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The Universe

A Synoptic View

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Introduction

My interest in astronomy went back to my high school days, when one night, I decided to find the North Star using what I had learned in a science class. I found it, and since then the dream of one day studying astronomy was embedded in my mind. But it was not to be, and I moved on to other things.

Yet this abiding interest remains. On my Web site, I have written about Mars exploration and the International Space Station, mostly to satisfy my own curiosity about space. But even Mars and the International Space Station are closer to home than we think.

The vast universe out there, extending to billions of light-years and still expanding, holds a great deal more mystery and wonder to our imagination and insatiable thirst for answers.

Where did all this universe come from? How did it come into being? Where it is going from here? Will it keep expanding forever, or will it someday contract to nothing? Where did matter come from? How did the galaxies, the stars, and the solar system form? How did life evolve?

All these questions and more have fascinated generations of inquisitive minds, who harnessed their energy and talent to accumulate a corpus of knowledge we now take for granted, and hold out hope that more light will be shed on the secrets of the universe.

And so the continuing saga of exploration and investigation keeps transfixing our minds, whether we are professional, amateur or lay people, for there is no more fundamental question than one that queries the origin of the universe.

This article offers a synoptic overview of the subject matter for the curious lay persons, touching upon different perspectives of the universe ranging from the Ptolemaic system to the current Big Bang theory, with sufficient information on astronomy and physics to appreciate the theories. For readers with a greater appetite the article includes a reference list of Web links for further research and study.

Consider this an adventure into a world of fascination and excitement as well as an intellectual journey of the first order. I hope you will come away with a greater sense of the hold the universe has on humans, and of our place in it. You will certainly gain a new perspective on our life and our own species, the one that asks the ultimate question, and continues to search for the answer.

I dedicate this work to an extraordinary person and friend of mine, Giang N. Trinh, D.Ph., for her interest in astronomy, and her urging and encouragement, without which it would probably never have seen the light of day.

Thomas D. Le

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Chapter I

1.0 The Curiosity

To paraphrase Carl Sagan, the late astrophysicist, we are made of star-stuff. By that he meant all the elements found in the cells and molecules in our bodies were made in the interiors of stars eons ago. It is quite a mind-boggling thought to realize that somewhere in the expanding universe, on a largely watery and rather puny planet, there evolved a form of life over some three million years that knows to ask grand questions about its own origin and learn how it all came to pass.

When you look at the clear night sky and see the myriad stars studding the firmament with varying degrees of light intensity, some merely shining, some twinkling, some clustered together, and some standing apart, what passes through your mind? The answer probably depends on your mood and your state of mind at the moment. You might be alone but serene, and are mystified by the vastness and awesomeness of the universe. You might be in a romantic mood, and see your lover in the brightest star, the blue-white Sirius most likely, hovering up there over the Northern Hemisphere all by itself, and eclipsing the rest. Or if you are like me, you will be wondering how all this universe has come about that is so immense, so powerful, so enthralling, so enigmatic, and so beautiful.

The universe has always held an awe-inspiring sway on man's imagination. History records this enormous hold that for thousands of years have inspired men from various civilizations throughout the world. Their observations have been put to diverse uses in religion, navigation, exploration, even in the conduct of war. In the Western world the question of the existence of the universe, simple as it was and is, has fascinated men, among whom were Hipparchus, Aristarchus, Eratosthenes, Ptolemy down to Copernicus, Kepler, Galileo, Newton, Einstein, Carl Sagan, Stephen Hawking and other contemporary scientists who devote their lives to penetrating its seemingly impenetrable veil of secrecy.

I want to share with you my fascination with the cosmos as a layman, an average curious person who never ceases to be amazed at the mystery that enshrouds the genesis of the universe and, along the way, the origin of us all.

We will briefly go over theories that were advanced over time to account for observational data about the universe, and appreciate how far we as humans have gone in gaining an understanding of its mystery. Within the last hundred years along with progress in physics, chemistry, mathematics, computer science, astronomy, and cosmology, men have pieced together a compelling picture of the structure and evolution of the universe. And although a complete account still remains elusive, we now have the tools to probe deeper, and to widen our inquiry.

2.0 The Ptolemaic System

Inquisitive minds in the pre-scientific era had asked questions about the origin of the universe, and from their observations of the movements of heavenly bodies, had pondered over their meanings and applications to daily life. Ancient civilizations from Egypt through the Fertile Crescent to India and China have all made keen observations of the planets and stars, and formulated and systematized them into bodies of knowledge that were known as astronomy, astrology or astromancy. Pre-Greco-Roman Europe bore traces of this rudimentary science in cults, and places like Stonehenge in Britain still mystify us with queries about their astrological meanings. New World civilizations of the Aztecs, Incas, and Mayas also made their contributions.

I will not dwell on these observations. Instead I will take you on a brief but exciting adventure into the world of astronomy and cosmology through time.

The first attempt to measure the world dated back to the third century B.C., when the Greek astronomer Eratosthenes (c. 276-196 B.C.), who lived in Alexandria, Egypt, noticed that on the first day of summer in

Syene (now Aswan) the sun was directly overhead. In Alexandria, however, the sun appeared slightly south of the zenith. Knowing the distance between these two cities and assuming that the sun's rays were parallel when they hit the earth, Eratosthenes was able, using simple geometry, to accurately calculate our planet's circumference to be 25,000 miles (40,000km).

But it was Claudius Ptolemaeus, better known as Ptolemy (c.100-170), whose 13-volume treatise *The Almagest* compiled the achievements of Greek astronomers to his day, who introduced the first general theory of cosmology, based largely on the works of perhaps the greatest of them all, Hipparchus (c. 190-c. 125 B.C.), who had discovered the precision of equinoxes and made the first catalog of stars. His geocentric model explained the movement of the seven "planets" of the known universe (the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn) through space around Earth. Since the ancient Greeks equated predicting the positions of the planets with understanding the universe, the distant stars were nothing more than a backdrop for planetary motion.

Ptolemy envisioned a perfect universe in which each planet moved in a circular orbit at a constant speed. To overcome observed difficulties such as changing speeds and the occasional east-to-west (as opposed to the normal west-to-east movement relative to fixed stars) or retrograde motion of the planets, he hypothesized that each planet moved in a small circle, called the epicycle, whose center described a larger circular trajectory, called a deferent, with Earth as its center. Since this scheme still fell a bit short, Ptolemy placed Earth slightly off-center of the deferent (which came a bit closer to being an ellipse), and had the epicycle move at a constant angular speed around a third point, called the equant, which is diametrically opposed to Earth from the deferent's center. This ingenious refinement allowed him to achieve reasonable, though imperfect, accuracy in his calculations.

Along with the Earth-centered view, the idea that Earth is flat remained in the public consciousness until Christopher Columbus' days, although the Greek philosopher Aristotle (384-322 B.C.) had argued convincingly for a spherical Earth from the apparent sinking or rising of the North Star (Polaris) depending on whether one travels south or north, and from the circular shadow of Earth against the Moon during a lunar eclipse. If Earth were a flat disk, its shadow would have been elliptical. The flat-earth myth was exploded once circumnavigation of Earth was accomplished in the 16th century.

Ptolemy's geocentric paradigm, which was undisputed for 1400 years, fit the Catholic Church's view of God's creation of the universe so perfectly that the Church adopted it as its canon, thus stifling further scientific inquiry for centuries.

3.0 The Renaissance and Post-Renaissance Theories and Contributions

It was not until the Renaissance, when classical ideas received renewed interest among philosophers and intellectuals, that modern scientific investigation into the cosmos began in earnest.

The Polish astronomer Copernicus (1473-1543), rejecting Ptolemy's cumbersome model, showed that computations of planetary positions would be far simpler by placing the Sun in the center of the universe, with Mercury, Venus, Earth, Mars, Jupiter and Saturn circling around (Uranus, Neptune, and Pluto had not yet been discovered.). Although this hypothesis had already been formulated by the ancient Greek astronomer Aristarchus (310-c.230 B.C.) of Samos 1500 years earlier, Copernicus gave it a modern impetus, and sparked a revolution in the science of the universe. This heliocentric concept envisions the daily movements of stars and other planets as a mere reflection of Earth's rotation on its own axis, and could explain the occasional retrograde movement of the planets in relation to Earth in a natural way. Since Earth moves at a faster speed than the outer planets, it periodically overtakes them, and they appear to move backward relative to the background. This is similar to the experience of a faster runner in an inner lane who sees his slower competitors in a farther outer lane moving backward as he passes them. By the same token, Mercury and Venus, which are closest to the Sun, never seem to stray too far from the Sun from Earth's vantage point. However, this model is still defective by Copernicus retaining the old notion that the planets move in circular orbits and at constant speeds. Like Ptolemy he had to devise a system of circles within circles for his calculations to be reasonably accurate.

Although the Copernican model does not prove that Earth revolves around the Sun, the heliocentric view began to take hold in most of northern Europe at a time when the Ptolemaic system prevailed in southern Europe, where the Catholic Church was entrenched. His book *Revolutionibus Orbium Coelestium (The Revolution of the Heavenly Spheres),* published in 1543, the year of his death, was dedicated to Pope Paul III, conceivably with an intent to placate the religious authorities into accepting, or at least not condemning, his contrarian view.

It devolved on the Danish astronomer Tycho Brahe (1546-1601) and the German astronomer Johannes Kepler (1571-1630) to finally explain the secrets of planetary motion. Using Brahe's precise naked-eye measurements of the planets' positions over a twenty-year period from 1576 to 1597, his assistant and successor Kepler modified Copernicus' concept by introducing a slightly elliptical, as opposed to the circular, orbit with the Sun at one focus, and found that Mars' positions almost exactly matched the elliptical path. Other planets behaved similarly. This elliptical orbit became the accepted first law of planetary motion. The second law Kepler discovered was the varying speed at which a planet travels around the Sun, fastest when closest to the Sun, and slowest when farthest away. And the third law of motion calculates with precision the relation between a planet's distance from the Sun and the amount of time the planet takes to make one complete revolution around the Sun. The value of these three laws of motion lies in their predictive power, i.e., they allow accurate prediction of the positions of the planets.

