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Further astrophysical quantities expected in a quasi-steady state Universe

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Abstract. In two previous papers we have described a new cosmological model which we have called the quasi-steady state cosmological model (QSSC) (Hoyle et al. 1993, 1994). In this theory matter is created only in strong gravitational fields associated with dense aggregates of matter.

In this paper and in Hoyle et al. (1994) we are attempting to show that many aspects of the observable universe are explicable using this theory so that it is a reasonable alternative to the classical Big-Bang model which has been so widely accepted.

We first review briefly the theory of the creation process and show how we arrived at the quasi-oscillatory model. In later sections we show how two of the three parameters of the theory P, and Q, are related to two observed quantities. Q is related to the value of the Hubble constant H_0 at the present epoch, and the counts of radio sources enable us to determine P/Q and hence P. We find that $Q = 40\,10^9$ years and $P = 8\,10^{11}$ years.

We then calculate numerical values for the mass density in the universe and the rate of creation. Finally we discuss the properties of galaxies including faint galaxies, creation events in individual galaxies, and the mass-to-light ratios in galaxies and clusters. The results here are particularly interesting since in this model stars can be much older than H_0^{-1}. This means that much of the mass in galaxies will naturally be baryonic and will consist of evolved stars. Thus very large mass-to-light ratios are expected in galaxies and in clusters.

We conclude by summarizing the results obtained in all three papers. More work is required, particularly on the cosmogonical aspects of the theory, but a very attractive aspect of it is that the creation process in the centers of galaxies leads to a comparatively simple way of understanding explosive phenomena.

Key words: cosmology: theory – dark matter – galaxies: formation

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1. Introduction

In an earlier paper (Hoyle, Burbidge & Narlikar 1993 hitherto described as HBN 1993) we have proposed a quasi-steady state cosmological model in which matter is created only in strong gravitational fields associated with dense aggregates of matter, i.e. in the centers of galaxies and the like. This enables us to explain in a natural way the general outpouring from a wide range of extragalactic objects ranging from protogalaxies through high energy events as for example radio galaxies and QSOs down to small creation events in the nucleus of our galaxy.

In Sect. 3 of HBN 1993 and in another paper (Hoyle, Burbidge & Narlikar 1995) we have discussed the classical field theoretical approach behind this model involving the C-field originally proposed by Hoyle & Narlikar (1962).

For this cosmological theory to be accepted as a reasonable alternative to the currently very popular standard cosmological model (cf Peebles 1993) it is necessary that it be demonstrated that as many aspects as possible of the observable universe be explicable using it. In this paper, and an accompanying paper (Hoyle, Burbidge & Narlikar 1994 – to be described as HBN 1994) we are attempting to achieve this goal.

In Sects. 2 and 3 we review briefly the theoretical approach to the creation process and show how we arrived at the quasi oscillatory model. In Sects. 4 and 5 we show how two of the three parameters of the theory, P and Q are related to two observed quantities in the universe - the Hubble constant H_0 at the present epoch from which we determine Q, and the counts of radio sources, which enable us to determine the ratio P/Q and hence P. We also summarise how we were able to explain the cosmic microwave background and the observed abundances of the light elements using this theory. Those computations were shown in detail in HBN 1994 and HBN 1993 respectively.

In Sect. 5 we calculate numerical values for the mean density ρ_0, for the rate of creation and for the mass of the portion of the universe observed back to a redshift of about 5. In Sect. 6 we turn to the properties of galaxies including the properties of

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faint galaxies, creation events in individual galaxies, and the mass-to-light ratios in galaxies and clusters.

2. The field theoretical approach to the creation process

Briefly, the following argument was given in Sect. 3 of HBN 1993, for doubting the correctness of the whole class of big-bang models. (We will assume $c = 1$, unless the value of the speed of light is explicitly needed in c.g.s. units.)

The action of a set of particles a, b, c... in such models is

$$\mathscr{A} = -\sum_a \int_{t=0} m_a \mathrm{d}a, \tag{1}$$

where $t = 0$ refers to the moment of the big-bang in a system of coordinates such that the cosmological line element takes the Robertson-Walker form,

$$\mathrm{d}s^2 = \mathrm{d}t^2 - S^2(t)\left[\frac{\mathrm{d}r^2}{1-kr^2} + r^2\left(\mathrm{d}\theta^2 + \sin^2\theta \mathrm{d}\phi^2\right)\right], \tag{2}$$

where $k = 0$ or ± 1, $S(t)$ is the scale expansion factor and r, θ, φ spherical polar coordinates with respect to the central observer. Observers associated with other galaxies in what is often described as the "Hubble flow" have coordinates r, θ, φ independent of the time t, which is synchronous for all observers in the Hubble flow. The objection to the big-bang models is simply that (1) is non-invariant. It has a special form in the coordinate system (2). Even if the lower limit $t = 0$ were dropped, the singularity theorems force us to adopt a singular beginning in standard cosmology, i.e. an epoch when the standard rules of physics break down. In view of the importance of the concept of invariance throughout physics, both with respect to coordinates and unitary transformations in abstract spaces, we consider this to be a fundamental weakness.

To avoid such a lack of invariance we replace (1) by

$$\mathscr{A} = -\int_{A_0} m_a(A)\mathrm{d}a - \int_{B_0} m_b(B)\mathrm{d}b - \ldots - C(A_0) - C(B_0) - \ldots, \tag{3}$$

in which $C(A_0)$, $C(B_0)$, ... are the values of a scalar field $C(X)$ at the creation points A_0, B_0, ... of the particles, the latter being required to satisfy the conservation conditions

$$\left(C_i C^i\right)_{A_0} = m_a^2(A_0) \ldots \tag{4}$$

The introduction of $C(X)$ then leads to a modification of the gravitational equations such that in a cosmological approximation with respect to the line element (2) the equations for $S(t)$ are

$$\frac{\ddot{S}}{S} = -\frac{4\pi G}{3}\overline{\rho} + \frac{8\pi G}{3} f\overline{\dot{C}^2}, \tag{5}$$

$$\frac{\dot{S}^2 + k}{S^2} = \frac{8\pi G}{3}\overline{\rho} - \frac{4\pi G}{3} f\overline{\dot{C}^2}, \tag{6}$$

$\overline{\dot{C}^2}$ being the cosmologically averaged value of $\dot{C}^2$, and $\overline{\rho}$ is the cosmological averaged value of the mass density ρ. The field $C(X)$ satisfies a wave equation having its sources at the creation points A_0, B_0, ..., with f a positive coupling constant determining the strength of the sources [1].

