



Searching for Exoplanets

Identifying planets orbiting stars other than our own might seem like an impossible task. Using even the most powerful telescopes, on Earth or in space, stars other than our own sun appear only as specs of light. Obtaining a visual image of planets orbiting these stars is all but hopeless. Yet, to date, astronomers (as well as novice individuals using programs available online) have identified thousands of other planets, outside our own solar system - exoplanets. How do they do it?

One method by which astronomers search for exoplanets is by measuring the extremely small changes in the light observed from the star as a planet transits (travels or moves across in front of) the star. This approach (called the transit method) is what we will model in this lesson.

With *Searching for Exoplanets*, you will learn:

- how the luminosity of a star is affected by the transition of a planet
- about factors used to categorize stars (luminosity, color, mass, radius)
- characteristics of planetary orbits (planet radius, period of orbit)
- how astronomers predict whether a planet could be “habitable” by Earth-life criteria

Materials

You will need a laptop or desktop computer with internet access, and a scientific calculator.

Getting Started

You will be presented with five different solar system scenarios, each with a star of different size and luminosity, and an orbiting planet. You will be calculating other parameters relating to the sun-planet system and, ultimately, try to determine if you think the planet might be in what astronomers would refer to as the “habitable zone.”

First, watch the YouTube video introduction <https://bit.ly/3agpXpd>

Then, go to the following link to run the simulation <https://bit.ly/39tkTP9>

Exploring the scenarios

Each of the five (numbered 1-5) scenarios will generate data for an exoplanet-star system. The data (the light curve graph) will look similar to the example in Figure 2. Below, is a view of the simulation window; highlights are identified in red.

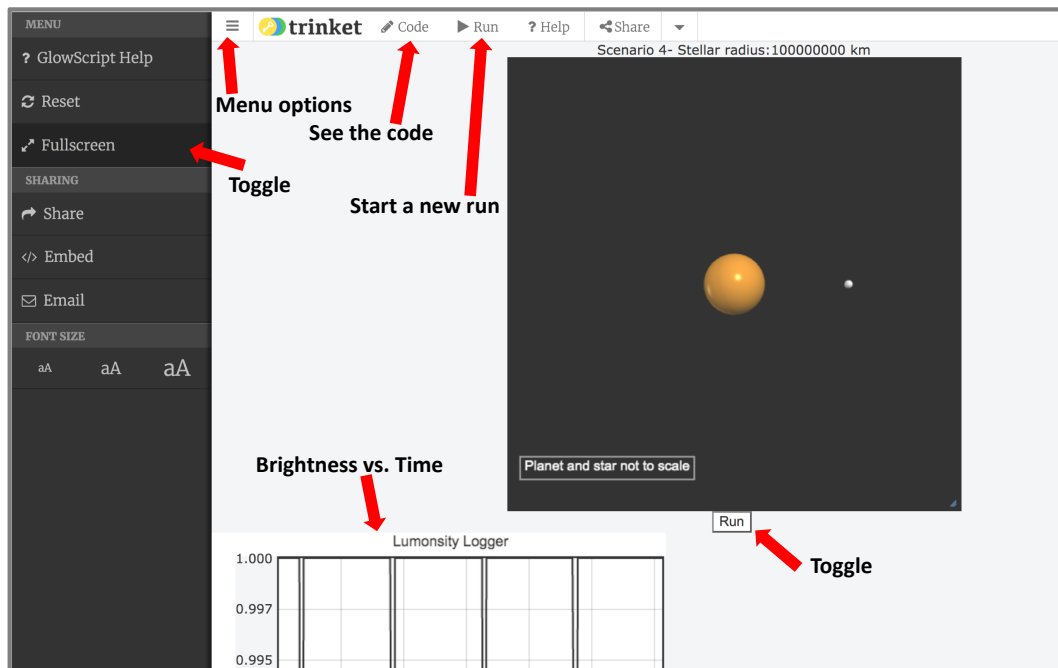


Figure 1. Screen view of Exoplanets simulation.

When you are ready to begin your investigation,

- Enter a scenario of your choice, from 1-5 when prompted (or select **Run** from the toolbar).
- You will need to **pause** the simulation to read data values from the luminosity logger.
- You can also grab the view and **zoom** in and out of the run to re-scale the view.
- Run and work through the calculations for **one scenario at a time** to become familiar with the interpretation and analysis of the data you collect.
- **Record your findings in the data table. (You may want to copy the table on a larger page.)**

Understanding the data

The key piece of evidence you will need for your analysis is the **light curve**. Each dip in the graph corresponds to the transit of a planet across a star, resulting in an infinitesimally small change in brightness. Knowing the time between the transits (dips), you can figure out the period of the planet's orbit. You can **use your mouse** to select points on the graph so you can more easily calculate the orbital period of the planet, and change in apparent brightness of the star.

