DR. M. G. R GOVT. ARTS AND SCIENCE COLLEGE FOR WOMEN-VILLUPURAM

Department Of Physics

Unit: I **Subject: Astrophysics**

Telescopes - an Introduction

For astronomical observations, the telescope is the most important instrument in use today. Telescopes which are used for observations in the optical wavelengths of the electromagnetic spectrum are known as optical telescopes. Those which are used to detect electromagnetic radiation emitted in the radio wavelength are known as the radio telescopes. Optical telescopes are of two kinds, viz. refracting and reflecting, having their objectives as a lens or a mirror respectively. The former is of more general use and smaller in size; however, the largest telescopes in the world are of the latter type.

Optical Telescopes

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Optical telescopes are of two kinds, viz. refracting and reflecting, having their objectives as a lens or a mirror respectively. The former is of more general use and smaller in size as a rule; however, the largest telescopes in the world are of the latter type. The fundamental principle is the same in both: a real image of a luminous object is formed at the focus of the large lens (refractor) or the mirror (reflector) of the instrument. This image is then magnified by an eyepiece which serves as a magnifying glass.

Magnifying Power: The main function of the eyepiece is to bring the image very close to the observer's eye with the help of a lens of very small focal length (usually 0".5 to 1"), and thus magnify the image several tens to hundreds of times. The magnifying power Q of a telescope is the ratio of the focal length F of the objective to the focal length/of the eyepiece.

Thus,

$$Q = F/f$$

For example, the magnification Q in a telescope of focal length 600" (e.g., the 120-inch reflector at Lick) and using an eyepiece of focal length 1" is 600, and so on.

Brightness of Image: The brightness of the image of an object formed at the focus of a telescope depends on the aperture of the objective. The light-gathering power of a lens or a mirror is proportional to the square of its aperture. Thus more and more faint objects are accessible with telescopes of larger and larger apertures. The 200-inch reflector at Mount Palomar can penetrate through objects four times as faint as can be penetrated with the 100-inch reflector and 25 times as faint as can be done with the 40-inch reflector at Kavalur.

In order to observe fainter and fainter objects, one has thus to increase the aperture of the telescope objective. There is no other known optical method to achieve the higher brightness of the image at the focus. The Keck telescopes at Mauna Kea, Hawaii are at present the largest optical telescopes in the world. For extended objects like the moon, planets and nebulae, the brightness of the image depends on both the aperture as well as the focal length of the telescope. The area of the image of an extended object, formed at the focus is proportional to the square of the focal length. If two telescopes have focal lengths in the ratio of 1:2, the diameter of the image of, say, jupiter or moon at the focus will also bear the same ratio. The surface area of the image will therefore be four times. Now, if these two telescopes have the same aperture, the total light gathered from the object by both is the same. Thus, the same amount of light is spread in the image of one with larger aperture over an area four times that of the other with smaller aperture. The brightness of the image in the former will, therefore, be four times dimmer than in the latter, since the amount of light per unit area is four times less in the former than in the latter. This is the reason why moon's surface is visible in considerable detail with a telescope of small aperture than with the naked eye. The details are washed out to the naked eye by the excessive flood of light, but when a telescope is used, the light is dimmed by spreading over larger areas showing the details there. In the case of stars, on the other hand, since they produce point images, the maximum advantage is gained by using the largest apertures.

Resolving Power: Due to the wave properties of light, it is subjected to diffraction and interference. Thus the image of a star produced at the focus of a telescope is not just a point image, but a diffracted image, that is, a tiny spot of finite size surrounded by concentric diffraction rings. The net effect of this is that the stellar image is produced on a much larger surface area than it would be if it was just a point image and there were no effects of diffraction. As a result, the chance of overlapping of the images of two stars which are close together is much more increased if the diffraction pattern is present than if this pattern is absent. This increased chance of overlapping limits the resolving power of a telescope. If the two stars are so close that their diffraction discs overlap, we say that the stars are not resolved. The diffraction discs are rendered smaller by using a larger aperture and the stars may then be separated. Thus the resolving power of a telescope depends on its aperture. There is no other optical means which can be applied to increase the resolving power. No amount of magnification is of any use. The limit of resolution is given by the formula

$$\textit{Limit of resolution} = \frac{4.5}{a} \ \textit{seconds of arc},$$

where a is the aperture of the telescope in inches. This is known as Dawes' rule. According to this formula, the limit of resolution of the Kavalur 40-inch reflector is 0".1125, while that of the 200-inch reflector at Mount Palomar is 0".0225, i.e. two stars separated by 0".0225 will be resolved by the 200-inch telescope.

The diffracted image of a star.

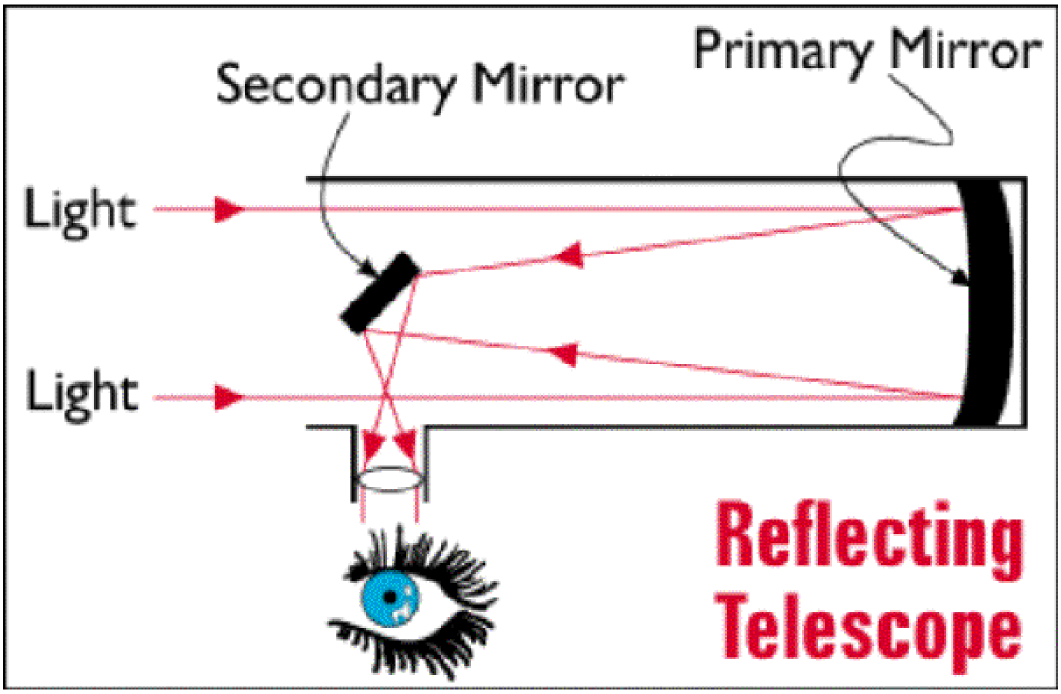
The f/a Ratio: The ratio of the focal length to the aperture of a telescope, called the focal ratio or f-ratio, is an important quantity to be designed in the construction of a telescope to serve some specific objectives. As we have already seen, the light gathering power of a telescope depends on a only, whereas the size of the image depends on/only. So the focal ratio will, in general, influence the brightness of the image. Large focal ratio indicates the spreading of the image over a larger area. Large reflectors generally have paraboloid mirrors with their focal ratios lying between 3 and 5, or somewhat larger. The focal ratio of the 200-inch Hale reflector is 3.3, which implies that its paraboloid mirror has a focal length of 660-inches. It is expressed as f/3.3. The 120-inch Lick telescope has a focal ratio of 5.0. In fact, f/5 is a traditional value for earlier large telescopes. The Magdonaid 82-inch telescope is JH.

Of the various advantages that may be derived from different /-ratios, those obtained from small/-ratios are more important. To mention two of them, one is the smaller expenditure for the complete construction, and the other is the availability of more accurately defined optical system. There are many other points in the construction technicalities as well as good functioning of a telescope which are related to the /-ratio. Also, since different foci are designed in large telescopes, the /-ratio changes from one focus to the other.

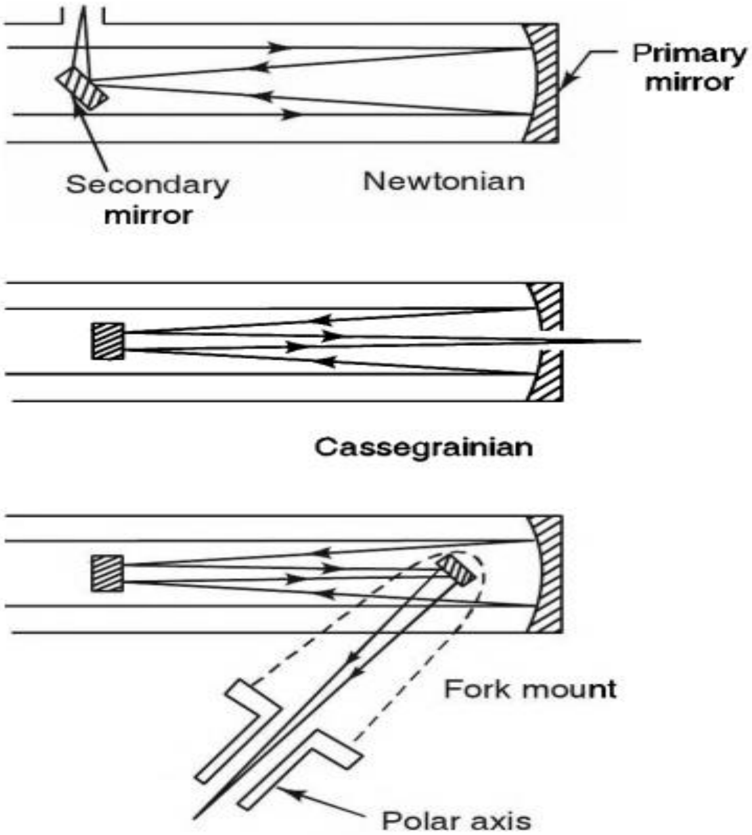
Types of Reflecting Telescopes

The design of reflecting telescope originated with the work of Sir Issac Newton.

In a reflecting telescope, or reflector, an image of a distant object is formed in the focus of a concave mirror. The objective of a reflecting telescope is typically a paraboloidal mirror. The incoming starlight is reflected by the concave mirror and converges to a focal point. The distance between the



mirror and the focal point is called the focal length. The paraboloidal mirror which reflects the parallel rays of light it collects from an object and focuses them at the focal point where image is formed. When the diameter of the objective is very large, the observer may be located at the focal point This system, seldom used for visual observation but used extensively in the photography and spectroscopy, is called prime focus.



Newtonian focus, invented by Newton, is a popular system for visual observation. It consists of a secondary flat mirror located in the axis of the telescope at an angle Of 450, which diverts the light rays to the side of the tube. The image is formed and observed through an eyepiece located on the side of the tube. A reflecting telescope having this optical design is called a Newtonian reflector.

Another popular optical design, called a Cassegrain focus also has a convenient, accessible focus point. It uses a secondary convex hyperbolic mirror located on the axis of the telescope at to the axis and a hole is drilled directly through the centre of the primary mirror. The secondary mirror diverts the light rays back through a hole in the objective and form the image behind the objective where it can be observed visually or photographed. The Cassegrain focus is a more convenient instrument than Newtonian focus, because a larger image with more magnification is produced with this system. Its disadvantage is a smaller field of view.

In a fourth design, a series of mirrors channels the light ray; away from the telescope to a remote focal point. The Coude's focus uses a secondary hyperbolic mirror similar to that in Cassegrain focus and a flat mirror located between the objective and the secondary mirror, which diverts the light down through a hole in the polar axis of the telescope to a stationary observation station. Coude's telescope is used for spectroscopic analysis.