The smoothed cosmological C-field is considered to be inadequate to satisfy the conservation conditions (4), so that only when C-field bosons happen to have their energies much increased by falling into a strong gravitational field of a highly condensed local object can creation take place. Thus this cosmological model depends on the distribution of highly condensed local objects, which themselves depend for their formation on the cosmological model, thereby generating a logical loop permitting many possibilities for the details of the model. Three such possibilities were considered in HBN 1993:

1. The distribution of local objects maintains $\overline{\dot{C}^2}$ at a constant value independent of t, in which case we have the classical steady-state theory, with the scale function $S(t)$ proportional to an exponential factor, exp Ht say, such that

$$\frac{3H^2}{4\pi G} = f\overline{\dot{C}^2} = \overline{\rho}, \tag{7}$$

with H a constant determined by the average creation rate.

2. The distribution of condensed local objects is such that $\overline{\dot{C}^2}$ varies slowly with t, in which case $S(t)$ can be considered as behaving again according to exp Ht but with H now a slowly varying function of t.

3. Creation is irregular, a situation that seems more plausible than the preceeding possibilities. This is because the $f\overline{\dot{C}^2}$ term, being positive in (5), has the effect of a negative pressure, causing expansion for the universe (i.e. tending to make $\ddot{S}$ positive) and causing disruptive explosions for sufficiently rapid creation near or in local objects. It therefore seems unlikely that a distribution of local objects with potentially explosive creation properties could be stable enough to satisfy the conditions needed for the classical steady-state model, or for a secular variation of such a model. It was for this reason that in HBN 1993 we preferred irregular creation.

While the general problem of irregular creation, involving a system of non-linear partial differential equations, is evidently very complex, there is one possibility that is relatively easy to grapple with, namely the case where the number of exploding local objects is comparativly few, implying a low average creation rate. We shall show that this model leads to what appear to be far-reaching conclusions.

3. The quasi-oscillatory model

A non-zero C-field behaves adiabatically in the absence of creation, with the $\overline{\dot{C}^2}$ term in (6) varying as S^{-4} for an oscillatory field, or S^{-6} for a static field. With the $\overline{\rho}$ term varying as S^{-3},

[1] In HBN 1993 particles at creation were considered to be Planck particles, in which case f^{-1} is of the order of the square of the half-life of the Planck particles.

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equation (6) in the absence of creation and for an oscillatory C-field (i.e. a boson field) takes the form

$$\frac{\dot{S}^2+k}{S^2} = \frac{2A}{S^3} - \frac{B}{S^4}, \tag{8}$$

where A, B are positive constants which depend on the initial values of $\overline{\rho}$, $f\overline{\dot{C}^2}$. Note that for a creation rate that is low or even zero at present B is not zero. Because matter is observed in the universe, a non-zero C-field has been generated at some time in the past, requiring $B > 0$. Provided the case $k = +1$ is chosen, the universe oscillates between the two values, S_1 and S_2 say, for which equation (8) gives $\dot{S}^2 = 0$. These are the roots of the equation

$$S^2 - 2AS + B = 0, \tag{9}$$

$$S_1, S_2 = A \mp \sqrt{A^2 - B}, \tag{10}$$

$$A^2 > B. \tag{11}$$

Since $S_1 > 0$ it is seen that a non-zero C-field excludes the big-bang models.

Thus it might be thought that an oscillatory model requires $k = +1$ in the line element (3). There is an alternative, however, namely to include terms involving a small cosmological constant λ in the gravitational equations. Then putting $k = 0$, Eqs. (5) and (6) are changed to

$$\frac{\ddot{S}}{S} = -\frac{4\pi G}{3}\overline{\rho} + \frac{8\pi G}{3} f\overline{\dot{C}^2} + \frac{1}{3}\lambda, \tag{12}$$

$$\frac{\dot{S}^2}{S^2} = \frac{8\pi G}{3}\overline{\rho} - \frac{4\pi G}{3} f\overline{\dot{C}^2} + \frac{1}{3}\lambda. \tag{13}$$

Provided $\lambda < 0$ and small enough, the scale factor can again be confined in the range $S_1 \leq S \leq S_2$ with S_1, S_2 now given by putting $\dot{S} = 0$ in (13). Using the same constants A, B as in (8), the approximate solutions for S_1 and S_2 are

$$S_1 \simeq \frac{B}{2A}, \; S_2 \simeq \left(-\frac{6A}{\lambda}\right)^{1/3}. \tag{14}$$

We must confess to a long-standing prejudice against the cosmological constant, due to its apparently ad hoc nature when the gravitational equations are obtained from a lagrangian in the usual way. However the most general analysis leads to the appearance of a cosmological constant (Hoyle, Burbidge & Narlikar 1995), making its adoption with $k = 0$ seem preferable to the case $k = +1$, $\lambda = 0$.

This is for an episode in which there is no creation of matter. Although the oscillation between S_1 and S_2 will not be strictly sinusoidal it can be thought of as being approximately so, with $S(t)$ given by

$$S(t) \simeq S_1 \cos\frac{2\pi t}{Q} + S_2 \sin\frac{2\pi t}{Q}, \tag{15}$$

the period of the oscillation being Q and the zero of the time t being at minimum phase. Because of the expansionary effect of the negative pressure exerted by the C-field, increasing the C-field through the creation of matter, which adds sources to the C-field, S_1 and S_2 increase secularly when the creation rate is slow, the nature of the increase being determined by the creation rate. This will now be taken such that S_1 and S_2 increase according to the exponential factor $\exp t/P$, with the constant P large. Then for a suitable choice of the zero of t, we have

$$S(t) \approx \exp\frac{t}{P}\left[1 + \alpha\cos\frac{2\pi t}{Q}\right], \; P \gg Q, \tag{16}$$

a situation in which α, P, Q are constants determining the model, with $P \gg Q$ a consequence of creation being slow. From here on we examine the astrophysical consequences of the scale factor $S(t)$ being given by (16).

We are thus concerned with an oscillatory model in which some matter creation occurs, especially near the minimum in each cycle, as was already visualized in HBN 1993. At each oscillation the universe experiences an expansive push. To give a framework for discussion, we suppose creation occurs so that the ratio S_1/S_2 stays fixed, as (16) requires it to do, with S_1 and S_2 both increasing as the slow exponential factor $\exp t/P$. Thus the time scale for the universe to expand irreversibly by e is $P \gg Q$, which is to say in each exponentiation there are many oscillations. The situation is analogous to the classical steady-state model but with each exponentiation of the scale factor broken into many oscillations.

