



Kepler Mission: A First Step Toward Finding Other Earths

by Alan Gould (UC Berkeley), Edna DeVore (SETI Institute), and Pamela Harman (SETI Institute)

What's the basic question?

Whenever the question comes up “Are there intelligent beings out there beyond our solar system?” people’s imaginations fire up. But, currently, we have skimpy to non-existent information about extraterrestrial life. The search is on, but, so far, ET has not been found. NASA’s Kepler Mission is underway to detect Earth-size extrasolar planets that could support life. To date, most of the extrasolar planets discovered are giant planets, the size of Jupiter and bigger. Kepler is poised to find small planets, 30 to 600 times less massive than Jupiter. The Kepler mission is designed to answer the question, “Are Earth-size planets in the habitable zone of stars common or rare in our galaxy?”

How?

NASA’s Kepler Mission uses the *transit method* to search for planets. This method relies on the simple fact that when the Kepler spacecraft observes a star as a planet passes in front of it, a tiny fraction of the starlight will be blocked—the star dims a minuscule amount. The word *transit* means “going” and in astronomy it means one heavenly object going in front of a larger heavenly object, like one of Jupiter’s moons going in front of (transiting) Jupiter, or a planet is going in front of (transiting) a star. If we detect one transit, it could be a planet. But, the dip in light could be caused by other phenomena: the random changes of a variable star or starspots (sunspots on other stars). When there are repeated transits at regular times, we may have discovered a planet. Other “false positives” must be ruled out, such as changes in brightness caused by a binary star that appears nearly in our line of sight with the target star. Earth-based observatories do follow-up work to study the target stars and eliminate phenomena that masquerade as transits.

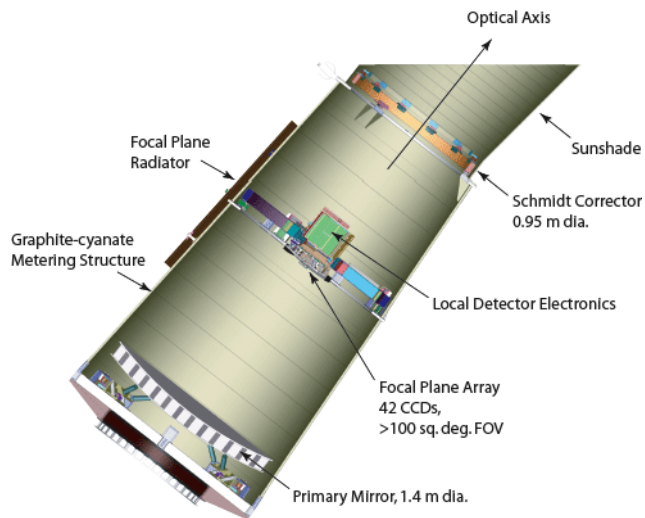


Credit: NASA Kepler Mission/Wendy Stenzel

Once a planet is discovered, we can determine the planet’s size from the drop in brightness—the “transit depth.” The orbital period of the planet is simply the time between successive transits. We use Johannes Kepler’s 3rd Law of Planetary Motion to calculate the average distance of the planet from its star from the orbital period. Knowing the planet’s distance from the star, we can estimate the planet’s surface temperature. Kepler seeks planets in the “habitable zone” of stars, the distance where liquid water can exist on the surface of the planet.

What?

The Kepler spacecraft is a 0.95 meter reflecting telescope—a Schmidt telescope with a wide field of view. At the focus of the telescope is the largest astronomical camera ever launched. The camera has 42 CCDs (charge-coupled devices) totaling 95 megapixels. Altogether, the array covers nearly a square foot in area. Compare this with cell phone or digital camera CCDs which are typically 1 to



Credit: NASA Kepler Mission

When?

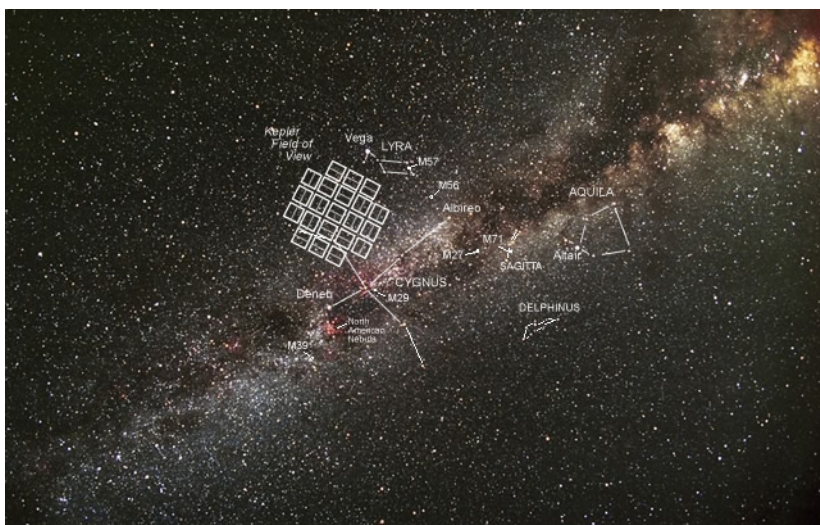
Kepler launched in March 2009, and, with data from the first month of observation, five giant planets were discovered. They are hot Jupiters, with temperatures over 1500 K (over 1100°C or 2200°F), that orbit their host stars in just a few days. To find habitable planets (surface temperature of liquid water), Kepler seeks transits of planets that have periods comparable to Earth's period, one year. This means that it takes at least a year to see two transits, which allows scientists to predict future transits. To confirm a discovery, scientists require that Kepler detects at least 3 or 4 transits with the same period and transit depth. Thus, the Kepler mission is scheduled for more than 3 years to achieve its science goal.