Advantages

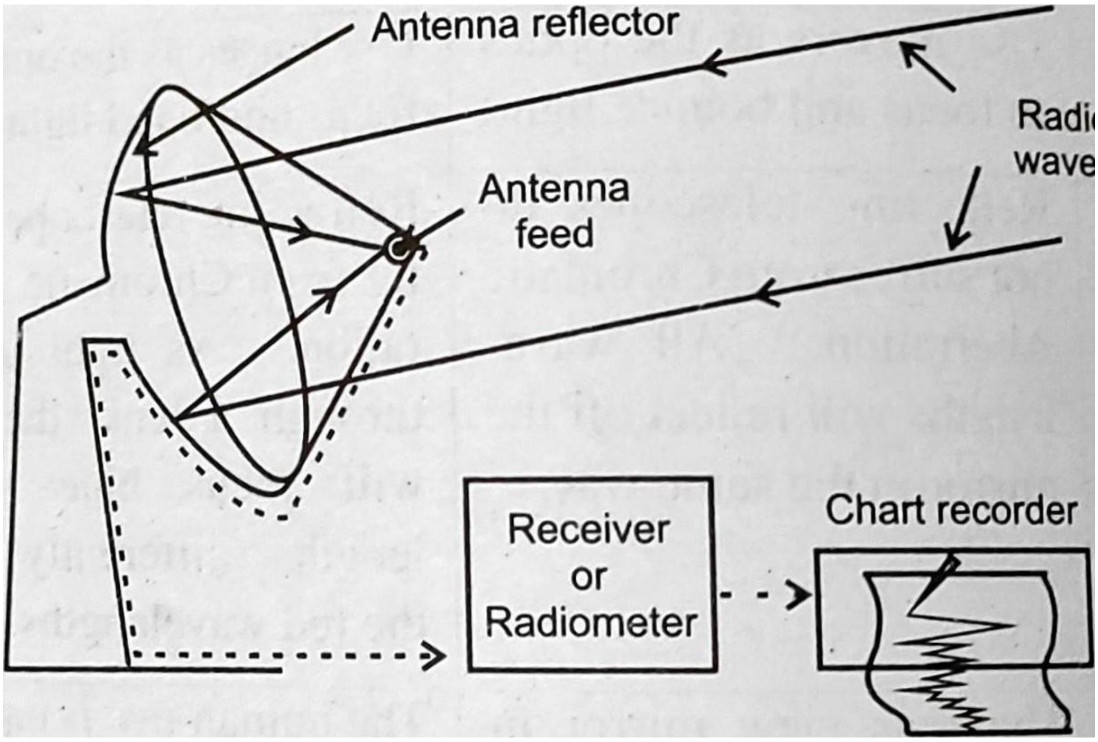
1. Reflector telescopes do not suffer from chromatic aberration because all wavelengths will reflect off the mirror in the same way
2. Support for the objective mirror is all along the back side so they can be made very big.
3. Reflector telescopes are cheaper to make than refractors of the same size.
4. Because light is reflecting off the objective, rather than passing through it, only one side of the reflector telescope's objective needs to be perfect

Disadvantages

- Often the optics of the telescope gets out of alignment.
- A reflector telescope's tube is open to the outside and the optics need frequent cleaning.
- Often a secondary mirror is used to redirect the light into a more convenient viewing spot. The secondary mirror and its supports can produce diffraction effect

Radio Telescope

The optical telescope limited our view of the universe to the visible wavelengths of the electromagnetic spectrum, but the branch of radio astronomy and the construction of radio telescopes greatly extended our astronomical horizons. It opened up a new window in the electromagnetic spectrum by permit, ting the use of radio region for the observations of extra-ter-restrial sources, such as stars, galaxies, pulsars and quasars, Most of the observations are made in the range from 1 mm to 15 meter wavelengths for which atmosphere is nearly transparent.



The elements of radio telescope

The principle of the radio telescope is based on several properties of radio waves. They can be refracted and reflected in the same manner as light waves; and they can be amplified by electronic techniques. In addition, except for the shortest radio waves, they are not influenced by the earth's atmosphere. The essential features of a radio telescope are the antenna and the receiver (radiometer) is shown in the schematic diagram. The antenna collects and concentrates the radio energy at its focus, where it is picked up by s “feed” that convey it to the radiometer, where energy is measured and its value recorded.

The resolving power of a radio telescope is its ability to separate the angular distance between two radio sources, ability varies inversely with wavelength and directly with diameter antenna dish, and is similar to the power of the optical telescope. Since the radio wavelength arc higher than wavelengths of visible light, the resolving power of a radio telescope is much less than that of optical telescope. But, large radio telescopes can produce somewhat better radio image, since the angular resolution is directly proportional to the diameter of the telescope. In other words, bigger the dish the better the resolution.
In some radio telescopes, the antenna is fixed and the rotation of the earth is used to direct the antenna to different areas of the sky. This procedure, limits the time an object can be observed. Some antennas have a fixed reflector with a movable "feed".

Some antennas are composed of' numerous small reflectors, each of which can be independently pointed at a radio source. The signals are then electronically added together, this technique is called aperture synthesis.

Advantages

1. Radio waves are not blocked by clouds and are unaffected by the Earth's atmosphere, thus radio telescopes can receive signals during cloud cover.
2. Radio telescopes are useful in astronomy because radio waves can be observed any time of' the day or night. exception being strong winds which affect the large dish and thunderstorms due to interference.

Astronomical Spectrographs

The spectroscope or spectrograph is an instrument that can separate a non-monochromatic beam of light into its constituent wavelengths and can record the intensities of the radiation according to the wavelengths. The instrument is so called according to the way it is used. If the observations are made with the naked eye with an eyepiece, the instrument is called a spectroscope. The same instrument is called a spectrograph if the record is photographed at the focus. For astronomical observations, it is used to analyze a starlight from which important information like the chemical composition, the physical conditions of the stellar atmospheres as also the evolutionary stage of the star may be known. From the study of the Doppler shifts of the spectral lines, we can calculate the radial velocities of stars and other objects in the sky.

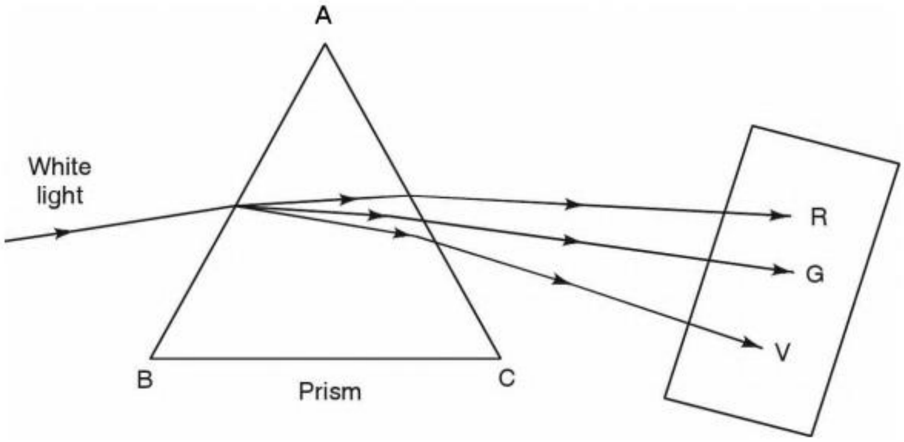
There are several other factors which have to be considered while choosing the suitable spectrograph for a particular purpose. The range of wavelengths over which the spectroscope would serve, its power of resolving two close lines in the spectrum, the nature of the dispersing material and its dispersive power, the variation of the dispersion with wavelengths of the incident radiation, the brightness and the speed of recording of the spectra of faint celestial sources, are some of the factors which should be taken as primary considerations.

Other factors like the absorption and scattering in the instrument and the size and shape of the instrumental profiles as well as those of the actual line profiles should also be observed with great care. The principal part of a spectrograph is the dispersing medium, which disperses light to different extents, depending on the wavelengths of the incident radiation and of the dispersing material used. All that we need is a good spectrum even for a very faint object, and the other parts of the spectrograph are designed accordingly. Sometimes scales are attached with the spectrographs to measure the wavelengths directly from the spectrum. These scales may be calibrated in microns, millimicrons or in angstroms to study the fine details. The dispersing medium in a spectrograph may be mainly of two types:

(a) the prism made of glass or quartz, and (b) the diffraction grating. These are now discussed.

The Prism

The prism is generally made of glass or quartz and is used in the form of an equilateral triangle. When white light is made to fall upon the face AB of the prism, it gets refracted and dispersed into its component colours. The amount of dispersion is proportional



Dispersion of light of different wavelengths through a prism.

to the component wavelengths and depends on the material (or refractive index) of the prism. It is found that the dispersion occurs as a result of the change of speed of the constituent wavelengths on entering the face AB and this change is greater for the shorter wavelengths. On emerging from the face AC of the prism, the rays are further refracted and dispersed to form a spectrum on a screen or on a photographic plate. In this spectrum, the colours are found to be placed in the order of their wavelengths and the violet ray (of shortest wavelength) is found to be the most deviated from its original direction and the red ray (of greatest wavelength) the least deviated.

The Diffraction Grating

A diffraction grating is a surface consisting of a large number of finely placed close equidistant lines called the diffraction lines. There are mainly two types of gratings which are used in practice for astronomical spectroscopy. They are: (a) the transmission grating, and (b) the reflection grating.

The transmission grating consists of a transparent surface (e.g. glass) ruled with a large number of fine parallel equidistant lines or grooves in a small surface (thousands of lines per inch, may be 10,000 lines or more per inch), so that light can only pass through and disperse by the surface between the lines (or scratches). This type of grating is generally used in small grating spectrometers and spectroscopes.

In a reflection grating, light encounters a polished surface (e.g. a mirror) which has similar fine, equidistant, close parallel lines or grooves, so that light is reflected by the polished surface between the lines or scratches. Reflection grating may be either plane or concave. The Rowland's concave grating named after H.A. Rowland is in much use as a dispersing medium of a spectrograph. Reflection gratings containing 5000 to as many as 30,000 lines or grooves per inch have been made possible. They are used mostly in large spectrographs.

Photographic Photometry

Photometry is the means for recording the brightness of stars and other heavenly objects with the help of suitable instruments and accessories placed at the focus of a telescope. Different accessories are used for different types of photometry, serving different astronomical objectives. Photographic photometry is chiefly used for its high sensitivity and the panoramic property of the photographic emulsions. The principal uses of this method lie in the fact that it integrates the light over the given exposure and that a good number of stars can be simultaneously photographed. This gives a permanent record of a large number of stars in a given region of the sky and the technique does not require high precision. The saving in telescopic time is also an advantage of this method. It is particularly useful in the field of astrophysics such as stellar statistics, variable star surveys or investigations of rich star clusters, galaxies and clusters of galaxies.

The fundamental principle of photographic photometry is that equal intensities of two sources should produce equal photographic effects on the emulsions under identical conditions. These conditions involve factors like the spectral energy distribution of the exposing light, the exposure time, the processing of the photographic plate, the pre- and past-exposure treatment of the plate, the size and structure of the optical image, the temperature and luminosity of the exposed source, etc.

The main disadvantage of using this method is that it is difficult to control the above factors carefully and account for the changes involved in some of these conditions. Also, the extreme variation of sensitivity of the photographic emulsions with wavelengths, the delay in photographic processing etc. are some of the factors which degrade the photographic photometry to some extent. In spite of these disadvantages, photographic photometry is widely used in astronomy. The intensity of a starlight is measured by the amount of blackening of the star image on the photographic negative. This blackening can be measured by passing a collimated beam of light through the star image on the negative. The attenuation of the beam is then measured with a photocell. The brighter the star, the darker is its image and more is the attenuation of the beam, while for a faint star, the attenuation is small and the image is thus less dark.

