Primordial Tensors from Inflation in String Theory

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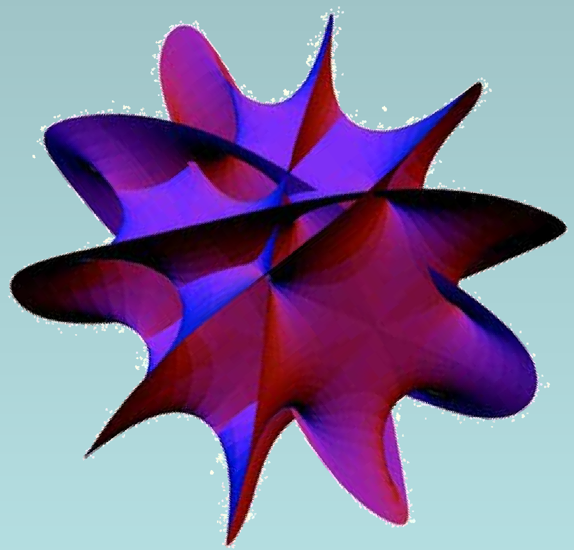
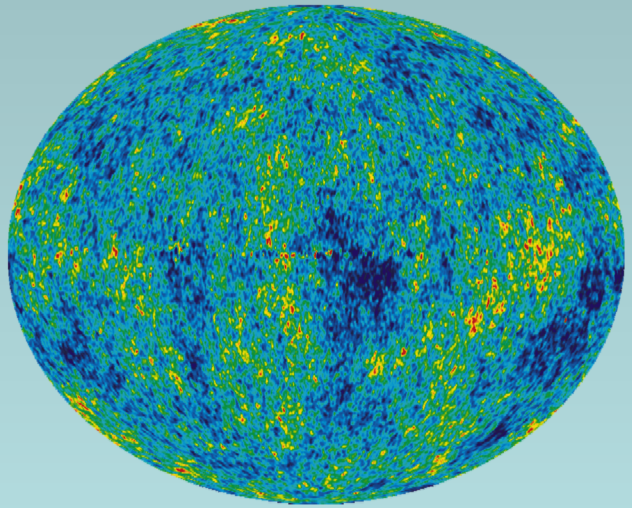


