Degenerate Vacua of the Universe and What Comes Beyond the Standard Model

B.G. Sidharth \(^1\ast\), C.R. Das \(^2\dagger\), C.D. Froggatt \(^3\ddagger\),
H.B. Nielsen \(^4\S\) and Larisa Laperashvili \(^5\¶\)

\(^1\) International Institute of Applicable Mathematics
and Information Sciences,
B.M. Birla Science Centre
Adarsh Nagar, 500063 Hyderabad, India

\(^2\) Bogoliubov Laboratory of Theoretical Physics
Joint Institute for Nuclear Research
International Intergovernmental Organization,
Joliot-Curie 6, 141980 Dubna, Moscow region, Russia

\(^3\) Glasgow University, UK

\(^4\) Niels Bohr Institute,
Blegdamsvej, 17-21, DK 2100 Copenhagen, Denmark

\(^5\) The Institute of Theoretical and Experimental Physics,
National Research Center “Kurchatov Institute”,
Bolshaya Cheremushkinskaya, 25, 117218 Moscow, Russia

\ast iiamisbgs@yahoo.co.in, birlasc@gmail.com
\dagger das@theor.jinr.ru
\ddagger Colin.Froggatt@glasgow.ac.uk
\S hbech@nbi.dk
\¶ laper@itep.ru
Abstract

We present a new cosmological model of the Universe based on the two discoveries: 1. cosmological constant is very small, and 2. Nature shows a new law in physics called “Multiple Point Principle” (MPP). The MPP predicts the two degenerate vacua of the Universe with VEV \( v_1 \approx 246 \text{ Gev} \) and \( v_2 \sim 10^{18} \text{ GeV} \), which provide masses of the Higgs boson and top-quark. A new cosmological model assumes the formation of two universal bubbles. The Universe at first stage of its existing is a bubble with a de-Sitter spacetime inside, having black-holes-hedgehogs as topological defects of the vacuum. Such a bubble has a “false vacuum” with VEV \( v_2 \), which decays very quickly. Cooling Universe has a new phase transition, transforming the “false” vacuum to the “true” (Electroweak) vacuum. Hedgehogs confined, and the universal bubble is transformed into the bubble having spacetime with FLRW-metric and the vacuum with new topological defects of \( U(1)_{\text{el-mag}} \) group: magnetic vortices and Sidharth’s pointlike defects. The problem of stability/metastability of the EW-vacuum is investigated. Noncommutativity of the vacua spacetime manifold is discussed. The prediction of a new physics is given by the future observations at LHC of the triplet \( SU(2) \) Higgs bosons (at energies \( E \sim 10 \text{ TeV} \)), and/or of the new bound states \( 6t + 6\bar{t} \) formed by top-antitop quarks (at \( E \sim 1 \text{ TeV} \)). The problem “What comes beyond the Standard Model” is discussed at the end of this paper.

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Introduction

In this paper we present a new standard cosmological model which is based on the two discovery of the XX(end)-XXI(beginning) century:

1. cosmological constant (Dark Energy) is extremely small, and
2. Nature shows a “new law of physics” which is named Multiple Point Principle (MPP).

Multiple Point Principle postulates:

There are several vacua in Nature with the same energy density, or cosmological constant, and all cosmological constants are zero, or approximately zero.

1 Dark Energy (DE) and Multiple Point Principle (MPP)

Multiple Point Principle (MPP) was first suggested by D.L. Bennett and H.B. Nielsen in Ref. [1].

A priori it is quite possible for a quantum field theory to have several minima of its effective potential as a function of its scalar fields (in our paper – scalar Higgs bosons). Postulating zero cosmological constant, we confront ourselves with a question: should the energy density, i.e. the cosmological constant, be (at least approximately) zero for all possible vacua or should it only be zero for that vacuum in which we live? The assumption would not be more complicated, if we postulated that all the vacua which might exist, as minima of the effective potential, should have approximately zero cosmological constant.

The MPP theory was developed in a lot of papers by H.B. Nielsen, D.L. Bennett, C.D. Froggatt, R.B. Nevzorov, L.V. Laperashvili, C.R. Das, and recently in Refs. [2–4].

Vacuum energy density of our Universe is the Dark Energy (DE), which is related with cosmological constant Λ by the following way:

\[ \rho_{DE} = \rho_{vac} = (M_{Pl}^{red})^2 \Lambda. \]

Here \( M_{Pl}^{red} \) is the reduced Planck mass: \( M_{Pl}^{red} \simeq 2.43 \times 10^{18} \text{ GeV} \).

Recent cosmological measurements (see Particle Data Group [5]) give:

\[ \rho_{DE} \simeq (2 \times 10^{-3} \text{ eV})^4. \]

According to [2], we have a very small value of cosmological constant Λ:

\[ \Lambda \simeq 10^{-84} \text{ GeV}^2. \]

This tiny value of \( \rho_{DE} \) was first predicted by B.G. Sidharth in 1997 [6,7], explaining that the Universe has an accelerating expansion. In 2011 S. Perlmutter, B. Schmidt
and A. Riess were awarded by the Nobel Prize for discovery of the Universe accelerating expansion.

