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# COSMOLOGY AND GRAVITATION

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# ALTERNATIVE COSMOLOGIES

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## ALTERNATIVES TO FRIEDMANN COSMOLOGIES

In 1922-24 when Friedmann produced the expanding universe solutions of Einstein's equations, his work largely went unnoticed. Subsequent to Hubble's discovery of nebular redshift, however, cosmologists recognized these models as the simplest starting point for discussing their subject. The physicists, on the other hand considered these attempts as naive and speculative and so they did not pay much attention to George Gamow's very seminal work on the early universe.

The turning point for cosmology came, however, in 1965 with the discovery of the microwave background radiation. The MBR seemed to confirm the early universe scenario and taken together with the extended validity of Hubble's law obtained by bigger and better telescopes, laid a solid foundation for cosmology as a branch of physics. By the mid 1970s a considerable body of physicists began to take the Friedmann cosmology seriously. More so after they realized that the big bang cosmology provides a setting, the only setting known so far, for testing their very high energy physics and the grand unification programme. Cosmologists also looked to particle physics for understanding the primary origin of matter. Thus the subject of *astroparticle physics* has grown out of joint speculations of big bang cosmologists and high energy particle physicists.

To what extent is Friedmann cosmology a correct theory of the origin and the large scale structure of the universe? While the majority of today's cosmologists would put their money on the Friedmann models, there have been a few 'agnostics' from time to time, who were not satisfied with them. Their criticism of standard model makes the following points:

1. It is highly speculative
2. It uses untested physics
3. It talks of early epochs that can never be seen.

And out of their efforts have emerged alternative theories of cosmology.

These theories have not been worked through to the depth that Friedman cosmology can boast of. This is hardly surprising considering the very limited number of people who worked on them. Nevertheless they contain different perspectives and are worth taking a look at, if only because they might offer a resolution of some of the outstanding

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problems that the Friedmann cosmology has been unable to solve. In these lectures, we describe a few such theories, in particular those based on the following concepts:

(1) Mach's Principle
(2) The Large Numbers Hypothesis
(3) Modified Newtonian Dynamics
(4) Creation of Matter.

## MACH'S PRINCIPLE

There are two ways of measuring the Earth's spin about its polar axis. By observing the rising and setting of stars the astronomer can determine the period of one revolution of the Earth around its axis : the period of $23^h 56^m 4^s.1$. The second method employs a Foucault pendulum whose plane gradually rotates around a vertical axis as the pendulum swings. Knowing the latitude of the place of the pendulum it is possible to calculate the Earth's spin period. The two methods give the same answer.

At first sight this does not seem surprising. If we are measuring the same quantity, we should get the same answer regardless of the method used. Closer examination, however, reveals why the issue is non-trivial. The two methods are based on different assumptions. The first method measures the Earth's spin period against a background of distant stars : while the second employs the standard Newtonian mechanics in a spinning frame of reference. In the latter case, we take note of how Newton's laws of motion get modified when their consequences are measured in a frame of reference spinning relative to the 'absolute space' in which these laws were first stated by Newton.

Thus, implicit in the assumption that equates the two methods is the coincidence of absolute space with the background of distant stars. It was Ernst Mach (1893) in the last century who pointed out that this coincidence is nontrivial. He read something deeper in it, arguing that the postulate of absolute space that allows one to write down the laws of motion and arrive at the concept of inertia, is somehow intimately related to the background of distant parts of the universe. We will analyse Mach's argument further.

When expressed in the framework of the absolute space, Newton's second law of motion takes the familar form

$$\mathbf{P} = m\mathbf{f}. \tag{1}$$

This law states that a body of mass $m$ subjected to an external force $\mathbf{P}$ experiences an acceleration $\mathbf{f}$. Let us denote by $\Sigma$ the coordinate system in which $\mathbf{P}$ and $\mathbf{f}$ are measured.

Newton was well aware that his second law has the simple form (1) only with respect to $\Sigma$ and those frames that are in uniform motion relative to $\Sigma$. If we choose another frame $\Sigma'$ that has an acceleration $\mathbf{a}$ relative to $\Sigma$, the law of motion measured in $\Sigma'$ becomes

$$\mathbf{P}' \equiv \mathbf{P} - m\mathbf{a} = m\mathbf{f}'. \tag{2}$$

Although (2) outwardly looks the same as (1), with $\mathbf{f}'$ the acceleration of the body in $\Sigma'$, something new has entered into the force term. This is the term $-m\mathbf{a}$, which has nothing to do with the external force but depends solely on the mass $m$ of the body and



the acceleration $\mathbf{a}$ of the reference frame relative to the absolute space. Realizing this aspect of the additional force in (2), Newton termed it "inertial force". As this name implies, the additional force is proportional to the inertial mass of the body. Newton discussed this force at length in his *Principia*, citing the example of a rotating water-filled bucket.

In this experiment, a water filled bucket is suspended from a ceiling by a rope. The rope is given a twist and let go. The bucket begins to spin and the water in the bucket also spins with it. It is observed that the surface of the water dips in the centre and rises at the boundary. Newton argued that spin introduces an absolute effect on the water surface, arising from inertial forces: thus one can give an unambiguous meaning to absolute space as a reference frame in which the water surface in the bucket is flat.

According to Mach, the Newtonian discussion was incomplete in the sense that the existence of the absolute space was postulated arbitrarily and in an abstract manner. Why does $\Sigma$ have a special status in that it does not require the inertial force? How can one physically identify $\Sigma$ without recourse to the second law of motion, which is based on it?

Mach argued that the answers to these questions were contained in the observation of the distant parts of the universe. It is the universe that provides a background reference frame that can be identified with Newton's frame $\Sigma$. Instead of saying that it is an accident that Earth's rotation velocity relative to $\Sigma$ agrees with that relative to the distant parts of the universe, Mach took it as proof that the distant parts of the universe somehow enter into the formulation of local laws of mechanics.

One way this could happen is by a direct connection between the property of inertia and the existence of the universal background. To see this point of view, imagine a single body in an otherwise empty universe. In the absence of any forces (1) becomes

$$m\mathbf{f} = \mathbf{0}. \tag{3}$$

What does this equation imply? Following Newton we would conclude from (3) that $\mathbf{f} = \mathbf{0}$, that is, the body moves with uniform velocity. But we now no longer have a background against which to measure velocities. Thus $\mathbf{f} = \mathbf{0}$ has no operational significance. Rather, the lack of any tangible background for measuring motion suggests that $\mathbf{f}$ should be completely indeterminate. And it is not difficult to see that such a conclusion follows naturally provided we opt for the alternative deduction, also possible from (3) that

$$m = 0. \tag{4}$$

In other words, the measure of inertia depends on the existence of the background in such a way that in the absence of the background the measure vanishes! This aspect introduces a new feature into mechanics not considered by Newton. The Newtonian view that inertia is the property of matter has to be augmented to the statement that inertia is the property of matter as well as of the background provided by the rest of the universe. This general idea is known as *Mach's principle*.

Such a Machian viewpoint not only modifies local mechanics, but it also introduces new elements into cosmology. For, except in the universe following the perfect cosmological principle [1], there is no basis now for assuming that particle masses would necessarily stay fixed in an evolving universe. This is the reason for considering cosmological models anew from the Machian viewpoint. Presented here are some instances of how different physicists have given quantitative expression to Mach's principle and arrived at new cosmological models.

## THE BRANS-DICKE THEORY OF GRAVITY

In 1961 C. Brans and R.H. Dicke provided an interesting alternative to general relativity based on Mach's principle. To understand the reasons leading to their field equations, we first note that the concept of a variable inertial mass itself leads to a problem of interpretation. For, how do we compare masses at two different points in spacetime? Masses are measured in certain units, such as masses of elementary particles, which are themselves subject to this change! We need an independent unit of mass against which an increase or decrease of a particle mass can be measured. Such a unit is provided by gravity, by the so called Planck mass :

$$\left(\frac{\hbar c}{G}\right)^{1/2} \cong 2.16 \times 10^{-5}\text{g}. \tag{5}$$

Thus the dimensionless quantity

$$\chi = m\left(\frac{G}{\hbar c}\right)^{1/2} \tag{6}$$

measured at different spacetime points can tell us whether masses $m$ are changing.

Or alternatively, if we insist on using mass units that are the same everywhere, a change of $\chi$ would tell us that the gravitational constant $G$ is changing.[2] This is the conclusion Brans and Dicke (1961) arrived at in their approach to Mach's principle. They looked for a framework in which the gravitational constant $G$ arises from the structure of the universe, so that a changing $G$ could be looked upon as the Machian consequence of a changing universe.

D.W. Sciama (1953) had given general arguments leading to a relationship between $G$ and the large-scale structure of the universe. We come across one example of such a relation in the Friedmann cosmologies :

$$\rho_0 = \frac{3H_0^2}{4\pi G} q_0. \tag{7}$$

[1] We will define it later: but it forces the conclusion that the large scale properties of the universe do not change with time.

[2] We could of course assume that $\hbar$ and $c$ also change. However, by keeping $\hbar$ and $c$ constant we follow the principle of least modification of existing theories. Thus special relativity and quantum theory are unaffected if we keep $\hbar$ and $c$ fixed.



If we write $R_0 = c/H_0$ as a characteristic length of the universe and $M_0 = 4\pi\rho_0 R_0^3/3$ as the characteristic mass of the universe, then the above relation becomes

$$\frac{1}{G} = \frac{M_0}{R_0 c^2} q_0^{-1} \sim \frac{M_0}{R_0 c^2} \sim \sum \frac{m}{rc^2}. \tag{8}$$

Given a dynamic coupling between the inertia and gravity, a relation of the above type is expected to hold. Brans and Dicke took this relation as one that determines $G^{-1}$ from a linear superposition of inertial contributions $m/rc^2$, the typical one being from a mass $m$ at a distance $r$ from the point where $G$ is measured. Since $m/r$ is a solution of a scalar wave equation with a point source of strength $m$, Brans and Dicke postulated that $G$ behaves as the reciprocal of a scalar field $\phi$ :

$$G \sim \phi^{-1}, \tag{9}$$

where $\phi$ is expected to satisfy a scalar wave equation whose source is all the matter in the universe.

## THE ACTION PRINCIPLE

The intuitive concepts described above are contained in the Brans-Dicke action principle, which may be written in the form

$$\mathscr{A} = \frac{c^3}{16\pi} \int_{\mathscr{V}} (\phi R + \omega \phi^{-1} \phi^k \phi_k) \sqrt{-g} d^4x + \Lambda. \tag{10}$$

Notice first that the coefficent of $R$ is $c^3\phi/16\pi$ instead of $c^3/16\pi G$ as in the Einstein-Hilbert action. The reason for this lies in the anticipated behaviour of $G$ as just given. The second term, with $\phi_k \equiv \partial\phi/\partial x^k$, ensures that $\phi$ will satisfy a wave equation, while the third term includes, through a Lagrangian density $L$, all the matter (and energy) present in the spacetime region $\mathscr{V}$. The $\Lambda$ denotes the matter part of the action, leading to energy momentum tensor $T^{ik}$ of matter through the usual relation. $\omega$ is a coupling constant.

The variation of $\mathscr{A}$ for small changes of $g^{ik}$ leads to the field equations

$$\begin{aligned} R_{ik} - \frac{1}{2} g_{ik} R = & - \frac{8\pi}{c^4 \phi} T_{ik} \\ & - \frac{\omega}{\phi^2}\left(\phi_i \phi_k - \frac{1}{2} g_{ik} \phi^l \phi_l\right) \\ & - \frac{1}{\phi}(\phi_{ik} - g_{ik} \Box \phi). \end{aligned} \tag{11}$$

Similarly, the variation of $\phi$ leads to the following equation for $\phi$ :

$$2\phi \Box \phi - \phi_k \phi^k = \frac{R}{\omega} \phi^2. \tag{12}$$

This latter equation can be simplified by substituting for $R$ from the contracted form of (11). We finally get

$$\Box\phi = \frac{8\pi}{(2\omega+3)c^4}T. \tag{13}$$

where $T$ is the trace of $T^i_k$. Thus (13) leads to the anticipated scalar wave equation for $\phi$ with sources in matter, $\Box$ being the wave operator.

Because it contains a scalar field $\phi$ in addition to the metric tensor $g_{ik}$, the Brans-Dicke theory is often referred to as the *scalar-tensor theory of gravitation*. Notice that the theory approaches general relativity as $\omega \to \infty$. The solar system tests of this theory have led to large lower limit on $\omega$, e.g., $\omega > 1000$.

