A Citizen Science-Based Approach to Learning About Transiting Exoplanets

Introduction

Considering just how vast outer space is, it's quite possible that we are not alone in the Universe. Life may exist on other planets beyond our Solar System. In 1995, scientists discovered the first planet outside of our Solar System orbiting around a Sun-like star. Since then, astronomers have discovered thousands of planets orbiting other stars in the Milky Way Galaxy - these planets outside of our Solar System are called **exoplanets**.

Discovering exoplanets is the first step along the path of determining whether or not these planets are suitable for life, but their discovery can be a tricky process. We cannot directly observe new planets by looking through a conventional (or even a really big) telescope. To discover exoplanets, scientists typically use indirect detection methods such as observing changes in a star's radial velocity resulting from it being pulled on by its partner planet (radial velocity method), or changes in a star's brightness caused by a planet blocking some of the star's light (transit method). In this Citizen Science-Based Activity, we will focus on the **transit method** for exoplanet detection.

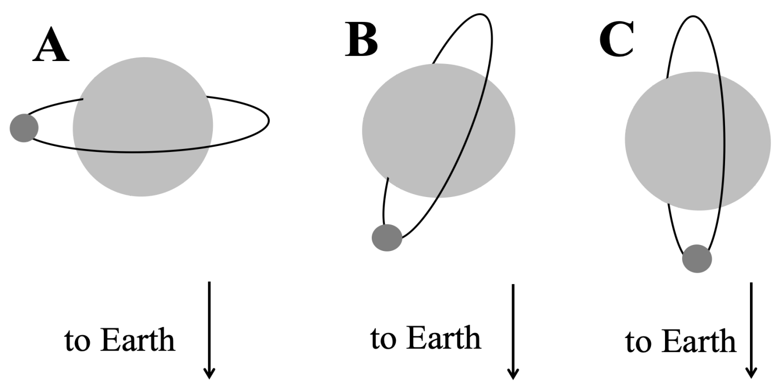
Citizen science provides the public with an opportunity to collaborate with scientists to help complete their research. This process can take on many forms, including identifying features in images, transcribing text, participating in wildlife surveys, and much more. This combined effort, commonly referred to as citizen science, gives non-scientists the ability to make meaningful contributions to research. The Zooniverse is the world's largest online platform for citizen science, with over 120 active projects across a wide array of disciplines and more than 2 million active volunteers. For this investigation, you will become official Zooniverse volunteers by helping the Planet Hunters team with their research to discover new worlds beyond our Solar System.

I. What is the Transit Method for Exoplanet Detection?

Transits occur when a planet passes in front of a star. Astronomers can measure the amount of light we detect from a star over a period of time and graph it to make a **transit light curve**. A light curve represents the star's brightness (on the y-axis) over a period of time (on the x-axis). During a transit event, a small percentage of the star's light is blocked by the passing planet; this causes a temporary decrease in the amount of light we receive from the star, and a dip to occur on the light curve. A planet will cause repeated dips in the star's light curve based on the planet's **orbital period** (how long it takes a planet to orbit its star). A close planet with a shorter orbital period will result in more frequent dips than a distant planet orbiting with a longer orbital period. The length of time the planet spends in front of the star, and consequently how wide the transit dip is, directly relates to the planet's orbital period and distance from its host star. The amount of light that is blocked, and how deep the transit dip is, directly relates to the **size or radius** of the planet.

Space Telescopes like Kepler and TESS are used to survey stars in different regions of the Milky Way Galaxy to see if any transiting planets can be detected. In order for this detection method to work, the planet must pass directly in front of its host star along the line of sight of the telescope. The detection of planets using the transit method allows scientists to uncover important information about the potential orbiting planet (size and orbital period), and therefore is one of the most popular methods for exoplanet detection.

Figure 1: Images A, B, and C show the orbits of three exoplanets around their host stars.



1. For each of the images above (A, B, C), could astronomers on Earth detect the presence of the exoplanet using the transit method? Explain your reasoning.