Up till then astronomers were content with theorizing and hypothesizing on the basis of naked-eye observations of the sky with the aid of crude instruments such the quadrant. It was not until 1608 that the Dutch optician Hans Lippershey invented the telescope, which the Italian Galileo quickly adopted in what was later recognized as the first truly scientific observation of our planetary system.

Galileo Galilei (1564-1642), who had abandoned his training in medicine in favor of mathematics, quickly turned the recently invented telescope to the sky, and within months found mountains and craters on the Moon and dark spots on the Sun. His discovery of the four moons (58 at latest count) orbiting Jupiter shattered the ancient notion that Earth was the center of all motion. And his discovery of the phases of Venus, similar to the phases of the moon, challenged the Ptolemaic system, which could allow Venus to show only its crescent phase. Galileo's work had thus lent observational support to the Copernican system.

By 1610 Ptolemy's view had begun its decline as a credible theory at least in northern Europe. Galileo, being an Italian living the Catholic Church's stronghold, was forced before the Inquisition to recant his findings and renounce his endorsement of the Copernican model. But the heliocentric model was going to prevail.

Giving modern astronomy an important boost were the contributions of the Englishman Isaac Newton (1642-1727). He clarified the laws of motion, and invented the first reflecting telescope whose basic design still remains in use, the preeminent mathematical tool of science, calculus, and the law of universal gravitation. Until the advent of Albert Einstein's general theory of relativity in the twentieth century, all cosmological models were based on his theories.

Back in the eighteenth century astronomers had suspected that the Sun was only a part of a larger conglomeration of stars, called a galaxy later known as the Milky Way, with the Sun at its center. Our concept of the universe thus expanded to other stars beyond the solar system. One puzzling discovery was the large masses of fuzzy light, the nebulae, that lay beyond our galaxy. The 18th-century French astronomer Charles Messier had catalogued more than 100 of these objects. By the beginning of the 20th century using small and medium-sized telescopes, astronomers have catalogued more than 10,000, many of which were identified as interstellar clouds of gas and dust and star clusters. But most still remain a mystery. Immanuel Kant had hypothesized that nebulae were galaxies, but no proof was proffered until well into the twentieth century. Before long the Sun-centered view became rather parochial, and soon would be replaced by the broader "galactocentric" concept.

4.0 The Stars

Before discussing the progress in science and technology that gives astronomers the tools they need in their investigation, it behooves us to understand essentials facts about the cosmos, and its fascinating inhabitants, the stars and other celestial objects.

4.1 What Is a Star?

The universe is full of giant clouds of gas and dust. As a massive and enormous interstellar cloud of dust and gas, mainly hydrogen, begins to contract under gravity, the atoms of gas and dust particles become denser, heat up to very high temperatures, take on a globular shape, and glow. A star is born. Contraction continues until hydrogen in the center is converted into helium by nuclear fusion, and generates outward pressure that counterbalances the inward gravitational pull. At this point the star stops shrinking, and maintains a stable life for millions or billions of years. Massive hot blue stars may reach this stage in hundreds of thousands of years whereas cooler yellow and orange stars may take millions of years. This process of nuclear reaction continues as long as there is enough hydrogen fuel to keep it going. When it has spent much of its fuel supply the star's core begins to lose its stability. Its core contracts until it reaches up to 100 million degrees C, and its gas pressure expands the overlying layers and make the star shine even brighter. When the hydrogen supply in the core is almost consumed, fusion continues in the outer layers, expanding the star further. The enormous surface of the star radiates sufficient light to transform it into a red giant or supergiant. In the meantime if the core's temperature is high enough, helium fuses into heavier carbon atoms. When the temperature reaches 3 billion degrees C, iron and other heavy metallic elements form. This is the end for the star. Iron is too heavy an element to fuel the nuclear reaction. After this thermonuclear reaction has used up all the hydrogen fuel, its core can no longer support the heavy outer layers, and the red giant collapses upon itself. The nuclei of its atoms are compressed together so tightly that the star shrinks to a hot white dwarf. Its interior begins to cool. However, due to residual heat the white dwarf may continue to glow faintly for another billion years. Eventually even the core becomes cold, and the star becomes dark and dies. Another possible scenario is violent death: the red giant may contract into a red variable star called nova before its collapse, and may even eject much of its overlying layers as a supernova, and shines as brightly as an entire galaxy before the final collapse. The matter thrown out by the supernova in its cataclysmic demise is used in the formation of new stars. Over billions of years, this process repeats itself as heavier elements are thus cooked up in the stellar furnaces, and form the building blocks of life. We are made from these fundamental building blocks.

Our Sun has been burning its fuel for 4.5 billion years, and is estimated to last another 5 billion years before it becomes a red giant and consumes the entire solar system. We still have plenty of time to put our earthly affairs in order!

4.2 Characteristics of The Stars

When peering at a star, astronomers are interested in determining its distance, diameter, mass (total amount of matter), density, surface temperature, chemical composition, motion, and formation. Beyond individual stars, they investigate galaxies, novae, nebulae, black holes, quasars, pulsars, and other exotic objects.

4.2.1 Distance Measurement

To measure astronomical distances, scientists use different units, such as the astronomical unit (AU), the light-year, and the parsec. For short distances within the solar system, the astronomical unit is the average distance from Earth to the Sun, or 93 million miles (about 150 million km). Longer distances are measured in light-years, a light-year being the distance traveled by light at the speed of 186,000 miles (300,000 km) per second for 365 days, or nearly 6 trillion miles (10 trillion km). The Sun is only 8 light-minutes from Earth, that is, it takes eight minutes for the Sun's rays to reach us. At the 1983 *Conference Generale des Poids et Mesures,* the SI (Systeme International) defines the meter as the distance traveled by light in a vacuum for 1/299,792,458 of a second, making the speed of light 299,792,458 m/s in a vacuum.

In 1838 the German astronomer Friedrich Wilhelm Bessel (1784-1846) first proved Earth's motion around the Sun by effecting a precise measurement of a small displacement of the nearby star 61 Cygni in relation to more distant stars. He thus estimated the distance to that star to be 65 trillion miles, or about 11 light-years. This displacement of a star is called *parallax*, a basis which astronomers use in measuring stellar distances. It is half the angle opposite the long axis of Earth's orbit, which serves as a baseline for a triangle with the two sides being lines of sight from a point on Earth to the star taken six months apart, i.e., on opposite sides of its orbit. The parallax is greater for a nearer star than for a distant one. In addition to light-years, astronomers use the parsec (coined from *par*allax of one *sec*ond), defined as the distance at which a star would have a parallax of one arc-second. A parsec is about 3.26 light-years, about 20 trillion miles, 3.085678×10^{13} km, or roughly 206,000 AU. Using the parallax, the distances to two other stars, Alpha Centauri and Vega, were determined. Alpha Centauri, the second brightest star in the Southern Hemisphere sky, and its invisible neighbor Proxima Centauri are about 25 trillion miles away. In the following decades more distances to the stars were calculated, and the universe became larger than scientists had expected.

4.2.2 Colors and Temperatures

Stars appear in different colors even to our unaided eye. In a spectrum analysis hot stars emit more light at the blue end of the spectrum, and cooler stars emit more light at the red end, very much what we experience in daily life. A blowtorch is hottest when its flame becomes blue-white. White light is decomposed by a glass prism into a *spectrum* of colors ranging by decreasing order of their wavelengths from red through orange, yellow, green, to blue, indigo, and violet. The spectrum of an element carries distinctive lines across the color band. These lines help observers to identify the chemical elements present in the stars. Astronomers group stars into seven classes according to their spectral lines. Class M, red stars such as Antares and Betelgeuse with a surface temperature of about 3,000° C; Class K, orange stars, e.g., Arcturus, Aldebaran, with a surface temperature of about 4,000° C; Class G, yellow stars, e.g., Sun and Capella, with a surface temperature of about 6,000° C; Class F, white-yellow stars, e.g., Canopus, Procyon, with a surface temperature of about 7,500° C; Class A, white stars, e.g., Sirius and Vega, surface temperature of 8,000° C to 11,000° C; Class B, blue-white stars, e.g., Rigel, Spica, surface temperature of 15,000° C to 30,000° C; and Class O, blue stars, e.g., Zeta Puppis, surface temperature of above 30,000° C. This classification shows that as hot as the Sun seems to us on Earth, it is only moderately so and therefore not very luminous.

4.2.3 Chemical Composition

Stars are composed of the same elements we have on Earth, but in very different proportions. Most stars consist primarily of hydrogen and helium with only about one percent of heavier elements such as iron, calcium, sodium, titanium, and other elements. Our sun is about 70 per cent hydrogen, 28 percent helium, with about 60 other elements forming the remaining 2 per cent of its mass. Most stars differ among themselves more in their temperature than in their composition.

4.2.4 Size, Mass, and Density

Stars vary in size from smaller than Earth to Epsilon Aurigae, which is about 2 billion miles in diameter. Our sun is an average star with a diameter of 864,000 miles as compared to Earth's 8.000 miles, and an average density 1.4 times that of water. Its mass is more than 300,000 times that of Earth. The red supergiant Betelgeuse has a density about one ten-millionth that of the sun. At the opposite end, the white dwarf star that accompanies Sirius is so dense one teaspoonful of it weighs about a ton.

Variation in mass is less pronounced. Stars range in mass between ten times the sun's mass to about one-fifth of its mass. Most stars range close to the sun.

