AHMEDABAD UNIVERSITY

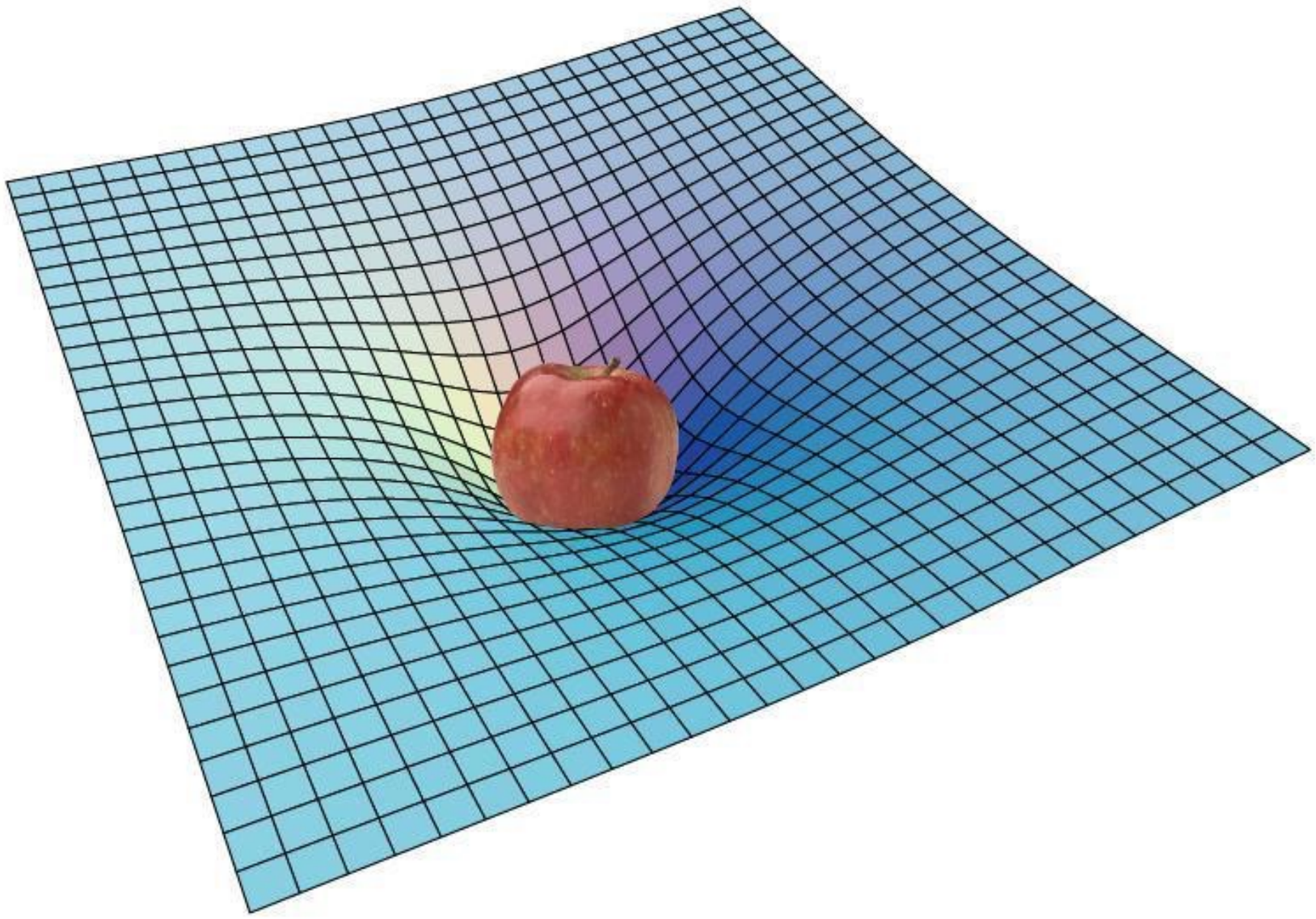
Extranatural Inflation Redux

Gaurav Goswami
Ahmedabad University

PHYSICAL REVIEW D 96, 083529 (2017),
arXiv:1705.11071

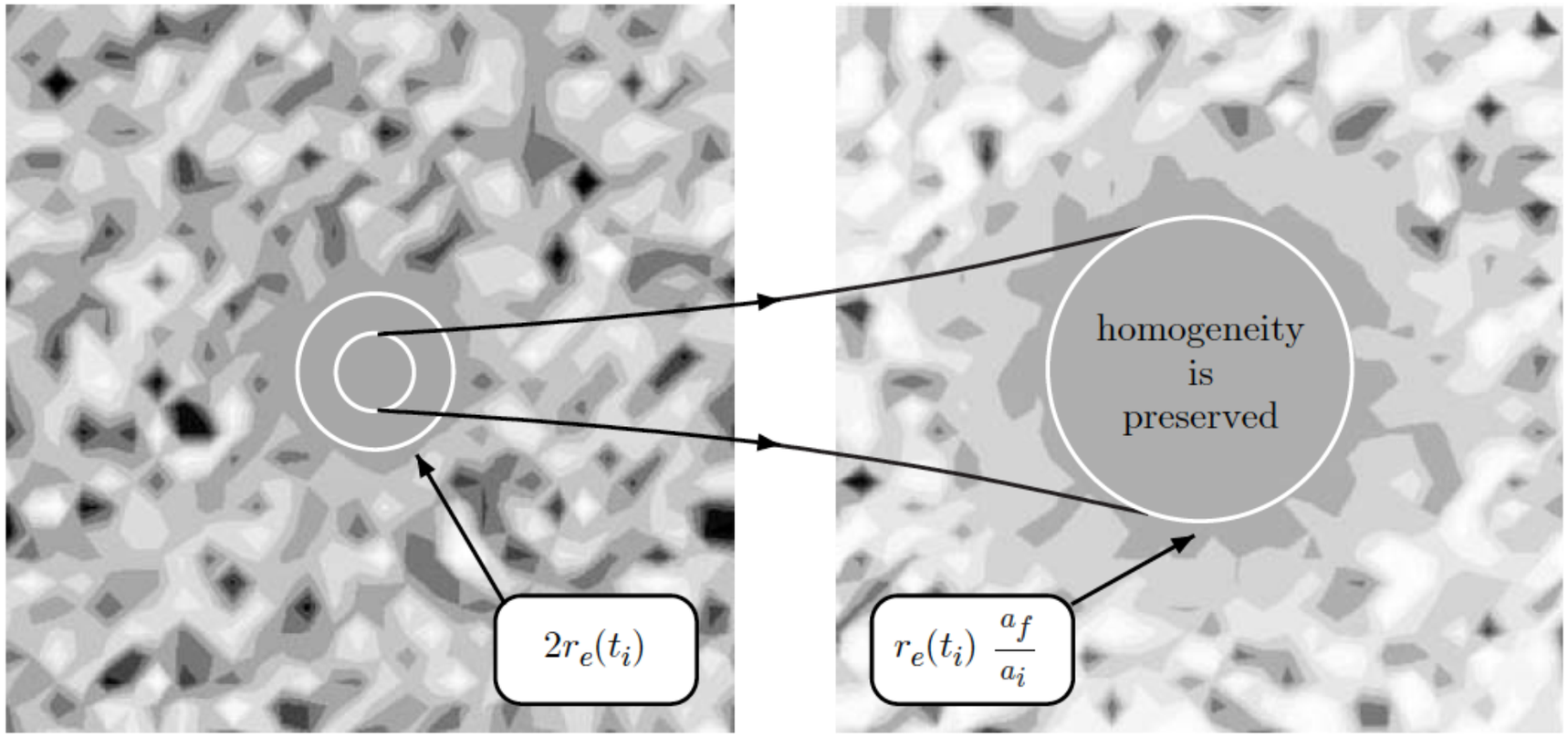
In collaboration with:
Mansi Dhuria (IIT-B, Mumbai)
Jayanti Prasad (IUCAA, Pune)

