Ground-Based Light Curve Follow-Up Validation Observations of TESS Object of Interest 3777.01

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Abstract

The objective of this research paper is to validate the findings on a potential exoplanet made by the Transiting Exoplanet Survey Satellite (TESS). Potential Exoplanet 3777.01 was found in 2021 and is located 1028.89 parsecs from Earth. In order to confirm that TOI 3777.01 is an exoplanet, data was gathered from the George Mason University 0.8m telescope. Once the data was collected, the Java astronomy program AstroImageJ was used to analyze the data. The transit method was used specifically, in which the light emitted from the candidate's host star is measured. When graphed through a light curve, a dip of the light emitted between the ingress and egress is an indicator of an exoplanet, as the planet orbiting in front of the star ends up blocking the emitted light of the host star, leading to the observed dip in the curve. To further enhance the effectiveness of the transit method, several functions of AstroImageJ were utilized in the analysis process, including plate solving, data reduction including dark subtraction and flat divisions, multi aperture photometry, stack editing and image calibration. Once the data was ready for construction, the emission of light from the target star was compared to other nearby stars, and a light curve was constructed (See Section 3). Based on the light curve, TOI 3777.01 can be classified as an exoplanet, as the brightness of the host star underwent a decrease and then an increase in transit, which is a clear indicator of an exoplanet orbiting a host star.

Section 1: Introduction

Through the history of humankind, the quest to understand the cosmos and the celestial bodies that compose the night sky has been a key propellant for human curiosity and scientific endeavors. One of the many celestial bodies that compose the observable universe are Exoplanets, which are defined as planets that reside outside our solar system. Since the discovery of the first exoplanet in January 1992 by Alexander Wolszczan and Dale Frail[4], the field of exoplanet discovery has seen massive growth, with over 5,600 exoplanets being confirmed. Early Exoplanets were discovered and documented using conventional ground-based telescopes. However, with the advancement of technology and new observational techniques, satellites in space are being increasingly employed for the discovery and validation of exoplanet candidates, or TOIs. The Transiting Exoplanet Survey Satellite was established on April 18th, 2018 by the National Aeronautics and Space Administration (NASA) in an effort to locate exoplanets that orbit nearby stars. As of June 27th, 2024, there are 7203 TESS Object of Interests (TOIs) awaiting review and so far 491 TESS planets have been confirmed. The TESS Satellite employs the transit method to identify and verify exoplanet candidates. The transit method works through the measurement of the light emitted from a host star during a set duration (Transit). An Exoplanet that orbits a host star will lead to a periodic dip in the emitted light as it blocks captured light. Once transit of a potential exoplanet has been confirmed, the data is used to determine other parameters of the candidate, including things such as its diameter, the radius and duration of its orbit, and ingress/egress times.

In this research paper, data collected from the TESS satellite for TOI 3777.01 was analyzed and constructed into a ground based light curve to confirm if a transit did occur. The specific radius of TOI 3777.01 is unknown, however it has an orbital period of 2.34 days.

