Spinflation

Damien Easson
(Durham University)

COSMO 07
University of Sussex

Outline

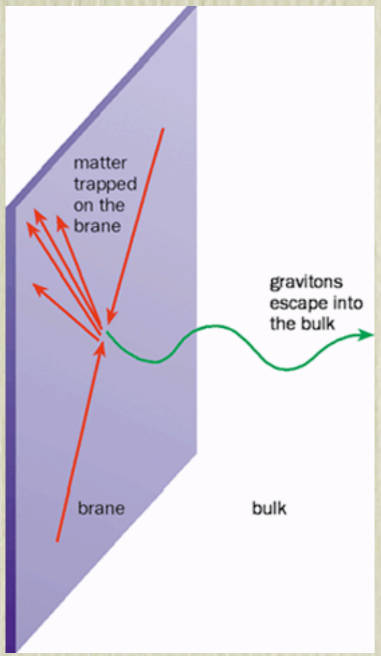
- Introduction
- Moduli Stabilization and Flux Compactifications
- Cycling in Warped Throats (using angular momentum)
- Mirage 'cosmology'
- *Spinflation:* brane inflation with angular momentum

DAE, Gregory, Tasinato, Zavala 2007

DAE, Gregory, Mota, Tasinato, Zavala *in progress*

String Cosmology

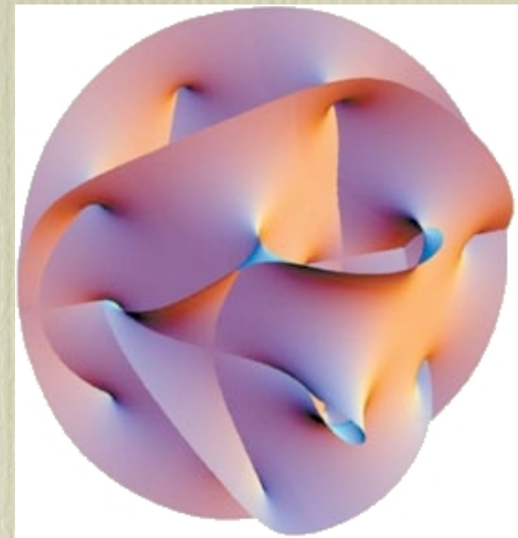
- The “Brane World” picture is often assumed.
- *What if the brane has non-zero angular momentum in the extra dimensions?*
- Implications for inflation

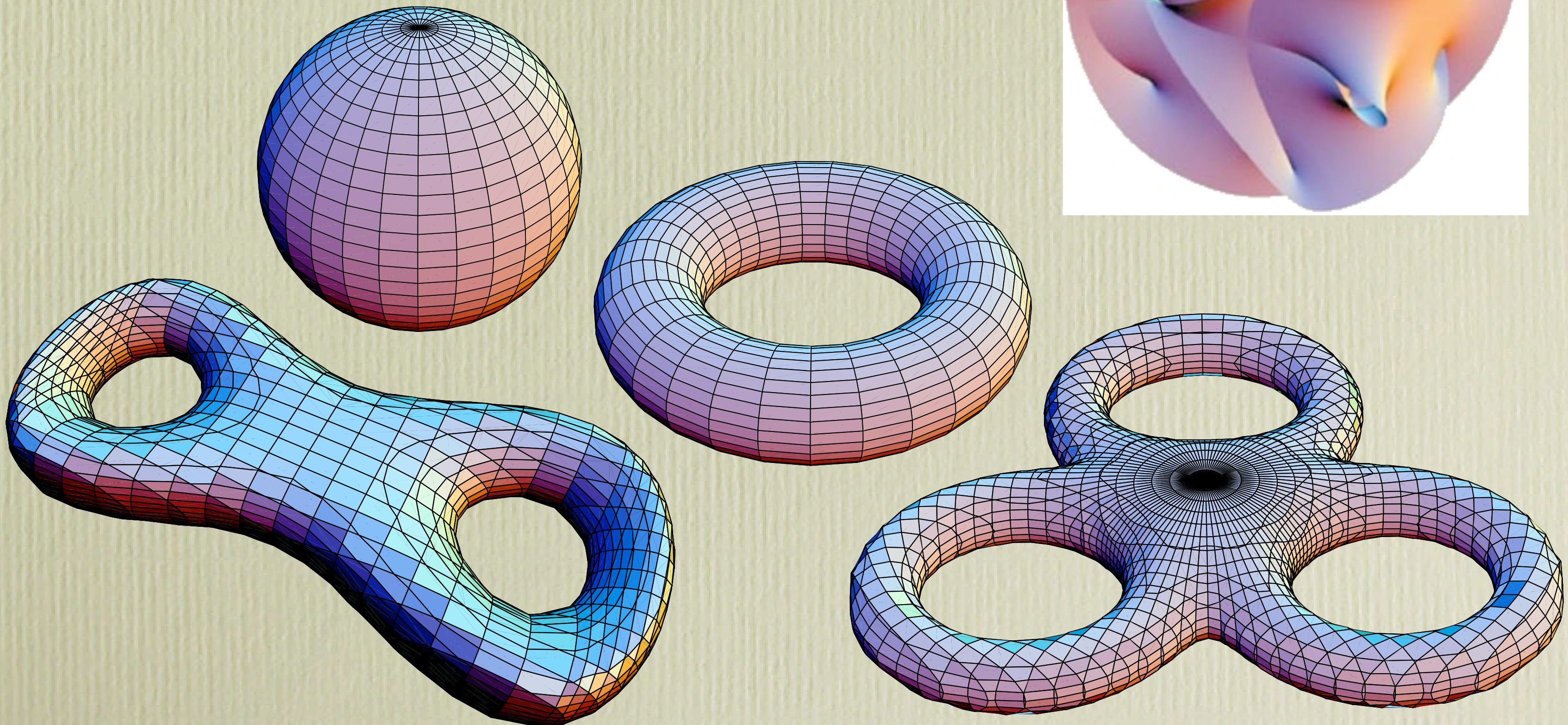


- We want to study this problem in a well controlled environment: *flux compactifications*

