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Cosmological model with black-holes-hedgehogs and two degenerate vacua of the Universe

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Abstract. We suggest a cosmological model of the Universe based on the two discoveries: (1) cosmological constant is very small, and (2) the Universe has two degenerate vacua, "false" and "true" ones. After the Big Bang, the Universe is presented by a Bubble with the de-Sitter spacetime metric inside, having a "false vacuum" with the VEV $\sim 10^{18}$ GeV. We show that black-holes-hedgehogs (BHH) are topological defects of this vacuum. Considering the Gravi-Weak Unification, we obtained a solution of the BHH giving its mass $M_{BH} \sim 10^{18}$ GeV, radius $R_{BH} \sim 10^{-21}$ GeV^{-1} and horizon radius $r_h \approx 2.29 R_{BH}$. We demonstrated that the cooling of the Universe leads to a new phase transition transforming the first universal bubble into the new bubble with the FLRW spacetime metric inside. This bubble has "the true vacuum" with new topological defects of the $U(1)_{(el\text{-}mag)}$ group. The noncommutative geometry of the vacua spacetime explains an almost zero cosmological constants. In this model, we predict a stability of the EW-vacuum, and a new physics producing at LHC the triplet $SU(2)$ Higgs bosons at energies $E \sim 10$ TeV. At the end of this paper, we discuss the problem what comes beyond the standard model.

Keywords: multiple point principle, degenerate vacua, gravi-weak unification

MSC numbers: 83E99

1. Introduction

In this letter, we present a new cosmological model which is based on the discovery of the very small cosmological constant (Dark Energy) [1–3] and on the existence of two almost degenerate vacua in the Universe [4, 5]. Vacuum energy density of our Universe is the Dark Energy (DE), which is related to cosmological constant Λ:

$$\rho_{DE} = \rho_{vac} = \left(M_{Pl}^{red}\right)^2 \Lambda. \tag{1}$$

Here $M_{Pl}^{red} \simeq 2.43 \times 10^{18}$ GeV is the reduced Planck mass. Recent cosmological measurements [6] give:

$$\rho_{DE} \simeq \left(2 \times 10^{-3}\ \text{eV}\right)^4, \tag{2}$$

$$\Lambda \simeq 10^{-84}\ \text{GeV}^2. \tag{3}$$

Such a tiny value of ρ_{DE} was first predicted by B.G. Sidharth in 1997 [1, 2], explaining an accelerating expansion of our Universe. In 2011 S. Perlmutter, B. Schmidt and A. Riess [3] were awarded by the Nobel Prize for the discovery of the accelerating expansion of the Universe by Hubble Space Telescope investigation of Type Ia super-novae.

Considering extremely small cosmological constant of our Universe, Bennett, Froggatt and Nielsen [4, 5] assumed only zero, or almost zero, cosmological constants for all vacua existing in the Universe and suggested the Multiple Point Principle (MPP). MPP postulates: *There are several vacua in Nature with the same energy density, or cosmological constant, and all cosmological constants are zero, or approximately zero.*

From experimental results, cosmological constants which corresponds to the minimum of the Higgs effective potential $V_{eff}(\phi_H)$ are not exactly equal to zero. Nevertheless, they are extremely small. By this reason, the authors of Refs. [4, 5] assumed to consider zero cosmological constants as a good approximation. If the effective potential has two degenerate minima, then according to the MPP, the following requirements are satisfied [4, 5]:

$$V_{eff}\left(\phi^2_{min1}\right) = V_{eff}\left(\phi^2_{min2}\right) = 0, \tag{4}$$

and

$$V'_{eff}\left(\phi^2_{min1}\right) = V'_{eff}\left(\phi^2_{min2}\right) = 0, \tag{5}$$

where

$$V'(\phi^2) = \frac{\partial V}{\partial \phi^2}. \tag{6}$$

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 [5]:

$$M_t = 173 \pm 5\ \text{GeV}; \quad M_H = 135 \pm 10\ \text{GeV}. \tag{7}$$

The prediction of Ref. [5] for the top quark mass M_t was confirmed by SLAC with great accuracy. The LHC result for the discovered Higgs boson: $M_H \approx 125.7$ GeV came in 2012. The prediction of the mass of the SM $SU(2)$-doublet Higgs boson given by Ref. [5] was improved in Refs. [7,8] by calculations of the 2-loop and 3-loop radiative corrections to the effective Higgs potential $V_{eff}(H)$. The prediction of Ref. [7]: $M_H = 129 \pm 2$ GeV provided the possibility of the theoretical explanation of the value $M_H \approx 125.7$ GeV observed at LHC.

2. Gravi-weak unification and bubbles of the Universe

After the Big Bang and Grand Unification phase, the Universe, according to A. Vilenkin's idea (see for example [9]) is a bubble with a de-Sitter space-time metric inside. The radius of such a bubble (radius of the Universe) is equal to the de-Sitter horizon radius:

$$R_{UN} \simeq R_{\textit{de-Sitter horizon}} \simeq 10^{28}\ \text{cm}. \tag{8}$$

Such a bubble has a vacuum with the Planck scale VEV: $v_2 \sim 10^{18}$ GeV. This vacuum decays very quickly, and for this reason, is called the "false vacuum".

If the vacuum of this bubble contains global monopoles as topological defects, then these monopoles lead to the inflation of the universal bubble, because they have magnetic repulsive forces of interaction.

In Refs. [10, 11] we have suggested the gravi-weak unification with a Clifford group of symmetry $G_{(GW)} = Spin(4,4)$ which is spontaneously broken into the following product:

$$G_{(GW)} \to SL(2,C)^{(grav)} \times SU(2)^{(weak)}. \tag{9}$$

Assuming that after the Big Bang there exists a Theory of Everything (TOE) rapidly broken down to the direct product of the following gauge groups:

$$\begin{aligned}
G_{(TOE)} &\to G_{(GW)} \times U(4) \to SL(2,C)^{(grav)} \times SU(2)^{(weak)} \times U(4) \\
&\to SL(2,C)^{(grav)} \times SU(2)^{(weak)} \times SU(4) \times U(1)_Y \\
&\to SL(2,C)^{(grav)} \times SU(2)^{(weak)} \times SU(3)_c \times U(1)_{(B-L)} \times U(1)_Y \\
&\to SL(2,C)^{(grav)} \times SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{(B-L)} \\
&\to SL(2,C)^{(grav)} \times G_{SM} \times U(1)_{(B-L)},
\end{aligned} \tag{10}$$

we obtain (below the see-saw scale $M_R \sim 10^9 \to 10^{14}$ GeV) the standard model (SM) group of symmetry:

$$G_{SM} = SU(3)_c \times SU(2)_L \times U(1)_Y. \tag{11}$$

The action $S_{(GW)}$ of the gravi-weak unification is given in Ref. [10] by the following expression:

$$\begin{aligned}
S_{(GW)} &= -\frac{1}{g_{uni}} \int_{\mathfrak{M}} d^4x \sqrt{-g} \left[\frac{1}{16} \left(R|\Phi|^2 - \frac{3}{2}|\Phi|^4 \right) \right. \\
&\quad \left. + \frac{1}{16} \left(aR_{\mu\nu}R^{\mu\nu} + bR^2 \right) + \frac{1}{2}\mathcal{D}_\mu \Phi^\dagger \mathcal{D}^\mu \Phi + \frac{1}{4} F^i_{\mu\nu} F^{i\,\mu\nu} \right],
\end{aligned} \tag{12}$$

where g_{uni} is a parameter of the gravi-weak 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 Φ^a (with $a = 1, 2, 3$) is an iso-vector scalar belonging to the adjoint representation of the $SU(2)$ gauge group of symmetry. In Eq. (12):

$$\mathcal{D}_\mu \Phi^a = \partial_\mu \Phi^a + g_2 \epsilon^{abc} A^b_\mu \Phi^c \tag{13}$$

