SESSION 4.5
Detecting Extrasolar Planets

Overview

The search for extrasolar planets—planets outside our Solar System orbiting other stars—is a rapidly growing and active area of current astronomy research. As of 2007, astronomers had found over 250 planets! As the list of newly discovered planets grows, however, the search for one that might be capable of supporting liquid water and habitable life continues. In this session, students learn about the search for extrasolar planets using the method of transit detection. Teams are given access to a variety of materials and asked to construct a model that can be used to demonstrate the transit of a planet across the face of a star. Each team exhibits its model to the class and discusses which aspects of a transit the model best represents. By viewing each other's models and observing the brightness of a star dim as it is transited by a planet, students discover yet another way scientists can analyze light to learn about distant objects. The student reading, Understanding the Scale of the Universe, may be assigned as homework after this session or incorporated into the next session. During this session, the key concept added to the classroom concept wall is:

- *When a planet transits a star, it blocks part of the light of the star.*

Detecting Extrasolar Planets	Estimated Time
The Hunt for Extrasolar Planets	10 minutes
Introducing Transits	5 minutes
Designing Transit Models	20 minutes
Modeling Transits	10 minutes
Total	**45 minutes**

What You Need

For the class:

- ❑ overhead projector or computer with large-screen monitor or LCD projector
- ❑ prepared key concept sheet from the copymaster packet or CD-ROM file
- ❑ transparency of the Sun with Venus in Transit from the transparency packet or CD-ROM file
- ❑ a marker
- ❑ a piece of butcher paper

Unit Goals

The Universe has a hierarchical structure; it is made up of billions of galaxies, and each galaxy is made up of billions of stars.

The Universe is enormous, and contains a diversity of objects with a variety of characteristics.

Vast distances of empty space separate objects in the Universe.

Scientists investigate and study very distant objects in the Universe by analyzing the light that comes to Earth from these objects.

Current planet detection methods are able to find only a small fraction of the number of planetary systems that exist in the Universe.

TEACHER CONSIDERATIONS

TEACHING NOTES

For this session, consider giving your student teams more time to construct their transit models.

The key concepts can be posted in many different ways. If you don't want to use sentence sheets, here are some alternatives:

- Write the key concepts out on sentence strips.
- Write the key concepts out before class on a posted piece of butcher paper. Cover each concept with a strip of butcher paper and reveal each one as it is brought up in the class discussion.

Key Vocabulary

Scientific Inquiry Vocabulary

Category
Characteristic
Evidence
Model
Observation
Prediction
Scale
Scale model
Scientific explanation

Space Science Vocabulary

Extrasolar planet
Galaxy
Life zone
Light minute
Light second
Light year
Milky Way Galaxy
Nebula
Planetary nebula
Spectrum
Star
Supernova
Transit
Universe

If you cannot find snake book lights, create a model "star" by setting up a light bulb and socket in the middle of the classroom for teams to demonstrate their transits. Or provide each team with their own light bulb and socket to work with. An alternative to the plastic beads is to have students use modeling clay to make the planets for their models. Be aware that this option may not be appropriate for all classes, especially those in which class management is an issue. Plastic beads (as long as they are opaque!) work well in the models.

For each team of 4–6 students:

- ❑ 1 snake book light
- ❑ 1 prepared Ping-Pong ball (see Getting Ready)
- ❑ several round, ***opaque*** plastic beads (ranging in size from 8 mm to 16 mm in diameter)
- ❑ 2 or more pipe cleaners (about 30 cm or 1 foot)
- ❑ 1 or 2 chopsticks or thin wooden dowels (about ⅛ inch in diameter, 30 cm or 1 foot)
- ❑ black thread (about 1 meter or a little over 1 yard)
- ❑ 4" x 6" index cards
- ❑ tape
- ❑ paper or plastic bag large enough to hold the above materials
- ❑ (optional) modeling clay

For each student:

- ❑ (optional) 1 copy of the Understanding the Scale of the Universe—Student Reading (two pages) from the copymaster packet or the CD-ROM file

GO! Getting Ready

1. **Arrange for the appropriate projector format to display images to the class.** Decide whether you will be using the overheads or the CD-ROM. Set up an overhead projector or a computer with a large-screen monitor or LCD projector.

2. **Prepare the key concept sheet.** Make a copy and have it ready to post onto the classroom concept wall during the session.

3. **Prepare a class chart.** Using a marker, write across the top of a piece of butcher paper Questions Astronomers Might Have About an Extrasolar Planet. Set this aside for use later, when the class begins to discuss the search for extrasolar planets. (Note: After the discussion, keep the class list of questions—you will need it for Session 4.6.)

4. **Decide how you will divide the class into teams of 4–6 students.**

5. **Prepare the snake book lights.** Carefully pull the colored shade off the tip of each light's flexible neck to expose the bare bulb.