Calabi-Yau Compactifications

- *6d* manifolds with special properties
- *cycles and holes related to particle content.*





Moduli fields

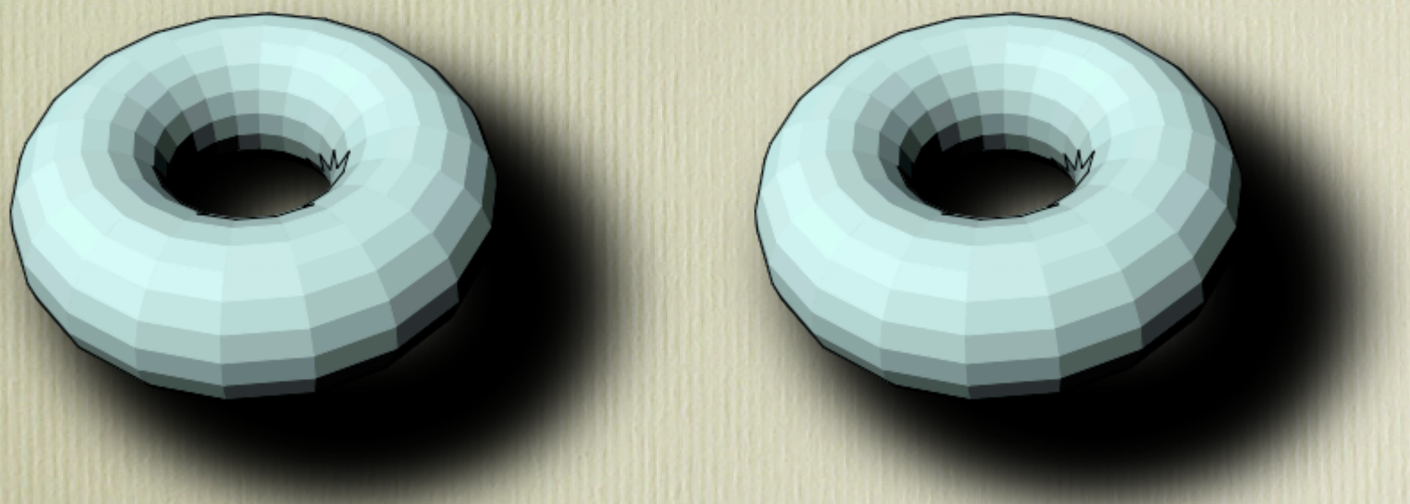
- The metric in the extra dimensions (sizes and shapes of cycles) depends on continuous parameters called *moduli*.

- The parameters of a solution correspond to scalar fields (unconstrained by EOM, i.e. *massless*) in four dimensions.

- In a realistic (CY) compactification there can be *many* of these moduli fields.

Two types of moduli

- Complex Structure – *Shape moduli*
- Kähler – *Volume*



Moduli Problems

These scalar fields have nonuniversal couplings to matter:

$$f_i(\varphi_i)L_m(\psi_i)$$

• Different types of matter get different accelerations from these forces, violating the equivalence principle.

• 'Fifth force' experiments constrain such forces to be very weak, but if fields remain massless we do not expect them to interact with matter more weakly than gravity.

• Moduli can overclose the Universe

Need to stabilise moduli !

String Model

$$S_{\mathrm{IIB}} = \frac{1}{2\kappa^2}\int d^{10}x\sqrt{-g_{\mathrm{s}}}\Big\{e^{-2\phi}\left[\mathcal{R}+4(\nabla\phi)^2\right]$$

$$-\frac{F_{(1)}^2}{2} - \frac{1}{2\cdot 3!}G_{(3)}\cdot\bar{G}_{(3)} - \frac{\tilde{F}_{(5)}^2}{4\cdot 5!}\Big\}$$

$$+\frac{1}{8i\kappa^2}\int e^{\phi}C_{(4)}\wedge G_{(3)}\wedge\bar{G}_{(3)} \; + \; S_{\mathrm{loc}}$$

$$G_{(3)} = F_{(3)} - \tau H_{(3)}$$

$$\tau = C_{(0)} + ie^{-\phi}$$

$$S_{\rm loc} = -\int_{R^4\times\Sigma} d^{p+1}\xi\, T_p\sqrt{-g} + \mu_p \int_{R^4\times\Sigma} C_{p+1}$$

In IIB RR potentials are:

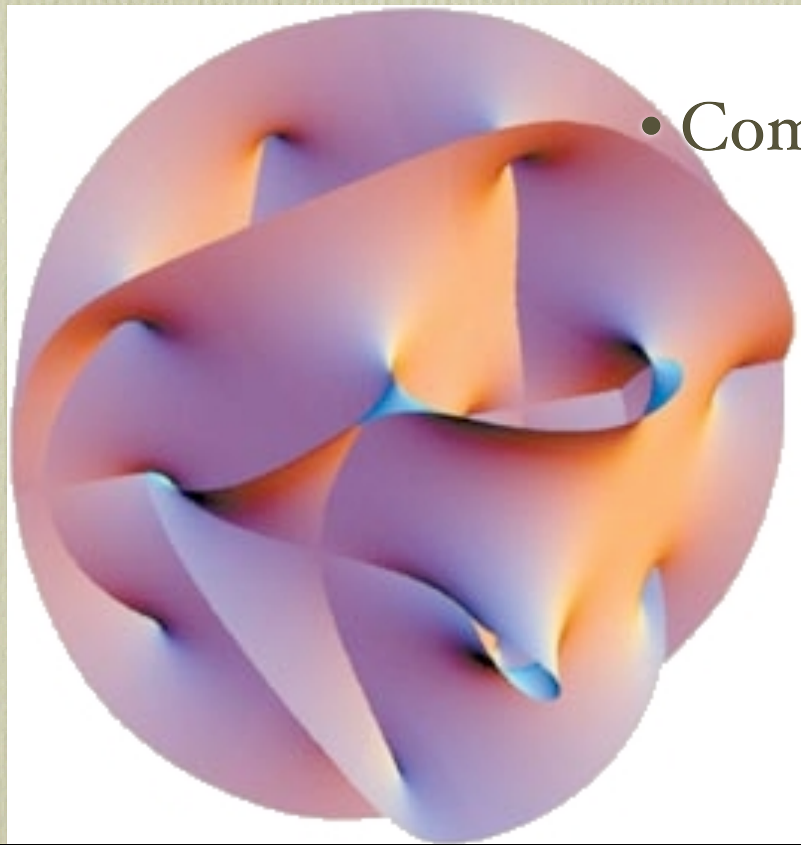
$$C_{(0)}, C_{(2)}, C_{(4)}, C_{(6)}, C_{(8)}$$

- Compactify this on a CY manifold and turn on fluxes and wrap branes to stabilise moduli fields.

