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Braneworld Flux Inflation

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Introduction

- Results from WMAP strongly support the idea of the inflationary universe.
- String theory is a candidate for theory of everything.
- We need to know what plays the role of an inflaton.

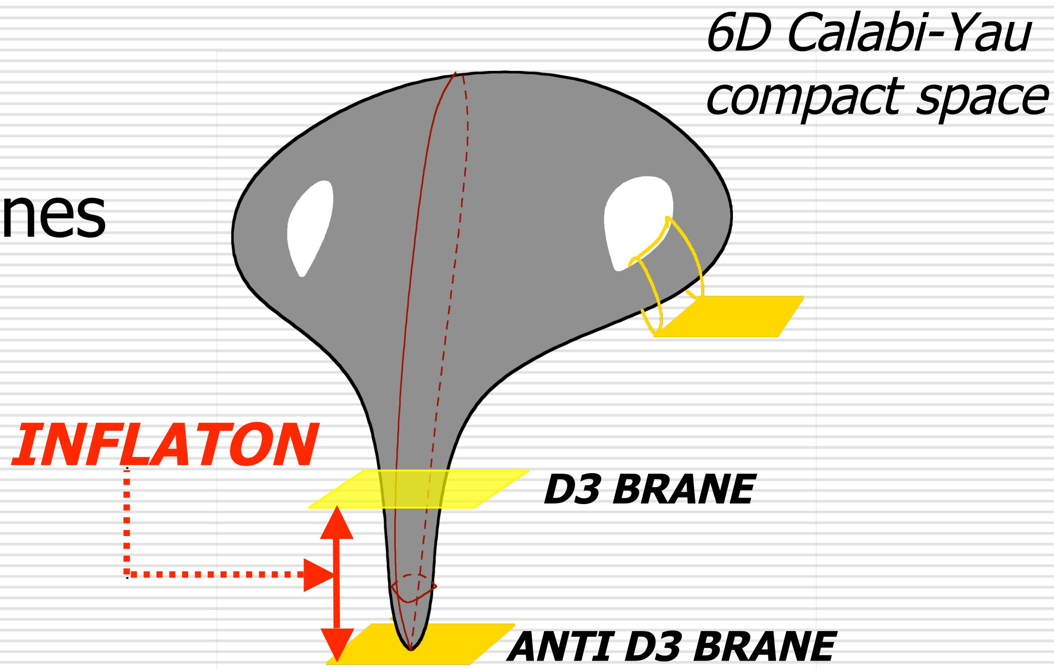
→ Construct an inflation model in string theory.

Motivation

Kachru, Kallosh, Linde, Maldacena, McAllister & Trivedi (2003)

Inflaton is the distance between D-brane and anti-D-brane.

Inflation is realized *geometrical* manner without introducing an ad hoc scalar field.



However, self-gravity of branes are not properly treated.

↓

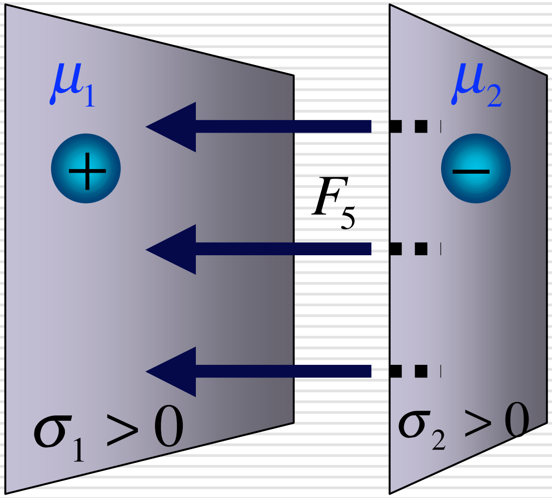
Braneworld

Flux-Driven Inflation

5D Action

$$S = \frac{1}{2\kappa^2}\int d^5x\sqrt{-g}\left[\overset{(5)}{\Re} - 2\Lambda\right] + \sum_i \int d^4x\sqrt{-h_i}\left[-\sigma_i + L^i_{matter}\right]$$

$$-\frac{1}{2\cdot 5!}\int d^5x\sqrt{-g}F_5^2 + \sum_i \mu_i \int C_4$$



where Brane charge (μ_i) 4-form potential field (C_4)