## COSMOLOGICAL SOLUTIONS OF THE BRANS-DICKE EQUATIONS

In analogy with the Friedmann models, we will consider only the homogeneous and isotropic cosmological models in the Brans-Dicke theory. Accordingly we start with the Robertson-Walker line element and the energy tensor for a perfect fluid. $\phi$ is now a function of the cosmic time only. Thus the field equations become

$$\frac{2\ddot{S}}{S} + \frac{\dot{S}^2+kc^2}{S^2} = -\frac{8\pi p}{\phi c^2} - \frac{2\dot{\phi}\dot{S}}{\phi S} - \frac{\omega\dot{\phi}^2}{2\phi^2} - \frac{\ddot{\phi}}{\phi}, \tag{14}$$

$$\frac{\dot{S}^2+kc^2}{S^2} = \frac{8\pi\varepsilon}{3\phi c^2} - \frac{\dot{\phi}\dot{S}}{\phi S} + \frac{\omega\dot{\phi}^2}{6\phi^2}. \tag{15}$$

$$\frac{d}{dS}(\varepsilon S^3) + 3pS^2 = 0. \tag{16}$$

In addition, we have the field equation for $\phi$ :

$$\frac{1}{S^3}\frac{d}{dt}(\dot{\phi}S^3) = \frac{8\pi}{(2\omega+3)c^2}(\varepsilon - 3p). \tag{17}$$

We anticipate that big bang solutions will emerge from these equations and set the big bang epoch at $t = 0$. Then the integral of (17) is

$$\dot{\phi}S^3 = \frac{8\pi}{(2\omega+3)c^2}\int_0^t (\varepsilon - 3p)S^3 dt + C, \tag{18}$$

where $C$ is a constant. Two types of solutions are obtained, depending on whether $C = 0$ or $C \neq 0$.

(i) $\mathbf{C = 0}$

We will consider a simple example of this type, with $k = 0,\ p = 0$, and $\varepsilon = \rho c^2$. This solution is therefore analogous to the Eisntein-de Sitter model of general relativity. Write



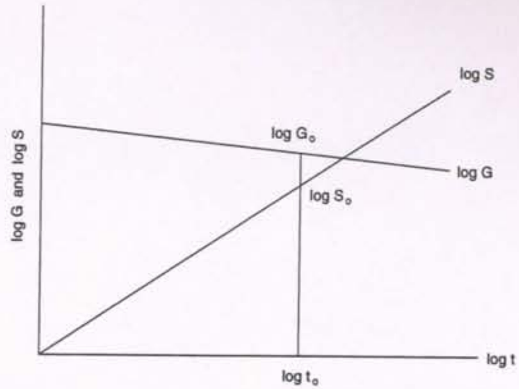


**FIGURE 1.** The temporal behaviour of the scale factor $S$ and gravitational constant $G$ plotted on a log-log plot.

$$S = S_0\left(\frac{t}{t_0}\right)^A, \quad \phi = \phi_0\left(\frac{t}{t_0}\right)^B. \tag{19}$$

so that $\rho \propto t^{-3A}$ and the field equations give

$$A = \frac{2\omega+2}{3\omega+4}, \quad B = \frac{2}{3\omega+4}. \tag{20}$$

and

$$\rho_0 = \frac{(2\omega+3)B\phi_0}{8\pi t_0^2}. \tag{21}$$

The temporal behaviour of $S$ and $G$ ($\propto \phi^{-1}$) is illustrated in Figure 1. It can be verified that as $\omega \to \infty$ this solution tends to the Einstein-de Sitter model.

An analogue of the radiation model can be obtained in this theory. H. Nariai (1968) obtained solutions for $p = n\varepsilon$ with $n$ in the range $0 \leq n \leq 1/3$.

(ii) $\mathbf{C \neq 0}$

In this case the $\phi$-terms dominate the dynamics of the universe in the early stages. Thus for small enough $t$ we have

$$\frac{8\pi}{(2\omega+3)c^2}\int_0^t (\varepsilon - 3p)S^3 dt \ll |C|, \tag{22}$$

both for the cases of dust and of radiation. For our power law solutions for the case $p = 0$, we have at small enough $t$

$$3A + B = 1, \quad t_0 = \frac{S_0^3\phi_0 B}{C}. \tag{23}$$

In the case of a radiation-dominated universe $p = \varepsilon/3$ and we can again try a solution of the form (19) to get as $t \to 0$

$$A^2 = -AB + \frac{\omega B^2}{6}. \quad (24)$$

Taking into account (22) we can solve (23) to get

$$A = \frac{\omega + 1 \pm \sqrt{(2\omega/3)+1}}{3\omega+4},$$
$$B = \frac{1 \pm 3\sqrt{(2\omega/3)+1}}{3\omega+4}.$$

The upper sign holds when $C > 0$ and the lower sign when $C < 0$. For $C > 0$, $\phi \to 0$ when $S \to 0$, while for $C < 0$, $\phi \to \infty$ for $S \to 0$. These conclusions hold irrespective of the values of $k$ or of the equation of state, since at small values of $S$ the dynamics of the universe are controlled by the $\phi$-term (See Figure 1).

## THE VARIATION OF $G$

Since $G \propto \phi^{-1}$, a time-dependent $\phi$ will mean a time-dependent gravitational constant. As seen from earlier equations, we have for $C = 0$

$$\frac{\dot{G}}{G} = -\frac{2}{3\omega+4}.\frac{1}{t} = -\frac{H}{\omega+1}. \quad (25)$$

Thus $|\dot{G}|$ is of the order of Hubble's constant unless $\omega$ is large and its sign indicates that the gravitational constant should decrease with time.

However, for a large enough $|C|$, the $\phi$-dominated solutions differ significantly from the matter-dominated ones even at the present epochs. In this case for $C$ large and negative we can have $G$ increasing with time even at relatively recent epochs.

## INFLATION IN BRANS-DICKE COSMOLOGIES

Because of its relative simplicity of formulation and interpretation of observable results, the Brans-Dicke cosmology has been studied in the 'very early universe' phase also. V.B. Johri and C. Mathiazhagan (1984) were the first to consider inflationary phase in this cosmology. The problem of bubble nucleation and coelescence that was faced by Guth's inflationary model, represented the difficulty of what has been known as the *graceful exit* from the inflationary phase into the Friedmann radiation dominated phase. La and Steinhardt had considered the Brans-Dicke framework to generate an *'extended inflation'*. The phase 'extended' arises because the expansion is not exponential but of a power-law type. The idea seemed to solve the graceful exit problem but ran into trouble because of the distortions it produced in the cosmic microwave background, distortions that were unacceptably high. Undeterred by these setbacks the inflation enthusiasts



explored a variation on the Brans-Dicke theme by adding higher order couplings of the scalar field with gravity. This led to the notion of *'hyper-extended inflation'*. However, none of these ideas seem to have received much following in later years.

To sum up, the Brans-Dicke theory had generated considerable interest as an alternative theory of gravity, but with the solar system tests giving values very close to the predictioins of general relativty with greater and greater accuracy, the $\omega-$ parameter that distinguished it from general relativity had to be larger and larger, thus making it more and more indistinguishable from general relativity at least on the scale of the solar system. On the cosmological front the theory has given different solutions from standard Friedmann cosmology, but these differences do not seem to have impressed theoreticians sufficiently for them to undertake detailed studies of the cosmogony of the universe from the very early epochs. For large $\omega$, as shown by equation (25), the rate of change of $G$ is expected to be small compared to $H$ and this is consistent with present measurements of $G$ and $\dot{G}$.

## DIRAC AND THE LARGE NUMBERS HYPOTHESIS

Dimensionless constants in physics play an important role in understanding natural phenomena. For example, the fine structure constant $\alpha = e^2/\hbar c \approx 1/137$ conveys an impression of the strength of electrodynamics as a basic interaction. Given $e, G$, and the masses of proton and the electron $m_p$ and $m_e$, we can construct another dimensionless constant (that is, a constant with no units) :

$$\frac{e^2}{Gm_pm_e} = 2.3 \times 10^{39} \sim 10^{40}. \quad (26)$$

This constant measures the relative strength of the electrical and the gravitational forces between the electron and the proton. Like the fine structure constant $\alpha = e^2/\hbar c$ this constant reflects an intrinsic property of nature. However, unlike $\alpha$, the constant in (26) is enormously large! Why such a large number?

Perhaps the appearance of a large dimensionless constant might be dismissed as some quirk on the part of nature. The mystery deepens, however, if we consider another dimensionless number. This is the ratio of the length scale associated with the universe, $c/H_0$, and the length associated with the electron, $e^2/m_ec^2$. This ratio is

$$\frac{m_ec^3}{e^2H_0} = 3.7 \times 10^{40}h_0^{-1} \sim 10^{40}. \quad (27)$$

Not only do we have another large dimensionless number in (27), but it is of the same order as in (26).

We can generate another large number of special significance out of particle physics and cosmology. Assuming the closure density $\rho_c$, let us calculate the number of particles in a Euclidean sphere of radius $c/H_0$, the mass of each particle being $m_p$. The answer is

$$N = \frac{4\pi}{3m_p}\left(\frac{c}{H_0}\right)^3.\frac{3H_0^2}{8\pi G} = \frac{c^3}{2m_pGH_0}$$

$$= 4\times 10^{79} h_0^{-1}$$
$$\sim 10^{80}. \quad (28)$$

Thus taking $N$ as a standard we see that the large dimensionless numbers of (26) and (27) are both of the order of $N^{1/2}$.

Reactions among physicists have varied as to the significance of all these numbers. Some dismiss it as a coincidence with the rejoinder : "So what?" Others have read deep significance in these relationships. The latter class includes such distinguished physicists as A.S. Eddington and P.A.M. Dirac.

Dirac (1937) pointed out that the relationships (27) and (28) contain the Hubble constant $H_0$, and therefore the magnitudes computed in these formulae vary with the epoch in the standard Friedmann model. If so, the near equality of (26) and (27) has to be coincidence of the present epoch in the universe, unless the constant (26) also varies in such a way as to maintain the state of near equality with (27) at all epochs. With this proviso, the equality of (26) and (27) is not coincidental but is characteristic of the universe *at all epochs*. The proviso also implies that at least one of the so-called constants involved in (26), $e, m_p, m_e$, and $G$, must vary with the epoch.

## THE LNH

This proviso was generalized by Dirac to what he called the *Large Numbers Hypothesis (LNH)*. To understand this hypothesis we rewrite the ratio (27) as that between the time scale associated with the universe, $\tau_0 = H_0^{-1}$, and the time taken by light to travel a distance of the order of the classical electron radius, $t_e = e^2/m_e c^3$. The LNH then states that any large number that at the present epoch is expressible in the form

$$\left(\frac{\tau_o}{t_e}\right)^k.$$

where $k$ is of order unity, varies with the epoch $t$ as $(t/t_e)^k$ with a constant of proportionality of order unity.

Applied to (26), therefore, the LNH implies that the ratio $e^2/Gm_pm_e$ must vary as $(t/t_e)^{-1}$. Dirac made the distinction between $e, m_e, m_p$ on one side and $G$ on the other in the sense that the former are atomic (microscopic quantities) while $G$ has macroscopic significance. In the Machian cosmologies, $G$ is in fact related to the large-scale structure of the universe. Dirac therefore assumed that if we use "atomic units" that always maintain fixed values for atomic quantities, then $t_e$ will be constant and $G \propto t^{-1}$. That is, in terms of atomic time units the gravitational constant must vary with the epoch $t$, with $|\dot{G}/G| \sim H$.

Dirac (1973, 1974) wrote papers in which quantitative models based on the LNH were worked out. One consequence is that new matter is created continuously. In additive matter creation the rate of creation is proportional to volume whereas in the multiplicative creation the rate is proportional to the existing mass in the volume. The variation of $G$ in most of these models is, however, much faster than observed.



## MODIFIED NEWTONIAN DYNAMICS (MOND)

*Observational motivation* : Rotation curves of galaxies show that typical orbital velocity $V$ satisfies the Newtonian equation

$$\frac{GM}{R^2} = \frac{V^2}{R} \Rightarrow V^2 \propto \frac{GM}{R} \quad (29)$$

However, we get $V \approx$ constant at radial distance $R$ about 2-3 times the visible size of the galaxy. What does it mean?

a) *Conventional conclusion* : $M = M(R) \rightarrow M(R) \propto R$. $M(R)$ increasing with $R$ implies the existance of dark matter far beyond the visible extent of the galaxy. Further assumptions made by big bang cosmologists is that the dark matter is mostly nonbaryonic.

b) *Alternative conclusion* : It was proposed by Milgrom (1983) that at sufficiently low accelerations, Newton's second law of motion gets modified. This idea is called **MO**dified **N**ewtonian **D**ynamics or *MOND*.

## THE MOND ALTERNATIVE

The MOND prescription is briefly stated as follows: True gravitational acceleration = $g$. Newtonian gravitational acceleration = $g_N$. Then define

$$\mathbf{g}_N = \mu\left(\frac{|g|}{a_0}\right)\mathbf{g}; \; a_0 \approx 10^{-8}\text{cm s}^{-2} \quad (30)$$

where, $\mu(x) = 1$ for $x > 1$ and $\mu(x) = x$ for $x \leq 1$.

For example, for a galaxy of mass $= 10^{11} M_\odot$, acceleration at 10 kpc. towards the centre

$$a = \frac{\frac{2}{3}\times 10^{-7}\times 10^{11}\times 2\times 10^{33}}{(10^{18}\times 3\times 10\times 10^3)^2}\text{cm s}^{-2}$$
$$= 1.5\times 10^{-8}\text{cm}^{-2}$$

From (30) we get,

$$|g| \ll a_0, \mu(x) = x \Rightarrow \frac{g^2}{a_0} = g_N = \frac{GM}{R^2}$$

$$\Rightarrow g = \frac{(GMa_0)^{1/2}}{R}$$
$$V^2 = gR \Rightarrow V = (GMa_0)^{1/4} \quad (31)$$

Tully Fisher relation (TFR) as observed empirically, implies

$$L_{\text{H band}} \propto V^4 \quad (32)$$

If $L/M \approx$ constant for the class of galaxies chosen,

$$M \propto V^4 \tag{33}$$

MOND $\Rightarrow V^4 = GMa_0$. Thus MOND gives a natural explanation of TFR.

