Development of a Simple Planetary Transit Simulator for Exo-Planet J1407b

Introduction

In April of 2007, multiple substantial drops in the amount of light received from star 1SWASP J140747.93-394542.6 (its light curve) were detected over a period of 56 days. This is theorised to be caused by the transit of an exo-planet (designated J1407b) with a vast ring system. These rings extend up to 90 million km from the planet[1]. This makes the radius of the rings 320 times larger than Saturn's, which extend 282,000 km away[2].

Project Overview

This project aimed to develop a program within the MATLAB programming language that can simulate the transit of a planetary ring system in front of its parent star. This can then be used to generate the corresponding light curve and be tailored to the theorised structure of J1047b's ring system. The program is then able to be expanded upon in later years, creating an increasingly realistic simulation that can potentially be used in academic papers.

Methodology

Values for the size and optical depth of the ring system are taken directly from it's theorised properties based on the observed light curve. The percentage of light that passed through each ring is calculated from the optical depth using the equation:

$$I = I_o e^{-\tau} \times 100\%$$

The star and rings are approximated as many-sided regular polygons (currently 1,000 sides). This significantly reduces the complexity of the calculations and the number of sides can be increased to an arbitrary level of accuracy.

Rings are then rotated in 3D using rotation matrices (it is very unlikely the ring system will be directly facing).

The 3D rotation is then projected to 2D coordinates. A circle rotated in 3D produces the same image as a 2D ellipse.

The 2D projection of the ring system is then plotted on a series of graphs (with the star at the centre - point (0,0)) and moved along the x-axis. On each graph, the intersectional area of the star and each ring is calculated, then multiplied by the percentage of light blocked. These values are summed separately for each graph and plotted against the transit time to create a light curve.

Results

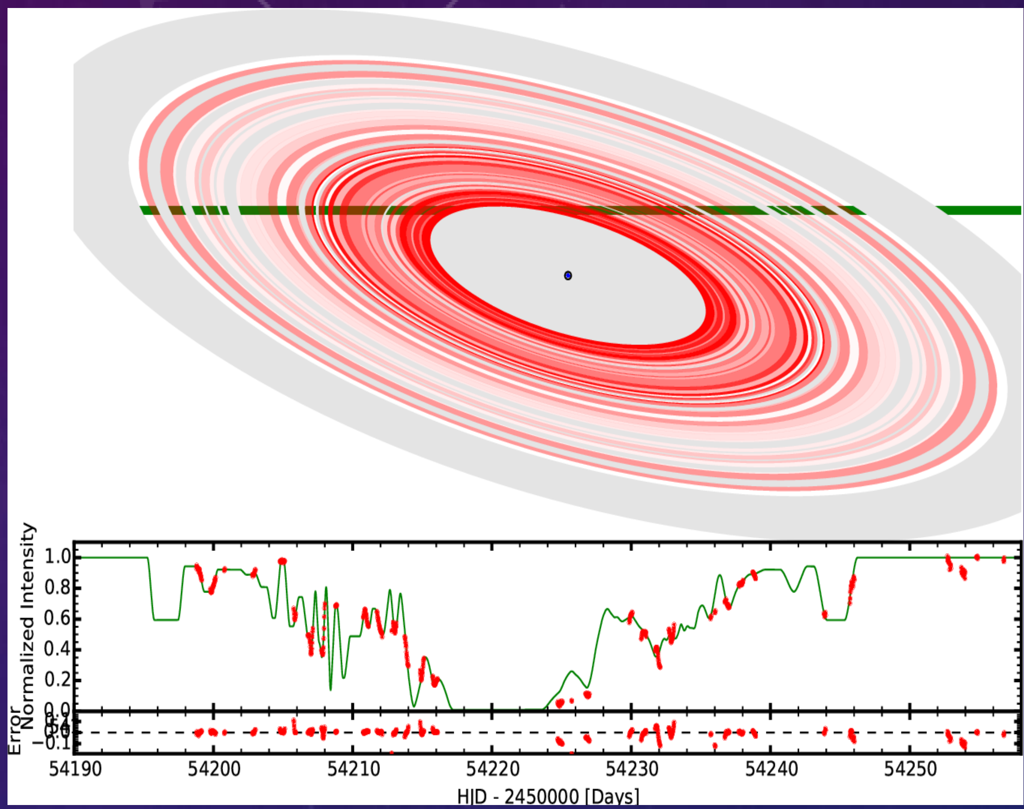

Figure 1: Theorised structure of ring system (top). Observed light curve (bottom)[1].

