# Ground-based Light Curve Follow-up Validation Observations of TESS Object of Interest TOI 5944.01

Aiden Wang[1], Dr. Peter Plavchan[2]

[1]John Champe High School, Aldie, VA
[2]Department of Physics and Astronomy, 4430 University Drive MS 3F3, George Mason University, Fairfax, VA 22030, USA

**Abstract**

The Transiting Exoplanet Survey Satellite (TESS) mission, launched in 2018, aims to discover exoplanets by observing transits across bright stars. Using the transit method, TESS collects planetary properties such as radius, mass, and orbital period which are all used to identify potentially habitable planets. In this study, we present ground-based follow-up observations of TOI 5944.01 using data collected at George Mason University Observatory. AstroImageJ was used to do tasks such as data reduction and light curve generation and a NEB check was conducted to indicate a potential false-positive that did not deny the possibility of a false-positive. The analysis calculated a transit depth of 15.53 parts per thousand, closely resembling TESS's reported 15.16 parts per thousand. TOI 5944.01 was classified as a Hot Jupiter due to a radius 12 times of Earth, an orbital period of 5.94 days, and a temperature of 947 K. However, further investigation is required to confirm a true transit due to the possibility of a Nearby Eclipsing Binary and assess its habitability.

## 1. Introduction

The Transiting Exoplanet Survey Satellite (TESS) mission launched in 2018 searches for thousands of planets outside our solar system known as exoplanets (NASA, 2019). The TESS mission surveys around 85% of the sky and searches for planets around bright host stars that allow for ground-based follow-up observations (Barclay, n.d.). By utilizing the transit method, numerous planetary properties can be obtained such as planet radius, planet mass, and orbital period (Eisner et al., 2020). Planet transit is monitored by TESS by tracking periodic drops in the brightness of host stars that indicate an exoplanet is passing in front of its host star (NASA, 2019). The properties gathered by the transit method can lead to the discovery of a habitable planet with habitable planets likely possessing similar properties to Earth in composition, mass, and size (Jones et al., 2006). There are currently four recognized types of exoplanets: gas giants, Neptunian planets, super-Earths, and terrestrial planets (NASA, 2024). However, some exoplanet candidates are presumed to be false positives as a result of low spatial resolution causing an eclipsing binary to be mistaken as a transit (Giacomo Mantovan et al., 2022). As a result, a ground-based follow-up is necessary to validate whether a false positive has been detected as ground-based follow-up observations can confirm exoplanet discoveries, rule out false positives, provide information about host stars, and provide insights on planet habitability (Ciardi, n.d.).

Of the over 7000 TESS candidates, only around 550 have been confirmed (NASA, 2019). While a paper has been published on our TESS object of interest TOI 5944.01 with promising results, a Nearby Eclipsing Binary (NEB) test was not conducted resulting in the possibility of a false positive as well as TOI 5944.01 not being classified (Wang & Plavchan, n.d.). As a result, this presents the issue of 5944.01 being a possible false positive and needing a possible. In this paper, we will be presenting ground-based follow-up observations on TOI 5944.01 with data we gathered with the purpose of investigating if the transit occurs at the expected time with expected duration and depth.

## 2. Observations

We collected raw science images at the George Mason University Observatory using the 0.8m telescope and R filter. We collected a total of 194 raw science images with an exposure time of 90 seconds each. On July 10th, 2024, we began capturing images at 21:50 and ended capturing the next day, July 11th, at 4:45 for a total duration of 6 hours and 55 minutes. According to TESS

observations, TOI 5944.01 had a Right Ascension (RA) of 20h, 14m, 57.825s and a Declination (Dec) of 17h, 6m, 14.07s.In addition, TOI 5944.01 has a radius of 11.945 R_Earth, an orbital period of 5.94 days, and a depth of 15160 ppm. (ExoFOP TIC 88101924, 2015).