$F_5 = dC_4$,which can change the effective cosmological constant (C.C.) in the bulk

5-form e.o.m. $d * F_5 = 0, \; * F_5 = \mathrm{c(x)} \longrightarrow dc = 0 \quad \therefore \; c = \mathrm{const.}$

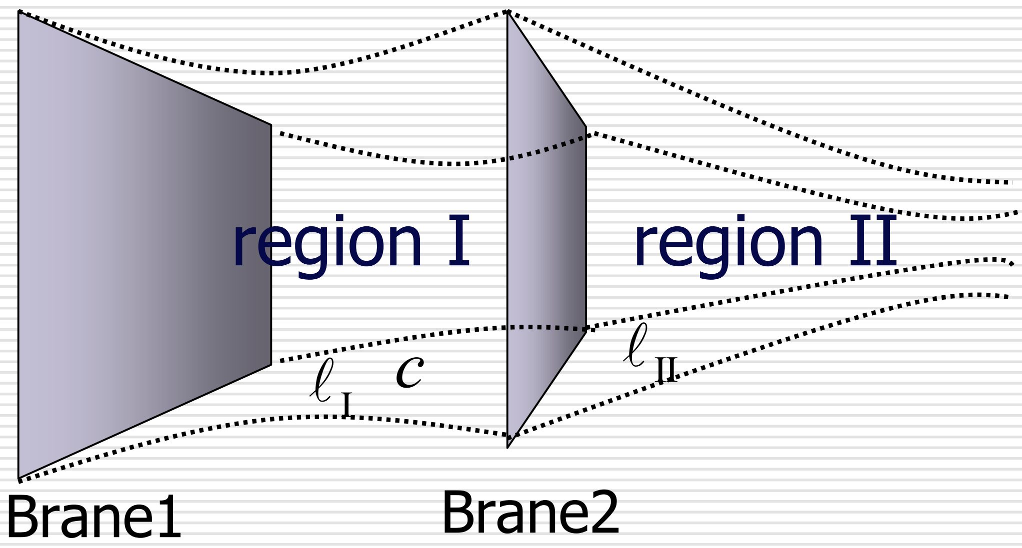
Brane C.C. $$\Lambda_{\mathrm{brane}} = \frac{\kappa^4\sigma^2}{36} + \frac{\Lambda}{6} + \frac{\kappa^2 c^2}{12}$$

Inflation is terminated by the brane collision.

Strategy

- Except for a collision point, we apply the moduli approximation method.
  - First, we obtain the moduli of static solution.
  - Next, lift them up to fields.
- At the collision point, we perform a fully 5D analysis.

Moduli of Static Solution



Junction condition

$$\kappa^2\sigma_1 = \frac{6}{\ell_{\rm I}}, \qquad \kappa^2\sigma_2 = \frac{3}{\ell_{\rm II}} - \frac{3}{\ell_{\rm I}}$$

$$\mu_1 = -2\mu_2 = -2c$$

Bulk geometry

$$ds_{\rm I}^2 = dy^2 + e^{-2\frac{y}{\ell_{\rm I}}}\eta_{\mu\nu}dx^\mu dx^\nu$$

$$ds_{\rm II}^2 = dy^2 + e^{-2\frac{y}{\ell_{\rm II}}}\eta_{\mu\nu}dx^\mu dx^\nu$$

where

$$\frac{6}{\ell_{\rm I}^2} = -\Lambda - \frac{\kappa^2 c^2}{2}, \qquad \frac{6}{\ell_{\rm II}^2} = -\Lambda$$

