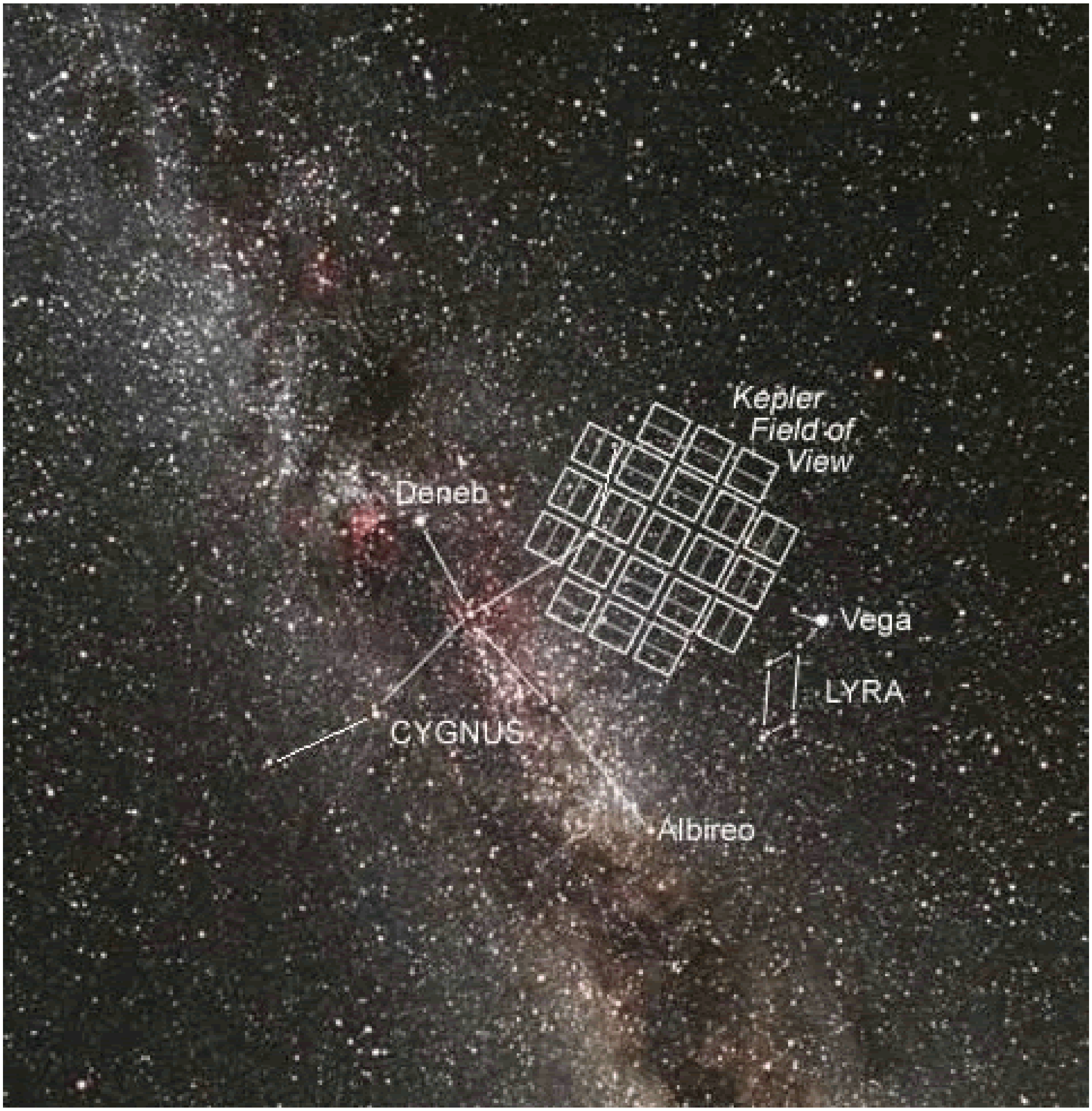
Planetarium Activities for Student Success

Strange Planets

Planetarium Show



by Steven W. White, Toshi Komatsu, and Alan Gould
A collaboration of Pacific Science Center and the Lawrence Hall of Science

Cover photo adaptation of Milky Way photo by Carter Roberts.

NASA Kepler spacecraft. Launched March 6, 2009. Artwork courtesy NASA.

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Planetarium Activities for Student Success

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https://gss.lawrencehallofscience.org/planetariums

Strange Planets

Planetarium Show

Contents

Preface

"Strange Planets" is a fifty-minute planetarium program about finding extrasolar planets, focusing especially on the transit method & the Kepler Mission. It was originally designed for a sixth-grade audience.

The primary goal of this planetarium show is for the audience to understand the difficulties of finding extrasolar planets, and to understand how those difficulties are overcome by modern astronomy techniques.

The audience will consider interstellar distances and grapple with the two challenges of finding extrasolar planets—extrasolar planets are very far away, and are very dim compared to the stars they orbit.

We discuss two ways it can be done: through the spectroscopic and the transit methods.

Simple outline:

5 min	*Intro*
10 min	*Spectroscopic Method*
5 min	*Stars with Planets (Pollux, Alrai)*
5 min	*Kepler's Laws & Habitable Zones*
10 min	*Transiting Planets*
10 min	*Finding an Earth-like Exoplanet*
5 min	*Kepler star field/Conclusion*

Objectives

Students will...

Introduction

Know that hundreds of planets outside our solar system have been discovered.

Know that planets outside the solar system are called extrasolar planets or exoplanets.

Spectroscopic Method

Comprehend the core difficulty in finding extrasolar planets: they are too faint to see.

Know that many planets have been found by observing spectra of starlight.

Understand that gravity of an extrasolar planet can induced a star to wobble causing shifting spectral lines (the Doppler shift).

Know that how much a star wobbles depends on the mass of extrasolar planet(s) going around it.

Know that how fast a star wobbles is an indicator of how close it is to its star and hence how high its temperature is.

Be shown that because closer, larger planets make their star wobble more they are easier to detect, so it is more likely to discover uninhabitable "Hot Jupiters."

Stars with Planets

Be shown the location of a bright star in the sky with a planet.

Know that planets can be "strange", e.g. have a binary star, or an orange star.

Kepler's Laws and Habitable Zones

Know that a habitable planet is one that has temperature and conditions for liquid water.

Know that planet orbits are oval or elliptical in shape and that how quickly a planet orbits its star depends on how close it is to its star.

Transiting Planets

Comprehend that a light meter can show brightness changes.

Know that the transit method of finding extrasolar planets relies on the fact that a planet periodically blocks starlight, even though we can't see the planet.

Know that the size of planet is directly related to that amount of starlight it blocks.

Know that how often starlight is blocked is related to how close a planet is to its star and hence the planet temperature and habitability.

Know some things about NASA's Kepler Mission.

Finding an Earth-like Exoplanet

Analyze a light curve to make conclusions about an extrasolar planet's size and distance from its star (and hence, temperature).

Materials

Figure 1. Rainbow Projector

1. Rainbow projector

Use a prism or diffraction grating mounted on a light source, such as a flashlight, overhead projector, or slide projector. Quality of spectrum is better with brighter light source and slit shaped source.

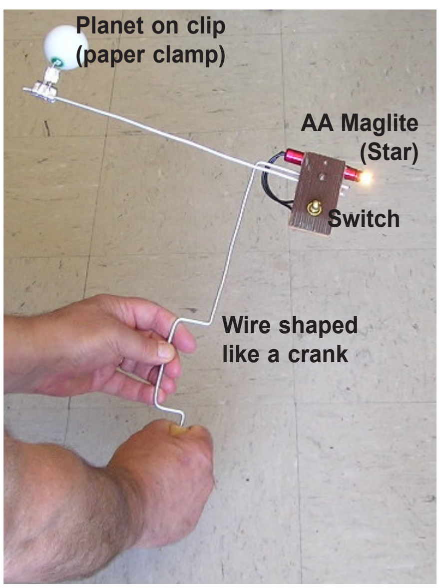
Easy **Alternative**: A movie or still image(s) depicting the flashlight/rainbow demonstration.

2. Portable star-planet model

Make a portable star-planet model that the presenter can carry around to demonstrate wobbling motion of a star. The star is a flashlight bulb and the planet a large bead or light-weight ball, such as 3/4" polystyrene sphere. They are mounted on sticks or stiff wire in a way that the model can be easily spun on a handle (e.g. with wire shaped into a crank) and the star is off-axis so it will exhibit wobbling motion (Figure 2). See Strange Planets area of PASS website for more ideas on how to build star-planet models (http://www.lawrencehallofscience.org/pass).

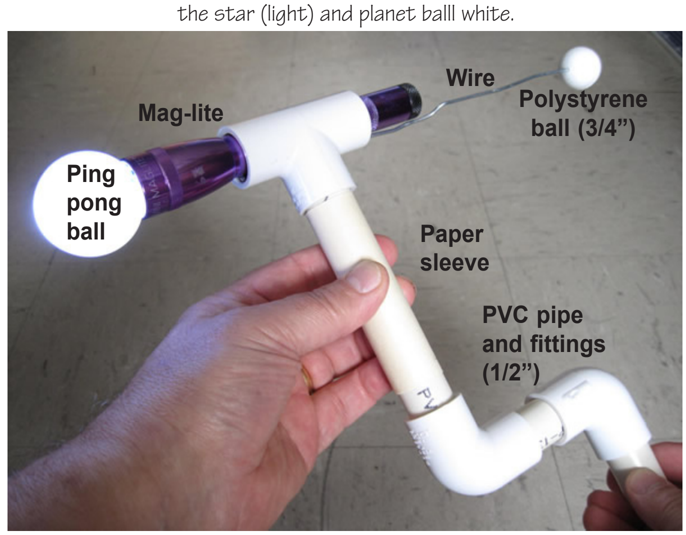
Easy **Alternative**: a movie of a person operating the portable star-planet model can be played instead of live presenter carrying a real model around.

Figure 2 Star-planet model—two variations.



Optional: make the star-planet distance and the amount of wobble adjustable. Also have option of swapping in two different size planets: large and small.

The effect is better still if the crank is black or dark colored, with only the star (light) and planet balll white.



3. Star-planet model for real-time light-curves

For the "Transiting Planets" section of the show, you need

a. a fixed star-planet model and

b. a light sensor, interface, graphing software, laptop, and videoprojector for projecting real-time light curves on the dome.

Easy Alternative for Star-planet model for real-time light-curves: movie of orrery being used to generate a light curve (Movies 22a through c; see visuals list on page 8).

The portable star-planet model used from (2) can be used as a fixed model also, as long as it can be mounted as target of the light sensor. Use a 15-25 watt large spherically-shaped light bulb as a light source instead of the flashlight as a model star. A swing-arm lamp serves well for this purpose (Figures 3 and 4). You need (a) two sizes of planets—interchangeable, and (b) a way to have planets at different distances from the model star. A simple binder clip with paper clip and a planet mounted serves nicely as adjustable distance (figures 4-5).

It's possible to make a multi-planet orrery from LEGO parts (Fig. 6). See the NASA Kepler website for instructions on how to build one (http://kepler.nasa.gov/ed/sim/lego.html). Fig. 6 also shows a complete setup of orrery, star (light bulb), sensor, and laptop with light curve visible.

As far as light sensor, our field tests were done with a Vernier light probe and Vernier Logger Lite software. The sensor needs to be mounted on a stand at about the same height as the "star" in the star-planet model. There are many types of stands possible. Figure 14 shows one made of PVC, but it can be made of metal wire also.

Tinker with the software settings so that you get a light curve with easy-to-see characteristics. A 40-second time period for data collection is adequate to generate two curves successively, for side-by-side comparison of different size or different distance planets. The procedure for acquiring the side-by-side light curves is described in the script, using the 1-planet model. Once you get the settings how you like them, save the file and use that to start up the software, so that the settings are automatically right for your program.

Optional: 2- or 3-planet Orrery—An orrery with hand crank and 2 or 3 orbiting planets. Instructions for making LEGO model orrery are at the Kepler website, http://kepler.nasa.gov in the Education>Simulations section.

Figure 3. Fixed star-planet model.

Figure 4. Planets on clips.

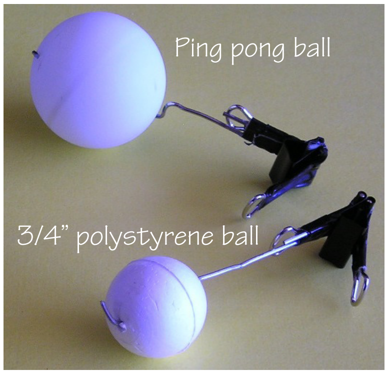
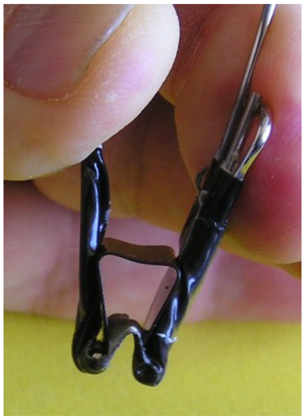


Figure 5. Closeup of clip for interchangeable planets. Black duct tape on the clip makes for a more secure connection to to the wire.



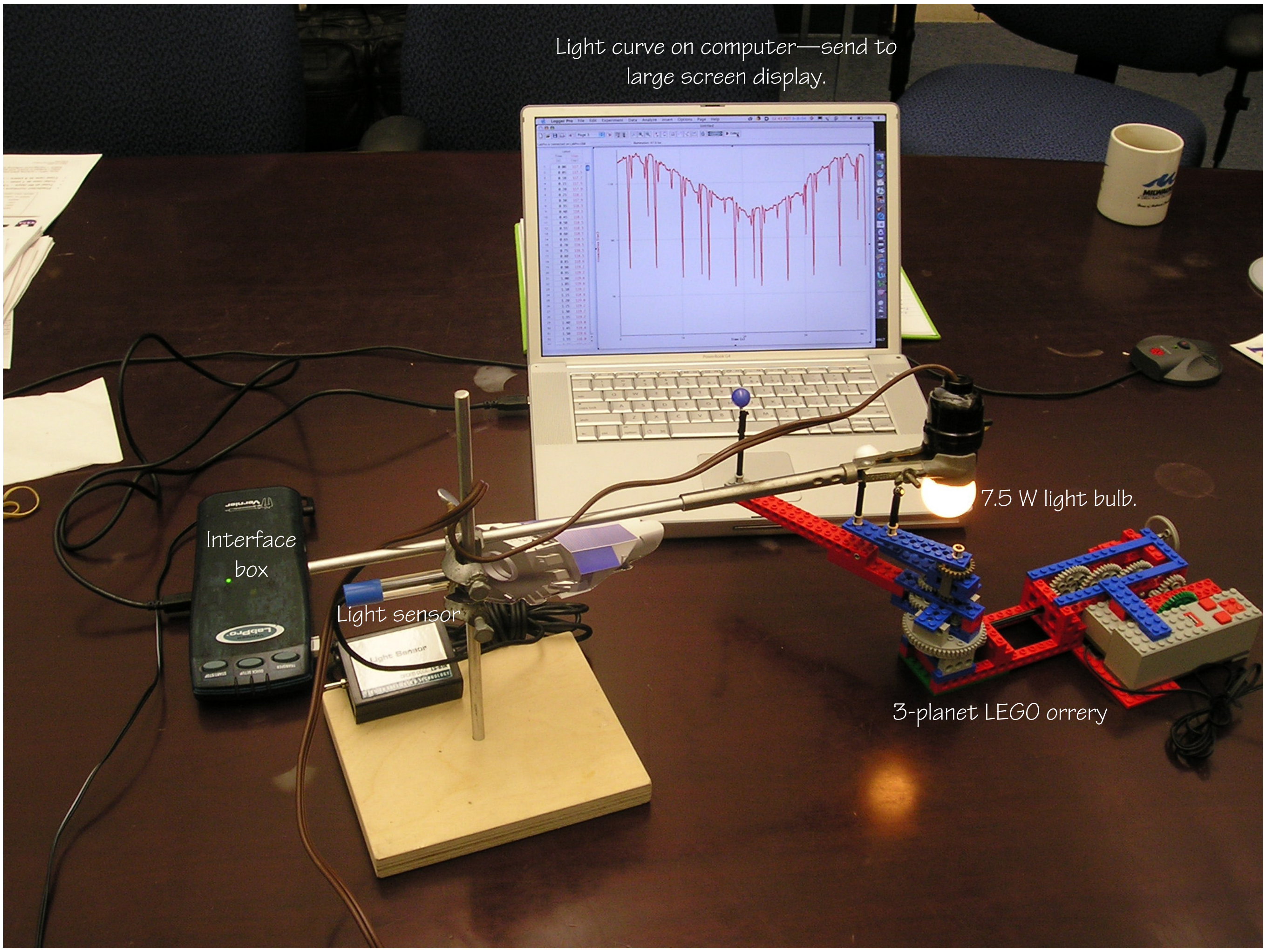


Figure 6. Real-time light curve setup using LEGO orrery, light sensor and light mounted on physics poles with clamps.

Another style orrery—2 planets. The crank is under the base, below the light. Sensor stand is attached to base at left.

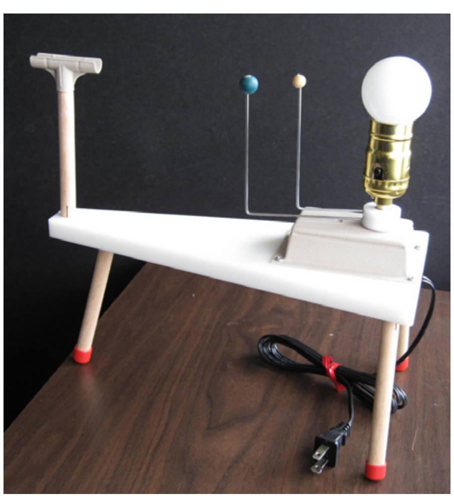
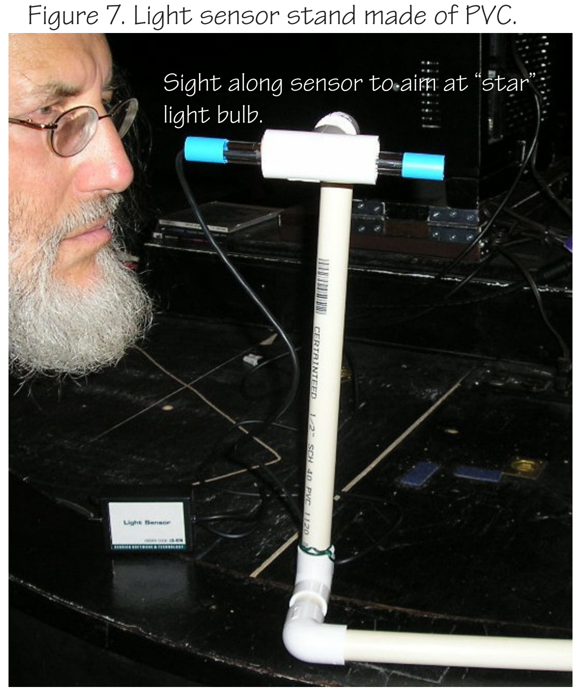


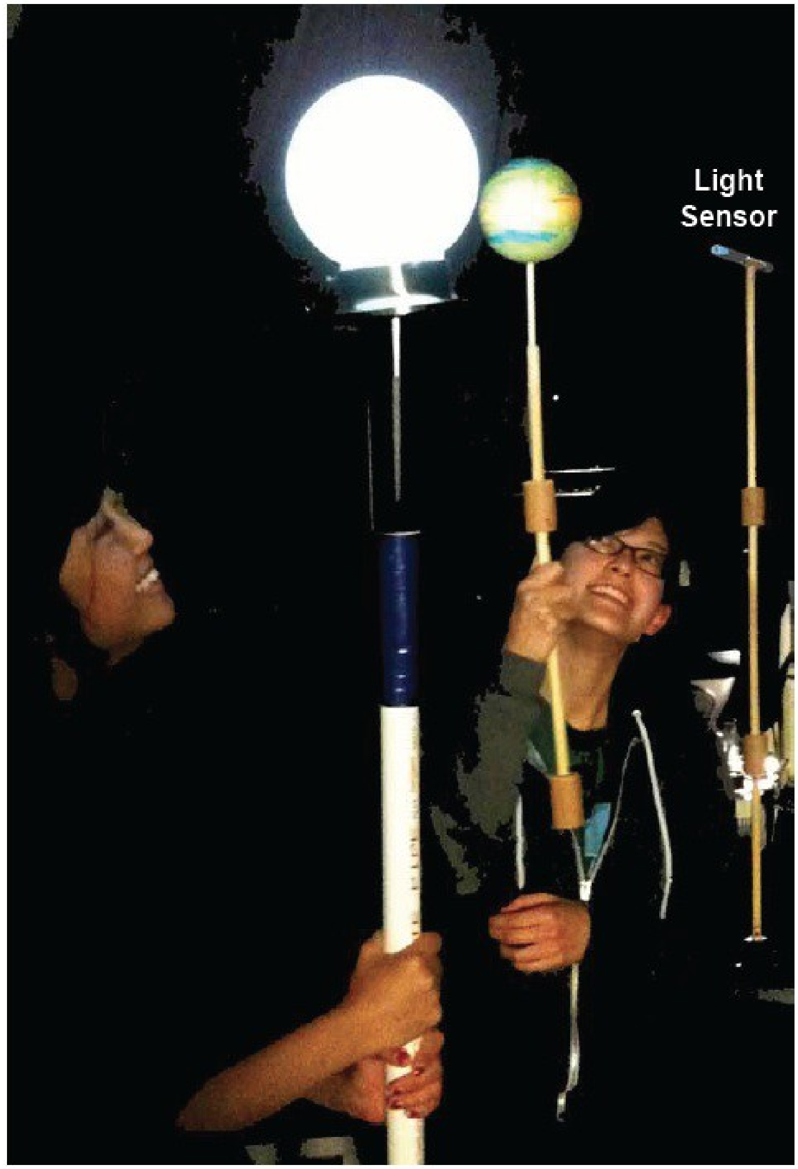
Figure 7. Light sensor stand made of PVC.



