UNIT 10 EXPLORING THE UNIVERSE

Structure

10.1 INTRODUCTION

In Unit 9 you had a brief glimpse of what the universe is made up of. You know that the universe has a structure. Seen on a large distance scale, it is made up of superclusters which are groups of large clusters. Clusters contain anything from a few, to a few thousand galaxies. The galaxies are, in turn, made up of stars and clouds of gas and dust. Our own star, the Sun, is an ordinary star in the Milky Way Galaxy, one among 100 billion stars. It is surrounded by nine planets including the Earth, that move around it.While reading all this, did you not wonder how we came to know about the structure of the universe in such detail? Because, all we can see by our unaided eyes are the few thousand stars scattered in the sky.

In this unit we are going to satisfy your curiosity on this count. We will describe the various techniques and instruments that have helped us in gathering information about the universe. But the information gathered is of no use if it cannot be analysed systematically and used to develop an understanding of the universe. This is what thousands of scientists all over the world are doing everyday. They take the bits and pieces of information from here and there and try to paint a coherent picture of the enigma that our universe is. We will try to present this picture before you, in as simple a way as possible. As we explore the universe, we may come across many puzzles that are rather difficult to solve. However, there is a tiny part in this whole universe that we understand a little better than the rest. That tiny part is the Solar System. In the next unit, we will tell you about the Solar System.

Objectives

After studying this Unit you should be able to:

- enumerate the various astronomical methods of exploring the universe, and explain how these methods are put to use to gather information,
- describe our current knowledge of the stars—their distances, brightness, temperature, motion etc.,
- explain, in a simple manner, how stars evolve,
- describe the prevalent theories about the origin and evolution of the universe alongwith the supporting evidence, if any.

10.2 PROBING THE UNIVERSE

'Now, my own suspicion is that the universe is not only queerer than we suppose, but queerer than we can suppose'.

J.B.S. Haldane (1892-1964) was a British biologist who became an Indian citizen, and settled in Cuttack, Orissa. You will read about his work in Unit 12.

This remark of Haldane, a famous scientist, reflects, in a way, what most of us feel about this subject. The universe is a rather difficult subject to study. We cannot bring it to the laboratory to carry out experiments on it. We cannot compare it with any other universe, this is the only universe we have. And finally, we are a part of it. We can study it only from within. We cannot go out of it and look at it from the outside.

So, how do we study it? It is here that the scientific method comes to our aid. You must understand that the study of the universe is a rather special example of the method of science, as we cannot experiment on it. However, the observations that we make about it provide us with an enormous amount of information that we can analyse and interpret in terms of the known laws of nature. Based on these laws, various theories and models of the universe are given by scientists.

Observations are the pillars on which models and theories are based. You may ask: What observations can be made about the universe? And how are they made? We will now answer these questions. We will not discuss the underlying principles of the methods and instruments in detail. Our aim is to give you an idea of the vast variety of tools and methods available for making observations about the universe.

Most of what we know about the universe has been learnt from a study of light, heat and other radiations like the radiowaves, X-rays, gamma rays etc. coming from the Sun and the stars. These radiations are detected by special instruments set up at astronomical observatories on the Earth and in orbit around the Earth. In the last few decades, we have been able to send probes to the neighbouring worlds. Many men have also visited the Moon and brought a lot of lunar material for study. Thus, there are a variety of ways for making observations and collecting information about the universe. However, before describing these methods, we will explain to you some features of the radiations from space that bring the secrets of the universe right to our doorstep.

10.2.1 Visible and Invisible Radiation

Light is very much a part of our existence. Without it we cannot see. It lends colour to the world around us. Light is also termed as **visible radiation**. There are other kinds of radiations in nature, that we **cannot see**. These are termed **invisible radiations**. Some examples of invisible radiations are the infrared and ultraviolet radiations, radiowaves, X-rays and gamma rays. We may come across all these radiations in our lives. For example, infrared (IR) radiation is given out by warm objects, such as our bodies, room heaters, buildings and the Earth after a warm day. Rattlesnakes detect infrared radiation very well. Ultraviolet (UV) radiation can kill germs. It is invisible to us but can be detected by bumblebees. Radiowaves are emitted by TV and radio broadcasting stations and are received by our TV or radio sets through the antennas. Thus, they are useful in communication. They can also be detected by bats. X-rays are used in medicine, gamma rays are used in cancer treatment and are also emitted in nuclear explosions.

All these radiations—the gamma ray, the X-rays, ultraviolet rays, light, infrared rays, and radiowaves—are useful in astronomy. Actually they are different forms of the same kind of radiation called the **electromagnetic radiation**. Electromagnetic radiation is a form of energy. There are other forms of energy with which you must be familiar, like heat, sound or the energy stored in the spring of a watch. We usually think of electromagnetic radiation as being made up of waves that travel with the speed of light in vacuum. Now, the simplest examples of waves that you may know are waves of water in a pond or sea, waves on a string. You may have seen waves on a curtain fluttering in the air. Some people have wavy hair. We will not go here into the details of what waves are, or the special nature of electromagnetic waves. For details, you may like to refer to the books listed at the end of the block.

But clearly, from their description given above, the various kinds of electromagnetic radiation do not seem to be alike. What is the difference between each of them?

The difference lies in their wavelengths and hence in the energy they carry.

What do we mean by the wavelength of a wave? Study Fig. 10.1 to understand this. This is the usual way of showing a wave. The distance between two successive crests (hills) or two successive troughs (valleys) is defined as its **wavelength.** It is measured in metres. The curve marked OABCD is called one cycle. The frequency of a wave is defined as the number of cycles it travels in a second. It is then measured in terms of cycles per second (cps) or Hertz. The product of the wavelength λ and the frequency f of an electromagnetic wave is equal to its speed c:

$$\lambda f \quad c$$

The symbol λ is a Greek letter pronounced as 'lambda' with 'b' silent.

