HS Stars, Galaxies, and the Universe

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CHAPTER 1 HS Stars, Galaxies, and the Universe

CHAPTER OUTLINE

The Whirlpool Galaxy, also known as M51, is a spiral galaxy about 23 million light-years from Earth. Its interactions with the yellowish dwarf galaxy NGC 5195 are of interest to astronomers because the galaxies are near enough to Earth to be well-studied.

Decades ago astronomers could not tell if these two galaxies were just passing each other but radio astronomy has supplied astronomers with important data outlining their interactions. Using this data, astronomers have simulated the interaction. NGC 5195 came from behind and then passed through the main disk of M51 about 500 to 600 million years ago. The dwarf galaxy crossed the disk again between 50 and 100 million years ago and is now slightly behind M51. These interactions appear to have intensified the spiral arms that are the dominant characteristic of the Whirlpool Galaxy.

Astronomers are able to learn about objects unimaginably far away from Earth using telescopes that sense all wavelengths on the electromagnetic spectrum. Imagine what Galileo would do if he could see the images and data astronomers have available to them now.

1.1 Stars

Lesson Objectives

- Define constellation.
- Describe the flow of energy in a star.
- Classify stars based on their properties.
- Outline the life cycle of a star.
- Use light-years as a unit of distance.

Vocabulary

- asterism
- black hole
- main sequence star
- neutron star
- nuclear fusion reaction
- parallax
- red giant
- star
- supernova
- white dwarf

Introduction

When you look at the sky on a clear night, you can see dozens, perhaps even hundreds, of tiny points of light. Almost every one of these points of light is a **star**, a giant ball of glowing gas at a very, very high temperature. Stars differ in size, temperature, and age, but they all appear to be made up of the same elements and to behave according to the same principles

Constellations

People of many different cultures, including the Greeks, identified patterns of stars in the sky. We call these patterns constellations. **Figure** 1.1 shows one of the most easily recognized constellations.

Why do the patterns in constellations and in groups or clusters of stars, called **asterisms**, stay the same night after night? Although the stars move across the sky, they stay in the same patterns. This is because the apparent nightly motion of the stars is actually caused by the rotation of Earth on its axis. The patterns also shift in the sky with the seasons as Earth revolves around the Sun. As a result, people in a particular location can see different constellations

FIGURE 1.1
The ancient Greeks thought this group of stars looked like a hunter, so they named it Orion after their mythical hunter. The line of three stars at the center is "Orion's Belt".

in the winter than in the summer. For example, in the Northern Hemisphere Orion is a prominent constellation in the winter sky, but not in the summer sky. This is the annual traverse of the constellations.

Apparent Versus Real Distances

Although the stars in a constellation appear close together as we see them in our night sky, they are not at all close together out in space. In the constellation Orion, the stars visible to the naked eye are at distances ranging from just 26 light-years (which is relatively close to Earth) to several thousand light-years away.

Star Power

The Sun is Earth's major source of energy, yet the planet only receives a small portion of its energy and the Sun is just an ordinary star. Many stars produce much more energy than the Sun. The energy source for all stars is nuclear fusion.

Nuclear Fusion

Stars are made mostly of hydrogen and helium, which are packed so densely in a star that in the star's center the pressure is great enough to initiate nuclear fusion reactions. In a **nuclear fusion reaction**, the nuclei of two atoms combine to create a new atom. Most commonly, in the core of a star, two hydrogen atoms fuse to become a helium atom. Although nuclear fusion reactions require a lot of energy to get started, once they are going they produce enormous amounts of energy (**Figure** 1.2).

In a star, the energy from fusion reactions in the core pushes outward to balance the inward pull of gravity. This energy moves outward through the layers of the star until it finally reaches the star's outer surface. The outer layer of the star glows brightly, sending the energy out into space as electromagnetic radiation, including visible light, heat, ultraviolet light, and radio waves (**Figure** 1.3).

In particle accelerators, subatomic particles are propelled until they have attained almost the same amount of energy as found in the core of a star (**Figure** 1.4). When these particles collide head-on, new particles are created. This process simulates the nuclear fusion that takes place in the cores of stars. The process also simulates the conditions that allowed for the first helium atom to be produced from the collision of two hydrogen atoms in the first few minutes of the universe.

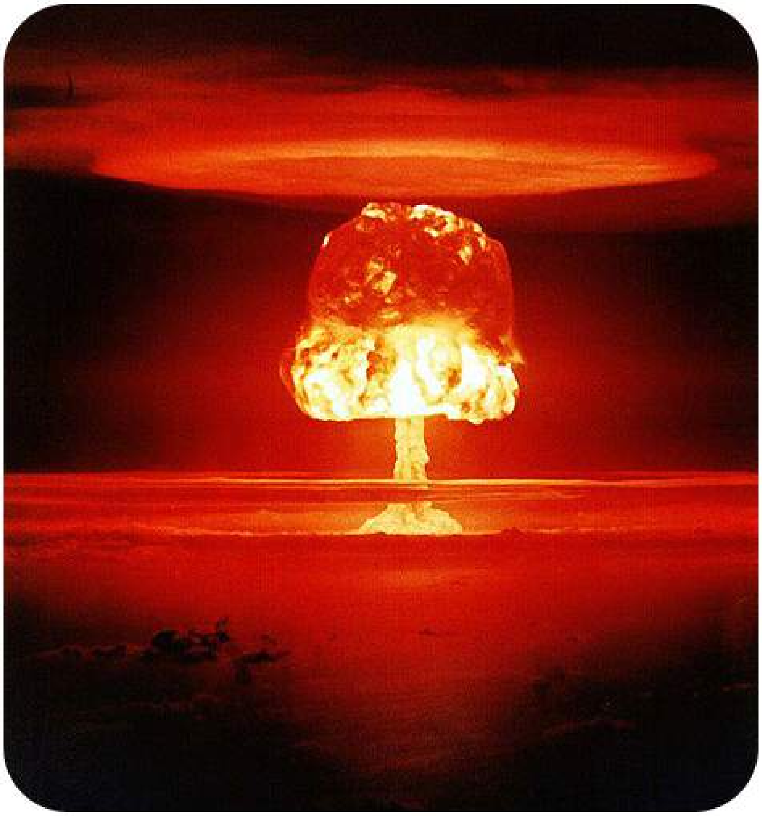


FIGURE 1.2
A thermonuclear bomb is an uncontrolled fusion reaction in which enormous amounts of energy are released.

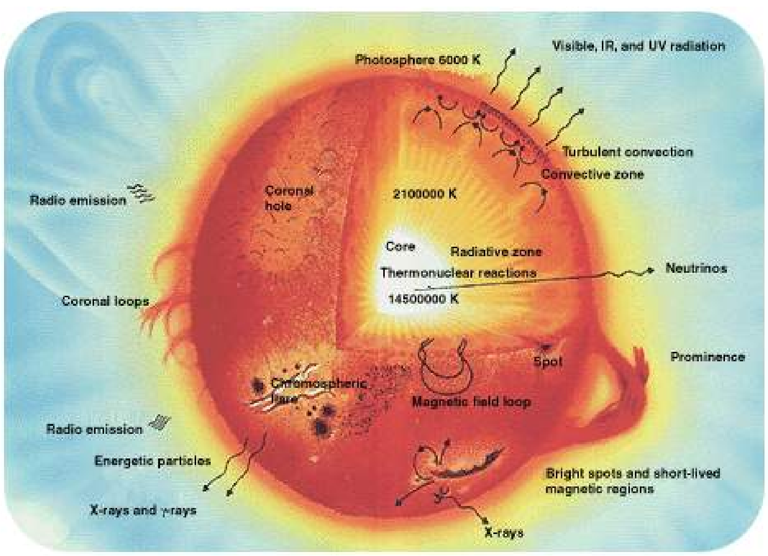
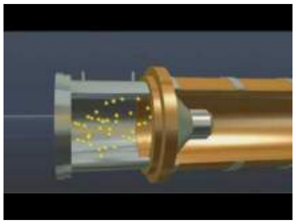


FIGURE 1.3
A diagram of a star like the Sun.

The CERN Particle Accelerator presented in this video is the world's largest and most powerful particle accelerator and can boost subatomic particles to energy levels that simulate conditions in the stars and in the early history of the universe before stars formed **(2e)**: http://www.youtube.com/watch?v=sxAxV7g3yf8 (6:16).

FIGURE 1.4
The SLAC National Accelerator Lab in California can propel particles a straight 2 mi (3.2 km).



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How Stars Are Classified

The many different colors of stars reflect the star's temperature. In Orion (as shown above) the bright, red star in the upper left named Betelgeuse (pronounced BET-ul-juice) is not as hot than the blue star in the lower right named Rigel.

Color and Temperature

Think about how the color of a piece of metal changes with temperature. A coil of an electric stove will start out black but with added heat will start to glow a dull red. With more heat the coil turns a brighter red, then orange. At extremely high temperatures the coil will turn yellow-white, or even blue-white (it's hard to imagine a stove coil getting that hot). A star's color is also determined by the temperature of the star's surface. Relatively cool stars are red, warmer stars are orange or yellow, and extremely hot stars are blue or blue-white (**Figure** 1.5).

Classifying Stars by Color

Color is the most common way to classify stars. **Table** 1.1 shows the classification system. The class of a star is given by a letter. Each letter corresponds to a color, and also to a range of temperatures. Note that these letters don't match the color names; they are left over from an older system that is no longer used.

