ExoExplorations Activity: Detecting a Planet Transit

For assistance and to give feedback contact: Calvin Schmidt schools@centreoftheuniverse.org, Friends of the Dominion Astrophysical Observatory.

This material was developed with the assistance of a Natural Science and Engineering Research Council PromoScience grant. It is a part of a larger project to present grade-appropriate material that matches 2020 curriculum requirements to help students understand planets, with a focus on exoplanets. This material is aimed at BC Grade 6 students.

Learning Objective

This activity is designed to show students one way that exoplanets are discovered and uses common household items.

Learning Outcomes

Students will learn:

- That planets outside our solar system (exoplanets) are usually too far away to see directly; their existence is often inferred through the "transit" method
- How planets are detected using the "transit method"

Materials and tools needed

- Flashlight (we used the light in a smartphone - if you use a flashlight use one with a single bulb)
- Lamp with a 40 watt (or less) lightbulb
- Cardboard paper towel tube (a toilet paper tube or any small box with opening on opposite ends)
- Tissue paper / kleenex is preferred, or you can use thin white paper (lined paper is ok)
- Scissors (if you use paper)
- Coins of different sizes (we used a toonie and a dime)
- Scotch Tape (or other type of clear tape)
- Something to hold things up (we used books)
- A stable surface like a table or dresser to set everything up on

Time required

This takes about half an hour, not including the time to find the materials.

Contents

The activities are marked in **orange.**

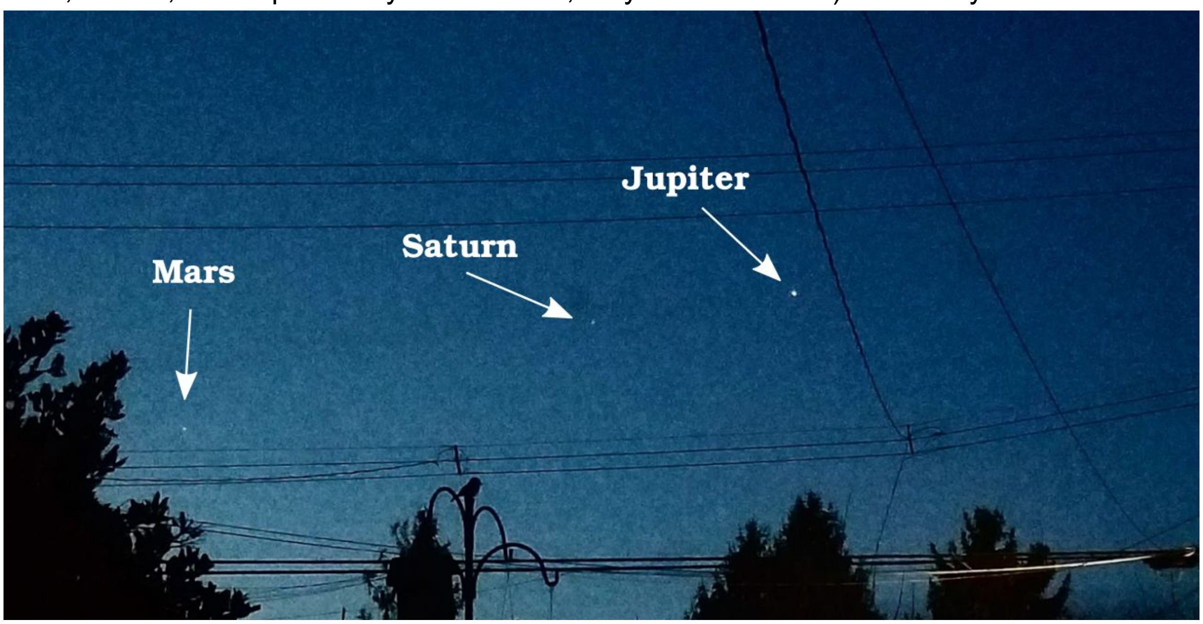
Distant Planets Are Hard to Find

We can see most planets in our own solar system by looking in the sky. Some of them we can see with our own eyes, but for others we need a telescope.