4.2.5 Brightness

The *true brightness* of a star depends on its size and surface temperature, and its *apparent brightness* also depends on its distance. The star's brightness is defined as its *magnitude.* Its apparent magnitude is its brightness as observed by the eye, or photography. Before the invention of the telescope astronomers distinguished six classes of magnitude, with first-magnitude stars being the brightest and sixth-magnitude barely visible to the unaided eye. Today the 200-inch telescope at Mount Palomar can photograph twenty-fourth magnitude stars with less than a billionth the apparent brightness of Betelgeuse. Since the ratio of brightness between two consecutive magnitudes is 2.5, a first-magnitude star is 100 times as bright as a sixth-magnitude star. Astronomers assign positive numbers with decimals for greater precision to less bright stars and negative values to stars with apparent magnitude brighter than first-magnitude stars. Thus, first-magnitude stars may have magnitudes between 1 and 0: Rigel 0.15, Capella 0.09, and Vega 0.04. The brightest star in the sky Sirius has the apparent magnitude of –1.6, and Alpha Centauri –0.27. The full moon's magnitude is –12.6 while our Sun's is –26.5.

The star's *apparent magnitude* indicates how bright it looks to us, not how bright it really is. Its *true magnitude* or *luminosity* cannot be determined directly because we cannot place stars at the same distance from Earth. Astronomers standardize calculations by defining the *absolute magnitude* as the apparent magnitude a star would have at a distance of 10 parsecs or 32.6 light-years. By this measure Betelgeuse has a high absolute magnitude of –5.8 whereas our sun's absolute magnitude of 4.8 makes it barely visible at 10 parsecs. Most stars are even less luminous than our sun.

In general we would expect hotter stars to be more luminous. We would expect blue or blue-white stars to have high luminosity and absolute magnitude. Sirius and Vega are hot blue-white and very luminous. Yet Capella and Arcturus with absolute magnitude of –1 and high luminosity are red stars. They are known as red giants. Supergiants include blue-white Rigel, white-yellow Canopus, and the red supergiants Antares and Betelgeuse. Red supergiants are the largest of all; they have to be in order to be luminous. Betelgeuse is so large that it consists mostly of near-vacuum. At the opposite extreme, less luminous stars are called dwarfs, which we expect to be red, orange or yellow stars. Again there are exceptions. White dwarfs are so dense a teaspoonful weighs about a ton, as mentioned above.

4.2.6 Motions

Stars in our galaxy rotate with the galaxy at high speeds that vary with their distances from the center of the galaxy. However, Vera Rubin (1928-) has shown in her study of star motion that stars' velocities remain fairly constant irrespective of their distances to the galaxy's center, and that most spiral galaxies contain about ten times more mass than is visible. The first finding contradicts our knowledge of planetary motion in our solar system, where velocities decrease with distances from the Sun. The second finding is startling in that the universe contains much more invisible matter than we ever suspected, *dark matter.* More about this in the discussion of the Big Bang theory below. Star motion may be described in two ways. *Proper motion*, the rate of change of the star's position relative to each other, can be detected by comparing two different photographs taken years apart of the same star among the same background stars. Their vast distances from us guarantee that very few stars move appreciably over short periods of a few years. However, proper motion will be much more appreciable in 50,000 years. By analyzing shifts of spectral lines astronomers can measure *radial velocity*, the rate at which a star moves away from or toward us. Most radial velocities range between 20 to 30 miles per second although 60 miles per second have been observed with some stars.

4.2.7 Variable Stars

Variable stars, so called for their varying brightness, include eclipsing variable stars, pulsating stars, and cataclysmic or eruptive stars.

Eclipsing variables are binary systems in which one star eclipses the other during each pulsation period, alternating between increase and decrease in light output. Beta Lyrae is one such eclipsing variable.

Pulsating stars expand and contract in regular cycles and change brightness accordingly. Expansion corresponds to cooler temperatures whereas contraction causes the star to become hotter and brighter. *Cepheid* variables (named after the constellation Cepheus) are regular in their pulsating patterns. Delta Cephei, the prototype for Cepheid variables, has regular periods ranging from one to several days. The longer a cepheid's period is, the greater is its absolute magnitude. It is this reliable relationship that astronomers use to calculate the distances to galaxies containing the cepheid, given that cepheids are bright and widely distributed.

Cataclysmic or *eruptive* variables are faint stars that explode into sudden outbursts thousands or hundreds of thousands of times as bright as before. Many such stars are *novae*, binary systems made up of a white dwarf and a red giant. Gravity exerted by the white dwarf draws matter from the less dense red giant toward it. Over hundreds or thousands of years enough material has accreted to trigger a thermonuclear explosion. For several days the star increases its brightness by as many as 10 magnitudes before slowly fading away. The detonation occurs again when enough material has been accumulated. Nova Cygni 1975 and Nova Herculis 1934 are two such well-known novae.

Occasionally a violent explosion flares with such brilliance, approaching hundreds or thousands of times that of a nova, that it is called a *supernova*, and its absolute magnitude is as great as that of an entire galaxy. One such convulsive supernova was observed in 1054. During the explosion most of the star's matter was lost, and it became an expanding cloud of gas now known as the Crab Nebula in the constellation Taurus. What remains after the giant explosion of this supernova is a core of hot neutrons (giving it the name of *neutron star*) thirty kilometers across, spinning rapidly, and emitting radio waves and visible light, flashing 30 times per second. Hence the name pulsating star, or *pulsar*. Other supernovae were recorded in 1572 by Tycho Brahe, and in 1604 by Johannes Kepler. In 1987 the Canadian astronomer Ian Shelton found Supernova 1987A, which over a period of three months reached magnitude 3, at which it was almost as luminous as all the other stars in the Large Magellanic Cloud. Within a year Supernova 1987A had faded to naked-eye visibility.

5.0 Galaxies

5.1 Star Clusters

Clustering occurs among stars when they are close together to form distinctive groups that move together. About 600 *star clusters* have been identified that fall into two classes. *Open* or *galactic clusters*, generally numbering in the tens or hundreds, consist of younger stars, and are called open because they are widely scattered, and galactic because they are found in our galaxy. The Pleiades, the Hyades are part of some 500 open clusters. *Globular clusters*, about 150 in number, are scattered throughout the sky, and when seen through a large telescope appear to be huge aggregations of up to a hundred thousand stars, some 15 billion years old, as old as the universe, all located in the core of the Milky Way. Stars in globular clusters consist mostly of light elements such as hydrogen and helium while younger stars in the open clusters also contain heavier elements such as calcium and iron. M22 in Sagittarius is a globular cluster.

5.2 Nebulae

Many fuzzy, blurred patches of light that lie among stars once thought to be nebulae have been resolved by large telescopes into galaxies. In 1923 and 1924 with the help of the 100-inch reflector at Mount Wilson, California, Edwin Hubble was able to resolve the Andromeda Nebula into individual stars. By comparing the nebula's apparent magnitude with its absolute magnitude, he estimated the nebula's distance at close to one million light-years. *Nebulae* are made up of cosmic dust and gas that do not have light of their own. *Bright nebulae* receive light from stars within them or in the neighborhood. Some bright nebulae are *reflecting nebulae* because starlight reflects off their dust. Others are ionized by intense emission of ultraviolet radiation from close stars, and glow as *emission nebulae*. The Great Nebula in Orion (M42, short for Messier's Catalog, Object No. 42) and the Lagoon Nebula (M8) are good examples. *Dark nebulae* have no nearby stars or background stars to give them light, and are thus called *coal sacks*. One such dark nebula, studied by the British astronomer John Herschel (1792-1871), lies in the southern sky by the Southern Cross. One of the best-known dark nebulae is the Horsehead Nebula in the constellation Orion.

5.3 Galaxies

Galaxies are huge systems of dust, gas, and billions of stars held together by gravity, and separated from each other by millions of light-years. Before powerful telescopes resolved them into galaxies in the 1920's they were called spiral nebulae. In 1926 Edwin Hubble classified galaxies into three main categories: *spirals*, *barred spirals*, and *ellipticals*. About seventy-five percent of bright galaxies have a spiral configuration consisting of a lens-shaped central disk populated by millions to billions of stars, and two spiral arms extending out of the center from opposite sides of the nucleus, and holding millions of young, hot stars, and bright emission nebulae. Open star clusters are distributed throughout the disk. Spiral galaxies range from 15,000 to 150,000 light-years in diameter. Typical spirals include the Andromeda (M31), the Whirpool (M51), and our Milky Way. About one-third of spirals show attributes of barred spirals, in which bright stars and ionized gas of the nucleus extend out to thousands of light-years in a straight bar on each side of the center. From the end of the bars spiral arms sweep back around the nucleus. Elliptical galaxies range from football-shaped to spherical, have no arms, and contain almost no gas or dust. The largest ellipticals measure at least 100,000 light-years in diameter, and may contain 10,000 billion stars. Large ellipticals such as M84 and M86 in Virgo make up about twenty percent of bright galaxies. Other types are *lenticular* galaxies with nuclei like spirals but no spiral structure, containing mostly old stars and very little gas. Finally there are *irregular* galaxies, so-called for their indistinct shape, making up about 5 percent of bright galaxies. The Small and Large Magellanic Clouds belong in this category.

At the beginning of the twentieth century, the Milky Way, also called the Galaxy, was thought to have 100 million stars and extend only a few thousand light-years across. In 1917 the American astronomer Harlow Shapley at Mount Wilson Observatory, California, showed that our solar system was farther out toward the edge of the Milky Way, some 50,000 light-years, later revised to 30,000 light-years, from its center, and that the Milky Way was the universe. Today we know the universe has 100 billion galaxies, each having an average of a hundred billions stars. And the Milky Way is a flat spiral galaxy with a wide bulge in the center, 1,500 light-years thick, with arms extending to 100,000 light-years, and containing some 200 billion stars. The Milky Way is only one among billions of galaxies in the universe. Around its disk a halo of older stars stretches out to another 150,000 light-years. Each star and nebula in our galaxy orbits its center, and follows its own independent path. The Sun, an average-sized star on one of the spiral arms, makes one complete orbit in about 240 million years. What is at the center of the Milky Way? It is still a mystery, but scientists now think they found a strong source of radio emission known as Sagittarius A*, or a black hole with the mass of millions of suns.