is a covariant derivative, and

$$F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g_2 \epsilon^{abc} A^b_\mu A^c_\nu \tag{14}$$

is a curvature of the gauge field A^a_μ 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 (12) is a special case of the $f(R)$-gravity when:

$$f(R) = R|\Phi|^2. \tag{15}$$

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

$$S = \frac{1}{2\kappa}\int d^4x\sqrt{-g}\, f(R) + S_{grav} + S_{gauge} + S_m, \tag{16}$$

where S_m describes matter fields (fermions and Higgs fields).

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

$$F(R)R_{\mu\nu} - \frac{1}{2}f(R)g_{\mu\nu} - \nabla_\mu\nabla_\nu F(R) + g_{\mu\nu}\Box F(R) = \kappa T^m_{\mu\nu}, \tag{17}$$

where:

$$F(R) \equiv \frac{df(r)}{dr}, \tag{18}$$

$r = R$ is a distance, $\kappa = 8\pi G_N$, G_N is the gravitational constant, and T^m is the energy-momentum tensor derived from the matter action S_m.

2.1 Parameters of the gravi-weak unification model

Assuming that at the first stage of the evolution (before the inflation), the Universe had the de-Sitter space-time – maximally symmetric Lorentzian manifold with a constant and positive background scalar curvature R – we have obtained the following relations from the action (12):

① The vacuum expectation value v_2 – the VEV of "the false vacuum" – is given by the de-Sitter scalar curvature R:

$$v_2^2 = \frac{R}{3}. \tag{19}$$

② At the Planck scale the squared coupling constant of the weak interaction is:

$$g_2^2 = g_{uni}. \tag{20}$$

The replacement $\Phi^a/g_2 \to \Phi^a$ leads to the following GW-action:

$$S_{(GW)} = -\int_{\mathfrak{M}} d^4x\sqrt{-g}\left(\frac{R}{16}|\Phi|^2 - \frac{3g_2^2}{32}|\Phi|^4 + \frac{1}{2}\mathcal{D}_\mu\Phi^\dagger\mathcal{D}^\mu\Phi + \frac{1}{4g_2^2}F^i_{\mu\nu}F^{i\,\mu\nu} + \text{grav. terms}\right). \tag{21}$$

Now considering the VEV of the false vacuum as $v = v_2$, we have:

$$v^2 = \frac{R}{3g_2^2}. \tag{22}$$

The Einstein-Hilbert action of general relativity with the Einstein's cosmological constant Λ_E is given by the following expression:

$$S_{EH} = \int d^4x\sqrt{-g}L_{EH} = -\frac{1}{\kappa}\int d^4x\sqrt{-g}\left(\frac{R}{2} - \Lambda_E\right). \tag{23}$$

(3) The comparison of the Lagrangian L_{EH} with the Lagrangian given by Eq. (21) near the false vacuum v leads to the following relations for the Newton's gravitational constant G_N and reduced Planck mass:

$$\left(M_{Pl}^{red}\right)^2 = (8\pi G_N)^{-1} = \frac{1}{\kappa} = \frac{v^2}{8}. \tag{24}$$

(4) Then we have:

$$v = 2\sqrt{2}M_{Pl}^{red} \approx 6.28\times 10^{18}\ \text{GeV}, \tag{25}$$

and

$$\Lambda_E = \frac{3g_2^2}{4}v^2. \tag{26}$$

Using the well-known in literature renormalization group equation (RGE) for the $SU(2)$ running constant $\alpha_2^{-1}(\mu)$, where $\alpha_2 = g_2^2/4\pi$ and μ is the energy scale, we can use the extrapolation of this value to the Planck scale [12, 13] and obtain the following result:

$$\alpha_2\left(M_{Pl}\right) \sim \frac{1}{50}, \quad g_{uni} = g_2^2 = 4\pi\alpha_2\left(M_{Pl}\right) \approx 4\pi\times 0.02 \approx 0.25. \tag{27}$$