**3. Analysis**

We used AstroImageJ, a software that does an assortment of tasks such as data reduction, multi-aperture photometry, and generating light curves. Of the 194 raw science images that were captured, 166 remained after low quality images were removed that consisted of streaks, significant shifts, and clouds. . Next, data reduction was performed by utilizing flats, science darks, and flat darks to improve efficiency and remove noise. A seeing profile can be seen in Figure 1 that tells us how the light from a target object is separated from the surrounding background.

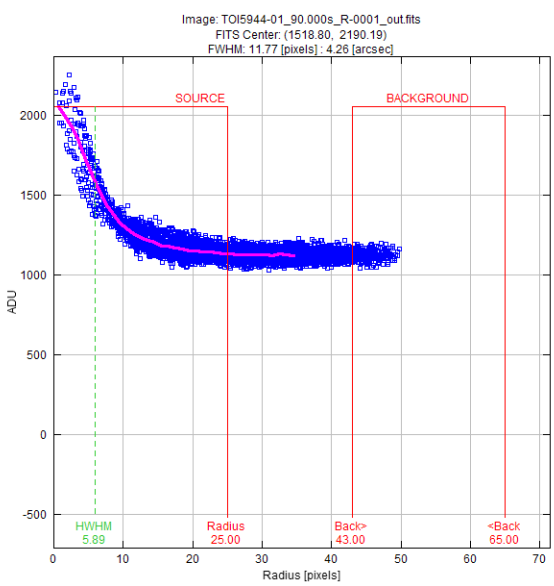


**Figure 1:** Seeing Profile of TOI 5944.01 with photometry radius of 25, inner annulus radius of 43, and outer annulus radius of 65

To plate solve the sciences, the sciences were centered around the previously mentioned celestial coordinates (RA and Dec) to generate a light curve to identify a transit. Figures 2 and 3 exemplify plate solving improving image quality that can be seen by interference in Figure 2 that is completely removed in Figure 3, allowing for more accurate results.

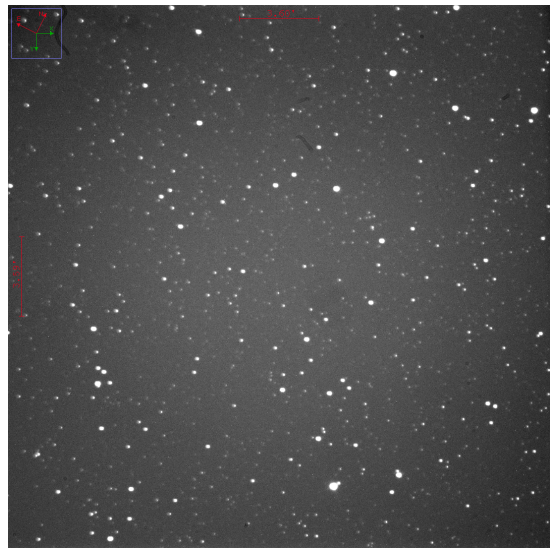

**Figure 2:** Unplatesolved image of TOI 5944.01

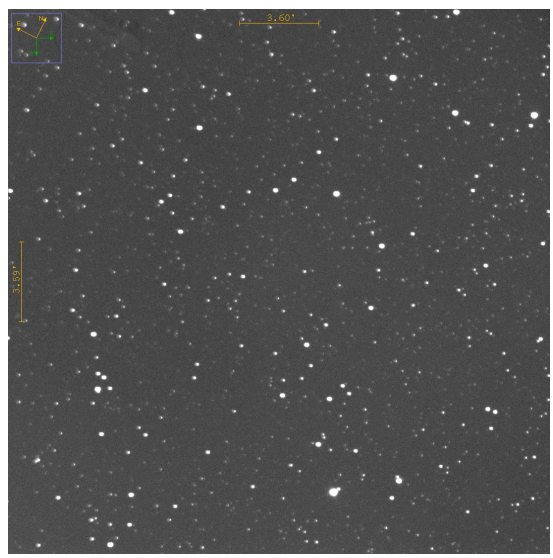

**Figure 3:** Platesolved image of TOI 5944.01 using AstroImageJ

After plate solving all 166 sciences, we created a measurement table in AstroImageJ by comparing reference stars with TOI 5944.01 that have similar brightnesses. Seen in Figure 4 are the reference stars used, imported from the Gaia database circled in green.

