Ground-based Light Curve Follow-up Validation Observations of TESS Object of Interest TOI 5886.01

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Abstract
The goal of the Transiting Exoplanet Survey Satellite (or TESS) is to detect exoplanet candidates by checking for a drop in the brightness of a star. If the drop happens periodically, then it could be caused by planet transits. The aim of this research is to generate a ground-based light curve for TOI 5886.01, which can be used as evidence to confirm it as an exoplanet. If the brightness drops the predicted amount at the predicted time, then it would confirm the candidate as an exoplanet. After reducing and plate-solving data collected from the GMU Observatory, we were able to generate a light curve using AstroImageJ. The light curve suggests that TOI 5886.01 is an exoplanet due to a drop in the light curve at the expected time and expected depth. However the NEB analysis came back as inconclusive, so future work must be done using longer exposure times. Additionally, a detailed statistical false-positive validation analysis must still be done to validate the TESS candidate as an exoplanet.

Introduction
Ever since the discovery of the first exoplanets in 1992 by Alexander Wolszczan and Dale Frail, many astronomers have dedicated themselves to finding more worlds outside our solar system [1]. This undertaking has become more simplified for astronomers to conduct due to the creation of new technologies, most significantly TESS. The Transiting Exoplanet Survey Satellite (or TESS) uses the transit photometry method, which checks for periodic drops in the brightness of a star that could be caused by an orbiting planet [2]. If TESS finds an exoplanet candidate, it will add it to its catalog where astronomers will conduct research to determine if the exoplanet candidate is a true exoplanet [2].

There have been 500 exoplanet candidates which have been confirmed, such as TESS Object of Interest (or TOI) 4633, which is a double-star system containing a “Mini-Neptune” [3]. However, there are still more than seven thousand exoplanet candidates requiring further research [4]. In this study, we aim to research TOI 5886.01 to help reveal if it is an exoplanet or a false positive.

In this paper we present follow-up observations of TOI 5886.01. The TESS candidate has a radius of 11.5845 ± 0.754258 $R_\oplus$ and an orbital period of 0.0.9655766 ± 0.0000024 days [5]. Additionally, it has a transit duration of 1.224 ± 0.24 hours and a transit depth of 3140 ± 299.993 ppm [5]. Our goal is to investigate whether or not the transit occurs on the expected star at the expected time, with the expected transit duration and transit depth.

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-based 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 future work.

Observations

In Section 2.1 we present the TESS Object of Interest 5886.01 and its exoplanet candidate properties and its host star properties from the NASA Exoplanet Archive. In Section 2.2 we present the TESS sector light curve. In Section 2.3, we present a summary of the observational data collected with the George Mason University 0.8m telescope.

Section 2.1

The data for TOI 5886.01 was created on November 8, 2022 and was last updated on March 7, 2024 [5]. The planet's right ascension value (or RA) is 20:27:57.323 sexagesimal and its declination value (or DEC) is +37:08:46.88 sexagesimal [5].

TOI 5886.01 has the host star TOI 5886, which is located 832.543 ± 23.6575 parsecs away [5]. The star has an effective temperature of 7542±254.4 and a stellar log(g) of 4.11±0.09 cm/s^2. Its radius is 1.92±0.08 R_Sun [5].