TABLE 1.1: **Classification of Stars By Color and Temperature**

Class	Color	Temperature Range	Sample Star
O	Blue	30,000 K or more	Zeta Ophiuchi
B	Blue-white	10,000–30,000 K	Rigel
A	White	7,500–10,000 K	Altair
F	Yellowish-white	6,000–7,500 K	Procyon A
G	Yellow	5,500–6,000 K	Sun
K	Orange	3,500–5,000 K	Epsilon Indi
M	Red	2,000–3,500 K	Betelgeuse, Proxima Centauri

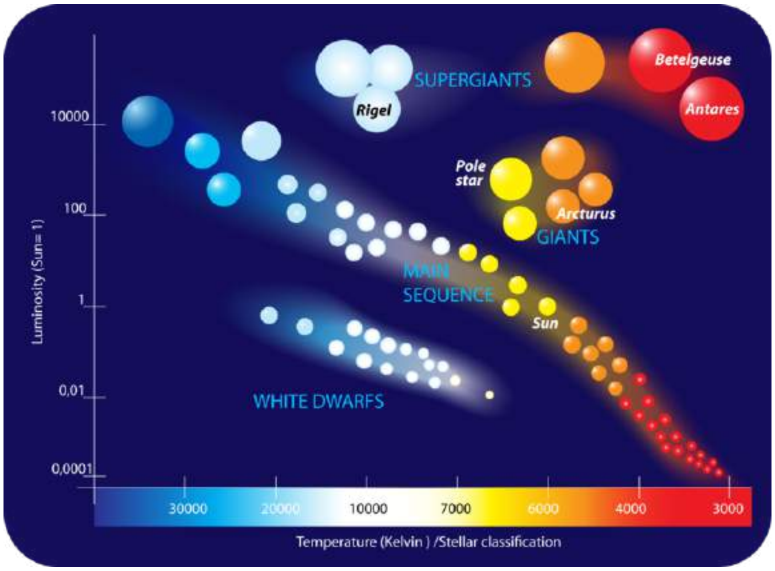


FIGURE 1.5

A Hertzsprung-Russell diagram shows the brightness and color of main sequence stars. The brightness is indicated by luminosity and is higher up the y-axis. The temperature is given in degrees Kelvin and is higher on the left side of the x-axis. How does our Sun fare in terms of brightness and color compared with other stars?

(*Sources*: http://en.wikipedia.org/wiki/Stellar_classification; http://en.wikipedia.org/wiki/Star, License: GNU-FDL)

For most stars, surface temperature is also related to size. Bigger stars produce more energy, so their surfaces are hotter. These stars tend toward bluish white. Smaller stars produce less energy. Their surfaces are less hot and so they tend to be yellowish.

Lifetime of Stars

Stars have a life cycle that is expressed similarly to the life cycle of a living creature: they are born, grow, change over time, and eventually die. Most stars change in size, color, and class at least once in their lifetime. What astronomers know about the life cycles of stars is because of data gathered from visual, radio, and X-ray telescopes.

Star Formation

As discussed in the Solar System chapter, stars are born in clouds of gas and dust called nebulas, like the one shown in **Figure** 1.6.

For more on star formation, check out http://www.spacetelescope.org/science/formation_of_stars.html and http://hurricanes.nasa.gov/universe/science/stars.html.

The Main Sequence

For most of a star's life, nuclear fusion in the core produces helium from hydrogen. A star in this stage is a **main sequence** star. This term comes from the Hertzsprung-Russell diagram shown above. For stars on the main sequence, temperature is directly related to brightness. A star is on the main sequence as long as it is able to balance the inward force of gravity with the outward force of nuclear fusion in its core. The more massive a star, the more it must burn hydrogen fuel to prevent gravitational collapse. Because they burn more fuel, more massive stars have higher temperatures. Massive stars also run out of hydrogen sooner than smaller stars do.

Our Sun has been a main sequence star for about 5 billion years and will continue on the main sequence for about 5

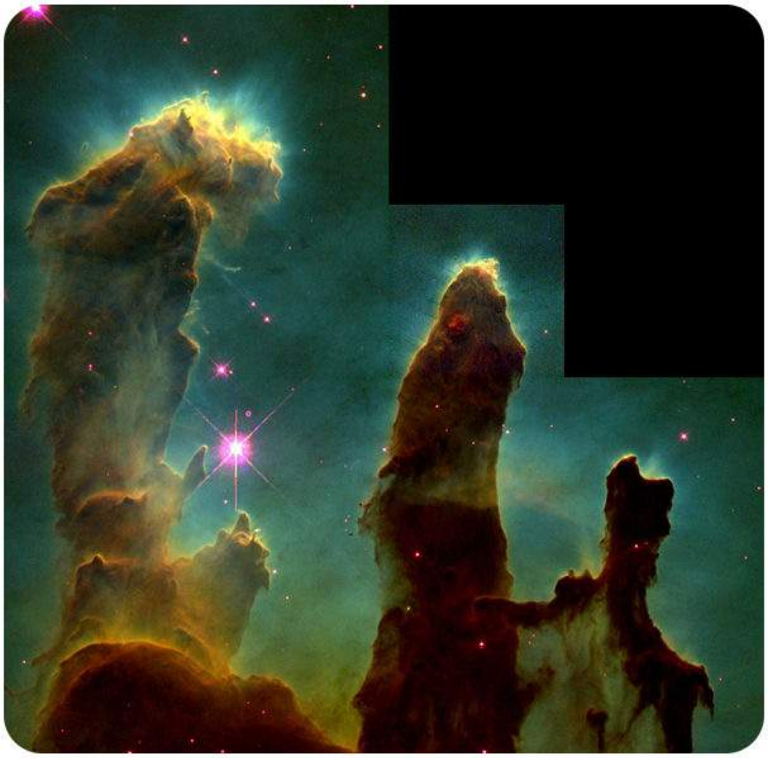


FIGURE 1.6
The Pillars of Creation within the Eagle Nebula are where gas and dust come together as a stellar nursery.

billion more years (**Figure** 1.7). Very large stars may be on the main sequence for only 10 million years. Very small stars may last tens to hundreds of billions of years.

The fate of the Sun and inner planets is explored in this video: http://www.space.com/common/media/video/player.php?videoRef=mm32_SunDeath.

Red Giants and White Dwarfs

As a star begins to use up its hydrogen, it fuses helium atoms together into heavier atoms such as carbon. A blue giant star has exhausted its hydrogen fuel and is a transitional phase. When the light elements are mostly used up the star can no longer resist gravity and it starts to collapse inward. The outer layers of the star grow outward and cool. The larger, cooler star turns red in color and so is called a **red giant**.

Eventually, a red giant burns up all of the helium in its core. What happens next depends on how massive the star is. A typical star, such as the Sun, stops fusion completely. Gravitational collapse shrinks the star's core to a white, glowing object about the size of Earth, called a **white dwarf** (**Figure** 1.8). A white dwarf will ultimately fade out.

Supergiants and Supernovas

A star that runs out of helium will end its life much more dramatically. When very massive stars leave the main sequence, they become red supergiants (**Figure** 1.9).

Unlike a red giant, when all the helium in a red supergiant is gone, fusion continues. Lighter atoms fuse into heavier atoms up to iron atoms. Creating elements heavier than iron through fusion uses more energy than it produces so stars do not ordinarily form any heavier elements. When there are no more elements for the star to fuse, the core succumbs to gravity and collapses, creating a violent explosion called a **supernova** (**Figure** 1.10). A supernova explosion contains so much energy that atoms can fuse together to produce heavier elements such as gold, silver,

FIGURE 1.7
Our Sun is a medium-sized star in about the middle of its main sequence life.

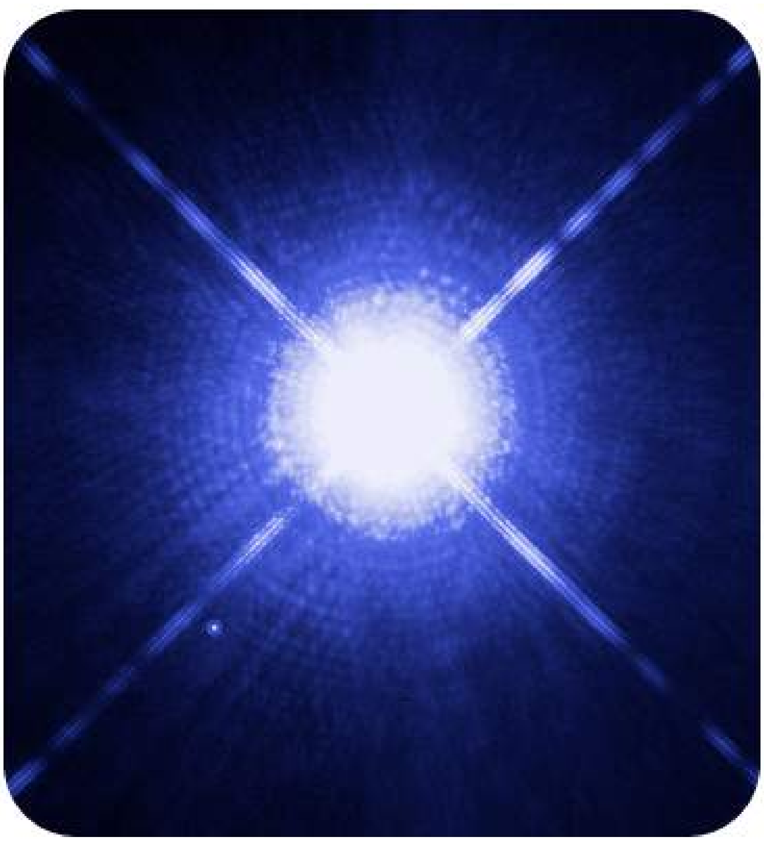


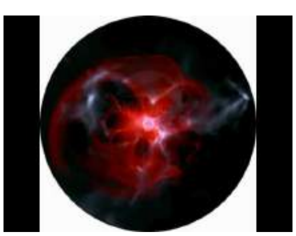
FIGURE 1.8
Sirius, the brightest star in the sky, is actually a binary star system. Sirius A is on the main sequence. Sirius B, the tiny dot on the lower left, is a white dwarf.

