# Measuring_Planet_Mass_Radius_and_Density

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**Title**: Measuring Planet Mass, Radius, and Density

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EARTHSC 5205: Planetary Science

## 1 Abstract

We present our findings using both the radial velocity and transit data of system GJ 436 b (data found using NASA's Exoplanet Archive). Utilizing the semi-amplitude of the radial velocity data allowed us to determine the planet mass, and, similarly, the transit depth allowed us to calculate the planet radius relative to the host star. These two values were then used to calculate the planet density. We used a Bayesian sampling model - a Markov Chain Monte Carlo - to estimate the uncertainty for each of these three calculations. We then compared our measurements of mass, radius, and density to (1) other exoplanets from NEA with similar masses and radii, and (2) the M-R relation from Chen & Kipping (2016). Further research is needed to confirm these observations and to explore the implications for our understanding of planet formation and evolution.

## 2 Motivations

Scientists at NASA were able to gain insight into thousands of exoplanets in our galaxy. More specifically, the Kepler Space Telescope was able to measure the transit depth of exoplanets, which is the amount of light blocked by a planet as it passes in front of its host star, which allowed scientists to calculate the radius of the planet relative to the host star. The radial velocity method was also used to measure the mass of exoplanets by observing the wobble of a star caused by the gravitational pull of an orbiting planet. By combining these two measurements, scientists were able to calculate the density of exoplanets.

The goal of this project is to determine the mass and radius (along with their uncertainities) of system GJ 436 b using its radial velocity and transit data stored in the NEA, and then use these values to calculate the planet's density (and uncertainty). We will also compare our measurements to other exoplanets with similar masses and radii, as well as to the mass-radius relation from Chen & Kipping (2016), to gain further insight into our system.

# 3 Estimating Mass

## 3.1 Calculating Period

The raw Radial Velocity and Transit data, along with their uncertainties, was imported from the NEA for our system (GJ 436 b). Both datasets were cleaned by removing all NaN values, or values outside of standard deviations of the mean, and plotted.

To start utilizing these datasets to find the mass of GJ 436 b, we first found the period for the exoplanet. A Lomb Scargle periodogram, which detects periodic signals in unevenly spaced data, was created to get an estimated period. The first peak on the periodogram (Figure 1) gave us a rough estimate for the period: around 2.64 days.

## 3.2 Markov Chain Monte Carlo Bayesian Sampling Estimations

A Markov Chain Monte Carlo Bayesian sampling model was then used to estimate the uncertainties in all our calculations. We then used the Keplerian model (Figure 2) to fit the radial velocity data, which allowed us to calculate the semi-amplitude (K) of the radial velocity curve. The semi-amplitude is related to the minimum mass of the planet and the mass of the star by the following equation: $M_p \sin i = \left[\frac{P \cdot K^3}{2\pi G}\left(1-e^2\right)^{3/2}\right]^{1/3} \cdot M_\star^{2/3}$, where $M_p$ is the mass of the planet, $P$ is the period, $K$ is the semi-amplitude, $G$ is the gravitational constant, $e$ is the eccentricity, and $M_\star$ is the mass of the star. We were able to find values for these parameters using the MCMC model estimations: * $P = 2.644$ days * $t_0 = 2451551.733$ JD * $K = 18.498$ m/s * $e = 0.2$ * $\omega = 0.065$ radians * $\gamma = 0.083$ m/s

## 3.3 Mass Calculations

Using these estimations, we were able to estimate the minimum mass of the exoplanet to be roughly 22.74 Earth masses, with an uncertainty of -0.69 / +3.15 Earth masses.

# 4 Estimating Radius

## 4.1 Calculating Transit Depth

The relation between radii $R_p$, $R_\star$, and transit depth $\delta$ is as follows: $\delta = (\frac{R_p}{R_\star})^2$. Which rearranged gives us: $R_p = R_\star\sqrt{\delta}$. We can find the transit depth by inspecting the Magnitude vs Julian days graph, and we already know $R_\star$.

We, once again, utiized the estimations of our MCMC to calculate $R_p$. We were able to estimate an average transit depth of 0.0107 mag.

