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Structure Formation in the Quasi-Steady State Cosmology

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In this paper we introduce a toy model for understanding the growth of structures and the two point correlation functions in the cotext of the Quasi-Steady State Cosmology (QSSC). The paper first describes the essential features of the QSSC and then addresses the problem of structure formation.

KEY WORDS : Two point correlation function

1. INTRODUCTION

The Quasi-Steady State Cosmology (QSSC) was first proposed in 1993 and explored further by Fred Hoyle, Geoffrey Burbidge and Jayant Narlikar in series of papers [4–8,10]. The QSSC offers an alternative to the commonly accepted big bang cosmology, and the above work claims to provide a singularity-free cosmological model, which is consistent with the data on discrete source populations, and can explain the production of light nuclei as well as the spectrum and anisotropy of the microwave background. Because the dynamical and physical conditions in this cosmology are considerably different from those in standard cosmology, the theoretical reasoning required to understand what is observed may differ too. In short, one may not simply lift a theoretical model from standard cosmology and expect to apply it to the same problem in the QSSC.

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One of the most outstanding problems in modern big bang cosmology is the problem of formation of large scale structures in the universe. Starting with prescribed primordial fluctuations of spacetime geometry and matter density, the standard approach consists in evolving them through an inflationary era, then letting them grow as gravitational instabilities, including effects of nonbaryonic dark matter, then carrying out N-body simulations of interacting masses which may eventually be identified with large scale structures like galaxies, clusters, superclusters and voids, etc. Although a lot of this work has gone into cosmology textbooks (see for example, Refs. 13,12), it is a fair comment to say that no unique and acceptable structure formation scenario has yet emerged in standard cosmology.

The problem of structure formation exists as a challenge in the QSSC also and it should be viewed against the background of the above standard approach. As we shall see in Section 2, the QSSC does not have an era when the baryonic matter density in the universe was $\sim 10^{81}$ times its present value, as it was in the big bang cosmology in the immediate post-inflation era. Thus the growth of fluctuations in the form of gravitational instabilities may not be similar in this cosmology to that in the standard cosmology. Indeed, as we shall show, the approach towards structure formation in this cosmology is quite different from the standard approach.

The organization of this paper is as follows. In Section 2 we briefly review the basic theory of QSSC. In Section 3 we will discuss what happens if we try the gravitational instability approach to this cosmology, and why it fails. We will then describe the alternative approach that makes use of the key physical feature of the QSSC that sets it apart from standard cosmology, namely the explosive creation of matter in the so-called minicreation events (MCE). Using the MCE as the basic contributors to large scale structures, a numerical toy model will be introduced in Section 5. Section 6 is devoted to computing the two-point correlation function of the numerical toy model and its comaprison with observations. In Section 7 we conclude by highlighting the success of this approach and how it can be further improved.

2. THE BASIC THEORY OF THE QSSC

The basic theory for the QSSC is the Machian theory of gravity first proposed by Hoyle and Narlikar [9,10] 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

$$\mathcal{A} = -\sum_a \int m_a ds_a \, , \tag{1}$$

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

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

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 (with the speed of light taken as unity):

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

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,

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

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.

2.1. 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.

The ejecta may be both in the form of dust-balls, or dust-jets, as well as coherent objects. This latter possibility arises because as a massive object contracts, the c-field strength inside it grows and because of its repulsive character, it makes the object unstable. It may therefore break up at least partially, ejecting bound coherent subunits.

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.

There is considerable evidence for such explosive activity in the universe. Quasars, active galactic nuclei and gamma-ray bursts are examples with *prima facie* evidence of outward ejection of energetic matter and radiation. It is usual to regard these as powered by massive black holes and their accretion discs, or colliding black holes. However, the signature of a black hole is inward motion of surrounding matter toward itself, rather than outward motion as observed. Highly contrived scenarios are therefore needed to understand these phenomena under the conventional black hole picture. The MCE on the other hand provide a natural mechanism for them.