Giddings, Kachru, Polchinski 2001
Kachru, Kallosh, Linde, Trivedi 2003

- Study dynamics of brane probes in this background

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu + \tilde{g}_{mn} dy^m dy^n$$



- Compactify on CY

$$ds^2 = e^{A(y)} g_{\mu\nu} dx^\mu dx^\nu + e^{-A(y)} \tilde{g}_{mn} dy^m dy^n$$

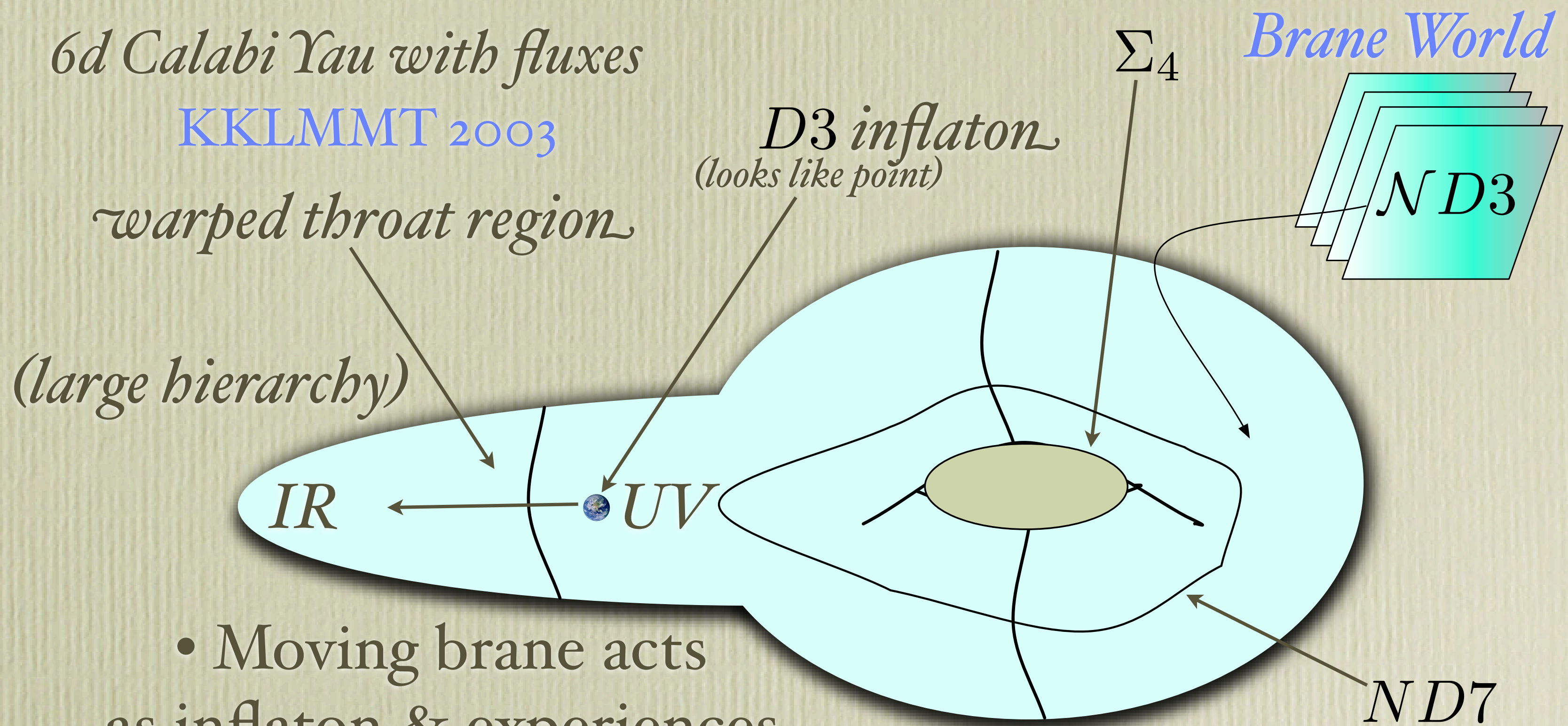
Why warping is nice

Randall, Sundrum 1999

- Simple model constructed from branes in AdS.
- Example of *warped compactification* (spacetime curves strongly away from the brane).
- Exponential warping produces exponential hierarchies in scales.
- Provides a concrete mechanism to explain the large differences between the electroweak and Planck scales in physics.
- Exponential warping gives exponential flatness to the inflaton potential *(caveat: n.p. effects)*.

Baumann, Dymarsky, Kebanov, Maldacena, McAllister, Murugan 2006

Model



• Moving brane acts as inflaton & experiences expansion/contraction as it moves in the throat - *mirage cosmology*

• Need nonperturbative effects to stabilise Kähler moduli.

