Exoplanets

Written by: Joey Chatelain, Jeremy Jones, and Ryan Sketch

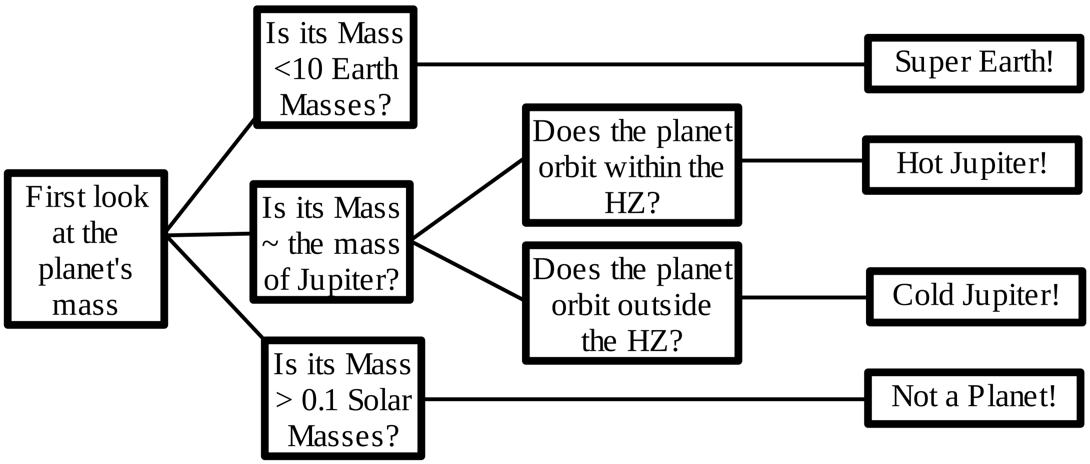
Introduction

Since 1995, when the first extrasolar planet was discovered around a main sequence star, astronomers have found over 500 exoplanets. These newly discovered worlds give us great insight on our own star system. There are many ways to find planets orbiting other stars, but only two methods have been used to discover the bulk of the exoplanets known to exist. In today's lab, we will be using these two methods and some real data to determine the properties of a handful of exoplanets. The first method we will look at is analyzing the radial velocity curves of host stars to see the wobble induced on the host star by its planet's gravitational tug. The second method we will look at is light curve analysis of transiting exoplanets to see the slight decrease in the host star's brightness we see as the planet orbits in front of the star in our line of sight.

Finding the Mass of an Exoplanet

1. **Find M_*:** The first step in finding the mass of an exoplanet is in determining the mass of the host star. Table I includes estimates for the mass of a star based on its spectral type. The spectral type of the star is listed in the bottom corner of the radial velocity plot. The mass on the table associated with this spectral type is M_*.
2. **Find V_*:** To find the velocity amplitude (V_*) of the star, take the difference of the maximum value and the minimum value of the radial velocity curve (in other words, subtract the value at the trough from the value at the peak). This will be twice V_*, so divide your answer by 2
3. **Find P in years:** Next, we want to find the period of the orbit in years. We already have the period in days (written on the radial velocity curve). Take this number and divide it by 365.
4. **Find a in AU:** Now, we want to find the semi-major axis (**a**) in AU. We do this by using Newton's modification of Kepler's third law:
$$(M_* + M_P)P^2 = a^3$$
Now, we assume that the planet's mass is much less than the star's mass, making this equation:
$$M_* P^2 = a^3$$
Rearranging this:
$$\boxed{a = \sqrt[3]{M_* P^2}}$$
5. **Find M_P in M_{sol}:** We assume that the orbit of the planet in question is mainly circular. This, combined with conservation of momentum (and some unit conversion) gives us the mass of the planet (M_P) in M_{sol}. P is the period of the system in years.
$$\boxed{M_P = (2.1 * 10^{-4}) \frac{M_* V_* P}{2\pi a}}$$
6. **Find M_P in M_{Jup}:** To convert from M_{sol} to M_{Jup}, multiply by 1047 (which is the mass of the Sun in M_{Jup}).
7. **Find M_P in M_E:** To convert from M_{Jup} to M_E, multiply by 318 (which is the mass of Jupiter in M_E).