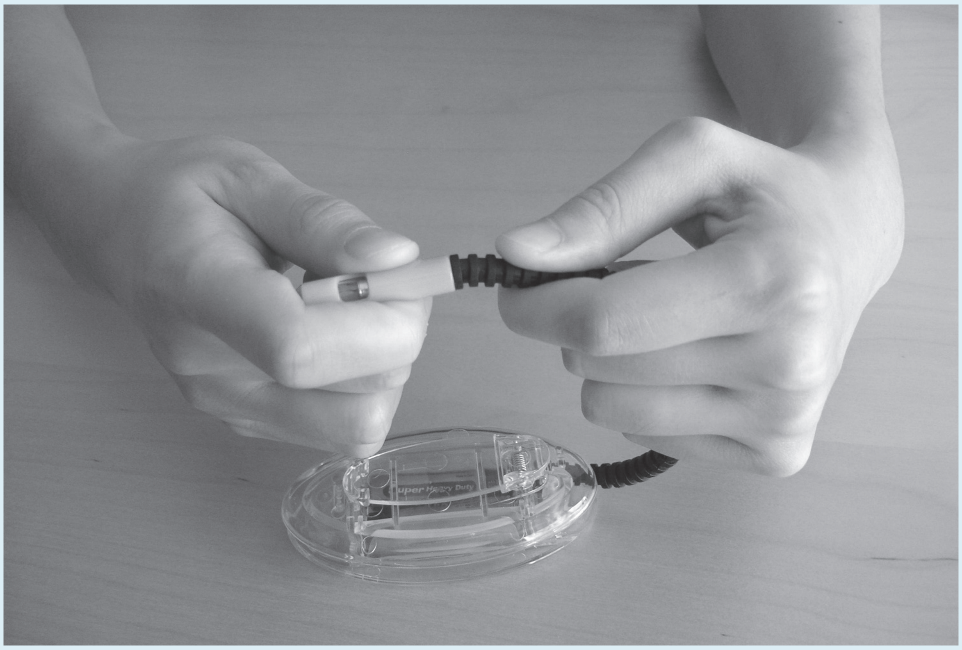
6. **Prepare a Ping-Pong ball "star" for each team.** Using a pencil, carefully poke a hole in each Ping-Pong ball. Slip the bulb of the book light into the hole, so that when the book light is switched on, the Ping-Pong ball glows like a star.

7. **Assemble a packet of materials for each team.** Place each team's transit model materials in either a paper or plastic bag. Wrap the thread around a folded index card to prevent it from tangling.

TEACHER CONSIDERATIONS

TEACHING NOTES

Depending upon the amount of class time available, you may choose to assign the student reading, Understanding the Scale of the Universe, as homework after students have completed this session or include it as an activity in Session 4.6.



8. **Arrange the classroom so each team has a workspace.** Each workspace should have enough space for a team to work on assembling their models.

9. **Reduce the amount of light in the room.** If possible, draw the curtains or blinds most of the way so students can make and demonstrate their models in dim light.

10. **Optional: Make a copy of the Understanding the Scale of the Universe—Student Reading (two pages) for each student.**

11. **Optional: Update your knowledge of current news about extrasolar planets.** Check the Extrasolar Planets Encyclopedia website at http://exoplanet.eu/ to find out how many extrasolar planets have been discovered and to catch up on related news. NASA's Kepler mission is designed to dramatically increase our understanding of extrasolar planets. Check the website at http://kepler.nasa.gov/ for news of the mission.

GO! The Hunt for Extrasolar Planets

1. **The possibility of planets orbiting other stars.** Ask the class if they think there may be planets orbiting other stars—*extrasolar* planets. Some students may reason that our Solar System is not unique, and that there are other systems similar to ours out there. Other students may have already heard about the ongoing search by astronomers for extrasolar planets.

2. **Stars with longer lifespans are more likely to harbor planets with life.** Ask students if all stars are the same size and temperature as our Sun. [No. Stars have vastly different sizes and temperatures.] Ask what information the temperatures of stars reveal. [Hotter stars have shorter lifespans, while cooler stars have longer lifespans.] Remind students that since life as we know it requires a very long time to evolve, stars with longer lifespans are more likely to have extrasolar planets harboring life.

3. **A star with a large life zone is ideal.** Remind the class that a life zone of a star is the area of space around it where liquid water can exist. Ask students why liquid water is important in the search for life on extrasolar planets. [Liquid water is necessary for life, as we know it, to develop.] Remind students of the posted key concept from Session 4.4:

   Liquid water is a necessary condition for the development of life as we know it.

TEACHER CONSIDERATIONS

ASSESSMENT OPPORTUNITY

CRITICAL JUNCTURE: REVIEWING SCALE AND ARRANGEMENT OF SYSTEMS IN THE UNIVERSE

During this discussion, you may notice some continuing confusion from your students about the scale and hierarchical arrangement of systems in the Universe. Some students may still be unsure about the distinction between planets orbiting the Sun in the Solar System and planets orbiting other stars much farther away. If needed, take some time to reinforce the concepts of hierarchy and scale introduced in Session 4.3.

4. **Searching for life beyond the Solar System.** Tell students that astronomers are interested in finding extrasolar planets—particularly ones that may have the potential to support life. Explain that habitable planets are more likely to be found orbiting stars with larger life zones that have conditions that are "just right" for life to develop, like our Sun.

5. **The ongoing search for extrasolar planets.** Tell the class that so far, as of late 2007, more than 250 extrasolar planets have been found. (Use current figures if you have them.) Explain that although none of the planets found have been exactly like Earth, three have been described as being Earth-sized, and there is evidence that one of those is the proper distance from its star, so that it is *potentially* capable of harboring water and life.

6. **Questions astronomers might have about extrasolar planets.** Have students volunteer questions they think an astronomer might ask about a newly discovered extrasolar planet. List their suggestions on the posted chart titled, Questions Astronomers Might Have About an Extrasolar Planet. Students may suggest the following questions:

   - How large is the planet?
   - How fast does the planet orbit around its star?
   - Is it in a planetary system with other planets?
   - Is the planet Earth-like?
   - Does the planet have life on it?

7. **Why extrasolar planets are difficult to detect.** Ask the class why they think it might be difficult for astronomers to determine whether or not another star has planets. If the following points are not mentioned, be sure to say that:

   - Other stars are very, *very* far away from us, which makes it difficult to detect planets orbiting them.
   - Unlike stars, planets don't generate their own light. Instead, they reflect the light coming to them from stars. Since the amount of light reflected by a planet is so small, it shines dimly.
   - Even when viewed through a telescope, the reflected light from a planet is usually overwhelmed by the light coming from the star it orbits.

8. **Methods used in the search for planets.** Tell the class that astronomers have developed several methods for detecting extrasolar planets. The class will learn about one method today.

