LESSON 2 What Lies Beyond

Quick Write

What other example can you give, either in history or from your own life, of an important discovery made during the search for something else?

Learn About

- other galaxies and their classifications
- five types of space objects
- the electromagnetic spectrum
- the big bang theory

In 1967 Jocelyn Bell (later Burnell) was a graduate student at Cambridge University, looking for quasars—extremely distant starlike objects giving off enormous waves of energy. But she ended up finding something else instead: pulsars, a kind of pulsating radio source.

The first sign of what would turn out to be a new discovery appeared as merely "noise" in the data. As she wrote afterward, "Six or eights weeks after starting the survey, I became aware that on occasions there was a bit of 'scruff' on the records, which did not look exactly like a scintillating source, and yet did not look exactly like man-made interference either."

It's been said that the most critical moments in science are not the times of textbook-perfect lab data, or of great flashes of inspiration, but the moment when someone thinks, "Hmm, that's funny. . . ."

Other Galaxies and Their Classifications

In the early twentieth century, scientists were trying to make sense of something astronomers had discovered in the late 1700s, but whose nature had remained a mystery: the so-called spiral nebula—nebulae, in the plural. At Mount Wilson Observatory in California, Adriaan van Maanen was convinced that these nebulae were vast clouds of gas. But in 1924 Edwin Hubble proved conclusively that they were separate galaxies like the Milky Way Galaxy.

That fact established, Hubble began a serious study of galaxies. As is common in science, his first steps were observation and classification. When scientists come to a group of objects about which they know little or nothing, they typically respond by observing them and grouping them into classes on the basis of what they note about them.

Vocabulary

- barred spiral galaxy
- variable star
- lenticular galaxy
- elliptical galaxy
- irregular galaxy
- apparent magnitude
- luminosity
- proper motion
- optical double
- fluorescence
- emission nebula
- reflection nebula
- dark nebula
- missing mass
- dark matter
- dark energy
- electromagnetic spectrum
- big bang

The Three Types of Galaxies

Hubble's own scheme for classifying galaxies became the basis for the one still used today. He divided galaxies into three major groups: *spiral*, *elliptical*, and *irregular*. Each of these groups has subdivisions. More recently, astronomers have discovered objects too peculiar even to qualify as "irregular."

The Characteristics of Spiral Galaxies

A spiral galaxy, which you first read about in Chapter 4, Lesson 1, is a disk-shaped galaxy with arms in a spiral pattern. Hubble divided galaxies of this group into two smaller groups: ordinary spiral galaxies and barred spiral galaxies. A barred spiral galaxy is *a spiral galaxy in which the spiral arms come from the ends of a bar through the nucleus, rather than from the nucleus itself*. Astronomers designate ordinary spirals with a capital S. They mark barred spirals with an SB. The Milky Way is a barred spiral galaxy.

Science further subdivides both groups into groups a, b, and c, depending on how tightly their arms wrap around their nucleus. The more tightly wound galaxies have the most prominent nuclear bulges. Galaxies designated "c" tend to have more gas and dust than those designated "a."

The Man Who Expanded the Universe

Edwin Hubble (1889–1953) entered the University of Chicago at 16. He studied law after he won a Rhodes scholarship to the University of Oxford in England. By his mid-20s, though, he had settled on astronomy. He began graduate study at the Yerkes Observatory in Wisconsin. Early in his time there, he heard a presentation by Vesto M. Slipher on a hot topic of the day: whether spiral nebulae were part of the Milky Way or separate galaxies in their own right. Slipher presented data that pointed in the latter direction. The question remained open, however.

Soon after, Hubble, perhaps inspired by Slipher's talk, started photographing nebulae with the 24-inch reflecting telescope at the observatory. His doctoral thesis grew out of this research. It was leading him to the conclusion that the nebulae were outside the galaxy.

World War I interrupted his work, though. He enlisted three days after receiving his PhD, although the Armistice was declared before his division reached Europe.

After the war he went back to his research. By 1924 he observed the Andromeda "nebula" and identified six distinct variable stars within it. A variable star is *a star that appears to brighten or dim either because of changes going on within the star itself or because something has moved between it and an observer on Earth*. Hubble's calculations weren't exact—they were off by a factor of more than two. But he showed that the nebulae he had studied were too far away to be within the Milky Way Galaxy's known limits.

