

Transit of TrES-2b

James Otto, Brian Halldorson, Fangming He, Rhiannon Griffin
University of North Texas

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Abstract

In this report we submit our results from observing the transit of exoplanet TrES-2b as it orbited its parent star. We report an 18 mmag average decrease in apparent magnitude of TrES-2 during the transit of its orbiting planet.

Introduction

Since the confirmed discovery of the first extrasolar planet (exoplanet) 51 Pegasi b in 1995 there has been a rise in interest among astronomers, both professional and amateurs alike, to seek out new exoplanets and monitor those already catalogued. Exoplanet research has been growing in popularity in the past decade among astronomers due to the fact that new and exciting data can be collected using relatively small telescopes compared to the meter-class telescopes found in large observatories.

The star that we observed has been given the designation TrES, which is the designation given to objects catalogued from the Trans-Atlantic Exoplanet Survey. The survey was created by David Charbonneau, Timothy Brown, and Edward Dunham. The TrES survey, which led to the discovery of TrES-2b and three other exoplanets orbiting different stars, consists of three 4-inch Schmidt-Cassegrain reflecting telescopes (SCRT's) located in the Canary Islands, the Palomar Observatory (San Diego, CA), and the Lowell Observatory (Flagstaff, AZ).¹

TrES-2b has a mass estimated at $1.28 M_{Jup}$ and orbits its parent star, GSC 3549:2811 (TrES-2), every 2.47 days. TrES-2 is a main sequence star of spectral type G0 V with a mass of $1.08 M_{Solar}$.² Our data for this transit was compiled using the Transit Method.

Theory

The Transit Method is defined as observing a star and monitoring how its apparent magnitude is slightly decreased by the movement of an exoplanet orbiting about that star. The duration of the transit depends on the distance of the exoplanet from its parent star and the star's mass. The change in brightness is dependent upon the size of the exoplanet. Generally, a decrease in apparent magnitude is on the order of 0.1% to 1.0%.³

Observations

At the Monroe Robotic Observatory (MRO), located near Gainesville, Texas at latitude $33^{\circ} 46' 36.8''$ N and longitude $97^{\circ} 12' 39.7''$ W, we have access to four SCRT's, one eleven-inch SCRT, two fourteen-inch SCRTs, and one sixteen-inch SCRT. These telescopes along with the SBIG SP-10 cameras can acquire accurate data that can be analyzed using IRAF, or MIRA photometry software.

Data was gathered from the Pier 3 mount at the MRO. Pier 3 consists of a fourteen-inch SCRT atop a Paramount ME German-equatorial mount using an SBIG ST-10 CCD camera. The controls to the SCRTs at the MRO are located in the Environmental Education, Science And Technology (EESAT) building on the University of North Texas campus in Denton, Texas.

We observed the transit of TrES-2b on 2010 May 7 between 8:35 and 10:50 UT from Pier 3. Before the transit, flat field frames, flat field dark frames, dark frames, and bias frames were obtained. Then the telescope was focused on TrES-2 (GSC 3549:2811) with an exposure time of 200 seconds and a V filter. We observed the star for 3.5 hours bracketing the predicted transit midpoint and obtained a total of 45 images.

Atmospheric Parameters

During the transit time, between UT 8:35 to 10:50, the sky was clear. The transparency of the atmosphere from the ground to space, which is calculated from the amount of water vapor, was average. The observing conditions during this time were poor, due to atmospheric turbulence combined with temperature differences in the atmosphere. The humidity during this time varied from 55% to 65% at the end of the transit. Humidity is an important factor, for it can indicate the likelihood of the telescope accumulating dew, which can add significant noise-related error to the images. The sky began to illuminate due to pre-dawn light beginning at 5:30am CDT which affected the final four frames at the end of the transit.

Analysis

Image reduction and photometry of this experiment were done using MIRA Pro 7. We followed the conventional method for making calibration frames, which included the master bias, the master dark, the master flat dark, and the master flat. These master frames were made using the median value

combine method, while the master flat was also normalized as usual. Once we had a set of calibrated data frames, we picked 3 non-collinear stars and tracked them through the image set so as to lineup the position of each star. We used FWHM results from MIRA to set values for aperture radii and the size of the annulus. These values were $r = 14$, $a_1 = 34$, and $a_2 = 44$, where a_1 and a_2 are the radii of the annulus.

At this point, we added an extra step before conducting photometry. We selected a random star and used it as a comparison star to check the magnitude of sixteen other stars that had clean annuli. This star was GSC 3549:2837 having a magnitude of 12.30. The idea was to statistically select the most non-varying stars in the field of view to be used in photometry. We first calculated the variance and the error on mean of the magnitude of these sixteen stars. Then we selected a group of four stars that had relatively low variances but similar errors on their mean values to be used as comparison stars for photometry. These four stars were GSC 3550:1224 (12.39 mag), GSC 3549:2871 (13.08 mag), GSC 3549:2804 (12.59 mag), and GSC 3549:2829 (12.95 mag).