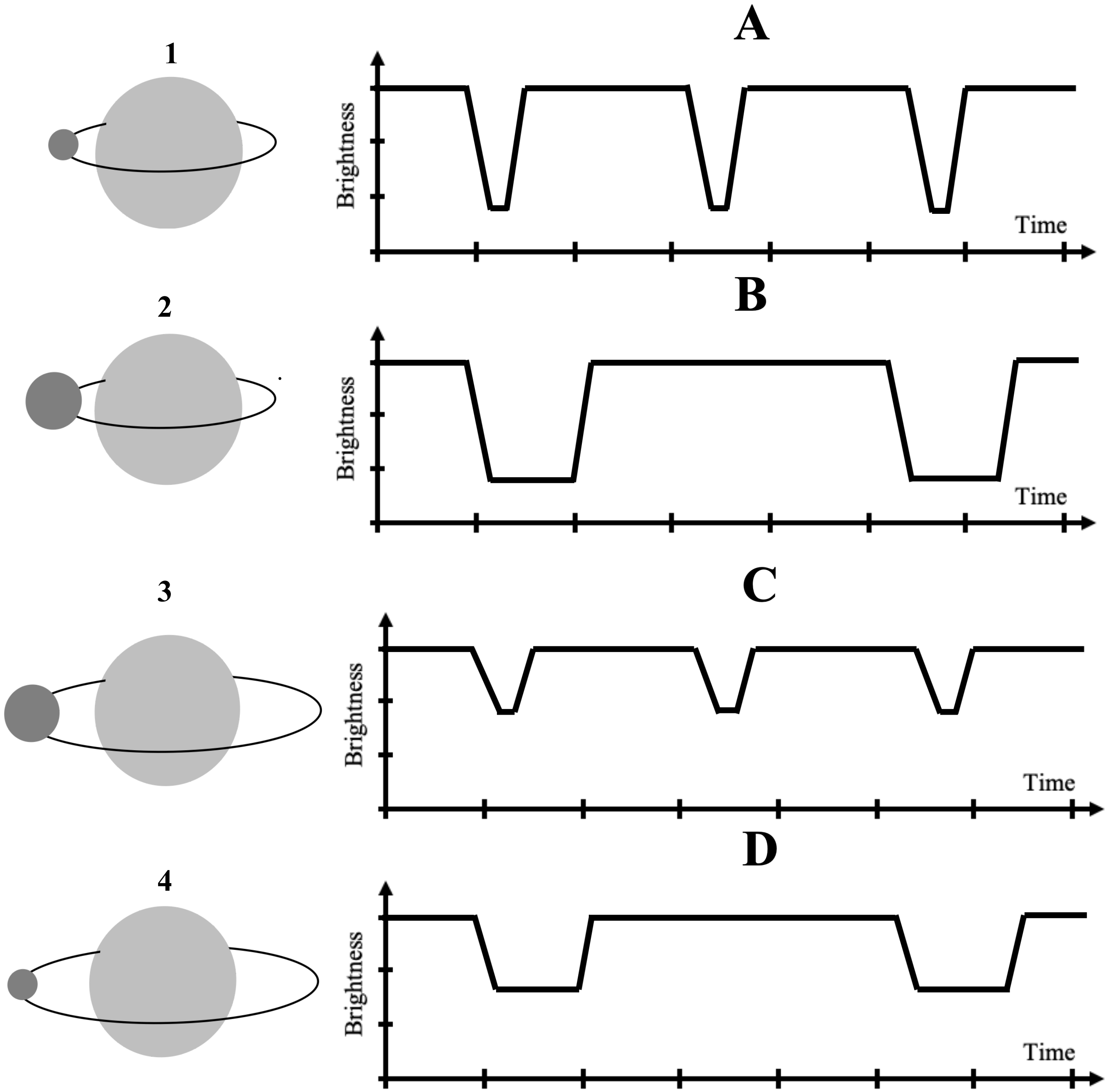
A:

B:

C:

2. If you can only observe a star for a limited amount of time (e.g., 6 months), are you more likely to find planets that orbit close to their star or far away from their star? Explain your reasoning

