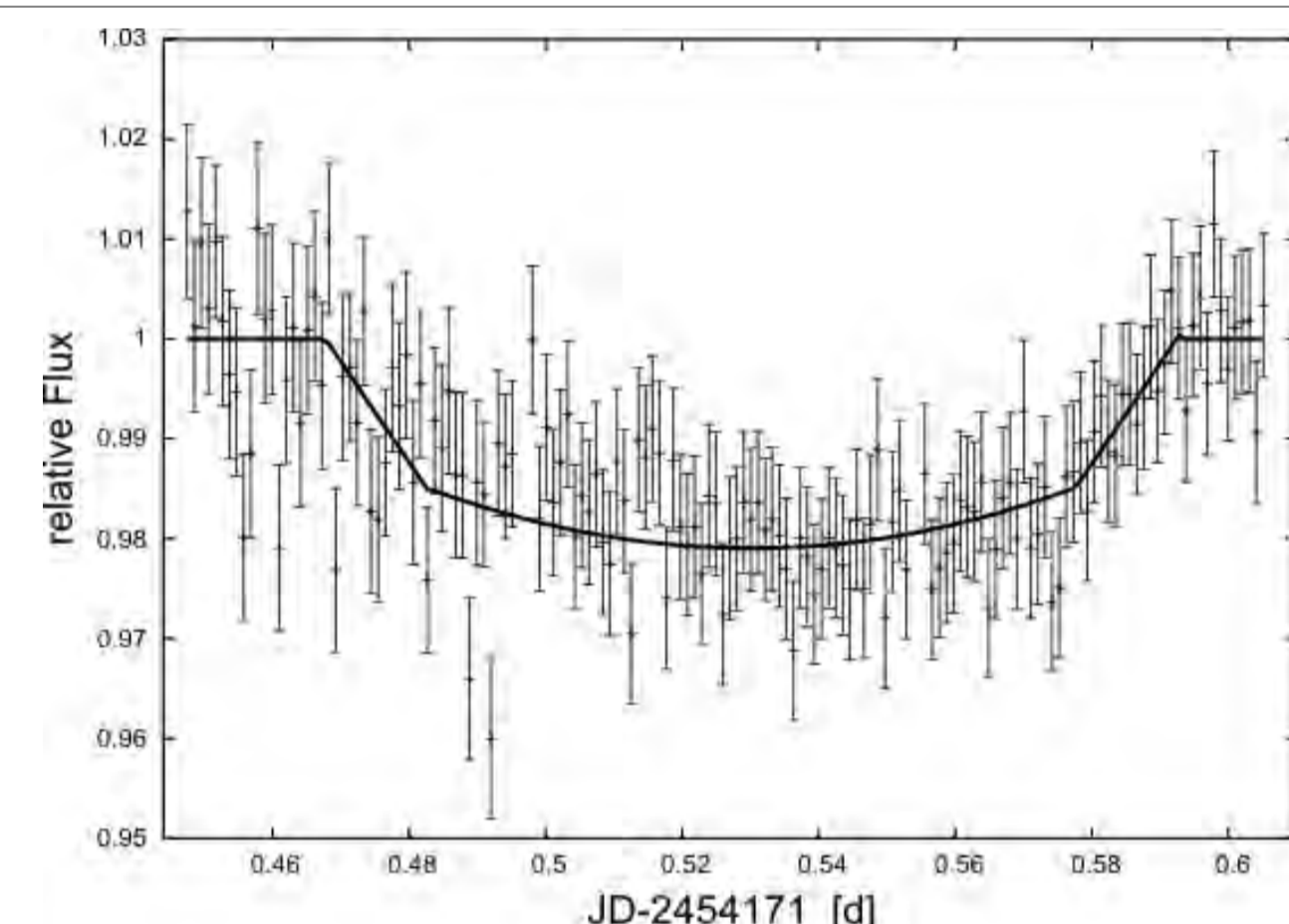


Fabricator: Finger Lake
Type: IMG 1024S
Detector: CCD TK1024 (Tektronix)
Pixel: 1024 x 1024 (24 µm)
Pixel scale: (2.2065 ± 0.0008)"/Pixel
Field of view: 37.7° x 37.7°
Filter: B, V, R, I, z
Focus: Cassegrain

XO-1b:

We observed the transit of the exoplanet XO-1b in the night of 2007 March 11/12.

We took 161 *I*-band exposures between 10:43 p.m. and 2:47 a.m. (UT). With an exposure time of 60s we achieve a mean cadence of the data points of 1.4 min.

