The Higgs Mass and the Emergence of New Physics

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We investigate the physical implications of formulating the electroweak (EW) part of the Standard Model (SM) in terms of a superconnection involving the supergroup $SU(2/1)$. In particular, we relate the observed Higgs mass to new physics at around 4 TeV. The ultraviolet incompleteness of the superconnection approach points to its emergent nature. The new physics beyond the SM is associated with the emergent supergroup $SU(2/2)$, which is natural from the point of view of the Pati-Salam model. Given that the Pati-Salam group is robust in certain constructions of string vacua, these results suggest a deeper connection between low energy (4 TeV) and high energy (Planck scale) physics via the violation of decoupling in the Higgs sector.

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Introduction and Overview

The Standard Model (SM) of particle physics is a phenomenologically successful theory whose last building block has recently been detected. In light of the apparent discovery of the Higgs boson, we address the connection between its mass and the structure of the electroweak (EW) sector of the SM, and argue that it points to some very exciting new physics at a rather low energy scale of 4 TeV.

A long time ago, Ne’eman and Fairlie independently discovered the relevance of a unique $SU(2/1)$ supergroup structure to SM physics. In this formalism, the even (bosonic) part of the $SU(2/1)$ algebra defines the $SU(2) \times U(1)$ gauge sectors of the SM, while the Higgs sector is identified as the odd (fermionic) part of the algebra. Although the model gives the correct quantum numbers of the SM, and it represents a more unified-hence more aesthetic-version of the SM, it suffers from the violation of the spin-statistic theorem, a common problem in the models giving the correct quantum numbers of the SM, and it represents a more unified-hence more aesthetic-version of the SM, it suffers from the violation of the spin-statistic theorem, a common problem in the models giving the correct quantum numbers of the SM.

In this work we adopt the superconnection approach of Ne’eman and Sternberg who observed that the $SU_L(2) \times U_Y(1)$ gauge and Higgs bosons of the SM could be embedded into a unique $SU(2/1)$ superconnection, and the quarks and leptons into $SU(2/1)$ representations. $SU(2/1)$ in this formalism is not imposed as a symmetry; it is rather only the structure group of the superconnection. Therefore, the $SU(2/1)$ structure can be interpreted as an emergent geometric pattern that involves the EW part of the SM, which avoids the problems with the ghosts.

The formalism fixes the ratio of the $SU_L(2) \times U_Y(1)$ gauge couplings, and thus the value of $\sin^2 \theta_W$, and the quartic coupling of the Higgs. The value of $\sin^2 \theta_W$ selects the scale $\Lambda \sim 4 \text{ TeV}$ at which the superconnection relations can be imposed, and renormalization group (RG) running leads to a prediction of the Higgs mass. However, the claim of Refs. [6, 7] that the predicted Higgs mass is around 130 GeV turns out to be incorrect.

In this Letter, we point out that the $SU(2/1)$ superconnection approach predicts the mass of the Higgs to be 170 GeV, which obviously disagrees with observation. Given the well-known issue with the ultraviolet incompleteness of the $SU(2/1)$ approach, which implies the emergent nature of this description, we should have no qualms in introducing new physics to fix the Higgs mass.

Here, we note a connection with the Spectral SM of Connes and collaborators in which spacetime is extended to a product of a continuous four dimensional manifold by a finite discrete space with non-commutative geometry. The SM particle content and gauge structure are described by a unique geometry, where the Higgs appears as the connection in the extra discrete dimension. Curiously, the original Higgs mass prediction of the Spectral SM was also 170 GeV, despite the fact that the boundary conditions imposed on the RG equations were quite different: in the Spectral SM, the usual $SO(10)$ relations among the gauge couplings are imposed at the GUT scale. In a recent paper, Chamseddine and Connes isolate a unique scalar degree of freedom that is responsible for the neutrino Majorana mass in their approach, which, when correctly coupled to the Higgs field, can reduce the mass of the Higgs boson to the observed

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1 For example, there are anticommuting Lorentz scalars (the Higgs fields) which represent ghost-like degrees of freedom in the model.

2 This scale is updated from the 5 TeV in Ref. [6] using more recent determinations of the gauge couplings. The difference does not play a noticeable role in the prediction of the Higgs mass.
value, $125 \sim 126 \text{ GeV}$.

