Neutrino mass generation in asymptotically safe gravity

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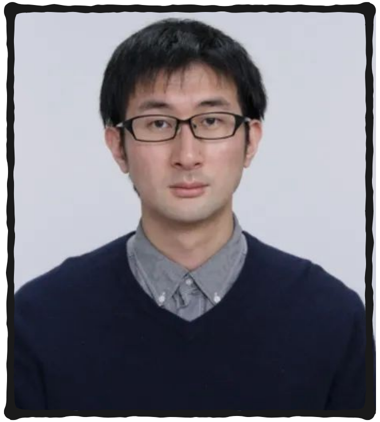
In collaboration with:

Astrid Eichhorn

Antônio D. Pereira



Masatoshi Yamada

To appear: 2504.XXXXX

Interplay between gravity and matter in asymptotic safety

Towards experimental tests of quantum gravity

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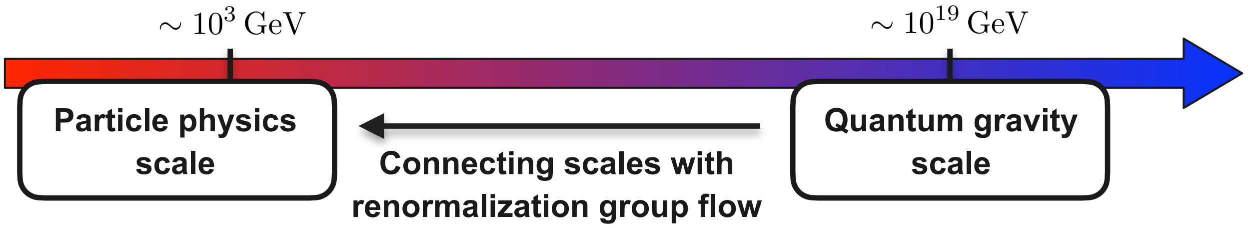

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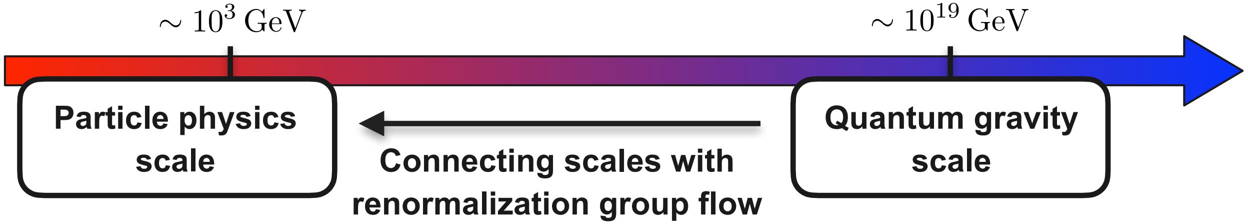

<u>Exciting results in the past 15 years</u>

- **Higgs mass from ASQG**
  Shaposhnikov, Wetterich (2009), …
- **Solution to the hypercharge triviality problem** Christiansen, Eichhorn (2017), …
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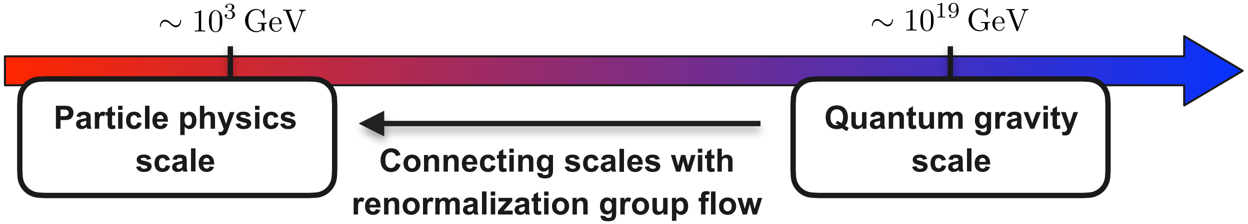

