Ground-based light curve follow-up validation observations of TESS Object of Interest (TOI) 5886.01

Authors

Peter Plavchan[1], Joshua Golden[2]

Affiliations

[1] Peter Plavchan, Department of Physics and Astronomy, 4400 University Drive MS 3F3, George Mason University, Fairfax, VA 22030, USA

[2] Joshua Golden, Lake Braddock Secondary School, Burke, VA 22015, USA

Abstract

The TESS Mission is one that surveyed the whole universe in several sections and searched for exoplanets using the transit method. They searched for any dips in brightness from a host star suggesting that an extraterrestrial object has blocked some of the emitted light, where then further research can be used to see if that object is an exoplanet or not. The goal of this research was to verify the existence of the TESS object of interest TOI 5886.01 using the transit method. We used AstroImageJ's plate-solving and multi-aperture photometry in order to track the star and scan its brightness throughout the night. Due to issues like light pollution, weather, and other causes of noise in the data, much of the data was skewed and unusable, but we were still able to compare the observed data to the expected and see a close relationship. The result of our observations is the possible confirmation of the existence of TOI 5886.01. On top of this, we were able to characterize this planet as a hot Jupiter.

Introduction

The TESS mission is one that scans the sky for exoplanets all over the universe. Further research is needed in order to verify the existence of these planets and goes through a candidate validation process. One of the growing methods for validation is known as the transit method [1]. This method is when astronomers track the light emitted from a host star. Then by analyzing the light curve/graph that is created by tracking the light, they check for any dips in brightness. These dips would mean that something would be blocking some of the light from the exoplanet. Then, by researching the time intervals of these blocks, you can conclude that an exoplanet exists or not. Our research is in order to try and eliminate the possibility of a false-positive that the exoplanet exists.

There are thousands of these exoplanets that are yet to be confirmed from the TESS mission [2]. This is why further research is needed from people in order to validate these exoplanets so that they can be analyzed for the potential of human habitation. Only a handful of these exoplanets have actually been confirmed so it is important that this research and information from the TESS mission was not in vain. There has been no research regarding the TESS object of interest TOI 5886.01 so this is why my research is one that will be needed and potentially vital to the research of exoplanets.

In this paper we present follow-up observations of TOI 5886.01. The goal of this paper was to determine whether the transit occurs at the correct time, at the correct depth, and see if there are any discrepancies in the data. For a comparison, the known information of TOI 5886.01 is as follows: 11.584500 earth radii, orbital period of 0.97 days, and a transit duration of 1.224 hours. This information will be instrumental later on in the paper when comparing our model to this information.

This paper will present our observations and analysis of TOI 5886.01. 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 5886.01 and our ground-base 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 ideas of future work that must be done.

Observations

In Section 2.1 we present the TESS Object of Interest 5886.01 and its exoplanet candidate properties, its host star properties from the NASA Exoplanet Archive 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 observational data collected with the George Mason University 0.8m telescope.

TESS Observational Data - 2.1

The data for TOI 5886, as described in the NASA Exoplanet Archive [3], was created in 2022. The RA and Dec coordinates of TOI 5886 are 20:27:57.32s and +37:08:46.80s, respectively.

Information that was analyzed about its candidate exoplanets is as follows: a transit midpoint of 2459823.1597170 days, an orbital period of 0.9655766 days, and a transit duration of 1.224 days. In addition, the transit depth of TOI 5886.01 is 3.14 ppm, its radius is 11.584500 Earth radii, and its equilibrium temperature is 2186 K.

In regards to the host star, its stellar effective temperature is 7542 K, a stellar mass of 1.74 M_Sun, the stellar log(g) is 4.1125600 cn/s^2, and the stellar radius is 1.91879 R_Sun.

GMU Telescope Observations - 2.2

In this observation of TOI 5886.01, we used the George Mason University 0.8m. This observation took place on 2024-06-18.

We observed a total of 222 exposures, with an exposure time of 85s each, starting from 21:50 ET to 4:30 ET on 2024-06-18. This telescope uses the R filter. The RA and Dec coordinates of TOI 5886 are 20:27:57.32s and +37:08:46.80s.

Analysis

In Section 3.1 we present our tools used to analyze the TESS sector light curve(s) curves using AstroImageJ/ExoFASTv1/ExoFASTv2. In Section 3.2, we present our analysis of the ground-based light curve using AstroImageJ.

