Spinflation

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- 0709.2666 [hep-th] *(Damien Easson, RG, David Mota, Gianmassimo Tasinato and Ivonne Zavala)*

Key Points

- From braneworlds to brane inflation
- Warped throats and probe branes
- Gravitating branes and cosmology
- Back reaction
- The importance of spin!
- Summary

Braneworlds…

..are a general framework for obtaining new compactifications of extra dimensions.

A braneworld is a slice through spacetime on which we live. We cannot (easily) see the extra dimensions perpendicular to our slice, all of our standard physics is confined.

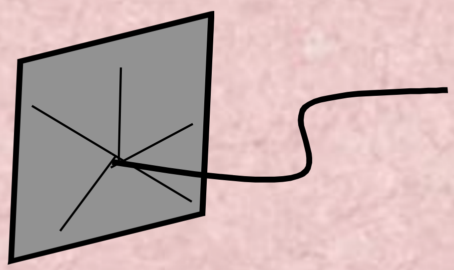
Warped compactification

Is the generic name given to models where spacetime curves strongly away from the brane.

- ★ Expect gravity to be localized at peaks in the warp factor.
- ★ Warping produces hierarchies between branes at different warp factors.
- ★ Moving branes experience contraction/expansion as they shift in the bulk - *mirage cosmology*.

Branes in String Theory

String theory is full of branes, extended object charged under RR or NSNS fields present in the low energy effective theory.



D-branes in string theory are surfaces on which open strings can end. The charges carried by the ends of the strings give gauge fields confined to the D-brane, which has a DBI effective action.

$$\mathcal{L}_{\mathcal{DBI}} = T\, e^{-\phi}\, |\det(g_{ab} + \mathcal{F}_{ab})|^{1/2}$$

D-branes in gravity

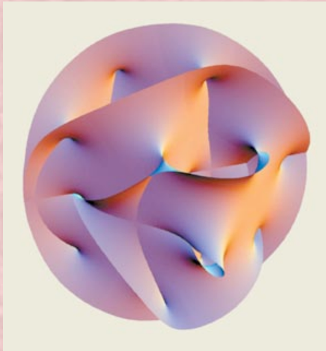
The D-branes can also be associated with extended charged solutions in supergravity, natural cousins of the domain walls or vortices on which braneworlds were originally based. For example, the D3 brane is sourced by the self-dual 5-form in IIB theory, and has the metric:

$$ds^2 = f^{-1/2}\, dx^2_{||} + f^{1/2}\, [\, dr^2 + r^2\, d\Omega^2_5\,]$$

$$f = 1 + 4\pi g N \alpha'^2 / r^4$$

Strings and Cosmology

String theory has 6 (or 7) extra dimensions, and is generally compactified on some small Calabi-Yau manifold. However, cosmologically, the various degrees of freedom, or moduli, of this compactification are problematic.



The phenomenon of flux stabilization allows string theory to have these complex manifolds with stable moduli, fixed by fluxes arising from wrapped branes.

(KKLT scenario)

Brane Inflation

In brane inflation, we imagine individual (or small groups of) branes moving on the CY, extended along the noncompact directions.

The position of the brane is localized, but it does not warp the spacetime locally in the CY.

Gravity is KK reduced to 4D, with the brane contributing to the 4D energy momentum.

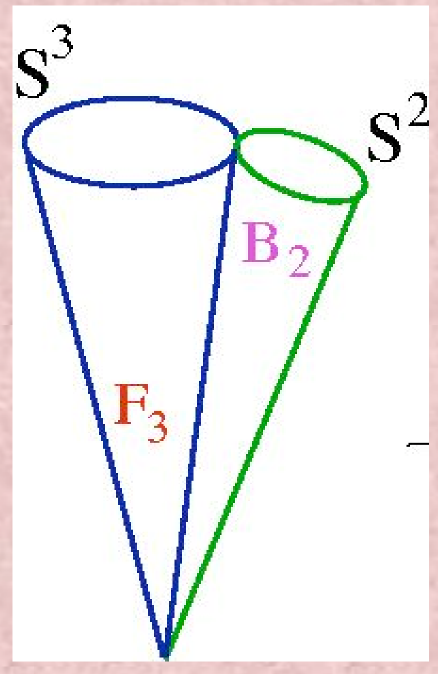
The higher dimensional information is encoded in a scalar describing the brane position: **The Inflaton**.

