Topological Inflation and D Anti D brane Annihilation

Or Inflation From a Bang

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Outline

I. Introduction and Motivation:

Why Inflation needs String Theory?

II. Review of Slow Roll D-brane Inflation

III. Topological Inflation

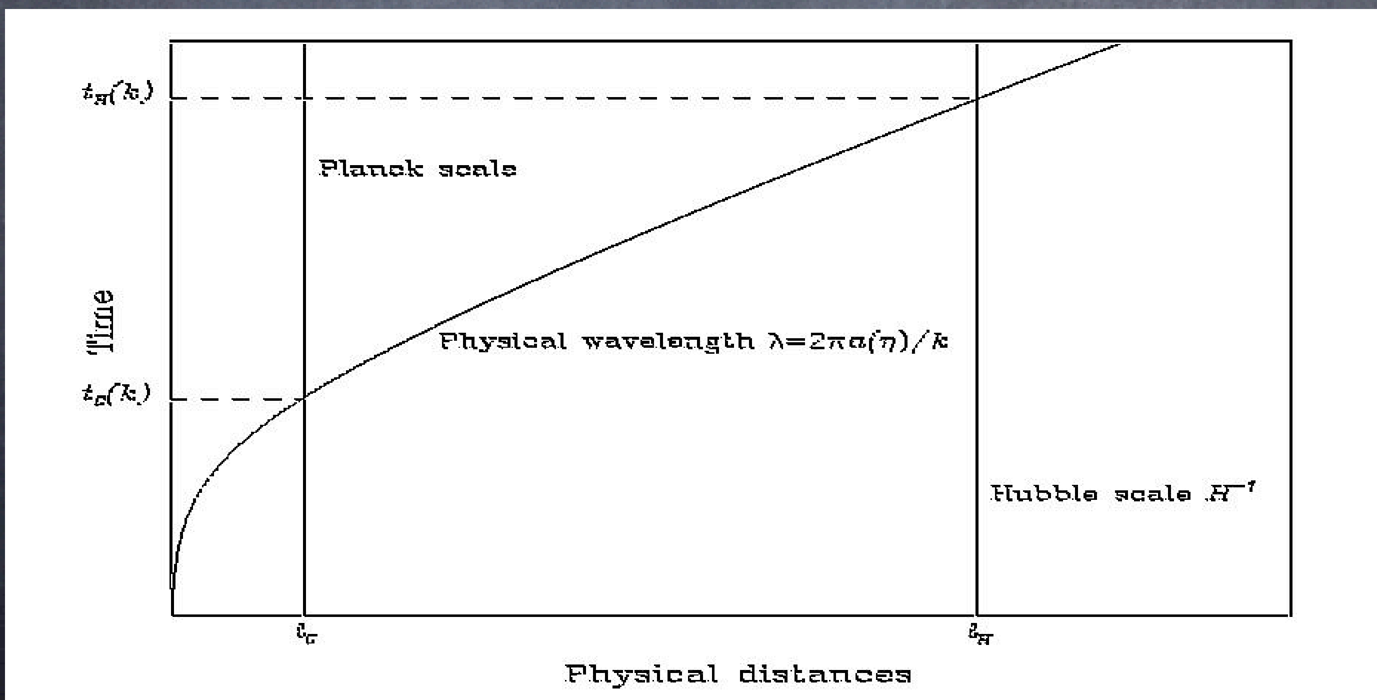
IV. Inflation from D-brane Annihilation

V. Non-Topological Inflation

VI. Unresolved Issues: Initial Conditions, Moduli Stabilization.

VII. Conclusions + Outlook

- Scalar field driven inflation models are singular at t->0
- The Fluctuation Problem requires technically unnatural fine tuning of □~10^{-14}
- Transplanckian Problem: Initial Fluctuations for LSS



What is the Lesson?

- Inflation has provided a economical framework to predict the features of CMB and resolve problems of SBB. . .
- But it still lacks a concrete realization in

A fundamental theory of quantum gravity.

- QFT weakly coupled to Gravity is not enough!

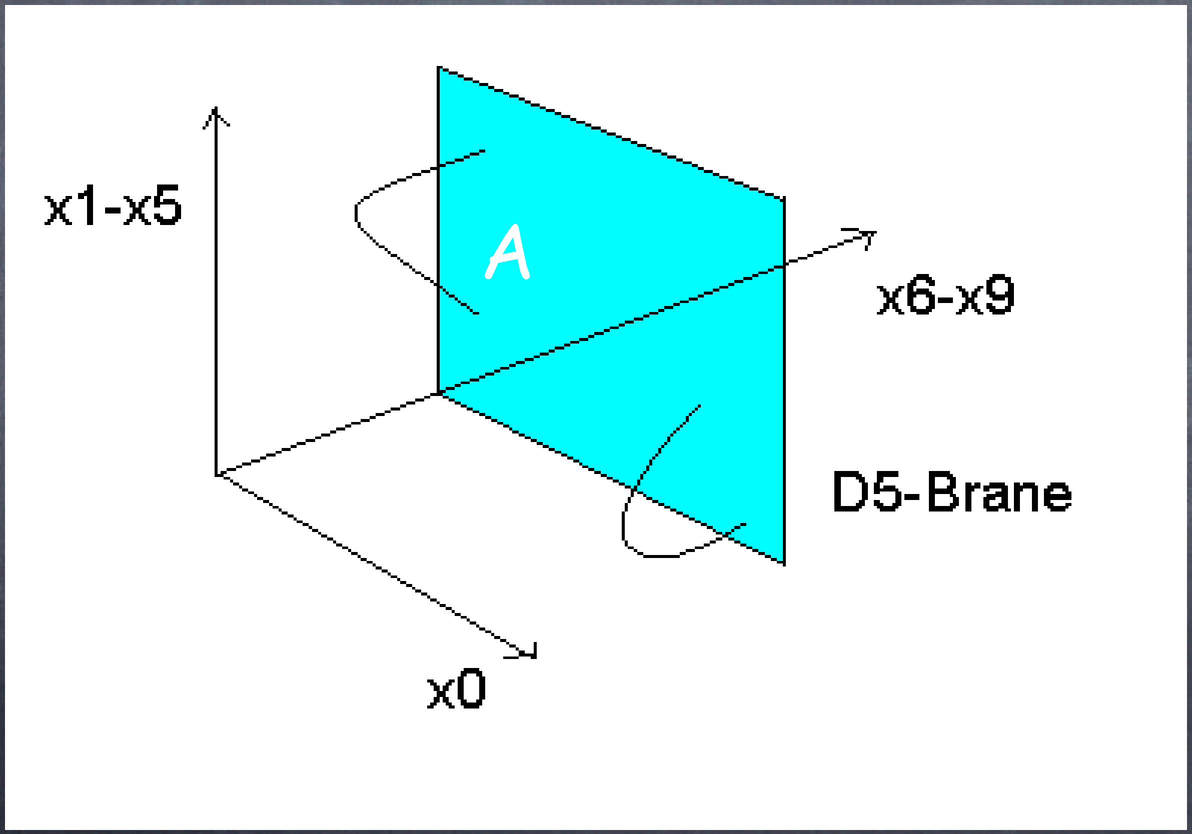
D-branes and Inflation

- Why can it help?

- D-brane dynamics encode field theories-> this will be useful for a depiction of inflation
- Massless W.V fields can be good candidates for inflatons.
- Massless open string modes decouple from closed string modes-> D-branes can be very heavy without causing backreaction. This may give insight into Transplanckian Problem since we can trace fluct. History to l_{pl}

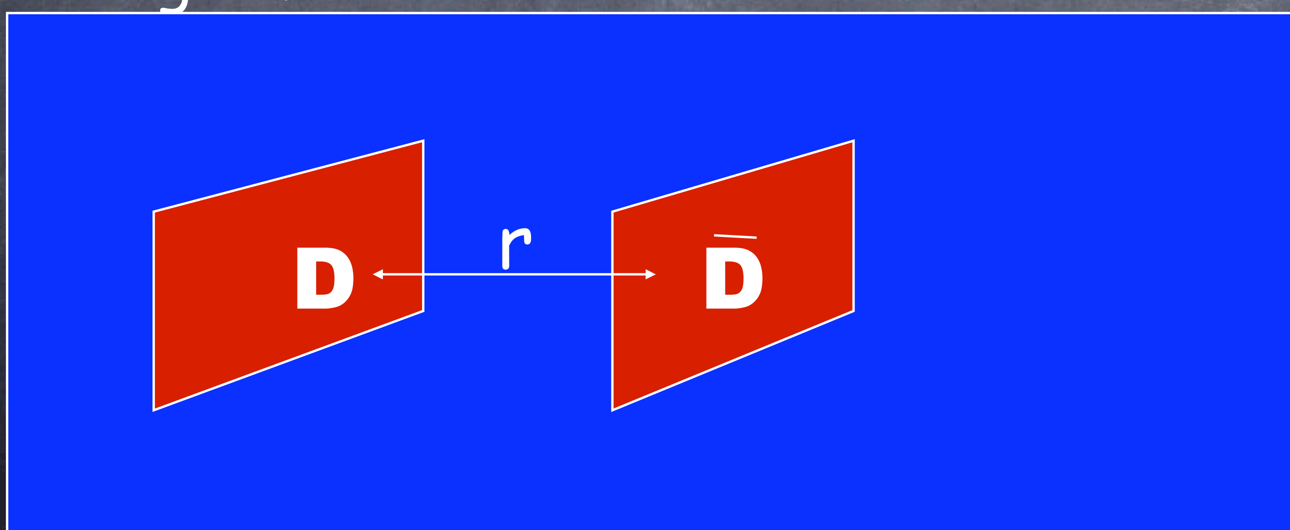
D-brane WV Dynamics

Longitudiaal fluctuations
encode
Gauge fields
Transverse fluctuations
encode scalars



Origin of D-Species: Slow Roll D-brane Inflation

- Slow roll inflation is realized from a Coloumbic potential V(□) which depends on the separation between two D-branes.
- This is encoded in the DBI Action (massless Open String modes) ; Cylinder diagram



$S = S_{bulk} + S_D + \bar{S}_D$

In an AdS5xS5 background the WV action takes the form

$$S = -T_3 \int \sqrt{-g}\, d^4x \left(\frac{r_1^4}{R^4}\right) \sqrt{1 - \frac{R^4}{r_1^4} g^{\mu\nu} \partial_\mu r_1 \partial_\nu r_1} + T_3 \int (C_4)_{tx^1x^2x^3}\, dt\, dx^1 dx^2 dx^3$$

Considering small velocities

$$S = \int d^4x \left(\frac{1}{2} T_3 g^{\mu\nu} \partial_\mu r_1 \partial_\nu r_1 - 2T_3 \frac{r_0^4}{R^4} \left(1 - \frac{1}{N} \frac{r_0^4}{r_1^4}\right)\right)$$

- This is a description of a D3 brane moving in an AdS5xX5 (warped) with 3-form flux. (Giddings, Kachru, Polchinski; DeWolfe, Giddings; KKLT, KKLMT)

In The original Slow Roll D-brane scenario this warp factor in the second term was missing. Without warping slow roll conditions are inconsistent.

- The Flux causes warping and 'flattens' potential leading to consistent slow roll conditions. $□_{new}=□e^{-k/gsM}<<1$

There is still a problem!

KKLT says: A successful stringy inflation must incorporate volume stabilization of internal dimensions!

$$2r = \rho + \bar{\rho} - k(\phi, \bar{\phi})$$

Volume of CY depends on slow roll field

$$T_{D3} \int d^4x \frac{\partial_\mu \phi^i \partial^\mu \bar{\phi}^{\bar{k}} k_{i\bar{k}}}{\rho + \bar{\rho}}$$

$$K(\rho, \phi, \bar{\rho}, \bar{\phi})_{D3} = -3 \log(\rho + \bar{\rho} - k(\phi, \bar{\phi}))$$

At small field values (slow roll) the inflaton gets a planck mass…spoils slow roll conditions.

Where to go from here?

Since F-term spoils the slow roll condition - Deal with D-term(this is being pursued) .

Evade slow roll inflation altogether

-> This will be our approach.

What are the general initial conditions for D-brane inflation?

Why is brane anti-brane interaction giving us inflation?

From Cliffords Lecture...

'Instability is non necessarily a bad thing'

The key physics for inflation is the same:

Consider the annihilation of two D-branes.

- D-branes annihilate from a tachyonic instability

- Inflation is also an instability towards superluminal expansion

The initial conditions for inflation
Is met by connecting the two instabilities.

What is this Connection?

A Different Outlook: Topological Inflation

Topological Defects trap false vacuum energy at their core.

From the Friedmann eq. If the core radius is comparable to Hubble radius -> INFLATION!

Lagrangian with Global Z2 Symmetry

$$L = \frac{1}{2}(\partial_\mu \phi)^2 - \frac{\lambda}{4}(\phi^2 - \frac{m^2}{\lambda})^2$$

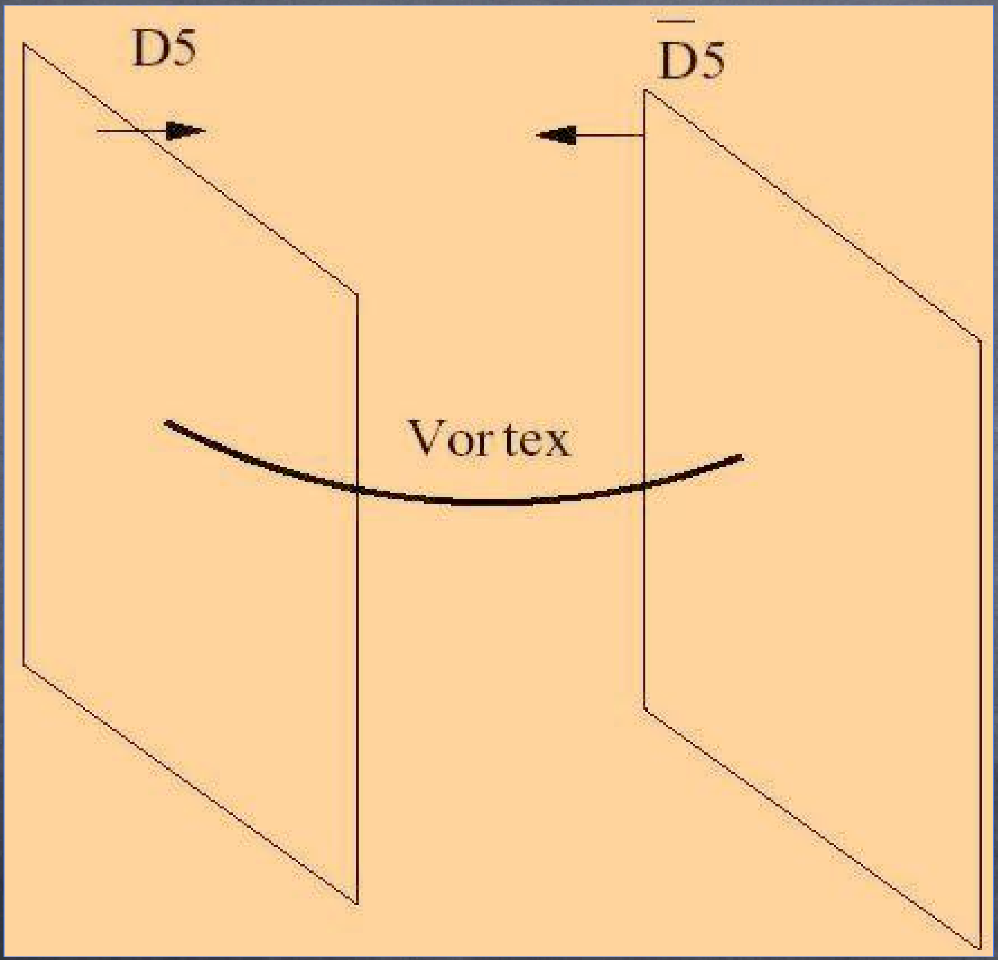
Admits Topologically Stable Walls

$$\phi = \eta \tanh(\sqrt{\frac{\lambda}{2}}\eta x)$$

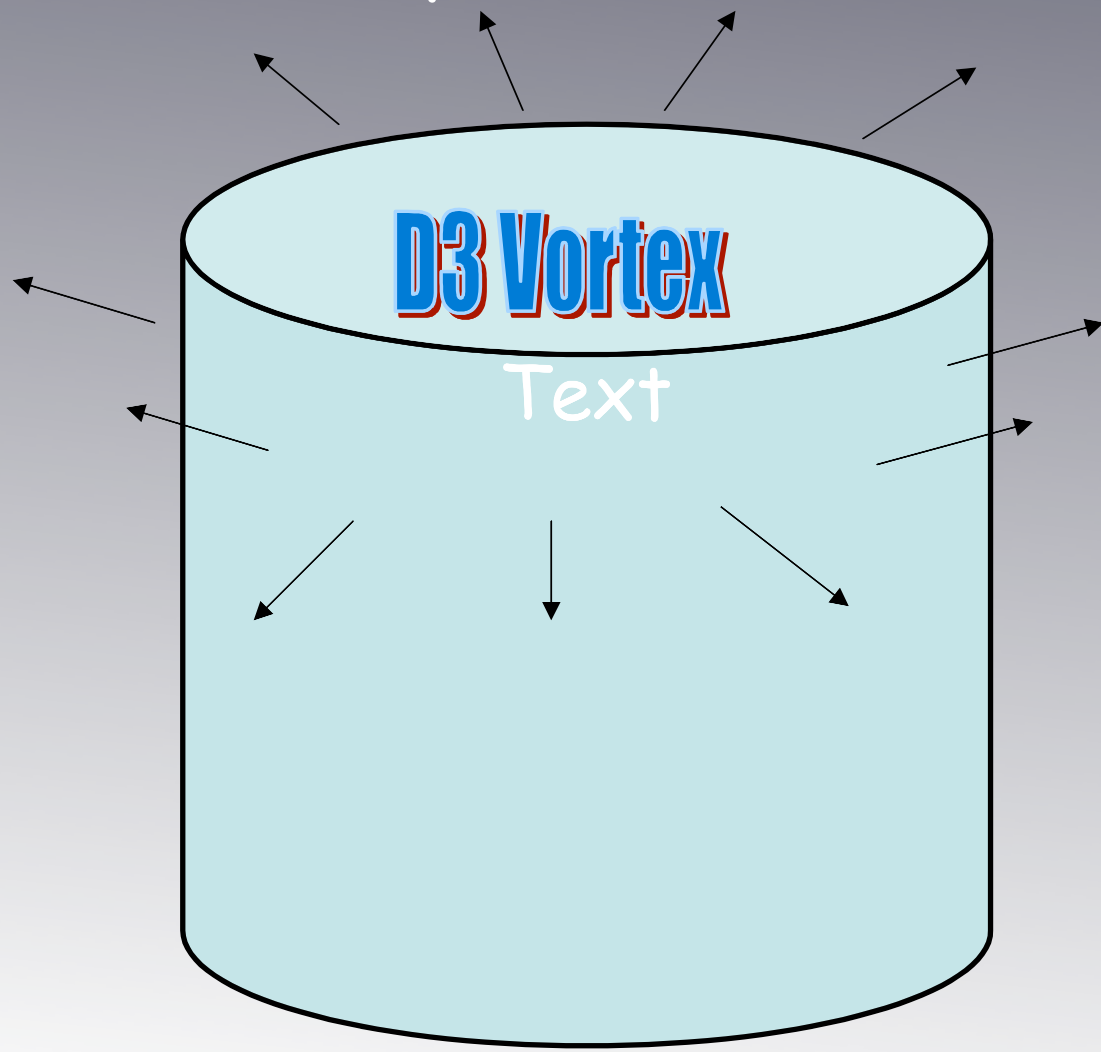
Plug into L and balance KE with PE
Solve for the thickness of core radius

$$\delta_0 \simeq \eta(V_0^{1/2})$$

THE MECHANISM



The Vortex Core Inflates



When the D5-D5 annihilate
A co-dimension 2 Tachyonic vortex forms
on the D5 worldvolume. (Sen)

$$2T_D + V(T_0) = 0$$

The Vortex is D3 Brane (K-theory).

D5-D5 WV Theory $U(1) \times U(1) \rightarrow U(1)$

$$\Pi_1(\mathcal{M}) \equiv \Pi_1(G/H) = Z$$

The false vacuum energy at the core
of the defect drives Topological Inflation

How Does Topological Inflation Work?

The defect's core radius has trapped false vacuum energy

$$\delta_0 \simeq \eta(V_0^{1/2})$$

From the E.E inflation occurs when H is constant

$$H^2 = \frac{8\pi}{3}G\rho$$

Putting the above two together

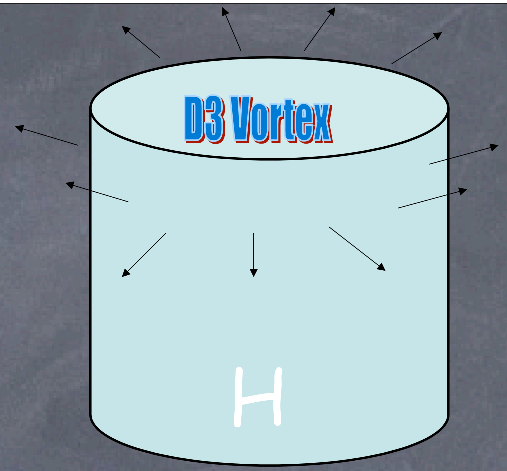
$$H_0^{-1} = M_p(\frac{3}{8\pi V_0})^{1/2}$$

-->

$$\eta \geq M_p$$

This is Problematic for F.T

But it works in String Theory!



- Core of D3 vortex is comparable to Hubble.
- Potential Energy in core is larger than tension energy.
- Simultaneously, string coupling can be small.
- $V(T=0) \ll Mpl^4$
- Toplogical inflation can work in Sting Theory

Assume: $M_4 \times R_6$ Compactification

Assume: M_4 is stabilized (ie flux)

6D Newton coupling → $G^6 = \frac{(\alpha')^4 g_s^2}{V(T^4)}$

+

Condition for Topological Inflation → $H_0^{-1} = M_p(\frac{3}{8\pi V_0})^{1/2}$

Tachyon potential → $V(T,\bar{T}) = \tau(\alpha')^2(|T|^2 - (\alpha')^{-1})^2$

Which will be consistent if: → $\alpha' < m_{\rm pl}^2$

Total Action

$$S_{Tot} = S_{Grav} + S_{DBI}^{D-\bar{D}} + S_{WZ}^{D-\bar{D}}$$

Wess-Zumino

$$\mathcal{L}_{\mathrm{WZ}} = \mathrm{T}_{\mathrm{D5}} \int_{\mathrm{M}_6} \mathrm{C} \wedge \mathrm{Str} e^{2\pi i \alpha' \mathcal{F}}$$

Supertrace

$$StrM = Tr(-)^F M = Tr \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} M$$

$$T_{D5} \int_{M_6} C_4 \wedge (2\pi\alpha') dT \wedge d\bar{T}$$

Energy Momentum

$$T_{\mu\nu} = \frac{\delta S}{\delta g^{\mu\nu}} = D_\mu T \bar{D}_\nu \bar{T} + D_\nu T \bar{D}_\mu \bar{T} - g^{\alpha\beta} F^-_{\mu\alpha} F^-_{\nu\beta} + g_{\mu\nu} \mathcal{L}$$

E.O.M

$$\nabla^\nu F^-_{\mu\nu} = ie(\bar{T} \nabla_\mu T - T \nabla_\mu \bar{T}) - 2e^2 A^-_\mu T \bar{T}$$

D3-Vortex

$$T(t,r) = \phi(t,r)e^{in\theta}$$

$$A_\mu^- = \frac{n}{e}\beta(t,r)\nabla_\mu\theta$$

General Metric

$$ds_{5+1}^2 = g_{\mu\nu}dx^\mu dx^\nu + g_{ij}dx^i dx^j$$

$$ds_{5+1}^2 = -dt^2 + B(t,r)^2dr^2 + H(t,r)^2(dx_1^2 + dx_2^2 + dx_3^2 \\ C^2(r,t)r^2d\theta^2$$

E.O.M for Tachyon

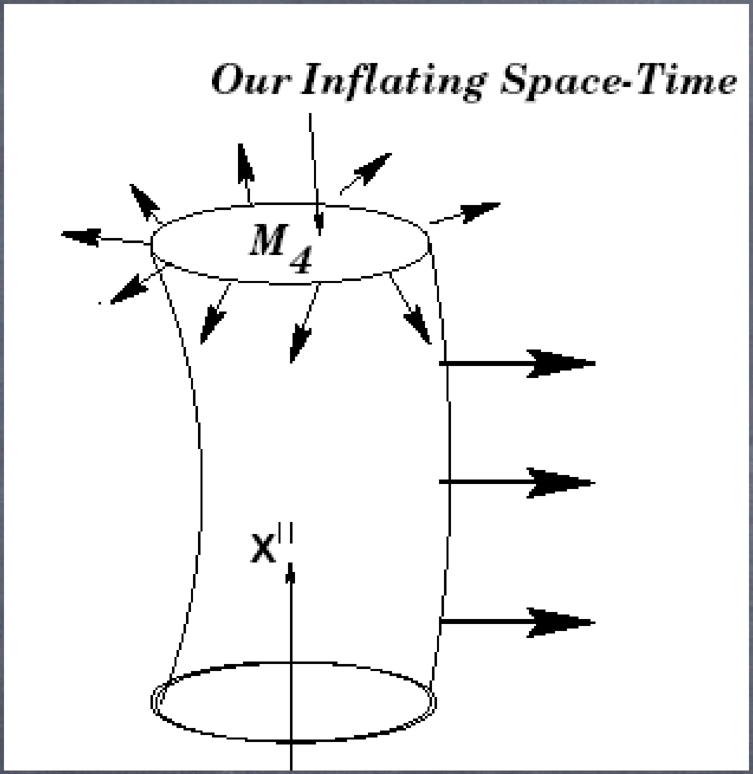
$$\ddot{T} + (\frac{\dot{B}}{B} - \frac{\dot{C}}{C} - \frac{\dot{H}}{H})\dot{T} \\ + \frac{T''}{B^2} + \frac{1}{C^2r^2}T(1-\alpha)^2 + T(T^2 - \psi^2) = 0$$

Condition for Topological Inflation!

$$\frac{\dot{B}}{B} = \frac{\dot{C}}{C} = \frac{\dot{H}}{H} = \sqrt{\frac{8\pi G}{3}V(T=0)}.$$

Solution Interpolates $dS_4 \times R_2$ <-->dS_6

The Role of Cosmic Strings



Gauge field correponds to a cosmic string
When there is a cosmic string we get 4D deSitter

But Defect is Topological, so inflation lasts ad infinitum.

Solution: Inflate from Embedded Vortex By D5-D5 in Type I

In Type I D3 is unstable because WV theory goes to

U(1)XU(1)->SU(2)XSU(2)

due to orientifold projection

The D3 is unstable-> we get an embedded defect.

When D5s annihilate the vacuum manifold

$SU(2) \times SU(2) \rightarrow SU(2)$ ⇒ $\mathcal{M} = S^3$ ⇒ $\Pi_1(\mathcal{M}) = 1$

So inflation can last for a finite time
as long as defect is stable
when it unwinds INFLATION ENDS

We can stabilize with plasma effects from the other SU(2).

Effective W.V theory

$$\mathcal{L}_{\rm eff} \;=\; -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}\bar{D}_\mu\chi D^\mu\chi + \frac{1}{2}\partial_\mu\bar{\phi}\partial^\mu\phi - V(\phi,\chi)$$

$$V(\phi,\chi) \equiv V_0(\phi,\chi) \;=\; \lambda\big(|\phi|^2 + |\chi|^2 - \eta^2\big)^2$$

In the presence of thermal bath of gauge field

$$< A_\mu >= 0\,, \quad < A_\mu A^\mu >= \kappa T^2$$

The effective potential becomes

$$V(\phi,\chi) = V_0(\phi,\chi) + g^2 \kappa T^2 |\chi|^2$$

Hence, the vacuum manifold is lifted in charged scalar field directions

Vacuum manifold of effective pot. becomes circle so embedded D3 vortex is stable until T<Tc

Stringy Graceful Exit

- D5s annihilate -> Unstable D3
- Open-string plasma stabilize D3
- Inflation begins until Tc

Text

- Vortex unwinds -> inflation ends
- If Tc is 10^-10 GeV (recombination)
- Onset of inflation 10^17 GeV->62 e-foldings

Graceful exit..

- for such small efoldings the physical wavelength of comoving scales which correspond to present day cosmological scales was > planck length
- This solves Transplanckian problem!

Discussion

- We have shown that is possible to get a consistent D-brane inflationary scenario with D-brane via. Toplogical Inflation.
- Our assumptions need to be checked (moduli stabilization)
- Cosmic strings are robust and seem to play a direct role in 6D-4D inflation.