Ground Based Light Curve Follow-Up Validation Observations of TESS Object of Interest (TOI) 5868.01

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Abstract

The objective of this study is to determine if TESS object of interest (TOI) 5868.01 proves to be a potential exoplanet utilizing the TESS transit method. In April of 2018, the Transiting Exoplanet Survey Satellite (TESS) mission was launched to search for potential exoplanets. With 542 confirmed planets and over 7,000 candidates, TESS' transit method has proven groundbreaking for exoplanet observation. Data collected from the ground-based GMU Observatory was reduced and plate solved by Java-based software, AstroImageJ (AIJ). This software generated a light curve as well as a NEB analysis through Multi-Aperture Photometry, two crucial representations used to determine the status of TOI-5868.01. Through close examination of the light curve, the existence of this TOI as an exoplanet is unclear. Further analysis of this data will need to be carried out in order to rightfully categorize TOI-5868.01 as an exoplanet.

1.Introduction

The Transiting Exoplanet Survey Satellite (TESS) is a NASA Astrophysics Explorer mission led and operated by MIT in Massachusetts, managed by NASA Goddard's Space Flight Center based in Maryland. It has countless partners all throughout the East Coast as well as in NASA's Ames Research Center in California's Silicon Valley. Launched aboard a SpaceX Falcon 9 in April 2018, TESS has four red-sensitive, wide-field cameras that monitor a 24x90 degree strip of the night sky for 27 days and nights a year. It employs the transit method, presumably the most useful of these methods, to search and identify potential exoplanets. This method consists of a dimming in the host star of the object. If the dimming exhibits periodic appearances, then apertures from the night sky, aligned through the process of aperture photometry, develop a light curve that shows if there is in fact a recurring dimming in the observations. If more than one transit is exhibited, this presents the possibility of an exoplanet. Further examination and classification of prospective objects can be found in the TFOP guidelines.

2.Observations

Section 2 presents the information available from TESS missions as well as other sources prior to analysis. In Section 3, the data collected is modeled as a light curve and analyzed in order to detect the existence of a dip. In Section 4, results are presented. In Section 5, these results are discussed and compared to brief analysis done previously by TESS. Lastly, Section 6 describes conclusions and the hope for future work.

TOI-5868.01 was first discovered on 2022-11-08 at 19:57:57. It was then modified on 2023-12-25 at 12:02:40. **Table 1** lists the preliminary data TESS had collected on this object of interest prior to GMU's own recollection of data on the night of June 24, 2024. Data was collected by GMU's 0.8 m ground based telescope with red filter.

	Data	**Source**
Date	2024-06-24	GMU Observatory
Exposure Time	65.000s	GMU Observatory
Start Time and End Time	22:50-1:43	GMU Observatory
Filter	R	GMU Observatory
Right Ascensi on (RA) and Declinat io n (DEC)	20:53:40.6 9 +34:21:05. 93	GMU Observatory
Ingress and Egress	22:50±1:43	GMU Observatory
Orbital Period	2.68 days	GMU Observatory

Table 1: *Preliminary data on TOI 5868.01.*

Figure 1: *Wide field image view. TOI-5868.01 (TIC ID 236158940.01) encircled in a 2.5' radius.*

3. Analysis

Section 3.1 presents the tools utilized to analyze the light curve. Section 3.2 discusses the process of data reduction. Section 3.3 mentions how images were plate solved and aligned. In Section 3.4, we demonstrate how to use aperture photometry and how this results in the modeling of our light curve. Section 3.5 examines the process of generating and scaling a light curve. Section 3.6 discusses the creation and importance of an NEB check.

Section 3.1 Tools for analysis

In order to correctly analyze this data, I performed the majority of my data processing in AstroImageJ (AIJ). AstroImageJ is a Java-based software and "an extension of ImageJ which provides an astronomy specific image display environment and tools for astronomy specific image calibration and data reduction" (Collins, n.d.).

Section 3.2 Data Reduction

The images provided by the GMU Observatory were comprised of 20 darks (10 of which were under the same exposure time as the flats, 3.000s), 10 flats, and 280 sciences, of which only 168 were functional. The darks and sciences were exposed during a time of 65.000s under an R filter. As mentioned before, only 168 sciences were available for generating the light curve and this confirmation came from data reducing the images. Since this is a ground based observation, data reduction works to minimize the effect of noise and background objects that can alter the images and provide false data. Dark images were taken with the shutter completely closed in order to subtract the thermal noise caused by long exposure times. Flat images were taken with the shutter completely open but for shorter exposure times to get rid of any artificial distortions that might have developed from the raw sciences. Lastly, some of the science images showed streaking which were erased before plate solving.