TEACHER CONSIDERATIONS

SCIENCE NOTES

Using spectroscopy to detect planets. Astronomers have several methods for identifying extrasolar planets. In addition to the detection of transits, spectroscopy is used to search for distant planets outside of our Solar System. The use of spectroscopy can give evidence that a star "wobbles" ever so slightly as a planet orbits it.

A star with a planet will wobble due to the planet's gravitational pull on the star as the planet orbits around it. This results in the star and planet both orbiting a common point called the center of mass of the planet-star system.

Using spectroscopy, astronomers can search for stars with slight wobbles. This is done by measuring the change in wavelength of the light coming from a star. If a planet-star system's orbit is along the observer's line of sight, spectroscopy can determine if the star is moving slightly toward or away from the observer. As the star moves toward the observer, its wavelength of light decreases, shifting toward the blue end of its spectrum. As the star moves away from the observer, its wavelength of light increases, shifting toward the red end of its spectrum. Called the *Doppler* effect, this change in a star's wavelength of light results from the star orbiting a common center of mass with a companion planet.

For more information, please see page 35 in the Background Information for Teachers section.

Introducing Transits

1. **Show of the Sun with Venus in Transit transparency.** Call on students to describe what they see. Confirm that the image is of our star, the Sun. Ask the class where they think the picture was probably taken from. [The clouds in the foreground of the image indicate that the picture was taken from Earth.]

2. **If no students mention it, point out the dark spot near the right edge of the Sun.** Tell them that this is the planet Venus passing in front of the Sun. This is called a *transit*. Explain that a transit is when a planet passes between an observer and a star, blocking out some of the star's light.

3. **What happens when a planet transits a star.** Ask students what observers might see if they were watching a planet making a transit across a star much more distant from us than the Sun. Have them discuss the question for a minute or two in pairs and then call on students to share their ideas. Explain that since other stars are so far away, it's unlikely that an observer would be able to see a dark spot on the star being transited. Instead, the observer would see the star becoming slightly dimmer as the planet passed in front of it. Post on the concept wall, under Key Space Science Concepts:

   When a planet transits a star, it blocks part of the light of the star.

4. **About the Kepler Mission.** Tell the class that scientists are interested in using transits to detect extrasolar planets—especially the smaller, Earth-like ones that might support life. A mission dedicated to detecting transits is being prepared for launch in 2009. Called the Kepler Mission, it's being designed to monitor the brightness of 100,000 stars and will be looking for evidence of planetary transits as it searches for potentially habitable Earth-size planets.

5. **Detecting transits is another form of analyzing light.** Remind students that in previous sessions they learned how scientists can learn about an object by analyzing its spectrum. Point out that by monitoring the brightness of stars being transited by planets, scientists are again using light as a tool to gather evidence about distant objects. Remind students of the posted key concept from Session 4.1:

   Scientists learn about distant objects in the Universe by analyzing the light that comes to Earth from these objects.

TEACHER CONSIDERATIONS

SCIENCE NOTES

(NASA) Astronomy Picture of the Day

June 23, 2004 (picture taken June 9, 2004)
Copyright by David Cortner.

Sun with Venus in Transit

Sun with Venus in Transit

The rare transit of Venus across the face of the Sun earlier this month was one of the better-photographed events in sky history. Both scientific and artistic images have been flooding in from the areas that could see the transit: Europe and much of Asia, Africa, and North America. Scientifically, solar photographers confirmed that the black drop effect is really better related to the viewing clarity of the camera or telescope than the atmosphere of Venus. Artistically, images might be divided into several categories. In the first category, the transit is captured in front of a highly detailed Sun. Another category captures a double coincidence such as both Venus and an airplane simultaneously silhouetted, or Venus and the International Space Station in low Earth orbit. A third category involves a fortuitous arrangement of interesting-looking clouds, as shown by example in the above image taken from North Carolina, USA. At first glance, the distant orb of giant Venus might have been mistaken for a small but unusually circular cloud.

PROVIDING MORE EXPERIENCE

The following additional discussion points about transits are highly recommended, if you have the time:

Other planets besides Venus that may transit the Sun. Ask the class whether, as seen from Earth, there are any other planets in the Solar System that transit the Sun. [Mercury.] Follow up by asking students why we wouldn't ever see Mars or any of the outer planets transit the Sun. [The orbits of these planets are outside of Earth's orbit, so they will never be between Earth and the Sun.]

What causes a solar eclipse. Ask the class whether the Moon ever transits the Sun. [Yes.] Solar eclipses occur when the Moon moves between Earth and the Sun.

Designing Transit Models

1. **Divide the class into teams of 4–6 students.** Tell the class that each team will construct a model to demonstrate the transit of a star by a planet.

2. **Review models briefly with the class.** Remind the class that while a model is not exactly like the real thing, it should accurately demonstrate or show something about the real thing. Refer to the posted key concept from Session 4.4:

   Scientists use models to demonstrate ideas, explain observations, and make predictions.

A useful tip to share with your students: If the pipe cleaners are too flimsy, twist two of them together to make them more rigid.

3. **Show teams materials to make models.** Hold up a bag of materials for the class to see. Show students the items in the bag and say that each team should devise its own way of using these materials to make a model of a transit. Explain that a small battery-powered light bulb with a Ping-Pong ball over it will represent the star in their model. The beads or other materials can be used to model the planet.

4. **Teams should be able to demonstrate a transit using their models.** Make sure teams understand that the model they make will be used to *demonstrate* a planetary transit for the class to observe. Tell teams they will only have about 10–15 minutes to create their model, so it should not be too elaborate.

5. **Teams should refer to the posted list of Questions Astronomers Might Have About an Extrasolar Planet as they work.** Ask teams to think about how the transit model they are designing might help to answer some of the questions listed on the class chart.

