JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
29: S1 ∼ S5, 1996

AN ALTERNATIVE COSMOLOGY

JAYANT V. NARLIKAR
Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India

ABSTRACT

Recent discussions of observational constraints on the standard hot big bang model are reviewed and it is argued that now there is room for considering alternative cosmologies. The quasi-steady state cosmology is briefly described. This model seems to explain most of the observed features of the universe, including the m-z relation, radio source count, the light nuclear abundances and the microwave background.

I. INTRODUCTION

The big bang cosmology gained considerable support with the discovery of the microwave background in 1965, and by the findings in the 1960s and 1970s that the light nuclear abundances are explained reasonably well by the nucleosynthesis in the early high temperature phase of the universe. This led to the particle physicists getting interested in even earlier phases of the big bang universe. The ideas on non-baryonic dark matter, cosmic strings, inflation and the findings by COBE and other observations of microwave background and their relationship to structure formation scenarios demonstrate the vibrant nature of big bang cosmology.

Recently, however, a serious reexamination of the standard big bang concept has become necessary because of the various constraints on the parameters of the model placed by cosmological observations. As I will briefly outline next, an exercise of constraining parameters of the standard model leads to the conclusion that, at best only a very contrived and fine tuned version of the model is allowed by the present observations.

It is, therefore, opportune to consider alternatives to the standard model. Competition between rival theories have always led to a healthy growth of cosmology. In this spirit I will describe a particular alternative to the standard model, namely the Quasi-Steady State Cosmology (QSSC) developed by F. Hoyle, G. Burbidge and myself.

II. CONSTRAINTS ON THE STANDARD MODEL

Twenty years ago Gunn and Tinsley (1975) took stock of the observational situation and concluded: "New data on the Hubble diagram, combined with constraints on the density of the universe and the ages of galaxies, suggest that the most plausible cosmological models have a positive cosmological constant, are closed, too dense to make deuterium in the big bang, and will expand for ever..." How does the theory vs observation scenario look today?

An exercise on the lines of Gunn and Tinsley was carried out recently by Bagla et al. (1996)(BPN). We summarize below their main conclusions.

Using k for the curvature parameter, and denoting the dimensionless matter density parameter as $\Omega_\circ$ and the cosmological constant parameter as Ω_λ:

$$\Omega_\circ = \frac{8\pi G\rho_\circ}{3H_\circ^2}, \quad \Omega_\lambda = \frac{\lambda c^2}{3H_\circ^2}. \tag{1}$$

where for this analysis we put $H_\circ = 100h\ km\ sec^{-1}\ Mpc^{-1}$.

BPN assumed that the currently fashionable standard big bang model with inflation predicts:

$$\Omega_\circ + \Omega_\lambda = 1, \ \ k = 0. \tag{2}$$

In addition they supposed that the model canonically predicts an initial power spectrum for the wave numbers of inhomogeneities in the form

$$\rho(\kappa) \propto \kappa^n, \qquad n = 1. \tag{3}$$

The spectrum gets modified at small scales by different physical processes and this change is described by a transfer function. BPN used the transfer function of Efstathiou et al. (1992). They also took into consideration the COBE data for normalizing the power spectrum. In addition to the above model BPN also considered the case $\Omega_\circ < 1, \Omega_\lambda = 0, k = -1$ of the open universe without the cosmological constant.

Apart from the ages of the globular clusters and the measured value of the Hubble's constant discussed earlier, BPN also considered the data on mass per unit volume in rich clusters identified from x-ray observations. One way of comparing theory with observations is to convert the number density of clusters into amplitude of density fluctuations. This amplitude is then scaled to a typical cluster scale of $8h^{-1}Mpc$ assuming a power law form for σ, the rms-fluctuations in density perturbations. The index is chosen to match that expected in the model being considered (cf White, Efstathiou & Frenk, 1993). The result is expressed as a constraint on the parameter σ_8, which is the value of σ at $8h^{-1}Mpc$, that is, it represents the rms fluctuation in mass density within spheres of radii $8h^{-1}Mpc$.

Another constraint considered by BPN is the baryon mass fraction of clusters, along with the ceiling value for baryon density from primordial nucleosynthesis. This places limits on the mass density parameter Ω_0. Finally, another constraint is provided by the existence of high redshift objects with damped Lyα Systems (DLAS). This tells us that the amplitude of density perturbations is of order unity at $M \approx 10^{11} M_\odot$ at redshift $z = 2$. The theoretical value of the density parameter should be greater than or equal to the observed value, as not all systems in the relevant mass range host a DLAS.

BPN described these constraints by limiting curves in a plot of h against Ω_0. In the upper panel of their Fig. 3 the crossed hatched area gave the permitted possible values of these two parameters when

1. the ages of the globular clusters are 15×10^9 years or more,
2. H_0 is considered to be possibly as low as $50 km\ s^{-1}\ Mpc^{-1}$,
3. the constraints on high redshift objects mentioned in the previous paragraph confine the possible values to lie between the two thick solid lines.

Weakening the observational requirements to the limit of what seems possible, and in particular lowering the ages of the oldest stars to 12×10^9 years, led to a very limited area as possible for h and Ω_0.

The lower panel of BPN, Fig 3 described the corresponding situation for the open Friedmann model with $k = -1,\ \lambda = 0$, where there is no cross-hatched region, no region with what are considered the most likely observational values and constraints. No model satisfies the most likely values without the cosmological constant, while even with the cosmological constant there is very little room for manoeuvre left.

Even on theoretical grounds the deduction that after inflation was over a residual cosmological term remained of just the right magnitude to enable the model to fall within the required tiny parameter space smacks of fine tuning. For, as has been pointed out by several authors (cf Weinberg 1989) it means that from the vacuum value operating during inflation the residual has managed to acquire the present value as a tiny fraction of a few parts in 10^{108}.

It is aganst this background that I will now describe an alternative cosmology.

III. THE QUASI-STEADY STATE COSMOLOGY

The quasi-steady state cosmology (QSSC) has been recently developed in a series of papers by Hoyle, Burbidge and Narlikar (1993, 1994a,b, 1995), with the intention of offering the theory as a viable alternative to the standard hot big bang cosmology. The hot big bang cosmology (HBBC) has two versions: *(i)* the orthodox version in which the universe expands from a singularity in a radiation dominated phase which changes over to a matter dominated one and *(ii)* the more recent, post-1981 version in which there is a brief interlude of inflation very early in the radiation dominated phase. The latter version, the so-called inflationary big bang cosmology (IBBC) was proposed to get rid of some of the conceptual and practical defects of the orthodox HBBC. While it has been partially successful in this enterprise, it has problems of its own. (For a review, see Narlikar and Padmanabhan, 1991.)

The QSSC can explain the temperature, spectrum and anisotropies of the cosmic microwave background, offers a different theory for the origin of light nuclei, and is consistent with the large scale observations of discrete sources. The QSSC is also able to account for the very old as well as the very young galactic systems, is consistent with the baryonic option for dark matter and relates the observed activity of galactic nuclei to mini creation events where matter and energy pour out in an explosive fashion.

Indeed the motivation for the QSSC was to replace the singular event of big bang cosmology which has no formal mathematical description within conventional physics by a rigorous formalism that describes creation of matter. Such a formalism is described in detail using a framework that is conformally invariant, incorporates Mach's principle and which in the many particle approximation leads to Einstein-like equations of general relativity including additional terms incorporating the creation of matter and a negative cosmological constant. The dynamics of the quasi-steady state cosmology follow from these field equations.

These equations are, however, more complicated to solve and to work out the observable details of the model. A similar situation exists in general relativity where the Einstein field equations cannot be solved for a realistic universe with all its observed inhomogeity and anisotropy and for the large scale motions of its galaxies. To make any progress with model building in relativistic cosmology, one has to simplify the problem to be solved, i.e., to assume a large scale regularity in the structure and dynamics of the universe.

