Two Interpretations of the Bounds on Non-Gaussianity

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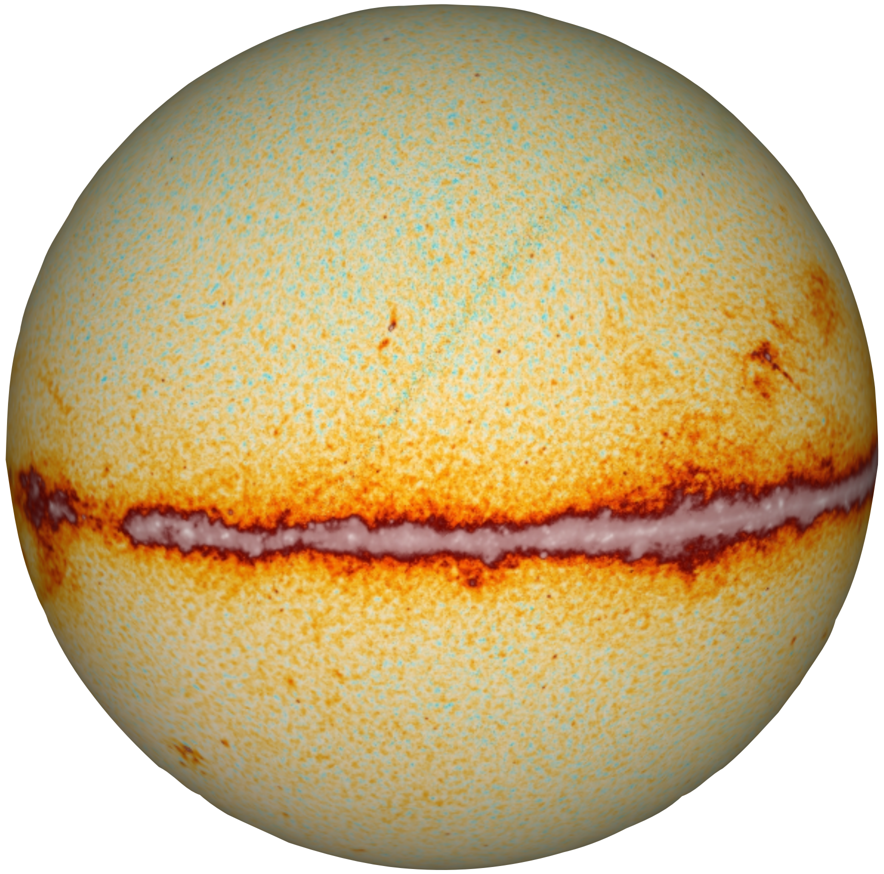


Courtesy of thecmb.org

1102.5343: with Baumann
1301.2630: with Lewandowski, Senatore, Silverstein and Zaldarriaga
1304.5226: with Assassi, Baumann, and McAllister

