Early Stages of the Universe: Brane Gas-Driven Bulk Dynamics

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Based on:

JHEP **0601**, 074 (2006)

PRL **96**, 161301 (2006)

by Robert Brandenberger, N.S.

Outline

- Overview
- Outline of the Approach
- Emerging Brane Inflation Models
- Remark on the horizon and entropy problems
- Conclusions

Overview

Motivation

Extra Dimensions:

- Main motivation - String Theory
- Often treated as static

  Exceptions e.g.
  - SGC
  - models of brane inflation
  - Ekpyrotic scenario

Can dynamics explain early stages of the Universe?

New Approach:

Bulk dynamics driven by a gas of p-branes

Basic Idea

Toy Phenomenological model motivated by String Theory

In Use:

- FRW Cosmology in extra dimensions
- Branes (neglect charges and fluxes) $\equiv$ topological defects
- Orbifold fixed planes

In our scenario:

- Topology distinguishes 3 'our' dimensions
- Difference in topology $\Longrightarrow$ difference in evolution

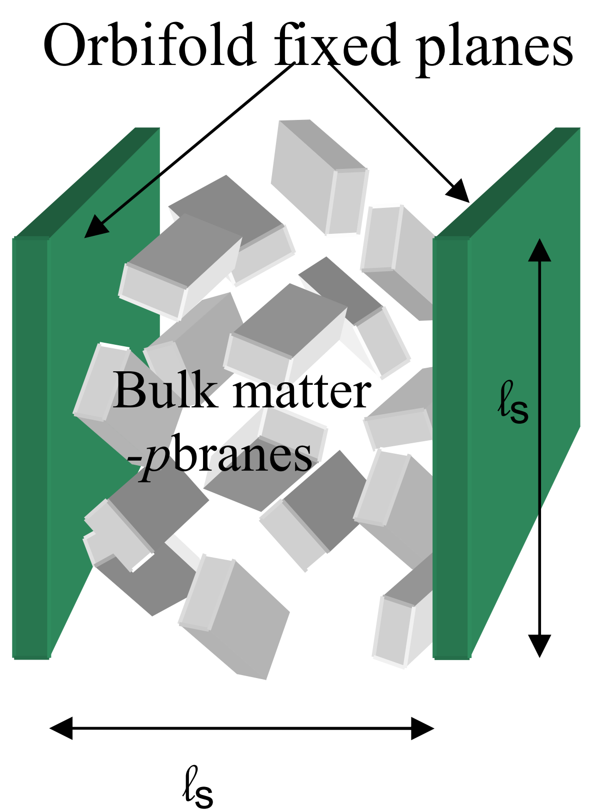
Starting point: A dense gas of branes

Outline of the Approach

Setup

Assumptions:

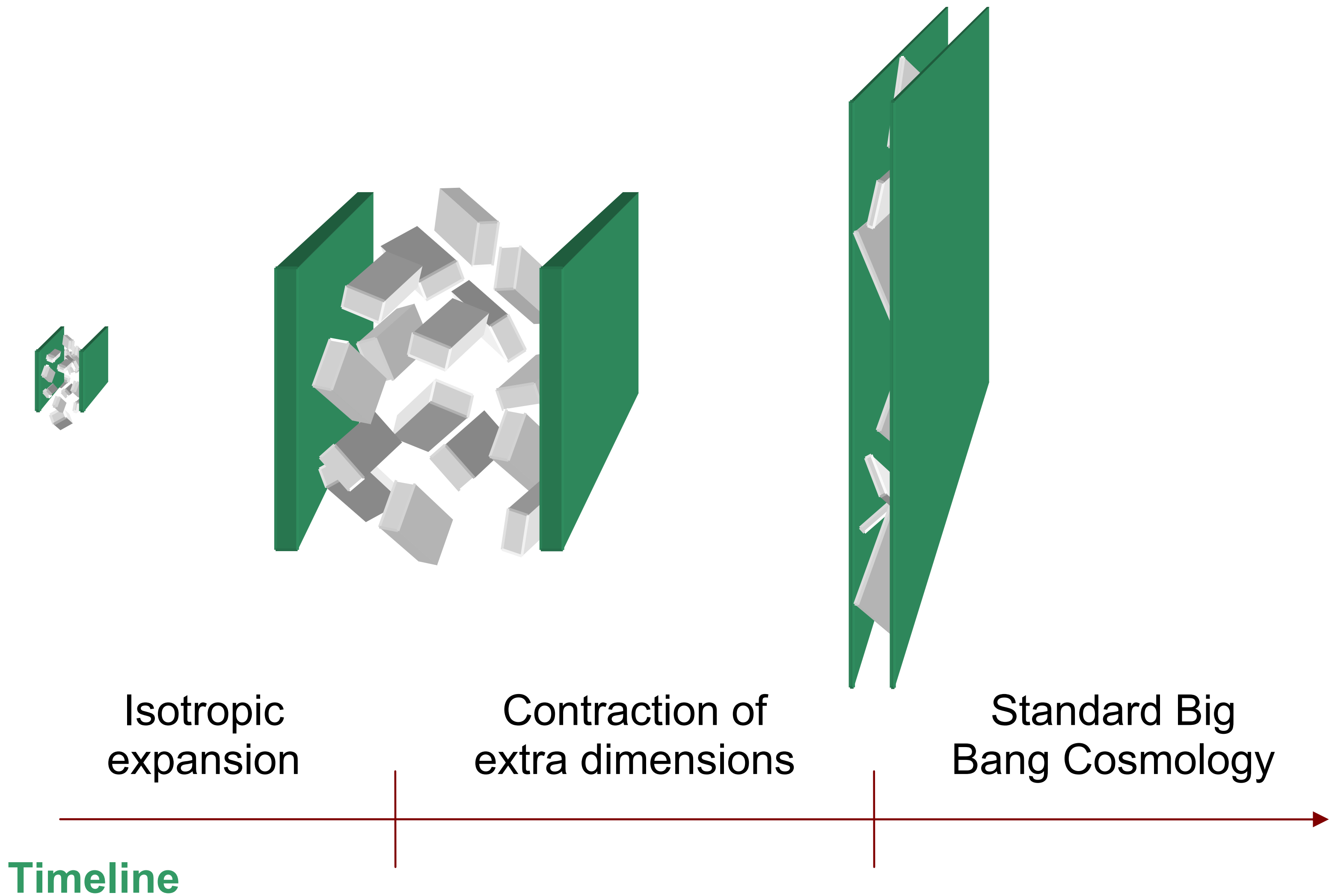
- $\mathcal{M} = \mathcal{R} \times T^3 \times T^d/Z_2$ (d - # of extra dimensions)
- Total Energy $= l^{-1}$ & $\rho_i = l^{-d-4}$ (e.g. $l \sim l_s$)



Standard Initial Conditions:

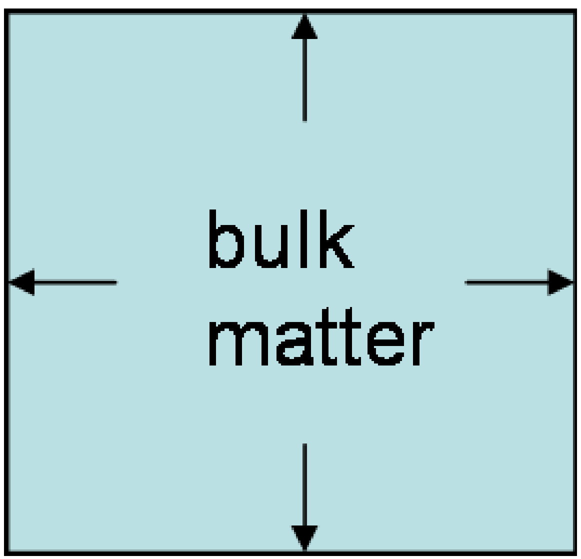
- Universe starts
  - Small
  - Dense
- Unique scale
- An isotropic brane gas

Overall Dynamics



Phase of Expansion

Metric: $ds^2 = dt^2 - a(t)^2 d\mathbf{x}^2 - b(t)^2 d\mathbf{y}^2$
Isotropy: $a(t) = b(t)$



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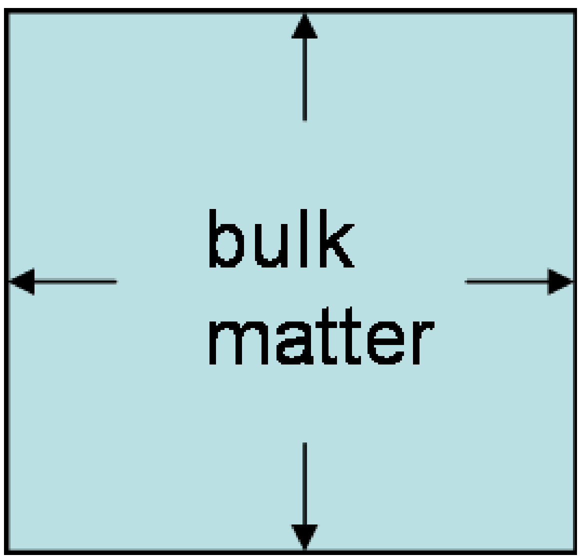


Expansion governed by

$$\frac{\ddot{a}}{a} + (2+d)(\frac{\dot{a}}{a})^2 = \frac{8\pi G}{3+d-1}[\rho - P]$$

