Mirror World, E(6) Unification and Cosmology

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Gran Sasso, Italy, Sep 22-Oct 4, 2008

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Contents:

1 Introduction: Superstring theory and a mirror world.

The present investigation is based on the following three assumptions:

• Grand Unified Theories (GUTs) are inspired by the basic theory of superstrings, which gives the possibility to unify all fundamental interactions including gravity:

M.B. Green, J.H. Schwarz and E. Witten, Superstring theory, Vol. 1,2, Cambridge University Press, Cambridge, 1988.

• There exists a mirror world, which is parallel to our ordinary world:

T.D. Lee and C.N. Yang, Phys.Rev. 104, 254 (1956);

I.Yu. Kobzarev, L.B. Okun and I.Ya. Pomeranchuk, Yad.Fiz. 3, 1154 (1966) [Sov.J.Nucl.Phys. 3, 837 (1966)].

• The mirror parity MP is broken:

We have an experience in Physics which usually shows that
"The only good parity ... is a broken parity!"

Z. Berezhiani, A. Dolgov and R.N. Mohapatra, Phys.Lett. B 375, 26 (1996);
Z. Berezhiani, Acta Phys.Pol. B 27, 1503 (1996);
Z.G. Berezhiani and R.N. Mohapatra, Phys.Rev. D 52, 6607 (1997).

Introduction: Superstring theory and a mirror world.

Superstring theory is a first candidate for the unification of all fundamental gauge interactions with gravity.

Superstrings are free of gravitational and Yang-Mills anomalies if a gauge group of symmetry is

$$\mathbf{SO(32)} \quad \text{or} \quad \mathbf{E_8} \times \mathbf{E_8}.$$

The 'heterotic' superstring theory $\mathbf{E_8} \times \mathbf{E'_8}$ was suggested as a more realistic model for unification:

D.J. Gross, J.A. Harvey, E. Martinec and R. Rohm,
Phys.Rev.Lett. 54, 502 (1985); Nucl.Phys. B256, 253 (1985).

M.B. Green, J.H. Schwarz and E. Witten,
Superstring theory, Vol. 1,2, Cambridge University Press, Cambridge, 1988.

This ten-dimensional Yang-Mills theory can undergo spontaneous compactification:

The integration over 6 compactified dimensions of the $\mathbf{E_8}$ *superstring theory leads to the effective theory with the* $\mathbf{E_6}$*-unification in 4-dimensional space.*

Introduction: Superstring theory and a mirror world.

In the present investigation:

C.R. Das and L.V. Laperashvili,
Int. J. Mod. Phys. A 23, 1863 (2008); arXiv: 0712.0253[hep-ph]

we consider the old concept:

there exists in Nature a 'mirror' (M) world (hidden sector) parallel to our ordinary (O) world.

This M-world is a mirror copy of the ordinary O-world and contains the same particles and their interactions as our visible world.

Observable elementary particles of our O-world have left-handed (V-A) weak interactions which violate P-parity.

The mirror particles participate in the right-handed (V+A) weak interactions and have an opposite chirality.

Lee and Yang were first who suggested such a duplication of worlds in the Universe trying to restore the left-right symmetry of Nature:

T.D. Lee and C.N. Yang, **Phys.Rev. 104, 254 (1956);**

The term 'Mirror World' was introduced by Kobzarev, Okun and Pomeranchuk:

I.Yu. Kobzarev, L.B. Okun and I.Ya. Pomeranchuk, **Yad.Fiz. 3, 1154 (1966) [Sov.J.Nucl.Phys. 3, 837 (1966)].**

They have investigated a lot of phenomenological implications of such parallel worlds.

The idea of the existence of the visible and mirror worlds became very attractive in connection with superstring theory $\mathbf{E_8 \times E'_8}$.

2 Particle content in the ordinary and mirror worlds.

We can describe the ordinary and mirror worlds by a minimal symmetry

$$\mathbf{G_{SM} \times G'_{SM}}, \quad \text{where}$$

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

stands for the Standard Model (SM) of observable particles (with three generations of quarks and leptons).
Then

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

is its mirror gauge counterpart.

The M-particles are singlets of $\mathbf{G_{SM}}$,
O-particles are singlets of $\mathbf{G'_{SM'}}$.

These different O- and M-worlds are coupled only by gravity (or maybe other very weak interaction).

Including Higgs bosons ϕ we have the following SM content of the O-world:

$$\mathbf{L-set:} \quad (\mathbf{u, d, e}, \nu, \tilde{\mathbf{u}}, \tilde{\mathbf{d}}, \tilde{\mathbf{e}}, \tilde{\mathbf{N}})_{\mathbf{L}}\,, \phi_{\mathbf{u}},\ \phi_{\mathbf{d}};$$

$$\tilde{\mathbf{R}}-\mathbf{set:} \quad (\tilde{\mathbf{u}}, \tilde{\mathbf{d}}, \tilde{\mathbf{e}}, \tilde{\nu}, \mathbf{u, d, e, N})_{\mathbf{R}}\,, \tilde{\phi}_{\mathbf{u}},\ \tilde{\phi}_{\mathbf{d}};$$

with antiparticle fields: $\tilde{\phi}_{\mathbf{u,d}} = \phi^*_{\mathbf{u,d}}$, $\tilde{\psi}_{\mathbf{R}} = \mathbf{C}\gamma_0\psi^*_{\mathbf{L}}$ and $\tilde{\psi}_{\mathbf{L}} = \mathbf{C}\gamma_0\psi^*_{\mathbf{R}}$,
and we have the following particle content in the M-sector:

$$\mathbf{L'-set:} \quad (\mathbf{u', d', e'}, \nu', \tilde{\mathbf{u}}', \tilde{\mathbf{d}}', \tilde{\mathbf{e}}', \tilde{\mathbf{N}}')_{\mathbf{L}}\,, \phi'_{\mathbf{u}},\ \phi'_{\mathbf{d}};$$

$$\tilde{\mathbf{R}}'-\mathbf{set:} \quad (\tilde{\mathbf{u}}', \tilde{\mathbf{d}}', \tilde{\mathbf{e}}', \tilde{\nu}', \mathbf{u', d', e', N'})_{\mathbf{R}}\,, \tilde{\phi}'_{\mathbf{u}},\ \tilde{\phi}'_{\mathbf{d}}.$$

In general, we can consider supersymmetric theories when $\mathbf{G \times G'}$ contains grand unification groups: $\mathbf{SU(5) \times SU(5)'}$, $\mathbf{SO(10) \times SO(10)'}$, $\mathbf{E_6 \times E'_6}$, etc.

3 Mirror world with broken mirror parity.

In general case the mirror parity MP can be not conserved. Then the ordinary and mirror worlds are not identical:

Z. Berezhiani, A. Dolgov and R.N. Mohapatra, **Phys.Lett. B 375, 26 (1996);**
Z. Berezhiani, **Acta Phys.Pol. B 27, 1503 (1996);**
Z.G. Berezhiani and R.N. Mohapatra, **Phys.Rev. D 52, 6607 (1997).**

If O- and M-sectors are described by the minimal symmetry group

$$\mathbf{G_{SM} \times G'_{SM'}}$$

with the Higgs doublets ϕ and ϕ', respectively, then in the case of non-conserved MP the VEVs of these Higgs fields: $< \phi >= \mathbf{v}$ and $< \phi' >= \mathbf{v}'$ are not identical: $\mathbf{v} \neq \mathbf{v}'$.