In practice one needs to model each galaxy as a Disc + Halo type combination. Matching of halo parameters is then needed with those of the disc to get the observed rotation curves. This demands fine tuning.

To relate to $L_H \propto V^4$ (TFR), $L_H$ comes from visible matter and $V$ from halo.

Halo-disc interactive models seem like fine tuning. Such models require dissipational collapse of gas into potential well of halo. It is usually hard to expect a sharp Tully - Fisher Relationship. However, explanation of TFR is claimed as a success by MOND.

**Other successes of MOND**

(i) Expect discrepancies with Newtonian mechanics in galaxies with surface mass density

$$\sigma < a_0 G^{-1}$$

This is found in dwarf spirals.

(ii) MOND predicts detailed shape of rotation curve from the observed part of matter, gas + stars + dust, using a single parameter $\Upsilon$.

(iii) Does MOND explain 'excess' of kinetic energy in clusters?
Yes. Sanders (2003) has argued that this is the case. But in some doubtful cases the clusters contain much more baryonic matter hithero undiscovered.

## MOND & COSMOLOGY

MOND was not proposed as a formal theory but as an empirical rule. To make it into a relativistic theory with action principle, Bekenstein (2004) proposed the TeVeS (Tensor-Vector-Scalar theory).

The tensor part is of course provided by the metric. This theory

1. Agrees with solar system tests,
2. Agrees with gravitational lensing observations without dark matter,
3. Needs no superluminal propagation, and
4. Can construct cosmological models.

Sanders' (2008) comments on this theory are as follows.

In some sense the relativistic MOND does require dark matter, e.g.,

1. CDM dark matter potential wells needed at recombination to explain the first two peaks of angular power spectrum of MBR.
2. Rebrightening of SNIa at $z > 1$ requires matter domination over vacuum energy, with $\Omega_{CDM} = 0.25$.
3. Numerical coincidence cannot be avoided. For example, the result



$$a_0 \simeq cH_0 \tag{34}$$

is not explained by the *TeVeS* theory.

Is MOND motivated by cosmology? The possible effect of the universe on local particles may recall Machian ideas as in the Brans-Dicke theory. In Sanders' version one talks of preferred frame cosmology, the preferred frame being 'Cosmological rest frame'. It should be noted that the Vector field is not invariant under Lorentz Transformations.

Although MOND is an interesting concept, it is not clear why it is to be preferred to the dark matter alternative.

The three approaches (Mach's Principle, Large Number Hypothesis and MOND) have been presented here in a somewhat sketchy form, largely because of shortage of time needed for a more comprehensive presentation. I will, however, now turn to an alternative cosmology with whose genesis I have been involved. This cosmology will be presented with somewhat greater detail.

## EVOLUTION OF COSMOLOGY IN THE 20TH CENTURY

The standard cosmological model accepted by the majority at present is centered about the big bang which involves the creation of matter and energy in an initial explosion. Since we have overwhelming evidence that the universe is expanding, the only alternative to this picture appears to be the classical steady-state cosmology, of Bondi, Gold and Hoyle, (Bondi and Gold, 1948, Hoyle, 1948) or a model in which the universe is cyclic with an oscillation period which can be estimated from observation. In this latter class of models the bounce at a finite minimum of the scale factor is produced by a negative energy scalar field. Long ago Hoyle and Narlikar (1964) emphasized the fact that such a scalar field will produce models which oscillate between finite ranges of scale. In the 1960s theoretical physicists shied away from scalar fields, and more so those involving negative energy. Later Narlikar and Padmanabhan (1985) discussed how the scalar creation field helps resolve the problems of singularity, flatness and horizon in cosmology. It now appears that the popularity of inflation and the so-called new physics of the 1980s have changed the 1960s' mind-set. Thus Steinhardt and Turok (2002) introduced a negative potential energy field and used it to cause a bounce from a non-singular high density state. It is unfortunate that they did not cite the earlier work of Hoyle and Narlikar which had pioneered the concept of non-singular bounce through the agency of a negative energy field, at a time when the physics community was hostile to these ideas. Such a field is required to ensure that matter creation does not violate the law of conservation of matter and energy.

Following the discovery of the expansion of the universe by Hubble in 1929, practically all of the theoretical models considered were of the Friedmann type, until the proposal by Bondi, Gold and Hoyle in 1948 of the classical steady state model. Bondi and Gold arrived at this model by postulating the *perfect cosmological principle*. This principle not only required the universe to be homogeneous and isotropic in space, but also unchanging in time. Thus statistically, all physical observables in such a universe should remain constant in time. A classical test of this model lay in the fact that, as distinct from all of the big bang models, it predicted that the universe must be accelerating (cf Hoyle and Sandage, 1956). For many years it was claimed that the observations indicated that the universe is decelerating, and that this finding disproved the steady state model. Not until much later was it conceded that it was really not possible to determine the deceleration parameter by the classical methods then being used. Gunn and Oke (1975) were the first to highlight the observational uncertainties associated with this test. Of course many other arguments were used against the classical steady state model (for a discussion of the history see Hoyle, Burbidge and Narlikar 2000 Chapters 7 and 8). But starting in 1998 studies of the redshift-apparent magnitude relation for supernovae of Type 1A showed that the universe *is* apparently accelerating (Riess et al. 1998, Perlmutter et al. 1999). The normal and indeed the proper way to proceed after this result was obtained should have been at least to acknowledge that, despite the difficulties associated with the steady state model, this model had all along been advocating an accelerating universe.

It is worth mentioning that McCrea (1951) was the first to introduce vacuum related stresses with equation of state $p = -\rho$ in the context of the steady state theory. Later Gliner (1970) discussed how vacuum-like state of the medium can serve as original (non singular) state of a Friedmann model.

The introduction of dark energy is typical of the way the standard cosmology has developed; viz, a new assumption is introduced specifically to sustain the model against some new observation. Thus, when the amount of dark matter proved to be too high to sustain the primordial origin of deuterium, the assumption was introduced that most of the dark matter has to be non-baryonic. Further assumptions about this dark matter became necessary, e.g., cold, hot, warm, to sustain the structure formation scenarios. The assumption of inflation was introduced to get rid of the horizon and flatness problems and to do away with an embarrassingly high density of relic magnetic monopoles. As far as the dark energy is concerned, until 1998 the general attitude towards the cosmological constant was typically as summarized by Longair in the Beijing cosmology symposium: "None of the observations to date require the cosmological constant" (Longair 1987). Yet, when the supernovae observations could not be fitted without this constant, it came back with a vengeance as dark energy.

Although the popularity of the cosmological constant and dark energy picked up in the late 1990s, there had been earlier attempts at extending the Friedmann models to include effects of vacuum energy. A review of these models, vis-a-vis observations may be found in the article by Carroll and Press (1992).

We concede that with the assumptions of dark energy, non-baryonic dark matter, inflation etc. an overall self consistent picture has been provided within the framework of the standard model. One demonstration of this convergence to self consistency is seen from a comparison of a review of the values of cosmological parameters of the standard model by Bagla, et al. (1996), with the present values. Except for the evidence from high redshift supernovae, in favour of an accelerating universe which came 2-3 years later than the above review, there is an overall consistency of the picture within the last decade or so, including a firmer belief in the flat ($\Omega = 1$) model with narrower error bars.

Nevertheless we also like to emphasize that the inputs required in fundamental physics through these assumptions have so far no experimental checks from laboratory physics. Moreover an epoch dependent scenario providing self-consistency checks, e.g. MBR anisotropies, cluster baryon fraction as a function of redshift does not meet the criterion



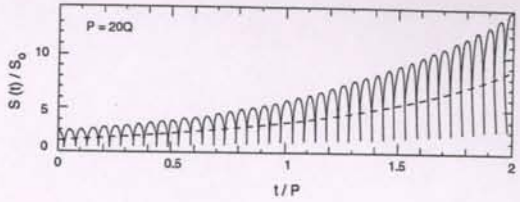


**FIGURE 2.** The oscillatory + expanding scale factor of QSSC.

of 'repeatability of a scientific experiment'. We contrast this situation with that in stellar evolution where stars of different masses constitute repeated experimental checks on the theoretical stellar models thus improving their credibility.

Given the speculative nature of our understanding of the universe, a sceptic of the standard model is justified in exploring an alternative avenue wherein the observed features of the universe are explained with fewer speculative assumptions. We review here the progress of such an alternative model known as the Quasi-Steady State Cosmology.

## THE QUASI-STEADY STATE COSMOLOGY (QSSC)

In this model creation of matter is brought in as a physical phenomenon and a negative kinetic energy scalar field is required to ensure that it does not violate the law of conservation of matter and energy. A simple approach based on Mach's principle leads naturally to such a field within the curved spacetime of general relativity. The resulting field equations have the two simplest types of solutions for a homogeneous and isotropic universe: (i) those in which the universe oscillates but there is no creation of matter, and (ii) those in which the universe steadily expands with a constant value of $H_o$ being driven by continuous creation of matter. The simplest model including features of both these solutions is the *Quasi-Steady State Cosmology* (QSSC), first proposed by Hoyle, Burbidge and Narlikar (1993). It has the scale factor in the form:

$$S(t) = \exp\left(\frac{t}{P}\right)\{1+\eta\cos\theta(t)\},\ \theta(t) \approx \frac{2\pi t}{Q}, \tag{35}$$

where $P$ is the long term 'steady state' time scale of expansion while $Q$ is the period of a single oscillation. The function $\theta(t)$ satisfies a known differential equation but can be approximated by the linear function $2\pi t/Q$. The scale factor is plotted in Figure 2. Note that it is essential for the universe to have a long term expansion; for a universe that has only oscillations without long term expansion would run into problems like the Olbers paradox. It is also a challenge in such a model to avoid running into 'heat death' through a steady increase of entropy from one cycle to next. These difficulties are avoided if there is creation of new matter at the start of each oscillation as happens in the QSSC, and also, if the universe has a steady long term expansion in addition to the oscillations. New matter in such a case is of low entropy and the event horizon ensures a constant entropy within as the universe expands.

## CONSIDERATIONS OF COSMOGONY

Before I describe this cosmological model, I want to indicate the importance of the observed behavior of the galaxies (the observed cosmogony) in this approach.

Now that theoretical cosmologists have begun to look with favor on the concepts of scalar negative energy fields, and the creation process, they have taken the position that this subject can only be investigated by working out models based on classical approaches of high energy physics and their effects on the global scale. In all of the discussions of what is called precision cosmology there is no discussion of the remarkable phenomena which have been found in the comparatively nearby universe showing that galaxies themselves can eject what may become, new galaxies. I believe that only when we really understand how individual galaxies and clusters etc. have formed, evolve, and die (if they ever do) shall we really understand the overall cosmology of the universe. As was mentioned earlier, the method currently used in the standard model is to suppose that initial quantum fluctuations were present at an unobservable epoch in the early universe, and then try to mimic the building of galaxies using numerical methods, invoking the dominance of non-baryonic matter and dark energy for which there is no independent evidence.

In one sense I believe that the deficiency of the current standard approach is already obvious. The model is based on only some parts of the observational data. These are: all of the details of the microwave background, the abundances of the light elements, the observed dimming of distant supernovae, and the large scale distribution of the observed galaxies. This has led to the conclusion that most of the mass-energy making up the universe has properties which are completely unknown to physics. This is hardly a rational position, since it depends heavily on the belief that all of the laws of physics known to us today can be extrapolated back to scales and epochs where nothing is really testable; and that there is nothing new to be learned.

In spite of this, a very persuasive case has been made that all of the observational parameters can be fitted together to develop what is now becoming widely accepted as a new standard model, the so-called ΛCDM model (Spergel et al., 2003). There have been some publications casting doubt on this model, particularly as far as the reality of dark energy and cold, dark matter are concerned (Meyers et al. 2004; Blanchard et al. 2003). It is usual to dismiss them as controversial and to argue that a few dissenting ideas on the periphery of a generally accepted paradigm are but natural. However, it is unfortunately the case that a large fraction of our understanding of the extragalactic universe is being based on the belief (for which there is no independent evidence) that there *was* a beginning and an inflationary phase, and that the seeds of galaxies all originate from that very early phase.

I believe that an alternative approach should be considered and tested by observers and theorists alike. In this scheme the major themes are (1) that the universe is cyclic and there was no initial big bang, and (2) *all* of the observational evidence should be used to test the model. As we shall show, this not only includes the observations which are used in the current standard model, but also the properties and interactions of galaxies and QSOs which are present in the local ($z < 0.1$) universe.

Possibly the most perceptive astronomer in recent history was Viktor Ambartsumian the famous Armenian theorist. Starting in the 1950s and 1960s (Ambartsumian, 1965)



he stressed the role of explosions in the universe arguing that the associations of galaxies (groups, clusters, etc.) showed a tendency to expand with far larger kinetic energy than is expected by assuming that the gravitational virial condition holds.

