UNIT 11

Astronomy

Chapter 32

The Universe

Introduction to Chapter 32

So far in this unit, you have learned mostly about objects that are relatively close to Earth such as other planets, their moons, and the sun. The solar system occupies a very tiny portion of the Milky Way Galaxy. This galaxy contains hundreds of billions of stars like the sun, and is one of many billions of galaxies in the universe. The universe is a term astronomers use to describe everything that exists including all matter and energy. In this chapter, you will learn about objects that are very far away including stars and galaxies. You will also read about how many scientists believe the universe began.

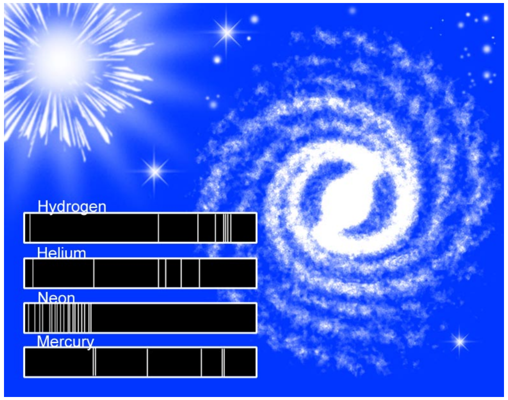
Investigations for Chapter 32

32.1	**Stars**	*What are stars made of?*

Astronomers use a spectrometer to analyze the light emitted by stars and determine the elements from which stars are composed. In this Investigation, you will use a spectrometer to analyze light and examine spectral diagrams to determine the composition and temperature of stars.

32.2	**Galaxies and the Universe**	*How do we use light to measure the distances to stars and galaxies?*

Distances to stars and galaxies in the universe are so vast that they are very difficult to measure. One of the tools astronomers use to measure distances in the universe is light. In this Investigation, you will discover the mathematical relationship between how bright an object appears from a distance, and how much light it actually gives off. This important relationship is used by astronomers to calculate distances in the universe.



Learning Goals

In this chapter, you will:

- Identify the conditions necessary for fusion to occur inside a star.
- Describe the information that spectroscopy provides about stars.
- Relate the color of a star to its temperature.
- Explain the factors that determine the brightness of a star in the sky.
- Discuss the importance of the H-R diagram to astronomers.
- Explain the relationship between mass and the life cycle of a star.
- Describe the phases in the life cycle of a sun-like star.
- Discuss how the death of a massive star is responsible for the creation of elements heavier than helium on the periodic table.
- Describe how the composition and size of planets is related to their formation and proximity to the sun.
- Identify the structure of the Milky Way Galaxy and the location of our solar system within the galaxy.
- Explain how astronomers measure the distance to stars and galaxies.
- Identify the scientific evidence that supports the Big Bang theory.

Vocabulary

absolute brightness
apparent brightness
Big Bang
Cepheid
constellation
Doppler shift
H-R diagram
inverse square law
main sequence stars
nebula
parallax
planetary system
protostar
spectroscopy
standard candle
supernova

32.1 Stars

During the day, we see only one star, the sun, which is 150 million kilometers away. On a clear night, about 6,000 stars can be seen without a telescope. The closest star in the nighttime sky is Alpha Centauri—4.3 light years (41 trillion kilometers) away. Where do stars come from? How long do they last? In this section you will find the answers to these questions and more.

Stars and fusion

What is a star?

A *star* is essentially a giant, hot ball of gas. Stars generate light and heat through nuclear reactions. Specifically, they are powered by the fusion of hydrogen into helium under conditions of enormous temperature, mass, and density. When hydrogen atoms fuse, helium is created. During this process, some mass is lost and converted to energy as described in Albert Einstein's famous equation:

$$\overset{\substack{\text{Energy}\\ \downarrow}}{E} = \overset{\substack{\text{Mass}\\ \downarrow}}{m}\,\underset{\substack{\uparrow\\ \text{Speed of light}}}{c}^{2}$$

What makes fusion occur?

The conditions required for the continuous fusion of hydrogen include extremely high values for temperature, density, and mass. Furthermore, hydrogen fusion does not take place throughout the star, but only deep in its core, where the temperature is hot enough. The minimum temperature required for fusion to occur is 7 million°C. The sun's core reaches a temperature of 15 million°C.

Density and mass

Even though stars are made of gas, they have extremely high values for density and mass. For example, the density of the sun's core is about 158.0 g/cm^3. This is about 18 times the density of copper. The sun has a total mass that is equal to 330,000 Earths. Stars can range in mass from about 100 times that of the sun to less than one-tenth its mass. At masses lower than this, the internal temperature does not get hot enough to sustain the fusion of hydrogen.

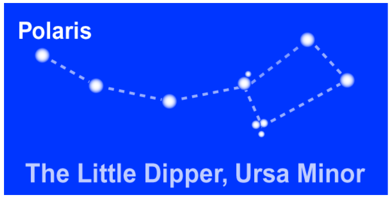


Figure 32.1: *The star at the tip of the Little Dipper's handle is called Polaris. If you look toward Polaris, you are facing the North Pole.*

Constellations

A **constellation** is a group of stars that, when seen from Earth, form a pattern. The stars in the sky are divided into 88 constellations. The largest, Centaurus, contains 101 stars. The most familiar star formation, the Big Dipper, is actually part of a larger constellation called Ursa Major (the Great Bear). The Little Dipper, part of Ursa Minor, contains Polaris, the North Star, which is located at the tip of the handle (Figure 32.1). Anybody in the Northern Hemisphere who is looking toward Polaris is facing the North Pole.

Examining light from stars

What is spectroscopy?

Stars shine because they are hot. Astronomers analyze the light emitted by stars, and other "hot" objects in space in order to determine their chemical composition and temperature. Sometimes they can even determine how fast the object is moving, its mass, and its density by analyzing the light it emits. Spectroscopy is a tool of astronomy in which the electromagnetic radiation (including visible light) produced by a star or other object (called its spectrum) is analyzed.

Chemical composition of stars

During the mid-1800s, scientists used a device called a *spectrometer* to observe flames produced by burning substances. A spectrometer splits light into a spectrum of colors and displays lines of different colors along a scale. The scale measures the wavelength of each of the lines of color in nanometers (nm). The scientists discovered that each element has its own unique pattern of lines—like a fingerprint. For example, when the element sodium is burned, two prominent yellow lines at precisely 589.0 and 589.6 nanometers are observed when the light is passed through a spectrometer (Figure 32.2). *Spectroscopy* was born, and astronomers now had a tool they could use to determine the chemical composition of the stars.

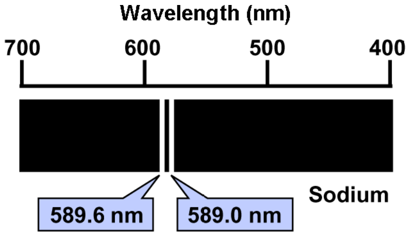


Figure 32.2: *When the element sodium is burned, two prominent yellow lines are observed at 589.0 and 589.6 nanometers on the scale of a spectrometer.*

The composition of the sun

In 1861, Sir William Huggins, an amateur astronomer in England, used spectroscopy to determine that the sun and the stars are composed mostly of hydrogen. A few years later, his countryman Sir Joseph Norman Lockyer observed a line at the precise wavelength of 587.6 nanometers. Since no known element on Earth had a line at this wavelength, he concluded that this must be an undiscovered element and named it helium, after the Greek name for the sun, *Helios*. Today, we know that hydrogen is the most abundant element in the universe, with helium second (Figure 32.3).

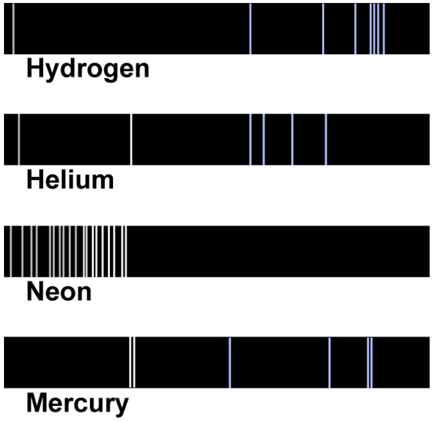


Figure 32.3: *Spectral lines for some of the other elements.*

Color and temperature

When a bar of iron is heated, it first glows red. As its temperature increases, its color changes to orange, yellow, and finally white. The hottest objects have a bluish color. Scientists use this fact to determine the temperature of stars and other objects in space. For example, red stars have the coolest temperatures while blue stars have the hottest. Our sun is yellow, which means that its temperature is somewhere in between those of red stars and blue stars.

