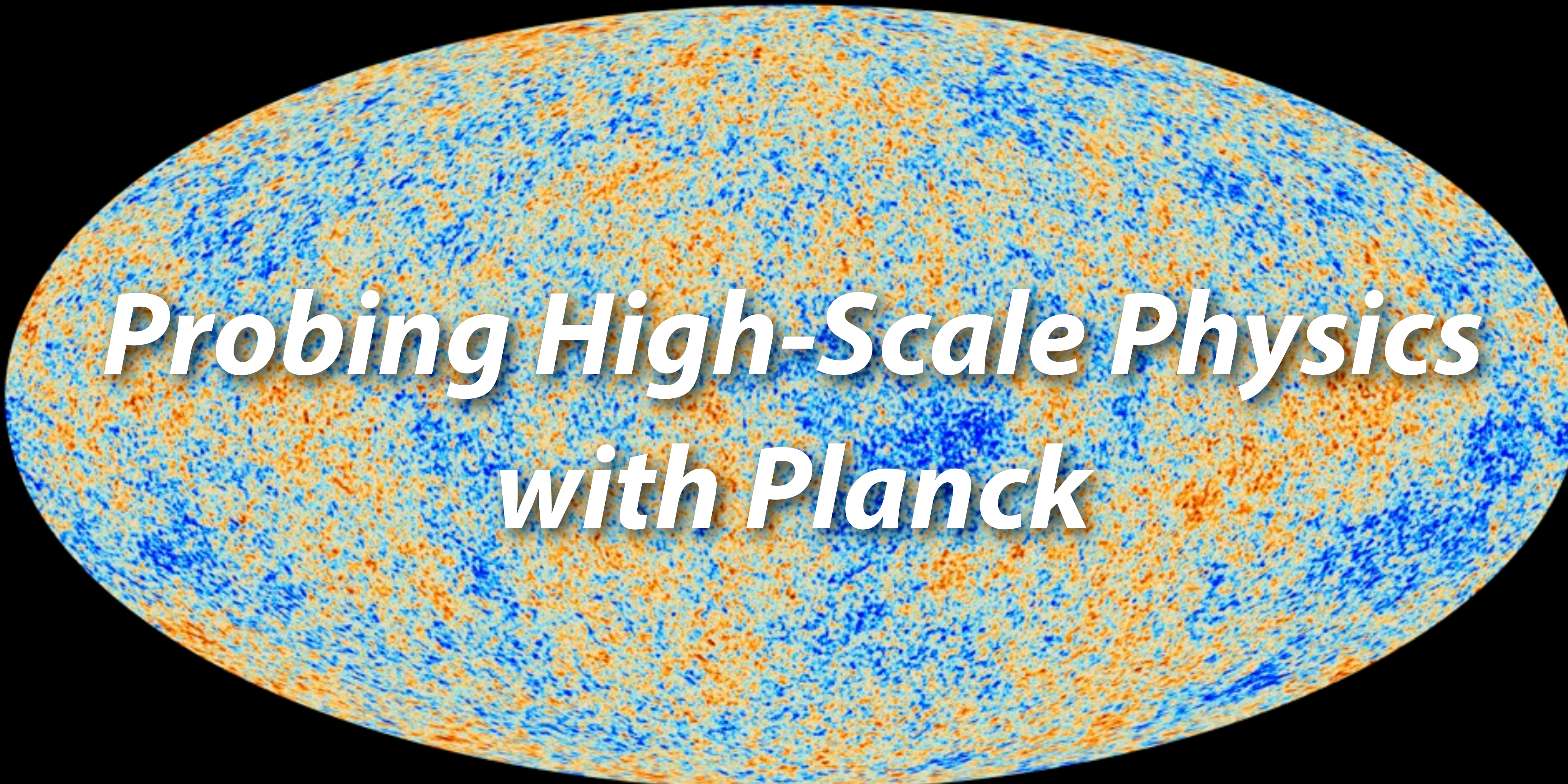


Probing High-Scale Physics with Planck

Daniel Baumann

DAMTP
Cambridge University

based on

Valentin Assassi, DB, Daniel Green and Liam McAllister

Planck-Suppressed Operators

[arXiv:1304.5226]

DB and Daniel Green

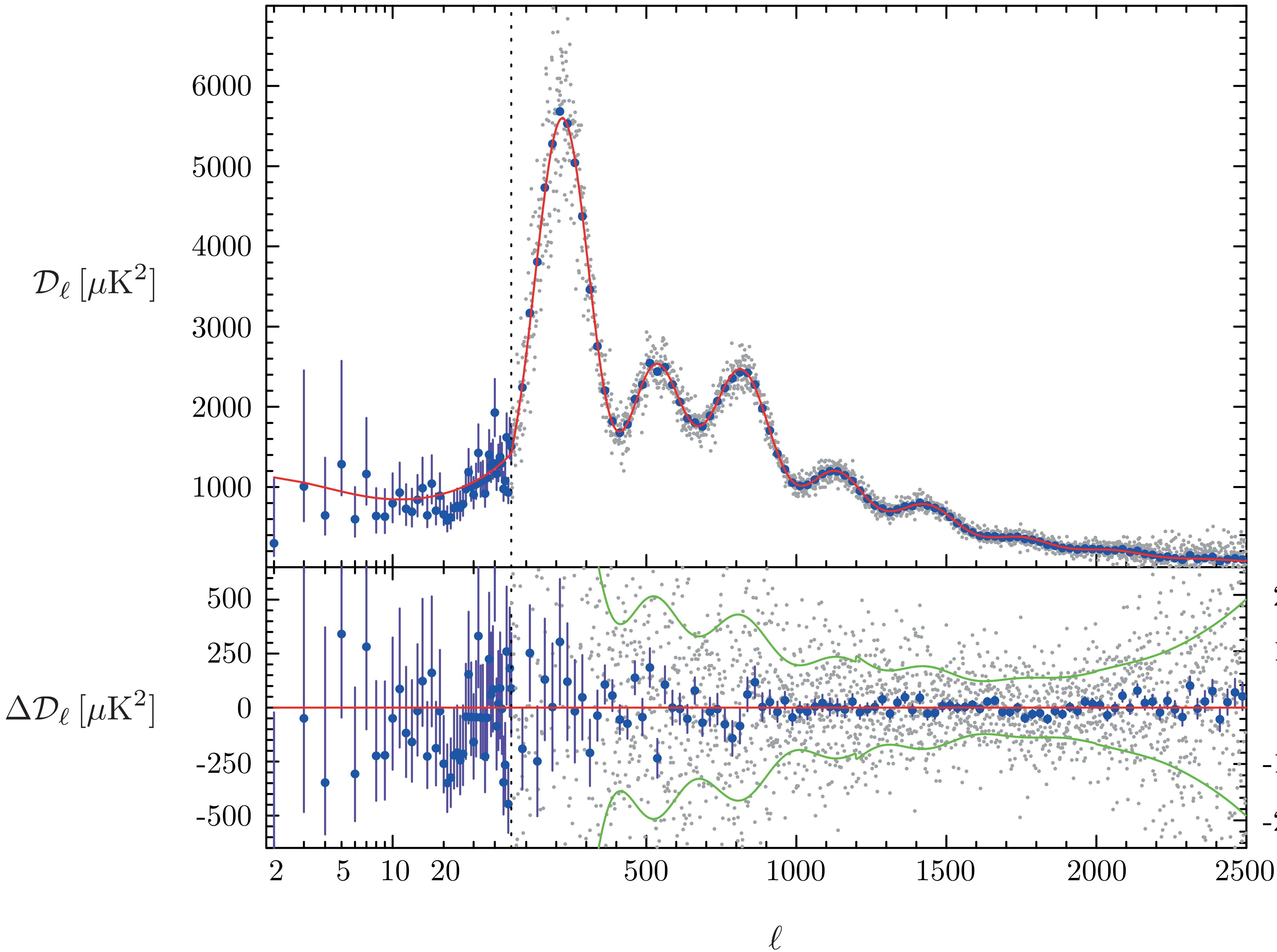
Equilateral Non-Gaussianity and New Physics on the Horizon

[arXiv:1102.5343]

supported by

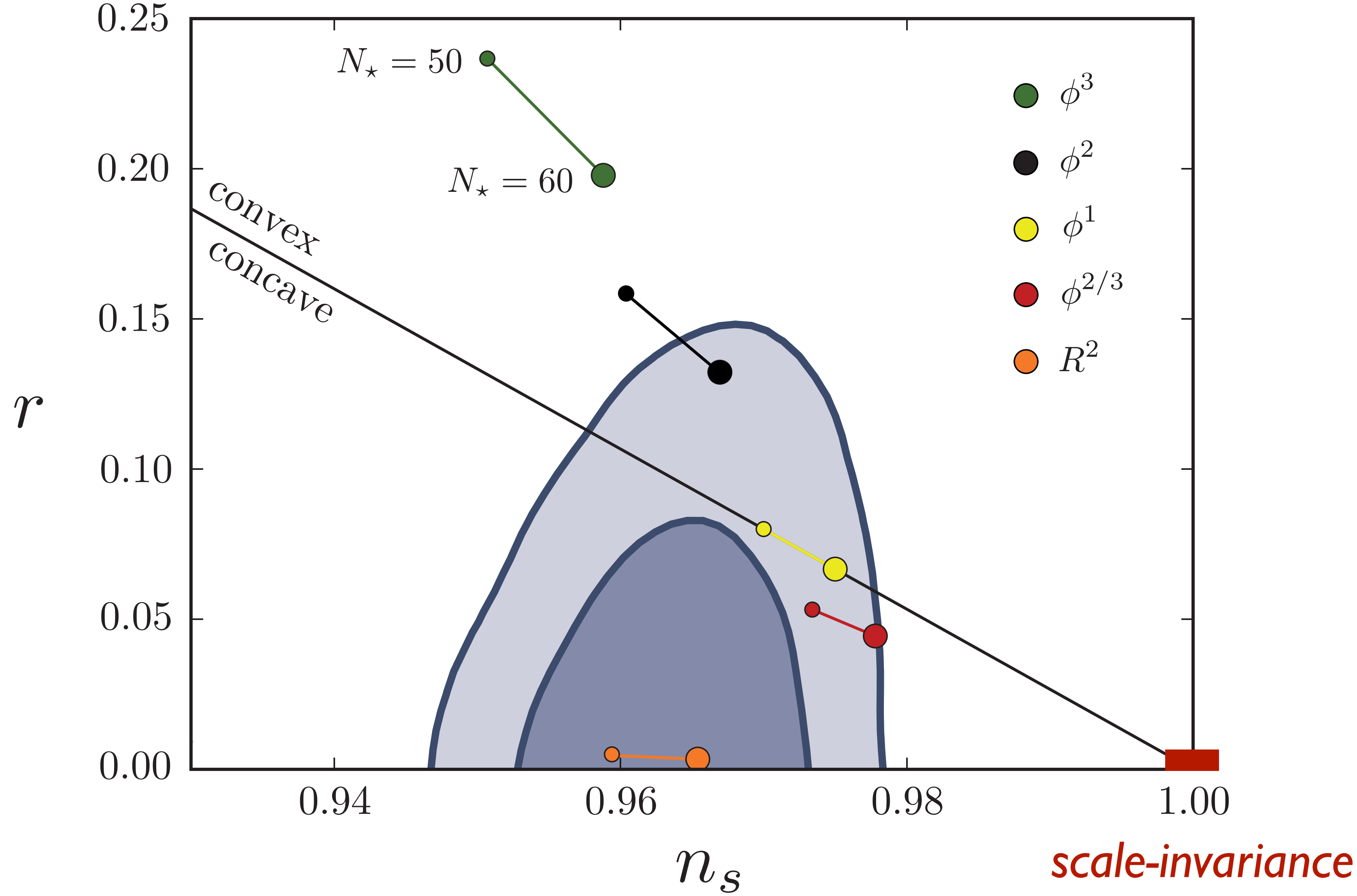
erc

European Research Council



Planck (Paper 16)

2-Point Function



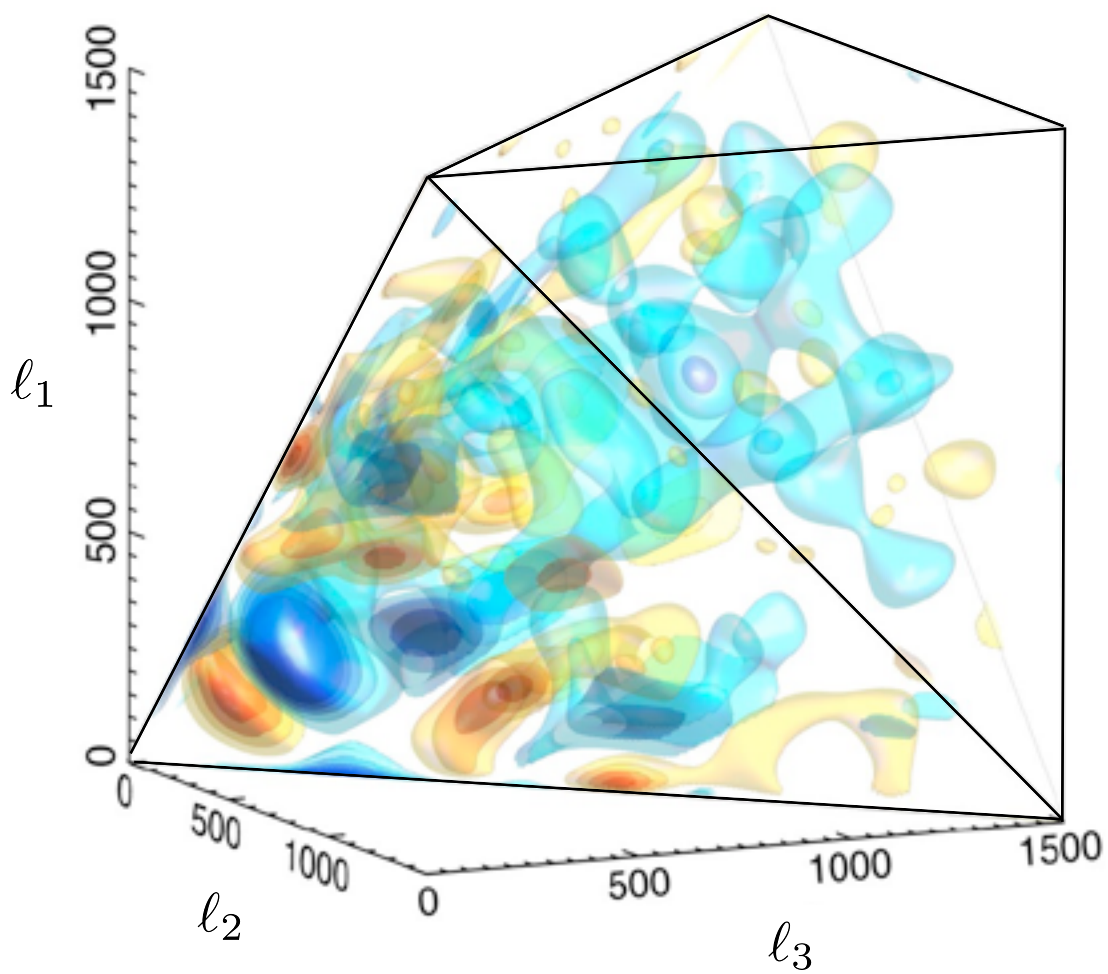
6-σ detection of non-scale-invariance

$$n_s = 0.961 \pm 0.011$$

Planck (Paper 22)

