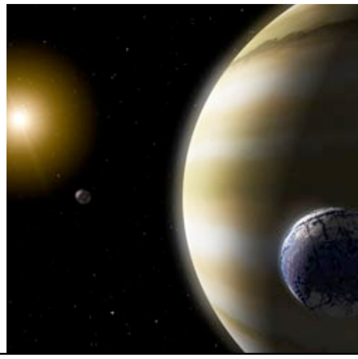


Artist Conception Courtesy
NASA/JPL-Caltech

Artist's conception of an extrasolar gas giant. planet

In this Exploration, find out:

- How and when were the outermost planets in our own solar system discovered?
- What are the problems in hunting for other (extrasolar) planets?
- How can astronomers find a planet without really “seeing it”?

Planet Hunting 1: Finding Planets Teacher Guide

In Part One of this two-part exercise, students will learn about the historical discoveries of the outer three planets in our solar system, some of the challenges involved in ongoing efforts to find planets around other stars, and the ways astronomers currently search for planets. In Part Two, the students will learn about the planetary systems astronomers have found around other stars, make scale models of some of these systems, and compare them to our solar system. Students will also learn about exciting new technologies that may help astronomers find Earth-like planets in the future. This activity builds upon the other activities in the *Stars and Planets* program, especially the Scale Model Solar System, Sizes of Stars, and Stellar Distances activities, and is intended to be the final activity in the sequence. Like the other lessons in the program, Planet Hunting is a math activity as well as a science activity.

Recommend Prerequisites: Scale Model Solar System, Sizes of Stars, Stellar Distances, and Lifetimes of Stars

Grade Level: 6-8

Curriculum Standards: The Planet Hunting Part One lesson is matched to:

- National Science and Math Education Content Standards for grades 5-8.
- National Math Standards 5-8
- Texas Essential Knowledge and Skills (grades 6 and 8)
- Content Standards for California Public Schools (grade 8)

Time Frame: The activity should take approximately 45 minutes to 1 hour to complete, including a short introduction, discussion, demonstrations, and follow-up. The student readings will take additional time and may be assigned as homework.

Purpose: To bring together the concepts presented in the previous *Stars and Planets* lessons in an investigation of the challenges astronomers face in the ongoing search for extrasolar planets. Students will also be introduced to the Astronomical Unit (AU).

Key concepts:

- Some planets in our own solar system cannot be seen with out a good telescope, and were only discovered in the past few centuries.
- Planets shine by reflecting light from their parent star.
- Stars are much brighter than planets.
- Planets can be detected without being "seen".

Supplies for Planet Hunting Part 1:

- A copy of the student handout for part 1 for each student
- A blue candy sprinkle taped to a black card or piece of construction paper
- A white candy sprinkle taped to a black card or piece of construction paper
- A candy sprinkle taped to the end of a toothpick
- A lamp without a shade
- A clear (unfrosted) light bulb – 100 W recommended
- One grapefruit or 14 cm yellow ball (for the Sun)*
- A map of the United States, map of the world, or globe
- A calculator for each student or small group of students*
- A single-pitch noise maker on a string (optional)
- Hula hoop to demonstrate planetary orbits (optional)

*Optional, but highly recommended. Objects should be the same or similar to those used in the Scale Model Solar System and Sizes of Stars activities.

Note: The use of *italics* indicates information or instructions from the student version

Introduction:

Begin the activity by asking the students some questions about their own observations of planets in our solar system.

- Have any of the students seen planets in the sky, and if so, which ones?
- Have any of the students seen a planet in a telescope? If so, which one(s)?
- Do any of the planets appear to be as bright as stars?

If the students will complete the student reading as homework before doing the lesson in class, try to introduce the lesson in a brief discussion before the end of the class in which you make the assignment. Whether or not you assign the student sheet as homework, discuss the information and questions in the student sheet with the class the day of the activity.

