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THE IMPACT OF THE ORBITAL GEOMETRY OF EXOPLANETS Kepler-117 b, Kepler-117 c, Kepler-433 b, TOI-1518 b AND TOI-481 b ON THEIR TRANSIT CHARACTERISTICS

Physics

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ABSTRACT

The transit method of finding exoplanets has been the most successful till date. It relies on observing the fall in the brightness of the star being orbited by the exoplanet. In order to better characterise such exoplanets, it is important to explore what factors may influence their transits. This paper attempts to explain the effect of an exoplanet's eccentricity, inclination, and radius (considered as its ratio to the stellar radius) on the fall in the brightness of the star. The paper presents an analysis of the data of 5 different exoplanets (Kepler-117 b, Kepler-117 c, Kepler-433 b, TOI-1518 b and TOI-481 b), obtained from the TESS (Transiting Exoplanet Survey Satellite) and Kepler databases available in the MAST (Mikulski Archive for Space Telescopes). The package Lightkurve v2.4 (written in Python) was used to process this data.

KEYWORDS

Exoplanets, eccentricity, inclination, transit

INTRODUCTION

The transit method of finding exoplanets has been the most successful till date. It relies on observing the fall in the brightness of the star being orbited by the exoplanet. In order to better characterise such exoplanets, it is important to explore the factors that may influence their transits. This paper presents the effect of an exoplanet's eccentricity, inclination and radius (considered as its ratio to the stellar radius) on the fall in the brightness of the star and the transit duration. The paper presents an analysis of the data of 5 different exoplanets (Kepler-117 b, Kepler-117 c, Kepler-433 b, TOI-481 b and TOI-1518 b), obtained from the TESS (Transiting Exoplanet Survey Satellite) and Kepler databases available in the MAST (Mikulski Archive for Space Telescopes). The package Lightkurve v2.4 (written in Python) was used to process this data.

METHODOLOGY

4 planets were selected from the NASA Exoplanet Archive using the following filters:

Number of Stars = 1
Discovery Method = Transit

The planets were Kepler-117 b, Kepler-433 b, TOI-481 b and TOI-1518 b. Kepler-117, the host star of Kepler-117 b, has a second known planet in its orbit, which is Kepler-117 c. That exoplanet, too, was taken into consideration. The data on the eccentricity, inclination and radius (considered as its ratio to the stellar radius) of these exoplanets was obtained from the NASA Exoplanet Archive.

Using their TOI (TESS Object of Interest) or KOI (Kepler Object of Interest) IDs, the target pixel files of these planets were extracted from the Transiting Exoplanet Survey Satellite (TESS) and Kepler databases hosted on the Barbara A. Mikulski Archive for Space Telescopes (MAST) and processed using code written in Python with the Lightkurve v2 package. In most cases, the data found on MAST had multiple available solutions. In this case, the values of the parameters in the solutions (excluding the candidate solutions, as they are not confirmed published solutions) were averaged (in some cases the parameter of a solution was missing / not calculated, so that solution wasn't taken into account only for that particular parameter).

The resulting lightcurves were interpreted to determine the change in flux during a transit event, and were then analysed alongside the data acquired from the NASA Exoplanet Archive to obtain the following results.

RESULTS

Common Trends

Ratio Of Planet Radius To Stellar Radius

It is evident that a greater planet to stellar radius ratio will result in a larger dip in brightness, since a larger part of the star will be covered.

Inclination

Generally, the planet with the larger inclination had the greater change in flux. This can be explained as follows: a greater inclination will result in a smaller impact parameter, as given by the equation:

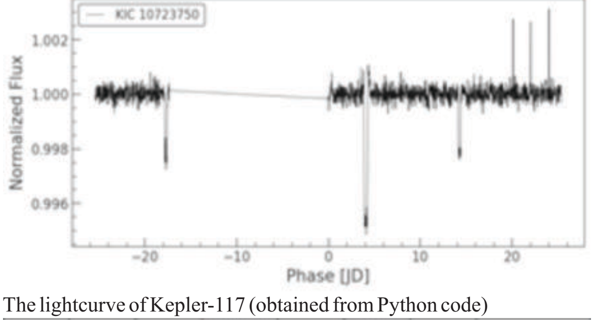
$$b = \frac{a \cos(i)_2}{R_*}$$

where a is the orbital semi-major axis, i is the angle of inclination, and R_* is the radius of the star. This means that, for the same distance from the star, a smaller angle of inclination will bring the exoplanet closer to its star, and hence cause a smaller decrease in brightness since the exoplanet will block a smaller area of the star observed due to their proximity.

