TOPIC 4 Bigger and Smarter Telescopes

You learned in Topic 3 that most astronomers today use spectroscopy to examine stars. But to collect enough light to detect a spectrum, astronomers have always needed telescopes. Over the past two centuries, astronomers have built bigger telescopes to look deeper into the universe. In Topic 4, you will find out about some of these telescopes.

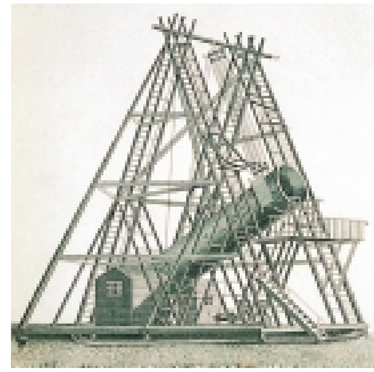


Figure 5.27 Sir William Herschel built one of the first really large telescopes. He discovered the planet Uranus with it in 1781.

New Discoveries

Bigger telescopes enable astronomers to find new astronomical objects. In 1773, Sir William Herschel, an English astronomer, built a large reflecting telescope in Great Britain. Using this telescope, he discovered the planet Uranus. This was an exciting discovery because no one had ever suspected the existence of other planets in the solar system.

At the end of the nineteenth century, the largest refracting telescope in the world was the 101 cm telescope at the Yerkes observatory near Chicago. Gerald Kuiper discovered methane gas in Saturn's moon, Titan, and two new moons of Uranus with this instrument.

Cool Tools

In 1948, the Hale reflecting telescope, 5 m in diameter, was built on Mount Palomar in northern San Diego County, California. It is so large that astronomers can ride around inside it! Its objective mirror alone weighs about 18 t!

Combining Telescopes

Today, telescope design has moved to things that were not even dreamed of 100 years ago. Using powerful computers, it is now possible to combine images from two or more telescopes. This creates the equivalent of one telescope the size of the total distance between the two. Using this method the twin Keck telescopes have a resolving power equivalent to being able to distinguish each headlight on a car 800 km away!

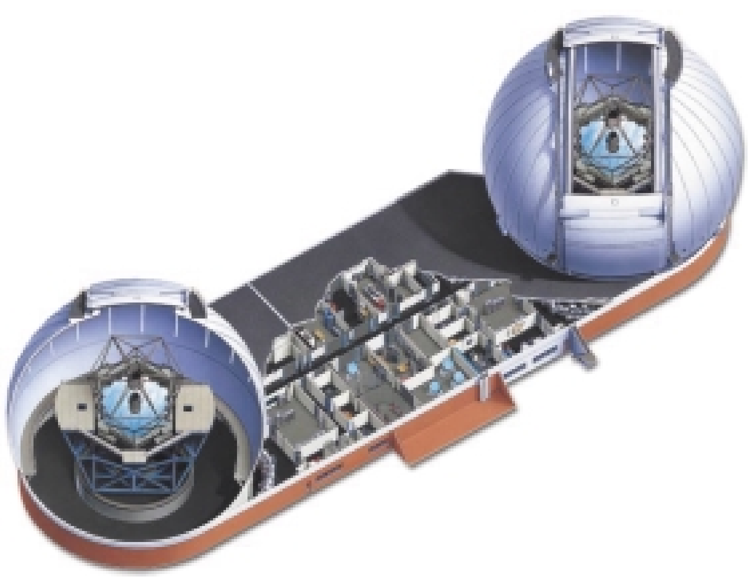


Figure 5.28 The twin Keck telescopes located in Mauna Kea, Hawaii.

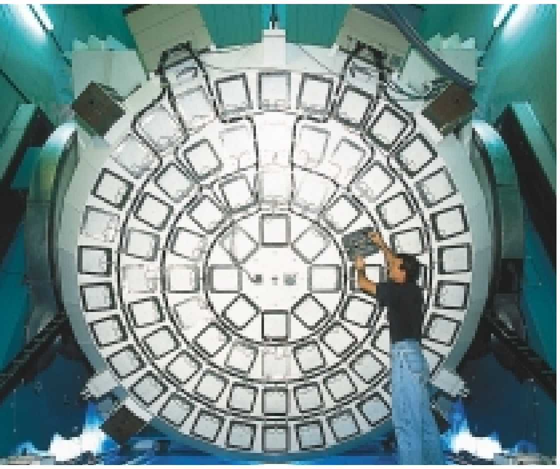


Figure 5.29 The New Technology Telescope (NTT) is one of the telescopes pioneering adaptive optics. Its mirror is constantly deforming in time with the atmosphere to remove the twinkling effect.

