

Measuring Distances Beyond the Solar System

The Sun, our nearest star, appears as a large, bright disc in the sky because it is relatively close to Earth—approximately 150 million (1.5×10^8) km away. The next nearest star to the Sun is Proxima Centauri, which appears as a twinkling dot of light. Proxima Centauri is approximately 40 trillion (4.01×10^{13}) km from Earth, which is about 267 000 times farther away from Earth than the Sun. Most stars are more than 100 trillion (1.0×10^{14}) km from Earth.

Distances beyond the Solar System are so vast that scientists cannot measure them in the same way they measure distances on Earth. For example, if you were to measure the distance from the Sun to Proxima Centauri using kilometres it would be like measuring the distance from Vancouver Island to Prince Edward Island in centimetres!

In Chapter 8 you learned about the astronomical unit (AU). The AU can be used to measure distances within the Solar System, but it is too small for measuring the enormous distances beyond the Solar System. Instead, scientists use more convenient units of distance to measure the distances between stars.

The Light Year

Astronomers use **light years** to measure the distance to stars or other celestial objects outside of the Solar System. Although it sounds like a unit of time, the light year is, in fact, a unit of distance. A light year is the distance that light travels in a vacuum (empty space) in one year. In space, light travels at a constant speed of approximately 300 000 km/s. This means that 1 light year (ly) is approximately equal to 10 trillion (9.46×10^{12}) km. Table 1 shows the approximate distances of some celestial objects beyond the Solar System.

We can use the following equation to determine the distance between two celestial objects in light years:

$$1 \text{ ly} = 9.46 \times 10^{12} \text{ km}$$

SAMPLE PROBLEM 1 Calculating the Distance to a Star in Light Years

If Proxima Centauri is 4.01×10^{13} km from Earth, what is its distance from Earth in light years?

Given: distance to Proxima Centauri = 4.01×10^{13} km
 $1 \text{ ly} = 9.46 \times 10^{12} \text{ km}$

Required: distance to Proxima Centauri in light years (ly)

Analysis: distance in light years = $4.01 \times 10^{13} \text{ km} \times \frac{1 \text{ ly}}{9.46 \times 10^{12} \text{ km}}$

Solution: distance to Proxima Centauri = 4.24 ly

Statement: The distance from Earth to Proxima Centauri is 4.24 ly.

Practice

Polaris is 400 ly from Earth (Table 1). Calculate the distance from Earth to Polaris in kilometers.

LEARNING TIP

Large Numbers

A trillion is a million million. That is 1 000 000 000 000 (1.0×10^{12}).

DID YOU KNOW?

Proxima Centauri

Proxima Centauri is the nearest star to the Sun and is only visible in the southern hemisphere. If you could travel to Proxima Centauri in a vehicle going 1000 km/h, it would take almost 46 million years to get there!

light year the distance that light travels in a vacuum in 1 year (365.25 days); equal to 9.46×10^{12} km

MATH TIP

SI Units

1 km = 1×10^3 m

1 AU = 1.5×10^{11} m

1 ly = 9.46×10^{15} m

Table 1 Distance of Some Celestial Objects

Star or galaxy	Approximate distance from Earth (ly)
Alpha Centauri	4.3
Vega	25
Polaris	400
Deneb	1400
Andromeda Galaxy	2 600 000



Figure 1 Vega

The farther a star is from Earth, the longer it takes for the light from that star to reach Earth. For example, the star Vega is approximately 25 ly from Earth (Figure 1). The light from Vega travels at the speed of light, which means that it takes the light from Vega approximately 25 years to reach Earth. When you observe Vega in the night sky, you see it as it was 25 years ago, not as it is today! Some celestial objects are thousands or even millions of light years from us, so when astronomers look at them through telescopes, they are actually looking back in time thousands or millions of years.

While the astronomical unit is useful for measuring distances within the Solar System, the light year is typically used to measure distances to stars and other celestial objects beyond the Solar System. Figure 2 shows which units are used for various distances.

DID YOU KNOW?

Distance to the Sun

The Sun is approximately 0.000016 ly away from Earth. Light from the Sun takes approximately 0.000016 years (or 8 minutes) to reach us.

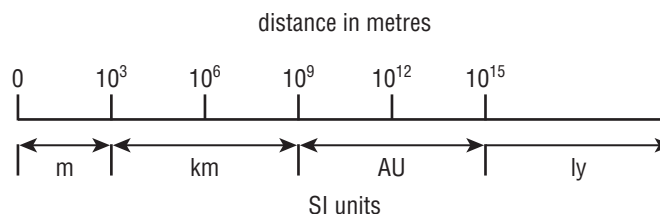


Figure 2 This chart (which is not to scale) shows which units are appropriate for different distances. The top line shows distances, written in scientific notation and measured in metres. The bottom line shows the SI units that are used for different distances.

