Ultraviolet Sensitivity of Peccei–Quinn Inflation

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XXV SIGRAV Conference

September 5, 2023

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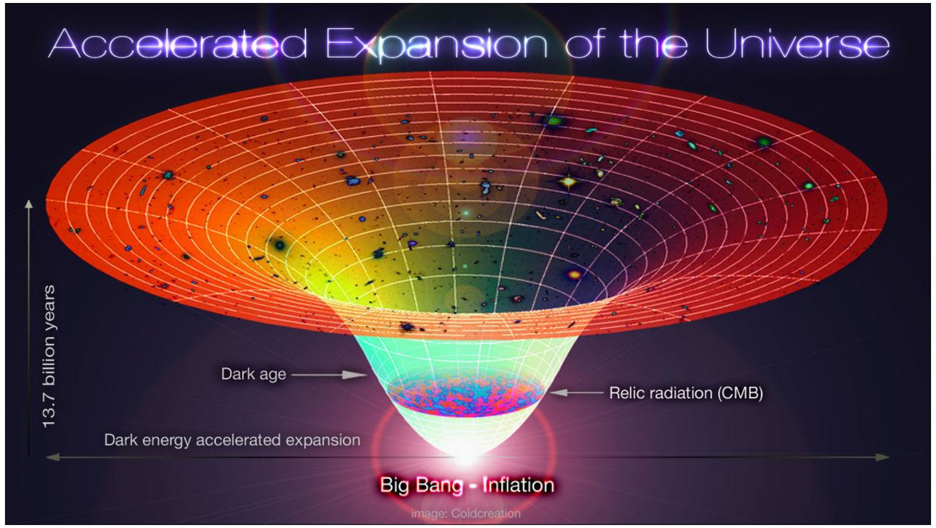
arXiv:2305.18524

Peccei-Quin (PQ) inflation: Motivations



Credit: Alex Mittelmann/Coldcreation

Inflation=accelerated expansion.

Introduce to explain the observed flatness, homogeneity of the universe and the origin of the primordial curvature perturbation

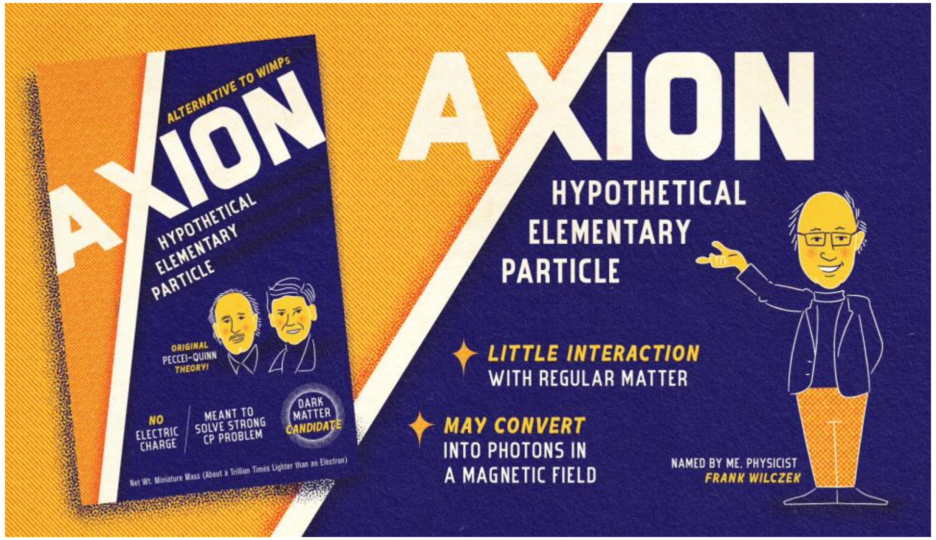


Illustration by Sandbox Studio, Chicago with Steve Shanabruch

Peccei-Quin is a possible solution for the strong CP problem.

Φ is the complex Peccei-Quin field.

We can combine inflation, dark matter and CP problem
Pointed out in:
M.Fairbairn, R.Hogan and D.J.E.Marsh, (2015)

$\lambda\phi^4$ does not work!

