Name: ____________________

# Astronomy 101 Lab: Hunt for Alien Worlds

Be prepared to make calculations in today's lab. Laptops will also be used for part of the lab, but you aren't required to bring your own.

**Pre-Lab Assignment**: In class, we've talked a little about planets around other stars. In this lab, you'll use the tools that astronomers use to look for planets orbiting around other stars. Answer the following questions before coming to lab.

***A) Explain the Doppler effect for light.***

***B) As an object moves toward you, does the wavelength of the light received increase or decrease?***

***C) How can Doppler shift be used to find planets around other stars?***

***D) Recall that the force of gravity is proportional to the product of the two masses attracting each other and inversely proportional to the square of the distance between the objects. Is it easier to detect high mass planets or low mass planets using the Doppler shift?***

***E) Is it easier to detect planets close to the star or far from the star using the Doppler shift?***

**Introduction**: Since ancient times, humans have wondered if we are alone in the Universe and if there are other places in our universe where other life could arise. In more recent times, we've identified Earth as just one of many planets that reside within the Solar System. But we quickly discovered that the other planets in the Solar System are quite different than Earth and are not friendly to our kind of life. Thus, the search for life was extended outward to look for Earth-like worlds that reside beyond the Solar System.

For many years, the question of whether there were planets orbiting around other stars remained unanswered. All of this changed in 1992 when several planets were discovered orbiting around a neutron star. Only three years later, astronomers announced the discovery of a planet orbiting around a star like the Sun.

In the intervening years, thousands of exoplanets have been detected. In this lab, you'll take a look at the current state of the planet search and you'll employ some of the same techniques that the astronomers have used to detect planets orbiting around other stars.

**Procedure**: Much of this lab involves you accessing the catalog of extrasolar planets located at NASA's Exoplanet Archive. Find the date of the last update here. https://exoplanetarchive.ipac.caltech.edu/index.html

***1. How many total exoplanets have been discovered and on what date was the catalog last updated?***

**A. Doppler shift (radial velocity) detection method:** We'll start with using the radial velocity section of the catalog. Click on "Confirmed Planets" to see the list. Note that the number of planets listed at the bottom matches the number you recorded for #1. You can filter the table by typing in the search fields at the top of each column. Type "Radial Velocity" in the "Discovery Method" column and press Enter.

***2. What percentage of the current total extrasolar planets has been detected using this method? (Hint: Find the number of planets detected by radial velocity, divide it by the total number of planets, and multiply that number by 100.)***

You will now analyze five plots labeled "Doppler Shift Star A" through "Doppler Shift Star E". These are plots of the velocity for the star as a function of time. Remember that positive velocities mean the star is moving away from Earth, so the distance increases. Accordingly, negative velocities mean the star is moving toward Earth. They can found on the table or at the links below.

***3. Based on what you've discussed in class and in the pre-lab, explain how the velocity curves of these stars prove that there are planets orbiting around them. How are the planets causing the stars to move?***

Analyze the plots to fill in the information in Table 1 on the next page. Use a ruler to make precise measurements.

A. Find the maximum speed for the star by looking for the peak of the star's curve.
B. We need to determine how long it takes for the light curve of the star to complete one cycle of motion. Measure the period of the oscillations in the following manner:

i) If you can see two peaks or two troughs, find the time between those two points. You may have more than two, but pick two adjacent peaks or troughs.
ii) If you have one peak and one trough, find the time between them and multiply it by two.
iii) If you have only one peak or trough, find the time between it and the zero point and multiply it by four.

C. Consult the chart provided on your table called "Period versus orbital size" to determine the size of the exoplanet's orbit in astronomical units that corresponds to the period you just measured.

D. Calculate the exoplanet's speed by using the following formula:

$$\text{Planet speed (km/s)} = 10{,}908 \times \text{Orbital size} \div \text{period}$$

E. Calculate the mass of the exoplanet by using the following formula:

$$\text{Planet Mass } (M_J) = 1.05 \times \text{Star speed} \div \text{Planet speed}$$

If you hadn't already guessed, $M_J$ stands for Jupiter masses and the stars that you've just analyzed came from the Extrasolar Planet catalog.

