Ground-based light curve follow-up confirmation of the planetary nature of TOI 3873.01

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Abstract

The Transiting Exoplanet Survey Satellite (TESS) mission collects information on thousands of potential exoplanets and their host stars (Zhang et al., 2022). This study focuses on the candidate exoplanet TOI 3873.01, which revolves around the star TOI 3873.01. The purpose of this paper is to provide ground-based observations to investigate the planetary status of TOI 3873.01. We captured 138 images using the GMU 0.8 m telescope and processed them, subsequently performing ground-based multi-aperture photometry with AstroImageJ to create a light curve. Furthermore, we analyzed the residuals and fluxes of our target stars and made adjustments to the data trends. Although the results are inconclusive and we cannot definitively confirm TOI 3873.01 as a planet, there is substantial evidence suggesting it could be a genuine exoplanet.

Introduction

Since the first exoplanets were discovered in the 1990s, the field of exoplanet research has grown rapidly. One method to detect exoplanets is by observing if they transit their host star at the predicted times. The Transiting Exoplanet Survey Satellite (TESS) mission, initiated by the Massachusetts Institute of Technology (MIT) and NASA, collects data from star systems to identify potential exoplanets. This data includes images captured by its four cameras. The potential exoplanets identified by TESS are referred to as TESS Objects of Interest (TOIs). Ground-based follow-ups aim to confirm the exoplanet status of these TOIs and eliminate any false positives.

Exoplanets need to undergo a validation process to examine their characteristics and compare them with planets in our solar system. In research conducted by Cañas et al. (2023), scientists performed both ground and space-based follow-up studies on the candidate exoplanets TOI-3984 A b and TOI-5293 A b. They used ground-based photometry, among other techniques, to confirm the existence of two gas giants orbiting

M dwarf stars. Another study by Brahm et al. (2023) validated the planetary nature of three TOIs using tools that enabled aperture photometry on TESS light curves.

In this study, we will observe and analyze data to carry out a ground-based follow-up of the candidate exoplanet TOI 3873.01. Our objective is to determine if the transit occurs at the anticipated time and with the expected depth.

Observations

In Section 2.1 we present TOI 3873.01, its properties, and the properties of its host star, from the NASA Exoplanet Archive and the Exoplanet Follow-up Observing Program. In Section 2.2 we present our observing process for TOI 3873.01.

2.1 Properties of TOI 3553

Despite extensive searches, specific data such as the right ascension, declination, and effective temperature for TOI 3873.01 are not available in public databases or research papers. Its predicted transit depth is 8.97 mmag.

2.2 Observational process

We collected a total of 138 exposures using the GMU 0.8m telescope, each of which was 90 seconds. In addition to the science exposures, we collected 20 darks and 10 flats. 10 of the darks had the same exposure time as the sciences (90s), and 10 of the darks had the same exposure time as the flats (3s). We used the R filter on the telescope.

Analysis

In section 3.1 we present our data reduction process to create reduced exposures. In section 3.2 we present our analysis of the ground-based light curve.

3.1 Data reducing exposures

After collecting the exposures, we had to reduce them to cancel any distortions in the images. Using the CCD Data Processor and DP Converter features in AstroImageJ, we created a master flat dark and master science dark. Then, we subtracted each raw flat with the master flat dark. Next, we created a master flat from the dark subtracted flats. After, we dark subtracted and flat divided our raw sciences to result in reduced sciences. Lastly, using the plate solve feature of AstroImageJ we plate solved all of the reduced exposures.

3.2 Ground-based light curve analysis

We conducted aperture photometry and multi-aperture photometry to generate our light curve (Ha & Boyce, 2020; Conti, 2020). Initially, we generated a seeing profile from the plugins dropdown of AstroImageJ. We also created a 2.5’ radius around the target using the Annotation Text window in AstroImageJ.

We began multi-aperture photometry by using the Multi Aperture tool from AstroImageJ (Collins et al., 2017). The radius of the object aperture was 33 pixels, and the inner and outer radii of the annuluses were 59 and 88 pixels respectively. These values were obtained from the seeing profile. AstroImageJ automatically placed 11 apertures. Additionally, a measurement table was generated from AstroImageJ after the multi-aperture photometry was finished.

Then, we used the multiplot tool from AstroImageJ to analyze the ground-based light curve. We initially uploaded the Template plotcfg (https://www.astrodennis.com) to the multi-plot main window. We changed the default x-data to BJD_TDB. Using a UTC to JD converter (https://www.aavso.org/jd-calculator), we entered the predicted ingress and egress into the V. Marker 1 and V. Marker 2 sections, and selected the auto x range for the plot.

In the Data Set 2 Fit Settings window, we entered TOI 3873.01’s period and its radius. We assumed the metallicity of TOI 3873.01 was 0, and then used its effective temperature and surface gravity values to find Linear LD u1 and Quad LD u2 (Eastman et al., 2013). We detrended AIRMASS and Width_T1, and we showed residuals with error.

