Symmergent Gravity and Seesawic BSM

Durmuş Demir

SABANCI UNIVERSITY
ISTANBUL, TURKEY

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Facts & Needs

quarks, leptons

strong ($g$)

EM ($\gamma$)

weak ($W^{\pm}, Z$)

inertial ($H$)

SM

BSM

dark matter

axion

flavon

right-handed neutrino

inflaton

metric ($g_{\mu\nu}$)

connection ($g\Gamma^\lambda_{\mu\nu}$)

GR

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Symmergent Gravity
SM cannot hold beyond $\Lambda_W = 550 \text{ GeV}$ since thereat correction to the Higgs mass exceeds the LHC result:

$$\delta m^2_H = c_H \Lambda^2_W = (m^2_H)_{LHC}$$
SM’s UV Extension (Experiment)

\[ \Lambda_{LHC} = \text{TeV}/s \]

\[ \delta m_H^2 = c_H \left( -\Lambda_W^2 + \Lambda_{LHC}^2 \right) \gg \left( m_H^2 \right)_{LHC} \]

... but LHC revealed that SM holds good up to TeV’s with no indication of the SM-induced large correction.
having already crossed the forbidden border $\Lambda_W$, SM can extend out to high scales $\Lambda_U$, presumably with a BSM sector, such that $\Lambda_U \gtrsim m_{BSM}$ just as $\Lambda_W \gtrsim m_{SM}$
SM’s UV Overextension (\textit{a posteriori} BSM)

... but having no BSM signal from LHC and DM searches it is reasonable to start with “pure SM” and a “putative \(\Lambda_U\)” and determine BSM and \(\Lambda_U\) from physical consistency.
Effective SM

\[ F(E < \Lambda_W) \quad F(\Lambda_W \leq E \leq \Lambda_U) \]

\[ e^{iS_{eff}(\eta, F)} = \int_{[\Lambda_W]}^{[\Lambda_U]} D F e^{iS(\eta, F, F)} \]

\[ F = \text{high-frequency modes} \quad \text{(integrated out!)} \]

\[ F = \text{low-frequency modes} \quad \text{(survive in } S_{eff} \text{!)} \]

\[ \eta_{\mu \nu} = \text{flat metric} \]
Effective SM

\[ S_{\text{eff}}(\eta, F) = S_{\text{tree}}(\eta, F) + \delta S_{\text{log}}(\eta, F) + \delta S_{\text{pow}}(\eta, H, V_\mu) \]

\[ \delta S_H + \delta S_O + \delta S_V \]

\[ -\int d^4x \sqrt{-\eta} c_H (\Lambda^2_U - \Lambda^2_W) H^\dagger H \]

\[ -\int d^4x \sqrt{-\eta} \left\{ c_O (\Lambda^4_U - \Lambda^4_W) + c_F m^2_F (\Lambda^2_U - \Lambda^2_W) \right\} \]

\[ \sum_{V=\gamma,g,W,Z} \int d^4x \sqrt{-\eta} c_V (\Lambda^2_U - \Lambda^2_W) \text{Tr}[V_\mu V^{\mu}] \]
$S_{\text{eff}}(\eta, F) = S_{\text{tree}}(\eta, F) + \delta S_{\text{log}}(\eta, F) + \delta S_{\text{pow}}(\eta, H, V_\mu)$

$V = V_0 + \tilde{c}_F M_F^4 \log \frac{\Lambda_W}{\Lambda_U} + c_F M_F^2 (\Lambda_U^2 - \Lambda_W^2) + c_O (\Lambda_U^4 - \Lambda_W^4)$

cosmological constant problem (CCP)
\[ S_{\text{eff}}(\eta, F) = S_{\text{tree}}(\eta, F) + \delta S_{\log}(\eta, F) + \delta S_{\text{pow}}(\eta, H, V_\mu) \]

\[ m^2_H = m^2_{H0} + \hat{c}_F M^2_F \log \frac{\Lambda_W}{\Lambda_U} + c_H \left( \Lambda_U^2 - \Lambda_W^2 \right) \]

big hierarchy problem (BHP)
Problem With $W$ & $Z$ Masses

\[ S_{\text{eff}}(\eta, F) = S_{\text{tree}}(\eta, F) + \delta S_{\log}(\eta, F) + \delta S_{\text{pow}}(\eta, H, V_\mu) \]