There is also evidence of ejection of massive objects from disturbed galaxies, although much of it tends not to be believed as it conflicts with Hubble's law of expansion of the universe and also because conventional dynamics cannot provide adequate explanation for it. For a discussion of such evidence as well as the sociology behind not believing it, see two books by Arp [1,2]. The QSSC and its MCE-mechanism offers a natural explanation for such apparently anomalous observations.

2.2. 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 de Sitter 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.* [14] have computed the simplest such solution with the line element given by

$$ds^2 = dt^2 - S^2(t)\,[dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2)], \tag{6}$$

where 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.* [14]. 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.

2.3. Observational checks

Hoyle *et al.* [5,6] 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:

$$P \approx 20Q,\ Q \approx 4\times10^{10}\text{yrs},\ \eta = 0.75,\ \lambda = -2.8\times10^{-56}\text{cm}^{-2},\ t_0 = 0.7Q.$$

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.

The above framework thus outlines a cosmological model without a beginning and without an end, in which a de Sitter-type exponential expansion, characterized by a very long time scale P, is superposed on finite size oscillations of a shorter time scale Q. The cycles are statistically identical in their physical properties. In this sense the universe is 'quasi-steady'. We next see whether structures might grow and proliferate in such a universe through gravitational instability. The next section summarizes the work of Banerjee and Narlikar [3].

3. GRAVITATIONAL PERTURBATIONS

We begin by imposing a small perturbation on the Robertson–Walker line element, for $k = 0$, for which we redefine the metric tensor as

$$g_{\mu\nu} = -S^2(\eta_{\mu\nu} + h_{\mu\nu}), \quad g_{0\mu} = h_{0\mu}\,, \quad g_{00} = 1 + h_{00}\,, \tag{8}$$

where $\eta_{\mu\nu} = 1, \mu = \nu$ and $\eta_{\mu\nu} = 0$, $\mu \neq \nu$; $\mu, \nu = 1, 2, 3$ also $S \equiv S(t)$ and $h_{ij} \equiv h_{ij}(t, x^\mu)$. We have considered a comoving preferred observer for which all the off-diagonal components of the metric tensor are assumed to be zero. In the present coordinate system the matter flow vector need not be comoving. We define the first-order perturbation of flow vector as u_1^i, the zero'th order being $u_0^i \equiv (1, 0, 0, 0)$. Thus,

$$T^{ik} = \rho_0 u_0^i u_0^k + \rho_1 u_0^i u_0^k + \rho_0 (u_0^i u_1^k + u_1^i u_0^k), \tag{9}$$

where

$$\rho \equiv \rho_0 + \rho_1\,, \qquad \rho_0 = \frac{\bar{\rho}\bar{S}^3}{S^3}\,, \tag{10}$$

ρ_1 being the density perturbation given as $\rho_1 = \rho_0 \zeta$. The perturbation vector u_1^i need not be along the four-vector $u_0^i = \delta_0^i$ but will have small departures from the normal direction. A perturbation is similarly assumed for the c-field as

$$c_i \equiv c_{0i} + \xi_i\,, \qquad c_0 \equiv c_0(t), \qquad \xi_i \equiv \xi_i(t, x^\mu). \tag{11}$$

h_{ij}, ζ, ξ_i and u_1^i are quantities of the first order of smallness. In the non-creative mode the field equations for the Robertson–Walker metric ($k = 0$, $c = 1$) are then given by the following three groups of equations.

(i) *Conservation equations for matter-field*:

$$\dot{\zeta} + \frac{1}{2}(\dot{h}_{11} + \dot{h}_{22} + \dot{h}_{33}) + u^{\mu}_{1\,,\mu} = 0, \tag{12}$$

$$\frac{\partial(S^2u_1^1)}{\partial t} = -\frac{1}{2}\,h_{00,\,1}\,, \tag{13}$$

$$\frac{\partial(S^2u_1^2)}{\partial t} = -\frac{1}{2}\,h_{00,\,2}\,, \tag{14}$$

$$\frac{\partial(S^2u_1^3)}{\partial t} = -\frac{1}{2}\,h_{00,\,3}\,. \tag{15}$$

(ii) *Conservation equations for creation-field*:

$$\bigtriangledown^2\xi = \frac{3}{2}\,\frac{\partial(S^2\dot{\xi})}{\partial t} + \frac{B}{2}\left\{\dot{h}_{11} + \dot{h}_{22} + \dot{h}_{33} - \frac{3}{2}\,\dot{h}_{00}\right\}, \tag{16}$$

$$\frac{\partial(S^2\xi_1)}{\partial t} = \frac{B}{2}h_{00,\,1}\,, \tag{17}$$

$$\frac{\partial(S^2\xi_2)}{\partial t} = \frac{B}{2}h_{00,\,2}\,, \tag{18}$$

$$\frac{\partial(S^2\xi_3)}{\partial t} = \frac{B}{2}h_{00,\,3} \qquad (B = \text{constant}). \tag{19}$$

(iii) *Einstein's gravitational field equations*:

$$\begin{aligned}\frac{2\ddot{S}}{S} &+ \frac{\dot{S}^2}{S^2} + \frac{3\dot{S}}{2S}(\dot{h}_{22} + \dot{h}_{33}) - \frac{\dot{S}}{S}\,\dot{h}_{00} + \frac{1}{2}\,(\ddot{h}_{22} + \ddot{h}_{33}) \\ &- \frac{1}{2S^2}\,(h_{22,\,33} + h_{33,\,22}) - \frac{1}{2S^2}\,(h_{00,\,22} + h_{00,\,33}) \\ &= 3\lambda(1 + h_{00}) + 2\pi Gf\,\frac{B}{S^2}\left(\frac{B}{S^2} + 2\dot{\xi}\right),\end{aligned} \tag{20}$$

$$\begin{aligned}\frac{2\ddot{S}}{S} &+ \frac{\dot{S}^2}{S^2} + \frac{3\dot{S}}{2S}\,(\dot{h}_{11} + \dot{h}_{33}) - \frac{\dot{S}}{S}\,\dot{h}_{00} + \frac{1}{2}\,(\ddot{h}_{11} + \ddot{h}_{33}) \\ &- \frac{1}{2S^2}\,(h_{11,\,33} + h_{33,\,11}) - \frac{1}{2S^2}\,(h_{00,\,11} + h_{00,\,33}) \\ &= 3\lambda(1 + h_{00}) + 2\pi Gf\,\frac{B}{S^2}\left(\frac{B}{S^2} + 2\dot{\xi}\right),\end{aligned} \tag{21}$$

$$\begin{aligned}\frac{2\ddot{S}}{S} &+ \frac{\dot{S}^2}{S^2} + \frac{3\dot{S}}{2S}\,(\dot{h}_{11} + \dot{h}_{22}) - \frac{\dot{S}}{S}\,\dot{h}_{00} + \frac{1}{2}\,(\ddot{h}_{11} + \ddot{h}_{22}) \\ &- \frac{1}{2S^2}\,(h_{11,\,22} + h_{22,\,11}) - \frac{1}{2S^2}\,(h_{00,\,11} + h_{00,\,22}) \\ &= 3\lambda(1 + h_{00}) + 2\pi Gf\,\frac{B}{S^2}\left(\frac{B}{S^2} + 2\dot{\xi}\right),\end{aligned} \tag{22}$$

$$\frac{3\dot{S}^2}{S^2} + \frac{\dot{S}}{S}\,(\dot{h}_{11} + \dot{h}_{22} + \dot{h}_{33})$$
$$- \frac{1}{2S^2}\,(h_{11,\,22} + h_{11,\,33} + h_{22,\,11} + h_{22,\,33}) - \frac{1}{2S^2}\,(h_{33,\,11} + h_{33,\,22})$$
$$= 3\lambda(1 + h_{00}) + 8\pi G\rho_0(1 + \zeta + h_{00}) - 6\pi G f\,\frac{B}{S^2}\left(\frac{B}{S^2} + 2\dot{\xi}\right), \quad (23)$$