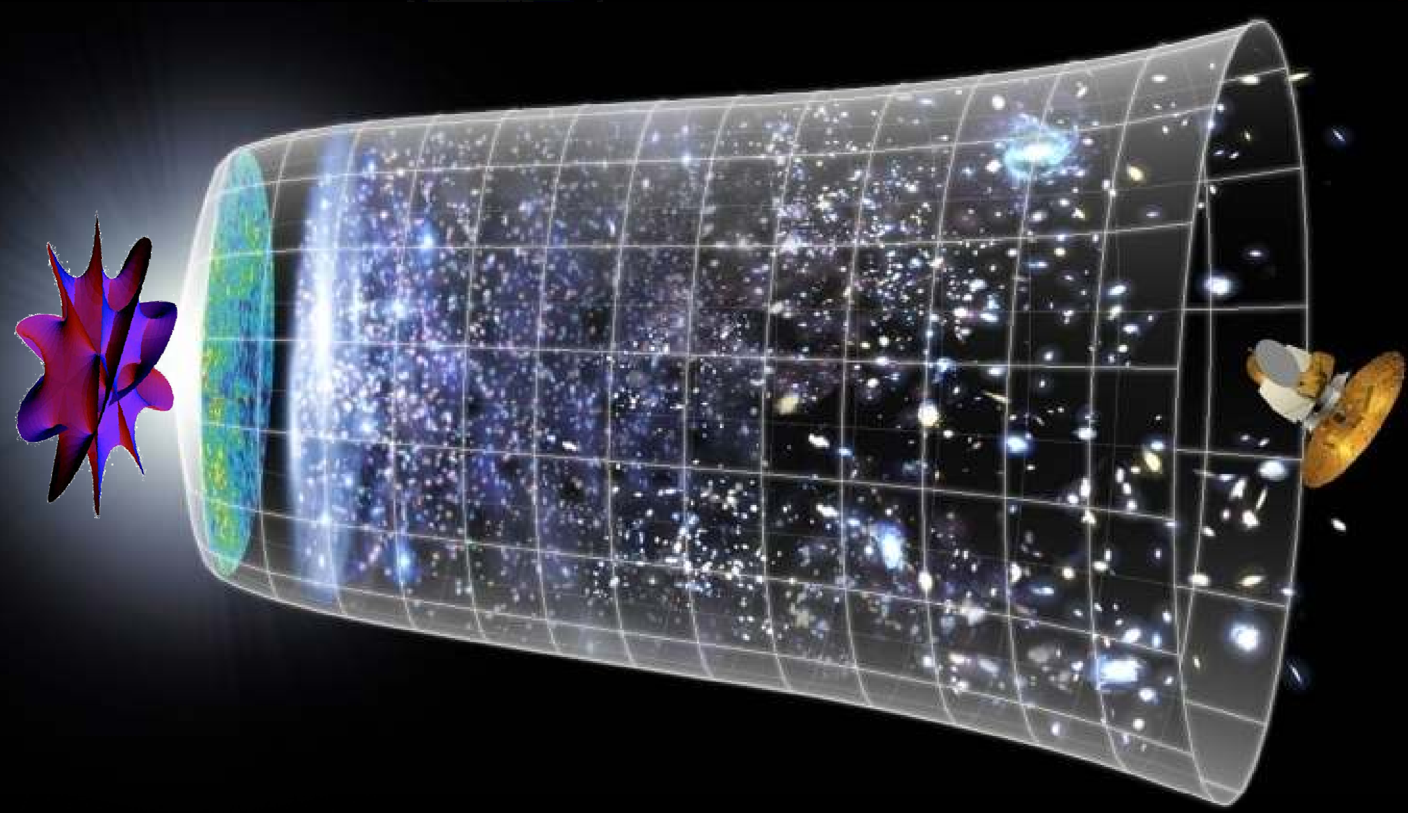


BNL

November 7, 2008

Based on:

L.M., E. Silverstein, and A. Westphal, 0808.0706



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Central Idea

If we detect primordial tensor perturbations in the CMB, we will know that the inflaton moved more than a Planck distance in field space.

Understanding such a system requires confronting true quantum gravity questions. String theory provides tools for this task, and constraints on tensors will give a powerful selection principle for inflation models, particularly those in string theory.

Inflation

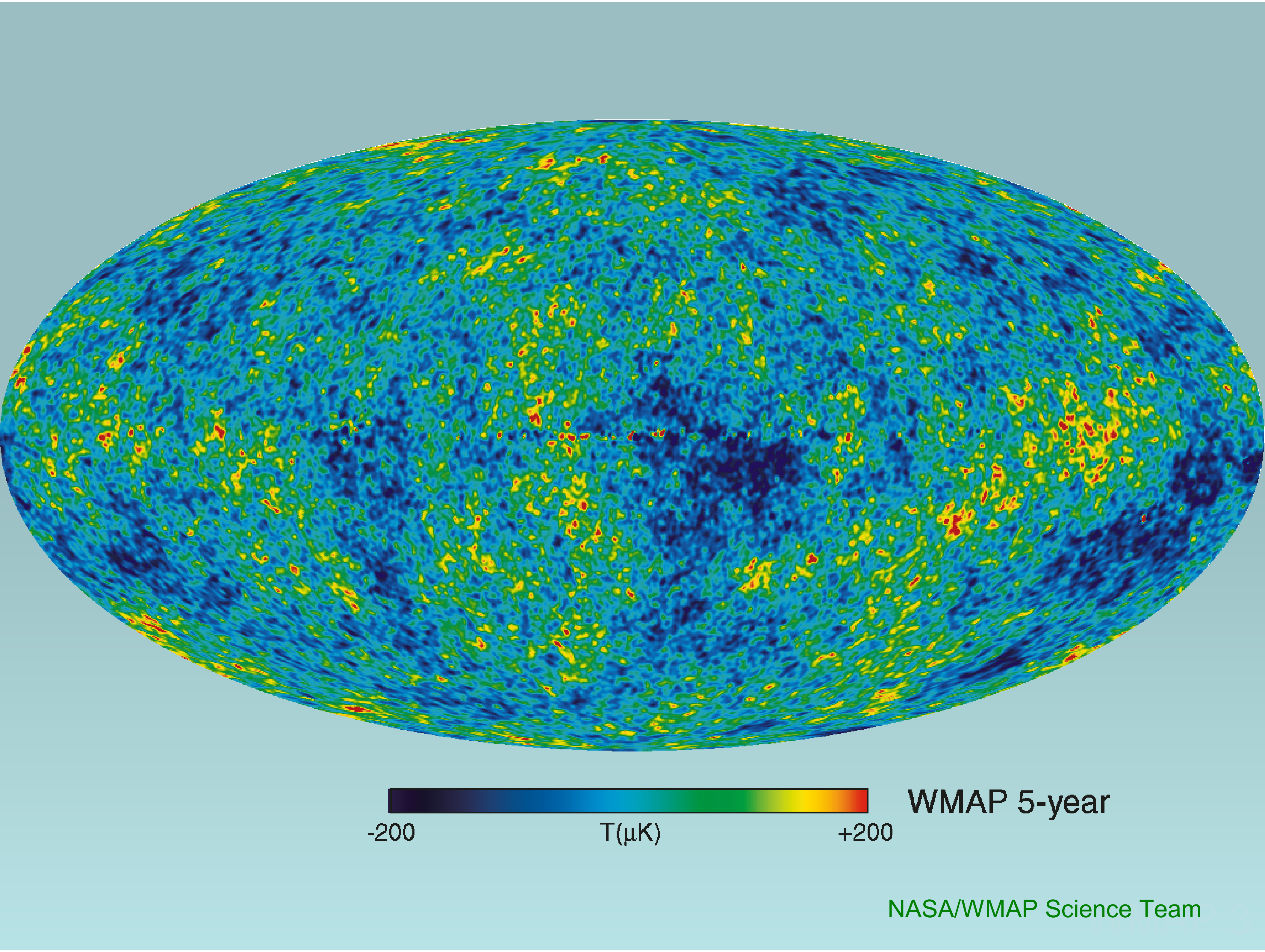
A period of accelerated expansion

$$ds^2 = -dt^2 + e^{2Ht} d\vec{x}^2 \qquad H \approx const.$$

- Solves horizon, flatness, and monopole problems. *i.e.* explains why universe is so large, so flat, and so empty.

