Large-field Inflation with Multiple Axions and the Weak Gravity Conjecture

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Based on: arXiv:1504.03566 & work in progress

Outline

Introduction

Field excursion in N-axion models

Conclusions

Introduction

Inflation with Axions

Large-field inflation is sensitive to Planck-suppressed operators

→ use an axion as the inflaton

Freese, Frieman, Olinto 90

Shift symmetry protects inflaton potential from perturbative corrections

Non-perturbative scalar potential $V(\phi) \sim \cos\frac{\phi}{f}$ f: axion decay constant

Ubiquitous in string theory

However: $f > M_p$ difficult to realize

Banks, Dine, Fox, Gorbatov 03

Two main proposals to overcome this problem:

1. Axion monodromy (not in this talk)
2. Use multiple axions → field space diagonals with enhanced field range

Silverstein, Westphal 08
McAllister, Silverstein, Westphal 08
Marchesano, Shiu, Uranga 14; Blumenhagen, Plauschinn 14; Hebecker, Kraus, Witkowski 14

Kim, Nilles, Peloso 04
Dimopoulos, Kachru, McGreevy, Wacker 05
...

Is $f > M_p$ consistent in quantum gravity?

The Weak Gravity Conjecture

In any U(1) gauge theory coupled to gravity, ∃ at least one charged particle satisfying

$$m \lesssim g M_p$$

Arkani-Hamed, Motl, Nicolis, Vafa 06

Magnetically charged particles: $g \to 1/g$

Can be generalized to multiple U(1)'s

Cheung, Remmen 14

Axion version of the conjecture:

∃ at least one instanton satisfying

$$S \lesssim \frac{M_p}{f}$$

Intuitively:

instanton tension $S \leftrightarrow$ mass m,   instanton-axion coupling $1/f \leftrightarrow$ electric coupling g

Precise map to U(1)'s via T-dualities

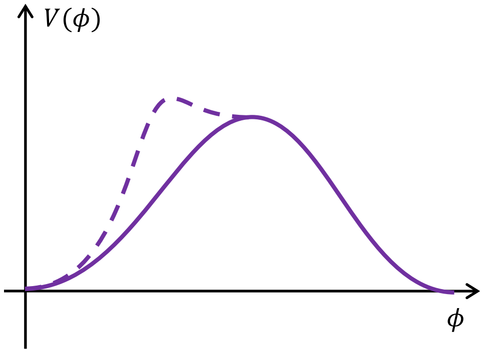
Brown, Cottrell, Shiu, Soler 15

Implications for large-field inflation?

Bound on field excursion?

(Multi-)instanton corrections to scalar potential:

$$V(\phi) \sim \mathrm{e}^{-nS}\left(1 - \cos\frac{n\phi}{f}\right)$$



Instantons are unsuppressed for $nS \lesssim 1 \overset{\text{WGC}}{\leftrightarrow} n \lesssim \frac{f}{M_p}$

→ $\Delta\phi$ constrained to be sub-Planckian

Possible loophole: instanton satisfying the WGC could be suppressed

→ bound on f would be relaxed

Brown, Cottrell, Shiu, Soler 15

Can such a loophole be realized in string theory?

Status quo: ongoing debate, outcome unclear

this talk: different perspective on the problem

Rudelius 14, 15
de la Fuente, Saraswat, Sundrum 14
Montero, Uranga, Valenzuela 15
Brown, Cottrell, Shiu, Soler 15
Bachlechner, Long, McAllister 15
Hebecker, Mangat, Rompineve, Witkowski 15

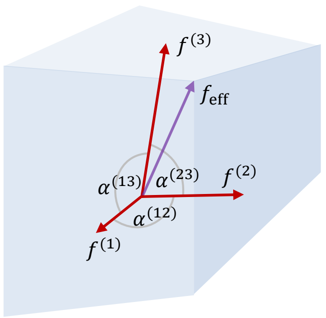
Field excursion in N-axion models

„Bottom-up" perspective

General scalar potential: $V(\phi_i) = \sum_{j=1}^{P} \Lambda_j^4 \left[1 - \cos\left(\sum_{i=1}^{N} c_{ij}\phi_i\right)\right]$

Fundamental domain: N-polytope, P instantons $\leftrightarrow$ $2P$ facets Bachlechner, Long, McAllister 14

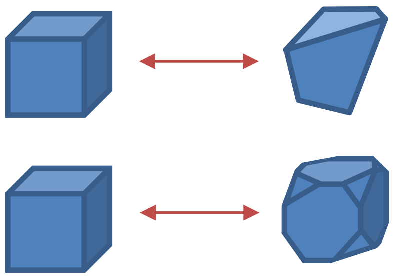
Max. field excursion $f_{\rm eff}$ is towards a vertex



→ Compute $f_{\rm eff}$ in terms of N distances $f^{(i)}$
and $\frac{N(N-1)}{2}$ angles $\alpha^{(ij)}$ encoded in $V(\phi_i)$

In general: any enhancement possible depending on

- Amount of alignment Kim, Nilles, Peloso 04
- Number of instantons P (facets)



Special cases:

N-flation	$f_{\rm eff} \sim \sqrt{N}$	Dimopoulos, Kachru, McGreevy, Wacker 05
power-law enhancement	$f_{\rm eff} \sim N, N^{3/2}$	Bachlechner, Long, McAllister 14
exponential enhancement	$f_{\rm eff} \sim n^N$	Choi, Kim, Yun 14

Quantum gravity constraints

WGC: Assuming a strict bound on f_{eff},
how would string theory forbid a parametric enhancement $f_{\text{eff}} \sim N^x$ for large N?

Several possibilities:

- Individual $f^{(i)}$'s are downscaled such that
  naive enhancement is cancelled, $f^{(i)} \sim N^{-x}$
  May be true up to some N but cannot hold parametrically due to magnetic WGC

- No string compactifications exist beyond a certain N
  No evidence, Calabi-Yau's can easily yield several 1000 axions. Moduli stabilization?

- 4D Planck mass renormalization: $M_{\text{p}} \sim N^x$
  Argued to scale at most like $M_{\text{p}} \sim \sqrt{N}$, milder in actual string models (at NLO)

Dvali 07
Bachlechner, Long, McAllister 14

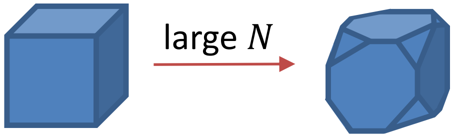
- New unsuppressed instanton contributions to $V(\phi)$

- Loophole?

Quantum gravity constraints

How many instantons are required in order to bound the field range (= no parametric enhancement) at large N?

Simple example: N-cube ($P = N$)



cap off 2^N vertices along which $f_{\mathrm{eff}} \sim \sqrt{N}$

→ exponentially large number $P \sim 2^N$ of unsuppressed terms in the scalar potential

cf. typical string compactifications: $P \approx N$

Similar conclusion applies to general polytopes:

Use algorithm for f_{eff} to test polytopes with $P \sim N, \;\; P \sim N^2, \;\; P \sim 2^N$

→ parametric enhancement unless P grows faster than quadratically with N

suggests loophole such that bound $f_{\mathrm{eff}} < M_p$ can be violated at large N

Conclusions

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- Weak gravity conjecture puts constraints on large-field inflation with axions

  Open question: strict bound on the axion field range or loopholes possible?

- Different perspective: how would string theory actually ensure a bound at large N?

  Enormous number of instanton corrections required, alternative explanations also problematic → suggests existence of a loophole

- Future work: construct explicit models realizing a loophole or else show that such models must fail on a fundamental level

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Thank you!