Exoplanet Detection Methods

Question 1– Exoplanet Characterization

In this question, you will estimate the mass and radius of a planet from its radial velocity
and transit data.
A mysterious new (and fake!) planet, GJ 8999 b, has been detected orbiting the M dwarf
GJ 8999. GJ 8999 is a very small star, with a mass of 0.2$M_\odot$ and a radius of 0.2$R_\odot$. (If
you haven't seen those symbols before, $M_\odot$ and $R_\odot$ are the mass and radius of the Sun,
respectively.)
The cunning astronomer you are, you have been measuring transit and radial velocity
data of this star to figure out the planet's mass and radius of this planet, so you can publish
a paper on the system! Let's characterize this planet now.

▼ **a) What is the inclination of GJ 8999 b?**

Since we were able to measure the planet's transit, its orbit must be nearly edge-on, so its inclination is close to 90 degrees.

▼ **b) What is the period of this exoplanet?**

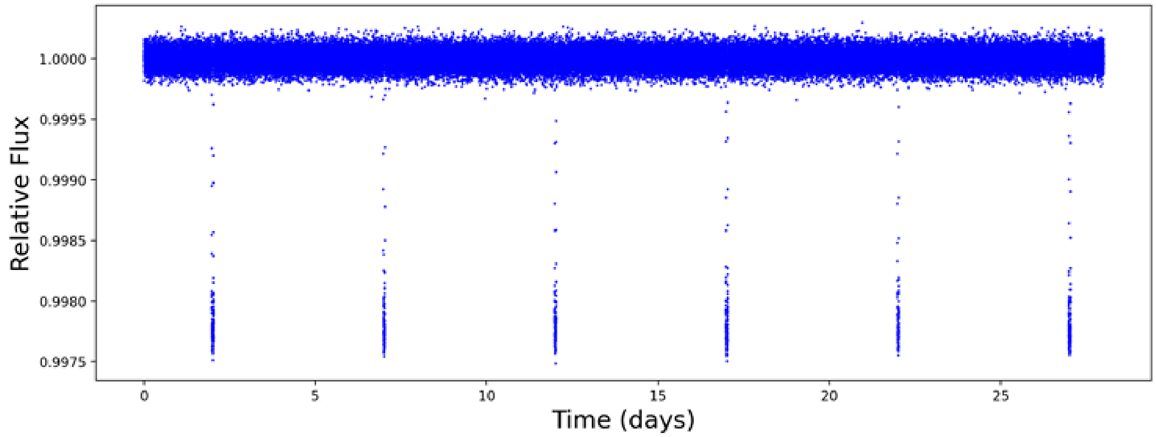

Figure 1: A plot of the flux of GJ 8999 over time over a 28-day period.

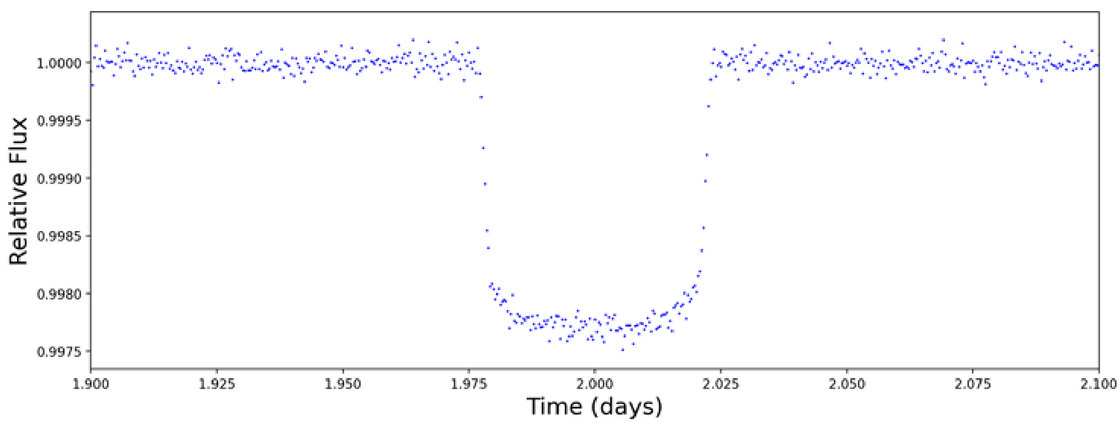

Figure 2: A plot of the flux of GJ 8999 over time, zoomed into a single exoplanet transit.

