Ground-based light curve follow-up validation observations of the TESS object of interest TOI 5907.01

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Abstract

This research paper analyzes candidate exoplanets and their host stars using data collected from the NASA Transiting Exoplanet Survey Submission and George Mason University's Ground-based telescope observations. Specifically, this paper targets the planetary nature of TESS Object of Interest 5907.01, which orbits the host star TOI 5907. TOI 5907.01 was first detected by the Tess Mission in 2022. Afterwards, the data were reduced, used to plate solve images, and performed multi-aperture photometry to plot and analyze the light curve. Processing was done through the software AstroImageJ.

Through this process, we found that there is no satisfactory light curve to which a planetary nature could be confirmed. Therefore, TOI 5907.01 is likely not an exoplanet and shouldn't be considered a candidate. However due to several data collection issues, further data collection should be held for TOI 5907.01 with a longer imaging duration.

Introduction

A critical point in the Astronomical timeline came in 1992: the initial discovery of an exoplanet – planets that orbit around a star outside of our Solar System. From that point forward, 6,032 exoplanets have been discovered. The primary exploration for exoplanets is from the NASA TESS (Transiting Exoplanet Survey Satellite) Mission. The primary mission was conducted from 2018 up until July 4th, 2020. A cycle of 27 Days of imaging 26 sectors in the span of those 2 years.

The brightest dwarf stars – any star of average or low luminosity, mass, and size (Britannica Dwarf Stars)– are targeted using cameras located on the satellite to collect data. Then, exoplanet candidates are detected, TESS Objects of Interest (TOI), by observing dips or transits in the star's light curve. Eventually, ground-based follow-up observations are conducted, which collect further data in the form of science, images of the sky. This data is then used to confirm the existence of an exoplanet. Currently, there are over 7,500 exoplanet candidates (NASA Exoplanet Archive), but only 686 have been confirmed.

With thousands of exoplanet candidates, research on all is a necessity for the scientific community and for the furthering of humanity. For example, in 2020, a wide variety of scientists across the globe collaborated on the validation of TOI-700, an Earth-like planet. This paper found that the exoplanet was located within the habitable or Goldilocks zone – the area around a star where it is not too hot and not too cold for liquid water to exist on the surface of surrounding planets (NASA). Another paper deemed that TOI-5581.01 could not be concluded as an exoplanet due to insufficient data, requiring further data to be collected.

In section 2 of our paper, we present our observations from the initial Tess Mission alongside the ground-based follow-up from the 0.8m telescope of George Mason University. In Section 3, we present our analysis of the light curve for TOI 5907.01 and our ground-based light curve analysis. In Section 4, we present our light curve results. In Section 5, we present a discussion on our results. In section 6, we present our conclusion and future work.

Observations:

In Section 2.1, we describe TESS Object of Interest 5907.01, including the properties of its exoplanets and the host star derived from the TESS input catalog, the *Gaia* mission, and other archival databases. Section 2.2 presents the TESS Sectors light curve(s), while Section 2.3 presents observational data from George Mason University's 0.8m telescope.

2.1

TOI 5907.01 has a radius of 8.315 solar radii and a period of 0.66 days. TOI 5907.01's host star has a Stellar Effective Temperature of 5766 Kelvin, a stellar radius of 1.06 times the radius of our sun, and a stellar log(g) – the stellar gravity as a base 10 logarithm (Stellar Gravity Wikipedia) – of 4.38cm/s^2. TOI 5907.01 has a right ascension (RA) of 21h00m52.77s and a declination (Dec) of +17d06m59.10s. The RA and DEC are angles that give a position in space relative to the Earth, such as longitude and latitude. TOI 5907.01 also has a predicted depth of 3740 parts per million. It boasts a Stellar Equilibrium Temperature – predicted temperature – of 1,963 K; the Earth's, for comparison, is 255 K.

2.2

Through George Mason University's 0.8 m telescope, 172 Sciences –images of the target star– were collected alongside 10 flats –images that correct for pixel imperfections– and darks –images that are taken with the telescope shutter closed–, on July 28th, 2024. The Sciences had an exposure time of 90s while the flats had an exposure time of 3s. The duration of imaging was from 9:50 pm until 4:35 am the following day. The weather was mostly clear during the duration of the imaging. The telescope used the red filter, which blocks out blue and green wavelengths, to capture the images.

Analysis

In Section 3.1, the process of data reduction is presented, while Section 3.2 presents the process of data alignment. Section 3.3 presents the tools used to analyze the TESS light curves using AstroImageJ.

