POINCARE BREAKING AND GAUGE INVARIANCE:

A ROAD TO EMERGENT GRAVITY AND NEW PARTICLES

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SUMMARY

- In effective QFTs with a UV cutoff Λ, all gauge bosons acquire masses in proportion to Λ.

    - Gauge symmetries, broken explicitly by Λ, can be restored by invoking “Higgs mechanism”.

        - The anticipated ”Higgs field” must break Poincare symmetry since the cutoff Λ does so.

        - The “Higgs field” can be linked to curvature as they both break the Poincare symmetry.

    - Gravity emerges then holographically as a completion of the flat spacetime effective QFT.

- Proper emergence of gravity brings in a plethora of new particles that do not have to couple to the known ones.

AN ILLUSTRATIVE CASE: SAKHAROV'S INDUCED GRAVITY

- Sakharov's setup involves a flat spacetime QFT bordered in the UV by a UV cutoff Λ.

- Matter loops are assumed to have a curved metric $g_{\alpha\beta}$, and they can induce gravity therefore if Λ lies at the Planck scale.

- … and yet Sakharov's induced gravity comes with all sort of UV sensitivity problems in the QFT sector:

$$S_{ind} = \int d^4x \sqrt{-g} \left\{ - a_R \Lambda^2 R(g) - a_O \Lambda^4 - \sum_m c_m m^2 \Lambda^2 - a_\phi \Lambda^2 \phi^\dagger \phi - a_V \Lambda^2 g_{\alpha\beta} \mathrm{tr}[V^\alpha V^\beta] \right\}$$

Newton's constant ($a_R \Lambda^2 \equiv \frac{1}{16\pi G_N}$)

Planckian vacuum energy (cosmological constant problem)

Planckian scalar masses (gauge hierarchy problem)

Planckian gauge boson masses (explicit gauge symmetry breaking)

Can gravity emerge in a way alleviating these problems ?

FLAT SPACETIME EFFECTIVE QFT

Quartic and quadratic corrections from matter loops in flat spacetime:

$$\delta S(\eta,\Lambda) = \int d^4x \sqrt{-\eta}\,\{-c_O\Lambda^4 - \sum_m c_m m^2\Lambda^2 - c_\phi \Lambda^2 \phi^\dagger\phi + c_V\Lambda^2\eta_{\alpha\beta}\mathrm{tr}[V^\alpha V^\beta]\}$$

flat metric $\eta_{\mu\nu}$

$c_{\text{Higgs}} \approx \frac{3h_t^2}{4\pi^2}$

$c_{g^a}^{(SM)}$	$\frac{21g_3^2}{16\pi^2}$
$c_{W^i}^{(SM)}$	$\frac{21g_2^2}{16\pi^2}$
$c_B^{(SM)}$	$\frac{39g_1^2}{32\pi^2}$

$$\sum_m c_m\, m^2 \propto \mathrm{str}[M^2]$$

$c_O = \frac{n_b - n_f}{64\pi^2}$

$(\text{mass})^2$ matrix of fields

all the bosons (n_b)
and fermions (n_f)

We may restore gauge symmetries by invoking some sort of "Higgs mechanism".

LOOP-INDUCED GAUGE BOSON MASS TERM

- Gauge boson anomalous mass term (flat metric): $\delta S_V(\eta,\Lambda) \equiv \int d^4x\sqrt{-\eta}c_V \mathrm{tr}[V^\alpha \Lambda^2 \eta_{\alpha\beta} V^\beta]$

- Carrying gauge boson mass term to curved spacetime:

  - Consider these two kinetic structures:

$$I_V(\eta) = \int d^4x\sqrt{-\eta}\, c_V \mathrm{tr}\left[V^{\alpha\beta}V_{\alpha\beta}\right] \xleftrightarrow{\text{by-parts}} \tilde{I}_V(\eta) = \int d^4x\sqrt{-\eta}\, c_V \mathrm{tr}[V^\alpha(-D^2\eta_{\alpha\beta} + D_\alpha D_\beta + iV_{\alpha\beta})V^\beta + \partial_\alpha\left(V_\beta V^{\alpha\beta}\right)]$$