Since these phenomena appear on the extragalactic scale and involve quasi-stellar objects, active galaxies, powerful radio sources and clusters and groups of galaxies at all redshifts, we believe they must have an intimate connection with cosmology. Indeed, if one looks at standard cosmology, there too the paradigm centers around the 'big bang' which is itself an explosive creation of matter and energy. In the big bang scenario the origin of all of the phenomena is ultimately attributed to a single origin in the very early universe. No connection has been considered by the standard cosmologists between this primordial event and the *mini-creation events* (MCEs, hereafter) that Ambartsumian talked about. In fact, the QSOs and AGN are commonly ascribed to supermassive black holes as 'prime movers'. In this interpretation the only connection with cosmology is that it must be argued that the central black holes are a result of the processes of galaxy formation in the early universe.

In the QSSC we have been trying to relate such mini-creation events (MCEs) directly to the large scale dynamics of the universe. It can be shown that the dynamics of the universe is governed by the frequency and power of the MCEs, and there is a two-way feedback between the two. That is, the universe expands when there is a large MCE activity and contracts when the activity is switched off. Likewise, the MCE activity is large when the density of the universe is relatively large and negligible when the density is relatively small. In short, the universe oscillates between states of finite maximum and minimum densities as do the creation phases in the MCEs.

This was the model called the *quasi-steady state cosmology* or QSSC in brief. The model was motivated partly by Ambartsumian's ideas and partly by the growing number of explosive phenomena that are being discovered in extragalactic astronomy. In the following sections I discuss the cosmological model and then turn to the various phenomena which are beginning to help us understand the basic cosmogony.

## GRAVITATIONAL EQUATIONS WITH CREATION OF MATTER

The mathematical framework for our cosmological model has been discussed by Hoyle, Burbidge and Narlikar (1995; HBN hereafter), and we outline briefly its salient features. To begin with, it is a theory that is derived from an action principle based on Mach's Principle, and assumes that the inertia of matter owes its origin to other matter in the universe. This leads to a theoretical framework wider than general relativity as it includes terms relating to inertia and creation of matter. These are explained in the Appendix, and I use the results derived there in the following discussion.

Thus the equations of general relativity are replaced in this theory by

$$R_{ik} - \frac{1}{2}g_{ik}R + \lambda g_{ik} = 8\pi G\left[T_{ik} - f\left(C_iC_k - \frac{1}{4}g_{ik}C^lC_l\right)\right], \qquad (36)$$

with the coupling constant $f$ defined as

$$f = \frac{2}{3\tau^2} \tag{37}$$

[I have taken the speed of light $c = 1$.] Here $\tau = \hbar/m_P$ is the characteristic life time of a Planck particle with mass $m_P = \sqrt{3\hbar/8\pi G}$. The gradient of $C$ with respect to spacetime coordinates $x^i (i = 0, 1, 2, 3)$ is denoted by $C_i$. Although the above equation defines $f$ in terms of the fundamental constants it is convenient to keep its identity on the right hand side of Einstein's equations since there we can compare the $C$-field energy tensor directly with the matter tensor. Note that because of positive $f$, the $C$-field has *negative* kinetic energy. Also, as pointed out in the Appendix, the cosmological constant $\lambda$ is *negative* in this theory.

The question now arises of why astrophysical observation suggests that the creation of matter occurs in some places but not in others. For creation to occur at the points $A_0, B_0, \ldots$ it is necessary classically that the action should not change (i.e. it should remain stationary) with respect to small changes in the spacetime positions of these points, which can be shown to require

$$C_i(A_0)C^i(A_0) = C_i(B_0)C^i(B_0) = \ldots = m_P^2. \tag{38}$$

This is in general not the case: in general the magnitude of $C_i(X)C^i(X)$ is much less that $m_P^2$. However, as one approaches closer and closer to the surface of a massive compact body $C_i(X)C^i(X)$ is increased by a general relativistic time dilatation factor, whereas $m_P$ stays fixed.

This suggests that we should look for regions of strong gravitational field such as those near collapsed massive objects. In general relativistic astrophysics such objects are none other than black holes, formed from gravitational collapse. Theorems by Penrose, Hawking and others (see Hawking and Ellis 1973) have shown that provided certain positive energy conditions are met, a compact object undergoes gravitational collapse to a spacetime singularity. Such objects become black holes before the singularity is reached. However, in the present case, the negative energy of the $C$-field intervenes in such a way as to violate the above energy conditions. What happens to such a collapsing object containing a $C$-field apart from ordinary matter? It can be shown (Narlikar et al. 2006) that such an object does not become a black hole. Instead, the collapse of the object is halted and the object bounces back, thanks to the effect of the $C$-field. The $C$-field strength grows as the object shrinks and so its repulsive effect ultimately dominates over gravity. This is why the object bounces. We will refer to such an object as a compact massive object (CMO) or a near-black hole (NBH).

Thus, such an object after bouncing at a minimum radius will expand and as its radius increases the strength of the $C$-field falls while for small radii, the size of the object increases rapidly. This expansion therefore resembles an explosion.

It is worth stressing here that even in classical general relativity, the external observer never lives long enough to observe the collapsing object enter the horizon. Thus all claims to have observed black holes in X-ray sources or galactic nuclei really establish the existence of compact massive objects, and as such they are consistent with the NBH concept. A spinning NBH, for example can be approximated by the Kerr solution limited to region outside the horizon (- in an NBH there is no horizon). In cases where $\dot{C}$ has not



gone to the level of creation of matter, an NBH will behave very much like a Kerr black hole.

The theory would profit most from a quantum description of the creation process. The difficulty, however, is that Planck particles are defined as those for which the Compton wavelength and the gravitational radius are essentially the same, which means that, unlike other quantum processes, flat spacetime cannot be used in the formulation of the theory. A gravitational disturbance is necessarily involved and the ideal location for triggering creation is that near a CMO. The $C$-field boson far away from a compact object of mass $M$ may not be energetic enough to trigger the creation of a Planck particle. On falling into the strong gravitational field of a sufficiently compact object, however, the boson energy is multiplied by a factor, $(1 - 2GM/r)^{-1/2}$ for a local Schwarzschild metric.

Bosons then multiply up in a cascade, one makes two, two makes four, ..., as in the discharge of a laser, with particle production multiplying up similarly and with negative pressure effects ultimately blowing the system apart. This is the explosive event that we earlier referred to as a *mini-creation event* (MCE). Unlike the big bang, however, the dynamics of this phenomenon is *well defined and non-singular*. For a detailed discussion of the role of a NBH as well as the mode of its formation, see Hoyle et al. (2000), (HBN hereafter) p. 244-249.

While still qualitative, we shall show that this view agrees well with the empirical facts of observational astrophysics. For, as mentioned in the previous section, we do see several explosive phenomena in the universe, such as jets from radio sources, gamma ray bursts, X-ray bursters, QSOs and active galactic nuclei, etc. Generally it is assumed that a black hole plays the lead role in such an event by somehow converting a fraction of its huge gravitational energy into large kinetic energy of the 'burst' kind. In actuality, we do not see infalling matter that is the signature of a black hole. Rather one sees outgoing matter and radiation, which agrees very well with the explosive picture presented above.

## COSMOLOGICAL MODELS

The qualitative picture described above is too difficult and complex to admit an exact solution of the field equations (36). The problem is analogous to that in standard cosmology where a universe with inhomogeneity on the scale of galaxies, clusters, superclusters, etc., as well as containing dark matter and radiation is impossible to describe exactly by a general relativistic solution. In such a case one starts with simplified approximations as in models of Friedmann and Lemaitre and then puts in specific details as perturbation. The two phases of radiation-dominated and matter-dominated universe likewise reflect approximations implying that in the early stages the relativistic particles and photons dominated the expansion of the universe whereas in the later stages it was the non-relativistic matter or dust, that played the major role in the dynamics of the universe.

In the same spirit we approach the above cosmology by a mathematical idealization of a homogeneous and isotropic universe in which there are regularly phased epochs when the MCEs were active and matter creation took place while between two consecutive epochs there was no creation (- the MCEs lying dormant). We will refer to these two situations as creative and non-creative modes. In the homogeneous universe assumed here the $C$-field will be a function of cosmic time only. We will be interested in the matter-dominated analogues of the standard models since, as we shall see, the analogue of the radiation-dominated state never arises except locally in each MCE where, however, it remains less intense than the $C$-field. In this approximation, the increase or decrease of the scale factor $S(t)$ of the universe indicates an average smoothed out effect of the MCEs as they are turned on or off. The following discussion is based on the work of Sachs, et al. (1996).

We write the field equations (36) for the Robertson-Walker line element with $S(t)$ as scale factor and $k$ as curvature parameter and for matter in the form of dust, when they reduce to essentially two independent equations :

$$2\frac{\ddot{S}}{S}+\frac{\dot{S}^2+k}{S^2}=3\lambda+2\pi Gf\dot{C}^2 \tag{39}$$

$$\frac{3(\dot{S}^2+k)}{S^2}=3\lambda+8\pi G\rho-6\pi Gf\dot{C}^2, \tag{40}$$

where we have set the speed of light $c=1$ and the density of dust is given by $\rho$. From these equations we get the conservation law in the form of an identity :

$$\frac{d}{dS}\{S^3(3\lambda+8\pi G\rho-6\pi Gf\dot{C}^2)\}=3S^2\{3\lambda+2\pi Gf\dot{C}^2\}. \tag{41}$$

This law incorporates "creative" as well as "non-creative" modes. We will discuss both in that order.

## The creative mode

This has

$$T^{ik}_{;k}\neq 0 \tag{42}$$

which, in terms of our simplified model becomes

$$\frac{d}{dS}(S^3\rho)\neq 0. \tag{43}$$

For the case $k=0$, we get a simple steady-state de Sitter type solution with

$$\dot{C}=m, \quad S=\exp(t/P), \tag{44}$$

and from (50) and (51) we get

$$\rho=fm^2, \quad \frac{1}{P^2}=\frac{2\pi G\rho}{3}+\lambda. \tag{45}$$

Since $\lambda<0$, we expect that



$$\lambda\approx-\frac{2\pi G\rho}{3}, \quad \frac{1}{P^2}\ll|\lambda|, \tag{46}$$

but will defer the determination of $P$ to after we have looked at the non-creative solutions. Although Sachs, et al. (1996) have discussed all cases, we will concentrate on the simplest one of flat space $k=0$.

The rate of creation of matter is given by

$$J=\frac{3\rho}{P}. \tag{47}$$

As will be seen in the quasi-steady state case, this rate of creation is an overall average made of a large number of small events. Further, since the creation activity has ups and downs, we expect $J$ to denote some sort of temporal average. This will become clearer after we consider the non-creative mode and then link it to the creative one.

## The non-creative mode

In this case $T^{ik}_{;k}=0$ and we get a different set of solutions. The conservation of matter alone gives

$$\rho\propto\frac{1}{S^3}, \tag{48}$$

while for (59) and a constant $\lambda$, (52) leads to

$$\dot{C}\propto\frac{1}{S^2}. \tag{49}$$

Therefore, equation (51) gives

$$\frac{\dot{S}^2+k}{S^2}=\lambda+\frac{A}{S^3}-\frac{B}{S^4}, \tag{50}$$

where $A$ and $B$ are positive constants arising from the constants of proportionality in (46) and (47). We now find that the exact solution of (48) in the case $k=0$, is given by

$$S=\bar{S}[1+\eta\cos\theta(t)] \tag{51}$$

where $\eta$ is a parameter and the function $\theta(t)$ is given by

$$\dot{\theta}^2=-\lambda(1+\eta\cos\theta)^{-2}\{6+4\eta\cos\theta+\eta^2(1+\cos^2\theta)\}. \tag{52}$$

Here, $\bar{S}$ is a constant and the parameter $\eta$ satisfies the condition: $|\eta|<1$. Thus the scale factor never becomes zero and the model oscillates between finite scale limits

$$S_{\min}\equiv\bar{S}(1-\eta)\leq S\leq\bar{S}(1+\eta)\equiv S_{\max}, \tag{53}$$

The density of matter and the $C$-field energy density are given by

$$\bar{p} = -\frac{3\lambda}{2\pi G}(1+\eta^2), \tag{54}$$

$$f\dot{C}^2 = -\frac{\lambda}{2\pi G}(1-\eta^2)(3+\eta^2), \tag{55}$$

while the period of oscillation is given by

$$Q = \frac{1}{\sqrt{-\lambda}}\int_0^{2\pi} \frac{(1+\eta\cos\theta)d\theta}{\{6+4\eta\cos\theta+\eta^2(1+\cos^2\theta)\}^{1/2}}. \tag{56}$$

The oscillatory solution can be approximated by a simpler sinusoidal solution with the same period :

$$S \approx 1+\eta\cos\frac{2\pi t}{Q}. \tag{57}$$

Thus the function $\theta(t)$ is approximately proportional to $t$.