The Conifold throat

Conifolds correspond to special points in the moduli space of Calabi-Yau manifolds, and are regular manifolds apart from isolated “conical” singularities. The standard example is a simple cone based on a complex hypersurface in $\mathbf{C}^4$.

$$\sum_{A=1}^{4} (w^A)^2 = 0 \qquad (w = x + i\, y)$$

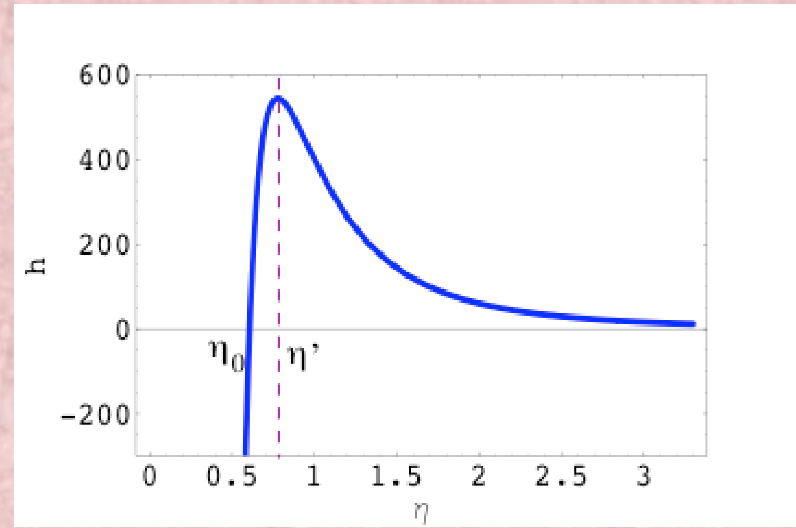
$$\mathbf{x}^2 = \mathbf{y}^2 = r^2/2$$
$$\mathbf{x} \cdot \mathbf{y} = 0$$

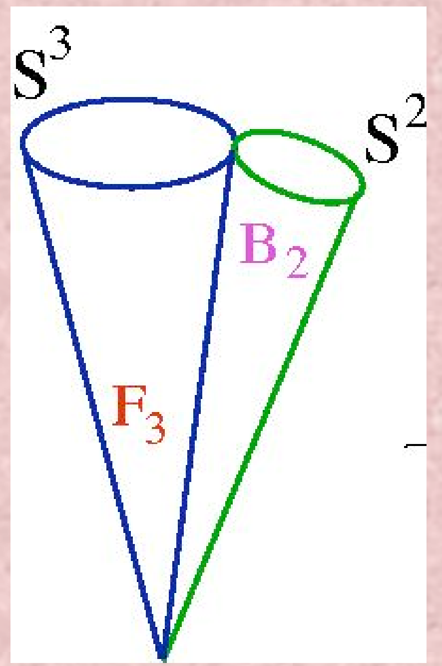


Adding flux: Klebanov-Tseytlin

Adding flux to stabilize the CY produces warping:

$$ds^2 = h^{-1/2}\, d\mathbf{x}^2 \;\square\; h^{1/2}\,(d\square^2 + \square^2\, ds^2_{T11})$$