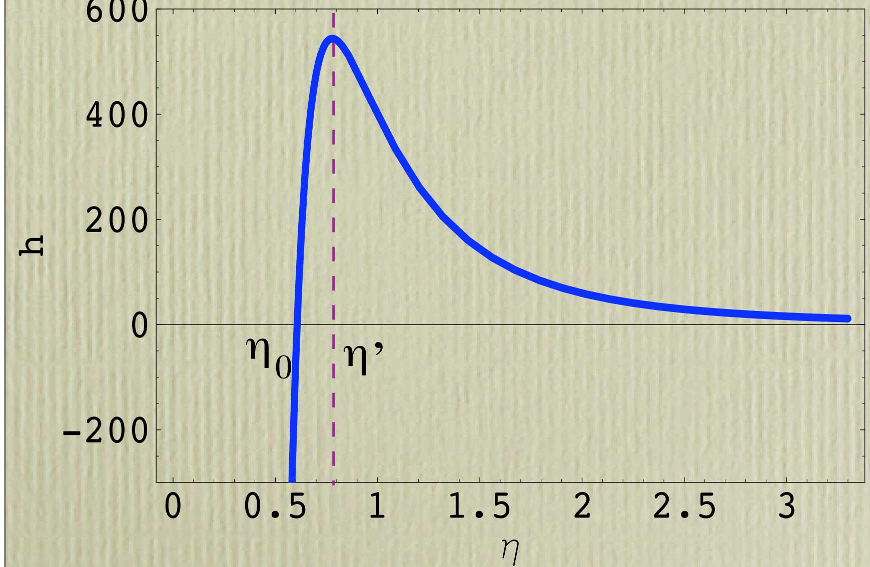
Warped Conifold Klebanov, Tseytlin 2000

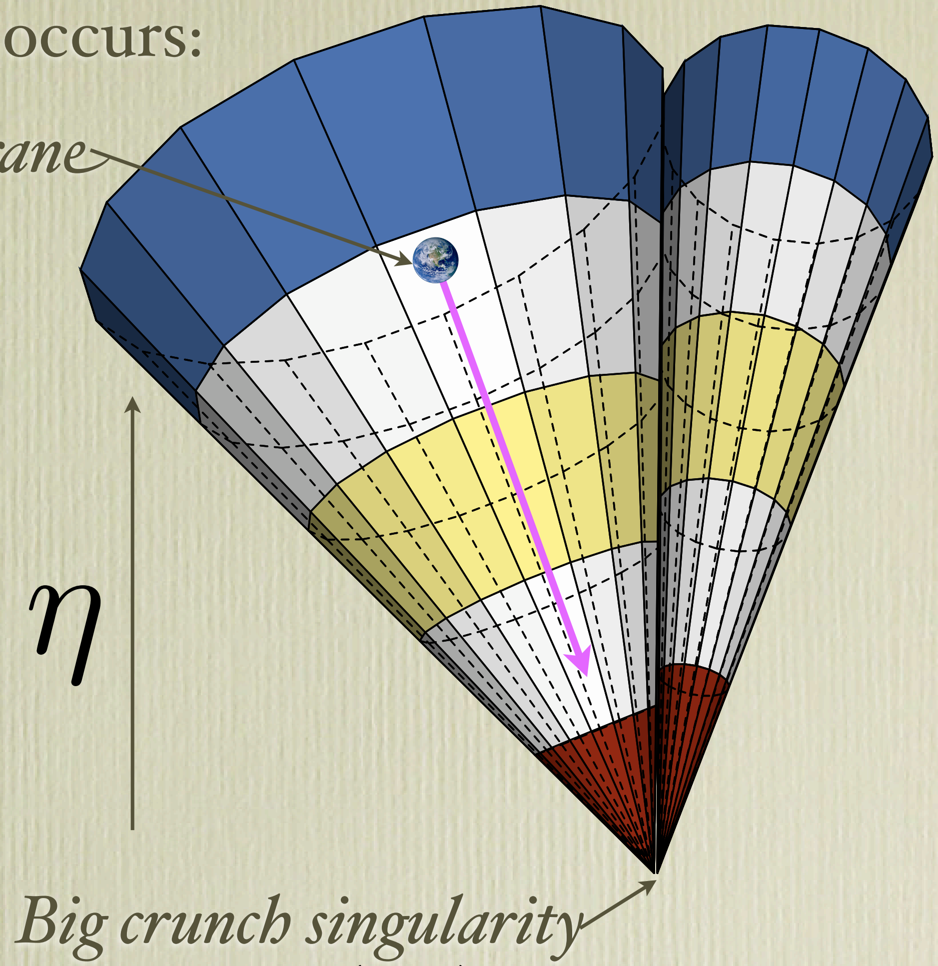
When flux is added warping occurs:

$N \; D3$

$M \; fractional \; D3$

Branes source: $F_3 \quad H_3$





$$T^{(1,1)} = S^2 \times S^3$$

$$ds_{10}^2 = h^{-1/2}(\eta)\, dx_\mu dx^\mu + h^{1/2}(\eta)(d\eta^2 + \eta^2 ds^2_{T^{1,1}})$$

Warped Deformed Conifold

Klebanov, Strassler 2000

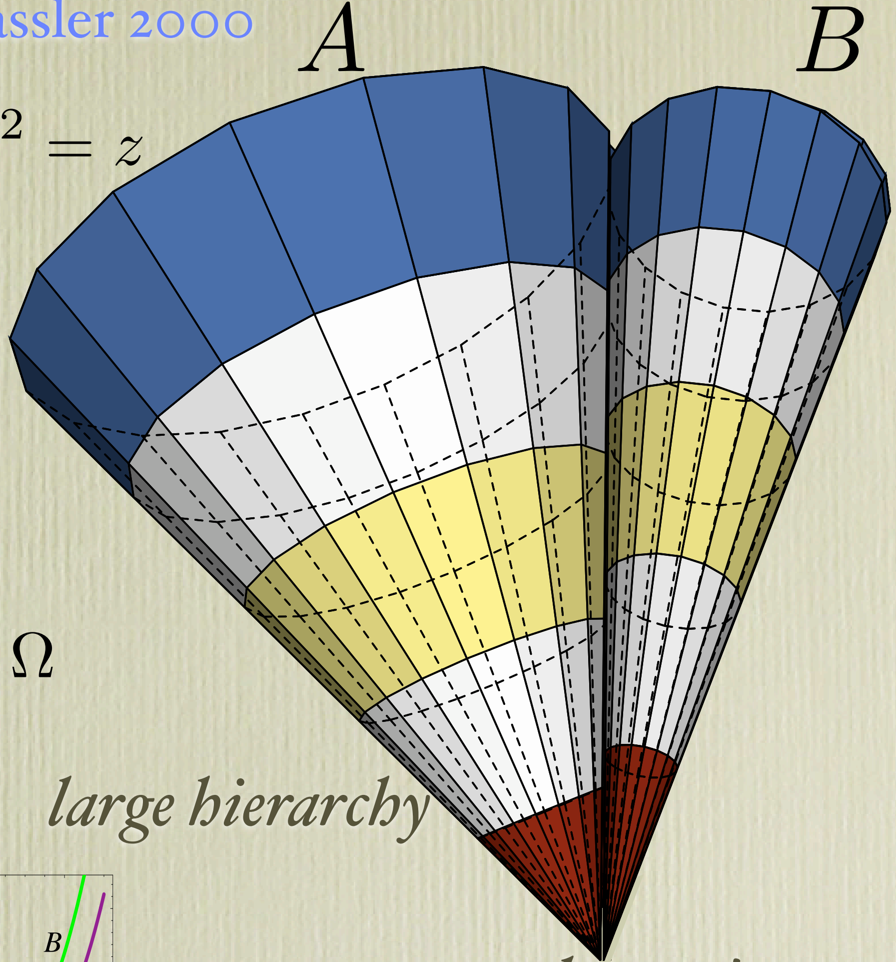
- Based on *deformed conifold*: $\sum_A (w^A)^2 = z$

