

# Gravi-Weak Unification and Multiple Point Principle

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# Introduction

We construct a model unifying gravity with some, e.g. weak,  $SU(2)$  gauge and the “Higgs” scalar fields.

We assume the existence of a visible and an invisible (hidden) sector of the Universe. The hidden world is a Mirror World which is not identical with the visible one.

This Hidden World (HW) is assumed to be a Mirror World (MW) with broken mirror parity (MP).

We used the extension of Plebanski’s 4-dimensional gravitational theory, in which the fundamental fields are two-forms containing tetrads and spin connections, and in addition certain auxiliary fields.

We develop the model of Unification of gravity, gauge and Higgs fields suggested in the reference:





## **LSS model:**



A. Garrett Lisi, L. Smolin and S. Speziale,  
*Unification of gravity, gauge fields, and Higgs bosons,*  
*J. Phys. A* **43**, 445401 (2010), arXiv:1004.4866.

# Unification models and the Plebanski's theory of gravity

Originally General Relativity (GR) was formulated by Einstein as the dynamics of a metric,  $g_{\mu\nu}$ . Later Plebanski, Ashtekar and others presented GR in a self-dual approach:

-  J. F. Plebanski, *On the separation of Einsteinian substructures*, J. Math. Phys. **18**, 2511 (1977).
-  A. Ashtekar, *New variables for classical and quantum gravity*, Phys. Rev. Lett. **57**, 2244 (1986); Phys. Rev. D **36**, 1587 (1987).
-  R. Capovilla, T. Jacobson, J. Dell and L. J. Mason, *Selfdual two forms and gravity*, Class. Quant. Grav. **8**, 41 (1991).
-  R. Capovilla, T. Jacobson and J. Dell, *A Pure spin connection formulation of gravity*, Class. Quant. Grav. **8**, 59 (1991).

# Unification models and the Plebanski's theory of gravity

In this approach, the true configuration variable is a connection corresponding to the gauging of the local Lorentz group,  $SO(1,3)$ , and the spin group,  $Spin(1,3)$ .

In general, in the unification models, the fundamental variable is a connection,  $A$ , valued in a Lie algebra,  $\mathfrak{g}$ , that includes a subalgebra  $\tilde{\mathfrak{g}}$ :

$$\tilde{\mathfrak{g}} = \mathfrak{g}^{(spacetime)} \oplus \mathfrak{g}_{YM},$$

which is the direct sum of the Lorentz algebra and a Yang–Mills gauge algebra.

In **LSS model**:

$\mathfrak{g}^{(spacetime)} = \mathfrak{spin}(1, 3)$  is the gravitational gauge algebra, and the Yang–Mills gauge algebra is a spin algebra,  $\mathfrak{g}_{YM} = \mathfrak{spin}(N)$ . Finally, a model of unification of gravity, the  $SU(N)$ , or  $SO(N)$ , gauge fields and Higgs bosons is based on the full initial gauge algebra of type  $\mathfrak{g} = \mathfrak{spin}(p, q)$ .

In the Plebanski's formulation of the 4-dimensional theory of gravity the gravitational action is the product of two 2-forms, which are constructed from the connections  $A^{IJ}$  and tetrads (or frames)  $e^I$  considered as independent dynamical variables.

# Unification models and the Plebanski's theory of gravity

Both  $A^{IJ}$  and  $e^I$ , also  $A$ , are 1-forms:

$$A^{IJ} = A_{\mu}^{IJ} dx^{\mu} \quad \text{and} \quad e^I = e_{\mu}^I dx^{\mu},$$

$$A = \frac{1}{2} A^{IJ} \gamma_{IJ}.$$

Here the bivector generators  $\gamma_{IJ}$  can be understood as the product of  $Cl(1, 3)$  Clifford algebra basis vectors:

$$\gamma_{IJ} = \gamma_I \gamma_J.$$

The indices  $I, J = 0, 1, 2, 3$  refer to the spacetime with Minkowski metric

$$\eta_{IJ} : \eta^{IJ} = \text{diag}(1, -1, -1, -1).$$

This is a flat space which is tangential to the curved space with the metric  $g_{\mu\nu}$ .

# Unification models and the Plebanski's theory of gravity

The world interval is represented as

$$ds^2 = \eta_{IJ} e^I \otimes e^J,$$

i.e.

$$g_{\mu\nu} = \eta_{IJ} e_\mu^I \otimes e_\nu^J.$$

Considering the case of the Minkowski flat spacetime with the group of symmetry  $SO(1,3)$ , we have the capital latin indices  $I, J, \dots = 0, 1, 2, 3$ .

In the general case of the gauge symmetry  $\mathfrak{G}$  with the Lie algebra  $\mathfrak{g} = \mathit{spin}(p, q)$ , we have  $I, J = 1, 2, \dots, p + q$ .