Classifying stars

How are stars classified?

At least 6,000 stars are visible in the night sky without the aid of a telescope. There are countless billions of stars in the universe that you cannot see. Astronomers classify stars according to their physical characteristics. The main characteristics used to classify stars are *size*, *temperature*, and *brightness*.

Sizes of stars

The sun, with a diameter of 1.4 million kilometers, is a *medium-sized* star. The closest star to the sun, Alpha Centauri, is also a medium-sized star. The largest stars, called *supergiants*, have a diameter that can exceed 1,000 times that of the sun. The largest known supergiant is 2,700 times the diameter of the sun. The next largest group of stars, simply called *giants*, are about 250 times the diameter of the sun. Stars that are smaller than the sun come in two categories, *white dwarfs* and *neutron stars*. White dwarfs are about the size of the smaller planets. Sirius B, the largest known white dwarf, has a diameter of 10,400 kilometers, making it slightly smaller than Earth. Neutron stars are even smaller—their diameter is only 20 to 30 kilometers! Figure 32.4 shows the relative sizes of each type of star.

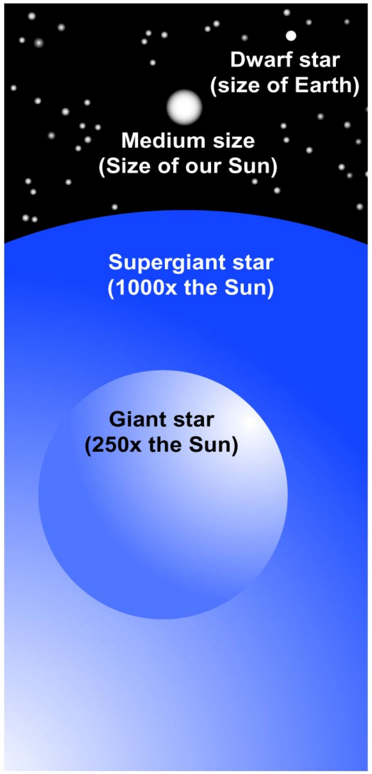


Figure 32.4: *Comparing different sizes of stars.*

Temperatures of stars

If you look closely at the stars on a clear night, you will see slight differences in their colors. This is related to the fact that their surface temperatures are different. You have already read that a red star is cooler than a white star, while blue stars are the hottest. The table below names some stars and gives their colors and their surface temperatures.

Table 32.1: ***Stars, their colors, and their surface temperatures***

Star	Color	Temperature range (°C)
Betelgeuse	red	2,000 to 3,500
Arcturus	orange	3,500 to 5,000
Sun	yellow	5,000 to 6,000
Polaris	yellow-white	6,000 to 7,500
Sirius	white	7,500 to 11,000
Rigel	blue-white	11,000 to 25,000
Zeta Orionis	blue	25,000 to 50,000

Magnitudes

You will notice too that stars vary in their brightness. About 2,200 years ago, a Greek astronomer named Hipparchus classified the stars into six groups according to their brightness. He called these groups *magnitudes*. In his system, the brightest stars were called first-magnitude stars, and the faintest stars sixth-magnitude. Hipparchus' system is still in use. Because of improved tools, the magnitude scale has been extended to include fainter and brighter objects. Through a good telescope, we can see much fainter stars, almost to the 30th magnitude. This is 4 billion times fainter than the human eye can see unaided!

Apparent and absolute brightness

How bright a star appears in the sky depends on two factors: the star's distance from Earth and the amount of light (energy) it actually gives off. Astronomers define a star's brightness as observed from Earth as its **apparent brightness**. This quantity can be measured fairly easily using a *photometer* (an instrument that measures brightness). A star's **absolute brightness** is defined as the brightness the star would have if it were a standard distance from Earth. Astronomers arbitrarily set the standard distance at 10 *parsecs*. One parsec is equal to 3.26 light years. This means that 10 parsecs equals 32.6 light years.

The difference between apparent and absolute brightness

Imagine observing a candle that is two meters from you, and a campfire that is 100 meters away. From where you are, the candle appears brighter than the campfire, even though the campfire is giving off much more light. At these distances, the candle has a greater *apparent* brightness than the campfire. Suppose the candle and campfire are moved so that both are now 10 meters from you. When this happens, the campfire appears much brighter than the candle. This is because the campfire has a greater *absolute* brightness than the candle. Therefore, absolute brightness is a measure of how much light an object actually emits (Figure 32.5).

Apparent brightness decreases as distance increases

This example explains why the apparent brightness of an object depends on its absolute brightness and on how far away it is from an observer. As Figure 32.6 shows, just because one star appears brighter than another does not mean that it has a higher absolute brightness. The apparent brightness of an object decreases the farther away from it you move regardless of its absolute brightness. If you were to observe the sun from Pluto, the farthest planet, the sun would appear much dimmer. The relationship between apparent brightness, absolute brightness, and distance will be explored in Section 32.2.

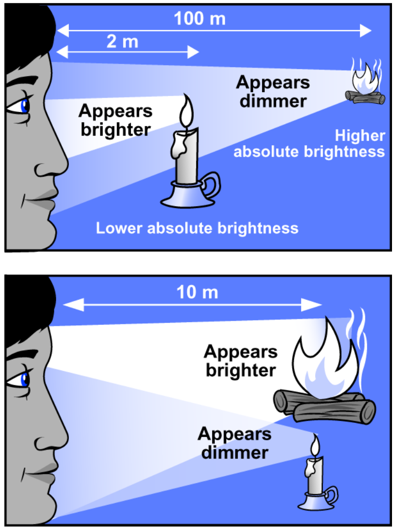


Figure 32.5: *An illustration of apparent and absolute brightness.*

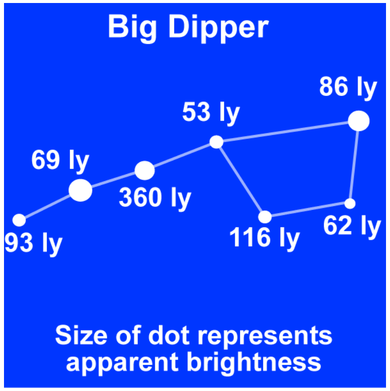
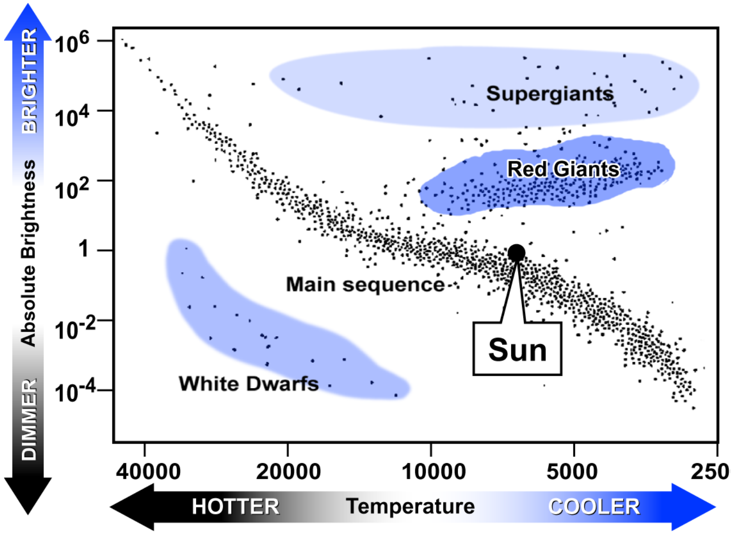


Figure 32.6: *The diagram above shows the stars in the Big Dipper, how bright they appear from Earth, and how far away they are in light years. Which star do you believe has the greatest absolute brightness? Explain your answer.*

Comparing temperature and brightness of stars

H-R diagrams

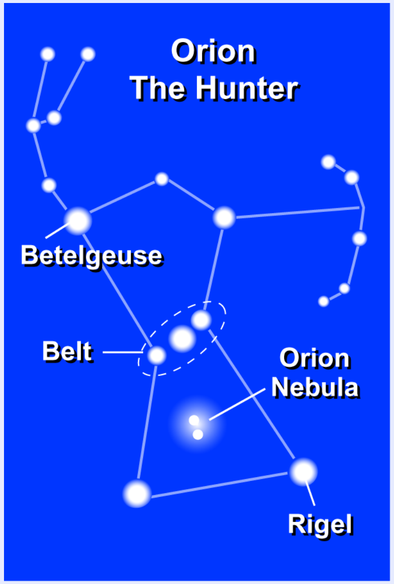
In the early 1900s, the Danish astronomer Ejnar Hertzsprung and American astronomer Henry Russell developed an important tool for studying stars. They made a graph in which they plotted the temperature of the stars on the x-axis and the absolute brightness on the y-axis. The result is known as the *Hertzsprung-Russell*, or H-R diagram. In the example below, each dot on the diagram represents a star whose absolute brightness and temperature are known.