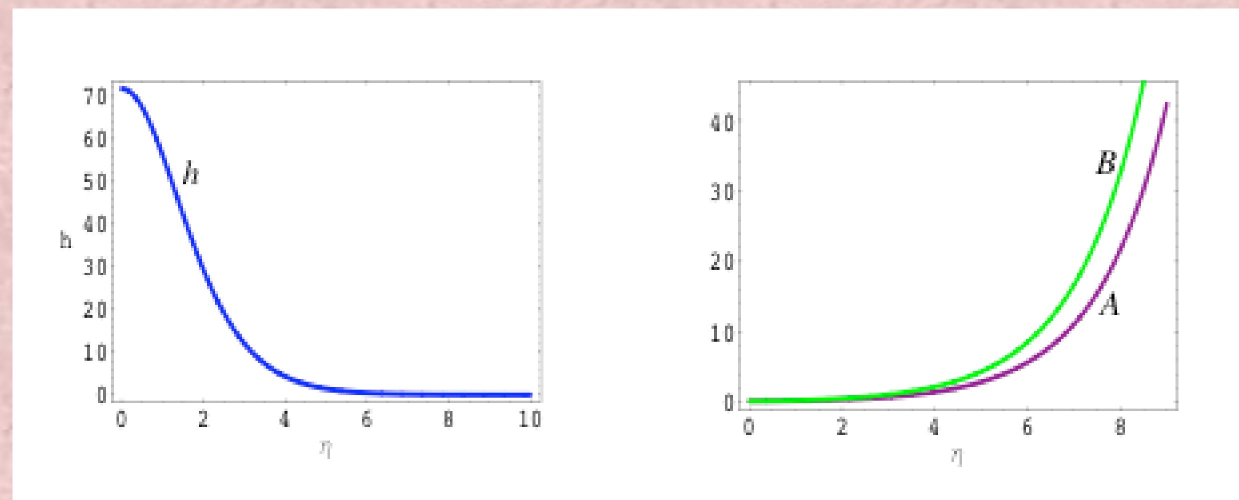
Klebanov-Strassler

The KS solution has a similar structure to KT, but is based on the deformed conifold:

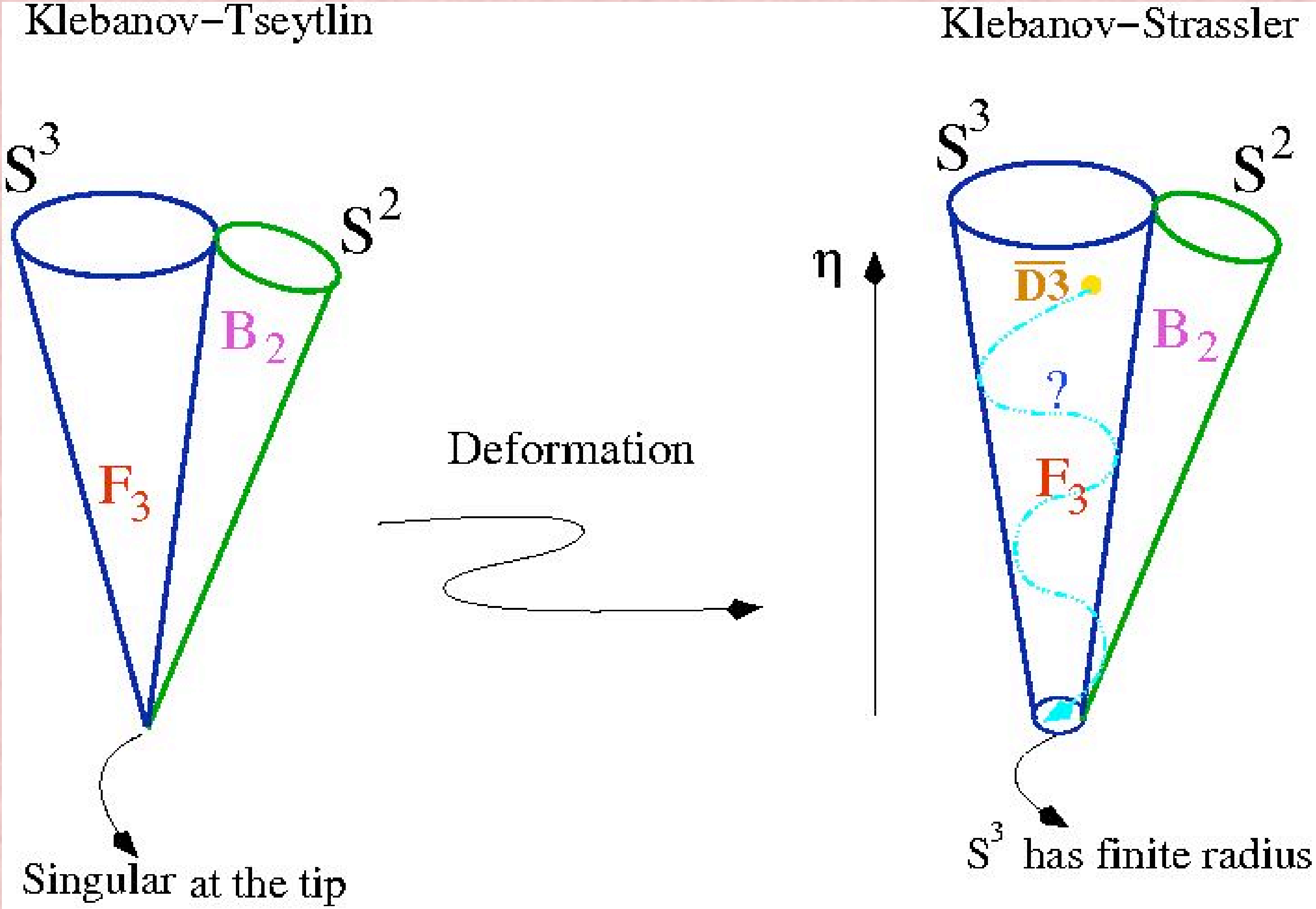
$$\square\ (w^A)^2 = \square^2$$

$$ds^2_6 = A(\square)\ [d\square^2 + (g^5)^2\ ] + B_1\ [(g^3)^2 + (g^4)^2] + B_2\ [(g^1)^2 + (g^2)^2]$$

$B_2/B_1 = \tanh^2 \square$, and A, B are analytic functions of $\square$.



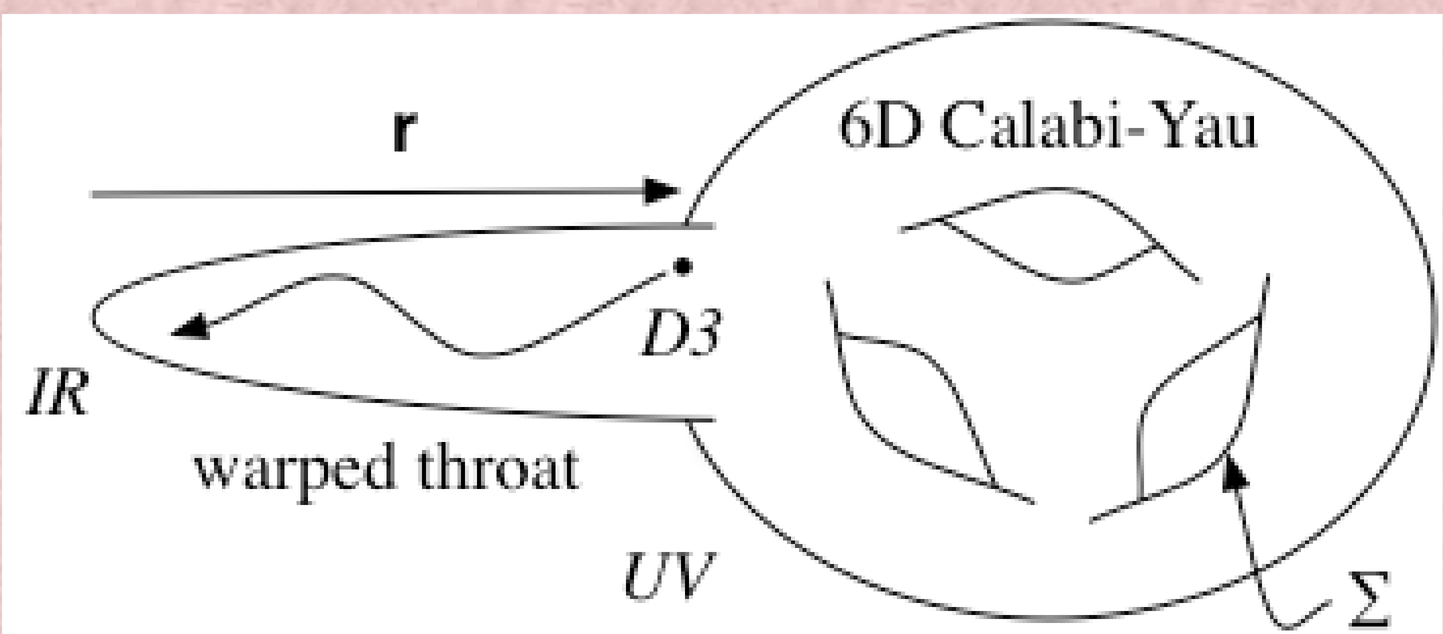
Klebanov-Tseytlin/Strassler



Brane Spinflation : Geometry

Although we use the details of the KS throat to explore brane cosmological trajectories and gravity, the key features of the throat are

★ warped ★ smooth ★ angular Killing vectors



Brane Cosmology in String Theory: is it a Mirage?

