Ground-Based Light Curve Follow-Up Validation Observations of TESS Object of Interest TOI 6209.01

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Abstract

The NASA TESS Mission aims to discover exoplanets and other astronomical entities outside of our solar system. TOI 6209.01 was identified as an exoplanet candidate in the NASA TESS Mission. This paper attempts to validate the existence of the exoplanet through analyzing an occurrence of a transit. We made this attempt through data collected and a generated light curve. Through the softwares AstroImageJ and the embedded Astrometry, we are able to create the light-curve, along with a dmagRNS plot. However, due to influxes in data, we were unable to provide a complete observation of the transit. We could not plate-solve several images, and so we removed them. After the analysis, we were unable to validate the existence of the exoplanet, but there is no evidence against the existence of the exoplanet. Further work is still required for a solid validation.

Keywords: exoplanet, TESS Mission, NASA, TOI 6209.01, transits

Introduction

Observing the night sky and the search for planetary bodies have long back into the history of mankind, with the "first documented records of systematic astronomical observations" dating back in 1000 BCE in Mesopatamia. There have been more than 5,000 discovered exoplanets, which are planets that are "beyond our solar system" ("Overview"). Studying these exoplanets and pursuing for the discovery of more has allowed mankind to gain a new perspective on Earth as well as contribute to our understanding of space ("Why Should"). This continuing exploration also pushes scientists to develop new technologies that benefits our daily lives on Earth ("Why Go"). Specifically, the TESS mission has been established for the discovery of new exoplanets as well as monitoring the changes of brightness of astronomical objects ("Tess").

However, due to the mass number of more than 7,000 exoplanet candidates, it is crucial for a systematic, organized, and accurate validation processes made. For example, the 2023 paper titled "Ground-Based Light Curve Follow-up Validation Observations of TESS Object of Interest 5691.01" by Adam Tong, Aiden Kriel, and Peter Plavchan serves a similar purpose as this paper: a validation of an exoplanet's existence through observations done by ground-based telescope ("Tong"). Both papers also utilize light curves of transit occurrences as a method of validation.

There is a need of this paper as the groundwork for further observations regarding the TESS object of interest TOI 6209.01. More work is still required to be done for an accurate validation of the existence of this exoplanet, yet this paper remains as a step towards the ultimate validation.

In this paper, we present follow-up observations of TOI 6209.01. It has an R_p of 0.5517, an orbital period of 0.747693, and it orbits a K-type main-sequence star. The goal of this paper is to investigate whether the transit of the exoplanet occurred on this star at expected times, durations, and depths.

In the "Method" section, we present our observations as well as the processes of generating the light curve. In the "Results" section, we present our analysis of the light curve as well as the light curve results. In the "Discussions" Section, we discuss our results, and present conclusions and future work.

Method

Main Softwares Employed

AstroImageJ

The main software used for astronomic photometry analysis was AstroImageJ, developed primarily by Karen Collins of the Smithsonian Astrophysical Obervatory, Kevin Eastridge of George Mason Universtiy, and John Kielkopf of the University of Louisville ("Astroimagej"). We use this software to identify our target of interest and analyze the FITS files in order to generate a light curve for further analysis.

Astrometry

Astrometry was utilized as an add-on feature to AstroImageJ, and was used to identify the different stars in the field of vision of the telescope. This contributed to determining the location of the reference stars, and AstroImageJ was then able to analyze the brightness of the target star compared to reference stars in order to generate an accurate light curve. These softwares introduces will prove to be crucial during the procedures that we carry out.

Major Procedures

We have selected the target TOI 6209.01, and has taken telescope images on September 5th, 2023 as an attempt to capture a predicted transit occurring.

Applying Calibration Frames

We then applied calibration frames, such as dark images and flat images. The dark images attempt to cancel out the noise mainly caused by temperature, exposure time, and ISO (Staff).The flat images attempts to calculate the correct optical factors of each pixel, allowing light to be evenly observed throughout the images (Staff). We first averaged out the 10 dark images and the 10 flat images, then stacked the averaged calibrated frame onto each of the scientific images. This allows the signal-to-noise ratio to increase, further allowing us to better observe the transit of our target exoplanet (Staff). After applying calibration frames, we then prepared the image for aperture photometry through plate-solving.

Plate Solving of Images

We used the Astrometry add-on in AstroImageJ to carry out the plate solving of the images. We navigate to the data processing window of AstroImageJ, selected all of the calibrated images, and began to plate solve. In this process of plate solving, we identify the specific "patch", or field of vision, of the night sky during observation, and was able to locate the star after labelling celestial coordinates, specifically RA coordinates, onto the images. This allows the target star to be easily located for further analysis.

