

# Astronomy: The Original Science

## BEFORE YOU READ

After you read this section, you should be able to answer these questions:

- How do astronomers define a day, a month, and a year?
- What is the difference between the Ptolemaic and Copernican theories about the universe?
- What contributions did Brahe, Kepler, Newton, Galileo, and Hubble make to astronomy?

## National Science Education Standards

ES 3a, ES 3b, ES 3c

## How Does Astronomy Affect Our Calendar?

Imagine that it is 5,000 years ago. You do not have a modern clock or calendar. How can you know what day it is? How can you know what month it is? One way is to study the movement of the moon, the planets, and the stars.

People in ancient cultures used the movements of the stars, planets, and moon to mark the passage of time. People observed that the objects in the solar system move in regular and predictable ways. Farmers used these cycles to figure out the best time of year to plant and harvest. Sailors used the stars to navigate their ships. ✓

The early observations of the night sky led to the first calendars. Our modern calendar is also based on the movements of the bodies in our solar system. In our modern calendar, a **year** is the amount of time it takes the Earth to orbit the sun once. A **month** is about the same amount of time that the moon takes to orbit the Earth once. A **day** is the time it takes for the Earth to rotate once on its axis.

Unit	Description
Day	
Month	
	the time it takes the Earth to orbit the sun once

Over time, the study of the night sky became the science of astronomy. **Astronomy** is the study of the universe. Scientists who study astronomy are called *astronomers*. Modern astronomy is based partly on the work of early astronomers.

## STUDY TIP

**Compare** As you read, make a chart comparing the different scientists that are mentioned in this section. In your chart, describe each scientist's contributions to astronomy.

## READING CHECK

**1. Explain** How did people in ancient cultures mark the passage of time?

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## TAKE A LOOK

**2. Identify** Fill in the blank spaces in the table.

**SECTION 1** Astronomy: The Original Science *continued*

### How Did Early Astronomers Affect Astronomy?

Almost everything that early astronomers knew came from what they could observe with their eyes. Therefore, most early astronomers thought the universe was made only of the moon, the planets, and the sun. They thought that all the stars were at the edge of the universe.

Early theories about the universe were incorrect in many ways. However, over time, more data became available to astronomers. As a result, theories about the universe began to change. ✓

**READING CHECK**

**3. Explain** Why have astronomers changed their theories about the universe over time?

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#### PTOLEMY: AN EARTH-CENTERED UNIVERSE

Claudius Ptolemy was a Greek astronomer. In 140 CE, he wrote a book that brought together many ancient astronomical observations. He used these observations, together with careful calculations, to develop what is known as the *Ptolemaic theory*. According to this theory, the Earth is the center of the universe. The Ptolemaic theory also states that all other objects in the universe orbit the Earth.

Today, we know that the Ptolemaic theory is incorrect. However, Ptolemy’s calculations predicted the motions of the planets better than any other theory at the time. The predictions fit the observations that other astronomers made. Therefore, the Ptolemaic theory was accepted as correct for more than 1,500 years.

#### COPERNICUS: A SUN-CENTERED UNIVERSE

In 1543, a Polish astronomer named Nicolaus Copernicus published a new theory. His theory stated that the sun is the center of the universe and that the planets revolve around the sun.

Scientists did not accept Copernicus’s theory immediately. However, when it was accepted, it caused major changes in science and society. These changes were called the *Copernican revolution*.

### Critical Thinking

**4. Compare** Today, scientists know that only part of Copernicus’s theory is correct. Which part of Copernicus’s theory is not correct?

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### TAKE A LOOK

**5. Describe** Fill in the blank spaces in the table.

Astronomer	Description of theory
Ptolemy	
	The sun is the center of the universe, and the planets orbit the sun.

**SECTION 1** Astronomy: The Original Science *continued***TYCHO BRAHE: A WEALTH OF DATA**

In the late 1500s, a Danish astronomer, Tycho Brahe, made the most detailed astronomical observations so far. Brahe thought the sun and moon revolved around the Earth, and the other planets revolved around the sun. Although his theory was incorrect, his precise observations helped future astronomers. ✓

**JOHANNES KEPLER: LAWS OF PLANETARY MOTION**

Johannes Kepler was Brahe's assistant. He continued to analyze Brahe's data after Brahe died. Kepler determined that the planets revolve around the sun in *elliptical*, or oval-shaped, orbits. He also developed three laws that describe planetary motion. These laws are still used today.

**GALILEO: TURNING A TELESCOPE TO THE SKY**

Galileo Galilei was one of the first people to use a telescope to observe objects in space. Before his time, astronomers observed space using only their eyes. Galileo made many important observations about the solar system. Some of these observations are listed below.

- There are craters and mountains on the surface of the Earth's moon.
- Jupiter has at least four moons.
- Dark spots sometimes appear on the surface of the sun.

