Ground-Based Follow-Up Observations of TESS Object of Interest (TOI) 5372.01

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Abstract

The purpose of this study is to further investigate TESS Object of Interest (TOI) 5372.01 through a ground based follow up, in order to determine whether it is a genuine exoplanet detection. We hope to validate the object using the transit photometry method in AstroImageJ. Through these methods, though we saw further indication of the existence of a transiting exoplanet, we were not able to fully verify its existence.

Introduction

Over the past several decades, the search for and study of exoplanet candidates has expanded rapidly. The goal of the Transiting Exoplanet Survey Satellite (TESS) is to identify and gather data on potential exoplanet candidates, in particular using the transit photometry method, or looking for variations in the brightness of stars that could potentially be caused by a transiting planet obstructing the light. In depth analysis is needed because these fluctuations can often turn out to be from other sources, leading to false positives. TESS's use of the transit technique can also help back up and confirm false positives raised by other techniques, such as the radial velocity (RV) method (Simpson et al., 2022). Over the course of its primary two year mission from 2018 to 2020, TESS surveyed around 75% of the sky, producing thousands of candidate planets, with many more discovered as a product of the extended TESS mission that ensued (*Transiting Exoplanet*, n.d.). Thousands of these candidates are still awaiting study and validation. Follow up observations to these candidates are a critical step in the process of expanding human knowledge of the worlds outside of our solar system.

A number of studies have been published following up on the many TESS candidates, including wide ranging surveys of false positive detection methods such as that by Mantovan et. al. However, no follow up to candidate TOI-5372.01 has yet been conducted, and this study aims to undergo that data analysis to determine whether TOI-5372.01 is a genuine exoplanet or a false positive of some kind. This study builds upon previously discovered and tested methods to determine whether a transit occurs to

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contribute to the body of knowledge of valid exoplanet detections. Such methods include normalizing for a wide variety of possible noise sources and attempting to fit measured light curves to models that correlate to a particular type of exoplanet detection.

As noted previously, the focus of this study is TOI 5372.01. The candidate exoplanet has a predicted orbital period of 11.6270831±0.0000708 days, and a radius of approximately .90862 times that of Jupiter (*TOI-5372 Overview*, n.d.). It is therefore a large, gaseous planet, as it well exceeds the rough upper limit for possible rocky planet size of 2 Earth radii (Lopez & Fortney, 2014). The planet candidate orbits a star of 1.040000 solar masses and 1.5995600 solar radii (*TOI-5372 Overview*, n.d.). Notably, this is a binary star system, but the companion star has been determined to be an unlikely source of the possible transit events (*TOI-5372 Overview*, n.d.).

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 the candidate planet as well as ground-based light curve analysis. In Section 4, we present light curve results. In Section 5 we discuss our findings and in Section 6 we present our conclusions and future work.

Observations

In Section 2.1 we include the properties of TESS Object of Interest 5372.01 as detailed in the TESS Input Catalog, the *Gaia* mission, and other sources. In Section 2.2 we present the light curves derived from the TESS mission. Finally, in section 2.3, we present a summary of the observational data collected with the George University 0.8m telescope.

2.1

According to the data collected by TESS and archives in the TESS catalog, TOI 5372, the star that TOI 5372.01 orbits, is approximately 459.882 parsecs away, with RA and Dec coordinates of 02:54:17.47 and +23:11:57.07, respectively. It has an effective temperature of 5776.12 K, a mass 1.04 times that of our sun, and a radius of 1.59956 solar radii. Like our sun, it is a G type star, although it is significantly less dense and slightly less metallic. Its metallicity is predicted to be -0.021±0.056 M/H (*TOI-5372 Overview*, n.d.).

TOI 5372.01 itself has a predicted insolation flux of 58.1485, a period of 11.6270831±0.0000708 days, and a radius 10.184700±0.888093 times that of Earth. The predicted transit depth is 0.35500000±0.00147949%, and the transit duration is 2.383±0.753 hours.

