Project 2: Measuring Planet Mass, Radius, and Density

Team 6

Motivation

Looking at exoplanet GJ436b, there are many questions that may arise. While values for the general parameters are present in NASA's Exoplanet Archive, the process of deriving those values was the primary goal, along with comparing those values with existing data. By using the processes shown below, the strengthening of measurement skills for planetary parameters was strengthened, and new methods were learned that can be applied to future projects.

Methods

By selecting the exoplanet system GJ 436, the following methods were used to calculate the planet's mass, radius, density, and their respective uncertainties.

To determine planet radius, transit depth is used via the following equation:

$$(1)\ \delta = \left(\frac{R_p}{R_s}\right)^2$$

Rearranging Eq (1), the planetary radius can be found using

$$(2)\ R_p = \sqrt{\delta} * R_s$$

GJ 436b's star has a radius of $R_s = 0.417 \pm 0.0075\ R_{Sun}$ (Rosenthal et al. 2021).

GJ 436b's mass was determined using the amplitude of the radial velocity model under the assumption that $M_p << M_s$ by the following equation,

$$(3)\ M_p = \left(\frac{P}{2\pi G}\right)^{\frac{1}{3}} \frac{M_s^{2/3} K}{sini}$$

Finally, the planetary density was calculated using the previously found parameters through the following equation,

$$(4)\ \rho_p = \frac{3M_p}{4\pi R_p^3}$$

The radial velocity model was determined using the parameter output from EXOFAST, an integrated tool part of the NASA Exoplanet Archive. The model was calculated using the following equation:

$$(5)\ RV = \gamma + Kcos(2\pi\frac{t}{P} + \frac{esin\omega}{ecos\omega})$$

The uncertainty of the planetary radius and mass was found utilizing the EXOFAST tool. A Markov Chain Monte Carlo (MCMC) simulation is run based off of the photometric light curve and radial velocity curve data. The uncertainty is extracted from the parameter output of the simulation.

Results

Through the use of the equations above, the analysis resulted in the following graphical representations. Concerning the calculation of flux over time, Figure 1 shows the severe drop. Being consistent with the model (shown in red), this change can be used with Equation 2 to calculate the exoplanet's radius, as presented in Table 1.