The Discovery of Planets in Our Own Solar System:

Civilizations across the globe have known of Mercury, Venus, Mars, Jupiter, and Saturn since ancient times. The two outermost planets, and the dwarf planets, were all discovered in the past few centuries, and with the aid of telescopes. Before Uranus was discovered, astronomers didn't expect to find any planets other than the five visible with the unaided eye and the Earth. Why are Uranus and Neptune harder to see from the Earth than the other five planets? Why wasn't dwarf planet Pluto discovered until the 20th century?

Comparing the sizes and distances of the planets will help you answer these questions. The diameters and average distances from the Sun for the planets in our solar system are given in Table 1. An easy way to compare average distances between the planets is to look at them in terms of the Earth-Sun distance, which is called an ***Astronomical Unit****. The symbol for an Astronomical Unit is* ***AU****.*

Discovery of Uranus

Uranus was discovered in 1781 by musician and amateur astronomer William Herschel. Uranus was the first planet not known about by ancient people all over the world.

While observing the constellation of Gemini with a homemade telescope, Herschel discovered a unique object that didn't act like a star or a comet. After carefully recording his observations over several years, Hershel was able to show that he had found a new planet!

Uranus was named after the Greek god of the sky.

For Tables 1 and 2 complete the last columns with distances in AU using the given distance from the Sun in kilometers for each planet or dwarf planet.

Table 1: Planets in Our Solar System

Planet	***Date Discovered***	***Diameter***	***Distance from Sun***	***Distance from Sun in AU***
Mercury	*Ancient Times*	*4,878 km*	*58 million km*	0.39
Venus	*Ancient Times*	*12,104 km*	*108 million km*	0.72
Earth	-----	*12,756 km*	*150 million km*	*1.0*
Mars	*Ancient Times*	*6,794 km*	*228 million km*	1.5
Jupiter	*Ancient Times*	*142,796 km*	*778 million km*	5.2
Saturn	*Ancient Times*	*120,660 km*	*1,427 million km*	9.5
Uranus	*1781*	*51,118 km*	*2,871 million km*	19
Neptune	*1846*	*54,523 km*	*4,497 million km*	30

Table 2: Dwarf Planets in Our Solar System

Planet	Date Discovered	Diameter	Distance from Sun	Distance from Sun in AU
Ceres	1801	950 km	441 million km	2.9
Pluto	1930	2,300 km	5,913 million km	39
Eris	2003	2,400 km	10,150 million km	68

As is apparent from Table 1 and the Scale Model Solar System activity, Uranus and Neptune are far away from both the Sun and the Earth in comparison with the other planets. Even though the inner planets are all smaller than Uranus and Neptune, the fact that Mercury, Venus, and Mars are relatively close to both the Sun and the Earth makes them easy to see from our own planet. Table 2 shows that each of the dwarf planets is smaller than the eight planets, and Pluto and Eris are far from the Sun, making them doubly hard to find.

What about planets orbiting other stars?

*Planets orbiting other stars (**extrasolar planets**) are much harder to find than planets in our own solar system. The first such planet orbiting another normal main sequence star or giant star wasn't discovered until 1995!*

Review the Scale Factor:

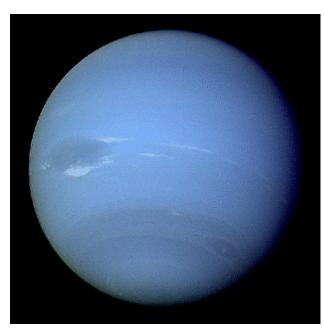
The scale factor for this scale model is 1:10 billion, and is the same as the size/distance scale used in most of the other Stars and Planets activities. If your students have done one or more of these activities, simply remind them that the scale factor is the same. Every centimeter in the model equals 10 billion real centimeters. Similarly, a kilometer in this scale model equals 10 billion kilometers.

The Discovery of Neptune and the Power of Math!

Astronomer's began the hunt for Neptune because Uranus' orbit, its path around the Sun, was not shaped as expected. Uranus seemed to have gravity from an unseen planet tugging on it.

Astronomers John Coach Adams and Urbain-Jean-Joseph Le Verrier both made their own mathematical predictions for where this unseen planet would be in the sky.

