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 $0.2M_\odot$ and a radius of $0.2R_\odot$. (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?

Answer: Here, according to the data, the planet exhibits transit, so the inclination angle will be very similar to 90^o or $i = 90^o$

b) New transit data from the Transiting Exoplanet Survey Satellite (TESS) has come in, and it very much looks like we have some exoplanet transits! A plot of the flux from the full 28-day observation period of TESS is shown here, as well as a plot that is zoomed into a single transit.

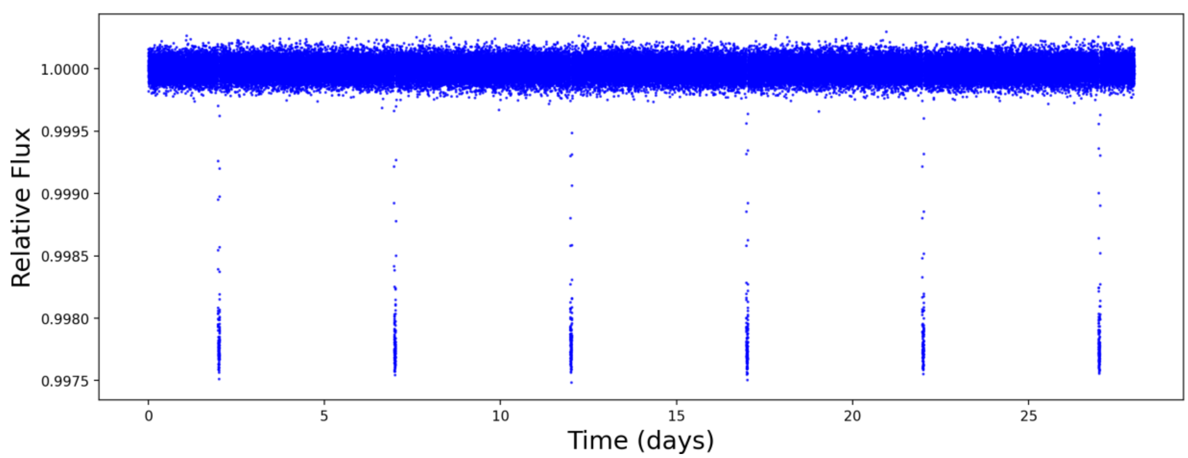

Figure 1: A plot of the flux of GJ 8999 over time over a 28-day period.

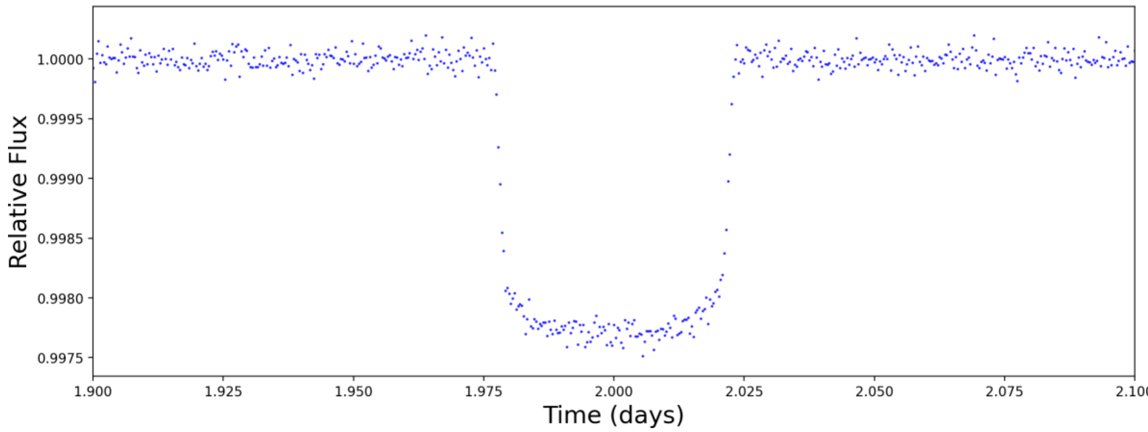

Figure 2: A plot of the flux of GJ 8999 over time, zoomed into a single exoplanet transit.

What is the period of this exoplanet?

Answer: From figure 1 we can see that the planet is completing its transit every 5 days. So, we can say that this planet has period of 5 days.

c) What is the radius of this planet?

Given, Z= (1-0.9975) = 0.0025
and $R_* = 0.2R_o$
Answer: we know, $z = \left(\frac{R_p}{R_*}\right)^2$
Therefore, $R_p = (0.0025)^{1/2} \times 0.2R_o$
Or, $R_p=0.01R_o$
Now, $R_o/R_e = 109$ [R_e=radius of earth, R_o= radius of sun]
So, $R_p=1.09R_e$

d) Luckily for us, we have gotten some radial velocity data to figure out this planet's mass, too. This data, taken over a period of 30 days, measures the star's Doppler shift as it moves back and forth due to the planet's gravity.

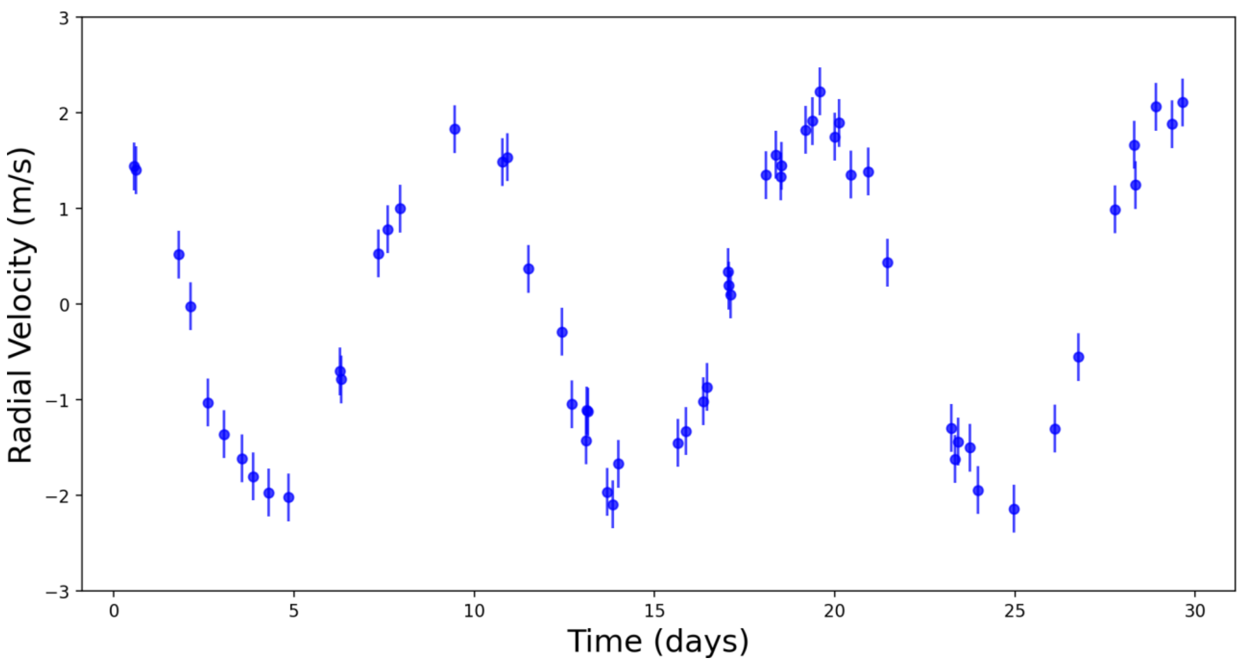

Figure 3: A plot of the radial velocity of GJ 8999 over time.

What is the semi-amplitude K of this planetary signal?

Answer: K = (2-(-2))/2 =2 , as we see the planet moving back and forth.

e) What is the mass of this planet?

We know,

$$M_p = \left(\frac{K}{sini}\right)\left(\frac{2\pi G}{PM_*^{\ 2}}\right)^{-1/3}$$

Given,
K=2
G=6.67×10^{-11}
i=90^o
P=5 days = 43200s
M_*=$0.2M_o$

So, M_p= $(2/\sin 90)\ (2\pi \times 6.67 \times 10^{-11}/\ 43200 \times 0.04 \times (1.989 \times 10^{24})^2)^{-1/3}$=$1.09 \times 10^{25}$ kg

M_p= 1.09×10^{25} kg = $1.83M_e$

f) So, now that we've found the mass and radius of our planet, let's try to figure out what it's made of!