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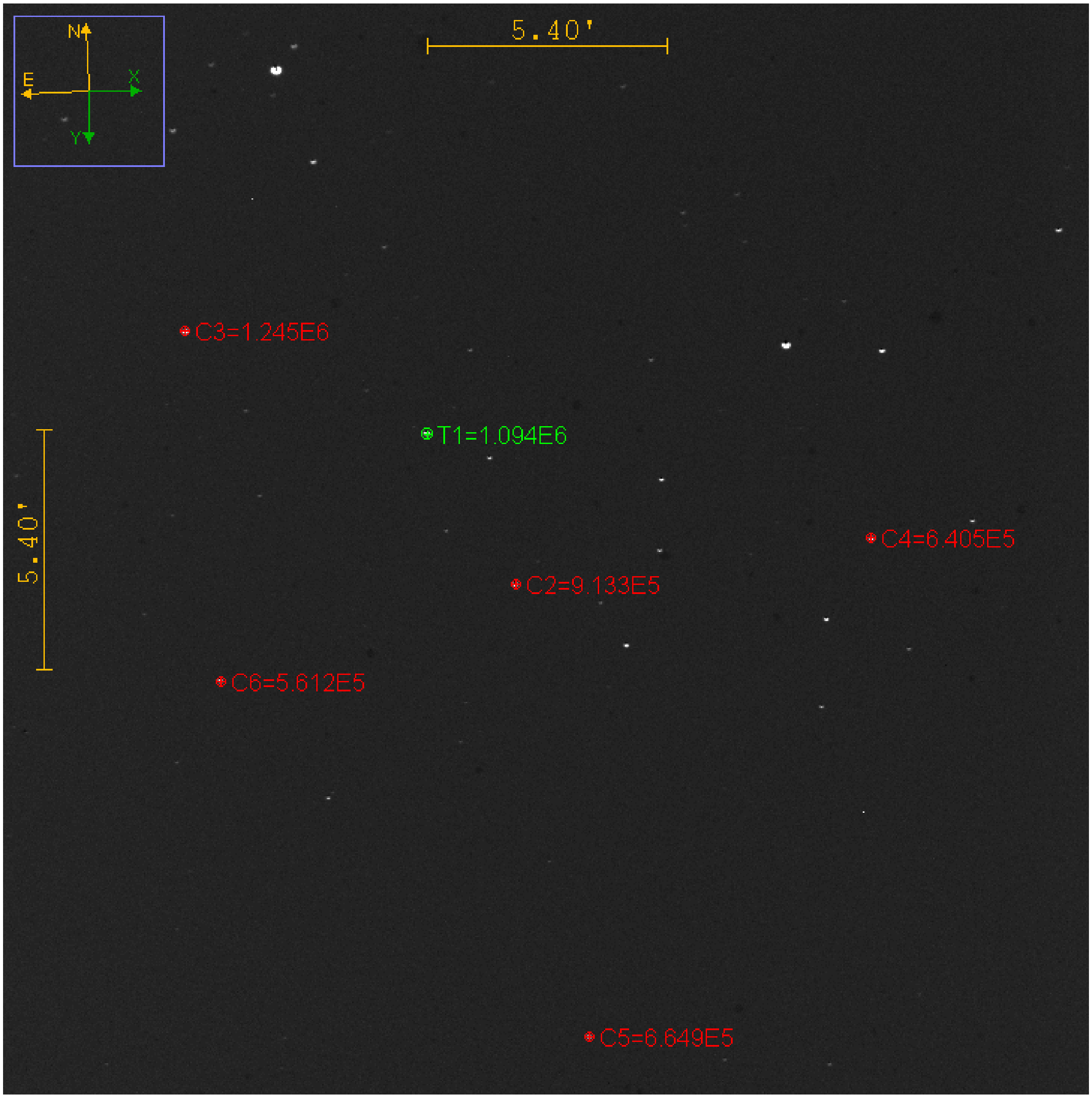
[4] "Historic Timeline." *NASA*, NASA, 26 July 2022, exoplanets.nasa.gov/alien-worlds/historic-timeline/#first-planetary-disk-observed.

Section 2 documents our methodology and procedures in the analysis of our data through AstroImageJ and creating the light curve, and section 3 presents our graphical visualizations created using AstroImageJ. Section 4 then discusses the interpretations of our graphs and further discussions related to TOI 3777.01. It should be stressed that even though our results demonstrate a solid probability of our candidate being an exoplanet, it is likely that further research will be needed to verify to truly confirm that TOI 3777.01 is an exoplanet, and that there were no false indicators of a transit, such as asteroid for example.

Section 2: Methodology for Analysis

TOI 3777.01 was observed using the George Mason University Observatory telescope. The sciences were taken using an exposure time of 85 seconds, and the data was collected by the telescope from 22:16 to 00:47. The collected data consisted of science images, darks, and flats in the FITS file format. Before plate-solving could be conducted, each science image needed to be visually inspected first to identify any possible artifacts and defects, including streaking, light pollution, the target being out of focus, or weather factors such as clouds covering the candidate. Once defective images were removed, data-reduction was performed on the images, including dark subtraction, flat division and the creation of flat darks. In this process, key information about the candidate such as standard coordinates and target proper motion were inputted in the DP Coordinate Converter and CCD Data Processor windows to generate a master dark and master flat file. Once data reduction was complete, photometric measurements and a seeing profile for the candidate were created by conducting aperture photometry using the Aperture Photometry tool in AstroImageJ. In this process, the images were aligned and a reference star was selected, to generate a seeing profile to analyze if any exoplanet transit activity occurred during the duration of observation. After the previous steps were completed, the Multiple Aperture Tool in AstroImageJ was employed on the now aligned data set. In this process, a green T1 marker was placed on the target star, and reference stars were selected that are similar in brightness and size to the target star.



