Ground-Based Light Curve Follow-Up Validation Observations of TESS Object of Interest 5886.01

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Abstract

This study aims to conduct a follow-up investigation and validate the observations of a potential exoplanet candidate, Target of Interest TOI 5886.01, discovered by the Transit Exoplanet Survey Satellite (TESS) program by NASA and confirm its existence. For this study, we obtained observational data from the ground-based George Mason University (GMU) Observatory. This data was then reduced through Alnitak and visualized through AstroImageJ. We created a final light curve plot despite removing some images due to streaking. However, uncertainties remained, which did not allow us to clear the possibility of a false positive caused by a NEB or Hot Jupiter. As a result of the difference between the predicted transit and that shown on both light curves produced by this study and the TESS project, along with the previously mentioned uncertainties, the results for this research are inconclusive. Although there is currently no concrete statement as to the status of TOI 5886.01, statistical false-positive validation analysis should be conducted in the future, along with more intensive data collection, to better confirm this detection's origin.

Introduction

The Transit Exoplanet Survey Satellite (TESS), a NASA space telescope of immense importance, is extensively used to find and identify exoplanets using the Transit method. The Transit Method is a powerful tool in the search for exoplanets, which involves monitoring a star's brightness and identifying recurring dips in the light source caused by a planet passing in front of it. Since the discovery of the first transiting exoplanet, HD 209458, this method has emerged as one of the most successful detection techniques. It has surpassed the total detection counts of all other methods and produced the most significant quantity of characterized exoplanets, inspiring hope for further discoveries.[3] (Deeg & Alonso 2024) It was based on this discovery that the TESS program was created. Following discussions and proposals by the Massachusetts Institute of Technology funded by private investors, NASA approved it as a Medium Explorer mission and launched on 18 April 2008. Thanks to TESS, the plethora of newly discovered exoplanets provides numerous fresh opportunities for in-depth follow-up investigations. Over the last six years of its mission, it has imaged up to 7,204 TESS candidates and 556 already confirmed exoplanets.

While the TESS mission has gathered large quantities of data on these thousands of targets, researchers must conduct in-depth inquiries to confirm that these exoplanets do indeed exist and that the satellites were not alerted by false positives. Only after follow-up analysis can future observers begin analyzing the parameters and characteristics of target exoplanets.

Our current investigation is of utmost importance as it focuses on the TESS Object of Interest (TOI) 5886.01, a candidate planet discovered in 2022. We are striving to determine the existence of this exoplanet through observation data of TOI 5886.01 obtained from the George Mason University Observatory and software tools like ansvr and AstroImageJ. Our goal is to create a seeing profile and light curve to confirm the occurrence of an exoplanet transit, which holds significant implications for our understanding of the universe.

[3] https://arxiv.org/pdf/1803.07867

Section 2 presents our Observations from TESS and George Mason University 0.8 telescope. Section 3 presents our analysis of the TESS light curve for TOI 5886.01. Section 4 presents our light curve results. Section 5 discusses our results, and Section 6 presents our conclusions and future work.

Observations

Section 2.1 presents the TESS Object of Interest 5886.01 and its exoplanet candidate properties, host star parameters from the TESS Input Catalog, the *Gaia* mission, and other archival sources. Section 2.2 presents the TESS sector light curve(s). In Section 2.3, we present a summary of the observational data collected from the George Mason University 0.8m telescope.

2.1 Properties of TOI 5886.01 and its host star

In 2022, an exoplanet candidate with a planet radius ($R_\oplus$) of 11.585 was discovered at the Right Ascension (RA) at 20:27:57.32 and declination (DEC) of +37:08:46.88 by the TESS mission while observing the star TOI-5886. The potential exoplanet, now named TOI 5886.01 or TIC 15682927.01, was seen to have a period of 0.97 days, a depth (ppt) of 3.1, and a predicted planetary mass (M_Earth) of 92.31. Its proper motion (mas/yr) was also recorded, with its Right ascension being -2.16209 and declination as -4.98222. The TESS Project observed the star TOI-5886 on 2019-04-15 with a recorded stellar effective temperature (Teff) of 7542K, radius (R_Sun) of 1.91879, surface gravity log(g) of 4.11256, and stellar mass (M_Sun) of 1.74.[4] (ExoFop 5886.01 2024)

2.2 TESS sector light curve

TESS created the following light curve plot in Figure 3 from its data collection of TOI 5886.01 to move towards identifying a possible planetary transit. It was published to ExoFop on 2023-06-28 at 14:57:55. As seen in the plot, a potential transit can be seen offset from the predicted ingress and egress of 0.497 and 0.548. Possible causes are outlined in Section 5.1.