Analysis Tools - 3.1

AstroImageJ(AIJ) is a software that is used to be able to view and analyze images from telescopes and develop data from these images. Some of the tools in AIJ that were vital during this process was its plate-solving using astrometry.net, data reduction, multi-aperture photometry, and light curve generation. [5]

Analysis Using AstroImageJ - 3.2

Through AstroImageJ, we were able to construct a light curve of our object, TOI 5886.01.

First, we downloaded the images that were taken during the night of the observation from the George Mason University 0.8m telescope. Then, we were able to distinguish between the flat, dark, and science images in order to prepare to data reduce the images.

Second, we data reduced the science images using the flat and dark images by matching up their exposure times and creating data reduced images. These images are important as they reduce the noise of the raw images. Many of the images were skewed due to weather and streaking so there were around 52 images that were eliminated.

Next, the images were plate-solved. By using AstroImageJ and astrometry.net, it located various stars in the sky in order to pinpoint the coordinates in each image so we could be able to locate our target star, TOI-5886.

Then, we create a measurement table for TOI 5886.01. The table contains the changing fluxes of our target star, the Gaia stars [4], and the reference stars with time. We then find a seeing profile of TOI 5886.01. We achieve a photometry radius of 30.00, an inner annulus radius of 52, and an outer annulus radius of 78 pixels - see **Figure 1**. We then perform multi-aperture photometry while using 11 Gaia stars as reference. We also used 10 other stars that had a similar brightness as TOI 5886 in order to compare models. See **Figure 2** for the apertures. After multi-aperture photometry, a measurement table was finally created. We then use this measurement table to create the light curve.