Following Berezhiani-Dolgov-Mohapatra, we assume that

$$\mathbf{v}' >> \mathbf{v}$$

and introduce the parameter characterizing the violation of MP:

$$\zeta = \frac{\mathbf{v}'}{\mathbf{v}} >> 1.$$

Then the masses of fermions and massive bosons in the mirror world are scaled up by the factor ζ:

$$\mathbf{m'_{q',l'}} = \zeta \mathbf{m_{q,l}},$$

$$\mathbf{M'_{W',Z',\phi'}} = \zeta \mathbf{M_{W,Z,\phi}},$$

but photons and gluons remain massless in both worlds.

4 Gauge coupling constant evolutions in the O-world.

Let us consider now the following evolutions of the inverse fine structure constants:

$$\alpha_{\mathbf{i}}^{-1}(\mu) = \frac{\mathbf{b_i}}{2\pi} \ln \frac{\mu}{\mathbf{\Lambda_i}}$$

— in the O-world, and

$$\alpha'^{-1}_{\mathbf{i}}(\mu) = \frac{\mathbf{b'_i}}{2\pi} \ln \frac{\mu}{\mathbf{\Lambda'_i}}$$

— in the M-world,
where

$$\alpha_{\mathbf{i}} = \frac{\mathbf{g_i^2}}{4\pi},$$

and $\mathbf{g_i}$ are gauge coupling constants.

A big difference between the Electroweak scales v and v′ will not cause a big difference between scales $\mathbf{\Lambda_i}$ and $\mathbf{\Lambda'_i}$:

$$\Lambda'_i = \xi \Lambda_i \quad \text{with} \quad \xi > 1.$$

The values of ζ and ξ were estimated by astrophysical implications

(by Berezhiani-Dolgov-Mohapatra),

which gave:

$$\zeta \approx \mathbf{30} \quad \text{and} \quad \xi \approx 1.5.$$

Gauge coupling constant evolutions in the O-world.

As for neutrino masses, the same authors have shown that:

$$\mathbf{m}'_\nu = \zeta^2 \mathbf{m}_\nu,$$

$$\mathbf{M}'_\nu = \zeta^2 \mathbf{M}_\nu,$$

where $\mathbf{m}_\nu$ are light left-handed and $\mathbf{M}_\nu$ are heavy right-handed neutrino masses in the O-world,
and $\mathbf{m}'_\nu, \mathbf{M}'_\nu$ are the corresponding neutrino masses in the M-world.
The last relation gives the following relation for seesaw scales:

$$\mathbf{M}'_\mathbf{R} = \zeta^2 \mathbf{M}_\mathbf{R}.$$

Here $\mathbf{M}_\mathbf{R}$ and $\mathbf{M}'_\mathbf{R}$ are the seesaw scales, where heavy right-handed neutrinos appear.

In the present investigation we consider the running of all gauge coupling constants in the SM and its extensions which are well described by the one-loop approximation of the renormalization group equations (RGEs), because from the Electroweak (EW) scale up to the Planck scale ($\mathbf{M}_\mathbf{Pl}$) we deal with the asymptotically free theories.

We assume that in the ordinary world, from the SM up to the $\mathbf{E}_6$-unification, there exists the following chain of symmetry groups:

$$\mathbf{SU(3)_C \times SU(2)_L \times U(1)_Y \to [SU(3)_C \times SU(2)_L \times U(1)_Y]_{SUSY}}$$

$$\mathbf{\to SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X \times U(1)_Z}$$

$$\mathbf{\to SU(4)_C \times SU(2)_L \times SU(2)_R \times U(1)_Z}$$

$$\mathbf{\to SO(10) \times U(1)_Z \to E_6}.$$

Recently (in preparation) we have considered the following possibility:

Cosmological Consequences of the Breakdown $\mathbf{E_6 \to SU(3)_C \times SU(3)_L \times SU(3)_R}$ in the Ordinary and Mirror Worlds

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4.1 Standard Model and MSSM.

We start with the SM in our ordinary world:

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

In the SM for energy scale $\mu \geq M_t$ (here M_t is the top quark pole mass) we have the following evolutions (RGEs) for the inverse fine structure constants α_i^{-1} ($i = 1, 2, 3$ correspond to the $U(1)$, $SU(2)_L$ and $SU(3)_C$ groups of the SM):

C. Ford, D.R.T. Jones, P.W. Stephenson, M.B. Einhorn, Nucl.Phys. B 395, 17 (1993),

which are revised using updated experimental results:

C.R. Das, C.D. Froggatt, L.V. Laperashvili and H.B. Nielsen, Mod.Phys.Lett. A 21, 1151 (2006)

C.D. Froggatt, L.V. Laperashvili, H.B. Nielsen, Phys.Atom.Nucl. 69, 67 (2006); Yad.Fiz. 69, 3 (2006).

$$\alpha_1^{-1}(t) = 58.65 \pm 0.02 - \frac{41}{20\pi}t,$$
$$\alpha_2^{-1}(t) = 29.95 \pm 0.02 + \frac{19}{12\pi}t,$$
$$\alpha_3^{-1}(t) = 9.17 \pm 0.20 + \frac{7}{2\pi}t,$$

where

$$t = \ln\left(\frac{\mu}{M_t}\right)$$

is the evolution variable. We have used the central value of the top quark mass (Particle Data Group):

$$M_t \approx 172.6 \text{ GeV}.$$

Standard Model and MSSM.

The Minimal Supersymmetric Standard Model (MSSM) extends the conventional SM and gives the evolutions for $\alpha_i^{-1}(\mu)$

from the supersymmetric scale M_{SUSY} up to the seesaw scale M_R.

Coefficients b_i, describing this running, are given by the Table 1.

In Figs. 1(a,b) we have presented examples with the following scales:

$M_{SUSY} = 10$ TeV, $M_R = 2.5 \cdot 10^{14}$ GeV, $\zeta = 30$.

Here and below red lines correspond to the ordinary world.

In Figs. 1(a,b) we have

$$x = \log_{10}\mu\,(\mathrm{GeV}), \quad t = x \cdot \ln 10 - \ln M_t.$$

Fig. 1(b) shows the running of gauge coupling constants near the scale of the E_6-unification (for $x \geq 15$).