Why this geometry?

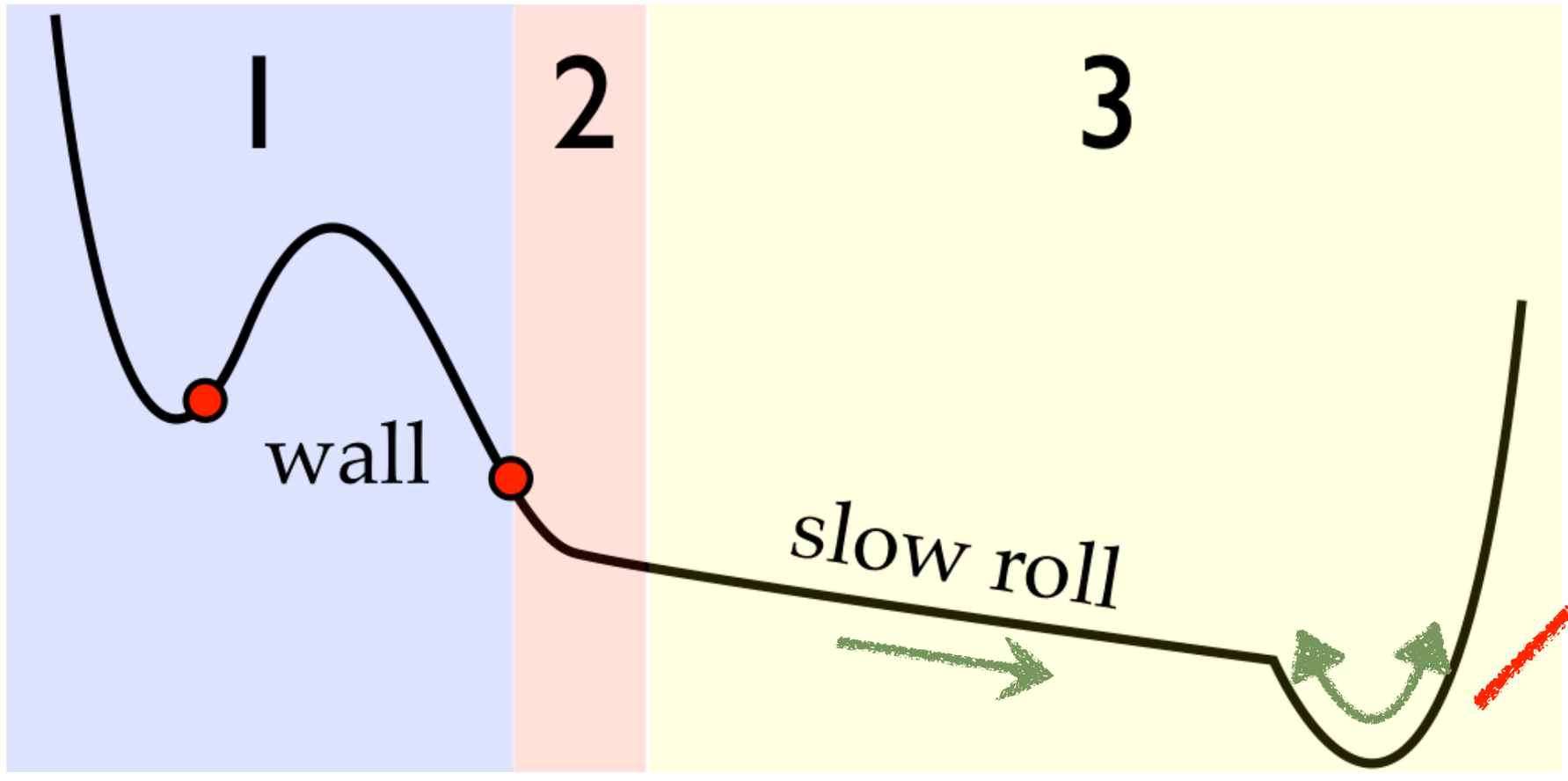


Why do we find ourselves in a spatially flat FRW (homogeneous and isotropic) spacetime?

