Title: Is Brane Inflation Eternal?

Date: Nov 21, 2006 02:00 PM

URL: http://pirsa.org/06110015

Abstract: It will be shown that eternal inflation of the random walk type is generically absent in the brane inflationary scenario. Eternal inflation will be analysed both in the context of KKLMMT and the DBI inflationary models. A Langevin analysis will be employed for a more careful treatment. The DBI action, and the relativistic nature of the brane motion in DBI inflationary model, leads to new subtleties in formulating a Langevin approach.

# Is Brane Inflation Eternal?

Sash Sarangi
ISCAP Columbia University
*Xingang Chen, Henry Tye, Jiajun Xu*
hep – th / 0608082

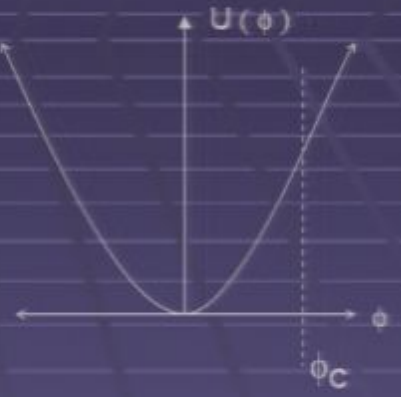
# Eternal Inflation in Field Theory

Classical Change in $\phi$ ~ $\Delta\phi \sim \dot{\phi} H^{-1}$

Quantum Change in $\phi \sim \delta\phi \sim H / 2\pi$

For $\phi > \phi_c$ Quantum Fluctuations win.

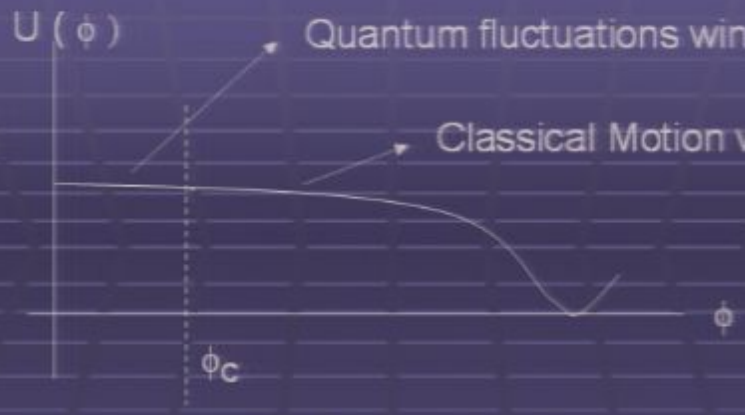
I.e., $\delta\phi > \Delta\phi$




Some Hubble patches of spacetime always stuck in regions with large inflaton quantum fluctuations!

.... Eternally Inflating Regions of the spacetime!

## Flat Potential




- Motion of inflaton is a result of a combination of a classical drift motion and quantum kicks.
- The resulting motion of the inflaton field can be described by Langevin equation , or , equivalently, by Fokker-Planck equation.
- A similar picture arises when the potential has a metastable minimum with +ve VEV, with the tunneling rate much less than the rate of expansion.

We shall distinguish between two types of Eternal Inflations:

- Eternal Inflation of the random walk type.
- Eternal Inflation of the tunneling type.

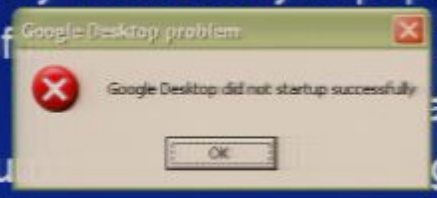
In particular, in this talk, we shall concern ourselves with details of the Eternal Inflation of the random walk type in certain Brane Inflationary Models – shall find certain distinguishing features in these string motivated models.

# Eternal Inflation and the Cosmic Landscape

- A growing belief that there is a plethora of stringy supersymmetric and non-supersymmetric vacua : courtesy String Theory.
- String theory predicts atleast $10^{500}$ vacua, if not less!
- Eternal inflation is a very natural way to populate these vacua.
- Other efficient ways of populating vacua …. Resonace tunneling.
  (Tye; Davoudiasl, Sarangi, Shiu)
- Need to understand tunneling between stringy vacua.

# Eternal Inflation and the Cosmic Landscape

- A growing belief that there is a plethora of stringy supersymmetric and non-supersymmetric vacua : courtesy String Theory.
- String theory predicts atleast $10^{500}$ vacua, if not less!
- Eternal inflation is a very natural way to populate these vacua.
- Other efficient ways of [illegible] Resonace tunneling.
- [illegible]asl, Sarangi, Shiu)
- Need to understand tu[illegible]gy vacua.



# Eternal Inflation and the Cosmic Landscape

- A growing belief that there is a plethora of stringy supersymmetric and non-supersymmetric vacua : courtesy String Theory.
- String theory predicts atleast $10^{500}$ vacua, if not less!
- Eternal inflation is a very natural way to populate these vacua.
- Other efficient ways of populating vacua …. Resonace tunneling.
  (Tye; Davoudiasl, Sarangi, Shiu)
- Need to understand tunneling between stringy vacua.

# Brane Inflation Models

- Shall focus on two models : KKLMMT & DBI (both UV (Silverstein & Tong) and IR (Chen) ).

  Apologies to the other models!

- Virtues of string motivated inflationary models:

- UV physics well understood for string theory models.
- Various models have their own distinguishing observational features.
- Observations might rule out various models.

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

r = distance between brane antibrane.

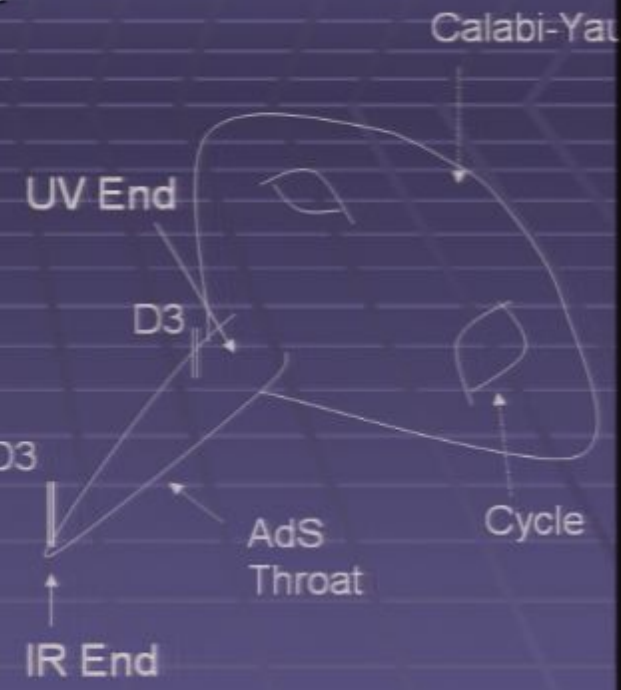
Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$

For slow roll inflation, $0 < \beta < 1/7$.




N = Background D3 brane charge sourcing the warped throat geometry.

# Conclusion (contd)

- New features in stringy inflationary models.
- Langevin analysis of DBI model : is there a superluminal problem?
- Brane dynamics intimately tied with evolution of 4D spacetime during eternal inflation.

- These indicate that a better understanding of stringy physics will aid in better understanding of eternal inflation.
- Thanks!

# DBI Model

Models with large inflaton mass, $\beta >> 1$. Brane moves relativistically.

$$S = -\int d^4x\, a^3(t) \left[ T(\phi) \left\{ 1 - v(\phi)^2 / T(\phi) \right\}^{1/2} + V(\phi) - T(\phi) \right],$$

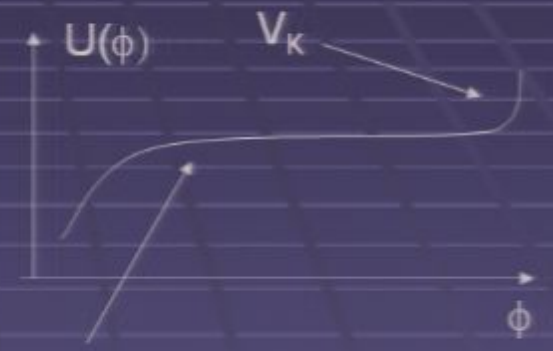
$$T(\phi) = T_3\, h(\phi)^4,$$

$$V(\phi) = \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2 \phi_A^4}{27N} \left( 1 - \frac{\phi_A^4 (\gamma+1)^2}{N\phi^4 4\gamma} \right)$$

# KKLMMT (contd)

Due to the Kahler contribution, $\Delta\phi$ is bounded from below.

Requiring $\Delta\phi_{min} < \delta\phi$ leads to a constraint on Kahler parameter $\beta$.




- $\delta_H \sim H^2 / 2\pi \dot{\phi}$ at 55 efolds ~ $10^{-5}$

Important Constraint

- $\phi_A < \phi_E < \phi_{55} < \phi_i < \phi_{edge}$ .

$\phi_{edge} = (T_3)^{1/2} R$, R = curvature radius of the AdS throat.

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

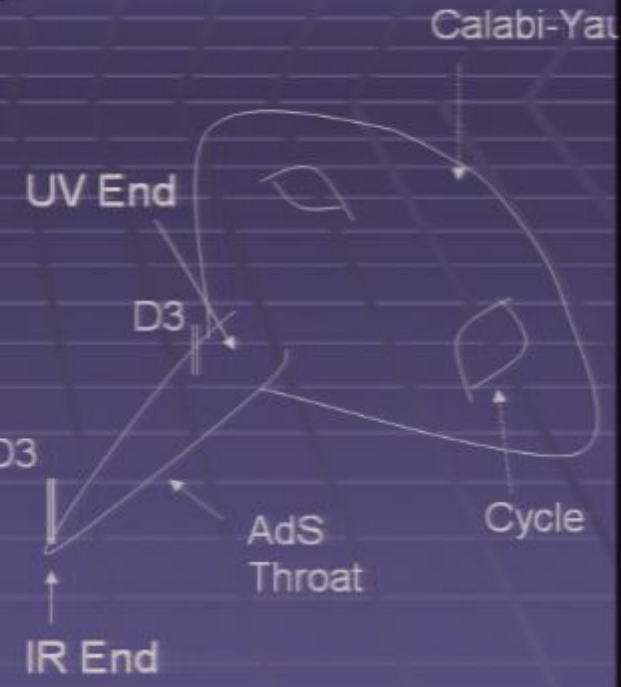
r = distance between brane antibrane.

Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$




For slow roll inflation, $0 < \beta < 1/7$.

N = Background D3 brane charge sourcing the warped throat geometry.

# KKLMMT (contd)

For eternal inflation, $\delta\phi > \Delta\phi$.

Equivalently, $\delta\phi / \Delta\phi = H^2 / 2\pi \dot{\phi} > 1$.

But... certain constraints should be satisfied :

- $\delta_H \sim H^2 / 2\pi \dot{\phi}$ at 55 efolds ~ $10^{-5}$
- $\phi_A < \phi_E < \phi_{55} < \phi_i < \phi_{edge}$.

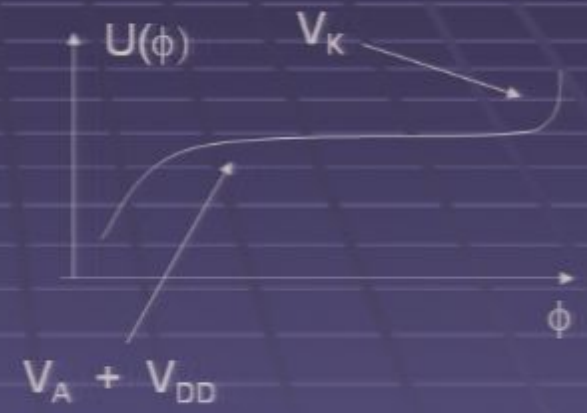
Important Constraint

$\phi_{edge} = (T_3)^{1/2} R$, R = curvature radius of the AdS throat.

# KKLMMT (contd)

Due to the Kahler contribution, $\Delta\phi$ is bounded from below.

Requiring $\Delta\phi_{min} < \delta\phi$ leads to a constraint on Kahler parameter $\beta$.




To have eternal inflation, $\beta < 10^{-8}$.
Fine tuning! Moduli stabilization generically gives order 1 $\beta$.

However, there is an even stronger constraint that rules out eternal inflation of this random walk type.

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

r = distance between brane antibrane.

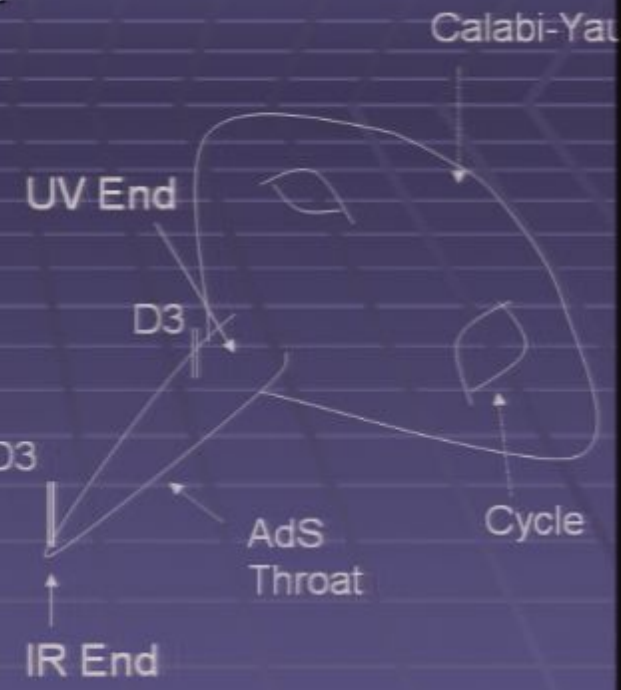
Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$

For slow roll inflation, $0 < \beta < 1/7$.




N = Background D3 brane charge sourcing the warped throat geometry.

# KKLMMT (contd)

For eternal inflation, $\delta\phi > \Delta\phi$.

Equivalently, $\delta\phi / \Delta\phi = H^2 / 2\pi \dot{\phi} > 1$.

But... certain constraints should be satisfied :

- $\delta_H \sim H^2 / 2\pi \dot{\phi}$ at 55 efolds ~ $10^{-5}$
- $\phi_A < \phi_E < \phi_{55} < \phi_i < \phi_{edge}$.

Important Constraint

$\phi_{edge} = (T_3)^{1/2} R$, R = curvature radius of the AdS throat.

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

r = distance between brane antibrane.

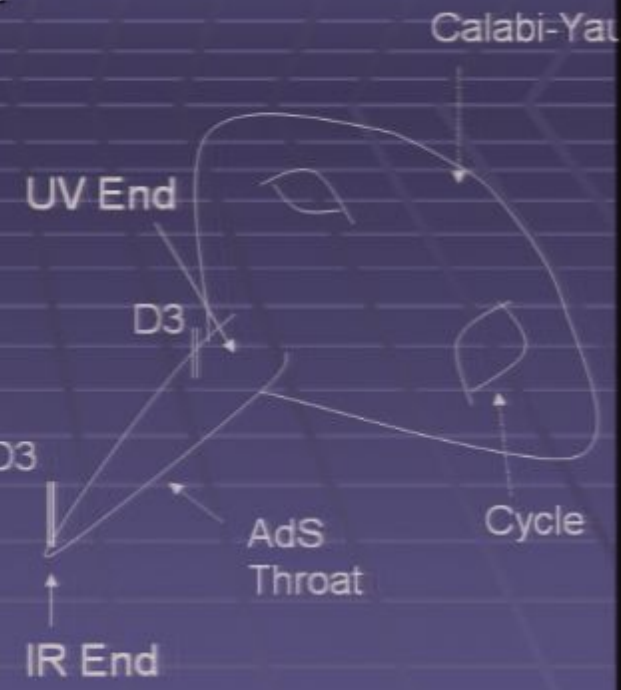
Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$

For slow roll inflation, $0 < \beta < 1/7$.