Galaxies are distributed unevenly in the universe and are separated by great distances. Our galaxy is one of a conglomeration of some 30 galaxies called the Local Group, with the Milky Way and the Andromeda (M31) being the largest. And the Local Group is part of a supercluster of galaxies which includes the constellations Coma Berenices and Virgo, the latter 65 million light-years distant and containing 2,500 galaxies. Galaxies within a cluster are bound together by gravity, but the clusters themselves are pulled away from each other by the expansion of the universe.

5.4 Black Holes and Quasars

Stars owe their brilliance to the process of thermonuclear reaction going on in their cores. When a star exhausts its hydrogen nuclear fuel in millions or billions of years, the energy produced by nuclear fusion is no longer able to counteract the inward pull of gravity, its core collapses, and its overlying layer caves in upon itself creating a cataclysmic implosion. In 1971 John Archibald Wheeler named the resulting object a *black hole*. The star crosses into its *event horizon* and disappears. The event horizon is the black hole's radius beyond which no light escapes; and any event taking place inside it cannot be detected. It is a point of no return. All known laws of physics break down inside the event horizon, including Einstein's gravitational laws. However, not all stars collapse into black holes. A star with a mass less than 1.4 times that of the sun forms a *white dwarf*. A star between 1.4 and 3 solar masses becomes a *neutron star*. If a neutron star gets to around 3 solar masses the force of gravity overwhelms the outward pressure, and it keeps contracting to a tiny mass and collapses into a black hole. Stars greater than 3 solar masses become black holes. A black hole can also be produced by compression from outside forces, such as that hypothesized as the primordial black hole at the origin of the universe, or a singularity. A *singularity* is a region in spacetime (i.e., 4-dimensional space, three dimensions for space and one for time) in which gravitational forces are so strong no light can escape from it. It marks the point of infinite spacetime curvature, in other words, a point of zero volume and infinite density. Einstein's general relativity requires that a singularity be formed under two circumstances: first, during the creation of a black hole, such as at the death of a star, when it runs out of fuel and collapses upon itself crushed by gravitational interaction, and second, under certain reasonable assumptions, an expanding universe like ours must have begun as a singularity. This hypothesis is the Big Bang theory discussed below.

Albert Einstein's general theory of relativity suggests that a black hole, with its enormous density of matter compressed into a tiny volume, has such tremendous gravity that light inside it cannot escape to be seen. The British theoretical physicist Stephen Hawking (1942-), of Cambridge University, showed in 1974 that black holes can radiate energy. He believes that matter or energy can be created from "empty" space for there is no such thing as empty space, according the uncertainty principle. The quantum vacuum is filled with particles and antiparticles that appear briefly and disappear quickly. Consider this scenario, thought of by some physicists as "pop-science," but still accepted as a heuristic: If a pair of virtual particle-antiparticle forms near the event horizon, three possible scenarios exist if they don't annihilate each other first. Firstly, the pair falls into the black hole. Secondly, the pair escapes from the edge of the black hole. In the third scenario, one virtual particle falls into the black hole, restores the conservation of energy by taking on a negative charge to be absorbed by the black hole, which then loses further mass and shrinks. The remaining particle becomes real to be a source of radiation to the outside observer. Hawking calculated that the energy radiation is very small, of the order of $6 \times 10^{-8}/M$ Kelvin, where M is the black hole's mass in terms of solar masses. This phenomenon is known as *Hawking radiation*, still not observed because the only known black holes are so hot this radiation is undetectable.

Because of its invisibility a black hole is very difficult to detect. Detection therefore has to depend on other phenomena. First, although the star is no longer visible, its gravitational field remains as strong as before the collapse, and its planets continue to orbit about, as if about nothing. Next, the black hole's powerful gravity pulls dust and gas particles from nearby stars with such enormous speed and force that X-rays are emitted in the process. Astronomers have detected several binary star systems with strong X-ray emission, in which one star orbits its massive, invisible companion. Cygnus X-1, a strong invisible X-ray emitter, has a blue supergiant star orbiting it. The M87 galaxy harbors a supergiant black hole with 2 billion times the mass of the sun. The last technique of black hole detection is referred to as *gravitational lensing*. When a massive object, in this case a black hole, passes between Earth and a star, the black hole acts as a refracting lens bending the star's light rays and focusing them to Earth, where an observer sees the star brighten. Einstein's theory of relativity suggests that the star's light follow the path of bent time and space, bent by the black hole's gravity.

Today astronomers believe most galaxies and all quasars have a black hole at their cores. The first evidence was discovered in 1974 with the detection of a strong source of radiation, called Sagittarius A*, emanating from the center of the Milky Way. *Quasars*, short for quasi-stellar radio sources, were discovered in the early 1960s in the cores of distant galaxies. Astronomers were puzzled over their luminosity and their strong radio emission from a region about the size of our solar system. They emitted great energy by burning up to trillions of times the energy of the Sun, or up to a thousand large galaxies. Maarten Schmidt used Hubble's Law to deduce their great distances from the observation that their spectrum was highly redshifted. Most astronomers now believe that quasars lie in the centers of young galaxies, where supermassive black holes attract passing stars and gas clouds to form accretion disks around the black holes, emitting both intense visible light and radio waves.

5.5 Wormholes

This is still in the domain of science-fiction. Imagine a light beam traveling between two points in curved spacetime. It would take longer if it had to take to normal path between two points. Now imagine a "bridge" connecting two regions of spacetime, providing a shortcut. The light beam going through this shortcut would get to its destination in far shorter time. This bridge, now called a *wormhole*, was proposed in 1935 by Albert Einstein and Nathan Rosen, who realized it was allowed by general relativity. Any shortcut would raise the possibility of time travel. Until recently physicists believed wormholes exist only briefly, and anyone entering one would fall into a singularity. Quantum effects would destroy the wormhole before a space traveler could enter it. However, more recent calculations show that with "negative energy" an advanced civilization could prevent the wormhole from crushing itself out. Stephen Hawking, at first was not convinced that time travel would be possible, but since then he has come around, and thought only that it would be impractical.

If a black hole rotates and/or have charge, you can fall in without hitting a singularity. It could conceivably join up with its exact opposite, the *white hole*, and form a tunnel called the wormhole. Whereas there is evidence that a black hole exists, a white hole is only the result of a mathematical symmetry of the equations of general relativity that describe the black hole. The while hole is something like a mirror image of the black hole, with opposite properties. If nothing inside the black hole can escape, the white hole ejects anything that "falls" in it. In reality, there is no white hole. But the idea is tantalizing that if you can tunnel through a black hole to a white hole and emerge to the other side of the spacetime curvature, you have in effect traveled through time!

Chapter II

Advances in Science And Technology

In this chapter I will go over a number of scientific advances, in their chronological order when possible, that when taken together are responsible for shaping our modern view of the universe. They are presented first, as background information, without any attempt at systematization or cohesion. I hope this information will aid in your understanding of the theories to be introduced in the following chapter.

1.0 Spectroscopy

Energy in space manifests itself in the form of electromagnetic radiations or waves, and can be detected by various means. For example, visible light is emitted by a light source such as the incandescent filament of an electric lamp or a star, and can be detected by our unaided eyes or a telescope, and recorded on photographic film. Gamma rays, released by the radioactive decay of uranium, are detected by a Geiger counter. X-rays, emitted when high-speed electrons are shot against metals, can be detected by special photographic plates, as are infrared and ultraviolet rays. Night-vision scopes and some modern video cameras and camcorders can also detect infrared rays, which are emitted by a source of heat, such as a human body or a star. And radio waves are received by radio receivers and transformed into sound, or as spectra that the computer can digitize for analysis.

Astrophysics made its humble debut in Munich in 1814, when the German physicist and lens-maker Joseph von Fraunhofer (1787-1826) passed the light from the Sun and stars through a triangular glass prism, which breaks the white light down to a *spectrum* of colors arrayed according to their wavelengths, with red having the longest wavelength and violet the shortest, and orange, yellow, green, blue, indigo in between. The glass prism, mounted between a collimator that produces parallel rays of light, and a small view telescope to view the rays dispersed or refracted by the prism, becomes the spectroscope. If a photographic plate replaces the eyepiece, the spectroscope becomes the spectrograph. This instrument plays a vital role in astrophysics. Although visible light is only a small part of the entire spectrum of electromagnetic radiation in the universe, ranging in descending order of wavelengths from radio waves (hundreds of feet in length), heat or infra-red radiation through visible light, ultra-violet radiation, x-rays, to gamma rays (less than one hundred-millionth of an inch) and cosmic rays, a study of this tiny visible window along with observations of the other segments of the electromagnetic spectrum reveals a great deal about the chemical composition, distance, speed, energetic radiation, magnitude, and movement of celestial bodies, all being essential in the construction of a theory of the universe's origin.

Fraunhofer recorded the spectrum of various elements, and found that each of the bands had hundreds of distinctive dark lines across its width. The spectroscope gives three spectra. The *continuous spectrum* is an unbroken band of colors coming from a source of light that emits all visible wavelengths. The *bright-line spectrum*, which consists of an unevenly spaced array of lines of different colors and brightness, shows that its source is sending out rays of specific wavelengths. The *dark-line spectrum* is a continuous spectrum with dark lines in exactly the same positions as in the bright-line spectrum for the same element. No one understood these lines until in 1859 the German physicist Gustav Kirchhoff (1824-1887) showed that each chemical element produced a distinct pattern of lines in the spectrum of the Sun. He correctly deduced that the dark lines are caused by the absorption of light by the same element, as is the case when the Sun's rays pass through its cooler outer gases and Earth's atmosphere. We now know that the bright lines are emitted by a gaseous element such as neon or sodium, and the corresponding dark lines are absorbed by the same element when its light passes through cooler gas.

