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Baryogenesis in cosmological model with superstring-inspired E_6 unification

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ABSTRACT

We have developed a concept of parallel existence of the ordinary (O) and hidden (H) worlds with a superstring-inspired E_6 unification, broken at the early stage of the Universe into $SO(10) \times U(1)$ – in the O-world, and $SU(6)' \times SU(2)'$ – in the H-world. As a result, we have obtained in the hidden world the low energy symmetry group $G'_{SM} \times SU(2)'_\theta$, instead of the Standard Model group G_{SM}. The additional non-Abelian $SU(2)'_\theta$ group with massless gauge fields, "thetons", is responsible for the dark energy. We present a baryogenesis mechanism with the $B - L$ asymmetry produced by the conversion of ordinary leptons into particles of the hidden sector.

1. Introduction

A cosmological model has been proposed in Ref. [1] with the superstring-inspired E_6 unification arising at the early stage of the Universe. Considering a parallel existence of the ordinary (O) and hidden (H) worlds, it was assumed that the E_6 group was broken differently in the O- and H-sectors with the following breakings:

$$E_6 \to SO(10) \times U(1) \tag{1}$$

– in the O-world, and

$$E'_6 \to SU(6)' \times SU(2)' \tag{2}$$

– in the H-world.[1]

Using the model [1], we have tried to explain the origin of the Dark Energy (DE), Dark Matter (DM) and visible matter with energy densities given by recent cosmological observations, confirming the ΛCDM cosmological model with a tiny value of the cosmological constant. The study [1] is a development of the ideas considered previously in Refs. [2]. In the present investigation we describe the inflation epoch of our Universe and baryogenesis scenario.

For the present epoch, the Hubble parameter $H = H_0$ is given by the following value [3,4]:

$$H_0 = 1.5 \times 10^{-42}\ \text{GeV} \tag{3}$$

and the critical density of the Universe is

$$\rho_c = 3H^2/8\pi G = \left(2.5 \times 10^{-12}\ \text{GeV}\right)^4. \tag{4}$$

Cosmological measurements give the following density ratios of the total Universe [3,4]:

$$\Omega = \Omega_r + \Omega_m + \Omega_\Lambda = 1, \tag{5}$$

where $\Omega_r \ll 1$ is a relativistic (radiation) density ratio and

$$\Omega_\Lambda = \Omega_{DE} \sim 75\% \tag{6}$$

for the mysterious Dark Energy (DE), which is responsible for the accelerated expansion of the Universe. The matter density ratio is:

$$\Omega_m \approx \Omega_M + \Omega_{DM} \sim 25\%, \tag{7}$$

with $\Omega_M \approx \Omega_B \approx 4\%$ – for (visible) baryons, and $\Omega_{DM} \approx 21\%$ – for the Dark Matter (DM). We can calculate the dark energy density using (4) and (6):

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[1] The superscript 'prime' denotes the H-world.

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$$\rho_{DE} = \rho_{vac} \approx 0.75\rho_c \approx \left(2.3 \times 10^{-3}\ \text{eV}\right)^4. \quad (8)$$

The result (8) is consistent with the present model of accelerating Universe dominated by a tiny cosmological constant and Cold Dark Matter (CDM).

2. Superstring theory and E_6 unification

Superstring theory [5–7] is a paramount candidate for the unification of all fundamental gauge interactions with gravity. The 'heterotic' superstring theory $E_8 \times E_8'$ reasonably was suggested as a realistic model for unification of all fundamental gauge interactions with gravity [6]. This ten-dimensional theory can undergo spontaneous compactification. The integration over six compactified dimensions of the E_8 superstring theory leads to the effective theory with the E_6 unification in the four-dimensional space [7].

Superstring theory has led to the speculation that there may exist another form of matter – hidden "shadow matter" – in the Universe, which only interacts with ordinary matter via gravity or gravitational-strength interactions [8] (see also the reviews [9]). The shadow world, in contrast to the mirror world [10], can be described by another group of symmetry (or by a chain of groups of symmetry), which is different from the ordinary world symmetry group.

Three 27-plets of E_6 contain three families of quarks and leptons, including right-handed neutrinos N_i^c (where $i = 1, 2, 3$ is the index of generations). We omit generation subscripts, for simplification.

Matter fields (quarks, leptons and scalar fields) of the fundamental 27-representation of the E_6 group decompose under $SU(5) \times U(1)_X$ subgroup as follows (see Ref. [11]):

$$27 \to (10, 1) + (\bar{5}, 2) + (5, -2) + (\bar{5}, -3) + (1, 5) + (1, 0). \quad (9)$$

The first and second numbers in the brackets in Eq. (9) correspond to the dimensions of the $SU(5)$ representations and to the $U(1)_X$ charges, respectively. These representations decompose under the groups with the breaking

$$SU(5) \times U(1)_X \to SU(3)_C \times SU(2)_L \times U(1)_Z \times U(1)_X. \quad (10)$$

We consider the following $U(1)_Z \times U(1)_X$ charges of matter fields: $Z = \sqrt{\frac{5}{3}} Q^Z$, $X = \sqrt{40} Q^X$.