PHOTOELECTRIC PHOTOMETRY

Today, the stellar magnitudes are determined much more accurately by modern photoelectric methods. Photoelectric photometry provides such measurements where higher sensitivity and greatest possible accuracy is demanded. This employs a photoelectric photometer by which the intensity of a star light can be accurately measured. The principal parts of an astronomical photoelectric, photometer are:

- Finding-guiding eyepiece
- A focal plane diaphragm containing a hole isolating the object to be viewed
- A field lens
- Suitable filters
- A suitable detector with amplifier and a recording system.

The last one includes a photomultiplier. The photomultiplier is a photoelectric cell placed at the focus of the telescope. The star light is focussed by telescope on the photo emissive cathode of the photocell through its transparent envelope. When light from a source hits the photocell, electrons are emitted from the inner surface of the photocathode which is usually coated with potassium or antimony-cesium alloys or with cesium oxide. The electrons emitted are accelerated by the voltage existing between the terminals of the photoelectric cell and are then made to strike a second photosensitive surface called a dynode. When the photoelectrons from the cathode encounter this dynode, they dislodge more electrons from the surface than their original number. This emission of the secondary electrons is proportional to the number of primary electrons striking the dynode which again are proportional to the intensity of the celestial source.

The secondary electrons, in turn, encounter a second dynode which gives off more electrons than the secondary ones, and this process is repeated through successive dynodes until a considerably strong current is obtained. This current is amplified by an external amplifier and then recorded by a pen on a continuously rolling sheet of paper. It has been experimentally found that if we use a dozen dynodes, we might record a current whose strength would be a million times that produced by the primary electrons from the photocathode.

The photoelectric photometry has been most successfully and widely used for the study of variable and eclipsing binary stars and also for finding the colour magnitude diagrams of clusters of stars. These points will be further discussed in the respective chapters. Several filters are usually used successively to record the intensity at several different narrow bands of wavelengths. The most popular are the U, B, V bands that give rise to the three-colour photometry. This has been very extensively used and is being used still to study the colour, magnitude or other aspects of stars. In particular, U, B, V photometry has excelled in the study of the light and colour curves of the variable stars. The V magnitude in the three colour system nearly corresponds to the usual visual magnitude of a star.

The three-colour photometry has been extended to include the broader wavelength regions. This gives rise to six-colour photometry which ranges from the ultraviolet to infrared regions of the spectrum and covers the range of wavelengths from 3300 to 12,500 A. The six-colour system is chiefly used for the determination of colours of stars (specially the bright ones having the magnitude value up to +7), from which their energy distributions are known. The disadvantage of this method is the excessive loss of telescopic time. The photometric observations yield chiefly the brightness of celestial objects as a function of certain parameters, such as wavelength, and time. For each set of observations, these parameters have to be determined in order to get the brightness of objects. The wavelength is almost an essential parameter. The direct measures of brightness which are obtained in any photometric study are functions not only of the above mentioned parameters but also of various other parameters related to the equipment which receives the light and to the atmosphere through which the light passes. Also, the particles in the interstellar-space dim or extinct the light during its journey through space and this dimming is proportional to the distance of the source of light. For any useful measure of a set of observational material, corrections must be made for all these various factors.

Spectrophotometry

In photographic and photoelectric photometry, the total intensity of radiation is measured from a star and accordingly the magnitude of the star is assigned. These methods do not always require the actual spectral energy distribution of the source of light, whereas, spectrophotometry is used solely for measuring the spectral energy distribution of the light source. This involves the relative measurement of the intensities of the spectral lines with those due to a standard laboratory source in the same spectral region. By a comparative study with the known lines of the standard source, the energy distribution of the desired object at each wavelength may be known.

Stellar spectrophotometry involves both the relative and absolute measurements of the spectral energy distribution of the stars in all observable regions. Such measurements should be made accurate for studying the physical conditions of the atmosphere of a star. The most frequent problem in stellar spectrophotometry is to measure the continuous energy distributions in stellar spectra and to determine the intensities of the spectral lines relative to that of the continuum. The intensity of the spectral energy distribution of a star is measured either by photographic or by photoelectric methods. The photographic or photoelectric detector is placed at the focus of a spectrograph attached to a telescope.

In the photoelectric method, the detector is a photometer which scans the stellar spectrum according to the wavelengths and thus provides an accurate measurement of stellar energy distribution. Photographic spectrophotometry, although less accurate, has some advantages over the photoelectric method, the principal one among these being that it covers a wide range of wavelengths in a single exposure and integrates the light received over a given exposure. This method is also useful for the sensitivity of the photographic plate over a large range of wavelengths (starting from UV up to 12,000 A) and for the permanency of the photographic negatives, which can be used at any time. There are, however, many disadvantages of photographic spectrophotometry, decided chiefly by the limitations of the photographic emulsions.

The variation of the spectral sensitivity curve of a photographic plate with wavelengths and with the type of emulsion used is one of the principal disadvantages of this method. Photoelectric spectrophotometry, on the other hand, is unrivalled for its high accuracy which is demanded by the advanced astrophysics of today. Precise measurements of the stellar energy distribution and the line profiles are done by this method. The chief advantages of this method are the linearity of response of the photo-emissive surfaces (i.e. the linear relation existing between the number of incident photons and the electrical output), their high sensitivity and speed of response (quantum efficiency). The main disadvantage is, however, its inability to record more than one picture at a time in a single exposure. Thus, a lot of valuable telescopic time has to be spent on each single source.

Detectors and Image Processing

The light gathered by telescopes from heavenly objects, either single or many at a time within the field of view of the telescope, is recorded by astronomers with a detector, and the recorded images are analyzed and studied conveniently under desired conditions, the classical and most extensively used detector over many decades is the photographic plate, usually glass plate coated with light-sensitive emulsion. Photography still serves as the old standby when recording of a large amount of storable information is desired in a short time. The plates are often specially treated to increase their sensitivity to light, but still their quantum efficiency (i.e., percentage of photons striking the detector which activate it, relative to the total incoming photons striking the detector) remains very low, only to the level of a few per cent.

The incident light knocks out electrons from certain materials inside the tube which later multiply to many times (- 105 times) by repeating the process inside the tube. Such tubes are therefore called photomultipliers. The displaced electrons flow in the form of a current, the measured strength of which tells about the intensity of the incident light. In such a device, wavelength bands can be isolated by using filters in the light path in front of the photomultiplier. The quantum efficiency of photomultipliers is much higher than that of the photographic plates. Its response is smoothly linear—twice the flux produces twice the current.

The accuracy of measurement of the current or counting the rate of production of the individual photons may be very high. At present, however, the dream detector of astronomers is the *Charge-Coupled Device* (CCD) which has been made possible by the great advancement in solid-state microelectronics. A CCD is a thin silicon wafer a few to 10 mm on each side. The chip consists of a large number of small regions, each of which makes up a picture element called a pixel, A typical CCD chip may contain 1000 by 1000 pixels (106 total) arranged in rows and columns that can be controlled electronically. Each pixel converts photons to electrons (thus behaves like a small phototube) and builds, up charge over a very long time. The integrated charges are then moved in a regimented way to preserve the spatial pattern of light intensity falling on the chip in computers, which then process the image for astronomers to study at ease. The quantum efficiency of CCDs is very high, nearly 100 per cent, so that even small telescopes equipped with CCDs can imitate the efficiency of large telescopes. Also, CCDs are smoothly linear; hence light intensity can be measured accurately. Like photographic plates, CCDs also gather a large amount of information in one exposure. But the advantage over photographic plates is that CCDs collect information in digital format for easy manipulation by computers.

Unit - 3
Stars

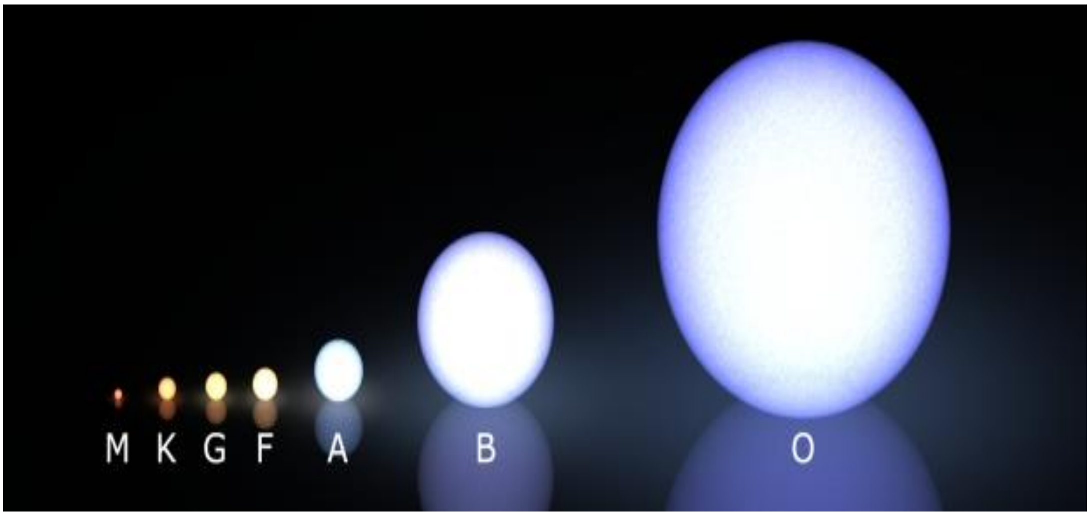
Star Cluster

Stars are massive, luminous balls of hot gas (plasma), which are held together by gravity.
Although they look small, they are actually large bright objects like the Sun. They look so small because they are very far away - the **nearest** star, Alpha Centauri is 4.3 light years away, this is approximately 41,000,000,000,000 km away!
All the energy in a star is produced in its centre, or **core**, by nuclear fusion. This energy emerges from the star as heat and light so that the star appears to glow, i.e. it is luminous.
In astronomy we measure the brightness of stars in different ways.
Stars come in lots of different **sizes** and **colours**, which can tell us a lot about what type of star they are.
Stars exist because of a **balance** between gravity trying to make the star shrink and all the heat from the middle trying to make it grow.

Stars "live" for many millions of years, but they do not change much during most of that time. However, amazing things can happen when they are born or when they run out of nuclear fuel and die. Explore this more in the **life cycle** section below.

Stellar Classification

Different **stars** can be categorised into certain groups, depending on their **mass** and **temperature**. Over the centuries, the classification of stars has evolved into seven distinct **classes** or groups. This system was created by **Annie Jump Cannon** and the groups are known as O, B, A, F, G, K and M. Stars classified in the 'O' group are the most massive and hottest, with temperatures exceeding 30,000°C, whilst those in the 'M' group are the smallest and coolest, with temperatures less than 3,000°C.



Stars of different temperatures appear to shine with **different colours**. This is similar to what happens when you heat up a lump of metal to very high temperatures. After heating the metal for some time, it will start to glow red. As it gets hotter still, that red will evolve into yellow, then white and eventually the metal will be glowing a bright blue colour. In the same way, it turns out that blue stars are very hot and are therefore classed as 'O' stars, whereas the cooler, red stars, are placed into the 'M' class.

When we think about our star, the **Sun**, we picture it as being yellow. It is therefore not surprising to discover that the Sun is classed as a 'G' star, with a temperature of approximately 5,500°C. The following table lists the different classes of stars, along with their approximate temperatures and colours.

