39A
UNIVERSE

39.1 INTRODUCTION

Have you ever felt the urge to ask yourself the questions like these: Who am I? What is life and how did it come into existence? How did the universe itself come into existence? These are difficult questions, some of these perhaps touching on areas other than science. The last of these questions, about the origin of the universe, could also not be discussed in puerly scientific terms till about a hundred years ago.

In this lesson we shall discuss this question in simple nd purely scientific terms. Besides the description of the evolution of he universe, its age and its expansion, in this lesson you will also study bout the different types of galaxies and their important components.

39.2 OBJECTIVES

After studying this lesson, you should be able

- *state where the interstellar gas clouds are located and that they may be bright or dark*
- *explain that the new stars are born in the interstellar gas clouds*
- *name the important components of our Galaxy and give reason why the whole mass of the Galaxy cannot be concentrated near its centre*
- *explain what is meant by an expanding universe*
- *explain what a Hubble diagram is and how it is used to estimate the age of the universe*
- *explain the red shift of galaxies and its use to get the velocities of external galaxies*
- *describe how distances of very distant objects are found*
- *describe the rival theories of the origin of the universe*
- *describe the cosmic background radiation and the support that it lends to the evolving universe*
- *describe the meaning of open and closed universes and to reason whether the universe is open or closed*

39.3 HISTORY OF THE ORIGIN OF UNIVERSE

The question of the origin of the universe is, of course, not new. Sacred books of almost all religions have speculated about it. The *Rig Veda*, believed to be the oldest religious text, contains in its Xth book a hymn where the mystery of the origin of the universe is highlighted. Its first part rendered in English reads as follows.

"Then was not non-existent nor existent; there was no realm of air, no sky beyond it. What covered in and where and what gave shelter? Was water there, unfathomed depth of water Death was not then, nor was there aught immortal; no sign was there the day's and night's divider. That one thing breatheless, breathed by its own nature; apart from it was nothing whatsoever. Darkness was there; at first concealed in darkness this all was indiscriminated chaos. All that existed then was void and formless; by the great power of Warmth was born that Unit."

The Sanskrit version of this is as given below:

विश्वसृष्टेगेहनता
नासदासीन्नो सदासीत् तदानीं
नासीद्रजो नो व्योमा परो यत्।
किमावरीवः कुह कस्य शर्मन्
अम्भः किमासीद् गहन गभीरम् ॥ १ ॥

न मृत्युरासीदमृतं न तर्हि
न रात्या अह्न आसीत् प्रकेतः।
आनीदवातं स्वधया तदेकं
तस्माद्धान्यं न परः किंच नास ॥ २ ॥

तम आसीत्तमसा गूळ्ह–
मग्रेऽप्रकेतं सलिलं सर्वेमा इदम्।
तुच्छ्येनाभ्वपिहितं यदासीत्
तमसस्तन्महिनाजायतैकम् ॥ ३ ॥ (R.V., 10.129 1-3)

The Bible, as we all know, contains an acount of the creation of the world in seven days. The other religious texts, too, have deliberated upon this question. The philosophers have also discussed this question since very early times. But all these have had very little scientific content. Only since the beginning of the twentieth century have scientists been able to address this question from a purely scientific point of view. This has been possible due to developments-some of which we shall discuss in this lesson.

The first of these developments was the method for determination of distances in the universe by using the Cepheid variable stars. The second was the discovery by Hubble that the external galaxies are rushing away from us. This came to be popularly known as the expanding universe. The third development of great importance was the opening of the radio window to the universe. So far the astronomical observations were confined to the optical radiation. But immediately after the second World War it was discovered that it was possible to observe far off objects at radio frequencies. Many objects which could not be seen optically became accessible to observation through radio waves.

The most important development on the theoretical side was the foundation of the theory of genetal relativity by Einstein. It became now possible to write down equation governing the evolution of the universe and discuss the problem of the origin of the universe in scientific terms as distinct from religious and philosophic terms.

It is interseting to see how our view of the universe has changed during the last few thousand years. The early Greek scientists believed that the Earth was at the centre of the universe and that all other objects revolved around it. This is called the **geocentric universe**. There was no estimate of the size of the universe. The geocentric view of the universe prevailed for about two thousand years. Copernicus in the sixteenth century proposed that the Earth and other planets were revolving round the Sun. This notion goes by the name of **heliocentric universe**. About a hundred years later when Galileo fabricated a telescope and used it for astronomical observations, he found evidence in favour of the Earth revolving round the Sun. Since the view that the Earth revolves round the Sun was against the official Christian beliefs, Galileo had to undergo punishment for propagating his views. Only after his death was his work published and became widely known. The work of Kepler, and later of Newton, confirmed the views of Copernicus and Galileo. Astronomical observations in this century established that the Sun was not even at the centre of our own Galaxy; it was tucked away near a corner. This was the death of the heliocentric universe. Future work may even show that the humans are not unique in the universe, and that there are other and, perhaps, more advanced civilization in the univese. So, from being at the centre-stage of the universe, man has been pushed to a rather unimportant position of being an inhabitant of an ordinary planet orbiting a rather ordinary star situated near a corner of one of the billions of galaxies in the universe. Some retreat this!

39.4 OUR GALAXY

Have you heard of the river ***Ganga*** in the sky? If you look at the sky on a dark night from a place where there is no dust and not much city light, you can even see this river (Fig 39.1). This is know as **Akash Ganga**, or the **Milky Way.** Of course, we are not talking about the actual river ***Ganga*** of water that we see on the Earth. So what is this ***Akash Ganga***? This is the ***patch of light in the sky which appears like a river***. That is why it is called ***Akash Ganga*** or the Milky Way. Actually, this is a very dense collection of stars, so dense that with the naked eye we cannot see the stars apart, and we see only a patch of light crossing the sky. It was Galileo who first resolved the stars with his telescope towards the beginning of the seventeenth century. We now know that these stars form the central plane of our Galaxy. That is why our Galaxy is known as the Milky Way Galaxy, or ***Akash Ganga*** in India.