STRANGE PLANETS

Page 7b—UPDATE: MATERIALS FOR A "HUMAN TRANSIT MODEL"

Instead of Materials item #3, "Star-planet model for real-time light-curves" we discovered that a "human transit model" illustrated by the photo at right is much simpler to set up and involves two audience volunteers in operation.



The model star on the left in the photo is a translucent light globe (from hardware store) with a battery powered light source (flashlight) inside. The model planet is simply a polystyrene ball painted to look like a giant planet with atmospheric bands. The light sensor is mounted on a fixed pole while the model planet and model star are mounted on poles that can be held by volunteers from the audience.

The output of the light sensor feeds through graphing software and projects in real time onto the dome with a video projector. In the projected brightness vs time graph the audience can see how the model star brightness drops slightly every time the model planet passes between the model star and the light sensor.

Visuals

	Media: Still Image / Animation / Movie	Credit/Source
1.	Kepler launch and dust cover ejection	NASA; Dana Berry
2.	Still: The first extrasolar planet discovered.	Debivort http://commons.wikimedia.org/wiki/Image:51_Pegasi_b_v3.jpg
3.	Still: Geoff Marcy	Volker Steger
4.	ALTERNATIVE MOVIE of rainbow demo	LHS: Sindhu Kubendran, A. Gould
5.	Still: Spectroscopy 1 (star, telescope, diffraction grating, and absorption spectrum)	A. Enevoldsen/T. Komatsu
6.	ALTERNATIVE MOVIE of Wobbling Star demo	LHS: Sindhu Kubendran, A. Gould
7.	Animation: Spectroscopy 2 (spectral lines shift)	A. Enevoldsen/T. Komatsu
8.	Still: Jupiter (has a big wobble)	Cassini Mission - NASA/JPL/University of Arizona http://photojournal.jpl.nasa.gov/catalog/PIA02873
9.	Still: Mercury (has a fast wobble)	NASA/MESSENGER Mission - NASA/Johns Hopkins/Carnegie http://photojournal.jpl.nasa.gov/catalog/PIA10398
10.	Still or Animation: Artist's rendition of a hot Jupiter	NASA/JPL/Cal Tech (still); Dana Berry (animation)
11.	Pot outline for Big Dipper	G. Steerman, Lawrence Hall of Science
12.	Bear outline for Big Dipper	G. Steerman, Lawrence Hall of Science
13.	Planet with two suns	Tim Jones, MacDonald Observatory http://mcdonaldobservatory.org/news/releases/2002/1009.html
14.	Sun-Orange Giant-Red Giant	http://en.wikipedia.org/wiki/Red_giant
15.	Top-view diagram of Solar System, with planets and Sun labeled	http://commons.wikimedia.org/wiki/Image:Solar_sys.jpg (use full-dome digital version if available)
16.	Animation: Habitable zone	NASA Kepler Mission/Dana Berry
17.	Still: Johannes Kepler	Museum der Sternwarte Kremsmünster
18	Still: 1st Law - Orbits are ovals	A. Gould
19.	Still: 2nd Law - Equal times/equal areas graphic	http://en.wikipedia.org/wiki/Image:Kepler-second-law.svg
20.	Animation: 2nd Law - elliptical orbit	http://commons.wikimedia.org/wiki/Image:Classical_Kepler_orbit_80frames_e0.6_smaller.gif
21.	Still: 3rd Law - $T^2 \propto r^3$ chart	A. Gould, Lawrence Hall of Science
22.	a-c Movies of Orrery and Live Graphing	LHS: Margaret Nguyen, Alexandra Race, A. Gould
23.	Still: Kepler spacecraft	NASA Kepler Mission
24.	Light Curves A through E	LHS: A. Gould/T. Komatsu, Lawrence Hall of Science
25.	a-c. Size and Distance Lookup Charts	LHS: A. Gould
26.	a and b. Artist's depiction of Earth-like planet	LHS: Susan Stanley
27.	Still: Kepler's target area	NASA Kepler Mission/A. Gould/Carter Roberts
28.	Animation: Kepler's Orbit	NASA, Dana Berry
29.	a and b. Alternative transit animations	NASA http://www.nasa.gov/mov/159635main_v0634bs.mov or H. Deeg and R. Garrido http://www.iac.es/proyecto/tep/transitanim.html
30.	Animation and movie: Diversity of Life	NASA, Dana Berry

Additional animatons and movies can be found at the NASA Kepler website animations page:

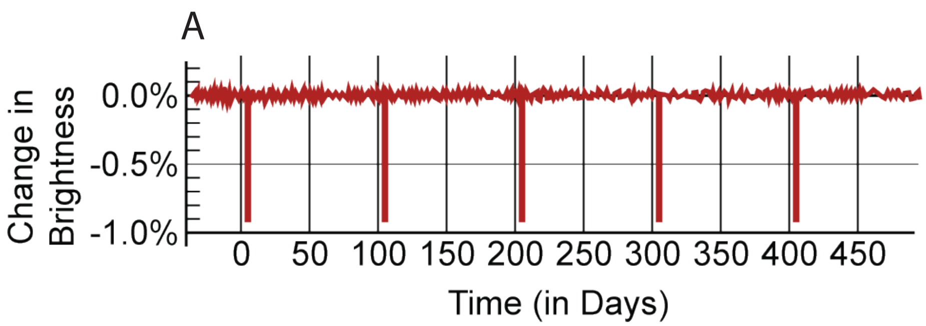
http://kepler.nasa.gov/media/animations.html

Exoplanet Size and Distance Lookup Chart*

Brightness Drop (%)	Planet Size (Earth=1)	Orbit Time (days)	Orbit Distance (Earth=1AU)
0.01	1.0	25	1/6
0.02	1.4	50	1/4
0.04	2.0	100	0.42
0.06	2.4	150	1/2
0.08	2.8	200	2/3
0.10	3.2	250	0.78
0.12	3.5	300	7/8
0.14	3.7	350	.97
0.3	5.5	400	1.06
0.5	7.1	450	1.15
0.7	8.4	500	1.23
0.9	9.5	550	1.31
1.0	10.0	600	1.39

For Sun-like stars

Strange Planets



Period (days)

____

Distance from Star (AU)

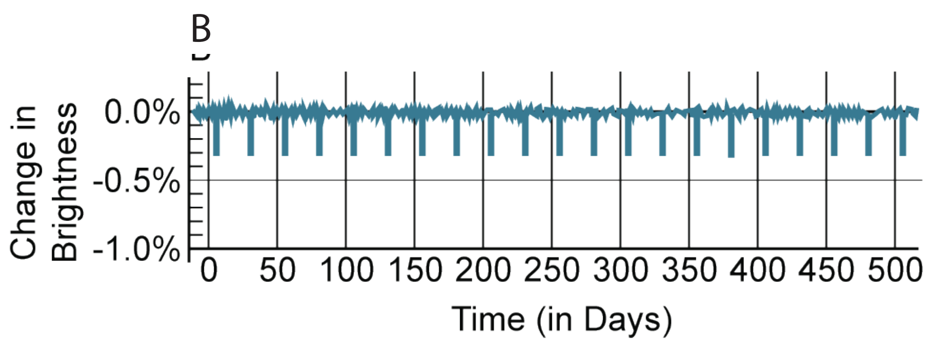
____

Brightness Change (%)

____

Planet Size (Earth radii)

____



Period (days)

____

Distance from Star (AU)

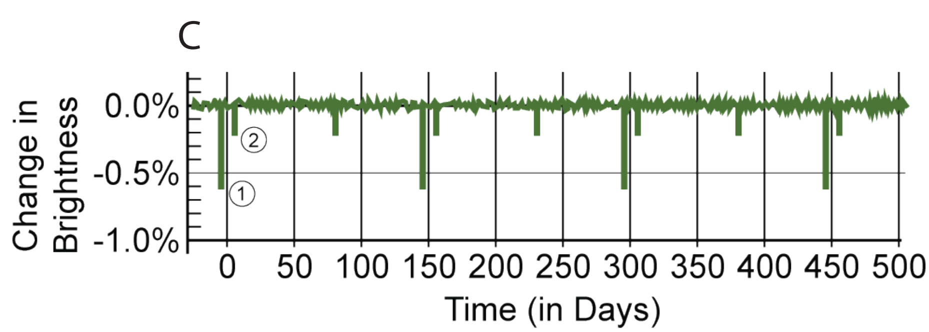
____

Brightness Change (%)

____

Planet Size (Earth radii)

____



Period (days)

1.________ 2.________

Distance from Star (AU)