[4] https://exofop.ipac.caltech.edu/tess/target.php?id=15682927

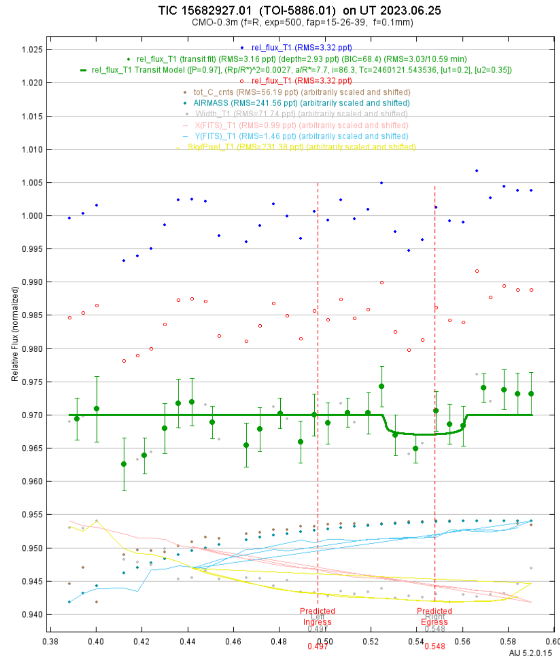

Figure 3: Light curve produced from TESS data collection of the target and nearby stars.

2.3 Data Collected from GMU

Following TESS's potential discovery, George Mason University performed a follow-up observation using its ground-based 0.8m telescope to confirm its existence. On 2024-06-18, the GMU Observatory gathered 219 Science images, each with an exposure time of 85.000s, 10 Flat images of 2.500s, and two sets of 10 Dark images with both exposure times, using an R filter, beginning at 21:49 and ending at 4:31 (America/New_York) time. The predicted ingress and egress for the target are 0.6919 to 0.7428.

Analysis

In section 3.1, we present our tools for analyzing the TESS sector light curve(s) using AstroImageJ/ExoFASTv1/ExoFastv2. In section 3.2, we present our analysis of the ground-based light curve using AstroImageJ.

3.1 Data Analysis

We obtained the observational data used for our research of TOI 5886.01 from the ground observatory at George Mason University (GMU), Virginia. On Tuesday, 2024-06-18, it was observed at nautical twilight from 21:49 to 4:31 local time for approximately 1:13 with an R filter. During this period, of the 219 science images with an exposure time of 85.000s, we removed 26 due to streaking from small movements and corrections in the observatory telescope, which would otherwise greatly impact our results negatively. We moved these files to a separate 'bad' folder with the reason for removing them. We then reduced the remaining 193 images through Python script using the Alnitak software and API key from astrometry.net. All images were successfully plate-solved after entering the science, science dark, and flat dark images. Using AstroImageJ, we imported a virtual stack of the plate-solved images to create a seeing profile using the processed pictures to obtain aperture and annuli radius values, as seen in Figure 1.