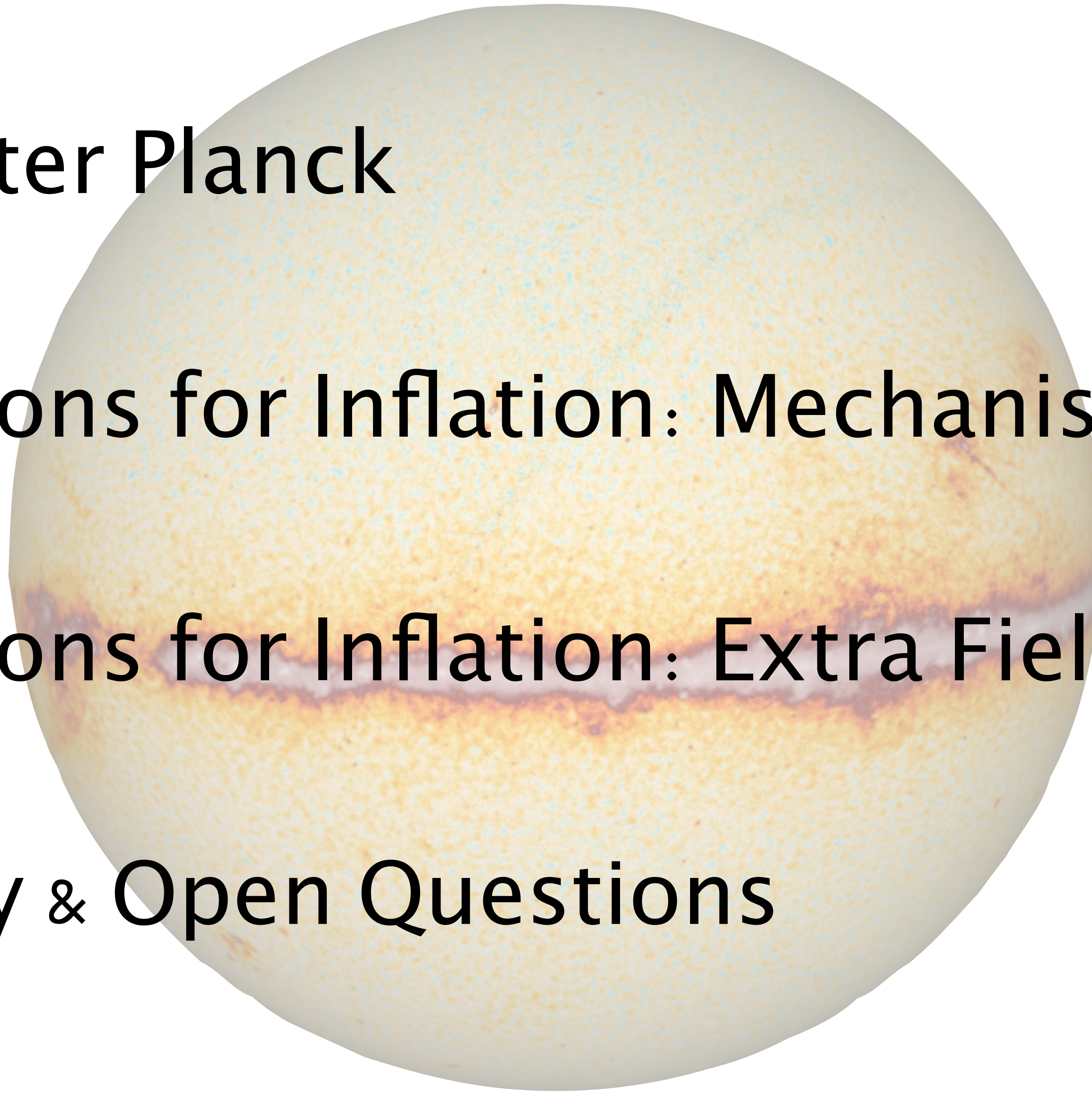
Outline

Limits after Planck

Implications for Inflation: Mechanism

Implications for Inflation: Extra Fields

Summary & Open Questions

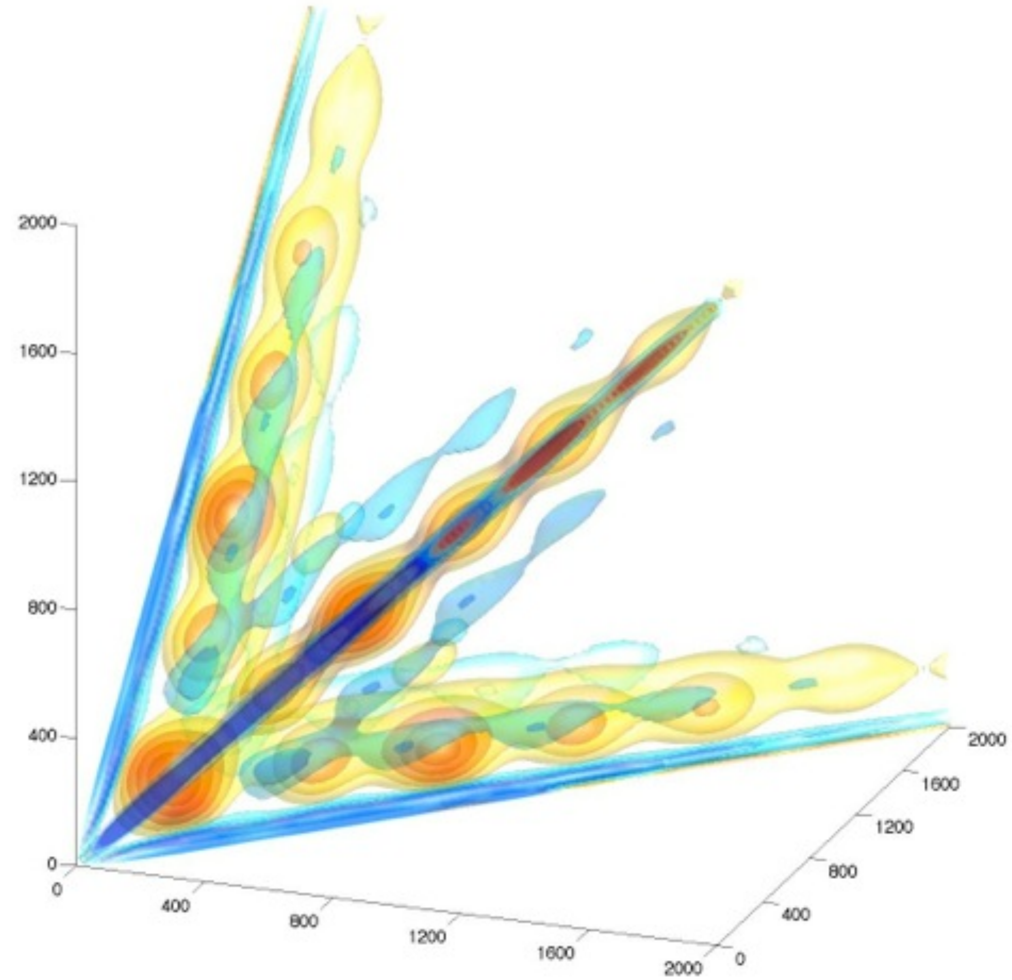


Courtesy of thecmb.org

Limits after Planck

Planck Bounds

Planck reports limits on 3 templates:

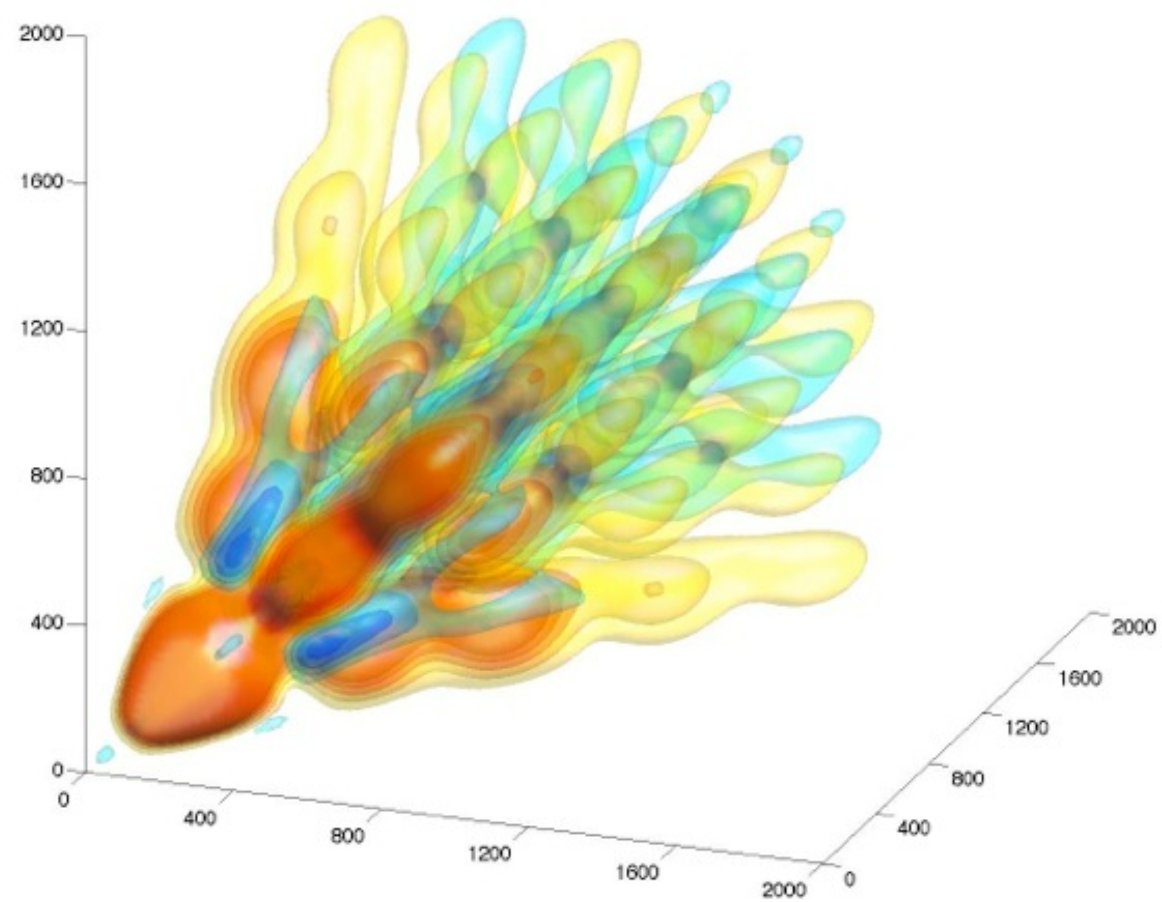


$$f_{\rm NL}^{\rm local} = 2.7 \pm 5.8 \quad \text{(68\% C.I.)}$$

Courtesy of Fergusson & Shellard

Planck Bounds

Planck reports limits on 3 templates:

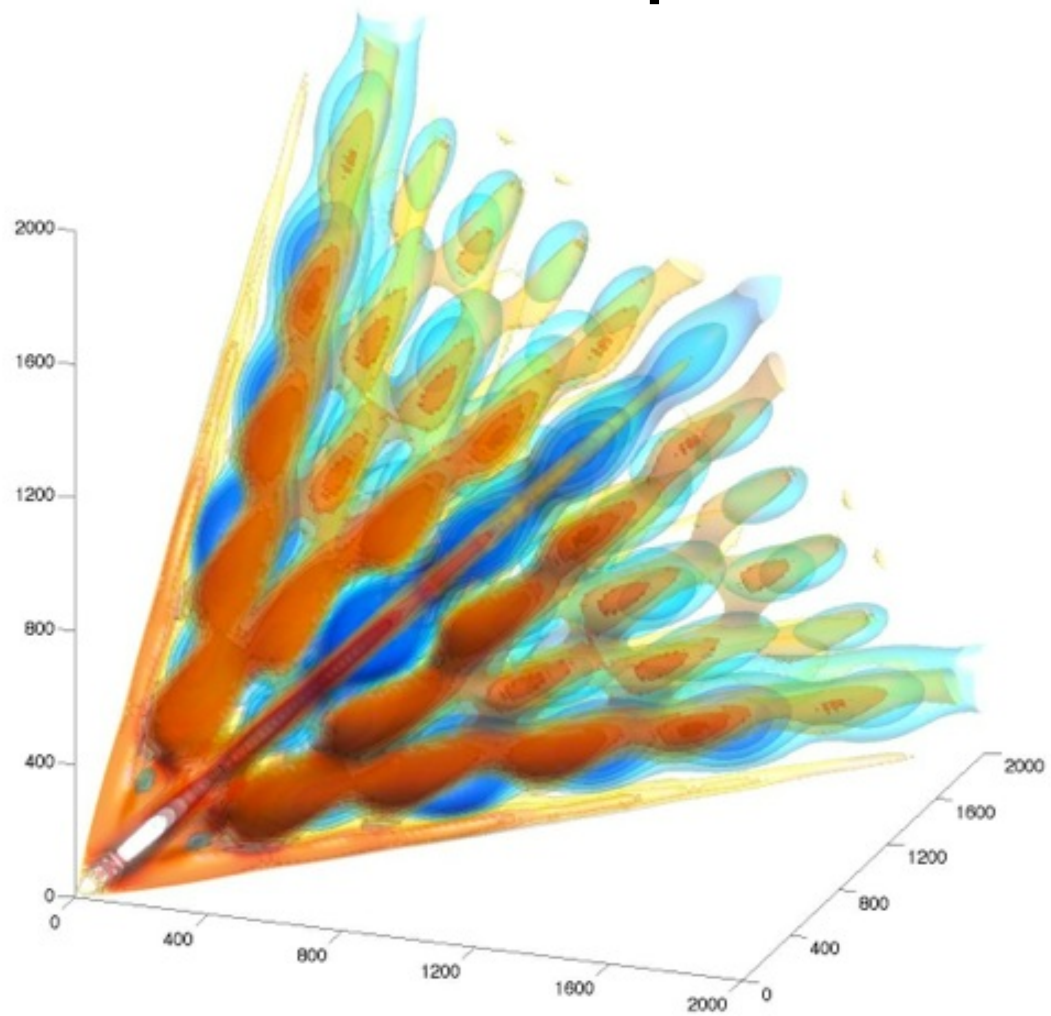


$$f_{\rm NL}^{\rm equil} = -42 \pm 75 \quad \text{(68\% C.I.)}$$

Courtesy of Fergusson & Shellard

Planck Bounds

Planck reports limits on 3 templates:



$$f_{\rm NL}^{\rm ortho} = -25 \pm 39 \text{ (68\% C.I.)}$$

Courtesy of Fergusson & Shellard

Planck Bounds

Common sentiments:

'Bounds on NG (strongly?) favor a simple mechanism'

'Data has ruled out exotic models'

Are these statements true?

Is there a model-independent expectation for the size of NG in non-slow roll models?

