Are there ALPs in the asymptotically safe landscape?

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Based on 2112.08972 (with Astrid Eichhorn and Gustavo P. de Brito)

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Motivation

• Unknown nature of dark matter.
• Candidate: Axion-like particles **(ALPs)**:
→ Ultra-light dark matter.
→ Searches by new generation of experiments.
[Carena et al. '20, Ferreira '20, Irastorza '21]

• Can quantum gravity (QG) provide constraints on the theoretical models for dark matter?

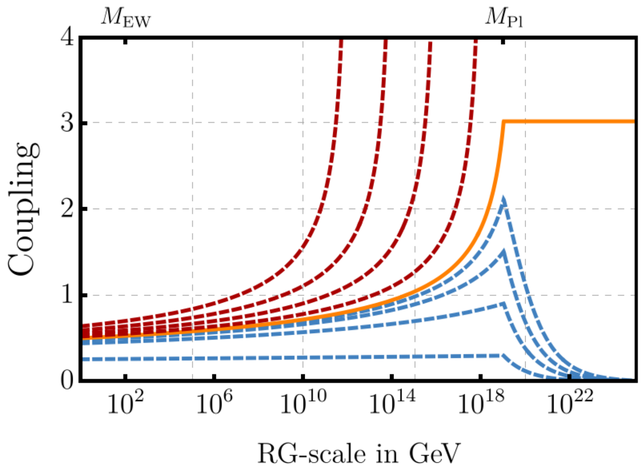
• Can ALPs be accommodated in QG?
→ The *predictive power* of **asymptotic safety**.
→ Theoretical constraints on the ALP parameter space.

Asymptotic safety

• **Asymptotic safety**:
→ Realization of quantum scale symmetry.
[Weinberg '79]
A theory is *asymptotically safe* if it has an interacting fixed point ($g_* \neq 0$) and a finite number of free parameters (predictive).

• **Asymptotically safe quantum gravity**:
→ UV completion and predictive power are restored by AS. [Reuter '98]

• **Interplay between matter and gravity**:
→ Quantum scale symmetry imposes constraints on the dynamics of the theory.
→ Imprints of the Planck scale (QG) on lower energy physics (experiments).
→ Pathway towards observational tests of asymptotic safety! [Eichhorn '18]



• The **asymptotically safe landscape** is the set of effective field theories for matter fields which are compatible with an asymptotically safe UV completion.

• **Functional Renormalization Group**:
→ Effective average action Γ_k.
→ FRG flow equation: [Wetterich '93]

$$\partial_t \Gamma_k = \frac{1}{2}\mathrm{STr}\left[\partial_t \mathbf{R}_k \left(\Gamma_k^{(2)} + \mathbf{R}_k\right)^{-1}\right]$$

→ **Beware:** Euclidean space and truncation!

Executive summary

• **Are there ALPs in the asymptotically safe landscape?**
→ Tentative answer: (Most likely) no!

• Toy-model: **ALP-photon interaction**
→ Consistence with *dark matter scenarios* require *large* gravitational fixed-points, G_* and Λ_*, unfavoured by asymptotic safety, e.g. *weak-gravity bound*.

Are ALPs compatible with the asymptotically safe landscape?