Where?

The choice of where to point Kepler was governed by the requirement that the field-of-view is always clear of the Sun

10 megapixels, and physically much smaller. The Kepler instrument is an extremely sensitive light meter also known as a *photometer*, designed to precisely detect changes in brightness. The field of view is a bit over 10 degrees on a side (or 100 square degrees, an area of sky the size of your hand at arm's length). Most telescopes have a field of view as a small pebble or even grain of sand held at arm's length. Kepler's wide field of view allows scientists to observe more than 150,000 stars simultaneously in the search for transits.

To find an Earth-size planet, the photometer must be able to detect a drop in brightness of only 1/100 of a percent. This is akin to sensing the drop in brightness of a car's headlight when a fruitfly moves in front of it. The photometer must be space-based to obtain this precision.



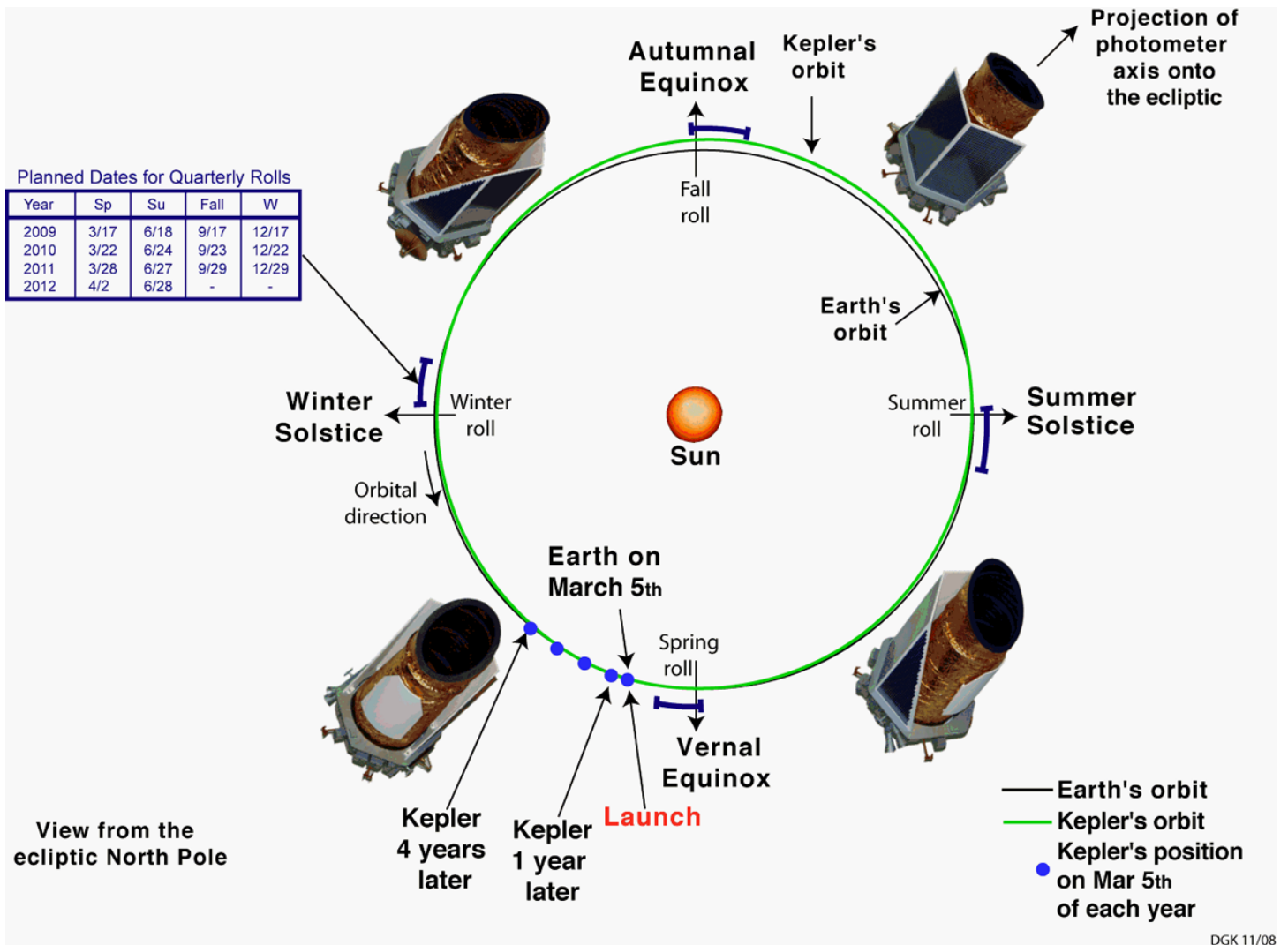
Credit: NASA Kepler Mission



Artist's depiction of a very hot giant planet that could be something like the first planets Kepler discovered. Credit: NASA Kepler Mission/Dana Berry

and the Moon. Kepler points away from the ecliptic—the line in the sky where the Sun, Moon, and solar system planets traverse. Additionally, scientists chose to look at an arm of the Milky Way galaxy that has stars similar in age and composition to our Sun, and at about the same distance from the center of the galaxy. They settled upon region in the constellations Cygnus and Lyra, north of the visible band of the Milky Way.

The Kepler spacecraft travels in an *Earth-trailing heliocentric orbit* with a period of 372.5 days (slightly longer than an Earth-year). *Heliocentric* means Sun-centered; *geocentric* means Earth-centered. In its longer-period, Earth-trailing orbit, the spacecraft slowly drifts away from Earth.



DGK 11/08

Credit: NASA Kepler Mission

What Next?

By the time the separation between Earth and the Kepler spacecraft approaches 50 million miles (75 million km, 0.5 AU), the Kepler scientists should have collected sufficient data to answer the question “Are Earth-size planets in the habitable zone of stars common or rare in our galaxy?” We’ll know whether or not small, habitable planets exist elsewhere in our galaxy.

