UNIT 4 SCIENTIFIC THEORIES ON THE ORIGIN AND END OF THE UNIVERSE

Contents

4.0. OBJECTIVES

In this unit we introduce the different theories on the origin, evolution, and future of the Universe. The most prominent theories in this field are the Big Bang Theory and the Steady State theory. Among them the Big Bang theory is the widely accepted one. Hence it is given prominent place in the discussion. By the end of this discussion you should be able to form a scientific view on

- The structure of the universe
- Evidences for the Big Bang Origin and Evolution of the Universe
- The future of the Universe
- And develop a scientific mind regarding the world you live in.

4.1. INTRODUCTION

Ever since human being has started to think, the question about the origin and end of the world in which he lives loomed in his mind. How did this universe begin? How exactly is it structured? What does it contain? How will it end? What is our place in this universe? These are the questions humans have been asking for thousands of years. The answers found over the ages are expressed in art, myths, and religions. This unit seeks answers to the above questions by turning to modern science. In particular we shall seek answers in this chapter to questions about the origin of the Universe and about its eventual fate.

Our search for the past and future, that is, the origin and end, of the universe must begin from the present since it is from the present that we can build up its past and future. Hence our study must begin with the present structure of the universe.

4.2. THE STRUCTURE OF THE UNIVERSE

The best way to see the structure of the universe is to have a journey through the distant galaxies and have a direct look at it. Since the universe is unimaginably large in size we have to go through it at an unimaginable speed. The speed with which we travel on earth (certain kilometers, per hour) will reach us nowhere in this regard. Hence we have to take an imaginary journey from earth to the distant galaxies on a rocket that will travel at the speed of light. Traveling at that speed allows us to tell how far we have come just by looking at a clock. Every second of time we will cover a distance of light-second, which is 300,000 kilometers. At that speed if we are going around the earth we can make seven and a half trips around it in one second. Our imaginary journey will last billions of years of time and it will take us across billions of light-years of space.

The Milky Way Galaxy

Within four minutes of lift-off from Earth we are already crossing the orbit of Mars and ten minutes later we are passing through the Asteroid belt, between Mars and Jupiter. Soon the giant outer planets – Jupiter, Saturn, Uranus, and Neptune – briefly fill our viewing window. And in just a little over five hours we have left all of the Sun’s nine planets behind. All along, the Sun has been growing fainter and is now just one of many bright stars in the sky.

It will be four years before we encounter the first stars beyond the Sun. Every few years we pass another star. They brighten up as we approach them and then fade in the distance. After just 50 years we lose sight of the Sun.

The centuries and millennia of our journey tick away. We are passing thousands upon thousands of stars. Many are alone; others are double and triple star systems. Eventually the concentration of stars lessens and we break out of the obscuring layer of gas and dust associated with them. Looking back we see an enormous number of stars, star clusters, and clouds, arranged in a huge but very flat disk-like distribution. What we are seeing is the **Milky Way galaxy –** our home galaxy measuring about 100,000 LYs across and combines about 150 billion stars. Apart from its central bulge or nucleus, its most distinctive feature is the pattern of spiral arms. In fact, our journey began from an inconspicuous spot at the inner edge of one of them, roughly 30000 light-years from the center of the Galaxy.

The Local Group

Ahead of us lies the Universe filled with many billions of galaxies. Each is like an island universe, separated from the others by many light-years of emptiness. On our way we come across spiral, elliptical and irregular galaxies. They appear in small and large clusters of galaxies. The small clusters contain up to a few dozen galaxies, while the large clusters have thousands of them.

The Milky Way belongs to a small cluster of galaxies, known as the **Local Group**, that contains some thirty members. Andromeda is one of the most spectacular galaxies (spiral) in the local group.

The Virgo Super Cluster

After we have inspected at close range the Andromeda galaxy and several other galaxies in the same vicinity, we change course once again and leave the Local group. Each of them contains one or two large galaxies about which other smaller one are gathered.

If we leave the local group the nearest large cluster of galaxies is Virgo Cluster. This cluster is some 50 million LYs distant, and on the way we come across small clusters similar to local group.

As we travel on past the Virgo Cluster the concentration of galaxies begins to thin and we encounter now and then a small cluster of galaxies.