Section 3.3 Plate solved and Aligned Images

Plate solving is a method by which objects in an image frame are assigned RA (right ascension) and DEC (declination) coordinates from comparing it to a database of star positions (N.I.N.A. contributors, 2019). This mostly aids with the process of differentiating the host/target star from the reference stars for when we analyze the light curve and NEB check. After plate solving the science images, we needed to place apertures on the target and reference stars in order to align them. Utilizing AIJ's "Stack Aligner" feature, I set a radius for the target star and an inner and outer radius for the background annulus. With these parameters, I placed apertures on the target and reference stars which meant that the process of reducing and aligning images was complete.

Section 3.4 Aperture Photometry

Aperture photometry is the process through which the raw flux value of an object is obtained. This was measured by counting the amount of electrons in a set radius of the aperture in the CCD image. In AstroImageJ, I first had to develop the Seeing Profile to find the exact measures of the inner and outer radii background annulus as well as the radius of the aperture, described in ***Figure 2***. Then, using the same aligned field image, a radius of 2.5’ was placed around the host star for the Multi-Aperture Photometry.

The Multi-Aperture Photometry tool distributes the parameters chosen for the target star to all the reference stars located inside of the 2.5’ radius found from dropping a Gaia stars file. These reference stars are similar in both size and brightness to T1, the chosen star. From this, AstroImageJ develops a measurement table that I used to form the light curve.

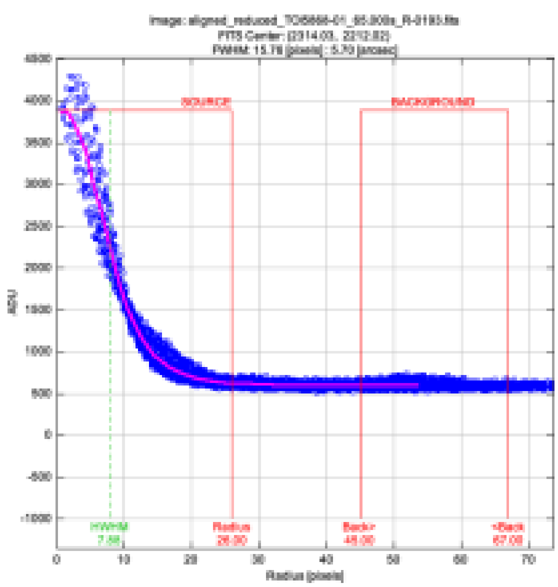

Figure 2*: Seeing Profile of TOI-5868.01. Radius of aperture is 26.00, inner radius of background annulus is 45.00, and outer radius of background annulus is 67.00.*

Section 3.5 Light Curve

Generation

For AstroImageJ to generate the light curve, it had 4 windows that needed input of various data from the host star and potential transit. The first window was the “Multi-Plot Main”. These settings managed the axis and overall plot information. “V. Marker 1” and “V. Marker 2” stood for the ingress and egress times, respectively. For the “X-axis Scaling”, I chose “Auto X-range” because this would rightfully separate the ingress and egress times.

The “Data Set 2 Fit Settings” moderates the majority of the star’s information. I inputted the host star’s stellar radius, effective temperature, metallicity, and surface gravity parameters, all provided by ExoFOP databases.

In the “Multi-plot Y-data” window, I plotted the following detrending parameters: Sky/Pixel_T1, Width_T1, AIRMASS, tot_C_cnts, X(FITS)_T1, and Y(FITS)_T1. Following the TFOP Guidelines, I set the default “Scale” and “Then Shift” to 15, -15 for AIRMASS, and -42, respectively. The last step in this settings window was to determine which stars should and should not be used as reference stars, since they would later be plotted in the NEB check. This is determined by plotting them and seeing how they affect the light curve plot.

Lastly, the “Multi-plot Reference Star Settings” lists which of the reference stars are in use and which are deleted from the NEB Check. Those that are reference stars start with a “C” while those that do not start with a “T”, except for T1, the host star.

Section 3.6 NEB Check

The “TFOP SG1 NEB Analysis Macro" tool in AstroImageJ is utilized in this section to check if T1 belongs to a Nearby Eclipsing Binary System (NEB). This would mean that the change in flux or dip in the light curve is caused by the orbiting star and not an exoplanet. It runs a check of all the reference stars inside of the 2.5’ radius to check if they both orbit their center of gravity. 213 reference stars were submitted to the NEB check.

