

Reflect

When you look up at the night sky, thousands of objects sparkle into view. If you gazed through a telescope, you would see many more of these objects. You are observing stars, which give off energy in the form of visible light.

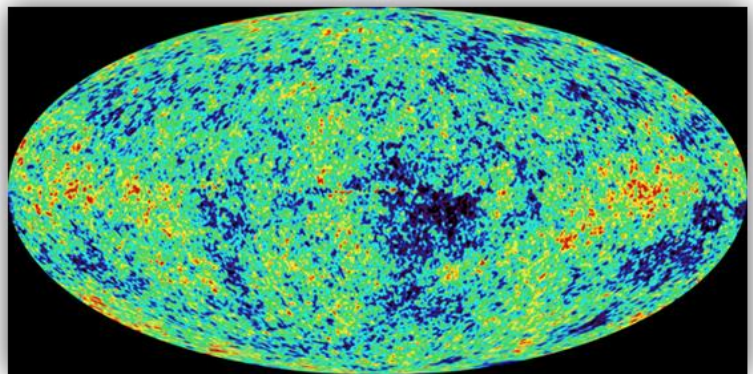
However, the stars you can see are only a very small portion of the universe. What objects in space, other than stars, make up the universe? What kinds of energy, other than light, do these objects give off? And how do scientists answer these—and other—questions about objects that are so far away?



The universe encompasses all of space, time, matter, and energy.

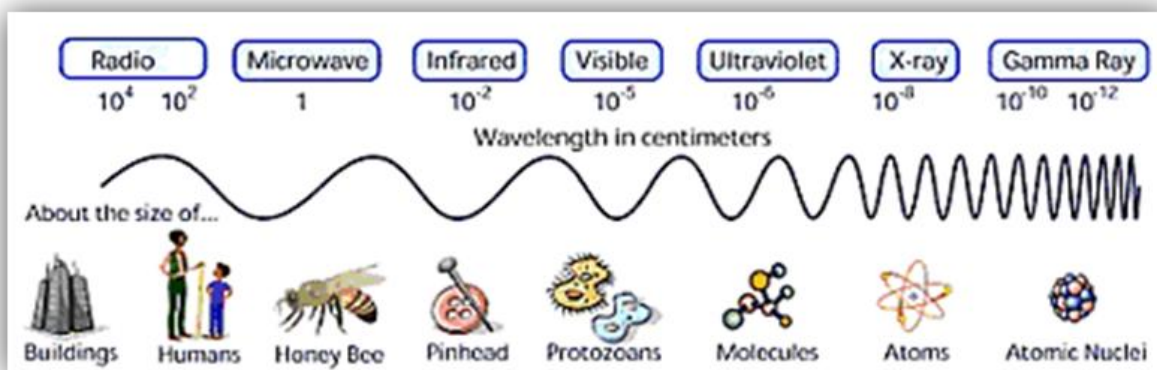
The *universe* contains everything that exists, from particles of matter smaller than an atom to the largest stars. The universe also includes all forms of energy, from the light you see streaming from stars to invisible radio waves and X rays. Even time is part of the universe. Scientists think of time as beginning when the universe began.

All the matter and energy in the universe is contained in a volume of space that scientists have discovered is constantly expanding. The expanding universe is similar to a balloon that is constantly inflating. Scientists do not know how large the universe is now. However, they have gathered evidence that the universe started very small and has grown in all directions ever since. The most distant objects that have been detected are about 13.7 light-years away from Earth. A *light-year* is a unit of distance. It is equal to the distance traveled by light in one year, which is approximately 9.5 trillion kilometers. So, light from the most distant objects scientists have observed began its journey to Earth 13.7 billion years ago. If these objects are actually the most distant objects in space, they are also the farthest back in time. For these reasons, scientists estimate the universe is about



The photo—taken by a satellite in 2003—shows the most distant part of the universe that has been observed from Earth. The different colors are masses of matter as they were a short time after the universe was born. These masses of matter would later become stars and galaxies.

