COMMITTEE VI
The Universe and Its Origin:
From Ancient Myth to Present Reality
and Fantasy

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COSMOLOGY - MODERN VIEWS

by

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Cosmology - Modern Views

Introduction.

Cosmology is the study of the origin, constitution, structure and evolution of the universe. As we know today, the universe extends far beyond the solar system. Much of our current knowledge of the unvierse, out to perhaps 10^10 light years, is derived from data collected by giant telescopes. At such distances, even the brightest galaxies are speckles of light. To decipher the messages brought to us by the light that travelled billions of years, we need not only the most sophisticated instrumentation to detect and sort out the signals, but also theoretical knowledge to interpret the data collected. The edge of the universe is far beyond the limit of vision of our largest telescopes. Indeed, progress in cosmology depends on a combination of theoretical and experimental efforts.

Since the dawn of civilization, man has never given up searching for the unknown, and one of his major tools is reasoning. From observation of his surroundings, aided by experiments designed by him, man gradually enlarged his box of tools of reasoning. From reasoning man enlarged his knowledge of the universe. Although we will never be able to leave our own Galaxy, the Milky Way, to cross the gap of interstellar void to visit even the closest galaxy, say one of the two Magellanic clouds, we understand other galaxies as if they were our own.

Can the same physics laws derived from observations carried out on our earth be used to interpret data from the most remote part of our universe? As technology advanced, the degree of precision with which our physics laws are confirmed in earth laboratories increased so that there is no doubt as to the applicability of these physics laws even in the remotest corner of the universe. Thus, we can proceed with the assumption that all physics laws observed on our earth are applicable to cosmological problems.

Historical Background.

We can describe advances in our views of our universe in two respects: observationally and theoretically. Although advances in these two aspects seemed at times to be disparate and unrelated, they eventually merged (especially within the last fifty years).

The history of cosmology has been one of continued diminution of man's position in the universe. In the 1400's Nicolaus Copernicus (1473-1543) was the first in the Western world to espouse the view that the earth is not at the center of the universe, thus enlarging our view of the universe from our earth to the entire solar system. A couple of centuries later, Giordano Bruno (1548?-1600) enlarged our view even further. He postulated that all stars were like our sun and that the reason for their faintness was that they were far away. (In present terminology, Bruno enlarged our universe to a size of tens of light years). Sad to say, one believer of Copernicus' theory, Galileo Galilei (1564-1642), paid for his belief with his freedom, and Bruno, with his own life. Since their persecutions for holding non-establishment cosmological views have virtually stopped.

Observational View.

Advances in telescopes and associated mechanical improvements, notably in the 19th century, further enlarged our views of the universe to tens of thousands of light years. For the first time, the distances of some nearby stars were actually measured. It was then recognized that our Milky Way was a conglomerate of stars like our sun, some brighter and some dimmer, as Bruno had predicted.

The twentieth century brought major technology developments. The use of electricity became widespread; results of the industrial revolution were felt around the world. Man was engulfed with confidence in his abilities, such as the unsinkable Titanic. That tide led to the then biggest astronomical instrument, the Mt. Wilson 100 inch telescope, bringing surprising discoveries that enlarged our view to hundreds of millions of light years and laid the foundations of our current cosmological theories.

The 100 inch telescope was powerful enough to resolve individual stars in some of the nearby nebulae, now called galaxies. There is no longer any doubt that these nebulae are indeed star systems similar to our Milky Way. Further, a number of a type of variable stars, called Cepheid variables, were discovered within these galaxies. These stars were known for a precise relationship between their brightness and their period of variation, established through the laborious efforts of Henrietta Swan Leavitt and Harlow Shapley. Knowing their real brightness, one could establish the distance scale to the nearby galaxies: the distance to the Andromeda galaxy, the brightest galaxy in the sky other than our own, was around 500,000 light years. (In the

1950's this distance was revised to be over 1,000,000 light years.)