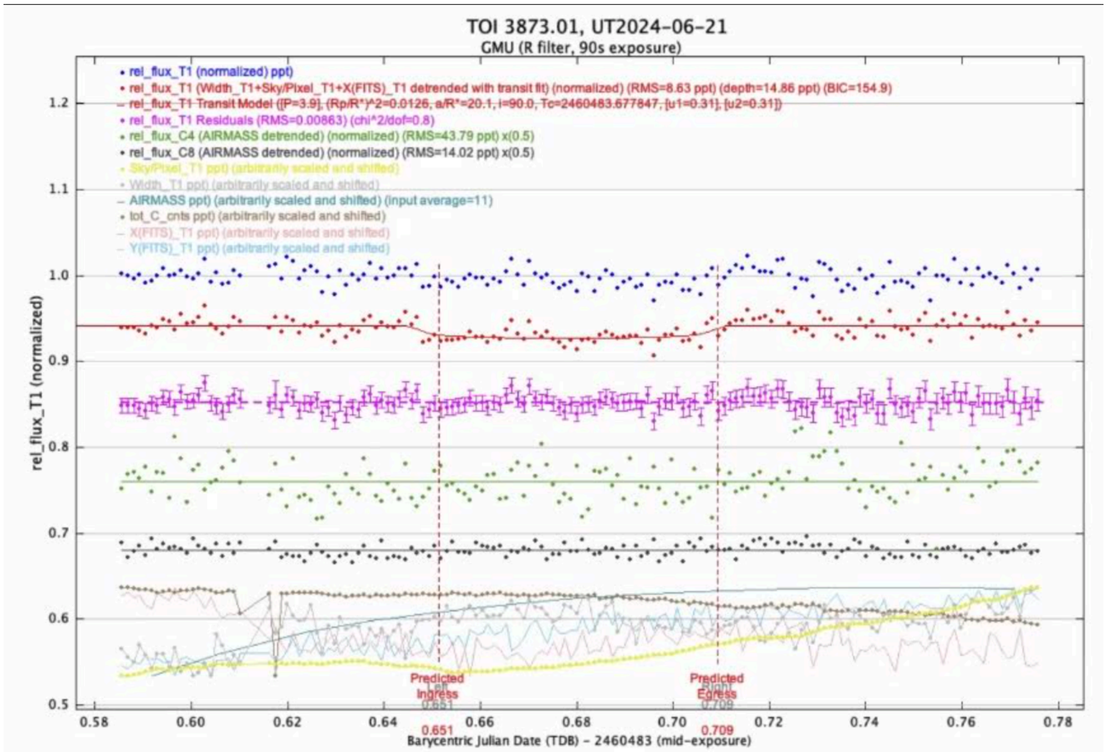
We plotted Sky/Pixel_T1, Width_T1, AIRMASS, tot_C_cnts, X(FITS)_T1, Y(FITS)_T1 using recommended scale, shift, and color from the latest TFOP SG1 Guidelines.

Results

In Section 4.1 we present our ground-based light curve from our data analysis.

4.1 Figures

Figure 1 Plot of Ground-Based Light Curve



The normalized transit depth on the curve is 14.86 ppt

Discussion

In section 5.1 we discuss our interpretation of our results. In section 5.2 we discuss our results in the context of the greater field of follow-up research for the NASA TESS mission.

5.1 Interpretation of results

We were not able to confirm the planetary nature of the candidate exoplanet TOI 3873.01. The predicted ingress time was accurate, but the predicted egress was too late, as shown by the red and gray vertical lines in Figure 1. The clearer egress time can be applied in other analyses of this exoplanet. The transit depth from our ground-based light curve (14.86 ppt) was larger than the predicted depth (8.97 mmag). We will assume 1 mmag = 1 ppt. Detrending the AIRMASS may have adjusted the transit depth.

5.2 Results in the context of the greater field

Other works were able to classify their candidate exoplanets as gas giants (Cañas et al., 2023; Brahm et al., 2023). Additionally to not being able to conclude 3873.01 as a real exoplanet, we were not able to classify the planet or discover its properties. However, there is convincing evidence that it could be a real exoplanet. There has been no work published on the observation or ground-based analysis of this exoplanet.

Conclusion and Future Work

Our goal was to confirm the planetary nature of TOI 3873.01 using data reduction and multi-aperture photometry to generate a light curve and conduct NEB analysis. We created a ground-based light curve of the transit of TOI 3873.01. The light curve showed a clear transit with egress and transit center time later than expected. The transit depth was larger than expected.

Further analysis can be conducted on TOI 3873.01 in the future. Further research can be done on the properties of this exoplanet to learn more about its characteristics. The light curve can be further analyzed in software like ExoFASTv1 to determine more of its properties and detrend more values. In addition, we were unable to perform false positive testing for TOI 3873.01, so that can be done in future research.

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