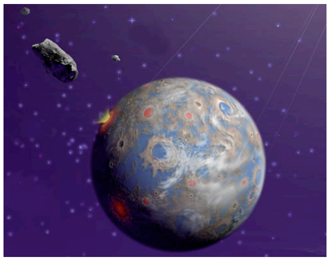
Earthlike Extrasolar Planet



(*Artist conception, Courtesy: NASA/JPL-Caltech Planetquest).*

In this Exploration, find out:

- *What planets have been found around other stars?*
- *How does our own solar system compare to the newly found planetary systems?*
- *What are the limitations of current and planned planet hunting efforts?*

Planet Hunting 2: New Discoveries Teacher Guide

In this lesson, Part 2 of Planet Hunting, students will be introduced to 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 designed to help astronomers find Earth-like planets in the future. The lesson 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 follow Planet Hunting Part 1.

Recommend Prerequisites: Planet Hunting Part 1, Scale Model Solar System, Sizes of Stars, Stellar Distances, and Lifetimes of Stars

Grade Level: 6-8

Curriculum Standards: The Death of Stars 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 and follow-up. Reading may be assigned as homework or given in class.

Purpose: To increase student awareness of the cutting-edge science of the hunt for extrasolar planets and compare planetary systems around other stars with our own solar system.

Key concepts:

- The first planet orbiting another normal star was discovered in 1995, and hundreds more have since been found.
- Many of the Jupiter-sized planets around other stars are at very different distances from their stars compared with the distance between the Sun and Jupiter. Some are much closer to their star than any planet in our solar system is to the Sun.
- Earth-like planets are much harder to find than Jupiter-like planets.
- The number of known extrasolar planets is constantly growing.
- Dozens of efforts to find extrasolar planets are currently underway or being planned. Some of these efforts use telescopes here on Earth and some will use telescopes in space. NASA's Kepler and Terrestrial Planetfinder missions will focus on finding Earth-sized planets around normal stars.

Supplies for Planet Hunting Part 2:

- A copy of the student handout for part 2 for each student
- A copy of Table 3: A Sampling of Extrasolar Planets (with or without all of the columns filled in)
- Three marbles (to represent Jupiter-like planets), and three peppercorn or corn kernel (to represent a Neptune-like planet)*
- Two candy sprinkles taped to index cards to represent Earth-like planets
- One grapefruit or 14 cm yellow ball (for a Sun-like Star)*
- One orange (for a K class star)*
- One cherry tomato or small red ball (for a M class star)*
- One cantaloupe (for a F class star)*
- A calculator for each student*

* 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:

Start the activity by asking the students introductory questions.

- Which type of planet do you think will be easier to find around another star: an Earth-like planet or Jupiter-like planet?

- Do you know about any of the recently discovered planets around other stars?

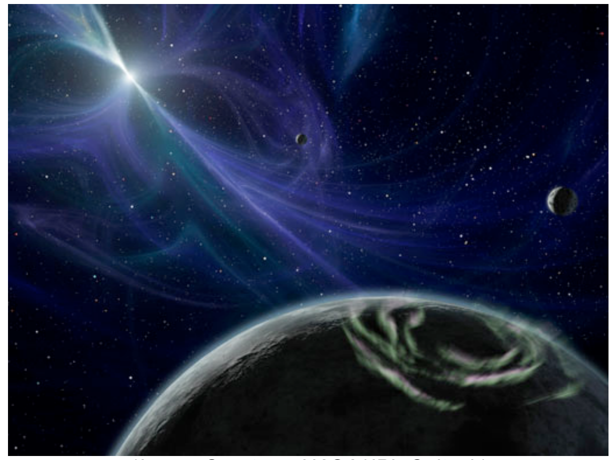
If the students read the information sheet on their own, discuss what they learned as a class. Each of your students also need a copy of Table 3 (with or without the last column filled in) as a reference.