The Standard Model (SM) family which contains the doublets of left-handed quarks Q and leptons L, right-handed up and down quarks u^c, d^c, and also right-handed charged lepton e^c, belongs to the $(10, 1) + (\bar{5}, 2)$ representations of $SU(5) \times U(1)_X$. Then, for the decomposition (10), we have the following assignments of particles:

$$(10, 1) \to Q = \begin{pmatrix} u \\ d \end{pmatrix} \sim \left(3, 2, \frac{1}{6}, 1\right),$$
$$u^{\mathbf{c}} \sim \left(\bar{3}, 1, -\frac{2}{3}, 1\right),$$
$$e^{\mathbf{c}} \sim (1, 1, 1, 1), \quad (11)$$

$$(\bar{5}, 2) \to d^{\mathbf{c}} \sim \left(\bar{3}, 1, \frac{1}{3}, 2\right),$$
$$L = \begin{pmatrix} e \\ \nu \end{pmatrix} \sim \left(1, 2, -\frac{1}{2}, 2\right), \quad (12)$$

$$(1, 5) \to S \sim (1, 1, 0, 5). \quad (13)$$

The remaining representations in (10) decompose as follows:

$$(5, -2) \to D \sim \left(3, 1, -\frac{1}{3}, -2\right),$$
$$h = \begin{pmatrix} h^+ \\ h^0 \end{pmatrix} \sim \left(1, 2, \frac{1}{2}, -2\right). \quad (14)$$

$$(\bar{5}, -3) \to D^{\mathbf{c}} \sim \left(\bar{3}, 1, \frac{1}{3}, -3\right),$$
$$h^{\mathbf{c}} = \begin{pmatrix} h^0 \\ h^- \end{pmatrix} \sim \left(1, 2, -\frac{1}{2}, -3\right). \quad (15)$$

To the representation $(1, 5)$ is assigned the SM-singlet field S, which carries non-zero $U(1)_X$ charge. The light Higgs doublets are accompanied by the heavy colour triplets of exotic quarks ('diquarks') D, $D^{\mathbf{c}}$ which are absent in the SM (see Ref. [11]).

The right-handed heavy neutrino is a singlet field N^c represented by $(1, 0)$:

$$(1, 0) \to N^{\mathbf{c}} \sim (1, 1, 0, 0). \quad (16)$$

3. Breaking of the E_6 unification in cosmology

The results of Refs. [12] are based on the hypothesis of the existence in Nature a mirror (M) world parallel to the visible ordinary (O) world. The authors have described the O- and M-worlds at low energies by a minimal symmetry $G_{SM} \times G'_{SM}$ where

$$G_{SM} = SU(3)_C \times SU(2)_L \times U(1)_Y$$

stands for the observable Standard Model (SM) while

$$G'_{SM} = SU(3)'_C \times SU(2)'_L \times U(1)'_Y$$

is its mirror gauge counterpart. The M-particles are singlets of G_{SM} and the O-particles are singlets of G'_{SM}. These different O- and M-worlds are coupled only by gravity, or possibly by another very weak interaction.

If the ordinary and mirror worlds are identical, then O- and M-particles should have the same cosmological densities. But this is immediately in conflict with recent astrophysical measurements. Mirror parity (MP) is not conserved, and the ordinary and mirror worlds are not identical. Then the VEVs of the Higgs doublets ϕ and ϕ' are not equal:

$$\langle\phi\rangle = v, \qquad \langle\phi'\rangle = v' \quad \text{and} \quad v \neq v'. \quad (17)$$

Introducing the parameter characterizing the violation of MP:

$$\zeta = \frac{v'}{v} \gg 1, \quad (18)$$

we have the estimate of Refs. [12]: $\zeta \sim 100$. Then the masses of fermions and massive bosons in the mirror world are scaled up by the factor ζ with respect to the masses of their counterparts in the ordinary world:

$$m'_{q',l'} = \zeta m_{q,l}, \qquad M'_{W',Z',\Phi'} = \zeta M_{W,Z,\Phi}, \quad (19)$$

while photons and gluons remain massless in both worlds.

In contrast to Refs. [12], in the present Letter we consider a cosmological model with E_6 unification when at the early stage of the Universe the O- and H (actually M)-worlds have the same GUT-scales and GUT-coupling constants: $M_{E6} = M'_{E6'}$ and $g_{E6} = g'_{E6'}$. Later the E_6 unification undergoes breakings which are different for O- and H-worlds.

It is well known (see [13]) that there exist the following three schemes for breaking of the E_6 group: