PREONS, DARK MATTER AND THE PRODUCTION OF EARLY COSMOLOGICAL STRUCTURES

V.Burdyuzha\textsuperscript{1}, O.Lalakulich\textsuperscript{2}, Yu.Ponomarev\textsuperscript{1}, G.Vereshkov\textsuperscript{2}

\textsuperscript{1} Astro Space Center of Lebedev Physical Institute of Russian Academy of Sciences
Profsoyuznaya 84/32, 117810 Moscow, Russia

\textsuperscript{2} Rostov State University,
Stachki str. 194, 344104 Rostov on Don, Russia

Abstract

If the preon structure of quarks, leptons and gauge bosons will be proved then in the Universe during relativistic phase transition the production of nonperturbative preon condensates has been occured collective excitations of which are perceived as pseudogoldstone bosons. Dark matter consisting of pseudogoldstone bosons of familon type contains a ”hot” component from massless particles and a ”cold” (nonrelativistic) component from massive particles. It is shown that such dark matter was undergone to two relativistic phase transitions temperatures of which were different. In the result of these phase transitions the structurization of dark matter and therefore the baryon subsystem has taken place. Besides, the role of particle generations in the Universe become more evident. For the possibility of structurization of matter as minimum three generations of particles are necessary.
1. INTRODUCTION

Observational data of distant objects (quasars at $z > 4$ [1] and CO molecular lines at $z \approx 4.69$ [2]) show that some baryon objects and baryon large-scale structure (LSS) were created at least at redshifts $z \sim 6 \div 8$. This is the difficulty for standard CDM and CHDM models to produce their and in more early epoches ΛCDM model describes LSS formation better. The conventional scenario to explain the formation of the most structures at $z \sim 2 \div 3$ is the bottom-up hierarchical formation scenario such as CDM [3]. If early baryon cosmological structures were produced on $z$ more than 10 then the key role in this process must play dark matter (particles forming more than 90 % of the Universe mass).

In the standard model dark matter (DM) consists of ideal gas of light $m \approx 0$ particles practically noninteracting with usual matter (till now they are not detected because of their superweak interaction with baryons and leptons[4]). In a new theory of DM an effect of strong structurization of DM must be inevitably in early epoches. The problem is to find the character of this phenomena.

In the frame of purely phenomenological approximation one can propose that values of initial fluctuations in DM were not connected with the value of relic radiation fluctuations. In this case the selection of the values of DM initial fluctuations can provide any moment of structure production. Authors of articles [5-6] have considered DM as the gas of pseudogoldstone bosons (PGB) in which a relativistic phase transition (RPT) is possible at superlow (comparing with the usual scale of elementary particle physics) temperature. The fact of this phase transition proposes strong nonlinearity of DM, that is these PGB must strongly interact with each other. In the mirror models this property is realized automatically. In the gas of PGB particles this phenomenon is exotic and it imposes strict limits on the hypothesis about the nature of PGB.

PGB as physical objects arise as the result of the spontaneous breaking of the continuous symmetries of vacuum. In modern theories of elementary particles four types of PGB are discussed: axions, arions, familons, and majorons. The small masses of PGB arise in the result of superweak interactions of Goldstone fields with nonperturbative vacuum condensates. The values of these mass are limited by astrophysical data [7]:

$$m_{PGB} \sim 10^{-3} \div 10^{-5} \text{ eV}$$  \hspace{1cm} (1.1)

(laboratory experiments admit masses of PGB to $\sim 10 \text{ eV}$ [7]). The estimation (1.1) has been got from assumption that PGB are elements of DM influencing on dynamics of the Universe expansion and on the process of production of baryon LSS.

The emergence of massive terms in Lagrangian of Goldstone fields corresponds formally mathematically the effect of the production of PGB masses. From general considerations it is possible to propose, that, dependending on the PGB type and the structure of nonperturbative vacuum, massive terms can arise as with "right" as with "wrong" sign. This sign predetermines the destiny of residual symmetry of pseudogoldstone fields. In the case of wrong sign for low temperatures

$$T < T_c \sim m_{PGB} \sim (0.1 \div 10^5) \text{ K}$$  \hspace{1cm} (1.2)

a Goldstone condensate produced inevitably and the symmetry of the vacuum state breaks spontaneously. The appearence of a condensate at $T = T_c$ and more low temperatures is a relativistic phase transition (RPT) from the high symmetric (HS) phase in low symmetric (LS) phase of PGB gas. As it is known, the general theory of cosmological RPT was formulated by Kirzhnits and Linde [8].
The idea of RPT in the cosmological gas of PGB in the connection with baryon large scale structure problem was formulated by Frieman et al. [6]. In this article we discuss the properties of cosmological gas containing PGB of familon type and investigate the preon-familon model of this RPT quantitatively. The familon symmetry is experimentally observed as the fact, that different generations of quarks and leptons absolutely identically participate in all gauge interactions. The breaking of familon symmetry is manifested in the values of particle masses of different generations.

There were proposed some models (see as the example [9]) where the familon symmetry is the horisontal gauge symmetry, breaking down by Higgs condensates. The hypothesis is quite natural because it is based on general ideas about the unification of particles and interactions.