Table 1: **Ordinary world**

Nonsupersymmetric groups:	$\mathbf{SU(3)_C}$	$\mathbf{SU(2)_L}$	$\mathbf{U(1)_Y}$	
$\mathbf{b_i}$**:**	7	19/6	-41/10	
Supersymmetric groups:	$\mathbf{SU(3)_C}$	$\mathbf{SU(2)_L}$	$\mathbf{U(1)_Y}$	$\mathbf{SU(4)_C}$
$\mathbf{b_i}$**:**	3	-1	-33/5	5
	$\mathbf{SU(2)_L \times SU(2)_R}$	$\mathbf{U(1)_X}$	$\mathbf{U(1)_Z}$	$\mathbf{SO(10)}$
	$\mathbf{b_{22} = -2}$	-33/5	-9	1

Table 1

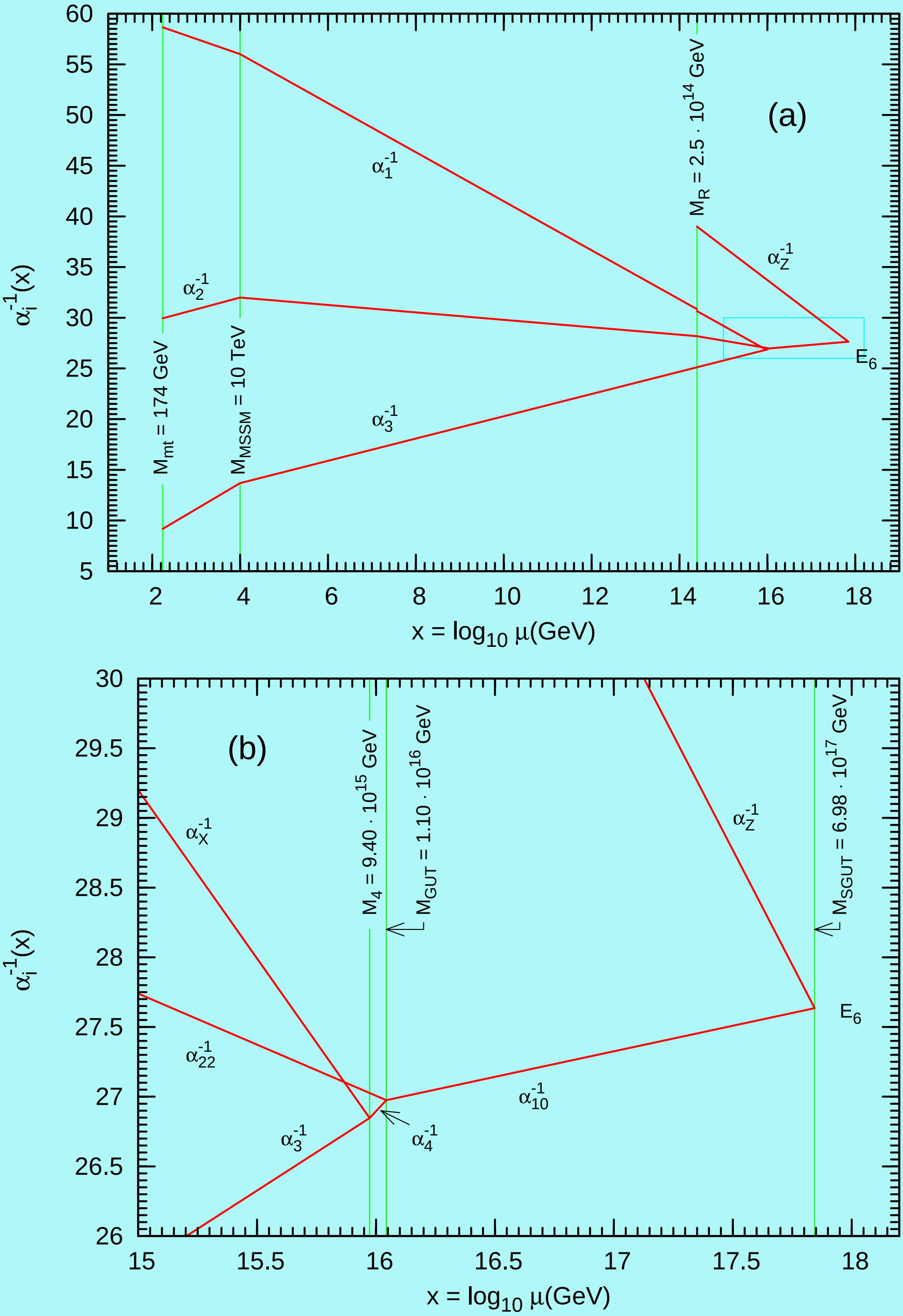

Fig. 1: Figure (a) presents the running of the inverse coupling constants $\alpha_i^{-1}(x)$ in the ordinary world from the Standard Model up to the E_6 unification for SUSY breaking scale $M_{SUSY} = 10$ TeV and seesaw scale $M_R = 2.5 \cdot 10^{14}$ GeV. This case gives: $M_{SGUT} \approx 6.96 \cdot 10^{17}$ GeV and $\alpha_{SGUT}^{-1} \approx 27.64$. (b) is same as (a), but zoomed in the scale region 10^{15} GeV up to the E_6 unification to show the details.

4.2 Left-right symmetry, SO(10) and E_6-unification.

We assume that the following supersymmetric left-right symmetry originates at the seesaw scale M_R :

$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X \times U(1)_Z.$$

J.C. Pati, A. Salam, **Phys.Rev. D 10, 275 (1974),**
R.N. Mohapatra, J.C. Pati, **Phys.Rev. D 11, 566 (1975); ibid., 2558 (1975).**

The next step is an assumption that the group

$$\mathbf{SU(4)_C \times SU(2)_L \times SU(2)_R}$$

by Pati and Salam originates at the scale M_4 giving the following extension of the symmetry group :

$$\mathbf{SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X \times U(1)_Z}$$

$$\to \mathbf{SU(4)_C \times SU(2)_L \times SU(2)_R \times U(1)_Z}. \tag{1}$$

At the scale $M_{\mathbf{GUT}}$ the SO(10)-unification comes:

$$\mathbf{SU(4)_C \times SU(2)_L \times SU(2)_R \to SO(10)}. \tag{2}$$

The evolution $\alpha_{10}^{-1}(\mu)$, corresponding to the SO(10), "runs" from the scale $M_{\mathbf{GUT}}$ up to the superGUT scale $M_{\mathbf{SGUT}}$ of the E_6-unification:

$$\mathbf{SO(10) \times U(1)_Z \to E_6}.$$

The superGUT scale is:

$$M_{\mathbf{SGUT}} = M_{\mathbf{E6}} \sim 10^{18}\mathbf{GeV}.$$

5 Mirror gauge coupling constant evolutions

5.1 Gauge coupling constant evolutions in the mirror SM' and MSSM'.

Let us consider now the mirror M-world and the extension of the SM'.

The first steps of such an extension is:

$$\mathbf{SU(3)'_C \times SU(2)'_L \times U(1)'_Y}$$

$$\rightarrow \mathbf{[SU(3)'_C \times SU(2)'_L \times U(1)'_Y]_{MSSM}}$$

$$\rightarrow \mathbf{[SU(3)'_C \times SU(2)'_L \times U(1)'_X \times U(1)'_Z]_{MSSM}},$$

and then

$$\mathbf{[SU(3)'_C \times SU(2)'_L \times U(1)'_X]_{MSSM}}$$

$$\rightarrow \mathbf{SU(4)'_C \times SU(2)'_L}.$$

In the SM'-sector of the M-world we have the following evolutions:

$$(\alpha')^{-1}_{\mathbf{i}}(\mu) = (\alpha')^{-1}_{\mathbf{i}}(\mathbf{M'_t}) + \frac{\mathbf{b_i}}{\mathbf{2\pi}}\mathbf{t'} = \frac{\mathbf{b_i}}{\mathbf{2\pi}} \ln \frac{\mu}{\mathbf{\Lambda'_i}}, \tag{3}$$

where

$$\mathbf{M'_t = \zeta M_t}.$$

It is necessary to notice that the scales $\mathbf{\Lambda'_i}$ and $\mathbf{\Lambda_i}$ are different, if we have the broken mirror parity MP,
but the slopes are the same ones:

$$\mathbf{b'_i = b_i}.$$

Gauge coupling constant evolutions in the mirror SM' and MSSM'.