Class	Temperature (°C)	Colour
O	> 30,000	Blue
B	20,000	Blue-White
A	10,000	White
F	7,000	Yellow-White
G	6,000	Yellow
K	5,000	Orange
M	3,000	Red

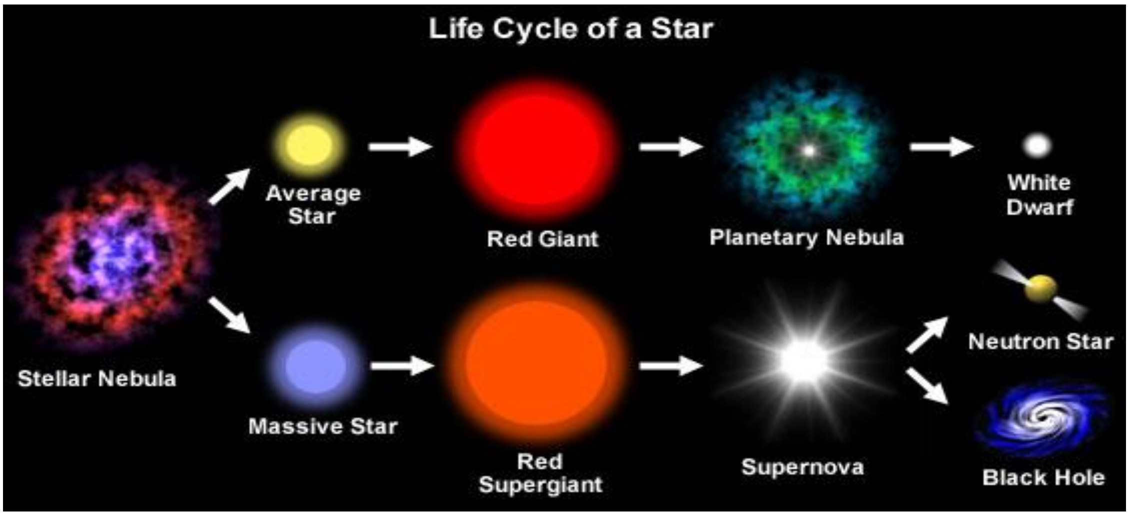
Stars can be more accurately categorised under this system, by the addition of a number between 0-9 to the group letter. For example, G2 (the Sun’s more precise spectral class) is hotter than G7, but cooler than a G0. Similarly, a B9 star is cooler than a B4.

Colours of Stars

Stars come in lots of different colours, and their colour depends on the temperature of the star.
We find that small stars are cool (less than 3000°C) with a **red**-ish appearance, whereas big heavy stars are hot (over 30,000°C), and have a **blue**-ish glow. At about 6,000 °C, the **Sun** is considered to be on the cooler side and, as we all know, has a **yellow**-ish look about it.
In fact, the temperature of a star, and therefore its colour, actually depends on the amount of **mass** it has. Very massive stars, which can be over ten times the mass of the Sun, are the hottest, and smaller stars, with less than half the mass of the Sun, are the coolest.
Although they are bigger, the hot, blue stars do not "live" as long as the smaller ones, because they use up their **nuclear fusion** much more quickly. The hottest stars will only live for a few million years, whereas the smallest stars will live for hundreds of billions of years.
Our Sun is around halfway through its 10 billion year **lifetime**.

Life Cycle of a Star

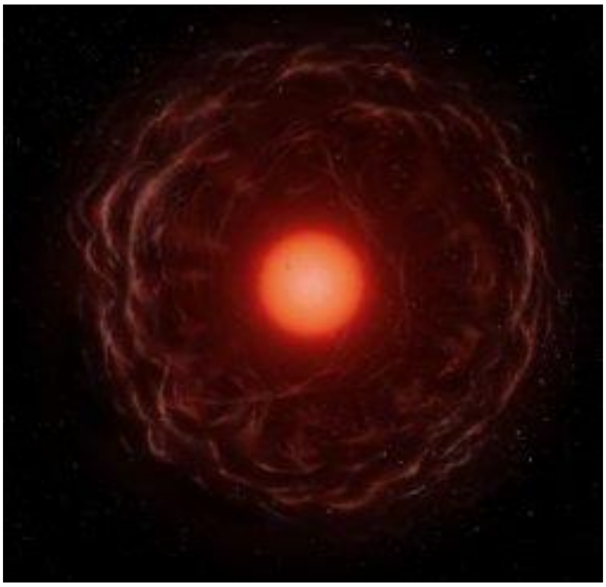
Stars are **formed** in clouds of gas and dust, known as nebulae. **Nuclear reactions** at the centre (or core) of stars provides enough energy to make them shine brightly for many years. This stage is known as the '**main sequence**'. The exact lifetime of a **star** depends very much on its **size**. Very large, massive stars burn their fuel much faster than smaller stars and may only last a few hundred thousand years. Smaller stars, however, will last for several billion years, because they burn their fuel much more slowly.



Eventually, however, the hydrogen fuel that powers the nuclear reactions within stars will begin to run out, and they will enter the final phases of their lifetime. Over time, they will expand, cool and change colour to become **red giants**. The path they follow beyond that depends on the **mass** of the star.
Small stars, like the **Sun**, will undergo a relatively peaceful and beautiful death that sees them pass through a **planetary nebula** phase to become a **white dwarf**, which eventually cools down over time and stops

glowing to become a so-called "black dwarf". Massive stars, on the other hand, will experience a most energetic and violent end, which will see their remains scattered about the cosmos in a enormous explosion, called a **supernova**. Once the dust clears, the only thing remaining will be a very dense star known as a **neutron star**, these can often be rapidly spinning and are known as **pulsars**. If the star which explodes is especially large, it can even form a **black hole**.

Red Giant



When hydrogen fuel at the centre of a **star** is exhausted, **nuclear reactions** will start move outwards into its atmosphere and burn the hydrogen that's in a shell surrounding the core. As a result, the outside of the star starts to expand and cool, turning much redder. Over time, the star will change into a **red giant** and grow to more than 400 times its original size.

As they expand, red giants engulf some of their close-orbiting planets. In the **Sun's** case, this will mean the fiery end of all the **inner** planets of our Solar System, which might also include the **Earth**; but don't worry, this won't happen for another 5,000,000,000 years.

While the atmosphere of the star grows, its core shrinks due to **gravity**. Temperatures and pressures in the middle increase until the conditions are right for **nuclear fusion** to start again, but this time using **helium** as a fuel, rather than hydrogen.

With the star being powered by helium, its outer layers return to normal for a while and it starts to shrink, get hotter and turn a little more blue. However, this stage only lasts for a million years or so, as the helium quickly runs out. When it does, the core shrinks again and this time the helium starts burn in a shell around the core and hydrogen may start burning in a shell around that! The outer layers of the star starts to grow, cool and turn red again as it enters its **second red giant phase**.

What happens next depends on the **mass** of the star. Small sun-like stars move into a **planetary nebula** phase, whilst stars greater than about 8 times the mass of the Sun are likely to end their days as a **supernova**.

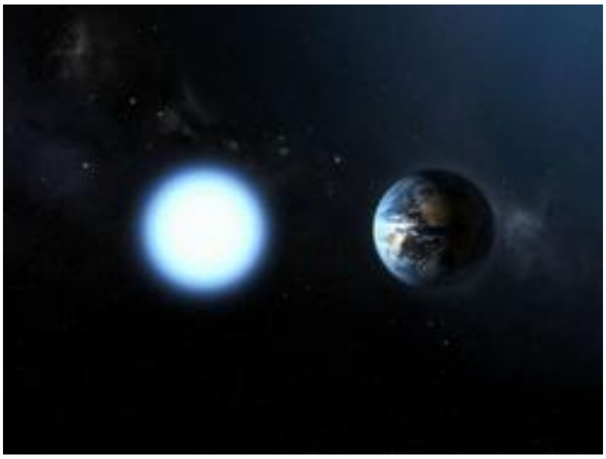
White Dwarf

A **white dwarf** is the remaining compact core of a low-**mass** star that has come to the end of its **lifetime** following a **planetary nebula** event. They are thought to make up roughly 6% of all known stars in the Sun's neighbourhood.

White dwarfs are made of highly compressed carbon and oxygen material, and are so dense that their mass is comparable to that of the **Sun**, even though their size is similar to that of the **Earth's**. A matchbox of white dwarf material would weigh the same as fifteen elephants.

Newly created white dwarfs have some of the hottest surface temperature of any star, at over 100,000°C, but because of their small size, they appear quite faint from a distance.

As **nuclear reactions** no longer occur in white dwarfs, they have to rely on their thermal store of energy for all heat and light. Over time this will gradually radiate away, allowing them to cool down and **change colour**. Eventually, they will disappear from sight to become cold black dwarfs.



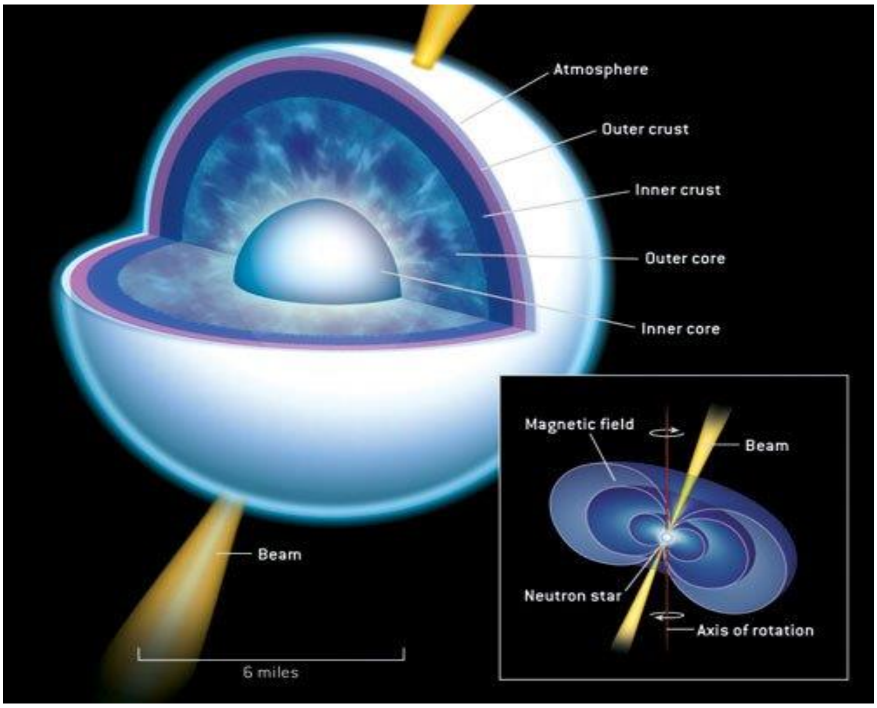
White dwarf in comparison to Earth

Neutron Stars

Let us now discuss the fate of the core of a star that explodes as a supernova. As iron fills the core of a massive star, the temperatures are so high that the iron nuclei begin to break apart into smaller units like alpha particles (helium nuclei). The pressure is no longer high enough to counteract gravity and the core collapses. As the density increases, the electrons are squeezed into the nuclei and react with the protons there to produce neutrons and neutrinos.

$$\mathbf{P^{+} + e^{-} \rightarrow n + v}$$

The neutrinos escape. A gas composed mainly of neutrons is left behind in the dense core as the outer layers explode as a supernova. Now the core has a very high density. At this density a condition called neutron degeneracy, in which the neutrons cannot be packed any more tightly, appears. The pressure caused by neutron degeneracy balances the gravitational force that tends to collapse the core. As a result, the core reaches equilibrium as a neutron star.Typically neutron stars have a radius of about 10 km, although in mass they are comparable with the sun. The chunk of their matter the size of a small sugar cube contains about 108 tons of neutrons. Neutron stars have masses between 1.4 and ~ 3 M_{sun}.



