Ground-based Light Curve Follow-up Validation Of TESS Object of Interest (TOI) 5443.01 Transit

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1 Abstract

This study presents a light curve indicating a high possibility of a transiting exoplanet. This potential exoplanet, TOI 5443.01, was originally theorized to exist by the Transiting Exoplanet Survey Satellite (TESS), which uses the transit method to attempt to find exoplanets. It is necessary, however, to perform ground-based follow-up observations and analysis of a potential exoplanet to prove it exists. In this study, we demonstrate that TOI 5443.01 most likely exists by utilizing AstroImageJ and a Python program named Alnitak, with images taken by the George Mason University 0.8-meter telescope. However, a detailed follow-up analysis on Nearby Eclipsing Binaries (NEBs) within the Gaia field of the star TOI 5443 must be performed.

2 Introduction

Exoplanets are planets that are located outside of our solar system. These exoplanets, just like the ones within our solar system, orbit around a star. Identifying and studying exoplanets can help answer many of the most prominent questions in astronomy. For example, finding and studying exoplanets are essential to finding life outside our solar system. To find said exoplanets, scientists would use a method called the "transit photometry method". This method requires many images of the target star to be taken over the predicted duration of its transit. Then, a light curve is generated to fit the photon output of the star at various times during the night to prove that a planet has passed in front of the target star. To perform this task at a large scale, the National Aeronautics

and Space Administration (NASA) created the Transiting Exoplanet Survey Satellite (TESS).
TESS would scan the sky and search for transit signals in stars, thus indicating a potential exoplanet. These potential exoplanets are labeled with the title "TOI". Currently, TESS has found thousands of potential exoplanets, but only a couple hundred of them have been confirmed to exist. Of these planets, many have undergone more detailed and rigorous study of their characteristics, which have resulted in many interesting findings. The potential exoplanets haven't been confirmed to be exoplanets yet because the measurements of TESS's telescope can be inaccurate. This is because TESS is monitoring such a huge portion of the night sky, and thus its findings must be verified to confirm that an exoplanet is truly there. To confirm whether an exoplanet orbits a specific star, a follow-up study performed with data from a ground-based telescope observation is necessary.
In this study, we are going to be focusing on the potential exoplanet; TOI 5443.01. The host star of this potential exoplanet (TOI 5443) has a predicted radius of about 1.52775 times that of our sun, and a predicted mass of approximately 1.52 times our sun. The exoplanet itself has a predicted radius of approximately 7.62588 earth radii and a predicted period of approximately 1.6757659 days.
The telescope that is being used in this study is the 0.8-meter George Mason University (GMU) Telescope, with which all of the science images used in this study will be gathered.

3 Methods

3.1 Data Collection

First and foremost, the emitted light of TOI 5443 must be measured by the George Mason University Telescope during the night of predicted transit of TOI 5443.01. This was done on the night of 2024-01-07. A total of 269 85-second exposure science images, 10 3-second exposure darks, 10 85-second exposure darks, and 10 3-second exposure flats were taken in the Red filter the during this observation.

3.2 Data Reduction

Of the science images collected from the GMU telescope, the first 21 were discovered to have pointing issues and thus were unusable. The remaining images had noise in them, which needed to be removed.

3.2.1 Data Analysis with AstroImageJ

Originally, the AstroImageJ (AIJ) program was run to attempt to reduce the data, but it failed at the plate-solving phase of data reduction.

Before the program failed, it did manage to reduce the science images of noise. To do so, we did the following (in numerical order):

1. We created a set of dark images with the same exposure time as the flat field images.

2. The same thing was done for the dark images with the same exposure time as the science images.

3. The set of dark images with the same exposure time as the flat field images were used in dark subtraction on the flat field images to create a master flat file.

4. The set of dark images with the same exposure time as the science images and the master flat image were used in dark subtraction and flat division on the science images to create a set of reduced science images with minimal noise.

After this was done, plate-solving was attempted on the science images. To do this, Astrometry.net was used through AIJ to try to match each science image to its position in the sky using the celestial coordinates of RA and DEC (Right Ascension and Declination). The coordinates of the target star (RA and DEC) were found via the ExoFOP database This process kept failing due to connection issues, so a backup plan was instead performed.

3.2.2 Data Reduction with Python (Alnitak)

Since the previous program failed to plate-solve, the process was restarted using a separate program coded in the high-level coding language; Python. This program is named "Alnitak", and was written by Kevin Collins (Department of Physics and Astronomy, 4400 University Drive MS 3F3, George Mason University, Fairfax, VA 22030, USA).
This program both reduces the science images and plate-solves them. During this process, many images were found unfit for study, and thus were removed, with only 143 images being used in the final light curve graph.

3.3 Aperture Photometry

The next step is to perform aperture photometry using AstroImageJ on the stars in the image. This allows us to measure the flux of the target star (TOI 5443). A seeing profile (referenced in **Figure 1**) was created using AIJ to decide the radii of the aperture and annuli.

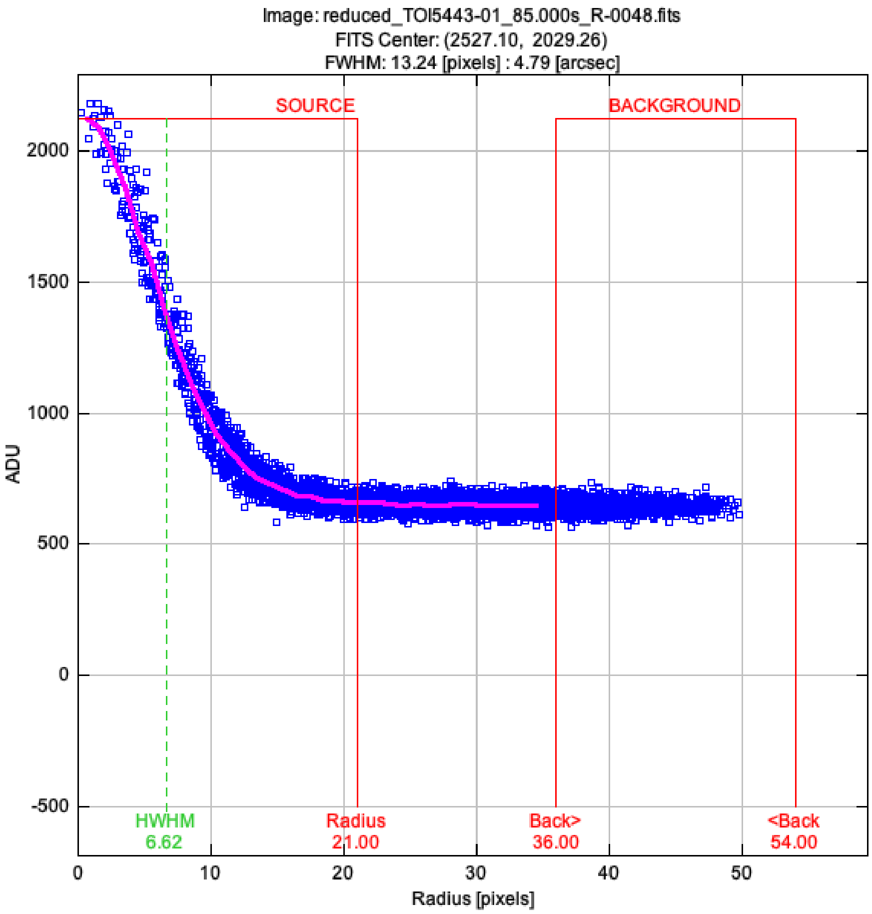

Figure 1: A seeing profile of TOI 5443 created in AIJ

An aperture with the radii indicated by the seeing profile was then placed on the target star using AIJ's Aperture Photometry Tool. A circle of radius 2.5' was created, and the Gaia stars in this field were loaded onto the image sequence. AIJ also automatically placed apertures on nearby reference stars in the process. These reference stars must be in the Field of View of the science images, and resemble the target star in size and brightness. A measurement table of all necessary variables was also created. One of the science images with all placed apertures is shown below in **Figure 2**.

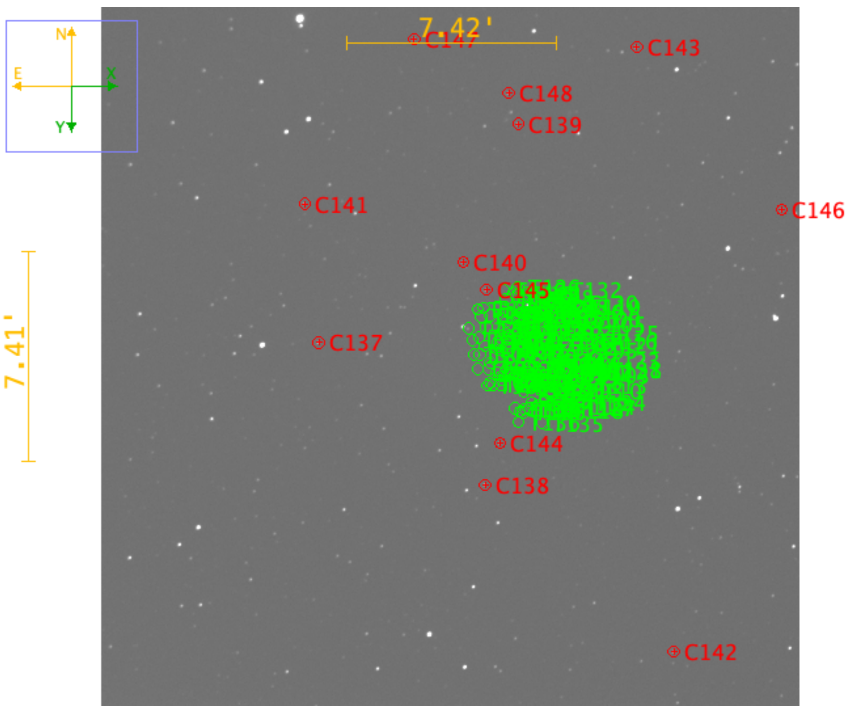

Figure 2: A platesolved science images with apertures placed

3.4 Light Curve Creation

To create the light curves, a template of the AIJ settings was imported from www.astrodennis.com/Template.zip. Next, all specific parameters were set using data from the ExoFOP database. The light curve (referenced in **Figure 4**) was detrended using only the tot_C_cnts filter, with the observed time of transit being shorter than predicted, but still lying within the predicted ingress and egress times. AIJ was also used to generate a dmagRMS plot of the Gaia stars within the field to check for Nearby Eclipsing Binaries (NEBs) that could cause a false positive in TESS's initial evaluation. This is shown in **Figure 3** in **Section 4**.

4 Results

From the data that we have collected, we acquired a dmagRMS plot of the gaia stars in this field and a light curve with the tot_C_cnts filter using both the Alnitak program in Python and AIJ. These data points are stored in a measurement table that contains essential parameters for creating the light curve such as the Barycentric Julian Date in TBD, The rel_flux, air mass (AIRMASS), the total photon count of comparison stars (tot_c_cnts), etc. A slight, but visible dip can be seen in the light curve plot shown in **Figure 4**. In this graph, the variation in flux of the light curve has a chi-squared value of approximately 172.523 (with chi-squared over the degree of freedom being approximately 1.307), and a subsequent p-value of approximately 0.9904.

