

The next long term step would be to develop transducers for linking conventional computers and neuro computers on the one hand and neuro computers and the human brain on the other.

Abstract

Informatics, characterized in the long term by extensive nationwide computer-communication networks, is projected here as a necessary tool for decentralised scientific, economic and social development. Outlining the evolution of distributed databases on networks, the design of an integrated Management Information System for development administration is described with respect to one-dimensional and spacial databases as well as on-line monitoring and support for large development projects.

With the fusion of computer science and communication science into an integrated infrastructure for Informatics, its offshoots like teletext, videotex, teleconferencing, voice mail, text mail and Fax mail have substantially increased the role of informatics as a tool for development. This synergetic discipline called 'compunication' is poised to transform the office, the factory and the home.

Analyzing the medium term technology trends in microelectronics, software engineering, supercomputing and knowledge processing, a case study of evolution of communication in India is outlined. It is forecast that, in the very long-term these technologies based on electronics, will give way to those based on Optonics, Quantonics and Bionics.

References

- Ha, T.T. (1989) *IEEE J. Selected Areas Communications* 7 (2): pp. 235.
- Kobayashi, K. (1986) *Computers and Communications*, MIT Press, Cambridge.
- Naderi, F.M. & Wu, W.W. (1988) *IEEE Commn. Mag.* pp. 13-22.
- Seshagiri, N., *IT as a tool for development - Experience with computer-communication network and Future vision*. APO Workshop on Information Technology, Asian Productivity Organization, Kuala Lumpur, 4-7 October 1989.
- Seshagiri, N. et al. 'NICNET - A Hierarchic Distributed Computer Communication Network for Decision Support in the Indian Government', Proceedings of the International Conference on Computer-Communication for Developing Countries (CCDC-87), ICC New Delhi, October 1987, pp. 367-379.
- Seshagiri, N. *Private VSAT Networks*. Proceedings of the Workshop on Very Small Aperture Terminal (VSAT) Technologies (International Telecom Union), Jakarta, July 1989, pp. 67-76.

192C

Glimpses of Science in India, Ed. U. S. Srvastava
© (1991) Malhotra Publishing House, New Delhi-110 064, India

SIXTY YEARS OF COSMOLOGY

J. V. Narlikar

Inter-University Centre for Astronomy and Astrophysics
Post Bag 4, Ganeshkhind
Pune 411 007

Historical Background

In the 1930's cosmology had taken off as an important branch of astronomy after major developments on theoretical and observational fronts. These developments can be summarized as follows :

- 1918 : Einstein's model of the static closed universe with uniform density (Einstein, 1917)
de Sitter's model of the empty but exponentially expanding universe (de Sitter, 1917)
- 1922-24 : Friedman's models of uniformly dense expanding universe (Friedman, 1922, 1924)
- 1929 : Hubble's discovery of the redshift magnitude relation (Hubble, 1929)
- 1935-36 : The Robertson-Walker models (Robertson, 1935; Walker, 1936)

Einstein's model was the first cosmological solution of his newly proposed general theory of relativity. In constructing this model, Einstein had assumed three simplifying properties for the large scale structure of the universe :

- The universe is homogeneous,
- The universe is isotropic, and
- The universe is static.

As a first attempt and taking into account the near total absence of any data on the extragalactic universe, this was a reasonable set of assumptions for a theoretical model. However, Einstein found that no such solution emerged from his original equations of general relativity:

$$R_{ik} - \frac{1}{2} g_{ik} R = - \frac{8\pi G}{c^4} T_{ik} \quad (1)$$

R_{ik} \equiv Riccitenor, R \equiv scalar curvature, g_{ik} \equiv spacetime metric, G \equiv Newtonian gravitational constant, c \equiv speed of light and T_{ik} \equiv energy momentum tensor of the universe. To obtain a solution with the properties A,B and C, Einstein needed to add an extra term to the left hand side of his equations as follows:

$$R_{ik} - \frac{1}{2} g_{ik} R + \lambda g_{ik} = - \frac{8\pi G}{c^4} T_{ik} \quad (2)$$

known popularly as the 'lambda term', this extra input represented an additional force of cosmic repulsion between any two particles of matter.

Einstein had hoped that his model would turn out to be unique, apart from being factually correct and that it would demonstrate how the large scale distribution of matter unequivocally determines the geometry of the universe. The de Sitter model gave a counter example to all these expectations. Here was a universe that satisfied (a) and (b) but not (c), it was empty and still satisfied the modified eqns. (2).