Section 2.2

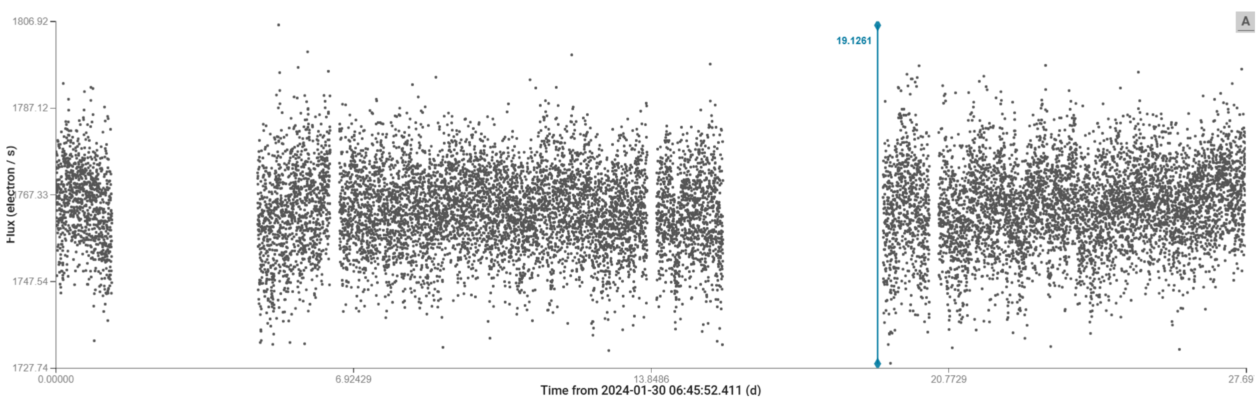

Figure 1: TESS Sector Light Curve taken from the MAST archive

The gaps in the TESS sector light curve (**Figure 1**) show evidence of a planet transit, resulting in it being labeled a TESS Object of Interest.

Section 2.3

We collected 223 Science exposures with exposure times of 85s using the George Mason University 0.8m telescope. We began collecting on June 18, 2024 at 21:50 to June 19, 2024 at 4:30, using an R filter. Additionally, we collected 10 darks with an exposure time of 3s and 10 darks with an exposure time of 85s as well as 10 flats with an exposure time of 3s.

Analysis

In Section 3.1 we present our tools used to generate the light curve for TOI 5886.01. In Section 3.2, we present our method used to generate the light curve for TOI 5886.01.

Section 3.1

We used AstroImageJ to generate the light curve. AstroImageJ can display images captured by the GMU 0.8m telescope. It also has various useful tools that are required to create an accurate ground-based light curve. This includes data-reducing, plate-solving, multi-aperture photometry, NEB analysis, and light-curve generation.

Section 3.2

First we downloaded the sciences, darks, and flats captured by the GMU telescope and separated them into folders (including separating the darks into science darks and flat darks based on the exposure time). We then observed every science using AstroImageJ, looking for streaking, targets outside the field-of-view, or considerable shifting or jolting of the target between each frame. We marked down all the bad sciences on a text file along with an explanation for the removal. Once we checked every science, we moved the bad images to a separate folder.

Our next step was to data-reduce the sciences using data processing in AstroImageJ. We median combined the flat darks into a master flat dark, which we then subtracted from the raw flats. After, we median combined the flats into a master flat. Next, we median combined the science darks into a master science dark which we subtracted from the raw sciences. Finally, we flat divided the sciences by the master flat. Additionally, we plate-solved this science in this step, which centered each science around TOI 5886.01's RA and DEC coordinates.

The third step is to generate a measurement table for the light curve. We first needed to find the aperture and annulus sizes, which we got from a seeing profile generated by AstroImageJ (see **Figure 2**). After inputting those values in Aperture Photometry Settings, we were ready to do multi-aperture photometry. To do this, we manually selected reference stars that had a similar brightness to TOI 5886 and also used stars located on the Gaia database. **Figure 2** shows the stars selected for this step. A measurement table was then created which we used to generate our light curve.