One big problem about doing cosmology on a Calabi-Yau is in figuring out how to describe your brane.

★ Gravitational back-reaction with codimension 3 or more is not well defined.

★ Taking single branes is not a well-defined problem in supergravity, except very far from the brane.

DB-I-nflation

★ Take the DBI D-brane action, and use this as a Lagrangian to determine the motion of the (probe) brane in the throat.

$$\mathcal{L} = -m\, h^{-1} \left[(1 - h\, v^2)^{1/2} - 1 \right]$$

★ *Mirage:* Take the induced metric on the brane and use this to construct the cosmology.

$$ds^2 = h^{-1/2} [(1 - h\, v^2)\, dt^2 - d\mathbf{x}^2] = d\tau^2 - a^2\, d\mathbf{x}^2$$

Angular Momentum

Expect the most important aspect of brane motion to be the radial motion up and down the throat.

However, the brane can also spin in the throat - how important are these degrees of freedom?

Conserved angular momenta: $l_r = g_{rs} \dot{\theta}^s (1 - h v^2)^{-1/2}$

$v^2 = (\dot{\rho}^2 + l^2) / (1 + h\, l^2)$

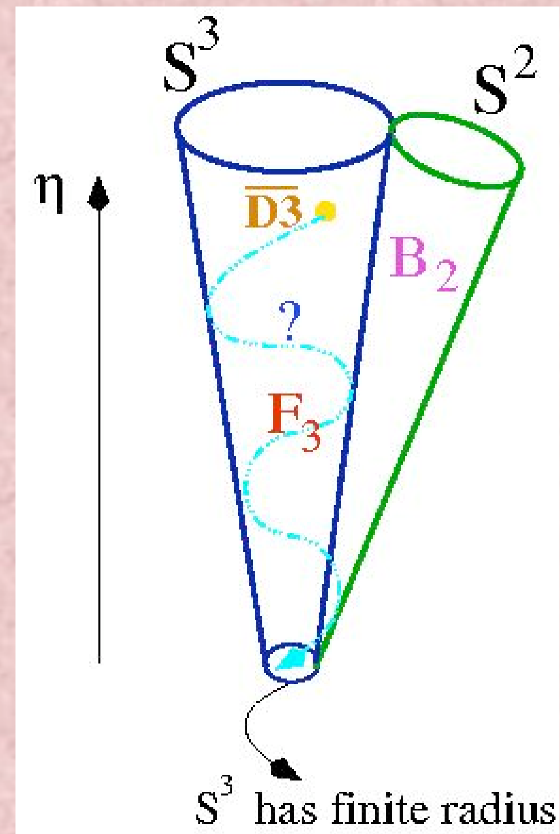
$l^2(\rho) = g^{rs} l_r l_s$

Orbiting the conifold:

Conserved angular momentum: $l_r = g_{rs} \dot{\square}^s (1 \square h v^2)^{-1/2}$

★ KS is nonsingular at the tip, so branes can now pass through, or even sit at □=0.

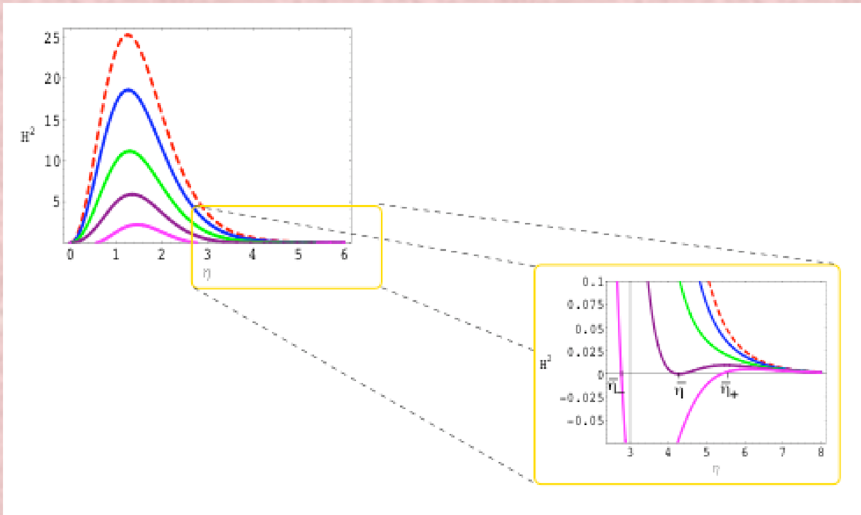
★ Because the cone base is warped, there are different angular momenta which contribute differently to the overall energy.



