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COSMOGENESIS WITHOUT BIG BANG. A NEW MODEL OF THE EARLY UNIVERSE

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Abstract

The problem of genesis of matter in the universe is examined. The hypothesis of creation of particles (baryons/photons) out of gravitational energy is discussed and a new model of the early universe is proposed in which the universe starts expanding from a vacuum fluctuation accompanied with creation of particles out of gravitational energy. A suitable choice of particle creation function leads to inflation and subsequent change-over to friedmann era. Growth of density fluctuations during inflation is investigated.

Key Words: Cosmology, Early Universe, Genesis of Matter out of Gravitational Energy.

1 Introduction

The traditional big bang cosmology relies on the explosive origin of the universe to generate a fireball phase and to provide a tremendous impluse for the expansion of the universe; but of late, the big bang theory is facing a serious challenge since there is no observable relic or astrophysical evidence available in support of the stipulated 'big bang' as the origin of the universe. The observations of the cosmic microwave background radiation and the abundance of light elements, such as helium and lithium, simply confirm that the universe has emerged out of a fireball phase; whether the fireball phase is a sequel of big bang or an alternative mechanism is an open question. On the other hand, the quantum cosmological considerations indicate a very low possibility of the occurence of the big bang singularity in the universe. Hawking [1] expresses reservation about the primordial singularity in quantum cosmology. Moreover, the success of the inflationary scenario in solving the horizon, flatness and magnetic monopole problems has stolen the thunder from the big bang theory and has reduced it to the status of a 'whimper' (if it occured at all) since almost all the matter, energy and entropy of the universe are produced during inflation and not at the conjectured big bang epoch.

It is true that inflation is now regarded as a milestone in the evolution of the universe but it offers no satisfactory explanation about the tremendous amount of vacuum energy which inflates the universe by 28 orders of magnitude or more while its energy density remains constant. Alan Guth [2] and Hawking [3] have suggested that the energy of the inflating universe might have been drawn from the gravitational field but no mechhanism of the transfer of gravitational energy into matter was put forward by them. Recently Johri,Kalligas,Singh and Everitt [4] have discussed the role of gravitational energy in the expanding universe and have shown that the creation of matter in the universe might take place from the negative gravitational field energy without the violation of the energy conservation law. Prigogine et al [5] have given a thermodynamic treatment of the creation of matter particles out of gravitational energy in the expanding universe.

Synthesizing the above two approaches, a new model of expanding universe is proposed in which the role of the big bang is taken over by the creation of particles in inducing expansion and the genesis of matter in the early universe. The creation of matter and radiation out of gravitational energy is seen to be a natural and irreversible phenomenon which takes place in the expanding phase of the universe under suitable conditions.

2 Universe as a Vacuum Fluctuation. Initial Conditions

In the proposed scenario, the universe starts expanding from high energy vacuum fluctuation. The idea that a closed universe could be a vacuum fluctuation was first suggested by Tryon [6] and later on independently by Fomin [7]. A similar idea of the creation of the universe by quantum tunneling from 'nothing' to de Sitter space and the possibility of several nucleating universes was given by Vilenkin [8]. But on account of the transfer of gravitational energy [9], the energy density of vacuum will not remain constant; as such, the

vacuum fluctuation may not lead to de Sitter expansion. It is already established [10] that the rate of the induced expansion depends upon the mode of creation of particles, characterised by the particle creation function N(t).
Recently the question of the initial state of the universe has assumed great importance. As one extrapolates the evolution of the universe backwards in the time, the curvature and the energy density approach the planck scale where the quantum gravitational effects become important. In modern apporach to quantum cosmology initiated by Hartle and Hawking [11], Vilenkin and Halliwell [12], it is necessary to propose a law of initial condition to single out just one solution of Wheeler-DeWitt equation where the wave function is peaked about a set of solutions to the classical Einstein field equations, assuming that the notion of classical space time is a reasonable approximation to use. In the classical theory, this implies tagging of initial conditions to the vacuum fluctuations which induce expansion and genesis of matter in the universe. But in a universe which starts expanding from random vacuum fluctuations, different regions of the universe might evolve in entirely different ways depending upon the particle creation function N(t) associated with the vacuum fluctuation; as such choice of N(t) may be regarded as the initial condition in this scenario. It follows by Anthropic Princile that the observable universe around us might have resulted from a vacuum fluctuation with a typical particle creation function as discussed in section 5.

