Astronomy: The Anatomy of the Universe

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OUR PLACE IN SPACE

Earth: Earth is the third planet from the Sun, and the densest and fifth-largest of the eight planets in the Solar System. It is also the largest of the Solar System’s four terrestrial planets.

The Solar System: The Solar System consists of the Sun and those celestial objects bound to it by gravity, all of which were formed from the collapse of a giant molecular cloud approximately 4.6 billion years ago. Of the many objects that orbit the Sun, most of the mass is contained within eight relatively solitary planets whose orbits are almost circular and lie within a nearly flat disc called the ecliptic plane. The four smaller inner planets, Mercury, Venus, Earth and Mars, also called the terrestrial planets, are primarily composed of rock and metal. The four outer planets, the gas giants, are substantially more massive than the terrestrials. They are Jupiter, Saturn, Uranus and Neptune.

The Sun: The Sun is the star at the center of the Solar System. It has a diameter of about 1,392,000 kilometers about 109 times that of Earth, and its mass (about $2 \times 10^{30}$ kilograms, 330,000 times that of Earth) accounts for about 99.86% of the total mass of the Solar System.

The Milky Way Galaxy: The Milky Way Galaxy is the galaxy in which the Solar System is located. The Milky Way is a barred spiral galaxy that is part of the Local Group of galaxies. It is one of billions of galaxies in the observable universe.

The Local Group: The Local Group is the group of galaxies that includes our galaxy, the Milky Way. The group comprises more than 30 galaxies (including dwarf galaxies), with its gravitational center located somewhere between the Milky Way and the Andromeda Galaxy.

- The Milky Way’s satellite system consists of Sagittarius Dwarf Galaxy, Large Magellanic Cloud, Small Magellanic Cloud, Canis Major Dwarf, Ursa Minor Dwarf, Draco Dwarf, Carina Dwarf, Sextans Dwarf, Sculptor Dwarf, Fornax Dwarf, Leo I, Leo II, and Ursa Major Dwarf.

- Andromeda’s satellite system comprises M32, M110, NGC 147, NGC 185, And I, And II, And III, And IV, And V, Pegasus dSph (aka And VI), Cassiopeia Dwarf (aka And VII), And VIII, And IX, and And X.

- The Triangulum Galaxy, the third largest and only other ordinary spiral galaxy in the Local Group, may or may not be a companion to the Andromeda galaxy but probably has Pisces Dwarf as a satellite.
In astronomy, a celestial coordinate system is a coordinate system for mapping positions on the celestial sphere.

ASTRONOMICAL COORDINATES

In astronomy and navigation, the celestial sphere is an imaginary sphere of arbitrarily large radius, concentric with the Earth and rotating upon the same axis. All objects in the sky can be thought of as projected upon the celestial sphere. Projected upward from Earth’s equator and poles are the celestial equator and the celestial poles. The celestial sphere is a very practical tool for positional astronomy.

The celestial sphere is divided by projecting the equator into space. This divides the sphere into the north celestial hemisphere and the south celestial hemisphere.

As the Earth rotates from west to east around its axis once every 23 hours 56 minutes, the celestial sphere and all objects on it appear to rotate from east to west around the celestial poles in the same time. This is the diurnal motion.

On the next night a particular star will rise again, but with our normal clocks running a 24 hour 0 minutes cycle, it will do so 4 minutes earlier. By the following night the difference will be 8 minutes, and so forth with every following night (or day).

The reason for this apparent misadjustment of our clocks is that the Sun is not standing still on the celestial sphere, as the stars do, but moves about 1° per day eastwards over a great circle known as the ecliptic (which is 360° or a full circle in one year, the annual motion of the Sun). As an angle of 1° corresponds to 4 minutes in time (360° = 24 hours), we need therefore 4 extra minutes of diurnal motion to see the Sun back on (for example) the meridian again, making the duration of one rotation just 24 hours exactly (on the average, ignoring small seasonal variations, see equation of time).

Normal clocks therefore indicate solar time. Astronomers studying the movements of stars may want clocks indicating sidereal time, going around once in 23h56m (solar time units).
The celestial equivalent of latitude is called **declination** (\( \delta \)) and is measured in degrees North (positive numbers) or South (negative numbers) of the Celestial Equator. The celestial equivalent of longitude is called **right ascension** (\( \alpha \)). It is more common to measure right ascension in time (hours, minutes, seconds).

**Equinoxes and Solstices**

The zero point for celestial longitude (that is, for right ascension) is the **Vernal Equinox**, which is that intersection of the ecliptic and the celestial equator near where the Sun is located in the Northern Hemisphere Spring. The other intersection of the Celestial Equator and the Ecliptic is termed the **Autumnal Equinox**. When the Sun is at one of the equinoxes the lengths of day and night are equivalent (equinox derives from a root meaning "equal night"). The time of the Vernal Equinox is typically about March 21 and of the Autumnal Equinox about September 22.

The point on the ecliptic where the Sun is most north of the celestial equator is termed the **Summer Solstice** and the point where it is most south of the celestial equator is termed the **Winter Solstice**. In the Northern Hemisphere the hours of daylight are longest when the Sun is near the Summer Solstice (around June 22) and shortest when the Sun is near the Winter Solstice (around December 22). The opposite is true in the Southern Hemisphere. The term solstice derives from a root that means to “stand still”; at the solstices the Sun reaches its most northern or most southern position in the sky and begins to move back toward the celestial equator. Thus, it “stands still” with respect to its apparent North-South drift on the celestial sphere at that time.
The right ascension (R.A.) and declination (dec) of an object on the celestial sphere specify its position uniquely, just as the latitude and longitude of an object on the Earth's surface define a unique location. Thus, for example, the star Sirius has celestial coordinates 6 hr 45 min R.A. and -16 degrees 43 minutes declination.

**ASTRONOMICAL MEASUREMENTS**

**LENGTH**

1 angstrom $= 9.46 \times 10^{-12}$ km (atomic physics, spectroscopy)
1 nanometre (nm) = $10^{-9}$ m (interstellar dust and gas)
1 micron ($\mu$) = $10^{-6}$ m (astrophysics)

1 astronomical unit (A.U) = $149.6 \times 10^{11}$ m. It will be accepted as

$1$ A.U $= 150.10^4$ km

1 astronomical unit is the distance between Earth and the Sun.

1 light year (ly) = $9.46 \times 10^{12}$ km (stars, galactic astronomy)
1 parsec (pc) = $3.26$ ly = $206265$ AB (star clusters)
1 kiloparsec (kpc) = 1000 pc (cosmology)
1 megaparsec (Mpc) = $10^6$ pc (cosmology)

**MASS**

Mass of Earth $\quad M_\oplus = 5.98 \times 10^{24}$ kg
Mass of the Sun $\quad M_\odot = 2 \times 10^{30}$ kg

**TIME**

1 Earth Day = 86400 s
1 Earth Year = $3.16 \times 10^7$ s

Velocity of light (c) = 300.000 km/sn

**RADIUS**

Radius of Earth = 6378 km
Radius of the Sun = 700.000 km
ASTRONOMICAL CATALOGS

An **astronomical catalog** or **catalogue** is a list or tabulation of **astronomical objects**, typically grouped together because they share a common type, morphology, origin, means of detection, or method of discovery. Astronomical catalogs are usually the result of an **astronomical survey** of some kind.

1) **MESSIER CATALOG (M)**

The **Messier objects** are a set of astronomical objects catalogued by the French astronomer **Charles Messier** in his “Catalogue des Nébuleuses et des Amas d’Étoiles” (“Catalogue of Nebulae and Star Clusters”), originally published in 1771, with the last addition (based on Messier’s observations) made in 1966.[1]

Because Messier was interested in finding only **comets**, he created a list of non-comet objects that frustrated his hunt for them. The compilation of this list, in collaboration with his assistant Pierre Méchain, is known as the Messier catalogue. This catalogue of objects is one of the most famous lists of astronomical objects, and many **Messier objects** are still referenced by their Messier number.[2]

The first edition included 45 objects, with Messier’s final list totaling 103 objects. Other astronomers, using side notes in Messier’s texts, eventually filled out the list to 110 objects.

2) **ABELL CATALOG (A)**

The **Abell catalog of rich clusters of galaxies** is an all-sky catalog of 4,073 rich galaxy clusters of nominal redshift $z \leq 0.2$. This catalog supplements a revision of George Ogden Abell’s original “Northern Survey” of 1958, which had only 2,712 clusters, with a further 1,361 clusters — the “Southern Survey” of 1989 — from those parts of the south celestial hemisphere that had been omitted from the earlier survey.

3) **INDEX CATALOG (IC)**

The **Index Catalogue (IC)** — also known as the **Index Catalogue of Nebulae**, the **Index Catalogue of Nebulae and Clusters of Stars**, **IC I**, or **IC II**— is a catalogue of galaxies, nebulae and star clusters that serves as a **supplement** to the **New General Catalogue**. It was first published in 1895, and has been expanded to list 5,387 objects, known as the **IC objects**.

The catalogue was compiled by **J. L. E. Dreyer** in the 1880s, who published it as two **appendices** (IC I[1] & IC II[2]) to the New General Catalogue. It summarized the discoveries of galaxies, clusters and nebulae between 1888 and 1907.
4) NEW GENERAL CATALOG (NGC)

The New General Catalogue (NGC) is a well-known catalogue of deep sky objects in astronomy. It contains 7,840 objects, known as the NGC objects. The NGC is one of the largest comprehensive catalogues, as it includes all types of deep space objects and is not confined to, for example, galaxies.

The catalogue was compiled in the 1880s by J. L. E. Dreyer using observations mostly from William Herschel and his son John, for total of 7,840 objects. Dreyer had already published an update to the Herschel's Catalogue of Nebulae, but a new update was turned down by the Royal Astronomical Society, who asked Dreyer to compile a New General Catalogue.

The NGC was later expanded with two Index Catalogues (IC I in 1896 & IC II in 1905), adding a further 5,326 objects. Most of these later discoveries had been made possible by the advent of photography.

CONSTELLATIONS

A constellation is a group of celestial bodies, usually stars, which appear to form a pattern in the sky.

In 1922, Henry Norris Russell aided the IAU in dividing the celestial sphere into 88 official constellations.

Typically, these modern constellations share the names of their Greco-Roman predecessors, such as Orion, Leo and Scorpius. While such celestial formations were originally linked to a mythical event, creature or person, the categorization of the night sky into recognizable patterns was important in early land and naval navigation prior to the invention of the compass during the Age of Discovery.

The sky of the northern hemisphere is traditionally divided into constellations based on those described by the Ancient Greeks.

ZODIAC CONSTELLATIONS

In astronomy, the zodiac is the ring of constellations that lines the ecliptic, which is the apparent path of the Sun across the sky over the course of the year.

Babylonian astronomers at some point during the early 1st millennium BC divided the ecliptic into twelve equal zones of celestial longitude to create the first known celestial coordinate system: a coordinate system that boasts some advantages over modern systems.

There are 12 Zodiac constellations which are used to find way or any stellar object in the sky.

<table>
<thead>
<tr>
<th>no.</th>
<th>symbol</th>
<th>long.</th>
<th>Latin name</th>
<th>English translation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>♈</td>
<td>0°</td>
<td>Aries</td>
<td>The Ram</td>
</tr>
<tr>
<td>2</td>
<td>♉</td>
<td>30°</td>
<td>Taurus</td>
<td>The Bull</td>
</tr>
<tr>
<td>3</td>
<td>♊</td>
<td>60°</td>
<td>Gemini</td>
<td>The Twins</td>
</tr>
<tr>
<td>4</td>
<td>♋</td>
<td>90°</td>
<td>Cancer</td>
<td>The Crab</td>
</tr>
<tr>
<td>5</td>
<td>♌</td>
<td>120°</td>
<td>Leo</td>
<td>The Lion</td>
</tr>
<tr>
<td>6</td>
<td>♍</td>
<td>150°</td>
<td>Virgo</td>
<td>The Virgin</td>
</tr>
<tr>
<td>7</td>
<td>♎</td>
<td>180°</td>
<td>Libra</td>
<td>The Scales</td>
</tr>
<tr>
<td>8</td>
<td>♏</td>
<td>210°</td>
<td>Scorpio</td>
<td>The Scorpion</td>
</tr>
<tr>
<td>9</td>
<td>♐</td>
<td>240°</td>
<td>Sagittarius</td>
<td>Centaur The Archer</td>
</tr>
<tr>
<td>10</td>
<td>♑</td>
<td>270°</td>
<td>Capricorn</td>
<td>“Goat-horned” (The Sea-Goat)</td>
</tr>
<tr>
<td>11</td>
<td>♒</td>
<td>300°</td>
<td>Aquarius</td>
<td>The Water Bearer</td>
</tr>
<tr>
<td>12</td>
<td>♓</td>
<td>330°</td>
<td>Pisces</td>
<td>Fish</td>
</tr>
</tbody>
</table>
PRECESSION AND ZODIAC CONSTELLATIONS

The earth’s axis is not stable. The earth is not a perfect sphere, but flattens out at the poles and bulges at the equator. It reacts to the gravitational influence of the sun and moon like a spinning top whose rotation is distorted by some external force: this causes what has been termed the earth’s precession - which means that the earth’s axis itself rotates in a circle, leading to a conical movement around the fixed pole of the ecliptic. One complete rotation around this cone takes roughly 26000 years. This shifting of the earth’s axis causes the celestial equator to shift so that the point of intersection between it and the ecliptic - the vernal equinox - moves from east to west along the circle of the ecliptic, i.e. in the opposite direction to the standard zodiac.

It takes about 26000 years for the vernal equinox to make one complete revolution around the ecliptic, i.e. through all of the twelve constellations. It takes around one twelfth of this time - roughly 2160 years - to traverse one sign of the zodiac. In antiquity the vernal equinox was situated between the signs of Pisces and Aries, and because of its retrograde movement through the zodiac is at present situated in the border zone between the constellations of Pisces and Aquarius, moving slowly towards Aquarius. Because the constellations lack clear boundaries, it is difficult to say exactly when the vernal equinox will move from the constellation of Pisces into that of Aquarius, i.e. when the so-called Age of Aquarius will begin. Depending on where the boundary is drawn this will occur somewhere between 2100 and 2500 AD.

The vernal equinox is the point of reference from which both astronomers and astrologers begin their measurement of the ecliptic, and it marks the beginning of the division of the zodiac into twelve equal segments. This is why the segment of the zodiac known as “Aries” is situated where the fixed star constellation of Pisces is. On 30th March, the sun is situated at roughly 10° of the astrological segment of the ecliptic known as Aries, but if one were to look up into the night sky one would see the fixed star constellation of Pisces.

The theoretical beginning of Aries is the moment of vernal equinox, and all other dates shift accordingly. The precise Gregorian times and dates vary slightly from year to year as the Gregorian calendar shifts relative to the tropical year.\[15\] These variations remain within less than two days’ difference in the recent past and the near-future, vernal equinox in UTC always falling either on 20 or 21 of March in the period of 1797 to 2043, falling on 19 March in 1796 the last time and in 2044 the next.\[15\] In the long term, if the Gregorian calendar isn’t reformed, the equinox will move to earlier dates: it will fall on 18 March for the first time in AD 4092.
<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Tropical zodiac (2010, UTC)</th>
<th>Sidereal zodiac (Jyotisha) (2010, UTC)</th>
<th>IAU constellation boundaries (2010)</th>
<th>Solar stay</th>
<th>Brightest star</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aries</td>
<td>♈</td>
<td>20 March – 20 April</td>
<td>14 April – 7 May</td>
<td>19 April – 14 May</td>
<td>25.5 days</td>
<td>Hamal</td>
</tr>
<tr>
<td>Taurus</td>
<td>♉</td>
<td>20 April – 21 May</td>
<td>14 May – 7 June</td>
<td>14 May – 21 June</td>
<td>38.2 days</td>
<td>Aldebaran</td>
</tr>
<tr>
<td>Gemini</td>
<td>♊</td>
<td>21 May – 21 June</td>
<td>14 June – 7 July</td>
<td>21 June – 21 July</td>
<td>29.3 days</td>
<td>Pollux</td>
</tr>
<tr>
<td>Cancer</td>
<td>♋</td>
<td>21 June – 22 July</td>
<td>14 July – 6 August</td>
<td>21 July – 11 August</td>
<td>21.1 days</td>
<td>Al Tarf</td>
</tr>
<tr>
<td>Leo</td>
<td>♉</td>
<td>22 July – 23 August</td>
<td>14 August – 7 September</td>
<td>17 September – 17 September</td>
<td>36.9 days</td>
<td>Regulus</td>
</tr>
<tr>
<td>Virgo</td>
<td>♎</td>
<td>23 August – 23 September</td>
<td>13 September – 6 October</td>
<td>13 September – 31 October</td>
<td>44.5 days</td>
<td>Spica</td>
</tr>
<tr>
<td>Libra</td>
<td>♍</td>
<td>23 September – 23 October</td>
<td>13 October – 7 November</td>
<td>31 October – 21 November</td>
<td>21.1 days</td>
<td>Zubeneschamali</td>
</tr>
<tr>
<td>Scorpio</td>
<td>♍</td>
<td>23 October – 22 November</td>
<td>13 November – 6 December</td>
<td>21 November – 30 November</td>
<td>8.4 days</td>
<td>Antares</td>
</tr>
<tr>
<td>Serpentarius</td>
<td>♍</td>
<td>n/a</td>
<td></td>
<td>30 November – 18 December</td>
<td>18.4 days</td>
<td>Rasalhague/Alpha Ophiuchi</td>
</tr>
<tr>
<td>Sagittarius</td>
<td>☐</td>
<td>22 November – 22 December</td>
<td>13 December – 6 January</td>
<td>18 December – 21 January</td>
<td>33.6 days</td>
<td>Kaus Australis</td>
</tr>
<tr>
<td>Capricorn</td>
<td>♑</td>
<td>December – 20 January</td>
<td>13 January – 8 February</td>
<td>21 January – 17 February</td>
<td>27.4 days</td>
<td>Deneb Algedi</td>
</tr>
<tr>
<td>Aquarius</td>
<td>♒</td>
<td>20 January – 18 February</td>
<td>12 February – 7 March</td>
<td>17 February – 13 March</td>
<td>23.9 days</td>
<td>Sadalsuud</td>
</tr>
<tr>
<td>Pisces</td>
<td>♓</td>
<td>18 February – 20 March</td>
<td>15 March – 8 April</td>
<td>13 March – 20 April</td>
<td>37.7 days</td>
<td>Eta Piscium</td>
</tr>
</tbody>
</table>

**Note:** The dates are approximate and subject to slight variations depending on the method of calculation.
The zodiac is a spherical celestial coordinate system. It designates the ecliptic as its fundamental plane and the position of the Sun at Vernal equinox as its prime meridian.

In astronomy, the zodiacal constellations are a convenient way of marking the ecliptic (the Sun’s path across the sky) and the path of the moon and planets along the ecliptic.

Zodiac is also used to refer to the zodiacal cloud of dust grains that move among the planets.

Unlike the zodiac signs in astrology, which are all thirty degrees in length, the astronomical constellations vary widely in size. The boundaries of all the constellations in the sky were set by the International Astronomical Union (IAU) in 1930. This was, in essence, a mapping exercise to make the work of astronomers more efficient, and the boundaries of the constellations are not therefore in any meaningful sense an ‘equivalent’ to the zodiac signs.

Along with the twelve original constellations, the boundaries of a thirteenth constellation, Ophiuchus (the serpent bearer), were set by astronomers within the bounds of the zodiac.

ANCIENT ASTRONOMY

Babylonian Astronomy: Babylonian astronomy refers to the astronomical methods and theories that were developed in Mesopotamia (modern-day Iraq), particularly in Babylonia but inheriting earlier concepts developed in Sumer. Babylonian astronomy was the basis for much of the astronomical traditions that later developed in Greek and Hellenistic astronomy, in Sassanid Persian astronomy, in Syrian and Byzantine astronomy, in medieval Islamic astronomy, and in Western European astronomy.