If Kepler finds other Earths, future space missions will seek evidence of substances in the planets’ atmospheres that indicate life. And SETI searches will listen for signals in the EM spectrum from all the Kepler planets, seeking evidence of ET’s technology. Kepler is a key step toward finding life beyond our solar system. As Bill Borucki, the Principal Investigator for the Kepler mission says, “We won’t find ET, but we might find ET’s home!”

What do I do in the Classroom?

For information on the Kepler, please visit the website <http://kepler.nasa.gov/>

Classroom activities are in the education section: <http://kepler.nasa.gov/education>

They include:

Grades K-3: [Kepler Coloring Sheet](#)

Grades 2-adult: LEGO™ [Orrery](#)

Grades 4–adult: [Kepler Star Wheels](#)

Grades 3-8: [Morning Star and Evening Star](#)

Grades 6-8: [Detecting Planet Transits](#), [Human Orrery](#), [Observing the Jupiter System](#)

*Grades 7-10: [Transit Tracks](#), [Orbits of Jupiter’s Moons](#)

Grades 9–12: [Tracking Jupiter’s Moons](#), [Exoplanet Transits](#)

College: [Transit Problem](#)

Online Interactive: [Exoplanet Transit Hunt](#)

*An abbreviated version of “Transit Tracks” appears with this article. A longer, PDF version may be downloaded from the Kepler website.

Transit Tracks (abbreviated; Grades 7–10)

Materials

- Optional: light bulb and bead on a string (about 50cm long) for transit demonstration.
- “Transit Light Curves” and worksheet on last 2 pages.

A. What is a transit?

1. Demonstrate a transit by swinging the bead on a string in a circle around the light bulb, with the bulb at the center of the plane of the orbit. Tell the class that the light bulb represents a star and the bead a planet.
2. Ask if anyone can see the bead go directly in front of the star. If the bulb is high enough, none of the students will be able to see the bead go directly in front of the star.
3. Ask students to move to where they can see the bead go directly in front of the star—it’s OK to stand or crouch.
4. Confirm that is what we mean by a transit—an event where one body goes in front of another, like a planet goes in front of a star.

B. How does a planet’s size and orbit affect the transit?

Ask the students “How do planets differ from each other?” They should identify: size, color, period, distance from the star. Ask them, “Is there any relationship between how long it takes the planet to orbit its star (called its *period*) and how far it is from the star? By holding the string so that it makes a shorter swing, demonstrate that closer the bead is to the light, the shorter its period.