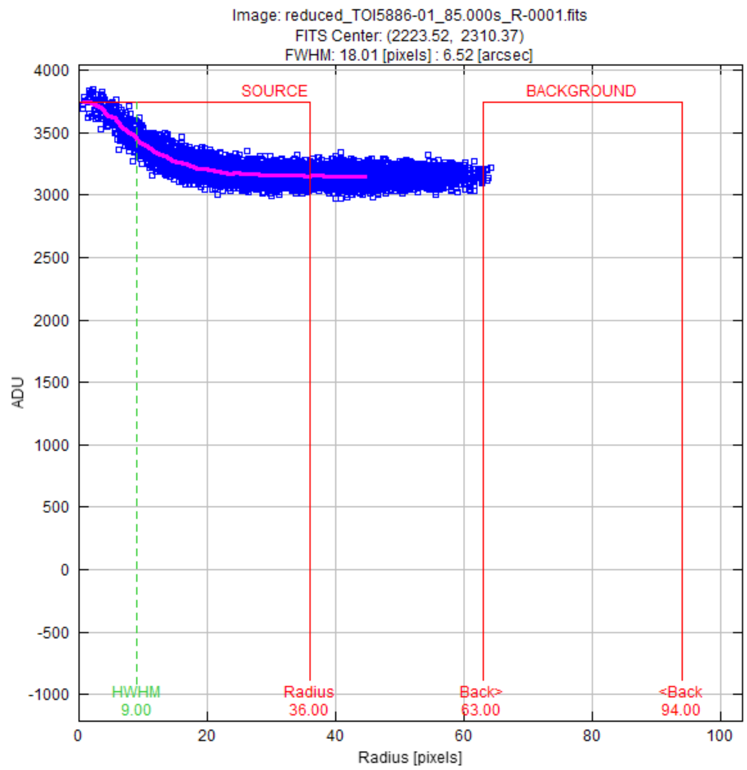

Figure 1: The seeing profile of data obtained from TOI 5886.01.

3.2 Light curve generation/analysis

Our process for generating a light curve began with 150 possible reference stars of TOI 5886.01, which we imported onto the virtual stack. This was made possible by the Gaia stars .radec file, allowing us to generate a measurement table for a light curve. After placing apertures using the Multi-Aperture Measurement tool in AIJ, we created a measurement table that will be needed to create a light curve plot. We then generated a dmag_vs_RMS curve to identify possible outlying stars and to clear the possibility of false positives. We scaled the plot to show all data points and updated all measurements with parameters concerning TOI 5886.01. Multi-plot data settings were updated to be in accordance with TFOP SG1 Guidelines.[5] (Conti 2020)We then detrended Y(FITS)_T1 to approximately match the scale of the predicted ingress and egress and performed multi-aperture photometry to generate a light curve plot to confirm the existence of our exoplanet candidate.

The data between the predicted ingress and egress will likely indicate a transit when examining the final light curve. A new exoplanet may be discovered if a prospective transit is

[5] TFOP_SG1_Guidelines_Latest.pdf (astrodennis.com)

identified and there is a noticeable difference in light between the potential transit and the average light signature.

