Outline of Contents

Ptolemaic model of Solar System

- About 140 C.E. the ancient Greek astronomer Claudius Ptolemy, who lived and worked in Alexandria, Egypt, published a 13-volume treatise on mathematics and astronomy called *Megale mathmatike systaxis* ("The Great Mathematical Compilation"), which is better known today as ***The Almagest.***
- According to the Ptolemaic model, **Earth stands at the center of the universe,** and is **orbited by the Moon, the Sun, Mercury, Venus, Mars, Jupiter, and Saturn**. The stars in the sky are all positioned on a celestial sphere surrounding these other objects at a fixed distance from Earth.
- Although the Ptolemaic model of the solar system was proven wrong by Galileo, Kepler, Newton, and other great scientists starting in the seventeenth century, it was very important for the development of astronomy as a modern science.

Heliocentric model of the solar system

- Polish mathematician and astronomer Nicholas Copernicus (1473–1543; in Polish, Mikolaj Kopernik) suggested in 1507 that the Sun was at the center of the solar system, not Earth.
- His "heliocentric" model had been proposed by the ancient Greek astronomer Aristarchus around 260 B.C.E., but this theory did not survive past ancient times.
- Copernicus, therefore, was the first European after Roman times to challenge the geocentric model in his work titled "*De Revolutionibus Orbium Coelestium"*
- *De Revolutionibus Orbium Coelestium* was placed on the Catholic Church's list of banned books in 1616, where it remained until 1835.
- Eventually, Galileo Galilei (1564–1642) used astronomical observations to prove that the heliocentric model was the correct model of the solar system; Johannes Kepler (1571– 1630) formulated the laws of planetary motion that described the behavior of planets in the heliocentric model; and Isaac Newton (1642–1727) formulated the Laws of Motion and the Law of Gravity, which explained why the heliocentric model works.

- Galileo was the first person to use a telescope to study space
- In 1609 he published his discoveries in *The Starry Messenger,* which created a tremendous stir of excitement and controversy
- Through his works *A Dialogue Concerning the Two Chief World Systems* and *Discourse on Two New Sciences,* Galileo described the basics of how objects move both on Earth and in the heavens.
- Galileo's support of the heliocentric model was considered a heretical viewpoint in Italy at the time. The Catholic Church, through its Inquisition, threatened to torture or even kill him if he did not recant his writings. Ultimately, Galileo did recant his discoveries and lived under house arrest for the last decade of his life.It is said that, in a private moment after his public recantation, he stamped his foot on the ground and said, "Eppe si muove" ("Nevertheless, it moves.")

Johannes Kepler

- German astronomer Johannes Kepler (1571–1630) was very interested in the mathematical and mystical relationships between objects in the solar system and geometric forms such as spheres and cubes.
- In 1596, before working as an astronomer, Keplerpublished *Mysterium Cosmographicum,* which explored some of these ideas. Later, working with Danish astronomer Tycho Brahe and his data, Kepler helped establish the basic rules describing the motions of objects moving around the Sun.

Kepler's First Law of **planetary motion**

- According to Kepler's First Law, planets, comets, and other solar system objects travel on an elliptical path with the Sun at one focus point. The effect can be subtle or profound; Earth's orbit, for example, is very nearly circular, whereas the orbit of Pluto is noticeably oblong, and the orbits of most comets are highly elongated.

Kepler's Second Law of **planetary motion**

- According to Kepler's Second Law, planetary orbits sweep out equal times in equal areas. This means that a planet will move faster when it is closer to the Sun, and slower when it is farther away. Future scientists such as Isaac Newton showed that the Second Law is true because of an important property of moving systems called the conservation of angular momentum.

Kepler's Third Law of **planetary motion**

- According to Kepler's Third Law, the cube of the orbital distance between a planet and the Sun is directly proportional to the square of the planet's orbital period.
- Kepler discovered this law in 1619, ten years after the publication of his first two laws of planetary motion. It is possible to use this third law to calculate the distance between the Sun and any planet, comet, or asteroid in the solar system, just by measuring the object's orbital period.

Joseph-Louis Lagrange

- Joseph-Louis Lagrange (1736–1813) was an Italian mathematician who developed some of the most important theories of mechanics, both regarding Earth and the universe.
- His analysis of the wobble of the Moon about its axis of rotation won him an award from the Paris Academy of Sciences in 1764.

Lagrange points

Lagrange also worked on an overall description of the way that forces act on groups of moving and stationary objects, a project that Galileo Galilei and Isaac Newton had begun years before. He eventually succeeded in devising several key general mathematical tools to analyze such forces. These were published in a 1788 work called *Mechanique Analytique* ("Analytical Mechanics"). Lagrange went on to explore the interaction between objects in the solar system as a complex system of objects; he discovered what are called Lagrange points: places around and between two gravitationally bound bodies where a third object could stay stationary relative to the other two. This proves useful today for placing satellites in space.

Energy & Matter Dogma

- Energy is that which makes things happen in the universe. It is that which is exchanged between any two particles in order for those particles to change—their motion, their properties, or anything else—in any way. Energy is everywhere around us; it takes so many different forms that it is hard to pin down. Heat is energy; light is energy; everything that moves carries kinetic energy. Even matter itself can be converted into energy, and vice versa.
- Matter, the stuff out of which every object in the universe is made, is everything in the universe that has mass. Mass is a quality that is hard to describe. Very roughly, it is the "drag" through spacetime that an object experiences. An object with more mass will move more slowly through spacetime than an object with less mass, if both have the same amount of either momentum or kinetic energy.

$E = mc^2$

- $E=mc^2$ was discovered by Albert Einstein in 1905. It is a major result of his **Special Theory of Relativity**, which describes the relationship between how objects and electromagnetic radiation move through space and how they move through time.
- It means that the amount of energy in a piece of matter is equal to the mass of that piece of matter multiplied by the speed of light squared.
- Matter can change into energy, and energy can change into matter, but they are not identical. They are like two different convertible currencies. The exchange rate between matter and energy is given by the famous equation $E=mc^2$, which was discovered in 1905 by Albert Einstein.
    - Photons are special subatomic particles that contain and carry energy but have no mass. Photons, in fact, can be imagined as particles of light.
    - Photons are produced or destroyed whenever electromagnetic force is transferred from one place to another.

Electromagnetic Radiation

- Electromagnetic waves are electromagnetic radiation, which is light. Usually, on Earth, humans think of light just as the kind of radiation that our eyes can detect.
- There are seven general kinds of electromagnetic radiation: Gamma Rays, X Rays, Ultraviolet, Visible, Infrared, Microwaves, and Radio Waves. Gamma rays, X rays, and ultraviolet rays have shorter wavelengths than those of visible light; infrared waves, microwaves, and radio waves have wavelengths longer than those of visible light.

- The speed of light is the same as the speed of an electromagnetic wave because they are the same thing.
- Light travels through a vacuum at almost exactly 299,792.5 kilometers per second. As of now, nothing can travel faster than light in a vacuum, not even neutrino.

Time

- Time is actually a dimension, a direction that things in the universe can travel in and occupy. Just as objects in the universe can move up and down; forward and backward; or side to side, objects can also move through time. Unlike the three spatial dimensions, however, different kinds of objects in our universe move through time in only specific directions.
- Mathematically, it is correct to say that matter— galaxies, stars, planets, and people—only move forward in time.
- Meanwhile, particles made of antimatter only move backward in time; and particles of energy—such as photons, which have no mass—do not move in time.

Relationship of Space & Time

- Three dimensions of space and one dimension of time are linked together as a four-dimensional fabric called **spacetime.**
- Albert Einstein first realized that travel through space and travel through time must be intimately linked. His special theory of relativity, published in 1905, showed that the faster an object moves through space, the slower it moves through time. Einstein thought there must be a very strong connection between space and time and that this connection was essential to describe the shape and structure of the universe.

General Theory of Relativity

The fundamental idea in the general theory of relativity is that space and time are knit together in a four-dimensional fabric called spacetime, and that spacetime can be bent by mass.

- Massive objects cause spacetime to "**dimple" toward the object**.
- In the four-dimensional spacetime of the universe, if a less massive object approaches a more massive object (for example, a planet approaches a star), the less massive object will follow the lines of curved space and be drawn toward the more massive one.
- According to the general theory of relativity, this is how gravity works. Newton's theory of universal gravitation, according to Einstein, is almost completely correct in describing *how* gravity works, but it was not quite complete in explaining *why* it works.

Was General Theory of Relativity proved correct?

- The general relativistic formulation of gravity predicts that light, as well as matter, will follow the path of space that is bent by massive objects.
- If general relativity was correct, then the light from distant stars would follow a curved path through space caused by the gravity of the Sun.
- The apparent positions of the stars in the part of the sky near the Sun's location, therefore, should be different from their apparent positions when the Sun is not in that place.
- To test this prediction, British astrophysicist Arthur Eddington (1882– 1944) organized a major scientific expedition in 1919 to observe the sky during a solar eclipse.
- With the Moon shading the Sun's bright light, astronomers measured the relative positions of distant stars near the Sun's position at that time. Then they compared them to those positions measured at night, when the Sun was not in the field of view.
- The apparent positions were indeed different, and the discrepancies were consistent with the results predicted by Einstein's theory.
- This observational confirmation of the general theory of relativity changed the field of physics forever. The discovery made news headlines, and Albert Einstein became an international celebrity.

Special Theory of Relativity

- According to the special theory of relativity, the speed of a beam of light is the same, no matter who observes it or how the observers are moving.
- This means that the speed of light is the fastest speed at which anything can travel in the universe.
- Furthermore, if the speed of a light beam is constant, that means that other properties of motion must change.

Basics of Universe

- The universe is all of **space, time, matter, and energy** that exist. Universe is not just space, but space is just the framework, the "scaffolding" in which the universe exists. As mentioned above the, Space and time are intimately connected in a four-dimensional fabric called spacetime.

Age of Universe

- The universe is not infinitely old. According to modern astronomical measurements, the universe began to exist about 13.7 billion years ago.

Size of Universe

- It has not yet been scientifically determined exactly how large the universe is. It may indeed be infinitely large, but we have no way yet to confirm this possibility scientifically.

What is Cosmic Horizon ?

- The farthest limit to our viewing is called the cosmic horizon, which is about 13.7 billion light-years away in every direction. Everything within that cosmic horizon is called the observable universe.

Structure of Universe

- The structure of the universe—as opposed to the structure of matter in the universe— is determined by the shape of space. The shape of space is, surprisingly, curved.
- On a very large scale—millions or even billions of light-years across—space has a three-dimensional "saddle shape" that mathematicians refer to as "negative curvature."

Big Bang Theory

- The scientific theory that describes the origin of the universe is called the Big Bang.
- According to the Big Bang theory, the universe began to exist as a single point of spacetime, and it has been expanding ever since. As that expansion has occurred, the conditions in the universe have changed—from small to big, from hot to cold, and from young to old—resulting in the universe we observe today.

Development of Big-Bang theory

- In 1917 Dutch astronomer Willem de Sitter (1872–1934) showed how Albert Einstein's general theory of relativity could be used to describe an expanding universe.
- In 1922, Russian mathematician Alexander Friedmann (1888–1925) derived an exact mathematical description of an expanding universe.
- In the late 1920s, the Belgian astronomer Georges-Henri Lemaître (1894–1966) independently rediscovered Friedmann's mathematical formulation. Lemaître deduced that if the universe were indeed expanding, and has been doing so for its entire existence, then there would have to be a moment in the distant past when the whole universe occupied just a single point. That moment, and that point, would be the origin of the cosmos.
- Lemaître's work, and that of de Sitter and Friedmann, were eventually confirmed through observations; since Lemaître was a Jesuit priest as well as an astronomer, he has sometimes been called "the father of the Big Bang."
- The Russian-born American physicist George Gamow (1904–1968) furthered the Big Bang model by including the distribution of energy in the universe. If such a bang had occurred, he argued, the universe would have been incredibly hot very soon after the bang—somewhere in the area of trillions upon trillions of degrees.
- As the universe expanded, the heat in the universe would become distributed over a larger volume, and the temperature would go down. After one second, the average cosmic temperature would drop to about a billion degrees; after half a million

years, the average temperature would be a few thousand degrees; and so on. Even after billions of years had passed, however, Gamow showed that this background heat would persist.

- After about 15 billion years, it would appear as a background radiation field that would be just a few degrees above absolute zero. Gamow predicted that this cosmic background radiation could be detected by its microwave radiation. In 1965 the cosmic microwave background radiation was indeed discovered.

Has Big Bang Theory proved as a fact?

- Big Bang theory remains a theory as of now. The Big Bang theory does not explain why the Big Bang actually happened. A well-established hypothesis is that the universe began in a "quantum foam"—a formless void where bubbles of matter, far smaller than atoms, were fluctuating in and out of existence on timescales far shorter than a trillionth of a trillionth of a trillionth of a second.
- In our universe today, such quantum fluctuations are thought to occur, but they happen so quickly that they never affect what happens in the cosmos.
- But if, 13.7 billion years ago, one particular fluctuation appeared but did not disappear, suddenly ballooning outward into a gigantic, explosive expansion, then it is possible that something like today's universe could have been the eventual result.

Rate of Expansion?

- Scientists say that the universe has not always expanded at the same rate. Very soon after the Planck time, the universe went through a hyperinflationary period that suddenly increased the diameter of the universe by at least a factor of ten billion billion; this is called the inflationary model.
- Long after the hyperinflation ended, the expansion returned to an almost-constant rate, slowed down very slightly, and then billions of years ago started speeding up. Right now, the expansion rate of the universe is slowly but surely increasing. We live in an accelerating universe.

Any important scientific observation of big-bang theory?

- The first scientific evidence confirming the Big Bang theory was "Cosmic Microwave Background".
- **I**n the 1960s, astronomers Arno Penzias (1933–) and Robert Wilson (1936–) were conducting research at Bell Telephone Laboratories in Holmdel, New Jersey, USA. For their telescope they were using a very sensitive, horn-shaped antenna that was originally developed to receive weak microwave signals for use in wireless communications.
- While they were testing this antenna, they detected a ubiquitous microwave static that came from all directions in the sky.
- After examining four years of data, and checking carefully to be sure there was no interference or malfunction in the equipment, they interpreted their "static" as a real signal, coming from outer space in every direction. After consulting with astrophysics colleagues at Princeton, they realized that they had indeed detected the cosmic microwave background.
- They published their results in 1965, and it was immediately recognized as scientific evidence confirming the Big Bang theory.
- So far, most convincing evidence confirming the Big Bang theory is the cosmic microwave background radiation: the leftover energy from the hot, early universe that still fills space and permeates the cosmos in every direction.
- Scientists had predicted that such background radiation would indicate that the temperature of space would be several degrees above absolute zero. The detection of the background radiation showed that the temperature was very close to 3 degrees Kelvin. This was a spectacular success of the scientific method.

Hubble Constant

The expansion rate of the universe is called the Hubble Constant in honor of Edwin Hubble (1889–1953). Currently the best measured value of the Hubble Constant is about 73 kilometers per second per megaparsec.

- That means that, if a location in space is one million parsecs from another location, then in the absence of any other forces or effects the two locations will be moving apart from one another at the speed of 263,000 kilometers per hour.

Doppler Effect

- Doppler Effect is named after Christian Johann Doppler (1803–1853).
- Doppler effect occurs when a source of sound is moving toward or away from a listener. If the source is moving toward the listener, the sound wave's wavelength decreases, and the frequency increases, making the sound higher-pitched.
- Conversely, if the source is moving away from the listener, the sound wave's wavelength increases, and the frequency decreases, making the sound lower-pitched. The next time a car or train passes by you on the street, listen to the sound it is making as it approaches and then moves away.
- Hubble measured the galaxies' Doppler effect—the shift in the observed color of objects moving toward or away from an observer—by mounting a machine called a spectrograph on a telescope.
- He split the light from distant galaxies into its component parts and measured how far the wavelengths of emitted light shifted toward longer wavelengths.

Doppler effect for light: Blue shift and Red Shift

- When an object emitting light—or any kind of electromagnetic radiation, for that matter— moves toward someone, the wavelength of its emitted light is decreased.
- Conversely, when the object moves away, the wavelength of its emitted light is increased.
- For visible light, the bluer part of the spectrum has shorter wavelengths, and the redder part of the spectrum has longer wavelengths. Thus, the Doppler effect for light is called a "blueshift" if the light source is coming toward an observer, and a "redshift" if it is moving away. The faster the object moves, the greater the blueshift or redshift.