About 100 million LYs after leaving the Milky Way the frequency of galaxies diminishes still further and we find ourselves in mostly empty space. We have left our local cosmic neighborhood. Looking back we see we have come from a huge super cluster of galaxies measuring more than 100 million LYs across.

Virgo Super cluster is not alone in this universe. There are many of them coming across in whichever direction we travel. On the average we cross another Super cluster every 100-200 million years.

4.3. THE BIG BANG THEORY

The **Big Bang** is the cosmological model of the initial conditions and subsequent development of the universe that is supported by the most comprehensive and accurate explanations from current scientific evidence and observation. As used by cosmologists, the term *Big Bang* generally refers to the idea that the universe has expanded from a primordial hot and dense initial condition at some finite time in the past, and continues to expand to this day. The theory bases itself on three evidences: the expansion of the universe, the cosmic microwave background radiation, and the primordial abundance of elements.

The Expansion Of The Universe

Up to 500 years ago most humans believed in a Geo-centric universe with earth at the centre, and the Sun, Moon, and stars circling around it. The Polish astronomer Nicolaus Copernicus (1473-

1543) revolutionized that point of view by placing the Sun at the centre of the universe and making Earth one of its planets. In the following centuries, astronomers gradually realized that the Sun is just one star among many millions in the Milky Way and that it is far from the centre of the Galaxy. The prevailing view was that the Milky Way galaxy comprised the entire universe. By 18^{th} century people predicted the existence of separate galactic systems. Now with the help of the modern equipment we understand that the universe is much bigger than anyone had imagined and is in a process of expansion.

The Hubble Constant

Our understanding of the expansion of the universe is based on the phenomenon known as the Hubble constant.

Among the pioneers who participated in the discoveries regarding the universe was the great American astronomer Edwin P. Hubble (1889-1953). After the true nature of the galaxies has been established, he turned his attention to their motions. He was motivated to do this by a puzzling report by Vesto M. Slipher (1875-1969) of the Lowell Observatory of Arisona that many of the faint nebulae are moving away from us with velocities of hundreds and thousands of kilometers per second. That seemed peculiar, for the stars in the Milky Way have velocities much smaller than that and some move away while others move towards us. In contrast, the velocities of nearly all galaxies are always directed away from us. Slipher had made his observations during the 1910s, before anyone was certain that these nebulae were really galaxies far beyond the Milky Way. In 1920s Hubble and his colleague Humason who knew that the faint nebulae were separate galactic systems, began a systematic study of the relation between their velocities and their distances.

They let the faint light of the distant galaxies pass through a spectrograph, an instrument that splits electromagnetic radiation into its spectoral components. In almost every case they found that the light was shifted towards red colour. This meant the galaxies are receding from us. This confirmed Slipher's earlier observation.

Furthermore, they noticed that the recession velocities vary regularly with distances. Galaxies that have 2, 3, 10 times recession velocities than nearby ones are approximately 2,3,10 times farther away. A calculation of recession velocity verses distance shows that on an average for every increase in distance by 1 million light years there exists a corresponding increase in velocity by 15 km/se. This rate of increase of recession velocity with distance is referred to as Hubble constant.

The Big Bang

The relation between recession velocities of galaxies and their distances has powerful implications for the origin and evolution of the Universe. It suggests that the entire universe be in a state of expansion. This in turn implies that in the past the Universe was much more compact than it is today and that, possibly, at some long-ago time it came into existence in one gigantic explosion. The explosion sent matter flying in all directions. Matter that initially acquired large velocities relative to us is consequently very distant from us today, and matter that acquired a small velocity is comparatively still quite close. The situation may be compared with the explosion of a grenade. The energy of the explosion breaks the grenade into many fragments, some of which acquire high velocities and others low velocities. As the fragments fly apart, the ones with high velocities fly farther than those with smaller velocities. This analogy should, however, not be taken too literally, for there exists a definite centre in the case of the explosion of the grenade. There is no such centre in the case of the Universe.

Observers from other galaxies, if there are any, see the expansion of the Universe as we do, except from their vantage point it is our galaxy that is moving away from them. And the more distant we are from them, the faster they see the Milky Way receding. Hence, they share our impression that the Universe was born in a gigantic explosion – the Big Bang.

Cosmic Microwave Background Radiation

We came to the conclusion that the universe started with a Big Bang by extrapolating from the present expansion of the Universe. If the universe started with a Big Bang then there should be additional evidences in its support. One such support now available is the Cosmic Background Radiation.

