Nonvanishing gravitational contribution to matter beta functions for vanishing dimensionful regulators

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Based on: 2201.11402 [hep-th]
In collaboration with Astrid Eichhorn

SDU University of Southern Denmark

CP3

VILLUM FONDEN

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

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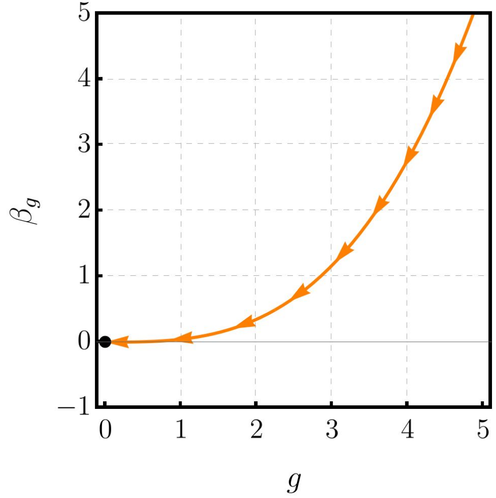
Flow of Abelian-gauge couplings



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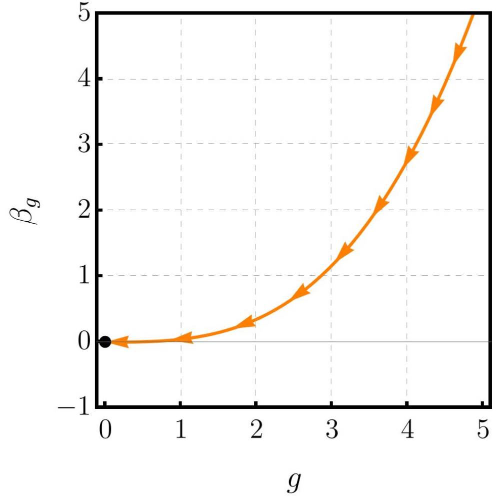

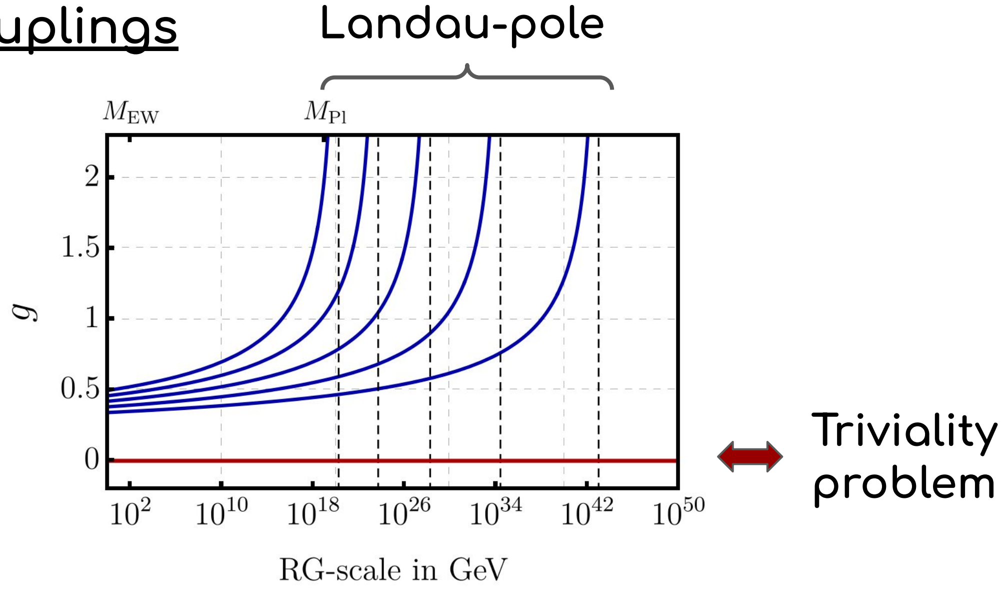

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Flow of Abelian-gauge couplings + Gravity

Gravity has no effect on β_g

Gravity acts with screening contribution to β_g

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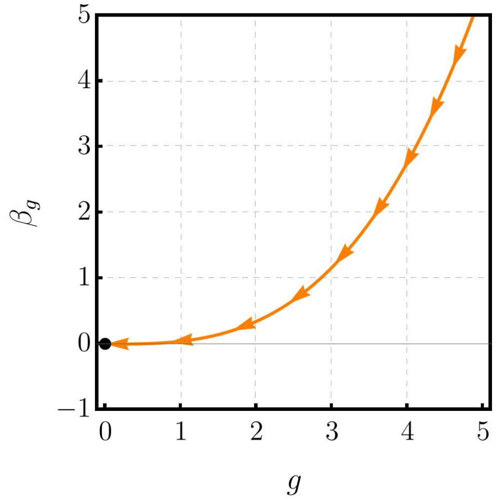

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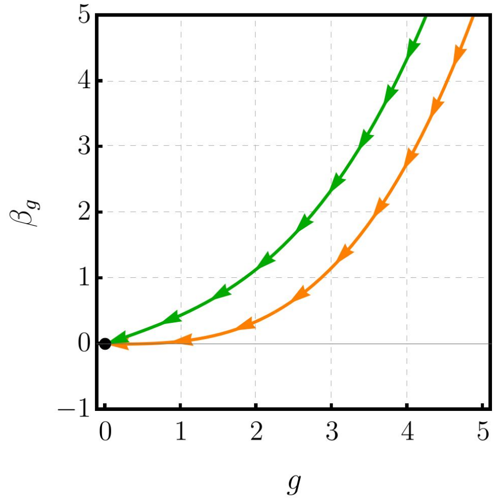

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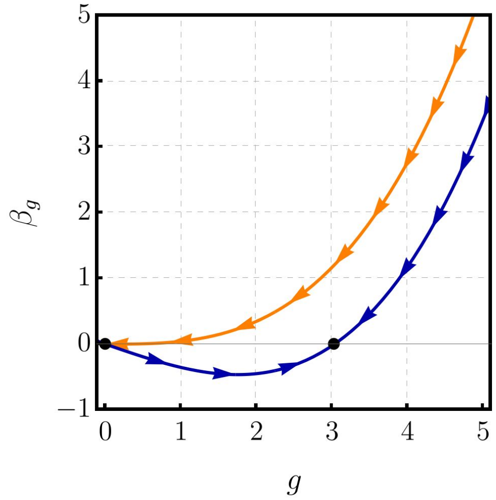

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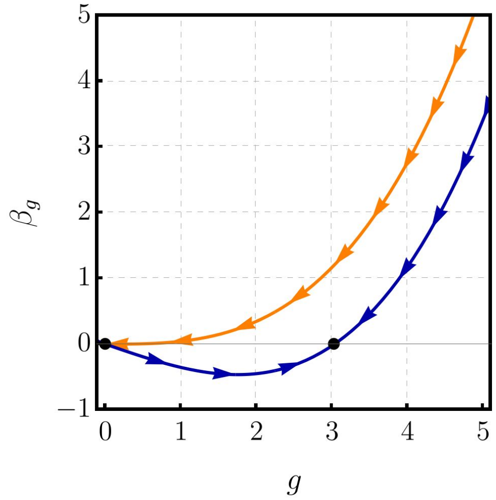

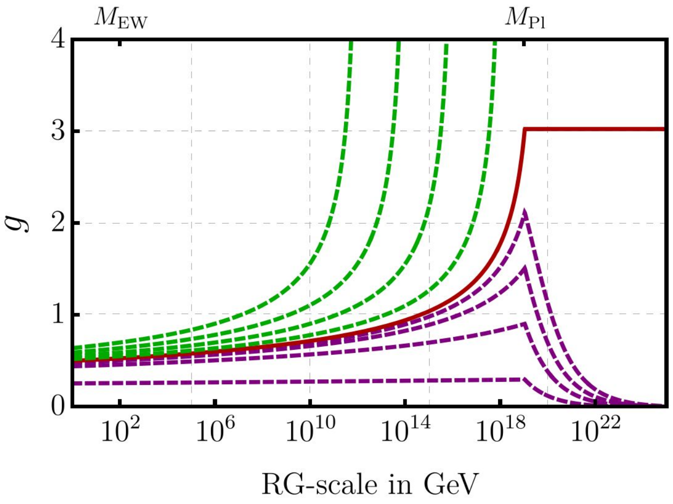

Interesting possibilities based on the interplay between gravity and matter

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

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

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

Robinson and Wilczek, 0509050 [hep-th]
Toms, 0809.3897 [hep-th]
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- Others claim that this contribution cannot be associated with any physical meaning due to spurious scheme-dependencies

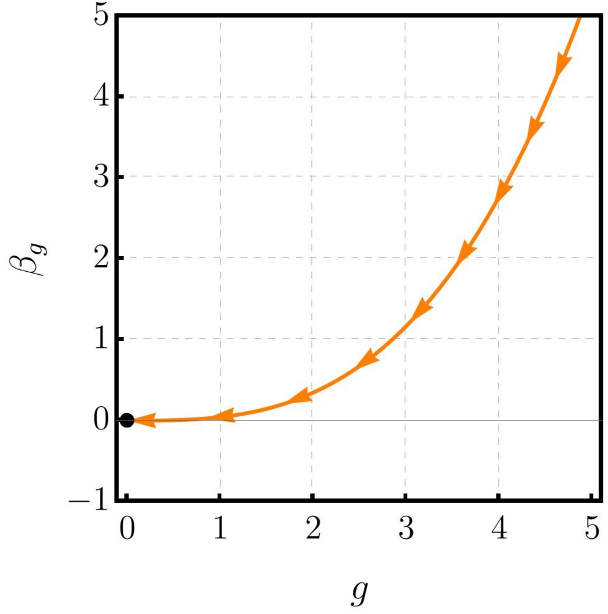
"We can set $\beta_g|_{\text{grav}} = 0$ by a choice of scheme"

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

Flow of Abelian-gauge (hypercharge) coupling

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



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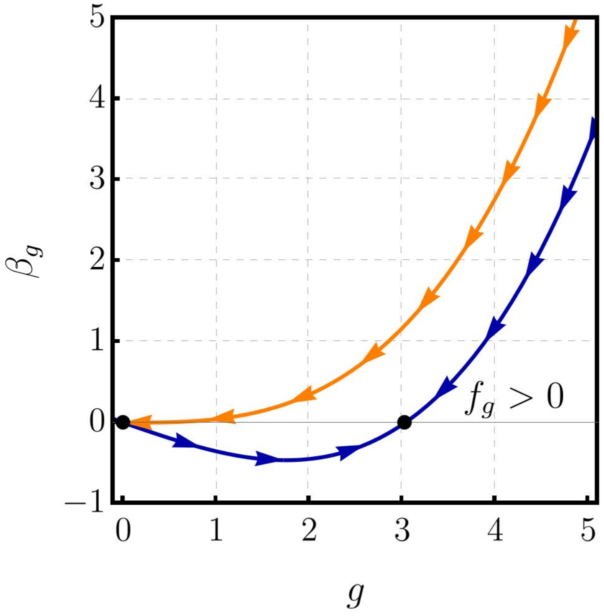
$\beta_g = \frac{41}{96\pi^2} g^3 - f_g\, g$ ⟺ Matter+Gravity

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



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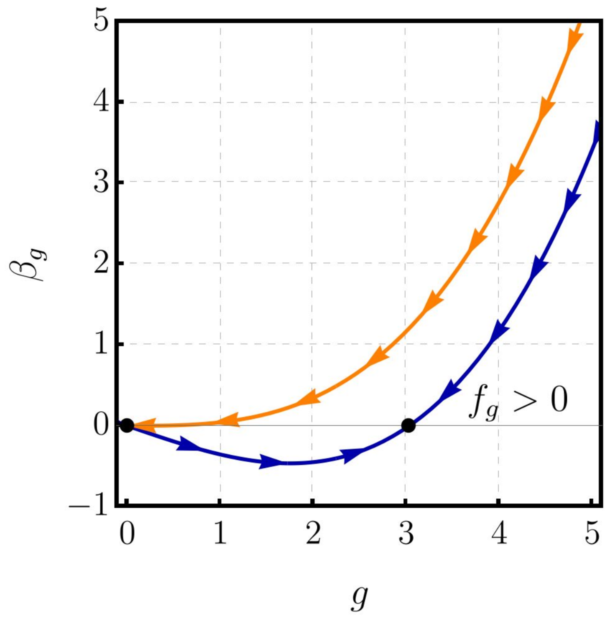
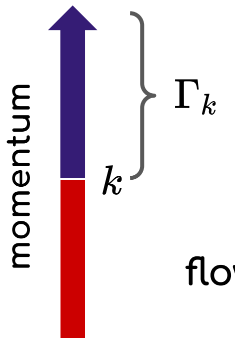


* Supported by various Functional RG calculations

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



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

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

** Euclidean

flowing "effective action"

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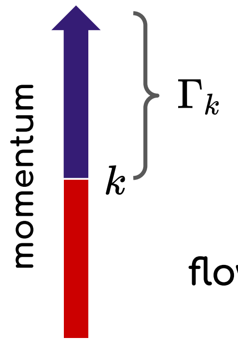

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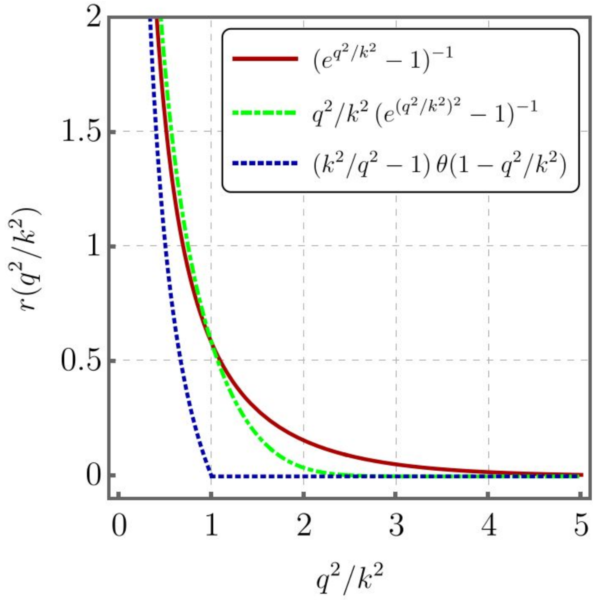
- Part of the non-universalities comes from the FRG regulator

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

Shape function



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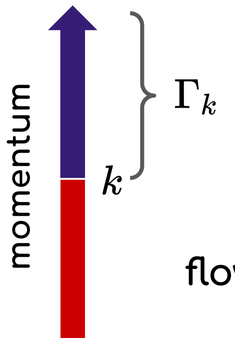

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$$\mathbf{R}_k(q^2) = q^2\, \underbrace{r(q^2/k^2)}_{\text{Shape function}}$$

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

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

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

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

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 $\overline{\text{MS}}$ 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
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Vanishing-regulators

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

$r(y)$ → “Standard” FRG shape-function

a → Modulating parameter

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

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Vanishing-regulator limit: $a \to 0$

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

Gravity-Matter systems with vanishing regulators

Setup: Gravity + SM-like interactions

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

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

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Gravity contribution to the flow of matter couplings

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

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

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

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

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Main Idea:

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 regulators

Vanishing-regulator limit: “naive” limit

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

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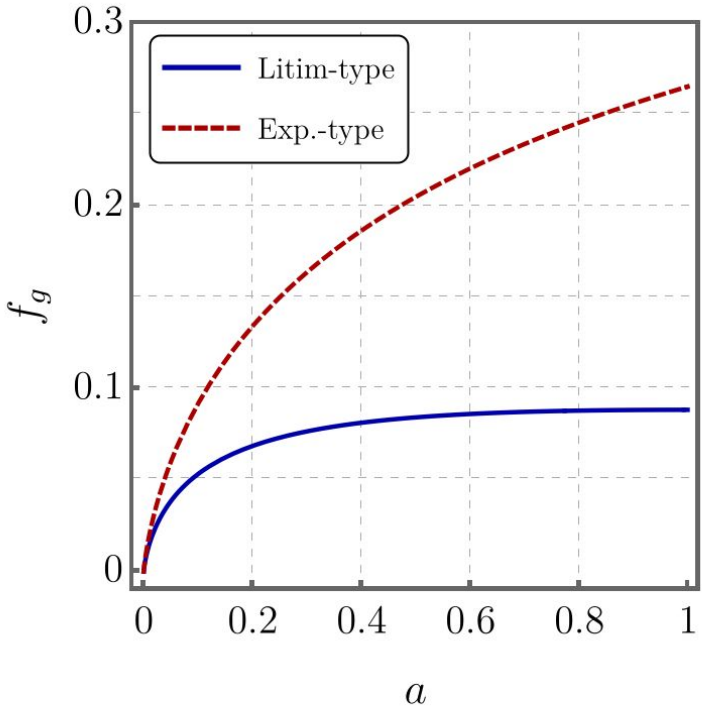

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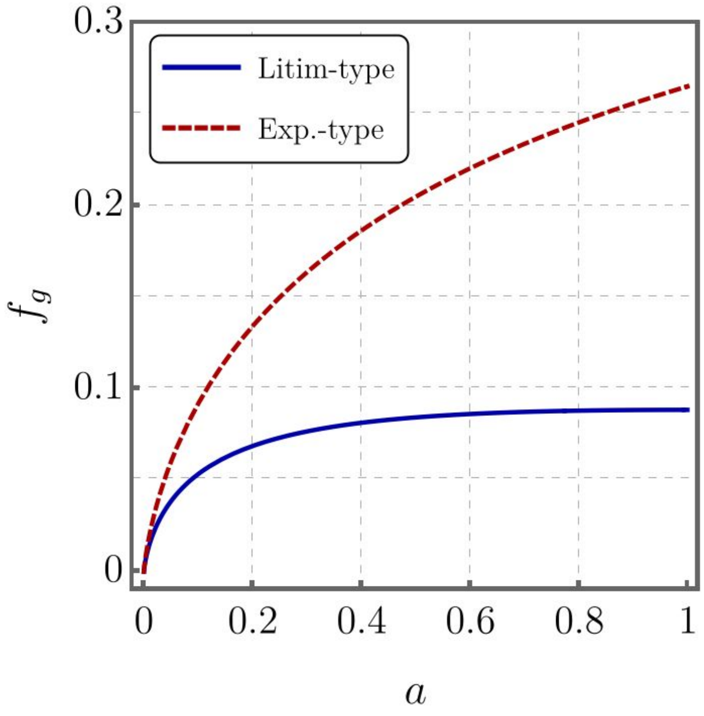

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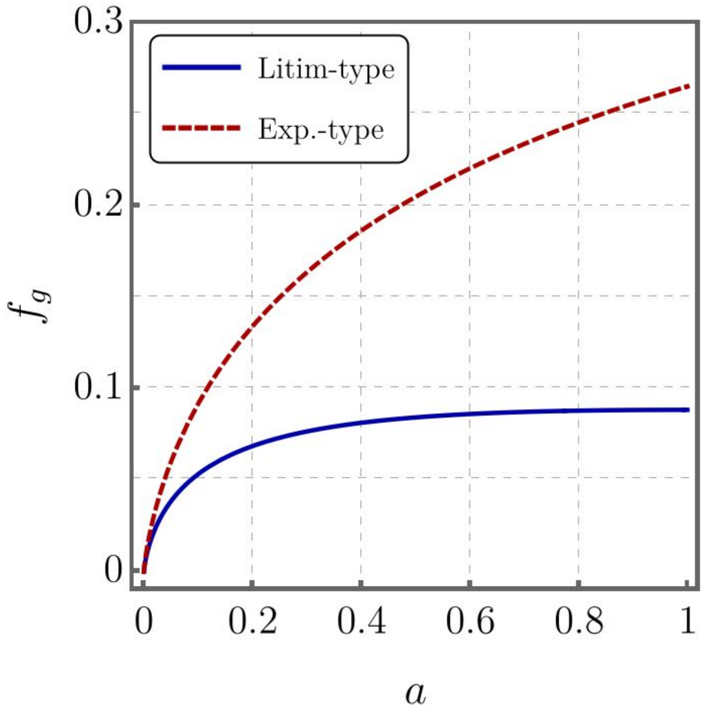
This is not the full story....



