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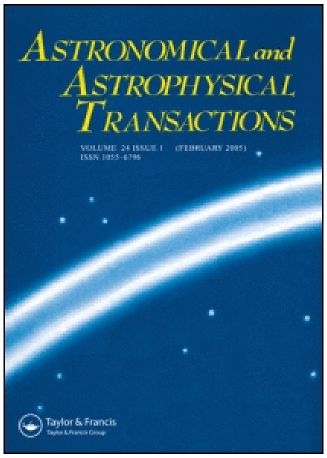

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Generation of the 128 $\mathbf{h}^{-1}$ Mpc periodicity of the universe in the scalar field condensate baryogenesis scenario

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Online Publication Date: 01 June 1996
To cite this Article: Chizhov, M. V. and Kirilova, D. P. (1996) 'Generation of the 128 $\mathbf{h}^{-1}$ Mpc periodicity of the universe in the scalar field condensate baryogenesis scenario', Astronomical & Astrophysical Transactions, 10:1, 69 - 75
To link to this article: DOI: 10.1080/10556799608203247
URL: http://dx.doi.org/10.1080/10556799608203247

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Astronomical and Astrophysical Transactions, 1996,
Vol. 10, pp. 69–75
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GENERATION OF THE 128 h^{-1} Mpc PERIODICITY OF THE UNIVERSE IN THE SCALAR FIELD CONDENSATE BARYOGENESIS SCENARIO

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(Received November 10, 1994)

A mechanism for generating baryon density perturbations in the scalar field condensate baryogenesis scenario is proposed. Both the observed baryon asymmetry and the observed periodicity in the large scale structure of the Universe with the characteristic scale $128h^{-1}$ Mpc can be explained as due to the evolution of a complex of a complex scalar field condensate formed at the inflationary stage.

1 INTRODUCTION

Pencil beam surveys [1] performed in the directions towards the Galactic poles up to $1000h^{-1}$ Mpc in both directions, found an intriguing periodicity in the very large scale distribution of luminous matter in the Universe with a characteristic periodicity scale of about $128h^{-1}$ Mpc. The analysis of the observational data on the basis of the models of clustering of galaxies [2] showed that the probability to obtain such a periodicity in the framework of the standard models for galaxy clustering is extremely small being less than 0.1%. While the rest of the power spectrum is consistent with the clustering hypothesis and Gaussian statistics, the single prominent spike at $128h^{-1}$ Mpc is not. So, the $128h^{-1}$ Mpc periodicity is inconsistent with local ($\leq 100h^{-1}$ Mpc) observations and the standard picture of galaxy clustering, and is rather to be ragarded as a new feature appearing only when very large scales ($> 100h^{-1}$ Mpc) are probed. In this connection we propose a mechanism for generating baryon density perturbations in the scalar field condensate baryogenesis scenario, which may be essential for the Universe large-scale structure formation and particularly, may be relevant for the observed periodic distribution of the visible matter in the Universe.

A similar mechanism was already discussed in [3] and the basic idea was formulated in [4]. It was proved that in the models of spontaneous or stochastic CP violation the CP-odd amplitudes are naturally space-dependent and in the case when the CP-odd complex classical field did had not reached equilibrium before the baryogenesis moment t_b it can produce the observed periodic fluctuations of the baryonic number density. Following these basic considerations we discuss here the generation and evolution of baryon density perturbations in the scenario of the scalar field condensate baryogenesis [5]. There exist many baryogenesis scenarios [6] which provide very interesting perturbations with a variety of possible spectra. Here we discuss the case of a spectrum corresponding to a periodic in space distribution of baryonic matter. This kind of baryonic density distribution can be obtained provided that the following assumptions are realized [7]. (a) There exists a complex scalar field ϕ with a mass small in comparison with the Hubble parameter during inflation. (b) Its potential contains nonharmonic terms. (c) A condensate of ϕ forms during the inflationary stage and it is a slowly varying function of position in space. All of these requirements are naturally fulfilled in the scenario of the scalar field condensate baryogenesis [5].