If we extrapolate the present structure and expansion of the Universe back in time, we find that the galaxies were closer together. Eight billion years ago they were approximately twice as close as they are today and 10 billion years ago they were three times as close. At the time of the Big Bang the matter must have been compressed to exceedingly high densities and heated to enormous temperatures. If the Universe started from such extreme conditions, some remnant of the early, intense heat might still be around today in the form of electromagnetic radiation and perhaps it can be detected.

This was the kind of reasoning that in the 1940s led George Gamow (1904-1968) to calculate what the cosmic radiation left over from the Big bang should be like today. He assumed that the radiation, if it existed at all, should be very faint, fill the entire universe, and come from all directions. Unfortunately at that time no one took Gamow's bold predictions seriously, and no efforts were made to search for cosmic background radiation. Since 1964 the cosmic background radiation as it is now known, has been observed by radio –astronomers around the world, as was predicted by Gamow 20 year earlier.

The discovery of the cosmic background radiation is one of the great achievements of the 20th century. The discovery made it possible to obtain information about cosmic process that took place a very long time ago. The background radiation comes from all regions of the sky at a low level and is the *weak remnant of the radiation of the Big Bang.*

There are, in the universe, objects that are natural emitters of radio waves, which is the source of background radiation. These objects were the most distant yet found. The optical counterparts of these radio-sources were at large distances yet appeared star-like. Because of this they were called quasi-stellar objects or Quasars. In Quasars the energy of thousands of normal galaxies is concentrated in a region of space not much larger than our solar system.

Quasars have the largest amount of red shift (that is, five times longer than the normal). The red shift suggests that they are receding at more than 90% of the speed of light. Some remain at a distance of 13 billion years.

What is important is that we are seeing such objects not as they are now but as they were in the distant past. This is because of what astronomers call look back time. Because these radio waves, which are a form of light has the finite velocity of light and it takes time to traverse the enormous distances of space. Hence the radio waves we receive from a radio wave source set off on its journey at some time in the past. The effect of look back time is severe when we consider the quasars. When we look at them we see the waves that set off when the universe was only a tenth of its present size and age. Hence by looking deeper and deeper into space we can look further and further back in time and are able to determine what the universe was like in its youth and how it has since developed. Quasars hence are a phenomenon of early universe.

Primordial Abundance of Elements

Since the discovery that the Universe is expanding Big-Bang theory had a number of rivals, such as the steady state Theory. The steady State Theory of the Universe proposes that the Universe is expanding forever, yet it never changes. Matter is created continuously and new galaxies are formed just at the rate at which old galaxies recede due to the expansion of the universe. A steady Universe has neither a beginning nor an end.

However none of the other theories is able to explain both the expansion of the universe and cosmic background radiation. Nor are they able to explain the primordial abundance of elements which is a third evidence for the Big Bang origin of the universe.

The primordial abundance of the elements refers to the composition matter acquired when it was created by the Big-Bang. Astronomers have estimated this abundance by examining the spectrum of light emitted by the stars on our and other galaxies. They found that out of every 100 atoms, approximately 93 are Hydrogen and seven are Helium. By mass this amounts to approximately 76% Hydrogen and 24% Helium. This ratio of helium to Hydrogen in the stars is consistent with the Big-Bang model of creation. The universe started out explosively from a very hot and dense state and quickly cooled as it expanded. This hot and dense conditions lasted long enough for some hydrogen to fuse into helium, but not so long as to allow the production of significant amounts of the heavier elements. They were made in the interiors of massive stars.

Check Your Progress 1

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) What do you understand by Local Group?

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2) Write a short note on Big Bang Theory.

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Age of the Universe: Based on Hubble Constant

The relation between the recession velocity and distance allows us to estimate the age of the Universe by the following reasoning. From the Hubble constant we know that on the average, galaxies at a distance of 100 million light years move away from us with 15000 km/se. If, for example we assume that galaxies at 100 million light-years have been receding from us with a velocity of 1500 km/se since the Big Bang, we can compute how long it took them to reach that distance:

$$\text{Time} = \frac{\text{distance}}{\text{Velocity}} = \frac{100 \text{ million LY}}{1500 \text{ km/se}} = 20 \text{ billion years}$$

Thus we conclude that the Universe was born approximately 20 billion years ago.