However for existence of familons as physical objects it is necessary that at least some Goldstone degrees of freedom were not transferred to vector states as their longitudinal polarizations. If this condition is completely fulfilled then familon fields are complex and they possess residual global U(1) symmetries. If these familon fields have mass terms with wrong sign then these residual symmetries must be spontaneously broken as temperature has decreased. The properties of any pseudogoldstone bosons (as pseudogoldstone bosons of familon type) depends on physical realization of Goldstone modes. These modes can be arisen from fundamental Higgs fields (as it is done in the work [9]) or from collective excitations of a heterogenic nonperturbative vacuum condensate, more complicated than quark-gluon one in QCD. The second possibility can be realized in the theory in which quarks, leptons and intermediated bosons are composite objects. Such model is called the preon model of elementary particles. Thus we will discuss the properties of familon gas predicted by the preon theory, and will investigate the cosmological consequences of the simplest boson-familon model [10]. Our interest to the preon model is induced by the possible interpretation of HERA experiment [11] as the leptoquark resonance if a leptoquark is the composite object.

RPT in the cosmological familon gas is a phase transition essentially of the first order with a wide temperature region of HS and LS phase coexistence. The numerical modelling of this RPT has shown that the space interchange of HS and LS phases with the contrast of the energy density $\delta \rho/\rho \sim 1$ arises in the Universe in the epoch of the phases coexistence. The characteristic scale of the block-phase structure is defined by the distance to horizon in RPT moment, that is the large scale structure of DM is produced. The baryon subsystem duplicates the DM large-scale structure due to gravitational interaction with DM. To explain the hierarchy of modern structures our model describes at least two RPT at temperatures no more than a few electronvolt, one phase transition occurs at the postrecombination epoch.

2. THE PHYSICAL NATURE OF FAMILONS AS THE EXCITATIONS OF NONPERTURBATIVE VACUUM

As we have already noted, the breaking of familon symmetry makes itself evident in the splitting of quarks and leptons masses. Therefore the discussion of the physical nature of familons must appeal to the problem of the origin of fermion masses. There are two mechanisms of mass generation: Higgs and nonperturbative one, in which the masses generation are the result of fermion fields interactions with non-perturbative vacuum condensates (in the simplest case they are quadratic on quantum fields). In QCD the second mechanism is drawn for the mass generation of $u$ and $d$ quarks. The effect of mass generation of quarks is illustrated by the diagram:
The numerical values of gluon and quarks condensates standing in (2.1) are known from experimental data [12]:

\[ \langle 0 | \frac{\alpha_s}{\pi} \pi \sum a \sum \mu \nu G^a_{\mu \nu} | 0 \rangle = (360 \pm 20 \text{ MeV})^4 \]  

(2.2)

\[ \langle 0 | \bar{u}u | 0 \rangle = \langle 0 | \bar{d}d | 0 \rangle = -(225 \pm 25 \text{ MeV})^3 \]

The basic characteristic of QCD vacuum is the gluon condensate, originating from the nonperturbative fluctuations of gluon fields being arisen in the processes of gluon vacuum tunnelling among degenerated on energy states with different topological numbers [12]. The quark condensates are induced by the fluctuations of initially massless quark fields appearing as a reaction of quark fields on vacuum fluctuations of gluon fields. The initial massless of \( u, d \) quarks provides the essentially high intensity of these reactions that represents the value of the quark condensate is smaller but not very small comparing with the value of gluon condensate.

In the frame of QCD the masses of heavy quarks \( (s,c,b,t) \) have not the analogous interpretation. Really, QCD predicts that magnitudes of heavy quarks vacuum condensates are in inverse proportion to the meaning of their mass:

\[ \langle 0 | \bar{Q}Q | 0 \rangle \approx -\frac{1}{12m_Q} \langle 0 | \frac{\alpha_s}{\pi} \pi \sum a \sum \mu \nu G^a_{\mu \nu} | 0 \rangle, \quad Q = s,c,b,t. \]  

(2.3)

But in the nonperturbative mechanism masses of quarks are proportional to the value of the corresponding condensate. In this case it is necessary to attract the additional physical considerations for the explanation of spectra of heavy quark masses. Phenomenologically these masses can be brought using Higgs mechanism, although the additional introduction of a great number of constants of unknown nature is requested. But Higgs bosons are not detected till now while signals a new physics have created [11].

Let us consider now the simplest boson-fermion preon model of left-handed quarks and leptons. The basic elements of this model are: chiral fermionic preons of up \( U^o_L \) and down \( D^o_L \) type, and scalar preons of quarks \( \phi_{ia}^a \) and leptons \( \chi_{ie}^a \) types. Here \( i \) is the color index of QCD; \( a, b, c = 1, 2, 3 \), \( l, m = 1, 2, 3 \) are numbers of quark and lepton generations; \( \alpha \) is the index of metacolor corresponding to a new metachromodynamical interaction, connecting preons in quarks and leptons. The following is the structural formula illustrating the interior structure of elementary particles:

\[ u^i_{La} = U^o_{La} \phi^+_{ia} \quad u^i_{La} = (u^i_L, e^i_L, \tau^i_L) \]

\[ d^i_{La} = D^o_{La} \phi^+_{ia} \quad d^i_{La} = (d^i_L, s^i_L, b^i_L) \]

\[ \nu^i_{Li} = U^o_{Li} \chi^+_{ia} \quad \nu^i_{Li} = (\nu^i_L, \mu^i_L, \tau^i_L) \]

\[ l^i_{Li} = D^o_{Li} \chi^+_{ia} \quad l^i_{Li} = (e_L, \mu_L, \tau_L) \]  

(2.4)
The structure of the good known particles is the formulae (2.4). The structure of leptoquarks is the formula (2.5).

The interior of quarks and leptons the metagluon fields $G_{\mu\nu}^\alpha$ and scalar preon fields are the confinement state. This effect on itself physical nature is identical with confinement of quarks and gluons interior of hadrons and it is provided by the existence of nonperturbative metagluon and preon condensates

$$
(0 \left| \frac{\alpha_{mc}}{\pi} \right. G^\gamma_{\mu\nu} G^\gamma_{\nu\rho} \left| 0 \right) \sim \Lambda_{mc}^4
$$

(2.6)

$$
(0 \left| \phi_{a}^{ia} \phi_{b}^{ia} \right| 0) = V_{ab} \sim -\Lambda_{mc}^2
$$

(2.7)

$$
(0 \left| \chi_{i}^{a} \chi_{m}^{a} \right| 0) = V_{im} \sim -\Lambda_{mc}^2.
$$

(2.8)

The condensates (2.6) and (2.7) in combination with gluon and quark condensates (2.2) and (2.3) provide the mechanism of mass production of quarks of all three generations

$$
\langle 0 \left| \bar{\phi}_{c}^{r\alpha} u_{Rb} \right| 0 \rangle \equiv \langle 0 \left| \bar{u}_{Lc}^{m} u_{Rb} \right| 0 \rangle
$$

(2.9)

$$
\langle 0 \left| \phi_{a}^{ia} \phi_{b}^{ia} \right| 0 \rangle
$$

(2.10)

$$
\langle 0 \left| \chi_{i}^{a} \chi_{m}^{a} \right| 0 \rangle
$$

(2.11)

here $G_{\mu\nu}^{ik} = \lambda_{n}^{jk} G_{\mu\nu}^{in}$, $\lambda_{n}^{in}$ are Gell-Mann matrixes; $G_{\mu\nu}^{\alpha\beta} = \lambda_{\alpha}^{\beta\gamma} G_{\mu\nu}^{\gamma}$, $\lambda_{\alpha}^{\beta\gamma}$ are the analog of a Gell-Mann matrix for metacolour.

As it is seen from (2.9) the basic contribution in the breaking of vacuum familon symmetry is formed by preon condensates (2.7). For a realistic vacuum state the condensate matrixes must be brought to diagonal form. From the suggestion (2.1) the equality $V_{11} = 0$ follows. Thus on the preon level the chiral-familon symmetry $SU(2)_{L} \times SU(2)_{R}$ joining quarks of the second and third generations must be considered.

The importantest prediction of diagram (2.9) is that the interactions of quark excitations with complex condensates containing preon and quark-preon components must be considered for full discription of the production mass effect

$$
M_{ab}^{(u)} = \langle 0 \left| \phi_{a}^{ia} \phi_{c}^{ia} \bar{u}_{Lc}^{\beta} \phi_{Rb}^{i} \left| 0 \right) \right.
$$

(2.10)

$$
M_{ab}^{(d)} = \langle 0 \left| \phi_{a}^{ia} \phi_{c}^{ia} \bar{D}_{Lc}^{\beta} \phi_{Rb}^{i} \left| 0 \right) \right.
$$

(2.11)

In (2.10) and (2.11) for simplicity the gluon and metagluon condensates as sources of nonperturbative preon condensates are not brought. Their role is evident from diagram (2.9). Therefore the theory of preon predicts a complicated structure of the heterogenic
nonperturbative vacuum. The element (2.10) from this structure participates in the process of mass production of up quarks from the second and third generations, for down quarks the element (2.11) does the same. The analogous analysis of generation mass process for charge leptons of the second and third generations gives yet one element of the interior structure of vacuum

\[ M_{lm}^{(i)} = \langle 0 | \chi_l^\alpha \bar{\chi}_r^\beta \bar{D}^\beta_L \chi_r^\alpha | L \rangle \]  

(2.12)

Formally formulae (2.10), (2.11) and (2.12) are 2 x 2 matrices of general form containing 8 numbers. It is easy to calculate that a number of parameters in real and diagonal matrices (2.10), (2.11) and (2.12) equals a number of particles containing in the second and third quark and lepton generations.

Familons as physical objects are collective excitations of nonperturbative condensates (2.10), (2.11) and (2.12). These excitations are the result of local processes of weakening and rebuilding of correlations among fields. Three types of condensates correspond to three families of familon fields. Evidently, also that the number of familons in a family equals eight that is it coincides with a maximum numbers of parameters of condensate matrixes. In each family two familon fields are arisen as the consequence of the local perturbation of condensate density energy. If a familon family is described by complex 2 x 2 matrixes of general form then perturbation of density energy will correspond to diagonal elements of this matrix. Perturbations of energy density have a mass around scale of metacolour confinement \( \Lambda_{mc} \).

The rest six familons of a family are arisen as a results of rebuilding of a condensate. A small mass of rest the Goldstone modes gain interacting with quark condensates (their status in this case are PGB). On the diagram (2.9) the mass of quarks is formed by interaction of quantum components of quark subsystems with condensate components of preon subsystems. In the similar spirit a small mass of pseudogoldstone familons is gained for interaction of perturbations of condensate preon subsystems with condensate components of quark subsystems (2.3).

For cosmological applications of the familon theory based on the hypothesis about preon structure of vacuum and elementary particles the most interest presents the predictions related to DM. In frame of this theory DM is interpreted as the system of familon collective excitations of the heterogenic nonperturbative vacuum. This system contains three subsystems: familons of upper-quark type; familons of lower-quark type and familons of lepton type. On stages of the cosmological evolution which are far from quarkonization and leptonization of preon plasma \( T \leq \Lambda_{mc} \) heavy unstable familons are absent as evidently. On these stages each familon subsystems are described by five field degrees of freedom. The destiny of each subsystems of low energetic familon gas depends radical mean on the sign of rest mass squares which are generated by interactions of familons with quark condensates.

3. THE INEVITABILITY OF RESIDUAL SYMMETRY SPONTANEOUS BREAKING OF PSEUDOGOLDSTONE FAMILON FIELDS

The presentation about physical nature of familons is uniquely formalized in a theorectico-field model. For simplicity the model of familon subsystem corresponding to up quarks of the second and the third generations \( Q = (c, t) \) is considered. Because of the chiral nature of quarks is the good known fact then the symmetry group of model must be only the chiral-familon group \( SU(2)_L \times SU(2)_R \). The familon excitations must be described by the eight measure reducible representation of this group factorized on two irreducible representations \( (F, fa); (\psi, \varphi_a) \) which differ each other by a sign of
space chirality

\[ L = \frac{1}{2} (\partial_\mu \psi \partial^\mu \psi + \partial_\mu \varphi_a \partial^\mu \varphi_a + \partial_\mu F \partial^\mu F + \partial_{mu} f_a \partial^\mu f_a + \frac{1}{2} \mu^2 (\varphi^2 + \varphi_a \varphi_a) + \\
+ \frac{1}{2} \mu^2_2 (F^2 + f_a f_a) - \frac{1}{4} \lambda_1 (\psi^2 + \varphi_a \varphi_a)^2 - \frac{1}{4} \lambda_2 (F^2 + f_a f_a)^2 - \frac{1}{2} \lambda_1 (\psi^2 + \varphi_a \varphi_a)(F^2 + \\
f_a f_a) - \frac{1}{2} \lambda_0 (\psi^2 + \varphi_a f_a)^2 - g_1 \bar{Q} (\psi + i \gamma_5 \tau_a \varphi_a) Q + g_2 \bar{Q} (\tau_a \varphi_a - i \gamma_5 F) Q \] (3.1)

The quark fields are presented in (3.1) by induce nonperturbative fluctuations (2.3) only which describe phenomena taking place outside a hadron space. The terms with mass parameters \( \mu_1^2, \mu_2^2 \sim \Lambda_m^2 \) are included in (3.1) “wrong” signs to provide the spontaneous breaking of familon symmetry on the scale of metacolor confinement. In a condensate the mean values of scalar (non pseudoscalar) fields drop out:

\[ \langle \psi \rangle = v, \quad \langle f_3 \rangle = u, \] (3.2)

that provides the conservation of parity in strong interactions. The investigation of model (3.1) in detail has shown that these vacuum expectations break the initial chiral-familon symmetry to the residual \( U(1) \) symmetry, corresponding to conservation of the quark flavors

\[ SU(2)_L \times SU(2)_R \rightarrow U(1) \] (3.3)

The condensates of scalar fields (3.2) generate according to the structure of two last terms (3.1) splitted spectrum of quark masses (on the preon level this effect is described by (2.9))

\[ m_{ab} Q_a Q_b = m_c \bar{c} c + m_t \bar{t} t \]

\[ m_c = g_1 v - g_2 u, \quad m_t = g_1 v + g_2 u \] (3.4)

As it is seen from (3.4) for \( v, u \sim \Lambda_m \gg 1 \) Tev the experimentally observable values of masses \( m_c \approx 1.3 \) Gev, \( m_t \approx 175 \) Gev are only created for very small values of constants \( g_1, g_2 \) of quark-familon interactions.

A smallness of these constants provides the hyperweakness of familon interactions with usual matter. The preon model allows an understanding of the reason of this smallness. Really, as it is seen from (2.10) and (2.11) a complex heterogeneous condensate is responsible for generation of quark masses is arisen as the result of correlations of fluctuation fields belonged to strongly different levels of structure. The chromodynamical fluctuations on the scale \( \Lambda_c \sim 100 \) Mev must be correlated with metachromodynamical ones on the scale \( \Lambda_m \gg 1 \) Tev. Evidently that phenomenological constants \( g_1, g_2 \) is proportional the probability of these correlations. Therefore a smallness of these constants reflects a small probability of correlations of different scale fluctuations.

Equations for vacuum expectations fixing spontaneous breaking of familon symmetry contain quark vacuum condensates:

\[ \mu^2_1 v - \lambda_1 v^3 - \lambda_1 u^2 v - g_1 (\langle cc \rangle + \langle ll \rangle) = 0 \]

\[ \mu^2_2 u - \lambda_3 u^3 - \lambda_1 u^2 v + g_2 (\langle cc \rangle - \langle ll \rangle) = 0 \] (3.5)

These equations are used for extraction from Lagrangian (3.1) of quantum components of familon fields. First and foremost we have interest to the spectrum of familon masses. The spontaneous breaking of the symmetry (3.3) transforms the six parametric group of symmetry in one parametric one. According to the Goldstone’s theorem
5 degrees of freedom must be practically massless on scale \( \Lambda_{mc} \). Therefore 3 heavy familons must be in this model also. Two from their are perturbations of condensate density energies (3.2) and they are described by orthogonal superpositions of the quantum components of scalar fields \( \psi \) and \( f_3 \):

\[
M^2_{\psi'} \approx 2(\lambda_1 v^2 + \lambda_2 u^2); \quad M^2_{f'} \approx \frac{2(\lambda_1 \lambda_2 - \lambda_1^2)u^2v^2}{\lambda_1 v^2 + \lambda_2 u^2} \tag{3.6}
\]

The third heavy familon is identified with one from two orthogonal superpositions of pseudoscalar fields \( F \) and \( \varphi_3 \) (the second superposition goes to pseudogoldstone sector) and its mass is

\[
M^2_{F'} \approx \lambda_0 (u^2 + v^2)
\]

The pseudogoldstone modes can be constituted as a real pseudoscalar field with mass:

\[
m^2_{\varphi'} \approx \frac{1}{24(u^2 + v^2)} \left( \frac{\alpha s}{\pi} G_{\mu\nu} G^{\mu\nu} \right) \left[ \frac{(m_t + m_c)^2}{m_c m_t} - \frac{(m_t - m_c)^2}{m_c m_t} \right] = \frac{1}{6(u^2 + v^2)} \left( \frac{\alpha s}{\pi} G_{\mu\nu} G^{\mu\nu} \right) \tag{3.7}
\]

a complex pseudoscalar field with mass:

\[
m^2_{\varphi} = \frac{1}{24u^2} \left( \frac{\alpha s}{\pi} G_{\mu\nu} G^{\mu\nu} \right) \left[ \frac{(m_t + m_c)^2}{m_c m_t} \right] \tag{3.8}
\]

and a complex scalar field whose square of a mass is negative:

\[
m^2_f = -\frac{1}{24u^2} \left( \frac{\alpha s}{\pi} G_{\mu\nu} G^{\mu\nu} \right) \left[ \frac{(m_t - m_c)^2}{m_c m_t} \right] \tag{3.9}
\]

The complex fields with masses (3.8) and (3.9) are nontrivial representations of the group of residual symmetry \( U(1) \), real fields with more masses than (3.6) and the field with the small mass (3.7) are unit representations of this group. These masses are estimated as:

\[
M_{\psi'}, M_{f'}, M_{F'} \sim \Lambda_{mc} \tag{3.10}
\]

\[
m_{\varphi'} \sim \frac{\Lambda^2_c}{\Lambda_{mc}} \tag{3.11}
\]

\[
m_{\varphi} \mid m_f \mid \sim \frac{\Lambda^2_c}{\Lambda_{mc}} \sqrt{m_t/m_c} \tag{3.12}
\]

As we noted before light pseudogoldstone bosons with masses (3.10), (3.11), (3.12) must be included in composition of DM. The negative square mass of complex scalar field means that for low temperatures

\[
T < T_{c(u)} \sim m_f \mid \sim \frac{\Lambda^2_c}{\Lambda_{mc}} \sqrt{m_t/m_c} \tag{3.13}
\]

PGB vacuum is unstable. That is for the temperature \( T = T_{c(u)} \) the relativistic phase transition in the state with spontaneously breaking residual symmetry \( U(1) \) must take place necessarily (this is the dynamical realization of vacuum properties). Two other
familon subsystems are studied by the analogous method. The down quark of familon subsystem consists of pseudoscalar familons with positive square masses

\[ m_{\varphi^\prime}(d) \approx \frac{1}{24(u_d^2 + v_d^2)} \left( \frac{\alpha_s}{\pi} C_{\mu\nu} G_{\mu\nu}^n \right) \left( \frac{(m_b + m_s)^2}{m_b m_s} - \frac{(m_b - m_s)^2}{m_b m_s} \right) = \frac{1}{6(u_d^2 + v_d^2)} \left( \frac{\alpha_s}{\pi} C_{\mu\nu} G_{\mu\nu}^n \right) \]

and scalar familons square mass of which is negative

\[ m_{\varphi}(d) = \frac{1}{24u_d^2} \left( \frac{\alpha_s}{\pi} C_{\mu\nu} G_{\mu\nu}^n \right) \left[ \frac{(m_b - m_s)^2}{m_b m_s} \right] \]

The latter means that the downquark familon subsystem for low-temperatures is unstable also and for \( T = T_{c(d)} = m_{f(d)} \) the relativistic phase transition in the state with spontaneously breaking residual symmetry \( U(1) \) must be realized. From foregoing results it is seen that quantitative characteristics of familon subsystems are in fact controlled by only one parameter - the scale of metacolour confinement. The values of all other parameters is possible to take from an experiment or theoretical predictions of QCD. Unfortunately analyzing the subsystem of leptonic familons we meet with experimental unknown values - lepton condensates. The values of these condensates, however, can be parametrized by masses muon \( (m_\mu) \), \( \tau \)-lepton \( (m_\tau) \) and two renorm parameters \( \mu_\mu, \mu_\tau \):

\[ \langle \bar{\mu}\mu \rangle = -\frac{1}{4\pi} m_\mu^3 \ln \frac{m_\mu^2}{\mu_\mu^2}, \quad \langle \bar{\tau}\tau \rangle = -\frac{1}{4\pi} m_\tau^3 \ln \frac{m_\tau^2}{\mu_\tau^2} \]

Using (3.17) it is easy to show that PGB sector of lepton familons consists of pseudoscalar particles square of masses of which is positive for \( m_\tau > \mu_\tau \)

\[ m_{\varphi_{lep}} \approx \frac{1}{4\pi^2(u_{lep}^2 + v_{lep}^2)} m_\tau^3 m_\mu \ln \frac{m_\tau^2}{\mu_\mu^2} \]

\[ m_{\varphi_{lep}} \approx \frac{1}{8\pi^2 v_{lep}^2} m_\tau^4 \ln \frac{m_\tau^2}{\mu_\tau^2} \]

and scalar particles having for the same conditions negative square of masses

\[ m_{f_{lep}} \approx -\frac{1}{8\pi^2 u_{lep}^2} m_\tau^4 \ln \frac{m_\tau^2}{\mu_\tau^2} \]

Thus from mass formulae it is seen that DM consisting of familon type PGB is a manycomponent heterogenous system evolving by complicated thermodynamical way. In the content of DM particles with 9 different masses of rest are included. During evolution this system undergone to two relativistic phase transitions temperatures of which can differ each other more. Note that after RPT each from complex fields decay on two real fields one from which is massless and the second has a mass \( \sim | m_{f(u),(d)} | \). The each complex pseudoscalar field decay also on two real with masses which are different from zero. Thus, DM consisting from PGB of familon type contains
a "hot" component from massless particles and a "cold" (nonrelativistic) component from massive particles.

4. THE THERMODYNAMICS OF A PHASE TRANSITION AND THE BLOCKLY-PHASE STRUCTURE OF FAMILON GAS

Since the preon vacuum is the nonlinear medium formed by the strong chromodynamical and metachromodynamical interactions therefore the strong nonlinearity of perturbations of this medium is evident. That is the own nonlinearity of familon system provides firstly the existence of RPT with spontaneous breaking of familon fields of residual symmetry and secondly allows to describe RPT by the thermodynamical method. Really, if the constants of bound $\lambda_0, \lambda_1, \lambda_2, \lambda_{12}$ in the Lagrangian (3.1) are not anomally small then the familon gas created during evolution of the Universe in the moment of production of metachromodynamical and preon condensates must quickly relax to thermodynamical equilibrium state. Certainly, the total thermodynamical equilibrium between familons and usual particles (quarks, leptons, photons, gluons ...) can not be and the temperatures of familon gas do not need to coincide with thermodynamical temperatures of all other subsystems of the Universe. Thus our task is to build the thermodynamics of the field system with Lagrangian (3.1) by the method of the temperature quantum theory of field. In this task the specific element takes place which is absent in early studying models.

In the tree approximation spontaneous breaking of symmetry in Lagrangian (3.1) is impossible (if this approximation takes into attention then the stable familon vacuum is absent). Also evidently that the approximation is wrong for the task about RPT in familon gas because of the scale of pseudogoldstone mass more than ten orders smaller the scale of metacolor confinement (for which this Lagrangian is deduced). For lowering with up scale to down scale the effect of renorm group evolution follows to take into account. We have done the theoretico-field investigation of Lagrangian (3.1) and have got the result that stable vacuum arises only for realizatio of the strong bound regime on the scale of metacolour confinement. That is the strong own nonlinearity of familon field is simultaneously the condition of familon vacuum stability.