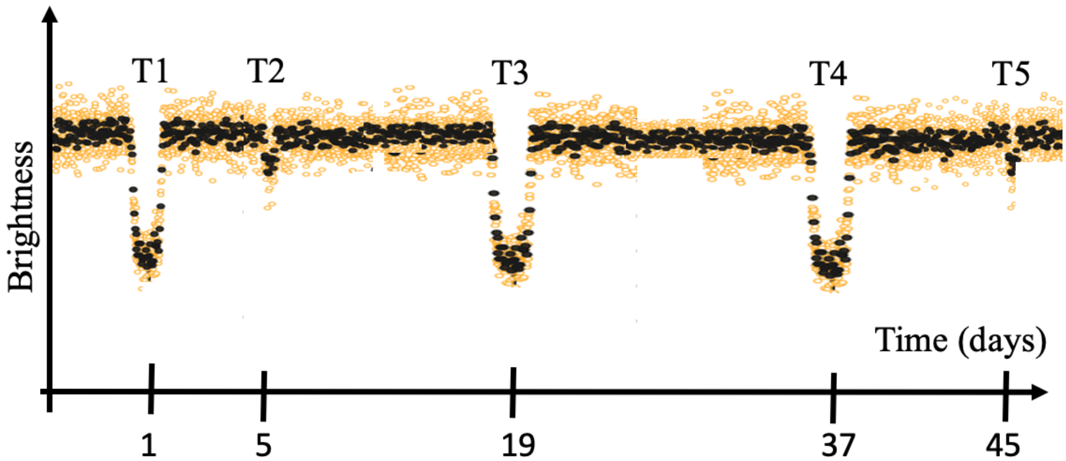
3. In the figure below, four different exoplanetary systems are shown on the left (1, 2, 3, 4), and four different graphs of brightness versus time (transit light curves) are shown on the right (A, B, C, D). Assume all of the stars are identical, and that each exoplanet crosses directly between its host star and Earth.



Which exoplanetary system matches with each transit light curve? Explain your reasoning.

The transit light curve data presented in the figure below comes from a real exoplanetary system containing 2 planets. The locations of the transits are marked with T1, T2, T3, T4, and T5, respectively.

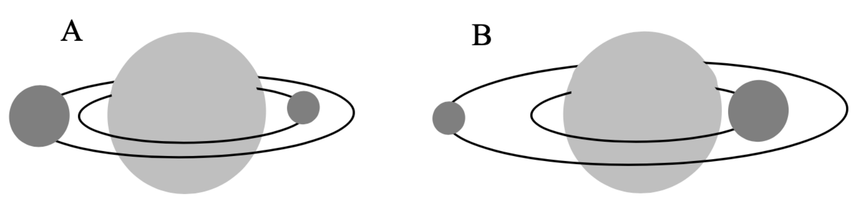
Figure 2: Brightness versus time data for a real exoplanetary system containing two planets.



4. What is the orbital period (in days) of the larger planet?

5. What is the orbital period (in days) of the smaller planet?

6. Which of the following scenarios (A or B) shown below does the light curve in Figure 2 best represent? Explain your reasoning.



7. On what day would we expect the next transit (T6) to occur? Would it be from the smaller planet or the larger planet?

8. On what day would we expect the seventh transit (T7) to occur? Would it be from the smaller planet or the larger planet?

Table 1: Radius and orbital period of the planets in our Solar System.

Planet	**Radius (Earth = 1)**	**Orbital Period (Days)**
Mercury	0.383	88
Venus	0.949	225
Earth	1	365
Mars	0.532	687
Jupiter	11.21	4331
Saturn	9.45	10759
Uranus	4.01	30687
Neptune	3.88	60190

9. Based on the values in Table 1, can the planetary system in Figure 2 be represented by any of the planets in our Solar System? Explain your reasoning.

II. How can we use Citizen Science to Identify Planetary Transits?

Now that you understand the link between transits and the discovery of new exoplanets, it's time to apply that knowledge to looking at real transit light curves!

The recently launched Transiting Exoplanet Survey Satellite (TESS) is providing scientists with a huge amount of data that lets them look for exoplanets. Over the next two years TESS will be busy surveying **two-hundred-thousand** bright nearby stars, measuring and recording their brightness every two minutes. With your help, the research team hopes to uncover lots of interesting planets, allowing them to explore the properties of these previously undiscovered worlds.

You could be the first person who spots the signature of a potentially undiscovered exoplanet! Want to give it a try?

You will do this in two parts. First, you will practice identifying dips (transits) in real light curves. For each light curve, you will receive feedback regarding whether or not you have correctly identified the location of the transit. Once you finish the practice section, you will go on to look at **never before seen** TESS light curves, contributing to the Planet Hunters research team's efforts. Not all of the light curves in the TESS data will have transits, but if they do, you'll be an expert on how to spot them!