$V = \frac{\lambda}{4!}(|\Phi|^2 - F^2)^2$ Peccei-Quinn potential

Promote the radial part ϕ of PQ field to be the inflaton

Prediction from inflation:

$$P(k) = A_s \left(\frac{k}{k_*}\right)^{n_s - 1}, r = 16\epsilon$$

$$n_s - 1 = 2\eta - 6\epsilon$$

$n_s = 0{,}965, A_s = 2 \times 10^{-9}, r < 0{,}036$

Observed quantities (Planck)

η, ϵ constructed from the potential

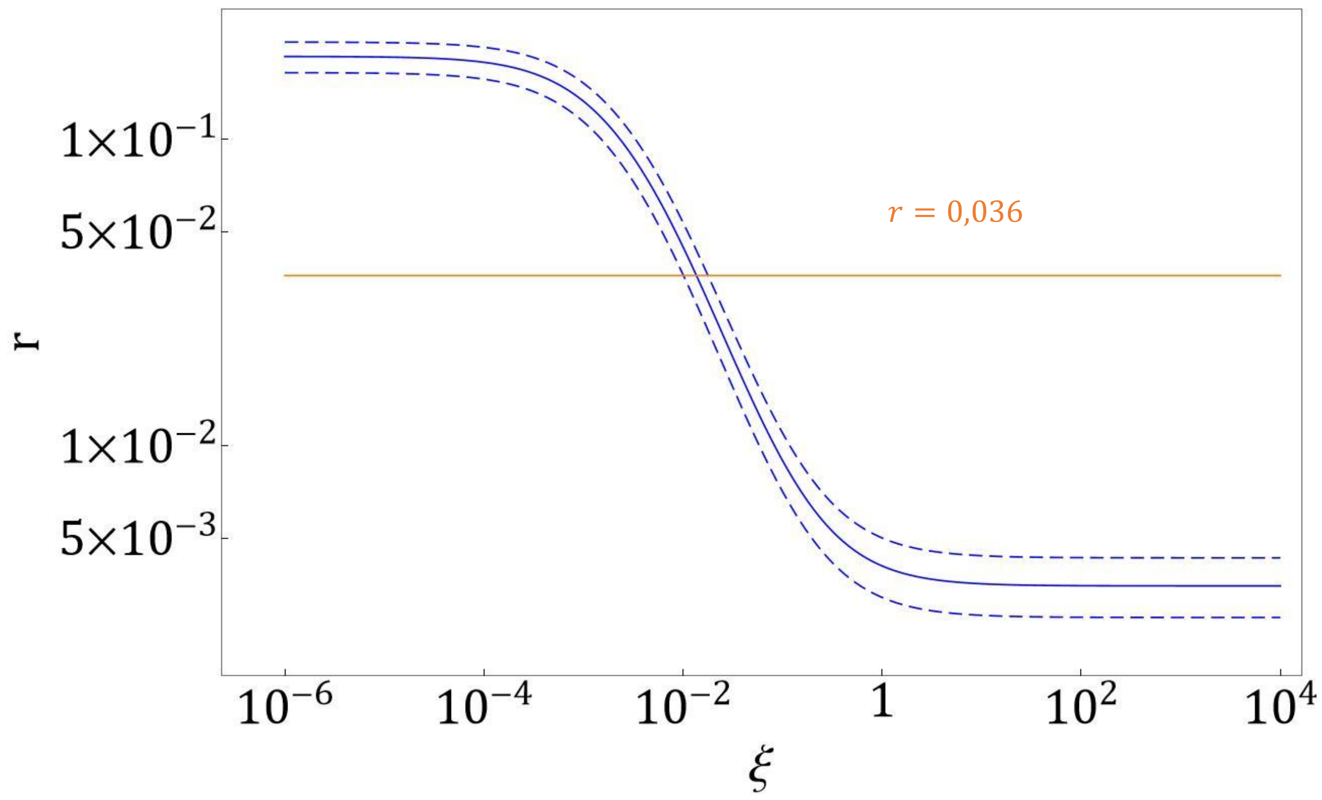
Pro:
Good prediction for n_s, A_s
Solve the Big-Bang problems
(Horizon,flatness…)

Problem:
$\lambda\phi^4$ predicts a large value for r .
Potential is too steep. Need for a flat potential.

Solution:
Introduce a non-minimal coupling to gravity: $R(\xi|\Phi|^2)$

Peccei-Quin (PQ) inflation: Predictions

Prediction for r with a non-minimal coupling to gravity.