Eccentricity

While the eccentricity doesn't seem to have an impact on the drop in brightness of the star, the visual interpretation of the lightcurves below indicate that as the eccentricity increases the transit duration decreases. However, since the transit duration wasn't a factor we were considering initially, the data from final published solutions about transit duration and other important factors (such as argument of periastron) is unavailable for some exoplanets. These factors are therefore not added to the table, but are discussed in the following sections.

Kepler-117 b and Kepler-117 c



The lightcurve of Kepler-117 (obtained from Python code)

Planet name	Host star	Eccentricity	Ratio of planet radius to star radius	Inclination (deg)	Planet radius (in Jupiter radius)	Star radius (in Solar radius)	Change in Flux
Kepler-117 b	Kepler-117	0.0493	0.05489	88.74	0.692	1.43	0.002489056327656170
Kepler-117 c	Kepler-117	0.0323	0.07072	89.64	1.021	1.43	0.005156645710673979

Data on the exoplanets Kepler-117 b and Kepler-117 c

The greater drop in brightness is due to the larger size, and therefore larger ratio of planet radius to star radius, of Kepler-117 c as compared to Kepler-117 b.

The inclination of the two planets has a difference of 0.9˚, and it can be observed that the planet with a larger inclination (Kepler-117 c) has a larger change in flux. The change in flux of Kepler-117 c is more than double that of Kepler-117 b, which is due to the difference in their orbital semi-major axes (for 117-b it's approximately 0.14 AU, while for 117-c it's about 0.285 AU).

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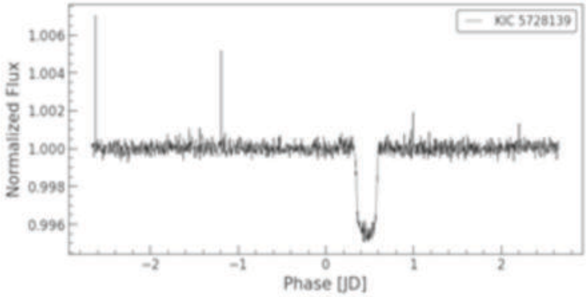
While both the planets have small eccentricities, 117-b's eccentricity is greater than that of 117-c which could explain why it has a smaller transit duration (approximately 7.35 hours compared to 117-c's 10.85 hours).

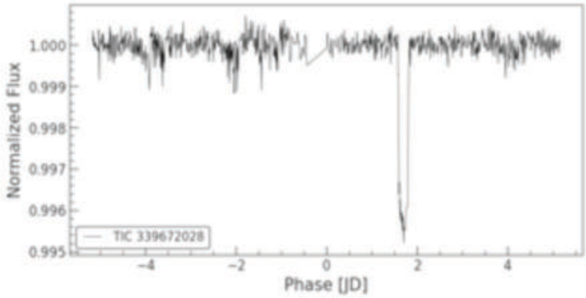
Kepler-433 b, TOI-481 b, and TOI-1518 b

Planet name	Host star	Eccentricity	Ratio of planet radius to star radius	Inclination (deg)	Planet radius (in Jupiter radius)	Star radius (in Solar radius)	Change in Flux
Kepler-433 b	Kepler-433	0.119	0.06566	89.21	1.33	1.96	0.004862319385846692
TOI-481 b	TOI-481	0.153	0.06190	89.2	0.99	1.70	0.004799336994944281
TOI-1518 b	TOI-1518	0.01	0.09880	77.84	1.875	1.89	0.008224748211126065

