PART II

WHAT KIND OF UNIVERSE EXISTS?

THIS SECTION EXPLORES THE CURRENT SCIENTIFIC THOUGHT ABOUT cosmology in relation to the Christian doctrines of creation, revelation, and incarnation. The question of worldview emerges as a dominant issue which has a profound impact on broad culture. In this light, alternate worldviews from Islam, Hinduism, Buddhism, Tao, and Shintoism will be introduced to illustrate how a worldview affects both science and religion.

When science shifted from the study of the universe as it is (cosmology) to the origins of the universe (cosmogony), then the biblical accounts of creation came into question. Since the Renaissance, theologians have read the creation accounts as science. Important issues in this discussion include the meaning of "light" and the meaning of "time" in the creation accounts. The creation accounts not only describe what kind of universe exists but also, more importantly, what kind of God exists. The Christian ideas of "revelation" and "incarnation" depend upon the existence of a Creator.

CHAPTER FOUR

ORIGIN AND STRUCTURE OF THE UNIVERSE

PEOPLE HAVE ALWAYS BEEN INTERESTED IN THE STRUCTURE (*cosmology*) and origin (*cosmogony*) of the universe. Most Western models have been *static*—either an earth- or sun-centered machine that repeats its cycle annually and endlessly. These models gave no clue to the universe's origin; the universe they portrayed was the same yesterday, today, and tomorrow. Only in the twentieth century has a *dynamic* view emerged. The Big Bang model involves cosmogony which states that the universe began with a singularity as well as a dynamic cosmology which states that the universe is expanding.

Cosmology at the End of the Nineteenth Century

At the end of the nineteenth century, astronomers would have presented the following model of the universe. The cosmology or structure of the universe consisted of the Milky Way galaxy with the sun at the center of the galaxy.

Static Universe

This is a static system which provides no cosmogonical information about its origin or even if it had an origin. Ideas that went into forming this static view of the universe can be traced all the way back to ancient Greece. From Aristotle (384–322 B.C.) came the idea of a static universe, although his was *geocentric* or earth-centered with circular orbits for the moon, sun, planets, and stars. The final form of this model was developed by Ptolemy (c. 100–c.165 A.D.) (see Fig. 4.1). Aristotle also proposed a universe

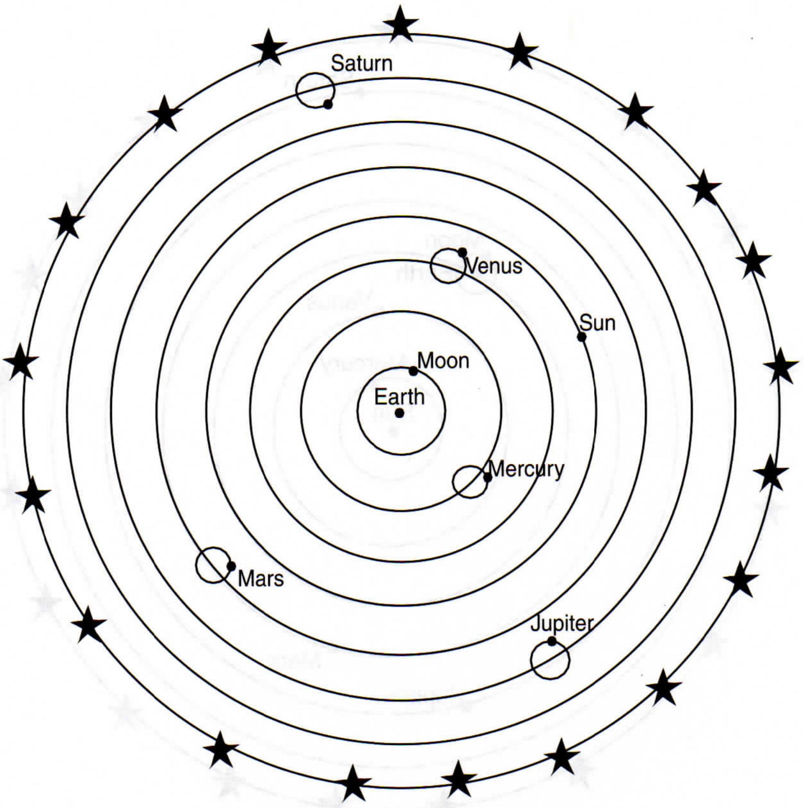


Fig. 4.1. The Ptolemaic or Earth-Centered Model of the Universe.

with no beginning. He also believed that the earth and the heavens were fundamentally different; the earth underwent change, while the heavens were perfect and changeless. When Aristotle's writings were reintroduced into the West in the twelfth and thirteenth centuries, Thomas Aquinas (1225–74) incorporated the Aristotelian model into the prevailing Christian worldview by proposing that God had created the universe *ex nihilio* (out of nothing) and that God was needed to maintain the creation.