Adaptive Optics

Have you ever wondered why stars twinkle? Stars twinkle because the motion of Earth's atmosphere refracts their light randomly. This makes it difficult for astronomers to get a clear view of stars. To help deal with this problem, astronomers now connect computers to telescopes. Computer programs tell the computer to sense when Earth's atmosphere moves. The computer controls devices under the objective mirror. These devices distort the objective mirror just the right amount to cancel out the twinkling effect. The twinkling is cancelled out because the mirror has the correct "wrong" shape to compensate for the atmospheric distortions.

This technology is called **adaptive optics** — "adaptive" because the computers that control the image you see are always adapting the mirror to changes in Earth's atmosphere. The New Technology Telescope, in La Silla, Chile, uses adaptive optics. Astronomers attach adaptive optics technology to older telescopes too. Computer software processes the images they make to remove the blurring effect of the atmosphere.

Find Out ACTIVITY

Comparing the Effects of Light Pollution

Most big professional telescopes are located in remote places, far from cities. An advantage of observing or filming the sky in a remote location is the absence of light pollution. Light pollution is the glow in the sky at night caused by high concentrations of artificial lighting, such as that found in and around cities. The effect of this high amount of light is that it makes it difficult for observers of the night sky to see any but the brightest stars.

Procedure — Performing and Recording

1. Obtain a cardboard tube from an empty roll of paper towels.
2. Select a night when clear skies are predicted. Go outside about two hours after sunset. Observe a constellation of your choice through the cardboard tube.
3. Count the number of stars you are able to observe without moving the observing tube. Record this number. Repeat this exercise on two more clear nights, from the same location and looking at the same constellation.
4. Plan a way to determine the average number of stars that can be observed through the tube from your location.

What Did You Find Out? — Analyzing and Interpreting

1. In class, compare the number of stars you were able to see with those that other students saw from their locations.
2. As a class, brainstorm the reasons for the differences in your observations and write these on the chalkboard.

Distance to the Stars

As telescope size increases, it enables astronomers to see more distant stars. These telescopes pinpoint star positions with better precision. Where are these stars? How far away are they from Earth? How big is the universe? These are questions most people ask when they look up into the sky — whether you use a telescope or not! Astronomers ask these questions too. To find answers to some of these questions, astronomers developed methods to measure the distances to the stars.

Measuring with Triangulation

You and a friend are standing beside a lake, looking out at an island. You are thinking of rowing out to the island, but you do not know how far away it is. Because you do not have a map of the lake and there is no bridge to the island, you have no means of measuring the distance directly. Is there some other way you can estimate it?

The answer is yes. By using a distance you know, you can calculate the unknown distance indirectly. One of the most common ways of doing this is called triangulation. **Triangulation** (also referred to as the **parallax technique**) is a method of measuring distance indirectly by creating an imaginary triangle between an observer and an object whose distance is to be estimated (see Figure 5.30). It is the same method that astronomers use to measure distances to celestial objects.

Figure 5.31 on the next page describes step by step how you could use the technique to estimate the distance across a lake to an island. It is important to remember, when measuring distances with triangulation, that the longer the baseline, the more accurate the results.

DidYouKnow?

Christian Huygens was a Dutch physicist and a contemporary of Newton. Huygens used a brass plate with a hole in it to estimate the distance to the star Sirius. The hole was small enough so that through it, the Sun appeared to be as bright as Sirius, which Huygens remembered from the night before. The hole was 1/28 000 the size of the Sun's apparent size, so Sirius, he reasoned, should be 28 000 times as far away as the Sun. His result is wrong only because he assumed that Sirius and the Sun are truly as bright as each other.