Extrasolar Planet Discoveries

*The very first planet found outside of our solar system was discovered in 1992 orbiting the core of a "dead" high-mass star - a type of neutron star called a **pulsar**. Pulsars send beams of radio waves into space regular basis, and like a lighthouse, the rotation of the pulsar causes the beams to sweep across space. A pulsar seems to switch on and off as the beams of light it produces sweep by. Orbiting planets will cause small changes in the timing of the pulses of light that can be measured by radio telescopes on the Earth.*

Planets around pulsars are easier to find than planets around normal stars. Even planets the size of Earth's moon have enough gravity to pull on a pulsar enough to make a noticeable change in the timing of pulsar pulses. The three planets orbiting pulsar PSR B1257+12 are small and may be similar to the Earth in terms of their mass. But the planetary system is very different from our solar system. Before PSR 1257+12 became a neutron star, it was a very massive star that went supernova! Any planets that orbited the star before the violent end of its life as a normal star are unlikely to have survived. The planets orbiting the pulsar probably formed from debris left behind after the original star went supernova.

Pulsar Planets



(*Image Courtesy: NASA/JPL-Caltech)*

This image is an artist's conception of the pulsar planet system discovered by Aleksander Wolszczan in 1992. Pulsar planets may form much the way other planets do – from disks of gas and dust circling a star. In the case of pulsar planets, however, the gas and dust are debris left over from the supernova of a massive star. And the star these planets orbit is the collapsed core of the star that exploded.

The term "extrasolar planet" literally means a planet outside our solar system.

First Planet around a Sun-Like Star

In 1995, astronomers M. Mayor and D. Queloz announced the discovery of the first extrasolar planet orbiting a Sun-like star called 51 Pegasi or just 51 Peg. The planet was nothing like what was expected! Most planetary scientists had assumed astronomers would find extrasolar planets that were very similar to planets in our own solar system. The planet orbiting 51 Peg, however, is very strange. It is a Jupiter-like planet, but is only 0.05 AU away from its star. (How far away is Jupiter from our own star, the Sun?)

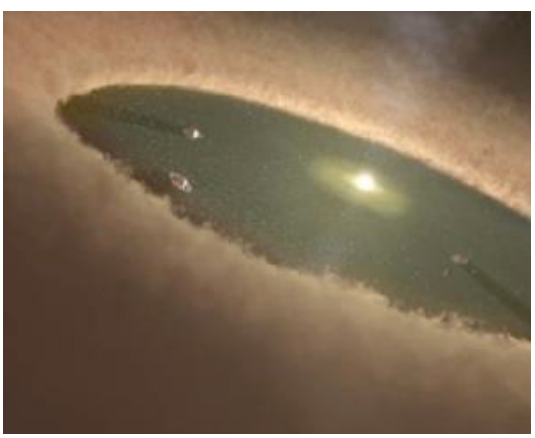
Note: Roughly speaking, since main sequence G class stars have similar masses, differences in masses between different G class stars can be ignored when comparing orbit times (or planetary years). Orbit times for planets around other G-class stars will scale with the average distance of the planets from their star. Some astronomers classify 51 Pegasi, or 51 Peg for short, as a main sequence G-class star. Others classify 51 Peg as yellow subgiant, a sun-like star in the process of dying. Whichever is the proper classification for 51 Peg, the distinction is unnecessary for students at the middle school level.

Even More Planets Found

Using clever techniques and careful observations astronomers had found more than 250 planets orbiting other stars by September 2007. Many more have probably been found by the time you read this. Most of the 250+ planets have been discovered with the method called a Radial Velocity Search, and at least one planet has also been "seen" by the Transit Method. Table 3 contains a sampling of some of the planetary systems that have been discovered around normal main sequence stars. Some planetary systems are known to have multiple planets. By 2007, most of the objects found orbiting nearby main sequence stars are Jupiter-like planets and some failed stars called ***brown dwarfs.*** *As telescopes and observing techniques improve, astronomers are finding smaller planets.*

Planet Formation

Planets are believed to grow from the solid material in a disk around a young star.



(Image courtesy: *NASA/JPL-Caltech)*

Artist's conception: Planets sweep away a clearing in mass of dust surrounding a fledgling star.