Orbital period =Time between successive transits

Since the planet transits every 5 days, its orbital period is 5 days.

c) What is the radius of this planet?

We can calculate the planet's radius using the Transit depth:

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

Transit depth is the dip in a light curve when a planet blocks light. Thus from figure(2):

$$\delta = 1 - 0.9975 = 0.0025$$

$$\sqrt{0.0025} = \frac{R_p}{0.2R_\odot}$$

$$R_p = 0.01R_\odot$$

$$\text{1. Planet's Actual Radius (in kilometers):}$$

$$R_p = 0.01 \times 695,700 \text{ km} = 6,957 \text{ km}$$

$$\text{2. Planet's Radius in terms of Earth Radii:}$$

$$\text{where } R_\oplus = 6,371 \text{ km}, \text{ we get:}$$

$$R_p \text{ (in Earth radii)} = \frac{6,957 \text{ km}}{6,371 \text{ km}} \approx 1.09$$

▼ **d) What is the semi-amplitude K of this planetary signal?**

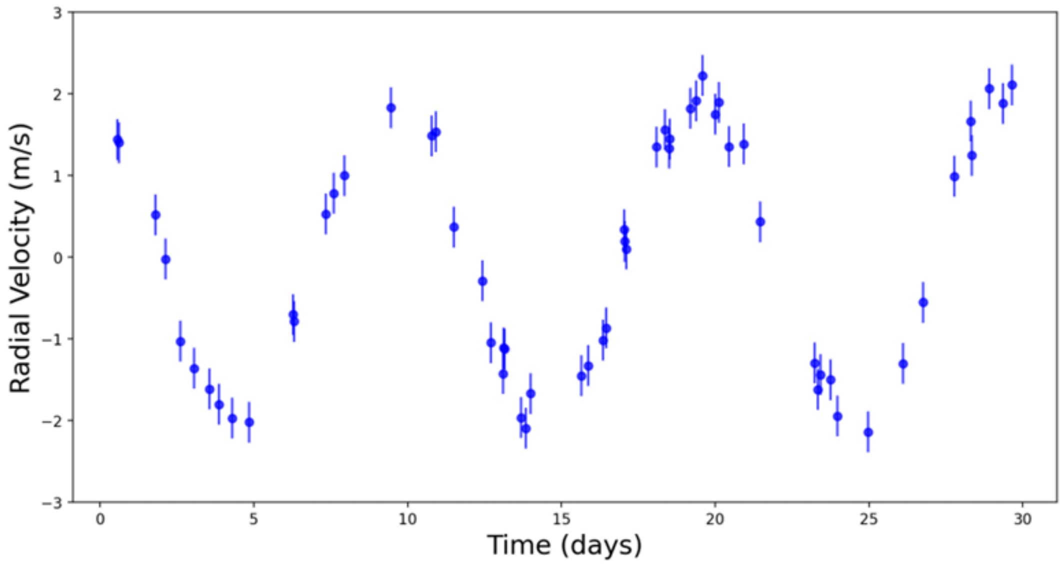

Figure 3: A plot of the radial velocity of GJ 8999 over time.

The semi-amplitude is half of the height between a crest and a trough. Thus, from figure 3:

$$K = 2.0 \pm 0.2\ m/s$$

e) What is the mass of this planet?

We can calculate the mass of the planet using the formula:

$$K = M_p \sin i \cdot \left(\frac{2\pi G}{P M_\star^2}\right)^{1/3}$$

$$
\begin{aligned}
&\text{Given values:}\\
&P = 5\text{ days} = 5 \times 24 \times 3600 = 432{,}000\text{ s}\\
&M_\star = 0.2 M_\odot = 0.2 \times 1.989 \times 10^{30} = 3.978 \times 10^{29}\text{ kg}\\
&G = 6.67430 \times 10^{-11}\text{ m}^3\text{kg}^{-1}\text{s}^{-2}\\
&K = 2\text{ m/s}\\
&\sin i = 1 \quad (\text{edge-on orbit, i} = 90^\circ)
\end{aligned}
$$

$$
\begin{aligned}
&\text{Substituting:}\\
&M_p = \frac{2}{1}\left(\frac{2\pi \times 6.67430 \times 10^{-11}}{432000 \times (3.978 \times 10^{29})^2}\right)^{\frac{1}{3}}\\
&\Rightarrow M_p \approx 1.09 \times 10^{25}\text{ kg}
\end{aligned}
$$

The planet has a mass of approximately 1.82 Earth masses, which is nearly twice as massive as Earth.

▼ **f) What is the composition of GJ 8999 b?**

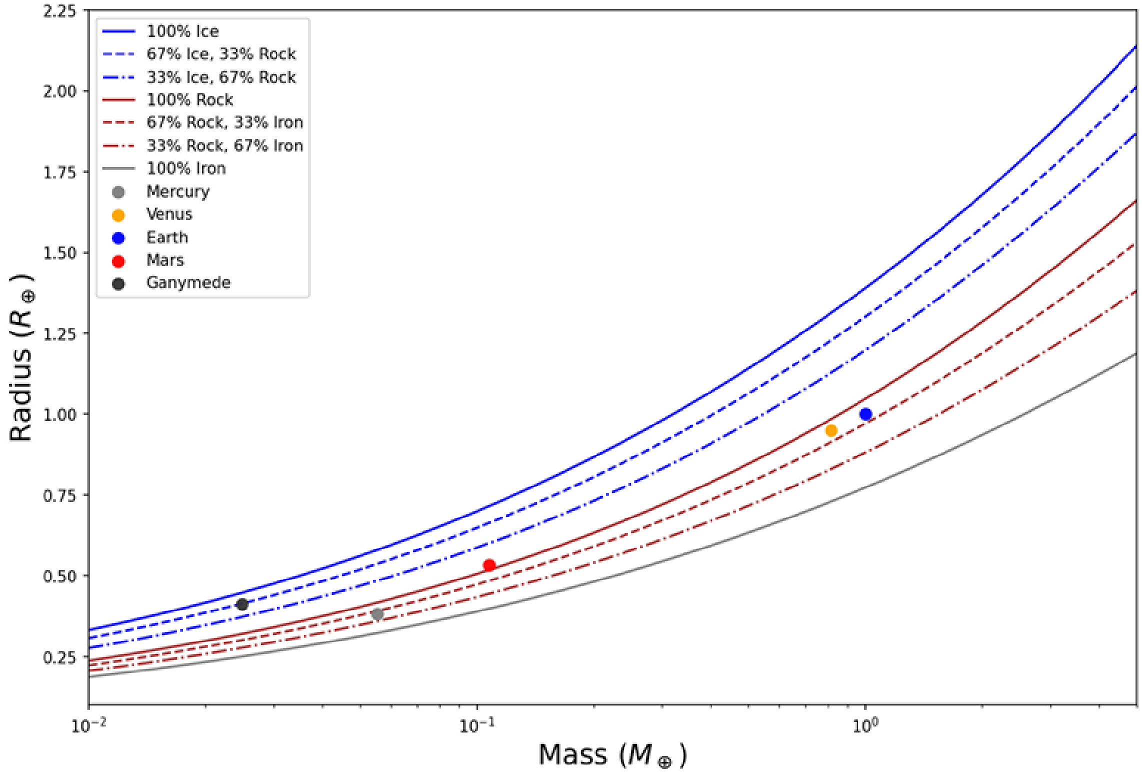

Figure 4: A plot showing the mass-radius curves for different exoplanet compositions.

The planet with a mass about twice that of Earth and a radius 1.09 times Earth's would fall on the 67% iron, 33% rock composition curve, implying it has a higher density.