Pro:
Good prediction for n_s, A_s.
r in agreement with Planck and testable

Pro:
Solve the Big-Bang problems (Horizon,flatness…)

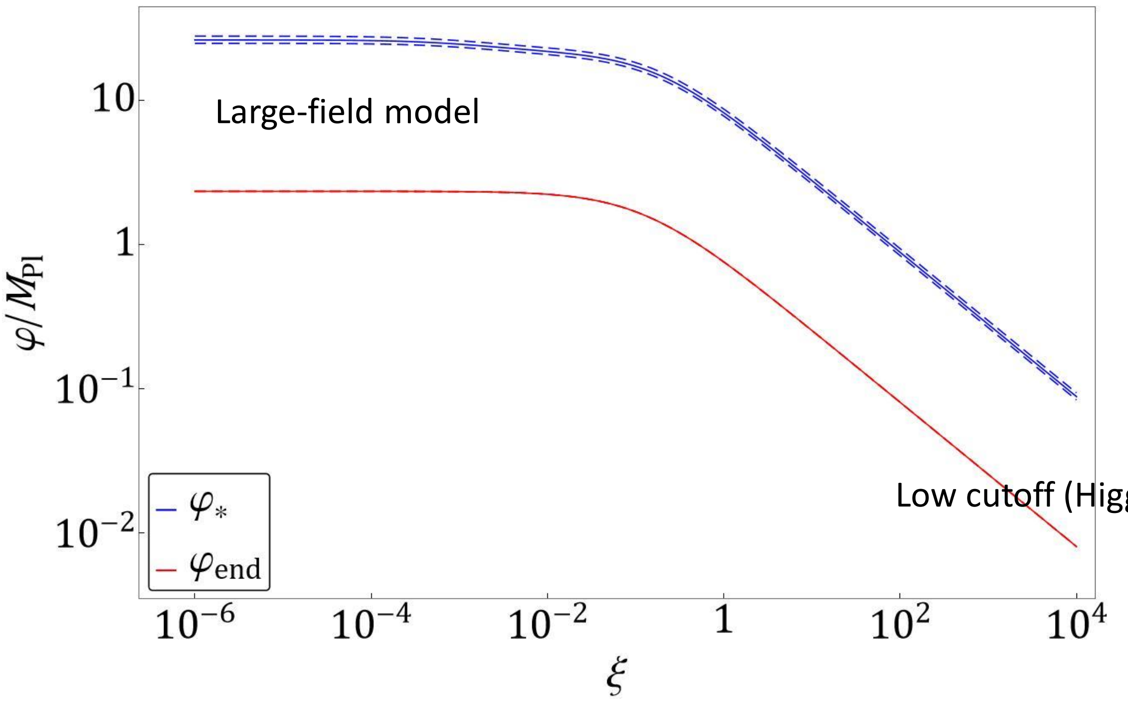
CMBPol, PRISM , CORE aim to reach $r \sim 10^{-3}$