Brane positions

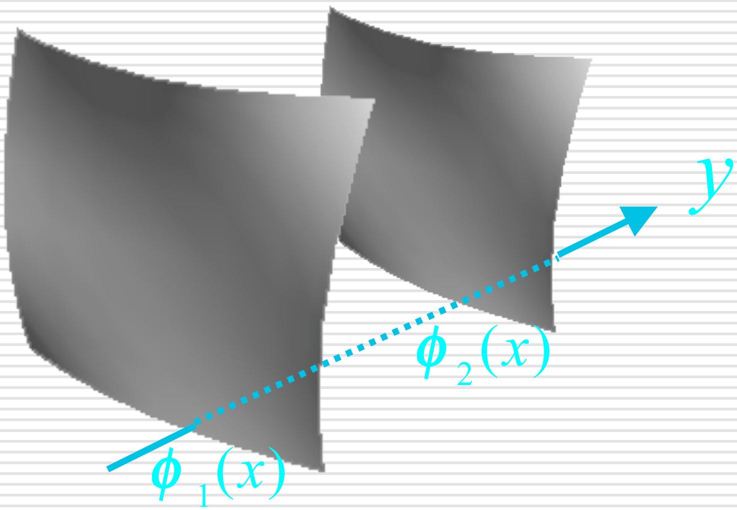
$$y = \phi_1, \qquad y = \phi_2$$

moduli   moduli

Moduli approximation method

Brane Position (moduli field)

$$y = \phi_1(x)\ ,\quad \phi_2(x)$$

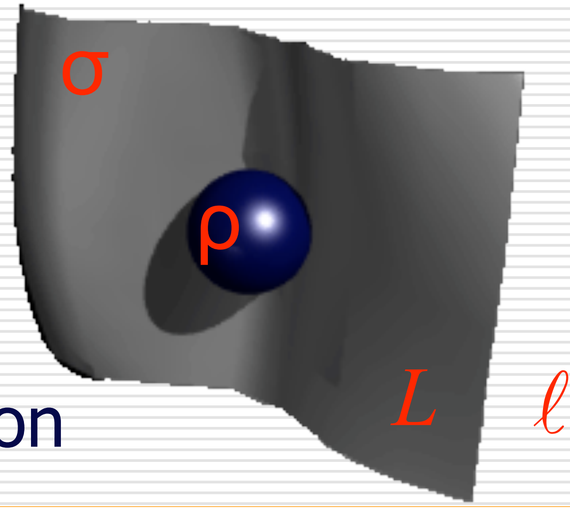


Low energy

$$\varepsilon \equiv \frac{\rho}{\sigma} \sim \left(\frac{\ell}{L}\right)^2 \ll 1$$

$$dS_5^2 = dy^2 + a_i^2(y)\, g_{\mu\nu}(x)\, dx^\mu dx^\nu$$

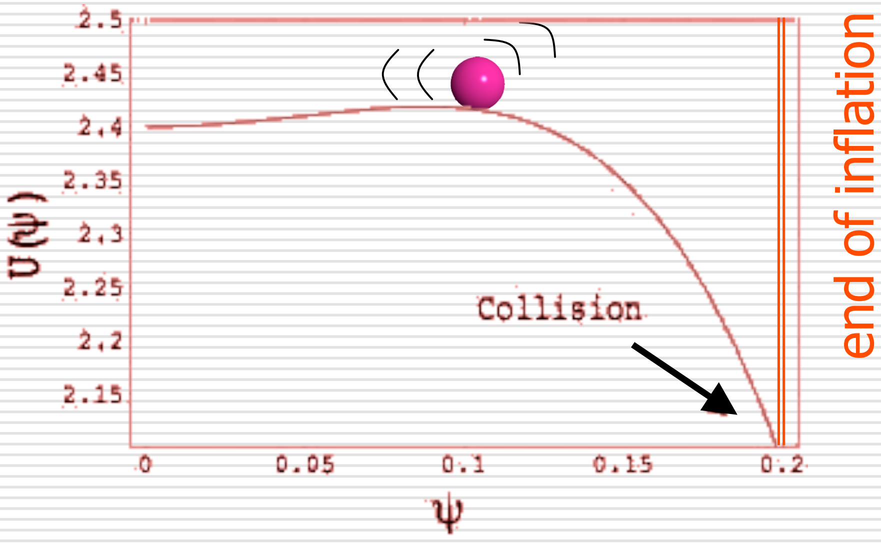
where $a_I(y) = e^{-\frac{y}{\ell_{\mathrm{I}}}}$ $\quad a_{II}(y) = e^{-\frac{y}{\ell_{\mathrm{II}}}}$



