EXPLORATION 5:  TO THE STARS!

# Can we communicate with an alien star system?

The purpose of this exploration is to use the telescope to take images of stars similar to our Sun, and to use the images to determine how far away the stars are.

- Astronomers use "standard candles"—stars of known brightness—to help determine distance.
- The apparent brightness of a star decreases inversely as the square of its distance from the observer.
- Stars are so distant that it would take years to reach even the nearest stars at the speed of light.

In this investigation, students are challenged to determine the distance to a star using only the telescope and a simple software tool for measuring the brightness of the star.

This activity introduces several fundamental ideas:

- **The distance to the stars**, which is central to determining the size and scale of the universe and to appreciating our place in it.
- **The inverse-square law**, used widely throughout physical science.
- **Scientific notation**, which is basic to physical science.
- **Experimental and interpretive skills** that are fundamental to most scientific investigation.

**GRADE LEVEL:**
9-12

**TIME OF YEAR:**
Anytime

**SCIENCE STANDARDS:**
Distance to the stars
Properties of light

**MATERIALS NEEDED:**
✔Online telescopes (or use archived images.)
✔ Software, free from Internet
✔ Image of Sun from archive
✔ Printer (optional)

**TIME NEEDED:**
3 - 5 class periods

**TEXTBOOK LINK:**
Hewitt, ***Conceptual Physics***, Chapter 8, p. 147, inverse-square law.

## *Materials Needed*

| | |
|---|---|
| | *For each team of students* |
| | On local computer, image of the Sun downloaded from http://cfa-www.harvard.edu/webscope/archive/sun.FITS |
| | *For the class* |
| | Internet access to the MicroObservatory online telescopes |
| | Image-processing software (MOImage) on your local computer |
| | Printer (black-and-white) |
| | *For the teacher* |
| | Two or three grapes, or marbles, to represent stars in a scale model |
| | |

# Background

At first glance, a star might seem like the most boring of all objects: a nearly featureless ball of hot gas that looks the same for millions or billions of years. But stars are truly the cauldrons of creation; without them, no life would exist.

Stars are the place where the chemical elements are created. Deep inside stars, nuclear reactions transform hydrogen—the simplest element—into chemical elements that make up our bodies and the world around us. These nuclear reactions produce the enormous heat that keeps the star shining. A star is the only place in nature that is hot enough and dense enough for these nuclear reactions to occur. (Scientists have duplicated this “fusion” process, in an uncontrolled way, in the hydrogen bomb; however, no one has yet found a way to sustain or harness these fusion reactions to create useful power.)

Large stars burn through their hydrogen fuel more quickly; their lifetimes are measured in millions rather than billions of years. They end their lives with a gigantic explosion, called a supernova. This explosion is nature’s way of scattering the chemical elements—produced over the star’s lifetime and during the explosion itself—into space.

These ashes from the star's explosion will become the raw material for a new generation of stars and planets: Under the relentless tug of gravity, smaller clumps of matter will collapse to form planets. A large enough clump will collapse to form a new star: As the clump collapses under its own weight, it heats up, igniting the nuclear fires once again. Our own Sun is believed to be a second- or third-generation star. We—and everything on Earth—are made of the ashes from a long-dead star that exploded long ago in our cosmic neighborhood.

A star like our Sun has just the right mass to burn for billions of years—long enough to nurture the formation and evolution of life. Our Sun is about 5 billion years old. (We can tell how old the Sun and planets are by studying the proportions of their radioactive elements and decay products.) The Sun will die a relatively quiet death in another 5 billion years, sloughing off its outer layers of gas, but avoiding the catastrophic explosion that awaits larger stars.

Somehow, nature has found an exquisite balance—creating some short-lived stars that seed the universe with the chemical elements for life, and some long-lived stars that cradle the development of life.

## How far away are stars?

The ancient idea that stars are all at the same distance from Earth might seem silly today, yet it is not so easy to show otherwise. The most direct scientific method for determining distance is to use "parallax." This is the effect you see when you hold your thumb at arm's length and look at it through one eye and then the other. The more distant your thumb, the less it appears to "jump" against the distant background as you observe it from different viewpoints. By viewing an object from two different vantage points and observing how much the object appears to move relative to the very distant background, one can use geometry to calculate the distance to the object.