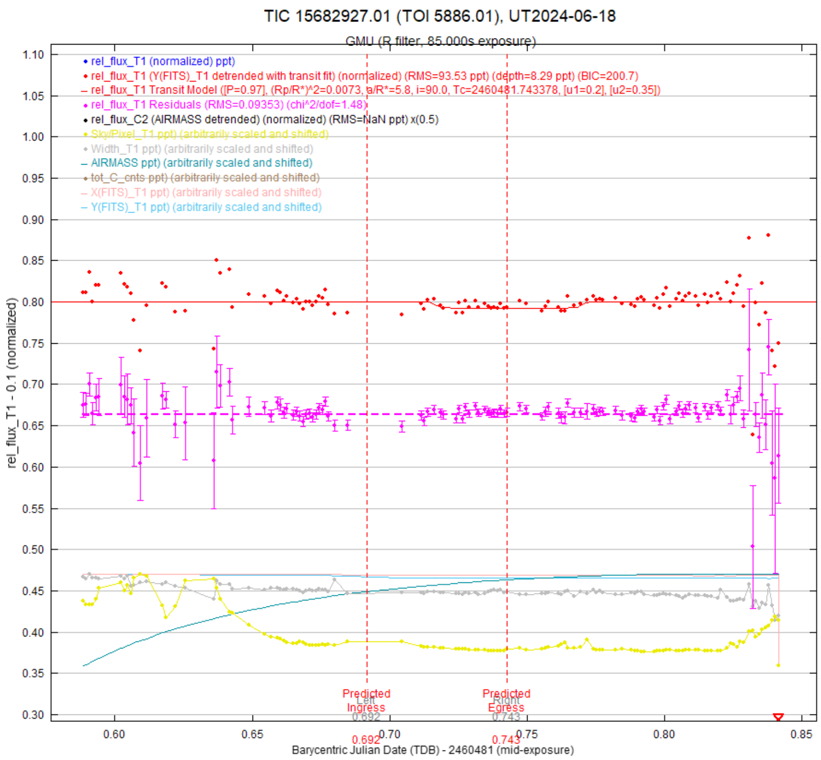

Figure 2: Light curve plot of 5886.01 generated from the collected data.

Results

Following the previously described data reduction and usage to create a light curve plot, Figure 1 depicts the seeing profile created from plate-solved images via AstroImageJ and Alnitak, while Figure 2 shows the final constructed light curve plot of TOI 5886.01.

Discussion

In Section 5.1, we present our interpretation of our results. In Section 5.2, we place our results in the context of the greater field of follow-up of candidate exoplanets from the NASA TESS mission.

5.1 Interpretation of Results

The observational data from the GMU Observatory regarding TOI 5886.01 yielded 219 images, of which 196 were usable. We removed the remaining photos due to image streaking caused by shifts in the telescope. While sufficient for creating a light curve plot, the streaking images caused some gaps in the data, part of which exists in the predicted transit. However, we detected a dip in luminosity in the final light curve in Figure 2, approximately matching the scale of the expected transit, although offset, similar to the light curve constructed by the TESS program in Figure 3. The offset light dip likely results from transit timing uncertainty, or “stale ephemerides,” possibly due to uncertainties in measuring the orbital period precisely. This, in turn, could be caused by a change in ephemeris since some orbital parameters can change over time.[6] (Koks 2017) After creating an NEB search, as seen in Figure 4, however, we could not either certainly or likely clear the plot boundary for any targets, pointing towards an inconclusive NEB check. While this does not disprove the existence of TOI 5886.01 as a transiting exoplanet, we cannot confirm that it is not a NEB false positive.

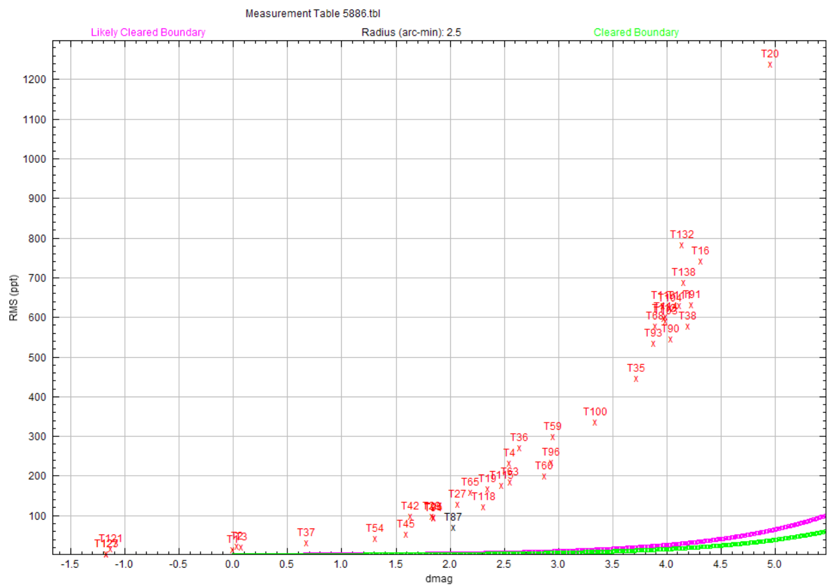

Figure 4: dmagRMS plot created from observational data of TOI 5886.01

5.2 Greater Context

The equilibrium temperature of TOI 5886.01 is 2186K, likely clearing it of the possibility of being caused by a Super-hot Jupiter, being under the threshold of 2200K+, however we cannot clear it of being a false positive caused by a Hot Jupiter as it still within the upper threshold of 2000-2300K. As of the time of writing, there are no published works on either the observation or identification of the exoplanet candidate.