\[ m_Z^2 = m_{Z0}^2 + \tilde{c}_F M_F^2 \log \frac{\Lambda_W}{\Lambda_U} + c_Z (\Lambda_U^2 - \Lambda_W^2) \]

\[ m_W^2 = m_{W0}^2 + \tilde{c}_F M_F^2 \log \frac{\Lambda_W}{\Lambda_U} + c_W (\Lambda_U^2 - \Lambda_W^2) \]

big hierarchy problem (BHP)
Problem With Photon & Gluon Masses

\[ S_{\text{eff}}(\eta, F) = S_{\text{tree}}(\eta, F) + \delta S_{\text{log}}(\eta, F) + \delta S_{\text{pow}}(\eta, H, V_\mu) \]

\[ m_{\gamma}^2 = 0 + 0 + c_{\gamma}(\Lambda_U^2 - \Lambda_W^2) \]

\[ m_g^2 = 0 + 0 + c_g(\Lambda_U^2 - \Lambda_W^2) \]

charge & color breaking (CCB)
\( \delta S_H \) and \( \delta S_V \) can’t be included in a renormalization of \( S_{tree} \):

- \( m_{\gamma,g}^2 = 0 \) can’t absorb nonzero \( \delta m_{\gamma,g}^2 = c_{\gamma,g}(\Lambda_U^2 - \Lambda_W^2) \)

- \( \Lambda_U \) is “physical” (not a regularization scale!)
Problem With Incorporating Gravity Into Effective SM

\[ S_{\text{eff}}(\eta) \xrightarrow{\eta_{\mu\nu} \leftrightarrow g_{\mu\nu}} S_{\text{eff}}(g) \text{ by “equivalence principle” (EP)} \]

\[ S_{\text{eff}}(g) \xrightarrow{\text{curvature}} S_{\text{eff}}(g) - \int d^4x \sqrt{g}\left\{ ?R(g) + ?R^2(g) + ?(\ldots) \right\} \]

incalculable, arbitrary terms since loops had already been used up!

Effective (not classical) FTs don’t allow “curvature-by-hand”!

It therefore is necessary to find a mechanism that creates curvature out of various scales \((\Lambda_U, \Lambda_W, \ldots)\) in \(S_{\text{eff}}(\eta)\)!
Physically, CCP, BHP, CCB and gravity are all crucial.

Traditionally, priority has always been given to BHP.

Pivotaly, however, priority is better be given to CCB since its neutralization can lay foundation for a symmetry-based mechanism that may have a say on CCP, BHP and gravity.
\[
\delta S_V(\eta) \rightarrow \hat{\delta S}_V(\eta)
\]

\[
\delta S_V(\eta) = \delta S_V(\eta) + I_V(\eta) - I_V(\eta) \equiv \hat{\delta S}_V(\eta)
\]

- This is a trivial identity in that the kinetic structure

\[
I_V(\eta) = \int d^4x \sqrt{-\eta} \frac{c_V}{2} \text{Tr}[V_{\mu\nu} V^{\mu\nu}]
\]

is added and subtracted back!
\[ \delta S_V(\eta) \xrightarrow{\text{a trivial identity}} \hat{\delta} S_V(\eta) \]

- Expand \( \delta S_V(\eta) \), expand \( I_V(\eta) \) but keep \( I_V(\eta) \):

\[
\hat{\delta} S_V(\eta) = \int d^4x \sqrt{-\eta} c_V (\Lambda^2_U - \Lambda^2_W) \text{Tr}[V_\mu V^\mu]
\]

\[
+ \int d^4x \sqrt{-\eta} c_V \text{Tr}[V^\mu (-D^2 \eta_{\mu\nu} + D_\mu D_\nu + V_{\mu\nu})V^\nu]
\]

\[
+ \int d^4x \sqrt{-\eta} c_V \text{Tr}[\partial_\nu (V_\mu V^{\mu\nu})]
\]

\[
- I_V(\eta)
\]

\[ D = \partial - V \]
\[ \hat{\delta S}_V(\eta) \xrightarrow{\text{curved metric } g_{\mu\nu}} \hat{\delta S}_V(g) \]

\[
\hat{\delta S}_V(\eta) \xrightarrow{\eta_{\mu\nu} \xrightarrow{g_{\mu\nu}}  \partial_\mu \xrightarrow{g \nabla_\mu}} \int d^4x \sqrt{-g} c_V (\Lambda_U^2 - \Lambda_W^2) \text{Tr}[V_\mu V^\mu] \\
+ \int d^4x \sqrt{-g} c_V \text{Tr}[V^\mu (-g D^2 g_{\mu\nu} + g D_\mu g D_\nu + V_{\mu\nu}) V^\nu] \\
+ \int d^4x \sqrt{-g} c_V \text{Tr}[g \nabla_\nu (V_\mu V^{\mu\nu})] \\
- I_V(g)
\]

\[ g D = g \nabla - V \equiv \partial + g \Gamma - V \]

\[ \frac{1}{2} g^{\lambda\rho} (\partial_\nu g_{\mu\rho} + \partial_\mu g_{\rho\nu} - \partial_\rho g_{\mu\nu}) = g \Gamma_\mu^\lambda_{\nu} \]
\[ \delta S_V(g) \rightarrow g_{\mu\nu}, \text{ can } \Lambda_U^2 - \Lambda_W^2 \text{ also morph?} \]

\[ \delta S_V(g) = \int d^4x \sqrt{-g} c V \text{Tr} \left[ V^\mu \left( -g D^2 g_{\mu\nu} + g D_\mu g D_\nu + V_{\mu\nu} + (\Lambda_U^2 - \Lambda_W^2) g_{\mu\nu} \right) V^\nu \right] \]

\[ + \int d^4x \sqrt{-g} c V \text{Tr} \left[ g \nabla_\nu (V_\mu V^{\mu\nu}) \right] \]

\[ - I_V(g) \]

could this be morphed into something else?
\[ \delta \mathcal{S}_V(g) \quad \text{what if } \Lambda_U^2 - \Lambda_W^2 \text{ morphs into curvature?} \]

\[
\delta \mathcal{S}_V(g) = \int d^4x \sqrt{-g} c_V \text{Tr} \left[ V^\mu \left( -g \mathcal{D}^2 g_{\mu\nu} + g \mathcal{D}_\mu g \mathcal{D}_\nu + V_{\mu\nu} + (\Lambda_U^2 - \Lambda_W^2) g_{\mu\nu} \right) V^\nu \right] \\
+ \int d^4x \sqrt{-g} c_V \text{Tr} \left[ g \nabla_\nu (V_\mu V^\mu_\nu) \right] \\
- I_V(g)
\]

just like \( \eta_{\mu\nu} \rightarrow g_{\mu\nu} \), what if \( (\Lambda_U^2 - \Lambda_W^2) g_{\mu\nu} \rightarrow R_{\mu\nu}(^g \Gamma) \)?
The map \((\Lambda^2_U - \Lambda^2_W) g_{\mu\nu} \leftrightarrow R_{\mu\nu}(^g\Gamma)\) turns \(\delta\hat{S}_V(g)\) into:

\[
\delta\hat{S}_V(g, R) = \int d^4x \sqrt{-g_{CV}} \text{Tr}\left[V^\mu\left(-gD^2g_{\mu\nu} + gD_\mu gD_\nu + V_{\mu\nu} + R_{\mu\nu}(^g\Gamma)\right)V^\nu\right]
\]

\[
+ \int d^4x \sqrt{-g_{CV}} \text{Tr}\left[g\nabla_\nu(V_\mu V^{\mu\nu})\right]
\]

\[- I_V(g)
\]

\[= I_V(g) - I_V(g) = 0\]

if \(c_V\left(\frac{\Lambda_W}{\Lambda_U}\right)\) is held unchanged while \((\Lambda^2_U - \Lambda^2_W) g_{\mu\nu} \leftrightarrow R_{\mu\nu}(^g\Gamma)\)
\[
\delta S_V(g, R(g)) = 0, \text{ but } ...
\]

- quite unexpectedly, curvature seems to be the remedy!

- it prevents the CCB if the hierarchy \( \frac{\Lambda_W}{\Lambda_U} \) is preserved 😊

- but \( (\Lambda_U^2 - \Lambda_W^2) g_{\mu \nu} \leftrightarrow R_{\mu \nu} (g \Gamma) \) contradicts with \( \eta_{\mu \nu} \leftrightarrow g_{\mu \nu} \) 😞
\( \frac{\delta \mathcal{S}_V(g)}{\delta S_V(g)} \) what if \( \Lambda^2_U - \Lambda^2_W \) morphs into affine curvature?

\[
\frac{\delta \mathcal{S}_V(g)}{\delta S_V(g)} = \int d^4x \sqrt{-g} c_V \text{Tr} \left[ V^\mu \left( -g D^2 g_{\mu\nu} + g D_\mu g D_\nu + V_{\mu\nu} + \left( \Lambda^2_U - \Lambda^2_W \right) g_{\mu\nu} \right) V^\nu \right] \\
+ \int d^4x \sqrt{-g} c_V \text{Tr} \left[ g \nabla_\nu (V_\mu V^\mu) \right] \\
- I_V(g)
\]

just like \( \eta_{\mu\nu} \hookrightarrow g_{\mu\nu} \), what if \( \left( \Lambda^2_U - \Lambda^2_W \right) g_{\mu\nu} \hookrightarrow \mathbb{R}_{\mu\nu}(\Gamma) \)?

affine connection \( \Gamma^\lambda_{\mu\nu} \neq g \Gamma^\lambda_{\mu\nu} \)

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The map \((\Lambda_U^2 - \Lambda_W^2)g_{\mu\nu} \mapsto \mathbb{R}_{\mu\nu}(\Gamma)\) turns \(\hat{\delta}S_V(g)\) into:

\[
\hat{\delta}S_V(g, \mathbb{R}) = \int d^4x \sqrt{-g} c_V \text{Tr} \left[ V^\mu \left( -g D^2 g_{\mu\nu} + g D_\mu g D_\nu + V_{\mu\nu} + \mathbb{R}_{\mu\nu}(\Gamma) \right) V^\nu \right]
\]

\[
+ \int d^4x \sqrt{-g} c_V \text{Tr} \left[ g \nabla_\nu (V_\mu V^{\mu\nu}) \right]
\]

\[
- I_V(g)
\]

\[
= \int d^4x \sqrt{-g} c_V \text{Tr} \left[ V^\mu \left( \mathbb{R}_{\mu\nu}(\Gamma) - R_{\mu\nu}(g\Gamma) \right) V^\nu \right]
\]

if \(c_V(\frac{\Lambda_W}{\Lambda_U})\) is held unchanged while \((\Lambda_U^2 - \Lambda_W^2)g_{\mu\nu} \mapsto \mathbb{R}_{\mu\nu}(\Gamma)\)
$\delta S_V(g, R) \neq 0$, but...

$\begin{align*}
\text{\large \blacktriangleright} \quad & \left( \Lambda^2_U - \Lambda^2_W \right) g_{\mu\nu} \hookrightarrow R_{\mu\nu}(\Gamma) \text{ doesn't contradict with } \eta_{\mu\nu} \hookrightarrow g_{\mu\nu} \smiley \\
\text{\large \blacktriangleright} \quad & \text{but it doesn't prevent CCB either} \frowny
\\
\text{\large \blacktriangleright} \quad & \text{it can prevent CCB only if } R_{\mu\nu}(\Gamma) \leadsto R_{\mu\nu}(g\Gamma) \text{ dynamically} \smiley
\end{align*}$
Gravity can be properly incorporated into flat spacetime effective SM of UV scale $\Lambda_U$, IR scale $\Lambda_W$, and metric $\eta_{\mu\nu}$ by first letting

$\eta_{\mu\nu} \rightarrow g_{\mu\nu}$

and then

$(\Lambda_U^2 - \Lambda_W^2) g_{\mu\nu} \rightarrow R_{\mu\nu}(\Gamma) @ \text{fixed } \frac{\Lambda_W}{\Lambda_U}$

so that in the limit

$R_{\mu\nu}(\Gamma) \sim R_{\mu\nu}^g(\Gamma)$

CCB disappears and GR arises as gauge symmetry-restoring emergent gravity theory or “SYMMERGENT GRAVITY”, in brief.
## Symmergent Gravity