The origins of Western astronomy can be found in Mesopotamia. The history of astronomy in Mesopotamia, and the world, begins with the Sumerians who developed the earliest writing system—known as cuneiform—around 3500–3200 BC. The Sumerians developed a form of astronomy that had an important influence on the sophisticated astronomy of the Babylonians. Astrolatry, which gave planetary gods an important role in Mesopotamian mythology and religion, began with the Sumerians. They also used a sexagesimal (base 60) place-value number system, which simplified the task of recording very great and very small numbers. The modern practice of dividing a circle into 360 degrees, of 60 minutes each, began with the Sumerians.

During the 8th and 7th centuries BCE, Babylonian astronomers developed a new empirical approach to astronomy. They began studying philosophy dealing with the ideal nature of the universe and began employing an internal logic within their predictive planetary systems. This was an important contribution to astronomy and the philosophy of science, and some scholars have thus referred to this new approach as the first scientific revolution.

The Babylonians were the first to recognize that astronomical phenomena are periodic and apply mathematics to their predictions. Tablets dating back to the Old Babylonian period document the application of mathematics to the variation in the length of daylight over a solar year. The Venus tablet of Ammisaduqa, which lists the first and last visible risings of Venus over a period of about 21 years. It is the earliest evidence that planetary phenomena were recognized as periodic.
In Babylonian cosmology, the Earth and the heavens were depicted as a “spatial whole, even one of round shape” with references to “the circumference of heaven and earth” and “the totality of heaven and earth”. Their worldview was not exactly geocentric either. The idea of geocentrism, where the center of the Earth is the exact center of the universe, did not yet exist in Babylonian cosmology, but was established later by the Greek philosopher Aristotle’s On the Heavens.

**Greek Astronomy:** The development of astronomy by the Greek and Hellenistic astronomers is considered by historians to be a major phase in the history of astronomy. Greek astronomy is characterized from the start by seeking a rational, physical explanation for celestial phenomena. Most of the constellations of the northern hemisphere derive are taken from Greek astronomy, as are the names of many stars and planets. It was influenced by Babylonian and, to a lesser extent, Egyptian astronomy; in turn, it influenced Indian, Arabic-Islamic and Western European astronomy.

The name “planet” comes from the Greek term, meaning “wanderer”, as ancient astronomers noted how certain lights moved across the sky in relation to the other stars. Five planets can be seen with the naked eye: Mercury, Venus, Mars, Jupiter, and Saturn.

Since the planets disappear from time to time when they approach the Sun, careful attention is required to identify all five. Observations of Venus are not straightforward. Early Greeks thought that the evening and morning appearances of Venus represented two different objects, calling it Hesperus (“evening star”) when it appeared in the western evening sky and Phosphorus (“light-bringer”) when it appeared in the eastern morning sky.

In classical Greece, astronomy was a branch of mathematics; astronomers sought to create geometrical models that could imitate the appearances of celestial motions. This tradition began with the Pythagoreans, who placed astronomy among the four mathematical arts (along with arithmetic, geometry, and music).

The two-sphere model is a geocentric model. It divides the cosmos into two regions:

- A spherical Earth, central and motionless (the sublunary sphere).
- A spherical heavenly realm centered on the Earth, which may contain multiple rotating spheres made of aether.

**Plato**’s main books on cosmology are the Timaeus and the Republic. In them he described the two-sphere model and said there were eight circles or spheres carrying the seven planets and the fixed stars. He put the celestial objects in the following order, beginning with the one closest to Earth:
1. Moon
2. Sun
3. Venus
4. Mercury
5. Mars
6. Jupiter
7. Saturn
8. Fixed stars
The Almagest is one of the most influential books in the history of Western astronomy. In this book, Ptolemy explained how to predict the behavior of the planets, as Hipparchus could not, with the introduction of a new mathematical tool, the equant. The Almagest gave a comprehensive treatment of astronomy, incorporating theorems, models, and observations from many previous mathematicians.

In the 2nd century, Hipparchus, aware of the extraordinary accuracy with which Babylonian astronomers could predict the planets’ motions, insisted that Greek astronomers achieve similar levels of accuracy. Somehow he had access to Babylonian observations or predictions, and used them to create better geometrical models. For the Sun, he used a simple eccentric model, based on observations of the equinoxes, which explained both changes in the speed of the Sun and differences in the lengths of the seasons. For the Moon, he used a deferent and epicycle model. He could not create accurate models for the remaining planets, and criticized other Greek astronomers for creating inaccurate models.

Hipparchus also compiled a star catalogue. According to Pliny the Elder, he observed a nova (new star).

In the 3rd century, Aristarchus of Samos proposed an alternate cosmology (arrangement of the universe): a heliocentric model of the solar system, placing the Sun, not the Earth, at the center of the known universe (hence he is sometimes known as the "Greek Copernicus"). His astronomical ideas were not well-received, however, and only a few brief references to them are preserved. We know the name of one follower of Aristarchus: Seleucus of Seleucia.

Aristarchus also wrote a book On the Sizes and Distances of the Sun and Moon, which is his only work to have survived. In this work, he calculated the sizes of the Sun and Moon, as well as their distances from the Earth in Earth radii. Shortly afterwards, Eratosthenes calculated the size of the Earth, providing a value for the Earth radii which could be plugged into Aristarchus’ calculations.

Arabic Astronomy: In the history of astronomy, Islamic astronomy or Arabic astronomy refers to the astronomical developments made in the Islamic world, particularly during the Islamic Golden Age (8th-15th centuries), and mostly written in the Arabic language. These developments mostly took place in the Middle East, Central Asia, Al-Andalus, and North Africa, and later in the Far East and India.

Islamic interest in astronomy ran parallel to the interest in mathematics. Especially noteworthy in this regard was the Almagest (c. 150) of the astronomer Ptolemy (c. 100-178). The Almagest was a landmark work in its field, assembling, as Euclid’s Elements had previously done with geometrical works, all extant knowledge in the field of astronomy that was known to the author. This work was originally known as The Mathematical Composition, but after it had come to be used as a text in astronomy, it was called The Great Astronomer.
In observational astronomy, the first major original Muslim work of astronomy was *Zij al-Sindh* by al-Khwarizimi in 830. The work contains tables for the movements of the sun, the moon and the five planets known at the time. Between 825 to 835, Habash al-Hasib al-Marwazi conducted various observations at the Al-Shammiyyah observatory in Baghdad, where he estimated a number of geographic and astronomical values. He compiled his results in *The Book of Bodies and Distances*, in which many of his estimates come closer to modern values than any of his predecessors.

Muhammad ibn Jābir al-Harrānī *Al-Battānī* (Albatenius) (853-929) produced “improved tables of the orbits of the sun and the moon” that “contained his great discovery that the direction of the sun’s excentric …, as recorded by Ptolemy, was changing.” Among other things, he worked on timing the first appearance of the moon’s crescent following a new moon, the lengths of the solar and sidereal years, the prediction of eclipses, and the phenomenon of parallax.

In the 10th century, *Abd al-Rahman al-Sufi* (Azophi) carried out observations on the stars and described their positions, magnitudes, brightness, and colour and drawings for each constellation in his Book of Fixed Stars (964). He also gave the first descriptions and pictures of “A Little Cloud” now known as the Andromeda Galaxy.

In 1006, the Egyptian astronomer *Ali ibn Ridwan* observed SN 1006, the brightest supernova in recorded history, and left a detailed description of the temporary star. He says that the object was two to three times as large as the disc of Venus and about one-quarter the brightness of the Moon, and that the star was low on the southern horizon.

The transit of Venus and transit of Mercury were claimed to have been observed by medieval Islamic astronomers. In the 11th century, the Persian polymath Avicenna claimed to have observed the transit of Venus across the Sun. He took this as evidence that Venus was, at least sometimes, below the Sun (in the Ptolemaic cosmology).

*Ulug Bey* was a Timurid ruler as well as an astronomer, mathematician and sultan. Ulug Bey was also notable for his work in astronomy-related mathematics, such as trigonometry and spherical geometry. He built the great observatory in Samarkand between 1424 and 1429.

The astronomical tradition established by the Maragha school continued at the *Ulug Bey Observatory* at Samarkand, in modern-day Uzbekistan. Founded by Ulug Bey in the early 15th century, the observatory made considerable progress in observational astronomy.

An *astrolabe* is a historical astronomical instrument used by astronomers, navigators. Its many uses include locating and predicting the positions of the Sun, Moon, planets, and stars; determining local time. They were used in Classical Antiquity and through the Islamic Golden Age and the European Middle Ages and Renaissance for all these purposes.

*Ali Kuşçu* was an astronomer, mathematician, physicist and scientist from Central Asia. He is best known for his development of an astronomical physics independent from natural philosophy and for providing empirical evidence for the Earth’s motion in his treatise, Concerning the Supposed Dependence of Astronomy upon Philosophy, in addition to his contributions to Ulugh Beg’s famous work Zij-i-Sultani and his efforts in founding Sahn-i Seman University, one of the first Ottoman universities.
MODERN ASTRONOMY

While already considered by ancient Greek Aristarchus around 300 B.C., the heliocentric system was finally established in 1543 by Nicolaus Copernicus (1473-1543) from Poland when his book, De Revolutionibus ("On Revolutions") appeared. This model considered the Sun and no more the Earth to be the center of planetary motions, and the apparent annual motion of the Sun as an illusional effect caused by this motion, while the diurnal rotation of the stellar sky is explained by a rotation of the Earth around its axis. The observed apparent motion of the planets can be understood as their motion around the Sun, viewed from a moving Earth. However, as Copernicus kept the circular orbits, he also considered an epicycle system to describe planetary motion accurately.

After Copernicus, Danish astronomer Tycho Brahe (1546-1601) proposed a hybrid model of Moon and Sun orbiting the Earth and the other planets moving around the Sun, still needing epicycles for accurate description of their orbits. Strangely, he kept the idea that the sky and all planets encircle a static Earth daily, and got in conflict with Nikolaus Baer who thought Earth was rotating. Tycho also established the nature of comets as objects of translunar space and not atmospheric phenomena, as had been postulated by Aristotle, by measuring a lower limit of the distance of several times the Lunar distance for one comet, and observed a supernova in 1572, thus proving that the stellar skies are not so unchangeable as people had believed previously.

German astronomer Johannes Kepler (1571-1630) used Brahe’s Mars observations to establish that planets move on elliptical orbits around the Sun, and derived his three laws of planetary motion:

1. The orbit of each planet is an ellipse with the Sun in one focus.
2. The radius vector from Sun to planet sweeps equal areas at each time, meaning that the planet moves faster when closer to the Sun.
3. The squares of the revolution periods are proportional to the cubes of the mean distances from the Sun for all planets.

The establishment of the Kepler laws of planetary motion was the last great achievement of the pre-telescopic era of astronomy, although Kepler himself had also developed a type of telescopes.

It was finally left to Galileo to give evidence for the heliocentric model with his telescopic discoveries of the moons of Jupiter and the phases of Venus. However, he got in serious trouble with the Roman Inquisition for his advocacy of the Copernican system, and the Church authorities kept the old geocentric system of Ptolemy as their doctrine for a long time.

Italian astronomer and physicist Galileo Galilei (1561-1642) was one of the first astronomers using a telescope. Invention of the telescope is accepted as the beginning of Modern Astronomy.

Galileo observed:
- The phases of Venus
- The four satellites of Jupiter (Galilean Moons)
- Sunspots
- Craters on the Moon

He also observed Saturn but he could not realize its rings.
**Sir Isaac Newton** (1642 – 1726) was an English physicist, mathematician, astronomer, natural philosopher, alchemist, and theologian who is considered by many scholars and members of the general public to be one of the most influential people in human history.

**Newton’s law of universal gravitation** states that every massive particle in the universe attracts every other massive particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

\[
F = G \frac{m_1 m_2}{r^2},
\]

where:

- \( F \) is the magnitude of the gravitational force between the two point masses,
- \( G \) is the gravitational constant,
- \( m_1 \) is the mass of the first point mass,
- \( m_2 \) is the mass of the second point mass, and
- \( r \) is the distance between the two point masses.

Newton’s law of gravitation resembles Coulomb’s law of electrical forces, which is used to calculate the magnitude of electrical force between two charged bodies.

The problem is that Newton’s Theories and his mathematical formulas explain and permit the (inaccurate) calculation of the effects of the precession of the perihelions of the orbits and the deflection of light rays. However, they did not and do not explain the equivalence of the behavior of various masses under the influence of gravity, independent of the quantities of matter involved.

**HISTORY OF TELESCOPES**

The earliest known working telescopes appeared in 1608 and are credited to Hans Lippershey. The design of these early refracting telescopes consisted of a convex objective lens and a concave eyepiece. Galileo used this design the following year. In 1611, Johannes Kepler described how a telescope could be made with a convex objective and eyepiece lens and by 1655 astronomers such as Christiaan Huygens were building powerful but extremely large and unwieldy Keplerian telescopes with compound eyepieces.

Isaac Newton is credited with building the first “practical” reflector in 1668 with a design that incorporated a small flat diagonal mirror to reflect the light to an eyepiece mounted on the side of the telescope. Laurent Cassegrain in 1672 described the design of a reflector with a small convex secondary mirror to reflect light through a central hole in the main mirror.

Important developments in reflecting telescopes were John Hadley’s production of larger paraboloidal mirrors in 1721; the process of silvering glass mirrors introduced by Léon Foucault in 1857 and the adoption of long lasting aluminized coatings on reflector mirrors in 1932. Almost all of the large optical research telescopes used today are reflectors.
The first giant reflecting telescope can be said to be William Herschel’s great reflector with a mirror of 49 inches (124 cm) and a focal length of 40 ft (12 m) built in 1789.

In 1856-57, Karl August von Steinheil and Léon Foucault introduced a process of depositing a layer of silver on glass telescope mirrors. The silver layer was not only much more reflective and longer lasting than the finish on speculum mirrors, it had the advantage of being able to be removed and re-deposited without changing the shape of the glass substrate. Very large silver on glass mirror reflecting telescopes were built such as the 36 inch (91 cm) Crossley Reflector. The rise of 1948 saw the completion of the 200 inch (508 cm) Hale reflector at Mount Palomar which was the largest telescope in the world up until the completion of the massive 605 cm (238 in) BTA-6 in Russia seventeen years later.

The 1990s saw a new generation of giant telescopes appear, beginning with the construction of the first of the two 10 m (394 in) Keck telescopes in 1993. Other giant telescopes built since then include: the two Gemini telescopes, the four separate telescopes of the Very Large Telescope, and the Large Binocular Telescope.

These telescopes all depend on adaptive optics (AO), the latest technology used to improve the performance of telescopes. It reduces the effects of rapidly changing optical distortion due to the motion of air currents in the Earth’s atmosphere. It is especially used in astronomical telescopes to remove the effects of atmospheric distortion. Adaptive optics works by measuring the distortions in a wavefront usually with a laser and then compensating for them by rapid changes of actuators applied to a deformable mirror or with a liquid crystal array filter.
THE SOLAR SYSTEM

The Formation of The Solar System
The formation and evolution of the Solar System is estimated to have begun 4.568 billion years ago with the gravitational collapse of a small part of a giant molecular cloud. Most of the collapsing mass collected in the centre, forming the Sun, while the rest flattened into a proto planetary disk out of which the planets, moons, asteroids, and other small Solar System bodies formed.

The Solar System has evolved considerably since its initial formation. Many moons have formed from circling discs of gas and dust around their parent planets, while other moons are believed to have formed independently and later been captured by their planets. Still others, as the Earth’s Moon, may be the result of giant collisions. Collisions between bodies have occurred continually up to the present day and have been central to the evolution of the solar system. The positions of the planets often shifted, and planets have switched places. This planetary migration now is believed to have been responsible for much of the Solar System’s early evolution.

In roughly 5 billion years, the Sun will cool and expand outward to many times its current diameter (becoming a red giant), before casting off its outer layers as a planetary nebula, and leaving behind a stellar corpse known as a white dwarf. In the far distant future, the gravity of passing stars gradually will whittle away at the Sun’s retinue of planets. Some planets will be destroyed, others ejected into interstellar space. Ultimately, over the course of trillions of years, it is likely that the Sun will be left alone with no bodies in orbit around it.

The nebular hypothesis maintains that the Solar System formed from the gravitational collapse of a fragment of a giant molecular cloud. The cloud itself had a size of about 20 pc, while the fragments were roughly 1 pc (several light-years) across. The composition of this region with a mass just over that of the Sun was about the same as that of the Sun today, with hydrogen, along with helium and trace amounts of lithium produced by Big Bang nucleosynthesis, forming about 98% of its mass. The remaining 2% of the mass consisted of heavier elements that were created by nucleosynthesis in earlier generations of stars. Late in the life of these stars, they ejected heavier elements into the interstellar medium.

Formation of the Planets
The various planets are thought to have formed from the solar nebula, the disc-shaped cloud of gas and dust left over from the Sun’s formation. The currently accepted method by which the planets formed is known as accretion, in which the planets began as dust grains in orbit around the central protostar. Through direct contact, these grains formed into clumps up to 200 metres in diameter, which in turn collided to form larger bodies (planetesimals) of ~10 kilometres (km) in size. These gradually increased through further collisions, growing at the rate of centimetres per year over the course of the next few million years.
The inner Solar System, the region of the Solar System inside 4 AU, was too warm for volatile molecules like water and methane to condense, so the planetesimals that formed there could only form from compounds with high melting points, such as metals (like iron, nickel, and aluminium) and rocky silicates. These rocky bodies would become the terrestrial planets (Mercury, Venus, Earth, and Mars).

When the terrestrial planets were forming, they remained immersed in a disk of gas and dust. The gas was partially supported by pressure and so did not orbit the Sun as rapidly as the planets. The resulting drag caused a transfer of angular momentum, and as a result the planets gradually migrated to new orbits. Models show that temperature variations in the disk governed this rate of migration, but the net trend was for the inner planets to migrate inward as the disk dissipated, leaving the planets in their current orbits.\[30\]

The gas giant planets (Jupiter, Saturn, Uranus, and Neptune) formed further out, beyond the frost line, the point between the orbits of Mars and Jupiter where the material is cool enough for volatile icy compounds to remain solid. The ices that formed the Jovian planets were more abundant than the metals and silicates that formed the terrestrial planets, allowing the Jovian planets to grow massive enough to capture hydrogen and helium, the lightest and most abundant elements. The four gas giants comprise just under 99% of all the mass orbiting the Sun.
MERCURY

Mercury is the innermost and smallest planet in the Solar System, orbiting the Sun once every 87.969 Earth days. The orbit of Mercury has the highest eccentricity of all the Solar System planets, and it has the smallest axial tilt. It completes three rotations about its axis for every two orbits.

Mercury is similar in appearance to the Moon: it is heavily cratered with regions of smooth plains, has no natural satellites and no substantial atmosphere. However, unlike the Moon, it has a large iron core, which generates a magnetic field about 1% as strong as that of the Earth.

Surface temperatures range from about -183°C to 427°C. Recorded observations of Mercury date back to at least the first millennium BC. Before the 4th century BC, Greek astronomers believed the planet to be two separate objects: one visible only at sunrise, which they called Apollo; the other visible only at sunset, which they called Hermes.

Mercury, Venus, Earth, and Mars are terrestrial (rocky) planets. Among these, Mercury is an extreme: the smallest, the densest (after correcting for self-compression), the one with the oldest surface, the one with the largest daily variations in surface temperature, and the least explored.

The MESSENGER mission, spacecraft, and science instruments are focused on answering six key outstanding questions that will allow us to understand Mercury as a planet.

**Question 1: Why is Mercury so dense?**

Mercury’s density implies that a metal-rich core occupies at least 60% of the planet’s mass, a figure twice as great as for Earth! MESSENGER will acquire compositional and mineralogical information to distinguish among the current theories for why Mercury is so dense.

**Question 2: What is the geologic history of Mercury?**

Before the MESSENGER mission, only 45% of the surface of Mercury had been photographed by a spacecraft! Using its full suite of instruments, MESSENGER will investigate the geologic history of Mercury in great detail, including the portions of the planet never seen by Mariner 10.

**Question 3: What is the nature of Mercury’s magnetic field?**

Mercury has a global internal magnetic field, as does Earth, but Mars and Venus do not. By characterizing Mercury’s magnetic field, MESSENGER will help answer the question of why the inner planets differ in their magnetic histories.