We argue that a similar ‘fix’ works for the superconnection formalism; one needs to introduce extra scalar degrees of freedom which modify the RG equations. We further point out that this can be accomplished by the embedding of SU(2)/1 into SU(2)/2, and thus, in effect, a left-right (LR) symmetric extension of the EW sector, which is also natural from the point of view of the Pati-Salam model. The SU(2)/2 formalism, as in the SU(2)/1 case, selects the scale $\Lambda \sim 4\text{ TeV}$ via the value of $\sin^2 \theta_W$. Therefore, $4\text{ TeV}$ in this formalism is the prediction for the energy scale of new physics, which is the LR symmetric model in this case.

We also note the peculiarity of the Higgs sector, which due to the relation between the coupling and the mass, violates decoupling. When interpreted from either the emergent superconnection or the non-commutative geometry viewpoint, this violation of decoupling offers an exciting connection between the SM and short distance physics, such as string theory, via the non-decoupling of the $4\text{ TeV}$ and the Planck scales.

In particular, the embedding of SU(2)/1 into SU(2)/2 would be interesting from the point of view of string vacua, where it has been observed that the Pati-Salam group appears rather ubiquitously in a large number of vacua. Though we lack a fundamental understanding of this phenomenon, it is quite intriguing in our context as it would point to a new relationship between low energy (SM-like) and high energy physics (quantum-gravity-like) which is not seen in the standard effective field theory approach to particle physics.

The SU(2)/1 formalism and the Higgs mass

Here we summarize the superconnection approach to the SM based on the supergroup SU(2)/1. Obviously, this supergroup has as its bosonic subgroup the EW gauge group SU(2)_L \times U(1)_Y. What is highly non-trivial is that the embedding of SU(2)_L \times U(1)_Y into SU(2)/1 also gives the correct quantum numbers for all the physical degrees of freedom. Furthermore, the Higgs sector comes out naturally as a counterpart of the gauge sector. These have natural analogs in the Spectral SM as well, as already emphasized in the conclusion to the review Ref. [9]. We concentrate on the superconnection formalism which should be understood as an emergent framework, because of the fundamental ultraviolet incompleteness of gauged supergroup theories.

We start by defining the supercurvature as $\mathcal{F} = \mathbf{d} \mathcal{J} + \mathcal{J} \cdot \mathcal{J}$ where $\mathcal{J}$ is the superconnection, which is of the form

$$\mathcal{J} = \begin{bmatrix} M & \phi \\ \bar{\phi} & N \end{bmatrix}.$$  \hspace{1cm} (1)

Since we would like to embed SU_L(2) × U_Y(1) and the Higgs into SU(2)/1, M and N are respectively $2 \times 2$ and $1 \times 1$ matrices valued over one-forms, while $\phi$ and $\bar{\phi}$ are respectively $2 \times 1$ and $1 \times 2$ matrices valued over zero-forms. The superconnection $\mathcal{J}$ is written as $\mathcal{J} = i\lambda^a_j J^a$, $a = 1, 2, \cdots, 8$. The generators $\lambda^a_j$ are valued in supertrace zero. Therefore, they are the usual SU(3) $\lambda$-matrices except for $\lambda^a_3$ which is

$$\lambda^a_3 = \frac{1}{\sqrt{3}} \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -2 \end{bmatrix}.$$  \hspace{1cm} (2)

To obtain the superconnection we need to make the identifications $J^1 = W_i$ ($i = 1, 2, 3$) and $J^8 = B$, where $W_i$ and $B$ are one-form fields corresponding to the SU_L(2) and U_Y(1) gauge bosons. The zero-form fields are identified as $J^4 = i\lambda^a_1 J^a = \sqrt{2} \phi^2$, $J^6 = -i J^7 = \sqrt{2} \phi^0$, and $J^6 + i J^7 = \sqrt{2} \phi^0$. Then, the superconnection is

$$\mathcal{J} = i \begin{bmatrix} \mathcal{W} - \frac{1}{\sqrt{3}} B \cdot \mathbf{I} \sqrt{2} \Phi \\ \sqrt{2} \mathbf{F} + \frac{2}{\sqrt{3}} B \cdot \mathcal{W} \end{bmatrix}.$$  \hspace{1cm} (3)

Here, $\mathcal{W} = W^i \tau^i$ (where $\tau^i$ are the Pauli matrices) and $\mathbf{I}$ is a $2 \times 2$ unit matrix, and $\Phi = [\phi^+ \phi^0]^T$. To obtain the supercurvature $\mathcal{F}$, we recall the rule for supermatrix multiplication

$$\begin{bmatrix} A & C \\ D & B \end{bmatrix} \begin{bmatrix} A' & C' \\ D' & B' \end{bmatrix} = \begin{bmatrix} A \wedge A' + (-1)^{[D']} C \wedge D' & A \wedge C' + (-1)^{[B]} C \wedge B' \\ (-1)^{[A']} D \wedge A' + B \wedge D' & (-1)^{[C']} D \wedge C' + B \wedge B' \end{bmatrix}.$$  \hspace{1cm} (4)

where $|A|$ denotes the $Z_2$ grading of the differential form $A$. Then, the supercurvature (after introducing the dimensionless coupling $g$, $\mathcal{J} \rightarrow g \mathcal{J}$) reads as

$$\mathcal{F} = ig \begin{bmatrix} F_W - \frac{1}{\sqrt{3}} F_B \cdot \mathbf{I} + 2i g \Phi \Phi^\dagger \sqrt{2} D \Phi \\ \sqrt{2} (D \Phi)^\dagger - \frac{2}{\sqrt{3}} F_B + 2i g \Phi \Phi^\dagger \Phi \end{bmatrix}.$$  \hspace{1cm} (5)

where $D \Phi = d\Phi + ig \mathcal{W} \Phi + ig \frac{1}{\sqrt{3}} B \Phi$, $F_B = dB$ and $F_W = (F_W)^k \tau^k = [dW^k + ig \tau^k W^i \wedge W^j] \tau^k$. The Action reads as follows

$$S = \int \frac{-1}{4g^2} \text{Tr} [\mathcal{F} \cdot \mathcal{F}^\ast].$$

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3 Given the similarities between the outcomes of the Spectral Model of Connes and Chamseddine and the superconnection formalism, there may be a relation between these models.

4 Note that $\ast$, which we will use to denote the Hodge product later in the paper, here denotes taking complex conjugate of a field.
\[ \mathcal{L} = \frac{1}{4} F_{\mu\nu}^W F_{\mu\nu}^W - \frac{1}{4} F_{\mu\nu} B_{\mu\nu} \\
+ (D\Phi)^\dagger \phi^4 - \lambda (\phi^\dagger \phi) \phi^2 . \] (7)

Note that the explicit forms of the curvature derivatives have the standard forms: \( F_{\mu\nu}^W = \partial_\mu W_\nu^i - \partial_\nu W_\mu^i + 2ig g^i_j W_j^k W^i_k \), \( F_{\mu\nu} B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu + ig (\Phi^\dagger W_\mu\rho) \Phi + ig B_\rho \Phi \), with \( g'/g = g^i_j / 2 \) (which is the missing part in [2]) which also changes our constraint at the symmetry breaking energy to \( \lambda = g'^2 / 2 \). Now we address the prediction for the Higgs mass. In what follows we use the relation \( M_H^2 = 8M_0^2 (\lambda / g'^2) \) and the RG equations for \( \lambda \) and top Yukawa coupling \( g_t \) which are

\[ \frac{d\lambda}{d\mu} = \frac{h_t}{(4\pi)^2} \left( \frac{9}{2} \lambda^2 - \frac{17}{12} g'^2 + \frac{9}{4} g^2 + 8g_s^2 \right) , \]

\[ \frac{d\lambda}{d\mu} = \left( \frac{12}{4\pi^2} \left( 12h_t^2 - (3g'^2 + 9g^2) \right) \lambda - 6h_t^4 \right) \]

\[ + 24\lambda^2 + \frac{3}{8} (g'^2 + 2g^2 g'^2 + 3g^4) , \] (8)

where \( g', g, \) and \( g_s \) are the \( U(1)_Y, SU(2)_L \), and \( SU(3)_c \) coupling constants, respectively, \( h_t = \sqrt{2}M_t/v \), and \( M_t = 173.4 \) GeV is the mass of the top quark. We will follow Ref. [2] to find the boundary condition on \( \lambda \). To find the scale of emergence of \( SU(2)/1 \) \((\Lambda_8)\), we find the scale where the group theoretical value for \( \theta_W \), \( g = \sqrt{3}g' \) \((\sin^2 \theta_W = 0.25) \), holds. We use

\[ \frac{1}{|g_i(\Lambda_8)|^2} = \frac{1}{|g_i(\Lambda_0)|^2} - 2b_i \ln \frac{\Lambda_8}{\Lambda_0} \quad (i = 1, 2, 3) \] (9)

where the respective constants \( b_i \) read as:

\[ b_1 = \frac{1}{16\pi^2} \left( \frac{20n_f}{9} + \frac{n_H}{6} \right) , \]

\[ b_2 = -\frac{1}{16\pi^2} \left( \frac{4n_f}{3} - \frac{n_H}{6} + \frac{22}{3} \right) , \]

where the * on \( F^* \) denotes taking the Hermitian conjugate of the supermatrices and the Hodge dual (denoted as *) of the differential forms, and \( \lambda = \equiv 2g'^2 \). Note that we need to break \( SU(2)/1 \) explicitly in order to introduce the Higgs doublets. In 4 dimensions we have the following explicit form of the Lagrangian (given the metric \( g_{\mu\nu} = \text{diag}(1, -1, -1, -1) \)):

\[ (\text{6}) \]

\[ b_3 = -\frac{1}{16\pi^2} \left( \frac{4n_f}{3} + 11 \right) . \] (10)

Setting the number of fermion families to \( n_f = 3 \), and the number of Higgs doublets to \( n_H = 1 \), we find \( \Lambda_8 \approx 4 \) TeV (note that \( g_1 = g' \)). Using Eq. (8) with the boundary conditions \( \lambda = g'^2 / 2 \) at 4 TeV and \( h_t = \sqrt{2}M_t/v \) at \( M_Z \), we find that \( \lambda(M_Z) \approx 0.24 \) and thus \( M_H \approx 170 \) GeV. The numerical value \((\overline{\text{MS}})\) we use in this calculation \([\overline{\text{12}}]\) are \( \alpha^{-1}(M_Z) = 98.36 \), \( \alpha^{-1}(M_Z) = 29.58 \), \( \alpha^{-1}(M_Z) = 8.45 \), where \( \alpha^{-1} = 4\pi/g^2 \).

The SU(2)/2 embedding

Given the incorrect mass of the Higgs and the fact that the superconnection approach suffers from ultraviolet incompleteness, and thus it has to be considered only as an emergent description, we now introduce new emergent physics to correct the Higgs mass. In this section, we use \( SU(2)/2 \) instead of \( SU(2)/1 \) to do the embedding. (From the Spectral SM viewpoint \( SU(2)/2 \) would correspond to a symmetric non-commutative geometry.) In this case, the embedded gauge group is \( SU(2)_L \times SU(2)_R \times U(1)_{B-L} \). We follow the same route as in the previous section and find the energy scale of the new physics predicted by this structure. We also make the simplifying assumption that this energy scale is also the energy scale at which \( SU(2)_L \times SU(2)_R \times U(1)_{B-L} \) breaks to the SM. First, we find the superconnection we need. Given the generators of \( SU(2)/2 \), \( J \) can be expressed as \( J = i\lambda_8^a \sigma^a \), \( a = 1, 2, \cdots 15 \). We make the following identifications: \( J^1, 2, 3 = W_{L, R}^1, J^3 = \frac{1}{2} \sigma^a \), \( J^5 = \sqrt{2} \sigma^0 \), \( J^6, 7 = \sqrt{2} \sigma^a \), \( J^8 \cdots J^{15} = \sqrt{2} \sigma^a \), \( J^9 \cdots J^{17} = \sqrt{2} \sigma^0 \). Here \( W_L \) and \( W_R \) are 1-forms and the others are 0-form fields corresponding to the left- and right-handed gauge bosons and the bidoublet Higgs field. As a result, we obtain the superconnection, a \( 4 \times 4 \) supermatrix, in the following form

\[ J = i \begin{bmatrix} W_L - \frac{1}{\sqrt{2}} W_{BL} \cdot \mathbf{1} & \sqrt{2} \Phi \\
\sqrt{2} \Phi^\dagger & W_R - \frac{1}{\sqrt{2}} W_{BL} \cdot \mathbf{1} \end{bmatrix} \] (11)

where

\[ W_L = W_L^i \tau^i , \quad W_R = W_R^i \tau^i , \quad \Phi = \left[ \begin{array}{c} \phi_0^0 \\ \phi_0^+ \end{array} \right] . \] (12)

This leads to the following expression for \( F \) (after rescaling \( J \) as \( gJ \))

\[ F = ig \left[ \begin{array}{c} F_L - \frac{1}{\sqrt{2}} \tilde{F}_{BL} + 2ig\Phi^\dagger \\
\sqrt{2}(D\Phi)^\dagger \\
F_R - \frac{1}{\sqrt{2}} \tilde{F}_{BL} + 2ig\Phi^\dagger \end{array} \right] \] (13)
where \( W_{LR} = W_{i,R} \), \( \tilde{F}_{BL} = F_{BL} \cdot I = d W_{BL} \cdot I \), \( F_{L,R} = (F_{i,L,R})^\tau \), \( \tau^\mu = (d W_{i,L,R} + i g (W_{LR} \wedge W_{LR})) \), and \( DF = d \Phi + ig W_{i} \Phi - ig W_{i} \tilde{\Phi} \). The corresponding action \( S = \int 1/4 \sigma^2 [F \cdot F]^* \) now reads as

\[
S = \left\{ \begin{array}{l}
\left( 1/2 (F_L)^2 + (F_R)^2 \right)
+ \frac{1}{2} F_{BL}^2 + F_{BL}^2 - \text{Tr} \left[ (DF)^2 + (DF)^* \right] \\
+ \frac{1}{2} \lambda \left[ \text{Tr} \left[ (\Phi^4)^2 + (\Phi^4)^* \right] + \text{Tr} \left[ (\Phi^4)^2 + (\Phi^4)^* \right] \right]
\end{array} \right.
\]

where \( \lambda \equiv g^2 \). In 4 dimensions, with the metric \( g_{\mu \nu} = \text{diag}(1, 1, 1, 1) \), the Lagrangian (again with the rescaling \( g \to g/2 \)) becomes

\[
\mathcal{L} = -\frac{1}{4} F_{L \mu \nu} F_{L}^{\mu \nu} - \frac{1}{4} F_{R}^{\mu \nu} F_{R}^{\mu \nu} - \frac{1}{4} F_{BL \mu \nu} F_{BL}^{\mu \nu} + \text{Tr} \left[ (D_{\mu} \Phi)^2 + (D_{\mu} \Phi)^* \right] - \lambda \text{Tr} \left[ (\Phi^4)^2 + (\Phi^4)^* \right] .
\]

This can be accomplished by a doublet as well. The advantage of the triplet representation is that it can yield a Majorana mass term for the right-handed neutrino.

The observed Higgs boson mass from \( SU(2)/2 \)

Let us now discuss how the observed Higgs mass comes about. We have seen that both \( SU(2)/1 \) and \( SU(2)/2 \) embeddings predict the scale of new physics as \( \sim 4 \) TeV, provided in the latter case that the \( SU(2)/2 \) emerges at the same scale as where the \( SU(2)_L \times SU(2)_R \times U(1)_{B-L} \) breaks down to \( SU(2)_L \times U(1)_Y \). Moreover, they require the same boundary condition at 4 TeV. This makes the \( SU(2)/2 \) embedding more appealing since there are a variety of terms that can bring the Higgs mass down to its measured value. In this section, we will investigate the simplest option as an example. We will assume that only a scalar singlet survives dominantly at low energies (\( \sim M_Z \)) which is responsible for the mass of the right-handed neutrino and which comes out naturally in the Spectral SM \( [12] \). The model in which the SM is extended with a scalar has been worked out before in detail in the contexts of vacuum stability of the SM \( [20] \) and dark matter \( [21] \). We will explore the parameter space of this model in the framework of \( SU(2)/2 \). The RG equations can be written as

\[
\frac{d h_i}{d \mu} = \frac{h_i}{\lambda_{HS}} \left( \frac{9}{(4\pi)^2} \left( \frac{9}{2} h_i^2 + 2 h_i^2 - \left( \frac{17}{12} g^2 + \frac{9}{4} g^2 + 8 g^2 \right) \right) \right),
\]

\[
\frac{d h_r}{d \mu} = \frac{h_r}{\lambda_{HS}} \left( \frac{3 h_r^2 + 6 h_r^2 - \left( 2 \lambda h_r + 3 g^2 \right) \lambda - 2 h_r^2}{(4\pi)^2} \right),
\]

\[
\frac{d \lambda}{d \mu} = \frac{1}{(4\pi)^2} \left( \frac{(12 h_i^2 + 4 h_i^2 - 3 g^2 + 9 g^2) \lambda - 2 h_r^2 - 6 h_i^2 + 2 \left( 12 \lambda + 2 \lambda_{HS} + \frac{3}{16} (g^4 + 2 g^2 g^2 + 3 g^4) \right)}{(4\pi)^2} \right),
\]

\[
\frac{d \lambda_{HS}}{d \mu} = \frac{\lambda_{HS}}{(4\pi)^2} \left( \frac{6 h_i^2 + 2 h_r^2 + \frac{3}{2} g^2 + \frac{9}{2} g^2 + 2 \lambda_{HS}}{(4\pi)^2} \right)
\]

\[
\frac{d \lambda_{HS}}{d \mu} = \frac{1}{(4\pi)^2} \left( 8 \lambda_{HS} + 18 \lambda_{3} \right),
\]

where \( h_i \) and \( h_r \) are the top-quark and right-handed neutrino Yukawa couplings, \( \lambda \) and \( \lambda_{HS} \) are the Higgs and the singlet quartic couplings, and \( \lambda_{HS} \) is the Higgs-singlet coupling. The boundary conditions we use are \( h_i(M_Z) = 0.997 \), obtained from \( h_i(M_Z) = \sqrt{2} M_v / v \), and \( \lambda(A_R) = g^2(A_R) / 2 \), where the latter is fixed by the \( SU(2)/2 \) construction. We also assume \( h_r \sim 10^{-6} \), which is necessary to generate the correct light neutrino mass from the TeV scale seesaw, if the Dirac mass \( M_D \approx M_v \).

There are still two more boundary conditions, corresponding to ones on \( \lambda_S(A_R) \) and \( \lambda_{HS}(A_R) \), which are not fixed by \( SU(2)/2 \). The mass of the Higgs can be determined by using \( [12] \)

\[
M_H^2 = \lambda v^2 + \lambda_S v_R^2 - \sqrt{(\lambda v^2 - \lambda_S v_R^2)^2 + 4 \lambda_{HS} v^2 v_R^2} \\
\approx 2 \lambda v^2 \left( 1 - \frac{\lambda_{HS}}{\lambda S} \right),
\]

where \( v_R = A_R \approx 4 \) TeV in our case. The correlation between the values for \( \lambda_S(A_R) \) and \( \lambda_{HS}(A_R) \) for the correct Higgs mass is shown in FIG. 1, which represents the predictions of \( SU(2)/2 \) at 4 TeV. The plot shows some values (0.15 – 0.25) in the perturbative region. We can also find larger values for these couplings as long as

\[ \text{Either } \kappa \text{ or } \kappa' \text{ must be very small or vanishing as required by the suppression of the flavor changing neutral-currents (FCNC) } [23]. \]

\[ \text{This can be accomplished by a doublet as well. The advantage of the triplet representation is that it can yield a Majorana mass term for the right-handed neutrino.} \]
I give a geometric meaning to the low energy world, which also offers an explanation for the robustness of the SM. However, the model does not predict the Higgs mass correctly. Therefore, in this emergent geometric approach, we introduce new physics in the form of $SU(2/2)$ which involves the left-right symmetric model ($SU(2)_L \times SU(2)_R \times U(1)_{B-L}$). Although this formalism does not uniquely predict the Higgs mass (thus it is not the unique extension of $SU(2)/1$), we show that there is an available parameter space in this model which accommodates the observed mass of the Higgs.

This formalism predicts the scale of the onset of new physics (the left-right symmetric model) as 4 TeV. In addition to the usual implications of the TeV scale left-right symmetric model, it also predicts constraints, presumably valid at 4 TeV, which relate the quartic Higgs and Yukawa couplings to the gauge coupling of $SU(2)_L$. The latter brings the problem of Yukawa coupling universality which should be lifted via some suitable mechanism, e.g. taking into account mixing with heavy states.

Given the observation made in Ref. [12] regarding the violation of decoupling in the Higgs sector, and given the similarities between the superconnection approach and the Spectral SM, this violation of decoupling in the Higgs sector could be viewed in the context of non-commutative geometry as indicating the mixing of the UV and IR degrees of freedom. Similar UV/IR mixing is known in the simpler example of non-commutative field theory [22] and is expected to appear in the more general context of non-perturbative quantum gravity [23]. In view of such non-decoupling, one could imagine that the appearance of the Pati-Salam structure (as well as the embedded SM) might be expected at a low energy scale of 4 TeV, and conversely, the Pati-Salam structure (and the embedded SM) might point to some unique features of the high energy physics of quantum gravity. In this context, we should briefly mention the observations made in Ref. [10] about the special nature of the Pati-Salam group in certain constructions of string vacua. This opens an exciting possibility of new experimental probes of fundamental short distance physics.

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