Black Holes

- The most massive objects in the universe exert the most gravity. However, the strength of a gravitational field near any given object also depends on the size of the object.
- The smaller the object, the stronger the field. The ultimate combination of large mass and small size is the black hole.
- One definition of a black hole is an object whose escape velocity equals or exceeds the speed of light. The idea was first proposed in the 1700s, when scientists hypothesized that Newton's law of universal gravitation allowed for the possibility of stars that were so small and massive that particles of light could not escape. Thus, the star would be black.
- When the general theory of relativity was confirmed, scientists started to explore the implications of gravity as the curvature of space by matter.
- Scientists realized that there could be locations in the universe where space was so severely curved that it would actually be "ripped" or "pinched off." Anything that fell into that location would not be able to leave.
- This idea of an inescapable spot in space—a hole where not even light could leave—led physicists to coin the term "black hole."

How Black Holes are detected?

- The key to finding black holes is their immense gravitational power. One way to find black holes is to observe matter moving or orbiting at much higher speeds than expected.
- This is because, by carefully mapping the motion, one can apply the third law of Kepler and measure the mass of the object without even seeing the object. The deep gravitational field of a black hole can also produce a tremendous amount of light nearby and around itself, even if the hole itself is dark. Matter falling into a black hole runs into a lot of other material that has collected around the hole. Just as a meteorite or spacecraft gets hot as it enters Earth's atmosphere, the infalling matter gets hot from the frictional drag too, sometimes reaching temperatures of millions of degrees. That hot material glows brightly and emits far more X-ray radiation and radio waves than would normally be expected from such a small volume of space.
- Thus, astronomers can detect black holes by searching for sources of X-ray radiation.

Types of Black Holes:

- There are two categories of black holes are known to exist, and a third kind has been hypothesized but not yet detected.

- One kind, known loosely as a stellar black hole or low-mass black hole, is found wherever the core of a very massive star (usually 20 or more times the mass of the Sun) has collapsed.
- The other known kind, called a super massive black hole, is found at the centers of galaxies and is millions or even billions of times more massive than the Sun. Our Galaxy also has a black hole at the centre.
- The third kind of black hole, called a *primordial black hole*, is found at random locations in space. It is hypothesized that these black holes were created at the beginning of cosmic expansion as little "imperfections" in the fabric of spacetime. However, no such black hole has yet been confirmed to exist.

How many black holes are known today?

- Today, thousands of black holes are known to exist, and the total population of black holes may number in the many billions.

Structure of a Black hole?

- The center of the black hole is called the **singularity**. It is a single point that has no volume but infinite density.
- The laws of physics as we understand them simply do not work at the singularity of a black hole the way they do in the rest of the universe.
- Surrounding the singularity is a boundary called the **event horizon**. **This is the place of no return**, **where the escape velocity for the black hole is the speed of light**.
- The more massive the black hole is, the farther the event horizon is from the singularity, and the larger the black hole is in size.

What is Hawking Radiation?

- British physicist Stephen Hawking (1942–) stipulated that energy can slowly leak out of a black hole. It is contrary to the general belief that nothing can escape the black holes.
- This leakage, called Hawking radiation, occurs because the event horizon (boundary) of a black hole is not a perfectly smooth surface, but "shimmers" at a subatomic level due to quantum mechanical effects.
- At these quantum mechanical scales, space can be thought of as being filled with so-called virtual particles, which cannot be detected themselves but can be observed by their effects on other objects.
- Virtual particles come in two "halves," and if a virtual particle is produced just inside the event horizon, there is a tiny chance that one "half" might fall deeper into the black hole, while the other "half" would tunnel through the shimmering event horizon and leak back into the universe.
- Hawking radiation is a very, very slow process.
- According to theoretical calculations, a black hole having the mass of Mount Everest—would have an event horizon smaller than an atomic nucleus.

Size of the Black Holes - Schwarzschild radius

- The singularity at the center of any black hole has no volume. The size of the event horizon—the boundary of no return—of a black hole, on the other hand, varies depending on the black hole's mass.
- The mathematical relationship between the mass of a black hole and the size of its event horizon was derived by the German astrophysicist Karl Schwarzschild (1873–1916).
- The radius of a black hole's event horizon is named the **Schwarzschild radius** in his honor.
- The Schwarzschild radius of a stellar black hole is about a hundred miles, while the Schwarzschild radius of a supermassive black hole ranges from a few million to a few billion miles.
    - If the Sun were squeezed small enough to become a black hole, its Schwarzschild radius would be about three miles; and if Earth were squeezed small enough to become a black hole, its Schwarzschild radius would be about three-quarters of an inch.

Properties of Black holes

- **B**lack holes only have very basic properties; they do not have any complex structures the way stars or galaxies might.
- The only properties that black holes are thought to have are **mass (weight), rotation (spin), and electric charge.**

Density of Black Holes

- Based on Karl Schwarzschild's formula for the radius of a black hole's event horizon, the density of a black hole depends very strongly on its mass.
- A black hole the mass of Earth would have more than 200 trillion trillion times the density of lead. However, , a black hole that is one billion times the mass of the Sun would have an average density much lower than the density of water.

Wormholes

- A wormhole is an imperfection in spacetime that has two ends. Instead of a black hole, which only has one point singularity in space-time, a wormhole could have one point where matter can only enter and another point where matter can only exit.
- Wormholes are only theory. No wormhole has ever been detected. Science fiction writers like to invoke wormholes as useful ways to violate the known laws of physics (for instance, making objects disappear into nothingness or appear out of nowhere, for no apparent reason).

Cosmic String

- A cosmic string is a giant vibrating strand or closed loop of matter; it is almost like a black hole, but long and thin, rather than a point or sphere.
- Cosmic strings may have been produced by gravitational shifts in the early universe.
- They could be envisioned as "creases" left in an otherwise smooth transition from the initial phases of cosmic evolution.
- They might also be described as "wrinkles" in the texture of the universe, moving and wiggling around in spacetime.
- A cosmic string may be many light-years long, but far thinner than the width of a human hair, and may contain the mass of billions upon billions of stars. A cosmic string may also carry an extremely strong electrical current.
- Like wormholes, Cosmic strings also have been never detected.

Dark matter

- In the 1930s, astronomer Fritz Zwicky noticed that, in the Coma cluster of galaxies, many of the individual galaxies were moving around so fast that there had to be a tremendous amount of gravitational pull toward the center of the cluster; otherwise, the galaxies would literally fling themselves out of the cluster.
- The amount of matter that needed to exist in the cluster to produce that much gravity far exceeded the amount of matter observed in all the galaxies in the cluster put together.
- This extra matter became known as "dark matter."
- In 1970 astronomer Vera C. Rubin and physicist W. Kent Ford showed that stars in the *Andromeda Galaxy were moving so fast that for the stars to stay in the galaxy there had to be a tremendous amount of matter surrounding and enveloping the entire galaxy like a giant cocoon.*
- Since this matter is not visible to telescopes by the light it emits, but rather only by the gravity it exerts, this, too, is an example of evidence for dark matter.
- After decades of further study, dark matter has now been confirmed as an important constituent of matter around galaxies, in clusters of galaxies, and throughout the universe as a whole.
- According to the latest measurements, about **80 percent of the matter in the universe is dark matter.**

Dark Energy

- Albert Einstein had introduced a mathematical term into his equations to keep a balance between cosmic expansion and gravitational attraction. This term became known as the "**cosmological constant,"** and seemed to represent an unseen energy that emanated from space itself.
- After Edwin Hubble and other astronomers showed that the universe was indeed expanding, the cosmological constant no longer appeared to be necessary, and so it was not seriously considered again for decades.
- Then, starting in the 1990s, a series of discoveries suggested that the "dark energy" represented by the cosmological constant does indeed exist.

- Current measurements indicate that the **density of this dark energy throughout the universe is much greater than the density of matter—both luminous matter and dark matter combined**.
- Though astronomers have measured the presence of this dark energy, scientists still have no idea what causes this energy, nor they have a clue what this energy is made of.
- The quest to understand the cosmological constant in general, and dark energy in particular, is one of the great unsolved questions in astronomy.
- **Composition of Dark Matter**
    - Nobody has any real idea of what dark matter is. Some hypothetical entities such as a new class of "weakly interacting massive particles" (WIMPs) or huge agglomerations of them ("WIMPzillas"); another class of "charged undifferentiated massive particles" (CHUMPs); or very light, neutral subatomic particles called neutralinos.
    - No dark matter particle has ever been detected.

    Implication of dark matter on shape of universe

        - Dark matter in the universe exerts a gravitational pull in the expanding universe.
        - The more dark matter there is in the universe, the more likely it would be that the universe would have a closed geometry, and that the universe would end in a Big Crunch.
        - Continued expansion of the universe means that the total amount of dark energy keeps increasing.
        - Since the total amount of mass in the universe is not increasing, that means that the expansive effect of dark energy will ultimately overcome the contractive effect of dark matter.
        - The more dark energy there is, the more open the geometry of the universe will tend to be, and the faster the expansion rate of the universe will increase over time.

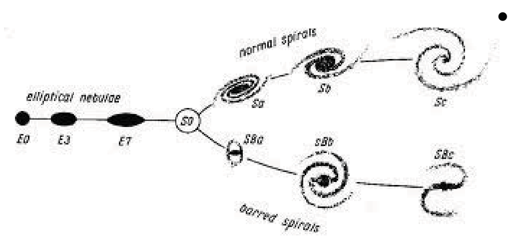
Galaxy

- A galaxy is a vast collection of stars, gas, dust, **and dark matter** that forms a cohesive gravitational unit in the universe.
- In a way, galaxies are to the universe what cells are to the human body: each galaxy has its own identity, and it ages and evolves on its own, but it also interacts with other galaxies in the cosmos.
- Within the observable universe alone, there exist an estimated 50 to 100 billion galaxies.

Types of Galaxies

- Galaxies are generally grouped by their appearance into three types: spiral, elliptical, and irregular.
- These groups are further subdivided into categories like barred spiral and grand design spiral, giant elliptical and dwarf spheroidal, and Magellanic irregular or peculiar.
- Galaxies are also often categorized by characteristics other than their appearance. For example, there are starburst galaxies, merging galaxies, active galaxies, radio galaxies, and many more.

Hubble Sequence



- Hubble had proposed a way to classify galaxies based on their shapes. He proposed a "sequence" of galaxy types: from E0 (sphere-shaped elliptical galaxies) to E7 (cigar-shaped ellipticals), S0 (lenticular galaxies) to Sa and SBa (spiral galaxies with large bulges and bars), Sb and SBb (spirals with medium-sized bulges and bars), and Sc and SBc (spirals with small bulges and bars). The sequence is known as the **Hubble sequence**, and it is often shown visually as a Hubble "**tuning fork diagram.**"

An irregular galaxy is a galaxy that does not fit well into the standard categories of elliptical, spiral, or barred spiral galaxies. Two examples of irregular galaxies are the **Large Magellanic Cloud** and **Small Magellanic Cloud**, *which are visible from Earth's southern hemisphere.*

Size of Galaxies

- Galaxies range greatly in size and mass. The smallest galaxies contain perhaps 10 to 100 million stars, whereas the largest galaxies contain trillions of stars.
- There are many more small galaxies than large ones. The Milky Way, which has at least 100 billion stars, is on the large end of the scale; its disk is about 100,000 light-years across.

Dwarf Galaxy

- Dwarf galaxies have the least mass and fewest stars. The **Large Magellanic Cloud**, a **galaxy that orbits the Milky Way**, is considered a large dwarf galaxy; it contains, at most, about one billion stars.

Distribution of Galaxies

- Galaxies are distributed unevenly throughout the universe.
- Majority of galaxies are collected along vast filamentary and sheetlike structures many millions of lightyears long.
- These filaments and sheets connect at dense nodes—clusters and superclusters— of galaxies, and the net result is a three-dimensional weblike distribution of matter in the universe. This is known as Cosmic Web.
- Between the filaments and sheets are large pockets of space with relatively few galaxies; these sparse regions are called **voids.**

Group of Galaxies

- Group of Galaxies contains two or more galaxies of bigger size and a dozen or more smaller galaxies.
- The *Milky Way and Andromeda galaxies are the two large galaxies in the **Local Group***. There are a few dozen smaller galaxies in the group, including the **Magellanic Clouds**, the dwarf elliptical **Messier 32,** the small spiral galaxy **Messier 33,** and many small dwarf galaxies.
- The Local Group of galaxies is a few million light-years across.

Cluster of Galaxies

- A cluster of galaxies is a large collection of galaxies in a single gravitational field.
- Rich clusters of galaxies usually contain at least a dozen large galaxies as massive as the Milky Way, along with hundreds of smaller galaxies.
- At the center of large clusters of galaxies there is usually a group of elliptical galaxies called "cD" galaxies. Clusters of galaxies are usually about ten million light-years across.
- **The Milky Way galaxy is near, but not in, the Virgo cluster**, **which itself is near the center of the Virgo supercluster**.

Supercluster of Galaxies

- Superclusters are the largest collections of massive structures.
- There are usually many clusters of galaxies in a supercluster, or a single very large cluster at its center, along with many other groups and collections of galaxies that are collected in the supercluster's central gravitational field.
- Superclusters contain many thousands—and sometimes millions—of galaxies.
- **The Milky Way galaxy is located on the outskirts of the Virgo supercluster.**

Milky Way

- The Milky Way is the galaxy we live in.
- It contains the Sun and at least one hundred billion other stars. Some modern measurements suggest there may be up to 500 billion stars in the galaxy.
- The Milky Way also contains more than a billion solar masses' worth of free-floating clouds of interstellar gas sprinkled with dust, and several hundred star clusters that contain anywhere from a few hundred to a few million stars each.

Where Milky Way finds place on Hubble Tuning Fork Diagram?

- Milky Way is a barred spiral galaxy, probably classified as a SBb or SBc on the Hubble tuning fork diagram.

Location of Milky Way in Universe

- The Milky Way sits on the outskirts of the Virgo supercluster.

- The center of the Virgo cluster is about 50 million light-years away from Milky Way.

Location of Earth in Milky Way

- Earth orbits the Sun, which is situated in the Orion Arm, *one of the Milky Way's spiral arms*.
- Earth and the Sun are about 25,000 light-years away from the galactic center.

Size of Milky Way

- The Stellar disk of the Milky Way is about 100,000 light-years across and 1,000 light-years thick.
- Based on current measurements, at least 90 percent of the mass in the Milky Way's gravitational field is made up of dark matter, so the luminous stars, gas, and dust of the galaxy are embedded at the center of a huge, roughly spherical dark matter halo more than a million light-years across.

Movement of Earth within the Milky Way Galaxy

- Earth (and the solar system) is moving through the Milky Way's disk in a stable, **roughly circular orbit** around the galactic center.
- Our orbital velocity around the center of the Milky Way is about 200 kilometers per second. Even so, the Milky Way is so huge that one complete orbit takes about 250 million years.

Can we see the whole Milky Way?

- Much of the galaxy is blocked from our view on Earth.
- Dusty gas clouds create barriers that scatter and block much of the light in the Milky Way from reaching us. Using infrared, microwave, and radio astronomy techniques, it is possible to penetrate much of this dusty fog.
- But overall, at least half of the stars and gas in the Milky Way are not viewable from our vantage point.

Neighbors of Milky Way

- Within a few million light-years of the Milky Way are several dozen galaxies that make up the Local Group.
- Some of those galaxies, such as the Sagittarius dwarf galaxy, are almost in physical contact with the Milky Way's outskirts.

Largest Galaxy in the Local Group

- The Andromeda galaxy, which is slightly larger than the Milky Way, is the largest galaxy in the Local Group.
- Andromeda is also known as **Messier 31**, or M31. It is called so because it is the thirty-first object listed in the famous catalog of night-sky objects compiled by Charles Messier in 1774.

Similarities between Andromeda and Milky Way

- **T**he Andromeda galaxy shares many characteristics with the Milky Way. It is a large spiral galaxy, like the Milky Way; it appears to be roughly the same age as the Milky Way; and it contains many of the same types of objects as the Milky Way, including a super massive black hole at its center.
- Andromeda is somewhat larger than the Milky Way, but it is still close to 100,000 light-years (or about 600,000 trillion miles, or one million trillion kilometers) across.

The super massive black hole in Milky Way

- The center of the Milky Way is in the direction of the constellation Sagittarius; right at the center, there is an object called Sag A* (pronounced "Sagittarius A-star") that emits much more X-rays and radio waves than expected for a star-sized body.
- After mapping the motions of stars near Sag A* for more than a decade, astronomers concluded that Sag A* is an invisible object that is more than three million times the mass of the Sun.
- The only kind of object like that in the universe is a supermassive black hole.

Please note that every galaxy that has contained very hot, luminous stars—stars 20 times or more the mass of the Sun—almost certainly contains stellar black holes. However, every galaxy does not contain supermassive black hole. Based on current observations, the majority of galaxies do contain one. Among nearby galaxies, more than 90 percent of all galaxies that have been measured so far appear to contain a super massive black hole.

