# LOOKING INTO THE PAST BY LOOKING INTO THE DISTANT:

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Interest in understanding the creation, evolution and the structure of the universe has been present in most cultures we know of. Cosmology has formed an integral part of all civilizational and cultural traditions. The earliest comprehensive theories were Ptolemaic which assumed the earth to be at center of the universe (geocentric view). Almost after 14 centuries of Ptolemy came the Copernican revolution and the gradual acceptance of the heliocentric view , one which has the sun at the center .Then for almost 400 years, a lot of observational data was collected which established the presence of our galaxy, the Milky Way, of which our solar system is a part. This galaxy is among the millions which are arranged in clusters of mind boggling sizes. It is also established that the extent of the universe is a staggering 10 billion light years ! (a light year is the distance traveled by light, moving at 300 million metres per second , in a year. In conventional units, 1 light year is roughly equal to 95 Billion Kms.) Galaxies are also not stationary; they are observed to be receding from each other at varying speeds.

On the theoretical front, Einstein proposed his general theory of relativity around the turn of the century. This theory was soon established as the correct theory of gravitation, replacing the theory propounded by Isaac Newton about three centuries ago. The stage was now set for propounding a comprehensive theory of the universe with the huge volume of observational data and the theory of relativity providing the theoretical underpinning. Many theories were proposed to explain the data, but around mid 1960's, the Big Bang model (BBM) of the universe became the preeminent model.

The BBM assumes that at the "beginning" of time, all the matter and energy of the universe was concentrated in a primeval fireball of extremely high temperature and density. Then with a massive explosion, The Big Bang, the universe started about 10 - 15 billion years ago and has been expanding since. This model has had a spectacular success in explaining many diverse aspects of our observed universe. The recession of galaxies, first observed by Hubble, is explained because of the expansion. the abundance of light elements like hydrogen and helium predicted by the BBM is in agreement with the experiment. Another remarkable prediction of this model was the existence of a sea of background radiation in the microwave region in the universe --- a fact which was confirmed in 1966.

Successful as it was, the BBM had its share of problems. The microwave radiation was too isotropic (i.e. the radiation observed from whichever direction looks the same). This was termed the "horizon problem" . Another major problem with the BBM was the flatness problem. It turns out that the universe is very flat. Now according to the Theory of Relativity, the curving up of space is related to the amount of matter (or energy ) in the space. Thus we observe that our universe has an energy density which is very close to the critical energy density. This in itself is not bad, but for these two quantities to be so close now, they would have to be equal to a fantastic degree in the past.

Finally, even though for very large distances our universe is uniform and homogenous, the presence of galaxies, stars and indeed ourselves, indicates that there are inhomogenities at small distances. This distribution of galaxies has to be explained in any viable model of the universe and the BBM has no mechanism to really explain this. Even with all these problems, BBM was the most complete theory we had of the universe. All the events which occurred 1 second or after off the Big Bang could be nicely explained in this model. All the above mentioned problems were caused by events occurring at earlier times, roughly a trillionth, trillionth, millionth second after the Bang.

Until about 1980, attempts to understand the universe during the first second of the Bang failed. The reason was that during this time the temperatures are very high; higher than 10 billion degrees Centigrade and the behavior of matter at such extreme conditions was not well understood. This picture started changing when cosmologists tried to explain the universe in the framework of new developments in Particle Physics. Particle Physics is the branch of Physics which tries to understand the interactions between sub atomic particles which make up matter. Even with the new developments in particle physics, one could only hope to understand phenomenon occurring after (10 -45) seconds, since before that even Einstein's General Theory of relativity is not applicable . One has to apply a quantum theory of gravity, i.e. a theory of gravity consistent with quantum mechanics. Such a theory has proved to be very elusive despite persistent efforts by physicists for over half a century now.

The interaction of particle physics (the physics of the sub microscopic distance) and cosmology (the science of vast distances or the universe) , evolved into a new paradigm in the seminal work of Alan Guth in 1981. Guth proposed the idea of an "inflationary" universe to solve all the cosmological conundrums associated with the BBM. If the universe went through a phase of rapid expansion or inflation around (10 -40) seconds after the bang, then all of the previous problems would not arise. During this period the diameter of the universe would increase by a factor of about (10 +50). This proposal had a tremendous appeal.

All of the matter and energy in the universe could now be created out of "nothing" !To make a workable inflationary universe model, a theory of matter at very high temperatures was required. The last 15 years has seen a tremendous growth in our understanding of matter at very high energies. The theoretical framework for this is supplied by Grand Unified Theories (GUTs). These theories unify within a single framework, what are perceived as three independent forces; the strong nuclear force (responsible for holding the nucleus in an atom together), the weak force (responsible for the decay of the neutrons) an the electromagnetic force (responsible for the production of light).

These theories , GUTs, are difficult to verify experimentally because their distinctive predictions occur at extremely high energies. Yet, to the scientist, they have an unmistakable esthetic appeal. The essential idea behind Guth's scenario was the occurrence of a phase transition in the early universe. A phase transition is simply the change of matter from one phase to another --- like steam condensing to water. A large amount of energy is released during some such transitions (much like the latent heat released when steam condenses) and it is this energy which is responsible for inflation. What was remarkable was that such transitions occur naturally in GUTs! These occurred when the symmetry unifying three interactions was broken and the interactions emerged as distinct entities.

Once the inflationary paradigm was established, a lot of effort has been made in evolving models which best fit the observational data. Again different theories of particle physics were evoked. Among the favorite candidates were Supersymmetric and Supergravity theories. These are theories which relate one kind of particles called the fermions (like the electron and the proton) to another kind called bosons (like the photon, the carrier of light). These theories apart from being esthetically appealing are also the favored candidates for an understanding of the quantum theory of gravity.

Even though the inflationary scenario is very successful in explaining the universe, it faces problems in explaining the origin of galaxies and stars. To remedy this theories of cosmic strings were developed. Cosmic strings are basically lines of very high energy which emerge as defects during a phase transition in the GUT. These provide seeds for galaxy formation. Although most of this is highly speculative, several large scale computer simulations indicate the correctness of the basic approach in understanding the data. The field of galaxy formation is emerging as an exciting and challenging field of investigation.

If particle physics has contributed to an enhanced understanding of the universe, cosmology also has provided a lot of inputs to particle physics. The reason for this is simple . to understand the behavior of matter, one needs to study its properties at very high energies. The energies required will never be accessible in the particle accelerators; the laboratories of particle physics. To get an idea of this, the biggest accelerator today has an energy which is a trillion times smaller than that required to study the effects of GUTs. The only "laboratory" with such energies is the very early universe where matter is subject to extreme conditions. This obviously neccesitates an interaction of cosmology and particle physics.

In an evolving universe, the astronomer looks into the past by looking into the distant. The reason for this is the finite velocity of light. Objects which are very far away, if observed now provide us with information at very early times, because light reaching us now must have started a long time ago. For example, in 1987, a galaxy was observed which was 10 billion light years away. Looking at this galaxy gives us information about the state of the galaxy 10 billion years ago! Thus a better observation of very distant objects will be crucial in our understanding of the very early universe. The emergence of space based telescopes in the future will surely provide lots of data from the far reaches of the universe. This data will help us in answering certain key questions relating to galactic structure and other issues.

The overall picture emerging is one of an interlocking of particle physics and cosmology. A better understanding of one would lead to an increased knowledge of the other. The two seem to be irrevocably looped into a symbiotic relationship with observations of the very large and very small providing important inputs. One hopes that from this will emerge a true understanding of the universe, not only within the realms of general relativity but beyond it in the realm of a quantum theory of gravity.