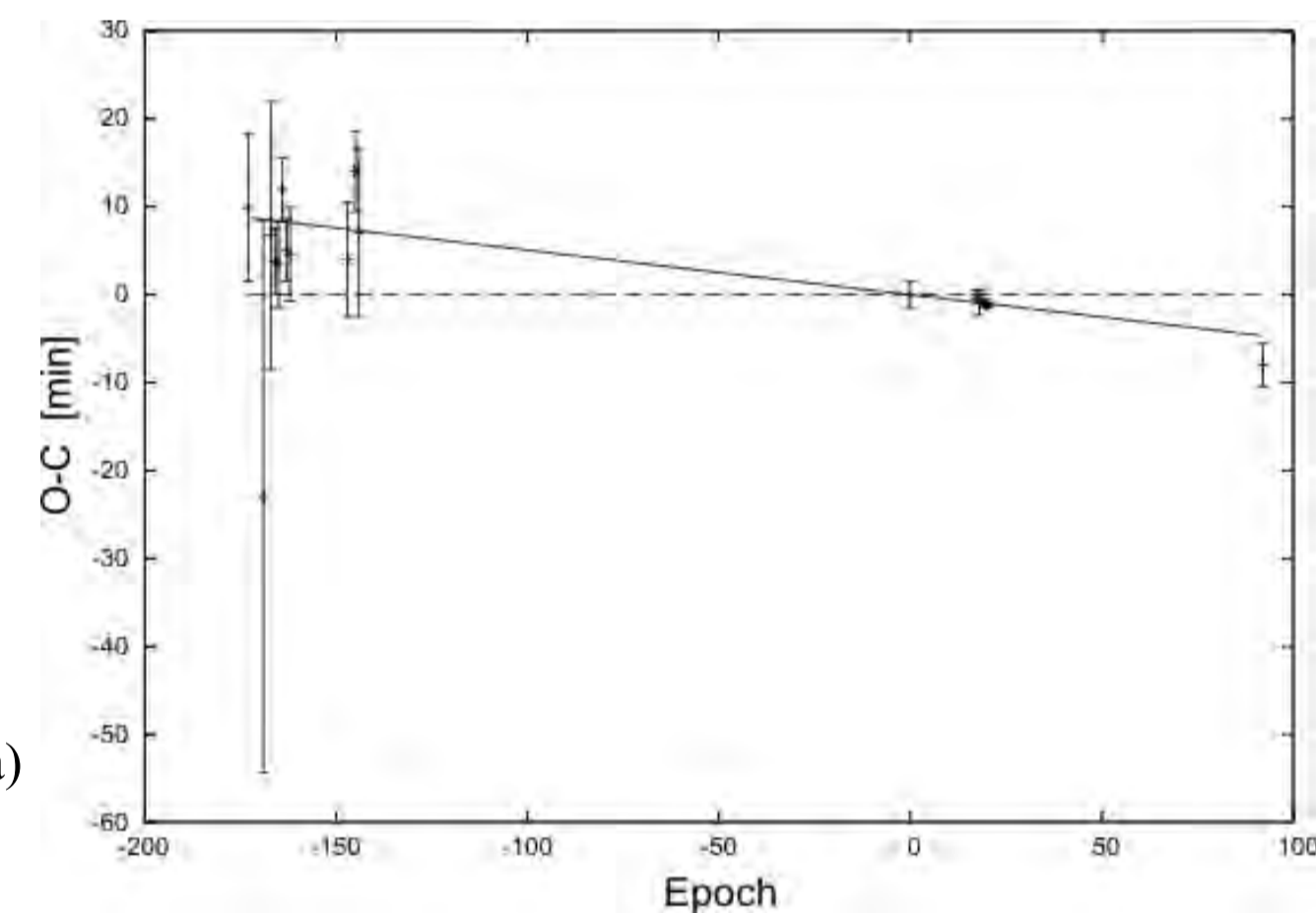


Relative *I*-band photometry of XO-1. The solid line shows the best-fitting model