<table>
<thead>
<tr>
<th>Physical Quantities in Flat Spacetime</th>
<th>Physical Quantities in Curved Spacetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_{\mu\nu}$</td>
<td>$g_{\mu\nu}$</td>
</tr>
<tr>
<td>$(\Lambda_U^2 - \Lambda_W^2)\eta_{\mu\nu}$</td>
<td>$\mathcal{R}_{\mu\nu}(\Gamma)$</td>
</tr>
</tbody>
</table>

\[
\downarrow
\]

\[
\Gamma^\lambda_{\mu\nu} = \Gamma^\lambda_{\mu\nu}(g) + f(g, V, H)
\]

\[
\downarrow
\]

\[
\mathcal{R}_{\mu\nu}(\Gamma) = R_{\mu\nu}(g) + F(g, V, H)
\]

- GR
- Planck-suppressed

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Symmergent Gravity
Symmergent Gravity: BHP Disappears

\[ \int d^4 x \sqrt{-\eta} c_H (\Lambda_U^2 - \Lambda_W^2) H^\dagger H \]

\[ \int d^4 x \sqrt{-g} \frac{c_H}{4} g^\mu\nu \mathcal{R}_{\mu\nu}(\Gamma) H^\dagger H \]

\[ \rightarrow \text{BHP disappears!} \]

\[ \text{(but LHP stays!)} \]
Symmergent Gravity: CCP Recedes

\[ \int d^4 x \sqrt{-\eta} \left\{ c_O (\Lambda_U^2 - \Lambda_W^2)^2 + \left( 2c_O \Lambda_W^2 + c_F M_F^2 \right) (\Lambda_U^2 - \Lambda_W^2) \right\} \]

\[ \int d^4 x \sqrt{-g} \left\{ \frac{c_O}{16} \left( g^{\mu\nu} R^{\mu\nu}_{\mu\nu}(\Gamma) \right)^2 + \left( \frac{c_O}{2} \Lambda_W^2 + \frac{c_F}{4} M_F^2 \right) g^{\mu\nu} R^{\mu\nu}_{\mu\nu}(\Gamma) \right\} \]

\[ \frac{M_{Pl}^2}{2} \]

no contribution left to CC
Symmergent Gravity: Gravitational Constant Necessitates BSM

\[ M_{Pl}^2 = \frac{1}{2} c_O \Lambda_W^2 + \frac{1}{4} c_F M_F^2 \]

\[ \text{1-loop} \quad \frac{1}{64\pi^2} \left( \text{Str}[1] \Lambda_W^2 + \text{Str}[M^2] \right) \]

\[ = \frac{-62}{\Lambda_W^2} \]

wrong sign, wrong size

a BSM sector is necessary!

(BSM fields \( F' = \{ H', V'_\mu, \psi' \} \))
Part of the SM + BSM action containing affine connection $\Gamma_{\mu\nu}^\lambda$:

$$\mathcal{S}_{SM+BSM} \supset \int d^4x \sqrt{-g} \left\{ - \frac{M_{Pl}^2}{2} g^{\mu\nu} \mathcal{R}_{\mu\nu}(\Gamma) - \frac{(c_O + c_{O'})}{16} \left( g^{\mu\nu} \mathcal{R}_{\mu\nu}(\Gamma) \right)^2 \right\}$$

$$- \sum_{\varphi=H,H'} \int d^4x \sqrt{-g} \frac{c_\varphi}{4} \varphi^\dagger \varphi g^{\mu\nu} \mathcal{R}_{\mu\nu}(\Gamma)$$

$$+ \sum_{V=V,V'} \int d^4x \sqrt{-g} c_V \text{Tr}\left[ \mathcal{V}^\mu \left( \mathcal{R}_{\mu\nu}(\Gamma) - R_{\mu\nu}(g\Gamma) \right) \mathcal{V}^\nu \right]$$

The first step towards the GR is to integrate out $\Gamma_{\mu\nu}^\lambda$!

This step can lead to GR only if the Levi-Civita connection $g\Gamma_{\mu\nu}^\lambda$ is the mere geometrical variable left!
Symmergent Gravity

**Equation of motion for** $\Gamma_{\mu\nu}^\lambda$:

$$\frac{\delta}{\delta\Gamma_{\mu\nu}^\lambda} S_{SM+BSM} = 0 \implies \nabla_\lambda \left( \sqrt{-g} Q_{\mu\nu} \right) = 0$$

**Solution for** $\Gamma_{\mu\nu}^\lambda$:

$$\Gamma_{\mu\nu}^\lambda = g \Gamma_{\mu\nu}^\lambda + \frac{1}{2} (Q^{-1})^{\lambda\gamma} \left( g \nabla_\mu Q_{\nu\gamma} + g \nabla_\nu Q_{\gamma\mu} - g \nabla_\gamma Q_{\mu\nu} \right)$$