In Fig. 1 we show $S(t)$ plotted against t/P and against t/Q for an assumed value of $P = 20Q$. We also put $\alpha = 0.75$. The time in Fig. 1 is measured in units of Q. In order to relate this model to the current state of the observed universe we also need to assign a value for t_0, the present epoch, in relation to the phase of the oscillatory cycles. We choose $t_0 = 0.85$ being 85 per cent of the way through the current cycle, cycles being reckoned maximum to maximum.

4. The relationship of astrophysical quantities to this model

The parameter Q is related to the observed values of the Hubble constant H_0 and the deceleration term q_0 respectively. For $P \gg Q$, the effect on H_0, q_0 of the overall expansion will hardly be noticed. The time dependent quantities H, q defined as

$$H = \frac{\dot{S}}{S}, \; q = -\frac{S\ddot{S}}{\dot{S}^2} \tag{17}$$

have the following properties. Starting from the minimum phase of an oscillation, H begins at zero, rises to a maximum and then falls back to zero at maximum phase, while q starts sharply negative and grows to zero, and then goes to markedly positive values as maximum phase is approached. The observed value of H, H_0, lies between $\sim 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ (cf Sandage 1993) and $\sim 80\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ (cf Tully 1993) while Kristian et al. (1978) gave $q_0 \simeq 1.5$ but with considerable uncertainty.

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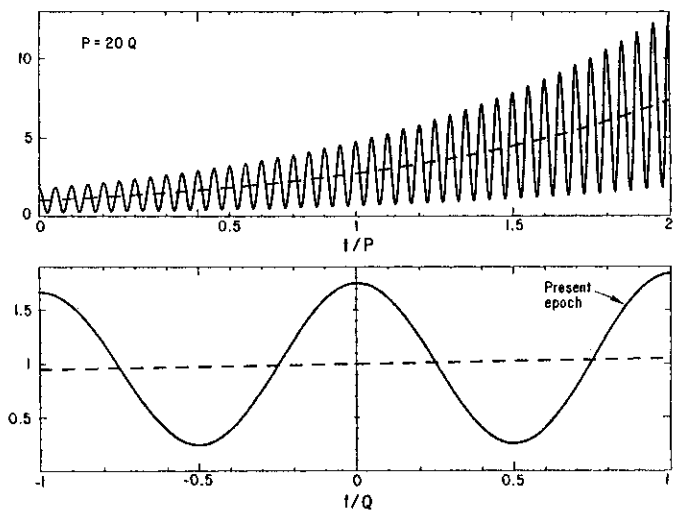

Fig. 1. $S(t)$ plotted against t/P (upper panel) and against t/Q (lower panel).

These values are generally indicative of a phase in the current oscillation approaching maximum. Without knowing the precise present-day phase, the time that has elapsed since the last minimum is somewhat uncertain but is probably close to $\frac{1}{2}H_0^{-1}$.

This leads us to the numerical values relating Q to H_0 given in Table 1.

In HBN 1994 we chose the value $Q = 40\,10^9$ years with $H_0 = 64.7\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ as a compromise between the high and low values of H_0 which are a subject of continuous debate. The parameter q_0 is determined from (16) to be 1.725, again close to the value given above. With the choices of α and t_0 the maximum redshift of objects in the present cycle is $z = 4.86$ (HBN 1994). This is not a limit, however, since the corresponding redshift from the previous cycle will be $z = 5.166$ and so on step by step. However the Hubble diagram for this model shows that the objects in each cycle will be fainter than those in the most recent cycle by about 3 magnitudes. Thus by specifying α, t_0 and the parameter Q based on the observed value of H_0, we obtain reasonable values for q_0, the maximum redshift in this cycle, and a Hubble diagram.

In this model we also have to explain two other properties of the observed Universe which have previously been thought to provide strong evidence for the so-called standard model.

Table 1.

Q(years)	H_0 ($\mathrm{km\,s^{-1}\,Mpc^{-1}}$)
$30\,10^9$	86.2
$40\,10^9$	64.7
$50\,10^9$	51.7

4.1. The cosmic microwave background

It has been known for many years that the energy density of the microwave background is almost exactly equal to the energy released in the conversion of hydrogen to helium in the visible baryonic matter in the universe (cf Hoyle 1968). This density is $\rho \simeq 3\,10^{-31}\,\mathrm{g\,cm^{-3}}$ and we suppose that about $7.5\,10^{-32}\,\mathrm{g\,cm^{-3}}$ is He. Thus the energy released in the production of this He through the conversion H $\rightarrow$ He is $4.5\,10^{-13}\,\mathrm{erg\,cm^{-3}}$, which if thermalized gives a radiation field of 2.78 K.

In the standard Big-Bang cosmology this agreement with the observed value is considered to be purely fortuitous, but within the framework of QSSC it is a clear indication that the microwave background was generated ultimately by the burning of hydrogen into helium in stars, through many creation cycles each of length Q. The optical and ultraviolet light must have progressively been degraded and scattered by dust, much of it in the form of iron needles so that it now forms a smooth black body form, as discussed at length in HBN 1994, where we predict a temperature of 2.68 K, very close to the observed temperature of 2.735 ± 0.06 K (Mather et al. 1990).

How many cycles are required, i.e. what is the value of P/Q? We have shown in HBN 1994 that the ratio P/Q can be obtained from the observed $\log N - \log S$ curves for radio sources. This is because radio sources from earlier cycles are contained in the counts. The reason for this is that while there will be optical obscuration near oscillatory minima and optical sources from earlier cycles will not be easily detectable, this will not apply at long enough radio wavelengths. For a simple model in which it is assumed that radio sources appear at a uniform rate per unit proper volume, we find that $P/Q \simeq 20$. With this value we not only can understand the origin of the microwave background but also the shape of the $\log N - \log S$ radio observations to very faint levels. Thus we have shown that in this model we have two timescales $Q = 40\,10^9$ years and $P = 8\,10^{11}$ years.

4.2. Production of the light isotopes

In the standard model the production of the light elements is attributed to nuclear reactions early in the explosion. In HBN 1993 (Sect. 6 and Appendix) and in Hoyle (1992) a detailed analysis has been given of a similar process in QSSC in which the light elements are synthesized in a creation process starting with a Planck fireball. It is shown there that the observed abundances of D, He^3, He^4, Li^7, Be^9, B^{11} and the isotope ratios Li^6/Li^7 and B^{10}/B^{11} can be reproduced.