4. Results

This section presents the generated light curve as well as other crucial results that constitute for the purpose of this paper.

As shown in ***Figure 3*****,** a total of 9 out of 228 stars were utilized as reference stars, while the other 219 were analyzed in an NEB check. None of these stars cleared either of the boundaries.

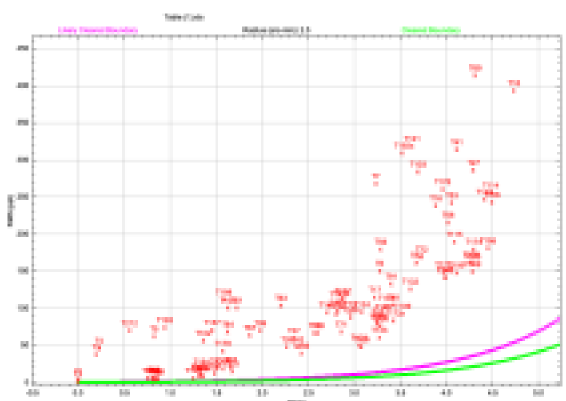

Figure 3*: NEB analysis check. None of the reference stars clear either of the boundaries.*

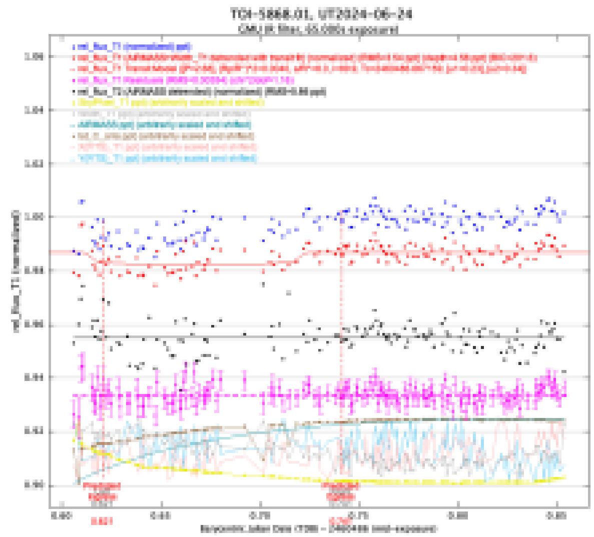

Figure 4*: Light curve of TOI-5868.01. Questionable transit between predicted ingress and egress times. Depth is 4.56 ppt.*

5. Discussion

In this section, I discuss my results. Section 5.1 interprets the results of the light curve and NEB check. Section 5.2 compares my results to the greater interpretation done by NASA’s TESS team’s previous examination of TOI-5868.01.

Section 5.1 Light Curve and NEB results

To rightfully determine whether TOI-5868.01 is an exoplanet, a variety of parameters and analysis plots have to correlate in results. As for the light curve, an apparent change in flux is present in the ingress and egress boundary lines. However, this is a faint demonstration of a dip since it does not show a clear and prominent concavity. Furthermore, the transit depth TESS had predicted was 3.3 ppt; in my light curve, it stands to be 4.56 ppt. Given that there is a small discrepancy between the transit depths, it can be expressed that this data shows to be inconclusive since a larger transit depth exhibited a small dip. Another reason for why the data seems inconclusive is due to the NEB check. Since none of the stars cleared under the boundary, there might be a nearby eclipsing binary system instead of an exoplanet orbiting the host star or around it.

Section 5.2 TESS Team Analysis

From the "Transit Info" Google Sheet provided by the GMU Observatory, I was able to compare my work to that of somebody who had researched TOI-5868.01. Bob Massey, from Villa 39 Observatory in Landers, CA, discovered a full transit on 2024-08-04 with a transit depth of 3.1 ppt. This poses the question of how the nearby eclipsing binaries may come into play when looking at this TOI from a larger scope. Further data was unfortunately not available on ExoFOP, no spectroscopy or imaging observations had been done.

6. Conclusions & Future Work

Although an extensive amount of analysis was able to be done on this TOI, this in no way concludes the end of researching and evaluating it. This is only one of the first few steps that can be done to collect extensive research on 5868.01 to rightfully determine its place in our universe. Since many factors could have contributed to false data or a wrong analysis, further research should be done on this TOI to be certain. Performing another QLP faint-star search could help us arrive at a better conclusion. Moreover, this can also include an in-depth spectroscopy observation to determine the overall composition of the host star and the reference stars around it.

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