COSMOLOGICAL SLINGSHOT SENARIO

ALEX KEHAGIAS
(NTU ATHENS)

in collaboration with
Cristiano Germani
Nicolas Grandi

hep-th/0611246, hep-th/0706.0023

based on mirage cosmology
work in collaboration with
Elias Kiritsis

hep-th/9910174

Patra June 2007

OVERVIEW

- Inflation vs Slingshot

- Set up

- Cosmology of Slingshot

- Comparison with other proposals

- Conclusion

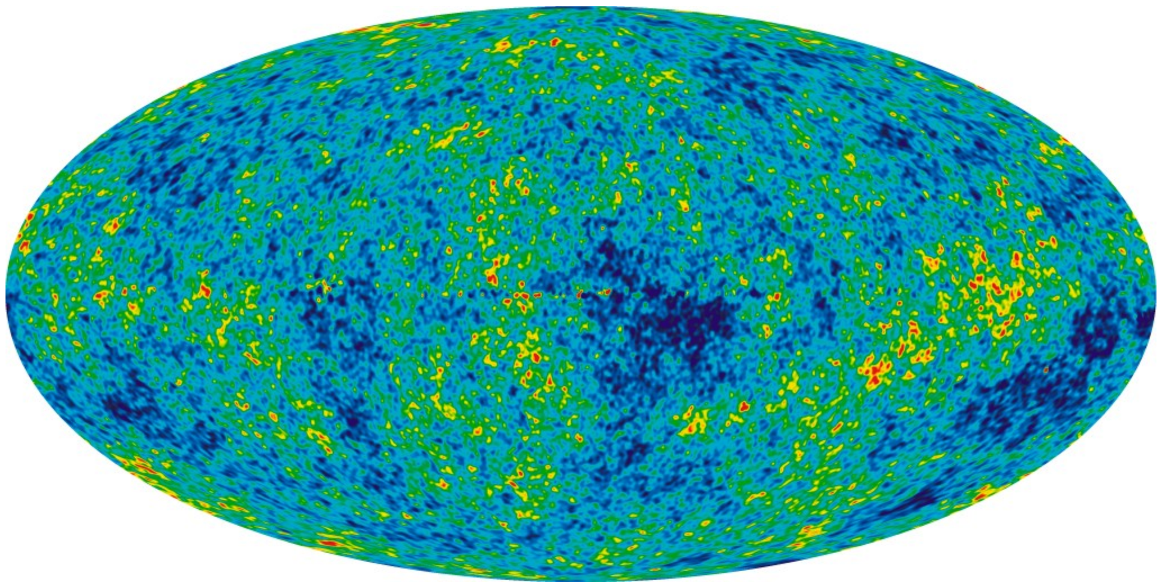
Inflation explains:

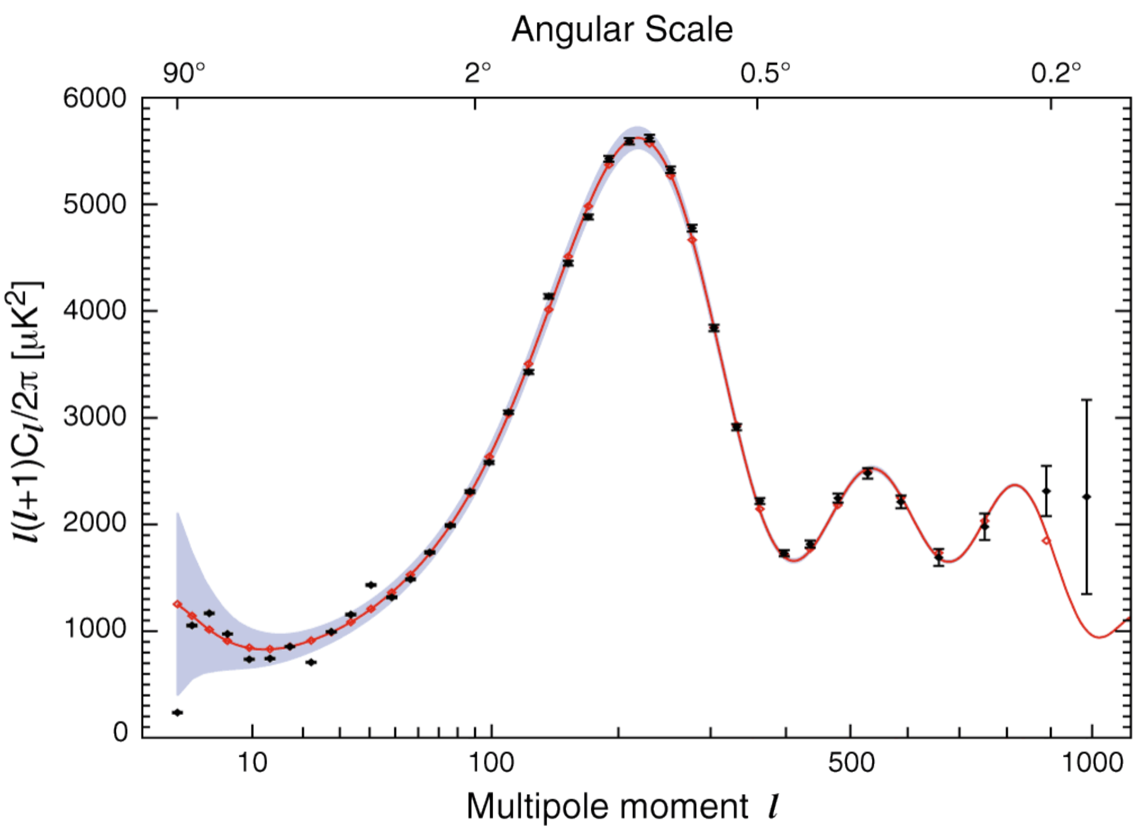
1) Homogeneity problem
2) Isotropy problem
3) Horizon problem
4) Flatness
5) Structure formation
6) Monopole, gravitino, etc. problems

