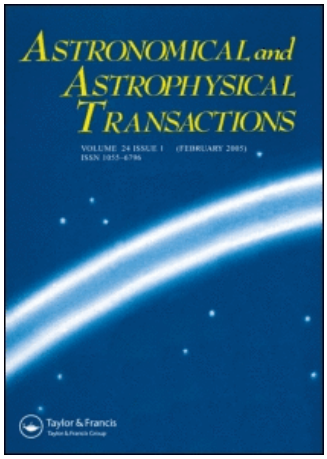

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FAMILON MODEL OF DARK MATTER

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If the next fundamental level of matter occurs (preons), then dark matter must consist of familons containing a 'hot' component from massless particles and a 'cold' component from massive particles. During the evolution of the Universe this dark matter occurred up to late-time relativistic phase transitions the temperatures of which were different. Fluctuations created by these phase transitions had a fractal character. As a result the structuration of dark matter (and therefore the baryon subsystem) occurred, and in the Universe some characteristic scales which have caused this phenomenon arise naturally. Familons are collective excitations of non-perturbative preon condensates that could be produced during an earlier relativistic phase transition. For structuration of dark matter (and the baryon component), three generations of particles are necessary. The first generation of particles produced the observed baryon world. The second and third generations produced dark matter from particles that appeared when symmetry between the generations was spontaneously broken.

KEYWORDS: next fundamental level, dark matter

1 INTRODUCTION

Using the preon structure of quarks and leptons the familon model of dark matter (DM) proposed by Hill *et al.* (1989) and Frieman *et al.* (1992) is revived. This model has more physical and cosmological consequences if the next structure level of matter is involved. Our interest in the preon model of elementary particles was also induced by the possible of resonance leptoquarks in the HERA experiment (Adloff *et al.*, 1997; Breitweg *et al.*, 1997) and the possibility of researching the pair production of scalar leptoquarks at the FERMILAB Tevatron (Kramer *et al.*, 1997; Affolder *et al.*, 2001). The standard model of physics of elementary particles is not expected to be a complete theory (it does not explain the number of fermion families and their mass hierarchy and does not provide a unified description of all gauge symmetries). However, the standard model, of course, describes very well all experiments on fundamental fermions and their interactions via gauge bosons. Compositeness models of quarks and leptons postulate a new strong dynamics which bind constituents (preons) although the motivation for these models has been absent until now. First, the important cosmological and physical consequences are enumerated. If DM consist of familons, then, in this medium, late-time phase transitions were possible and fluctuations created by these phase transitions

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had a fractal character. These fractal fluctuations could develop into a fractal large-scale structure (LSS) of the baryon component. Note that the fractal structure of the baryon component is not observed on all scales (Bak and Chen, 2001; Wu *et al.*, 1999). In the Universe these late phase transitions also produced some characteristic scales. Also, understanding three generations of elementary particles has now progressed. The observed baryon world and DM may be realized only when three generations of particles occur. The first generation of particles produced the baryon world. The second and third generations produced DM. The structuration of DM (and the baryon component) was produced and particles appeared when the symmetry between generations was spontaneously broken.

The preon structure of matter was introduced by Pati and Salam (1974) and was studied by many researchers (Lane *et al.*, 1977; Terazawa *et al.*, 1977; Terazawa, 1980; Eichten *et al.*, 1984). We have studied the structure of the preon non-perturbative vacuum that may arise as a result of the correlation of non-Abelian fields on two scales. $\Lambda_{\mathrm{mc}} \gg 1$ TeV is the confinement scale of metacolour and $\Lambda_{\mathrm{c}} \approx 150$ MeV is the quantum chromodynamics (QCD) scale. We have detected that, in the spectrum of excitations of a heterogeneous non-perturbative preon vacuum, pseudo-Goldstone modes of familon type appear. Familons are created when the symmetry of quark–lepton generations is spontaneously broken and their non-zero masses are the result of superweak interactions with quark condensates. The physics of the spontaneously broken symmetry of generations (production of familons) were considered by Feng *et al.*, (1998). The distinguishing characteristic of these particles is the availability of the residual $U(1)$ symmetry and the possibility that it spontaneous breaks for a temperature $\Lambda_{\mathrm{mc}}/\Lambda_{\mathrm{c}}^2 \approx 10^{-3}$ eV as a result of relativistic phase transitions (RPTs).

We have proposed that these RPTs had a direct relation to the production of primordial perturbations in DM the evolution of which leads to the fractal baryon LSS. Note also that the idea of RPTs in the cosmological gas of pseudo-Goldstone bosons in connection with LSS problems was earlier formulated in articles by Hill *et al.* (1989) and Frieman *et al.*, (1992). Here we have investigated quantitatively the preon–familon model of these RPTs.

First, the astrophysical motivation of our theory is discussed more detail. Observational data show that some baryon objects such as the quasar at $z \approx 4.9$, the galaxy at $z \approx 6.68$ and the CO lines at $z \approx 4.43$ and $z \approx 4.69$ (Omont *et al.*, 1996; Chen *et al.*, 1999) were produced as minima for red the shifts at $z \approx 6$–8. This is the difficulty for the standard cold dark matter (CDM) and Λ mixed dark matter (ΛMDM) models to produce their (the best fit is $z \approx 2$–3 (Madau, 1999) and observations support this). If early baryon cosmological structures are produced at $z > 10$, then the key role must play DM particles with non-standard properties.

Probably DM consists of ideal gas particles with $m \approx 0$ and almost non-interacting with usual matter (until now they have not been detected because of their superweak interaction with baryons and leptons). The standard CDM model contains 25% of the total density, that is

$$\Omega_0 = \Omega_\Lambda + \Omega_{\mathrm{CDM}} + \Omega_\nu + \Omega_{\mathrm{b}} = 0.7 + 0.25 + 0.02 + 0.03 = 1.$$

In the article by Caldwell (2004), more exact data on Ω_Λ have been given. Also the important point is to know the end of the formation of the observed baryon structures. The characteristic moment at which the most of the formation of cosmological structures finishes remains the same ($z \approx 2$–3). The appearance of baryon structures at high red shifts ($z > 4$) was the result of the evolution of statistical outbursts of the spectrum of DM density perturbations. Therefore early cosmological baryon structures may be connected to statistical outbursts only in the sharply nonlinear physical system which is a medium that occurs after RPTs (the production of inhomogeneities).

Note again that we have investigated the idea in which the baryon component of matter repeats the structure of DM owing to gravitation. That is RPTs have produced DM fractal

fluctuations in which baryons have subsequently clustered. The fractal structure of the baryon component was studied by Bak and Chen (2001) and Wu *et al.* (1999) starting from the article by Coleman *et al.*(1988) in which they suggested that the Universe has a fractal structure up to some megaparsecs (the fractal structure was observed up to 50 Mpc by Martinez and Coles (1994) and a sharp transition to homogeneity was predicted at 300 Mpc also by these workers). Only critical phenomena such as a phase transition creates fractal structures.

A new theory of DM must combine the properties of the superweak interaction of DM particles with baryons and leptons and the intensive interaction of these particles with each other. Such interactions are provided by the nonlinear properties of the DM medium. This is the condition for realization of RPTs.

2 THE BASIC ARGUMENTS

The familon symmetry is experimentally observed (the different generations of quarks and leptons participate in gauge interactions in the same way). The breaking of this symmetry gives the masses of particles in different generations. A hypothesis about the spontaneous breaking of familon symmetry is natural and the creation of Goldstone bosons is inevitable. The properties of any pseudo–Goldstone bosons and pseudo–Goldstone bosons of familon type depend on the physical realization of Goldstone modes. These modes may be arisen from fundamental Higgs fields or from collective excitations of a heterogenic non-perturbative vacuum condensate more complex than that of a quark–gluon nature in QCD. A second possibility is a theory in which quarks and leptons are composite particles, that is the preon model of elementary particles. If leptoquarks can be detected, then two explanations could occur. If the leptoquark resonance is high and narrow, then these leptoquarks come from the grand unified theory or supersymmetry (SUSY) theory. A low and wide resonance can be explained only by composite particles.

