Photometric Observation of WASP-52b and TrES-3b

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Abstract. We present the photometric observation of transiting exoplanets WASP-52 b and TrES-3 b using Bosscha Robotic Telescope. The transit method relies on measuring the flux drops of the target star when the planet is transiting in front of it. We have derived physical parameters of these planets using single transit light curve and the results are consistent with the discovery paper which used more observation data.

1. Introduction
Most of the exoplanets found today were detected by the transit photometric method. Transit photometric observation was carried out when the exoplanet transiting in front of their parent star viewed from Earth. When the event takes place, the planet will only obscures just a tiny fraction of the light from its parent star but with the right instruments and observational methods this change can be measured precisely.

Exoplanet has been part of the Bosscha Observatory observational program in the past few years. This has been done by observing large number of confirmed exoplanets in a good amount period of time so that we can derived the physical parameters of the exoplanet. The main objective of this exoplanet program is to build and develop a robust exoplanet observation system, in line with the National Observatory development project. This paper discusses two exoplanets observed in 2018 at the Bosscha Observatory, WASP-52 b and TrES-3 b.

WASP-52 is a K2V spectral type star with stellar mass of 0.87(±0.03)M⊙ and stellar radius of 0.79(±0.02)R⊙ [1]. The star located in Pegasus at the coordinate RA2000 = 23h13m59.90s and δ2000 = +08°45′41″, having V = 12 magnitude in brightness. WASP-52 b was discovered by survey project SuperWASP-North. This exoplanet estimated to have a planetary mass of 0.46MJup and 1.26RJup in radius with orbital period 1.75 days [1].

Whilst TrES-3 is a G spectral type of star with a stellar mass of 0.924(±0.04)M⊙ and stellar radius of 0.813(±0.027)R⊙ [2]. This V = 12.4 magnitude of star located in RA2000 = 17h52m07.40s and δ2000 = +37°32′46″. The transit of TrES-3b exoplanet first detected by Trans-atlantic Exoplanet Survey (TrES) project in 2007. The estimated planetary mass of this exoplanet is 0.46MJup and planetary radius 1.91RJup with orbital period 1.3 days [2].

2. Data and Analysis
2.1. Observation
WASP-52 b transit was observed on May 11, while the TRES-3b transit was on May 31, 2018. Data collection was carried out one hour before the transit event began and ended...
one hour after the transit event ended. Details of the observation parameters are shown in the Table 1. Both transit were observed at Bosscha Observatory, Lembang, using Bosscha Robotic Telescope (BRT). BRT is a f/7.2 Corrected Dall-Kirkham (CDK) design telescope from PlaneWave Instruments\(^1\) with 0.35-meter diameter primary mirror.

| Target   | Date       | Exposure time (s) | Cadence (s) | FWHM (arcsec) | rms (mag) from reference stars |
|----------|------------|-------------------|-------------|----------------|--------------------------------|
| WASP-52  | 2018 May 11| 60                | 80          | 1.40           | 0.004                          |
| TrES-3   | 2018 May 31| 60                | 80          | 1.95           | 0.001                          |

The telescope was equipped with a 4008 × 2672 pixels Finger Lakes Instrumentation (FLI) ProLine PL11002M Interline CCD camera. The un-binned pixel scale was 0.72 arcsec/pixel resulting in a total field of view of 48.38 × 32.26 arcmin. Considering signal-to-noise ratio (SNR), exposure times, and spatial sampling of the stellar profile for the seeing that is typically achieved at the observing site, we then used 2 × 2 binning mode. The data we present here were all taken through the R band because of its higher quality SNR compared to the other filters, which would introduce more noise.

Observations have been carried out by fully autonomous robotic software. The software accepted inputs as a list of observing request and set of constrains to perform the observation automatically. The automatic focusing process is performed by searching the best Full Width at Half Maximum (FWHM) of a selected 7-8 magnitude star. The typical focusing process is about 3 minutes, including the slew time. We have a predefined focus offset to skip focusing through each filter. The focusing is performed in the beginning of each night or if the statistical value of FWHM changed by 50%.

Another strategy applied to this observation is to always try to place the target star fall on the same pixel during the observation time. This is crucial to achieve high photometric precision. We do this by employing a closed-loop guiding system that operates on the main camera in real time as described in [3].

2.2. Data Calibration

The flat field, dark, and bias images are taken regularly at dusk and dawn time. The flats are taken using a sky flats where the telescope picks a position in the sky on the solar circle near the zenith, offsetting in the anti-solar direction by 15 degrees. This should be ”close enough” for most uses, including precision photometry[4].

AstroImageJ [5] (AIJ) software was used to calibrate and produce the light curve. AIJ uses one run to accomplish calibration process. Master files are first created from individual bias, dark, and flat files, then these master files are used to calibrate all the science images. Finally, the FITS headers (airmass, barycentric julian date, world coordinate system, etc.) of the resulting calibrated files are updated.