N = Background D3 brane charge sourcing the warped throat geometry.

# KKLMMT (contd)

For eternal inflation, $\delta\phi > \Delta\phi$.

Equivalently, $\delta\phi / \Delta\phi = H^2 / 2\pi \dot{\phi} > 1$.

But... certain constraints should be satisfied :

- $\delta_H \sim H^2 / 2\pi \dot{\phi}$ at 55 efolds ~ $10^{-5}$
- $\phi_A < \phi_E < \phi_{55} < \phi_i < \phi_{edge}$.

Important Constraint

$\phi_{edge} = (T_3)^{1/2} R$, R = curvature radius of the AdS throat.

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

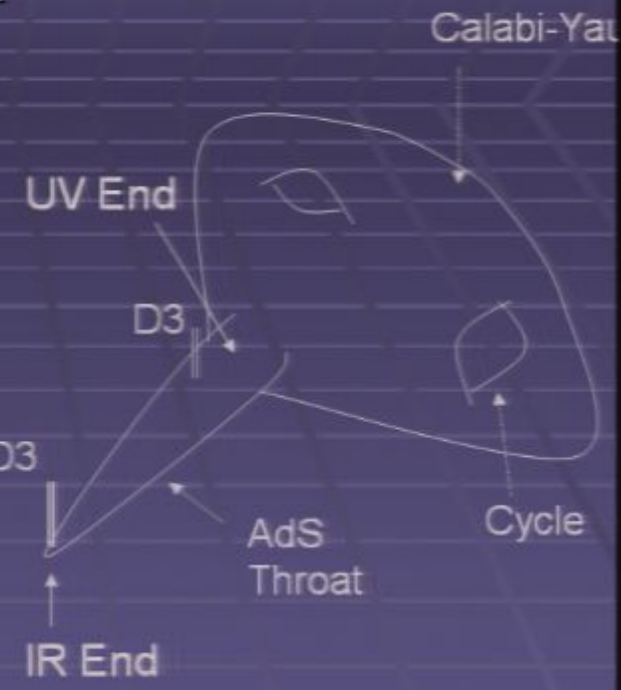
r = distance between brane antibrane.

Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$




For slow roll inflation, $0 < \beta < 1/7$.

N = Background D3 brane charge sourcing the warped throat geometry.

# Brane Inflation Models

- Shall focus on two models : KKLMMT & DBI (both UV (Silverstein & Tong) and IR (Chen) ).

  Apologies to the other models!

- Virtues of string motivated inflationary models:

- UV physics well understood for string theory models.
- Various models have their own distinguishing observational features.
- Observations might rule out various models.

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

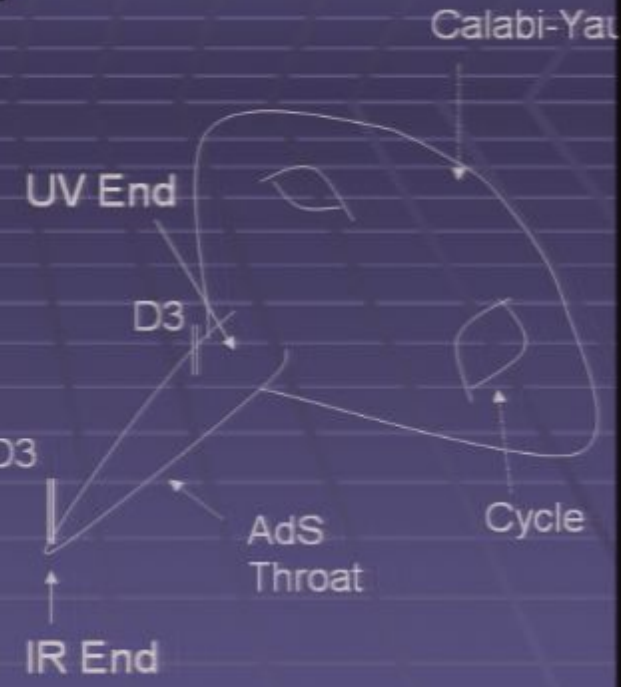
r = distance between brane antibrane.

Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$




For slow roll inflation, $0 < \beta < 1/7$.

N = Background D3 brane charge sourcing the warped throat geometry.

# KKLMMT (contd)

For eternal inflation, $\delta\phi > \Delta\phi$.

Equivalently, $\delta\phi / \Delta\phi = H^2 / 2\pi \dot{\phi} > 1$.

But... certain constraints should be satisfied :

- $\delta_H \sim H^2 / 2\pi \dot{\phi}$ at 55 efolds ~ $10^{-5}$
- $\phi_A < \phi_E < \phi_{55} < \phi_i < \phi_{edge}$.