Cosmic inflation

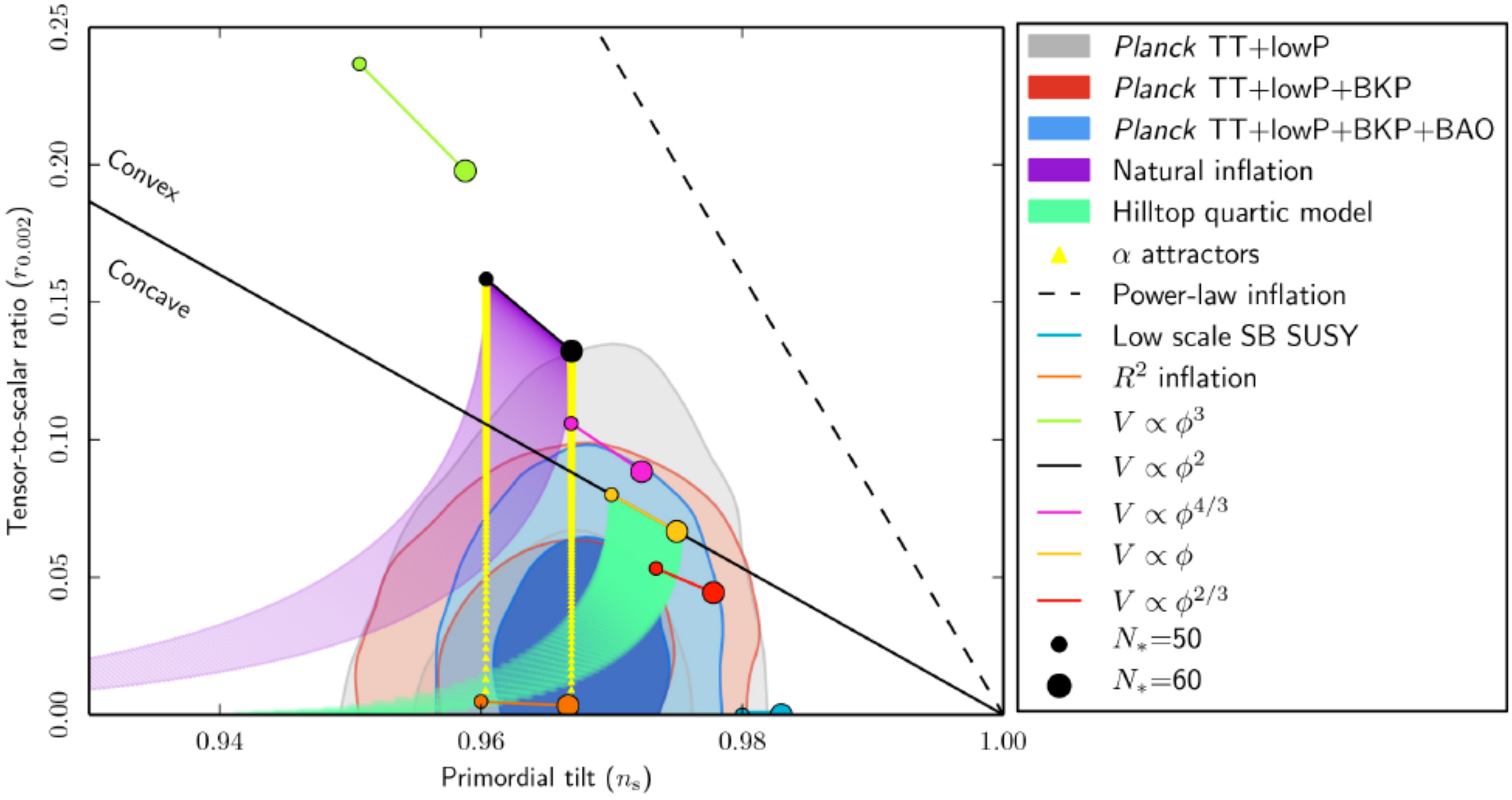


Additionally:
mostly Adiabatic, mostly Gaussian, perturbations with nearly scale invariant power spectrum.



Hot
Big Bang!

Large field inflation



UV sensitivity…

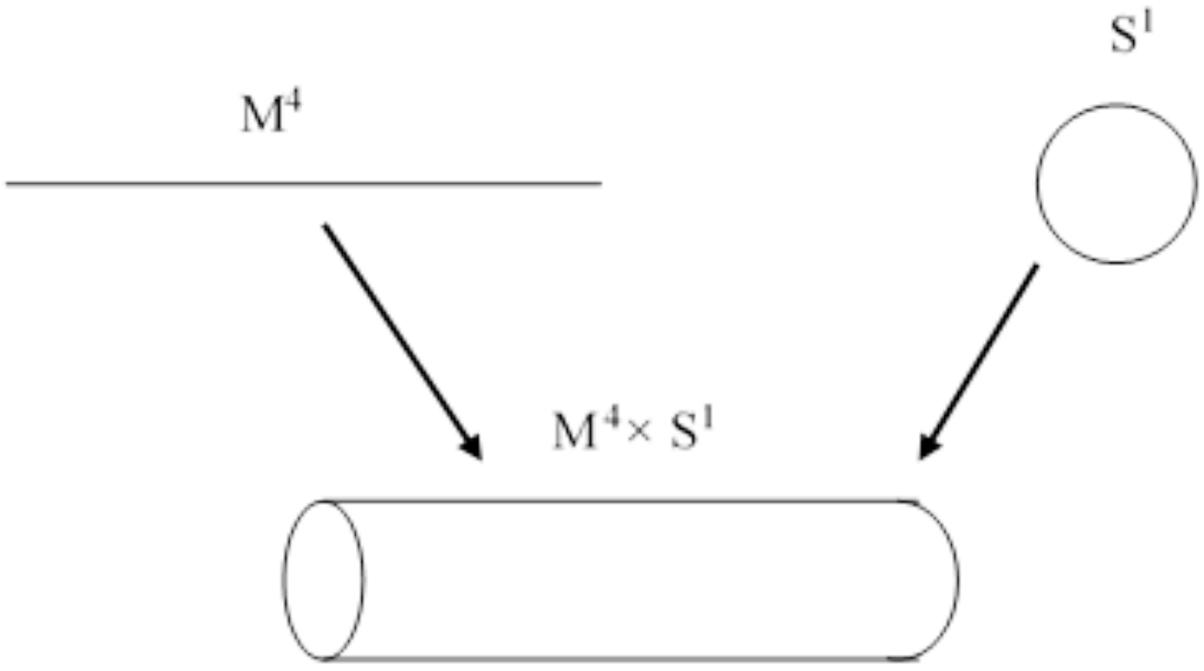
(+4290)
+
(-467321894371289463728197 8923)
+
(+47583920542)
+
(+7458392157829013278190547825)
+
(-321)
+
… (UNKNOWN, BUT LARGE CONTRIBUTIONS)
=
ORDER (1) NUMBER!

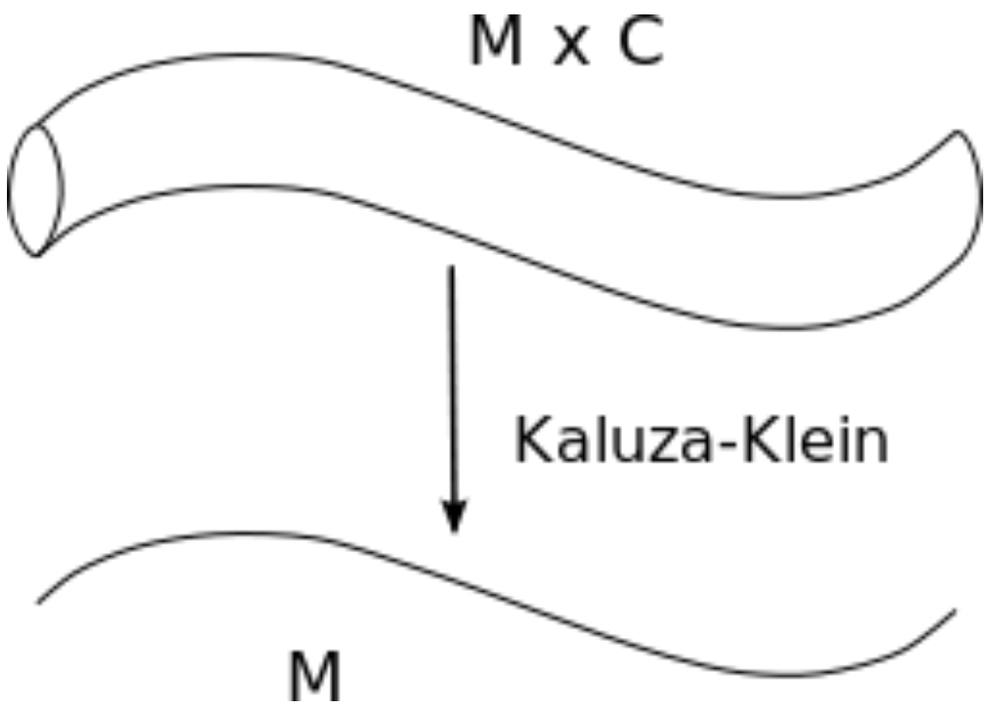
…possible but extremely peculiar!

