Ground-based light curve follow-up validations observations of TESS object of interest TOI 3521.01

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Abstract

The reason for this study was to confirm whether TOI- 3521.01, detected by the Transiting Exoplanet Survey Satellite (TESS) is in fact an exoplanet. We finalized this finding by separating the Dark and Flat images, data-reduced the sciences, aligned the plate-solved images, and placed multiple apertures on the previously aligned images. We received ground-based observations of TOI - 3521.01 and were expected to utilize multiple programs to classify this science. Through our model, we were unable to identify TOI - 3521.01 as an exoplanet, due to lack of sufficient data to properly finalize the science (Oxford Academic et al. 2022).

Introduction

The purpose of the TESS (Transiting Exoplanet Survey Satellite) is to explore the night sky in search of planet candidates. However, its cameras are of “low spatial resolution” (Oxford Academic et al. 2022). TESS detects False Positives more often than not, meaning multiple screenings need to occur before confirming or denying the observations. The images need to go through AstroImageJ, and python programming to be data-reduced, plate solved, aligned, and have multiple apertures. Following that, the data is plotted to be analyzed.

There have been multiple studies regarding TESS missions and have been gaining ever-growing importance for future studies. TESS is used to detect smaller planets with bright host stars so that we could potentially do missions to that planet for further research. However, without ground-based research we cannot know for certain if we were given a false positive or images of an actual small planet. When conducting this research we can figure out what the planet's mass is and if it is similar to Earth's. This research can eventually lead to the question of whether we can explore that planet's territory even more.

From the new investigations that have arisen due to the ever-approaching problems of our world, we have turned to exploring other planets. Through the National Aeronautics and Space Administration TESS missions, we have been able to explore planets beyond our scope almost 20 years ago that we couldn't even think about. Many others have found planets that have been crucial in our on-going investigation to find planets that can sustain life. TOI - 3521.01 has been identified as a potential prospect, but further research will need to be conducted to be completely positive.

In this paper, we present follow-up observations of TOI-3521.01. Although inconclusive due to difficulties with the identification programs, we have collected data that can be used for later research. TOI - 3521.01's orbital period is approximately 3 days. Through this paper, we will present the data that we were able to collect and what leads the data to be inconclusive.

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. In Section 5 we discuss our results and in Section 6 we present our conclusions and future work.

Observations

In Section 2.1 we present the TESS Object of Interest 3521.01 and its exoplanet candidate properties, its host star properties from the TESS Input Catalog, the Gaia mission, and other archival sources. In Section 2.2, we present the TESS sector light curve(s). In Section 2.3, we present a summary of the observations data collected with the George Mason University 0.8m telescope.

2.1:

We started with the raw data and needed to plate-solve and align the images to make sure there were not any "compromised" images, i.e. blurry or clouded. TOI - 3521.01 had 195 exposures with an exposure time of 90s. The images were taken on 2024 - 06- 17 using the R filter. Using the Gaia .radec files, the RA and Dec values were 21:07:45.528 and 31:46:51.43, respectively (Exofop et al. 2017).

2.2:

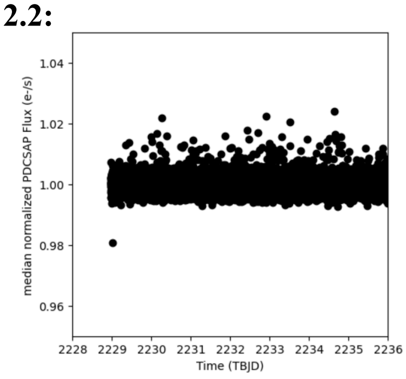

Figure 1. Normalized and modeled transit light curve graph of TOI - 3521.01

To analyze the flux in comparison to time, we needed a normalized light curve and by inputting the specific data, we were able to generate a graph that showed the relationship (*Figure 1*). We calculated the transit depth (RP/R*) of TOI - 3521.01 to 10.72, with no previous literature to compare it against (Exoplanet Archive et al. 2011).

2.3:

From the above data, we can see that the amount of energy from a luminous object that reaches a given surface or location is not fluctuating except for a few uncommon instances. Imagine a star of luminosity L, surrounded by a huge spherical shell of radius 2. Then assuming that no light is absorbed during its journey out to the shell, the radiant flux, F, measured at distance r is related to the star's luminosity. This is the equation:

$$F = \frac{L}{4\pi r^2},$$

Equation 1. Equation to calculate star luminosity.

<u>Analysis</u>

In Section 3.1 we present our tools used to analyze the TESS sector light curve(s) using AstroImageJ. In Section 3.2, we present our analysis of the ground-based light curve using AstroImageJ.