$$\frac{\dot{S}}{S}\,h_{00,\,1} - \frac{1}{2}\,(\dot{h}_{22,\,1} + \dot{h}_{33,\,1}) = -8\pi G S^2 \rho_0 u_1^1 - 8\pi G f\,\frac{B}{S^2}\xi_1\,, \quad (24)$$
$$\frac{\dot{S}}{S}\,h_{00,\,2} - \frac{1}{2}\,(\dot{h}_{11,\,2} + \dot{h}_{33,\,2}) = -8\pi G S^2 \rho_0 u_2^2 - 8\pi G f\,\frac{B}{S^2}\,\xi_2\,, \quad (25)$$
$$\frac{\dot{S}}{S}\,h_{00,\,3} - \frac{1}{2}\,(\dot{h}_{11,\,3} + \dot{h}_{22,\,3}) = -8\pi G S^2 \rho_0 u_3^3 - 8\pi G f\,\frac{B}{S^2}\,\xi_3\,, \quad (26)$$

$$\frac{1}{2S^2}\,(h_{00,\,12} + h_{33,\,12}) = 0, \quad (27)$$
$$\frac{1}{2S^2}\,(h_{00,\,13} + h_{22,\,13}) = 0, \quad (28)$$
$$\frac{1}{2S^2}\,(h_{00,\,23} + h_{11,\,23}) = 0. \quad (29)$$

The above equations together lead to a second-order linear differential equation in ζ and the scale factor (S) given by

$$\frac{d^2\zeta}{dS^2} + \left\{\frac{1}{2Q}\,\frac{dQ}{dS} + \frac{4}{S}\right\}\frac{d\zeta}{dS} + \frac{4\pi G\bar{\rho}\bar{S}^3}{S^3 Q}\,\zeta = \frac{-0.06}{S\sqrt{Q}}\,, \quad (30)$$

where

$$Q(S) = \lambda S^2 + \frac{8\pi G\bar{\rho}\bar{S}^3}{3(1/S^2)}\,. \quad (31)$$

The above equation could be solved numerically in the light of the present solution, i.e.,

$$P = 20Q,\ Q = 4\times 10^{10}\text{yrs},\ \lambda = -2.8\times 10^{-56}\text{cm}^{-2},\ \eta = 0.75, \quad (32)$$

in the form

$$\frac{d^2\zeta}{dS^2} + \frac{(-14S^4 + 87.5S - 3)}{S(-2.8S^4 + 17.5S - 1)}\,\frac{d\zeta}{dS} + \frac{26.3\zeta}{S(-2.8S^4 + 17.5S - 1)}$$
$$= \frac{-0.06}{\sqrt{(-2.8S^4 + 17.5S - 1)}}\,. \quad (33)$$

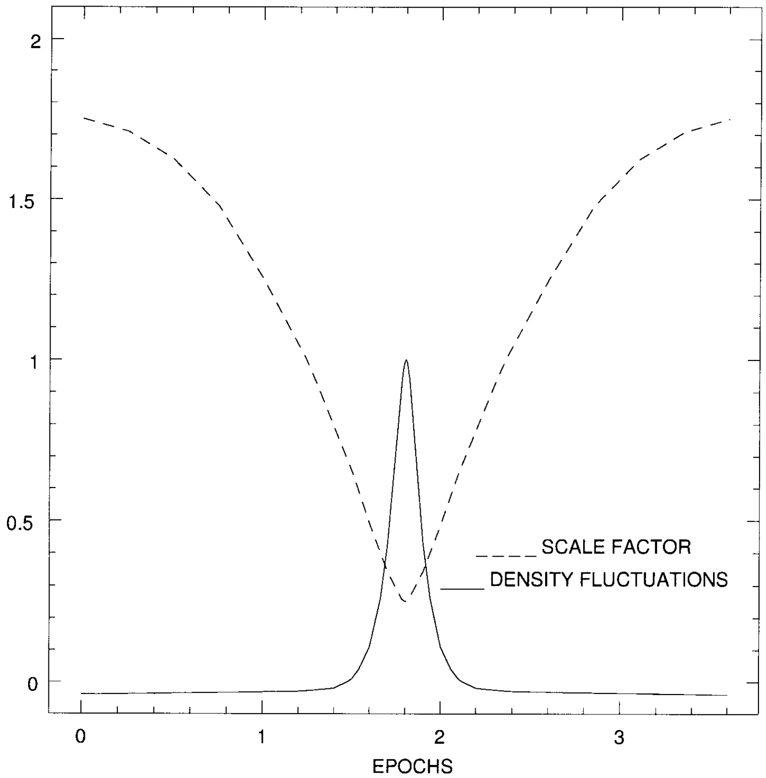

Figure 1. Plot of the scale factor and density fluctuations over 1 cycle. The density fluctuations are too small to be adequately represented on the vertical scale of this graph. They have been magnified by a factor ~ 100 for easy comparison.

