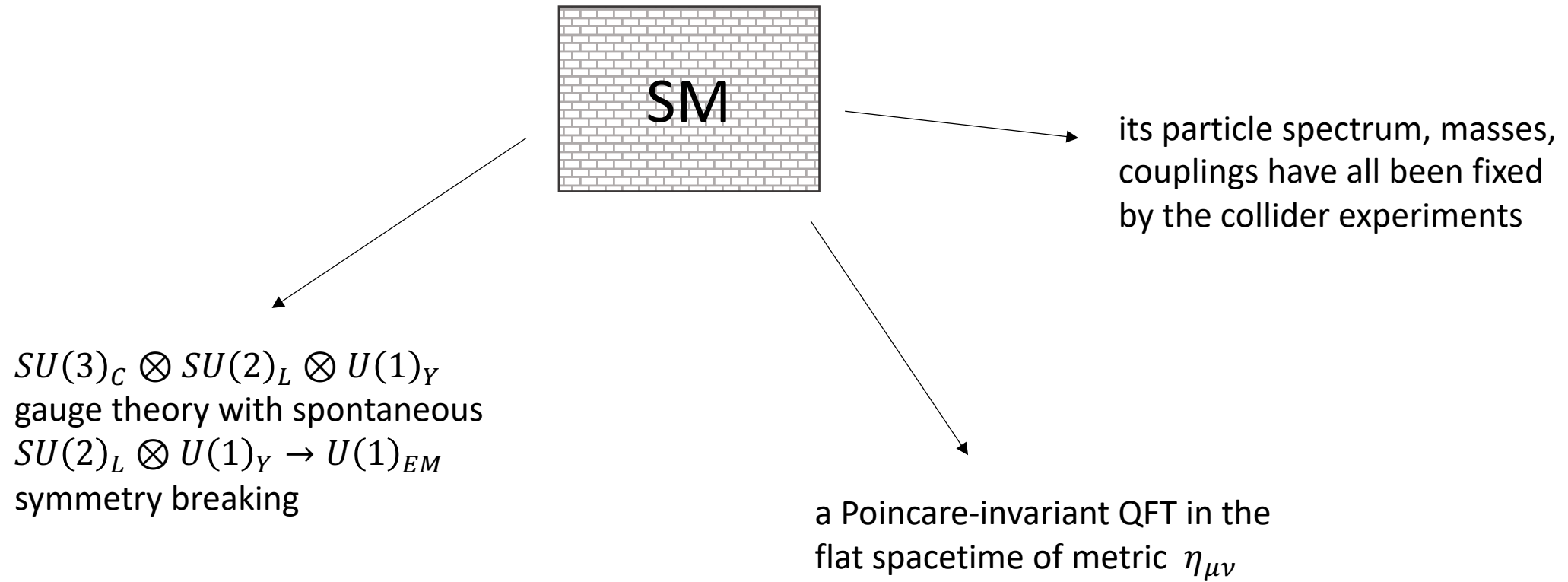


GAUGE INVARIANCE AND QFT-GR BLEND

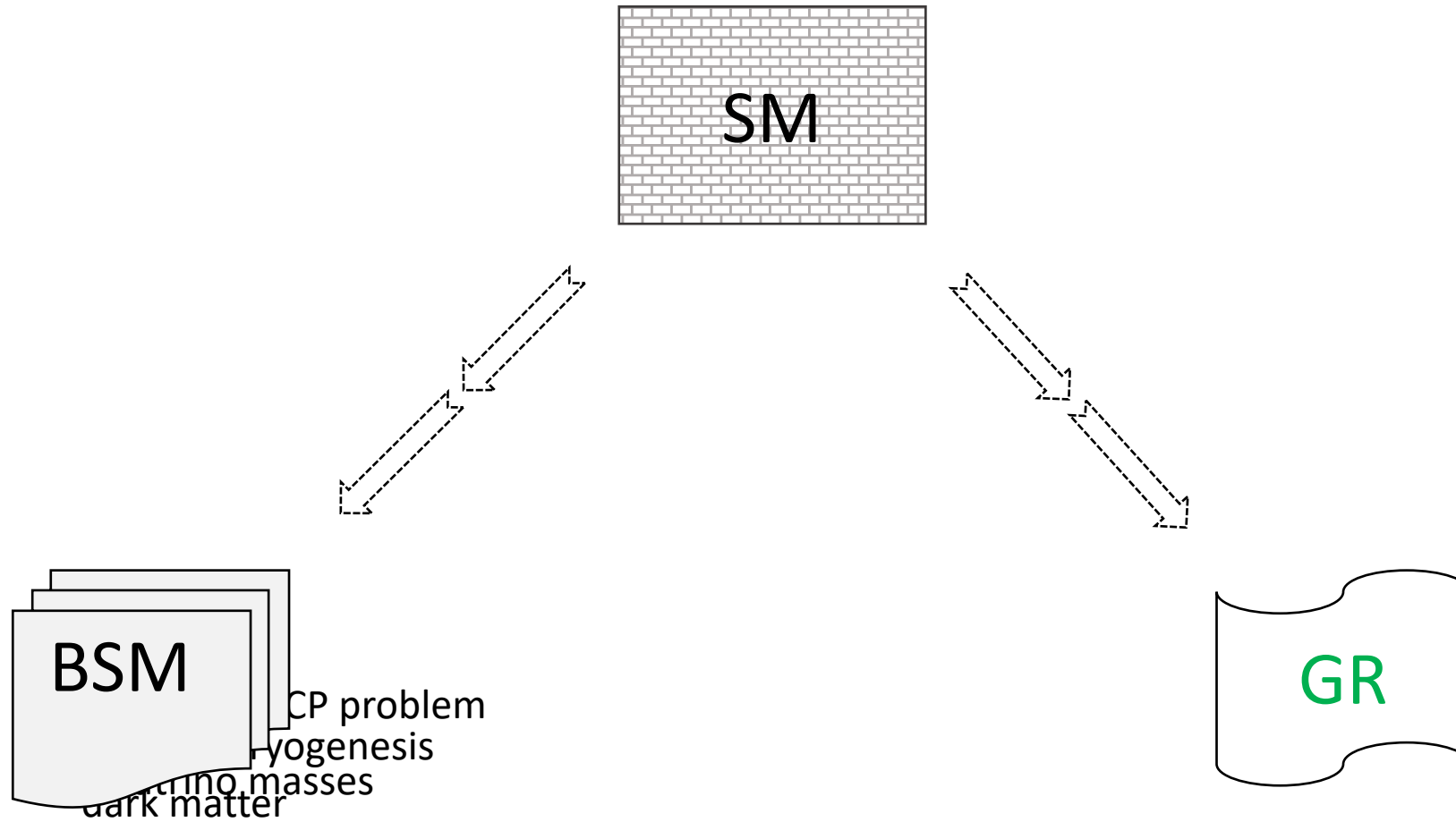
Durmuş Demir



The discovery of the Higgs boson “completed” the Standard Model of elementary particles (SM).



However, there are phenomena which require the SM to be extended/metamorphosed.



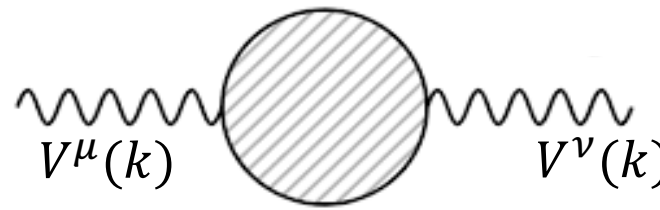
Each extension comes with its own scale and mechanism :

Experimental Fact	Extension of the SM	Mechanism
“neutrinos have mass”	Lepton # breaking at a scale $m_N < \infty$ leads to neutrino mass: $m_N \hookrightarrow m_\nu$	see-saw
“neutron EDM is small”	Peccei-Quinn breaking at a scale $f < \infty$ leads to axion mass: $f \hookrightarrow m_a$	relaxation

Each extension comes with its own scale and mechanism :

Experimental Fact	Extension of the SM	Mechanism
“neutrinos have mass”	<p>Lepton # breaking at a scale $m_N < \infty$ leads to neutrino mass:</p> $m_N \hookrightarrow m_\nu$	see-saw
“neutron EDM is small”	<p>Peccei-Quinn breaking at a scale $f < \infty$ leads to axion mass:</p> $f \hookrightarrow m_a$	relaxation
“gravity exists”	<p>Poincare breaking at a scale $\Lambda_\phi < \infty$ leads to curvature:</p> $\Lambda_\phi^2 \hookrightarrow \mathbb{R}$	equivalence

- As a Poincare-invariant QFT, the SM ends at energies $\sim \Lambda_\phi$ (or distances $\sim 1/\Lambda_\phi$).
- All loop momenta are thus cut off at Λ_ϕ .
- This hard UV cutoff gives $\mathcal{O}(\Lambda_\phi)$ masses to all bosons, including the gauge bosons:



The diagram shows a gauge boson line with momentum k and index μ , labeled $V^\mu(k)$, entering a shaded circular loop. Another gauge boson line with momentum k and index ν , labeled $V^\nu(k)$, exits the loop. A curved arrow points from the loop to the equation below.

$$\equiv V^\mu(k) \{ \Pi(k^2) (k_\mu k_\nu - k^2 \eta_{\mu\nu}) + c_V \Lambda_\phi^2 \eta_{\mu\nu} \} V^\nu(k)$$