To use the parallax effect, astronomers make two observations of a star taken six months apart—so that the observations are made at opposite sides of the Earth's orbit around the Sun. These are the most widely separated viewpoints we can achieve from Earth. Yet even so, stars are so far away that the parallax effect is very slight even for the closest stars. As the great astronomer William Herschel wrote in 1817:

> The parallax of the fixed stars has also been an object of attention; and although we have hitherto had no satisfactory result from the investigation, the attempt has at least so far succeeded as to give us a most magnificent idea of the vast expans[e] of the... heavens.

It wasn't until 1836 that the German scientist Friedrich Bessel used the parallax effect to confidently determine a star's distance. He found the star to be 700,000 times further away than the Sun.

In 1817, **William Herschel** described a way to find the distance to a star, by comparing its brightness to that of a "standard star."

Herschel suggested a second way to determine distance to stars: by measuring their brightness:

> It will be admitted, that the light of a star is inversely as the square of its distance; if therefore we can find a method by which the degree of light of any given star may be ascertained, it distance will become a subject of calculation.

Herschel realized that *two* factors might make a star look dim; one was its distance, the other was whether the star was intrinsically dim, the way a low-wattage light bulb is intrinsically dim. He wrote that "in order to draw valid consequences" from experiments, he had to *assume* that the stars he observed were "individuals belonging to the same species"—that is, were of the same intrinsic brightness. (In this exploration, students observe stars that are very close twins of our own Sun and that are thought to have the same intrinsic brightness as the Sun.) The search for astronomical "standard candles"— celestial objects whose intrinsic brightness is known—is fundamental to the effort to determine distance scales in the universe.

Today we know that even the closest star beyond our Sun is so distant that our fastest rocket ship would take 70,000 years to get there!

## Planets around other stars

People have long imagined that the stars might be home to planets like our own. Until recently, however, the nine planets that orbit the Sun were the only planets known in the universe. In the last few years, astronomers have detected planets orbiting more than 100 stars. For the first time in history, we know that our solar system is not alone.

We can not see these alien planets directly—even the largest planet is much too small to see at such great distances. Instead, astronomers look for a telltale wobble in the star—i.e., a slight back and forth motion— as the planet orbits periodically. (Due to the tug of Earth's gravity as it orbits, e.g., our own Sun wobbles back and forth by about one yard every year!)

**Giordano Bruno** (1548 – 1600) was burned at the stake, in part for suggesting that stars might be worlds like Earth.

The planets that are easiest to detect are the ones that create the greatest tug and the greatest wobble; these are planets that are large and very close to the star they orbit. Therefore, almost all the planets detected to date are Jupiter-sized planets that are much too close to their star to harbor life. Astronomers were surprised to find Jupiter-sized planets so close to the parent stars, and they have had to revise their theories of how solar systems form.

NASA has plans to launch a "Terrestrial Planet Finder" mission sensitive enough to detect planets the size of Earth around nearby stars. By analyzing the light from such a planet, it would be possible to tell whether the planet had an oxygen atmosphere—a telltale sign of plant life. Such indirect evidence for life beyond Earth would be one of the greatest milestones in the exploration of our universe.

## Before you begin

Students should already be familiar with the solar system. They should understand that the Sun is orbited by nine planets and many smaller objects. It is important for students to understand that our Sun is a star and that the stars are suns. Stars give off their own light—unlike planets, which merely reflect light from the star they orbit. The activity assumes, but not discuss, that "nothing can travel faster than light."

**MISCONCEPTION WATCH:** Students often confuse stars and planets, which look similar in the night sky. Adding to the confusion, Venus and Jupiter are often called "the evening star" (or "morning star") even though they are planets, not stars. Also, the meteors that streak across the night sky are often called "shooting stars," even though they are small pieces of rock, ice, or other debris and have nothing to do with stars.

## Part 1. Students' ideas about stars

*"What's the nearest star to Earth?"*

It's easy to forget that the Sun is the nearest star... and the stars are suns!