FIGURE 1.9
The red star Betelgeuse in Orion is a red supergiant.

and uranium. A supernova can shine as brightly as an entire galaxy for a short time. All elements with an atomic number greater than that of lithium were formed by nuclear fusion in stars.

An animation of the Crab Supernova is seen here: http://www.youtube.com/watch?v=0J8srN24pSQ&feature=fvw.

This video looks at the origin of the universe, star formation, and the formation of the chemical elements in supernovas **(2c)**: http://www.youtube.com/watch?v=8AKXpBeddu0&feature=related (8:30).



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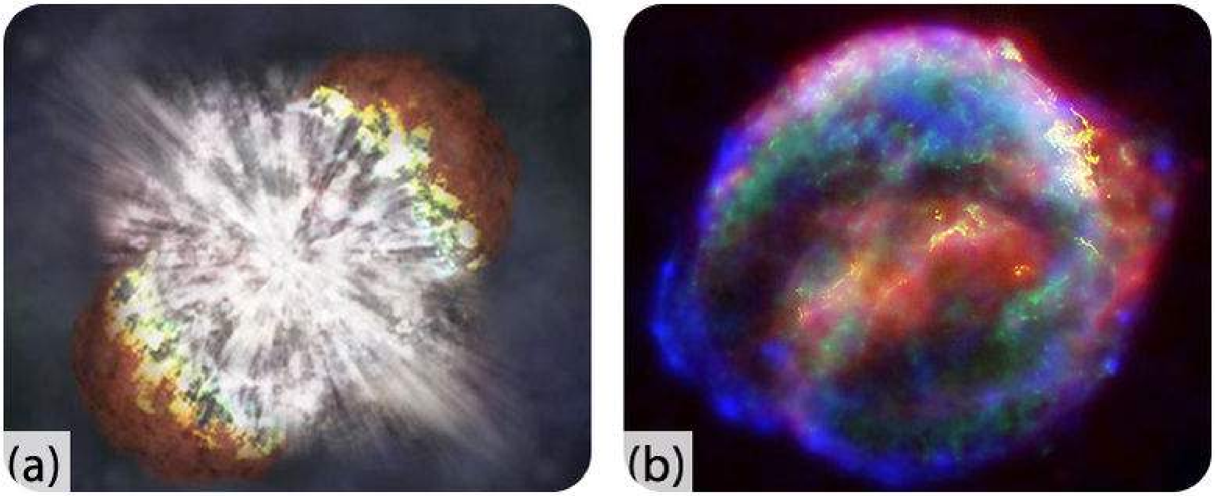

FIGURE 1.10
(a) NASA's Chandra X-ray observatory captured the brightest stellar explosion so far, 100 times more energetic than a typical supernova. (b) This false-color image of the supernova remnant SN 1604 was observed as a supernova in the Milky Way galaxy. At its peak it was brighter than all other stars and planets, except Venus, in the night sky.

Neutron Stars and Black Holes

After a supernova explosion, the leftover material in the core is extremely dense. If the core is less than about four times the mass of the Sun, the star becomes a **neutron star** (**Figure** 1.11). A neutron star is made almost entirely of neutrons, relatively large particles that have no electrical charge.

If the core remaining after a supernova is more than about five times the mass of the Sun, the core collapses into a **black hole**. Black holes are so dense that not even light can escape their gravity. With no light, a black hole cannot be observed directly. But a black hole can be identified by the effect that it has on objects around it, and by radiation that leaks out around its edges.

How to make a black hole: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop.

A video about black holes is seen on Space.com: http://www.space.com/common/media/video/player.php?videoRef=black_holes.

A Star's Life Cycle video from Discovery Channel describes how stars are born, age and die **(2f)**: http://www.youtube.com/watch?v=H8Jz6FU5D1A (3:11).

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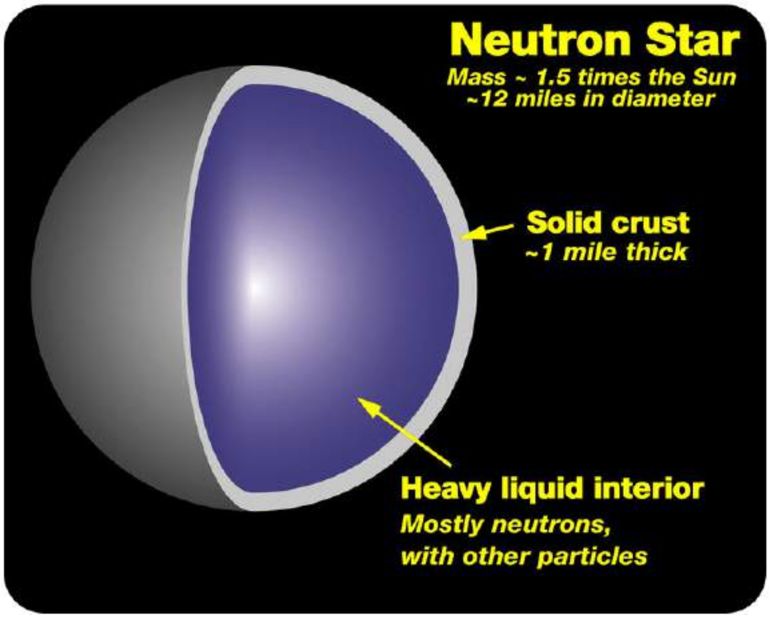

FIGURE 1.11
After a supernova, the remaining core may end up as a neutron star. A neutron star is more massive than the Sun, but only a few kilometers in diameter.

A video of neutron stars is available at: http://www.youtube.com/watch?v=VMnLVkV_ovc (4:24).

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Measuring Star Distances

How can you measure the distance of an object that is too far away to measure? Now what if you don't know the size of the object or the size or distance of any other objects like it? That would be very difficult, but that is the problem facing astronomers when they try to measure the distances to stars.

Parallax

Distances to stars that are relatively close to us can be measured using **parallax**. Parallax is an apparent shift in position that takes place when the position of the observer changes.

To see an example of parallax, try holding your finger about 1 foot (30 cm) in front of your eyes. Now, while focusing on your finger, close one eye and then the other. Alternate back and forth between eyes, and pay attention to how your finger appears to move. The shift in position of your finger is an example of parallax. Now try moving your finger closer to your eyes, and repeat the experiment. Do you notice any difference? The closer your finger is to your eyes, the greater the position changes because of parallax.

As **Figure** 1.12 shows, astronomers use this same principle to measure the distance to stars. Instead of a finger, they focus on a star, and instead of switching back and forth between eyes, they switch between the biggest possible differences in observing position. To do this, an astronomer first looks at the star from one position and notes where the star is relative to more distant stars. Now where will the astronomer go to make an observation the greatest possible distance from the first observation? In six months, after Earth moves from one side of its orbit around the Sun to the other side, the astronomer looks at the star again. This time parallax causes the star to appear in a different position relative to more distant stars. From the size of this shift, astronomers can calculate the distance to the star.

For more about parallax, visit http://starchild.gsfc.nasa.gov/docs/StarChild/questions/parallax.html.

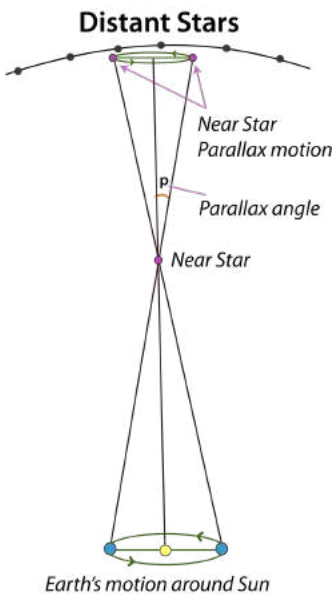

FIGURE 1.12
Parallax is used to measure the distance to stars that are relatively nearby.

A parallax exercise is seen here: http://www.astro.ubc.ca/ scharein/a311/Sim/new-parallax/Parallax.html.

Other Methods

Even with the most precise instruments available, parallax is too small to measure the distance to stars that are more than a few hundred light years away. For these more distant stars, astronomers must use more indirect methods of determining distance. Most of these methods involve determining how bright the star they are looking at really is. For example, if the star has properties similar to the Sun, then it should be about as bright as the Sun. The astronomer compares the observed brightness to the expected brightness.