Edwin Hubble (1889–1953)

Courtesy of California Institute of Technology

Soon after this, Hubble started investigating the idea that the universe is expanding. In 1929 he published a paper stating what's known as the Hubble law of redshifts. It indicates that the universe is expanding because the velocities of galaxies increase at increasing distances from any chosen point. Hubble's work has influenced other astronomers and, in fact, scientists named the famed Hubble Space Telescope after him.

This photo shows an example of an ordinary spiral galaxy, M77, in the constellation Cetus.
Courtesy of NOAO/AURA/NSF

This photo shows an example of a barred spiral galaxy known as NGC1365, about 60 million light-years from the Milky Way. Note the horizontal bar through the nucleus. The two prominent arms stem from either end of the bar, rather than directly from the nucleus.
Courtesy of Todd Boroson/NOAO/AURA/NSF

About two-thirds of spiral galaxies have bars. A few seem to have the nuclear bulge and disk of a spiral galaxy, but no arms. Hubble called these lenticular galaxies. A lenticular galaxy is *a galaxy with a flat disk like a spiral galaxy, but with little spiral structure, and a large bulge in the nucleus*. Lenticular means shaped like a lens. Hubble designated such galaxies as S0.

The Characteristics of Elliptical Galaxies

An elliptical galaxy is *a galaxy with a smooth spheroidal shape*. That is, round but not perfectly round.

Astronomers classify elliptical galaxies by their degree of eccentricity. But it's hard to tell from Earth just what the shape of a given galaxy is. Is it extremely eccentric—or is it just the angle from which people on Earth are viewing it? Because scientists can't really answer that question with the current level of technology, science classifies elliptical galaxies according to how they appear from Earth, from round (E0) to very elongated (E7).

This photo shows M59, a type E5 elliptical galaxy in the constellation Virgo.
Courtesy of NOAO/AURA/NSF

The Large Magellanic Cloud, the second-nearest galaxy to the Milky Way at only 160,000 light-years away, is generally classified as an irregular galaxy. It is visible primarily in the Southern Hemisphere.

Courtesy of NOAO/AURA/NSF

The Characteristics of Irregular Galaxies

An **irregular galaxy** is *a galaxy of irregular shape that cannot be classified as spiral or elliptical*. Fewer than one-fifth of all galaxies fall into this group. They tend to be small, with normally fewer than 25 percent as many stars as are in the Milky Way.

The Magellanic Clouds are usually classified as irregular galaxies. Some astronomers, however, think the Large Magellanic Cloud is a barred spiral that has been disrupted by being so close to the Milky Way—and perhaps by a past collision with the Small Magellanic Cloud.

Scientists calculate that collisions between galaxies are not unusual because relatively small distances separate them—only 20 times their diameter. Stars *within* a galaxy, on the other hand, are relatively farther apart when their much smaller diameters are taken into account. This leads to few collisions between individual stars. When galaxies collide, they actually pass through each other or merge—at least, this is what computer simulations suggest. The distances involved are so great and the apparent motions so small that scientists have to rely on simulations rather than direct observation.

Five Types of Space Objects

Galaxies are made up of many objects, which have different properties. These objects, along with the galaxies themselves, are in constant motion. Human beings have known about some of these objects, such as stars, since they first looked at the night sky. Others have only recently been discovered. This section will discuss five types:

1. Stars—specifically their brightness, luminosity, and motion
2. Optical doubles and binary star systems
3. Interstellar clouds and nebulae
4. Pulsars
5. Dark matter.

The Brightness, Luminosity, and Motions of the Stars

Earlier in this lesson you read about the classes of galaxies based on a system Edwin Hubble devised in the twentieth century. The system for classifying stars goes back to the ancient Greeks. The astronomer Hipparchus, who lived in the second century BC, compiled a list of some 850 stars and put them into six groups, according to their brightness. First-magnitude stars were the brightest. Sixth-magnitude stars were the dimmest. Today's astronomers can use photographic and electronic techniques to measure brightness. But they still use a version of Hipparchus's system.