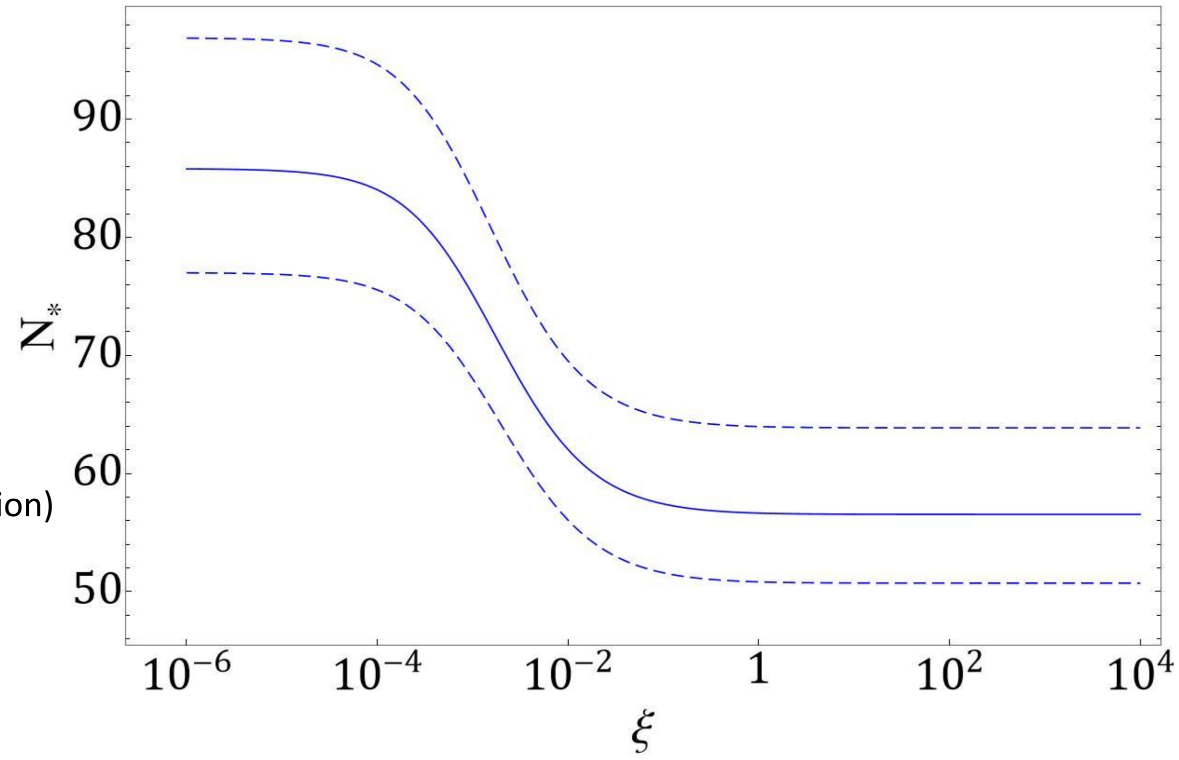
Middle $n_s = 0{,}965$ central value

Solid $n_s = 0{,}968$ $(+\sigma)$

Dashed $n_s = 0{,}961$ $(-\sigma)$

Peccei-Quin (PQ) inflation: Predictions





Evaluate the effects of Planck-suppressed higher-dimensional operators on PQ inflation

Action of the theory

$$-\int dx^4\sqrt{g}\, R\left(\frac{M_{pl}^2}{2}+\xi|\Phi|^2\right)+\int