Other planets we can see with our eyes:

- Mercury
- Venus
- Mars
- Jupiter
- Saturn

Figure 1: Here are three planets in a row seen from Victoria, BC in April 2020 (Left to Right: Mars, Saturn, and Jupiter: they are so small, they look like stars.) - Photo by Don Moffatt

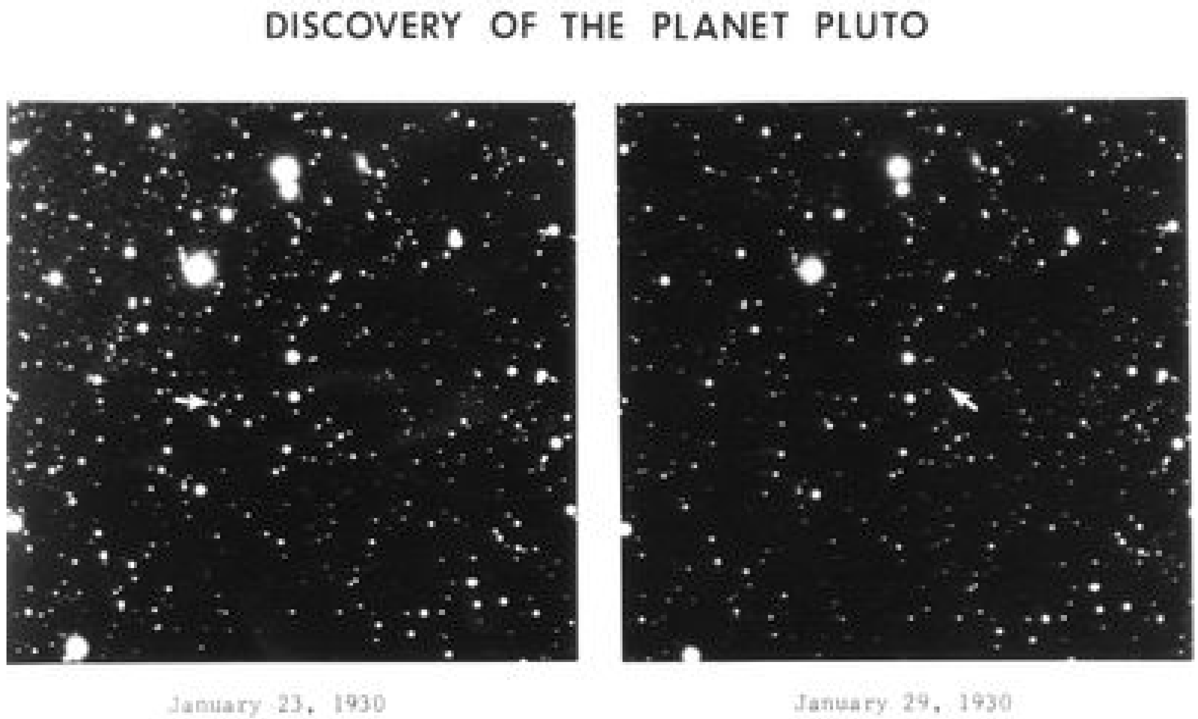


We need a telescope to see the other planets in our solar system:

- Uranus
- Neptune
- Dwarf planets like Pluto

Figure 2: Here are the discovery photos of Pluto (courtesy Lowell Observatory Archive).

Pluto looks just like a star. Look for the arrow! You can barely see the dot!



The Sun's light hits a planet and some reflects back so we can see it. The further the planet is from us and the Sun, the harder it is to see partly because there is less sunlight reaching it. If it is far away from us, less light will make it back to us, too.

We're not the only solar system

Our solar system is not the only one! At the time of writing, April 2020, we know of 3,149 solar systems containing a total of 4,260 planets. There are 695 of these solar systems that have more than one planet. Here is a link that you can use to look up the discoveries. https://en.wikipedia.org/wiki/Exoplanet#Confirmed_discoveries

How far from us?

Stars other than the Sun are really far away. So far, in fact, that they appear as a point of light. If you were to make a scale of our solar system where the Sun was the size of a golf ball, the Earth would be the size of the period at the end of this sentence about 4 meters away. The next closest star would be another golf ball about 1200 km away! That's like the distance between Victoria and Saskatoon. It is incredible that we can see the stars at all because they are so far away. But up close, each of these distant suns is warm and bright like our own Sun.

If these remote suns are so far away that they look as dim as stars, the planets orbiting them will be much, much dimmer, and will appear very close to them. It is like trying to see a mosquito next to a streetlight from thousands of kilometers away.These exoplanets are so dim and appear so close to their star that we can only see a few of the ones nearest to us by using giant telescopes to gather lots of light and magnify the image. These telescopes have special cameras, like the Gemini Planet Imager camera on the Gemini Telescope. Canada helped build both the Gemini telescope and camera. Even so, most solar systems are so far away that we can't see the planet directly even with such a good camera.

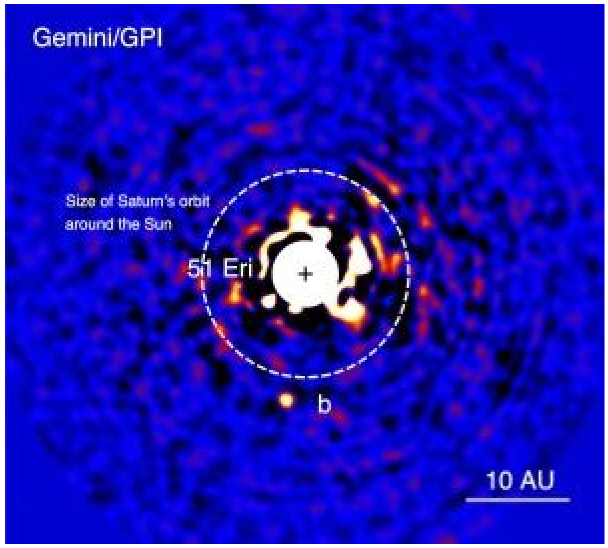
Figure 3: Gemini telescope with visitors (courtesy Gemini.edu)

Figure 4: the Gemini Planet Imager (courtesy Gemini.edu)

Here is the camera being moved to the telescope.

Figure 5: A nearby star and exoplanet taken with the Gemini Planet Imager (courtesy Gemini.edu)

This is a star called 51 Eridani in the middle. Most of its light has been blocked so that we can see the exoplanet. The dot marked “b” is the exoplanet orbiting it. The dotted line shows how big Saturn’s orbit would be in comparison.



Solar Eclipses and Planetary Transits

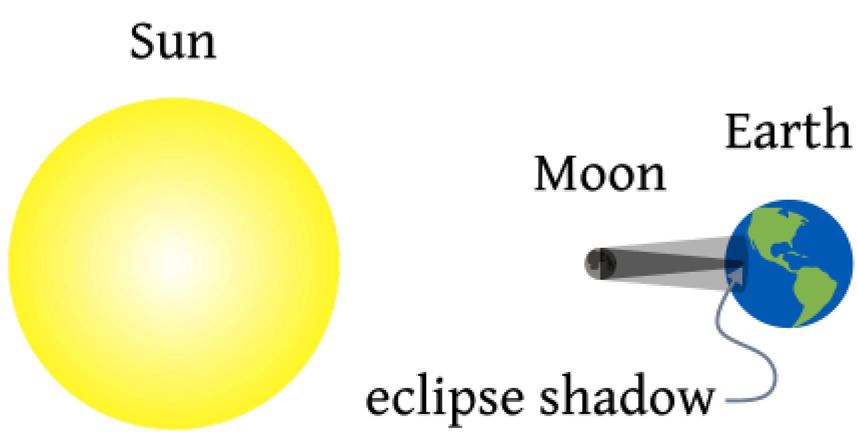
So how DO we find these exoplanets around other far away stars? There are, in fact, a few ways we can do this and this activity shows you how you can use one of these special methods. It is called the Transit Method. It has nothing to do with buses (astronomy joke). To explain this, let's go back to our own solar system, first, and look at a solar eclipse.

