PTPS

The TCfA Transit Timing Survey

Gracjan Maciejewski[1,2], Andrzej Niedzielski[1,3]

[1]Toruń Centre for Astronomy, N. Copernicus University, ul. Gagarina 11, 87-100 Toruń, Poland
[2]Astrophysikalisches Institut und Universitäts-Sternwarte Jena, Schillergäßchen 2-3, 07745 Jena, Germany
[3]Department for Astronomy and Astrophysics, Pennsylvania State University, 525 Davey Laboratory, University Park, PA 16802

Abstract
First results of the exotransit timing survey at the Toruń Centre for Astronomy are presented. The accuracy of determining the midtransit moment, transit's duration and depth are discussed in a context of utilising a 60-cm class telescope.

1 Introduction

The transit timing and analysis of O-C diagrams for known transiting exoplanets may be used for the following issues:

- Improving the orbital period of transiting exoplanets (e.g. Vaňko et al. 2009).
- Detecting the multiplicity of exoplanet host stars *via* the long-term transit time variation (TTV). The multiplicity rate of exoplanet host stars appears to be about 17% (Mugrauer & Neuhäuser 2009).
- Detecting additional extrasolar planets in known transiting systems by the TTV method (Holman & Murray 2005, Steffen et al. 2007). At least 28% of known planetary systems detected by radial-velocity surveys contain multiple planets (Wright et al. 2008). Transit timing appears to be quite sensitive for low-mass planets. A terrestial-mass planet pertubing a hot-Jupiter gas giant is expected to cause the TTV amplitude of ∼1 minute (Steffen et al. 2007). A signal grows sharply as bodies approach a mean motion resonance (MMR). The conclusions of TTV studies are significant for planet formation theory and planet migration theory.
- Detecting exomoons around transiting planets *via* the TTV method and transit duration variation (TDV). Earth-mass moon around transiting gas giants can be discovered if the TDV accuracy is much better than a presently reachable value of ∼50 s (Kipping 2009).

Ground-based telescopes are believed to be capable to provide the photometric data accurate enough to pursue these objectives now or in the near future. Nowadays it is possible to obtain the millimagnitude photometry for stars of $11-13$ magnitude with a 60-cm class telescope. This photometric accuracy allows to determine the mid-transit time with a precision of to tens of seconds (Steffen et al. 2007).

2 Instrument and observations

Observations are performed with the 60-cm f/12.5 Cassegrain Telescope (CT60, Fig. $1-3$) located at the Astronomical Observatory of the Nicolaus Copernicus University in Piwnice near Toruń, Poland. The telescope is equipped with the SBIG STL-1001E CCD camera with the KAF-1001E CCD detector (1024 × 1024 pixels × 24 μm). The field of view of the instrument is 11.′8 × 11.′8 with the scale of 0.69 arcsec per pixel. The defocusing and 2 × 2 binning are used to increase the signal-to-noise ratio. Standard $UBVR_CI_C$ filters are available. Exposures are usually acquired in R_C band due to the highest efficiency of the instrumental system in this spectral range. Some test observations were also gathered in V filter.

Figure 1: The dome of the 60-cm Cassegrain Telescope.

According to the observing strategy, the monitoring of a transiting star starts 1 hour before predicted beginning of a transit and last until 1 hour after a phenomenon. The manual guiding is used to compensate inaccuracies in telescope's tracking system. The exposure time is selected individually for each target to achieve the highest signal-to-noise ratio.