In discussing the brightness of a star, it's important to distinguish between its apparent brightness and the energy it actually emits. Scientists call a star's apparent brightness apparent magnitude. This is *the amount of light received from a celestial object*. Apparent magnitude depends partly on how far away the star is from Earth and on Earth's position in the galaxy. This measure contrasts with luminosity—*the rate at which electromagnetic energy is emitted from a celestial object*. That is, luminosity measures how much energy a star releases, rather than how bright it appears from Earth (apparent magnitude).

Motions of the Stars

Everything in the universe is moving, and that includes the stars. You may occasionally hear people speak of "fixed stars"—as if they were permanently attached somewhere. (That's what "fixed" means in this sense.) The stars do move relative to the Solar System, but they do so very slowly, which makes them appear fixed in place. Thus, the constellations known to the ancients have retained their shape to the present day. The star we identify as the North Star is the same one people identified 2,100 years ago. In 1718, however, Edmund Halley discovered that stars also move with respect to one another. That means that constellations do change shape over time. The North Star (Polaris) has, in fact, moved closer to true north than it was in the year 1 AD.

Star POINTS

Remember that the constellations are stars that appear to be grouped together when seen from Earth. If you could look at the same stars from a different vantage point, the pattern would be completely different.

Barnard's star is one of the closest stars to the Sun. It shows the greatest motion as observed from Earth. Proper motion is the term for *the angular velocity of a star as measured from the Sun*. (*Proper* in this sense means the motion that actually "belongs to" a star, as property is something that "belongs to" someone.) Proper motion is opposed to *observed* motion that is due to Earth's movement.

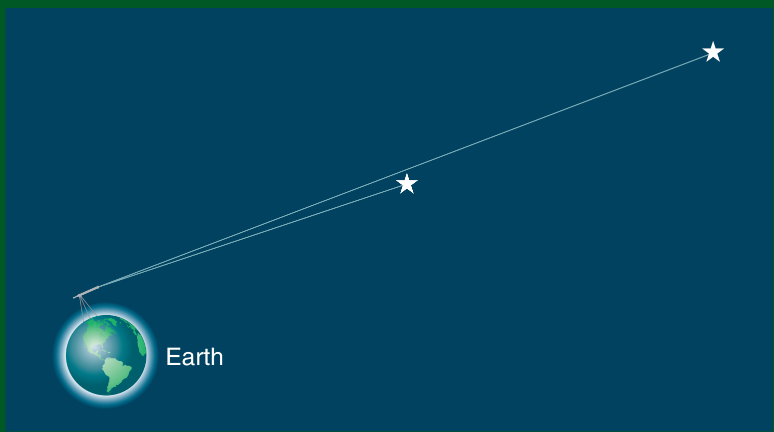
As stars go, Barnard's moves pretty fast. The arrows in the two pictures show Barnard's star at two different points more than 20 years apart. Each photo covers a section of the sky about one degree across. The full Moon appearing in either picture would cover about half the width of the image.
Courtesy of Yerkes Observatory

Optical Doubles and Binary Star Systems

In Chapter 4, Lesson 1, you read about binary star systems: systems of two stars gravitationally bound so that they orbit one another around a common center. Over time astronomers have come to see these as much more common than they used to think. Now they believe that more than half of what appear to be single stars are actually multiples of two or more stars.

There's an important distinction between true binaries, or other multiples, and so-called optical doubles. An optical double is *two stars that, from Earth, appear to be very close but are not actually gravitationally bound*. As the (not-to-scale) drawing in Figure 2.1 suggests, the apparent closeness may be a matter of sightlines.

Figure 2.1 This drawing illustrates how two stars some distance apart may appear to an observer on Earth to be a binary.



To put it in human terms: An optical double is like two trees in a field, one close to you, the other at the field's far end. If both trees are in your line of sight, they may *appear* to be close together from your perspective when in fact they are far apart and unrelated.

Interstellar Clouds and Nebulae

The dust and gas of the galaxies are not spread evenly around. They tend to clump together and form into interstellar clouds. Astronomers describe these clouds with a term borrowed from weather science: cirrus clouds. Cirrus clouds on Earth are the thin wispy kind, made up mostly of ice crystals. Interstellar cirrus clouds are even wispier than their counterparts on Earth. They spread over vast distances. Scientists reckon the total mass of one of them might be equivalent to that of a small-to-average star.