Notice that there is considerable similarity between the oscillatory solution obtained here and that discussed by Steinhardt and Turok (2002) in the context of a scalar field arising from phase transition. The bounce at finite minimum of scale factor is produced in both cosmologies through a negative energy scalar field. As we pointed out in the introduction, Hoyle and Narlikar (1964) [*see also* Narlikar (1973)] have emphasized the fact that such a scalar field can produce models which oscillate between finite ranges of scale. In the Hoyle-Narlikar paper cited above $\dot{C} \propto 1/S^3$, as opposed to (60), exactly as assumed by Steinhardt and Turok (2002) 38 years later. This is because instead of the trace-free energy tensor of Equation (2) here, Hoyle and Narlikar had used the standard scalar field tensor given by

$$-f\left(C_iC_k - \frac{1}{2}g_{ik}C_lC^l\right). \tag{58}$$

Far from being dismissed as physically unrealistic, negative kinetic energy fields like the $C$–field are gaining popularity. Recent works by Rubano and Seudellaro (2004), Sami and Toporensky (2004), Singh, et al. (2003) who refer to the earlier work by Hoyle and Narlikar (1964) have adapted the same ideas to describe phantom matter and the cosmological constant. In these works solutions of vacuum field equations with a cosmological constant are interpreted as a steady state in which matter or entropy is being continuously created. Barrow, et al. (2004) who obtain bouncing models similar to ours refer to the paper by Hoyle and Narlikar (1963) where $C$-field idea was proposed in the context of the steady state theory.

## The Quasi-Steady State Solution

The quasi-steady state cosmology is described by a combination of the creative and the non-creative modes. For this the general procedure to be followed is to look for a composite solution of the form



$$S(t) = \exp\left(\frac{t}{P}\right)\{1+\eta\cos\theta(t)\} \tag{59}$$

wherein $P \gg Q$. Thus over a period $Q$ as given by (54), the universe is essentially in a non-creative mode. However, at regular instances separated by the period $Q$ it has injection of new matter at such a rate as to preserve an average rate of creation over period $P$ as given by $J$ in (45). It is most likely that these epochs of creation are those of the minimum value of the scale factor during oscillation when the level of the $C$-field background is the highest. There is a sharp drop at a typical minimum but the $S(t)$ is a continuous curve with a zero derivative at $S = S_{\min}$.

Suppose that matter creation takes place at the minimum value of $S = S_{\min}$, and that $N$ particles are created per unit volume with mass $m_0$. Then the extra density added at this epoch in the creative mode is

$$\Delta\rho = m_0 N. \tag{60}$$

After one cycle the volume of the space expands by a factor exp $(3Q/P)$ and to restore the density to its original value we should have

$$(\rho+\Delta\rho)e^{-3Q/P} = \rho, \quad \text{i.e.,} \quad \Delta\rho/\rho \cong 3Q/P. \tag{61}$$

The $C$-field strength likewise takes a jump at creation and declines over the following cycle by the factor $\exp(-4Q/P)$. Thus the requirement of "steady state" from cycle to cycle tells us that the change in the strength of $\dot{C}^2$ must be

$$\Delta\dot{C}^2 = \frac{4Q}{P}\dot{C}^2. \tag{62}$$

The above result is seen to be consistent with (40) when we take note of the conservation law (39). A little manipulation of this equation gives us

$$\frac{3}{4}\frac{1}{S^4}\frac{d}{dS}(f\dot{C}^2S^4) = \frac{1}{S^3}\frac{d}{dS}(\rho S^3). \tag{63}$$

However, the right hand side is the rate of creation of matter per unit volume. Since from (59) and (60) we have

$$\frac{\Delta\dot{C}^2}{\dot{C}^2} = \frac{4}{3}\frac{\Delta\rho}{\rho}, \tag{64}$$

and from (42) and (43) we have $\rho = f\dot{C}^2$, we see that (61) is deducible from (59) and (60).

To summarize, we find that the composite solution properly reflects the quasi-steady state character of the cosmology in that while each cycle of duration $Q$ is exactly a repeat of the preceding one, over a long time scale the universe expands with the de Sitter expansion factor $\exp(t/P)$. The two time scales $P$ and $Q$ of the model thus turn out to be related to the coupling constants and the parameters $\lambda, f, G, \eta$ of the field equations. Further progress in the theoretical problem can be made after we understand the quantum theory of creation by the $C$-field.

These solutions contain sufficient number of arbitrary constants to assure us that they are generic, once we make the simplification that the universe obeys the Weyl postulate and the cosmological principle. The composite solution can be seen as an illustration of how a non-creative mode can be joined with the creative mode. More possibilities may exist of combining the two within the given framework. We have, however, followed the simplicity argument (also used in the standard big bang cosmology) to limit our present choice to the composite solution described here. HBN have used (59), or its approximation

$$S(t) = \exp\left(\frac{t}{P}\right)\left\{1 + \eta \cos\frac{2\pi t}{Q}\right\} \tag{65}$$

to work out the observable features of the QSSC, which we shall highlight next.

## THE ASTROPHYSICAL PICTURE

### Cosmological Parameters

Coming next to a physical interpretation of these mathematical solutions, we can visualize the above model in terms of the following values of its parameters:

$$P = 20Q,\ Q = 5\ \times 10^{10}\text{yrs},\ \eta = 0.811,$$
$$\lambda = -0.358\ \times 10^{-56}(\text{cm})^{-2}. \tag{66}$$

To fix ideas, we have taken the maximum redshift $z_{max} = 5$ so that the scale factor at the present epoch $S_0$ is determined from the relation $S_0 = \bar{S}(1-\eta)(1+z_{max})$. This set of parameters has been used in recent papers on the QSSC (Narlikar, et al. 2002, 2003). For this model the ratio of maximum to minimum scale factor in any oscillation is around 9.6.

These parametric values are not uniquely chosen; they are rather indicative of the magnitudes that may describe the real universe. For example, $z_{max}$ could be as high as 10 without placing any strain on the model. The various observational tests seek to place constraints on these values. Can the above model quantified by the above parameters cope with such tests? If it does we will know that the QSSC provides a realistic and viable alternative to the big bang.

### The Radiation Background

As far as the origin and nature of the MBR is concerned we use a fact that is always ignored by standard cosmologists. If we suppose that most of the $^4$He found in our own and external galaxies (about 24% of the hydrogen by mass) was synthesized by hydrogen burning in stars, the energy released amounts to about 4.37 x $10^{-13}$ erg $\text{cm}^{-3}$. This is almost exactly equal to the energy density of the microwave background radiation



with T = 2.74°K. For proponents of the standard model this has to be dismissed as a coincidence, but for the QSSC it is a powerful argument in favor of the hypothesis that the microwave radiation at the level detected is relic starlight from previous oscillations in the QSSC which has been thermalized (Hoyle, et al. 1994). Of course, this coincidence loses its significance in the standard big bang cosmology where the MBR temperature is epoch-dependent.

It is then natural to suppose that the other light isotopes, namely D, $^3$He, $^6$Li, $^7$Li, $^9$Be, $^{10}$B and $^{11}$B were produced by stellar processes. It has been shown (cf. Burbidge and Hoyle, 1998) that both spallation and stellar flares (for $^2$D) on the surfaces of stars can explain the measured abundances. Thus *all* of the isotopes are ultimately a result of stellar nucleosynthesis (Burbidge et al. 1957; Burbidge and Hoyle 1998).

This option raises a problem, however. If we simply extrapolate our understanding of stellar nucleosynthesis, we will find it hard to explain the relatively low metallicity of stars in our Galaxy. This is still an unsolved problem. We believe but have not yet established that it may be that the initial mass function of the stars where the elements are made is dominated by stars which are only able to eject the outer shells while all of the heavy elements are contained in the cores which simply collapse into NBHs. Using theory we can construct a mass function which will lead to the right answer (we think) but it has not yet been done. But of course our handwaving in this area is no better than all of the speculations that are being made in the conventional approach when it comes to the "first" stars.

The theory succeeds in relating the intensity and temperature of MBR to the stellar burning activity in each cycle, the result emphasizing the causal relationship between the radiation background and nuclear abundances. But, how is the background thermalized? The metallic whisker shaped grains condensed from supernova ejecta have been shown to effectively thermalize the relic starlight (Hoyle et al., 1994, 2000). It has also been demonstrated that inhomogeneities on the observed scale result from the thermalized radiation from clusters, groups of galaxies etc. thermalized at the minimum of the last oscillation (Narlikar et al., 2003). By using a toy model for these sources, it has been shown that the resulting angular power spectrum has a satisfactory fit to the data compiled by Podariu et al (2001) for the band power spectrum of the MBR temperature inhomogeneities. Extending that work further we show, in the following, that the model is also consistent with the first- and third- year observations of the Wilkinson Microwave Anisotropy Probe (WMAP) (Page et al. 2003; Spergel et al. 2006).

Following Narlikar et al (2003) we model the inhomogeneity of the MBR temperature as a set of small disc-shaped spots, randomly distributed on a unit sphere. The spots may be either 'top hat' type or 'Gaussian' type. In the former case they have sharp boundaries whereas in the latter case they taper outwards. We assume the former for clusters, and the latter for the galaxies, or groups of galaxies, and also for the curvature effect. This is because the clusters will tend to have rather sharp boundaries whereas in the other cases such sharp limits do not exist. The resultant inhomogeneity of the MBR thus arises from a superposition of random spots of three characteristic sizes corresponding to the three effects - the curvature effects at the last minimum of the the scale factor, clusters, and groups of galaxies. This is given by a 7 - parameter model of the angular power spectrum (for more details, see Narlikar et al, 2003):

$$\begin{aligned}\mathscr{C}_l &= A_1\ l(l+1)e^{-l^2\alpha_1^2}\\ &+A_2\,\frac{l^{\gamma-2}}{l+1}[\cos\alpha_2 P_l(\cos\alpha_2)-P_{l-1}(\cos\alpha_2)]^2\\ &+A_3\,l(l+1)e^{-l^2\alpha_3^2},\end{aligned} \tag{67}$$

where the parameters $A_1$, $A_2$, $A_3$ depend on the number density as well as the typical temperature fluctuation of each kind of spot, the parameters $\alpha_1$, $\alpha_2$, $\alpha_3$ correspond to the multipole value $l_p$ at which the $\mathscr{C}_l$ from each component peaks, and the parameter $\gamma$ refers to the correlation of the hot spots due to clusters. These parameters are determined by fitting the model to the observations by following the method we have used in (Narlikar, et al, 2003). We find that the observations favour a constant in place of the first gaussian profile in equation (78), resulting in a 6-parameter model with $A_1, A_2, A_3$, $\alpha_2, \alpha_3$ and $\gamma$ as the remaining free parameters. We should mention that the first gaussian profile of equation (78) had been conjectured by Narlikar, et al (2003) to be related to signature of spacetime curvature at the last minimum scale of oscillation. This conjecture was analogous to the particle horizon in the standard cosmology. In the QSSC, there is no particle horizon and the current observations suggest that the curvature effect on MBR inhomogeneity is negligible.

For the actual fitting, we consider the WMAP-three year data release (Spergel, et al, 2006). The data for the mean value of TT power spectrum have been binned into 39 bins in multipole space. We find that the earlier fit (Narlikar, et al, 2003) of the model is worsened when we consider the new data, giving $\chi^2 = 129.6$ at 33 degrees of freedom. However, we should note that while the new data set (WMAP-three year) has generally increased its accuracy, compared with the WMAP-one year observations, for $l \leq 700$, the observations for higher $l$ do not seem to agree. This is clear from Figure 3 where we have shown these two observations simultaneously. If we exclude the last three points from the fit, we can have a satisfactory fit giving $\chi^2 = 83.6$ for the best-fitting parameters $A_1 = 890.439 \pm 26.270$, $A_2 = 2402543.93 \pm 3110688.86$, $A_3 = 0.123 \pm 0.033$, $\alpha_2 = 0.010 \pm 0.0001$, $\alpha_3 = 0.004 \pm 0.000004$ and $\gamma = 3.645 \pm 0.206$, We shall see in the following that the standard cosmology also supplies a similar fit to the data. It should be noted that the above mentioned parameters in the QSSC can be related to the physical dimensions of the sources of inhomogeneities along the lines of Narlikar et al (2003) and are within the broad range of values expected from the physics of the processes.

For comparison, we fitted the same binned data, to the anisotropy spectrum prediction of a grid of open-CDM and $\Lambda$-CDM models within the standard big bang cosmology. We varied the matter density, $\Omega_m = 0.1$ to 1 in steps of 0.1; the baryon density, $\Omega_b h^2$ from 0.005 to 0.03 in steps of 0.004 where $h$ is the Hubble constant in units of 100 km $s^{-1}$ $Mpc^{-1}$; and the age of the universe, $t_0$ from 10 Gyr to 20 Gyr in steps of 2 Gyr. For each value of $\Omega_m$ we considered an open model and one flat where a compensating $\Omega_\Lambda$ was added. For the same binned data set, we find that the minimum value of $\chi^2$ is obtained for the flat model ($\Omega_m = 0.2 = 1 - \Omega_\Lambda$, $\Omega_b h^2 = 0.021$, $t_0 = 14$ Gyr and $h = 0.75$) with $\chi^2$=95.9 for the full data and $\chi^2$=92.7 from the first 36 points. The fit can be improved marginally by fine tunning the parameters further. However, it should



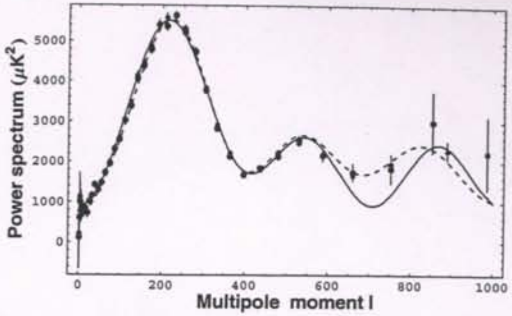


**FIGURE 3.** The plot showing the best-fitting angular power spectrum curves to the WMAP-three year data (shown in red colour) averaged into 39 bins. The continuous curve corresponds to the QSSC with 6 parameters and the dashed one to the big bang model with $\Omega_m = 0.2$, $\Omega_\Lambda = 0.8$. We notice that the highest parts of contribution to $\chi^2$ is from the last three points and the first 4 points of the data, on which the observations have not settled yet, as is clear from the comparision of these data with the WMAP-one year data (shown in blue colour). The rest of the points have reasonable fits with the theoretical curves.

be noted that the error bars (we have used) as given by the WMAP team provide only a rough estimate of the errors, not the exact error bars. For a proper assignment of errors, it is suggested to use the complete Fisher matrix. However, one should note that some components that go into making the Fisher matrix, depend on the particular models. This makes the errors model dependent which prohibits an independent assessment of the viability of the model. Hence until the model-independent errors are available from the observations, we are satisfied by our procedures and qualities of fit for both theories.