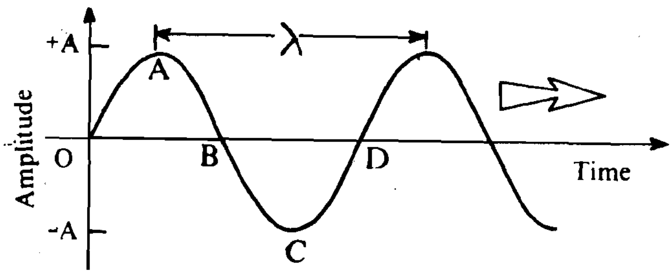

Fig. 10.1: Sketch of a wave showing its wavelength.

Thus, if we know any two of these parameters, we can determine the third. The energy E carried by a wave of frequency f is given as:

$$E = hf = hc/\lambda$$

where h is a constant number, known as Planck's constant. Thus, the higher the frequency of a wave or the lower its wavelength, the more energy it can carry across space. UV rays, X-rays and gamma rays carry huge amounts of energy. Therefore, constant exposure to them can prove very harmful. Luckily most of these harmful radiations are cut off by the Earth's atmosphere. All kinds of electromagnetic radiations arranged according to their wavelengths, constitute the **electromagnetic spectrum.** (Fig. 10.2)

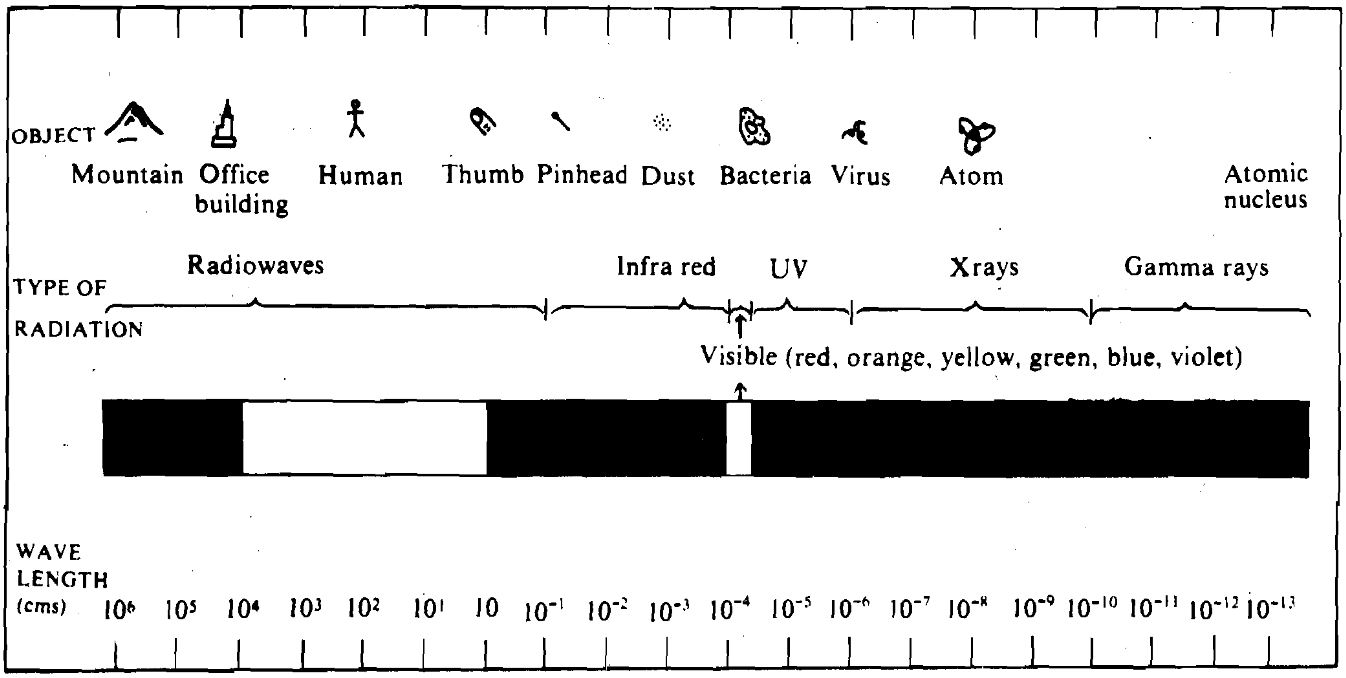

Fig. 10.2: Electromagnetic spectrum. The unshaded areas show the radio window, and the optical window which ranges from 4.0×10^{-5}cm. (violet) to 8.0×10^{-5} cm. (red) wavelengths. Objects shown in the figure are of the same dimensions as the corresponding wavelengths.

SAQ 1

a) An announcement of the day on any AIR station may start like this:
This is All India Radio. You are tuned to the medium wave band at 375 metres, that is 800 kilohertz.
What is the wavelength and frequency of the wave to which you have tuned the radio? In what region of the electromagnetic spectrum does it lie?

....

b) Calculate the speed of radio waves mentioned in part (a) in this SAQ?

....

c) What is the range of wavelengths and frequencies used for broadcasts made on radio? You may read the markings on a radio set ....
d) What are the waves with lowest wavelengths called? ....
e) What is the wavelength of the longest radiowaves? ....

Light is the radiation to which human eyes are sensitive, i.e., our eyes can detect visible radiation. However, it forms only a tiny part of the electromagnetic spectrum. The colours in white light or light from the Sun can be seen when it is sent through a prism which splits it into the familiar spectrum of rainbow colours—violet, indigo, blue, green, yellow, orange and red. By definition, each colour of visible light has a specific wavelength, the violet light having the shortest and red light the longest.