In addition to the one transit observed at the University Observatory Jena we could find 16 transit times from 2004-2006 in the literature (Wilson et al. 2006, McCullough et al. 2006 and Holman et al. 2006). This Figure shows the transit timing residuals for XO-1. The dashed line shows the ephemeris given by McCullough et al. (2006). The best-fitting line (solid line) is plotted, representing the updated ephemeris:

$$T_c(E) = (2453808.91698 + E \cdot 3.941500) \text{ d}$$

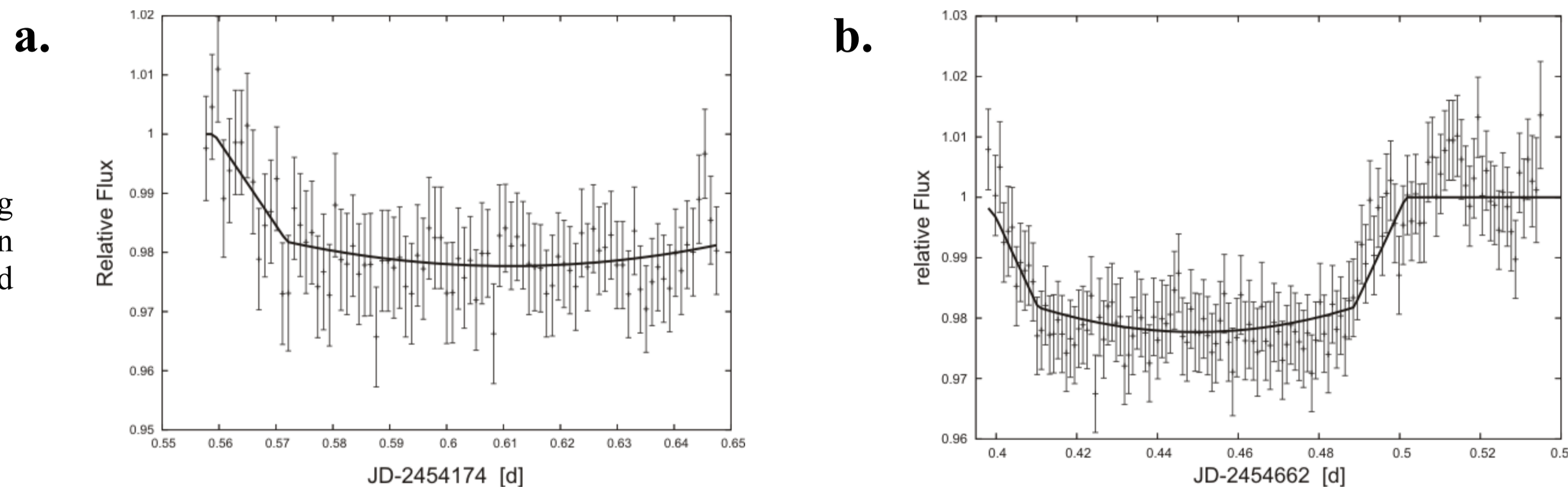
(Vaňko et al. 2009, Raetz et al. 2009a)



Within the error bars 65 % of the points are consistent with our calculated period. The remaining measurements deviate less than 2σ from the new "zero"-line (solid line)

TrES-1:

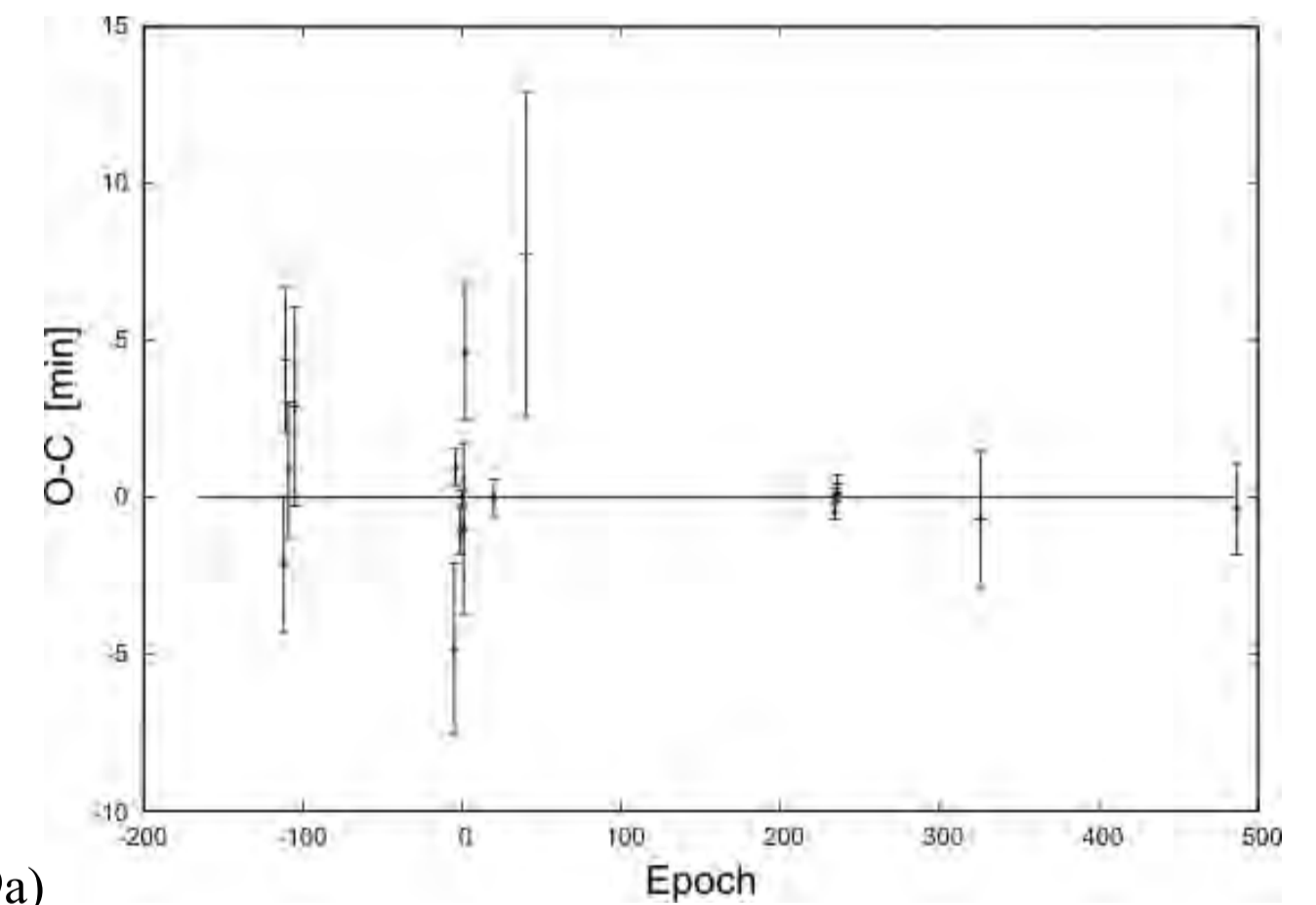
We observed two transits of TrES-1 in front of its parent star. The light curves from 2007 March 15 (a) and 2008 July 14 (b) include 88 and 146 *R*-band 60s exposures, respectively.



The best-fitting model is again shown as a solid line.