The Polish astronomer Nicolaus Copernicus (1473–1543) proposed that the sun was the center of the universe (see Fig. 4.2). The German astronomer Johannes Kepler (1571–1630) discovered that the planets orbit the sun in elliptical orbits (see Fig. 4.3). The English mathematician and physicist Isaac Newton (1642–1727)

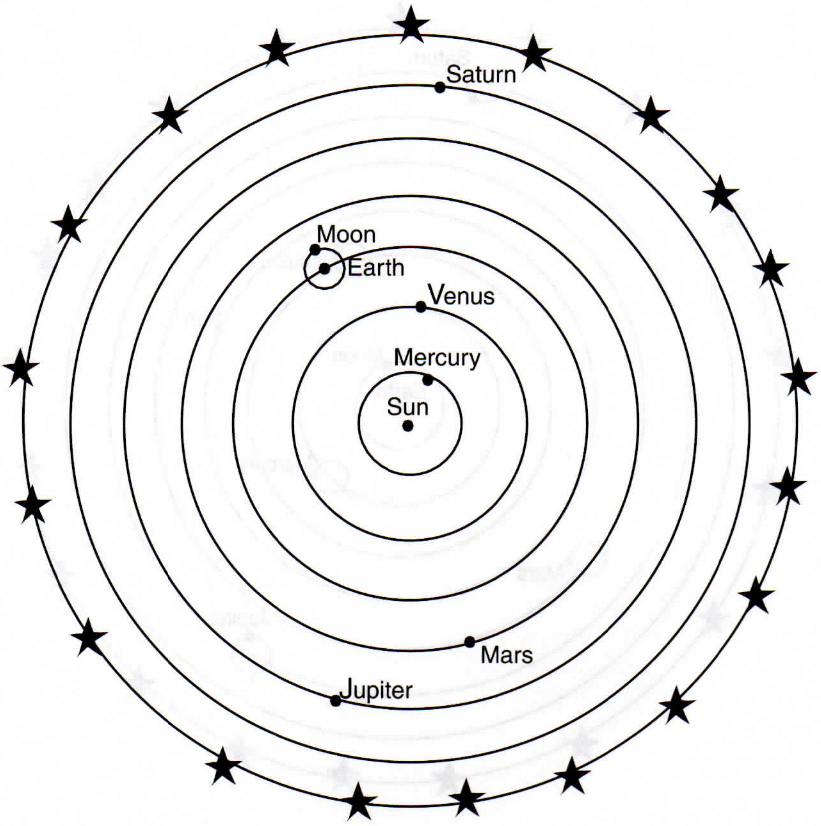


Fig. 4.2. The Copernican or Sun-Centered Model of the Universe.

succeeded in showing that terrestrial and celestial motion could be explained by the same set of laws of motion (Law of Universal Gravitation and the three Laws of Motion). At last, the earth and heavens were united into one universe. The Newtonian laws led to a view of the universe as a great machine whose parts were subject to universal laws that behaved in perfect order and harmony.

Using Newtonian mechanics, the French astronomer and mathematician Pierre Simon Laplace (1749–1827) developed the nebula hypothesis to present a physical explanation for the origin of the solar system. He proposed that a disk of particles orbiting the sun condensed into the planets. The German-English astronomer William Herschel (1738–1822) arrived at the Milky Way galaxy

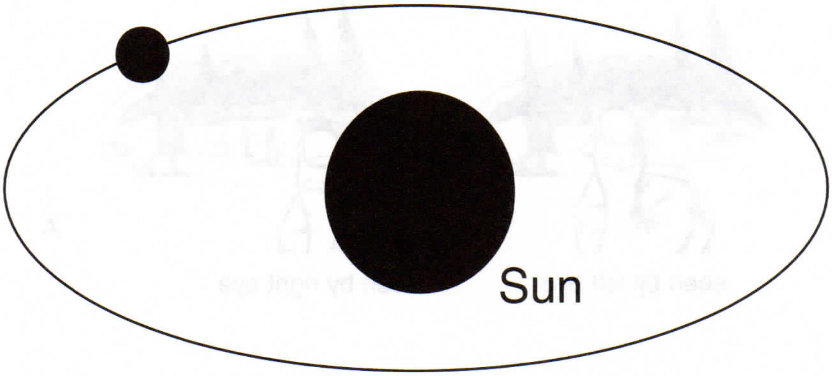


Fig. 4.3. The Elliptical Orbit of a Planet around the Sun.

model of the universe by counting stars in all directions and noting that their distribution defined the galactic plane. An indication of the stellar distances resulted from the observation of the stellar parallax by the German astronomer Friedrich Bessel (1748–1846) in 1838 (see Fig. 4.4). Alpha Centauri was shown to be the nearest star with a distance of 4.3 light years while the brightest star, Sirius, was at 8 light years. (In astronomy, the light year and parsec are used to measure the vast distances to the stars. A *light year* is the distance that light travels in one solar year or 9,461,000,000,000 km [5,880,000,000,000 mi]. The parsec was developed to express distances determined by parallax measurements. One *parsec* is equal to 3.26 light years. A Mpc is one million parsecs or 3.26 million light years.)

We have now returned to where we began this chapter—with a cosmology of a static universe composed of the Milky Way galaxy centered on the earth. The static model gave no information about whether the universe had an origin (cosmogony).

