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The quasi-steady state cosmology: Theory and observations

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Abstract. This is a review of an alternative cosmology, recently proposed by Fred Hoyle, Geoffrey Burbidge and this author. It begins with a brief discussion of why one needs an alternative cosmology, when the standard hot big bang cosmology is claimed to be doing well. It is argued that the observational and theoretical constraints on the standard big bang cosmology, from various directions, leave a very narrow window, if any, in the parameter space of plausible models. There is thus a strong case for alternative cosmologies. The rest of the review concentrates on one alternative, the quasi steady state cosmology (QSSC) and summarises the recent work on this model. This includes, the theoretical formulation and simple exact solutions of the basic equations, their relationship to various observations, the stability of solutions and the toy model for understanding the growth of structures in the Universe.

Keywords. Gravity; alternate theory; cosmology.

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1. Introduction

The quasi-steady state cosmology (QSSC hereafter) was proposed in 1993 by Fred Hoyle, Geoffrey Burbidge and myself [1]. The observational and cosmogonic issues were discussed by us in two following papers [2,3]. The basic theoretical framework was laid down the following year [4]. Sachs *et al* [5] studied the exact solutions of the basic equations that give simple homogeneous and isotropic models. The production of light nuclei have been discussed by Hoyle *et al* [6] and by Burbidge and Hoyle [7]. Narlikar *et al* [8] have discussed the details of an alternative mechanism for generating and maintaining an isotropic Planckian radiation background. More recently, observational tests like the angular size-redshift relation and the magnitude-redshift relation in the QSSC were discussed by Banerjee and Narlikar [9] and by Banerjee *et al* [10]. The stability of the QSSC model for small fluctuations of density and creation process was demonstrated by Banerjee and Narlikar [11], while Ali *et al* [12] have shown how an elementary understanding of the process of structure formation in this cosmology can be achieved through a toy model. These results indicate the progress achieved by this model towards offering a viable alternative to the standard hot big bang cosmology. But before proceeding towards this task it is perhaps necessary to say why an alternative is being considered when, it is commonly believed that the standard cosmology offers a good approximation to the actual Universe.

I shall begin by questioning this premise. Recent observational checks on the standard model do not leave any reason for such a complacency. As was discussed by Bagla *et al* [13], the constraints of the Hubble constant, the ages of globular clusters, the existence of high redshift objects, the abundance of rich clusters and the deuterium abundance make it impossible for the hot big bang model with inflation and no cosmological constant to survive. Even granting the existence of a nonzero λ, the window of permissible values for H_0 and Ω_0 is very small and may altogether disappear if one takes seriously, the constraints from gravitational lensing. A non-zero λ is indeed indicated by the Type IA-supernova related magnitude-redshift relation [14,15]. The problem with such an 'inflation-induced' λ is to understand *why* only an extremely tiny $(\sim 10^{-108})$ fraction of the inflationary λ was left over after the epoch of graceful exit. This problem has been pointed out by Weinberg [16], as an instance of 'fine-tuning'.

Hence the standard model with or without λ is in trouble and it is therefore not premature to give some consideration to alternative cosmologies. Even so, any alternative proposed must do at least as well as the standard model, if it is to be taken seriously. In particular it must satisfy the following conditions:

1. It must explain the redshift magnitude relation for galaxies, the observations of counts of radio sources and galaxies, the data on angular size redshift relation and the evidence on the variation of surface brightness of galaxies with redshift.
2. It must give a theory for the origin of the microwave background, including its observed spectrum, isotropy and small scale inhomogeneities.
3. It must account for light nuclear abundances which cannot be otherwise understood within the framework of stellar evolution.

Having done so, the alternative cosmology may seek to explain other aspects of the large scale Universe where the big bang has so far proved inadequate. These include the elimination of a singular beginning, the problem of accommodating old stellar populations, an understanding of dark matter, and the origin of large scale structure.

Finally, the new cosmology should offer predictions that distinguish it from standard cosmology so that observational tests may be designed to find out which cosmology is right, or at least, closer to reality.

Here I will try to make a case that the QSSC does offer a serious alternative when judged by the above criteria.