The simplest boson–fermion preon model consists of left-handed fermion preons U_{L}^{α} and D_{L}^{α} and scalar preons of quark ($\Phi_a^{i\alpha}$) and lepton (χ_l^{α}) types. In this model the interior structure of elementary particles is

$$\begin{aligned} u_{\mathrm{L}a}^i &= U_{\mathrm{L}}^{\alpha}\Phi_a^{+i\alpha}, \quad u_{\mathrm{L}a}^i = (u_{\mathrm{L}}^i, c_{\mathrm{L}}^i, t_{\mathrm{L}}^i), \\ d_{\mathrm{L}a}^i &= D_{\mathrm{L}}^{\alpha}\Phi_a^{+i\alpha}, \quad d_{\mathrm{L}a}^i = (d_{\mathrm{L}}^i, s_{\mathrm{L}}^i, b_{\mathrm{L}}^i), \\ \nu_{\mathrm{L}l}^i &= U_{\mathrm{L}}^{\alpha}\chi_l^{\alpha}, \quad \nu_{\mathrm{L}l}^i = \nu_{\mathrm{L}e}, \nu_{\mathrm{L}\mu}, \nu_{\mathrm{L}\tau}, \\ l_{\mathrm{L}l}^i &= D_{\mathrm{L}}^{\alpha}\chi_l^{\alpha}, \quad l_{\mathrm{L}l}^i = (e_{\mathrm{L}}, \mu_{\mathrm{L}}, \tau_{\mathrm{L}}). \end{aligned} \tag{1}$$

In the case of leptoquarks, our model gives

$$(LQ)_{al} = \Phi_a^{i\alpha}\chi_l^{\alpha}. \tag{2}$$

Here and in the following, i is the colour index of QCD, $a, b, c = 1, 2, 3$ and $l, m, r = 1, 2, 3$ are the numbers of the quark and lepton generations respectively and α is the metacolour index corresponding to a new metachromodynamics interaction linking preons in quarks and leptons.

Inside quarks and leptons, metagluon fields $G_{\mu\nu}^{\omega}$ and scalar preon fields are in a confinement state like the confinement of quarks and gluons inside hadrons. This effect is provided by the existence of non-perturbative metagluon and preon condensates:

$$\left\langle 0 \left| \frac{\alpha_{\mathrm{mc}}}{\pi} G_{\mu\nu}^{\omega} G_{\omega}^{\mu\nu} \right| 0 \right\rangle \propto \Lambda_{\mathrm{mc}}^4, \tag{3}$$

$$\langle 0|\Phi_a^{+i\alpha}\Phi_b^{i\alpha}|0\rangle = V_{ab} \sim -\Lambda_{\rm mc}^2, \tag{4}$$

$$\langle 0|\chi_l^{+i\alpha}\chi_m^{\alpha}|0\rangle = V_{lm} \sim -\Lambda_{\rm mc}^2. \tag{5}$$

Here $\Lambda_{\rm mc}$ is the energy scale of preon confinement, and V_{ab} and V_{lm} are the condensate matrices. Condensates (3) and (4) together with gluon and quark condensates ($\langle 0|(\alpha_{\rm s}/\pi)G^a_{\mu\nu}G_a^{\mu\nu}|0\rangle$ and $(\langle 0|\bar{q}_{\rm L}q_{\rm R} + \bar{q}_{\rm R}q_{\rm L}|0\rangle)$ provide the mechanism for the mass quark production of all third generations. This is shown in Figure 1, with

$$\langle 0|\bar{U}_{\rm L}^{\alpha}\phi_c^{r\alpha}u_{{\rm R}b}^{r}|0\rangle \equiv \langle 0|\bar{u}_{{\rm L}c}^{m}u_{{\rm R}b}^{m}|0\rangle$$

and in which $G^{ik}_{\mu\nu} = \lambda_n^{ik}G^{in}_{\mu\nu}$ with λ_n^{ik} the Gell-Mann matrices, and $G^{\alpha\beta}_{\mu\nu} = \lambda_\omega^{\alpha\beta}G^{\omega}_{\mu\nu}$ with $\lambda_\omega^{\alpha\beta}$ an analogue of Gell-Mann matrices for metacolour. As can be seen from Figure 1, the main contribution in the effect of familon symmetry vacuum breaking is due to the preon condensates (4).