3 Thermodynamic Approach to Creation of Particles

Conventially, in the derivation of the field equations of general relativity from the variational principle

$$\delta(S_m + S_g) = 0$$

the variations in the actions of the material field S_m and the gravitational field S_g are worked out seperately with the tacit assumption that there is no interchange of energy between them. In this sense, the universe is regarded as a closed thermodynamical system. In order to admit creation of particles out of gravitational energy, Prigogine [5] regards the universe as an open thermodynamical system in which the particles of matter/radiation are created out of gravitational energy released due to space time variation in the expanding universe. To be more specific, let us consider a vacuum fluctuation of the cosmic soup inducing expansion of the universe accompanied with the creation of dN particles which contribute to internal energy dU and entropy increases dS in the system. Assuming that the only heat flow in the system is on account of the transfer of gravitational energy μdN in the form of newly created particles, the second law of thermodynamics for open system gives

$$dU = \mu dN - pdV \tag{1}$$

where μ is the chemical potential, p is the thermodynamic pressure and dV is the increase in the comoving volume. Since U and V are the extensive properties of the system (i.e. U and V are directly proportional to the number N of the particles included in the system), we have

$$dU/U = dN/N = dV/V \tag{2}$$

using (2) in (1), we find

$$\mu N = U + pV = (\rho + p)V = \tilde{H} \tag{3}$$

where ρ is the energy density and $\tilde{H}$ is the enthalpy of the system. Substituting for μ from (3) into (1), we have

$$dU = -(p + p_c)dV \tag{4}$$

where

$$p_c = -(\tilde{H}/N)(dN/dV) < 0 \tag{5}$$

and the Hubble constant H $\equiv \dot{R}$/R and V = R^3
Since entropy S is an extensive property of the system, we have

$$dS/S = dN/N = -(p_c dV/(p + \rho)V) \geq 0 \tag{6}$$

Since the entropy of a system cannot decrease, it follows from (6) that the only particle number variations admitted are such that

$$dN \geq 0 \tag{7}$$

This inequality implies that the energy in the space-time can produce matter, while the reverse process is thermodynamically forbidden. Thus, the relationship between space-time and matter ceases to be symmetrical as the transfer of the gravitational energy to the matter field is irreversible phenomenon which might take place only during the expanding phase of the universe subject to the particle creation function N(t). It is also consistent with the observation of Gunzig and Nardone [9] that a vacuum fluctuation in the primordial state is structurally unstable with respect to irreversible matter creation.

4 Dynamics of Matter Creation

As discussed in the previous section, the transfer of gravitatioal energy to the matter field gives rise to a negative pressure term p_c. Accordingly, the effective energy-momentum tensor of the cosmic fluid in presence of matter creation becomes

$$\tilde{T}_{ik} = (\rho + p + p_c)U_i U_k - (p + p_c)g_{ik} \tag{8}$$

and the field equations of general relativity

$$R_{ik} - 1/2 R^l_l g_{ik} = 8\pi G \tilde{T}_{ik}$$

for the standard FRW model

$$ds^2 = dt^2 - R^2(t)[dr^2/(1 - kr^2) + r^2(d\theta^2 + \sin^2\theta d\phi^2)]$$

lead to

$$H^2 + k/R^2 = 8\pi G\rho/3 \tag{9}$$

$$2\dot{H} + 3H^2 + k/R^2 = -8\pi G(p + p_c) \tag{10}$$

Eq (9) and (10) combine to give the energy conservation equation

$$\dot{\rho} + (\rho + p)\theta = -p_c\theta = (p + \rho)\dot{N}/N \tag{11}$$

where $\theta \equiv 3H = 3\dot{R}/R$
Assuming barotropic equation of state

$$p = \gamma\rho \quad 0 \leq \gamma \leq 1 \tag{12}$$

eqn (11) yields on integration

$$N(t) = N_o R^3 \rho^{1/(1+r)} \tag{13}$$

If n is the particle number density,

$$N = nV = nR^3 \tag{14}$$

eqn (13) leads to

$$\rho \propto n^{1+\gamma} \tag{15}$$

For relativistic particles

$$\rho \propto T^4, \gamma = 1/3 \tag{16}$$

we obtain a relation between the temperature T of the universe and particle number density

$$T \propto n^{1/3} \tag{17}$$

5 A New Model of Early Universe

We now propose a model of the early universe with a suitably chosen particle creation function which initially accelerates the expansion leading to inflationary era; eventually the particle creation stops and the universe enters the Friedmann era.

As argued earlier, the particle creation function N(t) in (11) may be taken as the initial condition and chosen arbitrarily for various cosmological models of the early universe
Let the creation function be

$$N(t) = e^{-3\beta/t} t^{-4/(1+\gamma)}, \beta > 0 \tag{18}$$

Differentiating (13) logarithmically, we get

$$\dot{N}/N = ((\dot{\rho}/\rho)/(1 + \gamma)) + 3H \tag{19}$$

If we consider a spatially flat ($k = 0$) model, eqn (9) gives

$$\rho = 3H^2/8\pi G \tag{20}$$

Using (18) and (20) and taking the initial state of the universe to be radiation dominated ($\gamma = 1/3$), eqn (19) may be rewritten as