Scientists have classified three types of interstellar clouds, or nebulae. If a cloud is near a hot star, the ultraviolet radiation from the star causes the cloud to fluoresce. **Fluorescence** is *the process of absorbing radiation of one frequency and re-emitting it at a lower frequency*. An **emission nebula** is *a cloud of interstellar gas receiving ultraviolet radiation and fluorescing as visible light*.

A **reflection nebula** is *a cloud of interstellar dust that becomes visible because it refracts and reflects light from a nearby star*. A **dark nebula** is *an interstellar molecular cloud whose dust blocks light from stars on the other side of it*.

Star POINTS

Interstellar material is in a constant state of flux. New stars use it up by including the material as the star is born, whereas dying stars replenish it.

This image illustrates two phenomena at once.

Just left of center it shows a bright young star, which lights up the reflection nebula NGC 1999 in the constellation Orion. To the right in the photo, and in front of NGC 1999, is a dark nebula blocking the star's light. A dark nebula is a condensation of cold molecular gas and dust so thick that it blocks light.

Courtesy of Hubble Heritage Team (STScI)/NASA

The Discovery of Pulsars

As you read earlier in this lesson, Jocelyn Bell was a graduate student who stumbled upon pulsars in 1967 while searching for quasars—small, intense celestial sources of radiation with a very large redshift. The radio telescope she was using had no giant dish. Rather, it looked more like a field of clotheslines. Its purpose was to pick up faint radio sources and see quick changes in their energy.

Soon she was picking up an unexpected, and unexplained, new source of radio waves. The signal pulsed rapidly every 1.3 seconds. This was much faster than any stellar source had previously been known to pulsate. So she and her team thought the signal perhaps had a terrestrial source, and wasn't really from outer space after all. But a check of local radio transmitters failed to turn up any that could be the source of the signal.

What's more, they picked up the signal four minutes earlier each night. They knew that any given star sets four minutes earlier each night because of the way the Earth moves around the Sun. So the researchers concluded that the signal was coming from outer space, with no human source.

Was it a signal from some extraterrestrial beings? That was the next tantalizing possibility to consider. In fact, the researchers referred to the source as "LGM"—for "Little Green Men," a reference to the way the extraterrestrials of science fiction are sometimes known.

But the pulsations continued in a very regular fashion. A message from space aliens would have some variety in its tones—something like the dots and dashes of Morse code, the researchers reasoned. That made them think the signal wasn't a message.

More convincing, however, was that Bell had soon identified three more signals. One message from an alien race was going to be a stretch. Four extraterrestrial civilizations trying to contact Earth at the same time was beyond belief. The "LGM" soon had a new name: pulsar. As you read in Chapter 4, Lesson 1, a pulsar is a pulsating radio source with a regular period, between a millisecond and a few seconds, believed to be associated with a rapidly rotating neutron star. A neutron star is one that, in essence, has collapsed.

Theories About Dark Matter in Space

Astronomers have several ways to measure the mass of galaxies. All are limited in precision, primarily because the distances involved are so great. Scientists can't wait for even a piece of a galaxy to complete a revolution. Instead, they use Doppler shift data to reach some conclusions about the speed of part of a galaxy, and combine what they find with Kepler's law to come up with an estimate of the mass of the part of the galaxy they are studying. Despite the lack of pinpoint accuracy, though, astronomers do have some ideas about the mass they're dealing with.

Sisterhood of the Telescopes

Up to this point, you've read about the contributions of male scientists to our understanding of the universe. But going back at least to the eighteenth century, women have made important contributions, too. As you read in Chapter 4, Lesson 1, Caroline Herschel worked with her brother William in efforts to understand the shape of the Milky Way Galaxy and to locate the Sun in it. She discovered eight comets and was one of the first two women elected to honorary membership in Britain's Royal Astronomical Society.

Annie J. Cannon was a member of the Harvard College Observatory for almost 50 years.

Courtesy of Harvard College Observatory

Maria (pronounced ma-RYE-a) Mitchell (1818–1889) learned astronomy from her schoolteacher father and her readings while she worked as a librarian. In 1847 she discovered a comet while observing the sky from her rooftop. This led to her becoming the first woman elected to the American Academy of Arts and Sciences.