Vladimir M. Slipher, an astronomer using the new 100 inch telescope between 1895 and 1914, successfully measured the Doppler shift of spectral lines of a number of nebulae, thus establishing their line of sight velocities. Velocities of stars in the Milky Way had been measured earlier. Typical values of stellar velocities were in the tens to at most 100 kilometers per second (km/s), with some stars moving towards us and others moving away from us. However, as Slipher discovered, the velocities of certain nebulae were all negative (moving away from us) and unusually large; they ranged from a few hundred km/s to 1000 km/s.

Edwin Hubble combined Slipher's observations of the velocities with the distances to the galaxies deduced by Leavitt and Shapley. Adding his own observations up to 1929, on galaxies several hundred million light years away, he discovered that there was a definite relationship between distance and velocity of recession of galaxy. He thus showed that the universe was expanding, a view enhanced by all later observations.

Theoretical View.

Although there had been many efforts to formulate a theory of the universe throughout history, Sir Isaac Newton (1642-1727) should be credited as the first who successfully unified observations of the visible universe at that time, the sun, moon and planets, into a theory of mechanics and gravitation still valid today for most applications. His theory explains the motion of planets via the concept of gravitation. Despite of its success in the prediction of the orbit (and of the return) of Halley's comet, and the prediction of a new planet (Neptune), a cloud hangs over some of its predicted consequences. At the end of the 18th century Marquis Pierre Simon Laplace (1749-1827) studied a hypothetical large mass, and he concluded that "A luminous star, of the same density as the earth, and whose diameter should be two hundred and fifty times larger than that of the sun, would not, in consequence of its attraction, allow any of its rays to arrive at us; it is therefore possible that the largest luminous bodies in the universe may, through this cause, be invisible.". Here he touched a most interesting subject, beyond the scope of Newton's original theory of gravitation. Laplace innocently crossed the boundary of Newtonian mechanics into Einstenian mechanics (general relativity), a theory that was not to be developed for another century.

No one has yet formulated a theory of the universe as successful in its predictions as Einstein's. Yet his 1915 theory of general relativity, at the time it was developed, can only predict a dynamic universe, one in which the entire universe is either in a state of expansion or contraction. (The expansion of the universe was not discovered and confirmed until the late 1920's.) Right after the introduction of his general theory of relativity, Einstein tried unsuccessfully to generate a static model of universe by means of his theory. In 1922 the Russian Alexandre Friedmann derived a model of an expanding universe, in strict accordance with Einstein's theory. Unfortunately

Friedmann's model was not known to many (his country being in a state of turmoil amidst revolution) and a Belgian priest, Abbe G. Lemaitre rediscovered it in 1927. Again, Lemaitre's work was published in a rather inaccessible journal, and in the words of another great astronomer, Sir Arthur S. Eddington, "seems to have remained unknown until 1930 when attention was called to it by de Sitter and myself." In the theories of Friedmann and Lemaitre, the universe began from a singular point, expanded either forever, or to a maximum extent and then contracting to a singular point again. Although this theory has theological overtones and was attacked as such, Lemaitre's model was based on strict scientific deductions without any ideology.

In the interim a number of other theories flourished. The most notable one is the steady state universe, proposed in a sequence of papers starting 1948, by Sir Fred Hoyle, Thomas Gold, Herman Bondi, and R. A. Lyttleton. A static-state universe has the beauty that it is always there. On the other hand, expanding universe appears to be a fact of life. The steady state universe combines the static-state universe with the expansion feature. In an expanding universe, matter density always decreases. In order to maintain a steady state, however, one is forced to postulate spontaneous creation of matter. Although this theory has many attractive features, one of its weaknesses is in the difficulty in the interpretation of the background microwave radiation discovered in 1963. (See below.)

Now it may seem pedantic to dispute the correctness of the idea of an expanding universe, a theory now taught even in elementary schools. However, it must be remembered that by the time the expansion of the universe was predicted and confirmed with observations in the late 1920's, quantum physics was still in its infancy and not completely developed. The neutron, a constituent of the nucleus, was not to be discovered until a few years later, and the nuclear source of stellar energy was not established until 1938 when Hans Bethe and C. L. Critchfield published the first precise formulation. Much microscopic properties of matter was not known. By late 1940's, nuclear physics was under rapid development. At this time, George Gamow and his student Ralph Alpher decided to add physics to the Friedmann-Lemaitre model. This combined theory is now known as the Big Bang theory, since the universe appeared to have been created amidst an explosion process.