But what is a galaxy? Before we seek answer to this question let us look at an important component of our Galaxy. We will come back to this question after we have been through the next section.

Fig. 39.1 : The Photograph shows the milky way in the constellation of agittarirs

39.4.1 Interstellar Gas Clouds

In the lesson 38 you studied about the stars. You saw that the stars are separated by huge distances. You must be wondering what that space is filled with? It is filled with gas. mostly atomic hydrogen, some molecular hydrogen and other molecules in very small quantities. ***The space between the stars within our Galaxy*** is called the **interstellar space** and the material that fills this space is called the **interstellar medium.** The density of this medium is extremely small. about 1 practicle of hydrogen in a cubic centemetre. The temperature of this medium is about 10^4 K. You can calculate the pressure in the interstellar space (using the relation p = nkT) and show that it is ***billions of times smaller than the pressure in the best vacuum that we can produce in our laboratories.***

The density in the interstellar space is not uniform. At places the density becomes very large, from 10 to a million times the average value. These regions of dense gas are called **interstellar gas clouds**. You would recall from the last lesson that these are the places where new stars are formed. Some of these clouds are huge in size, hundreds of parsecs across. Under certain circumstances these clouds become unstable and break up into smaller pieces. These pieces contract to become stars. How do we know this?

A protostar, before it settles down as a full-fledged star on the main sequence, radiates in the infra-red region of the sepctrum. Moreover, just before it reaches the main sequence, the star passes through a phase in which its brightness varies in a characteristic fashion. Such stars are called the T-Tauri stars. So, ***if a gas cloud is a strong emitter of infra-red radiation and shows T-Tauri stars in its midst, it is taken as evidence of the new stars being formed.*** Fig 39.2 shows a gas cloud in which astronomers believe new stars are being born.

Fig. 39.2: Photograph of a gas cloud in which new stars are being formed

Some interstellar clouds are bright, while some others are dark. If there are bright stars near or inside a gas cloud, the cloud becomes bright by reflecting the light of these stars. If there are no stars nearby then the cloud remains dark. But then how do we see such a dark object? We see this object when it obstructs the light of other objects coming from behind it. Fig 39.3 shows the Orion constellation and the locations of the two types of clouds.

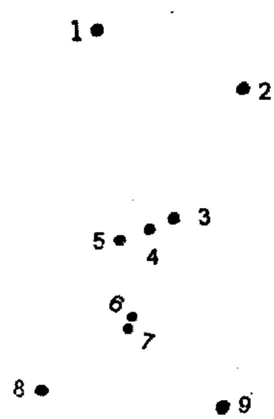

Fig. 39.3: Bright stars of the Orion consellation

Activity: Orion constellation is prominent in the winter months and it is easy to identify it. If you have interest in watching the night sky, this is an easy object to start with. With helps of Fig 39.3 locate the clouds and observe them through a telescope.

INTEXT QUESTION 39.1

1. *Calculate the density of the interstellar medium in kg/m³ if there is one hydrogen atom in a cubic centimetre* volume. *The mass of a hydrogen atom = 1.6×10^{-27} kg.]*

   ....

2. *Assume that an interstellar gas cloud is a sphere of radius 100 parsec. Assume that the average density of matter in the cloud is 10 hydrogen atoms/cm³. Calculate the mass of the cloud in units of solar mass.*

   ....

39.5 STRUCTURE OF THE GALAXY

The Sun, the stars, the interstellar medium and the interstellar gas clouds form a system which is gravitationally bound. This system is called the Galaxy. By gravitationally bound we mean that the mass of the system is such that all its components are attracted towards it with sufficient force so that none can escape it.

The stars in the Galaxy could not be static. If they were, they would be falling towards the centre of the Galaxy.

If Earth were stationary and not orbiting around the Sun, would it fall towards the Sun?

Since the collapse of the Galaxy is not observed, it is concluded that its components are not stationary. ***The solar system is orbiting round the centre of the Galaxy completes one full orbit in about 250 million years.*** This time interval is sometimes called cosmic year. The Sun is at a distance of about 8.5 kilo parsec from the centre of the Galaxy. If we assume that the mass of the Galaxy is concentrated within the orbit of the Sun, the mass of the Galaxy can be estimated, just as we estimated the mass of the Sun from the orbital speed the Earth.

39.5.1 Central Bulge

If we could see edge-on, we would see the Galaxy as shown in Fig 39.4. The Galaxy has a roughly spherical shape at the centre and beyond that it is a thin disc which is the plane of

Fig. 39.4: Sketch of our Galaxy as seen edge-on

the Galaxy. This is that plane where the number density of stars is so large that with the naked eye you cannot resolve them. That is why this plane appears as a patch of light in the night sky, and has been given the name of *Akash Ganga*, or the Milky Way.

Two features are immediately noticeable in the appearance of the Galaxy. The spherical component at the centre and a thin disc outside it. The spherical component has a radius of 4000-5000 parsec. It contains very old stars. Most of these stars are in the forms of **globular clusters**. Each globular cluster might contain 10^5 - 10^6 stars. The density of stars is so large that to naked eye a globular cluster appears like a roundish blob of light.

There is a great deal of interest in the globular cluster these days. The estimated age of some of the globular clusters has been found to be longer than the age of the universe. How can the age of a component of the universe be longer than the age of the universe itself? That is the question the astronomers are trying to answer.