A similar approach is used for the QSSC. Thus with the spacetime geometry approximated by the usual Robertson-Walker line element

$$ds^2 = c^2 dt^2 - S^2(t)\left\{\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta d\phi^2)\right\}, \tag{4}$$

where (r, θ, ϕ) are the comoving coordinates of the fundamental Weyl observers, t is the cosmic time and $k = 0, \pm 1$ represents the three possible curvature signatures for the spaces $t =$ constant, the scale factor for the QSSC is given as

$$S(t) = \exp\left(\frac{t}{P}\right)\left(1 + \eta\cos\frac{2\pi\tau(t)}{Q}\right). \qquad (5)$$

The simplest model has $k = 0$. Here P is the longer time scale for the steady state expansion and Q is the period of a typical oscillatory fluctuation from the steady state. η is a parameter whose magnitude lies between 0 and 1. As explained in the earlier papers (Hoyle et al, 1993,1994 a,b) these fluctuations arise because the creation activity follows a stop-go pattern summarized briefly below. The function $\tau(t)$ is determined by the field equations and is very nearly linear in t(see Sachs et al, 1996 for details).

Imagine the universe as having a smoothed out background of the creation field whose intensity falls short of the threshold required for the creation of a typical primary particle. The threshold corresponds to the equality of the energy-momentum of the creation field quantum with the 4-momentum of the created particle. The intensity of the field may rise above the average background and above the threshold near a collapsed massive object which therefore becomes a typical site for a creation event. Since the creation field has negative stresses it blows outwards not only the matter created but the space itself.

The long term steady state with time scale P thus represents an overall expansion of space produced by several of such minicreation events acting in unison. The ups and downs occur because the creation activity around a typical object rises and falls as the gap between the threshold and the background decreases or increases. If the gap narrows, the creation activity picks up thereby increasing the expansion rate above the steady rate. This leads to a lowering of the background level of the creation field which makes the gap wider. This in turn slows down the creation of matter and the expansion of the universe. At this stage the negative cosmological constant steps in to bring about the contraction of the universe. As the universe contracts the background level of the creation field rises and creation activity picks up. This converts the expansion into contraction. The time scale represents these physical processes.

IV. RELATION TO OBSERVATIONS OF DISCRETE SOURCE POPULATIONS

We now relate the parameters P and Q to the observable features of the QSSC.

Sachs, et al (1996) have worked with the following values of the model parameters:

$$\begin{aligned} P &= 20Q, \quad Q = 4.38\times 10^{10}\ \text{yrs.}, \\ \lambda &= -0.29\times 10^{-56}\ \text{cm}^{-2}, \\ \eta &= 0.8, \quad t_0 = 0.7Q \end{aligned} \qquad (6)$$

For these parameters we have the well known cosmological parameters as :

$$\begin{aligned} \text{Hubble parameter } h_0 &= 0.75, \\ \text{Deceleration parameter } q_0 &= 0.99. \end{aligned} \qquad (7)$$

These parameters are not uniquely chosen but their values may be considered as indicative. We now use them to work out two well known cosmological observations.

(i) The magnitude redshift relation : The standard formula is

$$m = 5\log D - 5 + M, \qquad (8)$$

with D being the luminosity distance in parsecs. Here

$$D = S_0 r(1+z), \qquad S_0 = S(t_0). \qquad (9)$$

As in HBN (1994a) Sachs et al (1996) used a standard absolute magnitude $M = -22.44$ to calculate the $m-z$ relation. Whereas there is no difference from the well known standard big bang results for bright sources, the situation changes dramatically when one goes to fainter and fainter objects. At a magnitude of about 25.5 the curve turns back to smaller apparent magnitudes and smaller redshifts. In fact, at a magnitude of $\simeq 23$ objects with small redshift or even blueshift are expected. Of course, the figure does not explicitly show any blueshifted objects, as we plotted the results on the usual logarithmic scale. In practice, absorption near $S = S_{\min}$ will increase the apparent magnitudes by $\Delta m \sim 2$. Thus blueshifted objects may be detected if one went to $m \gtrsim 25$.

(ii) The counting of radio sources : Sachs et al (1996) repeated the calculations of Hoyle et al (1994a) for the exact composite solution. As in *(i)* above they followed the same method of numerical computation for a radio luminosity function $\propto L^{-2.1}$ for the radio luminosity L in the range 3.10^{28} to 3.10^{29} $W\ Hz^{-1}$ to plot $\Delta N F^{5/2}$ against F on a logarithmic scale.