**with the definition**

$$Q_{\mu\nu} = \left( \frac{M_{Pl}^2}{2} + \frac{c_\varphi}{4} \varphi^\dagger \varphi + \frac{(c_O+c_{O'})}{8} g^{\alpha\beta} R_{\alpha\beta}(\Gamma) \right) g_{\mu\nu} - c_\mathcal{V} \text{Tr}[\mathcal{V}_\mu \mathcal{V}_\nu]$$

↓

this term must disappear for GR to arise!
Symmergent Gravity  
\[
\integrate out \quad \Gamma^\lambda_{\mu\nu} \text{ with } N_b = N_f \rightarrow \text{GR}
\]

\[Q_{\mu\nu} \not\supset R_{\alpha\beta}(\Gamma)\]
\[c_O + c_{O'} = 0\]
\[\text{or } \text{Str}[1] + \text{Str}[1'] = 0\]
\[\text{or } N_b - N_f = 0\]
\[(\text{as in SUSY models})\]

\[Q_{\mu\nu} \supset R_{\alpha\beta}(\Gamma)\]
\[c_O + c_{O'} \neq 0\]
\[\text{or } \text{Str}[1] + \text{Str}[1'] \neq 0\]
\[\text{or } N_b - N_f \neq 0\]
\[(\text{as in non-SUSY models})\]

\[\downarrow \]

no new dof in \[\Gamma^\lambda_{\mu\nu}\]
GR 😊

\[\downarrow \]

new dof in \[\Gamma^\lambda_{\mu\nu}\]
non-GR 😞

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Symmergent Gravity

\[ Q_{\mu \nu} \xrightarrow{N_b=N_f} \dot{Q}_{\mu \nu} = \left( \frac{M_{Pl}^2}{2} + \frac{c_\varphi}{4} \varphi^\dagger \varphi \right) g_{\mu \nu} - c_\gamma \text{Tr}[\mathcal{V}_\mu \mathcal{V}_\nu] \]

\[ \Gamma^\lambda_{\mu \nu} = g \Gamma^\lambda_{\mu \nu} + \frac{1}{M_{Pl}^2} \left( g \nabla_\mu \dot{Q}^\lambda_\nu + g \nabla_\mu \dot{Q}^\lambda_\nu - g \nabla^\lambda \dot{Q}_{\mu \nu} \right) + \frac{1}{M_{Pl}^4} (\ldots) \]

\[ \mathcal{R}_{\mu \nu}(\Gamma) = R_{\mu \nu}(g \Gamma) + \frac{1}{M_{Pl}^2} (\nabla^2)^{\alpha \beta}_{\mu \nu} \dot{Q}_{\alpha \beta} + \frac{1}{M_{Pl}^4} (\ldots) \]

\[ g \nabla^\alpha \nabla_\mu \delta_\nu^\beta + g \nabla^\alpha \nabla_\nu \delta_\mu^\beta - g \square \delta_\mu^\alpha \delta_\nu^\beta - g \nabla_\nu g \nabla_\mu g^{\alpha \beta} \]
The solution of the affine curvature results in the reductions:

\[
\int d^4x \sqrt{-g} \frac{M^2_{Pl}}{2} g^{\mu\nu} R_{\mu\nu}(\Gamma) \sim \int d^4x \sqrt{-g} \left\{ \frac{M^2_{Pl}}{2} g^{\mu\nu} R_{\mu\nu}(g\Gamma) + \frac{1}{M^2_{Pl}} (\cdots) \right\}
\]

\[
\int d^4x \sqrt{-g} \varphi^\dagger \varphi g^{\mu\nu} R_{\mu\nu}(\Gamma) \sim \int d^4x \sqrt{-g} \left\{ \varphi^\dagger \varphi g^{\mu\nu} R_{\mu\nu}(g\Gamma) + \frac{1}{M^2_{Pl}} (\cdots) \right\}
\]

\[
\int d^4x \sqrt{-g} \text{Tr} \left[ \mathcal{V}^\mu \left( R_{\mu\nu}(\Gamma) - R_{\mu\nu}(g\Gamma) \right) \mathcal{V}^\nu \right] \sim \int d^4x \sqrt{-g} \left\{ 0 + \frac{1}{M^2_{Pl}} (\cdots) \right\}
\]