2.2 The solution for the gravitational black-holes-hedgehogs

A global monopole is described by the part L_h of the Lagrangian $L_{(GW)}$ given by the action (21):

$$\begin{aligned} L_h &= -\frac{R}{16}|\Phi|^2 + \frac{3g_2^2}{32}|\Phi|^4 - \frac{1}{2}\partial_\mu\Phi^a\partial^\mu\Phi^a + \Lambda_E \\ &= -\frac{1}{2}\partial_\mu\Phi^a\partial^\mu\Phi^a + \frac{\lambda}{4}\left(|\Phi|^2 - v^2\right)^2 + \frac{\Lambda_E}{\kappa} - \frac{\lambda}{4}v^4 \\ &= -\frac{1}{2}\partial_\mu\Phi^a\partial^\mu\Phi^a + \frac{\lambda}{4}\left(|\Phi|^2 - v^2\right)^2. \end{aligned} \tag{28}$$

Here we have used $v = v_2$,

$$\Lambda_E = \frac{3g_2^2}{4}v^2, \tag{29}$$

and

$$\lambda = \frac{3g_2^2}{8}. \tag{30}$$

Substituting in Eq. (30) the value $g_2^2 \approx 0.25$ given by Eq. (27), we obtain:

$$\lambda \approx \frac{3}{32}. \tag{31}$$

Eq. (26) gives:

$$\frac{\Lambda_E}{\kappa} = \frac{3g_2^2}{32}v^4 = \frac{\lambda}{4}v^4, \tag{32}$$

and in Eq. (28) we have the compensation of the Einstein's cosmological term. Then

$$L_h = -\frac{1}{2}\partial_\mu\Phi^a\partial^\mu\Phi^a + V(\Phi), \tag{33}$$

where the Higgs potential is:

$$V(\Phi) = \frac{\lambda}{4}\left(|\Phi|^2 - v^2\right)^2. \tag{34}$$

This potential has a minimum at $\langle|\Phi|\rangle_{min} = v$, in which it vanishes:

$$V\left(|\Phi|^2_{min}\right) = V'\left(|\Phi|^2_{min}\right) = 0, \tag{35}$$

in agreement with the MPP conditions (4) and (5).

The field configurations describing a monopole-hedgehog [14, 15] are:

$$\Phi^a = vw(r)\frac{x^a}{r}, \tag{36}$$

$$A^a_\mu = a(r)\epsilon_{\mu ab}\frac{x^b}{r}, \tag{37}$$

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 Φ^a is parallel to $\hat{r}$ – the unit vector in the radial direction, and we have a "hedgehog" solution of Refs. [14, 15].

The field equations for Φ^a in the flat metric reduces to a single equation for $w(r)$:

$$w'' + \frac{2}{r}w' - \frac{2}{r^2}w - \frac{w(w^2-1)}{\delta^2} = 0, \tag{38}$$

where δ is the core radius of the hedgehog. The function $w(r)$ grows linearly when $r < \delta$ and exponentially approaches unity as soon as $r > \delta$. Barriola and Vilenkin [9] took $w = 1$ outside the core which is an approximation to the exact solution. As a result, the functions $w(r)$ and $a(r)$ are constrained by the following conditions:

$$w(0) = 0, \quad \text{and} \quad w(r) \to 1 \quad \text{when} \quad r \to \infty, \tag{39}$$

$$a(0) = 0, \quad \text{and} \quad a(r) \sim -\frac{1}{r} \quad \text{when} \quad r \to \infty. \tag{40}$$

2.3 The metric around of the global monopole

The most general static metric around of the global monopole is a metric with spherical symmetry:

$$ds^2 = B(r)dt^2 - A(r)dr^2 - r^2\left(d\theta^2 + sin^2\theta\, d\varphi^2\right). \tag{41}$$