We also showed in HBN 1994 that the difference between the cosmological density ρ_0 of $\sim 10^{-29}\,\mathrm{g\,cm^{-3}}$ and the observed density of visible matter $3\,10^{-31}\,\mathrm{g\,cm^{-3}}$ is likely to be made up of baryonic matter. Thus our theory suggests that, contrary to the requirement in the so-called standard model there is no non-baryonic matter. We shall return to this question later.

In the following section we use the numerical values of P and Q given in the above recapitulation to determine the present cosmological density of matter and the amount of creation re-

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quired through each cycle. Then we turn to the effect of two time scales on the observed properties of galaxies.

5. The present value of ρ and the rate of creation

Returning to the basic equation for S, equation (8), to obtain accurate values for S_1, S_2 a quartic equation in S has to be solved. The oscillation is not strictly sinusoidal as with the factor $1 + \alpha \cos 2\pi t/Q$ in (16). The latter has been taken as an approximation to facilitate the evaluation of certain integrals (c.f. HBN 1994).

When there is creation of matter, both A and B are functions of t, slowly varying on a time-scale P in the model. Over a restricted range of t it is always possible to write A as a constant multiplying an exponential factor $\exp 3t/P$, where P is determined by the functional dependence of A on t, contingent on what the creation rate happens to be. The factor $\exp 3t/P$ in A then cancels such a factor in $1/S^3$, which appears when $\exp t/P$ is included in $S(t)$, as in (16), so that the factor A/S^3 remains constant in the gravitational equation

$$\frac{\dot{S}^2}{S^2} = \frac{1}{3}\lambda + \frac{A}{S^3} - \frac{B}{S^4} \tag{18}$$

The time dependence of B is related to that of A by the conservation conditions of the creation process. The model is to be such that with the time dependence of A written as $\exp 3t/P$ that of B is $\exp 4t/P$, when this dependence of B cancels that of S^{-4}, and the $-B/S^4$ term in (18) is also a constant, making the right-hand side of the equation constant. By neglecting the time derivative of $\exp\ t/P$ when $P \gg Q$, the left-hand side also is constant. In this way we see how the scale factor is given by (16) when there is creation of matter at the slow rate implied by $P \gg Q$, at any rate given by (16) approximately over a limited range of t. The extent of the range of t depends on the degree to which the amount of creation per cycle remains approximately constant. A slow steadily maintained amount of creation per cycle gives an extensive range of t over which the form of $S(t)$ in (16), or as shown in Fig. 1, can be used. But this situation would be disrupted if in a particular cycle there was a sudden exceptionally large amount of creation. Then $S(t)$ would get a sudden kick not represented by (16).

Our motivation for considering this model in HBN 1994 was the following. When the slowly varying exponential $\exp\ t/P$ is omitted from $S(t)$ the oscillatory cycles given by $S = 1 + \alpha \cos 2\pi t/Q$ have an Olbers-like relation to each other with respect to the observer. That is to say, every kind of object which exists equally in each oscillation will relate between successive oscillations like objects in Euclidean space. This kind of behavior is well-known to apply over a limited range of flux to the counting of radio sources in surveys at frequencies from about 1.4 GHz downwards, for which there is little intergalactic absorption. The range of flux in question is from $\sim$ 2 Jy down to about 0.1 Jy. Eventually, however, the number of oscillations which the observer penetrates back in time become sufficient for the factor $\exp t/P$ to become significant, when an Olbers-like cut-off occurs, causing the radio source counts to fall away below a Euclidean level, as is observed for fluxes falling below 0.1 Jy. This is why the model can explain the broad features of the radio source counts.

5.1. The value of ρ_0

To determine ρ_0 we have no simple relation like $\rho_0 = 3H_0^2/8\pi G$ in the closure model of Friedmann cosmology. Instead, we have equation (18) in which we can write $A/S^3 = (8\pi/3)G\rho_0(S_0/S)^3$. Equation (18) can be simplified by noticing that the $-B/S^4$ term is important only near the minimum phase of each oscillatory cycle, and that with $t = 0.85$ at the presentday we are not near such a phase. Hence to a good approximation the $-B/S^4$ term can be omitted when (18) is applied from the presentday to the next maximum at $t = 1$ (t in units of Q), when we have

$$\frac{\dot{S}^2}{S^2} = \frac{8\pi G\rho_0}{3}\left(\frac{S_0}{S}\right)^3 + \frac{1}{3}\lambda\,. \tag{19}$$

Also neglecting the slight variation of $\exp t/P$ over the current half-cycle,

$$\frac{S_0}{S} = \frac{1 + 0.75\cos 1.7\pi}{1 + 0.75\cos 2\pi t} \tag{20}$$

in which $\alpha = 0.75$ and $t_0 = 0.85$ are used. Applying (19) and (20) at $t = 1$, the next maximum when $\dot{S} = 0$, the value of ρ_0 is related to λ by

$$\lambda = -0.558\pi G\rho_0\,. \tag{21}$$

Substituting λ given by (21) in (19) now gives

$$\frac{\dot{S}^2}{S^2} = \frac{8\pi G}{3}\rho_0\left[\left(\frac{S_0}{S}\right)^3 - 0.558\right]\,. \tag{22}$$

Since $\dot{S}^2/S^2$ at $t = t_0$ is H_0^2 we therefore get

$$0.442\rho_0 = \frac{3H_0^2}{8\pi G}\,, \tag{23}$$

the coefficient 0.442 being appropriate only for the present moment $t_0 = 0.85$. Putting $H_0 = 64.7\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$, ($Q = 40\ 10^9$) (HBN 1994) determines the presentday average cosmological density as

$$\rho_0 = 1.79\,10^{-29}\ \mathrm{g\,cm^{-3}}\,. \tag{24}$$

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5.2. The mass of the universe

It is often convenient to refer to a quantity which is called the "mass of the universe". In an open cosmology, there is, of course, no such literal finite mass. So a restriction on the spatial extent of the "mass of the Universe" is needed. The restriction is sometimes considered to be the range of observation, but this is not suited to precise discussion since the range of observation varies with the waveband used and with the instruments available. In Big-Bang cosmology there is an ideal limit to the range of observation, however, which although not attained in practice, is a useful concept. Such an ideal concept applied here would lead to an infinite mass, however, and a restriction must therefore be applied in some other way. We take it to be the mass of material, in principle observable, back to the last minimum of $S(t)$ at $t = 0.5$. The spatial volume back to the last minimum is

$$4\pi \int_0^{0.9572} \frac{r^2}{(1+z)^3} \mathrm{d}r \quad , \tag{25}$$

in which the factor $(1 + z)^{-3}$ converts coordinate volume to proper volume. Tables given in HBN 1994 show that the r-coordinate in units of cQ of an object observed at the last minimum must be 0.9572. The tables relate z to r, permitting (24) to be evaluated numerically, with the result 0.0916 for the volume back to the last minimum in units of $(cQ)^3$. In conventional units the volume is

$$0.0916(cQ)^3 = 0.0916 \left(\frac{2.646}{H_0} c\right)^3 = 4.94\, 10^{84}\, \mathrm{cm}^3 \, . \tag{26}$$

