Without discovering additional particles we can probe <u>very</u> high energy physics

1) · Field Range $\Delta\Phi$ of inflaton relative to <u>Planck Mass</u> using CMB polarization

· Number & Interactions (Non-Gaussianity) of Primordial Quantum Fields using CMB & large-scale structure

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2) · Cosmological constant & curvature using observations <u>and</u> theory (thought experiments!)

3) · Framework for cosmology and black holes and QG using theory (cf Hawking radiation)

Inflationary cosmology

- Accelerated expansion driven by potential energy

$$V(\phi)$$

↖ scalar inflaton

$$-dt^2 + a(t)^2 d\vec{x}^2 \qquad a(t) \simeq a_0 e^{Ht}$$

- Quantum fluctuations $\delta\phi(t,\vec{x})$ seed structure
- Fluctuations of the gravitational field are also generated

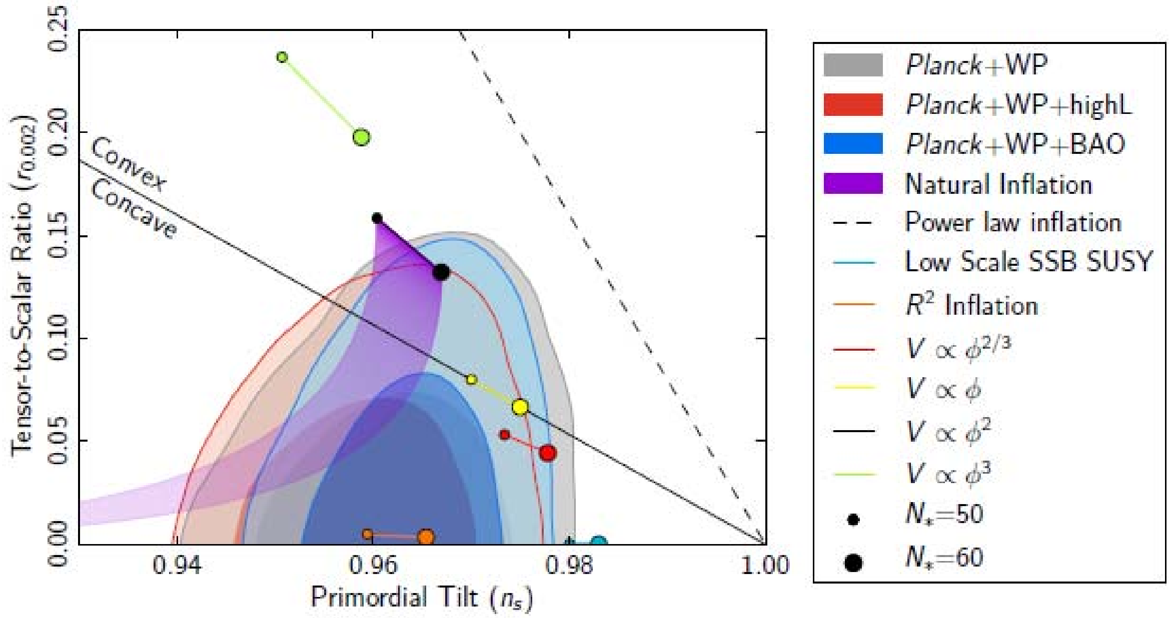


Figure 1-1. *Current CMB constraints on the combined n_s-r parameter space [18].*

Inflation + Quantum mechanics →

$$\langle \gamma_s \gamma_{s'} \rangle = \frac{2H^2}{M_p^2} \delta_{ss'} \delta(\vec{k}+\vec{k}') \quad \text{tensor}$$

$$\langle \zeta \zeta \rangle \sim H^4/\dot{\phi}^2 \, \delta(\vec{k}+\vec{k}') \quad \text{scalar}$$

$$ds^2 = -dt^2 + e^{2Ht} dx^i dx^j \left(e^{2\zeta}\delta_{ij} + \gamma_{ij}\right)$$

$$r = \frac{\langle \gamma\gamma \rangle}{\langle \zeta\zeta \rangle}$$

probed via CMB polarization (B-modes)

Significance

(1) Quantum mechanical fluctuations of the gravitational field!

$\langle \gamma \rangle = 0 \quad \langle \gamma\gamma \rangle \neq 0$

(2) $r \propto H^2 = \frac{V}{M_p^2}$: $V^{\frac{1}{4}} \sim \left(\frac{r}{.01}\right)^{\frac{1}{4}} \times 10^{16}$ GeV

Inflationary potential energy

not a wide range available

* GUT scale

(3) ✩ Lyth: r is related to field range

$$\frac{\Delta\varphi}{M_p} \sim \left(\frac{r}{0.01}\right)^{\frac{1}{2}}$$

observable (at 5σ level!)

highly UV sensitive if $\gtrsim 1$

As B-mode detectors scan from

$r \gtrsim .1$ (Current 2σ limit)