Important Constraint

$\phi_{edge} = (T_3)^{1/2} R$, R = curvature radius of the AdS throat.

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

r = distance between brane antibrane.

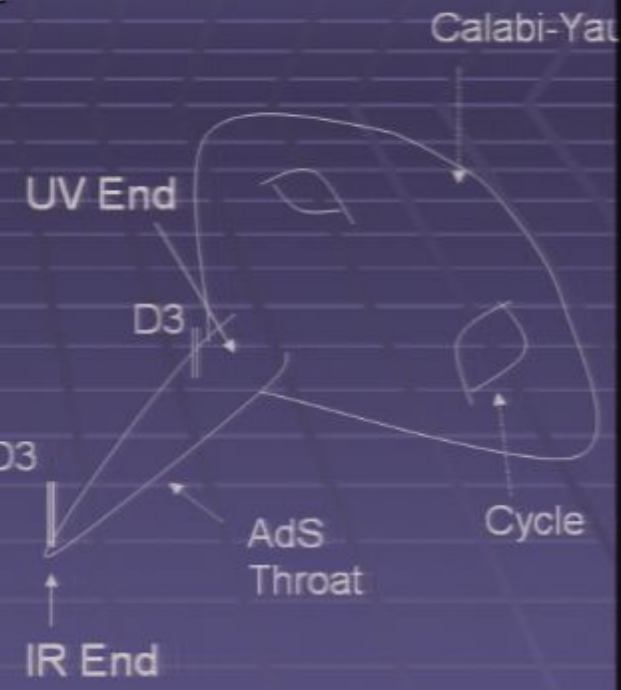
Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$

For slow roll inflation, $0 < \beta < 1/7$.




N = Background D3 brane charge sourcing the warped throat geometry.

# KKLMMT (contd)

For eternal inflation, $\delta\phi > \Delta\phi$.

Equivalently, $\delta\phi / \Delta\phi = H^2 / 2\pi \dot{\phi} > 1$.

But... certain constraints should be satisfied :

- $\delta_H \sim H^2 / 2\pi \dot{\phi}$ at 55 efolds ~ $10^{-5}$
- $\phi_A < \phi_E < \phi_{55} < \phi_i < \phi_{edge}$.

Important Constraint

$\phi_{edge} = (T_3)^{1/2} R$, R = curvature radius of the AdS throat.

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

r = distance between brane antibrane.

Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$


For slow roll inflation, $0 < \beta < 1/7$.

N = Background D3 brane charge sourcing the warped throat geometry.

# KKLMMT (contd)

For eternal inflation, $\delta\phi > \Delta\phi$.

Equivalently, $\delta\phi / \Delta\phi = H^2 / 2\pi \dot{\phi} > 1$.

But... certain constraints should be satisfied :

- $\delta_H \sim H^2 / 2\pi \dot{\phi}$ at 55 efolds ~ $10^{-5}$
- $\phi_A < \phi_E < \phi_{55} < \phi_i < \phi_{edge}$.

Important Constraint

$\phi_{edge} = (T_3)^{1/2} R$, R = curvature radius of the AdS throat.

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

r = distance between brane antibrane.

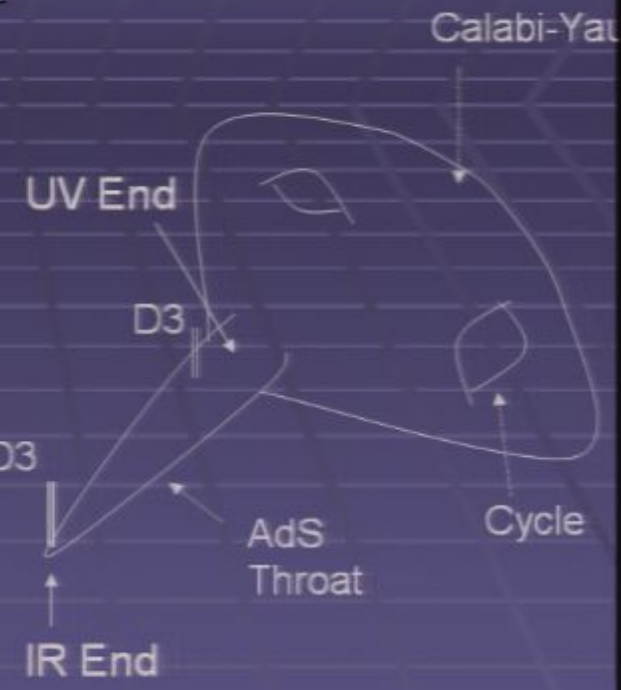
Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