Once all the references were selected, AstroImageJ generated a measurement table with all the data needed to construct the light curve (Figure 3), which was formatted using a template from www.astrodennis.com.

Section 3: Results

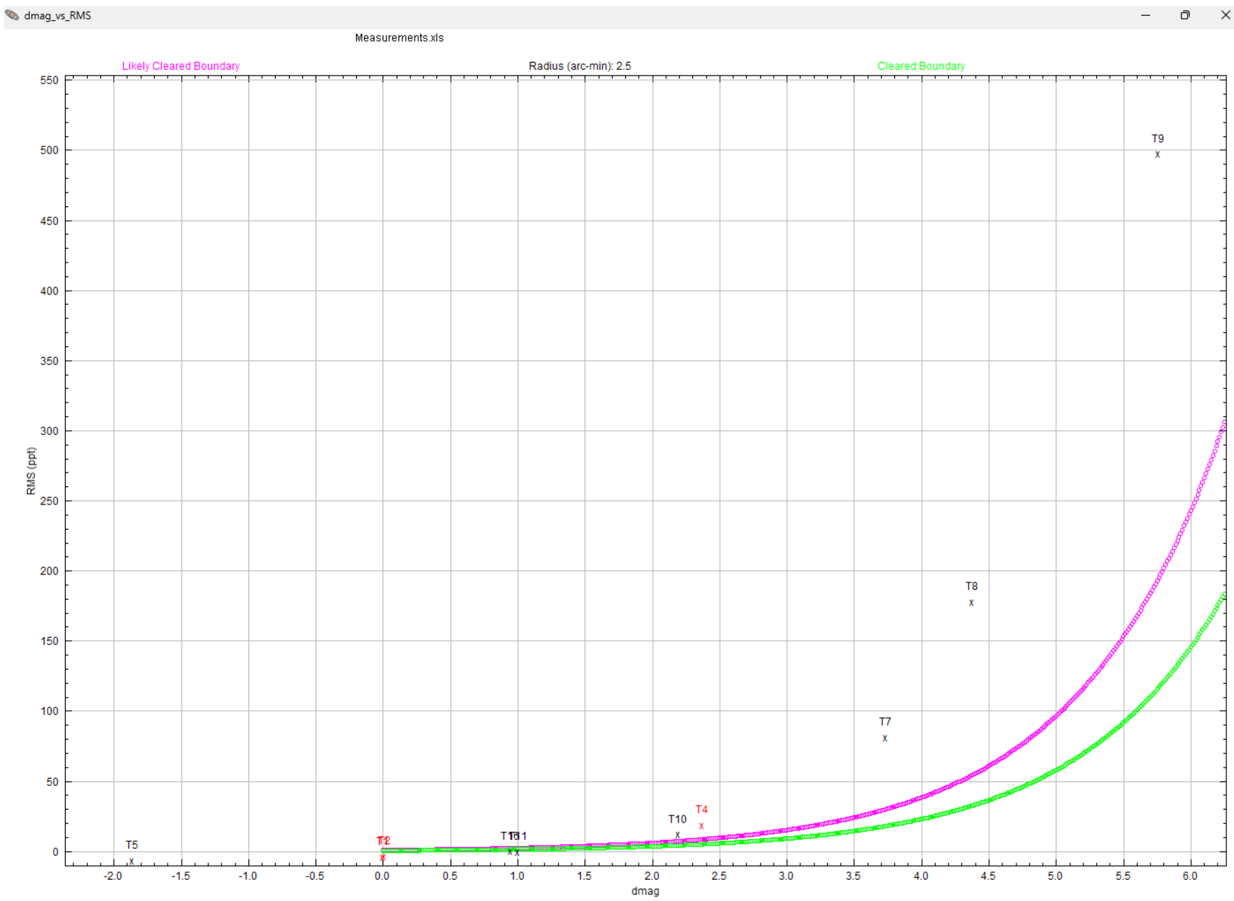


Figure 1: NEB Analysis plot

This figure is showing all the nearby stars of our target star. From this plot, we can see whether our results are false positives or not.