In a generic solution, Figure 1 shows ζ plotted against t for a complete cycle $(0 \leq \theta \leq 2\pi)$. The starting value of ζ has been taken as 0.004, at $\theta = 0$. In the first half cycle the scale factor (S) continuously decreases with time starting from its maximum value $S = 1.75$ and at the same time the density (ζ) goes up from its minimum point. One can therefore easily see in Fig. 1 that as the universe goes on contracting with time the density of the universe increases within a finite level and reaches its maximum limit at 0.14 where $S = 0.25$. Again for the next half cycle the figure shows that the scale factor starts increasing from its minimum position and goes up to the maximum where the density fluctuation has the minimum value : i.e. as the universe expands with time the density of the universe goes down. Other perturbed quantities would show a similar behaviour. This analysis demonstrates that the basic cycle of QSSC is stable as a cosmological solution and may be used as a robust model for testing cosmological predictions.

4. STRUCTURE FORMATION

This example shows that typically density perturbations grow by a modest factor ($\sim 10^2$) during the contracting phase whereas they decline during the expanding phase of the universe. This result is not unexpected, as in a purely gravitational scenario, expansion is expected to smoothen out inhomogeneities while contraction would make them more significant.

However, the relatively modest growth of $\delta\rho/\rho$ suggests that other non-gravitational forces must play a role in the creation of large scale structure. The clue to these lie in the creation events which operate near $S = S_{\min}$. The creative mode which leads to the $\exp t/P$ factor in the expansion of the universe has not been included in our analysis here.

The reason for this is, as pointed out by Hoyle *et al.* [4,5], the creation of matter takes place in strong gravitational fields near collapsed massive objects. In such situations the smoothed out solution used here, and its perturbation, would not apply. An altogether different approach will be needed to understand how creation of new units of matter take place and how they are ejected as coherent objects as these authors have claimed. This approach, based on the work of Nayeri *et al.* [11], will be described next.

5. A TOY MODEL FOR FORMATION OF STRUCTURES

In an attempt to understand how possibly structures may grow and distribute in space through the agency of the MCE, we have carried out the following numerical experiment in two- and three-dimensional space. We describe the 2D case first and come to the 3D modifications next.

5.1. 2D-simulations

A large number of points ($N \sim 10^5 - 10^6$), each one representing a mini-creation event, is distributed randomly over a unit square area. The average nearest-neighbour distance for such a distribution will then be $1/\sqrt{N}$. Now suppose that in a typical mini-creation event, each particle generates another neighbour particle in a distance, $d = x/\sqrt{N}$ in $2D$. Here, the number x is a fraction between 0 and 1. The sample area is then uniformly stretched by a factor $\sqrt{2}$. We now have the same density of points as before, i.e., $2N$ points over area of 2 units. From this enlarged square remove the periphery so as to retain only the inner unit square. This process thus brings us back to the original state but with a different distribution of an average N points over a unit square. This process is repeated n times. The number distribution of points evolves as the 'creation process' generates new points near the existing ones. Not surprisingly, soon after, i.e., after $n = 3 - 4$ iterations, of the above procedure, clusters and voids begin to emerge in the sample area. As the experiment is repeated voids grow in size while clusters become denser. Figure 2 illustrates a typical numerical simulation. It shows that expansion coupled with creation of matter is a natural means of generating voids and clusters. But what of the filaments? How do they arise?