In addition, we also import the Gaia Stars on the day of the telescope observation, which highlights nearby stars and their brightness.

Aperture Photometry Analysis

We then start the aperture photometry analysis. We analyzed the changes in the brightness of the star of interest using the "Multi-Aperture Photometry" function of AstroImageJ, and was able to generate a light curve.

Results

The results shows a significant flux in the brightness of the target star, suggesting an occurrence of a transit in the star (see Figure 1). However, the influx of luminosity of the target star was out of the predicted time frame, suggesting in a miscalculation in the predicted transit period.

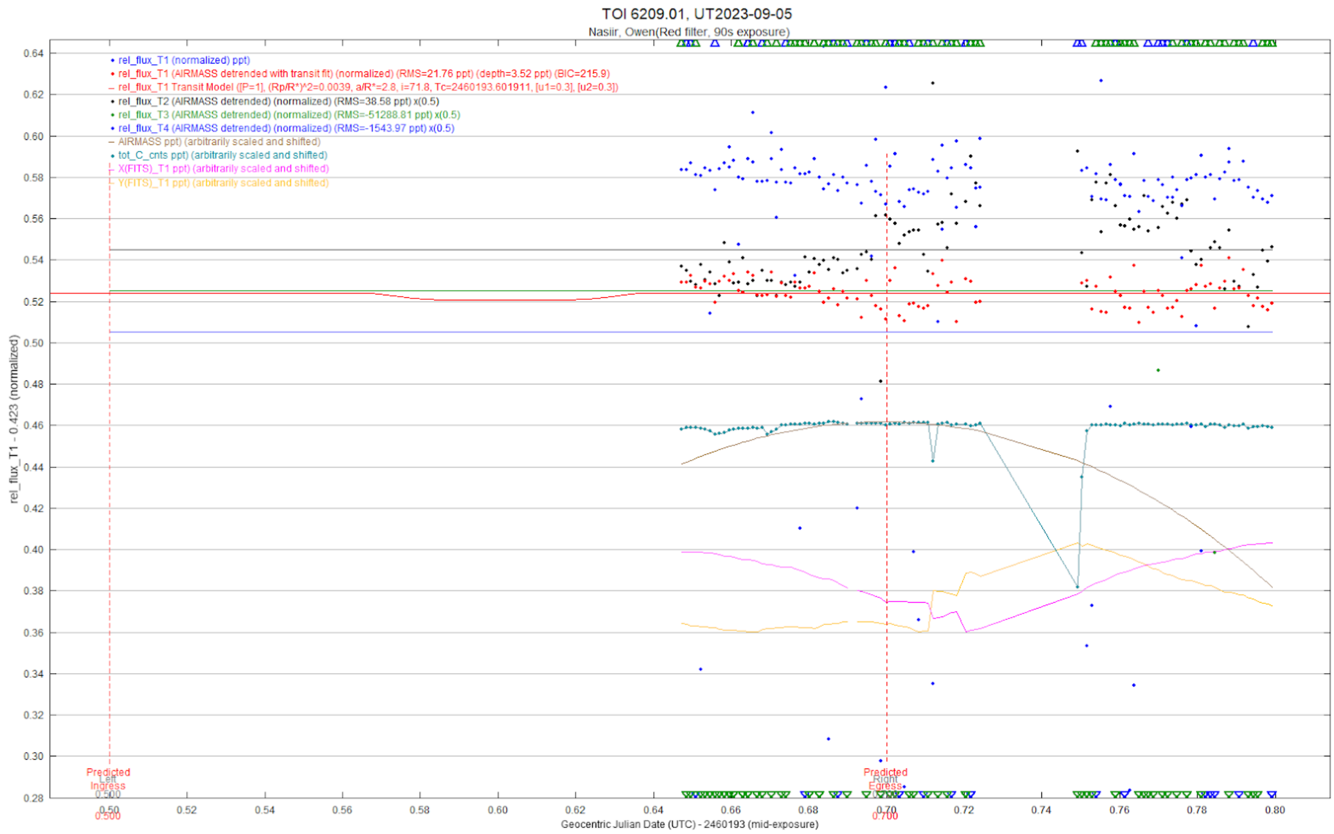

Figure 1. Light curve for TOI 6209.

In Figure 2, the data depicts the seeing profile of the target star of interest, displaying a centered, focused aperture on the target star.

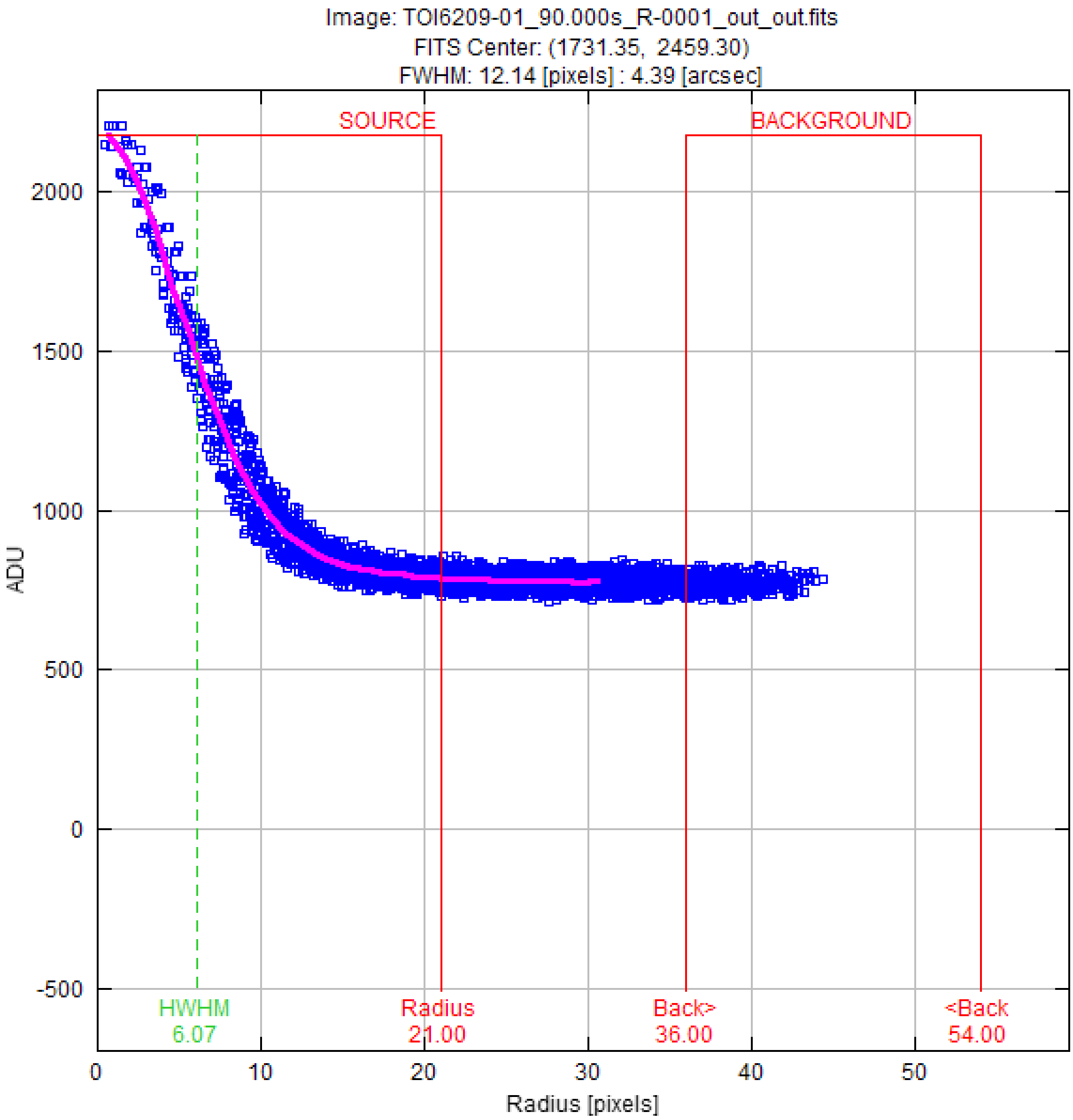

Figure 2. Seeing profile of TOI 6209 in the first telescope image after plate-solving.

In Figure 3, there is a significant difference in the brightness of the target star (marked in green) and the brightness of the reference stars (marked in magenta). Though more data is needed for verification of the transit's occurrence, the graph has evidence suggesting that there is a significant difference in the change between the brightness of reference stars and the brightness of the target star during the telescope observation.