down to $r = .01$ and then $r \gtrsim .001$

They cover a wide range of $\Delta\phi$

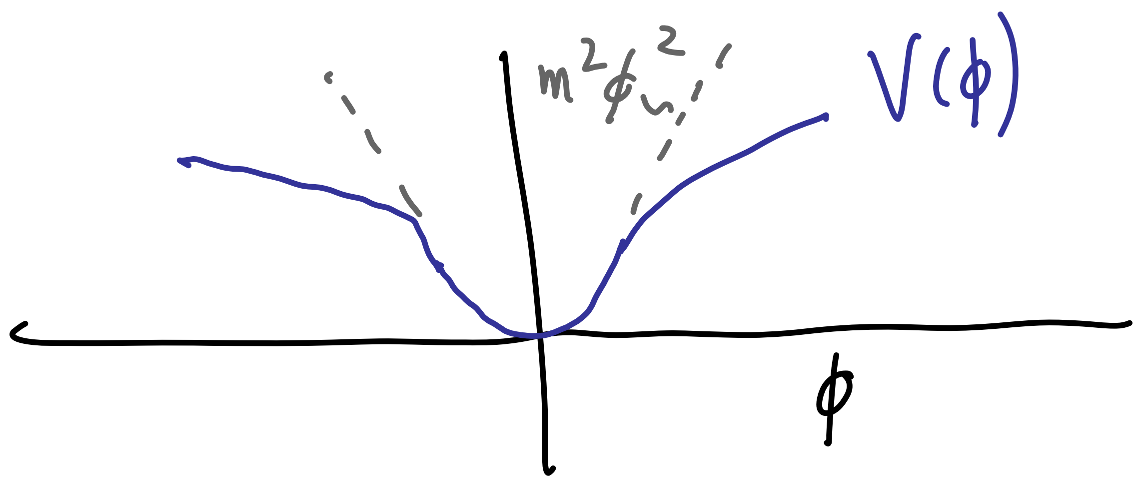
from $\Delta\phi \gtrsim 10 M_p$

to $\Delta\phi \sim M_p$ ← important threshold

in which inflation is sensitive to an ∞ sequence of quantum gravity corrections!

- Observational test of string theoretic mechanism(s) for large-field inflation

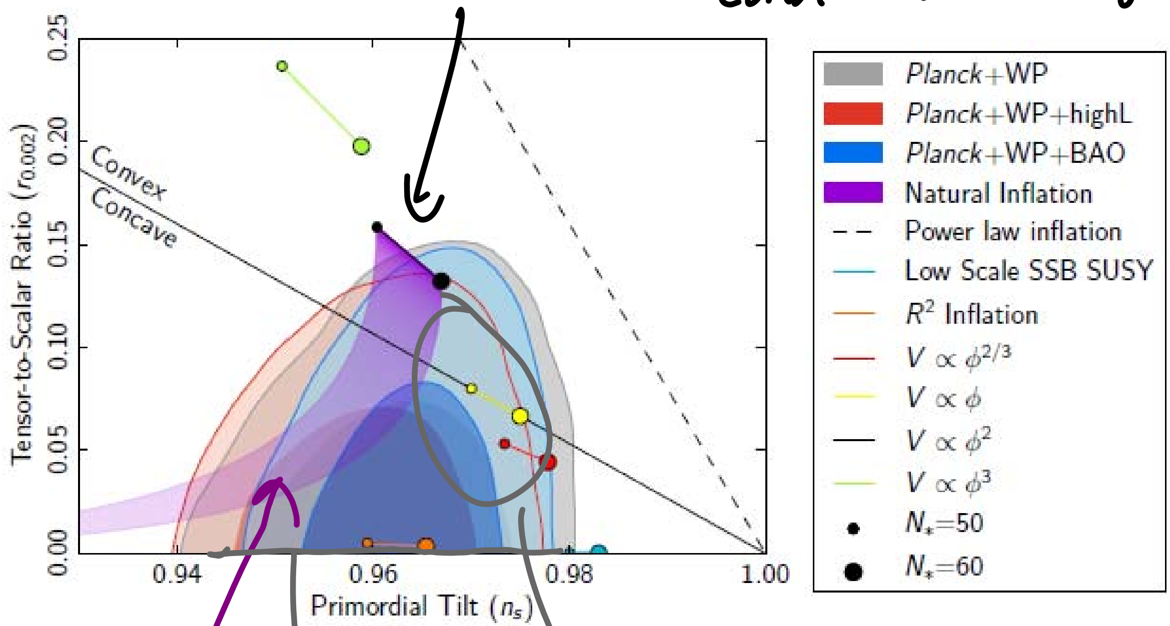
UV completion <u>Heavy</u> fields (mass > H) adjust in response to inflationary potential energy, <u>flattening</u> $V(\phi)$ (energetically favorable!)



- String theoretic large-field inflation (monodromy) has flattened $V(\phi)$ for essentially this reason.

$\rightarrow V \propto \phi^{p<2}$

$m^2\phi^2$: would → precision constraint on heavy fields



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QFT axions

string theoretic axion inflation

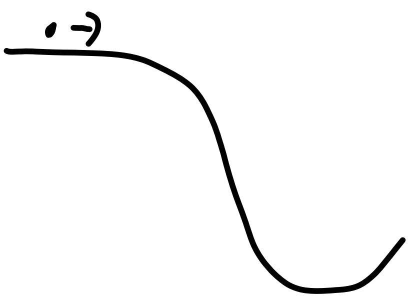
small-field inflation (also possible to UV-complete in string theory)

$V \neq m^2\phi^2 \Rightarrow$ beyond ΛCDM

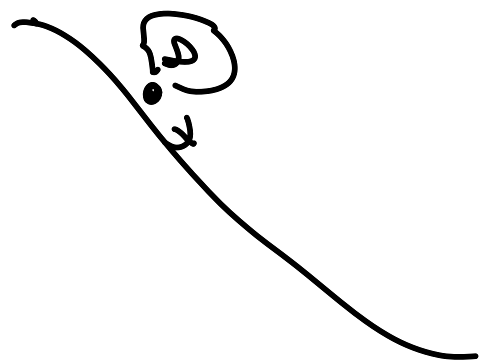
Non-Gaussianity

Roughly Speaking, 2 classes of Inflation Mechanisms:

Inflation → Slowly diluting potential energy



Flat potential



Steep potential, but interactions slow the field. ⇒ NG.

(e.g. causal restriction on speed)

Now Systematic (EFT) understanding for single-field; new effects for multiple fields