Cosmic objects emit radiations of all wavelengths. For instance, visible light forms only 40% of the Sun's radiation. The rest is made up of the other kinds of electromagnetic radiation. However, as these radiations fall on the Earth, all except light and radiowaves get absorbed in its atmosphere. Only the visible light waves and radiowaves penetrate the atmosphere to reach the Earth's surface. These are, therefore, referred to as the two windows to the universe. We can view the wavelengths lying outside these windows only if we move out of the Earth's atmosphere.

SAQ 2

a) What is the range of wavelengths for which electromagnetic radiation is visible to our eyes? Calculate the frequency of the violet and red colours.

....

b) Which colour of light carries more energy, blue or green?

....

c) What wavelengths of the electromagnetic radiation reach the surface of the Earth?

....

Now that you have some idea of the various kinds of radiations coming from the stars, let us see what different methods astronomers use to collect them. We start with a discussion on how light from the stars is collected.

10.2.2 In Pursuit of Starlight

The easiest method of studying light from a cosmic object is to collect it through a telescope and record it on a photographic plate. Photographic films are exposed for long periods of time—sometimes night after night—to the light being collected by a telescope aimed at distant stars. Since the Earth rotates on its axis, the stars appear to move in the sky. The telescope is rotated following the daily movement of the stars at which it is aimed. Thus, its movement is synchronised with the movement of the stars being studied, stars, far too faint for human eyes, slowly begin to register on the plate. This method of collecting and investigating light from the cosmos is called **optical astronomy**.

Over the centuries, astronomers have refined the telescope from the first crude lenses of Galileo's day to giant telescopes in use today. Three simple pieces of glass, the lens, the mirror and the prism over the period of a few hundred years, have turned into sophisticated and powerful tools in human hands. Shouldn't we marvel at the ingenuity of the human mind?

As of today, a huge optical telescope called the Hubble space telescope, after Edwin Hubble, is in orbit around the earth. Several large telescopes are stationed in the USA, Hawaii, Australia, Chile, Russia, U.K. etc. In India the major optical observatories are at Nainital, Gurusikhar (Near Mount Abu), Udaipur, Japal Rangapur (near Hyderabad), Kavalur and Kodai Kanal. Many smaller telescopes scan the skies every night, adding to our knowledge of the cosmos.

There are many other ways of learning about the heavens than by just studying the light coming from them. One of them is **radio astronomy**. Nowadays, scientists use very sensitive radio telescopes to tune in on the cosmic objects and study them. Let us see what this method is.

10.2.3 Tuning in on the Stars

The fact that stars emit radiowaves was discovered accidentally in 1932 by a young engineer Karl Jansky. He was trying to find the source of noise in a transatlantic telephonic link. He made an experimental radio receiver set to study this problem. To his surprise, he found that the disturbance was due to radiowaves coming from the Milky Way Galaxy. This was the beginning of **radio astronomy**, i.e. the study of cosmic objects through radiowaves emitted by them. The radio telescope, a basic tool of radio astronomy, collects radiations from space in the radiowave region. One of the largest radio telescopes in the world was designed and set up by Indian astronomers at Ootacamund. The other radio telescopes in India are stationed at Gulmarg, Ahmedabad, Gauribidanur near Bangalore.

Radio telescopes may be tuned to receive radiowaves of the desired wavelength in the same way as we tune a radio to receive only the station we want. Radio telescopes not only give a 'view' of the invisible universe, but can also probe much deeper into space when compared with optical telescopes. Radiowaves can propagate through dust clouds in space, just as radio signals on the Earth can penetrate cloudy or foggy weather. Thus, they enable radio astronomers to construct images of regions completely hidden from the view of optical telescopes. However, radio telescopes normally receive radiation within a narrow band of wavelengths.

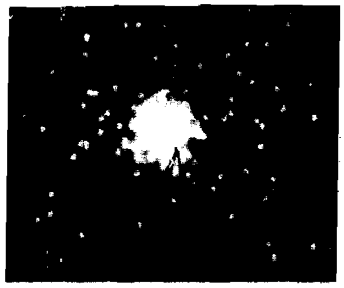

Fig. 10.3: A quasar.

Radio telescopes have led to the discovery of hundreds of cosmic objects that emit radiowaves. Most of these could be identified with the objects seen by optical telescopes. With the help of radio telescopes objects like **pulsars** were discovered. Pulsars are stars that send out pulses of light and radiowaves in regular bursts. For example, a pulsar in the centre of the Crab nebula at a distance of 6000 light years from the Earth sends out bursts of light and radiowaves 30 times a second.

Certain radio sources like 3c273, detected by radio telecopes and later examined by optical telescopes, were named **quasars** (Fig. 10.3). Quasar, an abbreviation of 'quasi-stellar radio source', is a star-like object situated billions of light years away. Not all quasars are radio sources. Since the electromagnetic waves from quasars are being detected on the Earth, they must be sending out huge amounts of energy. Quasars are comparatively small in size, only about a light month across. That is, if you imagined the Milky Way Galaxy to be a football field, a quasar would appear like a grain of sand. But it emits 100 times more energy than the entire Milky Way Galaxy.

Scientists have also found that many elliptical galaxies that seemed unimportant when seen through optical telescopes, were powerful sources of radiowaves. These galaxies were named **radio galaxies**. Often, the centre of a galaxy is a powerful source of radiowaves. Violent movements of huge quantities of matter and gas take place in the central part of the galaxies, emitting radiowaves in the process. Radio telescopes also showed that organic molecules exist in interstellar space.

SAQ 3

a) List four features which distinguish a radio telescope from the optical telescope.

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....

....

....

b) What new discoveries could be made with the help of radio telescopes?

