Axion Monodromy Inflation and its Signatures

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arXiv:0907.2916

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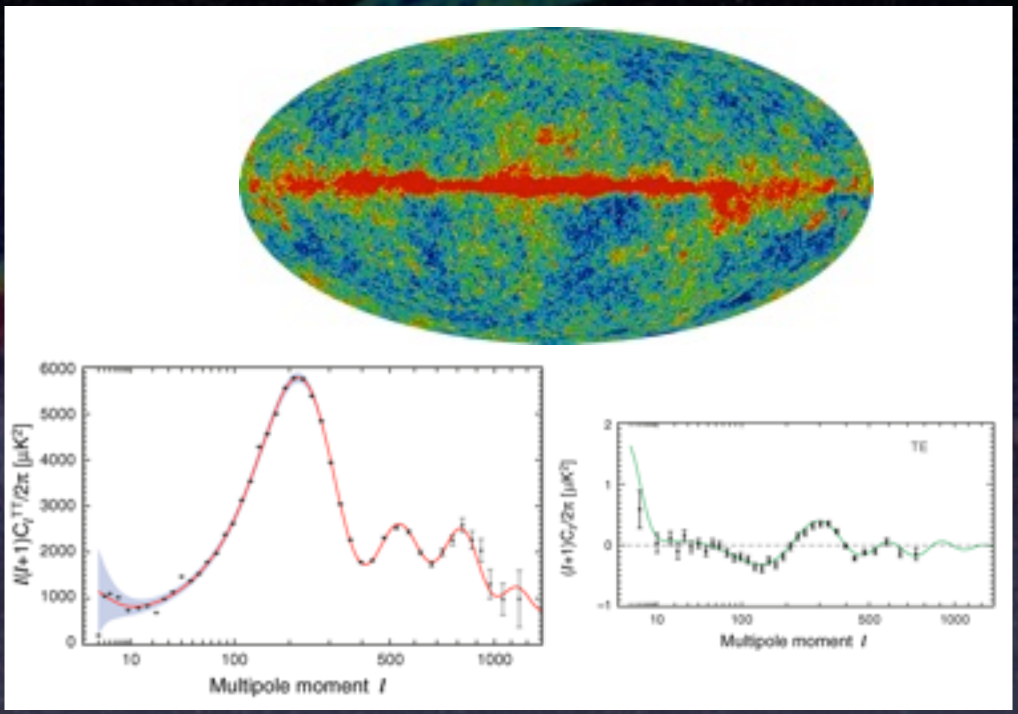
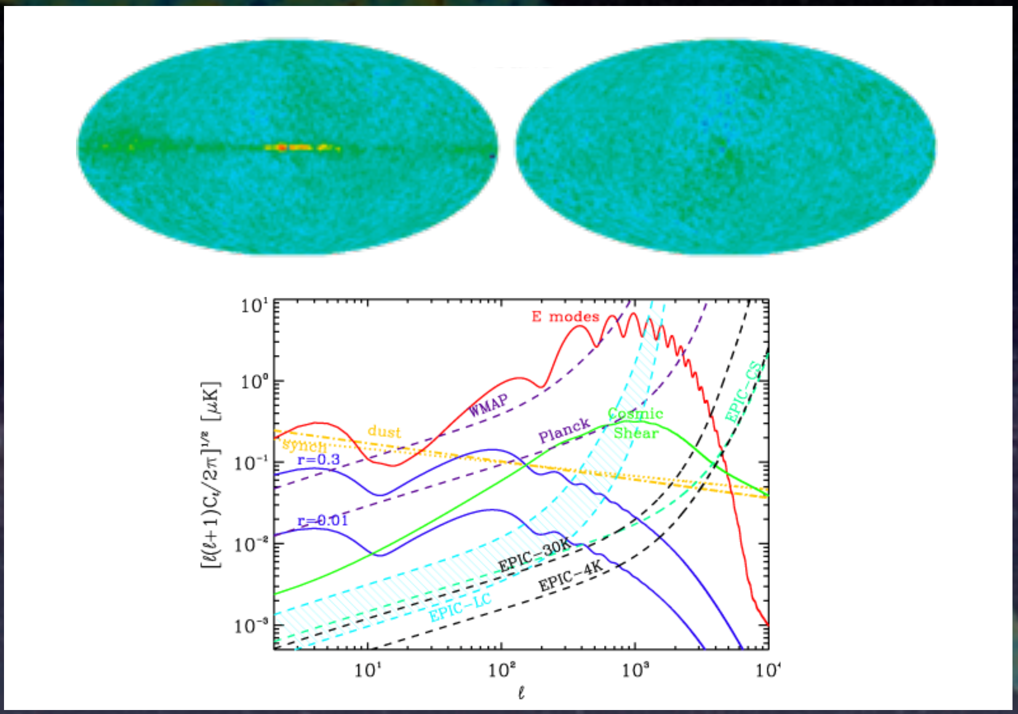
Motivation

(Jarosik et al. 2010)



(Larson et al. 2010)

(Jarosik et al. 2010)



(Bock et al. 2009)

If a tensor signal is seen, the inflaton must have moved over a super-Planckian distance in field space* (Lyth 1996)

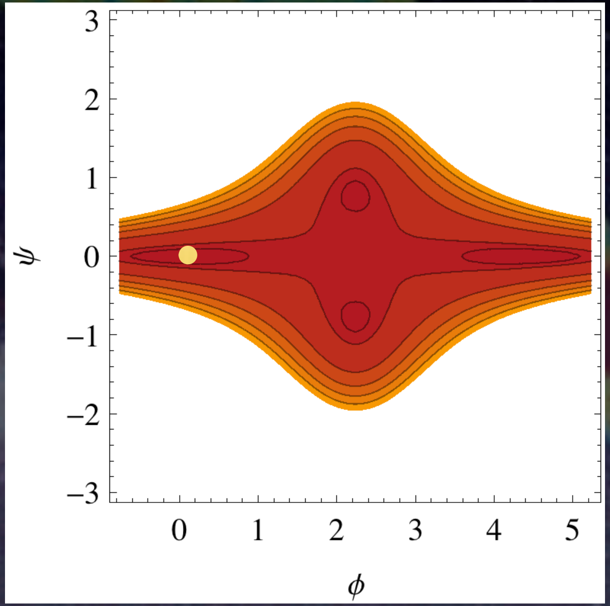
* For single field models with canonical kinetic term

Motivation

This is hard to control in an EFT field theory

$$V(\phi) = V_0 + \frac{1}{2}m^2\phi^2 + \frac{1}{3}\mu\phi^3 + \frac{1}{4}\lambda\phi^4 + \phi^4\sum_{n=1}^{\infty} c_n\left(\phi/\Lambda\right)^n$$

$$(\Lambda < M_p)$$



The c_n are typically unknown.
Even if they were known, the effective theory is generically expected to break down for $\phi > \Lambda$, e.g. because other degrees of freedom become light.

Motivation

Possible Solution:

Use a field with a shift symmetry.
Break the shift symmetry in a controlled way.

The inflaton as an axion

Freese, Frieman, Olinto, PRL 65 (1990)

$$V(\phi) = \Lambda^4 \left[1 + \cos\left(\frac{\phi}{f}\right)\right] \quad \text{with} \quad f \gtrsim M_p$$

However, such large f seem hard to realize string theory.

Banks, Dine, Fox, Gorbatov hep-th/0303252

Motivation

The inflaton as an axion in supergravity

Kawasaki, Yamaguchi, Yanagida, PRL 85 (2000)

First example of large field inflation in string theory

Silverstein, Westphal, arXiv:0803.3085

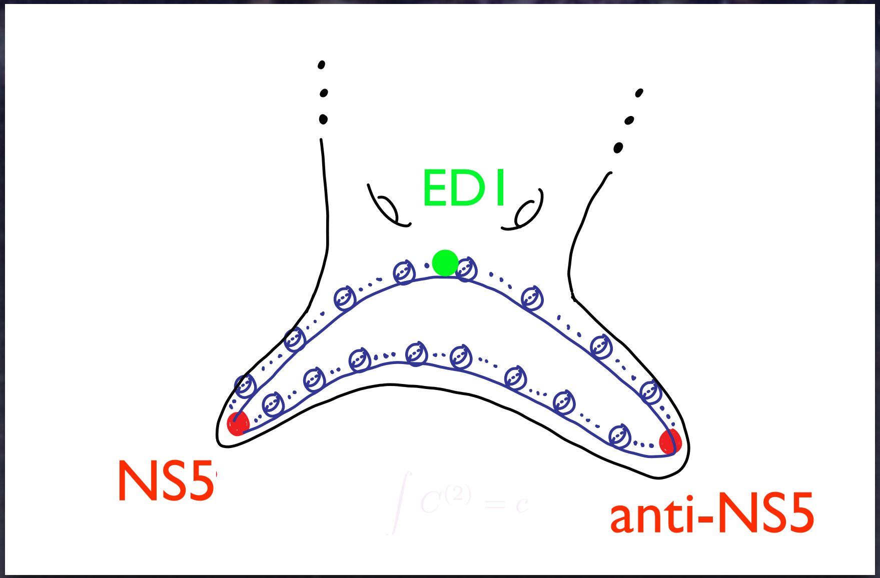
and more recently

McAllister, Silverstein, Westphal, arXiv:0808.0706
Flauger, McAllister, Pajer, Westphal, Xu, arXiv:0907.2916

Berg, Pajer, Sjors, arXiv:0912.1341

Kaloper et al., to appear

Basic Ingredients of Axion Monodromy Inflation



Axion Monodromy Inflation

Consider string theory on $M \times X$

Axions arise from integrating gauge potentials over non-trivial cycles in the compactification manifold.

$$b_I(x) = \int_{\Sigma_I^{(2)}} B$$

$$c_\alpha(x) = \int_{\Sigma_\alpha^{(p)}} C^{(p)}$$

where $\Sigma_\alpha^{(p)}$ is an element of an integral basis of $H_p(X, \mathbb{Z})$.

Axion Monodromy Inflation

These fields possess a shift symmetry to all orders in string perturbation theory.

The vertex operator for $b_I(x)$ in the limit of vanishing momentum is

$$V_{b_I}(0) = \int_{\mathcal{W}} d^2\xi \epsilon^{\alpha\beta} \partial_\alpha Y^i \partial_\beta Y^j \omega^I_{ij}(Y(\xi)) = \int_{\varphi(\mathcal{W})} \omega^I$$

with $\omega^I \in H^2(X, \mathbb{Z})$ dual to Σ_I

vanishes if $\varphi(\mathcal{W}) = \partial \mathcal{C}$ so that coupling vanishes.

Axion Monodromy Inflation

Breaking by branes

For definiteness consider a D5-brane wrapping a two-cycle $\Sigma^{(2)}$ of size L$\sqrt{\alpha'}$.

$$S_{\rm DBI} = -\frac{1}{(2\pi)^5 {\alpha'}^3 g_s} \int d^6\xi \sqrt{det(-\varphi^*(G+B))}$$

$$\supset -\frac{\epsilon}{(2\pi)^5 {\alpha'}^2 g_s} \int d^4x \sqrt{{}^{(4)}g} \sqrt{L^4 + b^2}$$

Axion Monodromy Inflation

Breaking by branes

This implies the following potential

$$V(b) = \frac{\epsilon}{(2\pi)^5 {\alpha'}^2 g_s} \sqrt{L^4 + b^2}$$

similarly for the $C^{(2)}$ axion in the presence of NS5 branes

$$V(c) = \frac{\epsilon}{(2\pi)^5 {\alpha'}^2 {g_s}^2} \sqrt{L^4 + {g_s}^2 c^2}$$

Axion Monodromy Inflation

Breaking by branes

For large field values in terms of the canonically normalized fields the potential then becomes

$$V(\phi) \approx \mu^3 \phi$$

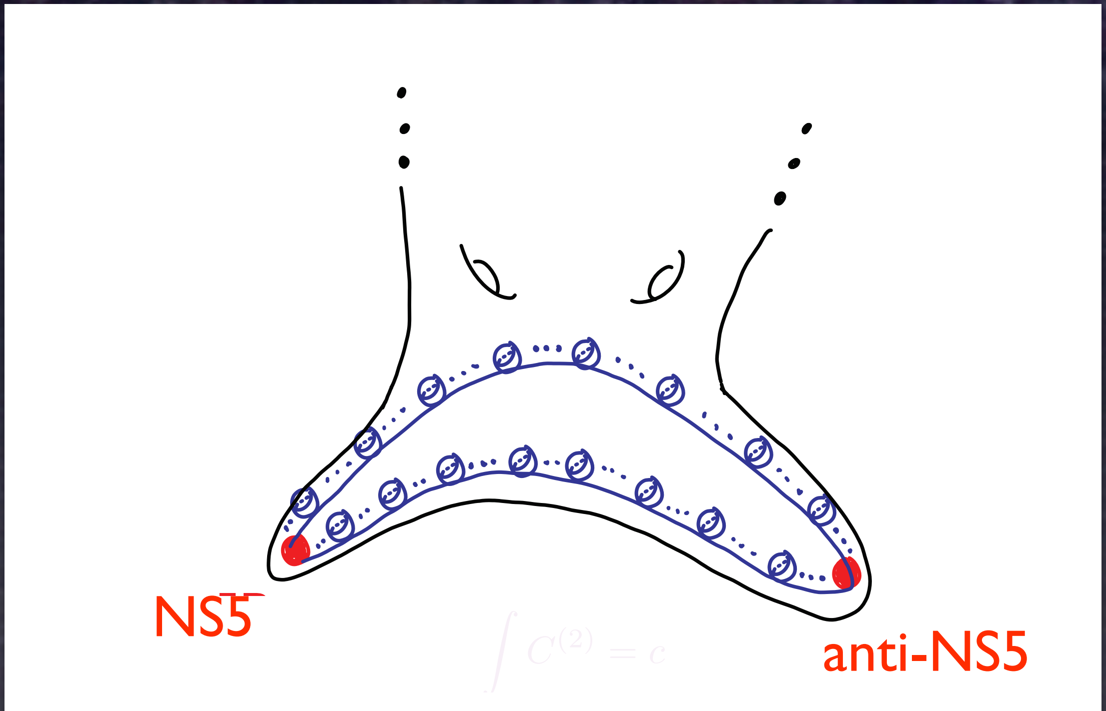
with $$\mu = \frac{\epsilon^{1/3}(2\pi)^3 g_s}{L^{10/3}} M_p$$ for b

$$\mu = \frac{\epsilon^{1/3}(2\pi)^3 g_s^{2/3}}{L^{10/3}} M_p$$ for c

Axion Monodromy Inflation

The basic setup

- Type IIB orientifolds with O3/O7
- Stabilize the moduli a la KKLT



Axion Monodromy Inflation

Consistency checks

The inflaton potential must be smaller than the potential barriers stabilizing the moduli.

