Ground-based light curve follow-up validation observations of TESS object of interest TOI 5907.01

Rutu Patil[1] and Dr. Peter Plavchan[2]
Acton Boxborough Regional High School, MA, USA [1]
Department of Physics and Astronomy, 4400 University Drive MS 3F3, George Mason University, Fairfax, VA 22030, USA [2]

Abstract

The Transiting Exoplanet Surveillance Satellite (TESS), created in 2018, is an MIT-led mission to detect exoplanets. It has gathered data for 75% of the night sky and confirmed 542 exoplanets, with 7208 candidates (3). This observational study aims to verify the existence of TESS Object of Interest (TOI) 5907.01, one of these candidates. We used AstroImageJ (AIJ) to perform multi-aperture photometry on the 77 exposures taken using GMU's 0.8 lens. Additionally, we conducted a Near Eclipsing Binary (NEB) check to verify that the transit caused was truly due to the planet, not a binary star close to the TOI. We found a clear transit at the expected times with the expected depth for TOI 5907.01. However, our NEB check was inconclusive, meaning we cannot fully rule out the possibility of a false positive.

Introduction

The first exoplanet was discovered in 1988 and later confirmed in 1992 by the Arecibo Observatory. (1). After this discovery, human curiosity about what lay beyond our solar system skyrocketed. With newly developing technology and advanced satellites, the number of confirmed exoplanets can likely increase by tens of thousands in under ten years (2). TESS has made a large amount of exoplanet discoveries. The satellite's mission began in 2018 intending to image 75% of the night sky in 2 years. This mission was largely successful, and the satellite has discovered over 7000 exoplanet candidates, with 543 confirmed. (3). TESS validates these candidates by "modeling the multicolor transit photometry with a transit model that includes a physics-based light contamination component" (4).

This study concerns TOI 5907.01, discovered by TESS in 2022 (5). A follow-up analysis of this planet is necessary, as no previously published literature verifies its existence as an exoplanet. Verifying TOI 5907's existence will add to existing knowledge of extrasolar planetary systems and increase the chances of finding possibly habitable worlds outside our solar system.

In this paper, we report on ground-based follow-up observations of TOI 5907.01. It has a radius of 8.31 Earth radii and a short orbital period of 0.66 days (6). The planet orbits TOI 5907, a type G star with a stellar effective temperature of 5766 Kelvin (7). We aim to determine whether the transit takes place on a predicted star at the expected time, along with the anticipated duration and depth.

In Section 2, we outline our observations from both TESS and the George Mason University 0.8m telescope. In Section 3, we detail our analysis of the TESS light curve for TOI 5907.01 alongside our ground-based light curve analysis. In Section 4, we present the findings from our light curve analysis. In Section 5, we discuss the implications of these results, and in Section 6, we offer our conclusions and suggestions for future work.

2 - Observations

In section 2.1 we discuss the properties of TOI 5907.01 and its host star, TOI 5907. In Section 2.2, we present a summary of the observational data collected.

2.1 - Candidate Properties

We observed the target planet on June 21st, 2024 from 9:50 pm to 4:00 am on June 22nd. TOI 5907.01 has a right ascension (RA) of 21h:00m:52.78s, and a declination (Dec) of +17d:06m:59.14s. We observed the target object using the George Mason University 0.8m telescope. Data from the NASA Exoplanet Archive shows that TOI 5907.01 has a radius of 8.31 Earth radii and an orbital period of 0.66 days. Also, its equilibrium temperature is 1963 Kelvin and an expected transit depth of 0.37 parts per thousand (ppt) (6).

2.2 - Observational Data

Using the George Mason University (GMU) 0.8m telescope with the R filter, 172 exposure science images were taken with a 90-second exposure time. After eliminating unusable images we were left with 77 science images for analysis and multi-aperture photometry.

3 - Methods and Analysis

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

3.1 - Analysis Tools and Process

To analyze the science images taken by GMU's 0.8m telescope, we used AstroimageJ (AIJ), a software application in which we plate-solved and performed multi-aperture photometry on the science images and generated a light curve from the data gathered.

To prepare for data reduction and processing in AIJ, we went through each of the science images taken and removed unusable images – ones in which the image was blurry, or streaking occurred on the objects in the image.