E.g. vacuum energy, Higgs mass, flatness of inflaton potential.

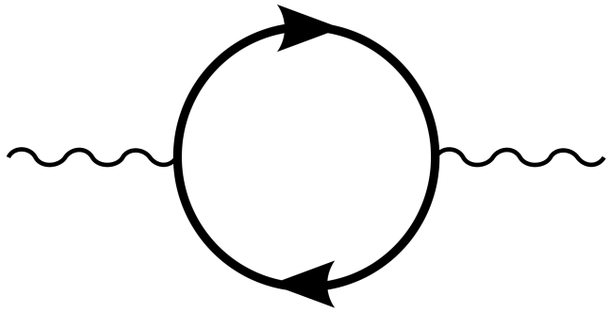
Extranatural Inflation…

- Resolves UV sensitivity (at the level of QFT),
- Makes use of gauge symmetry (and not global symmetry) and extra dimensions,
- Inflaton candidate is 4D scalar.





Extranatural Inflation…



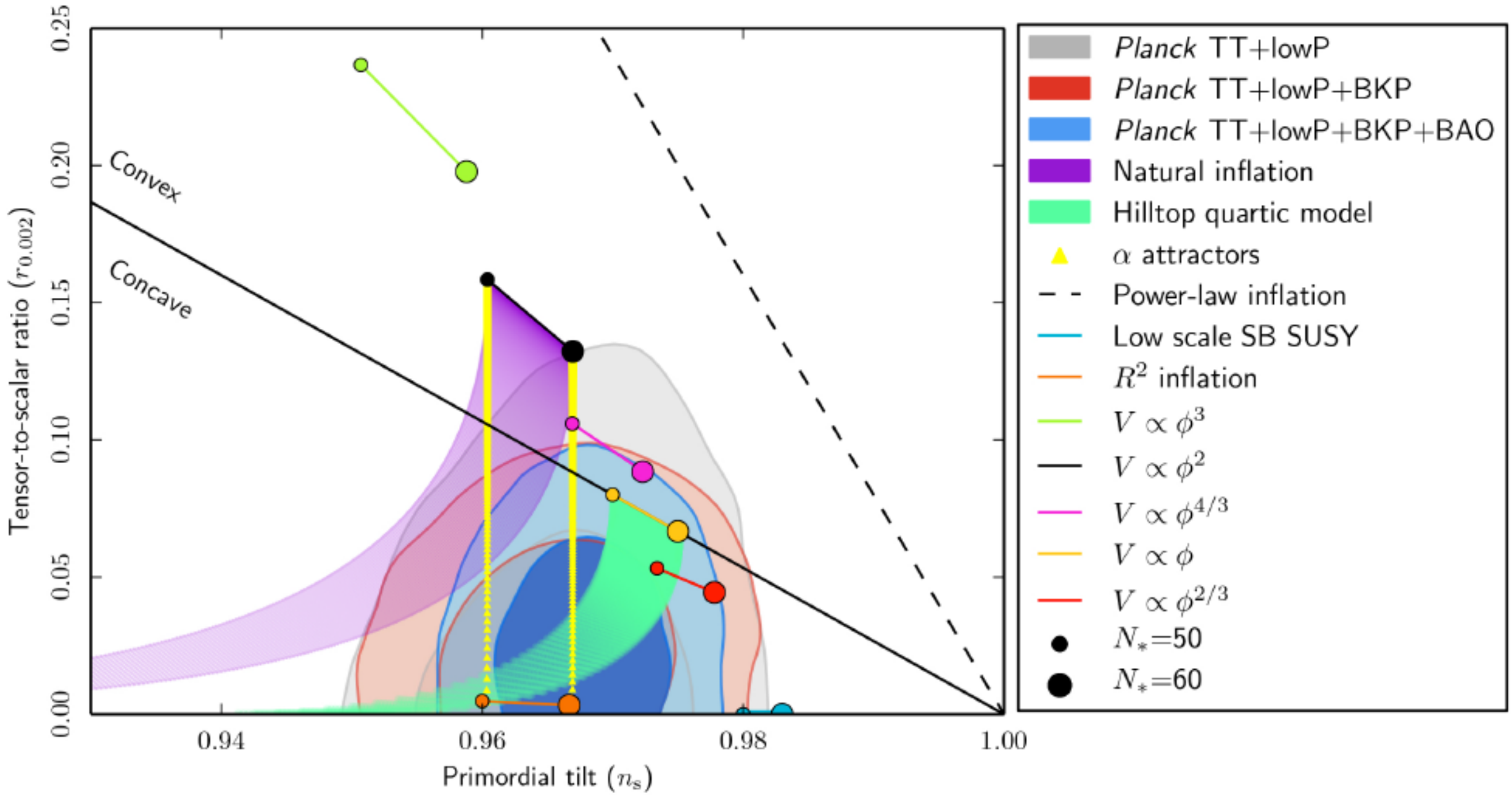
$$V(\theta) = \pm \frac{3}{64\pi^6 R^4} \sum_{n=1}^{\infty} \frac{\cos(nQ_a\theta)}{n^5} \ .$$

Noteworthy…

- No potential at tree level,
- Potential generated because of
  - loop corrections (bulk matter),
  - compactification of the 5th dimension,
- field dependent part of the potential is UV finite!
- the potential is “protected” from unknown heavy physics.

N. Arkani-Hamed, H. C. Cheng, P. Creminelli, and L. Randall, “*Extra Natural Inflation*”, Phys. Rev. Lett. 90, 221302 (2003).

$$f = \frac{1}{2\pi R g_4} \qquad g_4 \ll 1 \implies f > M_p \ , \qquad f > M_p \implies \Delta\phi > M_p \ .$$



Extranatural Inflation Redux

Can we use CMB observations to constrain light bulk matter?

$$V(\phi) = \frac{3}{64\pi^6 R^4}\left\{\sum_{n=1}^{\infty}\frac{1}{n^5}\cos\left(\frac{n\phi}{f}\right) + \mathcal{N}\sum_{n=1}^{\infty}\frac{1}{n^5}\cos\left(\frac{nQ\phi}{f}\right) + C\right\}.$$

$\mathcal{N}, R, f, Q$

$$f = \frac{1}{2\pi R g_4}$$

Mansi Dhuria, Gaurav Goswami and Jayanti Prasad, "*Extra Natural Inflation Redux*", Phys. Rev. D 96, 083529 (2017), arXiv:1705.11071.

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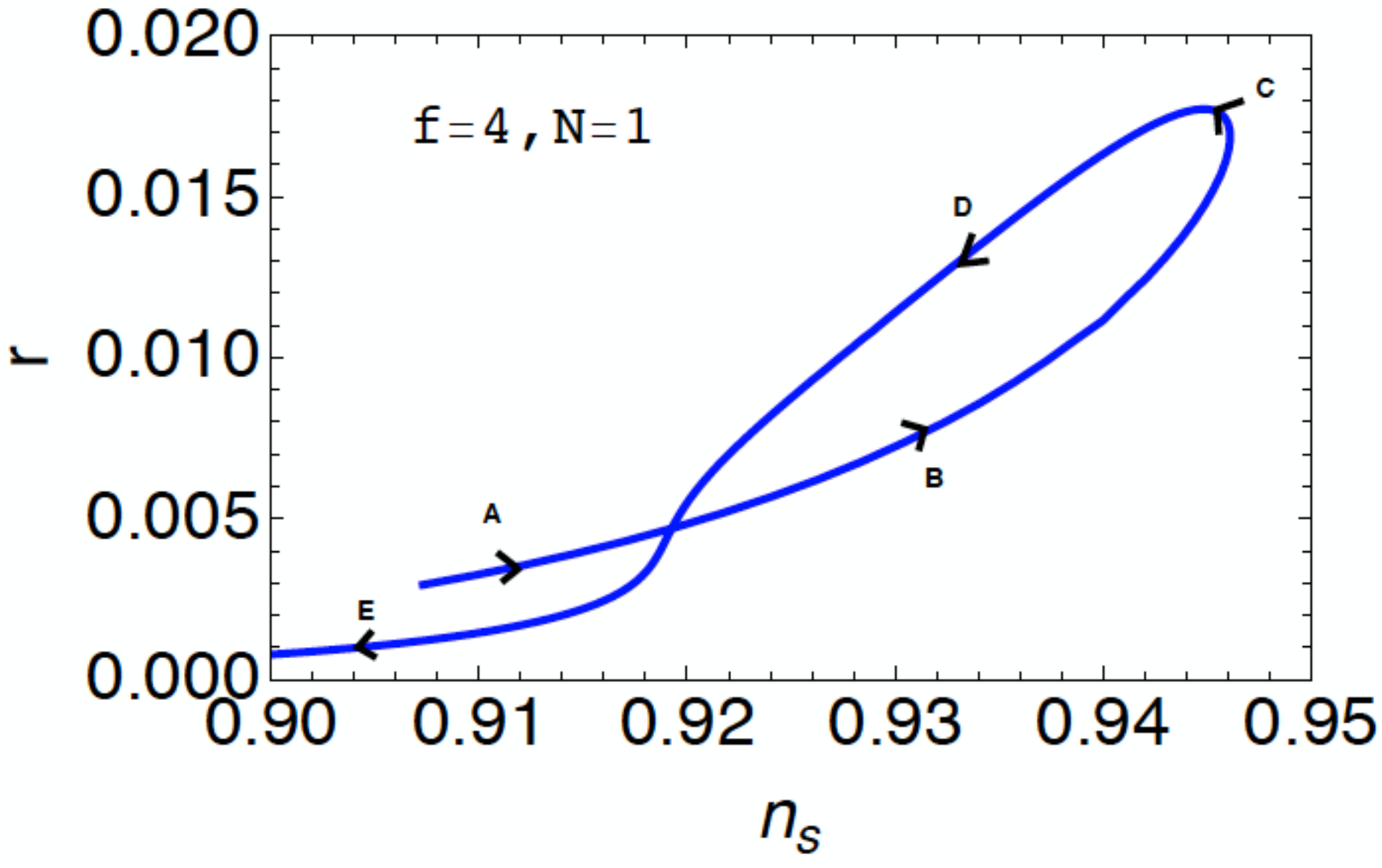

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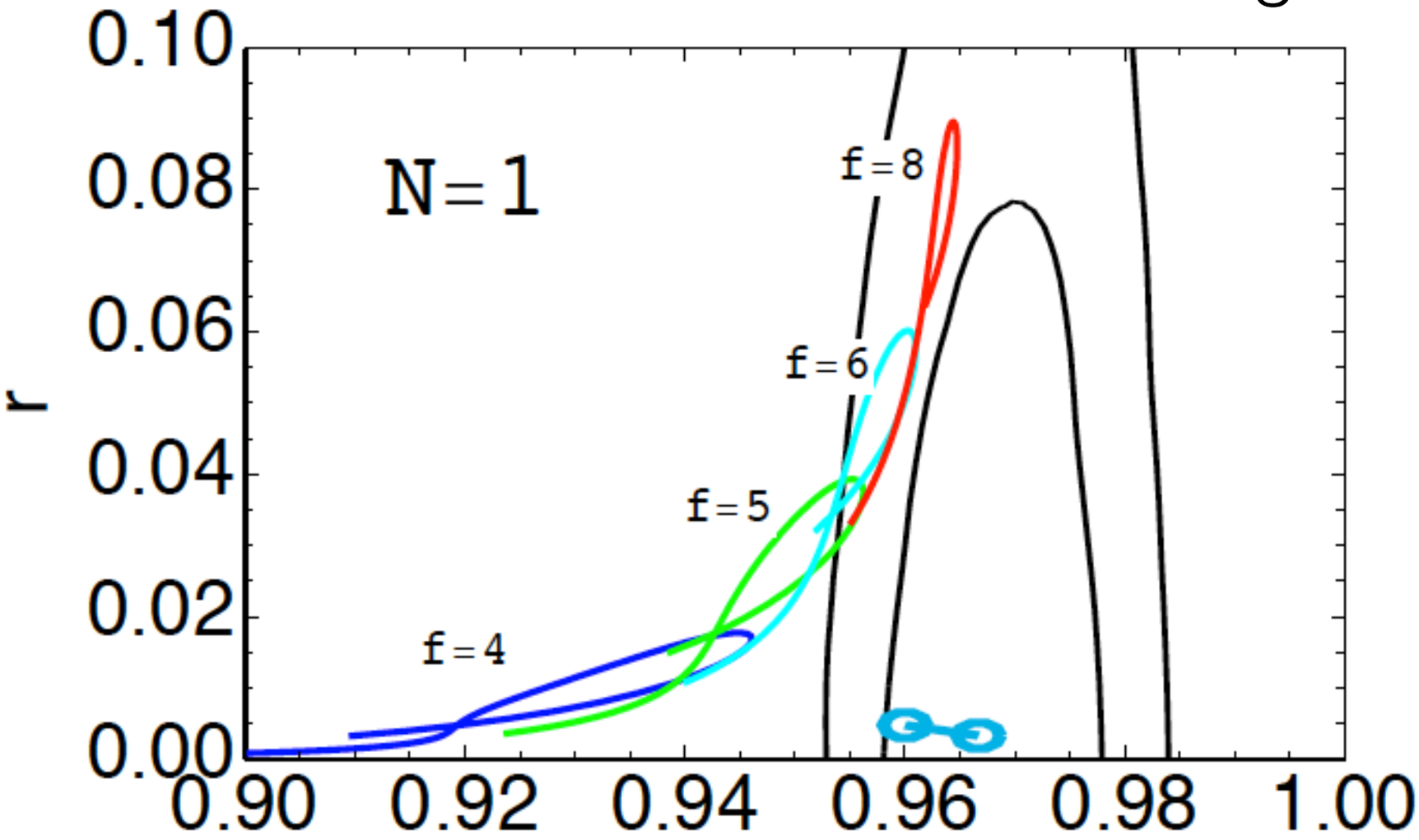

N=1 DOESN'T WORK!

Mansi Dhuria, Gaurav Goswami and Jayanti Prasad, "*Extra Natural Inflation Redux*", Phys. Rev. D 96, 083529 (2017), arXiv:1705.11071.

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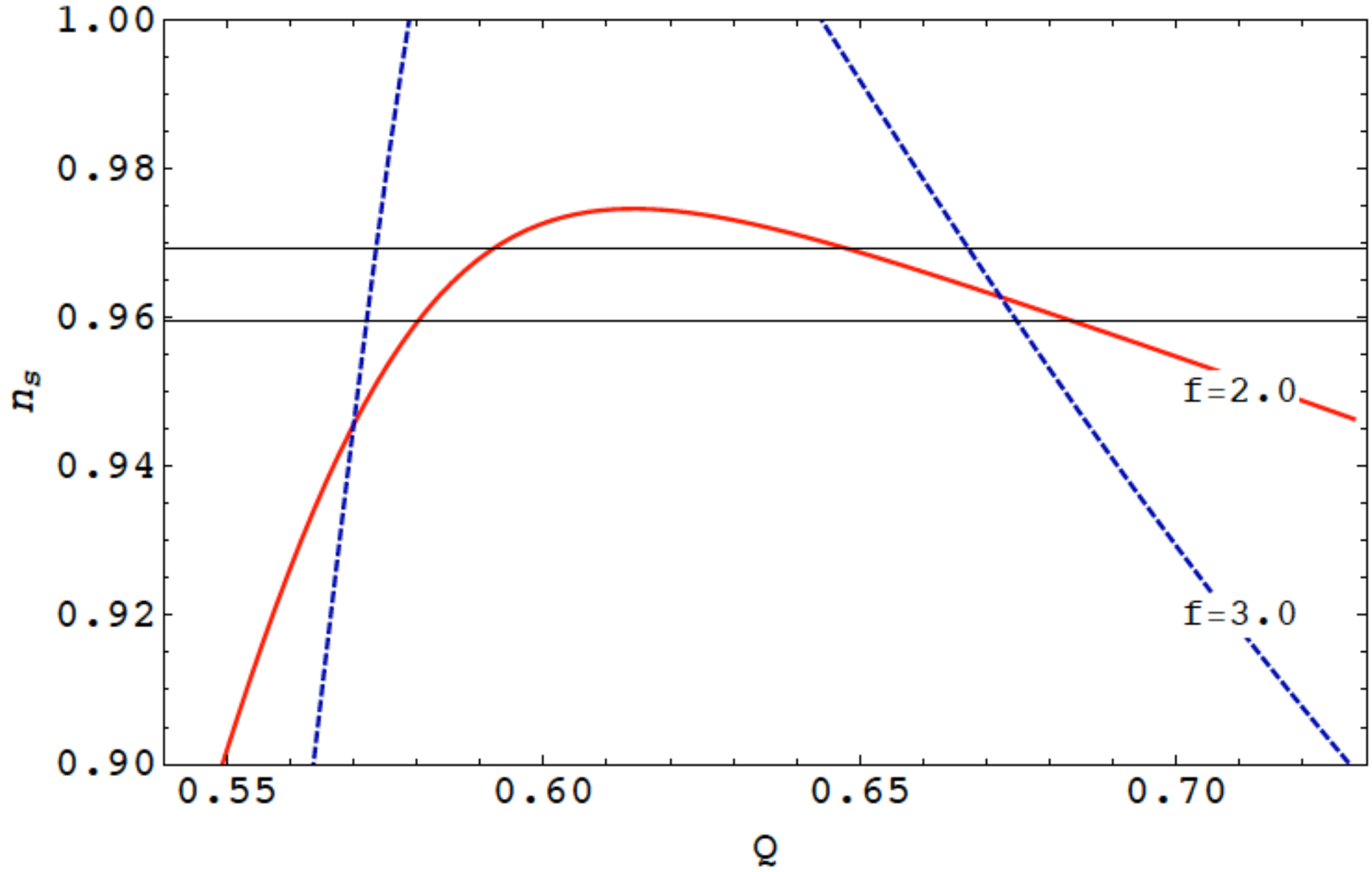

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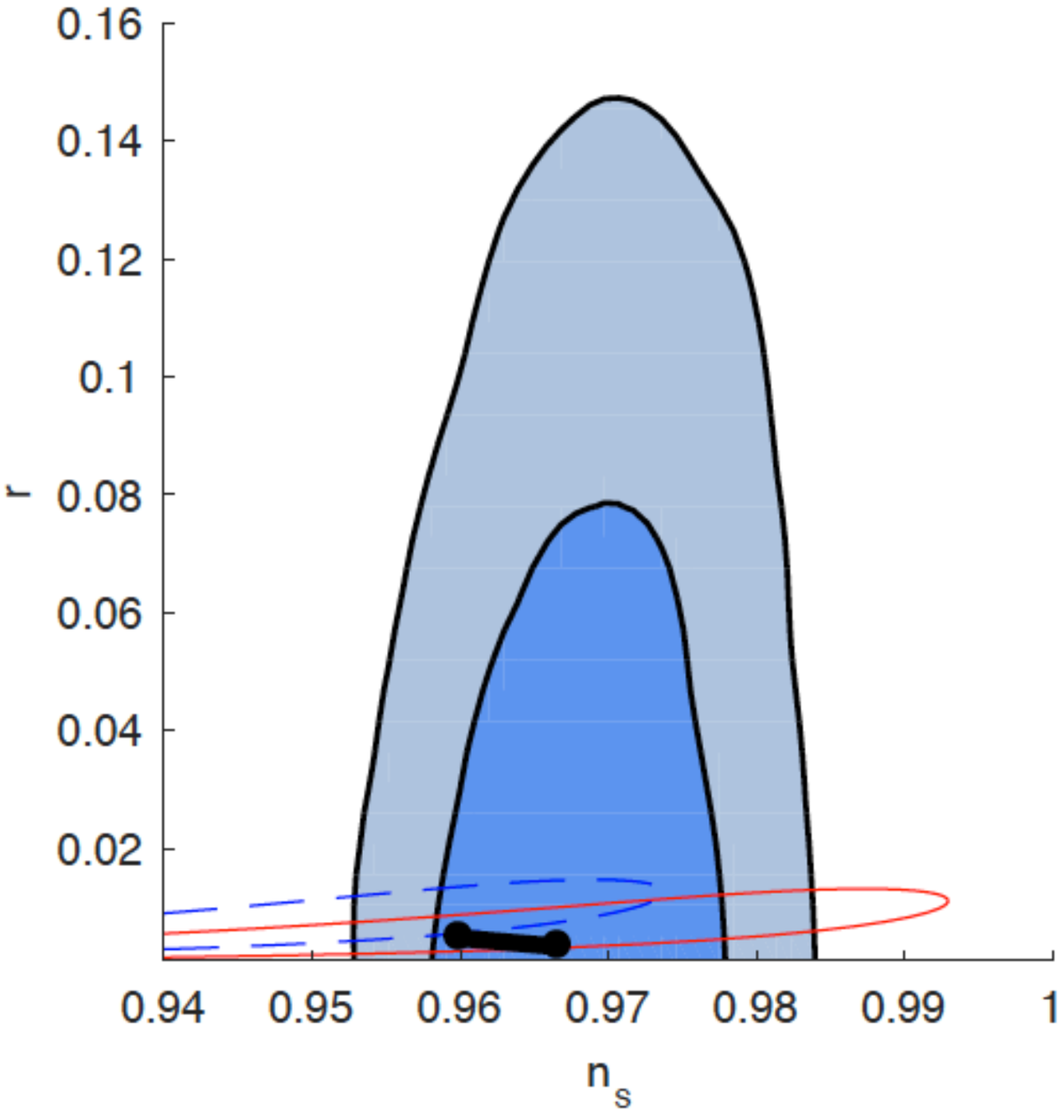
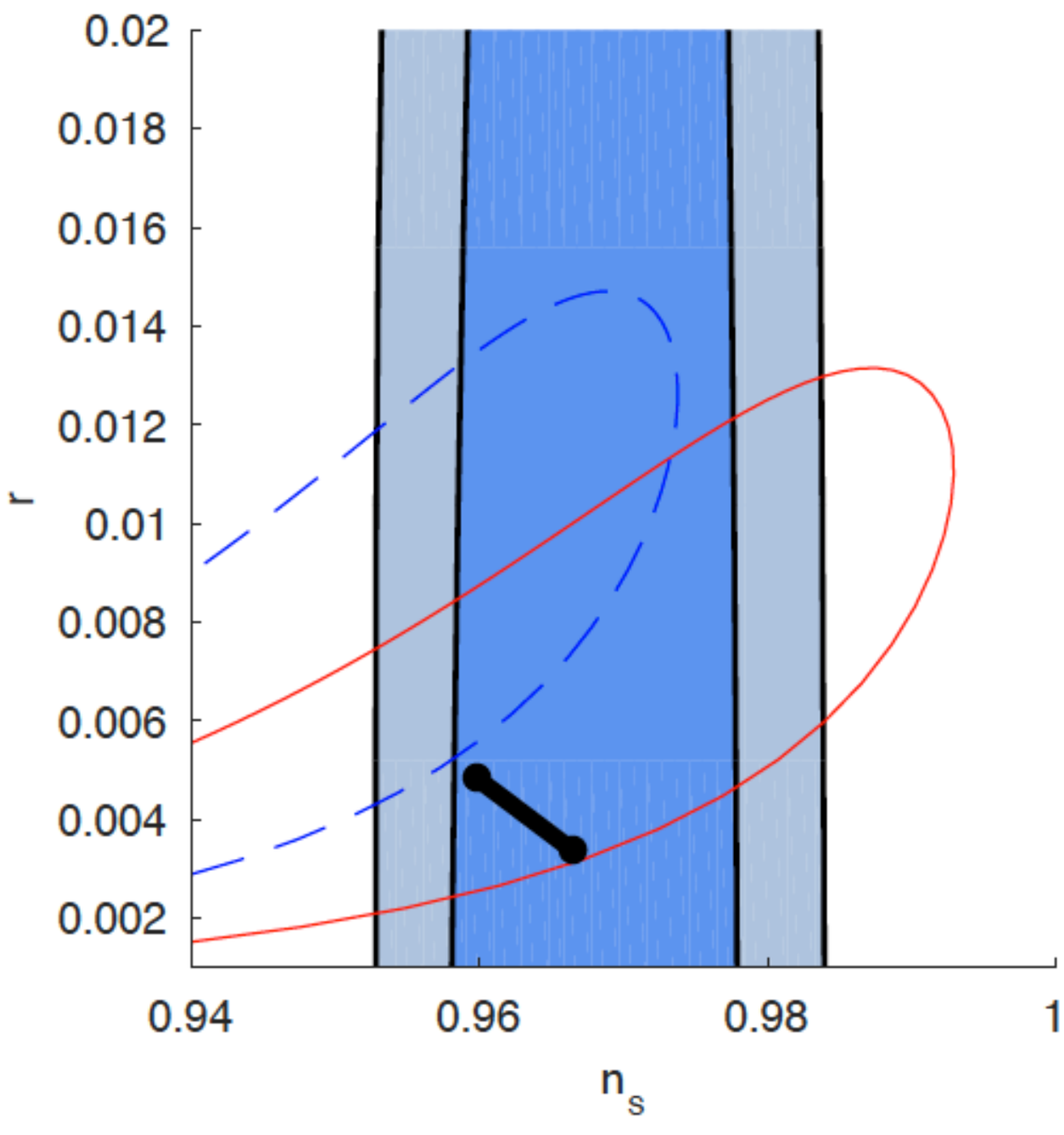




Mansi Dhuria, Gaurav Goswami and Jayanti Prasad, "*Extra Natural Inflation Redux*", Phys. Rev. D 96, 083529 (2017), arXiv:1705.11071.

