National Aeronautics and Space Administration

Planet-finding Activity Guide

How do we find planets around other stars?

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

JPL 400-1424 1/11

How Do We Find Planets Around Other Stars?

Big Question: Are there planets around other stars? How do we find planets like Earth around them?

Using the elements contained in this kit you can demonstrate three activities to explain different planet-finding techniques used by scientists.

Planet-Finding Methods:

- **Activity One:** Wobble

  A. Radial Velocity/Doppler Shift – Study the spectrum of a star looking for the “wobble” effect.

  B. Astrometry – Precisely measure a star’s position, in relation to another reference point, and watch for the wobble effect.

- **Activity Two:** Transits

  Study the light of a star to discover planets silhouetted as they cross between the star and us.

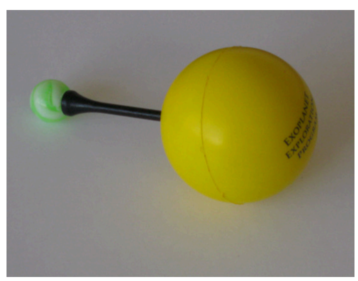
- **Activity Three:** Direct Imaging/Starlight Suppression

  Block out our view of a star’s light in order to see planets orbiting it.

Venue: The full set of activities can be demonstrated both indoors and outdoors – as long as there is some ambient light.

Kit Contents

- Yellow ‘star’ (foam balls)
- One large planet (rubber ball on golf tee, diameter ½ to ¾ inch)
- One super-Earth (wooden swizzle stick)
- One Earth-size (toothpick)



Helpful Hints:

- If you are performing this activity for more than about 10 people at once, you may want to acquire more activity materials and break the group into smaller groups of 5 or 6 each.
- If you have a large audience or seated group and have access to an overhead projector, you can also show the wobbling star by spinning the foam balls on the projection surface of the projector.
- The importance of scale: If you were to shrink the Sun to the size of the foam ball (approximately 3”), one light year would be equivalent to about 330 miles. Jupiter would be about 150 feet away (halfway down a football field). The nearest star (Alpha Centauri – at roughly 4 light years) is about 1,300 miles away (about halfway across the U.S.A.). The distance of a star 10 light years away would be the same as the distance between Los Angeles and New York. A star 35 light years away would be equivalent to half the distance to the Moon. This demonstration is not to scale and uses shorter distances in the examples.

1 **Activity One:** Wobble

Planet Finding Methods: Radial Velocity and Astrometry

Summary: In this activity two methods are demonstrated.

A Radial Velocity/Doppler Shift

B Astrometry

Spin “stars” to simulate stellar wobble (astrometry and radial velocity). Spinning a star with no planets, a star with a Jupiter-analog planet, and a star with an Earth or super-Earth analog planet shows three different amounts of star wobble.

Activity Guide:

To Say	To Do
• How many people know that scientists have found planets around other stars? How do you think we can tell the difference between stars that have planets and stars that don’t? • What do you notice about the motion of the star without a planet? This smooth spinning resembles the motion a star without a planet has against the sky.	• Put the yellow foam star on a smooth surface like a tabletop with at least an area of 2 feet by 2 feet, clear of obstacles. Direct the participants to spin and observe the motion of the star with out a planet.
• Does everyone know how a planet stays in orbit around a star? Gravity. Gravity pulls objects together. It keeps the Earth orbiting the Sun and us from floating away from Earth. But Newton’s Law tells us that just as a star pulls an orbiting planet, the planet pulls on the star. However, because planets are so much smaller than their host stars, this effect is small. This golf tee “gravi-tee” attaching the planet to the star represents the gravitational relationship between the star and its planet. • What do you notice about the motion of the star with the Jupiter-sized planet attached? Is it different from the motion of the star with no planet?	• Attach Jupiter-sized planet. • Direct participants to spin the star with the Jupiter-like planet attachment.
• What do you think will happen when a star has a smaller planet in its orbit? [You’ll notice that in addition to the planet being smaller, the “gravi-tee” is also smaller]. • What do you notice about the motion of the star with the smaller planets?	• Change out the different attachments. • Now direct participants to spin the star with the Neptune-like planet attachment, and again with the Earth-like planet.