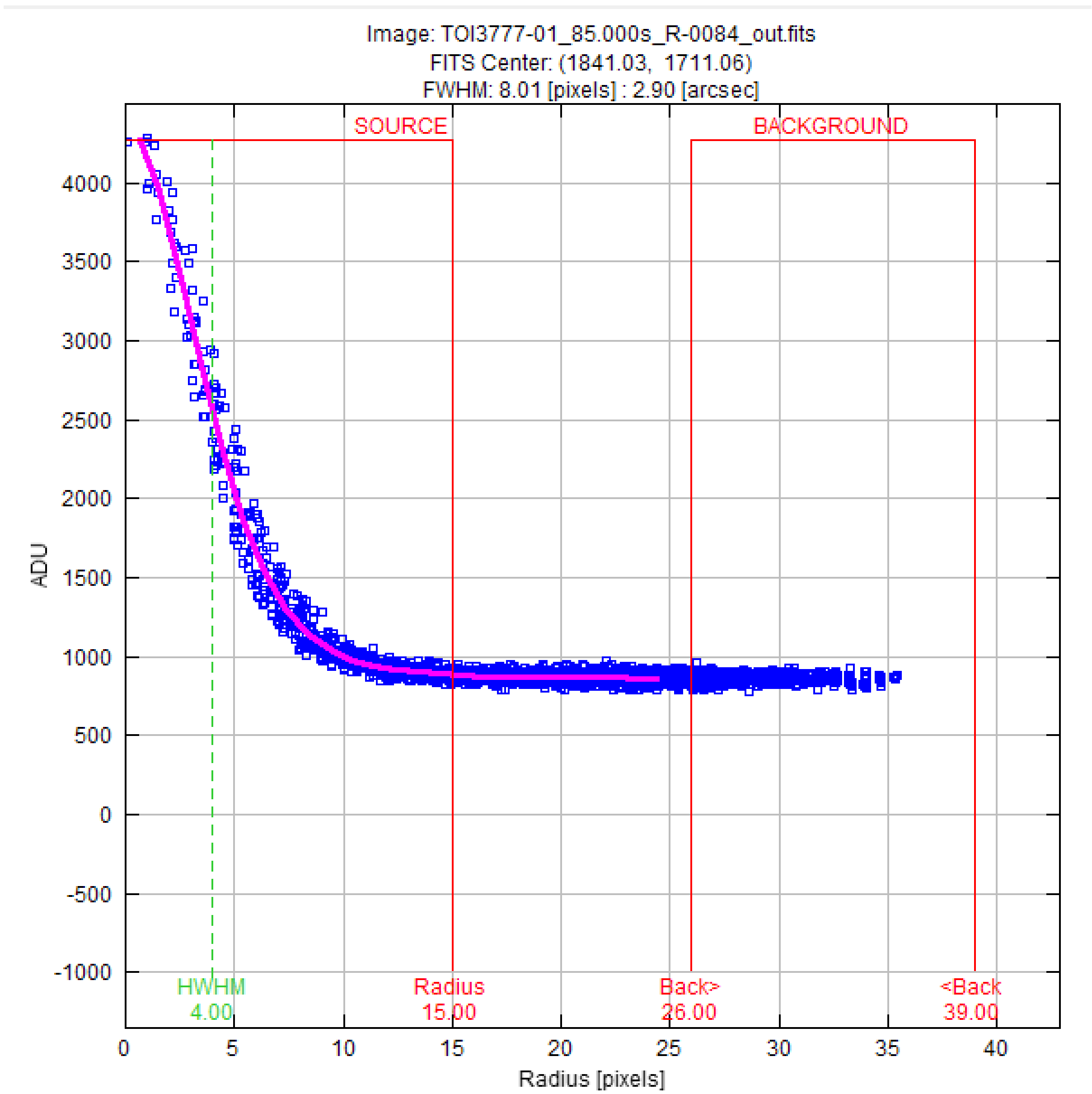


Figure 2: Seeing profile of TOI 3777.01

This figure shows the radius of the apertures of our target star. With this seeing profile, we will be able to place multiple apertures based off of this profile and generate our light curve. The inner radius of the background annulus was 26 arcseconds and the inner radius of the background annulus was 39 arcseconds.