In retrospect we can now say that the first working models of cosmology in the modern context were provided by those given by Friedman. He assumed (a) and (b), not (c) and no λ -term. Thus he got expanding models of the universe, which can be described essentially by two quantities: $S(t)$, the function of cosmic time that tells us how the overall linear scale of the universe changes with time and the parameter k whose three possible values tell us whether the space is flat Euclidean ($k = 0$), closed ($k = +1$) or open hyperbolic ($k = -1$). However, the Friedman models got their due recognition slowly, only after the idea of an expanding universe got observational support.

It was Hubble's discovery that dealt a death blow to Einstein's postulate (c). This first observational input about the extragalactic universe showed that the fractional shift (z) in the wavelengths of the spectrum of a typical galaxy is proportional to its distance (D) from us:

$$z = \frac{H}{c} D. \quad (3)$$

The constant H is now known as Hubble's constant. Of course, Hubble's measurements of extragalactic distances were based on the 'apparent magnitudes' of galaxies, i.e., on how faint they look from here. These estimates turned out to be grossly undervalued; thus his value $H = 530 \text{ kms}^{-1} \text{ Mpc}^{-1}$ was an overestimate*. The modern value of H is quoted as $H = 100 h \text{ kms}^{-1} \text{ Mpc}^{-1}$ where $1/2 \leq h \leq 1$. The uncertainty of the value of h demonstrates the difficulties of pinpointing the extragalactic distance scale, even today!

Nevertheless, if interpreted as Doppler effect, Hubble's law (3) tells us that the universe is not static on the large scale. Indeed, to give a correct picture of what is going on the notion of 'expanding space' is a useful one: exactly as Friedman had envisaged. Thus the linear distance between our Galaxy and another typical galaxy is increasing if $S(t)$ increases with time and so we notice the redshift effect. Later general relativistic calculation showed how to calculate the effect within the framework of curved spacetime. The answer is simple:

$$1 + z = \frac{S(t_0)}{S(t_1)} \quad (4)$$

Here S is calculated at the instant of emission of light by the galaxy ($t = t_1$) and at the instant of reception of that signal ($t = t_0$) by us in our Galaxy. For $z > 0$, $S(t_0) > S(t_1)$, i.e. the universe is expanding.

Robertson and Walker independently gave a solid mathematical foundation to these models by showing how the postulates of homogeneity and isotropy of space and the regularity of the large scale motion of galaxies give a unique format of the 'line element':

$$ds^2 = c^2 dt^2 - S^2(t) \left\{ \frac{dr^2}{1-kr^2} + r^2 (d\theta^2 + \sin^2\theta d\phi^2) \right\} \quad (5)$$

Had the spacetime been flat, we would have $S(t) = \text{constant}$, $k = 0$ and the above line element would reduce to that of special relativity.

These were exciting developments but their momentum could not be sustained in the 1930s and the early 1940s. For example, Hubble's attempts to calculate k by counting galaxies out to increasing distances turned out to be inconclusive. There were problems of accommodating stellar ages within the time frame of the 'age of the universe', i.e., the time taken to expand the universe from $S = 0$ to its present value. The problem of how galaxies form in a homogeneous universe seemed intractable. More importantly, cosmology was still considered a highly speculative branch of astronomy, even by the astronomers, let alone the physicists.

Two developments in the late 1940s did a lot to inject new life into the subject. We will consider them next in their chronological order.

The Early Universe of George Gamow

The Friedman models have one common feature: they all have a past epoch

* Mpc \equiv Megaparsec = 10^6 parsec is a common unit for measuring the extragalactic distances. The unit of 'parsec' arose from the astronomer's measurements of stellar distances by the method of trigonometric parallax. 1 Mpc $\approx 3 \times 10^{24}$ cm.

when S was zero. This would make the volume of space zero, its curvature infinite and the matter density infinite. In mathematical jargon this is known as 'the singular epoch'. In colloquial terms the name is 'the big bang epoch', the adjective 'big bang' signifying an 'instant of explosion'. Since the mathematical and physical description of the model cannot be continued to instants prior to $S = 0$, it is assumed to be the epoch of creation of the universe. As we shall see later, there may be problems in pushing the correctness of the model right back to $S = 0$. However, there is a case for discussing early instants soon after the big bang when the physics familiar to us might still have been applicable.