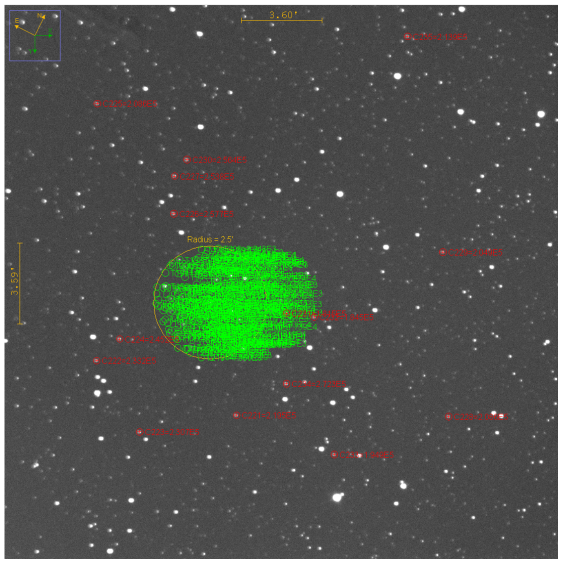


**Figure 4:** TOI 5944.01 and its reference stars imported from the Gaia database

A Nearby Eclipsing Binary (NEB) check is also conducted to eliminate the possibilities of a false-positive exoplanet classification due to a nearby binary system causing a similar dip in light that could be mistaken for a transit. Unfortunately, as seen in Figure 5, the NEB check did not yield any substantial results as none of the reference stars passed any boundary, resulting in the possibility of a false-positive that requires further analysis.

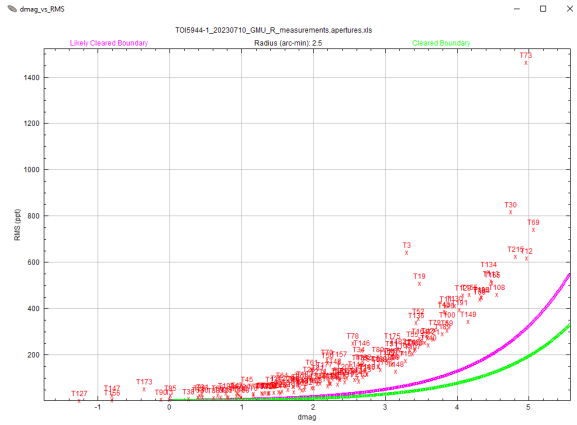


**Figure 5:** dmagRMS plot of TOI 5944.01 for potential NEBs.

## 4. Results

Seen in Figure 6, a light curve was generated for TOI 5944.01 using AstroImageJ with several plots.