3.1:

AstroImageJ is just one of many resources that have been used to discover over 5000 exoplanets or validated to orbit other stars to date (Akeson et al. 2013). The first step with AstroImageJ was Data-Reduction & Plate-Solving the raw data. This means extracting the Dark and Flat images and using them to create one singular plate-solved image. By plate-solving, we have "reduced" the pixels making the images smoother when we are using them for multi-apertures.

Multiple apertures occur after the images have been aligned using the Target Star and Reference Stars for location. Multiple apertures are used to collect more light so you can see more nearby stars and other faint objects. By doing this, we will be able to rule out any other objects from the field of vision and be able to focus only on the main Target Star.

Following the Multiple Apertures, we complete Light Curve Extraction. This is done using AstroImageJ measurement tables, a Seeing Profile, and many others. In the end, we create a light curve**,** which can be used for interpretation.

3.2:

Unfortunately, there was not enough data that was reduced and plate solved, so there was no proper light curve that was created. Below are two light curves, but they were corrupted due to a few "compromised" images. However, we were able to identify multiple reference stars that could be very helpful in identifying the science.

Results

In Section 4.1, we present our observations and graphs produced from our procedure. In Section 4.2, we present our observations on the light curves and possible problems.

4.1:

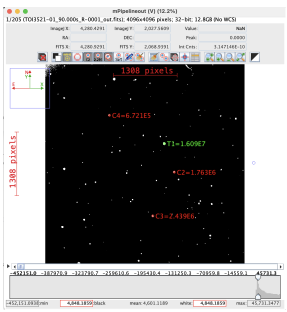

Figure 2. Plate solved image after data reduction

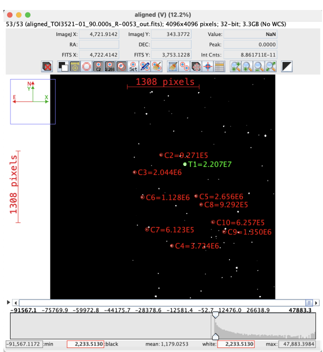

Figure 3. Multiple Apertures Placed, Red Stars are the Reference Stars and Green stars are the Target Stars.

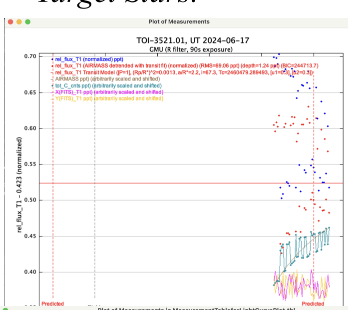

Figure 4. Light Curve uncentered due to egress and ingress times

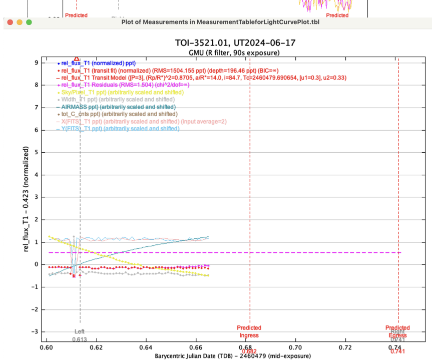

Figure 5. Light Curve corrupted with 3 "compromised" images

Plate-solving *(Figure 2)*was fundamental in creating the light curve which you can find above *(Figures 4&5)*. In order to get these curves, we need to create multi-apertures with a target and reference star. When the multi-apertures ran *(Figure 3),* it created data points which were graphed to create the light curve. Without the multi-apertures, there would be too many targets, so the target star would not be able to be identified correctly.

4.2:

In figures 4&5, the light curves are not centered nor are completely taking up the graph space. This could be for multiple reasons, such as insufficient data, failure to plate-solve, and compromised images. Due to this, our data light curves are not sufficient to identify whether the exoplanet is subject to future research.

Discussion

In Section 5.1 we present our interpretation of our results. In Section 5.2 we place our results into context of the greater field of the follow-up of candidate exoplanets from the NASA TESS mission.

5.1:

Unfortunately the plate solving software did not sync properly with the Apple computer, which resulted in inconclusive results. Further research will have to be conducted in order to completely rule out TOI - 3521.01 as not an exoplanet.

5.2:

TOI - 3521.01, was surrounded by reference stars that would suggest it is an exoplanet of some sort, but plate-solving was not completed. When attempting to create the NEB graph, it did not show reference and target stars so we cannot rule out a false positive from any uncleared stars.

Conclusions and Future Work

TOI - 3521.01, was unidentified due to an inability to create a light curve with sufficient data. This data was obscured since AstroImageJ was incapable of compiling the data into the NEB, and further, the light curve.

Due to the inability to complete the research conducted on TOI - 3521.01, the detailed statistical false-positive validation analysis will be left for future work. The light curves that were produced would need to be corrected and used as the first step in future research on this unidentified science. Longer exposure times would be preferable in future attempts as that would make the images easier to analyze for target and reference stars.

References

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