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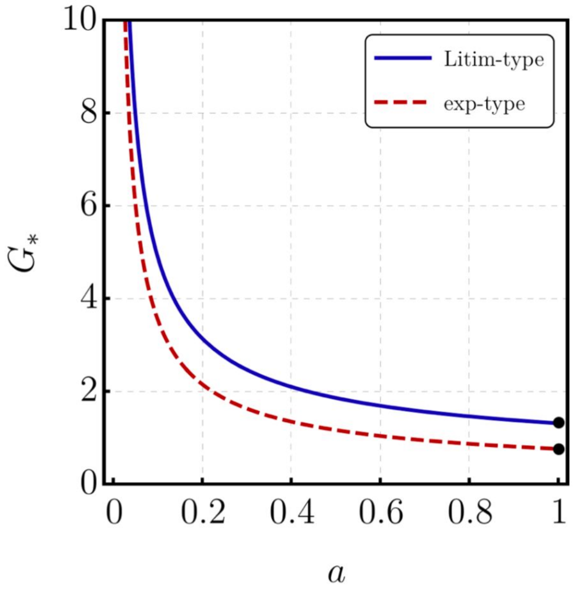
<u>Focusing on the fixed-point regime:</u>

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

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

Percacci, Talk at the ERG2020



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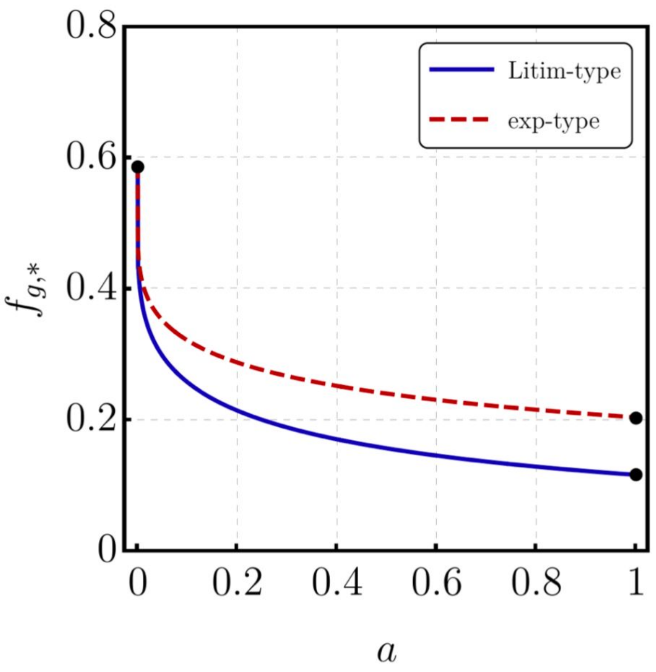

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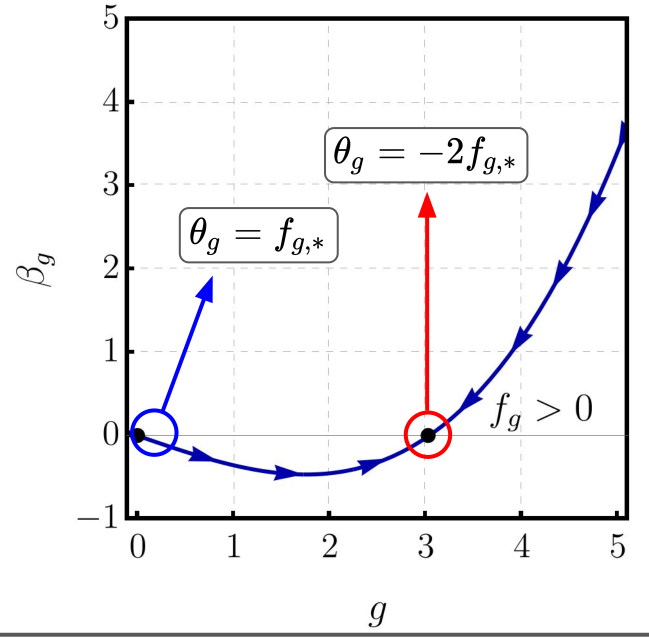
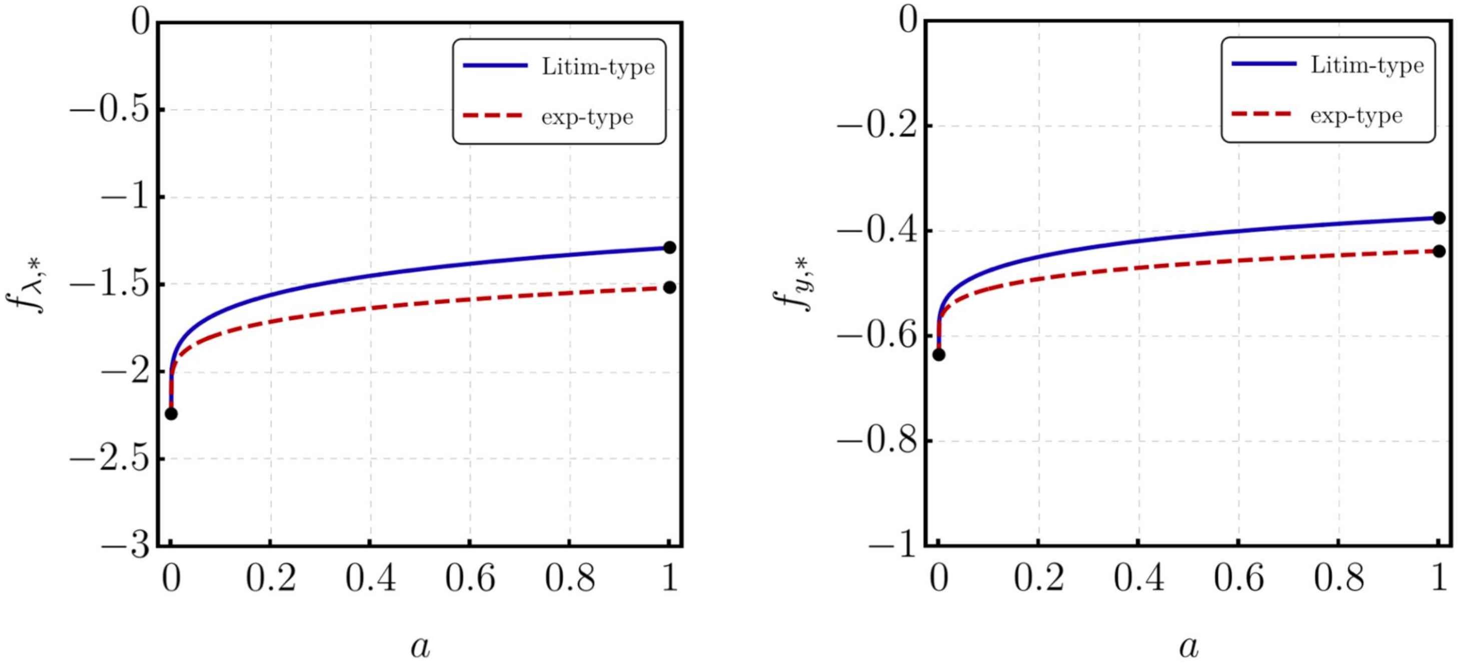
Relation to critical exponents



Gravity-Matter systems with vanishing regulators

<u>Scalar quartic coupling and Yukawa coupling</u>



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

Lessons from vanishing regulators - a fresh perspective

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  - ➪ 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 non-universal quantities – beta function contributions

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Focuses on universal quantities – critical exponents

Thank you for your attention!