The MSSM' is an extension of the SM', and the superpartners of particles, that is, "sparticles", have in the M-world the masses

$$\tilde{m}' = \zeta\tilde{m}.$$

This means that the supersymmetry breaking scale in the M-world is larger:

$$M'_{SUSY} = \zeta M_{SUSY}.$$

The mirror MSSM' leads to the evolutions

$$\alpha'^{-1}_i(\mu)$$

where

$$i = 1, 2, 3,$$

which run

from the scale M'_{SUSY}

up to the scale M'_{GUT} of the first unification in the M-world.

At the scale

$$M'_R \sim 10^3 M_R$$

the mirror right-handed neutrinos appear, and in the chain of the possible symmetries on the way leading to the E'_6-unification in the M-world we can observe the following symmetries:

$$[SU(3)'_C \times SU(2)'_L \times U(1)'_Y]_{MSSM}$$
$$\to [SU(3)'_C \times SU(2)'_L \times U(1)'_X \times U(1)'_Z]_{MSSM}, \qquad (4)$$
$$[SU(3)'_C \times SU(2)'_L \times U(1)'_X]_{MSSM} \to SU(4)'_C \times SU(2)'_L. \qquad (5)$$

Coefficients b_i (slopes), describing the evolutions in the mirror world, are given by the Table 2.

Table 2: **Mirror world**

Nonsupersymmetric groups:	$\mathbf{SU(3)'_C}$	$\mathbf{SU(2)'_L}$	$\mathbf{SU(2)'_Z}$	$\mathbf{U(1)'_Y}$
$\mathbf{b_i}$:	7	19/6	13/3	-41/10
Supersymmetric groups:	$\mathbf{SU(3)'_C}$	$\mathbf{SU(2)'_L}$	$\mathbf{SU(2)'_Z}$	$\mathbf{U(1)'_Y}$
$\mathbf{b_i}$:	3	-1	0	-33/5
	$\mathbf{S(4)'_C}$	$\mathbf{U(1)'_X}$	$\mathbf{U(1)'_Z}$	$\mathbf{SU'(6)}$
	5	-33/5	-9	11

5.2 Mirror gauge coupling constant evolutions from $SU(6)'$.

But in the mirror world with broken mirror parity MP the evolutions are quite different, and as a result, at the GUT scale M'_{GUT} we observe not $SO(10)'$-unification , but $SU(6)'$-unification:

$$SU(4)'_C \times SU(2)'_L \times U(1)'_Z \to SU(6)'.$$

Then we see the SU(6) evolution in the M-world up to the superGUT-scale

$$M'_{SGUT} = M'_{E6}.$$

In the M-world the final chain is:

$$SU(6)' \times SU(2)'_Z \to E'_6.$$

Now we are in confrontation with the question:
what group of symmetry $SU(2)'_Z$, unknown in the O-world, exists in the M-world (with the broken mirror parity MP), which ensures the E'_6-unification at the superGUT-scale M'_{SGUT}.

In this investigation we assume that at the very small distances (that is, at large energies) the mirror parity is restored giving the super-unification

$$E_6 = E'_6$$

at the superGUT scale M_{SGUT}:

$$M'_{SGUT} = M'_{E6} = M_{SGUT} = M_{E6} \sim 10^{18}\ \mathrm{GeV}. \quad (6)$$

Finally, we obtain the following chain of symmetries in the mirror M-world:

$$E'_6 \to SU(6)' \times SU(2)'_Z \to SU(4)'_C \times SU(2)'_L \times SU(2)'_Z \times U(1)'_Z$$
$$\to SU(3)'_C \times SU(2)'_L \times SU(2)'_Z \times U(1)'_X \times U(1)'_Z$$
$$\to [SU(3)'_C \times SU(2)'_L \times U(1)'_Y] \times SU(2)'_Z. \quad (7)$$

Now it is quite necessary to understand if there exists the group $SU(2)'_Z$ in the mirror world.

What it could be?

6 A new mirror gauge group $SU(2)'_Z$.

6.1 Particle content of the $SU(2)'_Z$ gauge group.

The reason of our choice of the $SU(2)'_Z$ particle content

was to obtain such an evolution $(\alpha')^{-1}_{2Z}(\mu)$, which:

• leads to the new scale in the M-world at extremely low energies:

$$\Lambda_Z \sim 10^{-3}\ \mathrm{eV}$$

See: *H. Goldberg,* Phys.Lett. B 492, 153 (2000);
P.Q. Hung, Nucl.Phys. B 747, 55 (2006); J.Phys. A 40, 6871 (2007); arXiv: hep-ph/0707.2791.

• and is consistent with the running of all inverse gauge coupling constants in the O- and M-worlds with broken mirror parity, considered in this investigation.

Only the following slopes correspond to our aim:

$$b_{2Z} = \frac{13}{3} \approx 4.33 \quad \text{and} \quad b_{2Z}^{SUSY} = 0.$$

Then the particle content of $SU(2)'_Z$ is as follows:

1. two doublets of fermions $\psi_i^{(Z)}$ and two doublets of scalar fields $\phi_i^{(Z)}$ with $i = 1, 2$, or

2. one triplet of fermions $\psi_f^{(Z)}$ with $f = 1, 2, 3$, which are singlets under the SM', and two doublets of scalar fields $\phi_i^{(Z)}$ with $i = 1, 2$.

3. We also consider a complex singlet scalar field: $\varphi_Z = (1, 1, 0, 1)$ under the symmetry group

$$G' = [SU(3)'_C \times SU(2)'_L \times U(1)'_Y] \times SU(2)'_Z.$$

In Figs. 2(a,b) we have shown the evolutions of all $\alpha'^{-1}(\mu)$ given by blue lines, together with $\alpha'^{-1}_{2Z}(\mu)$).

