More updates on warped brane inflation

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Based on

- H.-Y. Chen, JG and G. Shiu, JHEP0809, 001 (2009) arXiv:0807.1927 [hep-th]
- H.-Y. Chen and JG, Phys. Rev. D80:063507 (2009) arXiv:0812.4649 [hep-th]
- H.-Y. Chen, JG, K. Koyama and G. Tasinato, arXiv:1007.2068 [hep-th]

Outline

1. Introduction
2. Towards more complete descriptions
   - D3-brane potential in the entire throat
   - Multi-field effects
   - Bulk corrections
3. Conclusions

Inflation and string theory

Inflation

1. Leading candidate to solve cosmological problems e.g. horizon
2. Initial conditions for successful hot big bang
3. Strongly supported by observations: WMAP, SDSS, etc

BSM

1. No inflaton candidate in SM
   cf. F. L. Bezrukov and M. Shaposhnikov, Phys. Lett. B **659**, 703 (2008): SM Higgs = inflaton?
2. Better description of high energy physics
3. Plenty of scalar fields = *inflaton candidates*

$$\text{SUSY},\quad \text{SUGRA},\quad \underbrace{\text{string theory}}_{\text{Most fundamental?}}$$

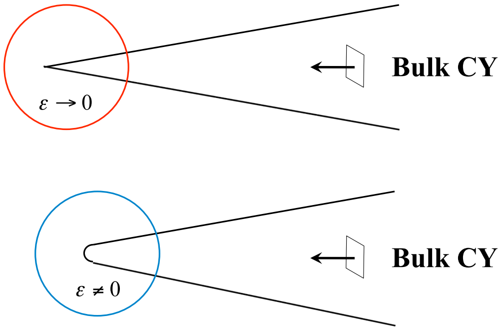
Inflation in string theory: warped brane inflation

The points to be addressed:

1. Concrete construction of the inflaton potential $V(\phi)$
2. Multi-field effects and further phenomenology
3. Possible corrections to $V(\phi)$

Conclusion first: **STILL FAR TO GO**

Deformed conifold: IR description



Complete *Infrared* description

- Precise identification of the CMB scales
- Non-trivial post-inflationary evolutions
- Further significant modifications: e.g. low scale inflation

A case study: Kuperstein embedding

Non-perturbative superpotential

$$W\left(z^\alpha,\rho\right) = W_0 + A\left(z^\alpha\right)e^{-a\rho}$$

Kuperstein embedding: embedding function $f\left(z^\alpha\right) = z_1 - \mu$

$$A\left(z^\alpha\right) = A_0\left[\frac{f\left(z^\alpha\right)}{f(0)}\right]^{1/n} = A_0\left(1-\frac{z_1}{\mu}\right)^{1/n}$$

1. Highly symmetric
2. Full $SO(4) \to SO(3)$ isometry of the deformed conifold

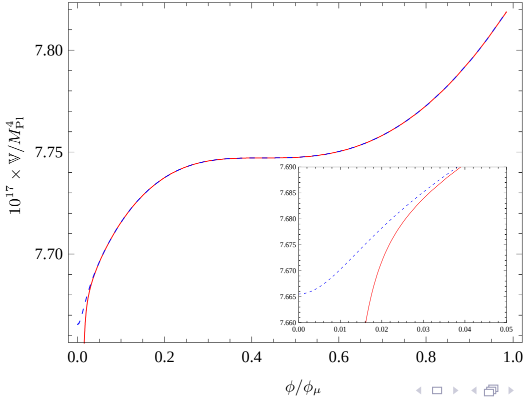
Inflaton potential for the *full deformed conifold*

$$V(\phi) = \frac{2a^2|A_0|^2 e^{-2a\sigma_\star(\tau)}}{\{U[\tau,\sigma_\star(\tau)]\}^2}|g(\tau)|^{2/n}\left\{\frac{U[\tau,\sigma_\star(\tau)]}{6}+\frac{1}{a}\left(1-\frac{|W_0|}{|A_0|}\frac{e^{a\sigma_\star(\tau)}}{[g(\tau)]^{1/n}}\right)+F(\tau)\right\}$$
$$+\frac{1}{\{U[\tau,\sigma_\star(\tau)]\}^2}\left[D_0\left(1-\frac{27D_0}{64\pi^2\phi^4}\right)+D_{\mathrm{others}}\right]$$

Sample results

n	$\lvert W_0\rvert$	$\lvert A_0\rvert$	s	α	β
8	2.92485×10^{-6}	0.0085	1.07535	1/200	1/508

H.-Y. Chen and JG, Phys. Rev. D80:063507 (2009) arXiv:0812.4649 [hep-th]



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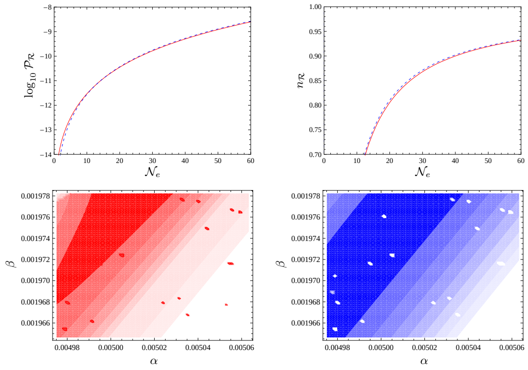
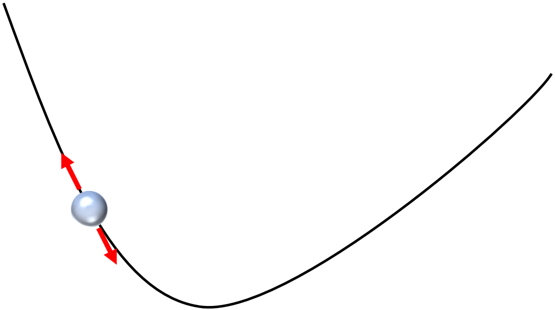


Trajectories in multi-field inflation

There are more than one orthogonal directions into which the field can be "*kicked*"



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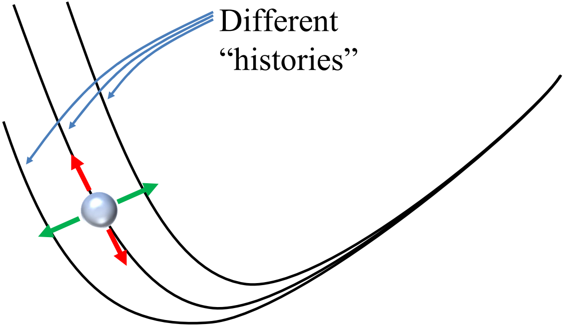

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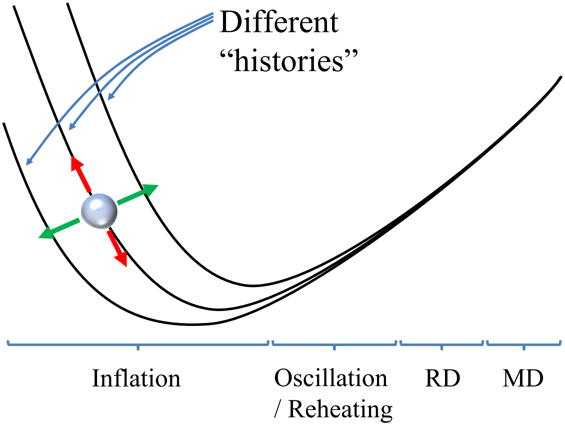

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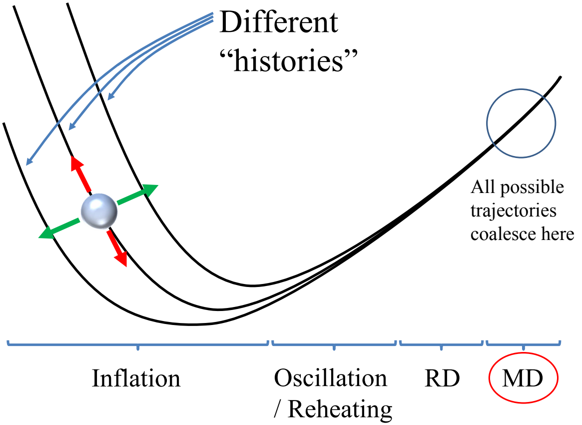
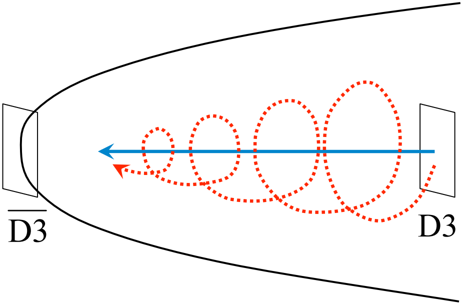


Multi-field trajectory in warped throat



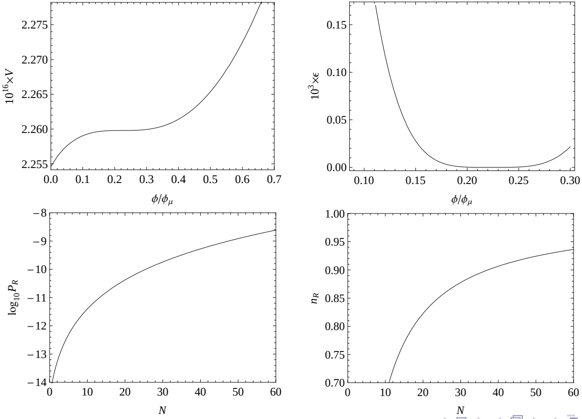
- Radial and **angular** directions: multi-field system in principle
- Kuperstein embedding: angular stable trajectory
  $z_1 = -\epsilon \cosh(\tau/2)$ *throughout the whole throat*
  D. H. Lyth, JCAP **0511**, 006 (2005)
- We need different embedding

Ouyang embedding

With $w_1 = (z_1 + iz_2)/\sqrt{2}$, the embedding function is given by

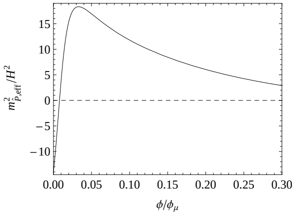
$$f(w_1) = \mu - w_1$$

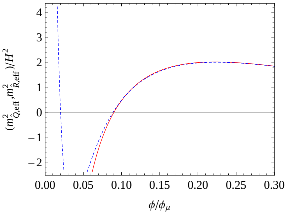
Slow-roll inflation is possible **BEFORE** instability



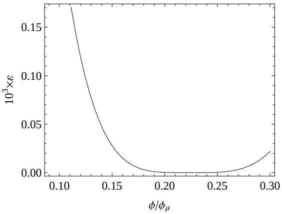
Instabilities in angular directions

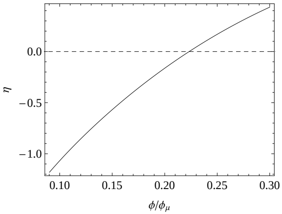
Angular masses become tachyonic near the tip





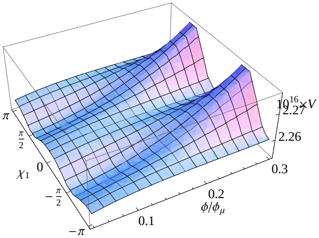
But still inflation: at instability $\varepsilon \approx 3.6 \times 10^{-4}$

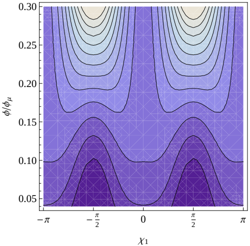




Multi-field potential

Angular fields become dynamically relevant





1. Periodic along angular directions
2. NDF/DF smoothly connected
3. More to consider:
    - More inflation along angular directions?
    - Long enough inflation?
    - DBI-ness?
    - Reheating?

UV completion of inflation

Importance of UV completion

- η problem: with nearly constant V_0

$$\Delta V \sim \mathcal{O}_4 \phi^2 \to \Delta\eta \sim \frac{\langle \mathcal{O}_4 \rangle}{V_0} \sim \mathcal{O}(1)?$$

- Higher derivatives: most general Lagrangian

$$\mathcal{L} = \mathcal{L}\left[\phi, \partial_\mu\phi, (\partial_\mu\phi)^2, \cdots\right] \to c_s \text{ dependence}$$

$$V(\phi) = \underbrace{V_{\rm stb}(\phi) + V_{\rm D3\overline{D3}}(\phi)}_{\text{local throat}} + V_{\rm bulk}(\phi)$$

Q: How to calculate the unknown bulk effects?

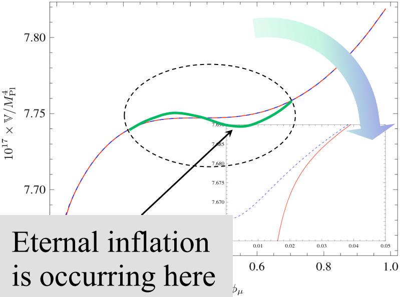
Incorporating bulk effects

Bulk physics parametrized from AdS/CFT

D. Baumann, A. Dymarsky, S. Kachru, I. R. Klebanov and L. McAllister, JHEP **0903**, 093 (2009) [arXiv:0808.2811 [hep-th]]

$$V_{\rm bulk} = -c_\Delta a_0^4 T_3 \left(\frac{\phi}{\phi_{\rm UV}}\right)^\Delta$$

$$= -|V_{\rm stb}(0)| c_\Delta{}' \alpha^{2\Delta/3} \left[\int_\tau \frac{d\tau'}{K(\tau')}\right]^\Delta \quad \left[\Delta = \begin{cases} 3/2(\text{chiral}) \\ 2(\text{non-chiral}) \end{cases}\right]$$



Disturbance from the bulk

We need unnaturally small couplings

H. Y. Chen and JG, Phys. Rev. D80:063507 (2009) arXiv:0812.4649 [hep-th]

			10^{-9}	10^{-8}	10^{-7}	10^{-6}
$c_{3/2}$	Distant sources	$\mathcal{P}_{\mathcal{R}} \times 10^9$	2.71386	3.17635	13.7483	26670.1
		$n_{\mathcal{R}}$	0.932540	0.927506	0.883792	0.657621
	Coulomb interaction	$\mathcal{P}_{\mathcal{R}} \times 10^9$	2.53682	2.95080	11.9644	11348.2
		$n_{\mathcal{R}}$	0.931448	0.926480	0.883233	0.657668
c_2	Distant sources	$\mathcal{P}_{\mathcal{R}} \times 10^9$	2.74701	3.58118	37.8218	0.0559217*
		$n_{\mathcal{R}}$	0.932149	0.923750	0.856258	0.552413
	Coulomb interaction	$\mathcal{P}_{\mathcal{R}} \times 10^9$	2.56657	3.31098	31.2301	0.0138777*
		$n_{\mathcal{R}}$	0.931062	0.922766	0.855908	0.552458

- Fine tuning of $c_{3/2}, c_2 \sim 10^{-9}$ or even smaller
- Marginalized scanning?
- Angular directions: sensitive or not?

Summary and challenges

Towards more concrete descriptions

1. Full local potential: under specific embeddings
2. Multi-field effects: dependent on setup
3. Bulk disturbance: severe fine tuning?

A list of challenges (selected by personal prejudice)

1. General construction: ever be possible at all?
2. Gravitino
   - in the simplest KKLT, $H \lesssim m_{3/2}$
   - $m_{3/2} \gg \mathcal{O}(\text{TeV})$ (bad for LHC) or $H \ll \mathcal{O}(\text{TeV})$ (bad for Planck)
   - Can we find $H \gg m_{3/2} \sim \mathcal{O}(\text{TeV})$?
3. Post-inflationary evolution: (multiple) curvaton, reheating, etc
   We need fully specified scenarios
4. And further: cosmic (super)strings, modified gravity, etc.

Next generation observables

In the coming decade, we will find

- Tensor-to-scalar ratio r: $V_{\rm Inf}^{1/4}(\ll, \sim, \gtrsim) M_{\rm GUT}$?
- Non-linear parameter $f_{\rm NL}$: beyond simplest paradigm?
- Isocurvature perturbation S: signature of multi-field?
- Running of the index α: geometry of the field space?

Even stronger constraints on inflation and the underlying theory

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WHAT WILL BE OUR FUTURE?