Multiplying (26) by (24) for ρ_0 gives the total mass of material observed back in the last minimum,

$$8.84\, 10^{55}\, \mathrm{g} = 4.44\, 10^{22}\, \mathrm{M}_\odot \, . \tag{27}$$

5.3. The rate of creation of mass

To maintain the mass given by (27) at a steady level cycle after cycle against the expansionary factor $\exp t/P$ in $S(t)$ it is necessary that creation of matter supply an amount given by (27) every $P/3Q$ cycles. With $P/Q = 20$ the requirement is for a creation rate back to $r = 0.9572$ of

$$6.67\, 10^{21}\, \mathrm{M}_\odot \text{per cycle} \, . \tag{28}$$

If creation occurs largely near oscillatory minima, then (28) is the needed amount of creation occurring near $t = 0.5$ for the coordinate range $0 \leq r \leq 0.9572$, or with the relation between r and z given by the tables of HBN 1994, (28) gives the amount of creation which occurred back to a redshift $z = 4.86$ at the last oscillatory minimum.

6. The properties of galaxies

We have two timescales, $Q = 40\, 10^9$ years and $P = 8\, 10^{11}$ years. In the standard big bang cosmology with $\Omega = 1$ the only timescale is $2/3H_0 = 13\, 10^9$ years for $H_0 = 50\, \mathrm{km\, s^{-1}\, Mpc^{-1}}$ and it is necessary to show that the ages of the oldest stars are no greater than this, and that galaxies can be formed and evolve to their present stages in this time. On the other hand in our theory we have *chosen* $Q/2$ to be of the order of H_0^{-1}, but galaxies and stars can clearly be older than this.

In fact, it is immediately obvious that with the longer time scale $\sim P$, it will be natural for a much larger fraction of the stars to evolve and die. Whole galaxies may do the same. Thus it is clear that much of the matter will be dark and will naturally be of baryonic form. In the following discussion we describe some of these effects in more detail.

6.1. Faint galaxies

The apparent luminosity of a galaxy of radial co-ordinate r and intrinsic luminosity L observed at a redshift z is given by

$$\sim \frac{L}{4\pi r^2} \frac{1}{(1+z)^2} \frac{1}{S^2(t_0)} \tag{29}$$

Putting $rS(t_0) \simeq cH_0^{-1} \simeq 2\, 10^{28}$ cm, $z = z_1 = 5$, a galaxy of absolute magnitude –21 would thus be observed with an apparent bolometric magnitude of about +27. Since this is within the range of observation it follows that galaxies with still larger values of r should also be observable, such galaxies having an emission time t that occurred in the previous universal oscillation. For those where emission occurred at the last oscillatory maximum there would be a blueshift with $S(t) > S(t_0)$ in (29). If we suppose that at the present we are not far from maximum phase, the blueshift will be comparatively small, and the second factor in (29) will be greater than unity but not greatly so. With $rS(t_0) \simeq 5\, 10^{28}$ cm in such a case, the apparent bolometric magnitude of a galaxy of absolute magnitude –21 would be somewhat fainter than +26 if absorption of a magnitude at the last oscillatory minimum is included. The theory thus predicts that a multitude of blue galaxies should be observed at about this brightness level, some indeed with spectrum lines that are blueshifted rather than redshifted. The blueness is not an intrinsic property of the galaxies themselves but arises from the oscillatory character of the scale function $S(t)$ together with there being many oscillations occurring in the characteristic expansion time $P \simeq 10^{12}$ years of the universe, and with there being little change of the universe from one oscillation to the next.

Thus the prediction is that faint blue galaxies will appear in profusion at faint magnitude levels. Other explanations of this *observed* phenomenon have been proposed (cf Koo and Kron 1992) but here we have an explanation which comes naturally out of the cosmological model.

Also in this model the universe changes much more slowly than had hitherto been supposed since the appropriate timescale

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is determined by P. Some 5-10 exponentiations of the scale factor $S(t)$ are required to expand an initially local situation with a dimension of a few megaparsecs to dimensions ~ 3000 Mpc. In terms of the galaxies we observe, the average age is $P/3 \sim 3\,10^{11}$ years, while the ages of the oldest objects at the limit of observation are $5 - 10P \approx 10^{13}$ years. Clusters of ellipticals like the Coma cluster may well have ages intermediate between these values, i.e. $\sim 2.10^{12}$ years. On this basis we would expect that a large part of the mass will be in the form of evolved stars, not only white dwarfs, neutron stars or black holes but also dead stars with $M < 0.5\,\mathrm{M}_\odot$, including brown dwarfs. Some part of this may be in the form of completely evolved galaxies.

6.2. The timing of creation events in individual galaxies

The oscillatory creation field, being scalar, consists of massless bosons, say of presentday energy $\hbar\nu_0$. At a general phase of the cosmological cycle the energy would be $\hbar\nu_0 S(t_0)/S(t)$, the bosons becoming more energetic towards minimum phase of the cycles. When such a boson falls to distance R from the center of a spherically symmetric mass M its energy is augmented by the factor $(1 - 2GM/c^2R)^{-1/2}$. When the mass M approaches sufficiently close to the event horizon at radius $2GM/c^2$ this factor becomes large enough for the creation condition obtained in HBN 1993 to become satisfied, viz

$$\hbar\nu_0 \frac{S(t_0)}{S(t)} \left(1 - \frac{2GM}{c^2R}\right)^{-\frac{1}{2}} = \text{Planck mass}\,. \tag{30}$$

The time interval as seen in the outside world for such a fall, and the time interval as seen for an outburst from the object, assumed to have reached a radius through contraction no larger than R, is

$$\frac{2GM}{c^3}\left(1 - \frac{2GM}{c^2R}\right)^{-\frac{1}{2}} \simeq 10^{-5}\frac{M}{\mathrm{M}_\odot}\left(1 - \frac{2GM}{c^2R}\right)^{-\frac{1}{2}}\text{s}. \tag{31}$$