2.2

Figure 2.2.1 is the light curve output of a Python script which plotted data from a 120 second TESS exposure on 9/20/2023 available through the MAST archive (*Barbara A. Mikulski*, n.d.). This graph shows a clear dip when the proposed transit occurs. A similar brightness fluctuation was observed and cataloged by TESS on 10/16/2023, as shown in Figure 2.2.2. These events lead to the designation of TOI-5372.01 and are the impetus behind this study's follow up.

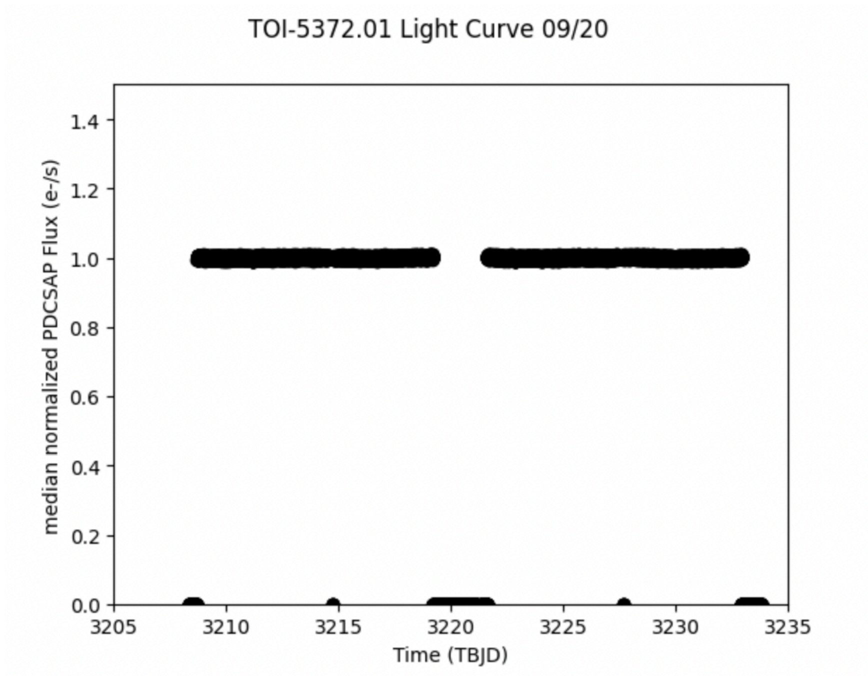

Figure 2.2.1: Light curve for the candidate exoplanet generated through aperture photometry previously performed on TESS survey data.

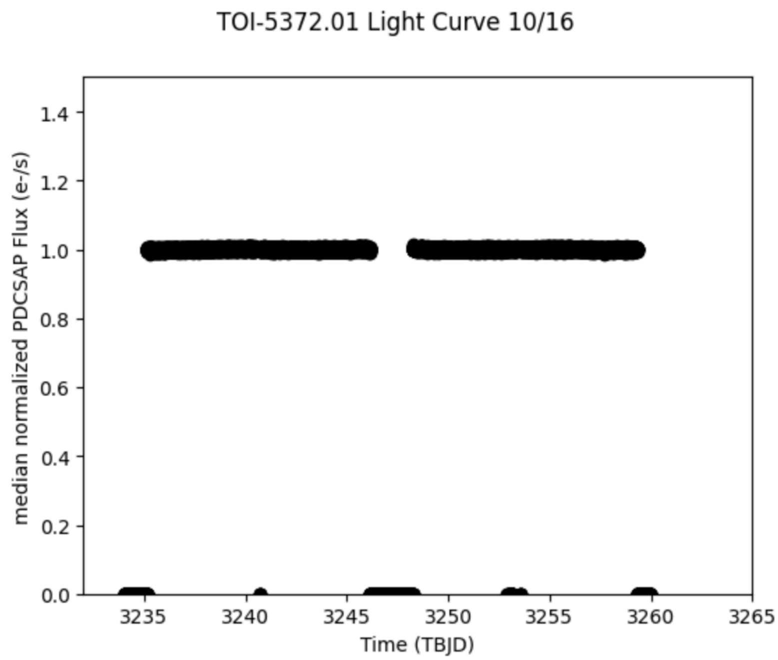

Figure 2.2.2: A second light curve for the candidate exoplanet generated through aperture photometry previously performed on TESS survey data collected around a month later.

