Key Terms
dark matter
dark energy

9.3 Unsolved Mysteries

The universe imagined by the ancient Greeks was, by their standards, huge. It contained the entire world—Earth, the Sun, the Moon, the planets, and all the stars. Their estimate of its size, however, was nowhere near the immense size estimated by astronomers today.

Over time, astronomers have revised their view of the universe. First, astronomers included the Milky Way galaxy of an unimaginable size. Then, they expanded their view to include an unknown number of galaxies. Today, astronomers are piecing together the story of the universe—its evolution, age, and size. As you will discover in this section, however, in spite of everything that astronomers have discovered, the universe still holds many mysteries and secrets. One of these mysteries is dark matter, illustrated in **Figure 9.14**.

Dark Matter

The structure of the Andromeda galaxy is similar to the structure of the Milky Way. Thus, astronomers have studied the Andromeda galaxy extensively, hoping to learn more about the Milky Way. By examining the total amount of light that the stars in the Andromeda galaxy emit, astronomers have been able to estimate the total mass of this galaxy with a high degree of confidence. The mass of the Andromeda Galaxy is about the same mass as the Milky Way galaxy.

Figure 9.14 **A** This image, taken by the Hubble Space Telescope, shows a galaxy cluster called Cl 0024+17. **B** This image shows the same galaxy cluster, except there is a blue ring around the cluster. The lighter blue overlay is a computer-generated model that shows where the mysterious dark matter must be.

Dark Matter and the Andromeda Galaxy

Just as the stars in the Milky Way orbit the centre of our galaxy, the stars in the Andromeda galaxy, shown in **Figure 9.15A**, orbit its centre. Using the estimated mass of the Andromeda galaxy, astronomers predicted the speeds of the stars at various distances from its centre. To verify their predictions, astronomers studied the spectra of the stars within the galaxy. Their results were astonishing. The stars are moving much faster than predicted.

One way that astronomers could explain the speed of the stars was by assuming that the galaxy contains about 90 percent more mass than can be accounted for by visible matter. Visible matter is everything that can be seen—all the planets, stars, and galaxies. Astronomers could not see the missing mass. Wherever this mass was located, it did not emit any light. So, the missing mass was at first called *dark matter*. The name was meant to be temporary, but it stuck. Astronomers still refer to the missing mass as dark matter. **Dark matter** is the most abundant form of matter in the universe. Except for the effects that astronomers have observed, dark matter has not been detected. Its true identity is unknown.

dark matter the most abundant form of matter in the universe; invisible to telescopes

The Search for Dark Matter

The search for dark matter has been going on since the 1990s. Its elusiveness is partly due to the fact that it only seems to interact with visible matter through its weak gravitational effects. Because dark matter interacts so weakly, it does not conform to the shape of a spiral galaxy. It seems to form a huge spherical halo around the Andromeda galaxy, as shown in **Figure 9.15B**.