...

Any theory alternative to Inflation should at least solve the problems Inflation does....

and consistent with WMAP





Inflation seems to work quit well, so why we should look for alternatives?

Motivation

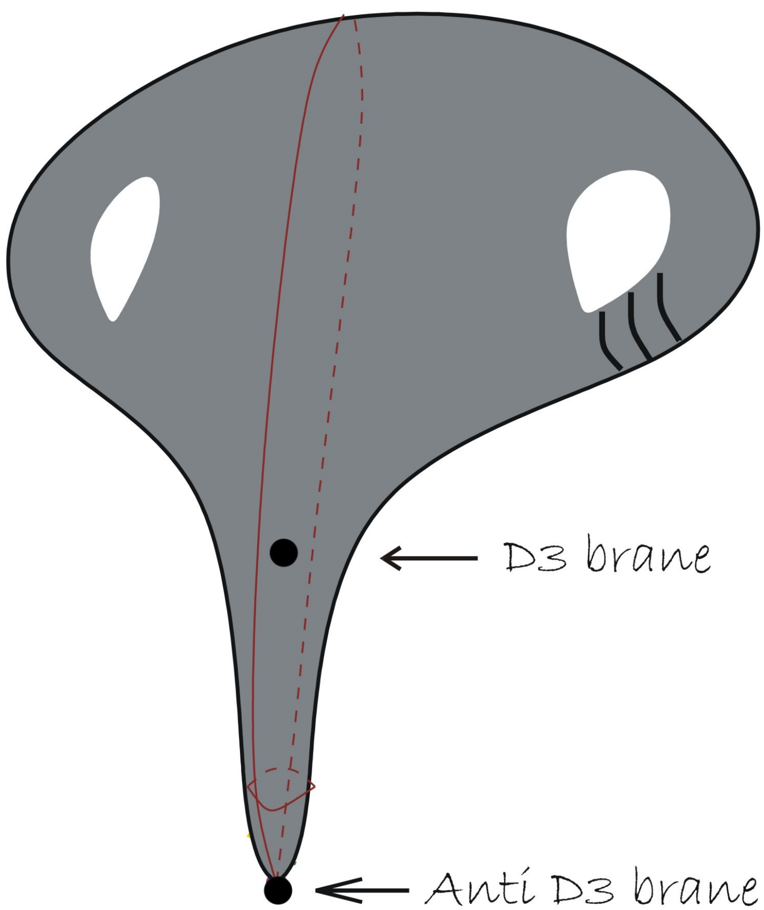
- If an alternative succeed, this will open a new avenue to cosmology
- If it fails, it will provide additional support and indirect demonstration of the advantages of inflation.

Proposals:

- Pre-Big-Bang
- Ekpyrotic
- Cyclic
- String-Gas
- ....
- Slingshot

SLINGSHOT SENARIO

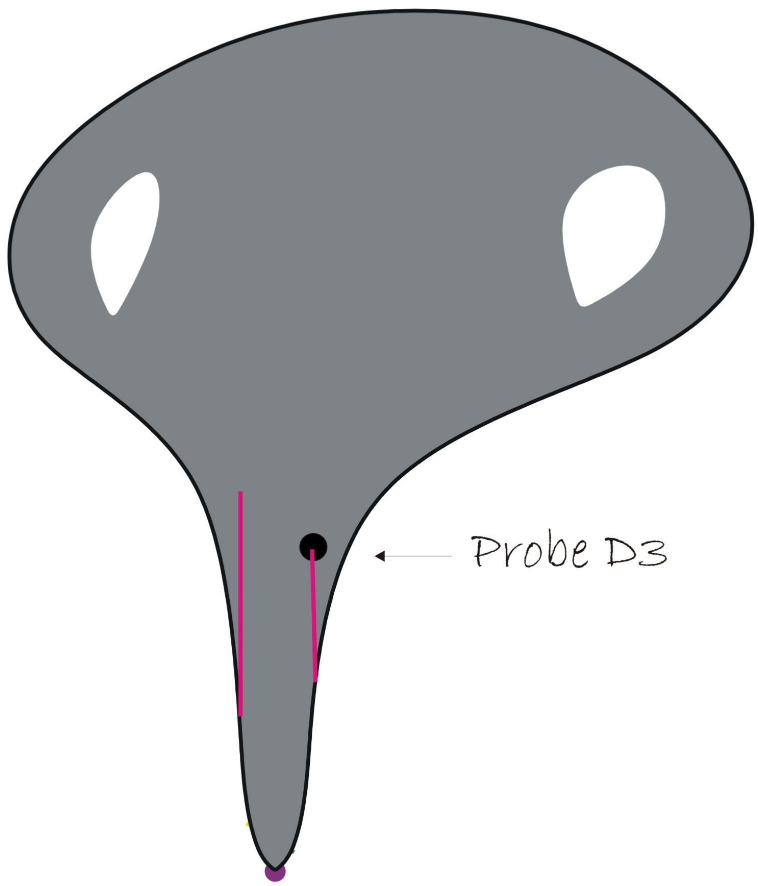
Similar to D3/anti-D3 brane Inflation



But in slingshot

NO anti-D3 and NO inflation!

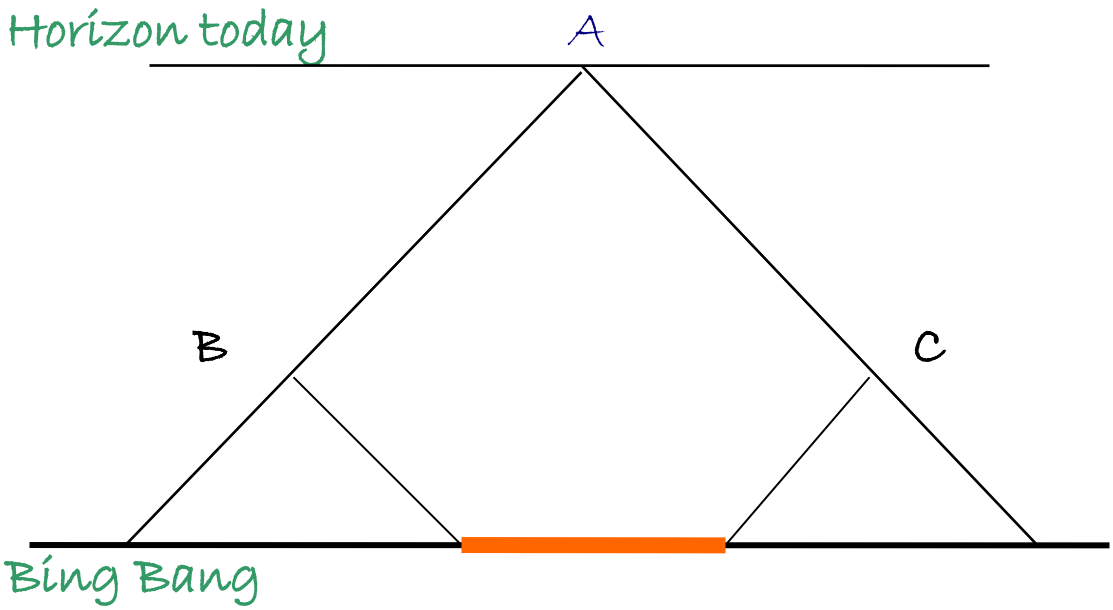
A probe D3 (our universe) is moving in the background sourced by N D3's.



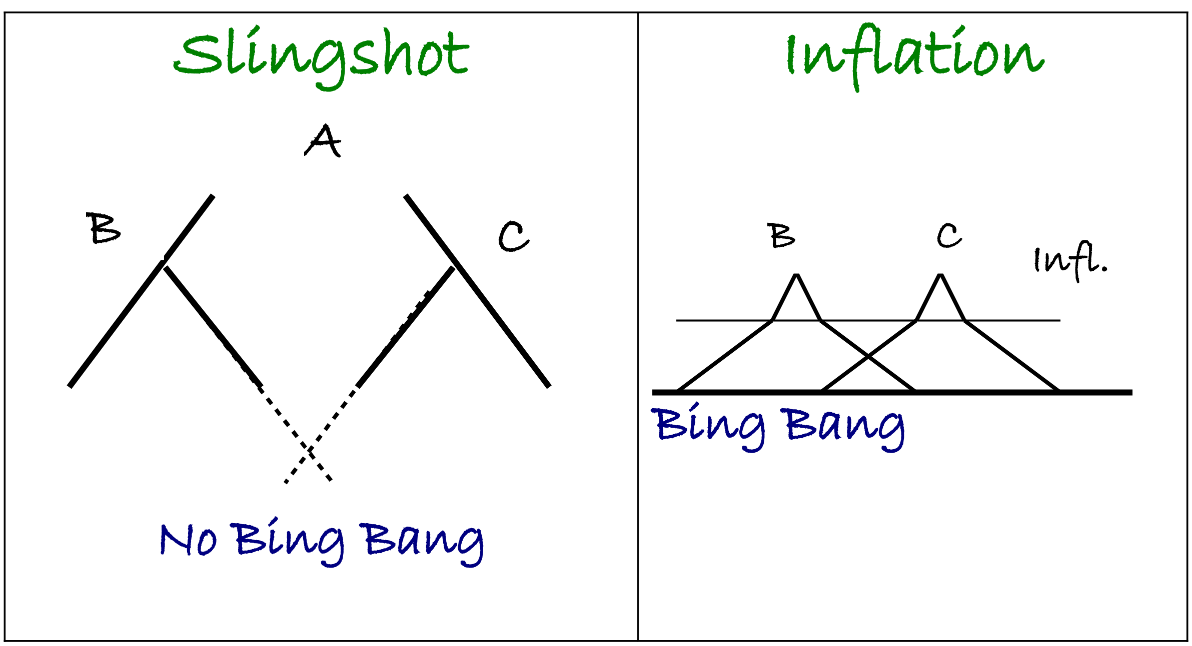
Cosmological Problems

- Isotropy of CMB → horizon problem

Standard GR



Solution



Isotropy

Friedmann equation

$$H^2 = \frac{8\pi G}{3}\left[\frac{\rho_m}{a^3} + \frac{\rho_r}{a^4} + \frac{\sigma_0}{a^6} + \ldots \rho_I\right] + \overbrace{\frac{\rho_{mir}}{a^8}}^{\text{mirage}}$$

Inflation mirage

matter radiation shear

In GR at small scales shear dominates and FRW becomes highly unstable.

Solution

Slingshot	Inflation
1) Scale factor a has a minimum before shear domination 2) mirage matter contribution scales like a^{-8} so shear never dominates	Once vacuum energy dominates, a rapid and long expansion washes out all other contributions.

Curvature Problem

$$\Omega_k\big|_{BBN} < 10^{-8}$$

If radiation dominates GR

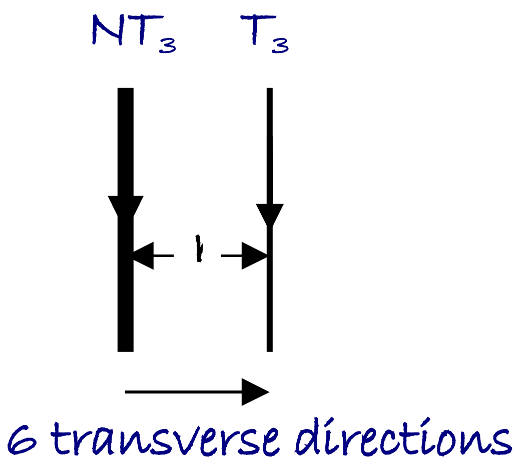
$$\Omega_k\big|_{Planck} < 10^{-60}$$

Solution

Slingshot	Inflation
1) There is a bounce so that we cannot reach too small scales 2) Universe started out in a flat empty initial state.	$\Omega_k \sim \frac{1}{a^2H^2}$ In inflation we have $a^2H^2 \downarrow$ back in time so $\Omega_k\big|_{Planck} >> 10^{-60}$

GENERAL SETUP:

D3-brane in the background sourced by N D3's.
In the static limit, there exists a gravitational attraction and a RR-gauge field repulsion

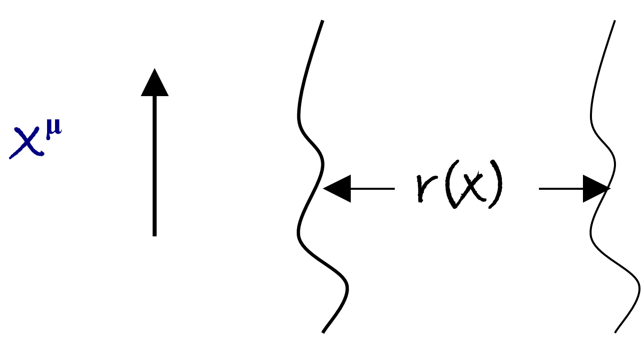


$$V_{gr} = -\kappa_{10} \frac{N T_3^{\,2}}{r^4}$$

$$V_{RR} = +\kappa_{10} \frac{N T_3^{\,2}}{r^4}$$

no force condition (BPS states)