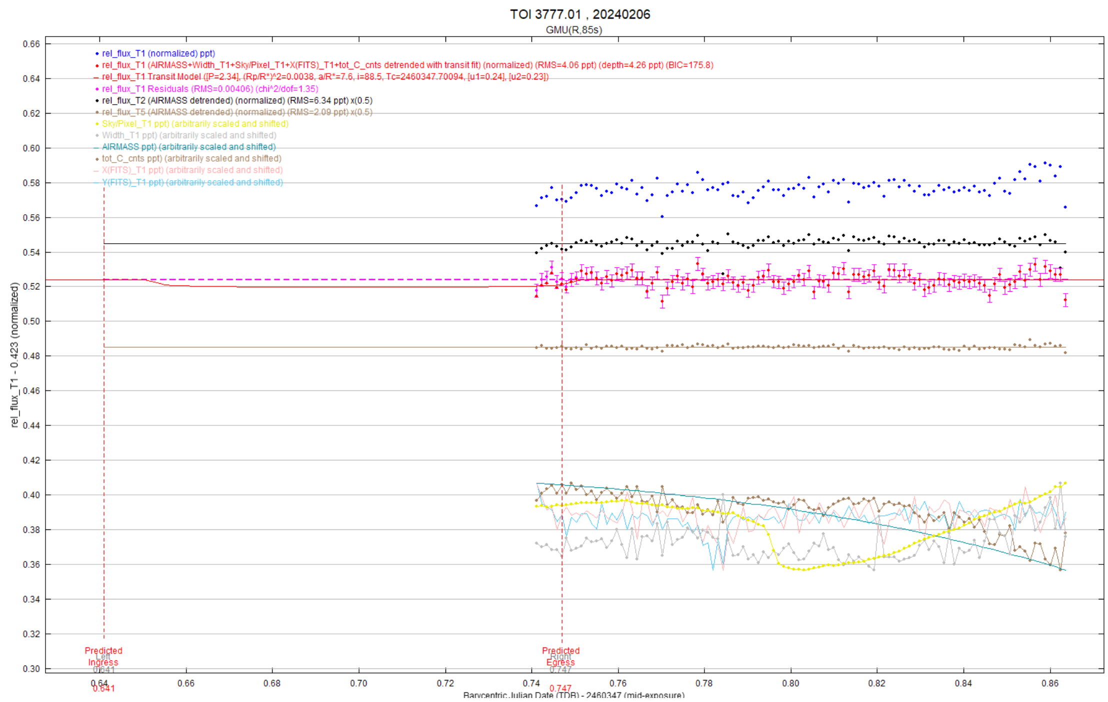


Figure 3: Light curve of TOI 3777.01

The light curve plot does show a noticeable dip, however, there is a lot of uncertainty within the timing. A potential reason behind this uncertainty is that the transit time was revised earlier than the predicted time when TOI 3777.01 was observed using the GMU telescope. The flux of the surrounding stars are uniform and don't contain a lot of spread, meaning that there is a good chance that the object is an Exoplanet.

