No Dark Matter Axion During Minimal Higgs Inflation

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Work[1] with Claire Rigouzzo

27th May 2025

[1] *No Dark Matter Axion During Minimal Higgs Inflation*, `arXiv:2504.02952`.

Inflation & dark matter

- Observations
  - Dark matter

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$\boxed{\text{We need more constraints.}}$

Outline

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The axion

- $\bar{\theta}$-term

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$$\mathcal{L} \supset -\frac{1}{2}\partial_\mu a \partial^\mu a + \left(\bar{\theta} + \frac{a}{f_a} c_G\right) \mathrm{Tr}\,G_{\mu\nu}\tilde{G}^{\mu\nu}$$

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- Non-perturbative potential: CP violation vanishes dynamically
- Axion: solution to strong CP problem and dark matter[3]

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[3] Review: L. Di Luzio, M. Giannotti, E. Nardi, L. Visinelli, *The landscape of QCD axion models*, `arXiv:2003.01100`.

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- Tension with many inflationary models

Higgs inflation[3]

- Standard Model coupled to gravity

$$\mathcal{L} = \frac{M_P^2}{2} R - \frac{1}{2}\partial_\alpha h \partial^\alpha h - \frac{\lambda}{4} h^4$$

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- Match CMB amplitude

$$\text{metric: } \xi \sim 10^4 \qquad \text{Palatini: } \xi \sim 10^8$$

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- Isocurvature perturbations $\sigma_\theta \sim H_{\mathrm{inf}}/f_{a,\mathrm{inf}}$ enhanced[6]

[6] Opposite case: M. Fairbairn, R. Hogan, D. Marsh, *Unifying inflation and dark matter with the Peccei-Quinn field: observable axions and observable tensors*, `arXiv:1410.1752`.
G. Ballesteros, J. Redondo, A. Ringwald, C. Tamarit, *Standard Model-axion-seesaw-Higgs portal inflation. Five problems of particle physics and cosmology solved in one stroke*, `arXiv:1610.01639`.

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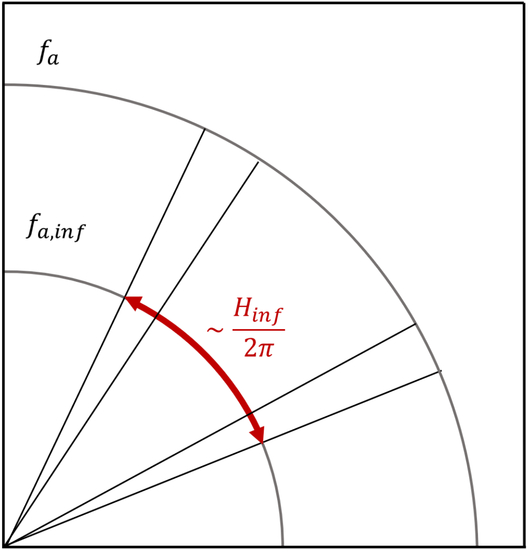

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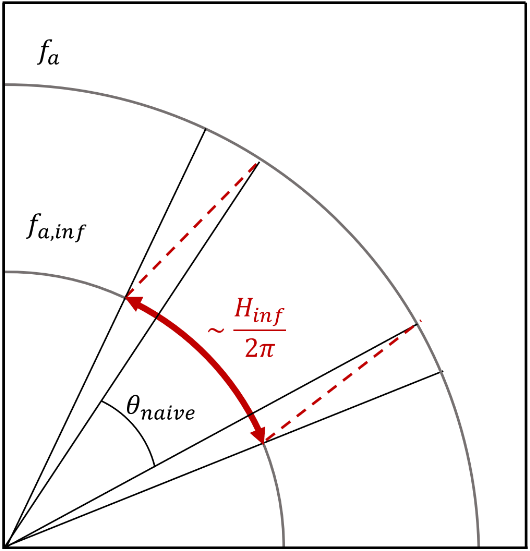

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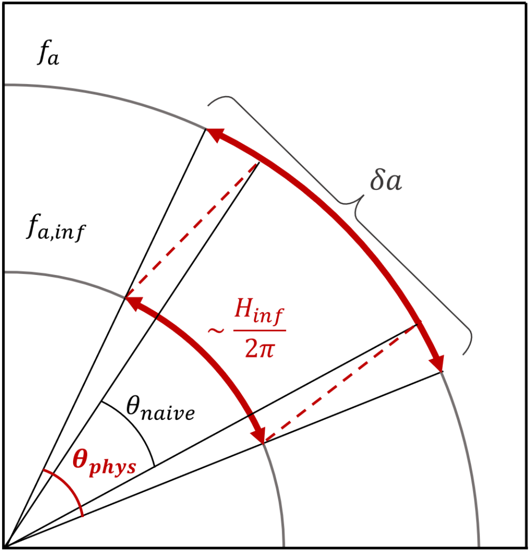

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Way out from non-minimal coupling to torsion

- Include:

$$\mathcal{L} \supset -\zeta f_a \partial_\alpha a T^\alpha \qquad \left(T^\alpha = g_{\mu\nu} T^{\mu\alpha\nu} \, , \quad 2 T^\mu{}_{\alpha\nu} \equiv \Gamma^\mu{}_{\alpha\nu} - \Gamma^\mu{}_{\nu\alpha} \right)$$

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- Integrate out torsion[6]

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[6] C. Rigouzzo, S. Z., *Coupling metric-affine gravity to the standard model and dark matter fermions*, `arXiv:2306.13134`. C. Rigouzzo, S. Z., *Coupling metric-affine gravity to a Higgs-like scalar field*, `arXiv:2204.03003`.

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- Integrate out torsion[6]

$$\mathcal{L} \supset -\frac{1}{2\Omega^2}\left(1 - \frac{3\zeta^2 f_a^2}{2M_P^2\Omega^2}\right)\partial_\alpha a \partial^\alpha a$$

- Low-energy modification of decay constant

$$f_a \to f_{a,\mathrm{IR}}(f_a) = \sqrt{1 - \frac{3\zeta^2 f_a^2}{2M_P^2}}\, f_a$$

- Isocurvature bound lifted if $f_{a,\mathrm{IR}} \lesssim f_{a,\mathrm{inf}}$

[6] C. Rigouzzo, S. Z., *Coupling metric-affine gravity to the standard model and dark matter fermions*, `arXiv:2306.13134`. C. Rigouzzo, S. Z., *Coupling metric-affine gravity to a Higgs-like scalar field*, `arXiv:2204.03003`.

Way out from non-minimal coupling to torsion

- Include:

$$\mathcal{L} \supset -\zeta f_a \partial_\alpha a T^\alpha \qquad \left(T^\alpha = g_{\mu\nu} T^{\mu\alpha\nu} \ , \quad 2T^\mu{}_{\alpha\nu} \equiv \Gamma^\mu{}_{\alpha\nu} - \Gamma^\mu{}_{\nu\alpha} \right)$$

- Integrate out torsion[6]

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- Low-energy modification of decay constant

$$f_a \to f_{a,\mathrm{IR}}(f_a) = \sqrt{1 - \frac{3\zeta^2 f_a^2}{2M_P^2}}\, f_a$$

- Isocurvature bound lifted if $f_{a,\mathrm{IR}} \lesssim f_{a,\mathrm{inf}}$: strong finetuning

[6] C. Rigouzzo, S. Z., *Coupling metric-affine gravity to the standard model and dark matter fermions*, `arXiv:2306.13134`. C. Rigouzzo, S. Z., *Coupling metric-affine gravity to a Higgs-like scalar field*, `arXiv:2204.03003`.

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Constraint for all inflationary models with non-minimal coupling