3- and 4-Point Functions

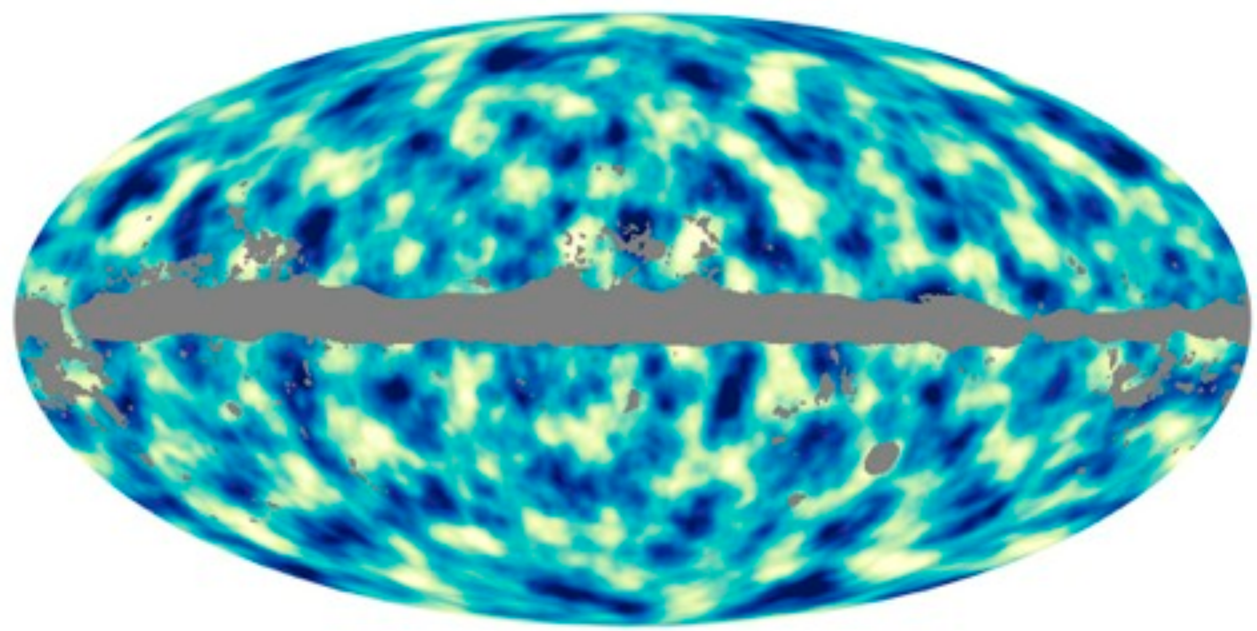
3-point function:



reconstructed bispectrum

Planck (Paper 24)

4-point function:

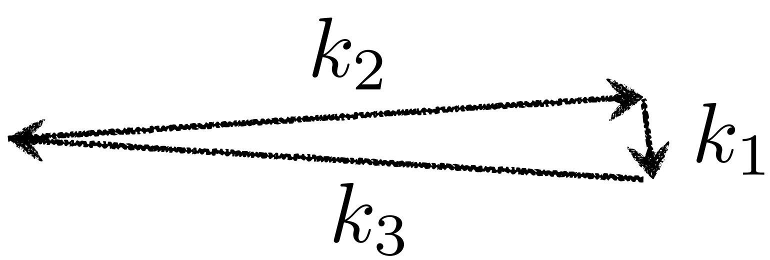


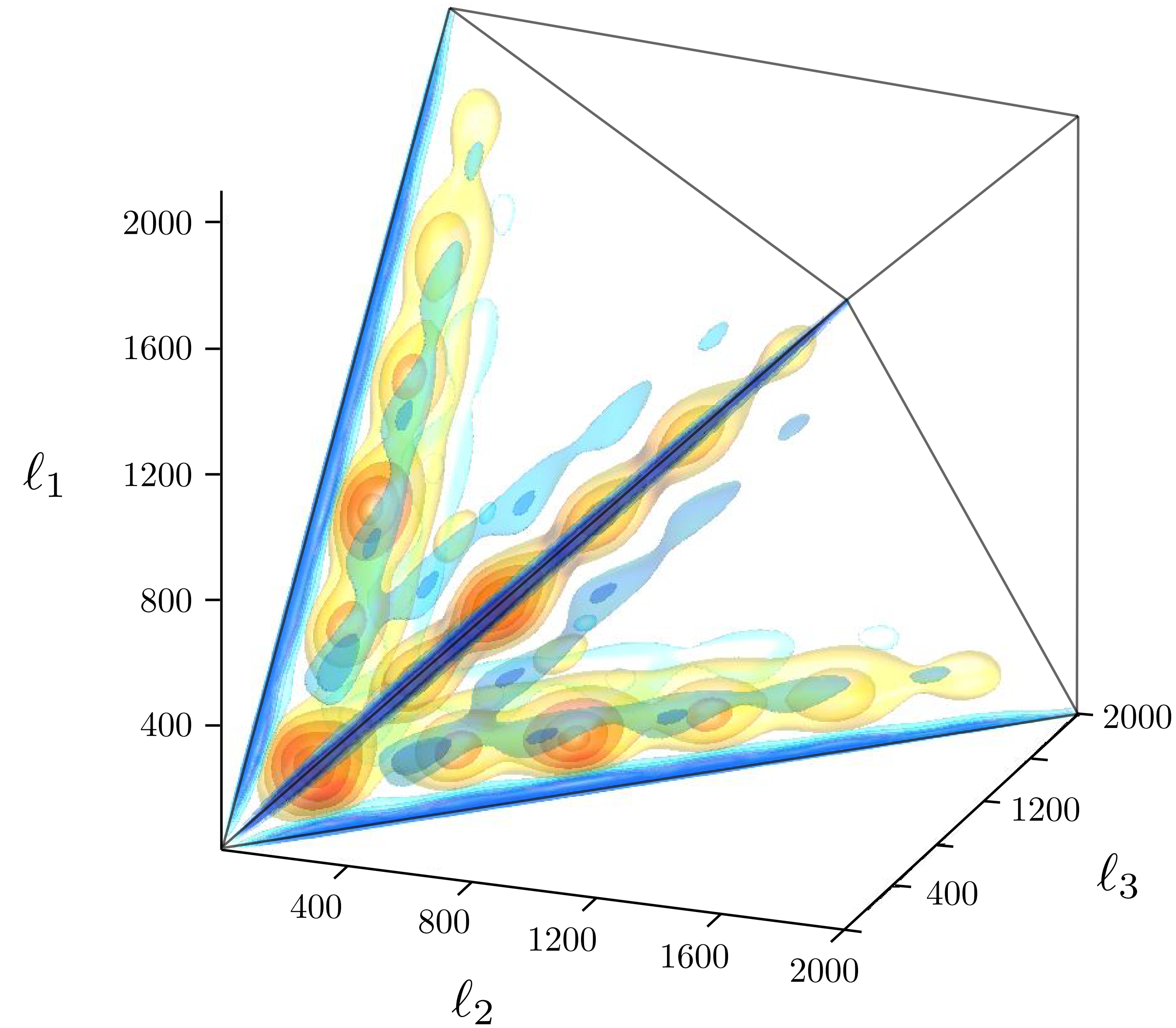
26-σ detection of lensing

Planck (Paper 17)

Planck reported limits on 3 templates:

local



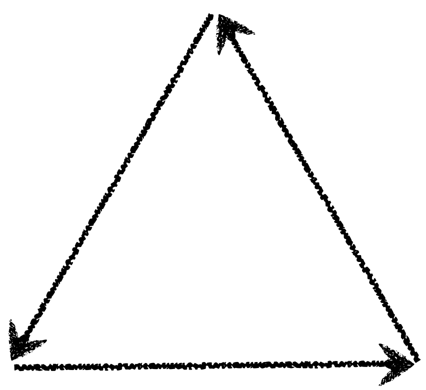


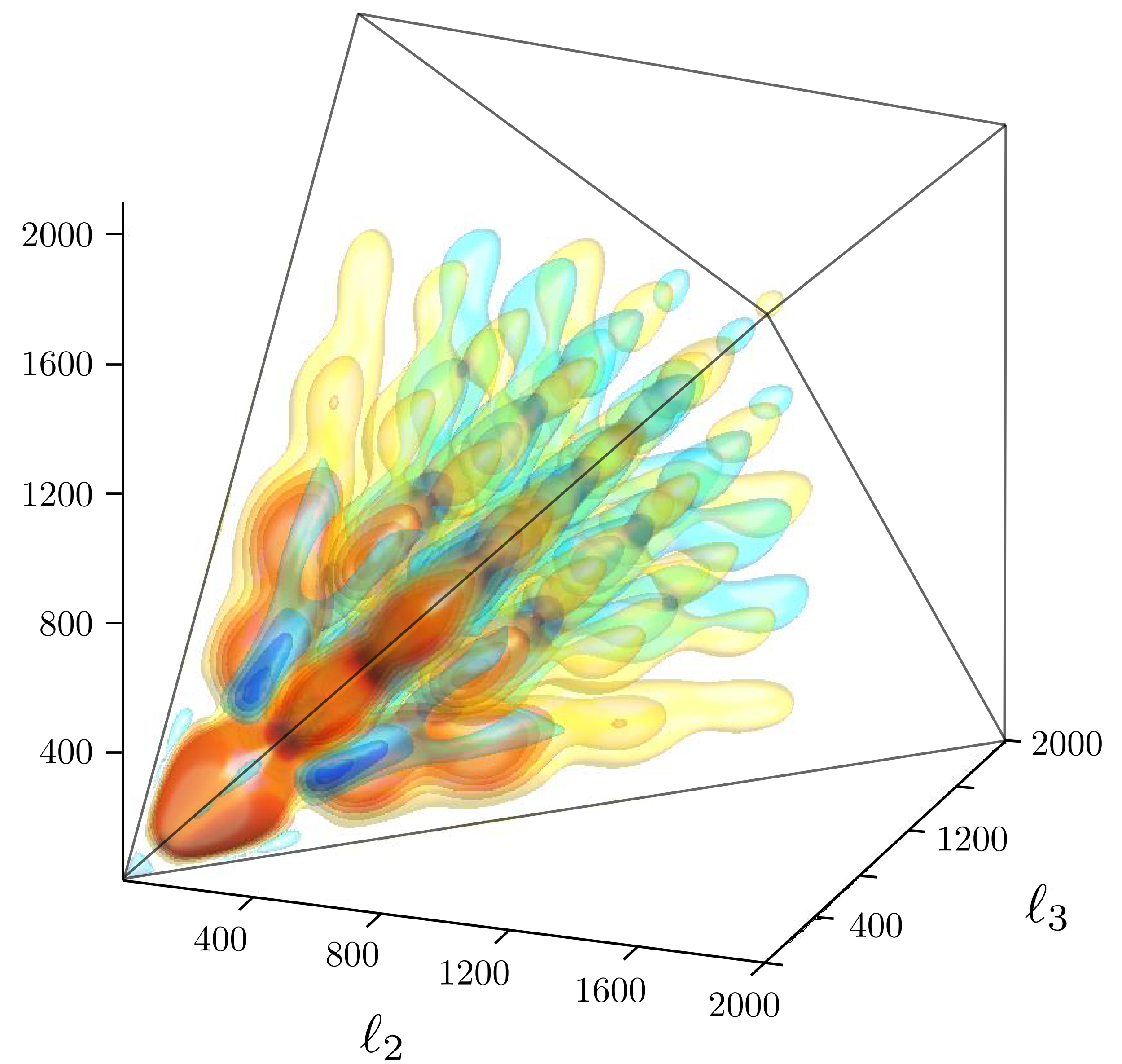
$$f_{\rm NL}^{\rm local} = 2.7 \pm 5.8$$

(figure courtesy of Paul Shellard)

Planck reported limits on 3 templates:

equilateral



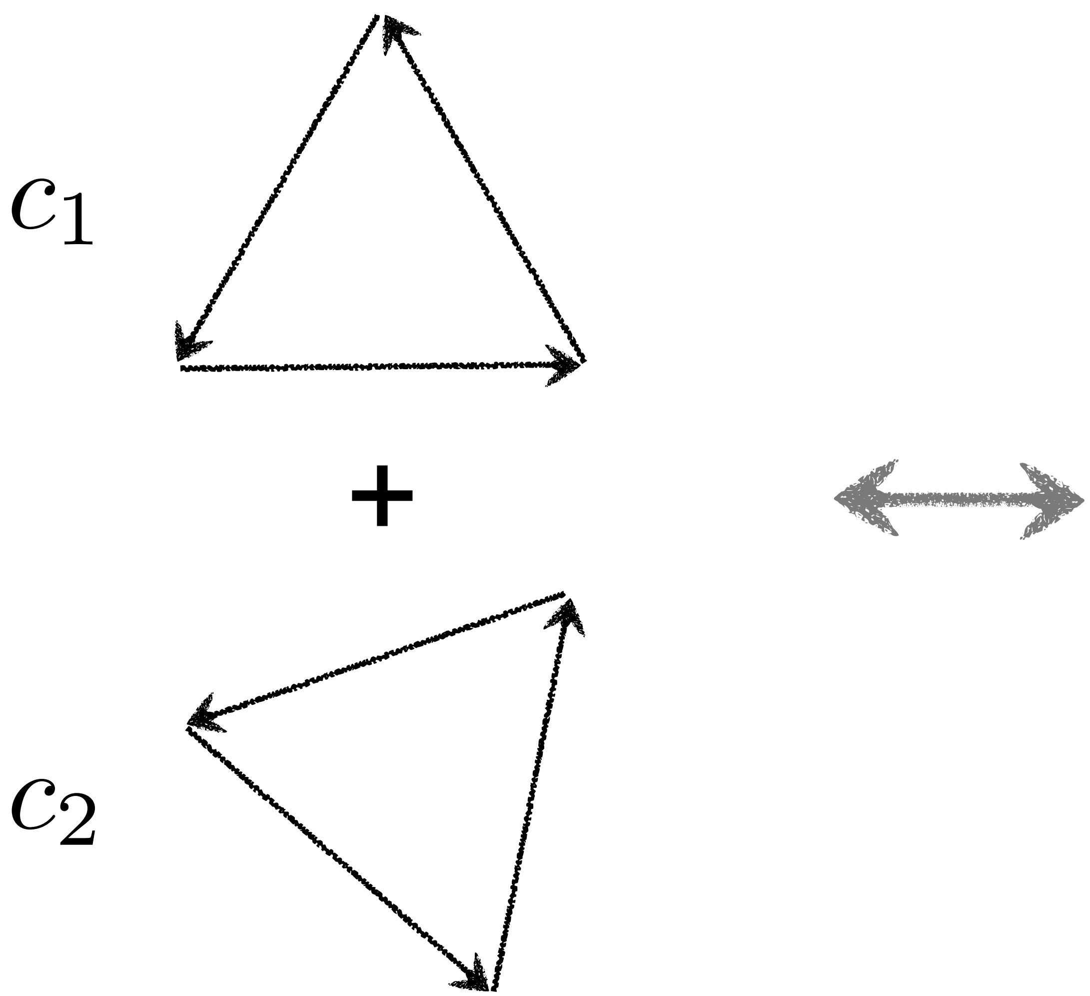


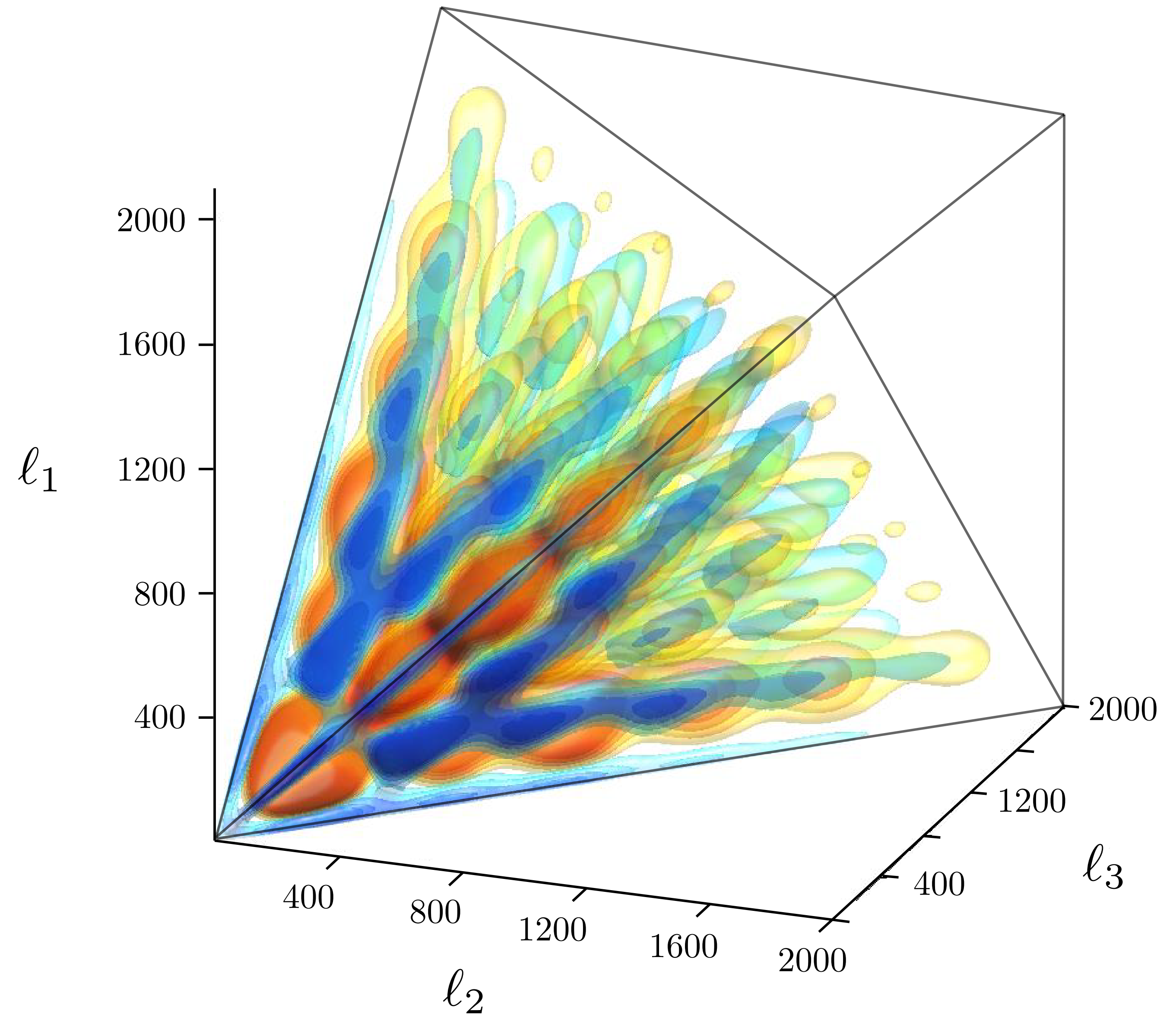
$$f_{\rm NL}^{\rm equil} = -42 \pm 75$$

(figure courtesy of Paul Shellard)

Planck reported limits on 3 templates:

orthogonal





$$f_{\rm NL}^{\rm ortho} = -25 \pm 39$$

(figure courtesy of Paul Shellard)

These are ***precision constraints***

$$\mathrm{NG} \equiv f_{\mathrm{NL}} \Delta_\zeta \lesssim 10^{-4}$$

These are ***precision constraints***

$$\mathrm{NG} \equiv f_{\mathrm{NL}} \Delta_\zeta \lesssim 10^{-4}$$

which probe ***high-scale physics***

$$\Lambda \gtrsim \mathcal{O}(10^5 - 10^2) H$$

cf. electroweak precision tests

Outline

I. The Physics of Inflation

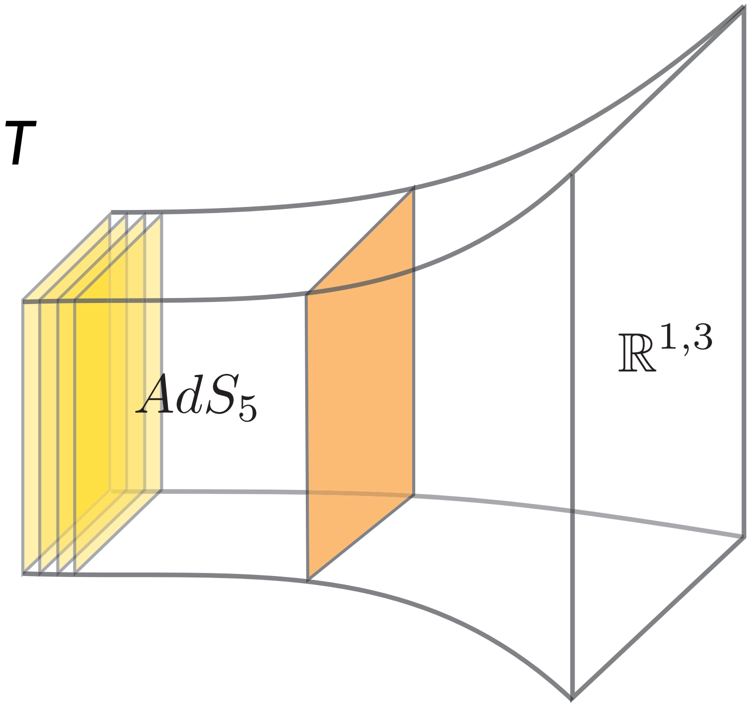
Motivation for Light Hidden Sectors

Effective Field Theory

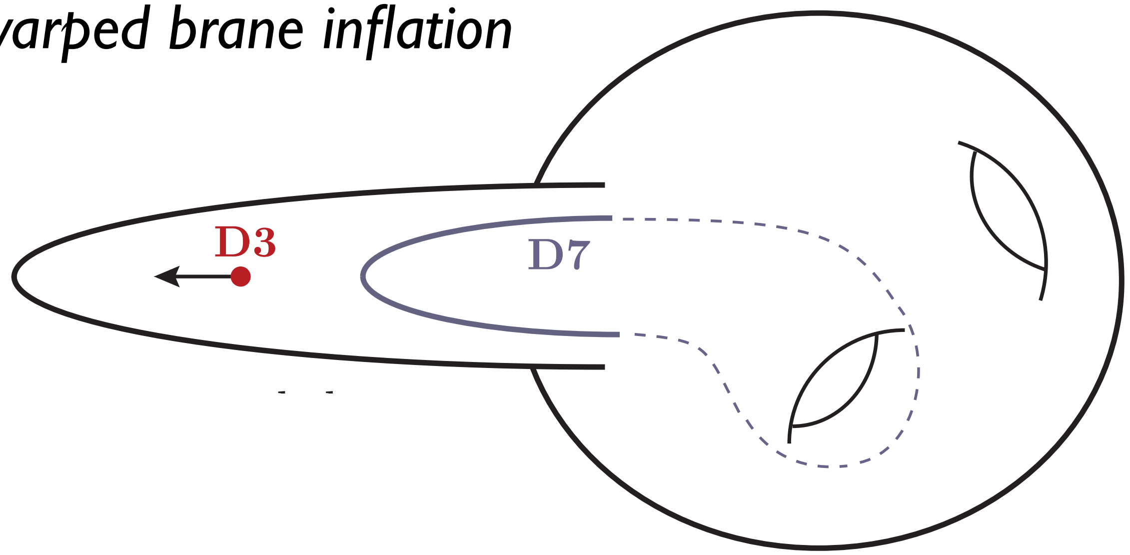
Non-Gaussian Phenomenology

II. Precision Constraints from PLANCK

KKLMMT

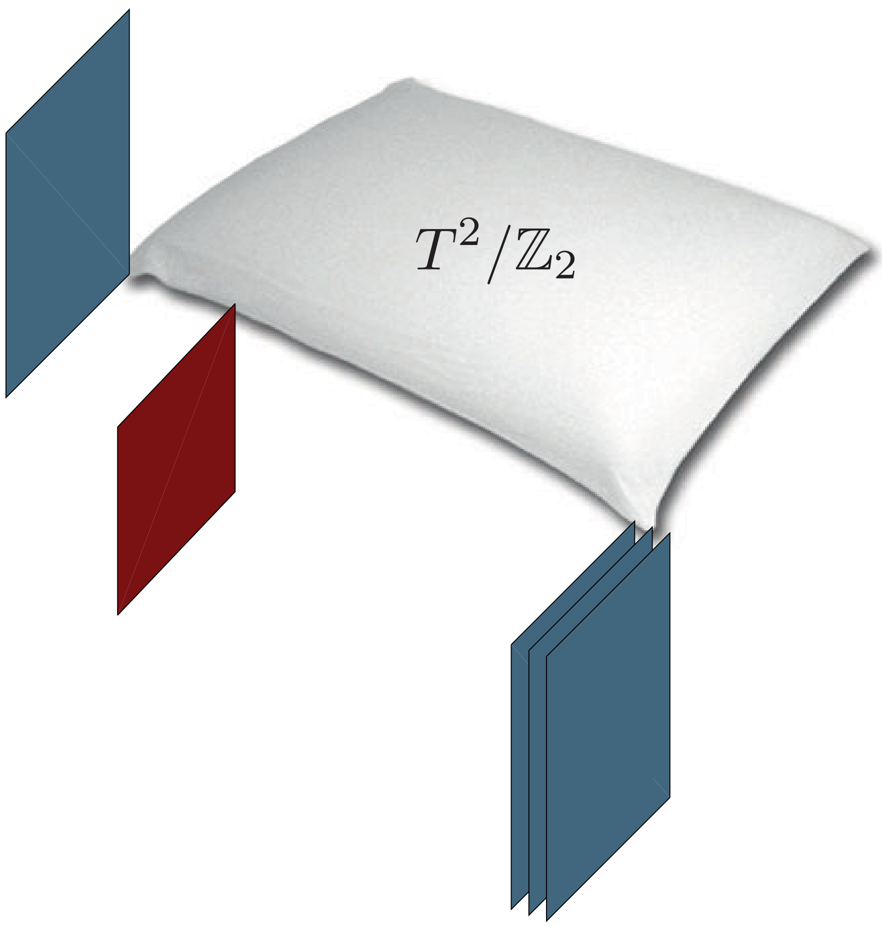


warped brane inflation

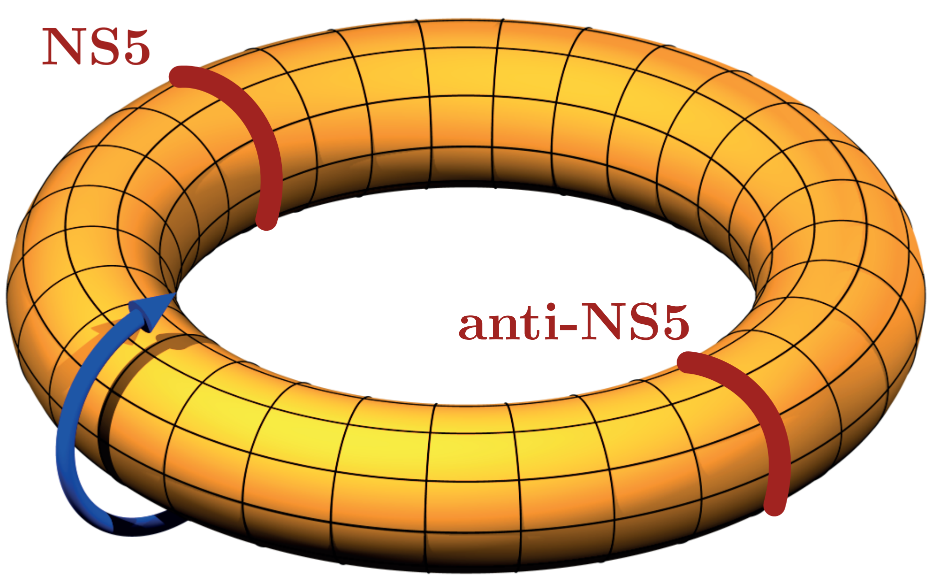


I. The Physics of Inflation

D3/D7



axion monodromy



DB and McAllister, Physics Report, *to appear*.