Reading H-R diagrams

H-R diagrams are useful because they help astronomers categorize stars into distinct groups. Stars that fall into the band that stretches diagonally from cool, dim stars to hot, bright stars are called main sequence stars. Main sequence stars, like the sun, are in a very stable part of their life cycle (described on the next page). *White dwarfs* are in the lower left corner of the diagram. These stars are hot and dim and cannot be seen without a telescope. *Red giants* appear in the upper right side of the diagram. These stars are cool and bright and can be seen without the aid of a telescope in the night sky. *Supergiants*, both red and blue, are found in the extreme upper portion of the diagram. H-R diagrams are also useful because astronomers can use them to predict the absolute brightnesses of stars for which that value has not been determined.

Observing stars



If you locate the constellation Orion in the night sky, you can see Betelgeuse, a red supergiant, and Rigel, a blue supergiant. It is easy to find this constellation because of the three stars that form its belt. Just below the belt is the Orion Nebula, which you can see with a pair of binoculars. You will learn about nebulas on the next few pages.

Life cycle of stars

Stars have a life cycle

Like living organisms, stars have a life cycle. Of course, stars are not truly "alive" but astronomers sometimes use the terms "born," "live," and "die" to represent parts of that cycle. Our sun, a medium-sized star, was born about 5 billion years ago. Because most medium-sized stars have a life span of around 10 billion years, it will live for another 5 billion years before it dies. Stars that are larger than the sun have shorter life spans.

How are stars born?

A star, regardless of its size, begins its life inside a huge cloud of gas (mostly hydrogen) and dust called a **nebula** (Latin for "mist"). Gravitational forces cause denser regions of the nebula to collapse, forming a *protostar*. A **protostar** is the earliest stage in the life cycle of a star. The gases at the center of the protostar continue to collapse, causing pressure and temperature to rise. A protostar becomes a *star* when the temperature and pressure at its center become great enough to start nuclear fusion. This is the nuclear reaction in which hydrogen atoms are converted into helium atoms and energy is released. Figure 32.7 shows a portion of the Orion Nebula, the birthplace of many stars.

> ***A star is born when temperature and pressure become great enough to start nuclear fusion.***

Main sequence stars

Once nuclear fusion begins, a star is in the *main sequence* stage of its life cycle. This is the longest and most stable part of a star's life. The length of the main sequence stage depends on a star's *mass*. You may suppose that stars with larger masses live longer than those with smaller masses because they contain more hydrogen fuel for nuclear fusion. The opposite is true. **Stars with large masses use up their hydrogen fuel more quickly than stars with small masses, so they have much shorter life spans.** Because of this, they burn brighter, and hotter than smaller stars. The main sequence stage of sun-like stars (stars with the same mass as the sun) lasts for about 10 billion years. The main sequence stage of stars with masses over 100 times that of the sun, lasts for only a few million years. This stage for stars that are less massive than the sun can last for more than 50 billion years.

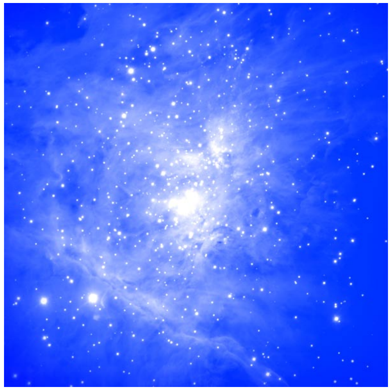


Figure 32.7: *A NASA/HST photo of a portion of the Orion Nebula. A group of protostars is visible in the center of the nebula.*

The Orion Nebula

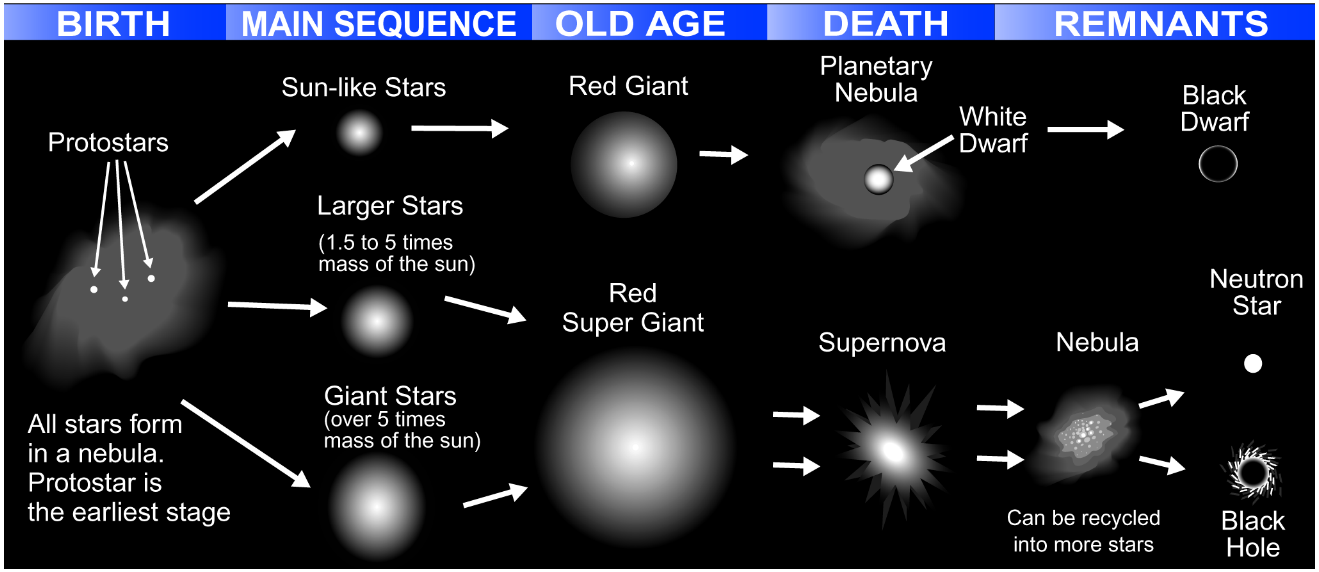
You can see the Orion Nebula if you look closely below the three stars that form Orion's belt. It will appear as a fuzzy spot to the naked eye on a very clear night. This nebula is over 20 light years in width. With binoculars, you can see some bright, young stars lighting up its center. With a powerful telescope, many protostars can be seen. When you look at the Orion Nebula, you are witnessing how our sun was born almost 5 billion years ago.

Old age As a star grows old, its core begins to run out of hydrogen fuel. Gravity causes the core to contract, raising its temperature and igniting the helium inside the core, along with any hydrogen in the outer layers. The star expands, and the outer layers begin to cool. At this stage in its life cycle, a small or medium-sized star becomes a *red giant*. When the sun reaches this stage in its life cycle (about 5 billion years from now), it will become so large that it will swallow up Mercury, Venus, and Earth.