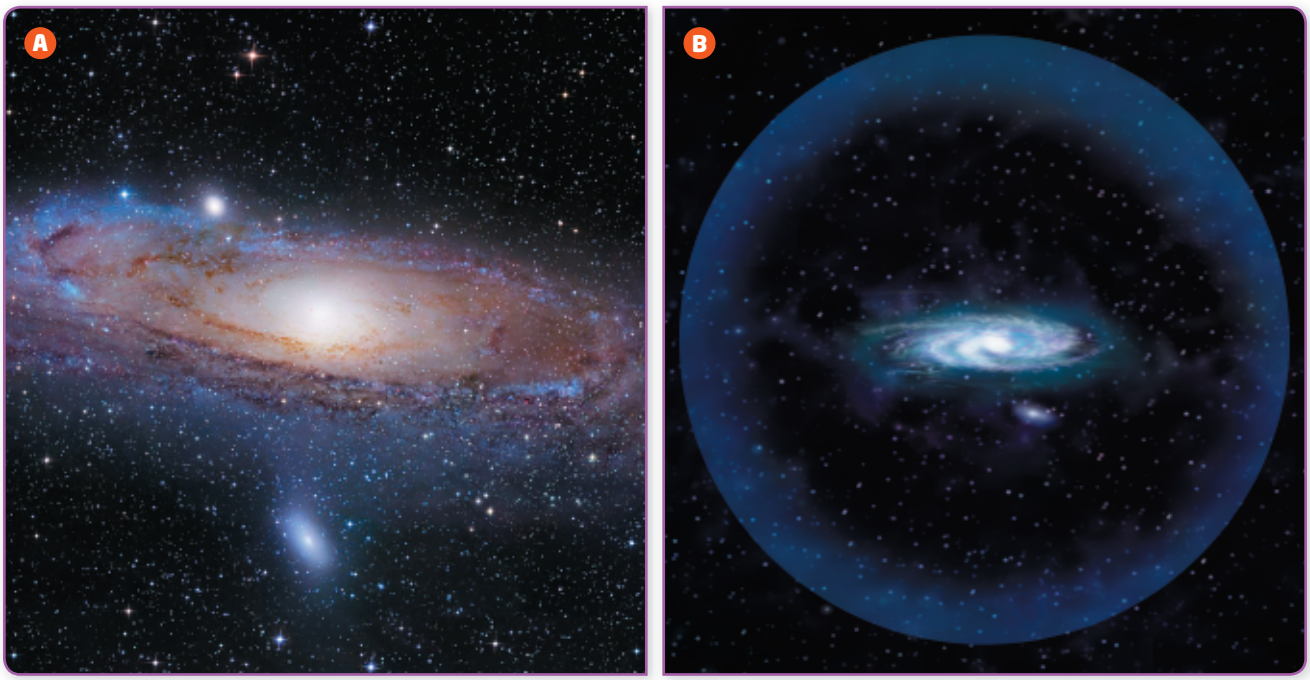


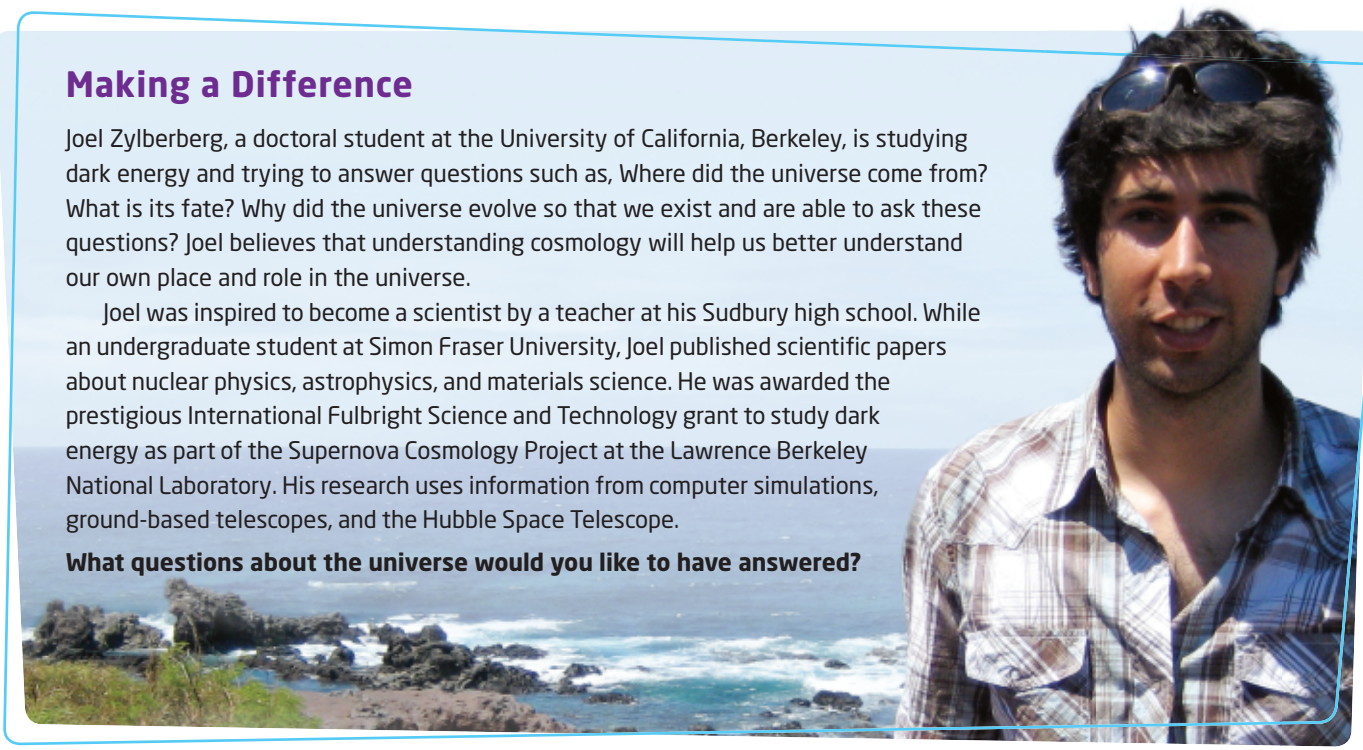
Figure 9.15 **A** The Andromeda galaxy is about 2.5 million light-years from Earth. **B** Astronomers hypothesize that there must be at least eight or nine times more dark matter than visible matter in the Andromeda galaxy.

Making a Difference

Joel Zylberberg, a doctoral student at the University of California, Berkeley, is studying dark energy and trying to answer questions such as, Where did the universe come from? What is its fate? Why did the universe evolve so that we exist and are able to ask these questions? Joel believes that understanding cosmology will help us better understand our own place and role in the universe.

Joel was inspired to become a scientist by a teacher at his Sudbury high school. While an undergraduate student at Simon Fraser University, Joel published scientific papers about nuclear physics, astrophysics, and materials science. He was awarded the prestigious International Fulbright Science and Technology grant to study dark energy as part of the Supernova Cosmology Project at the Lawrence Berkeley National Laboratory. His research uses information from computer simulations, ground-based telescopes, and the Hubble Space Telescope.

What questions about the universe would you like to have answered?