To learn about the properties of objects in space, scientists study the energy coming from these objects. The energy may be in the form of visible light or other components of the electromagnetic spectrum, such as radio waves and X rays. The *electromagnetic spectrum* is an arrangement of forms of energy that travel through space in waves. Objects in space emit these forms of energy in different patterns. Scientists use special telescopes to detect these patterns and learn about the objects emitting them.



The electromagnetic spectrum organizes waves of energy by wavelength. The largest electromagnetic waves are radio waves, followed by microwaves and infrared waves (or heat). Visible light waves are in the middle of the spectrum. Waves with shorter wavelengths include ultraviolet (or UV) rays, X rays, and gamma rays. The wavelength of a gamma ray is smaller than the nucleus of an atom!

From its birth to the present, the universe has changed tremendously. Huge pockets of gas have been pulled together by gravity to form stars. In turn, these stars have been drawn together by gravity to form families of billions of stars. Stars born long ago developed, aged, and died. This process goes on today, and it will continue to go on in the future.

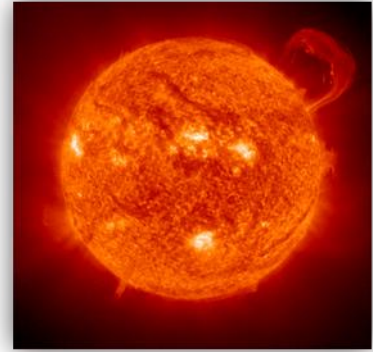
Look Out!

You may have difficulty imagining how gravity can “pull together” gases to form stars. Remember that gases, like all forms of matter, are composed of particles in motion. These particles are tiny, but they have mass, and so they are affected by gravity. As the density of a gas increases, gas particles collide more frequently and with greater force, causing the gas’s temperature to increase as well. Eventually, gases can become so hot they ignite, becoming huge, burning spheres, or stars.

Stars are large objects in space that generate their own energy.

Almost everything you see in the night sky with your unaided eyes is a star. (Exceptions include a few planets of our solar system, Earth's Moon, and an occasional comet.) A *star* is a huge ball of gas that produces its own energy, mostly through nuclear reactions in its core. Light is the most obvious form of energy produced by a star. However, stars produce many other forms of energy such as infrared radiation (or heat) and ultraviolet radiation. Gravity holds together the particles that make up the body of a star. In other words, a star is so massive, it is held together by its own gravity.

At an average distance of 149.6 million km (93 million miles), the Sun is the closest star to Earth. The next closest star, Proxima Centauri, is 4.22 light-years away. Recall that a light-year equals 9.5 trillion km; therefore, Proxima Centauri is about 40 trillion km from Earth. Light from this star takes 4.22 years to reach Earth. So, when we see Proxima Centauri through a telescope, we see the star as it existed 4.22 years ago.



Earth's star, the Sun, gives off tremendous amounts of energy.



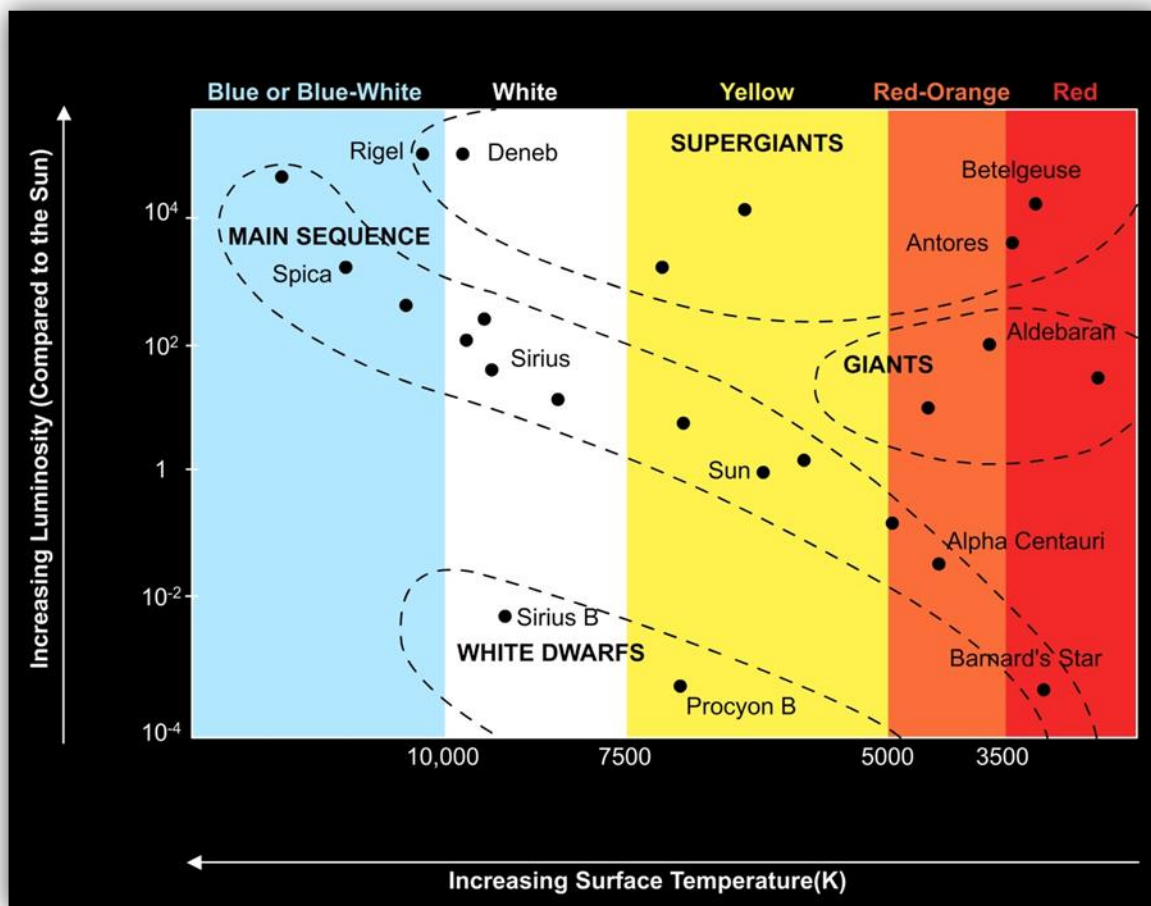
Inside this nebula, countless particles of gas and dust are pulled together by gravity. Eventually, the process gives birth to stars.

Scientists don't know for certain how stars form. The most commonly accepted hypothesis is that stars form from vast clouds of dust and gas called *nebulae* (singular: *nebula*). The force of gravity is strong between the countless particles of dust and gas. Gravity causes the cloud to condense and eventually to collapse on itself. As the center of the cloud becomes denser, it starts to spin and heat up. Gravity pulls more gas and dust particles into the hot, spinning mass, a process that continues for millions of years. Finally, the matter becomes so hot it ignites. Nuclear reactions begin, and the nebula has become a star.

Stars have life cycles.

The stars in the universe are not all the same. Some are very large, whereas others are relatively small. Some are extremely hot; others are cooler. Some emit great amounts of energy; others emit less energy. Stars may be young, middle-aged, old, or dying. They may be composed primarily of hydrogen, or they may contain mostly helium and heavier elements. Some are very bright; others are dimmer. Their colors range from blue and white to yellow and red.

In the early 1900s, Danish astronomer Ejnar Hertzsprung and American astronomer Henry Norris Russell developed a way to classify stars according to their luminosity, temperature, and color. (*Luminosity* is the brightness of a star relative to the brightness of other stars. Luminosity also is called *absolute brightness*.) This relationship is shown in a graph called the Hertzsprung-Russell (H-R) diagram, shown below.



- On the H-R diagram, stars are plotted along the bottom axis by increasing surface temperature, which is measured in units called kelvins (K). (To convert a measurement in kelvins to degrees Celsius, subtract 273 from the kelvin measurement.) Hotter stars are plotted on the left of the diagram, and cooler stars are plotted on the right.
- Stars are plotted along the left axis by increasing luminosity. Brighter stars are plotted at the top of the diagram. Less bright stars are plotted at the bottom of the diagram. The diagram on the previous page shows a star's luminosity relative to Earth's Sun. So, stars alongside the 10^2 tick mark are 100 times brighter than the Sun, and stars alongside the 10^{-2} tick mark are 100 times dimmer than the Sun.
- Stars are plotted along the top axis by color. Blue and white stars are plotted on the left of the diagram. Yellow stars are plotted on the center of the diagram. Red and orange stars are plotted on the right of the diagram.