These discoveries were important because they showed that the planets are physical bodies like the Earth. Until Galileo, people thought that the planets were stars that moved quickly through the sky.

**ISAAC NEWTON: THE LAWS OF GRAVITY**

In 1687, Sir Isaac Newton showed that all objects in the universe attract each other through a force called gravity. Heavy objects and objects that are close together have the strongest force of gravity. This explains why all the planets orbit the sun. The sun has more mass than any other object in the solar system.

**EDWIN HUBBLE: BEYOND THE MILKY WAY**

In 1924, Edwin Hubble used detailed observations to prove that other galaxies existed beyond the edge of our galaxy. His data confirmed that the universe is much larger than our own galaxy, the Milky Way.

**READING CHECK**

**6. Explain** How did Tycho Brahe's work help astronomers?

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**STANDARDS CHECK**

**ES 3a** The earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects, such as asteroids and comets. The sun, an average star, is the central and largest body in the solar system.

**7. Identify** What is the most massive object in the solar system?

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# Section 1 Review

NSES ES 3a, ES 3b, ES 3c

## SECTION VOCABULARY

<b>astronomy</b> the scientific study of the universe	<b>month</b> a division of the year that is based on the orbit of the moon around the Earth
<b>day</b> the time required for Earth to rotate once on its axis	<b>year</b> the time required for the Earth to orbit once around the sun

**1. Compare** What is the difference between a day, a month, and a year in terms of astronomy?

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**2. Describe** What did people in ancient cultures observe about the motions of the planets, the moon, and the sun?

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**3. Explain** Why was the Ptolemaic theory accepted for a long time?

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**4. Infer** How did Tycho Brahe's work help Kepler develop his laws of planetary motion?

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**5. Evaluate** What advantage did Galileo have over other, earlier astronomers?

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**6. Identify** What did Edwin Hubble prove about the size of the universe?

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**BEFORE YOU READ**

After you read this section, you should be able to answer these questions:

- What are telescopes?
- How can telescopes help scientists study space?

## How Can a Telescope Help Us Make Observations?

How much of the sky can you see when you gaze up at night? At most, you can see 3,000 stars. With a telescope, you can see millions of stars, as well as many other objects. A **telescope** is a tool that scientists use to study objects, such as stars, that are far away. A telescope collects light and other kinds of radiation from the sky and makes it brighter. In this way, telescopes make distant objects more visible.

An *optical telescope* is used to study visible light from objects in the universe. Simple optical telescopes, such as the one in the figure below, have two lenses. The *objective lens* collects light from distant objects. The objective lens focuses the light and forms an image at a focal point. A *focal point* is where rays of light that pass through a lens or reflect from a mirror come together. ✓

The second lens in a simple optical telescope is in the eyepiece. This lens *magnifies*, or makes bigger, the image that forms at the focal point.



This simple refracting telescope has an objective lens that collects light and a lens in the eyepiece to magnify the image.

**STUDY TIP**

**Learn New Words** As you read, underline words you don't know. When you figure out what they mean, write the words and their definitions in your notebook.

**READING CHECK**

**1. Define** What is a focal point?

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**TAKE A LOOK**

**2. Compare** How is the objective lens different from the lens in the eyepiece?

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**SECTION 2** Telescopes *continued***REFRACTING TELESCOPES**

**Refracting telescopes** are simple optical telescopes that use lenses to gather and focus light. The figure on the previous page shows a drawing of a refracting telescope. Refracting telescopes are the simplest telescopes, so they are usually easy to use. ✓

**READING CHECK**

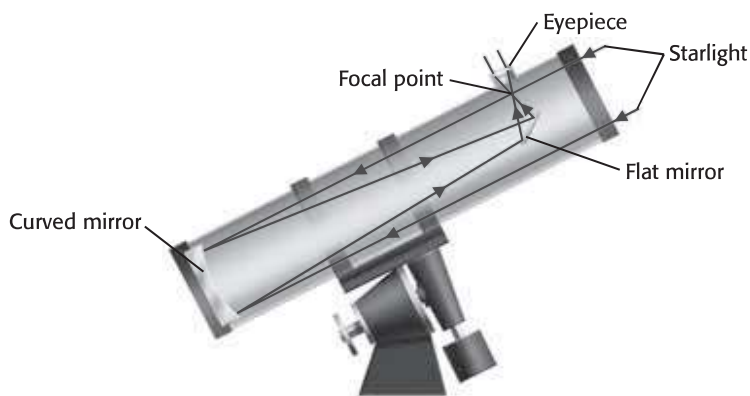
**3. Explain** How do refracting telescopes gather and focus light?

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There are two disadvantages to refracting telescopes. First, lenses focus different colors of light at slightly different distances. This means that images cannot be focused well. Second, refracting telescopes cannot be very large. Large telescopes have large objective lenses. The bigger the objective lens, the more light the telescope can gather. However, if the lens is too large, it can bend under its own weight. This causes the image to look fuzzy.