C. Interpreting Transit Graphs

1. *What’s a light curve?* Have students imagine they have a light sensor to measure the brightness of the star (light bulb). Move a large opaque object (e.g. a book or cardboard) in front of the star so that its light is completely blocked for all the students. Ask, “If we plotted a graph of brightness vs time—with brightness measured by our light sensor—and this [book] transited the star for 3 seconds, what would the graph look like?” Have volunteers come up and draw their ideas on the board and discuss with the class. We would expect the graph to look like the one shown in Fig. 1: a drop in brightness to 100% blocked.

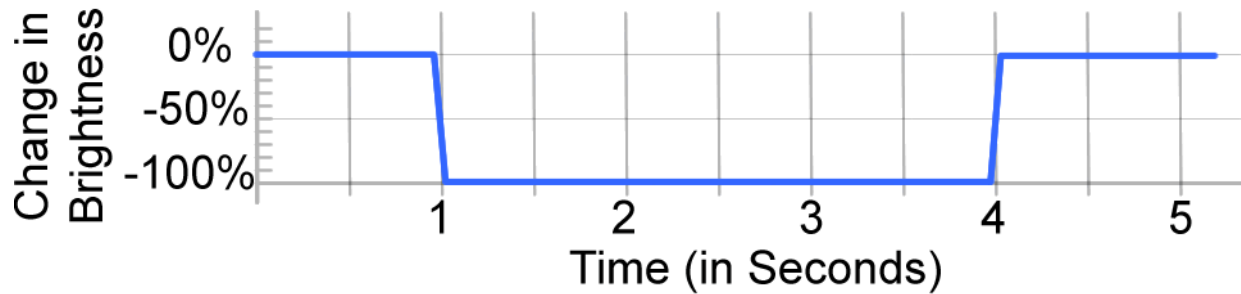


Figure 1. Light curve of book.

2. *What does a transiting planet light curve look like?* Ask the students, “What would a graph of sensor data look like for the orbiting planet, if we plotted brightness vs time?” Have volunteers draw their ideas on the board, and discuss with class. If their comments do not encompass the idea that the dips in brightness would be very narrow and that their depth would depend on the size of the beads/planets, ask them questions about how wide and deep the dips should be. We would expect the graph to look like the one shown in Fig. 2: horizontal line with dips in brightness to X% blocked.

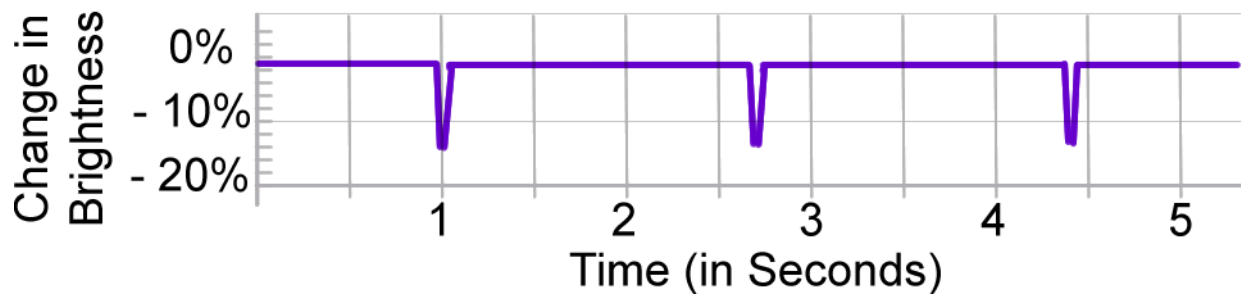


Figure 2. Light curve of bead.

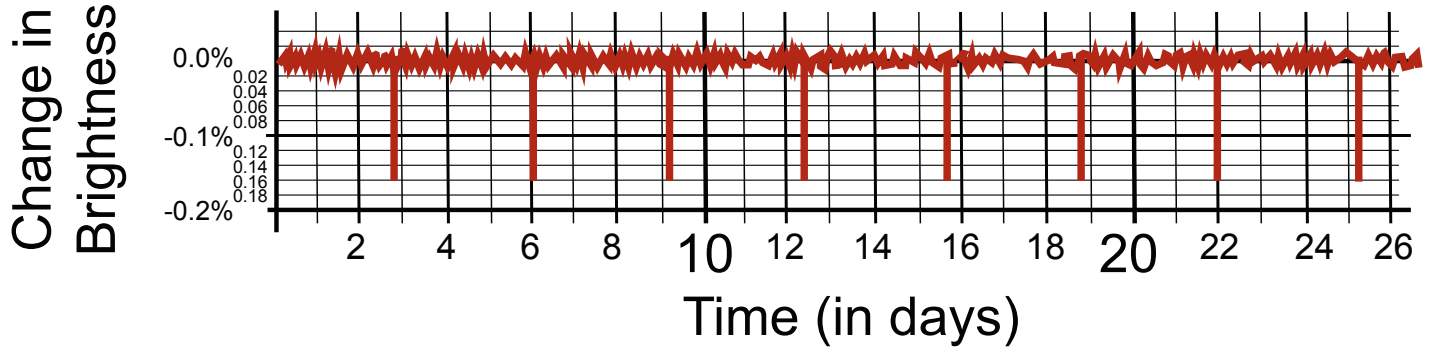
3. What can light curves tell us? Explain that with transit data, it’s possible to calculate a planet’s diameter and distance from its star. Ask, “Why do you think those two properties, planet diameter and distance from star, might be important?”