Death Once the nuclear reactions in the core of small to medium-sized stars cease there is nothing to prevent gravity from crushing the matter together as close as possible. At this stage, the core glows brightly and is called a *white dwarf*. It is about the size of Earth, and has the same mass as the sun. Because of its high density, a thimbleful of matter from a white dwarf on Earth would weigh about the same as an elephant! During the white-dwarf stage, the outer layers of the star expand and drift away from the core, forming what is called a *planetary nebula*. This is different from a nebula where stars are born.

Remnants When a white dwarf stops glowing, it is called a *black dwarf*, the final stage in the life cycle of small and medium-sized stars. The life cycle of stars is summarized in the diagram below. The death of massive stars is discussed on the following page.

Figure 32.8: *The famous Ring Nebula, showing the death of a sun-like star. The outer rings are called the planetary nebula. The glowing, white dwarf can be seen in the center. Photo courtesy NASA/HST.*



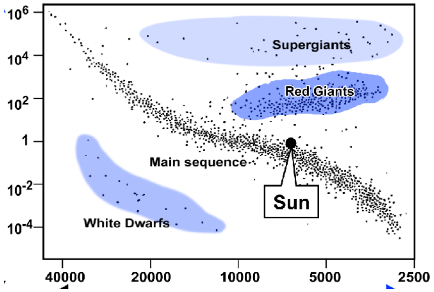


Figure 32.9: *Different stages in the star life cycle appear in clusters on the H-R diagram. Stars in the main sequence stage form the diagonal band that includes the sun. 90 percent of all stars are main sequence stars.*

The death of massive stars = the birth of elements

The creation of elements

Stars that are at least five times more massive than the sun have a different end to their life cycle. As the core begins to run out of hydrogen fuel, it yields to gravity and begins to shrink, growing hotter and denser. More heat is generated by this contraction than in a small or medium star, so the core does not become a white dwarf. Instead, the tremendous heat generated causes helium atoms to fuse into carbon and oxygen atoms. This is followed by the fusion of carbon and oxygen atoms into neon, sodium, magnesium, sulfur, and silicon. Meanwhile, the outer layers of the massive star expand and cool, making the star a *red supergiant*.

The end of fusion in the core

Once the carbon atoms in the core are depleted, it shrinks again, creating even greater pressure and temperatures. This causes the fusion of even heavier elements such as calcium, nickel, chromium, copper, iron, and others. When the core of the star contains mostly iron, the fusion stops. This is because iron's nuclear structure does not allow the fusion of heavier elements. In fact, the fusion of elements heavier than iron *requires* energy, rather than *producing* it.

Supernovas

Because a giant star has such a great mass, almost the moment fusion stops in its core, it begins to collapse from the tremendous gravity. This collapse of the entire mass of the star upon the core causes the temperature inside to rise to over 100 million °C as the iron atoms are crushed together. A huge repulsive force between the iron nuclei overcomes the force of gravity, causing a spectacular explosion to occur, called a **supernova**. The actual explosion takes only a few minutes (Figure 32.10). During this brief period, heavier elements such as gold and uranium are created, as atomic nuclei are smashed together. The explosion propels the matter out into space in all directions.

Neutron stars and black holes

The light and heat produced by a supernova fades over time, and the remnants become a nebula that can be recycled again to make more stars. All that remains of the original star is a core composed entirely of neutrons called a *neutron star*. This super-dense object is no more than a few kilometers in diameter! If a dying star has a core that is three or more times the mass of the sun, the force of its collapse is so strong that an explosion cannot occur. The gravitational forces are so strong that not even light can escape. All that is left is a phenomenon called a *black hole*.

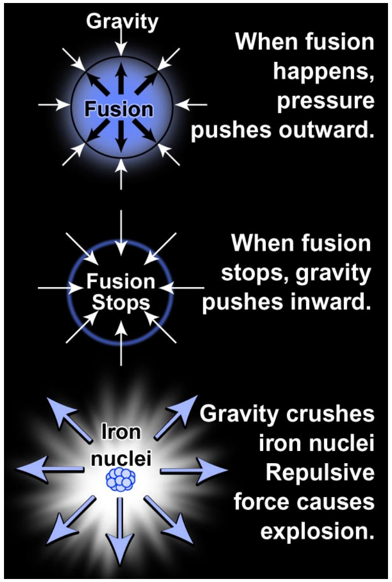


Figure 32.10: *How a supernova happens.*

Supernova sightings

In 1054 AD, a supernova was observed and recorded by Chinese astronomers. They observed a star so bright that it could be seen both night and day. The remnants make up the Crab Nebula. The only supernova to be observed in modern times occurred in 1987. Light from the explosion reached Earth on February 23, 1987, after a journey of 169,000 light years.

The formation of the solar system

Do other planetary systems exist?

In 1995, three Earth-sized planets were discovered orbiting a star much like our sun. This was among the first evidence of a star other than the sun with orbiting planets. A star with orbiting planets is called a **planetary system**. Since then several other planetary systems have been detected. Scientists now believe that planets are a natural by-product of the formation of stars. Therefore, planets of some type should exist around many stars in the universe.

How was our solar system formed?

The solar system was formed out of the same nebula that created the sun. As the sun was being formed 4.6 billion years ago, it was surrounded by a cloud of dust and gas. This cloud was made mostly of hydrogen and helium, but contained smaller amounts of other elements such as carbon, nickel, iron, aluminum, and silicon. As this cloud spun around, it flattened, with the help of gravity, into a disk-shape along the axis of its rotation. This explains why all of the planets formed in the same plane around the sun, and why they all orbit in the same direction.

Planet formation

At the center of the disk, temperatures became hot enough for fusion to begin, creating the sun. Farther away from the center, the heaviest molecules began to condense into solid and liquid droplets. These droplets began to collide, forming small clumps—the seeds of the planets. Through further collisions, these clumps of material grew larger and eventually formed into the planets.

The terrestrial planets

Terrestrial planets, like Earth, were formed in the warmer, inner regions of the disk. Because the heat drove off the lighter elements such as hydrogen and helium, these planets were made mostly of metals and rock. These materials made up less than one percent of the disk, these planets could not grow very large. Because of their small masses, their gravity could not attract hydrogen and helium and their atmospheres were thin and contained little of these elements.

The gas planets

The outer regions of the disk were rich in icy materials made of lighter elements and the planets there grew comparatively large. Because of their large masses, they were able to capture hydrogen and helium through their gravitational force and so form thick atmospheres. These became *gas planets*, rich in hydrogen and helium with dense, frozen cores. The outermost planet, Pluto, is neither a gas nor a terrestrial planet, but a tiny, frozen object with a thin atmosphere.

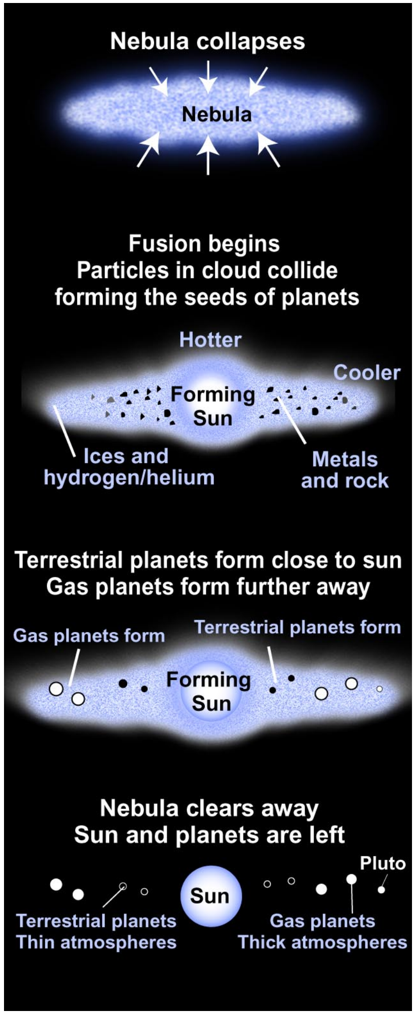


Figure 32.11: *The formation of our solar system. Scientists now believe that this is a common process in the universe.*

32.2 Galaxies and the Universe

Early civilizations believed that Earth was the center of the universe. In the 16th century, we became aware that Earth is a small planet orbiting a medium-sized star. It was only in the 20th century that we became aware that the sun is one of billions of stars in the Milky Way Galaxy, and that there are billions of other galaxies in the universe. In the past three decades, astronomers have found evidence that the universe is expanding and that it originated 10 to 20 billion years ago. In this section you will learn about galaxies and theories about how the universe began. You will also learn how astronomers measure the vast distances of galaxies and stars from Earth.