Considering extremely small cosmological constant of our Universe, Bennett, Froggatt and Nielsen [1,11,12] assumed only zero, or almost zero, cosmological constants for all vacua existing in the Universe.

a. Three vacua of the Standard Model (SM)

Restricted ourselves to the pure Standard Model (SM) we have only three vacua:

1. **Present Electroweak vacuum**, in which we live.
   It has vacuum expectation value (VEV) of the Higgs field equal to:
   \[ v_1 = v = \langle \phi_H \rangle \approx 246 \text{ GeV}. \]  
   \( (4) \)

2. **High Higgs field vacuum** – Planck scale vacuum, which has the following VEV:
   \[ v_2 = v = \langle \phi_H \rangle \sim 10^{18} \text{ GeV}. \]  
   \( (5) \)

3. **Condensate vacuum**. This third vacuum is a very speculative possible state inside the pure SM, which contains a lot of strongly bound states, each bound from 6 top + 6 anti-top quarks (see Refs. [8–10]).

From experimental results for these three vacua, cosmological constants which corresponds to the minimum of the Higgs effective potential \( V_{\text{eff}}(\phi_H) \), are not exactly equal to zero. Nevertheless, they are extremely small. By this reason, Bennett, Froggatt and Nielsen [1,11,12] assumed to consider zero cosmological constants as a good approximation. Then according to the MPP, we have a model of the pure SM being finetuned in such a way that these three vacua proposed have just zero energy density.

If the effective potential has three degenerate minima, then the following requirements are satisfied [11,12]:

\[ V_{\text{eff}}(\phi_{\text{min1}}^2) = V_{\text{eff}}(\phi_{\text{min2}}^2) = V_{\text{eff}}(\phi_{\text{min3}}^2) = 0, \]  
\( (6) \)

and

\[ V'_{\text{eff}}(\phi_{\text{min1}}^2) = V'_{\text{eff}}(\phi_{\text{min2}}^2) = V'_{\text{eff}}(\phi_{\text{min3}}^2) = 0, \]  
\( (7) \)

where

\[ V'(\phi^2) = \frac{\partial V}{\partial \phi^2}. \]  
\( (8) \)

Here we assume that:

\[ V_{\text{eff}}(\phi_{\text{min1}}^2) = V_{\text{present}}, \]

\[ V_{\text{eff}}(\phi_{\text{min2}}^2) = V_{\text{high field}}, \]

and

\[ V_{\text{eff}}(\phi_{\text{min3}}^2) = V_{\text{condensate}}. \]
b. Top-quark and Higgs boson mass prediction.

Assuming the existence of the two degenerate vacua in the SM:

1. the first Electroweak vacuum at $v_1 \approx 246$ GeV, and
2. the second Planck scale vacuum at $v_2 \sim 10^{18}$ GeV,

Froggatt and Nielsen predicted the top-quark and Higgs boson masses \(^{[11]}\):

$$M_t = 173 \pm 5 \text{ GeV}; \quad M_H = 135 \pm 10 \text{ GeV}. \quad (9)$$

In Fig. 1 it is shown the existence of the second (non-standard) minimum of the effective Higgs potential in the pure SM at the Planck scale.

2 TOE, Graviweak Unification and Bubbles of the Universe

a. Big Bang

With aim to explain why we have two universal vacua, let us start with the Big Bang.

The Universe was expanded from a very high density and high temperature state. Big Bang is a singularity, the result of the extrapolation of all known laws of physics to the highest density regime. This primordial singularity called “the Big Bang” is the “birth” of our Universe since it represents the point in time when the Universe entered into a regime where the laws of physics (General Relativity, SM, etc.) began to work.

The time that has passed since that event is known as “the age of the universe” $T_U$:

$$T_U \simeq 13.799 \pm 0.021 \text{ billion years.}$$

b. Theory of Everything (TOE)

Through years of research scientists learned that GR and QFT are mutually incompatible: they cannot both be right. This incompatibility between GR and QFT is essential only in regions of extremely small-scale and high-mass, which exist during the beginning stages of the Universe, from the moment immediately following the Big Bang.

To resolve this problem, theorists tried to construct a theory unifying gravity with the other three interactions. It was searching a single theory that is capable of describing all phenomena. This is a “Theory of Everything” - TOE.

This term was used by John Ellis in his article published in “Nature” in 1986.
In this goal, quantum gravity has become an area of successful research. The Superstring Theory intends to be the ultimate theory of the Universe - TOE.

On November 6, 2007, Antony Garrett Lisi (Hawai Univ.) suggested “An Exceptionally Simple Theory of Everything”, often referred to as “E₈ Theory”, which attempts to describe all known fundamental interactions in physics using the Lie algebra of the largest “simple”, “exceptional” Lie group, E₈. The paper describes how the combined structure and dynamics of all gravitational and Standard Model particle fields, including fermions, are part of the E₈ Lie algebra. See elementary particle states assigned to E₈ roots in Fig. 2.

The E₈ Lie group has applications in theoretical physics and especially in String theory and Supergravity.

E₈ × E₈ is the gauge group of one of the two types of heterotic string. Heterotic string theory was developed in 1985 (see Ref. [14]) by David Gross, Jeffrey Harvey, Emil Martinec, and Ryan Rohm (the so-called “Princeton String Quartet”).

c. Inflation of the Universe

TOE contains a statement that at the beginning of the Universe, up to 10⁻⁴³ seconds after the Big Bang, the four fundamental forces were once a single fundamental force.