dx^4\sqrt{g}\left(g^{\mu\nu}\partial_\mu\Phi\partial_\nu\Phi^* - V(\Phi)+\Lambda^4-\left(\frac{g|\Phi|^{2m}\,\Phi^n}{M_{pl}^{2m+n-4}}+h.c.\right)\right)$$

$\frac{g|\Phi|^{2m}\,\Phi^n}{M_{pl}^{2m+n-4}}$ most general local term.

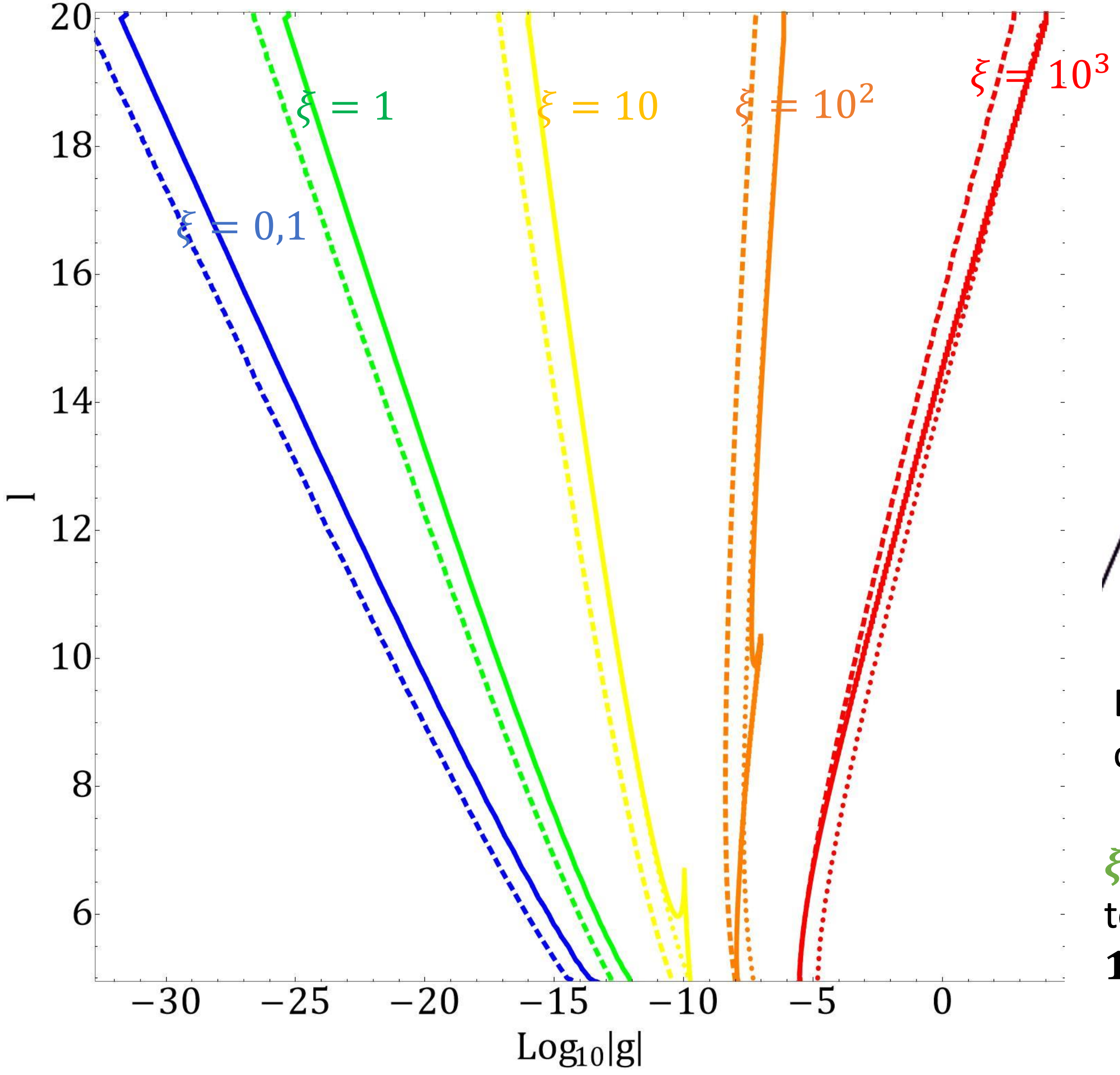
$n=0, \mathrm{U}(1)$ symmetry is preserved
$n\neq 0, U(1)$ symmetry is broken