Below are the steps you will need to complete the table for the planet in each scenario:

You are provided two tables; the **Information Table**, with data that you will need for your calculations, and a **Data Collection Table**, where you will enter the results of your calculations.

- 1) **Brightness and Period**
- 2) Use the light curve (the graph) from the simulation to determine the **period** of the planet by counting the number of Earth days between dips.
- 3) Convert the period from Earth days into **seconds** (there are 86,400 seconds per day).
- 4) Use the light curve (graph), to calculate ΔL , the **change in brightness** that occurs when the planet transits across the star. ΔL can be calculated directly from the graph as the difference between the observed brightness of the star during a transit (example below).

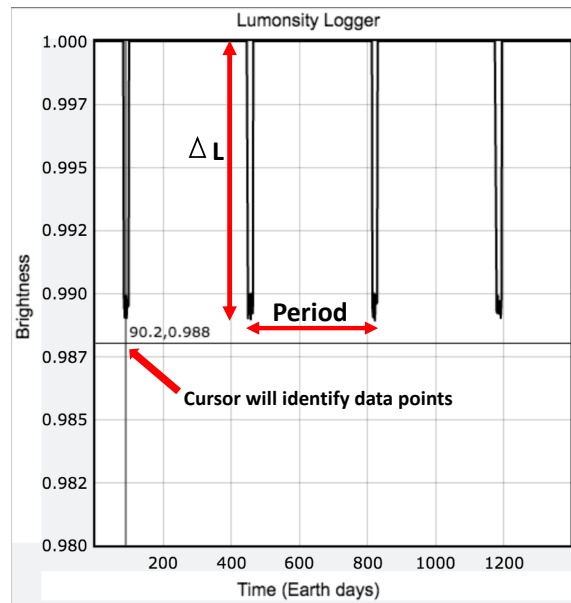


Figure 2. Brightness of Star vs. Time graph.

5) **Radius of the Planet.**

You will need to know the radius of the star (given on the Information Table), and your measured change in brightness.

The **radius of the star** (stellar radius) R_* , is will be given in the **Information Table** for each scenario. (The * symbol means that it relates to the star.) We will re-arrange the equation for you, below. Use the final equation to calculate the **radius of the planet** r_p , and record your answer in the table. (You do not need to report all of the digits your calculator gives you. Three digits will be good.)

$$\Delta L = \left(\frac{r_p}{R_*}\right)^2 \quad \text{or,} \quad \text{change in brightness} = \left(\frac{\text{radius of planet}}{\text{radius of star}}\right)^2$$

First, take the square root of both sides $\quad \sqrt{\Delta L} = \frac{r_p}{R_*}$

Then, multiply both sides by R_* and calculate r_p $\quad \sqrt{\Delta L} * R_* = r_p$

(Check to see if your answers are reasonable. The values for the planet radii should be in the range of 10^6 to 10^8 meters.)

6) **Orbital radius**, the average distance of the planet from the star it orbits.

Using the value for M_* (**mass of the star**) provided in the Information Table, and the values for P , the **orbital period** (you have to convert the period to units of seconds), that you determined from

the light curve, you can calculate the **orbital radius (r)** of the planet. Record your results in the table. (See the suggestion, that follows.) You will need the gravitational constant, $G = 6.67 \times 10^{-11} \frac{m^3}{kg \cdot s^2}$, which is also given in the Information Table.

$$r = \left(\frac{GM_* P^2}{4\pi^2} \right)^{1/3} \quad \text{or,} \quad \text{orbital radius} = \left(\frac{\text{Gravitational constant} \times \text{mass of star} \times (\text{period of orbit})^2}{4\pi^2} \right)^{1/3}$$

***Note: Solving the above equation is not trivial! There are different ways to approach this and not all brands of calculators work the same. If you need a suggestion, try:*

- Square P** (the period), you can use the x^2 function on your calculator, or just $P * P$.
- Then **multiply** that answer times the **mass of the star**
- Multiply** that answer times the gravitational constant G , $6.67 \times 10^{-11} \frac{m^3}{kg \cdot s^2}$
- Then divide by the denominator (use parentheses). In other words, $\div (4 * \pi^2) =$.
- Then take that answer to the $1/3$ power, in other words, **(your answer)^{1/3}**. You can do this using the x^y function on your calculator (or \wedge), using $1/3$ for the exponent.