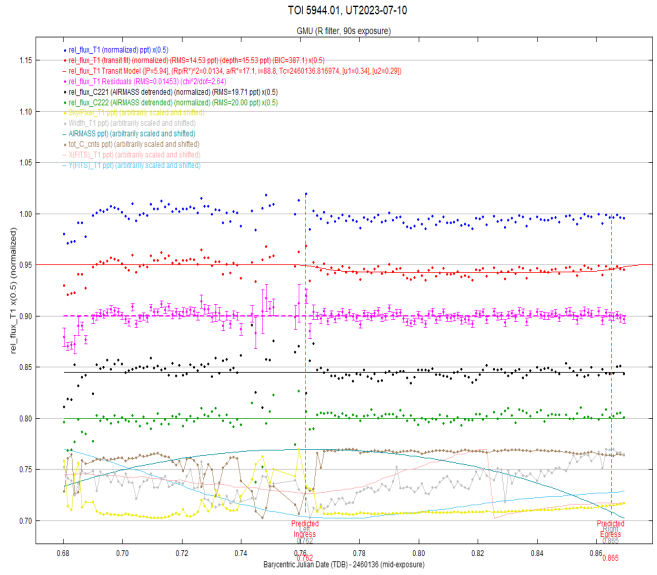


**Figure 6:** Light curve of TOI 5944.01 with an ingress time of 0.762 BJD and egress time of 0.855 BJD

Settings of the plots can be seen in Figure 7. Some important plots include air mass, tot_C_cnts, Width_T1, X(FITS), and Y(FITS) that are used to correct atmospheric effects and ensuring accurate analysis of light curves.

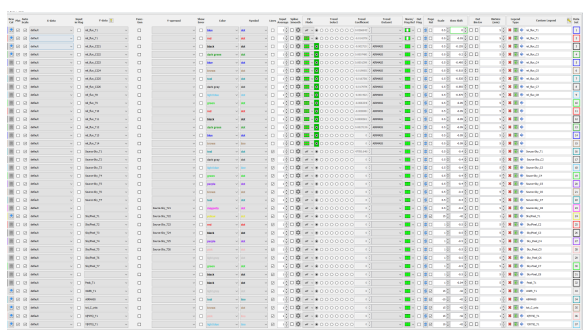

**Figure 7:** Plot settings used to generate Figure 6

Based on the light curve seen in Figure 6, the Data Set 2 Fit Settings in Figure 8 provides additional statistical analysis on the data gathered. It can be seen that a depth of 15.53 parts per thousand (ppt) was calculated and when compared to the TESS calculated depth of 15160 parts per million (ppm) or

15.16 ppt, the depths are extremely similar and support the claim that the data is accurate. In addition, an Root Mean Square value of 14.52 and a Chi Squared per Degree of Freedom of 2.64 was calculated, both supporting a set of accurate data. However, it should be noted that these values do suggest some overfitting and could impact the model's accuracy.

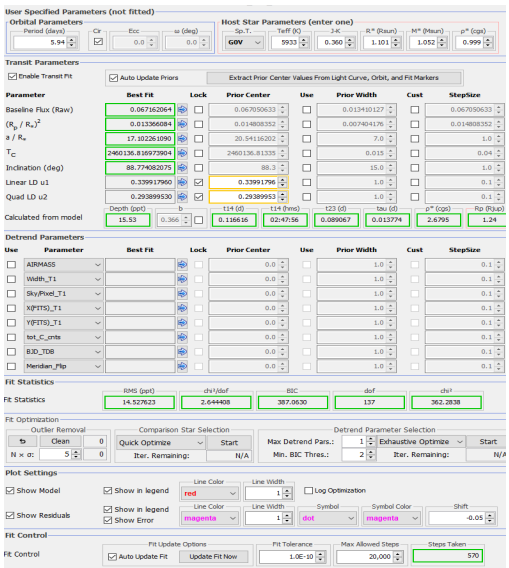


**Figure 8:** Data Set 2 Fit Settings that calculated a depth of 15.53 ppt, an RMS of 14.52, and a $\chi^2$/DOF of 2.644

## 5. Discussion

We will be attempting to validate whether or not TOI 5944.01 is an exoplanet, and if so, what type of exoplanet. To attempt to classify TOI 5944.01, it is important to know the temperature, orbital period, radius, and depth. To begin, the temperature was measured at 947 K which equates to ~674 C° that could indicate a potential Hot Jupiter. In addition, the orbital period of 5.94 days falls within the 3-10 day orbital period that many Hot Jupiters exhibit (Fortney et al., 2021). The radius of TOI 5944.01 is nearly 12 times that of Earth, and when compared to the Jupiter in our solar system which is 10 times that of Earth, this points to TOI 5944.01 being a Hot Jupiter (Hot Jupiter - NASA Science, 2008). Finally, the depth of TOI 5944.01 is 15160 ppm which indicates a significant amount of light is blocked by the potential planet when it passes its star, consistent with a potential Hot Jupiter.

