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Quasi Steady State Cosmology

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Abstract. Because of a number of unsatisfactory features of the standard hot big bang cosmology, it is argued that there is a case for exploring alternative approaches to cosmology. The approach described here called the quasi steady state cosmology (QSSC), uses a field theoretic description of matter creation within the framework of general relativity.

A cosmological solution with the universe expanding exponentially along with cycles of expansion and contraction arises from mini-creation events taking place near the event horizons of highly collapsed massive objects. The now familiar phenomena like QSOs, AGN, radio sources, etc. are the manifestations of matter creation in such events. In this way cosmology is seen to be related to high energy astrophysics in a very direct way. The QSSC can explain the abundances of light nuclei and the microwave background, the observed large scale features of the universe like the m–z relation, the source count, the angular size-redshift relation, as well as observed distribution of the ages of galaxies.

Key words: Cosmological models—creation of matter—steady state cosmology.

1. Introduction

Despite a widespread support for the standard big bang cosmology, the theory has failed to resolve some of the basic issues of cosmology such as (i) determination of the temperatures of the microwave background, (ii) the relationship of its very small anisotropy to large scale structures in the universe, (iii) a workable theory of structure formation consistent with observations of dark matter and the large scale streaming motions, (iv) the relation of discrete source populations to a realistic view of the evolving universe, (v) the awkward observations of the very old and very young systems of galaxies, globular clusters etc., (vi) the lack of any link between the primordial big bang and the smaller and relatively recent origin of violent phenomena like the QSOs and AGN and (vii) the theoretical problem of describing the big bang event within conventional physics.

For details of these points see earlier work of Arp *et al.* (1990) and Hoyle *et al.* (1993). Our main purpose here is to argue that despite the popularity enjoyed by the big bang cosmology today, the above list is sufficient to motivate an alternative approach to cosmology, an approach that does at least as well as the big bang and is better able to deal with the above issues.

2. Local creation of matter and cosmology

In 1948 Bondi & Gold (1948) and Hoyle (1948) had independently proposed the steady state theory as an alternative to the big bang cosmology. Bondi & Gold had adopted the Perfect Cosmological Principle as the starting point of their approach while Hoyle had taken a field theoretic description of matter creation as the main motivation. Here we will follow the second approach but with some significant modification.

The field equations are derived from an action principle. Although Hoyle *et al.* (1993) considered a direct particle interaction approach motivated by Mach's Principle, the following simplified derivation essentially reproduces their equations in the more familiar field theory format. Thus the classical Hilbert action leading to the Einstein equations is modified by the inclusion of a scalar field C of zero rest mass whose derivatives with respect to the spacetime coordinates x^i are denoted by C_i. For the notation followed and further details see Narlikar (1993). To allow for explicit description of creation the worldline of a typical matter particle has a beginning at a finite point in spacetime.

Thus, if the worldline of particle a begins at point A, then the action principle gives a necessary condition for creation of mass m_a as

$$C_i C^i = m_a^2 c^4. \tag{1}$$

This is the 'creation threshold' which must be crossed for particle creation.

Calculations show that a highly collapsed object of mass M and radius R (say) can achieve this condition close to its surface. For, $C_i C^i$ increases as $(1 - 2GM/c^2 r)^{-1}$ as $r \to R \approx 2GM/c^2$. So it is possible for the creation threshold to be reached *near* a massive collapsed object even if it is *below* the threshold far away from it. Thus, instead of a single big bang event of creation, we have mini-creation events (MCEs) near collapsed massive objects.

The C-field tensor has negative stresses which lead to the expansion of spacetime, as in the case of inflation. The formalism described here is essentially that used by Hoyle & Narlikar (1962, 1966a, b) in the 1960s to produce inflation type solution (which, of course predated Guth's inflationary cosmology by 15 years!).

Since the C-field is a global cosmological field, we expect the creation phenomenon to be globally cophased. Thus, there will be phases when the creation activity is large, leading to the generation of the C-field strength in large quantities. However, the C-field growth because of its large negative stresses leads to a rapid expansion of the universe and a consequent drop in its background strength. When that happens creation is reduced and takes place only near the most collapsed massive objects thus leading to a drop in the intensity of the C-field. The reduction in C-field slows down the expansion, even leading to local contraction and so to a build-up of the C-field strength. And so on!

