LAB 3

Detecting exoplanets with the transit method

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).

Over the next two weeks, you will learn how to use the transit method to detect exoplanets. You will use one of the MicroObservatory telescopes, built and maintained by the Harvard-Smithsonian Center for Astrophysics and located at the Whipple Observatory in Amado, Arizona to take a series of images of a "target" star in order to calculate a light curve for that star, which could be used to learn about the planet(s) orbiting them. These images will form the basis of your subsequent investigation in the DIY Planet Search.

3.1 Team roles

1. **Decide on roles** for each group member.

The available roles are:

- Facilitator: ensures time and group focus are efficiently used
- Scribe: ensures work is recorded
- Technician: oversees apparatus assembly, usage
- Skeptic: ensures group is questioning itself

These roles can rotate each lab, and you will report at the end of the lab report on how it went for each role. Some members will be holding more than one role. For example, you could have the skeptic double with another role. Consider taking on a role you are less comfortable with, to gain experience and more comfort in that role.

Additionally, if you are finding the lab roles more restrictive than helpful, you can decide to co-hold some or all roles, or think of them more like functions that every team needs to carry out, and then reflecting on how the team executed each function.

3.2 Add members to Canvas lab report assignment group

2. On Canvas, navigate to the People section, then to the "Groups" tab. Scroll to a group called "L3 Transit [number]" that isn't used and have each person in your group add themselves to that same lab group.

This enables group grading of your lab report. Only one person will submit the group report, and all members of the group will receive the grade and have access to view the graded assignment.

3.3 Scheduling observations

First, schedule the remote observations. The observations are made at night in Arizona, and they can be scheduled during the day before those observations.

3. As a group, create a single account that you will all log in to at the DIY Planet Search website at `https://waps.cfa.harvard.edu/microobservatory/diy/index.php`.
4. Navigate to About and read the "About DIY Planet Search" and "About MicroObservatory" sections.
5. Navigate to "DIYTools", watch the "Schedule Target Tutorial", and schedule observations of at least two different star systems. For both, choose "All hours" and 60 second exposures.

You will only analyze one star system, but it may be cloudy on one night, so observing two different ones makes it more likely you get data to analyze.

3.4 Analysis of sample data

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. The properties for the two star-planet systems are given in Table 4.1. Some are already filled in, and you will calculate the remaining ones.

6. Download the transit light curve data file from Canvas, in the Labs module. Open this in a spreadsheet program. The two planets are in separate tabs.

	Planet 1	Planet 2
star radius	$0.85 \times R_\odot$	$0.202 \times R_\odot$
star mass	$0.9 \times M_\odot$	$0.15 \times M_\odot$
star luminosity	$0.656 \times L_\odot$	$0.00292 \times L_\odot$
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 (W)		
planet temperature (K)		
planet temperature (°F)		

Table 3.1: Properties of two simulated star-planet systems.

7. For Planet 1, plot the light curve (flux versus time) and include it in your report.
8. 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.
9. 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).
10. Repeat the analysis for Planet 2 using only the first two days of data.
11. 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,

$$P^2 = \frac{4\pi^2}{GM} a^3 \,, \tag{3.1}$$

where P is the orbital period, a is the orbital radius, M is the mass of the host star, and $G = 6.674 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$ is Newton's gravitational constant.

12. 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

$$\text{irradiance} = \frac{\text{star luminosity}}{4\pi a^2} \,, \tag{3.2}$$

13. 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

$$\text{power absorbed} = \text{irradiance} \times \pi r^2 \,, \tag{3.3}$$

where r is the radius of the planet.

14. 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 blackbody (as in it does not reflect anything), the flux (power per unit area) radiated is related to the planet's temperature by the Stefan-Boltzmann law

$$\text{thermal flux} = \sigma \times T_p^4 \,, \tag{3.4}$$

where T_p is the temperature of the planet (in kelvins) and $\sigma = 5.67 \times 10^{-8}\ \mathrm{W \cdot m^{-2} K^{-4}}$ is the Stefan-Boltzmann constant.

The total power radiated by the planet is then given by

$$\text{thermal radiation} = 4\pi r^2 \times (\text{thermal flux}) \,. \tag{3.5}$$

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

$$\text{thermal radiation} = \text{power absorbed} \,. \tag{3.6}$$

15. Use this relationship to calculate the temperature of both planets (in kelvins) and record the value in the table.
16. To get a better sense of the temperature for each planet, convert your calculated temperature into Fahrenheit and record the values in the table. How do these temperatures compare with the weather outside?

3.5 Analyzing your own data

You will measure the brightness of the target star in each image that was taken. Since this will be around 80–100 images, you will probably want to split up the work among group members.

17. Log in to DIY Planet Search, navigate to "DIYTools", and select "Measure Brightness" from the menu at the left.
18. Watch the three tutorials at the right.
19. Select a "dark" image to use for calibration by opening it from the My Requests menu.
20. Follow the five steps listed for each image. In the first step, ensure that you calibrate your image by selecting "Calibrate"
21. If you cannot find the target star using the Finder, and your instructor cannot either, follow these instructions or ask your TA to follow these instructions to locate the star:
    a) Save the image locally as a FITS file using the Images menu.
    b) Navigate to `astrometry.net`, go to "Upload", and upload the FITS file. This website will "plate solve" the image, finding where in the sky the telescope was pointing, and assigning an RA,Dec coordinate to each pixel.
    c) Once it finishes analyzing, click "go to results page" and select "new-image.fits" to download a FITS file with the coordinates overlaid.
    d) Look up the star's name in Wikipedia or elsewhere to find its RA,Dec coordinates.
    e) Open the new FITS file in SaoImage DS9. Right-click on the image and drag around to adjust the contrast so you can see the stars.
    f) The RA, Dec coordinates of the mouse pointer are displayed at the top of the window. Move the pointer so that it points to the coordinates of the star. This should identify the target star.
22. Once all images have been analyzed, select "Interpret and Share" from the left-hand menu.
23. Use your data to estimate the transit depth and optionally share your comments and results to the whole DIY Planet Search community.
24. Using the guidance in the other tabs, estimate how big the planet is, whether it is tilted, and its distance to its star.

3.6 Report checklist and grading

Each item below is worth 10 points.

1. Data table from Part 1.
2. Plots of your light curves for Planet 1 and Planet 2.
3. Discuss how different features of the light curve connected to physical properties of the orbital system.
4. Your calculated temperature for Planet 1 and Planet 2, and your interpretation of the temperatures for the simulated planets.
5. Plot of your light curve from DIY Planet Search.

6. Your estimation of the transit depth, planet size, tilt, and star-planet distance of your observed star.

7. Write a 100–200 word paragraph reporting back from each of the four roles: facilitator, scribe, technician, skeptic. Where did you see each function happening during this lab, and where did you see gaps? What successes and challenges in group functioning did you have? What do you want to do differently next time?