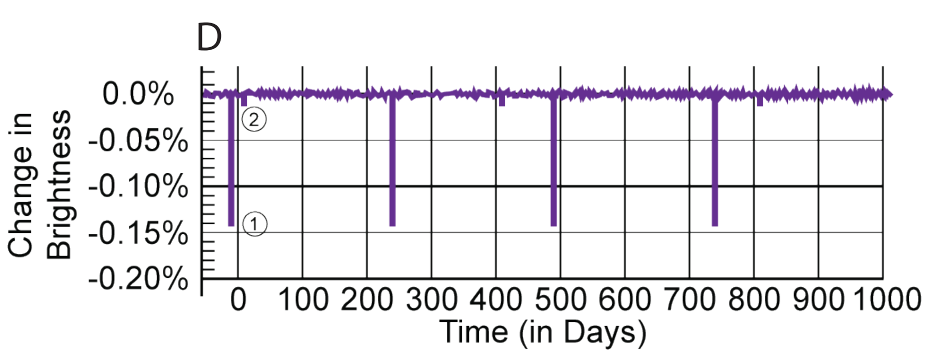
1.________ 2.________

Brightness Change (%)

1.________ 2.________

Planet Size (Earth radii)

1.________ 2.________



Period (days)

1.________ 2.________

Distance from Star (AU)

1.________ 2.________

Brightness Change (%)

1.________ 2.________

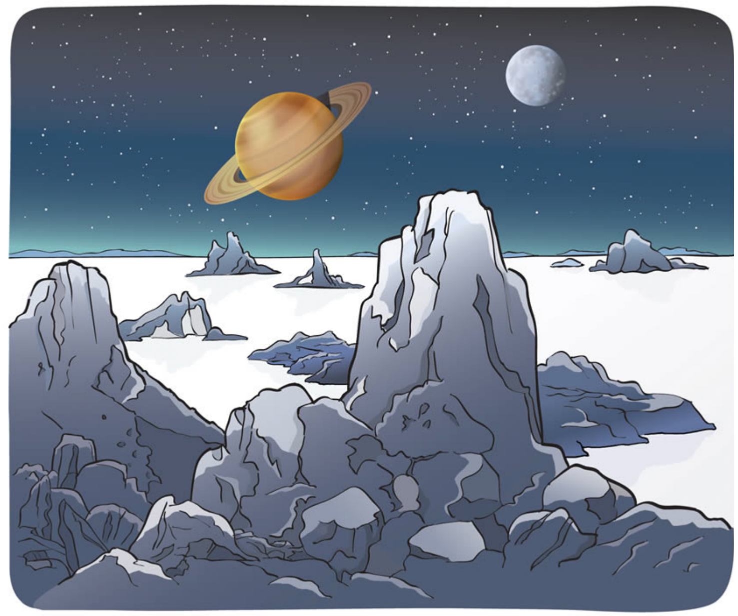
Planet Size (Earth radii)

1.________ 2.________

Orbit Time (in days)	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600
Distance from Star (in AU)	0.17	0.27	0.35	0.42	0.49	0.55	0.61	0.67	0.72	0.78	0.83	0.88	0.93	0.97	1.02	1.06	1.11	1.15	1.19	1.23	1.27	1.31	1.35	1.3

Brightness Change (i%)	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
Planet Size (in Earth-radii)	1.0	1.4	1.7	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.3	3.5	3.6	3.7	3.9	4.5	5.5	6.3	7.1	7.7	8.4	8.9	9.5	10.0

1 AU = average distance from Earth to the Sun
For a Sun-like star, the Habitable Zone is 0.95-1.37 AU.



Hypothetical Icy Planet.
Artwork by Susan Stanley

Are any of the planets nearly Earth-size and in the habitable zone of its star (near 1 AU)? Which one(s)? ___________

____

Links for more information:

Kepler Mission Home Page:
http://kepler.nasa.gov/

Kepler Star Wheel:
http://kepler.nasa.gov/ed/starwheel/

Make a LEGO® Orrery:
http://kepler.nasa.gov/ed/sim/lego.html

PlanetQuest: Exoplanet Exploration
http://planetquest.jpl.nasa.gov/

California & Carnegie Planet Search
http://exoplanets.org/

The Extrasolar Planets Encyclopaedia
http://exoplanet.eu/

Top 10 Most Intriguing Extrasolar Planets
http://www.space.com/scienceastronomy/extrasolar_planets.html

Setup

1. Set sky to a time when both Cygnus & Gemini are visible, e.g. May 25, 22:00, local time
2. Cue up images & videos
3. Rainbow maker ready (diffraction grating & flashlight)
4. Spinning star-planet models ready. Optional: Set up orrery
5. Set up Vernier Light sensor, interface, laptop with graphing software, and video-projector
6. Handouts ready: *Strange Planets* take-home handout and *Exoplanet Size and Orbit Size Lookup Chart*

Recommendations for Using the Script

We don't expect the script which follows to be memorized (as an actor might memorize a part) but to be used as a guide in learning, rehearsing, and improving presentations. We recommend that you read the script once or twice, then work with it in the planetarium, practicing the projector controls, slides, special effects, and music. You should be able to imagine yourself presenting information, asking questions, and responding to participants. For your first few presentations, you can have the script on hand, using major headings as reminders of what to do next.

The script is organized in blocks or sections. The purpose of these separations is only to help you learn and remember what comes next. Once you have begun a section, the slides or special effects and your own train of thought will keep you on track. When beginning a new section, make the transition logically and smoothly.

Directions for the instructor are printed in *italics* in the side column, the instructor's narrative is printed in regular type, and directions and questions to which the audience is expected to respond are printed in ***bold italics***. There is no point in memorizing narration word-for-word since what you need to say will depend upon the participants. The language you use and the number and kinds of questions you ask will depend on how old the participants are, how willing they are to respond, and how easily they seem to understand what is going on.

We believe that the most important elements of the program are the questions and the activities since these involve the audience in active learning. If you must shorten your presentation, we recommend that you borrow time from the narration.

Variations for Show Length

The show is intended to be 50 minutes long, including all sections, except for the detailed treatment of Kepler's Laws. However, many variations and adaptations are possible.

	Length of show in minutes 50	40	30
Introduction	✔	✔	✔
The Spectroscopic Method	✔	✔	
Stars With Planets	✔	✔	✔
Habitable Zones, Kepler's Laws	✔		
Transiting Planets	✔	✔	✔
Finding an Earth-like Exoplanet	✔		✔ or
Conclusion	✔	✔	✔

Script

Dim house lights and bring out stars.

Fade music.

Introduction

Hello, and welcome to the ________ Planetarium. Our program is called *Strange Planets*. But of course, *strange* is in the eye of the beholder. Any planet might seem strange.

We have eight planets in the Solar System, all very different and each strange in its own way. We know at least one has life—Earth, a strange planet, partly because of all the strange people on it.

Are there places other than Earth that could have life?

[Accept answers and encourage discussion with other questions.]

We use the word *habitable* for a place that can support life.

People have long wondered…are we alone? [Point towards starry sky.] If there are a lot of other planets circling stars out there beyond the Solar System, we could greatly expand the possibilities for finding habitable places.

There HAVE been planets discovered around other stars. They are called extra-solar planets or *exoplanets* for short.

Do you know how many exoplanets have been discovered?

[Accept answers. As of December 2009, "over 400" is correct. See The Extrasolar Planets Encyclopedia at http://exoplanet.eu/ or the New Worlds Atlas at the PlanetQuest website — http://planetquest.jpl.nasa.gov/]

If possible, show live or recent screenshot of the PlanetQuest New Worlds Atlas page that has up-to-date exoplanet count:

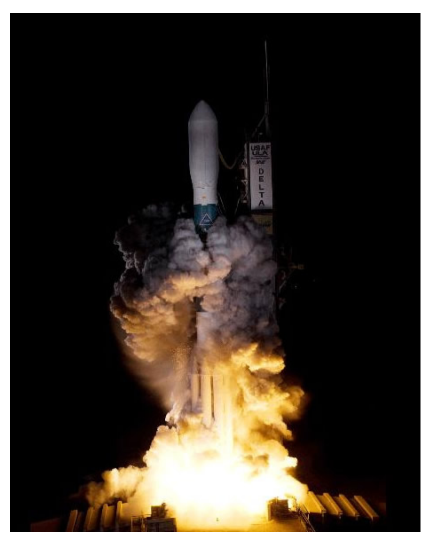
http://planetquest.jpl.nasa.gov/

Optional, if correct answer is not given:

Raise your hand if you think there are less than 50 planets discovered? Less than 100? Less than 400?

We've discovered over 400 [use current planet count] planets outside of our solar system. Most of the extrasolar planets discovered have been quite large—the size of Jupiter or even bigger.

VISUAL 1: Kepler Launch. Movie of Kepler spacecraft launch (2009 March 6) and animation of dust cover ejection (2009 April 7). Alternatively, show some combination of the launch, deployment, and/or dust cover ejection in videos sp01b–d. Add music for animations. ►



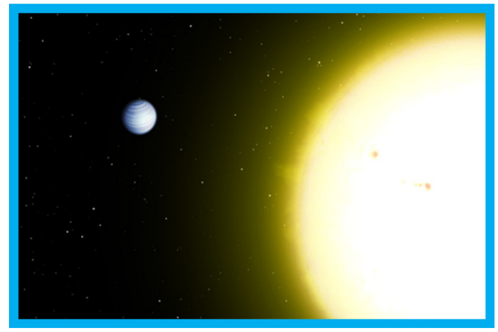
NASA's Kepler Mission, launched in March of 2009. When its dust cover was ejected, it started collecting data on the brightness of 100,000 stars. It is designed to detect evidence of planets that are roughly the size of the Earth and suitable for life!

The Spectroscopic Method

Finding extrasolar planets is really tough.

Why do you think finding exoplanets is so hard?

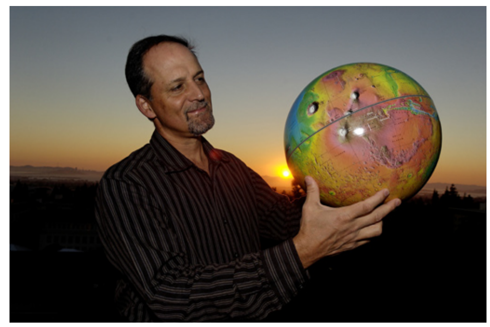
[Extrasolar planets are extremely dim, very close to their stars, and so far away that the star's glare ruins our chances of seeing the planets.] For decades, astronomers had suspected there were extrasolar planets out there, but there was never any proof until 1995.



VISUAL 2. Still image of 51 Pegasi, the first extrasolar planet discovered. Add music. ►

Here we see an artist's concept of the first confirmed extrasolar planet ever discovered, orbiting around a star called 51 Pegasi.

To find such planets, we must resort to clever and ingenious methods. Most exoplanets, so far, have been detected by the Spectroscopic Method.