**REFLECTING TELESCOPES**

**Reflecting telescopes** use curved mirrors to gather and focus light. Light enters the telescope and reflects off a large, curved mirror. The light then travels to a flat mirror near the eyepiece. The flat mirror focuses the image and reflects it to the eyepiece.



This reflecting telescope uses mirrors to collect and focus light.

**TAKE A LOOK**

**4. Describe** What does the flat mirror in a reflecting telescope do?

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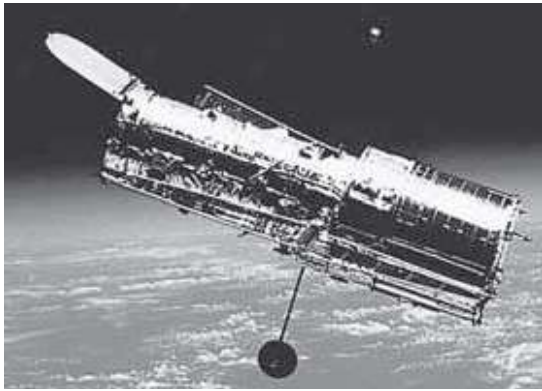
There are some advantages to reflecting telescopes. First, the mirrors can be large. This allows the reflecting telescope to gather a lot of light. Second, the light reflects off the mirrors instead of passing through them. This means that problems with the glass in the mirrors do not affect the image. Third, mirrors can focus all colors of light to the same focal point. Therefore, the images can be better focused than with refracting telescopes.

**SECTION 2** Telescopes *continued***LARGE TELESCOPES AND CLEAR IMAGES**

Some very large reflecting telescopes use several mirrors to collect and focus light. For example, the Keck Telescopes in Hawaii each use 36 mirrors to collect and focus light. However, even very large reflecting telescopes must be in a good location if they are to form clear images.

The light gathered by telescopes on the Earth is affected by the atmosphere. The motion of the air in the Earth's atmosphere causes starlight to shimmer and blur. Therefore, astronomers may place telescopes on mountain tops, where the air is thinner. There may also be less air and light pollution in these areas.

In order to avoid interference from the atmosphere, scientists have put telescopes in space. These telescopes can detect very faint objects because there is no air to blur the image.



The mirrors in the Hubble Space Telescope are smaller than the mirrors in many telescopes on the Earth. However, the Hubble Telescope can produce images of very faint objects because the Earth's atmosphere does not blur the images.

**What Is Light?**

Optical telescopes make the visible light from objects in space easier for us to see. Visible light is a form of electromagnetic radiation. However, visible light is not the only form of electromagnetic radiation. Other examples of electromagnetic radiation are gamma rays, X rays, and radio waves. The **electromagnetic spectrum** is made up of all the kinds of electromagnetic radiation.

Electromagnetic radiation travels in waves. Each kind of radiation has a different wavelength. Gamma rays have the shortest wavelengths. Radio waves have the longest wavelengths. ✓

Most of the electromagnetic spectrum is invisible. For example, we cannot see gamma rays or radio waves. The figure on the top of the next page shows some of the different kinds of electromagnetic radiation.

**Critical Thinking**

**5. Apply Concepts** Scientists may place telescopes in deserts or other areas where the air is dry. This is because dry air often produces less blurry images than moist air. What is the most likely reason that dry air produces less blurry images than moist air?

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**READING CHECK**

**6. Identify** Which kind of electromagnetic radiation has the shortest wavelength?

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**SECTION 2** Telescopes *continued*

 **Say It**

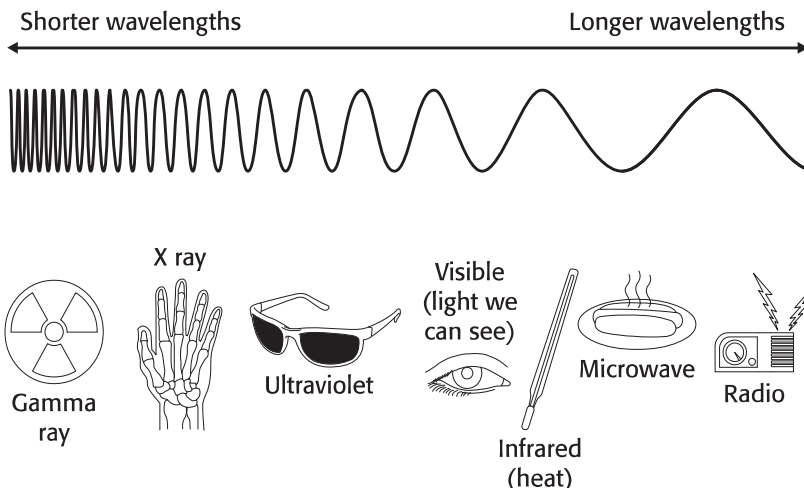
**Discuss** You may have heard or seen the terms “X ray,” “infrared,” and “ultraviolet” in other places. In a small group, talk about the ways that these words are used in other situations.