Before it collapses, the core has only a weak magnetic field. But as the core collapses, the magnetic field is concentrated, and grows stronger as a result. By the time the core shrinks to neutron star size, it has an extremely powerful magnetic field. Neutron stars were postulated in the 1930s and many astronomical observations confirm their existence. Neutron stars are believed to be pulsars if they rotate sufficiently rapidly and have sufficiently strong magnetic fields.

Pulsars: First discovered in 1968, a pulsar is believed to be a rotating neutron star. They emit radiation from relatively a small spot on the star. This situation produces an effect rather like the beam of a lighthouse. The distant observer receives a pulse of radiation as the beam sweeps across his position on each rotation of the star. A pulsar gives off pulses of radio waves. A very few objects *(example: Crab and the Vela pulsars)* are known to pulse γ-rays, X-rays, or visible light. The periods of known pulsars range between 33 milliseconds and 3.75 seconds. Pulse durations range from 2 to about 150 milliseconds with longer period pulsars generally having a longer pulse duration.

Black Holes

Consider stars with very large mass, say 5 to 10 M_{sun}. For such a star, the contraction cannot be arrested either at the white dwarf stage or at the stage of the neutron star. A star may continue to collapse beyond the neutron star stage. When the radius of the star is of the order of 15 kilometre, relativity predicts a most extraordinary phenomenon. According to the theory of relativity, a ray of light should possess mass and hence be subject to gravity. A ray of light emitted by a star will therefore be pulled back by the star's gravity. If the star is large in size, gravity will not be strong at its surface and a ray of light will be able to escape from the star. If the star shrinks to a size of about 15 kilometre radius, the force of gravity at its surface will be billions of times stronger than the force of gravity at the surface of the sun. A ray of light trying to leave the star will therefore be pulled back and it cannot escape from the star. And when light cannot escape, nothing else can escape from it. The star then becomes invisible. It becomes a black hole in space. The contraction continues inside a black hole. There is no force in nature which is strong enough to halt this contraction. The volume of the star must become smaller and smaller. The mass of the star however remains constant. Ultimately trillions and trillions of quintals of matter will have to be packed in a size less than a pinhead. Observational evidence of objects thought to be black holes comes from their effect on surrounding matter. Thus, if a black hole forms a binary system with another star it will attract and capture matter from this star. The material leaving the star first forms a rotating disc around the black hole, in which the matter becomes compressed. The disc is heated to such an extent that it emits X-rays. In the constellation Cygnus there is an X-ray source, Cygnus X-1, which consists of a supergiant revolving around a small invisible companion with a mass ten times that of the sun. The companion is thought to be a black hole.

The Basic Physics of Black Holes

Consider an escape velocity such that, when an object leaves with just the escape velocity, it will have zero velocity out at "infinity". There, its total energy is

$$TE = (KE + PE) = (1/2)\, mv^2 - GmM/R = 0.$$

Since total energy must be conserved, at the moment of launch we require

$$\begin{aligned} TE &= 0 = (1/2)\, mV^2_{esc} - GmM/R \\ (1/2)\, V^2_{esc} &= GM/R \\ V_{esc} &= (2GM/R)^{1/2} \end{aligned}$$

Now no object can travel faster than the speed of light, and so the maximum escape velocity is c. Then the equation for the black-hole radius is

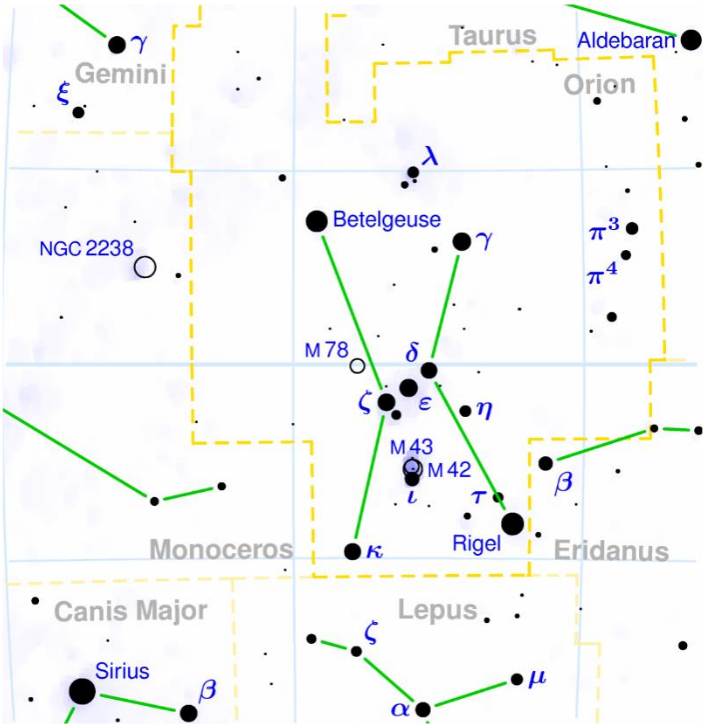
$$R = 2GM/c^2.$$

This critical radius is called the *Schwarzschild radius*.

Supernova Explosion

When a massive star starts rapidly collapsing, the interior gets heavily compressed and therefore also very hot. The core becomes converted into neutrons. If the compression is sudden and the heat generated is very high, then a violent explosion called supernova explosion takes place. It tears off the outer layers of the star and hurls them into space. What is left after a supernova explosion may be a remnant whose mass is greater than 1.4 M_{sun}. The Crab Nebula is the nearest supernova remnant.

Constellations



A constellation is a group of stars that can be joined together to form a shape or picture. Many ancient cultures around the world often created stories about the shapes they could see in the night sky.

Some well-known constellations contain familiar patterns of bright stars, such as Orion**,** which the ancient Greeks saw as a hunter, and Leo**,** which traces the outline of a lion.

These days, astronomers divide the sky into 88 constellations with exact boundaries (see image right), so that every point in the sky belongs within one of those constellations. We also have asterisms which are patterns of stars which are often smaller parts of a constellation.

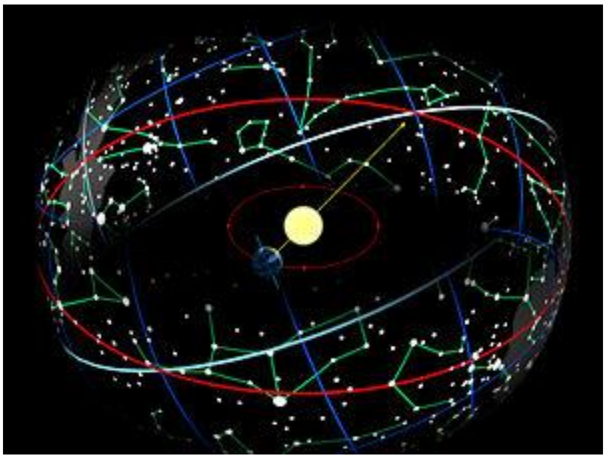
In the northern hemisphere, these are mostly based upon the constellations recorded by the ancient Greek culture, that have been passed down through the Middle Ages.

Of the modern constellations, there are 12 through which the Sun travels over the course of the year. These are known as the "signs of the zodiac" and are thought by many to have special significance.

For more information about the 88 constellations, try this LINK.

Our Stars and Stories Workshop for younger children provides an opportunity for pupils to develop knowledge and understanding of our world in space, as well as other cultures, through the constellations.

The zodiac is an area of the sky that extends approximately 8° north or south (as measured in celestial latitude) of the ecliptic, the apparent path of the Sun across the celestial sphere over the course of the year. The paths of the Moon and visible planets are also within the belt of the zodiac.



The Earth in its orbit around the Sun causes the Sun to appear on the celestial sphere moving along the ecliptic (red), which is tilted 23.44° with respect to the celestial equator (blue-white).

In Western astrology, and formerly astronomy, the zodiac is divided into twelve signs, each occupying 30° of celestial longitude and roughly corresponding to the star constellations: Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricorn, Aquarius, and Pisces.

These astrological signs form a celestial coordinate system, or even more specifically an ecliptic coordinate system, which takes the ecliptic as the origin of latitude and the Sun's position at vernal equinox as the origin of longitude.

The Zodiac & Horoscope

There is a band around the sky that is nine degrees above and below the ecliptic and it is called the **zodiac**. Ancient astrologers divided the zodiac into 30 degrees. Since there are twelve 30-degree sections in the circle, each section was given a sign. Each sign was named after an important constellation appearing along the ecliptic thousands of years ago. These ancient constellations include:

- Aries
- Taurus
- Gemini
- Cancer
- Leo
- Virgo
- Libra
- Scorpio
- Sagittarius
- Capricorn
- Aquarius
- Pisces

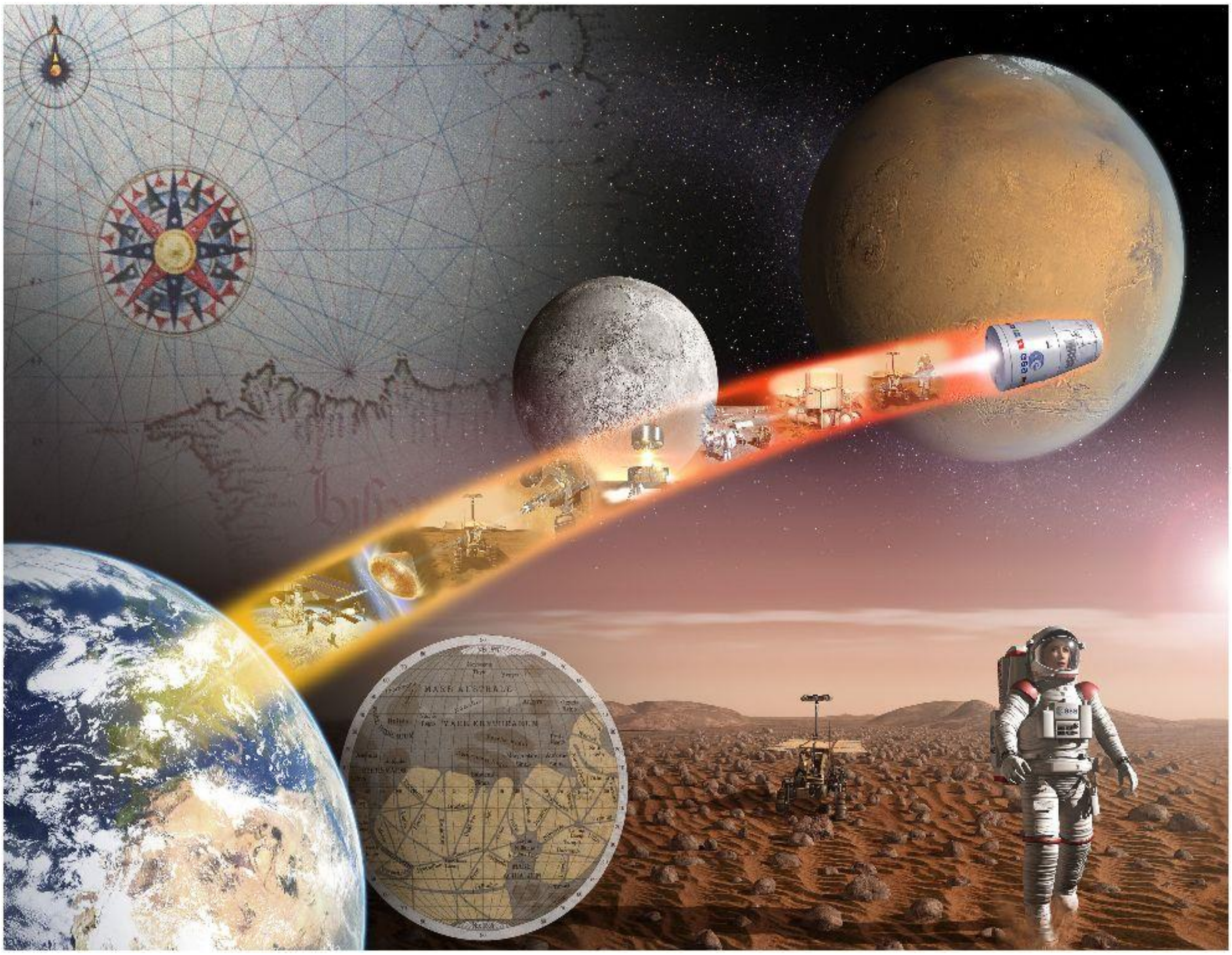
These names should be familiar to horoscope readers. A **horoscope** is a diagram that shows the location of the planets, moon, and sun around the ecliptic, as well as their position above or below the horizon for a specific date and time. The horoscope and the signs of the zodiac are not important in modern astronomy.