➔ Derive the low energy effective action

e-folding number

Radion potential



$$U = U_0 - 4H_0^2 \frac{\psi^2}{2}$$ (tachyonic)

H_0 : Hubble at the top

In the induced metric frame, the universe is always inflating.

e-folding number

$$N \equiv \log\left(\frac{\psi_*}{\psi_0}\right)$$

ψ_* : at collision

ψ_0 : initial value

$$\sim \log\left(5\sqrt{6}\,\frac{M_{\rm pl}}{H_0}\coth^{-1}\frac{1}{\sqrt{1-\ell_{\rm II}/\ell_{\rm I}}}\right)$$

Sufficient inflation is possible.

Brane Collision

We consider the simplest case of a completely inelastic collision.

In order to cause a collision, $H_2 > H_1$

Require no conical singularity around this collision point.

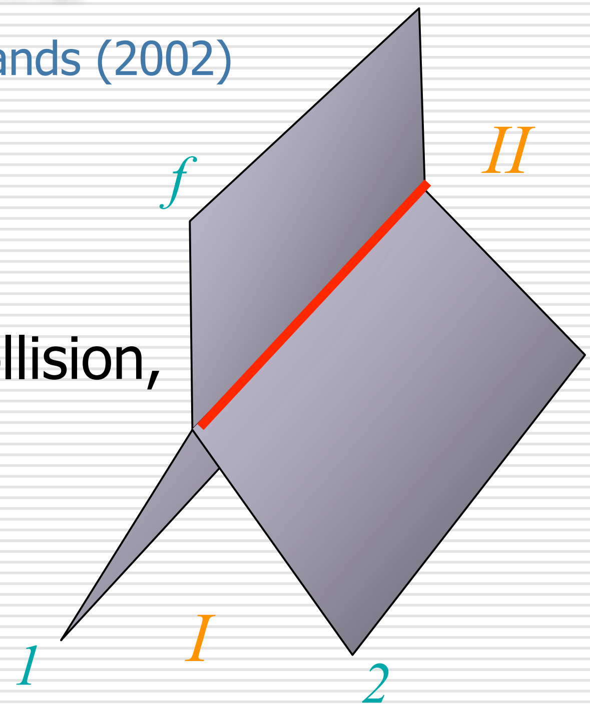
Neronov (2001); Langlois, Maeda & Wands (2002)

Energy conservation

$$\rho_f = \sigma_1 + 2\sigma_2$$

Momentum conservation

$$H_f = \frac{\ell_{\mathrm{I}}}{\ell_{\mathrm{II}}}\left[H_1 - (1 - \ell_{\mathrm{II}}/\ell_{\mathrm{I}})H_2\right]$$



In order to obtain an expanding universe after the collision,

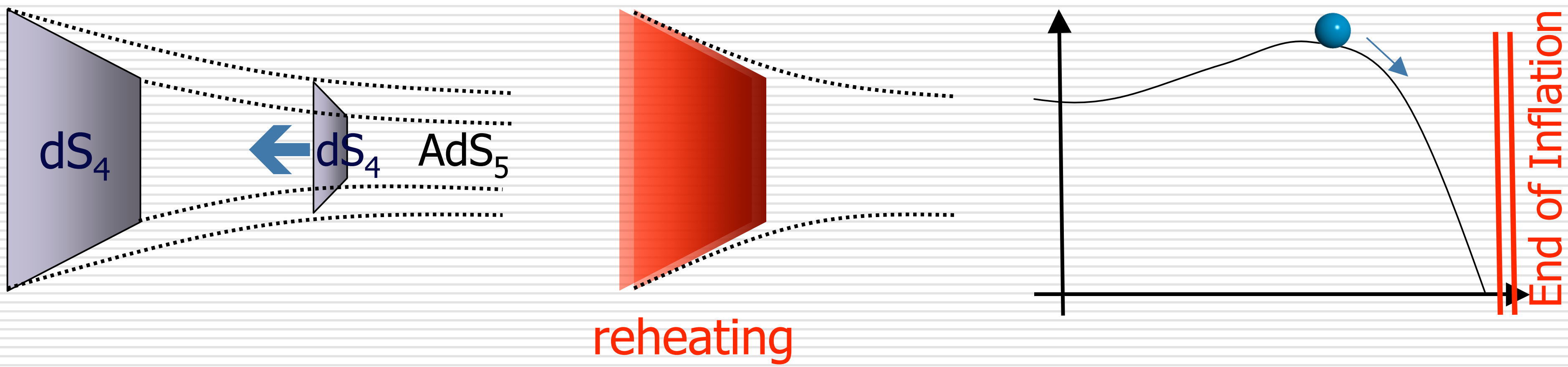
$$H_f > 0 \;\Rightarrow\; H_1 > (1 - \ell_{\mathrm{II}}/\ell_{\mathrm{I}})H_2$$

