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Sizing up GJ 436 b

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1. INTRODUCTION

In the hunt for life of one Earth, there is one key question that always permeates the conversation. Where does our Solar System place in relation to the general exoplanetary population? In order to better constrain the answer, exoplanet hunters need to understand the most foundational properties of planets: their mass and radius.

In this paper, we utilize photometry data to analyze the planet GJ 436 b (further denoted as just GJ). This work outlines the procedures and calculations conducted to obtain the mass, radius, and density for GJ. We also compare GJ 436 b, using these calculated parameters, to similar extrasolar planets in radius and mass.

2. DATA

We make use of two data from two ground-based observatories to make a transit and radial velocity detection of GJ. In order to search for the transits, we utilize near-infrared $8\mu m$ photometry from the *Spitzer Space Telescope* (Deming et al. 2007). To make a detection using the radial velocity method, we utilize V-band photometry from the High Resolution Echelle Spectrometer (HIRES) (Butler et al. 2006) at the Keck Observatory on Mauna Kea. This data was accessed using the NASA Exoplanet Archive (NEA) Akeson et al. (2013).

3. PLANET MASS

To solve for the mass of GJ we can upload data from Butler et al. (2006) to `ExoFast` (Eastman et al. 2013) in order to run a Markov Chain Monte Carlo (MCMC) fit using `emcee` (Foreman-Mackey

Planetary Parameters	Units	Value	Lower Error	Upper Error
Eccentricity	N/A	0.194197	0.038763	0.041378
Argument of Periastron	Degrees	1.555237	12.361738	12.475705
Period	Days	2.643973	0.000061	0.000067
Semi-Major Axis	AU	0.032965	0.003782	0.003013
Linear Limb-Darkening Coeff	N/A	0.026742	0.049978	0.050583
Quadratic Limb-Darkening Coeff	N/A	0.106018	0.054671	0.053328
Inclination	Degrees	86.102385	0.323197	0.366958
Impact Parameter	N/A	0.854223	0.009255	0.009840
Transit Depth	N/A	0.007092	0.000127	0.000123
Time of Periastron	BJD	2454510.323065	0.085994	0.103206
Time of Transit	BJD	2454510.807831	0.005335	0.005901
RV Semi-Amplitude	m/s	18.218436	1.021573	0.995890
Semi-Major Axis in Stellar Radii	N/A	13.113671	0.603123	0.599105

Table 1. Parameters returned from the MCMC run of `ExoFast` using both the *Spitzer* transit and Keck radial velocity data. Lower and upper errors denote the statistical 16th and 84th quantiles of the parameters.

et al. 2013) to our radial velocity data. Using the parameters returned from `Exofast`, we can solve for the mass of the planet given:

$$M_{GJ} = \frac{K}{sin(i)}\sqrt{\frac{aM_*}{G}} \tag{1}$$

Using parameters given in Table 1, we calculate a mass for GJ 436 b of $M_{GJ} = 24.6 \pm 2.0 M_{\oplus}$. This is an order of magnitude larger than the mass of Earth, hinting that GJ 436 b may be a Naptunian-class body.

4. PLANET RADIUS

To solve for the radius of GJ we can upload data from Deming et al. (2007) to `ExoFast` (Eastman et al. 2013) in order to run a Markov Chain Monte Carlo (MCMC) fit, using `emcee` (Foreman-Mackey