Section 3.4 presents our data vetting, while Section 3.5 specifies the settings used for the AstroImageJ light curve.

3.1

To start the process, inspection of all 172 Science images was done; any image that had significant streaking or blur was removed from our data set. This process left us with 76 clean science images, which we used during the following process.

3.2

Subsequently, we then created a Master Dark image and a Master Flat image using the AstroImageJ: Coordinate Converter and CCP Data Processor windows. Using the Master Dark and Flat images, we then reduced the sciences and data to plate solve the images – the process of aligning all of the sciences/images using the position of stars in the image. We used *Astrometry.net* and acquired a key, which was input into AstroImageJ to plate-solve the images, instead of having it done manually.

3.3

To perform multi-aperture photometry, through the plate solved images, we then used the seeing profile (Figure 1) from the AstroImageJ plug-ins and changed the settings. We first had to locate the target star using a finder chart. **Figure 1** (The Seeing Profile) was then generated with **annulus radii** of **31, 61,** and **122:**

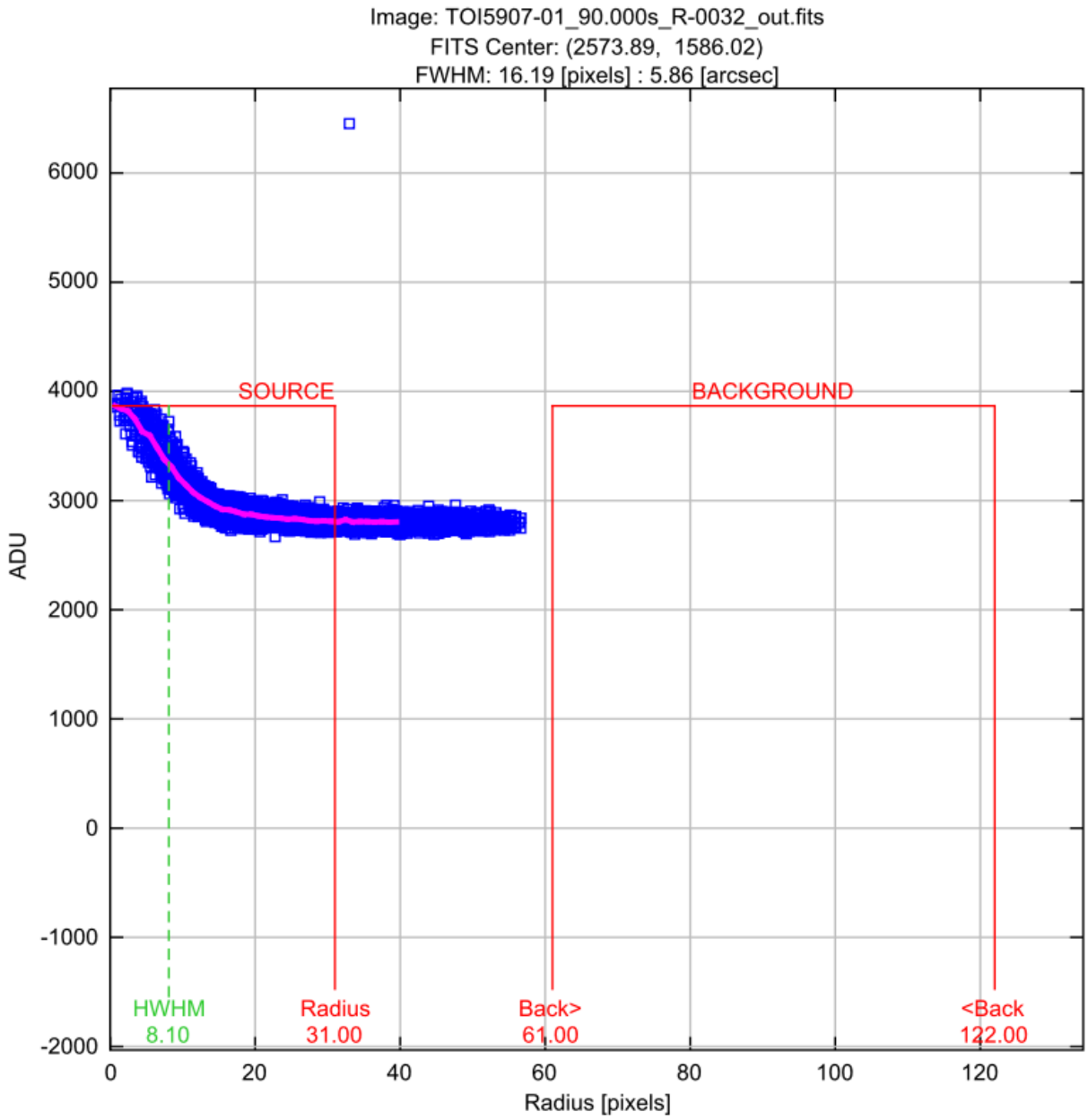

Figure 1: TOI 5907.01's Seeing Profile, subsequently used for multiaperture photometry. (The Seeing profile indicates the aperture and annuli sizes.)