Approximately in 10⁻³⁷ seconds, a phase transition caused a cosmic inflation, and the Universe began to grow exponentially during which time density fluctuations (occurred because of the uncertainty principle) were amplified into the seeds that would later form the large-scale structure of the Universe.

In Refs. [15][16] we have suggested the Graviweak unification with a group of symmetry

\[ G_{GW} = \text{Spin}(4, 4), \]

which is spontaneously broken into the

\[ SL(2, C)^{(grav)} \times SU(2)^{(weak)}. \]

We assumed that after the Big Bang there existed a Theory of Everything (TOE) which rapidly was broken down to the direct product of the following gauge groups:

\[
G_{(TOE)} \rightarrow G_{GW} \times U(4) \rightarrow SL(2, C)^{(grav)} \times SU(2)^{(weak)} \times U(4) \\
\rightarrow SL(2, C)^{(grav)} \times SU(2)^{(weak)} \times SU(4) \times U(1)_Y \\
\rightarrow SL(2, C)^{(grav)} \times SU(2)^{(weak)} \times SU(3)_c \times U(1)_{(B-L)} \times U(1)_Y \\
\rightarrow SL(2, C)^{(grav)} \times SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{(B-L)} \\
\rightarrow SL(2, C)^{(grav)} \times G_{SM} \times U(1)_{(B-L)}. \\
\]

And below the see-saw scale (\( M_R \sim 10^9 \rightarrow 10^{14} \text{ GeV} \)) we have the SM group of symmetry:

\[ G_{SM} = SU(3)_c \times SU(2)_L \times U(1)_Y. \]
3 Black-hole-hedgehog’s solutions

The action $S_{GW}$ of the Graviweak unification (obtained in our papers) is given by the following expression:

$$
S_{GW} = -\frac{1}{g_{uni}} \int d^4 x \sqrt{-g} \left[ \frac{1}{16} \left( R|\Phi|^2 - \frac{3}{2}|\Phi|^4 \right) + \frac{1}{16} \left( a R_{\mu\nu} R^{\mu\nu} + b R^2 \right) + \frac{1}{2} D_\mu \Phi^i D^\mu \Phi + \frac{1}{4} F_{\mu\nu}^i F^{i\mu\nu} \right],
$$

(10)

where $g_{uni}$ is a parameter of the graviweak unification, parameters $a, b$ (with $a + b = 1$) are “bare” coupling constants of the higher derivative gravity, $R$ is the Riemann curvature scalar, $R_{\mu\nu}$ is the Ricci tensor, $|\Phi|^2 = \Phi^a \Phi^a$ is a squared triplet Higgs field, where $\Phi^a$ (with $a = 1, 2, 3$) is an isovector scalar belonging to the adjoint representation of the $SU(2)$ gauge group of symmetry. In Eq. (10):

$$
D_\mu \Phi^a = \partial_\mu \Phi^a + g_2 \epsilon^{abc} A_\mu^b \Phi^c
$$

(11)

is a covariant derivative, and

$$
F_{\mu\nu}^a = \partial_\mu A_\nu^a - \partial_\nu A_\mu^a + g_2 \epsilon^{abc} A_\mu^b A_\nu^c
$$

(12)

is a curvature of the gauge field $A_\mu^a$ of the $SU(2)$ Yang-Mills theory. The coupling constant $g_2$ is a “bare” coupling constant of the $SU(2)$ weak interaction.

The GW action (10) is a special case of the $f(R)$-gravity when:

$$
f(R) = R|\Phi|^2.
$$

(13)

In a general case of the $f(R)$-gravity, the action can be presented by the following expression:

$$
S = \frac{1}{2\kappa} \int d^4 x \sqrt{-g} f(R) + S_{grav} + S_{gauge} + S_m,
$$

(14)

where $S_m$ corresponds to the part of the action associated with matter fields (fermions and Higgs fields).

Using the metric formalism, we obtain the following field equations:

$$
F(R) R_{\mu\nu} - \frac{1}{2} f(R) g_{\mu\nu} - \nabla_\mu \nabla_\nu F(R) + g_{\mu\nu} \Box F(R) = \kappa T^m_{\mu\nu},
$$

(15)

where:

$$
F(R) \equiv \frac{df(r)}{dr},
$$

(16)

$\kappa = 8\pi G_N$, $G_N$ is the gravitational constant, and $T^m_{\mu\nu}$ is the energy-momentum tensor derived from the matter action $S_m$.

Here we must emphasize a very important point of the present theory: the “$E_8$ Theory” (TOE), and consequently the Graviweak unification, contain the triplet $SU(2)$ Higgs field $\Phi^a$, in contrast to the SM, which considers doublet $SU(2)$ Higgs field $H^a$. 

7
Just this field $\Phi^a$ is responsible for the formation of the gravitational black-hole-hedgehogs inside a Bubble of the Universe with a de-Sitter spacetime inside, having hedgehogs as vacuum topological defects. The field $\Phi^a$ constructs the black-hole-hedgehog’s solutions in the GWU $f(R)$-gravity.

Following to the idea by A.Vilenkin [17], it is possible to consider the Universe at first stage of its existing as a bubble with a de-Sitter spacetime inside, having global monopoles as vacuum topological defects.

Hedgehogs are extended objects, which are global monopoles. They have repulsive forces of interaction, which lead to the inflation of the universal bubble. Such a bubble has a vacuum with a Planck scale VEV:

$$v_2 \sim 10^{18} \text{ GeV}.$$  

This vacuum decays very quickly, and by this reason is called the “false vacuum”.

A global monopole is described by the part $L_h$ of the Lagrangian $L_{(GW)}$, which contains the $SU(2)$-triplet Higgs field $\Phi^a$, VEV of the second vacuum $v_2 = v$ and cosmological constant $\Lambda = \Lambda_E$:

$$L_h = -\frac{R}{16} |\Phi|^2 + \frac{3g_2^2}{32} |\Phi|^4 - \frac{1}{2} \partial_\mu \Phi^a \partial^\mu \Phi^a + \Lambda_E$$

$$= -\frac{1}{2} \partial_\mu \Phi^a \partial^\mu \Phi^a + \frac{\lambda}{4} (|\Phi|^2 - v^2)^2 + \frac{\Lambda_E}{\kappa} - \frac{\lambda}{4} v^4 = -\frac{1}{2} \partial_\mu \Phi^a \partial^\mu \Phi^a + \frac{\lambda}{4} (|\Phi|^2 - v^2)^2. \quad (17)$$

Here we have: $\lambda = \frac{3g_2^2}{8}$.

The field configurations describing a monopole-hedgehog are:

$$\Phi^a = vw(r) \frac{x^a}{r},$$

$$A_\mu^a = a(r) \epsilon_{\mu ab} \frac{x^b}{r}, \quad (18)$$

where $x^a x^a = r^2$ with $(a = 1, 2, 3)$, $w(r)$ and $a(r)$ are some structural functions. This solution is pointing radially. Here $\Phi^a$ is parallel to $\hat{r}$ – the unit vector in the radial, and we have a “hedgehog” solution of Refs. [18, 19]. The terminology “hedgehog” was first suggested by Alexander Polyakov [19].

In Ref. [20] by solving the gravitational field equations we estimated the black-hole-hedgehog’s mass $M_{BH}$, radius $R_{BH}$ and horizon radius $r_h$:

$$M_{BH} \approx 3.65 \times 10^{18} \text{ GeV}, \quad R_{BH} \sim 10^{-21} \text{ GeV}^{-1}, \quad \text{and} \quad r_h \approx 2.29R_h \text{ respectively.}$$

We obtained a “hedgehog” – global monopole, that has been “swallowed” by the black-hole with mass core $M_{BH} \sim 10^{18}$ GeV and radius $\delta \sim 10^{-21}$ GeV$^{-1}$.

### a. Hedgehogs as topological defects of the “false vacuum”

We see that at the first stage of the evolution, the Universe is a Bubble with a de-Sitter spacetime inside, and the Universe radius is close to the de-Sitter horizon radius:
\( R_{\text{UN}} \simeq R_{\text{de-Sitter horizon}} \simeq 10^{28} \text{ cm}. \)

The vacuum of this Bubble which is a “false vacuum” of the Universe, contains black-hole-hedgehogs as topological defects.

Now the vacuum reminds a boiling water with little bubbles of vapor.

A global monopole is a heavy object formed as a result of the gauge-symmetry breaking during the phase transition of the isoscalar triplet \( \Phi^a \) system. The black-holes-hedgehogs are similar to elementary particles, because a major part of their energy is concentrated in a small region near the monopole core.

4 Non-commutativity of the vacuum’s spacetime manifold

Assuming that the Planck scale false vacuum is described by a non-differentiable spacetime having lattice-like structure, where sites of the lattice are black-holes with “hedgehog” monopoles inside them, we describe this manifold by a non-commutative geometry with a minimal length \( l = \lambda_{\text{Pl}} \).

In the non-commutative geometry coordinates obey the following commutation relations:

\[
[d_{\mu}, d_{\nu}] \approx \beta^{\mu\nu}l^2 \neq 0,
\]

containing any minimal cut off \( l \).

Previously the following commutation relation was considered by H.S. Snyder \[21\]

\[
[x, p] = \hbar \left( 1 + \left( \frac{l}{\hbar} \right)^2 p^2 \right), \text{ etc.,}
\]

which shows that effectively 4-momentum \( p \) is replaced by

\[
p \rightarrow p \left( 1 + \left( \frac{l}{\hbar} \right)^2 p^2 \right)^{-1}.
\]

Applied to the Compton wavelength this gives the so called Snyder-Sidharth dispersion relation:

\[
[x_i, x_j] = \beta_{ij} \cdot l^2,
\]

which leads to a modification in the Dirac and also in the Klein-Gordon equation, as described in details in Ref. \[22\].

The modified Dirac equation is

\[
\{ \gamma^\circ p^\circ + \Gamma + \gamma^5 a l p^2 \} \psi = 0,
\]

which contains an extra term. The extra term gives a slight mass for the neutrino which is roughly of order \( \sim 10^{-8}m_e \), where \( m_e \) being the mass of the electron. Thus, the non-commutative geometry gives a Lagrangian describing the electron neutrino mass \( m_{\nu_e} \).
a. Sidharth’s prediction for DE

Using the non-commutative theory of the discrete space-time, B.G. Sidharth predicted in Ref. [7] (see also the book [23]) a tiny value of cosmological constant:

\[ \Lambda \approx 10^{-84} \text{GeV}^2 \]
as a result of the compensation of Zero Point Fields contributions by non-commutative contributions of the vacuum lattice.

