# Ground-Based Light Curve Follow-Up Validation Observations of TESS Object of Interest 3772.01


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## Abstract

Transiting planets around host stars is crucial to understanding the formation and evolution of planetary systems. Through TESS, TOI-3772.01 was identified around a host star, TOI-3772. This paper focuses on validating the transiting method leading to the identification of TOI-3772.01. We present the characterization and possible confirmation of a transiting exoplanet around a host star. Through transit photometry, we created a ground-based light curve and performed analysis using the software AstroImageJ to validate the transit of our candidate exoplanet. Due to the limited scope of our research, we did not perform other detection methods such as radial velocity measurement using a high-resolution spectrograph, and false-positive analysis using Vespa. The light curve generated seems to indicate a definite detection of a planet. However, we cannot reach a definitive conclusion on whether host star TOI-3772 is orbited by candidate exoplanet TOI-3772.01 due to the NEB indicating a false positive. Future work using other methods like radial velocity, high contrasting imaging to rule out binaries, and false-positive analysis using Vespa will provide more conclusive evidence.


## Introduction

An exoplanet is an astronomical object with a minimum mass “sufficient both for self-gravity to overcome rigid body forces and for clearing the neighborhood around the object’s orbit” [1]. Since the launch of the Transiting Exoplanet Survey Satellite (TESS) in 2018, the National Aeronautics and Space Administration (NASA) has surveyed over 200,000 stars to detect exoplanets through transit spectroscopy [2], of which the majority were discovered through radial velocity and transit spectroscopy [3]. Light curve analysis is essential for inferring the presence of an exoplanet by the dimming of a star's brightness over time [4]. Currently, only about 2560 out of 7208 TESS candidates have been confirmed [5]. Confirmation of additional TESS candidates through ground-based observations is essential for improving the accuracy of estimations on the prevalence of various planetary types in our galaxy. This is crucial for gaining a deeper understanding of planet formation and evolution. TESS observations also found other Earth-size planets with habitable conditions, increasing the future possibilities of finding life on other planets. Since no publication has been written on TOI-3772.01, further studies are needed to validate the presence of the exoplanet to provide more insights into alternative models of planetary formation.

Here we present follow-up ground observations of candidate exoplanet TOI-3772.01 around the host star TOI-3772. The goal is to investigate whether or not transit occurs on 2023 December 12 with a transit time of 2.191±0.242 hours and a transit depth of 7081.420 ppm [6].

In **Section 2,** we present the observations and light curve of TOI-3772.01 from TESS as well as from the ground by the George Mason University 0.8m telescope. In **Section 3,** we present the analysis methodology of AstroImageJ. In **Section 4**, we present our ground-based light curve results. In **Section 5** we discuss our results. Finally, we present our conclusion in Section 6 and discuss future work.

# Observations

In **Section 2.1**, we present the observation dates of TOI TOI-3772.01 by TESS as well as its characterization from the TESS Input Catalog, the *Gaia* mission, and other archival sources. In **Section 2.2**, we present a summary of the observational data collected with the George Mason University 0.8m telescope.

## 2.1 TESS Observational Data

TOI-3772,01, or TIC 426319499, was first observed on Cycle 2 of the TESS mission in Sector 23. Further observations during Cycle 5 of TOI-3772.01, or TIC 426319499, comprised Sector 62 [7]. According to the EXOMAST website, TOI-3772.01 exhibits a temperature of 1050.89 Kelvin. Located 309.143 parsecs away from Earth, TOI-3772.01 has the right ascension of 05h44m10.44s, the declination of +36d04m50.35s, an orbital period of 4.1689145 Earth days, transit duration of 2.372±0.293 hours, transit depth of 3650±5.37467 ppm, Earth radius of 6.16071, Earth flux of 352.72 [6].

## 2.2 Data Collected From Ground Observations

We observed TOI-3772.01 overnight on 2023 December 12 using the George Mason University 0.8m telescope with a R filter. There were a total of 182 exposures taken, with the exposure time being 85 seconds starting at 6:35 p.m. EST and ending at 6:15 a.m. EST the next morning. The ingress time started at 10:35 p.m. EST on 2023 December 12 and ended at 12:54 a.m. EST on 2023 December 13. Thus the duration of the transit as seen from ground observation was 2 hours and 19 minutes.