Gamow (1946, 1948) and Alpher *et al.* (1948) were the first to take this point of view. Cosmological theory tells us that the densities of dust (pressure free matter) and radiation (and relativistic particles) fall as

$$\rho_{dust} \propto \frac{1}{S^3}, \quad \rho_{rad} \propto \frac{1}{S^4} \quad (6)$$

Thus at small enough S the universe was radiation dominated. The radiation temperature T falls off as S^{-1} . Gamow was able to obtain a relation of the following kind:

$$T = \alpha t^{-1/2} \quad (7)$$

where the constant α depends on G , c , the radiation constant a and the types of relativistic particles (including photons and neutrinos) present at the epoch t in thermodynamic equilibrium. For $t \sim 1$ s say, (7) gives $T = 10^{10}$ K.

Gamow and his colleagues Alpher and Hermann discussed in detail the primordial scenario in which protons and neutrons combine to form atomic nuclei. They found that in the period 1s-200s, light nuclei can be made in the high temperatures prevailing in the universe. Alpher and Hermann (1949) and Gamow (1953) also made an important prediction that the early hot era should leave today a relic radiation background of 5-7K.

This model of primordial nucleosynthesis did not gain immediate support because it failed to explain the existence of heavier nuclei like C, O, Ne, S, Fe, Co There was a general expectation that these nuclei would be made in stars. The main difficulty was to bridge the gap of nuclei of atomic weights 5-8, which are known to be unstable. Because of this and also because cosmological predictions were still regarded as speculative that the prediction of relic radiation was not tested, although the microwave technology did exist for testing it.

The Steady State Theory

The cosmological scene was livened up considerably by the idea of a steady state universe proposed by Bondi and Gold (1948) and Hoyle (1948). Unlike the

big bang universe, this model is without a beginning and without an end. Matter creation occurs in this universe at all times at a steady and very small rate rather than in the explosive fashion of the big bang model. Moreover, being 'steady' the universe is the same at all epochs and as such the observational comparison of the remote and nearby parts of the universe would give a direct test of the steady state idea. In other words, the model is vulnerable to observational test.

The vulnerability of the steady state theory to observational checks and its radical hypothesis of continuous creation of matter inspired several observers to undertake extragalactic observations. The early disproofs of the theory claimed by several observers have now been rendered invalid. These include the Stebbins-Whitford Effect (Stebbins & Whitford, 1948; Oke & Sandage, 1968), the deceleration parameter of the universe (Sandage, 1972; Gunn & Oke 1974), the counts of radio sources (Ryle, 1958; Scott & Ryle, 1961). A recent summary of the cosmological situation *vis-a-vis* the steady state theory is given in Arp *et al.*, (1990).

A criticism against the steady state theory in the 1940s and 1950s was that the theory appeared to violate the law of conservation of matter. It is true that in the Bondi-Gold formulation there is no field theory to tell us how the law of continuous creation of matter stands *vis-a-vis* the law of conservation of matter. In Hoyle's C-field formulation, however, there was the aim to express the steady state theory within the framework of Einstein's general relativity, and thus to make the two consistent.

The C-field cosmology as based on the action function framework of M.H.L. Pryce (preprint, 1961) does, adequately deal with this criticism. The action leads to the following field equations :

$$R_{ik} - \frac{1}{2} g_{ik} R = - \frac{8\pi G}{c^4} \left[T_{ik} - f \left\{ C_i C_k - \frac{1}{2} g_{ik} C^l C_l \right\} \right] \quad (8)$$

where C_i , $\partial C / \partial x^i$ is the gradient of the scalar field C ; f is the coupling constant that tells us how matter creation rate r is connected to the C -field:

$$\nabla C = r \quad (9)$$

There is overall conservation of matter and energy between matter and the C-field. The physical and astrophysical consequences of this cosmology were extensively discussed in the 1960s by Hoyle and Narlikar (1962, 1963, 1966)

Anisotropic Cosmologies

The Robertson-Walker metric describes a homogeneous and isotropic model. Can we have solutions of Einstein's equations which have homogeneity but no isotropy? Such models would exhibit shear and spin.

The interest in spinning universes was generated by a paper by Gödel (1949) where he found what he claimed to be an anti-Machian solution of Einstein's equations. In Gödel's model the distant parts of the universe spin relative to the local inertial frame of a typical observer. In other words, the speed of rotation of the Earth about its axis measured relative to distant stars will not be the same as measured by a Foucault pendulum experiment.

Gödel's model showed no expansion of the universe and so it was inconsistent with Hubble's law. It has used the λ -term whose status in relativity has been somewhat doubtful. More seriously, it contained closed timelike lines, i.e., an observer could meet himself in the past and future epochs. Was its anti-Machian nature a serious drawback of general relativity? Later work by Ozwath and Schucking (1962), and Ruzmikina and Ruzmikin (1969) showed that anti-Machian models without some or all of the drawbacks of Gödel's universe are possible in relativity.