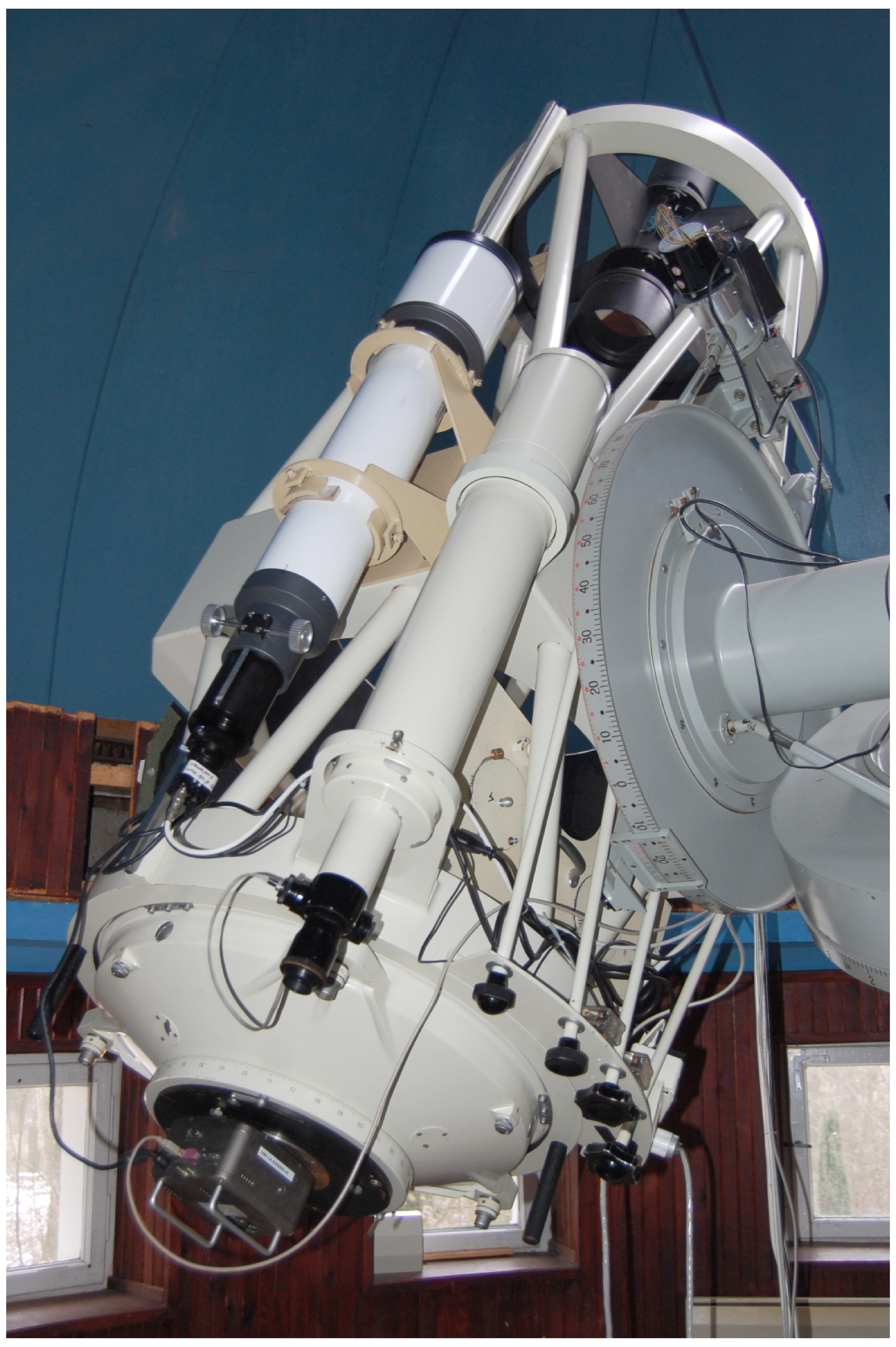

Figure 2: The 60-cm Cassegrain Telescope (CT60).