6. **Think about detecting transits with the models.** Tell teams they should keep in mind what a transit will look like with the model they are building, how an observer needs to be positioned to see a transit, and whether there are other ways—besides just looking directly at the star—a transit could be detected.

7. **Encourage students to save batteries.** Since the model star is a battery-powered light bulb, students should turn it on only when they need to see the "starlight" to get ideas about how to build the model or when they need to see how their model is working. They should leave it switched off at other times.

One teacher said, "Once I got the students started in thinking about ideas on how to model a transit, they created their own unique models. It really got their creative juices flowing and challenged them to think."

Another said, "Making their own models was fabulous. They did so get 'into' the spirit of transit. As is usual in my class, there developed a competition to see whose model dimmed the light more; which variables would make the biggest difference? They tested differences in revolution, speed, angle, and distance from the light source."

8. **Teams that finish early can make modifications to their models.** Give the class some ideas by suggesting a few options, such as changing the size of the planet or the size of its orbit. Encourage teams to be creative in coming up with their own modifications. Be sure to stress that only those teams who have finished their basic models with time to spare should work on modifications.

9. **Have teams begin constructing their models.** Circulate among teams to check that students are using their materials correctly and safely. Encourage teams to consider input from all members when creating their models.

10. **Teams prepare to demonstrate their models.** After 10–15 minutes have passed, let teams know they should begin finishing up their models. Give them a minute or so to discuss how they will demonstrate their model to the rest of the class.

Modeling Transits

1. **Have teams switch off light bulbs.** Only the team demonstrating its model should turn on its light bulb.

2. **Each team explains and demonstrates its model.** Have team members explain what each part of their model represents. If necessary, ask them to describe the best position for someone to observe their model. Have team members explain what aspect of a transit their model best demonstrates.

3. **Point out effect of light bulb's glare.** Students may notice that the glare from the light bulb can make it difficult to observe the models. (If not, point this out to them.) Use this opportunity to tell students that it is the glare of the real stars in the sky that makes it so difficult to see the planets.

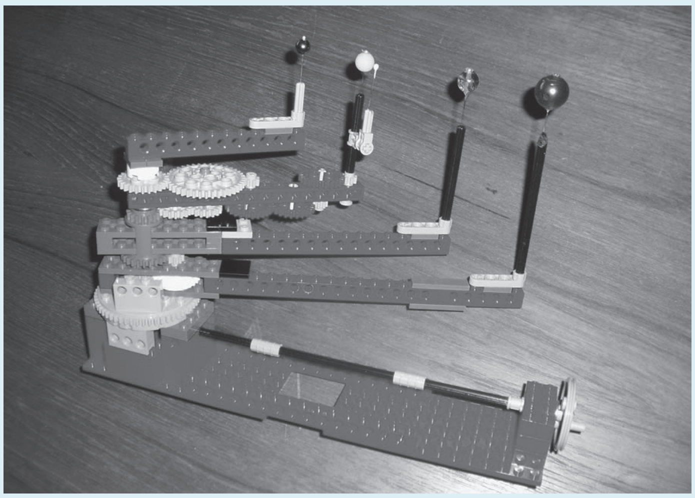
4. **Have students clean up materials.** If you are able to leave all or some of the models out for the next session, have students put their unused materials back in the bags and collect them. If you can't leave the models out, or if you are going to use the materials again for another class, have students disassemble their models and put *all* the materials back in their bags.

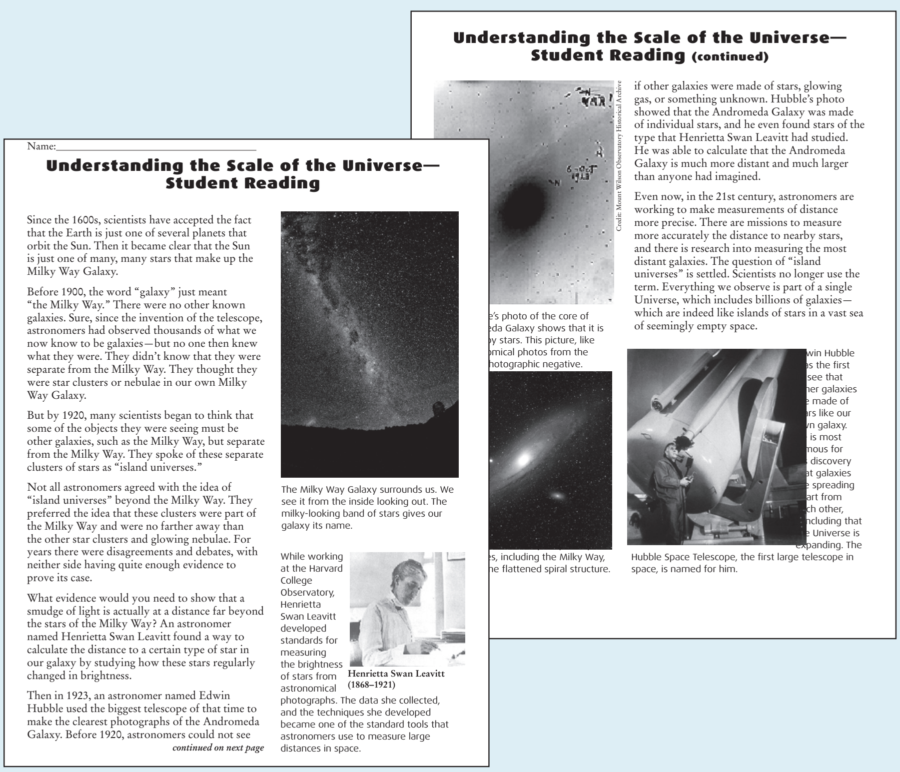
5. **More about transits in next session.** Tell the class that they will continue to discuss transits during the next session.

