Lab 5: Exoplanet Characterization PC 133: Astronomy, Block 8

Name: Lab section (circle one): Tue/Thu (Due 9am Thu) Wed/Fri (Due 9am Fri)

Group members:

Learning Goals:

- Utilize photometric and radial velocity data and information on the host star in order to characterize a hypothetical exoplanet.
- Determine the size of a star given both its luminosity and temperature.
- Understand the relationship between transit depth and exoplanet size.
- Understand the relationship between the star's maximal radial velocity and the mass of the host star, the mass of the planet, and the distance between the two.
- Create an argument detailing whether or not you think the planetary system could be inhabited by extraterrestrial life and why.

Introduction:

In this lab, we will examine some simulated data of a star system with a possible exoplanet. While this data is not from a real star system, it is modelled after real data. (Real data is generally not available for 75 straight days on a single star like it is in the spreadsheet template.) Our goal is to characterize the star and the planet that orbits it based on a light curve and radial velocity data. In other words, we will ask the following questions:

- How massive is the planet?
- What is the planet's radius?
- How often does the planet orbit its star?
- How far away is the planet from its star?
- What is the planet's density?
- Is the planet in the habitable zone?
- Could life possibly exist in this star system?

Each part of the lab below will walk you through calculations similar to those used in active research.

You may find some or all of the following quantities helpful (note: $\odot$ = Sun, and $\oplus$ = Earth):

$1\ AU = 1.496 \times 10^{11}\ m,\qquad 1\ M_{\odot} = 1.989 \times 10^{30}\ kg,\qquad 1\ L_{\odot} = 3.827 \times 10^{26}\ W$

$1\ R_{\oplus} = 6.371 \times 10^{6}\ m,\qquad 1\ M_{\oplus} = 5.792\ \times 10^{24}\ kg,\qquad 1\ R_{\odot} = 6.957 \times 10^{8}\ kg$

$$G = 6.67 \times 10^{-11}\ {m^3}/{(kg\ \cdot s^2)},\qquad \sigma_{SB} = 5.67 \times 10^{-8}\ {W}/{m^2K^4}$$

Part 1: Stellar Data

The star we are looking at has been observed to have a luminosity of $L = 0.0637\ L_{\odot}$ and a temperature of $T = 4200$ Kelvin. As such, the star is a K spectral type main-sequence star, with a habitable zone roughly between 0.1 and 0.6 AU. Because we know the star is spherical, the information from the observations tell us the star's radius (which equation should we use?). Moreover, stars of this type obey the following luminosity-mass relation:

$$\left(\frac{L}{L_{\odot}}\right) = \left(\frac{M}{M_{\odot}}\right)^4$$

a) Find the Radius and Mass of the star in units of solar radii and solar masses.
b) Convert both values to standard SI units (meters and kilograms) as well.

Part 2: Light Curve Photometry

Astronomers can build "light curves" from repeated observations of stars. In doing so, they watch the brightness of the star very carefully over time to see if there are any periodic dips. These dips indicate something is regularly blocking some of the light from the star. The bigger the object, the larger the fraction of light that is blocked – a quantity called the transit depth. Roughly speaking, the transit depth is the ratio of the area of the planet blocking the light and the area of the star facing the observer, which simplifies to:

$$Transit\ Depth = \frac{A_{planet}}{A_{star}} = \frac{\pi R_{planet}^2}{\pi R_{star}^2} = \left(\frac{R_{planet}}{R_{star}}\right)^2$$

a) Plot the relative luminosity data against time in a line chart in your Excel template and determine the transit depth of the exoplanet. Be sure to add this number to this sheet as well as your spreadsheet. Make a sketch of the plot to support your answer below.
b) At what time(s) will the planet transit in front of its star?
c) What is the period of the planet's orbit in days? In years?

Note: relative luminosity is about 1 for "normal" amounts of light and lower when light is blocked.

Part 3: Kepler's Laws

With the mass of the star and the orbital period of the planet now known, we can derive the semi-major axis of the orbit via Kepler's Third Law:

$$P^2 = \frac{a^3}{M_{star}}$$

Where a is in AU, P is in years, and Mass is in solar masses.

a) Find the semi-major axis of the orbit in units of AU and meters.
b) Is the planet located in the star's habitable zone?

Part 4: Radial Velocity Observations

By analyzing the spectra of stars over time, astronomers can observe small changes in the wavelengths of known absorption lines – small changes due to the doppler shift. This doppler shift occurs due to the planet's gravitational tug on the star, which "wobbles" enough for astronomers to measure. The doppler effect is observable when the **star** is moving radially away from (positive velocity) and radially toward (negative velocity) the observer. The size of this shift is related to the masses of the planet and star as well as the distance between them:

$$Maximal\ Radial\ Velocity = \frac{\sqrt{G}\ \cdot m_{planet}}{\sqrt{(M_{star} \cdot d)}}$$

a) Plot the radial velocity data against time in Excel as a scatter plot. Sketch a copy below.
b) Does the orbital period of the motion agree with the orbital period of the planet? Why or why not?
c) What is the maximal radial velocity?
d) What do you calculate for the mass of the planet? Give your answer in units of Earth masses.
e) Indicate on your sketch where the star is moving fastest toward and away from Earth. What is the star's radial velocity when the planet transits?

Part 5: Putting it all together

Your results so far have identified the planet's orbital period, semi-major axis, the planet's mass, and its radius. Given this information:

a) Find the density of the planet in units of kilograms per cubic meter. Compare this to the densities of planets in our solar system. Do you think this world is rocky? Gaseous? A water world? Something else?
b) Do you think life could be present in this star system? Why or why not? Defend your position with at least five sentences.