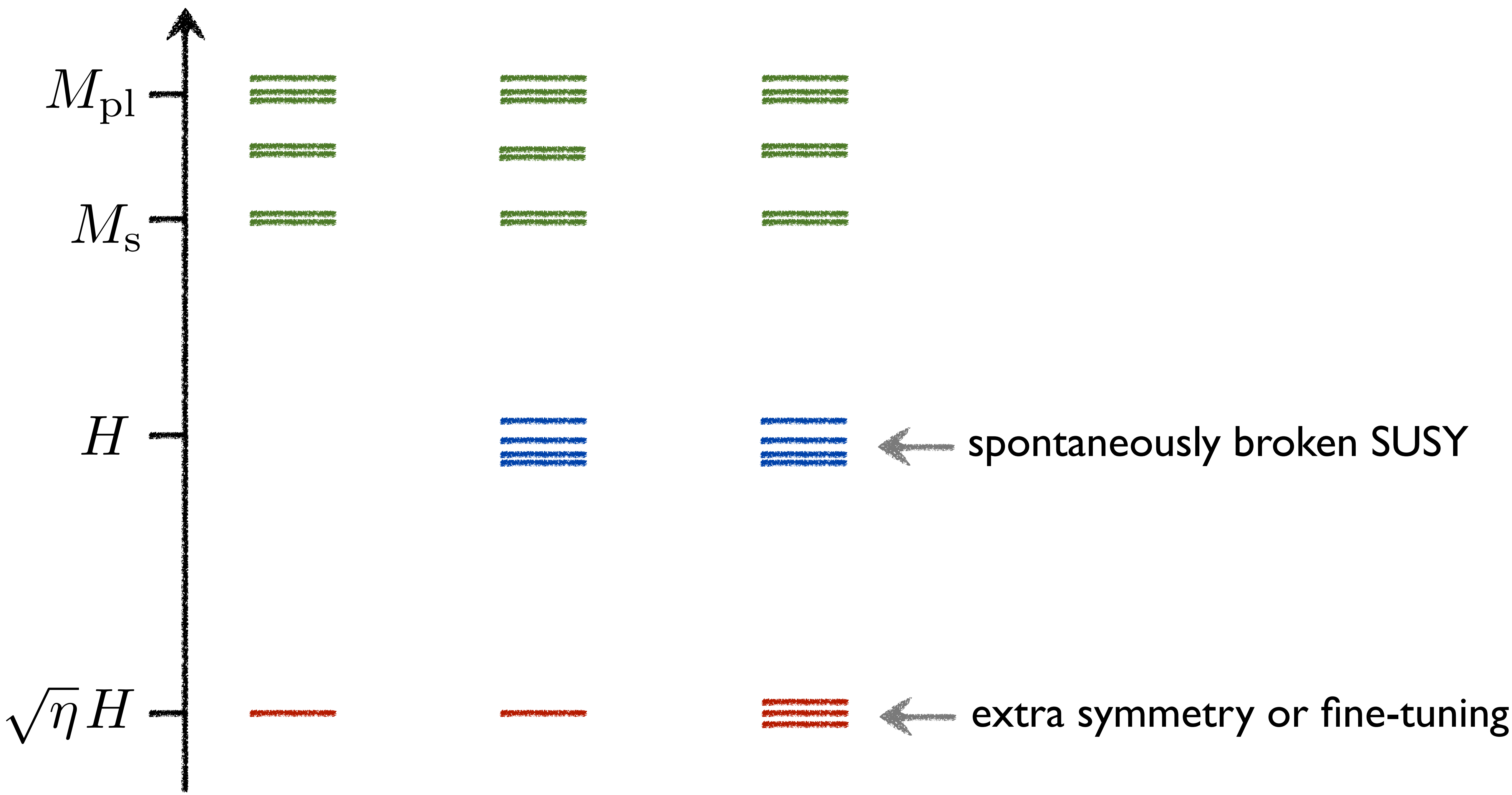
There are roughly two ways to confront these ideas with data:

Construct concrete models
and test specific predictions

or

Identify universal features and constrain
the corresponding effective theories

What all models have in common is
light hidden sector fields



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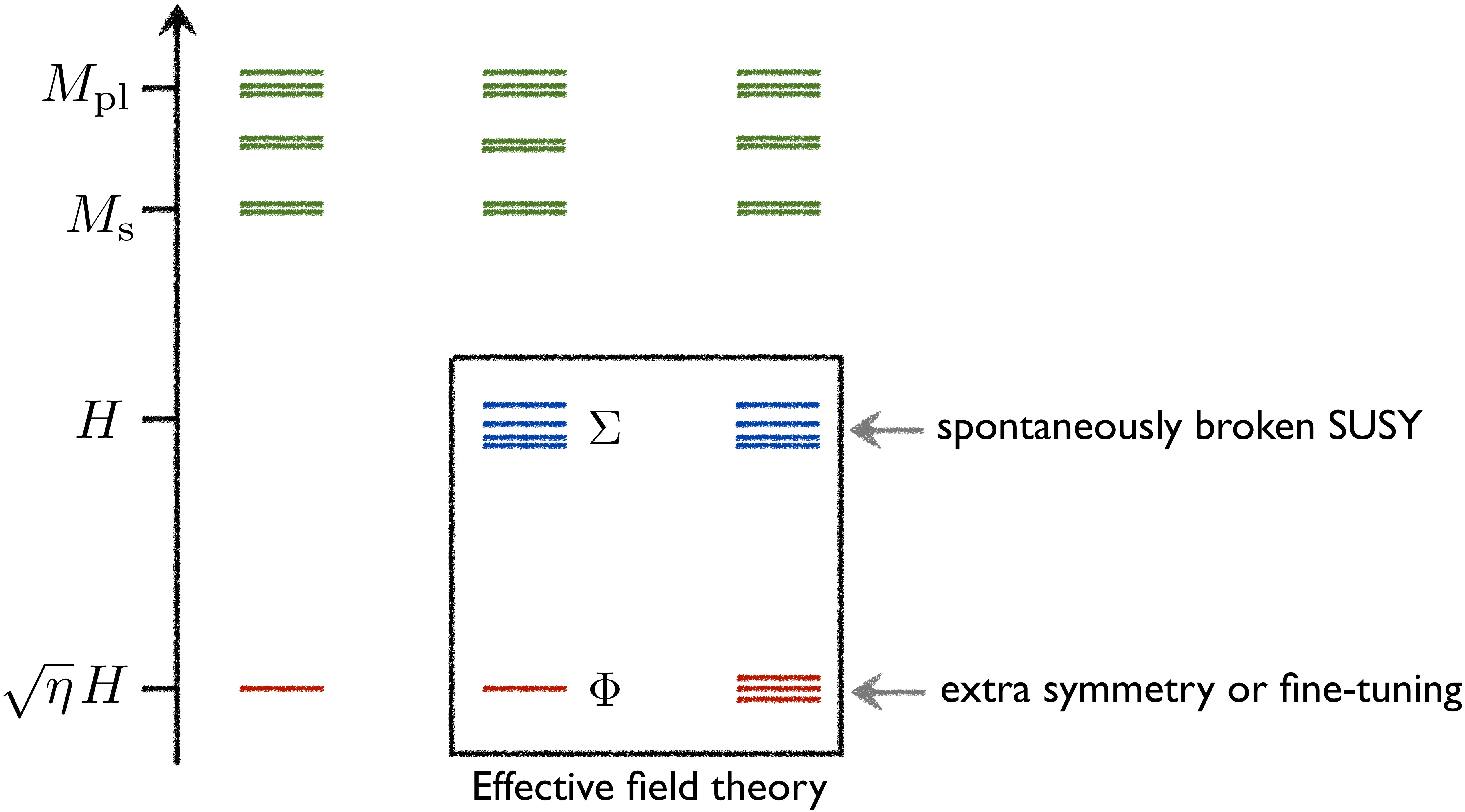
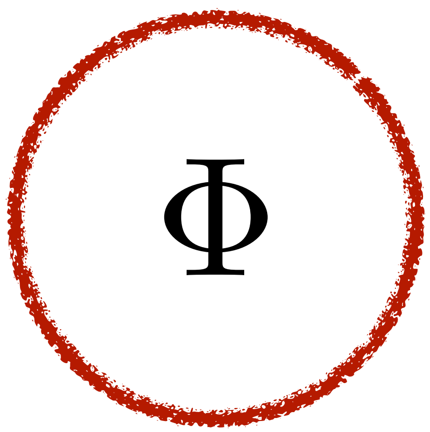


Effective Field Theory

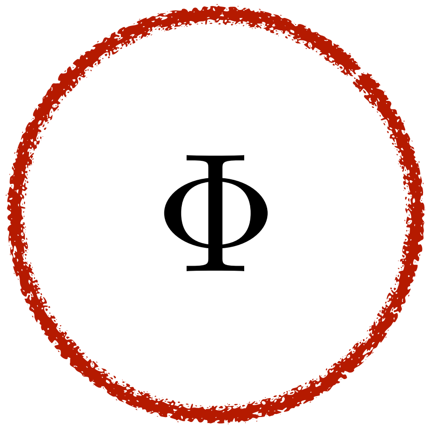
inflaton sector



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

Effective Field Theory

inflaton sector



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

approximate shift symmetry

$$\Phi \mapsto \Phi + const.$$

motivated both theoretically and observationally

(slow-roll) (scale-invariance)

Effective Field Theory

inflaton sector

$$\Phi$$

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

approximate shift symmetry

$$\Phi \mapsto \Phi + const.$$

motivated both theoretically and observationally

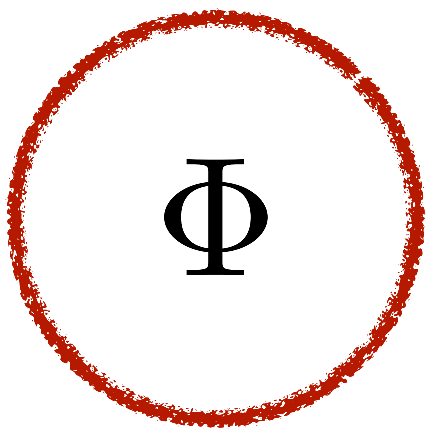
(slow-roll) (scale-invariance)

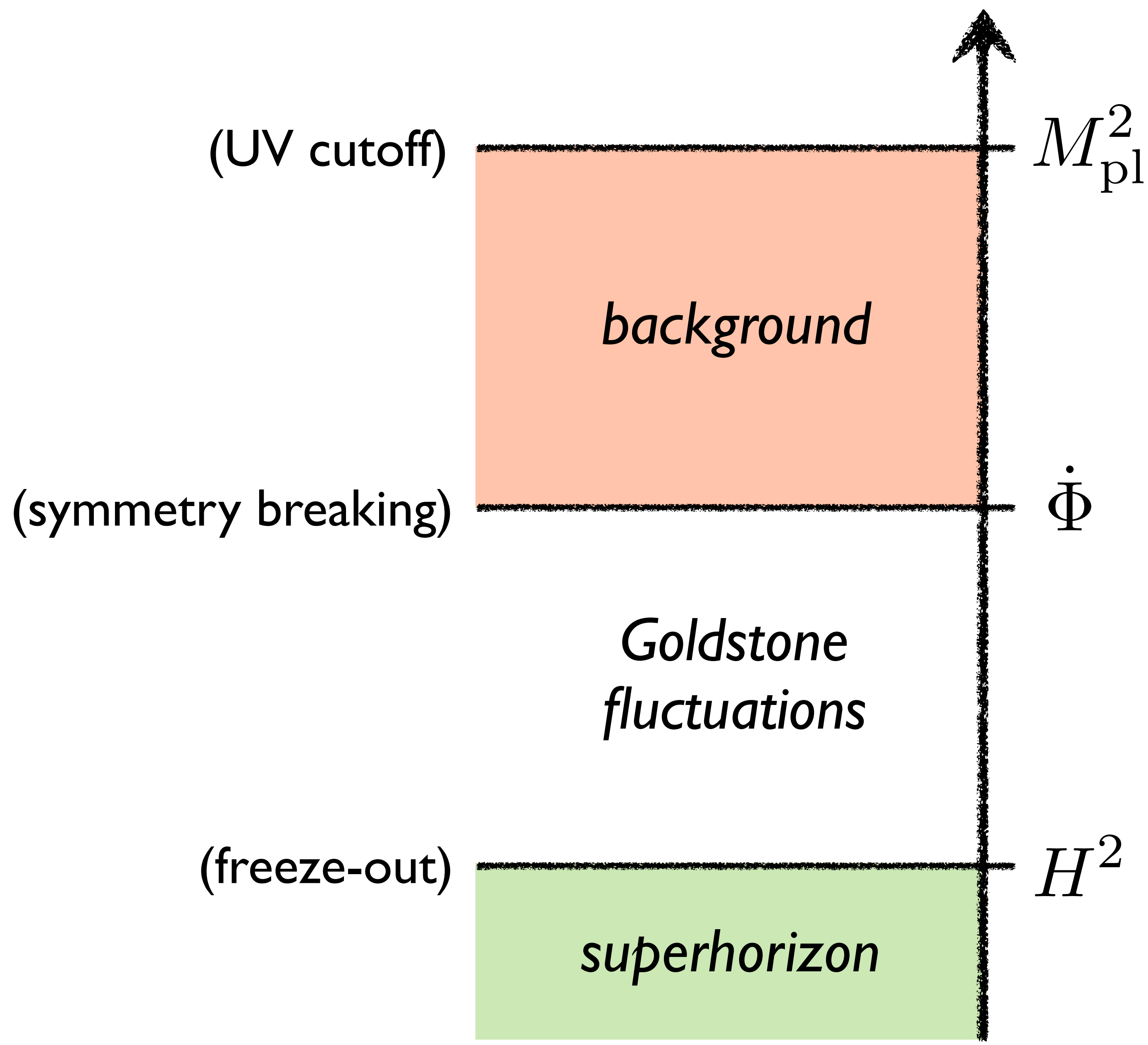
$$\zeta = -\frac{H}{\dot{\Phi}}\delta\Phi$$

