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

Krish Mehra[1] and Peter Plavchan[2], PhD Department of Physics and Astronomy, 4400 University Drive

MS 3F3, George Mason University, Fairfax, VA 22030, USA

Abstract:

The goal of this observational research was to confirm the existence of Tess Object of Interest 5907.01 using a light curve derived from data collected using the 0.8 meter observatory at George Mason University. We collected a total of 235 images: 20 darks, 10 flats, and 205 raw science images. We processed and analyzed these images using AstroImageJ and generated a light curve. This light curve showed a transit, however, this transit was misaligned with the predicted ingress and egress, as well as significant atmospheric noise and blurring in some images. We also checked for false positives using a non-eclipsing binary plot, which also came up inconclusive. Therefore, this data is inconclusive and more data is needed to confirm the existence of TOI 5907.01, such as data from space-based telescopes or using other methods of transit detection. Nevertheless, our data, despite its inconclusiveness, remains useful to future researchers and adds to the growing set of human knowledge.

Introduction:

TESS and other missions like it have made substantial advances in finding exoplanets over the past few decades. Since beginning operations in 2018, TESS has been systematically observing the sky, monitoring the luminosity of numerous stars in search of regular decreases in brightness that may indicate the presence of orbiting exoplanets. There are many methods of exoplanet detection, the two most popular ones being the transit method, in which a star has slight dips in brightness caused by a potential transiting exoplanet, and the Doppler method, using radial velocity. The transit method is by far the most popular method, with 79% of total discovered exoplanets being discovered (Cumulative Number of Exoplanets Discovered, by Method, n.d.). This is the method that we used for our study, as it is the most popular and therefore will more likely be used in the future.

TESS Object of Interest (TOI) 5907.01 is a possible exoplanet candidate that emerged from the TESS mission. Our study made use of the ground based 0.8-meter telescope at George Mason University. The purpose of our study is to validate the exoplanet candidate, create and examine a light curve, and identify whether the data confirms the existence of TOI 5907.01. We employed AstroImageJ for processing, and an Ansvr plugin that matched our telescope's specific parameters to plate-solve the images that we would eventually use for data analysis.

Method:

TOI 5907.01 was observed at the George Mason University Observatory on Thursday, June 20, 2024. The telescope was equipped with an R filter, and we employed an exposure time of 85 seconds for the science images and 10 of the dark frames, while a 3-second exposure time was used for the flat frames and 10 other dark frames. The observation session spanned from 21:50 to 04:32 (America/New York time), resulting in the collection of 10 dark frames with 85-second exposures, 10 dark frames with 3-second exposures, 10 flat frames with 3-seconds exposures, and 205 science images with 85-second exposures each.

When the science images were first examined, 19 of them had issues such as streaking and blurriness, which made them unfit for additional examination. After these photos were removed, there were only 186 science photos that could be used.

AstroImageJ (AIJ) software was used to process the acquired data, with an Ansvr plugin added for plate solving. The first step in the processing workflow was to open the 186 science images in AIJ's virtual stack. Next, by choosing the "DP" button in AIJ, the CCD Data Processor and DP Coordinate Converter tools were accessible. The Right Ascension (RA) and Declination (DEC) coordinates of TOI 5907.01 were entered into the DP Coordinate Converter in order to precisely align and process the images. The NASA Exoplanet Archive provided these coordinates, RA = 21:00:52.77 and DEC = +17:06:59.10, as well as other stellar information.

To create master images needed for calibration, the sets of dark and flat images need to be averaged individually in order to be removed from the raw science images. We created 2 master dark images, one of them using the 85s exposure time darks, and the other using the 3s exposure time darks. Then, using the flat frames and this master 3-second dark frame, a master flat image was created. The science processing involves subtraction by the master 85s dark, then division using the master flat.

Plate solving was used on the images during the processing stage. This method compares the star patterns in the pictures with corresponding real stars in the sky by using Astrometry.net. Plate solving is essential for producing a dependable light curve and enabling precise photometric measurements by precisely mapping celestial coordinates onto the images.

The final dataset consisted of 171 processed science images after an additional 15 were determined to be unusable during processing. After that, these surviving photos were used for additional examination in order to evaluate the light curve and confirm the possible exoplanet candidate TOI 5907.01

The following seeing profile was generated from the 171 processed sciences images. The seeing profile depicts the quality of the weather and atmosphere during the observation time.