Solar eclipses

The Moon, while orbiting the Earth, sometimes moves directly in front of the Sun. This will block the light from the Sun, casting a shadow onto the Earth. If you are under that shadow it will be very dark, at least until the Moon moves away from the Sun again. It just so happens that the Moon appears to be as big as the Sun, covering up most of the light. We know that the Moon is much smaller than the Sun, but because it is also closer to us, they happen to appear to be the same size. This is a coincidence, really. If the Moon were a little smaller, or a little further away from us, it would not completely cover the Sun. While an eclipse may look like Figure 6 to us on Earth, the Moon is casting a shadow onto the Earth, so from space it may look like the diagram in Figure 7.

Figure 6: The Moon partly blocking the Sun (left), and totally blocking the Sun (right). (courtesy nasa.gov)

Figure 7: Solar eclipse diagram: the moon gets in the way



Activity: Let's create our own eclipse

We can demonstrate an eclipse at home.

First, it is important to remember the simple idea that things look bigger when closer. Pick up one of your coins and compare it to objects in the background. If you hold it close to your eyes, the coin will look larger, and if you hold it further away, it will look smaller. It's the same with things in the sky.

Let's create an eclipse:

- Pick up the largest coin you have and stand across the room from a lit light bulb (not so bright that it hurts your eyes - 40 watts or less is ok). **Do not do this with the actual Sun as you will instantly blind yourself!**
- To see the eclipse effect, keep one eye closed. We are going to pretend that your open eye is you standing on the Earth, the coin is the Moon, and the light bulb is the Sun. Slowly move the coin in front of the light bulb. If the coin partly covers the bulb, that is like a partial solar eclipse, just like the NASA picture above.
- If it completely covers the bulb, that is like a total solar eclipse.
- Experiment with how far you have to hold the coin away from your face to make a total solar eclipse with the light bulb.

Activity: And now for Planetary Transits

We can show how planets move across the Sun, which will be important later when thinking about finding exoplanets. When Mercury or Venus moves across the Sun, it is called a transit. It does not, however, create a total eclipse because Mercury and Venus are too small and too far away. The disk of the Sun is much wider than the planet, so the planet looks like a black dot on the Sun. Notice how tiny Mercury looks in Figure 8; it is just a speck in front of the Sun!

Figure 8: Transit of Mercury (courtesy nasa.gov)

Find a coin that is smaller than the one you used as the Moon (for example, a nickel or dime). You can make it appear even smaller by moving it further away from your eye, too. How small do you think the coin would have to be to look like Mercury in this photo if you held it at arm's length?

Move the coin from one side of the light bulb to the other, parallel to the floor. This is a complete transit. **Remember, never try this with the actual Sun as you will instantly blind yourself**: astronomers use special, expensive filters to make photos like this.

Exoplanet Transits

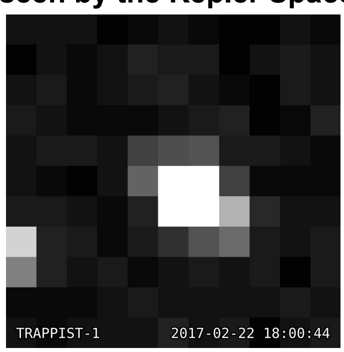
As we said earlier, the problem with stars other than the Sun, is that they are so far away, that they only appear as a point of light, and any planets that might be orbiting them will be way too small and way too dim to be able to see.