Radio Galaxies

- Radio galaxies are simply galaxies—usually very ordinary-looking elliptical galaxies when viewed by visible light—that radiate an unusually large amount of radio waves. Often, the total energy of the radio wave emission far exceeds that of the galaxy's visible light emission.
- The majority of the radio wave emission usually comes from huge, puffy "lobes" or narrow "jets" that can be much larger than the visible galaxy itself.
- The excess radio emission is probably produced when much of the energy generated by an AGN (Active Galactic Nucleus) is carried away by highly energetic streams of matter, which then interact with the interstellar medium in and around the host galaxy and cause copious emissions of radio waves.

Large Magellanic Cloud

- The Large Magellanic Cloud, or LMC, is the largest dwarf galaxy that orbits our own Milky Way galaxy. It is an **irregular** disk galaxy that is similar in shape to the Milky Way, and we see it sort of edge on, so it looks like an oblong-shaped cigar to viewers on Earth.
- The LMC is about 30,000 light-years across and 170,000 light-years.

Supernova 1987 A

- **O**n February 23, 1987, Supernova 1987A appeared in the Large Magellanic Cloud. It was discovered almost immediately by two astronomers, Ian Shelton and Oscar Duhalde, at Las Campañas Observatory in Chile. This event was significant to astronomers because it was the closest supernova—a titanic stellar explosion—to have been observed in hundreds of years.
- he event has given astronomers one of the most valuable stellar laboratories ever to examine how stars are born, live, and die.
- Supernova 1987A is still being carefully studied today.

Small Magellanic Cloud

- The Small Magellanic Cloud (SMC), like its bigger compatriot the Large Magellanic Cloud (LMC), is a small irregular galaxy that orbits the Milky Way galaxy.
- It is a roughly disk-shaped galaxy about 20,000 light-years across and about 200,000 light-years away.
- Like the LMC, the SMC is forming stars at a rate much faster than that of the Milky Way. That is why it is an important target for astronomers who are studying the formation and aging of stars and galaxies.

Quasi-stellar object or QSO

- A quasi-stellar object (QSO) is the general term given to an "active galactic nucleus" (AGN) that has very high luminosity. QSOs are so named because in typical astronomical images taken in visible light they usually look like stars, or stars with a little bit of fuzz or structure surrounding them.
- In fact, they are not stars at all, but they are so luminous compared to their host galaxy that they drown out the light from it.

Interstellar medium

- The interstellar medium is the matter that exists within galaxies, between and among—but not including—the stars.
- Almost all of the interstellar medium is comprised of gas and microscopic dust particles.
- Approximately one percent of the luminous mass of a galaxy like the Milky Way (that is, excluding the non-baryonic dark matter) is interstellar medium.
- The rest of the mass consists primarily of stars and the end stages of stellar evolution, including white dwarfs, neutron stars, and black holes.

Density of Interstellar medium

- On average, the interstellar medium in our region of the Milky Way galaxy has a density of about one atom of gas per cubic centimeter. By contrast, Earth's atmosphere at sea level contains about 1019 gas molecules per cubic centimeter.
- There is also about one dust particle per 10,000,000 cubic meters in the local interstellar medium.

- In some places, the interstellar medium can be much denser. When there is a large enough concentration of gas and dust in a given place, the interstellar medium can form clouds that are thousands of times denser than one atom per cubic centimeter.
- Still, the interstellar clouds are millions of times <u>*less dense than the best laboratory vacuum chambers*</u> can produce on Earth.

Nebula

- A nebula, meaning "mist," is any cloud or **collection of interstellar medium** in one location in space.
- Nebulae are produced in many different ways. For example, they can be gathered together by gravity, dispersed by stars, or lit up by a powerful radiation source nearby.
- Most of these beautiful nebulae contain only a few thousand atoms or molecules per cubic centimeter. This is many times sparser than even the best laboratory vacuum chambers on Earth can achieve.

Types of nebulae

- There are many kinds of nebulae, which bear informal as well as formal names.
- Generally, types of nebulae are described either by their appearance (for example, dark nebulae, reflection nebulae, and planetary nebulae) or the physical processes that create them (such as protostellar nebulae, protoplanetary nebulae, or supernova remnants).

Dark nebulae

- Dark nebulae look like black blobs in the sky. They are generally dark because they contain mainly ***cold, high-density, opaque gas, as well as enough dust to quench the light from stars behind them***.
- One example of a dark nebula is the **Coal Sack Nebula**.

Reflection nebulae

- Reflection nebula **is lit by bright, nearby light sources** because the dust particles in them act like countless microscopic mirrors, which reflect light from stars or other energetic objects toward Earth.
- *To the human eye, reflection nebulae usually look bluish. This is because blue light is more effectively reflected in this way than red light.*

Emission nebulae

- An emission nebula is a glowing gas cloud <u>*with a strong source of radiation—usually a bright star*</u>—within or behind it.
- If the source gives off enough high-energy ultraviolet radiation, some of the gas is ionized, which means the electrons and nuclei of the gas molecules become separated and fly freely through the cloud.
- When the free electrons recombine with the free nuclei to become atoms again, the gas gives off light of specific colors.
- What colors they emit depends on the temperature, density, and composition of the gas.
- For example the Orion Nebula glows mostly green and red.

Quasar

- Quasar refers to ***quasi-stellar radio source***.
- They were thought to be stars earlier but they are not stars at all, but rather active galactic nuclei.
- Nowadays, the word "quasar" is often used to mean any <u>*Quasi-Stellar Object (QSO), whether or not it emits radio waves.*</u>

Star

- A star is a mass of incandescent <u>**gas that produces energy at its core by nuclear fusion**</u>. Most of the visible light in the universe is produced by stars. The Sun is a star.
- A person with good eyesight can see about 2,000 stars on any given night. If both hemispheres are included, then about 4,000 stars are visible. With the help of binoculars or telescopes, however, the number of visible stars increases dramatically.

Closest stars to Earth

- The Sun is the closest star to Earth. It is 93 million miles away from Earth on average.
- The closest star system to Earth is the multiple star system Alpha Centauri. The faintest star in that system, known as Proxima Centauri, has been measured to be 4.3 light-years away from Earth. The main star in Alpha Centauri is about 4.4 lightyears away.
- Following are the starts that are closest to sun.
    1. Proxima Centauri→4.24
    2. Alpha Centauri→4.37
    3. Alpha Centauri→4.37
    4. Barnard's Star→5.96
    5. Wolf 359 M6V→7.78
    6. Lalande 21185→8.29
    7. Sirius A→8.58
    8. Sirius B→8.58

These stars are in the Alpha Centauri system.

Asterism

- An asterism is a group of stars in the sky that, when viewed from Earth, create an outline of some recognizable shape or pattern.
- Two well-known asterisms are the **Big Dipper,** which many astronomers use to point out the location of the North Star, and the **Summer Triangle**, which is marked by three of the most prominent stars in the Northern Hemisphere's summer night sky.

Constellation

- A constellation is much more complicated asterism, containing more stars or larger areas of the sky.
- Modern constellations are mostly named after mythological themes, such as gods, legendary heroes, creatures, or structures.
- The constellations encompass the entire celestial sphere and provide a visual reference frame.
- Astronomers can plot the stars and other objects in the universe using constellations, charting the apparent movement that is caused by Earth's own rotation and orbit.

Number of Constellations

- The current, internationally agreed upon map of the sky contains 88 constellations. Some well-known constellations include Aquila (the Eagle), Cygnus (the Swan), Lyra (the Harp), Hercules and Perseus (two mythological heroes), Orion the Hunter and Ophiucus the Knowledge-seeker (two other mythological characters), Ursa Major and Ursa Minor (the Big Bear and Little Bear), and the constellations of the zodiac.

North Star

- The North Star is any star near the spot in the sky called the north celestial pole: the place that Earth's rotational axis is pointing toward.
- Right now, and for the past several centuries, Polaris has been very close to the pole, and thus has served as a good north star. Earth's rotational axis changes its pointing location across the sky over the millennia.
- Thousands of years ago, while ancient Egyptian culture thrived, the **North Star was a dimmer star called Thuban**. Between then and now, there have been stretches of many centuries when there was no useful North Star at all.

South Star

- At present , there is no easily visible star near the south celestial pole. There are many asterisms and celestial objects relatively near the pole, so it is possible to triangulate between them and roughly find the location of the south celestial pole.

Brightest Star

- The brightest stars in the night sky as viewed from Earth are Sirius, the "Dog Star," in the constellation Canis Major (the Big Dog); Canopus, in the constellation Carina (the Keel); and Rigel Kentaurus, more commonly known as Alpha Centari, in the constellation Centaurus (the Centaur).

Sources of Light & Energy

- Stars shine because nuclear fusion occurs in their core. Nuclear fusion changes lighter elements into heavier ones and can release tremendous amounts of energy in the process.

Composition of stars

- **S**tars are mostly comprised of a special state of gas called plasma: gas that is electrically charged. Many people refer to plasma as the "fourth" state of matter.
- Other examples of plasma that we might observe in daily life include the air where a lightning bolt is traveling through, or the gas inside a fluorescent light bulb.

Photosphere

- The photosphere is the layer of a star's atmosphere that we see when viewing the Sun in visible light. It is sometimes referred to as the "surface" of a star. It is a few hundred miles thick, and it is made up of planet-sized cells of hot gas called granules.
- These gas cells are in constant motion, continuously changing size and shape as they carry heat and light through from the Sun's interior to its exterior.
- Sunspots, regions of intense magnetic activity, also occasionally appear in the photosphere and last from hours to weeks.

Chromospheres

- Chromosphere, the thin and usually transparent layer of the Sun's atmosphere between the photosphere and the corona, is a **highly energetic plasma** that is punctuated with flares—bright, hot jets of gas—and faculae consisting of bright hydrogen clouds called plages.
- The chromosphere is generally not visible except with ultraviolet or X-ray telescopes.
- The chromosphere is around 1,000 to 2,000 miles thick. It has some unexpected physical properties. For example, while the density of the gas decreases from the inner edge of the chromosphere to the outer edge, the temperature of the gas increases dramatically—from about 7,250 to 180,000 degrees Fahrenheit (4,000 to 100,000 degrees Celsius)—even though the distance to the Sun is actually increasing. At its outer limit, the chromosphere breaks up into narrow gas jets called spicules and merges into the Sun's corona.

Corona

- The corona is a very thin, but very large, layer of gas that extends from a star's photosphere and chromosphere out to a distance of about 10 million miles away from the Sun.
- It is much dimmer than the rest of the Sun, and can only be seen when the Sun is blocked from view—either by a scientific instrument called a coronagraph, or naturally during a solar eclipse.
- Even though it is thinner than the best laboratory vacuums on Earth and so far away from the Sun's core, the corona is very energetic and very hot, with its plasma reaching temperatures of millions of degrees.
- Scientists still have not been able to figure out how the corona gets so hot. Current research suggests that the strong electrical currents and magnetic fields in and around the Sun transfer tremendous amounts of energy to the corona, either generally or by special "hotspots" that form for short periods of time and then disappear again.
- All **stars** have layers like a **core, radiative zone, convective zone, photosphere, chromosphere,** and **corona**, but in different ratios of thickness depending on the star's temperature, mass, and age. Very hot, young stars can even be completely radiative and have no convective zone; very cool stars, on the other hand, can be completely convective andm have no radiative zone.
- The coronae around stars can also vary tremendously, depending on the strengths of the magnetic fields around the stars.

Sunspot

- Sunspots are dark blemishes on the Sun. Most sunspots have two physical components: the **umbra**, which is a smaller, dark, featureless core, and the **penumbra,** which is a large, lighter surrounding region.
- Within the penumbra are delicate-looking filaments that extend outward like spokes on a bicycle wheel.
- Sunspots vary in size and tend to be clustered in groups; many of them far exceed the size of our planet and could easily swallow Earth whole. Sunspots are the sites of incredibly powerful, magnetically driven phenomena.
- Even though they look calm and quiet in visible light, pictures of sunspots taken in ultraviolet light and in X rays clearly show the tremendous energy they produce and release, as well as the powerful magnetic fields that permeate and surround them.

Solar Flare

- Solar flares are sudden, powerful explosions on the surface of the Sun. They usually occur when large, powerful sunspots have their magnetic fields too tightly twisted and torqued by the hot, swirling plasma in the Sun.
- The magnetic field lines unwind and break suddenly, and the matter and energy that had been contained rushes outward from the Sun. Solar flares can be many thousands of miles long, and they can contain far more energy than all of the energy consumption of all of human history on Earth.

Coronal Mass Ejection

- A coronal mass ejection is a huge blob of solar material—usually highly energetic plasma—that is thrown outward into space in a huge solar surface explosion.
- Coronal mass ejections are associated with solar flares, but the two phenomena do not always occur together.
- When coronal mass ejections reach the space near Earth, artificial satellites can be damaged by the sudden electromagnetic surge caused by the flux of these charged particles.

Solar Wind

- The solar wind is the flow of electrically charged particles outward from the Sun.
- Aside from stormy outbursts like solar flares, it streams gently from the Sun's corona throughout the solar system. The solar wind can vary in its speed and intensity, just like wind on Earth; it is, however, streaming plasma and not moving air.
- The flow of plasma out from the Sun is generally continuous in all directions, typically moving at speeds of several hundred kilometers per second. It can, however, gust out of holes in the solar corona at 2,200,000 miles per hour (1,000 kilometers per second) or faster.
- As the solar wind travels farther from the Sun, it picks up speed, but it also rapidly loses density.
- The Sun's corona extends millions of miles beyond the Sun's surface. The plasma of the solar wind, however, extends billions of miles farther—well beyond the orbit of Pluto. Beyond there, the plasma density continues to drop.
- There is a limit, called the ***heliopause, where the influence of the solar wind dwindles to just about nothing***. The region inside the heliopause—which is thought to be some 8 to 14 billion miles (13 to 22 billion kilometers) from the Sun—is called the heliosphere. The heliopause is the theoretical boundary where the Sun's solar wind is stopped by the interstellar medium; where the solar wind's strength is no longer great enough to push back the stellar winds of the surrounding stars.

Impact of Solar activity on Earth

- **B**y the time the solar wind reaches the distance of Earth's orbit, its density is only a few of particles per cubic inch.
- Even so, it is enough to have caused substantial radiation damage to life on Earth over the several billion years of Earth's history, if not for Earth's protective magnetosphere.
- When solar activity is particularly strong, such as during a solar flare, the stream of charged particles can increase dramatically. In that case, these ions can strike molecules in the upper atmosphere, causing them to glow.

- Those shimmering lights are called the aurora borealis (Northern Lights) and aurora australis (Southern Lights). During this time, Earth's magnetic field can temporarily weaken, causing our atmosphere to expand; this can affect the motion of satellites in high-Earth orbit. In extremely strong periods of solar flux, electrical power grids can be affected.

Stellar Evolution

- Theory of stellar evolution is broad and complicated. Very much like to us, stars are born, go through immature stages, then are mature for a long time, and then undergo further and final changes toward the end of their lives.
- A star that is currently in the **main mature period of its life cycle** is called Main Sequence Star. Main sequence stars are converting hydrogen into helium and are in an equilibrium state.
- Most stars in any given population of stars are on the **main sequence**—that is, going through the longest equilibrium period of their life cycle—a small percentage of stars in that population are not.
- The stars that are not in the main sequence can be premain sequence, or "infant" stars, and post-main sequence, or "elderly" stars. Stars change and age throughout their existence.

Wolf-Rayet Star

- A Wolf-Rayet star is a high-mass star that is very young.
- It is pretty much a main sequence star, but it is so young that it has not reached a steady equilibrium; very strong stellar winds are gusting off the surface of the star, creating a wildly fluctuating, dynamic environment.

T Tauri star

- T Tauri star is an intermediate-mass star that is very young.
- It is so young that nuclear fusion has not yet begun at its core, or maybe has just begun.

Protostar

- A protostar is star that is not quite on the main sequence. In other words, one might call them "baby stars."
- T Tauri star can be considered an example of a protostar.

Protoplanetary Disk

- Once a star has begun sustained nuclear fusion at its core, its stellar winds start to clear out the surrounding dust, gas, and other debris. Some of that debris, however, settles into a thin, swirling disk that orbits around the newly born star.
- This structure is called protoplanetary disk. It is called so because that is where the raw materials for the planets in that star system have gathered, and where those planets themselves will likely be born.

Factors that influence, how stars will evolve

- It is the initial of a star when it is born—which is by far the most important factor that influences its evolution (i.e., the aging process). On this basis, stars are placed into five mass categories:
  1. very low mass (down to about 0.01 solar mass),
  2. low mass (about 0.1 solar mass),
  3. intermediate mass (about 1 solar mass),
  4. high mass (about 10 solar masses), and
  5. very high mass (up to about 100 solar masses).