Later we will see that this simple arithmetic leads to overestimating the age of the Universe. Gravity is continuously slowing down the expansion of the universe; hence, the value of the Hubble constant – that is the rate of the Universe's expansion – must have been greater in the past than it is today. Consequently, the Universe probably reached its present size in less than 20 billion years.

The Birth and Evolution of the Universe

We have seen that the Universe came into existence in one gigantic explosion some 13-15 billion years ago. During the earliest phase of this explosion, the temperatures and densities were so extreme that neither space and time, nor matter and energy, nor the laws of physics were as we know them today.

In order to obtain some knowledge about the early conditions of the universe we need to start from the known conditions today and extrapolate back in time. Our extrapolation will tell us that the initial extreme conditions passed in rapid succession through a number of transitions during which the universe acquired the characteristics that still distinguish it today. A single super-force which ruled in the beginning, split into the four forces we are accustomed to. Matter was spontaneously created and acquired the enormous expansion velocities that we still observe. There occurred a brief burst of primordial nucleosynthesis during which Hydrogen was converted into Helium. One by one the lightest of the elementary particles – gravitions, neutrinos, and photons – decoupled from the rest of the particles and began to evolve independently. The photons decoupled subsequently evolved into today's cosmic background radiation. Matter (Hydrogen and Helium) evolved on an independent course as well and began to condense into the lumpy distributions of clusters of galaxies, galaxies, stars and planets that we find in the universe today.

The first structures in the Universe

When matter set out on its independent evolution it consisted approximately 76% hydrogen and 24% Helium by Mass. It was in gaseous form and smoothly distributed. However this smoothness was not quite perfect; it contained weak, random fluctuations in density.

Formation of Primordial Clouds: Wherever there existed small enhancements in density, the attractive force of gravity counteracted and tended to slow the expanding matter. As a result the initial largest fluctuations extending over approximately 10^{15}- 10^{16} solar mass of matter extended more and more slowly and eventually began to contract. This led to the formation of huge primordial clouds of hydrogen and helium – the first large scale structures in the evolving universe.

Breakup of the primordial clouds: In many regions where the density within the clouds was greater than the average, gravity managed to contract the gas further and to intensify the concentration of matter. This led to the break-up of the primordial clouds into large numbers of cloud fragments.

The break up of the primordial clouds was chaotic and violent. The gravitational forces, which were weak at first, as the matter became clumped, increased in strength. And gaseous material fell together faster and faster. Eventually it reached large velocities relative to each other. This violent activity occurred in the first few hundred million years.

Birth of the first stars: Since there was little "elbow room" in the dense universe fragments of gas containing masses equal to millions of suns were ploughing into each other at thousands of km per hour. The shock waves created by the collisions compressed the gas of the fragments. This happened to such a degree that huge regions became gravitationally unstable and collapsed into compact clouds within which the first generations of stars began to form.

The birth of the first stars had two far-reaching consequences: 1. The newly formed stars began to pour forth their radiant energy and illuminate the gaseous matter surviving in their vicinity; 2. The gas that collapsed into stars became concentrated into relatively small volumes.

Birth of Galaxies and Cluster of Galaxies: As this sequence of collisions and mergers of fragments and of conversion of gas into stars progressed, the surviving systems looked more and more like star clusters and galaxies. The fragments that were most successful in capturing and assimilating others grew into large galaxies. Those that managed to retain their gaseous material became spiral galaxies like our Milky Way. Fragments that lost their gas or converted most of it into stars evolved into giant ellipticals. Fragments that grew less successfully became dwarf ellipticals and globular star clusters. Finally fragments that collided with another more massive galaxy experienced strong tidal perturbations and ended up with rather distorted shapes.

Most of the newly formed galaxies found themselves in the vicinity of others and were bound to each other by the force of gravity. This clustering was particularly pronounced near the central regions of what used to be the primordial clouds. Today that is where the rich clusters of galaxies with thousands of members are found, as Virgo cluster. Farther out the galaxies clustered into sparser groupings with only a handful to a few dozen members. Our Local Group is an example of such a small cluster. The Future of the Universe

So far we have been largely concerned with observational information about the Universe: the distribution of galaxies, the expansion of the universe, the cosmic background radiation, and the primordial abundance of elements. These observations led us to the conclusion that the Universe was created some 20 billion years ago by a gigantic explosion – the Big Bang – and has been expanding for ever since.