Henrietta Leavitt

Courtesy of Harvard College Observatory

Mitchell later taught astronomy at the newly established Vassar College. One of her students, Antonia Maury (1866–1952), went on to become one of a trio of notable women astronomers at Harvard College Observatory, along with Annie Jump Cannon (1863–1941) and Henrietta Leavitt (1868–1921).

In fact, the observatory's director, Edward Pickering, hired a group of some 40 women to work there, starting in the 1880s. Many people at that time still saw science as an inappropriate field for women. Pickering, for his part, was apparently motivated less by progressive principles than by the idea that women would probably work for less money than men.

In fact, the big issue in all these galactic calculations is what scientists call "missing mass." Remember what you read in Chapter 4, Lesson 1: Scientists see more pulling and tugging going on in the heavens than they can readily explain in terms of the celestial objects they can see.

Missing mass is *the difference between the mass of clusters of galaxies as calculated from Keplerian motions and the amount of visible mass*. Scientists know there must be something "out there" to account for all that mass. They just don't know what it is. By one reckoning, this amounts to 80 percent of the "ordinary matter" of the universe. Dark matter is the scientists' term for *matter that can be detected only by its gravitational interactions*. It makes up 20 percent of the universe, while normal matter makes up only 4 percent.

Astronomers are trying to understand dark matter better. They've offered several ideas to explain what it might consist of:

Ordinary nonluminous matter: Common examples include white dwarf stars, which no longer generate their own energy; brown dwarfs, which have never generated enough light to be easily observable; or planets, meteors, comets, and interstellar dust clouds.

Hot dark matter: This refers primarily to neutrinos. Even if these particles have only a small amount of mass, as experiments suggest, so many of them travel at high speeds around the universe that they could account for much of the missing mass.

Black holes: These come in all sizes, and astronomers speculate that they could contribute to the dark matter.

Cold dark matter: This is the term for a group of particles whose existence theories suggest must be there, but which scientists have not yet detected. These particles go by the name of *photinos*, *axions*, or *neutralinos*. The idea is that these particles are moving through space relatively slowly, in contrast with the way that "hot" neutrinos zip around the universe.

Along with dark matter in space is a force scientists call dark energy. This is *an exotic form of energy whose negative pressure speeds up the expansion of the universe*. Dark energy makes up about 70 percent of the universe.

Star POINTS

Astronomer Vera Rubin had a few words about missing mass. She said, "Nature has played a trick on astronomers. We thought we were studying the universe; now we know we are studying only the small fraction that is luminous."

Scientists are trying to understand the mystery of dark energy, because the fate of the universe depends on it. If the universe expands forever, the Solar System will slowly lose contact with the rest of the universe beyond the local supercluster of stars. If the strength of dark energy decreases with time or becomes attractive, gravity could lead to a big collapse into an incredibly dense ball. If dark energy gets stronger with time, it will eventually overcome all other forces and lead to a big rip, tearing apart everything in the universe.