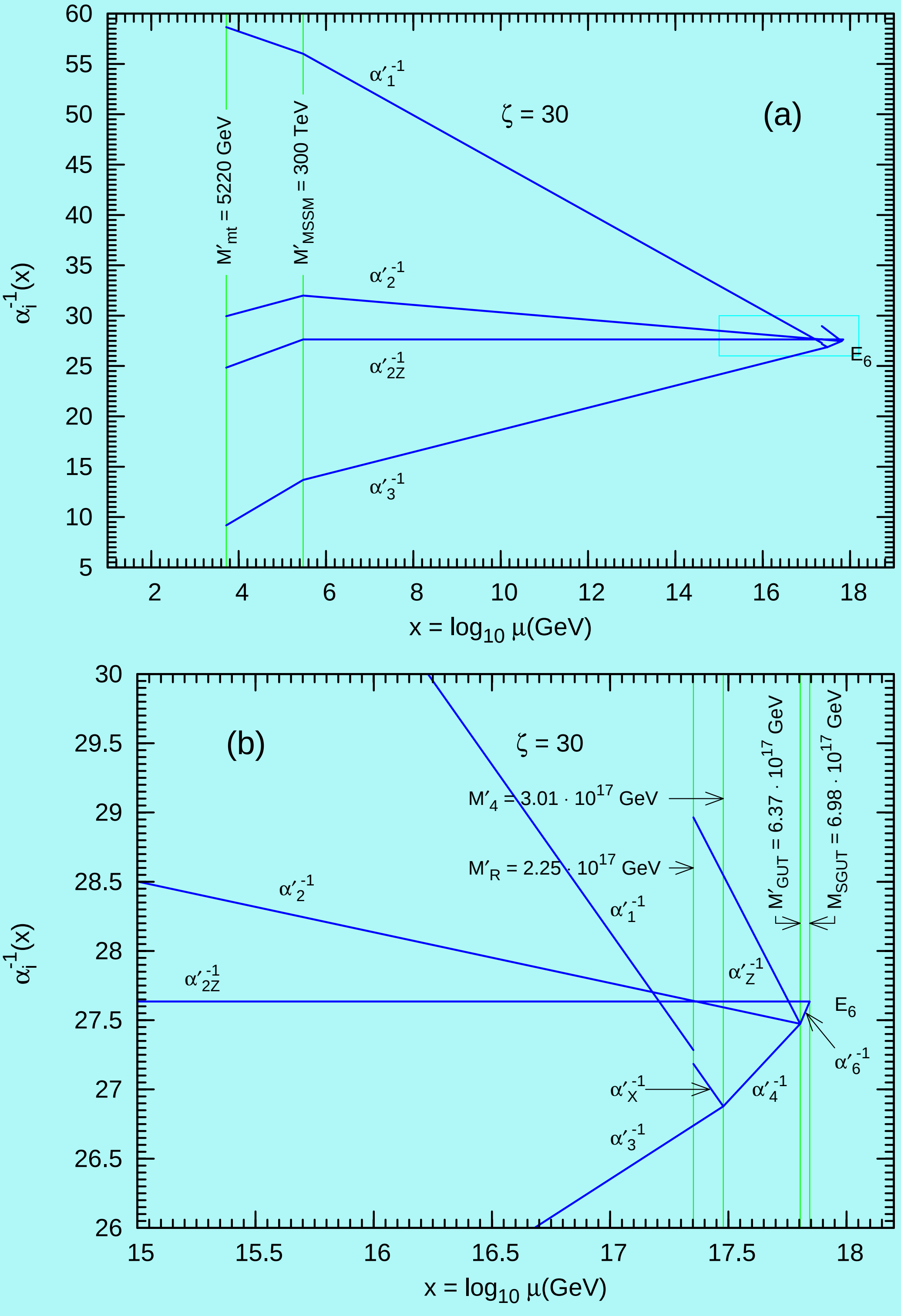

Fig. 2: Figure 2(a) presents the running of the inverse coupling constants $\alpha_i^{-1}(x)$ in the mirror world from the Standard Model up to the E_6 unification for SUSY breaking scale $\mathbf{M'_{SUSY}} = \mathbf{300}$ TeV and mirror seesaw scale $M'_R = 2.25 \cdot 10^{17}$ GeV; $\zeta = 30$. This case gives: $M_{SGUT} \approx 6.96 \cdot 10^{17}$ GeV and $\alpha_{SGUT}^{-1} \approx 27.64$. (b) is same as (a), but zoomed in the scale region 10^{15} GeV up to the E_6 unification to show the details.

The comparison of the evolutions in the O- and M-worlds is presented in Figs. 3(a,b).

We have considered such an example of parameters:

$$\mathbf{M_{SUSY} = 10\ \ TeV},$$

$$\mathbf{M_R = 2.5 \cdot 10^{14}\ \ GeV},$$

$$\mathbf{M'_R = 2.25 \cdot 10^{17}\ \ GeV},$$

$$\zeta = \mathbf{30}.$$

It is obvious that in this case

$$\mathbf{M'_{SUSY} = 300\ \ TeV}.$$

Here

$$\mathbf{M_{SGUT} \approx 6.96 \cdot 10^{17}\ GeV},$$

and

$$\alpha^{-1}_{\mathbf{SGUT}} \approx \mathbf{27.64}.$$

Red lines correspond to the O-world,

blue lines correspond to the M-world.

Fig. 3(b) is same as (a), but zoomed in the scale region from 10^{15} GeV up to the E_6 unification to show the details.