Lesson Summary

- Constellations and asterisms are apparent patterns of stars in the sky.
- Stars in the same constellation are often not close to each other in space.
- A star generates energy by nuclear fusion reactions in its core.
- The color of a star is determined by its surface temperature.
- Stars are classified by color and temperature: O (blue), B (bluish white), A (white), F (yellowish white), G (yellow), K (orange), and M (red), from hottest to coolest.
- Stars form from nebulas. Gravity causes stars to collapse until nuclear fusion begins.
- Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
- Typical, Sun-like stars expand into red giants, then fade out as white dwarfs.

- Very large stars expand into red supergiants, explode in supernovas, and end up as neutron stars or black holes.
- Parallax is an apparent shift in an object's position when the position of the observer changes. Astronomers use parallax to measure the distance to

relatively nearby stars.

Review Questions

1. What distinguishes a nebula and a star?

2. What kind of reactions provide a star with energy?

3. Stars are extremely massive. Why don't they collapse under the weight of their own gravity?

4. Of what importance are particle accelerators to scientists?

5. Which has a higher surface temperature: a blue star or a red star?

6. List the seven main classes of stars, from hottest to coolest.

7. What is the main characteristic of a main sequence star?

8. What kind of star will the Sun be after it leaves the main sequence?

9. Suppose a large star explodes in a supernova, leaving a core that is 10 times the mass of the Sun. What would happen to the core of the star?

10. Since black holes are black, how do astronomers know that they exist?

11. What is a light year?

12. Why don't astronomers use parallax to measure the distance to stars that are very far away?

Further Reading / Supplemental Links

- Myths and history of constellations: http://www.ianridpath.com/startales/contents.htm
- NASA World Book, Stars: http://www.nasa.gov/worldbook/star_worldbook.html
- NASA, parts of a star: http://imagine.gsfc.nasa.gov/docs/science/know_l1/stars.html

Points to Consider

- Although stars may appear to be close together in constellations, they are usually not close together out in space. Can you think of any groups of astronomical objects that are relatively close together in space?
- Most nebulas contain more mass than a single star. If a large nebula collapsed into several different stars, what would the result be like?

1.2 Galaxies

Lesson Objectives

- Distinguish between star systems and star clusters.
- Identify different types of galaxies.
- Describe our own galaxy, the Milky Way Galaxy.

Vocabulary

- binary star
- dwarf galaxy
- elliptical galaxy
- galaxy
- globular cluster
- irregular galaxy
- Milky Way Galaxy
- open cluster
- spiral arm
- spiral galaxy
- star cluster
- star system

Introduction

Where do you live? Sure you live in a house or apartment, on a street, in a town or city, in a state or province, and in a country. You may not think to mention that you live on planet Earth in the solar system (as if there is no other), which is in the Milky Way Galaxy. Our galaxy is just one of many billions of galaxies in the universe. These galaxies are incomprehensible distances from each other and from Earth.

Star Systems and Star Clusters

Although constellations have stars that usually only appear to be close together, stars may be found in the same portion of space. Stars that are grouped closely together are called **star systems**. Larger groups of hundreds or thousands of stars are called **star clusters**.

Star Systems

Although the star humans know best is a single star, many stars—in fact, more than half of the bright stars in our galaxy—are star systems. A system of two stars orbiting each other is a **binary star**. A system with more than two stars orbiting each other is a multiple star system. The stars in a binary or multiple star system are often so close together that they appear as one and only through a telescope can the pair be distinguished.

An animation of a solar system like ours but with two suns was created by NASA: http://www.spitzer.caltech.edu/video-audio/852-ssc2007-05v1-Two-Suns-Raise-Family-of-Planetary-Bodies-

Star Clusters

Star clusters are divided into two main types, **open clusters** and **globular clusters**. Open clusters are groups of up to a few thousand stars that are loosely held together by gravity. The Pleiades, shown in **Figure** 1.13, is an open cluster that is also called the Seven Sisters.

FIGURE 1.13
In the Pleiades, seven stars can be seen without a telescope, but the cluster has close to a thousand stars.

Open clusters tend to be blue in color and often contain glowing gas and dust. Why do you think that open clusters have these features? Open clusters are made of young stars that formed from the same nebula. The stars may eventually be pulled apart by gravitational attraction to other objects.

Globular clusters are groups of tens to hundreds of thousands of stars held tightly together by gravity. **Figure** 1.14 shows an example of a globular cluster. Globular clusters have a definite, spherical shape and contain mostly reddish stars. The stars are closer together, closer to the center of the cluster. Globular clusters don't have much dust in them — the dust has already formed into stars.

Check out http://seds.org/messier/cluster.html and http://hubblesite.org/newscenter/archive/releases/star-cluster/ for more information about star clusters.

Types of Galaxies

Galaxies are the biggest groups of stars and can contain anywhere from a few million stars to many billions of stars. Every star that is visible in the night sky is part of the Milky Way Galaxy. To the naked eye the closest major galaxy

FIGURE 1.14
M80 is a large globular cluster containing hundreds of thousands of stars. Note that the cluster is spherical and contains mostly red stars.

— the Andromeda Galaxy, shown in **Figure** 1.15 — looks like only a dim, fuzzy spot. But that fuzzy spot contains one trillion stars – 1,000,000,000,000 stars!

FIGURE 1.15
The Andromeda Galaxy is a large spiral galaxy similar to the Milky Way.

Galaxies are divided into three types according to shape: spiral galaxies, elliptical galaxies, and irregular galaxies.

Spiral Galaxies

Spiral galaxies spin, so they appear as a rotating disk of stars and dust, with a bulge in the middle, like the Sombrero Galaxy shown in **Figure** 1.16. Several arms spiral outward in the Pinwheel Galaxy (seen in **Figure** 1.16) and are appropriately called **spiral arms**. Spiral galaxies have lots of gas and dust and lots of young stars.

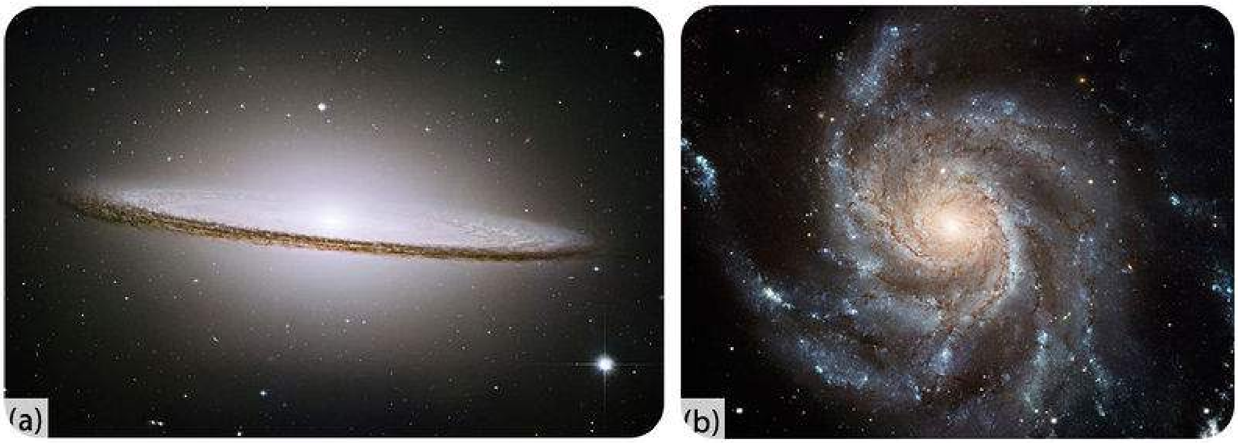

FIGURE 1.16
(a) The Sombrero Galaxy is a spiral galaxy that we see from the side so the disk and central bulge are visible. (b) The Pinwheel Galaxy is a spiral galaxy that we see face-on so we can see the spiral arms. Because they contain lots of young stars, spiral arms tend to be blue.

Elliptical Galaxies

Figure 1.17 shows a typical egg-shaped **elliptical galaxy**. The smallest elliptical galaxies are as small as some globular clusters. Giant elliptical galaxies, on the other hand, can contain over a trillion stars. Elliptical galaxies are reddish to yellowish in color because they contain mostly old stars.

Most elliptical galaxies contain very little gas and dust because the gas and dust has already formed into stars. However, some elliptical galaxies, such as the one shown in **Figure** 1.18, contain lots of dust. Why might some elliptical galaxies contain dust?

Irregular Galaxies and Dwarf Galaxies

Is the galaxy in **Figure** 1.19 a spiral galaxy or an elliptical galaxy? It is neither one! Galaxies that are not clearly elliptical galaxies or spiral galaxies are **irregular galaxies**. How might an irregular galaxy form? Most irregular galaxies were once spiral or elliptical galaxies that were then deformed either by gravitational attraction to a larger galaxy or by a collision with another galaxy.

Dwarf galaxies are small galaxies containing only a few million to a few billion stars. Dwarf galaxies are the most common type in the universe. However, because they are relatively small and dim, we don't see as many dwarf galaxies from Earth. Most dwarf galaxies are irregular in shape. However, there are also dwarf elliptical galaxies and dwarf spiral galaxies.

