2016

Earth's Place in Space

John J. Renton

Thomas Repine

EARTH'S PLACE in SPACE

I've always thought that a story should start at the beginning. Since this book is the story of Earth, we will start at the beginning. According to the astronomers, in the beginning, there was no need for geology because there were no minerals or rocks; there was no Earth; there was no Sun; there were no stars or planets. According to the astronomers, there was a time when even our present universe didn't exist. In the 1920s, the Belgian astronomer Georges Lemaitre hypothesized that everything presently contained within the entire Universe was once compressed into in a sphere he called the "primeval atom"; a sphere that was possibly the size of a golfball! As you might suspect, the conditions of temperature and pressure that would have existed in that golfball-sized sphere were so extreme that matter as we know it could not possibly have existed. Even the atoms of which matter is made could not have existed; even the parts of the atoms would have not survived such conditions. What, then, was contained within such a sphere? According to Lemaitre, his primeval atom contained quarks which physicists consider the most basic of all atomic particles that they are the smallest subdivision of matter. Then where did the Universe come from? The astronomers say that about 13.7 billion years ago, Lemaitre's primitive atom exploded and all of the quarks were released into space; an event called the Big Bang. The term Big Bang, by the way, was coined as a derogatory term by a leading astronomer of the 20th century, Fred Hoyle, who refused to accept such an origin.

The Formation of Stars and Galaxies

With the smallest fraction of a second following the Big Bang, the quarks combined to form protons while bundles of energy called electrons were created from the surrounding energy. In less than a minute after the Big Bang, protons and electrons began to join together to create atoms of hydrogen, ${}_1H^1$, that began to expand into space like a huge, growing bubble. Soon, hydrogen atoms became attracted to each other by the force of gravity and formed groups of hydrogen atoms that began to rotate and collapse under the force of gravity toward a central core. During this collapse, the core of the growing mass of hydrogen began to heat up as some of the gravitational energy was converted to heat. When temperatures within the cores of these rotating, collapsing masses of H atoms reached about $15M^{O}$ K, a thermo-nuclear reaction started that converted four H atoms into a He atom. I would point out that because a single hydrogen atom consists of 1.008 atomic mass units, four hydrogen atoms would give a single helium atom a mass of 4.032 atomic mass units (an atomic mass unit is simply the unit of measurement of the amount of matter contained within the nucleus of an atom). We seem to have a problem here in that a helium atom actually consists of 4.003 atomic mass units. Simple arithmetic indicates that for each of these transformations, 0.029 atomic mass units were unaccounted for. Could they have been lost? No, mass can't be lost. Could it have been destroyed? No; however Albert Einstein said that while mass cannot be destroyed, it could be converted to energy according to his equation $E = mC^2$. Although 0.029 units of mass doesn't seem very much, when multiplied by the square of the speed of light, C^2, the amount of energy, E, will be very large. Once this reaction begins, a star has been created. Our Sun is a star; a relatively young and small star as you will discover later in this discussion. The importance of stars is that without them, you and I would not be here.

After a million or so years, the number of stars within the expanding bubble of hydrogen atoms became so numerous that they began to be attracted to one another, creating a huge groups of stars called galaxies. How many stars make up a galaxy? The astronomers estimate that the average galaxy contains a few hundred billion stars. Our personal star, the Sun, belongs to the Milky Way Galaxy. Once formed, the galaxies began to rotate and collapse along the axis of rotation. I'm sure that you are aware that all rotating bodies collapse along their rotational axes. For example, the polar diameter of Earth is 27 miles (43 km) shorted than the equatorial diameter. While galaxies have different shapes, the astronomers tell us that because of their rotation they are discus-shaped with most of the stars concentrated in the center. Our Universe consists of galaxies. How many galaxys are in the Universe. Probable several hundred billion

Measuring Distances in Space

I cannot convey to you the size of the Universe. The best I can do is give you some idea of the distances between bodies within the Universe. Because of the enormity space, our earth-bound units, like miles and kilometers cannot be used to measure distance in outer space. Miles or kilometers can be used as long as one is restricted to the Solar System. For example, Earth to the Moon is only 238,000 miles, plus or minus a thousand miles or so. Earth to the Sun is about 92 million miles while from the Sun to the most distant reaches of our solar system is about 4 billion miles. However, once one goes beyond the solar system, the distances are so great that Earth-bound units are far too small. To measure distances in space, astronomers have devised other units of measurement, the best known being the light year, (LY). One light year is the distance a photon of light, moving at 186,000 miles per second (299,000 km/sec), travels in one year, a distance of about six trillion miles. Now for some distance measurements. The Milky Way Galaxy has a diameter of 100,000 LY and a thickness along the rotational axis of 20,000 LY. The nearest star to our sun, Alpha Centauri, is about 4 LY away. The Sun, near the outer edge of the galaxy, lies 30,000 LY from the center. The nearest galaxy, Andromeda, is 2.5

million light years away. Keep in mind what these distances say; traveling at the speed of light, it would take 100,000 years to cross the galaxy. If you want to visit Andromeda, it would take you 2,5 million years to get there. Assuming you want to return, it would be a round trip of 5 million years; that's about how long humans have been on Earth. It should be obvious that such trips are only possible on re-runs of Star Trek; unless Albert Einstein theory that the rate at which time passes decreases as ones velocity in space increases is correct. But that's probably a topic for another story.

Until 1927, it was thought that the Milky Way was the only galaxy within the universe. Then, Edwin Hubble, the namesake of the Hubble Telescope, published a paper indicating that what had been thought to be mere dust clouds within our own galaxy were, in fact, distant galaxies, a discovery that vastly expanded the dimensions of the Universe. Today, best estimates are that the universe contains about 150 billion galaxies. Hubble went on to show that all galaxies are moving away from each other, a finding that led to the concept of an expanding universe. It was, in fact, this published report that prompted Georges Lemaitre to theorize that if the Universe was expanding, it must have originated in the form of a compact primeval atom.

The Evolution of Stars

Now that you understand how stars are created, you can see that they are in reality fires in which hydrogen is being burned as the fuel and helium is being created as the ash. But being a star or a log in your fireplace, eventually the fuel is consumed and the fire goes out; meaning that stars have life expectancies. Stars are classified based on how much mass they contain using the mass of our Sun at one solar mass as the measuring stick. Our Sun, for example has a diameter of about 1.4 million km and represents one solar mass. The smallest stars are about 0.5 the mass of our Sun while the largest stars may be 100 or more times that of our Sun. Regardless of the size of the star, they all spend about 90% of their lives using hydrogen as a fuel. But sooner or later, when most of the hydrogen has been converted to helium, the stars begin to die by collapsing. The reason why they collapse is because the mass of each helium atom is four times that of each hydrogen atom. As the mass of the core increases, the gravitational energy affecting the core increases and results in its collapse. As collapse takes place, some of the gravitational energy is converted to heat resulting in an increase in the temperature of the core. The smallest stars simply collapse down to what the astronomers call white dwarfs which are very hot stars about the diameter of Earth and after a very long time, simply burn out. The larger stars, including our Sun, respond to the collapsing, heating core by expanding into what are called red giants. With high levels of energy available within the core, helium becomes the fuel and larger atoms are created including elements such as carbon, oxygen, silicon, and iron to name a few. What is so important about the ability to create new, larger atoms? Without carbon, you and I nor any other living thing would exist; we are all carbon products. Without oxygen, the higher forms of life that require oxygen for respiration couldn't exist. Silicon, you will discover in a later chapter, is a basic building block for Earth's major minerals and rocks. And where would we be without iron? After a short period in the red giant phase, the star giant stars rapidly collapse. While the smaller stars simply collapse and form other stars, what happens to the larger stars is what is so important. During their collapse, the energy being generated within the core becomes so great that the star explodes as a nova or supernova. It is during the nova or supernova that all of the other atoms out to the largest, uranium, were formed. In short, all of the natural elements from hydrogen to uranium were created during the life and death of the stars. You can now see why I said that without the stars, we wouldn't be here. It is ironic that with all of the courses I took as an undergraduate chemistry major, no instructor ever told us how the elements originated.