VISUAL 3. Still image of Geoff Marcy. Fade music. ►

This is the world's pre-eminent planet-finder—UC Berkeley astronomer, Geoff Marcy. He and his team pioneered a planet-finding technique called ***the spectroscopic method***. Here is how it works.

Switch on the flashlight & diffraction grating and beam a rainbow on the audience. Turn a circle and sweep the rainbow over everybody and across the dome.
OR ALTERNATIVELY...show

VISUAL 4. Rainbow movie (or still image) alternative to live demo of flashlight with diffraction grating. Use music. ►

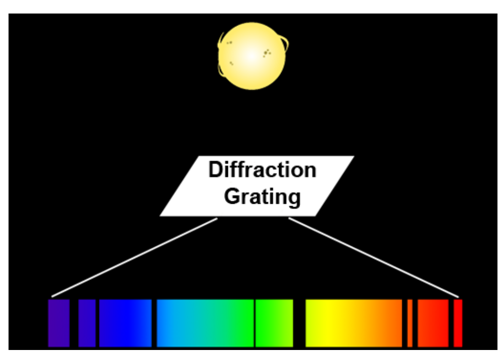
There is something called a ***diffraction grating*** on this flashlight. It works kind of like a prism.

What happens when light passes through a prism?

[Take any answers.]

The rainbow you see is called a ***spectrum***. You can see all the colors from the flashlight separately—each one all stretched out. [Fade music.]

VISUAL 5. (still) Spectroscopy 1, showing a star, a diffraction grating, and an absorption spectrum of the star with lines. ►



We look at a star with a telescope that has a diffraction grating; the starlight stretches out into a rainbow spectrum. You can see dark lines in the rainbow spectrum where the star is actually missing those colors because different chemicals, like hydrogen and helium and sodium, swallow up those colors. Now here's the key to planet-finding using the spectrum….

Switch on the "star" on the wobbling star/planet model and walk around the dome first without spinning /wobbling the star. Make the star move very smoothly. Add music.

Here we have a star with no planet orbiting it.

Does it seem to you to be moving steadily? [Yes.]

Now let's add a planet orbiting the star.

Start spinning/wobbling the star.

ALTERNATIVE:
VISUAL 6. Wobbling star movie can be played as alternative to showing the wobbling star model live. Add music. ►

What's unusual about how is "star" is moving now?

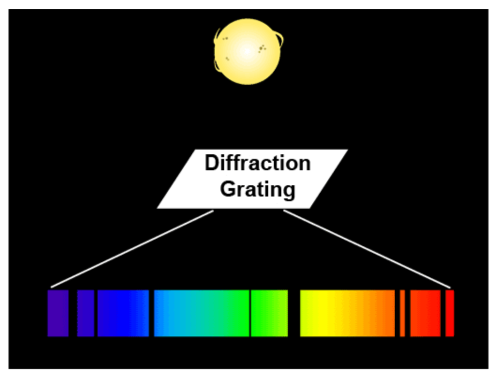
[It appears to wobble.]

What do you think is causing the star to wobble?

[The planet's gravity is tugging on its star.]

The planet's gravity makes the star move back and forth as the planet orbits, but since planets are so much smaller than stars, the wobble is a teeny-tiny wobble.

VISUAL 7. (animation) Spectroscopy 2, where the star is wobbling and the absorption lines wobble with it. Use music. ►



If the star is wobbling towards us and away from us, it affects the rainbow/spectrum of the starlight. When the star moves toward us, all the dark absorption lines in the spectrum shift slightly over toward the blue side of the rainbow spectrum. That's called a *blue shift.* When the star is moving away from us, all the absorption lines shift the other way, toward the red side.

Guess what that's called? **[Red shift.]**

OPTIONAL:

Have half the audience clap when the animation shows blue shift and the other half of the audience clap when the animation shows red shift.

The cause of red shift and blue shift is a lot like what happens when a sound, such as a train or race car, slides down in pitch as it goes by you.

Play audio sample of a Doppler shift.

When studying these wobbles, we look for two features—the size of the wobble, and the speed of the wobble.

What might cause a really big wobble?

[A big massive planet, ...or planet very close to the star.]

What might cause a really small wobble?

[A small planet, ...or planet far from the star.] It's the gravity of the planet that makes the star wobble and the force of gravity is stronger if the planet is more massive or closer to the star.

How about the speed of the wobble?

What might cause a really slow wobble?

[A slow wobble means the planet is orbiting slowly.] The further the planet is from its star, the slower the wobble.

What might cause a fast wobble?

[A fast wobble means the planet orbits quickly around its star, and hence is closer to its star.]

If an alien astronomer were watching the spectrum of our Sun, which planet do you think would create the biggest wobble?

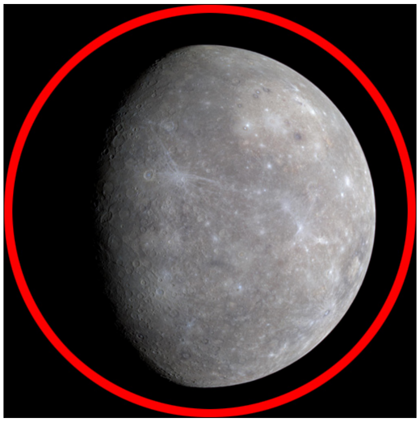
[Jupiter. If necessary, prompt by asking what the biggest planet is.]

VISUAL 8. (still) Jupiter (has big wobble). ►

Which planet would make the fastest wobble?

[Mercury. If necessary, prompt by asking what the closest planet to the Sun is.]

VISUAL 9. (still) Mercury (has fast wobble). ►

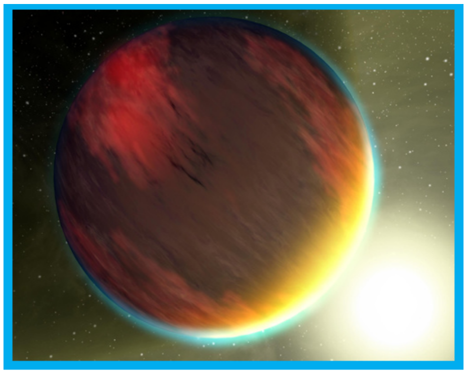


Actually, Mercury would make a *fast* wobble, but also a very *small* wobble since it's not very massive. Most of the extrasolar planets we know of have been found by studying these spectrum wobbles, and they have been quite large—many bigger than Jupiter. Not only that, most of the planet discoveries have been ones that orbit close to their stars. That's because large wobbles and fast wobbles are much easier to find than small, slow wobbles.

If a planet is orbiting close to its star, what would that do to the planet's temperature? **[Hot.]**

Those large planets with close in orbits we often call "hot Jupiters."

VISUAL 10 (still or animation) Artist's rendition of a hot Jupiter. ►



This is a picture of what a hot-Jupiter extrasolar planet might look like. Again, we've never seen one directly. It might look like Jupiter, but being so hot, it's a strange planet indeed. In fact, before they were discovered, people thought Jupiter-size planets so close to at star would be impossible in light of theories of solar system formation at the time. Theories were shattered.

Stars With Planets

In our planetarium sky, we can see a couple of stars that do have giant-size extrasolar planets orbiting them, but not so close as the hot Jupiters. They have more Mars-like orbits—farther out from their stars than Earth is from the Sun. Are they ***strange*** planets? You can see one of those stars year-round in the constellation of Cepheus. Cepheus is a little tricky to find, so let's start with an easier group of stars.

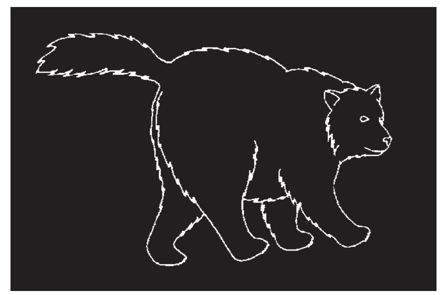
> ***Has anyone ever seen the Big Dipper before? Can you point it out for us?* [Take any answers.]**

It has seven bright stars, making a shape like a weird spoon, or like pot with a long curving handle.

VISUAL 11 Pot outline on the dipper stars. ►

There it is! Some people think of it as part of a giant ferocious bear.

VISUAL 12 Bear outline. ►



One of the coolest things about the Big Dipper is that it can point us to the North Star. See these two stars? ***[Indicate the Pointer Stars.]*** They're called the Pointer Stars because they point to the North Star, which is also called *Polaris*, and it's always in exactly the same spot in the north. If you can find the North Star, you'll never get lost.

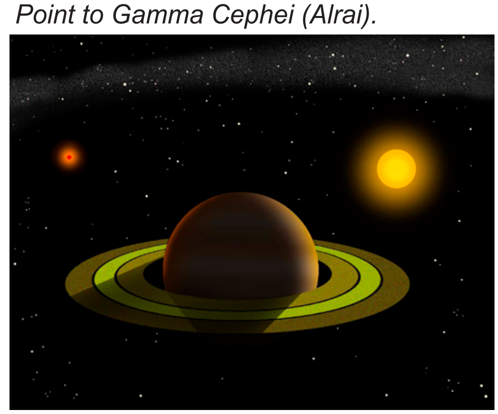
Follow the pointer stars to Polaris, and indicate.

Here's the North Star! And if you keep going a little farther ***[continue to Cepheus]*** you'll find this bright star.

Point to Gamma Cephei (Alrai).

It's just after the North Star, and it's in the constellation of Cepheus, the King. It's called Gamma Cephei, which means "third-brightest-in-Cepheus," or you can call it Alrai (a.k.a. Errai, or Er Rai). Gamma Cephei is 45 light-years away, and is a binary star system: two stars revolving around one another every 50 years or so. That alone might make this a strange planet—imagine having 2 suns in your sky!

**VISUAL 13. Planet with two suns.
Add music. ►**



Optional: Hand out Uncle Al's Kepler Star Wheels (master on Kepler website), have the audience set them for May 25 at 10 pm, and find Alrai (Gamma Cephei) on the star wheel. Explain how to adjust the Star Wheel, and let them know that you'll be telling them how to get their own copy to make from a web page that you'll give them.