The Friedmann-Lemaitre model is a simple model, consisting of uniformly distributed matter and radiation. We know there is interaction within matter itself and between matter and radiation. These interactions produce stars, galaxies, and other objects. Gamow and Alpher described the interaction of matter and radiation within the framework of the Friedmann-Lemaitre model. In fact, many of their conclusions remain valid to this day. For example, their theory predicted the existence of a general, extremely cold background microwave radiation, with a temperature of a few degrees K above the absolute zero, as well as the existence of primordial helium, synthesized within the first few minutes after the creation of the universe.

The past decade has seen new developments in cosmology, as our knowledge in physics advanced. Accepting the basic concepts of the Big Bang cosmology, theory has focused on understanding the creation process and its subsequent evolution, when the density and temperature are so great that conventional theories of matter are no longer applicable. The result is the so-called "inflationary model", according to which, during the very early epoch, the universe went through an inflationary phase whereby it achieved many of the large-scale properties we see today, such as isotropy and homogeneity.

Current Knowledge of the Universe

Following this brief historical survey I wish to give a more organized review of various properties of the universe, in conjunction with theoretical developments. The discussion will be divided into three parts: observable matter, radiation, and invisible matter.

Observable Matter of the Universe.

As stars are building blocks of a galaxy, galaxies must be regarded as the fundamental building blocks of the universe. When we look outside our galaxy, the Milky Way, the universe is largely void and the only visible occupants are galaxies and a small number of other entities such as quasars. So far at least, any attempt to discover matter between galaxies has been unsuccessful. We can safely assume that there is no intergalactic matter.

Galaxies are made of gas and stars, in a ratio of roughly 1 to ten (one part gas by mass to ten parts stars). The age of stars varies, for known stars from a few hundred thousand years to as long as 20 billion years. The composition of stellar matter also varies. Since all chemical elements are synthesized from the lightest element, hydrogen, younger stars tends to contain more of the heavier elements than old stars, a fact that is confirmed in almost all instances. An exception is helium, which according to the Big Bang theory, was synthesized shortly after the creation of the universe, with a concentration of around 20 per cent. It is expected that even in the oldest stars the helium content would not fall below this amount. But, because helium is very difficult to detect -- at least in old stars which have lower surface temperatures -- this point has not been satisfactorily settled .

The distribution of galaxies in the universe appears to be fairly uniform, with a degree of clustering that can be explained in terms of random fluctuations. The distribution is uniform in all directions (isotropic) and in all locations (homogeneity).

A uniform state of expansion of the universe is observed, from data of all galaxies discovered so far. The state of expansion can be expressed in terms of a linear law, known as Hubble's law. The rate of expansion is 75 km/s per megaparsec of distance. That is, at a distance of 1 megaparsec (3.26 million light years) the expansion velocity is 75 km/s, and at a distance of 2 megaparsec the expansion velocity is 150 km/s, and so on. According to this equation, at a distance of 4000 megaparsec the expansion velocity would be the velocity of light. Hubble's law thus must be modified in order to take account of relativistic effects near that distance (say, at distances greater than 2000 megaparsecs).

In addition, when we look at distant galaxies, we are also looking at past - thus looking at younger galaxies. Therefore, looking at galaxies at 1000 megaparsecs away, we are looking at light emitted almost 3 billion years ago. Things of course can be very different if we look far back enough.

Quasars are objects that exhibit very large red shifts, -- presumably very far away. They appear to be massive objects of rather small size, emitting large amount of energy with violent activities. Because they have large red shifts, they may represent what went on during the very early stage of our universe. Although there have been many theoretical studies about the nature of quasars, none of them seems to present any consistent answer. Even the applicability of Hubble's law to correlate the distance of quasars to us and their red shifts has been questioned. We should regard quasars as one of those remaining mysteries to be solved in the near future.

The density of matter in the universe can best be expressed in terms of number of hydrogen atoms per cubic meter (h/cbm). A current view, presented by Geoffrey Burbidge, is that the density of matter due to galaxies is 0.07 h/cbm. The most aggressive estimate cannot exceed 0.2 h/cbm. As we will see later, it requires a density of matter of at least 3 h/cbm to "close" our universe -- to make it contract by self gravitation-- a topic that we will cover later in this article.

Radiation in our Universe.

In 1964 Arno A. Penzias and Robert W. Wilson discovered that there is a uniform background microwave radiation (i.e., coming from all directions) in the universe, with a radiation temperature of 3 K. This radiation was predicted in Gamow's and Alpher's Big Bang model some 15 years earlier. Since then, much research work has been carried out to study details of this radiation. The discovery of this radiation, in addition to lending a firm support to the Big Bang theory, is important in the following respects:

(a) It establishes an absolute stationary coordinate system in our neighborhood. Since the background radiation must also be subject to red shift, it can be isotropic only in one frame of reference, that is, only when the observer is not moving with respect to the "center of gravity" of the expanding universe, he observes an absolutely isotropic radiation. However, the degree of anisotropy one anticipates is rather small -- in the neighborhood of one part per thousand. After the initial discovery of the microwave radiation, efforts were made to detect this anisotropy. Indeed, an anisotropy of the order of one part in one thousand has been measured. From this measurement we can conclude that our local group of galaxies has a net velocity of 550 km/s towards a certain direction with respect to the "center of gravity" of our expanding universe.

(b) After this velocity (of the local group) and the motions due to earth's rotation, earth's orbit around the sun, and the sun's motion in our galaxy, are taken care of, the radiation is extremely isotropic (better than one part in 10,000).

(c) Radiation is a form of energy; the equivalent mass density of this radiation is 0.0003 h/cbm, a rather small addition to the density of matter due to galaxies.

Invisible Forms of Matter - Dark Matter

Although an open universe, one with a beginning but without an end, would appeal to many, for a theorist working in the field of cosmology such a universe presents an enormous problem; to cite one, many quantities become infinite upon calculation, an unsatisfactory and aesthetically unacceptable premise. (A closed universe, one with a begininng and an end, would have none of these problems.) As mentioned earlier, the amount of matter required to close the universe is many times greater than the amount of matter present in the form of galaxies. One natural hypothesis from this esthetic point of view, is that some kind of forms of matter in invisible forms is present in order to furnish the missing mass. Beside the aesthetic reasons mentioned above, there are also compelling reasons to believe that some forms of invisible matter exist:

(1) Stars rovolve too fast in some galaxies. Galaxy is a conglomerate of stars; in a galaxy the conglomerate of masses (of the stars) produces a gravitational field that in turn controls stellar motions, just like planets around the sun. From the brightness distribution of the stars in a galaxy astronomers can deduce how fast stars must rotate around the galactic center. The theoretical galactic rotational velocities, however, are much smaller than the observed values. To explain this anomaly, one has either to assume the stars in these galaxies are underluminous (more massisve than stars of our galaxy for the same amount of brightness), or there are some invisible forms of

matter contributing to the mass of the galaxies.

(2) The same argument may be applied to galactic clusters. A galactic gluster is a conglomerate of galaxies bound by the combined gravitational field of the galaxies. Again the predicted differential velocities are smaller than those inferred from the masses of the galaxies which are in turn, inferred from the brightness of the component galaxies.

(3) In addition, as to be discussed later, at the beginning of the Big Bang process the temperature must have been very high, with particles and their antiparticles coexisting. Later, after the universe expanded and cooled down, these particle-antiparticle pairs annihilated. However, a certain fraction of particle-antiparticle pairs may be left, depending on the rate of expansion (and cooling down) of the universe. If the particles are weakly interacting particles, such as neutrinos, a substantial number of particle-antiparticle pairs may survive the annihilation process. Theory predicts that virtually all neutrino pairs survive the annihilation process.

At present the amount of invisible matter is quite unknown. Suffice to say, that the possibility remains that invisible dark matter may dominate over the visible forms of matter. We will discuss this later with regard to the evolution of the universe.

General Relativity

We have mentioned general relativity a number of times. It is time now to give a fuller description of general relativity.

General relativity theory describes the dynamics of particles in a gravitational field, just like the Newtonian theory of gravitation, but in a unique way. In the case of Newtonian mechanics a mas gives rise to a gravitational field that controls the dynamics of other particles and masses; in the case of general relativity a gravitating mass alters the geometry around the mass, thereby resulting in dynamic motions. To visualize this, imagine a two-dimensional plane make of elastic material, such as rubber. The presence of a mass will cause the rubber sheet to deform into a curved surface. Small test particles will "fall" towards the central deformation and if the deformation is just right, the test particles will follow exactly the same type of motion predicted by Newton's theory. This principle has been successfully utilized to build models of gravitation in science museums. What Einstein did was to prove that the geometrical description of gravitation forces is valid everywhere.

It has been known for some time that Newtonian mechanics is not applicable when the velocity is close to the velocity of light (as Laplace showed in the late 18th century), the general relativity, on account of the unique properties of the geometry created, can describe dynamical properties even under relativaistic velocities (velicities close to the velocity of light) The geometry (Riemannian geometry) used by general relativity not only includes time as one of its coordinates, it is also different from normal (3-dimensional) Euclidean geometry.

In order that the concept of a Newtonian gravitational potential be replaced by a space-time geometry, all particles must behave in exactly the same way in a gravitational field without regard to their composition. Because geometry makes no distinction between one type of particle and another, all trajectories must be the same. This principle is called the Principle of Equivalence.

Although Newton did recognize the equivalence of all masses in a gravitational field, the first modern conscientious effort to establish the principle of equivalence was that of R. Eotvos, of Hungary, in 1909. The equivalence princple has since been established to an accuracy of one part in 1000 billion.

The second principle upon which general relativity rests is the principle of covariance. It states that physical laws (specifically the law of gravitation) must be written in a form that is valid in any geometrical configuration (of space and time). To put is in a simple language, the physical laws must be like a 'universal currency' that can be used anywhere. This requirement appears reasonable, since we are talking about replacing a gravitational field by a geometrical configuration of space-time. Once stated in that way, mathematicians of the last century (Georg Friedrich Bernhard Riemann (1826-1866), who invented the geometry, and others who worked on it) already has made precise prescriptions of how the geometrical laws - and hence laws of gravitation -should be written.

As we mentioned earlier, the Newtonian laws of gravitation remain valid as long as the velocity is small compared with the velocity of light. Indeed, Einstein's theory of general relativity becomes Newtonian theory in the limit of small velocities. Nevertheless there are small differences which are detectable and these differences have been measured with great precision, thus confirming the Einstein theory.

At the time of publication of Einstein's theory of general relativity in 1915, he forwarded three tests of general relativity, as follows:

(1) He predicted a red shift of light from a gravitating object -- the light emitted from the surface of an object, such as a star or even the earth, will suffer a gravitational red shift when observed at large distances from the emitting object.

Because of difficulties in this experiment (one has to be able to measure a redshift in the amount of one part in 10,000 from the surface of the sun and one part in tens of millions from the surface of the earth) this experiment was successfully carried out only in the 1960's. Gravitational red shift from the sun and from the earth were measured in the same decade, thus confirming Einstein's predictions.

(2) Einstein predicted that light in skimming close to a gravitating object such as the sun, will suffer a small amount of bending (change in direction). The bending is also very small, being 1.75 arc seconds near the surface of the sun. The bending of star light near the sun's is most favorably observed during a solar eclipse. In 1918, Sir Arthur S. Eddington organized a solar eclipse expedition to observe the bendidng of star light. Results of this expedition (and subsequent ones) confirmed fully this prediction.

(3) Einstein also predicts that because of the geometrical distortion of space around a gravitating body, planets will not move in strict elliptical orbits as predicted by Kepler and Newton. The deviation is again extremely small, and is exhibited

in the form of a slow precession of the perihelion point in the orbit. The planet Mercury, having the most elliptical orbit and being closest to the sun, will have the largest amount of distortion. It has been known for some time at Einstein's time that there is an amount of unexplained precession of the perihelion of Mercury's orbit around the sun, being 43 arc seconds per century. Einstein's theory predicts this amount of deviation in the most natural way.