Following the nova or supernova, most of what remained of the star is blasting into space to form cosmic dust. Cosmic dust consists of bits and pieces of high-density materials such as metals, minerals, and rocks, while the light elements combined to form frozen gases or ices. This mixture of high- and low-density particles is then dispersed throughout interstellar space. The importance of the cosmic dust is that it is the stuff of which planets are made.

The Formation of Planets

I find it interesting that with everything we have learned about space in the past century, the most widely accepted hypothesis for the origin of the planets in our solar system dates back to 1755 when a German philosopher, Immanuel Kant, proposed that the planets formed from a cloud of interstellar dust and gas, a mixture we now call cosmic dust. Modern astronomers believe that the first step in the formation of a solar system is the creation of a new star, possibly caused by forces generated by a nearby supernova, surrounded by a sphere of cosmic dust. The next steps leading to the formation of a series of planets surrounding the newly-formed star are the result of two forces created by all stars, namely, a magnetic field and a force called the solar wind consisting of high-energy protons and electrons that are ejected from the star's surface. As the magnetic field emanating from the newly-formed star swept through the surrounding sphere of cosmic dust, it attracted magnetic materials contained within the cosmic dust such as bits of Fe and minerals such as magnetite (Fe_3O_4) and initiated the rotation of the dust cloud that remained surrounding the star. As we've seen before, rotating bodies tend to collapse along the axis of rotation. In this case, the sphere of cosmic dust surrounding the new star collapsed to form a disc of cosmic dust that extended outward from the equatorial plane of the newly-formed star. Simultaneously, the solar wind, sorted the particles in the dust disc by density; driving the low-density ices away from the star to the outermost reaches of the dust disc, while the high-density materials, such as metals, minerals, and rock, remained closer to the star. Once the dust disc formed, gravitational forces developed eddy currents within the dust disc that drew the dust particles toward the centers of the eddies as they orbit around the star. Eventually, an odd-shaped body began to form at the center of each eddy. As the amount of material within the body increased, the increased gravitational forces formed the body into a sphere called a proto-planet. Because of the original density segregation within the dust disc, the proto-planets nearest the star were composed of metals, minerals, and rock fragments, while the outermost proto-planets were made mainly of lower-density ices. At this point, we're getting close to a planet; the prefix "proto" means "almost".

The final step is one that we've seen before. As the proto-planets grew larger, some of the force of gravity was converted to heat, causing the temperatures within the interiors of the proto-planets to rise. Eventually, temperatures within the proto-planets rose high enough for their individual components to melt. The densest melt within each proto-planet settled towards the center, creating a core. In the case of the inner planets, the core was made of iron, the most abundant metal in the Universe. Because rock particles were present in the outer portion of the original dust sphere, the outermost planets are thought to have small cores of rock. With the core in place, other components began to density-layer around the core. In the case of the inner planets, the layers overlying the iron core were made of rock with densities decreasing outward to the surface. In the case of the inner planets, the layers were made of frozen and liquid gases with outermost layers of gaseous gas. With segregation complete, the proto-planets were converted into planets.

The Solar System

According to the astronomers, our solar system was born after the creation of the Sun about five billion years ago. The solar system features a single, relatively small star surrounded by eight known planets and one dwarf planet along with more than 30 satellites, millions of asteroids and meteoroids, and about 100 named comets. The four innermost planets, Mercury, Venus, Earth, and Mars, are grouped together and called the Terrestrial Planets because of their relatively small size, rock compositions, and densities of about 6. Density is mass per unit volume and reflects the overall composition of a material. In this case, it reflects the metals and minerals of which the inner planets are made.

I think that it's always interesting to consider how our neighboring planets differ from Earth. The temperatures on Mercury range from about 450^{O}C (843^{O}F) on the sun-lit side to about -175^{O}C (- 284^{O}F) on the dark side. This extreme range is due to its near absence of an atmosphere. Any atmosphere Mercury ever had was driven away long ago by the solar wind. The lack of an atmosphere precludes heat being conducted from the sun-lit side to the dark side, resulting in the highest range of surface temperatures among the planets. Life as we know it could not possibly exist on Mercury primarily because the single absolute requirement for life as we know it, namely water, is not present.