**Question 4: What is the structure of Mercury’s core?**

Through a combination of measurements of Mercury’s gravity field and observations by the laser altimeter, MESSENGER will determine the size of Mercury’s core and verify that Mercury’s outer core is molten.
**Question 5: What are the unusual materials at Mercury’s poles?**

At Mercury’s poles, some crater interiors have permanently shadowed areas that contain highly reflective material at radar wavelengths. Could this material be ice, even though Mercury is the closest planet to the Sun? MESSENGER will find out.

**Question 6: What volatiles are important at Mercury?**

MESSENGER will measure the composition of Mercury’s thin exosphere, providing insights into the processes that are responsible for its existence.

Mercury’s apparent magnitude varies between about -2.3—brighter than Sirius—and 5.7. The extremes occur when Mercury is close to the Sun in the sky. Observation of Mercury is complicated by its proximity to the Sun, as it is lost in the Sun’s glare for much of the time. Mercury can be observed for only a brief period during either morning or evening twilight. The Hubble Space Telescope cannot observe Mercury at all, due to safety procedures which prevent its pointing too close to the Sun.

**MISSION OF MARINER 10**

Mariner 10 was a robotic space probe launched on November 3, 1973 to fly by the planets Mercury and Venus. It was launched approximately 2 years after Mariner 9 and was the last spacecraft in the Mariner program (Mariner 11 and 12 were purposed to the Voyager program and redesignated Voyager 1 and Voyager 2). The mission objectives were to measure Mercury’s environment, atmosphere, surface, and body characteristics and to make similar investigations of Venus. Secondary objectives were to perform experiments in the interplanetary medium and to obtain experience with a dual-planet gravity assist mission. Mariner 10 was the first spacecraft to make use of an interplanetary “gravitational slingshot” maneuver, using Venus to bend its flight path and bring its perihelion down to the level of Mercury’s orbit. This maneuver, inspired by the orbital mechanics calculations of the Italian scientist Giuseppe Colombo, put the spacecraft into an orbit that repeatedly brought it back to Mercury. Mariner 10 used the solar radiation pressure on its solar panels and its high-gain antenna as a means of attitude control during flight, the first spacecraft to use active solar pressure control.

**MISSION OF MESSENGER**

( 4 – 8 December 2008 )

To become the first spacecraft to orbit Mercury, MESSENGER must follow a path through the inner solar system, including one flyby of Earth, two flybys of Venus, and three flybys of Mercury. This impressive journey is returning the first new spacecraft data from Mercury since the Mariner 10 mission over 30 years ago. NASA’s MESSENGER spacecraft will sweep low over Mercury September 29, when it will snap more than 1,500 pictures and adjust its trajectory for entering orbit in 2011.
VENUS

Venus is the second-closest planet to the Sun, orbiting it every 224.7 Earth days. The planet is named after Venus, the Roman goddess of love and beauty. After the Moon, it is the brightest natural object in the night sky, reaching an apparent magnitude of -4.6. Classified as a terrestrial planet, it is sometimes called Earth’s “sister planet” because they are similar in size and gravity.

Venus’s surface was a subject of speculation until some of its secrets were revealed by planetary science in the twentieth century. It was finally mapped in detail by Project Magellan in 1990–91. The ground shows evidence of extensive volcanism, and the sulfur in the atmosphere may indicate that there have been some recent eruptions.

The diameter of Venus is only 650 km less than the Earth’s, and its mass is 81.5% of the Earth’s. However, conditions on the Venusian surface differ radically from those on Earth, due to its dense carbon dioxide atmosphere. Venus and Earth suggests that they share a similar internal structure: a core, mantle, and crust.

About 80% of Venus’s surface is covered by smooth volcanic plains, consisting of 70% plains with wrinkleridges and 10% smooth or lobate plains.

Orbit and Rotation

Venus orbits the Sun at an average distance of about 108 million km (about 0.7 AU), and completes an orbit every 224.65 days. Although all planetary orbits are elliptical, Venus is the closest to circular. If viewed from above the Sun’s north pole, all of the planets are orbiting in a counter-clockwise direction; but while most planets also rotate counter-clockwise, Venus rotates clockwise in "retrograde" rotation.

As it moves around its orbit, Venus displays phases in a telescopic view like those of the Moon: In the phases of Venus the planet presents a small “full” image when it is on the opposite side of the Sun. It shows a larger “quarter phase” when it is at its maximum elongations from the Sun. Venus is at its brightest in the night sky and presents a much larger “thin crescent” in telescopic views as it comes around to the near side between the Earth and the Sun. Venus is at its largest and presents its “new passes” when it is between the Earth and the Sun. Since it has an atmosphere it can be seen in a telescope by the halo of light refracted around the planet.

Venus Transit

Venus’s orbit is slightly inclined relative to the Earth’s orbit; thus, when the planet passes between the Earth and the Sun, it usually does not cross the face of the Sun. However, transits of Venus do occur in pairs separated by eight years, at intervals of about 121.5 years, when the planet’s inferior conjunction coincides with its presence in the plane of the Earth’s orbit. The most recent transit was in June 2004; the next will be in June 2012.
Atmosphere of Venus and Greenhouse Effect

Venus’ atmosphere is about 90 times denser than Earth’s. That is, if we took two identical cups and filled one with Venus’ air, the other with Earth’s, and weighed the contents of both on Earth, the contents of the Venusan cup would be 90 times heavier. Measurements showed that Venus’ atmosphere is approximately 97% carbon dioxide (CO₂) and 3% nitrogen. Its thick clouds are made of water and highly corrosive sulfuric acid.

Venus’ thick clouds indeed block most of the sunlight, as early astronomers believed. Venus is closer to the Sun than Earth and gets more intense sunlight, but only little of this light reaches the ground.

But what is it about the atmospheres of the two planets which keep Earth warm enough to support life? Why is life as we know it impossible on Venus? Why is all the water of Venus found in the clouds above it, whereas the bulk of Earth’s water is in its oceans? Carbon dioxide, water vapor, and a few other gases have the wonderful property of letting sunshine in, but blocking some of the infrared radiation. They serve as a blanket, keeping the ground—the source of heat radiation—warmer by not letting this heat escape. This heat, having no place to go, is trapped. The greenhouse theory was first propounded by Rupert Wildt in the 1940s to explain the unexpectedly high temperatures of Venus. By the early 1960s, it was revived and championed by an American astronomer who is a household name in this country—Carl Sagan.

Spacecrafts that visited Venus

1) Name: **Mariner 2**
Launch: August 27 1962
From: USA
Intention: Flyby
Result: First successful planetary mission found that Venus has small magnetic field.

2) Name: **Pioneer Venus**
Launch: May 20 1978
From: USA Intention: Orbit
Result: Radar mapping, photo study of clouds, operated for 14 years!

3) Name: **Magellan**
Launch: May 4 1989
From: USA
Intention: Orbit
Result: High resolution radar mapping

4) Name : **Venera 7 and Venera 9**
From: Soviet Unions

5) **Venus Express**
How the mission was named: The name Venus Express comes from the short time to define, prepare and launch the mission. It took less than three years from the approval to the launch of the mission. To do this, ESA re-used the same design as the Mars Express mission and the same industrial teams that worked on that mission.

Prime contractor: EADS Astrium, Toulouse, France, leading a team of 25 subcontractors from 14 European countries.

Launch date: 9 November 2005 (Soyuz-Fregat from Baikonur, Kazakhstan).

Launcher: Soyuz/Fregat, built by Starsem, the European/Russian launcher consortium

Launch mass: 1270 kg (including 93 kg orbiter payload and 570 kg fuel)

Orbiter instruments: Venus Monitoring Camera (VMC); Analyser of Space Plasma and Energetic Atoms (ASPERA); Planetary Fourier Spectrometer (PFS); Visible/ Ultraviolet/Near-infrared Mapping Spectrometer (VIRTIS); Venus Express Magnetometer (MAG); Venus Radio Science Experiment (VeRa); Ultraviolet and Infrared Atmospheric Spectrometer (SPICAV/ SOIR);

Spacecraft operations: European Space Operations Centre (ESOC), Darmstadt, Germany

Ground stations: After launch, ground stations at Villafranca (15 m), Spain, New Norcia (35 m), Australia, and Kourou (15 m), French Guiana, will be used for communication and orbit determination.

At Venus, Cebreros (35 m) near Madrid, Spain. The New Norcia antenna will be used to support the Venus Radio science experiments.

Arrival at Venus: April 2006

EARTH – MOON SYSTEM

Evolution of Earth’s Surface

Earth is the third planet from the Sun. It is the fifth-largest of the eight planets, and the largest of the terrestrial planets (non-gas giant planets) in the Solar System in terms of diameter, mass and density.

Scientists have been able to reconstruct detailed information about the planet’s past. The earliest dated Solar System material is dated to 4.5672 ± 0.0006 billion years ago, and by 4.54 billion years ago (within an uncertainty of 1%) the Earth and the other planets in the Solar System formed out of the solar nebula—a disk-shaped mass of dust and gas left over from the formation of the Sun. This assembly of the Earth through accretion was largely completed within 10–20 million years. Initially molten, the outer layer of the planet Earth cooled to form a solid crust when water began accumulating in the atmosphere. The Moon formed shortly thereafter, 4.53 billion years ago, most likely as the result of a Mars-sized object (sometimes called Theia) with about 10% of the Earth’s mass impacting the Earth in a glancing blow. Some of this object’s mass would have merged with the Earth and a portion would have been ejected into space, but enough material would have been sent into orbit to form the Moon.
Out gassing and volcanic activity produced the primordial atmosphere. Condensing water vapor, augmented by ice and liquid water delivered by asteroids and the larger proto-planets, comets, and trans-Neptunian objects produced the oceans. The newly-formed Sun was only 70% of its present luminosity, yet evidence shows that the early oceans remained liquid—a contradiction dubbed the faint young Sun paradox. A combination of greenhouse gases and higher levels of solar activity served to raise the Earth’s surface temperature, preventing the oceans from freezing over.

**Magnetic Field**

The Earth's magnetic field is shaped roughly as a magnetic dipole, with the poles currently located proximate to the planet's geographic poles. According to dynamo theory, the field is generated within the molten outer core region where heat creates convection motions of conducting materials, generating electric currents. These in turn produce the Earth's magnetic field. The convection movements in the core are chaotic in nature, and periodically change alignment. This results in field reversals at irregular intervals averaging a few times every million years. The most recent reversal occurred approximately 700,000 years ago.

The field forms the magnetosphere, which deflects particles in the solar wind. The sunward edge of the bow shock is located at about 13 times the radius of the Earth. The collision between the magnetic field and the solar wind forms the Van Allen radiation belts, a pair of concentric, torus-shaped regions of energetic charged particles. When the plasma enters the Earth's atmosphere at the magnetic poles, it forms the aurora.

**Continental Drift**

Continental drift is the movement of the Earth's continents relative to each other. German scientist Alfred Wegener formed this idea of Continental Drift. He argued that today's continents once formed a single landmass, which he named Pangaea (Greek for “all land”). It broke into pieces due to the weaknesses in the earth's crust as they were made up of less dense materials, which drifted centimeter by centimeter over millions of years until they arrived at where they are now. Evidence for continental drift is now extensive. Similar plant and animal fossils are found around different continent shores, suggesting that they were once joined. Around 200 million years ago, the supercontinent Pangaea began to split apart.

The theory has unified the study of the Earth by drawing together many branches of the earth sciences, from paleontology (the study of fossils) to seismology (the study of earthquakes).

**THE MOON**

The Moon is Earth's only natural satellite and the fifth largest satellite in the Solar System. The average centre-to-centre distance from the Earth to the Moon is 384,403 kilometres. The Moon's diameter is 3,474 kilometres (2,159 mi), a little more than a quarter of that of the Earth. Thus, the Moon’s surface area is less than a tenth of the Earth (about a quarter of Earth’s land area, approximately as large as Russia, Canada, and the United States combined), and its volume is about 2 percent that of Earth. The pull of gravity at its surface is about 17 percent of that at the Earth’s surface.
The Moon makes a complete orbit around the Earth every 27.3 days (the orbital period), and the periodic variations in the geometry of the Earth–Moon–Sun system are responsible for the phases of the Moon, which repeat every 29.5 days (the synodic period).

The Moon is in synchronous rotation, which means it rotates about its axis in about the same time it takes to orbit the Earth. This results in it keeping nearly the same face turned towards the Earth at all times. The side of the Moon that faces Earth is called the near side, and the opposite side the far side. The far side of the Moon was first photographed by the Soviet probe Luna 3 in 1959.

The dark and relatively featureless lunar plains which can clearly be seen with the naked eye are called maria (singular mare), Latin for seas, since they were believed by ancient astronomers to be filled with water. These are now known to be vast solidified pools of ancient basaltic lava. The lighter-colored regions of the Moon are called terrae, or more commonly just highlands, since they are higher than most maria.

**Theories of Formation for the Moon**

Five serious theories have been proposed for the formation of the Moon (not counting the one involving green cheese):

1. **The Fission Theory**: The Moon was once part of the Earth and somehow separated from the Earth early in the history of the Solar System. The present Pacific Ocean basin is the most popular site for the part of the Earth from which the Moon came.

2. **The Capture Theory**: The Moon was formed somewhere else, and was later captured by the gravitational field of the Earth.

3. **The Condensation Theory**: The Moon and the Earth condensed together from the original nebula that formed the Solar System.

4. **The Colliding Planetesimals Theory**: The interaction of earth-orbiting and Sun-orbiting planetesimals (very large chunks of rocks like asteroids) early in the history of the Solar System led to their breakup. The Moon condensed from this debris.

5. **The Ejected Ring Theory**: A planetesimal the size of Mars struck the earth, ejecting large volumes of matter. A disk of orbiting material was formed, and this matter eventually condensed to form the Moon in orbit around the Earth.
Phases of the Moon

The Moon makes a complete orbit around the Earth with respect to the fixed stars about once every 27.3 day (its sidereal period). However, since the Earth is moving in its orbit about the Sun at the same time, it takes slightly longer for the Moon to show its same phase to Earth, which is about 29.5 days (its synodic period). Unlike most satellites of other planets, the Moon orbits near the ecliptic and not the Earth’s equatorial plane.

A **lunar phase** or **phase of the moon** refers to the appearance of the illuminated portion of the Moon as seen by an observer, usually on Earth. The lunar phases vary cyclically as the Moon orbits the Earth, according to the changing relative positions of the Earth, Moon and Sun. One half of the lunar surface is always illuminated by the Sun (except during lunar eclipses), and hence is bright, but the portion of the illuminated hemisphere that is visible to an observer can vary from 100% (full moon) to 0% (new moon).

When the Sun and Moon are aligned on the same side of the Earth the Moon is “new”, and the side of the Moon visible from Earth is not illuminated by the Sun. As the Moon waxes (the amount of illuminated surface as seen from Earth is increasing), the lunar phases progress from new moon, crescent moon, first-quarter moon, gibbous moon and full moon phases, before returning through the gibbous moon, third-quarter moon, crescent moon and new moon phases. The terms old moon and new moon are interchangeable, although new moon is more common. Half moon is often used to mean the first- and third-quarter moons.

In the northern hemisphere, if the left side of the Moon is dark then the light part is growing, and the Moon is referred to as **waxing** (moving towards a full moon). If the right side of the Moon is dark then the light part is shrinking, and the Moon is referred to as **waning** (moving towards a new moon).
ECLIPSES

LUNAR ECLIPSE

A lunar eclipse is an eclipse which occurs whenever the moon passes behind the earth such that the earth blocks the sun’s rays from striking the moon. This can occur only when the Sun, Earth, and Moon are aligned exactly, or very closely so, with the Earth in the middle. Hence, there is always a full moon the night of a lunar eclipse.

Every year there are usually at least two partial lunar eclipses, although total eclipses are significantly less common. If one knows the date and time of an eclipse, it is possible to predict the occurrence of other eclipses using an eclipse cycle like the Saros cycle. Unlike a solar eclipse, which can only be viewed from a certain relatively small area of the world, a lunar eclipse may be viewed from anywhere on the night side of the Earth.

The Saros cycle is an eclipse cycle with a period of about 18 years 11 days 8 hours (approximately 6585 1/3 days) that can be used to predict eclipses of the Sun and Moon. One cycle after an eclipse, the Sun, Earth, and Moon return to approximately the same relative geometry, and a nearly identical eclipse will occur west of the original location.

Types of Lunar Eclipses

1) Partial Lunar Eclipse: The shadow of the Earth can be divided into two distinctive parts: the umbra and penumbra. Within the umbra, there is no direct solar radiation. However, as a result of the Sun’s large angular size, solar illumination is only partially blocked in the outer portion of the Earth’s shadow, which is given the name penumbra. A partial lunar eclipse occurs when only a portion of the Moon enters the umbra.

A partial lunar eclipse will take place on New Year’s Eve, December 31, 2009, the last of four lunar eclipses in 2009. Only a tiny sliver of the Moon will be in the Earth’s umbral shadow, but there should be a distinct darkening visible over the Moon’s surface at greatest eclipse. It will be visible from all of Africa, Europe, Asia, and Australia.

2) Penumbral Lunar Eclipse: A penumbral eclipse occurs when the Moon passes through the Earth’s penumbra. The penumbra causes a subtle darkening of the Moon’s surface. A special type of penumbral eclipse is a total penumbral eclipse, during which the Moon lies exclusively within the Earth’s penumbra. Total penumbral eclipses are rare, and when these occur, that portion of the Moon which is closest to the umbra can appear somewhat darker than the rest of the Moon.

3) Total Lunar Eclipse: When the Moon travels completely into the Earth’s umbra, one observes a total lunar eclipse. A total lunar eclipse will take place on December 21, 2010, the second of two lunar eclipses in 2010. The previous lunar eclipse on June 26, 2010 will be partial. The previous total lunar eclipse occurred nearly three years earlier, on February 21, 2008. The following two lunar eclipses are also total, on June 15, 2011 and December 10, 2011. It will be followed two weeks later by the partial solar eclipse of January 4, 2011.
SOLAR ECLIPSES

A solar eclipse occurs when the moon passes between the Sun and the Earth so that the Sun is fully or partially covered. This can only happen during a new moon, when the Sun and Moon are in conjunction as seen from the Earth. At least two and up to five solar eclipses can occur each year on Earth. The Sun’s distance from the Earth is about 390 times the Moon’s distance, and the Sun’s diameter is about 400 times the Moon’s diameter. Because these ratios are approximately the same, the Sun and the Moon as seen from Earth appear to be approximately the same size: about 0.5 degree of arc in angular measure.

Types of Solar Eclipses

There are four types of solar eclipses:

1) A total eclipse occurs when the Sun is completely obscured by the Moon. The intensely bright disk of the Sun is replaced by the dark silhouette of the Moon, and the much fainter corona is visible. During any one eclipse, totality is visible only from at most a narrow track on the surface of the Earth.

2) An annular eclipse occurs when the Sun and Moon are exactly in line, but the apparent size of the Moon is smaller than that of the Sun. Hence the Sun appears as a very bright ring, or annulus, surrounding the outline of the Moon.

3) A hybrid eclipse (also called annular/total eclipse) transitions between a total and annular eclipse. At some points on the surface of the Earth it is visible as a total eclipse, whereas at others it is annular. Hybrid eclipses are comparatively rare.

4) A partial eclipse occurs when the Sun and Moon are not exactly in line and the Moon only partially obscures the Sun. This phenomenon can usually be seen from a large part of the Earth outside of the track of an annular or total eclipse. However, some eclipses can only be seen as a partial eclipse, because the umbra never intersects the Earth’s surface, passing above or below the Earth’s polar regions.

The photograph above was taken from Eyuboglu Twin Observatory. Visit the web site for more photographs.
MARS

*Mars* is the fourth planet from the Sun in the Solar System. The planet is named after Mars, the Roman god of war. *It is also referred to as the “Red Planet” because of its reddish appearance, due to iron oxide prevalent on its surface.*

Mars is a terrestrial planet with a thin atmosphere, having surface features reminiscent both of the impact craters of the Moon and the volcanoes, valleys, deserts and polar ice caps of Earth. *It is the site of *Olympus Mons*, the highest known mountain in the Solar System, and of *Valles Marineris*, the largest canyon.*

**Polar Ice Caps Of Mars**

A **polar ice cap** is a high latitude region of a planet or natural satellite that is covered in ice. There are no requirements with respect to size or composition for a body of ice to be termed a polar ice cap, nor any geological requirement for it to be over land; only that it must be a body of solid phase matter in the polar region.

