Motivation and Introduction

The most common way for humans to study other planets in the universe is through a telescope, but there are lots of planets in the universe that are too far for state-of-the-art telescopes to observe anything. Therefore, other techniques must be applied to study the exoplanets that are too far away to be directly observed through a telescope. One of the most important ways to detect those exoplanets for astronomy scientists is by analyzing the transit light curve. When an exoplanet orbits around another host planet, there will be a period when the exoplanet moves to the back of the star, resulting in part of its light being blocked by the other planet that it orbits around. Therefore, if we observe the lighting of an exoplanet, there will be a sudden decrease in light during the period when the light of the exoplanet is blocked by the host planet during the transit period. Through analyzing the transit lighting curve, we are able to find the evidence to prove the existence of those exoplanets and understand some of the characteristics of these planets, such as their orbital period and their radius. In this project, two models will be used to fit the observed transit lighting data of planet GJ 436b, which orbits around the host star GJ 436 and tries to prove the existence of this planet and find the radius of this planet using the transit lighting data.

Method

There are two models that could be used to fit the transit light curve of GJ 436b collected from the NASA exoplanet archive. The first model that will be used is a box model, in which the rotation of the planet will be separated into two phases. When the distance between current time and transit center time is less than half of the duration of transit time, it will be classified as a transit phase, and the flux value of this phase will be impacted by both flux change outside of transit and brightness change depth due to part of its light being blocked by the planet it orbits around. Other times will be considered out-of-transit phases, and the flux value will only depend on flux change. The other model that will be used to fit the data of GJ 436 is the trapezoid model, in which we introduce a new variable ingress time, which is the time from the exoplanet entering the transit until it is fully blocked by the start it orbits around, and it will be proven to be a better fit to the data than the box model. In this model, the rotation of the planet will be separated into three phases. The transit phase will be defined the same as the box model, and the ingress phase will be a linear function where flux decreases as the exoplanet enters transit until the transit phase, in which the flux of the exoplanet will decrease due to both flux change outside of transit and the block during transit. The reduced-chi square test, which is calculated as where O is the observation, C is the expected value by model, σ is variance, n is the number of data points, and m is the number of parameters, will be used to test how fit the models are. A smaller value of the reduced chi-square test suggests a better fit for a model. Another thing we could do with exoplanet light transit data is to calculate the radius of the exoplanet using the formula , where first R is the radius of the exoplanet, second R is the radius of the start that exoplanet orbits around, and depth is the amount flux change of the exoplanet during the transit.

Result and Interpretation

A graph with a red line

Description automatically generated

Figure 1. transiting light curve fitting using box model

A graph of a graph showing a model data

Description automatically generated with medium confidence

Figure 2. transiting light curve fitting using trapezoid model

A computer code with black text

Description automatically generated

Figure 3. calculate the radius of GJ 436b

We could tell from the two figures that the trapezoid model is a better fit with the data, and the reduced-chi square test suggests the same result that the reduced chi square for the box model is 2.1 and is 1.14 for the trapezoid model, which means that the trapezoid model fits better with the data. The depth of flux change due to transit could be observed from the data, which is around 0.007, and the radius of the host star GJ  436 is around 45.86 Earth radius. Substituting the parameters into the formula , we could get that the radius of the exoplanet is about 3.84 Earth Radius, or 0.35 Jupiter Radius, which is around 24500 km. Compared our results with the data of GJ 436b from the NASA exoplanet archive, which shows that GJ 436b has a radius of 4.1 Earth radius or 0.37 Jupiter radius, our calculation is pretty close to the actual radius of GJ 436b.

Conclusion

This project aims to find the best model to fit the transit light curve of an exoplanet and use the transit light data to find the radius of the exoplanet. The exoplanet to be analyzed in the project is GJ 436b, which is an exoplanet around the host star GJ 436. The first model used to fit the transit light curve of GJ 436b was a box model, and then a trapezoid model was used. The result of reduced-chi square suggests that the trapezoid model is a much better fit for the GJ 436b transit light curve. Since the data tells us the depth of flux change due to the light of GJ 436b being blocked during the in-transit period, the radius of GJ 436b could be calculated using the radius of its host star. Then the results show that the radius of GJ 436b is about 3.84 Earth radius, or 24500 km, a pretty close number compared to the statistics shown in the NASA exoplanet archive, which supports the accuracy of using transit light data to detect and study the exoplanets.