The theory of preons predicts the complex structure of a heterogeneous non-perturbative vacuum and that familons are collective excitations of these condensates. These excitations are the result of local processes of weakening and rebuilding of correlations among fields entering in condensates:

$$M_{ab}^{(u)} = \langle 0|\Phi_a^{\alpha k}\Phi_c^{\alpha k}\bar{U}_{\rm L}^{\beta}\Phi_c^{\beta_i}q^i_{{\rm R}_b}|0\rangle, \tag{6}$$

$$M_{ab}^{(d)} = \langle 0|\Phi_a^{\alpha k}\Phi_c^{\alpha k}\bar{D}_{\rm L}^{\beta}\Phi_c^{\beta_i}q^i_{{\rm R}_b}|0\rangle, \tag{7}$$

$$M_{lm}^{(l)} = \langle 0|\chi_l^{\alpha}\chi_r^{\alpha}\bar{D}_{\rm L}^{\beta}\chi_r^{\beta}l_{{\rm R}_m}|0\rangle. \tag{8}$$

Also it is necessary to note the peculiar properties of the first generation of quarks. Their masses are exclusively produced by the interaction with the quark–gluon condensate. The production of second and third generations of quark masses is outside the limits of QCD, but this may occur naturally in the preon model. Scalar preon condensates of the first generation are efficiently suppressed and they do not contribute to equations (6)–(8). This situation may be explained in the model containing composite scalar preons (on a scale greater than $\Lambda_{\rm mc}$). In this preon–subpreon model (Evnin, 1997) the initial familon symmetry $SU_{\rm F}(3) \to SU_{\rm F}(2)$ is broken on the scale $\Lambda_{\rm smc} \gg \Lambda_{\rm mc}$ and then on a lower scale the symmetry $SU_{\rm F}(2) \to U(1)$ is broken also. Therefore here we shall discuss the chiral–familon symmetry of second and third generations only (a discussion of the familon symmetry was given in detail given by

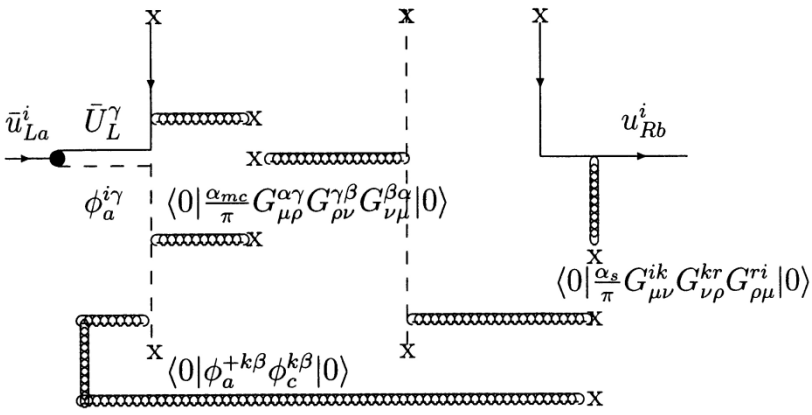

Figure 1. Mechanism for the mass quark production of all third generations.

Feng *et al.* (1998). Three types of non-perturbative condensate correspond to three types of familon field and a number of familons of every type equals 8. In each type, two familon fields arise as the local perturbation of a condensate energy density. The remaining six familon fields arise as the result of rebuilding of the condensate.

Thus, in the framework of preon theory, DM is interpreted as the system of familon collective excitations of the heterogeneous non-perturbative vacuum. This system consists of three subsystems:

(i) familons of up-quark type;
(ii) familons of down-quark type;
(iii) familons of lepton type.

At stages of cosmological evolution when $T \ll \Lambda_{\rm mc}$, heavy unstable familons are absent. Small masses of familons are the result of superweak interactions of Goldstone fields with non-perturbative vacuum condensates and therefore familons acquire the status of pseudo-Goldstone bosons. The value of these masses is limited by the astrophysical and laboratory magnitudes (Groom *et al.*, 2000).

$$m_{\rm astrophysical} \approx 10^{-3}\text{–}10^{-5}\,{\rm eV},$$
$$m_{\rm laboratory} \leq 10\,{\rm eV} \tag{9}$$

The effect of the mass production of familons formally corresponds mathematically to the appearance of mass terms in the Lagrangian of Goldstone fields. From general considerations one can propose that massive terms may arise with the 'right' and 'wrong' signs. The sign of the massive terms predetermines the destiny of the residual symmetry of Goldstone fields. In the case of the 'wrong' sign for low temperatures $T < T_{\rm c} \approx m_{\rm familons} \approx 0.1\text{–}10^5$K a Goldstone condensate is produced and the symmetry of the familon gas breaks spontaneously.

The representation of the physical nature of familon excitations described above is formalized in a theoretical-field model. As example we discuss the model of only one familon subsystem corresponding to up-quarks of second and third generations. The chiral–familon group of the model is $SU_{\rm L}(2) \times SU_{\rm R}(2)$. The familon excitations are described by an eight-measure (on the number of matrix components (6)) reducible representation of this group factorized on two irreducible representations (F, f_a); (ϕ, φ_a) which differ from each other in the sign of space chirality. In this model the interaction of quark fields with familons occurs. However, in all calculations, quark fields are represented in the form of non-perturbative quark condensates. From QCD and the experiment the connection between quark and gluon condensates is known:

$$\langle 0|\bar{q}q|0\rangle \approx \frac{1}{12m_q}, \left\langle 0 \left| \frac{\alpha_{\rm s}}{\pi} G^n_{\mu\nu} G^{\mu\nu}_n \right| 0 \right\rangle \approx \frac{3\Lambda_{\rm c}^4}{4m_q}. \tag{10}$$

Here $q = t, c$, $m_c \approx 1.5$ GeV, $m_t \approx 175$ GeV and $\Lambda_{\rm c} \approx 150$ MeV.

The spontaneous breaking of symmetry $SU_{\rm L}(2) \times SU_{\rm R}(2) \to U(1)$ is produced by vacuum shifts $\langle\psi\rangle = v$ and $\langle f_3\rangle = u$. The numerical values $v, u \approx \Lambda_{\rm mc}$ are unknown. They can be found experimentally if our theory corresponds to reality. The parameters u and v together with the value of condensates in equations (10) define the numerical values of basic magnitudes characterizing the familon subsystem. After the breaking of symmetry $SU_{\rm L}(2) \times SU_{\rm R}(2) \to U(1)$, light pseudo-Goldstone fields contain the real pseudoscalar field with the mass

$$m^2_{\varphi'} = \frac{1}{6(u^2+v^2)} \left\langle 0 \left| \frac{\alpha_{\rm s}}{\pi} G^n_{\mu\nu} G^{\mu\nu}_n \right| 0 \right\rangle, \tag{11}$$

the complex pseudoscalar field with the mass

$$m_\varphi^2 = \frac{1}{24v^2}\frac{m_t}{m_c}\left\langle 0 \left| \frac{\alpha_s}{\pi} G^n_{\mu\nu} G^{\mu\nu}_n \right| 0 \right\rangle, \tag{12}$$

and the complex scalar field the mass square of which is negative:

$$m_f^2 = -\frac{1}{24u^2}\frac{m_t}{m_c}\left\langle 0 \left| \frac{\alpha_s}{\pi} G^n_{\mu\nu} G^{\mu\nu}_n \right| 0 \right\rangle. \tag{13}$$

The complex field with masses (12) and (13) is the non-trivial representation of the residual symmetry of $U(1)$ group but the real field (11) is the sole representation of this group. We propose that cosmological DM consists of particles with these masses and their analogies from the down-quark–familon and the lepton–familon subsystems.

The negative mass square of a complex scalar field means that, for

$$T < T_{\mathrm{c(up)}} \propto |\bar{m}_f| \approx \frac{\Lambda_{\mathrm{mc}}}{\Lambda_{\mathrm{c}}^2}\left(\frac{m_t}{m_c}\right)^{1/2}, \tag{14}$$

the pseudo-Goldstone vacuum is unstable; that is, when $T = T_{\mathrm{c(up)}}$ in a gas of pseudo-Goldstone bosons, there should be RPTs in the state with spontaneous breaking $U(1)$ symmetry. Two other familon subsystems can be studied by the same methods. Therefore DM consisting of pseudo-Goldstone bosons of familon type is a many-component heterogeneous system evolving in a complex thermodynamic way.

In the phase of breaking symmetry, every complex field with masses (12) and (13) splits into two real fields with different masses. That is the familon subsystem of up-quark type consists of five kinds of particle with different masses. An analogous phenomenon takes place in the down-quark subsystem. The breaking of residual symmetry occurs when

$$T_{\mathrm{c(down)}} \approx \frac{\Lambda_{\mathrm{mc}}}{\Lambda_{\mathrm{c}}^2}\left(\frac{m_b}{m_s}\right)^{1/2}. \tag{15}$$

In a low-symmetry phase this subsystem consists also of five kinds of particle with different masses. In our theory the lepton–familon subsystem can occur up to RPTs also but leptonic condensates are elements of new physics that may arise in the future and probably their discussion is premature.

3 RESULTS

The RPTs in familon subsystems must be described in the framework of temperature quantum field theory. It is important to emphasize that sufficiently strong interactions of familons with each other provide the evolution of the familon subsystem through a state of local equilibrium type. Our estimates have shown that the transition in a non-thermodynamic regime of evolution occurs in the stage after RPTs even if the RPTs took place for temperatures of about $\approx 10^{-3}$ eV. The thermodynamics of a familon system may be formulated in the approximation of a self-coordinated field. The methods of RPT theory which were used by us are similar to those in a previous article by two of the present authors (Vereshkov and Burdyuzha,1995). The non-equilibrium Landau functional $F(T, \eta, m_A)$ of states depends on the order parameter η and

five effective masses of particles m_A, $A = 1, 2, 3, 4, 5$:

$$F(T, \eta, m_A) = -\frac{1}{3}\sum_A J_2(T, m_A) + U(\eta, m_A), \tag{16}$$

Here J_2 is a characteristic integral (similar integrals were used for the description of RPTs in the article by Burdyuzha *et al.*, (1997a,b). The conditions of the extremum of this functional on effective masses give the equation of connection $m_a = m_a(\eta, T)$ which defines formally the typical Landau functional $F(T, \eta)$. The condition of the minimum of this functional on the parameter of order η, that is

$$\frac{\mathrm{d}^2 F}{\mathrm{d}\eta^2} = \frac{\partial^2 F}{\partial \eta^2} + \sum_A \frac{\partial^2 F}{\partial \eta \partial m_A}\frac{\partial m_A}{\partial \eta} > 0, \tag{17}$$

agrees with the equation of state $\partial F/\partial \eta = 0$ that allows one, firstly, to establish the kind of RPT, secondly, to find the thermodynamic boundary of stability phases and, thirdly, to calculate the values of the observed magnitudes (energy density, pressure, thermal capacity, sound velocity, etc.) in each phase. More detail of the thermodynamics of the familon system have been discussed by Burdyuzha *et al.* (1998).

We have detected that RPTs in a familon gas are of the first kind with a wide region of coexistence of phases. Therefore in the epoch of RPTs or more exactly in the region of the coexistence of phases the Universe had a block-phase structure containing domains of different phases. The numerical modelling of this RPT has shown that the average contrast of density in the block-phase structure is $\delta\epsilon/\epsilon \approx 0.1$. This structure is illustrated in Figure 2 in some conditional dimensionless units.

The size of domains and the masses of baryon and dark matter inside domains are defined by the distance horizon to the horizon of the events at the moment of the RPT. As is seen from equations (14) and (15), the numerical values of these magnitudes, which are important for LSS theory, depend on the value of the parameter Λ_{mc}, of the preon confinement which is unknown today.

