

Title: Early stages of the universe: brane gas-driven bulk dynamics

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URL: <http://pirsa.org/06050025>

Abstract: We propose a new brane world scenario. In our model, the Universe starts as a small bulk filled with a dense gas of branes. The bulk is bounded by two orbifold fixed planes. An initial stage of isotropic expansion ends once a weak potential between the orbifold fixed planes begins to dominate, leading to contraction of the extra spatial dimensions. Depending on the form of the potential, one may obtain either a non-inflationary scenario which solves the entropy and horizon problem, or an improved brane-antibrane inflation model.





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

Natalia Shuhmaher (McGill)

Based on:

JHEP **0601**, 074 (2006)

PRL **96**, 161301 (2006)

by Robert Brandenberger, N.S.

Outline

- Overview
- The Model
- An Alternative to Inflation
- Emerging Brane Inflation Models
- Conclusions



Overview

Motivation

Extra Dimensions:

- predicted by String Theory - often treated as **static**

Exceptions e.g.

- SGC
- brane inflation models
- Ekpyrotic scenario

Can dynamics explain early stages of the Universe?

New Approach:

bulk dynamics driven by a gas of p-branes

Basic Idea



FRW Cosmology in extra dimensions with new ingredients:

- branes
- orbifold fixed planes

In our scenario:

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

Starting point: a dense gas of branes

Preview of Results

We present two brane world scenarios:

- one which solves non-inflationary entropy and horizon problems
- second which naturally provides initial conditions for brane inflation models



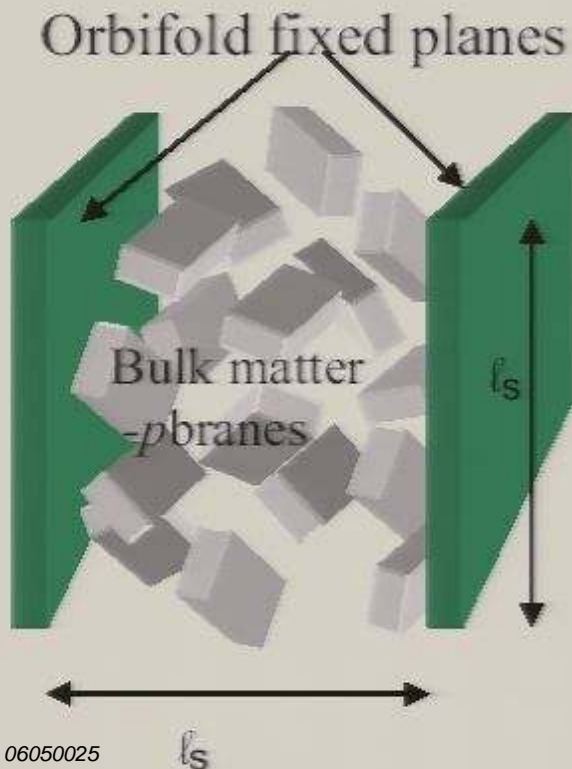
The Model

Setup



Assumptions:

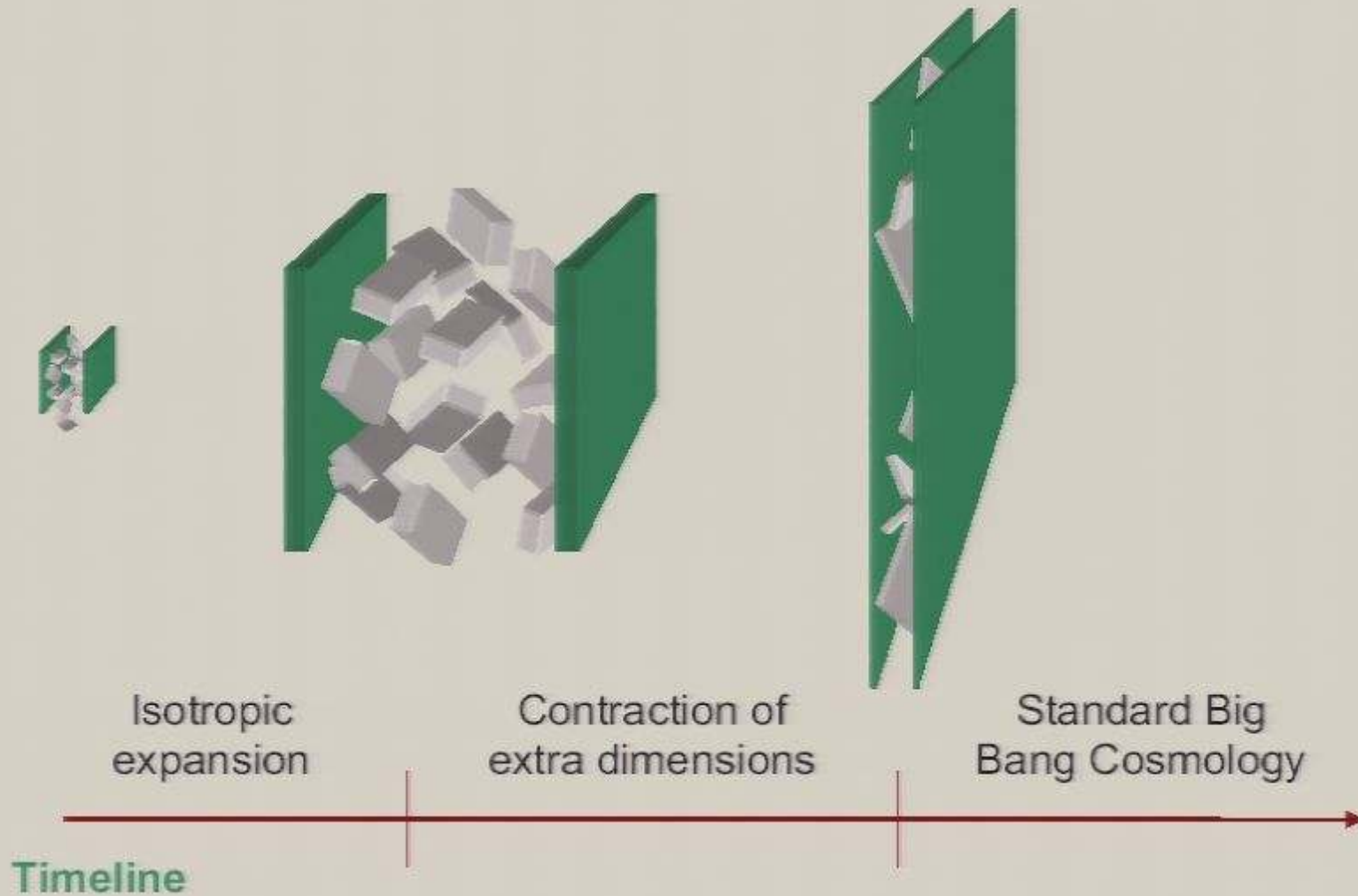
- $\mathcal{M} = \mathcal{R} \times T^3 \times T^d / \mathbb{Z}_2$ (d - # of extra dimensions)
- Total Energy = l^{-1} & $\rho_i = l^{-d-4}$ ($l \sim l_s$)



Standard Initial Conditions:

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

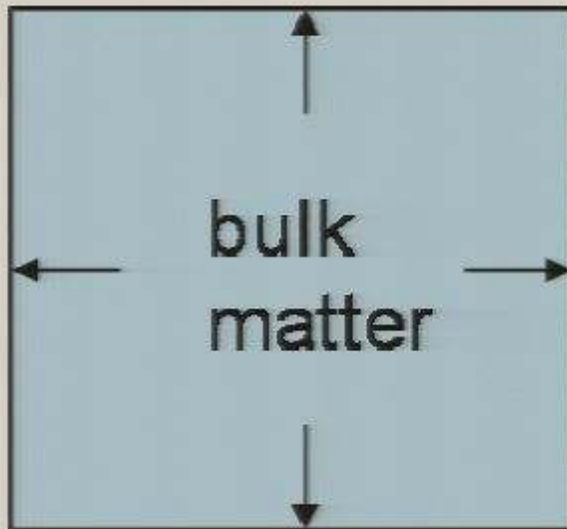
Overall Dynamics



Phase of Expansion

Metric: $ds^2 = dt^2 - a(t)^2 dx^2 - b(t)^2 dy^2$

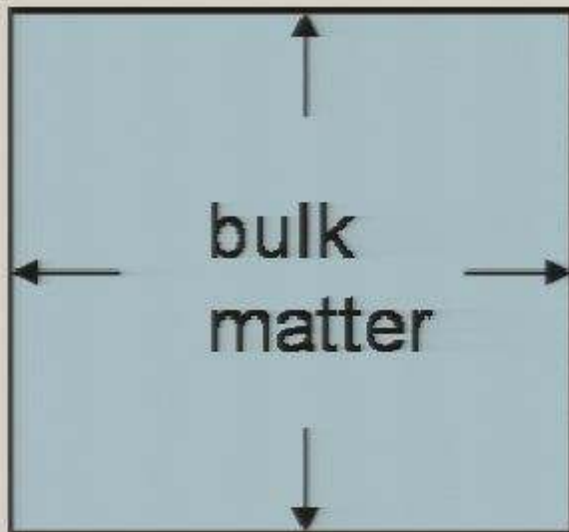
Isotropy: $a(t) = b(t)$



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Expansion governed by

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

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: $T_{\nu}^{\mu} = (\rho, -\rho, -\rho, -\rho, 0, \dots)$
- 5-brane: $T_{\nu}^{\mu} = (\rho, -\rho, -\rho, -\rho, -\rho, -\rho, 0, \dots)$
- Perfect fluid approximation for the brane gas

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

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Preparing to stand by...

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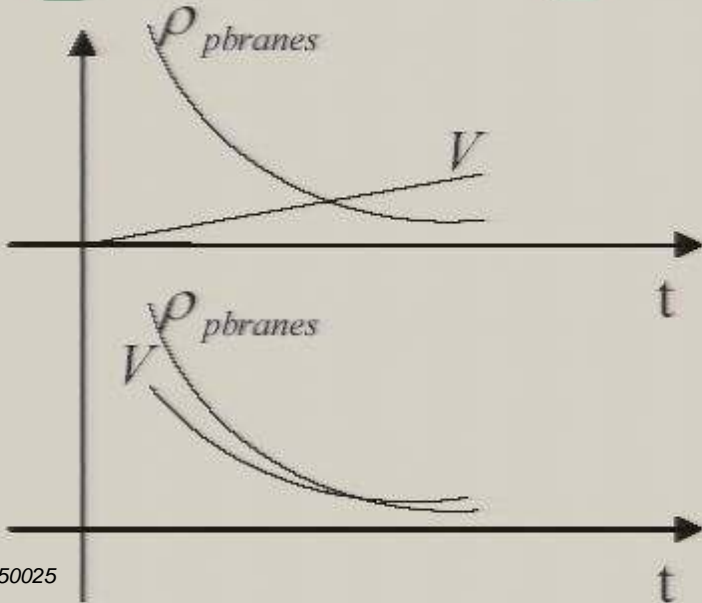
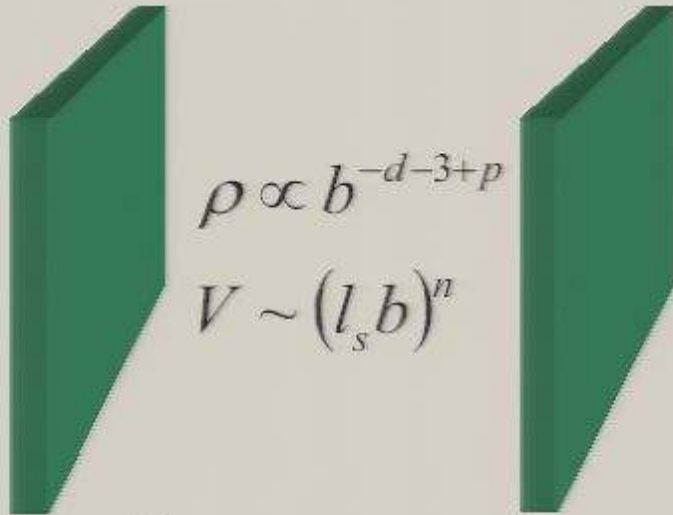
VGA-1

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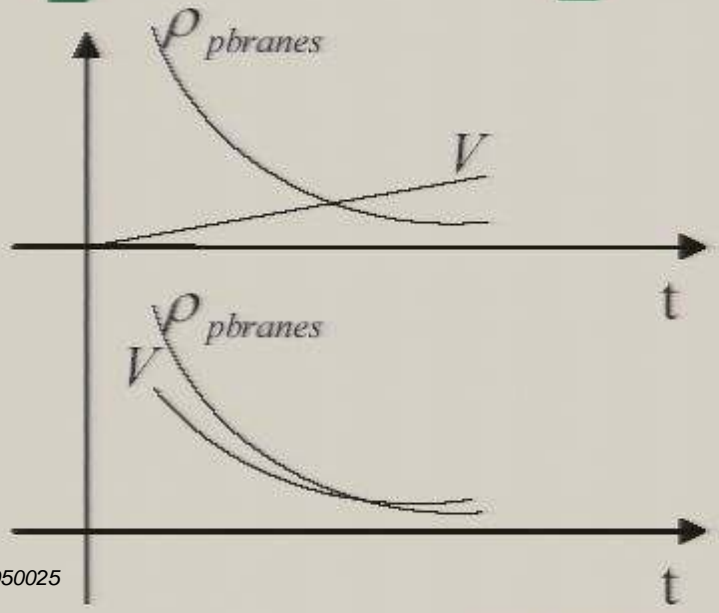
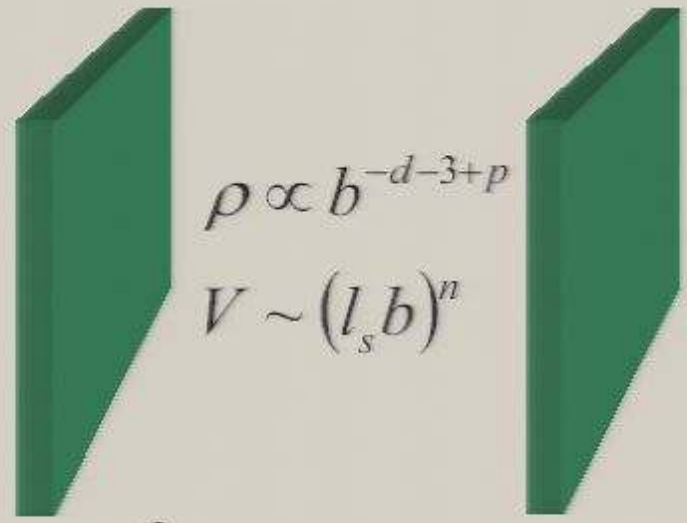
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From Expansion to Contraction



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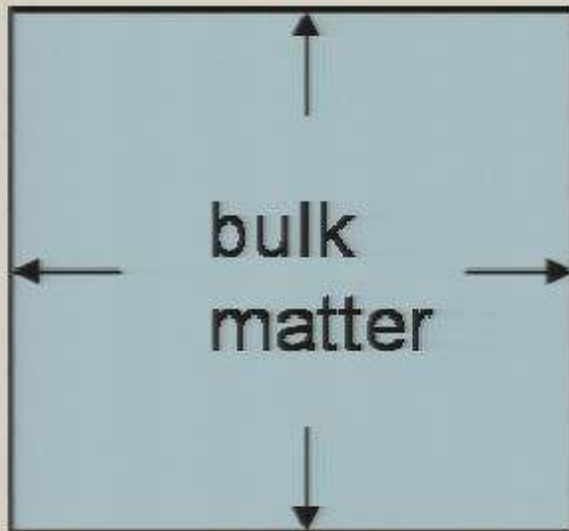
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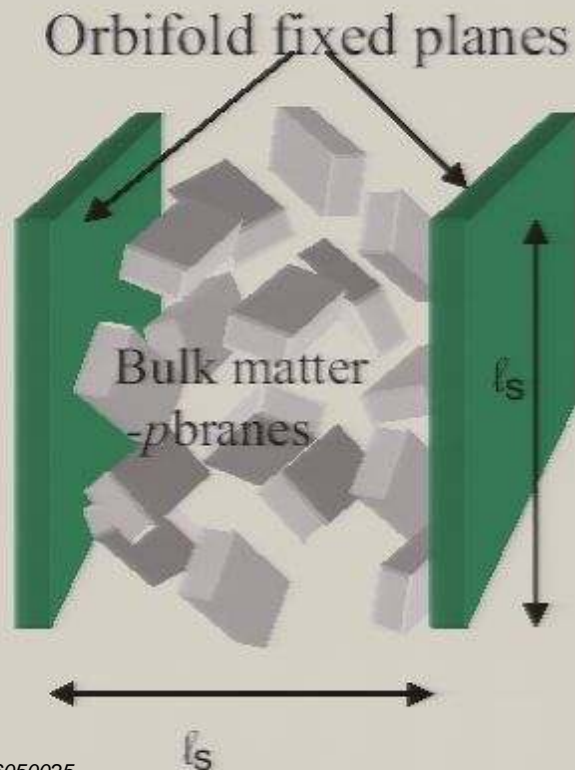
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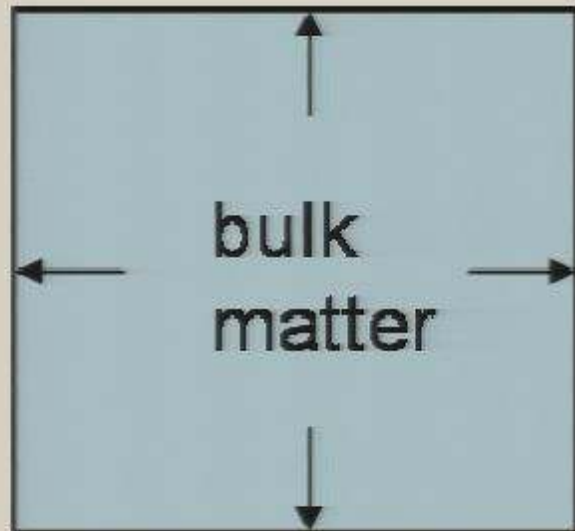
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Examples from String Theory:

- Type IIB superstring theory - $d = 6, p = 3 \implies a(t) = t^{1/3}$
- Heterotic string theory - $d = 6, p = 5 \implies a(t) = t^{1/2}$
- M-theory - $d = 7, p = 5 \implies a(t) = t^{2/5}$

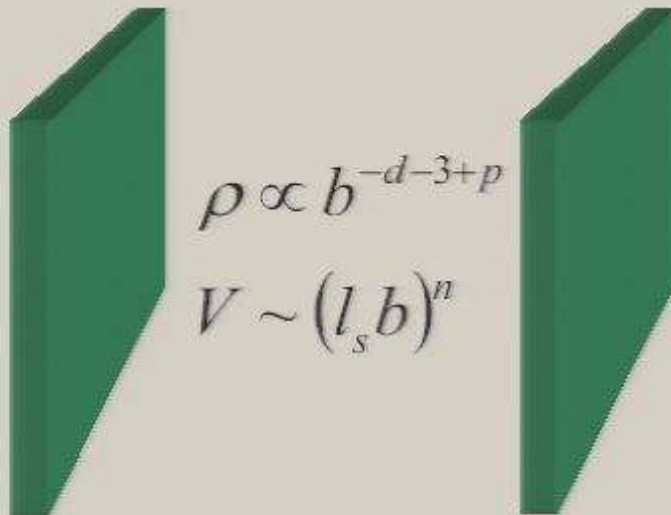
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From Expansion to Contraction



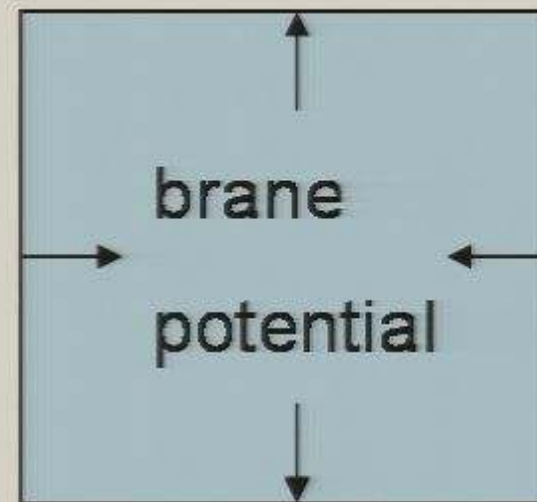
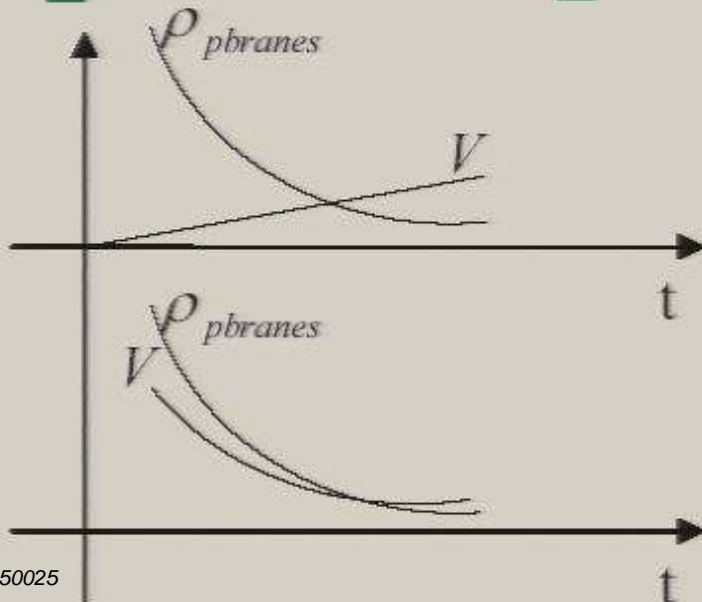
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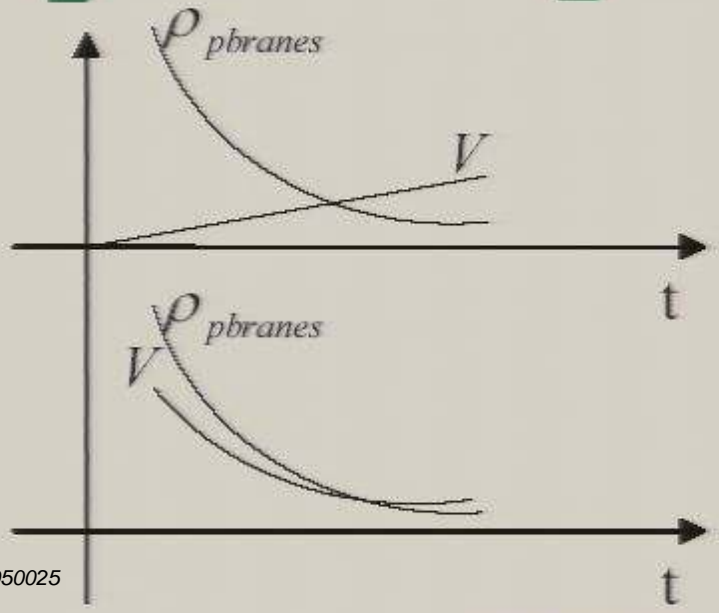
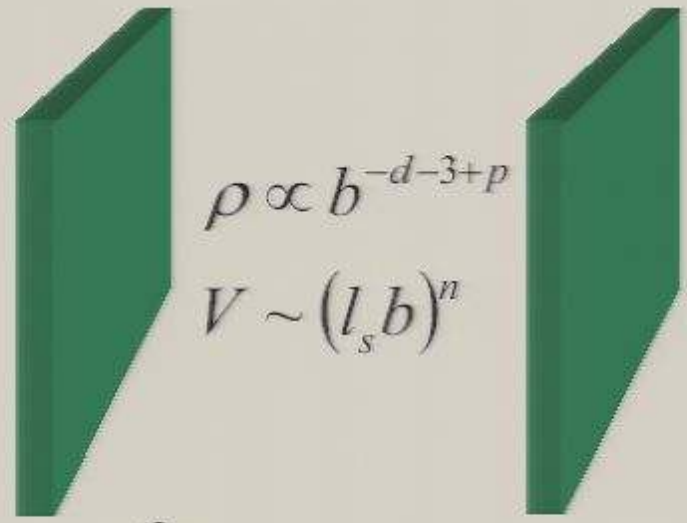
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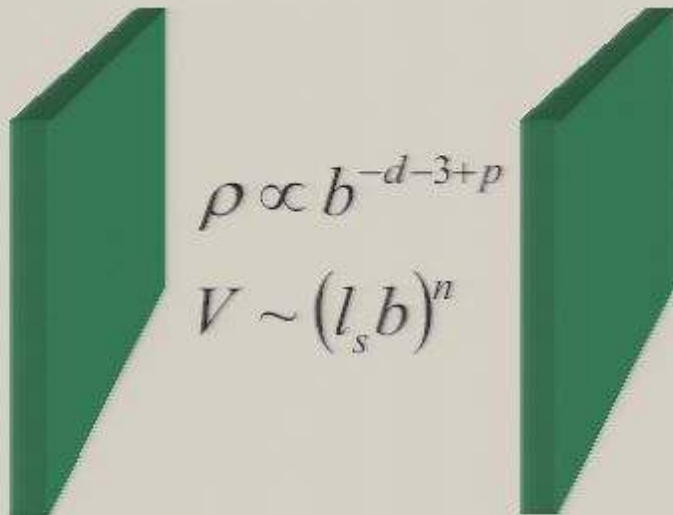
leading to contraction of extra dimensions



From Expansion to Contraction



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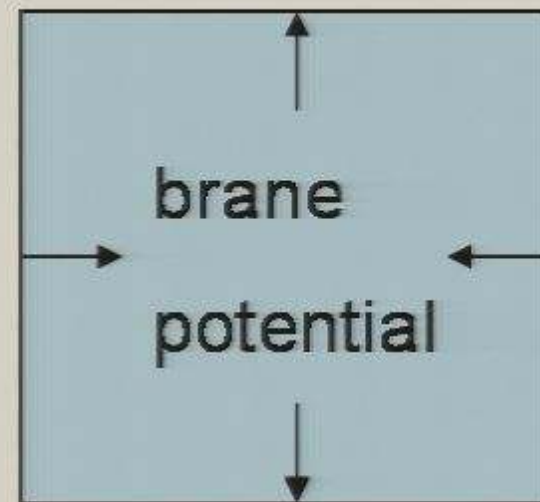
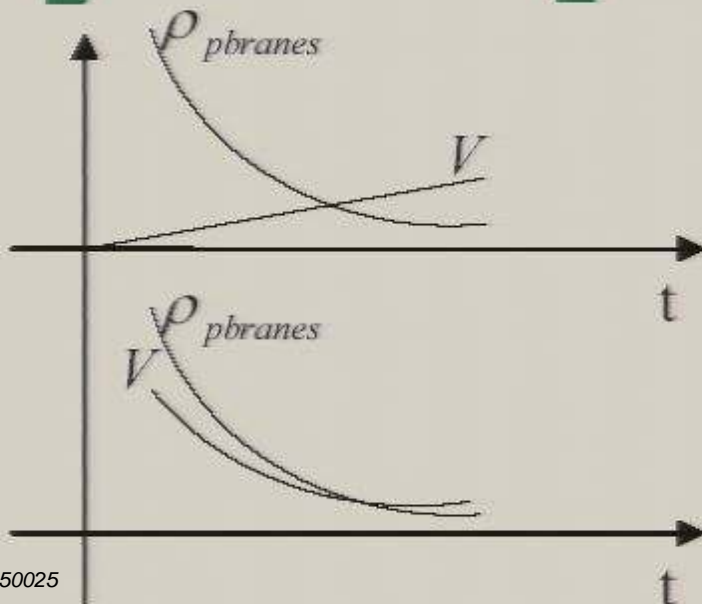
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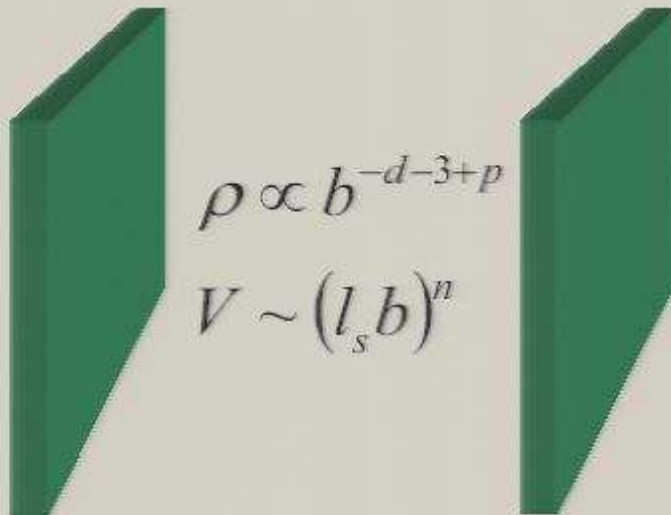


Phase of Contraction

Potential between fixed planes plays a crucial role

- a confining potential \Rightarrow an alternative to inflation
- a decaying potential \Rightarrow dynamically emerging initial conditions for brane inflation models

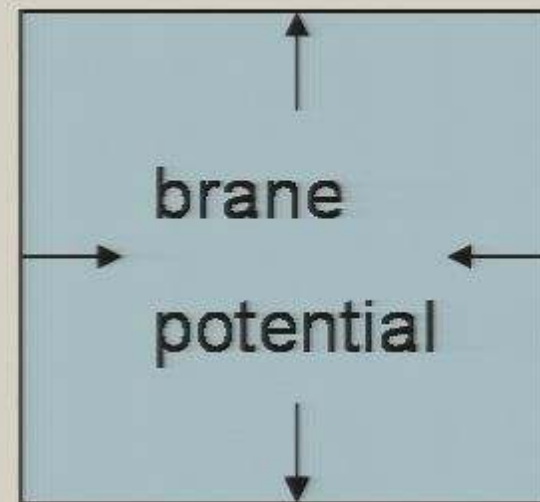
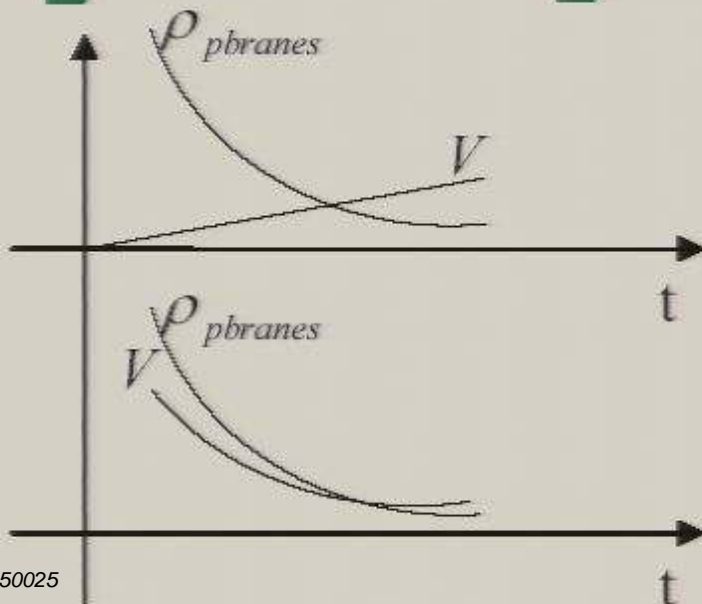
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An Alternative to Inflation

Motivation II

Inflation explains :

- flatness, **horizon**, **entropy**
- scale invariance of density perturbations

Conceptual problems:

- initial condition problem
- singularity

We address

horizon and **entropy** problems
starting with **standard initial conditions**

Note: this is the first time

entropy problem is addressed outside inflationary scenarios

Entropy Problem

Assuming adiabatic expansion

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

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

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

corresponds to Universe of **mm** size

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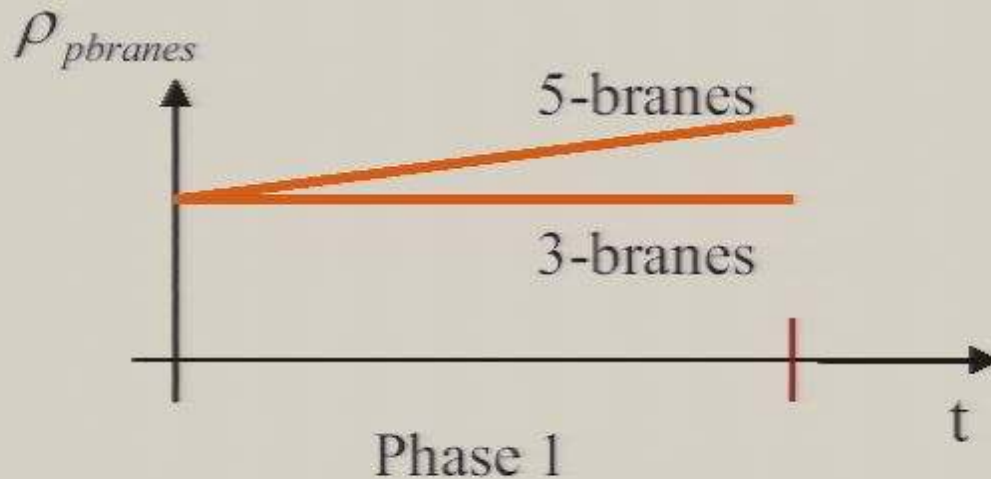
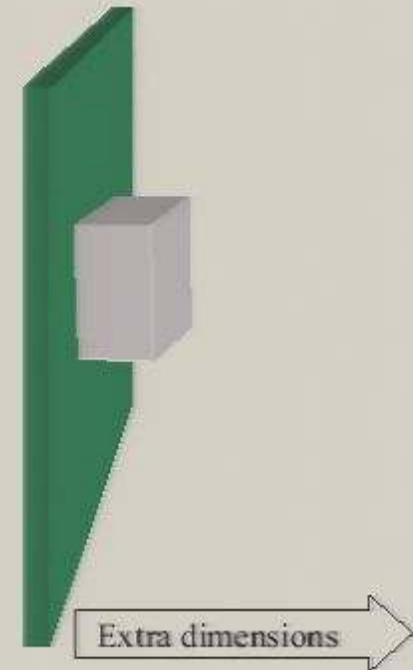
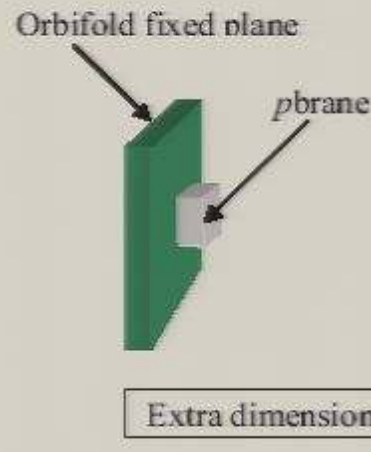
Standard Solution:

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

Unusual technic: Energy amplified in codimension ≥ 3 branes

\implies no accelerated expansion

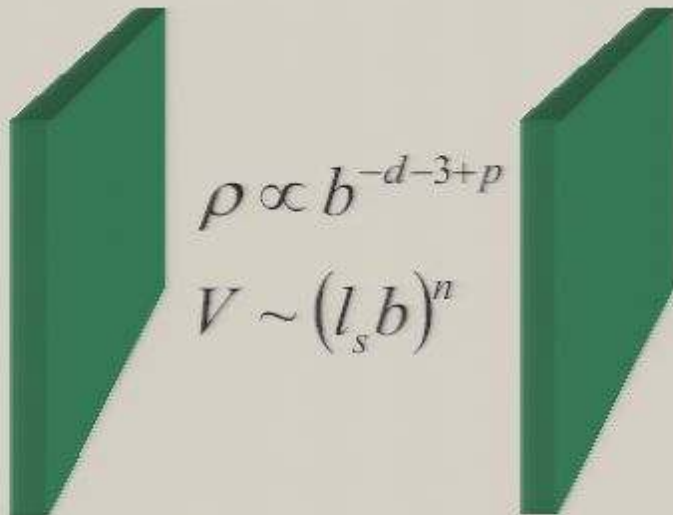
Projected Energy Density - Phase 1





An Alternative to Inflation

From Expansion to Contraction



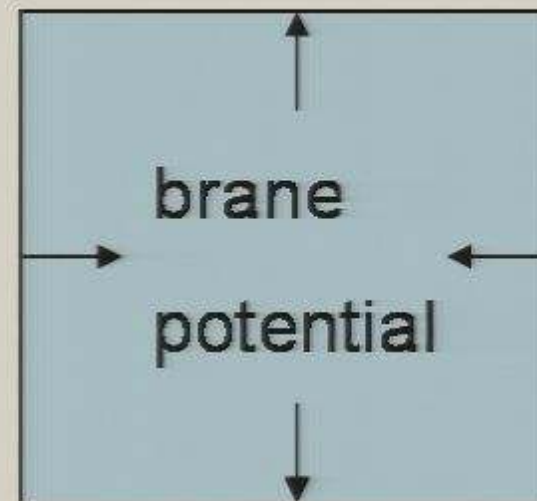
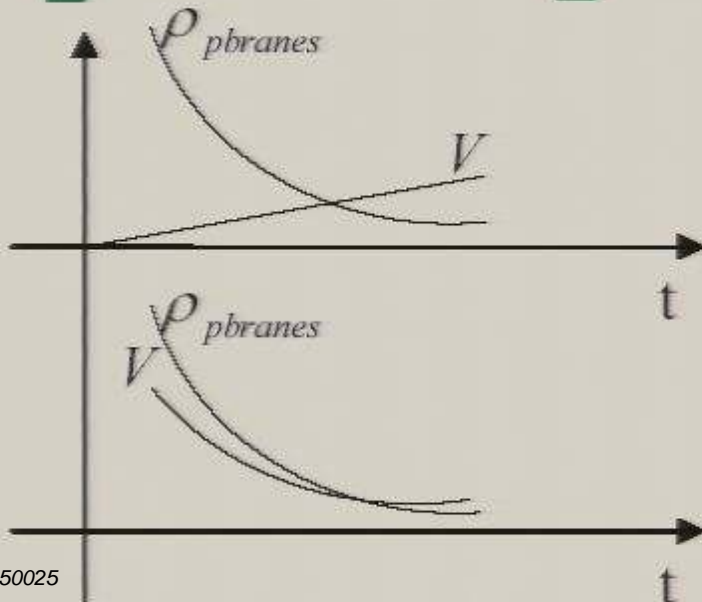
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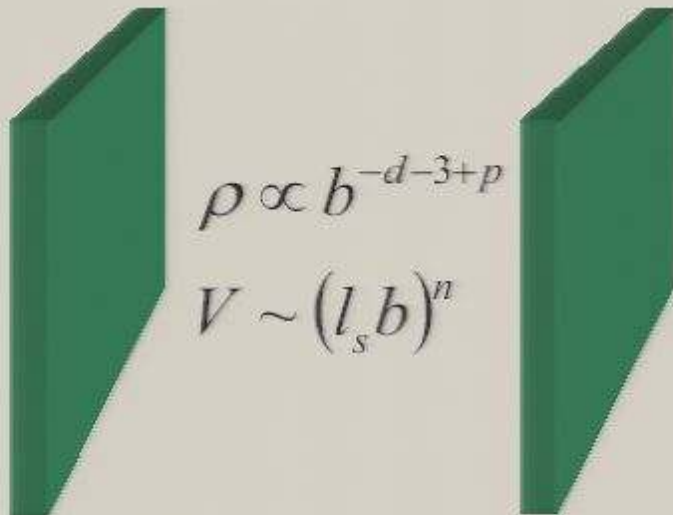
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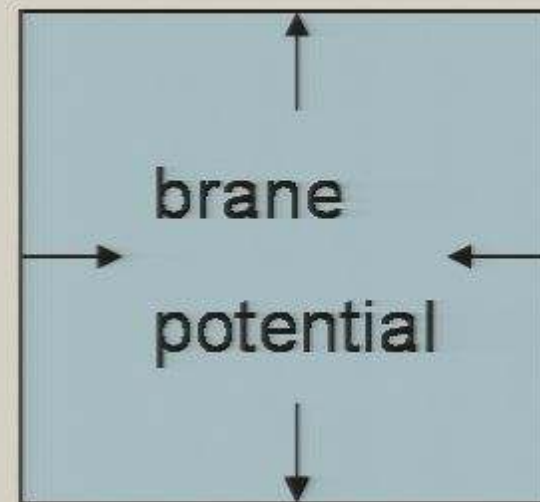
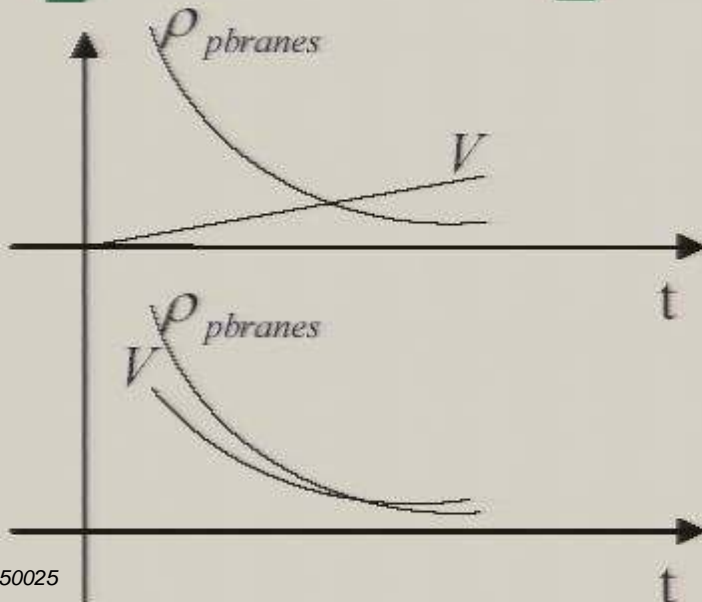
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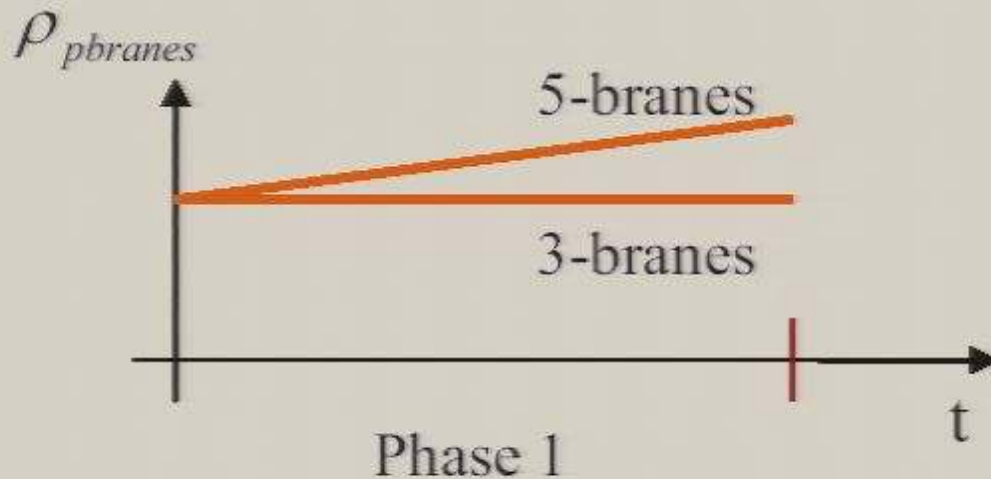
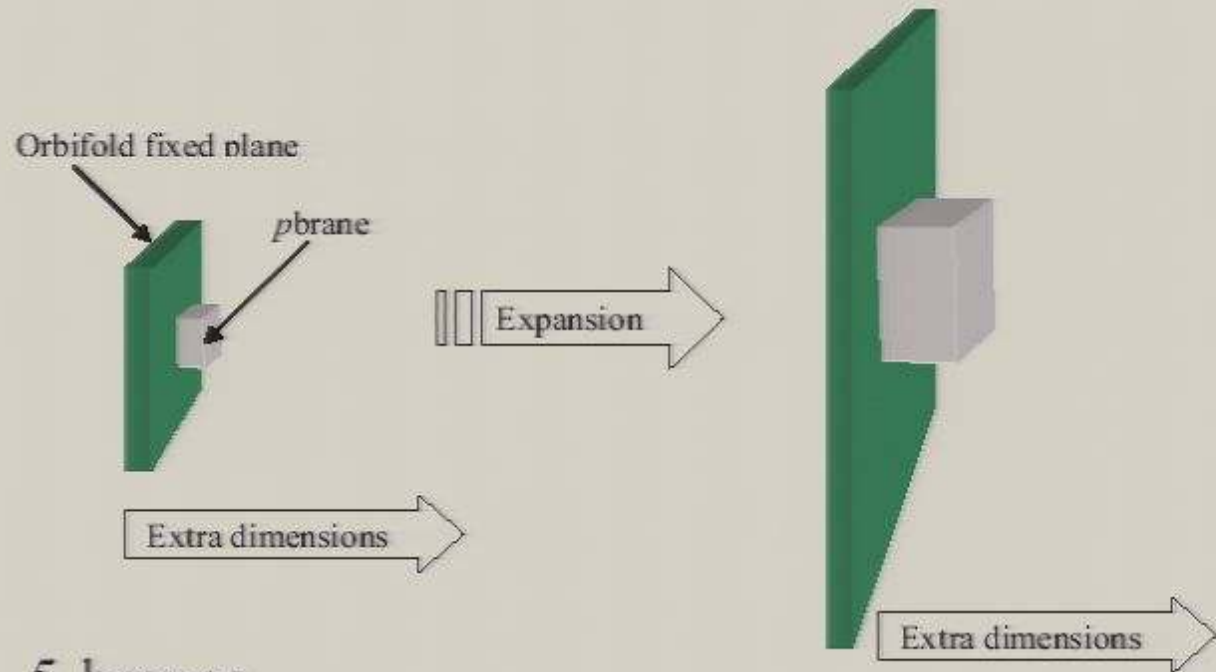
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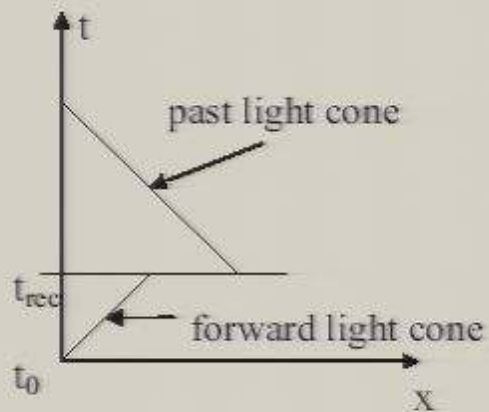


Projected Energy Density - Phase 1

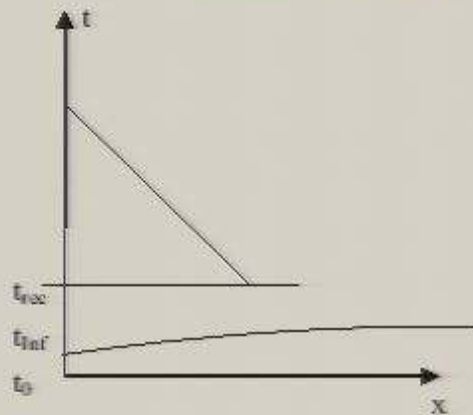


Horizon Problem

Standard Cosmology



Inflation



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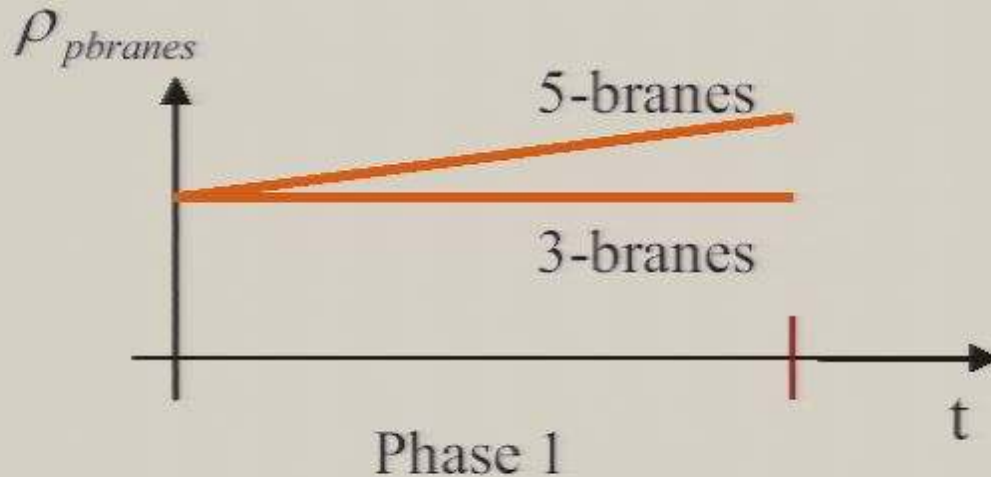
Orbifold fixed plane

ρ_{brane}

Expansion

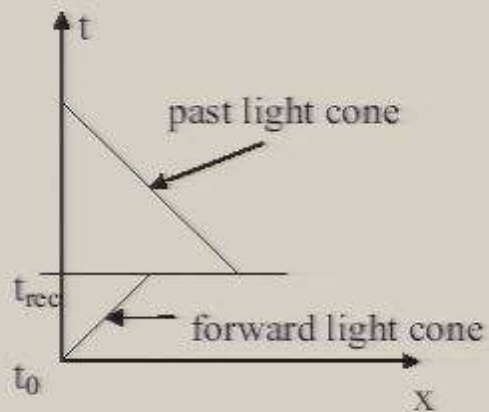
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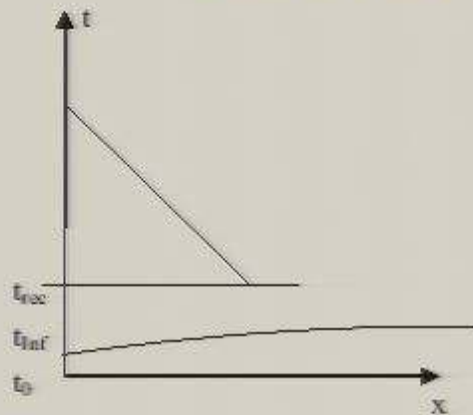


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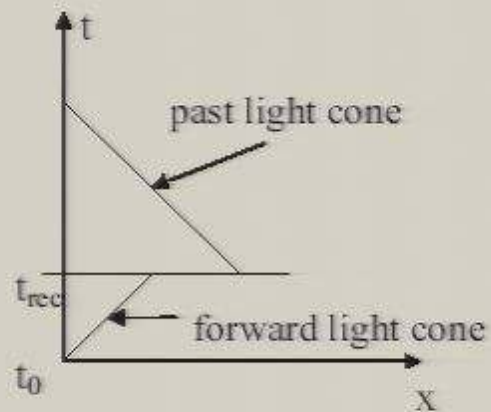


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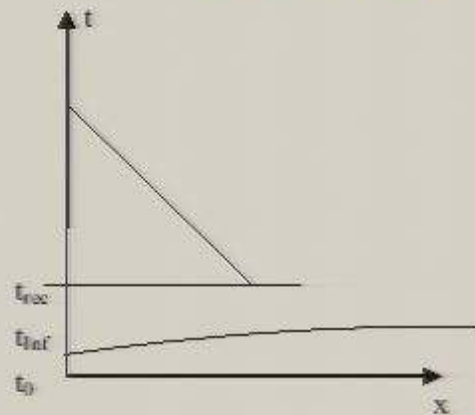


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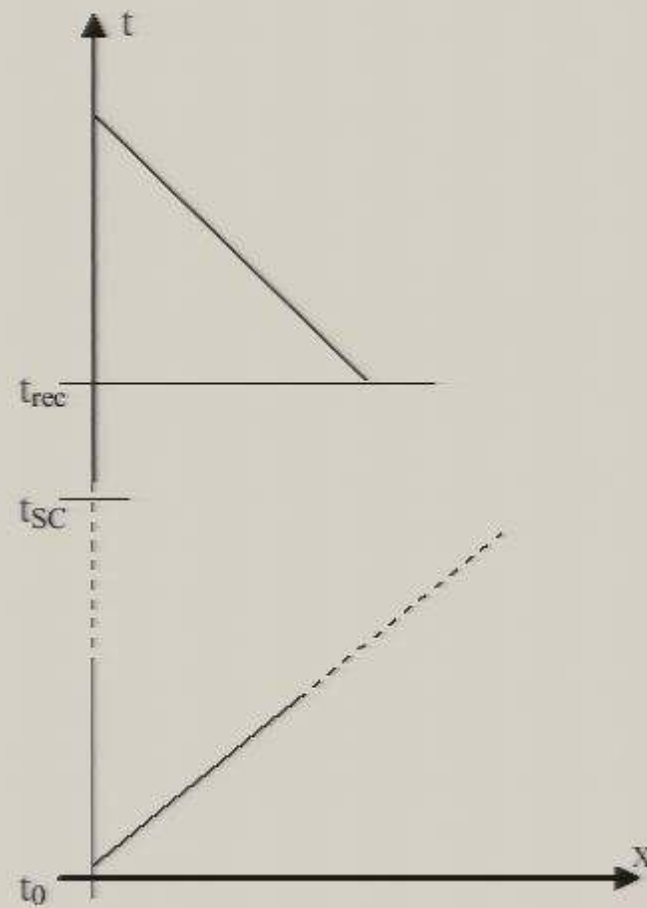
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Inflation



Our Scenario



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

$$V(l_s b) = \mu(l_s b)^n \implies V_{eff}(\varphi) \propto e^{\alpha\varphi/m_{pl}}$$

For $\alpha \gtrsim 1$ the evolution of $a(t)$ is **non-inflationary**.

Size problem:

$$l_s \sim 10^{-17} \text{GeV}^{-1} \rightarrow H(\text{today})^{-1} = 10^{42} \text{GeV}^{-1}$$

During standard cosmology

During earlier phases

$$a(t) \text{ increases by } T_{rh}/T_{today} \approx 10^{29} \quad \Rightarrow \quad 10^{30}$$

Energy scale of the potential $\mu \equiv \Lambda^{d+n+4}$

should satisfy

$$\Lambda \sim l_s^{-1} 10^{-30 \frac{d-p+3+n}{d+4+n}} \sim \text{electroweak scale}$$

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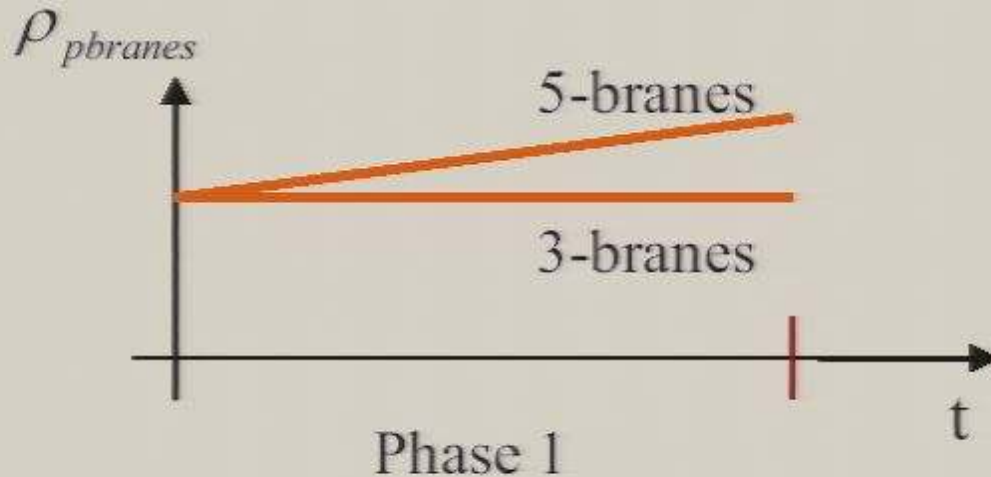
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Extra dimensions





or air

An Alternative to Inflation

or

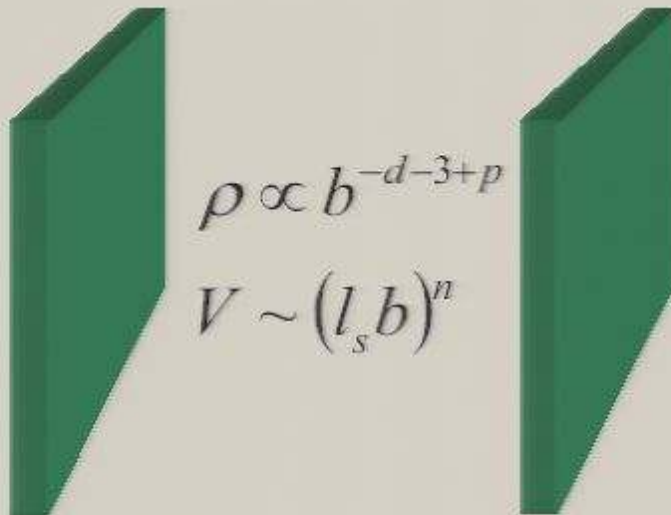
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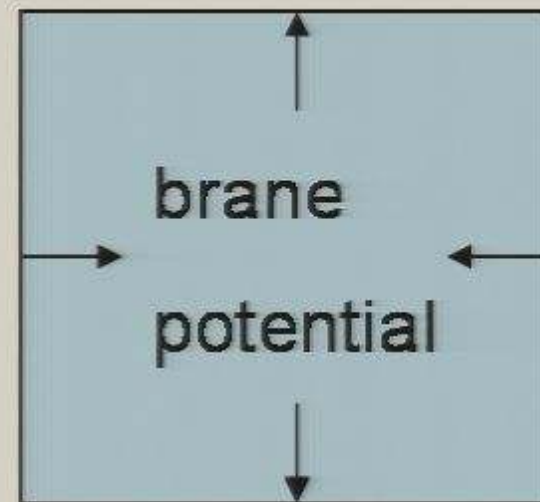
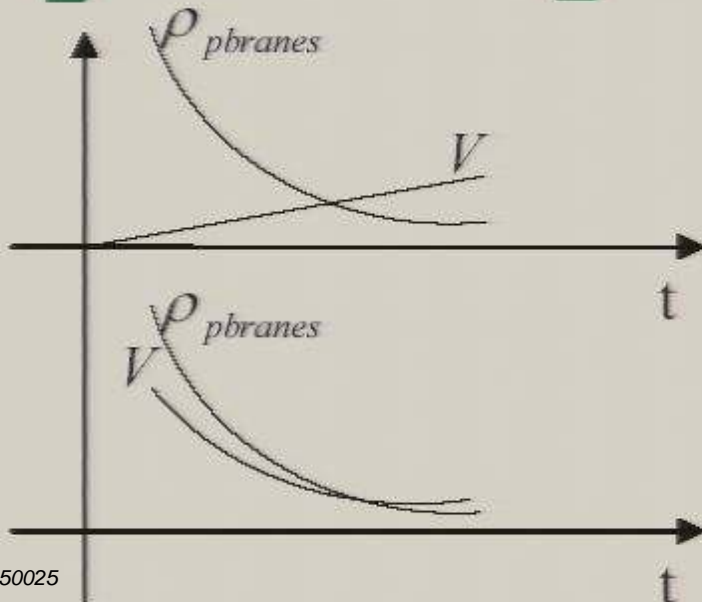
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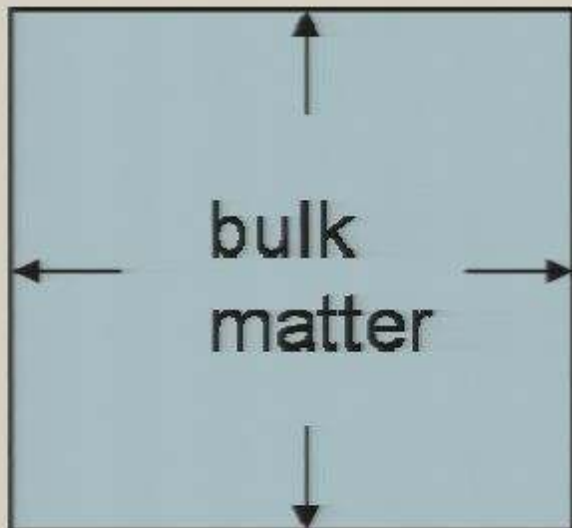
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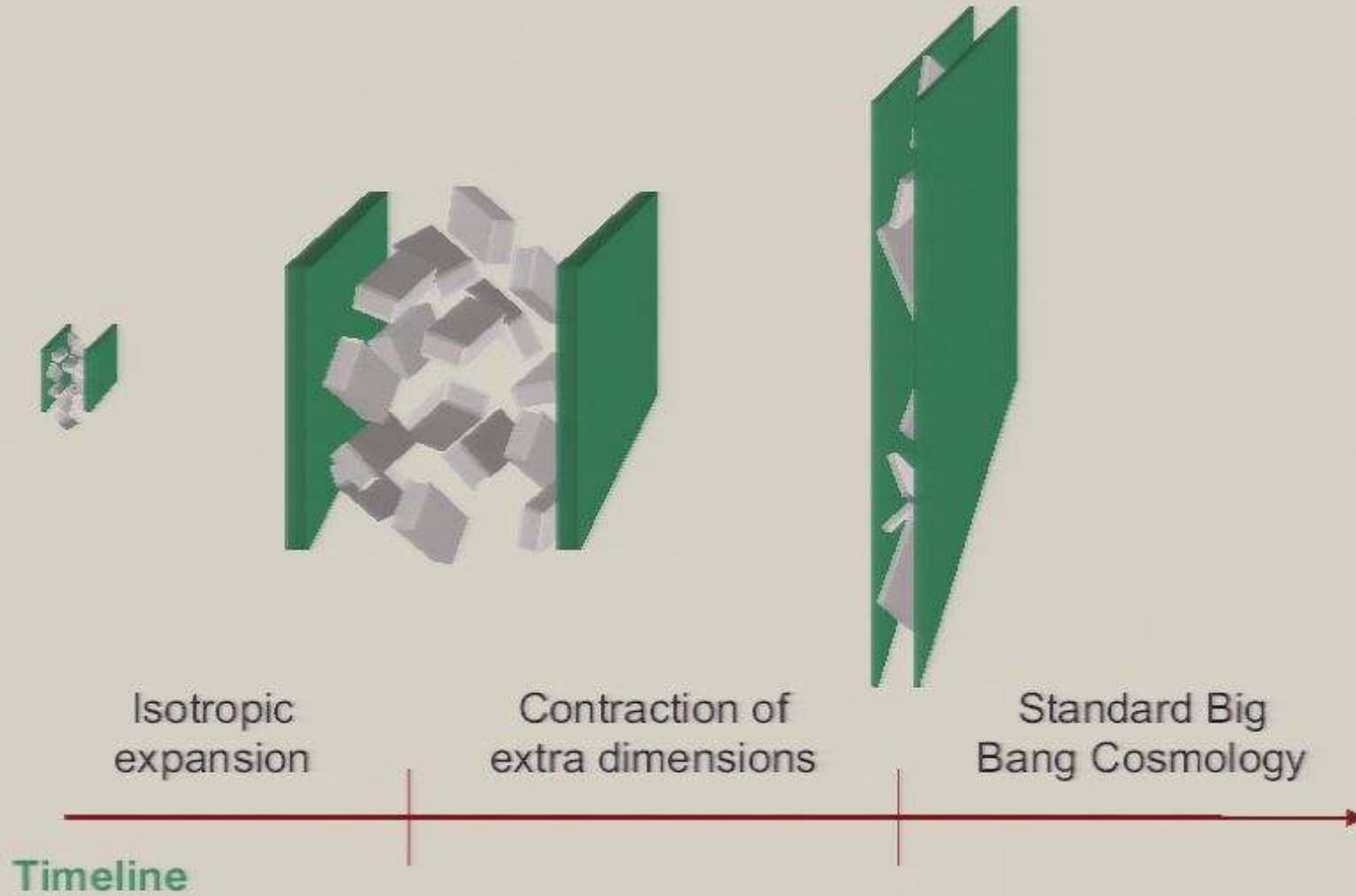
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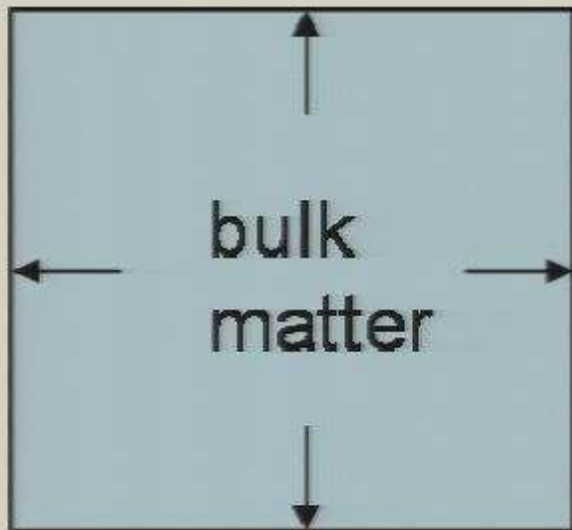
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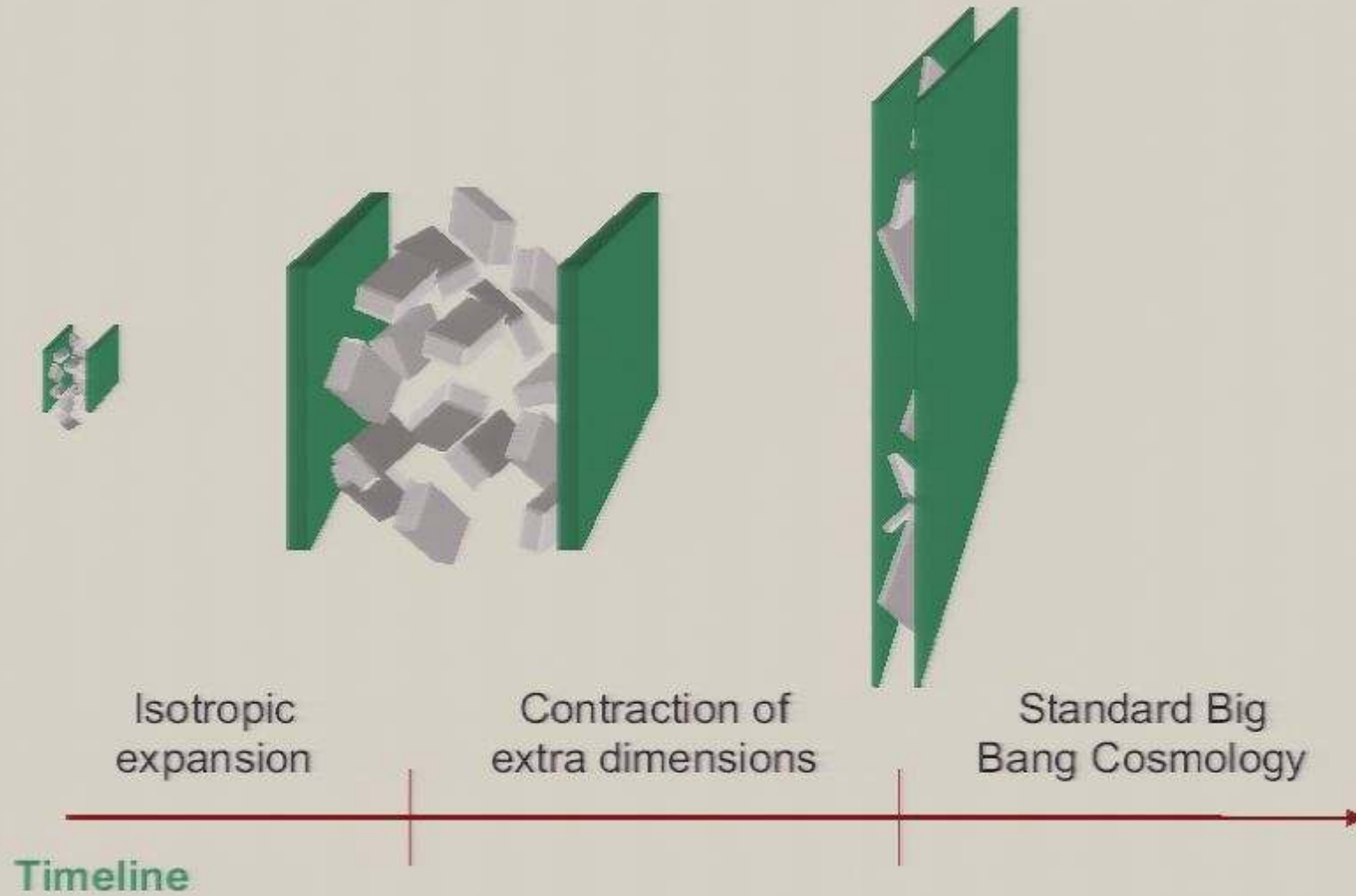
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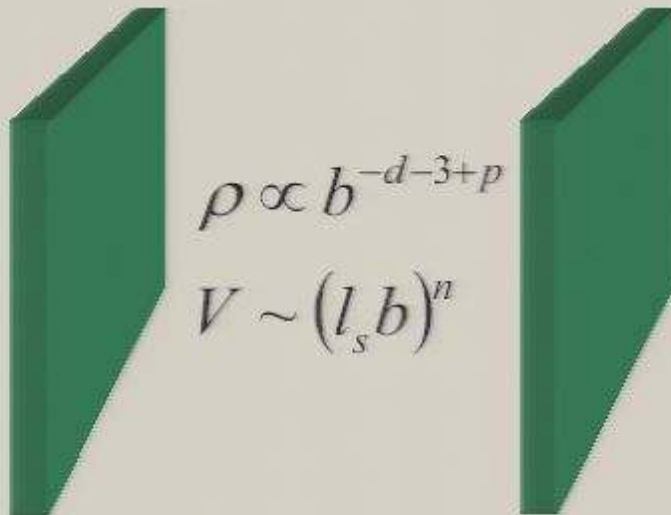


Timeline

Overall Dynamics



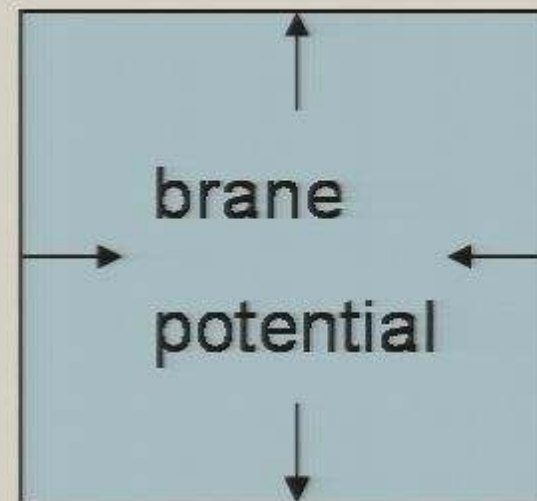
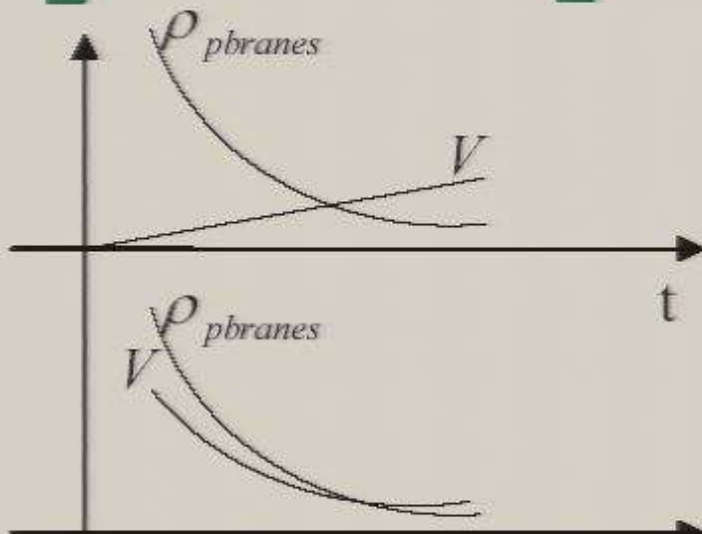
From Expansion to Contraction



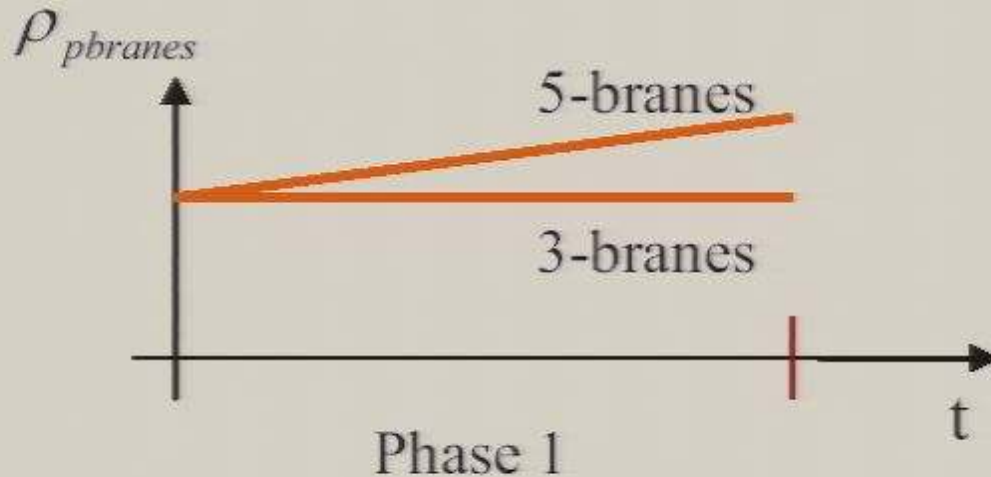
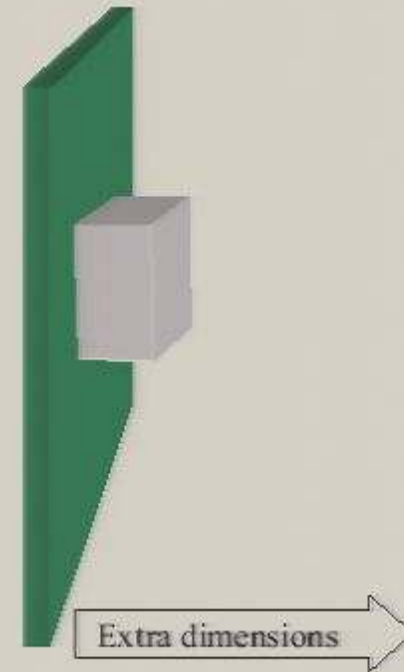
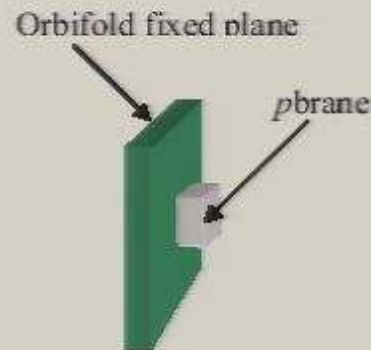
Brane potential dominates

when $V = \rho$

leading to contraction of extra dimensions



Projected Energy Density - Phase 1



Example

Consider inter-brane potential

$$V(l_s b) = \mu(l_s b)^n \implies V_{eff}(\varphi) \propto e^{\alpha\varphi/m_{pl}}$$

For $\alpha \gtrsim 1$ the evolution of $a(t)$ is **non-inflationary**.

Size problem:

$$l_s \sim 10^{-17} \text{GeV}^{-1} \rightarrow H(\text{today})^{-1} = 10^{42} \text{GeV}^{-1}$$

During standard cosmology

During earlier phases

$$a(t) \text{ increases by } T_{rh}/T_{today} \approx 10^{29} \quad \Rightarrow \quad 10^{30}$$

Energy scale of the potential $\mu \equiv \Lambda^{d+n+4}$

should satisfy

$$\Lambda \sim l_s^{-1} 10^{-30 \frac{d-p+3+n}{d+4+n}} \sim \text{electroweak scale}$$

Effective Field Theory Approach

Canonically normalized scalar field φ :

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

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Entropy Problem

Assuming adiabatic expansion

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

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

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

corresponds to Universe of **mm** size

not m_{pl}^{-1} size

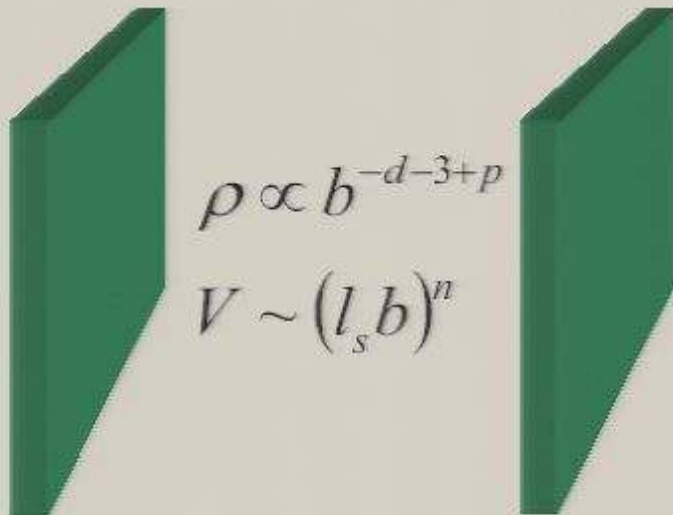
Standard Solution:

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

Unusual technic: Energy amplified in codimension ≥ 3 branes

\implies no accelerated expansion

From Expansion to Contraction



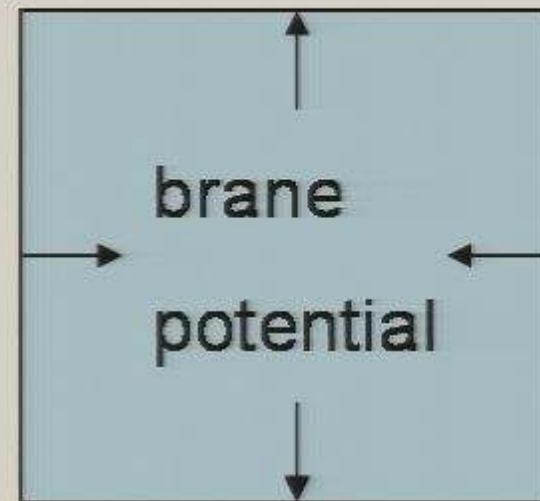
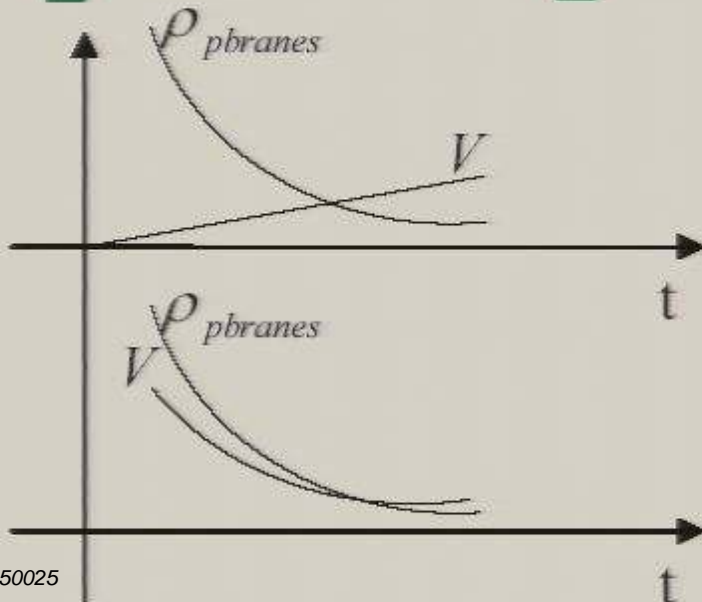
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$$V \sim (l_s b)^n$$

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Phase of Expansion

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

Isotropy: $a(t) = b(t)$

Expansion governed by

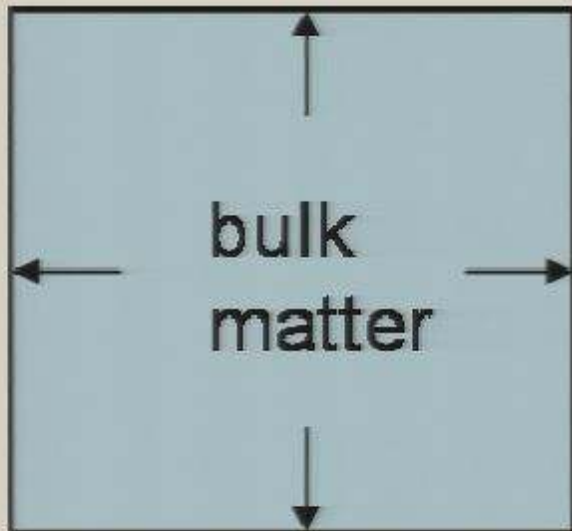
$$\frac{\ddot{a}}{a} + (2 + d)\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3 + d - 1}[\rho - P]$$

Equation of state

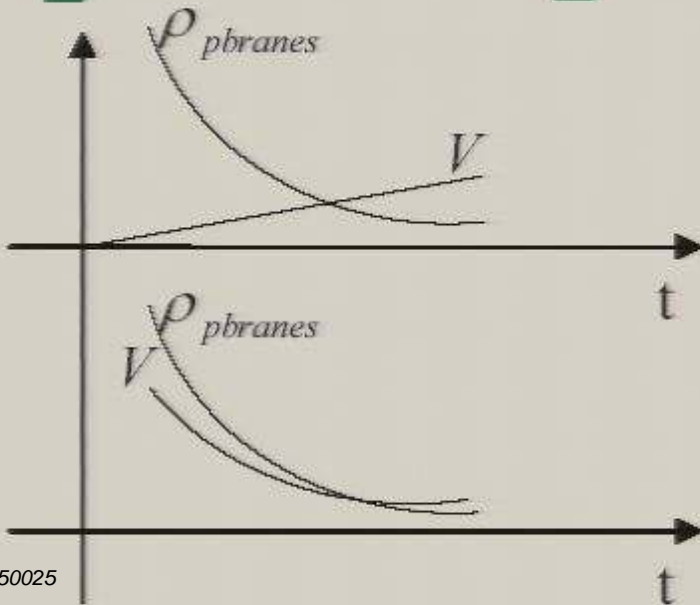
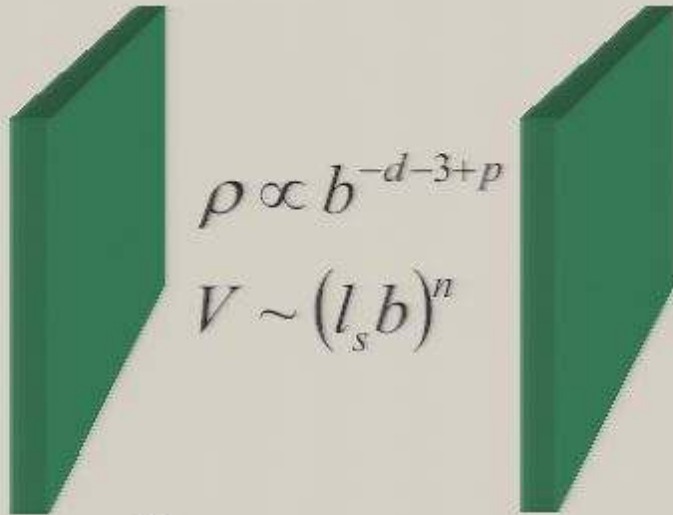
$$P = w\rho$$

Leads to

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



From Expansion to Contraction



Motivation II

Inflation explains :

- flatness, **horizon**, **entropy**
- scale invariance of density perturbations

Conceptual problems:

- initial condition problem
- singularity

We address

horizon and **entropy** problems
starting with **standard initial conditions**

Note: this is the first time

entropy problem is addressed outside inflationary scenarios

Entropy Problem

Assuming adiabatic expansion

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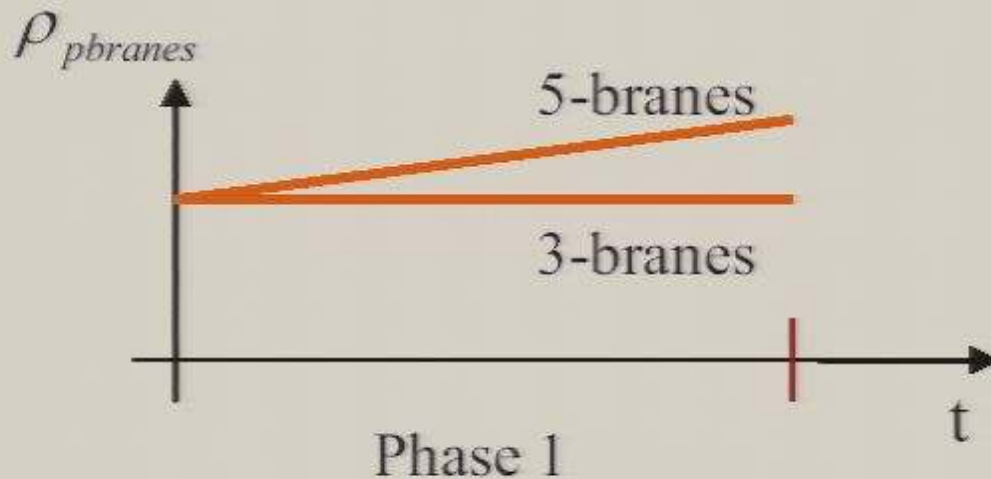
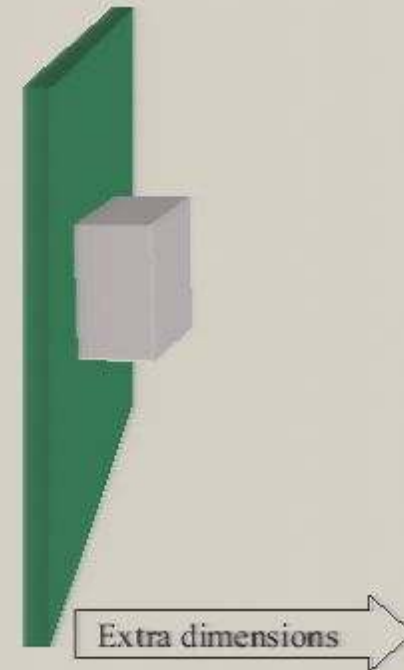
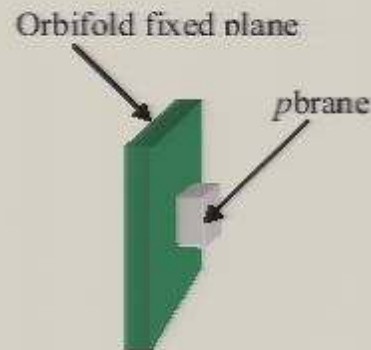
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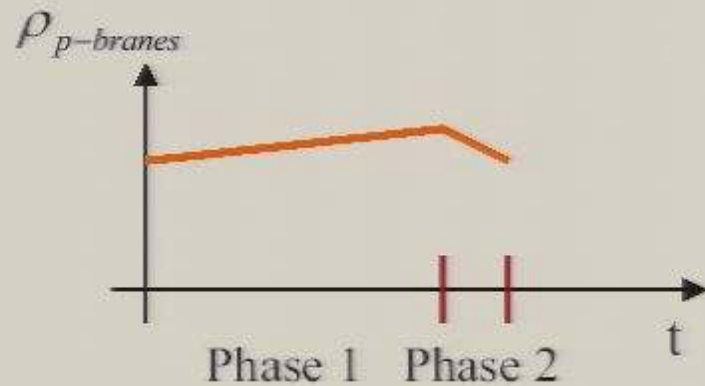
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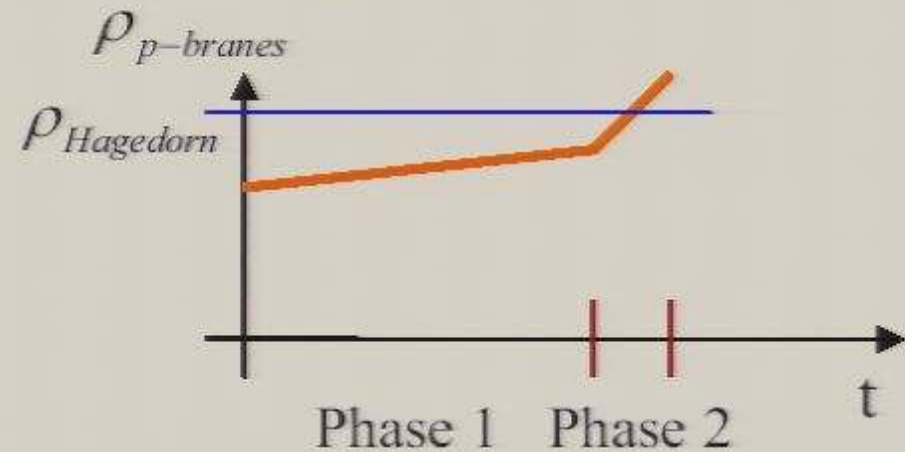
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Towards an Alternative

$$\Gamma_{p\text{-branes}} \gg t_{\text{collapse}} \Downarrow$$



$$\Gamma_{p\text{-branes}} \ll t_{\text{collapse}} \Downarrow$$



- Perturbations must be generated during the phases of expansion and contraction or before

- Perturbations are generated in the Hagedorn phase
A. Nayeri, R. H. Brandenberger and C. Vafa, hep-th/0511140.

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Summary

- No accelerated expansion in the model
- Horizon Problem: long period of dynamics in extra dimensions
- Entropy Problem reduces to Particle Physics Hierarchy Problem



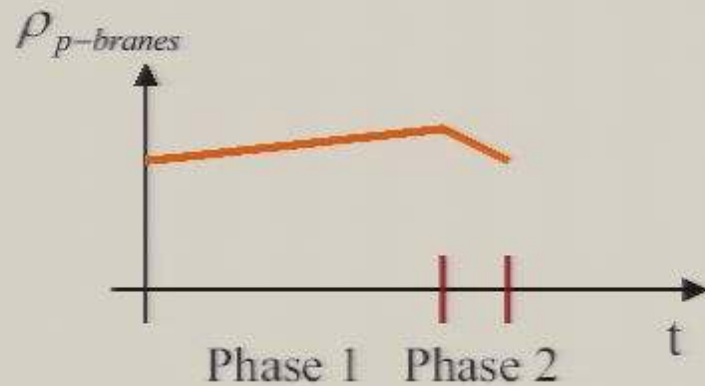
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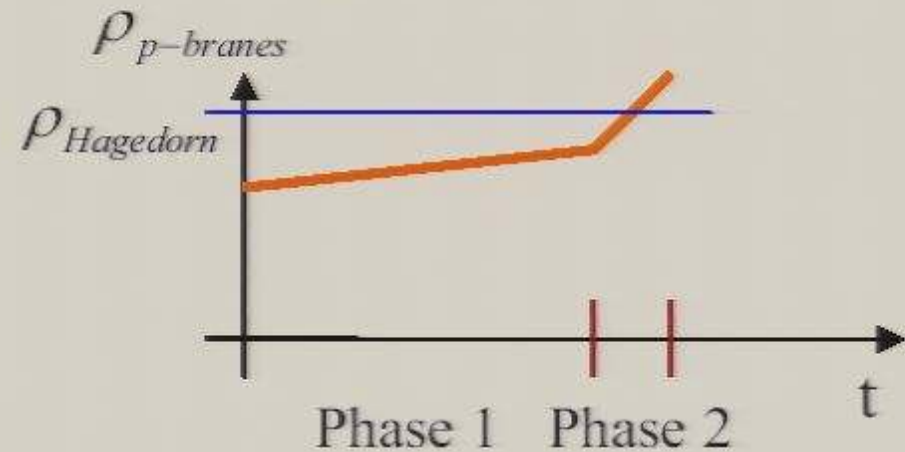
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Emerging Brane Inflation Models

Motivation III

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
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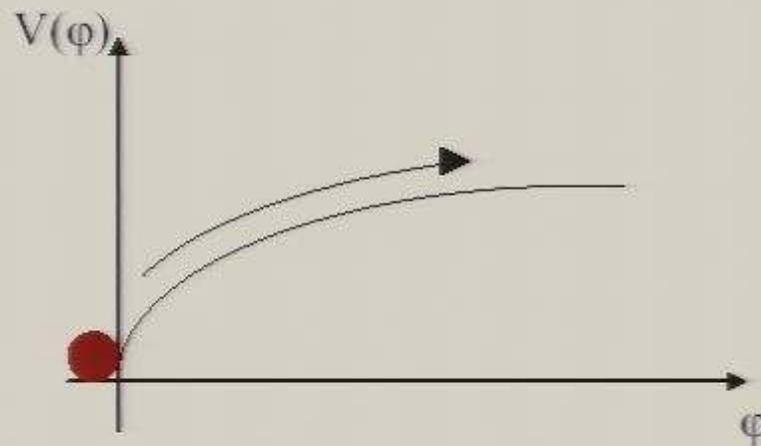
Conventional approaches: all extra dimensions are **static**
 \implies any starting point with $r \gg l_s$ poses **hierarchy problem**

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

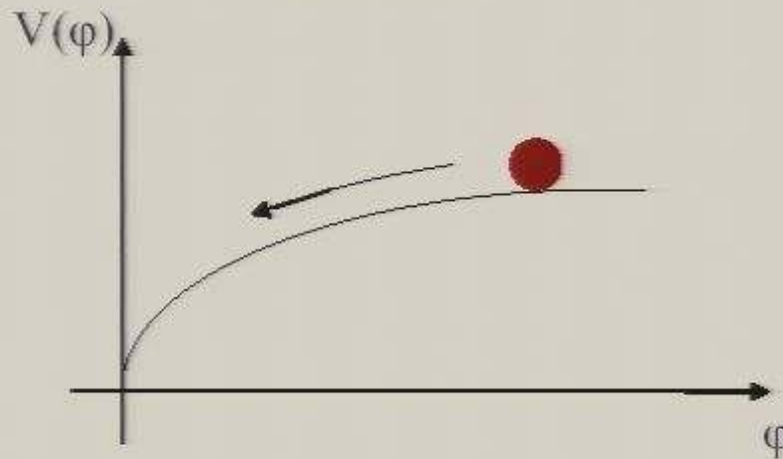
Advantage: **Natural starting point**

Effective 4d view

Bulk Expansion Phase



Inflation



Example

Consider inter-brane potential

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

Add brane tension

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
- Emerging large separation for brane inflation models
- Unique scale

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Conclusions

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- Natural starting point for string inspired cosmology
- Bulk expansion governed by p-branes provides
 - A venue towards an alternative to inflation
 - Emerging brane inflation models
- Details of the inter-brane potential determine the early stages of the universe
- A confining potential \rightarrow a non-inflationary solution of the entropy and horizon problems
- + Correct perturbation (Hagedorn phase ?)
 \implies An alternative to inflation (– flatness problem)
- A decaying potential \rightarrow emergent brane-antibrane inflation models.