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Theoretical cosmology—a historical survey*

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If one is to trace the history of cosmological thought without making the constraint that it should be based on what we call 'science', then one has to delve deep into different mythologies and old religious texts. That clearly is not the objective of the present study but I cannot resist the temptation of quoting a little from the Bible and the Rig Veda. Thus one finds in the Bible :

- In the begining God created the heaven and the earth. The earth was without form and void and darkness was upon the face of the deep; and the spirit of God was moving the face of the waters. And God said 'Let there be light' and there was light. The Rig Veda describes the creation in a somewhat more mystic language :

- Then there was neither Aught nor Nought, no air or sky beyond. What covered all? Where rested all? In watery gulf profound? Nor death was there, nor deathlessness, nor change of night and day.

  That one breathed calmly, self sustained nought else beyond it by. Gloom hid in gloom existed first—one sea, eluding view. That one, a void in chaos wrapt, by inward fervour grow. Within it first arose desire, the primal germ of mind, which nothing with existence links, as sages searching find.

  Who knows, who ever told, from where this creation rose ? No gods had then been born—who then can e'er the truth disclose?

These are English translations and being not the original language of the holy books, it is likely that nuances of the original have been greatly modified. Any way it is difficult to agree with Gal-Or (1981) when he writes, 'Most astrophysicists, cosmologists and astronomers agree that the Biblical account of the beginning of cosmic evolution, in stressing "a beginning" and the initial roles of "void", "light" and a structureless state, may be uncannily close to the verified evidence with which modern science has already supplied us'.

However it is interesting to note the similarities and dissimilarities of the Vedic version of creation and the Biblical account of genesis. Both emphasise a state of 'darkness' or 'gloom', mention the all pervading water which apparently signifies a formless fluid state of things. However while the Bible is content to ascribe the emergence of light just to the will of God, the Rig Veda is more subtle in imagining that all this began with 'desire—the primal germ of mind' and distinct from matter,

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and lastly the Rig Veda questions whether gods even really know the true story of creation.

But let us come to the thoughts of physicists. At first the idea of a beginning was repugnant to the average physicist for, in that case, the peculiar thing which we call 'time' should have a beginning and powerful conservation principles would either be violated or else their significance would be greatly changed. Denying therefore a beginning, the physicist was left with two lines of thought :

(a) The whole universe is a static system which on a large enough scale knows no change, or (b) the universe is going periodically through a cycle of changes over and over again. A cyclic universe, although consistent with the ideas of time reversibility, is difficult to reconcile with the principles of thermodynamics, that is the irreversible increase of entropy. Thus although the idea of a cyclic universe apparently finds a place in the old Hindu ideas of *srsti* (*i.e.* creation), *sthiti* (continued existence) and *pralaya* (dissolution), physicists generally considered the universe to be a static system.

The static universe idea suffers from some logical difficulties. The first such difficulty was pointed out by Olbers in 1815 (see Bode 1826). (This, by the way, seems to be the first truly scientific discussion on cosmology). Olbers's idea was essentially very simply—any static system would eventually attain thermodynamic equilibrium and hence radiating objects like stars should be in equilibrium with the radiation field around them. Clearly this was not so in actual practice.

The other difficulty for the universe to be static arises from dynamical considerations. The universe consists of a matter distribution, every bit of which is attracting every other bit owing to gravitational interaction. To maintain equilibrium, some other interaction—basically repulsive—must be there, but no such interaction seems to be effective as the stars are more or less electrically neutral. A solution to this problem was suggested by Newman (1896) and Seeliger (1895, 1896) towards the close of the last century. They introduced a long range repulsive interaction to neutralize gravitation—this was peculiar in the sense that it increased with distance. Besides there was absolutely no empirical evidence in favour of such a hypothetical force.

Cosmology, as we now understand, may be said to have been born with Einstein's paper in 1917 (Einstein 1917). He too was obsessed with the idea of a static universe. His discussion was based on the following assumptions :

(i) The universe is geometrically homogeneous and isotropic. As the general theory of relativity links up geometry and physics, the assumption implied physical homogeneity and isotropy. (ii) The universe is a static system. (iii) There is a nonvanishing 'cosmological term' in the field equation of general relativity corresponding to the repulsive interaction considered earlier by Neumann and Seeliger in their Newtonian discussions.

However Einstein's paper was physically barren—it did not have any observational data to explain and it did not predict anything which could readily be subjected to observational verification at that time. The next important development was in 1922, when Friedmann (1922) showed that Einstein's equations admitted solutions even if his assumptions (ii) and (iii) were given up. The universe is then dynamic-either expanding or contracting. Friedmann also noted that his solutions had singularities of infinite density but his impression was that his solution had nothing to do with the physical universe. Friedmann's work attracted little attention till two significant developments took place. First, the discovery of systematic redshift of light from galaxies indicated that the Einstein static model was not consistant with observations, and secondly Eddington showed that the equilibrium of the Einstein universe was unstable and hence the model theoretically untenable. Even then Friedmann's solutions obtained publicity only through Lemaitre's works (Lemaitre 1927).

Shortly after Einstein's paper was published, de Sitter (1917) gave a solution of the Einstein's equations from which one could obtain a red shift but for the de Sitter universe the matter density vanishes. Thus considering all aspects of the situation, only the Friedmann solutions could be considered satisfactory. Very satisfactory derivations of the Friedmann type of metrics were later given by Robertson (1935, 1936) and Walker (1936) based only on the consideration of cosmological homogeneity and isotropy and without making any use of the Einstein equations.

The Friedmann solutions allowed different types of the beginning of the universe. One that was favoured by Eddington had an indefinitely long past in the Einstein static state and then due to some perturbation the universe started expanding. The problem was then raised as to why the universe expands and not contracts. An answer was apparently provided by Sen (1933) who claimed to show that a condensation *i.e.* a localized increase of density does indeed set the universe expanding.

While Eddington's model was free from any singular state, it depended on the cosmological term and by and by the so-called point source models which started from a singular state of vanishing volume and infinite density gained popularity.

An impetus to research in cosmology was provided by the steady state idea of Bondi & Gold (1948) as well as Hoyle (1948).

The steady state idea had many appealing features like the freedom from a singular state and an eternally existing universe. However the idea of continuous creation involving a breakdown of the long cherished conservation principles was perhaps too bitter a pill for the general scientific community. On the other hand in early fifties Gamow came out with his theory of nucleogenesis in the early hot dense phase of the universe and though there were obvious difficulties, here was the first application of cosmological models for the solution of a physical problem.

The problem of the big-bang (*i.e.* the singular beginning of the universe) had given considerable headache to Einstien – indeed he came to the conclusion that it indicates a limitation of general theory of relativity itself (1950). Others like Eddington (1939) and Tolman (1949) were of opinion that the singularity might be a consequence of the assumptions of homogeneity and isotropy; these assumptions were apparently not true. Raychaudhuri (1955) showed that the singularity would persist even in anisotropic non-homogeneous models provided the universe is not rotating. In his paper Raychaudhuri obtained an equation which was later used in seventies by Hawking & Penrose (1970) to show that quite generally spacetime would be geodesically incomplete if classical physics and causality are not to break down.

But to go back to the fifties and sixties, Hoyle & Narlikar very actively pursued the study of different aspects of the steady state theory. However in 1965 came the discovery of the microwave background radiation which apparently indicated a hot dense career in the universe in the past supporting the expectations of the big bang models. Hoyle & Narlikar (1966) then put forward the idea of what may be called the bubble universe—according to which the observed part of the universe is merely a bubble where creation is not taking place and is embedded in a back ground of much higher density. Although at that time, the theory gained little support, it is interesting that many of its features are extremely similar to situations currently being considered in connection with the inflationary models.

Following the discovery of the microwave background radiation, the problem of nucleogenesis in the early universe which Gamow had studied previously, was revisited and taken up with greater seriousness. Finally Wagoner (1973) showed that one could indeed obtain a reasonably good agreement with the observed abundances of deuterium and helium if the baryonic matter density of the universe does not exceed about 10^{-31} g cm^{-3}, a value consistent with observational data on luminous matter.

A problem that is somewhat crucial is that of the formation of structure in the universe. The investigations of Tolman (1934) and Sen (1936) showed that under certain conditions perturbations could grow; however the very thorough work of Lifshitz (1946) convincingly proved that thermal fluctuations could not grow to the extent observed in present-day galaxies within the age of the universe. This problem of structure formation remains unsolved even today although there is reason to hope that the inflationary scenario, to which we shall presently refer, may give rise to suitable initial fluctuation of density. A problem which is perhaps related to that of structure formation is the nature of the dark matter whose presence is evident from dynamical considerations. What this dark matter is, we simply do not know as yet. A pioneering investigation on the possibility of neutrinos making up the missing mass was undertaken by Cowsik & McLelland (1973).

With the development of the grand unified theories (GUT), theoretical cosmology has taken a completely new turn. Guth (1981) introduced the idea of inflation which may be roughly described as follows. Consider, for example, a scalar field ϕ. At temperatures higher than a critical temperature there is complete symmetry and $\phi = 0$ is the ground state. Below the critical temperature, the symmetry is broken and the global minimum of energy occurs at $\phi \neq 0$. Thus as the universe starting from infinitely high temperatures cools down to the critical temperature, there would be a transition from the higher energy false vacuum to the lower energy true vacuum. However the transition may be delayed over a long period due to peculiar nature of the potential curve. The vacuum energy stress simulates the cosmological term and thus the universe may have a de Sitter regime of exponential expansion. This, as Guth claimed, may solve the problems of horizon and flatness. However in the simple form that Guth presented, inflationary models faced numerous difficulties. Later modifications claim to have removed some of these but perhaps the picture is even now not quite satisfactory.

GUT has raised hopes that the observed asymmetry in the form of absence of anti-baryons as well as the baryon/photon ratio may find an explanation in the baryon nonconserving reactions in the early universe. These reactions are mediated by superheavy mesons which quickly disappear below about 10^{28}K. However as yet the calculation of baryon/photon ratio is beset with difficulties in that it involves several parameters whose values are not known precisely. Anyway, pioneering work in this line has been due to Yoshimura (1978).

No account of the current history of cosmology can be considered complete without a reference to the challenging subject of quantum cosmology. The field is still not very well defined; in India a very active role is being played in quantum cosmology by Narlikar (1984) and Padmanabhan (1984). Indeed they have claimed that quantum cosmology admits singularity free models. However it is too early to say anything about this field as it is going through a turbulent period right now.

To conclude, a strange question comes to my mind—is it part of a historical study to attempt a forecast of future developments ? I do not know the answer but even if the answer is in the affirmative, I would plead my inability and only hope that observational cosmology would provide new challenges which may lead not only to revisions of our theoretical ideas but even to revolutionary changes in them.

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