$$\frac{1}{2\pi\alpha'}\int_A F_3 = 2\pi M$$

$$\frac{1}{2\pi\alpha'}\int_B H_3 = -2\pi K$$

$$W = \int G_3 \wedge \Omega \qquad z = \int_A \Omega$$

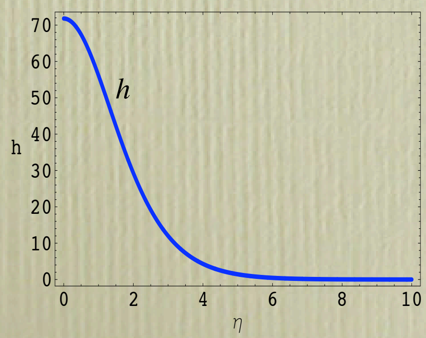
$$z = e^A \sim e^{-2\pi K/g_s M}$$

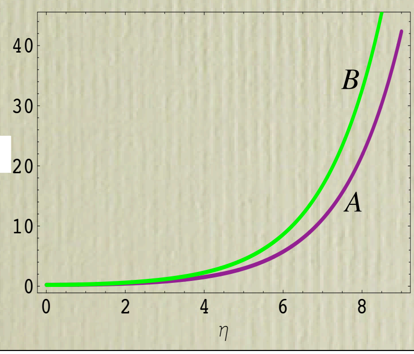


large hierarchy

can bounce!

$$Vol(T^{(1,1)}) = \frac{16\pi}{27}$$





Brane Dynamics & Mirage Cosmology

Kehagias, Kiritsis 1999

- The probe brane evolves according to the DBI action:

$$S_{\mathrm{DBI}} = -m \int d^4x \left[h^{-1} (\sqrt{1 - hv^2} - 1 \right]$$

$$ds^2 = h^{-1/2} \left(-(1 - h\, v^2)\, dt^2 + dx_i dx^i \right) = -d\tau^2 + a^2(\tau) dx_i dx^i$$

scale factor on the brane

- Bounces are possible. The *4D* effective theory on the brane is a scalar-tensor gravity that can violate the NEC.

- Represents a string theory resolution of a spacelike singularity.

Kachru, McAllister 2003

Turning on angular momentum

- What if the brane *spins* as it moves in the throat? Germani, Grandi, Kehagias 2006
  DAE, Gregory, Tasinato, Zavala 2007
- Cases: AdS, KT and KS
- Conserved angular momentum: $l_r = \dfrac{g_{rs}\,\dot{\theta}^s}{\sqrt{1-hv^2}}$

$$v^2 = \frac{g_{\eta\eta}\dot{\eta}^2 + \ell^2(\eta)}{1 + h\ell^2(\eta)} \qquad\qquad \ell^2(\eta) = g^{rs} l_r l_s$$

- Energy is also conserved and we may plot the radial velocity in terms of conserved quantities:

$$Q \equiv \dot{\eta}^2 = \frac{g^{\eta\eta}[\varepsilon(h\,\varepsilon + 2q)\; - \ell^2(\eta)]}{(h\,\varepsilon + q)^2}$$

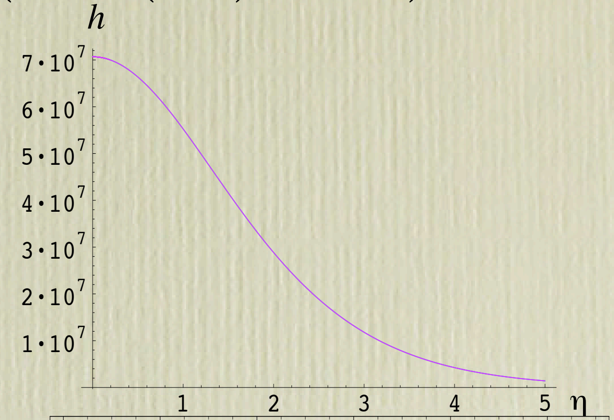
- Introducing angular momentum generates a centrifugal barrier for the brane.