For this metric the Ricci tensor has the following non-vanishing components:

$$\begin{aligned}
R_{tt} &= -\frac{B''}{2A} + \frac{B'}{4A}\left(\frac{A'}{A} + \frac{B'}{B}\right) - \frac{1}{r}\frac{B'}{A}, \\
R_{rr} &= \frac{B''}{2B} + \frac{B'}{4B}\left(\frac{A'}{A} + \frac{B'}{B}\right) - \frac{1}{r}\frac{A'}{A}, \\
R_{\theta\theta} &= -1 + \frac{r}{2A}\left(-\frac{A'}{A} + \frac{B'}{B}\right) + \frac{1}{A}, \\
R_{\varphi\varphi} &= \sin^2\theta R_{\theta\theta}.
\end{aligned} \tag{42}$$

The energy-momentum tensor of the monopole is given by

$$\begin{aligned}
T_t^t &= v^2\frac{w'^2}{2A} + v^2\frac{w^2}{r^2} + \frac{1}{4}\lambda v^4\left(w^2 - 1\right)^2, \\
T_r^r &= -v^2\frac{w'^2}{2A} + v^2\frac{w^2}{r^2} + \frac{1}{4}\lambda v^4\left(w^2 - 1\right)^2, \\
T_\theta^\theta &= T_\varphi^\varphi = v^2\frac{w'^2}{2A} + \frac{1}{4}\lambda v^4\left(w^2 - 1\right)^2.
\end{aligned} \tag{43}$$

Here $\kappa = 1$. Considering the approximation used in Ref. [9], we obtain an approximate solution for a monopole-hedgehog taking $w = 1$ out the core of the hedgehog (see also Refs. [16–19]). In this case scalar curvature R is constant and Eq. (17) comes down to the Einstein's equation:

$$\frac{1}{A}\left(\frac{1}{r^2} - \frac{1}{r}\frac{A'}{A}\right) - \frac{1}{r^2} = \frac{1}{v^2}T_t^t, \tag{44}$$

$$\frac{1}{A}\left(\frac{1}{r^2} + \frac{1}{r}\frac{B'}{B}\right) - \frac{1}{r^2} = \frac{1}{v^2}T_r^r, \tag{45}$$

where the energy-momentum tensor is given by the following approximation:

$$T_t^t = T_r^r \approx \frac{v^2}{r^2}, \tag{46}$$

$$T_\theta^\theta = T_\varphi^\varphi = 0. \tag{47}$$

Taking into account Eq. (46), we obtain the following result by subtraction of Eqs. (44) and (45):

$$\frac{A'}{A} + \frac{B'}{B} = 0, \tag{48}$$

and then asymptotically (when $r \to \infty$) we have:

$$A \approx B^{-1}. \tag{49}$$

From Eq. (44) we obtain a general relation for the function $A(r)$:

$$A^{-1}(r) = 1 - \frac{1}{r}\int_0^r T_t^t\, r^2 dr. \tag{50}$$

In the limit $r \to \infty$ we obtain:

$$A(r) = 1 - \kappa v^2 - \frac{2G_N\, M}{r} + ..., \tag{51}$$

$$B(r) = \left(1 - \kappa v^2 - \frac{2G_N\, M}{r} + ...\right)^{-1}. \tag{52}$$

3. The mass, radius and horizon radius of the black-hole-hedgehog

Then Eq. (50) suggests the following equation for the hedgehog mass M:

$$M = 8\pi \int_0^\infty T_t^t\, r^2 dr, \tag{53}$$

or

$$M = 8\pi v^2 \int_0^\infty \left(w'^2 + \frac{w^2 - 1}{r^2} + \frac{\left(w^2 - 1\right)^2}{4\delta^2} \right) r^2 dr. \tag{54}$$