5 The phase transition from the “false vacuum” to the “true vacuum”

At the early stage, the Universe is very hot, but then it begins to cool down. Black-holes-monopoles (as bubbles of the vapor in the boiling water) begin to disappear. The temperature dependent part of the energy density dies away. In that case, only the vacuum energy density can survive. Since this is a constant, the Universe expands exponentially, and an exponentially expanding Universe leads to the inflation. While the Universe is expanding exponentially, so it is cooling exponentially. This scenario was called supercooling of the Universe. When the temperature reached the critical value \( T_c \), the Higgs mechanism of the SM created a new condensate \( \phi_{\text{min}} \), and the vacuum became similar to superconductor, in which the topological defects are magnetic vortices.

The energy of black-holes is released as particles, and all these particles (quarks, leptons, vector bosons) acquired their masses \( m_i \) through the Yukawa coupling mechanism \( Y_f \bar{\psi}_f \psi_f \phi \). Therefore, they acquired the Compton wavelength, \( \lambda_i = \hbar/m_i c \). And according to the Sidharth’s theory, in the EW-vacuum we again have lattice-like structures formed by bosons and fermions, and the lattice parameters “\( l_i \)” are equal to the Compton wavelengths: \( l_i = \lambda_i = \hbar/m_i c \).

At some finite cosmic temperature which is the critical temperature \( T_c \approx 10^{15} K \), a system exhibits a spontaneous symmetry breaking, and we observe a phase transition from the bubble with the false vacuum to the bubble with the true vacuum.

Hedgehogs confined, and universal Bubble is transformed into the bubble having a spacetime with FLRW-metric (Friedmann-Lematre-Robertson-Walker metric), and vacuum acquires new topological defects. These new topological defects belong to the \( U(1)_{(el-mag)} \) group. They are:

1. magnetic vortices—“strings” by Abrikosov-Nielsen-Olesen [24,25], and
2. b. Sidharth’s Compton wave topological objects [26,27].

After the phase transition, the Universe begins its evolution toward the low energy Electroweak (EW) phase. Here the Universe undergoes the inflation, which leads to the phase having the VEV:

\[ v_1 \approx 246 \text{ GeV} \]

This is a “true” vacuum, in which we live.
6 Stability of the EW-vacuum

Here we must emphasize that due to the energy conservation law, the vacuum energy density before the phase transition (for \( T > T_c \)) is equal to the vacuum energy density after the phase transition (for \( T < T_c \)), therefore we have:

\[
\rho_{\text{vac}}(\text{at Planck scale}) = \rho_{\text{vac}}(\text{at EW scale}).
\] (25)

The analogous link between the Planck scale phase and EW phase was considered in Ref. [28]. It was shown that the vacuum energy density (DE) is described by the different contributions to the Planck and EW scale phases. This difference is a result of the phase transition. However, the vacuum energy densities (DE) of both vacua are equal, and we have a link between gravitation and electromagnetism via the Dark Energy. Here we see: since \( \rho_{\text{vac}} \) (at the Planck scale) is almost zero, then \( \rho_{\text{vac}} \) (at EW scale) also is almost zero, and we have a triumph of the Multiple Point Principle: we have the two degenerate vacua with almost zero vacuum energy density.

7 The prediction of a New Physics

In our model we investigated hedgehogs in the Wilson loops of the \( SU(2) \) Yang-Mills theory using the results of Ref. [29]. Considering their lattice result for the critical value of the temperature of hedgehog's confinement phase:

\[
\beta_{\text{crit}} \approx 2.5
\]

(here \( \beta = 1/g_2^2 \)) we predicted in our recent paper (see Ref. [20]) the production of the \( SU(2) \)-triplet Higgs bosons \( \Phi^a \) at LHC at energy scale

\[
\mu \sim 10 \text{ TeV}.
\]

At this energy we can expect to see at LHC the production of the triplet Higgs bosons with mass \( \gtrsim 5 \text{ TeV} \).

This provides a new physics in the SM.

8 Vacuum stability II

Taking into account that hedgehog fields \( \Phi^a \) produce a new physics at the scale \( \sim 10 \text{ TeV} \), we considered an additional confirmation of the vacuum stability and accuracy of the MPP.

As it was mentioned at the beginning of this paper, Froggatt and Nielsen predicted the top-quark and Higgs boson masses: \( M_t = 173 \pm 5 \text{ GeV} \) and \( M_H = 135 \pm 10 \text{ GeV} \), assuming the existence of two degenerate vacua in the SM (the first Electroweak vacuum and the second Planck scale one).
Their prediction for the mass of the SM $SU(2)$-doublet Higgs boson was improved in Refs. [30,31]. They gave calculations of the 2-loop and 3-loop radiative corrections to the effective Higgs potential $V_{\text{eff}}(H)$. The prediction of G. Degrassi et al. is: $M_H = 129 \pm 2$ GeV, which provides the possibility of the theoretical explanation of the value $M_H \simeq 125.7$ GeV observed at LHC.