  - Their sensitivity to spacetime curvature enable us to regularize the gauge boson mass term:

$$-I_V(\eta) + \tilde{I}_V(\eta) = 0 \quad \xrightarrow[\substack{\eta_{\alpha\beta}\to g_{\alpha\beta} \\ \partial_\alpha \to \nabla_\alpha}]{} \quad -I_V(g) + \tilde{I}_V(g) = -\int d^4x\sqrt{-g}\, c_V \mathrm{tr}[V^\alpha R_{\alpha\beta}({}^g\Gamma)V^\beta]$$

$$\delta\hat{S}_V(g,\Lambda) = -I_V(g) + \tilde{I}_V(g) + \delta S_V(g,\Lambda) = \int d^4x\sqrt{-g}c_V \mathrm{tr}[V^\alpha(\Lambda^2 g_{\alpha\beta} - R_{\alpha\beta}({}^g\Gamma))V^\beta]$$

$$\delta\hat{S}_V(\eta,\Lambda) = -I_V(\eta) + \tilde{I}_V(\eta) + \delta S_V(\eta,\Lambda) = \delta S_V(\eta,\Lambda)$$

We proceed with this regularized gauge boson anomalous mass term.

RESTORATION OF GAUGE SYMMETRIES

- Mass term for a vector boson V_μ (Proca field):

$$S_V(g, M_V) = \int d^4x\sqrt{-g}\; M_V^2 \eta_{\alpha\beta}\mathrm{tr}[V^\alpha V^\beta]$$

	M_V^2
Gauge breaking	Yes
Poincare breaking	No

E. Fermi, La Ricerca Scientifica **4**, 491 (1933)
H. Yukawa, Proc. Math. Soc. Jpn. **17**, 48 (1935)

- Loop-induced anomalous mass term for a gauge boson V_μ:

$$\delta\hat{S}_V(g, \Lambda) = \int d^4x\sqrt{-g}c_V\mathrm{tr}[V^\alpha(\Lambda^2 g_{\alpha\beta} - R_{\alpha\beta}({}^g\Gamma))\mathrm{V}^\beta]$$

	$\Lambda^2 - R$
Gauge breaking	Yes
Poincare breaking	Yes

H. Umezawa *et al.*, Prog. Theor. Phys. **3**, 317 (1948)
G. Kallen, Helv. Phys. Acta. **22**, 637 (1949)
M.Peskin & D. Schroeder, *Quantum Field Theory* (1995)
P. Chankowski *et al.*, Acta Phys. Pol. **B48**, 5 (2017)

RESTORATION OF GAUGE INVARIANCE

Higgsing massive gauge boson:

$$S_V(g, M_V) = \int d^4x\sqrt{-g}\; M_V^2\, g_{\alpha\beta}\,\mathrm{tr}[V^\alpha V^\beta]$$

$M_V^2 \Longrightarrow$ "spurion ϕ"
(Poincare-conserving)

$$S_V(g, \phi) = \int d^4x\sqrt{-g}\; g_{\alpha\beta}\,\mathrm{tr}[\phi^\dagger V^\alpha V^\beta \phi]$$

spurion $\Longrightarrow$ "Higgs"

$$S_V(g, \phi) = \int d^4x\sqrt{-g}\; g_{\alpha\beta}\,\mathrm{tr}[(D^\alpha\phi)^\dagger D^\beta \phi]$$

P. Anderson, Phys. Rev. Phys. **130**, 439 (1962)
F.Englert & R. Brout, Phys. Rev. Lett. **13,** 321 (1964)
P. Higgs, Phys. Rev. Lett. **13,** 508 (1964)

Higgsing anomalously massive gauge boson:

$$\delta\hat{S}_V(g, \Lambda) = \int d^4x\sqrt{-g}\,c_V\;\mathrm{tr}[V^\alpha(\Lambda^2 g_{\alpha\beta} - R_{\alpha\beta}({}^g\Gamma))V^\beta]$$

$\Lambda^2 \Longrightarrow$ "spurion Σ"
(Poincare-breaking)

$$\delta\hat{S}_V(g, \Sigma) = \int d^4x\sqrt{-g}\; c_V\,\mathrm{tr}[V^\alpha(\Sigma(x) g_{\alpha\beta} - R_{\alpha\beta}({}^g\Gamma))V^\beta]$$

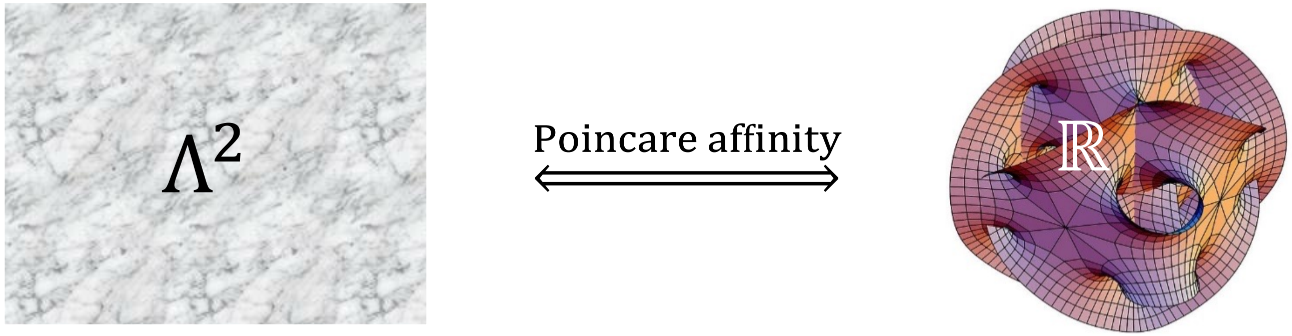
What is this spurion Σ ? It cannot be $\phi^\dagger\phi$ as it cannot break Poincare symmetry! Can it be related to spacetime curvature?

UV CUTOFF AND CURVATURE: POINCARE AFFINITY

- In an arbitrary second-quantized theory with no presumed properties, "… lack of translational invariance would just be interpreted as the effect of gravitational fields being present, which are not translational invariant."
  C. Froggatt & H. Nielsen, Ann. Phys. **517**, 115 (2007)

- Belonging inherently to the flat spacetime, QFTs have one natural Poincare (translation) breaking source: the UV cutoff Λ.
  DD, Gen. Rel. Grav. **53**, 22 (2021)

- On physical grounds, therefore, there is a Poincare affinity between the UV cutoff Λ in flat spacetime and curvature $\mathbb{R}$ in curved spacetime.
  DD, Gen. Rel. Grav. **53**, 22 (2021)



RESTORATION OF GAUGE INVARIANCE

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Higgsing anomalously massive gauge boson:

$$\delta\hat{S}_V(g, \Lambda) = \int d^4x\sqrt{-g} c_V\, \text{tr}[V^\alpha(\Lambda^2 g_{\alpha\beta} - R_{\alpha\beta}({}^g\Gamma))V^\beta]$$

$\Lambda^2 \Longrightarrow$ "spurion Σ"
(Poincare-breaking)

$$\delta\hat{S}_V(g, \Sigma) = \int d^4x\sqrt{-g}\, c_V\text{tr}[V^\alpha(\Sigma(x) g_{\alpha\beta} - R_{\alpha\beta}({}^g\Gamma))V^\beta]$$

$\Sigma(x)\, g_{\mu\nu}(x) = \mathbb{R}_{\mu\nu}(\Gamma(x))$
(affine curvature $\mathbb{R}$)

$\delta\hat{S}_V(\text{g}, \mathbb{R}) = \int d^4$

We can now form a symmetry-driven Palatini gravity (SPG) theory with the inclusion of non-gauge sectors.

