Title: Nonvanishing gravitational contribution to matter beta functions for vanishing dimensionful regulators

Speakers: Gustavo Pazzini de Brito

Series: Quantum Gravity

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Abstract: In this seminar, I will explore the effect of quantum gravity on matter couplings within a (Functional) Renormalization Group framework. I will mainly focus on gravitational contribution to the flow of gauge couplings. In particular, I will focus on results obtained from a class of interpolating regulators that allow us to extract certain universal pieces from non-universal quantities. I will argue that gravity might induce the UV completion of an Abelian-gauge sector, despite an apparent vanishing contribution to its flow when we consider only universal pieces. This result might offer a new perspective on the differences between perturbative studies and Functional Renormalization Group studies.

Zoom Link: https://pitp.zoom.us/j/97277305442?pwd=d240TXhrNnZ0TlErbGQ0bCtGU1NCZz09

Nonvanishing gravitational contribution to matter beta functions for vanishing dimensionful regulators

Gustavo P. de Brito

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Based on: 2201.11402 [hep-th]
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CP3

VILLUM FONDEN

What is the effect of quantum gravity on the flow of matter couplings?

<u>Motivation:</u>

Search for a fundamental quantum theory that describes both gravity and matter fields

- Many challenges on the gravity "side"
- But there are also challenges on the matter "side" (SM breaks down at trans-Planckian energies)

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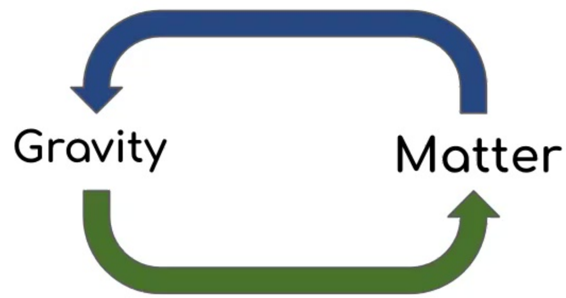

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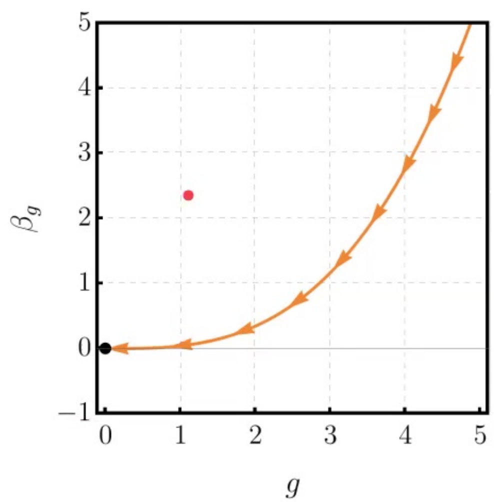
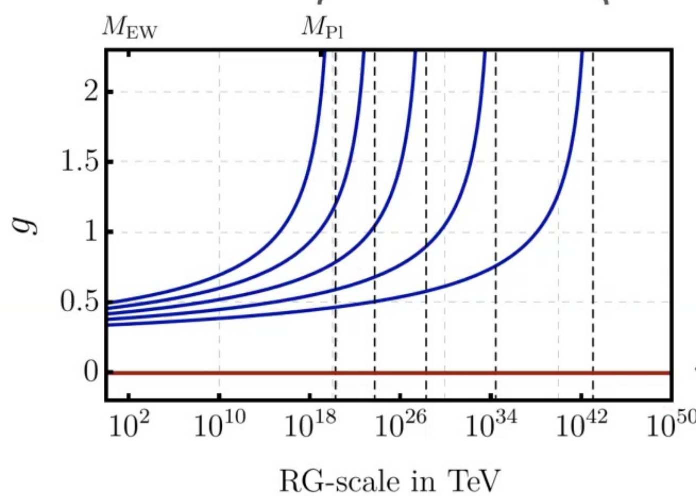
Flow of Abelian-gauge couplings



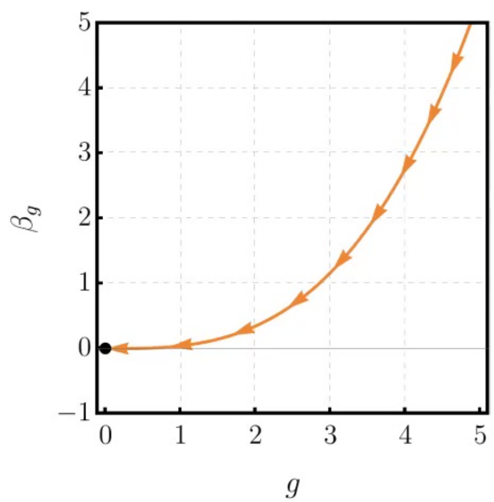
Landau-pole



Triviality problem

What is the effect of quantum gravity on the flow of matter couplings?

Flow of Abelian-gauge couplings + Gravity



Gravity has no effect on β_g

Gravity acts with screening contribution to β_g

Gravity acts with anti-screening contribution to β_g

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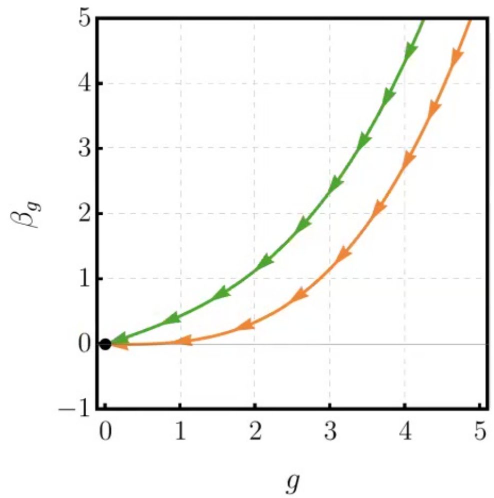
Flow of Abelian-gauge couplings + Gravity



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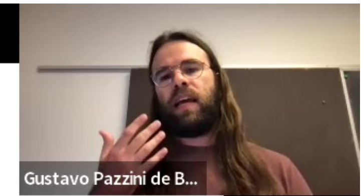

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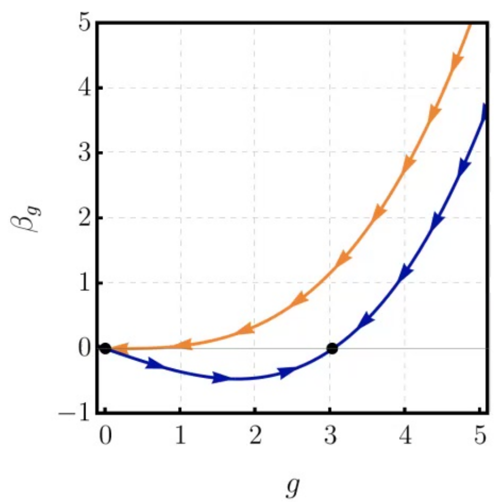

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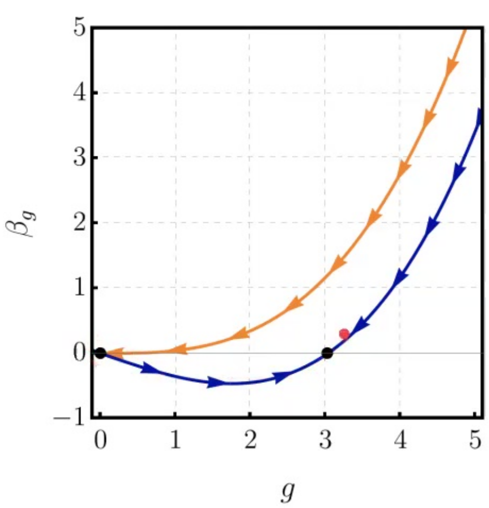
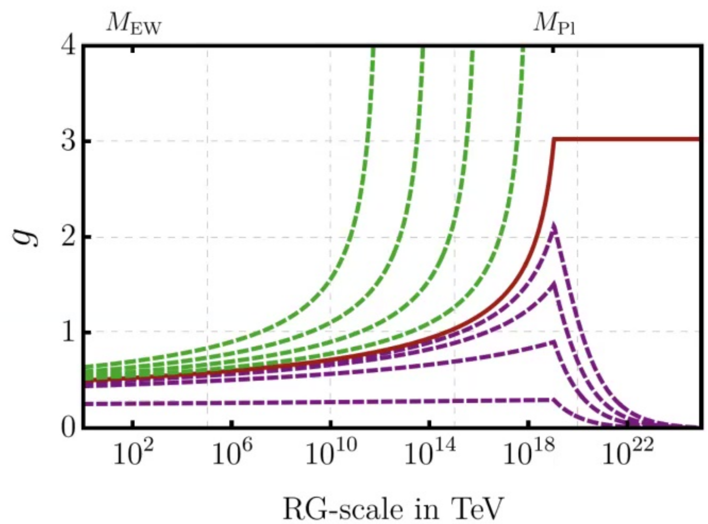
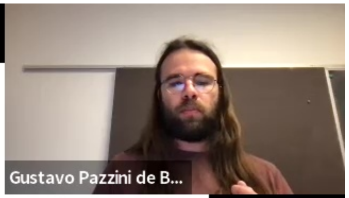
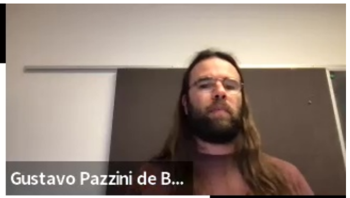






Interesting possibilities based on the interplay between gravity and matter

But... practical calculations lead to conflicting results



Perturbative quantum gravity perspective

- The gravitational contribution to the flow of gauge couplings was intensively explored in perturbative quantum gravity

- Part of the literature claims that gravity acts with anti-screening contribution

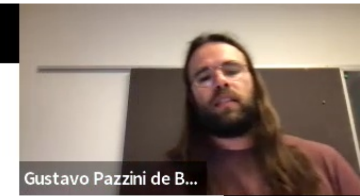
$$\beta_g|_{\mathrm{grav}} = -\,\#\,E^2 G_{\mathrm{N}}\,g$$

Robinson and Wilczek, 0509050 [hep-th]
Toms, 0809.3897 [hep-th]
Tang and Wu, 0807.0331 [hep-th]
Toms, 0908.3100 [hep-th]
Toms, 1010.0793 [hep-th]
Toms, PRD(2011) 084016

- Others claim that this contribution cannot be associated with any physical meaning due to spurious scheme-dependencies

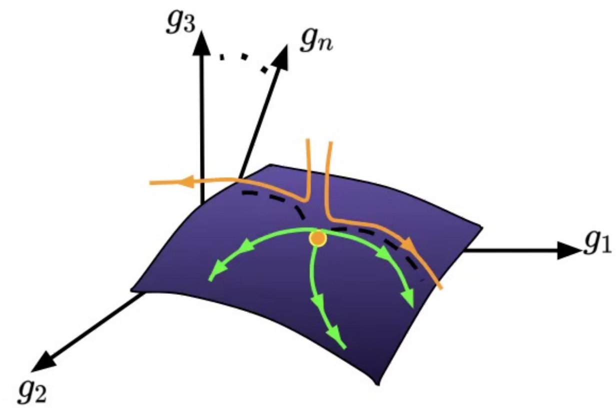
"We can set $\beta_g|_{\mathrm{grav}} = 0$ by a choice of scheme"

Pietrykowski, 0606208 [hep-th]
Toms, 0708.2990 [hep-th]
Ebert, Plefka and Rodigast, 0710.1002 [hep-th]
Anber, Donoghue and El-Houssieny, 1011.3229 [hep-th]
Elis and Mavromatos, 1012.4353 [hep-th]
Felipe, Brito, Sampaio and Nemes, 1103.5824 [hep-th]
Narain and Anishetty, 1211.5040 [hep-th]



Asymptotic safety perspective

- Asymptotic safety in a nutshell
  - ⇨ extends the notion of renormalizability beyond perturbation theory
  - ⇨ realization of quantum scale-invariance (fixed points on the RG-flow $\beta_i(g_*) = 0$)
  - ⇨ Conjecture: gravity can be quantized in an asymptotically safe way Weinberg, '79 (supported by Functional RG studies)



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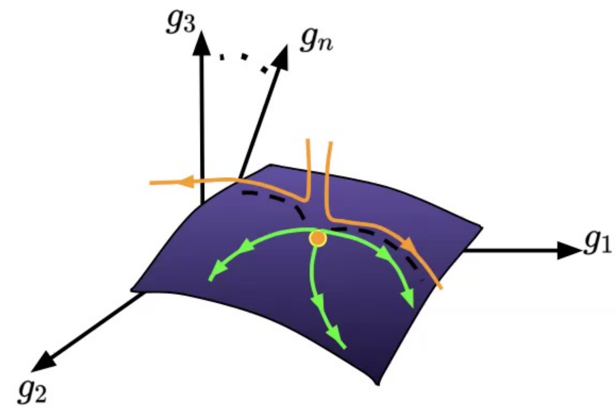
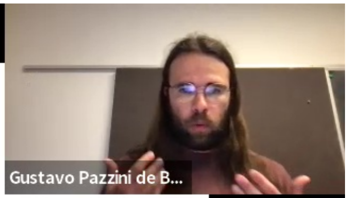


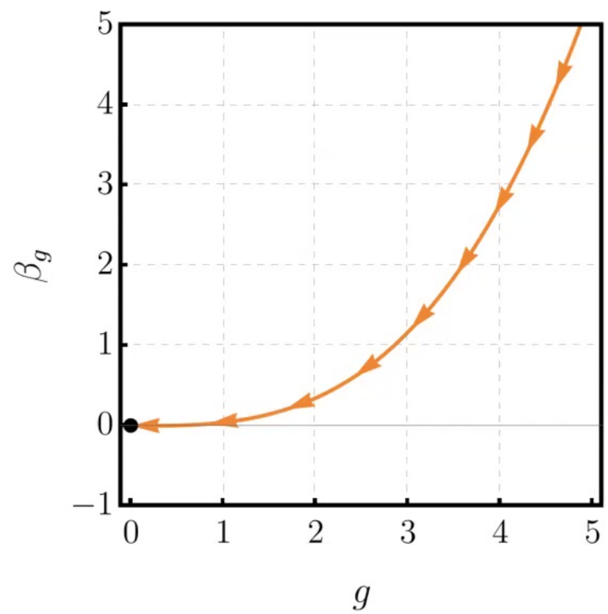
- Asymptotically safe quantum gravity+matter
  - ⇨ Anti-screening gravitational contribution plays an important role on inducing "safe trajectories" for SM couplings See, e.g. Eichhorn, 1810.07615 [hep-th]

Asymptotic safety perspective



Back to the flow Abelian-gauge (hypercharge) coupling

$$\beta_g = \frac{41}{96\pi^2} g^3$$

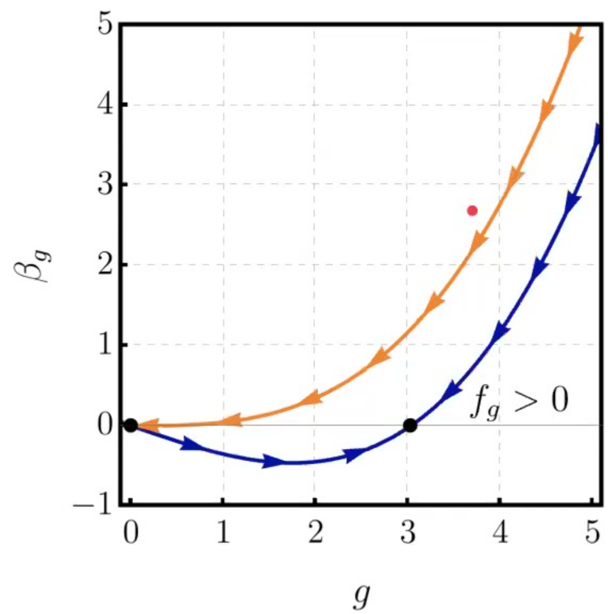


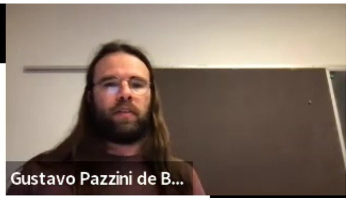
Asymptotic safety perspective

Back to the flow Abelian-gauge (hypercharge) coupling

$\beta_g = \frac{41}{96\pi^2} g^3 - f_g\, g$ ⟺ Matter+Gravity

- $f_g > 0$: Gravity acts anti-screening*
  ⇒ gravity-induced UV completion
- UV attractive fixed point at $g_* = 0$
- IR attractive fixed point at $g_* \sim \sqrt{f_g}$





Asymptotic safety perspective

Back to the flow Abelian-gauge (hypercharge) coupling

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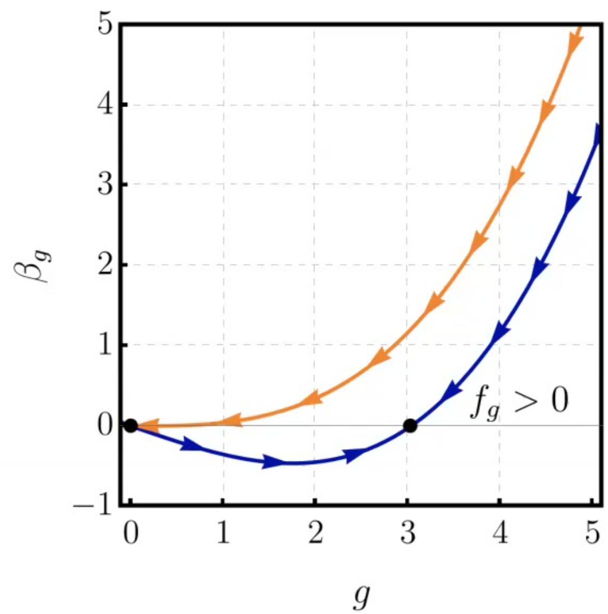
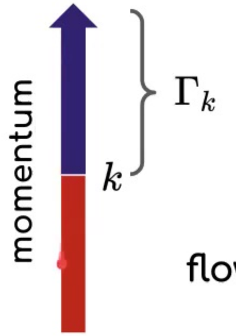


* Supported by various Functional RG calculations

Daum, Harst and Reuter, 0910.4938 [hep-th]
Harst and Reuter, 1101.6007 [hep-th]
Folkerts, Litim and Pawlowski, 1101.5552 [hep-th]
Christiansen and Eichhorn, 1702.07724 [hep-th]
Eichhorn and Versteegen, 1709.07252 [hep-th]
Christiansen, Litim, Pawlowski and Reichert, 1710.04669 [hep-th]
Eichhorn, Held and Wetterich, 1711.02949 [hep-th]
Eichhorn and Schiffer, 1902.06479 [hep-th]
GPB, Eichhorn and Pereira, 1907.11173 [hep-th]

Non-universalities from FRG calculations

Functional RG is a stepwise realization of a path-integral



$$e^{-\Gamma_k} \sim \int \mathcal{D}\phi \, e^{-S[\phi] - \frac{1}{2}\phi \cdot \mathbf{R}_k \cdot \phi}$$

** Euclidean

Γ_k: flowing "effective action"

$\mathbf{R}_k$: IR regulator: suppresses modes with momentum lower than the RG-scale k

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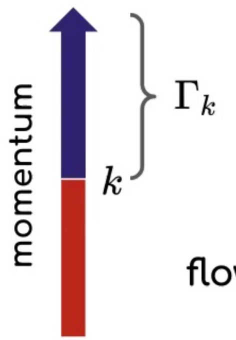
Functional RG is a stepwise realization of a path-integral



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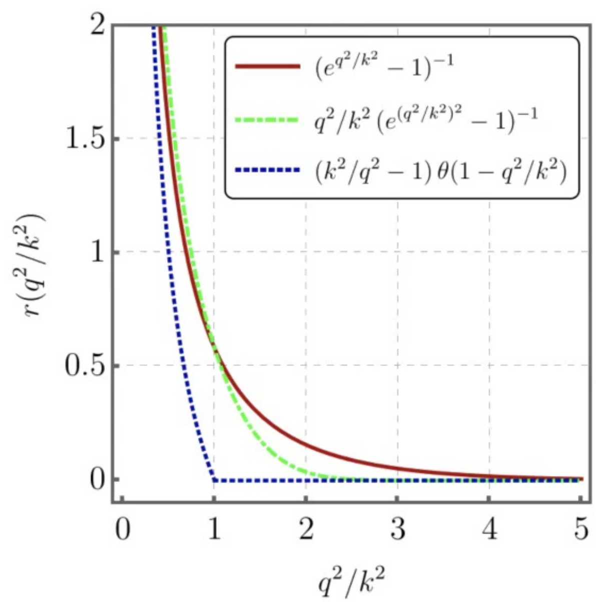
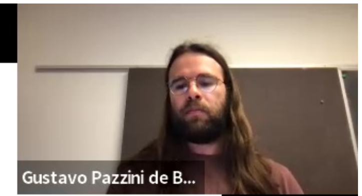
$\mathbf{R}_k$: IR regulator: suppresses modes with momentum lower than the RG-scale k

- Part of the non-universalities comes from the FRG regulator

$$\underbrace{\mathbf{R}_k(q^2) = q^2 \, r(q^2/k^2)}$$

Shape function





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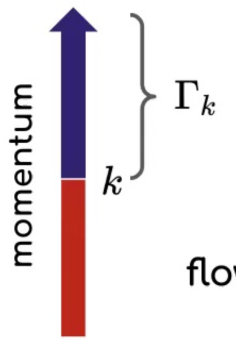

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flowing "effective action"

IR regulator: suppresses modes with momentum lower than the RG-scale k

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$$\underbrace{\mathbf{R}_k(q^2) = q^2\, r(q^2/k^2)}_{\text{Shape function}}$$

- $r^{\text{Litim}}(y) = \left(\frac{1}{y} - 1\right)\theta(1-y)$

  ⇨ $\beta_g|_{\text{grav.}} = -\frac{5}{18\pi} G\, g$

- $r^{\text{exp.}}(y) = \left(e^y - 1\right)^{-1}$

  ⇨ $\beta_g|_{\text{grav.}} = -\frac{5}{6\pi} G\, g$

FRG with vanishing regulators

Limit of vanishing regulator in the functional renormalization group

Alessio Baldazzi,[1,*] Roberto Percacci,[1,†] and Luca Zambelli[2,‡]

The nonperturbative functional renormalization group equation depends on the choice of a regulator function, whose main properties are a "coarse-graining scale" k and an overall dimensionless amplitude a. In this paper we shall discuss the limit $a \to 0$ with k fixed. This limit is closely related to the pseudoregulator that reproduces the beta functions of the $\overline{\mathrm{MS}}$ scheme that we studied in a previous paper. It is not suitable for precision calculations but it appears to be useful to eliminate the spurious breaking of symmetries by the regulator, both for nonlinear models and within the background field method.

DOI: 10.1103/PhysRevD.104.076026

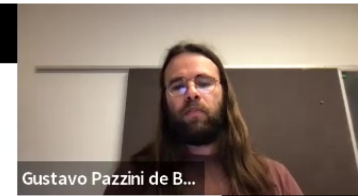
See also:
Baldazzi, Percacci and Zambelli
2009.03255 [hep-th]
for a more general class of
regulators including MS-bar

Vanishing-regulators

$$\hat{r}_a(y) = a\, r(y)$$

$r(y)$ → "Standard" FRG shape-function

a → Modulating parameter



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"Standard" FRG shape-function

Modulating parameter

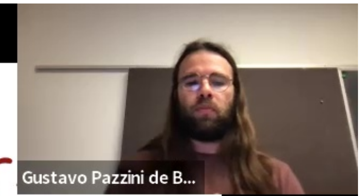
$\hat{r}_a^{\text{Litim}}(y) = a\left(\frac{1}{y}\right.$ ...

$\hat{r}_a^{\text{exp.}}(y) = a\left(e^{y}\right.$ ...

Vanishing-regulator limit: $a \to 0$

- Allow us to remove the regulator
- Selects only universal contributions

Gravity-Matter systems with vanishing regulator



Setup: Gravity + SM-like interactions

$$\Gamma_k^{\text{grav}} = -\frac{1}{16\pi G_{\text{N}}}\int_x \sqrt{g}\,R + \text{gauge-fixing terms}$$

$$\Gamma_k^{\text{SM-like}} = \frac{1}{4}\int_x \sqrt{g}\,F_{\mu\nu}^2 + \int_x \sqrt{g}\left(\frac{1}{2}(\partial_\mu\phi)^2 + \frac{\lambda}{4}\phi^4\right) + \int_x \sqrt{g}\,\left(i\bar{\psi}\gamma^\mu D_\mu\psi + iy\,\phi\bar{\psi}\psi\right)$$

Gravity contribution to the flow of matter couplings

$$\beta_g\big|_{\text{grav}} = -f_g(a)\,g$$

$$\beta_\lambda\big|_{\text{grav}} = -f_\lambda(a)\,\lambda$$

$$\beta_y\big|_{\text{grav}} = -f_y(a)\,y$$

See, e.g.

Eichhorn and Held, 1705.02342 [gr-qc]
GPB, Eichhorn and Pereira, 1907.11173 [hep-th]
GPB and Eichhorn, 2201.11402 [hep-th]
For discussion on the physical consequences of non-vanishing gravitational contribution to the flow of the quartic scalar and Yukawa couplings

Gravity-Matter systems with vanishing regulator

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$$\beta_y\big|_{\text{grav}} = -f_y(a)\, y$$

<u>Main Idea:</u>

Interpolate between “standard FRG results” ($a \to 1$) and “universal** results” obtained with $a \to 0$

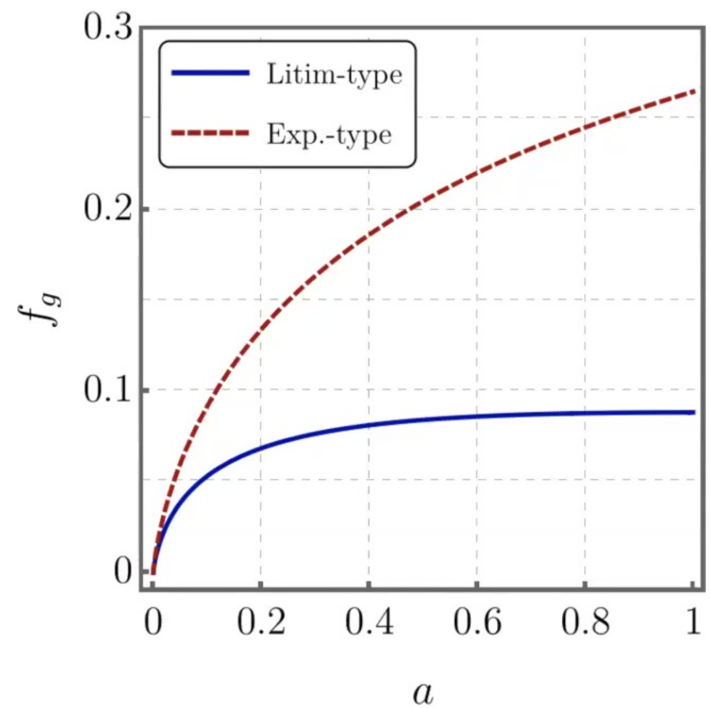
** Disclaimer: Universal with respect to $r(y)$

Gravity-Matter systems with vanishing regulator

Vanishing-regulator limit: “naive” limit

$$f_g^{\text{Litim}} = -\frac{10}{6\pi}\left(\frac{2a}{(1-a)^2} + \frac{a\,(a+1)\,\log(a)}{(1-a)^3}\right) G$$

$$f_g^{\text{Exp.}} = -\frac{10}{6\pi}\left(\frac{a}{1-a} + \frac{a\,\log(a)}{(1-a)^2}\right) G$$



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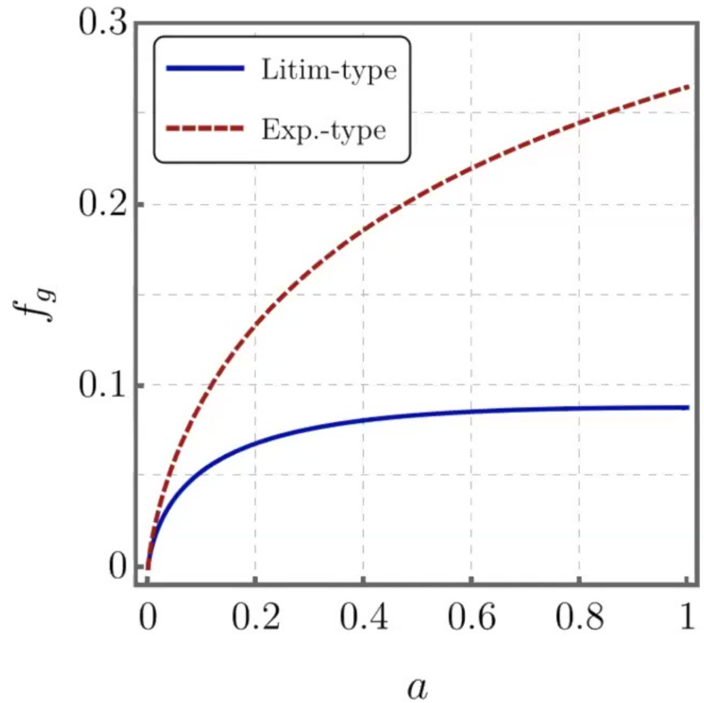
$$f_g^{\text{Exp.}} = -\frac{10}{6\pi}\left(\frac{a}{1-a} + \frac{a\,\log(a)}{(1-a)^2}\right) G$$

⬇

$$f_g \sim (-a\,\log(a) + \cdots)\, G$$

$$f_g \to 0 \quad \text{as} \quad a \to 0$$

This is not the full story....

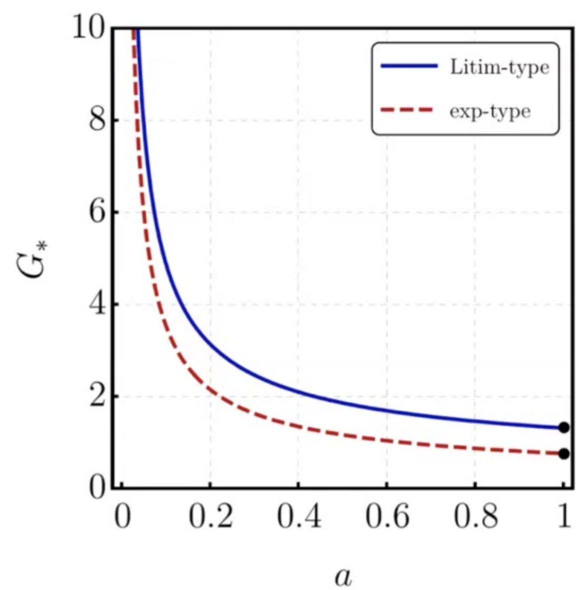


Gravity-Matter systems with vanishing regulator

- The flow of the Newton coupling depends on a

  $\beta_G = 2G - B(a)\,G^2$

- We should take into account the a-dependence of G when computing $f_g|_{a\to 0}$



<u>Focusing on the fixed-point regime:</u>

Interacting fixed-point: $G_*(a) = 2/B(a)$

$$G_*(a) \sim -\frac{6\pi}{17\,a\,\log(a)} + \cdots \quad \text{as} \quad a \to 0$$

Percacci, Talk at the ERG2020

Gravity-Matter systems with vanishing regulator

Non-trivial "vanishing-regulator" limit for f_g

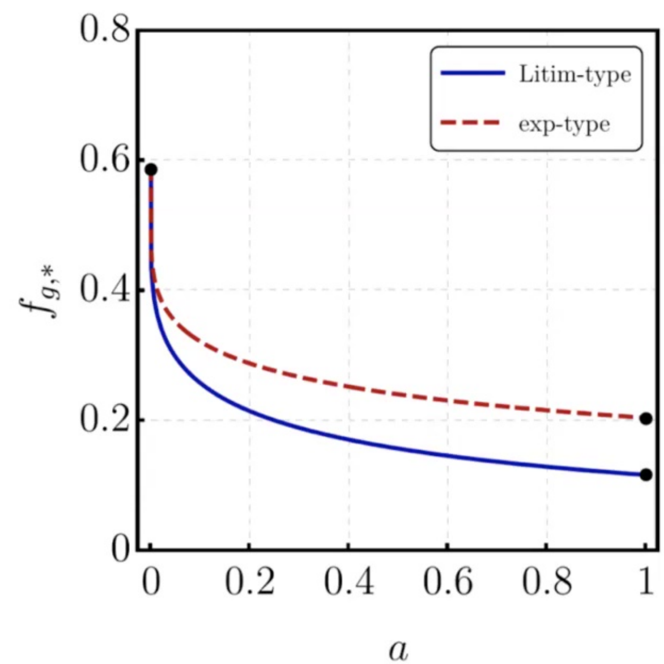
$$f_g|_{G_*(a)} \sim (-a \log(a) + \cdots)\, G_*(a)$$

$$G_*(a) \sim -\frac{6\pi}{17\, a\, \log(a)} + \cdots$$

$f_g|_{G_*(a)} \to 10/17$ as $a \to 0$

✱ This result is independent of the form of $r(y)$

** Thanks to an argument by B. Knorr



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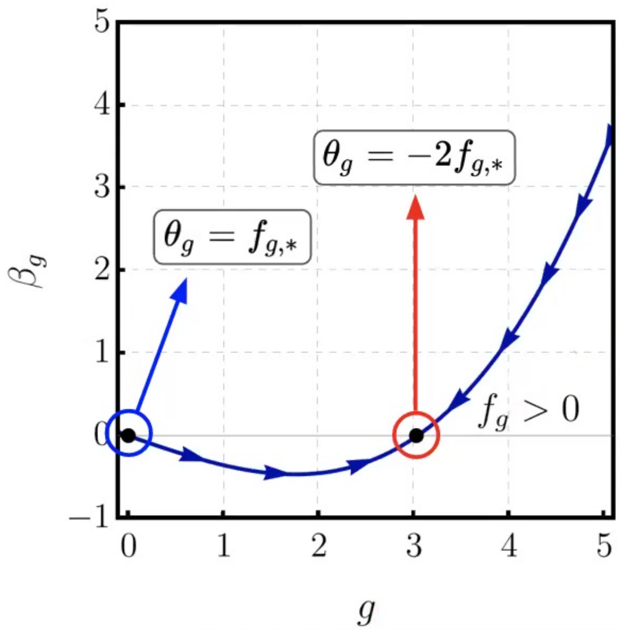
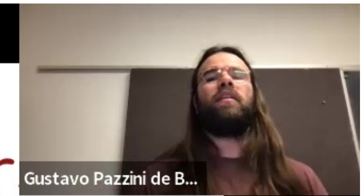
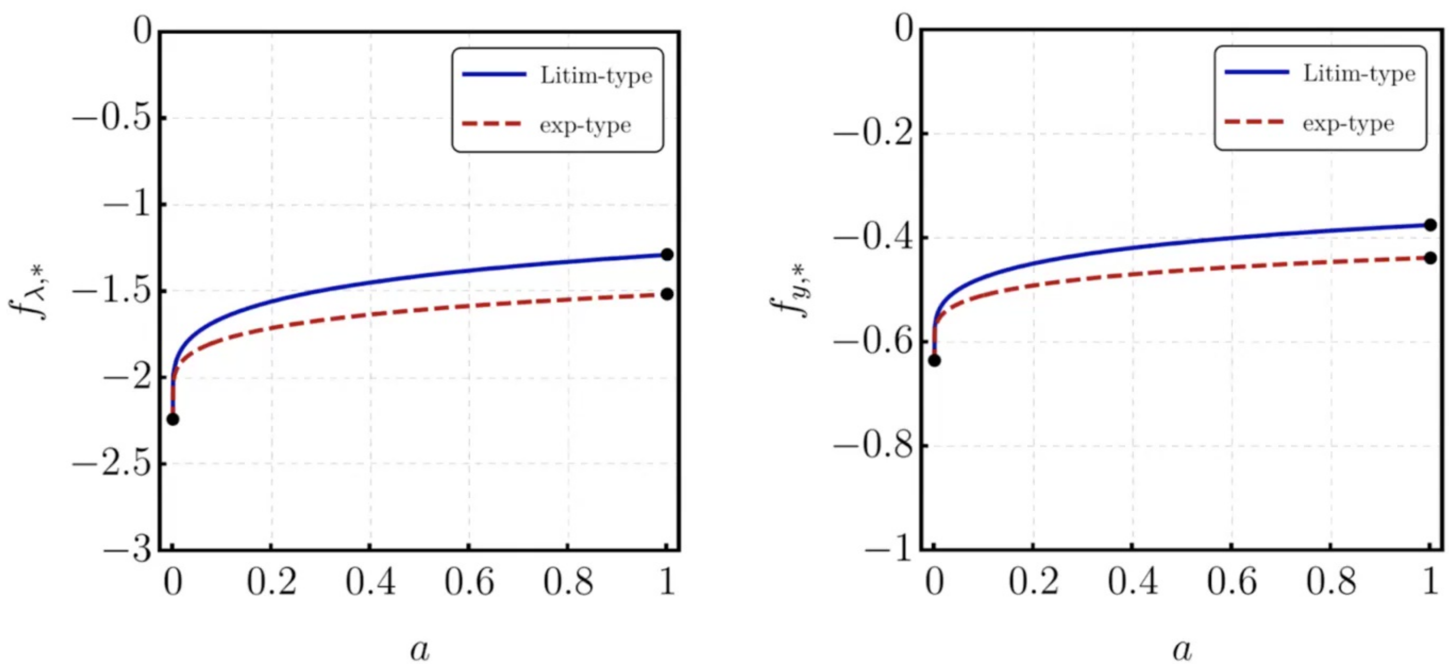
Relation to critical exponents





Gravity-Matter systems with vanishing regulator

Scalar quartic coupling and Yukawa coupling



What is the effect of quantum gravity on the flow of matter couplings?

Lessons from vanishing regulators - a fresh perspective

- Vanishing results from a “naive” vanishing-regulator limit
  - ⇨ Resonates with part of the perturbative studies

- Non-vanishing results at the fixed-point regime, even at $a \to 0$
  - ⇨ Non-trivial indication for gravity-induced UV completion of matter couplings

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Focuses on universal quantities – critical exponents

Concluding remarks

- We offer a new perspective to conflicting results concerning the effect of quantum gravity on the flow of matter couplings

- From the FRG perspective, we employ vanishing regulators as a way to extract universal pieces from non-universal "matter beta functions"

  ↪ "Naive" vanishing regulator limit leads to vanishing results ⟷ Focuses on non-universal quantities: "beta function contributions"

  ↪ Non-trivial results at the fixed-point regime with vanishing-regulator limit ⟷ Focuses on universal quantities: "critical exponents"

- It would be interesting to explore universal quantities (e.g. critical exponents) from a "perturbative setting"

  ↪ Stay tuned!

  GPB and Eichhorn, work in progress

  Based on the MS-bar regulator by Baldazzi, Percacci and Zambelli 2009.03255 [hep-th]

Thank you for your attention!