Implications for Inflation: Mechanism

Single Field Inflation

Inflation: Spontaneous breaking of time translations

Creminelli et al.; Cheung et al.; See Senatore's review talk

Some operator acquires VEV $\langle \mathcal{O} \rangle = f(t)$

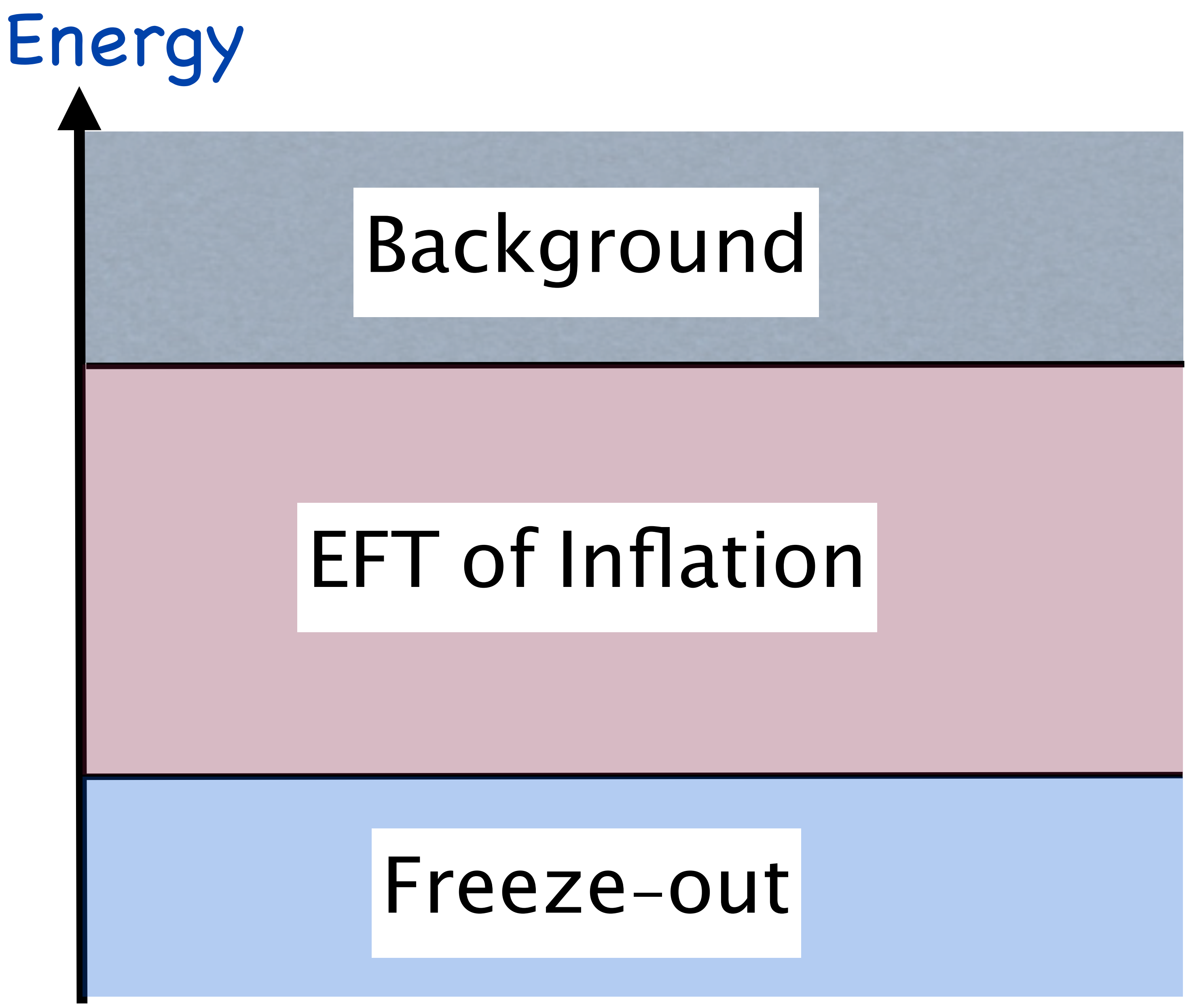
Fluctuations describe goldstone boson π

$$\mathcal{L}_\pi = F(t + \pi, \nabla^\mu, g^{\mu\nu})$$

Does not require a fundamental scalar

Single Field Inflation

Inflation: Spontaneous breaking of time translations



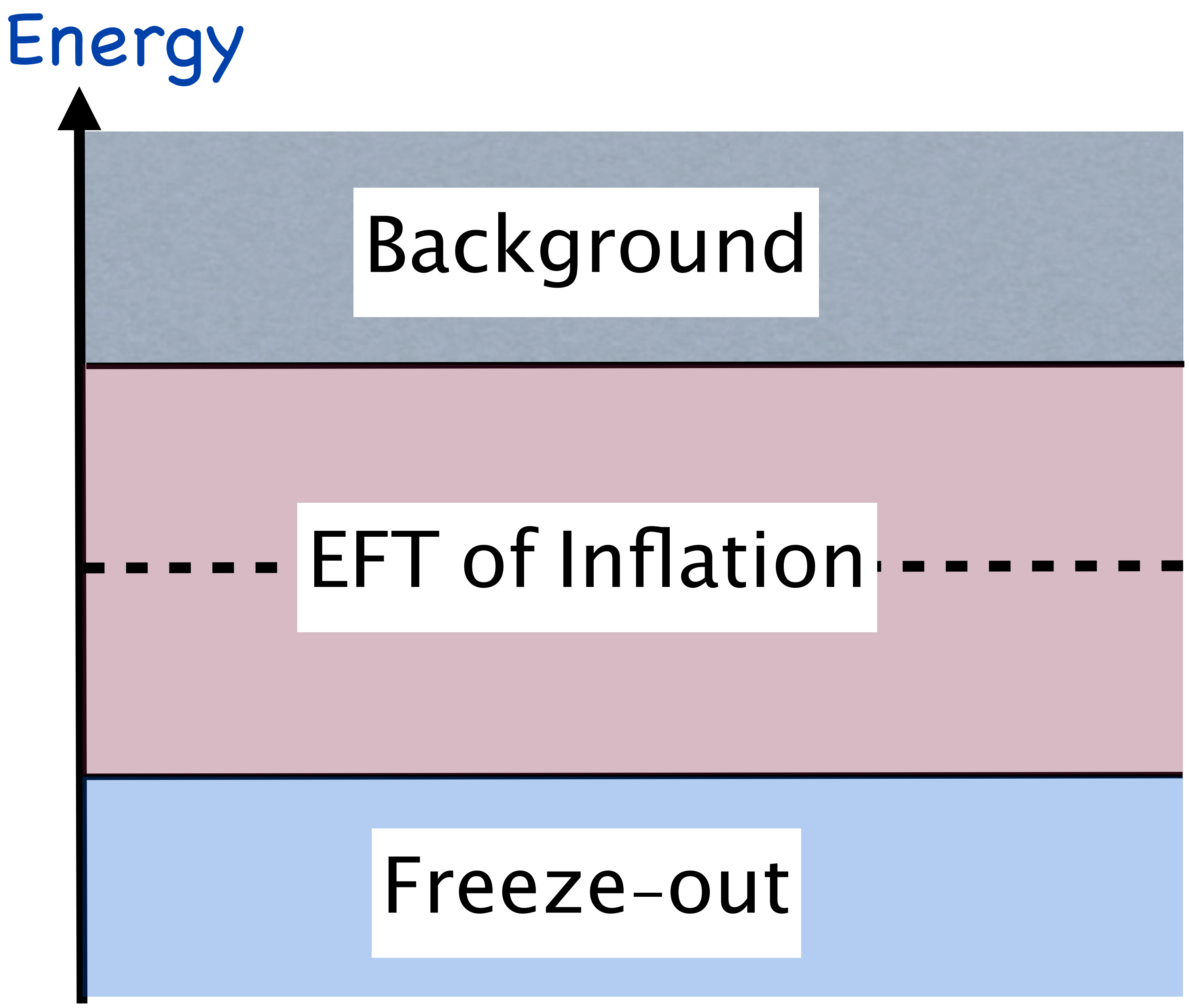
$$f_\pi = (\text{“}\dot{\phi}\text{”})^{1/2} \sim 57H$$

$$(2\pi)\Delta_\zeta = \left(\frac{H}{f_\pi}\right)^2$$

$$H_{\text{inflation}}$$

Interpreting the bounds

Constrain energy of interactions: $\mathcal{L} \supset \frac{1}{\Lambda^{\Delta-4}}\mathcal{O}_\Delta$



$f_\pi = (\text{“}\dot{\phi}\text{”})^{1/2} \sim 57H$

Λ ??

$H_{\rm inflation}$

Constraints

Interpreting the bounds on equilateral

(no local shape is possible in single field) Maldacena; Creminelli & Zaldarriaga

$$\mathcal{L}_3 \supset \qquad \frac{1}{\Lambda_1^2}\dot{\pi}_c\frac{(\tilde{\partial}\pi_c)^2}{a^2} \qquad \frac{1}{\Lambda_2^2}\dot{\pi}_c^3$$

$$f_{\rm NL}^{\rm equil.} \qquad \frac{85}{324}(2\pi\Delta_\zeta)^{-1}\frac{H^2}{\Lambda_1^2} \qquad \frac{20}{729}(2\pi\Delta_\zeta)^{-1}\frac{H^2}{\Lambda_2^2}$$

Planck (95%) $\qquad \Lambda_1 \gtrsim 2.4\,H \qquad \Lambda_2 \gtrsim 0.9\,H$

Constraints

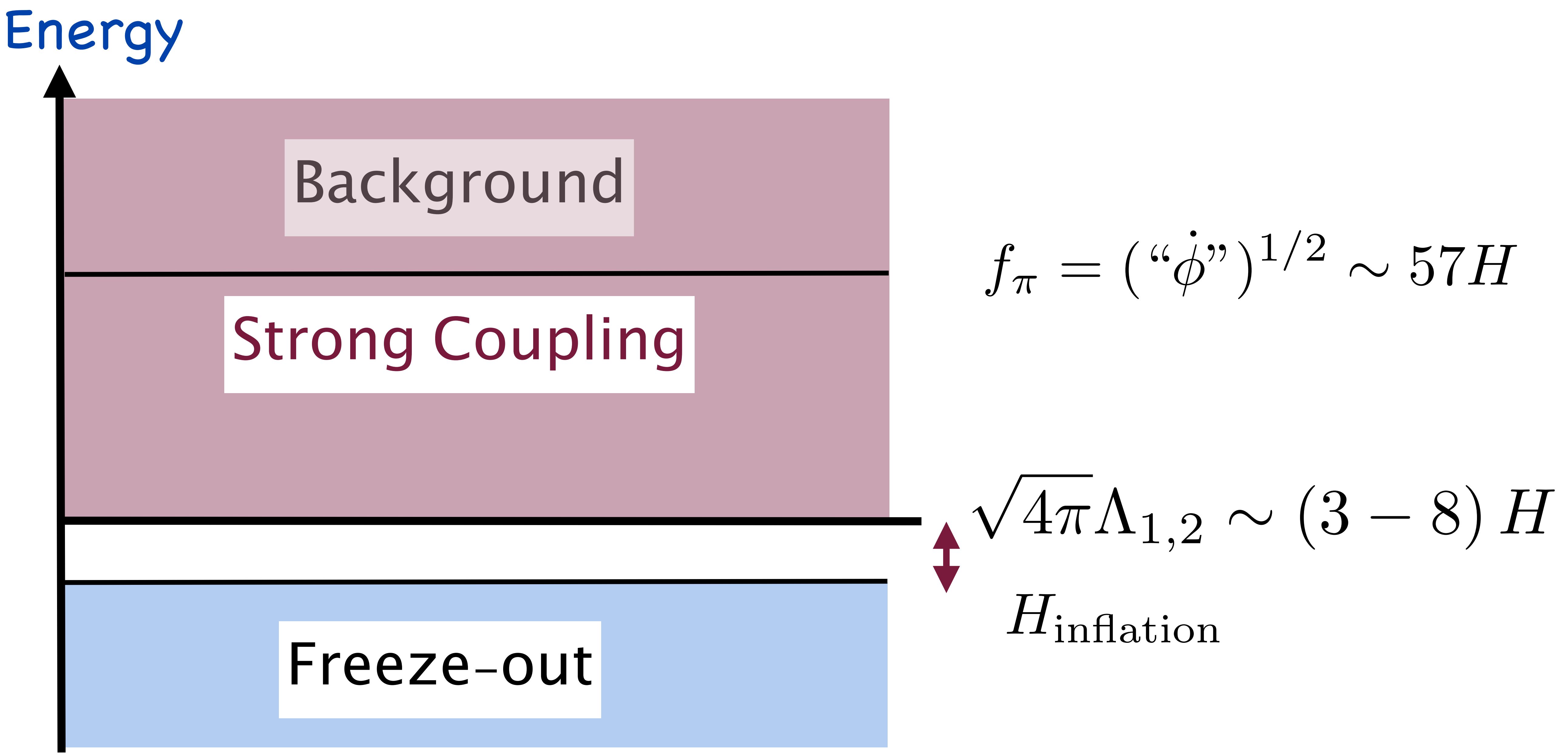
Interpreting the bounds on equilateral

(no local shape is possible in single field) Maldacena; Creminelli & Zaldarriaga

$\mathcal{L}_3 \supset$	$\frac{c_1}{f_\pi^2}\dot{\pi}_c\frac{(\tilde{\partial}\pi_c)^2}{a^2}$	$\frac{c_2}{f_\pi^2}\dot{\pi}_c^3$
$f_{\rm NL}^{\rm equil.}$	$\frac{85}{324}c_1$	$\frac{20}{729}c_2$
Planck (95%)	$c_1 \sim 30 \pm 560$	$c_2 \sim 693 \pm 4160$