(Check to see if your answers are reasonable. The values for the orbital radii should be in the range of 10^9 to 10^{11} meters.)

7) Mass of the Planet

A unique and mutual gravitational attraction exists between a planet, and the star it orbits. We will provide a value for that attraction as a "Force of Gravity" in the **Information Table** for each star/planet system. Using the orbital radius and Newton's Law of gravitation you will be able to determine the **mass of the exoplanet** for each system. Again, you will need the gravitational constant, $G = 6.67 \times 10^{-11} \frac{m^3}{kg \cdot s^2}$.

$$m_p = \frac{F_G r^2}{GM_*} \quad \text{or,} \quad \text{mass of planet} = \frac{\text{Force of gravity} * (\text{orbital radius})^2}{\text{Gravitational constant} * \text{mass of star}}$$

***Note: There are multiple ways to solve an equation like this, but you could try this:*

- Square the radius** (use the x^y function on your calculator), or just do $\text{radius} * \text{radius}$.
- Multiply** the answer by **force of gravity** (from the data table).
- Divide** that answer by the gravitational constant, $6.67 \times 10^{-11} \frac{m^3}{kg \cdot s^2}$
- Divide** that answer by the **stellar mass** (mass of the star).

(Check to see if your answers are reasonable. The values for the masses of the exoplanets should be in the range of 10^{24} to 10^{27} kilograms.)

8) **The Habitable Zone**

Could the planet be habitable? The mass of an exoplanet can give clues about whether the planet might be able to support life. A life-supporting planet must be massive enough to maintain an atmosphere. But having an atmosphere alone is not sufficient to sustain life.

The most important condition for a planet to be habitable is that the planet must contain liquid water. Detecting the presence of liquid water is exceptionally difficult but one simple test can be applied to exoplanets. A planet must be the correct temperature to possibly contain liquid water. The effective temperature of a planet is determined by the brightness of the host star and the planet's orbital radius

Using the given value for the luminosity, L listed in the data table, and the value of the orbital radius, r , that you calculated in Step 5, you can now calculate the **effective temperature**, T , of the planet using the equation below.

****Note:** You will use the *Luminosity of the Star*, L , from the Information Table, *not the change in brightness*, ΔL , that you calculated. The 1.4×10^6 term is a proportionality constant, relative to the calculation.

$$T = \left(1.4 \times 10^6 * \frac{L}{r^2}\right)^{1/4} \quad \text{or} \quad \text{temperature} = \left(1.4 \times 10^6 * \frac{\text{luminosity}}{(\text{orbital radius})^2}\right)^{1/4}$$

****Note:** Again, these steps may help you if you would like a suggestion:

- a. Enter the value for the **luminosity of the star** (from the Information Table).
- b. **Divide** by the orbital radius, and then divide by the orbital radius again.
- c. Then take that answer to the 1/4 power, in other words, **(your answer)^{1/4}**. You can do this using the x^y function on your calculator (or \wedge), using 1/4 or 0.25 for y .

Water freezes at 273 K and water boils at 373 K. To a rough estimate, an exoplanet is within the **habitable zone** of its solar system if the effective temperature is between 273 – 373 K.

Information Table					
Scenario	Stellar Radius (meters)	Stellar Mass (kilogram)	Force of Gravity (Newtons)	Luminosity of the Star (Watts)	Gravitational Constant, G $m^3 / kg * s^2$
1	1×10^9	2.2×10^{30}	5.3×10^{24}	7.6×10^{26}	6.67×10^{-11}
2	6.9×10^8	2×10^{30}	3.5×10^{22}	3.8×10^{26}	6.67×10^{-11}
3	8.2×10^7	1.8×10^{29}	2.7×10^{24}	3.8×10^{22}	6.67×10^{-11}
4	1×10^8	2.4×10^{29}	1.5×10^{23}	6×10^{23}	6.67×10^{-11}
5	1.4×10^9	2.9×10^{30}	5.6×10^{27}	2.5×10^{27}	6.67×10^{-11}

Data Collection Table								
Scenario	Orbital Period (Earth Days)	Orbital Period (seconds)	ΔL , Change in Brightness	Planet Radius (meters)	Orbital Radius (meters)	Planet Mass (kilograms)	Planet Temperature (Kelvin)	Habitable [Y/N]?
1								
2								
3								
4								
5								