What is a galaxy?

The discovery of other galaxies

A *galaxy* is a huge group of stars, dust, gas, and other objects bound together by gravitational forces. In the 1920s, American astronomer Edwin Hubble (1889-1953) discovered that there were galaxies beyond the Milky Way. He used a new, 2.5-meter reflecting telescope to establish that some of the many fuzzy patches of light long known to astronomers were indeed separate galaxies. For example, when he focused the huge telescope on an object thought to be a nebula in the constellation Andromeda, Hubble could see that the "nebula" actually consisted of faint, distant stars. He named the object the Andromeda Galaxy. Just since Hubble's time, astronomers have discovered a large number of galaxies. In fact, many new galaxies are detected each year using the telescope named after Hubble—the Hubble Space Telescope or HST.

Galaxy shapes

Astronomers classify galaxies according to their shape. *Spiral galaxies* like the Milky Way consist of a central, dense area surrounded by spiraling arms. *Elliptical galaxies* look like the central portion of a spiral galaxy without the arms. *Lenticular galaxies* are lens-shaped with a smooth, even distribution of stars and no central, denser area. *Irregular galaxies* exhibit peculiar shapes and do not appear to rotate like those galaxies of other shapes. Figure 32.12 shows an example of each galaxy shape. The Cartwheel Galaxy (Figure 32.13) demonstrates what happens when two galaxies collide. This shape occurred when a large, spiral galaxy was struck by a smaller galaxy. The ring-like band of stars formed much like ripples occur when a rock is dropped into water.

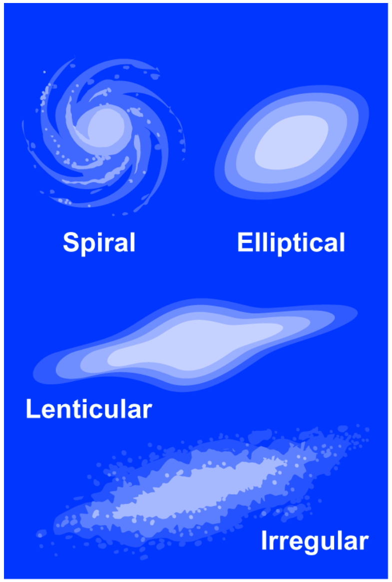


Figure 32.12: *Galaxy shapes.*

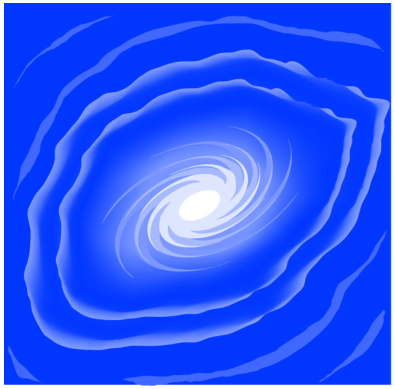


Figure 32.13: *When the Cartwheel Galaxy was struck by a smaller galaxy, a ring-like band of stars formed, much like ripples form in a pond.*

The Milky Way Galaxy

Structure of our galaxy

The sun, along with an estimated 200 billion other stars, belongs to the Milky Way Galaxy. The Milky Way is a typical spiral galaxy. From above, it would look like a giant pinwheel, with arms radiating out from a central region. The stars are arranged in a *disk* that is more than 100,000 light years across. If you could look at it from the side, you would see that our galaxy is much flatter than it is wide. In fact, it is only about 3,000 light years thick on average. At the center of the disk is a denser region of stars called the *nuclear bulge*. Surrounding the outer regions of the galaxy is an area containing clusters of older stars known as the *halo*. Figure 32.14 shows a diagram of the Milky Way Galaxy.

The disk

The disk of the Milky Way is a flattened, rotating system that contains young to middle-aged stars, along with gas and dust. The sun sits about 26,000 light years from the center of the disk and revolves around the center of the galaxy about once every 250 million years. When you look up at the night sky, you are actually looking through the disk of the galaxy. On a very clear night, you can see a faint band of light stretching across the sky. This is the combined light of billions of stars in the disk of our galaxy, so numerous that their light merges together.

The center of the galaxy

Since we are located in the outer part of the galaxy, the *interstellar* (between the stars) dust blocks out much of the visible light coming from objects within the disk. Because of this, astronomers use infrared and radio telescopes to study our galaxy. Using these tools, they have learned that the center of the galaxy is crowded with older stars and hot dust. Recent studies have suggested that a black hole, with a mass of more than a million suns, exists at the very center of the galaxy. It is believed that this black hole has enough gravitational pull to keep in orbit all of the stars, gas, and dust in the Milky Way Galaxy.

Evidence for the black hole theory

The evidence for a huge black hole comes from measurements of the orbital speeds of stars and gas at the center of the galaxy. In one study, an infrared telescope was used to measure the orbital speeds of 20 stars over a three-year period. It was determined that these stars were orbiting at speeds of up to 1,000 kilometers per second (3 million miles per hour!). This extremely high orbital speed requires an object with a mass that is over 2 million times that of the sun.

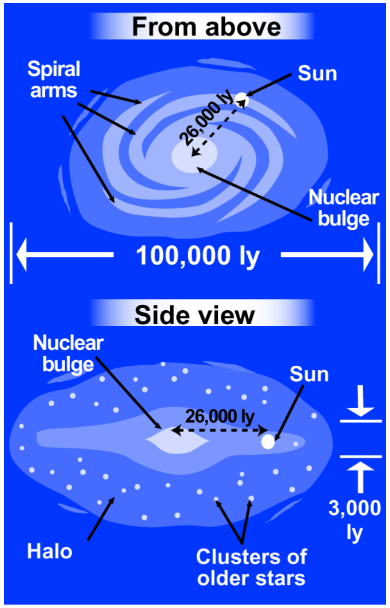


Figure 32.14: *The Milky Way is a typical spiral galaxy.*

The Local Group

The Milky Way is part of a cluster of galaxies known as the Local Group. In addition to our galaxy, the group contains other spiral galaxies such as the Andromeda Galaxy. Irregular galaxies in the Local Group include the Large and Small Magellanic Clouds. In all, there are about 40 galaxies in the Local Group. Other groups of galaxies also exist.

Determining distances to closer objects in the universe

Measuring the distance of closer stars

One of the greatest challenges facing astronomers is how to determine the vast distances of stars and galaxies from Earth. This information is key to mapping the universe. For objects that are under 1,000 light years from Earth, astronomers use a method called **parallax**. Parallax is the apparent change in position of an object when you look at it from different directions.

An illustration of parallax

To illustrate parallax, hold one finger about six inches from your nose. Close your left eye and look at your finger with your right eye. Next, close your right eye and look at your finger with your left eye. Because your eyes are in different positions, your finger appears to move. The same is true of stars in the sky. As Earth revolves around the sun, the stars appear to change positions in the sky over the course of one year. It is actually Earth that is changing position as it revolves around the sun, while the stars remain fixed in the background (Figure 32.15).