Substituting for $(1 - 2GM/c^2R)^{-\frac{1}{2}}$ in (31) from (30) the time interval is

$$\frac{\text{Planck mass}}{\hbar\nu_0}\frac{S(t)}{S(t_0)}.10^{-5}\frac{M}{\mathrm{M}_\odot}\text{seconds}\,, \tag{32}$$

a time that is shortest at phases of the oscillatory cycles when $S(t)$ is least, i.e. at minima where for $\alpha = 0.75, t_0 = 0.85$, (32) becomes

$$\sim 1.6\,10^{-6}\frac{M}{\mathrm{M}_\odot}\,.\,\frac{\text{Planck mass}}{\hbar\nu_0}\,\text{seconds}\,. \tag{33}$$

If (33) is comparable or greater than Q, the creation event associated with a mass concentration M must tend strongly to occur near a minimum phase of the cycles of $S(t)$. But if (33) is appreciably less than Q, the shortening of times towards minimum phase will not matter much so far as the average occurrence of outbursts per unit time is concerned. This will be controlled by the frequency with which objects of mass M fall close enough to their event horizons. Probably such infalls will still be concentrated towards minimum phases, however, because the average cosmological density is then greatest. Either way, minimum phases are favored for the occurrence of creation events.

The numerical condition for (33) to be of order $Q \simeq 1.26\,10^{18}$ seconds is

$$\frac{M}{\mathrm{M}_\odot} \simeq 10^{24}.\frac{\hbar\nu_0}{\text{Planck mass}}\,. \tag{34}$$

Unfortunately $\hbar\nu_0$ is not known and so (33) has to be used empirically. In particular, observations of relatively nearby galaxies show violent events on mass scales up to perhaps $10^9\,\mathrm{M}_\odot$ but not up to the masses of major galaxies, suggesting that creation events involving large masses, say upwards of $10^{12}\,\mathrm{M}_\odot$, occur only near oscillatory minima, and implying that $\hbar\nu_0$/Planck mass may be less than $\sim 10^{-12}$.

What does matter emerging from a creation event in a galaxy look like? Two possibilities suggest themselves depending on the mode of contraction of the object that triggers the creation event:

1. The object is rotating and it evolves slowly compared with an object in free fall. Creational instability occurs first at the boundary of the object in its equatorial regions. However, using the Kerr metric, the equatorial regions lie in the ergosphere from which escape does not occur (Chandrasekhar 1983). The metric is such that only at the poles of rotation, where the ergosphere shrinks to zero, can escape take place. Thus expelled material would be expected to be in nearly-collimated polar jets, a situation that may well apply to radio sources.

2. The object is nearly spherically symmetric and it collapses in nearly free fall, a situation leading to explosive creation since negative pressures tend to infinity as the object approaches an event horizon (HBN 1993). Although in some cases, particularly when the mass of the object is not large, the creational outburst may be violent at speed $\sim c$, observation suggests otherwise for masses of order of a galaxy or greater. It appears that the internal solution for the object imitates the behavior of the universe at large, according to a scale factor of the form of (2). That is to say, the object oscillates, expanding generally at each oscillation. Unlike the universe, however, which can go on-and-on in such a solution, a local object eventually comes apart as a dispersing mass of gas. The situation is analogous to that for an over-stable star, the oscillations building up until eventually the star comes apart.

Suppose a creation event of mass $\mathscr{M}$ occurs at the center of a galaxy of mass M, and let the event be analogous to an over-stable star, with the mass $\mathscr{M}$ coming apart at speed v small compared to c. A star at distance R from the galactic center experiences an acceleration $\sim G\mathscr{M}/R^2$ from the created mass that is operative for a time $\sim R/v$, the speed v being sufficiently high as not to be much affected by the gravitational field of the

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galaxy, say $v \simeq 1000\,\mathrm{km\,s^{-1}}$. What happens if

$$\frac{G\mathscr{M}}{Rv} > \left(\frac{GM}{R}\right)^{1/2} ? \tag{35}$$

In this case the previously existing disk of stars at distances up to ~ 15 kpc from the galactic center, in stable orbital motion before the creation event, will be shattered by the effect of the ejection, with the stars eventually being sprayed outwards to form either an extensive halo or expelled altogether into extragalactic space.

Our picture is that in each oscillatory cycle of the universe newly-created gaseous material falls into the inner 15 kpc of a galaxy to form a stellar disk. This is following on a catastrophic creation event of the type described above, when the emergence of a large mass $\mathscr{M}$ from the galactic center expelled the previously-existing disk out into intergalactic space. On this picture, the presently observed visible disks of galaxies consist of stars that were formed close to the last oscillatory minimum, i.e. a time $(0.85 - 0.5)Q = 14\,10^9$ years ago for $Q = 40\,10^9$ years. Stars now in the halos of galaxies are mainly an additional Q years older, i.e. they have ages of $50 - 60\,10^9$ years or more. Only small stars with masses $\lesssim 0.5\,\mathrm{M}_\odot$ or less can have maintained faint luminosities over time scales as long as this.

Thus we would expect galaxies to contain stars covering a wide range of ages. There are already indications of this. For example there is considerable evidence that at the galactic center in the region of Sgr A there is a cluster of massive stars ($\sim 50\,\mathrm{M}_\odot$) with high velocity dispersion ($\sim 200\,\mathrm{km\,s^{-1}}$) (Krabbe et al. 1991). These can have lifetimes only $\sim 10^6$ years. It is natural to argue that creation at a very low level is continuously going on at the galactic center and they are a result of this.

And of course we have long had evidence from observations in our own Galaxy that a range of stellar evolutionary ages all the way from 10^8 years for young galactic clusters to $15 - 20\,10^9$ years for the oldest globular clusters is present.

In other galaxies also more than one time scale is suggested from the ages of star clusters. Some globular clusters in other galaxies appear from their colors to be as old as $15 - 20\,10^9$ years. On the other hand, young globular clusters with ages $< 10^{10}$ years are found in the LMC and in NGC 1275 (Holtzman et al. 1992), while both of these systems contain much older stars. This again suggests that the young systems come from the present cycle, and the old systems come from the preceding cycle or cycles.