Challenges to the Size of the Universe

From 1914 to 1921, the American astronomer Harlow Shapley (1885–1972) studied *nebulae* or clusters of stars. Nebulae were first catalogued by the French astronomer Charles Messier (1730–1817), a contemporary of Herschel's. Shapley's observations caused two modifications to the Herschel model. Shapley observed that the sun was not at the center of the Milky Way galaxy; the sun

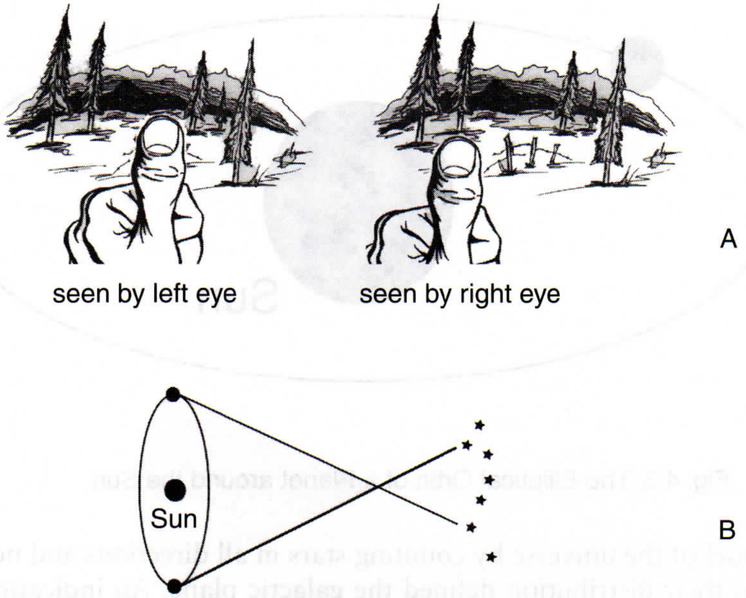


Fig. 4.4. Illustration of the Parallax Phenomenon. A. This demonstrates the parallax, or the apparent change in position of an object (the thumb) due to change in location of the observer (eye). B. The different star pattern as observed from two locations of the earth six months apart.

is about 30,000 light-years from the center in a galaxy 120,000 light-years in diameter and 1,000 light-years thick. Shapley also determined that the Clouds of Magellan, clusters of stars in the southern sky, were outside the Milky Way galaxy: the Large Magellanic Cloud at a distance of 160,000 light-years with the Small Magellanic Cloud at 180,000 light-years. The universe was no longer sun-centered and had just become a lot larger. It was still viewed as static.

Current Cosmology

At the end of the twentieth century, astronomers present a vastly different universe from their colleagues at the end of the nineteenth century. The universe contains billions of galaxies rather than one. The universe is not centered on the earth; there appears to be no preferred point of reference. The universe is vast with objects up to thirteen billion light-years away. In only one hundred years, how did these current cosmological views develop?

In the twentieth century, the scientific view of the universe changed with the development of more sensitive and new observation techniques. Visual observations expanded from the introduction of the one-hundred-inch telescope (1917) at the Mount Wilson Observatory to the launch of the Hubble Space Telescope in 1990. Other information about the composition of the universe became available with the use of radio telescopes (1940), infrared space telescopes (1983), ultraviolet space telescopes (1968), and X-ray telescopes (1949). From their observations, astronomers now state that the universe is very large with matter concentrated into galaxies. The most distant object observed is a galaxy which is thirteen billion light-years from the earth. Let us review four aspects of the current cosmology: stars, planetary systems, galaxies, and the expansion of the universe.

Stars

When one looks at the night sky, the most noticeable objects are the stars. A star is a dense ball of gas whose surface is heated to incandescence by the energy released by nuclear reactions (fusion) within the star. The size and temperature of a star result from the equilibrium between the inward force of gravity and the outward pressure of expansion due to the energy released by nuclear fusion. As gravity compresses the star's gas particles, the star heats and finally reaches the temperature necessary for fusion to occur. Once fusion occurs, the energy released opposes the force of gravitational attraction. The star will expand until the force of gravity is counterbalanced by the force of expansion. The more massive the star, the faster the star will burn its nuclear fuel and the brighter the star shines.

Stars can be classified by comparing their intrinsic brightness and surface temperatures. Such a comparison results in the Hertzsprung-Russell diagram (see Fig. 4.5) which shows that the stars can be classified into five groups. The sun is a *main sequence star* which is an "ordinary" star that steadily uses its nuclear fuel. *Red giants* have surface areas one hundred times that of the sun and are one hundred times more luminous than the sun. *White dwarf* stars are faint, white-hot stars about the size of the earth. The *cepheid variables* are stars whose variation in brightness