You might begin this activity by having students express their thoughts about stars in general and about life beyond our own solar system. Start by having students record their responses to the discussion questions in their journals:

> *Suppose that the Earth were always cloudy, so that no one had ever seen the night sky. Would it make a difference to you? If so, how?*
>
> *Describe some of the stories or movies you've seen in which humans travel between star systems. What do you think are some of the problems with traveling between stars?*
>
> *Do you think it's possible to travel to the stars? Would you want to go? If so, why? What would you expect / hope to find?*
>
> *Do you think there are intelligent creatures on planets orbiting other stars? Do you think any of them have ever visited Earth?*

Among the many interesting topics for further class discussion:

*Stars in our language and culture*. What are some of the ways that stars are part of our language and popular culture? What do stars represent? Examples:

- "Disaster" and "catastrophe" mean, literally, against the stars. Throughout much of history, people believed that the stars influence our lives. A "considerate" person was one who was, literally, "with the stars"—meaning that s/he had consulted the stars or an astrologer before making a decision. Shakespeare called Romeo and Juliet "star-crossed lovers"—yet in *King Lear*, Shakespeare has a character debunk the myth that stars influence our lives.

- Why do we call our celebrities "stars"? Why is a "gold star" a reward for high achievement? Do stars represent the unattainable? The beautiful?

- What advertising have you seen that uses stars or outer space to help sell commercial products?

*Experiencing the stars*. Have students discuss their most memorable star-gazing experiences.

- Do stars have different colors? Many people think of stars as all being white. In reality, stars range from red to orange, yellow, white, and blue. With practice and dark skies, you can learn to distinguish deep red stars from white or blue ones. The color of a star is a clue to its temperature, composition, and even age.

*Stars and science fiction*. Discuss with students their ideas about life in other star systems. Revisit these ideas with students after they have completed their investigations.

## Part 2. Planning the exploration

**Discuss ways to determine distances.** Explore students' initial ideas on how they might find the distance to an object without traveling to it. What kinds of clues could one use? You may want to discuss three kinds of clues with students:

> *Apparent size*. Most students will mention this effect. As objects get farther away, they appear smaller; we say that their "angular size" or apparent size decreases. However, stars are *so far away* that we cannot resolve their size at all in a telescope! That is, telescopes can not image the disks of stars. (A rare exception is the giant star Betelgeuse, in the constellation Orion, as viewed with the Hubble space telescope. A disk is barely visible.)
>
> **Note:** In telescope images, the brighter stars look larger than the dimmer stars. This effect is due to diffraction; you are

not actually seeing the disk of the star. If the telescope could image perfectly, each star would be a point, i.e., less than one pixel wide.

*Parallax*. This clue is more subtle, yet everyone has noticed it at one time or another. Try this simple experiment: Close one eye. Hold one finger up about four inches in front of your eye. Now move your head from side to side. Result: As your vantage point changes, your finger's position appears to change dramatically, but distant objects do not move noticeably. Try this again, with your arm outstretched. Your finger still appears to change position, but not as much. *When your vantage point changes, nearby objects appear to move more than distant ones*. Astronomers call this effect "parallax."

As the Earth orbits the Sun, our vantage point changes: nearby stars appear to move relative to the distant background of stars. By observing which stars appear to move more and which less, astronomers can gauge which stars are closer. Unfortunately, this method works only for the very closest stars: Stars are so far away that their apparent movement is very slight. [Insert historical note.]

*Apparent brightness*. The farther away a source of light, the dimmer it appears. This is the clue we'll use to determine the distance to a star. In fact, there is a simple relationship between distance and apparent brightness: A light source that is twice as far appears four times as dim. A light source X times farther away appears $X^2$ times as dim.

Of course, we can't move stars closer or farther away. But we *can* compare a star to a *reference star*—a similar star of known distance.

**Help students devise an experimental plan.** An important part of the investigation is for students to try to outline their own scientific approach to determining the distance to a star. First make certain that students are aware of the resources they'll have:

- a telescope for imaging their target star

- an archived image of the Sun—their reference star—whose distance from Earth is known

- a computer program to measure the brightnesses of the Sun and target star from their images

- a rule, "the inverse-square law," for comparing the distance of two objects once you have compared their brightness

**WHAT'S THE BIG IDEA?**
The area of a sphere is proportional to the square of its size .

Make sure that students devise a viable strategy—and that they understand the reason for it—before they tackle the technical details of how to image a star and how to measure its brightness.

**Help students refine their plan.** Students should reflect on this question: *"Why does your target star have to be similar to the Sun?"* If the target star could be *any* brightness—then the method would not work: We couldn't tell if we were looking at a bright star that appeared dim because it was very far—or if we were looking at a dim star that appeared bright because it was very close.