Dark Matter and the Milky Way Galaxy

The hypothesis about the halo of dark matter around the Andromeda galaxy led astronomers to wonder if the Milky Way galaxy is also sitting in the centre of a huge halo of dark matter. They think that it is. One clue comes from the motion of the galaxies within the Local Group. Astronomers have estimated the mass of the Milky Way to be about 200 billion solar masses. Yet the motion of small, nearby galaxies that are orbiting the Milky Way indicates that the mass of the Milky Way is at least 10 times larger than the estimated mass. This means that only 10 percent of the Milky Way is made of visible matter.

When astronomers study other galaxies that are in groups or clusters, they find that the motion of the galaxies can only be accounted for by assuming that the galaxies are surrounded by huge halos of dark matter. Visible matter makes up only 4 percent of the universe. Astronomers theorize that dark matter makes up about 23 percent of the universe, nearly six times more than visible matter. As described on the next page, dark energy makes up the rest of the universe.

Go to **scienceontario** to find out more

Learning Check

1. What is dark matter?
2. Why do astronomers study the Andromeda galaxy?
3. Review **Figure 9.14**. What does the lighter blue overlay represent?
4. Why do you think understanding dark matter is important to astronomers when they make models of the structure of the universe?

Dark Energy

At the end of the 20th century, astronomers were observing light from extremely bright Type Ia supernovae, like the one shown in **Figure 9.16**. Type Ia supernovae are explosions of white dwarf stars. The absolute magnitudes of Type Ia supernovae are well known and quite reliable. Astronomers plotted their absolute magnitudes against their redshifts and got quite a shock. The Type Ia supernovae were too faint. That is, the supernovae were farther away than astronomers had inferred.

Astronomers had predicted that, after the big bang, the expansion of the universe should be gradually slowing down under the influence of gravity. But the Type Ia supernovae data show that the expansion of the universe began accelerating about 7 billion years ago and continues to accelerate. For some reason, something began to overcome the effects of gravity that was originally slowing the expansion and is now causing the rate of expansion to increase. Without understanding the cause of this "anti-gravity" effect, scientists have simply called it **dark energy** to reflect its elusive and mysterious nature. Dark energy makes up 73 percent of the entire universe. Although it now has a name, astronomers do not understand its real nature.

dark energy a form of energy that makes up nearly three quarters of the universe; has the effect of increasing the expansion of the universe

Sense of place

Earth, the sky, and the stars constituted the entire universe of the early sky watchers. Today, we know that we inhabit a rock that orbits an average star, in one of hundreds of billions galaxies in an expanding universe. What do you think our place in the universe is?

Figure 9.16 The Type Ia supernova is the bright object at the lower left of the galaxy. Details of this supernova led scientists to hypothesize the existence of dark energy.

Section 9.3 Review

Section Summary

- The motions of stars and galaxies within clusters indicate that there are huge amounts of unseen matter, called dark matter, around each galaxy.
- Dark matter makes up about 23 percent of the universe—nearly six times more than visible matter.
- Dark energy makes up about 73 percent of the universe. Astronomers theorize that dark energy is responsible for the increased expansion of the universe.

Review Questions

T/I **1.** Draw a pie graph showing the breakdown of dark matter, visible matter, and dark energy in the universe. Give your graph a title.

K/U **2.** Why do astronomers think there is dark matter in the universe?

K/U **3.** What evidence do astronomers have for the existence of dark matter?

K/U **4.** Compared with visible matter, how much dark matter do scientists predict to be in the universe?

T/I **5.** In images such as the one shown below, the dark matter is added by an artist or it is generated by computer.

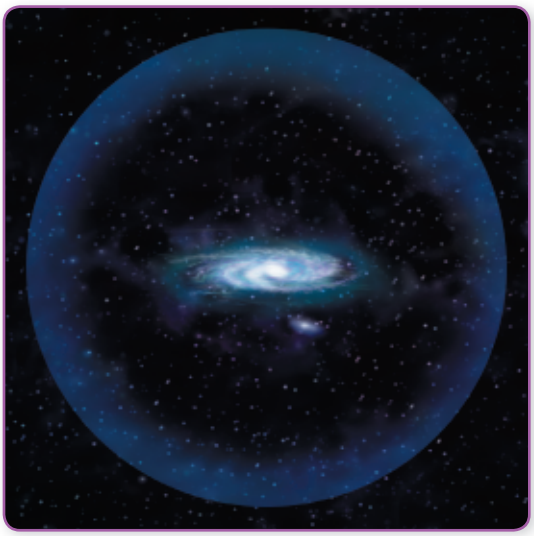
a. With the variety of telescopes that can detect different parts of the electromagnetic spectrum, why can astronomers not take an image of the dark matter around a galaxy? Explain your answer.

b. Why is dark matter shown as a halo around a galaxy? Explain your answer.

K/U **6.** Why do astronomers theorize that there is dark energy in the universe?

T/I **7.** How would the brightness of Type Ia supernovae observed at large redshifts have appeared to astronomers if there were no dark energy?

T/I **8.** Dark energy makes up most of the universe, yet its effects were not detected until the late 1990s. Suggest a reason why its effects were undetected for so long.



This is a computer-generated image of dark matter around the Andromeda galaxy.