The most obvious features of this relation are :

- the decrease down to fluxes of 50 Jy,
- the sharp rise that starts at about 30 Jy,
- the flattening at around 5 Jy,
- the plateau between 0.4 and 2 Jy,
- the gradual decline for even fainter sources.

With the ratio P/Q not much different from 20, Sachs et al (1996) obtained a good matching with the observational data by Kellermann and Wall (1987).

However, to demonstrate the range of possibilities in this cosmology Sachs et al found another way of obtaining the observed source count curve consistent with what is known of the radio sources from relatively local studies so far. Consider a different mixture of radio sources as given in Table 1. Notice that *(i)* low luminosity sources dominate in this solution and *(ii)* the class *II* & *III* sources switch off towards the low density part of each cycle. Imagine, in dimensionless time units a cycle is expressed by $0 \leq t \leq 1$, with $t = 0, 1$ describing maxima of S. The part of every cycle during which the different classes are present is then given by $t_{\min}$ and $t_{\max}$ in units of Q. This alternative was suggested by Hoyle, Burbidge and Narlikar (1995b) to highlight the fact that in contrast to the first solution in this alternative one would not expect any blueshifted sources in the optical identifications of sources $\gtrsim 1-2$ Jy. Clearly observational studies will play a crucial role in distinguishing between the two solutions.

In both these examples we have not included any evolutionary effects. In general these are inferred from the fits of theory to the observations: that is, if a non-evolutionary model does not fit the data one tries epicycles of evolution such as luminosity evolution or density evolution. The fits given by the present model to the $m - z$ relation or to source counts are so good that no strong evolutionary effects are needed. To what extent they are needed for very faint sources will no doubt be determined by future observations.

V. PROBLEMS OF HIGH ENERGY PHYSICS

The primary particle created in this cosmology has the mass determined by the fundamental constants $\hbar, c$ and G. This is the Planck mass with rest energy $\sim 10^{19}$GeV. What happens to this particle subsequently?

The Planck particle is unstable and within a timescale of $\sim 10^{-43}$s, it decays into a large number of secondaries. The process involves a release of high energy since it begins with energy source of $\sim 10^{19}$ GeV which gets distributed over particles and radiation, the ultimate decay products being baryons, leptons and photons etc. We may see here an analogy with the descending energy ladder in the big bang cosmology, from $\sim 10^{19}$ GeV, through the GUT energy of $\sim 10^{16}$ GeV, down to the electroweak unification energy of $\sim 10^2$ GeV, to ~ 1 GeV for baryons. Instead of a single big bang, however, we now have numerous mini-creation events involving 'Planck fireballs' centred on all decaying Planck particles.

This transition from 10^{19} GeV to 10^2 GeV has the same range of interesting physics that particle physicists like to study in the context of the big bang cosmology. The advantage with the QSSC is that the Planck fireballs are physical objects that can be studied just like any other repetative physical phenomena. (In the 'early universe' of big bang cosmology the events are non-repetative). Moreover, many mini-creation events occur at modest redshifts $\lesssim 5$) and so are, in principle directly accessible to extragalactic astronomy, which is not the case for the early universe of big bang cosmology. As an example DasGupta and Narlikar (1993) have shown that the mini-creation events can be detected by gravity-wave detectors being planned now.

One interesting issue that is handled differently by the QSSC is the observed lack of balance between matter and antimatter. In the big bang cosmology the symmetry between matter and antimatter is normally sought to be broken during the GUTs era. Somewhat contrived scenarios are needed to understand the observed photon to baryon ratio. In the QSSC the problem is posed differently. Since the universe 'renews itself' over a few oscillations, we have to understand *why*, given a matter dominated phase now, it will persist even with the renewed phase. Since the creation field is a globally interacting field the imbalance in the current phase is expected to be propagated into the next. How exactly the propagation of broken symmetry takes place is still to be worked out.

Finally, let us see what happens at the limit of the decay process, when from the Planck particle we end up with a group of baryons and radiation. At temperature $\gg 1$ GeV we expect an equipartition of all eight particles of the baryon octet. Eventually, however, all except the more long-lived neutron and proton decay to proton and end up as hydrogen nuclei. The neutron and proton combine to form the helium nuclei. A simple counting thus tells us that with two out of eight particles forming helium we expect the helium abundance to be ~ 0.25 by mass.