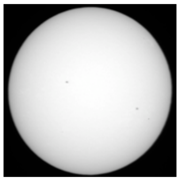
## Students' predictions

1. Have students model the scale of the solar system. Use a grape (or a grape-sized marble) to represent the Sun. Then ask for volunteers to represent each of the planets. Give each volunteer a Pocket Model of the Solar System card, and have each volunteer stand, one by one, at the appropriate distance from the Sun for their planet. Unless you do this activity outdoors, you will likely run out of room after Mars, but indicate that the outer planets would be hundreds of feet away.

2. Ask students to guess how far the nearest star would be at this scale? Where should the second grape be placed? Have students record their predictions in their journals, to be revisited after their exploration is completed.

# ***Pocket Model of the Solar System*** **Cards**

| | | | |
|---|---|---|---|
|  | . | Mercury | is 3 feet from the Sun |
| | . | Venus | is 3 feet farther |
| | . | Earth | is 2 feet farther |
| | . | Mars | is 5 feet farther |
| | • | Jupiter | is 33 feet farther |
| | • | Saturn | is 39 feet farther |
| | . | Uranus | is 86 feet farther |
| | . | Neptune | is 98 feet farther |
| | . | Pluto | is 85 feet farther |
| Courtesy Phil Sadler, Harvard-Smithsonian Center for Astrophysics | | | |

| | | | |
|---|---|---|---|
|  | . | Mercury | is 3 feet from the Sun |
| | . | Venus | is 3 feet farther |
| | . | Earth | is 2 feet farther |
| | . | Mars | is 5 feet farther |
| | • | Jupiter | is 33 feet farther |
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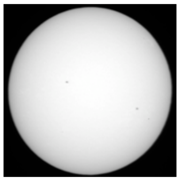
|---|---|---|---|
|  | . | Mercury | is 3 feet from the Sun |
| | . | Venus | is 3 feet farther |
| | . | Earth | is 2 feet farther |
| | . | Mars | is 5 feet farther |
| | • | Jupiter | is 33 feet farther |
| | • | Saturn | is 39 feet farther |
| | . | Uranus | is 86 feet farther |
| | . | Neptune | is 98 feet farther |
| | . | Pluto | is 85 feet farther |
| Courtesy Phil Sadler, Harvard-Smithsonian Center for Astrophysics | | | |

At the scale of the "grape solar system," the nearest star beyond our own Sun would be about 500 miles away.

> The nearest star is about 5 light-years away, which is 30 trillion miles. At a scale of 1 inch = 1 million miles, this is 30 million inches, or roughly 2.5 million feet, which is about 500 miles.

Most students' predictions will be much less than this. Allow students to revisit their predictions after they have completed their investigations and the questions in Part 4.

## Part 3. Carrying out the exploration

**Divide the class into teams.** Students work in teams of three or four.

**Have each team choose one star to investigate.** Students can investigate any star on the list provided. These are stars very much like our own Sun, and which are orbited by at least one planet. Encourage teams to choose different stars from each other; that way, students will discover that stars are not all the same distance from Earth. However, it is fine for different teams to choose the same star; the teams can then compare their results and critically examine their work.

**More Sun-like stars can be found at:**

http://www.starmapping.co.uk/sunlike.cfm

How do we know the stars on the list are similar to our Sun? Astronomers have determined the composition, mass, and other parameters of the star to be very similar to our own Sun. Therefore, for this investigation, we ASSUME that the stars on the list have about the same brightness as our own Sun.

If possible in your area, have students visually observe the star, or the constellation the star is in, from home. [ADD HERE -- HOW DO WE KNOW WHICH ARE VISIBLE?]

**Select time of night to take image.** Have students use the observing guide, which is in the margin of their journals next to the list of stars, to select the best time of night to take an image. In general, an object is dimmest when viewed near the horizon. Reason: Near the horizon, the line of sight goes through much more atmosphere than when viewing overhead. For this reason, students should try to schedule the image when the star is higher in the sky, if possible.