Λ^4 for the cosmological costant problem. (Not important in our discussion)

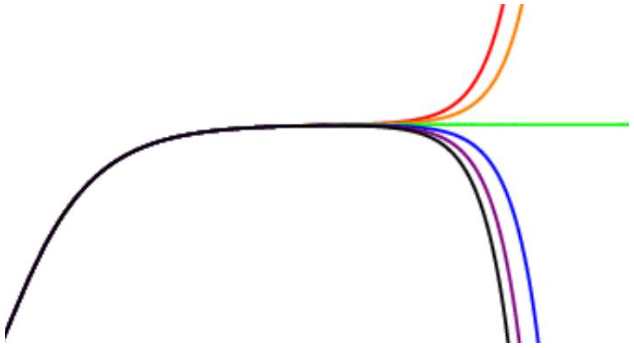
$\Phi=\frac{\phi e^{i\theta}}{\sqrt{2}}$
ϕ = inflaton
θ = axion
l=2m+n

$$V=\frac{\lambda}{4!}(|\Phi|^2-F^2)^2$$ F does not play any role. $\phi \gg F$

Numerical results



To the left of these lines, contributions from HDOs do not spoil inflation. $(50 < N_* < 60)$



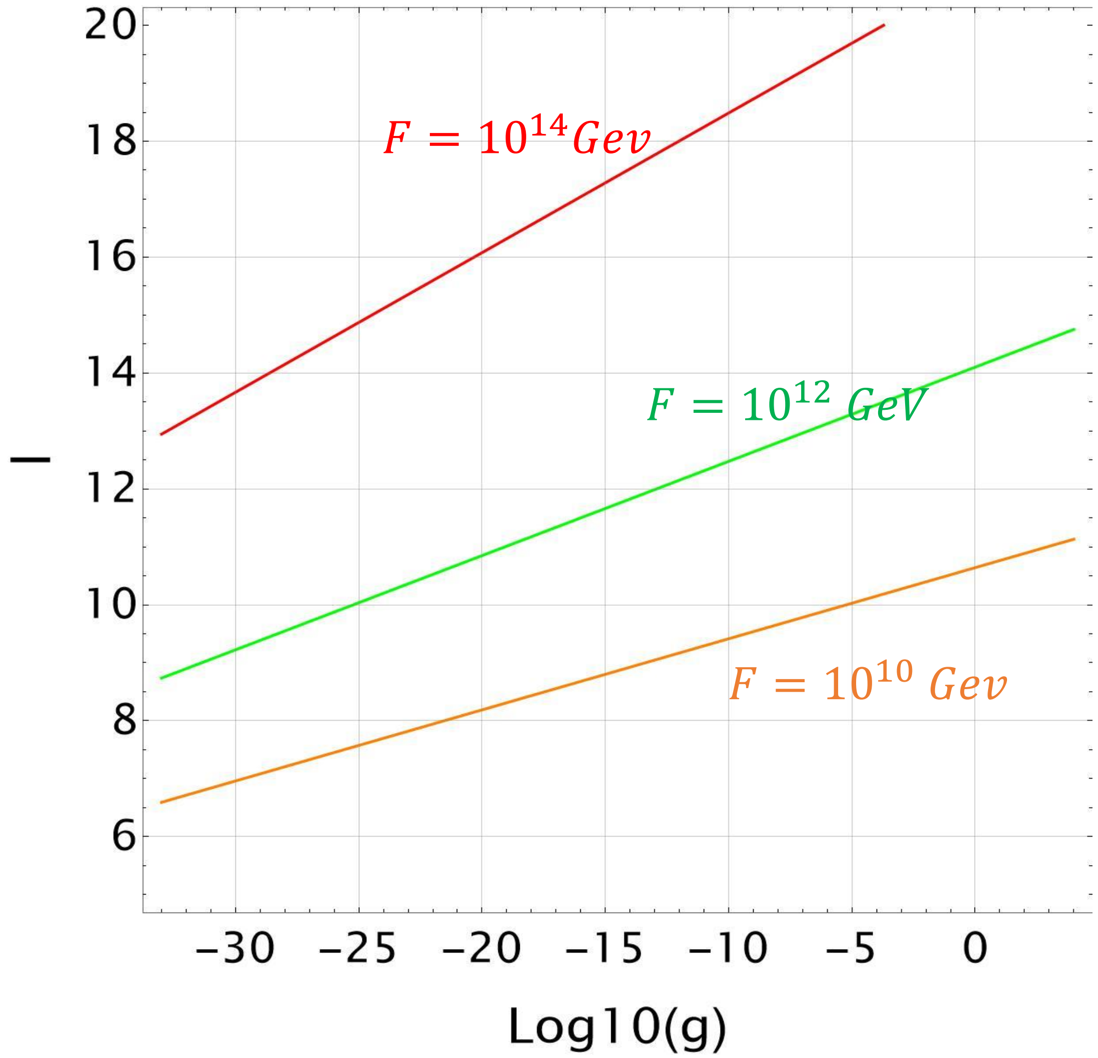
HDOs modify the potential, N is modified.