2.3

The ground observations for this study were performed from 17:50 on 12/13/2023 to 03:05 on 12/14/2023 from the 0.8m telescope at George Mason University, employing an R filter and a 75 second exposure time for each image. Figure 2.3.1 displays an outside view of the GMU telescope used for the observation. A total of 255 images were taken, but this study only uses the initial 224, as the later images were subject to considerable blurring and distortion and were deemed unusable. In addition, 20 "darks" and 10 "flats" were taken for the process of data normalization and to prevent the influence of noise on transit detection - for further details on this, see Section 3.2. Figure 2.3.2 shows a typical image before being processed in any way.

Figure 2.3.1: The 0.8 meter telescope at George Mason University.

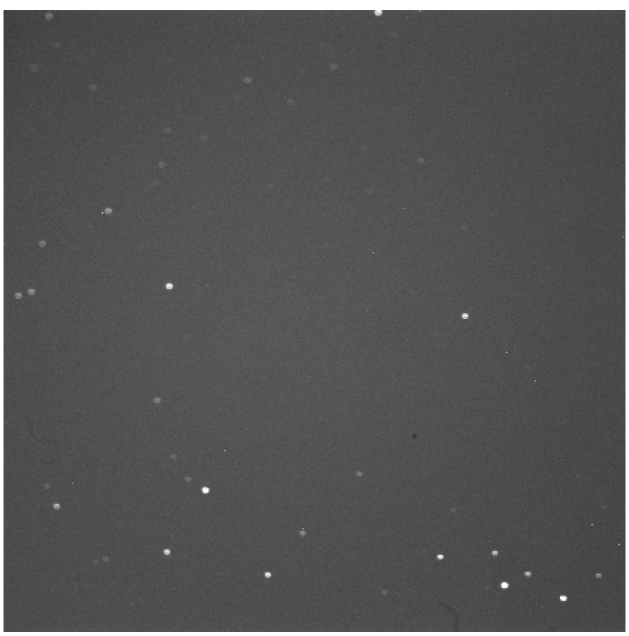

Figure 2.3.1: Image 123 before any data processing steps had been taken.

Analysis

In Section 3.1 we present our methods and tools of data reduction to prepare the images for data processing and analysis. In Section 3.2, we present the details of our analysis of the ground based light curve obtained using AstroImageJ.

3.1

The ‘darks’ (a series of images obtained on the night of observation by taking images of a covered telescope in order to detect background/instrumental noise) were median combined in AstroImageJ into two master darks, corresponding to the 3s and 75s exposure times of the flats and science images, respectively. The flat field images (taken with a uniform light exposure) were likewise median combined, and the 3s master dark was subtracted from this median image to produce the normalized flat field. The 75s master dark was subtracted from each science image, and this was then divided by the normalized flat field to produce a final reduced dark.

Simultaneously, the images were plate solved through comparison with the nova.astronomy.net database. This allowed the images to be properly aligned to the target and comparison stars even as the sky moved slightly relative to the telescope over the course of the night. Next, data was imported from the Gaia database to identify nearby stars, as shown in Figure 3.1.1.

Figure 3.1.1: Image 18 after being reduced and plate solved.