2. The basic theory

The basic theory for the QSSC is the Machian theory of gravity first proposed by Hoyle and Narlikar [17,18] in which the origin of inertia is linked with a long range scalar interaction between matter and matter. Specifically, the theory is derivable from an action principle with the simple action:

$$\mathcal{A} = -\sum_a \int m_a \mathrm{d}s_a, \tag{1}$$

where the summation is over the particles in the Universe, labelled by a, the mass of the ath particle being m_a. The integral is over the world line of the particle, ds_a representing the element of proper time of the ath particle.

The mass itself arises from interaction with other particles. Thus the mass of particle a at point A on its worldline arises from all other particles b in the Universe:

$$m_a = \sum_{b \neq a} m^{(b)}(A), \tag{2}$$

where $m^{(b)}(X)$ is the contribution of inertial mass from particle b to any particle situated at a general spacetime point X. The long range effect is Machian in nature and is communicated by the scalar mass function $m^{(b)}(X)$ which satisfies the conformally invariant wave equation

$$\Box m^{(b)} + \frac{1}{6} R m^{(b)} + [m^{(b)}]^3 = N^{(b)}. \tag{3}$$

Here the wave operator is with respect to the general spacetime point X. R is the scalar curvature of spacetime and the right hand side gives the number density of particle b. The field equations are obtained by varying the action with respect to the spacetime metric g_{ik}. The important point to note is that the above formalism is conformally invariant. In particular, one can choose a conformal frame in which the particle masses are constant. If the constant mass is denoted by m_p, the field equations reduce to

$$R^{ik} - \frac{1}{2} g^{ik} R + \lambda g^{ik} = -\frac{8\pi G}{c^4} [T^{ik} - \frac{2}{3}(c^i c^k - \frac{1}{4} g^{ik} c^l c_l)], \tag{4}$$

where c is a scalar field which arises explicitly from the ends of broken world lines, that is when there is creation (or, annihilation) of particles in the Universe. Thus the divergence of the matter tensor T^{ik} need not always be zero, as the creation or annihilation of particles is compensated by the non-zero divergence of the c-field tensor in eq. (4). The quantities G (the gravitational constant) and λ (the cosmological constant) are related to the large scale distribution of particles in the Universe. Thus,

$$G = \frac{3\hbar c}{4\pi m_p^2}, \quad \lambda = -\frac{3}{N^2 m_p^2}, \tag{5}$$

N being the number of particles within the cosmic horizon.

Note that the signs of the various constants are determined by the theory and not put in by hand. For example, the constant of gravitation is positive, the cosmological constant negative and the coupling of the c-field energy tensor to spacetime is negative. A more complete picture of creation of matter which incorporates inputs from quantum theory, is needed in order to determine the coupling of the c-field to matter and to determine the rate of creation. What is described below is a somewhat empirical picture which is purely classical.

3. Matter creation

The action principle tells us that matter creation is possible at a given spacetime point provided the ambient c-field satisfies the equality $c = m_p$ at that point. In normal circumstances, the background level of the c-field will be *below* this level. However, in the strong gravity obtaining in the neighbourhood of compact massive objects the value of the field can be locally raised. This leads to creation of matter along with the creation of negative c-field energy. The latter also has negative stresses which have the effect of blowing the spacetime outwards (as in an inflationary model) with the result that the created matter is thrown out in an explosion.

We shall refer to such pockets of creation as *minibangs* or *mini-creation events*. A spherical (Schwarzschild type) compact matter distribution will lead to a spherically symmetric explosion whereas an axi-symmetric (Kerr type) distribution would lead to jet like ejection along the symmetric axis. Because of the conservation of angular momentum of a collapsing object, it is expected that the latter situation will in general be more likely.

In either case, however, the minibang is *nonsingular*. There is no state of infinite curvature and terminating worldlines, as in the standard big bang, nor is there a black hole type horizon. The latter because the presence of the c-field causes the collapsing object to bounce outside the event horizon.

4. The cosmological solution

The feedback of such minibangs on the spacetime as a whole is to make it expand. In a completely steady situation, the spacetime will be that given by the deSitter metric. However, the creation activity passes through epochs of ups and downs with the result that the spacetime also shows an oscillation about the long term steady state. Sachs *et al* [5] have computed the simplest such solution with the line element given by

$$\mathrm{d}s^2 = c^2\mathrm{d}t^2 - S^2(t)[\mathrm{d}r^2 + r^2(\mathrm{d}\theta^2 + \sin^2\theta\,\mathrm{d}\phi^2)], \tag{6}$$

where c stands for the speed of light and the scale factor is given by

$$S(t) = e^{t/P}\left[1 + \eta\cos\frac{2\pi\tau(t)}{Q}\right]. \tag{7}$$

The constants P and Q are related to the constants in the field equations, while $\tau(t)$ is a function $\sim t$ which is also determined by the field equations. For details see Sachs *et al* [5] (*op. cit.*). The parameter η may be taken positive and is less than unity. Thus the scale factor never becomes zero: the cosmological solution is without a spacetime singularity.

5. The observations of discrete source populations

5.1 *The parameters of QSSC*

We now consider the parameters of the theory that provide a direct contact with observations. Hoyle *et al* [2,3] have shown that the above cosmology gives a reasonably good fit to the observations of discrete source populations, such as the redshift-magnitude relation, radio source count, angular diameter-redshift relation and the maximum redshifts so far observed, with the choice of the following set of parameters:

$$P \approx 20Q,\ Q \approx 4.4 \times 10^{10}\ \text{yrs},\ \eta = 0.8,$$
$$\lambda = -0.3 \times 10^{-56}\text{cm}^{-2},\ t_0 = 0.7Q. \tag{8}$$

Of these, the last is the present epoch of observation. It is not essential that the model has only these parameters. Indeed, the parameter space is wide enough to make the model robust. Moreover, the fitting of observations to theory does not require postulating ad hoc evolution which is commonly necessary in the case of standard cosmology.

In order to compare the QSSC with the standard cosmology, it is convenient to recast some of the above formulae in terms of the various Ω-parameters for density, cosmological constant, creation field energy, and space curvature. We begin by defining the following parameters for the c-field:

$$\rho_c = -\frac{3}{4} f \dot{c}^2 \quad p_c = -\frac{1}{4} f \dot{c}^2. \tag{9}$$

Note that although the pressure and energy density are both negative, they follow the equation of state for disordered radiation, viz. $p = \rho/3$. This is hardly surprising when we note that the trace of the energy momentum tensor of the c-field has zero trace. For this reason, we also find that the dependence of ρ_c on S is the same as for radiation, namely $\rho_c \propto S^{-4}$. In the QSSC, the Universe is never radiation dominated, and so the radiation term is dominated by the c-field term. Thus, although, in principle it is possible to imagine a Universe in which the radiation term dominates over the c-field term, thereby producing a spacetime singularity as in the standard models, there is no such possibility here.

We further define the dimensionless parameters by the following formulae:

$$\Omega_0 = \frac{8\pi G \rho_0}{3H_0^2} \quad \text{density parameter},$$
$$\Lambda_0 = \frac{\lambda}{3H_0^2} \quad \text{cosmological constant parameter},$$
$$\Omega_{c0} = \frac{8\pi G \rho_{c0}}{3H_0^2} \quad \text{creation density parameter},$$
$$q_0 = -\left[\frac{S\ddot{S}}{\dot{S}^2}\right]_0 \quad \text{deceleration parameter},$$
$$K_0 = \frac{k}{H_0^2 S_0^2} \quad \text{curvature parameter}, \tag{10}$$

where, to avoid confusion we have set the velocity of light equal to unity. The suffix zero indicates that the quantity is evaluated at the present epoch. Note that the present value of the scale factor S_0 need not be equal to the scale parameter $\bar{S}$. We define the ratio

$$x_0 = S_0/\bar{S}. \tag{11}$$

In view of the field equations we have the following relations between these parameters:

$$\Omega_0 = 2K_0 {x_0}^{-1} - 4\Lambda_0 {x_0}^{-3}(1+\eta^2),$$

$$\Omega_{c0} = -K_0 {x_0}^{-2}(1-\eta^2) + \Lambda_0 {x_0}^{-4}(1-\eta^2)(3+\eta^2). \tag{12}$$