All in all, there is no doubt about the correctness of the general relativity theory -- however, details of general relativity theory are still subject to uncertainties. These details will at most change quantitative predictions of Einstein's theory, but will not change the foundations of the theory of relativity. However, these details may effect a number of cosmological consequences.

Cosmology - Principles and Models

(1) Assumptions.

Now we are ready to derive cosmological models from Einstein's equations of general relativity. There are tens of equations in general relativaity and it may seem impossible to proceed. However, when two assumptions are imposed, these equations become surprisingly simple to solve. These two principles are homogeneity and isotropy:

(1) The universe is isotropic, that is, its properties do not depend on any particular direction, and

(2) The universe is homogeneous, that is, its properties do not depend on where we observe.

Originally these two assumptions were imposed so that a solution could be obtained (due to simplification of the equations as discussed above). But now a substantial amount of observational data has accumulated supporting these two assumptions. For example, the isotropy property is established through the background microwave radiation to an accuracy of better than one part in 10,000.

(2) Cosmological Models.

The cosmological models derived under the two assumptions (isotropy and homogeneity) are essentially the same as those of Friedmann and Lemaitre. In essence, the solutions are as follows:

(a) The universe started as a singular point (whose density is infinite in the context of general relativity), expanding outwards. The velocity of expansion decreases as expansion proceeds.

(b) Depending on the density of matter at a particular phase of expansion, three cosmological fates are predicted:

(i) If the matter density is below a certain critical value, the expansion will slow down but will go on forever. This is the case of the Open Universe.

(ii) If the matter density is just at the critical value, the expansion will gradually slow down and eventually will stop altogether when the universe is infinitely large. This is a particular case of the Open Universe.

(iii) If the matter density is above the critical value, the expansion will reach a maximum some time after creation. Beyond this time the expansion will reverse to become a contraction.

This contraction will bring the universe back to a singular point again. This is the case of the Closed Universe.

As mentioned previously, enormous theoretical difficulties exist regarding the case of the Open Universe. However, the density of observed matter in the form of visible galaxies is far below that needed for a Closed Universe. We will discuss the role played by invisible forms of matter below.

Physical Processes during Creation

This is the most exciting topic of current interest. In 1949 Gamow and Alpher studied cosmological models from the physicists' point of view. Starting from the singularity of creation, they worked out the physical processes that followed. At first there was the very high temperature state during which particle-antiparticle pairs co-existed. Later, as the universe expanded and temperature dropped, the particle-antiparticle pairs began to annihilate, although the annihilation process can never be complete. The number of particle pairs left behind depends on the time scale of expansion and the strength of interaction. Among particle pairs created are proton-antiproton pairs, neutron-antineutron pairs, electron pairs, neutrino pairs, etc. While the majority of neutrino pairs survived, most other particle pairs are almost completely annihilated. Conceivably some other not yet detected weakly interacting particle pairs also survived.

As the temperature cooled down to approximately one billion degrees, proton and neutrons can interact producing deuterium, a hydrogen isotope. Deuterium can further interact to produce helium. According to a number of calculations, during this stage

-- lasting only a few minutes -- from 20 to 25 per cent of matter was converted into helium, and virtually nothing heavier than helium. This helium composition would be present today even if no heavier elements were formed inside stars. Even the oldest stars should show this amount helium in their composition, assuming the correctness of the Big Bang cosmology theory. Unfortunately helium is one of the most difficult elements to detect in stars. However, so far no observational data contradict this conclusion.

As the universe cooled down further, nothing drastic happened. With the temperature of the universe falling below 10,000 K, matter previously in the form of free electrons and protons (and helium nuclei), combined into neutral matter. Below this temperature radiation and matter no longer interact. As the universe expanded further, radiation also cooled down. Eventually this radiation cooled down to 3 K, the background microwave radiation observed by Penzias and Wilson in 1964.