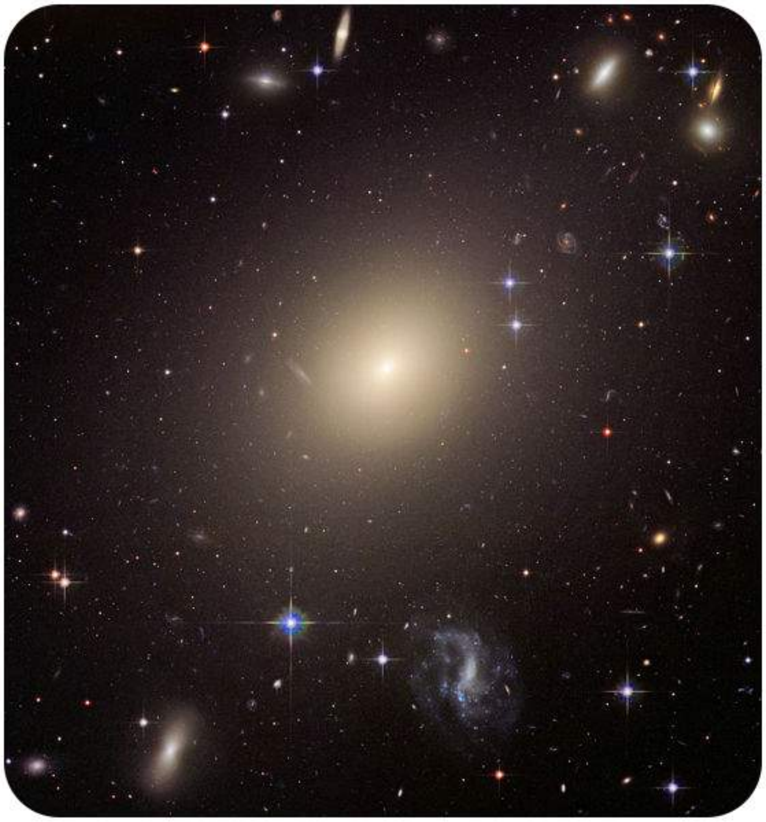

FIGURE 1.17
The large, reddish-yellow object in the middle of this figure is a typical elliptical galaxy. What other types of galaxies can you find in the figure?

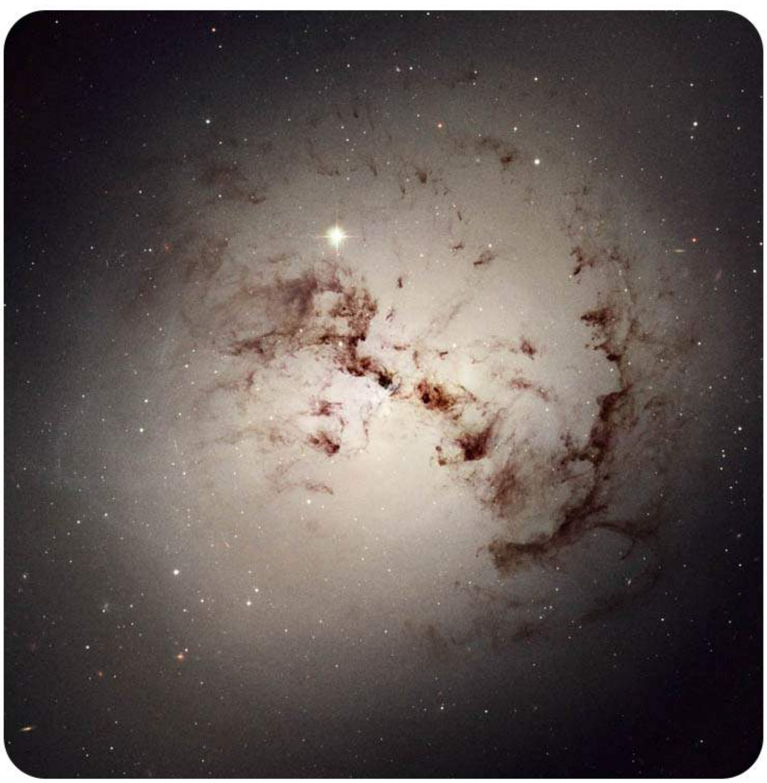

FIGURE 1.18
Astronomers believe that these dusty elliptical galaxies form when two galaxies of similar size collide.

FIGURE 1.19
This galaxy, called NGC 1427A, has neither a spiral nor an elliptical shape.

Look back at the picture of the elliptical galaxy. In the figure, you can see two dwarf elliptical galaxies that are companions to the Andromeda Galaxy. One is a bright sphere to the left of center, and the other is a long ellipse below and to the right of center. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

Images from the Hubble Space Telescope are seen in this video: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop.

The Milky Way Galaxy

On a dark, clear night, you will see a milky band of light stretching across the sky, as in **Figure** 1.20 . This band is the disk of a galaxy, the **Milky Way Galaxy**, which is our galaxy. The Milky Way is made of millions of stars along with a lot of gas and dust.

Shape and Size

Although it is difficult to know what the shape of the Milky Way Galaxy is because we are inside of it, astronomers have identified it as a typical spiral galaxy containing about 100 billion to 400 billion stars (**Figure** 1.21).

Like other spiral galaxies, our galaxy has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across and 3,000 light-years thick. Most of the Galaxy's gas, dust, young stars, and open clusters are in the disk. What evidence do astronomers find that lets them know that the Milky Way is a spiral galaxy?

1. The shape of the galaxy as we see it (**Figure** 1.22).
2. The velocities of stars and gas in the galaxy show a rotational motion.

FIGURE 1.20
The Milky Way Galaxy looks different than other galaxies because we are looking along the main disk from within the galaxy.

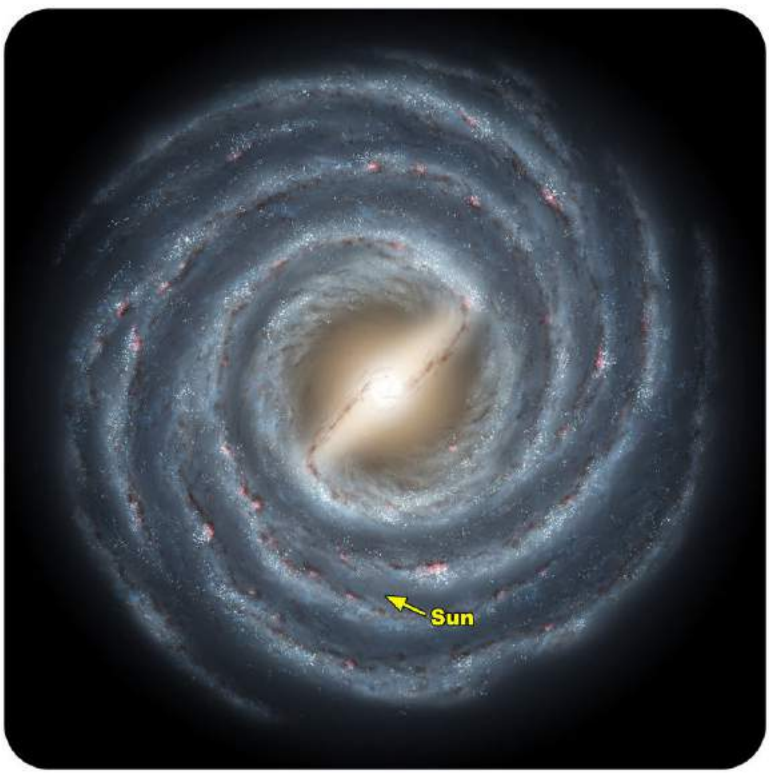

FIGURE 1.21
An artist's rendition of what astronomers think the Milky Way Galaxy would look like seen from above. The Sun is located approximately where the arrow points.

3. The gases, color, and dust are typical of spiral galaxies.

The central bulge is about 12,000 to 16,000 light-years wide and 6,000 to 10,000 light-years thick. The central bulge contains mostly older stars and globular clusters. Some recent evidence suggests the bulge might not be spherical, but is instead shaped like a bar. The bar might be as long as 27,000 light-years long. The disk and bulge are surrounded by a faint, spherical halo, which also contains old stars and globular clusters. Astronomers have discovered that there is a gigantic black hole at the center of the galaxy.

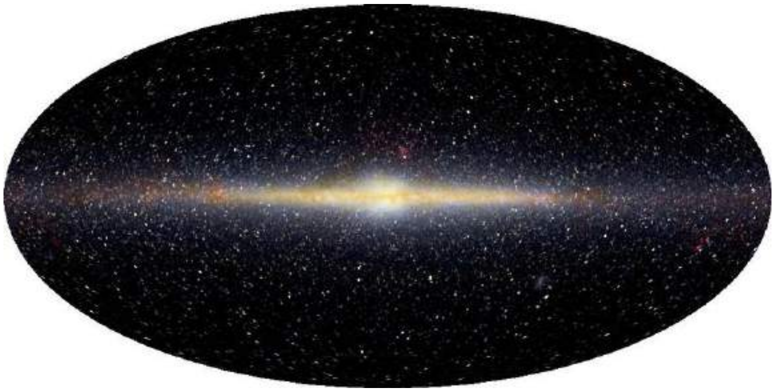

FIGURE 1.22
An infrared image of the Milky Way shows the long thin line of stars and the central bulge typical of spiral galaxies.

The Milky Way Galaxy is a big place. If our solar system were the size of your fist, the Galaxy's disk would still be wider than the entire United States!

A video closeup of the Milky Way Galaxy is seen here: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTopjjj.

Where We Are

Our solar system, including the Sun, Earth, and all the other planets, is within one of the spiral arms in the disk of the Milky Way Galaxy. Most of the stars we see in the sky are relatively nearby stars that are also in this spiral arm. We are about 26,000 light-years from the center of the galaxy, a little more than halfway out from the center of the galaxy to the edge.