***4.*** **Table 1**

| Star | Star Speed (m/s) | Period (days) | Orbital Size (AU) | Planet Speed (km/s) | Planet Mass ($M_J$) |
|---|---|---|---|---|---|
| A | | | | | |
| B | | | | | |
| C | | | | | |
| D | | | | | |
| E | | | | | |

Continue looking at the exoplanets discovered by the radial velocity method. Click the down arrow in the "Orbital Period" to sort the catalog with decreasing period. You can also filter the orbital period and the masses to narrow the options. Click on the question mark boxes for guidance.

***5. Find out the actual name of the exoplanet orbiting around Star A by matching both the period and the mass [Jupiter Mass]. You likely won't find an exact match, but there should be at least one within about 10% of both values.***

Now take a closer look at the exoplanets that have been discovered so far. Remove the "Radial Velocity" filter and add a filter to either of the Planet Mass columns. By checking the number of records at the bottom of the table, you can find how many planets have a mass in the Terrestrial or Jovian ranges. Remember that Jovian planets are massive planets and Terrestrial planets are low-mass planets.

***6. Jovian planets are greater than 0.03 $M_J$ or 10 $M_E$ (Earth masses) and Terrestrial planets are less than 0.03 $M_J$. Based on these mass ranges, are most of the extrasolar planets in the Extrasolar Planet catalog Jovian planets or Terrestrial planets? Explain your answer.***

Our Solar System formation model predicts that Terrestrial planets should form near the Sun (orbital size, *a*, of less than 5 AU) and Jovian planets should form far from the Sun (orbital size of greater than 5 AU).

***7. Do the five planetary systems you've analyzed agree or disagree with this prediction of the Solar System formation model? Explain your answer.***

***8. Are the planets you analyzed in Table 1 habitable? Explain your answer.***

Add filters to the orbital size and the planet mass for the next two questions. For example, if you only want to see planets between 1 AU and 1.5 AU from their star, type [1,1.5] to the orbit semi-major axis column.

***9. Which planet in the catalog is most like Jupiter, considering both mass and orbital size ($M_J$ = 1, orbital size = 5.2 AU)?***

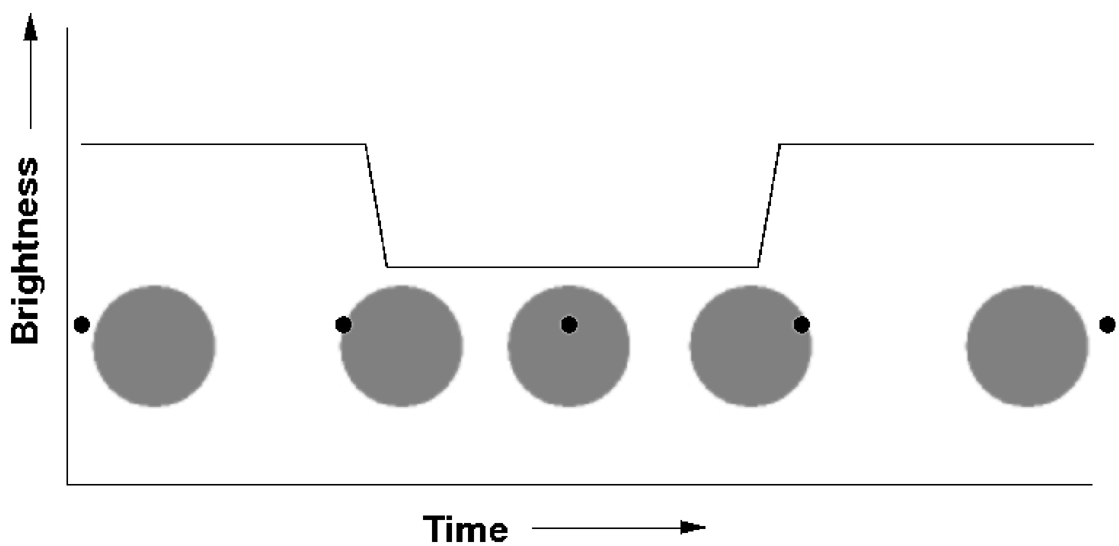
***10. Filter by radial velocity and sort by increasing planet mass. Which planet in the catalog detected by radial velocity is the least massive? How does its mass compare to Earth (0.003 $M_J$)? How does its orbital period compare to Earth?***

Consider now that these exoplanets were detected by the Doppler effect. With this in mind, answer the following questions.