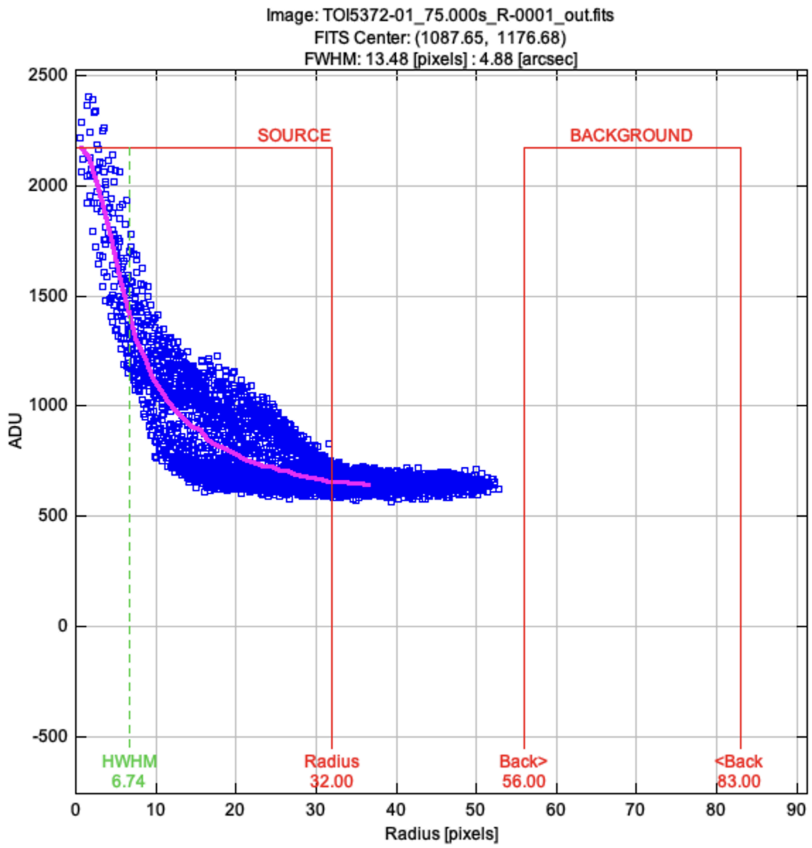

Figure 3.1.2: The AstroImageJ Seeing Radius curve for the target star in Image 1.

A Seeing Profile was derived for the target in the AstroImageJ software, with a resultant radius of 32.00 pixels, an inner annulus of 56.00 pixels and an outer annulus of 83.00 pixels. These values were used to begin aperture photometry, using comparison stars automatically selected by AstroImageJ, and depicted in Figure 3.1.3. Initially, T23, T24, and T29 were also used as comparison stars, but over the course of observation they fell out of the frame and so were excluded from analysis. The target star's brightness was compared in each frame to the brightness of the surrounding stars. This method helps mitigate the effect of atmospheric fluctuation and other noise on the data. Aperture photometry was stats with data from the George Mason University CCD, following the AstroImageJ tutorial. The lightcurve data produced was then plotted and fitted to a model by AstroImageJ using the RMS process, shown in Figure 3.1.3. The expected transit ingress and egress times were input into the Multi-Plot Main window. In the Data Set 2 Fit Settings window, the predicted orbital parameters and host star parameters (given in Section 2.1) were inputted to better match the curve.

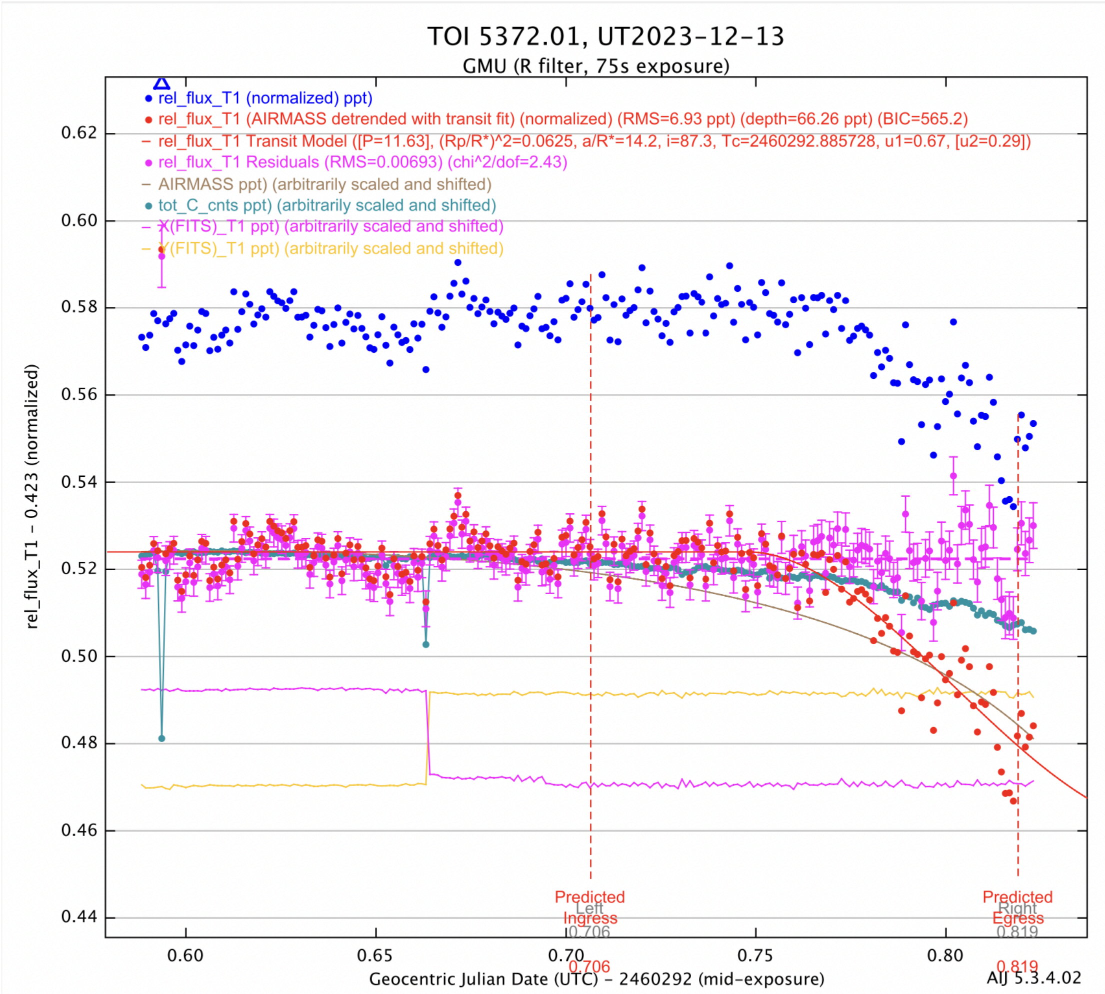

Figure 3.1.3: The final light curve for the target object, along with the Transit Model produced in AstroImageJ.

AstroImageJ was then used to conduct an NEB (Near Eclipsing Binary) check with Image 4 as an arbitrary reference frame. The NEB check was conducted in the TFOP SG1 Analysis Macro window with the estimated transit depth value of 3.550 ppt provided by GMU, again according to the settings in the TESS Follow-Up Light Curve Tutorial document (Plavchan et al., n.d.). As shown in Figure 3.1.4, no likely NEBs were uncovered by this Analysis.