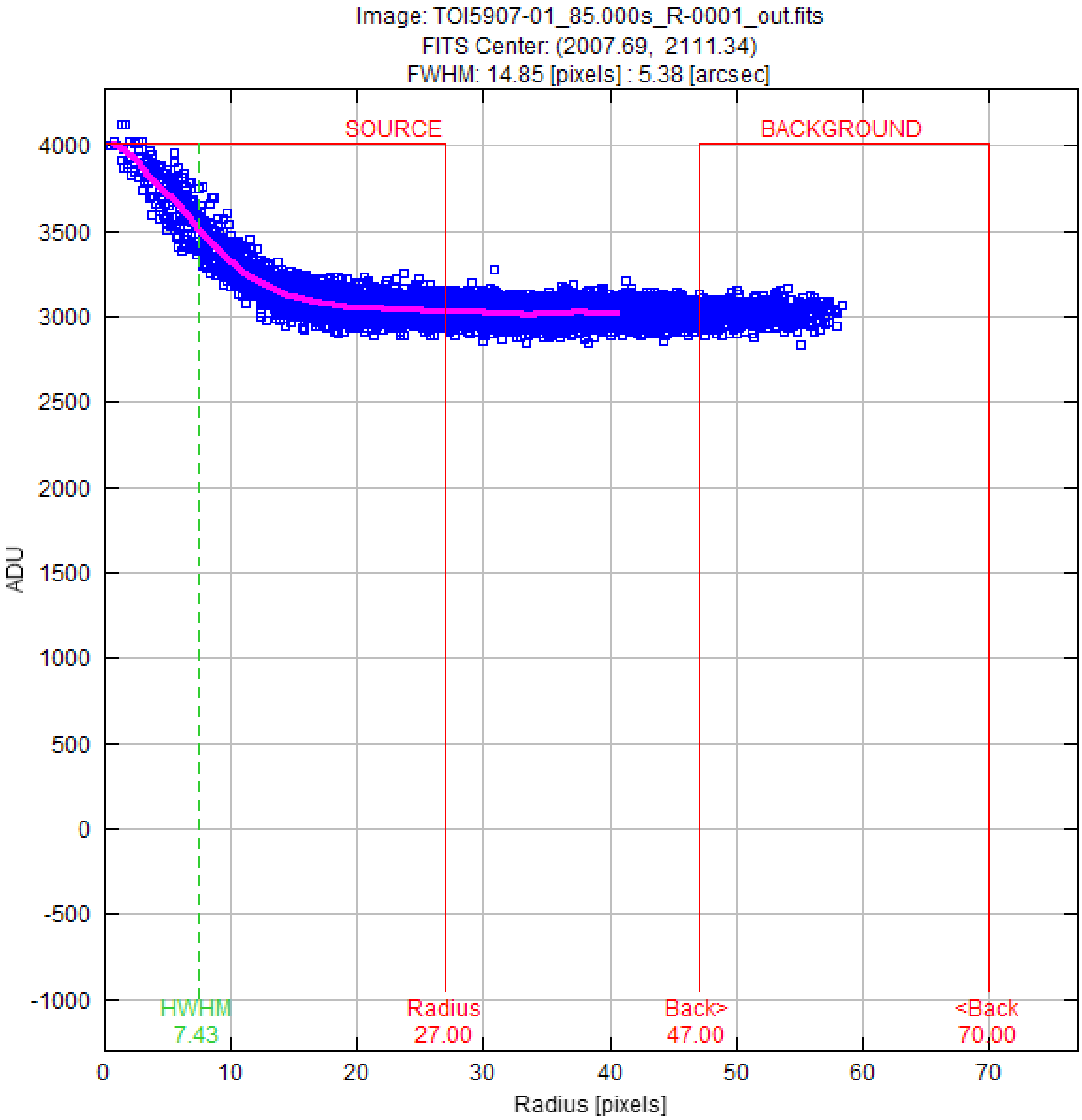

Figure 1. Seeing profile generated from data obtained from TOI 5907.01

Along with the seeing profile, the images were then used in conjunction with the Multiple-Aperture Photometry Tool in AIJ to generate a measurements table. For reference stars, we used stars that were similar in relative brightness and size to our target.