  Each of these categories follows a generally similar path from starbirth to star-death. The Sun, which by definition has one solar mass, is thus an intermediate-mass star.
- The main part of a star's life cycle is spent on what is called the main sequence. The higher the initial mass of a star is, the greater its main sequence luminosity is; **the bluer and hotter it is**; the larger its diameter is; and the shorter its main sequence lifetime is.

Supernova remnant

- **A**supernova remnant is the glowing emission nebula that is left over after a supernova explosion. It is comprised of the plasma that used to be part of the massive star which was blown apart.
- The remnant originally is pushed outward into space at a speed of up to 100 million miles per hour. Over time, the remnant forms bright filaments of highly energized gas.

- Furthermore, this gas is highly enriched with heavy elements, the result of the nuclear fusion right near the end of the progenitor star's life.
- These elements, such as calcium, iron, and even silver and gold, wind up being incorporated into the interstellar medium and become the raw materials for future generations of stars and planets. The Crab Nebula is a famous example of a supernova remnant.

Supernova

- A supernova is a tremendous explosion that occurs when the core of a star exceeds the Chandrasekhar limit, and its collapse is not halted by electron degeneracy.
- When that happens, it takes only a fraction of a second for the stellar core to collapse into a dense ball about ten miles across.
- The temperature and pressure becomes almost immeasurably hot and high; and the recoil of that collapse causes an enormous detonation. More energy is released in ten seconds than the Sun will emit in its entire ten billion year lifetime, as the guts of the star are blown outward into interstellar space.
- There are two general types of supernovae.
  - A Type I supernova is the result of an existing, older white dwarf that gains enough mass to exceed the Chandrasekhar limit, causing a runaway collapse.
  - A Type II supernova is produced by a single highmass star whose gravity is so strong that its own weight causes the stellar core to reach a mass beyond the Chandrasekhar limit.

Brown Dwarf

- A brown dwarf is another name for a very low-mass star.
- A Brown dwarf is a star with so little mass that there is almost no nuclear fusion in them, yet with much more mass than any planet in our solar system.
- They have been discovered very lately because their photospheres are so cool that they are very dim, emit very little visible light, and can be found only using infrared telescope technology.
- Due to development of infrared telescopes and infrared astronomical cameras, so many Brown Dwarfs have been identified that it is now hypothesized that the number of brown dwarfs may outnumber all the other stars in our galaxy put together.

Red Dwarf

- A red dwarf is another name for a **low-mass, main-sequence star**. They are cool compared to most other kinds of stars (their photospheric temperature is about 6,000 degrees Fahrenheit, or 3,000 degrees Kelvin), so they glow a dull red.
- Red dwarfs are small and faint compared to most other kinds of stars.

Red Giant

- Red giant is a kind of star that represents an evolutionary phase of intermediate and high-mass stars that have surpassed their main sequence lifetimes.
- When a star like the Sun becomes a red giant, a sudden burst of energy is produced by new fusion processes at the core of the star. This burst pushes the plasma in the star outward.
- When the equilibrium of the star's inward and outward forces are restored, the star has swelled to about one hundred times its original diameter.
- The swollen, bloated star is so large that its outer layers do not contain as much star-stuff, and the star's surface (photosphere) cools down to the temperatures of red dwarfs (3,000 Kelvin).
- The Sun is destined to become a red giant, and when it does, about five billion years from now, it will swallow the planets Mercury and Venus, and destroy Earth as well.

White Dwarf

- A white dwarf is a kind of stellar "corpse."

- Stars of intermediate and low mass tend to end their lives as white dwarfs. As the energy produced by nuclear fusion dwindles and ends in the cores of these stars, they collapse under their own weight until the atomic nuclei in the stars' plasma bump up against one another.
- Any further collapse of the star is halted by the atoms pushing against one another. This is called electron degeneracy
- The collapse concentrates the remaining heat of the dying star into a tiny space, causing the white dwarf to glow white-hot.
- A white dwarf the mass of the Sun will only be as large as our planet Earth, a shrinkage of about 100 times in diameter and a million times in volume. One teaspoon of white dwarf star material weighs several tons.
- Sirius B is the first white dwarf ever detected, and it remains one of the most massive white dwarfs known to astronomers.

Chandrashekhar Limit

- The Indian-American astrophysicist Subramanyan Chandrasekhar (1910–1995) first proposed the idea that **some stars** could **not end their lives** as **white dwarfs**.
- Chandra is perhaps best known for discovering that stars can evolve beyond white dwarfs to other, even denser states of matter.
- In 1930 Chandrasekhar used theories first presented by Arthur Eddington, as well as Albert Einstein's special theory of relativity, to calculate that a **star higher than a certain mass limit will not end its life as a white dwarf**.
- In other words, the electron degeneracy that would stop the collapse of a star's core would stop working because the pressure would be so great that the electrons would start moving too fast to provide outward pressure.
- In 1934 and 1935, he made further calculations showing that, above about 1.4 times the mass of the Sun, a stellar core will collapse beyond the white dwarf stage and turn into something far denser and more compact.
- Although this particular discovery was not immediately accepted by the astrophysical community, the discovery of the Crab Nebula pulsar and the realization that it was far smaller and denser than any white dwarf confirmed Chandrasekhar's calculations.
- That **upper mass limit is today called the Chandrasekhar limit** in his honor.

Blue Giant

- A blue giant big and blue. Such stars are usually **high-mass stars on the main sequence**.
- Blue giants live for only a million years or so, glowing a million times brighter than the Sun before they blow apart in titanic supernova explosions.

Neutron Star

- A neutron star is the collapsed core of a star that is left over after a supernova explosion.
- It is, so to speak, matter's last line of defense against gravity. In order to stay internally supported as an object and not be crushed into a singularity, the neutrons in the object press up against one another in a state known as neutron degeneracy.
- This state, which resembles the conditions within an atomic nucleus, is the densest known form of matter in the universe.
- A neutron star is about as dense as a neutron itself. In other words, it has the density of an object more massive than the Sun, yet it is only about ten miles across.
- That means that a neutron star is 10 trillion times denser than water. A single teaspoon of neutron star material would weigh about five billion tons.
- *A dime-sized sliver of neutron star material contains more mass than every man, woman, and child on Earth put together. If one dropped a chunk of neutron star material toward the ground, it would cut through our planet like it was not there; it would fall through the center of our planet, emerge out the other side, and keep traveling back and forth through the middle of Earth for billions of years, turning our planet into something like a big ball of Swiss cheese.*

Magnetar

- **A**magnetar is a neutron star with such a strong magnetic field that it creates unusual and fascinating physical conditions.

- These neutron stars are literally the most magnetized objects ever discovered, with field strengths trillions or even quadrillions of times stronger than those of the Sun.
- These fields are so strong that they can induce starquakes in the neutron stars, disruptions that cause dramatic bursts of gamma-ray radiation to erupt into space. The magnetar phenomenon is a highly energetic, short-lived phase in the lives of a small fraction of all known neutron stars. These "soft gamma repeaters," as they are also known, are not the so-called gamma-ray bursts; rather, it may be possible that magnetars are what is left after a gamma-ray burst caused by a supernova in a very fast-spinning high-mass star. This hypothesis has yet to be confirmed, however.

Pulsar

- When a neutron star spins, it sometimes spins incredibly fast—up to hundreds of times a second. A magnetic field billions of times stronger than Earth's can form as a result.
- If the field interacts with nearby electrically charged matter, it can result in a great deal of energy being radiated into space, a process called **synchrotron radiation**.
- The slightest unevenness or surface feature on the neutron star can cause a significant "blip" or "pulse" in the radiation being emitted. Each time the neutron star spins around once, a pulse of radiation comes out. Such an object is called a pulsar.
- As of now, more than 1,000 pulsars have been found throughout our galaxy. Perhaps the best known one is the **Crab Nebula pulsar**. It is at the center of the Crab Nebula and is a remnant from a supernova that was first observed in 1054 AD.
- It pulses once every 33 milliseconds, which shows that the body with the mass of the Sun is spinning more than 30 times per second ☺

X-Ray Star

- An "X-ray star" emits a great deal of X-ray radiation. X-ray stars may emit thousands of times more X rays than visible light radiation.
- X-ray stars are almost always binary star systems or multiple star systems. The interaction between the two or more stars in the systems—one of which is usually a compact object like a white dwarf, neutron star, or black hole—is what causes the strong X-ray emission.

Binary Star

- A binary star is a pair of stars that are so close together in the sky that they appear to be closely associated with one another.
- Some binary stars, called apparent binaries, are merely close together because of our point of view from Earth; they have nothing to do with one another physically.
- When two stars that are physically associated together make a binary star system, however, the two stars orbit each other around a single center of gravity. Physically associated binary stars are further divided into categories.
    - A visual binary is a pair where each star can be observed distinctly, either through a telescope or with the unaided eye.
    - An astrometric binary is a pair where the two stars cannot be distinguished visually, but the wobble of one star's orbit indicates the existence of another star in orbit around it.
    - An eclipsing binary is a pair where the plane of the stars' orbit is nearly edgewise to our line of sight; the stars take turns being partially or totally hidden by one another.
        - A spectroscopic binary is a pair where two stars can be detected by Doppler shifts or other spectral indicators from spectroscopic measurements. There are also multiple star systems, which may have three or four stars orbiting one another around a single center of gravity, although they are rarer and less likely to be in a long-term stable orbit.

Stars are often grouped together in space. These groupings are called star clusters, and they are different from constellations in that they are actually physically asso-ciated with one another, rather than just appearing that way. The best-known kinds of star clusters are globular clusters and open clusters.

Sun

- The Sun has been shining for 4.6 billion years. We know this from a variety of scientific studies. The most convincing evidence comes from the study of meteorites.
- Using various dating methods, some of these meteorites have been shown to have formed at the time the Sun began to shine. They have been dated to be 4.6 billion years old, so the Sun is estimated to be that old, as well.
- Sun will continue to conduct nuclear fusion at its core for about another five to six billion years.

Structure of Sun

- The Sun has a core at its center; a radiative zone surrounding the core; a convective zone surrounding the radiative zone; a thin photosphere at its surface; and a chromosphere and corona that extends beyond the photospheric surface.
- In all, the Sun is about 1,372,500 kilometers across, which is about 109 times the diameter of Earth.
- The different zones and layers in and around the Sun exist because the physical conditions—mostly temperature and pressure—of the Sun change depending on the distance from the Sun's center.
- At the core, for example, temperatures exceed 15 million degrees Kelvin, whereas the inner part of the convective zone is just under 1 million degrees Kelvin, and the photosphere is about 5,800 degrees Kelvin.

Composition of Sun

- The Sun's mass is composed of 71 percent hydrogen, 27 percent helium, and 2 percent other elements.
- In terms of the number of atoms in the Sun, 91 percent are hydrogen atoms, 9 percent are helium atoms, and less than 0.1 percent are atoms of other elements. Most of the stars in the universe have a similar chemical composition.

Mass of Sun

- The Sun has a mass of 1.99 million trillion trillion kilograms.
- The most massive supergiant stars have about one hundred times more mass than the Sun. The least massive dwarf stars and brown dwarfs contain about one-hundredth the mass of the Sun.

Rotation of Sun

- Sun rotates about its axis from west to east, the same direction that the planets orbit around the Sun. Since the Sun is not a solid object but rather a big ball of electrically charged gas, it spins at different speeds depending on the latitude.
- The Sun spins once around its axis near its equator in about 25 days, and in about 35 days near its north and south poles. This kind of spinning, in which different parts move at different speeds, is called **differential rotation**.

Implications of Sun's Spin

- Magnetic fields in the Sun, created by strong electric currents, are produced because of the Sun's spin.
- Since Sun has differential rotation, and its interior roils with tremendous heat and energy, the magnetic field lines in the Sun get bent, twisted, knotted, and even broken; sunspots, prominences, solar flares, and coronal mass ejections are the result.

Planetary System

- A planetary system is a system of astronomical objects that populate the vicinity of a star. This includes objects like planets, asteroids, comets, and interplanetary dust.
- In a more general sense, planetary system also includes the star itself, its magnetic field, its stellar wind, and the physical effects of those things, including ionization boundaries, and shock fronts.

Formation of Solar System:

- The solar system probably formed in a way that follows the basic ideas of the so-called nebular hypothesis, which was advanced in the eighteenth century by Pierre- Simon de Laplace and significantly updated since that time.

- About 4.6 billion years ago, the Sun formed from a large cloud of gas and dust that collapsed upon itself because of gravitational instability. When the Sun was born, not the entire nebula of gas and dust that had been gravitationally gathered was incorporated into the Sun itself.
- Some of it settled into a disk of orbiting material. As this material orbited in a protoplanetary disk, numerous collisions between the tiny grains led to some of the grains sticking together, making larger bodies. After millions of years, the largest bodies—planetesimals—had sufficient mass (and hence gravity) to start attracting other objects in the disk to them.
- Growing larger and larger, these planetesimals became protoplanets; the largest protoplanets grew larger still, until at last the planets were formed.
- Although the solar wind has removed much of the remaining, unprocessed gas and dust, numerous smaller objects (and some of the gas and dust, as well) still remain today, providing the rich variety of objects and phenomena in a solar system more than four and a half billion years later.

Sized of Solar System

- Solar system reaches out to the orbit of the most distant planet, Neptune, or about three billion miles (five billion kilometers) away from the Sun.
- *Beyond Neptune is the Kuiper Belt, a thick, doughnut-shaped cloud of small icy bodies that extends to about eight billion miles (12 billion kilometers).*
- **Beyond that still is the Oort Cloud**, which is a huge, thick, spherical shell thought to contain trillions of comets and comet-like bodies. The Oort Cloud may extend as far as a light-year, nearly six trillion miles, out from the Sun.

Planetesimals

- Planetesimals are early solar system objects that range in size from about 0.6–60 miles (1–100 kilometers) across. Like so many terms in science, this is not an exact definition.
- More generally, it refers to objects in the protoplanetary nebula that have formed by collisions and may be starting to accrete more material via their gravitational influence.

Protoplanets

- Protoplanets are early solar system objects that range in size from about 60–6,000 miles (100–10,000 kilometers) across.
- More generally, protoplanets are objects in the protoplanetary nebula that are large enough that they are growing in size and mass by attracting other, smaller objects with their gravitational pull.

Zones of Solar System

- Solar system is generally divided into five major zones:
  - the inner (or terrestrial) planet zone,
  - the asteroid belt,
  - the outer (or gas giant) planet zone,
  - the Kuiper Belt, and the
  - Oort Cloud.

There is no exact boundary for these zones, however, and their sizes are not well determined; there is also overlap, in the sense that objects from one zone often appear in another zone.

Planets

- There is no universally agreed-upon scientific definition of the term. Generally speaking, however, a planet usually refers to an object **that is not a star (that is, has no nuclear fusion going on in its core); that moves in orbit around a star; and is mostly round because its own gravitational pull has shaped it into, more or less, a sphere**.
- All the planets in our solar system, by the current scientific classification system, must satisfy three basic criteria\
  - A planet must be in **hydrostatic equilibrium**— a balance between the inward pull of gravity and the outward push of the supporting structure. Objects in this kind of equilibrium are almost always spherical or very close to it.

- A planet's primary orbit must be around the Sun. That means objects like the Moon, Titan, or Ganymede, are not planets, even though they are round due to hydrostatic equilibrium, because their primary orbit is around a planet.
- A planet must have cleared out other, smaller objects in its orbital path, and thus must be by far the largest object in its orbital neighborhood. This means that Pluto is not a planet, even though it meets the other two criteria; there are thousands of Plutinos in the orbital path of Pluto, and it crosses the orbit of Neptune, which is a much larger and more massive object.
- The eight objects in our solar system that meet all three criteria are Neptune, Uranus, Saturn, Jupiter, Mars, Earth, Venus, and Mercury.

International Astronomical Union

- International Astronomical Union has been the official standards-governing body of professional astronomers worldwide.
- Official names of objects in the universe—for example, asteroids or comets or planets—are suggested to, then approved or rejected by the IAU committee on names and nomenclatures.
- The IAU formed a special committee to decide how to classify planets in our solar system because it was becoming scientifically clear that Pluto and other Kuiper Belt Objects would have to be designated in a scientifically valid, practically sensible way.
- On August 24, 2006, the general assembly of the International Astronomical Union approved the current system of classifying planets in our solar system.
- This system added a specific scientific requirement for planethood: *it must have cleared all other significantly sized bodies out of its orbital path or neighborhood, probably through collisions or gravitational interactions.* This system also creates a new designation called a "**dwarf planet,**" which describes an object that fulfills all the criteria of a planet except this one.
- This system, like every other classification that has come before it, has strengths and weaknesses; no matter what, though, it gives all people a starting point to learn about—and hopefully understand—what planets are all about. This current classification system means that, officially, there are eight planets in the solar system—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune—and a **number of dwarf planets, including Pluto, Charon, Ceres, Eris.**

Planetary Ring

- A planetary ring is a system of huge numbers of small bodies—ranging in size from grains of sand to house-sized boulders—that orbit in a coherent ring-shaped pattern around a planet.
- The most spectacular planetary rings in the solar system orbit around Saturn; they are more than 170,000 miles across, and are less than one mile thick.