The function $w(r)$ was estimated in Ref. [19] at $r < \delta$:

$$w(r) \approx 1 - \exp\left(-\frac{r}{\delta}\right), \tag{55}$$

and we obtain an approximate value of the hedgehog mass:

$$M = -M_{BH} \approx -8\pi v^2 \delta. \tag{56}$$

There is a repulsive gravitational potential due to this negative mass. A freely moving particle near the core of the black-hole experiences an outward proper acceleration:

$$\ddot{r} = -\frac{G_N M}{r} = \frac{G_N M_{BH}}{r}. \tag{57}$$

We have obtained a global monopole with a huge mass (56), which has a property of the hedgehog. This is a black-hole solution, which corresponds to a global monopole-hedgehog that has been "swallowed" by a black-hole. Indeed, we have obtained the metric of Ref. [9]:

$$\begin{aligned} ds^2 \;\; = \;\; & \left(1 - \kappa v^2 + \frac{2G_N\, M_{BH}}{r}\right) dt^2 - \frac{dr^2}{1 - \kappa v^2 + \left(2G_N\, M_{BH}\right)/r} \\ & - r^2 \left(d\theta^2 + \sin^2\theta d\varphi^2\right). \end{aligned} \tag{58}$$

A black hole has a horizon. A horizon radius r_h can be calculated by solving the equation $A(r_h) = 0$ given by Eq. (51):

$$1 - \kappa v^2 + \frac{2G_N\, M_{BH}}{r_h} = 0, \tag{59}$$

and we have a solution:

$$r_h = \frac{2G_N\, M_{BH}}{\kappa v^2 - 1}. \tag{60}$$

According to Eq. (24), $\kappa v^2 = 8$, and we obtain the black-hole-hedgehog with a horizon radius r_h equal to:

$$r_h = \frac{2}{7} G_N\, M_{BH} = \frac{2}{7} \times \frac{\kappa}{8\pi} \times 8\pi v^2 \delta \approx 2.29\, \delta. \tag{61}$$

We see that the horizon radius r_h is larger than the hedgehog radius δ, and our concept that "a black hole contains the hedgehog" is justified.

The universal bubble with a "false vacuum" contains black-hole-hedgehogs as topological defects. Now the vacuum reminds a boiling water with little bubbles of vapour.

Assuming, for example, that hedgehogs form a hypercubic lattice with a lattice parameter $l = \lambda_{Pl}$ and with one monopole in the cell of a cubic lattice, we have the negative energy density of such a lattice equal to:

$$\rho_{lat} \simeq -M_{BH} M_{Pl}^3. \tag{62}$$

If this energy density of the hedgehogs lattice compensates the Einstein's vacuum energy (32), we have the following equation:

$$\frac{\lambda}{4} v^4 \approx M_{BH} M_{Pl}^3, \tag{63}$$

Using the estimation (25), we obtain:

$$\frac{3}{2} M_{Pl}^4 \approx M_{BH} M_{Pl}^3, \tag{64}$$

or

$$M_{BH} = \frac{3}{2} M_{Pl} \approx 3.65 \times 10^{18}\ \text{GeV}. \tag{65}$$

Therefore hedgehogs have a huge mass of order of the Planck mass. Eq. (56) predicts a radius δ of the hedgehog's core:

$$\delta \approx \frac{M_{BH}}{8\pi v^2} \approx \left(\frac{128\pi}{3} M_{Pl}\right)^{-1} \sim 10^{-21}\ \text{GeV}^{-1}. \tag{66}$$

We see that the black-hole-hedgehog, obtained in our model, is a very heavy object having the Planck scale mass and a very small radius. Nevertheless, these properties will be saved in a more correct model.

4 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 vapour 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 it 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 super-cooling of the Universe. When the temperature reaches the critical value T_c, the Higgs mechanism of the SM creates a new condensate ϕ_{min1} (here ϕ is the $SU(2)$ Higgs boson H), and the vacuum becomes similar to a 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, $\lambda_i = \hbar/m_ic$. At some finite cosmic temperature which is the critical temperature T_c, 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 the universal bubble is transformed into the bubble having a space-time with FLRW-metric (Friedmann-Lemaitre-Robertson-Walker metric). The vacuum of this bubble acquires new topological defects. These new topological defects belong to the $U(1)_{(el\text{-}mag)}$ group. They are: ⓐ magnetic vortices – "ANO strings" by Abrikosov-Nielsen-Olesen [20, 21], and ⓑ Sidharth's Compton wave topological objects [22, 23]. After the phase transition, the Universe begins its evolution toward the low energy electro-weak phase. Here the Universe undergoes the inflation, which leads to the phase having the VEV: $v_1 \approx 246$ GeV. This is a "true" vacuum, in which we live.