The 2-forms  $B^{IJ}$  and  $F^{IJ}$  are defined as:

$$B^{IJ} = e^I \wedge e^J = \frac{1}{2} e_\mu^I e_\nu^J dx^\mu \wedge dx^\nu,$$

$$F^{IJ} = \frac{1}{2} F_{\mu\nu}^{IJ} dx^\mu \wedge dx^\nu.$$



# Unification models and the Plebanski's theory of gravity

Here the tensor  $F_{\mu\nu}^{IJ}$  is the field strength of the spin connection  $A_{\mu}^{IJ}$ :

$$F_{\mu\nu}^{IJ} = \partial_{\mu}A_{\nu}^{IJ} - \partial_{\nu}A_{\mu}^{IJ} - [A_{\mu}, A_{\nu}]^{IJ},$$

which determines the Riemann–Cartan curvature:

$$R_{\kappa\lambda\mu\nu} = e_{\kappa}^I e_{\lambda}^J F_{\mu\nu}^{IJ}.$$

We also consider the 2-forms  $B$  and  $F$ :

$$B = \frac{1}{2}B^{IJ}\gamma_{IJ} \quad \text{and} \quad F = \frac{1}{2}F^{IJ}\gamma_{IJ},$$

$$F = dA + \frac{1}{2}[A, A].$$

# Unification models and the Plebanski's theory of gravity

In the Plebanski's BF-theory, the gravitational action with nonzero cosmological constant  $\Lambda$  is given by the integral:

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

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

For any antisymmetric tensors  $F_{\mu\nu}$  there exist dual tensors given by the Hodge star dual operation:

$$F_{\mu\nu}^* \equiv \frac{1}{2\sqrt{-g}} \epsilon_{\mu\nu}^{\rho\sigma} F_{\rho\sigma}.$$

# Unification models and the Plebanski's theory of gravity

For any antisymmetric tensors  $A^{IJ}$  there exists dual operation:

$$A^{*IJ} = \frac{1}{2} \epsilon^{IJKL} A^{KL}.$$

Here  $\epsilon$  is the completely antisymmetric tensor with  $\epsilon^{0123} = 1$ .

We can define the algebraic self-dual (+) and anti-self-dual (-) components of  $A^{IJ}$ :

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

# Unification models and the Plebanski's theory of gravity

The two projectors  $\mathcal{P}^\pm = \frac{1}{2}(\delta_{KL}^IJ \pm \epsilon_{KL}^IJ)$  realize explicitly the familiar homomorphism:

$$\mathfrak{so}(1, 3) = \mathfrak{su}(2)_R \oplus \mathfrak{su}(2)_L,$$

which rather than self-dual and anti-self-dual are more commonly dubbed right-handed and left-handed.

Then we define

$$A^{(\pm)i} = A^{(\pm)0i},$$

with  $i = 1, 2, 3$  as an adjoint index of  $SU(2)_L^{(grav)}$ .

# Unification models and the Plebanski's theory of gravity

The correct gauge was chosen by Plebanski, when he introduced in the gravitational action the Lagrange multipliers  $\psi_{ij}$  – an auxiliary fields, symmetric and traceless. These auxiliary fields  $\psi_{ij}$  provide the correct number of constraints.

Including the constraints, we obtain the following gravitational action:

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

The usual notations  $\Sigma^i = 2B^{0i}$  and:

$$(\Psi^{-1})_{ij} = \psi_{ij} - \frac{\Lambda}{6} \delta_{ij}.$$

Then Plebanski and other authors suggested to consider in the visible sector of our Universe the left-handed  $\mathfrak{su}(2)_L$ -invariant gravitational action with self-dual  $F = F^{(+)}$  and  $\Sigma = \Sigma^{(+)}$ , which is equivalent to the Einstein-Hilbert gravity.

# Graviweak action in the visible sector of the Universe

In Ref.:



C.R. Das, L.V. Laperashvili and A. Tureanu,  
*Graviweak unification, invisible Universe and dark energy*,  
Int. J. Mod. Phys. A **28**, 1350085 (2013), arXiv:1304.3069,

developing the graviweak unification model in the visible sector of the Universe, we started with a  $\mathfrak{g} = \mathfrak{spin}(4, 4)$ -invariant extended Plebanski's action:

$$I(A, B, \Phi) = \frac{1}{g_{uni}} \int_{\mathfrak{M}} \langle BF + \frac{\Lambda_0}{4} BB + B\Phi B + \frac{1}{3} B\Phi\Phi\Phi B \rangle.$$

The wedge product  $\langle \dots \rangle$  is assumed between the forms.

In this action with a parameter of the unification  $g_{uni}$ , the connection,  $A = A^{IJ}\gamma_{IJ}$ , is the independent physical variable describing the geometry of the spacetime, while  $\Phi$ , or  $\Phi_{IJKL}$ , are auxiliary fields.

# Graviweak action in the visible sector of the Universe

Here,

$$F = dA + \frac{1}{2}[A, A]$$

is the curvature and

$$B = B^{IJ}\gamma_{IJ}$$

is a  $\mathfrak{spin}(4, 4)$ -valued 2-form auxiliary field. The generators

$$\gamma_{IJ} = \gamma_I\gamma_J$$

of the  $\mathfrak{spin}(4, 4)$ -group have indices running over all  $8 \times 8$  values:

$$I, J = 1, 2, \dots, 7, 8$$

( $I, J = 1, 5, 6, 7$  - time like components, and  $I, J = 2, 3, 4, 8$  - spatial ones).

$\Lambda_0$  is the Plebanski's bare cosmological constant.

# Graviweak action in the visible sector of the Universe

Varying the fields  $A$ ,  $B$  and  $\Phi$ , we obtained the field equations:

$$\mathcal{D}B = dB + [A, B] = 0,$$

where  $\mathcal{D}$  is the covariant derivative,

$$\mathcal{D}_\mu^{IJ} = \delta^{IJ} \partial_\mu - A_\mu^{IJ},$$

and

$$F = -2 \left( \Phi + \frac{1}{3} \Phi \Phi \Phi \right) B,$$

$$B^{IJ} B^{KL} = -\frac{1}{16} B^{IJ} \Phi_{MN}^{KL} \Phi_{PQ}^{MN} B^{PQ}.$$

The first equation describes the dynamics, while last two determine  $B$  and  $\Phi$  respectively.

Here we assumed that  $\Lambda_0 = 0$ .



# Graviweak action in the visible sector of the Universe

With help of the equations of motion, we have obtained the following  $\mathfrak{g}$ -invariant gravitational, and weak  $SU(2)_L$  gauge and Higgs fields action:

$$I(e, A) = \frac{3}{8g_{uni}} \int_{\mathfrak{M}} \langle FF^* \rangle.$$

Considering the spontaneous symmetry breaking of the above  $\mathfrak{g}$ -invariant action we see that it produces the dynamics of the  $SU(2)_L$ -gravity, and the  $SU(2)_L$  gauge and Higgs fields with subalgebra

$$\tilde{\mathfrak{g}} = \mathfrak{su}(2)_L^{(grav)} \oplus \mathfrak{su}(2)_L.$$

The indices  $a, b \in \{0, 1, 2, 3\}$  are used to sum over a subset of  $I, J \in 1, 2, \dots, 7, 8$  for  $I, J = 1, 2, 3, 4$ , and thereby select a  $\mathfrak{spin}(1, 3)$  subalgebra of  $\mathfrak{spin}(4, 4)$ . The indices  $m, n \in \{5, 6, 7, 8\}$  sum over the rest. We also consider  $i, j \in \{1, 2, 3\}$ , thus selecting a  $\mathfrak{su}(2)_L^{grav}$  subalgebra of  $\mathfrak{spin}(4, 4)_L$ .

# Graviweak action in the visible sector of the Universe

The spontaneous symmetry breaking (SSB) of the graviweak unification gives separate parts of the connection in terms of the following 2-forms:

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

with the gravitational spin connection:

$$\omega = \omega^{ab}\gamma_{ab},$$

or

$$\omega = \omega^i\sigma_i,$$

which is valued in  $\mathfrak{su}(2)_L^{(grav)}$ . Here  $\sigma_i$  are Pauli matrices,  $i = 1, 2, 3$ .

# Graviweak action in the visible sector of the Universe

The frame-Higgs connection

$$E = E^{am} \gamma_{am}$$

is valued in the off-diagonal complement of  $\mathfrak{spin}(4, 4)$ , and assumed to have the expression:

$$E = e\phi = e_{\mu}^a \sigma_a \phi^i \tau_i dx^{\mu},$$

what corresponds to  $\mathfrak{su}(2)$ -subgroup of the Clifford algebra, where:

$$E = e\phi = e_{\mu}^a \gamma_a \phi^m \gamma_m dx^{\mu}.$$

The field  $\phi = \phi^i \tau_i$  is the scalar Higgs of  $\mathfrak{su}(2)_L$ ,

$\tau_i$  are Pauli matrices,  $i = 1, 2, 3$ .

# Graviweak action in the visible sector of the Universe

The gauge field:

$$A_W = \frac{1}{2} A^{mn} \gamma_{mn},$$

or

$$A_W = \frac{1}{2} A_W^i \tau_i,$$

is valued in  $\mathfrak{su}(2)_L$ .

Finally, we have the following graviweak action for the gravitational,  $SU(2)_L$  gauge and Higgs fields in the ordinary (visible) sector of the Universe:

$$I_{GWU}(e, \phi, A, A_W) = -\frac{3}{8g_{uni}} \int_{\mathfrak{M}} d^4x |e| \left( -\frac{1}{16} |\phi|^2 R + \frac{3}{32} |\phi|^4 \right. \\ \left. -\frac{1}{16} R_{ab}{}^{cd} R^{ab}{}_{cd} + \frac{1}{2} \mathcal{D}_a \phi^\dagger \mathcal{D}^a \phi + \frac{1}{4} F_{Wab}^i F_W^{iab} \right).$$

# Graviweak action in the visible sector of the Universe

Here  $R$  is the Riemann curvature scalar,  $|\phi|^2 = \phi^\dagger\phi$  is the squared magnitude of the Higgs field,  $\mathcal{D}\phi = d\phi + [A_W, \phi]$  is the covariant derivative of the Higgs field, and

$F_W = dA_W + [A_W, A_W]$  is the curvature of the gauge field  $A_W$ .

The third term of the action is a Stephenson-Kilmister-Yang (SKY) modification to the standard gravitation related to the Gauss-Bonnet topological action:



E.W. Mielke, *Einsteinian gravity from a topological action*, Phys. Rev. D **77**, 084020 (2008), arXiv:0707.3466.



G. de Berredo-Peixoto and I.L. Shapiro, *Conformal quantum gravity with the Gauss-Bonnet term*, Phys. Rev. D **70**, 044024 (2004), hep-th/0307030.



M.B. Gaete and M. Hassaine, *Topological black holes for Einstein-Gauss-Bonnet gravity with a nonminimal scalar field*, arXiv:1308.3076.

# Graviweak action in the visible sector of the Universe

The nontrivial vacuum solutions to the action give the non-vanishing Higgs vacuum expectation value (VEV):

$$v = \langle \phi \rangle = \phi_0,$$

at which the standard Higgs potential has an extremum corresponding to the de Sitter spacetime background solution:

$$v^2 = \frac{R_0}{3}.$$

Here  $R_0 > 0$  is a constant background scalar curvature.

# Graviweak action in the visible sector of the Universe

After the symmetry breaking of the graviweak unification, we obtain:

- 1 the Newton's constant in our Universe, equal to

$$G_N = \frac{128g_{uni}}{3v^2};$$

- 2 the cosmological constant  $\Lambda$ :

$$\Lambda = \frac{3}{4}v^2;$$

- 3 the weak coupling constant:

$$g_W^2 = \frac{8g_{uni}}{3}.$$

# Graviweak action in the visible sector of the Universe


All physical constants are determined by a parameter  $g_{uni}$  and the Higgs VEV  $v$ . It is necessary to note that all parameters – Newton's constant, the cosmological constant, the gauge couplings  $g_{YM} = g_W$ , considered in the action – are bare parameters, which refer to the Planck scale.

Assuming that the scalar field  $\phi$  is usual Higgs doublet of the SM,

we can use the experimentally known value of  $G_N$ , where

$$M_{Pl}^{red.} = 1/\sqrt{8\pi G_N} \approx 2.43 \times 10^{18} \text{ GeV},$$

and obtain the value of  $g_{uni}$ , if we relate the value  $g_W^2 = 8g_{uni}/3$  with the value of  $g_2^2$  obtained by the extrapolation of experimental values of running  $\alpha_2 = g_2^2/4\pi$  from the Electroweak scale to the Planck scale. See:

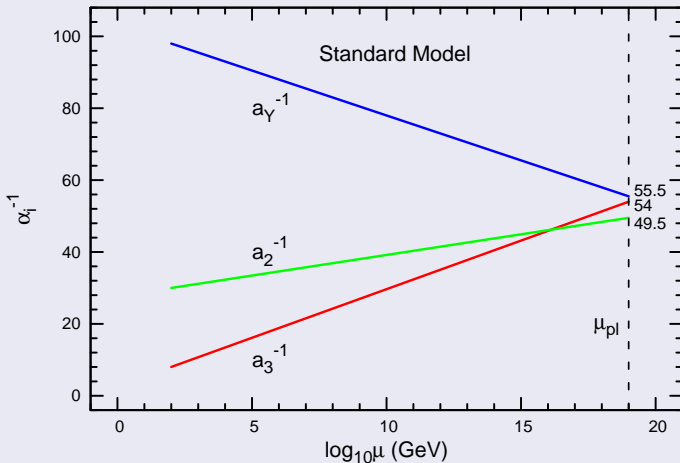
 [D.L. Bennett, L.V. Laperashvili and H.B. Nielsen, hep-ph/0612250 and arXiv:0711.4681.](#)

 [L.V. Laperashvili, Phys. Atom. Nucl. \*\*57\*\*, 471 \(1994\).](#)



# Graviweak action in the visible sector of the Universe

Fig. 1: The evolution of the inverse SM fine structure constants as functions of  $x$  ( $x = \log_{10} \mu$  (GeV)) up to the Planck scale  $M_{Pl}$ .



# Graviweak action in the visible sector of the Universe

Then we have no agreement of the graviweak unification with experimental measurements, giving

$$g_{uni} \sim 0.1,$$

if we have the well-known Newtonian constant  $G_N$ .

In this case we have:

$$v \approx 246 \text{ GeV}, \quad g_{uni} \approx 2.3 \cdot 10^{-35} \sim 0.$$

However, the self-consistent graviweak unification can be obtained in the model with the Multiple Point Principle developed by H.B.Nielsen and his collaborators (D.L. Bennett, C.D. Froggatt, R.B. Nevzorov, L.V.L., etc.).