There was one positive feature of Gödel's model that prompted research in another direction. There is no spacetime singularity in Gödel's universe. This is because in a stationary state, the centrifugal force created by rotation, balances gravity. So, the question was whether one could generate expanding and rotating models of the universe which are singularity-free.

Raychaudhuri (1955) proved an important result in this connection. In anisotropic expanding universes there are three dynamical features : volume expansion, shear and rotation. We denote the volume expansion rate per unit volume by the magnitude of shear by σ and that of spin by ω . Raychaudhuri's equation written in modern format is as follows:

$$\dot{\theta} + \frac{1}{3}\theta^2 \equiv 3\frac{\dot{S}}{S} = 2\omega^2 - 2\sigma^2 - \frac{4\pi G\rho}{4c^2} \quad (10)$$

Here S^3 is the volume scale factor and ρ the density. If the universe is to be singularity free it must have a minimum of S^3 at $S > 0$. Thus we need $S/\dot{S} > 0$ at $S/\dot{S} = 0$. From (10) we see that the only positive term on the right hand side is the spin-term $2\omega^2$. Thus spin does help towards removing singularity while the shear and matter density terms go the other way.

Heckmann and Schucking (1955, 1956) had argued that it may be possible to generate singularity free spinning universes. This expectation, however, could not be fulfilled at least within the framework of relativity. The trouble was that while shear could exist without rotation, the opposite was not true. Thus whenever rotation was introduced the resulting shear would dominate ($\sigma^2 > \omega^2$). Was this part of a general result? Was a spacetime singularity unavoidable in any relativistic cosmological model despite the hope held out by the Raychaudhuri equation?

The Singularity Theorems

Raychaudhuri's equation formed the base for further work a decade later. Could one make a general statement that singularity is inevitable in all relativistic cosmological models? Penrose, Hawking and Geroch proved a number of theorems on the global structure of spacetime (Hawking and Ellis, 1973). A typical theorem made certain 'reasonable' assumptions on the global geometry and the kind of physics contained in the spacetime. The conclusion always was that such a spacetime will have a singularity. Thus the big bang singularity of Friedman models is not a special artefact of symmetry arguments but a generic feature of all relativistic spacetimes.

It is worth noting that the steady state model and a number of other models obtained by the C-field cosmology do not satisfy the general assumptions of the Penrose-Hawking-Geroch singularity theorems and do not have singularities.

How does Newtonian cosmology compose with relativity on this count? Work by Narlikar (1963) had shown that for all homogeneous dust models the comoving volume of any region satisfies a fourth order differential equation with time as the independent variable. The computer solutions indicated that this volume would pass through a zero. An elegant analytical proof was, however, given later by Davidson and Evans (1973).

The Early Universe

The standard hot big bang model received considerable observational boost by the discovery of the microwave background radiation in 1965 by Penzias and Wilson (1965). This discovery came serendipitously but was subsequently recognized as a confirmation of Gamow-Alpher-Herman's prediction of relic radiation. Since then a number of observations have put together the spectrum of this radiation, the latest of these being the data collected by the COBE satellite. The spectrum is Planckian (as expected on the relic radiation hypothesis) with a temperature of 2.75K (Mather *et al.*, 1990).

Gamow's primordial nucleosynthesis idea also received support with the measurements of abundances of light nuclei. In particular, the abundance of ^4He by mass as high as 24 - 30% requires that a large fraction of it must come from the primordial process since stars, on their present rate of radiation cannot deliver so much helium in their main sequence fusion phase. The abundance of deuterium, although as small as 10^{-6} - 10^{-5} , fits in with the primordial process since stars are unable (so far as present understanding goes) to produce even this mass fraction of deuterium.

The successes of the hot big bang inspired more speculative probes into the history of the universe even closer to the $t = 0$ instant. This impetus was provided not by further observations but by particle theorists. The unification model of

Salam and Weinberg had shown a possible way of unifying all physical interactions. However, whereas the unification energy of the electroweak theory ($\sim 100\text{GeV}$) was within the reach of man made accelerators, the next step of unification with the strong interaction seems to require energies $\geq 10^{14}$ GeV. No particle accelerator in foreseeable future could generate such energies. And so, the only alternative scenario where such a unification theory could be tested seems to be in the very early stages of the universe.