6. **Optional: Assign the student reading, Understanding the Scale of the Universe, as homework.** If you have decided to assign the reading as homework, pass out a copy of it to each student.

PROVIDING MORE EXPERIENCE

A simulation of a mission to detect transits. A mechanical model of a system of stars and planets can be built with LEGOs. This is educational in itself, but with a computer-linked photometer, it becomes an excellent model of a transit-detecting mission. Students can see data of a model star's changing brightness on the computer screen as model planets pass in front of it. Details of construction and lesson ideas can be found on NASA's Kepler website: http://kepler.nasa.gov/ed/lego.html





Name:________________________________

Understanding the Scale of the Universe—Student Reading

Since the 1600s, scientists have accepted the fact that the Earth is just one of several planets that orbit the Sun. Then it became clear that the Sun is just one of many, many stars that make up the Milky Way Galaxy.

Before 1900, the word "galaxy" just meant "the Milky Way." There were no other known galaxies. Sure, since the invention of the telescope, astronomers had observed thousands of what we now know to be galaxies—but no one then knew what they were. They didn't know that they were separate from the Milky Way. They thought they were star clusters or nebulae in our own Milky Way Galaxy.

But by 1920, many scientists began to think that some of the objects they were seeing must be other galaxies, such as the Milky Way, but separate from the Milky Way. They spoke of these separate clusters of stars as "island universes."

Not all astronomers agreed with the idea of "island universes" beyond the Milky Way. They preferred the idea that these clusters were part of the Milky Way and were no farther away than the other star clusters and glowing nebulae. For years there were disagreements and debates, with neither side having quite enough evidence to prove its case.

What evidence would you need to show that a smudge of light is actually at a distance far beyond the stars of the Milky Way? An astronomer named Henrietta Swan Leavitt found a way to calculate the distance to a certain type of star in our galaxy by studying how these stars regularly changed in brightness.

Then in 1923, an astronomer named Edwin Hubble used the biggest telescope of that time to make the clearest photographs of the Andromeda Galaxy. Before 1920, astronomers could not see

continued on next page

The Milky Way Galaxy surrounds us. We see it from the inside looking out. The milky-looking band of stars gives our galaxy its name.

While working at the Harvard College Observatory, Henrietta Swan Leavitt developed standards for measuring the brightness of stars from astronomical photographs. The data she collected, and the techniques she developed became one of the standard tools that astronomers use to measure large distances in space.

Henrietta Swan Leavitt (1868–1921)

Understanding the Scale of the Universe—Student Reading (continued)

Credit: Mount Wilson Observatory Historical Archive

…e's photo of the core of …eda Galaxy shows that it is …y stars. This picture, like …omical photos from the …hotographic negative.

if other galaxies were made of stars, glowing gas, or something unknown. Hubble's photo showed that the Andromeda Galaxy was made of individual stars, and he even found stars of the type that Henrietta Swan Leavitt had studied. He was able to calculate that the Andromeda Galaxy is much more distant and much larger than anyone had imagined.

Even now, in the 21st century, astronomers are working to make measurements of distance more precise. There are missions to measure more accurately the distance to nearby stars, and there is research into measuring the most distant galaxies. The question of "island universes" is settled. Scientists no longer use the term. Everything we observe is part of a single Universe, which includes billions of galaxies—which are indeed like islands of stars in a vast sea of seemingly empty space.

…es, including the Milky Way, …he flattened spiral structure.

…win Hubble …s the first …see that …er galaxies …e made of …rs like our …n galaxy. … is most …nous for … discovery …t galaxies … spreading …art from …ch other, …ncluding that … Universe is expanding. The Hubble Space Telescope, the first large telescope in space, is named for him.

SESSION 4.6
Learning from Transits

Overview

In the relatively new field of planet detection, developing methods and technologies are expected to bring about major discoveries in the coming months and years. For the public and scientists alike, this is an exciting period of exploration. One current method, transit detection, is the focus of the Kepler Mission and its search for habitable extrasolar planets. In this session, students reflect on different planetary transit models and the practical aspects and limitations of using transits to detect planets. The class discusses what evidence transits could provide for questions astronomers might have about extrasolar planets. Students conclude that transit observations can provide information to help detect Earth-like planets. The class breaks into small discussion groups and generates a list of items necessary for a planet to be habitable and capable of supporting life. The session ends with a reading and brief discussion about the history of scientific efforts to understand the scale of the Universe and our place in it. The reading is an opportunity for students to review and deepen their understanding of the difference between our Solar System, our galaxy, and other galaxies in the Universe. During this session, the key concept added to the classroom concept wall is:

- *Current planet-detection methods, such as transit observation, detect only a small fraction of the planetary systems that exist.*

Learning from Transits	Estimated Time
Considering Other Transit Models	10 minutes
What Transits Reveal	10 minutes
Habitable Planets and the Search for Life	15 minutes
Understanding the Scale of the Universe—Student Reading	10 minutes
Total	**45 minutes**

What You Need

For the class:

- ❑ overhead projector or computer with large-screen monitor or LCD projector
- ❑ prepared key concept sheet from the copymaster packet or CD-ROM file
- ❑ 1 lamp socket (either with a tabletop base or clamp-on fixture)
- ❑ 1 extension cord (if necessary)
- ❑ a 25-watt incandescent light bulb
- ❑ 1 round, ***opaque*** plastic bead (about 16 mm in diameter)

Unit Goals

The Universe has a hierarchical structure; it is made up of billions of galaxies, and each galaxy is made up of billions of stars.

The Universe is enormous, and contains a diversity of objects with a variety of characteristics.

Vast distances of empty space separate objects in the Universe.

Scientists investigate and study very distant objects in the Universe by analyzing the light that comes to Earth from these objects.