Cycling universes

The combination of angular momentum and the warp factor neutralizes the DBI kinetic term, and allows for bound states of the brane orbiting near the tip. By the mirage interpretation, these correspond to eternally expanding and contracting cosmologies:

Cyclic ing
Universe



Oasis or Mirage?

Angular motion produces bounces in the mirage cosmology, the real question is whether these can be made into “honest to God” bouncing cosmologies.

Main obstruction:

Energy in mirage cosmology is *derived* from the induced geometry, assuming the 4D Einstein equations.

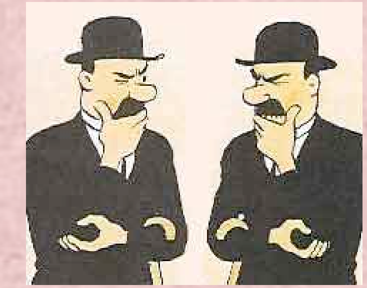
- How do we add matter?
- We have lost non-conventional cosmology.

Spinflation - the set-up

Looking for general properties of brane trajectories on warped internal manifolds. Specifically, a moving D3 brane in a Klebanov-Strassler (KS) throat.

- ★ Assume a DBI action for the brane
- ★ Consider general motion of the brane, i.e., radial *and* angular directions.
- ★ Assume a general potential for the radial variable to mock-up open string effects.
- ★ Assume an averaged gravitational effect on the noncompact dimensions, producing cosmology.
- ★ Check trajectories are gravitationally consistent.

Beyond the Mirage



* Need to find a way to couple in gravity - simplest and *only* consistent way is a 4D effective approach, going to field theory variables:

$\square = T^{1/2} \square^{2/3} \square$ h = f(□)/T

And adding the Einstein-Hilbert action to estimate the gravitational effect of the brane.

$$S = \frac{M_{Pl}^2}{2} \int d^4x \sqrt{-g}\, R$$

Inflaton

$$- g_s^{-1} \int d^4x \sqrt{-g} \left[h^{-1} \sqrt{1 + h\, g_{mn} g^{\mu\nu} \partial_\mu \phi^m \partial_\nu \phi^n} - q\, h^{-1} + V(\phi^m) \right]$$

The DBI action gives the brane energy momentum in the cosmological background, which we input into the standard FRW equations:

$$E = \frac{1}{h}[\gamma - q] + V \qquad P = \frac{1}{h}[q - \gamma^{-1}] - V$$

Where the □factor is now:

$$\gamma = \sqrt{\frac{1 + h\,\ell^2(\phi)/a^6}{1 - h\,g_{\phi\phi}\,\dot{\phi}^2}}$$

NOTE

Cosmological expansion damps the angular contribution.

The Geometry

$$ds^2 = h^{-1/2}\, dx^2 + h^{1/2}\, dy^2$$

FRW cosmology ↑ ↑ Unchanged CY

Add general motion on the CY, including angular momentum, essentially cosmological expansion damps the motion on the CY, spinning adds only a couple of e-foldings to inflation.

Tension!

Ultra-relativistic motion for DB-Inflation ⟷ Local gravitational back-reaction.

Bounces or Cycles?

It is clear from the form of E that there can be no bounces in the true cosmological scale factor. This is because cosmology is coming from a KK approach to gravity.
For inflation, we need the acceleration parameter ϵ<1:

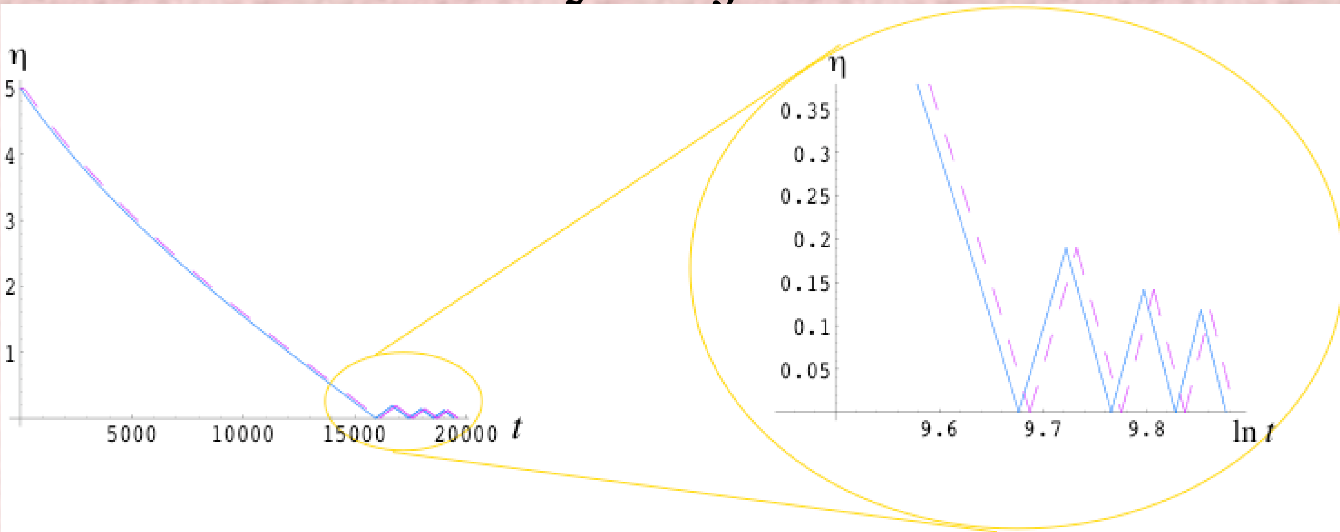
$$\epsilon \equiv -\frac{\dot{H}}{H^2}$$

With angular momentum:

$$\epsilon = \frac{3\beta}{2H^2}\left\{\left[q + h\left(\frac{3H^2}{\beta} - V\right)\right]\dot{\phi}^2 + \frac{l^2(\phi)}{a^6}\left[q + h\left(\frac{3H^2}{\beta} - V\right)\right]^{-1}\right\}$$

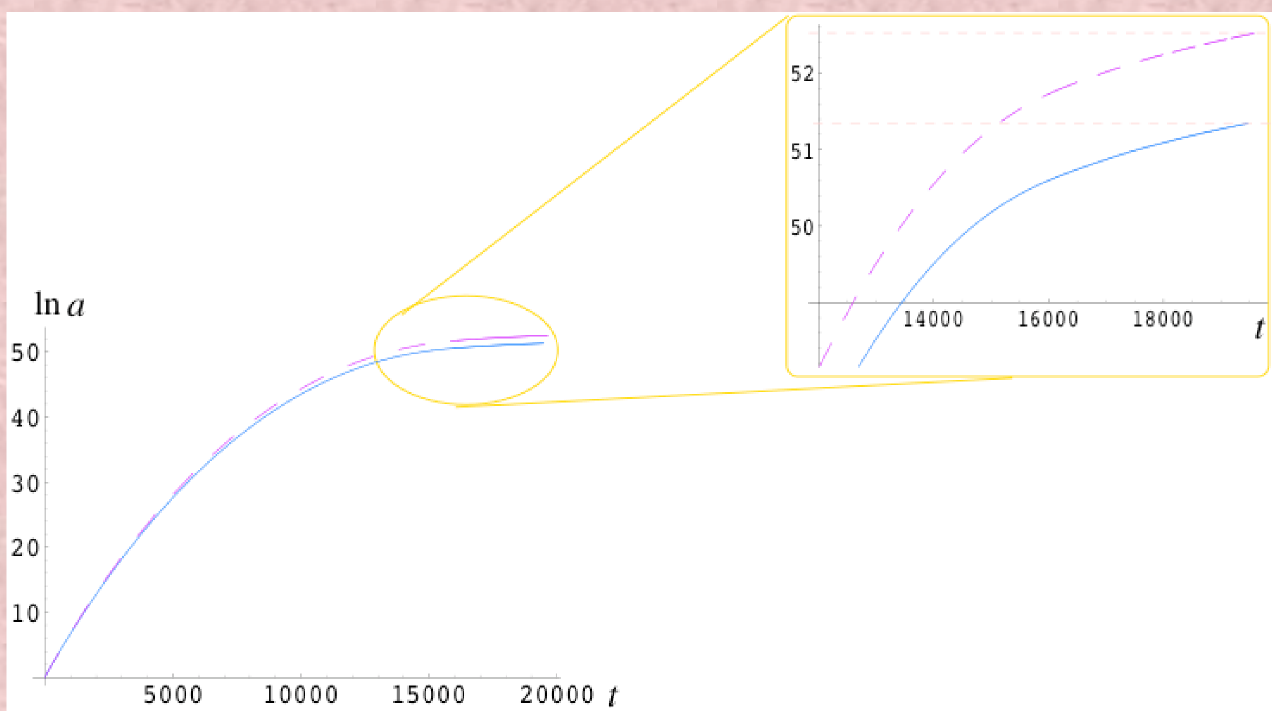
Although this contribution looks positive, in fact angular motion decreases $\dot{\phi}$, and overall *decreases* ϵ, increasing inflation.

