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Exploring Properties of HD 189733 b

Motivations

Radial velocity and transits are two of the most widely-used exoplanet detection methods in modern-day astronomy. By analyzing the data collected from these detection methods, we can determine parameters of exoplanets that allow us to make important discoveries about those planets' properties. From radial velocity data, we are able to find planetary mass and from transit data we are able to find planetary radii, which allow us to calculate density. In this paper, we found the parameters above from the detection data of HD 189733 b, a gas giant orbiting a k-type star and the closest hot Jupiter to Earth [NASA]. By comparing these measurements to other exoplanets and the M-R relation from Chen & Kipping (2016), we can both verify our model and better understand how HD 189733 compares to similarly sized exoplanets.

Methods

To find planet masses, we used the following equation from [Winn 2010], solving for planet mass:

$$K = 28.4329\left(\frac{M_p}{M_{jup}}\right)\left(\frac{M_*}{M_\odot}\right)^{\left(-\frac{2}{3}\right)}\left(\frac{P}{Yr}\right)^{\left(-\frac{1}{3}\right)}$$

This required us to know K, P and their uncertainties. For an initial estimate of the period, we used a lombscargle periodogram to find periodicities in radial velocity vs time data. With this information, we used the radvel package to model our radial velocity data. After using this package to visually infer a model, we performed a Markov Chain Monte Carlo (MCMC) simulation with uniform priors on all parameters. Our model included the period, eccentricity, time at periapsis, angle of periapsis, and the semiamplitude K.

The MCMC fit produced a model with uncertainties in P and K, but not the planet mass. We propagated these uncertainties to planet mass with a Monte Carlo (MC) simulation. MC simulations work by drawing new data from the initial sample, with each point being the center of a gaussian with a sigma equal to the uncertainty in the point. It is then possible to find a new value with the new sample. Creating a list of these values and calculating its mean and standard deviation provides the value of interest for the MC simulation, in this case the planet mass. Once we obtained the period, we could use the aforementioned equation to solve for the planet's mass. To find the planet's radius, we looked at the transit data being plotted against the time elapsed. Then, we divided our data into two categories - 'in transit' and 'out of transit'.

This is so that we can find the transit depth in order to solve for the planet's radius. Once we set our boundaries to not exceed 0.98 magnitude for the "in transit" magnitudes and to not fall under 0.995 magnitude for the "out of transit" magnitudes, we could calculate an array of transit depths. This was done by using the equation:

$$d = \left(\frac{M_{out} - M_{trans}}{M_{out}}\right)$$

From there, we can use the equation for transit depth, but rearrange it to equal the planet's radius, thus producing:

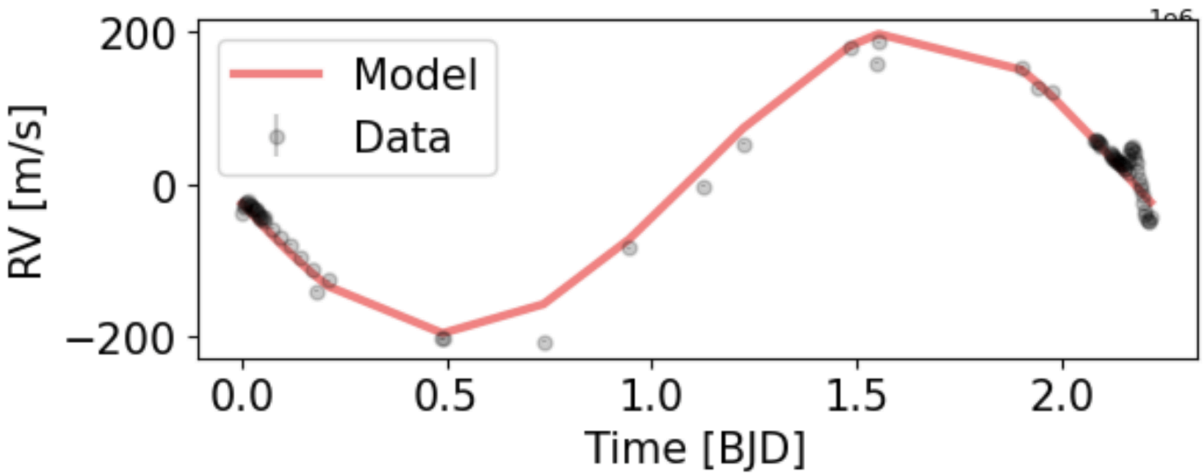
$$R_{planet} = (d)^{1/2} * R_{star}$$

Calculating the density was relatively simple. First, we converted everything into grams and centimeters. Then, we used the equation:

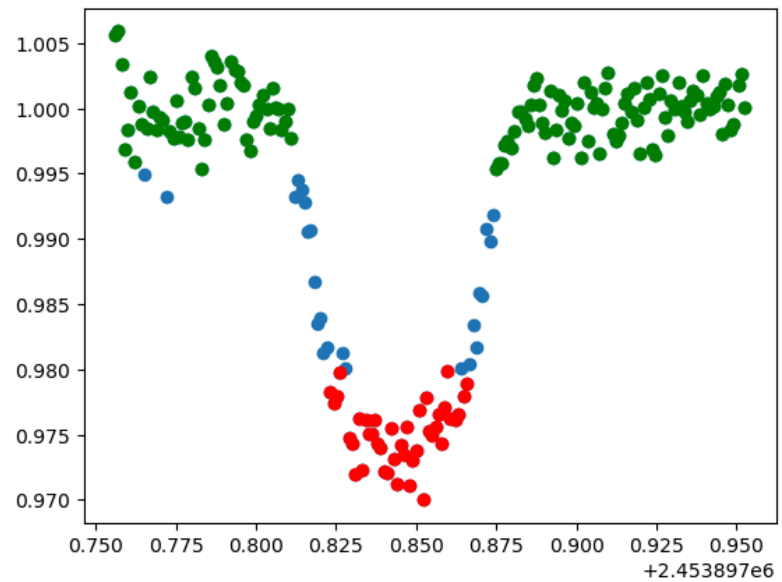
$$p_{planet} = \left(\frac{M_{planet}}{\frac{4}{3}\pi * R_{planet}^{3}}\right)$$

The density was then found by making an array of rho values and finding the mean and standard deviation.

Results



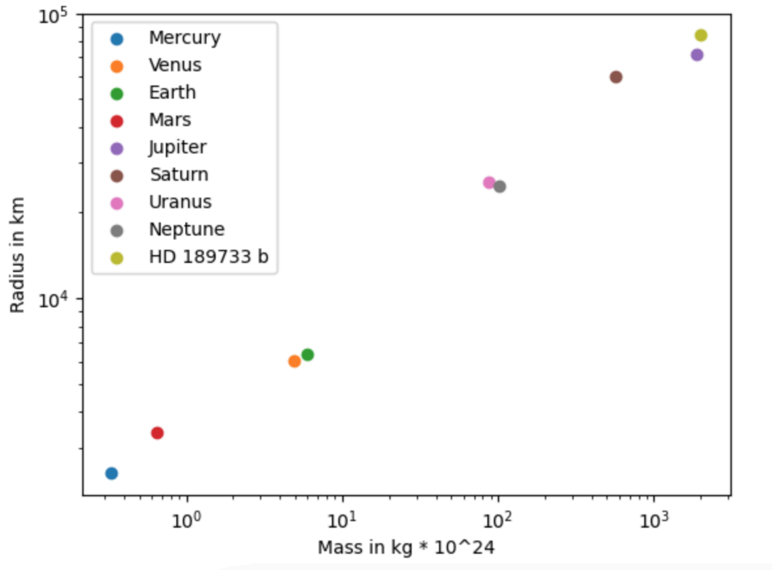
Through the Monte Carlo simulation, we found the planet's mass to be ~1.148 +/- ~0.0146 Jupiter masses. The star's radius was found on NEA and turned out to be 0.765 solar radii. We made an empty array for radii and then put this into a for loop, where we plugged in the transit depths array. At the end, we averaged the values for the final result of the planet's radius being ~1.199 Jupiter radii, found from the data curve created by plotting magnitude data:



The standard deviation gave the uncertainty, which was +/- ~0.0059. The calculated density of the planet using our model was found to be ~ 1.009 +/- ~0.0199 g/cm^3.

Conclusions

According to Chen & Kipping's (2016) M-R relation, HD 189733 b classifies as a Jovian planet, the same as Jupiter. HD 189733 b shares similar characteristics to Jupiter with only a slightly larger mass and radius.



The existence of such a similar planet to one within our own solar system points to the possibility of there being exoplanets sharing other conditions with planets in our solar system, including conditions for habitability. By exploring systems with planets sharing similar characteristics to those in our solar system and expanding our models to include more planets and parameters, we may be able to one day find signs of habitable exoplanets like Earth.

Works Cited

Lovis, Christophe & Fischer, Debra A. "Radial Velocity Techniques for Exoplanets." *Exoplanets*, University of Arizona Press, 2010, pp. 27-53.

"NASA Exoplanet Archive." *NASA Exoplanet Archive*, exoplanetarchive.ipac.caltech.edu/. Accessed 24 Feb. 2025.

"Planetary Fact Sheet." *NASA*, NASA, nssdc.gsfc.nasa.gov/planetary/factsheet/. Accessed 24 Feb. 2025.

Winn, Joshua N. "Exoplanet Transits and Occultations." *Exoplanets*, University of Arizona Press, 2010, pp. 55-77.