It's important to note that you shouldn't feel any pressure when you're classifying on the Planet Hunters project. Multiple volunteers will eventually look at each light curve, so even if you aren't exactly sure whether you've identified a transit correctly, the Zooniverse community is behind you!

Instructions:

1. To begin, head to https://www.zooniverse.org and click Register in the top right-hand corner to make an account. If you already have an account, sign in.
2. Once you're signed in, go to this planet hunters practice module to get started. If an instruction tutorial doesn't automatically pop up, click the Tutorial button and follow the instructions provided.
3. Continue identifying transits for the entire set of light curves (there are 16). Once you are finished with the dataset, you will see orange 'Already Seen' banners appear in the upper left-hand corner of your images.
4. Once you've completed the practice module, you'll be ready to help the Planet Hunters research team identify transits in their TESS data. Click here to access the Planet Hunters Tess project!
    a. Click the yellow box to get started and follow the instructions
    b. If the yellow box says 'Nothing to Classify', do not worry!

   i. Just click the white ‘CLASSIFY’ button on the top right-hand corner of the web page and follow the instructions
   ii. Your classifications will still help the research team. There are never too many eyes on each light curve - your help still counts!
5. Once you have spent about 20 minutes classifying on Planet Hunters - TESS, you can move on to the debrief questions below.

Debrief:

1. How did the practice light curves compare to the actual light curves you saw when identifying transits on Planet Hunters - TESS?

2. Did the practice light curves prepare you for the actual TESS data? Why or why not?

3. Did you identify any transits on the actual Planet Hunters - TESS project? If yes, about how many?

4. What does your answer to Question 3 tell you about how common transits are in the actual data?

III. Understanding the Characteristics of Transiting Extrasolar Planets

As you learned in the previous section, scientists are investigating exoplanets orbiting stars near us in the Milky Way Galaxy to better understand their characteristics. In this section of your class activity, we will provide you with data from recently discovered transiting exoplanets. **It is your job to analyze the data to determine whether our Solar System is typical or unique among the planetary systems we find near us in the galaxy.**

[NOTE: The data used to generate Figures 2-4, and the corresponding tables, is publicly available through the NASA Exoplanet Archive, a service of the NASA Exoplanet Science Institute. The citizen science data used to generate Figures 5 and 6, and the corresponding tables was provided directly to the curriculum developers by the Exoplanet Explorers research team, as well as from Becker et al., 2015; Wang et al., 2013; Eisner et al., 2020; Schmitt et al., 2014; and ExoFOP TESS].

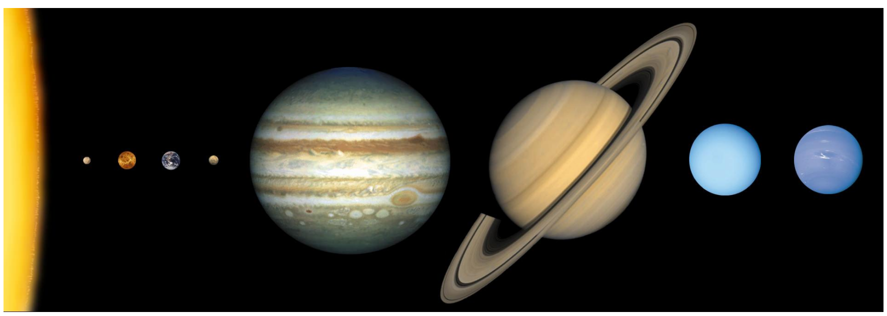
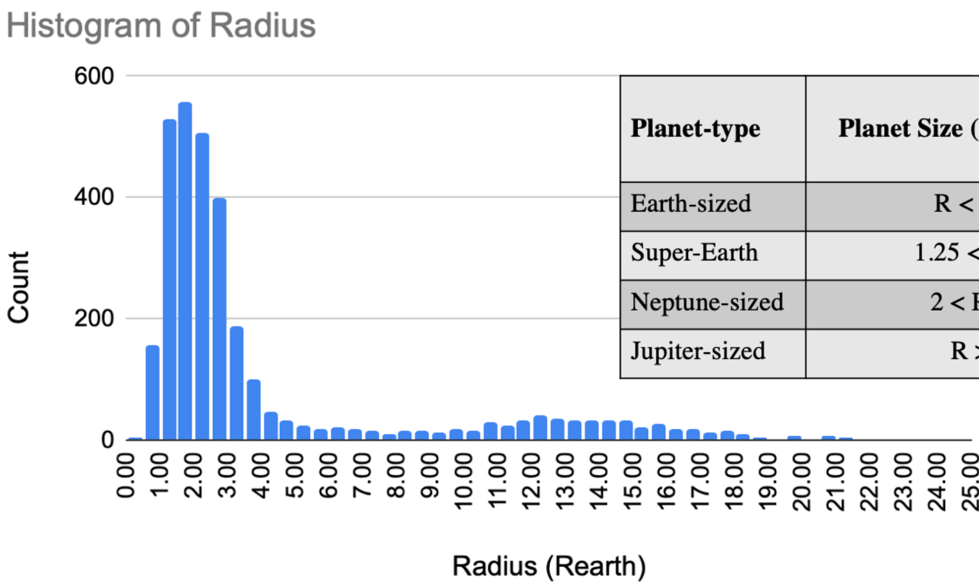