Figure 3 shows the best-fitting angular power spectrum curve obtained for QSSC by using the six parameter model. For comparison, we have also drawn the best-fitting big bang model. We mention in passing that recent work (Wickramasinghe 2005) indicates that small traces of polarization would be expected in the MBR wherever it passes through optically thin clouds of iron whiskers. These whiskers being partially aligned along the intracluster magnetic fields will yield a weak signal of polarization on the scale of clusters or smaller ojects.

It should be noted that the small scale anisotropies do not constitute as crucial a test for our model as they do for standard cosmology. Our general belief is that the universe is inhomogeneous on the scales of galaxy-cluster-supercluster and the QSSC model cannot make detailed claims of how these would result in the anisotropy of MBR. In this respect, the standard model subject to all its assumptions (dark matter, inflation, dark energy, etc.) makes much more focussed predictions of MBR anisotropy.

It is worth commenting on another issue of an astrophysical nature. The typical QSSC cycle has a lifetime long enough for most stars of masses exceeding $\sim 0.5 - 0.7 M_\odot$ to have burnt out. Thus stars from previous cycles will be mostly extinct as radiators of energy. Their masses will continue, however, to exert a gravitational influence on visible matter. The so-called dark matter seen in the outer reaches of galaxies and within clusters may very well be made up, at least in part, of these stellar remnants.

To what extent does this interpretation tally with observations? Clearly, in the big bang cosmology the time scales are not long enough to allow such an interpretation. Nor does that cosmology permit dark matter to be baryonic to such an extent. The constraints on baryonic dark matter in standard cosmology come from (i) the origin and abundance of deuterium and (ii) considerations of large scale structure. The latter constraint further requires the nonbaryonic matter to be cold. In the QSSC, as has been shown before, these constraints are not relevant. For other observational issues completely handled by the QSSC, see Hoyle et al. (2000).

The QSSC envisages stars from previous cycles to have burnt out and remained in and around their parent galaxies as dark matter. These may be very faint white dwarfs, neutron stars and even more massive remnants of supernovae, like near black holes. Their masses may be in the neighbourhood of $M_{\odot}$, or more, i.e., much larger than planetary or brown dwarf masses. Thus one form of baryonic dark matter could be in such remnants. In this connection results from surveys like MACHO or OGLE would provide possible constraints on this hypothesis.

## EXPLOSIVE COSMOGONY

### Groups and clusters of galaxies

We have already stated that it was Ambartsumian (1965) who first pointed out that the simplest interpretation of many physical systems of galaxies ranging from very small groups to large clusters is that they are expanding and coming apart. Since most of the observations are of systems at comparatively small redshifts it is clear that this takes place at the current epoch, and while we do not have direct evidence of the situation at large redshifts, it is most likely a general phenomenon.

Why has this effect been so widely ignored? The answer to this is clearly related to the beliefs of earlier generations of cosmologists. From an historical point of view, the first physical clusters were identified in the 1920s, and it was Zwicky, and later others who supposed that they must be stable systems. By measuring individual redshifts of a number of the galaxies in such a cluster it is possible to get a measurement of the line-of-sight random motions. For stability the virial condition $2E_K + \Omega = O$ needs to be satisfied where $E_K$ and $\Omega$ are the average values of the kinetic energy and potential energy of the cluster members. Extensive spectroscopic studies from the 1950s onward showed that nearly always the kinetic energy of the visible matter far exceeds the potential energy apparent from the visible parts of the galaxies. Many clusters have structures which suggest they are stable and relaxed. Thus it was deduced that in these clusters there must be enough dark matter present to stabilize them. This was, originally, one of the first pieces of evidence for the existence of dark matter.

The other argument was concerned with the ages of the galaxies. Until fairly recently it has been argued that all galaxies have stellar populations which include stars which are very old, with ages on the order of $H_o^{-1}$, i.e. that they are all as old as the classic big bang universe. However we now know that young galaxies with ages $\ll H_o^{-1}$ do exist. But the major point made by Ambartsumian was, and is, that there are large numbers of clusters of galaxies, and many small groups, which are physically connected but clearly from their forms and their relative velocities, appear to be unstable.



In this situation the use of the virial theorem is totally inappropriate. It is worthwhile pointing out that if the virial theorem holds the random motions of the galaxies should follow a steady state distribution such as

$$F(\mathbf{v}) \propto \exp\left[-\frac{\mathbf{v}^2}{2\sigma^2}\right]. \tag{68}$$

So far there is no observational demonstration that this is indeed the case. The conclusion drawn from $2E_K + \Omega > O$ as based on visible components only should rather be that the clusters are manifestly *not* in dynamical equilibrium.

Unfortunately, over the last thirty years the virial approach has been wedded to the idea that all galaxies are old, and it is this mis-reading of the data that led to the view that most galaxies were formed in the early universe and cannot be forming now. For example, in 1974 Ostriker, Peebles and Yahil (1974) argued in a very influential paper that the masses of physical systems of galaxies increase linearly with their sizes. As one of us pointed out at the time (Burbidge, 1975) this result was obtained completely by assuming that at every scale, for binary galaxies, very small groups, larger groups, and rich clusters, the virial condition of stability holds. Thus it was argued that more and more dark matter is present as the systems get bigger.

Modern evidence concerning the masses of clusters has been obtained from x-ray studies, the Sunyaev-Zeldovich effect, and gravitational lensing (cf. Fabian 1994; Carlstrom et al. 2002; Fort and Mellier 1994 and many other papers). All of these studies of rich clusters of galaxies show that large amounts of matter in the form of hot gas and/or dark matter must be present. However, evidence of enough matter to bind small or irregular clusters has not been found in general, and these are the types of configurations which Ambartsumian was originally considering. A system such as the Hercules Cluster is in this category. Also the very compact groups of galaxies (cf. Hickson 1997) have been a subject of debate for many years since a significant fraction of them ($\sim 40\%$) contain one galaxy with a redshift very different from the others. Many statistical studies of these have been made, the orthodox view being that such galaxies must be"interlopers"; foreground or background galaxies. Otherwise they either have anomalous redshifts, or are exploding away from the other galaxies.

We also have the problem of interacting galaxies, briefly referred to earlier in these lectures. In modern times it has been generally supposed that when two galaxies are clearly in interaction they must be coming together (merging) and never coming apart. There are valid ways of deciding whether or not mergers are occurring, or have occurred. The clearest way to show that they are coming together is to look for tidal tails (Toomre and Toomre 1972), or, if they are very closely interwoven, to look for two centres, or two counter rotating systems. For some objects this evidence does exist, and mergers are well established. But to assume that merging is occurring in all cases is unreasonable: there may well be systems where we are seeing the ejection of one galaxy from another as Ambartsumian proposed. Thus when the virial condition is not satisfied, and the systems are highly irregular and appear to be coming apart, then perhaps they *are* coming apart, and never have been separate. Here we are clearly departing from the standard point of view.

If one assumes that clusters may not be bound, their overall astrophysics changes from that of bound 'steady' clusters. Issues like the nature of intracluster medium, the role of the halo, generation of x-rays will require a new approach in the case where clusters are expanding. Further, the ejection of new matter provides additional inputs to the dynamics of the system. For example, the energy of ejection will play a role in heating the intracluster gas. This important investigation still needs to be carried out. However, a preliminary discussion may be found in Hoyle, et al. (2000), Chapter 20.

## Explosions in individual galaxies

By the early 1960s it had become clear that very large energy outbursts are taking place in the nuclei of galaxies.

The first evidence came from the discovery of powerful radio sources and the realization that the nuclei of the galaxies which they were identified with, had given rise to at least $10^{59}$ - $10^{61}$ ergs largely in the form of relativistic (Gev) particles and magnetic flux which had been ejected to distances of $\geq$ 100 kpc from the region of production.

A second line of evidence comes from the classical Seyfert galaxies which have very bright star-like nuclei which show very blue continua, and highly excited gas which has random motions $\gtrsim 3000$ Km sec$^{-1}$, and must be escaping from the nucleus. We know that the gas is being ejected because we see it through absorption in optical and X-ray spectra of Seyfert nuclei, and the wavelengths of the absorption lines are shifted to the blue of the main emission. The speeds observed are very large compared with the escape velocity. Early data were described by Burbidge et al. (1963).

In the decades since then it has been shown that many active nuclei are giving rise to x-rays, and to relativistic jets, detected in the most detail as high frequency radio waves. A very large fraction of all of the energy which is detected in the compact sources is non-thermal in origin, and is likely to be incoherent synchrotron radiation or Compton radiation.

Early in the discussion of the origin of these very large energies it was concluded that the only possible energy sources are gravitational energy associated with the collapse of a large mass, and the ejection of a small fraction of the energy, or we are indeed seeing mass and energy being created in the nuclei (cf. Hoyle, Fowler, Burbidge and Burbidge 1964).

Of course the most conservative explanation is that the energy arises from matter falling into massive black holes with an efficiency of conversion of gravitational energy to whatever is seen, of order 10%. This is the argument that has been generally advanced and widely accepted (cf. Rees 1984).

Why do we believe that this is not the correct explanation? After all, there is good evidence that many nearby galaxies (most of which are not active) contain collapsed supermassive objects in their centers with masses in the range $10^6$ - $10^8$ $M_\odot$.

The major difficulty is associated with the efficiency with which gravitational energy can be converted into very fast moving gas and relativistic particles, a problem that has haunted us for more than forty years (Burbidge and Burbidge 1965). In our view the efficiency factor is not 10% but close to 0.1% – 1%. The reasons why the efficiency



factor is very small are the following. If the energy could be converted directly the efficiency might be as high as $\sim 8\%$, or even higher from a Kerr rotating black hole. But this energy will appear outside the Schwarzschild radius as the classical equivalent of gravitons. This energy has to be used to heat an accretion disk or generate a corona in a classical AGN, or generate very high energy particles which can propagate outward in a radio source, then heat gas which gives rise to shock waves, which accelerate particles, which in turn radiate by the synchrotron process. Thermodynamics tells us that the efficiency at each of these stages is $\lesssim 10\%$. If there are 3 to 4 stages the overall efficiency is $\sim 10^{-3} - 10^{-4}$. This is borne out by the measured efficiency by which relativistic beams are generated in particle accelerators on earth, and by the efficiency associated with the activity in the center of M87. (cf. Churasov et al. 2002).

If these arguments are not accepted, and gravitational energy is still claimed to be the only reasonable source, another problem appears.

For the most luminous sources, powerful radio sources and distant QSOs the masses involved must be much greater than the typical values used by the black hole-accretion disk theorists. If one uses the formula for Eddington luminosity (cf. for details pages 109-111, 408-409 of Kembhavi & Narlikar 1999) one arrives at black hole masses of the order $10^8$ $M_\odot$ on the basis of perfect efficiency of energy conversion. An efficiency of $\leq 0.01$ would drive the mass up a hundred fold at least, i.e. to $10^{10}$ $M_\odot$ or greater. So far there is no direct evidence in any galaxy for such large dark masses. The largest masses which have been reliably estimated are about $10^9$ $M_\odot$.

In general it is necessary to explain where the bulk of the energy released which is not in the relativistic particle beams, is to be found. A possible explanation is that it is much of this energy which heats the diffuse gas in active galaxies giving rise to the extended X-ray emission in clusters and galaxies.

An even harder problem is to explain how the massive black holes in galaxies were formed in the first place. Were they formed before the galaxies or later? In the standard model both scenarios have been tried, but no satisfactory answer has been found.

In our model the energy comes with creation in the very strong gravitational fields very close to the central NBH, where the process can be much more efficient than can be expected in the tortuous chain envisaged in the classical gravitational picture.

Would very massive galaxies result if the universe allows indefinitely large time for galaxy formation? Earlier ideas (Hoyle, 1953, Binney 1977, Rees and Ostriker 1977, Silk 1977) seemed to suggest so. In the present case two effects intervene to make massive galaxies rather rare. The first one is geometrical. Because of steady long-term expansion, the distance between two galaxies formed, say, $n$ cycles ago, would have increased by a factor $\sim \exp n\ Q/P$, and their density decreased by the factor $\sim \exp - 3nQ/P$. For $n \gg 1$, we expect the chance of finding such galaxies very small.