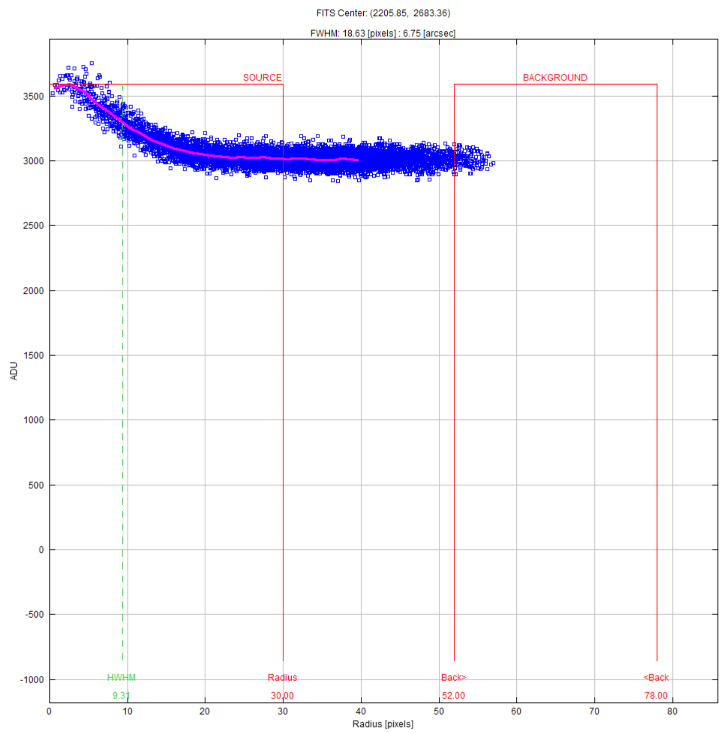

Figure 1: Seeing profile of TOI 5886.01 on AstroImageJ. See bottom for radiuses

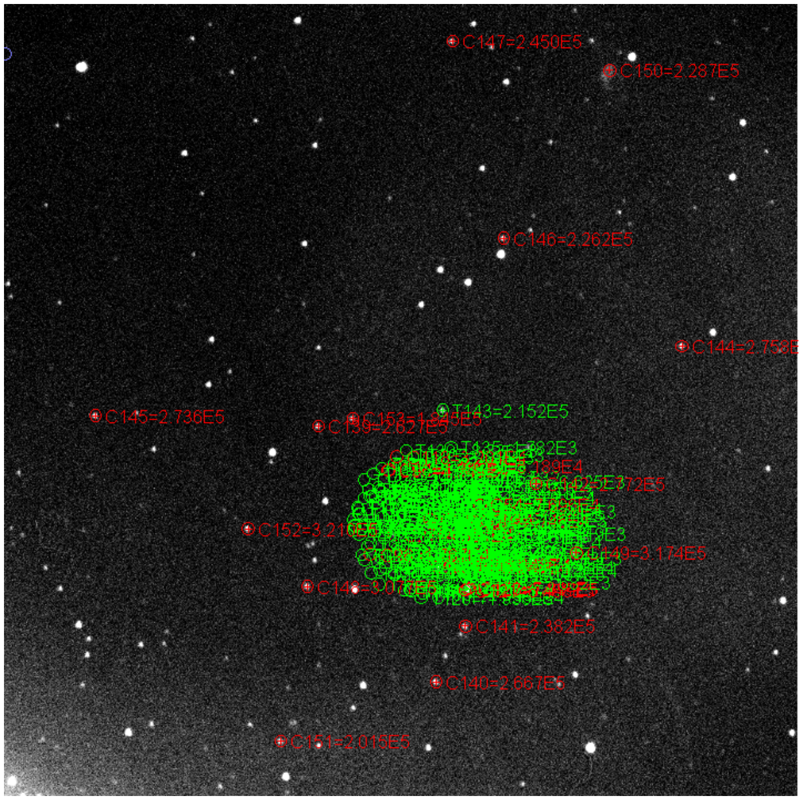

Figure 2: Multi-aperture photometry. This depicts all the stars that could've been potentially used as reference stars, only about 21 stars were used.

Next, we prepared to create the light curve for TOI 5886.01. We first input data collected by TESS, including our target exoplanet's period and host star radius. On top of this we input other information regarding the exoplanet such as the metallicity, Linear LD u1 and Quad LD u2, and effective temperature for quadratic limb darkening. Then, we input the predicted ingress and egress times which was 0.6919 and 0.7428. After that, we reviewed all the reference stars and chose the best ones with the least skewed graphs which amounted to around 21 stars. Next, we check the dmagRMS-plot for any outliers - see **Figure 3**. We can see that none of the points reach the green curve which will be expanded upon later on in the paper.

Finally, the light curve is created for TOI 5886.01. On top of this light curve creation, I used different detrending tools like AIRMASS in order to remove some of the effects of the atmosphere and the air mass. This made it much easier to distinguish the graph and determine the trend.

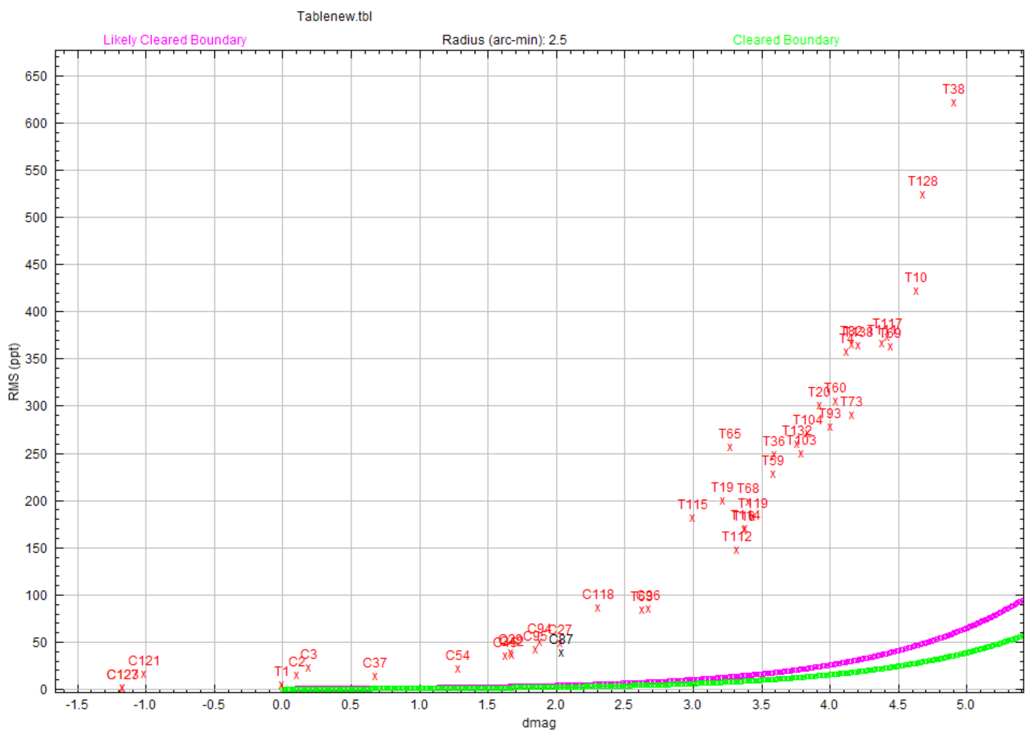

Figure 3: dmagRMS-plot represents the likelihood of an NEB(Nearby Eclipsing Binary)

Results

In Section 3.1 we present our findings of the NEB check. In Section 3.2 we discuss the results of the light curve created on TOI 5886.01.