A.Guth,1981.

- Predicts scalar fluctuations in CMB temperature:
  - approximately, but not exactly, scale-invariant
  - approximately Gaussian
- Predicts primordial tensor fluctuations


WMAP 5-year
-200
T(μK)
+200
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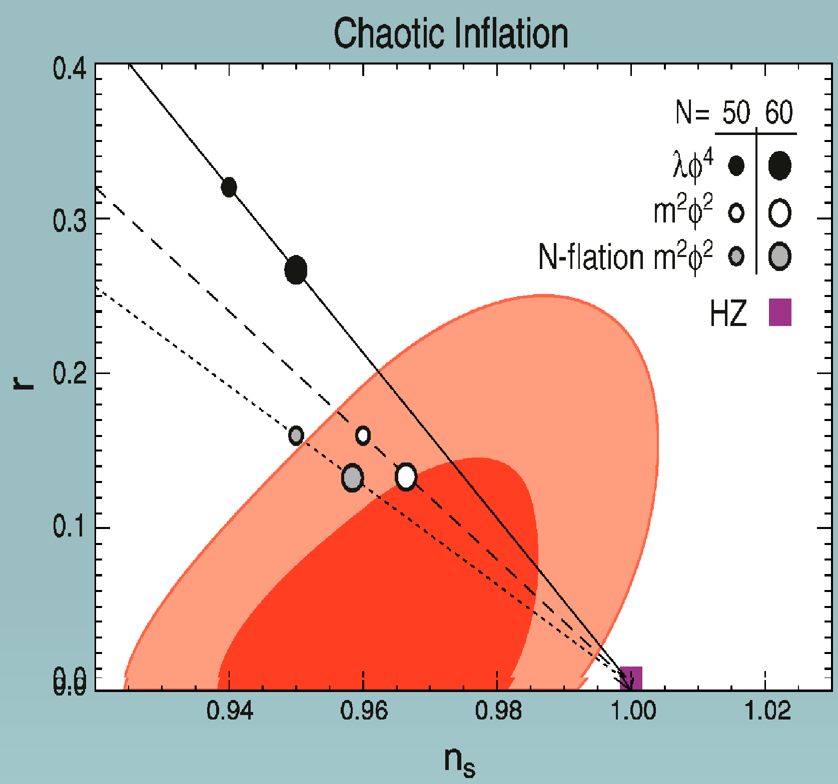
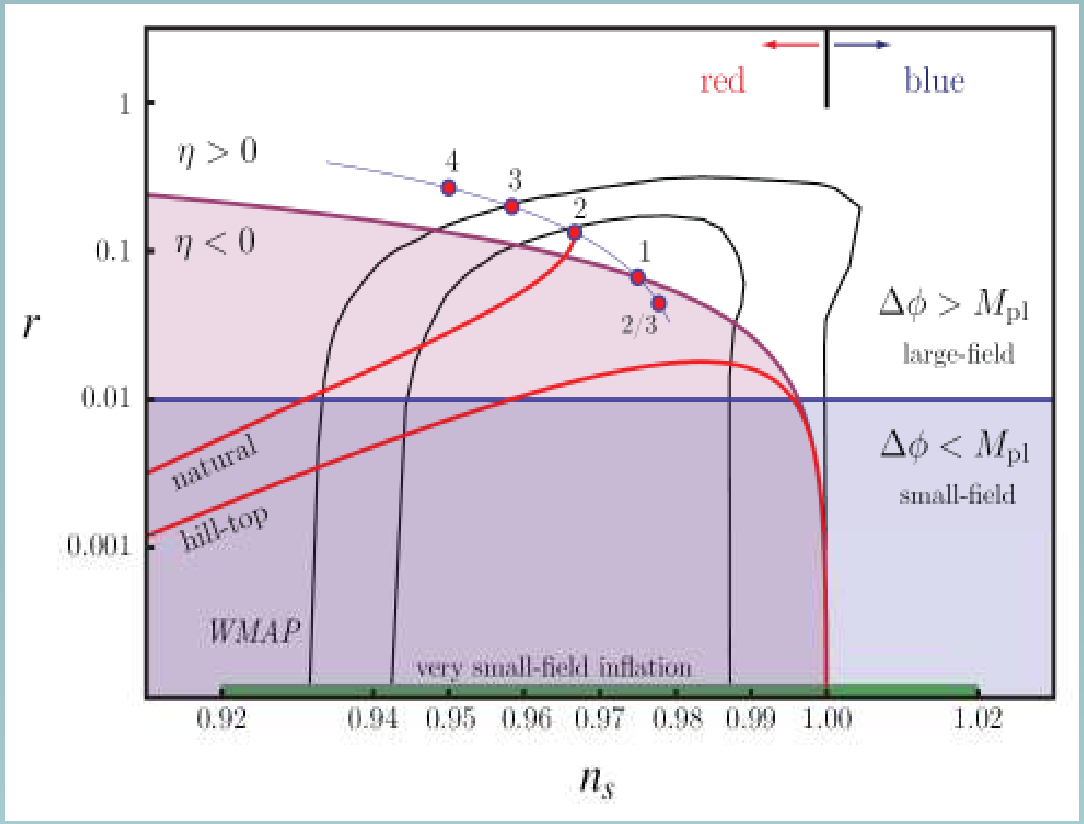
Current Constraints





$$n_s = 0.97 \pm .015 \quad (r \neq 0)$$

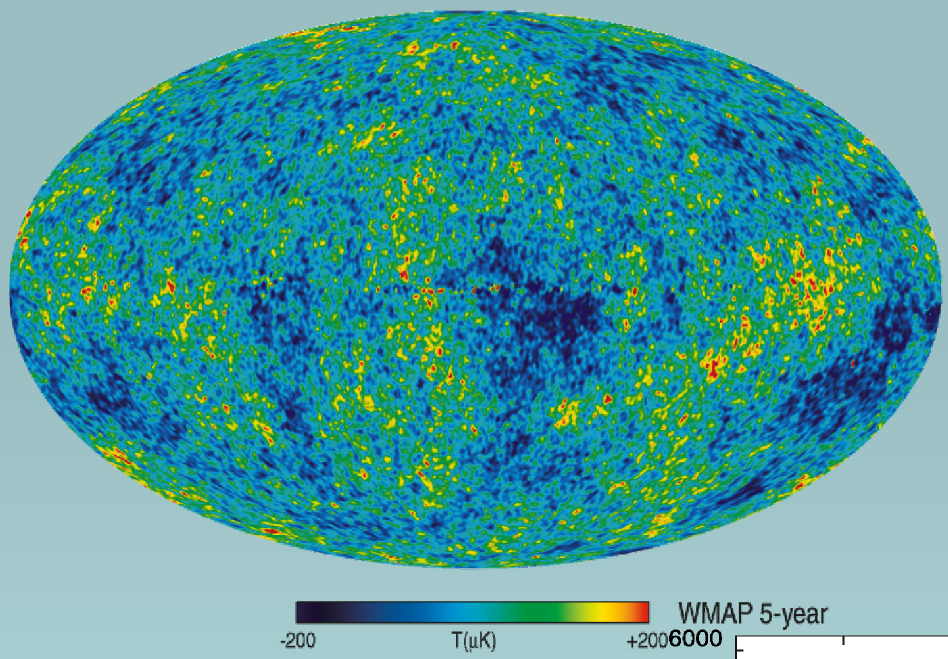
$$r < 0.22 \quad (95\%)$$

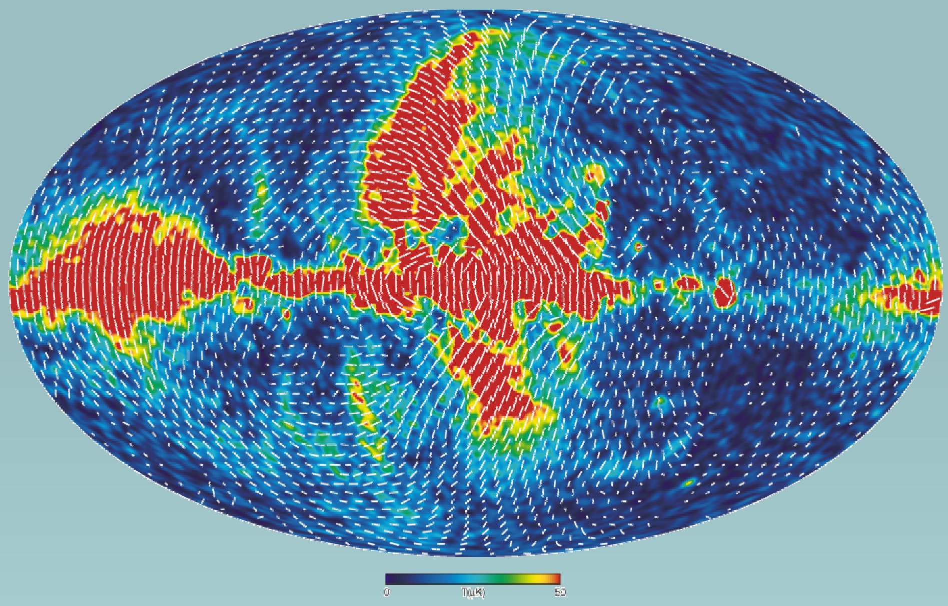
$$-9 < f_{NL}^{local} < 111$$

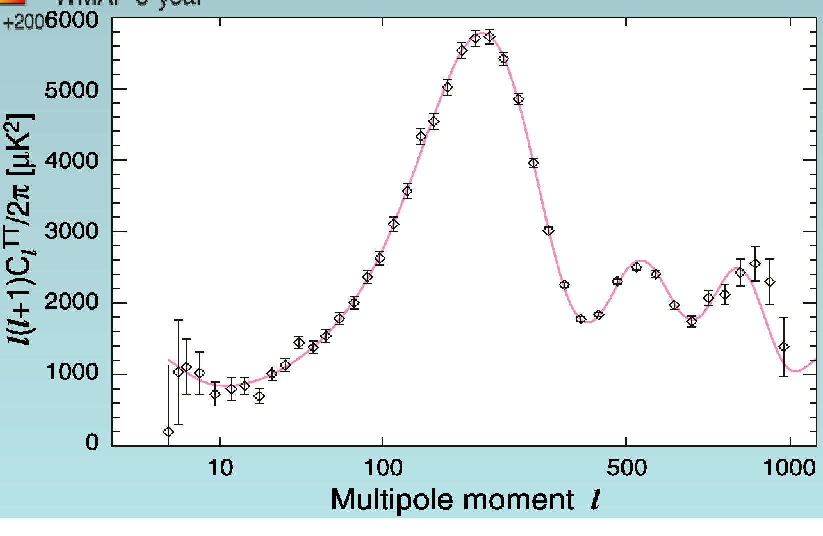
$$-151 < f_{NL}^{equil} < 253$$

Expect dramatic improvements in these limits in next 5-10 years: Planck, SPIDER, Clover, QUIET, BICEP, EBEX, PolarBEAR,...

Goal: develop theoretical models of the early universe suitable for an era of precision cosmology.







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Part II.

Inflation in String Theory: an extremely brief review

Why string inflation?

String theory provides:

- (many) fundamental scalar fields
- considerable UV control

Hope:

- use string theory to clarify UV issues in inflation
- use UV-sensitive aspects of inflation to constrain string theory – or at least, constrain string theory models of inflation

Warning: many aspects of inflation are not UV-sensitive.

Prospects for excitement

If vanilla inflation ($n_s<1$, $r=0$, $f_{NL}=0$) occurred, we may never get more clues about the inflaton sector than we have right now.

- We will have to be lucky.
- Fortunately, observationally non-minimal scenarios are often theoretically non-minimal!
  - Detectable tensors require a large field range, and this cries out for UV input (subject of this talk)
  - Large non-Gaussianity requires strong interactions and/or nontrivial kinetic terms, which are motivated and controllable in string theory. (e.g DBI scenario)

The challenge:

- Small-field inflation $\Delta\varphi \ll M_P$ requires controlling Planck-suppressed corrections up to dimension 6

$$\delta V = \frac{1}{M_P^2}\mathcal{O}_6 \Rightarrow \delta m_\varphi^2 \sim H^2$$

  Reasonable to enumerate and fine-tune these terms.

- Large-field inflation $\Delta\varphi > M_P$ requires control of Planck-suppressed contributions of arbitrary dimension!

$$\delta V \supset \varphi^4 \sum_{p=0}^{\infty} \lambda_p \left(\frac{\varphi}{\Lambda}\right)^p$$

  Symmetry clearly essential.

- Detectable tensors require super-Planckian displacements, so observations will distinguish these cases.

$$r \approx 0.01\left(\frac{\Delta\varphi}{M_P}\right)^2$$

  Lyth 1996

Status Report: Inflation in String Theory

- We now have many scenarios motivated or partially constructed in string theory.
- Modern models are far more realistic than those of 5-10 years ago. Moduli problem explicitly solved in some cases.
- Despite what one often hears in talks on the subject, making correct predictions is still very difficult!
  - A key lesson across scenarios has been that solving the moduli problem changes the scenario and can shift n_s, r dramatically. So one should be skeptical of predictions for these quantities in the absence of explicit stabilization.
- It is clear that many complete models will soon exist, but at present very few are worked out in enough detail to make correct predictions.
- Primordial tensor signature is an especially powerful discriminator, as we will see.

Part III.

Primordial Gravitational Waves
from
String Inflation

Vacuum Fluctuations: Tensors

$$\delta g_{ij} \equiv h_{ij} = h_+ e_{ij}^+ + h_\times e_{ij}^\times$$

$$\langle h(k) h(k') \rangle = \frac{2\pi^2}{k^3} \delta^3(k - k') \mathcal{P}_T$$

$$\mathcal{P}_T = \frac{8}{M_P^2} \left(\frac{H}{2\pi} \right)^2$$

$$\mathcal{P}_S = \left(\frac{H}{2\pi} \right)^2 \left(\frac{H}{\dot{\varphi}} \right)^2$$

$$r \equiv \frac{\mathcal{P}_T}{\mathcal{P}_S}$$

tensor-to-scalar ratio, a measure of the primordial tensor signal

May be visible through induced curl of CMB photons' polarization (B-mode): SPIDER, Clover, QUIET, BICEP, EBEX, PolarBEAR,...