39.5.2 Disc of the Galaxy

The other visible feature of the Galaxy is the disc. It has a radius of about 15000 parsec. The Sun is situated in this disc towards the edge, ***about 8500 parsec from the centre of the Galaxy***. The disc is really very thin, only about 1000 parsec in thickness. The disc constitutes the central plane of the Galaxy. Most of the stars and the interstellar clouds of the Galaxy reside in this plane. Cannot be resolved with the naked eye, and appear like a patch of lilght in the sky. It is from this that our Galaxy derives the name the Milky Way Galaxy, or *Akash Ganga* in India. The total number of stars may be as large as a few hundred billion. this indicates that the mass of the Galaxy is about a few hundred billion times the mass of the Sun.

There is so much material between the Sun and the centre of the Galaxy that our view of this side of the Galaxy is blocked. Much of the information that we have been able to gather about the central region comes from observations at radio wavelengths which are not as much absorbed as the optical wavelengths.

39.5.3 Halo and Corona

The ***whole of the Galaxy is surrounded by a thin shroud of matter***. This is called the halo of the Galaxy. In the plane of the Galaxy, its radius is about 20000 parsec. It is shown schematically in Fig 39.5. It consists mostly of old stars. Earlier it was thought that the halo has very little mass. But current estimates indicate that its mass may be about the same as that of the Galaxy, a few hundred billion solar masses.

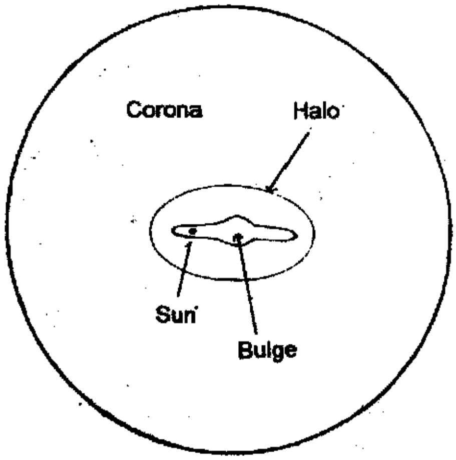

Fig. 39.5: Our Galaxy is surrounded by a halo & corona as sketched here.

The Galaxy and the halo are further surrounded by an extremely thin veil of matter. This is called the galactic **corona** (Fig 39.5). It extends on all sides to a distance of about 10^5 parsec. This is such a huge volume that despite its very low density, it has 2-3 times the mass of the Galaxy and halo put together. This means that the total mass of our Galaxy is close to 12 hundred billion solar masses.

The galactic coronas have been discoverd in the last 20-30 years. How this has come about is an interesting story. You have already noted that the Sun rotates about the centre of the galaxy. Similarly, other stars and components of the Galaxy rotate round the centre of the Galaxy. Now if the whole mass of the Galaxy were concentrated near its centre, the rotation velocity of any object of mass m will follow the familiar relation.

$$\boxed{\frac{mV^2}{r} = \frac{mMG}{r^2}} \quad \text{...(39.1)}$$

where M is the mass of the Galaxy and r is the distance of the object from its centre. This implies that as we go towards the edge of the Galaxy, the rotational speed of the objects should vary as $\sqrt{(1/r)}$. The observations, on the other hand, show that the speed either stays constant, or increases.. It implies that the mass of the Galaxy is not concentrated near the centre and that it is scattered over a large volume. This also meant that the mass of the Galaxy must be much larger than so far estimated. At the same time a group of astronomers were already arguing for a much more massive Galaxy, therefore, the idea of a corona surrounding the Galaxy found favour and was later accepted. Why did some astronomer want a more massive Galaxy? Their argument was that the thin disc of the Galaxy would fracture if it was not stabilized by the gravitational pulls on it from all sides. The mass of the halo was found to be insufficient for this purpose. The observation that the disc has not suffered any fracture, showed that a structure like the galactic corona