curvature perturbations

Effective Field Theory

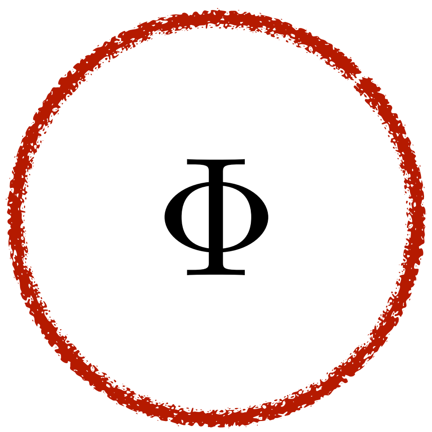
inflaton sector

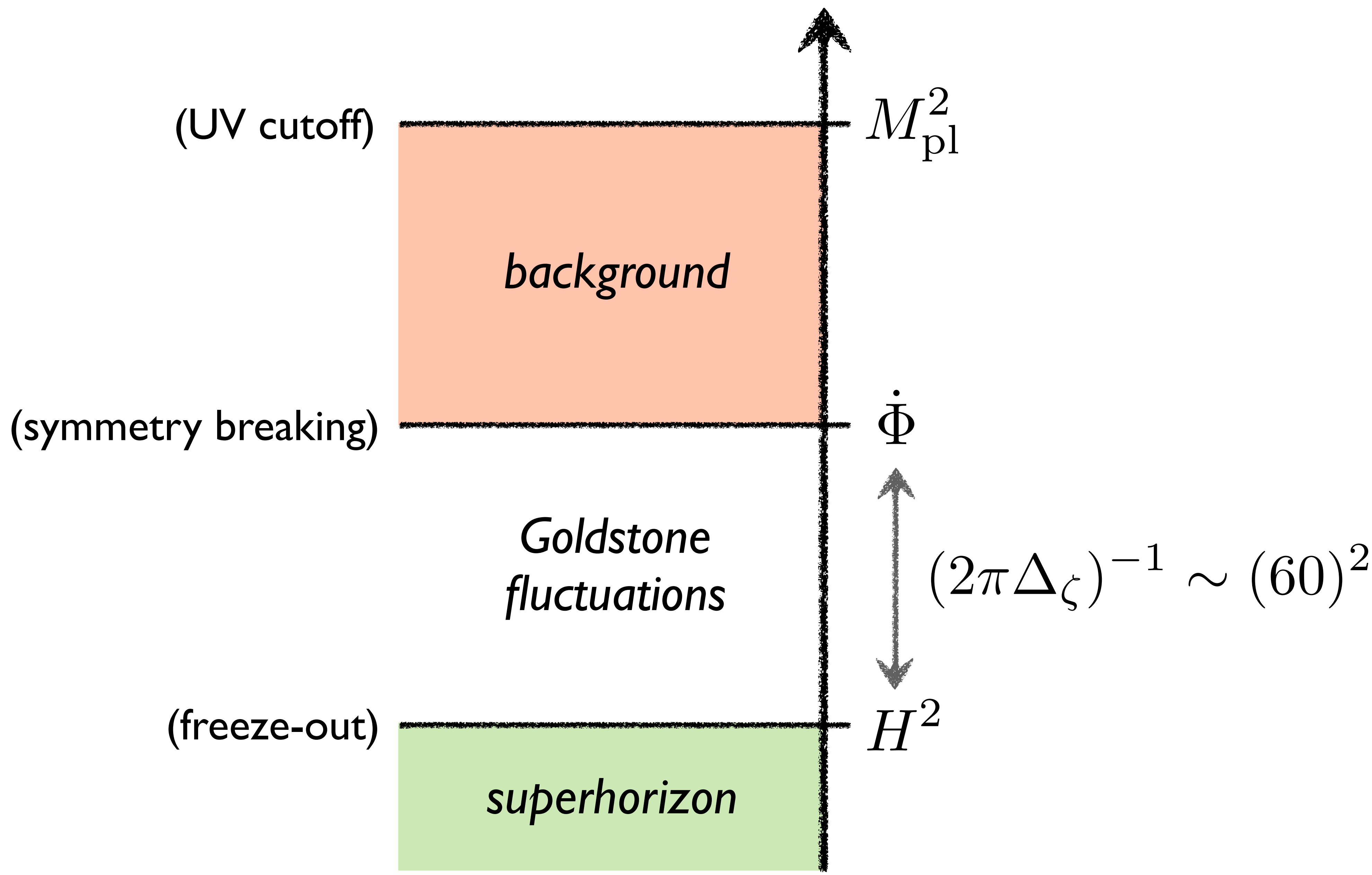




Effective Field Theory

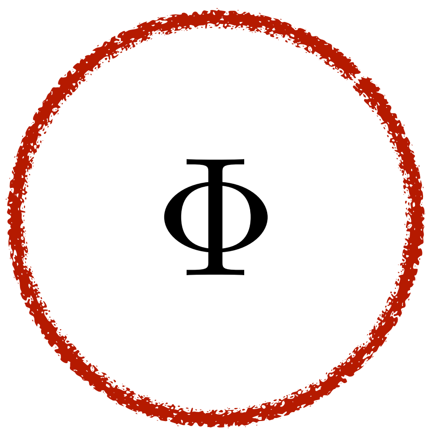
inflaton sector





Effective Field Theory

inflaton sector

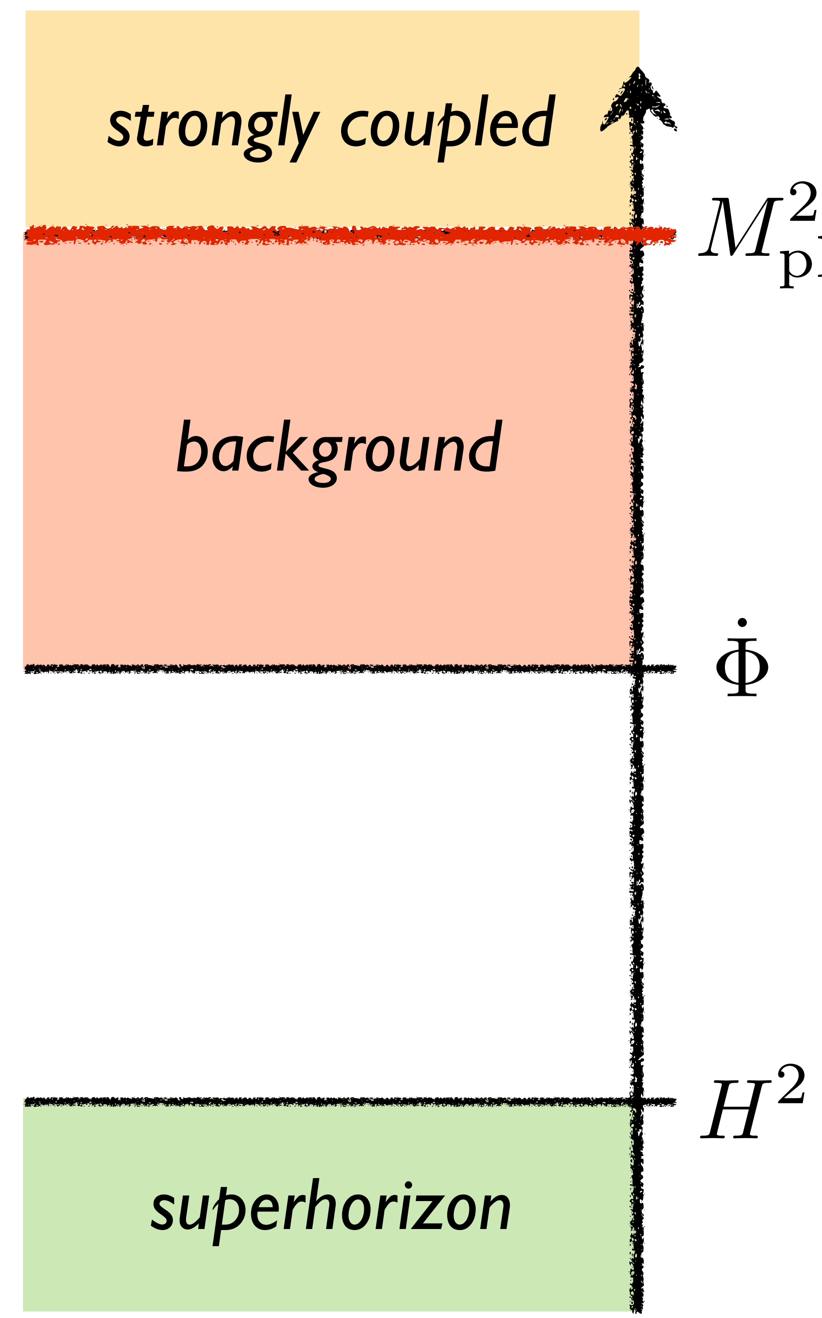


slow-roll inflation:

$$-\frac{1}{2}(\partial\Phi)^2 - V(\Phi)$$

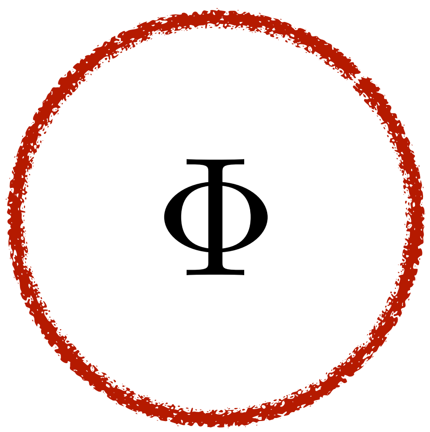
Interactions are constrained by the shift symmetry:

$$f_{\rm NL} \ll 1$$



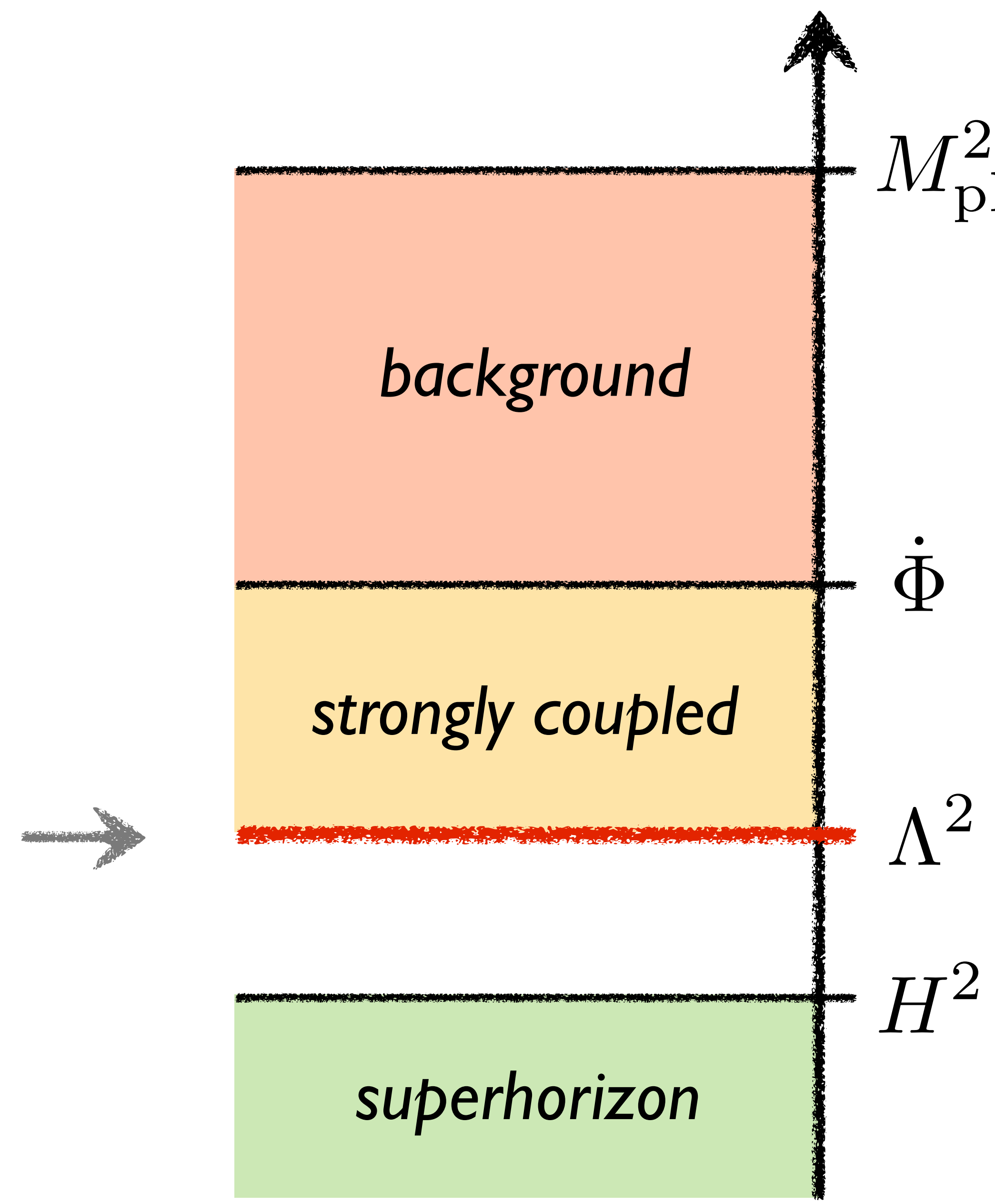
Effective Field Theory

inflaton sector



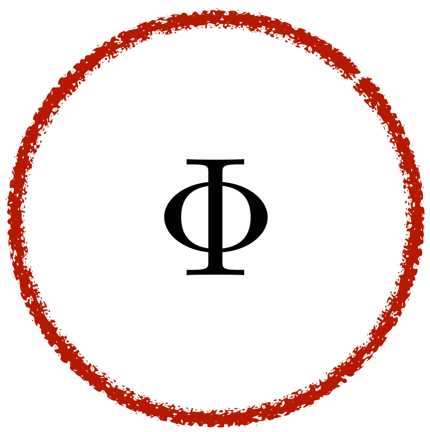
DBI inflation: $\frac{(\partial\Phi)^4}{\Lambda^4}$

Silverstein and Tong

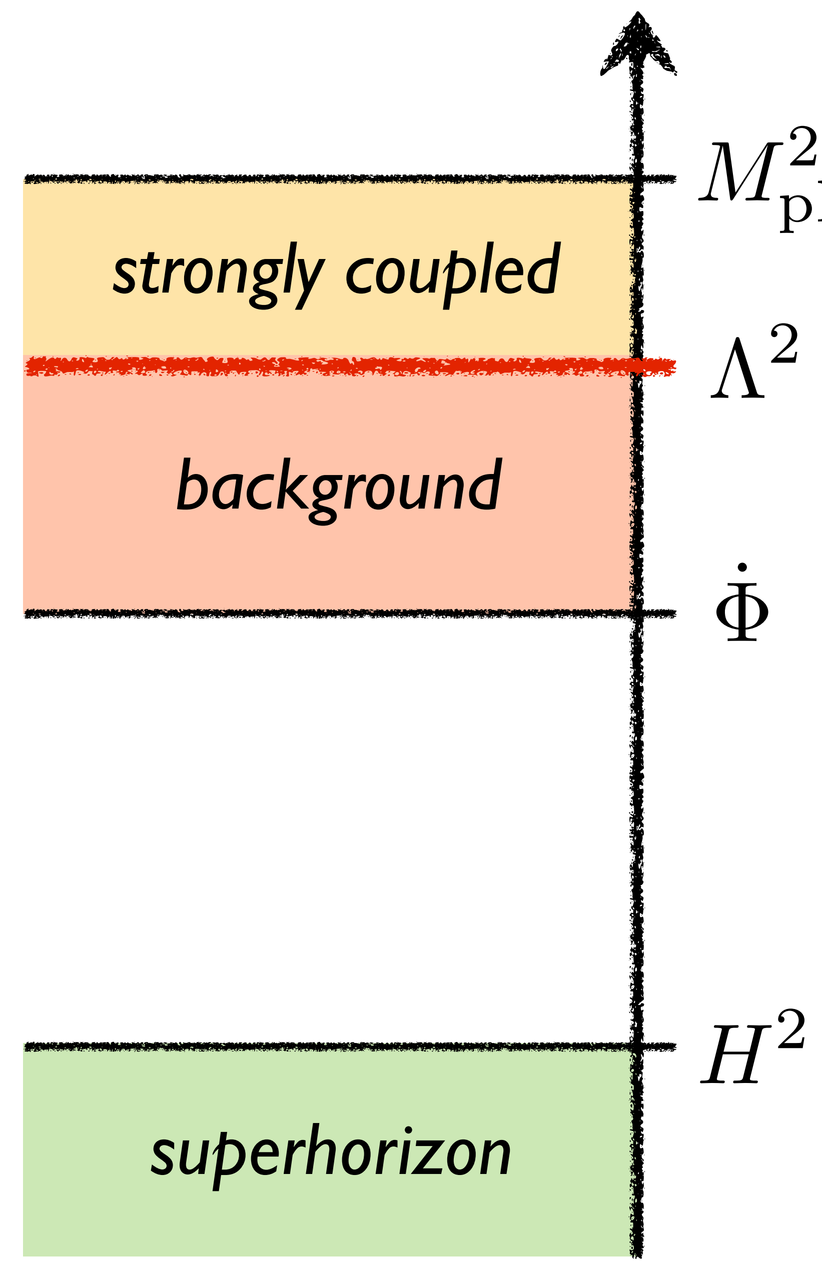


Effective Field Theory

inflaton sector

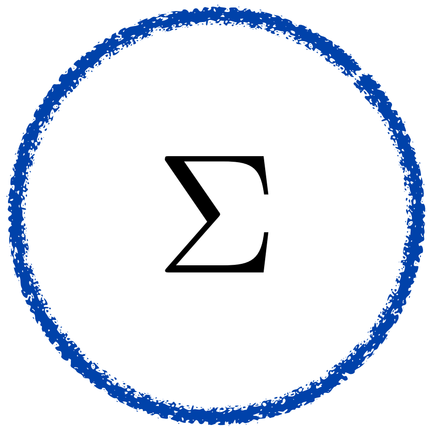


mixing with hidden sector: $\Sigma \rightarrow$



Effective Field Theory

hidden sector



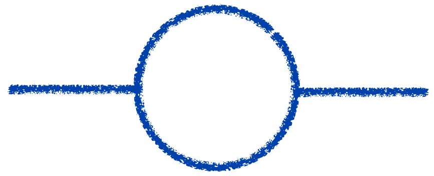
Interactions in the hidden sector
are much less constrained :

$$\mathcal{L}_\Sigma = -\frac{1}{2}(\partial\Sigma)^2 - m^2\Sigma^2 - A\Sigma^3 + \cdots$$

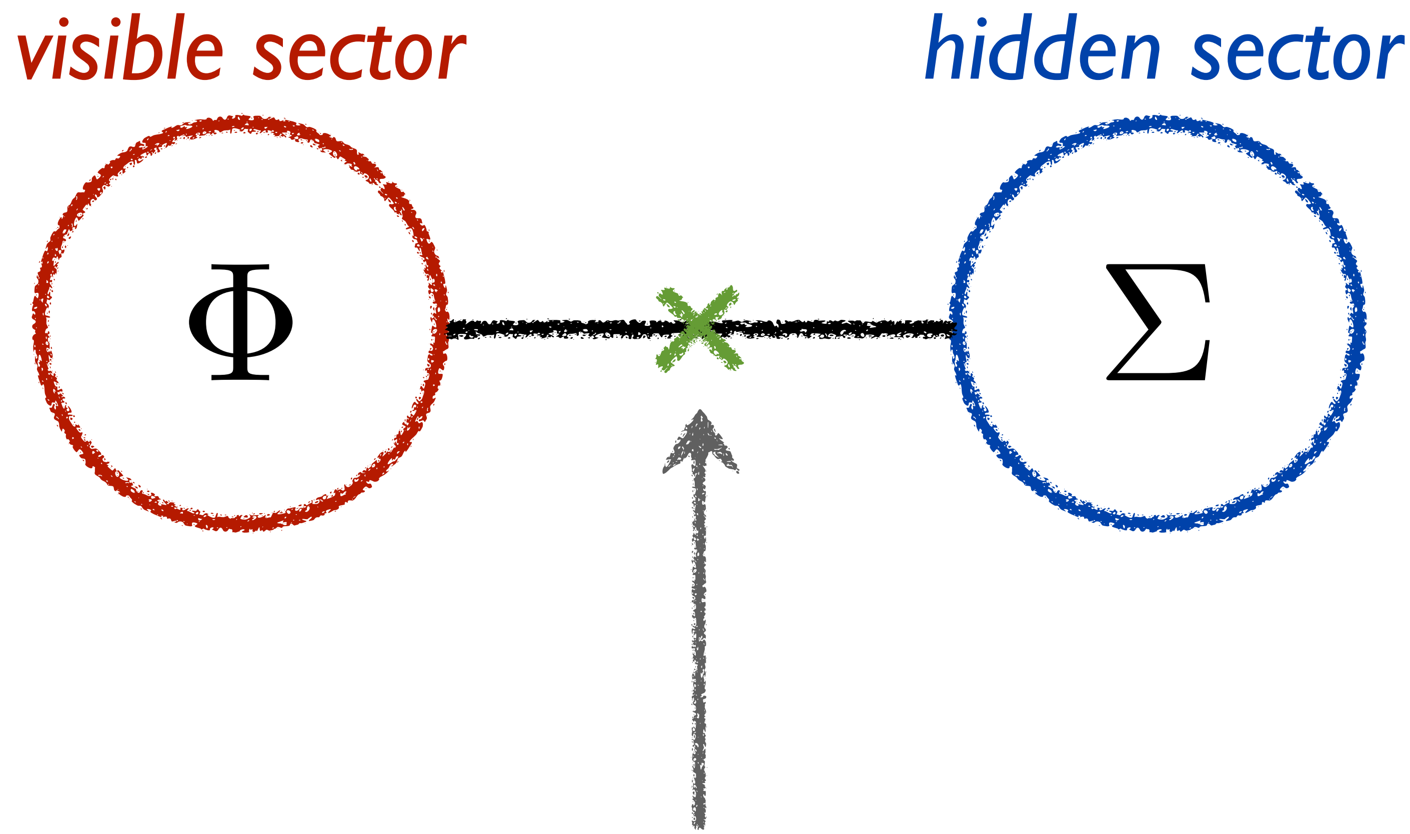
... and can naturally be large:

$$A \sim H$$

DB and Green

$\delta m^2 =$  $\sim A^2 \lesssim H^2$

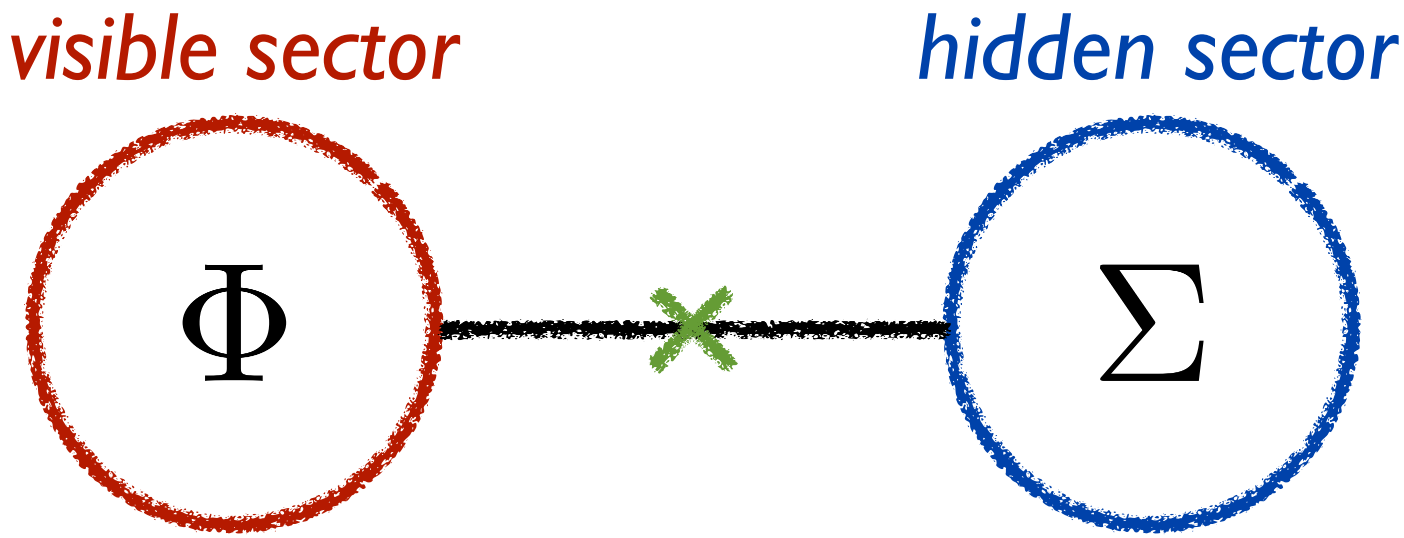
Effective Field Theory



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

Classify all couplings that preserve
the shift symmetry of the inflaton.

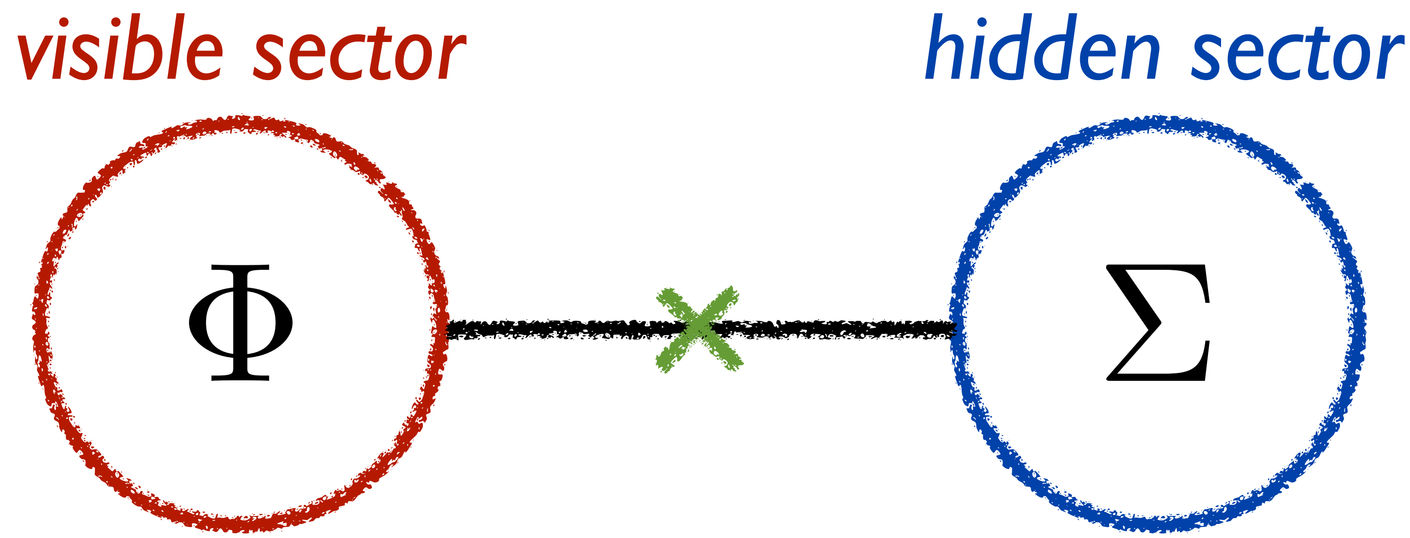
Effective Field Theory



dim-4: $\partial_\mu \Phi \partial^\mu \Sigma$

remove by a rotation in field space

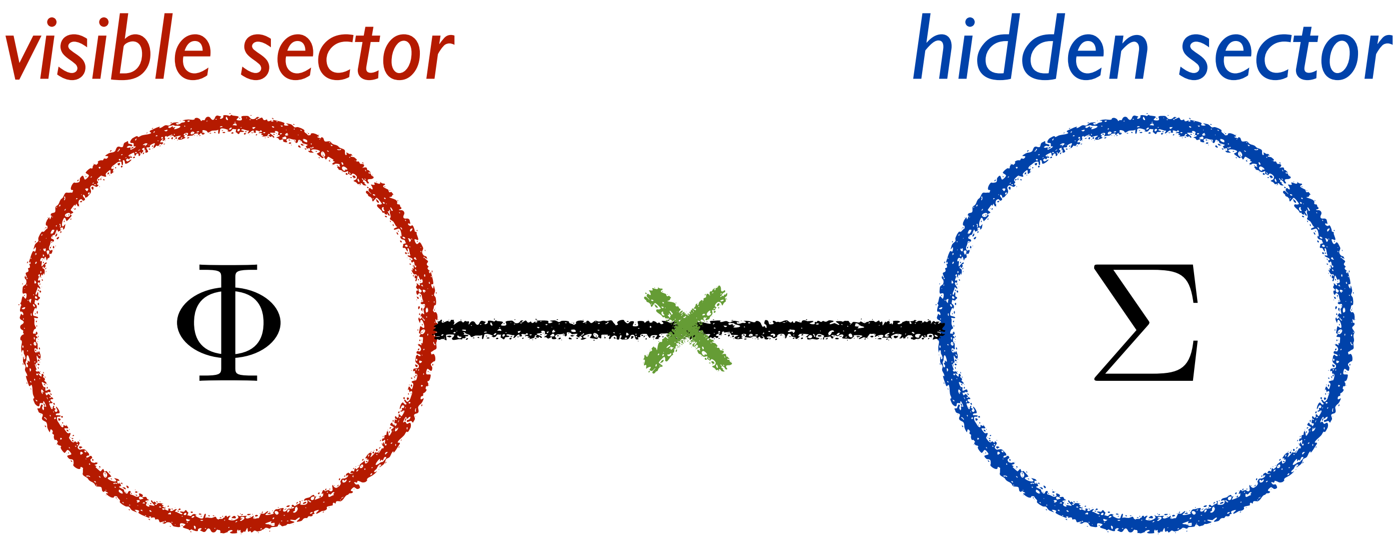
Effective Field Theory



dim-5: $$\frac{(\partial_\mu \Phi \partial^\mu \Sigma)\Sigma}{\Lambda} \mapsto -\frac{1}{2}\frac{\Box\Phi}{\Lambda}\Sigma^2$$

redundant operator

Effective Field Theory



field-dependent kinetic term

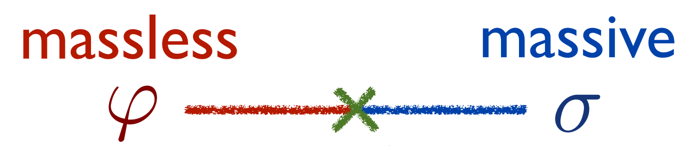
dim-5: $$\frac{(\partial_\mu \Phi \partial^\mu \Phi)\Sigma}{\Lambda}$$ dominant mixing

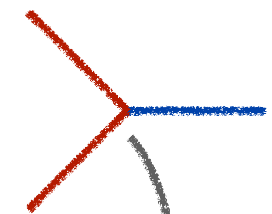
Use data to constrain the mixing scale.