Galaxies probably has not been formed yet and matter - hydrogen and 20 to 25 percent helium - in the universe, still is in the form of a homogeneously distributed gas. Here there is some dispute on the state of events - in one theory, when the temperature of the universe is in the neighborhood of 100 K, conditions became ripe for subcondensation of gas into lumps that eventually formed the galaxies we observe today. Others believe that condensation into galaxies occured much earlier - even before the recombination of gas at 10,000 K. We do not really know what happened.

As galaxies further evolved, more subcondensations took place -- in the form of star clusters or individual stars -- and eventually the galaxies became what we observe today.

Unresolved Problems

Although we have come a long way from the early theories of the universe, there are still a number of perplexing questions that remain to be answered. Some of these questions will be discussed below.

Homogeneity and Isotropy

As we have seen, observational evidence points to the fact that the universe is extremely isotropic and homogeneous. How was this state of homogeneity and isotropy attained? If we mix a number of different ingredients in a vessel, it takes great efforts to obtain a homogeneous mixture. In particular, we have to bring ingredients from one part of the vessel to the other and back and forth to produce an even mixture. Likewise, if the universe is so isotropic and so homogeneous, a generous mixing must have taken place in the past to produce this homogeneity. However, nothing can travel faster than the speed of light; and in cosmological models we have today, there was never enough time for light to travel from one end of the universe to the other. How, then does this mixing take place?

A new theory, called inflationary theory, originated in 1981 by Alan Guth, deals with this and other unsolved problems. The mixing must have taken place well before the universe was even bigger than a punctuation mark. As the universe evolved from the moment of creation, around a ten billion billion billion billionth of a second later,The universe went through a phase transition during which the which a rapid expansion took place. Mixing took place at this time, producing the observed homogeneity and isotropy. Subsequently the universe cooled down and expanded to the present state.

Today the inflationary model has only taken the shape of a skeleton structure. It may not even be the right theory. However, it is the first comprehensive attempt to correlate particle physics with cosmology, and to explain the origin of the properties of isotropy and homogeneity. It is based on a particle physics theory, called the Grand Unified Theory (GUT). GUT makes definite predictions, such as a finite lifetime of the proton, which is now being experimentally studied. In the next few years it is anticipated that this model will be further developed, and eventually this theory (or probably others evolved from it) may allow us to glimpse of what happened at the instant of creation.

Closure Properties of the Universe

We mentioned previously that a closed universe is needed to eliminate mathematical difficulties of the theory. Another compelling reason is that, the inflationary model is applicable only to a closed universe. Observationally, we see many inconsistencies if we take the masses of the galaxies at their face value (as obtained from the brightness distribution of stars within a galaxy). Among these inconsistencies are: The stars in galaxies rotate too fast around the galactic center, the mass of galactic clusters appears to be too small to bind the galaxies together, and so on. To remove these inconsistencies, the existence of some forms of invisible, dark matter is postulated. The required dark matter will probably not be ordinary matter. In all likelihood the dark matter will be almost noninteracting particles like the neutrino -- a number of which has been postulated but no experimental confirmation has been available. In addition, there is an inconsistency in the theory of formation of galaxies. If we apply conventional theories to explain the formation of galaxies, we obtain too small a mass. On the other hand, if dark matter exists, galactic formation can take place much earlier in the evolutionary scale of the universe, and with much greater masses.

The next question is, what forms of dark matter and how much? The question "how much" is easier to answer. If we want to close the universe, an equivalent of at least 3 h/cbm is needed. When compared with the density of matter due to galaxies which is at most 0.2 h/cbm, at aleast 2.8 h/cbm equivalent of dark matter is needed. The existence of this amount of dark matter -- at least 14 times that of ordinary matter that constitutes the galaxies, stars, earth, and last but not the least, man, further diminishes man's position in the universe. If dark matter exists as postulated, not only man has to accept the fact that he is an insignifant part of the universe, he also has to accept the fact that matter that comprised his body and his entire universe is an insignifant part of the universe.