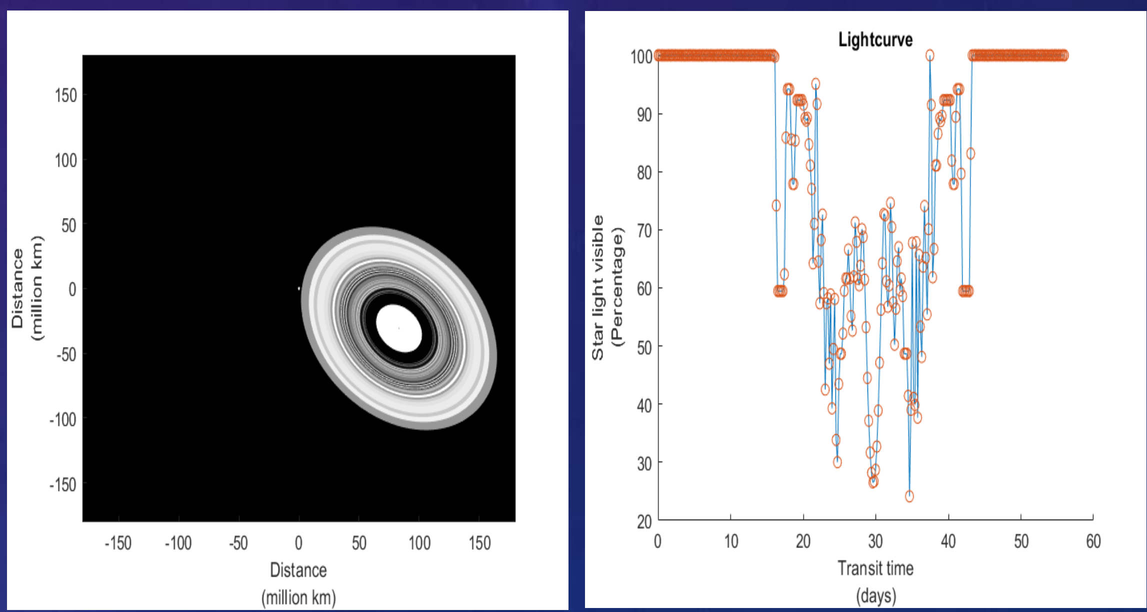

Figure 2: Simulated ring system((left). Associated light curve (right).

The shade of a ring directly corresponds to the amount of the star's light that passes through. The star is a small white dot next to the ring system.

Future Improvements

The next steps in the development of the program include:

Ensuring the transit of the planet begins and ends at the exact point the outermost ring begins to intersect the star. This will guarantee a higher level of accuracy in the light curve and avoid the large number of values of the left and right of the light curve plot with values of 100% (these are where the rings and the star do not intersect and are not part of the transit).

Taking into account of how the rotation of the rings changes their optical depth (the current optical depth values assume the ring is face-on).

Creating a program that calculates the intersectional area of ellipses rather than many-sided polygons.

Conclusion

As can be seen from the results, the program is capable of accurately replicating the size and optical depth of a planetary ring system rotated at an arbitrary angle – producing the corresponding light curve. This functioning prototype is now at the stage it can be developed into a nuanced planetary transit simulator for academic use.

References: [1] Matthew A. Kenworthy, Eric E. Mamajek, "Modelling giant extrasolar ring systems in eclipse and the case of J1407b: sculpting by exomoons?" *The Astrophysical Journal,* vol. 800, no. 2, Jan 2015. [Online] Available: https://arxiv.org/pdf/1501.05652.pdf

[2] "Saturn | In Depth," *NASA Science: Solar System Exploration,* Dec 2019. [Online] Available: https://solarsystem.nasa.gov/planets/saturn/in-depth/

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