Uncertainties in Measuring Planets

Astronomy 5205 SP22

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1. Motivations

- Determine uncertainties in using radial velocity and transit methods to calculate the density of a planet
- How do these calculations compare to exoplanets of other systems?
- Compare results with Chen & Kipping Plot

2. Methods

- From the exoplanet system HD209458 b
- Use radial velocity and transit data to determine
  - Mass
  - Radius
  - Density
- Data pulled from the NASA Exoplanet Archive

Mass

- Expression for radial velocity

$$K = \frac{m_p}{m_*} \cdot \sqrt{\frac{Gm_*}{a}} \cdot sin(i)$$

- Rearranged we get

$$m_p = Km_* \cdot \sqrt{\frac{a}{Gm_*}}$$

- K = radial velocity, m_*= mass of star, a = semi-major axis, G = gravitational constant. We assume sin(i) = 1, which is mostly true for transiting exoplanets.
- Values pulled from NEA

Mass Uncertainty

- Uncertainty of planet mass

$$\left(\frac{\sigma_{m_p}}{m_p}\right)^2 \approx \frac{4}{9}\left(\frac{\sigma_{m_*}}{m_*}\right)^2 + \left(\frac{\sigma_{K_*}}{K_*}\right)^2$$

- Using σ_{K*}=0.00826, K_*=84.7 m/s, and σ_{m*} = 1119.8544 M_J we are able to calculate the uncertainty.

Radius

- Expression for transit depth

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

- Rearranging we get

$$R_p = R_* \sqrt{\delta}$$

- Where δ is the transit depth and R_* is the radius of the star.
- Values pulled from NEA

Radius Uncertainty

- Uncertainty of the radius

$$\left(\frac{\sigma_{R_p}}{R_p}\right)^2 \approx \left(\frac{\sigma_{R_*}}{R_*}\right)^2 + \frac{1}{4}\left(\frac{\sigma_\delta}{\delta}\right)^2$$

- Given that $\sigma_{R*} = 0.017$ and $\sigma_\delta = 0.0016$, we can calculate uncertainty of the planet's radius.

Density

- Expression for density

$$p = \frac{m_p}{4\pi(R_p)^2}$$

- Using m_p and the R_p we found previously, we calculate density.
- Values pulled from NEA

Density Uncertainty

- Expression for the uncertainty of density

$$\left(\frac{\sigma_p}{p}\right)^2 \approx \left(\frac{\sigma_{m_p}}{m_p}\right)^2 + 9\left(\frac{\sigma_{R_*}}{R_*}\right) + \frac{9}{4}\left(\frac{\sigma_\delta}{\delta}\right)^2$$

- We found σ_{Rp}= 0.00159 and σ_{mp}= 0.0548 and calculate the uncertainty.