Just as Earth orbits the Sun, the Sun and solar system orbit the center of the Galaxy. One orbit of the solar system takes about 225 to 250 million years. The solar system has orbited 20 to 25 times since it formed 4.6 billion years ago. Astronomers have recently discovered that at the center of the Milky Way, and most other galaxies, is a supermassive black hole, although a black hole cannot be seen.

This video describes the solar system in which we live. It is located in an outer edge of the Milky Way galaxy, which spans 100,000 light years **(2a)**: http://www.youtube.com/watch?v=0Rt7FevNiRc (5:10).

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The Universe contains many billions of stars and there are many billions of galaxies. Our home, the Milky Way galaxy, is only one **(2a, 2b)**: http://www.youtube.com/watch?v=eRJvB3hM7K0&feature=related (5:59).

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Lesson Summary

- Many stars are in systems of two or more stars.
- Open clusters are groups of young stars loosely held together by gravity.
- Globular clusters are spherical groups of old stars held tightly together by gravity.
- Galaxies are collections of millions to many billions of stars.
- Spiral galaxies have a rotating disk of stars and dust, a bulge in the middle, and several arms spiraling out from the center. The disk and arms contain many young, blue stars.
- Typical elliptical galaxies are egg-shaped, reddish, and contain mostly old stars.
- Galaxies that are not elliptical or spiral galaxies are called irregular galaxies. These galaxies were probably deformed by other galaxies.
- The Milky Way Galaxy is a typical spiral galaxy. Our solar system is in a spiral arm of the Milky Way Galaxy, a little more than halfway from the center to the edge of the disk.

Review Questions

1. What is a binary star?
2. Compare globular clusters with open clusters.
3. Name the three main types of galaxies.
4. List three main features of a spiral galaxy.
5. Suppose you see a round galaxy that is reddish in color and contains very little dust. What kind of galaxy is it?
6. What galaxy do we live in, and what kind of galaxy is it?
7. What is the evidence that the galaxy we live in is this type of galaxy?
8. Describe the location of our solar system in our galaxy.

Further Reading / Supplemental Links

- Variety of astronomy news: http://www.space.com
- More about galaxies: http://stardate.org/resources/btss/galaxies/

Points to Consider

- Objects in the universe tend to be grouped together. What forces or factors do you think cause objects to form and stay in groups?
- Some people used to call galaxies “island universes.” Are they really universes?
- Can you think of anything, either an object or a group of objects, that is bigger than a galaxy?

1.3 The Universe

Lesson Objectives

- Explain the evidence for an expanding universe.
- Describe the formation of the universe according to the Big Bang Theory.
- Define dark matter and dark energy.

Vocabulary

- Big Bang Theory
- cosmology
- dark energy
- dark matter
- Doppler Effect
- redshift
- universe

Introduction

The study of the universe is called **cosmology**. Cosmologists study the structure and changes in the present universe. The **universe** contains all of the star systems, galaxies, gas and dust, plus all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe includes all of space and time.

Evolution of Human Understanding of the Universe

What did the ancient Greeks recognize as the universe? In their model, the universe contained Earth at the center, the Sun, the Moon, five planets, and a sphere to which all the stars were attached. This idea held for many centuries until Galileo's telescope helped allow people to recognize that Earth is not the center of the universe. They also found out that there are many more stars than were visible to the naked eye. All of those stars were in the Milky Way Galaxy.

In the early 20th century, an astronomer named Edwin Hubble **Figure** 1.23 discovered that what scientists called the Andromeda Nebula was actually over 2 million light years away — many times farther than the farthest distances that had ever been measured. Hubble realized that many of the objects that astronomers called nebulas were not actually clouds of gas, but were collections of millions or billions of stars — what we now call galaxies.

Hubble showed that the universe was much larger than our own galaxy. Today, we know that the universe contains about a hundred billion galaxies—about the same number of galaxies as there are stars in the Milky Way Galaxy.

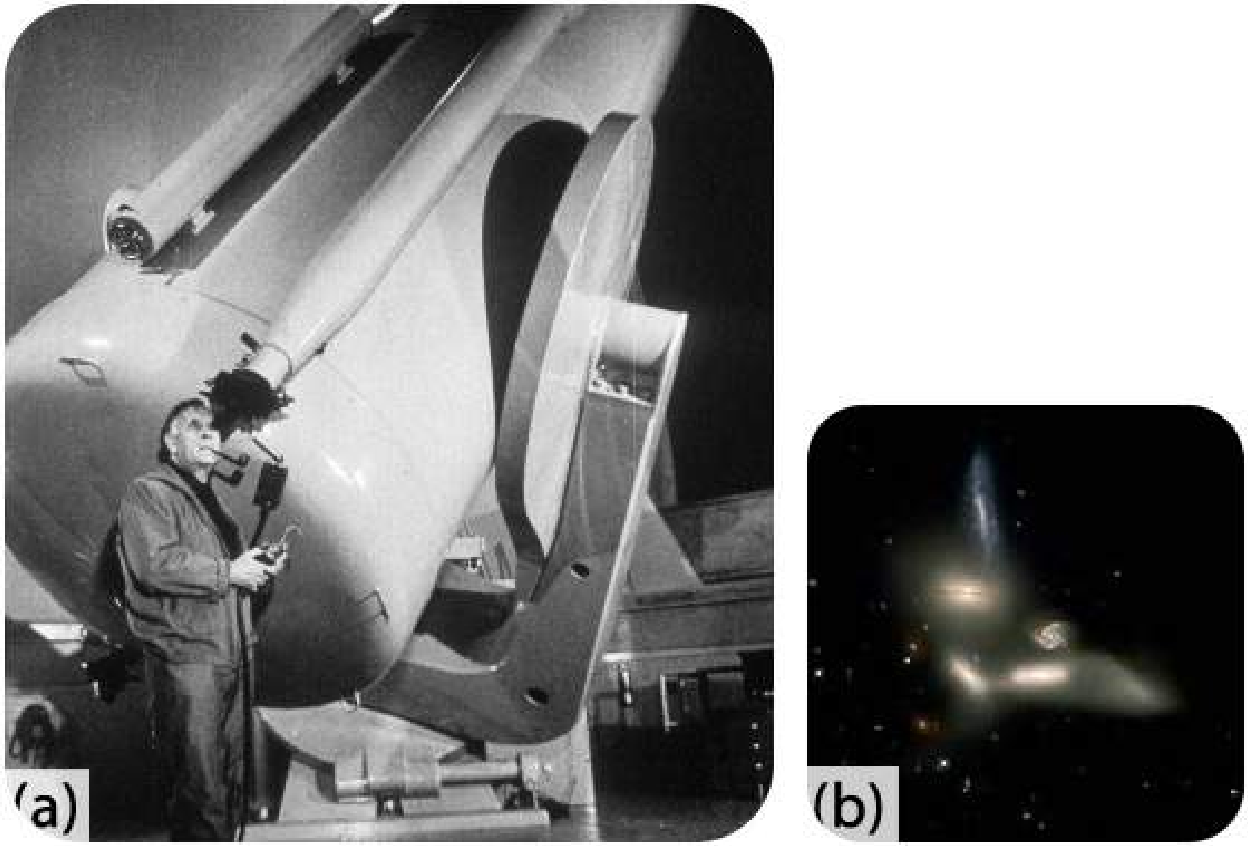

FIGURE 1.23

(a) Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California to show that some distant specks of light were galaxies. (b) Hubble's namesake space telescope spotted this six galaxy group. Edwin Hubble demonstrated the existence of galaxies.

Expansion of the Universe

After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show how the universe is changing, and would even yield clues as to how the universe formed.

Redshift

If you look at a star through a prism, you will see a spectrum, or a range of colors through the rainbow. The spectrum will have specific dark bands where elements in the star absorb light of certain energies. By examining the arrangement of these dark absorption lines, astronomers can determine the composition of elements that make up a distant star. In fact, the element helium was first discovered in our Sun — not on Earth — by analyzing the absorption lines in the spectrum of the Sun.

While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in **Figure** 1.24. This shift of absorption bands toward the red end of the spectrum is known as **redshift**.

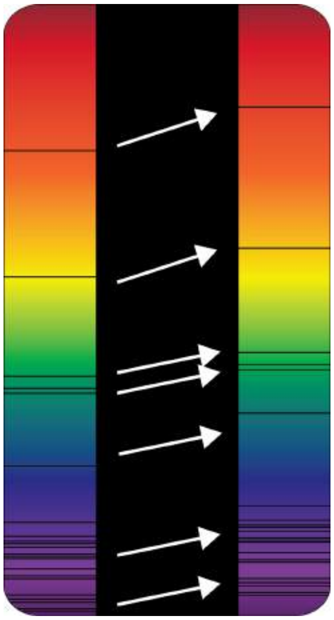

FIGURE 1.24

Redshift is a shift in absorption bands toward the red end of the spectrum. What could make the absorption bands of a star shift toward the red?

Redshift occurs when the light source is moving away from the observer or when the space between the observer and the source is stretched. What does it mean that stars and galaxies are redshifted? When astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth.

If galaxies were moving randomly, would some be redshifted but others be blueshifted? Of course. Since almost every galaxy in the universe has a redshift, almost every galaxy is moving away from Earth.

