Photometry and Transit Modelling of Exoplanet TOI 2109b

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Abstract

We conduct differential photometry on the exoplanet TOI 2109b and model the light curve to estimate the astrophysical parameters of the system. The target was observed for four nights during transit by a 0.8-metre telescope of Tarleton State University in the VBRI bandpass. The radius for TOI 2109b was estimated to be 1.451±0.104 Jupiter radii, with the planet orbiting its host star 0.67400±0.00136 days at an inclination of 71.02±0.28 degrees. The derived parameters are in formal agreement with those in the exoplanet discovery paper of 2021, although they are somewhat larger than those found in a recent independent study based on photometry of ExoFOP.

Introduction

An exoplanet is, in general, a planet that orbits a star other than the Sun. The first confirmed discovery of exoplanets was made in 1992. Since then, upto 5,500 exoplanets have been discovered to date. These discoveries have provided us with insight into the world beyond our own, paving the way for research that focuses on planetary system formation and their evolution. A variety of techniques are used to discover exoplanets. The Transit Photometry method is based on measuring the change in brightness of a star as a planet passes in front of it. To date, this is one the most successful method of exoplanet detection, and about 70% of exoplanets have been discovered with this method.

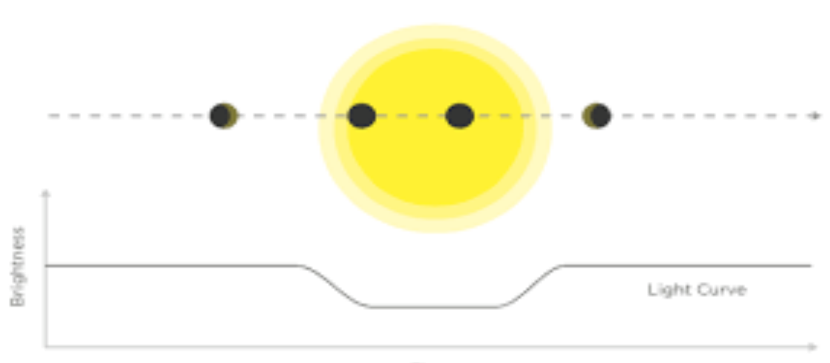

Fig 1: Schematic Diagram of Exoplanet Transit and Corresponding Light Curve

In this study, we examined the transit of exoplanet TOI 2109b. This exoplanet was discovered by Wong et al. (2021), an ultrahot Jupiter with mass of $5.02M_J$, orbiting its V = 10.2 F0 host star (R.A. (J2000) 16h 52m 44.71s, Dec. (J2000) +16 34' 47.7".

Instrument and Observation

The target was observed at Tarleton State University (TSU). The TSU telescope is located at 32° 13' 58.37" N, 98° 5' 51.46" W at an elevation of 344 m in Stephenville, Texas. The TSU observatory has a Ritchey-Chretien 0.8-meter telescope with a focal ratio of f/7 and a focal length of 5,600 mm. The telescope is equipped with an iKon-L CCD camera with a UVBIR Johnson filter, having a field of view of 0.497 arcseconds per pixel, readout noise of 2.5 electrons, and a pixel size of 23.5 × 13.5μm. The observations were impacted by intermittent cloud cover, such that on some nights we did not observe the target before the transit due to poor visibility. The observational details are summarized in Table 1.

Table 1: Observational details of TOI 2109b transit events

Observation Date	Time span[hours]	V	B	R	I
23-06-2022	2.01	63×30	63×60	63×15	63×10
30-06-2022	2.74	86×30	86×60	86×15	86×10
01-07-2022	3.03	95×30	95×60	95×15	95×10
05-07-2022	3.03	95×30	95×60	95×15	95×10
Total	10.81	339	339	339	339

Calibration and Photometry

First, we calibrated raw data to remove unwanted signals using the GCX photometry and data reduction software. The process included bias, dark, and flat calibration. The AAVSO was used to generate a finder chart for photometry, which helped identify the target and obtain reference stars on our images. Then calibrated images were stacked in AstroimageJ with suitable apertures to perform differential photometry on the series of images, and light curves of transits were generated. We removed all images from each dataset with a seeing greater than 1.5 arcseconds. Furthermore, observations of the target in the B and I bandpass show significant scatter, as the observation was carried out during cloudy weather, and shorter wavelengths of light scatter more in such conditions. The light curves in the R and V bandpass show minimal scatter. As a result, we performed photometry only in V and R bandpass data.

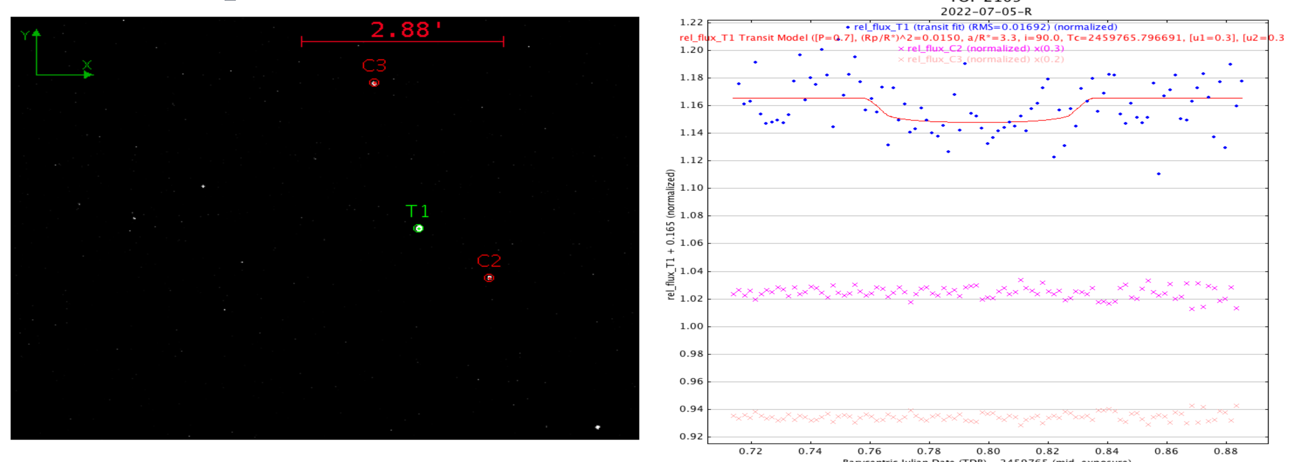

Fig 2: Target and Comparison Stars and Corresponding Their Light Curves in AstroImageJ

Light Curve Modelling

We used the EXOFAST package for modelling transit light curves, which is specifically designed to fit the transit and radial velocity observations of exoplanets. Before starting the modelling process, the data was cleaned to remove outliers and noise, after which the light curves were normalized. Initial estimates for the planetary and stellar parameters were made, including orbital period, transit duration, planet-to-star radius ratio, and limb darkening coefficients.

Then, using the Markov Chain Monte Carlo (MCMC) method, EXOFAST fits the model to the observed light curves and adjusts the parameters to minimise the difference between the observed and modelled data. This helps to estimate the uncertainties in the fitted parameters. The fitting process continues until the model converges to a stable solution and optimises the parameters based on the likelihood of the model given the data. Once the model converges, we analyse the fitted parameters and their uncertainties using the diagnostic plots and statistical information provided by EXOFAST to assess the quality of the fit. This ensures that our transit light curve modelling of TOI 2109b is accurate and reliable, providing us information about the properties of the exoplanet and its host star.

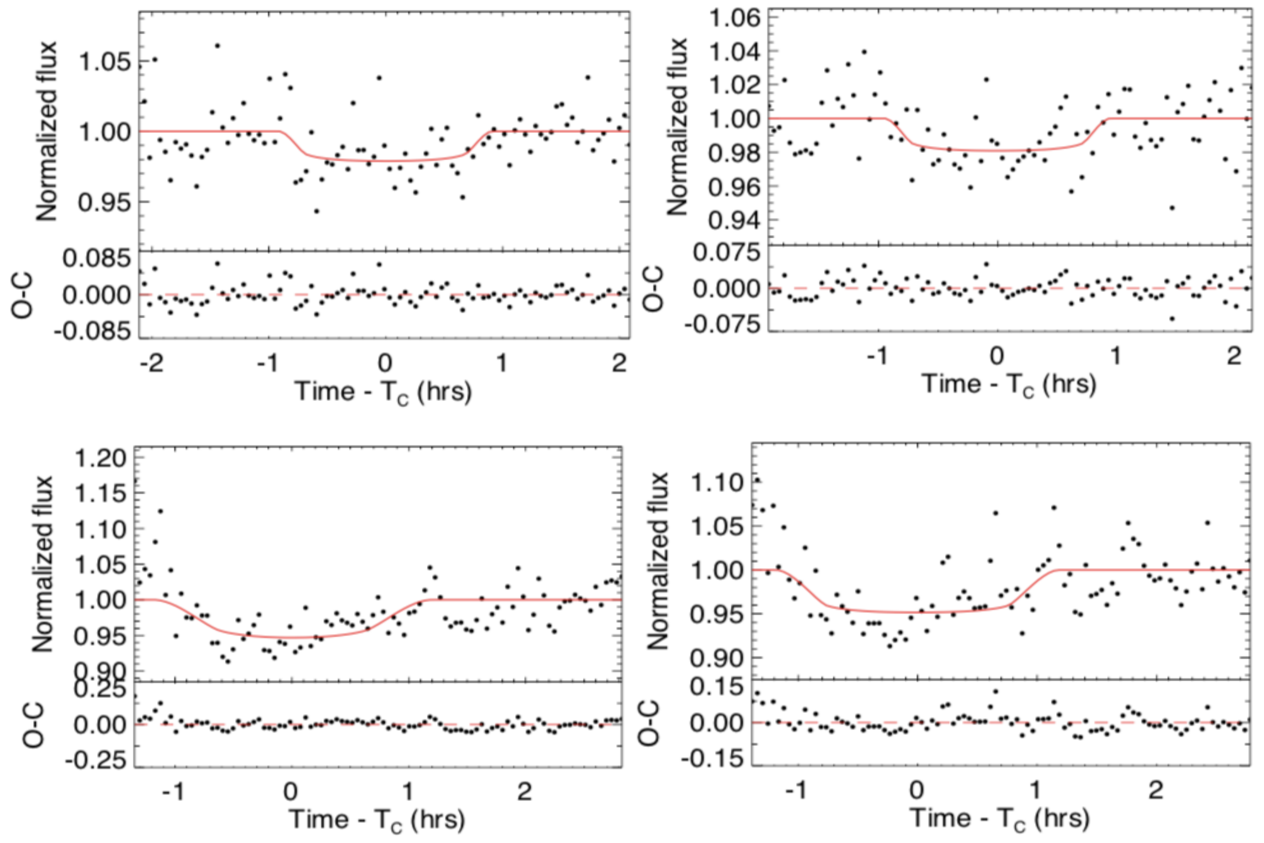

Fig 3: Model Fitted Over the Observed Transit Light Curve of TOI 2109 b in the V and R bandpass (right and left, respectively).

Result

The parameters of the planetary system calculated from the best-fitted model on the light curves are provided in Table 2.

Table 2: Parameters of planetary system determined from the transit light curve modelling.

Parametres	Our Results	Wong et al. (2021)
P (days)	0.67400±0.00153	0.67247
$\frac{R_p}{R_\star}$	0.08291±0.00136	0.08155
$\frac{a}{R_\star}$	2.4921±0.22	2.268
i (deg)	71.02±0.28	70.74
a (AU)	0.0175±0.004	0.01791
T_c (days)	2459765.798031±0.00042	2459378.459370
T_{eq} (K)	3027	3646

Conclusion

Our photometric study of the exoplanet TOI 2109b has provided valuable insights into the astrophysical parameters of the planetary system. We accurately modelled the transit light curves using the EXOFAST software and estimated key parameters such as the orbital period, radius of the planet, semimajor axis, and inclination angle. Furthermore, our analysis revealed a consistent transit profile across multiple observed epochs, indicating a stable planetary system. Our findings are in good agreement with previous studies conducted by Wong et al. and detailed on the ExoFOP platform.

Future Research Aspects

We plan to extend our analysis by observing additional transit events of TOI 2109b to improve the precision of our parameter estimates. Increasing the number of observed transits will help reduce uncertainties and refine our understanding of the orbital dynamics and physical characteristics of the exoplanet. We also intend to perform radial velocity measurements to complement our photometric data, which will enable us to better constrain the planetary mass and further characterize the system. Additionally, we aim to explore the potential presence of other planets in the TOI 2109b system by analysing transit timing variations. Future work would include comparing our results with data from the James Webb Space Telescope (JWST) and future mission of the European Space Agency's PLATO, to develop advanced capabilities for more detailed studies of exoplanetary atmospheres and compositions.

Acknowledgement

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