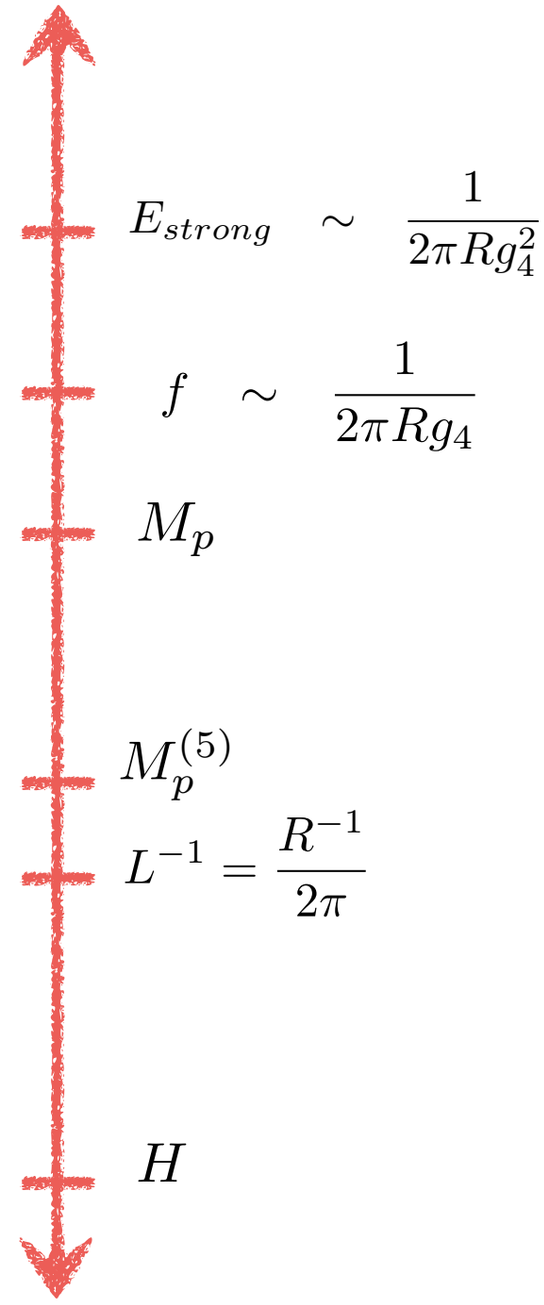
Extranatural Inflation Redux

Can we use CMB observations to constrain light bulk matter?

Yes!

$$\mathcal{N} = 2, \quad R = 29 M_{\rm Pl}, \quad Q = 0.58, \quad f = 2.5 M_{\rm Pl}.$$

$$g_4 = 0.0022$$



Mansi Dhuria, Gaurav Goswami and Jayanti Prasad, "*Extra Natural Inflation Redux*", Phys. Rev. D 96, 083529 (2017), arXiv:1705.11071.

A protected potential?

(1) Uncharged heavy particles: no effect on potential,
(2) Charged heavy particles: ~ exp(-RM),
(3) no dangerous higher-dimension operator can be generated in a local higher-dimensional theory,
(4) Non-local effects are exponentially suppressed.

$$V(\theta) = \pm \frac{3}{64\pi^6 R^4} \left[\sum_{n=1}^{\infty} c_n e^{-2\pi R n m_a} \mathrm{Re}\left(e^{inQ_a\theta}\right) \right],$$

N. Arkani-Hamed, H. C. Cheng, P. Creminelli, and L. Randall, "*Extra Natural Inflation*", Phys. Rev. Lett. 90, 221302 (2003).

A protected potential?

Natural inflation

The potential of a PNGB generated by gauge instantons…

$$S_{\rm gauge} = \frac{8\pi^2}{g^2} \implies V \sim \cos\theta$$

The effect of gravitational instantons (Giddings Strominger)…

$$S_{\rm gravity} = \frac{nM_p}{f} \implies \delta V \sim e^{-S_{\rm gravity}}$$

A protected potential?

How much is the effect of gravitational instantons?

The answer depends on the dirty details of compactification!

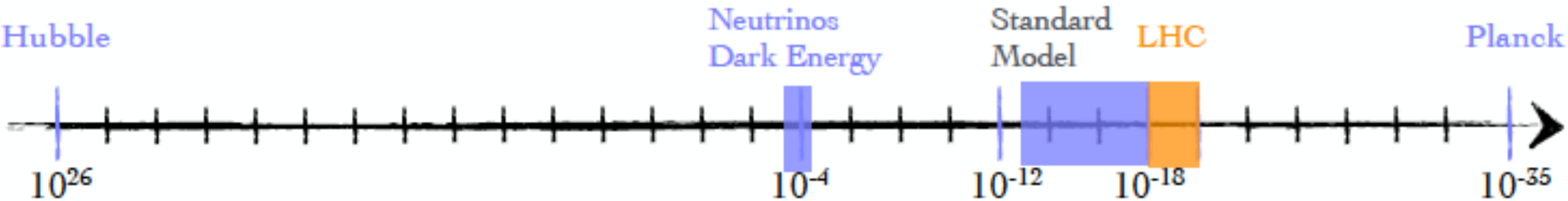
Arthur Hebecker, Patrick Mangat, Stefan Theisen, Lukas T. Witkowski, "*Can Gravitational Instantons Really Constrain Axion Inflation?*", JHEP 1702 (2017) 097, arXiv:1607.06814.

Issues...

- Recent literature on Weak Gravity Conjecture...
  - Is UV sensitivity really resolved? (gravitational instantons etc),
  - Can this be UV completed?
    - look for the compactifications which give
      - Small value of gauge coupling,
      - fermions with the right properties.
    - Study realistic compactifications of string theory
      - stabilise all moduli,
- obtain correct particle physics, obtain correct cosmology.

Thank You

The natural world at various length scales…



Scale in m

From microphysics...

A typical microscopic theory is specified by...

* Gauge group,
* Representation of fermions,
* Representation of scalars, and,
* the scalar potential.

The "Standard Model" of Cosmology

At early enough times (T ~ few MeV)

(1) Gravity: General Relativity
(2) To leading order: spacetime geometry is spatially flat FRW metric (space-like hypersurfaces: homogeneous, isotropic and flat),
(3) Matter
   - Dark Matter: cold, collisionless
   - cosmological constant (with a very tiny value: $\ell_{\rm Pl}^2 \Lambda \approx 3 \times 10^{-122}$),
   - SM particles: photons, neutrinos (and anti-neutrinos), electrons (and positrons), protons and neutrons
(4) Initially,
   - baryon to photon ratio is $\mathcal{O}(10^{-9})$
   - asymmetry in neutral leptons negligible
   - asymmetry in charged leptons s.t. the net electric charge is zero.
(5) At sub-leading order: scalar metric perturbations:
   - adiabatic,
   - Gaussian
   - nearly scale-invariant (tilted red)

Vacuum energy?