$$\dot{H} + 2H^2 = 2(\beta/t^2 - 1/t)H \tag{21}$$

It obviously has an exact solution

$$H = \beta/t^2 \tag{22}$$

which leads to the scale factor

$$R = ae^{-\beta/t}, a > 0 \tag{23}$$

Accordingly,

$$\dot{R} = a(\beta/t^2)e^{-\beta/t} > 0 \tag{24}$$

and

$$\ddot{R} = a\beta/t^3((\beta/t) - 2)e^{-\beta/t} \tag{25}$$

further from (18)

$$\dot{N}/N = 3\beta/t^2 - 3/t \tag{26}$$

Note that during the early universe, H(t) is large but $\ddot{R}(t) > 0$ until $t < \beta/2$. This implies that the rate of expansion of the universe goes on accelerating with the particle production for a short interval $t = \beta/2$; the expansion starts decelerating for $t > \beta/2$ and the particle creation stops ($\dot{N} = 0$) at $t = \beta$. Subsequently the field equation (21) reduces to

$$\dot{H} + 2H^2 = 0$$

which leads to the new scale factor $R \sim t^{1/2}$. This shows that at the end of the particle production phase, the universe enters the Friedmann era represented by radiation dominated model with the initial value of the Hubble constant $H_o = 1/2\beta$
Using (13) and (17), we get temperature-age relation in the model as

$$T \propto n^{1/3} \propto (N/R^3)^{1/3} \propto 1/t \tag{27}$$

Accordingly, the GUT epoch in this model is given by

$$t_{GUT}/t_{pl} = T_{pl}/T_{GUT} = 10^{19}GeV/10^{14}GeV = 10^5$$

Therefore,

$$t_{GUT} = 10^5 10^{-42} = 10^{-37}\ sec \tag{28}$$

The undetermined constant β in the model may be estimated by using the fact that the inflationary era and the end of the particle creation era must correspond to GUT epoch in order to obviate the magnetic monopole problem. As such

$$\beta \simeq t_{GUT} = 10^{-37} \tag{29}$$

The order of inflation of the universe during the particle creation phase, starting from the planck epoch, is given by

$$R_f/R_i = e^{-\beta(t_{GUT}^{-1} - t_{pl}^{-1})} = e^{-\beta(10^{37} - 10^{42})} \sim e^{10^5} \tag{30}$$

which is more than adequate to solve the horizon and flatness problem in the universe.

The order of the steep increase in the number of created particles and the consequent increase in the entropy is given by (18)

$$N_f/N_i = e^{3\times 10^5}/10^{15} \simeq 10^{10^5} \tag{31}$$

6 Growth of Density Fluctuations During Inflation

On perturbation, the energy conservation equation (11) and (12) with particle creation gives

$$\partial_o(\delta\rho) + (1+\gamma)\theta\delta\rho + (1+\gamma)\rho\delta\theta = (1+\gamma)\delta\rho\dot{N}/N + (1+\gamma)\rho\delta(\dot{N}/N)$$

or

$$\partial_o(\delta\rho)/\rho + (1+\gamma)(\theta - \dot{N}/N)\delta\rho/\rho + (1+\gamma)\delta\theta = (1+\gamma)\delta(\dot{N}/N) \tag{32}$$

Now $\partial_o(\delta\rho/\rho) = \partial_o(\delta\rho)/\rho - (\dot{\rho}/\rho^2)\delta\rho$, using (11)

$= \partial_o(\delta\rho)/\rho + (1+\gamma)\theta\delta\rho/\rho - ((1+\gamma)/\rho)(\dot{N}/N)\delta\rho$, using (32)

$=\mid \delta(\dot{N}/N) - \delta\theta \mid (1+\gamma)$, using(19) and (20)

$$= \delta(2\dot{H}/H) \tag{33}$$

$= \delta\partial_o(\ln H^2)$

Therefore

$$\delta\rho/\rho = \delta(\ln H^2) = 2\delta H/H \tag{34}$$

This shows that the growth of the density fluctuation is of the order of H^{-1} the horizon scale in the model.

7 Concluding Remarks

The idea of creation of particles in the cosmological background is not new. It was investigated earlier by Parker[13] in the context of spin 1/2 particles quantum mechanically in the background of spatially flat radiation-dominated universe; later on Brout[14] and his collaborators discussed quantum creation of massive particles in the framework of general relativity, their energy being extricated from the background gravitational field but the semi-classical equations are adiabatic and reversible as such they cannot account for the entropy production in the universe.

The inflationary scenario presented in this paper corresponds to a particular choice of the particle creation function which produces desired entropy and graceful exit into Friedmann

era. In fact, a variety of nonsingular cosmological models with different choice of particle creation function may be obtained.It is quite likely that the entire universe is not a uniquely determined system; the different regions of the universe beyond our event horizon might have exclusively disjoint properties, different from the observable universe around us.

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