A universal constraint on axion non-Abelian dynamics during inflation

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Based on: E. Dimastrogiovanni, M. Fasiello, **MM**, O. Özsoy, 2023, *arXiv:2405.17411*

Axion inflation with gauge fields

Natural inflation: (approximate) shift symmetry protects from large quantum corrections $\quad V(\chi) = \mu^4\left(1+\cos\frac{\chi}{f}\right)$

Freese, Frieman, Olinto, 1990

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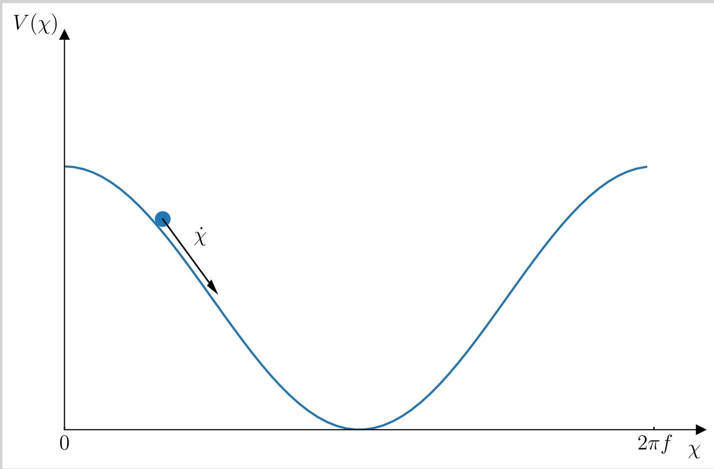
Gauge sector (non-Abelian) with parity-violating Chern-Simons coupling

Adshead, Wyman, 2012



$$\mathscr{L} \supset -\frac{1}{4}F^{a\mu\nu}F^a_{\mu\nu} - \frac{\lambda\chi}{8f\sqrt{-g}}\epsilon^{\mu\nu\rho\sigma}F^a_{\mu\nu}F^a_{\rho\sigma}$$

with $\quad F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g\,\epsilon^{abc}A^b_\mu A^c_\nu$

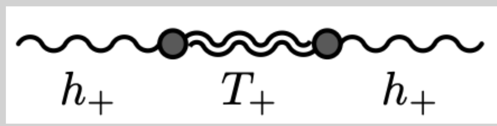
⟶ Axion kinetic energy transferred into gauge field production

With minimal axion sector, Chromo Natural Inflation $\quad -\frac{1}{2}g^{\mu\nu}\partial_\mu\chi\partial_\nu\chi + V(\chi)$

Enhanced tensor perturbations

Gauge tensors $\delta A^a_i \supset T_{ai}$

$$\frac{\mathrm{d}^2}{\mathrm{d}x^2}T_\pm + \left[1 + \frac{2(m_Q^2+1)}{x^2} \mp \frac{2(m_Q + m_Q^{-1})}{x}\right]T_\pm = \mathscr{O}(h_\pm), \qquad x \equiv -k\tau = \frac{k}{aH}$$



Tachyonic instability around horizon crossing $x \sim 1$

⟶ Chiral sourced gravitational waves via linear coupling

Background relation $\xi \simeq m_Q + m_Q^{-1}$

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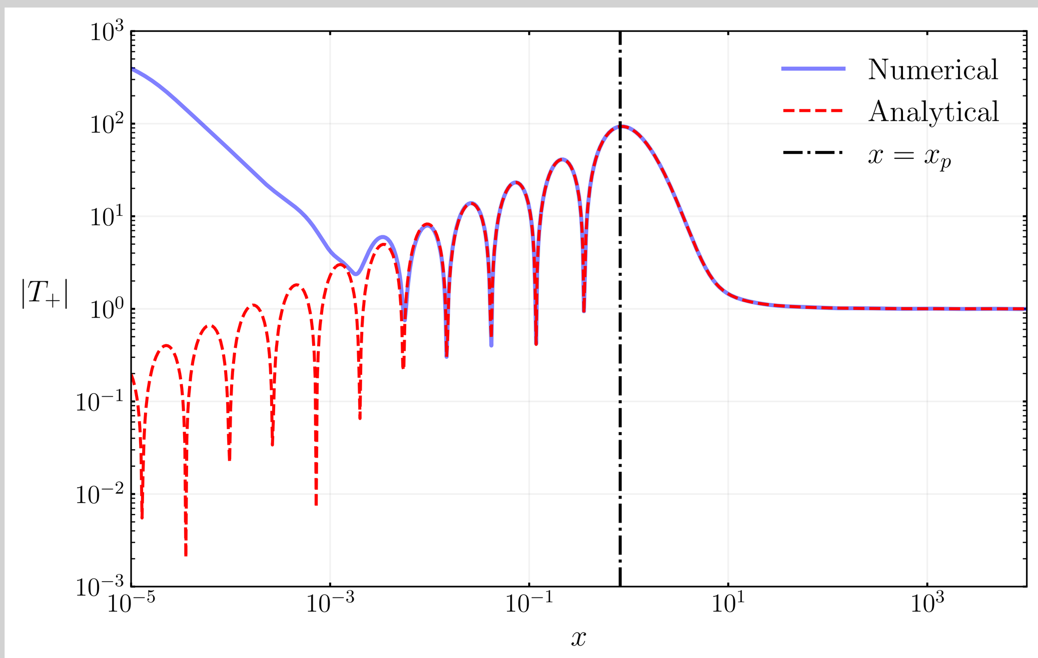
Analytical solution

$$T_+ \propto \exp\left(\frac{\pi}{2}m_Q\right)$$



Non linearities

Large chiral enhancement of gauge tensors

⟶ Non-linear effects on the dynamics of the system

- Backreaction on the background dynamics

Corrections to the background equations

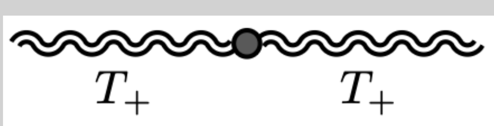
Dimastrogiovanni, Fasiello, Fujita, 2016

$$\ddot{Q} + 3H\dot{Q} + 2H^2Q + 2g^2Q^3 = \frac{\lambda g}{f}\dot{\chi}Q^2 + \mathscr{T}^Q_{\rm BQ}$$

$$\mathscr{T}^Q_{\rm BQ} = -\frac{g}{3a^2}\int\frac{\mathrm{d}^3k}{(2\pi^3)}\left(\xi H - \frac{k}{a}\right)|T_+|^2$$

- Perturbative corrections on the perturbation dynamics

Loop corrections to gauge tensor propagator



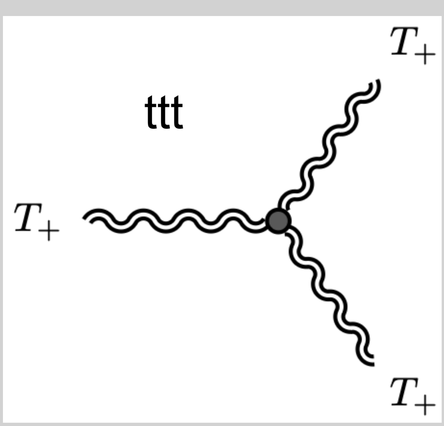
Perturbativity condition

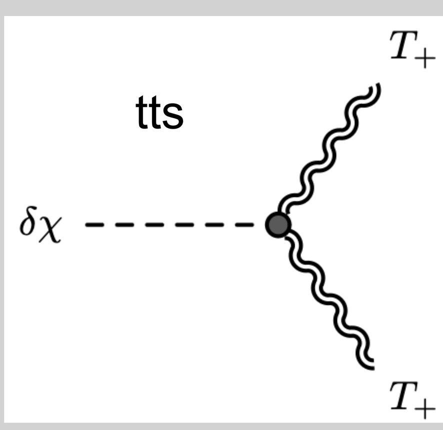
$$\mathscr{R}^{(\alpha)}_T\left(m_Q, \tau\right) \equiv \left|\frac{\delta^{(1)}_{(\alpha)}\left\langle \hat{T}_+(\tau,\vec{k})\hat{T}_+(\tau,\vec{k}')\right\rangle}{\left\langle \hat{T}_+(\tau,\vec{k})\hat{T}_+(\tau,\vec{k}')\right\rangle_{\rm tree}}\right| = \left|\frac{P^{(1)}_\alpha(\tau,k)}{P^{(0)}(\tau,k)}\right| \ll 1$$