The composition of the ice will vary. For example Earth’s polar ice caps are mainly water ice, while Mars’s polar ice caps are a mixture of solid phase carbon dioxide and water ice.

Polar ice caps form because high latitude regions receive less energy in the form of solar radiation from the sun than equatorial regions, resulting in lower surface temperatures.

**Mars’ Spacecrafts**

Until the first flyby of Mars by *Mariner 4* in 1965, many speculated that there might be liquid water on the planet’s surface. This was based on observations of periodic variations in light and dark patches, particularly in the polar latitudes, which looked like seas and continents, while long, dark striations were interpreted by some observers as irrigation channels for liquid water. These straight line features were later proven not to exist and were instead explained as optical illusions.

NASA’s *Viking program* consisted of a pair of space probes sent to Mars, *Viking 1* and *Viking 2*. Each vehicle was composed of two main parts, an orbiter designed to photograph the surface of Mars from orbit, and a lander designed to study the planet from the surface. The orbiters also served as communication relays for the landers once they touched down.

*It was the most expensive and ambitious mission ever sent to Mars. It was highly successful and formed most of the database of information about Mars until the late 1990s and early 2000s. The Viking program grew from NASA’s earlier, and more ambitious Voyager Mars program, which was not related to the successful Voyager deep space probes of the late 1970s. Viking 1 was launched on August 20, 1975, and the second craft, Viking 2, was launched on September 9, 1975, both riding atop Titan III-E rockets with Centaur upper stages. Each spacecraft consisted of an orbiter and a lander.*
Radar data from Mars Express and the Mars Reconnaissance Orbiter have revealed the presence of large quantities of water ice both at the poles (July 2005) and at mid-latitudes (November 2008). The Phoenix Mars Lander directly sampled water ice in shallow martian soil on July 31, 2008.

Mars is currently host to three functional orbiting spacecraft: Mars Odyssey, Mars Express, and the Mars Reconnaissance Orbiter.

Pathfinder

The Mars Pathfinder (MESUR Pathfinder) later called The Carl Sagan Memorial Station was launched on December 4, 1996 by NASA aboard a Delta II just a month after the Mars Global Surveyor was launched. After a 7-month voyage it landed on Ares Vallis, in a region called Chryse Planitia on Mars, in the Oxia Palus quadrangle, on 4 July 1997. During its voyage the spacecraft had to accomplish four flight adjustments on 10 January, 3 February, 6 May and 25 June. The lander opened, exposing the rover called Sojourner that would go on to execute many experiments on the Martian surface.

The mission carried a series of scientific instruments to analyze the Martian atmosphere, climate, geology and the composition of its rocks and soil.

In addition to scientific objectives, the Mars Pathfinder mission was also a “proof-of-concept” for various technologies, such as airbag-mediated touchdown and automated obstacle avoidance, both later exploited by the Mars Exploration Rovers. The Mars Pathfinder was also remarkable for its extremely low price relative to other unmanned space missions to mars. Originally, the mission was conceived as the first of the Mars Environmental Survey (MESUR) program.

Natural Satellites ( Moons ) Of Mars

Mars has two tiny moons, Phobos and Deimos, which are thought to be captured asteroids.

Both satellites were discovered in 1877 by Asaph Hall, and are named after the characters Phobos (panic/fear) and Deimos (terror/dread) who, in Greek mythology, accompanied their father Ares, god of war, into battle. Ares was known as Mars to the Romans.

The discovery of the two moons of Mars, Phobos and Deimos, occurred in 1877 when American astronomer Asaph Hall, Sr. identified them after a long search, although their existence had been speculated before.

If viewed from the surface of Mars near its equator, full Phobos looks about one third as big as the Earth’s full moon from Earth. Deimos looks more like a bright star or planet for an observer on Mars, only slightly bigger than Venus looks from earth. Both moons are tidally locked, always presenting the same face towards Mars.

The motions of Phobos and Deimos would appear very different from that of our own Moon. Speedy Phobos rises in the west, sets in the east, and rises again in just eleven hours, while Deimos, being only just outside synchronous orbit, rises as expected in the east but very slowly. Despite its 30 hour orbit, it takes 2.7 days to set in the west as it slowly falls behind the rotation of Mars, and has long again to rise.
Surface of Mars

The volcanoes on Mars are now extinct, but they indicate a preceding period of significant Martian volcanism. Such volcanoes are called shield volcanoes, because they look like shields. The largest volcano on Mars is not one of the three shown previously. It is called Olympus Mons. Olympus Mons is 600 km across its base and about 25 km above the surrounding plain.

The Martian surface has some large canyon systems. The largest is Valles Marineris, which extends for about 5000 km, is 500 km wide in the widest portions, and as much as 6km deep.

There are channels on Mars as much as 1500 km long and 200 km wide that appear to have been cut by running water. Under present atmospheric conditions on Mars (low pressure), water cannot exist as a free liquid on the surface (it must be gas or solid). Thus, evidence for water erosion suggests that the Martian atmosphere may have been more dense in the past. The following two images show portions of the Martian surface where the erosion patterns have regions that are very similar to those found for erosion by surface water on the Earth.

The atmosphere of Mars is thin (about 1/200 of the pressure of the Earth’s atmosphere), but this atmosphere supports high velocity seasonal winds that are correlated with solar heating of the surface and that produce duststorms that lead to a lot of surface erosion.

<table>
<thead>
<tr>
<th>Name and pronunciation</th>
<th>Image</th>
<th>Diameter (km)</th>
<th>Mass (kg)</th>
<th>Semi-major axis (km)</th>
<th>Orbital period (h)</th>
<th>Average moonrise period (h, d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mars I Phobos /ˈfəʊbəs/</td>
<td><img src="image1.png" alt="Image" /></td>
<td>22.2 km (27×21.6×18.8)</td>
<td>1.08 $\times$ 10$^{16}$</td>
<td>9 377 km</td>
<td>7.66</td>
<td>11.12 h (0.463 d)</td>
</tr>
<tr>
<td>Mars II Deimos /ˈdeɪməs/</td>
<td><img src="image2.png" alt="Image" /></td>
<td>12.6 km (10×12×16)</td>
<td>2 $\times$ 10$^{15}$</td>
<td>23 460 km</td>
<td>30.35</td>
<td>131 h (5.44 d)</td>
</tr>
</tbody>
</table>
JOVIAN PLANETS

A gas giant (sometimes also known as a Jovian planet after the planet Jupiter, or giant planet) is a large planet that is not primarily composed of rock or other solid matter. There are four gas giants in our Solar System: Jupiter, Saturn, Uranus, and Neptune. Many extrasolar gas giants have been identified orbiting other stars.

JUPITER

Jupiter is the fifth planet from the Sun and the largest planet within the Solar System. It is a gas giant with a mass slightly less than one-thousandth that of the Sun but is two and a half times the mass of all of the other planets in our Solar System combined. Jupiter is classified as a gas giant along with Saturn, Uranus and Neptune. Together, these four planets are sometimes referred to as the Jovian planets.

Jupiter is primarily composed of hydrogen with a quarter of its mass being helium; it may also have a rocky core of heavier elements. Because of its rapid rotation, Jupiter’s shape is that of an oblate spheroid (it possesses a slight but noticeable bulge around the equator). The outer atmosphere is visibly segregated into several bands at different latitudes, resulting in turbulence and storms along their interacting boundaries. A prominent result is the Great Red Spot, a giant storm that is known to have existed since at least the 17th century when it was first seen by telescope. Surrounding the planet is a faint planetary ring system and a powerful magnetosphere. There are also at least 63 moons, including the four large moons called the Galilean moons that were first discovered by Galileo Galilei in 1610. Ganymede, the largest of these moons, has a diameter greater than that of the planet Mercury.

Jupiter is 2.5 times the mass of all the other planets in our Solar System.

Although Jupiter would need to be about 75 times as massive to fuse hydrogen and become a star, the smallest red dwarf is only about 30 percent larger in radius than Jupiter. In spite of this, Jupiter still radiates more heat than it receives from the Sun. The amount of heat produced inside the planet is nearly equal to the total solar radiation it receives. This additional heat radiation is generated by the Kelvin-Helmholtz mechanism through adiabatic contraction. This process results in the planet shrinking by about 2 cm each year. When it was first formed, Jupiter was much hotter and was about twice its current diameter.

Cloud Layers of Jupiter

Jupiter is perpetually covered with clouds composed of ammonia crystals and possibly ammonium hydrosulfide. The clouds are located in the tropopause and are arranged into bands of different latitudes, known as tropical regions. These are sub-divided into lighter-hued zones and darker belts. The interactions of these conflicting circulation patterns cause storms and turbulence. Wind speeds of 100 m/s (360 km/h) are common in zonal jets. The zones have been observed to vary in width, color and intensity from year to year, but they have remained sufficiently stable for astronomers to give them identifying designations. The orange and brown coloration in the clouds of Jupiter are caused by upwelling compounds that change color when they are exposed to ultraviolet light from the Sun.
Great Red Spot and Other Storms

The best known feature of Jupiter is the Great Red Spot, a persistent anticyclonic storm located 22° south of the equator that is larger than Earth. It is known to have been in existence since at least 1831.

Storms such as this are common within the turbulent atmospheres of gas giants. Jupiter also has white ovals and brown ovals, which are lesser unnamed storms. White ovals tend to consist of relatively cool clouds within the upper atmosphere. Brown ovals are warmer and located within the “normal cloud layer”. Such storms can last as little as a few hours or stretch on for centuries.

Rings of Jupiter

Jupiter has a faint planetary ring system composed of three main segments: an inner torus of particles known as the halo, a relatively bright main ring, and an outer gossamer ring. These rings appear to be made of dust, rather than ice as is the case for Saturn’s rings.

Flyby Missions and Mission of Galileo

The Pioneer missions obtained the first close-up images of Jupiter’s atmosphere and several of its moons.

Six years later, the Voyager missions vastly improved the understanding of the Galilean moons and discovered Jupiter’s rings. They also confirmed that the Great Red Spot was anticyclonic.

The next mission to encounter Jupiter, the Ulysses solar probe, performed a flyby maneuver in order to attain a polar orbit around the Sun. During this pass the spacecraft conducted studies on Jupiter’s magnetosphere. However, since Ulysses has no cameras, no images were taken. A second flyby six years later was at a much greater distance.

In 2000, the Cassini probe, en route to Saturn, flew by Jupiter and provided some of the highest-resolution images ever made of the planet. On December 19, 2000, the spacecraft captured an image of the moon Himalia, but the resolution was too low to show surface details.

The New Horizons probe, en route to Pluto, flew by Jupiter for gravity assist. Its closest approach was on February 28, 2007. The probe’s cameras measured plasma output from volcanoes on Io and studied all four Galilean moons in detail, as well as making long-distance observations of the outer moons Himalia and Elara.

So far the only spacecraft to orbit Jupiter is the Galileo orbiter, which went into orbit around Jupiter on December 7, 1995. It orbited the planet for over seven years, conducting multiple flybys of all of the Galilean moons and Amalthea. The spacecraft also witnessed the impact of Comet Shoemaker-Levy 9 as it approached Jupiter in 1994, giving a unique vantage point for the event. However, while the information gained about the Jovian system from Galileo was extensive, its originally designed capacity was limited by the failed deployment of its high-gain radio transmitting antenna.
Galilean Moons (Io, Europa, Ganymede, Callisto)

**Io**
Io is the innermost of the four Galilean moons of the planet Jupiter and, with a diameter of 3,642 kilometres (2,263 mi), the fourth-largest moon in the Solar System. With over 400 active volcanoes, Io is the most geologically active object in the Solar System. This extreme geologic activity is the result of tidal heating from friction generated within Io's interior as it is pulled between Jupiter and the other Galilean satellites—Europa, Ganymede and Callisto. Several volcanoes produce plumes of sulfur and sulfur dioxide that climb as high as 500 km (310 mi) above the surface. Io’s surface is also dotted with more than 100 mountains that have been uplifted by extensive compression at the base of the moon’s silicate crust. Some of these peaks are taller than Earth’s Mount Everest. Unlike most satellites in the outer Solar System, which are mostly composed of water ice, Io is primarily composed of silicate rock surrounding a molten iron or iron sulfide core. Most of Io’s surface is characterized by extensive plains coated with sulfur and sulfur dioxide frost.

**Europa**
Europa is the sixth moon of the planet Jupiter, and the smallest of its four Galilean satellites. Europa was discovered in 1610 by Galileo Galilei. Slightly smaller than Earth’s Moon, Europa is primarily made of silicate rock and probably has an iron core. Its surface is composed of ice and is one of the smoothest in the Solar System. This surface is striated by cracks and streaks, while craters are relatively infrequent. The apparent youth and smoothness of the surface have led to the hypothesis that a water ocean exists beneath it, which could conceivably serve as an abode for extraterrestrial life. This hypothesis proposes that heat energy from tidal flexing causes the ocean to remain liquid and drives geological activity similar to plate tectonics.

**Ganymede**
Ganymede is a satellite of Jupiter and the largest satellite in the Solar System. Ganymede’s discovery is credited to Galileo Galilei, who was the first to observe it on January 7, 1610. It is the seventh moon and third Galilean satellite outward from Jupiter. Ganymede is composed of approximately equal amounts of silicate rock and water ice. It is a fully differentiated body with an iron-rich, liquid core. A saltwater ocean is believed to exist nearly 200 km below Ganymede’s surface, sandwiched between layers of ice.

**Callisto**
It was discovered in 1610 by Galileo Galilei. It is the third-largest moon in the Solar System and the second largest in the Jovian system, after Ganymede. Callisto has about 99% the diameter of the planet Mercury but only about a third of its mass. The surface of Callisto is heavily cratered and extremely old. Callisto is surrounded by an extremely thin atmosphere composed of carbon dioxide and probably molecular oxygen.

**Impacts**
Jupiter has been called the Solar System’s vacuum cleaner, because of its immense gravity well and location near the inner Solar System. During the period July 16, 1994 to July 22, 1994, over 20 fragments from the comet Shoemaker-Levy 9 collided with Jupiter’s southern hemisphere, providing the first direct observation of a collision between two Solar System objects. This impact provided useful data on the composition of Jupiter’s atmosphere.
**SATURN**

**Saturn** is the sixth planet from the Sun and the second largest planet in the Solar System, after Jupiter. Saturn, along with Jupiter, Uranus and Neptune, is classified as a gas giant. Together, these four planets are sometimes referred to as the Jovian, meaning “Jupiter-like”, planets.

The planet Saturn is composed of hydrogen, with small proportions of helium and trace elements. The interior consists of a small core of rock and ice, surrounded by a thick layer of metallic hydrogen and a gaseous outer layer. The outer atmosphere is generally bland in appearance, although long-lived features can appear. Wind speeds on Saturn can reach 1,800 km/h, significantly faster than those on Jupiter.

Saturn has a prominent system of rings, consisting mostly of ice particles with a smaller amount of rocky debris and dust. Sixty-one known moons orbit the planet, not counting hundreds of “moonlets” within the rings. Titan, Saturn’s largest and the Solar System’s second largest moon (after Jupiter’s Ganymede), is larger than the planet Mercury and is the only moon in the Solar System to possess a significant atmosphere.

**Cloud Layers**

Saturn’s celestial body atmosphere exhibits a banded pattern similar to Jupiter’s (the nomenclature is the same), but Saturn’s bands are much fainter and are also much wider near the equator.

In 1990, the Hubble Space Telescope observed an enormous white cloud near Saturn’s equator which was not present during the Voyager encounters, and, in 1994, another smaller storm was observed. The 1990 storm was an example of a Great White Spot, a unique but short-lived phenomenon which occurs once every Saturnian year, or roughly every 30 Earth years, around the time of the northern hemisphere’s summer solstice. Previous Great White Spots were observed in 1876, 1903, 1933, and 1960, with the 1933 storm being the most famous. If the periodicity is maintained, another storm will occur in about 2020.
Rings of Saturn

Saturn is probably best known for its system of planetary rings, which makes it the most visually remarkable object in the solar system.

The rings of Saturn have puzzled astronomers since Galileo Galilei discovered them with his telescope in 1610. Detailed study by the Voyager 1 and Voyager 2 spacecraft in the 1980s only increased the mystery.

There are thousands of rings made of up billions of particles of ice and rock. The particles range in size from a grain of sugar to the size of a house. The rings are believed to be pieces of comets, asteroids or shattered moons that broke up before they reached the planet.

Named alphabetically in the order they were discovered, the rings are relatively close to each other, with the exception of the Cassini Division.

The main rings are, working outward from the planet, known as C, B, and A. The Cassini Division is the largest gap in the rings and separates Rings B and A. In addition a number of fainter rings have been discovered more recently. The D Ring is exceedingly faint and closest to the planet. The F Ring is a narrow feature just outside the A Ring. Beyond that are two far fainter rings named G and E.

Satellites of Saturn

The moons of Saturn are numerous and diverse, ranging from tiny moonlets to the enormous Titan. Saturn has 61 moons with confirmed orbits, 53 of which have names, and most of which are quite small.

There are also hundreds of known moonlets embedded within Saturn’s rings. With seven moons that are large enough to have sufficient gravitational attraction to become spherical in shape.

Particularly notable are Titan, the second largest moon in the Solar System, with an earth-like atmosphere and a landscape including hydrocarbon lakes and river networks, and Enceladus, which may harbor liquid water under its south pole.
Saturn’s major satellites, compared with Earth’s Moon.

<table>
<thead>
<tr>
<th>Name</th>
<th>Diameter (km)</th>
<th>Mass (kg)</th>
<th>Orbital radius (km)</th>
<th>Orbital period (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mimas</strong></td>
<td>400 (10% Moon)</td>
<td>0.4×10^20</td>
<td>185,000</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Enceladus</strong></td>
<td>500 (15% Moon)</td>
<td>1.1×10^20</td>
<td>238,000</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Tethys</strong></td>
<td>1,060 (30% Moon)</td>
<td>6.2×10^20</td>
<td>295,000</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Dione</strong></td>
<td>1,120 (30% Moon)</td>
<td>11×10^20</td>
<td>377,000</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>Rhea</strong></td>
<td>1,530 (45% Moon)</td>
<td>23×10^20</td>
<td>527,000</td>
<td>4.5</td>
</tr>
<tr>
<td><strong>Titan</strong></td>
<td>5,150 (150% Moon)</td>
<td>1,350×10^20</td>
<td>1,222,000</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(180% Mars)</td>
<td></td>
</tr>
<tr>
<td><strong>Iapetus</strong></td>
<td>1,440 (40% Moon)</td>
<td>2×10^20</td>
<td>3,560,000</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(3% Moon)</td>
<td></td>
</tr>
</tbody>
</table>

**Observations by spacecraft**

Saturn was first visited by **Pioneer 11** in September 1979. It flew within 20,000 km of the planet’s cloud tops. Low resolution images were acquired of the planet and a few of its moons; the resolution of the images was not good enough to discern surface features.

In November 1980, the **Voyager 1** probe visited the Saturn system. It sent back the first high-resolution images of the planet, rings, and satellites.

Almost a year later, in August 1981, **Voyager 2** continued the study of the Saturn system. More close-up images of Saturn’s moons were acquired, as well as evidence of changes in the atmosphere and the rings. Unfortunately, during the flyby, the probe’s turnable camera platform stuck for a couple of days, and some planned imaging was lost.

On July 1, 2004, the **Cassini-Huygens** spacecraft performed the SOI (Saturn Orbit Insertion) maneuver and entered into orbit around Saturn. Cassini’s flyby of Saturn’s largest moon, Titan, has captured radar images of large lakes and their coastlines with numerous islands and mountains. The orbiter completed two Titan flybys before releasing the **Huygens probe** on December 25, 2004. Huygens descended onto the surface of Titan on January 14, 2005, sending a flood of data during the atmospheric descent and after the landing. During 2005, Cassini conducted multiple flybys of Titan and icy satellites. Cassini’s last Titan flyby commenced on March 23, 2008.
**Seasons on Saturn**

Since Saturn’s axis is tilted as it orbits the Sun, Saturn has seasons, like those of planet Earth but Saturn’s seasons last for over seven years. The Hubble Space Telescope took the above sequence of images about a year apart, starting on the left in 1996 and ending on the right in 2000.