We can describe this up and down type of activity as an oscillatory solution superposed on a steadily expanding deSitter type solution of the field equations by a scale factor that varies with cosmic time t as follows:

$$S(t) = \exp\left(\frac{t}{P}\right)\left\{1 + \alpha\cos\frac{2\pi t}{Q}\right\}. \tag{2}$$

Note that the universe has a long term secular expanding trend, but because $|\alpha| < 1$, it also executes non-singular oscillations around it. We can determine α and our present epoch $t = t_0$ by the observations of the present state of the universe. Thus an acceptable set of parameters is $\alpha = 0{\cdot}75$, $t_0 = 0{\cdot}85Q$, $Q = 4 \times 10^{10}$yr., $P = 20Q$. Although the set is not unique and there will be a *range* of acceptable values, we will work with this set to illustrate the performance of the model.

3. The origin of nuclei and the microwave background

We have as yet not said what particle is being created by the C-field. The answer is, the Planck particle whose mass is $m_p \approx (3\hbar/4\pi G)^{1/2} \sim 10^{-5}$g. This particle, however, has a very short lifetime $\sim 10^{-44}$s. It decays ultimately into the baryon octet and radiation. Most members of the octet except n and p are also short-lived and decay into protons. Only the neutron and the proton combine into stable helium nuclei. Thus approximately 25% by mass (2 out of 8 baryons) combine to form helium.

A more careful calculation gives the helium mass fraction to be around 23%, with a tiny fraction of 1–2% in the form of metals. This type of nucleosynthesis also generates ^{2}H, ^{3}H, ^{3}He, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}Be etc. in small amounts that are in agreement with the observations and in fact, lead to a better agreement than in the big bang model.

There is one further important consequence. In the big bang model the required production of deuterium imposes a stringent upper limit on the present day baryon density. This limit forces us to assume that the dark matter component of the universe must be largely nonbaryonic. In the QSSC, there is no such density limit from deuterium abundance and thus the dark matter component *can be baryonic*. We will discuss this point further in the following section.

What about the microwave background? The QSSC obtains it in the following way. First, each Planck particle decay is like a fireball: it produces lot of energy, including baryons ($\sim 10^{19}$ per Planck particle) and radiation. Bulk of the fireball energy goes into expansion. However, some radiation remains as relic of the fireball. Together with the starlight generated in the preceding oscillatory cycles this energy is to be thermalized to provide the microwave background. Does it provide enough radiant energy to give a 2·7 K background? Is the background thoroughly thermalized to produce a black body spectrum? Also, is it homogeneous to the extent given by COBE (Smoot *et al.* 1992) and other measurements? Quantitative studies (see Hoyle *et al.* 1993: preprint) answer all these questions in the affirmative.

Quantity-wise the starlight from several past generations of stars is sufficient to maintain a steady background of radiation whose present temperature is calculated to be ~ 2.7 K, provided, some agency is available to thermalize it. The agency proposed is dust in the form of metallic needles, mostly of iron which absorb the ambient radiation and reradiate it in the microwaves. Provided this has gone on long enough, the radiation spectrum will have an accurate black body form. Calculation shows that indeed the thermalization has occurred through as many as 10^3 absorptions and remissions by iron whiskers–sufficient to ensure an extremely close approximation to the black body curve. The iron whiskers are typically ~ 1 mm in length and 10^{-6} cm in radius of cross section. The iron itself is produced partly from stellar nucleosynthesis in supernovae and partly from the decay of the Planck particle. The required density in the form of such whiskers is only $\sim 10^{-35}\,\mathrm{g\,cm^{-3}}$: well within the observed cosmic abundances of iron. Further, it can be shown that the background produced will be very smooth with a patchiness of density of the order of 10^{-5}. Fluctuations of density and temperature of this or larger order get smoothed out by redistribution of iron grains by the radiation pressure. For fluctuations on smaller scales the dynamical smoothness-restoring forces are too small to make the radiation smooth. Thus, the COBE finding $\Delta T/T \sim 10^{-5}$ is consistent with the above picture.

4. Relationship to cosmology and Astrophysics

We highlight here the performance of the QSSC in the three classic tests of cosmology.

(i) *The redshift-magnitude relation*: For the oscillatory steady state model the apparent magnitude is not a monotonic function of distance; nor so is the redshift. Both m and z decrease as we go past the last oscillatory minimum. At magnitudes fainter than, say 24, we may see moderately blueshifted sources from the previous cycle.

(ii) *The counting of radio sources*: In the source count curve calculated for a typical low frequency survey there is a super-Euclidean slope at high flux levels arising from contributions of sources from previous cycle in addition to those from the present cycle. Indeed, this and other features of the source count curve observed over a wide range of flux densities from ~ 10 mJy to ~ 100 Jy (see for example Kellermann & Wall 1986) can be matched by our theoretical curve without recourse to any evolutionary parameters. A source may be located several cycles back and yet have a modest redshift. Optically such a source may be unobservable, but in the radio it would still have a detectable flux density and may be classified as an *empty field*.