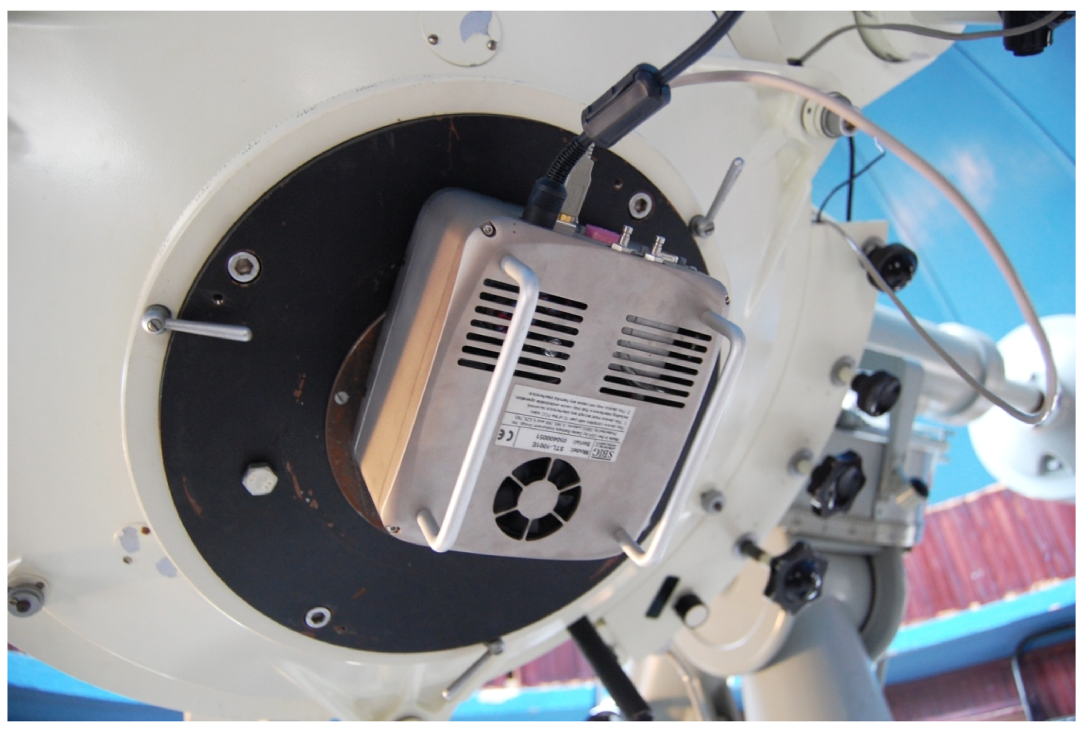

Figure 3: The SBIG STL-1001E CCD camera mounted at the Cassegrain focus.

3 Data reduction pipeline

Observations are reduced with the software pipeline developed for the Semi-Automatic Variability Search sky survey (Niedzielski et al. 2003, `http://www.astri.uni.torun.pl/~gm/SAVS`). CCD frames are processed with a standard procedure including subtraction of dark frames and flat-fielding. Instrumental stellar magnitudes are derived by the means of differential aperture photometry against selected standard stars. The instrumental coordinates of stars are transformed into equatorial ones based on positions of stars extracted from the Guide Star Catalog (GSC2.3, Lasker et al. 2008).
The online algorithm available at the Exoplanet Transit Database (`http://var.astro.cz/ETD`) is used for determining the time of mid-transit, the depth and duration of a transit. Default values of the limb darkening and the impact factor are used. The zero-point shift of the magnitudes is derived and systematic trends are removed after approximating by a linear or in some cases quadratic relation.

4 First results

Eleven transits have been observed so far. A sample of observed light curves is plotted in Fig. 4. The averaged deviations of data points from a model fit are in a range between 1.9 and 4.5 mmag with a mean value of 3 mmag.