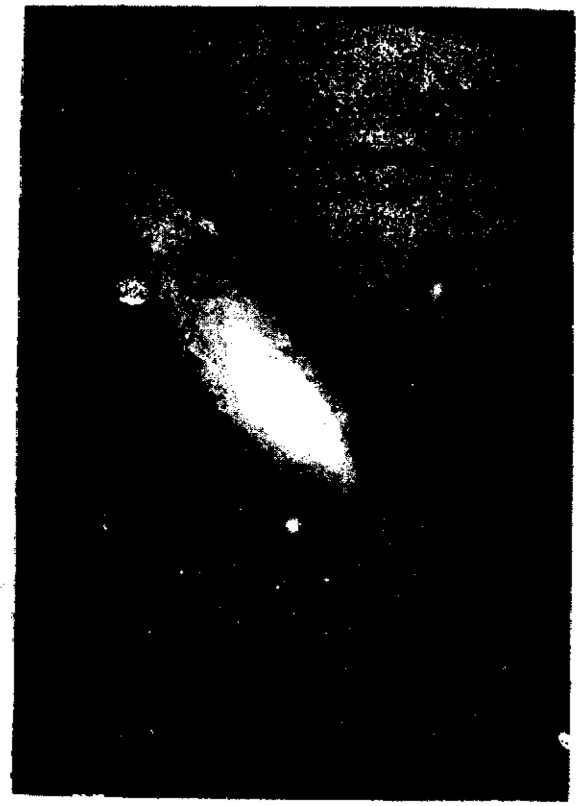

Fig. 39.6: Photograph of Andr omeda galaxy our neighbour er in space

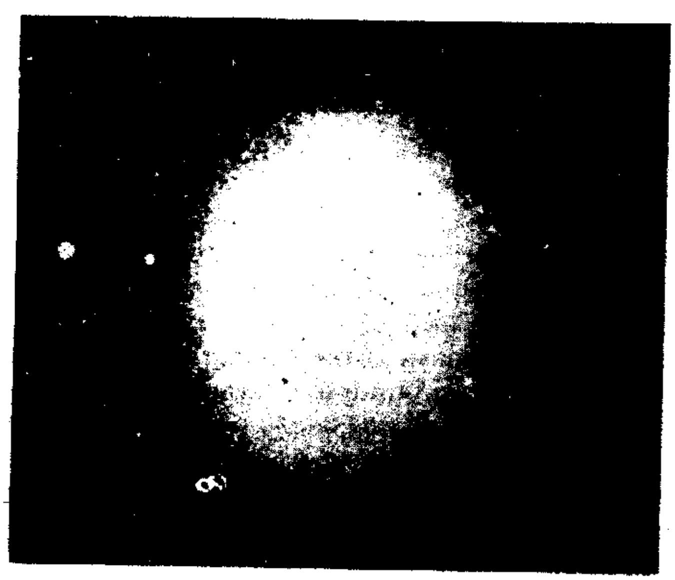

Fig. 39.7: Example of an elliptic galaxy

must exist to stabilize it. So, the existence of the corona was accepted.

INTEXT QUESTIONS 39.2

1. *The solar system orbits the centre of the Galaxy with a radius of 8.5 k parsec once in 250 million years. Find out its orbiting speed.*

   ....

2. *From the answer of the last problem, calculate the mass of the Galaxy assuming the whole mass of the Galaxy is concentrated near its centre. ($G = 6.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$)*

   ....

39.6 EXTERNAL GALAXIES

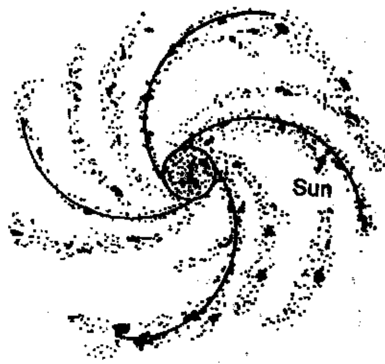

Fig. 39.8: Our Galaxy has a spiral shape as sketched here.

If we could look at our Galaxy from the top, we would see a picture somewhat like shown in Fig 39.8 . You see the bright centre surrounded by spiral arms. ***Galaxies which are characterized by a central bright region surrounded by spiral arms*** are called **spiral galaxies**. Ours is one of the largest spiral galaxies. Another large spiral galaxy is in our neighbour in space, the famous Andromeda galaxy, shown in Fig 39.6. Many galaxies do not show spiral structure. Some of these are elliptic galaxies. Sometimes the ellipticity is not very pronounced. Such galaxies are spheroidal. Some galaxies show no regular shape at all, for example our two neighbours, the large and the small Magellanic clouds, Qut galaxy has a spiral shape as sketched here (Fig. 39.8)

Have you noticed how large in size the galaxies are. The distance which separate them are also immense in size. The typical distance between two galaxies is of the order of a million parsec. The **intergalactic space** is filled with extremely thin gas. Its temperature may be as low as 100 K. This matter is difficult even to observe, though its mass may be many times more than the mass contained in galaxies, which is mostly visible.

How many galaxies are there in all? It is difficult to count them. It is estimated that there may be of the order of 10^{11} galaxies in the universe. In spite of the fact that they are separated by huge distances, the galaxies do interact with one other gravitationally. Some galaxies suck the matter of other galaxies. Sometimes the interaction ends in merging of galaxies. The time of interaction is, of course, in billions of years.

INTEXT QUESTIONS 39.3

1. *Imagine a sphere of radius 1 million parsec. Suppose the density of matter in the sphere is 0.1 hydrogen atoms/cm³. Calculate the mass of matter in this sphere in units of the mass of our Galaxy. You may take the mass of the Galaxy =10^{12} solar masses and mass of Sun = 2×10^{30} kg.*

   ....

2. *If the temperature in the integalactic space is 100 K. find the pressure there if the density of matter is 0.1 hydrogen atoms/ cm³ Boltzmann Constant* $k = 1.38 \times 10^{-23}$ J K^{-1}

   ....

39.7 THE EXPANDING UNIVERSE

In the earlier years of the twentieth century a very intersting observation was made by the astronomer Edwin Hubble. He found that all other galaxies are moving away from us. This gave rise to the name of **expanding universe.** It is important to remember that if we were in some other galaxy, we would still see all galaxies moving away from us. It was also found that more distant galaxies move away with larger speeds. In other words, the speed with which galaxies move away is proportional to their distance. So if we plot the speed of a galaxy against its distance, the graph is found to be linear. How do we find the speed of galaxies? And how do we find their distances? The answers to these questions are important since our estimate of the age of the universe depends on the accuracy with which we can measure these two quantities. Let us, therefore, seek answer to these questions.

39.7.1 Red Shift

You must have seen vehicles with sirens, such as ambulances or cars leading the VIP cars, passing by you at high speeds and with their sirens on. Did you notice any change in the sound of the siren when the vehicle is rapidly approaching you and when it is going away from you? If you have not had such an experience or do not recall the sound of the siren, you can repeat the experiment. Next time when you happen to go to a railway station, or are near a railway track, note carefully the sound of the whistle of the train approaching you and of the train going away from you. You would find that the sound of the approaching whistle becomes shriller, that is, its frequency increases. When the train has passed you and is moving away from you, there is drop in the frequency of the whistle. This effect is called the **Doppler effect.** Let us see what causes this change in the frequency of the sound of the whistle or the siren.

Imagine an observer at rest and a source emitting sound waves approaching the observer with speed v. Suppose the source is in the process of emitting a sound wave. Let this instant be $t = 0$, and let c be the speed of sound in air. A time T later, where T is the period of the sound wave, the previously emitted sound wave has travelled a distance cT. In the same time the source has travelled towards the observer a distance vT. and is about to emit the next wave. Therefore, the distance between the waves emitted one after the other (successive waves) is $(c - v)T$. Since the distance between the successive waves is equal to the wavelength of the sound wave, the observer will see the wavelength as $\lambda' = (c - v)T$. The actual wavelength, the one that the observer would receive if the source were stationary is $\lambda = cT$. Therefore.

$$\lambda'/\lambda = (c-v)/c \qquad ...(39.2)$$

From this we easily get the change in the wavelength $(\lambda - \lambda') = \Delta\lambda$ as

$$\boxed{\Delta\lambda = \frac{v}{c}\lambda} \qquad ...(39.3)$$

A similar effect is expected to happens with light waves. In that case v is the relative velocity between the source and the observer and c is the speed of light. If the relative speed is small in comparison with the speed of light, then the same expression as given in Eq (39.3) holds, though the method of derivation is somewhat different. Notice that when the source approaches the observer, $\lambda' < \lambda$. So there is a decrease in the wavelength. As you know, the wavelength decreases towards the blue. This means that the ***wavelength of light emitted by a source approaching the observer shows a shift towards blue.*** This is termed as **blue shift.** You can now argue yourself to show that the ***wavelength of ligh+ of a source moving away from you will be shifted towards red.*** This is called the **red shift.**

The method to measure the speed of an astronomical object moving away from us is therefore to measure the change in the wavelength of an identified spectral line. An example is given in Fig (39.9). Formula (39.3) then gives the speed of the object.

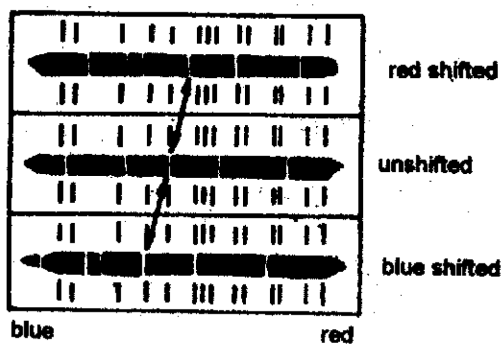

Fig. 39.9: An example of red shifted line

The formula (39.3) for the red shift is valid when the relative speed between the source and the observer is small compared with the speed of light. If the relative speeds is of the same order as the speed of light, this formula is not valid. It is then replaced by the following formula:

$$\boxed{\frac{\Delta\lambda}{\lambda} = \sqrt{\left(\frac{c+v}{c-v}\right)} - 1} \qquad ...(39.4)$$

The speed of recession of very far off objects is comparable with the speed of light. In their case, formula (39.4) must be used.

So, we have learnt the method for finding the speeds of astronomical objects. Our second objective was to find out how we can measure their distances.

39.7.2 Cosmic Distance Scale

In lesson 38 you learnt two methods of determining the **distances of stars.** One of them was the direct method, the other was **indirect. Can you name the direct method and point out its limitations?**

The indirect method was based on the relationship between the absolute magnitude and the apparent magnitude of an object. Can you recall this relationship?

We can use this method if we have some method of finding the absolute magnitude, since the apparent magnitude is a directly observable quantity.

For this purpose we use a type of stars whose luminosity varies with time. Such stars are called **Cepheid variable** stars. These stars can be recognized by the way their luminosity varies (Fig 39.10). We find some of these stars in our neighbourhood so that their parallaxes can be measured accurately. Their apparent magnitudes then give the absolute magnitudes by the relation 38.9 (a) derived in lesson 38

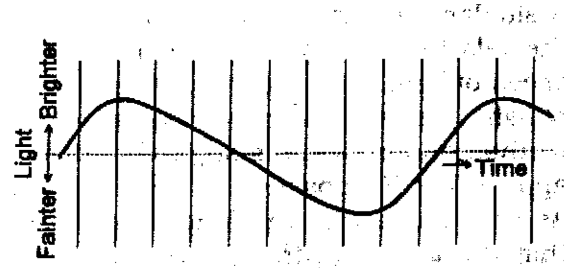

Fig. 39.10: Variation of brightness of a cepheid variable star with time

$M = m + 5 + 5 \log p$ ... (39.5)

It was discovered some fifty years ago that their mean absolutes magnitudes are directly proportional to the period of their variation (Fig 39.11). This relation is called the **period luminosity** relation. This relation forms the basis of distance determination of far off objects like the galaxies. The Cepheid variable stars are used like the **standard candles,** i.e. these are used as standards of luminosity.

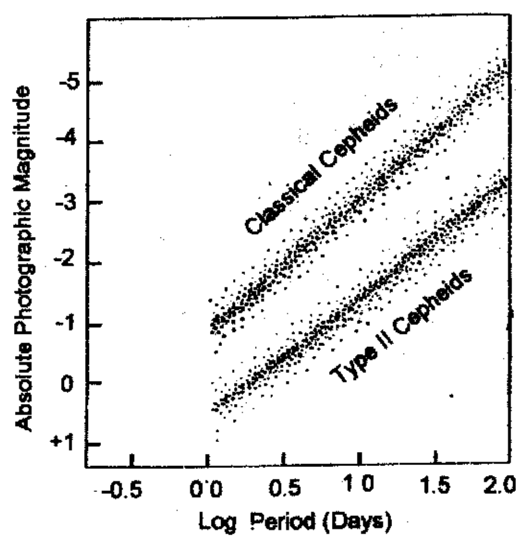

Fig. 39.11: Relation between absolute magnitude and period of cepheid variable stars

The distance determination proceeds in four steps. The first step is to identify Cepheid variable stars in the distant galaxy. How does one do that? As noted above these star can be recognized by the way their light varies. Once identified, the second step is to measure their periods. The third step is to find absolute magnitude using the period-luminosity relation. The fourth step is to measure their apparent magnitudes. The absolute magnitude and the apparent magnitude then give the distance in accordance with the relation (39.5). Sometimes it so happens that we cannot find Cepheid variables in a galaxy. In that case we use some other standard which has been carefully checked with the Cepheid variable stars.

INTEXT QUESTIONS 39.4

1. *The speed of a galaxy is observed to be 0.8 times the speed of light. Find the wavelength at which the Lyman Alpha line of hydrogen will appear in the spectra of that galaxy. The wavelength of the Lyman Alpha line in the laboratory is 1218 A.*

   ....

2. *Describe how the distances of external galaxies are measured.*

   ....

39.8 ORIGIN OF THE UNIVERSE

Now that we have learnt how to measure speeds and distances of far off galaxies, we can go back to the expanding universe discovered by Hubble. As mentioned earlier, Hubble showed that the distant galaxies move away from us and the speed of their flight is proportional to their distances. This is also known as Hubble's law. Fig 39.12 shows this law schematically by what is called the **Hubble diagram.**

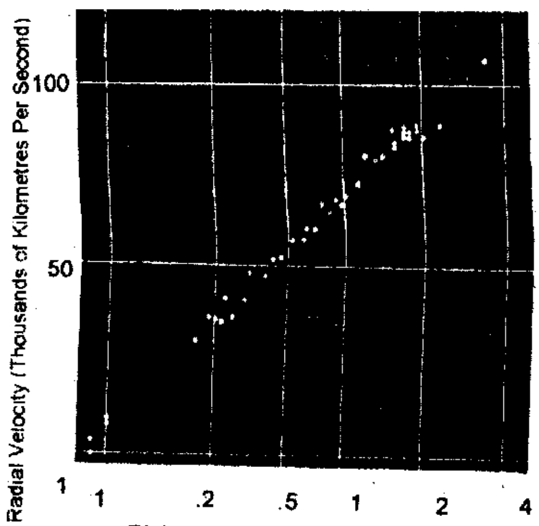

Fig. 39.12: Hubble diagram

ACTIVITY: You can yourself draw the Hubble diagram from the following data:

Location of the galaxy in	*Distance in Million parsec*	*Velocity in kms⁻¹.*
Virgo cluster	25	1,200
Ursa Major cluster	300	15,000
Corona Borealis cluster	430	22,000
Bootes cluster	750	39,000
Hydra cluster	1200	61,000

Since the galaxies are rushing away from one another today, it can be argued that in the past there was a time when they were all together in a small volume. This is generally identified with the birth of the universe. How much time has elaspsed since the birth of the universe? This can be found from the slope of the Hubble diagram. That is why tremendous effort goes in determining accurately the distances and speeds of very distant galaxies. If υ denotes the speed of recession and r the distance of an objects then the Hubble's law says that

$$\boxed{\upsilon = H_0 r} \qquad \text{-(39.6)}$$

where H_0 is a constant, called the **Hubble's constant**. Notice the subscript 0 with H. This indicates the Hubble's constant today. It is conceivable that its value in the past could be different. H_0 has the demensions of time^{-1}. The reciprocal of H_0 is therefore a measure of time and is usually taken to be the age of the universe. Thus, the age of the universet is given by

$$\tau = 1/H_0 \qquad \text{...(39.7)}$$

This simple derivation of the age of the universe is not correct. The role of gravitation in slowing down the expansion has been ignored. Moreover, in dealing with the theories of the universe the equations must be derived using Einstein's theory of general relativity. In this theory the geometry of space and time is determined by the strength of gravitation. Despite these defects, Eq (39.7) gives the right order of magnitude age of the universe, the actual age being somewhat shorter than $1/H_0$.

The value of H_0 is a matter of fierce debate these days. Several groups are trying to find its value, and all of them seem to be getting different values. The trouble is with the distance determination. The primary standard, the Cepheid variable stars, cannot be used because of the large distances involved. So, other standards must be used. The calibration of these standards poses problems which have not yet been solved. Therefore, different groups seem to get distances with which different groups cannot agree. Most of the recent values of H_0 are between 60 to 70 (km/s)/Megaparsec. These give the age of the universe around 15 $\times 10^9$ years.

The linear relation between the red shifts of cosmic objects and their distances, which we see in the Hubble diagram, is used for finding distances of very far off objects for which no other object is available. The red shifts of these objects are determined (which is very difficult task) and with the help of the Hubble diagram these are converted into distances.

39.8.1 Evolving Universe

While there is no dispute about the expanding universe, scientists have different ideas regarding the origin of the universe. Most scientists believe that the whole matter of the universe was once confined in a very small volume. At that time a violent event took place which caused the matter to fly away in all directions. The violent event is called the **Big Bang**, and the time of its occurrence taken as the instant of the birth of the universe. Since that time the universe is evolving. Its expansion is being slowed down by gravitation and the galaxies and stars have been formed out of the matter. The universe born and evolving in such circumstances is called the **evolutionary universe.**

39.8.2 Steady State Universe

A few scientists, on the other hand, believe that the universe has always been like this and it will always remain like this. Such a universe is called the **steady state universe.** How do these scientists explain the observed expansion of the universe which must make the universe less dense? These scientists say that new matter is generated to make good the fall in density due to expansion, and so there is no change in the appearance of the universe. But is not the creation of matter out of nothing a violation of the principle of conservation of matter and energy? These scientists do not think so. They say that the rate of formation of new matter is so small that the law of conservation of matter and energy holds to an extremely good approximation. Any violation cannot be detected and so there is no contradiction. There are observational tests, however, which can decide which of these theories is correct. It is not possible to go into these tests here. It is sufficient to say that the weight of all the arguments is in favour of the evolving universe.