We then plotted 9 reference stars while the GAIA files plotted an additional 92 stars within a 5' radius of the star, as shown in **Figure 2**. These star plots were later used to plot the TESS light curves.

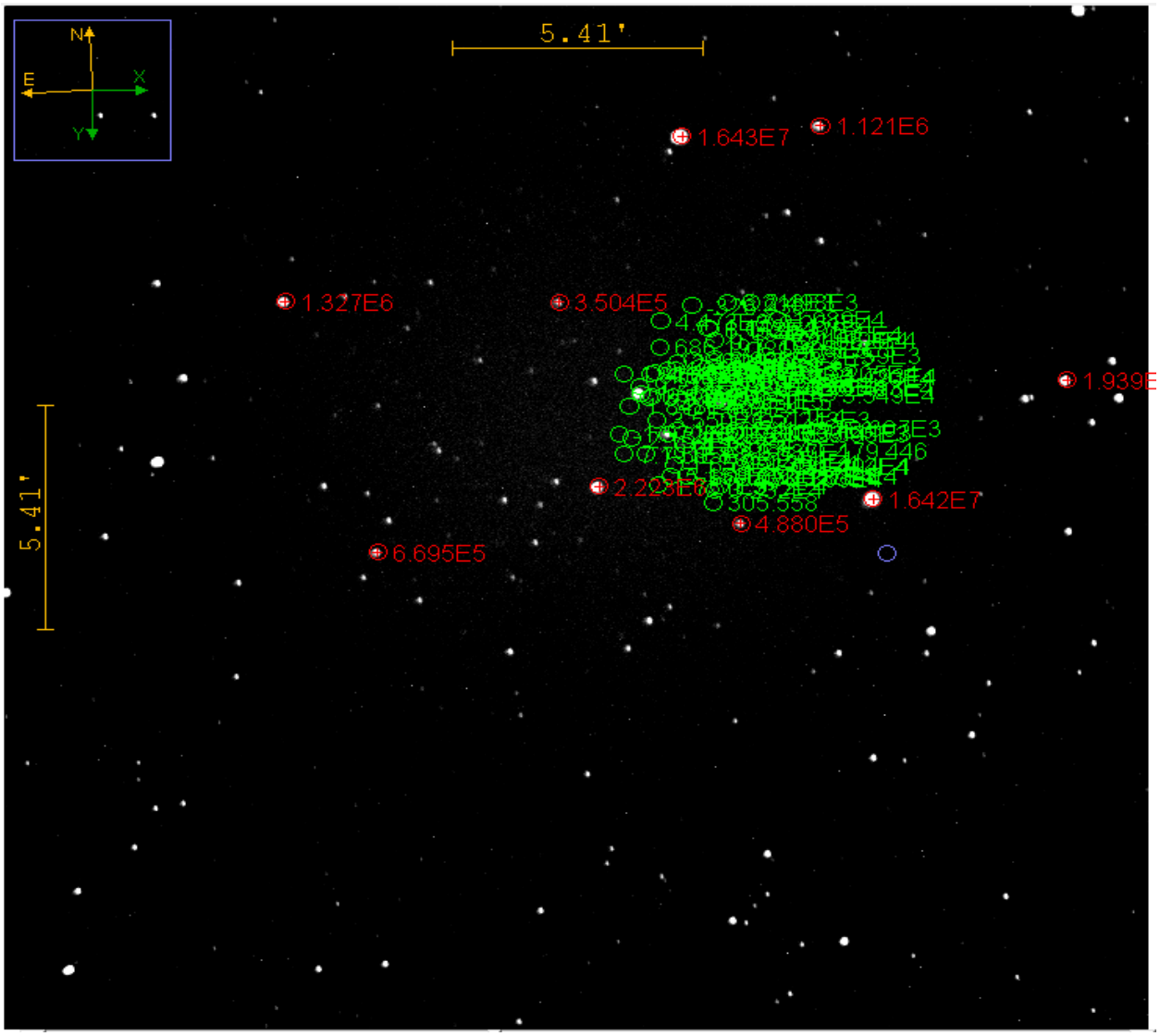

Figure 2: A plate solved the science of TOI 5907.01, alongside reference stars in red and *GAIA* stars in green.

3.4

Due to other stars possibly interfering with the exoplanet's transit, we have to check for nearby eclipsing binaries (NEB) – stars that orbit one another and interfere with exoplanet transit data. Therefore, we need to check if stars are cleared; if they are not cleared, they must be removed so as not to skew with data. Using the predicted ingress and egress times, alongside the plate solved images, we generated the NEB table **(Figure 3).**

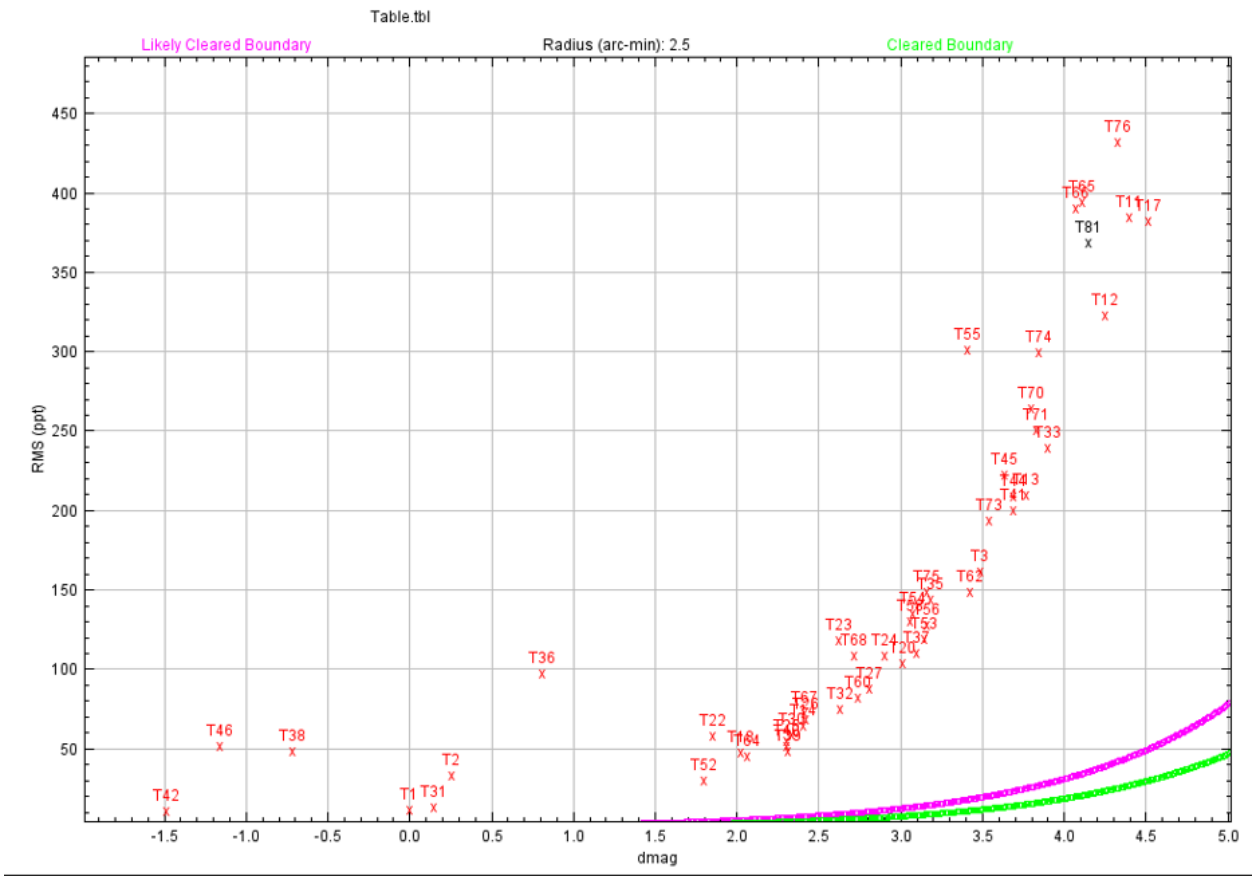

Figure 3: NEB table of TOI 5907.01, which plots RMS (Root-mean Square) – scatter noise or standard deviation – vs dmag– brightness compared to the target star.