**URANUS**

Uranus is the 3rd of the Gas Giant planets, and the first planet discovered in “modern” times (1781). It is the first planet which was discovered by using a telescope. It was found accidentally by William Herschel while he was searching the sky with a telescope in 1781. It had actually been seen many times before but dismissed as a star. It is barely visible from the Earth without a telescope, which explains why it was not known as a planet to the ancients, and why it had been observed various times after the telescope had been invented without the observers realizing that it was a planet and not a star. Documented sitings go back to at least 1690 when Flamsteed catalogued it as a star.

The blue color is because of methane gas in the atmosphere, which absorbs red and orange light strongly, leaving more blue light to be scattered to the observer. The clouds are thought to be mostly methane ice, with a temperature at the cloud tops of about -221 degrees Celsius.

Voyager 2 confirmed the suspicion that Uranus had a magnetic field. The field is about 50 times stronger than that of the Earth and is tilted about 60 degrees with respect to the rotation axis.

**RINGS OF URANUS**

The rings of Uranus (and some of its moons) are shown in the adjacent Hubble Space Telescope image. The rings were discovered from the Earth in 1977 when Uranus occulted (passed in front of) a star and it was noticed that there were dips in the brightness of the star before and after it passed behind the body of Uranus.

This data suggested that Uranus was surrounded by at least 5 rings. Four more rings were suggested by subsequent occultation measurements from the Earth, and 2 additional ones were found by Voyager 2, bringing the total to 11 (the adjacent image shows only some of the brighter rings.

Most of the rings are not quite circular, and most are not exactly in the plane of the equator.

The rings are very narrow (some only a few kilometers across) and no material can be detected in the regions between the rings. It is speculated that this stability of the narrow rings may be due to small “shepherding satellites”, as discussed in conjunction with Saturn’s rings.
Voyager 2 found two small shepherd moons for it, one just inside and one just outside. They appear to be about 20-30 km in diameter, and have been named Ophelia and Cordelia.

**SATELLITES OF URANUS**

5 largest satellites of Uranus are Miranda, Ariel, Umbriel, Titania, and Oberon. The most interesting moon geologically is Miranda. Even though it is only 500 km in diameter, it shows surface geological features that are as varied as any site in the Solar System.

It is not clear why Miranda has been so active geologically. Some theories invoke tidal heating effects earlier in its history, or a collision that tore it apart and allowed it to coalesce again. None are very conclusive.

**DAY – NIGHT AND SEASONS ON URANUS**

As a planet orbits the sun, if its rotation axis is tilted, the portion that is tilted toward the sun will receive an excess of sunlight and energy (summer), while the hemisphere which is tilted away from the sun will be deprived of sunlight and energy (winter). Half a year later, the hemisphere which receives the most sun will be reversed. The fact that there may be an excess or a deficit of light and energy affects planetary meteorology.

Because Uranus lies on its side, with the north pole facing the sun, Uranus’ seasons should be very strange. The north pole faces the sun, which means it is in daylight, and the atmosphere in that hemisphere never rotates to the nightside to cool. The south pole faces away from the sun, and the atmosphere in that hemisphere never rotates to the day. As Uranus orbits the sun, the north pole will be in daylight for half of a year (spring and summer). This means a Uranus day is the same as a Uranus summer. The meteorology of such a planet should be very strange.

**NEPTUNE**

Neptune is the eighth planet from the Sun in our Solar System. Named for the Roman god of the sea, it is the fourth-largest planet by diameter and the third-largest by mass. Neptune is 17 times the mass of Earth and is slightly more massive than its near-twin Uranus. Neptune has been visited by only one spacecraft, **Voyager 2**, which flew by the planet on August 25, 1989.

The bluish color of the adjacent image is, as for Uranus, because of methane in the atmosphere, which absorbs red light, leaving the light scattered from Neptune preferentially enhanced at blue wavelengths. The period of rotation is about 16 hours, comparable to that of Uranus and much slower than for Jupiter and Saturn. The temperatures at the cloud tops are about -216 degrees Celsius, slightly warmer than for Uranus. Neptune, like Jupiter and Saturn but unlike Uranus, has an internal heat source and produces 2.7 times more heat than it absorbs.

**Discovery of Neptune**

Discovered on September 23, 1846, Neptune was the first planet found by mathematical prediction rather than by empirical observation. Unexpected changes in the orbit of Uranus led Alexis Bouvard to deduce that its orbit was subject to gravitational perturbation by an unknown planet.
Neptune was subsequently observed by Johann Galle within a degree of the position predicted by Urbain Le Verrier, and its largest moon, Triton, was discovered shortly thereafter, though none of the planet’s remaining 12 moons were located telescopically until the 20th century. Galileo’s drawings show that he first observed Neptune on December 28, 1612, and again on January 27, 1613. On both occasions, Galileo mistook Neptune for a fixed star when it appeared very close to Jupiter in the night sky, hence, he is not credited with Neptune’s discovery.

In 1821, Alexis Bouvard published astronomical tables of the orbit of Neptune’s neighbor Uranus. Subsequent observations revealed substantial deviations from the tables, leading Bouvard to hypothesize that an unknown body was perturbing the orbit through gravitational interaction. In 1843, John Couch Adams calculated the orbit of a hypothesized eighth planet that would account for Uranus’s motion. He sent his calculations to Sir George Airy, the Astronomer Royal, who asked Adams for a clarification. Adams began to draft a reply but never sent it and did not aggressively pursue work on the Uranus problem. In 1845–46, Urbain Le Verrier, independently of Adams, developed his own calculations but also experienced difficulties in stimulating any enthusiasm in his compatriots. In June, however, upon seeing Le Verrier’s first published estimate of the planet’s longitude and its similarity to Adams’s estimate, Airy persuaded Cambridge Observatory director James Challis to search for the planet. Challis vainly scoured the sky throughout August and September. Meantime, Le Verrier by letter urged Berlin Observatory astronomer Johann Gottfried Galle to search with the observatory’s refractor. Heinrich d’Arrest, a student at the observatory, suggested to Galle that they could compare a recently drawn chart of the sky in the region of Le Verrier’s predicted location with the current sky to seek the displacement characteristic of a planet, as opposed to a fixed star. The very evening of the day of receipt of Le Verrier’s letter on September 23, 1846, Neptune was discovered within 1° of where Le Verrier had predicted it to be, and about 12° from Adams’ prediction. Challis later realized that he had observed the planet twice in August, failing to identify it owing to his casual approach to the work.

In the wake of the discovery, there was much nationalistic rivalry between the French and the British over who had priority and deserved credit for the discovery. Eventually an international consensus emerged that both Le Verrier and Adams jointly deserved credit. However, the issue is being re-evaluated by historians with the rediscovery in 1998 of the “Neptune papers” (historical documents from the Royal Observatory, Greenwich), which had apparently been stolen by astronomer Olin J. Eggen and hoarded for nearly three decades, not to be rediscovered (in his possession) until immediately after his death. After reviewing the documents, some historians suggest that Adams does not deserve equal credit with Le Verrier. Since 1966 Dennis Rawlins has questioned the credibility of Adams’s claim to co-discovery. In a 1992 article in his journal Dio he deemed the British claim “theft”. “Adams had done some calculations but he was rather unsure about quite where he was saying Neptune was,” said Nicholas Kollerstrom of University College London in 2003.
Composition of Neptune

The planet’s surface gravity is only surpassed by Jupiter, making the two gas giants the only planets in the solar system with a surface gravity higher than the Earth. Neptune and Uranus are often considered a subclass of gas giant termed “ice giants”, due to their smaller size and higher concentrations of volatiles relative to Jupiter and Saturn.

At high altitudes, Neptune’s atmosphere is 80% hydrogen and 19% helium. The mantle is equivalent to 10 to 15 Earth masses and is rich in water, ammonia and methane. As is customary in planetary science, this mixture is referred to as icy even though it is a hot, highly dense fluid. This fluid, which has a high electrical conductivity, is sometimes called a water-ammonia ocean. At a depth of 7000 km, the conditions may be such that methane decomposes into diamond crystals that then precipitate toward the core.

1. Upper atmosphere, top clouds.
3. Mantle consisting of water, ammonia, and methane ices.
4. Core consisting of rock and ice.

Rings of Neptune

Neptune has a planetary ring system, though one much less substantial than that of Saturn. The rings may consist of ice particles coated with silicates or carbon-based material.

Great Dark Spot of Neptune

One difference between Neptune and Uranus is the typical level of meteorological activity. Neptune’s weather is characterized by extremely dynamic storm systems, with winds reaching speeds of almost 600 m/s—nearly attaining supersonic flow.

In 1989, the Great Dark Spot, an anti-cyclonic storm system spanning 13000×6600 km, was discovered by NASA’s Voyager 2 spacecraft. The storm resembled the Great Red Spot of Jupiter. Some five years later, however, on November 2, 1994, the Hubble Space Telescope did not see the Great Dark Spot on the planet. Instead, a new storm similar to the Great Dark Spot was found in the planet’s northern hemisphere.

The Scooter is another storm, a white cloud group farther south than the Great Dark Spot. Its nickname is due to the fact that when first detected in the months before the 1989 Voyager 2 encounter it moved faster than the Great Dark Spot. Subsequent images revealed even faster clouds. The Small Dark Spot is a southern cyclonic storm, the second-most-intense storm observed during the 1989 encounter. It initially was completely dark, but as Voyager 2 approached the planet, a bright core developed and can be seen in most of the highest-resolution images.
The Moons of Neptune

Neptune has two large moons that are easily seen from Earth, Triton and Nereid. Voyager 2 discovered six additional moons. One of these is actually larger than Nereid, but could not be seen easily from Earth because it orbits close to Neptune. Triton is comparable in size with our own moon, and has a thin atmosphere, mostly of nitrogen. Voyager 2 found some of the most varied terrain in the Solar System, a thin atmosphere, and even evidence for ice volcanoes on Triton.

The six newly-discovered moons orbit with direct motion nearly in the equatorial plane. Most are closer to Neptune than its rings. Because this lies inside the Roche limit, these moons could not have formed by accretion in their present location. They must have formed elsewhere before coming to their present orbits, though we are not certain where.

PLUTO, DWARF PLANETS, ASTEROIDES AND ASTEROIDE BELTS IN THE SOLAR SYSTEM

DWARF PLANETS

A dwarf planet, as defined by the International Astronomical Union (IAU), is a celestial body orbiting the Sun that is massive enough to be rounded by its own gravity but has not cleared its neighbouring region of planetesimals and is not a satellite. More explicitly, it has to have sufficient mass to overcome its compressive strength and achieve hydrostatic equilibrium. It should not be confused with a minor planet.

The term dwarf planet was adopted in 2006 as part of a three-way categorization of bodies orbiting the Sun, brought about by an increase in discoveries of trans-Neptunian objects that rivaled Pluto in size, and finally precipitated by the discovery of an even larger object, Eris. This classification states that bodies large enough to have cleared the neighbourhood of their orbit are defined as planets, while those that are not massive enough to be rounded by their own gravity are defined as small solar system bodies. Dwarf planets come in between. The definition officially adopted by the IAU in 2006 has been both praised and criticized, and has been disputed by scientists such as Alan Stern.

The IAU currently recognizes five dwarf planets—Ceres, Pluto, Haumea, Makemake, and Eris. However, only two of these bodies, Ceres and Pluto, have been observed in enough detail to demonstrate that they fit the definition. Eris has been accepted as a dwarf planet because it is more massive than Pluto.

ASTEROID BELTS IN THE SOLAR SYSTEM

The asteroid belt is the region of the Solar System located roughly between the orbits of the planets Mars and Jupiter. It is occupied by numerous irregularly shaped bodies called asteroids or minor planets. The asteroid belt region is also termed the main belt to distinguish it from other concentrations of minor planets within the Solar System, such as the Kuiper belt and scattered disc.
There are 3 asteroid belts in the solar system:

1) **Apollo Asteroids:** The Apollo asteroids are a group of near-Earth asteroids named after 1862 Apollo, the first asteroid of this group to be discovered by Karl Wilhelm Reinmuth. They are Earth-crosser asteroids. The largest known Apollo asteroid is **1866 Sisyphus**, with a diameter of about 10 km. This is the most dangerous belt for Earth.

2) **Trojan Asteroids:** The term Trojan asteroid usually refers specifically to Jupiter trojans, which are thought to be as numerous as the asteroids of the main belt. In astronomy, the adjective trojan refers to a minor planet or natural satellite (moon) that shares an orbit with a larger planet or moon. This belt is between Mars and Jupiter. In the year 2000 there were only 237 Trojan asteroids known, by 2003 there were 1,600 and by 2009 there were 2,909. **624 Hektor** is the largest Trojan Asteroid. Its radius is 102 km.

3) **Kuiper Belt:** Kuiper belt is a region of the Solar System beyond the planets extending from the orbit of Neptune (at 30 AU) to approximately 55 AU from the Sun. It is similar to the asteroid belt, although it is far larger—20 times as wide and 20–200 times as massive. Like the asteroid belt, it consists mainly of small bodies, or remnants from the Solar System’s formation. While the asteroid belt is composed primarily of rock and metal, the Kuiper belt objects are composed largely of frozen volatiles (termed “ices”), such as methane, ammonia and water. It is home to at least three dwarf planets — **Pluto, Haumea and Makemake**.

It is suspected that at least another 40 known objects in the Solar System are dwarf planets, and estimates are that up to 200 dwarf planets may be found when the entire region known as the Kuiper belt is explored, and that the number might be as high as 2,000 when objects scattered outside the Kuiper belt are considered.

**OORT CLOUD**

Oort Cloud is a hypothesized spherical cloud of comets which may lie roughly 50,000 AU, or nearly a light-year, from the Sun. This places the cloud at nearly a quarter of the distance to Proxima Centauri, the nearest extrasolar star. The Kuiper belt and scattered disc, the other two known reservoirs of trans-Neptunian objects, are less than one thousandth the Oort cloud’s distance. The outer extent of the Oort cloud defines the gravitational boundary of our Solar System.

Oort cloud are largely composed of ices, such as water, ammonia, and methane.

**COMETS**

A comet is a small solar system body bigger than a meteoroid that, when close enough to the Sun, exhibits a visible coma and sometimes a tail, both because of the effects of solar radiation upon the comet’s nucleus. These comet nuclei are loose collections of ice, dust and small rocky particles, ranging from a few hundred metres to tens of kilometres across.
Orbits and Origin of Comets

Comets have a variety of different orbital periods, ranging from a few years, to hundreds of thousands of years, while some are believed to pass only once through the inner Solar System before being thrown out into interstellar space. Short-period comets are thought to originate in the Kuiper Belt, or associated scattered disc, which lie beyond the orbit of Neptune. Long-period comets come from much farther reaches of space, and so a cloud of ice, consisting of debris left over from the condensation of the solar nebula, has been hypothesized as the source of such comets. This cloud, termed the Oort cloud after astronomer Jan Oort, would be located well beyond the Kuiper Belt.

Parts Of Comets

1) **Nucleus**: Comet nuclei are known to range from about 100 metres to more than 40 kilometres across. They are composed of rock, dust, water ice, and frozen gases such as carbon monoxide, carbon dioxide, methane and ammonia. Because of their low mass, comet nuclei do not become spherical under their own gravity, and thus have irregular shapes.

2) **Coma**: As a comet approaches the inner solar system, solar radiation causes the volatile materials within the comet to vaporize and stream out of the nucleus, carrying dust away with them. The streams of dust and gas thus released form a huge, extremely tenuous atmosphere around the comet called the coma.

3) **Tails**: The force exerted on the coma by the Sun’s radiation pressure and solar wind cause an enormous tail to form, which points away from the sun. A comet has two kinds of tails. One of them is composed of dust (yellow tail), and the other one is composed of gas (blue tail). Dust tail reflects the sun light better than gas tail. Both the coma and tail are illuminated by the Sun and may become visible from Earth when a comet passes through the inner solar system, the dust reflecting sunlight directly and the gases glowing from ionisation. The dust tail is effected by the gravitational force of the Sun more than the gas tail and curves through the Sun. Both tails lays through the opposite of the Sun because of the solar winds.

**METEOR SHOWER**

A meteor shower is a celestial event in which a number of meteors are observed to radiate from one point in the night sky. These meteors are caused by streams of cosmic debris called meteoroids entering Earth’s atmosphere at extremely high speeds on parallel trajectories. Most meteors are smaller than a grain of sand, so almost all of them disintegrate and never hit the Earth’s surface. Fragments that do survive impact with Earth’s surface are called meteorites. A meteor shower is the result of an interaction between a planet, such as Earth, and streams of debris from a comet. Each time a comet swings by the Sun in its orbit, some of its ice vaporizes and a certain amount of meteoroids will be shed.

Because meteor shower particles are all traveling in parallel paths, and at the same velocity, they will all appear to an observer below to radiate away from a single point in the sky. Meteor showers are almost always named after the constellation from which the meteors appear to originate.
<table>
<thead>
<tr>
<th>Shower</th>
<th>Time</th>
<th>Parent object</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quadrantids</strong></td>
<td>Early January</td>
<td>The same as the parent object of minor planet 2003 EH, and perhaps comets C/1490 Y1 and C/1385 U1</td>
</tr>
<tr>
<td><strong>Lyrics</strong></td>
<td>late April</td>
<td>Comet Thatcher</td>
</tr>
<tr>
<td><strong>Pi Puppids</strong></td>
<td>late April</td>
<td>Comet 26P/Grigg-Skjellerup</td>
</tr>
<tr>
<td><strong>Eta Aquariids</strong></td>
<td>early May</td>
<td>Comet 1P/Halley</td>
</tr>
<tr>
<td><strong>Arietids</strong></td>
<td>mid June</td>
<td>Comet 96P/Machholz, Marsden and Kracht comet groups complex</td>
</tr>
<tr>
<td><strong>June Bootids</strong></td>
<td>late June</td>
<td>Comet 7P/Pons-Winnecke</td>
</tr>
<tr>
<td><strong>Southern Delta Aquariids</strong></td>
<td>late July</td>
<td>Comet 96P/Machholz, Marsden and Kracht comet groups complex</td>
</tr>
<tr>
<td><strong>Perseids</strong></td>
<td>mid-August</td>
<td>Comet 109P/Swift-Tuttle</td>
</tr>
<tr>
<td><strong>Giacobinids</strong></td>
<td>early October</td>
<td>Comet 21P/Giacobini-Zinner</td>
</tr>
<tr>
<td><strong>Orionids</strong></td>
<td>late October</td>
<td>Comet 1P/Halley</td>
</tr>
<tr>
<td><strong>Southern Taurids</strong></td>
<td>early November</td>
<td>Comet 2P/Encke</td>
</tr>
<tr>
<td><strong>Northern Taurids</strong></td>
<td>mid-November</td>
<td>Minor planet 2004 TG and others</td>
</tr>
<tr>
<td><strong>Leonids</strong></td>
<td>mid-November</td>
<td>Comet 55P/Tempel-Tuttle</td>
</tr>
<tr>
<td><strong>Geminids</strong></td>
<td>mid-December</td>
<td>Minor planet 3200 Phaethon</td>
</tr>
<tr>
<td><strong>Ursids</strong></td>
<td>late December</td>
<td>Comet 8P/Tuttle</td>
</tr>
</tbody>
</table>
Any other solar system body with a reasonably transparent atmosphere can also have meteor showers. For instance, Mars is known to have meteor showers, although these are different from the ones seen on Earth because the different orbits of Mars and Earth intersect orbits of comets in different ways. Although the Martian atmosphere has less than one percent of the density of Earth's at ground level, at their upper edges, where meteoroids strike, the two are more similar. Because of the similar air pressure at altitudes for meteors, the effects are much the same. Only the relatively slower motion of the meteoroids due to increased distance from the sun should marginally decrease meteor brightness.

A meteoroid is a sand- to boulder-sized particle of debris in the Solar System. The visible path of a meteoroid that enters Earth’s (or another body’s) atmosphere is called a meteor, or colloquially a shooting star or falling star. If a meteor reaches the ground and survives impact, then it is called a meteorite.