4. How do we analyze light curves? Hand out a set of 5 sample graphs of Transit Light Curves to each group of 2-5 students and have them interpret the graphs. Pose these questions: How big is the planet compared with the star? Assuming the star is Sun-like, and that Earth would make at 0.01% drop in brightness of the Sun if it transited, how big is the planet compared with Earth? What is/are the period(s) of the planet(s)? (In Earth years.) How far is the planet from its star? (Use graph of Kepler’s 3rd Law) Lead a whole class discussion about the graphs, ultimately aiming at answering the questions.

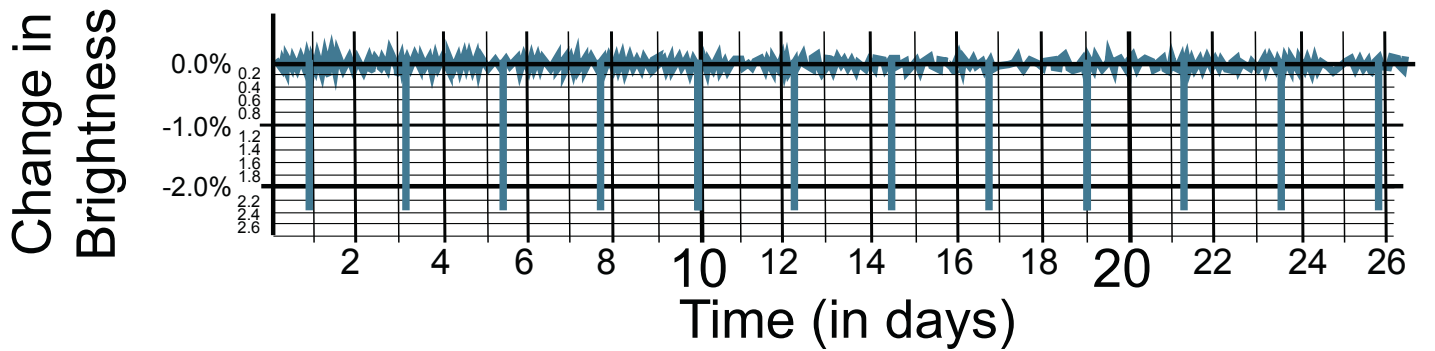
[For additional ideas for this activity, see version on the Kepler website]