Neptune was found on September 23, 1846 by Johann Gottfried Galle and his assistant, Louis d'Arrest, based on the mathematical predictions!



(Image Credit: NASA/JPL-Caltech, Voyager)

Neptune is named for the Roman god of the Sea.

The Search for Planets Around Other Stars:
The Problem of Distance

- *What star is closest to the Sun, and at a real distance of 40,000 billion km?*

Alpha Centauri (or Proxima Centauri, the smallest and closest star in the Alpha Centauri system.)

- *How far away would it be on a model with a 1:10 billion scale? (Hint: think about the Stellar Distances activity.)*

On a model with a 1:10 billion scale the model Sun and model Alpha Centauri would be about 4,000 km (or 2,500 miles) apart. This is about the distance between San Francisco and New York, or the width of the continental United States.

If your students have not done the Stellar Distances activity, ask them how far away they think the nearest star to the Sun would be on a model with a scale factor of 1:10 billion.

- *How many AU away from the Sun is Alpha Centauri?*

The distance between the Sun and the Alpha Centauri System is 40,000 billion km, or 40,000,000 million km. Dividing 40,000,000 million km by 150 million km per AU gives a distance of about 270,000 AU.

- *What object can be used to represent the Earth on a model with a scale factor of 1:10 billion? (Hint: Think about the Scale Model Solar System activity.)*

In several of the activities in Stars and Planets, a candy sprinkle has been used to represent the Earth. If your students have not done any of these activities, have them use the diameter of the Earth from Table 1 to calculate a scaled size and then suggest objects that are close to the correct size.

Now, imagine standing on a scale model on a 1:10 billion scale that includes both the solar system and the Alpha Centauri star system.

- *If you were to stand at the model of Alpha Centauri and look back at the model Sun and planets, how hard would it be to see the Earth?*

The answer to this question is that seeing the model Earth would be extremely difficult, and may even seem impossible! A way to think put this problem in perspective is:

Trying to see the Earth from Alpha Centauri is like trying to see a candy sprinkle on a donut in New York when you are standing in San Francisco!

The vast distances between the stars, and the relatively insignificant sizes of planets, present a major problem in the search for extrasolar planets. However, size and distance are not the only difficulties astronomers face when they look for planets around other stars.

The Problem of Brightness:

Stars are incredibly bright. The brightness of stars is the only reason we can see any stars other than the Sun without the aid of telescopes. Our own star puts out as much light as four trillion trillion hundred-Watt light bulbs!

(In scientific notation, four trillion trillion is 4×10^{24})

Stars are much larger than planets, but their larger size pales in comparison with the distances between them. Even with the best telescopes, most stars are visible as nothing more than points of light. Two exceptions are the Sun, and the red supergiant Betelgeuse.

Unlike stars, planets are visible only because of the light they reflect from their star. Because stars are so bright, and planets are so dim, planets can easily be lost in the glare of their star.

Discovery of Pluto

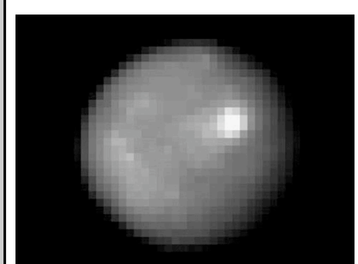
In 1915, American Percival Lowell predicted a ninth planet, based on the differences between calculated and observed orbits of Neptune and other planets. Although these calculations turned out to be wrong, without them Pluto might not have been discovered until much later!

Astronomer Clyde Tombaugh, at the Lowell Observatory in Flagstaff, Arizona, began an exhaustive search for "Planet X". In 1930, 84 years after Neptune's discovery, Tombaugh discovered Pluto.

Pluto was named in a contest for school children across the country.

Due to Pluto's size and orbit in a part of the solar system known as the Kuiper Belt, it is now considered a dwarf planet.

Did you know? *Ceres, the largest object in the asteroid belt, was briefly classified as a planet after its discovery in 1801.*



(Image credit: NASA/HST, ESA, J. Parker (SwRI) et al.)