From Degrassi et al. calculation, the effective Higgs field potential $V_{\text{eff}}(H)$ has a minimum, which slightly goes under zero, so that the present EW-vacuum is unstable for the experimental Higgs mass $M_H \simeq 125.7 \pm 0.24$ GeV.

The position of the second minimum depends on the SM parameters, especially on the top and Higgs masses, $M_t$ and $M_H$. This $V_{\text{eff}}(\text{min}2)$ can be higher or lower than the $V_{\text{eff}}(\text{min}1)$ showing a stable EW vacuum (in the first case), or metastable one (in the second case).

The red solid line of Fig. 3 by Degrassi et al. [30] shows the running of the Higgs self-interaction coupling constant $\lambda_{H,\text{eff}}(\mu)$ for $M_H \simeq 125.7$ GeV and $M_t \simeq 171.43$ GeV, which just corresponds to the Borderline vacuum stability, that is, to the stable EW-vacuum. In this case the minimum of the $V_{\text{eff}}(H)$ exists at the $\phi = \phi_0 \sim 10^{18}$ GeV, where according to MPP:

$$\lambda_{H,\text{eff}}(\phi_0) = \beta(\lambda_{H,\text{eff}}(\phi_0)) = 0.$$ 

Unfortunately, this case does not correspond to the current experimental values.

In Fig. 3 blue lines (thick and dashed) present the RG evolution of $\lambda_H(\mu)$ for current experimental values $M_H \simeq 125.7$ GeV and $M_t \simeq 173.34$ GeV. The thick blue line corresponds to the central value of $\alpha_s = 0.1184$ and dashed blue lines correspond to its errors equal to $\pm 0.0007$. We see that absolute stability of the Higgs potential is excluded by at 98% C.L. for $M_H < 126$ GeV.

Fig. 3 shows that asymptotically $\lambda_H(\mu)$ does not reach zero but approaches to the negative value:

$$\lambda_H \to -0.01 \pm 0.002,$$ 

indicating the metastability of the EW vacuum. We see that the current experimental values of $M_H$ and $M_t$ show the metastability of the present EW-vacuum of the Universe, and this result means that the MPP law is not exact.

Can the MPP be exact due to the corrections from hedgehogs’ contributions? We think that it is possible.

If we assume that in the region $E > E_{\text{threshold}}$ the effective Higgs potential contains not only the $SU(2)$-triplet field $\Phi^a$, but also the $SU(2)$-doublet Higgs field $H^a$ (where $a = 1, 2, 3$ and $\alpha = 1, 2$), then there exists an interaction (mixing term) between these two Higgs fields (see [20]). Of course, the effective Higgs self-interaction coupling constant $\lambda_{H,\text{eff}}(\mu)$ is a running function presenting loop corrections to the Higgs mass $M_H$, which arise from the Higgs bosons $H$ ($\Delta \lambda_H(\mu)$) and from hedgehogs $h$ ($\delta \lambda_H(\mu)$):

$$\lambda_{H,\text{eff}}(\mu) = \frac{G_F}{\sqrt{2}} M_H^2 + \Delta \lambda_H(\mu) + \delta \lambda_H(\mu),$$

(27)
where $G_F$ is the Fermi constant. The main contribution to the correction $\delta \lambda_H(\mu)$, described by a series in the mixing coupling constant $\lambda_{hH}$, is a term $\lambda_S$ given by the Feynman diagram of Fig. 4 containing the hedgehog $h$ in the loop:

$$\delta \lambda_H(\mu) = \lambda_S(\mu) + \ldots \tag{28}$$

Here the effective Higgs self-interaction coupling constant $\lambda_{H,eff}(\mu)$ is equal to $\lambda_{eff}(\mu)$ considered by Degrassi et al.

Our hedgehog is an extended object with a mass $M_h$ and radius $R_h$, therefore it is easy to estimate $\lambda_S$ at high energies $\mu > E_{\text{threshold}}$ by methods described in our paper \cite{32}. And we obtained:

$$\lambda_S(\mu) \approx \frac{1}{16\pi^2} \frac{\lambda_{hH}^2(\mu)}{(R_h M_h)^4}, \tag{29}$$

where $\lambda_{hH}(\mu)$ is a running coupling constant of the interaction of hedgehogs $h$ with the Higgs fields $H$. In Eq. (29) parameters $M_h = M_{BH}$ and $R_h = R_{BH}$ are the running mass and radius of the hedgehog, respectively.

As we have shown in \cite{20}, at high Planck scale energies they are:

$$M_h \sim 10^{18} \text{ GeV}, \quad R_h \sim 10^{-21} \text{ GeV}^{-1}, \tag{30}$$

and

$$R_h M_h \sim 10^{-3}. \tag{31}$$

As a result, we have:

$$\lambda_S \sim \frac{\lambda_{hH}^2}{16\pi^2} 10^{12}. \tag{32}$$

If hedgehog parameter $\lambda_{hH}$ is:

$$\lambda_{hH} \sim 10^{-6}, \tag{33}$$

then

$$\lambda_S \sim 0.01, \tag{34}$$

and the hedgehogs’ contribution transforms the metastable (blue) curve of Fig. 3 into the “Borderline vacuum stability MPP” (red) curve, and we have an exact stability of the EW-vacuum and the exact MPP, that is, two degenerate vacua in the Universe.