In conjunction with the four selected comparison stars, we again used GSC 3549:2837 (12.30 mag) as the sole check star for the photometry. MIRA gave the TrES-2 and check star magnitudes as well as the associated errors. We plotted the magnitude of both TrES-2 and the check star against the Heliocentric Julian Date (HJD). We also realized there was a 0.00801 mag (~ 8 mmag) difference between the mean of the check star magnitudes and the expected magnitude of each star. To fix this error, we made the assumption that the check star magnitudes are normally distributed, as we have a large sample size, and therefore allowing us to adjust the entire TrES 2 light curve by 8mmag. The decrease in magnitude for the TrES-2 transit was clearly distinguishable, as it extended about 0.02 mag below the baseline. Finally, we added error bars obtained from MIRA to the TrES-2 and check star light curves and applied the chi-squared test to both data sets (see Figures 1 and 2.).

To ascertain whether or not we observed a transit, we need to show that the star is variable and that we observed an 18 mmag dip in the light curve. To this end, we performed the χ^2 goodness-of-fit test for each case. To find the χ^2 test statistic, we used the equation

$$\chi^2 = \sum_{i=1}^n \left(\frac{O_i - E_i}{\sigma_i} \right)^2 \quad (1)$$

where n is the number of data points, O_i is the set of observed values, E_i

is the set of expected values, and σ_i is the set of errors. The χ^2 test statistic has approximately a χ_k^2 distribution with $k = n - 1$ degrees of freedom. The χ^2 test compares a null hypothesis to an alternative hypothesis. Depending on where the test statistic lies on the χ_k^2 distribution curve, we either accept or reject the null hypothesis. If the test statistic is greater than the χ_k^2 value, then we reject the null hypothesis.⁴

To show if TrES-2 is variable, we used the null hypothesis that TrES-2 is non-variable and has a constant magnitude of 11.48. We use the alternative hypothesis that the star is variable. We wanted to show that the radiant flux was variable due to our prior knowledge that an exoplanet transit was taking place. To find the χ^2 test statistic, we used the photometric data to compare the observed magnitudes to the expected magnitude of 11.48.⁵ This gave us a test statistic of 5130.596. This is much greater than $\chi_{40}^2 = 63.6907$ at the 1% significance level, therefore we rejected the null hypothesis and state that TrES-2 is variable.

To show if the light curve has a decrease of 18 mmag, we compared the 15 data points from midtransit that are along the base of the dip to the constant line value of 11.498 ($11.48 + 0.018$) mag. We used the null hypothesis that the dip of the light curve fits the constant magnitude of 11.498. We used the alternative hypothesis that the dip does not fit that constant magnitude. This gives us a test statistic of 20.0491. This is less than $\chi_{14}^2 = 29.1413$ at the 1% significance level, therefore we failed to reject the null hypothesis and state that we observed an 18 mmag dip in the light curve.

Conclusion

The currently accepted value of TrES-2 is 11.41 mag⁶, indicating there are possible errors in our experiment. These errors could have been the result of instrument calibration, daylight, or simply using a possibly out-of-date database for comparison star magnitudes.⁵

In summary, we have captured a transit of TrES-2 on May 7, 2010 at the UNT Robotic Observatory. Our result showed that TrES-2 indeed has a transiting planet, which created a 0.018 magnitude decrease in magnitude in the light curve of TrES-2 for about one hour. The errors for this experiment are acceptable, indicating that our equipment is capable of detecting such dim variable objects in the sky.

Figures

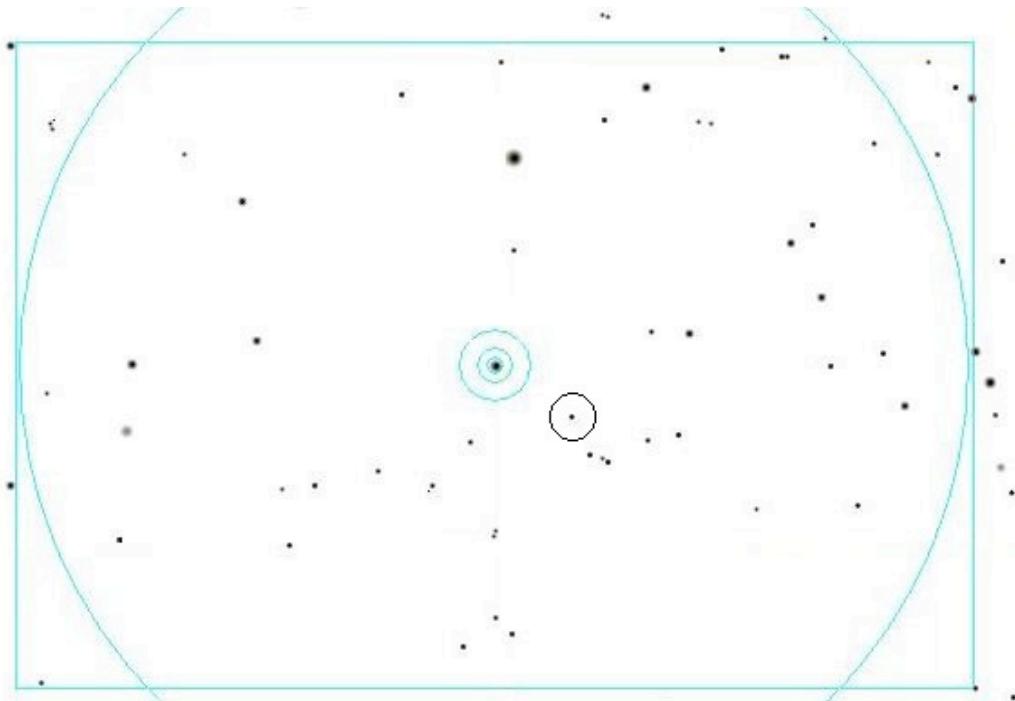


Figure 1: The object star, TrES-2, is centered in this image and the 12.30 mag check star is circled.