Figure 1: The terrestrial and jovian planets of our Solar System.

Image credit: https://www.universetoday.com/36649/planets-in-order-of-size/

1. What kind of planets (terrestrial or jovian) are easiest to detect in other solar systems using the transit method, based just on their size? Explain your reasoning.

Figure 2: Histogram of the radii (R) of exoplanets discovered using the transit method. With the histogram is a table providing the total number of exoplanets for four categories: Earth-sized, Super-Earth, Neptune-sized, and Jupiter-sized.



Planet-type	Planet Size (Earth Radii)	Count
Earth-sized	R < 1.25	388
Super-Earth	1.25 < R < 2	859
Neptune-sized	2 < R < 6	1315
Jupiter-sized	R > 6	583

2. Based on the range of radius values used to define the different planet categories in Figure 2, fill in the blank columns of Table 1 below with the corresponding planet category name (Earth-sized (ES), Super-Earth (SE), Neptune-sized (NS), or Jupiter-sized (JS)).

Table 1: Radius values (relative to Earth) for the planets in our Solar System.

Planet	Radius (Earth = 1)	Planet Type		Radius (Earth = 1)	Planet Type
Mercury	0.383		Jupiter	11.21	
Venus	0.949		Saturn	9.45	
Earth	1		Uranus	4.01	
Mars	0.532		Neptune	3.88	

3. Which category(s) of exoplanet (ES, SE, NS, JS) are not found in our Solar System?

4. Which *three* types of exoplanets are most common in the data from Figure 2?

5. What kind of planets (terrestrial or jovian) are easiest to detect in other solar systems using the transit method, based just on their orbital period? Explain your reasoning.

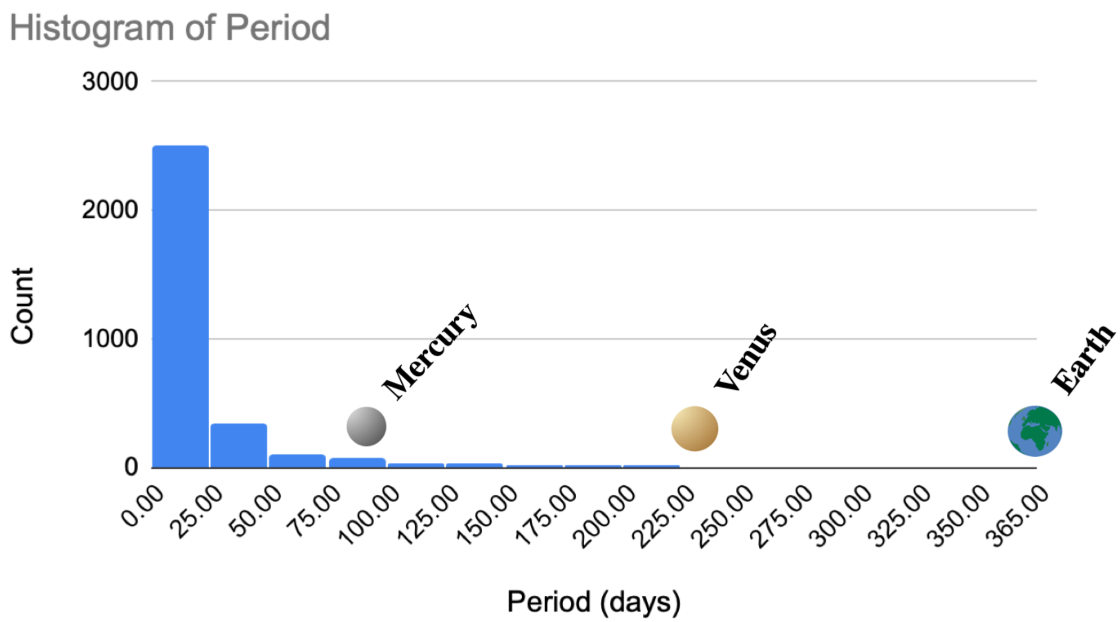
6. Two students are discussing their answers to Question 5.

Student 1: I think we are more likely to discover long period planets. We found out in Part I that the majority of planets discovered are larger than Earth, and in our Solar System the large planets are far from the Sun and would have long orbital periods.

Student 2: You're right that in our Solar System the larger planets are further from the Sun, but you are assuming that these other large planets we are discovering will be at the same locations as they would be in our Solar System. Overall I think exoplanets that move in front of their star more often will be easier to discover, so I think we are actually more likely to find exoplanets that are close to their stars regardless of size.

Do you agree or disagree with either or both of the students? Explain your reasoning.

Figure 3: Histogram of the orbital periods of exoplanets discovered using the transit method. The periods of Mercury, Venus, and Earth are marked on the histogram.

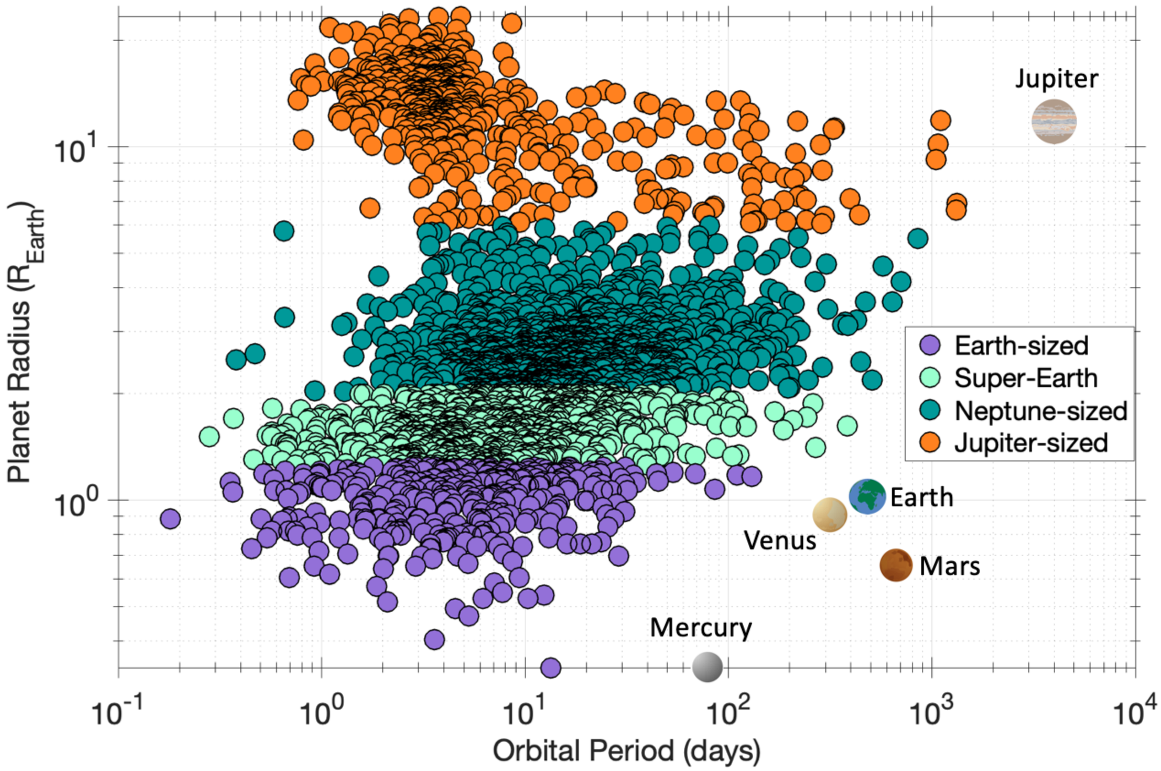


7. The majority of exoplanets have periods within what range? Does this make them close to, or far from the star they orbit?

8. Based on the orbital periods, where would the majority of newly discovered exoplanets be located if they were placed in our Solar System?

9. Describe the overall trends for planet size and distance from their stars for exoplanets discovered using the transit method.

Figure 4: Graph of planet radius (R_{Earth}) versus orbital period (days) for the four categories of exoplanets.



10. Is the data in the graph of Figure 4 consistent with your answer to Question 9? Explain your reasoning.

11. Do the distances from the Sun and sizes of the planets in our Solar System provide a good representation for the overall characteristics of the exoplanets we discover using the transit method? Explain your reasoning.

12. Three students are debating their answers to Question 11.

Student 1: Based on the histograms and the graph in Figure 4, it's clear that the transit method is better at finding larger planets that are close to their stars, so it's no wonder we have a data set that looks very different from the locations and sizes of planets in our Solar System.

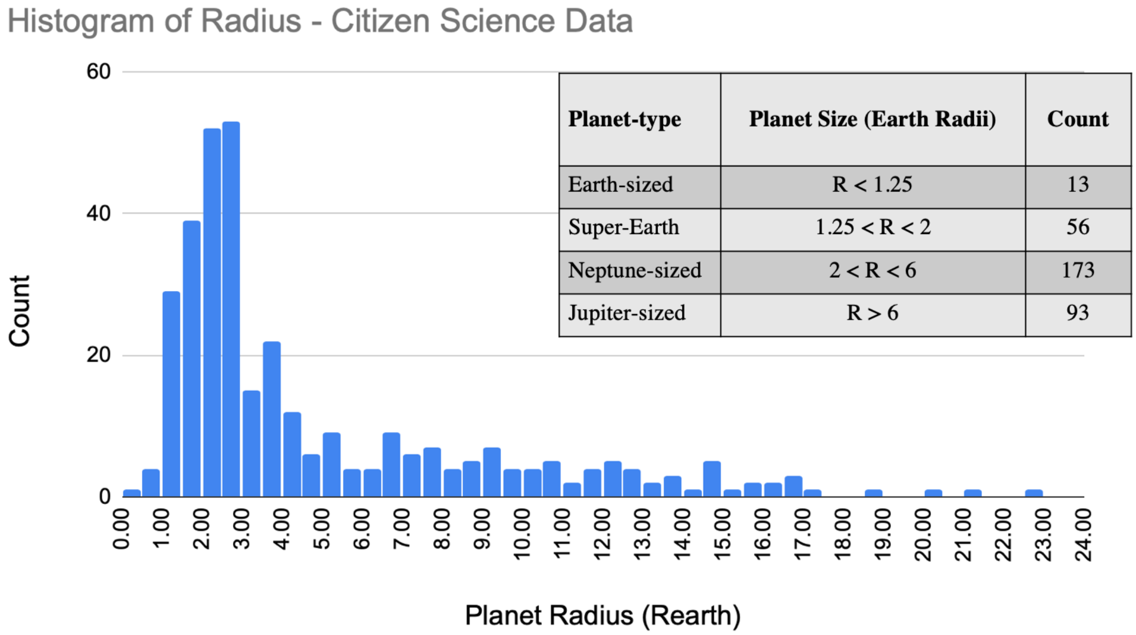
Student 2: Maybe all we need to do is search for a longer time, and we will start to find more large planets far away on long period orbits. This will show us that Jupiter-sized planets far away are more common than the current data set suggests.

Student 3: Whether our Solar System is typical or not, this data has shown us that there is a new category of exoplanet that we don't see in our Solar System, and that all types of planets can be found closer to their stars than what we previously thought.

Do you agree or disagree with any/all of these students? Explain your reasoning.