  - *Zeros of* Q *correspond to new turning points.*

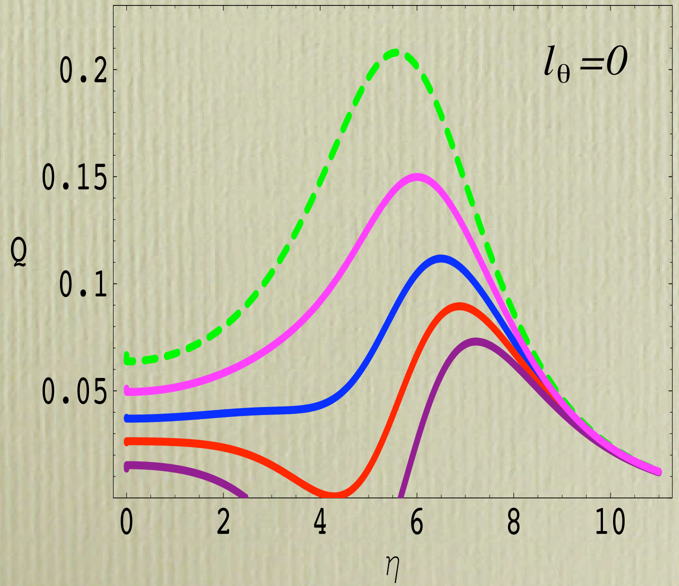
Klebanov Strassler

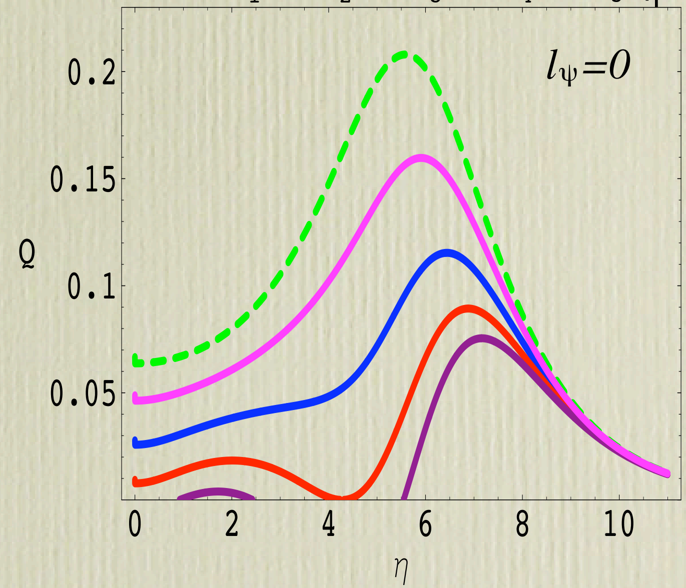
$$ds^2_{10} = h^{-1/2}(\eta)\, dx_\mu dx^\mu + h^{1/2}(\eta) ds^2_6$$

$$h(\eta) \propto \epsilon^{-8/3} \int_\eta^\infty dx \, \frac{x \coth x - 1}{\sinh^2 x} \, (\sinh(2x) - 2x)^{1/3}$$



- KS provides most rich structure.
- *Two types* of bounces and cycles.





- The mirage pictures has serious drawbacks, but it does provide an example of a time-dependent bounce and cyclic toy cosmologies in string theory.

- Try using spinning moving branes as inflatons instead.

DBI(nflation) in the Throat

Silverstein, Tong 2003

A moving brane sources inflation.

$$S = \frac{M_{Pl}^2}{2}\int d^4x\sqrt{-g}R + \int d^4x\sqrt{-g}\,P(X,\,\phi^m)$$

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

$$E = \frac{1}{h}\left[\gamma - q\right] + V$$

$$P = \frac{1}{h}\left[q - \gamma^{-1}\right] - V$$

$$\gamma \equiv \frac{1}{\sqrt{1 - hv^2}} \qquad\qquad v^2 = g_{mn}\dot{\varphi}^m\dot{\varphi}^n$$

Brane position in throat given by field: ϕ

$$\dot{H} = -\frac{3\beta}{2h}\left(\frac{h^2\left(\frac{H^2}{\beta}-V\right)^2+2qH\left(\frac{H^2}{\beta}-V\right)+q^2-1}{q+h\left(\frac{H^2}{\beta}-V\right)}\right)$$

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

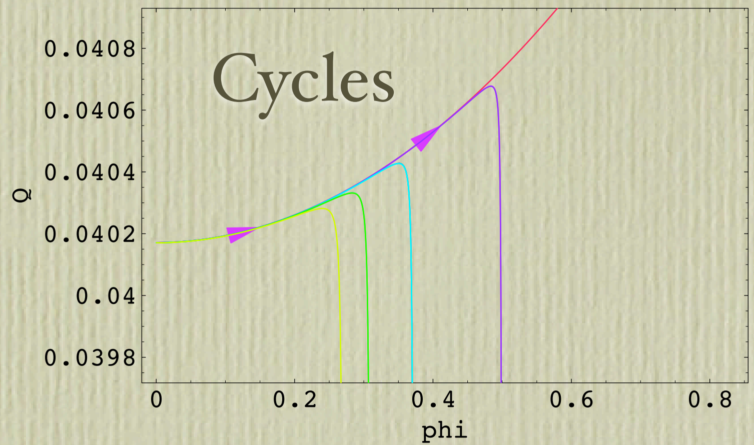
- Bounces remain (but not with sufficient efoldings of inflation).
- Cycles remain when brane passes through the nonsingular tip.

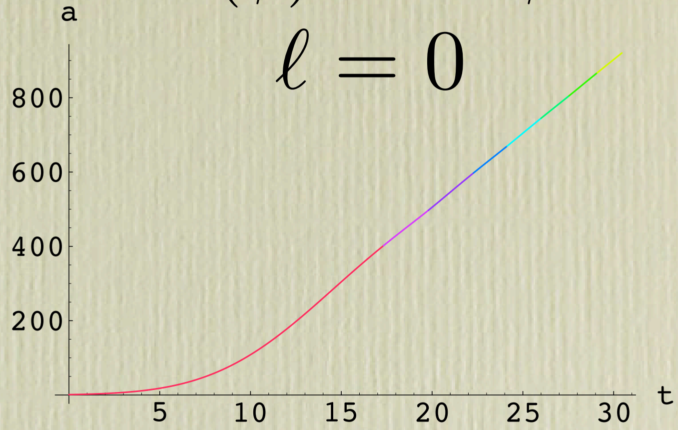
DBInflation in KS

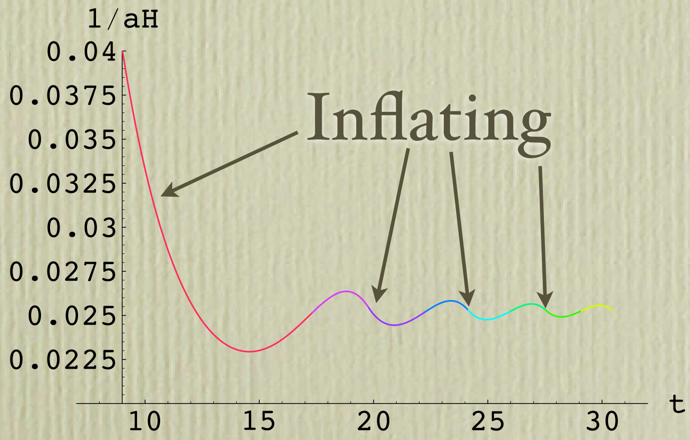
(General properties)

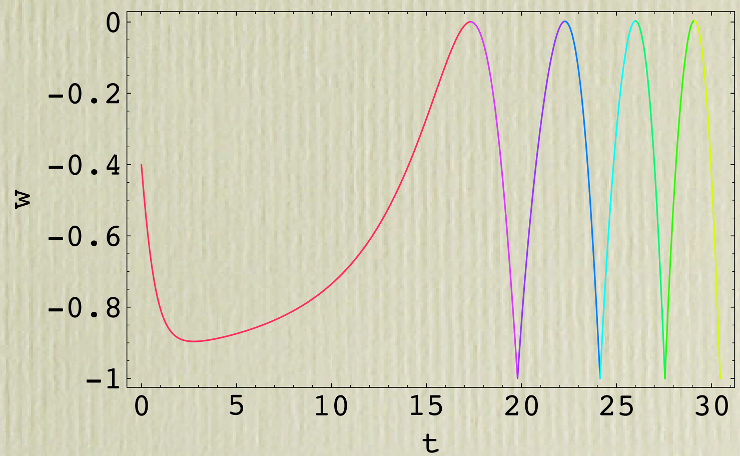
$$V(\phi) = m^2\phi^2$$

$$\ell = 0$$



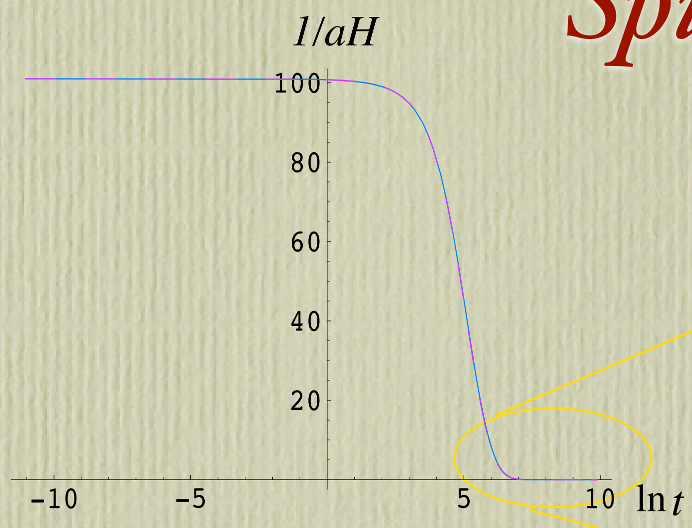


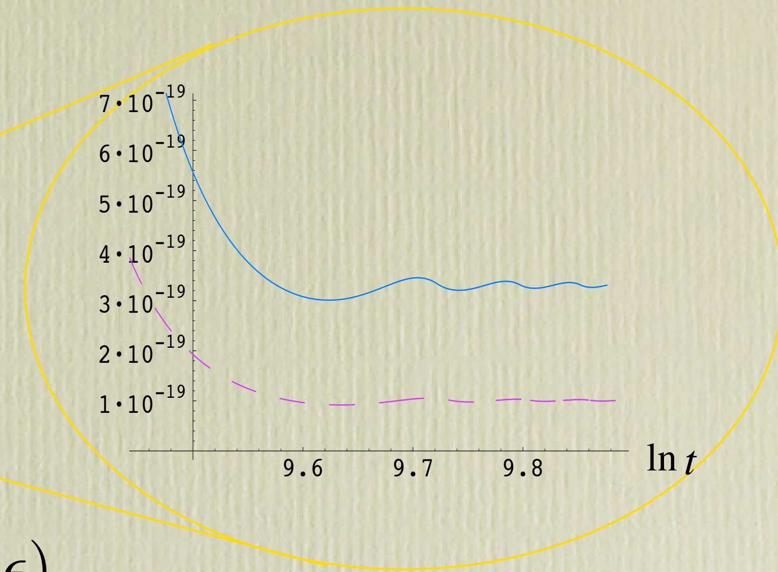




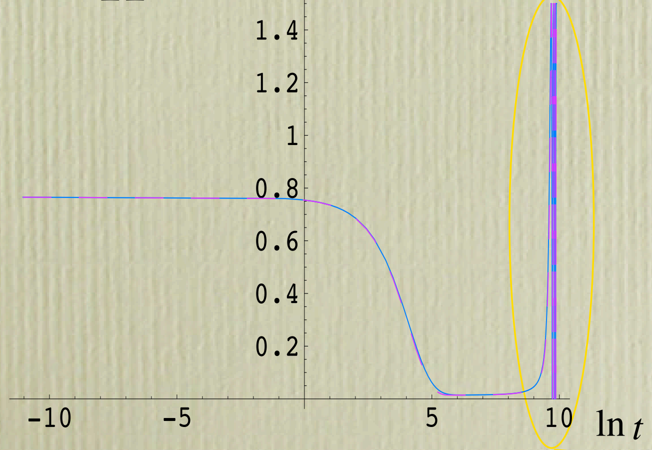
$$w_{eff} = \frac{P}{E} = \frac{1 - \gamma^{-1} - Vh}{\gamma - 1 + Vh}$$

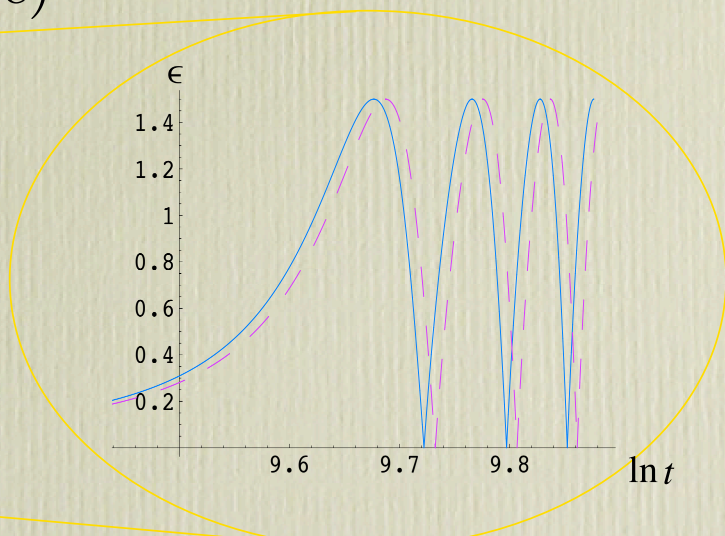
Spinflation

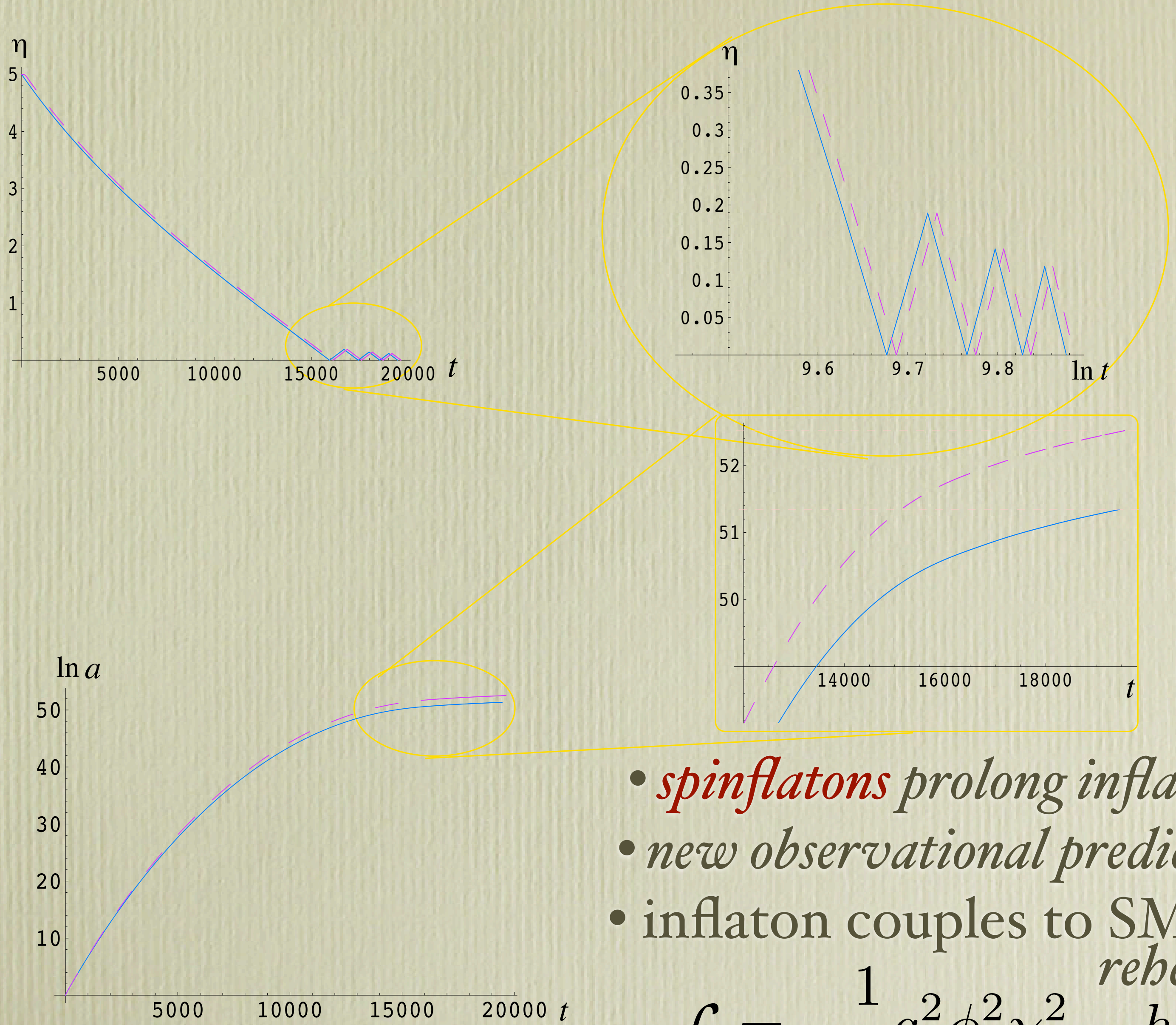




$$\epsilon = -\frac{\dot{H}}{H^2} \qquad \frac{\ddot{a}}{a} = H^2(1-\epsilon)$$







- *spinflatons prolong inflation*
- *new observational predictions*
- inflaton couples to SM fields:

reheating

$$\mathcal{L} = -\frac{1}{2}g^2\phi^2\chi^2 - h\bar{\psi}\psi\phi$$

Non-Gaussianities

- In Special Relativity particles (zero branes) move with action:

$$S = \int dt \sqrt{1 - \dot{x}^2}$$

- For a brane moving through a warped background:

$$S_{DBI} = \int dt\, d\vec{x}\, h^{-1}(\phi)\sqrt{1 - h(\phi)\partial^\mu\phi\partial_\mu\phi}$$

In standard slow roll inflation $|n_s - 1| << 1$

In DBI $\quad f_{NL} \propto \gamma^2 \qquad \gamma \equiv \dfrac{1}{\sqrt{1 - hv^2}}$

Conclusions

- Building rigorous models of inflation in string theory is new! Specific models make observational predictions (e.g. cosmic strings, non-gaussianity, gravity waves).

- Considering brane dynamics with angular momentum and cycling behavior gives rich, new phenomenology.

- Preliminary work (in progress) indicates angular momentum will not help much with getting a successful inflationary scenario... but it *can* help some.

- The search for observational effects of spinflation is on:

DAE, Gregory, Mota,Tasinato, Zavala *to appear*