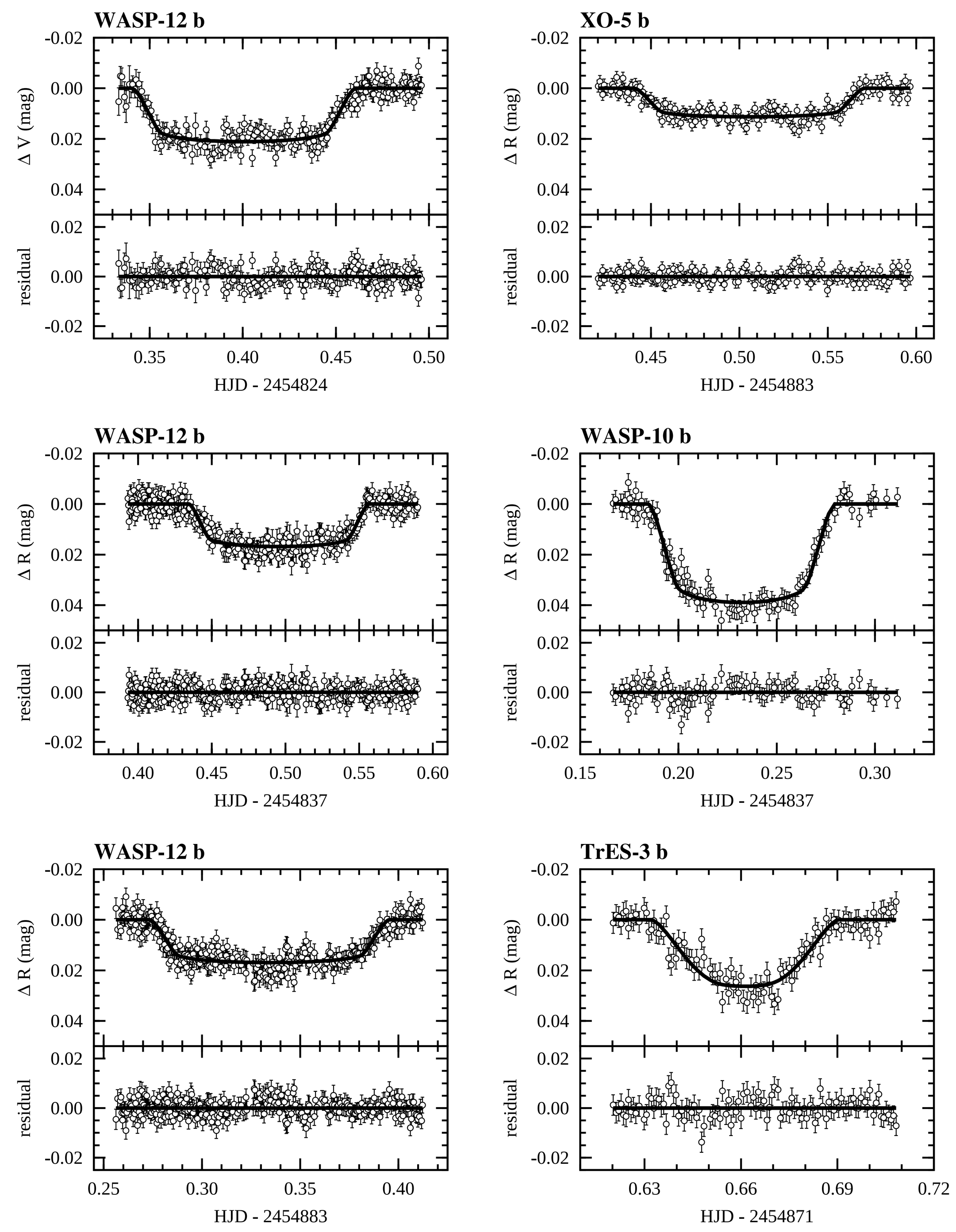

Figure 4: A sample of observed transits at the Astronomical Observatory of the Nicolaus Copernicus University.

The results of model fitting are collected in Table 1. The accuracy of mid-transit times is in the range between 0.5 and 1.7 min and depends on the quality of the photometry. The errors of transit depth are between 0.4 and 3.3 mmag and – as results for WASP-12 b suggest – a repeatability in the same filter is quite satisfactory. The accuracy of transit duration is not better than 1.1 min with a typical value of ∼2 min.

Object	Filter	Midtransit time HJD-2454800	Depth (mmag)	Duration (min)
HAT-P-3 b	R	30.6047 ± 0.0009	20.3 ± 1.4	119.9 ± 3.1
HAT-P-10	V	30.4145 ± 0.0012	23.6 ± 3.3	144.9 ± 4.2
TrES-3 b	R	71.66121 ± 0.00052	26.3 ± 1.1	83.9 ± 2.4
WASP-1 b	V	22.21133 ± 0.00074	20.6 ± 1.6	ingress only
WASP-10 b	R	37.23204 ± 0.00035	38.9 ± 0.8	136.6 ± 1.3
WASP-12 b	V	24.40060 ± 0.00062	21.1 ± 0.8	172.8 ± 2.0
WASP-12 b	R	37.49558 ± 0.00052	16.8 ± 0.4	176.1 ± 1.7
WASP-12 b	R	72.4181 ± 0.0010	15.2 ± 1.0	ingress only
WASP-12 b	R	83.33439 ± 0.00052	16.9 ± 0.5	175.8 ± 1.1
WASP-12 b	R	84.4240 ± 0.0010	19.7 ± 1.6	173.7 ± 3.1
XO-5 b	R	83.50575 ± 0.00085	11.3 ± 1.5	187.5 ± 2.8

Table 1: The time of mid-transit, the depth and duration of transits observed at the Astronomical Observatory of the Nicolaus Copernicus University.

5 Conclusions

A 60-cm class telescope is an appropriate instrument for exotransit timing with the accuracy of mid-transit times better than 1 minute. The upcoming upgrade of the CCD camera is expected to increase the accuracy of the TCfA Transit Timing Survey.

Acknowledgements: This work has made use of the Exoplanet Transit Database, `http://var.astro.cz/ETD`.

References

Holman M.J., Murray N.W. 2005, Science, 307, 1288
Kipping D.M. 2009, MNRAS, 392, 181
Lasker B., Lattanzi M.G., McLean B.J., et al. 2008, AJ, 136, 735
Mugrauer M., Neuhäuser R. 2009, A&A, 494, 373
Niedzielski A., Maciejewski G., Czart K. 2003, Acta Astron., 53, 281
Steffen J.H., Gaudi B.S., Ford E.B., et al. 2007, arXiv:0704.0632
Wright J.T., Upadhyay S., Marcy G.W., et al. 2008, arXiv:0812.1582
Vaňko M., Raetz St., Mugrauer M., et al. 2009, arXiv:0901.0625