Mission 7
Expecting Other Planetary Systems

Are There Planets Around Other Suns?

Notes

In Mission 6, students examined light and discovered that the elements that exist on Earth also make up the stars. This is also true of the diffuse clouds of matter scattered across the universe, although the proportions of elements are not the same. Still, the elements necessary for the development of life do exist throughout the universe. But just having the materials necessary for the development of life may be of no consequence to the development of extraterrestrials if planets are not also present!

Overview

In this mission, students investigate a question: Could there be other planetary systems in the cosmos? There are billions of stars and, therefore, billions of chances for planets to form around stars as our Earth formed around our Sun. Currently it is still difficult to directly image planets around other stars because the reflected light from a planet is too dim and is overpowered by the bright light from the star itself. Scientists are working on *direct* and *indirect* ways to detect the presence of planets. The Doppler shift (radial velocity) method and the transit method of detecting extrasolar planets have been the most successful methods. In Mission 7.1, students measure the center of mass of a binary system. In Mission 7.2, students use the Doppler shift (radial velocity) as a way to measure the very small "wobble" of stars that would indicate the presence of other planetary systems.

Mission 7.1
Materials

For a Class of 30

- Data projector, computer, PowerPoint file
- "Center of Mass" transparency or PowerPoint slide (page xxx)
- *(optional)* 100-watt bulb
- *(optional)* Orange marble

For Each Team

- Meter stick
- 4 erasers, quarters, or other objects of uniform weight

For Each Student

- "Center of Mass" worksheet (pages xxx)
- "Data Points" worksheet (page xxx)

- Pencil

Getting Ready

1. Copy the “Center of Mass” worksheet for each student.
2. Set up the data projector.

Classroom Action

1. **Discussion.** Divide the class into teams of four to five students each. The question of an individual star’s life-span has probably not come up in class. Ask students if stars have always existed. Or do stars have beginnings and ends? If they do have beginnings, how do they begin? Do other stars have planets, as our Sun does?

   Remind students that several of the nebulae they observed in Mission 6 are thought to be the places where new stars are forming. Help students understand the size of these nebulae relative to stars. Are they bigger or smaller than stars? *(Much larger since many stars can form in one nebula. What might be happening in these clouds of gas and dust to create stars?)*

   The force of gravity–the same force that causes objects to fall to the ground, toward the center of Earth–is pulling together the dust and gas particles that make up the great nebular clouds. As more and more particles come together, the gravitational force becomes stronger, building the pressure and temperature at the center until the material “turns on” its nuclear furnace, and a star is born!

   But are there planets around this star? Explain that as far as we know, life can only begin on planets. Consequently, it would be good to know whether planets are plentiful or not. Do most stars have encircling worlds like the Sun does? Or is a planetary system a rare or even unique item in the cosmos? Until very recently, the only planets we were sure existed are the nine (including the dwarf planet Pluto) that orbit the Sun. But beginning in 1992, astronomers began to find evidence for other planetary worlds. It seems that planets may orbit many, if not most, stars. As of early 2010, over 500 extrasolar planets have been discovered, including some small rocky planets.

2. **Demonstration.** A good planet is hard to find! Unfortunately, even the best telescopes cannot see planets around other stars directly. The reason is twofold. To begin with, planets are relatively dim. Remember, while stars produce their own brilliant light by means of nuclear reactions deep in their cores, planets are fairly cool bodies, and shine only because of light reflected from their star. In fact, if you looked at our solar system from a nearby star, you would see that planets like Saturn or Jupiter were a billion times fainter than the Sun, and Earth was fainter yet. The second problem is that planets are so close to their stars that even if we could detect the faint light they reflect, the planet’s dim, tiny image would be swamped by glare from the star.

   To get a better idea of the problem, use a 100-watt light bulb to represent the Sun. Set up a demonstration of this in a darkened classroom, or have students imagine the situation: “To simulate the darkness of space, picture this light bulb at one end of a football field at night.