The thousands of dark lines of the sun's spectrum tell us what elements it contains. By matching the dark lines of the sun's spectrum with the white lines of the bright-line comparison spectrum of say, glowing iron vapor, we know that the sun has iron vapor. Other elements can similarly be identified.

Spectroscopy is the analysis of light spectrum to determine the object's chemical composition, temperature, pressure, movement and velocity. By 1863 spectroscopy had allowed the English astronomer William Huggins to compile a catalog of stellar spectral lines. He also found that the Great Nebula in Orion was gaseous and contained hydrogen, which is found in the sun and in the spectrum of a nova. This is the first evidence that all stars contain hydrogen.

A more important application of spectroscopy is in determining whether an object is moving away from or toward Earth. In 1868 Huggins found that the dark lines of the star Sirius had shifted toward the red end of the spectrum; it had undergone a decrease in frequency, i.e., a lengthening of wavelength. In 1843 the Austrian physicist Christian Doppler (1803-1853) observed that when a sound (such as a train siren) moved toward an observer it increased in pitch, and trailed off as it moved away from her. This is known as the *Doppler effect*. The French physicist Hippolyte Louis Fizeau (1819-1896) independently discovered a similar change in frequency for light phenomena in 1848, and effected the first direct measurement of the speed of light in 1849. The shifting of spectral lines toward the red end, known as *redshift*, that Huggins found meant by the Doppler effect that Sirius was receding from Earth along the line of sight. Conversely a shift toward the violet end (a blueshift) means motion toward Earth along the line of sight. If the star moves at right angles to the line of sight no shifting of spectral lines occurs.

Studies begun in 1912 showed that most spiral nebulae were moving away from Earth, i.e., they were redshifted. In 1929 the American astrophysicist Edwin Hubble (1889-1953), using spectroscopy and the Doppler effect, determined that the farther away a galaxy is, the faster its velocity of recession. He thus formulated the empirical law, known as *Hubble's Law*, that galaxies move away from each other at the speed proportional to their distance, thereby giving empirical evidence that the universe was expanding, and laying the foundation for the Big Bang theory of the origin of the universe. The current expansion rate of the universe (ratio of velocity to distance) is referred to as the *Hubble Constant*.

2.0 The Telescope

Advances in the design and construction of the *telescope*, from the optical reflecting model to the refracting lenses, the catadioptric telescope, and the radio telescope, and the invention of photography and motion pictures, digital imaging, the computer, and satellites extend our capabilities to see farther and experiment more with our observations of the cosmos.

Refracting telescopes use a precisely ground lens at the top of the tube (the objective) to gather the star's light rays which are then bent (refracted) to a focus, and sent on to be seen through an eyepiece at the opposite end. Because of this construction refracting telescopes necessitate long tubes. The largest of refractors is the 40-inch telescope at the Yerkes Observatory at Williams Bay, Wisconsin. Reflecting telescopes reflect light collected by an objective mirror situated at the bottom of the tube, and send the light rays to an angled mirror farther up, where they are reflected to the eyepiece. In 1917 the 100-inch Hooker telescope was built on Mount Wilson, California. Other important reflectors are the 84-inch telescope of Kitt Peak Observatory, Arizona, and the 82-inch of the McDonald Observatory on Mount Locke, Texas. The 200-inch Hale Telescope on Mount Palomar, California, completed in 1948, was the world's largest until the Russians finished construction of their 240-inch Bolshoi Telescope in the Caucasus Mountains in 1977. But the current world's biggest are the Keck I Telescope (completed in 1992) and the Keck II Telescope (completed in 1995), both 400 inches in diameter, on Mauna Kea, Hawaii. The catadioptric telescope is a hybrid between the refractor and the reflector, in which light is reflected to a corrector lens near the top by a mirror mounted at the bottom of the tube, and transmitted to the eyepiece at the bottom. With proper accessories the hybrid Schmidt-Cassegrain is suitable for astrophotography, and the Maksutov is a perfect instrument for planetary observation.

All optical telescopes may be equipped with photographic equipment using fast, high-resolution film. In the 1970's light-sensitive electronic imaging cameras called charge-coupled devices (CCD's), which record starlight in pixels with a chip similar to the ones used in home camcorders. CCD cameras are available for the amateur astronomer. The lowest resolution of an amateur CCD camera is 196 x 165 pixels with the top-end camera reaching 4,000 x 4,000 pixels. And chips are getting larger, just like the microprocessor in your personal computer is getting faster and more powerful. With a top-end CCD camera, coupled to a telescope with a focal length of a least 1,000 mm, and image-processing software, today's amateurs can produce pictures of stars that rival the best ones achieved by the 200-inch Hale Telescope.

To minimize the effects of atmospheric conditions on the resolution and sharpness of ground-based telescopes, some telescopes are put into Earth's orbit. The most famous is the 95-inch Hubble Space Telescope launched in April 1990, which is controlled by a team of 400 astronomers and computer scientists at the Space Telescope Science Institute (STScI). It has provided spectacular photographs in visual, near-infrared, and ultraviolet wavelengths, and spectroscopic observations of nebulae, galaxies, and interstellar gas with the sharpness and resolution never before achieved. A new-generation space telescope is being readied for operation this year. Progress in computer-controlled adaptive optics system can now minimize the effects of turbulent atmospheric conditions on ground-based telescopes, and the technology is extended to all newer large telescopes.

While optical telescopes with the aid of spectroscopy focus on light radiation, radio telescopes peer deeper into space to uncover objects that optical telescopes cannot see, such as very distant galaxies, black holes, and cosmic radiation. Radio telescopes have huge saucer-shaped dishes as antennas to collect radio waves and feed them to special receivers, which record the strength and wavelengths of the signals and the direction from which they came. Among the largest radio telescopes are the 250-feet dish antenna of the University of Manchester steerable radio telescope at Jodrell Bank, England, and the world's largest antenna, 1,000-feet in diameter, of the non-steerable radio telescope of Cornell University located at Arecibo, Puerto Rico. The world's largest array of radio telescopes is the Very Large Array (VLA) near Socorro, New Mexico, consisting of 27 dish antennas, each 80-feet in diameter, arranged in a giant Y-shape, and connected together using a technique known as *interferometry*. This ingenious technique enhances resolution so much it now applies to some giant newer telescopes. Among the new interferometers are the twin 336-inch mirrors of the Large Binocular Telescope (LBT) in Arizona, the Keck telescopes in Hawaii, and the four 328-inch telescopes of the European Southern Observatory's Very Large Telescope (VLT) in Chile.

3.0 The Periodic Table of The Elements

In the late 1860's the Russian chemist Dmitri Mendeleev (1834-1907) arranged the 63 known elements (up from the Greeks' four elements of earth, water, fire, and air) into the first *periodic table of the elements* based on their atomic weights, and sorted them into groups with similar chemical properties. Thus sodium and potassium share similar properties and belong to one family whereas carbon, silicon, and titanium, members of another family, share a different set of properties Where gaps existed in the table, he was able to deduce their properties, and thus predicted their discoveries. The periodic table became essential in our understanding of the elements that make up the universe. But Mendeleev had no idea that the atom's weights and properties were indicative of its internal structure. Since Mendeleev's time, more elements have been discovered or created artificially, so that the number of known elements now stands at 115.

4.0 The Internal Structure of the Atom

In the Greek antiquity days, Democritus (c. 460-370 B.C.) had advanced the notion of the atom as the smallest indivisible element of matter. When scientists investigated the atom in the 19th century, they found evidence that the atom had structure, i.e., they are not fundamental. In 1895 the discovery of X-rays by the German physicist Wilhelm Roentgen (1845-1923) was followed by the French physicist Henri Becquerel's (1852-1908) discovery of *radioactivity*, the process by which one element is transformed into another. By this time scientists had found that not all elements are stable. The nuclei of heavy elements such as thorium, radium, uranium, and plutonium are radioactive, i.e., they decay into nuclei of lighter elements, releasing energy in the process. The Polish scientist Marie Curie née Sklodowska (1867-1934) and her French husband Pierre Curie (1859-1906) devoted their lives to studying radioactivity, and discovered two new elements polonium and radium. In 1897 the British physicist Joseph John Thomson (1856-1940) discovered the electron, the negatively charged particle with a mass of only 1/1837 that of hydrogen, which is the lightest element. Taken together, these discoveries and observations show that elements had smaller constituents.

The New-Zealander Ernest Rutherford (1871-1937), while studying radioactivity, showed that radioactive decay took three forms. He called the first form of radiation alpha particle, which turns out to be the nucleus of a helium atom, consisting of two protons and two neutrons, and is thus positively charged. The second type of rays was the energetic beta particle consisting of one electron or its antiparticle positron. The third are the gamma rays, which are the highest energy of light, the neutral photon. The amount of energy emitted by radioactive decay is calculated by Einstein's equation $E = mc^2$, i.e., the energy generated is the difference in mass between the original and final nuclei multiplied by the square of the speed of light. Note that this equation implies first that mass can be converted into energy and vice versa, and second that a small amount of mass can generate a tremendous amount of energy given that the conversion factor, the speed of light squared, is an enormous quantity. This is the secret of stars, whose centers are superhot furnaces where four lighter atoms of hydrogen combine into one heavier helium atom with a smaller mass than the total masses of the hydrogen atoms. The lost mass is then converted to the prodigious energy that makes the stars shine. The Sun, for example, has such an enormous mass that its 15-million degrees Celsius core converts 4 million tons of matter into energy every second for the past 4.5 billion years, with enough remaining mass for a further 5 billion years.

Most important was Rutherford's discovery of the atom's structure. In 1909 by shooting alpha particles at an extra thin zinc sulfide coated gold foil several hundred atoms thick placed in front of a curved screen, he noticed that while most of the particles went through the foil and struck the screen with flashes of light, some occasionally bounced back, some even hit the part of the screen that was in front of the foil. He hypothesized then that atoms are mostly made up of empty space, with positive nuclei repelling the positive alpha particles that hit them.