The Origin of the Zodiac

The history of the zodiac is quite interesting as it is a very important ancient concept, despite its uselessness today. It was in an

cient Babylon that the concepts of a modern horoscope were born. The division of the zodiac into 12 equal regions was an important prerequisite for a belief in the predictive capabilities of horoscopic charts and diagrams.

Unit-2
An Introduction to Space Exploration



Space exploration is the ongoing discovery and exploration of celestial structures in outer space by means of continuously evolving and growing space technology. While the study of space is carried out mainly by astronomers with telescopes, the physical exploration of space is conducted both by unmanned robotic probes and human spaceflight.

While the observation of objects in space, known as astronomy, predates reliable recorded history, it was the development of large and relatively efficient rockets during the early 20th century that allowed physical space exploration to become a reality. Common rationales for exploring space include advancing scientific research, uniting different nations, ensuring the future survival of humanity and developing military and strategic advantages against other countries.

Space exploration has often been used as a proxy competition for geopolitical rivalries such as the Cold War. The early era of space exploration was driven by a “Space Race” between the Soviet Union and the United States, the launch of the first man-made object to orbit the Earth, the USSR’s Sputnik 1, on 4 October 1957, and the first Moon landing by the American Apollo 11 craft on 20 July 1969 are often taken as landmarks for this initial period. The Soviet space program achieved many of the first milestones, including the first living being in orbit in 1957, the first human spaceflight (Yuri Gagarin aboard Vostok 1) in 1961, the first spacewalk (by Aleksei Leonov) on 18 March 1965, the first automatic landing on another celestial body in 1966, and the launch of the first space station (Salyut 1) in 1971.

After the first 20 years of exploration, focus shifted from one-off flights to renewable hardware, such as the Space Shuttle program, and from competition to cooperation as with the International Space Station (ISS).

Hubble constant

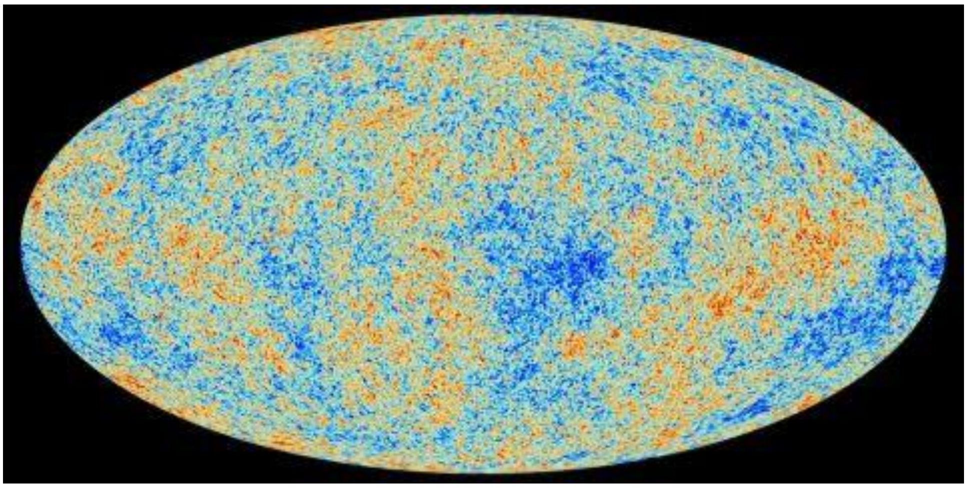
Hubble constant, in cosmology, constant of proportionality in the relation between the velocities of remote galaxies and their distances. It expresses the rate at which the universe is expanding. It is denoted by the symbol H_0, where the subscript denotes that the value is measured at the present time, and named in honour of Edwin Hubble, the American astronomer who attempted in 1929 to measure its value. With redshifts of distant galaxies measured by Vesto Slipher, also of the United States, and with his own distance estimates of these galaxies, Hubble established the cosmological velocity-distance law:

$$\text{velocity} = H_0 \times \text{distance}.$$

According to this law, known as the Hubble law, the greater the distance of a galaxy, the faster it recedes. Derived from theoretical considerations and confirmed by observations, the velocity-distance law has made secure the concept of an expanding universe. Hubble's original value for H_0 was 500 km (311 miles) per second per megaparsec (one megaparsec is 3,260,000 light-years). Modern estimates, using measurements of the cosmic microwave background radiation left over from the big bang, place the value of H_0 at about 67 km (42 miles) per second per megaparsec. The reciprocal of the Hubble constant lies between 13 billion and 14 billion years, and this cosmic timescale serves as an approximate measure of the age of the universe.

Big bang theory

The Big Bang Theory is our best guess about how the universe began.



A 2013 map of the background radiation left over from the Big Bang, taken by the ESA's Planck spacecraft, captured the oldest light in the universe. This information helps astronomers determine the age of the universe.

History of the Big Bang Theory:

The earliest indications of the Big Bang occurred as a result of deep-space observations conducted in the early 20th century. In 1912, American astronomer Vesto Slipher conducted a series of observations of spiral galaxies (which were believed to be nebulae) and measured their Doppler Redshift. In almost all cases, the spiral galaxies were observed to be moving away from our own.

In 1922, Russian cosmologist Alexander Friedmann developed what are known as the Friedmann equations, which were derived from Einstein's equations for general relativity. Contrary to Einstein's was advocating at the time with his a Cosmological Constant, Friedmann's work showed that the universe was likely in a state of expansion.

In 1924, Edwin Hubble's measurement of the great distance to the nearest spiral nebula showed that these systems were indeed other galaxies. At the same time, Hubble began developing a series of distance indicators

using the 100-inch (2.5 m) Hooker telescope at Mount Wilson Observatory. And by 1929, Hubble discovered a correlation between distance and recession velocity – which is now known as Hubble's law.
And then in 1927, Georges Lemaitre, a Belgian physicist and Roman Catholic priest, independently derived the same results as Friedmann's equations and proposed that the inferred recession of the galaxies was due to the expansion of the universe. In 1931, he took this further, suggesting that the current expansion of the Universe meant that the father back in time one went, the smaller the Universe would be. At some point in the past, he argued, the entire mass of the universe would have been concentrated into a single point from which the very fabric of space and time originated.
These discoveries triggered a debate between physicists throughout the 1920s and 30s, with the majority advocating that the universe was in a steady state. In this model, new matter is continuously created as the universe expands, thus preserving the uniformity and density of matter over time. Among these scientists, the idea of a Big Bang seemed more theological than scientific, and accusations of bias were made against Lemaitre based on his religious background.
Other theories were advocated during this time as well, such as the Milne Model and the Oscillary Universe model. Both of these theories were based on Einstein's theory of general relativity (the latter being endorsed by Einstein himself), and held that the universe follows infinite, or indefinite, self-sustaining cycles.
After World War II, the debate came to a head between proponents of the Steady State Model (which had come to be formalized by astronomer Fred Hoyle) and proponents of the Big Bang Theory – which was growing in popularity. Ironically, it was Hoyle who coined the phrase "Big Bang" during a BBC Radio broadcast in March 1949, which was believed by some to be a pejorative dismissal (which Hoyle denied).
Eventually, the observational evidence began to favor Big Bang over Steady State. The discovery and confirmation of the cosmic microwave background radiation in 1965 secured the Big Bang as the best theory of the origin and evolution of the universe. From the late 60s to the 1990s, astronomers and cosmologist made an even better case for the Big Bang by resolving theoretical problems it raised.
These included papers submitted by Stephen Hawking and other physicists that showed that singularities were an inevitable initial condition of general relativity and a Big Bang model of cosmology. In 1981, physicist Alan Guth theorized of a period of rapid cosmic expansion (aka. the "Inflation" Epoch) that resolved other theoretical problems.
The 1990s also saw the rise of Dark Energy as an attempt to resolve outstanding issues in cosmology. In addition to providing an explanation as to the universe's missing mass (along with Dark Matter, originally proposed in 1932 by Jan Oort), it also provided an explanation as to why the universe is still accelerating, as well as offering a resolution to Einstein's Cosmological Constant.
Significant progress was made thanks to advances in telescopes, satellites, and computer simulations, which have allowed astronomers and cosmologists to see more of the universe and gain a better understanding of its true age. The introduction of space telescopes – such as the Cosmic Background Explorer (COBE), the Hubble Space Telescope, Wilkinson Microwave Anisotropy Probe (WMAP) and the Planck Observatory – have also been of immeasurable value.
Today, cosmologists have fairly precise and accurate measurements of many of the parameters of the Big Bang model, not to mention the age of the Universe itself. And it all began with the noted observation that massive stellar objects, many light years distant, were slowly moving away from us. And while we still are not sure how it will all end, we do know that on a cosmological scale, that won't be for a long, LONG time!

Shape of universe

The theory of general relativity, under which space itself can curve, allows for the universe to take one of three forms: flat like a sheet of paper, closed like a sphere, or open like a saddle. This astronomical geometry is no trivial matter — the fate of the cosmos depends on it.

As Princeton University cosmologist David Spergel puts it, “The shape of the universe tells us about its past and its future." Whether the universe will expand forever or eventually collapse, and whether it’s finite or infinite — all are questions that tie back to its shape.

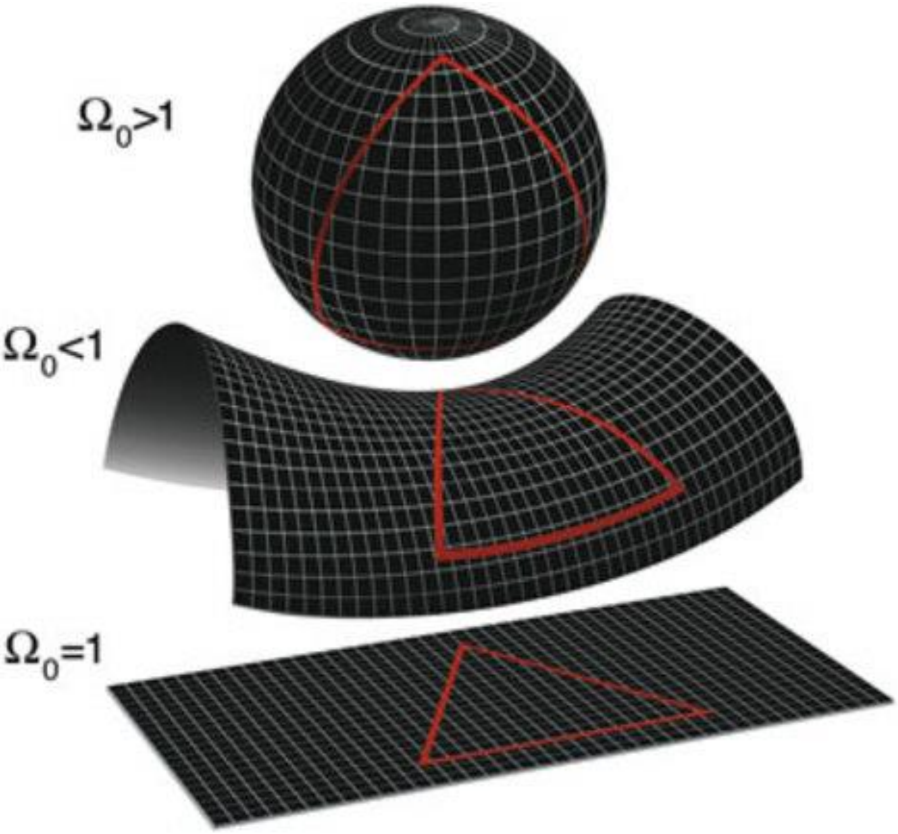
For a matter that bears on such grand questions, its components are remarkably simple. The ultimate structure of the universe depends on just two factors: its density and its rate of expansion.

Closed, Open or Flat Universe

Roughly 68 percent of the universe is dark energy and 27 percent is dark matter. The remainder is normal matter, which accounts for planets, stars and other bodies. The universe's density refers to how much of this matter is packed into a given volume of space.

If the universe's density is great enough for its gravity to overcome the force of expansion, then the universe will curl into a ball. This is known as the closed model, with positive curvature resembling a sphere. A mind-boggling property of this universe is that it is finite, yet it has no bounds. An intergalactic Ferdinand Magellan could circumnavigate it, traversing space forever without hitting a wall or falling over an edge.

On the other hand, if the universe's density is low and unable to stop the expansion, space will warp in the opposite direction. This would form an open universe with negative curvature resembling a saddle.



There's also a Goldilocks scenario for the universe, which scientists say is the most plausible. Most cosmological evidence points to the universe's density as being ***just right*** — the equivalent of around six protons per 1.3 cubic yards — and that it expands in every direction without curving positively or negatively. In other words, the universe is flat. (Perhaps this will come as some consolation to anyone disappointed by our planet’s roundness.)

Flat in 3D

What does a flat universe mean, though? This flatness isn’t the two-dimensional kind we often encounter in everyday life, but you can envision it with a few analogies.

Say you’re standing in one corner of a square room. Walk 10 feet along the wall to the next corner, then turn 90 degrees. Walk another 10 feet and turn 90 degrees again. Do this twice more and you’ll find yourself back where you started — you’ve completed a square. This is the standard Euclidean geometry that we all learned in high school, and if you add one more dimension you get a flat universe.

But conducting this experiment on a positively curved space that's representative of a closed universe would create a different outcome. This time, start at Earth's equator and walk to the North Pole. Then, turn 90 degrees and walk back to the equator. Turn 90 degrees once more and walk back to your starting point. In the flat universe example, it took four turns to get back to where you started, but only three in the closed universe example.

If you're (understandably) still confused, here's another example: In a flat universe, two rockets flying next to each other will always remain parallel. This is unlike a closed universe, in which the paths of these two rockets will diverge, trek along the curvature of space, and eventually loop around to meet where they started. And in a negatively curved, open universe, the rockets will separate and never cross paths again.

What does it mean when they say the universe is expanding

When scientists talk about the expanding universe, they mean that it has been growing ever since its beginning with the Big Bang.

The galaxies outside of our own are moving away from us, and the ones that are farthest away are moving the fastest. This means that no matter what galaxy you happen to be in, all the other galaxies are moving away from you.

However, the galaxies are not moving through space, they are moving in space, because space is also moving. In other words, the universe has no center; everything is moving away from everything else. If you imagine a grid of space with a galaxy every million light years or so, after enough time passes this grid will stretch out so that the galaxies are spread to every two million light years, and so on, possibly into infinity.

the universe encompasses everything in existence, from the smallest atom to the largest galaxy; since forming some 13.7 billion years ago in the Big Bang, it has been expanding and may be infinite in its scope. The part of the universe of which we have knowledge is called the observable universe, the region around Earth from which light has had time to reach us.

One famous analogy to explain the expanding universe is imagining the universe like a loaf of raisin bread dough. As the bread rises and expands, the raisins move farther away from each other, but they are still stuck in the dough. In the case of the universe, there may be raisins out there that we can’t see any more because they have moved away so fast that their light has never reached Earth. Fortunately, gravity is in control of things at the local level and keeps our raisins together.

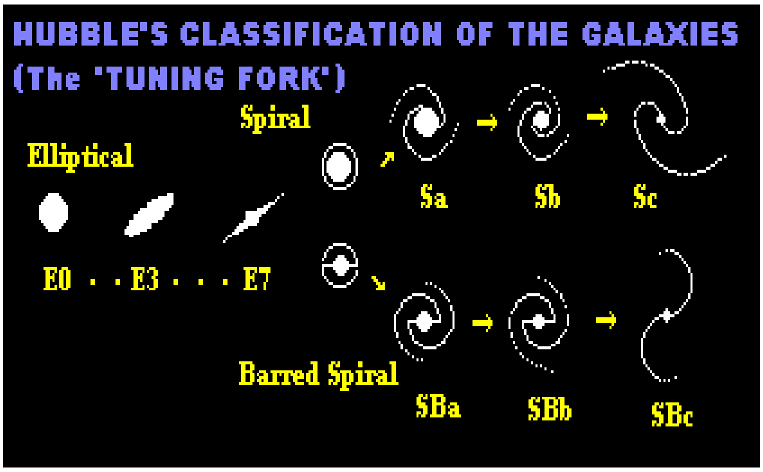
Galaxies Introduction

The discovery that galaxies are huge, remote stellar systems had a profound effect on the course of astronomy. The Universe is populated with galaxies, which comes in many shapes and sizes. Millions of galaxies spread across the sky. A typical Galaxy contains roughly 100 billion stars and measures about 100,000 light years in diameter. Because of their extreme faintness, the distant galaxies, unlike stars and planets, do not have traditional names. Instead, they have only numerical designadons taken from catalogs.

The first catalog to include galaxies was that compiled by Messier. Galaxies in the Messier catalog are denoted by "M" numbers, for example, M87. A far more complete list of galaxies is given in the New General Catalog (NGC), which was begun by Herschel, and in its supplement, the Index Catalog (IC). Many of the galaxies that have been studied recently are too faint to appear eVen as NGC objects. The Third and Fourth Cambridge Catalogs (3C and 4C), which are compiled from lists of radio sources, include a number of galaxies of this type.

Classification of Galaxies

Galaxies are the largest objects in the universe. In 1926 win Hubble was the first astronomer to propose a classification scheme for galaxies and it is still widely used. The Hubble classification scheme is based on the appearance of and he presented his famous "tuning fork". Hubble classified them into four categories:



Hubble's famous tuning fork diagram for classification galaxies

1. Elliptical galaxies
2. Spiral galaxies
3. Barred spiral galaxies
4. Irregular galaxies

The descriptions of these galaxies in detail are as discussing below.

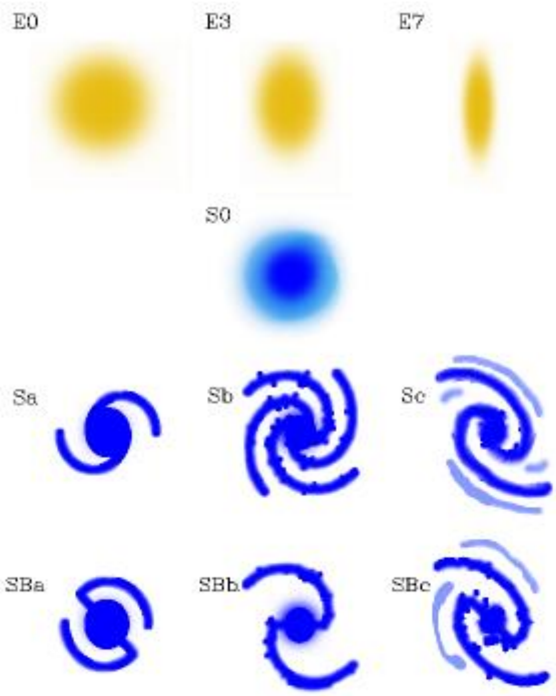
Elliptical galaxies

Elliptical galaxies have an amorphous elliptical appearance.

They look like blobs. Some of the most luminous galaxies are elliptical.

Elliptical galaxies, so named because of their distinct elliptical shapes and they have no spiral arms. The category of elliptical galaxies can be subdivided according to how round or flattened they look. Elliptical galaxies that are perfectly circular appearance are called E0 galaxies. The flattest appearing elliptical are E7 galaxies. The number which follows the letter E is used to designate the degree of flattening. For example, E5 Galaxy is slightly flatter than an E4 Galaxy. These numbers run from 0 (perfectly round elliptical) to 7 (the flattest elliptical).

Elliptical galaxies have a wide range of sizes and masses. Both the bigger and smallest galaxies in the universe are elliptical.



The hubble classification scheme

Spiral galaxies

Some of the most beautiful galaxies seen in the sky arc spiral galaxies. As their name suggests, these galaxies have a teristic spiral or pinwheel structure. They are classified mal spirals (S) and barred spirals (SB), according to the shape of their nuclei. The spirals are further divided into three classes (a, b, and c) according to the size of their nuclei and the tightness with which their spiral arms are wound around the nuclei,

The (a) designation (Sa) indicates a large nucleus, with thin spiral arms that are wound tightly, around a large, bright cleus. At the other extreme (c) designation (sc) indicates a small nucleus, with wide spiral arms that are wound loosely around the nucleus. In between the Sa and Sc subclasses are galaxies, which have moderate and tightly wound spiral arms originating from a medium-sized nucleus.

Our own Milky Way Galaxy is Sb spiral. The Andromeda Galaxy, at a distance of over two million light years, is probably the best known and most famous of all the spiral galaxies.

Barred spiral galaxies

About one quarter of all galaxies with spiral arms show a bar running through their nuclei. These are called barred spirals. Their spiral arms originate from the ends of the bar rather from their nuclei. Just as with spirals, the barred spiral can be subdivided further into three subclasses: SBa, SBb and SBc galaxies.

An SBa Galaxy has a large central bulge and thin, tightly wound spiral arms. Likewise, an SBb Galaxy is a barred spiral with a moderate central bulge and moderately wound spiral arms, while an SBC Galaxy has lumpy, loosely wound spiral arms and a tiny central bulge.

According to the Hubble's classification, the S0 or SB0 galaxies, also called lenticular galaxies, which is midway appearance between ellipticals and the two kinds of spirals.

Irregular galaxies

Finally, galaxies that do not fall into one of the three previous categories look very different. Such galaxies are called irregular. Some irregular galaxies are in the process of exploding, whereas others have been distorted heavily and bent out of shape by a collision with a neighboring Galaxy.

There are two types of irregular galaxies: Irregular I (Irr I) and Iregular II (Irr II).

Irr I galaxies, like underdeveloped spiral galaxies, The best examples of such Irr I galaxies are Large Magellanic Clouds (LMC) and the Small Magellanic Clouds (SMC), which are nearby companions of our Milky Way that can be seen with the naked eye.

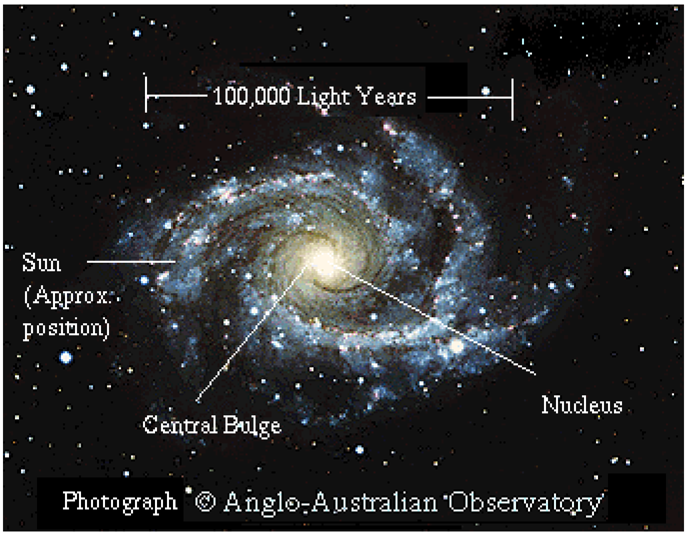
Irr II galaxies have asymmetrical, distorted shapes that seem to have been caused by collisions with other galaxies or by violent activity in their nuclei. The example of Irr II Galaxy is M82. It appears basically featureless and it seems to have undergone a violent explosion in its nucleus and may have ejected huge plumes of gas and dust out of its disk.