Imagine Jupiter, our solar system's largest planet, which (on this scale) would be an orange marble about 50 yards from the bulb. Finally, suppose that you are a researcher only 4% light-years away (the distance of the nearest star), looking for the marble around the light bulb. But 4% light-years corresponds to 3,000 miles in our scale model! Do you think you could see a dim marble in the glare of the light bulb from that distance?" NASA's *Kepler Mission*, launched March 2009, is detecting extrasolar planets by measuring the change in light from star when a planet transits the parent star. The planets are too small to detect, but the instrument is sensitive enough to detect very small changes in the star's light.

3. **Discussion.** Astronomers have just begun to discover extrasolar planets via direct imaging. To date, this method is only successful with very large planets orbiting small stars with a large degree of separation. So, scientists have to use to indirect methods when looking for planets. Discuss the indirect method. Indirect method is looking for the planet's effects, rather than for the planet itself. This is something like hunting for rare animals by searching for tracks, lost feathers, and other signs. The "wobble" method and transit method are indirect methods.

4. **Transparency Figure 7.4.** The most common method used by astronomers to see if stars have planets is to see if they "wobble." Why would a star wobble? This could happen if something is orbiting the star–such as a planet. Normally, when we think of planets orbiting a star, such as our Sun, we assume that the star stays still, and the planet does all the moving. In fact, this is only approximately correct. What really happens is that both the star and the planet revolve about a point called the center of mass.

   Explain that there are many stars that are double (binary): they are stars that have another star as a "buddy," or companion. If the two stars have equal mass, then they orbit around a point that is midway between them. The center of mass is between the stars. If one star is twice as heavy as its companion, then the center of mass will be closer to the heavy star, and the heavyweight will make smaller orbits than its lighter companion

5. **Activity.** Hand out the worksheets "Center of Mass" and "Data Points" to each student. Show how to use a meter stick to experiment with the concept of center of mass. Balance the meter stick on your outstretched index fingers, one at each end, and then slowly move your fingers toward the center of the stick. They will meet at the center of mass, right in the middle! Students should use erasers or any other small, uniform weights at one end of their meter sticks. As the mass increases, what happens to the center of mass? Students complete their worksheet, measuring and then graphing the changes in the center of mass.

Mission 7.2
Materials

For a Class of 30

- PowerPoint projector
- "Doppler Effect" PowerPoint slide 7.5 (page xxx)
- Electric buzzer with a 9-volt battery (see "Teacher Background Information" in the appendixes)

- Connecting wires with alligator clips

For Each Student:

- “Red Shift, Blue Shift” worksheet (page xxx)
- Pencil

Getting Ready

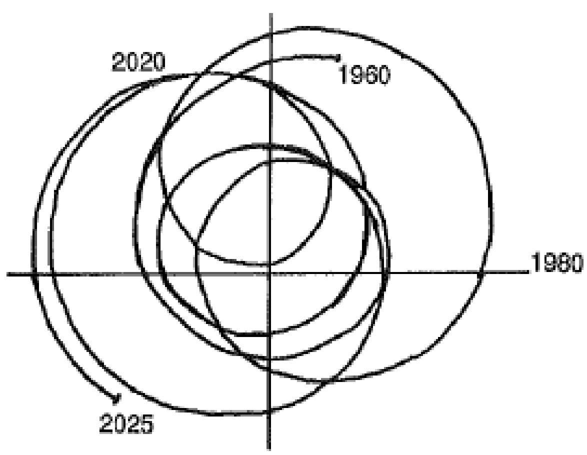
1. Copy the “Red Shift, Blue Shift” worksheet for each student.
2. Set up the data projector.

Classroom Action

1. **Discussion: Measuring Wobbles.** By now students have probably realized that while we say that Earth orbits around the Sun, the truth is that Earth and the Sun both orbit around their common center of mass, once per year. But because the Sun is about 300,000 times heavier than Earth, the center of mass is much closer to the Sun. In fact, it is *inside* the Sun, only about 100 miles from its center. So the Sun does not make a very big orbit. It moves only a few inches per second, or less than the speed of a crawling baby.

   That’s a very small wobble. But of course the Sun has other planets. Jupiter, being much larger than Earth, causes a bigger orbital dance. If you add up all the orbiting the Sun has to do because of its eight planets plus dwarf planets, you find that it traces out a path like the one in Figure 7.1.

Figure 7.1–0rbital Wobbling of the Sun.