Conclusions and Future Work

Our goal in this follow-up investigation was to confirm the planetary status of TOI 5886.01 by reducing ground-based observation data from the night of 2024-06-18 and conducting multi-aperture photometry to construct a light curve and NEBcheck. However, we could not confirm TOI 5886.01's status as an exoplanet due to timing uncertainties and the inability to clear the possibility of a false positive with current research. The transit depth was slightly larger than predicted, and the light curve displayed a transit later than the predicted

[6] DST-Group-RR-0443_0.pdf (defence.gov.au)

ingress and egress. After our investigation, more evidence must be gathered to prove the existence of TOI 5886.01.

Future research on TOI 5886.01 should carry out a detailed statistical false-positive validation analysis to rule out a NEB or Hot Jupiter. It may also want to account for the change in time since the initial ingress and egress predictions were made, along with the orbital ephemeris data from the night of the observation. Future observations should be of higher precision. Our final light curve should also be experimented on by detrending more values. Further research should be done to investigate its planetary characteristics if its planetary status is confirmed in the future.

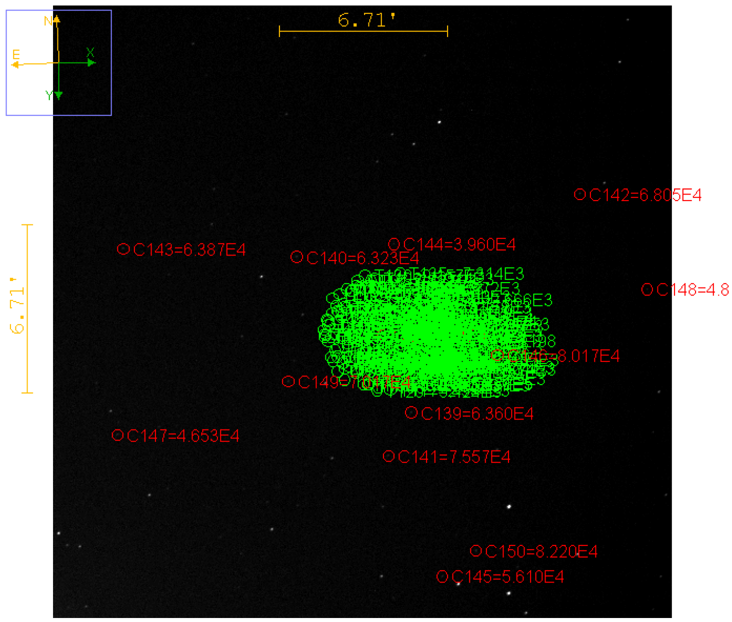

Figure 5: Field of View Image of TIC15682928.01 or TOI 5886.01 from GMU using an R filter.

Local evening date	Name	V mag	Start—Mid—End	Duration	BJD_{TDB} start-mid-end	Elev. at start, mid, end	% of transit (baseline) observable, Suggested obs. start, end	HA at start, mid, end	RA & Dec (J2000)	Period (days)	Depth (ppt)	Priority	R_{planet} ($R_\oplus$)	Comments and followup status
Tue. 2024-06-18: Nautical twilight 2024-06-18 21:49 — 2024-06-19 04:31 local time / 2024-06-19 01:49 — 2024-06-19 08:31 UTC														
Tue. 2024-06-18 Nautical twilight 21:49 – 04:31 (America/New_York)	☐ TIC 15682927.01 (TOI 5886.01) Add to TOC Finding charts: Annotated, Aladin; Info: ExoFOP, Simbad, Gaia, TIC, VSX, AIJ apertures, Vizier phot.; Airmass, ACP plan	12.98 Moon 91% @94°	00:29 00:32—01:09—01:46 01:49 ±0:03	1:13 ±0:14	10480.6919 10480.7174 10480.7428	52° 52°, 59°, 66° 67°	100% (100%) 23:32—02:46	-3.3 -3.2, -2.6, -2.0 -2.0	20:27:57.32 +37:08:46.88	0.97	3.1	3	11.6	PC PC RR qlp-s55-faintsearch Sectors:[14, 15, 41, 55] SG2:[TRES(1), Vrot=120]: found in faint-star QLP search; Roberto Zambelli/CMO-0.3m observed a full on 20230625 in R. Inconclusive. The next observation should be a high precision (<1.0 ppt/10 min) full transit in a red (r', R, i', I, z, Y) filter to attempt a firm detection of the event on target. Multi-band or blue (U, u', B, g') filter observations even better for a simultaneous chromaticity check.