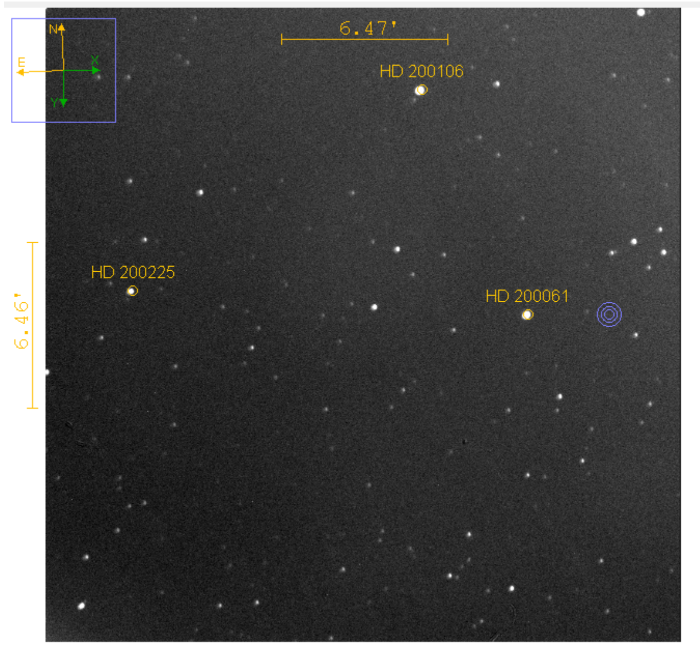


Figure 1: Plate solved stack of science images of TOI 5907.01

Additionally, we utilized dark and flat images taken by the telescope to correct for distortion and eliminate thermal noise in the science images. Afterward, we used AstroimageJ's plate-solving software and an astrometry.net plugin to align the images (Figure 1). Plate solving was helpful in the scientific process because it allowed us to align all the images into a stack, making it easier to locate the target object in the sky.

After plate solving, we performed multi-aperture photometry on the image stack using AIJ's multi-aperture photometry tool. We did this to find comparison stars for the target and generate a seeing profile to find the planet's radius (Figure 2). To perform multi-aperture photometry, we also needed to download a file of reference stars (Figure 3) from the Gaia mission, whose precise data allowed us to have accurate reference stars for the target object.

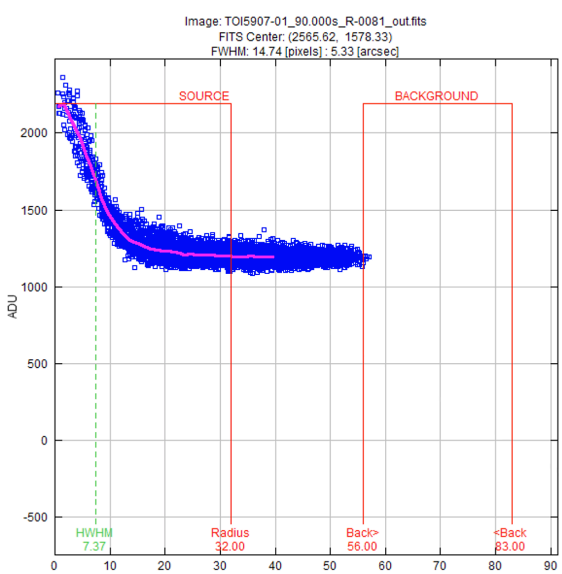


Figure 2: Seeing Profile of TOI 5907.01 generated by AIJ, displaying its radius

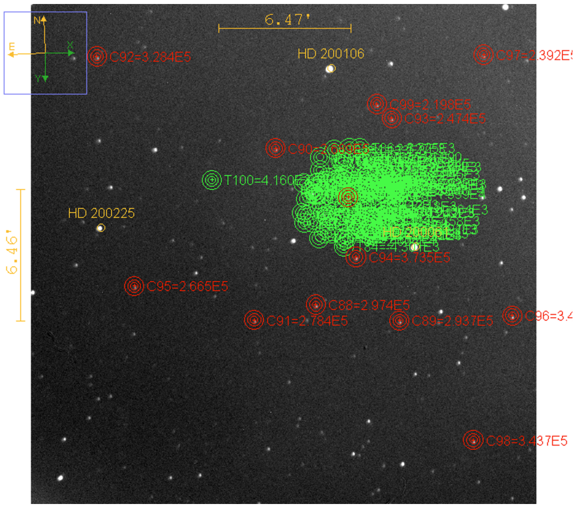
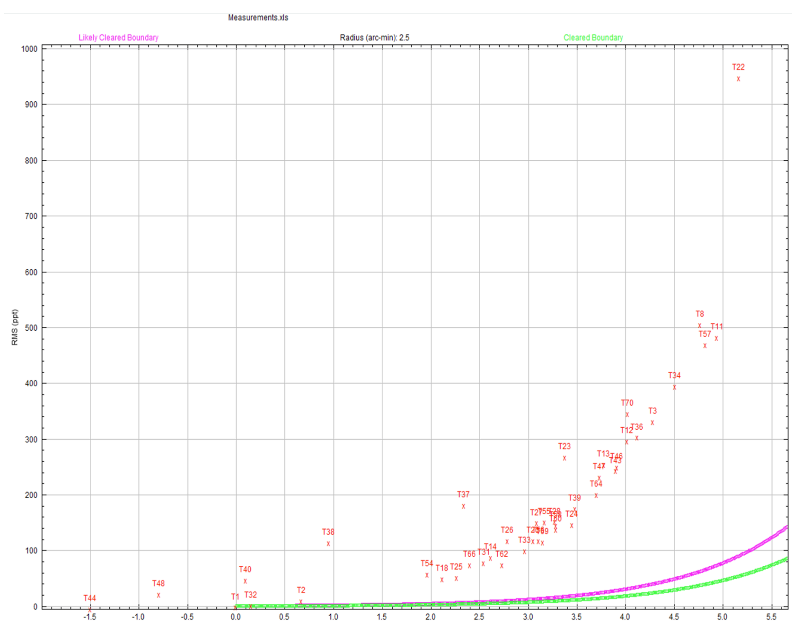