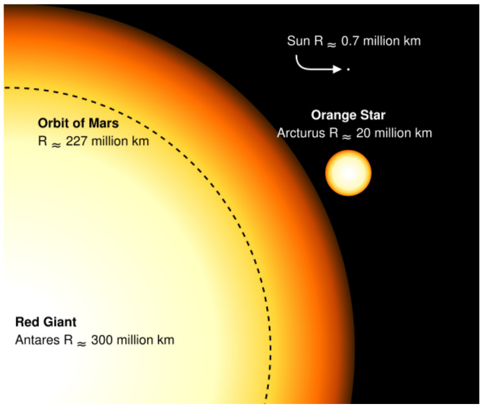
The planet is about 1.5 times the mass of Jupiter, and is going around the larger star in the binary system. It's year is 2.5 Earth years, which is a clue that it is a little farther from it's sun than our Mars is from our Sun.

Another star with a planet can be found in this very famous winter constellation, Gemini.

Point out Gemini, with outline.Fade music.

The brightest star in Gemini is this one, Pollux ***[point to and show label]***. It's only 34 light-years away, and is the brightest visible star that has a known extrasolar planet. The planet has more than twice the mass of Jupiter, and orbits in about 590 days, in an orbit similar to Mars in our solar system. You can see this star from about October (around midnight) through June (just after sunset). Is this a strange planet? Well, Pollux is an orange giant star, evolving into its red giant stage, so yes, you might call this a strange planet with an orange giant sun. Once Pollux is fully evolved into a red giant, it may well engulf this planet!

VISUAL 14. Sun, Orange Giant, Red Giant size comparison. ►



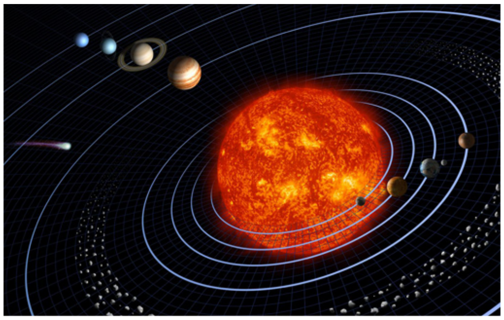
Optional: Find Pollux on Uncle Al's Kepler Star Wheels.

Optional: Show exoplanets (fulldome digital systems) and explain that it shows a some of the over 300 planets discov-ered to date.

Habitable Zones & Kepler's Laws

We're especially interested in planets that might be good homes for living things.

VISUAL 15. (still) Top-view diagram of Solar System. ►



Optional: Show fulldome digital view from above Solar System, with planets labeled/marked & orbits on.

Why don't we expect to find life on Jupiter or Mercury?

[Jupiter is made of mostly gas, with very high pressures, and we don't even know if it has a solid surface, though it's thought to have a rocky core. Mercury is simply too hot—water would vaporize rapidly.]

Hot Jupiters have a double whammy, gas giants that are too hot, and are unlikely to have life develop on them. Jupiter's moon, Europa, is another story altogether. It has liquid water ocean below a crust of ice.

So what about finding planets more like Earth?

What are the conditions that make Earth good for life?

[Take any answers, but focus towards the idea that Earth is not too hot, not too cold, not too big and not too small.]

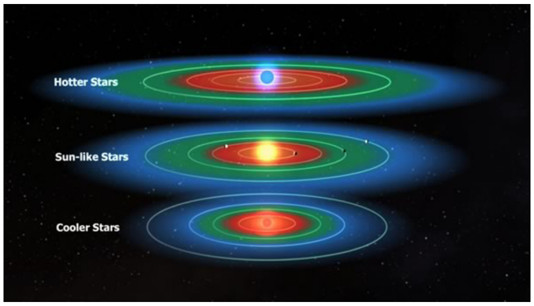
The key is water. And not just any kind of water.

What would happen to water on Mercury where the temperature is over 600 degrees? ***[Boils]***

What happens to water in the outer parts of the solar system where it's REALLY cold? ***[Freezes]***

Water in the form of ice or steam are not what we need for living things. We need LIQUID water on our planet's surface. So, like Goldilocks and the Three Bears, we need a planet that's not too hot, not too cold, but *juuust* right.

So we are interested in finding a planet has the right size orbit that keeps the planet not too far and not too close to its star. This is sometimes called the ***goldilocks zone***, but it's more formally called the ***habitable zone***.



VISUAL 16. (animation) Habitable Zone. ►

Size is also important.

Very small planets with low gravity would not be suitable for life? Why do you think that is?

[Not enough gravity to hold an atmosphere.]

And we already mentioned why a big planet is not suitable for life: gas giants have crushing atmospheric pressures. So just as with temperature, there is a magic "Goldilocks zone" of size: not too big and not too small, but juuuust right—about Earth-sized or thereabouts.

...Which brings us back to the NASA *Kepler* mission. It's designed to find both planet's size ***and*** distance from its star. It's main mission is to find Earth-size planets in the habitable zone of stars.

VISUAL 17. (still) Johannes Kepler. ►

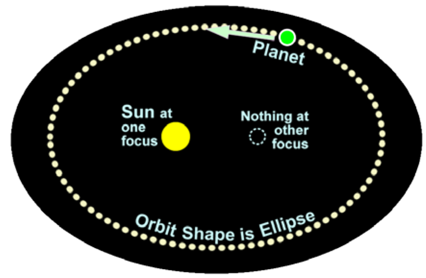
The following section on Kepler's Laws may be omitted for most audiences.

Kepler's name comes from a mathematician and astronomer named Johannes Kepler, who, 400 years ago was an assistant to Tycho Brahe—the greatest observational astronomer of his time. Brahe had made detailed astronomical observations over decades which produced astronomical tables that allowed Kepler to come up with three laws of planetary motion that, for the first time, would predict the positions of planets with great accuracy. His third law, the one that relates how long it takes a planet to orbit the Sun to the distance that planet is from the Sun, is especially loved by Kepler mission scientists.

Kepler's First Law

Do you know what shape orbits planets have? **[Ellipses, or ovals.]**

VISUAL 18. (still) Orbits are ovals graphic. ►



Optional: Keep showing fulldome digital top view of solar system.

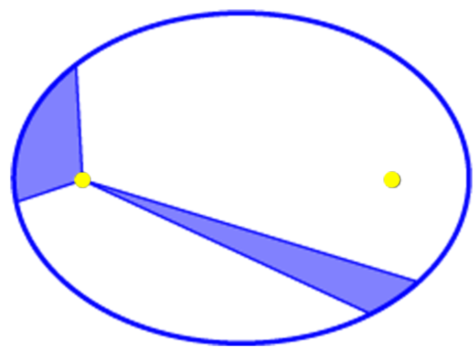
That's Kepler's First Law of Planetary Motion—that planets move in elliptical orbits. Most planets have nearly circular orbits, but not perfectly circular.

What keeps the planets in their orbits? **[Gravity.]**

Right. Kepler didn't know about gravity, but he did notice a pattern to how fast a planet moves at different places in its orbit.

Kepler's Second Law

VISUAL 19. (still) Equal times/equal areas graphic. ►



PLANETS ORBIT WITH VARIABLE SPEED

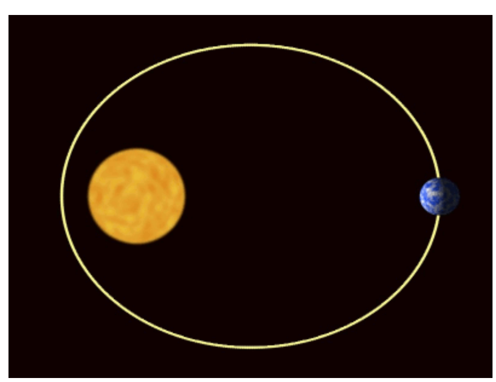
He described that precisely in terms of an imaginary a line drawn from a planet to its star. The area swept by that line when it's closer to the star looks different from the area swept by the line when the planet's farther from the star.

Which area looks larger, the one when the planet is closer or the one when the planet is farther from its star?

Actually, they are exactly the same size. Kepler's second law is that a planet sweeps out equal areas in equal times. A simpler way to think of it is that a planet moves faster when it is close to the Sun and slower when it is further from the Sun.

VISUAL 20. (animation) Equal times/ equal areas graphic. ►

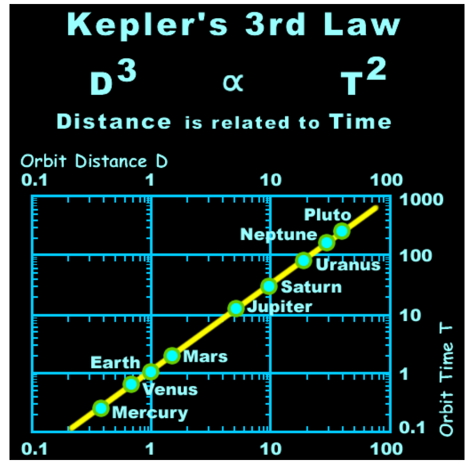
Music—music of the spheres....



***And what's causing that to happen—the planet moving faster when it's closer?* [Gravity.]**

Again, Kepler did not know *why* this was. In fact, no one had an explanation until Isaac Newton came along with his law of universal gravitation some 70 years later.

Kepler's Third Law



Kepler's third law is the most important one for the NASA *Kepler* mission. Johannes Kepler was a firm believer that the physical properties of the Universe could be described purely by mathematics. So, looking for more patterns in the data, he discovered the mathematical relationship between distance a planet is from its star and the time it takes to orbit.

VISUAL 21. (still) Graph of Kepler's 3rd Law ($T^2 \propto r^3$). Don't mention log scales unless someone asks. ►

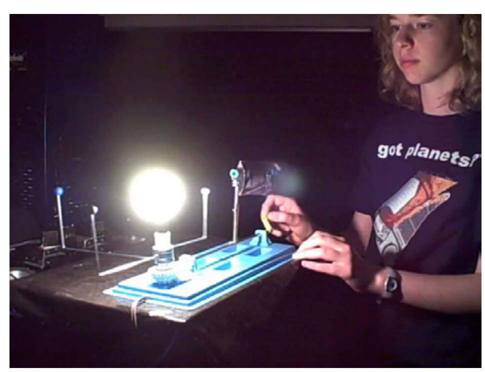
This graph shows Kepler's 3rd law. The x-axis is planet distance and the y-axis is planet orbit time. The distance is in "Astronomical Units" or AUs for short. You can see on the graph Earth's orbit time is 1 year and distance is one AU—in fact that's the definition of an AU: the average distance from the Earth to the Sun. Saturn's at about 10 AU and takes about 30 Earth years to orbit the Sun. Kepler's 3rd Law lets us calculate *the distance* of a planet from its star if we can find *the time* it takes to orbit. And the distance, as you now know, is critical to whether or not the planet is in the habitable zone!