Lyth Bound

D.H. Lyth, 1996

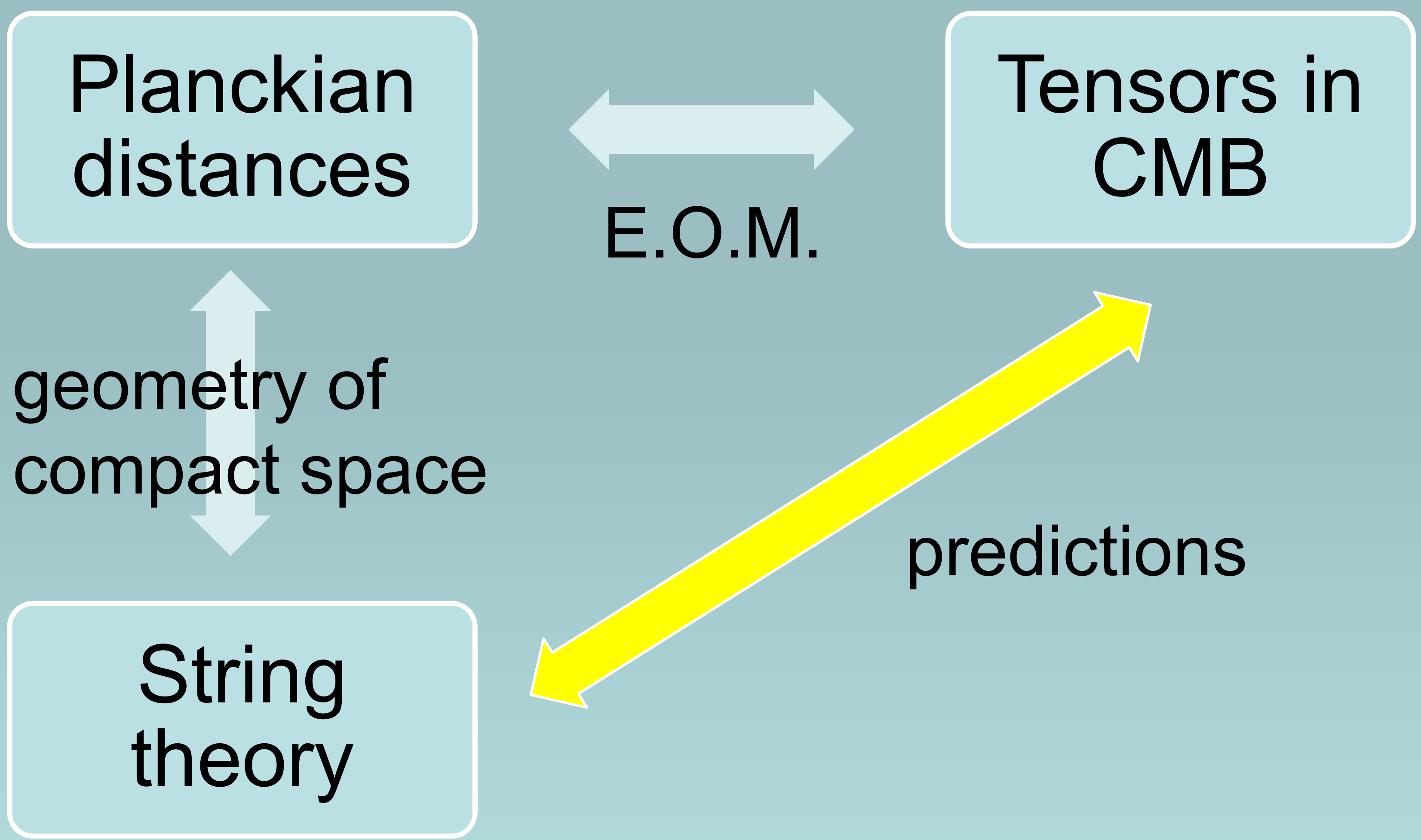
$$r_{CMB} \leq \frac{8}{N_{eff}^{2}} \left(\frac{\Delta\phi}{M_P} \right)^2_{MAX}$$

$$r \leq 0.009 \left(\frac{\Delta\phi}{M_P} \right)^2_{MAX}$$

Threshold for detection: $r \sim 10^{-2}$ next decade

$r \sim 10^{-3}$? ultimate

OBSERVABLE TENSORS REQUIRE TRANS-PLANCKIAN FIELD VARIATION WHICH REQUIRES ULTRAVIOLET INPUT.



Planckian distances
Tensors in CMB
E.O.M.
geometry of compact space
String theory
predictions

Part IV.

Linear Inflation from Axion Monodromy: Large-field Inflation in String Theory

L.M., Silverstein,& Westphal, 0808.0706

see also:

Silverstein & Westphal, 0803.3085.

Natural Inflation in string theory?

Freese, Frieman, & Olinto, 1990: $$V = \Lambda^4 \cos(\varphi / f)$$ $f > M_P$

Axion shift symmetry protects inflaton potential.

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

$f > M_P$ not attainable in string theory?