Figure 3: AIJ image stack of the target along with Gaia stars (green) and reference stars (red)

3.2 - Analysis of Ground-Based Lightcurve

After plate solving and multi-aperture photometry, we utilized AIJ to generate TOI 5907.01's light curve (Figure 5). The light curve created by AIJ used a detrending parameter of AIRMASS to correct for atmospheric interference, as well as the relative flux of a comparison star and the target star. To rule out the possibility of a false positive, we conducted a Near Eclipsing Binary (NEB) check (Figure 4). This analyzes the depth of magnitude (DMag) vs. root mean squared (RMS) of the transit to see if it was truly caused by the TOI or a different celestial object such as an asteroid or NEB.

Figure 4: AIJ Generated Dmag vs. RMS plot of TOI 5907's transit



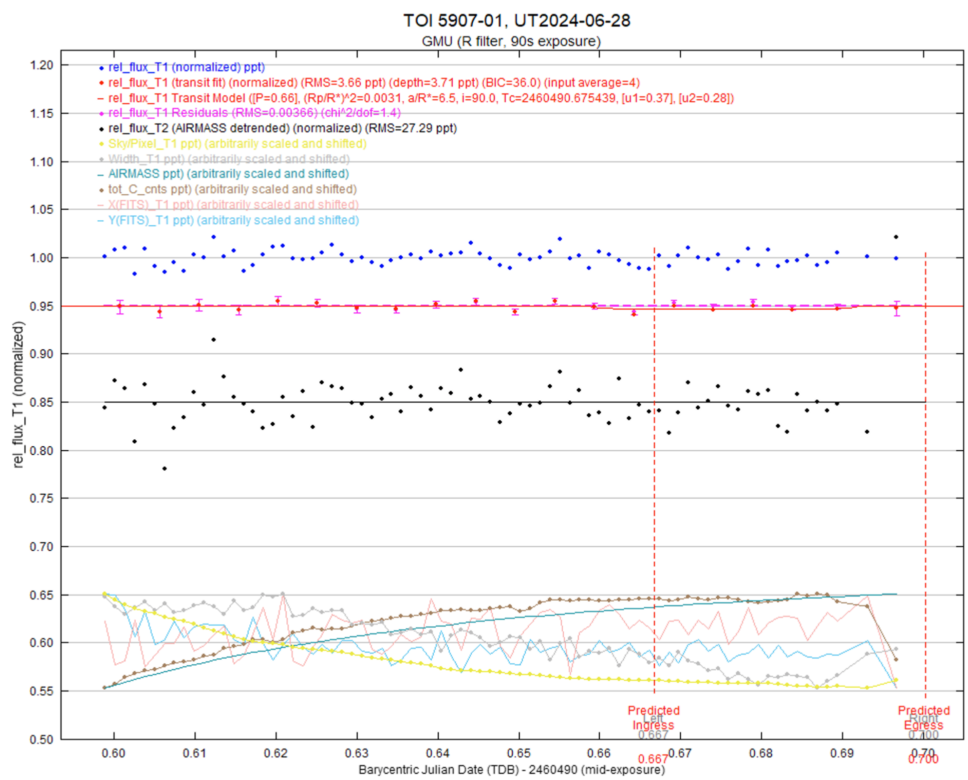


Figure 5: AIJ Generated Light Curve of TOI 5907.01

4 - Results

In Section 4, we discuss the results of our ground-based observational study.