Current planet detection methods are able to find only a small fraction of the number of planetary systems that exist in the Universe.

TEACHER CONSIDERATIONS

TEACHING NOTES

The key concepts can be posted in many different ways. If you don't want to use sentence sheets, here are some alternatives:

- Write the key concepts out on sentence strips.
- Write the key concepts out before class on a posted piece of butcher paper. Cover each concept with a strip of butcher paper and reveal each one as it is brought up in the class discussion.

Brand new ideas and discoveries in extrasolar planetary detection are occurring all of the time, so you and your students will want to keep up with this exciting, developing field through other resources. Let your students know about any recent developments and encourage them to bring in newspaper clippings or magazine articles to share with the class.

Key Vocabulary

Scientific Inquiry Vocabulary

Category
Characteristic
Evidence
Model
Observation
Prediction
Scale
Scale model
Scientific explanation

Space Science Vocabulary

Extrasolar planet
Galaxy
Life zone
Light minute
Light second
Light year
Milky Way Galaxy
Nebula
Planetary nebula
Spectrum
Star
Supernova
Transit
Universe

- ❑ 1 thin chopstick or wooden dowel (about ⅛" in diameter, 30 centimeters or 1 foot long)
- ❑ prepared chart on butcher paper from Session 4.5
- ❑ transparency of the Pre-unit 4 Questionnaire from Session 4.3

For each student:

- ❑ 1 copy of the Understanding the Scale of the Universe—Student Reading (two pages) from Session 4.5 or from the copymaster packet or the CD-ROM file
- ❑ scratch paper
- ❑ pencil

Getting Ready

1. **Arrange for the appropriate format to display images to the class.** Decide whether you will be using the overheads or the CD-ROM. Set up an overhead projector or a computer with a large-screen monitor or LCD projector.

2. **Prepare key concept sheet.** Make a copy and have it ready to post onto the classroom concept wall during the session.

3. **Prepare a simple transit model.** Tape the 15 mm plastic bead to the end of a thin wooden dowel or chopstick. Set up the 25-watt light bulb in a place where it will be visible to the whole class.

4. **Decide how to divide students into small groups.** Throughout this session, students discuss their ideas in small groups. If necessary, determine in advance how you'd like to divide up the class.

5. **Copy the student reading.** If you did not use the Understanding the Scale of the Universe—Student Reading in Session 4.5, make a copy for each student.

GO! Considering Other Transit Models

1. **Remind students of their transit models from last session.** Acknowledge the clever and creative designs student teams came up with to model the transit of a planet across a star.

2. **Another transit model.** Say that you have another transit model for them to observe. Explain that this model illustrates an important point about transits. (Note: If one of the teams' models is appropriate for demonstrating a vertical transit, you could use it instead of making your own.)

TEACHER CONSIDERATIONS

3. **Model a vertical transit.** Dim the lights in the classroom and switch on the light bulb. Remind the class that the light bulb represents a star. Show students the bead (attached to the end of a dowel or chopstick) and tell them it represents a planet. Stand facing the class while holding the light bulb "star" in one hand and the "planet" in the other. Move the planet slowly up and down around the star in a vertical orbit. (To do this: move the planet up between you and the star, then away from you over the top of the star, then down between the star and the class, then under the star back toward you, and then around again several more times.)

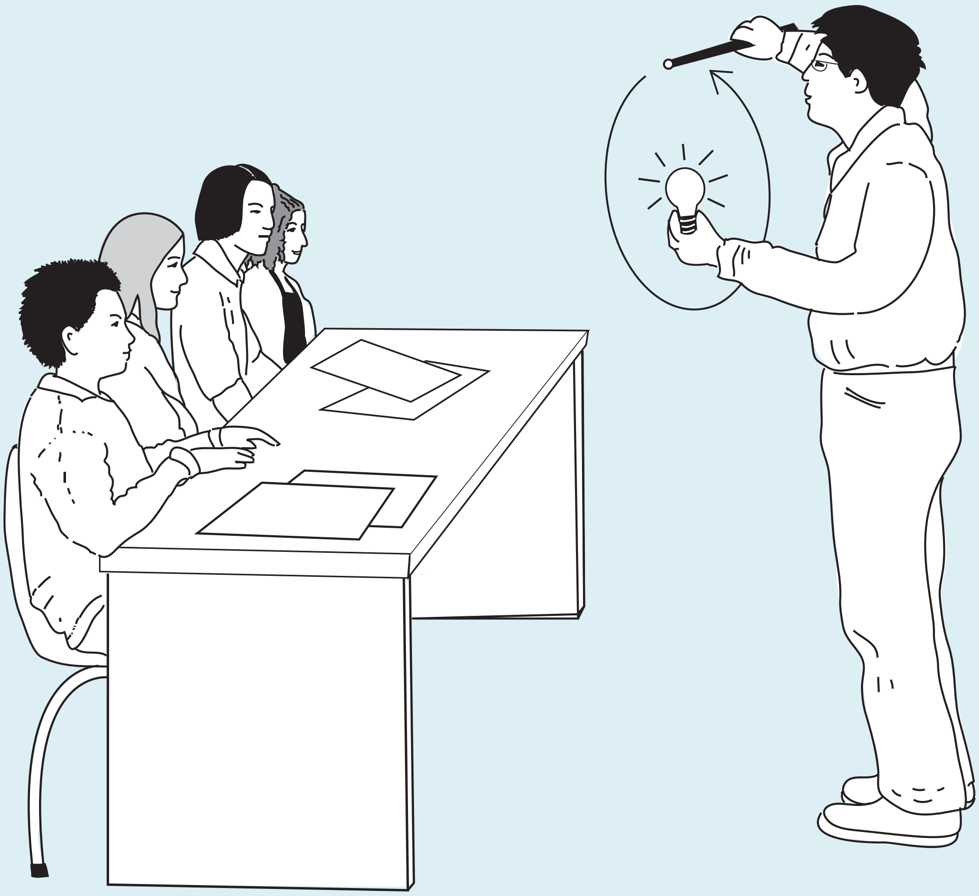
4. **Poll students to see how many observed a transit.** While you continue modeling the vertical transit, have students raise their hands if they can see the planet pass in front of the star. Only a few students— those who are seated in line with the plane of the planet's orbit—should raise their hands.