The exact definitions of brown dwarfs and giant planets are unclear. Almost all of the planetary systems look very different from our solar system. Some scientists use a set mass, usually around 10 times of the mass of Jupiter, as the dividing line between planets and brown dwarfs. Other scientists distinguish a planet from a brown dwarf based on how it formed. Planets are believed to grow from the solid material in a disk around a young star. *(This process of planet formation is called accretion).* Once a planet is massive enough, it can capture and hold on to gas in the disk. If a planet is able to hold add enough gas it will become a giant planet like Jupiter. In contrast, brown dwarfs are believed to form the way stars do - from the collapse of part of an interstellar cloud of dust and gas. Giant planets may also form from gas collapsing in the disks of gas and dust that circle many young stars. Currently, astronomers disagree on how to classify objects that are many times the mass of Jupiter but which are not massive enough for fusion to begin in their cores.

In 2005, the Earth-like first planet orbiting another main sequence star was found. The planet, Gliese 876 d, is more about 7.5 times more massive than the Earth. The rocky planet orbits its small M class star at a distance equal to only about 1/50th of the Earth-Sun distance. In 2007, two planets about the same size were found around another small M class star, Gliese 581. Both of these planets are closer to their star than Mercury is to our hotter and brighter sun. At the time of this writing, scientists are debating the probability that one or both of these two planets might have the right surface temperature for liquid water!

- *Look at Table 3. How do the distances of extrasolar planets from their star compare with the distances between the Sun and the Earth and the Sun and Jupiter? (Part 1, Table 1 may help you answer this question.)*

Gliese 581 c is about five times as massive as the Earth, and Gliese 581 d is about eight times as massive. Consider asking your students to imagine how life on those planets might be different from life on Earth.

When comparing Tables 1 and 3, it should be obvious that the distances between the planets and star in our own solar system are generally much larger. The planet discovered around 51 Pegasi orbits 20 times closer to its G-class star than the Earth does around the Sun. Jupiter, the closest giant planet to the Sun, orbits than 100 times further away from its star than does the planet orbiting 51 Peg! Many of the extrasolar planets that have been discovered so far are in similar orbits to 51 Peg's planet, with a few even closer to their stars. Several others, especially in planetary systems with multiple planets, have distances that would place them between the Earth and Jupiter if they were in our own solar system.

Comparing Other Planetary Systems with the Solar System

There is only one solar system, but astronomers now know that the solar system is only one of many planetary systems in our part of the galaxy. The first extrasolar solar planets discovered around other normal stars are closer to their stars than Jupiter is to the Sun, and many are closer than the Earth is to the Sun. These planets are often referred to as “hot Jupiters”. Some of these planets are so close to their star, and only take three days to complete an orbit! Mercury, which takes 88 days to complete an orbit, has the shortest year of any planet in our own solar system. Astronomers are now finding Jupiter-like planets in orbits that resemble Jupiter’s orbit around the Sun, but most planetary systems found so far are very different from our own.

Astronomers don't know yet how typical the recently discovered planetary systems are, or whether or not our own solar system is typical. Large, massive, Jupiter-like planets are much easier to find than Earth-like planets. Techniques that depend on the effect the gravity of a planet has on its star are also more likely to find planets that orbit close to their stars. The more mass a planet has, and the closer it is to its star, the stronger pull of the planet's gravity on the star will be.

Many extrasolar planets have been found around Sun-like G-class stars. Astronomers aren't able to search for planets around every star in the solar neighborhood. Instead, they must choose what stars to observe.

- *Why do you think that astronomers may have chosen more Sun-like stars than other classes of stars?*

Your students may come up with several answers to this question. If they have done the Lifetimes of Stars activity then they may bring up the search for life and lifetimes of stars. Some types of stars are also more common than others (see the Star Birth activity). Other motivations for focusing on Sun-like stars include looking for "twins" of our own solar system that may have habitable Earth-like planets, and limitations of detection methods. Doppler Spectroscopy, for example, can only be used with main sequence stars of classes M through F, and some types of giant stars.

Activity: Scale Models of Other Planetary Systems

We can make scale models of other planetary systems and compare them directly with our own solar system.

- *First, complete the last column of Table 3 with distances using the 1:10 billion scale factor also used to make the Scale Model Solar System.*

Your students may not realize how simple conversion from AU to scaled meters can be if they remember that 1 AU (the Earth-Sun distance) in the real solar system is equal to 15 m in the Scale Model Solar System. All the students need to do is multiple each of the distances in AU by 15 m/AU to get the number of meters for the last column of the table.

- *Using our scale model objects from previous activities construct scale models of all the planetary systems in the table.*

When your students have completed Table 3, you are ready to make your scale models. For the models of other planetary systems it is recommended to create selected models as a class so that the teacher can facilitate discussions of the differences and similarities of each planetary system to our own.

You will probably not have sufficient time to model all of the sample planetary systems, but try to pick a few with different types of stars and planets at different distances from the star. Before making the models, you can have your students note beside the column for each planet what object would be appropriate to use.

For planets 0.4 M_J or larger, use the same object used to represent Jupiter in the Scale Model Solar System (marble.) For planets about 0.05 M_J, use the same object used to represent Neptune (popcorn kernel or peppercorn). For objects about 0.02 M and smaller (masses in bold in Table 3), these are closer to Earth-sized planets and are probably rocky. Use both the Neptune-sized object and the largest object representing a rocky planet in the Scale Model Solar System (candy sprinkle). Ask students which should be used given that these planets have masses between those of Neptune and the Earth, but are probably rocky.

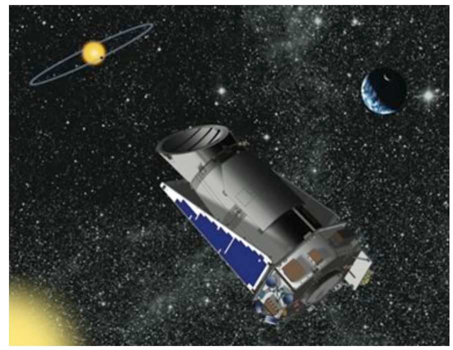
Sample objects and distances:

- **51 Pegasi** requires a grapefruit/14 cm yellow ball, 1 marble, and an area 0.75 m long
- **47 Ursa Majoris** requires a grapefruit/14 cm yellow ball, 2 marbles, and an area 112 m long
- **Upsilon Andromedae** requires a cantaloupe, 3 marbles, and an area at least 37.5 m long
- **Gliese 876** requires a 2.5 cm red ball or cherry tomato, 2 marbles, a peppercorn or popcorn kernel, a candy sprinkle taped to a card and an area 3.2 m long
- **Gliese 581** requires a 2.5 cm red ball or cherry tomato, three peppercorn or popcorn kernels, two candy sprinkles taped to index cards, and an area 1.1 m.
- **Epsilon Eridani** requires an orange, 1 marble, and an area at least 49.5 m long
- **HD 82943** requires an orange, 1 marble, and an area at least 0.75 m long

The data on each of these planetary systems is from the Extrasolar Planet Encyclopaedia (http://exoplanets.org) an informational web site for professional astronomers maintained by Jean Schneider (CNRS-LUTH, Paris Observatory). The search for extrasolar planets is a cutting-edge and dynamic field of science and the Extrasolar Planet Encyclopaedia is constantly updated with new information from the astronomical community.

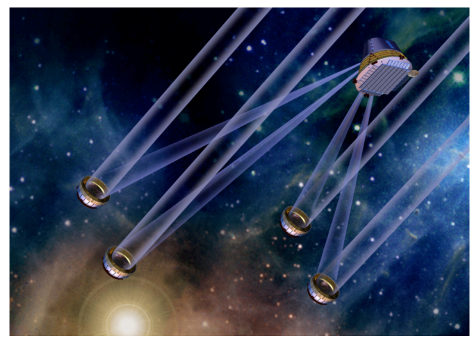
Searching for Earth-like Planets:

Dozens of planned and current efforts are involved in the search for extrasolar planets. Astronomers use telescopes here on Earth now and in the future plan to continue those "ground-based" efforts and also use new telescopes in space. Some of the most exciting planned missions will have the goal of finding Earth-like planets around other stars.