39.8.3 Cosmic Background Radiation

A discovery which has tilted the argument in favour of the evolving unvierse, came in 1965 quite by accident. Two scientists, Penzias and Wilson of the United States, were looking for the source of interference, in their electronic instruments from the sky. As you know the radiation from the sky is detected by antennas, much like your T.V. antenna. They found that their experimental antennas were receiving a particular radiation from every direction in the sky. First they thought that this was a local source interfering with their experiment. They tried their best to eliminate this source. But they could not do so. They expressed their concern to a few friends. From them they learnt that some scientists were

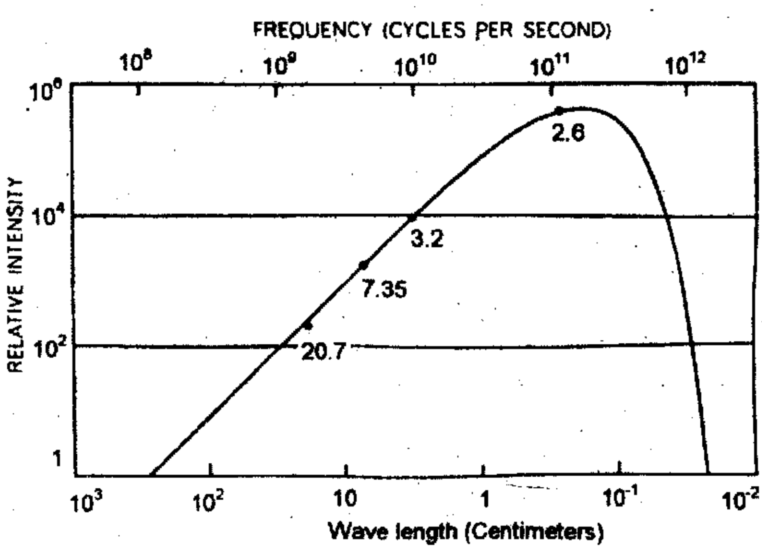

Fig. 39.13: Intensity of the background microwave radiation at various wavelengths

looking for a radiation which was the left-over of the Big Bang. They went back to their experiment, made sure that the radiation was coming from all directions, and determined its nature. They found that the radiation was thermal and had a temperature of only about 3 K. What do we mean by thermal radiation? ***Any radiation of which the intensity at various wavelengths is like the Planck distribution*** (for Planck distribution see Unit 3) is called **thermal radiation.** The radiation which Penzias and Wilson discovered fitted the Planck distribution at about 3 K extremely well (Fig 39.13). It was also found that the ***intensity of radiation was the same from all directions.*** Such a radiation is called **isotropic.** Since the radiation **fills the whole unvierse**, it is called the **cosmic background radiation.**

How did it help the theory of the evolving universe? When Big Bang occurred the temperature of the universe is expected to be very high. Since then the universe is expanding and any left over radiation from that time must be filling larger and larger volume. So its energy density must be continuously falling. The energy density of radiation is a measure of its temperature. ***If we calculate the temperature of the expected left-over radiation, it is found to be close to 3 K, which is the temperature of the cosmic background radiation discovered by Penzias and Wilson***. It was therefore immediately recognized that the newly discovered radiation is the left-over from the Big Bang. The existence of the cosmic background radiation also meant that an explosive event like the Big Bang could have taken place at the time of the birth of the unvierse. On the other hand, there seemed no convincing explanation to the cosmic background radiation in the steady state theory.

39.8.4 Open or Closed Universe?

If we accept that the universe was born in a Big Bang and is evolving since then, what about its future?. The future depends on how much matter there is in the universe. At the moment the universe is expanding, but if there is enough matter in the universe, it is possible that eventually the expansion would stop and contraction would follow. It is like a body thrown up. If there is sufficient matter attracting it back, its speed would not exceed the escape velocity, and gravitation would eventually pull it back. It is the same argument with the universe. If the average density of the universe is larger than a certain critical value, the expansion will change into contraction. The universe following this principle is known as an ***closed universe***. If the density of the universe is smaller than the critical value, the universe will always be expanding. Of course, its expansion will slow down but it will never change into contraction. Such a universe is said to be **open universe**. In between the two situations there is a critical case. In this case the density of the universe is equal to the critical value. The universe is still open, expanding always, but the speed of expansion is lower than it is in the open universe.

So the question of the kind of universe we have depends upont he average density of the universe. Determination of this is a tricky matter. If we take only the visible matter into account, then the average density is found to be less than the critical value by a factor of 10-100. However, there are scientists who argue that the average density is equal to the critical value. But, then, where is the additional matter to make up for the short-fall? They believe that the required amount of matter is there, only it is in an invisible form. Such matter is called **dark matter**. This controversy, like many others in astronomy, is still not resolved. The fierce debate goes on. But isn't it the way the science progresses?

INTEXT QUESTIONS 39.5

1. *Explain what is meant by the steady state universe. In view of the observed fact of the expanding universe, how does the theory propose to have the same density of matter for ever? State the arguments which are presented to avoid the violation of the law of conservation fo matter and energy.*

   ....

2. *Describe the discovery of the cosmic background radiation. What are its important features? How does it support the idea of the Big Bang?*

   ....