Background information:

- Radial velocity (or Doppler shift) involves measuring the redshift and blueshift of a star's spectral lines as it moves toward and away from us along our line of sight to the star ("radial" movement). The light is stretched out (wave lengths are lengthened, toward the red) when the star is moving away and gets bunched up (shorter wavelengths are compressed, toward the blue) when the star is coming toward us.

    - *Definition:* Spectral lines are "gaps," where light has been removed at specific wavelengths, in the star's spectrum (like the colors of a rainbow) because of the presence of certain elements in the star's atmosphere.

- Astrometry measures a star's position relative to some reference point, like another star. Because stars orbit around the center of our galaxy, over time, a star's position changes, described as "proper motion." If a planet or other object is orbiting the star, it will wobble somewhat in its path instead of following a straight line. Star positions can also appear to change due to a phenomenon called "parallax."

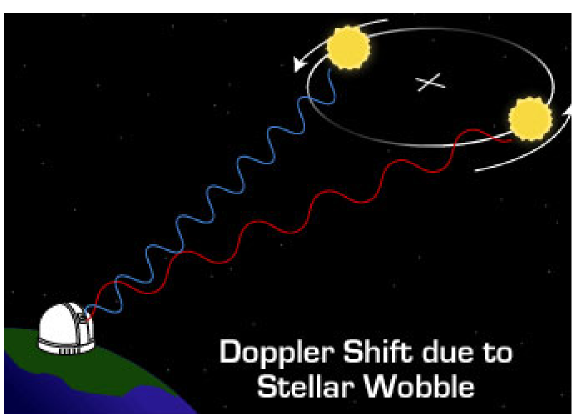
    - Definition: Parallax is the apparent change in the star's position caused by the Earth's annual motion around the Sun.
    - Definition: The star's proper motion is the actual path it takes in space as it moves through the galaxy.

Overarching Discussion

- Most methods for finding stars that have planets are dependent on detecting in some manner this movement (wobble) of a star caused by an orbiting planet. These methods are called "indirect" because they cannot directly detect the planet itself, just the movement of the star as a result of its having one (or more!) planets in orbit around it.
- Which is our biggest planet? Which planet do you think makes the Sun wobble the most?
- Methods we use today to detect the wobble are only sensitive enough to find planets about half the size of Neptune (about 1/30th the mass of Jupiter or larger). So do you think we've found any Earth-sized planets around other stars yet?

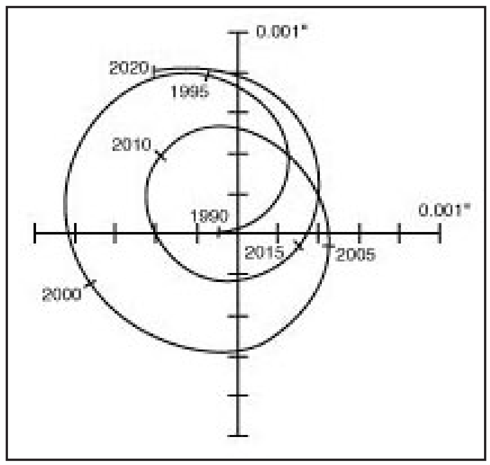
A Radial Velocity/Doppler Shift

- You can demonstrate how we might view stellar behavior from a great distance by holding the ball up and showing an exaggerated wobble in the air by waving it back and forth in relatively small motions.
- By analyzing starlight astronomers can use the radial velocity method to measure light waves as the star moves toward and away from us (as it wobbles). When a star moves toward us, light waves shift toward the blue end of the spectrum. When a star moves away from us, light waves shift toward the red end of the spectrum. This is called a "Doppler shift."