# Analysis

In **Section 3.1** we present our analysis of the light curve generated by AstroImageJ for TOI-3772.01.

## 3.1 Analysis using AstroImageJ

**Reduction/Plate Solving.**

AstroImageJ (AIJ) is used to perform data-reduction of observed night science images taken with the George Mason University 0.8m telescope. Each science image is inspected for issues such as overcast skies, light pollution, and instrumental errors. Problematic sciences are put into a separate file where they will not be analyzed by AIJ, which processes images by subtracting dark images and dividing them by flats. In conjunction with data reduction, AIJ automatically plate solves by connecting to nova.astrometry.net to identify astronomical objects in the image. After plate solving, AIJ assigns right ascension (RA) and declamation (DEC) coordinates to the image.

**Light Curve Extraction.**

Through aperture photometry, AIJ generates a light curve. We selected a target star using the aperture photometry tool, which pulls up a “Seeing profile” window showing the values of the radius, inner annulus, and outer annulus. Aperture photometry settings and information on the George Mason University Observatory CCD was inputted. The default template for aperture photometry is used [8]. In the “Multi-plot main” window, we input the value of the ingress and egress times of the star, as well as information about the star and planet. We chose the target star and Next, the Data Set 2 Fit settings page was pulled up. Details of the remaining steps leading to the creation of the light curve are stated in “AstroImageJ (AIJ) Tutorial for Transiting Exoplanet Data-Reduction & Analysis” [9]. For both overlay of the normalized relative flux depth over time for the target star in **Figure 2** and the dmagRMS plot as shown in **Figure 4**, we used the “Create NEB search reports and plots” option on the multi-plot main window. We then followed instructions 8b to 8e of the AstroImageJ Tutorial [8]. We used the measurement table for the ground-based light curve and uploaded exposure number 67 of the reduced images to create both charts.

# Results

In **Section 4,** we present the Seeing profile of TOI-3772.01 on AstroImageJ in **Figure 1**, AstroImageJ apertures illustrating TOI-3772.01and the reference stars in **Figure 2**, the results of our ground-based light curve shown in **Figure 3**, dmagRMS plot we generated as shown in **Figure 4,** dmagRMS plot of a confirmed exoplanet in **Figure 5**, and in **Figure 6**.