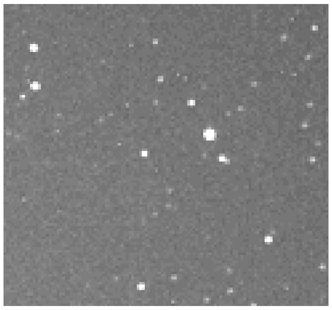
**Choice of filter.** Star images should be taken without any filter ("clear filter"). Note that the archived image of the Sun was taken with a solar filter which passed only 1/100,000,000 of the Sun's light. Below you will see how to correct for this filter factor in order to ensure a fair comparison between Sun and star.

**Exposure time.** Have students take several images using a range of exposure times, including 0.1, 0.5, 1, 5, and 10 seconds. In this way, they will be assured of getting an image in which the star is not overexposed ("saturated"). As described below, a star is overexposed when one or more of its pixels has a brightness value of 4095, which is the maximum.

**ALERT:** Be sure that students download their images in FITS format. Follow instructions on the Web page with your image.

Make certain that students record the exposure time for each image. This exposure time will be needed when making a fair comparison between the star's and the Sun's brightness.

**Download and save images in FITS format.** Many students forget to download their images onto their computer. Remind students that their images are deleted from the Web one week after they are taken.



**TIP:** Stars that appear larger in your image are not necessarily closer. The size of the spot is determined by the brightness of the star, not by its actual size or closeness.

Be certain that students download their images in FITS format. (Follow instructions at the top of the page containing your image.) The FITS format contains all the brightness information about your image; you will need it to measure the star's brightness. Note: The image that appears in your browser window, on the Web, is a GIF-format image; it does *not* contain the original brightness information you will need.

**Printing the image.**

Have students print an image containing their target star. To save to your printer's toner, it is useful to have students *invert* their images first so that they print black stars on a white background. (In MOImage or similar software program, choose **Invert** from the menu.)

**Identifying the target star.**

The target star will almost certainly be the brightest star in the field of view. However, students can check by using the star charts provided in the student journals. They can compare the pattern of stars in the chart with that in their image—noting that the scale of the star charts may not exactly match the scale of the printed images.

## Downloading an image of the Sun

To save time, it is best to have previously downloaded a reference image of the Sun from this URL, and to have made it available to students on their computers:

http://cfa-www.harvard.edu/webscope/archive/sun.FITS

This image was taken previously with the MicroObservatory telescopes, using a protective filter that blocks out most of the Sun's light.

## How the telescope measures brightness

The telescope's image sensing chip is divided into thousands of light-sensing wells. Each well corresponds to one pixel in the final image.

Each light-sensing well absorbs the light falling on it, and converts the light to a *number* between 0 and 4095. No light corresponds to 0. A lot of light corresponds to 4095.

The number is *proportional* to the amount of light falling on the sensor. For example, if dim light produces the number 135, then twice as much light will produce the number 270. Four times as much light would produce the number 540, and so on.

The proportionality ends when the chip is "saturated" with light, corresponding to 4095. More light than this is simply ignored by the sensor. When measuring the brightness of any celestial object, it is important that each of its pixels have a value less than 4095, so that you are measuring within the chip's range of proportionality.

## Students measure the Sun's brightness

Explain to students that the Sun is their *reference star*. They will measure the brightness of the Sun and then compare it to the brightness of their target star.

Have students follow these steps:

1. **Launch the image-processing program**. The MOImage program should already be on the computer. If not, download it from

   http://mo-www.cfa.harvard.edu/MicroObservatoryImage

2. **Open the Sun image.** From the MOImage program, open the Sun image. (From the **File** menu, select **Open Image on Local Disk**, and select your file. Remember: The image must be in FITS format. If not, students should go back and download the Sun image in FITS format.)

3. **Adjust the image display.** To see the image more clearly, go to the **Process** menu and select **Adjust Image**. When the dialog box appears, click the **Auto** button; the program will automatically adjust the contrast of the image.

4. **Explore your image:** To help students understand the measurements they're about to make, have them move the cursor over the image of the Sun. They'll see some numbers changing in the Image Info dialog box. The x- and y-values tell you *which pixel* you are measuring — this is the pixel under the cursor. The p-value shows you the **brightness of that pixel** under the cursor, on a scale from 0 to 4095 (where 0 is pure black and 4095 is pure white.)

   Have students move the cursor over the bright area of the Sun; they will see that the number is higher. If they move the cursor over the dark night sky, the number will be lower. The number for each pixel was determined by the telescope's light sensor, when the image was taken. The set of numbers is recorded in the FITS file for the image.