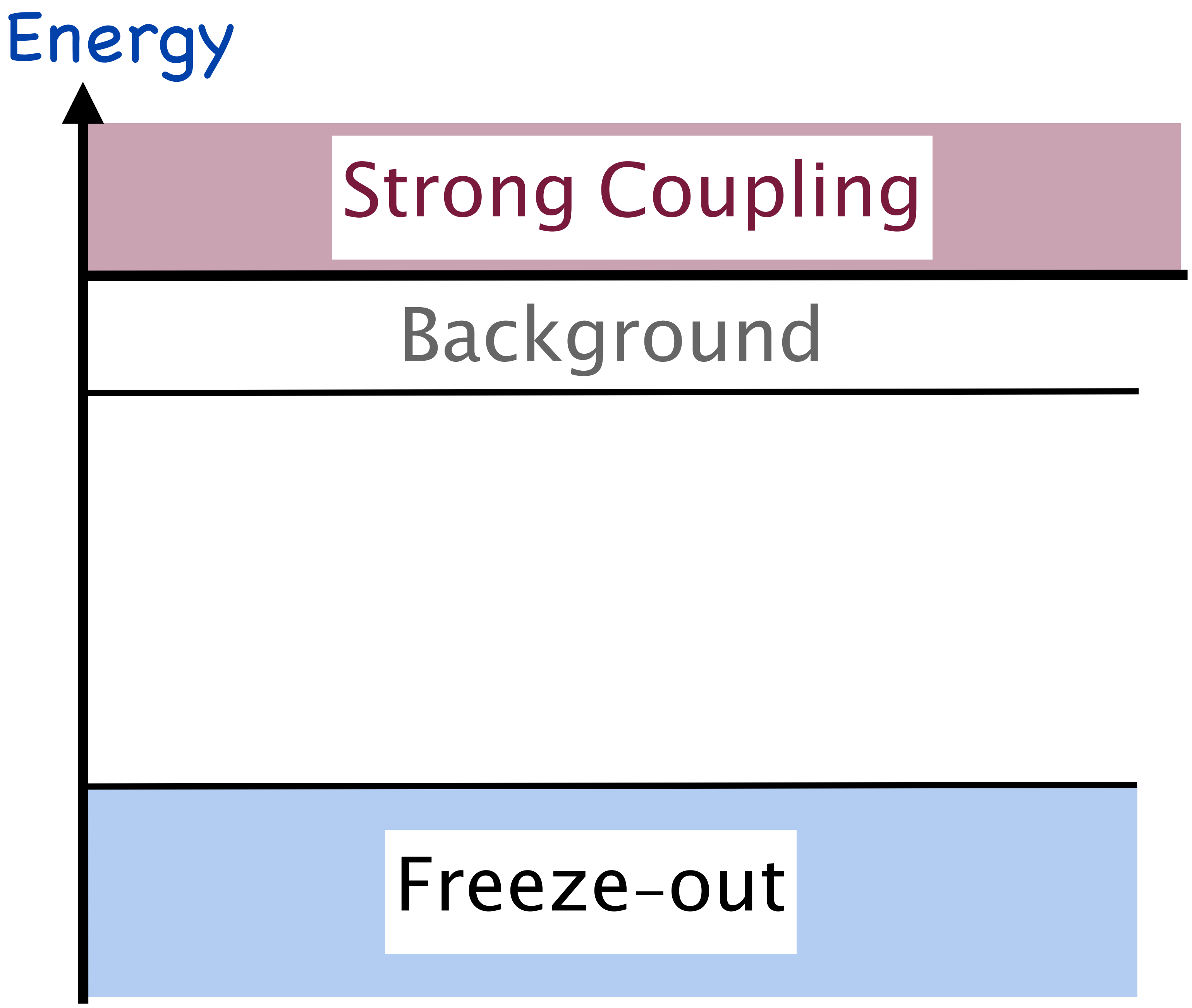
Constraints

Interpreting the bounds on equilateral



Implications

What would we expect from slow roll ?



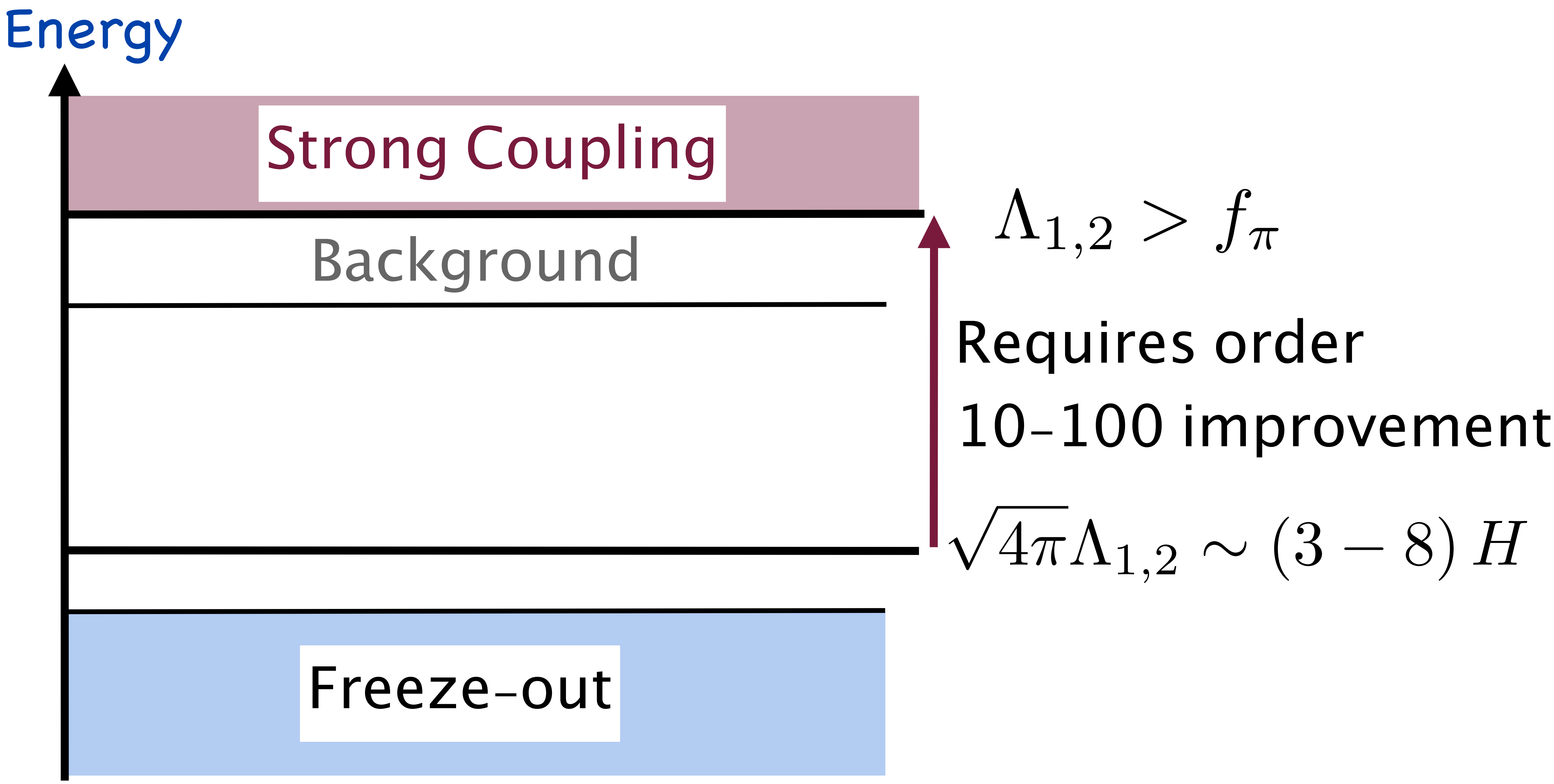
$$\Lambda > f_\pi$$

$$f_\pi = (\text{“}\dot{\phi}\text{”})^{1/2} \sim 57H$$

$$H_{\text{inflation}}$$

Implications

Long way to go before we reach the slow-roll picture



Implications

Coming back to the sentiments…

'Bounds on NG (strongly?) favor a simple mechanism'