### 9 What comes beyond the Standard Model

Standard Model of particle physics is the most complete theory. In this paper we present our (non trivial) efforts to go beyond the Standard Model (SM). We try to overcome the following shortcomings of the SM (see also Ref. \cite{33}):

1. SM doesn’t include gravity, the fourth fundamental interaction.
2. SM doesn’t deliver the mass of neutrino:
   neutrino remains a massless particle in the SM.
3. SM can be changed by the existence of new yet undiscovered particles:
(a) by Supersymmetry which presents the supersymmetric counterparts of the SM particles;
(b) by the existence of more heavy multiplets of the SM group $G_{(SM)}$;
(c) by the existence of new bound states (NBS) in the framework of the SM, for example, by the existence $6t + 6\bar{t}$ NBS, suggested in Refs. [8–10].

4. There is no place for Dark Energy in the SM.
5. SM doesn’t describe Dark Matter.
6. It is also difficult in the SM to accommodate the observed predominance of matter over antimatter (matter/antimatter asymmetry).
7. Finally, the SM cannot explain the 19 arbitrary constants which are contained in theory.

Earlier, the problem of the SM near the Planck scale was considered in the review [34].

Going beyond the SM we are able to explain some points of the SM shortcomings:

1. In the present theory gravity is included by consideration of the Graviweak Unification model [15,16].
2. The mass of neutrino is given by a theory of non-commutativity, applied to the universal vacuum by B.G. Sidharth [22, 35], who considered the modified Dirac equation and predicted the mass of neutrino:
   \[ m_\nu \sim 10^{-8} m_e, \]
   where $m_e$ is an electron mass.
3. (a) The present theory predicts that Supersymmetry cannot be observed at LHC because of the very high scale of SUSY: $M_{SUSY} \sim 10^{18}$ GeV.
   (b) In Ref. [20], reviewed in this paper, we predicted the production of the $SU(2)$ triplet Higgs bosons at energy $\sim 10$ TeV, which can be detected by LHC.
   (c) We also suggested a theory, which predicts the existence of the new bound states (NBS) created by the interaction of the SM Higgs bosons with 6 top and 6 antitop quarks [8–10]. Such $6t + 6\bar{t}$ resonances can be observed by LHC at energy $\sim 1$ TeV [36].
4. Sidharth’s theory of non-commutativity applied to the universal vacuum spacetime manifold, gives an explanation of the DE [6,7]. And although Supergravity also explains the smallness of the cosmological constant (i.e. DE) (see Ref. [37]), the present theory suggests the Sidharth’s explanation of the origin of DE.
5. There are a lot of different theories published in the world literature which are devoted to the origin of Dark Matter, but it has not yet been definitely found.
   A very interesting possibility is to consider the DM as a matter of the Hidden World (HW), where HW is a Mirror World with broken mirror parity (see for example Refs. [38–41]).
6. The Hidden World can explain the observed predominance of matter over antimatter (matter/antimatter asymmetry) \[43,44\]. But here we also have difficulties, and Dark matter still continues to be a mysterious phenomenon in cosmology.

7. Finally, 19 parameters of the SM can be described by Multiple Point Model (see attempts in Refs. \[8,42\]).

8. And Hierarchy problem can be solved (see Refs. \[45,46\]).

In conclusion, we wish to emphasize that the present cosmological model shows new possibilities in cosmology.

10 Conclusions

In this paper:

1. We have shown that the evolution of the Universe from the Grand Unification \(E_8\) (TOE) gives a possibility to construct a quite new cosmological model.

2. This new cosmological model is based on the two discovery:
   1. cosmological constant (Dark Energy) is extremely small, and
   2. Nature shows a “new law of physics” which is named Multiple Point Principle (MPP). MPP was first suggested by D.L. Bennett and H.B. Nielsen, and postulates: \textit{There are several vacua in Nature with the same energy density, or cosmological constant, and all cosmological constants are zero, or approximately zero.}

3. We have considered that vacuum energy density \(\rho_{\text{vac}}\) of our Universe is the Dark Energy (DE), which is related with cosmological constant \(\Lambda\): \(\rho_{\text{DE}} = \rho_{\text{vac}} = (M_{\text{Pl}}^{\text{red}})^2 \Lambda\), that a tiny value of \(\rho_{\text{DE}}\) was first predicted by B.G. Sidharth in 1997 who showed that \(\Lambda \approx 10^{-84}\) GeV\(^2\). B.G. Sidharth predicted: that this very small cosmological constant (and DE-density) provides an accelerating expansion of our Universe after the Big Bang.

4. We confirmed the existence of the two degenerate vacua in the SM: a. the first Electroweak vacuum at \(v_1 = 246\) GeV, which is a “true” vacuum, and b. the second “false” vacuum at the Planck scale with VEV \(v_2 \approx 10^{18}\) GeV.

5. We have shown that assuming the existence of the two degenerate vacua in the SM, Froggatt and Nielsen predicted the top-quark and Higgs boson masses: \(M_t = 173 \pm 5\) GeV and \(M_H = 135 \pm 10\) GeV. Their prediction for the top quark mass \(M_t\) was confirmed by SLAC with great accuracy. But the LHC result for the discovered Higgs boson: \(M_H \approx 125.7\) GeV came in 2012.