3.5

Finally, we plotted the light curve using the AstroImageJ multi-plot tool. The egress and ingress times were inputted, and we changed the default X-data to BJD_TBD. In window 2, we entered the target's stellar radius and period. Then, on the Multi Plot Y data window, we plotted Airmass, Sky/Pixel_T1, Y(*Fits*)_T1, *X(Fits)*_T1, tot_C_cnts, Width_T1, and 2 reference stars, properly fitting the TFOP SG1 Guidelines.

Results

In this section, we present our statistical findings **(Table 1)**, along with our transit curve for TOI 5907.01 **(Figure 4).**

Table: Transit Fit Parameters (TOI 5907.01 – T1)

Parameter	Value
RMS (ppt)	9.78
Depth (ppt)	26.22
Duration (days)	0.132
P (days)	0.66
Chi²	122.1
DOF	76

Table 1: Table containing TOI 5907.01 Statistical analyses from AstroImageJ

The table present the RMS ppt (Parts Per thousand), the Depth of Transit in ppt, the Duration of the Transit, the Period in days of the transit, the Chi² value – measures the goodness of fit, the lower the better–, and the DOF (Degrees of Freedom) – "minimum number of independent coordinates that can specify the position of the system completely." (Grasp Engineering).

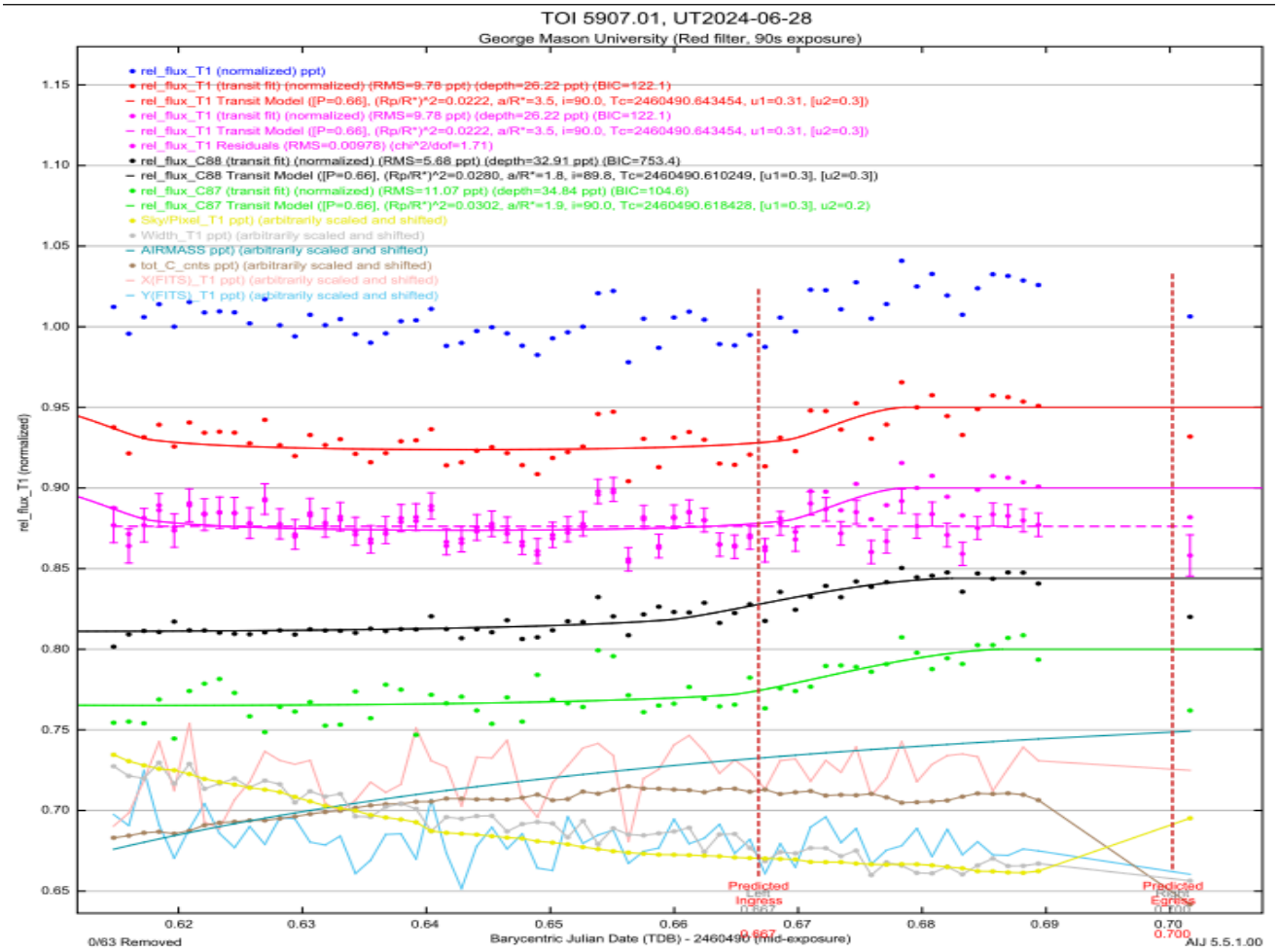

Figure 4: Light curve for TOI 5907.01. Reference stars T1, C88, and C77 in Red, Black, and Light blue, respectively.

Discussion

In this Section, we present our interpretations of the light curve we general while delving into our statistical findings. Thereafter, we connect our findings to the context of the greater field of follow-ups from candidate exoplanets from the NASA TESS Mission.

Research was done in a multitude of ways, allowing us to combine different figures, observations, and statistics to come to an understanding. In **Figure 4,** it is clear to see there is a small transit or dip. However, due to the graphing of nearby stars C88 and C87, we can see that their plots also have similar dips. The similarity of the graphs could indicate that a common event, unlike a transit, could have taken place, such as comets, etc, resulting in a common dip rather than a specific transit occurring for one of the stars. In addition, when regarding the predicted ingress and egress times, we can see they do not like up with the supposed transit. The supposed transit is longer than predicted and occurs at different times.

However, for the utmost certainty, we need to compare the statistical values given by AstroImageJ during error propagation – the effect of uncertainty on a measurement. First of all, the RMS is indicated in **Table 1** as 9.78 ppt (detrending to lower the RMS, as we noticed it had no productive impact). For a good fit of data: the lower the RMS, the better, preferably under 5 ppt. While 8.76 ppt is not relatively high, it is still much higher than preferred for the best fit of data.