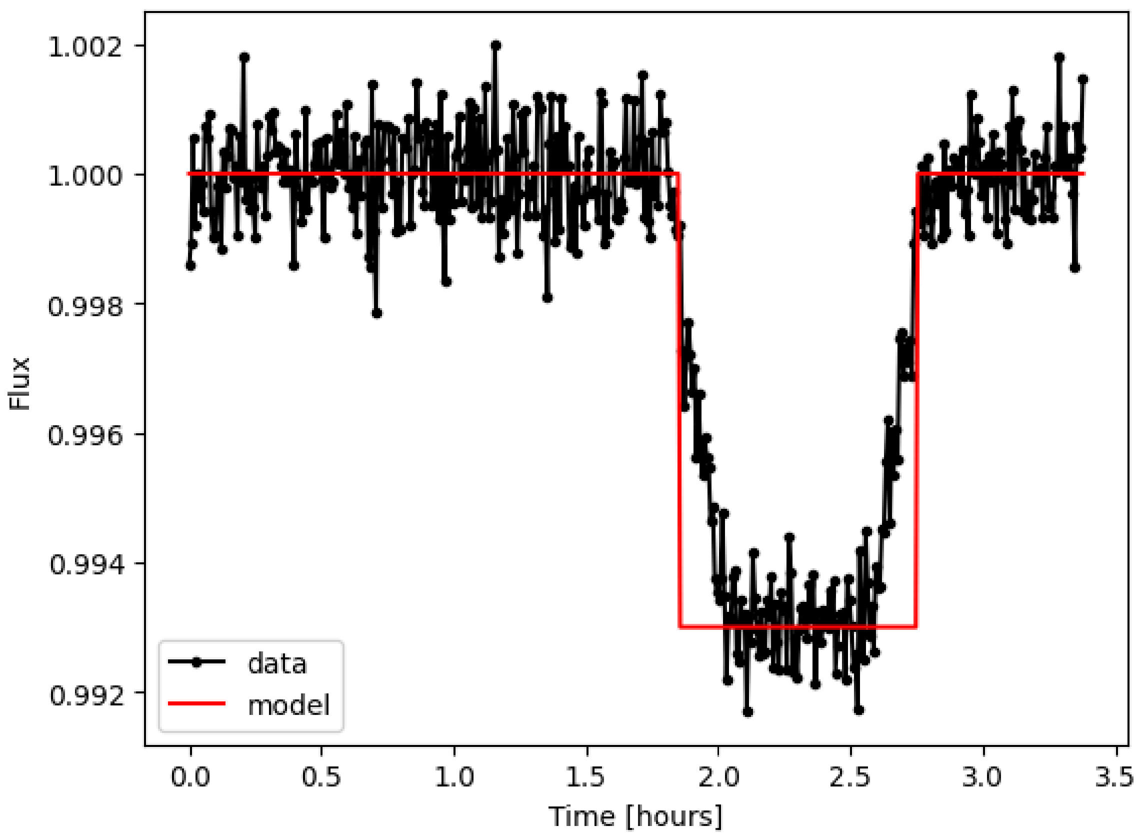


Figure 1: Flux as a function of time.

$$\delta = 0.007\ ,\ R_p = R_s\delta^{1/2} = 0.0837\,R_s = 0.035R_{sun}$$

The radial velocity data plotted below shows a general sinusoidal wave distribution of radial velocity for the exoplanet. The amplitude of the curve was then taken and implemented with Equation 3 to derive the mass of the planet, which is presented below in Table 1.

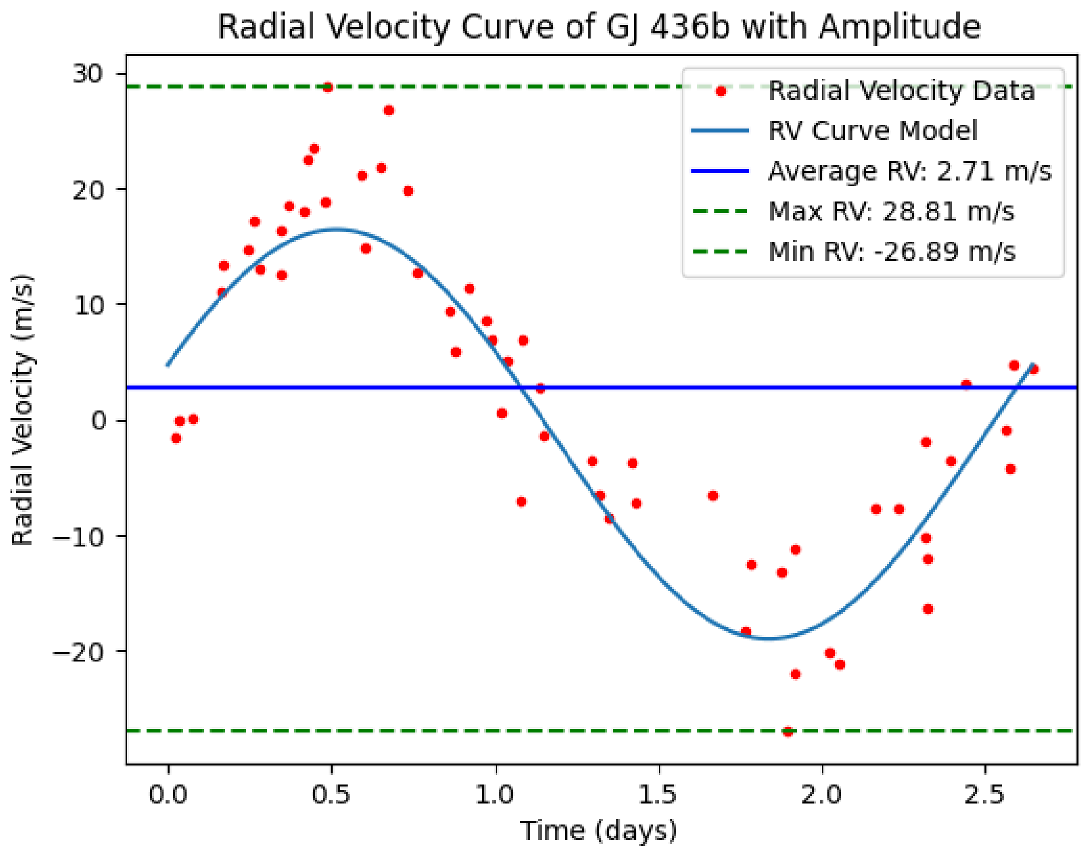
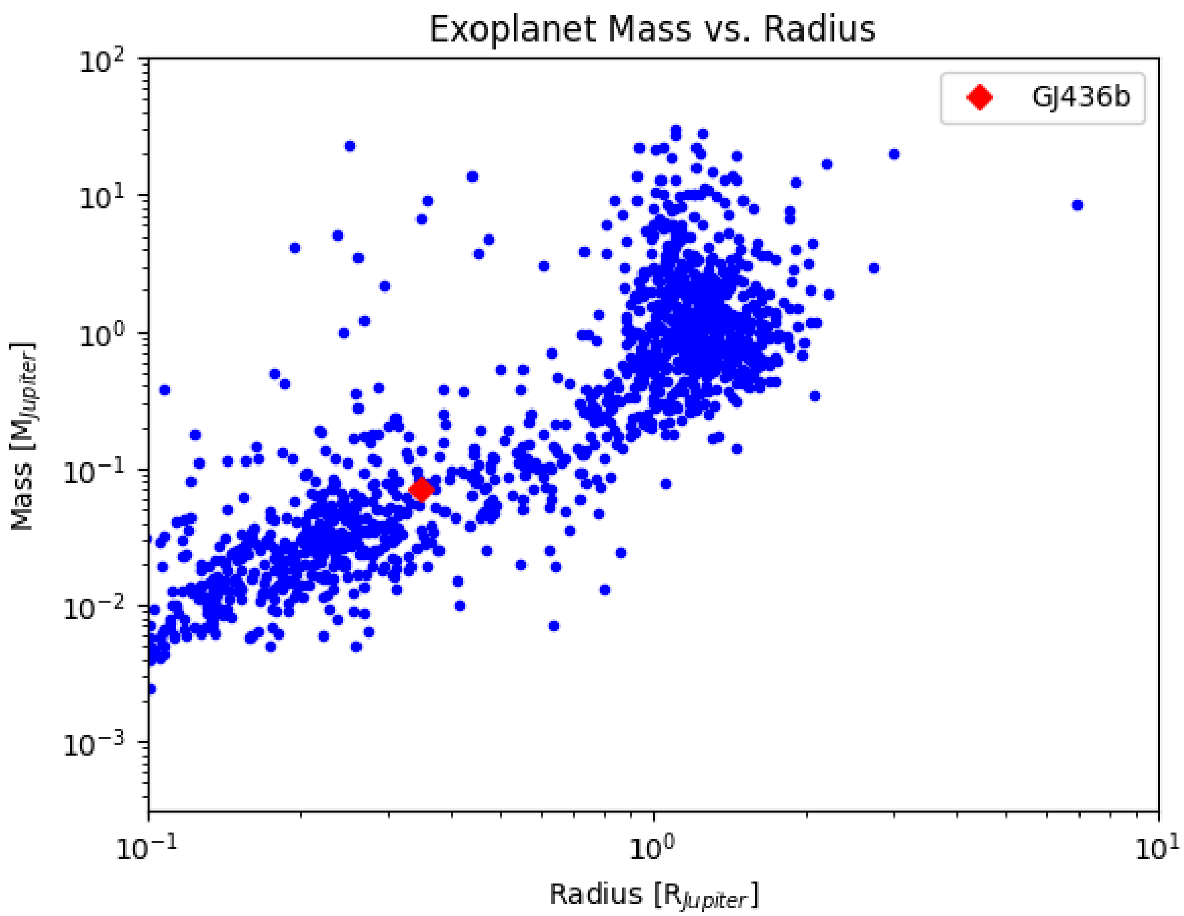