Venus is the brightest "star" in the northern sky due to the fact that it is totally enclosed within a thick cloud cover that reflects light efficiently. Think of how light from your headlights glare back at you upon encountering a night fog; fog is simply a low-flying cloud. Temperatures on Venus are about 460^{O}C (860^{O}F) everywhere, day and night, because of a super-greenhouse effect. The Venusian atmosphere, composed of about 95% carbon dioxide (CO_2), retains heat which an atmosphere that is 90 times more dense than Earth's uniformly conducts it throughout the Venusian surface. In terms of the possibility of life as we know it, conditions on Venus are probably even more severe than those on Mercury when one considers the constant high temperatures, the high concentration of carbon dioxide in the atmosphere plus the fact that the atmosphere also contains droplets of sulfuric acid.

The third planet from the Sun is Earth. While we will discuss Earth in later chapters, a few comments are appropriate at this time. The unique characteristic of Earth is the water that exists in its atmosphere and both on and below its surface. While other terrestrial planets may have had water at some point in their early history, Earth is the only planet the presently possesses abundant water. Without water, life as we know it on Earth cannot exist. Nor would many of the processes that shape and alter the land's surface be able to operate. Chemical weathering would not attack exposed rocks and produce important products such as the clay minerals that are the basis for the soils that support life on land. The major agents of erosion, streams and glaciers, would not sculpt the land's surface. Many of the materials that are responsible for the rocks seen throughout regions such as Appalachia would not be available. In particular, without aqueous environments, limestones such as those exposed throughout the Great Valley and those mined in quarries throughout Appalachia would not exist. Limestones not only provide various construction materials but are also used to manufacture the agricultural lime used to neutralize the acidic soils that characterize much of Appalachia. We will discuss Earth and, in particular Appalachia, in pages that follow.

Mars is the great red planet; the color of its surface due to concentrations of hematite, Fe_2O3. Galileo Galilei, the first to observe Mars through a telescope, not only noted the bright red color, but also the fact that its surface was grooved. I might point out that the misinterpretation of the grooves as being canals is what promoted the idea of the existence of Martians. Exploration of the Martian surface by NASA showed that the grooves were not canals but rather were channels. The difference between canals and channels is quite simple. Canals are ditches dug to transport water from one point to another while channels are natural features sculpted largely by streams. The presence of stream channels and channel deposits on the surface of Mars indicated that at some point in Mars' past, water existed on its surface; suggesting that at some time in the past the Martian atmosphere had a density similar to the Earth's. During that time, streams carved channels as they flowed to seas that existed on the Martian surface. These streams deposited sediment in the form of flood plains and deltas. Then, the Martian atmosphere disappeared and the water vaporized into space. Water may still be frozen beneath the CO_2 ice caps or deep within the soil, but it no longer exists on Mars' surface. No one knows what caused the Martian atmosphere to disappear. With an Earth-like atmosphere, there is every reason to believe that during this same period of time life as we know it could have existed on Mars. Life as we knew it could exist on Mars again, as long as they brought their environment with them. Day-time temperatures on the Martian equator, for example can rise to $25^{O}C$ ($77^{O}F$). However, night-time temperatures may drop to $-140^{O}C$ ($-220^{O}F$).

Other Orbiting Bodies

The outer planets, including Jupiter, Saturn, Uranus, and Neptune are collectively called the Jovian Planets. They are all large, ranging in diameter from Neptune's 40,000 miles (64,360 km) to the huge planet, Jupiter's 80,000 miles (128,720 km). It is said that if all of the other planets were rolled into a single ball, the ball wouldn't be as large as Jupiter. With the exception perhaps of a small rock core, the Jovian Planets are composed of frozen, liquid and gaseous gases. Because the Jovian planets contribute little to our understanding of Earth, we will not be consider them further. One of the former Jovian planets does, however, deserve mention.

Until 2006, Pluto was considered the ninth planet. From its discovery in 1933, Pluto's position as a planet has been debated because it doesn't conform to the features of the Jovian planets. For example, rather than being large and low density, Pluto is about the size of our Moon and is apparently made of rock. While all of the other planets orbit near to or within an imaginary equatorial plane emerging from the sun called the ecliptic, Pluto orbits at 17^{O} from the ecliptic. Also, all the other planets orbit the Sun in nearly circular elliptical orbits, but Pluto's orbit is so highly elliptical that it can be either outside or inside Neptune's orbit. In 2006, astronomers downgraded Pluto's status to a dwarf planet.