Quantum mechanics tells us that atoms are made up of subatomic particles: electrons (negatively charged), and nuclei consisting of protons (positively charged) and neutrons (no electrical charge). Further, each particle of matter has its antiparticle counterpart with the opposite electrical charge. Thus the electron has the positron as its antiparticle, the proton has its antiproton (with a negative charge), and the neutron has its antineutron (neutral). In the 1960's the American physicist Murray Gel-Mann showed that protons and neutrons have internal structures, and are made up of smaller particles that he dubbed *quarks*. Physicists now know there are six quarks, 6 leptons, and force carrier particles. Quarks come in six types or flavors: up, down, strange, charmed, top and bottom. Quarks exist only in combinations called *hadrons*, which fall into two classes: *baryons*, consisting of three quarks, and *mesons*, composed of a quark and an antiquark. A neutron has two down quarks and one up quark (udd) whereas the proton consists of two ups and one down (uud). They are therefore baryons. Other combinations are possible although unstable, and quickly decay to protons or neutrons. The other matter particle is the *lepton*. Of the six leptons, three have electrical charge, and three do not. The best known lepton is the negatively charged *electron*. The other two charged leptons are the *muon* and the *tau* both having a lot more mass than the electron. The remaining three leptons are the hypothesized *neutrinos*, which have no electrical charge, very little mass, and are hard to find.

Finally, to account for the interactions among matter particles, there are the *force carrier particles*. The *photon* is the electromagnetic force carrier particle. Photons have no mass, travel at the speed of light, and carry different energies for the entire electromagnetic spectrum from gamma rays to radio waves. It is the electromagnetic force that keeps atomic particles from flying away from one another, and thus allows atoms to bond and form molecules that make life possible. Think about it. The structure of the world exists (and that includes you and me) because protons and electrons have opposite electrical charges. That still does not explain what keeps the particles inside the nucleus together. Gravity is too weak to do the job. Physicists found that protons in the nucleus are bound by the *strong* carrier particle *gluon*, which "glues" quarks tightly together to form hadrons. The residual strong interaction between the quarks in one proton and those in another proton is strong enough to overcome the repulsive electromagnetic force. Another observation to account for is the fact that all the stable matter seems to be composed of the two least massive quarks (up quark and down quark), the least massive lepton (the electron), and the neutrinos. Unstable matter is heavier, more massive, and tends to decay spontaneously to less massive matter. Decay occurs when the *electroweak* force causes massive quarks and leptons to become lighter, less massive quarks and leptons, with the lost mass converted to energy. When a quark or lepton decays due to weak interaction, it is replaced by two or more quarks or leptons with a different flavor. The weak carrier particles are the electrically charged W+, W- particles, and the neutral Z particle. Electroweak interactions and electromagnetism have been combined into a unified electroweak theory, which so correctly predicted weak neutral currents and observed properties of the W and Z bosons, that it has been widely accepted as the Standard Model. Bosons are particles in the same quantum state that can exist together in the same place at the same time. They do not follow the *Pauli Exclusion Principle*. Particles that obey this principle, i.e., that cannot coexist in the same place at the same time, are called *fermions*.

Now we know that matter is composed of quarks and leptons, they are the ultimate building blocks of matter, and the early universe must have been a dense cosmic soup of quarks and antiquarks.

Predicted in 1928 by the British physicist Paul Dirac (1902-1984), one of the pioneers in quantum mechanics, antiparticles were discovered in 1932. When particles and antiparticles collide, they cause devastating results, annihilating each other, releasing enormous amounts of electromagnetic radiation, and creating neutral photons that our telescopes can see. Matter and antimatter exist, according to the laws of particle physics, in equal amounts in the universe. Yet observational evidence shows that at least in our galaxy and well beyond, there is more matter than antimatter. It is this bias toward matter, which still remains a mystery, that explains the existence of matter in the universe and eventually ourselves.

Before leaving this background section, let me mention one more name, Albert Einstein (1879-1955). Born in Ulm, Germany, Einstein went to Munich then studied mathematics and physics in Zurich, Switzerland, for a teaching career. Unable to find a teaching position, he worked as technical assistant at the Patent Office in Berne. In 1905 he published three significant papers. The first mathematically described random motions of tiny particles. The second described the photoelectric effect of light impact on certain metals resulting in electron emission. This work won him the Nobel Prize in physics in 1921. And the third paper was on special relativity in which he described the physics of motion at constant speeds, and discovered that mass is a form of energy as expressed by the equation $E = mc^2$. In 1916 he published his general theory of relativity, which lays the foundation for much of our understanding of the structure of the universe. It describes from planets orbiting the Sun to light bending as it passes massive objects, and predicts that the universe is expanding.

Chapter III

Twentieth-Century Theories

The origin of the universe has always been a vexing question for theoretical astrophysicists. Painstakingly and over three thousand years we as a species have pieced together one of the most fascinating stories ever told, the story of the cosmos, and of ourselves.

Within the last one hundred years, our understanding of the universe has exploded, and although a great deal remains to be learned, we now have a clearer picture of its origin and the tools to refine our theories.

We have gone from a belief in a flat earth to a that in a round earth, from placing Earth at the center of the universe to replacing it with the Sun, and finally to see our Milky Way galaxy as just another galaxy in billions of galaxies.

Most astronomers in the early twentieth century believed the universe never had a beginning, and would extend indefinitely into the future. This belief was intuitive and philosophically satisfying, and had a number of adherents through the 1950's and 1960's during a time when the Big Bang theory had already been gathering an increasing number of converts.

Keep in mind that theories in cosmology cannot be proved scientifically, but should be supported by, or be consistent with, observational evidence and known laws of physics, and have predictive power.

1.0 The Steady-State Theory

The Steady-State Theory was proposed in 1948 by the British astrophysicist Fred Hoyle, and the Austrian-born Thomas Bondi and Thomas Gold as an extension of the perfect *cosmological principle*, first introduced by the English astronomer Arthur Milne (1896-1950) in 1933. According to this view, the universe is homogeneous (the same in all places) and isotropic (the same in all directions). There is no beginning and no ending. Fred Hoyle (1915-2001) with his colleague William Fowler (1911-1995) showed that all elements from helium to heavy elements are made in the nuclear fusion taking place in the cores of stars. He also hypothesized that elements heavier than iron could form in the cataclysmic explosion of a supernova when the nuclear fuel in its core had been exhausted. Most scientists now accept this idea. However, he failed to show that enough helium was made in the stellar furnaces to account for large amounts of helium detected in the universe. Twenty-five percent of matter in the universe is made up of helium, and the steady-state theory cannot account for it.

Given that the universe was expanding (as shown convincingly by Edwin Hubble in 1929), and the critical density of the universe (density at which the expansion rate is just sufficient to prevent a recollapse) remains the same, supporters of the theory hypothesized that matter is being continuously created out of nothing.

In the early 1960's scientists discovered very distant sources of strong radio emission, called quasars, quasi-stellar radio sources. These sources were highly redshifted, and by Hubble's Law were found to be very distant, and moving away from Earth. The distant and ancient universe is therefore not the same as the younger, nearer one. The steady-state theory offers no explanation for this evolution.

The demise of the theory came when Arno Penzias (1933-) and Robert Wilson (1936-) of Bell Laboratories discovered *cosmic background microwave radiation* (CMB or CMBR) in the 1960's. With an antenna designed to track signals from the Echo satellite, they inadvertently stumbled on a radio hiss coming from all directions that they could not account for after considering all possible sources of error. This radio emission was identified, after consultation with Princeton physicist Robert Dicke, as the faint echo of the Big Bang glowing softly and fairly uniformly across the sky at about 3 degrees C above absolute zero (which is -273 degrees C), the lowest possible temperature, at which particles of matter that produce heat are at rest. This discovery earned Penzias and Wilson the Nobel Prize for physics in 1978.

The steady-state theorists could not explain this cosmic microwave background radiation. Consequently, the theory lost all credibility.

2.0 The Big Bang Theory

At this time there is nothing out there that has more currency about of the origin of the universe than the Big Bang Theory. To be more precise, the Big Bang Theory is not a theory of the origin of the universe, but of the aftermath of Big Bang. While it is not perfect, as will be discussed, it has no serious rivals.

It all began in 1915 when Albert Einstein introduced the general theory of relativity. In 1931 the Belgian cosmologist George Lemaitre (1894-1966) reasoned from the idea of an expanding universe, that if the process is reversed back in time, the pieces of the universe must have come closer together until they were crushed into a very small object which he termed “the primeval atom,” a few dozen times the size of the Sun. This “primeval atom” would then explode and eject all constituent parts in all directions, which kept splitting until the atoms of the universe formed. This basic idea was later refined as the Big Bang hypothesis, which is far different from what Lemaitre envisaged.

Einstein’s general relativity predicted an expanding universe, but the weight of tradition was so powerful that he had to introduce a fudge factor called the *cosmological constant*, a hypothetical repulsive force to balance the force of gravity, *anti-gravity,* as it was called, to bring the universe back to a stable condition, which he believed the universe ought to be in. It was not until 1929, when Edwin Hubble showed by their redshifts that all galaxies were moving away from each other at a speed proportional to their distances, that Einstein realized his error, and termed the cosmological constant “the biggest blunder of my life.” He later removed the cosmological constant from his equations, but it still remains in use for various purposes.

Besides, the cosmological constant would result in a very unstable model. If the universe grew slightly, the *vacuum energy density* stays the same. Recall that space vacuum is filled with virtual particle-antiparticle pairs, which have density in their very brief life before their mutual annihilation. At the same time, the matter energy density decreases slightly, and the resulting net negative gravitational acceleration would make the universe grow even more. Conversely, if the universe shrank slightly, the net positive gravitational acceleration would make the universe shrink further.