**TAKE A LOOK**

**7. Identify** Give two kinds of electromagnetic radiation that are invisible.

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The electromagnetic spectrum is made up of all the kinds of electromagnetic radiation. Visible light is light that we can see. However, most electromagnetic radiation is invisible.

**DETECTING ELECTROMAGNETIC RADIATION**

The atmosphere acts as a shield around the Earth. It blocks most kinds of invisible radiation that come from objects in space. However, some types of radiation, such as radio waves and microwaves, can pass through the atmosphere.

Scientists can study invisible radiation using *nonoptical telescopes*. These telescopes can detect invisible radiation and focus it to produce an image. Astronomers study the entire electromagnetic spectrum because each type of radiation reveals different clues about an object. ✓

 **READING CHECK**

**8. Explain** How do scientists study invisible radiation from objects in space?

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**RADIO TELESCOPES**

Radio telescopes detect radio waves. Radio wavelengths are much longer than visible wavelengths. Therefore, radio telescopes have to be much larger than optical telescopes. However, the reflecting surfaces of radio telescopes do not have to be as smooth as those in optical telescopes. In addition, radio waves can be detected at night and during the day. Therefore, radio telescopes can be very useful, even though they are large.

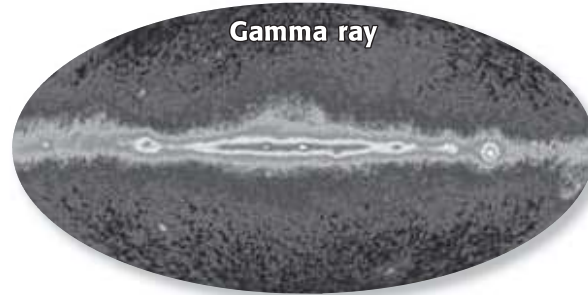
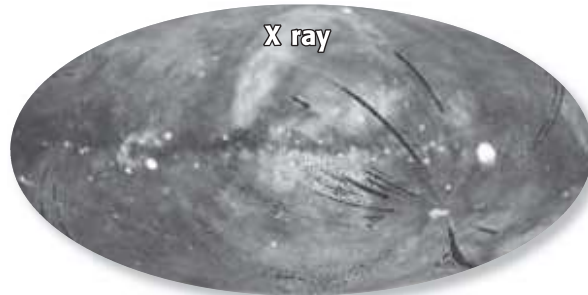
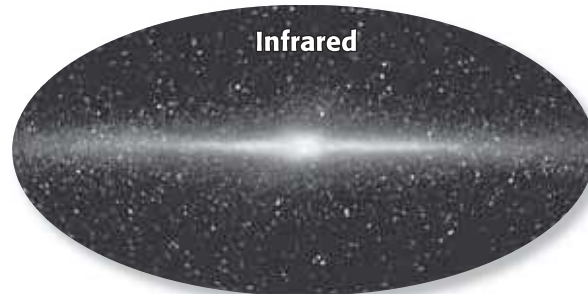
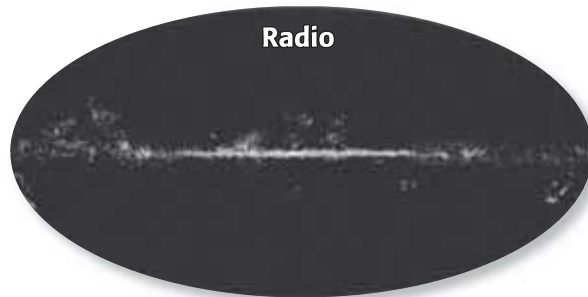
Astronomers can use many radio telescopes together to get more detailed images. When radio telescopes are linked together, they work like a single giant telescope. The Very Large Array (VLA) consists of 27 radio telescopes spread over 30 km. Together, the VLA telescopes act as a single telescope that is 30 km across.



**SECTION 2** Telescopes *continued*

**NONOPTICAL TELESCOPES IN SPACE**

Most electromagnetic waves are blocked by the Earth’s atmosphere. Therefore, scientists have placed some kinds of nonoptical telescopes in space. These telescopes produce images of objects in space using different kinds of electromagnetic radiation. For example, each figure below shows an image of our galaxy. The images look different because they were recorded from different types of electromagnetic radiation. ✓



Each of these images shows our galaxy, the Milky Way. Different features of the galaxy are visible at different wavelengths of electromagnetic radiation.