Millions of bits of rock called asteroids orbit the Sun between the orbitals of Mars and Jupiter with about 100,000 having been identified and catalogued. While most asteroids are odd shaped, a few have enough mass to have been shaped into spheres by gravity. The largest of these, Ceres, is considered a dwarf planet with a diameter of about 700 miles (1,126 km). Asteroids were once thought to have been the remains of a terrestrial planet that existed between Mars and Jupiter that collided with another celestial body. Today, however, asteroids are interpreted as bits of rock and metals that would have formed a terrestrial-type planet if they had not been prevented from getting together due to the opposing gravitational forces of Jupiter and the Sun.

Roaming through the solar system in seemingly random paths are untold millions of meteoroids. Meteoroids under the gravitational attraction of Earth plunge into our atmosphere. As they burn during entry, they generate a streak of light called a meteor. Most meteoroids are small, ranging in size from a speck of dust to that of a pea and do not survive the fall through our atmosphere. Meteoroids that do survive to fall on land are called meteorites. Meteorites are of three basic types: 1) stony meteorites, 2) iron meteorites, and 3) stony-iron meteorites. Stony meteorites account for 93% of the landings while iron meteorites only about 6%. The dominance of the stony meteorites probably reflects the difference in the numbers of mineral and rock particles in the original cosmic dust as compared to the pieces of iron. Impacts of stony-iron meteorites are rare.

The last major impact of a meteoroid and Earth occurred 50,000 years ago in what is now the northeastern Arizona. The excavation, commonly referred to as Meteor Crater is formally named the Barringer Crater after a mining engineer, Daniel Barringer who, in 1903, demonstrated that the feature was the result of the impact of an iron meteoroid. At the time of its impact, the Barringer meteorite was estimated at 130 feet (40 m) in diameter, weigh 300,000 tons, and was traveling 25,000 miles per hour (40,000 km/sec). The impact blasted a crater about a mile (!.6 km) in diameter and 500 feet (152 m) deep.

Comets are thought to consist mostly of water ice. In fact, they were described by the imminent American astronomer, Fred Whipple, as "dirty snowballs". The "dirt" consists of bits of pieces of rock and other cosmic debris. To early observers, comets seemed to appear irregularly. These spectacular celestial sights, with their glowing heads and streaming tails were considered to be omens of disasters.

The first step to a scientific understanding of comets was made by Edmond Halley, who noted recorded appearances of a comet in 1531, 1607, and 1682. He theorized that the appearances were repeat visitations by a single comet, with repeat appearances every 76 years. He also deduced that it followed a highly elliptical orbit that brought it close to the Sun at one end and beyond the orbit of Saturn at the other. Since then, searches of ancient reports have indicated that sightings of the same comet might go back to Chinese astronomers who reported the appearance of a comet every 76 years beginning in the 5th century BC.

Most comets are relatively small. Halley's Comet, for example, is only about nine miles (14.5 km) long by about six miles (9.6 km) wide. Most geologists believe that during proto-planet Earth's formation, the number of comets that impacted proto-Earth was so great that they introduced all of the water now present on Earth.

Comets follow huge elliptical paths that bring them from the most distant planets of our solar system to the vicinity of the Sun, where they are close enough to be seen by our unaided eyes. The comet's classic tail is initiated as it approaches the Sun. Solar wind vaporizes and ionizes the side of the comet facing the Sun and drives the byproducts away from the Sun. As the comet recedes From the Sun, the tail also loses length until it dies out at the orbital of Saturn. With each pass around the Sun, the comet loses ice and releases bits of the solid materials. These pieces become clusters of meteoroids that create the meteor showers that are seen as Earth passes through the former orbit path, in some cases on a yearly schedule. It is estimated that during the 1986 passage, Halley's Comet lost mass at the rate of about 50 tons per second. At this rate, Halley's Comet will be with us for another 100,000 years.