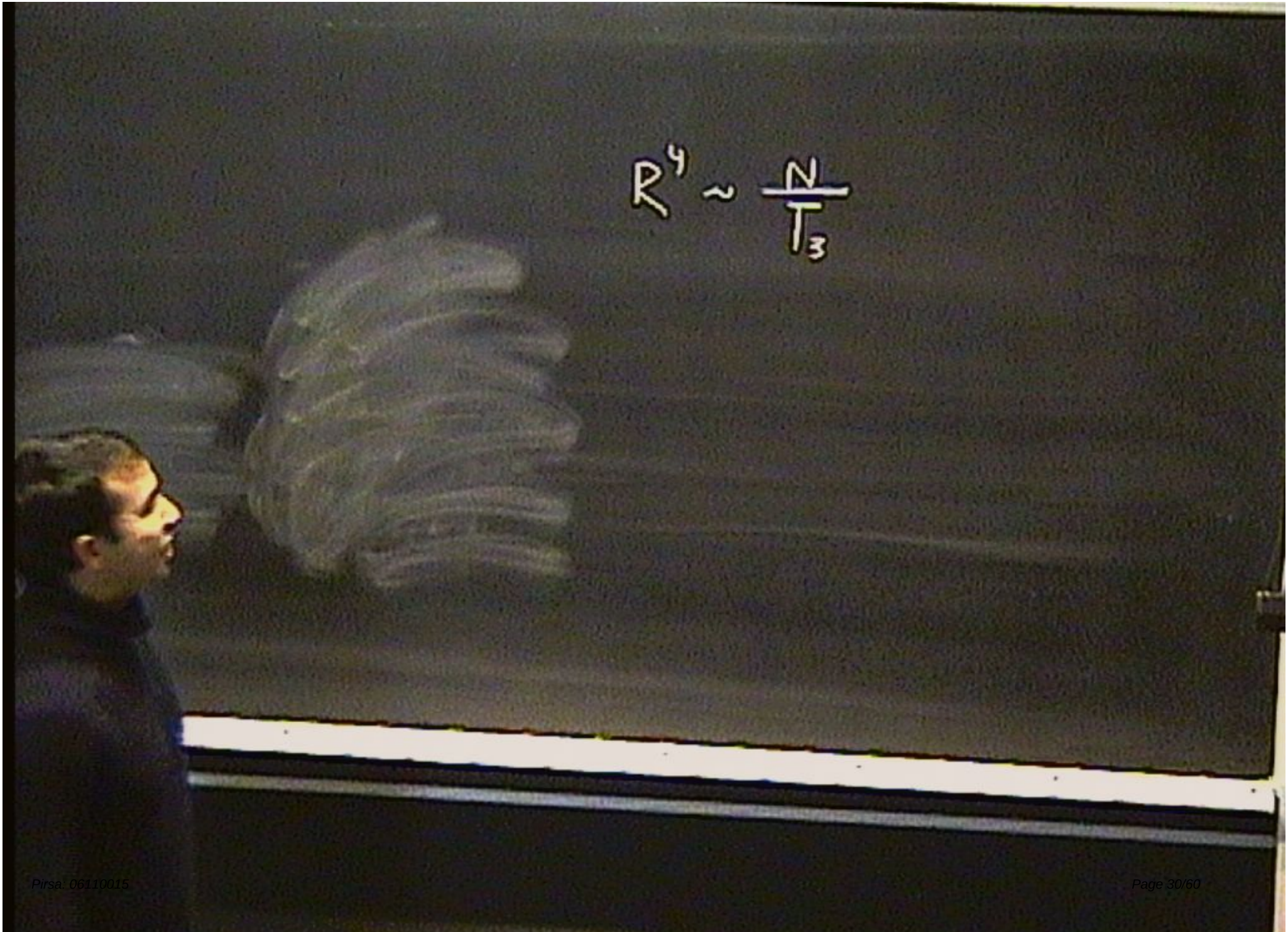
$V(\phi) = V_K + V_A + V_{D\bar{D}}$

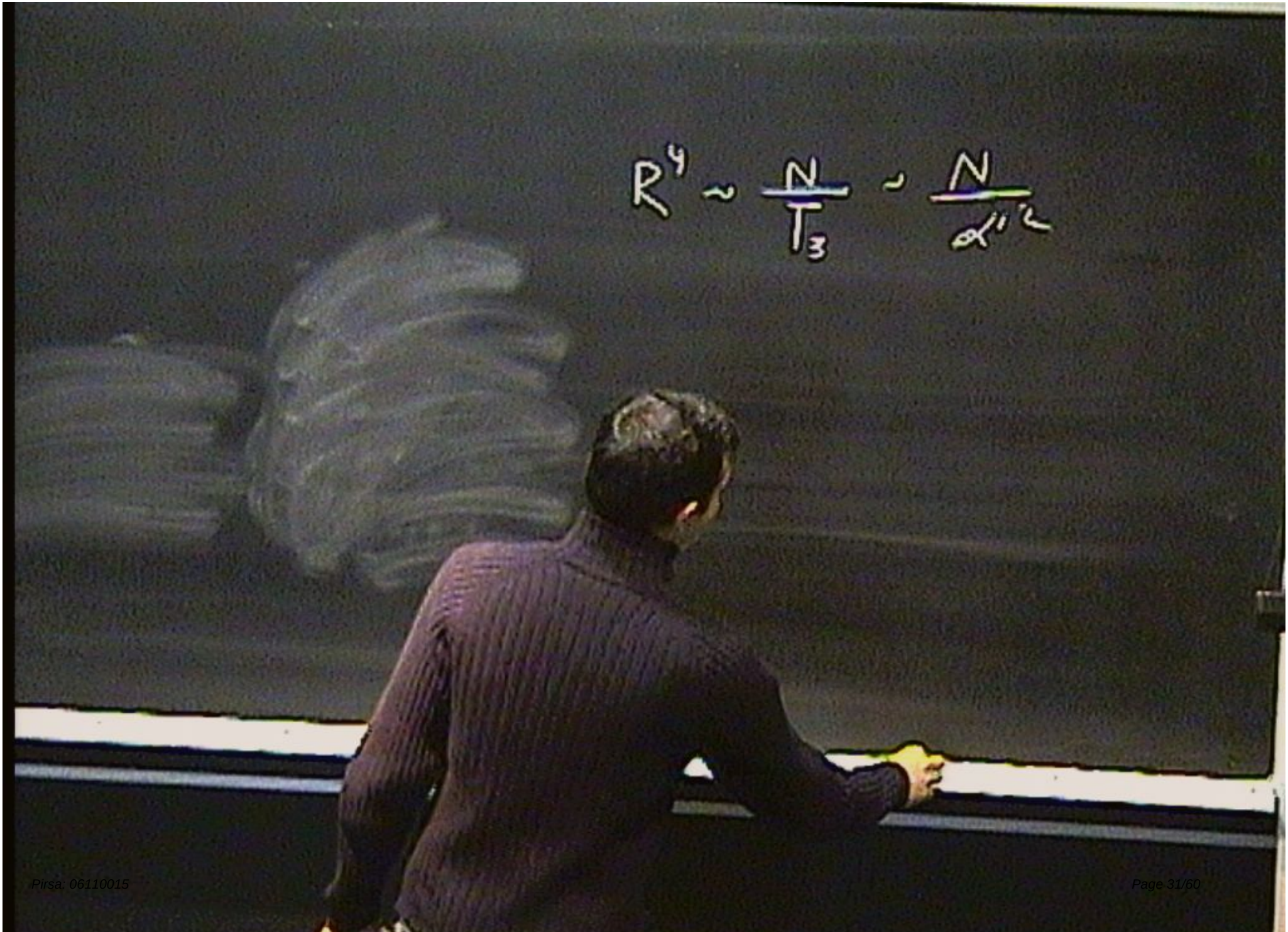
$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$

For slow roll inflation, $0 < \beta < 1/7$.




N = Background D3 brane charge sourcing the warped throat geometry.


$R^4 \sim \frac{N}{T_3}$


$R^4 \sim \frac{N}{T_3} \sim \frac{N}{\alpha'^2}$

# KKLMMT (contd)

For eternal inflation, $\delta\phi > \Delta\phi$.

Equivalently, $\delta\phi / \Delta\phi = H^2 / 2\pi \dot{\phi} > 1$.

But... certain constraints should be satisfied :

- $\delta_H \sim H^2 / 2\pi \dot{\phi}$ at 55 efolds ~ $10^{-5}$