We can also explain the different time scales which come from nuclear cosmochronology of isotopes in our own Galaxy. The Re/Os chronometer indicates a time scale of $15 - 20\,10^9$ years (Clayton 1988), while the $^{235}U, ^{238}U$ chronometer when taken alone gives the shorter time scale $\sim 7\,10^9$ years. We can now understand this by supposing that the uranium chronometer refers to r-process elements produced in the current oscillation half cycle, while the rhenium-osmium chronometer with a longer half-life is associated with the previous oscillatory cycle.

6.3. Stars in the galactic halo

The recent report of the detection of possible micro-lensing events (Alcock et al. 1993, Aubourg et al. 1993) in the halo of our Galaxy is very interesting. While the data are very preliminary they suggest that the individual stars involved may have masses $\lesssim 0.1\,\mathrm{M}_\odot$ which would agree very well with our earlier discussion showing how stars from the interior of the galaxy can be ejected out into the halo through explosive creation.

6.4. The stellar luminosity function and the mass-to-light ratios of galaxies

From observation we know that the masses of the stars range from $\sim 0.08\,\mathrm{M}_\odot$ (Burrows & Liebert 1993) to about $100\,\mathrm{M}_\odot$. This range of masses is expected theoretically, since for masses $\sim 10^{-3}\,\mathrm{M}_\odot$ (the mass of Jupiter) the star will never get hot enough to generate nuclear energy while above $\sim 10^2\,\mathrm{M}_\odot$ stars are unstable and will not form. Stars with mass $\sim 1\,\mathrm{M}_\odot$ have evolutionary time scales $\sim$ half an oscillatory cycle. Thus as we have already mentioned, we naturally expect there to be large amounts of baryonic dark matter. This can arise:

(a) from normal evolutionary processes involving *many* generations of stars in the range $1 - 100\,\mathrm{M}_\odot$, and a larger contribution from stars with $M < 1\,\mathrm{M}_\odot$ if several oscillatory cycles are involved,

(b) the possible condensation of objects with masses $\leq 10^{-3}\,\mathrm{M}_\odot$,

(c) the possible formation of very massive objects $\gg 100\,\mathrm{M}_\odot$ by the creation process.

Whether or not (c) makes any significant contribution, (a) and (b) will naturally give values of M/L greater than those expected in a big-bang model, where the total timescale available is only $\sim H_0^{-1}$.

In terms of stellar classification we can distinguish three groups.

(i) Stars of types F and earlier with lifetimes shorter than Q,

(ii) dwarfs of types M to G with masses from $\sim 0.5\,\mathrm{M}_\odot$ to $\sim 1\,\mathrm{M}_\odot$ with lifetimes of order Q,

(iii) dwarfs of mass $\sim 0.1\,\mathrm{M}_\odot$ with lifetimes much longer than Q.

It is well known that the values of M/L_B for spiral galaxies out to the Holmberg radius range from values near 4 with a considerable scatter for late-type spirals to ~ 10 for early type spirals (Faber & Gallagher 1979, Fig. 3) while for the luminous parts of ellipticals $M/L_B \sim 10$. If we also take into account the massive halos that are required around spirals to explain their flat rotation curves to central distances of ~ 50 kpc the value of M/L_B increases to 20-40, while if massive halos are present in ellipticals M/L_B for them rises to a comparable value. On the supposition that the material of galaxies is wholly stellar these high values require (iii) to be the dominant component. Even higher values ~ 100 or more for M/L_B are required for bound clusters of elliptical galaxies, suggesting that the intergalactic material in such clusters may be wholly of type (iii).

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The simplest possibility for explaining the genesis of stars is to suppose that they all come from essentially the same process. The three classes (i), (ii), (iii) are only an illustrative approximation to a single mass function. This is a strange mass function, with the overwhelming majority of mass $\sim 0.1\,M_\odot$ or less, a small fraction attaining the masses of M and G dwarfs, $(0.5 - 1.0\,M_\odot)$, and a still smaller fraction of more massive stars. The star formation process needs to be overwhelmingly egalitarian on the one hand, and strongly elitist on the other. The difference here from the way the situation has been viewed in the usual theory is that in that picture M and G dwarfs were previously thought of as egalitarian, but here they are elitist. We can think of at least two ways to understand this each of which we shall consider in detail elsewhere. We discuss them briefly below.

6.5. Accretion

The earliest form of the stellar accretion theory (Hoyle & Lyttleton, 1939) is a process with properties of a kind that appear to fit this picture. Suppose that stars form in a cloud of density $\sim 10^{-20}\,g\,cm^{-3}$ with a diameter $\sim 1pc$, the stellar masses being typically $\sim 0.1\,M_\odot$. Their motions relative to the gas will in general be $\sim 10\,km\,s^{-1}$, but by chance aided by gravitational viscous damping a small fraction will be expected to have motions v appreciably less than this, say $v \sim 3\,km\,s^{-1}$. It is these exceptional cases that grow in mass significantly by accretion, doubling their initial mass M_0 say in a time $v^3/(8\pi G^2\rho M_0)$ which for $M_0 \simeq 0.1\,M_\odot, v = 3\,km\,s^{-1}$, $\rho = 10^{-20}\,g\,cm^{-3}$ is $\sim 3\,10^9$ years, i.e. a time of the order occupied by the minimum phase of a universal oscillatory cycle in our cosmological model. And the time required for the mass to grow to a value much larger than M_0 is twice this, $v^3/4\pi G^2\rho M_0$. It is this feature of the accretion process, that the time for a large increase of mass is only twice the time for a doubling of the mass, that is one of the two reasons to bring back into the picture an argument that has been forgotten over the period since it was first proposed. It is a process of the winner-takes-all kind, with the few stars that first grow to appreciable mass taking the entire supply of gaseous material, giving rise to a cluster of stars, most with small mass, and a few with appreciable mass in a long extended tail, such a mass distribution as appears to be required in order to explain (i), (ii) and (iii). Then over the time-scale $\leq Q$, such clusters of several hundred stars mostly become disrupted and form part of the general galactic disk.

The second reason for considering this process seriously is the following. Stars forming generally in the cloud will be separated by distances of a few times 10^{17} cm. Over $\sim 10^9$ years there will be a very large number of dynamical encounters between them, occasionally leading to physical pairs, triplets and occasionally higher multiplicities being formed. Dynamical encounters in the absence of accretion would make such associations only temporary, and they will easily be disrupted. But in a multiple system, say an incipient binary system with both components growing by accretion, something dramatically different happens. Since accreted material will on the average have essentially no systematic angular momentum about the center of mass of an incipient multiple system, the effect of accretion is to cause the components to draw together, with their separations decreasing as the cube of the mass for the case in which the components grow equally. Thus a binary initially with separation 10^{17} cm and components of mass $0.1\,M_\odot$ draws together to a separation of 10^{14} cm should its components grow by accretion to $M_\odot$. The well-known circumstance that the majority of M to F dwarfs are members of multiple systems is thereby explained. As far as we are aware no convincing alternative for explaining the origin of multiple systems has been made. The growth of mass to $\sim 5\,M_\odot$ means that the separation will shrink to $\sim 10^{12}$ cm, the scale of a spectroscopic binary.