# Multiple Point Principle

The vast majority of the available experimental information is already explained by the SM. All accelerator physics is in agreement with the SM, except for neutrino oscillations.

One of the main goals of physics today is to find out the fundamental theory beyond the SM. In first approximation we might ignore the indications of new physics and consider the possibility that the SM essentially represents physics well up to the Planck scale.

# Multiple Point Principle

In Ref. **FLN**:



C.D. Froggatt, L.V. Laperashvili and H.B. Nielsen,  
*The Fundamental-weak scale hierarchy in the Standard Model*,  
*Phys. Atom. Nucl.* **69**, 67 (2006), hep-ph/0407102

we suggested a scenario, using only the pure SM, in which an exponentially huge ratio between the fundamental (Planck) and Electroweak scales results:

$$\frac{\mu_{fund}}{\mu_{ew}} \sim e^{40} \sim 10^{17}.$$

We suggest a model, which contains simply the SM itself up to the scale  $\sim 10^{19}$  GeV, or at least  $10^{16}$  GeV.

This model reminds us “the Bjorken-Rosner nightmare”, when there is no new physics up to the Planck scale (except perhaps see-saw scale). In such a scenario it is reasonable to assume the existence of a simple postulate, which helps us to explain the SM parameters: couplings, masses and mixing angles.

# Multiple Point Principle

Such a postulate is based on a phenomenologically required result in cosmology (see Particle Data Group): the cosmological constant is zero, or approximately zero, meaning that the vacuum energy density (dark energy) is very small. A priori it is quite possible for a quantum field theory to have several minima of the effective potential as a function of its scalar field. Postulating zero cosmological constant, we can assume that all the vacua, which might exist in Nature (as minima of the effective potential), should have zero, or approximately zero cosmological constant. This postulate corresponds to what we call the Multiple Point Principle (MPP).

# Multiple Point Principle

## MPP postulates:

*There are many vacua with the same energy density, or cosmological constant, and all cosmological constants are zero or approximately zero.*

If we have the first minimum of the Higgs effective potential at  $v = \phi_{min1} \approx 246$  GeV, then we have the possible existence of a second (non-standard) minimum at the fundamental scale:

$$\phi_{min2} \gg v = \phi_{min1}.$$

In accord with cosmological results, we take the cosmological constants  $C$  for both vacua equal to zero (or approximately zero):  $C = 0$  (or  $C \approx 0$ ).

# Multiple Point Principle

The following requirements must be satisfied in order that the SM effective potential should have two degenerate minima:

$$V_{eff}(\phi_{min1}^2) = V_{eff}(\phi_{min2}^2) = 0,$$

$$V'_{eff}(\phi_{min1}^2) = V'_{eff}(\phi_{min2}^2) = 0,$$

where

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

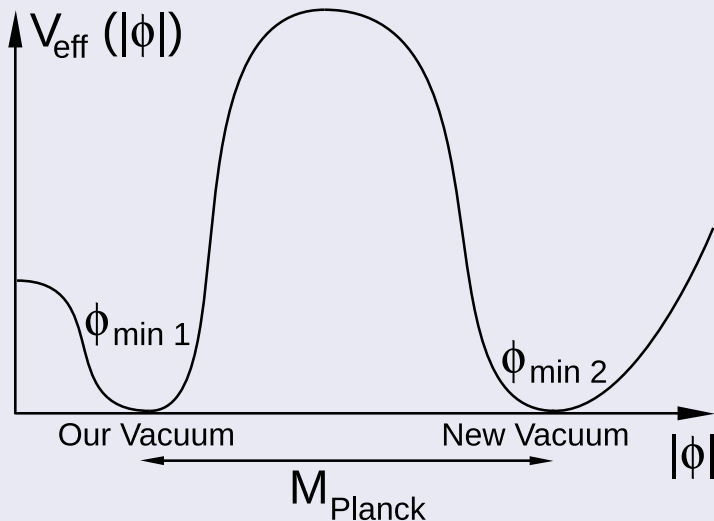
These degeneracy conditions correspond to the MPP expectation.

*The first minimum is the standard “Weak scale minimum”, and the second one is the non-standard “Fundamental scale minimum” (if it exists).*

An illustrative schematic picture of  $V_{eff}$  is presented in Fig. 2.