5. Non-commutativity of the vacuum's space-time manifold

A hedgehog is a heavy object formed as a result of the gauge-symmetry breaking during the phase transition of the iso-scalar triplet Φ^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. Assuming that the Planck scale false vacuum is described by a non-differentiable space-time 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 $l = \lambda_{Pl}$.

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

$$[dx^\mu, dx^\nu] \approx \beta^{\mu\nu} l^2 \neq 0, \tag{67}$$

containing any minimal cut off l. Previously the following commutation relation was considered by H.S. Snyder [24]

$$[x,p] = \hbar\left(1+\left(\frac{l}{\hbar}\right)^2 p^2\right), \text{ etc.,} \tag{68}$$

which shows that effectively 4-momentum p is replaced by

$$p \to p\left(1+\left(\frac{l}{\hbar}\right)^2 p^2\right)^{-1}. \tag{69}$$

Snyder-Sidharth dispersion relation:

$$[x_\imath, x_\jmath] = \beta_{\imath\jmath}\cdot l^2 \tag{70}$$

leads to a modification in the Dirac and Klein-Gordon equations (see Ref. [25]). The modified Dirac equation:

$$\left\{\gamma_\mu p_\mu + m + \gamma_5 \alpha l p^2\right\}\psi = 0, \tag{71}$$

contains an extra term which gives a slight mass m_{ν_e} for the electronic neutrino (having $m = 0$ in the SM), which is roughly of order $\sim 10^{-8} m_e$, where m_e is the mass of the electron. Thus, the non-commutative geometry leads to a Lagrangian describing the electronic neutrino mass $m_{\nu_e} \neq 0$.

Sidharth's prediction for DE: Using the non-commutative theory of the discrete space-time, B.G. Sidharth predicted in Ref. [2] (see also the book [34]) a tiny value of cosmological constant:

$$\Lambda \simeq 10^{-84}\ \mathrm{GeV}^2, \tag{72}$$

as a result of the compensation of Zero Point Fields contributions by non-commutative contributions of the vacuum lattice.

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: $l_i = \lambda_i = \hbar/m_i c$. Cosmological constant of the universal bubble having EW-vacuum with VEV $v_1 \approx 246$ GeV again is very small due to the non-commutative contributions.

6. Stability of the EW-vacuum

The energy conservation law tells us that 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:

$$\rho_{vac}(\text{at Planck scale}) = \rho_{vac}(\text{at EW scale}). \tag{73}$$

The analogous link between the Planck scale phase and EW phase was considered in Ref. [22]. It was shown that the vacuum energy density (DE) is described by different contributions to these 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. Eq. (73) shows: since ρ_{vac} (at the Planck scale) is almost zero, then ρ_{vac} (at EW scale) also is almost zero, and we have a triumph of the Multiple Point Principle, confirming that our Universe has two degenerate vacua with an almost zero vacuum energy density.

7. The prediction of a new physics

Using lattice results for hedgehogs in the Wilson loops of the $SU(2)$ Yang-Mills theory presented by Ref. [26], we considered the critical value of $\beta = 1/g_2^2 = \alpha_2^{-1}/4\pi$ in hedgehog's confinement phase. Ref. [26] gives:

$$\beta_{crit} \approx 2.5. \tag{74}$$

Using this result, we predicted in our recent paper Ref. [27, 28] the production of the $SU(2)$-triplet Higgs bosons Φ^a at LHC at energy scale ~ 10 TeV.