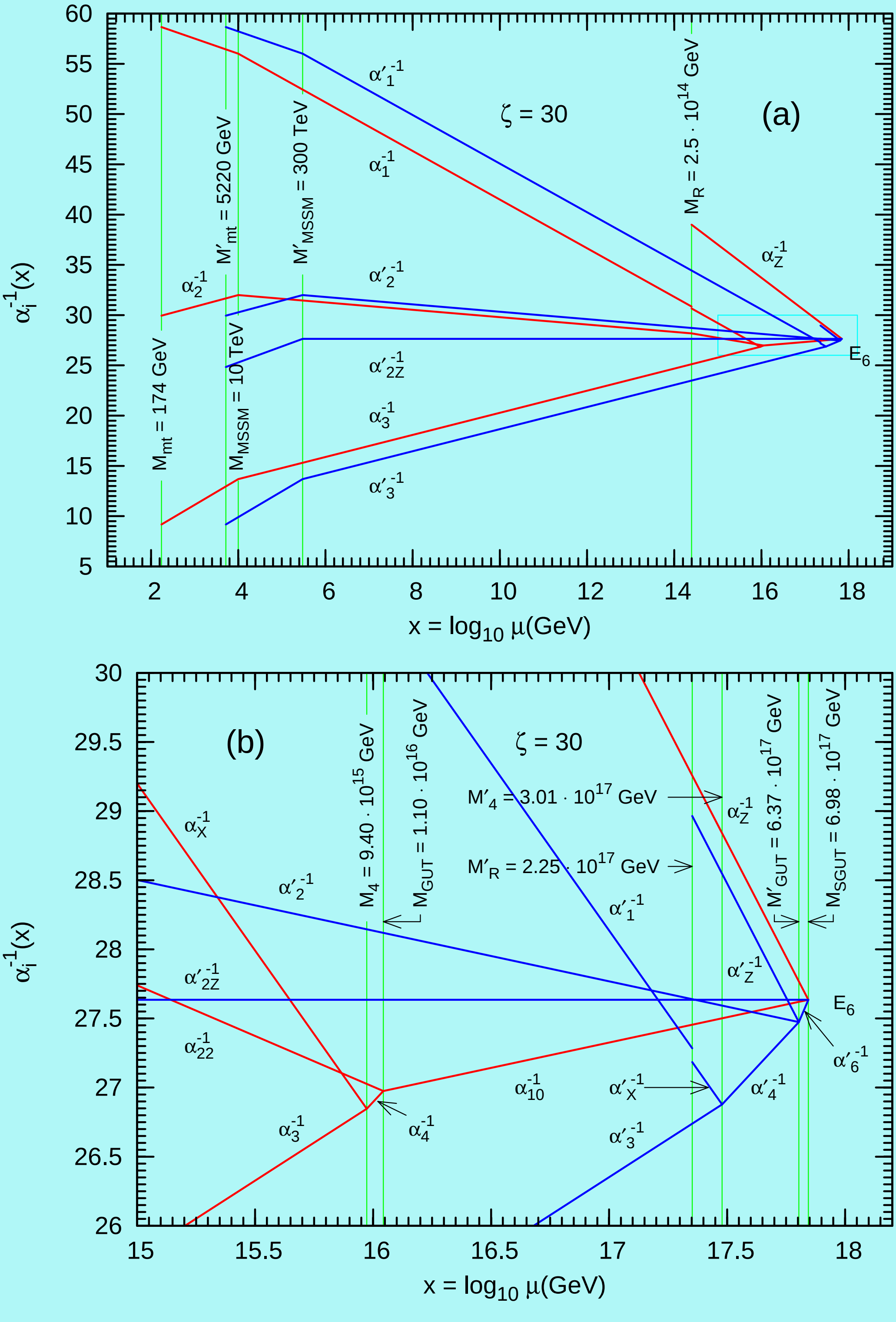

Fig. 3: In (a) the running of the inverse coupling constants $\alpha_i^{-1}(x)$ in both ordinary and mirror worlds with broken mirror parity from the Standard Model up to the E_6 unification for SUSY breaking scales $M_{SUSY} = 10$ TeV, $M'_{SUSY} = 300$ TeV and seesaw scales $M_R = 2.5 \cdot 10^{14}$ GeV, $M'_R = 2.25 \cdot 10^{17}$ GeV; $\zeta = 30$. This case gives: $M_{SGUT} \approx 6.96 \cdot 10^{17}$ GeV and $\alpha^{-1}_{SGUT} \approx 27.64$. (b) is same as (a), but zoomed in the scale region 10^{15} GeV up to the E_6 unification to show the details.

6.2 The axion potential.

The Lagrangian corresponding to the group of symmetry

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

exhibits a $\mathbf{U(1)^{(Z)}_A}$ global symmetry.

The singlet complex scalar field $\varphi_\mathbf{Z}$ considered in theory reproduces the Peccei-Quinn (PQ) model (well-known in QCD):

R. Peccei and H. Quinn, Phys.Rev.Lett. 38, 1440 (1977).

Then the potential:

$$\mathbf{V} = \frac{\lambda}{4}(\varphi^+_\mathbf{Z}\varphi_\mathbf{Z} - \mathbf{v^2_Z})^2$$

gives the VEV for $\varphi_\mathbf{Z}$:

$$< \varphi_\mathbf{Z} >= \mathbf{v_Z}.$$

Representing the field $\varphi_\mathbf{Z}$ as follows:

$$\varphi_\mathbf{Z} = \mathbf{v_Z} \exp(\mathbf{i a_Z/v_Z}) + \sigma_\mathbf{Z},$$

we obtain the following VEVs:

$$< \mathbf{a_Z} >=< \sigma_\mathbf{Z} >= \mathbf{0}.$$

A boson $\mathbf{a_Z}$ is an axion
— the imaginary part of a singlet scalar field φ_Z.
This axion is a massless Nambu-Goldstone (NG) boson
if the $U(1)^{(Z)}_A$ symmetry is not spontaneously broken.

The axion potential.

The spontaneous breakdown of the global $\mathbf{U(1)_A^{(Z)}}$ by $SU(2)'_Z$ instantons gives masses to fermions $\psi^{(Z)}$
and inverts $\mathbf{a_Z}$ into a pseudo Nambu-Goldstone boson (PNGB).

Then the field $\varphi_\mathbf{Z}$ is described by the following expression:

$$\varphi_\mathbf{Z} = \exp(\mathbf{ia_Z/v_Z})(\mathbf{v_Z} + \sigma(\mathbf{x})) \approx \mathbf{v_Z} + \sigma(\mathbf{x}) + \mathbf{ia_Z(x)},$$

where the field σ is an inflaton.

In the last equation the axion $\mathbf{a_Z(x)}$ is just the famous PQ-axion.

Its mass is very small:

$$\mathbf{m_a^2 \sim \Lambda_Z^3/v_Z \sim 10^{-30}\ Gev^2}.$$

The axion potential, given by PQ model, has (for small $\mathbf{a_Z}$) the following expression:

$$\mathbf{V_{axion}} \approx \frac{\lambda}{4}(\varphi_\mathbf{Z}^+\varphi_\mathbf{Z} - \mathbf{v_Z^2})^2 + \mathbf{K}|\varphi|\cos(\mathbf{a_Z/v_z}),$$

where K is a positive constant: $\mathbf{K > 0}$.

It is well-known that this potential exhibits two degenerate minima at

$$\mathbf{< a_Z >= 0},$$

and at

$$\mathbf{< a_Z >= 2\pi v_Z}.$$

The minimum at $\mathbf{< a_Z >= 0}$ corresponds to the 'true' vacuum, the second minimum at $\mathbf{< a_Z >= 2\pi v_Z}$ is called the 'false' vacuum.

Such properties of the present axion leads to the 'quintessense' model of the accelerating expanding Universe and the axion $\mathbf{a_Z}$ could be called an acceleron.

Fig. 4 demonstrates the axion potential.

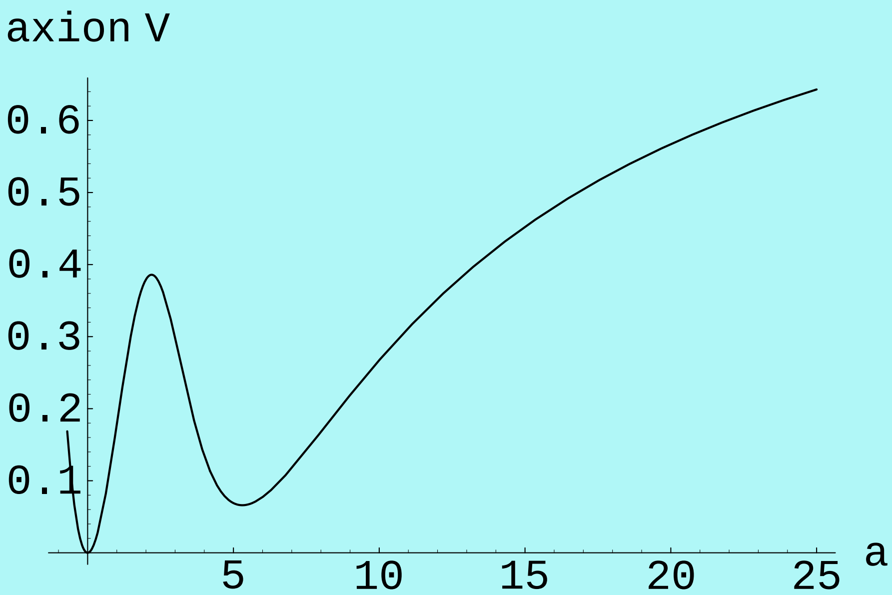

Fig. 4: The axion potential $\mathbf{V}$ as a function of $\mathbf{a} = |\mathbf{a_Z}|$. It shows the 'true' vacuum at $< \mathbf{a_Z} >= \mathbf{0}$ and the 'false' vacuum at $< \mathbf{a_Z} >= \mathbf{2}\pi\mathbf{v_Z}$.

6.3 A new cosmological scale $\Lambda_Z \approx 3 \times 10^{-3}$ eV.

The modern models of the Dark Energy (DE) and Dark Matter (DM) are based on the precise measurements in Astrophysics:

See:
A.G. Riess et al., **Astron.J. 116, 1009 (1998); ArXiv: astro-ph/9805201.**
S.J. Perlmutter et al., **Nature 39, 51 (1998); Astrophys.J. 517, 565 (1999).**
C. Bennett et al., **ArXiv: astro-ph/0302207.**
D. Spergel et al., **ArXiv: astro-ph/0302209.**
P. Astier et al., **ArXiv: astro-ph/0510447.**
D. Spergel et al., **ArXiv: astro-ph/0603449.**

These models lead to the following state equation for the dark energy DE:

$$\mathbf{w = p/\rho}, \tag{8}$$

where p is a pressure, and ρ is a density.
The constant w was measured in the reference:

P. Astier et al., **ArXiv: astro-ph/0510447,**

and is given as follows:

$$\mathbf{w = -1.023 \pm 0.090 \pm 0.054}. \tag{9}$$

The value w $= -1$ is consistent with the present quintessence model of accelerating Universe dominated by a tiny cosmological constant CC:

P.J.E. Peebles and A. Vilenkin, **Phys.Rev. D 59, 063505 (1999),**
C. Wetterich, **Nucl.Phys. B 302, 668 (1998),**
L.J. Hall, Y. Nomura, S.J. Oliver, **Phys.Rev.Lett. 95, 141302 (2005); ArXiv: astro-ph/0503706.**

A new cosmological scale $\Lambda_Z \approx 3 \times 10^{-3}$ eV.

Here we present the quintessence scenario, which was developed in connection with the existence of a new gauge group $SU(2)'_Z$ in the mirror M-world.

Considering the Cosmological Constant:

$$CC = \rho_{vac} \approx (3 \times 10^{-3}\ )^4,$$

we assume that at present time our Universe exists in the 'false' vacuum of the mirror axion potential.

The Universe will live there for a long time (hundred billions).

Its CC (measured in cosmology) is tiny, but nonzero.

However, at the end the Universe will jump into the 'true' vacuum and will get a zero cosmological constant: CC=0.

A new asymptotically free gauge group $SU(2)'_Z$ gives the running of $(\alpha')^{-1}_{2Z}(\mu)$.

Near the scale $\Lambda_Z \sim 10^{-3}$ eV the coupling constant of the group $SU(2)'_Z$ infinitely grows.

Now it is worth the people's attention to observe that in the mirror world we have three scales (presumably corresponding to the three vacua of the Universe):

$$\Lambda_1 = \Lambda_Z \sim 10^{-12}\ \text{GeV}, \qquad \Lambda_2 = \Lambda_{EW} \sim 10^3\ \text{GeV},$$

$$\Lambda_3 = \Lambda_{SGUT} \sim 10^{18}\ \text{GeV}.$$

They obey the following interesting relation:

$$\Lambda_1 \cdot \Lambda_3 \approx \Lambda_2^2.$$

7 Dark energy and cosmological constant.

The axion potential $V(a_Z)$ determines the origin of DE:

when the temperature of the Universe T is high:

$$\mathbf{T >> \Lambda_Z},$$

the effects of the $SU(2)'_Z$ instantons are negligible,
and the axion potential is flat.

When the temperature T begins to decrease, the Universe gets the false vacuum with $CC = \rho_{vac} = \Lambda_Z^4 \approx (3 \times 10^{-3}\ eV)^4$.

In fact, the Universe lives in the false vacuum for a very long time.

The first order phase transition to the true vacuum is provoked by the bubble nucleation.
Then the Universe trends to get the true vacuum with zero CC.

8 Dark matter.

The existence of DM in the Universe, which is non-luminous and non-absorbing matter, is now well established in Astrophysics.

We assume that the best candidate for DM is the mirror M-world (mirror quarks, mirror leptons, mirror bosons and their superpartners).

This M-world interacts with the ordinary O-world only by gravity, or by another unknown very weak interaction.

This is a serious problem for the future investigations in the Quantum Field Theory.

Here we want to emphasize that the fermions $\psi_i^{(Z)}$ belonging to the group $SU(2)'_Z$ can be considered as candidates for the Hot Dark Matter (HDM),

but the bound states — "hadrons" of the group $SU(2)'_Z$ — can be good candidates for the Cold Dark Matter (CDM).

9 Conclusions.

1. In this talk we have discussed cosmological implications of the parallel ordinary and mirror worlds with the broken mirror parity MP.

2. We have considered the parameter characterizing the breaking of MP, which is $\zeta = \mathrm{v}'/\mathrm{v}$, where v' and v are the VEVs of the Higgs bosons – Electroweak scales – in the M- and O-worlds, respectively.

3. During our numerical calculations, we have used the value $\zeta \approx 30$, in accordance with a cosmological estimate obtained by Berezhiani, Dolgov and Mohapatra.

4. We have assumed that at the very small distances there exists E_6-unification predicted by Superstring theory. We have chosen a theory, which leads to the asymptotically free E_6 unification, what is not always fulfilled.

5. We have shown that, as a result of the MP-breaking, the evolutions of fine structure constants in O- and M-worlds are not identical, and the extensions of the Standard Model in the ordinary and mirror worlds are quite different.

6. We have assumed that the E_6-unification, being the same in the O- and M-worlds, restores the broken mirror parity MP.

7. We have considered the following chain of symmetry groups in the ordinary world:

$$\mathrm{SU(3)_C \times SU(2)_L \times U(1)_Y}$$

$$\to \mathrm{SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X \times U(1)_Z}$$

$$\to \mathrm{SU(4)_C \times SU(2)_L \times SU(2)_R \times U(1)_Z \to SO(10) \times U(1)_Z \to E_6}.$$

Conclusions.

8. We have shown that a simple logic leads to the following chain in the mirror world:

$$\mathbf{SU(3)'_C \times SU(2)'_L \times SU(2)'_Z \times U(1)'_Y}$$

$$\mathbf{\to SU(3)'_C \times SU(2)'_L \times SU(2)'_Z \times U(1)'_X \times U(1)'_Z}$$

$$\mathbf{\to SU(4)'_C \times SU(2)'_L \times SU(2)'_Z \times U(1)'_Z}$$

$$\mathbf{\to SU(6)' \times SU(2)'_Z \to E'_6.}$$

9. The comparison of both evolutions in the ordinary and mirror worlds is given in Figs. 3(a,b), where we have presented the running of all fine structure constants. Here the SM (SM') is extended by MSSM (MSSM'), and we see different evolutions. Figs. 3(a,b) correspond to the SUSY breaking scales

$$\mathbf{M_{SUSY} = 10\ TeV, \quad M'_{SUSY} \approx 300\ TeV,}$$

according to the MP-breaking parameter $\zeta \approx 30$. We have considered the value of seesaw scale in the O-world

$$\mathbf{M_R \sim 10^{14}\ GeV,}$$

and in the M-world:

$$\mathbf{M'_R \sim 10^{17}\ GeV.}$$

10. It was shown that the (super)grand unification $\mathbf{E'_6}$ in the mirror world is based on the group

$$\mathbf{E'_6 \supset SU(6)' \times SU(2)'_Z.}$$

11. The existence of a new gauge group $\mathbf{SU(2)'_Z}$ in the M-world gives significant consequences for cosmology: it explains the 'quintessence' model of our accelerating Universe.

Conclusions.

12. We have presented in Figs. 2(a,b) and 3(a,b) the running of the $SU(2)'_Z$ gauge coupling by the evolution $\alpha'^{-1}_{2Z}(\mu)$, which takes its initial value at the superGUT scale

$$M_{SGUT} \sim 10^{18}\ \mathrm{GeV}$$

and then runs down to very low energies, giving an extremely strong coupling constant at the scale $\Lambda_Z \sim 10^{-3}$ eV.

13. We have discussed a 'quintessence' model of our Universe: at the scale $\Lambda_Z \sim 10^{-3}$ eV the instantons of the gauge group $SU(2)'_Z$ induce a potential for an axion-like scalar boson a_Z, which can be called "acceleron". The acceleron gives the value $w = -1$ and leads to the acceleration of our Universe.

14. It was shown that the existence of the scale $\Lambda_Z \sim 10^{-3}$ eV explains the value of cosmological constant:

$$CC \approx (3 \times 10^{-3}\ \mathrm{eV})^4,$$

which is given by astrophysical measurements. Also recent measurements in cosmology fit the equation of state for DE: $w = p/\rho$ with a constant $w \approx -1$.

15. Following P.Q. Hung, we have assumed that at present time our Universe exists in the 'false' vacuum given by the axion potential. The Universe will live there for a long time and its CC (measured in cosmology) is tiny, but nonzero. However, at the end the Universe will jump into the 'true' vacuum and will get a zero CC. But this problem is not trivially solved, and at present time we have only a hypothesis.

16. It was observed that the mirror world has three scales:

$$\Lambda_1 = \Lambda_Z \sim 10^{-12}\ \mathrm{GeV}, \qquad \Lambda_2 = \Lambda_{EW} \sim 10^3\ \mathrm{GeV},$$

$$\Lambda_3 = \Lambda_{SGUT} \sim 10^{18}\ \mathrm{GeV}.$$

They obey the following interesting relation:

$$\Lambda_1 \cdot \Lambda_3 \approx \Lambda_2^2.$$

Conclusions.

17. In our model of the Universe with broken mirror parity we have obtained the following particle content of the group $SU(2)'_Z$:

    • two doublets of fermions $\psi_i^{(Z)}$ $(i = 1, 2)$,
    or a triplet of fermions $\psi_f^{(Z)}$ $(f = 1, 2, 3)$;

    • two doublets of scalar fields $\phi_i^{(Z)}$ $(i = 1, 2)$.

18. Also, as H. Goldberg and P.Q. Hung, we have considered an existence of a complex singlet scalar field φ_Z, which produces "acceleron" a_Z and "inflaton" σ_Z and gives a 'quintessence' model of our Universe with the low scale inflationary scenario.

19. Unfortunately, we cannot predict exactly the scales M_{SUSY} and M_R presented in our Figs. 1-3(a,b). The numerical description of the model depends on these scales. Nevertheless, we hope that a qualitative scenario for the evolution of our Universe, developed in this paper, is valid.

20. We have discussed a possibility to consider the fermions $\psi_i^{(Z)}$ of the group $SU(2)'_Z$ as candidates for HDM and composites ("hadrons" of $SU(2)'_Z$) as WIMPs in CDM.

21. Finally, it is necessary to emphasize that this investigation opens the possibility to fix a grand unification group from Cosmology.

    Is it E_6 or not?

10 E6

Three 27-plets of E_6 contain three families of quarks and leptons, including right-handed neutrinos N_i^c (i=1,2,3 is the index of generations). Matter fields (quarks and leptons) of the fundamental 27 representation of the flipped E_6 decompose under $SU(5)\times U(1)_X$ subgroup as follows:

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

The first and second quantities in the brackets of Eq.(10) correspond to $SU(5)$ representation and $U(1)_X$ charge, respectively. The SM family which contains the doublets of left-handed quarks Q and leptons L, right-handed up and down quarks u^c, d^c, also e^c and right-handed neutrino N^c belong to the $(10,1)+(\bar{5},-3)+(1,5)$ representations of the flipped $SU(5)\times U(1)_X$. These representations decompose under

$$SU(5)\times U(1)_X \to SU(3)_C \times SU(2)_L \times U(1)_Z \times U(1)_X. \qquad (11)$$

Then for the decomposition (11), we have:

$$\begin{aligned}
(10,1) \to Q = & \begin{pmatrix} u \\ d \end{pmatrix} \sim \left(3, 2, \frac{1}{6}, 1\right), \\
& d^{\mathbf{c}} \sim \left(\bar{3}, 1, -\frac{2}{3}, 1\right), \\
& N^{\mathbf{c}} \sim (1,1,1,1)\,. \qquad (12)\\
(\bar{5},-3) \to & \; u^{\mathbf{c}} \sim \left(\bar{3}, 1, \frac{1}{3}, -3\right), \\
L = & \begin{pmatrix} e \\ \nu \end{pmatrix} \sim \left(1, 2, -\frac{1}{2}, -3\right), \qquad (13)\\
(1,5) \to & \; e^{\mathbf{c}} \sim (1,1,1,5)\,. \qquad (14)
\end{aligned}$$

The remaining representations in Eq. (??) decompose as follows:

$$
\begin{aligned}
(5,-2) \rightarrow \quad & D & \sim \left(3,1,-\frac{1}{3},-2\right), \\
h = & \begin{pmatrix} h^+ \\ h^0 \end{pmatrix} & \sim \left(1,2,\frac{1}{2},-2\right). \qquad (15) \\
(\bar{5},2) \rightarrow \quad & D^{\mathbf{c}} & \sim \left(\bar{3},1,\frac{1}{3},2\right), \\
h^{\mathbf{c}} = & \begin{pmatrix} h^0 \\ h^- \end{pmatrix} & \sim \left(1,2,-\frac{1}{2},2\right). \qquad (16)
\end{aligned}
$$

The light Higgs doublets are accompanied by coloured Higgs triplets $D, D^{\mathbf{c}}$.

The singlet field S is represented by (1,0):

$$
(1,0) \rightarrow S \sim (1,1,2,2). \qquad (17)
$$

It is necessary to notice that the flipping of our $SU(5)$:

$$
d^{\mathbf{c}} \leftrightarrow u^{\mathbf{c}}, \quad N^{\mathbf{c}} \leftrightarrow e^{\mathbf{c}}, \qquad (18)
$$

distinguishes this group of symmetry from the standard Georgi-Glashow $SU(5)$ [?].