Table 1: Final Results

Parameter	Value	Error
Radius	$3.821R_{Earth}$	± 0.347
Mass	$22.22M_{Earth}$	± 2.34
Density	$1.92\frac{g}{cm^3}$	± 0.28

As a direct comparison of mass and radius, the team's calculations for mass and radius place GJ436b well within the general data, which assists in validating the analysis detailed above.



Looking at the mass-radius relation from Chen & Kipping (2016), the team's calculations for the parameters of GJ436b place it within the Neptunian world's portion of the data. This being true for the exoplanet further supports the calculated values for mass and radius.

Conclusion:

Overall, the analysis on GJ436b by team 6 addresses all major points presented by the project. By using the transit depth to calculate radius, and radial velocity to calculate mass, the exoplanet's density was then derived. This allowed for a direct comparison to the Chen & Kipping (2016) paper, of which the derived data concurs with, confirming that the calculations performed by the team are sufficient in deriving general parameters for GJ436b.

References:

Any and all equations used are from materials provided on Carmen.
GJ 436 information from NEA.

AI Usage Disclosure:

In this project the team utilized Google Gemini (an advanced AI model), which is offered as a feature in Colab, in hopes of more efficiently debugging our code and further supplementing it.

Google Presentation link:
https://docs.google.com/presentation/d/1vML-mFsNdYeP7HeLGpLjPu3dtzXm2L3s_hnotsWGzEo/edit?usp=sharing