There are only speculations as to what forms of dark matter should exist in the universe. One possibility is that neutrinoes comprise 90 or more percent of the dark matter in the universe - there are some experimental evidence that the rest mass of the neutrino is not zero. Other views, including some hypothetical particles such as photinos and axions, are equally valid, at least theoretically.

Conclusion

In this paper I have skimmed over modern views of cosmology, which have been under development for the past several centuries. Our current concept of the universe is a far outcry from the primitive view held in the medieval times, that the earth comprises the entire universe. The age of the universe was expanded from the biblical value, around 6000 years, to over 20 billion years, according to the most modern view. Not only have we been able to reconstruct the events that occurred almost at the time of creation, we have also been able to prove our reconstructions by observations and experiments. At present it appears that we have almost reached the moment of creation. However, as we make one further step towards the moment of creation, our step size seems to have diminished by almost the amount we have advanced. We have now reached perhaps the first second of creation, and if the inflationary theory is successful, the first ten billion billion billion billionth of a second, but we no longer count time by seconds; we count time perhaps in units of time so small that is beyond our ability of measurement. Yet time has a meaning in the universe itself; the universe has to cross the seemingly infinitesimal time interval in order to evolve to the one second state. The evolution of the universe is its own clock. Are we to cross the seemingly infinitesimal time gap to reach the moement of creation? Are we never to cross this final barrier? Probably not. However, man is a curious being. As long as there is the least amount of unknown left to be searched, he will continue his search. Ten years ago cosmologists talked about the state of events at the first minute of creation. Now we have reached the threshold of ten billion billion billion billionth of a second, although we have yet to cross it. Ten years from now we may still be trying to cross this threshold, or we may have crossed it and be confronted with still another unknown barrier. Are we forever going to be confronted with barriers that grow smaller but more difficult? Probably. However, the past has told us that the human civilization will continue to prosper as long as we are always curious. To search for the moment of creation of our universe is as sacred a task as to trace one's roots in history. There always will be some one who will dare the unknown, even at the risk of his life or freedom.

No doubt the next decade should be the most exciting one as far as cosmology is concerned. The scheduled launching of the Space Telescope -- appropriately named the Hubble Telescope -- in 1986 will bring back data of undreamed quality. Theoretically the amount of work done in the past decade on this subject probably is equivalent to several centuries of work done in the past. Coupled with the forthcoming data from the Hubble telescope, the next decade should prove to be even more productive. Yet we probably will never reach the moment of creation but we will always continue our efforts to reach it.

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References

General References

Cosmology is such a vast subject that it is hard to give a reference list. Many original works dealing with early cosmological models were written in obscure style with heavy emphasis on mathematics used. The following references give a comprehensive coverage to topics covered in this article. Individual references are found in these literatures. (1) Milton K. Munitz, Editor. "Theories of the Universe", Free Press of Glencoe, Macmillan Company, New York, NY (1957). This book contains original essays from the ancient to the year of publication of this book, with many personal notes by cosmologists involved. Among authors whose articles are included in this book are: Ptolemy, Copernicus, Bruno, Galilei, Kepler, Newton, Einstein, Lemaitre, Gamow, Bondi, Hoyle, Eddington.

(2) Stephen Weinberg "The First Three Minutes", Basic Books, Inc. New York, NY (1977). A well known particle physicist describes the state of events from the first one-hundredth second to the first three minutes of our universe. Element synthesis, fire ball (which eventually leads to the 3 K background microwave radiation), and other topics are discussed. Weinberg's work is intimatedly related to what was to take place in the 1980's cosmology, like the inflationary universe.

Technical reference.

(3) G. W. Gibbons, S. W. Hawking, and S. T. C. Siklos, "The Very Early Universe", Cambridge University Press, Cambridge UK (1982).

The authors themselves are forefront workers in cosmology. Hawking, for example, is noted for his discovery of a decay mechanism for black holes via a radiation which now bears his name. This is the proceedings of the Nuffield Workshop in Cosmology, held in Cambridge, June 21 to July 9, 1982. This book is not for laymen. It contains detailed descriptions of all modern concepts of cosmology, such as inflationary universe. More technical references can be found in this book.