For, if we pursue the scenario of a universe dominated by relativistic particles and radiation, further back towards $t = 0$ we encounter higher and higher energies. Typically we may relate the average particle energy in GeV to the time t seconds after the big bang by the relation

$$t_{\text{second}} = 2.4 \times 10^{-6} g^{-1/2} E_{\text{GeV}}^2 \quad (11)$$

where g is a constant measuring the effective number of spin states of all particle species in relativistic thermodynamic equilibrium (Narlikar 1983). We thus see that with $g \sim 100$ at $t \sim 10^{-2}\text{s}$, particle energies were high enough for unification to have operated.

The injection of ideas from particle theory into the big bang theory though inevitable brought as many new problems as it solved. One positive feature was that the so called 'grand unification' theories allow for creation or destruction of baryon number and thus it becomes possible to have a scenario in which from an initial zero baryon number, a positive value could arise, of a magnitude large enough to explain the currently observed baryon to photon number ratio in the range 10^{-10} to 10^{-9} . Ironically this supported the idea of continuous creation of baryon number in the steady state theory.

It was also possible to think of seeds of the galaxies of today being shown in those early epochs through quantum fluctuations. Further, these new ideas in particle physics including those from supersymmetry proposed many possible candidates for 'dark matter' which is discussed later in this article. There were, however, problems involving relic monopoles, horizon and flatness that posed more problems. A review of these difficulties is given by Narlikar and Padmanabhan (1986).

The Inflationary Universe

Several authors, including Guth who named his model as 'the inflationary universe' pointed out around 1980-81 that the dynamics of the expansion of the universe is likely to be considerably modified by the phase transition that occurs when the spontaneous breakdown of grand unification symmetry takes place (Guth, 1981; Kazanas, 1980; Sato, 1981). At the phase transition the nature of vacuum (the state of lowest energy of the mediating field) changes. If the new vacuum is of lower energy, there may develop a situation analogous to the

supercooling of steam. In such a case the universe may persist in the earlier state longer than warranted and thus operate on a false vacuum of higher energy. This causes a lambda-term to appear that drives the universe in the de Sitter exponential expansion mode. This mode lasts until the phase transition is over.

The inflationary model seemed an attractive solution to many of the outstanding problems of the early universe. In particular, it offered resolution of the monopole, horizon and flatness problems. However it brought new problems of its own! The most difficult one was that of pregalactic fluctuations: they seem to grow too large for comfort! If such growths were allowed it would be hard to understand the extraordinary smoothness of the microwave background. Further, the lambda term that appears during inflation is far too large compared to any that might be observed today, thus requiring its complete cancellation (to less than one part in 10^{100}). A review of the inflationary universe models is given by Narlikar and Padmanabhan (1991).

Quantum Cosmology

If we carry the classical theory of general relativity too close to $t = 0$, we run into a problem. The typical size of a region (with dimensions specified by curvature) becomes so small that quantum instead of classical physics becomes applicable to it. This size is known as the Planck length.

$$L_p = \sqrt{\frac{G\hbar}{c^3}} \sim 10^{-33} \text{ cm.} \quad (12)$$

The characteristic time for this phase was $t \leq t_p \sim 10^{-44}\text{s}$.

Quantum gravity *per se* has still not taken off as a working theory so that cosmological models can be constructed out of it. Under certain limited frameworks one can talk of the 'wave function of the universe' (Hartle, 1988; Narlikar and Padmanabhan, 1983). Nevertheless, if one only quantises the conformal degrees of freedom, then one can show that the problems of space-time singularity and particle horizon disappear as does the problem of flatness. This approach was initiated by Narlikar and has been explored further by him and Padmanabhan (1986).

Is the Universe Evolving?

In the steady state vs. big bang debate, one crucial observational evidence was on the evolution of the universe. If it is found that a population of extragalactic objects at large redshifts is different in some physical properties from a similar population close by then we have evidence that the universe cannot be in steady state. Thus evidence for evolution becomes important. Although such evidence has been claimed by observers from time to time further studies reveal that there

are 'ifs' and 'buts' attached to the claim. In fact the most telling blow to the steady state model came not from evolution but from the discovery of microwave background. Unless the steady state theory can offer an alternative scenario in which the background is continually being produced, it has to be counted out as a viable cosmological alternative to the big bang. This point will be discussed later.

The most persistent claim for evolution has centred around number counts. In a Euclidean universe with a uniform distribution of extragalactic sources, the number N brighter than a flux level S will fall off as $S^{-3/2}$. Non-evolving source populations in either the steady state or the big bang cosmologies show a flatter rise of N as S decreases. A steeper rise will, therefore, be evidence for evolution. Such a rise has been claimed by radio astronomers for radio sources (Wall and Peacock, 1985) and the optical astronomers for quasars (Schmidt, 1986).

If quasars are not as far away as implied by their redshifts (see discussion towards the end of this article) they cannot be used to study the evolution of the universe. If we remove quasars from the list of radio sources then it can be shown that the data on number counts of radio galaxies are consistent with the non evolving hypothesis (Narlikar *et al.*, 1988; Das Gupta, 1989).

It was pointed out by Hoyle and Narlikar (1961) far back in 1961 that if the universe is inhomogeneous in the large scale, a pseudo evolutionary effect may emerge in source count depending on the location of the observer. In view of the emerging evidence for inhomogeneity in the form of superclusters and voids this warning needs to be heeded.

An important study of evolution in the linear sizes of radio sources was made by the radio astronomers with the Ooty telescope. In particular, by measuring the angular sizes of radio sources by the lunar occultation method and plotting them against their flux densities Kapahi (1975) argued that the data can be explained by assuming that the linear sizes were smaller in the past than now. Narlikar and Chitre (1977), however, showed that a non-evolving model also fits the data provided one assumes a correlation between power and linear size.

More recently Kapahi (1986) has plotted median angular size vs. median redshift and claimed evolution. Dasgupta (1989) has shown, however, that even here a non-evolving model fits if one assumes a power-linear size correlation. Nevertheless a large body of cosmologists today feels that evolution has been demonstrated.

Dark Matter and Galaxy Formation

In the seventies the measurements of motions of large hydrogen clouds in galaxies (including ours) showed that the rotational speeds stay constant much further beyond the visible concentration of matter. According to Kepler's law the

motion should have dropped as $r^{-1/2}$, provided Newtonian gravitation is valid. On a larger scale, the random motions of galaxies in clusters are far in excess of what would be expected under the virial theorem. Both these observations imply that if the inverse square law of gravitation is correct, there must be more gravitating mass present in galaxies and clusters than visible. What is this dark matter made of?

A pioneering suggestion was made in 1972 by Cowsik (1972) that the dark matter may be in the form of massive neutrinos. This suggestion came long before the above evidence.

Alternatives like baryonic, blackhole or jupiters (brown dwarfs) or non baryonic matter being explored. Each hypothesis can be linked to the process of galaxy formation, for, the dark matter if present, must have influenced the process through its gravitational influence. As yet no clearcut claimant for this role has emerged (Carr, 1982).

The formation of discrete structure like galaxies, clusters and superclusters has been something of a mystery. There is a large scale inhomogeneity in their distribution which contrasts with the smoothness of the microwave background. If both the discrete structures and radiation are of relic origin, why is one component inhomogeneous and the other smooth? Several attempts to understand and solve this problem have so far failed (Longair, 1988).

Non-standard Viewpoints in Cosmology

In the six decades since Hubble's law, the balance of opinion has tilted heavily in favour of the hot big bang picture with an inflationary phase very early on. Most of the current research is based on this view-point. This is also reflected in the projects submitted to the Hubble Space Telescope. In India, the Giant Meterwave Radio Telescope is being designed to look for pregalactic neutral hydrogen clouds at large redshifts - a scenario of galaxy formation in the standard model. Nevertheless the cosmological problem is probably too deep to have lent itself to solution so soon.

In a recent assessment of the standard model Arp *et al.* (1990) have pointed out several drawbacks of the currently accepted scenario. They highlight the following points (for details see the above paper and the references therein):

- (1) There is increasing evidence of preferential association between high redshift quasars and low redshift galaxies. It seems unlikely that such cases can be explained by gravitational microlensing and so one must examine the implications of the possibility that such quasars and galaxies are physically associated. One immediate implication is that the universal applicability of Hubble's law to extragalactic objects breaks down, thus shaking the very foundation of modern cosmology.

- (2) Even if one assumes modern cosmology to be right, the value of Hubble's constant (even at the lowest end of its range) is too high if one trusts the astrophysical age determinations of the old stars in the Galaxy. These ages (15-18 billion years) seem to exceed the age of the big bang model with inflation ($6.6h^{-1}$ billion years).
- (3) The abundances of light nuclei, especially lithium, deuterium and helium do not seem to fall in a viable parameter space of the standard models, if one takes the theory and observations at face value.
- (4) The microwave background radiation is too smooth to be of relic origin : there are no imprints on it of the processes that led to the formation of discrete structures in the universe.
- (5) The evidence for an evolving universe does not appear (on closer scrutiny) as incontrovertible as it is made out to be.

Although this report has concentrated on the standard (popular) version of cosmology, for completeness it is necessary to list a few alternative pictures that have emerged or that once played a stimulating role as possible rivals to the big bang:

- (1) The steady state theory already referred to in this report.
- (2) The Brans-Dicke cosmology based on the scalar tensor theory of gravity proposed by Brans and Dicke (1961).
- (3) The Dirac cosmology (Dirac 1937, 1973, 1974) based on Dirac's large numbers hypothesis.
- (4) The Hoyle-Narlikar cosmology based on the conformal theory of gravity of Hoyle and Narlikar (1974).
- (5) Segal's chronometric cosmology (Segal 1976) in which the topology of the universe is different and the redshift does not need expansion.
- (6) Alfvén's matter-antimatter symmetric cosmology (Alfvén, 1965).

For details of these and some other model, refer to Narlikar and Kembhavi (1988).

Some of these cosmologies specifically address themselves to the problems raised above. Although none can be called completely satisfactory, they illustrate the importance of keeping in mind alternatives to the popular theory especially with the historical background that astronomy has proved to be a graveyard of many theories once believed to be correct by the majority community.

The Indian Contribution

In this report, we have presented a global picture of developments in cosmology including the contributions made by the Indian scientists. The references listed include such contributions, without having been specifically so identified. The highlights are in the Raychaudhuri equation, the search for evolution in linear sizes of radio sources, the idea of primordial massive neutrinos, in the C-field cosmology and the Hoyle-Narlikar theory, in quantum cosmology, in exact solutions of cosmological equations of Einstein's equations, the Einstein-Maxwell equations and the Brans-Dicke theory etc. With the opening of new facilities in the country the output is expected to increase both in quality and quantity:

Abstract

A global picture of developments in cosmology including the contributions made by the Indian Scientists has been presented.

References

- Alfvén, H. (1965) *Rev. Mod. Phys.* 37: 652.
- Alpher, R.A. & Herman, R.C. (1949) *Phys. Rev.* 75: 1093.
- Alpher, R.A., Bethe, H.A. & Gamow, G. (1948) *Phys. Rev.* 73: 80.
- Arp, H., Burbidge, G., Hoyle, F., Narlikar, J.V. & Wickramasinghe, N.C. (1990) *Nature* (to be published).
- Bondi, H. & Gold, T. (1948) *M.N.R.A.S.* 108: 252.
- Brans, C. & Dicke, R.H. (1961) *Phys. Rev.* 124: 125.
- Carr, B. (1988) *Highlights of Gravitation and Cosmology* (Ed., Iyer, B.R., Kembhavi, A., Narlikar, J.V. & Vishveshwara, C.V.), Cambridge, p. 144.
- Cowsik, R. & McClelland, J. (1972) *Phys. Rev. Lett.* 29, 669.
- Das Gupta, P. (1989) *Ph.D. thesis*, Bombay University, Bombay.
- Davidson, W. & Evans, A.B. (1973) *Int. J. Theo. Phys.* 7: 353.
- de Sitter, W. (1917) *Proc. Akad. Wetensch, Amsterdam* 19: 1217.
- Dirac, P.A.M. (1937) *Nature* 139: 323.
- Dirac, P.A.M. (1973) *Proc. Roy. Soc.* A333: 403.
- Dirac, P.A.M. (1974) *Proc. Roy. Soc.* A338: 439.
- Einstein, A. (1917) *Preuss. Akad. Wiss., Berlin, Sitzber.* p. 142.
- Friedman, A. (1922) *Z. Phys.* 10: 377.
- Friedman, A. (1924) *Z. Phys.* 21: 326.

- Gamow, G. (1946) *Phys. Rev.* 70: 572.
- Gamow, G. (1948) *Nature* 162: 680.
- Gamow, G. (1953) *Kong. Dansk. Ved. Sels.* 27: 10.
- Godel, K. (1949) *Rev. Mod. Phys.* 21: 447.
- Gunn, J.E. & Oke, J.B. (1974) *Ap. J.* 195: 255.
- Guth, A. (1981) *Phys. Rev.* 23: 347.
- Hartle, J.E. (1988) *Highlights in Gravitation and Cosmology* (Ed., Iyer, B.R. Kembhavi, A., Narlikar, J.V. & Vishveshwara, C.V.), Cambridge, p. 144.
- Hawking, S.W. & Ellis, G.F.R. (1973) *The Large Scale Structure of Space-time*, Cambridge.
- Heckmann, O. & Schucking, E. (1955) *Z. Astrophys.* 38: 95.
- Heckmann, O. & Schucking, E. (1956) *Z. Astrophys.* 40: 81.
- Hoyle, F. (1948) *M.N.R.A.S.* 108: 372.
- Hoyle, F. & Narlikar, J.V. (1961) *M.N.R.A.S.* 123: 133.
- Hoyle, F. & Narlikar, J.V. (1962) *Proc. Roy. Soc.* A270: 334.
- Hoyle, F. & Narlikar, J.V. (1963) *Proc. Roy. Soc.* A273: 1..
- Hoyle, F. & Narlikar, J.V. (1966) *Proc. Roy. Soc.* A290: 177.
- Hoyle, F. & Narlikar, J.V. (1966) *Proc. Roy. Soc.* A290: 142.
- Hoyle, F. & Narlikar, J.V. (1966) *Proc. Roy. Soc.* A290: 162.
- Hoyle, F. & Narlikar, J.V. (1974) *Action at a Distance in Physics and Cosmology*, W.H. Freeman, New York.
- Hubble, E.P. (1929) *Proc. Nat. Acad. Sci. (USA)* 15: 168.
- Kapahi, V.K. (1975) *M.N.R.A.S.* 172: 513.
- Kapahi, V.K. (1986) *Observational Cosmology*, IAU Sympo. No. 124 (Ed., Hewitt, A., Burbidge, G. & Fang, L.Z.), Reidel, Dordrecht, p. 251.
- Kazanas, D. (1980) *Ap.J.* 241: L59.
- Longair, M.S. (1988) *Highlights of Gravitation and Cosmology* (Ed., Iyer, B.R., Kembhavi, A., Narlikar, J.V. & Vishveshwara, C.V.), Cambridge, p. 192.
- Mather, J.C. et al. (1990) *Ap. J.* 354: L37.
- Narlikar, J.V. & Chitre, S.M. (1977) *M.N.R.A.S.* 180: 525.
- Narlikar, J.V. & Kembhavi, A.K. (1988) *Galaxies and Cosmology, Handbook of Astronomy, Astrophysics & Geophysics*, Vol. II (Ed., Canuto, V.M. & Elmegreen, B.G.), Gordon and Breach, New York, p. 301.

- Narlikar, J.V. & Padmanabhan, T. (1986) *Gravity, Gauge Theories and Quantum Cosmology*, Reidel, Dordrecht.
- Narlikar, J.V. & Padmanabhan, T. (1991) *Ann. Rev. Astron. Astrophys.* (to be published).
- Narlikar, J.V. & Padmanabhan, T. (1983) *Physics Reports C* 100: 151.
- Narlikar, J.V. (1963) *M.N.R.A.S.* 120: 203.
- Narlikar, J.V. (1983) *Introduction to Cosmology*, Jones and Bartlett, Boston.
- Narlikar, J.V., Das Gupta, P. & Burbidge, G. (1988) *A.J.* 95: 5.
- Oke, B. & Sandage, A. (1968) *Ap. J.* 154: 21.
- Ozsvath, L. & Schucking, E. (1962) *Recent Developments in General Relativity*, Pergamon, Oxford.
- Penzias A.A. & Wilson, R.W. (1965) *Ap. J.* 142: 419.
- Raychaudhuri, A.K. (1955) *Phys. Rev.* 98: 1123.
- Robertson, H.P. (1935) *Ap. J.* 82: 248.
- Ruzmaikina, T.V. & Ruzmaikin, A.A. (1969) *Soviet Physics JETP.* 29: 934.
- Ryle, M. (1958) *Proc. Roy. Soc.* A248: 289.
- Sandage, A. (1972) *Ap. J.* 178: 1.
- Sato, K. (1981) *M.N.R.A.S.* 195: 467.
- Schmidt, M. (1986) *Observational Cosmology*, IAU Symposium No. 124 (Ed., Hewitt, A., Burbidge, G. & Fang, L.Z.), Reidel, Dordrecht, p. 619.
- Scott, P.F. & Ryle, M. (1961) *M.N.R.A.S.* 122: 389.
- Segal, I.E. (1976) *Proc. Nat. Acad. Sci. (USA)* 73: 669.
- Stebbins, J. & Whitford, A.E. (1948) *Ap. J.* 108: 413.
- Walker, A.G. (1936) *Proc. Lond. Math. Soc.* 42: 90.
- Wall, J.V. & Peacock, J.J. (1985) *M.N.R.A.S.* 216: 173.