An observational constraint on the QSSC model is provided by the maximum redshift observable in the present cycle. Denoting it by $z_{\rm max}$ we arrive at the following relation:

$$x_0 = (1-\eta)(1+z_{\rm max}). \tag{13}$$

These relations show that the parameter η which describes the oscillatory part of the solution is related to the relative physical magnitudes of the three controlling agencies, matter, the c-field and the cosmological constant. In particular, if $\eta \to 1$, the model tends to have a singular state as in the big bang. The above relation shows that in this limit, the c-field term ceases to be effective in causing a bounce.

Corresponding to the relations in the standard cosmology, those connecting these dimensionless quantities in the QSSC are

$$1 + K_0 = \Lambda_0 + \Omega_0 + \Omega_{c0} \tag{14}$$

and

$$\Omega_0 = 2[q_0 + \Lambda_0 - \Omega_{c0}]. \tag{15}$$

For k=0, K_0=0, whereas for, say, $k = -1$ the parameter K_0 will be negative. At the maximum redshift ($z = z_{\rm max}$) we have the relation

$$0 = \Lambda_0 - K_0(1+z_{\rm max})^2 + \Omega_0(1+z_{\rm max})^3 + \Omega_{c0}(1+z_{\rm max})^4 \tag{16}$$

which is satisfied identically for all values of the parameters η and K_0.

5.2 *The angular size-redshift relation*

Recently, the angular size (θ)-redshift (z) relation has received special attention in the context of ultracompact radio sources. Kellermann [19], Gurvitz [20] and Jackson and Dodgson [21] have used the fact that an ultracompact VLBI-detected source, being deeply embedded in a radiosource will not be susceptible to evolutionary effects on its size arising from the changes in the intergalactic medium. Using such a population of high redshift ($z > 0$) objects they were able to argue that the dependence of angular size θ on redshift z can be used to constrain the cosmological models. While Kellermann (*op. cit.*) found the Einstein–de Sitter model (the standard $\Omega = 1$ model) consistent with his data, Jackson and Dodgson, with their increased database found the model giving a marginally good fit. They found that models with large negative cosmological constant give a better fit to the data.

Against this background, Banerjee and the author [9] have found that the QSSC model with the parameters described above gives a better (and very good) fit to the $\theta - z$ data. In particular, the flattening of the curve at large redshifts is in conformity with the data.

5.3 *The magnitude-redshift relation*

The one of the earlier QSSC papers [2] had worked out the $m - z$ relation, although at the time there was no great interest in that cosmological test. Recently, this test has become sharper, with the possibility of measuring distances of galaxies of large redshifts by observing the light curves of Type IA supernovae in them. The work of Riess [15] and Perlmutter *et al* [14] has shown that to obtain a good fit to the observed $m - z$ relation, the standard cosmology must have a substantial positive cosmological constant ($\Lambda_0 \sim 0.6$), playing a more dominant role in determining the spacetime curvature than the matter density parameter Ω_0 through the relation $\Omega_0 + \Lambda_0 = 1$ for the flat inflationary Universe. How does the QSSC fit the new data?

Preliminary work [10] shows the following results:

1. The simplest flat QSSC model gives a passable fit to the data. However, a model with negative spatial curvature gives a better fit.
2. Although the QSSC model has a *negative* Λ_0, it gives a good fit to the observed data, because the c-field has negative energy density and it leads to a repulsive effect akin to that produced by the cosmological constant.
3. The behaviour of the c-field in the immediate past crucially affects the theoretical $m - z$ relation. If we assume that matter is created in a sharply limited epoch at the minima of the oscillatory scale factor, then the c-field increases close to that epoch. If the creation is continuing, albeit at a reduced rate throughout the growing part of the oscillation, then the growth in the c-field is at a steadier rate and over a longer period. It is found that the latter mode gives a better fit to the data.