Transiting Planets

Using another very clever technique, we can not only discover extrasolar planets, but determine fairly accurately how big they are and, armed with Kepler's Third Law, we can find out how far they are from the star.

If you do not have a star-planet model (orrery) with light sensor, and the system for projecting light curve graphs in real time, you may use the Orrery and Live-Graph movies.

However, using the real live orrery/light curve set-up is much more fun....

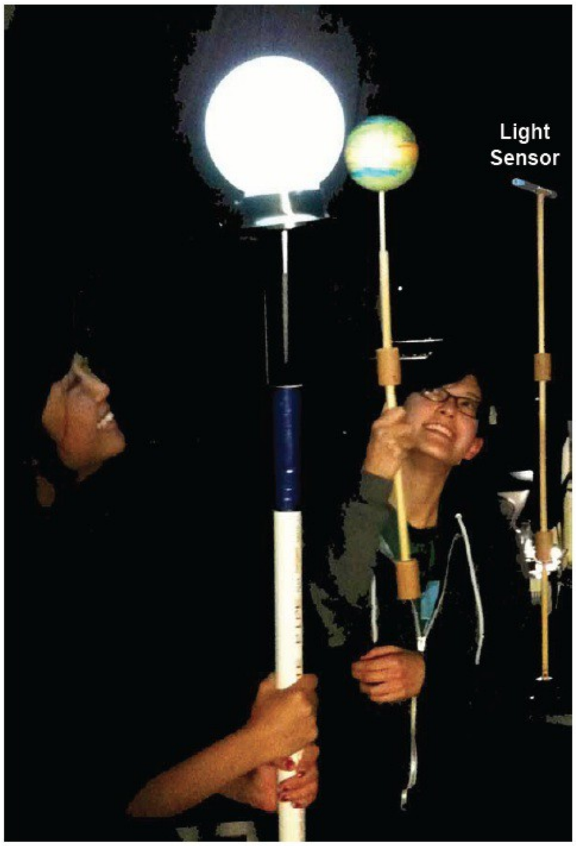


VISUAL 22a. Orrery movie. Point out light sensor, model star (light) and planets. Explain that the sensor will feed star brightness data to a computer and show us a graph of brightness changes. ►

STRANGE PLANETS

Page 21b—UPDATE: A "HUMAN TRANSIT MODEL"

The following pages have the original transit modeling activity. with questions and actions to guide the audience to understand how a light sensor (representing the Kepler light sensing instrument) can detect changes in brightness of a star-planet model (orrery) when the orrery's model planet passes in front of (transits) the orrery's model star.



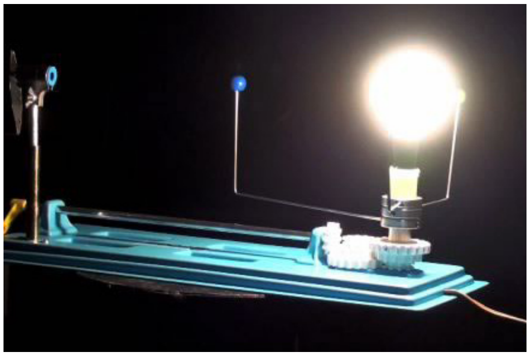
The "human transit model" illustrated by the photo on this update page is much simpler to set up and will work with those same guiding questions that are on the subsequent pages. It also has the advantage of involving two audience volunteers to operate it.

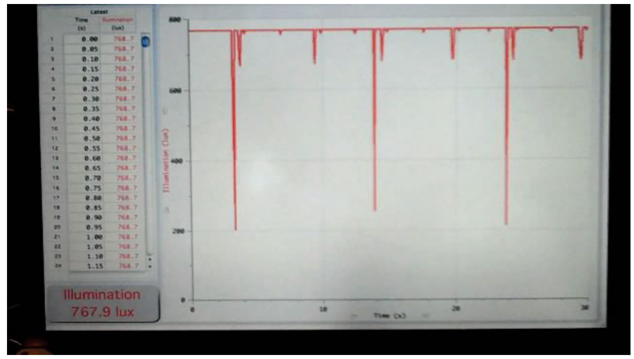
The model star on the left in the photo is a translucent light globe (from hardware store) with a battery powered light source (flashlight) inside. The model planet is simply a polystyrene ball painted to look like a giant planet with atmospheric bands. The light sensor is mounted on a fixed pole while the model planet and model star are mounted on poles that can be held by volunteers from the audience.

The volunteer holding the the model star simply holds it still at approximately the same height as the light sensor. The volunteer holding model planet walks around the model star, careful to hold the planet at about the same height as the model star and the light sensor.

The output of the light sensor feeds through graphing software in real time and projects onto the dome. The audience can see in the brightness vs time graph how the model star brightness drops slightly every time the model planet passes between the model star and the light sensor.

VISUALS 22b and c. Movie of the orrery in action synchronized with the live light curve graph. You can show these side by side or one above the other, in lieu of the a full-blown sumulation setup.





On the live star-planet model make sure the light sensor is aimed at the star-bulb. Switch on the video projector and wake up the laptop, to feed data from the light sensor to the projector, to show Brightness vs. Time graph on the dome.

Caution the audience that you are about to turn on a model star, then turn on the model star, but do not spin it yet.

This is a light sensor that measures the brightness of the star. We can think of this as a model of the NASA *Kepler* spacecraft and its light sensing camera. [Optional: It's also called a photometer because it measures amount of photons of light.]

This is a model star with extrasolar planets we are trying to find.

Vary the display in an obvious way—by putting your fingers or hand between the sensor and the light.

Look! That picture shows the brightness of the star! It's a graph of light brightness—called a *light curve*. You can even tell how long my hand is blocking the light without even being able to see my hand. Just look at the light curve....

Optional: Have audience volunteers block the light with their hands.

Let the graph stabilize so the audience can see the flat line that represents the normal star's brightness, as detected by our "telescope" sensor. Then, turn the crank on the star-planet model so the planets periodically block the light entering the sensor, making a light-curve graph. If using a volunteer instruct them to crank gently and steadily. If the volunteer is somewhat erratic, you can comment that it looks like our solar system machinery is "only human."

What happens when this extrasolar planet passes between the star and our photometer? *[There is a dip in the graph.]*

The extrasolar planet is blocking the light from the star, and our sensor detects it! What a great way to find extrasolar planets! It's like an eclipse. Astronomers call it a "transit," which means "going across." Looking for stars that are having their light blocked as a planet goes across is called the "Transit Method" of finding extrasolar planets.

One limitation of the Transit Method is that it only works if the extrasolar planet and its star are tipped just the right way.

What if the extrasolar planet orbited the star at an angle that was not lined up with our sensor? [No transit could be detected.]

Let's see what we can tell from this light curve graph.

Have a volunteer come up to crank the Star-Planet model.

How can you tell from the light curve if a planet is big or small?

[Big planets make deeper dips in brightness.]

We can also measure how often light is blocked—that means how much time passes from here to here on the graph ***[point out the distance between dips on the projected graph]***. We saw this before, too! That's the period.

How can you tell from the light curve if the planet is close to or far away from its star?

[Farther out planets make dips that are more widely spaced.]

If the dips on the light curve graph are close together—then the planet is orbiting the star really fast, and it must be really close to the star. *That* means it is a *hot* planet.

Look how close the dips are in that light curve graph!

[Point to most closely spaced dips]

That's a close, hot planet!

[Point to most widely spaced dips]

Then the planet would have to be far away from the star, and that means it is a colder planet. Look how far apart the dips are on that light curve graph! That planet is really creeping—must be far from its star. Brrr! That's a cold planet!

Since big planets block a lot of light and small planets only block a little bit of light, big planets are easier to find than small planets! Just like with the spectra of star wobbles. Big hot Jupiters are the easiest to find.

If you have an orrery with only 1 planet, you can still analyze light curves as follows: Have an audience member turn the crank and explain that, after 15 or 20 seconds, you are going to ask them to stop cranking so you can put a different size planet on. Ask them to keep cranking at as steady a speed as they can. In this way, you will generate two "half" light curves, side by side. In many ways, this is even easier for people to analyze than the light curve with both planets going simultaneously.

To compare the effect of orbit distance, again have a volunteer crank the Star-Planet model, but this time, explain that instead of changing planet size, you are going to change how far the planet is from the star.

Have the volunteer start by cranking fairly fast, with the planet about a third to halfway out on the model arm. Start the data collecting and, after 15-20 seconds, have the volunteer stop. Move the planet out to the end of the arm and have the volunteer continue cranking slower.

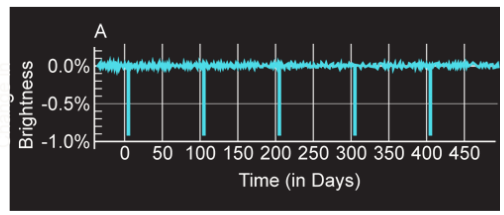
VISUAL 23. Still image of Kepler spacecraft. ►

The Kepler instrument uses a light sensor like the one we've been using today, except that it's huge, with nearly 100 million pixels, and it's in a big telescope to collect lots of light. How many pixels does your digital camera have? 5 megapixels? 8 megapixels? I bet it's not 100 megapixels, like the Kepler spacecraft camera!

Finding an Earth-like Exoplanet

So if we will be getting all this data from the Kepler mission, how will we know if we do find an Earth-like planet in the habitable zone? Let's imagine we are the planet finders and have look at some data.

VISUAL 24a. Light Curve A. ►



Here is light curve data from a model star with an exoplanet. We can determine how big the planet is from how deep the dips in brightness are.

On graph A, how deep is the dip, in % brightness drop?

[Almost 1%. Maybe 0.9%.]

VISUAL 25a or b. Still image of Planet Size Lookup Chart. ►

Exoplanet Size Lookup Chart*

Brightness Drop (%)	Planet Size (Earth=1)
0.01	1.0
0.02	1.4
0.04	2.0
0.06	2.4
0.08	2.8
0.10	3.2
0.12	3.5
0.14	3.7
0.3	5.5
0.5	7.1
0.7	8.4
0.9	9.5
1.0	10.0

* For Sun-like stars

Look at the Brightness Change vs Planet Size Lookup Chart.

How big is a planet with 1% or 0.9% brightness change?

[About 10 times Earth radii]

You can also determine how far the planet is from it's star by measuring how widely-spaced the brightness drops are, to find the planet's orbit time (period).