# Graviweak action in the visible sector of the Universe


Fig. 2:





# Multiple Point Principle

The predictions of Ref.:

 C.D. Froggatt and H.B. Nielsen, *Standard model criticality prediction top mass  $173 \pm 5$  GeV and Higgs mass  $135 \pm 9$  GeV*, Phys. Lett. B **368**, 96 (1996), hep-ph/9511371

for the top-quark and Higgs masses from the MPP requirement of the existence of a second degenerate vacuum, were as follows:

$$M_t = 173 \pm 5 \text{ GeV}, \quad M_H = 135 \pm 9 \text{ GeV}.$$

For large values of the Higgs field:  $\phi^2 \gg m^2$  the effective potential  $V_{\text{eff}}$  is very well approximated by the quartic term  $\lambda(\phi^+\phi)^2$  and the degeneracy conditions give:

$$\lambda(\phi_{\text{min}2}) = 0,$$

$$\lambda'(\phi_{\text{min}2}) = 0.$$

# Multiple Point Principle

These conditions can be expressed in the form:

$$\beta_\lambda(\phi_{min2}, \lambda = 0) = 0.$$

In Ref. **FLN**: the scale  $v_2 = \phi_{min2}$  (depending on the experimental data uncertainties) was calculated in the second loop approximation of the Higgs effective potential.

It was shown that in the 2-loop approximation, the experimental values of the coupling constants allow the existence of the SM effective potential second minimum.

We have calculated this position numerically. It exists in the interval:

$$\phi_{min2} \in (10^{16}; 10^{22}) \text{ GeV}.$$

# Multiple Point Principle

It is necessary to emphasize that, for the central values of the experimental parameters, we predict the fundamental scale (the position of the second minimum) to be close to the Planck scale  $\mu_{fundamental} \sim 10^{19}$  GeV.

The MPP-model of the SM also predicts a value for the Higgs mass. In spite of the large uncertainty in the position of the second minimum, the value of  $\lambda$  at the Electroweak scale lies in the narrow interval:

$$\lambda(M_t) \in (0.26; 0.34),$$

which corresponds to the prediction of the interval of the Higgs mass equal to:

$$M_H \in (125; 143) \text{ GeV}.$$

This interval covers the LHC prediction of the Higgs mass ( $\approx 126$  GeV) and the prediction of Froggatt-Nielsen. ( $M_H = 135 \pm 9$  GeV), what means that the radiative corrections to the Higgs effective potential explains the value of the Higgs mass observed at the LHC.

# Multiple Point Principle

The same subject was considered in Ref.:



G. Degrassi, S. Di Vita, J. Elias-Miro, J.R. Espinosa, G.F. Giudice,  
G. Isidori and A. Strumia,  
*Higgs mass and vacuum stability in the Standard Model at NNLO*,  
JHEP **1208**, 098 (2012), arXiv:1205.6497.

# Planck scale values of the graviweak unification parameters

The SM-MPP model gives the self-consistent description of the graviweak unification, giving the well-known value of  $G_N$ , also

$$v_2 \approx 2.5 \times 10^{19} \text{ GeV},$$


and

$$g_{uni} \sim 0.1.$$

But the idea that the vacuum value of  $\langle \phi \rangle$  could be (according to the Multiple Point Principle) the second minimum  $v_2$  of the Higgs field effective potential, turns out not to be viable. The reason is that the Newtonian constant  $G_N$  was measured in the vacuum  $\langle \phi \rangle = v_1 \approx 246$  GeV - in the vacuum, in which we live.

Then only another assumption can give a self-consistent description of the Graviweak Unification: to consider the existence of the axion scalar field  $\phi_{axion}$ , which gives an additional vacuum of our Universe at  $v_{axion} \sim 10^{19}$  GeV.

The analogous possibility was considered in our paper:

-  C.R. Das, L.V. Laperashvili, H.B. Nielsen and A. Tureanu, *Mirror world and superstring-inspired hidden sector of the Universe, dark matter and dark energy*, Phys. Rev. D **84**, 063510 (2011), arXiv:1101.4558.

Thus, the axion field that has a Planck scale expectation value could have a better chance of being the scalar field unified with gravity. This possibility is a goal of our future papers.

# Graviweak action in the Hidden sector of the Universe

In Ref.:



D.L. Bennett, L.V. Laperashvili, H.B. Nielsen and A. Tureanu,  
*Gravity and mirror gravity in Plebanski formulation*,  
Int. J. Mod. Phys. A **28**, 1350035 (2013), arXiv:1206.3497

we suggested to describe the gravity in the visible Universe by the self-dual left-handed Plebanski's gravitational action, while the gravity in the invisible (hidden) Universe – by the anti-self-dual right-handed gravitational action:

$$I_{(gravity)}^{(\prime)}(\Sigma^{(\prime)}, A^{(\prime)}, \psi^{(\prime)}) = \frac{1}{\kappa^{(\prime)2}} \int [\Sigma^{(\prime)i} \wedge F^{(\prime)i} + (\Psi^{(\prime)-1})_{ij} \Sigma^{(\prime)i} \wedge \Sigma^{(\prime)j}],$$

where the superscript 'prime' denotes the M- or hidden H-world. Here  $\Sigma = A^{(+)}$ ,  $\Sigma^{(+)}$  are self-dual (left-handed) fields in the OW, and  $A', \Sigma' = A^{(-)}$ ,  $\Sigma^{(-)}$  are anti-self-dual (right-handed) fields in the MW.