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10.2.4 Messengers from the Sky

Light and radiowaves are not the only messengers from the sky to our planet Earth. There are others; like the meteorites entering the Earth's atmosphere from time to time. They bring us many messages about the cosmic objects from which they were chipped off. Earth is also constantly bombarded by cosmic rays which, as you've read earlier, are beams of electrons, protons and helium nuclei that cruise through space at very high speeds, approaching the speed of light. Their origin and their travel through space is a puzzle that scientists have not yet been able to solve completely. Once it is

A description of meteorites has been given in Sec. 11.4. of Unit 11.

solved, we will get to know a lot more about interstellar gas clouds, the stars and the galaxies.

10.2.5 Ventures in Space

Sometimes the atmospheric conditions distort the light or radiowaves coming in from space. For instance, there may be a storm disturbing the radiowaves. Or clouds may obscure light. Then it is not possible to study the universe in these regions of the electromagnetic spectrum. Even otherwise, modern science and technology have given astronomers several new ways and means of probing the universe. We will briefly describe each one of them.

Observatories in Space

With the coming of the Space Age, observatories equipped with telescopes and cameras could be placed right in space, beyond the Earth's atmosphere. An observatory in space may be in the form of an orbiting satellite like the Unmanned Orbiting Solar Observatories, Orbiting Astronomical Observatory, Skylab, Einstein Observatory, IRAS (Infra Red Astronomy Satellite) and many others. An observatory may also be stationed on the Moon or any other planet having suitable temperature and other conditions. Instruments are also put aboard high flying balloons, rockets and aircrafts to record observations. These observatories can record radiation from a cosmic object in the regions of the spectrum such as the IR, UV, gamma rays and X-rays that do not penetrate the Earth's atmosphere.

Visiting the Neighbouring Worlds

As space research came of age, it became possible for us to send spacecraft to other planets and even land men and instruments on the Moon. These ventures also provided a rich stock of information about the Solar System. For instance, astronauts of the Apollo mission to the Moon in the nineteen seventies brought back lunar rocks and soil samples, photographs of the lunar surface and left several instruments there for further study.

We have been able to send spacecraft, also called probes, across the Solar System to know more about our planetary neighbours. Space probes have visited a number of planets and a host of their moons, and successfully landed and operated on the surfaces of Mars and Venus.

The American spacecraft, Pioneer-10, crossed the orbit of Neptune in 1983, and, thus, became the first man-made object to leave the Solar System. With the help of observations from the Earth and the data sent by these probes, scientists have been able to arrive at a better theoretical understanding of the origin and evolution of the Solar System. We will present this information about the Solar System derived from observations in Unit 11.

SAQ 4

a) What is the difference between the Einstein Observatory and the probe Pioneer-10?

....

....

b) What other ways than the space observatories and space probes, have been used to collect information about the universe from beyond the Earth's surface?

....

....

To sum up, in this section we have given you a bird's eye view of the wide variety of tools and methods that astronomers use to make observations about the universe. We gave this brief description so that you may appreciate the importance of observations in astronomy. The universe is far more complex than we can imagine. Whatever hypotheses or theories we come out with, must be validated by observations. This is the reason why astronomers devise newer and better techniques of observation, to know more about the universe, to test their hypotheses and theories.

At this point, we advise you to take a break! Have a cup of tea or coffee and review what you have studied so far.

10.3 UNDERSTANDING THE UNIVERSE

So far you have studied how information about the universe is collected. It is stored mainly in the form of photographs of the cosmic objects, and spectra of their light. The other radiations coming in from space are recorded in various ways. This information is analysed and interpreted to construct theories about the universe and the objects that constitute it.

The hypotheses and theories about the universe and its constituents are always open to change in the light of new discoveries. Quite often a given theory may turn out to be wrong. Observed data may also be misinterpreted. In fact, a given theory may never agree hundred percent with the observations about the universe. A good scientific theory about the universe is one that is extremely close to all relevant observations. At the other extreme are tentative and speculative theories. We will now present some theories and concepts which represent the best possible understanding of stars, galaxies and the universe as a whole. Let us see what can be known about stars on the basis of the information obtained.

10.3.1 Let Us Know about Stars

The point-like stars have always presented astronomy with many questions such as: Where are the stars? How bright are they really? What is their temperature, size, age, etc.? What are they made up of? The developments in astronomy have provided astronomers with an ability to interpret starlight correctly and answer such questions.

Where are the Stars?

Astronomers use various methods to measure the distances to stars. For determining the distances to nearby stars, the method of stellar parallax is used (see Fig. 9.6). For stars farther away, more sophisticated methods are used. We will not go into their details. The distance to astronomical objects situated very far away is found by measuring the 'red shift' of their spectral lines. As far away objects, such as galaxies and quasars, move away from us, the lines in their optical spectra are shifted towards the red end. This shift can be measured and their distances calculated by using appropriate formulae.

Fingerprinting the Stars

Maximum information about starlight can be derived from its spectrum. When a lens-sized prism is put over the front (or objective) end of a telescope, each star can be seen as a colourful spectrum. We can place a photographic film at the focal plane of the lens-sized prism. Then it becomes possible to register the spectrum of starlight. Ironically, the astronomer sees the spectra, not as brilliant rainbows, but as black and white patterns shown in Fig. 10.4. Each star has its own characteristic spectrum—a fingerprint of its individual personality. From its spectrum, we can learn what elements a star is made up of, what its temperature is, how bright it is, how fast it is moving etc.

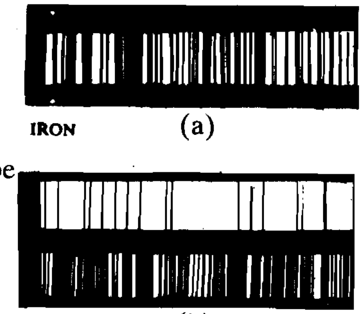

Fig. 10.4: (a) The composition of a star is found by identifying the pattern of lines cast across its spectrum by its chemical elements.
(b) The temperature of a star is shown by the number of lines in its spectrum. Stars at higher temperatures have fewer lines, as in upper spectrum.