B Astrometry

- Again, you can demonstrate how we might view stellar behavior from a distance by holding the ball up and showing an exaggerated wobble in the air.
- Astrometry involves measuring a star's position related to some reference point, like another star. Over time, its position changes. If an object like a planet is orbiting the star, it will wobble somewhat in its path. From the distance of about 35 light years, Jupiter would cause the Sun's position to change by 1/1000th of an arc second over a 12-year period. But how much is that?
- This is about the same as detecting the change in position of this ball as it wobbles from a distance of 3,300 miles – or if you were in Los Angeles and the ball (our star) was in New York.
- Another way of explaining this: If you were in Los Angeles and I was in New York, this is like you being able to see me hold up my finger and wiggle it side to side.



- Here we can see what the wobble effect looks like using the precise measurements of astrometry, with proper motion removed. Imagine a pin inserted directly in the center of the star. If that star has a planet in orbit around it, the star's orbit would be a tiny mirror image of the planet's orbit. The Sun's actual motion would look something like this because Jupiter, Saturn, Uranus, and Neptune orbit the Sun at different rates and how they align changes over time, creating this complicated movement for the Sun.

2 **Activity Two:** Transits

Planet Finding Method: Transit Photometry

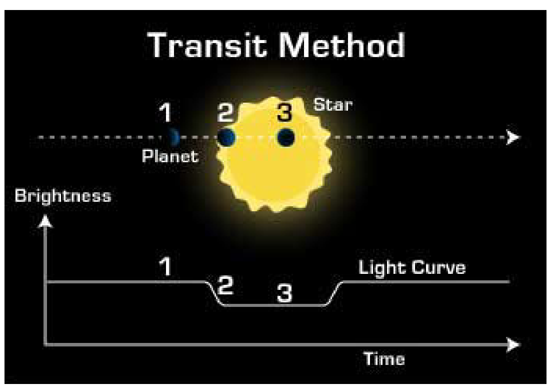
Summary: While your audience pretends to be telescopes staring at the star, slowly turn the star until the planet transits across the face of the star. Use the different sized planets to show different views.

Activity Guide:

To Say	To Do
• Imagine that this star is bright like the Sun. As the planet orbits in front of the star, the planet blocks out a little of the star's light. Now, imagine that this star is a few hundred miles away. We can't see the planet, just the change in the amount of light coming from the star.	• Put the star with a planet onto a skewer. Hold the star with a planet at eye level and slowly turn the skewer, orbiting the planet in front of the star from the participant's perspective. Note that some of audience will see a transit while others will not. Adjust the angle of rotation and repeat until all of the audience sees a transit.

Background information:

- The transit method uses photometry ("light-measure") to measure changes in the apparent brightness of a star. If a planet passes directly in front of a star on an observer's line of sight, it blocks out a tiny portion of the star's light, thus reducing its apparent brightness.
- Astronomers view these changes as 'dips' on a light curve. Imagine a straight line on a graph extending as time passes. This line represents the constant level of light a star emits. If an object passes in front of the star, a dip occurs as the level of light we see lessens for a short period of time before returning to its regular levels. From the length and depth of these transits, the orbit and size of the planet can be calculated. Smaller planets will produce a smaller dip and larger planets a larger dip.



Learn how NASA is already using the transit method to observe planets.

Kepler Space Telescope (NASA)
http://kepler.nasa.gov/

3 Activity Three: Direct Imaging/Starlight Suppression

Planet Finding Methods: Direct Imaging

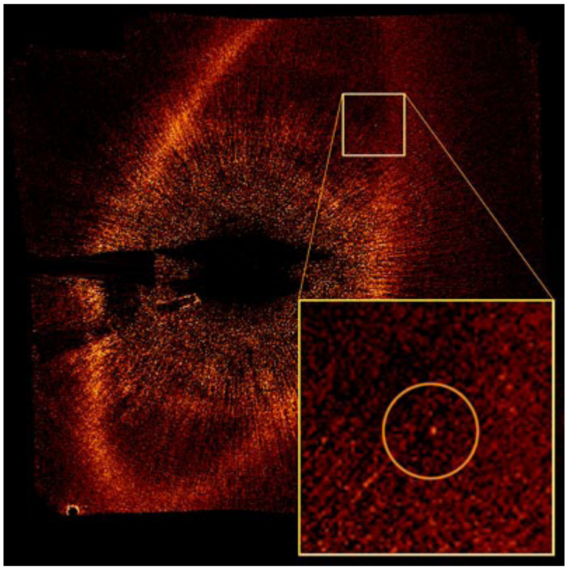
Summary: While your audience pretends to be telescopes staring at the star, hold the star so that the view of the planet is sideways to the viewers' lines of sight, neither obstructed (occulted) by the star nor transiting the star. Have the participants hold their thumbs out in front of their view to block the star from view – they have just suppressed the starlight!