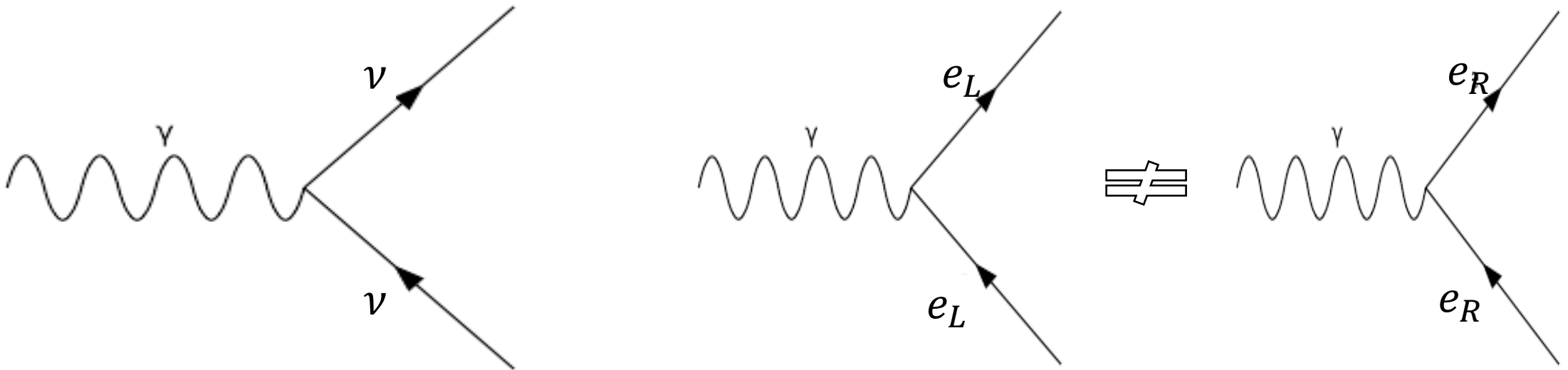
$$\delta S_V(\eta, \Lambda_\phi) = \int d^4x \sqrt{-\eta} \{ c_V \Lambda_\phi^2 + 0 \cdot \log \Lambda_\phi \} \text{tr}[V_\mu V^\mu]$$

The loop factor c_V changes from gauge group to gauge group. Its one-loop values are:

Gauge Boson (V^μ)	Loop Factor (c_V)	Broken Symmetry
$g_\mu^{a=1,\dots,8}$	$c_g = \frac{21}{16\pi^2} g_s^2$	color
$W_\mu^{i=1,\dots,3}$	$c_W = \frac{21}{16\pi^2} g_2^2$	isospin
B_μ	$c_B = \frac{39}{32\pi^2} g_Y^2$	hypercharge

- Color breaking demolishes confinement and destructs therefore all the hadronic structures.
- Isospin is broken explicitly and spontaneously (by $\langle H \rangle \neq 0$).
- Electromagnetism is broken explicitly by $c_W \neq 2 c_B$:

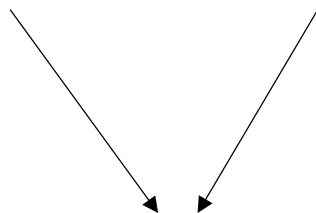
$$\tan 2\tilde{\theta}_W = \frac{(g_2^2 - g_Y^2) \langle H \rangle^2}{(g_2^2 - g_Y^2) \langle H \rangle^2 + 2(c_W - 2c_B)\Lambda_{\phi}^2} \tan 2\theta_W \Rightarrow \partial_\mu J_{EM}^\mu \neq 0$$



- How to prevent charge and color breaking (CCB)?
 - How to ensure spontaneity of the electroweak breaking?
- } no known answer with a physical Λ_{\varnothing} !

In the hope of finding an answer, it proves efficacious to start with this trivial identity:


$$\delta S_V \equiv -I_V + \delta S_V + I_V$$




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

- Keep “ $-I_V$ ” untouched
- Integrate “ $+I_V$ ” by parts, and
- combine it with $\delta S_V(\eta, \Lambda_\phi)$ to get

$$\delta S_V(\eta, \Lambda_\phi) \equiv -I_V(\eta) + \int d^4x \sqrt{-\eta} c_V \text{tr}[V^\mu (-D_{\mu\nu}^2 + \Lambda_\phi^2 \eta_{\mu\nu}) V^\nu + \partial_\mu (V_\nu V^{\mu\nu})]$$


$$D_{\mu\nu}^2 = D^2 \eta_{\mu\nu} - D_\mu D_\nu - V_{\mu\nu}$$

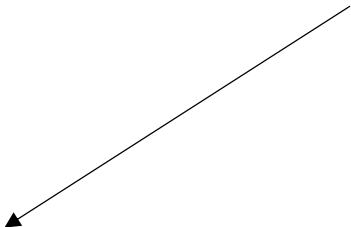

$$D_\mu = \partial_\mu + ig V_\mu$$

Footstep of gravity is a (putative) curved metric $g_{\mu\nu}$. In fact, general covariance

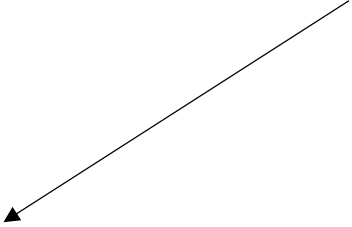
$$\eta_{\mu\nu} \hookrightarrow g_{\mu\nu}$$

takes $\delta S_V(\eta, \Lambda_{\emptyset})$ into curved geometry of $g_{\mu\nu}$:


$$\delta S_V(g, \Lambda_{\emptyset}) \equiv -I_V(g) + \int d^4x \sqrt{-g} c_V \text{tr}[V^\mu (-\mathcal{D}_{\mu\nu}^2 + \Lambda_{\emptyset}^2 g_{\mu\nu}) V^\nu + \nabla_\mu (V_\nu V^{\mu\nu})]$$



$$\mathcal{D}_{\mu\nu}^2 = \mathcal{D}^2 g_{\mu\nu} - \mathcal{D}_\mu \mathcal{D}_\nu - V_{\mu\nu}$$



$$\mathcal{D}_\mu = \nabla_\mu + ig V_\mu$$



$${}^g\Gamma_{\mu\nu}^\lambda = \frac{1}{2} g^{\lambda\rho} (\partial_\mu g_{\nu\rho} + \partial_\nu g_{\rho\mu} - \partial_\rho g_{\nu\mu})$$

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

takes $\delta S_V(\eta, \Lambda_\emptyset)$ into curved geomet

$$\delta S_V(g, \Lambda_\emptyset) \equiv -\int d^4x \sqrt{-g} \Lambda_\emptyset$$

for dynamical $g_{\mu\nu}$ add «by hand» a curvature sector :

$$\delta S_V(g, \Lambda_\emptyset) \rightarrow \delta S_V(g, \Lambda_\emptyset) + \int d^4x \sqrt{-g} \left\{ \widetilde{M}^2 g^{\mu\nu} R_{\mu\nu}(g\Gamma) + \widetilde{c}_2 \left(g^{\mu\nu} R_{\mu\nu}(g\Gamma) \right)^2 + \frac{\widetilde{c}_3}{\widetilde{M}^2} \left(g^{\mu\nu} R_{\mu\nu}(g\Gamma) \right)^3 + \dots \right\}$$

$$+ i g V_\mu$$

$$g\Gamma_{\mu\nu}^\lambda = \frac{1}{2} g^{\lambda\rho} (\partial_\mu g_{\nu\rho} + \partial_\nu g_{\rho\mu} - \partial_\rho g_{\nu\mu})$$

Footstep of gravity is a (putative) curved metric $g_{\mu\nu}$. In fact, general covariance

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

takes $\delta S_V(\eta, \Lambda_\phi)$ into curved geometry of $g_{\mu\nu}$:

$$\delta S_V(g, \Lambda_\phi) \equiv -I_V(g) + \int d^4x \sqrt{-g} c_V \text{tr}[V^\mu (-\mathcal{D}^2 + \mathcal{D}_\nu V^{\mu\nu})]$$

... but $\widetilde{M}^2, \widetilde{c}_2, \widetilde{c}_3, \dots$ are all incalculable constants
(matter loops have been used up in flat geometry)

$$\mathcal{D}_\mu \mathcal{D}_\nu - V_{\mu\nu}$$

$$\mathcal{D}_\mu = \nabla_\mu + ig V_\mu$$

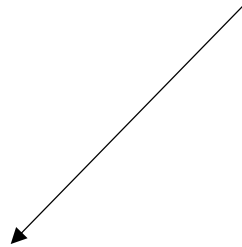
$$g \Gamma_{\mu\nu}^\lambda = \frac{1}{2} g^{\lambda\rho} (\partial_\mu g_{\nu\rho} + \partial_\nu g_{\rho\mu} - \partial_\rho g_{\nu\mu})$$

- By its nature, Λ_{\wp}^2 is to curvature whatever $\eta_{\mu\nu}$ is to $g_{\mu\nu}$.
- Extend thus “general covariance” by an «affine curvature map»

$$\Lambda_{\wp}^2 g_{\mu\nu} \hookrightarrow \mathbb{R}_{\mu\nu}(\Gamma)$$

which takes $\delta S_V(g, \Lambda_{\wp})$ into “metric-affine” geometry:

$$\begin{aligned} \delta S_V(g, \mathbb{R}) &\equiv -I_V(g) + \int d^4x \sqrt{-g} c_V \text{tr} [V^\mu (-\mathcal{D}_{\mu\nu}^2 + \mathbb{R}_{\mu\nu}(\Gamma)) V^\nu + \nabla_\mu (V_\nu V^{\mu\nu})] \\ &= \int d^4x \sqrt{-g} c_V \text{tr} [V^\mu (\mathbb{R}_{\mu\nu}(\Gamma) - R_{\mu\nu}({}^g\Gamma)) V^\nu] \end{aligned}$$



$$\Gamma_{\mu\nu}^\lambda \neq {}^g\Gamma_{\mu\nu}^\lambda$$

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$$\begin{aligned} \delta S_V(g, \mathbb{R}) &\equiv -I_V(g) + \int d^4x \sqrt{-g} \left[(-\mathcal{D}_{\mu\nu}^2 + \mathbb{R}_{\mu\nu}(\Gamma)) V^\nu + \nabla_\mu (V_\nu V^{\mu\nu}) \right] \\ &= \int d^4x \sqrt{-g} \left[(\mathbb{R}_{\mu\nu}(\Gamma) - R_{\mu\nu}(^g\Gamma)) V^\nu \right] \end{aligned}$$

c_V and hence $\log \Lambda_\emptyset$ must be held unchanged while $\Lambda_\emptyset^2 \hookrightarrow \mathbb{R}_{\mu\nu}(\Gamma)$

$$\Gamma_{\mu\nu}^\lambda \neq {}^g\Gamma_{\mu\nu}^\lambda$$

➤ By its nature, Λ_{\emptyset}^2 is to curvature whatever $\eta_{\mu\nu}$ is to $g_{\mu\nu}$.

➤ Extend this covariance may by an «affine curvature map»

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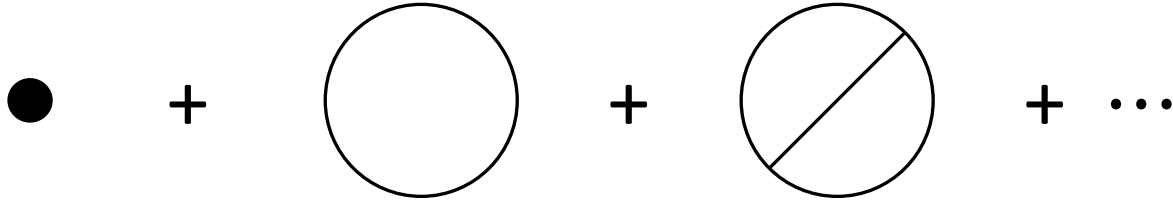
which takes $\delta S_V(g, \Lambda_{\emptyset})$ into “metric-affine”

$$\delta S_V(g, \mathbb{R}) \equiv -I_V(g) + \int d^4x \sqrt{|g|} [V^\mu (-\mathcal{D}_{\mu\nu}^2 + \mathbb{R}_{\mu\nu}(\Gamma)) V^\nu + \nabla_\mu (V_\nu V^{\mu\nu})]$$

CCB gets suppressed if $\mathbb{R}_{\mu\nu}(\Gamma) \rightarrow R_{\mu\nu}(g\Gamma)$,
and this is decided by the dynamics of $\Gamma_{\mu\nu}^\lambda$.

$$\Gamma_{\mu\nu}^\lambda \neq g\Gamma_{\mu\nu}^\lambda$$

- $\Gamma_{\mu\nu}^\lambda$ dynamics is set by curvature sector, and
- curvature sector stems from corrections to the vacuum and Higgs sectors:



$$\delta S_{OH}(\eta, \Lambda_{\wp}) = -\int d^4x \sqrt{-\eta} \{c_4 \text{str}[1] \Lambda_{\wp}^4 + c_m \text{str}[m^2] \Lambda_{\wp}^2 + c_h \Lambda_{\wp}^2 h^2\}$$

$$c_m = 2 c_4 = \frac{1}{32\pi^2}$$

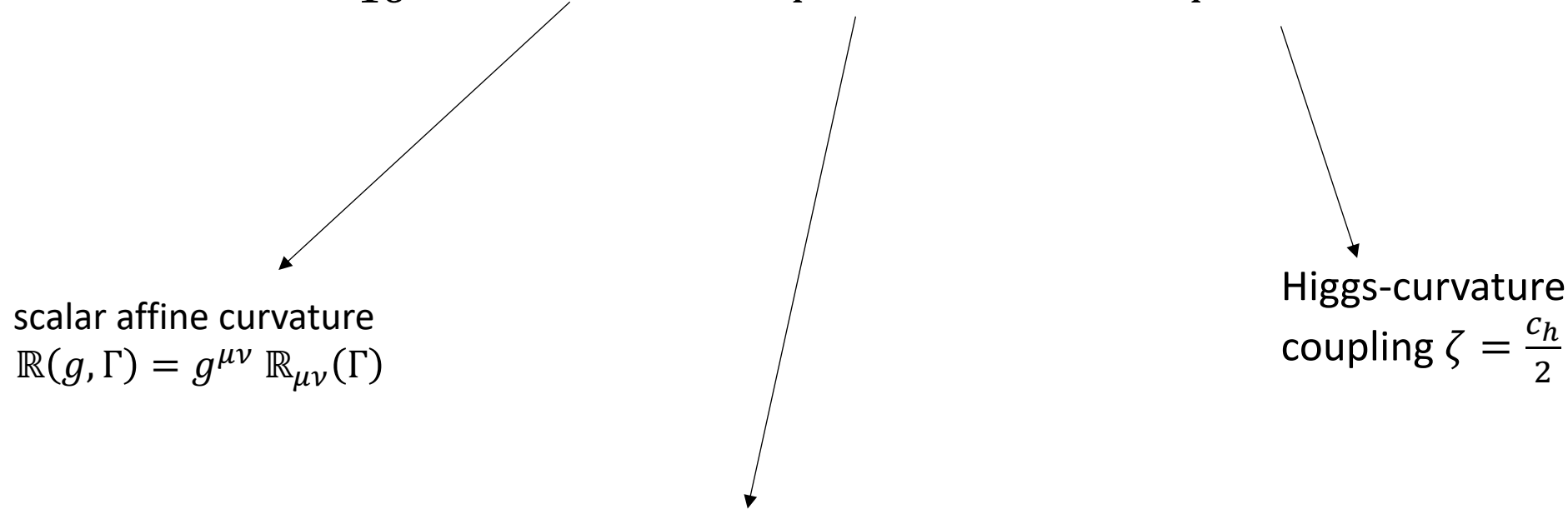
(cosmological constant problem)

$$c_h = \frac{1}{32\pi^2 \Lambda_W^2} (2 m_h^2 + \text{str}[m^2])$$

(gauge hierarchy problem)

Under extended covariance, the vacuum and Higgs sectors lead to the curvature sector:

$$\delta S_{OH}(g, \mathbb{R}) = -\int d^4x \sqrt{-g} \left\{ \frac{c_4}{16} \text{str}[1] (\mathbb{R}(g, \Gamma))^2 + \frac{c_m}{4} \text{str}[m^2] \mathbb{R}(g, \Gamma) + \frac{c_h}{4} \mathbb{R}(g, \Gamma) h^2 \right\}$$



scalar affine curvature
 $\mathbb{R}(g, \Gamma) = g^{\mu\nu} \mathbb{R}_{\mu\nu}(\Gamma)$

Higgs-curvature
coupling $\zeta = \frac{c_h}{2}$

➤ SM masses: $m = \{m_h, m_V, m_f, \dots\}$

➤ $\text{str}[\dots]$ must lead to M_{Pl}^2 !

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$$\delta S_{OH}(g, \mathbb{R}) = -\int d^4x \sqrt{-g} \left\{ \frac{c_4}{16} \text{str}[1] + \frac{c_m}{4} \text{str}[m^2] \mathbb{R}(g, \Gamma) + \frac{c_h}{4} \mathbb{R}(g, \Gamma) h^2 \right\}$$


M_{Pl}^2 comes out wrong
 $(\text{str}[m^2] < 0, \text{str}[m^2] \sim \Lambda_W^2)$
 \Rightarrow BSM sector is necessary!

Higgs-curvature
 coupling $\zeta = \frac{c_h}{2}$

- SM masses: $m = \{m_h, m_V, m_f, \dots\}$
- $\text{str}[\dots]$ must lead to M_{Pl}^2 !

- BSM sector must contain new fields (of masses $m' = \{m_{h'}, m_{V'}, m_{f'}, \dots\}$) so that

$$M_{Pl}^2 = \frac{1}{2} (c_m \text{str}[m^2] + c_{m'} \text{str}[m'^2]) \xrightarrow{\text{one-loop}} \frac{1}{64\pi^2} \text{str}[\mathcal{M}^2]$$

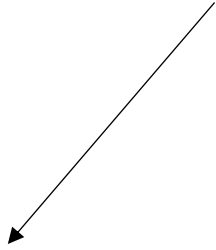


$$\mathcal{M} = \{m_h, m_V, m_f, m_{h'}, m_{V'}, m_{f'}, \dots\}$$

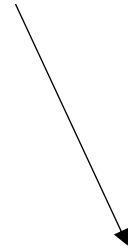
- BSM sector must be bosonic or must contain heavy bosons.
- BSM fields do not have to interact with the SM fields (a vital feature of BSM!).

SM+BSM leads to the complete curvature sector :

$$\delta S(g, \mathbb{R}) = \int d^4x \sqrt{-g} \{ -Q^{\mu\nu} \mathbb{R}_{\mu\nu}(\Gamma) + \frac{c_4}{16} \text{str}[1] (\mathbb{R}(g, \Gamma))^2 - c_V R_{\mu\nu}(g, \Gamma) \text{tr}[\mathcal{V}^\mu \mathcal{V}^\nu] \}$$



$$Q^{\mu\nu} = \left(\frac{M_{Pl}^2}{2} + \frac{c_4}{8} \text{str}[1] \mathbb{R}(g, \Gamma) \right) g^{\mu\nu} + \mathcal{K}^{\mu\nu}$$



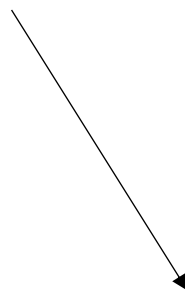
$$\mathcal{K}^{\mu\nu} = \frac{c_{\mathcal{H}}}{4} \mathcal{H}^2 g^{\mu\nu} - c_V \text{tr}[\mathcal{V}^\mu \mathcal{V}^\nu]$$

$\Gamma_{\mu\nu}^\lambda$ obeys the equation of motion

$$\Gamma \nabla_\alpha Q_{\mu\nu} = 0$$

with the solution

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



a non-linear PDE for $\Gamma_{\mu\nu}^\lambda$ because
 $Q_{\mu\nu}$ involves the affine curvature
 $\mathbb{R}(g, \Gamma) \sim \partial\Gamma + \Gamma\Gamma$

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

GR is guaranteed if $\Gamma_{\mu\nu}^\lambda$ contains no
«geometrical degrees of freedom»
beyond $g \Gamma_{\mu\nu}^\lambda$!

a non-linear PDE for $\Gamma_{\mu\nu}^\lambda$ because
 $Q_{\mu\nu}$ involves the affine curvature
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$\Gamma_{\mu\nu}^\lambda$ obeys the equation of motion

$$\Gamma_{\nu\alpha} \nabla_\alpha Q_{\mu\nu} = 0$$

with the solution

$$\Gamma_{\mu\nu}^\lambda = g_{\mu\nu} \Gamma_{\mu\nu}^\lambda + \dots$$

... and this happens if
 $\text{str}[1] = 0$
 or equivalently if
 $n_{\text{SM+BSM}}^{(b)} = n_{\text{SM+BSM}}^{(f)}$

is a PDE for $\Gamma_{\mu\nu}^\lambda$ because
 involves the affine curvature
 $\mathcal{K}(g, \Gamma) \sim \partial\Gamma + \Gamma\Gamma$

$\text{str}[1] = 0$ reduces the relationship between $\Gamma_{\mu\nu}^\lambda$ and ${}^g\Gamma_{\mu\nu}^\lambda$ to an algebraic one:

$$\Gamma_{\mu\nu}^\lambda = {}^g\Gamma_{\mu\nu}^\lambda + \frac{1}{2} \left(\left(\frac{M_{Pl}^2}{2} g + \mathcal{K} \right)^{-1} \right)^{\lambda\rho} (\nabla_\mu \mathcal{K}_{\nu\rho} + \nabla_\nu \mathcal{K}_{\rho\mu} - \nabla_\rho \mathcal{K}_{\mu\nu})$$

$$= {}^g\Gamma_{\mu\nu}^\lambda + \frac{1}{M_{Pl}^2} (\nabla_\mu \mathcal{K}_{\nu\rho} + \nabla_\nu \mathcal{K}_{\rho\mu} - \nabla_\rho \mathcal{K}_{\mu\nu}) + \mathcal{O}\left(\frac{\nabla \mathcal{K}^2}{M_{Pl}^4}\right)$$



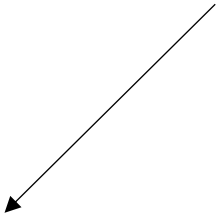
only the scalars \mathcal{H} and gauge bosons \mathcal{V}_μ in SM+BSM!

The solution of the affine connection gives the affine curvature

$$\mathbb{R}_{\mu\nu}(\Gamma) = R_{\mu\nu}(^g\Gamma) + \mathcal{O}\left(\frac{\nabla^2 \mathcal{K}}{M_{Pl}^2}\right)$$

with which the notorious CCB action reduces to

$$\delta S_V(g, \mathbb{R}) \equiv \int d^4x \sqrt{-g} c_V \text{tr} [V^\mu (\mathbb{R}_{\mu\nu}(\Gamma) - R_{\mu\nu}(^g\Gamma)) V^\nu] = \mathbf{0} + \int d^4x \sqrt{-g} c_V \mathcal{O}\left(\frac{\nabla^2 \mathcal{K}}{M_{Pl}^2}\right)$$



no contribution to scalar
and gauge boson masses!

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$$\delta S_V(g, \mathbb{R}) \equiv \int d^4x \sqrt{-g} [V^\mu (\mathbb{R}_{\mu\nu}(\Gamma) - R_{\mu\nu}(^g\Gamma)) V^\nu] = \mathbf{0} + \int d^4x \sqrt{-g} c_V \mathcal{O}\left(\frac{\nabla^2 \mathcal{K}}{M_{Pl}^2}\right)$$

charge and color breaking (CCB) is suppressed



no contribution to scalar
and gauge boson masses!

The solution of the affine connection leads to the affine curvature

$$\mathbb{R}_{\mu\nu}(\Gamma) = R_{\mu\nu}(^g\Gamma) + \mathcal{O}\left(\frac{\nabla^2 \mathcal{K}}{M_{Pl}^2}\right)$$

so that the notorious CCB gauge

$$\delta S_V(g, \mathbb{R}) \equiv \delta \left[\int d^4x \sqrt{-g} \left(-\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{1}{2} g_{\mu\nu} \partial^\mu \phi \partial^\nu \phi \right) \right] = 0 + \int d^4x \sqrt{-g} c_V \mathcal{O}\left(\frac{\nabla^2 \mathcal{K}}{M_{Pl}^2}\right)$$

gauge symmetry-restoring emergent gravity
or briefly
«symmergent gravity»

no contribution to scalar
and gauge boson masses!

Under the solution of the affine curvature

$$\mathbb{R}_{\mu\nu}(\Gamma) = R_{\mu\nu}(^g\Gamma) + \mathcal{O}\left(\frac{\nabla^2 \mathcal{K}}{M_{Pl}^2}\right)$$

entire curvature sector reduces to:

$$\begin{aligned} \delta S(g, \mathbb{R}) &= \int d^4x \sqrt{-g} \left\{ -Q^{\mu\nu} \mathbb{R}_{\mu\nu}(\Gamma) + \frac{c_4}{16} \text{str}[1] \left(\mathbb{R}(g, \Gamma) \right)^2 - c_V R_{\mu\nu}(^g\Gamma) \text{tr}[\mathcal{V}^\mu \mathcal{V}^\nu] \right\} \\ &= \int d^4x \sqrt{-g} \left\{ -\frac{M_{Pl}^2}{2} R(g) - \frac{c_{\mathcal{H}}}{4} R(g) \mathcal{H}^2 + \mathcal{O}\left(\frac{\mathcal{K} \nabla^2 \mathcal{K}}{M_{Pl}^2}\right) \right\} \end{aligned}$$

Under the solution of the affine curvature

$$\mathbb{R}_{\mu\nu}(\Gamma) = R_{\mu\nu}(g\Gamma) + \mathcal{O}\left(\frac{m^2}{M_{Pl}^2}\right)$$

entire gauge sector reduces to a

is gauge hierarchy problem solved ?