Stellar Motion

Stars are not fixed in the heavens. They are moving within the galaxies. The speed of a star moving toward or away from the Earth is indicated by a shift of its spectral lines. If a star is approaching the Earth, its lines shift towards the blue end of the spectrum. If it is moving away from the Earth, its lines shift towards the red end of the spectrum. The greater the star's speed, the more its lines shift.

You have read that there are many kinds of stars—blue, yellow or red, normal or giant, pulsating or releasing excessive energy. Most stars move together in groups. Only one out of four stars may travel alone. Of the rest, almost a third are double stars and the rest are groups of many stars. In a double star system, known as a binary, two stars orbit one another. In a triple system, there are three stars—all three may move around each other, or two of them may move around the third. Then there are loose clusters, with a few dozen stars, to the large globular clusters containing hundreds of thousands of stars, all moving in many possible ways.

SAQ 5

List four pieces of information that can be deduced by analysing the fingerprint of a star i.e. the spectrum of its light.

....

Having studied the stars in terms of their distances, colour, brightness, motion etc., astronomers and astrophysicists have turned more and more to questions like: How did the stars come to be as they are? The search for answers has revealed a grand picture of stellar evolution. This picture tells us the story of how a star is born, how it evolves and how it dies. We can now explain the diversity of stars as also the unusual species of stars, simply as different stages in the lives of normal stars.

But, in this brief observation span of a few decades, how has it been possible to construct the story of stellar evolution which takes place at a time scale of millions and billions of years? How this is done can be seen by a simple analogy. Suppose a visitor from outer space arrives on Earth for one hour and wants to know about us within that time. He lands his spaceship in a busy place and hurriedly videotapes the people there. After departing he looks at the tape. He observes that the majority of the people are of the same size, but some are quite small, some are so tiny that they need to be carried. Still others, although of normal size, walk bent over with the help of canes. Being intelligent, our visitor soon realises that he is observing an ageing process: people are born very tiny, they grow up and spend most of their lives as active adults, and eventually they become old. Since the old people are few in number, he concludes that in the end they die.

Astronomers are in the same position with regard to the stars as our visitor from outside is with regard to people on the Earth. In a relatively short span of time, astronomers have observed more than a million stars. They have taken detailed spectra of their light, measured the brightness and surface temperatures. By carefully analysing this information they have deduced the story of stellar evolution. We will now relate this story.

10.3.2 The Life Story of a Star

A young star is thought to be composed largely of hydrogen gas. Hence, the most likely place for a star to be born is in one of the numerous clouds of hydrogen gas that exist in the interstellar space. Stars are now believed to form inside large dense interstellar clouds of gas. It may happen that for some reasons, not fully known so far, a gas cloud starts contracting. Under the influence of gravitational pull of the gas, its contraction may continue further. Once such a process begins, a very large volume of gas clouds is affected. As gravity pulls in the clouds, the pressure in the cloud increases. Also, as the cloud contracts, the temperature at its centre increases. At this stage, it is called a **protostar**.

When the temperature becomes sufficiently high (about 4 million degrees centigrade), a nuclear reaction starts in the protostar, in which the hydrogen nuclei fuse together to make helium nuclei (see Fig. 10.5). In this process a large amount of energy is released. The energy travels to the surface of the star and is radiated in the form of light, heat and other electromagnetic radiation. This energy creates an outward pressure and force. The contraction of the star stops only when the inward pull of gravity is balanced by the outward force of this radiant energy. At such a time the star becomes stable in size and temperature.

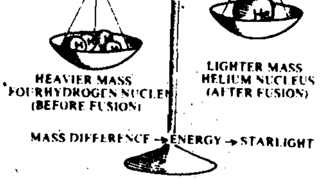

Fig. 10.5: An imaginary sketch showing the nuclear fusion process in stars.

The Sun has been in such a stable situation for the past 5 billion years. Nuclear reactions in the Sun convert about four hundred million tons (4×10^{14} gms) of hydrogen into helium every second. It is expected that the Sun will remain in this state for another 5 billion years.

As the star consumes a significant percentage of the hydrogen fuel in its core, the nuclear reaction decreases and the outforce of the radiant energy weakens. The core of the star further contracts because its gravitational pull becomes more than the out-force of radiant energy.

But this raises the temperature of the core. Meanwhile, the hydrogen nuclei 'burn' in the outer layer or shell surrounding the core. The extra heat from the core as well as the heat generated in the outer layers cause the star's outer region to 'boil' and expand. The star becomes big and its brightness increases. But, as the outer layer expands farther away from the nuclear furnace, its temperature falls. The puffed-up star looks red and cool. If it is many times more massive than the Sun, it becomes a **red super giant** like the Betelgeuse. If it is sun-sized or only slightly more massive than the Sun, it becomes a slightly swollen **red giant**.

The red giant stage of a star is a relatively short stage. In this stage, the star consumes its hydrogen at a very fast rate, piling up helium in its core. As the fuel burns, the core contracts further, producing temperatures as high as 100 million $^{\circ}$C. At this point the helium nuclei in the core fuse together in another nuclear reaction to form carbon nuclei. This is a critically unstable moment in a star's life with two layers of the star burning at the same time—an outer layer where hydrogen is being turned into helium and inner core where helium is being turned into carbon. Hereafter the fate of the star depends on the mass of its core. We will merely describe the process without going into the reasons.