Demonstration:

Here is where you will use the lamp and the black cards with the blue and white candy sprinkles. If the students have already done the Scale Model Solar System activity or Sizes of Stars, show them the grapefruit or 14 cm yellow ball that represents the Sun. Tell them that for the purposes of this demonstration, the light bulb will represent the model Sun instead of the grapefruit/ball, and that once again the blue candy sprinkle will represent the Earth.

1. Prepare your classroom to be as dark as possible with the lights off.
2. Set up the lamp in one corner of the room, and turn it on, and turn off the room lights.
3. Ask a student to hold the card with the blue candy sprinkle up so that it can reflect the light of the bulb and the other students will be able to see it. It is unlikely that you will be able to put the candy sprinkle and the lamp 15 meters apart (which represents the Earth-Sun distance of a scale of 1:10 billion). Just put them as far apart as possible (preferably with the candy sprinkle in the darkest part of the classroom).
4. If your students have done the Scale Model Solar System activity, ask them if they how far apart the model Sun and model Earth should be if the scale factor is 1:10 billion. (The answer is 15 m.)
5. Next, talk about how much easier it is to see the light bulb than the candy sprinkle.
6. Ask another student to hold the card with the white candy sprinkle next to the card with the blue candy sprinkle. The white candy sprinkle is easier to see than the blue one because it reflects more light, but it is still much harder to see than the light bulb.

When the light is on one side of the room, and the candy sprinkle is on the other side, the situation is more similar to searching for Uranus, Neptune, and the dwarf planets in our own solar system than it is searching for other stars. When astronomers look for planets around other stars, the planet and the star will be very close together in the sky. That is because the distances between the planets and their stars are much, much smaller than the distances between stars.

To roughly simulate this problem, bring the card with the white candy sprinkle as close to the light bulb as possible without blocking the light bulb.

Ask the students: How much harder is it to see the candy sprinkle?

Although the model planet reflects more light when it is closer to the light source, it will be lost in the glare from the unfrosted bulb much in the way a real planet is lost in the glare of its star.

Summarizing the Problem:

Actually seeing a planet around another star is an extremely hard problem. The size of even the largest planets is almost nothing compared with the vast distances between stars. Stars are very bright and planets are relatively dim. However, despite the difficulties involved, astronomers from all around the world have been willing to tackle the problem and have come up with some very clever ways to find extrasolar planets. Most of the techniques astronomers are using to hunt for new planets involve indirect evidence; they are looking for the tiny effects that a planet has on the star it orbits.

Finding a Planet without "Seeing" it:

Astronomers have come up with ways of finding extrasolar planets by using the light of the stars planets orbit instead of using the light reflected by the planets.

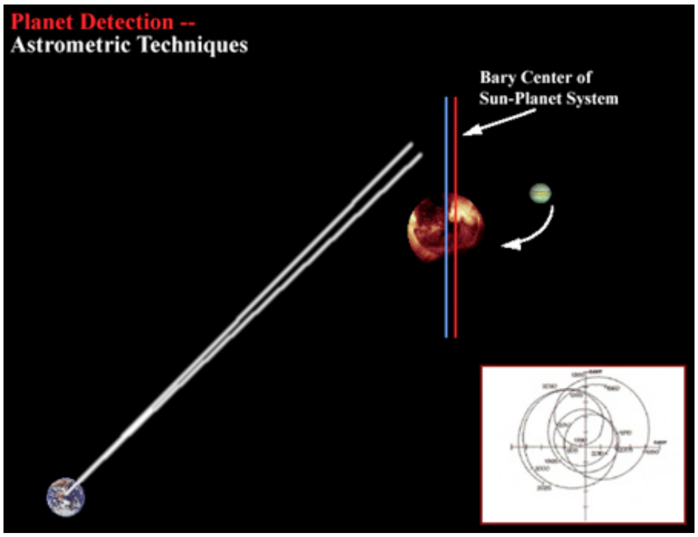
A Matter of Gravity:

*Planets have mass and therefore also have gravity that pulls on the matter around them, just as the Earth's gravity pulls on us. Stars, however, have much more mass than planets do. The ability of a planet's gravity to move a star is extremely small in comparison with the star's ability to move the planet. As a planet orbits its star, it causes the star to move with it or "wobble" by a very slight amount. Astronomers can detect the wobble of a star caused by a planet in two different ways. They can look at extremely small changes in the position of a star in the sky with very sensitive instruments in a technique called **Astrometry**.*

*Using another method, called a **Radial Velocity Search** or **Doppler Spectroscopy**, astronomers look for a slight shift in the color of the star. If a star is pulled away from us it will look redder, and if it is pulled toward us it will look more blue. This is called Doppler shift.*

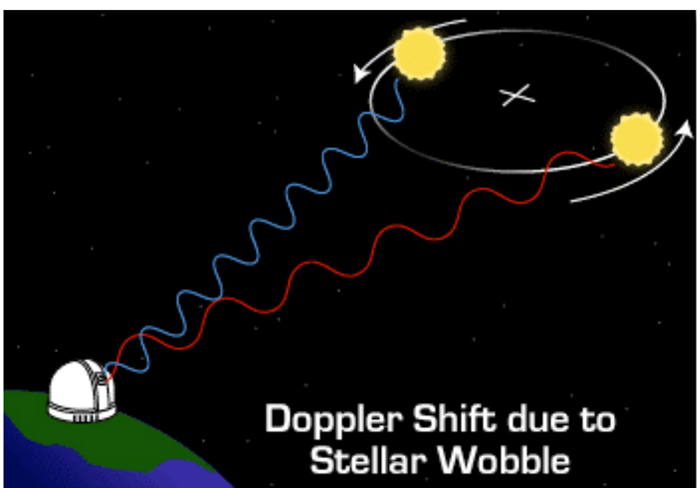
Methods of Detecting Extrasolar Planets

Astrometry



(Image Courtesy NASA/JPL-Caltech)

Radial Velocity Search



(Image Courtesy NASA/JPL-Caltech)

For more on planet hunting methods, including an interactive explanation, see http://planetquest.jpl.nasa.gov/science/finding_planets.cfm

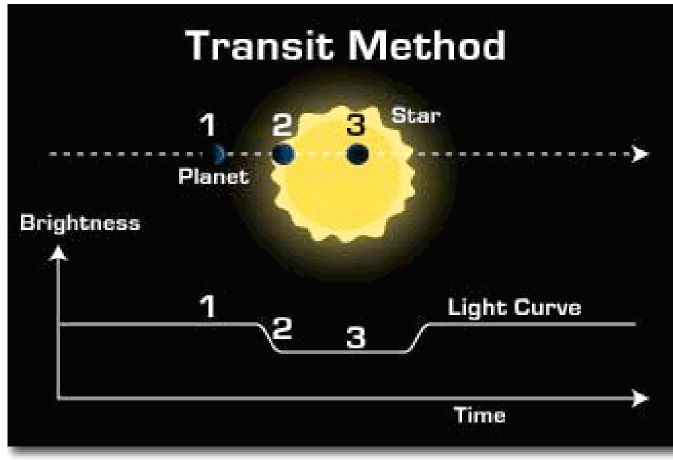
Optional Demonstration:

To model the Doppler shift caused by a planet pulling on a star using sound instead of light, attach a noisemaker to the end of a string and spin the noisemaker around. It doesn't matter what type of sound the noisemaker creates, as long as it is loud and makes a constant pitch. An inexpensive battery-powered buzzer is a good noisemaker, and can be put inside a tennis ball. When you spin the noisemaker so that it moves closer to your students and then farther away from them, they will hear the pitch rise and fall. The frequency of sound they hear is Doppler shifted, much like the light of a star wobbling from the pull of an unseen planet.