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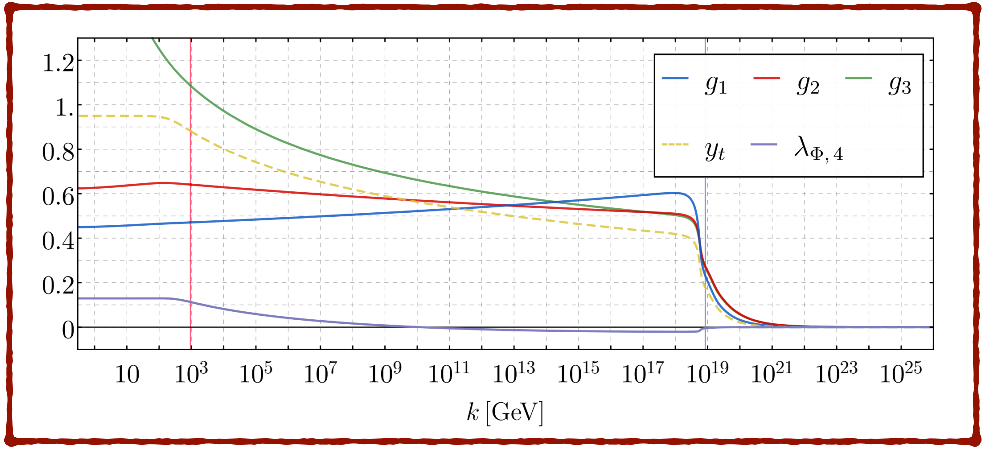
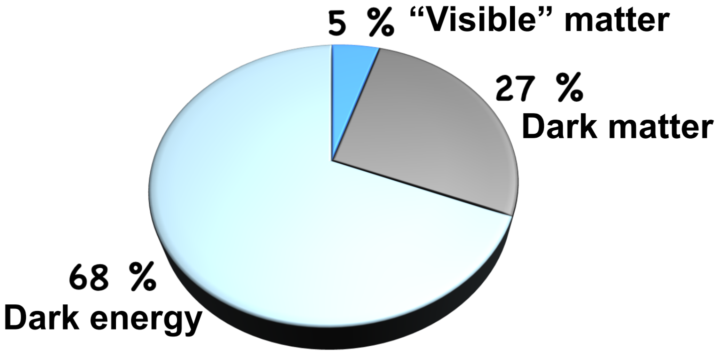


Pastor-Gutiérrez, Pawlowski, Reichert (2022)

Missing pieces of the Standard Model

The Standard Model is incomplete



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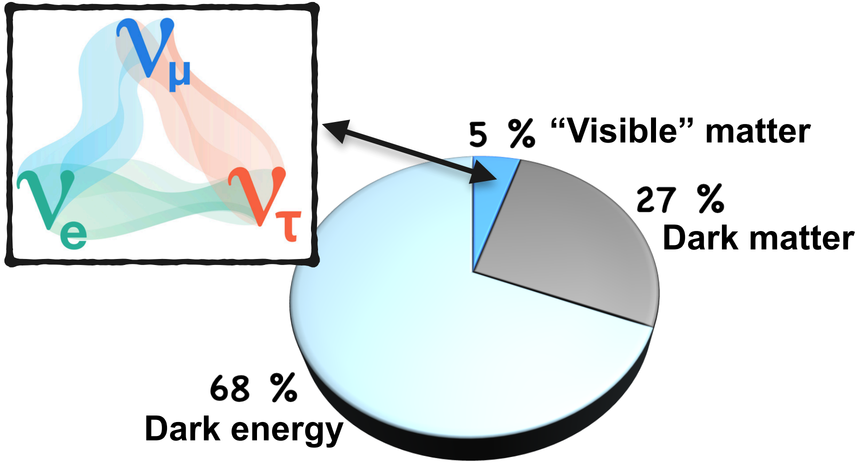

Quick detour in the dark side of asymptotically safe gravity

- Asymptotically safe gravity can lead to theoretical constraints on Dark Matter candidates

- Active searches of dark matter could work as indirect tests of asymptotically safe gravity

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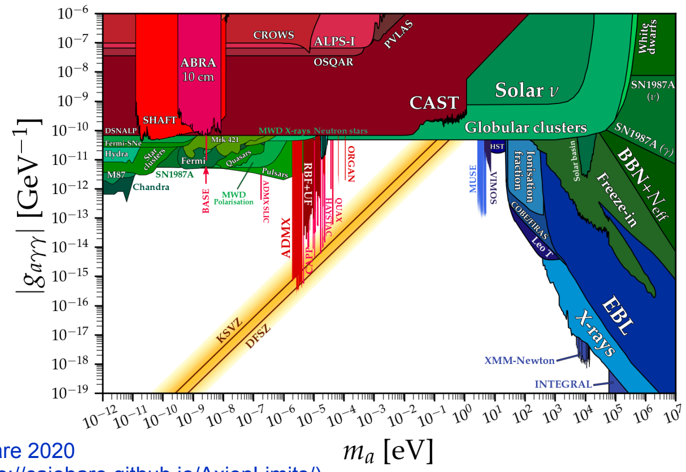
Axion-Like Particles (ALPs) in ASQG?