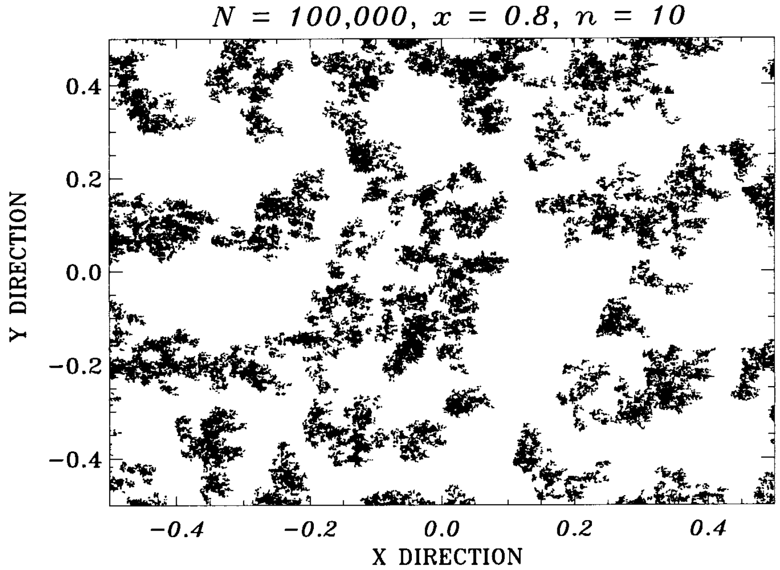

Figure 2. A cluster-void distribution generated in the $2D$ toy model for $N = 100,000$ initially randomly distributed particles, with typical separation parameter $x = 0.8$, and the number of iterations $n = 10$. Each particle denotes a galaxy. For further discussion see the text.

Here we recall that the creation process near a typical compact massive object will not be isotropic if the mass is spinning. Matter will be preferentially ejected along the axis of spin. To build this effect into the above simulation we adopt the following algorithm.

We assume that in a typical $n \geq 2$ iteration, the creation of the new neigbour particle B around a typical particle A is not entirely random, but, instead, related to the previous history of creation of A. So the direction AB is broadly aligned with the direction in which A itself was ejected. Typically this is ensured by assuming that the ejection is at a random angle in the forward semicircle. Thus, if the original creation event was at X, say, the ejection of A was along XA, and if the line XA is extended in the forward direction along AC, then the ejection of the created particle B at A will be along the direction such that the angle $\angle BAC$ lies between $-\pi/2$ and $+\pi/2$. Although this algorithm does not demand strict alignment, it is interesting to note that the filamentary structure grows along with voids as n increases. Features generated in this way show very suggestive similarities with the observed large scale structure.

5.2. 3D-simulations

The 3D simulation is similar, with the necessary modifications for the higher dimensionality. Here we start with a unit cube with N points distributed at random within it. Thus the typical interpoint distance is $N^{-1/3}$. Creating a new near neighbour for each particle by the same rule as in the 2D case, we need to expand each edge of the cube by the factor $2^{1/3}$. We next apply the same algorithm favouring aligned ejection. To compare the three-dimensional distributions with the observed distributions made up from redshift surveys, we need to take a thin inside slice of the cube perpendicular to one of its edges and examine the distribution of points therein. Figure 3 shows a typical case. Again we see that inhomogeneities of clusters-voids-filaments naturally emerge.

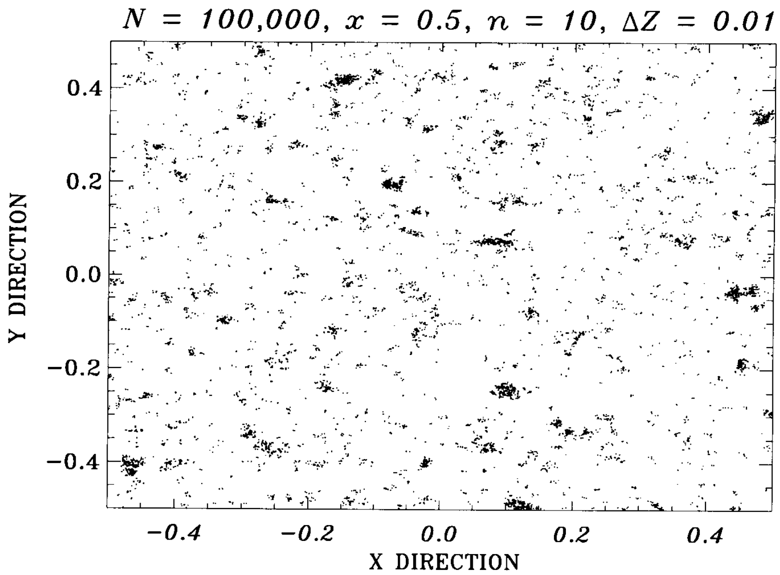

Figure 3. A filament-void distribution after 10 iterations starting with a random distribution, with new points following the aligned ejection rule in three-dimensional space, for $N = 100,000$ and $x = 0.5$.

5.3. Simulations of QSSC cycles

To bring the toy model closer to reality of the QSSC, we proceed as follows. We expect the creation activity to be confined largely to a narrow era around a typical oscillatory minimum, when the c-field is at its strongest. By considering the number density of collapsed massive objects at one oscillatory minimum of QSSC to be f, the number density at the next oscillatory minimum would fall to $f \exp(-3Q/P)$, if no new massive objects were added. Thus to restore a steady state from one cycle to the next,

$$\alpha f \equiv [1 - \exp(-3Q/P)]f \sim (3Q/P)f, \tag{34}$$

masses must be created anew. In other words, a fraction $(3Q/P)$ of the total number of massive objects must duplicate themselves in the above fashion.

Therefore, instead of creating a new neighbour particle around each and every one of the original set of N particles, we do so only around αN of these points, where the fraction α is as defined in (34). Likewise, the sample volume is homologously expanded by the factor $\exp(3Q/P)$ only instead of factor 2. We choose the inner cube as before. Figure 4 shows the simulated distribution in a cubical slice for aligned ejections. After a few iterations clusters and voids begin to appear along with filaments.

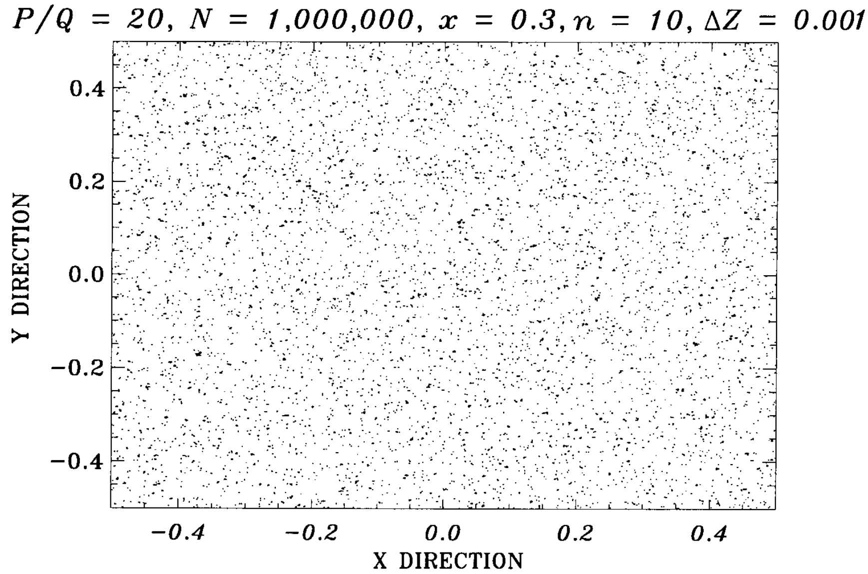

Figure 4. A 3-dimensional version with aligned ejection, adapted for the QSSC with $N = 1,000,000$, $x = 0.3$, $n = 10$, and $P/Q = 20$. Slice thickness in the Z direction is $\Delta Z = 0.001$. Evidently, voids are seen separated by filamentary structures.

6. THE TWO POINT CORRELATION FUNCTIONS

Although visual inspection of such figures, and their comparison with observed distributions based on redshift surveys suggests that the simulation is proceeding along the right lines, an objective and *quantitative* measure of the cluster-void distribution will help in comparing facts with simulations.