These studies illustrate the intimate connection between the creation process and the expansion of the Universe. A word of caution is, however, required, in the sense that the supernova method has not yet been fully debugged and systematic errors in distances measured therefrom could still be significant. The possible extinction by the whisker-like dust emitted by supernovae can also make them appear dimmer than their assumed luminosity, as pointed out by Aguirre (1999). This type of dust plays a crucial role in the thermalization of radiation leading to the observed microwave background, as we shall see next.

6. The microwave background

In the QSSC, the microwave background is the thermalized relic starlight left by stars which have burnt during the previous cycles. The present day stellar activity allows us to estimate the total star-burning activity during a typical cycle of duration Q. We can use it to work out the background energy that can be maintained at the same level from cycle to cycle. Thus if the energy density of radiation at a typical minimum-S state of a cycle is u, then the energy density at the end of the cycle to the next minimum state would be $u \exp(-4Q/P)$. For $P \gg Q$, the depletion is by an amount $\approx -4uQ/P$, and this has to be made up by the starlight energy produced during the cycle. Equating the two we can estimate the value of u at the minimum-S phase, and hence at the present epoch. It is very reassuring to find the present day temperature of the microwave background is close to 2.7 K. I may mention that the big bang cosmology does not predict the value of the present MBR temperature: its value is assumed as a given parameter for the big bang models.

But what about spectrum and isotropy? Although Hoyle *et al* [2] had discussed these issues, the case of the spectrum has recently been discussed by Narlikar *et al* [8] who have shown that iron whiskers of around 0.5–1 mm length and about 10^{-5}mm cross sectional diameter can act as efficient thermalisers of starlight without blacking out the extragalactic radio and optical Universe. The extinction properties are wavelength–dependent and the outcome is a spectrum of radiation that is Planckian out to wavelengths shorter than ~ 20 cm. Thus there is no conflict with the present observations. Whether the differences from the Planckian spectrum at long wavelengths are present cannot be decided at present as there is considerable contamination of data at these wavelengths from galactic radiation.

I should perhaps point out that an earlier criticism of a similar idea discussed in the context of the old steady state theory is not valid here. The criticism was based on the calculation of optical depth and the number of scatterings of starlight, and claimed that the observed close agreement to the Planckian spectrum could not be achieved this way. That criticism does not apply to the QSSC, as here the distance the radiation travels through in a typical cycle itself is much larger and the scattering takes place over many cycles.

Narlikar *et al* [8] have discussed the origin and evolution of the metallic whiskers and their detectability through various astronomical observations in the galaxy, in other galaxies as well as in radio sources. Thus the idea has applications that go beyond the explanation of the MBR. Recently, it has been pointed out that the excessive dimming of Type IA supernovae noticed in the $m - z$ test above could be due to the whiskers [22].

The prediction of large scale isotropy, subject to the dipole anisotropy due to the Earth's motion is consistent with observations. The COBE data on small scale inhomogeneities can also be understood as arising from more recent local contributions and also from the inhomogeneities of distribution of grains. The latter effect arises in this way. For a large enough temperature gradient between adjacent regions there will be a tendency towards equality through temperature gradients pushing the grains in the direction of regions of lower temperature. However, this effect stops when the ΔT is so small that the grains can no longer be pushed. This temperature fluctuation, which cannot be further smoothed out, is of the right order of magnitude.

7. The origin of light nuclei

The origin of light nuclei in this cosmology can be related directly to the decay products of the basic particle created. As seen from eq. (5), the basic particle has the Planck mass which is $\sim 10^{-5}$g, i.e., an energy equivalent of $\sim 10^{19}$ GeV. This particle is short-lived, with a time scale of $\sim 10^{-43}$s. What happens to its decay products? This is a problem for the high energy physicists to solve. It is worth pointing out that the energy regime of these developments is the same as that in the very early Universe. The difference is that in the QSSC, such events are of recurring nature, happening every time that there is a minibang; whereas in the standard cosmology this happened only once and that too at an epoch that cannot be directly observed. Thus on counts of both repeatability and observability the QSSC provides a physically more realistic scenario for the so-called astroparticle physics.