D-branes are dynamical objects (they can fluctuate)



Dynamics described by the DBI action:

$$S = -T_3 \int d^4x \, e^{-\varphi} \sqrt{-\det(g_{ind})} - T_3 \int C_4$$

φ = the dilaton, C_4=RR-4-form potential,
g_{ind} is the induced metric from the background.

The background for the slingshot is the Klebanov-Strassler throat of a CY_3. The near-horizon geometry of N coincident D3 branes at the tip of a cone preserving N=1 susy is $AdS_5 x T^{1,1}$ and the metric is

$$ds^2 = \frac{r^2}{L^2}\left(-d\eta^2 + d\vec{x}^2\right) + \frac{L^2}{r^2}\left(dr^2 + r^2 ds_{T^{1,1}}\right)$$

$T^{1,1}$ is like $S^2 x S^3$. At the tip of the cone, $S^3 \rightarrow 0$. One may deform the geometry such that the manifold closed off smoothly at some $r=r_{IR}$.
The conifold can be described by 4 complex coordinates W_i with one complex condition

$$\sum_{i=1}^{4} W_i^2 = z$$

z=0 Singular conifold
z ≠ 0 deformed conifold

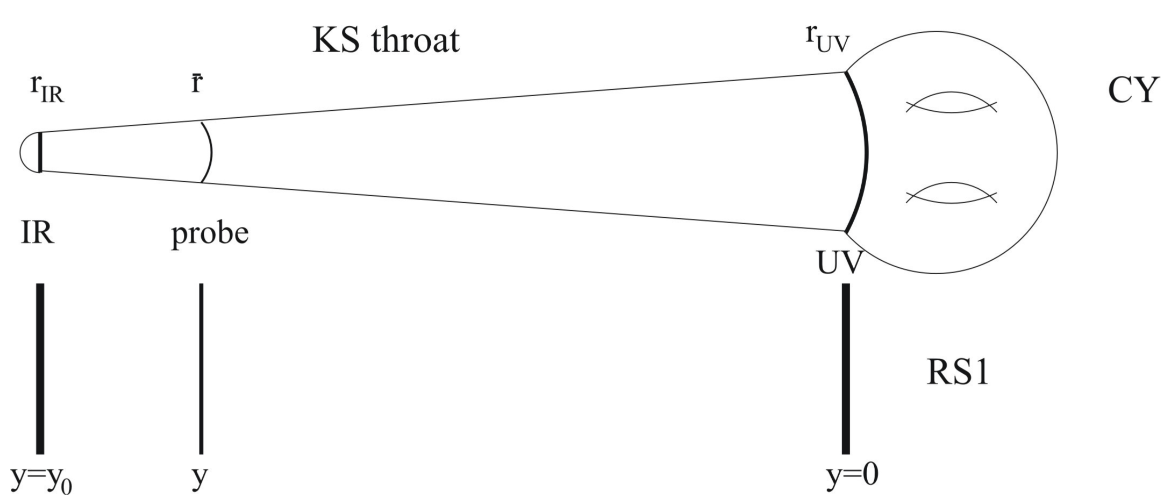
z is a dynamical field; the complex structure modulus. It is a flat direction if there are no fluxes. In the presence of fluxes acquires a potential and can be stabilized by H_3 (NS-NS) and F_3 (R-R) fluxes. With

$$\left(\frac{M_s}{2\pi}\right)^2 \int_A F_3 = M, \qquad \left(\frac{M_s}{2\pi}\right)^2 \int_A H_3 = -K$$

z is stabilized to $z = e^{-2\pi K/g_s M} = a_0^3$

$a_0 = r_{IR}/L$ the warp factor at the bottom of the throat.

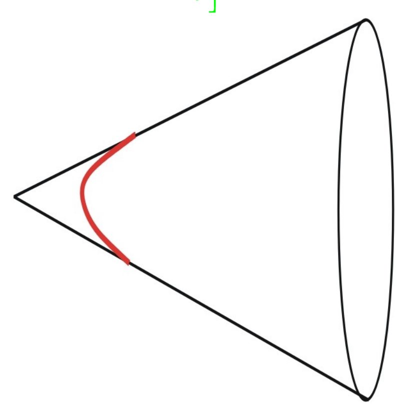
However, r is not a "good" global coordinate. It can be cut off at $r=r_{UV}$ and glued back to CY_3. This construction looks very much the same with RS1 where the IR brane corresponds to $r=r_{IR}$ and the UV one to $r=r_{UV}$.



