Ground-based Light Curve Follow-up Validation Observations of TESS Object of Interest TOI 3521.01

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Abstract

TESS Mission was launched on April 18th, 2018. It was designed to find the exoplanets by using the transit method. Our goal is to confirm TOI-3521.01 by analyzing the light curve and its NEB check. We use AIJ to do preparation, such as reducing data, plate solving, generating measurement tables, and creating light curves. Then, we examine light curves of our interest by looking for a similar depth and duration as predicted. Our data leads us to be inconclusive, which means that we cannot make sure there is an exoplanet orbit around our host star, because we didn't rule out false positives.

1. Introduction

The discovery of the first exoplanet in 1992 opened a new field of astronomy. From then on, scientists began to develop a series of methods to examine the existence of exoplanets, and the transit method is one of them. It is being used to detect the change of light of a star when a planet passes through. This method was also the mainstay of the Transiting Exoplanet Survey Satellite (TESS) Mission, which NASA and MIT launched to explore the exoplanets better. Usually, TESS will first detect and send back some signals from an exoplanet. Then, a follow-up validation is needed to verify. During its survey, it has confirmed 542 exoplanets. (https://exoplanets.nasa.gov/tess/)

However, only some candidates are true positives, and for various reasons, TESS may send some false information back to the ground that interferes with the examination. Therefore, the ground-based light curve follow-up validation of interest plays a vital role in the mission. Thousands of candidates are waiting for scientists to be analyzed and verified. This is why our paper is needed.

There has been no previous work on our TESS Object Interest 3521.01, so it needs more follow-up observation. Our object is TOI-3521.01, and its orbital period is around 3.24 days. Our goal is to confirm the information sent by TESS to investigate whether or not the transit occurs on the expected star at the expected time, with the expected duration and depth.

In Section 2, we present our Observations from TESS and the George Mason University 0.8m telescope. In Section 3, we present our analysis of the TESS light curve for TOI 3521.01 and our ground-based light curve analysis. In Section 4, we present our light curve results. Finally, in Section 5, we discuss our results and present future work.

2. Observations

In Section 2.1, we present the TESS Object of Interest 3521.01 and its properties from the NASA Exoplanet Archive and other resources. In Section 2.2, we present a summary of the observational data collected with the George Mason University 0.8m telescope.

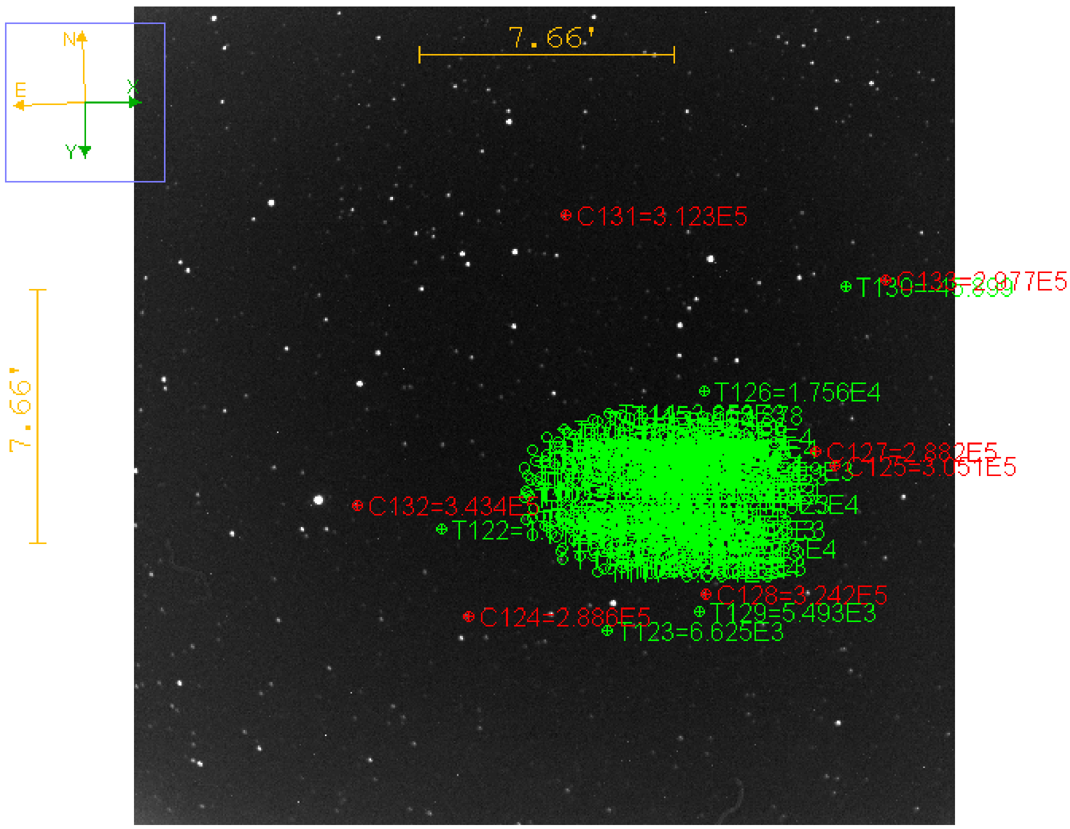
2.1 TOI-3521.01 was first founded in 2021 by using the transit method. The RA and DEC for our object are 21:07:45.53 and +31:46:51.43. Its transit duration is around 1 hour and 26 minutes, its orbital period is 3.24 days, and its depth is 10.7 ppt. (https://exoplanetarchive.ipac.caltech.edu/overview/TOI-3521.01#overview)

2.2 Our observation happened on June 17th at George Mason University. After removing the bad ones, including streaking, targets outside the field, or considerable shifting of the target between each image, we acquired 168 usable images. The exposure time for our target is 90 seconds, and we used an R filter to observe the images.

3. Analysis

In Section 3.1 we present our tools used to analyze the TESS sector light curves using AstroImageJ/ExoFASTv1/ExoFASTv2. In Section 3.2, we present our analysis of the ground-based light curve using AstroImageJ.

3.1 AstroImageJ(AIJ) is a powerful tool we can use to analyze our sciences. The first thing to do is to split the data into four parts(science darks, flat darks, flats, and sciences). Next, import the science images to AIJ and visually remove any bad images(viewed section 2.2 to identify bad images). Then, AIJ will be used to generate master darks and master flats to reduce sciences. This step can ensure that no external sources will affect the later analysis. After gaining those plate-solved data, we need to find the target on the first science image and create a seeing profile that provides us the aperture and annuli radius needed to fill in the "Aperture Photometry Settings" window(double click on APT to open this window). The next step is to do multi-aperture photometry. Drag the Gaia stars .radec file to the AIJ to get green T stars. Click on the bottom that says "perform multi-aperture photometry," it will automatically choose reference stars for you. (Your images may look like this.)



3.2 We should revert our windows to proper settings to analyze light curves by uploading this file. (www.astrodennis.com/Template.zip). In the Multi-plot Main window, change the "Default X-data" to "BIJD-TDB" and enter the decimal portion of ingress and egress times in the "V.Marker 1" and "V.Marker 2" boxes. Fill in the title and subtitle section with proper content. In the "Data Set 2 Fit Settings" window, enter the target's period and radius of the host star. Uncheck all detrending parameters and check "Show Residuals" and "Show Error." Go to "Multi-plot Y-data", check and uncheck the boxes to examine the fluxes of the stars(make sure the settings are correct) and eliminate any lousy reference stars. Finally, do an NEB check to rule out any false positives.

**You can see a detailed explanation of steps and specific settings in*

Campus Telescope TESS Follow-Up Light Curve Tutorial - Schar Program.docx

4. Results

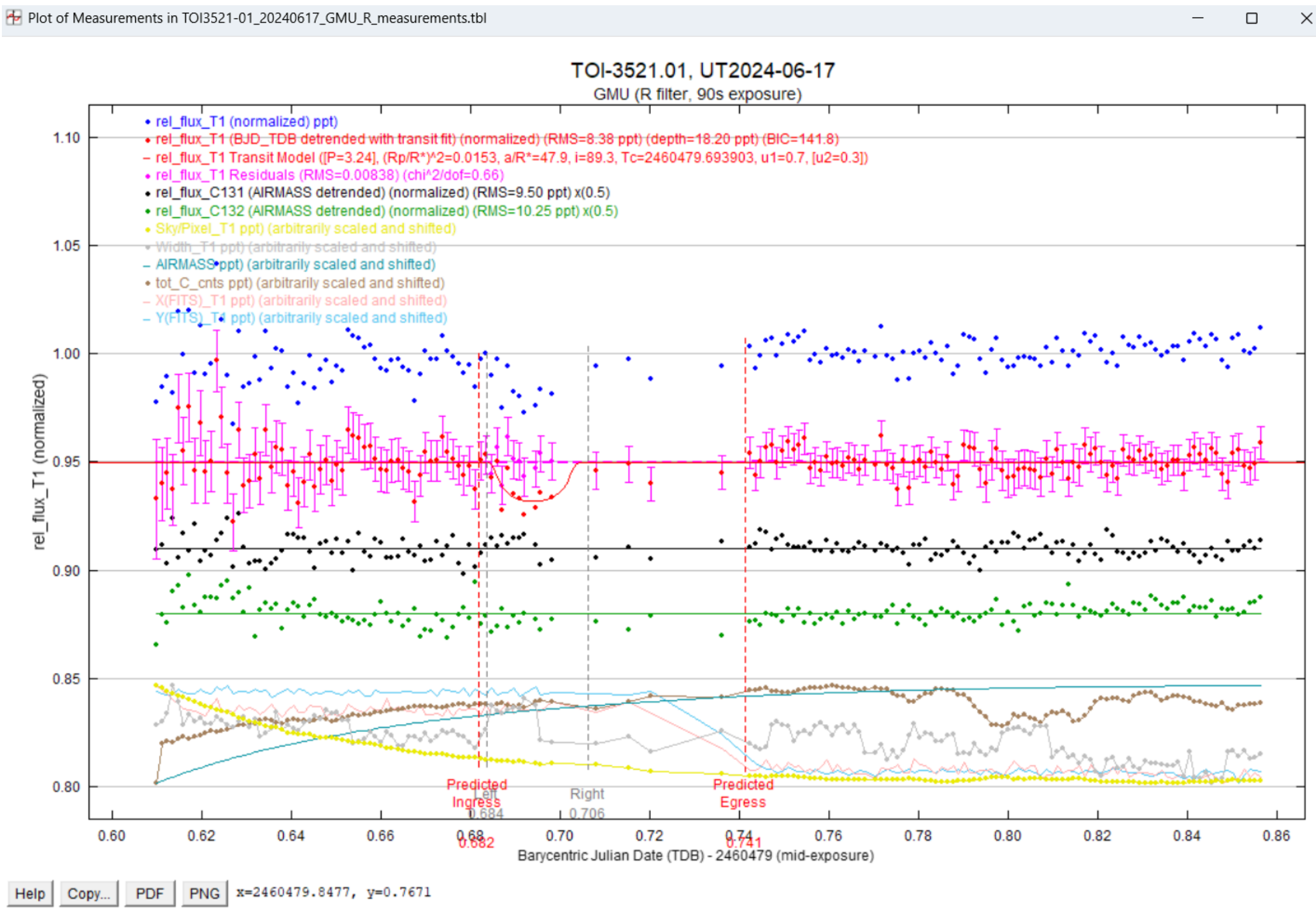


Figure 1. *light curves of TOI-3521.01*

The light curve was detrended by BJD-TDB. We can see an obvious dip(red) between the ingress time 0.684 and the egress time 0.706. The transit depth is 18.2ppt.

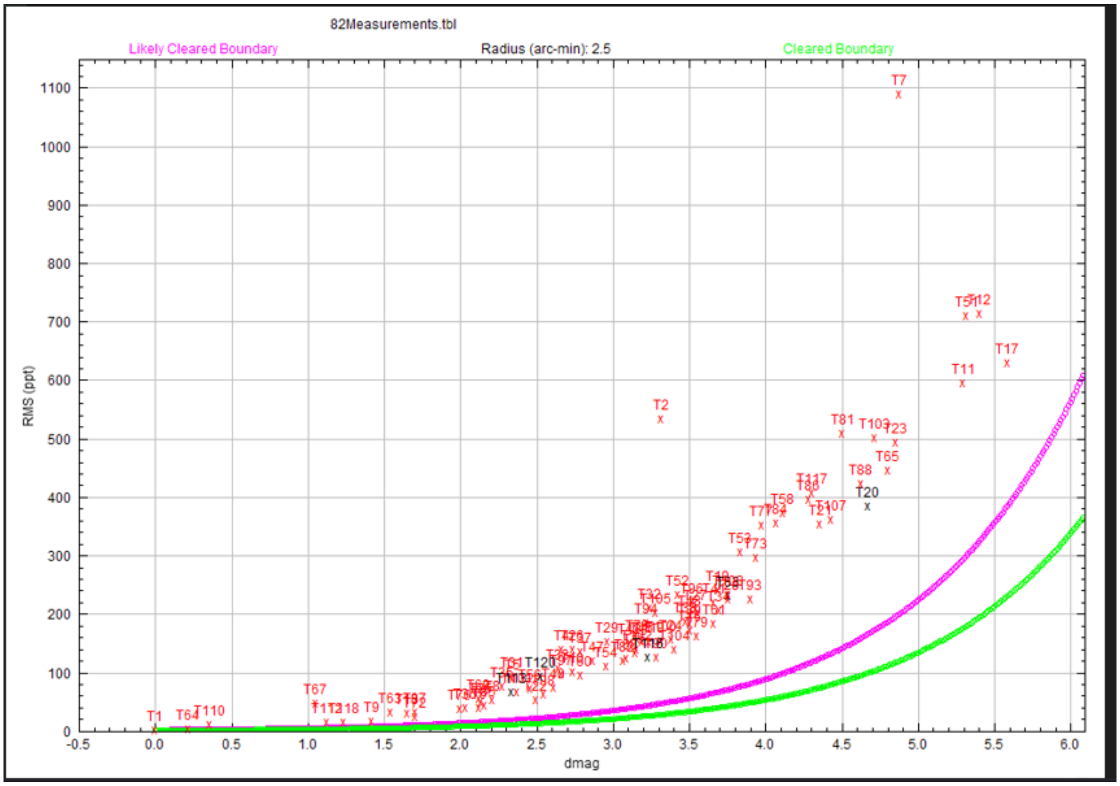


Figure 2. *NEB checks*

NEB stands for nearly eclipsing binary. The job of the NEB check is to rule out these NEBs to avoid a false positive result. In our NEB check, 30 are marked as “Not Cleared-flux too low,” 89 are marked as “Not Cleared,” and one is marked as “Cleared-too faint.” All the stars are above the “likely cleared” boundary.

5. Discussion and Future Work

In Section 5.1 we present our interpretation of our results. In Section 5.2 we present our conclusion and improvement for future work.

5.1 In Figure 1, the visible dip indicates that there may be an exoplanet(or others) blocking a part of the light of our target star when passing through. Using predicted ingress and egress time as a reference, we can say our transit occurs within a reasonable time. However, the transit depth, 18.2ppt is quite different from the expected depth, which is 10.7 ppt. To further verify, we did our NEB checks. In Figure 2, we cannot rule out false positive signals since none of the stars were below the likely cleared boundary. In other words, we cannot determine if an exoplanet causes the transit dip in Figure 1.

5.2 Our follow-up validation didn't succeed in verifying the existence of an exoplanet. However, future observations can use a larger telescope with longer exposure times to ensure the NEB is ruled out.

References

1.https://exoplanets.nasa.gov/tess/

2.https://docs.google.com/document/d/1MZU2kb9ahNhv7tdghKX7EUUo-ub_7mJr/edit

3.https://exoplanetarchive.ipac.caltech.edu/overview/TOI-3521.01#overview