As is well known, the subject of high energy physics is currently passing through a state of flux, with several ideas ranging from quantum gravity, superstring theories, GUTs, phase transitions and cosmic strings, etc. There is no final TOE (theory of everything) in the offing yet. However, if one follows the standard model of particle physics, which so far is holding out well, then the generally accepted view leads to the group theoretic break-up at lower energies after the GUTs era, of $SU(3) \times SU(2)_L \times U(1)$. At this stage the final products will include the baryon octet, pions, photons and leptons.

Why not antibaryons? The answer is that the Universe is already in a broken symmetric state dominated by matter. Given this situation in a particular cycle, the subsequent creation and decay will propagate this broken symmetry to the next cycle. Thus, unlike the big bang cosmology where elaborate departures from symmetry (e.g. CP-violation) are needed to justify why the Universe, after a symmetric beginning, is matter dominated today, here the requirement is to understand how the broken symmetry propagates from one cycle to next. Inputs from particle physics are needed to understand this effect.

However, in the neighbourhood of a typical minicreation event the release of decay particles at high energy will establish a fireball with thermodynamic equilibrium. At temperatures very high compared to the rest mass energy of the baryons the eight members of the octet will be in equal numbers. Of these, all (six) except the neutron and the proton are very short lived and decay to protons whereas the neutron and the proton combine to form the helium nuclei. Thus the fraction by mass of helium will be close to 2/8, i.e., 0.25. More exact calculation considering the details of photons and other decay products will bring down the fraction to between 0.22 and 0.23. In addition the light nuclei like deuterion, lithium, etc., are also produced. The overall abundance distribution does agree very well with observations. For details see Hoyle *et al* [6].

The density and temperature regime for this nucleosynthesis is very different (higher by several orders of magnitudes) compared to that in the standard hot big bang nucleosynthesis, while the time scales are much shorter. The outcome is that a small quantity of metals are produced as well and the deuterium abundance is not so sensitively linked to the baryon density as in the standard hot big bang.

The abundance of metals in the early stages resolves one difficulty faced by workers in the field of stellar evolution, namely the evolution of massive stars. For such stars the C–N–O cycle cannot operate in a big bang cosmology since these elements are produced in stars later. To get round this difficulty in standard cosmology, massive Population III stars are postulated, which burn slowly on the p–p chain but do manage to produce some metals later. In the QSSC this problem does not arise.

More recently, however, Burbidge and Hoyle [7] have made a parsuasive case that all nuclei, light as well as heavy can be made in stars provided sufficient time is available. In the standard cosmology the stellar activity cannot be of longer than $\sim 10^{10}$ years duration, which is not enough to make the required helium. However, in the QSSC, the time scales are much longer and the observed abundance of helium can be explained as of stellar origin. They argue that the same holds for Li, Be, B isotopes as well as to ^{3}He. The deuterium production is still problematic in astrophysical terms, but these authors argue that with better understanding of stellar processes even this nucleus will fall within the astrophysical basket.

8. The nature of dark matter

Let me clarify that the dark matter problem takes on a different complexion in this cosmology. First, there is no restriction like $\Omega = 1$ in this cosmology and so the dark matter component need not be very high. The extent of dark matter has to be estimated from improved observations. In the big bang cosmology a restriction arises from the deuterium abundance which restricts the baryon density to $\Omega_{\rm baryon} <\sim 0.02$. In the big bang cosmology nonbaryonic matter is needed for another reason: to lower the temperature fluctuations of the microwave background to the low values observed. Neither of these reasons operate in the QSSC where the need for nonbaryonic matter is, therefore, not so compelling. Instead it is possible to argue that dark matter in galaxies arises from the relics of stars of previous generations or in the form of small planetary mass objects. In this sense the MACHO or EROS type observations carry a great significance.

9. The ages of galaxies and stars

The age problem which has assumed significance in the big bang cosmology does not cause any problem for the QSSC. Since the minima of the scale factors do not represent epochs of very high density, the stars and galaxies of previous cycles are able to survive into the present cycle. Thus very old stars (age much larger than the value H_0^{-1}, H_0 the present value of Hubble's constant) may exist. In fact, stars born during the previous cycles with masses around half a solar mass may just now be evolving off the main sequence. If such stars (with estimated ages in the range 40–50 Gyr) are found, it will be hard to maintain the standard cosmology.