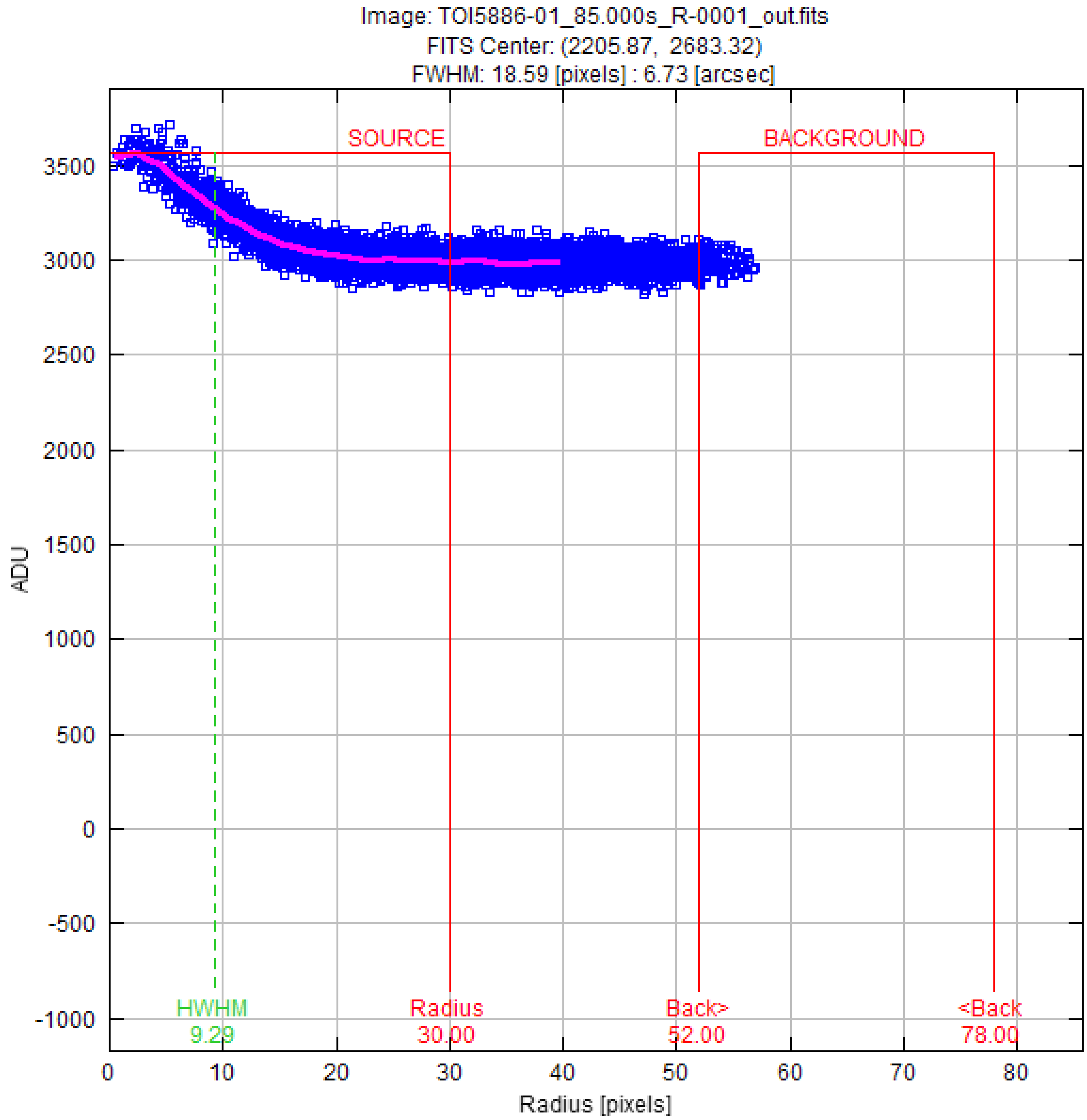

Figure 2: Seeing Profile of TOI 5886.01 on AstroImageJ. The radius is equal to the aperture size and the background's inner and outer radii are equal to the annulus sizes.

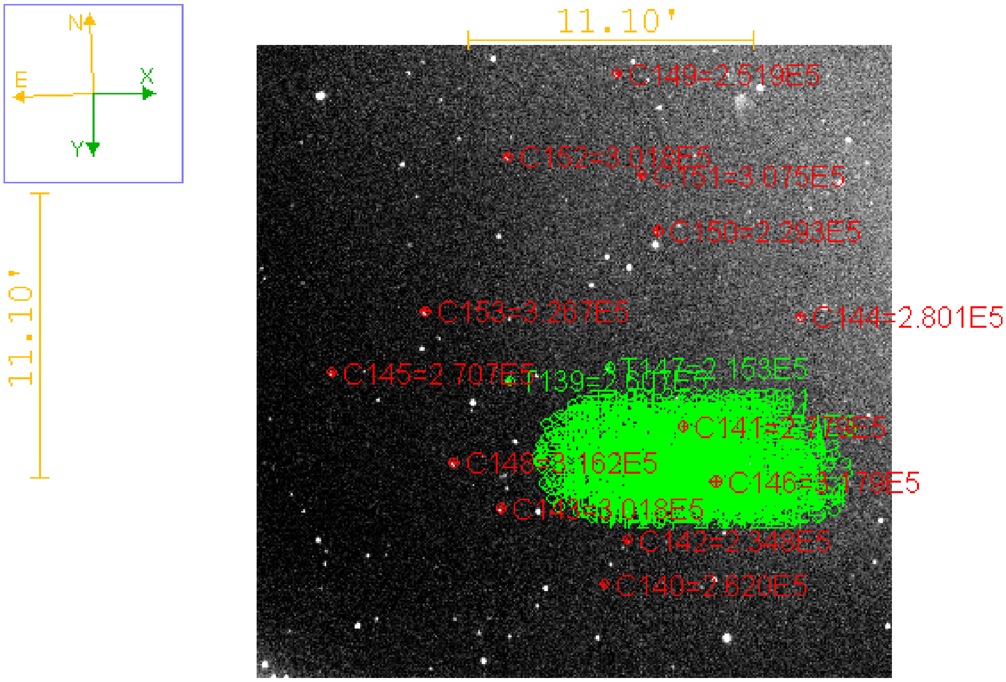

Figure 3: AstroImageJ aperture displaying TOI 5886.01 and all reference stars.