Activity Guide:

To Say	To Do
• All the other methods we've looked at detect some kind of a change in the star. Why do you think we can't see the planets directly? • [Typical answers: too dim, too far away, too small, too close to the star, star is too bright] • [TIP: Many people do not understand how small planets are compared to a star. Example: If our Sun were the size of the foam ball (our example star) – about 3" in diameter – Earth would be the size of a poppy seed. Jupiter would be a bit smaller than the eraser on a pencil.] • If we can block out some of the light we see from the star – or suppress it – direct imaging will allow us to detect the actual light form the star reflected off the planet, so we can detect the planets themselves.	
• Imagine that this star is bright like the Sun and located several hundred miles away. Do you think it would be easy to see the planet next to the star? • Hold out one or two fingers to cover just the bright star but not the planet. Do you think it might be easier to see the planet now?	• Hold up the star with a planet at eye level for your participants. Have them close one eye and block the star with one or more fingers. This is similar to the way a coronagraph works. • Alternatively, hold up the star with a planet at eye level for your participants. With your fingers extended and together, hold your hand palm-out to the audience and cover just the bright star, but not the planet, as seen by members of the audience (rotate yourself as necessary). This is similar to the way a star shade works. • While both demonstrations above really are external occulters, the size of the occulters are very different for a coronagraph (smaller than a pinhead) and a star shade (tens of meters in diameter), and that is what is demonstrated here. The scale is also way off, since a star shade never gets close to the star but it is very distant from the telescope, just as your occulter-hand is distant from the audience.

Background information:

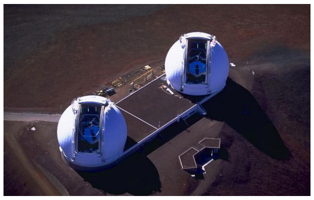
- There are three ways we can achieve starlight suppression in our observations:
  - Coronagraph – At its simplest, a coronagraph is a telescope with an internal disk that blocks out the star, the brightest source of light in a planetary system. What remains is a halo-like ring of starlight scattered by the telescope, much weaker than the star's direct light, and starlight reflected by any objects around the star, including any planets and dust clouds orbiting the star.
  - Star Shade (External Occulter) – This approach is a variation on the coronagraph. A giant disk, external to the telescope at a great distance, is used to block out the star's direct light. What remains is starlight scattered by the shade and telescope and starlight reflected by any planets and dust clouds orbiting the star.
  - Interferometry and Nulling: An alternative way to get a picture of a distant planet is to replace one large mirror (in a telescope) with two or more smaller mirrors and combining their light in a process called interferometry. This technique requires combining the light from the collectors at several different orientations. The results are then combined to form one image. Interferometers are very good at sorting out which light waves come from which part of the star system. Additionally, an interferometer can be "tuned" so that the light coming from the exact center (the star) will be blanked out, or nulled, while the light from any other area will be viewed normally. Nulling allows the reflected light of a planet to be studied while the star's light is suppressed.



The planet Fomalhaut b (pictured in close up on right) was imaged using a coronagraph assembly inside the Hubble Space Telescope to suppress light from the star Fomalhaut.

Learn how NASA is already observing planets using direct imaging..

Large Binocular Telescope Interferometer – Mt. Graham, Arizona (NASA)
http://lbti.as.arizona.edu



Keck Interferometer – Mauna Kea, Hawaii (NASA)
http://www.keckobservatory.org/

Appendix One:

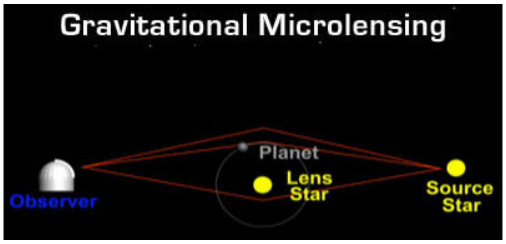
Other Planet-Finding Methods:

NASA and its partners also plan to use Gravitational Microlensing to find planets around other stars.