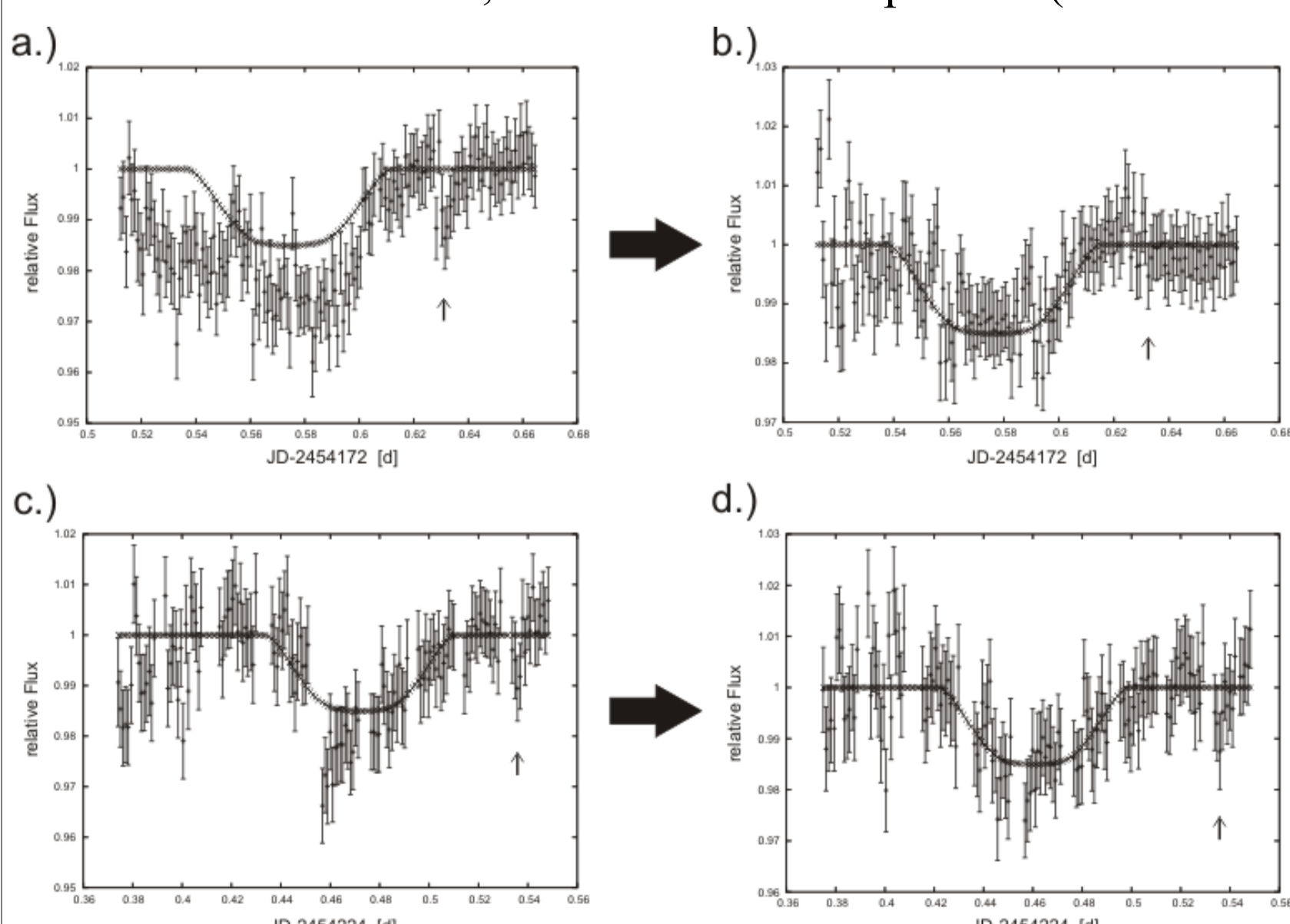
For TrES-1 we found 15 additional midtransit times between 2003 and 2006 in the literature (Charbonneau et al. 2005, Alonso et al. 2004 and Winn et al. 2007). The following figure shows the transit timing residuals for TrES-1. The solid line shows the ephemeris given by Winn et al. (2007). The data points from the University Observatory Jena (last two) are consistent with a constant period.

(Vaňko et al. 2009, Raetz et al. 2009a)



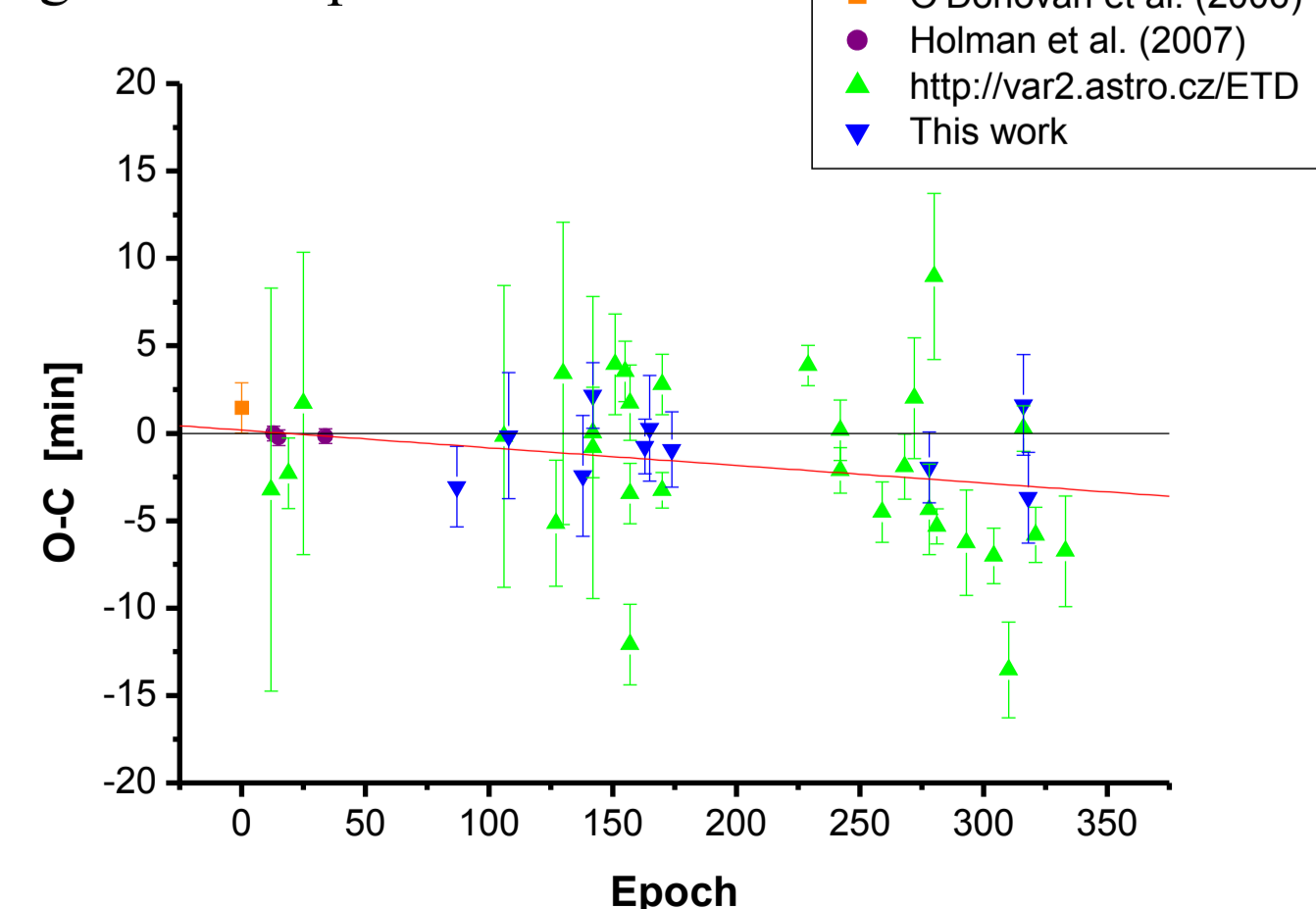
TrES-2:

For our TrES-2 observations, started in March 2007, we used 40 nights since March 2007 to November 2008. Overall, 4289 60s *I*-band exposures (in total 71.48 h of observation) of the TrES-2 parent star were taken.



We observed ten different transits. We could detect the second dip only after our first two transit observations. After using Sys-Rem the dip disappeared for the first transit (a & b) while it became stronger for the second transit (c & d). We tried to explain its existence. Four different theories have been created: a nearby variable star or a blended eclipsing binary, an additional planet in the system, a transit over a background star or a transit over a wide companion of the TrES-2 host star after the actual transit is finished. Up to now none of these theories could be rejected or confirmed as a definitive solution.

In our first observations of a transit of TrES-2 we could detect a second dip after the end of the transit. An indication of the existence of the dip is published by O'Donovan et al. (2006) in a TELAST *R*-band light curve in their Fig. 1, where one can clearly recognize a brightness drop.



Transit timing residuals for TrES-2. The black line shows the ephemeris given by Holman et al. (2007). The best-fitting line (red line) is plotted, representing the updated ephemeris:

$$T_c(E) = (2453957.63479 + E \cdot 2.470618) \text{ d}$$

(Raetz et al. 2009b)

Discussion and Outlook

Using our observations at the University Observatory Jena with a 25 cm Cassegrain telescope equipped with the optical CCD camera CTK we could observe the known planetary transits of XO-1b, TrES-1 and TrES-2.

XO-1 was the first transit observed with our telescope. We determined that the orbital period is lower than previously expected. Thus our measurement of the transit time lead to a refined estimate of the ephemeris.

The second star with a known transiting planet observed in our observatory was TrES-1. With this observation of two transits of TrES-1 we could confirm the ephemeris given by Winn et al. (2007).

We observed the parent star of the transiting planet TrES-2 over a longer period at the University Observatory Jena. We observed several transit events and almost a complete orbital period. We determined the orbital period to be slightly smaller (~0.3 s) than previously expected.

Furthermore, we found a second dip after the transit which could either be due to a blended variable star or occultation of a second star or even an additional object in the system. The mean photometric precision of the observed stars (*V* = 11-12 mag) with known transiting planets is 0.008 mag and the precision in the determination of the transit times is ~0.0013 d. This allows us to register transit time variations of around ~2 min.

We will continue observing TrES-2 to confirm the existence of the dip and search for transit time variations for the next few years to decades. We are also working on methods to improve the precision of our transit times.

This year we will start our own search for planetary transits where we monitor different regions of young open clusters with our new CCD camera for the Schmidt focus of the 90 cm reflector. This camera will have a smaller pixel scale and a higher sensitivity. Our transit observations will benefit strongly from the new camera.