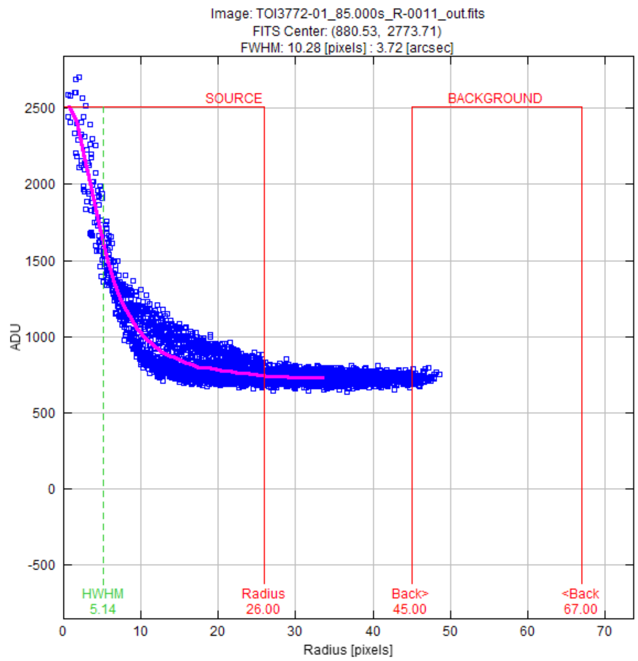


**Figure 1**: Seeing profile of TOI-3772.01 on AstroImageJ


**Figure 2:** AstroImageJ apertures illustrating TOI-3772.01 (green) and the reference stars (red)

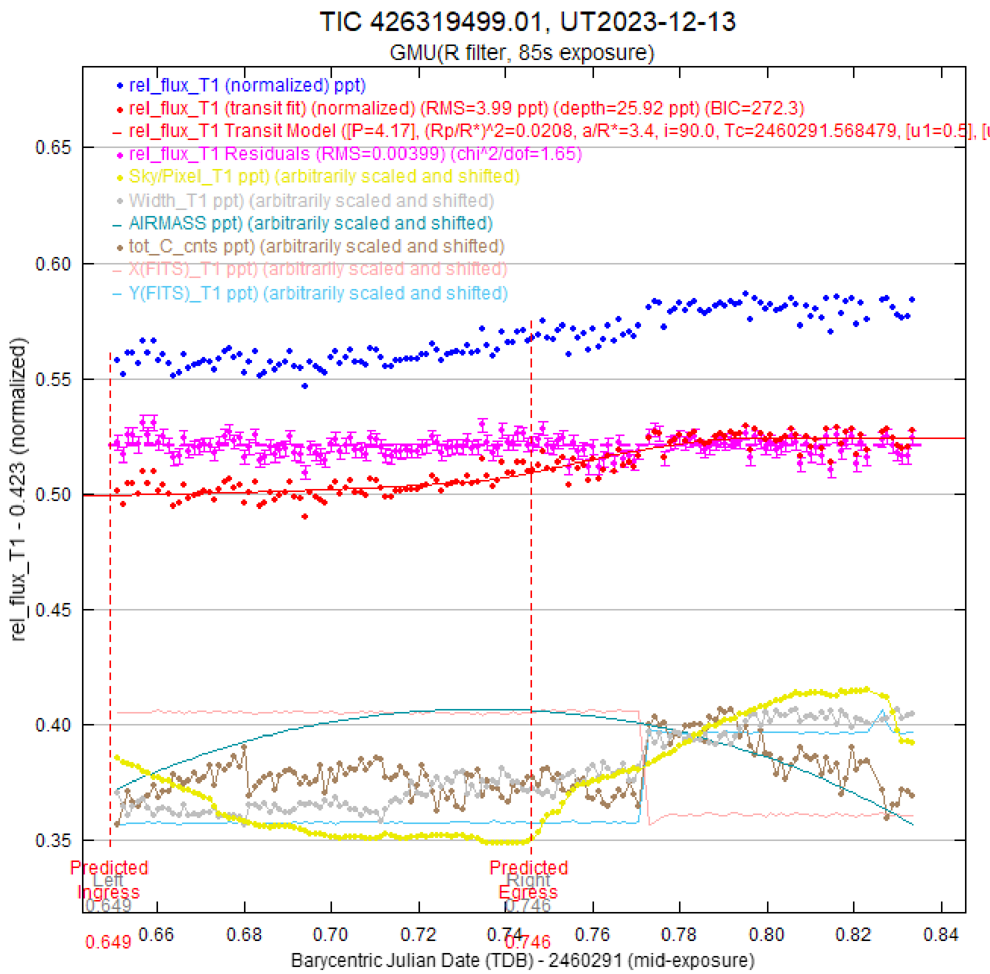


**Figure 3:** Ground-based light curve of TOI 3772.01

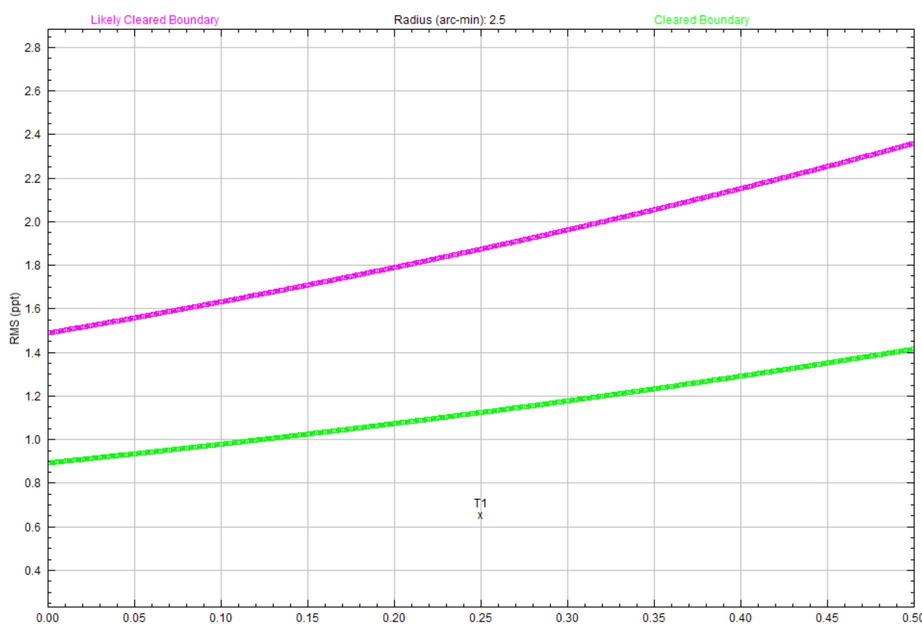


**Figure 4:** dmagRMS plot of TOI 3772.01

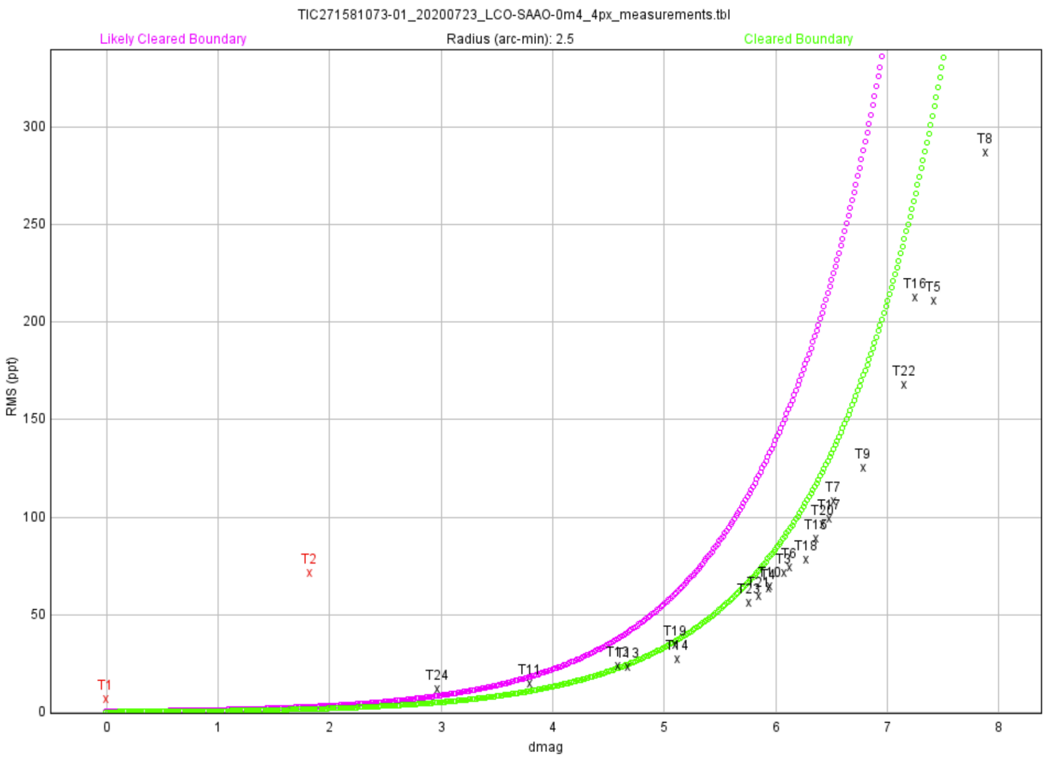


**Figure 5:** dmagRMS plot of a confirmed exoplanet.

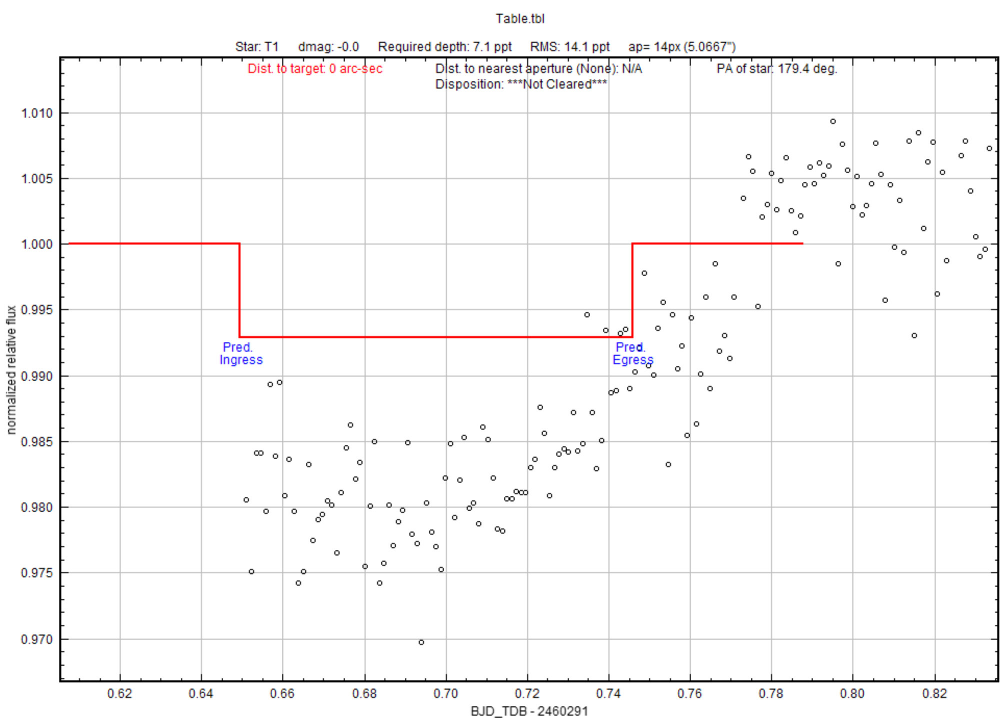


**Figure 6:** Near Eclipsing Binary (NEB) plot

# Discussion

In **Section 5.1** we present our interpretation of our results.

## 5.1 Interpretation of the Results

Since only 27 images are quarantined from a total of 182 images, the relatively small number of quarantined images suggests that clouds and instrumental errors have a minor impact on the ground-based light curve results. When comparing **Figure 4** (our dmagRMS plot) with **Figure 5** (dmagRMS plot of a