We can't see transits

When we look at a star in the sky, we only see a point of light. This is different from the Sun, where we can see it as a circle. We can't look for a dark spot moving across the face of the star like we did with Mercury and the Sun.

Even a telescope only sees it as a tiny splotch: the star lights up the pixel but is actually even smaller. Figure 9 shows what a telescope sees zoomed in when it looks at a star such as Trappist 1, which is 39 light-years away (390 million times a million kilometers!).

Figure 9: The star Trappist 1 as seen by the Kepler Space Telescope (courtesy nasa.gov)



If we only get to see one point of light, how can we tell there is a planet going in front of it? Let's investigate!

Activity: Making an exoplanet detector

While we can't see the planet go in front of the distant star like we can with Mercury or Venus, we can see how it makes the star look dimmer from Earth.

To do this, we're going to project our planetary transits through a paper towel tube with paper at both ends. The paper is going to spread out the light so that we can't see any shadows being cast, but we will be able to see how bright the light is. Astronomers use the same basic techniques to measure the change in the light coming from the star with sophisticated light detectors.

Assemble the pieces of the exoplanet detector

- Find a room that can be darkened by turning off the lights and closing the curtains or blinds. If the room can only be made a little darker than normal then make sure you use tissue paper in this experiment.
- Get a paper towel or toilet paper tube. A small box with two open ends may work as well.
- Cut two pieces of paper, a couple centimeters larger than the opening (if it is tissue paper you might be able to tear a piece the right size). The size of each paper needs to be bigger than the tube opening, but overall shape isn't too important.
- Cover each end of the tube with the pieces of paper. Tape them down on the sides to hold them in place.
- Put tape on both sides of the toonie and the dime as shown in the photo so that each is held securely (put the sticky sides together). Make each strip about 10 or 12 cm long. You should be able to dangle each coin while holding the tape. Rounding off the corners with scissors is optional