5. **Even horizontal transits can be difficult to detect.** Ask students what kind of orbit the planet would have to make so that almost everyone in the class would see a transit. Under their direction, demonstrate the orbit. It will be a horizontal one, with the planet passing between the star and the students. Even with this orbit, though, some students may not see the planet pass directly in front of the bulb. Assure the class that this is okay. In fact, it illustrates the fact that—**the likelihood of seeing a transit is low!**

6. **An even more difficult transit to see.** Ask what kind of orbit would allow **none** of the students to observe a transit. [An orbit where the planet does not pass between the observer and the star.] Have the class direct you in demonstrating this orbit. It may be easiest to show by simply modeling the vertical orbit while facing sideways so that all students will observe the planet move in a circle around the star, without it ever crossing in front of the star. Call on students to tell you where someone would need to be to observe a transit in this situation.

7. **Extrasolar planets are difficult to find.** Have small groups of students consider this statement: "If a star has an orbiting planet, astronomers can usually detect it by transit observations." Tell them to discuss whether the models they have observed so far support this statement. [No. The models suggest that we can observe transits of only a very few of the planets that are actually out there. The alignment between the star, the planet, and the observer has to be just right.] Post on the concept wall, under Key Space Science Concepts:

   Current planet-detection methods, such as transit observation, detect only a small fraction of the planetary systems that exist.



8. **More about the Kepler Mission.** Remind the class that the Kepler Mission will monitor about 100,000 stars simultaneously, measuring changes in their brightness and looking for evidence of transits. Explain that only the small fraction of planets and stars that are lined up just right to make transits will be detected. The rest will be missed. Kepler scientists calculate that less than 1% of planetary systems will be detectable by the transit technique. This means that each planet found by this method represents over a hundred more extrasolar planets not found!

9. **Go over the scale of the model.** Ask students to imagine that the models you've demonstrated today represent a planet with an orbit about the size of Earth's orbit. (That's 150,000,000 km, or about eight light minutes.) Remind students that the nearest stars in our galaxy are several light years away, which is roughly a million times the orbit of the planet. In a scale model, then, the observer would be hundreds of kilometers away from the light bulb.

10. **Revisit Question #5 on the Pre-unit 4 Questionnaire.** Show the transparency of the Pre-unit 4 Questionnaire. Ask the class how they might answer Question #5 now.

What Transits Reveal

1. **Refer to the posted class chart.** Ask students if there are any other questions that should be added to the Questions Astronomers Might Have About an Extrasolar Planet class chart. Add any new questions students suggest.

2. **Discuss whether transit observations could provide evidence that helps answer any of the questions.** Go through the list of questions one by one. Have small groups of students discuss each question and then call on students to report their ideas to the class. Put a check mark next to each question that transit observations might help to answer. Below are a few ideas students might suggest for each question:

   - How large is the planet?
     CHECK: The change in brightness of the star during a transit gives evidence about how big the planet is that is blocking the light. The transit method is one of the most likely to be able to detect planets the size of Earth.
   - How fast does the planet orbit around its star?
     CHECK: A planet will make a transit each time it orbits its star. Measuring the time between transits tells us how long it takes the planet to orbit its star.

- Is it in a planetary system with other planets?
  CHECK: If more than one planet is making a transit, they will most likely be different sizes and traveling in different orbits at different speeds. The timing of transits and the changes of brightness during the observed transits give evidence of the number of planets transiting the star. Not every planet in a system will transit its star, though.
- Is the planet Earth-like?
  MAYBE CHECK: By finding out how large the planet is, astronomers hope to find out whether planets the size of Earth are common and how many of them are about the same distance from their stars as Earth is from the Sun. That distance would make liquid water possible. An Earth-size planet is big enough to have an atmosphere suitable for life, but transit observations alone cannot positively determine whether or not there actually is liquid water or an atmosphere, much less what the atmosphere is made of.
- Does the planet have life on it?
  NO CHECK: If many Earth-like planets are detected, that would be evidence that life is ***possible*** *in other parts of the Milky Way Galaxy. It wouldn't give any information about whether a particular planet under observation has life.*

3. **Tell students they've been doing what scientists do.** Remind students of the key concepts from Sessions 4.1 and 4.4:

   Scientific explanations are based on evidence gathered from observations and investigations.

   Scientists use models to demonstrate ideas, explain observations, and make predictions.

Point out to students that what they have just done—look at models, make observations, and come up with explanations to questions—are exactly the kinds of things scientists do!

Habitable Planets and the Search for Life

1. **Tell students that in the next session they will be discussing the possibility that there is extraterrestrial life.** They will need to use everything they've learned so far about the Universe beyond the Solar System. One thing they have already studied is how to recognize Sun-like stars and how to find Earth-like planets.

TEACHING NOTES

Extraterrestrials, not aliens. Students will often refer to beings from other planets as *aliens*. Scientists, especially those involved in the search for life on other planets, prefer the term *extraterrestrial* (or simply, E.T.) An *alien* is someone (or something) from somewhere else. If there are beings on other planets, they are not technically aliens, since they are on their own home planet. In movies or other works of fiction in which spacefaring humans encounter other beings, it would be more correct to call the humans the aliens since they are the ones who are from another place!