6. The Froggatt-Nielsen prediction of the mass of the SM \(SU(2)\)-doublet Higgs boson was improved by calculations of the 2-loop and 3-loop radiative corrections to the effective Higgs potential \(V_{\text{eff}}(H)\). Their prediction: \(M_H = 129 \pm 2\) GeV provided the theoretical explanation of the value \(M_H \approx 125.7\) GeV observed at LHC.
7. We described the evolution of Bubbles of the Universe. We have shown that it is possible to consider the Universe at first stage of its existing as a bubble with a de-Sitter spacetime inside, having hedgehogs as vacuum topological defects. The spacetime inside the bubble with “the true vacuum”, has the geometry of an open FLRW universe. The low-energy “true vacuum” is Electroweak (EW) vacuum, in which we live. This vacuum has topological defects of $U(1)_{(el-mag)}$ group: the Abrikosov-Nielsen-Olesen magnetic vortices (“ANO strings”) and Sidharth’s Compton wave objects.

8. We demonstrated that after the Big Bang Universe undergoes several phase transitions. The breaking of the $E_8$ group leads to the Graviweak Unification (GWU). We have shown that the GWU action is a special case of the $f(R)$-gravity, and contains not a Higgs doublet boson of the SM, but a triplet Higgs boson $\Phi^a$, which leads to the construction of the black-hole-hedgehog solutions.

9. We have obtained a solution for a black-hole in the region which contains a global monopole in the framework of the GWU $f(R)$-gravity. The gravitational field, isovector scalar $\Phi^a$ with $a = 1, 2, 3$, produced by a spherically symmetric configuration in the scalar field theory, is pointing radially: $\Phi^a$ is parallel to $\hat{r}$ – the unit vector in the radial direction. And in the GWU approach, we obtained a “hedgehog” solution (in Alexander Polyakov’s terminology). We also showed that this black-hole-hedgehog solution corresponds to a global monopole that has been “swallowed” by a black-hole.

10. We have shown, that hedgehogs having magnetic repulsive forces of interaction lead to the inflation of the universal bubble. Such a bubble has a vacuum with a Planck scale VEV: $v_2 \sim 10^{18}$ GeV. This vacuum decays very quickly, and by this reason is called “false vacuum”.

11. We described a cooling Universe which had a new phase transition, transforming the “false” vacuum to the “true” vacuum. Hedgehogs confined, and the universal bubble is transformed into the bubble having spacetime with FLRW-metric and new vacuum topological defects of $U(1)_{(el-mag)}$ group: magnetic vortices (“strings”) by Abrikosov-Nielsen-Olesen, and Sidharth’s Compton wave objects (pointlike defects). These topological defects are responsible for an almost zero cosmological constant.

12. We have emphasized that, due to the energy conservation law, the vacuum energy density before the phase transition (for $T > T_c$) is equal to the vacuum energy density after the phase transition (for $T < T_c$). Since the vacuum energy densities (DE) of both vacua are equal, then there is a link between gravitation and electromagnetism via the Dark Energy.

13. Since $\rho_{vac}$ (at the Planck scale) is almost zero, then $\rho_{vac}$ (at EW scale) also is almost zero, and we confirmed a triumph of the Multiple Point Principle predicted the existence of two universal degenerate vacua with almost zero vacuum energy density.

14. We also suggested a theory, which predicts the existence of new bound states (NBS) created by the interaction of the SM Higgs bosons with 6 top and 6 antitop quarks. Such $6t + 6\bar{t}$ resonances can be observed by LHC at energy $\sim 1$ TeV.
15. We have investigated whether the EW-vacuum is stable, unstable, or metastable. It was shown, that hedgehogs, as bound states, can transform metastability of the EW-vacuum to its stability. Also we discussed the confirmation of the vacuum stability by the correction to the Higgs mass coming from the scalar bound state $S$ of $6\ell + \bar{6}\ell$.

16. We predicted the production of the $SU(2)$ triplet Higgs bosons at energy $\sim 10$ TeV which can be detected at LHC.

17. At the end of the paper, we discussed a question: What comes beyond the Standard Model? Our new cosmological model opens great possibilities and is predictable: it predicts the mass of neutrino, solves the hierarchy problem in the SM, predicts that supersymmetry cannot be detected at LHC, predicts that new particles - triplet Higgs bosons - can appear at LHC at energy $\sim 10$ TeV, predicts that bound states $6\ell + \bar{6}\ell$ can be detected at LHC at energies $\sim 1$ TeV.

Acknowledgments

LVL greatly thanks to the B.M. Birla Science Centre (Hyderabad, India) and personally Prof. B.G. Sidharth, for hospitality, collaboration and financial support. HBN wishes to thank the Niels Bohr Institute for the status of professor emeritus and corresponding support. CRD is thankful to Prof. D.I. Kazakov for support.

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Fig. 1: It is shown the existence of the second (non-standard) minimum of the effective Higgs potential in the pure SM at the Planck scale.
Fig. 2: Elementary particle states assigned to $E_8$ roots corresponding to their spin, electroweak, and strong charges according to $E_8$ Theory.
Fig. 3: RG evolution of $\lambda$.

Fig. 4: Hedgehog $h$ in the loop.