Figure 10: Materials and tool used in making the exoplanet detector

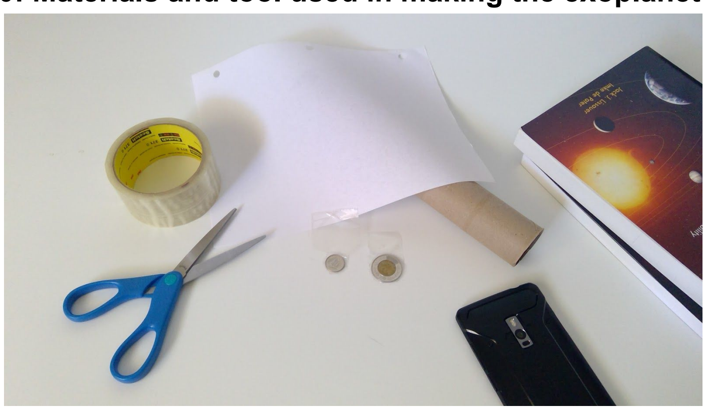


Figure 11: Cut two squares and tape one to each opening in the tube

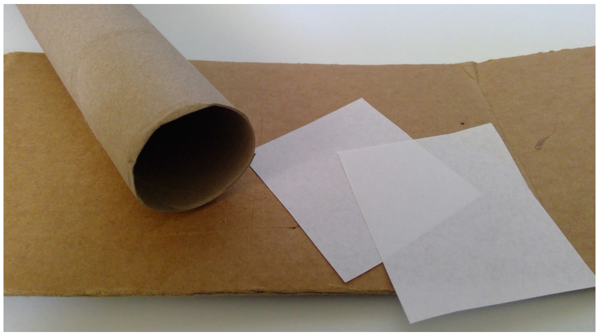


Figure 12: A toonie and a dime each with handle made of clear tape

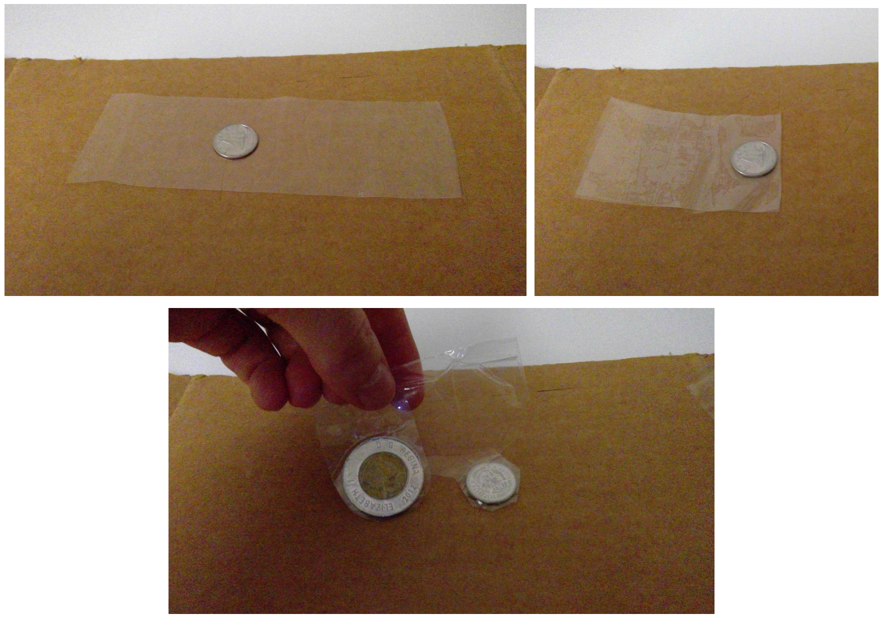


Figure 13: The entire setup, using books to make sure everything is lined up

Figure 14: The flashlight shines into one side, and the observer looks at the other

Now shine the phone light at one end of the tube. Make sure it is lighting up the whole paper. Set up the light about 10cm away, though this may depend on how bright the light is. You may need something to hold the light up, while you hold the tube.You will need one hand free. The other end of the tube will glow from the light going through it.

Activity: Simulating an exoplanet transit using the detector

- Now block the flashlight with your hand so that none of the light hits the paper covering the hole. As you'll see, the paper that you look at goes dark. That would be like totally eclipsing the star so that none of it reaches your eye.
- Now we're going to pretend that a large planet is moving in front of the star. Get your biggest coin and dangle it from the tape in front of the beam between the flashlight and the piece of paper over the hole. We can see that in Figure 16.
- As you move the coin in and out of the beam, you should notice the light reaching the Earth (you) getting dimmer when the coin blocks some of the light, and brighter again when it moves out of the beam. But you can't see the transit itself. Looking for a dimming in the light reaching us is how astronomers detect exoplanets: they measure how much the light dims.
- Of course, in real life we'd see the star as a point that changes its brightness, but the message here is that light dims and that we can't see the transit directly like we can with Mercury or Venus..

Figure 15: Put the object between the paper and the light, then look at the end of the box