The current official definition of a meteoroid from the International Astronomical Union is “a solid object moving in interplanetary space, of a size considerably smaller than an asteroid and considerably larger than an atom.

**THE SUN**

**The Sun as a star**

It is the star at the center of the solar system. About three-quarters of the Sun’s mass consists of hydrogen, while most of the rest is helium. Less than 2% consists of other elements, including iron, oxygen, carbon, neon, and others.

**Its stellar classification, based on spectral class, is G2V,** and is informally designated a yellow star, because the majority of its radiation is in the yellow-green portion of the visible spectrum. In this spectral class label, G2 indicates its surface temperature of approximately 5,778 K (5,505 °C), and V (Roman five) indicates that the Sun, like most stars, is a main sequence star, and thus generates its energy by nuclear fusion of hydrogen nuclei into helium.

The Sun is a Population I, or heavy element-rich, star.

**The Parts of the Sun**

1) **Core** : In this part the temperatures and pressures are so great that nuclear fusion reactions can take place. It’s the hottest part of the Sun with a temperature of close to 15 million kelvins. 3.6 x 10^{28} protons are converted into helium nuclei every second. This releases 3.8 x 10^{26} watts of energy every second.

2) **Radiative Zone** : Surrounding the core is the Sun’s radiative zone. This part of the Sun is hot and dense enough that energy from the core can radiate outward. Ions of hydrogen and helium emit photons. These photons travel a short distance and then are absorbed by another ion nearby. Photons make a slow journey up through the radiative zone in this way. Astronomers believe that a single photon might take 100,000 years to journey through the radiative zone.
3) **Convection Zone**: In this outer part of the Sun, the solar plasma isn’t hot and dense enough to transfer energy through radiation. Instead it uses a process called convection, similar to a lava lamp, where thermal columns carry heat from the edge of the radiative zone up through the convective zone to the surface of the Sun. The plasma in the thermal columns release their heat and then sink back down through the convective zone to heat up again.

4) **Photosphere**: The part of the Sun that we can see is called the photosphere. This is the point where photons generated at the core of the Sun can finally reach space. Below the photosphere and the Sun is opaque to visible light. And above the photosphere, becomes the Sun’s atmosphere. This is also the region where we see sunspots, and where solar flares and coronal mass ejections are generated.

5) **Chromosphere**: The chromosphere (literally, “color sphere”) is a thin layer of the Sun’s atmosphere just above the photosphere, roughly 2,000 kilometres deep. The chromosphere is more visually transparent than the photosphere. The name comes from the fact that it has a reddish color, as the visual spectrum of the chromosphere is dominated by the deep red H-alpha spectral line of hydrogen. The most common solar feature within the chromosphere are spicules, long thin fingers of luminous gas which appear like the blades of a huge field of fiery grass growing upwards from the photosphere below. Finally, solar prominences rise up through the chromosphere from the photosphere, sometimes reaching altitudes of 150,000 kilometers. These gigantic plumes of gas are the most spectacular of solar phenomena, aside from the less frequent solar flares.

6) **Corona**: A corona is a type of plasma “atmosphere” of the Sun or other celestial body, extending millions of kilometers into space, most easily seen during a total solar eclipse, but also observable in a coronagraph. The sun’s corona is much hotter (by a factor of nearly 200) than the visible surface of the Sun: the photosphere’s average temperature is 5800 kelvins compared to the corona’s one to three million kelvins. The corona is 10^{-12} times as dense as the photosphere. The outer edges of the Sun’s corona are constantly being transported away due to open magnetic flux generating the solar wind.

**SUN SPOTS**

Sunspots are temporary phenomena on the surface of the Sun (the photosphere) that appear visibly as dark spots compared to surrounding regions. They are caused by intense magnetic activity, which inhibits convection, forming areas of reduced surface temperature.

The manifestation of intense magnetic activity, sunspots host secondary phenomena such as coronal loops and reconnection events. Most solar flares and coronal mass ejections originate in magnetically active regions around visible sunspot groupings. Similar phenomena indirectly observed on stars are commonly called starspots and both light and dark spots have been measured.

Sunspot populations quickly rise and more slowly fall on an irregular cycle of 11 years. Significant variations of the 11-year period are known over longer spans of time.
Sunspots are observed with land-based and Earth-orbiting solar telescopes. These telescopes use filtration and projection techniques for direct observation, in addition to various types of filtered cameras. Specialized tools such as spectroscopes and spectrohelioscopes are used to examine sunspots and sunspot areas. Turkish Astronomers of Istanbul University observe sun spots at the Astronomy Department Observatory in Beyazıt, Istanbul.

Butterfly Diagram: Throughout the solar cycle, the latitude of sunspot occurrence varies with an interesting pattern. Sunspots are typically confined to an equatorial belt between -35 degrees south and +35 degrees north latitude. At the beginning of a new solar cycle, sunspots tend to form at high latitudes, but as the cycle reaches a maximum (large numbers of sunspots) the spots form at lower latitudes. Near the minimum of the cycle, sunspots appear even closer to the equator, and as a new cycle starts again, sunspots again appear at high latitudes. This recurrent behavior of sunspots gives rise to the “butterfly” pattern shown, and was first discovered by Edward Maunder in 1904. The reason for this sunspot migration pattern is unknown.

SOHO

The Solar and Heliospheric Observatory (SOHO) is a spacecraft that was launched on a Lockheed Martin Atlas IIAS launch vehicle on December 2, 1995 to study the Sun, and began normal operations in May 1996. It is a joint project of international cooperation between the European Space Agency (ESA) and NASA. Originally planned as a two-year mission, SOHO currently continues to operate after over ten years in space. In October 2009, a mission extension lasting until December 2012 was approved.

In addition to its scientific mission, it is currently the main source of near-real time solar data for space weather prediction.

THE EVOLUTION OF THE SUN

- A cloud of gas and dust begins to contract under the force of gravity.
- The protosun collapsed. As it did, its temperature rose to about 150,000 degrees and the sun appeared very red. Its radius was about 50 present solar radii.
- When the central temperature reaches 10 million degrees, nuclear burning of hydrogen into helium commences.
- The star settles into a stable existence on the Main Sequence, generating energy via hydrogen burning. This is the longest single stage in the evolutionary history of a star, typically lasting 90% of its lifetime. Thermonuclear fusion within the Sun is a stable process, controlled by its internal structure.
• The hydrogen in the core is completed burned into helium nuclei. Initially, the temperature in the core is not hot enough to ignite helium burning. With no additional fuel in the core, fusion dies out. The core cannot support itself and contracts; as it shrinks, it heats up. The rising temperature in the core heats up a thin shell around the core until the temperature reaches the point where hydrogen burning ignites in this shell around the core. With the additional energy generation in the H-burning shell, the outer layers of the star expand but their temperature decreases as they get further away from the center of energy generation. This large but cool star is now a red giant, with a surface temperature of 3500 degrees and a radius of about 100 solar radii.

• The helium core contracts until its temperature reaches about 100 million degrees. At this point, helium burning ignites, as helium is converted into carbon (C) and oxygen (O). However, the core cannot expand as much as required to compensate for the increased energy generation caused by the helium burning. Because the expansion does not compensate, the temperature stays very high, and the helium burning proceeds furiously. With no safety valve, the helium fusion is uncontrolled and a large amount of energy is suddenly produced. This helium flash occurs within a few hours after helium fusion begins.

• The core explodes, the core temperature falls and the core contracts again, thereby heating up. When the helium burns now, however, the reactions are more controlled because the explosion has lowered the density enough. Helium nuclei fuse to form carbon, oxygen, etc.

• The star wanders around the red giant region, developing its distinct layers, eventually forming a carbon-oxygen core.

• When the helium in the core is entirely converted into C, O, etc., the core again contracts, and thus heats up again. In a star like the Sun, its temperature never reaches the 600 million degrees required for carbon burning. Instead, the outer layers of the star eventually become so cool that nuclei capture electrons to form neutral atoms (rather than nuclei and free electrons). When atoms are forming by capturing photons in this way, they cause photons to be emitted; these photons then are readily available for absorption by neighboring atoms and eventually this causes the outer layers of the star to heat up. When they heat up, the outer layers expand further and cool, forming more atoms, and releasing more photons, leading to more expansion. In other words, this process feeds itself.

• The outer envelope of the star blows off into space, exposing the hot, compressed remnant core. This is a planetary nebula.

• The core contacts but carbon burning never ignites in a one solar mass star. Contraction is halted when the electrons become degenerate, that is when they can no longer be compressed further. The core remnant as a surface temperature of a hot 10,000 degrees and is now a white dwarf.

• With neither nuclear fusion nor further gravitational collapse possible, energy generation ceases. The star steadily radiates is energy, cools and eventually fades from view, becoming a black dwarf.
THE DISTANCES OF STARS

There are two important problems in Astronomy. One of them is calculating the mass of stars, and the other one is calculating the distances of them. You will learn 2 main and 2 sub methods to calculate the distances of stars.

Calculating The Distance of a Star

- PARALLAX METHOD
- POGSON’S FORMULA
- USING CEPHEIDS
- USING NOVA S

I. PARALLAX METHOD

Parallax is an apparent displacement or difference in the apparent position of an object viewed along two different lines of sight, and is measured by the angle.

Astronomers use the principle of parallax to measure distances to objects (typically stars) beyond the Solar System.

On an interstellar scale, parallax created by the different orbital positions of the Earth causes nearby stars to appear to move relative to more distant stars. By observing parallax, measuring angles and using geometry, one can determine the distance to various objects. When the object in question is a star, the effect is known as stellar parallax.

Assuming the angle is small, the distance to an object (measured in parsecs) is the reciprocal of the parallax (measured in arcseconds):

\[
\text{Distance} = \frac{1}{\text{Parallax}}
\]

\[
d(\text{parsec}) = \frac{1}{p''}
\]
EXAMPLE: The parallax of Proxima Centauri is 0.7687". Find the distance of the star in:
   a) parsec:
   b) A.U:
   c) km:

HOMEWORK:

1) The parallax of Barnard’s star is 10.3". Find the distance of the star in pc, A.U and km. ( 0.98 pc, 20025.7 A.U, 3\times 10^{12} \text{km} )

2) The parallax of 61 Cygni is 0.3136". Find the distance of the star in light years. ( 1 pc = 3.261556 \text{ly} ) ( 10.4 \text{ly} )

3) Can we use the parallax method to find the distance of stars which are very far from us? Why or why not?

BRIGHTNESS (MAGNITUDES) OF STARS

1) Visible Brightness: (Apparent Magnitude) The apparent magnitude ($m$) of a celestial body is a measure of its brightness as seen by an observer on Earth, normalized to the value it would have in the absence of the atmosphere. The brighter the object appears, the lower the value of its magnitude.

The brightest stars were said to be of first magnitude ($m = 1$), while the faintest were of sixth magnitude ($m = 6$), the limit of human visual perception (without the aid of a telescope).

This somewhat crude method of indicating the brightness of stars was popularized by Ptolemy in his Almagest, and is generally believed to have originated with Hipparchus. This original system did not measure the magnitude of the Sun.

In 1856, Norman Robert Pogson formalized the system by defining a typical first magnitude star as a star that is 100 times as bright as a typical sixth magnitude star; thus, a first magnitude star is about 2,512 times as bright as a second magnitude star.

<table>
<thead>
<tr>
<th>App. Mag. (V)</th>
<th>Celestial object</th>
</tr>
</thead>
<tbody>
<tr>
<td>−29.30</td>
<td>Sun as seen from Mercury at perihelion</td>
</tr>
<tr>
<td>−26.73</td>
<td>Sun (449,000 times brighter than full moon)</td>
</tr>
<tr>
<td>−19.3</td>
<td>Sun as seen from Neptune</td>
</tr>
</tbody>
</table>
As you can see from the table the visible brightness of the object is effected by the distance between the object and the observer.

2) Absolute Visual Brightness : ( Absolute Magnitude ) In astronomy, absolute magnitude ( M ) measures a celestial object’s intrinsic brightness. To derive absolute magnitude from the observed apparent magnitude of a celestial object its value is corrected from distance to its observer. The absolute magnitude then equals the apparent magnitude an object would have if it were at a standard luminosity distance (10 parsecs, or 1 AU, depending on object type) away from the observer, in the absence of astronomical extinction. It allows the true brightness of objects to be compared without regard to distance.

Many stars visible to the naked eye have an absolute magnitude which would be capable of casting shadows if they were to lie at 10 parsecs from the Earth: Rigel (~7.0), Deneb (~7.2), Naos (~6.0), and Betelgeuse (~5.6). For comparison, Sirius has an absolute magnitude of 1.4 which is greater than the Sun’s absolute visual magnitude of 4.83 . The Sun’s absolute bolometric magnitude is 4.75

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Distance (light years)</th>
<th>Apparent Magnitude</th>
<th>Absolute Magnitude</th>
<th>Spectral Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td></td>
<td>-</td>
<td>-26.72</td>
<td>4.8</td>
<td>G2V</td>
</tr>
<tr>
<td>Sirius</td>
<td>Alpha CMa</td>
<td>8.6</td>
<td>-1.46</td>
<td>1.4</td>
<td>A1Vm</td>
</tr>
<tr>
<td>Canopus</td>
<td>Alpha Car</td>
<td>74</td>
<td>-0.72</td>
<td>-2.5</td>
<td>A9II</td>
</tr>
<tr>
<td>Arcturus</td>
<td>Alpha Boo</td>
<td>34</td>
<td>-0.04</td>
<td>0.2</td>
<td>K1.5IIIp</td>
</tr>
<tr>
<td>Vega</td>
<td>Alpha Lyr</td>
<td>25</td>
<td>0.03</td>
<td>0.6</td>
<td>A0Va</td>
</tr>
<tr>
<td>Capella</td>
<td>Alpha Aur</td>
<td>41</td>
<td>0.08</td>
<td>0.4</td>
<td>G6III + G2III</td>
</tr>
<tr>
<td>Rigel</td>
<td>Beta Ori</td>
<td>~1400</td>
<td>0.12</td>
<td>-8.1</td>
<td>B8Iae</td>
</tr>
<tr>
<td>Procyon</td>
<td>Alpha Cmi</td>
<td>11.4</td>
<td>0.38</td>
<td>2.6</td>
<td>F5IV-V</td>
</tr>
<tr>
<td>Betelgeuse</td>
<td>Alpha Ori</td>
<td>~1400</td>
<td>0.50</td>
<td>-7.2</td>
<td>M2Iab</td>
</tr>
<tr>
<td>Altair</td>
<td>Alpha Aql</td>
<td>16</td>
<td>0.77</td>
<td>2.3</td>
<td>A7Vn</td>
</tr>
<tr>
<td>Aldebaran</td>
<td>Alpha Tau</td>
<td>60</td>
<td>0.85</td>
<td>-0.3</td>
<td>K5III</td>
</tr>
<tr>
<td>Antares</td>
<td>Alpha Sco</td>
<td>~520</td>
<td>0.96</td>
<td>-5.2</td>
<td>M1.5Iab</td>
</tr>
<tr>
<td>Spica</td>
<td>Alpha Vir</td>
<td>220</td>
<td>0.98</td>
<td>-3.2</td>
<td>B1V</td>
</tr>
<tr>
<td>Pollux</td>
<td>Beta Gem</td>
<td>40</td>
<td>1.14</td>
<td>0.7</td>
<td>K0IIib</td>
</tr>
<tr>
<td>Fomalhaut</td>
<td>Alpha PsA</td>
<td>22</td>
<td>1.16</td>
<td>2.0</td>
<td>A3Va</td>
</tr>
<tr>
<td>Deneb</td>
<td>Alpha Cyg</td>
<td>1500</td>
<td>1.25</td>
<td>-7.2</td>
<td>A2Ia</td>
</tr>
<tr>
<td>Regulus</td>
<td>Alpha Leo</td>
<td>69</td>
<td>1.35</td>
<td>-0.3</td>
<td>B7Vn</td>
</tr>
<tr>
<td>Castor</td>
<td>Alpha Gem</td>
<td>49</td>
<td>1.57</td>
<td>0.5</td>
<td>A1V + A2V</td>
</tr>
</tbody>
</table>

Luminosity : In astronomy, luminosity is the amount of electromagnetic energy a body radiates per unit of time.
II. POGSON’S FORMULA

1) Comparing Luminosities of Stars: The magnitude of a star is a logarithmic scale of observed visible brightness. The apparent magnitude is the observed visible brightness from Earth, and the absolute magnitude is the apparent magnitude at a distance of 10 parsecs.

The difference in apparent magnitude is related to the stellar luminosity ratio according to:

\[ m_1 - m_2 = 2.5 \log \frac{L_2}{L_1} \]

Example: According to the given list above compare the luminosities of Rigel and Procyon.

HOMEWORK

1) According to the given table above, find the ratio of luminosity of Antares to Sirius. (0.108)

2) If the ratio of luminosity of star A to star B is 1000, and the apparent magnitude of star A is 5ᵐ, then find the apparent magnitude of star B. (-2.5ᵐ)

2) Calculating the Distances of Stars:

\[ m_1 - m_2 = 2.5 \log_{10} \left( \frac{I_2}{I_1} \right) \]

The light intensity of an object is inversely proportional with the square of its distance.

\[ I = \frac{1}{d^2} \]

If we substitute this in the given formula, then

\[ m_1 - m_2 = 2.5 \log \left( \frac{(1/d_2)^2}{(1/d_1)^2} \right) \]

\[ m_1 - m_2 = 2.5 \log \left( \frac{d_1}{d_2} \right)^2 \]

\[ m_1 - m_2 = 5 \log \frac{d_1}{d_2} \]
The absolute magnitude is the brightness of the star if we accept it is 10 pc far from us.

\[ m - M = 5 \log(d/10) \]
\[ m - M = 5( \log d - \log 10 ) \]
\[ m - M = 5( \log d - 1 ) \]
\[ m - M = 5 \log d - 5 \]

**EXAMPLE** : The apparent magnitude of Vega is 0.03\(^m\), and absolute magnitude is 0.6\(^m\). Find the distance of Vega in parsec.

b) If 1 pc = 3.261556 ly , then find the distance of Vega in ly.

**EXAMPLE** : The distance between star A and Earth is 10000 pc. If the apparent magnitude of star A is 4\(^m\), then find the absolute magnitude of it.

**EXAMPLE** : The apparent magnitude of star A is 3\(^m\), the ratio of light intensity of star B to star A is 10\(^3\). If the absolute magnitude of star B is -4\(^m\), then find the distances of star B.

**HOMEWORK**

1) According to the given table, which one of the star is further than 10 pc ? Give your answer without calculation and explain the reason.

<table>
<thead>
<tr>
<th>Stars</th>
<th>m</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sirius</td>
<td>-1.46</td>
<td>1.4</td>
</tr>
<tr>
<td>Canopus</td>
<td>-0.72</td>
<td>-2.5</td>
</tr>
<tr>
<td>Arcturus</td>
<td>-0.04</td>
<td>0.2</td>
</tr>
</tbody>
</table>
2) Calculate the distances of Sirius, Canopus and Arcturus. Compare their distances.

3) Calculate the ratio of light intensities of Sirius to Arcturus. ($L_s = 0.568 \, L_c$)

4) The ratio of light intensities Castor to Regulus is 0.82. The apparent magnitude of Regulus is $1.35^m$. If the absolute magnitude of Castor is $0.5^m$, then find the distance of Castor.

**STAR CLASSIFICATION**

Astronomers can classify stars according to their temperatures, colors or brightness. In each case, only thing that they have from a star is its light. So how can we learn every detail about a star (its color, temperature, evolution etc.) from its light?

There are two main classification of stars: 

- a) Spectral Classification
- b) Luminosity classes

**What is a spectra?** In the 17th century the word *spectrum* was introduced into optics, referring to the range of colors observed when white light was dispersed through a prism. The term *spectrum* was soon applied to other waves, such as sound waves, and now applies to any signal that can be decomposed into frequency components. To get a spectrum, the measured function has to be transformed in their independent variable to frequencies and the dependent variable has to be reduced in regions, where the independent variable is stretched. For this imagine that the spectrum of pulse with a finite number of particles is measured on a film or a CCD.
**What is a spectrograph?** A spectrometer (spectrophotometer, spectrograph or spectroscope) is an instrument used to measure properties of light over a specific portion of the electromagnetic spectrum, typically used in spectroscopic analysis to identify materials.

### I. Spectral Classification

The rapid spread of spectroscopy in the late Nineteenth century resulted in a large number of stellar spectra.

Based on the appearance of the spectra of stars, a spectral classification scheme was devised in the late 1800s and the early 1900s. The criteria used to define the sequence were based primarily on the strengths of the hydrogen Balmer lines but other features were also considered. Today, other criteria are used and so the ordering is rather more obscure.

The ordering is O, B, A, F, G, K, M. This is a temperature sequence starting from the hottest stars at O going to the coolest stars at M.

**Why do different stars have different lines?** This question is the key to helping us classify stars. If we compare an O-class star with an M-class star they have very different lines. The key factor at work here is temperature.

In very hot stars, helium can be ionised so we can expect to see spectral lines due to absorption by helium ions. In most stars the temperature is too cool for helium to ionise so no such lines can form in the spectrum. Some stars are cool enough that molecules can exist in outer layers without being ripped apart. As the number of possible electron transitions is much greater in molecules than single atoms there are many possible spectral lines that can form hence cool stars typically have many lines.

<table>
<thead>
<tr>
<th>Spectral Class</th>
<th>Temperature</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>28,000-50,000 K</td>
<td>ionized atoms, especially helium</td>
</tr>
<tr>
<td>B</td>
<td>10,000-28,000 K</td>
<td>neutral helium, some hydrogen</td>
</tr>
<tr>
<td>A</td>
<td>7,500-10,000 K</td>
<td>strong hydrogen, some ionized metals</td>
</tr>
<tr>
<td>F</td>
<td>6,000-7,500 K</td>
<td>hydrogen and ionized metals, such as calcium and iron</td>
</tr>
<tr>
<td>G</td>
<td>5,000-6,000 K</td>
<td>ionized calcium and both neutral and ionized metals</td>
</tr>
<tr>
<td>K</td>
<td>3,500-5,000 K</td>
<td>neutral metals</td>
</tr>
<tr>
<td>M</td>
<td>2,500-3,500 K</td>
<td>strong molecular lines, e.g., titanium oxide, and some neutral calcium</td>
</tr>
<tr>
<td>Spectral Class</td>
<td>Effective Temperature (K)</td>
<td>Colour</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>O</td>
<td>28,000 - 50,000</td>
<td>Blue</td>
</tr>
<tr>
<td>B</td>
<td>10,000 - 28,000</td>
<td>Blue-white</td>
</tr>
<tr>
<td>A</td>
<td>7,500 - 10,000</td>
<td>White</td>
</tr>
<tr>
<td>F</td>
<td>6,000 - 7,500</td>
<td>White-yellow</td>
</tr>
<tr>
<td>G</td>
<td>4,900 - 6,000</td>
<td>Yellow</td>
</tr>
<tr>
<td>K</td>
<td>3,500 - 4,900</td>
<td>Orange</td>
</tr>
<tr>
<td>M</td>
<td>2,000 - 3,500</td>
<td>Red</td>
</tr>
<tr>
<td>L?</td>
<td>&lt;2,000</td>
<td>Tentative new (2000) classification for very low mass stars.</td>
</tr>
</tbody>
</table>

**II. Luminosity Classes**

One problem facing early attempts at classifying stellar spectra was the fact that two spectra could have the same lines present, indicating that the stars had the same effective temperature, but the lines in one star’s spectrum were broader than in the other. When the star’s were plotted on an HR diagram it also became apparent that two stars could have the same effective temperature (hence also colour and spectral class) but vary enormously in luminosity and thus absolute magnitude. To account for this a second classification scheme of Luminosity Class was added to the original concept of Spectral Class. A simplified version of the MK system of luminosity classes is shown in the table below.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Class of Star</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Extreme, luminous supergiants</td>
<td></td>
</tr>
<tr>
<td>Ia</td>
<td>Luminous supergiants</td>
<td>Betelgeuse</td>
</tr>
<tr>
<td>Ib</td>
<td>Less luminous supergiants</td>
<td>Antares</td>
</tr>
<tr>
<td>II</td>
<td>Bright giants</td>
<td>Canopus</td>
</tr>
<tr>
<td>III</td>
<td>Normal giants</td>
<td>Aldebaran</td>
</tr>
<tr>
<td>IV</td>
<td>Subgiants</td>
<td>Procyon</td>
</tr>
<tr>
<td>V</td>
<td>Main sequence</td>
<td>Sun</td>
</tr>
<tr>
<td>sd</td>
<td>Subdwarfs</td>
<td>Kapteyn’s Star (HD 33793)</td>
</tr>
<tr>
<td>wd or D</td>
<td>White dwarfs</td>
<td>Sirius B</td>
</tr>
</tbody>
</table>

**HERTZSPRUNG – RUSSELL DIAGRAM**

The Hertzsprung–Russell diagram is a scatter graph of stars showing the relationship between the stars’ absolute magnitudes or luminosity versus their spectral types or classifications and effective temperatures. Hertzsprung-Russell diagrams are not pictures or maps of the locations of the stars. Rather, they plot each star on a graph measuring the star’s absolute magnitude or brightness against its temperature and color.

Hertzsprung–Russell diagrams are also referred to by the abbreviation H-R diagram or HRD. The diagram was created circa 1910 by Ejnar Hertzsprung and Henry Norris Russell and represents a major step towards an understanding of stellar evolution or “the lives of stars”.

There are several forms of the Hertzsprung–Russell diagram. The original diagram displayed the spectral type of stars on the horizontal axis and the absolute magnitude on the vertical axis.

Another form of the diagram plots the effective surface temperature of the star on one axis and the luminosity of the star on the other. This is what theoreticians calculate using computer models that describe the evolution of stars. This type of diagram should probably be called temperature-luminosity diagram, but this term is hardly ever used, the term Hertzsprung–Russell diagram being preferred instead.
EVOLUTION OF STARS

Stellar evolution is the process by which a star undergoes a sequence of radical changes during its lifetime. Depending on the mass of the star, this lifetime ranges from only a few million years (for the most massive) to trillions of years (for the least massive), considerably more than the age of the universe.

Stellar evolution is not studied by observing the life of a single star, as most stellar changes occur too slowly to be detected, even over many centuries. Instead, astrophysicists come to understand how stars evolve by observing numerous stars at the various points in their life, and by simulating stellar structure with computer models.

I. EVOLUTION OF LOW MASS STARS (0.08Mₘ ≤ M ≤ 0.4Mₘ)

A star of less than about 0.5 solar mass will never be able to fuse helium even after the core ceases hydrogen fusion. There simply is not a stellar envelope massive enough to exert enough pressure on the core. These are the red dwarfs, such as Proxima Centauri, some of which will live thousands of times longer than the Sun. Recent astrophysical models suggest that red dwarfs of 0.1 solar masses may stay on the main sequence for almost six trillion years, and take several hundred billion more to slowly collapse into a white dwarf. If a star’s core becomes stagnant (as is thought will be the case for the Sun), it will still be surrounded by layers of hydrogen which the star may subsequently draw upon. However, if the star is fully convective (as thought to be the case for the lowest-mass stars), it will not have such surrounding layers. If it does, it will develop into a red giant as described for mid-sized stars below, but never fuse helium as they do; otherwise, it will simply contract until electron degeneracy pressure halts its collapse, thus directly turning into a white dwarf.

II. EVOLUTION OF MIDDLE MASS STARS (0.4Mₘ ≤ M ≤ 8Mₘ)

Stars with 0.4Mₘ ≤ M ≤ 4Mₘ

Once the hydrogen fuel in the core of a middle mass star is used up, this marks the Main-Sequence Turnoff Point. Hydrogen fusion is still occurring, but in a shell that surrounds the core. All that is left in the core is helium ash. In a nutshell, this is what happens next:

- Hydrogen shell continues fusion
- Helium ash from hydrogen shell collects at the core - the core has remnant helium ash from prior core fusion
- Helium ash build as does pressure and temperature - helium flash then core helium fusion
- Hydrogen shell and helium core fusion continues - core helium fusion ends soon (more heat, faster burning)
- Ash in core now carbon, helium shell burning begins, hydrogen shell burning continues
- Carbon ash compresses as outer layers fluctuate
- Outer layers shed in planetary nebula
- Insert, compressed carbon core (White Dwarf) remains
For stars under 4 Solar masses:

It is at this point that the outer layers of the star expand; however this time they are lost - expelled in the form of a planetary nebula.

The end result of the thermal pulsing from the helium and hydrogen shell burning is a planetary nebula - like this image of the Ring nebula.

The remnant carbon core cools and contracts to form a White Dwarf. The star at the center of the Ring nebula (above) is a white dwarf.

**Stars with $4M_{\text{sun}} < M \leq 8M_{\text{sun}}$**

- Inert O-Ne-Mg core contracts & heats up
- C, He, & H burning shells

Thermal pulses destabilize the envelope:

- Eject the envelope in a massive stellar wind.
- Leave O-Ne-Mg white dwarf core behind.

**III. EVOLUTION OF HIGH MASS STARS ( 8MS < MS ≤ 20MS )**

It is important to state that while the fusing of hydrogen to helium is being performed in both low and high mass stars, high mass stars primarily burn hydrogen through the CNO cycle (Carbon, Nitrogen, Oxygen)

The hydrogen burning shell and helium ash core also exist in the high mass star.

One major difference between a high mass star and a low mass star at this point is the helium flash - there is no flash of helium fusion in a high mass star.

In massive stars, the core is already large enough at the onset of hydrogen shell burning that helium ignition will occur before electron degeneracy pressure has a chance to become prevalent. Thus, when these stars expand and cool, they do not brighten as much as lower mass stars; however, they were much brighter than lower mass stars to begin with, and are thus still brighter than the red giants formed from less massive stars. These stars are known as **red supergiants**.

The core grows hotter and denser as it gains material from fusion of hydrogen at the base of the envelope. In a massive star, electron degeneracy pressure is insufficient to halt collapse by itself, so as each major element is consumed in the center, progressively heavier elements ignite, temporarily halting collapse. If the core of the star is not too massive (less than approximately 1.4 solar masses, taking into account mass loss that has occurred by this time), it may then form a white dwarf (possibly surrounded by a planetary nebula) as described above for less massive stars, with the difference that the white dwarf is composed chiefly of oxygen, neon, and magnesium.

Once the nucleosynthesis process arrives at iron-56, the continuation of this process consumes energy (the addition of fragments to nuclei releases less energy than required to break them off the parent nuclei). If the mass of the core exceeds the Chandrasekhar limit, electron degeneracy pressure will be unable to support its weight against the force of gravity, and the core will undergo sudden, catastrophic collapse to form a **neutron star** or (in the case of cores that exceed the Tolman-Oppenheimer-Volkoff limit), a **black hole**.
EVOLUTION OF STARS ON HERTZSPRUNG – RUSSELL DIAGRAM

The Hertzsprung–Russell diagram is a scatter graph of stars showing the relationship between the stars’ absolute magnitudes or luminosity versus their spectral types or classifications and effective temperatures. Hertzsprung-Russell diagrams are not pictures or maps of the locations of the stars. Rather, they plot each star on a graph measuring the star’s absolute magnitude or brightness against its temperature and color.

The diagram was created circa 1910 by Ejnar Hertzsprung and Henry Norris Russell and represents a major step towards an understanding of stellar evolution or “the lives of stars”.

On the diagram, “Ia” and “Ib” represents Supergiants, “II” Bright Giants, “III” Giants, “IV” Subgiants, “V” Main Sequence Stars, and there is also a White Dwarfs part.

There are several forms of the Hertzsprung–Russell diagram. The original diagram displayed the spectral type of stars on the horizontal axis and the absolute magnitude on the vertical axis. Contemplation of the diagram led astronomers to speculate that it might demonstrate stellar evolution, the main suggestion being that stars collapsed from red giants to dwarf stars, then moving down along the line of the main sequence in the course of their lifetimes.
STELLAR REMNANTS

I. WHITE DWARFS

For a star of 1 solar mass, the resulting white dwarf is of about 0.6 solar mass, compressed into approximately the volume of the Earth.

White dwarfs are stable because the inward pull of gravity is balanced by the degeneracy pressure of the star's electrons.

The chemical composition of the white dwarf depends upon its mass. A star of mass on the order of magnitude of the Sun will be unable to ignite carbon fusion, and will produce a white dwarf composed chiefly of carbon and oxygen, and of mass too low to collapse unless matter is added to it later. A star of less than about half the mass of the Sun will be unable to ignite helium fusion, and will produce a white dwarf composed chiefly of helium.

In the end, all that remains is a cold dark mass sometimes called a black dwarf. However, the universe is not old enough for any black dwarf stars to exist yet.
II. NEUTRON STARS (PULSARS)

A neutron star is a type of remnant that can result from the gravitational collapse of a massive star during a Type II, Type Ib or Type Ic supernova event. Such stars are composed almost entirely of neutrons, which are subatomic particles without electrical charge and roughly the same mass as protons. Neutron stars are very hot.

A typical neutron star has a mass between 1.35 and about 2.1 solar masses, with a corresponding radius of about 12 km. The gravitational field at the star’s surface is about \(2 \times 10^{14}\) times stronger than on Earth. The escape velocity is about 100,000 km/s, which is about one third the speed of light. A neutron star is so dense that one teaspoon (5 milliliters) of its material would have a mass over \(5 \times 10^{12}\) kg. The resulting force of gravity is so strong that if an object were to fall from just one meter high it would only take one microsecond to hit the surface of the neutron star.

Neutron stars rotate extremely rapidly after their creation due to the conservation of angular momentum; like spinning ice skaters pulling in their arms, the slow rotation of the original star’s core speeds up as it shrinks. A newborn neutron star can rotate several times a second.

**PULSARS**: Neutron stars have been observed to “pulse” radio and x-ray emissions believed caused by particle acceleration near the magnetic poles, which need not be aligned with the rotation axis of the star. Through mechanisms not yet entirely understood, these particles produce coherent beams of radio emission. External viewers see these beams as pulses of radiation whenever the magnetic pole sweeps past the line of sight. The pulses come at the same rate as the rotation of the neutron star, and thus, appear periodic. Neutron stars which emit such pulses are called pulsars.

III. BLACK HOLES

When a massive star (20 M\(_\odot\)) explodes (SNII), the degenerated core of it continues to collapse by its own gravity. The density and gravitational force of the remaining core is extremely high.

According to the general theory of relativity, a **black hole** is a region of space from which nothing, including light, can escape. It is the result of the deformation of spacetime caused by a very compact mass. Around a black hole there is an undetectable surface which marks the point of no return, called an **event horizon**. It is called “black” because it absorbs all the light that hits it, reflecting nothing.

Despite its invisible interior, a black hole can be observed through its interaction with other matter. A black hole can be inferred by tracking the movement of a group of stars that orbit a region in space. Alternatively, when gas falls into a stellar black hole from a companion star, the gas spirals inward, heating to very high temperatures and emitting large amounts of radiation that can be detected from earthbound and Earth-orbiting telescopes.

For a non rotating (static) black hole, the **Schwarzschild radius** delimits a spherical event horizon. The Schwarzschild radius of an object is proportional to the mass.
At the center of a black hole as described by general relativity lies a gravitational singularity, a region where the spacetime curvature becomes infinite. For a non-rotating black hole this region takes the shape of a single point and for a rotating black hole it is smeared out to form a ring shape lying in the plane of rotation. In both cases the singular region has zero volume. It can also be shown that the singular region contains all the mass of the black hole solution. The singular region can thus be thought of as having infinite density.

An observer falling into a schwarzschild black hole cannot avoid the singularity. Any attempt to do so will only shorten the time taken to get there. When he reaches the singularity he is crushed to infinite density and his mass is added to the total of the black hole. Before that happens he will have been torn apart by the growing tidal forces in a process sometimes referred to as spaghettification or the noodle effect.

STAR CLUSTERS

**Star clusters** or **star clouds** are groups of stars that are formed by the same nebula. Two types of star clusters can be distinguished: Open Clusters and Globular Clusters. Globular clusters are tight groups of hundreds of thousands of very old stars which are gravitationally bound, while open clusters, a more loosely clustered group of stars, generally contain less than a few hundred members, and are often very young. Open clusters become disrupted over time by the gravitational influence of giant molecular clouds as they move through the galaxy, but cluster members will continue to move in broadly the same direction through space even though they are no longer gravitationally bound; they are then known as a stellar association, sometimes also referred to as a moving group.

Star clusters visible to the naked eye include Pleiades, Hyades and the Beehive Cluster.

**Globular Clusters** : Globular clusters, or GC, are roughly spherical groupings of from 10,000 to several million stars packed into regions of from 10 to 30 light years across. They commonly consist of very old Population II stars—just a few hundred million years younger than the universe itself—which are mostly yellow and red, weighing a bit less than two solar masses. Such stars predominate within clusters because hotter and more massive stars have exploded as supernovae, or evolved through planetary nebula phases to end as white dwarfs. Yet a few rare blue stars exist in globulars, thought to be formed by stellar mergers in their dense inner regions; these stars are known as blue stragglers.

Our galaxy has about 150 globular clusters, some of which may have been captured from small galaxies disrupted by the Milky Way, as seems to be the case for the globular cluster M79. Some galaxies are much richer in globulars: the giant elliptical galaxy M87 contains over a thousand.

**Open Clusters** : Open clusters, (OC) are very different from globular clusters. Unlike the spherically distributed globulars, they are confined to the galactic plane, and are almost always found within spiral arms. They are generally young objects, up to a few tens of millions of years old, with a few rare exceptions as old as a few billion years, such as Messier 67 (the closest and most observed old open cluster) for example. Open clusters usually contain up to a few hundred members, within a region up to about 30 light-years across. The most prominent open clusters are the Pleiades and Hyades in Taurus.
Stellar clusters are important in many areas of astronomy. Because the stars were all born at roughly the same time, the different properties of all the stars in a cluster are a function only of mass, and so stellar evolution theories rely on observations of open and globular clusters.

Clusters are also a crucial step in determining the distance scale of the universe. A few of the nearest clusters are close enough for their distances to be measured using parallax. A Hertzsprung-Russell Diagram can be plotted for these clusters which has absolute values known on the luminosity axis. Then, when similar diagram is plotted for a cluster whose distance is not known, the position of the main sequence can be compared to that of the first cluster and the distance estimated. This process is known as main-sequence fitting. Reddening and stellar populations must be accounted for when using this method.

**BINARY STARS**

A binary star is a star system consisting of two stars orbiting around their common center of mass. The brighter star is called the primary and the other is its companion star, comes, or secondary.

Binary star systems are very important in astrophysics because calculations of their orbits allow the masses of their component stars to be directly determined, which in turn allows other stellar parameters, such as radius and density, to be indirectly estimated.

Binary stars are often detected optically, in which case they are called visual binaries. Many visual binaries have long orbital periods of several centuries or millennia and therefore have orbits which are uncertain or poorly known. They may also be detected by indirect techniques, such as spectroscopy (spectroscopic binaries) or astrometry (astrometric binaries). If a binary star happens to orbit in a plane along our line of sight, its components will mutually eclipse and transit each other; these pairs are called eclipsing binaries, or, as they are detected by their changes in brightness during eclipses and transits, photometric binaries.

1) **Visual Binaries** : A visual binary star is a binary star for which the angular separation between the two components is great enough to permit them to be observed as a double star in a telescope. The brighter star of a visual binary is the primary star, and the dimmer is considered the secondary.

2) **Spectroscopic Binaries** : Sometimes, the only evidence of a binary star comes from the Doppler effect on its emitted light. In these cases, the binary consists of a pair of stars where the spectral lines in the light emitted from each star shifts first toward the blue, then toward the red, as each moves first toward us, and then away from us, during its motion about their common center of mass, with the period of their common orbit.

In these systems, the separation between the stars is usually very small, and the orbital velocity very high.

The orbit of a spectroscopic binary is determined by making a long series of observations of the radial velocity of one or both components of the system. The observations are plotted against time, and from the resulting curve a period is determined. If the orbit is circular then the curve will be a sine curve. If the orbit is elliptical, the shape of the curve will depend on the eccentricity of the ellipse and the orientation of the major axis with reference to the line of sight.