10. Structure formation

I will conclude with a few remarks on structure formation in the QSSC. Unlike the big bang cosmology, where structures have to evolve out of primordial inhomogeneities which are put in by hand, here the problem is to reproduce the structure in the present cycle from what existed in the previous ones. Since the mini-creation events play a pivotal role in this cosmology, it is expected that new nuclei of creation would grow out of matter ejected from them.

Nevertheless, it is worth seeing first, as to how the gravitational instability grows in this cosmology. In a recent work by Banerjee and Narlikar (1997a) the following approach was taken. The metric, the density and the c-field were perturbed, and by restricting to only first order quantities, the changes in these perturbations were calculated in the background spacetime. Predictably, the density inhomogeneities grew during the contracting phase of an oscillation, and were damped during the expanding phase. Thus there was no significant instability in the solution. While this generates confidence in the robustness of the basic solution, it also forces one to look for non-gravitational effects to produce structure. The creation process provides a possibility.

In a recent attempt to understand how structures may grow and distribute in space the following numerical experiment suggested by Fred Hoyle was tried by H Nayeri, Engineer and the author [23].

A large number of points ($N \sim 10^5 - 10^6$) were distributed over a square area at random. Each point was made to produce a random neighbour within a specified fraction x of the average interparticle distance of the original set. The area was then scaled to twice the original size, so that the particle density remained the same. Then from the expanded area a central portion corresponding to the original area was retained, the rest being thrown away. With this new square the experiment was repeated.

Very soon, i.e., after three or four iterations, of the above procedure, clusters and voids began to appear in the picture and voids grew in size while the clustering became denser as the experiment was repeated. If the creation of the new neighbour B around a typical point A was not entirely random, but linked to previous history of creation of A, so that the direction AB was broadly aligned with the direction in which A had been ejected, then the filamentary structure grows along with voids. This latter alignment may be related to the spinning supermassive creation centre discussed in §3. Pictures generated this way show very suggestive similarity with the observed large scale structure.

The experiment has been repeated in three dimensions and slices of two dimensions examined for structures. Again these look remarkably similar to the filaments and voids found in redshift surveys.

These are preliminary attempts to come to grips with what is admittedly a formidable problem. Yet, the similarity of the pictures generated with relatively simple assumptions, with the actual large scale structure suggests that the approach is worth following up further. To bring the experiment closer to the dynamics of the QSSC, the initial cube is expanded by a factor $\exp(Q/P)$ in each direction and only a fraction

$$f = [1 - \exp(-3Q/P)], \tag{17}$$

of the original set of points is allowed to produce new neighbours. Preliminary work shows that filaments and voids begin to appear after a few iterations. What is more interesting is that the 2-point correlation function approaches the observed -1.8 power law in the case of the QSSC. These results [23] are encouraging enough to proceed further. It may be necessary to study how the structure produced in the beginning of a cycle at the minimum scale phase, develops during the cycle through gravitational clustering.

11. Future tests

This concludes a brief review of the recent work on the QSSC. It is clear that it does offer a prima facie alternative to the standard cosmology. More work is needed to study its implications in depth. However, progress on that front will necessarily depend on the human power available to tackle the problems.

To the oft-heard criticism from the standard cosmologists that alternatives like these unnecessarily involve 'new physics', I can only reply that the standard cosmology itself involves untested new physics, e.g., inflation at 10^{16} GeV, cosmic strings, non-baryonic dark matter, etc. The QSSC has brought in a scalar field not unlike that used in inflation, which itself finds echos in the 'bubble Universe' version of the old steady state theory [24].

I may conclude with a few tests which will set this cosmology apart from the hot big bang cosmology. These are:

(A) The discovery of a few objects (galaxies) with modest blueshifts of the order of 0.1. These belong to the previous cycle and will necessarily be faint.

(B) The discovery of a class of very old stars, e.g., faint white dwarfs, low mass giants, low mass horizontal branch stars, etc. which are far too old compared to the age of the big bang Universe.

(C) The finding of baryonic dark matter well above the limit tolerated by the big bang cosmology.

(D) The detection of gravitational waves by mini-creation events.

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