Transit Light Curves Set 1

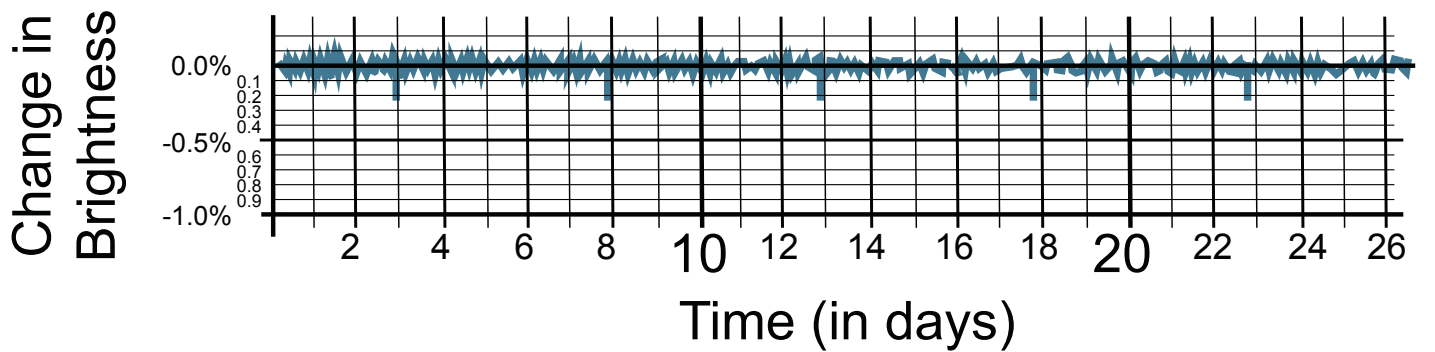
Kepler 4b



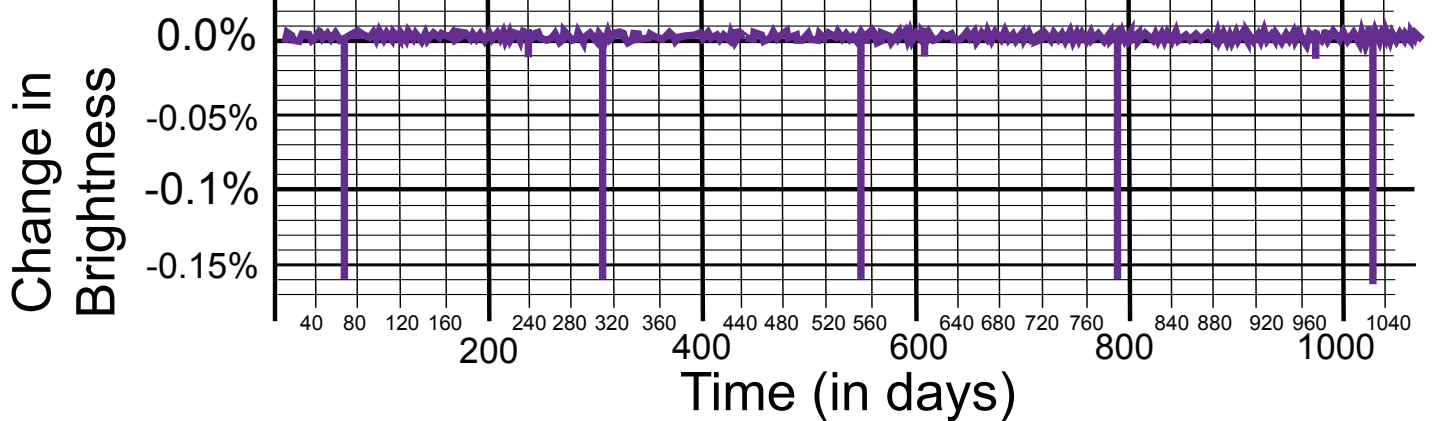
HAT-P-7b



HAT-P-11b

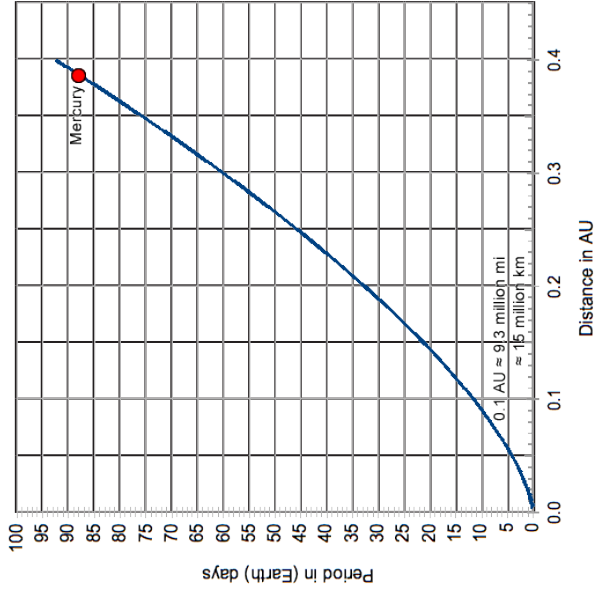


Mystery

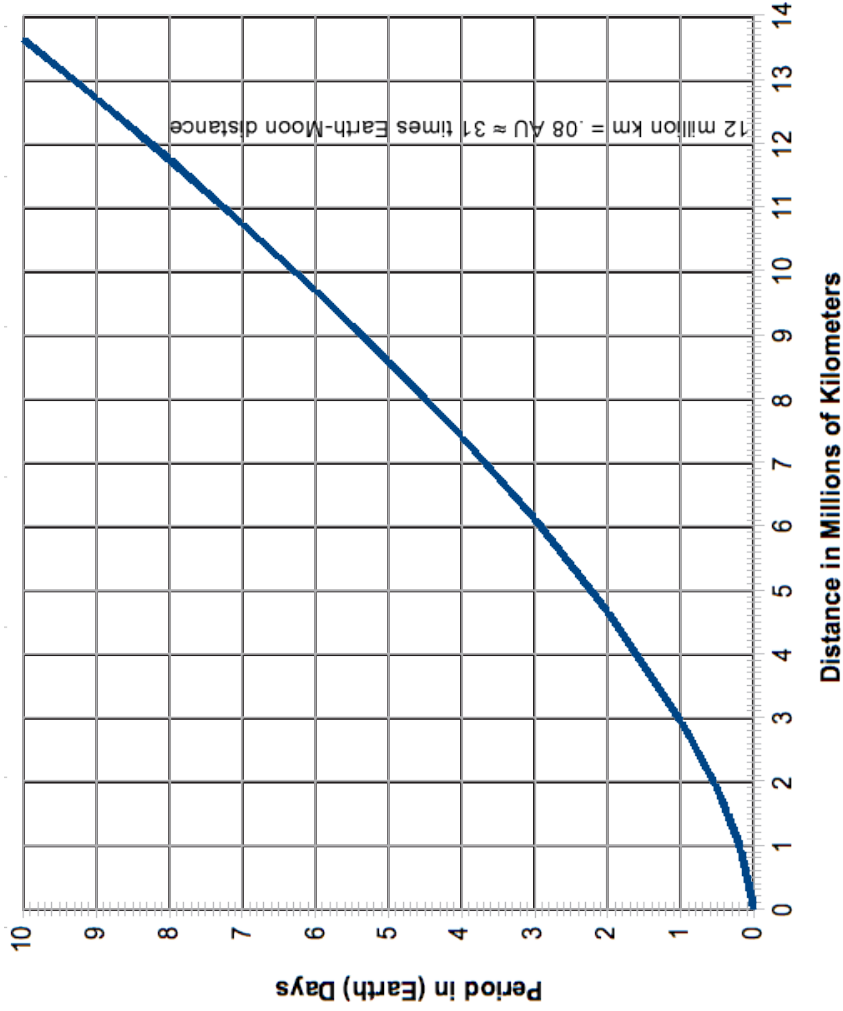


Kepler's 3rd Law Graphs

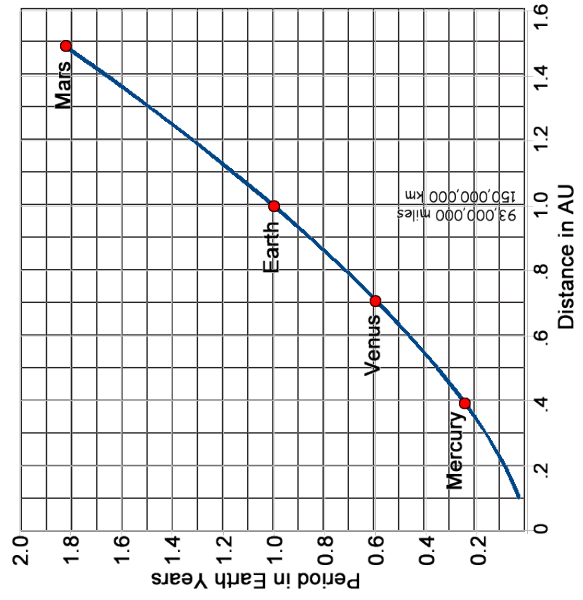
Kepler's 3rd Law Graph for Periods Less Than 100 Days



Kepler's 3rd Law Graph for Periods less than 10 days



Kepler's 3rd Law Graph for the Inner Solar System (periods less than 2 years)



Analyzing Light Curves

Names: _____

Instructions: The “Transit Light Curves” show the light of 9 different stars and how the light level changes when a planet transits each star. Study the light curves to find the period of the planet. The period is the time between transits and is year-length for a planet.

Use “Kepler’s 3rd Law Graphs” to find the “Orbital Distance” of the planet from its parent star. The “Planet’s Size” is found by measuring the “Change in Brightness,” a small percentage drop in the light level as the planet transits. Calculate the planet’s radius using the formula in the table below.

Orbital Distance (from Kepler’s 3rd Law graph)		
Planet Name	Period Units _____	Orbital Distance Units _____
Kepler 4b		
HAT-P-7b		
HAT-P-11b		
Mystery-b		
Mystery-c		
Tres-2b		