Most stars on the H-R diagram fall into one of four groups. Stars in the *main sequence* make up the vast majority of stars in the universe. In general, the hotter a star is on the main sequence, the brighter and bluer it is. As stars age, they fall outside the main sequence and become *giants* or *supergiants*, depending on their mass. As less-massive stars die, they become relatively tiny *white dwarfs*. More massive stars die by exploding into a powerful *supernova*. (Even smaller stars live for billions of years. The Sun, an average-sized star in the main sequence, is about midway through its 10-billion-year life cycle.)



This photograph shows the remains of a supernova that happened more than 1,000 years.

What Do You Think?

Study the H-R diagram on the previous page. Can you locate Earth's Sun? (HINT: It's close to the center.) How would you describe the Sun's temperature, brightness, and color compared to other stars? Do you notice any patterns in the H-R diagram? For example, what color are most hotter stars? Which are brighter: giants, supergiants, or white dwarfs?

Galaxies consist of families of stars, gases, and space dust.

Every star you see in the night sky is part of a galaxy called the Milky Way. This is our home galaxy. However, the Milky Way is only one of billions of galaxies in the universe, each of which contains hundreds of billions of stars, gases, and dust held together by the force of gravity. Most galaxies are invisible to the unaided eye. However, if you have keen vision you might spot one on a clear night. It would look like a faint, fuzzy patch of light. Viewed through powerful telescopes, galaxies appear in various shapes.

- **Spiral:** These galaxies are shaped like disks with arms spiraling from a central bulge. Most of the galaxies known to scientists—including the Milky Way—are spiral galaxies. The stars and other objects in a spiral galaxy rotate in the same direction around the galaxy's center like an incredibly fast-spinning pinwheel.



- **Lenticular:** These galaxies form a subgroup of spiral galaxies. *Lenticular* means “lens-shaped.” Like spiral galaxies, lenticular galaxies have a central bulge but lack arms. They are sometimes referred to as “armless” spiral galaxies.

- **Elliptical:** These galaxies look a bit like footballs. (An *ellipse* is an oval.) The stars and matter in an elliptical galaxy rotate around the galaxy's center in a variety of directions. The largest galaxies in the universe are elliptical. They may be millions of light years across and hold trillions of stars.



- **Irregular:** These galaxies have shapes that are difficult to classify. Some are long and thin like needles. Others are shaped like rings or clouds. Astronomers think the gravity of nearby galaxies may be pulling irregular galaxies into their disorganized shapes.

Scientists in the Spotlight: Stephen Hawking and Black Holes

In addition to stars, planets, and nebulae, the universe contains mysterious objects whose gravity is so powerful that they cause nearby material to spiral toward them. Because not even light can escape the gravitational pull of these objects, they are called *black holes*.

Black holes have been a focus of the work of one of the greatest scientific thinkers of the past century, Stephen Hawking. Although Hawking has a disease that confines him to a wheelchair and prevents him from speaking, he has developed a number of theories about black holes. Hawking communicates his ideas through an electronic device that converts the movements of muscles in his cheeks into words.

Hawking argues that black holes were created at the birth of the universe and have been with us ever since. In the beginning, they may have been no larger than single protons. Today, however, some are thought to be so large that



Not even light can escape the gravity of a black hole.

Although the concept of black holes is still being investigated, scientists have several theories about how they form and affect nearby matter and energy. As extremely massive stars age, they begin to collapse. Scientists think the matter in these stars is drawn inward, creating an extremely small yet dense object. A black hole the size of a pea could have the mass of Earth!

Scientists once assumed the gravity of black holes pulled everything into them forever, like super-powerful whirlpools. However, Hawking has theorized that black holes give off some kinds of radiation. If so, black holes should be detectable. As it turns out, scientists have uncovered evidence of a black hole at the center of our very own galaxy!

What Do You Know?