Redshift can occur with other types of waves too. This phenomenon is called the **Doppler Effect**. An analogy to redshift is the noise a siren makes as it passes you. You may have noticed that an ambulance seems to lower the pitch of its siren after it passes you. The sound waves shift towards a lower pitch when the ambulance speeds away from you. Though redshift involves light instead of sound, a similar principle operates in both situations.

An animation of Doppler Effect http://projects.astro.illinois.edu/data/Doppler/index.html.

The Expanding Universe

Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a relationship, which is now called Hubble's Law: The farther away a galaxy is, the faster it is moving away from us. What could this mean about the universe? It means that the universe is expanding.

Figure 1.25 shows a simplified diagram of the expansion of the universe. One way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. Also the dots farther away from you on the balloon would move away faster than dots nearby.

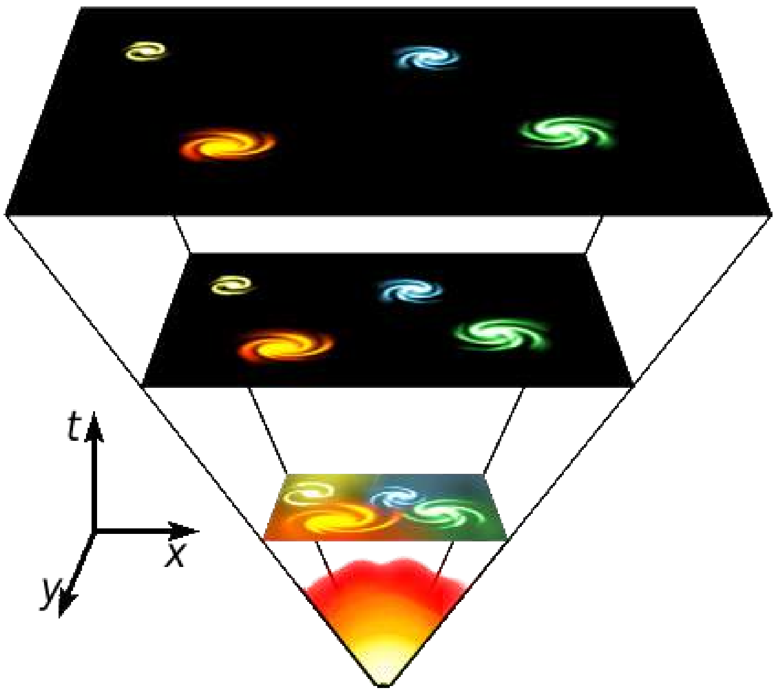

FIGURE 1.25
In this diagram of the expansion of the universe over time, the distance between galaxies gets bigger over time, although the size of each galaxy stays the same.

Expansion of the Universe Diagram

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching out between galaxies like the rubber stretches when a balloon is inflated. This stretching of space, which increases the distance between galaxies, is what causes the expansion of the universe.

An animation of an expanding universe is shown here: http://www.astro.ubc.ca/ scharein/a311/Sim/bang/BigBang.html.

One other difference between the universe and a balloon involves the actual size of the galaxies. On balloon, the dots will become larger in size as you inflate it. In the universe, the galaxies stay the same size, just the space between the galaxies increases.

Formation of the Universe

Before Hubble, most astronomers thought that the universe didn't change. But if the universe is expanding, what does that say about where it was in the past? If the universe is expanding, the next logical thought is that in the past it had to have been smaller.

The Big Bang Theory

The **Big Bang theory** is the most widely accepted cosmological explanation of how the universe formed. If we start at the present and go back into the past, the universe is contracting – getting smaller and smaller. What is the end result of a contracting universe?

According to the Big Bang theory, the universe began about 13.7 billion years ago. Everything that is now in the universe was squeezed into a very small volume. Imagine all of the known universe in a single, hot, chaotic mass. An enormous explosion — a big bang — caused the universe to start expanding rapidly. All the matter and energy in the universe, and even space itself, came out of this explosion.

What came before the Big Bang? There is no way for scientists to know since there is no remaining evidence.

After the Big Bang

In the first few moments after the Big Bang, the universe was unimaginably hot and dense. As the universe expanded, it became less dense and began to cool. After only a few seconds, protons, neutrons, and electrons could form. After a few minutes, those subatomic particles came together to create hydrogen. Energy in the universe was great enough to initiate nuclear fusion and hydrogen nuclei were fused into helium nuclei. The first neutral atoms that included electrons did not form until about 380,000 years later.

The matter in the early universe was not smoothly distributed across space. Dense clumps of matter held close together by gravity were spread around. Eventually, these clumps formed countless trillions of stars, billions of galaxies, and other structures that now form most of the visible mass of the universe.

If you look at an image of galaxies at the far edge of what we can see, you are looking at great distances. But you are also looking across a different type of distance. What do those far away galaxies represent? Because it takes so long for light from so far away to reach us, you are also looking back in time (**Figure** 1.26).

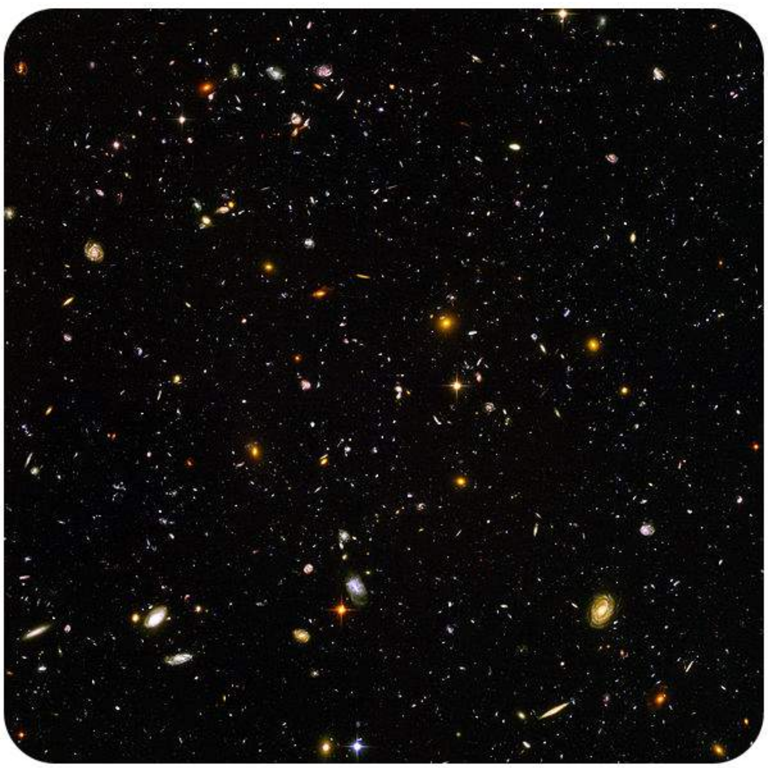

FIGURE 1.26
Images from very far away show what the universe was like not too long after the Big Bang.

After the origin of the Big Bang hypothesis, many astronomers still thought the universe was static. Nearly all came around when an important line of evidence for the Big Bang was discovered in 1964. In a static universe, the space between objects should have no heat at all; the temperature should measure 0 K (Kelvin is an absolute temperature scale). But two researchers at Bell Laboratories used a microwave receiver to learn that the background radiation in the universe is not 0 K, but 3 K (**Figure** 1.27). This tiny amount of heat is left over from the Big Bang. Since nearly all astronomers now accept the Big Bang hypothesis, what is it usually referred to as?

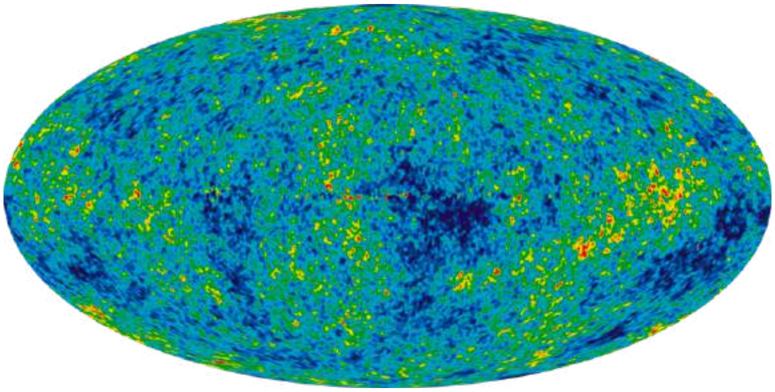

FIGURE 1.27
Background radiation in the universe was good evidence for the Big Bang Theory.

An explanation of the Big Bang: http://dvice.com/archives/2009/08/big-bang-animat.php.

How we know about the early universe: http://www.youtube.com/watch?v=uihNu9Icaeo&feature=channel.

History of the Universe, part 2: http://www.youtube.com/watch?v=bK6_p5a-Hbo&feature=channel. *The Evidence for the Big Bang in 10 Little Minutes* provides a great deal of scientific evidence for the Big Bang **(2g)**: http://www.youtube.com/watch?v=uyCkADmNdNo (10:10).

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KQED: Nobel Laureate George Smoot and the Origin of the Universe

George Smoot, a scientist at Lawrence Berkeley National Lab, shared the 2006 Nobel Prize in Physics for his work on the origin of the universe. Using background radiation detected by the Cosmic Background Explorer Satellite (COBE), Smoot was able to make a picture of the universe when it was 12 hours old. Learn more at: http://science.kqed.org/quest/video/nobel-laureate-george-smoot-and-the-origin-of-the-universe/.