The following light curve plot was generated using the measurements table created from performing Multiple-Aperture Photometry on our 171 processed science images using AstroImageJ.

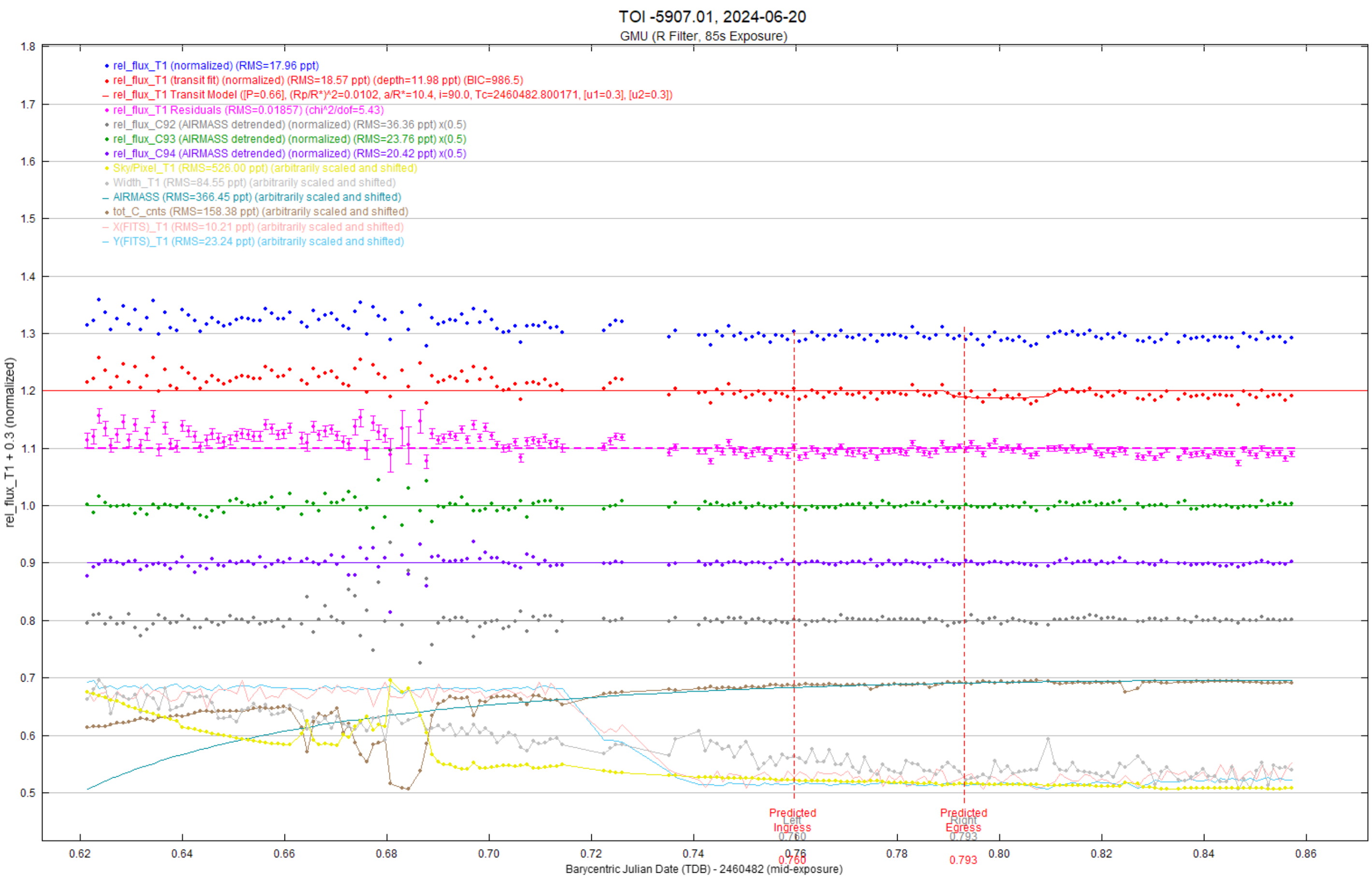

Figure 2. Light curve plot generated from data obtained from TOI 5907.01 (in red) and other similar reference stars in relative proximity