**READING CHECK**

**9. Explain** Why have scientists placed some nonoptical telescopes in space?

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**TAKE A LOOK**

**10. Compare** On each image, circle a feature that is not found in any of the other images.

# Section 2 Review

## SECTION VOCABULARY

<p><b>electromagnetic spectrum</b> all of the frequencies or wavelengths of electromagnetic radiation</p> <p><b>reflecting telescope</b> a telescope that uses a curved mirror to gather and focus light from distant objects</p>	<p><b>refracting telescope</b> a telescope that uses a set of lenses to gather and focus light from distant objects</p> <p><b>telescope</b> an instrument that collects electromagnetic radiation from the sky and concentrates it for better observation</p>
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**1. Compare** What is the main difference between a refracting telescope and a reflecting telescope?

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**2. Describe** What limits the size of a refracting telescope? Explain your answer.

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**3. Identify** List five types of electromagnetic radiation. Put them in order, from the longest wavelengths to the shortest.

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**4. Explain** Why do radio telescopes have to be larger than optical telescopes?

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**5. Explain** Why do astronomers place telescopes in space? Give two reasons.

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# Mapping the Stars

## BEFORE YOU READ

After you read this section, you should be able to answer these questions:

- What are constellations?
- How can we precisely locate stars in the night sky?

## What Are Constellations?

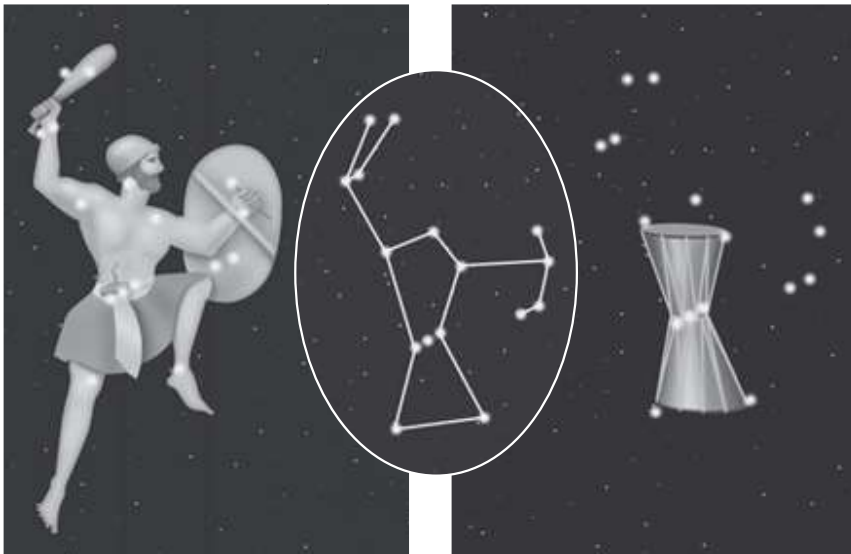
People in ancient cultures grouped stars into patterns and named sections of the sky based on those patterns.

**Constellations** are sections of the sky that contain recognizable star patterns.

Different civilizations had different names for the same constellations. For example, the Greeks saw a hunter (Orion) in the northern sky, but the Japanese saw a drum. Today, different cultures still see different shapes in the stars in the sky. However, astronomers have agreed on the names and locations of the constellations.



**Summarize in Pairs** Read this section quietly to yourself. With a partner, talk about what you learned. Together, try to figure out things that you don't understand.



The ancient Greeks saw a hunter in this set of stars. The Japanese saw the same set of stars as a drum.



**Infer** Why is it important for modern astronomers to agree on the names and locations of the constellations? In a small group, talk about what might happen if astronomers did not agree on these things. How might the science of astronomy be different?

**SECTION 3** Mapping the Stars *continued*

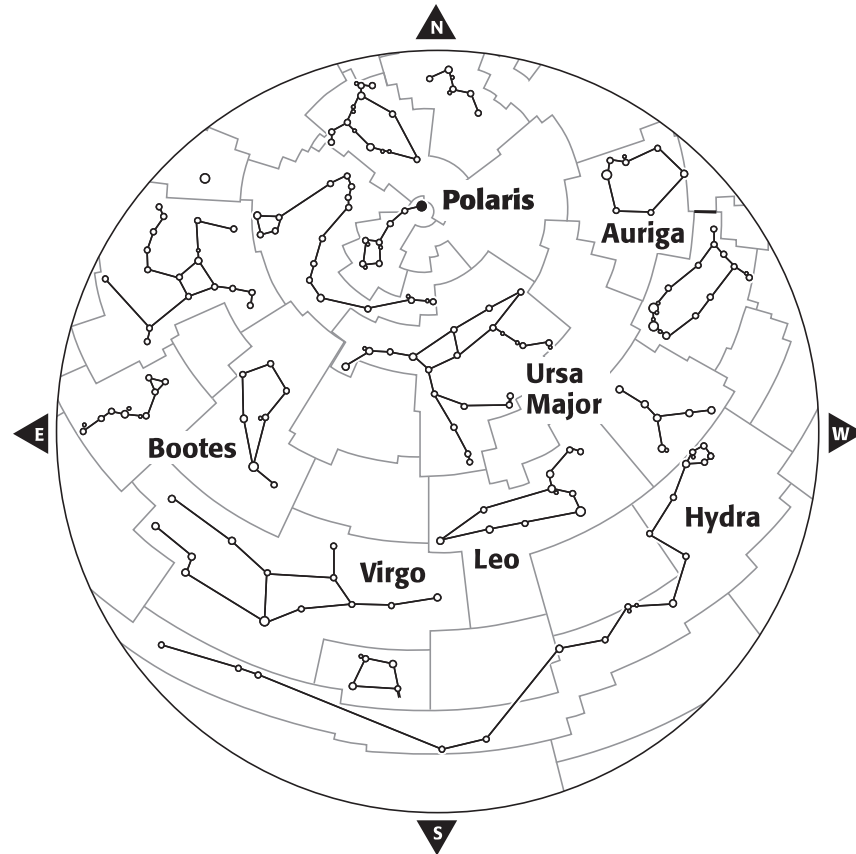
**CONSTELLATIONS: ORGANIZING THE SKY**

Many people think of constellations as stick figures made by connecting bright stars with imaginary lines. However, to an astronomer, a constellation is an entire section of the sky. Just as Texas is a region of the United States, Ursa Major is a region of the sky. Each constellation shares a border with a neighboring constellation. Every star or galaxy in the sky is located within one of 88 constellations. ✓

**READING CHECK**

**1. Identify** How many regions do astronomers break the sky into?

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This sky map shows some of the constellations that are visible in the Northern Hemisphere at midnight in the spring.

**TAKE A LOOK**

**2. Identify** Which constellation takes up a large part of the southern and southwestern sky in the spring in the Northern Hemisphere?

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**READING CHECK**

**3. Explain** Why can't you use the same star map to show all of the stars that are visible to everyone on the Earth?

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**SEASONAL CHANGES**

The figure above shows what the midnight sky in the Northern Hemisphere looks like in the spring. However, as the Earth travels around the sun, different areas of the universe are visible. In addition, different constellations are visible from different points on the Earth. Therefore, this map is not accurate for the Northern Hemisphere during seasons other than spring, or for the Southern Hemisphere. ✓

**SECTION 3** Mapping the Stars *continued***THE PATH OF STARS ACROSS THE SKY**

You know that the sun seems to move across the sky during the day. In the same way, the stars and planets rise and set during the night. This apparent motion is caused by Earth's rotation. As the Earth rotates, different parts of the universe become visible to people on the Earth. ✓

Near the poles, some stars can be seen at all times of year and all times of night. These stars are called *circumpolar stars*. *Circum* means “around” or “circling.” Circumpolar stars seem to move through the sky in circles around the poles.

**READING CHECK**

**4. Identify** Why do the stars seem to move across the sky?

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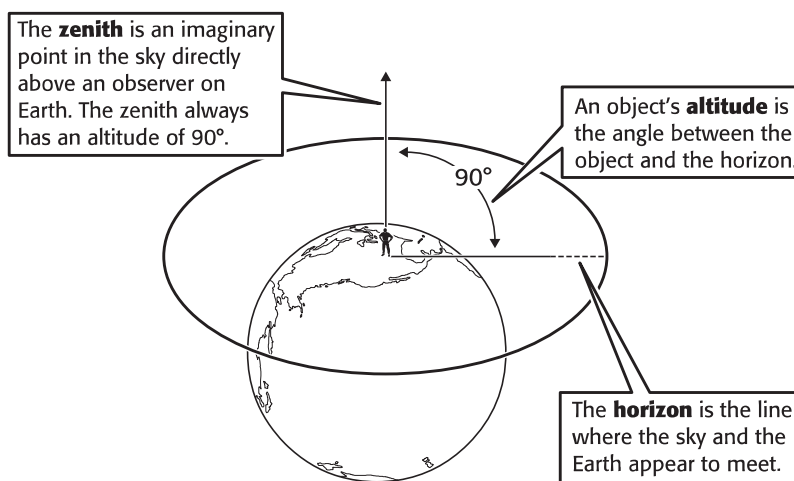


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**How Can You Describe the Location of a Star?**

Have you ever tried to point out a star to someone? It can be very difficult to describe the exact location of an object in the sky. You can use a tool called an *astrolabe* to help you describe the location of such an object.

To use an astrolabe, you need to understand the differences between horizon, altitude, and zenith. The **horizon** is the line where the Earth and the sky seem to meet. An object's **altitude** is the angle between the object and the horizon. The **zenith** is an imaginary point in the sky that is directly above your head. The zenith always has an altitude of  $90^\circ$ . The figure below shows these three reference points.

**Math Focus**

**5. Estimate Angles** On the figure, draw a star to show the location of an object with an altitude of about  $45^\circ$ .

**SECTION 3** Mapping the Stars *continued*

**THE CELESTIAL SPHERE**

To talk to each other about a star, astronomers must have a common method of describing the star's location. The method that astronomers use is based on the celestial sphere. The *celestial sphere* is an imaginary sphere that surrounds the Earth. Remember that we use latitude and longitude to describe the location of objects on the Earth's surface. In the same way, astronomers use declination and right ascension to plot positions in the sky.

Remember that latitude is a measure of the distance north or south of the equator. *Declination* is the distance of an object north or south of the celestial equator. The *celestial equator* is an imaginary circle formed by extending the Earth's equator into space, as shown in the figure below.

Remember that longitude is a measure of the distance east or west of the prime meridian. *Right ascension* is a measure of how far east an object is from the vernal equinox. The *vernal equinox* is the position of the sun on the first day of spring.

**Critical Thinking**

**6. Compare** How is latitude similar to declination? How are they different?

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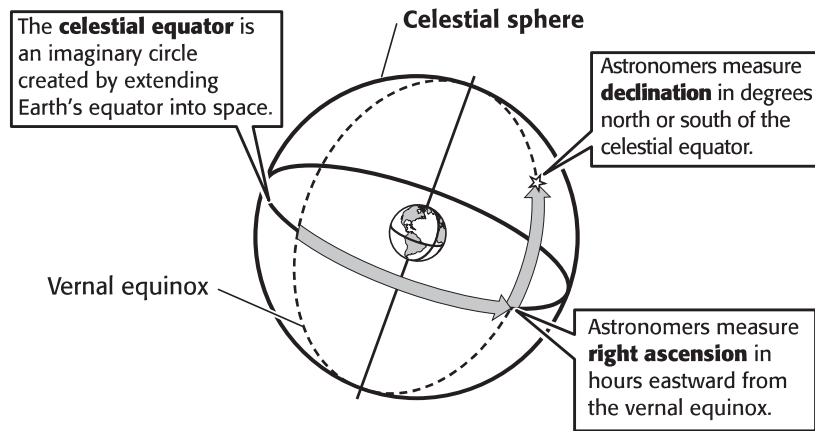
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**The Celestial Sphere**



**TAKE A LOOK**

**7. Define** What is the celestial equator?

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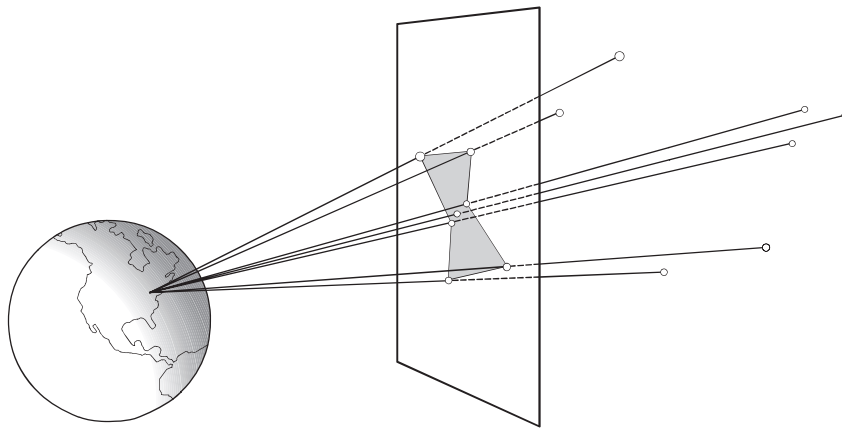
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**SECTION 3** Mapping the Stars *continued*

**How Big Is the Universe?**

In the 1500s, Nicolaus Copernicus noticed that the planets appeared to move, but the stars did not. He thought the stars must be farther away than the planets. Stars are so distant that a new unit of length, the light-year, was invented to measure their distance. A **light-year** is the distance that light travels in 1 year. One light-year is equal to 9.46 trillion kilometers. The farthest objects we can observe are more than 10 billion light-years away! ✓

Many of the stars in the sky look the same. For example, the stars in Orion all seem to be about the same size in the sky. However, some stars are much closer than others. The figure below shows how stars that are very far apart can look the same to people on the Earth.



The stars in Orion seem to be very close together. However, they are actually very far apart.

**THE SCALE OF THE UNIVERSE**

When you think about the universe, it is important to think about scale. For example, stars appear to be very small when you see them in the sky. However, we know that most stars are much larger than the Earth. They look small in the sky because they are very far away. The figure on the next page shows how distance can affect the apparent size of objects. ✓

✓ **READING CHECK**

**8. Define** What is a light-year?

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**TAKE A LOOK**

**9. Infer** How might the pattern of stars that we see in Orion change if the Earth were further away from the stars than it is?