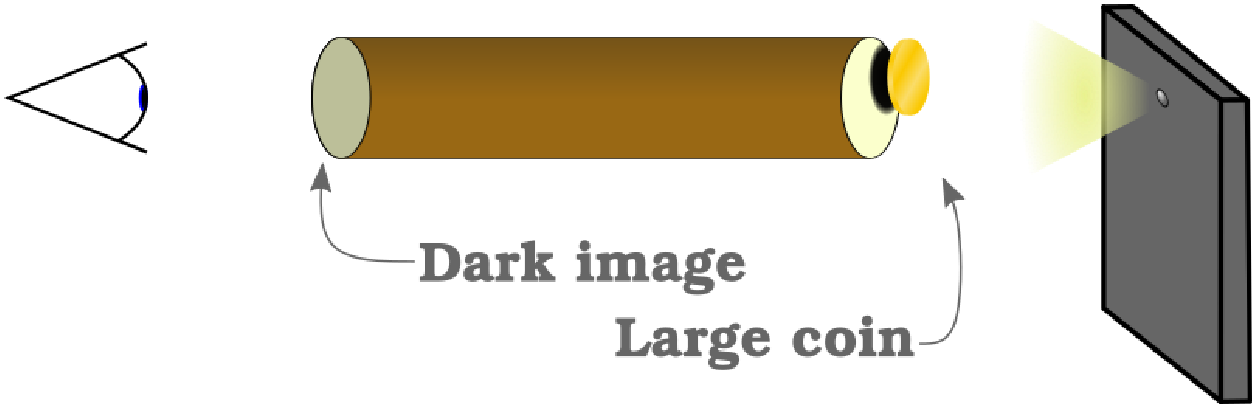


Figure 16: It is best to have the coin very close to the paper, to make sure the shadow is smaller than the hole.

What do you think will happen if the planet is smaller? If you use a dime, and hold it where you held the bigger coin, you should notice the light reaching the "Earth" will be dimmed less. How much smaller than a dime do you think a coin could be and still see the light dim? Is there a limit to how small a planet astronomers can detect this way? What other factors might influence the dimming of the light? For instance, does it make a difference how dark the room is?

Figure 17: Diagram showing that a planet transit from a smaller coin will only slightly darken the view

What if aliens tried to detect Jupiter or Earth this way?

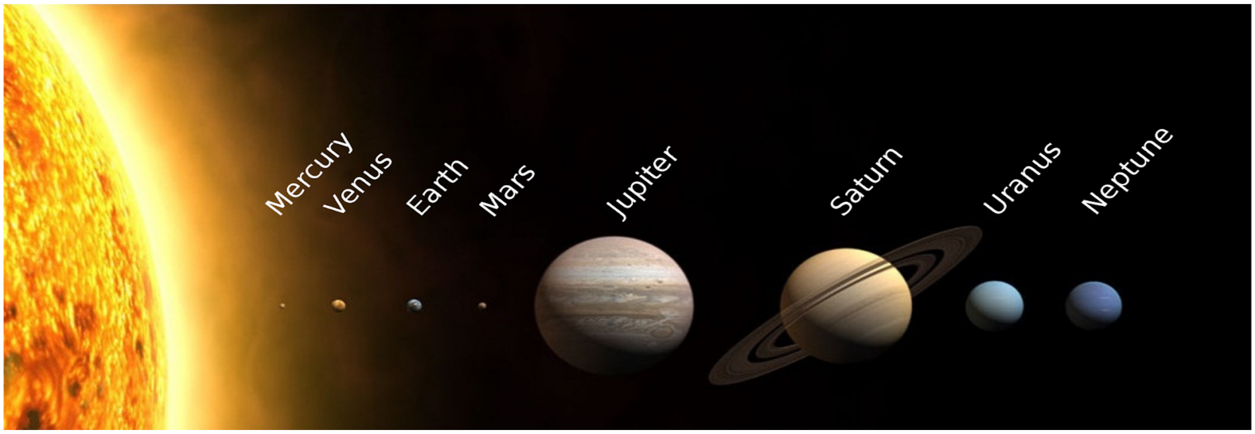
The easiest objects to detect will be the biggest planets around a star. So how big are the biggest planets compared to the star that they orbit?

Jupiter, the largest planet in our solar system, is ten percent (1/10) the size of the Sun. You can see a size comparison of the planets in our solar system with the Sun in Figure 18. If we were really far away, and trying to detect a transit of Jupiter, it would only cover up 1 percent (1/100) of the Sun's surface, so we would need to be able to see the light from the Sun dim by 1%. Your eyes can't detect such a small change! Astronomers use telescopes equipped with cameras that are accurate enough to do the job. Alien astronomers with space telescopes like ours would find it easy to detect Jupiter transiting the Sun.