Local geometry of the KS throat has metric:

$$ds^2 = h^{-1/2}(\tau)\eta_{\mu\nu}dx^\mu dx^\nu + h^{1/2}(\tau)ds_6^2$$

$$ds_6^2 = \frac{1}{2}z^{2/3}K(\tau)\left[\frac{1}{3K^3(\tau)}\left\{d\tau^2 + (g^5)^2\right\} + \cosh^2\left(\tau/2\right)\left\{(g^3)^2 + (g^4)^2\right\} + \right.$$
$$\left. + \sinh^2\left(\tau/2\right)\left\{(g^1)^2 + (g^2)^2\right\}\right]$$



$$K(\tau) = \frac{\left(sinh(2\tau) - 2\tau\right)^{1/3}}{2^{1/3}sinh(\tau)}$$

$$h(\tau) = 2^{2/3}m^2 z^{-4/3} I(\tau)$$

$$I(\tau) = \int_\tau^\infty dx \frac{x Coth(x) - 1}{sinh^2(x)}\left(sinh(2x) - 2x\right)^{1/3}$$

limits:

Small τ

$$ds^2 \approx \frac{z^{2/3}}{2^{1/3} a_0^{1/2} g_s M\alpha'} \eta_{\mu\nu} dx^\mu dx^\nu + a_0^{1/2} 6^{-1/3} (g_s M\alpha') \left(\frac{1}{2} d\tau^2 + \frac{1}{2}(g^5)^2 + (g^3)^2 + (g^4)^2 + \frac{1}{4}\tau^2 \left[(g^1)^2 + (g^2)^2 \right] \right)$$

$a_0 \approx .71805$

Large τ (Klebanov-Tseytlin)

$$ds^2 \approx \frac{r^2}{L^2 \sqrt{\ln(r/r_s)}} dx^\mu dx_\mu + \frac{L^2 \sqrt{\ln(r/r_s)}}{r^2} ds^2_{T^{1,1}}$$

Dynamics described by the DBI action in the KS throat. Complicated dynamics which however simplifies considerably in the slow-roll approximation. In any case, for illustration we may consider the motion of the probe D3 in an $AdS_5 x S^5$ throat as the latter captures all essential features of slingshot.

In the $AdS_5 x S^5$ case:

$$ds^2 = h^{-1/2} dx^\mu dx_\mu + h^{1/2} \left(dr^2 + r^2 d\Omega_5^2 \right)$$

$$h = \frac{r^4}{L^4}, \quad \varphi = \varphi_0, \quad C_4 = 1 - \frac{1}{h} = C$$

Probe D3-brane motion is specified by r(t), Ω_5(t).
From the DBI action, we get that

$$r'^2 = -V = \frac{1}{h}\left[1 - \frac{1}{h^2(1-C-u)^2}\left(1 + \frac{hJ^2}{r^2}\right)\right]$$

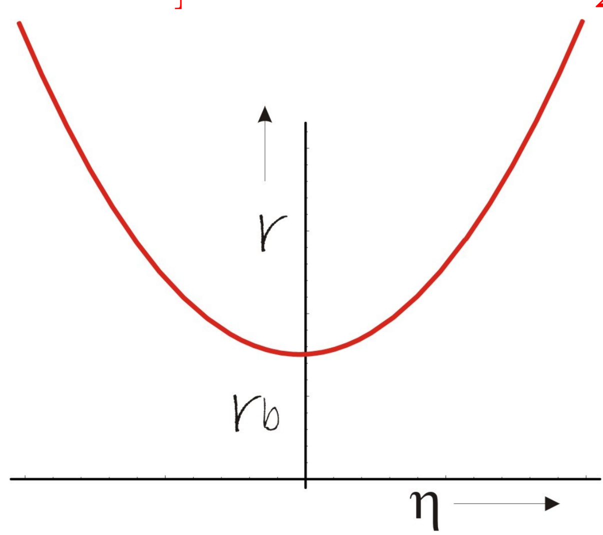
u is "energy" and J angular momentum in S^5 .