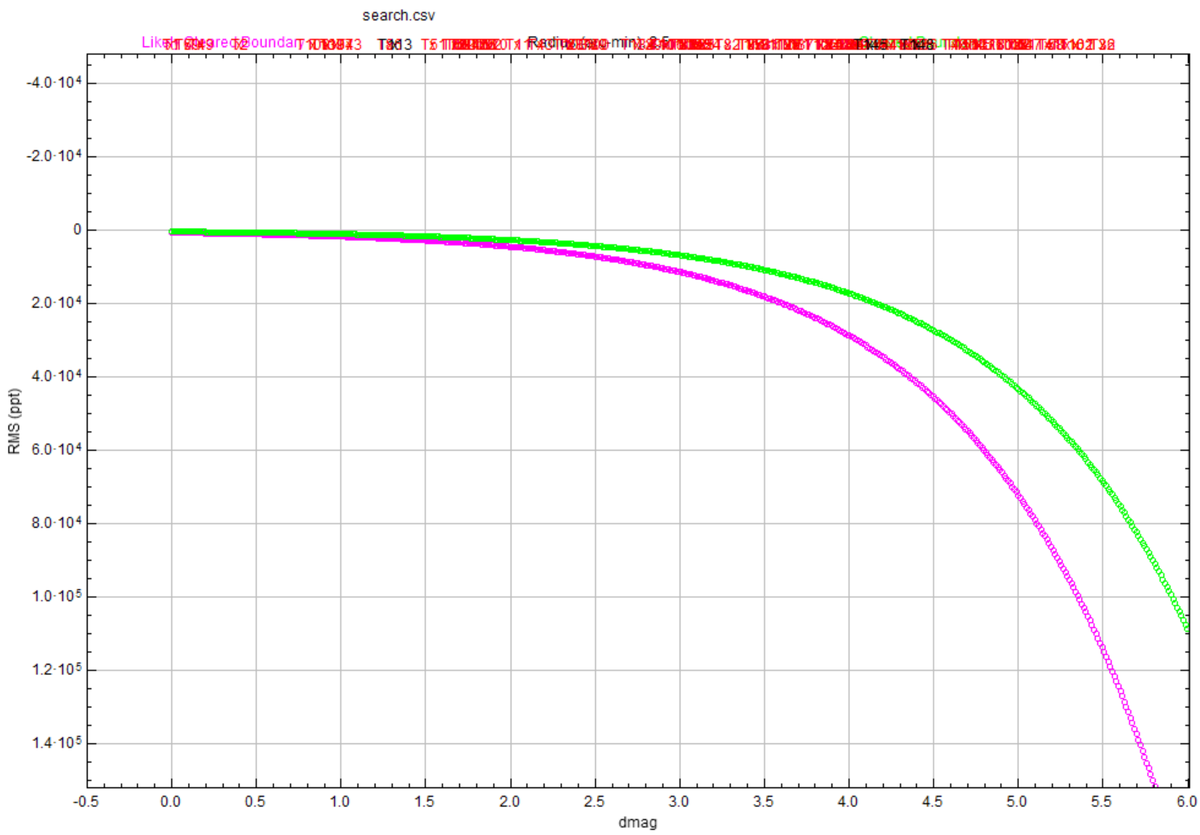

Figure 3. dmagRNS plot.

Discussion

Although the result suggests an accurate prediction of the transit of the target of interest, more work still has to be done. This is merely a surface-level analysis, especially with the light curve somewhat incomplete. For example, the data points have suggested, in Figure 1, that the transit is likely slightly out of the predicted time of transit. In addition, the dmagRNS-plot yields indeterminate results of a transit taking place. Therefore, we strongly advocate for more data to be collected on this target of interest in the future, as well as more advanced methods to generate the light curve, with other functions of AstroImageJ or other softwares as needed. The analysis from observing the transit of TOI 6209.01 has been rudimentary, and therefore the verification of the existence of the exoplanet TOI 6209.01 is still incomplete.

References

"Astroimagej." *Vanderbilt Initiative in Data-Intensive Astrophysics (VIDA)*, astro.phy.vanderbilt.edu/~vida/aij.htm. Accessed 2 Sept. 2024.

"Overview." *NASA*, NASA, 2 Apr. 2021, exoplanets.nasa.gov/what-is-an-exoplanet/overview/.

Staff, Practical Astrophotography. "A Brief Guide to Calibration Frames: Bias, Dark, Flats and Dark Flats." *Practical Astrophotography Magazine*, 14 Mar. 2022, practicalastrophotography.com/a-brief-guide-to-calibration-frames/.

"Tess (Transiting Exoplanet Survey Satellite) - NASA Science." *NASA*, NASA, science.nasa.gov/mission/tess/. Accessed 2 Sept. 2024.

Tong, Adam, et al. *Ground-Based Light Curve Follow-Up Validation Observations of TESS Object of Interest 5691.01*.

"Why Go to Space." *NASA*, NASA, 22 Sept. 2023, www.nasa.gov/humans-in-space/why-go-to-space/#:~:text=Through%20space%20exploration%2C%20we%20gain,tinkerers%2C%20engineers%2C%20and%20scientists.

"Why Should We Explore Space? What Are the Benefits for Us?: American Public University." *APU*, 21 May 2024, www.apu.apus.edu/area-of-study/math-and-science/resources/why-should-we-explore-space/.