Inflation requires flat potential, very stringent bound on g

Different lines are associated with different initial consitions (θ_{in}, n)

$\xi = 1$ and dimension-five Planck-suppressed operator needs to be further suppressed by a coupling as small as $|\boldsymbol{g}| <$ $\mathbf{10^{-13}}$.

Axion quality problem



First studied by M. Kamionkowski and J. March-Russell, (1992) .

HDOs give a mass to the axion. These contribution may spoil the solution of the strong CP problem.

$$V \sim F^2 m_a^2 (1 - \cos(\theta + \beta)) + F^2 (m_\theta)^2 (1 - \cos(n\theta)\ )$$

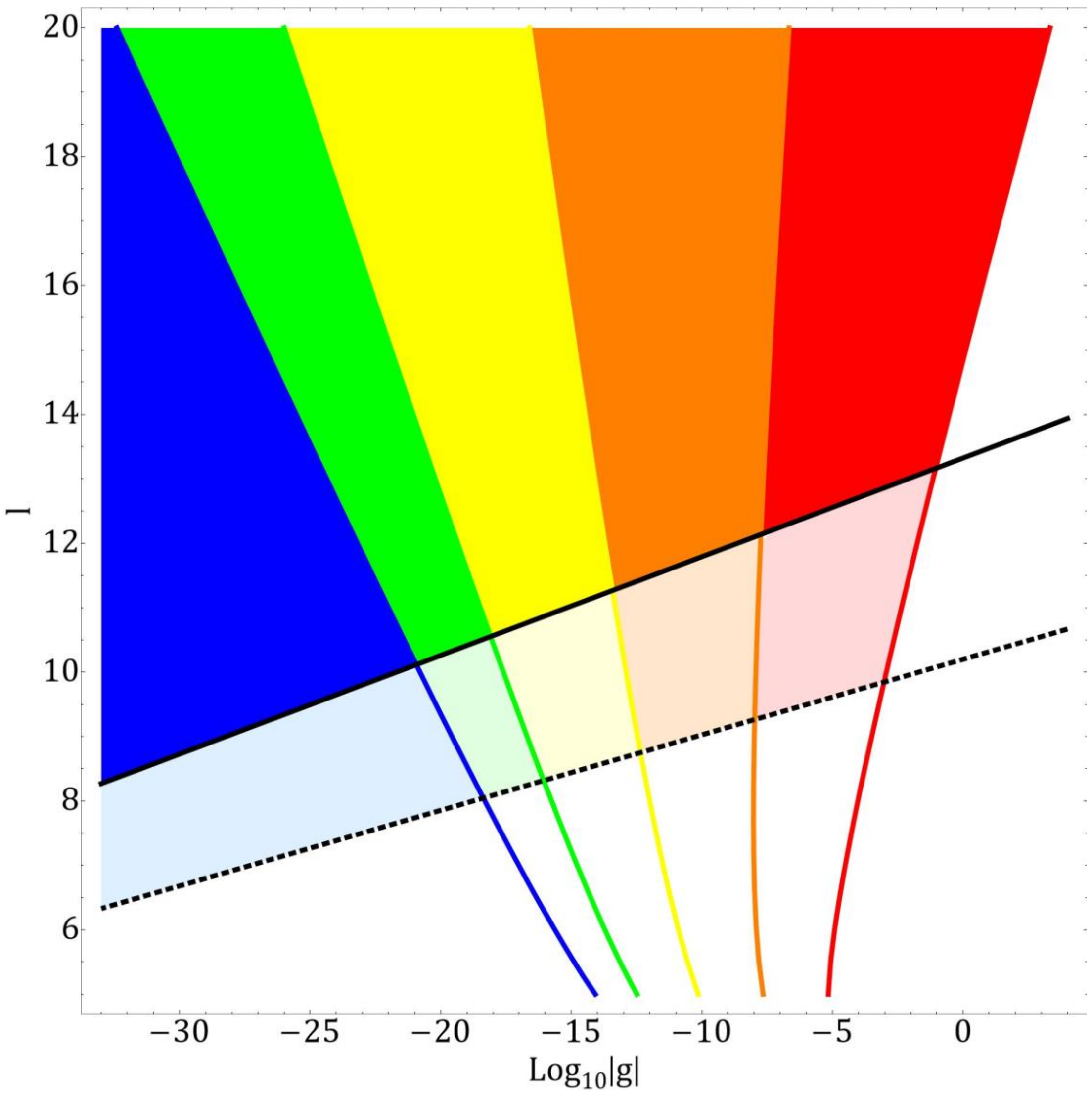
$$m_\theta^2 \sim n^2 g \left(\frac{F}{\sqrt{2}}\right)^{l-2} \quad \text{HDO} \qquad m_a \sim \frac{0{,}4(f_\pi m_\pi)}{F} \quad \text{QCD}$$

$$|g| \leq 10^{-88} \left(\frac{\sqrt{2}\, M_{Pl}}{F}\right)^{l}$$ In order not to spoil CP problem

The couplings of these operators have to be very small in order to preserve the strong CP problem.

Allowed regions above each lines.

UV sensitivity



The new bounds are complementary to the standard quality problem. Reduction of the parameter space.

$F = 10^{12}\ GeV$

$F = 10^{10}\ GeV$

$\xi = 1$ and dimension-ten Planck-suppressed operator needs to be further suppressed by a coupling as small as $|\boldsymbol{g}| < \mathbf{10^{-18}}$.

Summary

- PQ inflation is extremely sensitive to the presence of these Planck suppressed operators (UV physics)
- Bounds become weaker going to large ξ .(Sub-Planckian regime)
- The new bounds are complementary to the standard quality problem. Reduction of the parameter space.

- Thank you for your attention

- Additional slides

Analytical arguments

- $dN \sim -d\phi \frac{Uf^2}{U_\phi}$ Number of e-folds in slow-roll is controlled by the potential.
- The presence of HDOs modify the potential, the leading term is:

$$dN \sim -\frac{1+6\xi}{4}\phi d\phi\left(1+\underbrace{\frac{6\xi g}{\lambda}\left(\frac{\phi}{\sqrt{2}}\right)}^{l-2}(l-4)\cos(n\theta_*)\right)$$

$$\kappa = \frac{m_\theta^2\phi^2}{n^2H^2}.$$

Golden parameter, size of HDOs.

SISSA

Analytical arguments

$$N_* \sim \frac{(1+6\xi)\phi_0^2}{8}\left[1+\kappa_0 \cos n\theta_* \left(\frac{(l-4)}{6l}+\frac{(l-4)^2}{24}\right)\right]$$