The final step was to analyze and interpret the light curve. After inputting the measurement table into AstroImageJ, it was able to generate a light curve, but we still needed to fix the graph. We first inputted data from TESS, such as the predicted ingress and egress times, target's period, and the host star's stellar radius. Then, we checked each reference star's flux, removing those with a large variation or scattering. After, we ran an NEB analysis, which checks for potential eclipsing binary stars, outputting a dmagRMS-plot. Finally, we detrended the graph with air mass and formatted the graph to showcase all the curves clearly.

Results

In this section we will present our ground-based light curve.

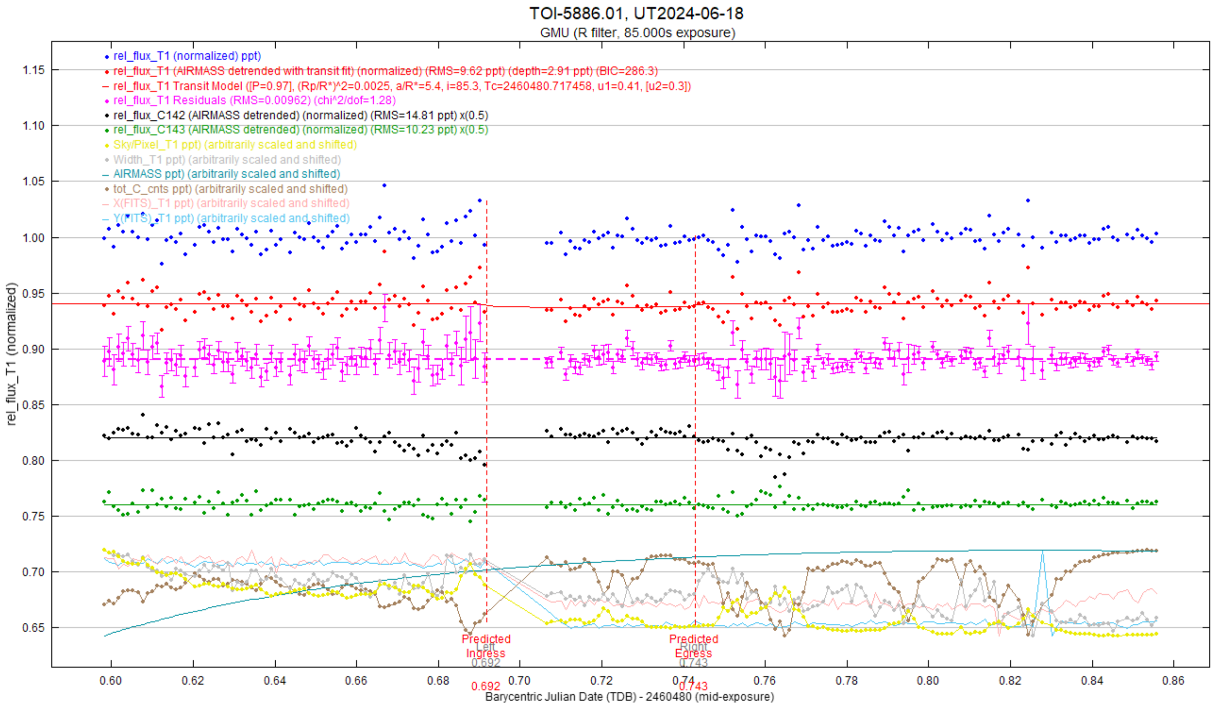

Figure 4: Light curve of target TOI 5886.01 from AstroImageJ

The light curve consists of several plots. The first plot, in blue, is of the normalized flux of TOI 5886.01. The second plot, in red, is the normalized flux of TOI 5886.01 detrended with air mass. The third plot, in red, is the transit model of TOI 5886.01 and the fourth plot, in pink, shows the residuals using the chi 2 fit test. The next two plots, in black and green, are the normalized flux of reference star C142 and C143 detrended with air mass. The plot in yellow is the normalized flux for light in the sky over time and the plot in gray shows the width of TOI 5886.01 over time. The plot in teal shows the amount of atmospheric thickness the light travels through and the plot in brown shows the sum of all the counts for every star, over time. The plots in pink and light blue show the x-coordinate of T1 over time and y-coordinate of T1 over time, respectively.