Inner Solar System

- The planets that are collectively thought of as belonging to the inner solar system are **Mercury, Venus, Earth, and Mars**.
- These four objects are called the terrestrial planets because they resemble one another (specifically, Earth) in their structure: a metallic core, surrounded by a rocky mantle and thin crust.
- There are three moons in the terrestrial zone as well: **Earth's moon, and the two moons of Mars: Phobos and Deimos**.

Mercury

- Mercury's diameter is a little more than one-third that of Earth's, and it has just 5.5 percent of Earth's mass.
- On average, Mercury is 58 million kilometers away from the Sun. *That is so close to the Sun that Mercury's orbit is rather tilted and stretched into a long elliptical shape*.
- Mercury orbits the Sun in just 88 Earth days, but Mercury's day— the time it takes to rotate once around its polar axis—is about 59 Earth days.
- Mercury's surface is covered with deep craters, separated by plains and huge banks of cliffs. There is absolutely no water on the planet.
- Mercury's most notable surface feature is an ancient crater called the **Caloris Basin**, which is a huge pit for such a small planet.

- Mercury's very thin atmosphere is made primarily of *sodium, potassium, helium, and hydrogen*.
- On its day side (the side facing the Sun), temperatures reach 430°C ; on its night side, the heat escapes through the negligible atmosphere, and temperatures plunge to -170°C.
- Mercury is so close to the Sun, the glare of the Sun makes it difficult to observe Mercury from Earth. Mercury is therefore visible only periodically, when it is just above the horizon, for at most an hour or so before sunrise and after sunset.
- It also moves more quickly across the sky than the other planets. Even when Mercury is visible, the sky is often so bright that it is hard to distinguish it from the background sky.

Venus

- Venus is similar to Earth in many ways. *Venus is closer in distance to Earth than any other planet, and it has a similar size and composition.*
- However, the surface characteristics differ greatly.
- A year on Venus is equal to 225 Earth days, compared to Earth's 365-day year. Venus, however, *rotates on its polar axis backwards compared to Earth, so a Venus sunrise occurs in the west and sunset is in the east*.
- A Venusian day is Earth days long, which makes it even longer than a Venusian year. The surface conditions of Venus are far different from that of our own planet.
- It is blanketed by a thick atmosphere nearly 100 times denser than Earth; it is made mostly of carbon dioxide, along with some nitrogen and trace amounts of water vapor, acids, and heavy metals.
- Venus's clouds are laced with poisonous sulphur dioxide, and its surface temperature is 500°C. *Interestingly, this is even hotter than Mercury, which is much closer to the Sun*. These hostile conditions are because of a runaway greenhouse effect on Venus that persists to this day.
- The heat trapped by the Venusian atmosphere caused the surface temperature to get so high that the rocky crust began to release greenhouse gases like carbon dioxide. The atmospheric insulation consequently became even thicker, which caused more heat to be trapped, which caused the temperature to rise higher still, which caused even more greenhouse gas to be released. After finally reaching thermal equilibrium, Venus is now the inferno , as it is seen today.
- Since Venus is closer to the Sun than Earth, it is never up in the sky at midnight. Rather, Venus is visible in the sky either just after dark or just before sunrise, depending on the season, so it is called Morning or Evening Star.
- Due to its proximity to Earth, and to the **highly reflective cloud layers in its atmosphere**, Venus can look incredibly bright and beautiful in the sky. At its brightest, it is the third brightest object in the sky, after the Sun and the Moon.
- Through a small telescope, it is possible to see Venus undergo phases, just like the Moon. This occurs because, from our point of view on Earth, we see only the parts of Venus that are illuminated by sunlight at any given time.
- Unlike the Moon, though, Venus is usually brighter to our view in its crescent phase than in its full phase.

Mars

- **M**ars is known as the red planet because it looks red from Earth. The reddish color comes from the high concentration of iron oxide compounds—that is, rust—in the rocks of the Martian surface.
- Mars is the fourth planet from the Sun in our solar system. Its diameter is about half that of Earth, and its year is about 687 Earth days.
- That means that its seasons are about twice as long as on Earth.
- However, a Martian day is very close in length to an Earth day—only about 20 minutes longer.
- The Martian atmosphere is very thin—only about 7000th the density of Earth's atmosphere. The atmosphere is mostly carbon dioxide, with tiny fractions of oxygen, nitrogen, and other gases.
- At the equator, during the warmest times of the Martian summer, the temperature can reach nearly –18°C at the poles, during the coldest times of the Martian winter, temperatures drop to -85°C and beyond.
- Mars is known for fascinating geologic features on its surface; it is covered with all sorts of mountains, craters, channels, canyons, highlands, lowlands, and **even polar ice caps.**

- Scientific evidence strongly suggests that once, billions of years ago, Mars was much warmer than it is now, and was an active, dynamic planet.

Polar Ice Caps on Mars

- Polar Ice Caps were first observed by Italian astronomer Gian Domenico Cassini, who is known for many important discoveries, including a gap in Saturn's rings (This is called Cassini division).
- He made detailed observations of Mars, and discovered light-colored patches at the Martian north and south poles. These polar caps showed seasonal variations, spreading during the Martian winter and shrinking during the summer.
- Martian polar ice caps are made up **mostly of frozen carbon dioxide, also known as "dry ice."** Some frozen water, or just plain ice, may also be imbedded within the polar caps.
- Due to the atmospheric conditions on the surface of *Mars, however, neither the ice nor the dry ice would melt to make water or liquid carbon dioxide when the temperatures go up; rather, they would sublimate, or turn directly into gas.* Thus, polar ice caps on Mars are not a source of liquid water.

Geological features of Mars

- Mars has a rich variety of geological features: huge craters, broad plains, tall mountains, deep canyons, and much more, all with colorful names.
- **The tallest mountain in the solar system, the extinct volcano Olympus Mons**, rises 24 kilometers above the Martian surface.
- A massive canyon called the ***Vallis Marineris*** (Mariner Valley) cuts across the northern hemisphere of Mars for more than 3,200 kilometers; it is three times deeper than the Grand Canyon, here on Earth.
- On the southern hemisphere of Mars is **Hellas,** an ancient canyon that was probably filled with lava long ago and is now a large, light area covered with dust.

Martian meteorite ALH84001

- **A**LH84001 was so named because it was found in the *Allan Hills region of Antarctica in 1984* . It is the most famous of a number of meteorites that are thought to have been pieces of the Martian surface millions of years ago.
- They were probably knocked loose by a powerful collision from a comet or asteroid, which sent pieces of rock into orbit around the Sun that later landed on Earth.
- Mars Exploration Rovers, *Spirit* and *Opportunity,* are geological robots that have explored several areas of Mars. Among the many discoveries made with them are minerals that form only in the long term presence of water; microscopic *mineral structures nicknamed "blueberries" that only form when moisture is present,* along with chemical and isotopic ratios in Martian rocks that would have formed only if liquid water were in the environment.
- The strong scientific conclusion is that Mars is currently dry on its surface, but that this was not always the case. It may even have been awash with liquid water billions of years ago.

Several kinds of scientific evidence are used to determine where meteorites come from. These include the crystallization age of the meteorite, its chemical and physical composition, the effects that cosmic rays have had on it, and the composition and concentrations of gases trapped long ago in tiny fissures and bubbles in the meteorite.

Gas Giants

- Gas giant planets are so named because they are much larger than the terrestrial planets, and they have atmospheres so thick that the gas is a dominant part of the planets' structure. Jupiter, Saturn, Uranus, and Neptune are all categorized as gas giants.
- The gas giant zone is the part of the solar system roughly between the orbit of Jupiter and the orbit of Pluto. It contains the outer (gas giant) planets Jupiter, Saturn, Uranus, and Neptune. Each of the gas giant planets has a host of moons and rings or ringlets.

Jupiter:

- Jupiter is the largest planet in our solar system. It is about twice as massive as all the other planets, moons, and asteroids in our solar system put together.

- However, its day is only 10 hours long, less than half an Earth day. The fifth planet out from the Sun, Jupiter is 1,300 times Earth's volume and 320 times Earth's mass.
- More than 90 percent of Jupiter's mass consists of swirling gases, mostly hydrogen and helium; in this incredibly thick, dense atmosphere, ***storms of incredible magnitude rage and swirl.***
- The largest of these storms is the **Great Red Spot**, which is often visible from Earth through even a small telescope.
- Jupiter has a rocky core made of material thought to be similar to Earth's crust and mantle. Around this core, in these extreme conditions*, it is likely that a thick layer of compressed hydrogen is present; the hydrogen in this layer probably acts like metal, and may be the cause of Jupiter's intense magnetic field, which is five times greater than even that of the Sun.*
- As of now , 66 moons orbit Jupiter. Many of them are only a few miles across and are probably captured asteroids. However, four of them—***Io, Europa, Ganymede, and Callisto***—are about the size of Earth's Moon or larger.

Atmosphere of Jupiter:

- The mini-probe launched in 1995 from the *Galileo* spacecraft made detailed measurements of Jupiter's atmosphere down to about 90 miles (150 kilometers) below the cloud-tops.
- This probe found that these upper layers of Jupiter's deep, dense atmosphere contain *water vapor, helium, hydrogen, carbon, sulfur, and neon, all in lower concentrations than were previously predicted*. On the other hand, it had higher concentrations of other gases, such as krypton and xenon. Rather than several dense cloud layers of ammonia, hydrogen sulfide, and water vapor, as was predicted, the probe only detected thin, hazy clouds. Also, scientists had predicted tremendous amounts of lightning discharges; but only faint signs of lightning at least 600 miles (1,000 kilometers) away were detected. This suggested that, at these atmospher-ic depths, lightning occurs on Jupiter only about one-tenth as often as it does on Earth. It is important to note, though, that the surprising results from *Galileo*'s miniprobe were only obtained from one area in Jupiter's atmosphere. It is possible that the atmospheric conditions there were not representative of the entire atmosphere.
- Jupiter's upper atmosphere is composed of about 88–92% hydrogen and 8–12% helium by percent volume or fraction of gas molecules. Since a helium atom has about four times as much mass as a hydrogen atom, the composition changes when described as the proportion of mass contributed by different atoms. Thus the atmosphere is approximately 75% hydrogen and 24% helium by mass, with the remaining one percent of the mass consisting of other elements. The interior contains denser materials such that the distribution is roughly 71% hydrogen, 24% helium and 5% other elements by mass. The atmosphere contains trace amounts of methane, water vapor, ammonia, and silicon-based compounds. There are also traces of carbon, ethane, hydrogen sulfide, neon, oxygen, phosphine, and sulfur. The outermost layer of the atmosphere contains crystals of frozen ammonia.

The Great Red Spot at Jupiter

- **T**he Great Red Spot is a huge windstorm more than 14,000 kilometers wide and 26,000 kilometers long.
- The storm that perpetuates the Spot is apparently powered by the upswell of hot, energetic gases from deep inside Jupiter's atmosphere, which produce winds that blow counterclockwise around the Spot at 400 kilometers per hour.
- The Great Red Spot *may derive its red color from sulfur or phosphorus, but this has not been conclusively shown*.
- Beneath it are three white, oval areas; each is a storm about the size of the planet Mars. There are thousands of huge and powerful storms on Jupiter, and many of them can last for a very long time.
- Great Red Spot has been going on for at least 400 years, and which was first studied by Galileo Galilei, remains the biggest and most visible Jovian storm yet recorded.
- Jupiter is the archetypal gas giant planet—*so much so that gas giants are often called Jovian planets.*

Magnetic Field of Jupiter

- Magnetic Field of Jupiter is about five times the intensity of the Sun's.
- Jupiter's magnetosphere is so big that it would take up a good part of our night sky—much larger than the full Moon—if we could see it with our eyes.

- Also, like Earth, there are large belts of trapped, highly energized charged particles around Jupiter; these "**Van Allen" belts are confined by lines of magnetic force that have naturally developed in Jupiter's magnetic field**.

Rings of Jupiter

- Jupiter has several very faint rings. They are nothing like Saturn's enormously developed and beautiful rings, but they can be detected through careful observations with instruments like the Hubble Space Telescope.

Saturn

- Saturn is similar to Jupiter, though about one-third the mass.
- Saturn is 95 times more massive than Earth. Saturn's average density is actually lower than that of water. A day on Saturn is only 10 hours and 39 minutes long; it spins so fast that its diameter at the equator is 10 percent larger than its diameter from pole to pole.
- Saturn has a solid core likely made of rock and ice, which is thought to be many times the mass of Earth. Covering this core is a layer of liquid metallic hydrogen, and on top of that are layers of liquid hydrogen and helium.
- These layers conduct strong electric currents that, in turn, **generate Saturn's powerful magnetic field**.
- Saturn has 62 confirmed moons, and its largest moon is Titan, which is larger than Earth's own moon and has a thick, opaque atmosphere.
- The most spectacular part of Saturn is its magnificent system of planetary rings, which stretch some 300,000 kilometers across.
- Saturn has hazy, yellow cloud-tops made primarily of crystallized ammonia. The clouds are swept into bands by fierce easterly winds.

Saturn's Ring System

- Saturn's ring system is divided into three main parts: the bright A and B rings and the dimmer C ring. There are many other fainter rings as well.
- The A and B rings are divided by a large gap called the Cassini Division, named after Gian Domenico Cassini.
- Within the A ring itself is another division, called the **Encke Gap** after Johann Encke, who first found it in 1837.
- Although these gaps appear to be completely empty, they are nonetheless filled with tiny particles, and, in the case of the Cassini Division, dozens of tiny ringlets.
- Although Saturn's rings measure more than 100,000 miles across, they are only about a mile or so (one or two kilometers) thick. That is why they sometimes seem to disappear from view here on Earth. When the orbit of Saturn is such that we see the rings edge-on, the rings look like a thin line and can be nearly invisible.
- One idea about formation of Rings is that the rings were once larger moons that were destroyed, either by collisions, or by tidal interactions with Saturn's gravity tearing them apart. The bits of moons then settled into orbit around Saturn.

Uranus

- Uranus is the seventh major planet in our solar system, and the third of four gas giant planets. It is 51,200 kilometers in diameter, just under four times the diameter of Earth.
- Like the other gas giant planets, Uranus consists mostly of gas. Its pale blue-green, cloudy atmosphere is made of 83 percent hydrogen, 15 percent helium, and small amounts of methane and other gases.
- *Uranus gets its color because the methane in the atmosphere absorbs reddish light and reflects bluish-greenish light*. Deep down below its atmosphere, a slushy mixture of ice, ammonia, and methane is thought to surround a rocky core.
- Although it orbits the Sun in a perfectly ordinary, near-circular ellipse every 84 Earth years, Uranus has an extremely odd rotation compared to the other major planets. It rotates on its side, almost like a bowling ball rolling down its lane, and its polar axis is parallel rather than perpendicular to its orbital plane.
- This means that **one end of Uranus faces the Sun for an entire half of its orbit, while the other end faces away during that time.** So one "day" on Uranus is equal to 42 Earth years.
- Uranus is orbited by 27 known moons and several thin rings.

Neptune:

- Neptune is the eighth major planet in our solar system, 17 times more massive than Earth and about four times its diameter.
- The most remote of the four gas giant planets in our solar system, Neptune takes 165 Earth years to orbit the Sun once.
- A "day" on Neptune, however, is only 16 Earth hours.
- Similar to Uranus, Neptune's cloud-top temperature is a frosty –210°C
- Neptune is bluish-green in color, which might seem fitting for a planet named after the Roman god of the sea. However, the color does not come from water; it is due to the gases in Neptune's atmosphere reflecting sunlight back into space. Neptune's atmosphere consists mostly of hydrogen, helium, and methane. Below the atmosphere, scientists think there is a thick layer of ionized water, ammonia, and methane ice, and deeper yet is a rocky core many times the mass of Earth.

Moons

Moons of Mars - Phobos and Deimos

- **T**he physical appearances of Phobos and Deimos, the two moons of Mars , are very similar to small asteroids. That, and the proximity of Mars to the asteroid main belt, suggests that they were indeed once asteroids whose orbits took them close to Mars.
- The orbital conditions were just right for Mars to capture them with its gravity, causing them to enter into stable orbits around Mars.
- Phobos and Deimos are irregularly shaped rocky objects. They look very much like asteroids. Phobos is about 10 miles across, and Deimos is about half that size.