Section 3.1 - Results for NEB Check

See **Figure 3** for dmagRMS-plot

This check is one that discusses the findings of the Nearby Eclipsing Binary check and one that is vital when trying to rule out the false positive that the transit may have been misinterpreted as a nearby eclipsing binary.

When reading the dmagRMS-plot, we can see that none of the points clear the green “Cleared Boundary” line and therefore are not very accurate. All of the points are outliers and therefore it means that much of the data is not reliable. This is most likely due to the conditions during the night of the observation like dust, atmosphere, weather, noise, light pollution, etc.

Section 3.2 - Results for light curve

See Figure 4 for the light curve.

This light curve is a graph of the light emitted from the host star TOI 5886. What we looked for in this curve was any noticeable dips in the graph that would signify a transit of an exoplanet.

This light curve shows many different things. The blue line is the raw light curve of the planet without any detrending. The second plots the relative flux of T1 using AIRMASS as a detrending tool. It shows a depth of 4 ppt and a RMS of 8.95. The third black plot depicts the relative flux of C127 with an RMS of 5.79 ppt. The yellow line plots the normalized flux for light in the sky over time. The gray plots the width of T1 over time. The dark blue plots the AIRMASS detrending over time, which increases throughout the night. The brown line plots tot_C_cnts, or the sum of all the counts for every star, over time. The ninth plots the X(FITS) or the x-coordinate of T1 over time. Finally, the tenth plots the Y(FITS) or the y-coordinate of T1 over time.

When looking at the graph, it may not appear to have a huge dip in the light curve, but the dip is represented as having a depth of 4.00 ppt which is close to the predicted depth of 0.314 ppt. This value does pass the chi squared test and therefore meaning that the results are significant.