SYMMETRY-DRIVEN PALATINI GRAVITY THEORY

- Affine curvature $\mathbb{R}$ gives rise to SPG gravity via $\Sigma(x)\, g_{\mu\nu}(x) = \mathbb{R}_{\mu\nu}(\Gamma(x))$:

$$\delta\hat{S}(g,\mathbb{R}) = \int d^4x\,\sqrt{-g}\,\left\{-\frac{c_O}{16}\left(g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)\right)^2 - \frac{g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)}{16\pi G_N} - \frac{c_\phi}{4}g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)\phi^\dagger\phi + c_V(\mathbb{R}_{\alpha\beta}(\Gamma) - R_{\alpha\beta}({}^g\Gamma))\,\mathrm{tr}\left[V^\alpha V^\beta\right]\right\}$$

- Equation of motion for the affine connection $\Gamma^\lambda_{\alpha\beta}$ (${}^\Gamma\nabla_\lambda$ covariant derivative wrt $\Gamma^\lambda_{\alpha\beta}$):

$${}^\Gamma\nabla_\lambda \mathrm{Q}_{\alpha\beta} = 0$$

- Field metric:

$$Q_{\alpha\beta} = \left(\frac{1}{16\pi G_N} + \frac{c_S}{4}g^{\alpha\beta}S^\dagger S + \frac{c_O}{8}g^{\mu\nu}\mathbb{R}_{\mu\nu}(\Gamma)\right)g_{\alpha\beta} - c_V\mathrm{tr}[V_\alpha V_\beta]$$

- Newton's constant:

$$G_N^{-1} = 4\pi\sum_m c_m m^2 \xrightarrow[1-\mathrm{loop}]{} 4\pi\,\mathrm{str}[M^2]$$

Now, we integrate out the affine connection $\Gamma^\lambda_{\mu\nu}$ to determine the resulting metrical gravity theory.

INTEGRATING-OUT THE AFFINE CONNECTION

- General solution for the affine connection :

$$\Gamma^{\lambda}_{\alpha\beta} = {}^{g}\Gamma^{\lambda}_{\alpha\beta} + \frac{1}{2}(Q^{-1})^{\lambda\rho}\left(\nabla_{\alpha} Q_{\beta\rho} + \nabla_{\beta} Q_{\rho\alpha} - \nabla_{\rho} Q_{\alpha\beta}\right)$$

- Enormity of the Planck scale $G_N^{-1/2}$ leads to:

- $\Gamma^{\lambda}_{\alpha\beta} = {}^{g}\Gamma^{\lambda}_{\alpha\beta} + 8\pi G_N\left(\nabla_{\alpha} Q^{\lambda}_{\beta} + \nabla_{\beta} Q^{\lambda}_{\alpha} - \nabla^{\lambda} Q_{\alpha\beta}\right) + \mathcal{O}(G_N^2)$

- $\mathbb{R}_{\alpha\beta}(\Gamma) = R_{\alpha\beta}({}^{g}\Gamma) + 8\pi G_N\left(\nabla^{\mu}\nabla_{\alpha}\delta^{\nu}_{\beta} + \nabla^{\nu}\nabla_{\alpha}\delta^{\mu}_{\beta} - \Box\delta^{\mu}_{\alpha}\delta^{\nu}_{\beta} - \nabla_{\alpha}\nabla_{\beta} g^{\mu\nu} + (\alpha \leftrightarrow \beta)\right) Q_{\mu\nu} + \mathcal{O}(G_N^2)$

derivatives of the scalars ϕ and gauge fields V_i^{α}

EMERGENCE OF THE GR FROM RESTORATION OF GAUGE SYMMETRIES

Integration-out of $\mathbb{R}_{\alpha\beta}(\Gamma)$ reduces SPG to the GR ($R(g) = g^{\alpha\beta} R_{\alpha\beta}({}^{g}\Gamma)$):

gauge symmetries got restored !

- $\int d^4x \sqrt{-g}\{c_V(\mathbb{R}_{\alpha\beta}(\Gamma) - R_{\alpha\beta}({}^{g}\Gamma))\, \mathrm{tr}[V^\alpha V^\beta]\} = \int d^4x \sqrt{-g}\, \{0 + \mathcal{O}(G_N)\}$

GR emerged!

- $\int d^4x \sqrt{-g}\left\{-\frac{1}{16\pi G_N} g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)\right\} = \int d^4x \sqrt{-g}\, \left\{-\frac{R(g)}{16\pi G_N} + \mathcal{O}(G_N)\right\}$

quadratic UV sensitivity of scalar masses gives cause to curvature-scalar fields couplings

- $\int d^4x \sqrt{-g}\{-c_S g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma) S^\dagger S\} = \int d^4x \sqrt{-g}\, \left\{-\frac{c_\phi}{4} R(g)\phi^\dagger\phi + \mathcal{O}(G_N)\right\}$

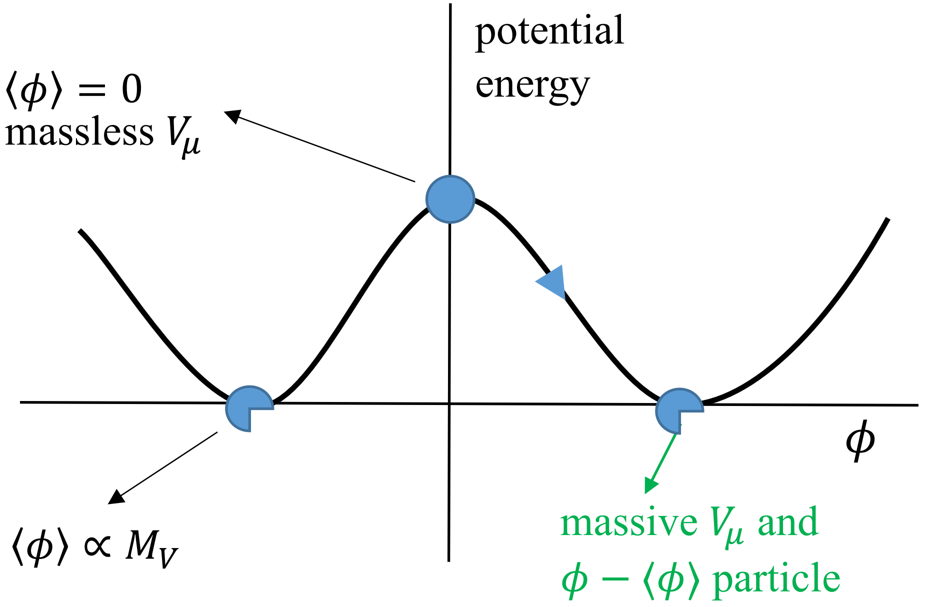
- $\int d^4x \sqrt{-g}\left\{-\frac{c_O}{16}\left(g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)\right)^2\right\} = \int d^4x \sqrt{-g}\, \left\{-\frac{c_O}{16}(R(g))^2 + \mathcal{O}(G_N)\right\}$

quartic UV sensitivity in flat spacetime gives cause to quadratic curvature terms

Summary: Higgs Mechanism

$M_V^2 \eta^{\mu\nu} V_\mu V_\nu$ $\quad$ $\phi^\dagger \phi\, \eta^{\mu\nu} V_\mu V_\nu$ $\quad$ $\eta^{\mu\nu} (D_\mu \phi)^\dagger D_\nu \phi$

spurion ϕ $\quad$ dynamical ϕ



Max of energy ⇒ massless V_μ (exact gauge symmetry)

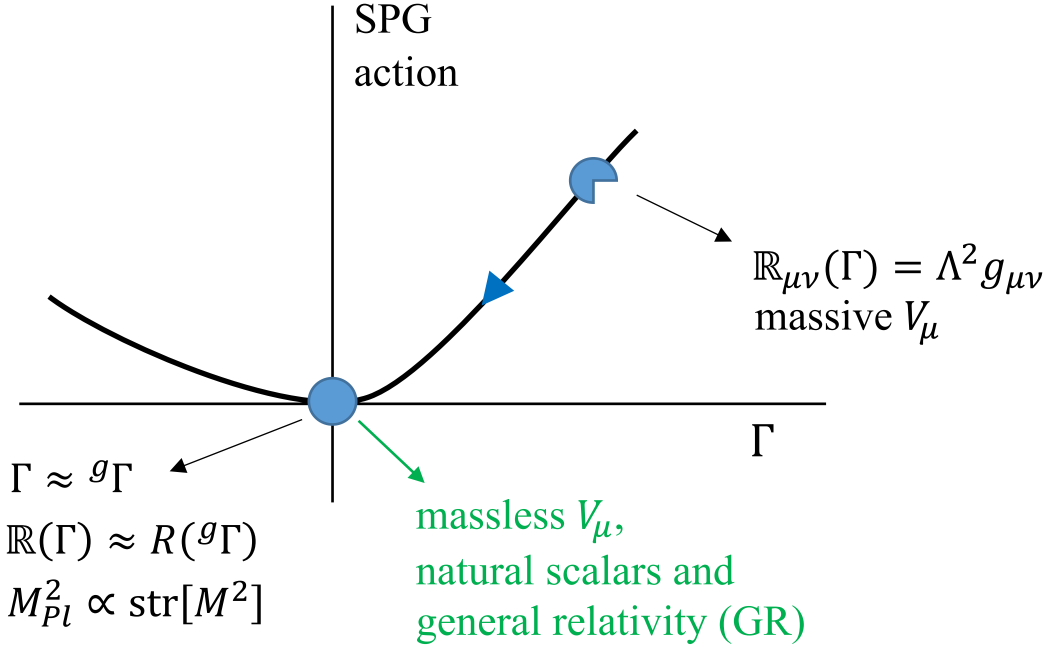
Min of energy ⇒ massive V_μ (broken gauge symmetry)

Summary: Affine Curvature Mechanism

$c_V \Lambda^2 \eta^{\mu\nu} V_\mu V_\nu$ $\quad$ $c_V V_\mu \left(\Lambda^2 g^{\mu\nu} - R^{\mu\nu}({}^g\Gamma)\right) V_\nu$ $\quad$ $c_V V_\mu \left(\mathbb{R}^{\mu\nu}(\Gamma) - R^{\mu\nu}({}^g\Gamma)\right) V_\nu$

general covariance
$(\eta_{\mu\nu} \to g_{\mu\nu}\,, \partial_\mu \to \nabla_\mu)$

spurion $\mathbb{R}(\Gamma)$
$(\Lambda^2 g^{\mu\nu} \to \mathbb{R}^{\mu\nu}(\Gamma))$



Non-extrema of SPG action ⇒ anam. massive V_μ (broken gauge symmetry)

Extremum of SPG action ⇒ massless V_μ (exact gauge symmetry and **GR**)

RENORMALIZED QFT + EMERGENT GRAVITY:

$$S_{QFT+GR} = S(g,\psi) + \delta S(g,\psi) + \int d^4x \sqrt{-g} \left\{ -\frac{R(g)}{16\pi G_N} - \frac{c_O}{16} R(g)^2 - \frac{c_\phi}{4} R(g)\phi^\dagger\phi + \mathcal{O}(G_N) \right\}$$

QFT with

- dimensional-regularization in the classical curved background geometry,
- loop corrections computed in the flat spacetime QFT

$R + R^2$ gravity with

- non-minimal coupling to scalars,
- $\mathcal{O}(G_N)$ remainder involving derivatives of scalars and gauge fields,
- loop-induced coefficients computed in the flat spacetime QFT.

symmetry-restoring emergent gravity = "symmergent gravity"

HOLOGRAPHIC STRUCTURE

Energy density in flat spacetime:

$$c_O\Lambda^4 + c_m m^2\Lambda^2 + c_\phi\Lambda^2\phi^\dagger\phi + c_V\Lambda^2\mathrm{tr}[V^\alpha V_\alpha]$$

through the affine dynamics

Curvature sector ($\Lambda_{IR}^2 \propto R$):

$$\left(\frac{1}{8\pi G_N} + \cdots\right)R = \frac{c_O}{16}R^2 + \frac{R}{8\pi G_N} + \frac{c_\phi}{4}R\phi^\dagger\phi$$

G. 't Hooft, arXiv:gr-qc/9310026 (1993)

PREDICTIONS OF THE SYMMERGENT GRAVITY

new massive particles are a must for Newton's constant to take right value

neutrinos must be Dirac for the Higgs mass to remain stable

black hole shadow, photon radius and quasiperiodic oscillations show distinctive features

dark matter must couple with a strength $\lesssim m_h^2/m_{DM}^2$ to known particles for the Higgs mass to remain stable

Higgs-curvature coupling is about $10\ \%$ in the SM, and deviations indicate Higgs coupling to new particles

detection of new particles can wait for high-luminosity LHC

pure Einstein gravity is attained if bosons and fermions are equal in number

cosmic inflation is expected to be of Starobinsky type

DD, Adv. High Energy Phys. 6727805 (2016)

DD, Adv. High Energy Phys. 4652048 (2019)

DD, Gen. Rel. Grav. **53**, 22 (2021)

K. Cankoçak *et al*., Eur. Phys. J. C**80**, 1188 (2020)

DD & C. S. Ün, arXiv: 2005.03589 [hep-ph] (2020)

DD, Galaxies **9**, 2 (2021)

I. Çimdiker, Phys. Dark Universe **30,** 100736 (2020)

DD, B. Puliçe & N. Sönmez, work in progress (2022)

I. Çimdiker, DD & A. Övgün, Phys. Dark Univ. **34,** 100900 (2021)

J. Rayimbayev, R. Pantig, A. Övgün, A. Abdujabbarov & DD, arXiv: 2206.06599 [gr-qc]

R. Pantig, A. Övgün & DD, arXiv: 2208.02969 [gr-qc]

GRAZIE MILLE !

BACK UP SLIDES 1

REALIZING POINCARE AFFINITY: DETACHMENT OF POWER-LAWS AND LOGARITHMICS

- $\log\Lambda$ corrections to particle masses can cause equivalence principle violation under the Poincare affinity $\Lambda^2 \Rightarrow \mathbb{R}(x)$.
- This violation can be prevented by detaching power-law and logarithmic corrections so that:
  - power-laws involve Λ
  - logarithmics involve a different scale μ
- The detached regularization can be constructed as an extension of the dimensional regularization:
  - DimReg continues loop amplitudes from 4 to D momentum space dimensions ($n = 0,1,2$)

$$I_n = \int \frac{d^4p}{(2\pi)^4} \frac{1}{(p^2 - m^2 + i0)^n} \Longrightarrow \mu^{4-D} \int \frac{d^Dp}{(2\pi)^D} \frac{1}{(p^2 - m^2 + i0)^n}$$

and comprises logarithmic, quadratic and quartic divergences as $D \to 4$, $D \to 2$ and $D \to 0$.

I. Jack & D. Jones, Nucl. Phys. **B342**, 127 (1990); M. Al-Sarhi, D. Jones & I. Jack, Nucl. Phys. **B345**, 431 (1990)

  - DimReg can be extended to form the Detached Regularization:

$$I_n = \mu^{4-D} \int \frac{d^Dp}{(2\pi)^D} \frac{1}{(p^2 - m^2 + i0)^n} \Longrightarrow f(\Lambda, \mu; D, n) \int \frac{d^Dp}{(2\pi)^D} \frac{1}{(p^2 - m^2 + i0)^n}$$

What is the function $f(\Lambda, \mu; D, n)$?

REALIZING POINCARE AFFINITY: DETACHMENT OF POWER-LAWS AND LOGARITHMICS

- If Λ −dependence is to reminesence the cutoff regularization and if DimReg results are to remain unchanged then the function $f(\Lambda, \mu; D, n)$ must have the form:

$$f(\Lambda, \mu; D, n) = \underbrace{\left(\frac{8-2D}{8-D^2}\right)^2 \frac{1}{(8\pi)^{2-n}} \Lambda^{4-2n} \mu^{2n-D}}_{\text{vanishes as } D \to 4} + \underbrace{\left(\frac{D(D-2)(16-3D)}{32}\right)^2 \mu^{4-D}}_{\text{vanishes as } D \to 0 \text{ and } D \to 2}$$