(iii) *The angular size-redshift relation*: This test first proposed by Hoyle (1959) has not, however, yielded any clearcut answer as there are several observational uncertainties. A detailed working out of Hoyle's formula for the QSSC shows it also to be compatible with Kellermann's (1993) findings for compact radio sources. For the larger sources considered by Kapahi (1987) and others the linear size would be expected to be more and more compressed as we go more and more towards the oscillatory minimum. Calculations by Hoyle *et al.* (1993: preprint) show that this leads to a fall off not very different from the $1/z$ law found by Kapahi.

The minicreation events (MCEs) have several points of contact with astrophysics. We briefly enumerate a few:

(i) *Gravity wave sources*: The explosive creation near compact massive objects makes them potential sources of gravity waves, provided the events are sufficiently anisotropic. Narlikar & Das Gupta (1993) have shown that such events in the mass range of 100–1000 $M_\odot$ can be detected by the laser interferometric detectors being planned worldwide. Further, the gravity wave background created by such MCEs may also detectably affect the timing mechanism of millisecond pulsars.

(ii) *High energy sources*: The explosive nature of energy generation in QSOs and AGN as well as in the gamma ray burst sources makes the MCEs ideal candidates for these energy sources. This is in keeping with Ambartsumian's conjecture (1958, 1965) that the AGN are likely sites for matter creation in explosive form.

(iii) *The age of the universe*: According to QSSC the universe is infinitely old but the average age of astronomical objects is $1/3P \sim 3 \times 10^{11}$ yrs. This makes many clusters much older than hitherto assumed. Even our Galaxy might have age of this order with several generations of stars formed, evolved and burnt out. The dark matter component in the Galaxy may be largely made of burnt out stars.

5. Concluding remarks

In this alternative cosmology there is considerable scope for inputs from high energy particle physics, in particular (i) in giving a quantum formalism of the C-field (which is described here only classically) and (ii) in working out the details of how the created Planck particle decays to baryons.

Some of the main predictions that distinguish the QSSC from big bang cosmology are (i) the existence of faint blue shifted galaxies (ii) the dark matter turning out to be baryonic (iii) the existence of very old and very young galaxies (iv) the detection of gravity waves from the MCEs, and (v) the evidence for matter creation in sources of high energy astrophysics.

References

Ambartsumian, V. A. 1958, 1965, *Proc. of the Solvay Conference on The Structure of the Universe*, p. 241, and *Proc. of the Solvay Conference on The Structure and Evolution of the Galaxies*, p. 1

Arp, H. C., Burbidge, G., Hoyle, F., Narlikar, J. V., Wickramasinghe, N. C. 1990, *Nature*, **346**, 807.

Bondi, H., Gold, T. 1948 *Mon. Not. R. astr. Soc.*, **108**, 252.

Hoyle, F. 1948 *Mon. Not. R. astr. Soc.*, **108**, 372.

Hoyle, F. 1959, *Paris Symposium on Radio Astronomy*, Ed. R.N. Bracewell (Stanford University Press), p. 529.

Hoyle, F., Narlikar, J. V. 1962 *Proc. R. Soc.*, **A270**, 334.

Hoyle, F., Narlikar, J. V. 1966a *Proc. R. Soc.*, **A290**, 143.

Hoyle, F., Narlikar, J. V. 1966b *Proc. R. Soc.*, **A290**, 162.

Hoyle, F., Burbidge, G., Narlikar, J. V. 1993, *Astrophys. J.*, **410**, 437.

Kapahi, V. K. 1987, *Observational Cosmology, IAU Symp. No. 124*, Ed. A., Hewitt, G. Burbidge & L. Z. Fang, (Dordrecht: D. Reidel), p. 251.

Kellermann, K. 1993 *Nature*, **361**, 134.

Kellermann, K., Wall, J. V. 1987 *Observational Cosmology, IAU Symp. No. 124* (1987, Ed. A. Hewitt, G. Burbidge & L. Z. Fang), (Dordrecht: D. Reidel), p. 545

Narlikar, J. V. 1993 *Introduction to Cosmology*, 2nd Edition, (Cambridge).

Narlikar, J. V., Das Gupta, P. 1993 *Mon. Not. R. astr. Soc.*, **264**, 489.

Smoot, G. F. *et al.* 1992 *Astrophys. J.*, **396**, L1.