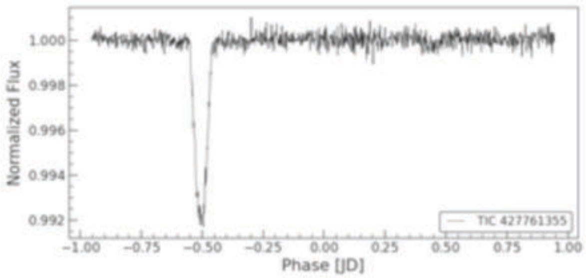
Data on the exoplanets Kepler-433 b , TOI-481 b TOI-1518 b



The lightcurve of Kepler-433



The lightcurve of TOI-481



The lightcurve of TOI-1518

Comparing these three planets, we can see that all three planets follow the trend observed for the ratio of planet radius to star radius, wherein as the ratio increases, so does the change in flux. There is little difference (about 6.3 x 10^{-5}) between the change in flux of Kepler-433 and TOI-481, and likewise the difference in ratio of the radius of the planet to that of the star is also quite less (0.003761, to be exact). TOI-1518 has the greatest change in flux and the greatest planet radius to star radius ratio.

The inclinations of Kepler-433 b and TOI-481 b are nearly identical (due to the difference in precision, Kepler-433 b's inclination is recorded to be 0.01˚ greater than that of TOI-481 b), and although they follow the pattern wherein a greater inclination results in a greater change in flux (again, due to the small difference in inclination there is a small difference in the change of flux), TOI-1518 b deviates from this trend. It has the smallest inclination and yet the greatest change in flux. This exoplanet has the smallest eccentricity of the three and yet its transit duration is also the shortest of the three (2.36536933853578 hours as per a candidate solution).

As per the observed trend, the smaller inclination should mean a smaller change in flux. TOI-1518 b, despite having the smallest inclination of all the 5 planets, has the greatest change in flux. One way to explain this could be that as the inclination increases, the impact parameter decreases. The rest of the planets have inclinations ≥88.74˚, while TOI-1518 b has an inclination of 77.84˚. This gives the following ratio of their cosine values:

$$\cos(77.84^\circ) = 0.21064237999$$

$$\cos(88.74^\circ) = 0.02198937609$$

$$\frac{\cos(77.84^\circ)}{\cos(88.74^\circ)} = 9.57927951788$$

Therefore due to the difference in inclination alone, the impact parameter of TOI-1518 b should be at least 10 times greater than that of any of the other planets. However, TOI-1518 has a greater stellar radius and a much smaller semi-major axis:

$$\frac{a}{R_*} = 4.291 \quad \text{(for TOI-1518 b)}$$

$$\frac{a}{R_*} = 19.67 \quad \text{(for Kepler-117 b)}$$

Therefore due to the difference in semi-major axis to radius, the impact parameter of TOI-1518 b should be

$$\frac{4.291}{19.67} = 0.72653787493$$

times that of Kepler-117 b (the planet whose inclination is 88.74˚).

There is a large difference between the difference (on the impact parameter) that the angle of inclination makes and the difference that the ratio of the semi-major axis to the stellar radius makes. Here, the angle of inclination has a greater effect, which is why the impact parameter of TOI-1518 is high.

To account for TOI-1518 b's high change in flux, we can infer that at the time the transit was recorded, the exoplanet was closer to apoapsis than to periapsis. However, that shouldn't make much of a difference- due to the low eccentricity of the planet's orbit, there will be a lesser difference between the semi-major and the semi-minor axes. The most fitting explanation with the available data is that the greater change in flux is due to the significantly larger planetary radius of TOI-1518 b compared to the planetary radii of the other two planets here.

A reason for the transit duration being shorter than thot of the other planets could be that those planets were closer to apoapsis during the transit while whether TOI-1518 b was closer to periapsis or apoapsis won't matter much since it has a low eccentricity (i.e. an almost completely circular orbit) so being at apoapsis or periapsis wouldn't have that great an impact on the transit duration.

CONCLUSION

By analysing these five exoplanets, two major trends were observed. The first is that as the inclination increases, so does the change in flux. The exception to this was TOI-1518b due to its radius being much larger than those of the exoplanets alongside which it was being analysed. An increase in the ratio of planetary radius to stellar radius also causes an increase in the change of flux.

To further strengthen these findings, the data of more exoplanets should be analysed. Additionally, the impact of other parameters which were mentioned only briefly (such as the semi-major axis).

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