In the early 1920’s the Russian physicist Alexander Friedmann was the first to accept Einstein’s general relativity, which called for a universe in motion. Friedmann envisioned two scenarios. (1) *A Closed Universe*, which at large enough scales, is homogeneous and isotropic (by the cosmological principle) and in motion (by using Einstein’s equations). The universe begins with a Big Bang, and continues its expansion for billions of years. This is the stage we are in now. After long enough periods of time the gravitational pull of all matter will stop the expansion, and the universe will pull back upon itself, reversing the expansion. Eventually the universe collapses into a singularity, and the result is the *Big Crunch*. (2) The second scenario is the *Open Universe*, in which there is not enough matter to effect the collapse, and the universe expands forever, albeit at a slower rate of expansion as time goes by. Eventually, all the stars exhaust their fuel, and become cold and dark. Intermediate between these two possibilities lies the *Flat Universe*, which expands forever until the expansion rate approaches zero.

Whether the universe will expand forever or recollapse depends on the ratio of the density of the universe to its critical density. Recall that critical density is the density sufficient and necessary to keep the expanding universe from a recollapse into a Big Crunch. Current data suggests that the universe’s density is less than or equal to the critical density, and hence, the universe will expand forever.

2.1 A Brief History of Big Bang

The Big Bang begins not as a black hole, but as a singularity. A black hole, too, is a singularity, but one extending through all time at a single point whereas the Big Bang singularity extends through all space from a single instant. Before the Big Bang, there was nothing. Recall that at a singularity all known laws of physics do not apply. A zero second, there is only a tiny point of zero volume with infinite density and temperature. Time and space come into existence. A region about 10^{-33} cm across is homogeneous and isotropic. There is perfect symmetry. The temperature stands at 10^{32} K. The quantum wavelength of the universe is greater than the universe itself. All four fundamental forces of nature, gravity, electromagnetism, the strong nuclear force, and the weak nuclear force are united into one.

At 10^{-43} second, also called the *Planck time*, the symmetry of the Grand Unified Theory (GUT), the theory that describes the unification of the fundamental forces, is broken, and gravity separates from the other forces. The temperature drops to 10^{27} K to 10^{28} K at 10^{-35} seconds after the Big Bang during the period called *false vacuum*. The inflation era begins at 10^{-34} second, and ends at 10^{-32} second. The universe expands rapidly, doubling its size every 10^{-37} second until the false vacuum decays, and the cosmological principle exists temporarily. The large vacuum energy density that drives inflation, around 10^{71} gm/cc., is converted into heat. At the end of inflation the expansion rate is extremely fast so that the apparent age of the universe is only 10^{-35} seconds. This inflation, acting on the cosmological principle, explains the uniformity of temperature throughout the universe as we observe it today.

At 10^{-32} second the electroweak era begins, and between 10^{-32} second and 10^{-11} second, the electroweak force breaks down to the weak nuclear force (responsible for radioactivity), and the electromagnetic force, which holds the subatomic particles together. The temperature is at 10^{15} K, and the universe is 2 light-minutes across. We are entering the era of the quark soup.

The next period begins at $2x10^{-7}$ second, at a temperature between $2x10^{13}$ K and $1x10^{13}$ K, with the universe about the size of the solar system. Tau and antitau annihilate, and the matter energy density is no longer sufficient to create quarks.

At $1x10^{-6}$ second, the universe now at 1.4 light-days enters *baryogenesis*, or creation of excess baryons. The temperature is $12x10^{12}$ K, the energy density is no longer sufficient to create protons, so annihilation of baryons takes place. Yet there is evidence of bias toward matter, 100,000,001 protons for every 100,000,000 antiprotons (and 100,000,000 photons). Annihilation wipes out all baryons and antibaryons leaving 1 baryon per hundred million. Small as it is, this bias toward matter proves to be crucial to the dominance of matter.

As the universe cools, at $7x10^{-5}$ seconds and a temperature of $3x10^{12}$ K, muons and antimuons annihilate.

The universe grows to 4 light-years, and cools to 10^{10} K, one second after the Big Bang. The weak interaction freezes out with a proton/neutron ratio of about 6.

The universe continues to grow and cool until 100 seconds after the Big Bang, when the temperature drops to 1 billion degrees, 10^{9} K. Electrons and positrons annihilate to create more photons while protons and neutrons combine to make deuterons. Nucleosynthesis (helium making) begins when almost all of the deuterons combine to make helium. The final result: the universe is 3/4 hydrogen, 1/4 helium by mass; with a deuteron/proton ratio of 30 parts per million. There are about 2 billion photons per proton or neutron.

Two hundred seconds after the Big Bang the universe grows to 55 light-years and cools to $8.4x10^{8}$ K.

After one thousand seconds nucleosynthesis stops, no more helium is produced, and the universe is a cool $4x10^{8}$ K.

One month after the Big Bang the universe expands faster than the conversion of radiation field to a blackbody spectrum, so the spectrum of the Cosmic Microwave Background (CMB) preserves information back to this time. A *blackbody* is an object with a constant temperature that absorbs all radiation that hits it

Matter density equals radiation density 3,000 years after the Big Bang. The temperature is 60,000 K. *Dark matter*, which does not emit, absorb, or propagate light, but has gravity, starts to collapse.

Three hundred thousand years after the Big Bang, protons and electrons combine to form neutral hydrogen, and the universe becomes transparent. The temperature is 3,000 K. Matter predominates. Ordinary matter can now fall into the dark matter clumps. The CMB travels freely from this time until now.

The first stars form 100-200 million years after the Big Bang. One billion years go by before the first galaxy form. Supernovae explode and spread carbon, nitrogen, oxygen, silicon, magnesium, iron, all the way up through uranium throughout the universe. Galaxies continue to form as many clumps of dark matter, as stars and gas merge together. Finally clusters of galaxies form. And by about two billion years most elements have formed.

The solar system and Sun formed 4.6 billion years ago. And life began to emerge on Earth about 8.5 billion years after the Big Bang.

We are now 12-15 Gyr (gigayear or billion years) after the Big Bang, and the temperature of the universe is uniformly cold at 2.726 K. Some accounts put our universe's age at 13.7 billion years.

2.2 Evidence for the Big Bang

Recall that Hubble's Law shows the universe is expanding. Furthermore, it is expanding at an accelerating pace. This evidence comes from observing the brightness of distant supernovae. The redshift tells us by what factor the supernova has receded since its explosion.

The existence of the blackbody CMB, cosmic microwave background, indicates that the universe has evolved from a dense, isothermal state.

The existence of quasars, which are very distant sources of radio emission, shows that the ancient universe is far away whereas the more recent universe is closer.

2.3 Questions and Elucidations on the Big Bang

Cosmology is a branch of physics that studies the origin, structure, and evolution of the universe. Since nothing exists outside the universe, the observer must also be inside the universe. Unlike in other sciences where the observer maintains her objectivity by staying outside looking in, the cosmologist is inside trying to describe the environment. It is just like she is in one tiny corner of a huge building trying to understand the structure of the entire building without leaving her corner. Anything she knows about the building comes from observations, experiments, and a set of rules (laws) that have proven to have predictive power. So it is with theories about the universe, including the Big Bang Theory.

It is assumed that there was nothing before the Big Bang. In other words, everything begins with the Big Bang. At time zero the Big Bang is a singularity. This means nothing can be defined, not even time since spacetime is singular. Although it is hard to conceive that an infinite universe expanding forever should have begun all by itself along with the spacetime curvature, there is evidence for the concept of self-organization of complex systems, the Darwinian theory of evolution being one. Recently the same concept has spread to various disciplines from physics to biology and economics. The theoretical physicist Lee Smolin at Penn State University advanced the idea that the most important principle of 20th century physics is that all observable properties of things are about relationships. The provocative conception is to extend the Darwinian idea that the structure of a system must be formed from *within* by natural processes of self-organization, including the properties of space and time. Self-organized systems turn out to be complex systems in terms of the interactions of the parts within the systems. Space and time too are defined in terms of relationships. Since everything that exists, exists inside the universe, there can be nothing outside the universe to create it.

At the time of the Big Bang the universe is a singularity, where no known laws of physics apply. Both quantum mechanics and the general relativity break down. That is a loose end that occupies physicists for the rest of the twentieth century until now. Physicists are hard at work trying to find a single and elegant set of laws that describe all the fundamental forces of nature. Theoretically, they run into a thorny problem, the mathematical incompatibility of quantum mechanics and the general theory of relativity. Quantum mechanics provides a superb description of the smallest structures such as electrons and quarks. And general relativity does equally well for the force of gravity that applies to large structures such as stars, galaxies, black holes, and ultimately, the universe. But in extreme circumstances which combine enormous large-scale structures (requiring general relativity) and tiny structures (requiring quantum mechanics), such as a spacetime singularity, in the center of a black hole, or the state of the universe just before the big bang, the incompatibility of quantum mechanics and general relativity yield nonsensical answers.

We obviously need a theory that combines the strengths of both. Einstein had spent the last 30 years of his life on that effort, unsuccessfully trying to develop a “theory of everything.” At this time there are several candidates, all varieties of the string theory. The problem to be resolved lies in the bad behavior of equations when particles interact with each other across minute distances on the order of 10^{-33} cm, called the *Planck length.* String theory is based on the premise that on extremely tiny scales particles do not behave as points but rather as closed loops of string with radii approximately of Planck length. This view provides a way to harmonize gravity and quantum mechanics into a unified theory. Unfortunately, the string hypothesis requires that the universe contain ten spatial dimensions. Instead of going too far into an esoteric hypothesis that keeps scientists up at night, suffice it to say that we are still nowhere near a solution. This leaves room for all of us with imagination to plunge in and have some fun probing, hypothesizing, and agonizing in the process. As an aside, modern particle accelerators, such as the 27-km circular one at the Centre Europeen de Recherches Nucleaires (CERN) near Geneva, can probe particles down to distance scales around 10^{-16} cm only.