Moons of Jupiter- Jupiter's moon Io

- Io, the closest of the Galilean moons to Jupiter, is affected so strongly by the gravitational tides exerted on it by Jupiter and the other moons that it is the most geologically active body in our solar system.
- The *Voyager* spacecraft first detected huge volcanoes spewing lava and ash into space, and the surface is completely recoated with fresh lava every few decades.

Impact of Jupiter on its Io – Io Torus

- **J**upiter's tremendous gravitational influence on its surroundings causes tidal activity on the Galilean moons.
- The tides alternately stretch and compress the cores of these moons.
- Another important influence exerted by Jupiter on its moons comes from the giant planet's magnetic field.
- *Jupiter spins so fast, and contains so much mass, that the magnetic field generated by it engulfs the nearby moons and bathes them with ionization and charged particles.*
- Meanwhile, powerful volcanoes that erupt on the surface of Io eject large amounts of small particles into space; many of them are swept up into Jupiter's magnetosphere, forming a doughnut-shaped torus of volcanic particles that form an ethereal envelope around the Jovian environment. This is called Io torus.

Jupiter's moon Europa:

- Europa is the second closest to Jupiter of the four Galilean moons. Its surface is covered with frozen water ice.
- Studies by the *Galileo* spacecraft show that the ice has been moving and shifting much the same way that densely packed ice behaves on Earth's polar oceans.

Jupiter's moon Ganymede

- ***Ganymede is the largest moon in the solar system,*** about one-and-a-half times as wide as Earth's Moon. It has a very thin atmosphere and its own magnetic field.

Jupiter's Moon Calisto

- Callisto, the furthest away from Jupiter of the four Galilean moons, is scarred and pitted by ancient craters.
- Its surface may be the oldest of all the solid bodies in the solar system.

Moons of Saturn

- Saturn has 62 confirmed moons. Also like Jupiter, many of these are small moons that are likely to be asteroids captured in Saturn's gravitational field.

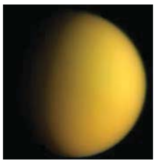
Saturn's moon Mimas

- Mimas, the victim of a huge cratering collision long ago, looks almost exactly like the fictional "Death Star" space station from the movies.
- Mimas has a diameter of 396 kilometers. It is the smallest known body in the solar system that became round because of its own gravitation.

Saturn's moon Enceladus

- Enceladus was recently (2005) detected as having **geysers of water shooting out from its surface**, suggesting the **presence of liquid water deep in its core**.
- Enceladus is one of only three outer Solar System bodies (along with Jupiter's moon Io and Neptune's moon Triton) where active eruptions have been observed.
- The craters of Enceladus have been named Alibaba and Alladin ☺

Saturn's Moon Titan



- Titan is perhaps the most complex moon in the entire solar system. It is the largest moon of Saturn. Titan was discovered by Christian Huygens (1625–1695) around 1655.
- Over the centuries, astronomers discovered that this largest of Saturn's moons is the **only moon in the solar system with a dense atmosphere—it is even denser than the atmosphere of planet Earth**.
- Titan's atmosphere appears to be composed mainly of nitrogen and methane, with many other ingredients as well. Observations with the space probe *Voyager 1,* and with other telescopes, suggested that Titan might harbour liquid nitrogen or methane at its surface, perhaps in lakes and seas, and that its clouds may produce chemical rains and other weather patterns.
- Any detailed view is blocked by Titan's thick, opaque atmosphere, however.
- The *Cassini* spacecraft launched the *Huygens* probe into the atmosphere of Titan in January 2005. Despite its numbing cold (–300 degrees Fahrenheit), there are topological features that look like tall mountains, rocky beaches, rivers, lakes, and even seas and shorelines.
- Liquid appears in abundance on the surface of Titan, but it is not liquid water. At those temperatures, water is frozen solid and as hard as granite. Rather, the liquid is probably methane—liquid natural gas.
- Titan is 5,150 km across, compared to 4,879 km for the planet Mercury, 3,474 km for Earth's Moon, and 12,742 km for the Earth. Before the arrival of Voyager 1 in 1980, Titan was thought to be slightly larger than Ganymede (diameter 5,262 km) and thus the largest moon in the Solar System; this was an overestimation caused by Titan's dense, opaque atmosphere, which extends many kilometres above its surface and increases its apparent diameter.

Moons of Uranus

- Uranus, the seventh planet of the Solar System, has **27 known moons**, all of which are named after characters from the works of William Shakespeare and Alexander Pope.
- The moons of Uranus are smallish structures made of ice and rock, ranging in size from about 15 miles (25 kilometers) to 1,000 miles (1,600 kilometers) across.
- The two largest, **Oberon and Titania**, were discovered by William Herschel; the next largest two moons, Umbriel and Ariel, were discovered in 1851 by William Lassel.
- In 1948, Gerard Kuiper detected **Miranda,** the fifth Uranian moon.
- The *Voyager 2* flew by Uranus in January and February 1986, and discovered at least 10 new moons—all smaller than about 90 miles (145 kilometers) across.

Moons of Neptune

- Neptune has thirteen known moons, by far the largest of which is **Triton**, discovered by William Lassell on October 10, 1846, just 17 days after the discovery of Neptune itself.
- The second Neptunian moon to be discovered was **Nereid**, and that did not happen until 1949. It was discovered by Gerard Kuiper.

- During its 1989 flyby of Neptune, the *Voyager 2* found six other moons, ranging in size from 3 miles (50 kilometers) to 250 miles (400 kilometers) across.

Neptune's moon Triton

- ***Triton is the coldest known place in the solar system*** at –235 degrees Celsius, yet it has a very active environment.
- It harbors volcanic activity, with several volcanoes shooting not ash, but frozen nitrogen crystals as high as 6 miles (10 kilometers) above the surface.
- Scientists think that volcanoes on Triton once covered the moon's surface with a slushy ammonia-and-water-ice "lava," which is now frozen in patterns of ridges and valleys.
- Triton is also the only major moon in the solar system that orbits in a direction opposite to that of its planet. Triton makes an orbit around Neptune about once every six days. It is possible that Triton was once a large comet-like object, like Pluto, and was captured into Neptune's gravitational field.

Kuiper Belt

- Kuiper Belt or the **Kuiper-Edgeworth Belt** is a doughnut-shaped region that extends between about three to eight billion miles (5 to 12 billion kilometers) out from the Sun (its inner edge is about at the orbit of Neptune, while its outer edge is about twice that diameter).

Kuiper Belt Objects

- Kuiper Belt Objects (KBOs) are objects that originate from or orbit in the Kuiper Belt.
- Only one KBO was known for more than 60 years: Pluto.
- Many KBOs have been discovered since 1990s, however, and the current estimate is that there are millions, if not billions, of KBOs.
- **KBOs are basically comets without tails**: icy dirtballs that have collected together over billions of years. If they get large enough—such as Pluto did—they evolve as other massive planet like bodies do, forming dense cores that have a different physical composition than the mantle or crust above it. Most short-period comets— those with relatively short orbital times of a few years to a few centuries—are thought to originate from the Kuiper Belt.

Largest KBOs in our solar system:
(Diameter: km)

- Eris → 2300-2400
- Pluto → 2,306
- Sedna → 1,500
- Quaoar → 1,260
- Charon → 1,210
- Orcus → 940
- Varuna → 890
- Ixion → 820
- Chaos → 560
- Huya → 500

Plutinos

- Plutinos are Kuiper Belt Objects that are smaller than Pluto, have many physical characteristics similar to Pluto, and orbit around the Sun in much the same way that Pluto does.
- The discovery of Plutinos led to the recognition that the Kuiper Belt is heavily populated, and that Pluto itself is a Kuiper Belt Object.

Asteroids

- Asteroids are relatively small, primarily rocky or metallic chunks of matter that orbit the Sun.
- They are like planets, but much smaller; ***the largest asteroid, Ceres, is only about 930 kilometers across, and only ten asteroids larger than 250 kilometers across are known to exist in the solar system***.
- While most asteroids are **made mostly of carbon-rich rock, some are made at least partially of iron and nickel**.
- Aside from the largest ones, asteroids tend to be irregular in shape, rotating and tumbling as they move through the solar system.
- The four largest asteroids are the dwarf planet Ceres, Pallas, Vesta, and Hygiea. Other well-known asteroids include Eros, Gaspra, Ida, and Dactyl.

Asteroid belt

- The asteroid belt (or the "main belt") is the region between the **orbit of Mars and the orbit of Jupiter**—about 240 to 800 million kilometers away from the Sun.

- The vast majority of known asteroids orbit in this belt. The main belt itself is divided into thinner belts, separated by **object-free zones called Kirkwood Gaps**. The gaps are named after the American astronomer Daniel Kirkwood, who first discovered them.
- Even though there are at least a million or more asteroids in the main belt, the typical distance between asteroids is huge—thousands or even millions of miles.

Asteroids located other than Asteroid Belt

- There are many asteroids in other regions of the solar system. **Chiron, for example, which was discovered in 1977, orbits between Saturn and Uranus.**
- Another example is the **Trojan asteroids** that follow the orbit of Jupiter near Lagrange points—one group preceding the planet, the other following it—and can thus orbit safely without crashing into Jupiter itself.

Origin of Asteroids

- The origin of asteroids remains the subject of scientific study. Astronomers today think that most asteroids are planetesimals that never quite combined with other bodies to form planets.
- Some asteroids, on the other hand, may be the shattered remains of planets or protoplanets that suffered huge collisions and broke into pieces.

2010TK7 : Earth's Trojan Satellite

Recently, it has been discovered that Earth is not alone in its orbit around the Sun. There is a small 'Trojan' asteroid 2010TK7 that sits in front of earth and leads it. This is the 1st Trojan Asteroid of Earth discovered using the WISE Telescope. It has now become the First known Trojan Asteroid in Earth's Orbit. *A Trojan asteroid shares an orbit with a larger planet or moon, but does not collide. So a Trojan has a particular position in a stable spot - either in front of a planet or behind it called Lagrangian points. Because the asteroid and planet are constantly on the same orbit, they can never collide.Trojan asteroids were anticipated in earth's orbit but never discovered yet. Nasa discovered the asteroid, which lies 80 million km from Earth, using its Widefield Infrared Survey Explorer (WISE) telescope. Astronomers have long thought that Earth did have Trojans but their discovery has proved elusive because they can't be seen in daylight.*

Number of Asteroids:

- Many thousands of asteroids are being tracked regularly, and tens of thousands have been identified and catalogued. At least one million asteroids are estimated to exist; of those, astronomers estimate that about one in ten can be observed from Earth.

Comets

- Comets are basically "**snowy dirtballs" or "dirty snowballs**"—collections of rocky material, dust, and frozen water, methane, and ammonia that move through the solar system in long, **highly elliptical orbits** around the Sun.
- When they are far away from the *Sun, comets are simple, solid bodies; but when they get closer to the Sun, they warm up, causing the ice in the comets' outer surface to vaporize.* This creates a cloudy "coma" that forms around the solid part of the comet, called the "nucleus."
- The loosened comet vapor forms long "tails" that can grow to millions of miles in length.
- The English astronomer Edmund Halley (1656–1742) calculated the paths traveled by 24 comets recorded by astronomers over the years. Among these, he found that three—one visible in 1531, one in 1607, and one that Halley himself had observed in 1682—had nearly identical flight paths across the sky. This discovery led him to the conclusion that comets follow in an orbit around the sun, and thus can reappear periodically.
- In 1695 Halley had predicted that a comet which has been seen thrice would return 76 years after its last sighting, in the year 1758. Unfortunately, Halley died before he could see that he was, indeed, correct. The comet was named in his honor, and to this day Halley 's Comet remains the best-known comet in the world. It last passed by Earth in 1986, and will return again in 2062.

Origin of Comets

- Most of the comets that orbit the Sun originate in the *Kuiper Belt or the Oort Cloud*, two major zones in our solar system beyond the orbit of Neptune.
- "Shortperiod comets" usually originate in the Kuiper Belt.
- Some comets and comet-like objects, however, have even smaller orbits; they may have once come from the Kuiper Belt and Oort Cloud, but have had their orbital paths altered by gravitational interactions with Jupiter and the other planets.

Comet Shoemaker-Levy 9

- *The encounter between Comet Shoemaker-Levy 9 and the planet Jupiter was the first collision between solar system bodies ever directly observed by humans.*
- As the comet approached Jupiter in 1994, it broke up into a long chain of fragments. Astronomers observed with amazement in July 1994 as these fragments crashed, one by one, into the gas giant's thick atmosphere.

Earth

- Earth is the third planet in the solar system, orbiting at a distance of about 93 million miles (150 million kilometers) from the Sun. It is the largest and most massive of the terrestrial planets.
- Its interior structure consists of a metallic core, which has both a liquid and solid compenent; a thick rocky mantle; and a thin rocky crust.
- The study of the size and shape of Earth is called geodesy. People have studied geodesy for millennia. Eratosthenes used the shadow of the Sun to compute that Earth was a sphere about 25,000 miles in circumference. This was impressively close to the modern value.
- Dutch physicist, astronomer, and mathematician Willebrord Snell , best known for Snell's law, explaining the angle of refraction (bending) of light through different materials, figured out how to measure distances using trigonometry. He used a large quandrant to measure angles of separation between two points. From this he could calculate distances between them and measure the radius of Earth.
- The German mathematician and scientist Karl Friedrich Gauss (1777–1855) invented the heliotrope, an instrument that reflects sunlight over great distances to mark positions accurately while surveying.

Spin of Earth

- Earth's spin is mostly the *result of angular momentum left over during the formation process of Earth* There are three distinct motions, the most noticeable being Earth's rotation.
- Earth rotates once every 23 hours, 56 minutes, causing our cycles of day and night.
- Earth also has precession (a wobble of the rotational axis) and nutation (a back-and-forth wiggle of Earth's axis), caused primarily by the gravitational pull of the Moon as it orbits Earth.
- Precession and nutation, over long periods of time, cause Earth's north and south poles to point toward different stars.

Foucault's pendulum

- Jean-Bernard-León Foucault (1819–1868) is known for his famous pendulum and also for his invention of gyroscope, made the most accurate measurement of the speed of light up to that time, and instituted improvements in the design of telescopes.
- Foucault was also the first person to use a camera to photograph the Sun.
- Foucault's pendulum was a simple, Earth-bound way of proving that Earth's rotation is real, and not an optical illusion caused by the Sun and stars revolving around it.

Earth's magnetic field

- Electromagnetic force permeates earth and the Earth itself acts like a giant spherical magnet.
- *This is caused primarily by the motion of electrical currents within Earth, probably through the liquid metallic part of Earth's core. Combined with Earth's rotation, the core acts like an electric dynamo, or generator, creating a magnetic field.*
- Earth's magnetic field extends thousands of miles outward into space. Magnetic field lines, carrying and projecting electromagnetic force, anchor at Earth's magnetic poles (north and south) and bulge outward, usually in large loops.
- Occasionally, they stream outward into space. *The magnetic north and magnetic south poles of Earth's magnetic field are very close to the geographical north and south poles, which mark the axis of Earth's rotation.*
- Earth's surface, it is about one gauss in most places. However, the energy in a magnetic field depends strongly on its volume; so since the field is bigger than our entire planet, overall, Earth's magnetic power is formidable.
- The *magnetic field of Earth is constantly changing, though very slowly*. The *magnetic poles actually drift several kilometers each year, often in seemingly random directions.*
- *Earth's magnetic field can reverse directions— the north magnetic pole becomes the south magnetic pole, and vice versa.* According to scientific measurements, our planet's magnetic field last had a polarity reversal about 800,000 years ago.

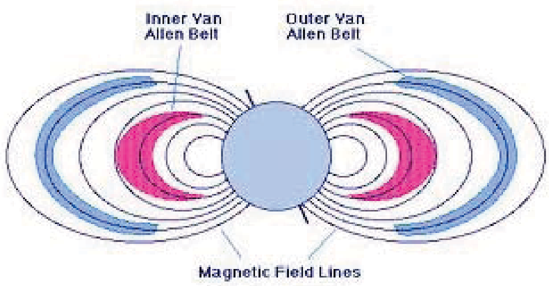
- If Earth's **magnetic field flips** upside down, probably not much will happen to our daily lives when Earth's magnetic field undergoes a polarity reversal. There is no scientific reason to believe, that any disasters will occur.
- All planets and stars with magnetospheres are thought to undergo magnetic polarity reversals. The Sun, for example, undergoes a magnetic field polarity reversal every eleven years. Astronomers can see and study this effect in other astronomical bodies, and from them, learn more about the changes in Earth's own magnetic field.