***11. Why are exoplanets with larger orbits harder to detect? (If you aren't sure, check your pre-lab.)***

***12. Why are smaller exoplanets harder to detect? (If you aren't sure, check your pre-lab.)***

**B. Transit detection method:** In March 2009, the Kepler spacecraft was launched. This mission was designed to use the transit method for finding planets orbiting around other stars. When the planet passes in front of the star, it will block some of the star's light. Kepler monitors the amount of light coming from the stars as a function of time, something that astronomers call the "light curve." From this information, they can determine the period of the orbit and estimate the mass of the planet.




In the figure above, you can see a planet passing in front of its star and making the star appear dimmer for a short period. The brightness will decrease as the planet moves in front of the star, it will stay dimmer while the planet crosses the face of the star, and then the brightness will increase as the planet moves from in front of the star. The amount by which the star dims and the time it takes to go from maximum to minimum brightness tells us about the size of the planet. The time between the start of one eclipse and the start of the next one tells us the period of the planet's orbit.

You will now analyze five plots labeled "Transit Star A" to "Transit Star E". These are plots of the brightness of the star as a function of time. They are on your table. Use them to fill in Table 2 on the next page.

A. In the **top** frame for each star, measure the period using the time between when the planet begins to eclipse the star to when it begins to eclipse the star the next time.
B. Use the chart to convert period to orbital size.
C. Use the equation given in the Doppler effect section to calculate the planet's speed.
D. In the **bottom** frame for each star, measure the amount of time it takes for the star to go from full brightness to minimum brightness as the planet begins to eclipse it. (Crossing Time)
E. Use the following equation to calculate the size (compared to Jupiter's radius) of the planet:

$$\text{Planet Size } (R_J) = \text{Planet Speed} \times \text{Crossing Time} \div 142{,}984$$

***13.***

**Table 2**

| **Star** | **Period (days)** | **Orbital Size (AU)** | **Planet Speed (km/s)** | **Crossing Time (s)** | **Planet Size ($R_J$)** |
|---|---|---|---|---|---|
| A | | | | | |
| B | | | | | |
| C | | | | | |
| D | | | | | |
| E | | | | | |

As you can see, we get slightly different information from the transit method than from the Doppler effect method. Rather than directly obtaining the mass of the planet, we obtain the size of the planet instead. From there, if we want to know how massive the planet is, we need to make an assumption about the planet's composition.

For the next few questions, use the planet in Table 2 with the smallest planet size. If we assume that the smallest planet is a Jovian world with Jupiter's density of 1,330 $kg/m^3$, we can convert the planet size to a mass in Jovian masses ($M_J$).

***14. Find the mass of the planet in Jovian masses by calculating 1.07 × (planet size)$^3$.***

If we assume that the smallest planet is a Terrestrial world with Earth's density of 5,500 $kg/m^3$, we can convert the planet size to a mass in Earth masses ($M_E$).

***15. Find the mass of the planet in Earth masses by calculating 1,403 × (planet size)$^3$***

***16. Recall that the mass division between Terrestrial and Jovian worlds is roughly 0.03 $M_J$ or 10 $M_E$. Based on your answers to Questions #14 and #15, do you think that this world is more likely a rocky Terrestrial world or a gaseous Jovian world? Explain your answer.***

***17. Do we see planets like these in the Solar System? Explain your answer.***

***18A. Future telescopes will observe the spectra of the atmospheres of planets such as these. Based on the light we are detecting during a transit, what type of spectrum would we observe?***

***18B. Which gases would tell you the exoplanet is a Terrestrial world?***

***18C.Which gases would tell you the exoplanet is a Jovian world?***