Fluctuations

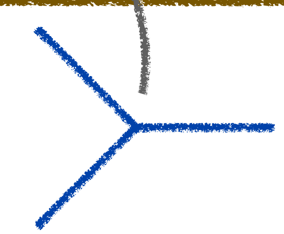
- Expand around background vev's:

$$\Phi(t,\vec{x}) = \Phi_0(t) + \varphi(t,\vec{x})$$
$$\Sigma(t,\vec{x}) = \Sigma_0 + \sigma(t,\vec{x})$$





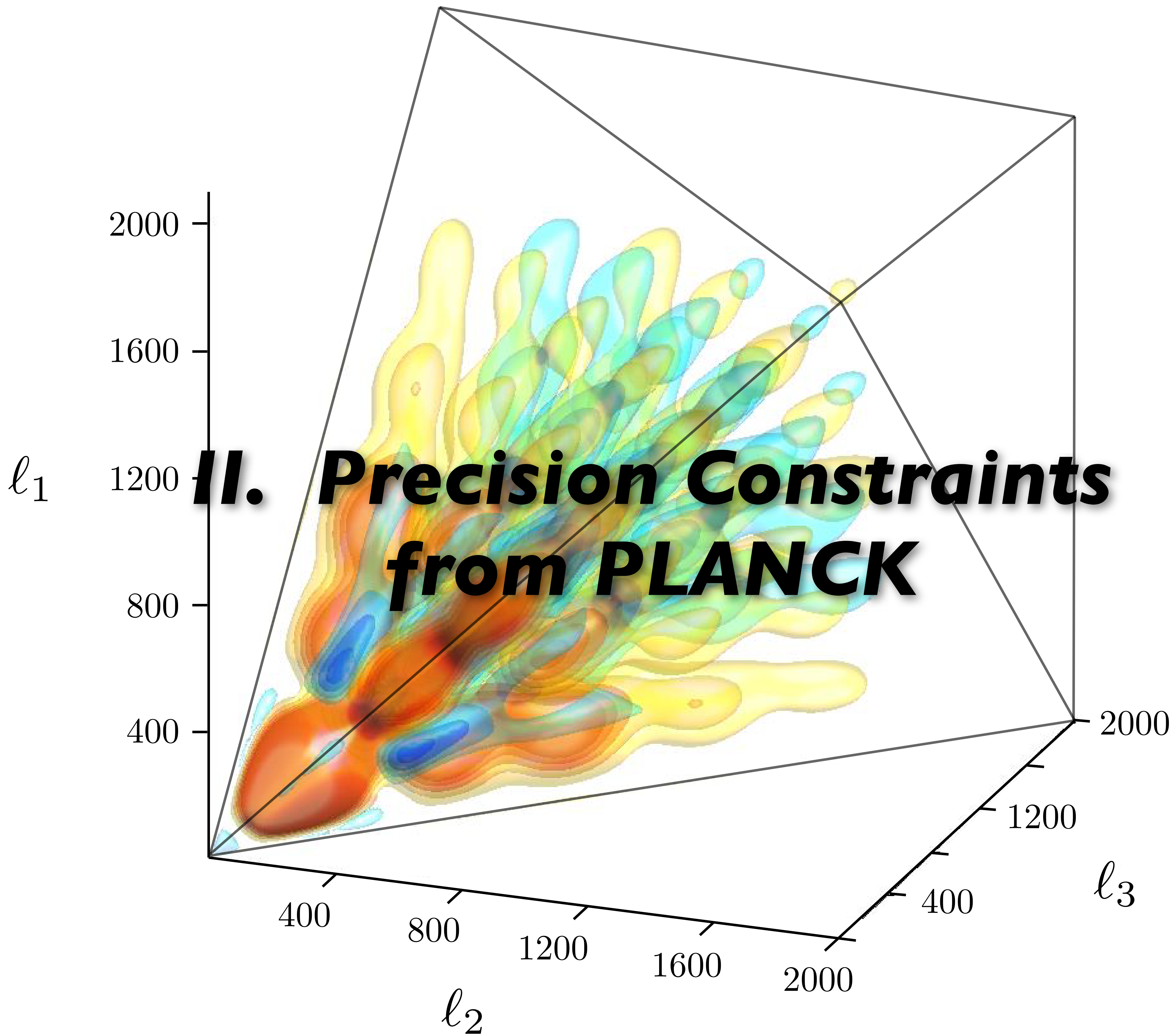
$$\mathcal{L}_\Phi + \mathcal{L}_\Sigma + \mathcal{L}_{\rm mix} = -\frac{1}{2}(\partial\varphi)^2 + \frac{\dot{\Phi}_0}{\Lambda}\dot{\varphi}\sigma - \frac{1}{2}\frac{(\partial\varphi)^2\sigma}{\Lambda}$$
$$-\frac{1}{2}(\partial\sigma)^2 - m^2\sigma^2 - A\,\sigma^3$$



- Solve numerically.

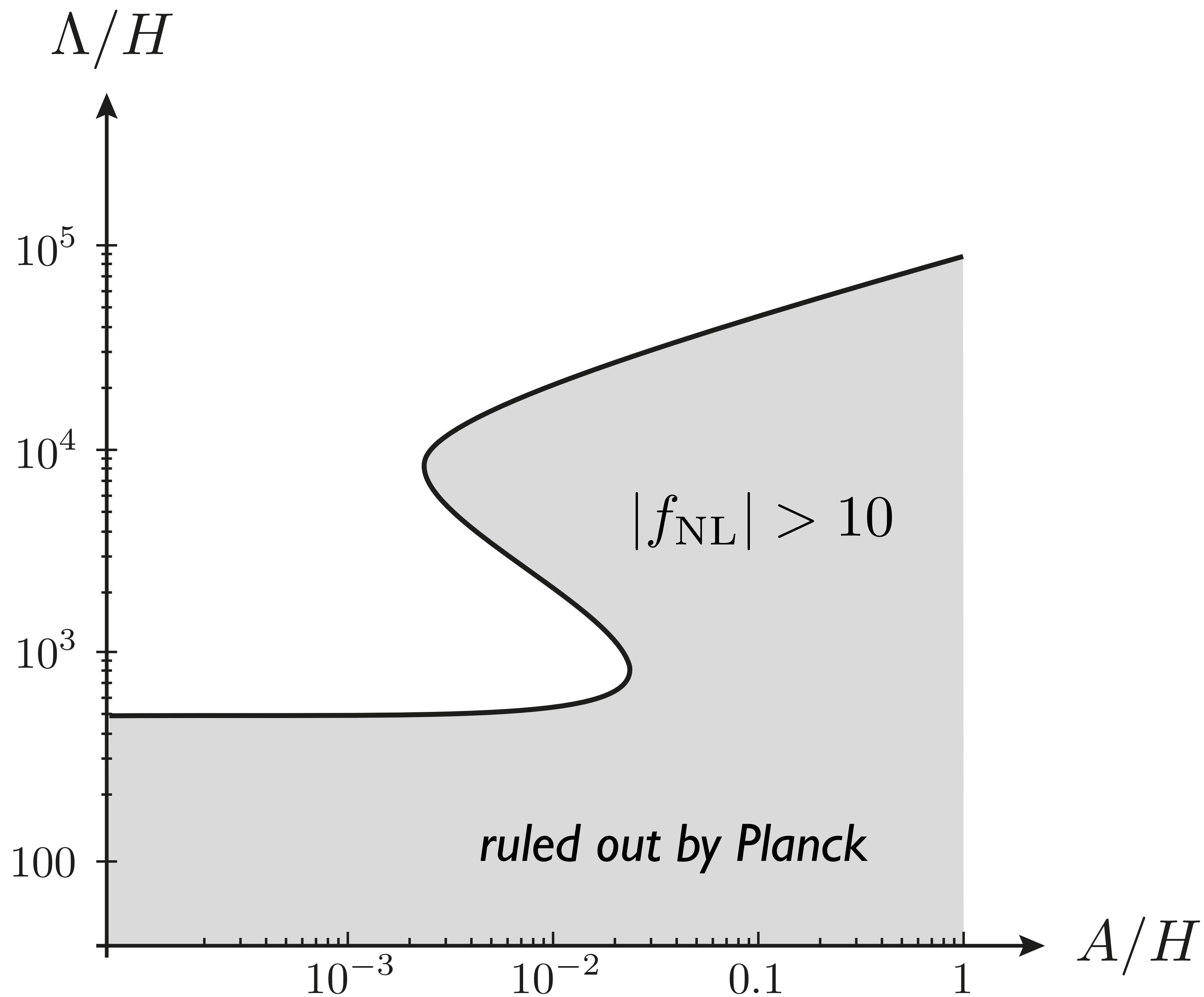
Assassi, DB, Green and McAllister

II. Precision Constraints from PLANCK



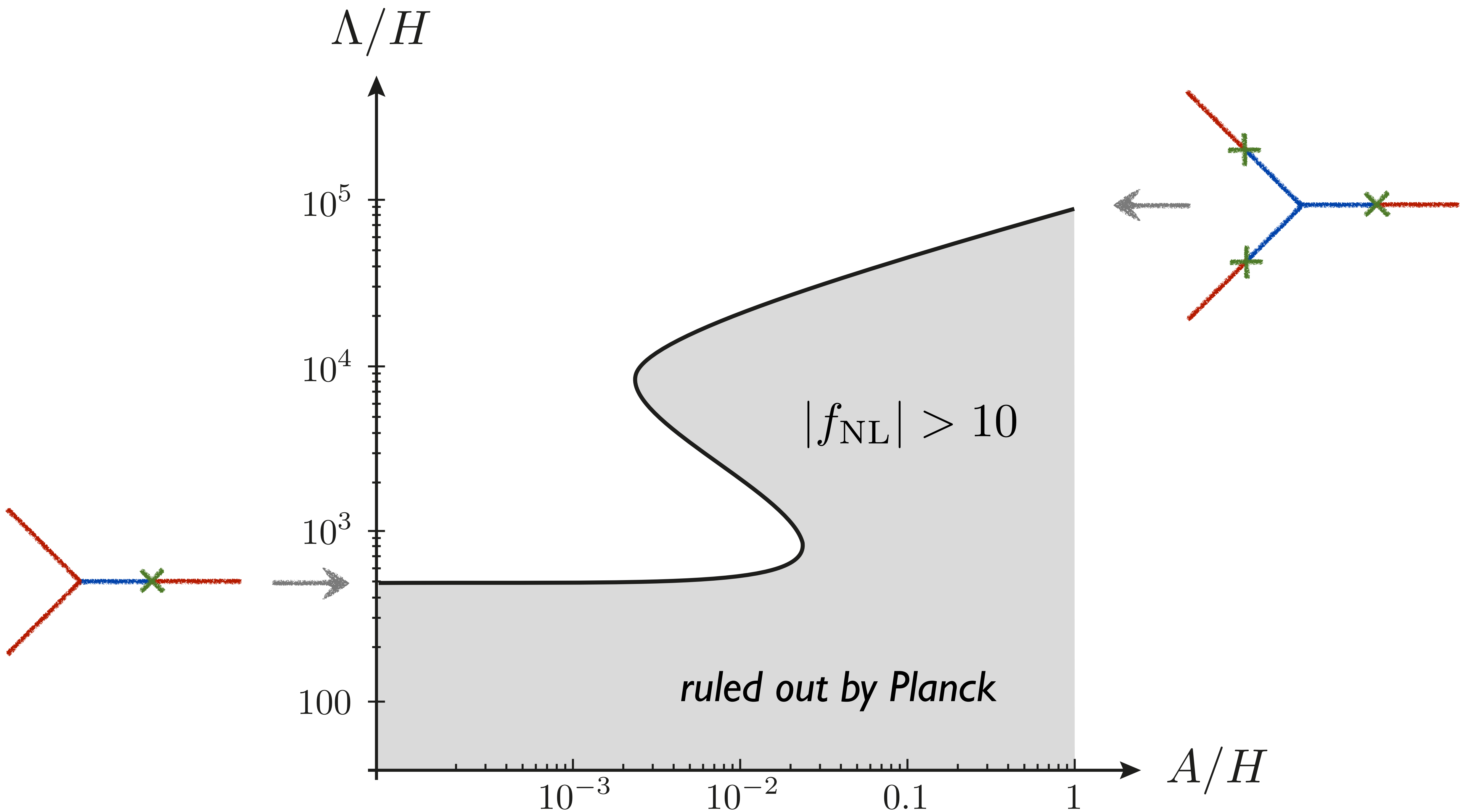
Precision Constraints

Assassi, DB, Green and McAllister



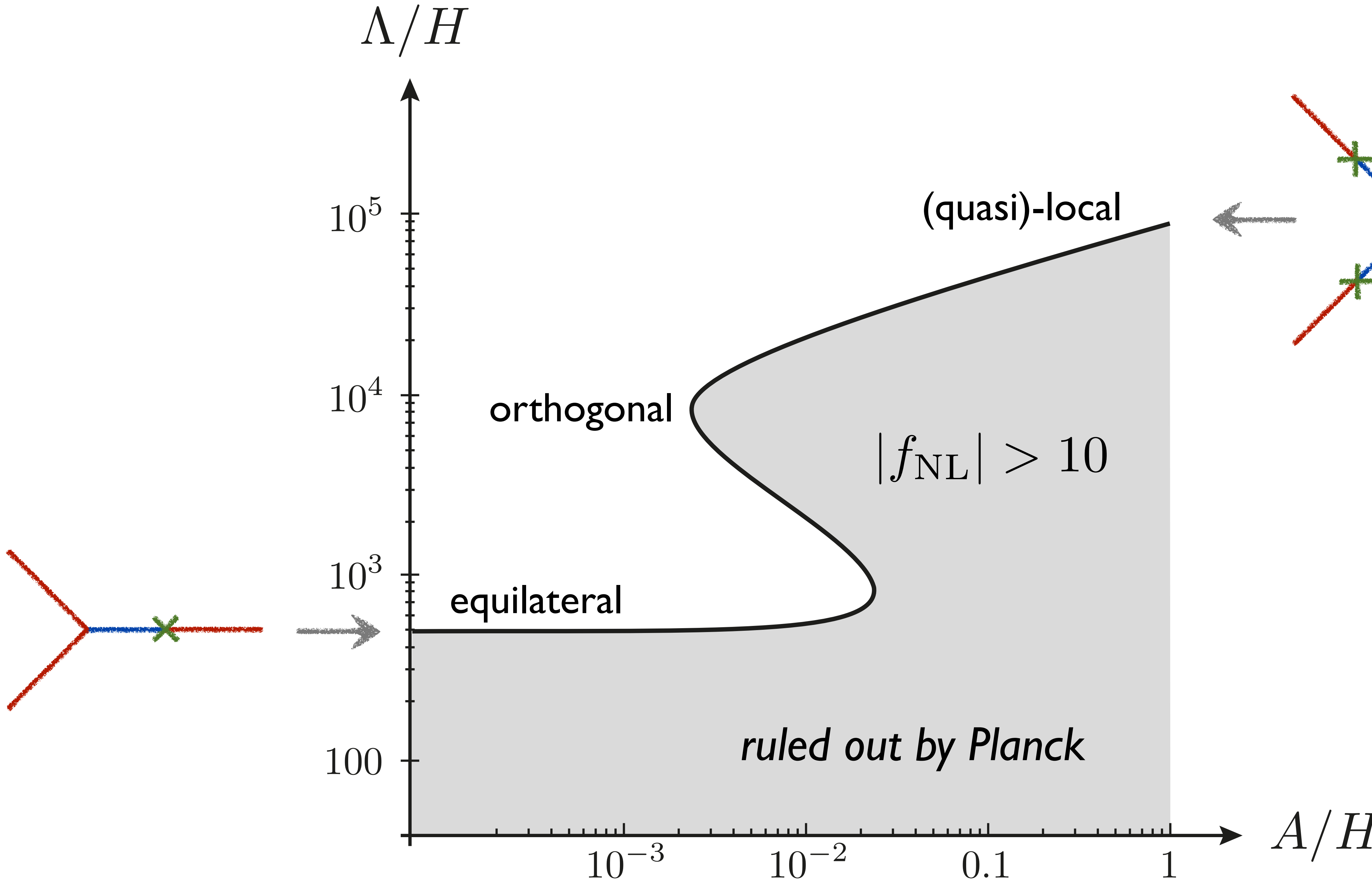
Precision Constraints

Assassi, DB, Green and McAllister



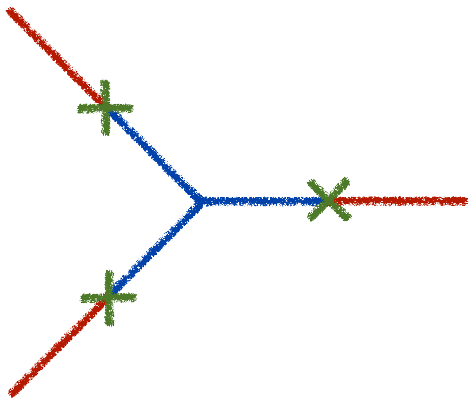
Precision Constraints

Assassi, DB, Green and McAllister



Precision Constraints

Assassi, DB, Green and McAllister



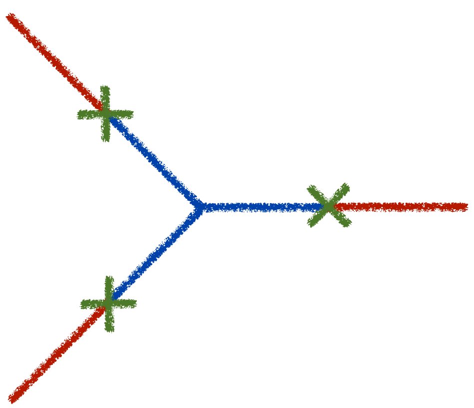
perturbative calculation

$$f_{\rm NL} \sim \frac{1}{\Delta_\zeta}\left(\frac{A}{H}\right)\left(\frac{\dot{\Phi}_0}{\Lambda H}\right)^3$$