The model of baryogenesis [5], based on the original Affleck and Dine scenario [8], has several very attractive features. It can solve both the problems connected with the low postinflation temperature [9] and those due to a possible destruction of the previously created baryon excess during the electroweak phase transition [10]. An especially attractive feature of the model, concerning the Universe structure formation, is that neither explicit not spontaneous charge symmetry violation is needed. The charge symmetry is stochastically broken by quantum fluctuations. Therefore, matter and antimatter domains with a given baryon charge can be formed without domain walls. As it will be shown in what follows, in the framework of this scenario an attractive possibility can be realized, namely, the scalar field relevant for the Universe baryogenesis could be also the creator of the observed large-scale periodicity of the visible matter.

2 QUALITATIVE DESCRIPTION OF THE MODEL

The essential ingredient of the model is a complex scalar field ϕ which is a scalar superpartner of a colourless and electrically neutral combination of quark and lepton fields [5, 8]. It could have achieved a nonzero expectation value $\langle\phi\rangle \neq 0$ during the inflationary period if B and L were not conserved, as a result of the enhancement of quantum fluctuations [11] of the ϕ field, $\langle\phi^2\rangle = H^3t/4\pi^2$, until they reach the limiting value $\langle\phi^2\rangle \sim H^2/\sqrt{\lambda}$ in case that $\lambda\phi^4$ dominates in the potential energy of ϕ. The baryon charge of the field is not conserved at large values of the field amplitude due to the presence of the B-nonconserving self-interaction terms in the field's potential. As a result, quantum fluctuations of the field during the inflation create a baryon charge density of the order of H_I^3, where H_I is the Hubble parameter at the inflationary stage.

First we briefly describe the model of baryon generation [5]. During the inflationary stage, ϕ slowly moves to the equilibrium point because of the Hubble friction. After inflation ϕ starts to oscillate around its equilibrium point with a decreasing amplitude. This decrease is due to the Universe expansion and to the particle production by the oscillating scalar field [12, 5]. Fast oscillations of ϕ after inflation result in particle creation due to the coupling of the scalar field to fermions $g\phi\bar{f}_1, f_2$ where $g^2/4\pi = \alpha_{SUSY}$. Therefore, the amplitude of ϕ is damped as $\phi \rightarrow \phi\exp(-\Gamma t/4)$ and the baryon charge, contained in the ϕ condensate, is exponentially reduced. This may lead to a practically complete destruction of the baryon charge of the condensate (as, for example, in the case with flat directions of the potential in ref. [5]). However, in the case without flat directions in the field's potential, the damping process may be slow enough and for a considerable range of values of m, H, α, and λ the baryon charge contained in ϕ may survive until the advent of the B-conservation epoch, when ϕ decays to quarks with non-zero average baryon charge. This charge, diluted further by some entropy generating processes, dictates the observed baryon asymmetry.

Now let us explore the spatial distribution behavior of the scalar field condensate. It is natural to accept that ϕ is a function of space coordinates, $\phi(r,t)$. When the potential of ϕ is not strictly harmonic, a monotonic initial behavior in r results in spatial oscillations of ϕ, because the oscillation period depends on the amplitude, and it in turn depends on r. So there will be different time periods at different space points. Therefore, the space behavior of ϕ will become quasiperiodic [3, 13].

During Universe expansion, the characteristic scale of the variation of ϕ, r_0, will be inflated up to a cosmology significant size. Then if ϕ has not reached the equilibrium point at the moment of the baryogenesis t_B, the baryogenesis would make a snapshot of $\phi(r,t)$ (if the characteristic time scale of baryogenesis is small in comparison with $\phi/\dot{\phi}$). So, according to that model, the present periodic distribution of the visible matter dates from the spatial distribution of the baryon charge contained in the ϕ field at the advent of the B-conservation epoch t_B. The detailed calculations show that for a natural range of parameter values the model may predict the observational values for the baryon asymmetry and the scale of periodicity in the large-scale structure of the Universe.

3 THE MODEL - CHARACTERISTICS, CALCULATIONS AND RESULTS

In the expanding Universe, ϕ satisfied the equation

$$\ddot{\phi} - a^{-2}\partial_i^2\phi + 3H\dot{\phi} + \frac{1}{4}\Gamma\dot{\phi} + U'_\phi = 0, \tag{1}$$

where $a(t)$ is the scale factor and $H = \dot{a}/a$.

The potential $U(\phi)$ is generically of the form (at least near equilibrium)

$$U(\phi) = m^2|\phi|^2 + \frac{\lambda_1}{2}|\phi|^4 + m_1^2(\phi^2 + \phi^{*2}) + \frac{\lambda_2}{4}(\phi^4 + \phi^{*4}) + \frac{\lambda_3}{4}|\phi|^2(\phi^2 + \phi^{*2}). \tag{2}$$

The mass parameters of the potential must be small in comparison with the Hubble constant during inflation, $m \ll H_I$. Otherwise oscillations of ϕ will be exponentially damped in several Hubble times. In supersymmetric theories the constants λ_i are of the order of the gauge coupling constant α, and m is the mass of the ϕ field after symmetry breaking. In a large class of a supersymmetric models, a natural value of m is $10^2 \div 10^4$ Gev. Anyway, we assume $m \ll H_I$. The following initial values for the field variables can be derived from the natural assumption that the energy density of ϕ at the inflationary stage is of order H_I^4 : $\phi_0^{\max} \sim H_I \lambda^{-1/4}$ and $\dot{\phi}_0 = 0$.

The term $\Gamma\dot{\phi}$ in the equations of motion accounts for the eventual damping of ϕ as a result of particle creation processes by the time-dependent scalar field. The production rate Γ was calculated in [12]. For simplicity here we have used the perturbation theory approximation for the production rate $\Gamma = \alpha\Omega$, where Ω is the frequency of the scalar field. For $g < \lambda^{3/4}, \Gamma$ considerably exceeds the rate of the ordinary decay of the field $\Gamma_m = \alpha m$ at the stage of B-nonconservation.

As has been noted before the space derivative term is suppressed by exponentially rising scale factor $a(t) \sim \exp(H_I t)$ and can be safely neglected. Then the equations of motion for $\phi = x + iy$ read

$$\ddot{x} + 3H\dot{x} + \frac{1}{4}\Gamma_x \dot{x} + (\lambda + \lambda_3)x^3 + \lambda' x y^2 = 0,$$
$$\ddot{y} + 3H\dot{y} + \frac{1}{4}\Gamma_y \dot{y} + (\lambda + \lambda_3)y^3 + \lambda' y x^2 = 0, \qquad (3)$$

where $\lambda = \lambda_1 + \lambda_2, \lambda' = \lambda_1 - 3\lambda_2$.

We assume that at the end of inflation the Universe is dominated by a coherent oscillations of the inflation field $\psi = m_{PL}(3\pi)^{-1/2}\sin(m_\psi t)$, so that the Hubble parameter was $H = 2/(3t)$. In this case it is convenient to make the substitutions $x = H_I(t_i/t)^{2/3}u(\eta)$ and $y = H_I(t_i/t)^{2/3}v(\eta)$ where $\eta = 2(t/t_i)^{1/3}$. The functions $u(\eta)$ and $v(\eta)$ satisfy the equations

$$u'' + \frac{3}{4}\alpha\Omega_u(u' - 2u\eta^{-1}) + u[(\lambda + \lambda_3)u^2 + \lambda' v^2 - 2\eta^{-2}] = 0,$$
$$v'' + \frac{3}{4}\alpha\Omega_v(v' - 2v\eta^{-1}) + v[(\lambda + \lambda_3)v^2 + \lambda' u^2 - 2\eta^{-2}] = 0. \qquad (4)$$

The baryon charge in the comoving volume $V = V_i(t/t_i)^2$ is $B = 2(u'v - v'u)$. The numerical calculations were performed for the range of initial conditions $u_0, v_0 \in [0, \lambda^{-1/4}], u'_0, v'_0 \in [0, 2/3\lambda^{-1/4}]$.

We considered the case $\lambda_1 > \lambda_2 \sim \lambda_3$. Then the unharmonic oscillators u and v are weakly coupled. The oscillations of the baryon charge $B(\eta)$ proceed around zero (see Figure 1). That must be expected as far as the equilibrium value of ϕ is zero and ϕ oscillates around zero. We have calculated the baryon charge evolution for different initial conditions of the field's space distribution (see Figure 2). As expected, spatial distribution of baryons at the moment of baryogenesis is found

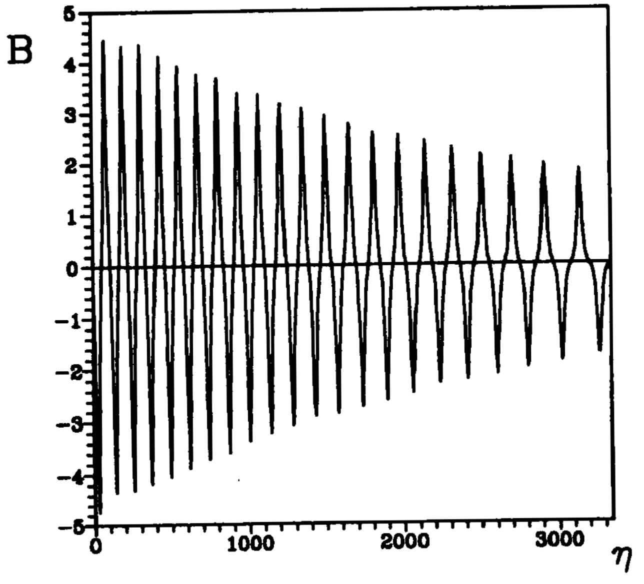

Figure 1 The evolution of the baryon charge $B(\eta)$ contained in the condensate $\langle\phi\rangle$ for $\lambda_1 = 5 \times 10^{-2}$, $\lambda_2 = \lambda_3 = \alpha = 10^{-3}$, $H_I/m = 10^7, \phi_0 = H_I\lambda^{-1/4}$, and $\dot{\phi}_0 = 0$.

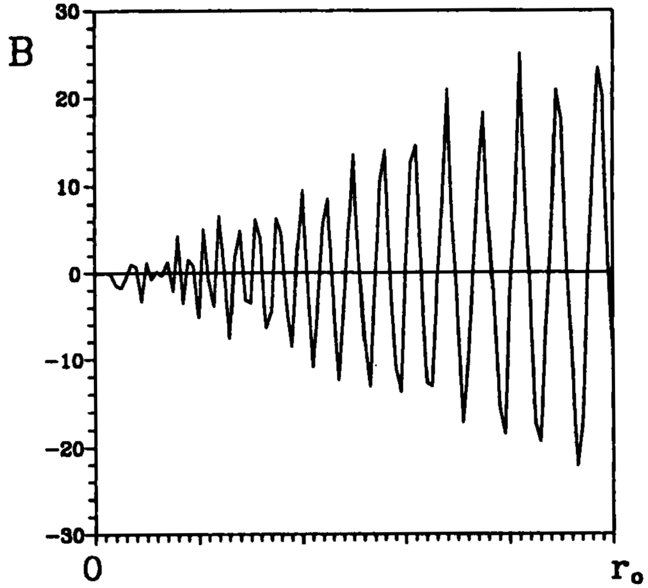

Figure 2 The space distribution of baryon charge at the moment of baryogenesis for $\lambda_1 = 10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $\alpha = 10^{-4}, H_I/m = 10^7$.

to be periodic. Baryonic layers in that model are alternated by antibaryonic ones. The number of roots N, i.e., the number of baryonic-antibaryonic shells in the Universe is defined by the parameters λ_i and the initial values of the field. The spatial distribution of the visible matter at the present moment t_0 will be defined by the spatial distribution of the baryon charge of the ϕ field at the moment of baryogenesis t_b. The baryon density distribution in turn can be expressed through the number of roots at that moment, $N(t_b)$. Then the void's size at the present moment t_0 is obtained from $\Delta r = r_0/N(t_b)$, where t_b is the moment of baryogenesis.