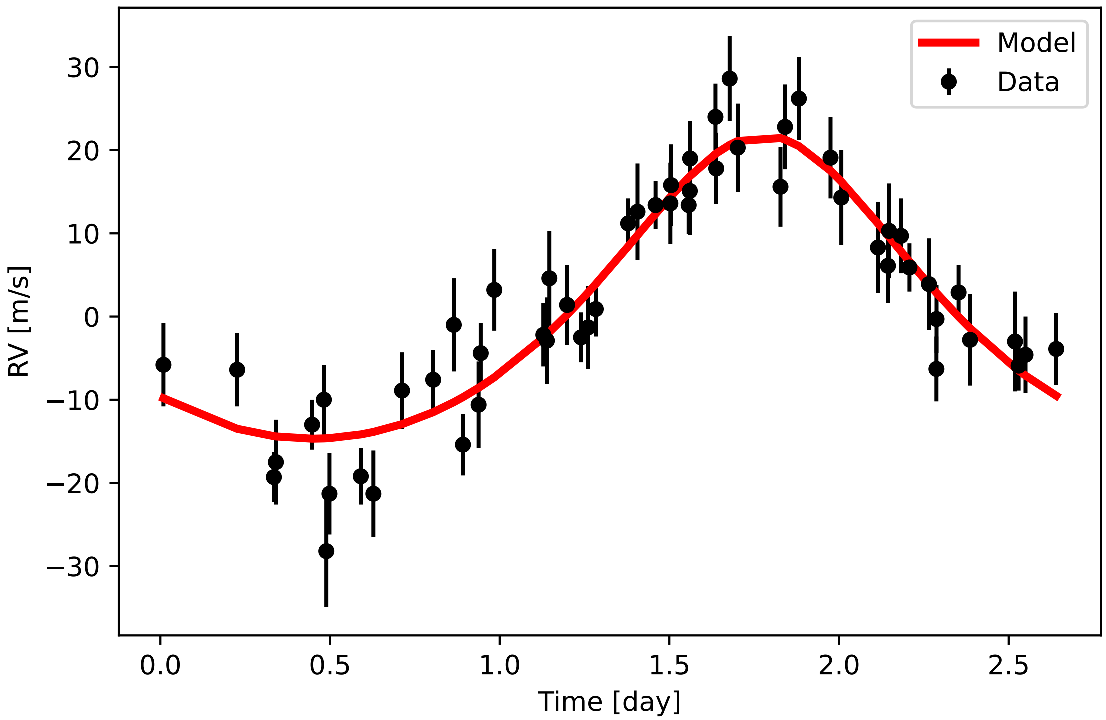

Figure 1. Radial velocity data including RV fit using `ExoFast` parameters of GJ.

et al. 2013), to the transit light curve given in Fig. 2. Using the parameters given back by `ExoFast`, we can solve for the radius of the planet given:

$$\delta = \left(\frac{R_{GJ}}{R_*}\right)^2 \tag{2}$$

The transit depth returned from `ExoFast` is given in Table 1. For the stellar radius, we use values obtained from Rosenthal et al. (2021) of $R_* = 0.417 \pm 0.008$. This results in a radius for GJ 436 b of $R_{GJ} = 3.83 \pm 0.08 R_\oplus$.

5. PLANET DENSITY

To calculate the density of GJ, we utilize the planet mass and radius measurements solved for using Eq.1 and Eq.2. We make the assumption that GJ 436 b is spherical, resulting in the following equation for density:

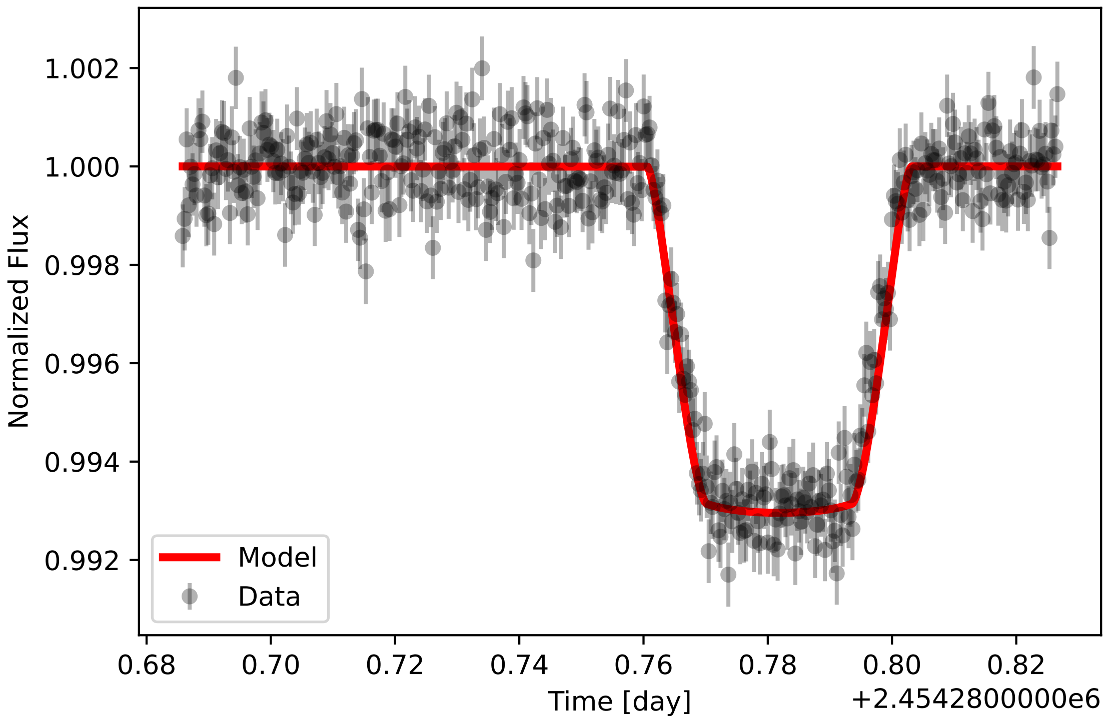

Figure 2. Transit data including transit fit using `ExoFast` parameters of GJ.

$$\rho = \frac{M_{GJ}}{V_{GJ}} = \left(\frac{3M_{GJ}}{4\pi R_{GJ}^3}\right) \tag{3}$$

The resultant density for the planet is thus $\rho_{GJ} = 2.41 \pm 0.19 g/cm^3$. The density of the planet is plotted on a mass-radius relationship given in Fig. 3, comparing GJ 436 b to similarly sized planets from the NEA.