- $\phi_A < \phi_E < \phi_{55} < \phi_i < \phi_{edge}$.

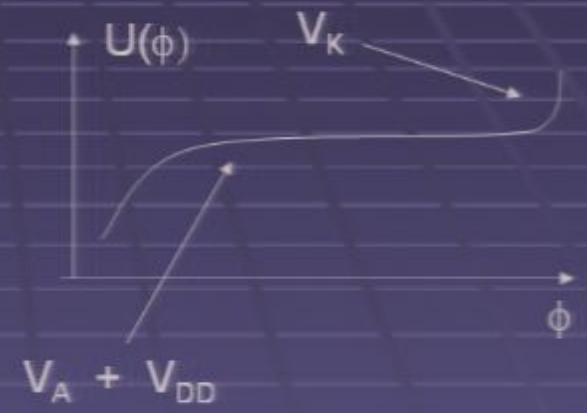
Important Constraint

$\phi_{edge} = (T_3)^{1/2} R$, R = curvature radius of the AdS throat.

# KKLMMT (contd)

Due to the Kahler contribution, $\Delta\phi$ is bounded from below.

Requiring $\Delta\phi_{min} < \delta\phi$ leads to a constraint on Kahler parameter $\beta$.



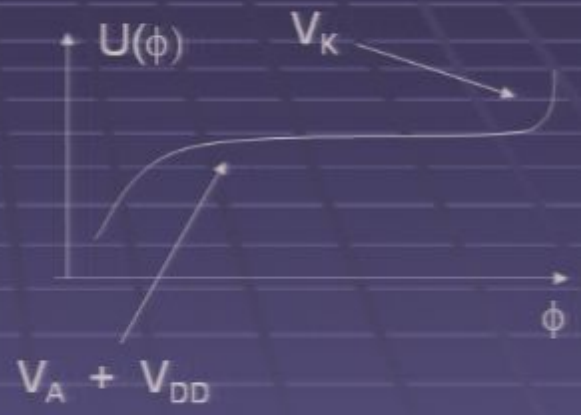

To have eternal inflation, $\beta < 10^{-8}$.
Fine tuning! Moduli stabilization generically gives order 1 $\beta$.

However, there is an even stronger constraint that rules out eternal inflation of this random walk type.