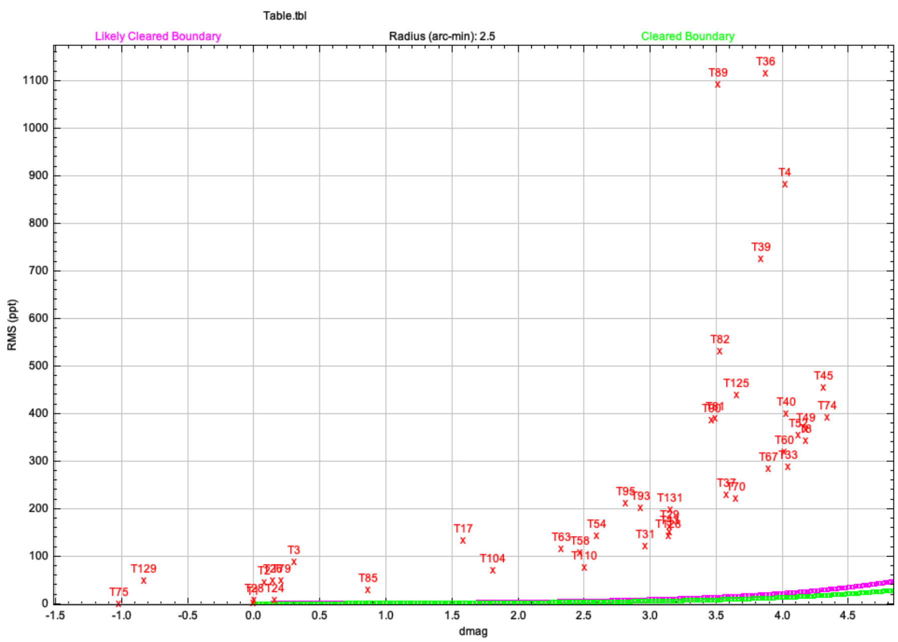

Figure 3: A dmagRMS plot created in AIJ

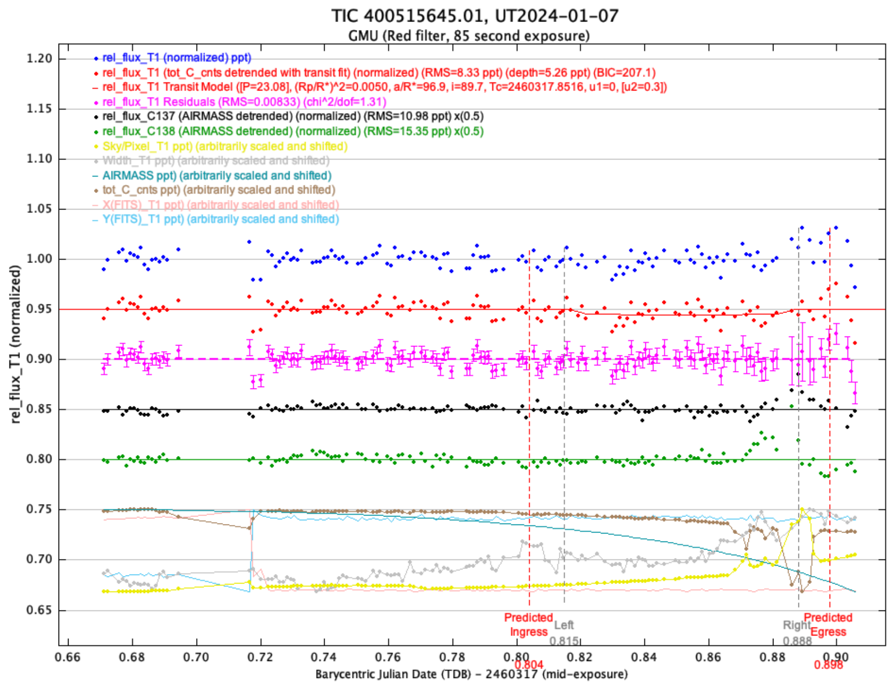

Figure 4: Light curve of TOI 5443.01's predicted transit on the night of 2024-01-07 created using AIJ

5 Discussion

From the generated light curve, it can be seen that there is a high chance that a transit indeed occurred within the predicted ingress and egress times. This is because the light curve graph was a good fit, as shown by the chi-squared/p value. Additionally, there is a noticeable drop in the flux of TOI 5443 during the predicted ingress and egress times, as shown in **Figure 4**.

On the other hand, we could not draw any conclusions from the dmagRMS plot, as the nearby Gaia stars of TOI 5443 are neither within the likely cleared nor within the cleared boundaries (as shown in **Figure 3**). This means that a future study must be conducted to verify that there are no NEBs. Additional testing for other sources of false positives may also be necessary.

6 Acknowledgements

I sincerely thank Doctor Peter Plavchan for creating an opportunity to perform a follow-up analysis for TESS, thus making it possible for this paper to be written. In addition, I thank Kevin Collins for his remarkable mentorship, including but not limited to answering some of my questions at some questionable hours. I also thank the support from other individuals in the 2024 Schar West Cohort. Finally, I would like to thank all of the mentors who made this program possible.

7 References (MLA 9)

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