confirmed exoplanet), the flatter graph on **Figure 4** suggests a false positive. We perform the AstroImageJ's nearby eclipsing binary (NEB) check to further confirm false positive. The light curve was detrended with AIRMASS and tot_C_cnts. The overlay of apertures over slice 120 as shown in **Figure 6** shows a 0.0075 flux difference, with roughly half of the stars being below the NEB analysis plot. This indicates that there is a chance of a false positive. While there was a definite dip in the light curve, we could not reach a definite judgment regarding whether or not the dip in the light curve was the result of a transiting planet because the NEB check indicated a false positive. Furthermore, **in Figure 3**, the ingress time does not align with the dip in the detected light while the egress aligns. This abnormality and the star's small size indicate that there may have been a larger object that we observed that transited the star than the one that was observed by the TESS satellite.

# Conclusion and Future Work

The resulting light curve from ground observation shows the exoplanet candidate as a possible transiting planet orbiting the host star TOI-3772. The NEB check from AstroImageJ is inconclusive regarding it as a false positive due to errors in processing the data and the limitation of the telescope used for ground observation.

Additional work is required to further validate TOI-3772.01 as an exoplanet. We could perform radial velocity measurements using high-resolution spectrographs to help find accurate mass and density and also to detect minute Doppler shifts caused by planets orbiting stars. Additionally, the detection of the presence of eclipsing binary stars using the Radial Velocity Method will definitely rule out false positives. We could also use a Python package like Vespa to further assess the potential of false positives [10]. All these methods will assist us in future confirmation.

# References

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