The dimensionless autocorrelation function

$$\xi(r) = \langle \rho(\mathbf{r}_1)\rho(\mathbf{r}_1 + \mathbf{r})\rangle / \langle \rho \rangle - 1, \quad (35)$$

is one convenient measure of such irregularities in the space distribution. Observationally, it is believed that the two point correlation function for galaxy distribution obeys the following scaling law:

$$\xi(r) = \left(\frac{r}{r_0}\right)^{-\gamma}, \quad (36)$$

with $\gamma \simeq 1.8$ and $r_0 = 5h^{-1}$Mpc, where h measures the Hubble constant in units of 100 km s^{-1}Mpc^{-1}. For clusters of galaxies, $r_0 = 25h^{-1}$Mpc.

We have calculated the average correlation function for the QSSC model. It turned out that for small value of x and for large enough number of iteration, say, $n = 10$, the average correlation function actually obeys the scaling law (36). Figure 5 shows the average correlation function for $x = 3$ and $n = 5, 7, 9$ in the QSSC simulations.

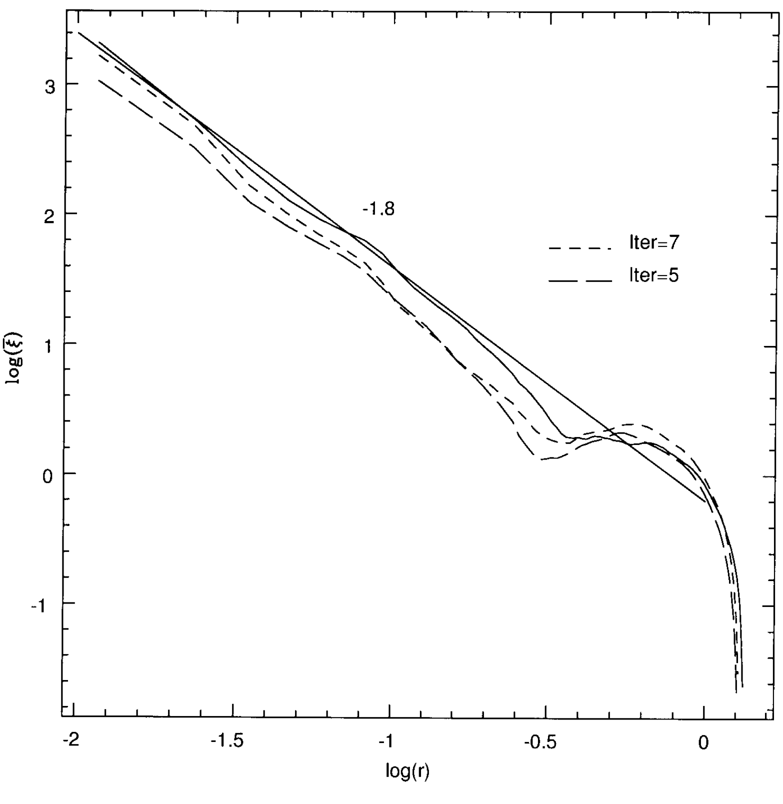

Figure 5. The two point correlation function for the QSSC based model. Here, $N = 100,000$ and $x = 0.3$. As "time" goes on, the curve approaches more and more closely the slope of -1.8. The solid curve shows the result after 10 iterations.

Typically we can determine the characteristic cluster size by examining the value of r at which ξ drops below unity. From our calculations we estimate the typical strucure size to be β times the box size chosen for simulations, with β lying between $\sim 0.15 - 0.30$. Taking the upper end of the limit as corresponding to $r_0 = 25h^{-1}$Mpc, we find that our box-size is around 85 Mpc.

7. CONCLUSION

The problem of formation of large scale structure being a complex one, it is desirable to keep the theoretical options open in the underlying cosmology. A different approach here, as indicated by the QSSC, already appears promising. In this approach, the main process which generates structures in the universe is the creation of matter around MCE rather than gravitational instability. Our computer simulations show very clearly that the filament-cluster-void pattern observed in large scale structure can be generated simply from a creation algorithm. More sophisticated simulations together with gravitational instability would be needed to follow up this work. We also need to outline a more detailed cosmogonic theory than given here, that tells us how coherent objects are ejected by the mini-creation events. However, the success of this approach so far offers encouragement for these future steps.

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