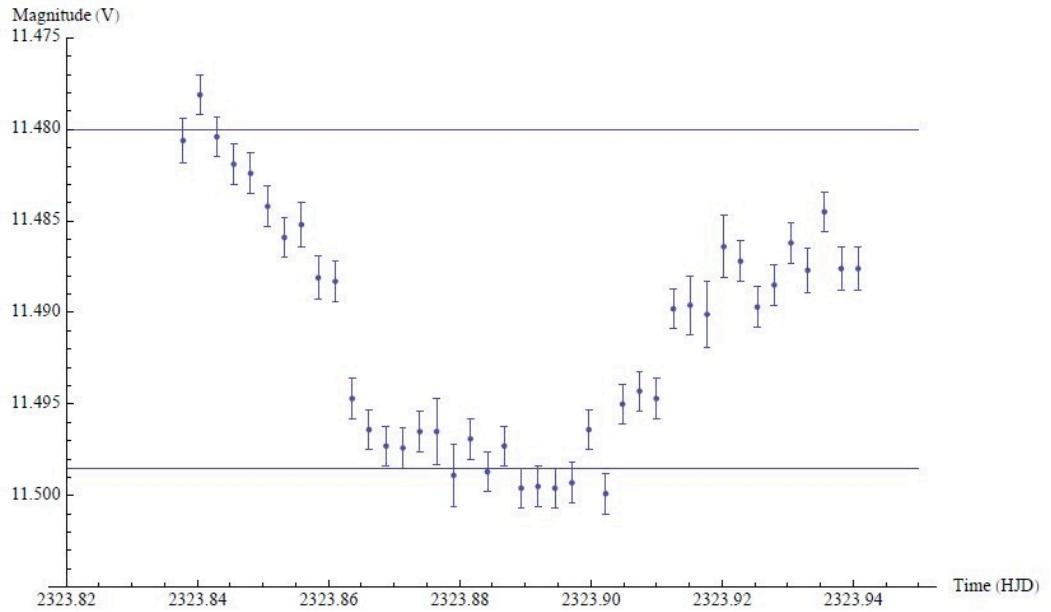


Figure 2: The lines indicate the expected value for the magnitude of TrES-2 and the average value for the decrease in magnitude during the transit showing the 18 mmag decrease.

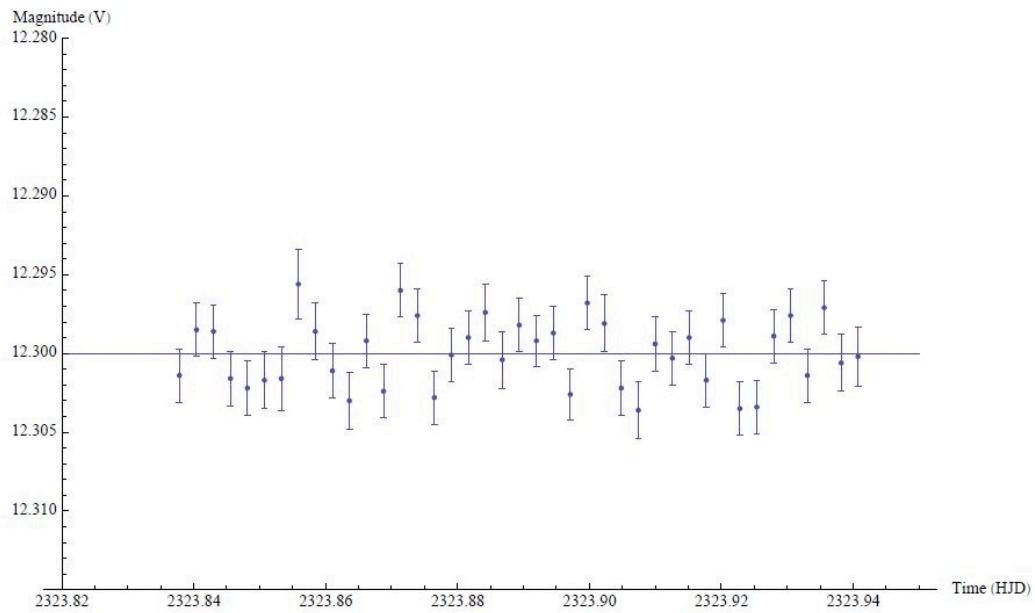


Figure 3: The observed magnitude of our check star, GSC 3549:2837, has an expected magnitude of 12.30

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References

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