$\delta m_h^2 \sim \Lambda_\phi^2$ turns into Higgs-curvature coupling!

$$\delta S(g, \mathbb{R}) = \int d^4x \sqrt{-g} \left\{ -Q^{\mu\nu} \mathbb{R}_{\mu\nu}(\Gamma) + \frac{1}{2} \mathcal{H}^2 + \mathcal{O}\left(\frac{\mathcal{K} \nabla^2 \mathcal{K}}{M_{Pl}^2}\right) \right\}$$



$\delta m_h^2 \sim \lambda_{\psi\psi'} m'^2 \log\left(\frac{m'^2}{\Lambda_\phi^2}\right)$ is suppressed if $\lambda_{\psi\psi'} \sim \frac{m_h^2}{\Lambda_\phi^2}$
 this works only in symmergence where $\lambda_{\psi\psi'}$ is free
 (impossible in SUSY, extra dimensions or compositeness)

Under the solution of the affine curvature

$$\mathbb{R}_{\mu\nu}(\Gamma) = R_{\mu\nu}(^g\Gamma) + \mathcal{O}\left(\frac{\nabla^2 \mathcal{K}}{M_{Pl}^2}\right)$$

entire curvature sector reduces to a simple

$$\delta S(g, \mathbb{R}) = \int d^4x \left[\mathcal{Q}^{\mu\nu} \mathbb{R}_{\mu\nu}(\Gamma) + \frac{c_4}{16} \text{str}[1] (\mathbb{R}(g, \Gamma))^2 - c_V R_{\mu\nu}(^g\Gamma) \text{tr}[\mathcal{V}^\mu \mathcal{V}^\nu] \right]$$

$$\int d^4x \sqrt{-g} \left\{ -\frac{M_{Pl}^2}{2} R(g) - \frac{c_{\mathcal{H}}}{4} R(g) \mathcal{H}^2 + \mathcal{O}\left(\frac{\mathcal{K} \nabla^2 \mathcal{K}}{M_{Pl}^2}\right) \right\}$$

symmergent gravity is exact Einstein gravity!



- Fundamentally, $\log \Lambda_{\varnothing}$ is soft; it does not give cause to any gauge symmetry breaking.
- It has thus been left untouched by symmergence.
- Presence of $\log \Lambda_{\varnothing}$ completes the picture! Indeed, they imply nothing but the Dimensional Regularization:

$$\log \Lambda_{\varnothing}^2 = \frac{1}{\epsilon} - \gamma_E + \log(4\pi\mu^2) + 1$$

- Independence of n-point function from μ leads to the usual RGEs!

([K. Hagiwara](#) *et al.*, Phys. Rev. D **48** (1993) 2182)

$$M_{Pl}^2 = \frac{1}{64\pi^2} \text{str}[\mathcal{M}^2]$$

$$\text{str}[1] = 0$$

global SUSY broken at $8\pi M_{Pl}$?

highly fine-tuned (split SUSY)

$$M_{Pl}^2 = \frac{1}{64\pi^2} \text{str}[\mathcal{M}^2]$$

$$\text{str}[1] = 0$$

SM and BSM do not have to interact!

a rich pheno and astro! (dark matter, dark photon, dark energy in non-SUSY QFT)

Symmergence is a “new way” of putting QFT in curved spacetime or incorporating gravity into QFT.

- It works on any renormalizable QFT in flat spacetime:

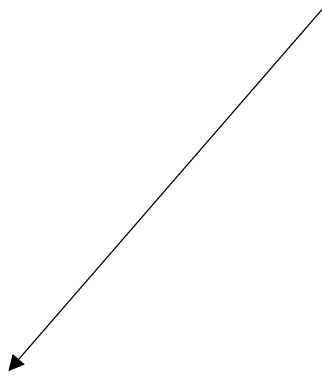
$$\text{QFT}(\eta_{\mu\nu}, \Lambda_{\wp}^2, \log \Lambda_{\wp}) \xrightarrow{\text{symmergence}} \mathcal{QFT}(g_{\mu\nu}, \mathbb{R}, \log \mu)$$

- It stabilizes scalars and vectors against quantum fluctuations, and leads to Einstein gravity.
- The problem of CCP remains ($\delta V \sim \Lambda_{\wp}^4$ is gone but $\delta V \sim m'^4 \log(m'^2 / \Lambda_{\wp}^2)$ remains).
- The question of whether there is a SUSY structure or whether SM and BSM are two decoupled sectors is one for phenomenology and experiment, and there are a lot to be done in that direction.

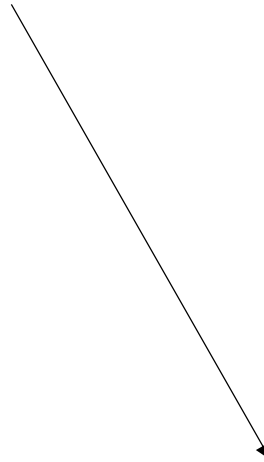
In the memory of Rahmi hocam – a great physicist and a candid friend.

The affine curvature obeys a non-linear PDE (\mathcal{H} and \mathcal{V}_μ are dropped, for simplicity):

$$\mathbb{R} = R - 3\nabla^2 \log\left(1 + \frac{2\text{str}[1]\mathbb{R}}{M_{Pl}^2}\right) - \frac{3}{2}\nabla_\mu \log\left(1 + \frac{2\text{str}[1]\mathbb{R}}{M_{Pl}^2}\right)\nabla^\mu \log\left(1 + \frac{2\text{str}[1]\mathbb{R}}{M_{Pl}^2}\right)$$



$$\mathbb{R}(g, \Gamma) \simeq R({}^g\Gamma) \text{ for } \mathbb{R}(g, \Gamma) \ll M_{Pl}^2$$



for $\mathbb{R}(g, \Gamma) \sim M_{Pl}^2$ non-linearities
dominate, gravity deviates from GR!