This method derives from one of the insights of Einstein's theory of general relativity: gravity bends space. We normally think of light as traveling in a straight line, but light rays become bent when passing through space that is warped by the presence of a massive object such as a star. This effect has been proven by observations of the Sun's gravitational effect on starlight.

When a planet happens to pass in front of a star along our line of sight, the planet's gravity will behave like a lens. This focuses the light rays and causes a temporary sharp increase in brightness and change of the apparent position of the star.

Astronomers can use the gravitational microlensing effect to find objects that emit no light or are otherwise undetectable.



Appendix Two:

For more exoplanet information read about these planet-observing missions:

Kepler Space Telescope (NASA)
http://kepler.nasa.gov/

Keck Interferometer – Mauna Kea, Hawaii (NASA)
http://www.keckobservatory.org/

Large Binocular Telescope Interferometer – Mt. Graham, Arizona (NASA)
http://lbti.as.arizona.edu

Spitzer Space Telescope (NASA)
http://www.spitzer.caltech.edu/

Hubble Space Telescope (NASA)
http://hubble.nasa.gov/

Extrasolar Planet Observations and Characterization (EPOCh) (NASA)
http://epoxi.umd.edu/

COnvection ROtation and planetary Transits (CoRoT) (CNES)
http://www.esa.int/esaMI/COROT/index.html

Microvariability and Oscillations of STars (MOST) (CSA)
http://www.astro.ubc.ca/MOST/

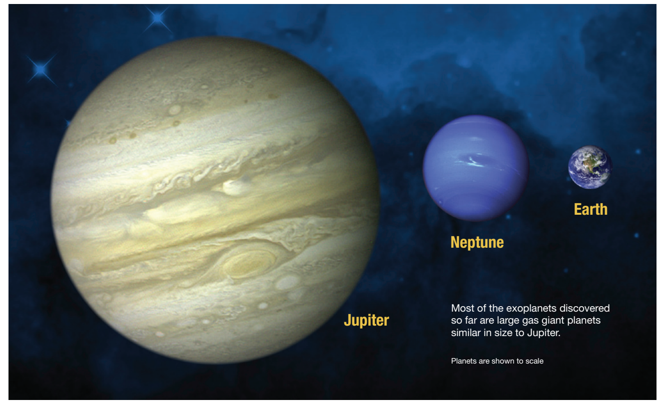
Wide-Field Infrared Survey Telescope (WFIRST) (NASA)
http://wfirst.gsfc.nasa.gov/

James Webb Space Telescope (NASA)
http://www.jwst.nasa.gov/

Gaia (ESA)
http://sci.esa.int/science-e/www/area/index.cfm?fareaid=26

For additional planet-observing information, including information on historical mission concepts, please visit:
http://planetquest.jpl.nasa.gov/

Appendix Three:



National Aeronautics and Space Administration

Planet-finding Activities

Using the elements contained in this kit you can demonstrate three activities to explain planet-finding techniques:

- Wobble (astrometry and radial velocity/Doppler shift): Spin the stars; first with no planet, then with the Jupiter-like planet, the Neptune-like planet, and the Earth-like planet, noting the differences in the ways the 'star' wobbles. Explain the differences between radial velocity (Doppler shift) and astrometry (measurement of stellar position).
- Transit: Have your audience pretend to be a telescope staring at the star. Holding it at their eye level, slowly turn the star until the planet transits across the face of the star. Use the different sized planets to show different views.
- Direct Imaging/Starlight Suppression – Have your audience pretend to be a telescope staring at the star. Hold the star so that the view of the planet is not obstructed and so that it does not appear to be transiting the star. Have participants hold their thumb out in front of their view to block the star from view. They have just suppressed the starlight and should be able to see the planet next to it!

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov