Why is the Inflaton Light?

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Based mostly on

recent work with

Daniel Green

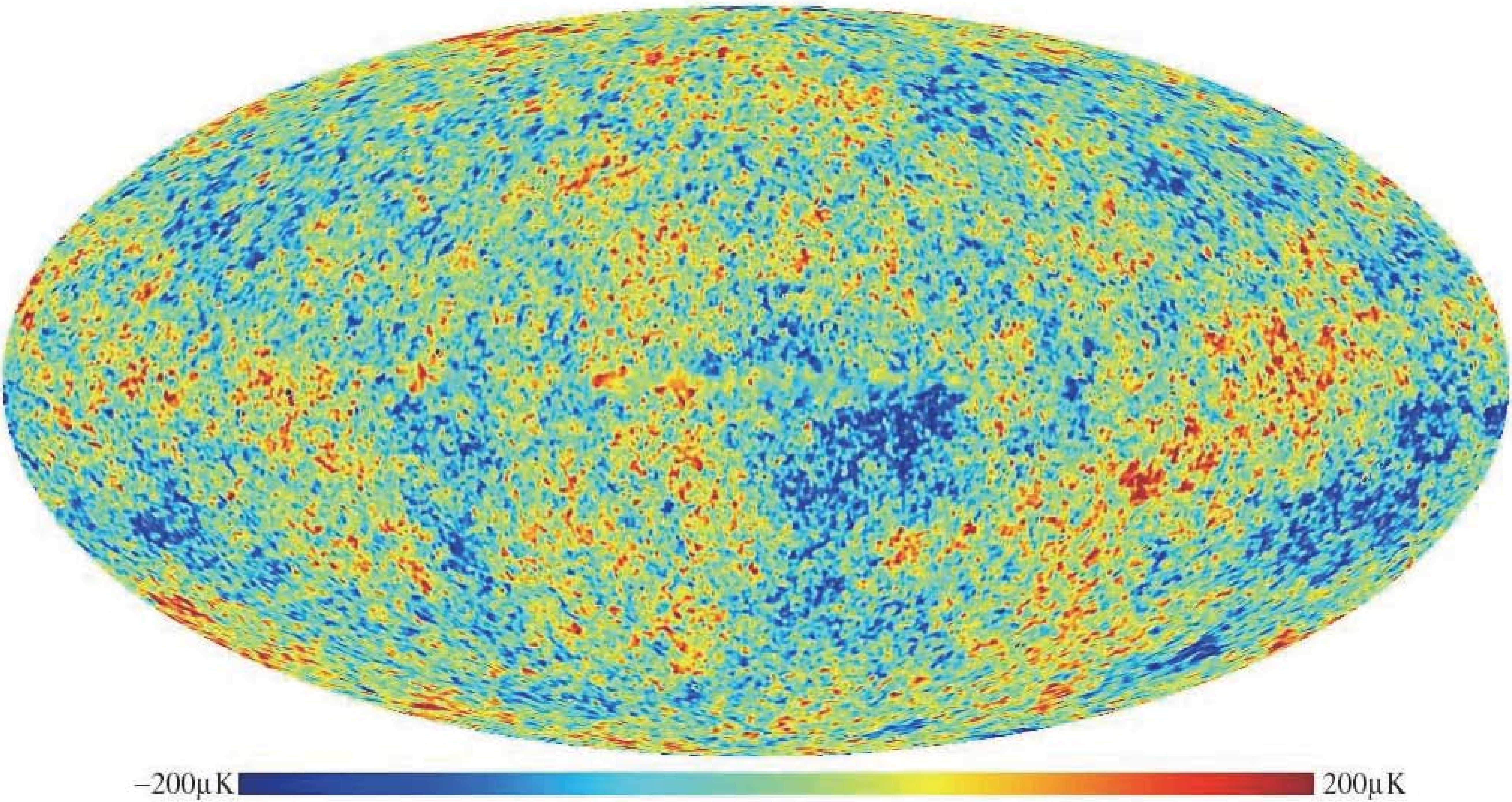
arXiv: 1004.3801, 1009.3032

and a series of works with

Liam McAllister, Anatoly Dymarsky, Shamit Kachru,
Igor Klebanov, and Juan Maldacena

arXiv: hep-th/0607050, 0705.3837, 0706.0360,
0808.2811, 0912.4268, 1001.5028

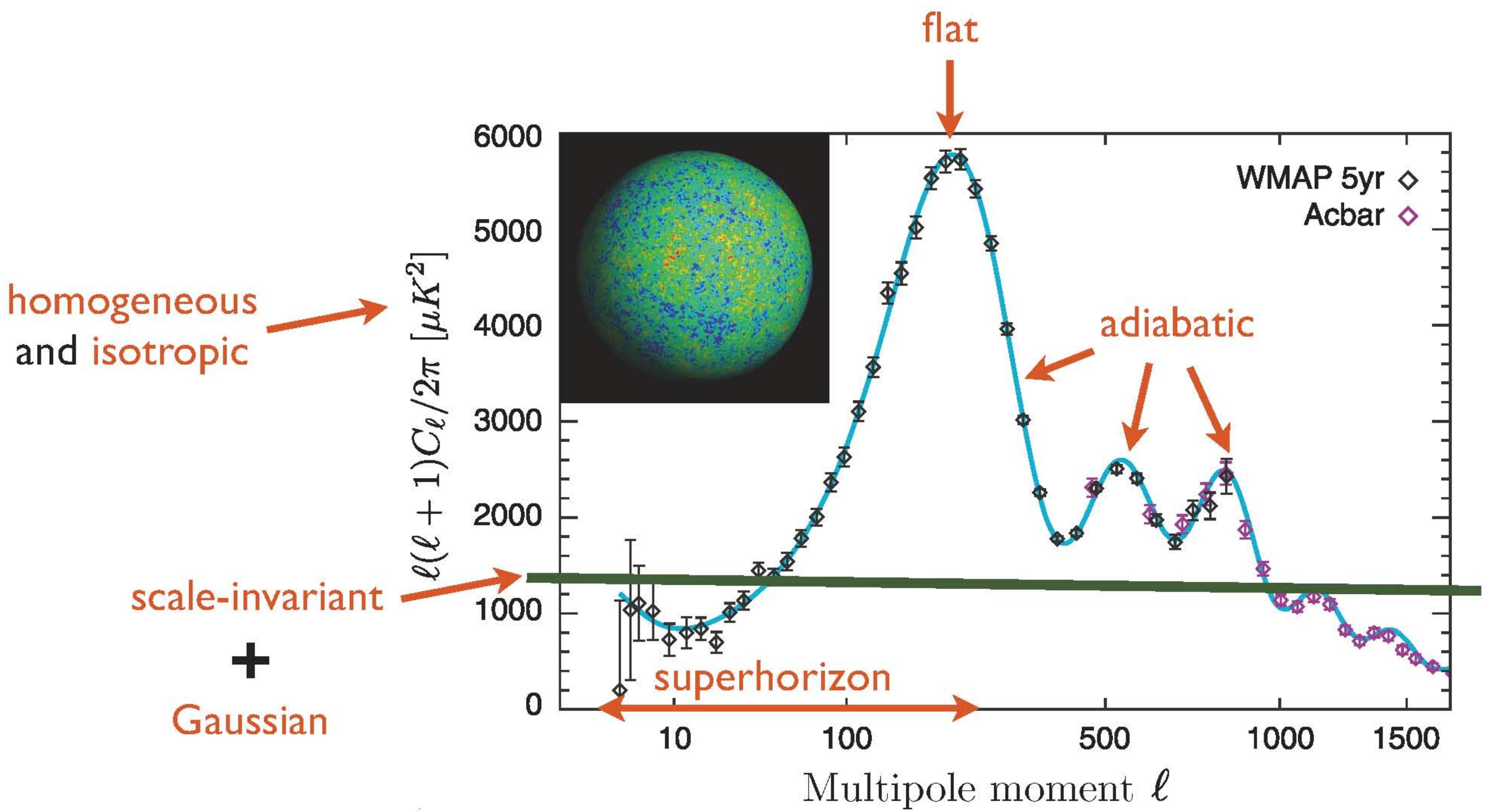
What is the Origin of Structure?



Inflation

Guth (1980)

... is an elegant explanation for the data:



Inflation is sensitive to Planck-scale physics!

Planck-suppressed operators make critical contributions to the inflaton mass.

Slow-Roll Inflation

model inflation by the evolution of a scalar field

$$\boxed{\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi)}$$

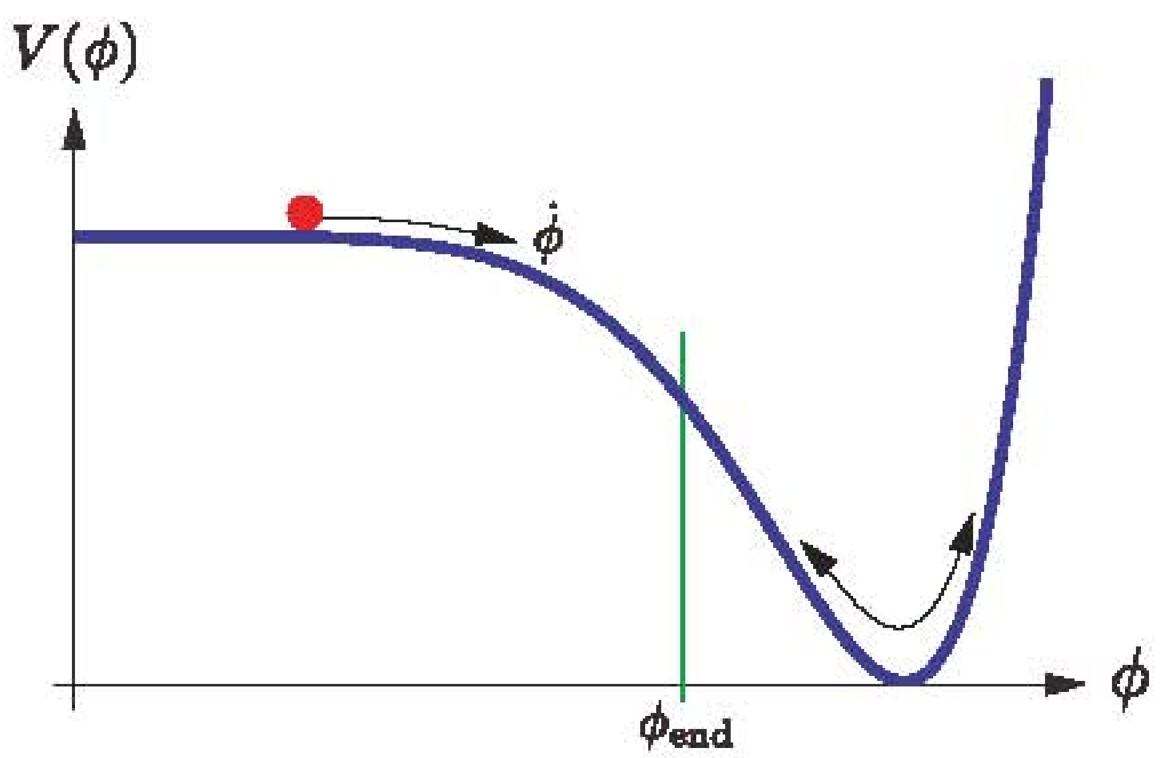
60 e-folds of quasi-de Sitter requires:

$$\varepsilon = \frac{M_{\rm pl}^2}{2}\left(\frac{V'}{V}\right)^2 \ll 1$$

$$\eta = M_{\rm pl}^2\frac{V''}{V} \ll 1$$

measure of the inflaton mass

$$\eta \approx \frac{m_\phi^2}{H^2}$$



Linde (1982), Albrecht and Steinhardt (1982)

Inflation in EFT

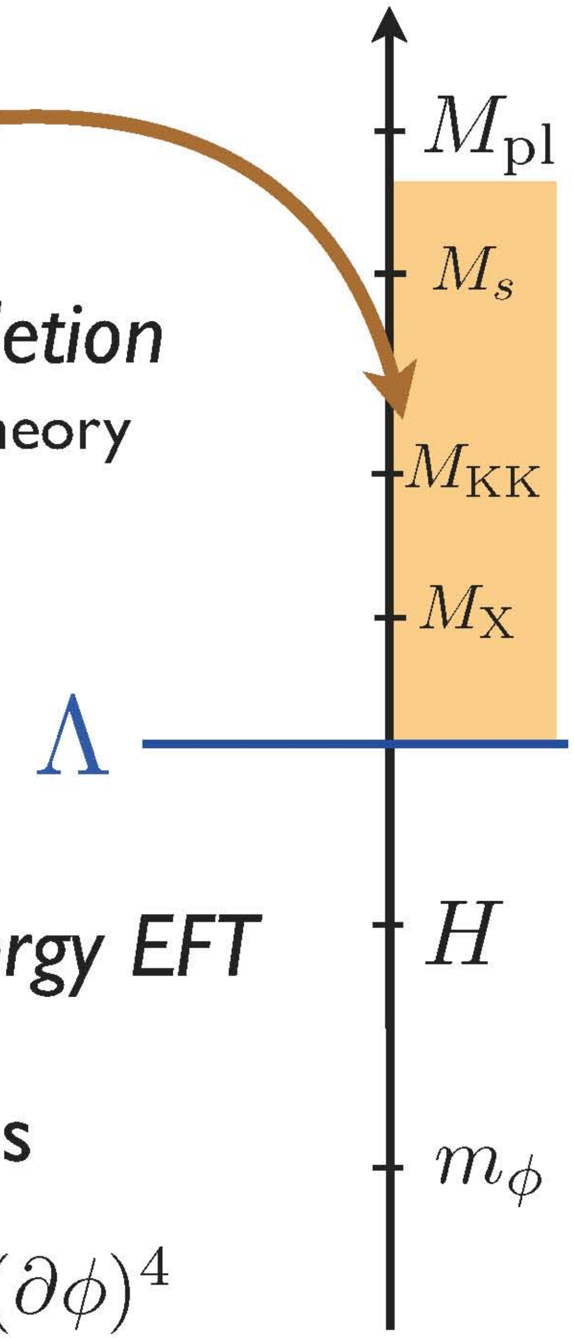
- If we begin with a UV-complete theory, we derive an effective description by integrating out massive fields $M > \Lambda$

- Otherwise, we parameterize our ignorance of the UV theory by writing the most general EFT consistent with (postulated) symmetries

UV-completion

e.g. string theory

low-energy EFT



★ Result:

new non-renormalizable interactions among the light fields

$$\Delta\mathcal{L} = \frac{\mathcal{O}_\Delta}{\Lambda^{\Delta-4}} \qquad \text{e.g.} \quad \frac{\phi^6}{\Lambda^2} \quad \frac{(\partial\phi)^4}{\Lambda^4}$$

★ ***In inflation, even Planck-suppressed interactions cannot be ignored!***

The Eta Problem

Given some $V(\phi)$ with $\eta = M_{\rm pl}^2 \frac{V''}{V} \ll 1$

add ***Planck-scale corrections***

$$V(\phi) \;\rightarrow\; V(\phi) + c_1 \frac{\phi}{M_{\rm pl}} V(\phi) + c_2 \frac{\phi^2}{M_{\rm pl}^2} V(\phi) + \cdots$$

where $c_i \sim 1$

$\boxed{\varepsilon \sim (c_1)^2}$ $\boxed{\eta \sim c_2 \sim 1}$

Inflation is sensitive to ***dimension 5 and 6 Planck-suppressed operators***

The Eta Problem

Can we compute the corrections ?

In *small-field inflation* only a finite number of operators contribute to the inflaton mass

Given a UV-complete theory we can therefore in principle compute all relevant corrections

In some region of parameter space the corrections may cancel against each other to give a small inflaton mass.

e.g. brane inflation

The Eta Problem

Can we forbid corrections with a symmetry ?

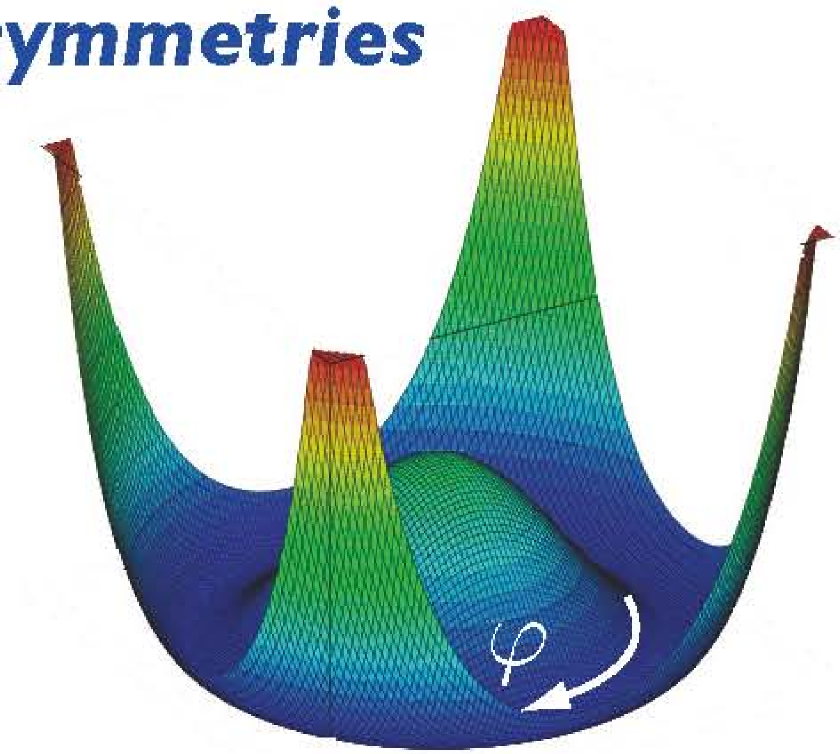
dangerous corrections are forbidden
if the inflaton respects a ***shift symmetry***

$$\varphi \rightarrow \varphi + const.$$

arise naturally in theories with
spontaneous breaking of global symmetries

Inflaton = ***Pseudo-Nambu Goldstone Boson***

$$\phi = \rho\, e^{i\varphi/f}$$



spontaneously broken global U(1)

Global Symmetries in QG

"Quantum gravity breaks global symmetries."

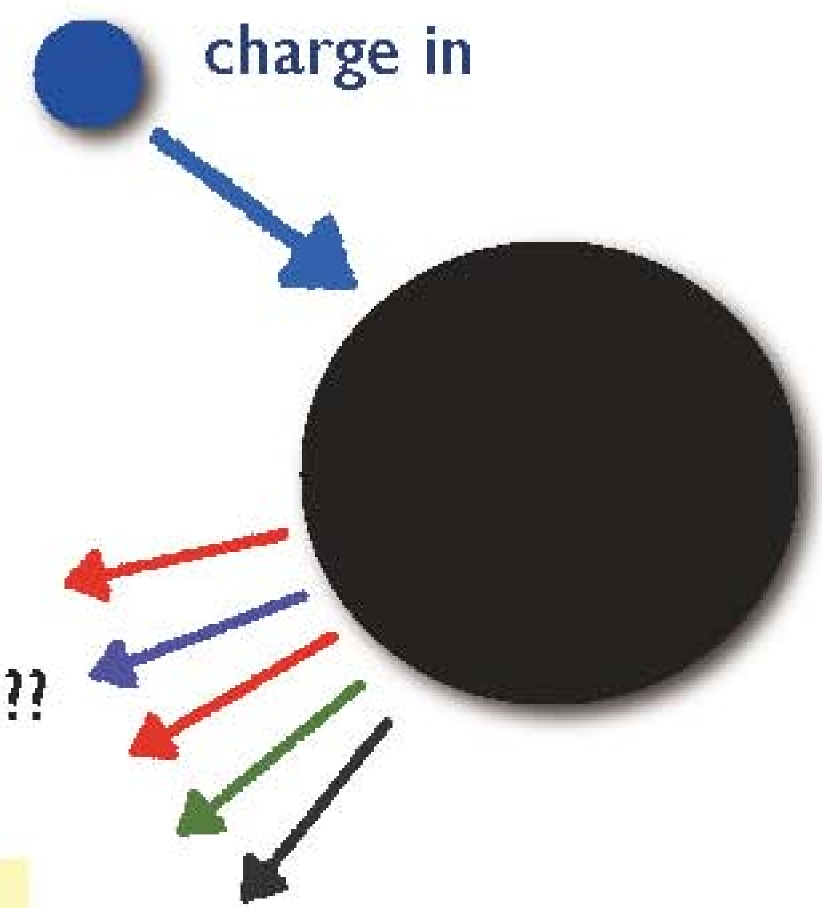
This is a theorem in perturbative string theory

Banks et al. (1999)

More generally:

Black evaporation violates global symmetries

e.g. Kallosh et al. (1995)



The associated Planck-suppressed operators reintroduce the eta problem !

Outline

1. Inflating with Baryons

   Suppress dangerous UV corrections with a ***gauge symmetry***

2. Sequestering the Planck-Scale

   Suppress dangerous UV corrections with ***RG flow***

3. D-brane Inflation

   Cancel *dangerous UV corrections against each other*

Inflating with Baryons

with Daniel Green

Proton Decay in the SM

experimental fact:

the proton has a very long lifetime

"I can feel it in my bones."
Wigner (1943)

imagine we didn't know about quarks and treated the proton as fundamental:

dimension 5 Planck-suppressed operators

$$\frac{p\,\mathcal{O}}{M_{\rm pl}}$$

$\longrightarrow$

induce rapid proton decay

$$\Gamma \sim \frac{m_p^3}{M_{\rm pl}^2} \sim 10^{-13} s^{-1}$$

Proton Decay in the SM

experimental fact: the proton has a very long lifetime

explanation:

the Standard Model has an

"accidental" baryon number symmetry

i.e. given the gauge symmetries and the particle content of the SM, there are no renormalizable interactions that violate baryon number

in fact, there are NO dimension 5 operators

leading operators are dimension 6

$$\frac{qqq\,l}{M_{\rm pl}^2}$$

☑

Can we solve the eta problem in a similar way?

A New Solution to the Eta Problem

↓

Find a theory with an accidental global symmetry because its gauge symmetries and field content forbid symmetry breaking operators with dimensions less than 7

existence proof:

baryons in SUSY QCD

Supergravity Eta Problem

Copeland et al.

$$V = e^{K/M_{\rm pl}^2}\left[K^{\Phi\bar{\Phi}} D_\Phi W \overline{D_\Phi W} - \frac{3}{M_{\rm pl}^2}|W|^2\right]$$

F-term vacuum energy drives inflation: $D_X W = \mu^2$

$$V = \mu^4\left[1 + \frac{K}{M_{\rm pl}^2} + \cdots\right]$$

$$K = \Phi^\dagger\Phi \xrightarrow[\varphi \equiv |\Phi|]{} \eta = 1 + \cdots$$

tied to kinetic term

extra terms from $W(\Phi)$

can lead to (fine-tuned) cancellations

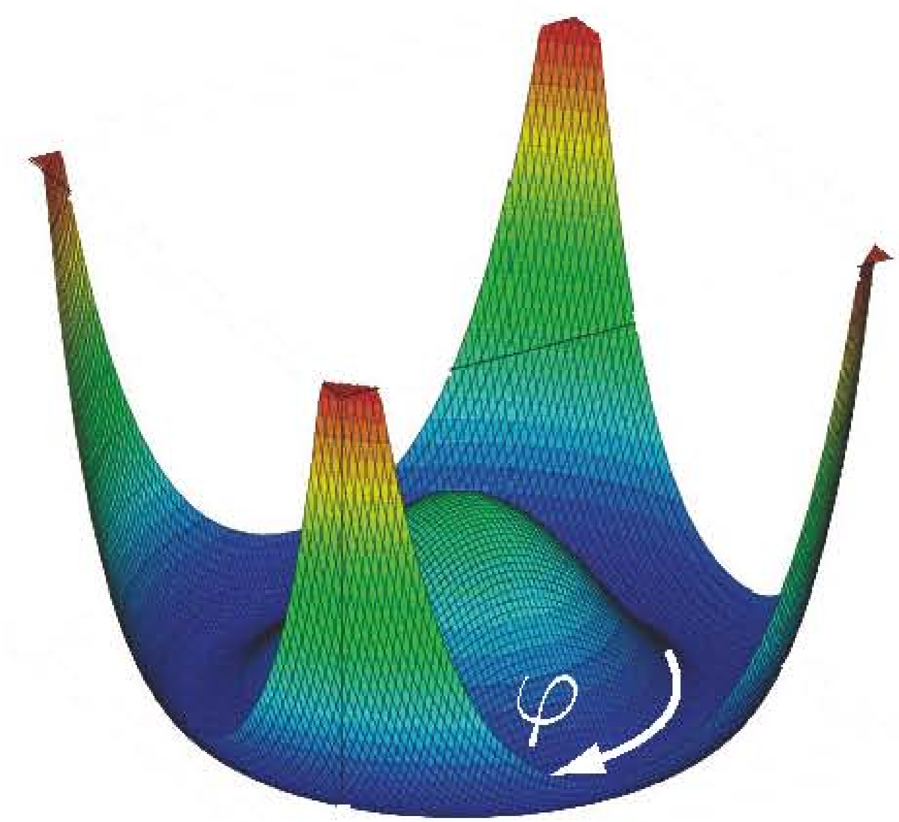
cf. brane inflation

PNGBs in SUGRA

no mass for

$$\Phi = f e^{\phi} \longrightarrow K = \Phi^\dagger \Phi = f^2 e^{\phi+\phi^\dagger} \longrightarrow \varphi \equiv f\,\mathrm{Im}(\phi)$$

i.e. "a Goldstone boson coupled to gravity is a Goldstone boson"



mass is only generated by explicit symmetry breaking

A Simple Model

vacuum energy spontaneous symmetry breaking

$$W = -X\mu^2 + S(\Phi\tilde{\Phi} - f^2)$$

spurion

singlet

chiral superfields

breaking scale

$$F_X = \mu^2 \qquad F_S = 0$$

$$V_0 = \mu^4 \qquad \Phi = f e^{\phi} \quad \tilde{\Phi} = f e^{-\phi}$$

$$\boxed{\begin{array}{c}\textit{inflaton = PNGB}\\ \varphi = f\,\mathrm{Im}(\phi)\end{array}}$$

A Simple Model

vacuum energy — spontaneous symmetry breaking

$$W = -X\mu^2 + S(\Phi\tilde{\Phi} - f^2)$$

add *waterfall fields* to end inflation

$$\Delta W = m(\varphi)\,\psi\tilde{\psi} + y^2 X\,\psi^2$$

inflaton-dependent mass

e.g. $m(\varphi) = \Phi + \tilde{\Phi}$

$m(\varphi \approx 0) \gg y\mu \qquad V \approx V_0 > 0$

$m(\varphi = \varphi_\star) < y\mu \qquad V \to 0$

$\longrightarrow$ *hybrid inflation*

A Simple Model

Pseudo Natural Inflation

Arkani-Hamed et al.

$$\boxed{W = S(\Phi\tilde{\Phi} - f^2) + \lambda(\Phi + \tilde{\Phi})\,\psi\tilde{\psi} + X(y^2\psi^2 - \mu^2)}$$

Planck-Scale Corrections

Pseudo Natural Inflation

Arkani-Hamed et al.

$$\boxed{W = S(\Phi\tilde{\Phi} - f^2) + \lambda(\Phi + \tilde{\Phi})\,\psi\tilde{\psi} + X(y^2\psi^2 - \mu^2)}$$

ΔK

Dimension 5: $c\,\frac{\Phi}{M_{\rm pl}} X^\dagger X \longrightarrow \eta = c\,\frac{M_{\rm pl}}{f} \gg 1$

Dimension 6: $(c_0\,\Phi^\dagger\tilde{\Phi} + c_1\,\Phi^2 + c_2\,\tilde{\Phi}^2)\frac{X^\dagger X}{M_{\rm pl}^2}$

$$\downarrow$$

$$\boxed{\eta = c_i \sim 1}$$

ΔW many dangerous corrections.

Goal: Construct a model of inflation that is insensitive to Planck-scale corrections.

↓

baryons in SUSY QCD

SUSY QCD

Consider $SU(N_c)$

with $N_f > 3N_c$ (IR free) flavors of quarks $(q_i)_a$

and anti-quarks $(\tilde{q}_i)^a$

flavor index, gauge index

two types of composite operators:

mesons $\mathcal{M}_{ij} = (q_i)_a (\tilde{q}_j)^a$

baryons $\mathcal{B}_{i..k} = \epsilon^{a..d} (q_i)_a .. (q_k)_d$

Baryon Symmetry

$U(1)_B$

$$F \to e^{iQ_B\alpha} F$$

		Q_B	Δ
quarks	q_i	$+1$	1
	$\tilde{q}_i$	-1	1
mesons	$\mathcal{M}_{ij}$	0	2
baryons	$\mathcal{B}_{i..k}$	$+N_c$	N_c
	$\tilde{\mathcal{B}}_{i..k}$	$-N_c$	N_c

$N_c \geq 3 \longrightarrow$ all baryon symmetry violating operators are irrelevant !

Inflating with Baryons

use the phase of a baryon as the inflaton

vacuum energy — spontaneous symmetry breaking

$$W = -X\mu^2 + S^{mn}(q_m\tilde{q}_n - f^2\delta_{mn})$$

flavor indices
$m, n = 1..N_c$

$$F_X = \mu^2 \qquad\qquad F_S = 0$$

$$\downarrow \qquad\qquad \downarrow$$

$$V_0 = \mu^4$$

$$(q_m)_a = f e^{i\frac{\varphi}{f}}\delta_{m,a}$$

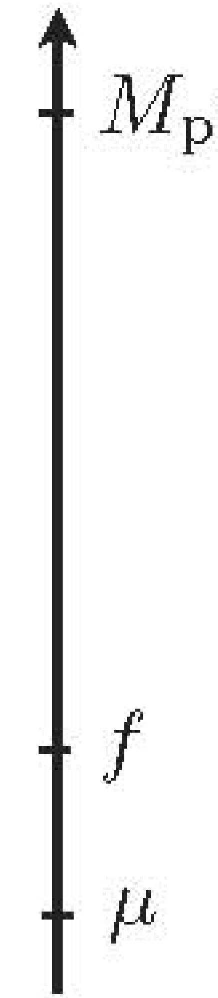
$$(\tilde{q}_n)^a = f e^{-i\frac{\varphi}{f}}\delta_n^a$$

Absence of the Eta Problem

Kähler Corrections

$$\Delta K = \frac{\mathcal{B}}{M_{\rm pl}^{N_c}} X^\dagger X \quad \longrightarrow \quad \Delta\eta = \left(\frac{f}{M_{\rm pl}}\right)^{N_c-2}$$

$\boxed{N_c \geq 3}$ *no Kähler corrections !!*



Superpotential Corrections

$$\Delta W = \frac{\mathcal{B}}{M_{\rm pl}^{N_c-2}} X \quad \longrightarrow \quad \Delta\eta = \left(\frac{f}{M_{\rm pl}}\right)^{N_c-4} \frac{f^2}{\mu^2}$$

$\boxed{N_c \geq 5}$ *everything suppressed !!*

How to End it?

add *waterfall fields* to end inflation

$$\Delta W \;=\; m(\varphi)\,\psi\tilde{\psi} \,+\, y^2 X\,\psi^2$$

simplest possibility

$$m(\varphi) = \lambda \frac{\mathcal{B}+\tilde{\mathcal{B}}}{M_{\rm pl}^{N_c-1}} \to \lambda f \left(\frac{f}{M_{\rm pl}}\right)^{N_c-1} \cos(\varphi/f)$$

problem: *mass of the waterfall has to be bigger than Hubble*

$$m \gg H \sim \frac{\mu^2}{M_{\rm pl}} \longrightarrow \lambda \gg (\Delta\eta)^{-1}\frac{M_{\rm pl}^2}{f^2} \gg 1$$

How to End it?

inflaton-waterfall coupling: $\lambda \dfrac{\mathcal{B}+\tilde{\mathcal{B}}}{M_{\mathrm{pl}}^{N_c-1}}\psi\tilde{\psi}$

problem: *mass of the waterfall can't be bigger than Hubble*

reason: *coupling between the inflaton and the waterfall is irrelevant*

solution: *mediate the baryon symmetry breaking effects by relevant couplings of quarks to larger representations of $SU(N_c)$*

I will illustrate this solution to the graceful exit problem with a concrete examples:

SU(5) SUSY QCD

An Explicit SU(5) Model

matter content

quarks q

baryons $\mathcal{B}$

waterfall ψ ⟵ singlet

messenger h ⟵ larger representation

$$\mathbf{10} \qquad h_{ab}$$

allows couplings to quarks
that break the baryon symmetry

e.g.

$$qhh \equiv \epsilon^{abcde} q_a h_{bc} h_{de}$$

we will use these couplings to construct marginal
operators that couple the inflaton to the waterfall fields

An Explicit SU(5) Model

$$W \supset m\psi\tilde{\psi} + \lambda\, q_1 h h$$ waterfall mass

$$+ (\psi q_3 + \tilde{q}_2 \cdot h) \cdot \tilde{Q}_6 + (\tilde{\psi} q_5 + \tilde{q}_4 \cdot h) \cdot \tilde{Q}_7$$ mediation

$$h_{23} = \psi\, e^{2i\frac{\varphi}{f}} \qquad h_{45} = \tilde{\psi}\, e^{2i\frac{\varphi}{f}}$$

$$\varphi \longleftrightarrow h \longleftrightarrow \tilde{Q} \longleftrightarrow \psi \longrightarrow m(\varphi)\,\psi\tilde{\psi}$$

An Explicit SU(5) Model

$$W \supset m\psi\tilde{\psi} + \lambda q_1 hh$$ waterfall mass

$$+ (\psi q_3 + \tilde{q}_2 \cdot h) \cdot \tilde{Q}_6 + (\tilde{\psi} q_5 + \tilde{q}_4 \cdot h) \cdot \tilde{Q}_7$$ mediation

$$h_{23} = \psi\, e^{2i\frac{\varphi}{f}} \qquad h_{45} = \tilde{\psi}\, e^{2i\frac{\varphi}{f}}$$

$$\boxed{W_{\text{eff}} = m\left(1 + d\, e^{5i\frac{\varphi}{f}}\right)\psi\tilde{\psi} + X\left(y^2\psi^2 - \mu^2\right)}$$

where $d \equiv \dfrac{\lambda f}{m}$

This is just our U(1) model,
but with the U(1) now *explained* !

(add Kähler and superpotential corrections as you wish)

Revisiting the Eta Problem

We added extra representations.

Do these introduce new dangerous contributions to eta?

NO

DB and Daniel Green

key point:

because the waterfall and mediator fields have ***zero vev's*** during inflation any operator coupling them to the inflaton field only corrects the inflaton potential at ***one-loop***

→ this is sufficient to keep eta small.

Summary

Explained origin of approximate U(1) symmetry !!

Baryon symmetry was only broken by irrelevant operators.

Constructed an explicit inflationary model

SU(5) gauge group

Waterfall fields in 10 + 1 representations

... without an eta problem !

All contributions to eta suppressed
(both Kähler and superpotential)

Sequestering the Planck-Scale

with Daniel Green

D-brane Inflation

with Dymarsky, Kachru, Klebanov, Maldacena and McAllister

In ***string inflation*** the dangerous UV corrections can arise from a variety of effects:

- string loop corrections
- α' corrections
- backreaction effects
- ...

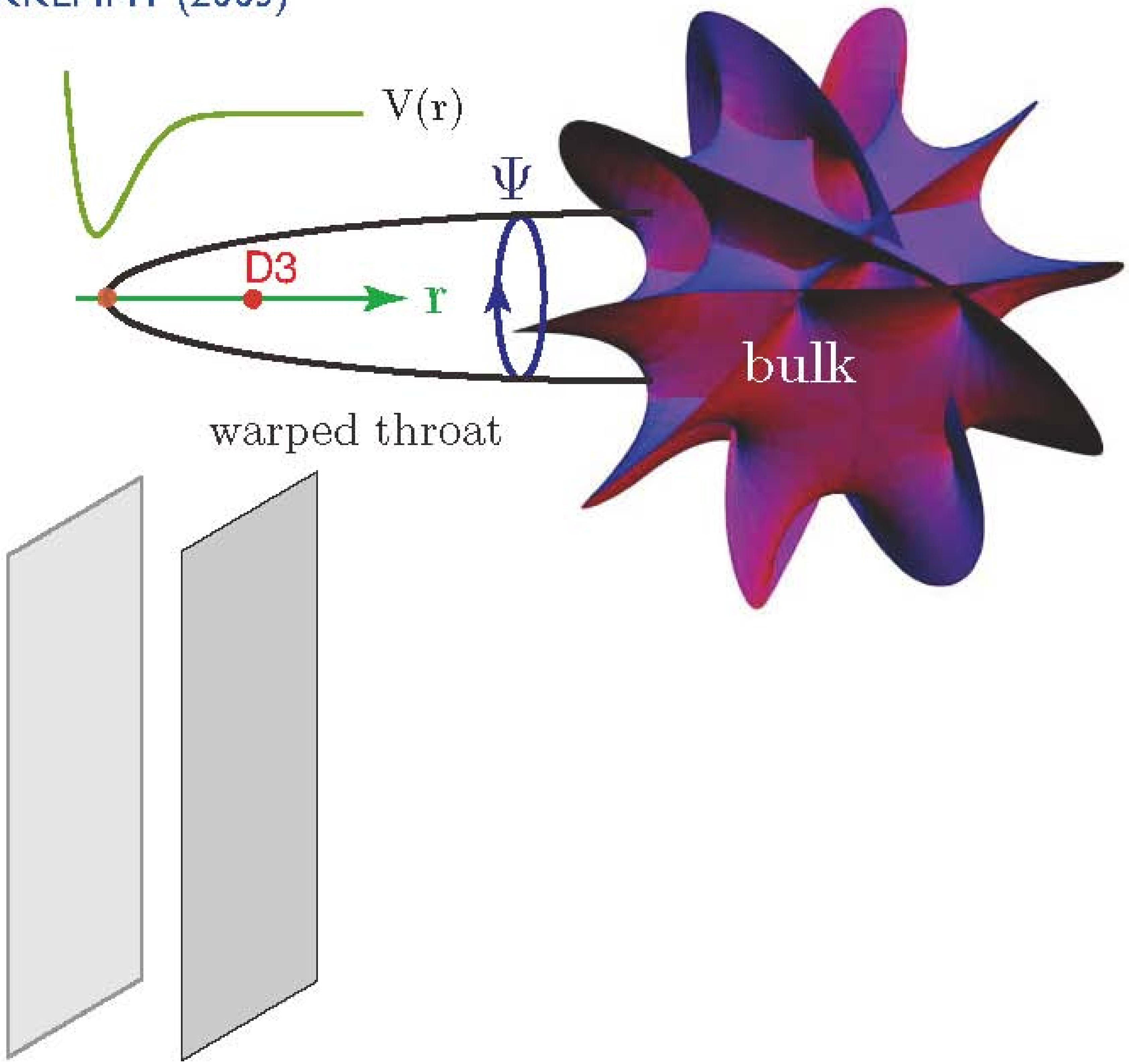
- In practice, most of these contributions may be understood as arising from ***integrating out massive moduli***.

- Computing the inflaton potential therefore requires detailed information about ***moduli stabilization***.

In ***brane inflation*** we have a systematic way to characterize these effects.

Warped D-brane Inflation

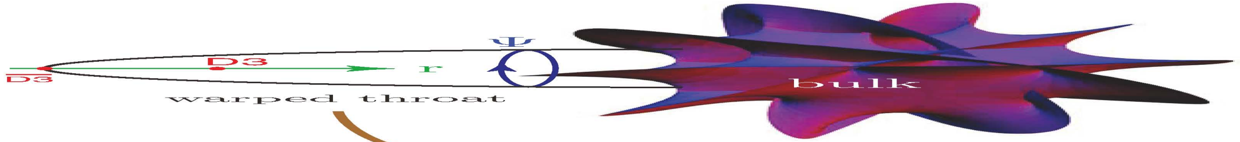
Dvali & Tye (1996), KKLMMT (2003)



Local Geometry

Warped Cones in Compact Spaces

$\times$



$$ds^2 = e^{2A(r)} \underbrace{g_{\mu\nu} dx^\mu dx^\nu}_{4d\ \text{spacetime}} + e^{-2A(r)} \underbrace{[dr^2 + r^2 ds^2_{X_5}]}_{6d\ \text{throat}}$$

warp factor

known metric

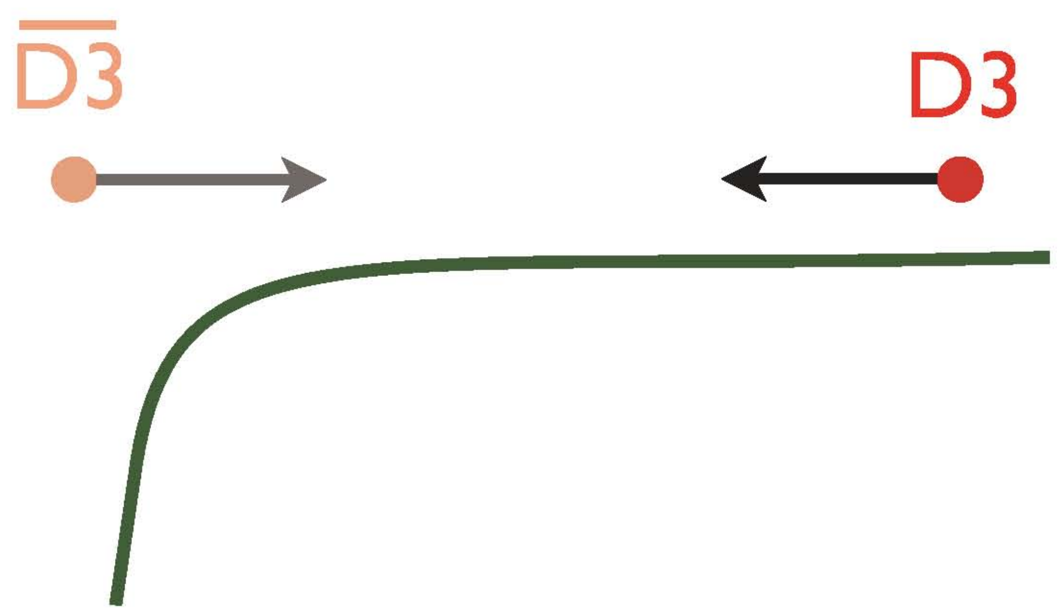
Local Geometry

Warped Cones in Compact Spaces

- non-compact warped cones exist as ***explicit solutions*** in type IIB supergravity   Klebanov & Strassler (& Tseytlin & Witten)
  - generic in flux compactifications
  - high degree of ***computability***
- compactification effects may be incorporated systematically   DB, Dymarsky, Kachru, Klebanov, and McAllister
- special features of the warped geometry:
  - hierarchy of scales   Randall & Sundrum
  - RG filtering of UV corrections
  - ***dual gauge theory***   Maldacena

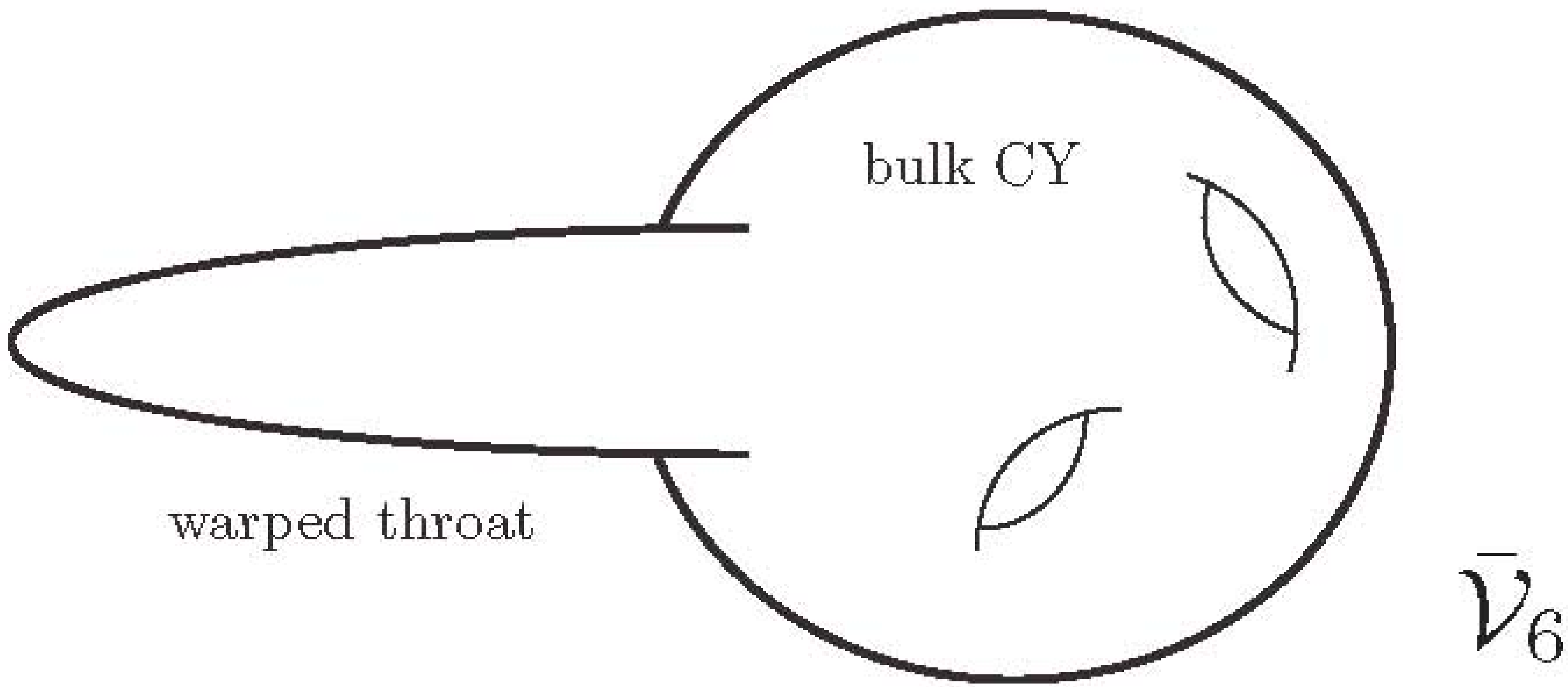
A brane and an anti-brane in a warped background feel an exponentially small Coulomb force

KKLMMT (2003)

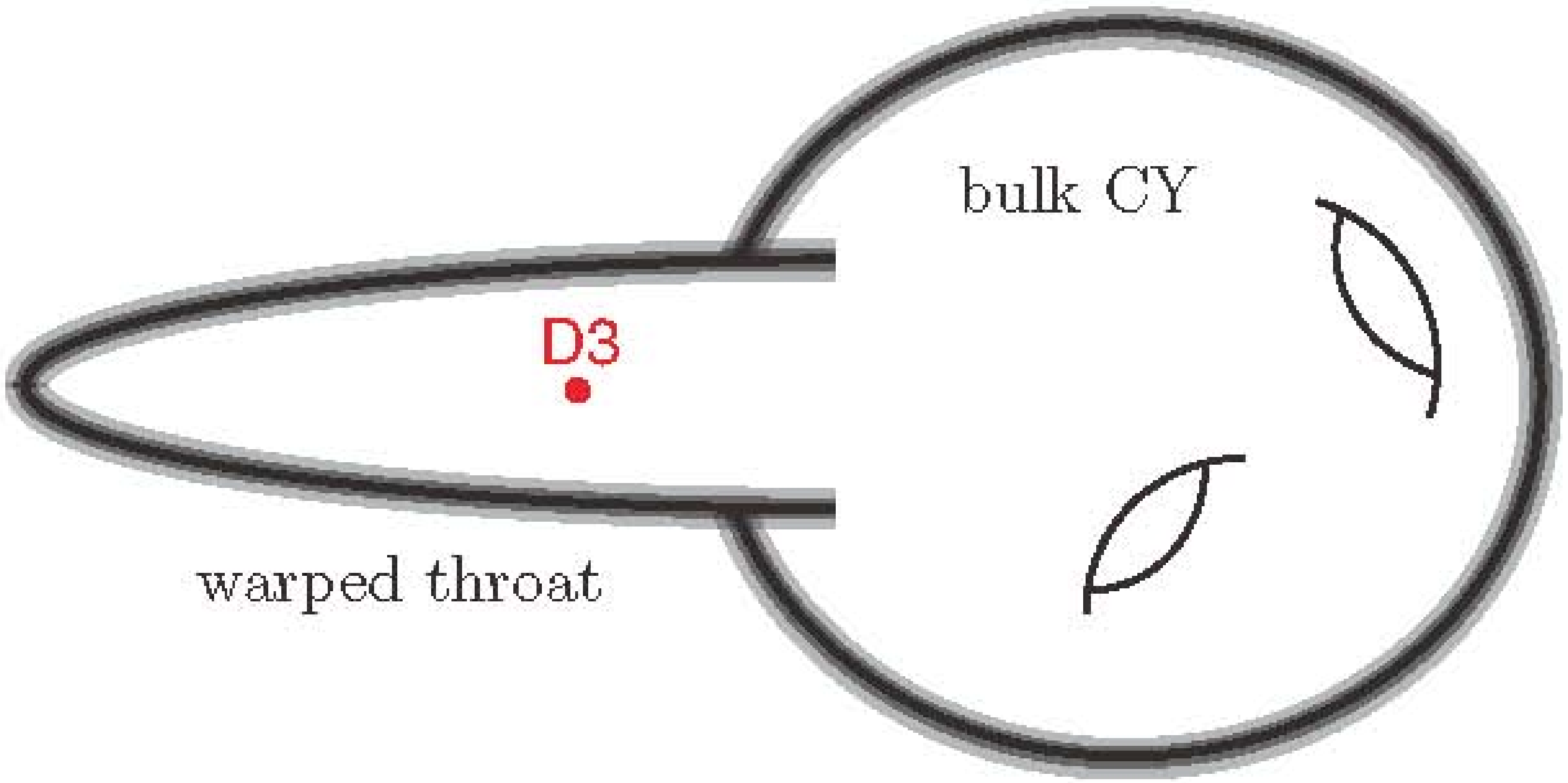


Does this mean that the system can source inflation with exponentially flat potential ?

D3-brane Backreaction



D3-brane Backreaction



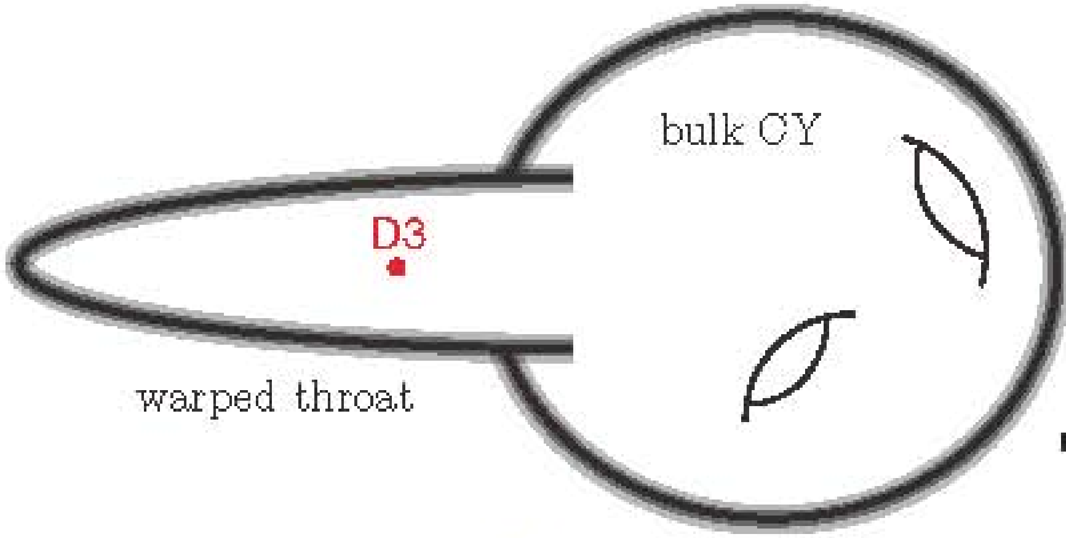
$$\mathcal{V}_6(\phi) \neq \bar{\mathcal{V}}_6$$

overall volume depends on the D3-brane position

even if the inflaton potential is flat in string frame it will not be flat in ***Einstein frame***

$$V_{\mathrm{E}}(\phi) = \frac{1}{\mathcal{V}_6^2(\phi)} \cdot V_{\mathrm{str}}(\phi)$$

D3-brane Backreaction



$$\eta \equiv M_{\rm pl}^2 \frac{V_{\rm E}''}{V_{\rm E}} = \frac{2}{3}$$

$$V_{\rm E}(\phi) = \frac{1}{\mathcal{V}_6^2(\phi)} \cdot V_{\rm str}(\phi)$$

Eta Problem

This is precisely the supergravity eta problem:

$$V(\phi) = e^K \left[|DW|^2 - 3|W|^2\right]$$

$$K = \phi\phi^\dagger + \cdots$$

$W(\phi)$?

$$\eta = \frac{2}{3} + \cdots$$

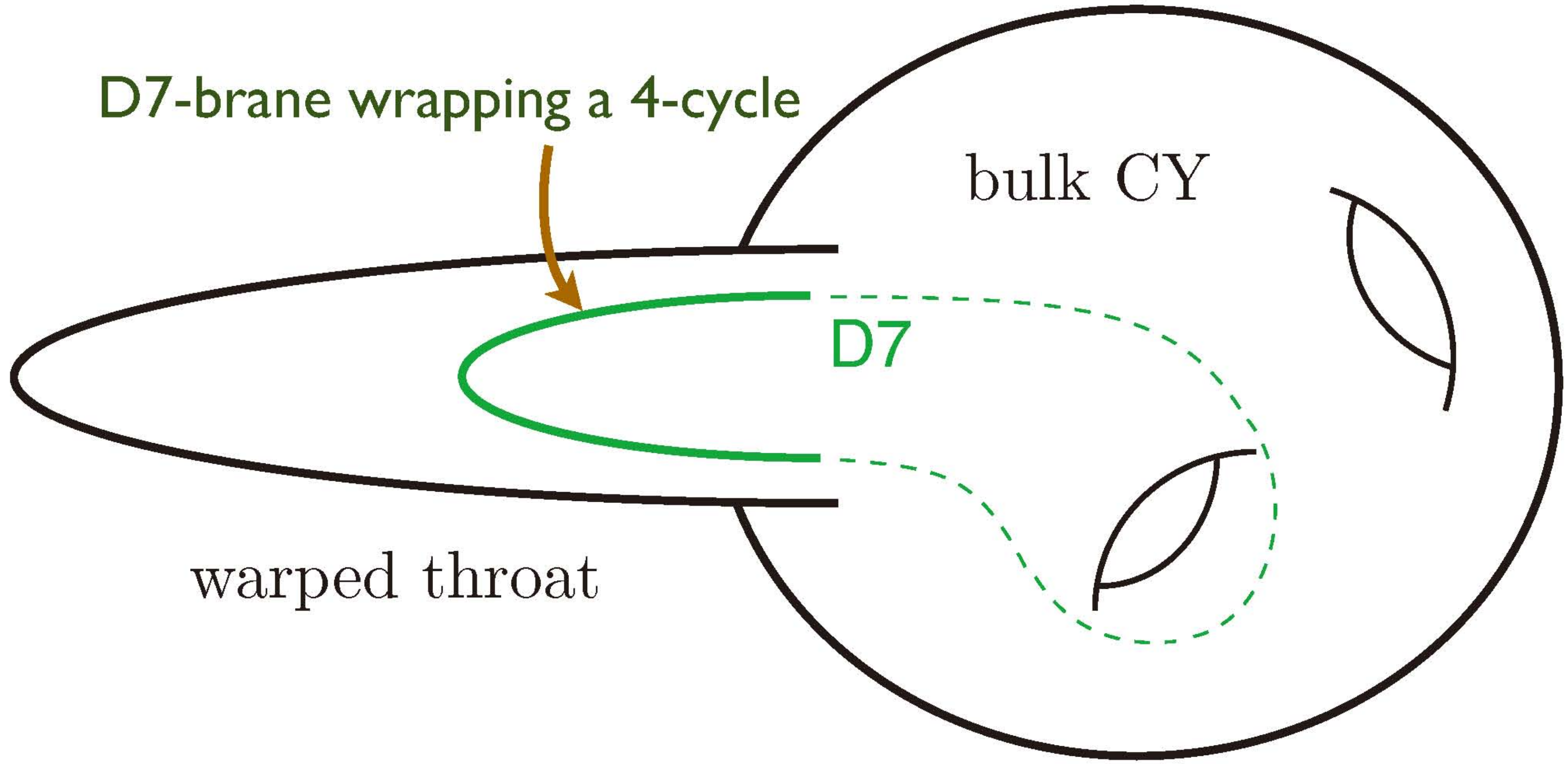
Nonperturbative Effects

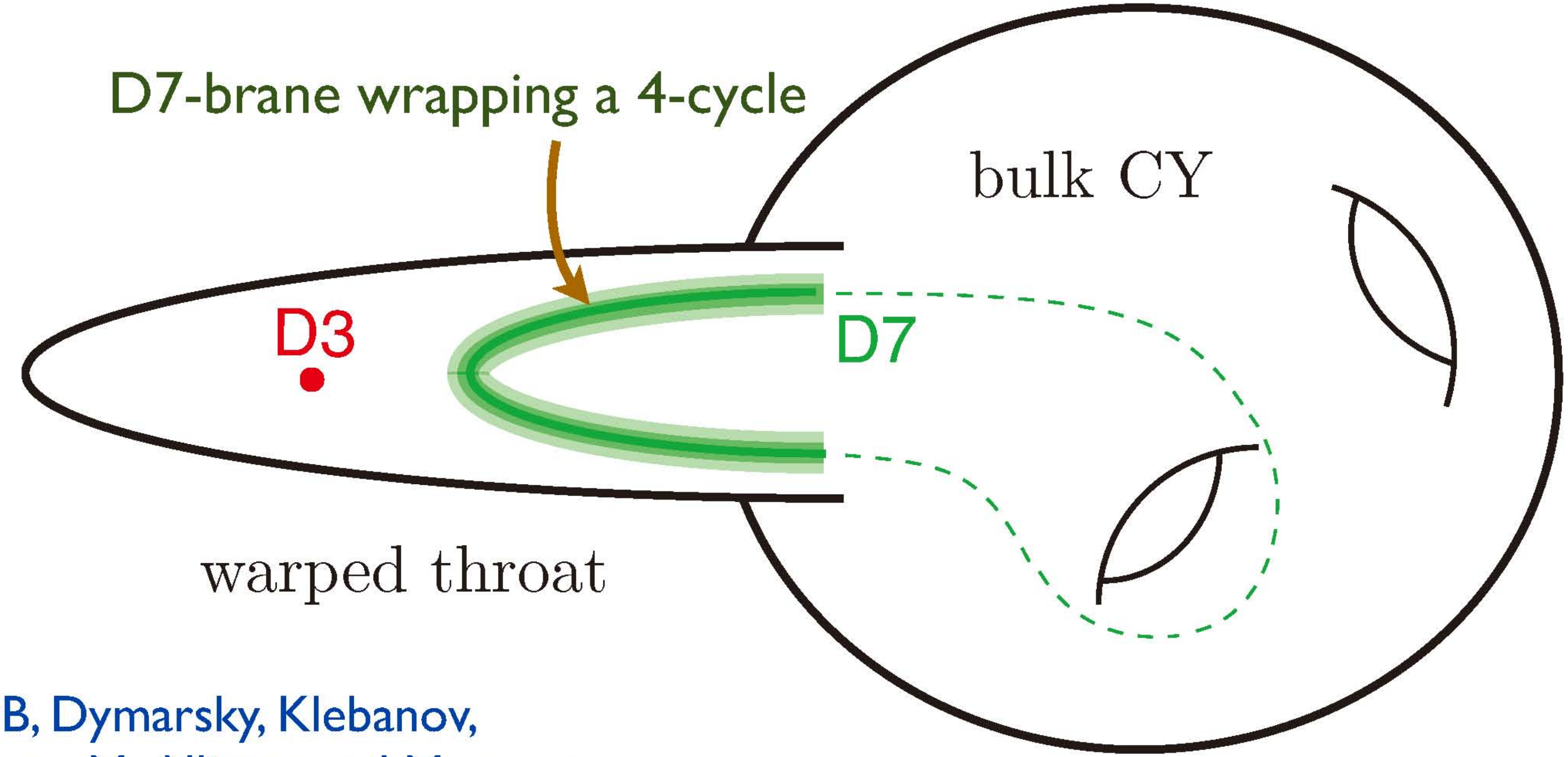
stabilizes the overall volume (Kähler moduli)

Gaugino condensation on D7-branes

interact with D3-branes
and change the inflaton potential

$$\eta = \frac{2}{3} + \eta_{\rm np}(\phi) \ll 1 \ ?$$


D7-brane wrapping a 4-cycle
bulk CY
D7
warped throat



DB, Dymarsky, Klebanov,
Maldacena, McAllister, and Murugan

D3-brane backreaction

- changes the 4-cycle volume $\mathcal{V}_4(\phi)$
- changes the effective gauge coupling $g^{-2} \propto \mathcal{V}_4$
- changes the nonperturbative effect $W_{\rm np}(\phi) \propto e^{1/g^2}$

DB, Dymarsky, Klebanov,
Maldacena, McAllister, and Murugan

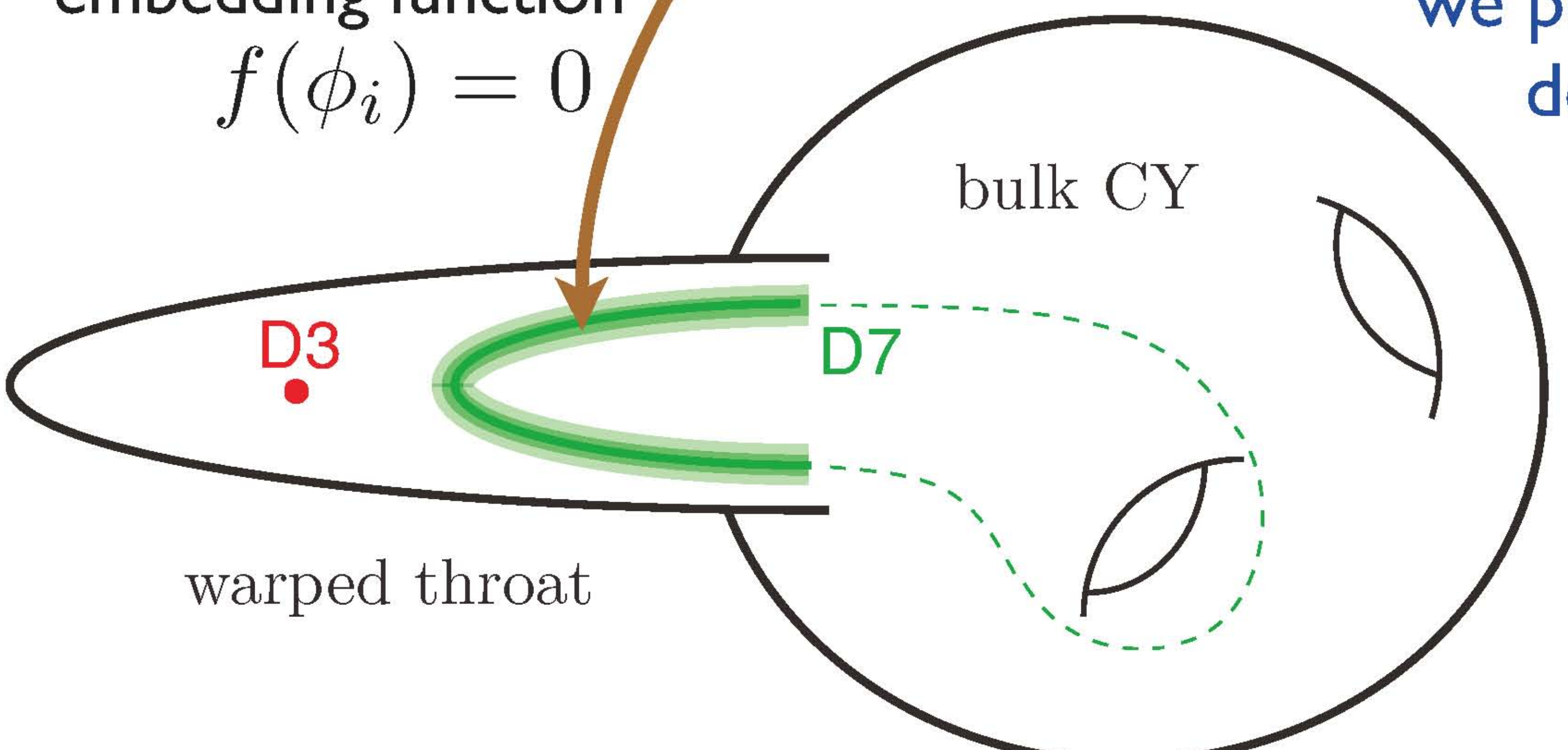
Result

no. of D7-branes

$$W_{\mathrm{np}}(\phi) = f(\phi)^{1/n} e^{-a\bar{\mathcal{V}}_4} \longrightarrow \eta_{\mathrm{np}}(\phi)$$

embedding function

$f(\phi_i) = 0$



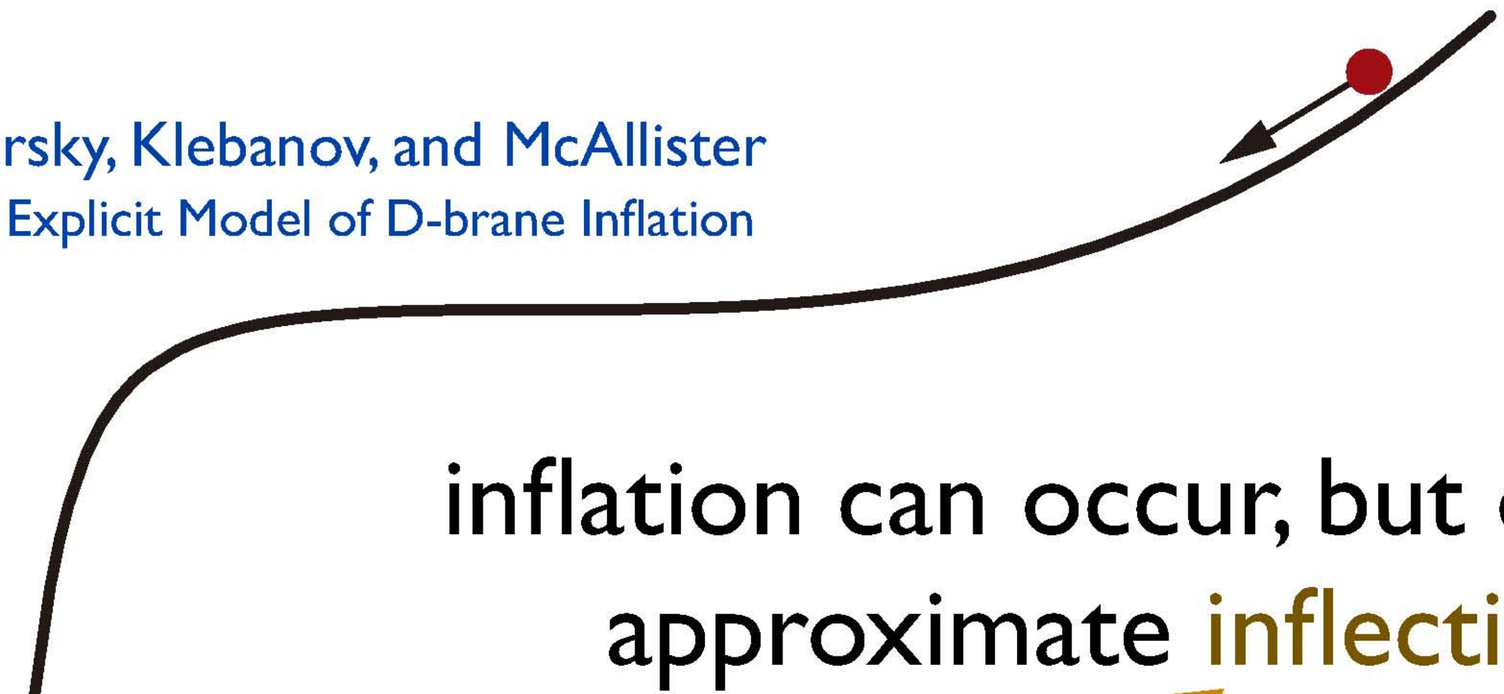
in the spirit of gauge/gravity duality:

we performed a *gravity* calculation to determine this *quantum* effect shape of the potential is determined by ***discrete string theory input*** with parameters constrained by ***global compactification constraints***

(tadpole cancellations, backreaction, ...)

DB, Dymarsky, Klebanov, and McAllister

Towards an Explicit Model of D-brane Inflation



$V(\phi)$

inflation can occur, but only near an approximate inflection point

$$V(\phi) = V_0 \left[1 + c_1\, \phi^1 + c_{3/2}\, \phi^{3/2} + c_2\, \phi^2 + \dots\right]$$

leading term

Compactification Effects

Although this example was *explicit* , the geometry of the compactification was rather special.

Furthermore, one may show that distant sources often do not decouple and can critically influence the dynamics during inflation.

How do we characterize more general compactification effects?

UV Perturbations

A systematic way to estimate the leading corrections to the throat solution is to add perturbations to the geometry at large radius (UV).

nonperturbative effects in the bulk

source

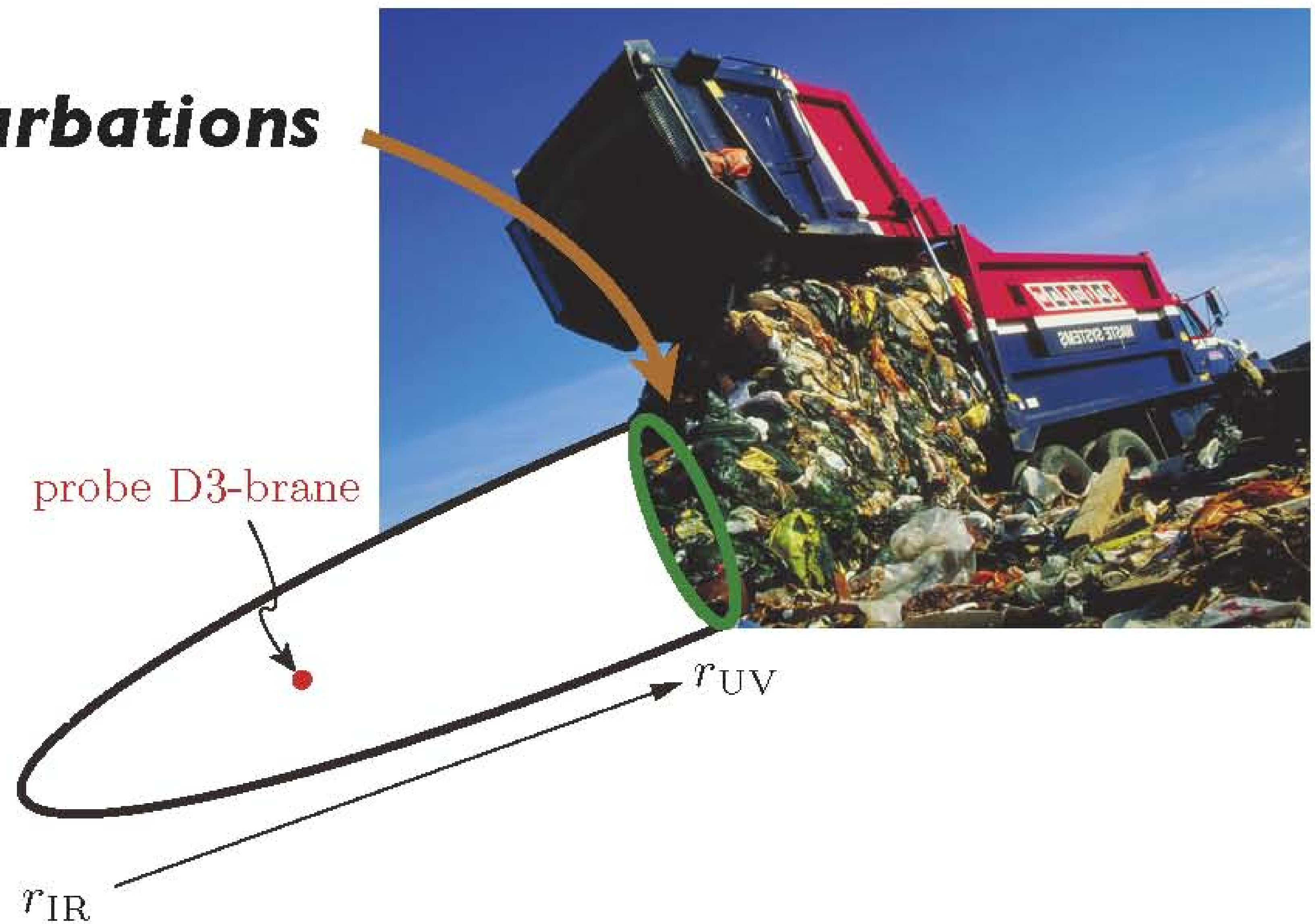
UV perturbations

satisfy

10d supergravity equations of motion

DB, Dymarsky, Kachru, Klebanov, and McAllister

D3-brane Potentials from Fluxes in AdS/CFT



D3-brane Potentials from Fluxes

D3-branes only couple to a very specific combination of background fields:

DBI CS

$$V(\phi) = T_3\left(e^{4A} - \alpha\right)$$

warp factor 5-form potential

satisfies

$$\boxed{\nabla^2 V(\phi) = |G_-|^2 + \mathcal{R}_4 + \text{local sources}}$$

Laplacian on M_6

3-form flux

imaginary-anti-self-dual component

$$G_- \equiv (i - \star_6)G_3$$

4d Ricci scalar

branes, O-planes

Results

DB, Dymarsky, Kachru, Klebanov, and McAllister
D3-brane Potentials from Fluxes in AdS/CFT

$$V(\phi,\Psi)=\sum_L c_L\left(\frac{\phi}{\Lambda}\right)^{\Delta(L)} j_L(\Psi)$$

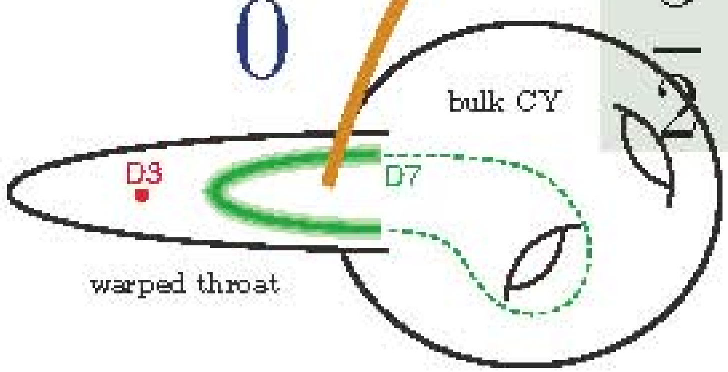
$$\Delta$$

this is the ***eta problem*** term $\eta=\frac{2}{3}$

$$\nabla^2 V = \quad \mathcal{R}_4 \qquad 2\,,\ 3\,,\ \frac{7}{2}\,,\ 4\,,\ \cdots$$

$$|G_-|^2 \qquad 1\,,\ 2\,,\ \frac{5}{2}\,,\ \sqrt{28}-\frac{5}{2}\,,\ \cdots$$

$$0 \qquad \frac{3}{2}\,,\ 2\,,\ 3\,,\ \cdots$$



allow global cancellation of the eta problem term

Relation to Nonperturbative Effects

I. ***A particular subset of the IASD flux solutions "geometrizes" the gaugino condensate superpotential !***

II. The D7-brane action contains a coupling between 3-form flux and gauginos

$$\boxed{\mathcal{L} \sim \int_\Sigma \sqrt{g}\, G_3 \cdot \Omega\, \bar{\lambda}\bar{\lambda}}$$

e.g. Camara et al.

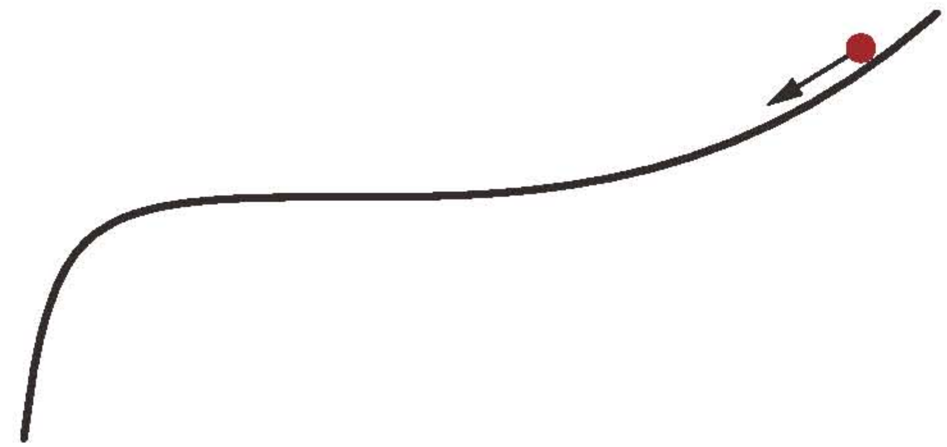
$$\langle \lambda\lambda \rangle = \frac{W_{\rm np}}{n}$$

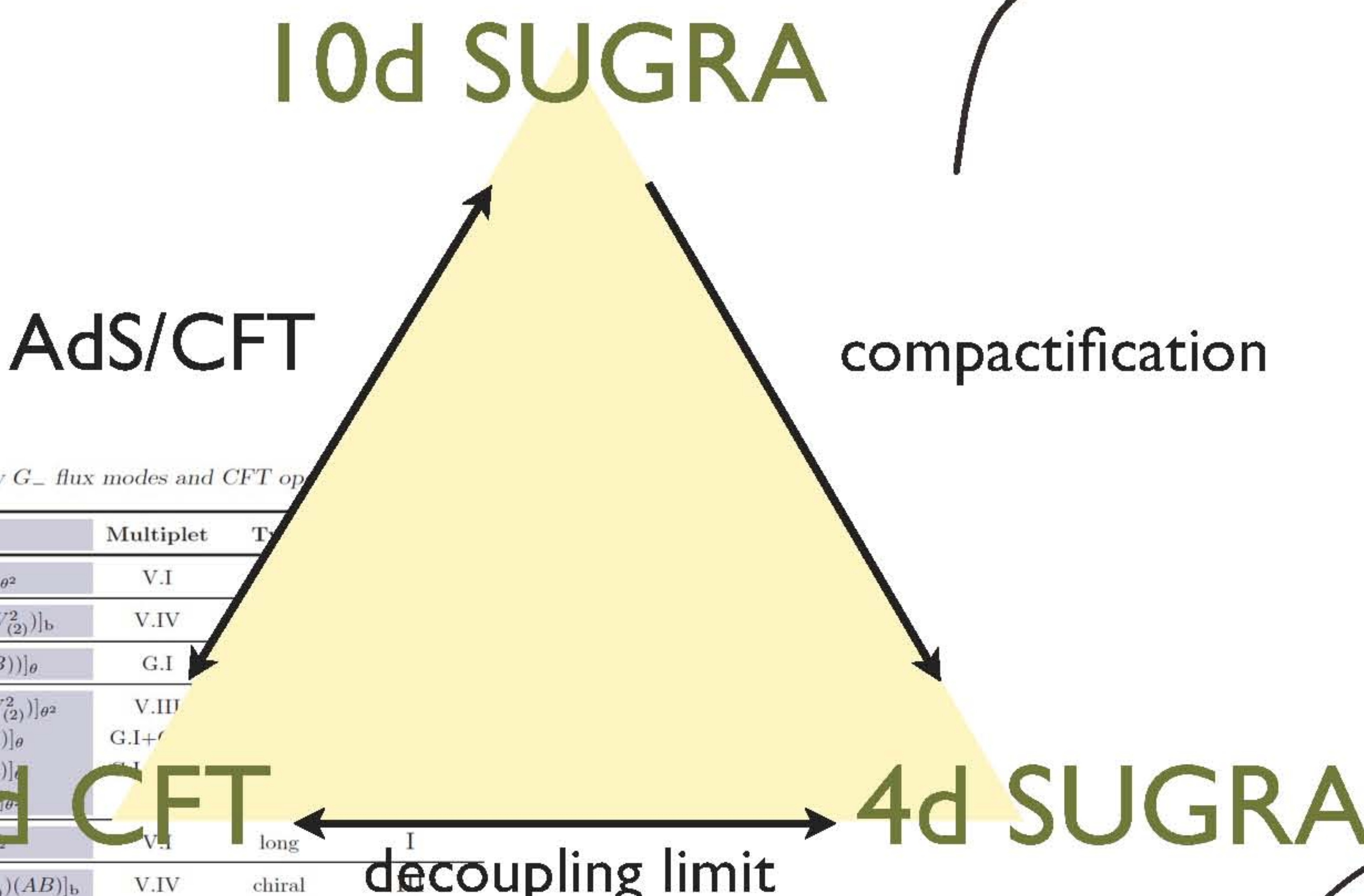
e.g. Seiberg

this sources exactly the right type of flux !

= a novel ***ten-dimensional*** supergravity interpretation of ***four-dimensional*** non-perturbative gauge theory effects

Summary





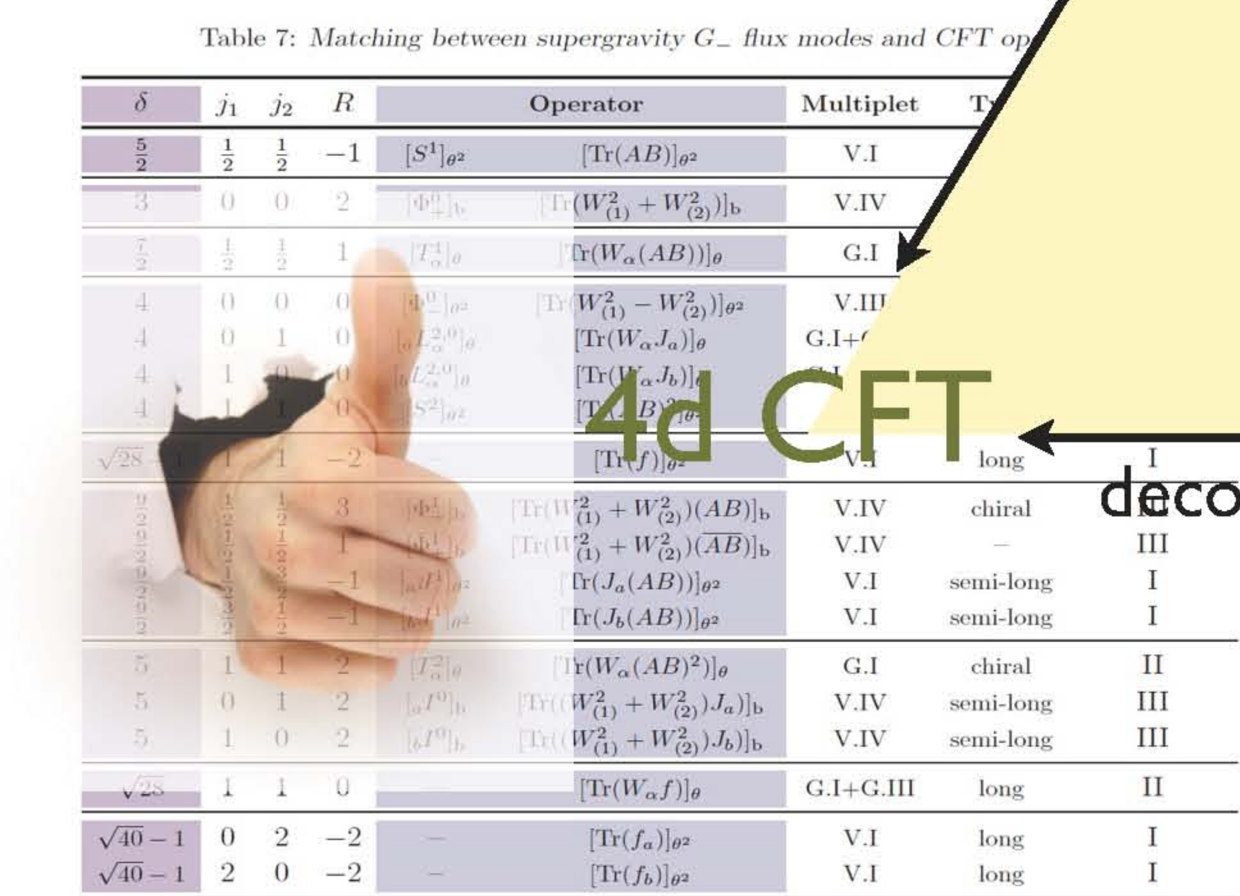
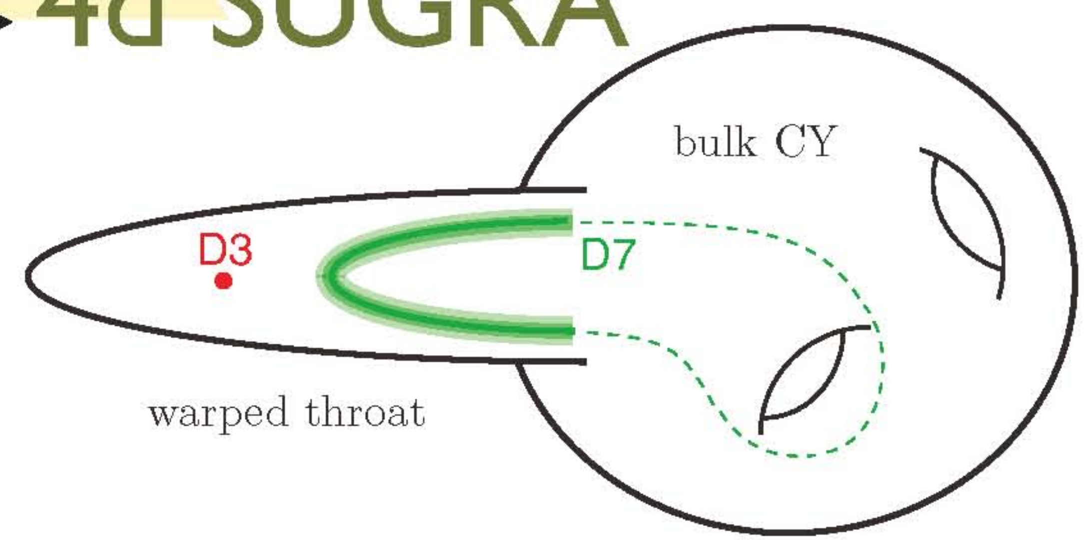


Table 7: *Matching between supergravity G_- flux modes and CFT op*

δ	j_1	j_2	R	Operator		Multiplet	Ty	
$\frac{5}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	-1	$[S^1]_{\theta^2}$	$[\mathrm{Tr}(AB)]_{\theta^2}$	V.I	[illegible]	[illegible]
3	0	0	2	$[\Phi^0_+]_{\mathrm{b}}$	$[\mathrm{Tr}(W^2_{(1)}+W^2_{(2)})]_{\mathrm{b}}$	V.IV	[illegible]	[illegible]
$\frac{7}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$[T^1_\alpha]_\theta$	$[\mathrm{Tr}(W_\alpha(AB))]_\theta$	G.I	[illegible]	[illegible]
4	0	0	0	$[\Phi^0_-]_{\theta^2}$	$[\mathrm{Tr}(W^2_{(1)}-W^2_{(2)})]_{\theta^2}$	V.III	[illegible]	[illegible]
4	0	1	0	$[{}_aL^{2,0}_\alpha]_\theta$	$[\mathrm{Tr}(W_\alpha J_a)]_\theta$	G.I+[illegible]	[illegible]	[illegible]
4	1	0	0	$[{}_bL^{2,0}_\alpha]_\theta$	$[\mathrm{Tr}(W_\alpha J_b)]_\theta$	[illegible]	[illegible]	[illegible]
4	1	1	0	$[S^2]_{\theta^2}$	[illegible]	[illegible]	[illegible]	[illegible]
$\sqrt{28}-1$	1	1	-2	–	$[\mathrm{Tr}(f)]_{\theta^2}$	V.I	long	I
$\frac{9}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	3	$[\Phi^1_+]_{\mathrm{b}}$	$[\mathrm{Tr}(W^2_{(1)}+W^2_{(2)})(AB)]_{\mathrm{b}}$	V.IV	chiral	[illegible]
$\frac{9}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$[\Phi^1_-]_{\mathrm{b}}$	$[\mathrm{Tr}(W^2_{(1)}+W^2_{(2)})(\overline{AB})]_{\mathrm{b}}$	V.IV	–	III
$\frac{9}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	-1	$[{}_aI^1]_{\theta^2}$	$[\mathrm{Tr}(J_a(AB))]_{\theta^2}$	V.I	semi-long	I
$\frac{9}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	-1	$[{}_bI^1]_{\theta^2}$	$[\mathrm{Tr}(J_b(AB))]_{\theta^2}$	V.I	semi-long	I
5	1	1	2	$[T^2_\alpha]_\theta$	$[\mathrm{Tr}(W_\alpha(AB)^2)]_\theta$	G.I	chiral	II
5	0	1	2	$[{}_aI^0]_{\mathrm{b}}$	$[\mathrm{Tr}((W^2_{(1)}+W^2_{(2)})J_a)]_{\mathrm{b}}$	V.IV	semi-long	III
5	1	0	2	$[{}_bI^0]_{\mathrm{b}}$	$[\mathrm{Tr}((W^2_{(1)}+W^2_{(2)})J_b)]_{\mathrm{b}}$	V.IV	semi-long	III
$\sqrt{28}$	1	1	0		$[\mathrm{Tr}(W_\alpha f)]_\theta$	G.I+G.III	long	II
$\sqrt{40}-1$	0	2	-2	–	$[\mathrm{Tr}(f_a)]_{\theta^2}$	V.I	long	I
$\sqrt{40}-1$	2	0	-2	–	$[\mathrm{Tr}(f_b)]_{\theta^2}$	V.I	long	I



Conclusions

Inflation is sensitive to Planck-scale physics!

Dimension 6 Planck-suppressed operators make critical contributions to the ***inflaton mass***.

I described ***three ideas to address the eta problem:***

1. Inflating with Baryons

   *Suppress dangerous UV corrections with a **gauge symmetry***

2. Sequestering the Planck-Scale

   *Suppress dangerous UV corrections with **RG flow***

3. D-brane Inflation

   ***Cancel** dangerous UV corrections against each other*

Thank you for your attention!

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