Have students record a typical value that they get for the Sun, and also for the background night sky. Does it make sense that the Sun is brighter than the background sky? Of course.

**"If I adjust the image display to make it brighter, will that change the pixel brightness that I measure?"**

No. The brightness tool measures the numbers in your original FITS image—*not* the brightness of the display on your screen. You can change the brightness and contrast of the image onscreen all you want, but that will not change the numbers in the image file, and it will not alter the numbers you read for each pixel value. Try it!

5. **Select only the Sun in the image**. Select the circle tool on the upper left corner of your image window. Using the mouse, click and drag the mouse to create a circle just large enough to encircle the image of the Sun. Try to encircle ONLY the Sun, getting as little background sky in the circle as possible. (You can move the circle with the cursor to position it over the Sun.)

6. **Measure the brightness of the Sun**. Under the **Process** menu, select **Measure**. Drag the corner of the dialog box that appears so that you can read all the numbers in the table. The **Area** shows you the number of pixels enclosed in your image. The **Mean** shows you the average value for each of those pixels. The **Total** shows you the total added brightness of all pixels within your circle. This is the brightness of the Sun in your image, which you'll compare to a similar measurement on your star, below.

   Make sure that students understand that the brightness of each pixel in their image can range from 0 (black) to 4095 (white). By adding up the individual brightnesses of all the pixels in the image of the Sun, they are getting a measure of the brightness of the Sun, which they will compare to the brightness of their star.

**IMPORTANT NOTE**: Note that their measurement of brightness has **no units**. This number lets you compare the *relative brightness* of two objects, as measured by the telescope. It does not tell you anything about the actual brightness of the Sun, for example in units such as lumens.

7. **Record your measurement.** Have students record their measurement of the Sun's brightness on their DATA PAGE.

   A typical value will be 305,000,000 units.

## Measuring your star's brightness.

Now have students measure the brightness of their target star, just as they measured the brightness of the Sun.

1. **Open the image of your target star.** Use the MOImage program, which should already be on your computer.
2. **Adjust the image display.** To see the image more clearly, go to the **Process** menu and select **Adjust Image**. When the dialog box appears, click the **Auto** button; the program will automatically adjust the contrast of the image.
3. **Find your target star.** The target star will usually be the brightest star in the image. (Reason: The Sun-like stars that astronomers prefer to study are nearby, and therefore brighter.) But to be certain, use the star charts provided, or other star chart, to identify your target star among the other stars.
4. **Check that the star's image is not overexposed.** Run the cursor over your target star and note the pixel values in the **Image Info** dialog box. **IMPORTANT:** If the maximum brightness of any pixel in your star reads 4095, then your image has "saturated," meaning that not all of the star's light was recorded by the telescope's sensor; use an image with shorter exposure time.
5. **Measure the star's brightness.** Using the circle tool, measure the star's brightness just as you did for the Sun.

6. **Record the star's brightness.** Have students record their star's brightness on their DATA PAGE.

   As a typical example, a star was found to have a total brightness of about 16,000 for a 1-second exposure, as measured by the MOImage program. (The maximum brightness of a single pixel in the star was found to be 2,252, well below the saturation limit of 4095.)

## Comparing the star's brightness with the Sun's

Explain to students that simply comparing the measured brightness of their star with the measured brightness of the Sun would not be a *fair comparison*. That's because the two images may have been taken in different ways.

Have each team discuss among themselves, "What factors might affect the brightness of the star in my image?" When they have assembled a list of possible factors, discuss these with the class.

Students should come up with several factors. The first four below are important for this investigation. The other factors affecting brightness can be ignored, because they will not greatly influence students' results:

- **The inherent brightness of the star**. The brighter the star, the brighter it appears in your image

- **The distance of the star**. The farther the star, the dimmer it appears.

- **The exposure time.** The longer the shutter is open, the more light reaches the sensor, and the brighter the image will appear.

- **The filter used.** Filters block some light from getting through, so the image will appear dimmer if a filter is used.

- **Clouds, mist, other atmospheric factors.** Stars appear to twinkle—vary in brightness—when seen through air of uneven density, caused by uneven heating from the ground.