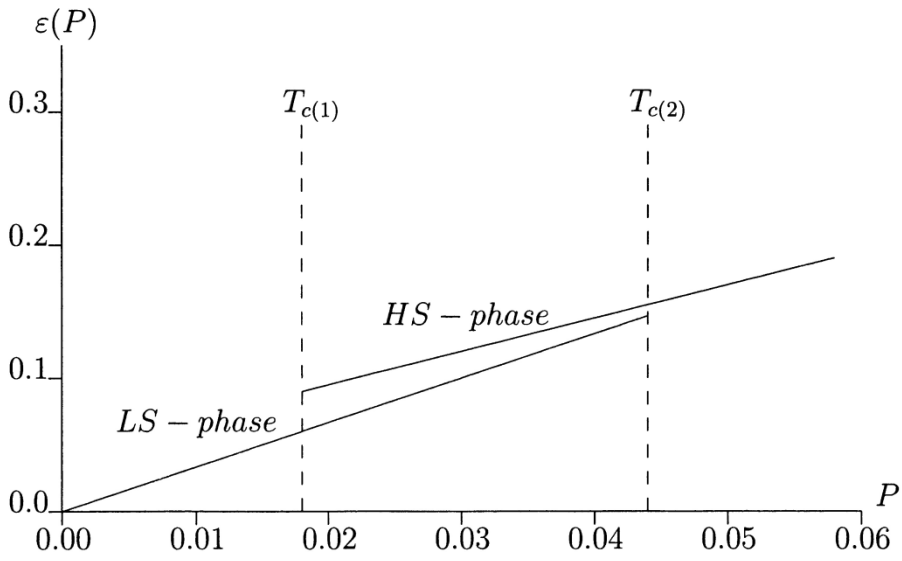

Figure 2. Block-phase structure: HS, LS. HS = high symmetry, LS = low symmetry.

If the inhomogeneities appearing during RPTs in familon gas have a relation to the observable scales of LSS (10 Mpc), then $\Lambda_{\rm mc} \approx 10^5$ TeV. A more detailed estimate today is premature but it is necessary to note that the suggested theory contains a minimum of two phase transitions and therefore two characteristic scales of baryon LSS. Now it would be speculation to define exactly the magnitudes of these scales (probably galaxies and clusters of galaxies) since we do not know the familon masses. Numerical estimates of the parameters of the inhomogeneities arising as the result of strong interaction of LS and HS phase domains in the region of their contact show that the density contrast may increase to $\delta\epsilon/\epsilon \approx 1$ on the scale $L \approx 0.1 L_{\rm horizon}$ at the moment of the phase transition and also that effects connected with fragmentation of DM medium may be superimposed in the spectrum of the cosmic microwave background (CMB) radiation.

Note that Hill *et al.*, (1989) have even proposed some laboratory tests for verification of the late-time phase transitions model (the neutrino–schison model). Their model, in the same way as our model, can potentially generate structures (baryon and DM) at red shifts $z > 10$. Also, if the fractal structure of the baryon component is proved finally, then the late-time phase transitions model becomes automatically the main model for the production of the baryon LSS. Then only phase transitions realize a fractal structure for seeds. Probably during the evolution of the baryon structures their fractal distribution is smoothed and it is not observed on large scales although there is general agreement about the existence of fractal galactic structures on moderate scales (Bak and Chen, 2001; Wu *et al.*, 1999; Guzzo *et al.* 1991).

Finally note that, for the structuration of DM (and the baryon component of the Universe), three generations of particles are obligatory. The first generation of particles produced the baryon world which is observed. The second and third generations of particles produced a fractal distribution as DM from familons (the baryon component repeated this distribution). Our first conclusion is that the preon structure (the next structural level of matter) must be detected since only the preon model (more exactly, phase transitions) may provide a fractal distribution as DM and as the baryon component. Only in the preon model could some scales be naturally produced during the evolution of the Universe. Of course, the familon DM is difficult to detect owing to its superweak interaction with usual matter. A recent search for familons by the CLEO collaboration gave a negative result (Ammar *et al.*, 2001). The latest publications on the research of DM can be found in some reports by Agashe and Servant (2004), Caldwell, (2004), Chen *et al.* (2004), Moffat (2004) and Sahni (2004).

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