The light year can be modified to produce values that are easier to work with. For example, remembering that 1 ly is equal to 9.46×10^{12} km and that there are 60 minutes in an hour and 60 seconds in a minute, we can determine the distance between two celestial objects in light minutes (lm) or in light seconds (ls).

DID YOU KNOW?

Light Nanosecond

In one billionth of a second, light travels approximately 30 cm. This is called a light nanosecond. Computer memory speed is measured in nanoseconds, as are many other modern technologies.

Radar uses the light nanosecond to measure the distance to objects in the air. A radar antenna sends out radio waves (which travel at the speed of light) and then counts the number of nanoseconds it takes for the waves to bounce back from the object in the air. The distance to the object can then be determined by dividing the number of nanoseconds by two.

SAMPLE PROBLEM 2 Converting Light Years to Light Seconds

If 9.46×10^{12} km = 1 ly, how many kilometres are there in 1 ls?

Given: 1 ly = 9.46×10^{12} km

Required: the number of kilometres that make up 1 ls

Analysis: 1 ly = $(60 \times 60 \times 24 \times 365)$ ls

1 ly = 3.15×10^7 ls

1 ls = $\frac{9.46 \times 10^{12} \text{ km}}{3.15 \times 10^7 \text{ ls}}$

Solution: 1 ls = 3.0×10^5 km

Statement: There are 3.0×10^5 km in 1 ls.

Practice

Betelgeuse is 5.7×10^{15} km from Earth. How many light seconds away is Betelgeuse?

SKILLS: Analyzing, Evaluating

In this activity, you will determine the distances of some objects in the Solar System using a variety of units based on the speed of light. You will learn more about probes in Chapter 10.

Equipment and Materials: computer; calculator

1. Copy Table 2 into your notebook.

Table 2 Distances of Robotic Probes

Probe	Distance (km)
<i>New Horizons</i>	
<i>Stardust</i>	
<i>Voyager 2</i>	
<i>Dawn</i>	
<i>Cassini</i>	

2. Using the Internet, research the current distances (in kilometres) to the robotic probes listed in Table 2. Record the data in Table 2.



GO TO NELSON SCIENCE

- A. Calculate the distance, in light years, from Earth to each of the five robotic probes. **T/I**
- B. Convert the distances you calculated in A into light minutes. **T/I**
- C. Which unit would be best for describing the distances to probes travelling in the Solar System? Why? **T/I**
- D. The Sun is 1.0 AU from Earth. Convert this distance into light seconds. **T/I**

Stellar Distances

Early astronomers discovered that over a period of weeks and months, the planets appeared to move against a background of stars. This led them to believe that stars are much farther away than the planets. However, early astronomers did not have a useful way of measuring the distance between celestial objects or the distance between these objects and Earth.

Scientists have since developed various methods of measuring interstellar distances—the distances between stars in the Universe. One method, parallax, relies on geometry. **Parallax** is the apparent change in position of an object against a fixed background when viewed from two different lines of sight (or locations). You can observe parallax when you hold your thumb upright at arm's length and view it first with one eye and then with the other (Figure 3).

parallax the apparent change in position of an object as viewed from two different locations that are not on a line with the object



Figure 3 (a) A student lines up his thumb with an island in the distance. (b) When the student views the same island through only the right eye, the island appears to move to the left. His thumb is no longer lined up with the island.

READING TIP

Restating an Idea

Paraphrasing involves restating an idea in your own words. Read a text silently. Ask yourself what the main idea and supporting details are. Look away from the text. Say aloud what you think the main idea is. For example, “Astronomers observe parallax and then use triangulation to determine how far away a star is from Earth.” Compare your version with what is in the text to make sure you have captured the main idea.

Each eye views your thumb (the object) from a slightly different direction. This results in an apparent change in the position of your thumb when you close one eye. When you have both eyes open, your brain uses parallax to get a sense of the distance between your eyes and your thumb. If you move your thumb halfway to your nose, you can see that parallax increases as distance decreases. Parallax is measured in angles (Figure 4).

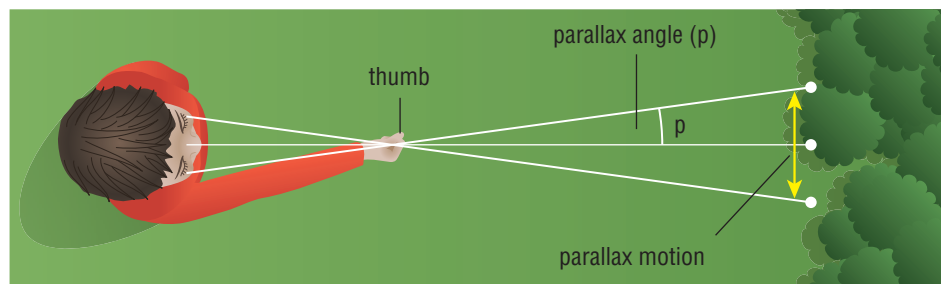


Figure 4 Parallax is the angle measured between the two lines of sight, divided by two.