6.6. Formation through a disk

There is an interesting alternative to this point of view. If $\sim 10^{11}\,M_\odot$ of gas is acquired by the inner regions of a galaxy, subsequent to an explosive event that robbed the inner regions of previously existing stars in the manner described earlier, but with an appreciable amount of dusty debris still around, the gas is likely to cool and to form a thin rotating disk. The maximum possible cooling is that dictated by the microwave background and will be $T_{min} \simeq 2.73(1 + z_{min})$ at an oscillatory minimum where we consider the present situation to be most likely to arise. Since $z_{min} \simeq 5, T_{min} \simeq 16\,K$, the thickness of a disk at this temperature would be $\sim \mathscr{R}T_{min}/\sigma G$, where $\mathscr{R}$ is the gas constant and σ the mass per unit surface area of the disk, perhaps $\sim 1\,g\,cm^{-2}$. This implies that an extraordinarily thin cool disk with thickness $d \sim 10^{16}$ cm will try to form. Now while rotary forces prevent the shrinkage of the disk perpendicular to the axis of rotation, rotation will not prevent condensations from forming on the scale of the thickness of the disk, with masses of the order of $\sigma d^2 \simeq 0.1\,M_\odot$ Then the stars required in (ii) and (iii) might be formed at places in the disk where σ happened to be $\sim 10^{-1}\,g\,cm^{-2}$ or less, thereby explaining (i), (ii) and (iii) all coming from the breakup of a thin disk. Ultimately after several major events, a disk of much greater thickness would result if each thin disk had a somewhat different direction for its angular momentum vector.

7. Conclusions

In the three studies so far completed (HBN 1993, 1994 and this paper) we have attempted to develop an alternative (the QSSC) to the standard cosmological model which is so widely popular at present.

What are the real differences between the two approaches and the relative strengths and weaknesses. What are the similarities?

In both theories the creation of matter is required. We believe that by using the C-field approach our theory allows creation through a field of negative energy described by a physically motivated action principle, whereas in the standard model the creation process is excluded from discussion. In both theories the redshifts of the galaxies are assumed to be due to expansion.

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In the standard Friedmann model the expansion obtained its energy in the big bang whose origin has never been explained. In the QSSC the expansion is maintained by many smaller outbursts whose dynamics can be explained through relativity.

These mini-creation events are potentially detectable by the proposed gravity wave detectors. This has been discussed by DasGupta & Narlikar (1993) who have also shown that the gravity wave background generated by such events may have a detectable effect on the timing of millisecond pulsars. In the standard model the abundances of some of the light isotopes are produced in the early fireball, but for others more complicated processes including spallation from cosmic rays is invoked. In our theory we have shown that all of the light isotopes can be synthesized in the decay of Planck particles.

In the simplest version of the standard model the production of the light elements requires that the density of the baryonic matter involved is only a fraction of the closure density. Thus it has become fashionable to argue that much of the matter is of non-baryonic form. In QSSC we also expect dark matter but it is made up of baryons. Also in QSSC we have a very long time scale $\sim 10^{12}$ years for the overall expansion of the universe so that we naturally expect that a large fraction of all of the stars will have evolved and died thus naturally giving rise to a large proportion of dark baryonic matter.

We turn again to the microwave background radiation. The fact that it was predicted to be present in the classical Friedmann cosmology is an argument in favor of that theory. Also the radiation arises naturally in the hot cloud and cools maintaining its blackbody form. At the same time no prediction of the temperature is given by that theory. On the other hand we have pointed out that the energy released in the burning of hydrogen to helium of the visible matter in the universe gives rise to black body radiation with almost exactly the temperature which has been measured. This would be a pure coincidence if the Friedmann model were correct, but within the framework of QSSC it very strongly suggests that the microwave background is due to hydrogen burning in stars. The degradation of the radiation must be due in our theory to dust, particularly in the form of very long thin iron needles. While they have not yet been discovered in the cosmos, their properties in the laboratory are well understood and the calculation of their scattering properties shows that the mechanism is plausible (HBN 1994). The iron is synthesized in supernovae. In our theory the curve will deviate from strict black body form at long wavelengths (HBN 1994). Also it may be possible to test our theory by attempting to measure the radiation in the GHz region in radio sources with high z. We showed in HBN 1994 that all of the measurements so far available are consistent with the theory.

Another possible cosmological test of QSSC can be made since we have also shown (HBN 1994) that a fraction of the radio sources of the previous minimum of the last cycle will have small blueshifts.

Another very important aspect of our theory which has only so far been discussed comparatively briefly in these three papers is the fact that creation processes taking place in regions of high density in galaxies can explain in a natural way the explosive phenomena in galaxies and QSOs which have been the subject of much discussion for the last 25 years. While this is the area in which much work needs to be done, we believe that our attempt to put into quantitative form the ideas of Ambartsumian (1958, 1965) who argued from the observations that matter was being formed and was exploding out from galaxies, is valuable. Because of the refusal of the mainstream theorists to consider possible theories of the creation of matter astrophysicists have been condemned over the last two decades to follow the logic required if it is assumed that the energy released by exploding objects is gravitational energy released very close to the Schwarzschild radius. This has led to an almost complete belief in the blackhole–accretion disk paradigm which has never been tested, but only assumed. The accretion theory, while it is continuously being used has not been shown to have any predictive power.

The Friedmann model has nothing to offer in the area of cosmogony. Initial condensations have to be *assumed*. From them galaxies form, gradual shrinkage and collapse takes place, and then a massive black hole is formed and an accretion disk. But this remains a sketch without quantitative detail. It should always be remembered that in the universe we see, matter is always expanding away from centers and rarely if ever falling in. Occam's razor might therefore suggest that Ambartsumian, and before him Jeans (1929), was right. If that is the case this is a very strong argument for the cosmogony embodied in the QSSC.

While much work needs to be done we believe that we have put the QSSC on a sufficiently firm footing for progress to be made. The next task is to try to do much more detailed modelling of galactic explosions on the one hand and to see if within the framework of this theory we can begin to understand the large scale distribution of galaxies.

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