Kepler 5b		
Kepler 6b		
Kepler 7b		
Kepler 8b		

Planet’s Size (radius using formula)			
Planet	Brightness Drop of Z (%)	\sqrt{Z}	Radius = $10 \times \sqrt{Z}$ (in Earth radii)
Kepler 4b			
HAT-P-7b			
HAT-P-11b			
Mystery-b			
Mystery-c			
Tres-2b			
Kepler 5b			
Kepler 6b			
Kepler 7b			
Kepler 8b			

Questions:

1. Which planet(s) are similar in size to Earth?
2. Jupiter’s radius is about 11 times Earth’s radius. Which planets are similar in size to Jupiter?
3. Describe the relationship between the period of the planets and their orbital distances.

The Search for Planets Around Other Stars

A Collection of Activities and Resources to Get Behind the Headlines

Andrew Fraknoi (*Foothill College & ASP*)

Version 1.0, Mar. 2010

Until the mid-1990's, the only planets astronomers knew about were the ones orbiting the Sun. But then, in a rapid series of technical breakthroughs, scientists developed a number of techniques for finding planets around other stars. In the most commonly used technique, astronomers measure the “pull” of a massive planet's gravity on its star, as the planet goes around. While the planet is too dim to detect directly, the planet's gravity causes the star to “wobble” back and forth during its complete orbit, and it is this tiny wiggle that can now be found.

