Graviweak Unification in the Visible and Invisible Universe and Inflation from the Higgs Field False Vacuum

C.R. Das\textsuperscript{1} and L.V. Laperashvili \textsuperscript{2}\textsuperscript{†}

\textsuperscript{1} Centre for Theoretical Particle Physics (CFTP), University of Lisbon, Avenida Rovisco Pais, 1 1049-001 Lisbon, Portugal and Theoretical Physics Division, Physical Research Laboratory, Navrangpura, Ahmedabad - 380 009, India

\textsuperscript{2} The Institute of Theoretical and Experimental Physics, National Research Center “Kurchatov Institute”, Bolshaya Cheremushkinskaya, 25, 117218 Moscow, Russia

Abstract

In the present paper we develop the self-consistent Spin$(4,4)$-invariant model of the unification of gravity with weak $SU(2)$ interactions in the assumption of the existence of visible and invisible sectors of the Universe. It was shown that the consequences of the multiple point principle predicting two degenerate vacua in the Standard Model (SM) suggest a theory of Inflation, in which the inflaton field $\sigma$ starts trapped in a cold coherent state in the “false vacuum” of the Universe at the value of the Higgs field’s VEV $v \sim 10^{18}$ GeV (in the visible world). Then the inflations of the two Higgs doublet fields, visible $\phi$ and mirror $\phi'$, lead to the emergence of the SM vacua at the Electroweak scales with the Higgs boson VEVs $v_1 \approx 246$ GeV and $v'_1 = \zeta v_1$ (with $\zeta \sim 100$) in the visible and invisible worlds, respectively.

Keywords: unification, gravity, mirror world, inflation, cosmological constant, dark energy

PACS: 04.50.Kd, 98.80.Cq, 12.10.-g, 95.35.+d, 95.36.+x

\textsuperscript{*}crdas@cftp.ist.utl.pt, crdas@prl.res.in
\textsuperscript{†}laper@itep.ru
1 Introduction

In Ref. [1] a model of unification of gravity with the weak $SU(2)$ gauge and Higgs fields was constructed, in accordance with Ref. [2]. Previously gravi-weak and gravi-electro-weak unified models were suggested in Ref. [3–5].

In this investigation we imagine that at the early stage of the evolution of the Universe the GUT-group was broken down to the direct product of gauge groups of the internal symmetry $U(4)$ and Spin(4,4)-group of the Graviweak unification.

In the assumption that there exist visible and invisible (hidden) sectors of the Universe, we presented the hidden world as a Mirror World (MW) with a broken Mirror Parity (MP). In the present paper we give arguments that MW is not identical to the visible Ordinary World (OW). We started with an extended $g = \text{spin}(4,4)_L$-invariant Plebanski action in the visible Universe, and with $g = \text{spin}(4,4)_R$-invariant Plebanski action in the MW. Then we have shown that the Graviweak symmetry breaking leads to the following sub-algebras: $\tilde{g} = \mathfrak{sl}(2,C)^{(grav)}_L \oplus \mathfrak{su}(2)_L$ – in the ordinary world, and $\tilde{g}' = \mathfrak{sl}(2,C)^{(grav)}_R \oplus \mathfrak{su}(2)_R'$ – in the hidden world. These sub-algebras contain the self-dual left-handed gravity in the OW, and the anti-self-dual right-handed gravity in the MW. Finally, at low energies, we obtain a Standard Model (SM) group of symmetry and the Einstein-Hilbert’s gravity. In this approach we have developed a model of Inflation, in which the inflaton $\sigma$, being a scalar $SU(2)$-triplet field, decays into the two Higgs $SU(2)$ doublets of the SM: $\sigma \to \phi^\dagger \phi$, and then the interaction between the ordinary and mirror Higgs fields (induced by gravity) leads to the hybrid model of the Inflation.

In Section 2 we considered the Plebanski’s theory of gravity, in which fundamental fields are 2-forms, containing tetrads, spin connections and auxiliary fields. Then we have used an extension of the Plebanski’s formalism of the 4-dimensional gravitational theory, and in Section 3 we constructed the action of the Graviweak unification model, described by the overall unification parameter $g_{\text{uni}}$. Section 4 is devoted to the Multiple Point Model (MPM), which allows the existence of several minima of the Higgs effective potential with the same energy density (degenerate vacua). The MPM assumes the existence of the SM itself up to the scale $\sim 10^{18}$ GeV, and predicts that there exist two degenerate vacua into the SM: the first one – at the Electroweak (EW) scale (with the VEV $v_1 \simeq 246$ GeV), and the second one – at the Planck scale (with the VEV $v = v_2 \sim 10^{18}$ GeV).

In Section 5 we consider the existence in the Nature of the Mirror World (MW) with a broken Mirror Parity (MP): the Higgs VEVs of the visible and invisible worlds are not equal\[1\] $\langle \phi \rangle = v$, $\langle \phi' \rangle = v'$ and $v \neq v'$. The parameter characterizing the violation of the MP is $\zeta = v'/v \gg 1$. We have used the result $\zeta \simeq 100$. In Section 6 we suggest a hybrid model of Inflation provided with the visible Higgs field $\phi$ and mirror Higgs boson $\phi'$, which interact during Inflation via gravity. This interaction leads to the emergence of the SM vacua at the EW scales with the Higgs boson VEVs $v_1 \approx 246$ GeV and $v_1' = \zeta v_1$ (with $\zeta \sim 100$) in the visible and invisible worlds, respectively, while the original “false vacuum” existed at the Planck scale and had VEV $v = v_2 \sim 10^{18}$ GeV. Section 7 contains Conclusions.

2 Plebanski’s formulation of General Relativity

General Theory of Relativity (GTR) was formulated by Einstein as dynamics of the metrics $g_{\mu\nu}$. Later, Plebanski [6] and other authors (see for example [7,8]) presented GTR in the self-dual approach, in which fundamental variables are 1-forms of connections $A^{ij}$.
and tetrads $e^I$:

$$ A^{IJ} = A^{IJ}_\mu dx^\mu, \quad e^I = e^I_\mu dx^\mu. \tag{1} $$

Also 1-form $A = \frac{1}{2} A^{IJ} \gamma_{IJ}$ is used, in which generators $\gamma_{IJ}$ are products of generators of the Clifford algebra $Cl(1,3)$: $\gamma_{IJ} = \gamma_I \gamma_J$. Indices $I, J = 0, 1, 2, 3$ belong to the space-time with Minkowski’s metrics $\eta^{IJ} = \text{diag}(1, -1, -1, -1)$, which is considered as a flat space, tangential to the curved space with the metrics $g_{\mu\nu}$. In this case connection belongs to the local Lorentz group $SO(1,3)$, or to the spin group $Spin(1,3)$. In general case of unifications of gravity with the $SU(N)$ or $SO(N)$ gauge and Higgs fields (see [2]), the gauge algebra is $g = \text{spin}(p, q)$, and we have $I, J = 1, 2, \ldots, p+q$. In our model of unification of gravity with the weak $SU(2)$ interactions we consider a group of symmetry with the Lie algebra $\text{spin}(4, 4)$. In this model indices $I, J$ run over all $8 \times 8$ values: $I, J = 1, 2, \ldots, 7, 8$.

For the purpose of construction of the action for any unification theory, the following 2-forms are also considered:

$$ B^{IJ} = e^I \wedge e^J = \frac{1}{2} e^I_\mu e^J_\nu dx^\mu \wedge dx^\nu, \quad F^{IJ} = \frac{1}{2} F^{IJ}_\mu dx^\mu \wedge dx^\nu, $$

where $F^{IJ}_\mu = \partial_\mu A^{IJ} - \partial_\nu A^{IJ}_\mu + [A_\mu, A_\nu]^{IJ}$, which determines the Riemann-Cartan curvature: $R_{\kappa \lambda \mu \nu} = e^I_\kappa e^J_\lambda F^{IJ}_\mu$. Also 2-forms of $B$ and $F$ are considered:

$$ B = \frac{1}{2} B^{IJ} \gamma_{IJ}, \quad F = \frac{1}{2} F^{IJ} \gamma_{IJ}, \quad F = dA + \frac{1}{2} [A, A]. \tag{2} $$

The well-known in literature Plebanski’s $BF$-theory is submitted by the following gravitational action with nonzero cosmological constant $\Lambda$:

$$ I_{(GR)} = \frac{1}{\kappa^2} \int e^{JKL} \left( B^{IJ} \wedge F^{KL} + \frac{\Lambda}{4} B^{IJ} \wedge B^{KL} \right), \tag{3} $$

where $\kappa^2 = 8\pi G_N$, $G_N$ is the Newton’s gravitational constant, and $M_{Pl}^2 = 1/\sqrt{8\pi G_N}$.

Considering the dual tensors:

$$ F^{*\rho\sigma}_\mu = \frac{1}{2\sqrt{-g}} F^{\rho\sigma\mu}, \quad A^{*IJ} = \frac{1}{2} e^{JKL} A^{KL}, $$

we can determine self-dual (+) and anti-self-dual (-) components of the tensor $A^{IJ}$:

$$ A^{(\pm)IJ} = (\mathcal{P}^{\pm} A)^{IJ} = \frac{1}{2} (A^{IJ} \pm i A^{*IJ}). \tag{4} $$

Two projectors on the spaces of the so-called self- and anti-self-dual tensors

$$ \mathcal{P}^{\pm} = \frac{1}{2} \left( \delta^{IJ}_{KL} \pm i e^{IJ}_{KL} \right) $$

carry out the following homomorphism:

$$ \mathfrak{so}(1, 3) = \mathfrak{sl}(2, C)_R \oplus \mathfrak{sl}(2, C)_L. \tag{5} $$

As a result of Eq. (5), non-zero components of connections are only $A^{(\pm)i} = A^{(\pm)0i}$. Instead of (anti-)self-duality, the terms of left-handed (+) and right-handed (-) components are used.

Plebanski [6] and other authors [7,8] suggested to consider a gravitational action in the (visible) world as a left-handed $\mathfrak{sl}(2, C)_L^{(grav)}$, invariant action, which contains self-dual fields $F = F^{(+i)}$ and $\Sigma = \Sigma^{(+i)}$ (i=1,2,3):

$$ I_{(grav)}(\Sigma, A, \psi) = \frac{1}{\kappa^2} \int \left[ \Sigma^i \wedge F^i + (\Psi^{-1})_{ij} \Sigma^i \wedge \Sigma^j \right]. \tag{6} $$

3
Here $\Sigma' = 2B^0$, and $\Psi_{ij}$ are auxiliary fields, defining a gauge, which provides equivalence of Eq. (6) to the Einstein-Hilbert gravitational action:

$$I_{(EG)} = \frac{1}{\kappa^2} \int d^4x \left( \frac{R}{2} - \Lambda \right),$$

where $R$ is a scalar curvature, and $\Lambda$ is the Einstein cosmological constant.

### 3 Graviweak unification model

On a way of unification of the gravitational and weak interactions we considered an extended $g = \text{spin}(4,4)$-invariant Plebanski’s action:

$$I(A, B, \Phi) = \frac{1}{g_{\text{uni}}} \int_M \left\langle BF + B\Phi B + \frac{1}{3}B\Phi\Phi B \rightangle,$$

where $\langle \ldots \rangle$ means a wedge product, $g_{\text{uni}}$ is an unification parameter, and $\Phi_{IJKL}$ are auxiliary fields.

Having considered the equations of motion, obtained by means of the action (8), and having chosen a possible class of solutions, we can present the following action for the Graviweak unification (see details in Refs. [1, 2]):

$$I(A, \Phi) = \frac{1}{8g_{\text{uni}}} \int_M \langle \Phi FF \rangle,$$

where

$$\langle \Phi FF \rangle = \frac{d^4x}{32} \epsilon^{\mu\nu\sigma\tau} \Phi_{\mu\nu} \varphi_{IJ} \varphi_{KL} \varphi_{\sigma\tau},$$

and

$$\Phi_{\mu\nu} \varphi_{ab} \varphi_{cd} = (e^f_{\mu})(e^g_{\nu}) \epsilon_{kl}^i (e_i^l)(e_i^s) \delta_{cd}.$$  

A spontaneous symmetry breaking of our new action that produces the dynamics of gravity, weak $SU(2)$ gauge and Higgs fields, leads to the conservation of the following sub-algebra:

$$\tilde{g} = sl(2, C)_{L}^{(\text{grav})} \oplus su(2)_L.$$

Considering indices $a, b \in \{0, 1, 2, 3\}$ as corresponding to $I, J = 1, 2, 3, 4$, and indices $m, n$ as corresponding to indices $I, J = 5, 6, 7, 8$, we can present a spontaneous violation of the Graviweak unification symmetry in terms of the 2-forms:

$$A = \frac{1}{2} \omega + \frac{1}{4} E + A_W,$$

where $\omega = \omega_{ab}\gamma_{ab}$ is a gravitational spin-connection, which corresponds to the sub-algebra $sl(2, C)_{L}^{(\text{grav})}$. The connection $E = E_{\alpha\beta}^m\gamma_{\alpha\beta}$ corresponds to the non-diagonal components of the matrix $A_{IJ}$, described by the following way (see [2]): $E = e_\alpha \varphi = e_\alpha^\mu \gamma_\mu \gamma_{\alpha}d\psi$. The connection $A_W = \frac{1}{2} A_{mn}\gamma_{mn}$ gives: $A_W = \frac{1}{2} A_W^i \tau_i$, which corresponds to the sub-algebra $su(2)_L$ of the weak interaction. Here $\tau_i$ are the Pauli matrices with $i = 1, 2, 3$.

Assuming that we have only scalar field $\varphi^m = (\varphi, \varphi')$, we can consider a symmetry breakdown of the Gravi-Weak Unification, leading to the following OW-action [1]:

$$I_{(OW)}(e, \varphi, A, A_W) = \frac{3}{8g_{\text{uni}}} \int_M d^4x |e| \left( \frac{1}{16} |\varphi|^2 R - \frac{3}{32} |\varphi|^4 + \frac{1}{16} R_{ab} \rho_{cd} R_{ab} \rho_{cd} - \frac{1}{2} D_a \varphi^D \varphi - \frac{1}{4} F_{Wab} F_{W}^{ab} \right).$$

(12)
In Eq. (12) we have the Riemann scalar curvature \( R \); \(|\varphi|^2 = \varphi^\dagger \varphi\) is a squared scalar field, which from the beginning is not the Higgs field of the Standard Model; \( \mathcal{D} \varphi = d \varphi + [A_W, \varphi] \) is a covariant derivative of the scalar field, and \( F_W = d A_W + [A_W, A_W] \) is a curvature of the gauge field \( A_W \). The third member of the action (12) is a topological term in the Gauss-Bone theory of gravity (see for example [9,10]).

Lagrangian in the action (12) leads to the nonzero vacuum expectation value (VEV) of the scalar field: \( v = \langle \varphi \rangle = \varphi_0 \), which corresponds to a local minimum of the effective potential \( V_{\text{eff}}(\varphi) \) at \( v^2 = R_0/3 \), where \( R_0 > 0 \) is a constant de Sitter space-time background curvature [2].

According to (12), the Newton gravitational constant \( G_N \) is defined by the expression:

\[
8 \pi G_N = (M_{\text{Pl}}^{\text{red.}})^{-2} = \frac{64 g_{\text{uni}}}{3 v^2}, \tag{13}
\]
a bare cosmological constant is equal to

\[
\Lambda_0 = \frac{3}{4} v^2, \tag{14}
\]
and

\[
g_W^2 = 8 g_{\text{uni}}/3. \tag{15}
\]
The coupling constant \( g_W \) is a bare coupling constant of the weak interaction, which also coincides with a value of the constant \( g_2 = g_W \) at the Planck scale. Considering the running \( \alpha_2^{-1}(\mu) \), where \( \alpha_2 = g_2^2/4\pi \), we can carry out an extrapolation of this rate to the Planck scale, what leads to the following estimation [11,12]:

\[
\alpha_2(M_{\text{Pl}}) \sim 1/50, \tag{16}
\]
and then the overall GWU parameter is: \( g_{\text{uni}} \sim 0.1 \).

### 4 Multiple Point Model

The radiative corrections to the effective Higgs potential, considered in Refs. [13,14], bring to the emergence of the second minimum of the effective Higgs potential at the Planck scale. It was shown that in the 2-loop approximation of the effective Higgs potential, experimental values of all running coupling constants in the SM predict an existence of the second minimum of this potential located near the Planck scale, at the value \( v_2 = \varphi_{\text{min}2} \sim M_{\text{Pl}} \).

In general, a quantum field theory allows an existence of several minima of the effective potential, which is a function of a scalar field. If all vacua, corresponding to these minima, are degenerate, having zero cosmological constants, then we can speak about the existence of a multiple critical point (MCP) at the phase diagram of theory considered for the investigation (see Refs. [16,17]). In Ref. [16] Bennett and Nielsen suggested the Multiple Point Model (MPM) of the Universe, which contains simply the SM itself up to the scale \( \sim 10^{18} \) GeV. In Ref. [18] the MPM was applied (by the consideration of the two degenerate vacua in the SM) for the prediction of the top-quark and Higgs boson masses, which gave:

\[
M_t = 173 \pm 5 \text{ GeV}, \quad M_H = 135 \pm 9 \text{ GeV}. \tag{17}
\]

Later, the prediction for the mass of the Higgs boson was improved by the calculation of the two-loop radiative corrections to the effective Higgs potential [13,14]. The predictions: \( 125 \text{ GeV} \lesssim M_H \lesssim 143 \text{ GeV} \) in Ref. [13], and \( 129 \pm 2 \text{ GeV} \) in Ref. [14] – provided the possibility of the theoretical explanation of the value \( M_H \approx 126 \text{ GeV} \) observed at the LHC.
The authors of Ref. [15] have shown that the most interesting aspect of the measured value of $M_H$ is its near-criticality. They have thoroughly studied the condition of near-criticality in terms of the SM parameters at the high (Planck) scale. They extrapolated the SM parameters up to large energies with full 3-loop NNLO RGE precision. All these results mean that the radiative corrections to the Higgs effective potential lead to the value of the Higgs mass existing in the Nature.

Having substituted in Eq. (13) the values of $g_{uni} \simeq 0.1$ and $G_N = 1/8\pi(M_P^{red.})^2$, where $M_P^{red.} \approx 2.43 \cdot 10^{18}$ GeV, it is easy to obtain the VEV’s value $v$, which in this case is located near the Planck scale:

$$v = v_2 \approx 3.5 \cdot 10^{18} \text{GeV}.$$  \hspace{1cm} (18)

Such a result takes place, if the Universe at the early stage stayed in the “false vacuum”, in which the VEV of the Higgs field is huge: $v = v_2 \sim 10^{18}$ GeV. The exit from this state could be carried out only by means of the existence of the second scalar field. In the present paper we assume that the second scalar field, participating into the Inflation, is the mirror Higgs field, which arises from the interaction between the Higgs fields of the visible and invisible sectors of the Universe.

5 Mirror world with broken mirror parity

As it was noted at the beginning of this paper, we assumed the parallel existence in the Nature of the visible (OW) and invisible (MW) (mirror) worlds.

Such a hypothesis was suggested in Refs. [19,20].

The Mirror World (MW) is a mirror copy of the Ordinary World (OW) and contains the same particles and types of interactions as our visible world, but with the opposite chirality. Lee and Yang [19] were first to suggest such a duplication of the worlds, which restores the left-right symmetry of the Nature. The term “Mirror Matter” was introduced by Kobzarev, Okun and Pomeranchuk [20], who first suggested to consider MW as a hidden (invisible) sector of the Universe, which interacts with the ordinary (visible) world only via gravity, or another (presumably scalar) very weak interaction.

In the present paper we consider the hidden sector of the Universe as a Mirror World (MW) with broken Mirror Parity (MP) [21–25]. If the ordinary and mirror worlds are identical, then O- and M-particles should have the same cosmological densities. But this is immediately in conflict with recent astrophysical measurements [13,15]. Astrophysical and cosmological observations have revealed the existence of the Dark Matter (DM), which constitutes about 25% of the total energy density of the Universe. This is five times larger than all the visible matter, $\Omega_{DM} : \Omega_M \simeq 5 : 1$. Mirror particles have been suggested as candidates for the inferred dark matter in the Universe [21,29,30] (see also [31]). Therefore, the mirror parity (MP) is not conserved, and the OW and MW are not identical.

The group of symmetry $G_{SM}$ of the Standard Model was enlarged to $G_{SM} \times G'_{SM}$, where $G_{SM}$ stands for the observable SM, while $G'_{SM}$ is its mirror gauge counterpart. Here O(M)- particles are singlets of the group $G_{SM}$ ($G'_{SM}$).

It was assumed that the VEVs of the Higgs doublets $\phi$ and $\phi'$ are not equal:

$$\langle \phi \rangle = v, \hspace{0.5cm} \langle \phi' \rangle = v', \hspace{0.5cm} \text{and} \hspace{0.5cm} v \neq v'.$$

The parameter characterizing the violation of the MP is $\zeta = v'/v \gg 1$. Astrophysical estimates give: $\zeta > 30$, $\zeta \sim 100$ (see references in [32,33]).
The action \( I_{(MW)} \) in the mirror world is represented by the same integral (12), in which we have to make the replacement of all OW-fields by their mirror counterparts: \( e, \phi, A, A_W, R \to e', \phi', A', A_W', R' \). Then:

\[
G'_N = \zeta G_N, \quad \Lambda'_0 = \zeta^2 \Lambda_0, \quad M'_{Pl}^{red} = \zeta M_{Pl}^{red}.
\] (19)

However, \( g'_W = g_W \): it is supposed that at the early stage of evolution of the Universe, when the GUT takes place, mirror parity is unbroken, what gives \( g'_\text{uni} = g\text{uni} \).

6 Inflation model

It is well-known that the hidden (invisible) sector of the Universe interacts with the ordinary (visible) world only via gravity, or another very weak interaction (see for example [20,30,34]). In particular, the authors of Ref. [35] assumed, that along with gravitational interaction there also exists the interaction between the initial Higgs fields of both OW- and MW-worlds:

\[
V_{int} = \alpha_h (\varphi^\dagger \varphi)(\varphi'^\dagger \varphi'),
\] (20)

which begin to interact during the Inflation via gravitational interactions. The existence of the second Higgs field \( \varphi' \) could be the cause of the hybrid inflation (see the model of Hybrid inflation by A. Linde [36]), bringing the Universe out of the “false vacuum” with the VEV \( v_2 \sim 10^{18} \) GeV. This circumstance provided the subsequent transition to the vacuum with the Higgs VEV \( v_1 \) existing at the Electroweak (EW) scale. Here \( v_1 \approx 246 \) GeV is a vacuum, in which we live at the present time.

In Section 3 we obtained the GWU action given by Eq. (12). The gravitational part of the action is:

\[
I_{(OW)}(e, \varphi, A, A_W) = \frac{3}{64g\text{uni}} \int_M d^4x |e| \left( \frac{1}{2} |\varphi|^2 R - \frac{3}{4} |\varphi|^4 + \ldots \right).
\] (21)

Considering the background value \( R \simeq R_0 \), we can find a minimum of the potential:

\[
V_{eff}(\varphi) \sim -\frac{1}{2} |\varphi|^2 R_0 + \frac{3}{4} |\varphi|^4
\] (22)

at \( \varphi_0 = <\varphi> = v \). Here \( v^2 = R_0/3 \). Then according to (13), we obtain:

\[
I_{(OW)}(e, \varphi, A, A_W) = \int_M d^4x \sqrt{-g} \left( \frac{M_{Pl}^{red}}{v} \right)^2 \left( \frac{1}{2} |\varphi|^2 R - \frac{3}{4} |\varphi|^4 + \ldots \right).
\] (23)

In the action (23) the Lagrangian includes the non-minimal coupling with gravity [37,39].

We see that the field \( \varphi \) is not stuck at \( \varphi_0 \) anymore, but it can be represented as

\[
\varphi = \varphi_0 - \sigma = v - \sigma,
\] (24)

where the scalar field \( \sigma \) is an inflaton. Here we see that in the minimum, when \( \varphi = v \), the inflaton field is zero (\( \sigma = 0 \)) and then it increases with falling of the field \( \varphi \).

Considering the expansion of the Lagrangian around the background value \( R \simeq R_0 \) in powers of the small value \( \sigma/v \), and leaving only the first-power terms, we can present the gravitational part of the action as:

\[
I_{(\text{grav \ OW})} = \int_M d^4x \sqrt{-g} \left( \frac{M_{Pl}^{red}}{v} \right)^2 \left( \frac{1}{2} R_0 |1 - \sigma/v|^2 - \Lambda_0 |1 - \sigma/v|^4 + \ldots \right).
\] (25)
Here $\Lambda_0 = \frac{3}{4} v^2 = R_0/4$. Using the last relations, we obtain:

$$I_{(\text{grav OW})} = \int_M d^4x \sqrt{-g} \left( M_{\text{Pl}}^{\text{red}} \right)^2 \left( \Lambda_0 - \frac{m^2}{2} |\sigma|^2 + ... \right), \quad (26)$$

where $m^2 = 6$ and $m$ is the bare mass of the inflaton in units $M_{\text{Pl}}^{\text{red}} = 1$.

In the Einstein-Hilbert action the vacuum energy is:

$$\rho_{\text{vac}} = \left( M_{\text{Pl}}^{\text{red}} \right)^2 \Lambda. \quad (27)$$

In our case (26) the vacuum energy density is negative:

$$\rho_0 = - \left( M_{\text{Pl}}^{\text{red}} \right)^2 \Lambda_0. \quad (28)$$

However, assuming the existence of the discrete space-time of the Universe at the Planck scale and using the prediction of the non-commutativity suggested by B.G. Sidharth [40, 41], we obtain that the gravitational part of the GWU action has the vacuum energy density equal to zero or almost zero.

Indeed, the total cosmological constant and the total vacuum density of the Universe contain also the vacuum fluctuations of fermions and other SM boson fields:

$$\Lambda \equiv \Lambda_{\text{eff}} = \Lambda_{ZMD} - \Lambda_0 - \Lambda^{(NC)}_s + \Lambda^{(NC)}_f, \quad (29)$$

where $\Lambda_{ZMD}$ is zero modes degrees of freedom of all fields existing in the Universe, and $\Lambda^{(NC)}_s,f$ are boson and fermion contributions of the non-commutative geometry of the discrete spacetime at the Planck scale. If according to the theory by B.G. Sidharth [40, 41], we have:

$$\rho_{\text{vac}}^{(0)} = \left( M_{\text{Pl}}^{\text{red}} \right)^2 \Lambda^{(0)} = \left( M_{\text{Pl}}^{\text{red}} \right)^2 \left( \Lambda_{ZMD} - \Lambda_0 - \Lambda^{(NC)}_s \right) \approx 0, \quad (30)$$

then Eq. (26) contains the cosmological constant $\Lambda^{(0)} \approx 0$. In Eqs. (29) and (30) the bosonic (scalar) contribution of the non-commutativity is:

$$\rho^{(NC)}_{(\text{scalar})} = m^4 \quad \text{(in units : } \hbar = c = 1), \quad (31)$$

which is given by the mass $m_s$ of the primordial scalar field $\phi$. Then the discrete spacetime at the very small distances is a lattice (or has a lattice-like structure) with a parameter $a = \lambda_s = 1/m_s$. This is a scalar length:

$$a = \lambda_s \sim 10^{-19} \text{ GeV}^{-1},$$

which coincides with the Planck length: $\lambda_{\text{Pl}} = 1/M_{\text{Pl}} \approx 10^{-19} \text{ GeV}^{-1}$. The assumption:

$$\Lambda^{(0)} = \Lambda_{ZMD} - \Lambda_0 - \Lambda^{(NC)}_s \approx 0 \quad (32)$$

means that the Gravi-Weak Unification model contains the cosmological constant equal to zero or almost zero.

B.G. Sidharth gave in Ref. [42] the estimation:

$$\rho_{DE} = \left( M_{\text{Pl}}^{\text{red}} \right)^2 \Lambda^{(NC)}_f, \quad (33)$$

considering the non-commutative contribution of light primordial neutrinos as a dominant contribution to $\rho_{DE}$, which coincides with astrophysical measurements [43–45]:

$$\rho_{DE} \approx (2.3 \times 10^{-3} \text{ eV})^4. \quad (34)$$
Returning to the Inflation model, we rewrite the action (26) as:

\[ I_{(grav \ OW)} = - \int_M d^4 x \sqrt{-g} \left( \frac{M_{Pl}^{red}}{v} \right)^2 \left( \Lambda + \frac{m^2}{2} |\sigma|^2 + \ldots \right), \tag{35} \]

where the positive cosmological constant \( \Lambda \) is not zero, but is very small.

Taking into account the interaction of the ordinary and mirror scalar bosons \( \varphi \) and \( \varphi' \), given by equation analogous to Eq. [20] \[35\], we obtain:

\[
I_{(grav)} = \int_M d^4 x \sqrt{-g} \left[ \left( \frac{M_{Pl}^{red}}{v} \right)^2 \left( \frac{1}{2} |\varphi|^2 R - \frac{3}{4} r |\varphi|^4 - \alpha_h |\varphi|^2 |\varphi'|^2 + \ldots \right) + \ldots \right] + \int_M d^4 x \sqrt{-g} \left[ \left( \frac{M_{Pl}^{red}}{v'} \right)^2 \left( \frac{1}{2} |\varphi'|^2 R' - \frac{3}{4} r |\varphi'|^4 - \alpha_h |\varphi|^2 |\varphi'|^2 + \ldots \right) + \ldots \right] \tag{36}.
\]

Considering the Planck scale Higgs potential, corresponding to the action (36), we have:

\[
V(\varphi, \varphi') \approx \left( \frac{M_{Pl}^{red}}{v} \right)^2 \left( - \frac{1}{2} |\varphi|^2 R_0 + \frac{3}{4} |\varphi|^4 + \alpha_h |\varphi|^2 |\varphi'|^2 \right)
+ \left( \frac{M_{Pl}^{red}}{v'} \right)^2 \left( - \frac{1}{2} |\varphi'|^2 R_0' + \frac{3}{4} |\varphi'|^4 + \alpha_h |\varphi|^2 |\varphi'|^2 \right). \tag{37}
\]

According to (13), we have:

\[
\left( \frac{M_{Pl}^{red}}{v} \right)^2 = \left( \frac{M_{Pl}^{red}}{v'} \right)^2, \tag{38}
\]

and the local minima at \( \varphi_0 = v \) and \( \varphi'_0 = v' \) are given by the following conditions:

\[
\frac{\partial V(\varphi, \varphi')}{\partial |\varphi|^2} \bigg|_{|\varphi|=v} = \left( \frac{M_{Pl}^{red}}{v} \right)^2 \left( - \frac{1}{2} R_0 + \frac{3}{2} v^2 + 2 \alpha_h |\varphi'|^2 \right) = 0, \tag{39}
\]

\[
\frac{\partial V(\varphi, \varphi')}{\partial |\varphi'|^2} \bigg|_{|\varphi'|=v'} = \left( \frac{M_{Pl}^{red}}{v} \right)^2 \left( - \frac{1}{2} R_0' + \frac{3}{2} v'^2 + 2 \alpha_h |\varphi|^2 \right) = 0, \tag{40}
\]

which give the following solutions:

\[
v^2 \simeq \frac{R_0}{3} - \frac{4}{3} \alpha_h |\varphi'|^2, \tag{41}
\]

\[
v'^2 \simeq \frac{R_0'}{3} - \frac{4}{3} \alpha_h |\varphi|^2, \tag{42}
\]

and

\[
V(\varphi = v, \varphi' = v') = - \frac{1}{4} \left[ (M_{Pl}^{red})^2 R_0 + (M_{Pl}^{red})^2 R_0' \right] = -(M_{Pl}^{red})^2 \Lambda_0 - (M_{Pl}^{red})^2 \Lambda_0'. \tag{43}
\]

Finally, according to (13), we obtain:

\[
V(\varphi = v, \varphi' = v') = - (1 + \zeta^4)(M_{Pl}^{red})^2 \Lambda_0, \tag{44}
\]

what gives the negative vacuum energy density.
However, the cosmological constant is not given by Eq. (44). According to the ideas of non-commutativity given by B.G. Sidharth in Refs. [40–42], it must be replaced by the cosmological constant Λ, which is related with the potential $V(\varphi = v, \varphi' = \nu')$ and with the Dark Energy density (34) by the following way:

$$V(\varphi = v, \varphi' = \nu') = (M_{Pl}^\text{red})^2 \Lambda = \rho_{DE},$$  \hspace{1cm} (45)

where

$$\Lambda = \Lambda_{eff} + \Lambda'_{eff},$$

$\Lambda_{eff}$ is given by Eq. (29), and $\Lambda'_{eff}$ is its mirror counterpart.

Then using the notation:

$$\varphi = v - \sigma  \quad \text{and} \quad \varphi' = \nu' - \sigma',$$

and neglecting the terms containing $\alpha_h$ as very small, it is not difficult to see that the potential near the Planck scale is:

$$V(\varphi, \varphi') = (M_{Pl}^\text{red})^2 (\Lambda + \frac{m^2}{2}|\sigma|^2 + \frac{m'^2}{2}|\sigma'|^2 + ...),$$  \hspace{1cm} (47)

where $m^2 \simeq 6$ and $m'^2 \simeq 6\zeta^2$ (compare with (34)).

The local minimum of the potential (17) at $\varphi_0 = v$, when $\sigma = 0$, and $\varphi'_0 \neq \nu'$ ($\sigma' \neq 0$) gives:

$$V(v, \varphi') = (M_{Pl}^\text{red})^2 (\Lambda + \frac{m'^2}{2}|\sigma'|^2 + ...).$$  \hspace{1cm} (48)

The last equation (48) shows that the potential $V(v)$ grows with growth of $\sigma'$, i.e. with falling of the field $\varphi'$. It means that a barrier of potential grows and at some value $\sigma' = |\sigma'|_{in}$ potential begins its inflationary falling. Here it is necessary to comment that the position of the minimum also is displaced towards smaller $\varphi$ (bigger $\sigma$), according to the formula (41).

Our next step is an assumption that during the inflation $\sigma$ decays into the two Higgs doublets of the SM:

$$\sigma \rightarrow \phi^b + \phi.$$  \hspace{1cm} (49)

As a result, we have:

$$\sigma = a_d|\phi|^2,$$  \hspace{1cm} (50)

where $\phi$ is the Higgs doublet field of the Standard Model. The Higgs field $\phi$ also interacts directly with field $\phi'$, according to the interaction (20) given by Ref. [35]. It has a time evolution and modifies the shape of the barrier so that at some value $\phi'_E$ can roll down the field $\varphi$. This possibility, which we consider in our paper, is given by the so-called Hybrid Inflation scenarios [36]. Here we assume that the field $\phi$ begins the inflation at the value $\phi|_{in} \simeq H_0$.

Using the relations given by GWU, we obtain near the local “false vacuum” the following gravitational potential:

$$V(\phi, \phi') \simeq \Lambda + \frac{\lambda}{4}|\phi|^4 + \frac{\lambda'}{4}|\phi'|^4 + \frac{a_h}{4}|\phi|^2|\phi'|^2,$$  \hspace{1cm} (51)

where $\lambda = 12a_d$ and $\lambda' = 12(a'_d)^2$ are self-couplings of the Higgs doublet fields $\phi$ and $\phi'$, respectively.

Returning to the problem of the Inflation, we see that the action of the GWU theory has to be written near the Planck scale as:

$$I_{grav} \simeq - \int_M d^4x \sqrt{-g} \left( M_{Pl}^\text{red} \right)^2 \left( \Lambda + \frac{\lambda}{4}|\phi|^4 + \frac{\lambda'}{4}|\phi'|^4 + \frac{a_h}{4}|\phi|^2|\phi'|^2 + ... \right),$$  \hspace{1cm} (52)
where the cosmological constant $\Lambda$ is almost zero (has an extremely tiny value).

The next step is to see the evolution of the Inflation in our model, based on the GWU with two Higgs fields $\phi$ and mirror $\phi'$. In the present investigation we considered only the result of such an Inflation, which corresponds to the assumption of the MPP, that cosmological constant is zero (or almost zero) at both vacua: at the "first vacuum" with VEV $v_1 = 246$ GeV and at the "second vacuum" with VEV $v = v_2 \sim 10^{18}$ GeV. If so, we have the following conditions of the MPP (see section 4):

$$V_{\text{eff}}(\phi_{\text{min}1}) = V_{\text{eff}}(\phi_{\text{min}2}) = 0,$$

$$\frac{\partial V_{\text{eff}}}{\partial |\phi|^2} \bigg|_{\phi=\phi_{\text{min}1}} = \frac{\partial V_{\text{eff}}}{\partial |\phi|^2} \bigg|_{\phi=\phi_{\text{min}2}} = 0.$$  

(53) (54)

Considering the total Universe as two worlds, ordinary OW and mirror MW, we present the following expression for the low energy total effective Higgs potential (which is far from the Planck scale):

$$V_{\text{eff}} = -\frac{\mu^2}{2} |\phi|^2 + \frac{1}{4} \lambda(\phi)|\phi|^4 - \frac{\mu'^2}{2} |\phi'|^2 + \frac{1}{4} \lambda'(\phi')|\phi'|^4 + \frac{1}{4} \alpha_h(\phi, \phi')|\phi|^2|\phi'|^2,$$  

(55)

where $\alpha(\phi, \phi')$ is a coupling constant of the interaction of the ordinary Higgs field $\phi$ with mirror Higgs field $\phi'$.

According to the MPP, at the critical point of the phase diagram of our theory, corresponding to the "second vacuum", we have:

$$\mu = \mu' = 0, \quad \lambda(\phi_0) \simeq 0, \quad \lambda'(\phi'_0) \simeq 0,$$

(56)

and then

$$\alpha_h(\phi_0, \phi'_0) \simeq 0, \quad \text{if} \quad V_{\text{eff}}^{\text{crit}}(v_2) \simeq 0.$$  

(57)

At the critical point, corresponding to the first EW vacuum $v_1 = 246$ GeV, we also have $V_{\text{eff}}^{\text{crit}}(v_1) \simeq 0$, according to the MPP prediction of the existence of the almost degenerate vacua in the Universe.

Then we can present the full scalar Higgs potential by the following expression:

$$V_{\text{eff}}(\phi, \phi') = \frac{1}{4} \left( \lambda(|\phi|^2 - v_1^2)^2 + \lambda'(|\phi'|^2 - v_1'^2)^2 + \alpha_h(\phi, \phi')(|\phi|^2 - v_1^2)(|\phi'|^2 - v_1'^2) \right),$$  

(58)

where we have shifted the interaction term:

$$V_{\text{int}} = \frac{1}{4} \alpha_h(\phi, \phi')|\phi|^2|\phi'|^2,$$  

(59)

in such a way that the interaction term vanishes, when $\phi' = \phi'_0 = v_1'$, recovering the usual Standard Model.

At the end of the Inflation we have: $\phi' = \phi'_E$, and the first vacuum value of $V_{\text{eff}}$ is given by:

$$V_{\text{eff}}(v_1, \phi'_E) = \frac{1}{4} \left( \lambda'(|\phi'_E|^2 - v_1'^2)^2 + \alpha_h(v_1, \phi'_E)(|\phi'_E|^2 - v_1'^2)v_1^2 \right) = 0,$$  

(60)

and

$$\frac{\partial V_{\text{eff}}}{\partial |\phi|^2} \bigg|_{\phi = v_1, \phi' = \phi'_E} = 0.$$  

(61)

This means that the end of the Inflation occurs at the value:

$$\phi'_E = v'_1 = \zeta v_1,$$  

(62)
which coincides with the VEV $< \phi' >$ of the field $\phi'$ at the first vacuum in the mirror world MW. Thus,

$$V_{eff}(\phi, \phi' E) = \frac{1}{4} \lambda (|\phi|^2 - v_1^2)^2,$$

which means the Standard Model with the first vacuum, having the VEV $v_1 \approx 246$ GeV.

7 Conclusions

In the present paper we constructed a model of unification of gravity with the weak $SU(2)$ gauge and Higgs fields. Imagining that at the early stage of the evolution the Universe was described by a GUT-group, we assumed that this Grand Unification group of symmetry was quickly broken down to the direct product of the gauge groups of internal symmetry and Spin(4,4)-group of the Graviweak unification.

Also we assumed the existence of visible and invisible (hidden) sectors of the Universe. We have given arguments that modern astrophysical and cosmological measurements lead to a model of the Mirror World with a broken Mirror Parity (MP), in which the Higgs VEVs of the visible and invisible worlds are not equal: $< \phi > = v, \quad < \phi' > = v'$ and $v \neq v'$. We estimated a parameter characterizing the violation of the MP: $\zeta = v'/v \gg 1$. We have used the result: $\zeta \sim 100$ obtained by Z. Berezhiani and his collaborators. In this model, we showed that the action for gravitational and $SU(2)$ Yang–Mills and Higgs fields, constructed in the ordinary world (OW), has a modified duplication for the hidden (mirror) sector of the Universe (MW).

Considering the Graviweak symmetry breaking, we have obtained the following sub-algebras: $\tilde{g} = su(2)_{L}^{(grav)} \oplus su(2)_{L}$ – in the ordinary world, and $\tilde{g}' = su(2)_{R}^{(grav)} \oplus su(2)_{R}'$ – in the hidden world. These sub-algebras contain the self-dual left-handed gravity in the OW, and the anti-self-dual right-handed gravity in the MW. We assumed, that finally at low energies, we have a Standard Model and the Einstein-Hilbert’s gravity.

We reviewed the Multiple Point Model (MPM) by D.L. Bennett and H.B.Nielsen, who assumed the existence of several minima of the Higgs effective potential with the same energy density (degenerate vacua of the SM). In the assumption of zero cosmological constants, MPM postulates that all the vacua, which might exist in the Nature (as minima of the effective potential), should have zero, or approximately zero, cosmological constant. The prediction that there exist two vacua into the SM: the first one – at the Electroweak scale ($v_1 \approx 246$ GeV), and the second one – at the Planck scale ($v_2 \sim 10^{18}$ GeV), was confirmed by calculations in the 2-loop approximation of the Higgs effective potential. The prediction of the top-quark and Higgs masses was given in the assumption that there exist two vacua into the SM.

In the above-mentioned theory we have developed a model of Inflation. According to this model, a singlet field $\sigma$, being an inflaton, starts trapped from the “false vacuum” of the Universe at the value of the Higgs field’s VEV $v = v_2 \sim 10^{18}$ GeV. Then during the Inflation $\sigma$ decays into the two Higgs doublets of the SM: $\sigma \rightarrow \phi' \phi$. The interaction between the ordinary and mirror Higgs fields $\phi$ and $\phi'$, induced by gravity, generates a hybrid model of the Inflation in the Universe. Such an interaction leads to the emergence of the SM vacua at the Electroweak scales: with the Higgs boson VEVs $v_1 \approx 246$ GeV – in the OW, and $v_1' = \zeta v_1$ – in the MW.

8 Acknowledgments

L.V. Laperashvili greatly thanks the Niels Bohr Institute (Copenhagen, Denmark) and Prof. H.B. Nielsen for hospitality, collaboration and financial support. L.V.L. also deeply
thanks the Department of Physics and University of Helsinki for hospitality and financial support, and Prof. M. Chaichian and Dr A. Tureanu for fruitful discussions and advises.

C.R. Das acknowledges a scholarship from the Fundação para a Ciência e a Tecnologia (FCT, Portugal) (ref. SFRH/BPD/41091/2007), and greatly thanks the Department of Physics, Jyväskylä University, in particular Prof. Jukka Maalampi (HOD) for hospitality and financial support. This work was partially supported by FCT through the projects CERN/FP/123580/2011, PTDC/FIS-NUC/0548/2012 and CFTP-FCT Unit 777 (PEst-OE/FIS/UI0777/2013) which are partially funded through POCTI (FEDER). C.R. Das also sincerely thanks Physical Research Laboratory and Prof. Utpal Sarkar (Dean) for Visiting Scientist position.

References

[1] C.R. Das, L.V. Laperashvili and A. Tureanu, Int. J. Mod. Phys. A28, 1350085 (2013) [arXiv:1304.3069].

[2] A. Garrett Lisi, L. Smolin and S. Speziale, J. Phys. A43, 445401 (2010) [arXiv:1004.4866].

[3] S. Alexander, Isogravity: Toward an Electroweak and Gravitational Unification, arXiv:0706.4481.

[4] F. Nesti, Eur. Phys. J. C 59, 723 (2009), [arXiv:0706.3304].

[5] S. Alexander, A. Marciano and L. Smolin, Gravitational origin of the weak interaction’s chirality, arXiv:1212.5246.

[6] J.F. Plebanski, J. Math. Phys. 18, 2511 (1977).

[7] A. Ashtekar, Phys. Rev. Lett. 57, 2244 (1986).

[8] R. Capovilla, T. Jacobson, J. Dell and L.J. Mason, Class. Quant. Grav. 8, 41 (1991).

[9] E.W. Mielke, Phys. Rev. D77, 084020 (2008) [arXiv:0707.3466].

[10] G. de Berredo-Peixoto and I.L. Shapiro, Phys. Rev. D70, 044024 (2004), arXiv:hep-th/0307030.

[11] D.L. Bennett, L.V. Laperashvili and H.B. Nielsen, Relation between finestructure constants at the Planck scale from multiple point principle, in: Proceedings to the 9th Workshop on ‘What Comes Beyond the Standard Models?’ Bled, Slovenia, July 16-27, 2006 (DMFA, Založnictvo, Ljubljana, 2006) [arXiv:hep-ph/0612250].

[12] D.L. Bennett, L.V. Laperashvili and H.B. Nielsen, Finestructure constants at the Planck scale from multiple point principle, in: Proceedings to the 10th Workshop on ‘What Comes Beyond the Standard Models?’ Bled, Slovenia, July 17-27, 2007 (DMFA, Založnictvo, Ljubljana, 2007) [arXiv:0711.4681].

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

[14] G. Degrassi, S. Di Vita, J. Elias-Miro, J.R. Espinosa, G.F. Giudice, G. Isidori and A. Strumia, JHEP 1208, 098 (2012) [arXiv:1205.6497].
[15] D. Buttazzo, G. Degrassi, P.P. Giardino, G.F. Giudice, F. Salab, A. Salvio, A. Strumia, JHEP 1312, 089 (2013) [arXiv:1307.3536].

[16] D.L. Bennett and H.B. Nielsen, Int. J. Mod. Phys. A9, 5155 (1994).

[17] L.V. Laperashvili, Phys. Atom. Nucl. 57, 471 (1994) [Yad. Fiz. 57, 501 (1994)].

[18] C.D. Froggatt and H.B. Nielsen, Phys. Lett. B368, 96 (1996) [arXiv:hep-ph/9511371].

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

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

[21] R. Foot, H. Lew and R.R. Volkas, Phys. Lett. B272, 67 (1991).

[22] R. Foot, Mod. Phys. Lett. A9, 169 (1994), [arXiv:hep-ph/9402241].

[23] Z. Berezhiani, A. Dolgov and R.N. Mohapatra, Phys. Lett. B375, 26 (1996), [arXiv:hep-ph/9511221].

[24] R. Foot, Int. J. Mod. Phys. D13, 2161 (2004), [arXiv:astro-ph/0407623].

[25] Z. Berezhiani, Through the looking-glass: Alice’s adventures in mirror world, in: Ian Kogan Memorial Collection "From Fields to Strings: Circumnavigating Theoretical Physics", Vol. 3, eds. M. Shifman et al. (World Scientific, Singapore, 2005), pp. 2147-2195, [arXiv:hep-ph/0508233].

[26] A. Riess et al., Astrophys. J. Suppl. 183, 109 (2009), [arXiv:0905.0697].

[27] W.L. Freedman et al., Astrophys. J. 704, 1036 (2009), [arXiv:0907.4524].

[28] K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014).

[29] L.B. Okun, Phys. Usp. 50, 380 (2007), [arXiv:hep-ph/0606202].

[30] S.I. Blinnikov, Phys. Atom. Nucl. 73, 593 (2010), [arXiv:0904.3609].

[31] Z.K. Silagadze, Mirror dark matter discovered?, ICFAI U. J. Phys. 2, 143 (2009), [arXiv:0808.2595].

[32] E.K. Akhmedov, Z.G. Berezhiani and G. Senjanovic, Phys. Rev. Lett. 69, 3013 (1992), [arXiv:hep-ph/9205230].

[33] Z. Berezhiani, P. Ciarcelluti, D. Comelli and F.L. Villante, Int. J. Mod. Phys. D14, 107 (2005), [arXiv:astro-ph/0312605].

[34] E.W. Kolb, D. Seckel and M.S. Turner, Nature 314, 415 (1985).

[35] R. Foot, A. Kobakhidze and R.R. Volkas, Phys. Rev. D84, 09503 (2011), [arXiv:1109.0919].

[36] A. Linde, Hybrid Inflation, Phys. Rev. D49, 748 (1994), [arXiv:astro-ph/9307002].

[37] F.L. Bezrukov and M. Shaposhnikov, Phys. Lett. B659, 703 (2008), [arXiv:0710.3755].

[38] F.L. Bezrukov and Gorbunov, JHEP 1307, 140 (2013), [arXiv:1303.4395].
[39] F. Bezrukov, J. Rubio and M. Shaposhnikov, *Living beyond the edge: Higgs inflation and vacuum metastability*, arXiv:1412.3811.

[40] B.G. Sidharth, The Thermodynamic Universe. World Scientific, Singapore, 2008.

[41] B.G. Sidharth, Int. J. of Mod. Phys. A13, 2599 (1998).

[42] B.G. Sidharth, Found. Phys. Lett. 18(4), 393 (2005); ibid., 18(7), 757 (2006).

[43] A. Riess et al., Astrophys. J. Suppl. 183, 109 (2009), arXiv:0905.0697.

[44] W.L. Freedman et al., Astrophys. J. 704, 1036 (2009), arXiv:0907.4524.

[45] K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014).