6. RESULTS

We make a detection of the exoplanet GJ 436 b using both radial velocities and transits of the planet. These resulted in planetary parameters of $M_{GJ} = 24.6 \pm 2.0 M_{\oplus}$, $R_{GJ} = 3.83 \pm 0.08 R_{\oplus}$, and $\rho_{GJ} = 2.41 \pm 0.19 g/cm^3$. This categorizes GJ 436 b as a super-Neptune, having a size of order that of Neptune.

7. DISCUSSION

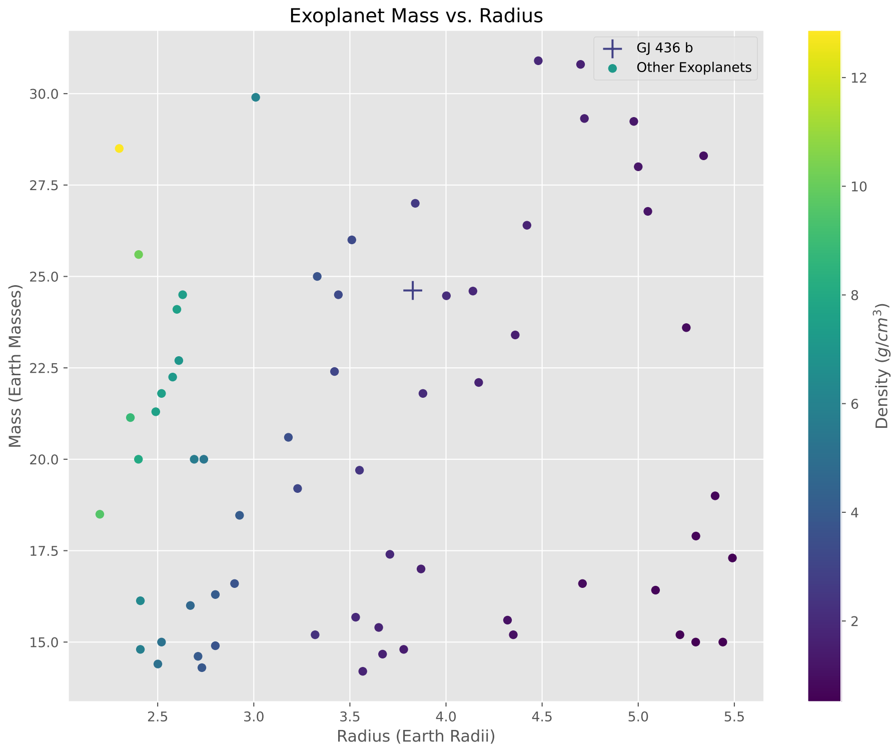

Figure 3. GJ 436 b in relation to other Neptunian-sized planets.

Comparing our results with the mass and radius relations given in Chen & Kipping (2017) we can conclude that GJ 436 b falls under the category of a Neptunian World. The relationship between mass and radius for a Neptunian-type planet is has been inferred to be $R \approx R_{Neptune}(M/M_{Neptune})^{0.59}$ by Chen & Kipping (2017). Using this relationship we can predict a Neptunian planet's mass given their radius, and vice-versa. If we envoke this relation to each of our parameters, we would expect a mass of $M_{GJ} \approx 16.9M_{\oplus}$ and a radius of $R_{GJ} \approx 4.78R_{\oplus}$. These theorized values are close to our calculated values, being well within an order of magnitude.

With advancements in space telescopes such as *James Webb Space Telescope* and *Nancy Grace Roman Space Telescope* as well as ground-based facilities such as The Giant Magellan Telescope, in the future we can hope to collect data with higher accuracy to be able to improve upon these parameter measurements and their relations to one another. We can also attempt to confirm the planet(s) within the GJ 436 system using the *Transiting Exoplanet Survey Satellite* (*TESS*), as it is currently a target of interest for *TESS*.

8. CONTRIBUTIONS

- *Aiden Zelakiewicz* - AZ created the presentation for the project, fit the transit and RV using `ExoFast`, created the comparisons, contributed to the paper, and presented.
- *Sydney Petz* - SP obtained the data from the NEA, fit transit and RV data using `ExoFast`, compared results to Chen & Kipping (2017), contributed to the paper, and presented.
- *Justin Anderson* - JA explored the transit and RV data and provided creative input while learning advanced computational skills.

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