According to our model of baryogenesis, the moment of baryogenesis marks the beginning of B-conserving decays of the scalar field. The account for the particle creation processes by the scalar field may be important for the correct determination of t_b. For our model of baryogenesis [5], t_b coincides with the moment t_s after which the mass terms in the equations of motion for the ϕ field cannot be neglected. As far as the particle creation processes lead to an exponential damping of the field's amplitude, the moment t_s, when the particle production is accounted for, comes earlier than in the case without particle production. Thus estimated, time t_b may essentially differ from the time of B-conserving decays t'_b, obtained without the account for the particle creation processes by the oscillating scalar field: $t_b < t'_b$.

For the lower bound of the Universe size at the present moment t_0 we have accepted the size of the present-day horizon of the Universe, $R_0(t) = 10^{28}$ cm. Hence, for the value of the characteristic scale r_0 we have accepted $r_0 \geq R_0$. For a wide range of parameters the observed average distance between matter shells in the Universe can be obtained. For example, for $\phi_0 \sim H_I \lambda_1^{-1/4}, \lambda_1 \sim 10^{-2}, \lambda_2 \sim \lambda_3 \sim 10^{-3}, \alpha \sim 10^{-4}$ and $H_I t_b \sim 10^{11}$ the number of roots is $N = 30$, which corresponds to a void size $\bar{r} \sim 100$ Mpc. In conclusion we note that if the data of Ref. [1] is true, i.e., there exists a periodic distribution of the visible matter in the universe with the period of about 128 Mpc, the mechanism for generating baryon density perturbations proposed here constrains from beneath the time of baryogenesis. For example, from the constraint $r(t_0) \geq R_0$ at present, it follows $r(t_0) = N(t_b) \times 128h^{-1}$ Mpc$\geq R_0$. So, the time of baryogenesis must be larger than or equal to t_b^*, where t_b^* is the root of the equation $N(t_b) \times 128h^{-1}$Mpc$= R_0$.

Next we estimated the value of the generated baryon asymmetry. For this purpose it is necessary to determine the temperature of the relativistic plasma, resulting from decays of inflation and baryon charged scalar field. In the case discussed, the inflation energy density dominates until the moment t_s. After the decay of ϕ the inflation will still dominate the energy density, since energy density of relativistic particles decreases faster than energy density of nonrelativistic particles in the process of expansion. Hence, entropy will be determined mainly by the density of relativistic particles, resulting from the decay of the inflation: $T \approx [(\rho_\psi)_{t_\psi}]^{1/4}$, where t_ψ denotes the moment of inflation decay. The baryon asymmetry at the moment of the inflation decay is given by

$$\beta_\psi = \frac{N_B}{N_\gamma} \sim \frac{\pi^2 B_s}{\sqrt{H_I t_\psi}}, \tag{5}$$

where N_γ is the photon number density and B_s is the calculated baryon charge in the comoving volume at time t_s. For the parameters of the model the value of the estimated baryon asymmetry is greater than the observational value, but considerably less than unity. As far as the present-day baryon asymmetry is $\beta = \beta_s/S$, where S is a factor accounting for an additional dilution of B at later stages, it is easy to obtain the necessary value of β.

So, according to our model, at present the visible part of the Universe consists of baryonic and antibaryonic shells. The parameters of the model ensuring necessary observable size between the matter domains belong to the range of parameters for which the generation of the observed value of the baryon asymmetry may be possible in the model of scalar field condensate baryogenesis.

Acknowledgements

We are grateful to A. D. Dolgov for helpful discussions. This work is financially supported by Grant-in-Aid for Scientific Research F-214/2096 from the Bulgarian Ministry of Education, Science and Culture.

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