which make up the Einstein-Hilbert action + HO terms:

\[
S_{SM+BSM} \supset -\int d^4x \sqrt{-g} \left\{ \left( \frac{M^2_{Pl}}{2} + \frac{c_\varphi}{4} \varphi^\dagger \varphi \right) R(g) + \frac{1}{M^2_{Pl}} (\cdots) \right\}
\]

only scalars \( \varphi \) and vectors \( \mathcal{V}_\mu \)
$S_{SM+BSM} \supset \int d^4x \sqrt{-g}\left\{ \frac{1}{M_{Pl}^2} \hat{Q}^{\mu\nu} \left( \nabla^2 \right)_{\mu\nu}^{\alpha\beta} \hat{Q}_{\alpha\beta} + \frac{1}{M_{Pl}^4} (\cdots) \right\}$

no mass terms for $h, \gamma, g, \ldots$

$\begin{align*}
\frac{3c_{H'} c_H \langle H' \rangle}{2M_{Pl}^2} & \rightarrow p^2 \\
\frac{c_{H'} c_V \langle H' \rangle}{M_{Pl}^2} & \rightarrow (p_\mu p_\nu - p^2 \eta_{\mu\nu})
\end{align*}$
\[ S_{SM+BSM} \supset S_{tree}(g, g\Gamma, F) + S_{log}(g, g\Gamma, F, \Lambda^2 \log \frac{\Lambda_W}{\Lambda_U}) \]

\[ + S'_{tree}(g, g\Gamma, F') + S'_{log}(g, g\Gamma, F', M'_F, \log \frac{M'_{F'}}{\Lambda_U}) \]

\[ V_{eff}^{(1)} = V_{SM}^{(1)} + \frac{1}{64\pi^2} \text{Str} \left[ M'^4 \left( \log \frac{M'^2}{\Lambda^2_U} - \frac{1}{2} \right) \right] \]

\[ \mathcal{O}(\Lambda^4_W) \quad \mathcal{O}(M^4_{Pl}) \]
BSM Sector: It Doesn’t Have To Couple To SM

\[
M_{Pl}^2 = \frac{1}{2} (c_O + c_{O'}) \Lambda_W^2 + \frac{1}{4} (c_F M_F^2 + c_{F'} M_{F'}^2)
\]

\[
F = H, V_\mu, \psi
\]

\[
F' = H', V'_\mu, \psi'
\]

▶ The BSM is highly “unusual” because

- SM and BSM do not have to interact!
  
  \textit{(cf. SUSY, Extra Dimensions, Technicolor)}

- BSM can have any scale and spectrum
  
  provided that \( M_{Pl} \) comes out right!
BSM Sector: It Can Even Be Ebony (Pitch-Dark)

BSM

decoupled from SM (Ebony BSM)

coupled to SM

SM-singlet (Dark BSM)

SM-charged (Visible BSM)
BSM Sector: It Is Richer Than The Known BSM’s

Symmergence:

SUSY, Extra Dimensions, Technicolor:

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BSM Sector: Seesawic Couplings to SM

\[ S_{SM+BSM} \supset \int d^4x \sqrt{-g} \left\{ \lambda^2 \bar{H} H' H H' + \lambda_{BZ'} B_{\mu\nu} Z'^{\mu\nu} + \lambda_{H N'} \bar{L} H N' \right\} \]

\[ + \sum_{F'=H',Z',N'} \int d^4x \sqrt{-g} \tilde{c}_H \chi^2_{FF'} M_{F'}^2 \log \frac{M_{F'}}{\Lambda_U} H H' \]

electroweak stability: \( \chi^2_{FF'} \lesssim \frac{m_H^2}{M_{F'}^2} \)

legitimate since SM-BSM coupling is not a necessity as in SUSY, Extra Dim & others (symergence is quite hard to exclude!)