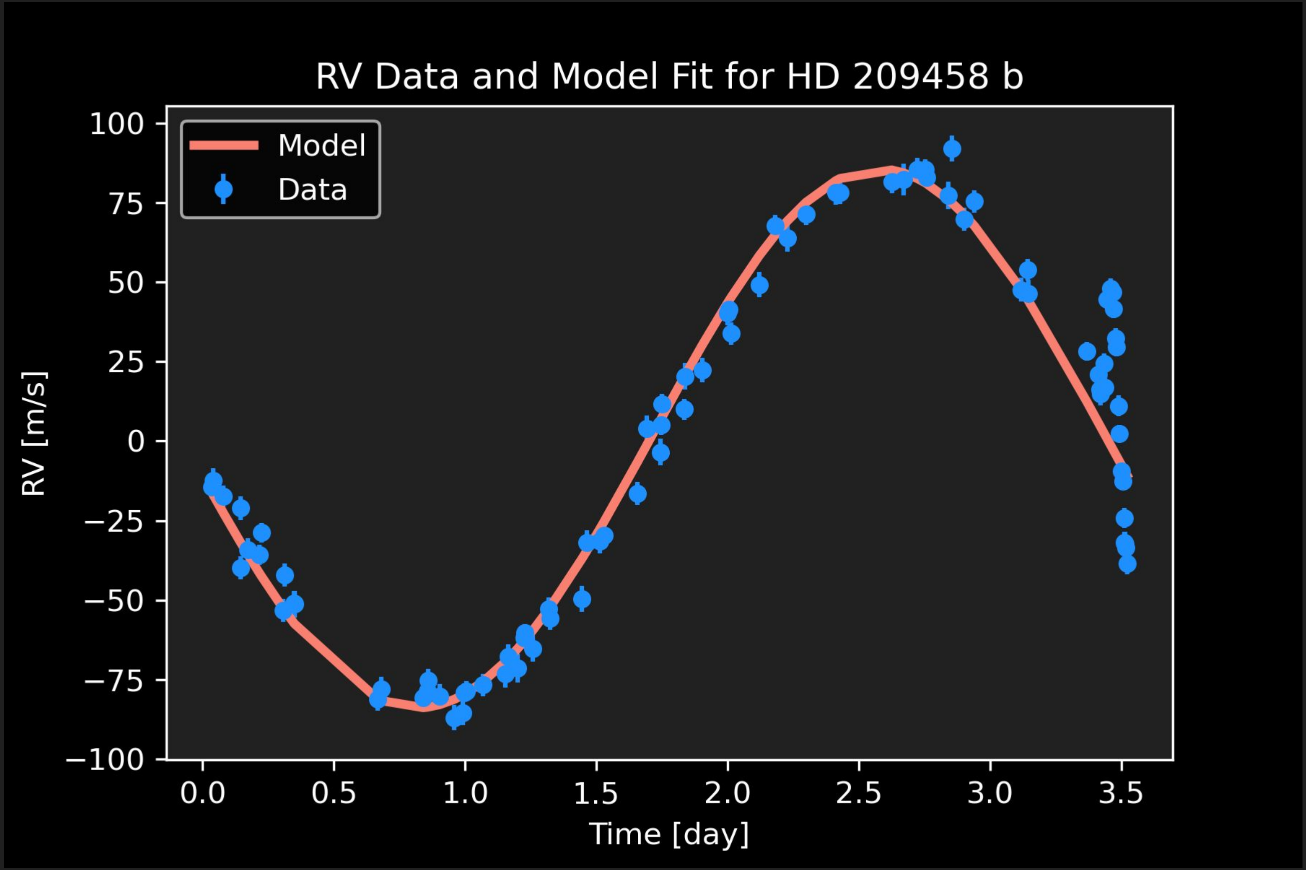
3. Results

- M_p: 0.701 Jupiter Masses
- Mass uncertainty: $7.084 \times 10^{-3}\%$

- R_p: 1.429 Jupiter Radii
- Radius uncertainty: 0.222%

- ρ: 0.636 kg m^{-3}
- Density uncertainty: 3.98%

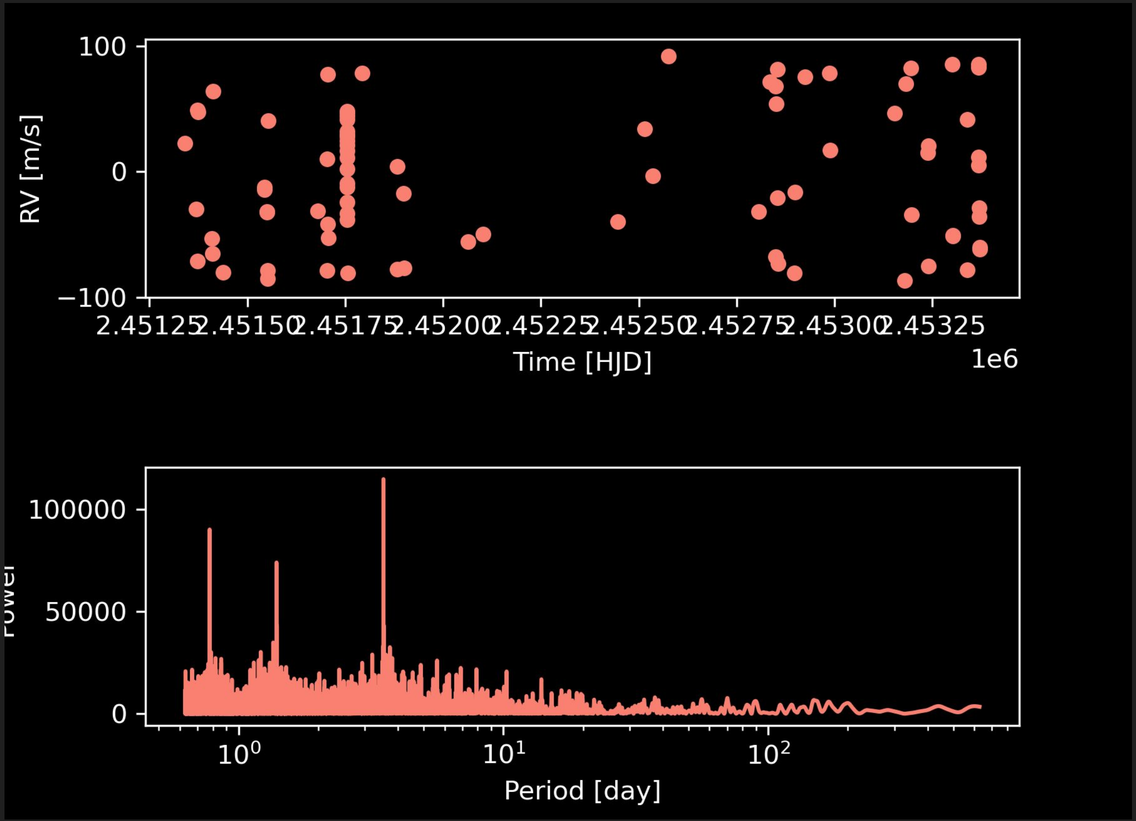
Radial Velocity Data Plots:



RV Data and Model Fit for HD 209458 b
Model
Data
RV [m/s]
Time [day]
100
75
50
25
0
−25
−50
−75
−100
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

RV, Period, and Power Relation

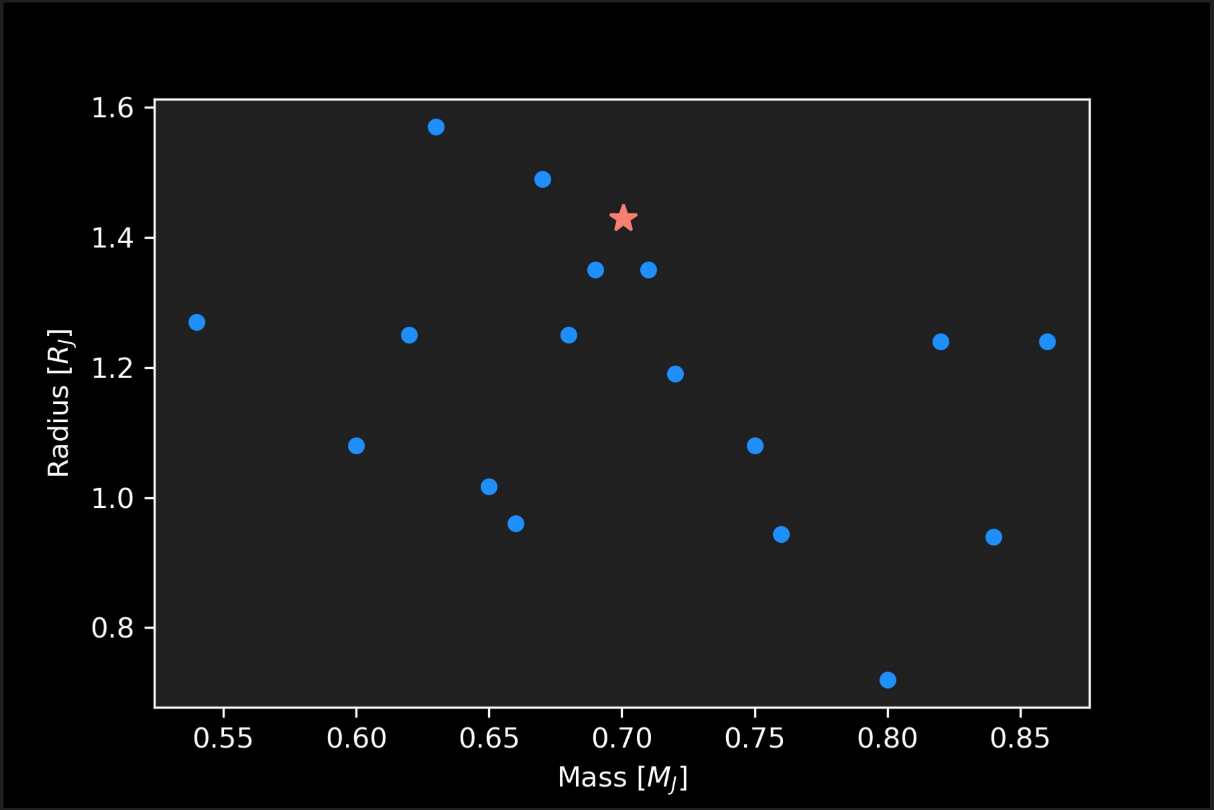
- The period is 3.52 days

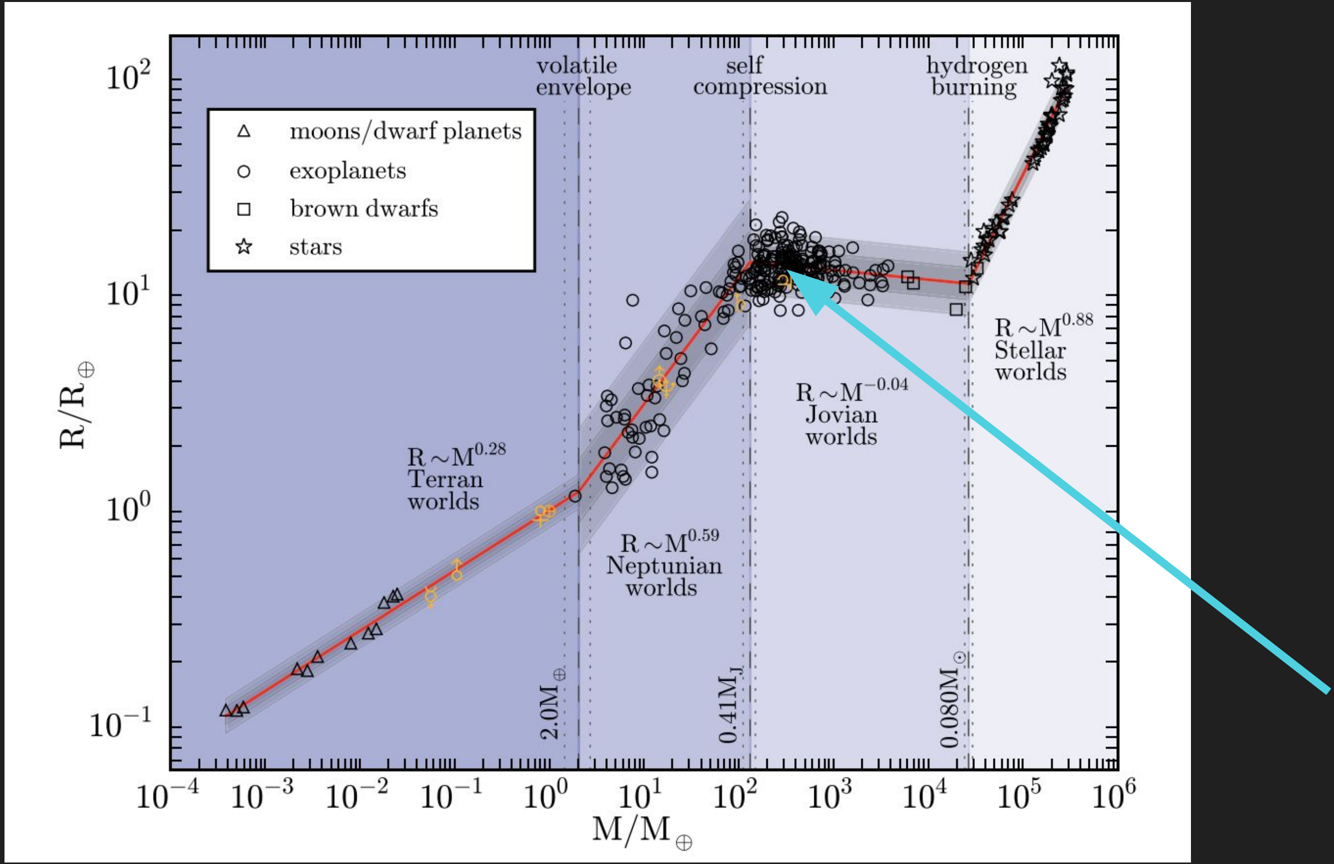


4. Conclusions

- Using radial velocity and transit data of HD209458 b we can find the following.
    - Mass of planet
        - 0.701 ± 0.00005 Jupiter Masses
    - Radius of planet
        - 1.429 ± 0.0031 Jupiter Radii
    - Density of planet
        - 318.429 kg/m^3
    - Period of planet
        - 3.52 days