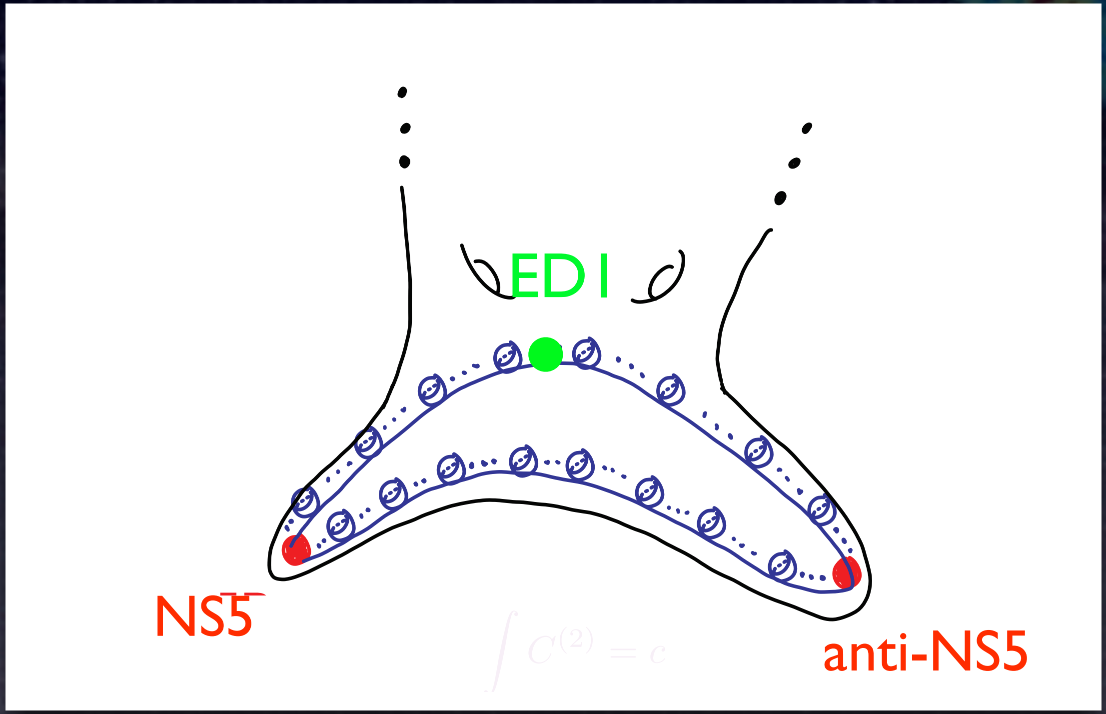
The backreaction on the geometry must be controlled.

Higher derivative corrections must be negligible.

Instanton corrections must be controlled.

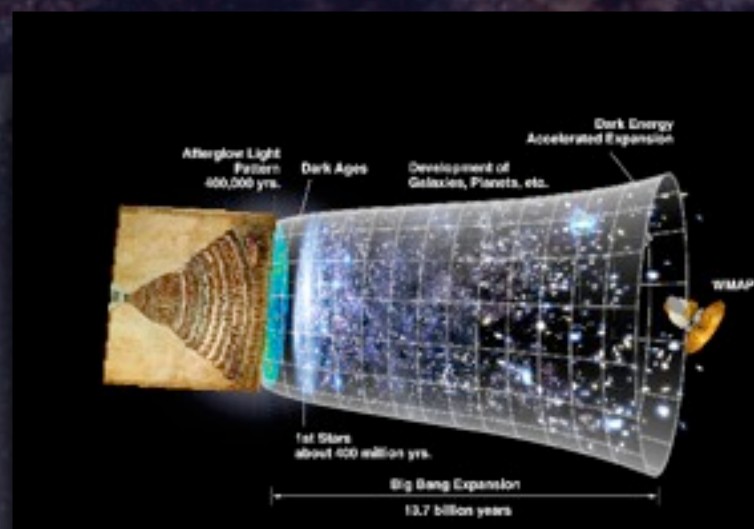
Axion Monodromy Inflation

Instanton corrections may lead to interesting signatures.



$$K = -2\log(\mathcal{V}_E + e^{-S_{ED1}}\cos(c))$$

Signatures of Axion Monodromy Inflation



Signatures of Axion Monodromy Inflation

During inflation, the low energy effective field theory for Axion Monodromy Inflation is that of a single scalar field with canonical kinetic term, minimally coupled to gravity, with potential

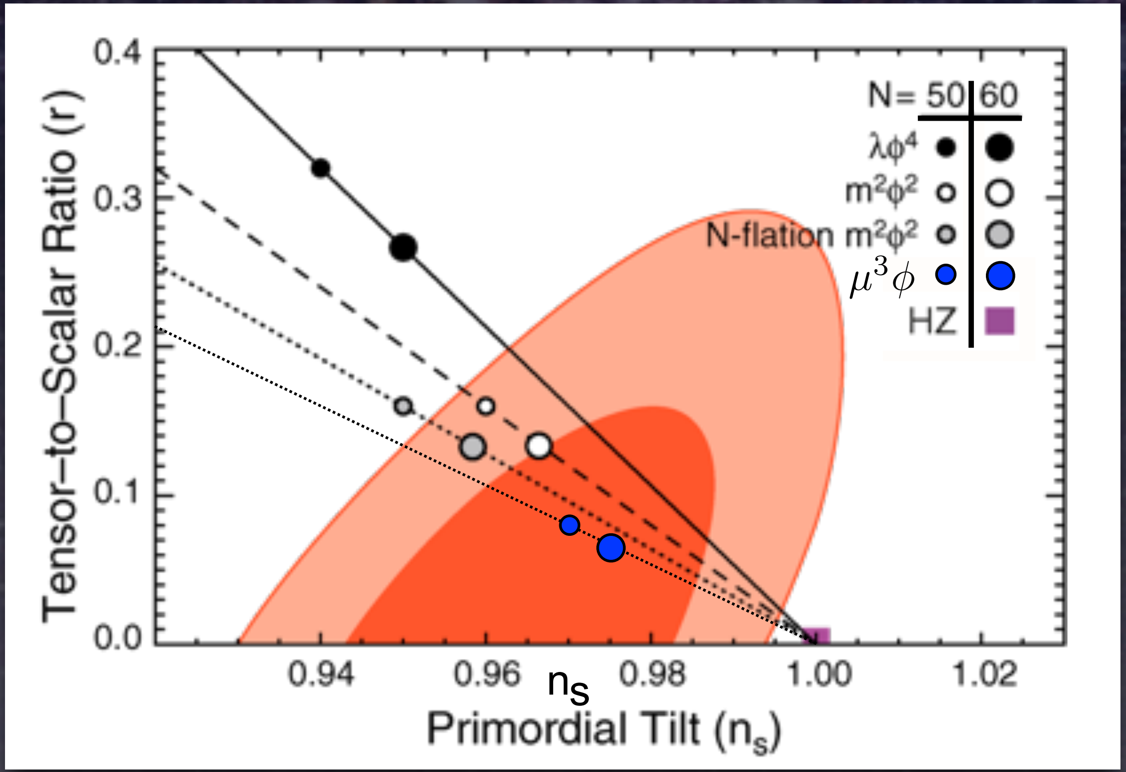
$$V(\phi) = \mu^3 \phi + b\mu^3 f \cos(\phi/f)$$

Signatures of Axion Monodromy Inflation

Observable 1: n_s and r

(no instanton corrections b=0)

(modification of Komatsu et al. 2010)



Signatures of Axion Monodromy Inflation

Observable 2: Corrections to the power spectrum

$$\Delta^2_{\mathcal{R}}(k) = \Delta^2_{\mathcal{R}}(k_*) \left(\frac{k}{k_*}\right)^{n_s - 1} \left[1 + \delta n_s \cos\left(\frac{\phi_k}{f}\right)\right]$$

with

$$\delta n_s = \frac{12b}{\sqrt{1 + (3f\phi_*)^2}} \sqrt{\frac{\pi}{8} \coth\left(\frac{\pi}{2f\phi_*} f\phi_*\right)}$$

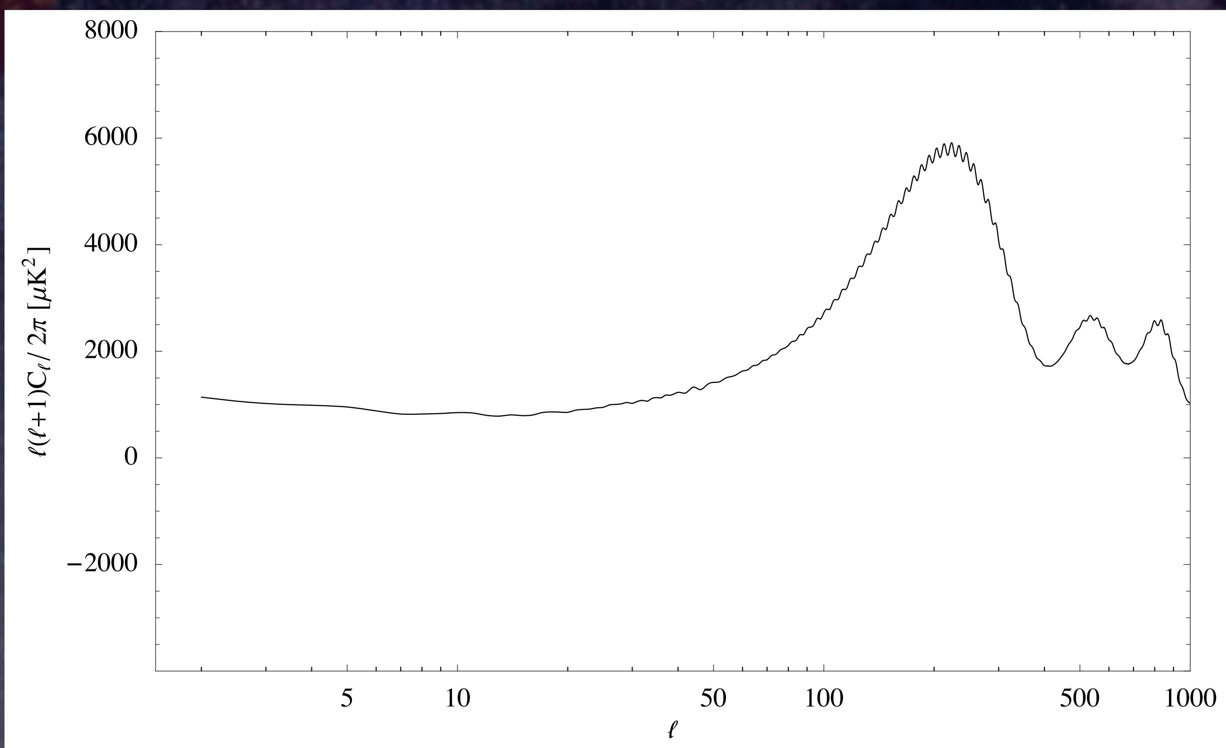
or for $f\phi_* \ll 1$:

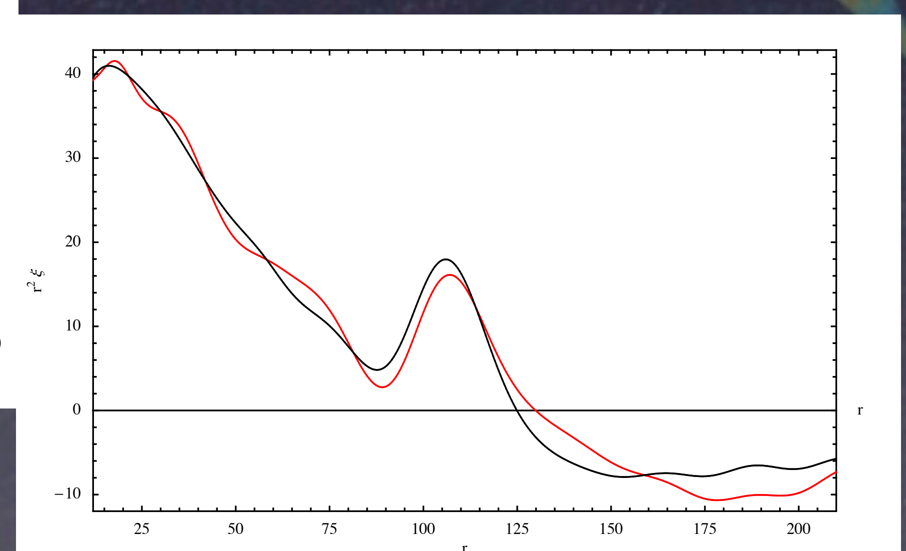
$$\delta n_s = 3b(2\pi f\phi_*)^{1/2}$$

Signatures of Axion Monodromy Inflation

The angular power spectrum

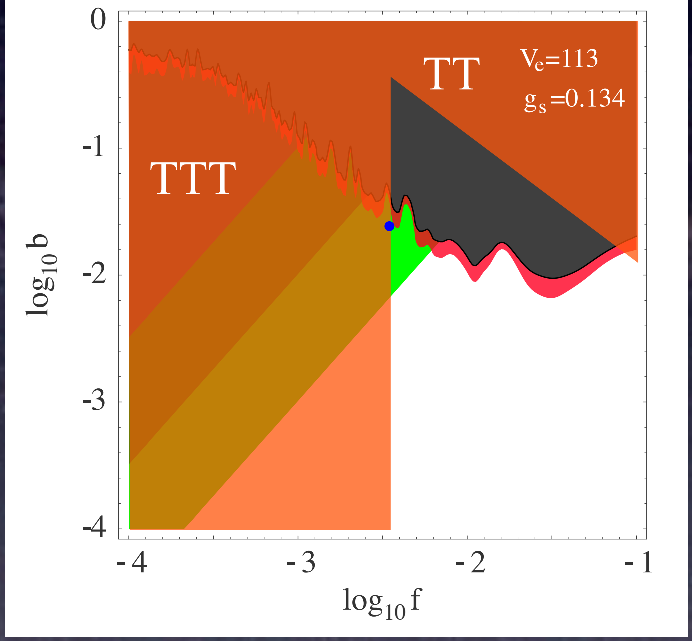
and matter correlation function

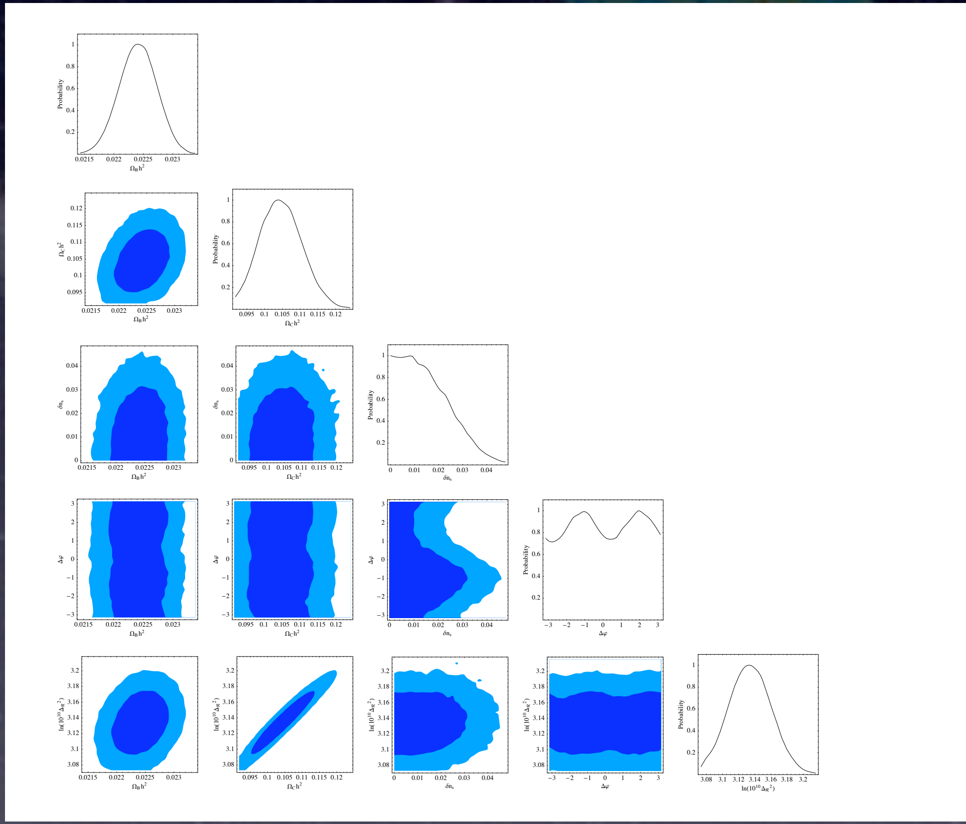




Signatures of Axion Monodromy Inflation

For constraints from WMAP5





see **Flauger, McAllister, Pajer, Westphal, Xu, arXiv:0907.2916**

Signatures of Axion Monodromy Inflation

Observable III: Resonant Non-Gaussianity

$$\frac{\mathcal{G}(k_1,k_2,k_3)}{k_1k_2k_3} = f^{\rm res}\left[\sin\left(\frac{\ln K/k_*}{f\phi_*}\right) + f\phi_*\sum_{i\neq j}\frac{k_i}{k_j}\cos\left(\frac{\ln K/k_*}{f\phi_*}\right)\right]$$

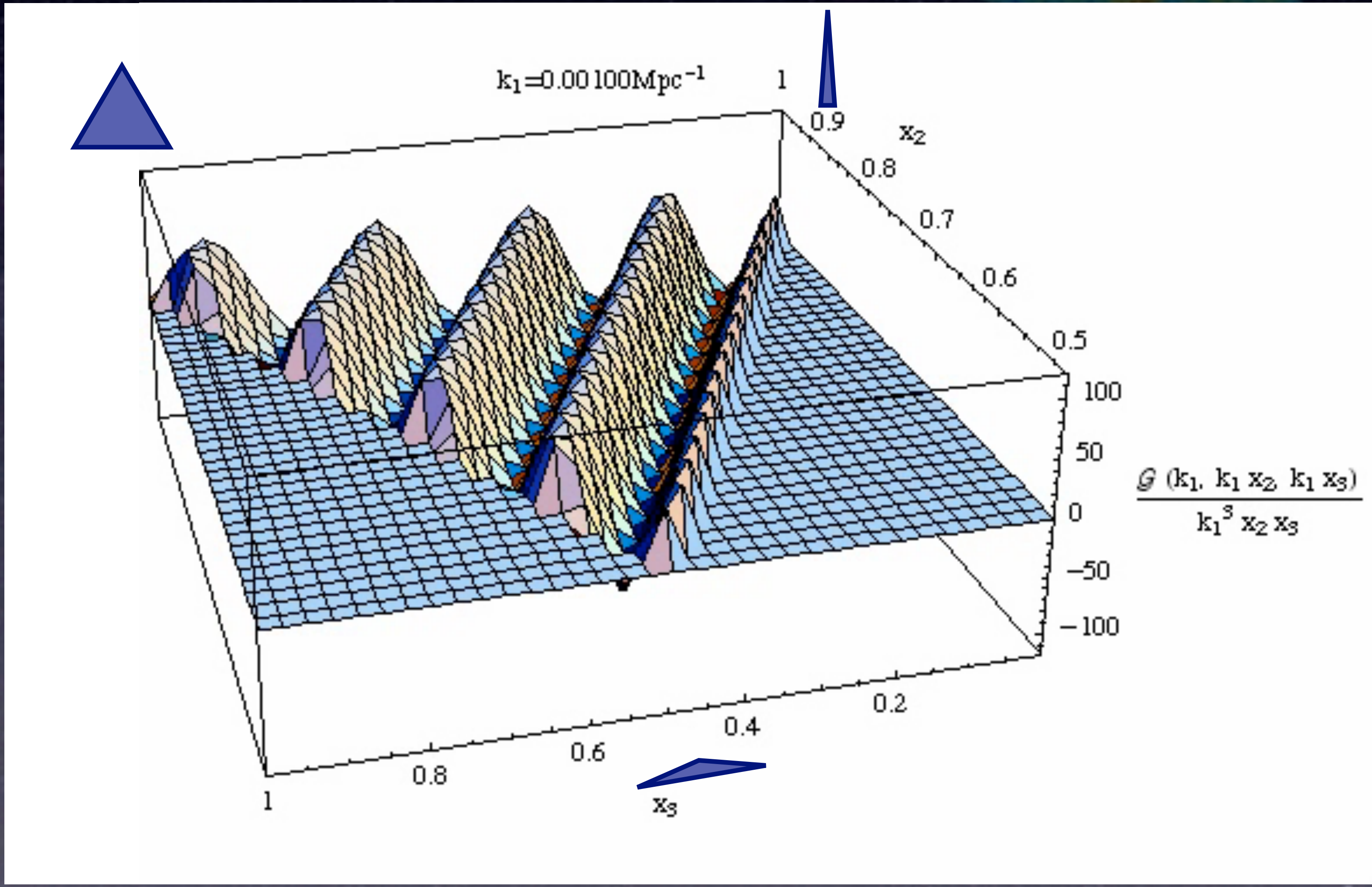
with

$$K = k_1 + k_2 + k_3$$

$$f^{\rm res} = \frac{3\sqrt{2\pi}b}{8(f\phi_*)^{3/2}}$$

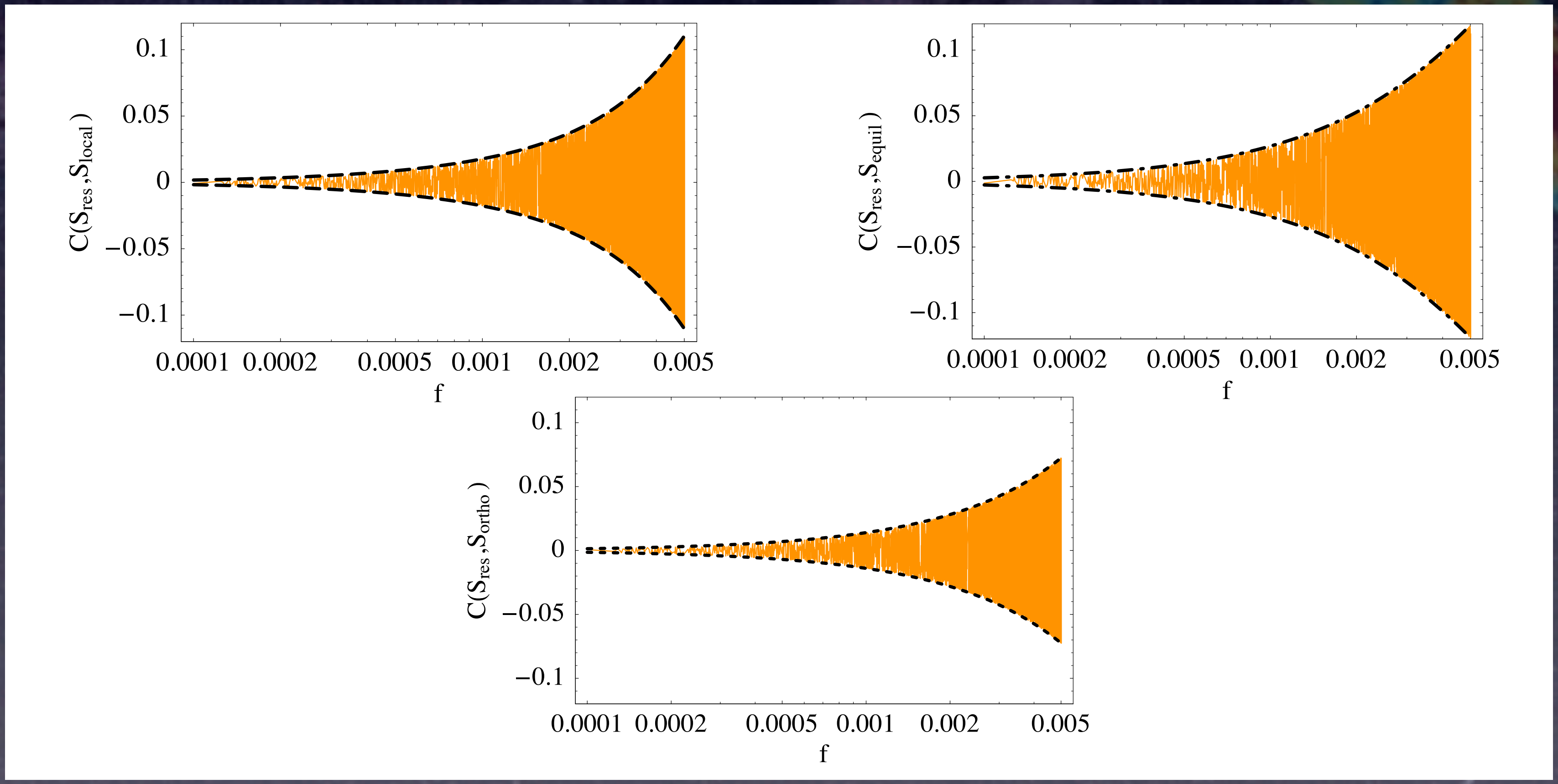
This satisfies the consistency condition.

Signatures of Axion Monodromy Inflation



Summary of Results

Existing constraints on local, equilateral, and orthogonal shapes cannot be used to infer constraints on this shape.



Conclusions

- These setups strongly suggest that large field inflation can be realized in string theory.
- The resulting models have interesting signatures:
  - a large tensor to scalar ratio
  - potentially a modulated power spectrum
  - potentially large non-Gaussianities (with a peculiar shape)
- An explicit compact model is still missing
- This kind of non-Gaussianities is currently poorly constrained and deserves further study in its own right.

Thank you

ご静聴ありがとうございました。