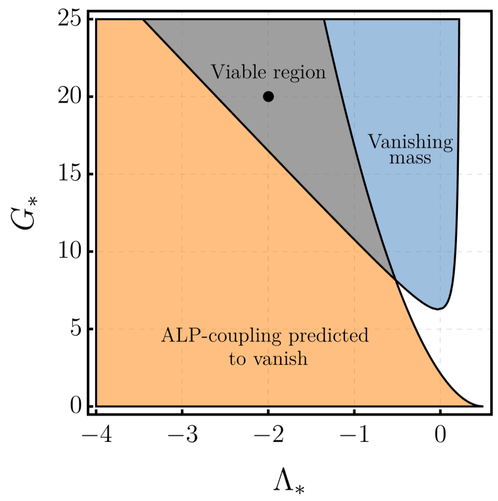
• Toy-model: **ALP-photon interaction**

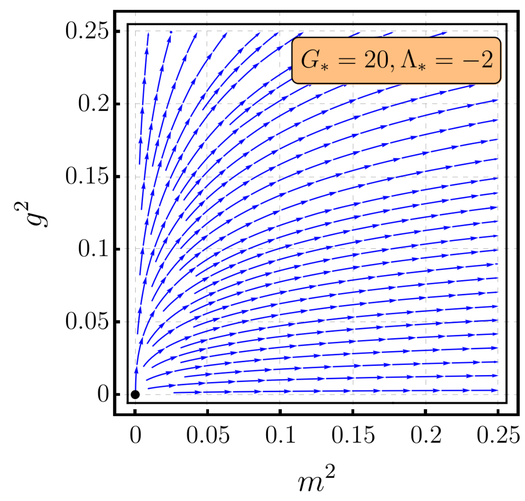
$$\Gamma_k = \int d^4x\sqrt{\det g}\left(\frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi + \frac{1}{4}g^{\mu\alpha}g^{\nu\beta}F_{\mu\nu}F_{\alpha\beta} + \frac{m^2k^2}{2}\phi^2 + \frac{igk^{-1}}{8}\frac{\epsilon^{\mu\nu\alpha\beta}}{\sqrt{\det g}}\phi F_{\mu\nu}F_{\alpha\beta} + \frac{1}{16\pi G\,k^{-2}}\left(2\Lambda\,k^2 - R\right)\right) + \Gamma_{k,\mathrm{gf}}.$$

→ Matter sector motivated by phenomenological considerations at low energy.
→ Matter minimally coupled to the gravitation sector (Euclidean Einstein-Hilbert term).

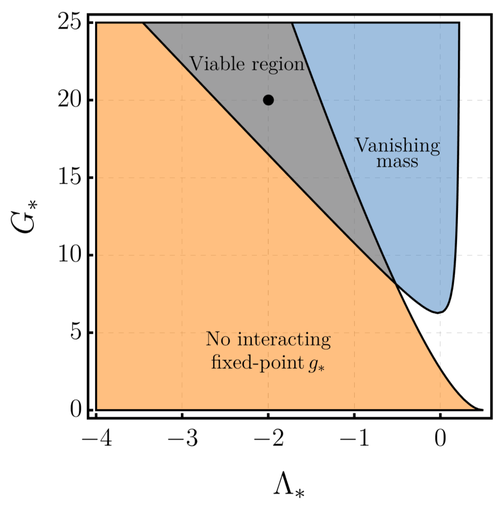
• **Fixed points** for ALP-photon coupling g^2 and mass m^2.

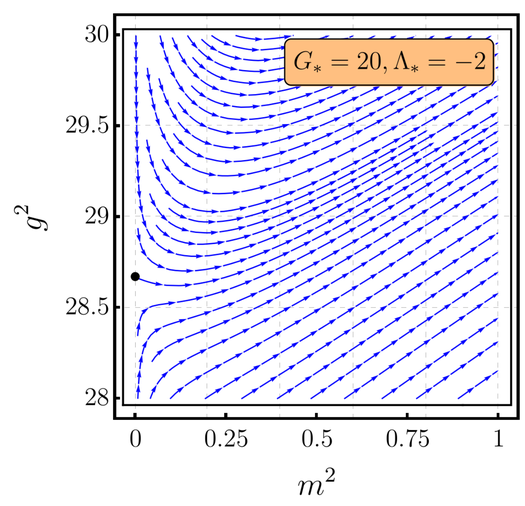
→ **Gaussian fixed point:** $(g_*^2 = 0, m_*^2 = 0)$





→ On viable region: g^2 and m^2 are free parameters; flow towards non-vanishing IR values.
→ **Interacting fixed point:** $(g_*^2 > 0, m_*^2 = 0)$





→ On viable region: prediction for g^2; flow towards non-vanishing IR values of g^2 and m^2.

• Both scenarios require large values of G_* and Λ_*, far from perturbative regime! Therefore, unlikely to accommodate ALPs in asymptotically safe gravity-matter systems.

• **Outlook:** Enlarge the theory space: axion-electron coupling, QCD axion, SM fermions?

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