# Graviweak action in the Hidden sector of the Universe

Developing these ideas, we consider the graviweak unification model in both sectors of the Universe, visible and invisible.

Now we distinguish the following two actions:

- 1 the  $\mathfrak{spin}(4, 4)_L$ -invariant action  $I_{left}(A, B, \Phi)$  with self-dual left-handed fields  $A = A^{(+)}$ ,  $B = B^{(+)}$  and auxiliary fields  $\Phi_{IJKL}$  – in the ordinary (visible) world OW, and
- 2 the  $\mathfrak{spin}(4, 4)_R$ -invariant action  $I_{right}(A', B', \Phi')$  with anti-self-dual right-handed fields  $A' = A^{(-)}$ ,  $B' = B^{(-)}$  and auxiliary fields  $\Phi'_{IJKL}$  – in the hidden (invisible) world MW.

Instead of fields  $A, B, F$  and  $\Phi$ , similar equations hold in MW for  $A', B', F'$  and  $\Phi'$ .



# Graviweak action in the Hidden sector of the Universe

For completeness, we briefly present the spontaneous symmetry breaking of the  $\mathfrak{g}$ -invariant action that produces the dynamics of the  $SU(2)_L$ -gravity, and the  $SU(2)_L$  gauge and Higgs fields with subalgebra

$$\tilde{\mathfrak{g}} = \mathfrak{su}(2)_L^{(grav)} \oplus \mathfrak{su}(2)_L.$$

Analogous equations are valid in the MW with the initial  $\mathfrak{spin}(4, 4)_R$ -algebra, and with a subalgebra:

$$\tilde{\mathfrak{g}}' = \mathfrak{su}(2)'_R^{(grav)} \oplus \mathfrak{su}(2)'_R.$$

# Graviweak action in the Hidden sector of the Universe

After the spontaneous symmetry breaking of the graviweak unification, we have the following actions for gravitational gauge and Higgs fields in the ordinary  $SU(2)_L$  and hidden  $SU(2)'_R$  sectors of the Universe:

$$I^{(\prime)}(e^{(\prime)}, \phi^{(\prime)}, A^{(\prime)}, A_{W^{(\prime)}}^{(\prime)}) = -\frac{3}{8g_{uni}} \int_{\mathfrak{M}} d^4x |e^{(\prime)}| \left( -\frac{1}{16} |\phi^{(\prime)}|^2 R^{(\prime)} + \frac{3}{32} |\phi^{(\prime)}|^4 \right. \\ \left. -\frac{1}{16} R^{(\prime)}{}_{ab}{}^{cd} R^{(\prime)ab}{}_{cd} + \frac{1}{2} \mathcal{D}_a \phi^{(\prime)\dagger} \mathcal{D}^a \phi^{(\prime)} + \frac{1}{4} F^{(\prime)i}{}_{W^{(\prime)},ab} F^{(\prime)i}{}_{W^{(\prime)}} \right).$$

# Graviweak action in the Hidden sector of the Universe

Here  $g_{uni} = g'_{uni}$ , since we assume that this equality is a consequence of the existence of the Grand Unification at the early stage of the Universe, when the mirror parity was unbroken. In the action  $R^{(i)}$  are the Riemann curvature scalars. Similar notations  $A', \phi', A'_{W'}$  were used instead of the fields  $A, \phi, A_W$ . The nontrivial vacuum solutions to the actions give the non-vanishing Higgs vacuum expectation values (VEVs):

$$v^{(i)} = \langle \phi^{(i)} \rangle = \phi_0^{(i)}.$$

After the symmetry breaking of graviweak unification in the hidden sector of the Universe, we obtain:

$$G'_N = \frac{128g_{uni}}{3v'^2}, \quad \Lambda' = \frac{3}{4}v'^2, \quad g'^2_{W'} = \frac{8g_{uni}}{3},$$

and we have the following relations between O- and M-parameters:

$$G'_N = \frac{G_N}{\zeta^2}, \quad \Lambda' = \zeta^2 \Lambda, \quad M'_{PI} = \zeta M_{PI}, \quad g'_{W'} = g_W.$$

All physical constants of the Universe are determined by a parameter  $g_{uni}$  and the Higgs VEVs  $v, v'$ .

# The action describing the Universe

The dynamics of the two worlds of the Universe, visible and hidden, is governed by the following action:

$$I = \int [L_{(grav)} + L'_{(grav)} + L_{SM} + L'_{SM'} + L_{(mix)}] |e| d^4x,$$

where  $L_{(grav)}$  is the gravitational (left-handed) Lagrangian in the visible world, and  $L'_{(grav)}$  is the gravitational right-handed Lagrangian in the hidden world,  $L_{SM}$  and  $L'_{SM'}$  are the Standard Model Lagrangians in the O- and M-worlds, respectively.

$$G_{SM} = SU(3)_c \times SU(2)_L \times U_Y(1),$$

$$G'_{SM'} = SU(3)'_c \times SU(2)'_R \times U_Y(1)'.$$

$L_{(mix)}$  is the Lagrangian describing all mixing terms giving small contributions to physical processes: mirror particles have not been seen so far, and the communication between visible and hidden worlds is hard.