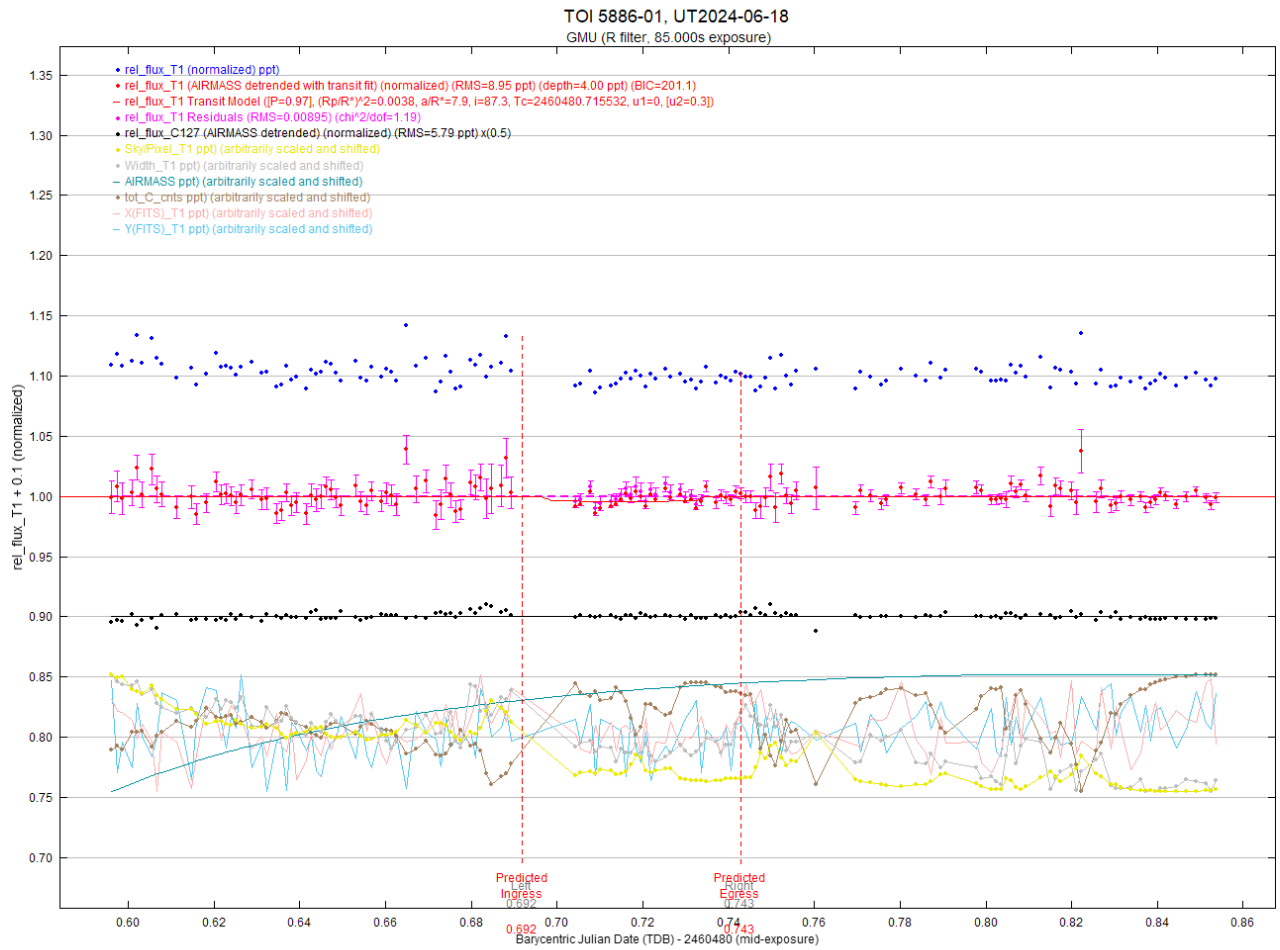

Figure 4: Light curve from AstroImageJ. Blue is raw, red is detrended by AIRMASS

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 follow-up of candidate exoplanets from the NASA TESS mission.

5.1 - Discussing results

When analyzing the light curve and the dmagRMS-plot, we are able to see significant trends and pull data and information from what is on the graph. Much of the data from the beginning was skewed and deemed unusable due to weather, light pollution, and other causes of noise. This caused the data to be harder to interpret and may have caused the transit depth that was detected to be incorrect. In the end, I was able to see that the light curve does show a small dip in the graph and the observed depth(4 ppt) is close to that of the expected depth(3.1 ppt) and passes the chi squared test.

However, none of the reference stars or the target object passed the green curve "Cleared Boundary" on the dmagRMS-plot, therefore we are unable to rule out the false positive as well as the possibility of a nearby eclipsing binary.

5.2 - TOI 5886.01 Analysis

When analyzing the information obtained from AstroImageJ and most importantly, the Exoplanet Archive(TOI-5886 | NASA Exoplanet Archive (caltech.edu)), we are able to analyze the characteristics of the exoplanet. They are as follows: equilibrium temperature of 2186 K, stellar irradiance of 3796 solar constants, an orbital period of 0.97 days, a radius of 1.0335 R_jup, a transit depth of 3.14 ppt, and transit duration of 1.224 hours. All these characteristics point directly to the existence of a hot Jupiter, from the extreme temperatures to the short orbital period which is indicative of a short distance between the planet and the star(sign of a hot Jupiter), and a radius extremely close to that of Jupiter [6].

It is very likely that TOI 5886.01 is a hot Jupiter.

The identification and characterization of hot Jupiters from TESS data are critical for enhancing our understanding of planetary formation, migration, and atmospheric dynamics. These findings contribute to the success of the TESS mission by confirming its discoveries. Hot Jupiters, due to their extreme characteristics and accessibility, offer valuable data that influence the broader field of exoplanet research.

Conclusions and Future Work

From our follow up observations of candidate exoplanet TOI 5886.01, we were able to create a light curve and compare the data that we obtained from observations to that of the TESS mission. From this comparison, we were able to confirm the existence of TOI 5886.01 as an exoplanet. Additionally, we were able to characterize TOI 5886.01 as a hot Jupiter. However, we were unable to rule out the false positive of a possible nearby eclipsing binary.

If I were to advise for future work in this analysis, I would hope that observations be made on a night with clearer skies in better conditions so that we would be able to minimize the noise and scatter of the plot. Along with this, I would advise that the next researchers take the additional steps to carry out the detailed statistical false-positive validation analysis in order to calculate the risk of a nearby eclipsing binary.

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