\(^1\) http://planewave.com/products-page/telescopes/14-inch-cdk-optical-tube-assembly/
2.3. Differential Photometry
Differential photometry measures the flux of a target star relative to the combined flux of one or more comparison stars. We conducted the measurement using AIJ by performing single aperture photometry on the exoplanet host star and one or more comparison stars. The strategy adopted to retain the best comparison stars consists of first selecting possible candidates which are close in magnitude to that of the target and then examine whether they are sufficiently constant over the whole series. The initial radii settings of the aperture photometry can be determined using the seeing profile associated with the target star, usually 10-15 pixels. AIJ then produce the light curve, resulting in Figure 1 (top).

The light curve in Figure 1 shows the data distribution of the transit event of WASP-52 b and TRES-3 which display the data collection of the whole transit event. Whilst on the TrES-3 b light curve we can found that there is a distribution of data with a fairly high error at the moment before ingress and after the transit event ends. This is caused by the passing clouds in the sky when the observation took place.

![Figure 1. A single transit light curve of WASP-52 b and TrES-3 b. The solid black points (top) are the raw light curve, the cyan points are the detrended light curve, the solid red line is the best-fit model, and the magenta points (bottom) are the residual from the best-fit model.](image)

2.4. Light Curve Analysis
We used the transiting exoplanet model described in [6]. The transit is modeled as an eclipse of a spherical star by an opaque planetary sphere. The model parameters are:

- planetary radius in units of the stellar radius \( \frac{R_p}{R_*} \),
- semimajor axis of the planetary orbit in units of the stellar radius \( \frac{a}{R_*} \),
- transit center time \( T_C \),
- impact parameter of the transit \( b \),
- quadratic limb darkening parameters \( u_1 \) and \( u_2 \).
The orbital inclination can be calculated as $i = \cos^{-1}\left(\frac{bR_*}{a}\right)$. The best-fit model is found by minimizing $\chi^2$ of the model residuals using the downhill simplex method to find local minima. AIJ is currently limited to finding the best-fit model parameter values and does not provide estimates of the parameter uncertainties [5].

AIJ uses a fixed orbital period $P$ and radius $R_*$ of the host star. We obtained these parameters from http://exoplanets.org, [1] and [2]. We also use a fixed quadratic limb darkening coefficients, these values $u_1$ and $u_2$ were extracted from the theoretical models [7] using a website tool 2. Light curve detrending is accomplished by including a $\chi^2$ contribution for airmass in the overall light curve fit.

3. Result and Discussion

We listed the model parameters for both WASP-52 b and TrES-3 b in Table 2 and Figure 1. The calculated results are within the error of the accepted values given for both exoplanet. This suggests that the method applied at Bosscha Observatory for observing and analyzing exoplanet transits is reliable.

The main obstacle in high-precision photometric observation at the Bosscha Observatory is the stable condition of the photometric sky. In the near future, improvements and upgrades will be made on the instruments and data collection and processing software.

| Parameter | Symbol | WASP-52 b (observed) | WASP-52 b (ref.) | TrES-3 b (observed) | TrES-3 b (ref.) |
|-----------|--------|---------------------|-----------------|-------------------|----------------|
| Orbital period (day) | $P$ | 1.7497798 | fixed | 1.30619 | fixed |
| Orbital eccentricity (deg) | $e$ | 0 | fixed | 0 | fixed |
| Stellar radius ($R_\odot$) | $R_*$ | 0.79 | fixed | 0.812 | fixed |
| Quad LD $u_1$ | $u_1$ | 0.52749864 | fixed | 0.37396711 | fixed |
| Quad LD $u_2$ | $u_1$ | 0.1796986 | fixed | 0.27450785 | fixed |
| Transit duration (day) | $t_T$ | 0.079726388 | 0.0754 | 0.056153077 | 0.0569 |
| Planet/star area ratio | $\left(\frac{R_p}{R_*}\right)^2$ | 0.027587736 | 0.0271 | 0.030551503 | 0.02739025 |
| Impact parameter ($R_*$) | $b$ | 0.588279358 | 0.6 | 0.85590105 | 0.84 |
| Scaled semimajor axis | $\frac{a}{R_*}$ | 7.082311333 | 7.380073801 | 6.037457935 | 5.926 |
| Orbital inclination (deg) | $i$ | 85.23534018 | 85.35 | 81.85 | 81.85 |
| Transit center epoch (BJD) | $T_C$ | 2458250.374 | - | 2458270.349 | - |
| Planet Radius ($R_{jup}$) | $R_p$ | 1.275358397 | 1.27 | 1.379387979 | 1.336 |

4. Summary

We derive some physical parameters of WASP-52 b and TrES-3 b from the transit light curve data observed at Bosscha Observatory. The calculated results are within the error of the accepted values given for both exoplanet. This method can be relatively easy to replicate by other observatory or amateur astronomers in Indonesia.

2 http://astroutils.astronomy.ohio-state.edu/exofast/limbdark.shtml
References
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