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Symmergence Hints At Trans-Planckian SUSY

\[ M_{Pl}^2 = \frac{1}{(16\pi)^2} \text{Str}[M^2] \]

→ mass sum rule in broken SUSY

exact SUSY above \(16\pi M_{Pl}\)?
Symmergence Predicts Einstein Gravity

\[ S_{SM+BSM} \supset - \int d^4 x \sqrt{-g} \left\{ \left( \frac{M^2_{Pl}}{2} + \frac{c_H}{4} H^\dagger H \right) R(g) + \cdots \right\} \]

no higher-curvature terms!

durmuş demir

this is impossible to guarantee in GR!

symmergence predicts Einstein gravity!
Symmergence Predicts Higgs-Curvature Coupling

\[ S_{SM+BSM} \supset - \int d^4x \sqrt{-g} \left\{ \left( \frac{M_{Pl}^2}{2} + \frac{c_H}{4} H^\dagger H \right) R(g) + \cdots \right\} \]

\[ \frac{c_H}{4} = \frac{3}{64\pi^2|\langle H \rangle|^2} \left( 4m_t^2 - 2M_W^2 - M_Z^2 - m_H^2 \right) + \lambda_{HF'} \times (BSM \text{ loops}) \]

\[ \approx 1.29 \times 10^{-2} + \lambda_{HF'} \times (BSM \text{ loops}) \]

\[ \approx 1.29 \times 10^{-2} \]

\[ \text{too small to enable Higgs inflation} \]

(Einstein frame \approx Jordan frame)
Symmergence Predicts Dimensional Regularization

holding \( \log \frac{\Lambda_W}{\Lambda_U} \) unaffected while \( (\Lambda_U^2 - \Lambda_W^2)g_{\mu\nu} \to \mathbb{R}_{\mu\nu}(\Gamma) \)

\[
\log \frac{\Lambda_W}{\Lambda_U} \sim -\frac{1}{\epsilon} - \log \frac{\mu}{\Lambda_W}
\]

\[\delta S_{log} \left( F, \log \frac{\Lambda_W}{\Lambda_U} \right) \text{ in Dim. Reg.}\]

the usual RGEs
Seesawness Necessitates High-Luminosity Colliders

\[ \lambda_{FF'}^2 \]

excluded by LHC

allowed

disallowed

\[ \frac{m_{F'}^2}{m_H^2} \]

high-lumi colliders
Seesawness Limits Dark Matter Mass

- $H'$ is stable provided that $<H'> = 0$
- $H'$ acquires correct relic density if $\lambda_{HH'}^2 \approx 3\times10^{-4} \ (m_{H'}/\text{GeV})$
- and seesawic structure imposes $m_{H'} \leq 400 \ \text{GeV}$
Neutrinos acquire a mass \( m_\nu = \lambda_{HN}^2 \left| \langle H \rangle \right|^2 / M_N \)

and seesawic structure of \( \lambda_{HN} \) imposes \( M_N \leq 1000 \text{ TeV} \)
The real challenge is to understand how CC can be reduced down to \( \frac{m^4}{M_{Pl}^4} \simeq H_0^2 \).

The one-loop vacuum energy

\[
V(\Lambda_U) = V_{tree}(\langle \varphi \rangle) + \frac{1}{64\pi^2} \left( \log \frac{M^2}{\Lambda^2_U} - \frac{1}{2} \right)
\]

is an explicit function of the UV cutoff \( \Lambda_U \).

The CCP might be suppressed for some \( \Lambda_U = \Lambda_U^0 \) as a determination of \( \Lambda_U \). The BSM might help suppress CCP.
Yet To Be Understood: MAG

\[ n_{b'} - n_{f'} \neq 62 \]

\[ \Gamma^\lambda_{\mu\nu} \] involves new degrees of freedom and thus:

- gravity is governed not by GR but by MAG
- charge & color breaking can be strong!
- high curvatures can lead to scale invariance!
Gravity emerges in order to restore the gauge symmetries broken explicitly by the hard UV cutoff. It thus symmerges.

Birth of the gravitational constant necessitates a BSM sector, which does not have to interact with the SM.

BSM involves insular (ebony) and SM-singlet (dark) components. Electroweak stability requires dark-BSM to couple seesawically.

Symmergence predicts Einstein gravity, Higgs-curvature coupling, BSM sector, and Dimensional Regularization.

Seesawic dark-BSM couplings require high-lumi colliders, and bound DM and RH neutrino masses from above.

Trans-Planckian SUSY might have a say on the CCP. Its solution might fix the UV scale.
Thank You For Your Attention

Reference:

*Symmergent Gravity, Seesawic New Physics, and their Experimental Signatures*, arXiv:1901.07244

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