Our scenario is realized under the condition

$$\frac{H_1}{1 - \ell_{\mathrm{II}}/\ell_{\mathrm{I}}} > H_2 > H_1$$

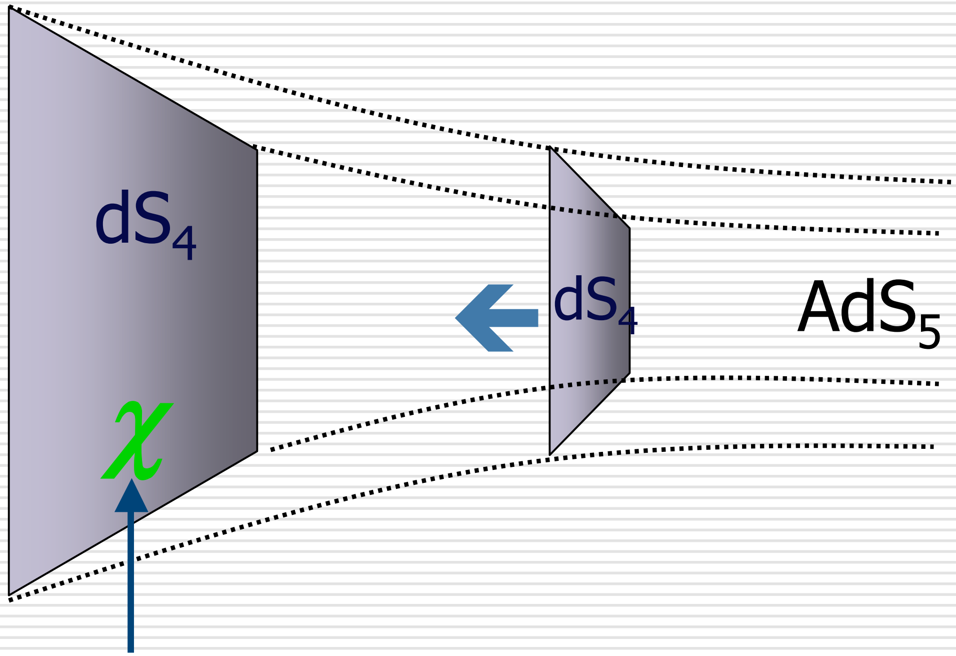
Note that $\ell_{\mathrm{I}} > \ell_{\mathrm{II}}$

Spectrum of curvature perturbation



- radion perturbation ➔ brane curvature perturbation , ζ
- 4D theory breaks down at brane collision (➔ reheating)
- 5D energy-momentum conservation ➔ conserved perturbation, ζ
- ... but m^2 = -4H^2 at maximum ➔ ***steep red spectrum***

Brane Curvaton



Moroi & Takahashi (2001)
Enqvist & Sloth (2002)
Lyth & Wands (2002)

light scalar degree of freedom on brane sees de Sitter expansion ➔ ***scale-invariant spectrum***

decays after collision ➔ primordial density perturbation

Summary

- We proposed a geometric brane inflation model driven by the flux.
- Brane collision terminates the inflation.
- We gave the rule for evolution through the collision using the 5D conservation low.
- Radion has large tachyonic mass.
  - fine-tuned initial conditions for sufficient inflation.
- Curvaton type field gives scale-invariant spectrum.