Indeed, from Eq. (74) we have:

$$\alpha_{2,crit}^{-1} \approx 31.4. \tag{75}$$

The renormalization group equation (RGE) for $\alpha_2^{-1}(\mu)$ (for example, see [29] and references there) is given by the following expression:

$$\alpha_2^{-1}(\mu) = \alpha_2{}^{-1}(M_t) + b\,t, \tag{76}$$

where $t = \ln(\mu/M_t)$, and $M_t \simeq 173.34$ GeV is the top quark mass.

Usually RGE is a function of x: $x = \log_{10}\mu$. Then

$$t = \ln\left(\frac{10^x}{M_t}\right) = x\ln 10 - \ln M_t \approx 2.3\,x - 5.16. \tag{77}$$

For $SU(2)$-gauge theory $b \approx 19/12\pi$ and $\alpha_2^{-1}(M_t) \approx 29.4 \pm 0.02$, and we obtain the following RGE equation [29]:

$$\alpha_2^{-1}(x) \approx 29.4 + 0.504(2.3\,x - 5.16). \tag{78}$$

Then we can calculate x_{crit} using the following result:

$$\alpha_{2,crit}^{-1} \approx 31.4 = 29.4 + 1.16\,x_{crit} - 2.6, \tag{79}$$

which gives:

$$x_{crit} \sim 4, \tag{80}$$

or

$$\mu_{crit} \sim 10^4 \text{ GeV}. \tag{81}$$

This result means that the hedgehog's confinement happens at energy of 10 TeV, which is a threshold energy of the production of a pair of the $SU(2)$-triplet Higgs bosons Φ^a:

$$E_{threshold} \sim 10^4 \text{ GeV} = 10 \text{ TeV}. \tag{82}$$

At this energy we can expect to see at LHC the production of the triplet Higgs bosons with mass $\gtrsim 5$ TeV. This provides a new physics in the SM.

8. What comes beyond the standard model

The standard model of particle physics is an almost complete theory. In Ref. [30] we presented our (non-trivial) efforts to go beyond the standard model (SM). We try to overcome the following shortcomings of the SM (see also Ref. [31]): The SM (1) doesn't include gravity; (2) doesn't solve hierarchy problem; (3) doesn't deliver the mass of neutrino (neutrino remains a massless particle in the SM); (4) can be changed by the existence of new yet undiscovered particles: (a) by super-symmetric 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. [32, 33]; (5) doesn't describe Dark Energy; (6) doesn't describe Dark Matter; (7) cannot accommodate the observed predominance of matter over antimatter (matter/antimatter asymmetry); (8) finally, cannot describe 19 arbitrary parameters which are contained in theory.

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 gravi-weak Unification model [10, 11]. (2) Hierarchy problem can be solved by MPP [32]. (3) The mass of neutrino is given by a theory of non-commutativity, applied to the universal vacuum by B.G. Sidharth [2, 25, 34]. (4) The present theory predicts that super-symmetry cannot be observed at LHC because of the very high SUSY breaking scale: $M_{SUSY} \sim 10^{18}$ GeV. (5) In Refs. [27, 28, 30] we predicted the production of the $SU(2)$ triplet Higgs bosons at energy ~ 10 TeV, which can be detected by LHC. (6) 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 [32, 33, 35]. Such $6t + 6\bar{t}$ resonances can be observed by LHC at energy ~ 1 TeV [35]. (7) Sidharth's theory of non-commutativity applied to the universal vacuum space-time manifold gives an explanation of the DE [2, 25, 34]. (8) There are a lot of different theories published in the world literature which are devoted to the origin of the 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. [36, 37]). (9) The Hidden World can explain the observed predominance of matter over antimatter (matter/antimatter asymmetry) [38,39]. (10) Finally, 19 parameters of the SM can be described by the Multiple Point Model (see attempts in Ref. [32]).

In conclusion, we want to emphasize that our cosmological model is predictable and opens new possibilities for the development of this theory.

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