The pseudogoldstone part of terminally-renorm Lagrangian can be written as:

\[
L = \frac{1}{2}(\partial_\mu \varphi' \partial^\mu \varphi' - m_\varphi^2 \varphi' \varphi') + \partial_\mu \varphi^+ \partial^\mu \varphi - m_\varphi^2 \varphi^+ \varphi + \partial_\mu f^+ \partial^\mu f - m_f^2 f^+ f - \frac{1}{2} \lambda_1 (\varphi^+ \varphi)^2 - \frac{1}{2} \lambda_2 (f^+ f)^2 - \frac{1}{4} \lambda_3 \varphi^4 - \lambda_{12} \varphi^+ \varphi f^+ f - \frac{1}{2} k_{12} (\varphi^+ f + f^+ \varphi)^2 - \frac{1}{2} \varphi^2 (\lambda_{13} \varphi^+ \varphi + \lambda_{23} f^+ f) - \frac{1}{2} [M_1^2 (\delta v)^2 + M_2^2 (\delta u)^2 + M_{12}^2 \delta u \delta v] - \delta v (h_1 \varphi^+ \varphi + h_2 f^+ f + \frac{1}{2} h_3 \varphi^2) - \delta u (k_1 \varphi^+ \varphi + k_2 f^+ f + \frac{1}{2} k_3 \varphi^2)
\]  

(4.1)

where $\varphi', \varphi = \frac{1}{\sqrt{2}} (\varphi_1 + i \varphi_2)$ are pseudoscalar familon fields, $f = \frac{1}{\sqrt{2}} (f_1 + i f_2)$ is the scalar familon field which drops out as a condensate for superlow temperatures

\[
(f) = \frac{1}{\sqrt{2}} \langle f_1 \rangle = \frac{1}{\sqrt{2}} \eta
\]

(4.2)

(in the subsequent discussion $\eta$ is named as own parameter of order PO), $\delta v$ and $\delta u$ are nonown PO which are responsible for vacuum shifts of heavy familon fields induced by an own PO. All constants in (4.1) are terminally-renorm version of other initial constants of the Lagrangian or their combinations. (Some from constants of bound
have been marked by the letters $\lambda$ but they do not coincide with analogous symbols in (3.1)).

The thermodynamics of the Lagrang system (3.1) was formulated in the approximation of self-coordinated field [13]. The basic task is to find Landau nonequilibrium functional state that is the density of free energy $F(\eta,T)$. For strong nonlinear systems, like to discussed, the Landau functional failed to find in an explicit form. In a nonexplicit form in the approximation of self-coordinated field the Landau functional is given by a functional depending on the own and the nonown PO and 5 effective masses of particles. Besides, to this functional system nonlinear equations of bound are added allowing to express the effective masses of particles through the parameter of order and the temperature. Fortunately the calculation of all observable values and finding of stability condition of phases can be conducted in technics of a more simple functional which is in the form:

$$
F(T, \eta, m_{11}, m_{12}, m_3, m_{21}, m_{22}) = -\frac{1}{3} \sum_A J_2(T, m_A) + U(\eta, m_A) \tag{4.3}
$$

$$
\begin{align*}
\frac{1}{16\pi^2} m_{11}^4 \ln \frac{m_{11}^2}{m_{11}(0)} + J_1(T, m_{11}) + &= \\
\frac{1}{16\pi^2} m_{12}^4 \ln \frac{m_{12}^2}{m_{12}(0)} + J_1(T, m_{12}) + &= \\
\frac{1}{16\pi^2} m_3^4 \ln \frac{m_3^2}{m_3(0)} + J_1(T, m_3) + &= \\
\frac{1}{16\pi^2} m_{21}^4 \ln \frac{m_{21}^2}{m_{21}(0)} + J_1(T, m_{21}) + &= \\
\frac{1}{16\pi^2} m_{22}^4 \ln \frac{m_{22}^2}{m_{22}(0)} + J_1(T, m_{22}) + &=
\end{align*}
\tag{4.4}
$$

Here $m_{11}$ and $m_{12}$ are the effective masses (depending on temperature) of real pseudoscalar fields arisen in LS phase for decay of the complex field $\phi$ (in HS phase $m_{11} = m_{12} = m_1$); $m_{12}$ and $m_{22}$ are analogous masses of real scalar fields arisen in HS phase for decay of complex field $f$ (in HS phase $m_{21} = m_{22} = m_2$); $m_3$ is the effective mass of the real pseudoscalar field $\phi'$;

$$
J_n(T, m_A) = \frac{1}{2\pi^2} \int \frac{p^{2n} dp}{\sqrt{p^2 + m_A^2 (\exp \frac{p^2 + m_A^2}{T} - 1)}} \quad n = 1, 2, 3; A = 11, 12, 3, 21, 22
$$

is the characteristic integral through which expresses observable values.

The expression (4.3) can consider and as the performing functional when equations of bound (4.4) lie on its extremalies in space of effective masses. If this circumstance takes into attention then the necessary condition of nonequilibrium functional minimum on own PO can write in the form:

$$
\eta (m_{21}^2 - 2\lambda_2 \eta^2) = 0 \tag{4.5}
$$

which must be solved together with equations of bound (4.4). All branches of solutions of this equations system are testified on equilibrium by the sufficient conditions of minimum:

$$
\frac{d^2 F}{d\eta^2} = \frac{\partial^2 F}{\partial\eta^2} + \sum_A \frac{\partial^2 F}{\partial\eta \partial m_A} \left( \frac{\partial m_A}{\partial\eta} \right) > 0 \tag{4.6}
$$
The system of equations (4.4) and (4.5) was being solved numerically in the region temperatures $0 < T < 5 \, | m_f \, |$, where $| m_f \, |$ is defined by formula (3.9). The solution for LS phase exists in the region of temperatures $0 < T < 2.5 \, | m_f \, |$ that is $T_{c(1)}$ is the upper thermodynamical boundary of LS phase stability. This system of equations is integrated independently for HS phase for $\eta = 0$. The HS phase exists for $T > 0.5 \, | m_f \, |$ that is $T_{c(2)} = 0.5 \, | m_f \, |$ is the lower boundary of HS phase stability.

Thus the region of coexistence HS and LS phases is realized in wide temperature interval $0.5 \, | m_f \, | < T < 2.5 \, | m_f \, |$. By mathematically the coexistence of phases is expressed in presence of two stable branches of solutions (4.4) and (4.5) for the same thermodynamical parameters. In the middle of coexistence region for $T_{eq} = 1.5 \, | m_f \, |$ the phase equilibrium point is fixed by equality of free energies $F(HS) = F(LS)$. In the different phases the system possesses different equations of state therefore the mechanical equilibrium between regions of HS and LS phases which is reached for equality of their pressure can be realized only for inequility of their density energies. On Fig. 1 the dependences of density energies $\epsilon^{HS}(p)$ and $\epsilon^{LS}(p)$ in region of phase existence are shown. From Fig. 1 it can see the equilibrium phase in the region of their coexistence is possible only for sharp contrast of the density

$$\frac{2 \, | \epsilon^{HS}(p) - \epsilon^{LS}(p) \, |}{\epsilon^{HS}(p) + \epsilon^{LS}(p)} > 1$$

Thus the cosmological familon gas evolves thermodynamically from the region of HS phase stability in the region of LS phase stability. For temperatures $T < T_{c(1)}$ the most part of familon gas which has been in HS phase starts to arise seeds of LS phase. However these seeds are unstable till to temperature of equilibrium of phases $T_{eq}$. In this temperature region the spontaneous creation and death of seeds occur. The production of seeds is the process of generation of density inhomogeneity the development of which must come to gravitation instability of DM. More strong the familon gas condenses in the temperature range $T_{c(2)} < T < T_{eq}$, Here seeds of LS phase are stable and coexist with rests of HS phase in regime of the density high contrast. Probably that the more dense HS phase in these conditions starts to collapse gravitationally and to isolate from regions of the LS phase.

Thus at the region of RPT in familon gas catastrophic phenomena happen one from consequenses which is temperary coexistense of blocky-phase structure (the space alternation of HS and LS phase regions). The characteristic scale of this structure is determined by the distance to horizon events at the moment of RPT. The same scale certainly determines and the characteristic scale of baryon subsystem structure which reacts gravitationally on fragmentation of DM. If the heterogeneity of familon gas takes into attention then this phenomena in the Universe must be repeated as minimum two times for different temperatures of familon gas that is for different sizes of horizon of events. Probably this mechanism of DM structurization allows better to understand the origin of scale hierarchy of the baryon component.

5. CONCLUSION

Our model is unambiguously connected with preon model of elementary particles having a good perspective of experimental check on colliders. The experimental status for this model may get only after the detection of familons in rare decays of heavy mesons. After getting of the experimental status the reception of this model in cosmology will be inevitably. The quality of this model with point of view of cosmology is explicit today. The role of particle generations in the Universe become more evident.
The structurization of DM (and the baryon subsystem as consequence) gives particles arising only for consideration of symmetry among generations. That is for possibility of structurization of matter it is necessary as minimum three generations of particles.

References
1. I.M. Hook, R.G. McMahon. MN, 294, L7 (1998)
2. A. Omont et al. Nature 382, 428 (1996); Guilloteau et al. Astron. Astrophys. 328, L1 (1997)
3. M. Rees. Proc. Natl. Acad. Sci. USA, 95, 47 (1998); Ch.C. Steidel. Proc. Natl. Acad. Sci. USA 95, 22 (1998)
4. L. Bergstrom. Nucl.Phys.B (Proc.Suppl.) 70,31(1999); D.O. Caldwell. Nucl. Phys. B (Proc.Suppl.) 70,43 (1999)
5. C.T. Hill, D.N.Schramm, J. Fry. Comments of Nucl. and Particle Phys. 19, 25 (1989)
6. J.A. Frieman, C.T. Hill, R. Watkins. Preprint Fermilab Pub.-91/324-A (1991)
7. R.M. Barnet et al. Phys. Rev. D54 (1996)
8. D.A. Kirzhnits and A.D. Linde. JETP 67, 1263 (1974)
9. M.Yu. Khlopov, A.S. Sakharov. Phys.Atom.Nucl. 57,651 (1994)
10. H. Fritzsch, G. Mandelbaum. Phys. Lett. B 102, 319 (1981)
11. C. Adloff et al. Z. Phys. C 74, 191 (1997); J.Z. Breitweg. Phys. C 74, 207 (1997)
12. M.A. Shifman, A.I. Vainstein, V.I. Zakharov. Nucl. Phys. B 147, 385 (1979)
13. G. Vereshkov, V. Burdyuzha. Intern. J. of Modern Phys. 10, 1343 (1995)
Fig. 1 The energy density as a function of pressure in the region of phases coexistence.