Transits: Part 1

Introduction

In the previous lab, we studied the Radial Velocity technique which is used for both detecting and studying systems of exoplanets. In this lab, we will explore another technique, called transit photometry, which complements the radial velocity technique. The transit method is employed by instruments like the Kepler satellite to discover new exoplanets and to measure their properties including the orbital size and the size of the planet. In turn, these properties can be combined with the temperature of the star to estimate the planet's characteristic temperature to answer the question as to whether an exoplanet is habitable (capable of supporting biological life similar to that of Earth).

For this lab, you will be utilizing the "Laboratory for the Study of Exoplanets" (LSE) online lab found at https://www.cfa.harvard.edu/smgphp/otherworlds/ExoLab/index.html. Copy this link and click on "GO TO THE LAB." Through the online part of this lab, you will learn about the concepts relevant to the transit technique, schedule remote observations of exoplanet systems, and analyze the transit data that you took. In addition to the online portion of the lab, there are spreadsheets with simulated transit data which you will analyze in more detail.

This will be a two-part lab spanning two weeks. This document describes the activities to be done in the first week

Modeling transits

Click on the "Modeling Lab" tab in the LSE and go through the exercise pages. Don't worry about saving your graphs, just go through the exercises.

After completing the LSE tutorials, load the Excel sheets "TransitLightCurves_Planet[]," available on the Canvas course website. Each sheet has simulated transit light curve data for one of two hypothetical planets, Planet 1 and Planet 2.

You will now analyze the simulated transit data. Complete as much of this as you can the first day. If you aren't able to finish to analysis, complete it when you return the second day.

Below is a table of properties for the system.

- 1 AU = 1.496e11 meters
- $R_\odot$ = 696,300 km
- R_J = 69,911 km
- R_E = 6,371 km
- $M_\odot$ = 1.989e30 kg
- $L_\odot$ = 3.846e26 W

	Planet 1	Planet 2
Star radius	0.85*$R_\odot$	0.202* $R_\odot$
Star mass	0.9*$M_\odot$	0.15* $M_\odot$
Star luminosity	0.656*$L_\odot$	0.00292* $L_\odot$
Planet radius (in R_J or R_E)		
Orbital period	12.164 days	
Orbital radius (in AU)		
Irradiance at planet (W/m^2)		
Power absorbed by planet		
Planet temperature (K)		

For Planet 1, plot the light curve (flux versus time) and print it out (include it in your write up). On the plot, mark where the transit starts and stops. Estimate the flux of the star for when the planet is transiting and when it isn't. Write down your values on the plot. From these numbers, calculate the radius of Planet 1 and record it in the table. Report the radius in the appropriate units (either R_J , if the planet is closer in size to Jupiter, or R_E, if the planet is closer in size to Earth). Repeat the analysis for Planet 2 using only the first two days of data.

For Planet 2, plot the light curve for the first 14 days of data and estimate the orbital period for Planet 2.

We can use the orbital periods together with the mass of the host star to determine the distance of the planet from the star (the orbital radius) using Kepler's third law

$$P^2 = \frac{4\pi^2}{GM} a^3$$

where P is the orbital period, "a" is the orbital radius, M is the mass of the host star, and G = 6.674e−11 N·m^2/kg^2 is Newton's gravitational constant. Use Kepler's law to determine the orbital radius for Planet 1 and Planet 2 and write down your values in the table.

The irradiance at the planet corresponds to the radiated flux (power per unit area) by the host star at the planet's orbital radius. It is calculated as

$$irradiance = \frac{Star\ luminosity}{4\pi a^2}$$

where "a" is the orbital radius. Use the above formula to fill in the table for the two planets.

If we assume that the planet absorbs all of the light hitting it from its host star, we can then calculate the total power absorbed by the planet by multiplying the irradiance by the cross sectional area of the planet

$$Power\ absorbed = irradiance * \pi r^2$$

where r is the radius of the planet. Calculate the absorbed power and enter it in the table.

The planet not only absorbs radiation, but it also emits thermal radiation. Assuming that the planet radiates as a perfect black body, the flux (power per unit area) radiated is related to the planet's temperature by the Stefan-Boltzmann law

$$thermal\ flux = \sigma * {T_p}^4$$

where T_p is the temperature of the planet (in Kelvin) and σ = σ = 5.67e−8 W m^{-2} K^{-4} is the Stefan–Boltzmann constant.

The total power radiated by the planet is then given by

$$thermal\ radiation = 4\pi r^2 * thermal\ flux$$

If the planet has a stable temperature, then the power absorbed must equal the thermal power emitted, that is,

$$thermal\ radiation = power\ absorbed$$

Use this relationship to calculate the temperature of both planets (in Kelvin) and record the value in the table.

To get a better sense of the temperature for each planet, convert your calculated temperature into Farenheit below.

Temperature Planet 1 (in F):

Temperature Planet 2 (in F):

How do these temperatures compare with the weather outside?