8. **Determine the Object Type:** To determine what type of planet these exoplanets are, look at the mass and the semi-major axis. The habitable zone of a star is given in Table I based on its spectral type.



Finding the Radius of HD 209458 b

Another tool we can use to discover properties of an exoplanet is the light curve of the host star. If the orbit of the planet is edge-on, so that the planet will pass in front of the star during part of its orbit, we can see this as a small decrease in the amount of light we receive. We used this same principle to determine the sizes of eclipsing binary stars in an earlier lab.

If we compare the time between first contact, $\boldsymbol{t_1}$, and second contact, $\boldsymbol{t_2}$, to the total time it takes the planet to complete one orbit, this should be the same as the comparison between the planet's diameter and the total distance the planet travels in one orbit. In equation form we have:

$$\frac{t_2-t_1}{P}=\frac{R_p}{\pi a}$$

1.) **Find t_1 and t_2 in days:** find the time at which the light curve first begins to fall for t_1 and the time at which it seems to begin to shallow out for t_2.

2.) **Find radius of the planet:** If we rearrange the previous equation and solve for R_p we get the following. Be sure to use the period of the planet in *years* and a in *AU.* The constant ensures that your final answer is in meters.

$$R_p=(4.1*10^8)\frac{\pi a(t_2-t_1)}{P}$$

3.) **Find the Density:** Using the mass in solar masses of HD209458 b that you found in the previous section and the radius you found above, calculate the density of the planet in kg/m^3. For comparison, note that water has a density of 1000 kg/m^3.

$$\rho=(2*10^{30})\frac{M_P}{\frac{4}{3}\pi R_p^3}$$

4.) **Find surface gravity:** Finally, calculate the surface gravity using the Gravitational constant G=6.67*10^{-11} m^3/(kg s^2), the mass of the planet in Solar Masses and the radius found above. For reference, the surface gravity of earth is 9.8 m/s^2

$$g=(2*10^{30})\frac{GM_p}{R_p^2}$$

The Drake Equation

In 1961, SETI founder Frank Drake developed a simple equation to figure out how many intelligent alien species are out there that we can communicate with. This equation is:

$$N = \frac{N^*}{T_g} \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

where:

N is the number of civilizations in our galaxy with which we could possibly communicate
$\mathbf{N^*}$ is the number of stars in the galaxy now [100-400 billion]
$\mathbf{T_g}$ is the age of the galaxy [13.2 billion years]
$\mathbf{f_p}$ is the fraction of those stars that have planets [0.3-1.0]
$\mathbf{n_e}$ is the average number of planets per star which can support life [1-4]
$\mathbf{f_l}$ is the fraction of these planets which actually develop life [0.2-1]
$\mathbf{f_i}$ is the fraction of the above that develop intelligent life [0.01-1]
$\mathbf{f_c}$ is the fraction of civilization that develop detectable signs of their civilization (i.e. radio waves) [0.01-1]
L is the length of time such a civilization is detectable [50-1,000,000 years]

While the equation itself is simple enough, the trick comes in determining the values of all the terms in it. The study of exoplanets allows us to constrain more terms than we were previously able to.

Using the Drake equation and the instructions below, find an estimate for the average distance to the nearest communicable alien civilization (assuming a homogeneous galaxy) for three cases: the pessimistic case, the optimistic case, and what you think is most appropriate.

For the pessimistic case, assume all the values are the minimum possible values.
For the optimistic case, assume all the values are the maximum possible values.
For your case, choose values within the given range of possible values.

To find the distance to the nearest civilization, we must first find the number of civilizations per unit volume (also called the number density of civilizations, n). n is simply the number of civilizations in the galaxy, N divided by the volume of the galaxy (7.85×10^{12} ly^3). d, the average distance between civilizations is given by the equation:

$$d = \sqrt[3]{\frac{7.85 \times 10^{12}}{N}}$$

For each case, is there another civilization in the galaxy?