In-in formalism

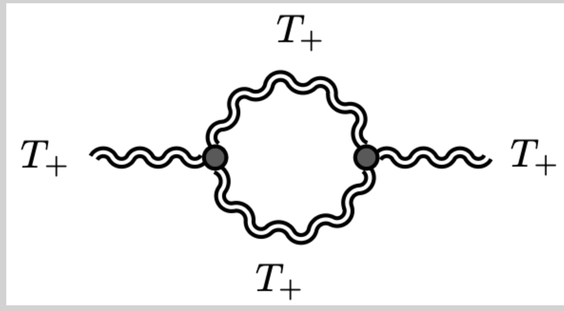
$$\delta^{(1)}_{(\alpha)}\left\langle \hat{T}_+(\tau,\vec{k})\hat{T}_+(\tau,\vec{k}')\right\rangle = -\int_{-\infty}^{\tau}\mathrm{d}\tau'\int_{-\infty}^{\tau'}\mathrm{d}\tau''\left\langle\left[\left[\hat{T}_+(\tau,\vec{k})\hat{T}_+(\tau,\vec{k}'), \hat{H}^{(3)}_\alpha(\tau')\right], \hat{H}^{(3)}_\alpha(\tau'')\right]\right\rangle$$

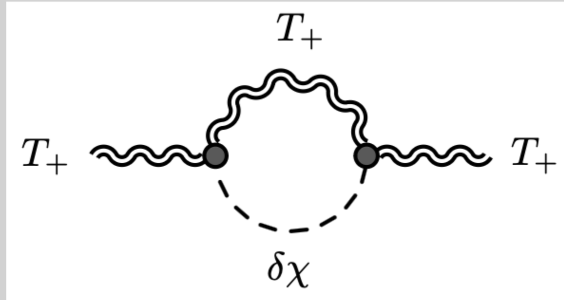
Two types of interactions





One-loop corrections





Universal diagram (from non-Abelian self coupling)

$$\mathscr{L}_{ttt} = -g\left[\epsilon^{abc}T_{ai}T_{bj}\left(\partial_i T_{cj} + \frac{1+m_Q^2}{3m_Q\tau}\epsilon^{ijk}T_{ck}\right) + \frac{m_Q}{\tau}T_{ij}T_{jk}T_{ki}\right]$$

From Chern-Simons interaction

$$\mathscr{L}_{tts} = \frac{\lambda}{f}\left\{\delta\chi\left[\frac{g}{2}(aQ\,T_{ab}T_{ab})' - \epsilon^{ijk}T'_{ai}\partial_j T_{ak}\right] + \right.$$
$$\left. + \left[\frac{g^2a^2Q^2}{-\partial^2 + 2g^2a^2Q^2}\delta\chi\right]\partial_j\left(\epsilon^{ijk}T'_{ai}T_{ak}\right)\right\}$$

⟶ tts depends on the details of the axion perturbation dynamics

Gravitationally-enhanced friction

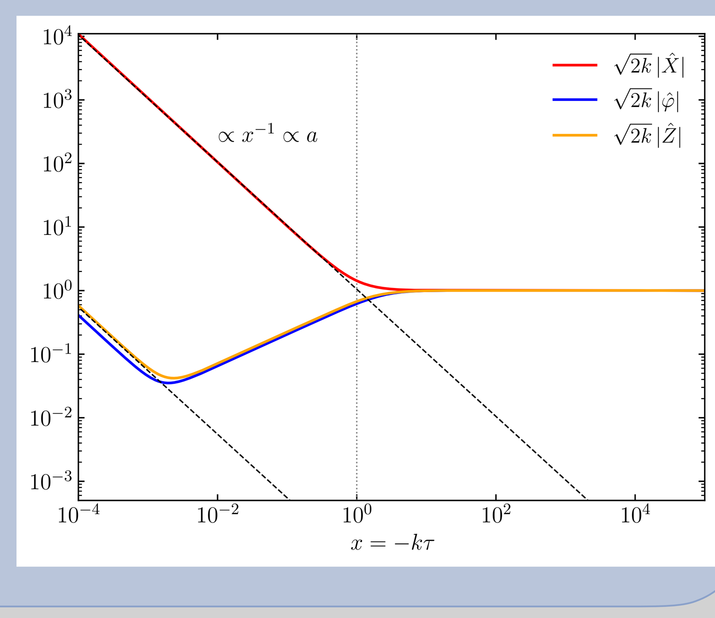
Dimastrogiovanni, Fasiello, MM, Pinol, 2023

$$\mathscr{L}_{\rm GEF} = -\frac{1}{2}\left(g^{\mu\nu} - \frac{G^{\mu\nu}}{M^2}\right)\partial_\mu\chi\partial_\nu\chi - V(\chi), \qquad F_g = 1 + \frac{3H^2}{M^2} \gg 1$$

In this regime, equation for axion perturbation

$$\hat{X} = a\sqrt{F_g}\,\delta\chi, \qquad \hat{X}'' + \left(1 - \frac{2}{x^2}\right)\hat{X} \simeq 0$$

$$\longrightarrow \quad \hat{X}(x) = \frac{1}{\sqrt{2k}}\left(1 + \frac{i}{x}\right)e^{ix}$$

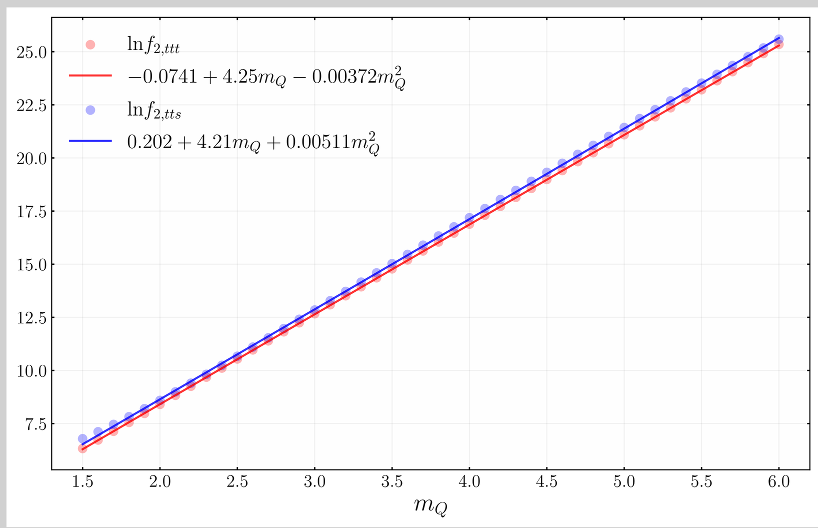


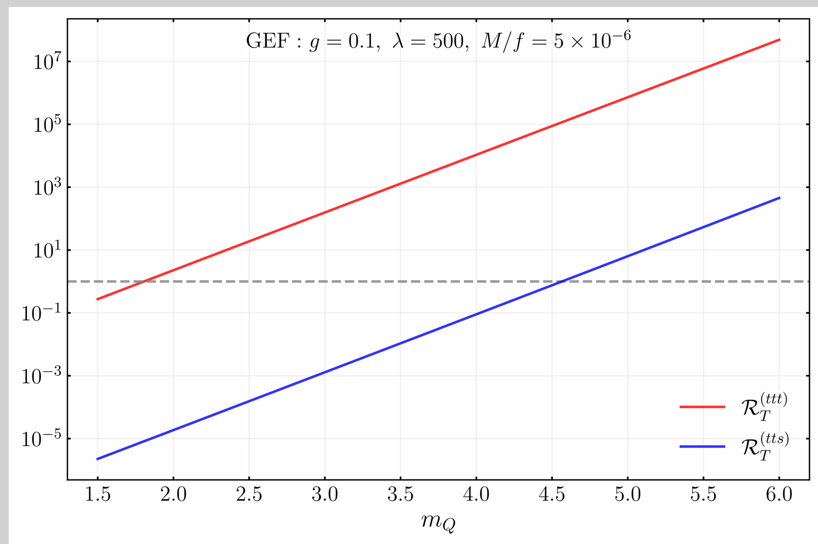
Hierarchy of the corrections

Requiring a consistent perturbative expansion of T_+

$$\mathscr{R}^{(ttt)}_T(x_p, m_Q) = \frac{g^2}{2\pi^2}f_{2,ttt}(x_p, m_Q) \ll 1$$

$$\mathscr{R}^{(tts)}_T(x_p, m_Q) = \frac{\lambda^2H^2}{64\pi^2f^2F_g}f_{2,tts}(x_p, m_Q) \ll 1$$





$$\frac{\lambda^2H^2}{64\pi^2f^2F_g} \ll \frac{g^2}{2\pi^2} \qquad \text{with} \qquad F_g \gg 1$$

⟶ Bounds from the ttt diagram

Universal constraint

Universal perturbativity constraint from ttt diagram

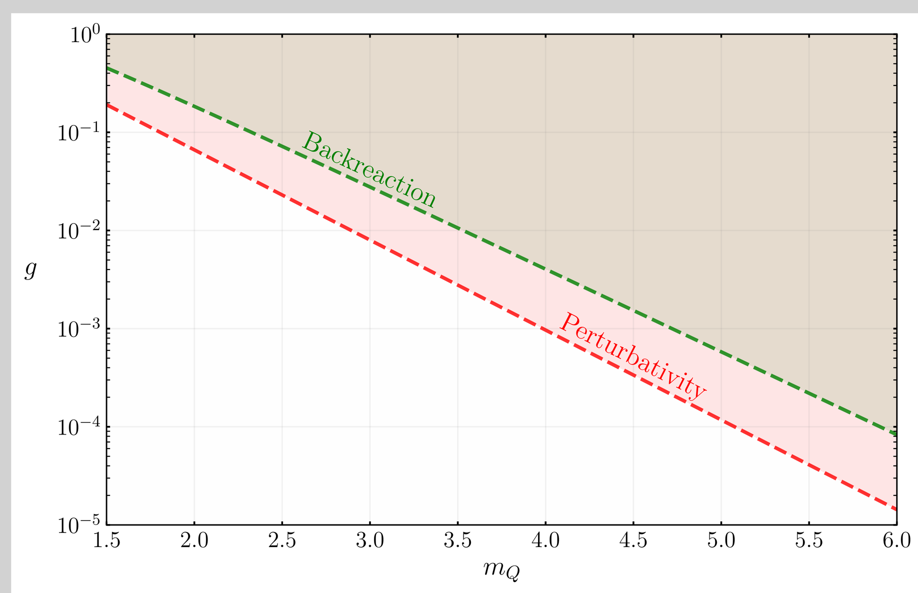
$$g \ll \left(\frac{2\pi^2}{f_{2,ttt}(m_Q)}\right)^{1/2}$$

↕

Constraint from backreaction

Papagiorgiou, Peloso, Ünal, 2019

$$g \ll \left(\frac{24\pi^2}{\mathscr{B} - \tilde{\mathscr{B}}/\xi}\frac{1}{1 + 1/m_Q^2}\right)^{1/2}$$



Stronger bounds from perturbativity considerations

Take-home message

- In the context of axion non-Abelian dynamics during inflation, enhanced tensor perturbations may induce sizeable non linearities, including perturbative corrections to cosmological correlators
- Universal constraints on the parameters can be derived by requiring perturbative effects to remain under control
- On top of backreaction, perturbativity may play an important role and has to be considered in inflationary models with axion non-Abelian dynamics