Results:

A transit was detected in the light curve plot, however, the results are inconclusive due to the transit being outside of the predicted ingress and egress times. This error could be due to chance, however it has been determined that more data is needed and additional testing will need to be conducted in order to confirm the transit of TOI 5907.01

Discussion/Future Work:

There are many factors that contribute to the reason why this data came out inconclusive. The seeing profile showed a FWHM of 5.38 arc sec, which would indicate a moderate amount of blurring and/or weather conditions that could have affected our data. Also, as seen in the light curve plot, the transit is outside of the predicted ingress and egress times, shown by the red vertical lines. The ingress and egress times not being aligned raises concerns, as a confirmed transit should be perfectly aligned. The residuals (shown in pink) could also tell another story of poor weather conditions before the transit that could have affected the results. The residuals show high amounts of variation in their error bars, indicating high variation in the amount of noise in the images and blurring caused by the Earth's atmosphere.

It was observed that there was a significant difference in many data points between this light curve and the recorded data from the telescope. According to the Transit Finder Info provided by the GMU Telescope operators with the use of multiple exoplanet archives such as ExoFOP, Simbad and Gaia, the predicted depth (ppt) of transit was 3.7, while the observed depth was 11.98. The residuals also contained more variation than expected, with a chi^2/dof equal to 5.43. This is far from the ideal value of one, which again could indicate high amounts of noise and/or blurring.

For these reasons, this data has been deemed inconclusive. However, we would like to take some time to highlight how important new data is, whether it is inconclusive or not, to scientific research and the knowledge and understanding of the world as we know it. Future research can still be conducted on this possible transiting exoplanet, which could include using other detection methods, such as the Doppler effect, or combining data with high precision space-based telescopes such as Hubble or JWST.

Conclusions:

In conclusion, our attempts to confirm the existence of the transiting exoplanet TOI 5907.01 were deemed inconclusive due to certain factors such as a misaligned transit timing, high variation in residuals indicating blurring or high amounts of noise in the images, and statistically significant differences in data when compared to existing databases such as NASA Exoplanet Archive. Future research into the confirmation of TOI 5907.01 could include different methods of transit detection such as the Doppler effect (radial velocity) or using data from space-based telescopes such as Hubble or JWST. The inconclusiveness of this data does not make it invalid, but instead highlights the many factors that go into exoplanet research, as well as bring more attention to the need for more data on TOI 5907.01 in order to be fully confirmed.

Citations:

Ricker, G. R., Winn, J. N., Vanderspek, R., Latham, D. W., Bakos, G. Á., Bean, J. L., Berta-Thompson, Z. K., Brown, T. M., Buchhave, L., Butler, N. R., Butler, R. P., Chaplin, W. J., Charbonneau, D., Christensen-Dalsgaard, J., Clampin, M., Deming, D., Doty, J., De Lee, N., Dressing, C., & Dunham, E. W. (2015). Transiting Exoplanet Survey Satellite (TESS). Journal of Astronomical Telescopes, Instruments, and Systems, 1(1), 014003. https://doi.org/10.1117/1.JATIS.1.1.014003

TOI-5907 | NASA Exoplanet Archive. (2022). Caltech.edu. https://exoplanetarchive.ipac.caltech.edu/overview/TOI%205907.01#planet_TOI-5907-01_collapsible

SIMBAD: (n.d.). Simbad.u-Strasbg.fr. https://simbad.u-strasbg.fr/simbad/sim-fbasic

Gaia Archive. (2020). Esa.int. https://gea.esac.esa.int/archive/

Collins, K. A., Kielkopf, J. F., Stassun, K. G., & Hessman, F. V. (2017). ASTROIMAGEJ: IMAGE PROCESSING AND PHOTOMETRIC EXTRACTION FOR

ULTRA-PRECISE ASTRONOMICAL LIGHT CURVES. The Astronomical Journal, 153(2), 77. https://doi.org/10.3847/1538-3881/153/2/77

Cumulative number of exoplanets discovered, by method. (n.d.). Our World in Data. https://ourworldindata.org/grapher/cumulative-exoplanets-by-method

Astrometry.net. (n.d.). Nova.astrometry.net. https://nova.astrometry.net/