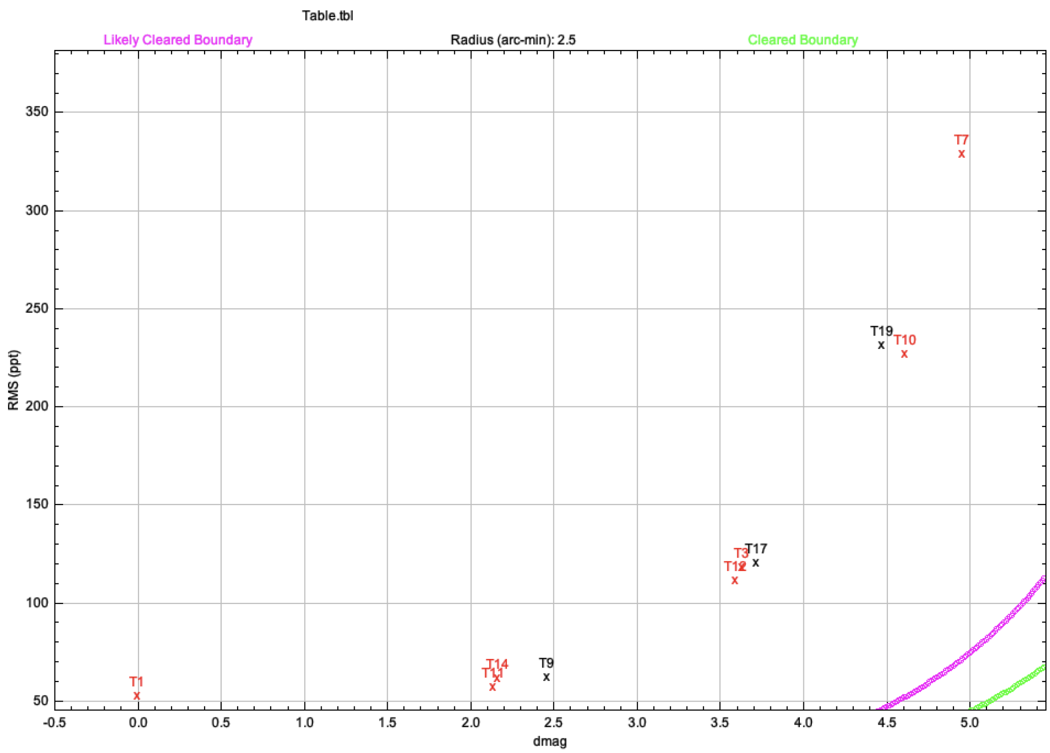

Figure 3.1.4: The NEB plot generated by AstroImageJ with nearby Gaia sources plotted.

Results

In Section 5.1 we present our interpretation of our results. In Section 5.2 we place our results within the broader context of the field of follow-up observation of TESS Objects of Interest.

5.1

Unfortunately, the data gathered is not sufficient to confidently detect a transit. The significant dip in measured relative brightness seen towards the end of Figure 3.1.3 seems to indicate that the actual transit event took place well outside of the predicted ingress and egress times of 0.706 and 0.819 UTC. This indicates that the previously predicted ingress/egress times were inaccurate, and further research should seek to update these predictions. The actual ingress time seems to have been closer to 0.760 UTC. Unfortunately, with these altered ingress and egress times, the full transit was not able to be detected on the night of observation 12/13/2023 due to the fact that the later images taken were blurred and unusable for analytical purposes, and therefore had to be discarded from the data set.

However, the trailing end of the data does seem to indicate a transit event, and we recommend a follow up study be conducted to take more images over a larger time period, to ensure that the actual transit event is captured. It seems likely that there does exist a transient exoplanet, although we of course cannot rule out other factors such as the slim possibility that a companion star is causing the fluctuation. Our analysis of potential NEBs turned up no results, so we can likely rule out that issue as a potential source of noise.

5.2

Though our results present no definitive answers as to whether TOI 5372.01 is a genuine transiting exoplanet, they do provide strong indication that this may be the case, and warrant further follow up study. They also contribute to the wider body of knowledge about exoplanet candidates. Further follow up study could perform Radial Velocity measurements and draw more conclusions about the properties of the transiting exoplanet candidate, as well as further refine the predicted orbital properties and ingress and egress times. This method will also rule out false positives and the possibility that a binary star is causing the transit events.

Faster and more efficient methods of detecting exoplanets and ruling out false positives should continue to be developed, as well as working towards more accurate measurements of TOI 5372.01 specifically and also the wider body of unconfirmed TESS Objects of Interest.

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