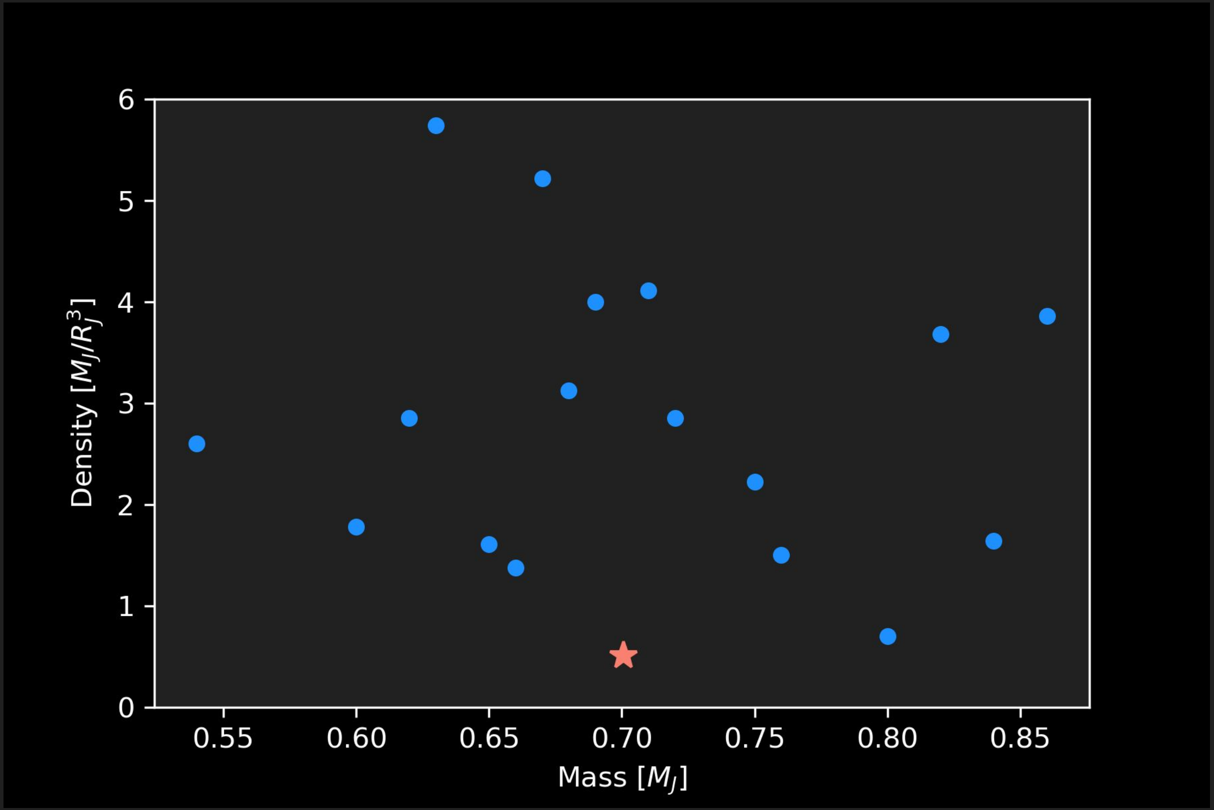
Comparisons





moons/dwarf planets
exoplanets
brown dwarfs
stars
volatile envelope
self compression
hydrogen burning
$R \sim M^{0.28}$ Terran worlds
$R \sim M^{0.59}$ Neptunian worlds
$R \sim M^{-0.04}$ Jovian worlds
$R \sim M^{0.88}$ Stellar worlds
$2.0 M_\oplus$
$0.41 M_J$
$0.080 M_\odot$
$R/R_\oplus$
$M/M_\oplus$

Comparison cont.



Citations

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