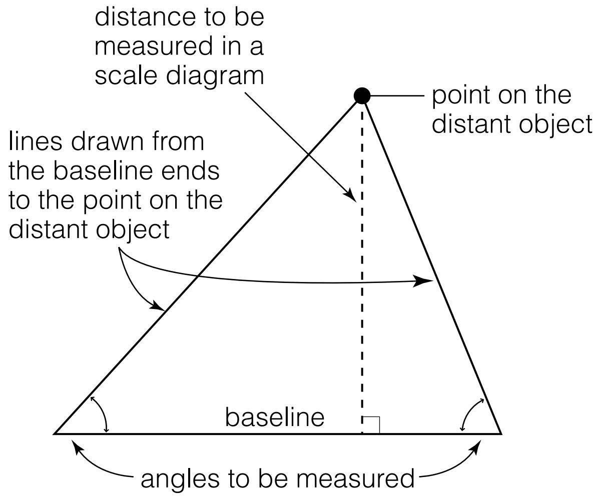
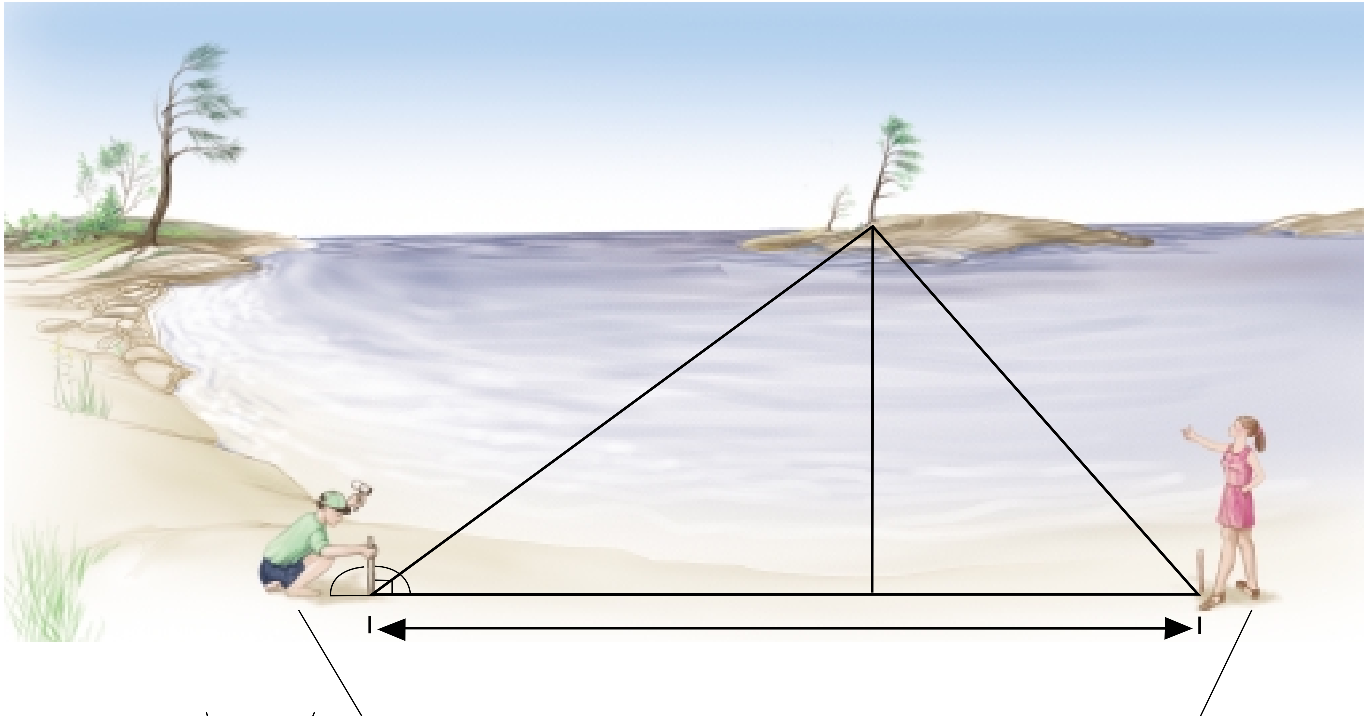
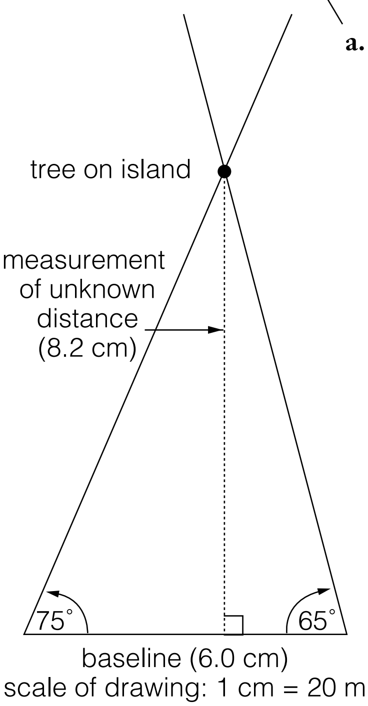