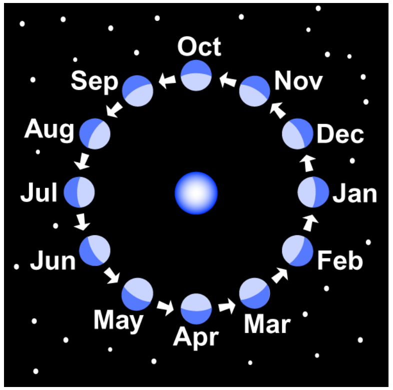


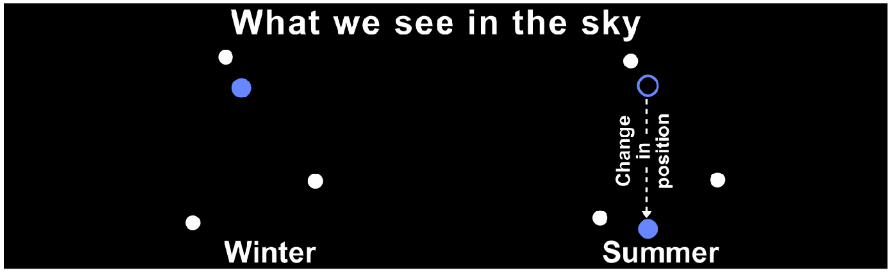
Figure 32.15: *The night side of Earth always faces away from the sun. As Earth revolves around the sun, the stars seen in the sky appear to move even though they remain fixed.*

Parallax only works for closer stars

Parallax only works for stars that are relatively close because as distance from Earth increases, the change in angle of a star becomes less measurable. You can demonstrate this by looking at a finger held before your nose as you did before. This time, try moving your finger farther and farther away from your nose while looking at it with each eye. You will notice that the farther away it is, the smaller the movement appears to become until you can detect no movement at all.

How to measure distance using parallax

To use parallax, astronomers determine the position of a star in the sky in relation to other stars that are too far away to show movement. Next, they look at the star six months later—when Earth is on the opposite side of the sun, and measure its change in position in relation to the faraway stars. Using geometry, they can determine the distance of the star from Earth (Figure 32.16 and below).



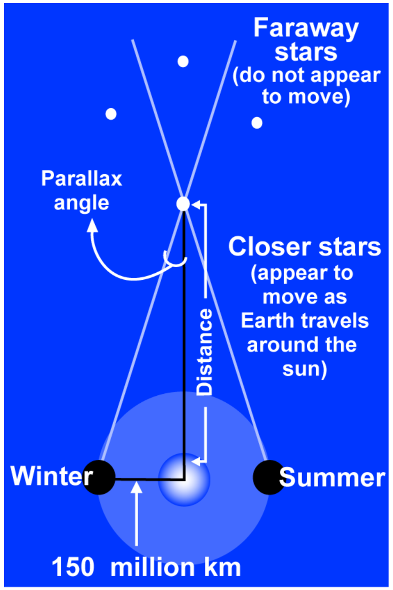


Figure 32.16: *Using parallax to measure the distance to a star.*

Measuring distances to faraway objects in the universe

The inverse square law

Light is very important to astronomers in measuring the distances to objects that are more than 1,000 light years away. Recall that the apparent brightness of an object depends on how far away it is, and how much light it actually gives off (its absolute brightness). The mathematical relationship between these variables is known as the inverse square law and is used to determine the distance to stars and galaxies.

Inverse square law

Absolute brightness

Apparent brightness →

$$B = \frac{L}{4\pi D^2}$$

Constant (4 x 3.14)

Distance

Apparent brightness vs. distance

$$B \,\alpha\, \frac{1}{D^2}$$

The inverse square law shows how the apparent brightness of an object decreases as you move away from it. The amount of decrease in apparent brightness can be quantified using the formula at left. The symbol α indicates a proportional relationship. For example, if you are looking at a candle from one meter away, and then you move two meters away, its apparent brightness will decrease by a factor of *four*. Or if you move three meters away, its apparent brightness will decrease by a factor of *nine*. By what factor will its apparent brightness decrease if you move 10 meters away? If you did an experiment where you measured the apparent brightness of a candle at various distances, starting at one meter, your graph would look similar to Figure 32.17.

Solving for distance

$$D = \sqrt{\frac{L}{4\pi B}}$$

The inverse square law is important to astronomers because if they know the apparent and absolute brightness of an object, they can determine its distance by rearranging the variables to solve for D as shown in the equation at left.

Recall that apparent brightness (B) can be easily measured using a photometer. The challenge facing astromomers is how to determine the absolute brightness (L) of faraway objects.

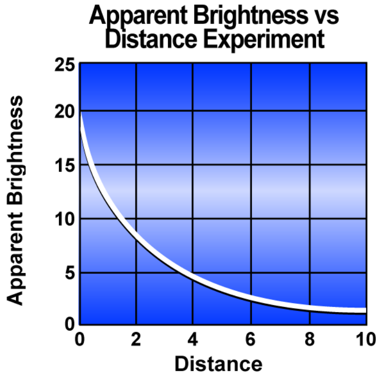


Figure 32.17: *A graph of the apparent brightness of a candle at various distances.*

Measuring brightness

Brightness is measured in units of power. In the laboratory, you can measure the brightness of a light source in *watts*. Because the brightness of objects in space is so great, astronomers developed *solar luminosity units*. One solar luminosity unit is equal to the brightness of the sun, or about 3.9×10^{26} watts. This is comparable to the combined brightness of 400 trillion trillion 100-watt light bulbs! Our galaxy emits as much light as 1.0×10^{10} suns.

Standard candles

Astronomers have found a way to *infer* values for absolute brightness (*L*) using a source of light called a **standard candle**. A standard candle is an object, such as a star, whose absolute brightness is known.

Measuring the distance to stars in the Milky Way

You are already familiar with one type of standard candle called *main sequence stars*. Recall that main sequence stars are found in a diagonal band on the H-R diagram. It is estimated that 90 percent of all stars are main sequence. Through observation, astronomers can determine if a star is a main sequence star by comparing it to stars on the H-R diagram. By determining the unknown star's temperature (using a spectrometer), they can infer its absolute brightness by choosing a similar main sequence star on the H-R diagram as shown in Figure 32.18. Next, they measure the unknown star's apparent brightness, and use the inverse square law to calculate its distance. Astronomers use this method to measure distances to stars in the Milky Way and nearby galaxies—out to distances of about 200,000 light years. Beyond that, astronomers cannot see main sequence stars and must rely on other types of standard candles.

Measuring distances to galaxies

A second type of standard candle is called a **Cepheid** star. This type of star was discovered by Henrietta Leavitt (1868-1921), an American, in the early 1900s. Cepheid stars "pulsate" in regular periods ranging from a few days to a few weeks. Leavitt discovered that there is a relationship between the period of Cepheid star and its absolute brightness. This meant that by measuring the period of a Cepheid star, astronomers could determine its absolute brightness and then, use the inverse square law to calculate its distance. Astronomers locate Cepheids in faraway galaxies and use them to map distances between galaxies in the universe. The Hubble Space Telescope actively searches for Cepheids in faraway galaxies.

Going even farther

Beyond 100 million light years, Cepheid stars are too faint to observe—even with the Hubble. For these distances, astronomers must rely on a third type of standard candle—a certain type of supernova. By observing the rate at which light from the supernova fades after the initial explosion, astronomers can use a mathematical formula to determine its absolute brightness, and then use the inverse square law to infer the distance to the galaxy in which the supernova resides.

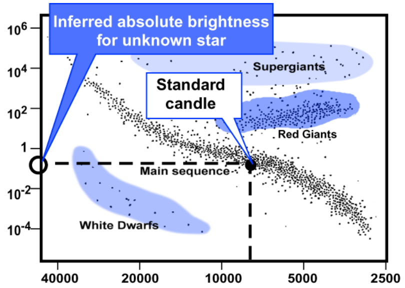


Figure 32.18: *Inferring the absolute brightness of an unknown star using the H-R diagram and main sequence stars as a standard candle.*

The North Star

The North Star is the brightest Cepheid star. Because it is only 390 light years from Earth, its distance can also be measured using parallax. This is one of the stars that helped astronomers refine the use of Cepheids to determine distances. The Cepheid star first discoverd, Delta Cephei, is also relatively close to Earth at 300 light years.

The Big Bang theory

What is the Big Bang theory?

The *universe* is defined as everything that exists, including all matter and energy. While there are many theories about how it began, the one that has gained credibility among scientists is called the Big Bang. The Big Bang theory states that the universe began as a huge explosion that occurred somewhere between 10 and 20 billion years ago.

The explosion

According to the Big Bang theory, all of the matter and energy in the universe started out compressed into a space no bigger than the nucleus of an atom. Suddenly, a huge explosion occurred that sent everything that makes up the universe out in all directions. For an instant, the universe was an extremely hot ball of fire that began to expand rapidly. Extreme heat from the explosion (10 billion°C) caused the formation of subatomic particles.

Formation of hydrogen and helium

Immediately after the explosion, the universe began to expand and cool. Some scientists believe that it expanded from the size of an atomic nucleus, to 6×10^{30} kilometers in a fraction of a second! In less than a second, the expansion of the universe started to slow down. The universe became a cloud of matter and energy that was rapidly cooling and becoming less dense as it expanded. After a few minutes, at temperatures of around 1 billion°C, hydrogen nuclei began forming. Next, hydrogen nuclei began combining in pairs to form helium nuclei.

Radiation period

Ten thousand years after the explosion, most of the energy in the universe was in the form of electromagnetic radiation of different wavelengths including X rays, radio waves, and ultraviolet radiation. As the universe continued to cool and expand, these waves were changed into a form called *cosmic microwave background radiation* which can be measured today.

The first galaxies

After 300,000 years, the temperature had cooled to around 10,000°C. Lithium atoms began to form at this stage and electrons joined with the atomic nuclei to form the first stable (neutral) atoms. The universe continued as a giant cloud of gas until about 300 million years after the Big Bang. Parts of the gas cloud began to collapse and ignite to form clusters of stars—the first galaxies. The universe has continued to form galaxies since then. These galaxies continue to expand outward from the initial point of the Big Bang.

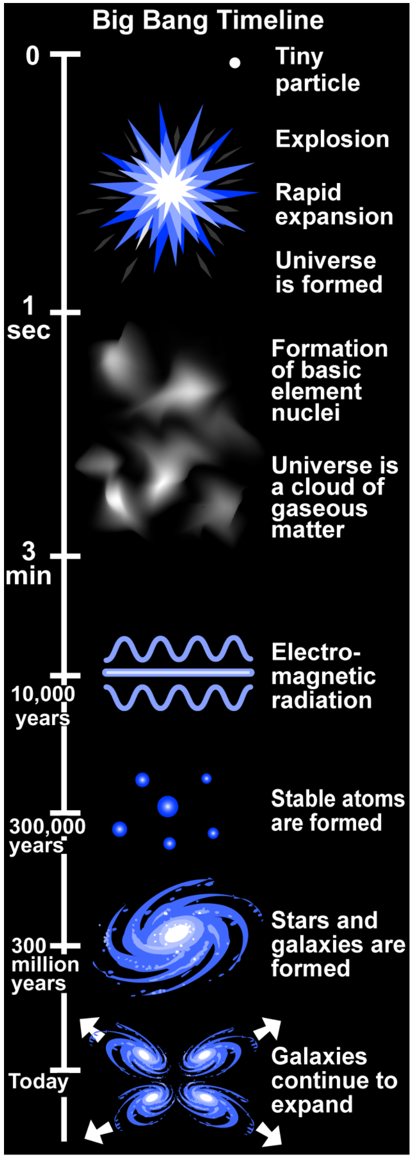


Figure 32.19: *A timeline for the Big Bang.*

Evidence for the Big Bang

Growing evidence

When it was first introduced, not everyone believed the Big Bang. In fact, the name "Big Bang" was made up by scientists to mock the theory. Unfortunately for them, the name stuck! As with any new theory, the Big Bang became more accepted as new scientific tools and discoveries established supporting evidence. In particular, scientific understanding of electromagnetic waves such as visible light, X rays, and microwaves, has provided important evidence for supporting the Big Bang theory.

Doppler shift

In the 1800s, Christian Doppler (1803-53), an Austrian physicist, discovered that when the source of a sound wave is moving, its frequency changes. You may have noticed this effect if you have heard a car drive by with its horn blaring. As the car approaches, you hear the horn playing high "notes," and as the car passes, you hear the horn shift to lower notes as the car moves farther away. The change in sound you hear is caused by a **Doppler shift** (also called the Doppler effect).

How does it work?

As the car is moving toward you, the sound waves are compressed relative to where you are standing. This shortens the wavelength and causes the frequency to increase (recall that wavelength and frequency are inversely related). As the car moves away, the sound waves are stretched out, causing longer wavelengths and lower frequencies (Figure 32.20). The sound of the horn changes as the car passes by because the sound waves are being compressed and then stretched. If you could measure the rate of change in the frequency, you could measure the speed of the car.

Doppler shift and electromagnetic waves

Doppler shift also occurs with electromagnetic waves such as visible light, X rays, and microwaves. This phenomenon is an important tool used by astronomers to study the motion of objects in space. For example, if an object is moving toward Earth, the light waves it emits are compressed, shifting them toward the violet end (shorter wavelengths, higher frequencies) of the visible spectrum. If an object is moving away from Earth, the light waves it emits are stretched, shifting them toward the red end (longer wavelengths, lower frequencies) of the visible spectrum (Figure 32.21).

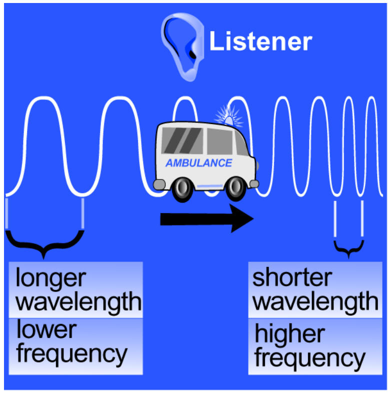


Figure 32.20: *The Doppler effect occurs when an object is moving toward or away from an observer.*

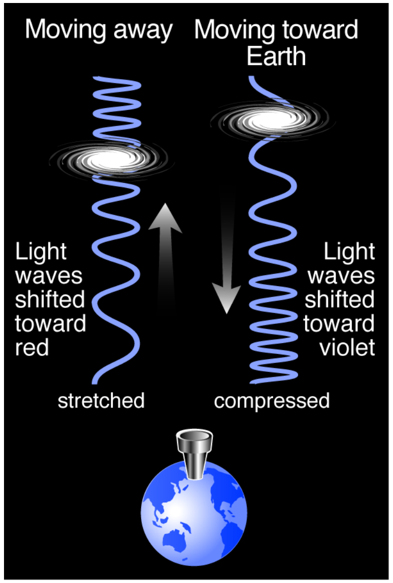


Figure 32.21: *Doppler shift is used to study the motion of objects in space.*

Sirius is moving away from Earth

In the 1890s, astronomers began to combine the use of spectroscopy and Doppler shift to study the motion of stars and other objects in space. One of the first stars they studied, Sirius, had spectral lines in the same pattern as the spectrum for hydrogen. However, these lines did not have the exact same measurements as those for hydrogen. Instead, they were shifted toward the red end of the visible spectrum. Scientists realized that this meant that Sirius was moving away from Earth. They could even determine how fast Sirius was moving away by measuring the amount that the lines had shifted toward red (Figure 32.22).

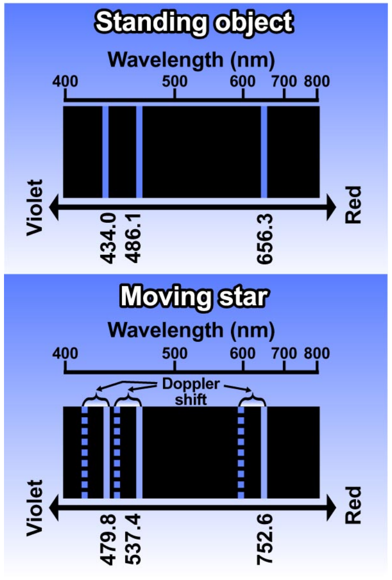


Figure 32.22: *The top diagram shows the wavelength of hydrogen spectral lines for an object that is not moving. The bottom diagram shows the hydrogen spectral lines for a moving star. While the lines are in the exact same pattern, the values for wavelength have shifted toward the red end of the spectrum. Astronomers can determine how fast the object is moving away by calculating the amount of shift that has occurred.*

Evidence for the Big Bang

In the early 1900s, Hubble began to study the motion of galaxies. He used Cepheid stars to determine the distances of galaxies from Earth. Next, he studied the Doppler shift of each galaxy and found that the farther away a galaxy was, the faster it was moving. He was also able to determine the direction that each galaxy was moving. By the early 1930s, he had enough evidence to prove that galaxies were moving away from a single point in the universe. This supported two key parts of the Big Bang Theory: that the universe is expanding and that it originated from a single point.