But then consider trying to detect something smaller, like an Earth-sized planet, which is one one hundredth the size of the Sun. The light would dim by only 1 in ten thousand, 1/100th of 1 percent. If aliens had space telescopes like ours they would just barely be able to detect the Earth.

Bonus activity: How small an object (try using buttons) can you use in the experiment and still notice the drop in light? Does it make a difference how bright the room is?

Figure 18: Size comparison of Earth, Jupiter, and the Sun.



Conclusion

We hope that by doing these experiments you were able to model how exoplanet transits work. By using common objects around your home you should have been able to see that larger objects such as a toonie caused greater dimming of the light than smaller objects. Similarly with exoplanet hunting bigger exoplanets are usually easier to detect as they cause more dimming while small exoplanets cause less dimming and are harder to find.

But just as you may have had a hard time seeing some of the differences in the dimming of the light so do the astronomers. If our eyes can't detect small changes in the dimming and brightening then how is it possible? Astronomers use detectors attached to their telescopes that are more accurate than our eyes.

The best telescopes for doing this are in space orbiting the Earth, where our atmosphere does not change the amount of light reaching the telescope. The data is transmitted to Earth then astronomers measure the changes from the detectors using computer programs. Most exoplanets have been found by a space telescope called Kepler, named for a famous astronomer who lived 400 years ago. Unfortunately, this telescope no longer works but there is a new one that uses the same method called TESS that is up in space right now looking for exoplanets using the transit method just like you did in your experiments.

Self-Quiz

(look for the answers by re-reading the lesson, above, if you aren't sure)

- Why can't we see planets moving across a star like we can with Mercury or Venus moving across the disk of our Sun?
- How does an astronomer know there is a planet there if they can't see it directly?
- How many planets do we know of besides the planets in our own solar system?
- How many solar systems have been discovered so far?

- How much of the Sun's light would Earth block for an alien astronomer studying our solar system if it was transiting the Sun?

Resources

If you would like to find out more about transits and how exoplanets are found then here are some resources you can use.

- Kepler Space Telescope Mission: https://www.nasa.gov/mission_pages/kepler/overview/index.html
- Transiting Exoplanet Survey Telescope Mission: https://tess.mit.edu/
- Astro At Home, Emily Deibert on exoplanets: https://www.youtube.com/watch?v=sg0A8OYnrH0&list=PLbQI77YYeSpaSEvenhlI1IZ60fIdyMSKq&index=21&t=0s
- A graduate student at the University of British Columbia discovered 17 new exoplanets:
    - https://www.macleans.ca/society/science/this-young-canadian-scientist-has-found-21-new-planets-and-counting/
    - https://research2reality.com/space-quantum/astronomy-and-physics/shes-discovered-more-planets-than-you-have/
    - An older story about her work: https://you.ubc.ca/ubc_stories/michelle-kunimoto-planet-discovery/
- Podcasts by Elizabeth Tasker on Hunt for Habitable Planets:
    - https://spaceq.ca/the-excitement-and-mysteries-as-we-hunt-for-habitable-worlds/
- The different types of exoplanets:
    - https://www.planetary.org/explore/space-topics/exoplanets/notable-exoplanets.html
- Teenager finds new exoplanet with TESS:
    - https://www.cbc.ca/kidsnews/post/u.s-teen-discovers-new-planet-canadian-astronaut-reacts
- Paper model of TESS you can build yourself:
    - https://github.com/tessgi/tess-3d-printing-model/blob/master/paper-model-files/TESS-model-v2.pdf

Acknowledgments: This material was developed by Calvin, Don, Lauri, and Rami. Thank you to Nathan, Drea, Katherine, and others who tested the material.