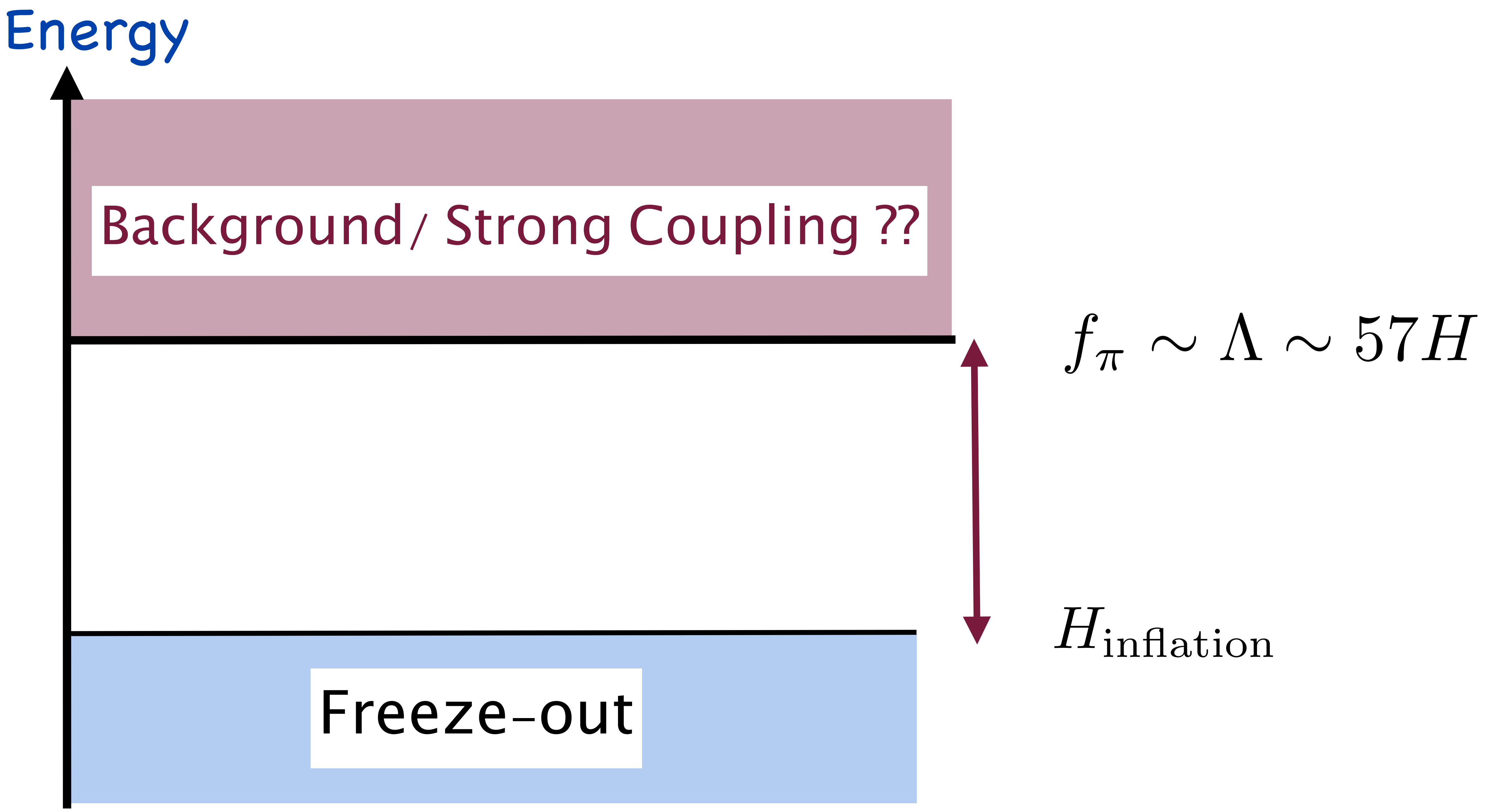
'Data has ruled out exotic models'

It seems like there is a big window left

Can we think of something "exotic" ?

Implications

Could the the background be strongly coupled?



Implications

Could the the background be strongly coupled?

Analogy: Chiral Symmetry breaking in QCD

$$\langle q\bar{q}\rangle \neq 0 \qquad SU(3)\times SU(3) \to SU(3)_{\rm diag.}$$

Pseudo-goldstone bosons are weakly coupled

From the lattice: $\mathcal{L} \sim \frac{(4.3 \pm 0.1)}{48\pi^2 f_\pi^4}(\partial\pi)^4$

Colangelo, Gasser & Leutwyler

Implications

Could the the background be strongly coupled?

By analogy (conjecture):

$$\partial_t \langle q\bar{q} \rangle \sim f_\pi^4 \qquad \mathrm{Diff}(dS_4) \to \mathrm{Diff}(R^3)$$

Goldstone bosons are weakly coupled (eaten by ζ)

$$\mathcal{L} \supset \frac{\mathcal{O}(1-10)}{f_\pi^2} \dot{\pi} (\partial \pi)^2 \longrightarrow f_{\rm NL}^{\rm equil.} \lesssim 5 \quad ??$$

Very challenging to measure.

Implications for Inflation: Additional Fields

Two-field model

Consider a slow-roll model + 1 Extra field

$$\mathcal{L}_{\rm eff}[\Phi,\Sigma] = \mathcal{L}_\Phi + \mathcal{L}_\Sigma + \mathcal{L}_{\rm mix}[\Phi,\Sigma]$$

$$\mathcal{L}_\Phi = -\frac{1}{2}(\partial\Phi)^2 - V(\Phi)$$

Slow-roll : $M_{\rm pl}^2(V'/V)^2 \ll 1$

$$\mathcal{L}_\Sigma = -\frac{1}{2}(\partial\Sigma)^2 - \tilde{V}(\Sigma)$$

Unconstrained

$$\mathcal{L}_{\rm mix} = -\frac{1}{2}\frac{(\partial\Phi)^2\Sigma}{\Lambda}$$

Bounded by Planck limits

Two–field model

Expand in fluctuations are background

$$\mathcal{L} = \underbrace{\boxed{-\tfrac{1}{2}(\partial\phi)^2 - \tfrac{1}{2}(\partial\sigma)^2 - m^2\sigma^2 + \frac{\dot{\Phi}}{\Lambda}\dot{\phi}\sigma}}_{\mathcal{L}_2} + \frac{(\partial\phi)^2}{\Lambda}\sigma - \mu\sigma^3$$

Includes massive and massless fluctuations

Massive field converts to massless through $\dot{\phi}\sigma$

Massive field does not affect inflation: $\zeta \simeq -\frac{H\phi}{\dot{\Phi}}$