Figure 6: Transit information collected by GMU of TOI 5886.01

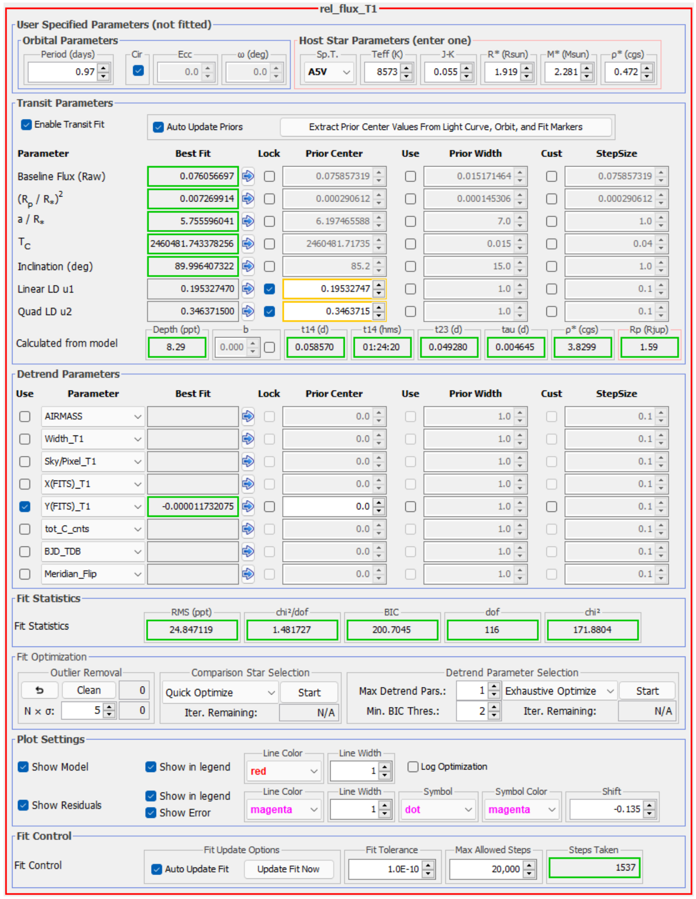

Figure 7: R_Fit Panel on AstroImageJ used to create the light curve plot for TOI 5886.01

References

[1] Deeg, H., Alonso, R.. "Transit Photometry as an Exoplanet Discovery Method". Instituto de Astrofísica de Canarias, Tenerife, Spain, Departamento de Astrofísica, Universidad de La Laguna, La Laguna, Tenerife, Spain. 2024. Volume 01. Page 03.

[2] "TIC 15682927". Caltech. (n.d.). TOIs. Exofop. 2024.

[3] Conti, D.. "TFOP SG1 Observation Guidelines". TESS Follow-Up Observing Program Working Group (TFOP WG). 2020. Page 09.

[4] Koks, D.. "An Investigation into the Possibility of Numerical Ephemeris Extention for GPS". Cyber and Electronic Warfare Division Defense Science and Technology Group, Australian Government Department of Defense, Edinburgh, Australia. 2017. Page 01-07.

[5] Plavchan, P., Matzko, W., Hamze, B., Wittrock, J., Bowen, M., Alfaro, O., Collins, K., et al.. "iAstroImageJ (AIJ) Tutorial for Transiting Exoplanet Data-Reduction & Analysis". George Mason University, Virginia, USA. 2024.