If the mass of the core is less than $1.4_{\odot}$, where $M_{\odot}$ is the Sun's mass, the contraction of the core halts when it is about the size of the Earth. This limit of $1.4M_{\odot}$ is known as the Chandrasekhar limit, after S. Chandrasekhar, the famous Indian scientist who won the Nobel Prize for this work. He had settled in the U.S.A. Such a star is known as a **white dwarf**. From the Earth it would be seen as very small and very faint but it is hotter than the Sun. One of the first stars recognised as a white dwarf was Sirius B, the faint companion of the bright star Sirius. Sometimes a white dwarf suddenly flashes millions of times more brightly. Such a phenomenon is known as '**nova**'. As it cools, a white dwarf may turn into a black dwarf, disappearing from our vision.

If the core mass of the star is in the range $1.4M_{\odot}$—$3M_{\odot}$, or the star mass is between $8M_{\odot}$ to $15\ M_{\odot}$, the core shrinks to a radius of about 10 km and a **neutron star** is formed. If a neutron star is born rotating very fast, it emits electromagnetic radiation, which astronomers detect as pulses of radiowaves. Such stars are called pulsars. Pulsars were discovered in 1967 and about 400 are now known.

In stars with higher mass, the helium in the core turns into carbon. However, it continues burning in the outer layer. The core goes on contracting and becoming hotter. It sets the carbon nuclei burning to form oxygen nuclei. As each nuclear fuel is exhausted in the core, it contracts, increasing the temperature and sets the fuel in the core burning. Meanwhile, the earlier fuel keeps burning in the shell surrounding the core. Thus, the star contains several nuclear burning shells (see Fig. 10.6). This process may go on in massive stars all the way upto a core of iron.

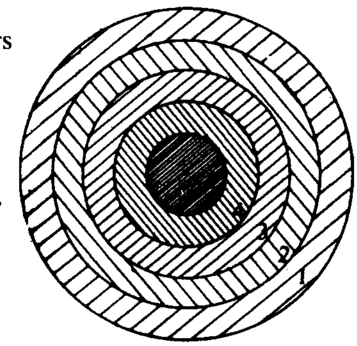

Fig. 10.6: The structure of a massive star ($30M_{\odot}$) at a late stage in its evolution. The star consists of several layers with different composition separated by nuclear burning shells. The layers are of Hydrogen (1), Helium (2), Carbon, Oxygen (3), Silicon (4), and Iron (5).

If a star starts with a mass of more than $20\ M_{\odot}$, its contraction continues. Then the core of the star collapses to become a black hole. Its gravity is now so strong that nothing, not even light, can leave it. Obviously, we cannot see a black hole.

Sometimes, massive stars (with the core mass between $3\ M_{\odot}$and $15\ M_{\odot}$) explode, releasing a tremendous amount of energy. Such explosions are called '**supernova**'. The brightest of the supernova hurl out almost as much light as the entire galaxy—its brightness becoming equal to hundred million Suns. A supernova was seen in the Milky Way Galaxy as recently as in 1987 A.D.

SAQ 6

a) Arrange the following stages of a star in their correct sequence:
i) protostar ii) stable star iii) gas cloud

....

....

b) What happens when a gas cloud contracts?

....

....

c) What is the source of energy in a star?

....

d) When does a star become stable?

....

The evolutionary stages of any real star involve many factors which are not completely known. Nature may not adhere strictly to the sequence described above. The description of the final stages in the life of a star is purely theoretical and, therefore, open to change. For example, in a supernova explosion it is very uncertain whether what remains will be a neutron star, a black hole or nothing at all. Every new set of observations makes the life cycle of a star clearer to astronomers.

Stars may be regarded as laboratories that allow scientists to study many natural phenomena like the synthesis of heavy elements or the triggering of interstellar cloud collapse. Such events resulted in the formation of the Solar System and life on Earth.

Stars, as you know, are themselves part of galaxies. Do galaxies evolve the same way as the stars? Scientists think that the answer is yes, but they have yet to work out a very convincing theory of evolution of galaxies. However, the study of galaxies has provided one very interesting piece of information about the universe—that it is expanding.

10.3.3 The Expanding Universe

As you saw in Sec. 9.2.3, Hubble's observations had proved the existence of galaxies. After mapping as many galaxies as could be seen by the telescopes then available, he turned his attention to the motion of galaxies. He was motivated to do this by a puzzling report of V.M. Slipher, an American astronomer. He had discovered in 1912 that many of the faint nebulae were moving away from the Earth at very great speeds. Their spectral lines exhibited large shifts towards the red end (what is called as red shift). This seemed peculiar because stars in the Milky Way Galaxy move at much smaller speeds, some moving away from us with others moving towards us. Slipher had made these observations a decade before galaxies were discovered. Then it was thought that the nebulae were objects in our own galaxy. He did not know what to make of his observations.

But as Hubble knew that these nebulae were galaxies, he began a systematic study of the relation between their speeds and their distances alongwith his colleague M.L. Humason. What they found was very interesting. To put it simply, his observations showed that;

i) all galaxies were moving away from us;
ii) the farther away a galaxy was from our Galaxy, the greater was the speed at which it moved away.

Hubble's discovery put forth the picture of an expanding universe. But if all the galaxies are moving away from us, are we at the centre of the Universe? No. If we were situated in another galaxy, even then the other galaxies would seem to move away from us. You can understand this picture of an expanding universe if you study Fig 10.7 and also perform a simple activity.

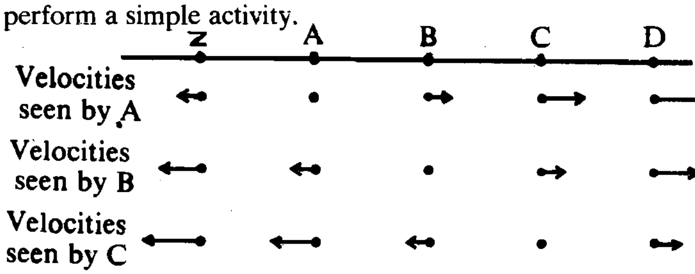

Fig.10.7: A string of equally spaced galaxies Z, A, B, C, etc. are shown. Their speeds as measured from A or B or C are indicated by the lengths of arrows: The directions of arrows indicate the directions in which the galaxies would appear to move. Seen from any galaxy, any other galaxy would appear to move away with a speed proportional to the distance between them.

Activity

Take a balloon and mark a few points on it with a pen. Inflate the balloon. What can you say about the movement of points with respect to each other?

Did you observe that each point on the balloon moves farther away from the other as you inflate it more and more? We can picture the movement of galaxies in a similar fashion. However, this is a rather simplistic experiment because here you are viewing the balloon from outside, whereas, when we observe the universe, we are within one galaxy. This was just to give you an idea of how the universe is expanding.

Now, if the universe is expanding, then it was much more compact million of years ago and the galaxies were much nearer to each other. Does it set you wondering what the universe was like in the beginning? What caused it to expand like this? We will now describe what theories cosmologists have given about the origin and evolution of the universe.

10.3.4 Closing in on Creation

The study of the universe, as a whole, of its large scale structure, its origin and evolution is called cosmology.

The most important current theory for the origin of the universe is the **Big Bang** theory.According to this theory, the universe started with a huge explosion. It was not an explosion like the ones with which we are familiar, which start from a definite centre and spread out. It was an explosion which occurred everywhere in space at the same time. It filled all space from the beginning, with every particle of matter rushing apart from every other particle. This was not a burst of matter into space but rather an explosion of space itself. Every particle of matter rushed away from every other particle. It is so far impossible to 'picture' the first moment of 'creation' of the universe.

One-hundredth of a second after the creation of the universe is the earliest time about which scientists can speak with any confidence. At this instant, the temperature of the universe was about a hundred billion degrees centigrade. This is much hotter than in the centre of even the hottest star. At such temperatures none of the components of ordinary matter, atoms, molecules, or even nuclei of atoms, could have held together. Instead, the matter rushing apart in the explosion consisted of various types of elementary particles. The particles most abundant in the early universe were the electrons, positrons and neutrinos. There were also some protons and neutrons. The rest of the universe was filled with energy. It was a kind of a cosmic soup.

As the explosion continued, matter and energy rushed apart, the universe expanded and the temperatures dropped, reaching 30 billion (3×10^{10}) degrees centigrade after about one-tenth of a second; 10 billion degrees after about one second; and 3 billion degrees after about fourteen seconds. At the end of the first three minutes, the universe became cool enough (about 1 billion $^{\circ}$C) for the protons and neutrons to begin to form into simple nuclei. The first to be formed was the nucleus of heavy hydrogen which was made up of one proton and one neutron. There were also helium nuclei made of two protons and two neutrons. It was still too hot for atoms to hold together, they were ripped apart as soon as they were created. This matter continued to rush apart, becoming steadily cooler and less dense.

Many thousands of years later, it became cool enough for electrons to join with nuclei to form atoms of hydrogen and helium. Soon, the resulting gas began to form clumps under the influence of gravitation. These clumps ultimately condensed to form the galaxies and stars of the present-day universe, almost 5 billion years after the Big Bang.

There is another theory about the origin of the universe known as the **steady state** theory. This theory holds that the universe has always been just about the same as it is now. As it expands, new matter is created continuously to fill up the gaps between the galaxies. Thus, the problem of the origin and early moments of the universe is banished: there was no early universe.

However, the Big Bang theory is the most favoured by the astronomers and astrophysicists. Why is it so? This is due to the evidence based on observations which lend support to the 'Big Bang' universe.

Evidence Favouring the Big Bang

One piece of evidence comes from the expansion of the universe which we have already described. The expanding universe suggests that the matter was packed much more densely in the early stages of the universe. The proof for this also comes from the distant objects quasars. When we 'look' at quasars situated 6 to 8 billion light years away, we are looking at them as they existed then. If the universe were more dense in that epoch, we should be able to see some evidence of that density in the quasars. We do see such high density among the quasars.

Another substantial bit of evidence for the Big Bang theory comes from the **cosmic**

background radiation. For many years the astronomers believed that if there was a cosmic explosion long ago, radiation from that event should still exist within the universe. This radiation may be weak, it may have lost its energy due to the expansion and cooling of the universe, but it should exist. Radio-astronomers have, indeed, discovered faint signals—a constantly present background radio noise that pervades all space. Calculations done by astrophysicists show that this radiation, called the cosmic microwave background radiation, is a relic of the ancient past when the universe was in its first throes of creation in the Big Bang.

An additional discovery made by astronomers in the past two decades is that of the **primordial abundance of elements**, i.e. the elements hydrogen and helium first created in the aftermath of creation are found to be most abundant in the universe. By examining the light coming from the various parts of the universe, astronomers have found out that, out of every 100 atoms, almost 93 are hydrogen atoms and seven are helium atoms. Elements heavier than helium are present in traces only. This suggests that the universe started out with a Big Bang from a very hot and dense state and quickly cooled as it expanded. The hot and dense conditions lasted long enough for some hydrogen to fuse into helium. But they did not last long to allow other heavier elements to form in significant amounts. These were made much later in the interior of massive stars.

SAQ 7

a) State one difference between the Big Bang and the steady state theory?

....

....

b) Which three among the following observations support the Big Bang theory of the origin of the universe? Tick (✓) the correct answers.

   i) Stellar spectra show blue shift as well as red shift in the spectral lines.
   ii) The elements hydrogen and helium are the most abundant in cosmic matter with other heavier elements occurring in traces only.
   iii) The spectra of light from galaxies shows a red shift suggesting that the universe is expanding.
   iv) There is a cosmic radiation pervading the entire space.