$$\frac{2}{1-n_s} \sim 56$$

δN

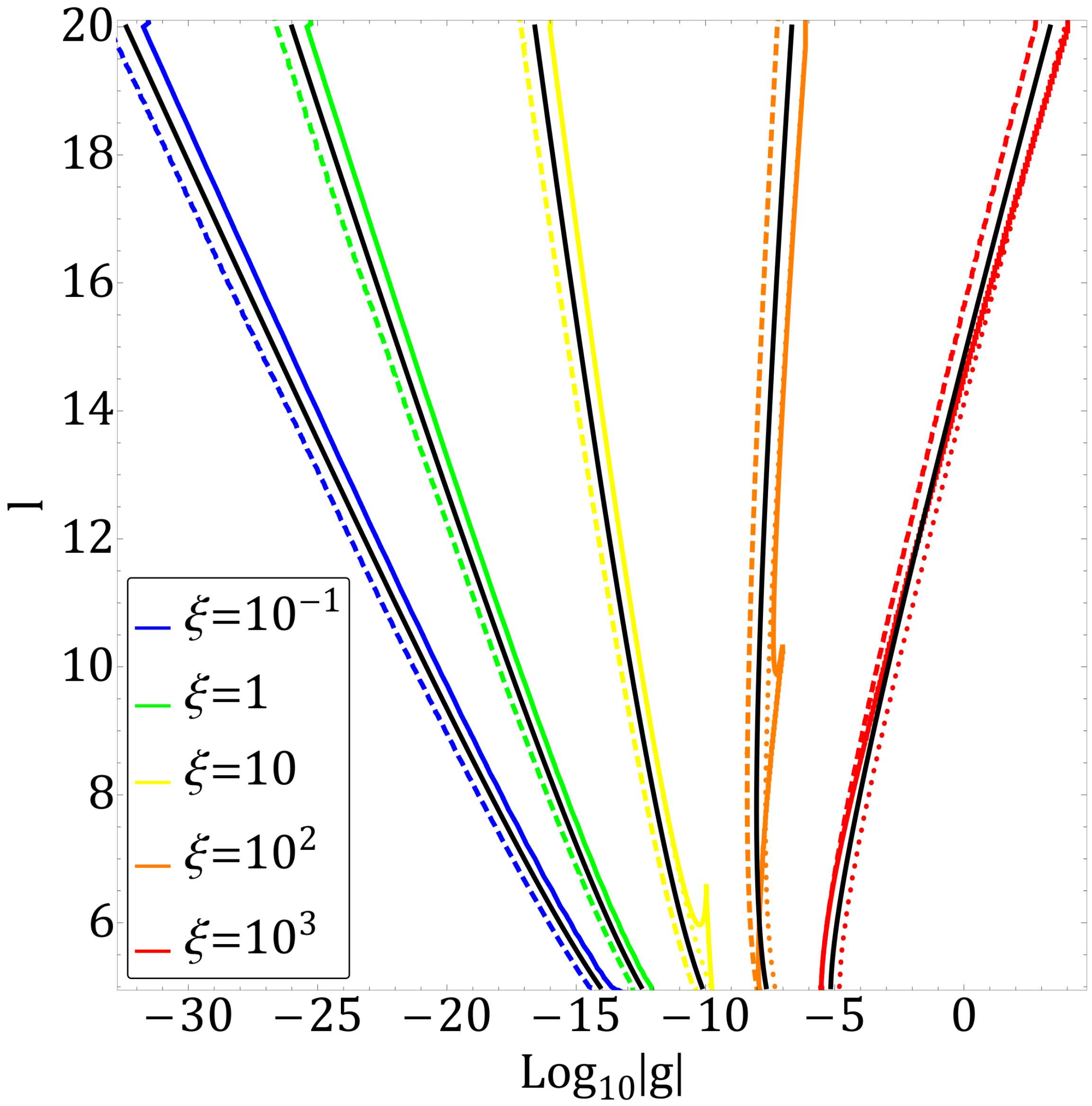
$50 < N_* < 60$ to have a good cosmology.

$\boldsymbol{\delta N \sim 10\%\ N}$ **HDOs give 10% modification**

$$\frac{g\left(\frac{16}{2(1+6\xi)(1-n_s)}\right)^{\frac{l}{2}-1} 4}{(1+6\xi)\pi^2 A_s (1-n_s)^2}\left(\frac{(l-4)}{6l}+\frac{(l-4)^2}{24}\right) \sim 0{,}1$$

n_s, A_s fixed by experiment (Planck)
g, l coupling and power of HDOs

Analytical arguments



$$\left(\frac{(l-4)}{6l}+\frac{(l-4)^2}{24}\right)\frac{g\left(\frac{16}{2(1+6\xi)(1-n_s)}\right)^{\frac{l}{2}-1}4}{(1+6\xi)\pi^2A_s(1-n_s)^2}\sim 0{,}1$$

All the complicated nonlinear physics is reproduced by this analytical estimate

Tilt of the curves given by $\frac{16}{2(1+6\xi)(1-n_s)}$

Negative tilt are link to super-Planckian regime (ξ is small)
Positive tilt are link to sub-Planckian regime (ξ is large)