Chen and Wang

Precision Constraints

Assassi, DB, Green and McAllister



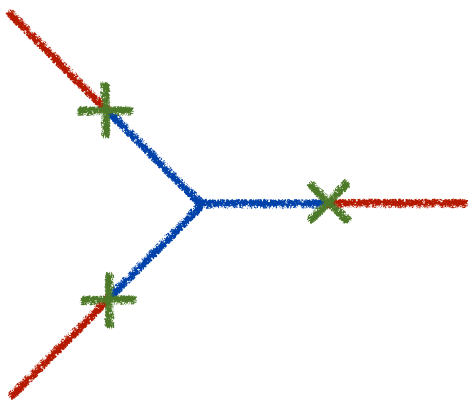
perturbative calculation *PLANCK constraints*

$$f_{\rm NL} \sim \frac{1}{\Delta_\zeta}\left(\frac{A}{H}\right)\left(\frac{\dot{\Phi}_0}{\Lambda H}\right)^3 \quad \lesssim \; 10$$

Chen and Wang

Precision Constraints

Assassi, DB, Green and McAllister



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$$f_{\rm NL} \sim \frac{1}{\Delta_\zeta}\left(\frac{A}{H}\right)\left(\frac{\dot{\Phi}_0}{\Lambda H}\right)^3 \lesssim 10$$

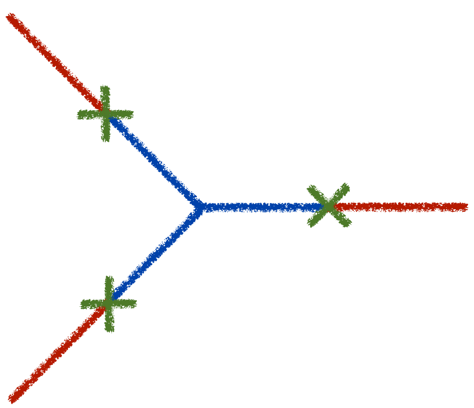
Chen and Wang

bound

$$\Lambda \gtrsim 0.4 \times 10^5 \left(\frac{A}{H}\right)^{1/3} H$$

Precision Constraints

Assassi, DB, Green and McAllister



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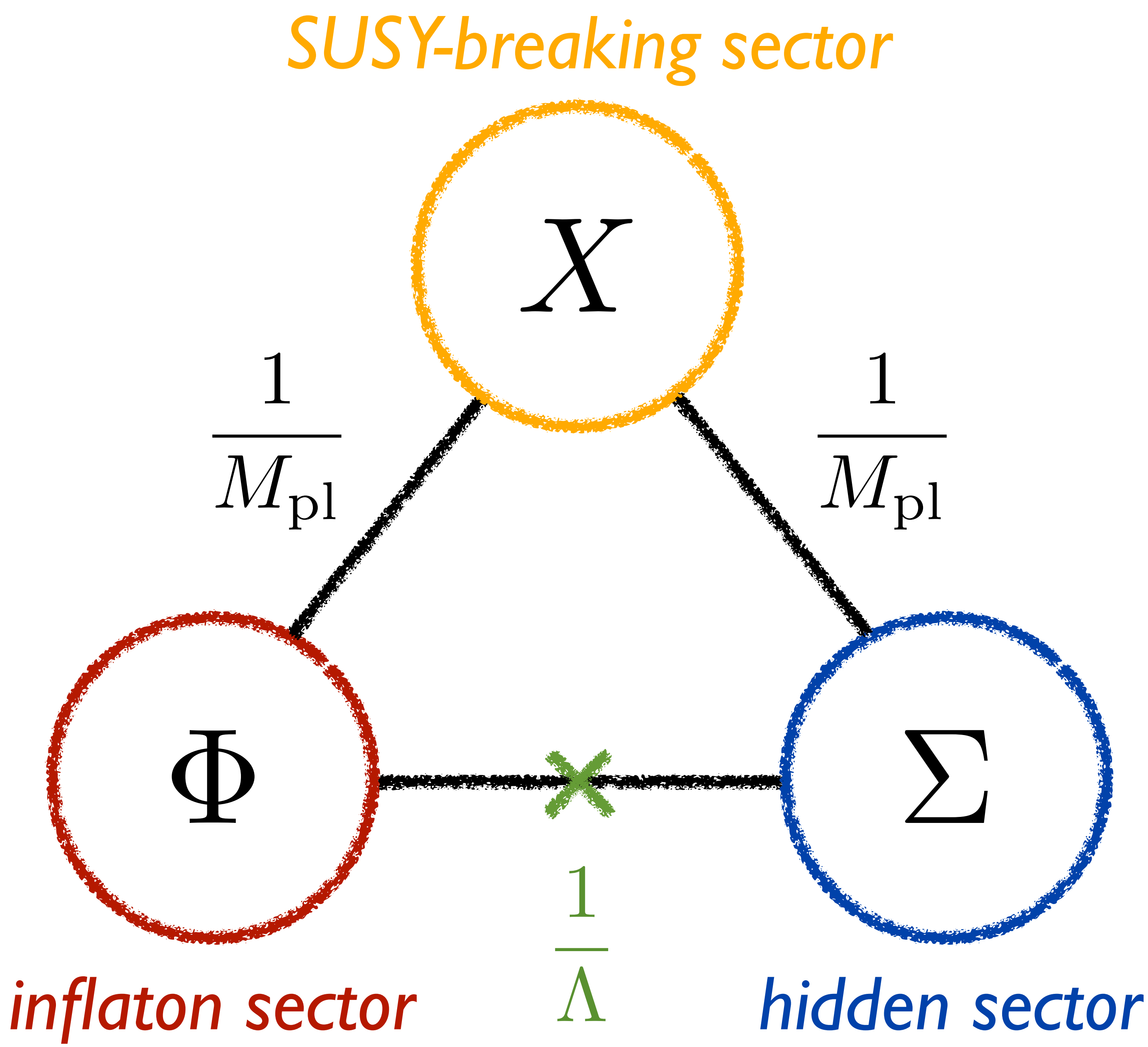
Chen and Wang

bound

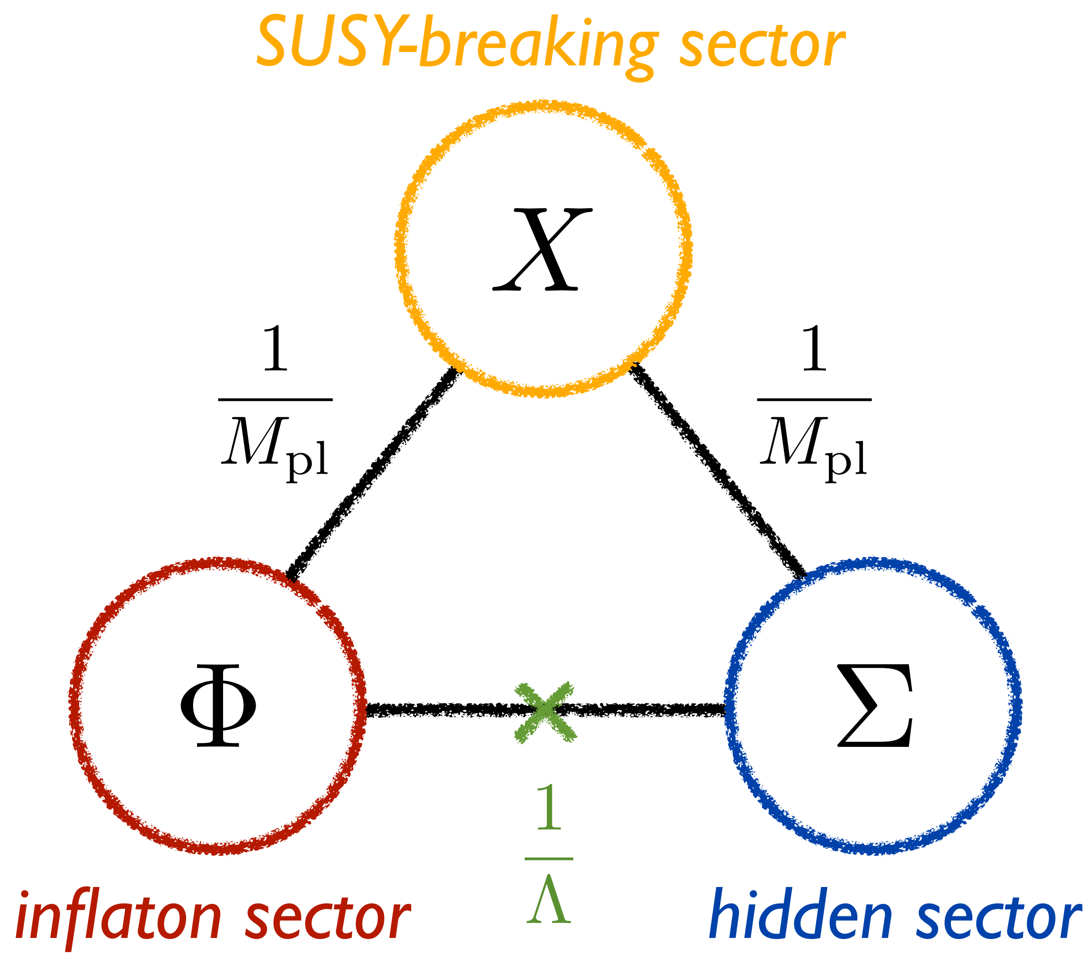
$$\Lambda \gtrsim 0.4 \times 10^5 \left(\frac{A}{H}\right)^{1/3} H$$

What is the natural size of the cubic coupling?

Supersymmetry Breaking

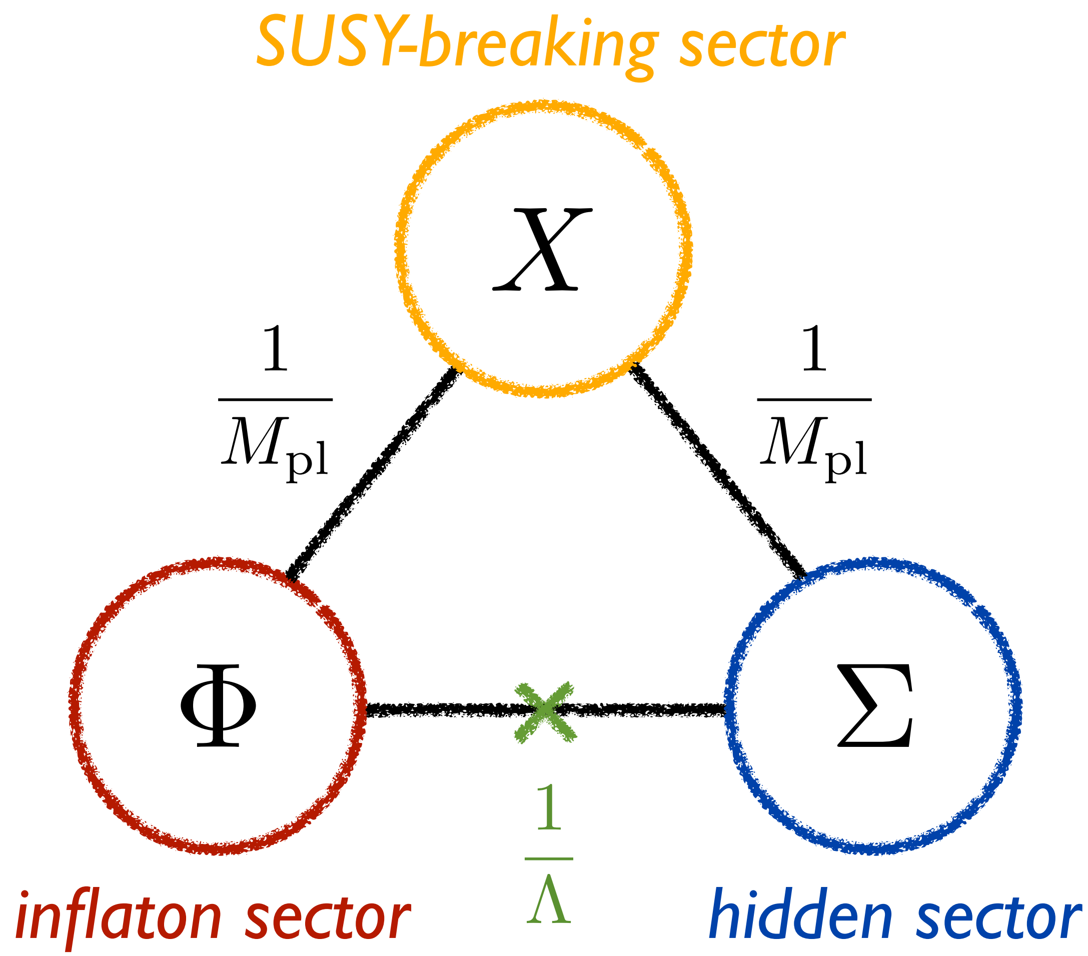


Supersymmetry Breaking



$$|F_X|^2 = V(\Phi) \approx M_{\rm pl}^2 H^2$$

Supersymmetry Breaking



$$|F_X|^2 = V(\Phi) \approx M_{\rm pl}^2 H^2$$

$$m_\Sigma = \frac{F_X}{M_{\rm pl}} \approx H \qquad A_\Sigma \approx H^{\,*}$$

* *unless SUSY-breaking is sequestered:*

$$A_\Sigma \approx \frac{H^2}{M_{\rm pl}} \ll H$$

Planck-Suppressed Operators

Our bound can be expressed in terms of the Planck scale:

$$\Lambda \gtrsim 0.5 \left(\frac{A}{H}\right)^{1/3} \left(\frac{r}{0.01}\right)^{1/2} M_{\rm pl}$$

Assassi, DB, Green and McAllister

tensor-to-scalar ratio

If gravity waves are observed, then this is a strong constraint on Planck-suppressed operators.

Generalizations

- higher-dimensional scalar operators: $$\frac{(\partial\Phi)^2\mathcal{O}_\Delta}{\Lambda^\Delta} \longrightarrow \Lambda \gtrsim (10^5)^{1/\Delta}\, H$$

  Green et al.

- gauge fields: $$\frac{\Phi F\tilde{F}}{\Lambda} \longrightarrow \Lambda \gtrsim 10^4\, H$$

  Barnaby and Peloso

Conclusions

- String theory strongly motivates considering scenarios with many light fields: $m \sim H$

- The couplings of these fields to the inflaton are strongly constrained by the PLANCK data:

$$\Lambda > 10^5 H > \sqrt{\frac{r}{0.01}} M_{\rm pl}$$


Danke für Ihre
Aufmerksamkeit !
Hope to see you in Cambridge for
COSMO 2013
2-6 September