If the universe is expanding, what is it expanding into? This is a misconception fostered by the balloon analogy used to explain the universe’s expansion. Imagine the universe is like a balloon being blown. Then any two dots on the balloon surface will move away from each other as the balloon expands. Unfortunately this analogy is a 2-D spherical object (the balloon’s surface) expanding into a 3-D space. Nothing that we can measure about the universe shows anything about the larger 3-D space. Everything we measure is within the universe, and the universe has no boundary, no edge, or center of expansion. Thus the universe is not expanding into anything. Keep in mind that what we can observe is only a tiny part of the universe.

Is there a possibility of a Big Crunch, where the whole universe throws itself into reverse expansion and implodes? That depends, as seen above, on the density of the universe and the critical density. If the universe’s density is less than or equal to the critical density, there will not be a Big Crunch, and the universe will expand forever. However, some scientists speculate that a Big Crunch may not be the end. Perhaps another Big Bang will follow this Big Crunch, and thus bangs follow crunches which follow bangs in an endless cycle known as an oscillating universe. The only problem is no one has yet developed a theory to explain how this universe works.

The inflation era is introduced very early after the explosion to bolster the standard Big Bang theory, which sees the universe as flat, to explain why the temperature of the universe is the same everywhere, now standing at 2.726 K. While the universe is still very small it is a lot easier for it to go through phase transitions and reach uniform temperatures than when it is larger. Phase transitions are various states of matter as its temperature changes, as observed in water when it changes from solid to liquid, and gaseous states, and reaches thermal equilibrium. But the universe must be out of equilibrium from the very beginning in order for matter to form.

Inflation relies on the modern particle physics findings that extremely high temperatures lead to a form of matter called *false vacuum*, which causes gravity to be repulsive rather than attractive, and allows the expansion of the universe to accelerate exponentially, instead of decelerate, in a very short time.

Where does matter come from? Recall that during baryogenesis, matter forms, 100,000,001 protons for every 100,000,000 antiprotons (and 100,000,000 photons). Annihilation wipes out all baryons and antibaryons leaving 1 baryon per hundred million. If the universe contains matter and antimatter in equal amounts, they annihilate one another completely, release energy, destroy all mass, and there is nothing left to make stars, you and me. In 1964, J. H. Christenson found evidence of this bias toward baryons during interactions among certain baryons in laboratory experiments. It is this fundamental matter-antimatter asymmetry (also known as *charge parity violation*) that insures dominance of matter in the universe.

We know from thermodynamics, the physics of hot systems, that matter "loses its memory" at high temperatures, meaning it does not remember its former state, and takes on the ambient temperature, eventually to end up at the same temperature as its environment. This is called thermal equilibrium. But in order for matter to pass from one state to another, it must be out of equilibrium. Fortunately, this is precisely what happens every day: when water vapor condenses into liquid, it passes from one phase to another, a phenomenon called phase transition. The early universe went through phase transitions as well. However, knowing that nature exhibits a bias toward matter is not the same as explaining the mechanism of this bias. We have yet to come up with a particle physics model to account for this mechanism.

Finally, does dark matter exist? What is made of? Nucleosynthesis suggests that dark matter is non-baryonic, is not ordinary matter, i.e., not proton, electron or neutron, and that the density of ordinary matter (made from atoms) is at most 10% of the critical density. Thus most of the universe does not emit, scatter, or absorb light, and is not even made out of atoms. This invisible matter manifests itself only by gravitational interaction.

One piece of evidence for dark matter is the velocities of galaxies and galaxy clusters. In one 1930's study made of the Coma cluster and the Virgo cluster revealed that their velocities were ten to a hundred times larger than expected. One explanation could be that some invisible matter exerts gravitational pull that accelerates the clusters' motion.

Another piece of evidence for dark matter relates to Kepler's laws of motion, that the speed of rotation of a galaxy is a function of its distance from its center and the galaxy's total mass within the orbit. By finding the rotation velocities along a galaxy, we can determine the mass of the galaxy inside that orbit. Along the edge of a galaxy the amount of light quickly starts falling off, and we would expect the rotation speeds to diminish. Instead, the rotation speeds remain unexpectedly high, which indicates that there is a great deal of invisible mass in the galaxy.

When the masses and luminosities of the stars near the Sun are added up, astronomers find that there are about 3 solar masses for every 1 solar luminosity. A comparison of the total mass of clusters of galaxies and the total luminosity of the clusters shows about 300 solar masses for every solar luminosity. Thus most of the mass in the universe is dark.

Vera Rubin (1928-) observed that the velocities of stars revolving around the galaxy's center remained fairly constant regardless of their distances from the center, unlike in the solar system, where planets closer to the Sun move faster than those farther out. This observation can be accounted for only if vast invisible halos exist around the galaxies and galaxy clusters to provide gravitational pull. Calculations estimate that dark matter adds up to ten times more mass than the visible stars, dust and gas.

The amount of matter in the universe is expressed in terms of a parameter called *Omega*. A closed universe, massive enough that it eventually collapses back onto itself, has Omega larger than 1; an open universe, one that expands forever, has Omega less than 1; and a flat universe, balanced between the two, has Omega of 1. The amount of visible matter in the universe is about Omega equals 0.05. If the total of all of the mass is Omega equals 1, then dark matter makes up 95% of the universe. Even at a more realistic Omega no larger than about 0.4, the amount of dark matter still makes up about 35% of the universe.

Candidates for dark matter include the ubiquitous *neutrinos* (hot dark matter), which are particles with little mass but exist in huge quantities, one billion for every proton or electron; cold dark matter *WIMPs*, or weakly interacting massive particles, heavy particles that only interact weakly with other matter. Predicted by theory, WIMPs have so far remained undiscovered. Another candidate goes by the name of *MACHO* (massive compact halo objects) that could exist in vast halos around galaxies. Brown dwarfs, ranging in size from a normal star to a planet, could be a type of MACHO. They form like stars but have so little mass that nuclear fusion reactions did not occur.

Given the huge mass of dark matter, the fate of the universe may well depend on it. More mass means the universe will eventually collapse, and less mass means the universe will expand forever.

Conclusion

The universe is a fascinating subject of inquiry. Within the twentieth century, we have gained an unprecedented understanding of matter, and how it forms and makes up everything in it. The elements on which life is based, carbon, oxygen, hydrogen, nitrogen, and more were all made from matter that began forming by baryogenesis at $1x10^{-6}$ second after the Big Bang. Since then the universe has expanded its reach, and keeps going.

Out of this evolution, life appeared 8.5 billions after the momentous Big Bang. Our species began its fantastic career on Earth only about 3 million years ago, a tiny fraction in the long timeline of the universe. Yet it is our species that has pushed its curiosity beyond daily concerns to ask inquisitive questions about how we came about, and where we go from here.

A great deal more remains to be learned, but just like the universe, our inquiry and knowledge keep expanding. It is with optimism, tempered by humility, that we face our future, in which the survival of our species may just depend on how much we understand the universe, and dare to venture forth into other worlds in our galaxy and beyond.

References

Burnham, Robert, Dyer, A., Garfinkle, R. A., George, M., Kanipe, J., Levy, D. H. 2002. *Practical Skywatching.* San Francisco: Fog City Press

Sagan, Carl. 1983. *Cosmos*. New York: Random House

Big Bang

http://www.kheper.net/cosmos/universe/universe.htm

http://wwww.astro.ucla.edu/~wright/BBHistory.html

http://www.damtp.cam.ac.uk/user/gr/public/bb_history.html

http://www.damtp.cam.ac.uk/user/gr/public/bb_home.html

http://origins.jpl.nasa.gov/

Black Holes

http://www2.corepower.com:8800/~relfaq/universe.html

http://casa.colorado.edu/~ajsh/collapse.html

http://www.damtp.cam.ac.uk/user/gr/public/bh_home.html

http://cosmology.berkeley.edu/Education/BHfaq.html

Cosmology

http://www.astro.ucla.edu/~wright/cosmology_faq.html

http://www.damtp.cam.ac.uk/user/gr/public/cos_home.html

http://www.astro.ucla.edu/~wright/cosmolog.htm

Dark Matter

http://www.damtp.cam.ac.uk/user/gr/public/gal_dm.html
http://www.astro.queensu.ca/~dursi/dm-tutorial/dm1.html

Galaxies

http://www.damtp.cam.ac.uk/user/gr/public/gal_home.html
http://www.damtp.cam.ac.uk/user/gr/public/gal_lss.html

Gravitational Lensing

http://vela.astro.ulg.ac.be/themes/extragal/gravlens/bibdat/engl/grav_lens.html

http://www.iam.ubc.ca/~newbury/lenses/research.html

http://www.theory.caltech.edu/people/patricia/obsertop.html

Hawking Radiation

http://casa.colorado.edu/~ajsh/hawk.html

Stephen Hawking's Universe

http://www.pbs.org/wnet/hawking/html/home.html

Hubble Space Telescope

http://clyde.as.utexas.edu/SpAstNEW/Papers.html
http://news.bbc.co.uk/2/hi/science/nature/2940333.stm

Particle Physics

http://www.particleadventure.org/particleadventure/index.html

http://www.hep.net/documents/drell/sec3.html

Phase Transitions in Early Universe

http://www.damtp.cam.ac.uk/user/gr/public/cs_phase.html

Relativity, General and Special

http://math.ucr.edu/home/baez/relativity.html

http://math.ucr.edu/home/baez/gr/gr.html

http://casa.colorado.edu/~ajsh/relativity.html

http://casa.colorado.edu/~ajsh/sr/sr.shtml
http://www2.corepower.com:8080/~relfaq/relativity.html

Space Telescope Science Institute (for Hubble Space Telescope)

http://www.stsci.edu/resources/

Spacetime

http://www.theory.caltech.edu/people/patricia/st101.html

Singularities

http://casa.colorado.edu/~ajsh/singularity.html

Superstring Theory

http://www.lassp.cornell.edu/GraduateAdmissions/greene/greene.html

Wormholes

http://casa.colorado.edu/~ajsh/schww.html

http://cosmology/berkeley.edu/Education/BHfaq.html