Discussions

In this section, we present our interpretation of the results.

If the transit occurs at the expected time, with the expected duration and depth, then it is likely that TOI 5886.01 is an exoplanet. Looking at the light curve, we can see the transit model dropping at the predicted ingress and rising at the predicted egress. Looking at **Figure 5**, we see depth equal to 2.91 ppt which is also 2910 ppm. This falls in the expected range of 3140 ± 299.993 ppm. Therefore, the transit seems to occur at the expected time.

However, looking at **Figure 6**, we can see that the nearby stars are outside the clear boundary. Since the stars fall on a well-ordered curve, we do not have the precision to confidently say that there are no NEB signals. This is because the exposure times of our sciences are based on the bright target star, not the much fainter neighbors, so the NEB analysis was not able to clear any of the surrounding stars. We would need significantly longer exposure times and better observing conditions to confirm if there is a nearby eclipsing binary.

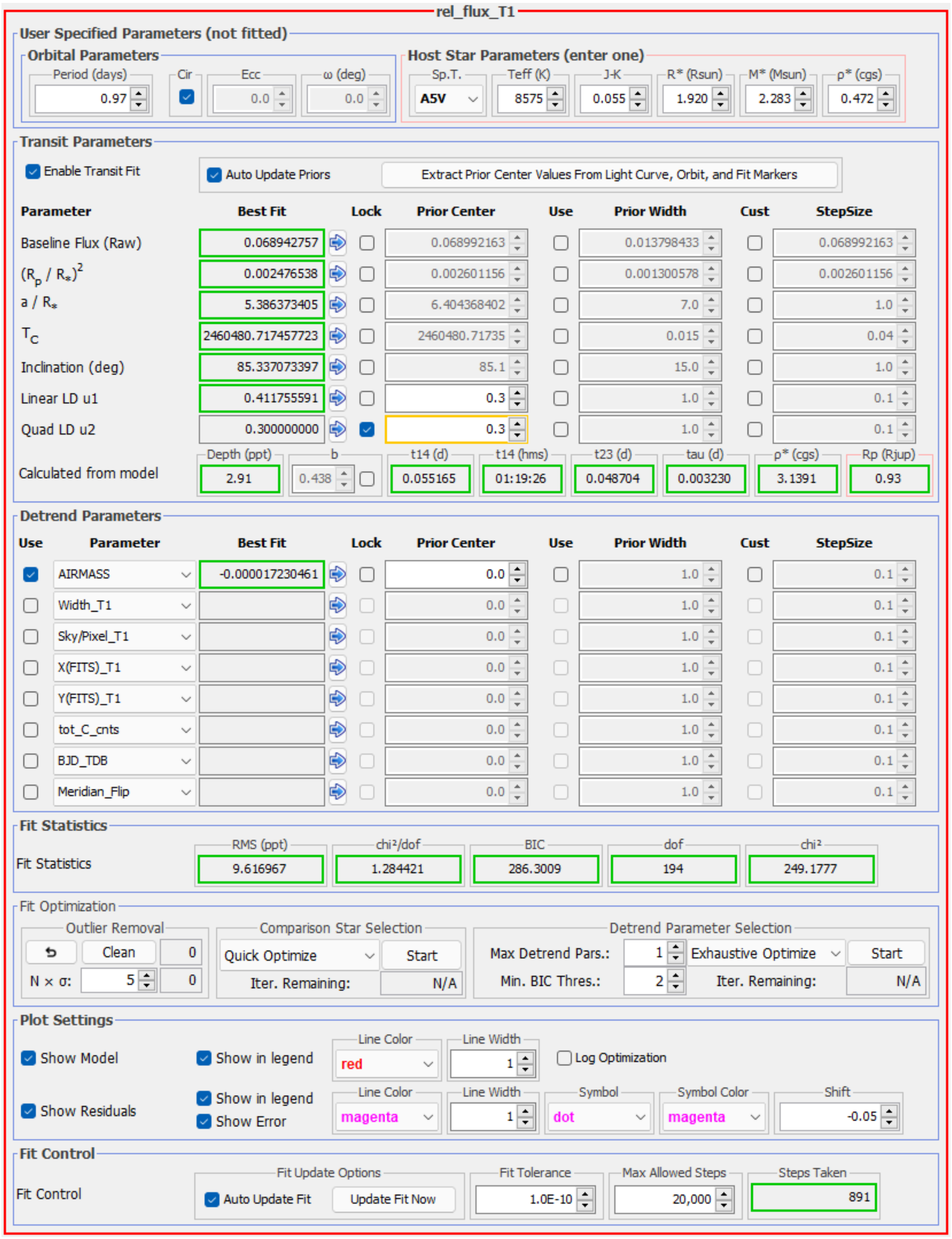

Figure 5: Data Set 2 Fit Settings on AstroImageJ. Note the transit depth of 2.91 ppt (Located next to Calculated from Model).