- **Typical ALP-photon interaction:**

$$\mathcal{L}_{\gamma-\mathrm{ALP}} = \frac{g_{a\gamma\gamma}}{4}\,\varphi\,F_{\mu\nu}\tilde{F}^{\mu\nu}$$

- **Popular candidate for ultra-light (non-thermally produced) dark matter**

Reviews on ALPs: Arias et.al.(2012), Ringwald (2012,2014), Irastorza, Redondo (2018), Irastorza (2021), …



O'Hare 2020 (https://cajohare.github.io/AxionLimits/)

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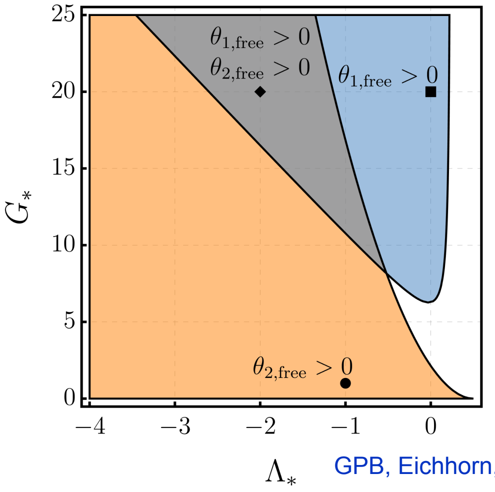

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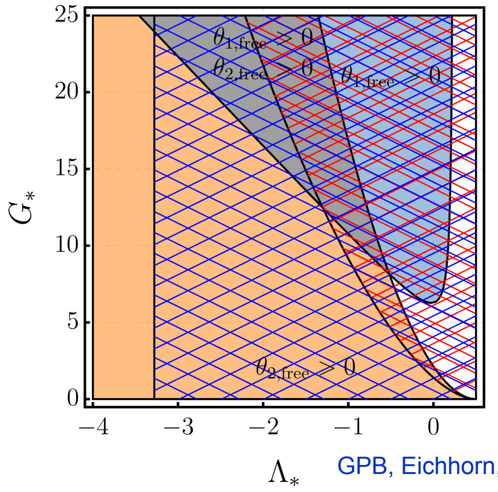

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Ruling out vector dark matter models in ASQG

- DM via hidden gauge sector

$$\mathcal{L}_{\mathrm{DM}}^{\mathrm{U_D}(1)} = -\frac{1}{4} V_{\mu\nu} V^{\mu\nu} + (D_\mu S)^* (D^\mu S) - V(\Phi, S)$$

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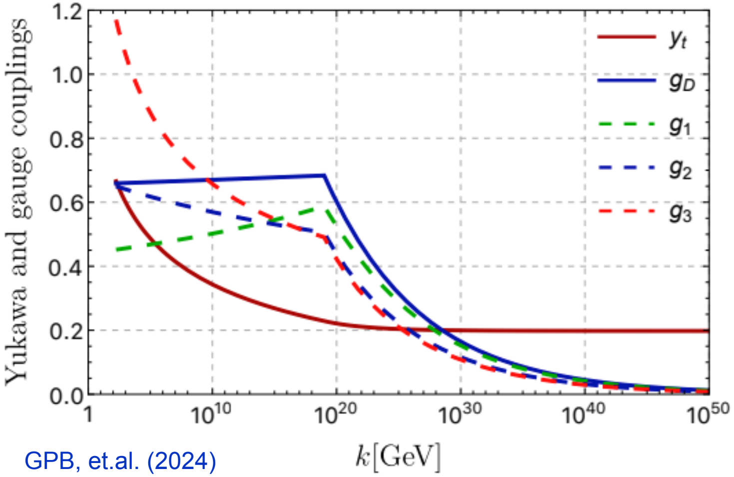

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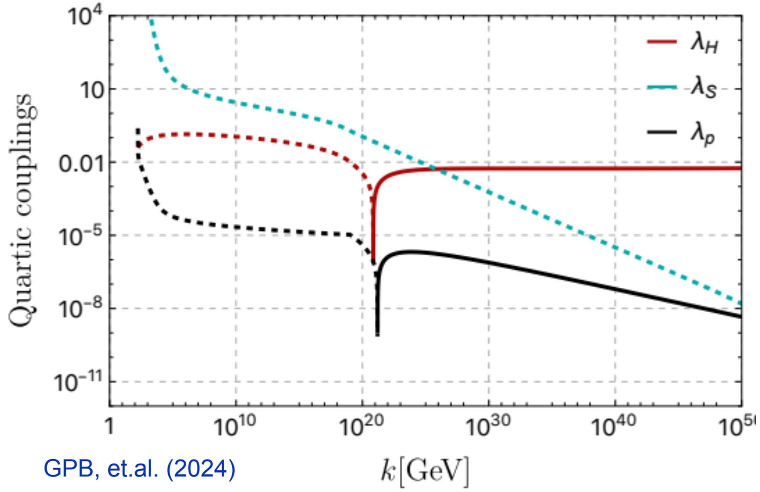

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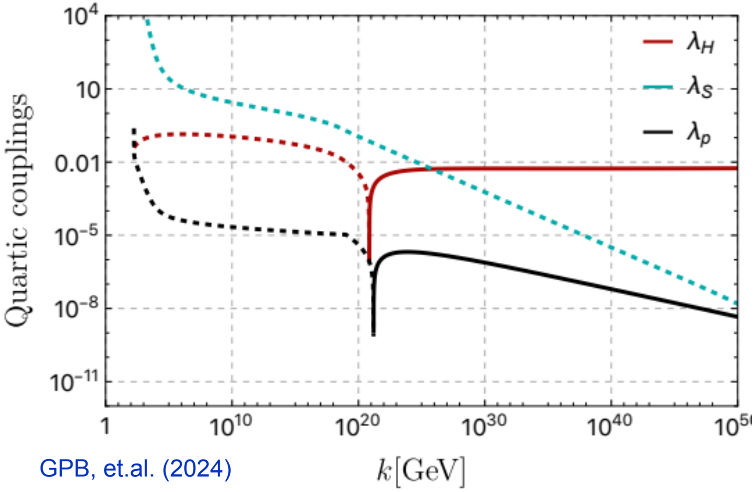

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Massive Neutrinos: another missing ingredient in the SM

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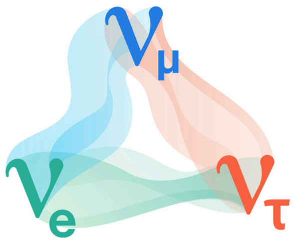

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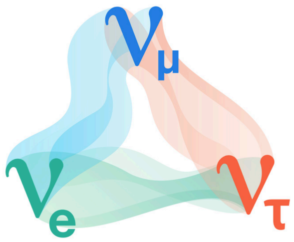

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➡ Explanation: Neutrinos are massive particles (with mass basis different from flavour basis)

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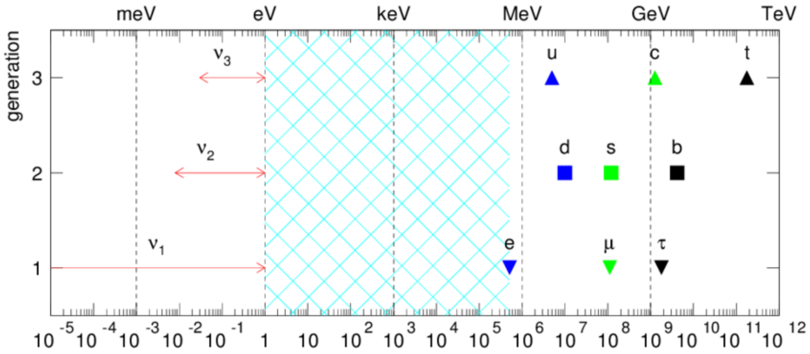

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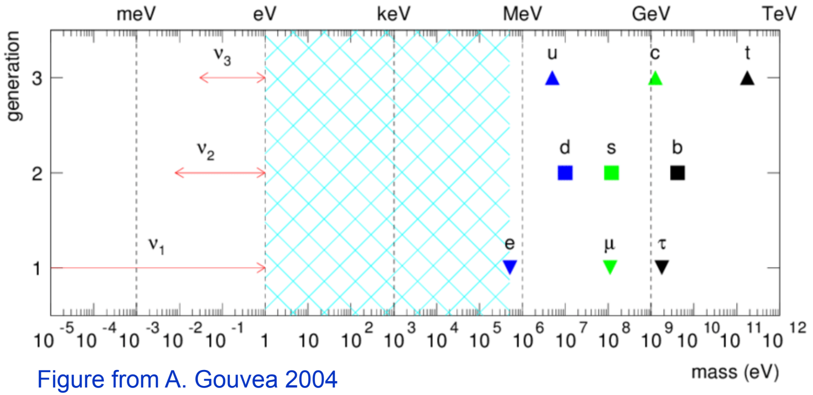

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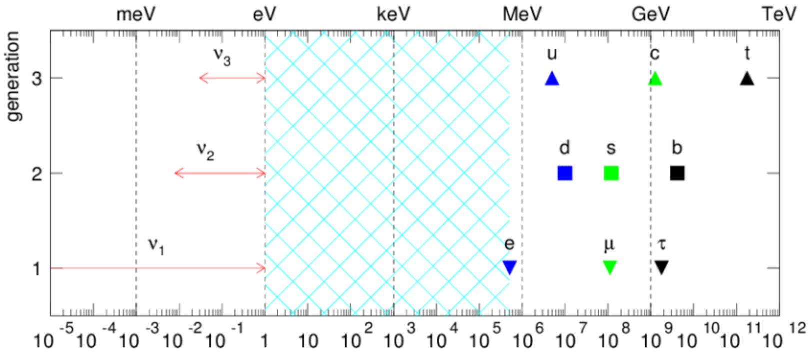

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- What is the origin of neutrino masses?
- Is it possible to explain the the large hierarchy between neutrino masses and other fermion masses?

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Neutrino Masses in Asymptotically Safe Gravity

- Many alternatives in the market (Dirac neutrinos, See-Saw, Weinberg operator…). Is there a theoretical principle to select a few of them?
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Naturally small Yukawa couplings from trans-Planckian asymptotic safety

Kamila Kowalska, Soumita Pramanick and Enrico Maria Sessolo

Abstract: In gauge-Yukawa systems embedded in the framework of trans-Planckian asymptotic safety we discuss the dynamical generation of arbitrarily small Yukawa couplings driven by the presence of a non-interactive infrared-attractive fixed point in the renormalization group flow. Additional ultraviolet-attractive fixed points guarantee that the theory remains well defined up to an infinitely high scale. We apply this mechanism to the Yukawa couplings of the Standard Model extended with right-handed neutrinos, finding that asymptotically safe solutions in agreement with the current experimental determination of the masses and mixing angles exist for Dirac neutrinos with normal mass ordering. We generalize the discussion by applying the same mechanism to a new-physics model with sterile-neutrino dark matter, where we generate naturally the feeble Yukawa interaction required to reproduce via freeze-in the correct relic abundance.

See also:

Domenech, Goodsell and Wetterich, 2021
Chikkaballi, Kowalska and Sessolo, 2023

For massive neutrinos with see-saw scale

Dynamically vanishing Dirac neutrino mass from quantum scale symmetry

Astrid Eichhorn [a], Aaron Held [b,c,*]

A B S T R A C T

We present a mechanism which drives Dirac neutrino masses to tiny values along the Renormalization Group flow, starting from an asymptotically safe ultraviolet completion of the third generation of the Standard Model including quantum gravity. At the same time, the mechanism produces a mass-splitting between the neutrino and the quark sector and also generates the mass splitting between top and bottom quark. The mechanism hinges on the hypercharges of the fermions and produces a tiny neutrino Yukawa coupling, because the right-handed neutrino is sterile and does not carry hypercharge.

See also: A. Held Ph.D. thesis, 2019

Neutrino Masses in Asymptotically Safe Gravity

In the rest of this talk, I will discuss three scenarios for massive neutrinos in ASQG

- **Scenario I:**
  Massive neutrinos from Weinberg operator (without right-handed neutrinos)

- **Scenario II:**
  Majorana massive neutrinos from see-saw mechanism (type I)

- **Scenario III:**
  Pseudo-Dirac massive neutrinos

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  - ➡ **Upper bound on the see-saw scale:**
    $m_R \lesssim 10^{14}\,\mathrm{GeV}\,(\text{assuming } m_{\nu,\mathrm{obs}} \sim 10^{-10}\,\mathrm{GeV})$

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➡ **Compatible with asymptotically safe gravity**
➡ **No upper or lower bound from this scenario**
➡ **We can tune the relevant parameters to embed this scenario into asymptotically safe gravity**

Neutrino Masses in Asymptotically Safe Gravity

Working hypothesis:

"Asymptotically Safe Gravity is Near-Perturbative"

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Strong evidence from pure gravity and gravity + “minimal matter”

Falls, Litim, Nikolakopoulos and Rahmede, 2013
Falls, Litim and Schröder, 2018
Eichhorn, Lippoldt, Pawlowski, Reichert and Schiffer, 2018

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$$\mathcal{L}_{\text{Weinberg}} = \frac{\zeta}{k}\left((\bar{L}\sigma_2 H^*)(H^\dagger \sigma_2 L^C) + \text{h.c.} \right)$$

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- **Usually considered as part of the SMEFT (as a lepton number violating term)**

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➡ **We look at the beta function of ζ including quantum gravity contributions**

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➡ **The Weinberg operator scenario does not become UV complete under the impact of gravity**

➡ **Asymptotically safe gravity seems to require new degrees of freedom in the neutrino sector**

➡ **This results does not rule exclude the Weinberg operator in a EFT setting**

Majorana Neutrinos and See-Saw Mechanism

- **A popular scenario for massive neutrinos is based on the see-saw mechanism**

$$\mathcal{L}_\nu \supset \frac{m_R}{2}\left(\bar{\nu}_R \nu_R^C + \text{h.c.}\right) + y_\nu \left(\bar{L}\tilde{H}\nu_\text{R} + \text{h.c.}\right) \underset{\text{SSB}}{\rightarrow} \mathcal{L}_\nu \supset \frac{m_R}{2}\left(\bar{\nu}_R \nu_R^C + \text{h.c.}\right) + m_D\left(\bar{\nu}_L \nu_\text{R} + \text{h.c.}\right) + \cdots$$

$$m_D = \frac{1}{\sqrt{2}} y_\nu v_\text{H}$$

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- **Yes! We can construct explicit RG trajectories that are UV complete for all couplings**

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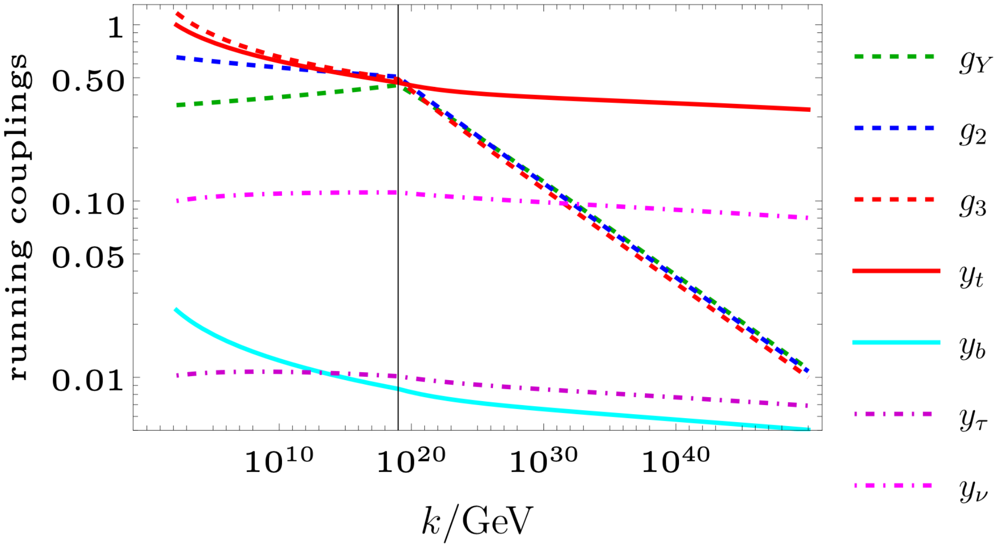
Thus, we have enough freedom to accommodate non-vanishing Majorana masses in the infrared



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Asymptotically safe gravity generates an upper bound on the see-saw scale

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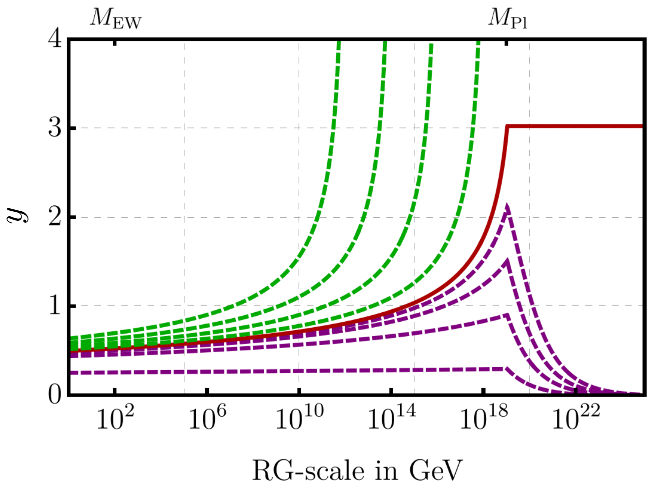

$$\beta_y = \#y^3 - f_y\, y$$

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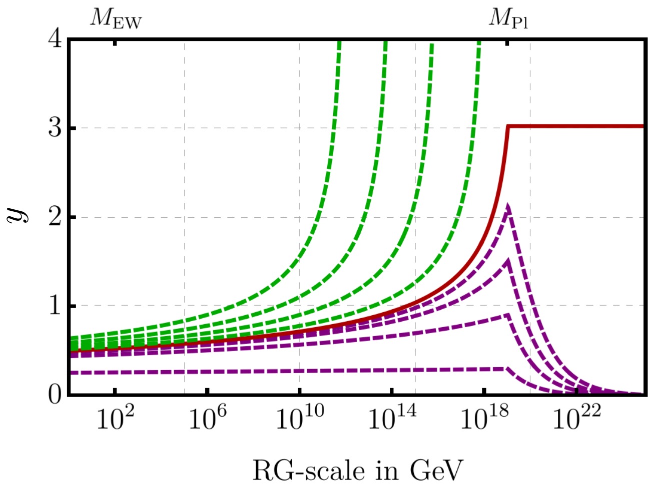

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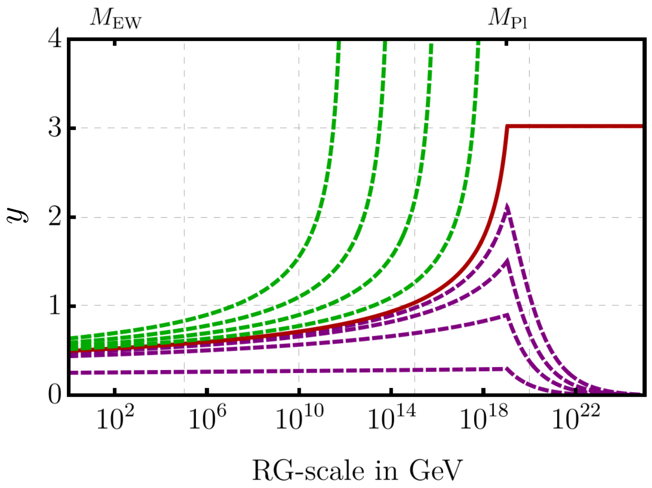

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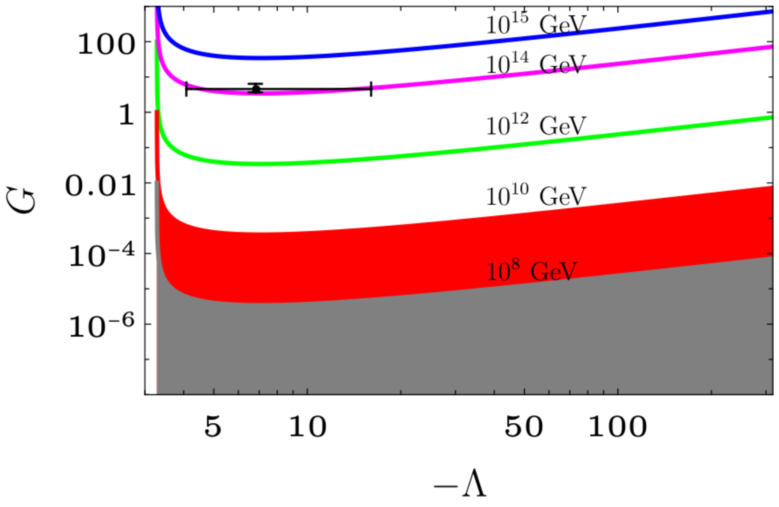

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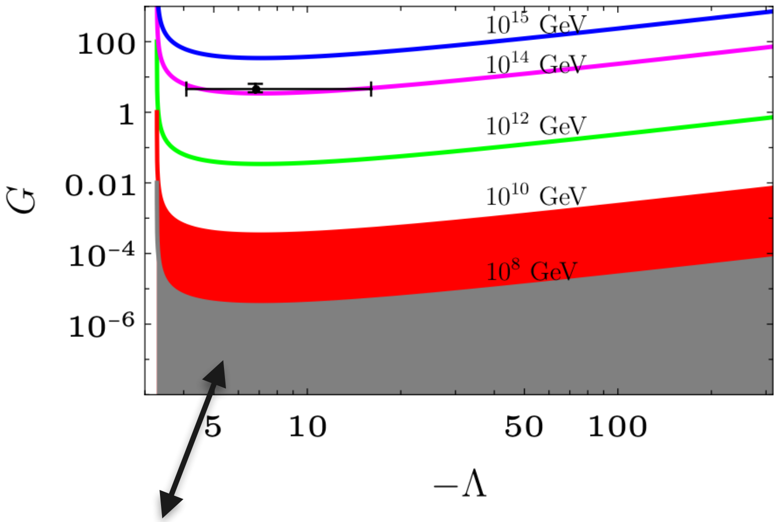

Excluded if we impose from Davidson-Ibarra bound (thermal leptogenis)

Pseudo-Dirac Massive Neutrinos

- **A different perspective on neutrinos with Majorana masses**

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✳ **Experimental searches at JUNO and DARWIN**

Franklin, Perez-Gonzalez and Turner, 2023
de Gouvêa, et. al., 2022

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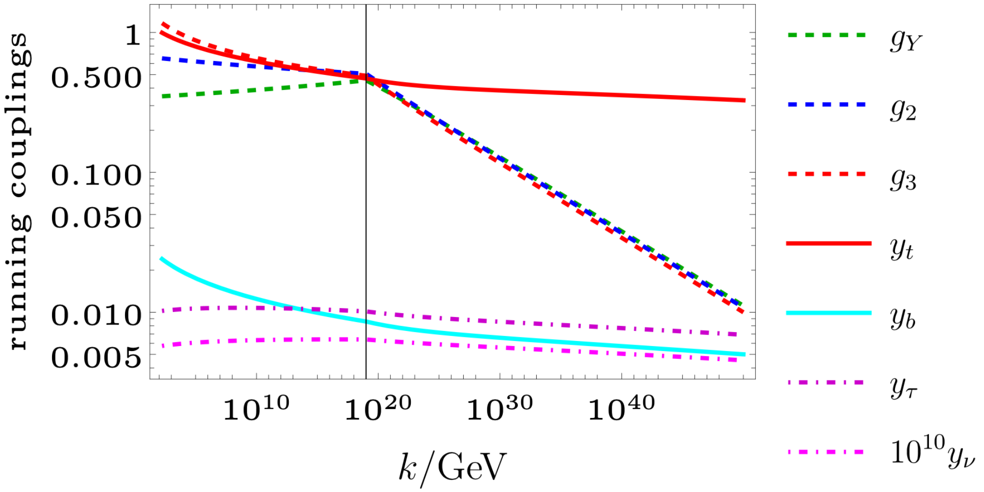

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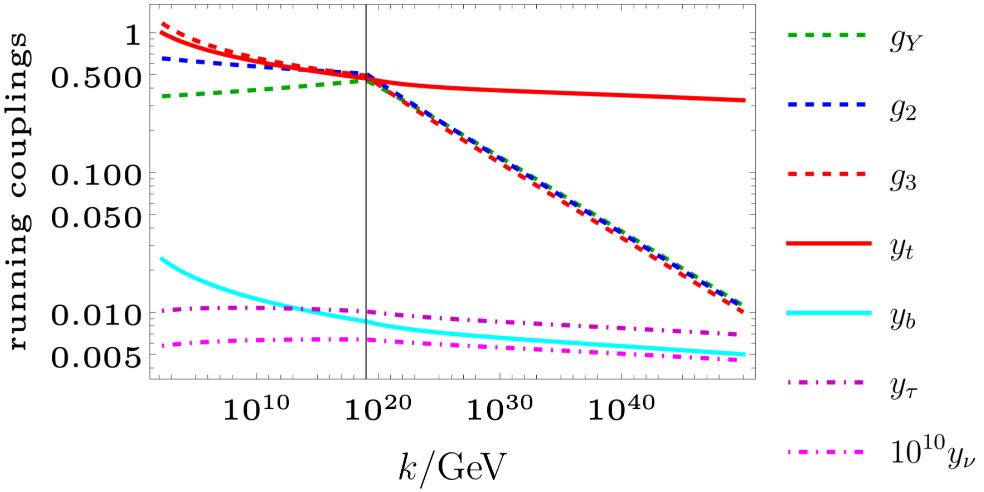

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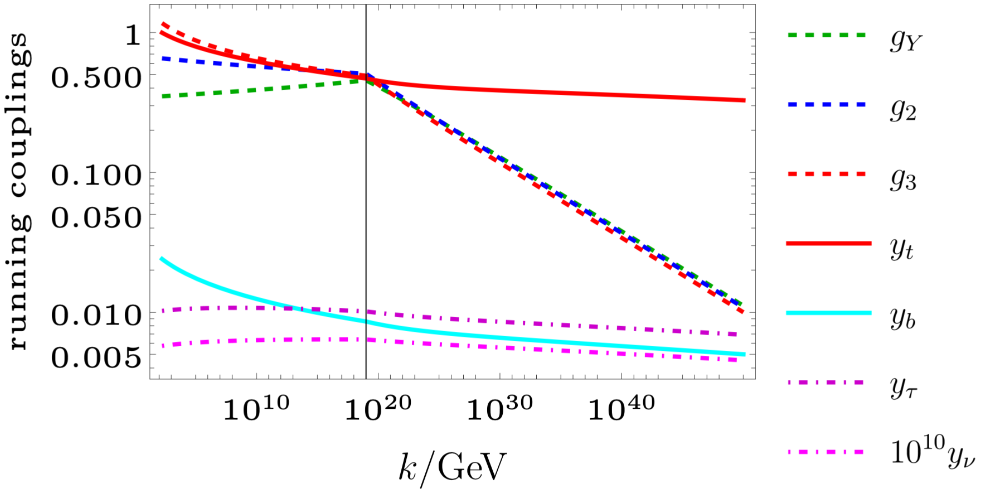

Summary

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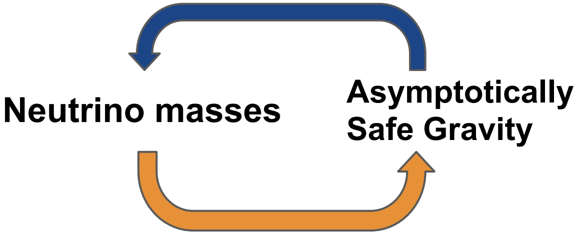

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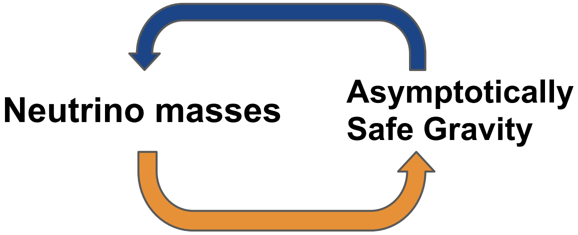

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Pseudo-Dirac massive neutrinos

- ➡ There is enough room to tune the free parameters in harmony with asymptotic safety
- ➡ No upper or lower bound from this scenario

Thank you for your attention!