Two-field model

Expand in fluctuations are background

$$\mathcal{L} = -\tfrac{1}{2}(\partial\phi)^2 - \tfrac{1}{2}(\partial\sigma)^2 - m^2\sigma^2 + \frac{\dot{\Phi}}{\Lambda}\dot{\phi}\sigma + \boxed{\frac{(\partial\phi)^2}{\Lambda}\sigma - \mu\sigma^3}$$

$\mathcal{L}_3$

Non-gaussianity a function of (m^2, μ, Λ)

Natural to have $(m^2, \mu^2) \sim H^2$ see McAllister's talk

Potentially large NG: $\Delta_\zeta f_{\rm NL} \sim (\frac{\dot{\Phi}}{\Lambda H})^3 \frac{\mu}{H}$

Constraints

Universal constraint: $\mu \sim 0$

Dominant kinetic term: $\frac{\dot{\Phi}}{\Lambda}\dot{\phi}\sigma \qquad \frac{\dot{\Phi}}{\Lambda} \equiv \rho \gg H$

Dominant interaction: $\frac{1}{\Lambda}\partial_i\phi\partial^i\phi\sigma$

Shape: equilateral or orthogonal

Constraint (95%): $\Lambda \gtrsim 66\, H$

Constraints

Strongest constraint: $\mu \sim H$

Dominant kinetic term: $(\partial\phi)^2$ $\rho \lesssim H$

Dominant interaction: $\mu\sigma^3$

Shape: local or equilateral

Constraint (95%): $\Lambda \gtrsim 10^5 H$

Constraints

Strongest constraint: $\mu \sim H$

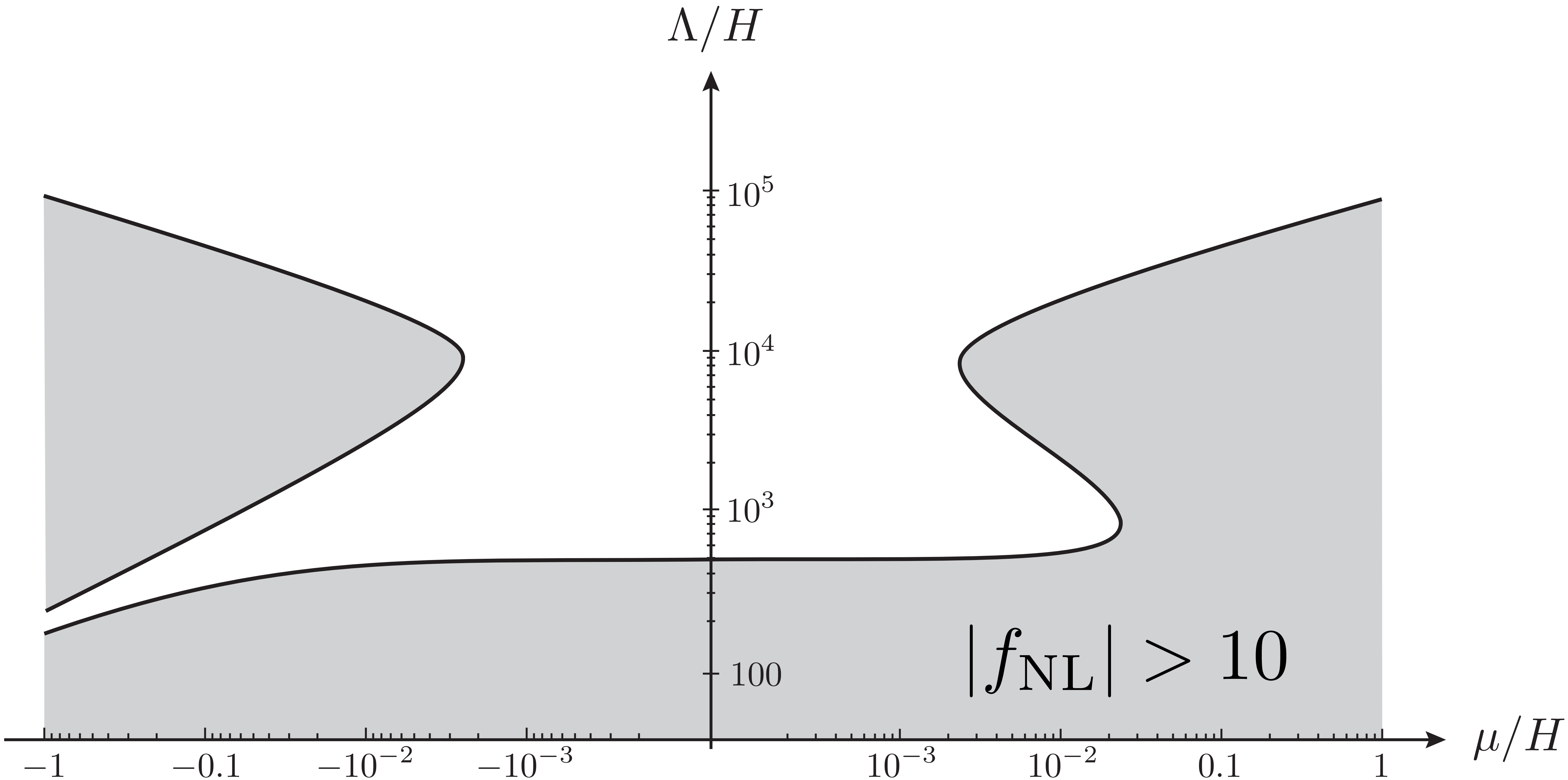
Dominant kinetic term: $(\partial\phi)^2$ $\rho \lesssim H$

Dominant interaction: $\mu\sigma^3$

Shape: local or equilateral

Constraint (95%): $\Lambda \gtrsim 0.5\left(\frac{|\mu|}{H}\right)^{1/3}\left(\frac{r}{0.01}\right)^{1/2} M_{\rm pl}$

Constraints



Generalization

Limits on NG bound couplings between sectors

$$\mathcal{L} \supset \frac{1}{\Lambda^{\Delta}} (\partial\Phi)^2 \mathcal{O}_{\Delta}$$

For moderately NG hidden sectors

$$\Lambda \gtrsim (10^5)^{1/\Delta} \, H$$

Origin of the constraint largely insensitive to details

Related to single field bounds when $\Delta \gtrsim 4$

Summary & Discussion

Summary

Interpretations of the Planck results：

（1） Single-field mechanism：

Bounds on NG constrain physics at Hubble scale

Only weak limits on mechanism

（2） Extra fields coupled to slow-roll

Bounds on NG constrain physics at high scales

Strong limits on the mixing between sectors

（Especially if we measure tensor modes!）

Discussion topics

Some open questions:

Are there theoretical/observational reasons to dismiss a strongly-coupled background ?

How much will bounds on equilateral improve?

Is it fair to say multi-field is more constrained?