Aurora

- An aurora is a bright, colorful display of light in the night sky.
- *Aurorae are produced when charged particles from the Sun (usually solar wind particles, but sometimes coronal mass ejections as well) enter Earth's atmosphere. The particles are guided to the north and south magnetic poles by Earth's magnetic field. Along the way, these particles ionize some of the gas molecules they encounter by drawing away electrons from those molecules. When the ionized gas and their electrons recombine, they glow in distinctive colors; and the glowing gas undulates across the sky.*
- Aurorae, known also as the northern lights (aurora borealis) and southern lights (aurora australis), are most prominent at high altitudes near the north and south poles. They can also be seen sometimes at lower latitudes on clear nights.
- Every planet with a magnetic field will have aurorae. Beautiful aurorae—sometimes with features larger than the entire planet Earth—have been detected and photographed near the magnetic poles of *Jupiter and Saturn*.

Van Allen belts

- The Van Allen belts are two rings of electrically charged particles that encircle Earth.
- The belts are shaped like fat doughnuts, *widest above Earth's equator and curving downward toward Earth's surface near the polar regions.*
- These charged particles usually come toward Earth from outer space—often from the Sun—and are trapped within these two regions of Earth's magnetosphere.



- Since the particles are charged, they spiral around and along the magnetosphere's magnetic field lines. *The lines lead away from Earth's equator, and the particles shuffle back and forth between the two magnetic poles.*
- These trapped particles spiral along a system of imaginary lines curve from the north magnetic pole. The inner belt traps particles set free from the earth's atmosphere by cosmic rays. *The outer belt acquires particles from solar system — a continuous stream of charged particles from the sun and solar flares leading to magnetic storms. The strong fluctuation in the Earth's magnetic field is called magnetic storm*. **The overall level of magnetic storm activity varies with the recurring 11-year solar activity cycle.**
- The increased magnetic field of the sun not only causes magnetic storms but also shields the earth from high energy cosmic rays produced by exploding stars called supernova.
- The decrease in these cosmic rays bombarding the earth is known as the **Forbush effect.**
- The closer belt is about 3,000 kilometers, from Earth's surface, and the farther belt is about 15,000 kilometers away.
- All the gas giant planets are thought to have such belts, and in Jupiter's magnetic field such belts have been observationally confirmed.

Neutrino

- A neutrino is a tiny subatomic particle that is far smaller than an atomic nucleus; it has no electrical charge and a tiny mass.

We and Neutrinos

All of us and every square inch of Earth's surface are being continuously bombarded by neutrinos from space. Billions of neutrinos slice through our body every second. Fortunately, neutrinos are so unlikely to interact with any matter— including the atoms and molecules in the human body—that the billions upon billions of neutrinos that hit us every second have no discernible effect at all. In fact, the odds that any neutrino striking Earth will interact with any atom in our planet at all is about one in a billion. Even when it does happen, the result is merely a tiny flash of harmless light.

- Electrons are many thousands of times more massive than neutrinos, and protons and neutrons are many millions of times more massive.)
- Neutrinos are so tiny and ghostly that they almost always pass through any substance in the universe without any interference or reaction.
- Existence of neutrinos was first suggested in 1930 by the Austrian physicist Wolfgang Pauli , who noticed that in a type of radioactive process called beta decay, the range of the total energy given off in observations was greater than theoretical predictions. He reasoned that there must be another type of particle present to account for, and carry away, some of this energy.
- Since the amounts of energy were so tiny, the hypothetical particle must be very tiny as well and have no electric charge.
- After a few years, Enrico Fermi coined the name "neutrino" for this enigmatic particle. In 1956, when American physicists Clyde L. Cowan, Jr. (1919–1974) and Frederick Reines (1918–1998) detected neutrinos at a special nuclear facility in Savannah River, South Carolina, its presence was scientifically confirmed.

The Solar Neutrino Problem

- **F**rom the very beginning of research on neutrinos, the scientists had found a discrepancy between the theory of nuclear fusion and the number of neutrinos detected from the Sun.
- This was because the Neutrino telescopes on Earth detected only about half as many neutrinos as there should be. Where the rest of the neutrinos gone, was called "**Solar Neutrino Problem".** It was later confirmed that Neutrinos, as it turns out, *can actually change their characteristics when they strike Earth's atmosphere*.
- That meant that there were the right number of neutrinos leaving the Sun, but so many of them changed "flavor" upon reaching Earth that they escaped detection by the neutrino telescopes deep underground. This discovery was a major breakthrough in fundamental physics.

Source of Neutrinos

- The vast majority of neutrinos striking our planet come from the Sun. The nuclear reactions at the core of the Sun create huge numbers of neutrinos; and unlike the light that is produced, which takes thousands of years to flow their way out of the Sun's interior, the neutrinos come out of the Sun in less than three seconds, reaching Earth in just eight minutes.

Cosmic Rays

- Cosmic rays are invisible, high-energy particles that constantly bombard Earth from all directions.
- Most cosmic rays are protons moving at extremely high speeds, but they can be atomic nuclei of any known element. They enter Earth's atmosphere at velocities of 90 percent the speed of light or more.
- The cosmic rays were discovered by Victor Franz Hess , who got interested in a mysterious radiation that scientists had found in the ground and in Earth's atmosphere. This radiation could change the electric charge on an electroscope even when placed in a sealed container. In 1912 Hess took a series of high-altitude, hot-air balloon flights with an electroscope aboard. He made ten trips at night, and one during a solar eclipse, just to be sure the Sun was not the source of the radiation. Hess found that the higher he went, the stronger the radiation became. This discovery led Hess to conclude that this radiation was coming from outer space. For his work on understanding cosmic rays, Hess received the Nobel Prize in physics in 1936.

Source of Cosmic Rays:

- A continuous stream of electrically charged particles flows from the Sun; this flow is called the solar wind. So, a fraction of cosmic rays originate **from** the Sun, but the Sun alone cannot account for the total flux of cosmic rays onto Earth's surface.
- The source for the rest of these cosmic rays remains mysterious. *Distant supernova explosions could account for some of them; another possibility is that many cosmic rays are charged particles that have been accelerated to enormous speeds by interstellar magnetic fields*.
- All of us are being struck by cosmic rays all the time, however, at Earth ordinarily, they have no deleterious effect on our health. If we go beyond Earth's magnetosphere, cosmic rays can cause potentially more damage to your body's cells and systems.

Meteorite and meteors

Meteorite

- A meteorite is a large particle from outer space **that lands on Earth.** They range in size from a grain of sand on up.
- Around 30 thousand meteorites have been recovered in recorded history; about 600 of them are made primarily of metal, and the rest are made primarily of rock.

Meteors

- A meteor is a particle from outer space that enters Earth's atmosphere, **but does not land on Earth**. Instead, the particle burns up in the atmosphere, leaving a short-lived, glowing trail that traces part of its path through the sky.
- If a meteor is large enough to reach Earth, we call it a meteorite.

Sources of Meteors and Meteorites

- Most meteors, especially those that fall during meteor showers, are *the tiny remnants of comets left in Earth's orbital path over many, many years*. Most meteorites, which are generally larger than meteors, *are pieces of asteroids and comets that somehow came apart from their parent bodies*—perhaps from a collision with another body—and orbited in the solar system until they collided with Earth.

Meteor Showers

- **Every Year** the **Perseid meteor shower** happens in August, as Earth travels through the remnant tail of Comet 109P/Swift-Tuttle.
- In November, when earth moves through the remnants of Comet 55P/Tempel-Tuttle, it causes **Leonid meteor shower**.

Types of Meteorites

- There are two main categories of meteorites: **stony and metallic**.
- Each category is further subdivided into more detailed groups with similar characteristics.
  - **Vestoids**, for example, are all thought to have come from the asteroid Vesta, where, long ago, a powerful collision created shattered bits of Vesta that have been orbiting the solar system ever since.
  - **Chondrites** are one kind of stony meteorite; they are often the oldest meteorites.
  - Another category, the **pallasites**, have fascinating mixtures of stony and metallic material. Pallasites probably originated from boundary areas in larger asteroids, where rocky mantles were in physical contact with metallic cores.

Discovery of DNA components in meteorites

Carbonaceous chondrites or C chondrites are meteorites of 7 known and many unknown groups. Ureilite is a rare type of stony meteorite that has a unique mineralogical composition very different from that of other stony meteorites.
Both of them are rich on organic material.

- The notable carbonaceous chondrites are: Allende, Murchison, Orgueil, Ivuna, Murray, and Tagish Lake, while notable ureilites are the Novo Urei and the Goalpara.
- You must note that Goalpara is an Ureilite landed in town Goalpara of Assam in India.

Similarly, in 2008, a tiny asteroid 2008 TC3 entered Earth's atmosphere and exploded an estimated 37 kilometres above the Nubian Desert in Sudan. Fragments of this asteroid were recovered the following December and were found to be ureilite. It was reported that the scientists have discovered amino acids, the building blocks of life in this meteorite 2008 TC3 where none were expected taking into account the high temperatures reached in the explosion about 1000 °C. Recently, a NASA-funded study was published in the Proceedings of the National Academy of Sciences. As per this study, the scientists used advanced mass spectrometry instruments to scan 11 organic-rich meteorites called carbonaceous chondrites and one ureilite. The study found three nucleobases — purine, 6,8-diaminopurine and 2,6-diaminopurine — that are widely distributed in carbonaceous chondrites. These nucleobases are rare or absent in terrestrial biology. These components of DNA, the building blocks of life on Earth, in meteorites, is a discovery that, as per these scientists, confirms the theory that at least some of the materials needed to make early life forms came to our planet from space.

Moon

- The Moon is Earth's only natural satellite. It is 3,476 kilometers across, which is a little more than one quarter of Earth's diameter.
- The Moon orbits Earth once every 27.3 days.
- Moon, the fifth largest satellite in the Solar System, is largest natural satellite of a planet in the Solar System relative to the size of its primary, having a quarter the diameter of Earth and 1/81 its mass.

- Moon is the second densest satellite after the Jupiter's satellite Io.
- Moon is synchronous rotation with Earth, always showing the same face; the near side is marked with dark volcanic maria (sea) among the bright ancient crustal highlands and prominent impact craters.
- Moon is the brightest object in the sky after Sun but its surface is actually very dark, with a similar reflectance to coal.
- The Moon's gravitational influence produces the ocean tides and the minute lengthening of the day.
- Moon's current orbital distance, about thirty times the diameter of the Earth, causes it to appear almost the same size in the sky as the Sun, allowing it to cover the Sun nearly precisely in total solar eclipses.
- One formation theory is a giant impact event involving Earth. This impact theory has been challenged in 2012.
- Since 2004, Japan, China, India, the United States, and the European Space Agency have each sent lunar orbiters. These spacecraft have contributed to confirming the discovery of lunar water ice in permanently shadowed craters at the poles and bound into the lunar regolith.
- The Moon remains, under the Outer Space Treaty, free to all nations to explore for peaceful purposes.
- The Moon has no atmosphere and no liquid water (presence of water on moon has been proved recently in caves) at its surface, so it has no wind or weather at all.
- The Moon has no atmosphere; any substance on the lunar surface is exposed directly to vacuum. For water ice, this means it will rapidly sublime directly into water vapor and escape into space, as the Moon's low gravity cannot hold gas for any appreciable time. Over the course of a lunar day (~29 Earth days), all regions of the Moon are exposed to sunlight, and the temperature on the Moon in direct sunlight reaches about 395 K (395 Kelvin, which is equal to about 250 degrees above zero F). So any ice exposed to sunlight for even a short time would be lost. The only possible way for ice to exist on the Moon would be in a permanently shadowed area.
- On the lunar surface, there is no protection from the Sun's rays, and no ability to retain heat like the greenhouse effect on Earth. Temperatures on the moon range from 123°C to –233°C.
- The Moon's surface is covered with rocks, mountains, craters, and vast low plains called maria ("seas").

Our weight on moon

- **T**he gravitational acceleration at the surface of the Moon is about one-sixth that of Earth. So if we weigh 60 kg on Earth, we would weigh just 10 kg on the Moon.
- Our mass, on the other hand, would remain unchanged whether we were on Earth or on the Moon.

Composition of moon

- Moon is actually covered with rocks, boulders, craters, and a layer of charcoal colored soil.
- The charcoal-colored soil consists primarily of pulverized rocky and glassy fragments, and is up to several meters deep.
- Two main types of rock have been found on the moon: basalt, which is hardened lava, and **breccia**, which is soil and rock fragments that have melted together.
- Elements found in moon rocks include aluminum, calcium, iron, magnesium, titanium, potassium, and phosphorus. Unlike iron-rich Earth, the Moon appears not to have much metallic content.

		Maria	Highlands
silica	SiO_2	45.40%	45.50%
alumina	Al_2O_3	14.90%	24.00%
lime	CaO	11.80%	15.90%
iron(II) oxide	FeO	14.10%	5.90%
magnesia	MgO	9.20%	7.50%
titanium dioxide	TiO_2	3.90%	0.60%
sodium oxide	Na_2O	0.60%	0.60%
Total	99.90%	100.00%	

- The Moon is a differentiated body: it has a geochemically distinct crust, mantle, and core. The Moon has a solid iron-rich inner core with a radius of 240 kilometers and a fluid outer core primarily made of liquid iron with a radius of roughly 300 kilometers.

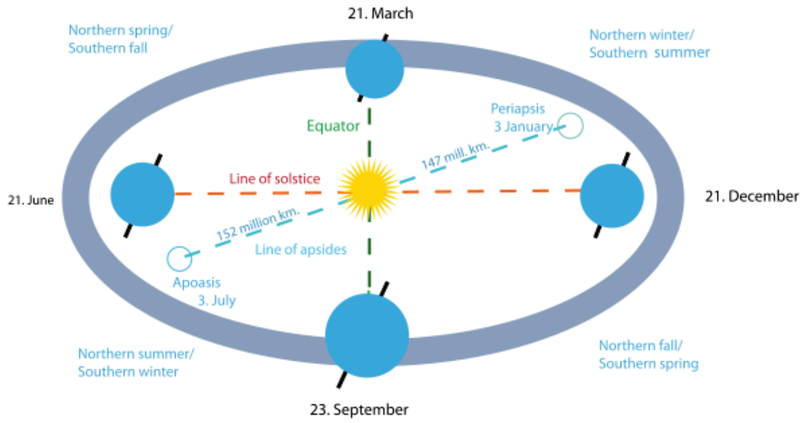
- Around the core is a partially molten boundary layer with a radius of about 500 kilometers. This structure is thought to have developed through the fractional crystallization of a global magma ocean shortly after the Moon's formation 4.5 billion years ago.
- Crystallization of this magma ocean would have created a mafic mantle from the precipitation and sinking of the minerals olivine, clinopyroxene, and orthopyroxene; after about three-quarters of the magma ocean had crystallised, lower-density plagioclase minerals could form and float into a crust on top.
- The final liquids to crystallise would have been initially sandwiched between the crust and mantle, with a high abundance of incompatible and heat-producing elements.
- Consistent with this, geochemical mapping from orbit shows the crust is mostly anorthosite,and moon rock samples of the flood lavas erupted on the surface from partial melting in the mantle confirm the mafic mantle composition, which is more iron rich than that of Earth. Geophysical techniques suggest that the crust is on average ~50 km thick.

Ecliptic Plane

- The ecliptic plane is the plane of Earth's orbit around the Sun.
- Ancient astronomers were able to trace the ecliptic as a line across the sky, even though they did not know Earth actually orbited the Sun. They merely followed the position of the Sun compared to the position of the stars in the sky, figured out where the Sun was every day, and noticed that every 365 days or so the positions would overlap and start going over the same locations again. That line marked a loop around the celestial sphere. Astronomers marked the line using twelve zodiac constellations positioned near and through the loop.

Ecliptic Plane versus Earth's Equatorial Plane

- The equatorial plane is the plane of Earth's equator extended indefinitely out into space. It turns out that Earth's rotation around its axis is not lined up with the ecliptic plane. Instead, Earth is tilted about 23.5 degrees.
- This tilt is the main cause of the seasons on Earth.
- Because Earth is tilted on its axis, either the southern or northern hemisphere is closer to the Sun as it orbits, thus creating the seasons.
- First day of spring happens on the vernal equinox; the first day of summer happens on the summer solstice; the first day of fall happens on the autumnal equinox; and the first day of winter happens on the winter solstice.



Seasons and motion of Earth

- It's a myth that seasons are caused by Earth being farther from the Sun in winter and closer to the Sun in summer.
- Earth's *elliptical orbit is close enough to a perfect circle* that distance is not the reason. In fact, Earth is closest to the Sun in early January and farthest in early July, which is exactly the opposite of our summer and winter seasons.
- *The reason for the seasons has to do with the angle at which sunlight strikes any particular place on Earth at any given time of year.*
- The angle changes throughout the year because the tilt of Earth's axis differs from the ecliptic. Put another way, the equatorial plane and the ecliptic plane are tilted with respect to one another by about 23.5 degrees.
- When one part of Earth is tilted toward the Sun, that part experiences summer; when it is tilted away from the Sun, it experiences winter; in between these phases Earth experiences spring and autumn.