The Future of the Universe

We now face the obvious question: will the universe go on expanding for ever or will it eventually fall back onto itself?

The eventual fate of the universe depends on how much matter it contains, its size, and how fast the matter is expanding (that is, its mass, size and expansion velocity).

- The more matter there is, greater is the gravitational force holding the universe together, and the more likely it is that the Universe is finite and will eventually collapse back on itself.
- Greater the present size of the universe, the further are the galaxies separated from each other, and the weaker will be the gravitational pull. This increases the likelihood that the universe is infinite and will expand forever.
- Greater the velocity of expansion, the harder it is for gravity to slow the expansion to zero and to reverse it. This contributes toward making the universe infinite and expanding.

Friedmann's Three Models of the Universe

Alexander Fiedmann a Russian mathematician obtained three models of the Universe basing on Einstein's equation. Each solution predicts that the universe began with an explosion, but they differ on the subsequent evolution for the future.

1. The universe expands for some time, reaches a maximum size, then contracts. This predicts a *finite and closed universe*.
2. The universe expands forever making it infinite, expanding even after all galaxies and the rest of its content have become infinitely dispersed. This will result in an *infinite and open universe.*
3. The universe expands, but its expansion velocity slowing to zero in the process. This is in border with the other two: and is called the *flat universe*.

The Age of the Universe: Revised Estimate

The models derived by Friedmann allow us to estimate the age of the Universe more accurately than we did earlier. The estimate of 20 million years was based on the assumption that the Universe has always been expanding at its current rate of 15 km/sec per million light years. This rate must have been greater in the past. Hence, it took the Universe less time to reach its present scale than we estimated. It turns out to be 13 to15 billion years

Critique:

1. The Big Bang Origin of the universe is the widely accepted theory regarding the origin of the universe. With the present scientific know how and with the best available information obtained regarding the universe based on observation with sophisticated instruments, this is what we can say regarding the origin and the subsequent evolution of the universe.
2. Any theory to be widely accepted needs to have different evidences in support of it. The Big Bang Theory satisfies this condition. The extrapolation from the present expansion of the universe towards the Big Bang origin is further corroborated by the existence of *cosmic microwave background radiation* and *the primordial abundance of elements.*
3. Although the theory points to the origin of the universe through a big explosion, the question remains regarding the source of that matter which exploded.
4. It is to be also noted that the description of the origin of galaxies merely represents some of the current thinking of astronomers. It is far from the final word on the subject. The description is largely based on theoretical deductions from observations of cloud collisions, on observations of collisions and near-encounters among some nearby galaxies, and on computer simulations. It is not based on observations of the actual events that produced the galaxies and galaxy clusters.

4.4. STEADY STATE THEORY

In cosmology, the **Steady State theory** (also known as the **Infinite Universe theory** or **continuous creation**) is a model developed in 1948 by Fred Hoyle, Thomas Gold, Hermann Bondi and others as an alternative to the Big Bang theory (known, usually, as the standard cosmological model). In steady state views, new matter is continuously created as the universe expands, so that the perfect cosmological principle is adhered to. Although the model had a large number of supporters among cosmologists in the 1950s and 1960s, the number of supporters decreased markedly in the late 1960s with the discovery of the cosmic microwave background radiation, and today only a very small number of supporters remain. The key importance of the steady-state model is that as a competitor to the Big Bang, it was an impetus in generating some of the most important research in astrophysics, much of which ultimately ended up supporting the Big Bang theory.

Theoretical calculations showed that a static universe was impossible under general relativity and observations by Edwin Hubble had shown that the universe was expanding. The steady state theory asserts that although the universe is expanding, it nevertheless does not change its look over time (the perfect cosmological principle); it has no beginning and no end.

The theory requires that new matter must be continuously created (mostly as hydrogen) to keep the average density of matter equal over time. Such a creation rate, however, would cause observable effects on cosmological scales.

An aesthetically unattractive feature of the theory is that the postulated spontaneous new matter formation would presumably need to include deuterium, helium, and a small amount of lithium, as well as regular hydrogen, since no mechanism of nucleosynthesis in stars or by other processes accounts for the observed abundance of deuterium and helium-3. (In the Big Bang model, primordial deuterium is made directly after the "bang," before the existence of the first stars).

