Defocused Observations of Selected Exoplanet Transits with T100 in TÜBİTAK National Observatory of Turkey (TUG)

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Abstract. It is crucial to determine masses and radii of extrasolar planets with high precision to have constraints on their chemical composition, internal structure and thereby their formation and evolution. In order to achieve this goal, we apply the defocus technique in the observations of selected planetary systems with the 1 m Turkish telescope T100 in TÜBİTAK National Observatory (TUG). With this contribution, we aim to present preliminary analyses of transit light curves of the selected exoplanets KELT-3b, HAT-P-10b/WASP-11b, HAT-P-20b, and HAT-P-22b, observed with this technique using T100.

1. Introduction

Transiting Extrasolar Planets (TEPs) are key objects in determining physical (masses and radii) and atmospheric properties with high accuracy when their spectroscopic and photometric observations are combined. More than 1000 TEPs have been discovered so far in over 600 planetary systems1, many of which do not have high-quality follow-up light curves. Deriving absolute parameters of an exoplanet is a difficult task, which relies on high quality photometric and spectroscopic data. In order to achieve the desired photometric precision, a very high signal-to-noise ratio (hereafter SNR) is essential. Defocused observations of bright targets is a well established technique based on collecting more photons and controlling the systematic affects arising mainly from imperfections of the detector and atmospheric seeing conditions (Southworth et al. 2009; Baştürk et al. 2014). We aim to present the transit light curves of four selected exoplanets obtained by heavily defocusing the 1 m Turkish telescope T100 located in TUG with this contribution.

1The Extrasolar Planets Encyclopedia: http://exoplanet.eu
Table 1. The log of the observations presented in this work

| Planet    | Date     | St. Time (UT) | End. Time (UT) | Exp. Time (s) | # of Pts. | Scatter (mmags) |
|-----------|----------|---------------|----------------|---------------|-----------|-----------------|
| HAT-P-10b | 2013-01-15 | 16:28        | 20:21          | 120           | 88        | 0.89            |
| HAT-P-20b | 2014-02-19 | 17:41        | 21:32          | 90            | 91        | 0.78            |
| HAT-P-22b | 2014-02-17 | 22:58        | 03:37          | 150           | 79        | 1.42            |
| KELT-3b   | 2014-02-18 | 17:39        | 03:20          | 150           | 161       | 0.58            |

2. Observations and Data Reduction

We make use of the defocusing technique to achieve high SNR by distributing the Point Spread Function (hereafter PSF) over many pixels which allow us to expose for longer durations, therefore diminish Poisson noise since the large PSFs are insensitive to focus or seeing changes (Southworth et al. 2009). The systematic errors brought about by flat-fielding is also reduced by two orders of magnitude with this technique.

We performed our observations with the 1 meter Turkish telescope, T100, using an $R_c$ filter in close accordance with the Johnson-Cousins photometric system. The weather conditions were suboptimal in the observations of HATNet project planets while we had extremely stable conditions during the observations of KELT-3b on the night of February 18, 2014 letting us reach one of the best precision values ever achieved with this telescope in spite of a $\sim 90\%$ waning moon’s phase. We give a log of our observations in Table 1.

We used a specific IDL code for deconvolved observations developed by Southworth et al. (2009) for all bias, dark, flat corrections, alignment of the images, and differential photometry with respect to a synthetic comparison star, which was formed by weighted flux summation of carefully selected stars to form an ensemble.

3. Analysis

The light curves were analysed with the JKTEBOP (version 34) code (Southworth 2008), a modified version of EBOP (Popper & Etzel 1981) for modeling transit light curves of exoplanets. We adjusted the inclination ($i$) parameter of the orbit, the sum ($r_p + r_s$) and the ratio of the fractional radii ($k = r_p / r_s$), the time of minimum of the light curve, while fixing the orbital periods to the values in Table 2 during our solutions. We used linear limb darkening law and fitted for the linear coefficient while holding the nonlinear coefficient fixed at the theoretical value. The best fits for the light curves of the selected exoplanets for this work are given in Figs. 1, 2, 3, and 4.

4. Results & Conclusion

We summarize our results in Table 3. Ratio of the radius of the planet to that of the star ($k = r_p / r_s$) is the most important parameter one can deduce from a light curve. The high precision that we achieved in the measurements of the parameter is mostly due to
Figure 1. Transit observation of HAT-P-10b in defocused mode with T100

Figure 2. Transit observation of HAT-P-20b in defocused mode with T100
Figure 3. Transit observation of HAT-P-22b in defocused mode with T100

Figure 4. Transit observation of KELT-3b in defocused mode with T100
Table 2. Information for targets in Figures 1, 2, 3, and 4

| Planet   | Period (days) | Epoch (mag) | V (mag) | Depth (mag) | Duration (min) |
|----------|---------------|-------------|---------|-------------|----------------|
| HAT-P-10b | 3.722469      | 2454729.90631 | 11.89   | 0.0254      | 159            |
| HAT-P-20b | 2.875317      | 2455080.92661 | 11.34   | 0.0204      | 111            |
| HAT-P-22b | 3.212220      | 2454930.22001 | 9.73    | 0.0119      | 172            |
| KELT-3b  | 2.703480      | 2456023.459   | 9.86    | 0.0098      | 197            |

Table 3. Parameters of the fits to the light curves of the selected exoplanets

| Planet   | $r_s + r_p$   | $k = r_p / r_s$ | $i$ (°) | $T_0$ (+2400000) |
|----------|--------------|----------------|--------|-----------------|
| HAT-P-10b | 0.0924 ± 0.0003 | 0.1345 ± 0.0005 | 89.8 ± 0.1 | 56308.237798 ± 0.000107 |
| HAT-P-20b | 0.2558 ± 0.0044 | 0.1393 ± 0.0010 | 81.9 ± 0.1 | 56708.356256 ± 0.000008 |
| HAT-P-22b | 0.4637 ± 0.0394 | 0.1294 ± 0.0049 | 73.6 ± 3.7 | 56706.589360 ± 0.000090 |
| KELT-3b  | 0.1619 ± 0.0047 | 0.0957 ± 0.0006 | 84.6 ± 0.4 | 56707.438255 ± 0.000207 |

the quality of the observations. However, we should stress that more light curves are needed to perform a rigorous analysis and the errors given in this study are mostly the formal errors obtained from the covariance matrix of the fitting (Levenberg-Marquardt) algorithm. Hence it will not be adequate to compare the resultant parameters with the previously published values. We have also computed the mid-transit times end their errors for these transits in Table 3 by fitting parabolas to the flat bottom sections of the light curves.

Our results show that T100 has a decent potential for follow-up transit observations of exoplanet transits, with the defocusing method in particular, giving a sub-millimagnitude photometric precision. We aim to accumulate additional data in the future and we are willing to share the data presented here with other researchers for them to carry out a more detailed/robust analysis.

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