Citizen scientists have been identifying dips in transit light-curves on projects like Planet Hunters and Exoplanet Explorers. Although identifying a planetary transit is a relatively rare occurrence, the data below is for transits first identified by citizen scientists. If a transit is identified by a citizen scientist, the research team can perform a series of tests to determine if the transit is, in fact, caused by an exoplanet.

Figure 5: Histogram of the radii (R) of exoplanets where the transits were first identified by citizen scientists. Within the histogram is a table providing the total number of exoplanets for four categories, Earth-sized, Super-Earth, Neptune-sized, and Jupiter-sized.



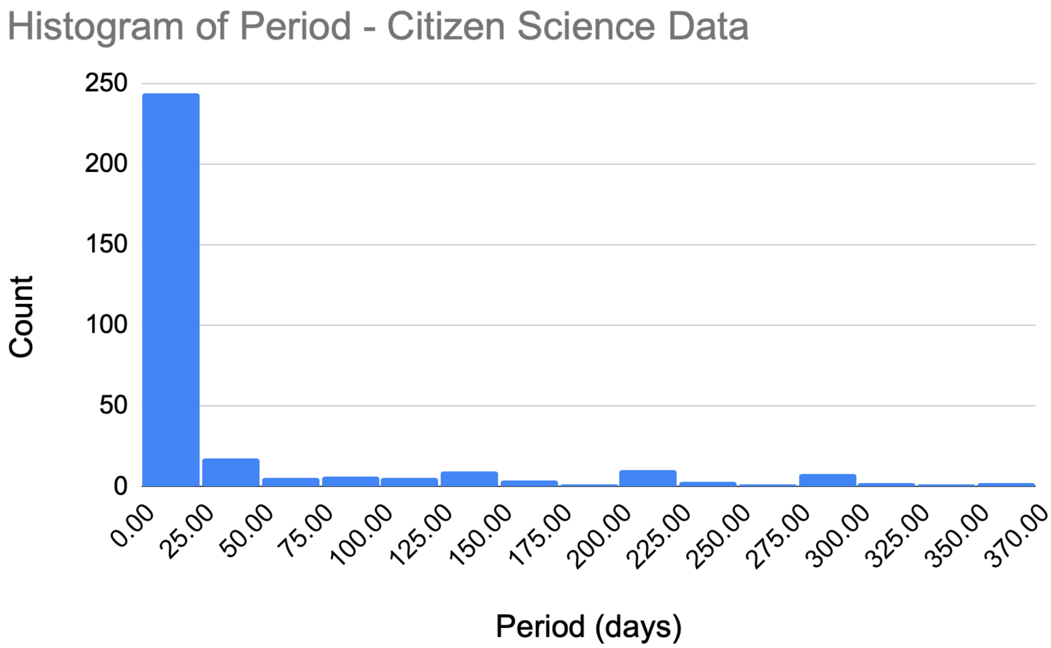
Planet-type	**Planet Size (Earth Radii)**	**Count**
Earth-sized	R < 1.25	13
Super-Earth	1.25 < R < 2	56
Neptune-sized	2 < R < 6	173
Jupiter-sized	R > 6	93

13. Do we observe the same four categories of planets in the citizen science data?

14. Which planet-type do we *not* observe in our Solar System?

15. Which *three* types of exoplanets are most common in the citizen science data? Is this consistent with the results from the full transit dataset from Figure 2?

Figure 6: Histogram of the orbital periods of extrasolar planets where the transits were first identified by citizen scientists.



16. Based on the orbital periods, where would the majority of the exoplanets from the citizen science dataset be located if they were placed in our Solar System? Is this consistent with the results from the full transit dataset?

17. Describe the overall trends for planet size and distance from their stars for exoplanets for the citizen science dataset.

From analyzing the full transit dataset, you were able to identify that:

1. A new type of planet exists
2. Super-Earths, Neptune-sized, and Jupiter-sized planets may be more common, as they make up greater percentage of the data
3. The majority of all planets in the dataset are found closer to their host star than Mercury is to our Sun
4. Our Solar System would not be considered "typical" when compared to this dataset

18. Does an analysis of the citizen-science data set lead to the same 4 outcomes? Explain your reasoning.

19. Does your answer to the previous question support the assertion that citizen scientists are making valuable contributions to the discovery of exoplanets?