2. **How to recognize stars that are about as hot as the Sun.** Call on students and ask how they would determine if a star is about as hot as the Sun. [The color of a star indicates its temperature. The Sun is a yellowish-white star, so another yellowish-white star would have about the same temperature as the Sun.] Remind the class that the spectra of stars are used by astronomers to scientifically compare their colors.

3. **Have small groups of students discuss why astronomers would expect a planet that orbits a Sun-like star to have the greatest possibility for harboring life.** Have them share and write down their ideas on scratch paper. Some possible ideas they may come up with are: A less massive, cooler star would provide less energy for life. A more massive, hotter star would explode before life could develop on a planet around it. The only example of life that we know of is around our Sun, so that indicates life is at least possible if a star is like the Sun.

4. **Call on students to remind you what was meant by an "Earth-like" planet when observing model transits.** An Earth-like planet is about the size of Earth and about the same distance from its star as Earth is from the Sun.

5. **Have groups of students prepare lists of qualities a planet should have to make it suitable for living things.** Give groups about five minutes to prepare their lists.

6. **Have student groups share lists.** After the groups have shared, point out some of the key items listed and ask students whether an Earth-like planet and a Sun-like star are important for these items. Be sure the following attributes are brought up:

    - **An atmosphere:** Most life we know of needs an atmosphere to breathe. An atmosphere can protect living things from harmful energies from a star. Small planets like Mercury do not have enough gravity to hold onto an atmosphere.
    - **Temperature and liquid water:** Students may simply say "water." Point out that ice or water vapor—without liquid water—are not known to support life. Also remind students of the key concept from Session 4.4:

    Liquid water is a necessary condition for the development of life as we know it.

    An Earth-like planet at just the right distance from a Sun-like star would have the right temperature for liquid water.

TEACHER CONSIDERATIONS

TEACHING NOTES

Students often ask, "How do we know that life in another part of the Universe needs the same conditions that life on Earth needs?" That is a very good question. The only models for life we have are the ones we have explored on Earth. The evidence from biology and chemistry that life requires liquid water is very compelling, but it does not prove that there aren't any other possibilities. Even on Earth there are places that have harsh conditions where scientists a century ago would have said life could not exist. Yet living things, mostly bacteria, are being discovered in the most inhospitable environments. Living organisms are found under frozen lakes in Antarctica, in undersea volcanic vents, and in water that is strongly acidic or that has a high concentration of salt or dissolved heavy metals. The existence of these *extremophiles* (organisms able to live in extreme environments) serves as a reminder to space scientists to remain open-minded about the conditions necessary for life.


Name:____________________________

Understanding the Scale of the Universe—Student Reading

Since the 1600s, scientists have accepted the fact that the Earth is just one of several planets that orbit the Sun. Then it became clear that the Sun is just one of many, many stars that make up the Milky Way Galaxy.

Before 1900, the word "galaxy" just meant "the Milky Way." There were no other known galaxies. Sure, since the invention of the telescope, astronomers had observed thousands of what we now know to be galaxies—but no one then knew what they were. They didn't know that they were separate from the Milky Way. They thought they were star clusters or nebulae in our own Milky Way Galaxy.

But by 1920, many scientists began to think that some of the objects they were seeing must be other galaxies, such as the Milky Way, but separate from the Milky Way. They spoke of these separate clusters of stars as "island universes."

Not all astronomers agreed with the idea of "island universes" beyond the Milky Way. They preferred the idea that these clusters were part of the Milky Way and were no farther away than the other star clusters and glowing nebulae. For years there were disagreements and debates, with neither side having quite enough evidence to prove its case.

What evidence would you need to show that a smudge of light is actually at a distance far beyond the stars of the Milky Way? An astronomer named Henrietta Swan Leavitt found a way to calculate the distance to a certain type of star in our galaxy by studying how these stars regularly changed in brightness.

Then in 1923, an astronomer named Edwin Hubble used the biggest telescope of that time to make the clearest photographs of the Andromeda Galaxy. Before 1920, astronomers could not see

continued on next page

The Milky Way Galaxy surrounds us. We see it from the inside looking out. The milky-looking band of stars gives our galaxy its name.

While working at the Harvard College Observatory, Henrietta Swan Leavitt developed standards for measuring the brightness of stars from astronomical photographs. The data she collected, and the techniques she developed became one of the standard tools that astronomers use to measure large distances in space.

Henrietta Swan Leavitt (1868–1921)

7. **Have students briefly discuss other items on their lists they think are important for life.** It is not important that they (or you) have all the information about each item they bring up. Scientists have many ideas about what makes planets habitable, but they do not have all the answers about what conditions are necessary for life. Scientists often discuss their ideas, just as students have done, to help them decide what kind of evidence they should be looking for.

Understanding the Scale of the Universe—Student Reading

1. **Pass out a copy of the reading to each student.** Read it aloud together or have students read silently. If you assigned the reading as homework after Session 4.5, give students a minute or two to re-acquaint themselves with the reading.

2. **Discussing evidence for a very big Universe.** Ask, "One hundred years ago, did scientists know that some star clusters visible in the sky were actually outside our galaxy?" [No.] "What evidence convinced them that some of the star clusters were actually separate galaxies?" [They were able to measure the distance to stars in other galaxies. Their measurements were evidence that these galaxies are incredibly far away. Stars in our galaxy are also far away, but they are much closer than stars in other galaxies.]

3. **Review the hierarchical arrangement of the Universe using the Pre-unit 4 Questionnaire.** Ask students to think back to everything they have learned about the scale and arrangement of objects in the Universe. Show the transparency of the Pre-unit 4 Questionnaire. Ask the class how they might order the list of things given under Question #4 now.

TEACHER CONSIDERATIONS

QUESTIONNAIRE CONNECTION

Use this opportunity to review the hierarchical structure of the Universe with your students by asking them to re-evaluate their answers to Question #4 on the Pre-unit 4 Questionnaire.