Binary stars that are both visual and spectroscopic binaries are rare.
3) Eclipsing Binaries: An eclipsing binary star is a binary star in which the orbit plane of the two stars lies so nearly in the line of sight of the observer that the components undergo mutual eclipses. Algol is the best-known example of an eclipsing binary.

Eclipsing binaries are variable stars, not because the light of the individual components vary but because of the eclipses. The light curve of an eclipsing binary is characterized by periods of practically constant light, with periodic drops in intensity. If one of the stars is larger than the other, one will be obscured by a total eclipse while the other will be obscured by an annular eclipse.

The period of the orbit of an eclipsing binary may be determined from a study of the light curve, and the relative sizes of the individual stars can be determined in terms of the radius of the orbit by observing how quickly the brightness changes as the disc of the near star slides over the disc of the distant star. If it is also a spectroscopic binary the orbital elements can also be determined, and the mass of the stars can be determined relatively easily, which means that the relative densities of the stars can be determined in this case.
VARIABLE STARS

A star is classified as variable if its apparent brightness as seen from Earth changes over time, whether the changes are due to variations in the star’s actual luminosity, or to variations in the amount of the star’s light that is blocked from reaching Earth.

It is convenient to classify variable stars as belonging to one of two types:

- **Intrinsic variables**, whose luminosity actually changes; for example, because the star periodically swells and shrinks.
- **Extrinsic variables**, whose apparent changes in brightness are due to changes in the amount of their light that can reach Earth; for example, because the star has an orbiting companion that sometimes eclipses it.

**Intrinsic variable stars**: stars where the variability is being caused by changes in the physical properties of the stars themselves. This category can be divided into three subgroups.

- Pulsating variables, stars whose radius alternately expands and contracts as part of their natural evolutionary aging processes.
- Eruptive variables, stars who experience eruptions on their surfaces like flares or mass ejections.
- Cataclysmic or explosive variables, stars that undergo a cataclysmic change in their properties like novae and supernovae.

**Extrinsic variable stars**: stars where the variability is caused by external properties like rotation or eclipses. There are two main subgroups.

- Eclipsing binaries, double stars where, as seen from Earth’s vantage point the stars occasionally eclipse one another as they orbit.
- Rotating variables, stars whose variability is caused by phenomena related to their rotation. Examples are stars with extreme “sunspots” which affect the apparent brightness or stars that have fast rotation speeds causing them to become ellipsoidal in shape.

The first variable star was identified in 1638 when Johannes Holwarda noticed that Omicron Ceti (later named Mira) pulsated in a cycle taking 11 months; the star had previously been described as a nova by David Fabricius in 1596. This discovery, combined with supernovae observed in 1572 and 1604, proved that the starry sky was not eternally invariable as Aristotle and other ancient philosophers had taught. In this way, the discovery of variable stars contributed to the astronomical revolution of the sixteenth and early seventeenth centuries.

The most common kinds of variability involve changes in brightness, but other types of variability also occur, in particular changes in the spectrum. By combining light curve data with observed spectral changes, astronomers are often able to explain why a particular star is variable.
**Variable star observations** Variable stars are generally analysed using photometry, spectrophotometry and spectroscopy. Measurements of their changes in brightness can be plotted to produce light curves. For regular variables, the period of variation and its amplitude can be very well established.

*Amateur astronomers* can do useful scientific study of variable stars by visually comparing the star with other stars within the same telescopic field of view of which the magnitudes are known and constant. By estimating the variable’s magnitude and noting the time of observation a visual light curve can be constructed. The *American Association of Variable Star Observers* collects such observations from participants around the world and shares the data with the scientific community.

From the **light curve** the following data are derived:

- are the brightness variations periodical, semiperiodical, irregular, or unique?
- what is the period of the brightness fluctuations?
- what is the shape of the light curve (symmetrical or not, angular or smoothly varying, does each cycle have only one or more than one minima, etcetera)?

From the **spectrum** the following data are derived:

- what kind of star is it: what is its temperature, its luminosity class (dwarf star, giant star, supergiant, etc.)?
- is it a single star, or a binary? (the combined spectrum of a binary star may show elements from the spectra of each of the member stars)
- does the spectrum change with time? (for example, the star may turn hotter and cooler periodically)
- changes in brightness may depend strongly on the part of the spectrum that is observed (for example, large variations in visible light but hardly any changes in the infrared)
- if the wavelengths of spectral lines are shifted this points to movements (for example, a periodical swelling and shrinking of the star, or its rotation, or an expanding gas shell) (Doppler effect)
- strong magnetic fields on the star betray themselves in the spectrum
- abnormal emission or absorption lines may be indication of a hot stellar atmosphere, or gas clouds surrounding the star.

**Intrinsic variable stars**

**Pulsating variable stars**

The pulsating stars swell and shrink regularly by stellar radius, magnitude and spectrum, most often with a defined period, sometimes semiregularly with an average period and amplitude. The two most important types are:

- Cepheids and cepheid-like stars. They have short periods (days to months) and their luminosity cycle is very regular;
- Long Period Variables. Their period is longer, on the order of a year, and much less regular.
Cepheids and cepheid-like variables

This group consists of several kinds of pulsating stars that swell and shrink very regularly by the star’s own mass.

Delta Cepheid, W Virginids, RR Lyrae variables and Delta Scutids belong to the instability strip which is believed to be driven by Eddington pulsations in helium, while for the Beta Cepheids the pulsation mechanism is unknown. The instability strip stars are spectral type late A through M stars (from “white” to “red” by convention). Beta cepheids belongs to type B or sometimes late O (“blue” and deeper “blue”).

One of the most important types of variables star are Delta Cephei variables, yellow giant stars which undergo pulsations with very regular periods. Usually referred to simply as Cepheid variables, they are named after Delta Cephei (δ Cep), the first of the class to be discovered, and have periods ranging from about a day to several weeks.

Cepheids are important because they are a type of standard candle. Their luminosity is directly related to their period of variation, with a slight dependence on metallicity as well. The longer the pulsation period, the more luminous the star. Once this period-luminosity relationship is calibrated, the luminosity of a given Cepheid whose period is known can be established. Their distance is then easily found from their apparent brightness. Observations of Cepheid variables are very important for determining distances to galaxies within the Local Group and beyond.

The relationship between a Population I Cepheid’s period $P$, and its luminosity, measured as its mean absolute magnitude $M_v$.

$$M_v = -2.81 \log_{10}(P) - (1.43 \pm 0.1)$$

W Virginis stars have clock regular light pulsations and a luminosity relation much like the δ Cephei variables, so initially they were confused with the latter category.

Example: If the period of a Cepheid type variable is 3 days, and its apparent brightness is 10$^m$ then find its distance.
Long Period Variables (Mira Type Stars)

Mira variables, named after the star Mira, are a class of pulsating variable stars characterized by very red colors, pulsation periods longer than 100 days, and light amplitudes greater than one magnitude. They are red giant stars in the very late stages of stellar evolution (the asymptotic giant branch) that will expel their outer envelopes as planetary nebulae and become white dwarfs within a few million years.

Eruptive variable stars

Proto stars are young objects that have not yet completed the process of contraction from a gas nebula to a veritable star. Most protostars exhibit irregular brightness variations.

Variability of more massive (2-8 solar mass) Herbig Ae/Be stars is thought to be due to gas-dust clumps, orbiting in the circumstellar disks.

Orion variables are young, hot pre-main sequence stars usually embedded in nebulosity. They have irregular periods with amplitudes of several magnitudes. A well known subtype of Orion variables are the T Tauri variables. Variability of T Tauri stars is due to spots on the stellar surface and gas-dust clumps, orbiting in the circumstellar disks.

These stars reside in reflection nebulae and show gradual increases in their luminosity in the order of 6 magnitudes followed by a lengthy phase of constant brightness. They then dim by 2 magnitudes (six times dimmer) or so over a period of many years. V1057 Cygni for example dimmed by 2.5 magnitude (ten times dimmer) during an eleven year period. FU Orionis variables are of spectral type A through G and are possibly an evolutionary phase in the life of T Tauri stars.

Cataclysmic or Explosive Variable Stars (Novae)

Cataclysmic variables (CVs) are binary star systems which have a white dwarf and a normal star companion. They are typically small - the entire binary system usually has the size of the Earth-Moon system - with an orbital period in the range 1-10 hrs. The white dwarf is often referred to as the “primary” star, and the normal star as the “companion” or the “secondary”. The companion star, a more or less normal star like our Sun, loses material onto the white dwarf via accretion.

Since the white dwarf is very dense, the gravitational potential energy is enormous, and some of it is converted into X-rays during the accretion process. There are probably over a million such cataclysmic variables in the Galaxy, but only those close to our Sun (several hundreds) have been studied in X-rays so far. This is because CVs are fairly faint in X-rays; they are just above the coronal X-ray sources and far below the X-ray binaries in terms of how powerful their X-ray emissions are.
Optical astronomers discovered CVs based on their outbursts in the middle of the 19th century. CVs are classified into subclasses according to the properties of the outbursts: classical novae and dwarf novae. Classical novae are seen to erupt once, and the amplitude of the outburst is the largest among CVs.

Novae are also the result of dramatic explosions, but unlike supernovae do not result in the destruction of the progenitor star. Also unlike supernovae, novae ignite from the sudden onset of thermonuclear fusion, which under certain high pressure conditions (degenerate matter) accelerates explosively. They form in close binary systems, one component being a white dwarf accreting matter from the other ordinary star component, and may recur over periods of decades to centuries or millennia. Novae are categorised as fast, slow or very slow, depending on the behaviour of their light curve. Several naked eye novae have been recorded, Nova Cygni 1975 being the brightest in the recent history, reaching 2nd magnitude.

The absolute magnitude of a nova is always $-7^m$ at maximum.

Example: The maximum apparent magnitude of a nova in a galaxy is $23^m$, find the distance of the galaxy.

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**GALAXIES**

A galaxy is a massive, gravitationally bound system that consists of stars and stellar remnants, an interstellar medium of gas and dust, and an important but poorly understood component tentatively dubbed dark matter.

Historically, galaxies have been categorized according to their apparent shape. Common form is the elliptical galaxy, which has an ellipse-shaped light profile. Spiral galaxies are disk-shaped assemblages with dusty, curving arms. Galaxies with irregular or unusual shapes are known as peculiar galaxies, and typically result from disruption by the gravitational pull of neighboring galaxies.
TYPES OF GALAXIES – HUBBLE CLASSIFICATION – THE FORK DIAGRAM

Hubble Galaxy classification or the Fork diagram does not show the evolution of galaxies but the types of them. Elliptical galaxies are classified according to their eccentricity. There are 8 sub types of elliptical galaxies. E0 denotes a circular shaped elliptical galaxy. Spiral Galaxies are classified according the magnitude of their nucleus and number of arms. There are 4 sub types of spiral galaxies. Sa denotes a huge nucleus and Un separated arms while Sb denotes a small nucleus and separated arms. Barred Spiral Galaxies are also classified as the normal spirals. The only difference between a Barred and a normal spiral galaxy is the shape of their nucleus.

MILKY WAY GALAXY

The Milky Way, is the galaxy in which the Solar System is located. It is a barred spiral galaxy that is part of the Local Group of galaxies. All the stars that the eye can distinguish in the night sky are part of the Milky Way Galaxy. The center of the galaxy lies in the direction of Sagittarius, and it is here that Milky Way looks brightest. A spiral galaxy like the Milky Way has 3 basic components to its visible matter: (1) the disk (containing the spiral arms), (2) the halo, and (3) the nucleus or central bulge.

Most of the gas and dust of the Milky Way is contained in the disk.

The halo of the galaxy is rather spherical in shape and contains little gas, dust, or star formation. It is difficult to measure precisely, but the halo appears to extend beyond the disk. The clusters found in the halo are globular clusters (approximately 100 of them), so the halo is population II, and contains very old stars. Dating of globular clusters by their turnoff points indicates that they may be as old as 15 billion years and are the oldest components of the galaxy. This implies that the galaxy itself is at least 15 billion years old.

The nuclear bulge or core contains the highest density of stars in the galaxy. Although some hot young stars may be found in the nucleus, the primary population of stars there is similar to the old stars found in the halo.

ACTIVE GALAXIES

Active Galaxies are galaxies characterized by certain properties: (1) High Luminosity, (2) Nonthermal Spectra that do not look like the sum of many stellar spectra, (3) Most of the luminosity is in a region of the spectrum other than optical (e.g., radio, UV, Infrared), (4) bright, star-like nucleus, (5) strong emission lines (most), (6) rapid variability, and sometimes (7) radio jets.
QUASARS
A quasi-stellar radio source (quasar) is a very energetic and distant galaxy with an active galactic nucleus. Quasars show a very high redshift, which is an effect of the expansion of the universe between the quasar and the Earth. They are the most luminous, powerful, and energetic objects known in the universe. Quasars are believed to be powered by accretion of material into supermassive black holes in the nuclei of distant galaxies, making these luminous versions of the general class of objects known as active galaxies.

RADIO GALAXIES
Radio galaxies and their relatives, radio-loud quasars and blazars, are types of active galaxy that are very luminous at radio wavelengths. Radio galaxies and radio-loud quasars have been widely used, particularly in the 80s and 90s, to find distant galaxies: by selecting based on radio spectrum and then observing the host galaxy it was possible to find objects at high redshift at modest cost in telescope time. The problem with this method is that hosts of active galaxies may not be typical of galaxies at their redshift. Similarly, radio galaxies have in the past been used to find distant X-ray emitting clusters, but unbiased selection methods are now preferred.

SEYFERT GALAXIES
Seyfert galaxies are characterized by extremely bright nuclei, and spectra which have very bright emission lines of hydrogen, helium, nitrogen, and oxygen. These emission lines may come from the surface of the accretion disk itself, or may come from clouds of gas illuminated by the central engine in an ionization cone. Seyferts were first classified as Type 1 or 2, depending upon whether the spectra show both narrow and broad emission lines (Type 1), or only narrow lines (Type 2).

GALAXY FORMATION AND EVOLUTION
The study of galaxy formation and evolution is concerned with the processes that formed a heterogeneous universe from a homogeneous beginning, the formation of the first galaxies, the way galaxies change over time, and the processes that have generated the variety of structures observed in nearby galaxies. It is one of the most active research areas in astrophysics.

After the Big Bang, the universe, for a time, was remarkably homogeneous, as can be observed in the Cosmic Microwave Background. As the universe cooled clumps of dark matter began to condense, and within them gas began to condense. The primordial fluctuations gravitationally attracted gas and dark matter to the denser areas, and thus the seeds that would later become galaxies were formed. These structures constituted the first galaxies. At this point the universe was almost exclusively composed of hydrogen, helium, and dark matter. Soon after the first proto-galaxies formed the hydrogen and helium gas within them began to condense and make the first stars. Thus the first galaxies were then formed.

In 2007 the Keck telescope, a team from California Institute of Technology found six star forming galaxies about 13.2 billion light years (light travel distance) away and therefore created when the universe was only 500 million years old.
The key properties of disk galaxies, which are also commonly called spiral galaxies, is that they are very thin, rotate rapidly, and often show spiral structure. One of the main challenges to galaxy formation is the great number of thin disk galaxies in the local universe. The problem is that disks are very fragile, and mergers with other galaxies can quickly destroy thin disks.

Our own galaxy (the Milky Way) has a tiny satellite galaxy (the Sagittarius Dwarf Elliptical Galaxy) which is currently gradually being ripped up and “eaten” by the Milky Way. It is thought these kinds of events may be quite common in the evolution of large galaxies. The Sagittarius dwarf galaxy is orbiting our galaxy at almost a right angle to the disk.

The most massive galaxies in the sky are giant elliptical galaxies. Their stars are on orbits that are randomly oriented within the galaxy. They are composed of old stars and have little to no dust. All elliptical galaxies probed so far have supermassive black holes in their center, and the mass of these black holes is correlated with the mass of the elliptical galaxy. They are also correlated to a property called sigma which is the speed of the stars at the far edge of the elliptical galaxies. Elliptical galaxies do not have disks around them, although some bulges of disk galaxies look similar to elliptical galaxies.

Commonly Observed Properties of Galaxies

- Spiral galaxies and the Galactic disk are quite thin, dense, and rotate very fast. The Milky Way disk is 100 times longer than it is thick.
- The majority of mass in galaxies is made up of dark matter, a substance which is not directly observable, and does not interact through any means except gravity.
- Halo stars are typically much older and have much lower metallicities (that is to say they are almost exclusively composed of hydrogen and helium) than disk stars.
- Many disk galaxies have a puffed up outer disk (often called the “thick disk”) that is composed of old stars.
- Globular clusters are typically old and metal-poor as well, but there are a few which are not nearly as metal-poor as most, and/or have some younger stars. Some stars in globular clusters appear to be as old as the universe itself (by entirely different measurement and analysis methods).
- High Velocity Clouds, clouds of neutral hydrogen are “raining” down on the galaxy, and presumably have been from the beginning (these would be the necessary source of a gas disk from which the disk stars formed).
- Galaxies come in a great variety of shapes and sizes (see the Hubble Sequence) from giant featureless blobs of old stars (called elliptical galaxies) to thin disks with gas and stars arranged in highly ordered spirals.
- The majority of giant galaxies contain a supermassive black hole in their centers, ranging in mass from millions to billions of times the mass of our sun. The black hole mass is tied to properties of the galaxy that hosts it.
- Many of the properties of galaxies (including the galaxy color-magnitude diagram) indicate that there are fundamentally two types of galaxies. These groups divide into blue-star forming galaxies that are more like spiral types, and red-nonstar forming galaxies that are more like elliptical galaxies.
THE BIG BANG THEORY

The Big Bang theory (or Big Bang model) is the prevailing cosmological theory of the early development of the universe. The theory postulates that the Big Bang event took place at some finite time in the past: according to the best available measurements as of 2009, around 13.7 billion years ago. According to the Big Bang model, the universe, originally in an extremely hot and dense state that expanded rapidly, has since cooled by expanding to the present diluted state, and continues to expand today. The theory is the most comprehensive and accurate explanation supported by scientific evidence and observations.

The ultimate fate of the universe is a topic in physical cosmology. Many possible fates are predicted by rival scientific theories, including futures of both finite and infinite duration. Once the notion that the universe started with a Big Bang became accepted by a consensus of scientists, the ultimate fate of the universe became a valid cosmological question, one depending upon the physical properties of the mass/energy in the universe, its average density, and the rate of expansion.

In astronomy and cosmology, dark matter is matter that is inferred to exist from gravitational effects on visible matter and background radiation, but is undetectable by emitted or scattered electromagnetic radiation.

THE FUTURE OF THE UNIVERSE

Closed Universe
In a closed universe lacking the repulsive effect of dark energy, gravity eventually stops the expansion of the universe, after which it starts to contract until all matter in the universe collapses to a point, a final singularity termed the “Big Crunch”, by analogy with Big Bang. However, if the universe has a large amount of dark energy (as suggested by recent findings), then the expansion of the universe can continue forever – even if \( \Omega > 1 \).

Open Universe
If \( \Omega < 1 \), the geometry of space is open, i.e., negatively curved like the surface of a saddle. The angles of a triangle sum to less than 180 degrees, and lines that do not meet are never equidistant; they have a point of least distance and otherwise grow apart. The geometry of such a universe is hyperbolic.
Even without dark energy, a negatively curved universe expands forever, with gravity barely slowing the rate of expansion. With dark energy, the expansion not only continues but accelerates. The ultimate fate of an open universe is either universal heat death, the "Big Freeze", or the "Big Rip", where the acceleration caused by dark energy eventually becomes so strong that it completely overwhelms the effects of the gravitational, electromagnetic and weak binding forces. Conversely, a negative cosmological constant, which would correspond to a negative energy density and positive pressure, would cause even an open universe to recollapse to a big crunch. This option has been ruled out by observations.

**Flat universe**

If the average density of the universe exactly equals the critical density so that $\Omega=1$, then the geometry of the universe is flat: as in Euclidean geometry, the sum of the angles of a triangle is 180 degrees and parallel lines continuously maintain the same distance. Absent dark energy, a flat universe expands forever but at a continually decelerating rate, with expansion asymptotically approaching a fixed rate. With dark energy, the expansion rate of the universe initially slows down, due to the effect of gravity, but eventually increases. The ultimate fate of the universe is the same as an open universe.
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