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Dark Matter and Dark Energy

The Big Bang theory is still the best scientific model we have for explaining the formation of the universe and many lines of evidence support it. However, recent discoveries continue to shake up our understanding of the universe. Astronomers and other scientists are now wrestling with some unanswered questions about what the universe is made of and why it is expanding. A lot of what cosmologists do is create mathematical models and computer simulations to account for these unknown phenomena.

Dark Matter

The things we observe in space are objects that emit some type of electromagnetic radiation. However, scientists think that matter that emits light makes up only a small part of the matter in the universe. The rest of the matter, about 80%, is dark matter.

Dark matter emits no electromagnetic radiation so we can't observe it directly. However, astronomers know that dark matter exists because its gravity affects the motion of objects around it. When astronomers measure how spiral galaxies rotate, they find that the outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot more matter in the galaxy than they can see.

Gravitational lensing occurs when light is bent from a very distant bright source around a super-massive object (**Figure** 1.28). To explain strong gravitational lensing, more matter than is observed must be present.

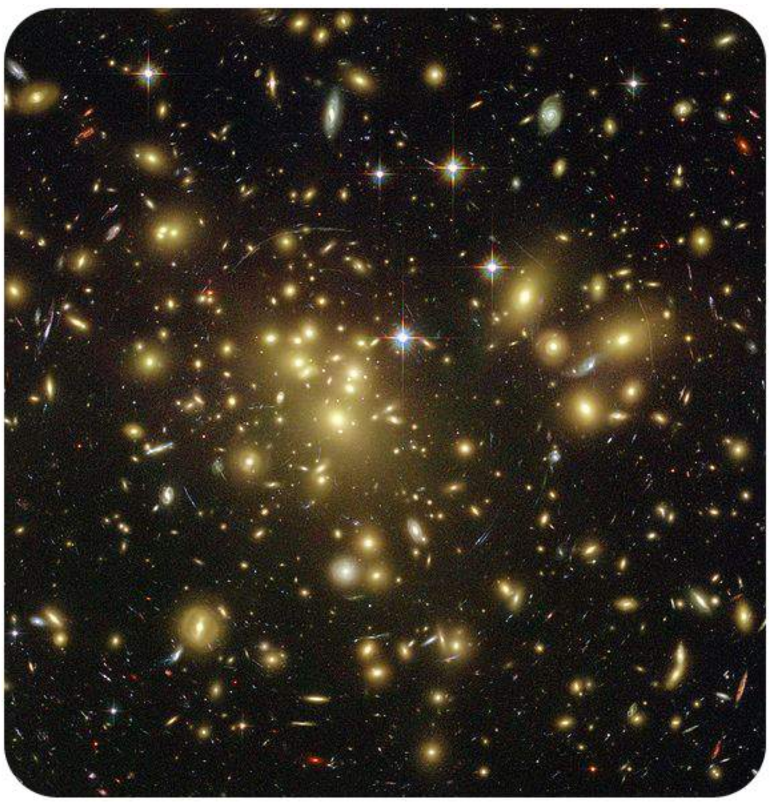

FIGURE 1.28
The arc around the galaxies at the center of this image is caused by gravitational lensing. The addition of gravitational pull from dark matter is required to explain this phenomenon.

With so little to go on, astronomers don't really know much about the nature of dark matter. One possibility is that it could just be ordinary matter that does not emit radiation in objects such as black holes, neutron stars, and brown dwarfs – objects larger than Jupiter but smaller than the smallest stars. But astronomers cannot find enough of these types of objects, which they have named MACHOS (massive astrophyiscal compact halo object), to account for all the dark matter, so they are thought to be only a small part of the total.

Another possibility is that the dark matter is thought to be much different from the ordinary matter we see. Some appear to be particles that have gravity, but don't otherwise appear to interact with other particles. Scientists call these theoretical particles WIMPs, which stands for Weakly Interactive Massive Particles.

Most scientists who study dark matter think that the dark matter in the universe is a combination of MACHOS and some type of exotic matter such as WIMPs. Researching dark matter is an active area of scientific research, and astronomers' knowledge about dark matter is changing rapidly.

A video explaining dark matter is here: http://www.youtube.com/watch?v=gCgTJ6ID6ZA.

Dark Energy

Astronomers who study the expansion of the universe are interested in knowing the rate of that expansion. Is the rate fast enough to overcome the attractive pull of gravity?

- If yes, then the universe will expand forever, although the expansion will slow down over time.
- If no, then the universe would someday start to contract, and eventually get squeezed together in a big crunch, the opposite of the Big Bang.

Recently astronomers have made a discovery that answers that question: the rate at which the universe is expanding is actually increasing. In other words, the universe is expanding faster now than ever before, and in the future it will expand even faster. So now astronomers think that the universe will keep expanding forever. But it also proposes a perplexing new question: What is causing the expansion of the universe to accelerate? One possible hypothesis involves a new, hypothetical form of energy called **dark energy** (**Figure** 1.29). Some scientists think that dark energy makes up as much as 72% of the total energy content of the universe.

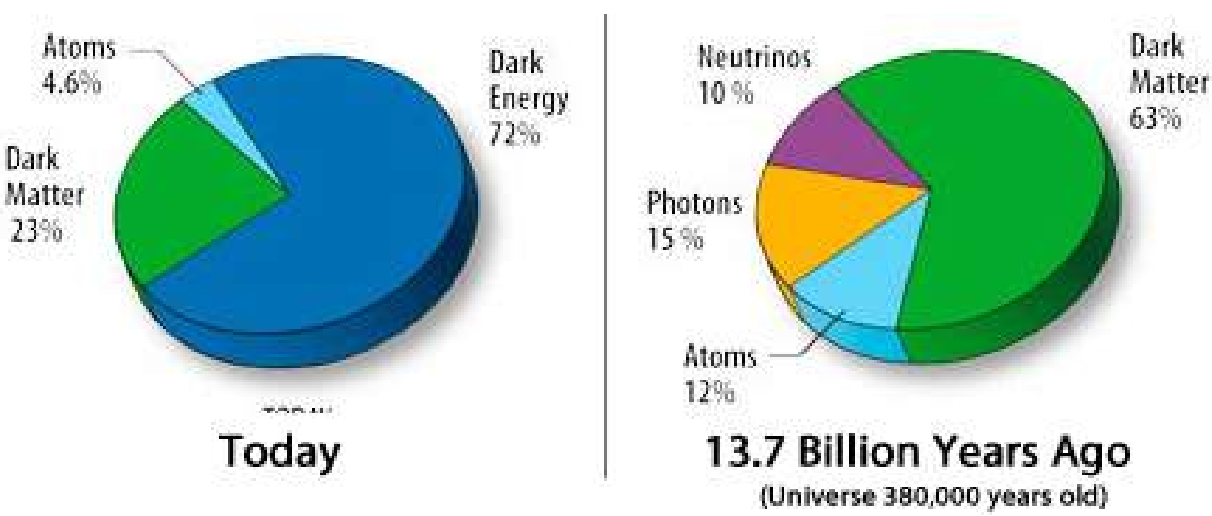

FIGURE 1.29

Today matter makes up a small percentage of the universe, but at the start of the universe it made up much more. Where did dark energy, if it even exists, come from?

Other scientists have other hypotheses about why the universe is continuing to expand; the causes of the universe's expansion is another unanswered question that scientists are researching.

KQED: Dark Energy

Meet one of the three winners of the 2011 Nobel Prize in Physics, Lawrence Berkeley Lab astrophysicist Saul Perlmutter. He explains how dark energy, which makes up 70 percent of the universe, is causing our universe to expand. Learn more at: http://science.kqed.org/quest/video/dark-energy/.

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Lesson Summary

- The universe contains all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe also includes all of space and time.
- Redshift is a shift of element lines toward the red end of the spectrum. Redshift occurs when the source of light is moving away from the observer.
- Light from almost every galaxy is redshifted. The farther away a galaxy is, the more its light is redshifted, and the faster it is moving away from us.
- The redshift of galaxies means that the universe is expanding.
- The universe was squeezed into a very small volume and then exploded in the Big Bang theory about 13.7 billion years ago.
- Recent evidence shows that there is a lot of matter in the universe that we cannot detect directly. This matter is called dark matter.
- The rate of the expansion of the universe is increasing. The cause of this increase is unknown; one possible explanation involves a new form of energy called dark energy.

Review Questions

1. What is redshift, and what causes it to occur? What does redshift indicate?
2. What is Hubble's law?
3. What is the cosmological theory of the formation of the universe called?
4. How old is the universe, according to the Big Bang theory?
5. Describe two different possibilities for the nature of dark matter.
6. What makes scientists believe that dark matter exists?
7. What observation caused astronomers to propose the existence of dark energy?

Further Reading / Supplemental Links

- The science of dark matter: http://cdms.berkeley.edu/Education/DMpages/index.shtml
- More about cosmology: http://stardate.org/resources/btss/cosmology/

- The Big Bang: http://hurricanes.nasa.gov/universe/science/bang.html

Points to Consider

- The expansion of the universe is sometimes modeled using a balloon with dots marked on it, as described earlier in the lesson. In what ways is this a good model, and it what ways does it not correctly represent the expanding universe? Can you think of a different way to model the expansion of the universe?
- The Big Bang theory is currently the most widely accepted scientific theory for how the universe formed. What is another explanation of how the universe could have formed? Is your explanation one that a scientist would accept?

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