Part 1: Stars:

The following text describes four different stars. Using the Hertzsprung-Russell diagram from earlier in the companion, determine whether each star is a giant, supergiant, white dwarf, or main sequence star:

- Star 1:
 - Color: Red-orange
 - Surface temperature: 4000 K
 - Luminosity: approximately 100 times dimmer than Earth's Sun
 - Where in its life cycle is this star?

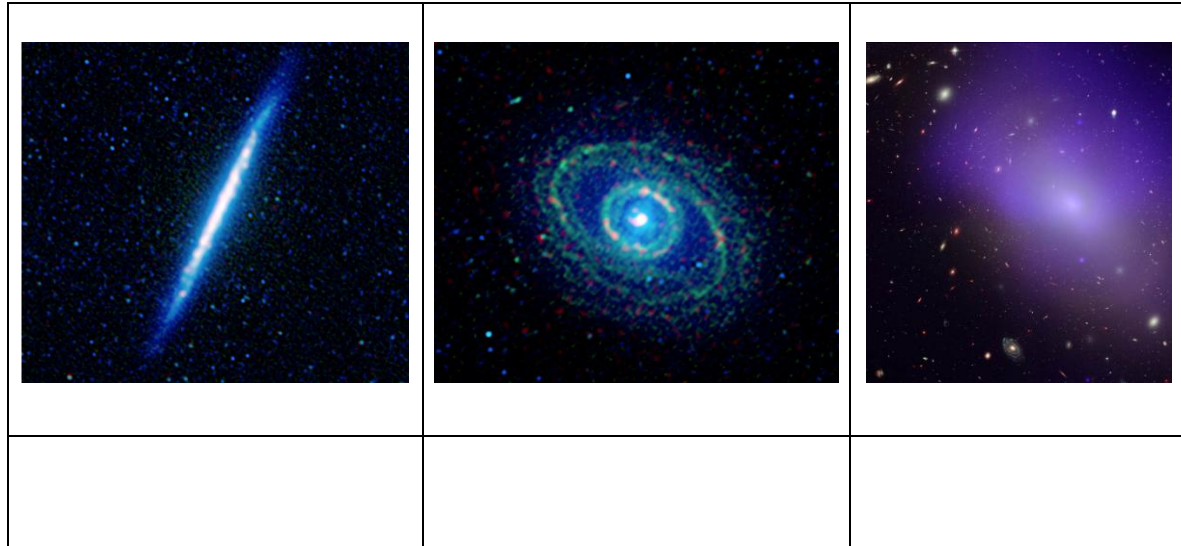
- Star 2:
 - Color: Yellow
 - Surface temperature: 5100 K
 - Luminosity: approximately 75 times brighter than Earth's Sun
 - Where in its life cycle is this star?

- Star 3:
 - Color: White
 - Surface temperature: 9000 K
 - Luminosity: more than 10,000 times brighter than Earth's Sun
 - Where in its life cycle is this star?

- Star 4:
 - Color: Yellow
 - Surface temperature: 6500 K
 - Luminosity: approximately 1,000 times dimmer than Earth's Sun
 - Where in its life cycle is this star?

Part 2: Galaxies:

The photographs below show three galaxies. Which galaxy is spiral, which is elliptical, and which is irregular? Write your answers beneath each photograph.

**Connecting With Your Child: Modeling the Milky Way Galaxy**

Galaxies come in a variety of shapes. Moreover, a galaxy may be viewed from any angle; in each case, the galaxy will look different.

Help your child find images of the Milky Way galaxy as viewed from different angles. You can do an Internet search for these images, or visit a planetarium if one is close by. Allow your child to choose the materials she or he would like to use to construct three-dimensional models of various views of the Milky Way.

After the models are completed, have your child do research to determine the approximate position of our solar system in the Milky Way. Have your child label that position in each model. For example, the label may consist of a toothpick stuck in the appropriate location in a clay model. A paper flag bearing the words “Solar System” might be taped to the top of the toothpick. Encourage your child to display the models in school.

Here are some questions to discuss with your child:

- Where is the central bulge in this view of the Milky Way? Where are the spiral arms?
- Where are Earth and our solar system located in this view of the Milky Way?
- Does the Milky Way appear to be different shapes depending on the angle from which it is viewed?