39.9 WHAT YOU HAVE LEARNT

- the interstellar gas clouds are the locations where new stars are formed
- the central bulge, the disc, the halo and the corona are the important components of our Galaxy
- the Sun lies towards the edge of the disc of the Galaxy and that it is rotating about the centre of the Galaxy with a speed of about 230 kms^{-1}.
- a galaxy may be spiral like our own, or it may be elliptical or irregular
- the external galaxies are rushing away from us and this gives rise to the notion of the expanding universe
- the velociy of recession of galaxies is found using red shift
- the distances of very distant objects are found using Cepheid variables and the Hubble diagram
- there are two rival theories of the origin of the universe
- the discovery of the 3 K radiation supports the origin of the universe in a Big Bang
- the universe may be closed or open depending upon the value of the average density of the universe

39.10 TERMINAL QUESTIONS

1. How does the Milky Way get its name?
2. The number density of hydrogen atoms in the interstellar cloud is $10^6/m$ and the temperature of the gas is 10^4 K. Calculate the pressure of the gas. (Boltzmann's constant is $k = 1.38 \times 10^{-23}$ JK^{-1}).
3. What are the observations which indicate that the new stars are born in the interstellar gas clouds?
4. Assume that the whole mass of the Galaxy, equal to 10^{12} solar masses, is distributed over the volume of the corona of the Galaxy, which you may assume to be a sphere of radius 10^5 parsec. Find the average density of matter in this volume.
5. The speed of recession of the galaxy in the Virgo cluster is 1,200 kms^{-1}. Calculate the observed wavelenth of the H line whose wavelength in the laboratory is 3,968Å (1Å = 10^{-10} m)
6. The speed of recession of the galaxy in the Hydra cluster is 61,000 kms^{-1}. Calculate the observed wavelength of the K line whose wavelength in the laboratory is 3,933Å. Remember that when speed is of the same order as the speed of light we have to use the formula (39.4)
7. A Cepheid variable star has a period of 10 days. Its apparent magnitude is 4.0. Using the period-luminosity relation given in Fig 39.11 find the distance of the star.
8. From the Hubble diagram that you drew using the data given in the text, estimate the age of the universe.

39.11 CHECK YOUR ANSWERS

Intext Questions 39.1

1. In one m^3 the number of hydrogen atoms will be 10^6. Therefore the density = $1.67 \times 10^{-27} \times 10^6 = 1.67 \times 10^{-21}$ kg/m^3.
2. The radius of the sphere, $r = 100 \times 3.086 \times 10^{16}$ m.

   The density of matter, $\rho = 10 \times 10^6 \times 1.67 \times 10^{-27}$ kg/m^3.

   The mass of the sun, $M_\cdot = 2 \times 10^{30}$ kg.

   Therefore, the mass of the cloud in solar masses = $(4\pi/3) \cdot r^3\ \rho\ /M_\cdot \approx 10^6$.

Intext Questions 39.2

1. If r is the radius of the orbit and T the period of revolution, then the orbital speed = $2\pi r/T = 2\pi\ 8.5 \times 10^3 \times 3.086 \times 10^{16}\ /\ (250 \times 10^6 \times 3\ 10^7)$ ms^{-1} (Notice that a year = 3×10^7 s) ≈ 220 kms^{-1}.
2. Equating the centripetal force provided by the force of gravitation exerted by the Galaxy, we get.

$v^2/r = MG/r^2$, where M is the mass of the Galaxy. Substituting the values of the various quantities and converting the mass in solar masses, we find $M \approx 10^{11}$ M.

Intext Question 39.3

1. The radius $r = 10^6 \times 3.086 \times 10^{16}$ m

   density, $r = 0.1 \times 10^6$ 1.67×10^{-27} kg/m^3

   The mass = $(4\pi/3)r^3\rho$

   To convert this mass into galactic masses we divide by $10^{12} \times 2 \times 10^{30}$ **kg, which is the mass of the Galaxy.**

   The answer si 10^4 galactic masses.

2. Pressure, $p = NkT$, where N is the number density of particles, T is the absolute temeprature of the intergalactic space, and k is Boltzmann constant = 1.38×10^{-23} J/K. Therefore $p = 0.1 \times 10^6 \times 1.38 \times 10^{-23} \times 10^2 = 1.38 \times 10^{-16}$ Nm^{-2}. (Just for comparison: note that the atmospheric pressure is approximately, 10^5 Nm^{-2}.)

Intext Question 39.4

1. Using (39.4)

$$\Delta\lambda = \lambda\left[\left(\frac{1+v/c}{1-v/c}\right)^{1/2} - 1\right] = \lambda\left(\sqrt{(1.8/0.2)}-1\right)$$

   Therefore, the observed wavelength is $\lambda + \Delta\lambda = 3654$ Å.

TERMINAL QUESTIONS

2. As in Question 2 of Intext Questions 39.3 the pressure is found to be 1.38×10^{-13} N/m^2.

4. Total mass, $M = 2 \times 10^{30} \times 10^{12}$ kg

   Total volume, $V = (4\pi/3) \times (3.086 \times 10^{16} \times 10^5)^3$ m^3

   Average density = $M/V = 1.6 \times 10^{-21}$ kg/m^3.

5. Since the velocity is small (less than 1/10) compared with the speed of light, (39.3) will be applicable. So.

   $\Delta\lambda = \lambda v/c = (1.2 \times 10^6/3 \times 10^8) \times 3968 = 15.9$A

6. The speed of the galaxy is not small compared with the speed of light, therefore (39.3) will be applicable. So,

$$\Delta\lambda/\lambda = \left[\left(3\times10^8 + 6.1\times10^7\right)/\left(3\times10^8 - 6.1\times10^7\right)\right]^{1/2} - 1 = 0.229$$

Thus.

$$\Delta\lambda = 0.229 \times \lambda = 0.229 \times 3933 = 901A$$

7. From the graph of Fig(39.11) $M = -1$ corresponding to $P = 10$ days. Thus

$M = m + 5 - 5 \log r$

$-1 = 4 + 5 - 5 \log r$

$\log r = 2$ or $r = 100$ parsec.

8. The slope is approximately $H_0 = 54$ kms^{-1} (Mpc)$^{-1}$, where Mpc denotes mega parsec. or 10^6 parsec. Substituting the value of Mpc, we get $H_0 = 54 \times 10^3$ ms^{-1}/3.086×10^{22}m $= 18 \times 10^{-19}$ s^{-1}. The age of the universe is $1/H \approx 18 \times 10^{-9}$ or 18 billion years.