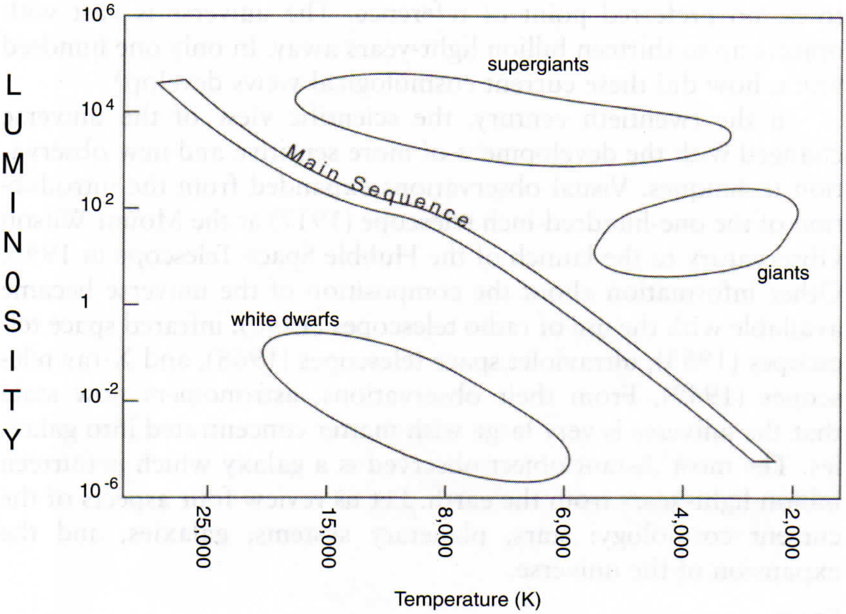


Fig. 4.5. A Hertzsprung-Russell Diagram. The main sequence contains roughly 90 percent of all stars.

changes through a regular pattern. *Novas* are stars that have a violent flare-up with their brightness increasing fifteen times over a short period of time.

One exciting and amazing explanation for all the various types of stars is that stars have a life cycle; they live and die. During the proposed life cycle of a star, the star moves from one classification to another. Stars on the main sequence, such as the sun, with masses between four-tenths and four times the mass of the sun have similar lives. At first these stars fuse hydrogen to produce helium. After about ten billion years, the sun will have used up all the hydrogen fuel in its core, and hydrogen fusion will stop. Gravity, being unopposed, will again contract the gas particles. This will result in a temperature large enough to fuse the hydrogen in the outer shell of the sun. The sun will then expand into a red giant (change of identity). Over a period of millions of years, the sun's core will heat enough to ignite the helium in the core. The sun will then have a radius that would extend out beyond the orbit of the earth. As helium burns, carbon accumulates. The sun is not massive enough to burn carbon.

Once most of the helium has burned, the sun will begin to contract again. Its core will become hot enough to blow off its outer layers, leaving a hot core. The sun will cool and contract into a white dwarf with a radius about the size of the earth. In some cases, one can imagine that a completely cooled white dwarf becomes a "diamond in the sky." The sun is middle-aged (five billion years old) and will continue to burn hydrogen for almost another five billion years.

Stars more massive than four times the mass of the sun will have a different fate after they blow off their outer layers at the end of the helium-burning stage. Such stars are massive enough for gravitational contraction to cause carbon to fuse. Such nuclear reactions occur until iron is produced. Iron cannot be fused by gravitational contraction. Once iron accumulates in the core, fusion stops and gravitational contraction begins again. The temperature of the star reaches such a high temperature that the star explodes as a *supernova*. For days the supernova becomes the brightest object in the sky. The supernova explosion causes nuclear reactions to synthesize all the elements up to uranium. The fate of the more massive star depends upon the mass of the core left after the supernova explosion. If the mass is less than 1.4 solar masses, a white dwarf is produced. If the mass of the core is between 1.4 and 3 solar masses, the core will collapse with such a force that the protons and electrons that make up atoms are crushed together with such force that only neutrons remain.

A *neutron star* is produced with a diameter of ten to twenty km. The rapid rotation of neutron stars produces intense pulses of radio waves. For this reason, neutron stars are also called *pulsars*. The first pulsar was detected in 1968. If the mass of the core is greater than three solar masses, the force of gravity overwhelms the nuclear forces and the star collapses to a *black hole* which has zero radius and is so dense that not even light can escape. (A dimensionless object of infinite density is called a *singularity*.) The Hubble Space Telescope in 1994 presented the first convincing evidence of a black hole. By measuring the acceleration of gases around the center of the M87 galaxy, astronomers found an object with a mass of between 2.5 billion and 3.5 billion solar masses.

Planetary Systems

Another observation one makes in looking at the night sky is that there are objects not associated with any star pattern that wander across the sky. These objects are the *planets*. This name comes from the ancient Greek word that means "to wander." Planets are different from stars in that they do not produce their own light. Rather, they shine by reflecting light from a star. Today we know that these planets form the solar system, a series of nine planets that orbit the sun. The planets range in size from the giant Jupiter (with a radius eleven times that of Earth) to the tiny Pluto (with a radius about two-tenths that of Earth). Until 1995, the solar system was the only known example where planets orbit a star. Since 1995, at least twenty-one planets orbiting stars other than the sun have been discovered. Planets orbiting other stars are detected indirectly by analyzing the variations in the light from the star. Such variations are thought to be caused by the gravitational effect of planets orbiting the star. Currently, only Jupiter-sized planets can be detected by this method.