- **How high the star is in the sky.** Viewing a star nearer the horizon makes it look dimmer, because you are looking through a greater thickness of atmosphere. (That's why the setting Sun isn't as bright as the mid-day Sun!)

- **Other factors.** Not all of the pixels in the telescope's light sensor are equally sensitive to light. Therefore a star may appear slightly dimmer or brighter depending on where its image falls in the field of view.

## Correcting the Sun's measured brightness

**Correcting for filter and exposure time.** The brightness of the Sun image is obviously much greater than the brightness of the distant star. However, in order to get a *fair comparison*, you must take into account the fact the Sun image was taken with a *filter* which let through only $10^{-8}$ (one hundred-millionth) of the sunlight! (Without the filter, the sunlight would have melted the telescope's light sensing chip.) Therefore, the sun is at least 100 million times brighter than your measurement indicates.

You have to multiply your brightness measurement by 100 million to take this into account.

Also, the sun image was exposed to light for 0.1 second — about 100 times less than the exposure time for the distant star. To make a *fair* comparison, therefore, you need to multiply the sun's brightness by another factor of 100 (or by however much longer your star exposure time is).

Multiplying the sun's brightness by these two factors thus gives you the "fair comparison" brightness of the sun: It is the brightness you *would have measured* if there were no filter and the sun's exposure time were the same as the distant star.

## Comparing the star and Sun

Now you can compare the star's brightness with the Sun's. In the sample activity shown here, the distant star's brightness is 16,000 counts. The sun's (corrected) brightness is $3.05 \times 10^{18}$ counts.

So the Sun appears $(3.05 \times 10^{18}) / 16,000 = 2 \times 10^{14}$ times brighter than the distant star. That is, the sample star appears 200 trillion times dimmer than the sun.

## Calculating the star's distance

Remind students of the *rule* that governs faintness versus distance:

> A star is that is 100 times fainter than its twin is only 10 times farther away. A star that is X times fainter than its twin is only $X^{1/2}$ times farther. (Equivalently, "the brightness falls off as the square of the distance.")

Have students calculate their star's distance by using this "inverse-square rule."

> In the sample activity, the star is 200 trillion times fainter than the Sun. Therefore it will be the square root of this times farther. That is, the star will be about 14 million times farther than the Sun.
>
> Since the Sun in 93 million miles from Earth, the star must be:
>
> 14 million x 93 million miles from Earth This is roughly 1300 trillion miles away.

## Introduce the "light-year"

After students have determined the distance to their star in miles, have them convert this value to light-years. Explain that distances in the universe are so vast, that astronomers use a measure of distance, called the *light-year*, which is more convenient. A light-year is the distance that light travels in one year — about 6 trillion miles.

***TIP:*** *The term "light-year" sounds as though it measures time, not distance. This could be confusing to students.*

> Light travels 186,000 miles per second. There are 32 million seconds in a year.
>
> So a light year = 186,000 miles/sec x 32 million sec/yr
> ~ 6 trillion miles / yr

The sample star is about 220 light-years from Earth. This means that light from the star takes 220 *years* to reach Earth!

## *Teachable Moment*

## The Art of Science: What's the right answer?

Many teachers and students want to know the "right" answer. You can compare your results with the published figures on this page, but keep in mind that nature doesn't come with a manual. *There is no "answer," there are only results*. Some results may be better than others, depending on how the experiments were done, but all results in science are tentative, and all have sources of error. By carefully examining how you carried out an investigation, you can learn to have confidence in your results.

Remember, "Don't look it up... look *UP!*"

| *Star* | *Light-years* |
|---|---|
| **Eta Cassiopeia** | *19* |
| **Upsilon Andromeda** | *44* |
| **55 Cancri** | *44* |
| **HR483** | *41* |
| **47 Ursae Majoris** | *43* |
| **61 Ursae Majoris** | *31* |
| **Beta Canum Venaticorum** | *27* |
| **Lambda Serpentis** | *38* |
| **HD209458** | *150* |
| **51 Pegasi** | *48* |

### How accurate is my result?

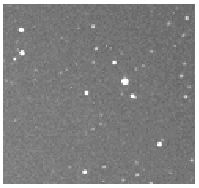
An important part of doing any investigation is to get a sense of how accurate your result is likely to be. If you have time, you may wish to have your students discuss: What are my likely sources of error? Where could my measurements have gone wrong?