## 4.2 Radius Calculations

Using the transit depth, we were able to calculate the radius of our exoplanet to be roughly 4.711 Earth radii, with an uncertainty of -0.0099 / +0.095 Earth radii.

## 5 Estimating Density

Now that we have a $R_p$ and $M_p$, we can find density $\rho$. We can calculate density from mass and radius using the following equation: $\rho = \frac{M_p}{\frac{4}{3}\pi R_p^3}$. We were able to estimate a density of 1.199 g/cm$^3$, with an uncertainty of -0.0104 / +0.0256 g/cm$^3$.

## 6 Comparing to Other Exoplanets and M-R Relation

We then compared our measurements of mass, radius, and density to (1) other exoplanets from NEA with similar masses and radii and (2) the M-R relation from Chen & Kipping (2016) (Figure 3). We found that our three measurements were consistent with other exoplanets with similar radii and mass, while being slightly above the M-R relation, indicating that GJ 436 b is a Neptune-like planet. We also found that the density of our system is consistent with the densities of similar exoplanets (Figure 4), which also points towards this planet being Neptune-like. Since we have a radius that is expected for the planet's mass, we have further evidence pointing towards the fact this exoplanet is a Neptune-like world. Further research is needed to confirm these findings and to explore the implications for our understanding of planet formation and evolution.

## 7 Conclusion

Throughout this project, we utilized the radial velocity and transit data of system GJ 436 b to estimate the mass, radius, and density of the exoplanet. We used a Markov Chain Monte Carlo Bayesian sampling model to estimate the uncertainties in our calculations. We then compared our measurements to other exoplanets with similar masses and radii, as well as to the mass-radius relation from Chen & Kipping (2016). Our findings suggest that GJ 436 b is a Neptune-like world consistent with both similar exoplanets and the M-R relation.

## 8 Contributions

- Ethan Johnson: Code Lead
- Rachel Price: Paper Lead
- Malachi Roark: Presentation Lead

The authors declare that they have used generative artificial intelligence, specifically ChatGBT, to assist in cleaning the raw code and helping when error statements arose throughout this project.

## 9 Appendix

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## Code temporarily deleted for PDF conversion
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Figure 1:

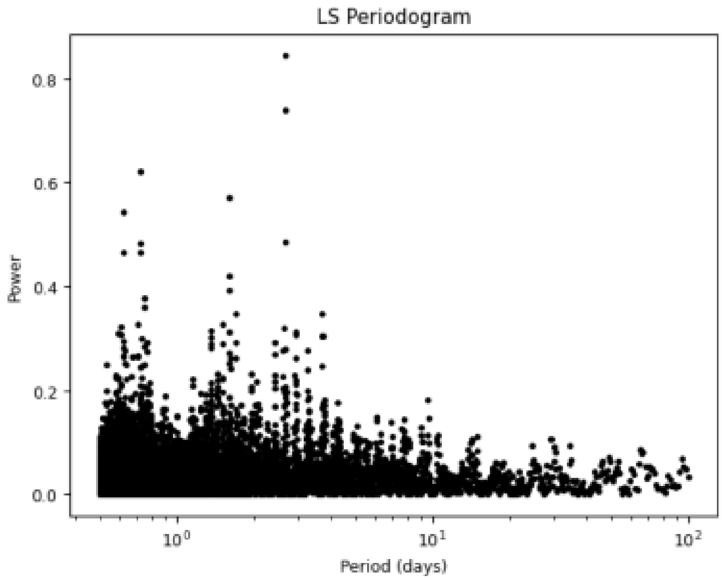



Figure 2:

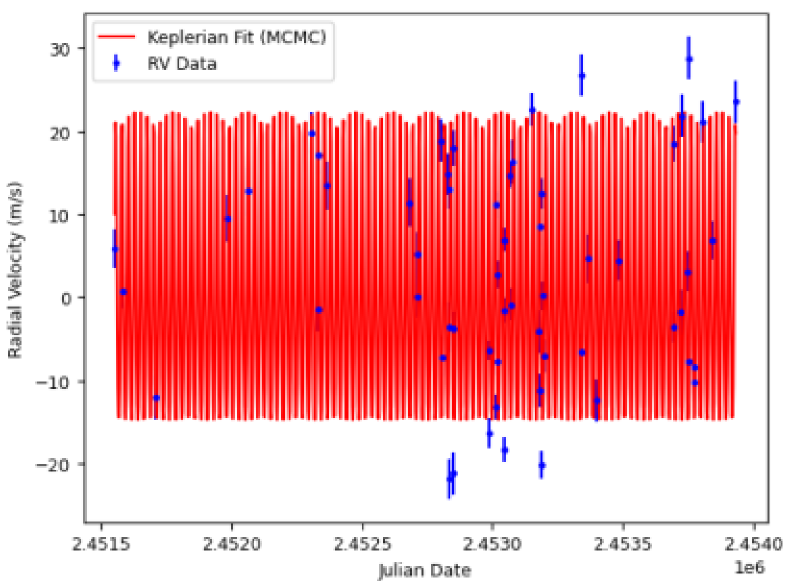



Figure 3:

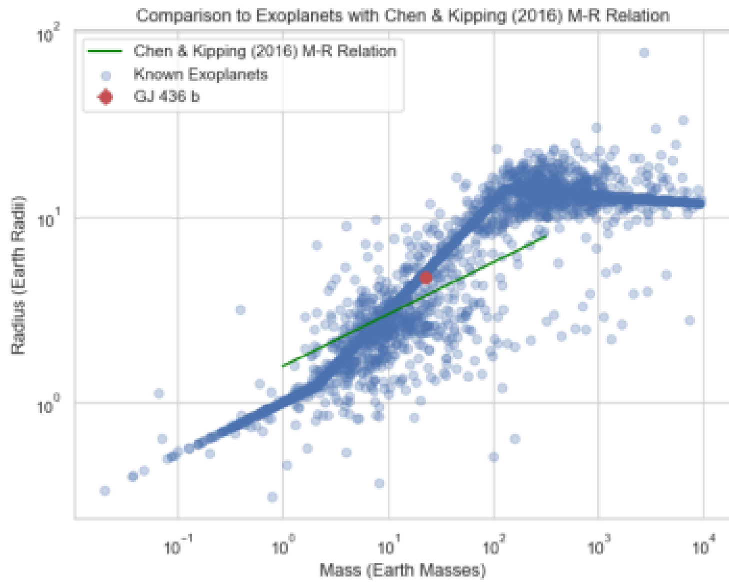
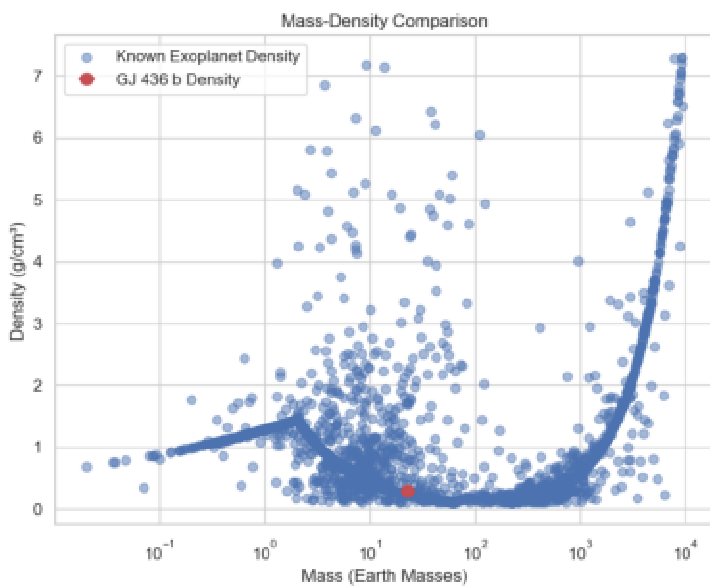

Comparison to Exoplanets with Chen & Kipping (2016) M-R Relation
Chen & Kipping (2016) M-R Relation
Known Exoplanets
GJ 436 b
Radius (Earth Radii)
Mass (Earth Masses)

Figure 4:


Mass-Density Comparison
Known Exoplanet Density
GJ 436 b Density
Density (g/cm³)
Mass (Earth Masses)