Inflationary trajectories:



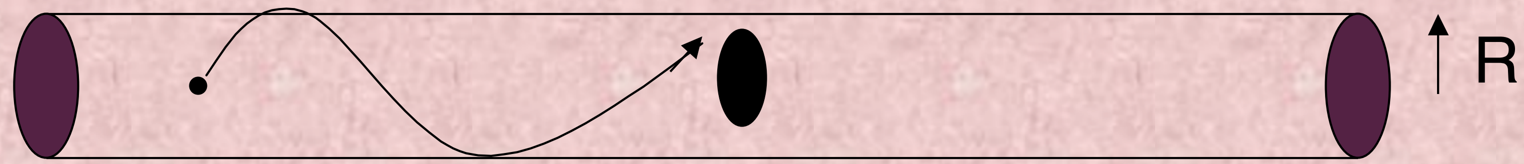
The number of e-foldings can be increased by spin.

The brane rapidly falls down the throat and oscillates near the tip.



Back-reaction:

To check the probe brane does not significantly warp the internal geometry, use a toy exact solution - D3 on $\mathbf{R}^9 \times S^1$



As the D-brane moves on the S^1 a horizon forms, and becomes larger as the brane moves faster. The proper energy of the D3 with respect to a Poincare observer also increases.

The probe brane approximation means that this curvature is always less than the ambient scale of the compact direction:

$\square^2_{10}\ \square << R^4$

$\square$ = proper ADM energy per unit brane volume

In our case $\square$ = hE, and R is the ambient curvature in the throat

$R^2 \sim gM\square'$

giving a geometric bound on the Lorentz factor: $\square < g\ M^2$

$g_s M \sim 10$

$g_s \sim 10^{-2}$

$\square$ $\square < 10^4$ (incredibly conservative)

Cosmological Perturbations

Even though the angular motion is damped along the (homogeneous) inflationary trajectory, fluctuations in the angular directions can and will happen at all times during inflation. We therefore have a 2^+ field model of DBI-inflation.

As with standard 2-field models, we can redefine our field coordinates to align with the inflationary trajectory.

$$\cos\alpha = \frac{\dot{\phi}}{\sqrt{2X}} \quad , \quad \sin\alpha = \frac{\phi\dot{\theta}}{\sqrt{2X}}$$

$$d\sigma = \cos\alpha\, d\phi + \phi \sin\alpha\, d\theta$$

$$ds = \phi\cos\alpha\, d\theta - \sin\alpha\, d\phi$$

Adiabatic and non-adiabatic perturbations propagate with different speeds.

$$\delta\ddot{\sigma}_\Phi + 3\left(H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = \left(\frac{H\,c_S^4}{a^3\dot{\sigma}}\right)\left[\frac{a^3\sin\alpha}{Hc_S^2}\left(1+c_S^2\right)V_\phi\,\delta s\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = \frac{k^2}{a^2}\sin\alpha\,\frac{c_S^4 H}{a\,\dot{\sigma}^2}\left(1+c_S^2\right)\xi$$

Need to solve these perturbation equations in detail for KS..

Summary

- The KS throat supports DB-Inflationary trajectories (better than ads).
- Probe brane approximation appears good.
- Angular motion gives new phenomenology, but not new inflation!
- Perturbations could tell an interesting story...
- But nongaussianity is a potential problem.