The following plot shows (very rough) 'mass-radius curves' of rocky exoplanets of different compositions. A planet lying on a given curve has a mass and radius consistent with being made of the corresponding composition.

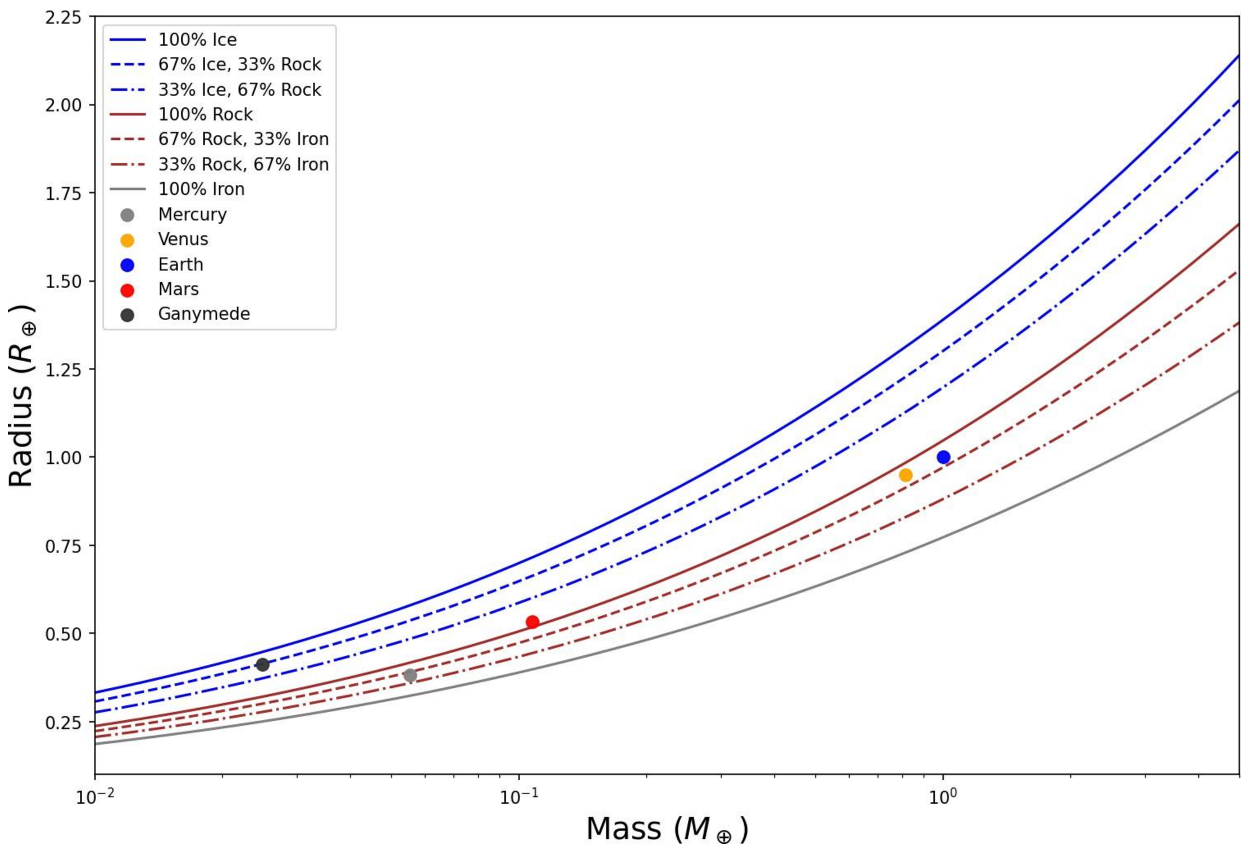

Figure 4: A plot showing the mass-radius curves for different exoplanet compositions.

The five rocky planets (plus Ganymede) are all shown on the plot as well. For example, Earth lies very near the '67% rock, 33% iron' curve, and Earth's composition is indeed about 67% rock and 33% iron.

With this in mind, what is the composition of GJ 8999 b?

Answer: Previously we've got the values of radius and the masses of the planet. Now from the graph the values of the radius and the mass of the planet are in between the region of 100% rock or 67% rock and 33% ice. From this analogy, we can conclude that the planet is mainly made of rocks with some portions of ice.