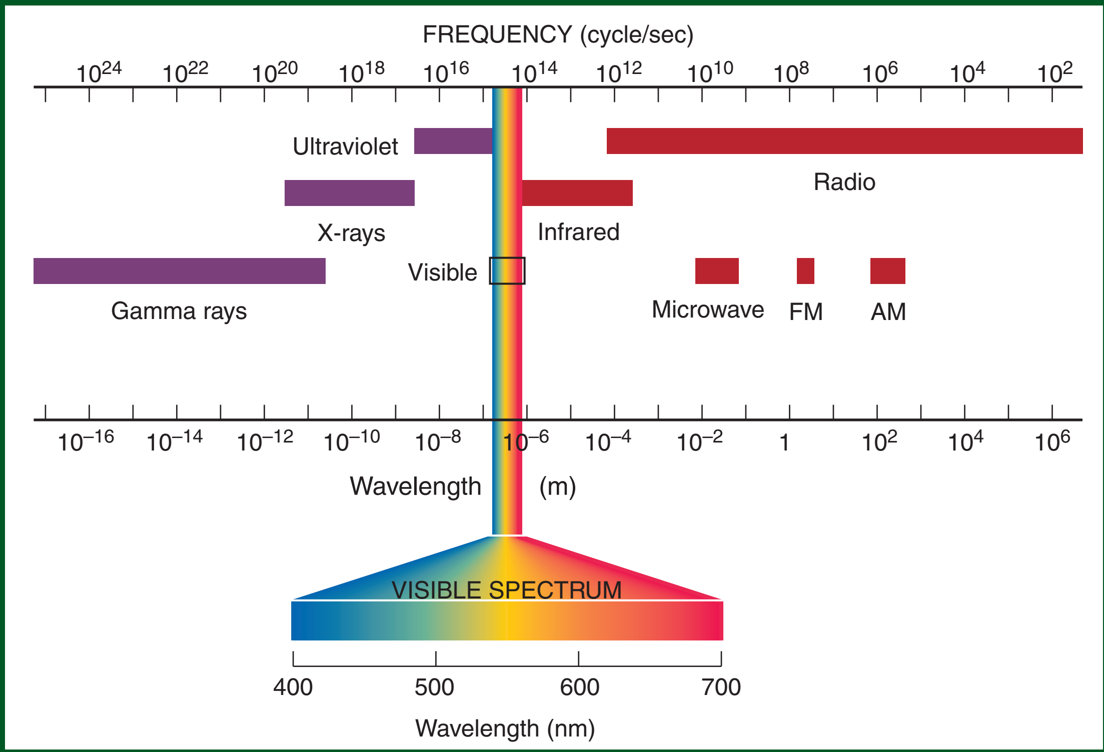


Figure 2.2 This chart shows the range of the electromagnetic spectrum, from gamma rays to radio waves.

The Electromagnetic Spectrum

Astronomers can't see dark matter with their eyes, although they can study its effects using instruments. They also can't see a large part of the electromagnetic spectrum, which affects people here on Earth every day. The electromagnetic spectrum is *the entire array of electromagnetic waves*. All the light you can see—visible light—consists of waves. Visible light takes up only a relatively narrow slice in the middle of the spectrum, however. Many other types of waves and rays exist besides visible light (Figure 2.2).

The Types of Electromagnetic Waves

The electromagnetic spectrum ranges from gamma rays, X-rays, and ultraviolet waves on through visible light and then infrared radiation and various forms of radio waves, including FM and AM. But all these waves are essentially the same phenomenon. They differ in wavelength, so they differ in properties. But they are all waves, and they do many useful things for people. This includes sending messages of all kinds, such as cell phone calls and television programs.

Star POINTS

The wavelength of visible light ranges from 400 nanometers (violet) to 700 nanometers (red). A nanometer equals 10^{-9} meter. On a linear scale, visible light makes up a mere 0.0035 percent of the electromagnetic spectrum.

Wavelengths are directly related to energy levels. The greater an object's energy, the shorter the wavelength. Radio waves result from far less energy than do gamma rays at the other end of the spectrum.

Astronomers are interested in electromagnetic waves because celestial objects emit waves up and down the spectrum. Visible light is only part of the story. Space scientists learn a great deal from the invisible radiation celestial objects emit.

The Atmospheric Absorption of Wavelengths

Most of this radiation does not pass well through air. Therefore it does not reach Earth's surface. Visible light and part of the radio spectrum are the exception. They can cut through the atmosphere. But the atmosphere blocks most of the rest of the electromagnetic spectrum to some degree.

In some cases, this blockage is a good thing. Ultraviolet radiation, for instance, kills living cells (including your skin cells), so it's good that not much gets through. Astronomers, however, are interested in picking up all kinds of radiation from outer space. They can get above enough of the Earth's atmosphere on mountaintop observatories and in aircraft to study some of the infrared spectrum. And they send up balloons and satellites to get instruments well up into the atmosphere, or even beyond it.

The Big Bang Theory

Waves and rays allow mankind to transmit messages to one another, just as information gathered from the study of space imparts messages to astronomers about Earth, the Milky Way Galaxy, and what lies beyond. These messages include answers about the universe's beginnings.

The motion of the galaxies has led scientists to think there was a time when all the matter in the universe must have been packed closely together. As they ran the imaginary "movie" of the universe's expansion backward in their minds, they decided an initial explosion must have jump-started that expansion. The big bang is *the theoretical initial explosion that began the universe's expansion*.

Understanding the Big Bang

In trying to understand the big bang, you must be careful not to think of the material of the big bang as being at a certain place in the universe. It *was* the universe—the whole thing.