# The action describing the Universe

There are several fundamental ways by which the hidden world can communicate with our visible world. The Lagrangian  $L_{(mix)}$  describes all possible mixing terms which are consistent with the symmetries of the theory:

$$L_{mix} = \alpha F^i \wedge F'^i + \frac{\epsilon_Y}{2} F_{Y,\mu\nu} F_Y'^{\mu\nu} + \lambda_2 \phi^\dagger \phi \phi'^\dagger \phi',$$

where the first term is the gravitational mixing term,  $F_{Y,\mu\nu}$  ( $F_Y'^{\mu\nu}$ ) is the  $U(1)_Y$  ( $U(1)'_Y$ ) field strength tensor and  $\phi$  ( $\phi'$ ) is the ordinary (mirror) Higgs doublet.

The left-handed gravity interacts not only with visible matter, but also with mirror matter. The right-handed gravity also interacts with matter and mirror matter. We assume that a fraction of the mirror matter exists in the form of mirror galaxies, mirror stars, mirror planets, etc., detected by gravitational microlensing.

The mirror particles are searching at the LHC.

# Dark Energy of the Universe

In our theory the dark energy density of the Universe is given by the expression:

$$\rho_{DE} = \rho_{vac} = \frac{\Lambda_{eff}}{8\pi G_N} + \frac{\Lambda'_{eff}}{8\pi G'_N},$$

where

$$\frac{\Lambda_{eff}^{(l)}}{8\pi G_N^{(l)}} = \frac{\Lambda^{(l)} + \Lambda_0^{(l)}}{8\pi G_N^{(l)}} + \rho_{vac}^{(SM^{(l)})},$$

All quantum fluctuations of the matter (SM and SM') contribute to the vacuum energy density  $\rho_{vac}$  of the Universe.

# Dark Energy of the Universe

Astrophysical measurements (Particle Data Group) give:

$$\rho_{DE} \approx 0.73\rho_{tot} \approx (2.3 \times 10^{-3} \text{ eV})^4.$$

We considered that all matter quantum fluctuations in SM and SM' are compensated by the contribution of cosmological constants  $\Lambda$  and  $\Lambda'$ :

$$\frac{\Lambda^{(r)}}{8\pi G_N^{(r)}} + \rho_{vac}^{(SM^{(r)})} = 0.$$

Taking into account the Einstein's cosmological constants  $\Lambda_0^{(r)}$  (presumably connected with zero-point energies of gravitational fields), we can describe  $\rho_{DE}$  by the following way:

$$\rho_{DE} = \frac{\Lambda_0}{8\pi G_N} + \frac{\Lambda'_0}{8\pi G'_N} = \frac{\Lambda_0}{4\pi G_N} \approx (2.3 \times 10^{-3} \text{ eV})^4.$$

# Conclusions

- 1 We constructed a model unifying gravity with some, e.g. weak,  $SU(2)$  gauge and “Higgs” scalar fields.
- 2 We assumed the existence of a visible and an invisible (hidden) sector of the Universe. The hidden world is a Mirror World which is not identical with the visible one.
- 3 We used the extension of Plebanski’s 4-dimensional gravitational theory, in which the fundamental fields are two-forms containing tetrads and spin connections, and in addition certain auxiliary fields.
- 4 Considering a  $Spin(4, 4)$  invariant extended Plebanski action, we started with a diffeomorphism invariant theory of a gauge field taking values in a Lie algebra  $\mathfrak{g}$ , which is broken spontaneously to the direct sum of the space-time Lorentz algebra and the Yang-Mills algebra.  
i.e.:  $\tilde{\mathfrak{g}} = \mathfrak{su}(2)_L^{(grav)} \oplus \mathfrak{su}(2)_L$  in the ordinary world, and  
 $\tilde{\mathfrak{g}}' = \mathfrak{su}(2)'_R^{(grav)} \oplus \mathfrak{su}(2)'_R$  in the hidden world.



# Conclusions

- 5 We recovered the actions for gravity,  $SU(2)$  Yang-Mills and “Higgs” fields in both (visible and invisible) sectors of the Universe.
- 6 We also discussed the total action, meaning an extension of our graviweak (GW) action to one containing also the weak hypercharge and QCD gauge theories and fermions.
- 7 After symmetry breaking of this GW unification its physical constants (Newton’s constants, cosmological constants, Yang-Mills couplings, etc.), are determined by a parameter  $g_{uni}$  of the GW unification and by the Higgs VEVs.
- 8 It is discussed if this “Higgs”  $\phi$  coming in the unification could be the Higgs of Standard Model: The idea that the vacuum value of  $\langle\phi\rangle$  could be the according to multiple point principle existing extra minimum in the Higgs field effective potential turns out not to be viable, but e.g. the axion field that has a Planck scale expectation value could have a better chance of being the scalar field unified with gravity.