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✓ **READING CHECK**

**10. Explain** Why do stars look very small, even though they are actually larger than the Earth?

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**SECTION 3** Mapping the Stars *continued*



**1** Let's start with home plate in a baseball stadium. You are looking down from a distance of about 10 m.



**2** At 100 km away, you see the city that contains the stadium and the countryside around the city.



**3** At 1,500,000,000 km (83 light-minutes) away, you can look back at the sun and the inner planets.



**4** By the time you are 10 light-years away, the sun looks like any other star in space.

**TAKE A LOOK**

**11. Infer** What is a light-minute?

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**5** At 1 million light-years away, our galaxy looks like the Andromeda galaxy, a cloud of stars set in the blackness of space.



**6** At 10 million light-years away, you can see a handful of galaxies called the *Local Group*.

**TAKE A LOOK**

**12. Identify** What is the local group?

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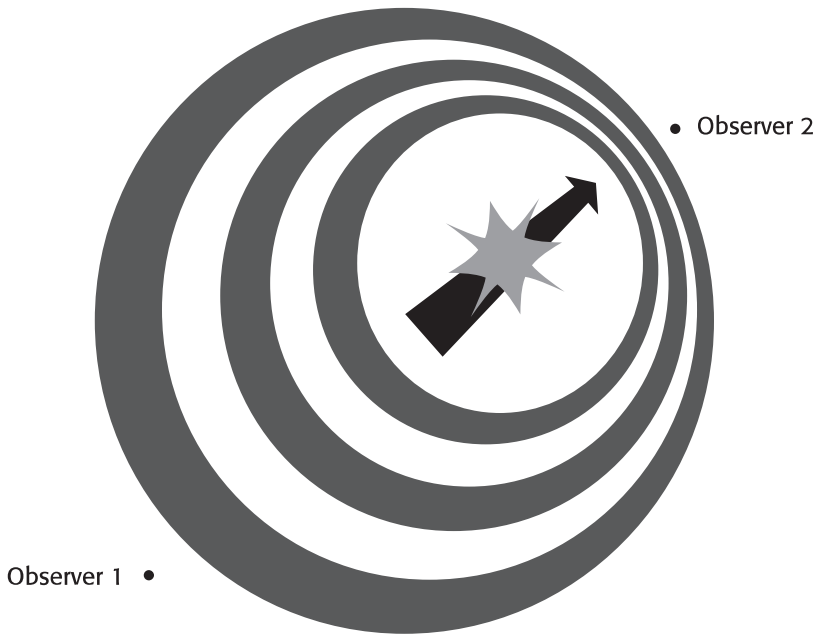
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**SECTION 3** Mapping the Stars *continued*

## How Do Scientists Know That the Universe Is Expanding?

We see stars and galaxies because they *emit*, or give off, visible light. The color of light that we see from stars can change if the stars are moving compared to the Earth. When stars or galaxies are moving away from the Earth, the light from them looks redder than normal. This effect is called *redshift*. When stars or galaxies are moving toward the Earth, the light from them looks bluer than normal. This effect is called *blueshift*. ✓



The galaxy is moving away from Observer 1 and toward Observer 2. To Observer 1, the light from the galaxy looks redder than normal. The waves of light are more spread out, so the wavelength is longer. To Observer 2, the light from the galaxy looks bluer than normal. The waves of light are closer together, so the wavelength is shorter.

Redshift and blueshift affect light only from objects that are moving very quickly. This is why cars and airplanes do not look redder or bluer when they pass by you. They are not traveling fast enough for you to see redshift or blueshift effects.

The astronomer Edwin Hubble studied the light from stars and galaxies in the universe. He discovered that light from all of these objects, except the ones closest to the Earth, is affected by redshift. This means that the stars and galaxies in the universe are moving away from each other and from the Earth. In other words, the universe is expanding. ✓

**READING CHECK**

**13. Explain** Why do we see stars and galaxies?

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**TAKE A LOOK**

**14. Identify** Which observer is seeing light that is affected by redshift?

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**READING CHECK**

**15. Explain** How did Edwin Hubble show that the universe is expanding?

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# Section 3 Review

## SECTION VOCABULARY

<p><b>altitude</b> the angle between an object in the sky and the horizon</p> <p><b>constellation</b> a region of the sky that contains a recognizable star pattern and that is used to describe the location of objects in space</p>	<p><b>horizon</b> the line where the sky and the Earth appear to meet</p> <p><b>light-year</b> the distance that light travels in one year; about 9.46 trillion kilometers</p> <p><b>zenith</b> the point in the sky directly above an observer on Earth</p>
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**1. Define** Write your own definition for *constellation*.

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**2. Explain** Why can we see different constellations in the fall than in the spring?

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**3. Identify** Fill in the spaces in the table below.

Term	Description
Declination	
Right ascension	
Celestial sphere	

**4. Calculate** About how many kilometers are in 0.5 light-years? Show your work.

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**5. Apply Concepts** Suppose that Edwin Hubble had observed that light from most stars and galaxies was affected by blueshift. What conclusion about the universe could be drawn from this observation? Explain your answer.

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