Figure 5 displays the light curve of TOI 5907.01 graphed using AIJ. The dip in the red line on the plot shows a detectable transit that mostly occurs during the predicted ingress and egress times, with the earlier part of the transit occurring before the predicted ingress time. However, there is a margin of error of 25 minutes for when the transit occurred, meaning the light curve model gives significant evidence to confirm the existence of TOI 5907.01. We used AIRMASS as a detrending parameter in the light curve plot. Figure 4 depicts the NEB check conducted for the target object. It came back inconclusive, showing that we cannot rule out the possibility of the transit being a false positive caused by a different object.

5 - Discussion

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

5.1 - Interpretation of Results

Since our NEB check was inconclusive (See Figure 5), we cannot conclude whether the transit detection was a false positive. This may be due to the lens of the telescope used for data collection being optimized to view the target object, as opposed to near eclipsing binaries that were not captured clearly due to the shorter exposure time of 90 seconds. These limitations are the main contributing factors to the failure of the NEB check. Additionally, with a reduced chi-squared value of 1.4, our model fits the data fairly well, but there is still room for improvement in future analysis of the target object. However, the predicted transit depth of 3.74 parts per thousand (ppt) matches very closely with the observed transit depth of 3.71 ppt, and the transit duration matched the expected ingress and egress times shown on the light curve plot (See Figure 4). This makes it more likely that TOI 5907.01 can be confirmed as an exoplanet.

5.2 - Implications for TESS Exoplanet Follow-up Studies

The target object has a radius of 8.31 Earth radii and an orbital period of 0.66 days. These characteristics make TOI 5907.01 most likely to be classified as a Hot Neptune (8). Despite the lack of previously published work on 5907.01, a confirmed exoplanet, TOI 674 b, is classified as a Hot Neptune with a radius of 5.25 Earth radii and an orbital period of 1.97 days (6). As both of these planets fall within the classification of Hot Neptunes, this provides significant evidence that TOI 5907.01 is likely a Hot Neptune, if not a false positive.

6 - Conclusion and Future Work

The goal of this observational study was to analyze data collected from George Mason University's 0.8m telescope to verify the existence of TOI 5907.01. We found that the transit occurred during the predicted ingress and egress times, with a depth of 3.71 ppt, similar to the predicted transit depth of 3.74 ppt (6). Additionally, future analysis of the target is necessary due to an inconclusive NEB check, maintaining the possibility of a false positive. Future analysis specific to an NEB check should use a larger telescope with a longer exposure time to make the check more likely to be conclusive.

Further, when compared to the parameters of confirmed exoplanet TOI 674, the target object is likely a Hot Neptune due to a temperature of 5766 Kelvin, an orbital period of 0.66 days, and a Neptune-like mass of 8.31 Earth radii. Future analysis could utilize Doppler spectroscopy to find the planet's density and provide insight into its composition (9). Using Doppler spectroscopy in future analysis will make the exoplanet classification of TOI 5907.01 clear.

References

1. Wolszczan, A., & Frail, D. A. (1992). A planetary system around the millisecond pulsar PSR1257 + 12. *Nature*, *355*(6356), 145-147. https://doi.org/10.1038/355145a0

2. Measuring Exoplanets', 04-02-2021, "Overview", Exoplanet Exploration: Planets Beyond our Solar System, https://exoplanets.nasa.gov/what-is-an-exoplanet/overview/
3. Planet Transits., 7-4-2020, "Transiting Exoplanets Survey Satellite (TESS)", Exoplanet Exploration: Planets Beyond our Solar System, https://exoplanets.nasa.gov/tess/
4. H. Parviainen, 1-3-2020, "MuSCAT2 multicolour validation of TESS candidates: an ultra-short-period substellar object around an M dwarf", Astronomy and Astrophysics, https://www.aanda.org/articles/aa/full_html/2020/01/aa35958-19/aa35958-19.html
5. ExoFOP, 07-25-2024, "ExoFOP", Caltech, https://exofop.ipac.caltech.edu/tess/view_toi.php
6. NASA Exoplanet Archive, NASA, https://exoplanetarchive.ipac.caltech.edu/index.html
7. Harvard CFA, "Spectral Classification", Harvard University, https://lweb.cfa.harvard.edu/~pberlind/atlas/htmls/note.html
8. Wuchterl, G., 12-31-2001, "Hot Neptunes: A Key To Giant Planet Formation", NASA/ADS, https://ui.adsabs.harvard.edu/abs/2002EGSGA..27.4469W/abstract
9. Laboratory for Atmospheric and Space Physics, 2007, "Extrasolar Planets", University of Colorado at Boulder, https://lasp.colorado.edu/outerplanets/exoplanets.php