Microwave background radiation

In the 1960s, Arno Penzias and Robert Wilson, two American astrophysicists, were trying to measure electromagnetic radiation emitted by the Milky Way. No matter how they refined their technique, they kept detecting a background noise that interfered with their observations. This noise seemed to be coming from all directions and had little variation in frequency. After publishing a paper describing their failed experiment, it was determined that they had discovered the cosmic microwave background radiation predicted by the Big Bang theory. Penzias and Wilson won the Nobel Prize for their discovery.

Chapter 32 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. apparent brightness
2. absolute brightness
3. main sequence star
4. protostar
5. nebula

a. A cloud of gas and dust that gives rise to stars
b. The most numerous category of stars in the universe
c. A diagram used to categorize stars
d. How bright an object appears from a distance
e. How bright an object actually is - for a star, how bright it appears from a standard distance
f. The earliest stage in the life cycle of a star

Set Two

1. parallax
2. inverse square law
3. standard candle
4. Big Bang theory
5. Doppler shift

a. A star with orbiting planets
b. An object, such as a star, whose absolute brightness is known
c. The universe began when a huge explosion occurred
d. The apparent change in position of an object when viewed from different positions
e. The relationship between apparent brightness, absolute brightness, and distance
f. A change in frequency of waves emitted by an obect related to its movement

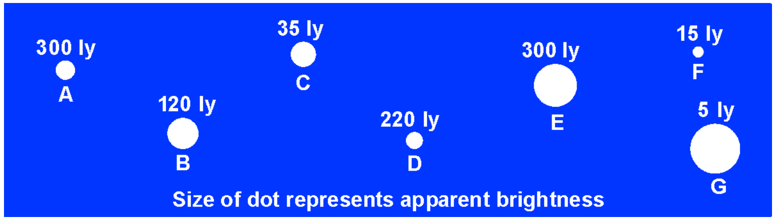
Concept review

1. Describe the conditions necessary to create a star.
2. Explain why spectroscopy is an important tool of astronomy.
3. What information does the color of a star provide?
4. What are the three main characteristics used to classify stars?
5. What is the difference between apparent brightness and absolute brightness?
6. What is the difference between a refracting telescope and a reflecting telescope?
7. What information about a star is required in order to plot it on the H-R diagram?
8. Why is the H-R diagram useful to astronomers?
9. Describe the life cycle of a sun-like star. Include in your description the following terms: nebula, protostar, red giant, planetary nebula, white dwarf, and black dwarf.
10. How long a star lives is related to which of the following quantities? (a)size; (b)temperature; (c)mass; or (d)color ?
11. How do astronomers classify galaxies?
12. What is a standard candle? How are they used to measure distances to faraway galaxies?
13. What is Doppler shift? How does Doppler shift provide evidence for the Big Bang theory?

Problems

1. A star is 15 parsecs from Earth. How far is this distance in light years? How far is it in kilometers?

2. The diagram below shows a group of stars as seen in the night sky. In the diagram, the relative size of each star indicates how bright it appears in the sky. Next to each star, its distance from Earth, in light years (ly) is shown. Use the diagram to answer the three questions below.



   a. Which star has the greatest apparent brightness? Explain your answer.

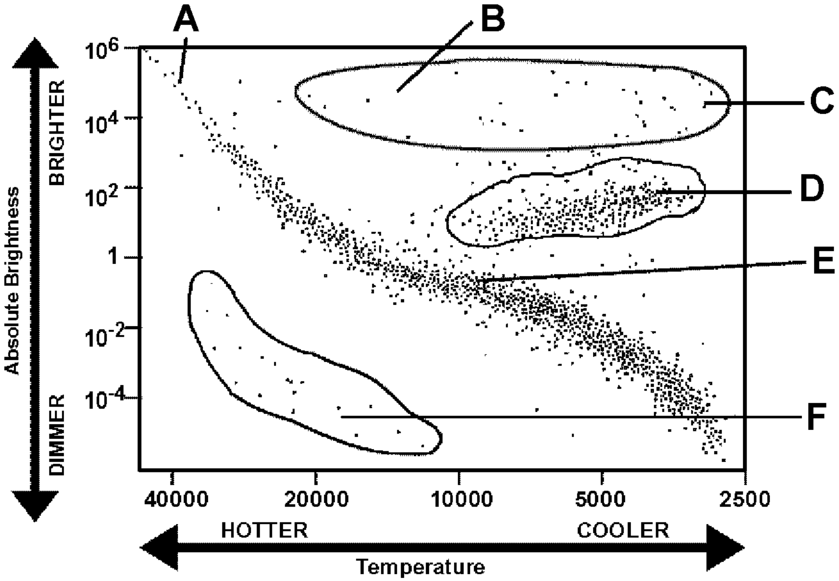
   b. If all of the stars in the diagram were moved to a distance of ten parsecs from Earth, which star would appear the brightest?

   c. Which star do you think has the lowest absolute brightness? Explain your answer.

3. Arrange the stars in the table below in order, from highest temperature, to lowest temperature.

Star	Color
A	white
B	orange
C	blue
D	red
E	blue-white
F	yellow

4. Use the H-R diagram below to answer the following questions.



   a. Which letter corresponds to a sun-like star?

   b. Which letter corresponds to a blue supergiant?

   c. Which letter corresponds to a white dwarf?

   d. Which letter corresponds to a red supergiant?

   e. Which letter corresponds to an old star that was once a sun-like, main sequence star?

5. You are looking at a candle from 3 meters away. By what factor will its apparent brightness decrease if you move 18 meters away?

6. You are looking at a candle from 20 meters away. By what factor will its apparent brightness increase if you move 10 meters closer to the candle?

Applying your knowledge

1. The table below lists some data for six stars. Use the table, and your knowledge of stars, to answer questions **a** through **g**.

Star	Color	Solar mass (× mass of the sun)	Solar diameter (× diameter of the sun)	Prominent spectral lines (elements present)
A	white	1.0	.02	carbon, helium
B	red	6.0	400	magnesium, sodium
C	yellow-white	1.5	1.5	hydrogen
D	blue	12.0	900	hydrogen, helium
E	blue	1.5	1.5	hydrogen, helium
F	red	1.5	250	carbon, helium

   a. Which star is the final stage of a sun-like star's life cycle? Explain your answer. What is the name astronomers give to this type of star?

   b. Which star is the most like our sun? Justify your answer.

   c. Which star is a blue supergiant?

   d. Which stars could become black holes? Explain your answer.

   e. Which star will have the shortest life span? Explain why.

   f. Which stars are most likely main sequence stars? Explain your answer.

   g. Which star resembles what our sun will become in about 5 billion years? Explain your answer.

2. Everything you are made of orignally came from the stars. Explain the meaning of this statement and why it is reasonable.

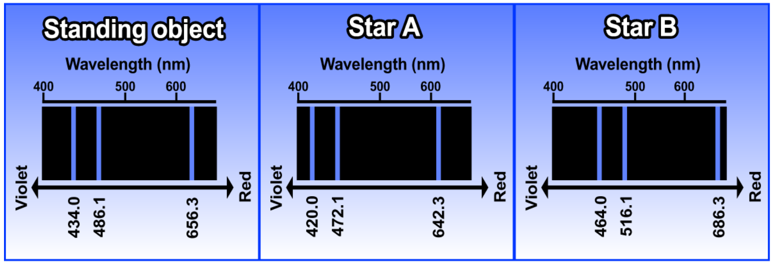
3. JAN FEB MAR Create a printed catalog or computer presentation about the astronomical objects you learned about in this unit (planets, stars, galaxies, etc. Follow these steps:

   a. Make a list of all of the astronomical objects you learned about in this unit (planets, stars, etc.).

   b. Write a definition and description of each type of object.

   c. Using the Internet, find images of each type of object to use for your catalog or presentation.

4. The light from two stars (A and B) is analyzed using a spectrometer. The spectral lines for these stars are shown below. Also shown are the spectral lines for hydrogen from a light source that is not moving.



Which star is moving toward Earth? Which star is moving away from Earth? Explain your answer in both cases.