Problems with the steady-state theory began to emerge in the late 1960s, when observations apparently supported the idea that the universe was in fact changing: quasars and radio galaxies were found only at large distances (therefore existing only in the distant past), not in closer galaxies. Whereas the Big Bang theory predicted as much, Steady State predicted that such objects would be found everywhere, including close to our own galaxy.

For most cosmologists, the refutation of the steady-state theory came with the discovery of the cosmic microwave background radiation in 1965, which was predicted by the Big Bang theory. Stephen Hawking said that the fact that microwave radiation had been found, and that it was thought to be left over from the Big Bang, was "the final nail in the coffin of the steady-state theory." Within the steady state theory this background radiation is the result of light from ancient stars which has been scattered by galactic dust. However, this explanation has been unconvincing to most cosmologists as the cosmic microwave background is very smooth, making it difficult to explain how it arose from point sources, and the microwave background shows no evidence of features such as polarization which are normally associated with scattering. Furthermore, its spectrum is so close to that of an ideal black body that it could hardly be formed by the superposition of contributions from dust clumps at different temperatures as well as at different redshifts

Hence, the Big Bang theory has been considered to be the best description of the origin of the universe. In most astrophysical publications, the Big Bang is implicitly accepted and is used as the basis of more complete theories.

4.5. LET US SUM UP

We have been discussing the theories regarding the origin of the universe. Though there are many scientific attempts to explain the origin of the universe the Big Bang theory remains to be the widely accepted one at present.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) Explain briefly the formation of primordial clouds?

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2) What will be the eventual fate of the universe?

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4.6 KEY WORDS

Astrophysics: Astrophysics (Greek: *Astro* - meaning "star") is the branch of astronomy that deals with the physics of the universe, including the physical properties (luminosity, density, temperature, and chemical composition) of celestial objects such as galaxies, stars, and the interstellar medium, as well as their interactions. Because astrophysics is a very broad subject, *astrophysicists* apply many disciplines of physics, including mechanics, electromagnetism, statistical mechanics, thermodynamics, quantum mechanics, relativity, nuclear and particle physics, and atomic and molecular physics.

Gravitons: Graviton is a hypothetical elementary particle that mediates the force of gravity in the framework of quantum field theory. To prove the existence of the graviton, physicists must be able to link the particle to the curvature of the space-time continuum and calculate the gravitational force exerted.

4.7. FURTHER READINGS AND REFERENCES

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4.8 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress I

1. Ahead of us lies the Universe filled with many billions of galaxies. Each is like an island universe, separated from the others by many light-years of emptiness. On our way we come across spiral, elliptical and irregular galaxies. They appear in small and large clusters of galaxies. The small clusters contain up to a few dozen galaxies, while the large clusters have thousands of them. The Milky Way belongs to a small cluster of galaxies, known as the 'Local Group' that contains some thirty members. Andromeda is one of the most spectacular galaxies (spiral) in the local group.

2. The 'Big Bang' is the cosmological model of the initial conditions and subsequent development of the universe that is supported by the most comprehensive and accurate explanations from current scientific evidence and observation. As used by cosmologists, the term *Big Bang* generally refers to the idea that the universe has expanded from a primordial hot and dense initial condition at some finite time in the past, and continues to expand to this day. The theory bases itself on three evidences: the expansion of the universe, the cosmic microwave background radiation, and the primordial abundance of elements.

Answers to Check Your Progress II

1. *Formation of Primordial Clouds:* Wherever there existed small enhancements in density, the attractive force of gravity counteracted and tended to slow the expanding matter. As a result the initial largest fluctuations extending over approximately 10^{15}- 10^{16} solar mass of matter extended more and more slowly and eventually began to contract. This led to the formation of huge primordial clouds of hydrogen and helium – the first large scale structures in the evolving universe.

2. The eventual fate of the universe depends on how much matter it contains, its size, and how fast the matter is expanding (that is, its mass, size and expansion velocity).

- The more matter there is, greater is the gravitational force holding the universe together, and the more likely it is that the Universe is finite and will eventually collapse back on itself.
- Greater the present size of the universe, the further are the galaxies separated from each other, and the weaker will be the gravitational pull. This increases the likelihood that the universe is infinite and will expand forever.
- Greater the velocity of expansion, the harder it is for gravity to slow the expansion to zero and to reverse it. This contributes toward making the universe infinite and expanding.