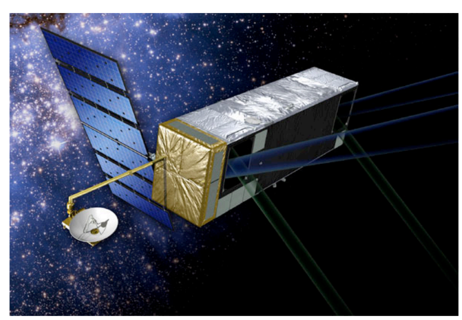
Kepler Mission

*The **Kepler mission** was selected by NASA for to look for small rocky planets from Earth orbit using the Transit method. One of Kepler's goals following its 2009 launch will be to find out if Earth-like planets are common in the solar neighborhood. Check out the Kepler Web site (http://www.kepler.arc.nasa.gov/) for more information on this exciting mission.*



Terrestrial Planet Finder

*Another NASA mission to find Earth-like planets, the **Terrestrial Planet Finder** (http://tpf.jpl.nasa.gov), is currently in the planning phase. Terrestrial Planet finder will actually have the capability to image Earth-like planets around other stars and find out information about the atmospheres of those planets that could tell scientists if other Earth-like planets are capable of supporting life. To accomplish its task, the Terrestrial Planet Finder will use four extremely light-sensitive telescopes orbiting the Earth together and a technique called **interferometry** to reduce the glare of parent stars a factor of more than one hundred-thousand to see planetary systems as far away as 50 light years. The mission will also study disks around forming stars to help astronomers better understand how planets form.*



SIM PlanetQuest

***SIM PlanetQuest** (formerly called Space Interferometry Mission), currently under development by NASA and Jet Propulsion Laboratory, will determine the positions and distances of stars several hundred times more accurately than any previous program. This accuracy will allow SIM to determine the distances to stars throughout the galaxy and to probe nearby stars for Earth-sized planets. SIM will open a window to a new world of discoveries. Check out the SIM Planet Quest website (http://planetquest.jpl.nasa.gov/SIM/sim_index.cfm) for more information on this planned mission.*

A list of the projects involved in the search for extrasolar planets is available on the Extrasolar Planet Encyclopaedia Web site at http://exoplanet.eu/searches.php.

Things to Think About:

- *If a planetary system is listed as having one planet does that mean that we know for certain that only one planet is orbiting the star?*

No. In Table 3, it is clear that many of the planets in multi-planet were found years apart from one another. As technology and techniques improve and planet searches gather more data, astronomers are finding new planets, many of which are smaller and/or farther from their stars than the planets that could be found before.

- *Many of the planetary systems that have been found so far, with giant planets very close to their stars, look nothing like our own. Does that mean that solar systems like our own are rare?*

Not necessarily. The planets we have found so far are the planets that are easiest to find with the techniques and technology astronomers currently have at their disposal. The impact of better techniques, technology, and data can be seen in the discovery dates of the smaller planets in Table 3.

- *How might the discoveries of planets around other stars affect the way scientists view the possibility of finding evidence of life on another planet?*

This is really a thought question for the students and doesn't necessarily have a right answer. The fact that we know of planets orbiting other stars makes life elsewhere seem more probable. However, we don't yet know what percentage of Sun-like stars have planetary systems that look like our own, with truly Earth-like planets. If we find that Earth-like planets in orbits similar to our own are common, that would make the possibility of finding evidence for life on another world much more likely.

For more information on the possibility of life on other worlds in our own solar system and beyond, see the resources for teachers provided by NASA's Astrobiology Institute at http://astrobiology.nasa.gov/nai/education-and-outreach/. Excellent resources for middle school include Life on Earth... and Elsewhere? An Educator Resource Guide in Astrobiology, available free of charge for download, and Astro-Venture (also available at http://astroventure.arc.nasa.gov/).