A more detailed calculation has been given by Hoyle et al (1993) and it leads to values of not only the helium abundance but also of D, Li, Be, B including their isotopes that agree with observations. The important difference is that instead of the values of density and temperature at the time of big bang nucleosynthesis we have here a different set of values for ρ and T with the result that the deuterium abundance does not constrain the cosmological baryonic matter density. In other words, dark matter can be baryonic. This issue therefore has implications not only for astrophysics and cosmology but also for particle physics.

Table 1. Properties of radio sources. n denotes a relative number density, $[t_{\min}, t_{\max}]$ is the interval during which the sources are present

class	L / W Hz^{-1}	n	$t_{\min}$	$t_{\max}$
I	3×10^{25}	5000	0	1
II	3×10^{26}	1000	0.32	0.68
III	3×10^{28}	1	0.40	0.60

VI. MICROWAVE BACKGROUND

The QSSC provides a radically new explanation of the microwave background. The basic idea involves renewing the reservoir of radiation from cycle to cycle.

The starlight produced in a typical cycle gets thermalized towards the end of the cycle when S approaches a minimum. Around this epoch the accumulated starlight gets thermalized. As the radiation energy density falls off as S^{-4}, the depletion of energy density from one minimum to next, due to the exponential expansion is by an amount

$$\Delta u = \frac{4Q}{P} u. \tag{10}$$

This deficit must be made up by the thermalized starlight.

The energy density of starlight generated during a cycle can be estimated from the present stellar activity. Hoyle, et al (1994a) estimated Δu and hence u. The value of u from a minimum to the present epoch would decline as S^{-4} and hence the radiation temperature at the present epoch can be estimated. The answer came very close to 2.7K.

How is the thermalization carried out? This has been extensively discussed by Narlikar et al (1995) in terms of a model of cosmic iron whiskers. They make out a plausible case for a ubiquitous distribution of such whiskers primarily produced in supernovae. It can be shown that several galactic and extragalactic phenomena can be understood in terms of the whisker model.

Calculations show that the whiskers efficiently thermalize the radiation upto $\lambda \lesssim 20$ cm. The present agreement of observations with a Planckian spectrum covers this range. At longer wavelengths the observational error bars are quite large. The radiation background tends to attain a uniform temperature because any non-uniformity sets up temperature gradients which drive the whiskers towards lower temperatures thereby reducing the temperature difference ΔT. However, this process has limitations as below a certain limit the ΔT is not powerful enough to push the whiskers. Calculations show that this inherent non-uniformity of T is over angular scales $\sim 10^\circ$ and also, $\Delta T/T \sim 10^{-5}$, matching the COBE findings.

VII. CONCLUSIONS

These investigations show that a viable alternative to the big bang cosmology is possible and that the QSSC prima facie meets the present observational constraints.

REFERENCES

Bagla, J.S., Padmanabhan, T. and Narlikar, J.V., Comments Astrophys., 18, 27 (1996).

Das Gupta, P. and Narlikar, J.V. 1993, MNRAS, 264, 469

Efstathiou, G., Bond, J.R. and White, S.D.M. 1992, MNRAS, 258, 16

Gunn, J.E. and Tinsley, B.M. 1975, Nature, 257, 454

Hoyle, F., Burbidge, G. and Narlikar, J.V. 1993, ApJ, 410, 437

Hoyle, F., Burbidge, G. and Narlikar, J.V. 1994a, MNRAS, 267, 1007

Hoyle, F., Burbidge, G. and Narlikar, J.V. 1994b, A&A, 289, 729

Hoyle, F., Burbidge, G. and Narlikar, J.V. 1995, Proc. R. Soc., A448, 191

Narlikar, J.V. and Padmanabhan, T. 1991, ARA&A, 29, 325

Narlikar, J.V., Wickramasinghe, N.C., Sachs, R. and Hoyle, F. 1995, preprint

Sachs, R., Narlikar, J.V. and Hoyle, F. 1996, A&A, to be published

White, S.D.M., Efstathiou, G. and Frenk, C.S. 1993, MNRAS, 262, 1023

Weinberg, S. 1989, Rev. Mod. Phys., 66, 1