In Figure 6, between the predicted ingress and egress times, a visible dip can be observed that corresponds with a transiting planet. In combination with the large size, high temperature, and short orbital period consistent with a Hot Jupiter, this leads us to the conclusion that there is an exoplanet transit and that TOI 5944.01 is a Hot Jupiter.

## 6. Conclusions and Future Work

In conclusion, we believe that this candidate demonstrated an exoplanet transit demonstrated by the dip in the light curve along with characteristics that align with those of a Hot Jupiter. However, further analysis is still required as there is still a possibility of a false-positive. Figure 5 proves this by none of the reference stars even passing the likely cleared boundary, implying significant possibility of a NEB. Future work could attempt to rule out a NEB as well as following up on characteristics of TOI 5944.01 to determine whether life can be supported. Overall, TOI 5944.01 still possesses many avenues to explore and still requires research from many angles to come to a more concrete conclusion.

## 7. References

1. Barclay, T. (n.d.). *NASA - TESS Science Support Center*. TESS. Retrieved August 17, 2024, from https://heasarc.gsfc.nasa.gov/docs/tess/objectives.html

2. Ciardi, D. (n.d.). *Exoplanet Exploration Program Analysis Group (ExoPAG) Study Analysis Group (SAG) 17 Final Report Resources Needed for Planetary Confirmation and Characterization*. Retrieved August 18, 2024, from https://exoplanets.nasa.gov/internal_resources/942/

3. Eisner, N. L., Barragán, O., Lintott, C., Aigrain, S., Nicholson, B., Boyajian, T. S., Howell, S., Johnston, C., Lakeland, B., Miller, G., McMaster, A., Parviainen, H., Safron, E. J., Schwamb, M. E., Trouille, L., Vaughan, S., Zicher, N., Allen, C., Allen, S., & Bouslog, M. (2020). Planet Hunters TESS II: findings from the first two years of TESS. *Monthly Notices of the Royal Astronomical Society*, *501*(4), 4669–4690. https://doi.org/10.1093/mnras/staa3739

4. *ExoFOP TIC 88101924*. (2015). Caltech.edu. https://exofop.ipac.caltech.edu/tess/target.php?id=88101924

5. Fortney, J. J., Dawson, R. I., & Komacek, T. D. (2021). Hot Jupiters: Origins, Structure, Atmospheres. *Journal of Geophysical Research: Planets*, *126*(3). https://doi.org/10.1029/2020je006629

6. Giacomo Mantovan, Montalto, M., G. Piotto, Wilson, T. G., A. Collier Cameron, Majidi, F. Z., L. Borsato, Granata, V., & V. Nascimbeni. (2022). Validation of TESS exoplanet candidates orbiting solar analogues in the all-sky PLATO input catalogue. *Monthly Notices of the Royal Astronomical Society*, *516*(3), 4432–4447. https://doi.org/10.1093/mnras/stac2451

7. *Hot Jupiter - NASA Science*. (2008, February 29). Nasa.gov. https://science.nasa.gov/resource/hot-jupiter/

8. Jones, B. W., Sleep, P. N., & Underwood, D. R. (2006). Habitability of Known Exoplanetary Systems Based on Measured Stellar Properties. *The Astrophysical Journal*, *649*(2), 1010–1019. https://doi.org/10.1086/506557

9. NASA. (2019, February 25). *Transiting Exoplanets Survey Satellite (TESS) - Exoplanet Exploration: Planets Beyond our Solar System*. Exoplanet Exploration: Planets beyond Our Solar System. https://exoplanets.nasa.gov/tess/

10. NASA. (2024). *Exoplanets - NASA Science*. Science.nasa.gov. https://science.nasa.gov/exoplanets/

11. Wang, H., & Plavchan, P. (n.d.). *Validation and Analysis of Exoplanetary Transit TOI594 4.01 Using Ground-based Observations*.