Blocking the Light:

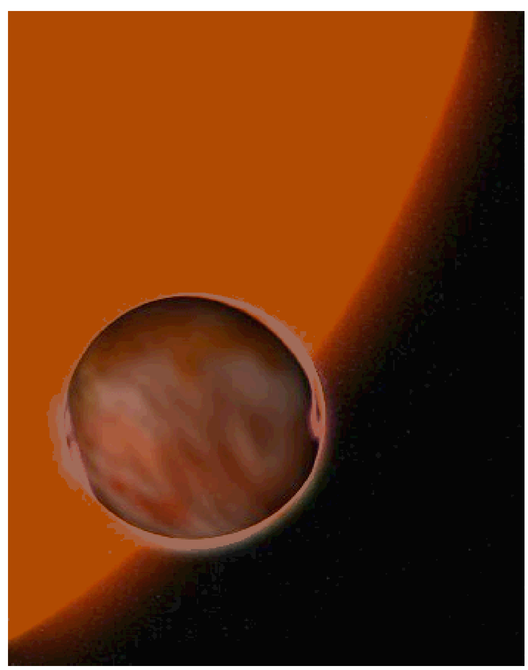
Sometimes astronomers may be fortunate enough to see a planet pass between the Earth and the star the other planet orbits. When our moon passes between the Earth and the Sun, and the Earth, Moon, and Sun are lined up just right, we see a solar eclipse. The Moon is able to block out most of the Sun's light because it is so close to us. Even though the Sun is much bigger than the Moon, the Moon is so close that it and the Sun appear to be about the same size in our sky. When Mercury or Venus passes directly between the Earth and the Sun, we call this event a ***transit*** *rather than an eclipse. This is*

Transit Method



(Image courtesy: NASA/JPL-Caltech)

Orbiting the sun-like star, X0-1, a planet has been discovered with the transit method by a team of amateur astronomers. Planet X0-1b has 0.9 times the mass of Jupiter and an orbit period of 4 days. During the transit it eclipses about 2% of the stars brightness. It is located in the constellation of Corona Borealis. It is located 600 light-years away from us.



(Artist Conception Courtesy: NASAESA/STScI) *because such a small percentage of the Sun's light is blocked out by Mercury or Venus. Transits by extrasolar planets also block out a small amount of their star's light. Astronomers can find planets using the* ***Transit Method*** *by carefully measuring the light we receive from a star.*

Demonstration:

Turn on the lamp and turn back on the lamp. Pass the candy sprinkle taped to the end of a toothpick in front of the light bulb to demonstrate the decrease in the light received from a star during a transit by a planet. The difference in the amount of light the students see should be unnoticeable.

Other Methods:

One method for finding planets that is not discussed in this lesson are the gravitational microlensing - the bending of light rays by a massive object, such as a star. If an unseen planet passes in front of a star acting as a gravitational lens to a background object, the stars rays may further be bent a bit more because of the added mass of the planet. Gravitational microlensing is a difficult concept for middle school children, and so has not been included in the student materials. More information on the technique is available: at JPL's PlanetQuest web site:
http://planetquest.jpl.nasa.gov/science/finding_planets.cfm.

Part 2:

In the second part of Planet Hunting students will be introduced to actual planets astronomers have found orbiting distant stars and NASA's future space-based missions designed to detect Earth-sized planets.

The masses of planets found so far are usually not well known. Most planets that had been found as of 2007 were detected using the radial velocity method. Both that method and astrometry depend on the star moving relative to our line of site.

A hula hoop can be used to demonstrate an orbital plane of a planet around a star. If the plane of the orbit is parallel to our line of sight (the hula hoop should be held parallel to the floor for this demonstration), then the planet will pull the star very slightly toward and away from us as it orbits. The mass we measure assumes the planet is in this optimum viewing geometry, and so gives us the minimum mass for the planet. This orbital orientation works best for Doppler spectroscopy.

If the planet's orbit around its star is perpendicular to our line of sight (the hula hoop held straight up and down facing the class, then the planet will not pull the star toward or away from us. This orientation does not work for Doppler spectroscopy, but is idea for astrometry.