(cf. also Svrcek & Witten, hep-th/0605206)

Dimopoulos, Kachru, McGreevy, & Wacker, hep-th/0507205

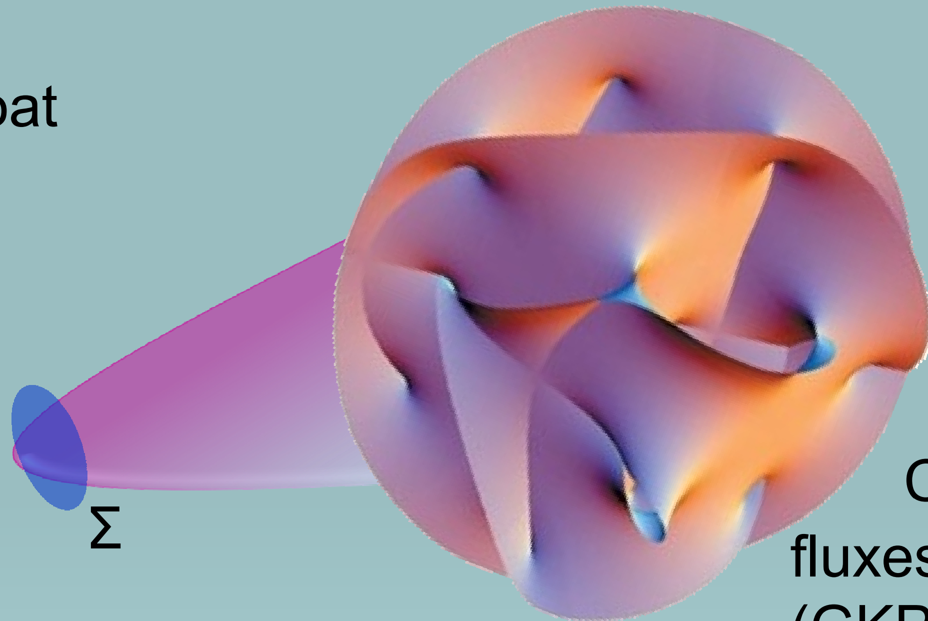
"N-flation": use $N \sim 10^3$ axions at once,

as a collective excitation.

Our idea: recycle a single axion N times.

Axion Inflation from Wrapped Fivebranes

warped throat

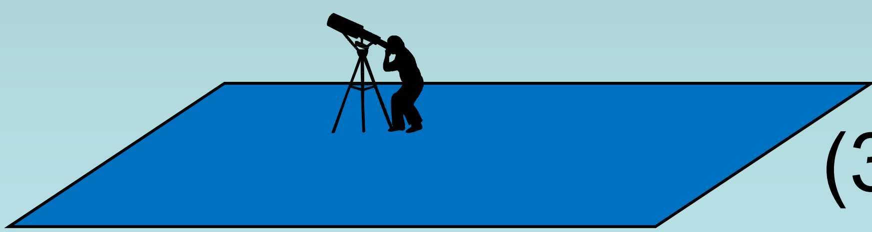


CY orientifold, with
fluxes and nonperturbative W
(GKP 2001, KKLT 2003)

D5-brane/NS5-brane

$$\int_\Sigma B_2 \qquad\qquad \int_\Sigma C_2$$

warped throat gives:
control of energy scales



(3+1)d

Axion monodromy from wrapped fivebranes

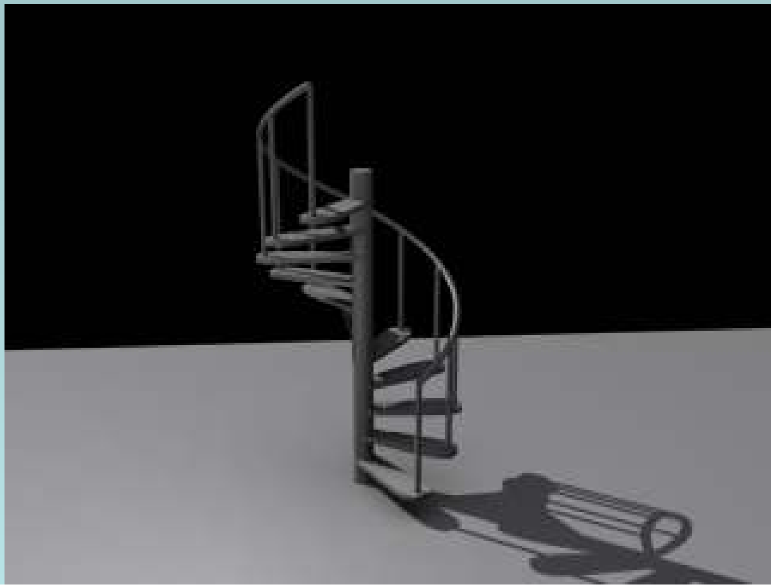
$$V = \int_\Sigma \frac{d^2\xi\, e^{-\Phi}}{(2\pi)^5 \alpha'^3}\sqrt{\det(G+B)} \approx \frac{1}{(2\pi)^5 g_s \alpha'^3}\sqrt{L^4+b^2} \approx \mu^3 \varphi_b$$

- Fivebrane contribution not periodic: as axion shifts by a period, potential undergoes a monodromy

  cf. inflation from D-brane monodromy Silverstein&Westphal, 0803.3085.

- This unwraps the axion circle and provides a linear potential over an *a priori* unlimited field range.

- In practice, controllable over large (>> M_P) but finite range.