Two major sources of error: Your star image may have been taken higher (or lower) in the sky than the sun image. (You can tell by checking the FITS header that comes with your image, or Image Info screen.) Thus there is not a fair comparison between the two images. If the star is imaged low in the sky (or if there is haze in the sky), it will appear dimmer, and therefore *farther away* than it actually is.

A second source of error comes in making the brightness measurement itself. You can minimize this error by making several measurements and averaging the results.

## DISTANCE TO A STAR

# SAMPLE DATA PAGE



Enter the name of your target star and the brightness you measure. To determine your star's distance, use the *Go Figure!* sheet.

| **TARGET STAR** (name) | **BRIGHTNESS** (total pixel count) | **EXPOSURE** (seconds) | **FILTER** (fraction of light passed) | **DISTANCE** (miles) |
|---|---|---|---|---|
| 51 Pegasi | 16,000 | 1.0 sec | 1 | ? |
| | | | | ? |
| | | | | ? |

Enter your measurement for the brightness of the Sun, which is your reference star:

| **REFERENCE STAR** (name) | **BRIGHTNESS** (total pixel count) | **EXPOSURE** (seconds) | **FILTER** (fraction of light passed) | **DISTANCE** (miles) |
|---|---|---|---|---|
| Sun | 44,000,000 | 0.1 | $10^{-8}$ | 93,000,000 |

The Sun was at an altitude of ____15____ degrees above the horizon.

My star was at an altitude of __________ degrees above the horizon.

# Part 4. Making sense of the results

The most important part of this investigation is for students to be able to make sense of the numbers that they get. What does it mean for a star to be, say 150 light-years away? Have students discuss with their team the questions in Making Sense, and have them record their responses in their journals.

- **Modeling the Universe.** If a grape (or a marble) represents our Sun, then a star that is 100 light years away will be represented by a second grape that is about 5000 miles away!

  Reason: In our scale model, 1/2 inch (the grape) represents about 1 million miles (roughly the width of the sun). Then 1 light-year (or 6 million million miles) will be represented by 1/2 x 6 million inches. That is, one light-year in the scale model will be about 3 million inches or about 250,000 feet or about 50 miles. So star that is 100 light-years away will be 50 x 100 = 5000 miles away in this model!

  Stars are incredibly far apart!

  - **Telescope as time machine.** Think of light as a stream of particles flowing from the star to Earth. For a star that is 150 light-years away, light that reaches the telescope today has been traveling for 150 years to Earth. So the image that arrives today shows the star as it looked 150 years ago! The star is still emitting light today, but that light won't get here for another 150 years.

  Telescopes are *time machines* in the sense that they show us how the universe looked in the past. The more distant the object that we image, the farther back in time we are looking!

  - **Travel to the stars?** At 100,000 miles per hour, how long would it take to travel, say, 1 light-year? Recall that 1 light-year is about 6 million million miles. It would take:

  (6 million million / 100,000) hours to travel this distance. This is .06 billion hours = 60 million hours. There are 8760 hours in a year (i.e., 24 x 365 hours / year). Therefore it would take

(60 million / 8760 ) years travel just a light-year. This is almost 7000 years in space! So to reach a star that is 100 light-years away would take nearly 700,000 years!

In the science fiction series *Star Trek*, the spacecraft can reach speeds of "warp 10," which is supposed to be 10 times the speed of light. We know of no way anything can travel faster than light—yet even at this fictitious speed of warp 10, it would take 10 years to reach a star system 100 light-years away.

Our galaxy is truly *huge*.

- **E.T. phone home?** The fastest known means of communication is light. At the speed of light, it would take 150 years for a message to reach a star that is 150 light-years away. It would take another 150 years for their message to return. Any conversation we had with our cosmic neighbors would take generations to complete!

## Puzzler

Students will be surprised to learn that all the stars they can see with their naked eye—including all the stars in this exploration—are contained well within the smallest circle in the diagram. Although the Milky Way creates the illusion of seeing vast numbers of individual stars, in reality we can discern fewer than 6000 individual stars by eye, even from the darkest and best observing spots on Earth. This is just a tiny fraction of the more than 100 billion stars in our galaxy.

The Milky Way galaxy is about 100,000 light-years across. The furthest star in this investigation is about 150 light-years away from Earth—at the scale of the diagram not even a pixel of separation from our solar system!