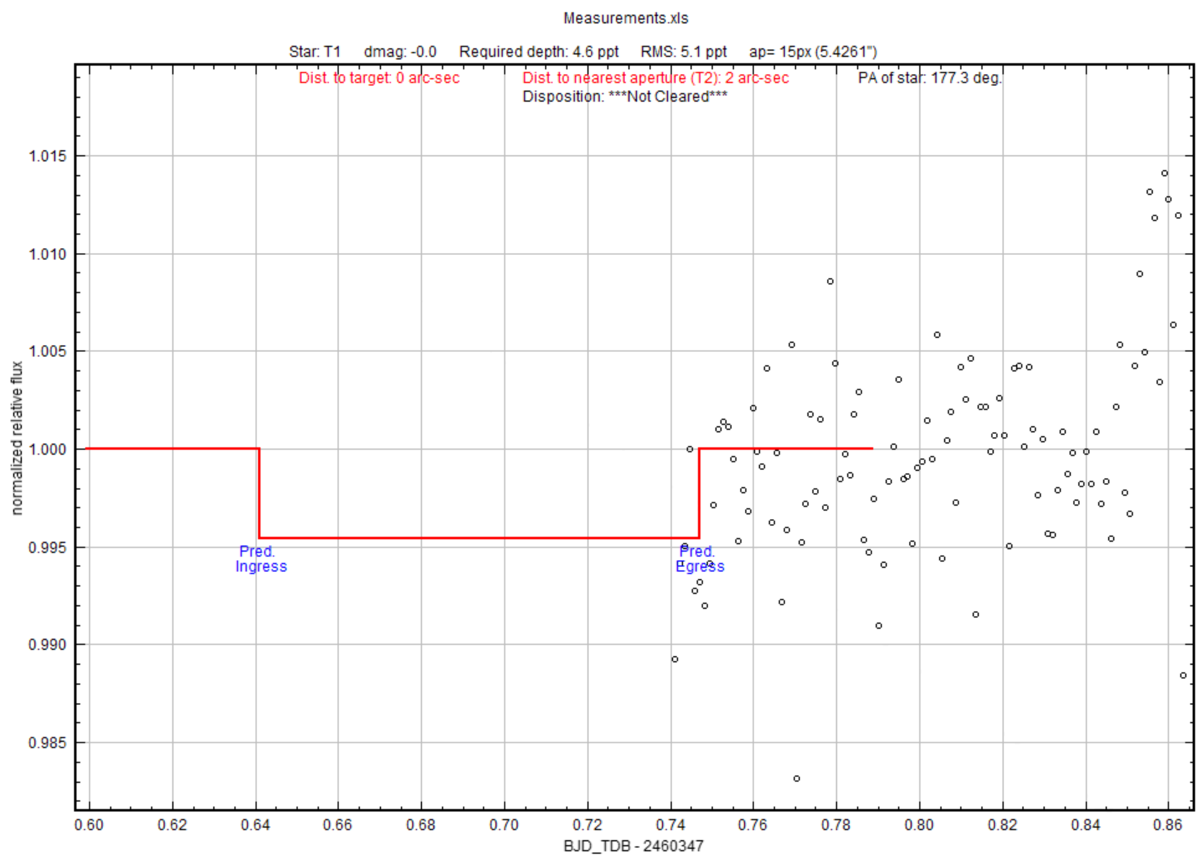


Figure 4: Light curve of TOI 3777.01
This plot shows the relative flux of our target between the ingress and egress. A clear dip can be seen between the predicted ingress and predicted egress.

Section 4: Analysis

The light curve supports the conclusion that TOI 3777.01 is an exoplanet. This is because from the light curve, there is a noticeable dip from the starlight that was measured. Also noting the duration of the dip, it is safe to assume that TOI 3777.01 is a celestial object. There is also not a lot of flux, as seen from the low spread of rel_flux_T5 and rel_flux_t2, indicating that there does seem to be a transit. As stated earlier in the previous figure, there is not a lot of flux near our object of interest. This is shown again in Figure 4. We see that there is actually only a 0.005 flux difference between the predicted ingress and egress times, meaning that our light curve should be very accurate, and not lead us to any false positive results. When we look at the NEB Analysis plot, we see that there is a noticeable curve and that all the stars are above the curve, meaning that there is a low chance that our light curve is a false-positive.

It should be noted however, that there is lots of uncertainty within the timing in the light curve. The most probable cause of this is that the predicted ingress and egress times given by George Mason University during observation were inaccurate, as they were revised beforehand. Although the light curve does show evidence of TOI 3777.01 being an exoplanet, it should be noted that there are other factors that could have led to this result. For example, another object such as an asteroid could have been orbiting the exoplanet candidate, leading to the observed dip in the light curve. It is recommended that further analysis with the most recent timings should be performed to ensure that the dip is a true indication of TOI 3777.01 in transit.

Section 5: Conclusion

It can be concluded that TOI 3777.01 underwent transit. However, the predicted timings are incorrect, and were likely revised before the candidate underwent observation using the George Mason Telescope. However, there is still a high likelihood of this candidate being a real exoplanet. This result was able to be reached through the analysis of data captured from the George Mason University telescope, and the usage of the program AstroImageJ to conduct analysis, refine the data and construct a light curve. However, it should be noted that factors such as weather could have affected the data, and that other occurrences such as passing asteroids and meteors could have led to a false positive dip indicating transit. It is recommended that further analysis be conducted with revised, accurate timings, to ensure that TOI 3777.01 had a valid transit, and that it is truly an exoplanet.

Section 5: Acknowledgements

We would like to acknowledge Professor Peter Plavchan of the George Mason University Department of Physics and Astronomy for the opportunity to be a part of this program, and allowing observation and data analysis through the George Mason campus telescope to be able to verify the candidacy of TOI 3777.01, as well as providing mentorship and guidance throughout the process of research, analysis and writing this paper. Additionally, we would like to thank Kevin Collins for the provided tutorials on AstroImageJ, and troubleshooting any issues with AstroImageJ as part of the analysis process and the construction of the light curve.

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4. "Historic Timeline." *NASA*, NASA, 26 July 2022, exoplanets.nasa.gov/alien-worlds/historic-timeline/#first-planetary-disk-observed.