Irregular galaxies usually contain Jots of gas and dust. Some Irregular galaxies show spiral structure. Irregular galaxies contain lots of young stars, whereas elliptical galaxies are composed mostly very old stars.

Milky Way Galaxy

By studying the Milky Way Galaxy, we explore the universe on a grand scale, instead of examining individual stars, we look entire system of stars.

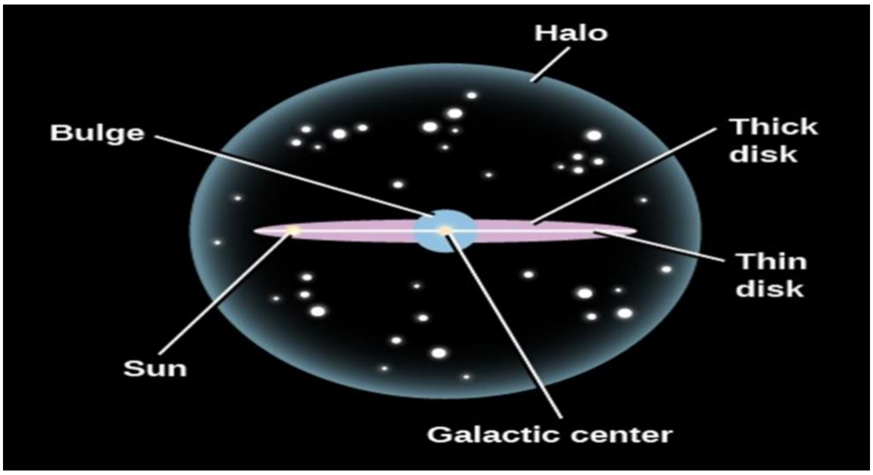
Galaxies are the largest coherent structures in the universe and possess a variety of forms. Our Milky W Galaxy is a flat disk surrounded by a spheroidal halo and con taining about 100 billion stars.



The schematic diagram of the structure of the Milky Way

The Milky Way Galaxy is about 100,000 light years across, consists of a giant disk containing stars, gas and dust with the located about 26,000 light years from the center. In 'he
disk, the stars and interstellar matter move in circular orbits about a central bulge of stars called nucleus. The nucleus is about 10,000 light years in diameter.

The main disk of the Galaxy is embedded in a giant halo of stars in which globular clusters are located. Different kinds of stars are found in the various compositions in our Galaxy. The stars in the disk are mostly young, metal-rich, population 1 stars like the Sun. The globular cluster in the halo is composed of old, metal-poor, population Il stars. They are known as high-velocity stars because of their high speed relative to the Sun. The orbit of the stars and globular clusters in the halo is entirely different from the orbit of the stars in the disk..



Orbits of the stars in the Milky Way

The disk of our Galaxy appears bluish in colour, because its light is dominated by radiation from young, hot O and B stars. The central bulge looks reddish, because of many red giants and red supergiants clustered around the center of our Galaxy. Also, the central bulge contains both population I and Il stars, suggesting that some stars are quite ancient whereas others were created recently.

Radio and optical observations reveal that our Galaxy has spiral arms, spiral shaped concentrations of gas and dust Milky Way Galaxy has four major spiral arms and several short a elements. Each star in the Galaxy moves in precessing ellipse about the galactic nucleus; gravity correlates their orbits and creating a spiral pattern.

Pin wheel shape of our Galaxy suggests that it rotates. If the stars in our Galaxy were not orbiting the galactic center they would fall into the galactic center. Radio observations revealed that our Galaxy does not rotate like a rigid body. The orbital speed of the stars and gas about the galactic center is fairly constant throughout the disk. However, the outer stars have taken longer time to travel in their orbit around the galatic centre than the inner stars. The result is that the outer stars lag behind the stars in the inner reaches of the Galaxy. This is known as *'differential rotation'*.

Just as the earth goes round the Sun once each year, it takes the Sun 200 million years to go once round the Galaxy. This huge period of time is called the galactic year. From this we can understand that how vast our Galaxy is.

The motion of stars in our Galaxy can be used to measure the mass of our Galaxy. If we assume that most of the mass of the Galaxy is concentrated in the centre of the Galaxy and the Sun revolves around it, the Galaxy's mass can be determined by substituting the Sun's distance from the Galaxy's centre (26,000 light years) and its orbital period (200 million years) in Kepler's third law as modified by Newton,

$(M_{Galaxy} + m_{sun}) (P_{sun})^2 = (a_{sun})3$

Where, 'P' is the orbital period of the Sun, and 'a' is the semimajor axis of the Sun's orbit.

When precise values are used for the Sun's motion, the Galaxy's mass is about 150 million times that of the Sun.

Regular clusters of galaxies arc much rarer objects corn pared to the irregular clusters. Regular cluster show a high degree of spherical symmetry along with a strong central con ccntration. In these rcspccts, they are analogous to the globular star clusters so that they arc rcfcrred to as globular cluster, of galaxies. Rich regular cluster contain thousands and even tens of thousand member galaxies, most of which are giant ellipti_ cals and SO galaxies.

Example: Coma Cluster and the Perseus Cluster.

The irregular clusters are much more common in space than the regular ones. They are referred to as open clusters ofgalaxies. Irregulars show no spherical symmetry or central concentration. They consist of amorphous grouping of galaxies scattered helter-skelter over a region of space. The number of galaxies in irregular clusters range from a few to many. They contain galaxies of all morphological types-ellipticals, SOS, spirals and irregulars, The Local Group of galaxies is a typical example of small irregular clusters. Examples of rich irregular clusters are Virgo and Hercules.

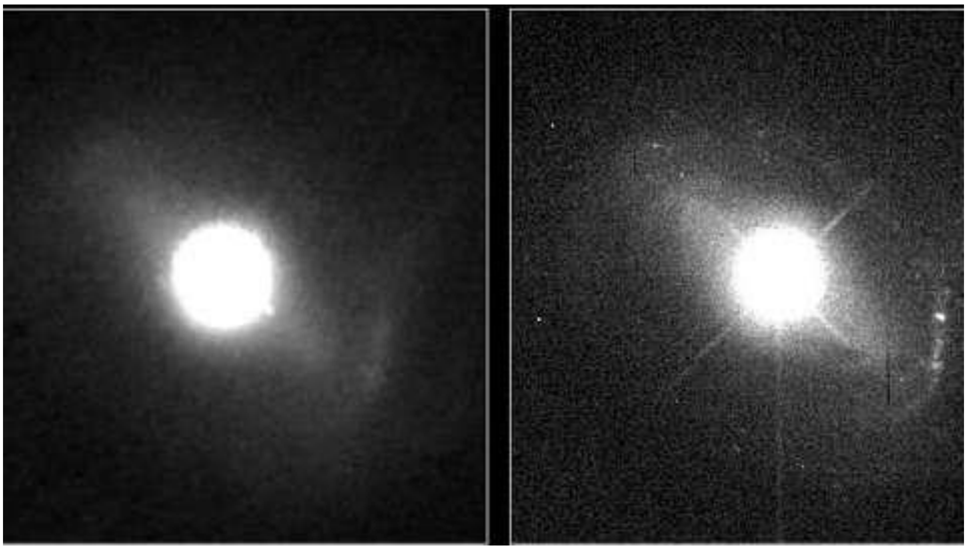
More recent developments suggest that clusters of galaxies group together in superclusters. A typical supercluster contains dozens of individual clusters spread over a region of space up to 100 million light years across. The superclusters have wide range of dimensions; usually lying between 30 to 300 Mpc, their average mass being the order of 1016M. The geometrical boundaries are generally not well defined and they usually have no pronounced concentration at any point inside including the centre. For example, our Local Group along with the Virgo cluster and a few smaller irregular clusters make up the local supercluster. The size of this supercluster is roughly 150 million light years and total mass of nearly a million billion suns.

Quasar

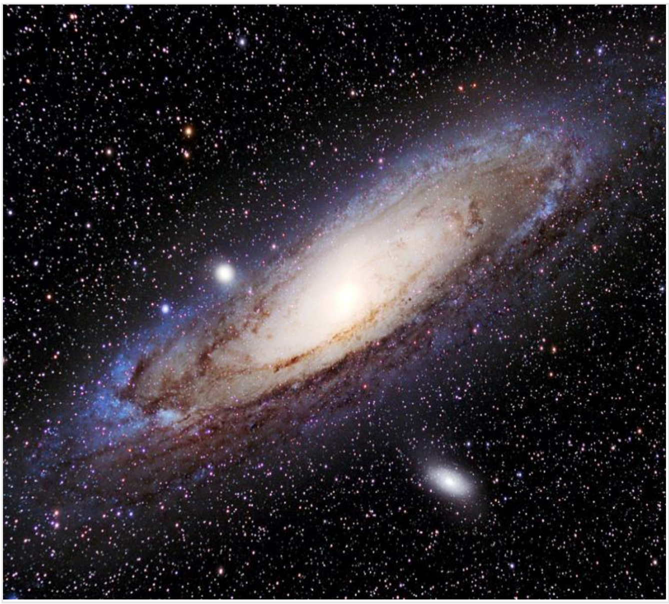
Quasar, an astronomical object of very high luminosity found in the centres of some galaxies and powered by gas spiraling at high velocity into an extremely large black hole. The brightest quasars can outshine all of the stars in the galaxies in which they reside, which makes them visible even at distances of billions of light-years. Quasars are among the most distant and luminous objects known.

Discovery of quasars

The term *quasar* derives from how these objects were originally discovered in the earliest radio surveys of the sky in the 1950s. Away from the plane of the Milky Way Galaxy, most radio sources were identified with otherwise normal-looking galaxies. Some radio sources, however, coincided with objects that appeared to be unusually blue stars, although photographs of some of these objects showed them to be embedded in faint, fuzzy halos. Because of their almost starlike appearance, they were dubbed "quasi-stellar radio sources," which by 1964 had been shortened to "quasar."



Quasar 1229+204, as observed by the Hubble Space TelescopeThis picture shows that the quasar is surrounded by spiral arms characteristic of galaxies. The tremendous light generated by quasars and their great distance from Earth work to obscure the fainter galactic structures in which they are embedded. This quasar is apparently fueled by a collision between its host galaxy and a dwarf galaxy



The optical spectra of the quasars presented a new mystery. Photographs taken of their spectra showed locations for emission lines at wavelengths that were at odds with all celestial sources then familiar to astronomers. The puzzle was solved by the Dutch American astronomer Maarten Schmidt, who in 1963 recognized that the pattern of emission lines in 3C 273, the brightest known quasar, could be understood as coming from hydrogen atoms that had a redshift (i.e., had their emission lines shifted toward longer, redder wavelengths by the expansion of the universe) of 0.158. In other words, the wavelength of each line was 1.158 times longer than the wavelength measured in the laboratory, where the source is at rest with respect to the observer. At a redshift of this magnitude, 3C 273 was placed by Hubble’s law at a distance of slightly more than two billion light-years. This was a large, though not unprecedented, distance (bright clusters of galaxies had been identified at similar distances), but 3C 273 is about 100 times more luminous than the brightest individual galaxies in those clusters, and nothing so bright had been seen so far away.