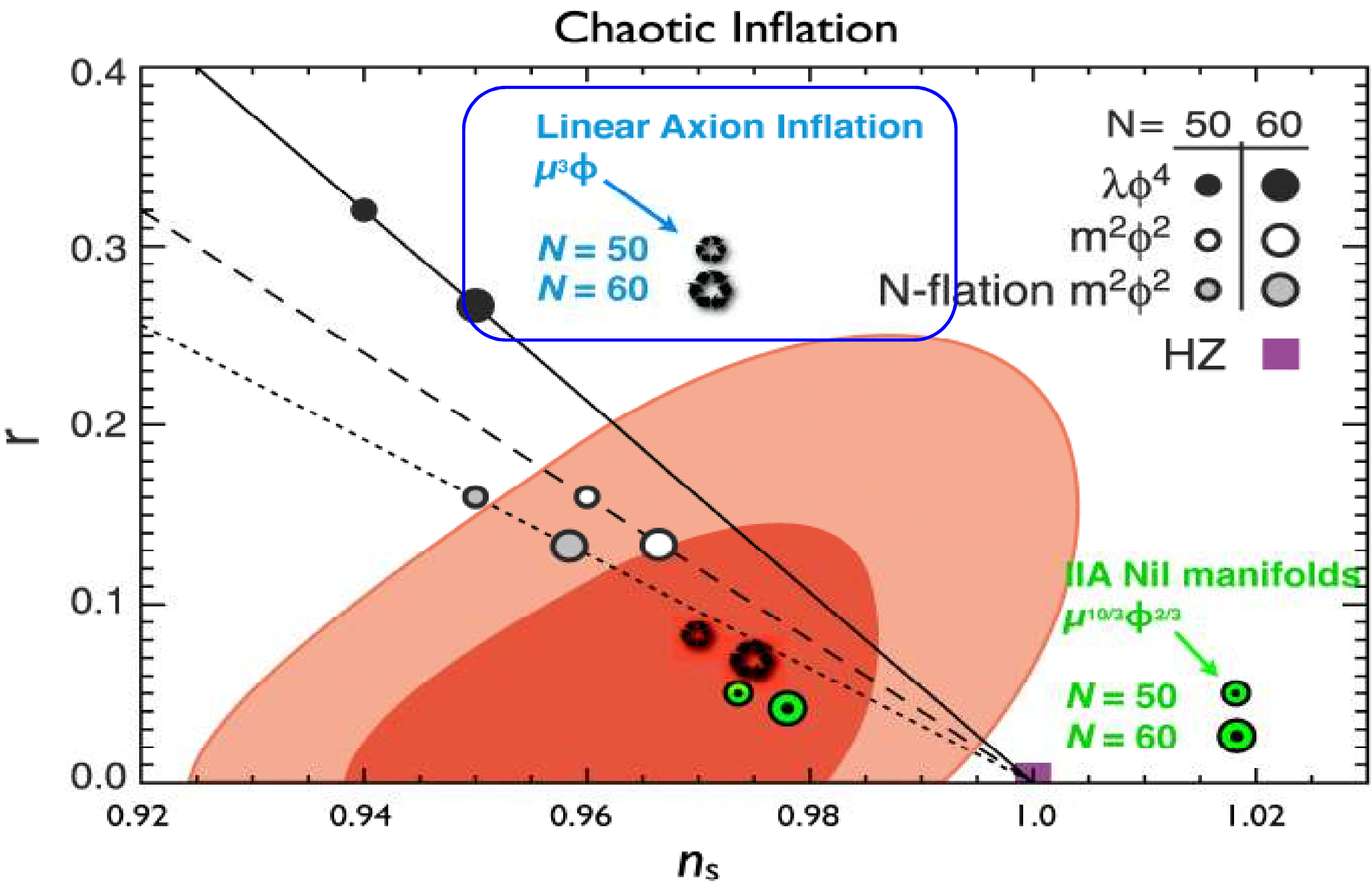


It Works

- Backreaction on local geometry can be made small.
- Checked consistency with moduli stabilization (KKLT scenario).
- Renormalization of Planck mass from many light species is small.

For very reasonable parameter choices, the instanton contributions to the effective action can be neglected, and the additional problems above are addressed.

- Assumptions Summarized:
  - NS5-brane wrapping a curve Σ that is in a warped region and stabilized at finite volume.
  - Remaining moduli stabilized as in KKLT, by fluxes and strong gauge dynamics (ED3 stabilization may be manageable as well).
  - Tadpole canceled by e.g. anti-NS5-brane on distant cycle homologous to Σ
- Reasonable to expect more efficient/minimal realizations.
- Core idea is very simple: the axionic shift symmetry protects the inflaton potential, just as in Natural Inflation.



Chaotic Inflation
Linear Axion Inflation
$\mu^3\phi$
$N = 50$
$N = 60$
N= 50 60
$\lambda\phi^4$
$m^2\phi^2$
N-flation $m^2\phi^2$
HZ
IIA Nil manifolds
$\mu^{10/3}\phi^{2/3}$
$N = 50$
$N = 60$
0.4
0.3
0.2
0.1
0.0
r
0.92
0.94
0.96
0.98
1.0
1.02
n_s

Conclusions

- We can construct string inflation models that are realistic, reasonably explicit, and falsifiable.
- These include examples of large-field inflation in string theory.
- General class of large-field models: axion monodromy from an NS5-brane wrapping a curve yields a linear potential for C_2 over a super-Planckian range.
  - ❑ Axion shift symmetry naturally controls contributions to the inflaton action.
  - ❑ Robust tensor prediction r=.07 can be falsified in 5-10 years.