Solstices

- A solstice is a time of the year when Earth is pointed either the closest toward the Sun or the farthest away from it.

- On the summer solstice, there are more minutes of daylight than there are on any other day of the year; on the winter solstice, there are fewer minutes of daylight than there are on any other day of the year.
- In the northern hemisphere, the summer solstice occurs around June 21 of each year, when the North Pole is pointed closest toward the Sun, and the winter solstice occurs around December 21 of each year, when the North Pole is pointed farthest away from the Sun.

Equinoxes

- Equinox is a time of the year when, in the course of Earth's orbit, our planet is at a location where the equatorial plane and the ecliptic plane intersect. In other words, the tilt of Earth's axis is pointed perpendicular to the line between Earth and the Sun at an equinox—Earth's poles are tilted neither "toward" nor "away" from the Sun, but tilted off to the "side."
- On the day of an equinox, there are as many minutes of daylight as there are of night—hence the term "equinox," meaning "equal darkness."
- In the northern hemisphere, the vernal (spring) equinox occurs around March 21 of each year, and the autumnal (fall) equinox occurs around September 21.

Eclipses

- An eclipse is the partial or total blocking of the light of one object by another.
- In the solar system, relative positions of the Sun, Moon, and Earth create solar eclipses and lunar eclipses.

Frequency of Eclipses

- Perfect alignments of the Sun, Moon, and Earth are *relatively uncommon, because the plane of Earth's orbit around the Sun (ecliptic plane) is not the same as the plane of the Moon's orbit around Earth.*
- Thus, during the new moon or full moon phases when an eclipse might be possible, the Moon is usually located just above or below the straight line that runs between Earth and the Sun, so no eclipse occurs.
- All three objects—Earth, Moon, and Sun—line up just right about twice a year.

Lunar Eclipse

- A lunar eclipse occurs when Earth passes between the Sun and the Moon in such a way that the Moon moves into Earth's shadow. When a partial lunar eclipse is going on, the curved shadow of our planet is apparent on the Moon's face; the Moon looks kind of like it is in a crescent phase, but the terminator line (the line between light and dark) is not curved the same way. When a total lunar eclipse is happening, the entire Moon is in Earth's shadow, and the Moon looks full, but glows only faintly red. Why?
- **The reason is as follows:** Earth's atmosphere is dense enough to act a little bit like a lens, so it refracts a small amount of sunlight shining through it toward the Moon. This small fraction of light, which is mostly red because that is the color of light that refracts best, bounces off the Moon's surface and comes back to Earth. Before and after totality, the direct sunlight reflected off the Moon is so strong by comparison that it drowns out this refracted light, so we normally cannot see it with our unaided eyes. During totality, however, the Earth-atmosphere-refracted light is quite visible as a soft reddish glow.

Solar Eclipse

- A solar eclipse happens when the Moon is directly in line between Earth and the Sun. The Moon's shadow sweeps across Earth's surface; at those places where the shadow lands, an eclipse is seen.
- Like Earth's shadow, the Moon's shadow consists of two parts: a dark, **central region called the umbra**, and a lighter region called the penumbra that surrounds the umbra. *Under the penumbra, a partial solar eclipse occurs. Under the umbra, a total eclipse or an annular eclipse is seen.*

> **Frequency of Solar Eclipse at a particular location on earth**
> The entire process of a solar eclipse, from the beginning of partial coverage until the end, usually takes about an hour. However, the totality of solar eclipse lasts at most only a few minutes. Most total solar eclipses last between 100 and 200 seconds— just about two to three minutes. Furthermore, total solar eclipses can be observed only from narrow bands on Earth's surface, and these bands change with each eclipse. In any given location on Earth, therefore, a total solar eclipse may appear only once every few centuries.

- **S**ince the Moon travels in a slightly elliptical orbit around Earth, rather than in a perfectly circular path, its distance from Earth is not always the same.
- If the Moon's umbra falls on Earth's surface when the two bodies are at a closer point in the Moon's orbit, the solar eclipse is total there.
- But if the Moon happens to be too far away from Earth at that time, the Moon does not cover enough of the sky to block the Sun's rays entirely. In that case, the Sun is seen as a ring, or annulus, of light glowing around the silhouette of the Moon.

Why does the Moon block the Sun so perfectly?

The Moon's diameter is just under 400 times smaller than the diameter of the Sun. Coincidentally, the Moon's distance from Earth is also just under 400 times smaller than the Sun's distance from Earth. That is why the Moon covers almost exactly the same amount of sky, when viewed from Earth's surface, as the Sun. We are able to see only Corona during Total solar eclipse.

- During totality of a solar eclipse, the Sun looks like a perfectly black disk surrounded by glowing light. This light is actually the Sun's corona, which is invisible under normal circumstances because the Sun is so bright.
- Away from the corona, the sky is dark, so planets and stars that ordinarily could be seen only at night become visible.

Historical Points in Astronomy

- NASA officially defines "outer space" as anywhere beyond an altitude of 100 kilometers above Earth's surface.
- **T**he most powerful liquid-fueled rocket ever built was the *Saturn V* rocket, which was designed to launch the Apollo missions to the Moon. Each rocket had five F-1 engines, each capable of generating more than 1.5 million pounds of thrust.
- In the Soviet Union, the man credited with creating the world's first successful space program was the Ukranian scientist Sergei Korolëv (1906–1966). In August 1957, he launched the first Russian intercontinental ballistic missile (ICBM).
- Less than two months later, a rocket based on the ICBM was used to launch *Sputnik 1,* the first man-made satellite to orbit Earth.
- During its three months in space, *Sputnik 1* orbited the planet once every 96 minutes, at a speed of nearly 17,400 miles (28,000 kilometers) per hour. The Soviets' success caught U.S. engineers—and the American public—by surprise, and launched the so-called "space race" between the two rival world superpowers of that time.
- The United States had a space program nearly ready to go when *Sputnik 1* was launched in 1957. Startled into action, the American government hurriedly rushed to launch the first orbiter, called *Vanguard,* on December 6, 1957. The launch was a failure: the rocket carrying the satellite burst into flames just a few feet off the ground. The following month, on January 31, 1958, a team led by Wernher von Braun at the Marshall Space Flight Center in Huntsville, Alabama, successfully launched *Explorer 1,* the first American satellite, into orbit on the nose of a Jupiter-C rocket.
- In 1959 *Luna 3* was the first space probe to send back pictures of the far side of the Moon. Then, in 1961, Korolëv led the design and construction of *Vostok 1,* which carried the first human being into space: Yuri Gagarin (1934–1968); and in 1963, the first woman, **Valentina Tereshkova**, was launched into space.
- The scientist generally considered to be the most influential figure in the American space program was the German physicist Wernher von Braun (1912– 1977).
- Under his leadership, the Germans developed the V-2 rocket, the first long-range rocket-launched missile weapon system.
- Near the end of World War II, von Braun and 126 other German scientists were hired by the United States government and brought to America under the code name **Project Paperclip**.
- von Braun led the effort to create the *Jupiter-C*— the first American rocket capable of launching spacecraft. This rocket launched America's first satellite into orbit, *Explorer 1.* It was followed by the *Saturn V,* which was used to launch the Apollo manned missions to the Moon.
- Soviet's **S***putnik 2* carried a dog named **Laika,** *which unfortunately died in space because the Russian space program did not provide for the safe return of the spacecraft or its passenger.*

- *Sputnik 5* carried two other dogs (Belka and Strelka) and a number of mice, rats, and plants; all the animals were safely recovered the next day when the spacecraft returned to Earth.
- *Sputnik 1,* the first artificial satellite ever launched, had communications capabilities. It was able to transmit radio signals at two frequencies. It lasted for about three months in orbit. However, the first long-lived communications satellite was called *Echo,* and was launched in 1960. Its successor, *Echo II,* was in service from 1964 to 1969. \
- The first active-transmitting communications satellites were *Telstar,* developed by AT&T Corporation, and *Relay,* developed by NASA. *Telstar* was launched in 1962 and transmitted telephone calls and television broadcasts between locations in Maine, England, and France. Together, *Telstar* and *Relay* demonstrated the potential of multi-satellite communications systems for long-distance global transmissions.
- On May 5, 1961, American astronaut Alan Bartlett Shepard Jr. became the first American to go for a space flight. Shepard rode on the Mercury- Redstone 3 mission, in the *Freedom 7* spacecraft, which flew on a sub-orbital trajectory. He reached an altitude of 116 miles (187 kilometers), and traveled a distance of 303 miles (488 kilometers) in space at a speed of 5,146 miles (8,280 kilometers) per hour. Shepard's 15-minute flight ended with a safe parachute landing into the Atlantic Ocean.
- On February 20, 1962, John H. Glenn Jr. (1921–) became the first American to orbit Earth. Glenn's historic flight was part of the Mercury program, which was initiated by NASA to send humans into space.
- Soviet cosmonaut Alexei Leonov was the first person to travel in outer space outside of a spacecraft. On March 18, 1965, he floated for twelve minutes outside of his vessel, *Voskhod 2*.
- Ellison Shoji Onizuka (1946–1986) was born in Hawaii, , became the first Asian American man in outer space on January 24, 1985.
- Dr. Kalpana Chawla (1961–2003) was born in Karnal, Haryana, India, and earned a Ph.D. in aerospace engineering in 1988 at the University of Colorado. She held a certified flight instructor rating and a commercial pilot's license for numerous kinds of aircraft. She became a naturalized U.S. citizen in 1990, and joined the NASA astronaut corps in 1995. On November 19, 1997, as a member of the crew of the space shuttle *Columbia,* Chawla became the first Asian American woman in outer space. Sadly, on her second mission into space, she and her fellow shuttle crew members were killed aboard the space shuttle *Columbia* on February 1, 2003.

Soyuz 11 tragedy

- **T**here have been dozens of manned launches of the Soyuz series vehicles, almost all of them successful. *Soyuz 11,* however, ended tragically. It launched on June 6, 1971, and completed its mission to rendezvous with the *Salyut 1* space station. During the crew's descent to Earth, however, a valve opened unexpectedly, allowing all the air in the cabin to escape. All three cosmonauts onboard suffocated. After this mishap, a number of changes were made to the Soyuz crafts, and the number of cosmonauts on any mission was reduced to two, allowing each occupant to wear a pressurized space suit during launch, docking, and re-entry.
- Wing Commander Rakesh Sharma, Hero of the Soviet Union, (born January 13, 1949) was the first Indian to travel in space.

Apollo Programme

- The Apollo program was the focus of the United States space program from 1967 to 1972. Beginning with *Apollo 11,* which landed on the Moon on July 20, 1969, Apollo spacecraft landed 12 men on the Moon's surface.
- Aside from gathering tremendous amounts of new information about the Moon, and bringing back 842 pounds (382 kilograms) of Moon rock, the Apollo program showed conclusively that it was possible for humans to set foot on an object in the universe other than Earth.
- The Apollo spacecraft consisted of three parts: a command module, where the astronauts would travel; a service module, which contained supplies and equipment; and a lunar module, which would detach to land on the Moon. In all, a total of 15 Apollo spacecraft were produced—three designed for unpiloted missions and 15 for piloted missions. The Apollo

missions were launched using the Saturn V rocket, designed by Wernher von Braun and still the most powerful rockets ever successfully operated.

- The first successful piloted mission, *Apollo 7,* was launched in October 11, 1968; three astronauts orbited Earth for eleven days. Two months later, the crew of *Apollo 8* became the first humans to escape Earth's gravitational field and orbit the Moon. *Apollo 9* and *Apollo 10* had flights in early 1969, and were used for final preparation runs for the landing mission in July.
- One of the most famous photographs in human history—the image of Earth rising over the lunar horizon—was taken by the *Apollo 8* crew as it orbited the Moon.
- American astronauts Neil Armstrong (1930–), Edwin Eugene "Buzz" Aldrin (1930–), and Michael Collins (1930–) were aboard *Apollo 11* when it made its historic trip to the Moon.
- When *Apollo 11* reached the Moon, Neil Armstrong and Buzz Aldrin headed for the surface in the lunar module, nicknamed "Eagle," while Michael Collins stayed in the command module in orbit around the Moon. After moving across the *Sea of Tranquility* in the lunar module, looking for a safe place to set down, Armstrong finally landed the Eagle with less than a minute of fuel to spare.
- Armstrong and Aldrin then planted the American flag on the Moon's surface, took photographs, held a telephone conversation with President Richard Nixon, set up several science experiments, and collected rocks and soil samples.
- Before they left the Moon's surface three hours later, they left behind a plaque that read, "Here men from the Planet Earth first set foot upon the Moon. July 1969 A.D. We came in peace for all mankind."

INTELSAT

- Seeing the need for a comprehensive, jointly owned and operated system of satellite communications, 11 nations formed the International Telecommunications Satellite Organization—INTELSAT—on August 20, 1964.
- On April 6, 1965, *Early Bird,* the organization's first satellite and the first commercial communications satellite, was launched. It was a metal cylinder a foot and a half tall and two feet wide, and was encircled by a band of solar cells. It could handle 240 telephone lines or one television channel at a time. Over the years, more nations joined the organization, and many more satellites were launched.
- In 2001 INTELSAT became a private company, Intelsat Limited. Today, it continues to provide satellite communications services with its fleet of more than 50 satellites.

Global Positioning System

- Hundreds of satellites in orbit around Earth—many of them are communications satellites that transmit phone, audio, television, and other electromagnetic signals all around the globe.
- One of the best known communications satellite systems is the NAVSTAR Global Positioning System, or GPS. This is a system of 24 satellites orbiting Earth at an altitude of about 12,000 miles (19,300 kilometers) and speeds of 7,000 miles (11,260 kilometers) per hour.
- By obtaining simultaneous communications signals from several satellites at once, it is possible to pinpoint the location of a GPS receiver to a precision of just a few feet or meters anywhere on Earth.

Skylab Space Station

- *Skylab* was a space station operated by the United States from 1973 to 1979. The two-story *Skylab* was much larger than its contemporary *Salyut* space stations. It contained a workshop, living quarters for three people, a module with multiple docks, and a solar observatory.
- At an altitude of 440 kilometers, *Skylab*holds the record for the largest orbital distance from Earth's surface of any humanoccupied space station.

Mir Space Station

- *Mir* was originally operated solely by the Soviet Union until its government collapsed in 1991. Strapped for funds, the Russian government that succeeded the Soviets sought ways to bring financial and scientific support for their space program.

- In 1993 Russia and the United States came to an agreement in which the two nations would pool their resources and expertise, together with contributions from other nations, to build a new international space station.
- *Mir* became the prototype and testbed for the new station; space shuttle missions were flown to *Mir,* and American astronauts began spending long periods of time aboard the station to learn from the Russians' extensive experience with living in space.
- Over the course of the Shuttle-*Mir* program, eleven shuttle missions were flown to *Mir,* and seven U.S. astronauts spent a total of 28 months on the station, starting in March 1995. Astronauts from many other nations also visited *Mir,* laying the groundwork for true international cooperation in space.
- By 1997 the *Mir* space station had more than doubled its original warrantied lifetime of five years. The years of service began to take its toll on the vessel's systems, and things began to break down. By June 1997, crises were becoming almost commonplace: a fire, a cooling system that leaked antifreeze, a faulty oxygen processing system, a collision with a space cargo ship, a computer crash, and more plagued the station.
- On August 28, 1999, the station's crew was returned to Earth—the first time in nearly 10 full years that *Mir* was left unoccupied. On April 4, 2000, a crew of two cosmonauts returned to *Mir* to assess the ship's condition and future prospects. After they left on June 16, no further visits to the station were made. To ensure the safety of people living on Earth, an unmanned rocket was sent to the station.
- Flight controllers then used that rocket to bring *Mir* down into the atmosphere and de-orbit the vessel. On March 23, 2001, *Mir* burned up upon re-entering Earth's atmosphere, lighting up the skies over the Fiji Islands and scattering debris harmlessly across the southern Pacific Ocean.

Space Shuttle program

- The Space Transportation System (STS), better known as the Space Shuttle program, is NASA's primary piloted space program. The space shuttle was designed in the 1970s as a half-spacecraft, half-airplane, reusable system that could frequently ferry people and cargo into low Earth orbit and back.
- There have been more than 120 space shuttle flights. Although it has had a checkered history marked with cost overruns and two terrible tragedies, the shuttle program has also created tremendous successes in human spaceflight and helped scientists and engineers understand what life in space—and the process of coming and going from space to Earth and back—may someday be like.
- **T**he *Challenger Space Shuttle* was destroyed during launch on January 28, 1986, with all seven crew members lost.
- The *Columbia* disintegrated after reentering the atmosphere on February 1, 2003; again, all seven crew members perished. The shuttle program has retired as of now.