Another method looks for planets that, as seen from Earth, cross the face of their parent star in the course of orbiting it. When they do, they block a tiny fraction of the star's light. While this small decrease in light is hard (but not impossible) to measure from the ground, it is a much easier task from the airless realm of space. Looking for such planetary crossings (or transits) is the task of the Kepler mission, and it is expected to add many more planets and less massive planets to our inventory of planet discoveries.

As of the first few months of 2010, over 400 planets have now been found around stars in our cosmic neighborhood — and more are being discovered all the time. This is one of the most active and successful areas of modern astronomy and no article or book can keep fully current on the torrent of new data. Still, the list below is a small selection of non-technical resources that you may find useful if you want to begin exploring the world of “extra-solar” planets (the ones beyond the Sun's influence.).

A. Introductory Material on Extra-solar Planets in General

A1. Selected Non-technical Books

Boss, Alan *The Crowded Universe: The Search for Living Planets*. 2009, Basic Books. A book brimming with optimism (and also full of good information) about the prospects of finding Earth-like worlds out there, by a noted astronomer.

Casoli, Fabrice & Encrenaz, Therese *The New Worlds: Extrasolar Planets*. 2007, Springer. Translated from the Italian edition, this is an illustrated guide to how we are discovering exoplanets.

Jones, Barrie *The Search for Life Continued: Planets around Other Stars*. 2008, Praxis/Springer. An introductory book by a British astronomer.

A2. Selected Non-technical Articles

Carlisle, C. “The Race to Find Alien Earths” in *Sky & Telescope*, Jan. 2009, p. 28. On early discoveries of planets with masses comparable to Earth's and the Kepler mission to find many more of them.

Marcy, G. “The New Search for Distant Planets” in *Astronomy*, Oct. 2006, p. 30. Fine 7-page overview by the leading planet hunter of our time. (The same issue has a dramatic fold-out visual atlas of extrasolar planets.)

Naeye, R. “Planetary Harmony: Resonances are a Key to Deciphering How Planetary Systems Form and Evolve” In *Sky & Telescope*, Jan. 2005, p. 44. On theory and observations of other star systems with more than one planet.

Seager, S. “Alien Earths from A to Z” in *Sky & Telescope*, Jan. 2008, p. 22. How we learn what planets around other stars are made of and the range of possible planets we might expect.

Seager, S. “Unveiling Distant Worlds” in *Sky & Telescope*, Feb. 2006, p. 28. Nice introduction to the types of planets we are finding and the methods astronomers use.

A3. Selected Introductory Web Sites

Exoplanets Database and California Planet Search is a site that highlights the work of the original American team of planet hunters (Marcy and Butler) and their colleagues, but has useful background information as well:

<http://exoplanets.org/>

PlanetQuest (from the Navigator Program at the Jet Propulsion Lab) is probably the best site for students and beginners, with introductory materials and nice illustrations, but it focuses mostly on NASA work and missions:

<http://planetquest.jpl.nasa.gov/>

The Planetary Society Exoplanets Pages are also very nice, with a dynamic catalog of planets found and good explanations: <http://www.planetary.org/exoplanets/>

The Extra-solar Planets Encyclopedia, maintained by Jean Schneider, Paris Observatory, has the best catalog of planet discoveries and useful background material (some of it more technical): <http://exoplanet.eu/>

B. Introductory Material on the Kepler Mission and Its Targets

B1. Selected Non-technical Articles

Doyle, L., et al. "Searching for the Shadows of Other Earths" in *Scientific American*, Sep. 2000, p. 58. On using transits to find extrasolar planets, and a preview of the Kepler mission to do this from space.

Jayawardhana, R. "Are Super-sized Earths the New Frontier?" in *Astronomy*, Nov. 2008, p. 26. On first discoveries of planets with masses comparable to Earth's.

B2. Selected Introductory Web Sites

Kepler Mission Web Site: <http://kepler.nasa.gov/> (Public web site for the telescope with good information, images, educational materials.)

News Items about the Kepler Mission (from *Astronomy Magazine*):

<http://www.astronomy.com/asy/default.aspx?c=a&id=7994>

Mar. 2009 article about Kepler in *The New York Times*: <http://www.nytimes.com/2009/03/03/science/03kepl.html>

A Brief Introduction to the Kepler Mission by Seth Shostak: <http://www.seti.org/Page.aspx?pid=673>

C. Specific Web Resources for Formal and Informal Educators

Activities from the Kepler Mission: <http://kepler.nasa.gov/education/activities/>

An Australian educator has a project to link students with Kepler data and activities at: <http://www.mykepler.com/>
The PlanetQuest Student Activities Guide highlights four short activities and some information on NASA projects:

http://planetquest.jpl.nasa.gov/resources/pq_activity_guide.pdf

How Do We Find Planets Around Other Stars (a demonstration activity from the JPL/ASP Night Sky Network):

http://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=59

Where are the Distant Worlds (an activity to map stars that have planets from the Night Sky Network):

http://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=320