Flavored string-dominated universe

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

Recently,[1] it has found in the case of the unified $SU(3)_H$ model[2–5] that there is a distinctive interplay between quark mixing and the flavored topological defects. Among them the Z_3 string-monopole networks are unambiguously singled out by the 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 course of evolution. They might constitute the bulk of the dark matter in the Universe required to make $\Omega = 1$ according to the inflationary scenario. Using some of the results of the numerical simulation,[6] we show here that there are good grounds for assuming a string-dominated Universe (SDU) in the case of flavored strings and monopoles we are considering here.

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, where most of the string segments have lengths comparable to the typical distance between monopoles d; (ii) the system evolves in a self-similar fashion, showing no tendency to relax to an equilibrium configuration or to decay into the small nets, and the intercommuting is unessential, inducing only $\sim 10\%$ difference in d; (iii) the main energy-loss mechanism for the network is the radiation of gauge quanta by ultrarelativistic monopoles with the unconfined $SU(3)_c$ and/or $U(1)_{em}$ magnetic charge prevents such networks in grand unification models from dominating the Universe.

It is now possible to directly use these results for the flavored Z_3 string-monopole network and to draw the same conclusions about its formation and evolution, except for the last one (iii). Instead of it, we find that (iv) all the magnetic flux from the flavored monopoles is confined in the strings because of the total spontaneous breakdown of the symmetry outside the strings. Therefore, we are inevitably led to the SDU.

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

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

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

$$\gamma = \frac{1}{3}(2\langle v_s^2 \rangle - 1), \quad -\frac{1}{3} \leqslant \gamma \leqslant \frac{1}{3}, \tag{2}$$

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

Solution of Eq. (1) with $\gamma(2)$, which does not change with time [self-similarity (iv)], leads to the typical length scale $d(t)$ of the 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 $a(t)$ the following expression (according to the evolution equation):

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

Here $t_0 \sim M_P V_H^{-2}$ is the 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 the time at which the strings begin to dominate the Universe ($t_s > t_{eq}$). Requiring now that the casuality condition be satisfied in each era (4) separately, we impose more stringent constraints on $\gamma(2)$:

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

Finally, the ratio of the string mass density, ρ_s, to the mass density of ordinary matter, $\rho \sim 1/Gt^2$, is

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

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 the present time $t_s \sim 10^{17}$ s, Eq. (6) with γ in the intervals (5) imposes constraints on the family unification scale V_H (for $t_s \sim t_{eq}$ they are nearly the same)

$$V_H \leqslant 10^4 - 10^{10} \quad \text{GeV}, \tag{7}$$

which meet the limitation $V_H \geqslant 10^4$ GeV, following from the laboratory experiments on the rare flavor-changing processes of quarks and leptons.[8] As can be seen from Eq. (6), if the flavored Z_3 strings are formed in a second-order phase transition ($d_0 \sim 1/V_H$), they will dominate the Universe very soon after the formation. Thus we have to assume a first-order phase transition with sufficiently large bubbles (on 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 virtually straight strings having relativistic speeds. The typical distance between the strings (monopoles) in the network, according to Eq. (3) is $d = 10^{13}–10^{18}$ cm for the intervals (5) and (7). Thus there should be many 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 about one year, if $V_H \approx 10^4$ GeV. As to the observational manifestations (see Ref. 1) of our network, they are related to its superconducting charge-carrying ability,[9] rather than to the gravitational interactions.

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

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

(H is the Hubble constant, $H = h \cdot 10^{-10} y^{-1}$, and $h = 0.5–1$), 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 each case

$$T^{net} = (0.7–2) t_{10}, \quad T^{ord} = (0.5–1) t_{10} \qquad (9)$$

($t_{10} = 10^{10} y$), 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 the age of the elements suggest[10] $T \geqslant 1.5 t_{10}$. One can thus see that the low-scale SDU scenario seems more preferable.

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[1]J. L. Chkareuli, Pis'ma Zh. Eksp. Teor. Fiz. [JETP Lett. **54**, 189 (1991)].
[2]J. L. Chkareuli, Pis'ma Zh. Eksp. Teor. Fiz. [JETP Lett. **32**, 671 (1980)].
[3]Z. G. Berezhiani and J. L. Chkareuli, Yad. Fiz. **37**, 1043 [Sov. J. Nucl. Phys. (1983)].
[4]Z. G. Berezhiani, Phys. Lett. B **129**, 99 (1983); **150**, 177 (1985).
[5]J. C. Wu, Phys. Rev. D **36**, 1514 (1987).
[6]M. Aryal, A. E. Everett, A. Vilenkin, and T. Vachaspati, Phys. Rev. D **34**, 434 (1986); T. Vachaspati and A. Vilenkin, Phys. Rev. D **35**, 1131 (1987).
[7]A. Vilenkin, Phys. Rep. **121**, 263 (1985).
[8]Particle Data Group, Phys. Lett. B **239**, 1 (1990).
[9]E. Witten, Nucl. Phys. B **249**, 557 (1985).
[10]G. Tamman, A. Sandage, and A. Yahil, "Physical Cosmology," eds. R. Balian, J. Audouze, and D. N. Shramm (North-Holland, Amsterdam, 1980).

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