The second reason working against the growth of mass in a region comes from the negative energy and pressure of the $C$-field. As the mass grows through creation, the $C$-field also mounts and its repulsive effect ultimately causes enough instability for the mass to break up. Thus the large mass grows smaller by ejecting its broken parts.

What is ejected in an MCE? Are the ejecta more in the form of particles or radiation or coherent objects? All three are produced. For a discussion of the mechanism leading to ejection of coherent objects, see Hoyle, et al. (2000), Chapter 18.

## Quasi-Stellar Objects

In the early 1960s QSOs were discovered (Matthews and Sandage 1963; Schmidt 1963; cf. Burbidge and Burbidge 1967 for an extensive discussion) as star-like objects with large redshifts. Very early on, continuity arguments led to the general conclusion that they are very similar to the classical Seyfert glaxies, i.e. they are the nuclei of galaxies at much greater distances. However, also quite early in the investigations, it became clear that a good case could also be made for supposing that they are more likely to be compact objects *ejected* from comparatively local, low redshift active galaxies (Hoyle and Burbidge 1966).

After more than thirty years of controversy this issue has not yet been settled, but a very strong case for this latter hypothesis based on the observations of the clustering of many QSOs about active galaxies has been made. (Burbidge et al. 1971; Arp 1987; Burbidge 1996).

If this is accepted, it provides direct evidence that in the creation process active galaxies are able to eject compact sources with large intrinsic redshifts. What was not predicted was the existence of intrinsic redshifts. They present us with an unsolved problem, but one which must be closely connected to the creation process. A remarkable aspect of this problem is that the intrinsic redshifts show very clear peaks in their distribution with the first peak at $z = 0.061$ and with a periodicity of the form $\triangle$ log $(1 + z) = 0.089$ (cf. Karlsson 1971, Burbidge and Napier 2001). The periodicity is in the intrinsic redshift component ($z_i$), and in order to single out that component, either the cosmological redshift component $z_c$ must be very small i.e., the sources must be very close to us, or it must be known and corrected for by using the relation $(1 + z_{obs}) = (1 + z_c)(1 + z_i)$. Thus a recent claim that the periodicity is not confirmed (Hawkins et al., 2003) has been shown to be in error (Napier and Burbidge, 2003).

It is admitted that the evidence from gravitational lensing provides an overall consistent picture for the standard cosmological hypothesis. The evidence on quasars of larger redshift being lensed by a galaxy of lower redshift, together with the time delay in the radiation found in the two lensed images can be explained by this hypothesis. This type of evidence needs to be looked at afresh if the claim is made that quasars are much closer than their redshift-distances. In such cases, the lensing models can be 'scaled' down but the time-delay will have to be checked for lower values. To our knowledge no such exercise has been carried out to date. We hope to examine this issue in a later paper.

## Gamma Ray Bursts

One of the most remarkable phenomena discovered in recent years relate to very short lived ($\lesssim$ minutes) bursts of high energy photons ($\gamma$-ray and x-ray) which can apparently occur anywhere in the sky, and which sometimes can be identified with a very faint optical and/or radio source, an afterglow, which may fade with time. Sometimes a very faint object remains. The first optical observation in which a redshift could be measured led to the conclusion that those sources are extragalactic. Using the redshifts as distance indicators this has led to the conclusion that the energies emitted lie in the range $10^{50}$



- $10^{54}$ ergs, with most of them $\gtrsim 10^{53}$ ergs, if the explosions take place isotropically. If energies involving single stars are invoked the energies can be reduced if beaming is present. The most recent observations have suggested that the events are due to forms of supernovae which are beamed. In the usual interpretation it is assumed that the redshifts which have been measured for the gamma ray bursts are cosmological (cf Bloom et al. 2001). However in a recent study using all (more than 30) gamma-ray bursts (GRBs) with measured redshifts it was shown that the redshift distribution strongly suggests that they are closely related to QSOs with the same intrinsic redshift peaks (Burbidge 2003, 2004). Also an analysis of the positions of all of the GRBs for which we have positions (about 150) shows that a number of them are very near to already identified QSOs (Burbidge 2003). All of this suggests that the GRBs are due to explosions of objects (perhaps *in* QSOs) which have themselves been ejected following a creation process from active galaxies. In general they have slightly greater cosmological redshifts and thus are further away ($\leq$ 500 Mpc) than the galaxies from which most of bright QSOs are ejected. While we do not claim that this hypothesis is generally accepted, Bloom (2003) has shown that there are peculiarities in the redshift distribution interpreted in the conventional way. More observations may clarify this situation.

# CONCLUDING REMARKS

The oscillating universe in the QSSC, together with a long-term expansion, driven by a population of mini-creation events provides the missing dynamical connection between cosmology and the 'local' explosive phenomena. The QSSC additionally fulfills the roles normally expected of a cosmological theory, namely (i) it provides an explanation of the microwave background radiation with temperature, spectrum and inhomogeneities related to astrophysical processes (Narlikar et al. 2003), (ii) it offers a purely stellar-based interpretation of all observed nuclei (*including* light ones)(Burbidge et al. 1957; Burbidge and Hoyle 1998), (iii) it generates baryonic dark matter as part of stellar evolution (Hoyle et al. 1994), (iv) it accounts for the extra dimming of distant supernovae *without* having recourse to dark energy (Narlikar, Vishwakarma and Burbidge 2002; Vishwakarma and Narlikar 2005), and it also suggests a possible role of MCEs in the overall scenario of structure formation (Nayeri et al. 1999). We have not been able to discuss some of these issues for lack of time. The references cited will provide details.

The last mentioned work shows that preferential creation of new matter near existing concentrations of mass can lead to growth of clustering. A toy model based on million-body simulations demonstrates this effect and leads to clustering with a 2-point correlation function with index close to $-1.8$. Because of repulsive effect of the $C$-field, it is felt that this process may be more important than gravitational clustering. However, we need to demonstrate this through simulations like those in our toy model, *together with* gravitational clustering.

There are two challenges that still remain, namely understanding the *origin* of anomalous redshifts and the observed *periodicities* in the redshifts. Given the QSSC framework, one needs to find a scenario in which the hitherto classical interpretation of redshifts is enriched further with inputs of quantum theory. These are huge problems which we continue to wrestle with.

**Appendix** : *Field Theory Underlying the QSSC*

Following Mach's principle, we begin with the hypothesis that inertia of any particle of matter owes its origin to the existence of all other particles of matter in the universe. If the particles are labelled $a, b, c, ...$ and the element of proper time of $a^{th}$ particle in Riemannian spacetime is denoted by $ds_a$, then we express the inertia of particle $a$ by the sum

$$M_a(A) = \sum_{b \neq a} \int \lambda_b \tilde{G}(A,B) ds_b = \sum_{b \neq a} M^{(b)}(A). \tag{A1}$$

where $A$ is a typical point on the world line of particle $a$ . $\tilde{G}(A,B)$ is a scalar propagator communicating the inertial effect from $B$ to $A$. The coupling constant $\lambda_b$ denotes the intensity of the effect and without loss of generality may be set equal to unity. Likewise we may replace $M_a(A)$ by a scalar mass function $M(X)$ of a general spacetime point $X$, denoting the mass acquired by a particle at that point. As in Riemannian geometry we will denote by $R_{ik}$ the Ricci tensor and by $R$ the scalar curvature.

The individual contributors to $M(X)$ are the scalar functions $M^{(b)}(X)$, which are determined by the propagators $\tilde{G}(X,B)$. The simplest theory results from choice of a conformally invariant wave equation for $M^{(b)}(X)$,

$$\Box M^{(b)}(X) + \frac{1}{6} R M^{(b)}(X) + M^{(b)}(X)^3 = \int \frac{\delta_4(X,B)}{\sqrt{-g(B)}} ds_b. \tag{A2}$$

The expression on the right hand side identifies the worldline of $b$ as the source. Why conformal invariance? In a theory of long range interactions influences travel along light cones and light cones are entities which are globally invariant under a conformal transformation. Thus a theory which picks out light cones for global communication is naturally expected to be conformally invariant. (A comparison may be made with special relativity. The *local* invariance of speed of light for all moving observers leads to the requirement of local Lorentz invariance of a physical theory.)

Although the above equation is non-linear, a simplification results in the smooth fluid approximation describing a universe containing a larger number of particles. Thus $M(X) = \sum_b M^{(b)}(X)$ satisfies an equation

$$\Box M + \frac{1}{6} R M + \Lambda M^3 = \sum_b \int \frac{\delta_4(X,B)}{\sqrt{-g(B)}} d^4 s_b. \tag{A3}$$

What is $\Lambda$? Assuming that there are $N$ contributing particles in a cosmological horizon size sphere, we will get

$$\Lambda \approx N^{-2}, \tag{A4}$$

since adding $N$ equations of the kind (A2) leads to the cube term having a reduced coefficient by this factor, because of the absence of cross products $M^{(b)} M^{(c)}$ type $(b \neq c)$.



Typically the observable mass in the universe is $\sim 10^{22} M_\odot$ within such a sphere, giving $N \sim 2 \times 10^{60}$ if the mass is typically that of a planck particle. We shall return to this aspect shortly. With this value for $N$, we have

$$\Lambda \approx 2.5 \times 10^{-121}. \tag{A5}$$

With these definitions we now introduce the action principle from which the field equations can be derived. In particle-particle interaction form it is simply

$$\mathscr{A} = -\sum_a \int M_a(A) ds_a. \tag{A6}$$

Expressed in terms of a scalar field function $M(X)$, it becomes

$$\begin{aligned} \mathscr{A} &= -\frac{1}{2} \int (M_i M^i - \frac{1}{6} R M^2) \sqrt{-g}\, d^4x + \frac{1}{4} \Lambda \int M^4 \sqrt{-g} d^4x \\ &- \sum_a \int \frac{\delta_4(X,A)}{\sqrt{-g(A)}} M(X) ds_a. \end{aligned} \tag{A7}$$

For example, the variation $M \to M + \delta M$ leads to the wave equation (A2). The variation of spacetime metric gives rise to gravitational equations. The variation of particle world lines gives rise to another scalar field, however, if we assume the worldlines to have finite beginnings. This is where creation of matter explicitly enters the picture. The characteristic mass of a typical particle that can be constructed in the theory using the available fundamental constants $c, G$ and $\hbar$ is the Planck mass

$$m_P = \left( \frac{3\hbar c}{4\pi G} \right)^{1/2}. \tag{A8}$$

We shall assume therefore that the typical basic particle created is the Planck particle with the above mass. We shall take $\hbar = 1$ in what follows. Imagine now the worldline of such a particle beginning at a world-point $A_0$.

A typical Planck particle $a$ exists from $A_0$ to $A_0 + \delta A_0$, in the neighborhood of which it decays into $n$ stable secondaries, $n \simeq 6.10^{18}$, denoted by $a_1, a_2, \ldots a_n$. Each such secondary contributes a mass field $m^{(a_r)}(X)$, say, which is the fundamental solution of the wave equation

$$\Box m^{(a_r)} + \frac{1}{6} R m^{(a_r)} + n^2 m^{(a_r)^3} = \frac{1}{n} \int_{A_0 + \delta A_0} \frac{\delta_4(X,A)}{\sqrt{-g(A)}} da, \tag{A9}$$

while the brief existence of $a$ contributes $c^{(a)}(X)$, say, which satisfies

$$\Box c^{(a)} + \frac{1}{6} R c^{(a)} + c^{(a)^3} = \int_{A_0}^{A_0+\delta A_0} \frac{\delta_4(X,A)}{\sqrt{-g(A)}} da,$$

(A10)

Summing $c^{(a)}$ with respect to $a, b, \ldots$ gives

$$c(X) = \sum_a c^{(a)}(X),$$

(A11)

the contribution to the total mass $M(X)$ from the Planck particles during their brief existence, while

$$\sum_a \sum_{r=1}^{n} m^{(a_r)}(X) = m(X)$$

(A12)

gives the contribution of the stable secondary particles.

Although $c(X)$ makes a contribution to the total mass function

$$M(X) = c(X) + m(X)$$

(A13)

that is generally small compared to $M(X)$, there is the difference that, whereas $m(X)$ is an essentially smooth field, $c(X)$ contains small exceedingly rapid fluctuations and so can contribute significantly to the derivatives of $c(X)$. The contribution to $c(X)$ from Planck particles $a$, for example, is largely contained between two light cones, one from $A_0$, the other from $A_0 + \delta A_0$. Along a timelike line cutting these two cones the contribution to $c(X)$ rises from zero as the line crosses the light cone from $A_0$, attains some maximum value and then falls back effectively to zero as the line crosses the second light cone from $A_0 + \delta A_0$. The time derivative of $c^{(a)}(X)$ therefore involves the reciprocal of the time difference between the two light cones. This reciprocal cancels the short duration of the source term on the right-hand side of (A10). The factor in question is of the order of the decay time $\tau$ of the Planck particles, $\sim 10^{-43}$ seconds. No matter how small $\tau$ may be, the reduction in the source strength of $c^{(a)}(X)$ is recovered in the derivatives of $c^{(a)}(X)$, which therefore cannot be omitted from the gravitational equations.

The derivatives of $c^{(a)}(X), c^{(b)}(X), \ldots$ can as well be negative as positive, so that in averaging many Planck particles, linear terms in the derivatives do disappear. It is therefore not hard to show that after such an averaging the gravitational equations become

$$R_{ik} - \frac{1}{2} g_{ik} R - 3\Lambda m^2 g_{ik} = \frac{6}{m^2}\Big[ - T_{ik} + \frac{1}{6}(g_{ik}\Box m^2 - m^2_{;ik}) + (m_i m_k - \frac{1}{2} g_{ik} m_l m^l) + \frac{2}{3}(c_i c_k - \frac{1}{4} g_{ik} c_l c^l)\Big].$$



(A14)

Since the same wave equation is being used for $c(X)$ as for $m(X)$, the theory remains scale invariant. A scale change can therefore be introduced that reduces $M(X) = m(X) + c(X)$ to a constant, or one that reduces $m(X)$ to a constant. Only that which reduces $m(X)$ to a constant, viz

$$\Omega = \frac{m(X)}{m_P}$$

(A15)

has the virtue of not introducing small very rapidly varying ripples into the metric tensor. Although small in amplitude such ripples produce non-negligible contributions to the derivatives of the metric tensor, causing difficulties in the evaluation of the Riemann tensor, and so are better avoided. Simplifying with (A14) does not bring in this difficulty, which is why separating of the main smooth part of $M(X)$ now proves an advantage, with the gravitational equations simplifying to

$$8\pi G = \frac{6}{m_P^2}, \quad m_P \text{ a constant},$$

(A16)

$$R_{ik} - \frac{1}{2} g_{ik} R + \lambda g_{ik} = -8\pi G [T_{ik} - \frac{2}{3}(c_i c_k - \frac{1}{4} g_{ik} c_l c^l)].$$

(A17)

We define the cosmological constant $\lambda$ by

$$\lambda = -3\Lambda m_P^2 \approx -2 \times 10^{56}\ \text{cm}^{-2}$$

(A18)

This value falls within the normally expected region of the magnitude of the cosmological constant. Note, however, that its sign is negative! This has been the consequence of the Machian origin of the cosmological constant through the non-linear equations (A2), (A3).

It has been on (A17) that the discussion of what is called the quasi-steady state cosmological model (QSSC) has been based. A connection with the $C$-field of the earlier steady state cosmology can also be given. Writing

$$C(X) = \tau c(X),$$

(A19)

where $\tau$ is the decay lifetime of the Planck particle, the action contributed by Planck particles $a, b, \ldots$,

$$-\sum_a \int_{A_0}^{A_0+\delta A_0} c(A) da$$

(A20)

can be approximated as

$$-C(A_0) - C(B_0) - \dots, \tag{A21}$$

which form corresponds to the $C$-field used in the steady state cosmology.

Thus the equations (A17) are replaced by

$$R_{ik} - \frac{1}{2}g_{ik}R + \lambda g_{ik} = -8\pi G\left[T_{ik} - f\left(C_iC_k - \frac{1}{4}g_{ik}C_lC^l\right)\right], \tag{A22}$$

with the earlier coupling constant $f$ defined as

$$f = \frac{2}{3\tau^2} \tag{A23}$$

[We remind the reader that we have taken the speed of light $c = 1$.]

The question now arises of why astrophysical observation suggests that the creation of matter occurs in some places but not in others. For creation to occur at the points $A_0, B_0, \dots$ it is necessary classically that the action should not vary with respect to small changes in the spacetime positions of these points, which was shown earlier to require

$$C_i(A_0)C^i(A_0) = C_i(B_0)C^i(B_0) = \dots = m_P^2. \tag{A24}$$

More precisely, the field $c(X)$ is required to be equal to $m_P$ at $A_0, B_0, \dots,$

$$c(A_0) = c(B_0) = \dots = m_P. \tag{A25}$$

(For, equation (A19) tells us that connection between $c$ and $C$ is through the lifetime $\tau$ of Planck particle.)

As already remarked in the main text, this is in general not the case: in general the magnitude of $C^iC_i$ is much less that $m_P$. However, close to the event horizon of a massive compact body $C_i(A_0)C^i(A_0)$ is increased by a relativistic time dilatation factor, whereas $m_P^2$ stays fixed. Hence, near enough to an event horizon the required conservation conditions can be satisfied, which has the consequence that creation events occur only in compact regions, agreeing closely with the condensed regions of high excitation observed so widely in astrophysics.

## REFERENCES


Ambartsumian, V.A. 1965, *Structure and Evolution of Galaxies, Proc. 13th Solvay Conf. on Physics, University of Brussels*, (New York, Wiley Interscience), 24

Arp, H.C. 1987, *Quasars, Redshifts and Controversies* (Interstellar Media, Berkeley, California)





Bagla, J.S., Padmanabhan, T. and Narlikar, J.V. 1996, *Comm. Astrophys.*, **18**, 289

Barrow, J., Kimberly, D. and Magueijo, J. 2004, *Class. Quant. Grav.*, **21**, 4289

Bekenstein, D. 2004, *Phys. Rev.*, **D70**, 083509

Binney, J. 1977, *Ap.J.*, **215**, 483

Blanchard, A., Souspis, B., Rowan-Robinson, M. and Sarkar, S. 2003, *A&A*, **412**, 35

Bloom, J.S. 2003, *A.J.*, **125**, 2865

Bloom, J.S., Kulkarni, S.R. and Djorgovsky, S.G. 2001, *A.J.*, **123**, 1111

Bondi, H. and Gold, T. 1948, *MNRAS*, **108**, 252

Brans, C. and Dicke, R.H. 1961, *Phys. Rev.*, **124**, 125

Burbidge, E.M., Burbidge, G.R., Fowler, W.A. and Hoyle, F. 1957, *Rev. Mod. Phys.*, **29**, 547

Burbidge, E.M., Burbidge, G., Solomon, P. and Strittmatter, P.A. 1971, *Ap.J.*, **170**, 223

Burbidge, G. 1975, *Ap.J.*, **106**, L7

Burbidge, G. 1996, *A&A*, **309**, 9

Burbidge, G. 2003, *Ap.J.*, **585**, 112

Burbidge, G. 2004, "The Restless High Energy Universe", *Conf. Proc. Nuclear Physics B.*, **305**, 132

Burbidge, G. and Burbidge, E.M. 1965, *The Structure and Evolution of Galaxies, Proc. of 13th Solvay Conference on Physics, University of Brussels*, (New York, Wiley Interscience), 137

Burbidge, G. and Burbidge, E.M. 1967, *Quasi-Stellar Objects*, (San Francisco, W.H. Freeman)

Burbidge, G. and Hoyle, F. 1998, *ApJ.*, **509**, L1

Burbidge, G. and Napier, W. M. 2001, *A.J.*, **121**, 21

Burbidge, G., Burbidge, E.M., and Sandage, A. 1963, *Rev. Mod. Phys.*, **35**, 947

Carlstrom, J., Holder, G. and Reese, E. 2002, *A.R.A.A.*, **40**, 643

Carroll, S.M. and Press, W.H. 1992, *A.R.A.A.*, **30**, 499

Churasov, E., Sunyaev, R., Forman, W. and Bohringer, H. 2002, *MNRAS*, **332**, 729

Datt, B. 1938, *Z. Phys.*, **108**, 314

Dirac, P.A.M. 1937, *Nature*, **139**, 323

Dirac, P.A.M. 1938, *Proc. R. Soc.*, **A165**, 199

Dirac, P.A.M. 1973, *Proc. R. Soc.*, **A333**, 403

Dirac, P.A.M. 1974, *Proc. R. Soc.*, **A338**, 439

Fabian, A.C. 1994, *A.R.A.A.*, **32**, 277

Fort, B. and Mellier, Y. 1994, *A&A Rev.*, **4**, 239

Gliner, E.B. 1970, *Soviet Physics-Doklady*, **15**, 559

Gunn, J.B. and Oke, J.B. 1975, *Ap.J.*, **195**, 255

Hawking, S.W. and Ellis, G.F.R. 1973, *The Large Scale Structure of Space-time*, Cambridge

Hawkins, E., Maddox, S.J. and Merrifield, M.R. 2002, *MNRAS*, **336**, L13

Hickson, P. 1997, *A.R.A.A.*, **35**, 377

Hoyle, F. 1948, *MNRAS*, **108**, 372

Hoyle, F.1953, *Ap.J*, **118**, 513

Hoyle, F. and Burbidge, G. 1966, *Ap.J.*, **144**, 534

Hoyle, F. and Narlikar, J.V. 1964, *Proc. Roy. Soc.*, **A278**, 465

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

Hoyle, F., Burbidge, G. and Narlikar, J.V. 1994, *MNRAS*, **267**, 1007
Hoyle, F., Burbidge, G. and Narlikar, J.V. 1995, *Proc. Roy. Soc.*, **A448**, 191
Hoyle, F., Burbidge, G. and Narlikar, J.V. 2000, *A Different Approach to Cosmology*, (Cambridge, Cambridge University Press).
Hoyle, F., Fowler, W.A., Burbidge, E.M. and Burbidge, G. 1964, *Ap.J*, **139**, 909
Hoyle, F. and Sandage, A. 1956, *P.A.S.P.*, **68**, 301
Johri, V.B. and Mathiazhagan, C. 1984, *Class. Quant. Grav.*, **1**, L29
Karlsson, K.G. 1971, *A&A*, **13**, 333
Kembhavi, A.K. and Narlikar, J.V. 1999, *Quasars and Active Galactic Nuclei*, (Cambridge, Cambridge University Press).
Longair, M.S. 1987, *IAU Symposium 124, "Observational Cosmology"*, (Editors, A. Hewitt, G. Burbidge, L.Z. Fang: D. Reidel, Dordrecht) p. 823
Mach, E. 1893, *The Science of Mechanics* (Chicago : Open Court)
Matthews, T.A. and Sandage, A.R. 1963, *Ap.J.*, **138**, 30
McCrea, W.H. 1951, *Proc.Roy.Soc.*, **A206**, 562
Meyers, A.D., Shanks, T., Outram, J.J., Srith, W.J. and Wolfendale, A.W. 2004, *MNRAS*, **347**, L67
Milgrom, M. 1983, *Ap.J*, **270**, 365
Napier, W. and Burbidge, G. 2003, *MNRAS*, **342**, 601
Nariai, H. 1968, *Prog. Th. Phys. (Japan)*, **40**, 49
Narlikar, J.V. 1973, *Nature*, **242**, 35
Narlikar, J.V. and Padmanabhan, T. 1985, *Phys. Rev.* **D32**, 1928
Narlikar, J.V., Apparao, M.V.K. and Dadhich, N.K. 1974, *Nature*, **251**, 590
Narlikar, J.V., Vishwakarma, R.G. and Burbidge, G. 2002, *P.A.S.P.*, **114**, 1092
Narlikar, J.V., Vishwakarma, R.G., Hajian, A., Souradeep, T., Burbidge, G. and Hoyle, F. 2003, *Ap.J.*, **585**, 1
Nayeri, A., Engineer, S., Narlikar, J.V. and Hoyle, F. 1999, *Ap.J.*, **525**, 10
Ostriker, J.P., Peebles, P.J.E. and Yahil, A. 1974, *Ap.J.*, **193**, L1
Page L., et al., 2003, Astrophys. J. Suppl. **148**, 233
Perlmutter, S. et al. 1999, *Ap.J.*, **517**, 565
Podariu, S., Souradeep, T., Gott III, J. R., Ratra, B. and Vogeley, M. S. 2001, *Ap. J. S.*, **559**, 9
Rees, M.J. 1984, *A.R.A.A.*, **22**, 471
Rees, M.J. and Ostriker, J.P. 1977, *MNRAS*, **179**, 541
Riess, A. et al. 1998, *A.J.*, **116**, 1009
Rubano, C. and Seudellaro, P. 2004, astro-ph / 0410260
Sachs, R., Narlikar, J.V. and Hoyle, F. 1996, *A&A*, **313**, 703
Sami, M. and Toporensky, A. 2004, *Mod. Phys. Lett. A*, **19**, 1509
Sanders, J.S. 2008, *Mass Profiles and Shapes of Cosmological Structures*, eds.Mamon, Combes, Deffayet, Fort, pp. 23
Sanders J.S. 2003, *MNRAS*, **342**, 901
Schmidt, M. 1963, *Nature*, **197**, 1040
Sciama, D. 1953, *MNRAS*, **113**, 34
Silk, J. 1977, *Ap.J*, **211**, 638
Singh, P., Sami, M. and Dadhich, N. 2003, *Phys. Rev.*, **D68**, 023522
Spergel, D. et al. 2003, *Ap.J.S.*, **148**, 175



Spergel, D.N., et al., 2006, astro-ph/0603449
Steinhardt, P.J. and Turok, N. 2002, *Science*, **296**, 1436
Toomre, A. and Toomre, J. 1972, *Ap.J.*, **178**, 623
Vishwakarma, R.G. and Narlikar, J.V. 2005, *Int.J.Mod.Phys.D*, **14**, 2, 345
Wickramasinghe, N.C. 2005, *Current Issues in Cosmology*, Proceedings of the Colloquium on 'Cosmology: Facts and Problems ', Paris. (Cambridge, Cambridge University Press), 152