   Astronomers have known about this orbital wobbling since the days of Isaac Newton. They realized that if another star has planets, it too would be moving back and forth and side to side.

But how can we possibly observe such small wobbles? Astronomers first tried to measure the tiny side-to-side wobbling of nearby stars by very accurately measuring the star's position over many years. This is called astrometry. They measured a nearby star's position relative to many distant "fixed" stars. These are very difficult measurements. Over the years, some astrometrists have claimed to detect planets, (*e.g*., around Barnard's Star). Unfortunately, these reports have turned out to be false alarms resulting from very slight changes in the telescopes themselves over a period of time.

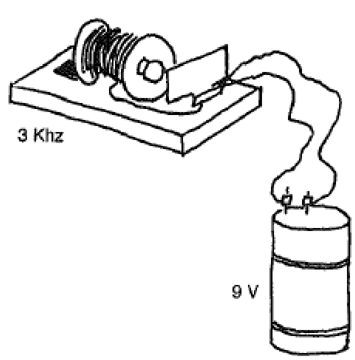
Another way to do it is to look for the forward and back wobble of the star. These radial velocity studies involve looking for slight changes in the color of the light coming from the star. If a star is moving toward you, its light turns a little bluer (called *blue shift).* If it moves away from you, the light gets a bit redder (called *red shift)* So, if a star is doing a "dance" because it has planets, then we should see its light subtly change color—a little bluer, a little redder, a little bluer, a little redder, and so on (radial velocity method). In fact, astronomers actually look at individual spectral lines from the star and observe whether their wavelength changes slightly from night to night over many years.

Optional: Ask students if we could detect a side-to-side wobble using this technique. *(No.)*

2. **Transparency or PowerPoint Slide Figure 7.5.** Why does the light change color? Because of an effect discovered by an Austrian physicist more than 150 years ago, when Christian Johann Doppler pointed out that any kind of waves–water waves, sound waves, and light waves–will get closer together if the object making the waves is coming toward you. They will get farther apart if the wave generator moves away from you. Show students the "Doppler Effect" transparency to help explain this concept. The spacing of the waves is related to the pitch, or frequency, of the waves. Have you ever noticed how the sound of a train or a car changes pitch as it passes you? When it comes toward you, the pitch is higher. Then it passes, moving away, and the pitch gets lower. This is called the Doppler Effect (radial velocity), and astronomers look for it all the time–in light waves. NASA's *Kepler Mission* uses this method as ground based follow-up, checking for the "wobble" to confirm its discoveries.

3. **Demonstration: Doppler Effect Experiment.** Wire an electric buzzer and a battery as shown in Figure 7.2.

Figure 7.2–Buzzer and Battery.



Ask a volunteer to attach the last lead and then swing the sound wave-generating buzzer in a circle about his or her head. Ask if they notice how the pitch changes? When is it higher? When is it lower? What if you swing it faster? The Doppler Effect can be used to tell us not only whether something is coming toward us or moving away from us, but also how fast it is moving. Now have a volunteer swing the buzzer in a big circle in front of his or her body. Because it is neither coming toward nor moving away from anyone, no change in frequency can be heard.

4. **Activity.** Hand out the “Red Shift, Blue Shift” worksheet to each student. For many years, astronomers have been using the Doppler Effect to see if any nearby stars move to and fro. If astronomers find one that does, then we might decide that there are planets around that star, even though we cannot see them directly. Instruct students to complete their worksheet by looking for a red shift or a blue shift in each of three unknown stars.

5. **Wrap-Up.** Ask students if they think scientists have found any real wobbling stars out in space. There are several stars that seem to wobble–shift positions—but these results are still a bit uncertain. The main problem is that astrometrists have not been looking long enough. To be sure that the wobble is really caused by a planetary companion, astrometrists must continue to observe a star for at least one orbital period of the planet. For large planets like Jupiter, in orbits far from their star, the planetary orbit can be tens of years, and so the wobble will require tens of years to observe. Another problem is that the wobbles are very tiny and difficult to measure accurately. It is important to keep everything very stable over the many years of observation to avoid the false alarms that have plagued astrometrists. However, researchers continue to work on this problem, and most think that within just a few years, they will be able to detect the wobbles of stars surrounded by planets.

   Explain that astronomers have seen wobble and observed very small shifts, to and fro, in the spectral lines of nearby stars. In 1995, a Jupiter-sized companion to a star was detected in the constellation Pegasus using the radial velocity method. The star’s name is 51 Pegasi. A few months later, two more stars were found to be the home of Jupiter-sized planets, 47 Ursae Majoris (a star in Ursa Major, the Big Dipper) and 70 Virginis (in Virgo). All three of the planets are about as large as Jupiter. As this research continues, hundreds more planets have been found. So far, astronomers have not found evidence of Earth-sized planets around normal stars. But, NASA’s *Kepler Mission*, a spacecraft mounted instrument, has found near Earth-sized planets and is poised to detected Earth-sized plants.

   These three Jupiter-sized planets are not the first discovered. Earlier, there was a most intriguing result in the search for planets from a very peculiar kind of star: *a pulsar.* What is a pulsar? It is the shrunken core of a large star that burned all its fuel and then blew up in a gigantic explosion called a supernova. The pulsar, which is all that remains of the star, is so small it would fit in downtown New York City! But pulsars spin very rapidly, sometimes as much as a thousand times every second; like lighthouse beacons, they “broadcast” light and radio waves into space. These broadcasts sound like the ticking of a clock, except that the ticks can be very fast (even a thousand ticks a second).

   Astronomers have noticed that, for at least one pulsar, the number of ticks per second increases for a few months, and then decreases. Then it increases again. What’s happening? The Doppler Effect is causing the change in tick frequency. This particular pulsar is thought to have three planets circling it, which cause it to wobble, which in turn produces the Doppler shift that we see.

Optional: There is one additional indirect method of detecting planets outside our solar system–it is called the *transit* method. If the planet just happens to move in front of the star, directly into our line of sight, then we will see a small reduction in the brightness of the star as the planet blocks its sun's light for a temporary period of time. NASA's *Kepler Mission* has already detected planets with a radius of less than 1.5 Earth's radius, and is sensitive enough to detect planets the same size as Earth in the Habitable Zone of other stars using this method. See www.Kepler.nasa.gov for classroom activities. The online Extrasolar Planet Almanac and Extrasolar Planet Encyclopedia provide up to date planet counts and details regarding the planets and their parent stars. The sites also note which one of the methods, astrometry, radial velocity – Doppler shifts, transit method, transit timing variation (TTV), gravitational microlensing, observation of circumstellar disks, direct imaging, contamination of stellar atmospheres, coronography, and pulsar timing); was employed to discover the planet.

Going Further

Activity: Massive

Tie a string between two equally weighted objects (balls). Use a colored piece of yarn to mark the center of the string. Throw the tied objects through the air so that the string is pulled taut and rotates. Students observe that the rotation occurs around the center of the string. Connect additional weight to one end of the string and show that this changes the center of rotation by moving it closer to the more massive object. The point of rotation is the center of mass. Taking this activity one step further, use a low-frequency strobe light while throwing the tied objects in a darkened room–this will emphasize the rotation about the center of mass.

Teacher's Note: *Do not use breakable objects. Warn students about the potential danger of flying objects.*

Activity: Mass, Density, and Volume

Do activities to show students that the mass of an object is not determined solely by its size but also depends on its density. A small, dense object can be more massive than a larger less-dense object. Show students the relationship between radius and volume for a spherical object. $V = (4/3)\,\pi r^3$, where r is the radius of the sphere. Then relate volume to density, showing that when the radius of a spherical object is doubled (while density remains constant), both the volume and the mass are multiplied by eight times.

Teacher's Note: $\textit{Density} = \dfrac{\textit{mass}}{\textit{volume}}$

Activity: Doppler Shift on the Street

Instruct pairs of students to go to an area where there is a lot of traffic and pick a spot where they can stand safely with eyes closed or blindfolded. To stay safe, students must do this activity in pairs! They should *listen* to the cars. Can they tell if cars are coming toward them or moving away from them by sound alone? One partner should take notes on the other's "guesses." How does this relate to the Doppler Effect studied in class?

Mission 7
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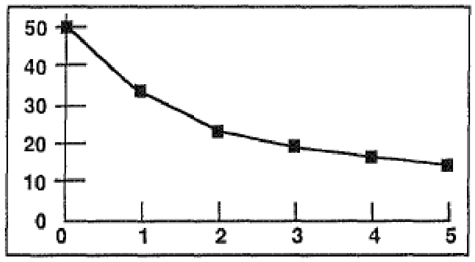
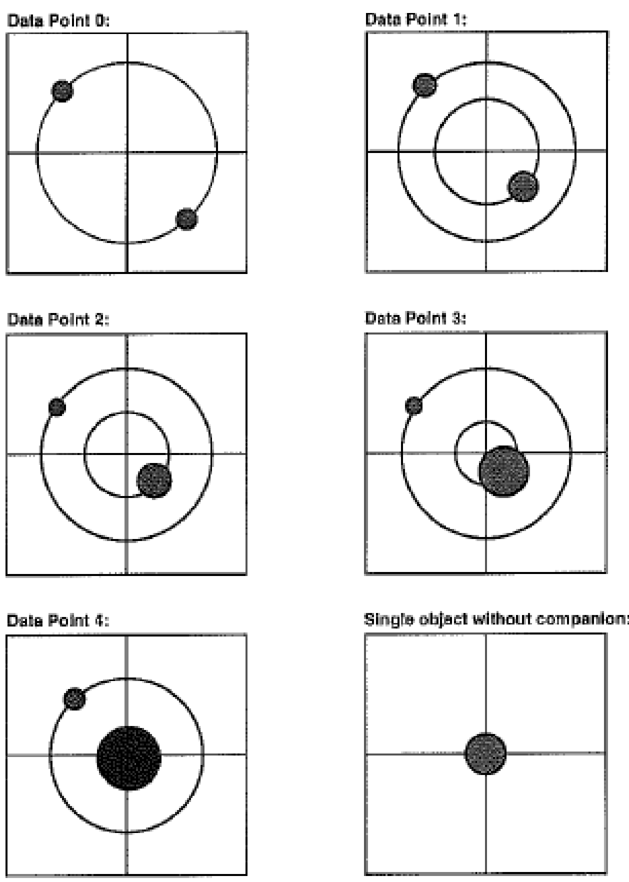
Center of Mass–Teacher's Key

Figure 7.3a.



Example graph. The actual numbers will vary, depending upon the objects used.

Figure 7.3b.



2. The mass of this object does not affect its orbit, because it does not have an orbit. Any motion that this object has is contained in its spinning upon its axis or is in a straight line through space.

Mission 7
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Red Shift, Blue Shift–Teacher's Key

Table 7.1–Teacher's Key for Red Shift, Blue Shift.

Star #1	**Doppler Shift**	**Movement of Star**
Observation 1	Red Sifted	Moving away from Earth
Observation 2	Not Shifted	Not moving relative to Earth
Observation 3	Blue Shifted	Moving toward earth
Observation 4	Not Shifted	Not moving relative to Earth

Star #2	***Doppler Shift***	***Movement of Star***
Observation 1	Red Shifted	Moving away from Earth
Observation 2	Red Shifted	Moving away from earth
Observation 3	Red Shifted	Moving away from Earth
Observation 4	Red Shifted	Moving away from Earth

Star #3	***Doppler Shift***	***Movement of Star***
Observation 1	Blue Shifted	Moving toward Earth
Observation 2	Blue Shifted	Moving toward Earth
Observation 3	Blue Shifted	Moving toward Earth
Observation 4	Blue Shifted	Moving toward Earth

1. Star # 1 is moving away from us in observation 1, then it is not moving in observation 2, then it is coming toward us in observation 3, and then it is not moving in observation 4.

2. Star # 2 is moving away from us in all four observations.

3. Star # 3 is moving toward us in all four observations.

4. Star # 1 is most likely to have a planet. Star # 1's back-and-forth motion could be caused by its "dance" with a planet, rotating about a common center of mass. Star # 1 has a wobble!