Equation of state

$$P = w\rho$$

Leads to

$$a(t) = b(t) \sim t^{\alpha}\,;\ \alpha = \frac{2}{(3+d)(1+w)}$$

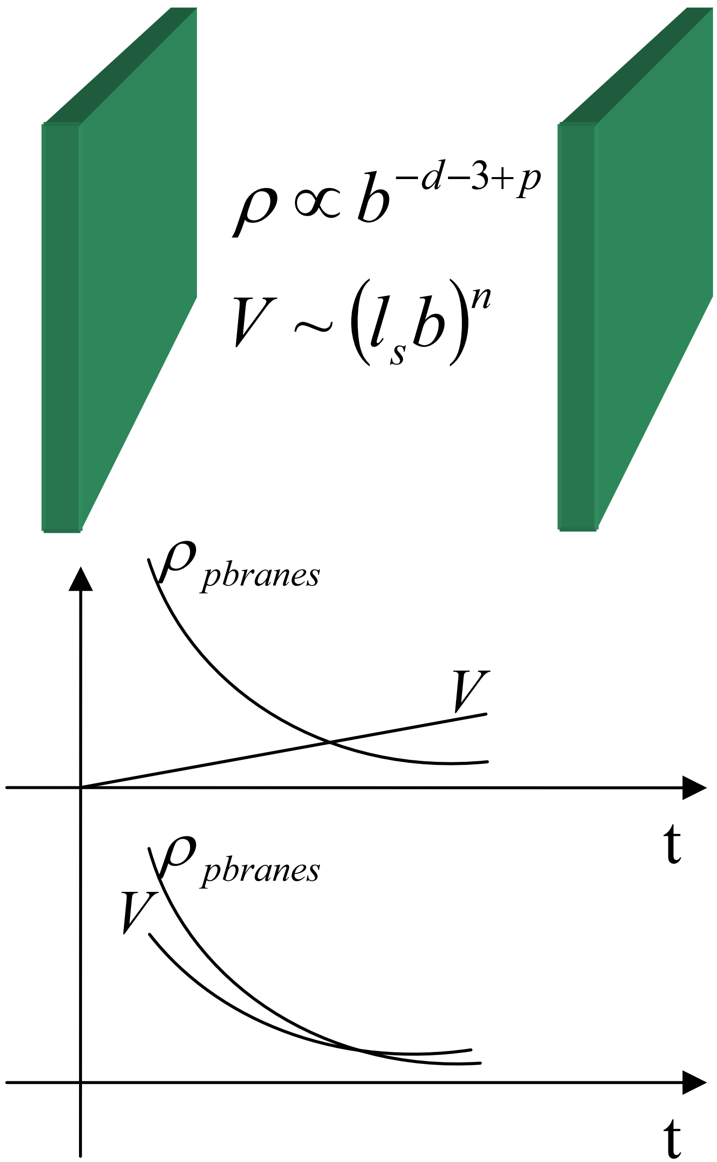
p-Branes

- 3-brane: $T^{\mu}_{\nu} = (\rho, -\rho, -\rho, -\rho, \, 0, ...)$
- 5-brane: $T^{\mu}_{\nu} = (\rho, -\rho, -\rho, -\rho, -\rho, -\rho, \, 0, ...)$
- Perfect fluid approximation for the brane gas

$$w = \frac{P}{\rho} = -\frac{p}{3+d} \Longrightarrow \alpha = \frac{2}{3+d-p}$$

Conclusion: The expansion phase is non-inflationary for codimension ≥ 3 branes

From Expansion to Contraction



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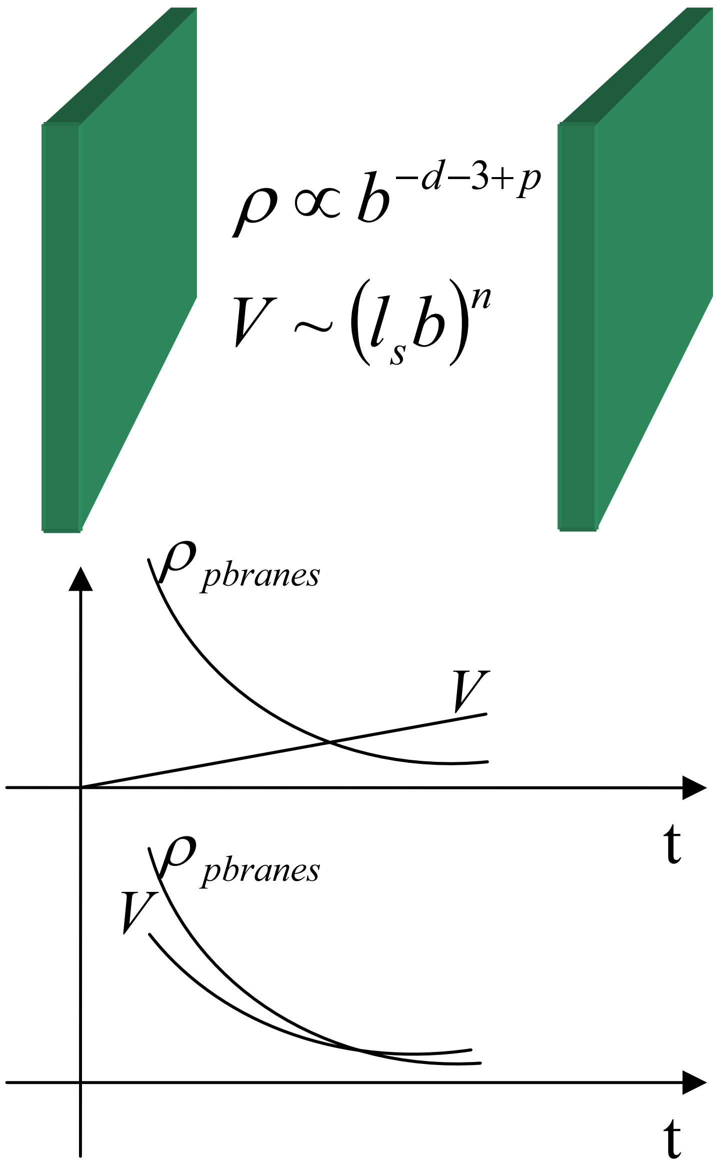
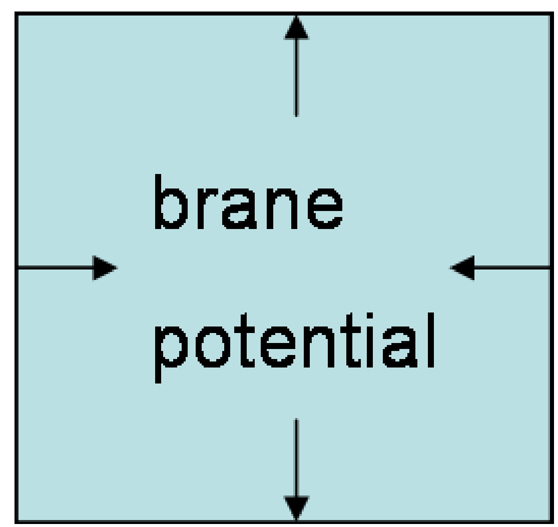