Figure 5.30 To use triangulation, you need to know the length of one side of the triangle (the "baseline") and the size of the two angles created when imaginary lines are drawn from either end of the baseline to the same point on the distant object.



a. *Create a baseline.* Mark off a long, straight line, 120 m long, just up from the shore. The end of the baseline where you start measuring can be marked with a stake.

b. *Measure the angles from the end of the baseline.* Stand at one end of the baseline, facing the island, and imagine a straight line extended to a point on the island (for example, to a tall tree). Then, measure the angle between that line and the baseline and record it. At the other end of the baseline, repeat the procedure. Suppose the two angles you record are 75° and 65°.



c. *Make a scale drawing of the imaginary triangle.* First, choose an appropriate scale (in this case, 1 cm = 20 m) and draw the baseline. Then, using a protractor and a ruler, draw a line from each end of the baseline at the angles you recorded. The point at which the two lines cross is the position of the object (in this example, the tree). The shortest distance from that point to the baseline (the dotted line) represents the distance between the shore and the tree on the island. In this case, the line measures 8.2 cm, or 164 m in real life.

Figure 5.31 This example shows how you and your friend could use triangulation to estimate the distance across the lake to the island.

DidYouKnow?

Almost 2000 years ago, the Greeks used triangulation to calculate the distance between Earth and the Moon. They realized that two people in two different cities pointing at the Moon simultaneously would be holding their arms at different angles from the ground. They used this information to create a triangle. The baseline was 300 km long. Then they used a scale drawing to figure out the distance to the Moon. In making their calculations, the Greeks also understood that they had to take the curvature of Earth's surface into account. Can you explain why this was an important factor and how it would affect the accuracy of results?

Triangulating on a Star

Astronomers use triangulation to determine the distance to nearby stars. The technique is similar to the one you just learned, as shown in Figure 5.31. In order to work from the longest possible baseline available without leaving Earth, two sightings of the nearby star are taken six months apart. Therefore, the baseline is the diameter of Earth's orbit, which is a known measurement. When the sightings of the nearby star are made, the star will appear to have moved against the background of fixed stars behind it, which are much farther away. The apparent shift in position of a nearby object when viewed from two different points, called "parallax," is used to provide reference points for measuring the two angles. Figure 5.32 illustrates the point.

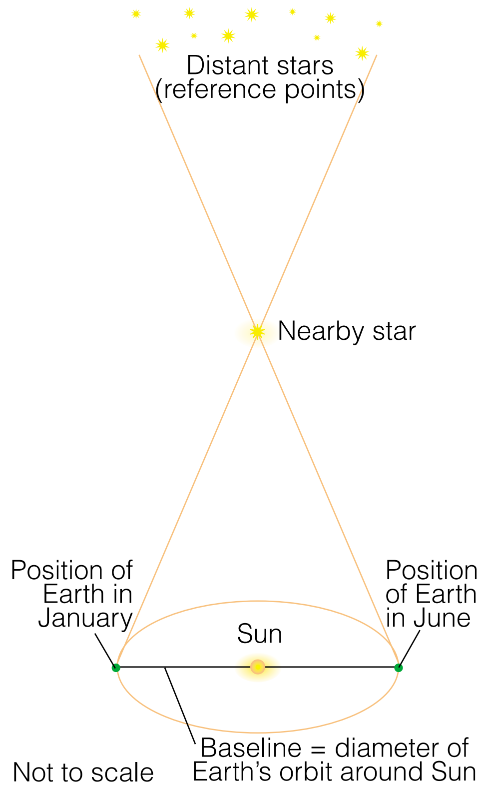


Figure 5.32 (diagram not to scale) Astronomers use the diameter of Earth's orbit as the baseline for triangulating on a nearby star. The angle between the baseline and the star's position is measured in January and June, for example. Distant stars appear to be fixed, providing a reference point for measuring the two angles.

Off the Wall

Astronomers can measure really small angles. Angles are measured in degrees. Astronomers divide 1° into 60 arcminutes. One arcminute is divided into 60 arcseconds. The best telescopes can measure angular distances of a few thousandths of an arcsecond. This would allow them to read the centimetre marks on a ruler 20 km away!