Until 1998, no planet around another star had been found at an earth-like distance. All were either very close to the star or much farther away from the star than the earth distance. (The Earth-like distance is very important for the possibility of life-supporting conditions on a planet. Life as we know it requires liquid water. If a planet is too close to its star, any water present will be boiled off as a gas. If the planet is too far from its star, any water present will be ice.) In 1998, a Jupiter-sized planet was found with an orbit a little

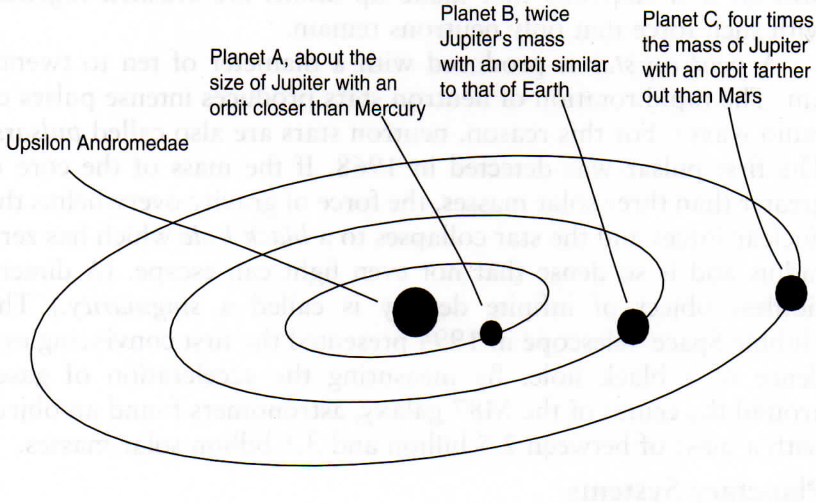
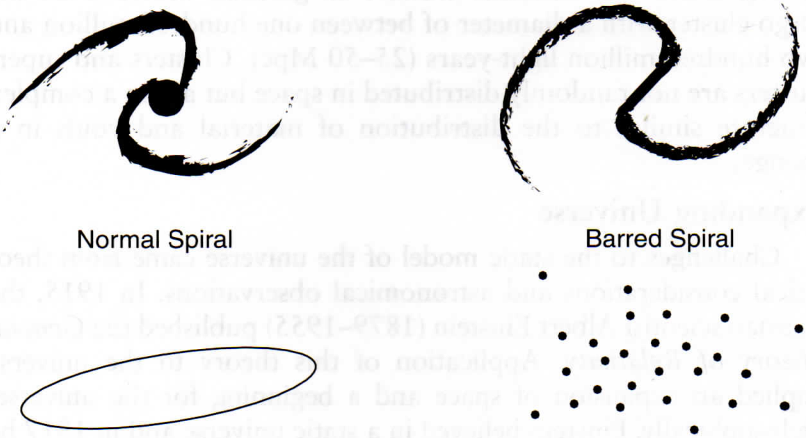


Fig. 4.6. The Proposed Three-Planet-System around Upsilon Andromedae.

wider than the Earth's. It takes this planet 437 Earth days to orbit its star, HD 210277, in the constellation Aquarius about 68 light-years from Earth. Until 1999, the solar system was the only known multiplanet system. Now a three-planet system has been reported around Upsilon Andromedae, 44 light-years away (see Fig. 4.6). The innermost planet is three-quarters the mass of Jupiter and only 6 million miles from the star. By contrast, Mercury is 36 million miles from the sun. The middle planet is about as far away as Venus and has twice the mass of Jupiter. The outermost planet is four times the mass of Jupiter at an orbital distance between that of Mars and Jupiter.

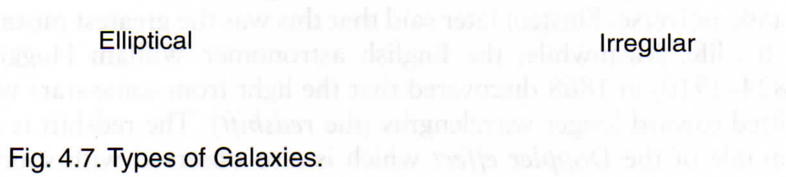
Galaxies

Another observable feature of the night sky is the Milky Way galaxy. At the end of the nineteenth century, the universe was thought to consist of one galaxy, the Milky Way. Today, astronomers estimate that there are 100 billion galaxies, each containing billions of stars. There are three types of galactic shapes: spiral, elliptical, and irregular (see Fig. 4.7). Most galaxies are elliptical. The Milky Way galaxy is a spiral galaxy, while the Magellanic Clouds are irregular galaxies. Galaxies range in size from dwarf



Normal Spiral

Barred Spiral



Elliptical

Irregular

Fig. 4.7. Types of Galaxies.

galaxies, such as GR8 near our galaxy—which are about 5000 light-years in diameter—to giant radio galaxies which extend out more than 3,000,000 light-years. Normal spiral galaxies, such as the Andromeda galaxy, have diameters of 100,000 to 500,000 light-years.

Astronomers have also discovered that most galaxies occur as *clusters* containing from a few to several thousand galaxies. The Milky Way galaxy belongs to a cluster called the Local Group which contains some two dozen galaxies, including the Magellanic Clouds and the Andromeda galaxy. The Andromeda galaxy is a large spiral galaxy comparable in size to the Milky Way galaxy and 2,000,000 light-years away. The Local Group is roughly 6.5 million light-years (2 Mpc) across. Clusters of galaxies can be sorted into poor and rich clusters. Poor clusters contain fewer than one thousand galaxies, with the Local Group as an example. Rich clusters contain a thousand or more galaxies. An example is the Virgo cluster which contains more than 2,500 galaxies. The Virgo cluster is 55 million light-years away and roughly 20 million light-years (6 Mpc) across.

Clusters of galaxies seem to associate together to form *superclusters*. The Local Group is part of the Local Supercluster containing about one hundred clusters of galaxies centered on the Virgo cluster with a diameter of between one hundred million and two hundred million light-years (25–50 Mpc). Clusters and superclusters are not randomly distributed in space but are in a complex structure similar to the distribution of material and voids in a sponge.

Expanding Universe

Challenges to the static model of the universe came from theoretical considerations and astronomical observations. In 1915, the German scientist Albert Einstein (1879–1955) published the *General Theory of Relativity*. Application of this theory to the universe implied an expansion of space and a beginning for the universe. Philosophically, Einstein believed in a static universe and in 1917 he modified his equations (added the cosmological constant) to ensure a static universe. Einstein later said that this was the greatest mistake of his life. Meanwhile, the English astronomer William Huggins (1824–1910) in 1868 discovered that the light from some stars was shifted toward longer wavelengths (the *redshift*). The redshift is an example of the *Doppler effect* which is also observed with sound.

Objects moving away from the observer will have their sound or light waves shifted to longer wavelengths (see Fig. 4.8.).

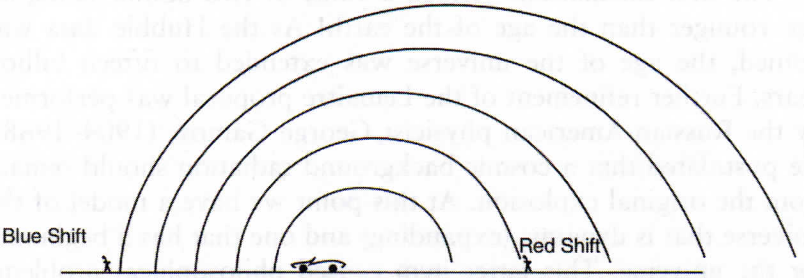


Fig. 4.8. Doppler Effect.

The American astronomer Vesto Slipher (1875–1969) used redshift data to show that most nebulae were moving away from the Milky Way galaxy. The American astronomer Edwin Hubble (1889–1953) in 1929 showed that the more distant an object, the larger was its redshift. How fast are the cosmic objects flying apart? In 1999, astronomers announced that a given galaxy appears to be moving 160,000 miles per hour faster for every 3.3 million light-years it travels away from the earth. The universe was no longer static; it was expanding. What was the cause of this expansion? Did it have cosmogonical implications?

The First Scientific Creation Cosmology (Cosmogony)

The Belgian priest and astronomer Georges Lemaître (1894–1966), after being ordained as a priest in 1922, studied astrophysics at Cambridge University and with Harlow Shapley at Harvard University. After reviewing Einstein's relativistic equations and the galactic redshift data, Lemaître, in 1931, proposed the first scientific creation cosmology or cosmogony. His cosmogony was also influenced by his belief that God's universe is revealed through human investigations. Lemaître's cosmogony was published in *Nature* as an article entitled "The Beginning of the World from the Point of View of Quantum Theory." He proposed that the universe began as a "primeval atom" which exploded to cause an expanding universe. Using the Hubble expansion data, scientists could estimate when the primeval atom exploded.

The first calculations yielded a value of two billion years, an age younger than the age of the earth! As the Hubble data was refined, the age of the universe was extended to fifteen billion years. Further refinement of the Lemaître proposal was performed by the Russian-American physicist George Gamow (1904–1968). He postulated that a cosmic background radiation should remain from the original explosion. At this point we have a model of the universe that is dynamic (expanding) and one that has a beginning for the universe. This latter item caused philosophical problems because of its religious overtones.

Counter Proposal to a Beginning for the Universe: Steady State Theory

In 1948, the Austrian-American astronomers Hermann Bondi (b. 1919) and Thomas Gold (b. 1920) published a paper entitled "The Steady-State Theory of the Expanding Universe." Bondi and Gold thought they had found a way to have an expanding universe without a beginning. They proposed that although the galaxies are moving apart, the universe has always existed in its present state. How can this be? They further stated that as the galaxies move apart, new matter appears between them and forms new galaxies. Thus, they stated that there must be continuous creation of matter rather than an origin for the universe. They have continuous creation *ex nihilio* rather than a one-time "creation" of the universe! The greatest supporter of the Steady-State Theory was the English astronomer Fred Hoyle (b. 1915). Many suspect that Hoyle's atheistic beliefs caused him to continue to defend the Steady-State Theory long after most had abandoned it. Hoyle also coined the term *Big Bang Theory* to distinguish the work of Lemaître and Gamow from the Steady-State Theory.

Before we examine the current cosmogony (the Big Bang Theory), let us review the scientific data that supports the Big Bang. Three major observations include the cosmic background radiation, quasars, and ratio of hydrogen to helium.

Cosmic Background Radiation

As mentioned previously, in the 1930s and 1940s, George Gamow had predicted that a residual cosmic background of radiation should remain from the Big Bang. Although the temperature of the Big Bang radiation would have been billions of degrees hot, this radiation would now have cooled to close to the temperature of space. In 1965, Arno A. Penzias (b. 1933) and Robert W. Wilson (b. 1936) of Bell Laboratories discovered a cosmic background radiation in the microwave part of the spectrum. In 1990, the Cosmic Background Explorer (COBE) satellite measured the temperature of the background to be 2.72 K which is in agreement with the predictions of the Big Bang Theory.

Quasars

Quasar is an acronym for quasi-stellar radio source. Quasars are blue, starlike objects that are strong radio emitters whose whole spectra are strongly redshifted. Hundreds of quasars have been found. Some are smaller than a light-year in diameter. Each emits more radiation than ten thousand galaxies. They are found at great distances as far out as thirteen billion light-years. This distance is where the Big Bang Theory predicts galaxy formation should have occurred. In contrast, the Steady State Theory predicts galaxy formation should be uniformly distributed throughout space.

Ratio of Hydrogen to Helium

The cosmic abundances of these elements are 75 percent hydrogen, 24 percent helium, and 1 percent other. This is the ratio predicted by the Big Bang Theory.

Current Cosmogony: Big Bang Theory

In order to understand the early events in the history of the universe, it is necessary to discuss the particles and forces that make up the universe. There are four fundamental forces (see Fig. 4.9) which control the interactions in the universe.

We are most conscious of gravity (apples fall) and the electromagnetic force (static electricity and compass). However, the strong nuclear force (holds atomic nuclei together) and the weak nuclear force (radioactivity) are also essential to our lives. Current scientific theory says that all matter is composed of quarks, leptons, or bosons (gauge particles) (see Fig. 4.10).

Three quarks combine to form the particles of the atomic nucleus (protons and neutrons), while electrons are a type of lepton. Gauge particles carry or mediate the fundamental forces. For

Type	Relative Strength	Action Distance
Strong Nuclear		Subatomic
Electromagnetic	10^{-2}	Long
Weak Nuclear	10^{-5}	Subatomic
Gravity	10^{-40}	No limit

Fig. 4.9. Four Fundamental Forces.

example, photons carry the electromagnetic force between atoms, while gravitons carry the gravitational force. For each particle there can be an antiparticle. Antiparticles or antimatter are mirror images of the ordinary matter that we know on earth. Antimatter has the same mass as matter, but it has the opposite value in some fundamental property. The antimatter electron is the positron. A positron is identical to an electron except that the positron is positively charged. When a particle and its antiparticle meet, they annihilate each other with the release of energy.

History of the Universe

The following history of the universe, as presented by the Big Bang theory, comes from both experimental and theoretical work. The Big Bang theory assumes that the universe began at a fixed time in the past as a high-temperature, high-density state (a singularity).

Quarks	Leptons	Bosons (Gauge Particles)	
up	electron	Type	Force Mediated
down	neutrino	photon	electromagnetic
strange		gluons	strong nuclear
charm		W and Z particles	weak nuclear
bottom		gravitons	gravity
down			

Fig. 4. 10. Fundamental Particles.

Since that beginning, the universe has been expanding, allowing matter to cool to form stars and galaxies. When one tries to imagine the beginning, it is easy to imagine some process like the expansion of a balloon. However, the expansion of a balloon model is faulty in that a balloon expands into something.

A possibly better model may be raisin bread. In this model of the Big Bang, the raisins represent the galaxies. Before the bread is baked, the raisins are close together. As the bread is baked, the dough expands, making every raisin farther from every other raisin. Similarly, the fabric of space is expanding, taking the galaxies along with it. The distance between the raisins or galaxies is increasing because the dough or space is expanding. Of course, the raisin bread model is not perfect because there is something outside the bread. In contrast, the Big Bang did not occur at some point and expand into something else. The singularity contained all of space. The Big Bang expanded this space into the universe that we observe today. The whole universe has been expanding; the space between galaxies is getting greater rather than one galaxy moving away from the other. This is very hard to visualize because one does not experience in daily life anything that behaves like the expansion of the universe.

The following cosmic history is derived from astronomical and high-energy physics observations and theoretical physics calculations. The closer one gets to the Big Bang, the less certain is the history as theoretical calculations have not yet been confirmed by high-energy physics experiments.

Scientists believe that the universe began about fifteen billion years ago as a singularity of infinite density and temperature (see Fig. 4.11). All of the universe that we observe today was included in that singularity. The singularity began to expand, or the Big Bang occurred. Currently there is no theoretical reason for the Big Bang. Once the universe began to expand, it started to cool. Initially the universe was so hot that the four fundamental forces were united as one force and all existed as high-energy radiation (photons) comparable to gamma rays. At these temperatures, when two photons collided, a particle and antiparticle would be created. They would immediately annihilate each other to produce two more photons. At these temperatures, no particle would be stable. Expansion quickly yielded a temperature cool enough for gravity to separate, followed soon by the separation of the strong nuclear force. The separation of these two forces released enough energy

Time	Temperature	Radius	Event
0	Infinite	zero	Singularity
		10^{-50} cm	Four forces are united and all exist as radiation energy
10^{-43}sec	10^{32} K		Gravity separates from other forces
10^{-35} sec	10^{27} K	Sudden expansion from volume of atom to volume of cherry pit	Strong nuclear separates Inflation
10^{-12} sec	10^{15} K	Volume: a few cubic meters	Weak and electromagnetic forces separate Particle era begins
10^{-4} sec	10^{12} K	150 m	Quarks combine to form protons and neutrons
10 sec	10^{10} K		Radiation era begins
3 min	10^{9} K		Atomic nuclei form
500,000 years	2000 K		Matter era begins Atoms form Universe becomes transparent
1 billion years			Galaxies form
10 billion years			Planets form
10 billion years			Microscopic life
15 billion years	3 K		Today

Fig. 4.11. History of the Universe.

for a sudden inflation in the size of the universe. The volume of the universe increased by a factor of 10^{30}, increasing from the volume of an atom to the volume of a cherry pit. Before the inflationary period, photons had enough energy to make particle-antiparticle pairs. After the inflationary period, the temperature was low enough that the photons no longer had enough energy to make particle-antiparticle pairs.

Since the inflationary period, the universe has gone through three stages: particle stage, radiation stage, and matter stage. The particle stage lasted about ten seconds. The temperature was now low enough for quarks and leptons to be stable. This particle stage raises an interesting question. Why is there any matter in the universe? At first sight, one would expect one particle to be made for one antiparticle and that their annihilation would eliminate all matter from the universe. This would have happened—except quantum mechanical calculations (see chapter 10) indicate that a slight excess of particles (one part in a billion) should be formed over antiparticles. This slight excess of particles survived the particle-antiparticle annihilation to form all the matter we see today.

At first during the particle stage, only free quarks and leptons existed. As the temperature fell, quarks began to combine to form protons and neutrons. Finally, protons and neutrons combined to form the nuclei of hydrogen and helium, which initiated the radiation stage.

The radiation stage lasted about five hundred thousand years. During this stage, the universe was a plasma of nuclei and electrons. A *plasma* is a mixture of positive ions and electrons. Examples of plasmas today are lightning bolts and discharges in neon and fluorescent tubes. During the radiation stage, the universe would have been opaque. The radiation stage ended when the temperature became low enough for electrons to bind to nuclei to form atoms (matter as we know it today).

The matter stage has lasted a little less than fifteen billion years. The atoms formed clumps of matter. Gravity gradually collected this matter into large clouds, which would be the beginning of galaxies. From these large clouds, first-generation stars would form. As discussed above, the first generation stars' life cycles synthesized all the known elements. From the remains of first-generation stars, second-generation stars would form. In the gaseous cloud around the second-generation stars would be the elements needed to form planets. Thus, about ten billion years after the Big Bang, planets began to form. After about another two billion years, life appeared. This is the topic of chapter 7.

Fate of the Universe

The universe's fate depends upon the relationship between the outward expansion due to the Big Bang and the inward contraction due to gravity. If the mass of the universe is great enough (called the *critical density*), then ultimately gravity will stop the expansion of the universe and contract the universe back into a new singularity (the *Big Crunch*), which might then undergo another Big Bang. If the mass is below the critical density value, then the universe would expand forever with the stars burning out and galaxies becoming cold and dark. A complication in determining the amount of matter in the universe and thus the universe's fate has been the realization that at least two types of matter may exist. Ordinary matter interacts with electromagnetic radiation and is visible. Dark matter does not react with electromagnetic radiation and is invisible. Astronomers postulate that dark matter exists because galaxies rotate too fast to be stable without the presence of dark matter. There are three possible categories of dark matter: massive compact halo objects (MACHO) such as dim neutron stars, brown dwarf stars, and black holes; neutrinos, subatomic particles that scientists now propose to have mass; and weakly interacting massive particles (WIMP), theoretical particles that would have mass but would not interact with ordinary matter.

The best estimate among scientists today is that there is not enough matter for gravity to overcome the Big Bang expansion. Thus, the universe should expand forever, becoming darker and colder.

Summary

At the end of the twentieth century, scientists propose that the universe began with a Big Bang about fifteen billion years ago and has been expanding ever since. As the temperature of the universe cooled, fundamental particles combined to form protons and neutrons, which combined to form atoms. This matter collected into galaxies from which the stars began their life cycles. Around second- and third-generation stars, planets formed. On at least one planet (the Earth) life occurred. The universe should continue expanding forever, becoming colder and darker. Finally, it should be emphasized that scientists' view of the universe is dynamic. Considering the changes in the last one hundred years, one can speculate that scientists' model of the universe will continue to change as new discoveries are made.