The geometry experienced by an observer on the D3 probe brane is determined by the induced metric (Mirage cosmology)

$$ds^2_{ind} = h^{-1/2}\left[-\left(1 - hr^2\right)d\eta^2 + dx^2\right]$$

In the "slow-roll" approximation $r' << 1$

$$ds^2_{ind} = \frac{r^2}{L^2}\left[-d\eta^2 + dx^2\right], \qquad r^2 = 2u\eta^2 + \frac{J^2}{2u}$$



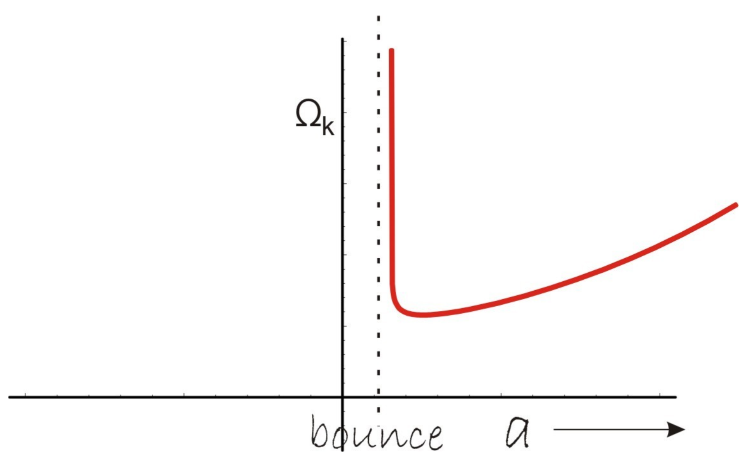
Bouncing Cosmology

Cosmological Problems Revisited

- Homogeneity: the comoving horizon diverges (no horizon problem)

- Isotropy: There is no Bing-Bang (scale factor never vanishes). Moreover, at small scales mirage matter contribution dominates over shear.

- Flatness:



or assume a flat (BPS) empty initial state.

DENSITY PERTURBATIONS

For "slow-roll" motion (adiabatic approximation)

$$S = -\frac{T_3}{2}\int d^4x \left(\partial_\mu r \partial^\mu r + r^2 \partial_\mu \Omega_5 \partial^\mu \Omega_5\right)$$

We may perturb the theory by

$$r \to r + \delta r, \quad \Omega_5 \to \Omega_5 + \delta\Omega_5$$

Then small fluctuations satisfy (in Fourier space):

$$S_\delta = \frac{T_3}{2}\int d\eta \left[\delta r_k'^2 + r^2 \delta\Omega_k'^2 - \left(k^2 - \Omega_5'^2\right)\delta r_k^2 - r^2 k^2 \delta\Omega_k^2 + 4r\Omega_5' \delta\Omega_k' \delta r_k\right]$$

Bardeen Potentials:

$$\Phi = -\frac{\delta r}{r} = -\Psi$$

are frozen ($\Phi' = \Psi' = 0$) for $k << \frac{J}{r^2}$

Then we find

$$P(k) = \frac{<\delta r_k^2>}{r^2} \sim \frac{1}{k^3}$$

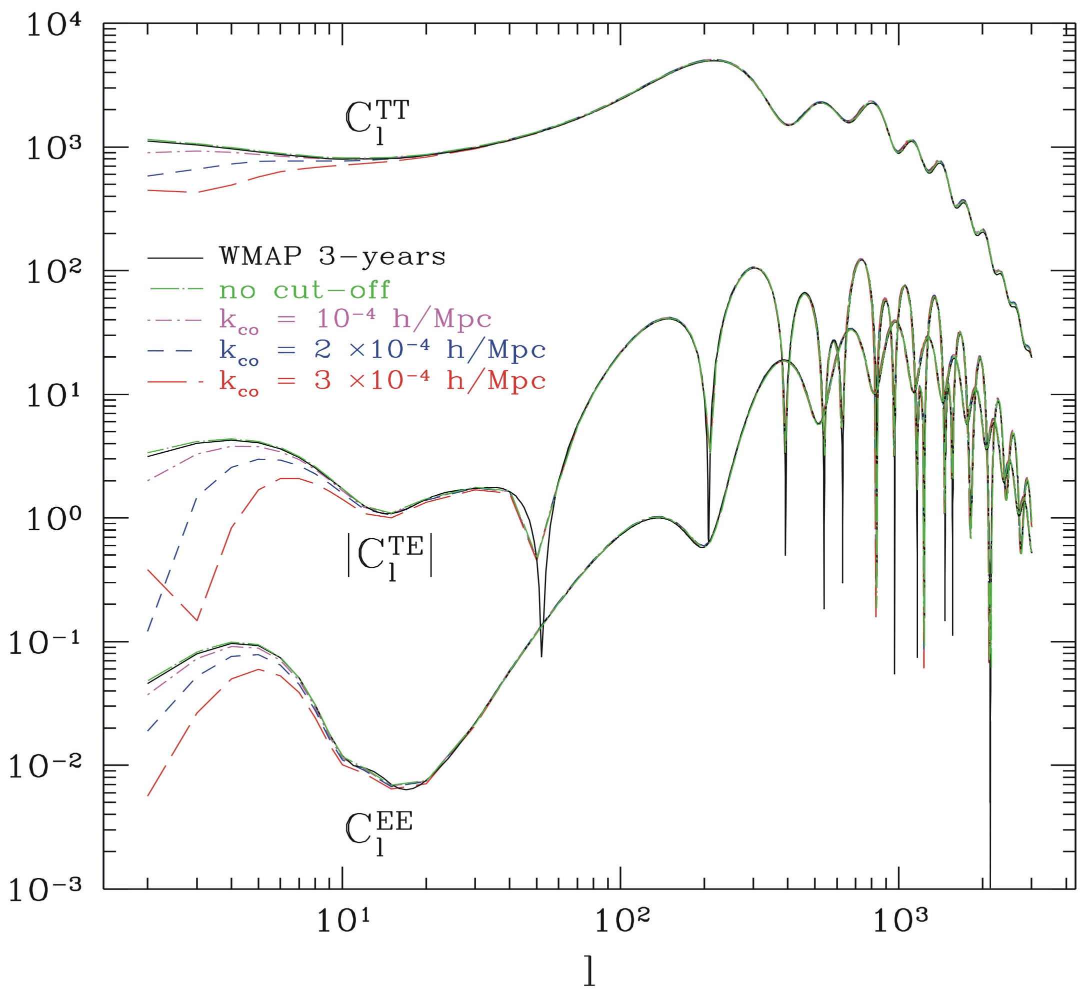
The spectral index is

$$n_s = \frac{d\ln(k^3 P)}{d\ln(k)} + 1 = 1$$

This is an exactly scale invariant power spectrum
Using the KS background, we find

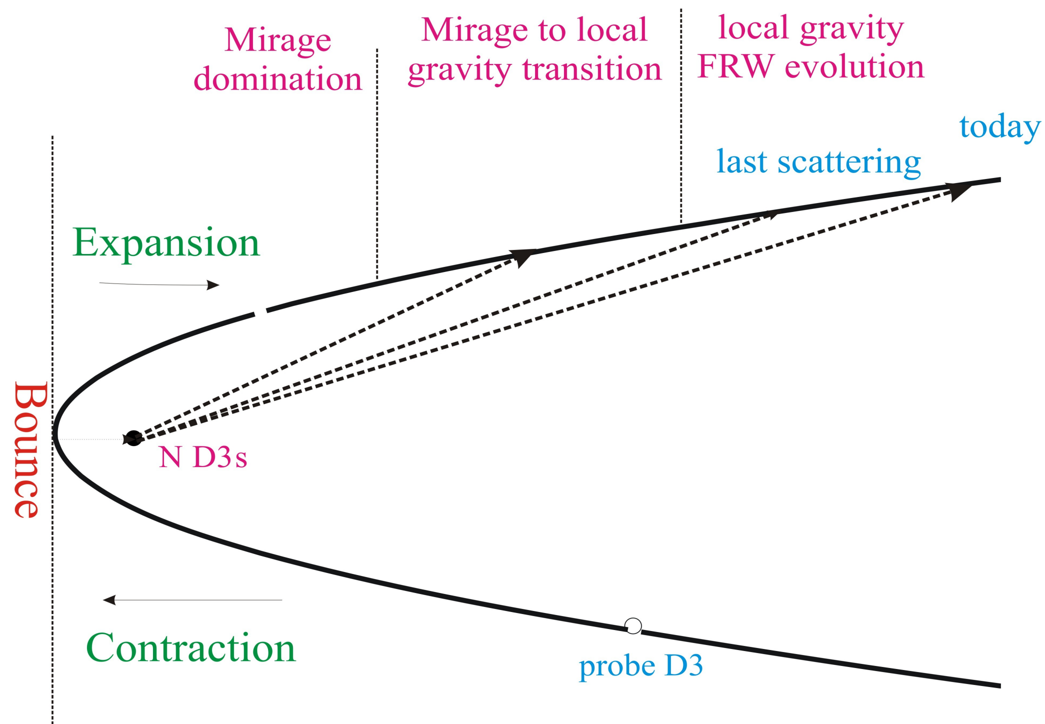
$$n_s \approx 1 - \frac{1}{2\ln(k/k_{co})} \approx .95 \quad at \quad k \approx .002 Mpc^{-1}$$

for appropriate k_{co} consistent with WMAP3:



Conclusions:

General picture



Allowing for a D3 brane moving with non-zero angular momentum in the KS throat :

- Bouncing Cosmology
- Homogeneity, isotropy, flatness problem solved

Allowing perturbations to be created at "string" scale

- Red-shifted almost scale invariant spectrum.

open problems: many