- Then, in the $\overline{MS}$ renormalization scheme, the loop amplitudes take the detached form:

$$I_n = \begin{cases} \dfrac{i\,\Lambda^4}{32\pi^2} & \text{for } D = 0, n = 0 \\[2ex] \dfrac{-i\Lambda^2}{16\pi^2}\left(1 - \log\dfrac{\mu}{m}\right) & \text{for } D = 2, n = 1 \\[2ex] \dfrac{im^2}{16\pi^2}\left(1 + 2\log\dfrac{\mu}{m}\right) & \text{for } D = 4, n = 1 \\[2ex] \dfrac{i}{8\pi^2}\log\dfrac{\mu}{m} & \text{for } D = 4, n = 2 \end{cases}$$

Detached regularization:

- Λ for power-law corrections
- μ for logarithmic corrections

DD, talk at Gravitex21 (2021)
DD, talk at FFP16 (2022)
DD, C. Karahan & O. Sargın, submitted (2022)

BACK UP SLIDES 2

STANDARD MODEL OF ELEMENTARY PARTICLES

SUCCESSES

- SM is a renormalizable QFT of the strong, weak and electromagnetic interactions.
- SM agrees with all the existing experimental data.
- SM is a natural QFT in isolation.

PROBLEMS

- SM cannot account for empirical facts like galactic flat rotation curves, neutrino masses, baryon asymmetry, inflation, and neutron magnetic moment.
- SM Higgs sector is destabilized by high-scale physics.

  (*e.g.* Heavy RH neutrinos generating the neutrino Majorana masses dest
- SM does not involve g

  (Basically, GR is not a

  G. 't Hooft & M. Veltman,

1. Give priority to gravity.
2. Study other problems in the setup involving gravity.

THE SM DOESN'T ACCORD WITH GRAVITY BECAUSE …

- GR is not a renormalizable QFT.
  G. 't Hooft & M. Veltman, Ann. de I.H.P **20**, 69 (1974)
  M. Goroff & A. Sagnotti, NPB **266**, 709 (1986)

- Classical GR is not eligible since QFTs (like the SM) are inherently specific to the flat spacetime with their Poincare-invariant vacuum states. They cannot thus be continued to curved spacetime.
  S. Hollands & R. Wald, Phys. Rep. **574**, 1 (2015)
  C. Gerard, arXiv: 1901.10175 (2019)

- Strings, LQG, asymptotic safety, causal dynamical triangulations and others are currently "work in progress".

But the SM may accord with induced/emergent gravity as it arises from the matter loops.

REALIZING POINCARE AFFINITY: EFFECTIVE ACTION IN DETACHED REGULARIZATION

Quantum corrections involve powers of Λ with $\log\mu -$ dependent loop factors:

$$\delta S = \int d^4x \sqrt{-\eta}\,\{-c_O\Lambda^4 - \sum_m c_m m^2\Lambda^2 - c_\phi\Lambda^2\phi^\dagger\phi + c_V\Lambda^2\eta_{\alpha\beta}\mathrm{tr}[V^\alpha V^\beta] + \delta L(\eta, \log\mu, \psi)\}$$

flat metric $\eta_{\mu\nu}$

$$c_{\mathrm{Higgs}}(\log\mu) \approx \frac{3h_t^2}{4\pi^2}$$

$\log\mu$ corrections

$$\sum_m c_m(\log\mu)\, m^2 = \frac{1}{32\pi^2}\mathrm{str}\left[M^2\left(1 + \frac{1}{2}\log\frac{M^2}{\mu^2}\right)\right]$$

(mass)^2 matrix of fields

$c_{g^a}^{(SM)}(\log\mu)$	$\frac{21g_3^2}{16\pi^2}$
$c_{W^i}^{(SM)}(\log\mu)$	$\frac{21g_2^2}{16\pi^2}$
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$$c_O(\log\mu) = \frac{n_b - n_f}{64\pi^2}$$

all the bosons (n_b)
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