Mission 7
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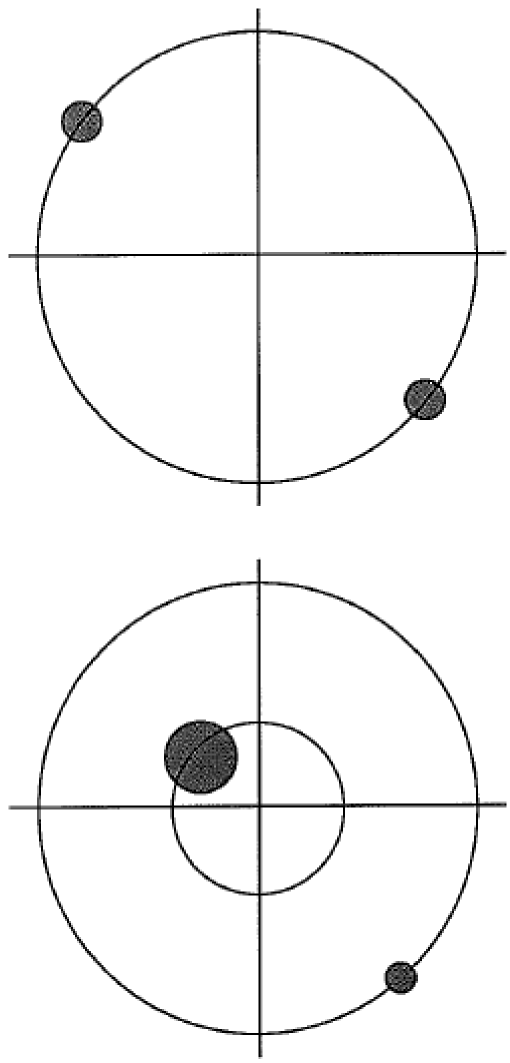
Center of Mass–Transparency or PowerPoint Slide

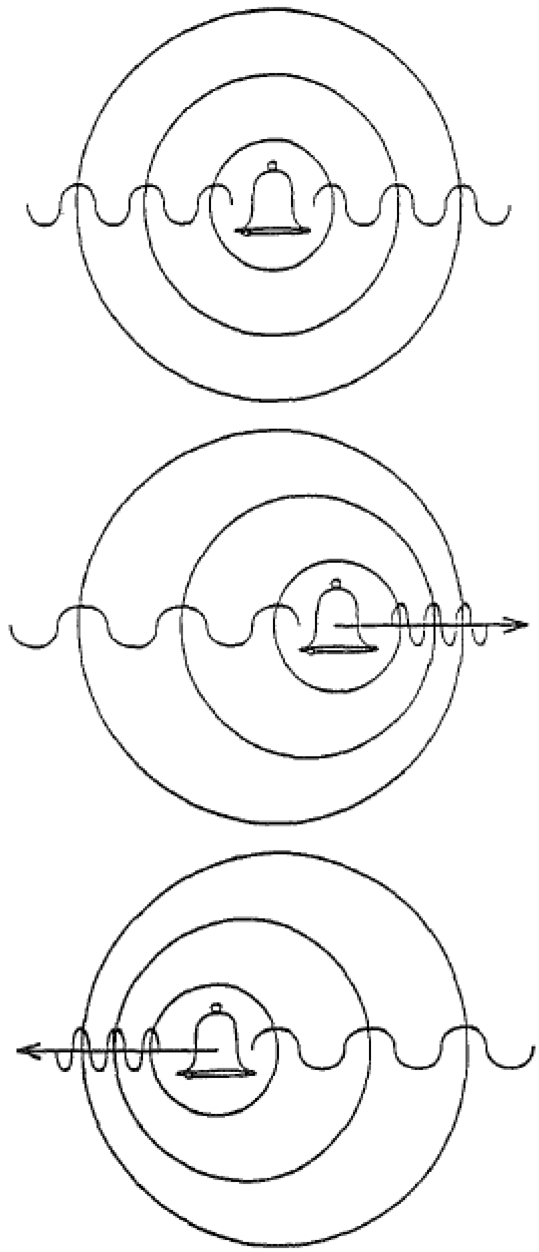
Figure 7.4.



Mission 7
Expecting Other Planetary Systems

The Doppler Effect–Transparency or PowerPoint Slide

Figure 7.5.



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