In conclusion, we find ourselves amidst an expanding universe which throws up puzzles with amazing regularity. With each question answered, many more questions arise. For example, an important question today is about the future of the universe. Will it go on expanding like this? Or, will its expansion stop some day? What will happen then? Will the universe remain as it were then or will it start contracting? We also find ourselves amidst an explosion of ideas and techniques being applied to study the universe. In this unit we have tried to give you a brief glimpse of the enigmatic nature of the universe and our undaunted efforts to understand it. Don't you feel that this brief insight was worthwhile? We end this unit with a quote of Edwin Hubble from his last paper:

'From our home on Earth we look out into distances and strive to imagine the sort of world into which we are born. Today we have reached far out into space. Our immediate neighbourhood we know rather intimately. But with increasing distance our knowledge fades .... until at the last dim horizon we search among ghostly errors of observations for landmarks that are scarcely more substantial. The search will continue The urge is older than history. It is not satisfied and it will not be suppressed.

10.4 SUMMARY

In this unit we have briefly described the various tools and methods of modern astronomy used to gather information about the universe and some theories and concepts about stellar evolution, the origin and evolution of the universe. Let us now sum up what we have discussed in this unit.

- Information about the universe can be gathered in many ways through optical astronomy, radio astronomy, space observatories, space probes etc.
- The information is analysed and interpreted to understand various phenomena

occurring in the universe and construct theories or models to explain them. One such theory is about stellar evolution.

- By observing the red shift in the spectral lines of starlight from millions of galaxies, it has been established that the universe is expanding.
- The most important theory of the origin of universe is the Big Bang theory. According to this theory the universe was created in a gigantic explosion which occurred everywhere in space at the same time.
- Another theory about the origin of the universe known as the steady state theory holds that the universe was always the same as it is now and will remain the same. There was no early universe.
- The evidences such as the expansion of the universe, cosmic background radiation, primordial abundance of elements support the Big Bang theory.

10.5 TERMINAL QUESTIONS

1) Match the various methods of astronomy listed in column 1 with their descriptions listed in column 2. Draw an arrow between the corresponding items.

1		2	
a)	Optical Astronomy	i)	Spacecraft carrying instruments are sent to neighbouring worlds.
b)	Radio Astronomy	ii)	Instruments are stationed in satellites going around the Earth, on the Moon or any other planet.
c)	Space Observatories	iii)	Meteorites, cosmic rays etc. coming from space also carry a lot of information about the universe.
d)	Space probes	iv)	Light from the planets, stars and galaxies is collected and analysed.
e)	Visitors from the Space	v)	The radiowaves emitted by various objects in the universe are collected and analysed.

2) List the methods that enable astronomers to analyse the IR, UV, X-rays, gamma rays coming from space.

....

3) a) How is each of the stars of masses 25 $M_{\odot}$, 10 $M_{\odot}$, 0.8 $M_{\odot}$, likely to evolve after the red giant stage?

....

b) State the difference between a 'nova' and a 'supernova'.

....

....

....

4) Describe in one or two lines the state of the universe against each instant of time given below, as suggested in the Big Bang theory.

i) The first moment of creation ....

....

ii) 1/100 sec. after Big Bang ....

....

iii) 3 minutes after Big Bang ....

iv) 10,000 years after Big Bang ....

v) 5 billion years after Big Bang ....

10.6 ANSWERS

Self Assessment Questions

1) a) 375 metres, 800 kilohertz; radiowaves region
   b) 3×10^8 m/s
   c) 530 kilohertz (KHz) to 1605 (KHz) in only the medium wave band; 530 kilohertz to 220 megahertz (MHz) in the medium wave to shortwave bands.
   d) gamma rays.
   e) A few kilometres.
2) a) 4×10^{-7} metres to 8×10^{-7} metres; 7.5×10^{14} Hz, 3.8×10^{14} Hz
   b) blue
   c) Wavelengths in the visible and the radiowave regions. You can write their values.
3) a) i) Radio telescopes collect and analyse radiowaves giving a view of the invisible universe; (ii) they can probe cosmic objects situated at much larger distances; (iii) radiowaves can penetrate dust clouds unlike light waves; (iv) radio telescopes are made for only specific wavelengths but optical telescopes collect all optical wavelengths at the same time.
   b) Pulsars, radiogalaxies, organic molecules in interstellar space.
4) a) The Einstein Observatory is an artificial satellite which revolves around the Earth. Pioneer-10 is a spacecraft that has moved out of the Earth's gravitational pull travelling across the Solar System.
   b) Through instruments stationed in rockets, high flying balloons and aircrafts.
5) Composition, temperature, brightness and motion of stars.
6) a) Gas cloud, protostar, stable star.
   b) As a gas cloud contracts, the temperature of its core increases.
   c) When the hydrogen nuclei in the core of a star fuse together to form helium nuclei, a lot of energy is released.
   d) A star becomes stable when its inward gravitational pull is balanced by the outward force of radiation energy.
7) a) The Big Bang theory says that the universe had a beginning in a huge explosion. According to the steady state theory there was no early universe. It has always been the same as it is now.
   b) (ii), (iii), (iv)

Terminal Questions

1) a), iv); b), v); c), ii); d), i); e), iii).
2) Through space observatories, rockets, balloons, space probes.
3) a) Black hole, neutron star or pulsar, white dwarf.
   b) A nova takes place when a white dwarf flashes millions of times more brilliantly; the explosion of a star with core mass between 3 $M_{\odot}$ and 15 $M_{\odot}$ is called a supernova.
4) i) the space explodes all at once in a Big Bang, matter starts rushing apart.
   ii) elementary particles such as electrons, positron, neutrinos, protons and neutrons form.
   iii) heavy hydrogen and helium nuclei form.
   iv) atoms of hydrogen and helium form.
   v) stars and galaxies form.