The big bang represents the highest concentration of energy ever reached in the history of the universe. After the initial explosion, the steady cooling of the universe allowed nuclear particles to form into atoms of low mass (hydrogen and helium). These atoms then clustered into stars, clusters of stars, galaxies, and clusters of galaxies. The clusters of galaxies are still moving apart.

The Prediction and Discovery of Cosmic Background Radiation

The evidence for the expansion of the universe was what led to the idea of the big bang. But scientists have to consider: What evidence is there to support the theory? The first evidence was found quite by accident when a prediction made earlier—by two independent groups of people—was found to be correct.

As scientists learned more about nuclear processes in the 1940s, they began to form some idea of what the universe was like shortly after the big bang. The material of the big bang was originally extremely hot. But it cooled as it expanded outward. And once it cooled to about 3,000 K, it became transparent to radiation—in other words, radiation could pass through unblocked. The universe has remained transparent to radiation since that time, and so scientists proposed that this radiation should still exist. If this radiation were detectable, it would be coming from far back in time and therefore from a great distance.

Star POINTS

K stands for kelvin, which is a way to measure temperatures down to what's called absolute zero, where energy is as low as it will go. The science community often relies on the Kelvin scale, named for Scottish scientist William Thomson, Lord Kelvin.

In 1948 scientists theorized that this cosmic microwave background radiation (CMB) would be striking Earth from all directions but that it should be very faint. At the time, scientists couldn't test the idea because they hadn't yet invented a way to detect such weak waves. So the idea was set aside temporarily.

Then in the mid-1960s some Princeton University physicists were studying the big bang. Once again, they posited the idea of CMB radiation—unaware others had already proposed the idea 15 years before. This group was confident they could build a radio receiver to detect the radiation, and they set about putting it together.

But they were too late. Coincidentally, just a few miles up the road at Bell Telephone Laboratories, Arno Penzias and Robert Wilson were doing some applied research on microwave transmission. They wanted to improve message transmission. They were frustrated, though, by some low-intensity radio waves reaching their receiver from all directions.

It was the CMB radiation predicted years before, as well as by the Princeton physicists, on the basis of the big bang theory. Penzias and Wilson won the Nobel Prize in 1978 for their discovery of something they were not looking for and of whose larger implications they were unaware. Their discovery established the big bang theory as the accepted explanation for the beginning of the universe.

Other Evidence for the Big Bang Theory

The big bang theory is the best current model for the universe's beginnings. In addition to the CMB radiation, other evidence supports it. The darkness of the night sky is another argument for a universe that had a starting point. The sky is dark at night because the universe is finite—limited—in size and age. A finite universe doesn't have enough stars to light up all of space. Hubble's findings about the expanding universe support the big bang theory as well.

The observed proportions of light chemical elements (deuterium, helium, and lithium) are consistent with the big bang theory. These proportions are consistent with a process of nuclear fusion in the first few minutes of a hot young universe.

As scientists continue to explore the universe's origins, they may find more supporting evidence for the big bang theory. Who knows what other discoveries they may make as well. As you've read, some of the most surprising scientific revelations over the years have been the most unexpected. The future should only grow more fascinating.

CHECK POINTS

Lesson 2 Review

Using complete sentences, answer the following questions on a sheet of paper.

1. What became of Hubble's system of classifying galaxies?
2. What is a lenticular galaxy?
3. How does science classify elliptical galaxies?
4. Why do scientists think that collisions between galaxies are not unusual?
5. Who was Hipparchus, and how did he contribute to scientists' understanding of the brightness of stars?
6. What is an optical double?
7. What is the difference between a reflection nebula and a dark nebula?
8. When Jocelyn Bell and her Cambridge University colleagues were trying to figure out the source of an unexplained pulsating radio signal, why was it significant that they detected the signal four minutes earlier each night?
9. What is "missing mass"?
10. Why are astronomers interested in electromagnetic waves?
11. Which types of electromagnetic waves can cut through Earth's atmosphere?
12. After the big bang's initial explosion, what did the steady cooling of the universe allow to happen?
13. What prediction did scientists make in 1948 that would lead to confirmation of the big bang theory?
14. How do the observed proportions of light chemical elements support the big bang theory?

APPLYING YOUR LEARNING

15. Explain why you think the big bang theory is difficult for people to understand.