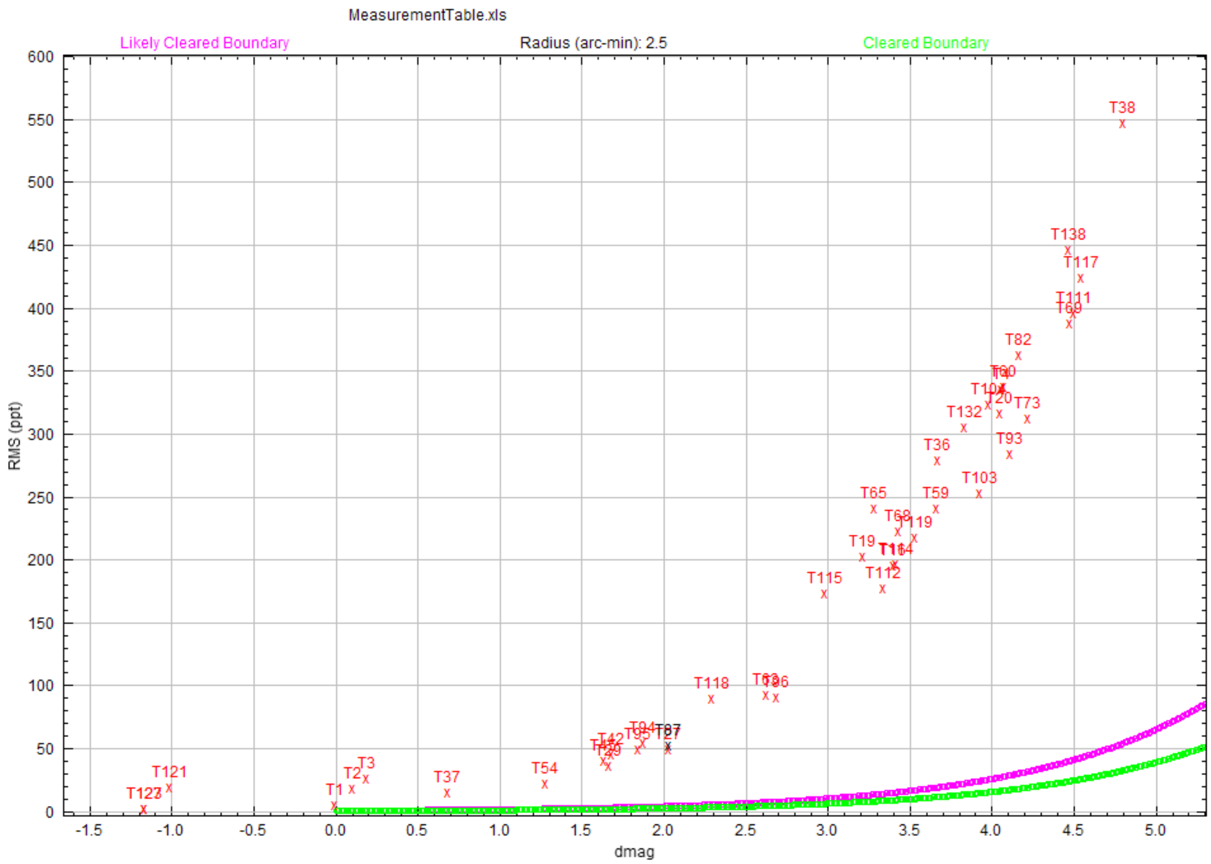

Figure 6: dmagRMS-plot of TOI 5886.01 (T1) and Gaia stars (T1-T138)

Future Work

While the light curve does match the expected time, duration, and depth, there is still much more work that is needed to be done to validate TOI 5886.01 as an exoplanet or false-positive. Future work should use longer exposure times for a conclusive NEB analysis. Afterwards, a detailed statistical false-positive validation analysis must be done to validate the TESS candidate as an exoplanet.

Acknowledgements

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This research made use of the MAST archive.

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