Parallax can be used to calculate the distance to stars using a method known as triangulation. Triangulation uses the principle that if you know the length of one side of a triangle and the angles of two corners, you can calculate all the dimensions of the triangle.

Figure 5 shows how astronomers use triangulation to calculate the distance from Earth to a star. The diameter of Earth’s orbit is the “known” side of the triangle. The star is then observed from two different positions in Earth’s orbit around the Sun. To do this, astronomers observe the star and then wait six months to observe it again while Earth is at the opposite end of its orbit. The “triangle” formed by these observations can be used to calculate the distance to the star.

DID YOU KNOW?

HIPPARCOS Satellite

Launched in 1989 by the European Space Agency, the High Precision PARallax COLlecting Satellite (HIPPARCOS) was the first satellite dedicated to accurately measuring star positions. After the mission ended in 1993, astronomers published the Hipparcos catalogue, which lists the most detailed position measurements ever made of 100 000 stars. The satellite’s name honours a Greek astronomer named Hipparchus who used triangulation in 150 BCE to determine the Moon’s distance from Earth.

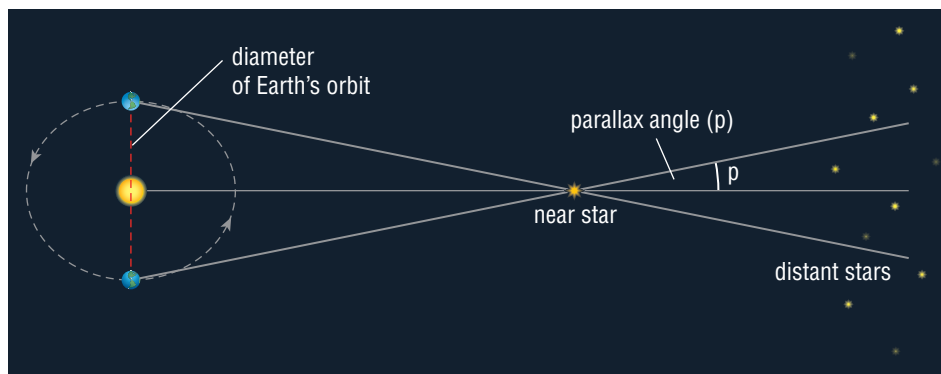


Figure 5 Because stars are distant, astronomers need to measure parallax from positions that are very far apart.

With the aid of extremely large telescopes, astronomers are able to use parallax to estimate the distances to stars as far as 100 ly away. For distances beyond this, using parallax becomes too imprecise. In the early 1990s, a unique satellite called the HIPPARCOS satellite was sent into space on a star-mapping mission. It was able to accurately measure star positions, parallaxes, and motions of stars up to 1000 ly away. The HIPPARCOS satellite was able to make more accurate measurements than observatories on Earth. In part, this was because it did not have to contend with the blurring effect of Earth’s atmosphere.

UNIT TASK Bookmark

You can apply what you have learned about distances in space to the Unit Task described on page 446.

IN SUMMARY

- The distances to stars and galaxies can be measured in light years.
- Astronomers use parallax to determine the distances to nearby stars, based on the apparent change in position of stars as seen from different locations along Earth's orbit.



CHECK YOUR LEARNING

1. Why do astronomers use special units such as light years to measure distances in space? **K/U**
2. Betelgeuse is 600 ly from Earth. Calculate the distance in kilometres. **T/I**
3. Polaris is 4.07×10^{15} km from Earth. Calculate the distance in light years. **T/I**
4. If you hold your finger out at arm's length and view it only with your left eye and then only with your right eye, it appears to jump sideways. Imagine that you have been asked to write a paragraph for a children's science magazine explaining this phenomenon. Include a diagram if you wish. **K/U C**
5. The HIPPARCOS satellite orbited Earth for four years observing stars. What properties did the satellite measure? **K/U**
6. The most distant objects in the Universe known to astronomers are 14 billion ly away. Convert this value to metres. **T/I**
7. The largest known star, VY Canis Majoris, is an incredible 9.18×10^{12} m in diameter. What is VY Canis Majoris's diameter in AU? **T/I**
8. Why would it not be practical to use light years to describe the distance from your school to your home? **T/I**
9. Many people think that a light year is a unit of time. Write a short letter to a family member explaining the importance of the light year as a unit of distance for astronomers studying distant objects. Include an example in your explanation. **K/U C**
10. How far does light travel in one nanosecond? **K/U**
11. Which unit would you use to measure the distance to the following celestial objects? **T/I**
 - (a) an asteroid found orbiting the Sun 4.7×10^{11} m away
 - (b) a meteor burning up in Earth's atmosphere 7.8×10^3 m above us
 - (c) a dwarf planet found in the Kuiper Belt, 6.6×10^{12} m from the Sun
 - (d) the next nearest star to our Sun, Proxima Centauri, which is 4.0×10^{16} m away
 - (e) a spy satellite orbiting Earth at an altitude of 3.5×10^7 m