Large Enough Units: AU and Light-Years

You have probably noticed that Figure 5.32 is very much out of scale. The nearest star to Earth, for example, is Proxima Centauri and it lies more than 272 000 astronomical units (AU) from the Sun. One **astronomical unit** is the distance from Earth to the Sun (150 million km). Because interstellar distances are so much greater than solar system distances, astronomical units quickly become impractical to use (impractical as, for example, using millimetres to measure the distance across Canada). Astronomers therefore created the light-year. A **light-year** represents the distance that light travels in one year, a distance equal to about 63 240 AU. On this scale, Proxima Centauri is 4.28 light-years away.

Cool Tools

Until a few years ago, astronomers using parallax measurements and triangulation could measure the distance to only about 10 000 of the nearest stars. All these stars were no farther than about 126 light-years from Earth. The Hipparcos satellite has recently changed this situation. Because its baseline of observation is longer, the satellite increases the range for triangulation to 1600 light-years. As a result, accurate parallax measurements have been obtained for more than 100 000 stars.

Math Connect

Light travels at 300 000 km/s (3.0×10^8 m/s). Show that a light-year is about 9.5 trillion km (9.5×10^{12} km).

INQUIRY

INVESTIGATION 5-F

SKILLCHECK

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Using Triangulation to Measure an Unknown Distance

How far is it from here to there? In the example described in Figure 5.31, you learned that triangulation can be used to estimate a distance indirectly. Now try the technique yourself.

Question

How can you estimate the distance to a landmark you can see without measuring that distance directly?

Prediction

Your teacher will provide you with the actual distance to the object. This distance becomes your predicted value. After completing this investigation, compare your measured value to the predicted value.

Apparatus

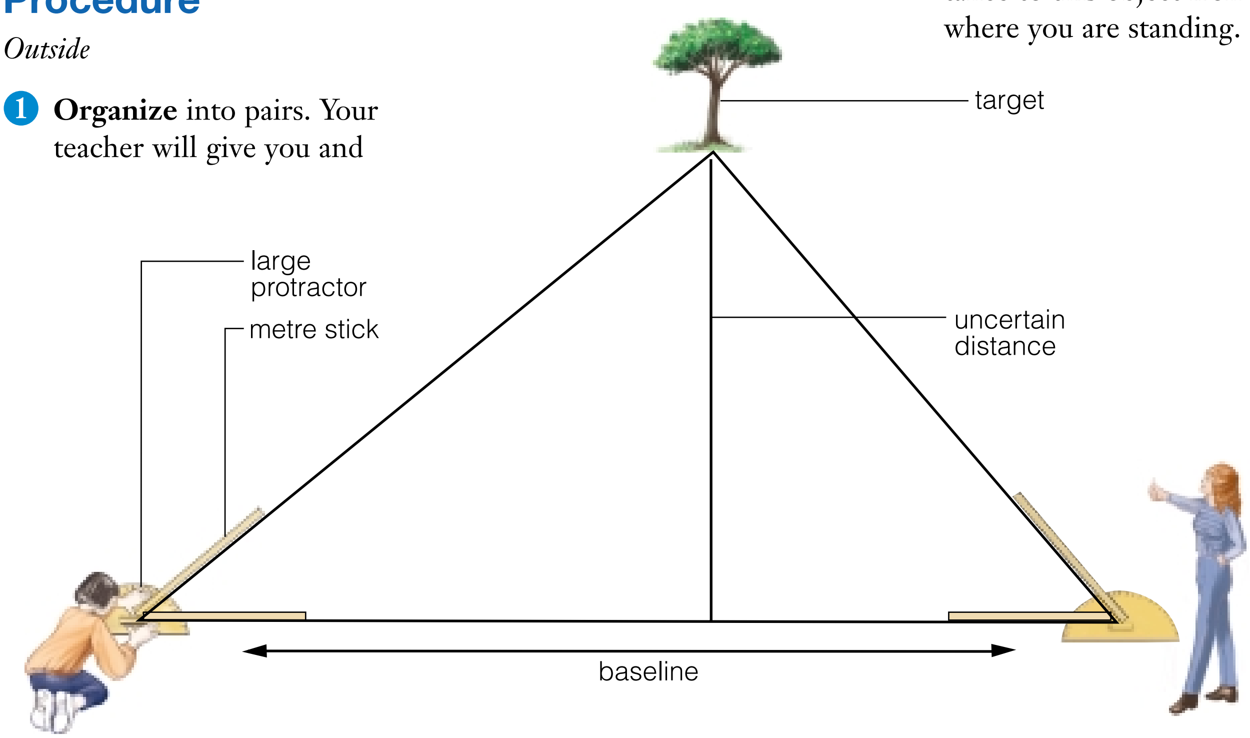
large chalkboard protractor
long measuring tape
two metre sticks
stake or other marker
ruler
small protractor

Procedure

Outside

1. **Organize** into pairs. Your teacher will give you and your partner a large protractor, a measuring tape, two metre sticks, and a stake or other marker for the starting end of your baseline.

2. Your teacher will choose a building, radio tower, tree, or other distant object that is clearly visible from the school grounds. You are going to **measure** the distance to this object from where you are standing.



3. With your partner, mark off a baseline, leaving a marker at the end where you start measuring. **Record** this distance. Remember: The longer your baseline, the more accurate your results will be.

4. At one end of the baseline, place one of the metre sticks on the ground along the baseline. Aim the other toward the object. Using the large protractor, **measure** the inside angle formed by the two metre sticks. **Repeat** at the other end of the baseline. **Record** both angles.

In the Classroom

5. Draw a scale diagram of the set-up in your notebook.
   - **(a)** With your partner, select a suitable scale. For example, you might represent 1 m of actual distance by 1 cm.
   - **(b)** Using the ruler, draw your baseline to scale. Then, with the small protractor, add lines at the angles you measured, extending them just until they cross. This "common point" is the object whose distance away you are measuring. (Refer back to Figure 5.31 if you need guidance.)
   - **(c)** Inside the triangle you have created, draw a straight line down from the object to the baseline. This should be the shortest distance between the object and the baseline. **Measure** the length of this line and, applying your scale, determine the true distance to the object.

Analyze

1. Compare your results with those of other students. What length of baseline did other students use? Are the distances you found similar? If not, why do you think that is?

Conclude and Apply

2. Summarize in a paragraph how baseline length seems to affect the accuracy of distances calculated using the triangulation technique. What is the longest possible baseline astronomers have available to them to measure distances to stars from Earth when they use triangulation? Explain your answer.

Extend Your Skills

3. Choose another one or two landmarks. Practise using triangulation to measure how far away they are from your school or home. Once you have made your calculations, check your results against the scale distance on a map.

Skill FOCUS

For tips on measuring, turn to Skill Focus 5. For help with technical drawing, turn to Skill Focus 11.

Pause& Reflect

Why is it important to use a relatively long baseline rather than a short one? Why is triangulation effective for measuring the distance to nearby stars, but not more distant ones? Answer these questions in your Science Log and include sketches to support your explanations.

Across Canada

At the age of 15, Helen Sawyer saw her first total eclipse of the sun. This event, which she described as "magnificent," inspired her to make astronomy her life.

Less than two decades later, Helen Sawyer Hogg had become well known as a Canadian astronomer and writer. She joined the University of Toronto in 1935, where she taught for 40 years. She frequently visited the David Dunlap Observatory in Richmond Hill, where she used its 185 cm telescope. Her husband, Dr. Frank S. Hogg, was appointed director of the observatory in 1946. Five years later, he died, leaving Helen with three teenaged children.

Dr. Sawyer Hogg charted clusters of stars within the Milky Way. She was an expert on globular clusters. She measured the changing level of brightness in "variable" stars within globular clusters and through these measurements was able to predict the distance of the stars from Earth. Most are between 5 and 70 thousand light-years away.

This world-renowned astronomer also wrote a column for the *Toronto Star* from 1951 to 1980. In addition, she wrote a book called, *The Stars Belong to Everyone: How to Enjoy Astronomy* (1976). In this book, she explained the wonders of the night sky in simple terms that the general public could understand. During her lifetime, Dr. Sawyer Hogg witnessed Comet Halley twice. The first time she was only five years old; the second time she was 80 — the same year (1985) she married her second husband, Frances Priestly. Among her many honours, Dr. Sawyer Hogg has had an asteriod named after her. This asteroid orbits between Jupiter and Mars.

Helen Sawyer Hogg

Dr. Sawyer Hogg passed away in 1993.

TOPIC 4 Review

1. Why do astronomers continue to build even larger telescopes?

2. What method do astronomers use to measure the distances to the nearest stars?

3. What is adaptive optics? How does this technology work?

4. Proxima Centauri, the closest star to our Sun, is 4.3 light-years away. Light travels at 300 000 km/s. Calculate how far away Proxima Centauri is in kilometres.

5. **Apply** How far away is the tree in this picture?