Письма в ЖЭТФ, том 54, вып.6, стр.301 - 304 25 сентября 1991 г.

FLAVORED STRING-DOMINATED UNIVERSE

J.L.Chkareuli

Institue of Physics, Academy of Sciences of Georgia
SU-380077, Georgia, USSR

Submitted 13 August 1991

We argue that the flavored Z_3 string-monopole networks related with the spontaneously broken family symmetry $SU(3)_H$ of quarks and leptons inevitably come to dominate the Universe in the cource of evolution. It follows that there should be a strict upper limit on the family unification scale, $V_H \lesssim 10^{10}$ GeV.

Recently [1], it has found in an instance of the family unified $SU(3)_H$ model [2–5] that there is the quite distinctive interplay between quark-mixing and the flavored topological defects. Among them the Z_3 string-monopole networks are unambigously singled out by requirement of the lack of domain walls in the model. Such networks could appear as a result of a phase transition in the early Universe and then come to dominate it in the cource of evolution. They might constitute the bulk of the dark matter in the Universe required to make $\Omega = 1$ according to the inflationary scenario. We show here using partially of the results of the numerical simulation [6] that there are good grounds for the string-dominated Universe (SDU) just in the considered case of flavored strings and monopoles.

Actually, the numerical simulation [6] of a general Z_3 string- monopole networks has revealed that: (*i*) the system is strongly dominated by one infinite network wherein most of the string segments have lengths comparable to the typical distance between monopoles d; (*ii*) the system evolve in a self-similar fashion showing no tendency to relax to an equilibrium configuration or to decay into the small nets, the intercommutings are unessential inducing the difference in d only $\sim 10\%$; (*iii*) the main energyloss mechanism for the network is the radiation of gauge quanta by ultra-relativistic monopoles with unconfined the $SU(3)_c$ and/or

$U(1)_{em}$ magnetic charge just what prevents such networks in grand unification models to dominate the Universe.

Now one can make use directly these results for our flavored Z_3 string-monopole network and have all the same conclusions about its formation and evolution but the last point (iii). Instead of it we have that (iv) all the magnetic flux from the flavored monopoles is confined in strings because of the full spontaneous breakdown of the family symmetry outside of the strings . Therefore we are inevitably led to the SDU.

The typical scale d of our network as function of time can be estimated more or less accurately following to the standard argumentation [7]. We adopt that the system rapidly approaches a quasi-equilibrium state which actually due to its basic features (i), (ii), and (iv) is quite close to a true equilibrium and can write the energy conservation law in an expanding Universe in a simple form

$$\dot{\rho}_H = -3\frac{\dot{a}}{a}(P_H + \rho_H). \tag{1}$$

Here $a(t)$ is the cosmic scale factor whereas ρ_H and P_H are the total energy density and the total pressure of the system, res- pectively. For the non-superheavy monopoles they merely come to the string ones $\rho_H \simeq \rho_s \sim V_H^2 d^{-2}$ and $P_H \simeq P_s = \gamma\rho_s$ with γ [6]

$$\gamma = \frac{1}{3}(2 < v_s^2 > -1), \quad -\frac{1}{3} \leq \gamma \leq \frac{1}{3}, \tag{2}$$

where v_s is the transverse velocity of the strings and angular brackets indicate statistical averaging.

Solving of eq.(1) with γ (2) which is not changed with time (self-similarity (iv)) leads to the typical length scale $d(t)$ of network

$$d(t) = \left[\frac{a(t)}{a(t_0)}\right]^{3(1+\gamma)/2} d(t_0) = \left(\frac{t}{t_s}\right)\left(\frac{t_s}{t_{eq}}\right)^{1+\gamma}\left(\frac{t_{eq}}{t_0}\right)^{3(1+\gamma)/4} d(t_0), \tag{3}$$

where we have used for the cosmic scale factor $a(t)$ (according to the evolution equation)

$$a(t < t_{eq}) \propto t^{1/2}, \; a(t < t_s) \propto t^{2/3}, \; a(t > t_s) \propto t^{2/3(1+\gamma)}. \tag{4}$$

Here $t_0 \sim M_P V_H^{-2}$ is time of formation of the strings (M_P is the Planck mass), $t_{eq} \sim 10^{11}$ s is the time of equal matter and radiation densities, and t_s is time when the strings come dominate the Universe ($t_s > t_{eq}$). Requiring now that the causality condition to be satisfied in each era (4) separately, we get more stringent constraints on γ (2)

$$-\frac{1}{3} \leq \gamma \leq 0. \tag{5}$$

Finally for the ratio of string mass density ρ_s to the mass den- sity of ordinary matter $\rho \sim 1/Gt^2$ is obtained

$$\frac{\rho_s}{\rho} \sim \epsilon_H^{3(1-\gamma)/2} \left(\frac{t_0}{d_0}\right)^2 \left(\frac{t_{eq}}{t_P}\right)^{(1+\gamma)/2} \left(\frac{t_s}{t_P}\right)^{-2\gamma}, \tag{6}$$

where $\epsilon_H = (V_H/M_P)^2$, t_P is the Planck time and $d_0 = d(t_0) < t_0$.

Now, if the string dominance ($\rho_s/\rho \sim 1$) actually starts at present time $t_s \sim 10^{17}$ s eq.(6) with γ in the intervals (5) gives constraints on the family unification scale V_H (for $t_s \sim t_{eq}$ they are practically the same)

$$V_H \leq 10^4 \div 10^{10} \text{ GeV}, \tag{7}$$

which meet the limitation $V_H \geq 10^4$ GeV following from the laboratory experiments on the rare flavor-changing processes of quarks and leptons [8]. One can easily seen from the eq.(6) if the flavored Z_3 strings are formed in a second-order phase transition ($d_0 \sim 1/V_H$) they dominate the Universe very soon after the formation. Thus we have to assume a first-order phase transition with sufficiently large bubbles (of the order of t_0).

In this SDU scenario the Universe at present is built up mainly from the three-dimensional flavored Z_3 string-monopole network with the practically straight strings having relativistic speeds. The typical distance between the strings (monopoles) in the network according to eq (3) is $d = 10^{13} \div 10^{18}$ cm for the intervals (5) and (7). Thus there should be a lot of strings of network passing our galaxy and even (for low scale V_H) through the Sun. For the Earth the typical time between two successive encounters with the strings is proved about one year if $V_H \approx 10^4$ GeV. As to the observational manifestations (see [1]) of our network they are related with its superconductive charge-carrying ability [9] rather than with the gravitational interactions.

And the last point concerning an age of the Universe in the flavored SDU model. Now it is

$$T^{net} = \frac{2}{3(1+\gamma)} H^{-1} \tag{8}$$

(H is the Hubble constant, $H = h \cdot 10^{-10} y^{-1}$, $h = 0,5 \div 1$) instead of the ordinary value $T^{net} = \frac{1}{2} H^{-1}$ when $\Omega = 1$ results from light relativistic particles [7]. Numerically we have in the both cases

$$T^{net} = (0,7 \div 2) t_{10}, \quad T^{ord} = (0,5 \div 1) t_{10} \tag{9}$$

($t_{10} = 10^{10} y$) taking into account all the uncertainties in γ (5) and H. On the other hand estimates of the ages of the oldest globular cluster stars and age of the elements suggest $T \geq 1,5 t_{10}$ [10]. So, one can see that the low-scale SDU scenario looks as quite more preferable.

I acknowledge gratefully stimulating conversations with Barbieri R., Berezhiani Z., Dvali G., Kancheli O. and Vilenkin A.

---

1. Chkareuli J.L. Pis'ma Zh.Eksp.Teor.Fiz., 1991, **54**, 193.
2. Chkareuli J.L. Pis'ma Zh.Eksp.Teor.Fiz., 1980, **32**, 684.
3. Berezhiani Z.G., Chkareuli J.L. Yad.Fiz., 1983, **37**, 1043.
4. Berezhiani Z.G. Phys.Lett.B, 1983, **129**, 99; 1985, **150**, 177.
5. Wu J.C. Phys.Rev.D, 1987, **36**, 1514.
6. Aryal M., Everett A.E., Vilenkin A., Vachaspati T. Phys.Rev.D, 1986, **34**, 434; Vachaspati T. and Vilenkin A. Phys.Rev.D, 1987, **35**, 1131.
7. Vilenkin A. Phys.Rep., 1985, **121**, 263.
8. Particle Data Group, Phys.Lett.B, 1990, **239**, 1.
9. Witten E. Nucl.Phys.B, 1985, **249**, 557.
10. Tamman G., Sandage A., Yahil A. In "Physical Cosmology", eds. R.Balian, J.Audouze and D.N.Shramm (North-Holland, Am- sterdam, 1980).