Cosmological Bang within Matter Era.

Is the Generation of Galactic-Scale Mass Possible?

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Abstract

A heuristic hypothesis about domination of Bose-Einstein statistics in the early Universe is suggested. The possibility of Bose-Einstein condensation (BEC) of primordial baryon-antibaryon pairs is considered. In accordance with this postulation enormous masses in the order of galactic mass may be accumulated within the cosmic scales. At the certain threshold value of the matter density the structural bosons decay into fermions and the sharp breakdown of quantum-mechanical symmetry of the particles wave functions occurs. Then, due to the Pauli principle of exclusion a large-scale phase transition occurs because of enormous pressure jump of the matter. This phenomenon might cause Cosmological Bang at the beginning stage of the Matter Era.

As a mechanism of accumulation of galactic mass much larger than the configuration with structural bosons, a hypothetical BEC of elementary bosons (gauge bosons $W^\pm$ and $Z^0$) is discussed as well.

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I. INTRODUCTION

As a possible version for observable evolution of the Universe an assumption may be put forward that the Universe has been started-up from the Radiation Era which probably may be discussed and commented in general arising from the energetic convenience of Bose-Einstein statistics. Based on this assumption, we predict that the evolution of the Universe has been started with the “Era of Bose-Einstein statistics”. At the further period of Matter Era the Fermi-Dirac statistics began act, and since this period the “Era of Fermi-Dirac statistics” dominates. In the result, like to Big Bang phenomenon (because of abrupt breakdown of supersymmetry (SUSY) at the earliest stage of Universe), an alternative Cosmological Bang at the beginning stage of Matter Era might occur as a consequence of spasmodically breakdown of quantum statistics. The great likelihood of Bose-Einstein statistics is directly connected with the energetic convenience of the particles population in the quantum microstates with possible lowest energy without any restriction, in contrast to Fermi-Dirac statistics where the Pauli principle excludes the occupation of the same energetic state by other fermions. This is a well-known macro-scale quantum phenomenon of Bose-Einstein condensation (BEC).

The stable baryonic configurations for considering problem were usually considered in assumption arising from the current state of the matter–already formed steady-state nucleosynthesis and existing nuclei within the model of Fermi-Dirac statistics. Such approach to the main cosmological problem, as the generation of cosmic objects is, seems to be a particular case of more general situation in the early Universe when before the thermodynamic equilibrium between the radiation and matter the Bose-Einstein and Fermi-Dirac statistics of primordial particles have been disjointed because of enormous values of corresponding thermodynamic potentials. This fact indicates in favor of initial large-scale phase transition within the evolution process of early Universe. On the base of above mentioned assumption concerning the Bose and Fermi statistics, and taking into account that the population of the same quantum microstates by the bosons stipulates incomparable less internal energy, a heuristic hypothesis about dominating of Bose-statistics in the early Universe is predicted. Such a physical assumption is in the accordance with the basic process of production of the structural Bose-pairs of primordial particles and antiparticles from the initial high energetic γ-photons in the early Universe. The astrophysical conditions of the Universe at the
beginning stage of Matter Era satisfy the physical requirements for BEC of such pairs.

For the beginning let us leave these heuristic abstractions (detailed investigation will be done separately) and concretize on the possibility of generation of structural bosons by the high energetic primordial photons. The theoretical aspects and mechanisms developed for electron-positron pairs production from high energy photons in the superdense nuclear matter and multiphoton production by the nonlinear channels in the strong radiation field of incomparable low frequencies than the threshold one in diverse astrophysical cases ([1, 2, 3, 4]; H.K.Avetissian, A.K.Avetissian, et. all.) principally can be generalized for the proton-antiproton pairs production. As to neutrons and antineutrons pairs, it is obvious that the mechanisms of their production in principle may be investigated through the other intermediate physical channels, because they do not involve in the electromagnetic interaction ([5]; W.Fauler, F.Hoyle; [6]; G.Feinberg, L.Lederman). Since the high energetic \( \gamma \)-photons may generate baryon-antibaryon pairs, and the photons are electrically pure neutral, they could create just pure neutral elementary particles–bosons, or even structural bosons with the total zero electrical charge within appropriate elementary phase space.

II. THEORETICAL PREREQUISITES

A. BEC of structural bosons

For the first quasi-qualitative/quasi-quantitative investigation we will start from the case of structural bosons, consisted from proton, neutron, electron and their antiparticles, respectively.

The spatial scale of quantum-electrodynamics phenomena, especially for \( \gamma + \gamma \rightarrow p + \bar{p} \) process, has the same order value as the proton’s Compton wavelength (the average phase-space localization of \( \gamma \)-photons): \( \lambda_p = \frac{\hbar}{m_p c} \approx 2.1 \times 10^{-14} \text{ cm} \). The physical approach about “point-or-elementary” assumption of structural bosons will maintain descriptive strength until the scattering amplitude of these structural bosons will exceed their own size by several times. If the average size of baryon-antibaryon pairs is nearly \( 2 \times 10^{-14} \text{ cm} \), the average distance between pairs at least must be in order of \( d_{p\bar{p}} \approx 5 \times 10^{-14} \text{ cm} \), which corresponds to the upper limit of pairs concentration \( n_{p\bar{p}} \approx 1.9 \times 10^{39} \text{ cm}^{-3} \).

For mentioned densities and supposed temperatures of the Universe \( T \sim 10^{10} \div 2 \times \)
10^8 K^0 at the beginning stage of Matter Era (see Ya.Zel’dovich, I.Novikov; and S.Weinberg) the baryon-antibaryon superdense degenerate plasma moderately reaches its relativistic bound. These temperatures are relatively close to the values $T_{\text{max}} \sim 5 \times 10^8$ K^0, obtained theoretically in (V.Urpin, D.Yakovlev) and in (D. Sedrakyan, A. Avetissian). Hence, the temperature of BEC may be obtained based on generalized relativistic formula

$$\frac{N}{V} = \frac{gT^3}{2\pi^2 (\hbar c)^3} \int_0^\infty \frac{z^2dz}{e^z - 1} = \frac{gT^3}{2\pi^2 (\hbar c)^3} \Gamma (3) \zeta (3).$$ \hspace{1cm} (1)

Here $c$ is the velocity of light, $\hbar$ is the Plank constant, $g = 2s + 1$- spin degeneracy factor, $\Gamma (x)$- Gamma function, and $\zeta (3) = 1.202$ - Ryman’s Zeta function (hereafter the Boltzman’s constant $k_B \equiv 1$). The temperature of BEC, obtained from (1), is:

$$T_0 = \left( \frac{2\pi^2}{2.4g} \right)^{1/3} \frac{\hbar c}{3} \left( \frac{N}{V} \right)^{1/3} = \begin{cases} 4.63 \\ 3.21 \end{cases} \times 10^{12} \text{ K}^0.$$ \hspace{1cm} (2)

The number on upper row of (2) corresponds to the spin-singlet state of baryonic pairs, on lower row – to the spin-triplet state. The relatively higher temperature of BEC indicates in favor of energetic efficiency of theoretical model, so the realization of spin singlet state of baryonic pairs is more likelihood.

The spherical-symmetric configuration of baryon-antibaryon pairs (so called hypothetical Universe) may be qualitatively described in presumption of convective stability; then the equations of thermodynamic and hydrodynamic equilibrium without relativistic corrections get the following form [8]:

$$\frac{dm}{dr} = \frac{4\pi}{c^2} r^2 \rho_\varepsilon (r),$$ \hspace{1cm} (3a)

$$\frac{dp}{dr} = -\frac{G}{c^2 r^2} m (r) \rho_\varepsilon (r).$$ \hspace{1cm} (3b)

Here $G$ is the Gravitation constant, $\rho_\varepsilon (r)$–BEC energy density of baryonic matter, $m (r)$–mass of the matter within the central sphere with radius $r$. The system (3) must be also completed by the equation of Bose-Einstein condensate state with baryon-antibaryon pairs:

$$p_{\text{BEC}} = \frac{gT^4}{6\pi^2 (\hbar c)^3} \Gamma (4) \zeta (4) = \frac{g\pi^2 T^4}{90 (\hbar c)^3}.$$ \hspace{1cm} (4)

It is easy to show that the photonic pressure is negligible in comparison with the BEC one. Then it is essential to investigate the physical approach when BEC of baryon-antibaryon
pairs can be considered as an ideal gas. The critical value of concentration when the amplitude of the pairs scattering is of the order of their own size, corresponds to the Compton wavelength:

\[ n_{cr} = \left( \frac{N}{V} \right)_{cr} \sim \frac{1}{(4\pi/3)\lambda_p^3} \sim 2.6 \times 10^{40} \text{ cm}^{-3}. \]  

(5)

Up to this critical density the baryon-antibaryon pairs do not "sense" the own inner structure and may be considered as elementary particles, so the equation of state of baryonic matter \([4]\) can be presented in more generalized form:

\[ p_{BEC} (r) = \frac{g\pi^2T^4 (r)}{90 (\hbar c)^3} \]  

(6)

The weak dependence on the radius of the functions \( p (r) \) or \( T (r) \) evidences that within the BEC state approximation the matter responds extremely weak on external pressure and in the result the gravitational pressing may accumulate huge masses within the cosmic scales.

The gravitational pressing of baryonic matter within the BEC and accumulation of mass up to above mentioned critical densities may be investigated within two alternative physical assumptions:

1) The process of gravitational pressing is assumed to be isothermal,

2) The gravitational pressing varies the temperature of baryonic matter from its initial value \( T \sim 10^{10} \text{ K} \) up to final \( T \sim 4.63 \times 10^{12} \text{ K} \) (i.e. until the temperature of the BEC).

Within the approximation of the process 1, at the end of gravitational pressing (just before the quantum symmetry breakdown) the pressure of baryonic matter in accordance with (6) achieves its extreme value

\[ p_{BEC}^{T=\text{const}} \approx 1.26 \times 10^{24} \text{ Pa}. \]  

(7)

In this intermediate state, such hypothetical configuration of baryon-antibaryon degenerate plasma appears within extremely non-stable state. Actually, because of scattering of pairs on each other, at the critical value of density \( n_{cr} \approx 2.6 \times 10^{40} \text{ cm}^{-3} \) this state should fail due to the breakdown of quantum statistics of Bose-pairs. This unstable state will be transferred from Bose-Einstein statistics to Fermi-Dirac one and in the result the pressure of the fermions system will increase significantly, in accordance with the Pauli exclusion principle:

\[ p_{F-D} \approx 3.36 \times 10^{35} \text{ Pa}. \]  

(8)
From the formulas (7) and (8) we obtain the corresponding jump of pressure in the phase transition within process 1, stipulated by the phenomenon of quantum mechanical symmetry breakdown:

\[
\frac{p_{F-D}}{p_{\text{const}}} \approx 2.27 \times 10^{11}.
\]  

(9)

2) At the end of gravitational collapse, the pressure achieves its extreme value:

\[
p_{T} \approx 5.8 \times 10^{34} \text{ Pa},
\]  

(10)

so for the corresponding pressure jump from the formulas (10) and (8) we obtain

\[
\frac{p_{F-D}}{p_{T}} \approx 5.8.
\]  

(11)

The comparison of expressions (9) and (11) shows that within the presumed model of BEC the alternative cosmological Bang is realized explicitly via quasi-isothermal process 1.

The results of numerical analyses of the theoretical model investigations are represented in Fig. 1-2. Figure 1 represents the behavior of radial pressure within the baryon-antibaryon configuration. Let specify: which value of radius must interrupt the numerical integration of the system (3)? This question is equivalent to the physical issue: what value of \( r_{\text{max}} \) should be recognized as a “effective radius of baryon-antibaryon stable configuration” (i.e. \( R_{\text{conf}}^{\text{eff}} = r_{\text{max}} \))? Both issues depend on the minimal value of pressure until which the approach of gaseous BEC may be considered physically reliable yet. This condition is equivalent to the physical requirement \( T >> T_{\text{cryst}} \), where \( T_{\text{cryst}} \) - is the temperature of crystallization of the outer crust of baryonic configuration. Based on analogues investigations (see e.g. [12]) one can estimate for the upper limit of this assumption \( T_{\text{cryst}} \leq 10^{8} \text{ K} \). In accordance with the above mentioned, the minimal value of pressure obtained from (4): \( p_{\text{min}} \leq 1.3 \times 10^{16} \text{ Pa} \). Finally, the criterion \( p \geq p_{\text{min}} \) determines the lower limits both for the effective radius \( R_{\text{conf}}^{\text{eff}} \) and effective mass \( M_{\text{conf}}^{\text{eff}} \) of the hypothetical Universe. As it is seen from Fig. 1, for \( p_{\text{min}} \leq 1.3 \times 10^{16} \text{ Pa} \) the radius of baryon-antibaryon configuration before the Cosmological Bang was approximately \( r_{\text{max}} \sim 10^{33} \text{ m} \).

Figure 2 represents the behavior of central mass of baryon-antibaryon configuration within radius \( r \). As it mentioned above, in accordance with the condition \( p \geq p_{\text{min}} \) the integration
of system (3) may be interrupted at $r_{\text{max}} \sim 10^{13}$ m. Then the effective radius of baryon-antibaryon stable configuration will be nearly about $R_{\text{conf}}^{\text{eff}} \approx 10^{13}$ m, and the effective mass $M_{\text{conf}}^{\text{eff}} \approx 10^{40}$ kg.

B. Hypothetical BEC of elementary bosons

Beside the structural bosons – baryon-antibaryon pairs at the generation of cosmic matter in the scope of proposed model one should probably take into account the elementary bosons as well ($W^\pm$ and $Z^0$). As the gauge bosons $W^\pm$ and $Z^0$ are almost 100 times as massive as the proton, so they may have significant contribution in the mass accumulation. Although these bosons have a very short-life time, they may be engaged in the phenomenon of BEC. These issues require an additional theoretical investigation to constitute: might the elementary bosons become stable particles at the extra high densities? The possibility of this exotic phenomenon, i.e. production of elementary Bose-particles after the breakdown of supersymmetry and separation of fundamental interactions requires an additional discussion in following aspect: might the intermediate carriers of weak interaction appear and be stabilized in superdense plasma? Alternatively, might they play a significant role in the phenomenon of mass generation and further accumulation of the matter until galactic masses? At last, might the above-mentioned elementary bosons be responsible for the phenomena of Dark Matter and Dark Energy?

For more substantial discussion of mentioned speculative ideas connected with primordial role of the electroweak interaction in the evolution of the Universe it is necessary to take into consideration the conditions at very early stages of Universe. If about baryonic BEC one can speak at the temperatures till $T \sim 10^{11}$ K$^0$, then above these temperatures, namely, about $T \sim 10^{13}$ K$^0$ the physical conditions allow the accumulation of sufficient number of $W^\pm$ and $Z^0$ bosons.

Very arrested alternative hypothesis may raise up regarding the mass generation problem within celestial objects. For instance, might much more densities of hypothetical plasma (compared with baryonic plasma!) consisted mainly of $W^\pm$ and $Z^0$ bosons be a consequence of 100 times smaller (compared with baryons) value of their Compton-length $\lambda_w = \hbar/m_wc \approx 2 \times 10^{-16}$ cm $^2$

In the same approximation of ideal nonrelativistic gas one can estimate the lower bound
for $W^\pm$ and $Z^0$ bosons concentration and BEC temperatures:

\[ n_{\text{min}} \sim 2 \times 10^{45} \text{ cm}^{-3}; \quad T_0 \sim 2.5 \times 10^{14} \text{ K}. \]

The corresponded to these values of densities and temperatures pressure of such bosonic system appears to be

\[ P(0) \sim 3.6 \times 10^{27} \text{ Pa}. \]

Note that because of absence of experimental data about $W^\pm$, $Z^0$ bosons scattering cross sections for estimation of the upper bound of $W^\pm$, $Z^0$ bosons concentration and corresponding BEC temperatures, the presented estimations are limited with the lower bound of bosons concentration. Otherwise, the larger values of the latter might give us the larger BEC temperatures and, consequently, would be physically more realistic to take into consideration the BEC phenomenon in the more earlier stages of Universe.

The results of numerical treatments of BEC in large-scale cosmic matter (hypothetical Universe) for both considered cases A and B are given in Fig. 1, 2. As is seen from the obtained graphics, the accumulated mass due to the BEC of $W^\pm$, $Z^0$ bosons by two order

![Figure 1](image.png)

**FIG. 1:** The radial dependence of pressure for baryon-antibaryon (solid line) and $W^\pm$, $Z^0$ bosonic (dashed line) configurations.
FIG. 2: The radial dependence of mass for baryon-antibaryon (solid line) and $W^\pm, Z^0$ bosonic (dashed line) configurations.

of magnitude exceeds the mass due to the baryonic BEC within the radius $r \sim 10^{10}$m of spherical symmetric configuration.

The stability of considered large-scale configuration will be a subject of further investigation.

III. DISCUSSION

It is physically clear that the possibility of generation of large-scale configurations in principle does not except just in one local cosmic space-time scales. Furthermore, this hypothesis and corresponding physical model, as well as its astrophysical applications might have cosmological consequences both within relatively small- and large-scales cosmic structures. Note that after predicted Cosmological Bang at the beginning stage of Matter Era the “islands” of similar configurations of degenerate matter might be accumulated, which might form then various stable cosmic objects. It is physically obvious that these objects principally might correlate in groups, clusters, or even associations.

May the predicted Cosmological Bang be candidate for a “generator of galactic-scale
masses”? This physical question requires additional analysis in the scope of considered hypothesis and corresponding astrophysical model. Besides, the considered problems require further investigation of the discussed analytical model and development of the main ideas presented here in the scope of general relativity. In addition, it is essential to take into consideration the various empiric equations for BEC which might be more realistic from the cosmological point of view.

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