On graph A, what is the orbit time? *[100 days.]*

VISUAL 25a or c. Still image of Orbit Distance Lookup Chart. ►

Exoplanet Distance Lookup Chart*

Orbit Time (days)	Orbit Distance (Earth=1AU)
25	1/6
50	1/4
100	0.42
150	1/2
200	2/3
250	0.78
300	7/8
350	.97
400	1.06
450	1.15
500	1.23
550	1.31
600	1.39

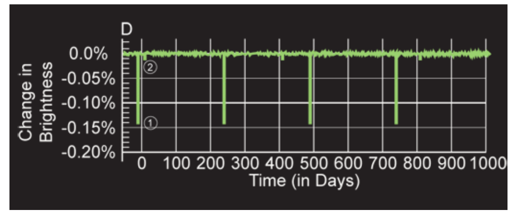
* For Sun-like stars

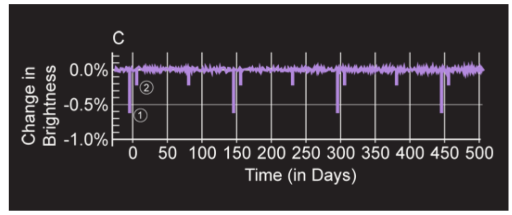
Now look on the Orbit Time vs Orbit Distance Lookup Chart.

How far out is a planet with a 100 day period?

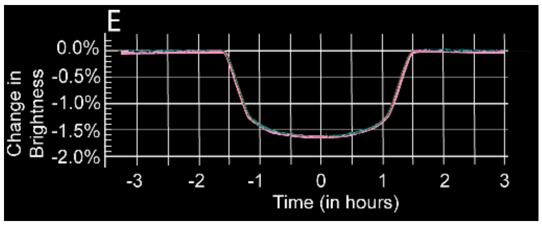
[0.42 AU or a little less than half the distance from Earth to the Sun.]

Is that an Earth size planet? Is it in the habitable zone?
[No.]



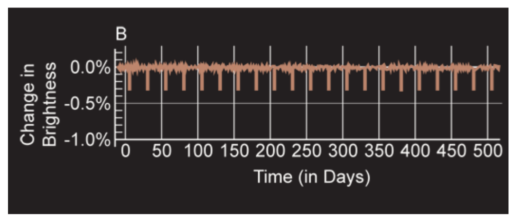


VISUALS 22b and c. Light Curves B and C are not normally used during the show, but are included on the handout sheets to give to audience to take home and have more fun finding planet sizes and orbit distances. Light Curve E (below) is a real light curve of data from the Hubble Space Telescope observing a transit of planet HD209458b.



Let's look at Light Curve D.

VISUAL 24d. Light Curve D. Leave A up also. ►



Here you should be able to see 2 planets in the same light curve.

> ***How deep is the dip, in % brightness drop for planet 1 on Light Curve B?*** *[.14%. The scale is much smaller than the one in Light Curve A.]*
>
> ***From the Planet Size Lookup Chart, how big is a planet with 0.14% brightness change?***
>
> *[About 3.7 times Earth's size]*
>
> ***What is the Orbit Time for planet 1?***
>
> *[About 250 days.]*

Now look on the Orbit Distance Lookup Chart**.**

How far out is a planet with a 240 day period?

> *[0.78 AU or about 3/4 the distance from Earth to the Sun.]*
>
> ***Is that an Earth size planet? Is it in the habitable zone?*** *[No.]*
>
> ***How about planet 2?***
>
> ***How deep is the dip, in % brightness drop for planet 2?*** *[.01%.]*
>
> ***How big is a planet with 0.01% brightness change?***
>
> *[Earths size!]*
>
> ***What is the Orbit Time for planet 2?*** *[About 400 days.]*

Now look on the Period vs Distance from Star chart**.**

Optional Technique (takes longer): After analyzing light curve A as a whole group, have "small groups" analyze the rest of the light curves, B though D. Give out the **Strange Planets take-home handout to each** *group to find Size and Distance for each of the exoplanets from the light curves. Remind them they are looking for an Earth-size planet that is in the habitable zone of its star. If a group finishes it's assigned star, they can go ahead and pick another star to work on.*

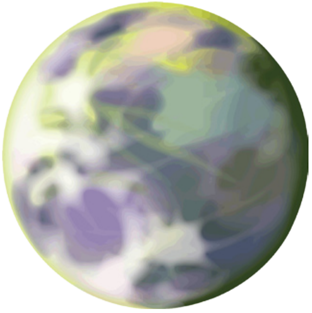
Turn on "planet-finding music."

After all have found results on their assigned star, have a discussion with the group as a whole about what planet(s) are Earth-like and habitable, and how they know that.

How far out is a planet with a 400 day period?

[1.06 AU — only slightly more than the distance from Earth to the Sun.]

Is that an Earth size planet? Is it in the habitable zone? *[Yes!]*



VISUALS 26a and b. Artist's conception of Earth-size planet. ►

What does it look like—this potentially habitable planet we found? What is its surface like? Does it actually have life? If it does, what is that life like?

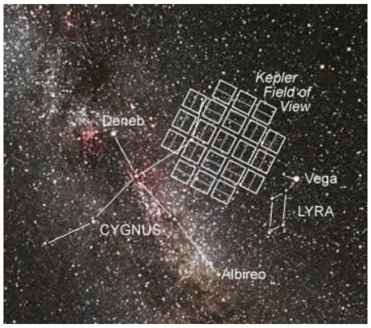
Isn't it amazing that just by studying a light curve graph of a star's brightness over time, we can learn such a tremendous amount? We can find out a planet's size, how long its year is, how far it is from its star, and even the prospects for it supporting life!

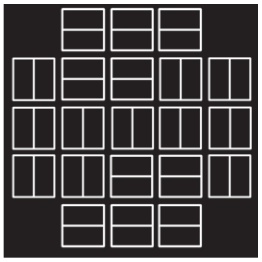
Conclusion

Fulldome digital: Turn on all exoplanets.

Music.

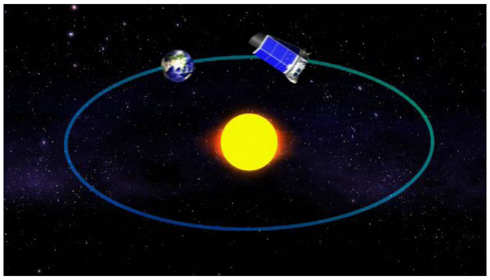
We are finding new extrasolar planets all the time. But the goal is to find these habitable, Earth-like planets.





VISUAL 27. (still) Kepler's target area. Two version of this are available. One has the star field with the CCD pattern superimposed. The other is just the CCD pattern that you can position over the actual stars in your planetarium—especially suitable for digital star projectors.

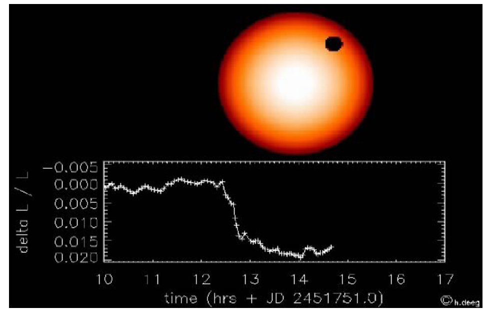
The NASA Kepler mission is specifically designed to survey our region of the Milky Way galaxy, to discover hundreds of Earth-size and smaller planets, some of which may be in the habitable zones of their stars. It will stare at a this section of the sky, that you see here near the constellation Cygnus (the Swan), for three and a half years, never blinking, and survey about 100,000 stars simultaneously.

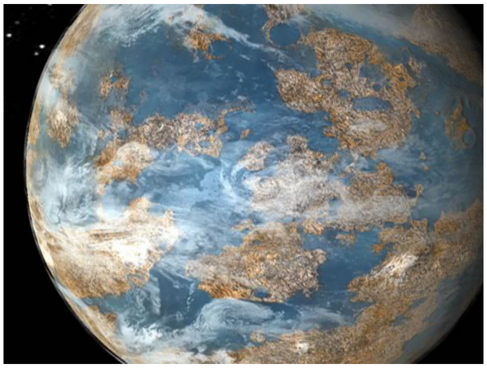


VISUAL 28. Animation of Kepler's orbit around the Sun. ►

Kepler will follow, or trail, Earth in its orbit around the Sun. Every three months, Kepler will roll to keep its solar panels pointed towards the Sun and its exquisitely sensitive photometer (light meter) aimed at those 100,000 stars.

VISUALS 29a and/or b. (animations) Transit. Animation (a) has no light curve graph. Animation (b) shows light curve along with transiting planet animation. ►





◄ VISUAL 30. Movie: Diversity of Life

The ultimate goal is not just to find planets, or even to find Earth-sized planets, but to find Earth-sized planets that are not too hot, and not too cold, but planets that are just right for life to develop. Some planets will be too hot, orbiting very close to their stars, possibly with lots of volcanoes continually erupting. Some planets will be too cold, far from their stars and eternally frozen. However, some planets will be just right and will have those essential ingredients for life—life, just as we see here on Earth.

If we do find Earth-sized planets, it will be a tremendous discovery. Equally exciting is that the Kepler mission is designed to settle the age old question of whether planets like ours are common or not. Even if we do not find Earth-sized planets, that would also really significant, because that would tell us that planets like ours are quite rare, and our home planet all that much more precious and worth preserving. And underlying everything, Kepler results have implications in answering questions about the possibility of life existing elsewhere in our galaxy. Are intelligent beings common or rare in the Universe? Kepler mission is a serious first step to get real data that may eventually lead to an answer that question!

Thank you for coming to our planetarium today!

About Exoplanets

California & Carnegie Planet Search
http://exoplanets.org/

The Extrasolar Planets Encyclopedia website at
http://exoplanet.eu/

Kepler Mission website
http://kepler.nasa.gov/

Kepler Star Wheel:
http://kepler.nasa.gov/ed/starwheel/

Make a LEGO® Orrery:
http://kepler.arc.nasa.gov/ed/sim/lego.html

PlanetQuest Website
http://planetquest.jpl.nasa.gov/

Wikipedia, the free encyclopedia— "Extrasolar Planet" Wikimedia Foundation.
http://en.wikipedia.org/wiki/Extrasolar_planets

Top 10 Most Intriguing Extrasolar Planets
http://www.space.com/scienceastronomy/extrasolar_planets.html

Worldwide Web Connections

**and updated information may be found at:
http://www.lhs.berkeley.edu/pass**

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