Brane potential dominates

when $V = \rho$

leading to contraction of extra dimensions



Emerging Brane Inflation Models

Motivation II

Main Problem:

Brane inflation doesn't occur for generic initial conditions

one needs either

- much weaker couplings than expected from string theory
- large initial separation ($r \gg l_s$)

Conventional approaches: all extra dimensions are static

$\Longrightarrow$ any starting point with $r \gg l_s$ poses hierarchy problem

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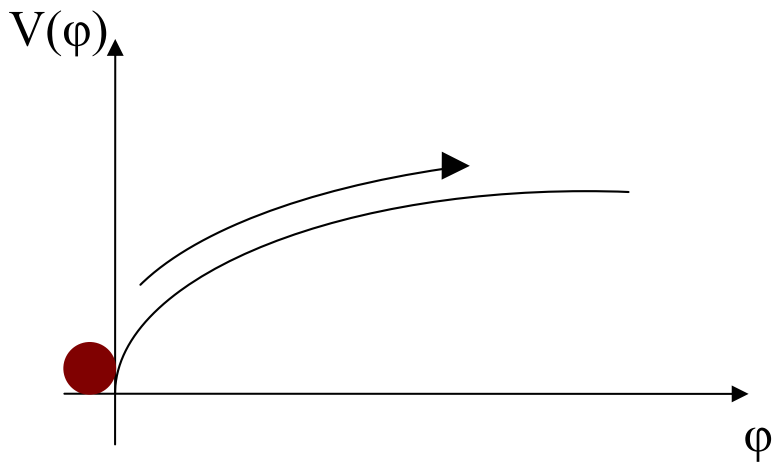
New approach: preceding expansion phase due to a gas of p-branes leads to a large separation.

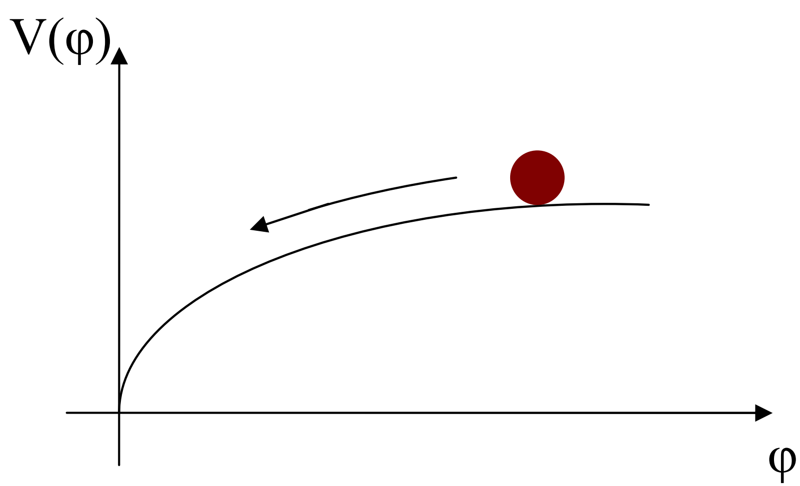
Advantage: Natural starting point

Effective 4d view

Bulk Expansion Phase



Inflation



Effective Field Theory Approach

Canonically normalized scalar field φ:

$$\varphi = \sqrt{\frac{d(d+2)}{2}} m_{pl} \log(b)$$

Effective 4d potential:

$$V_{eff}(\varphi) = g_s^2 l_s^d b(\varphi)^{-d} V(b(\varphi))$$

Example

Consider inter-brane potential

$$V(l_s b) = -\mu \frac{1}{(l_s b)^n}, \; n < d + 3 - p \implies V_{eff}(\varphi) \propto -e^{-\alpha\varphi/m_{pl}}$$

Add brane tension/ account for zero cosmological constant

$4d$ potential

$$V(\varphi) = \Lambda^{4+d-n} l_s^{d-n} - \Lambda^{4+d-n} l_s^{d-n} e^{-\alpha \frac{\varphi}{m_{pl}}}$$

If

$$\varphi \gg m_p/\alpha \ln(\alpha^2 + 1)$$

then $a(t)$ is accelerating

N e-foldings require

$$l_s \Lambda \lesssim (\alpha^2 N)^{-\frac{d+3-p-n}{(d+n)(d+4-n)}}$$

Allowing

$$\Lambda \sim 0.1 \, l_s^{-1}$$

Summary

- Natural starting point
- Radion serves as an inflaton
- Emerging initial conditions for inflation
- Unique scale

Remark on Horizon and Entropy problems

Entropy Problem

Assuming adiabatic expansion

Entropy per co-moving volume which corresponds to H_0^{-1}:

$$S_U = \# H_0^{-3} T_0^3 = 10^{90} \approx (1mm)^3 T_{pl}^3$$

Entropy problem $=$ Hierarchy problem: $\rho = m_{pl}^4$

corresponds to Universe of mm size

not m_{pl}^{-1} size

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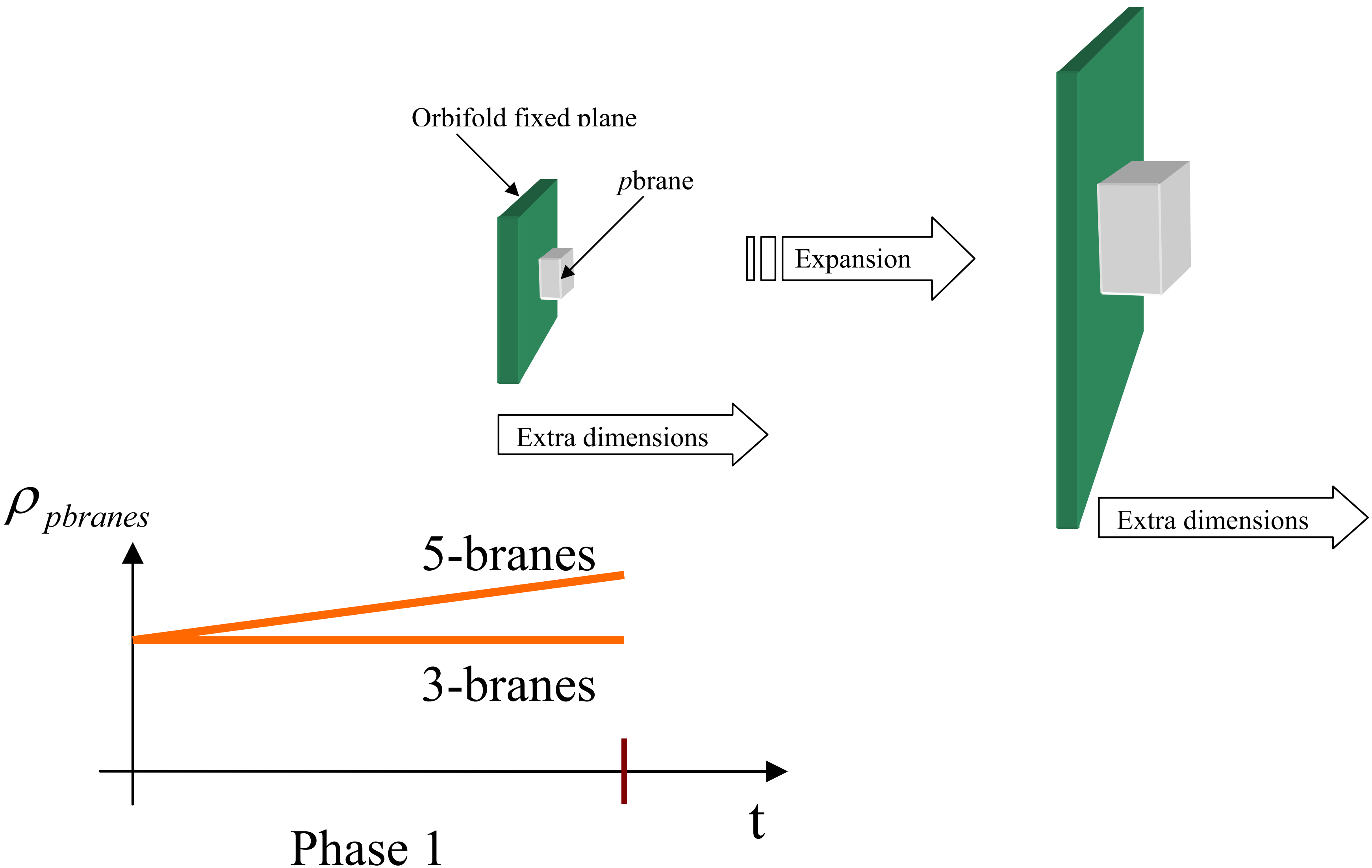
Standard Solution:

- Amplification of energy during early phase
- Non-adiabatic phase transition converting energy to radiation

Unusual technic: Energy amplified in codimension ≥ 3 branes

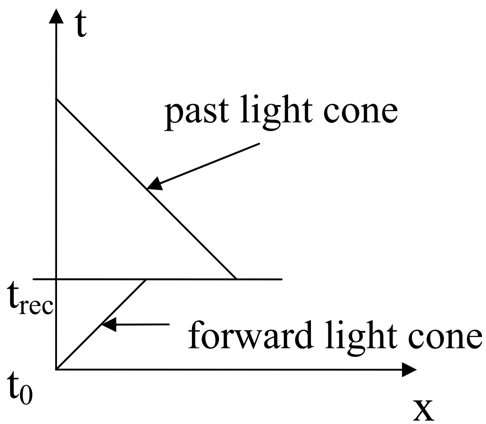
$\Longrightarrow$ no accelerated expansion

Projected Energy Density - Phase 1

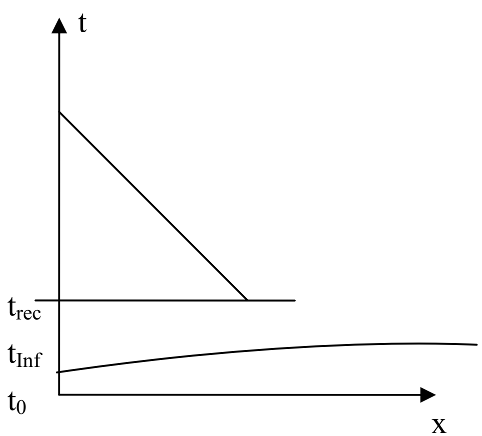


Horizon Problem

Standard Cosmology



Inflation



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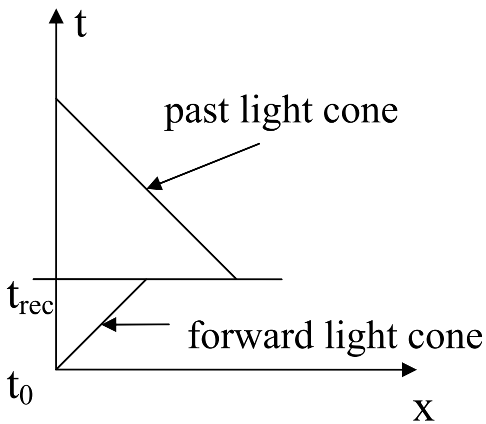

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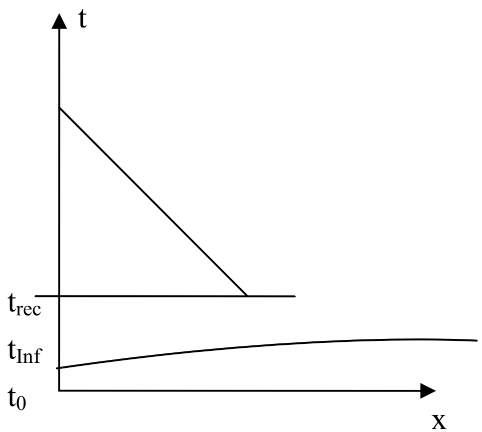
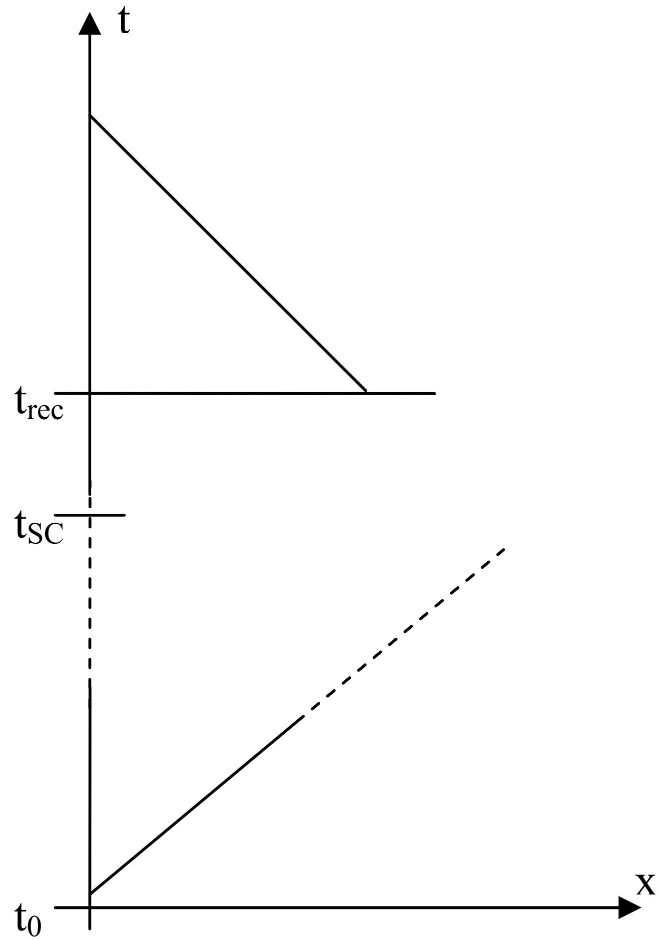


Scenario without inflation



Summary

- Horizon Problem: long period of dynamics in extra dimensions
- Entropy problem is addressed outside inflationary scenarios

Conclusions

Conclusions

- Natural starting point for string inspired cosmology
- New phase in the early Universe: bulk expansion governed by p-branes
- Undressing hierarchies:
  - dynamical solution of initial conditions problem (inflationary)
  - entropy problem (non inflationary)
- Possible solution of horizon problem in non-inflationary context