Secondly, we attained the Chi^2 goodness of fit, which uses an equation (Chi Squared equation) to assess the value. To properly conclude the deviation of the line, we then divide by Degrees of Freedom (DOF). The value of Chi^2/DOF was equal to 1.71, which is a relatively good value as it is very close to 1, so the line did not deviate from a proper transit line relative to the scale.

Despite these calculations seeming like the line is a good fit, we still must compare them to the previously collected TESS Mission data. For example, we attained a depth of 26.22 ppt while the TESS Mission collected a depth of 3.7 ppt. This is a striking difference, meaning either some astronomical event interfered or our data was inaccurate for the depth. Additionally, when comparing our NEB data (**Figure 3)**, almost all of the stars, bar one, said the flux was too low. This means that it cannot be concluded whether there was actually an eclipsing binary or not.

Finally, it can be seen in **Figure 4** that between 0.69 and 0.70, there is a big gap in the data. This is most likely because, due to streaking, only 76/172 of the original sciences were kept.

Conclusion and Future Works.

Considering the large number of sciences missing, it is probable to say that the light curve is mostly inconclusive. Due to the lack of data, NEB figures, results, and our analytical values, we deem our follow-up observations to be inconclusive. This seems to be a trend in past works for TOI 5907.01, and for the most part, there does not seem to be in transit. Unfortunately, due to the previous reasons stated, we cannot conclude this with certainty. Therefore, future work would be beneficial, including a longer duration of

science collection, as this would make up for a lack of data. A more precise and powerful telescope should also be used when considering the Non-eclipsing binary check. More detailed statistical false positive analysis should be carried out to conclude the planetary nature of TOI 5907.01.

Acknowledgements

We would like to thank Dr. Peter Plavchan, along with the Schar Scholars education program, including Kasey Davidson, S Falgiano, Kevin Collins, and Owen Alfaro. Without these people, none of this would be possible; they have guided, curated, and taught so much, it is imperative to say these people and these programs were the fuel for the creation of this paper.

We would also like to thank the NASA Tess Mission for providing data and allowing exploration of this exoplanet—additionally, the Mikulski Archive for Space Telescopes provided us key telescope data, which was used repeatedly in this paper. George Mason University for letting the Ground follow-up observations with their program and their telescope. These organizations and people are truly the reasons why such research and this paper are possible.

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