# KKLMMT (contd)

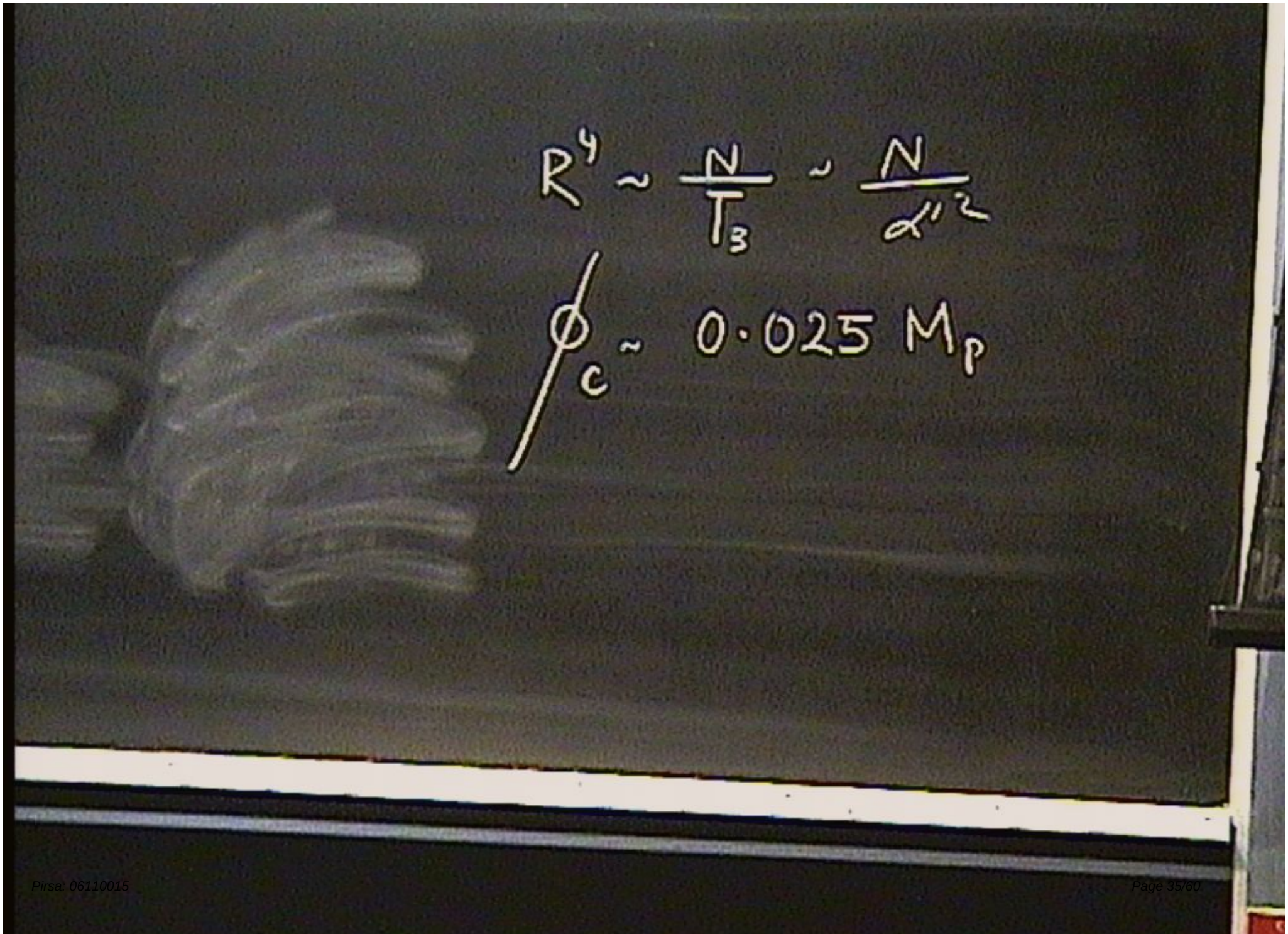
Due to the Kahler contribution, $\Delta\phi$ is bounded from below.

Requiring $\Delta\phi_{min} < \delta\phi$ leads to a constraint on Kahler parameter $\beta$.




To have eternal inflation, $\beta < 10^{-8}$.
Fine tuning! Moduli stabilization generically gives order 1 $\beta$.

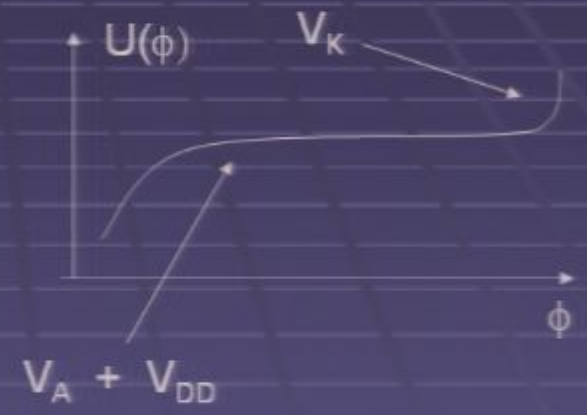
However, there is an even stronger constraint that rules out eternal inflation of this random walk type.


$R^4 \sim \frac{N}{T_3} \sim \frac{N}{\alpha'^2}$
$\phi_c \sim 0.025\, M_p$

# KKLMMT (contd)

Due to the Kahler contribution, $\Delta\phi$ is bounded from below.

Requiring $\Delta\phi_{min} < \delta\phi$ leads to a constraint on Kahler parameter $\beta$.



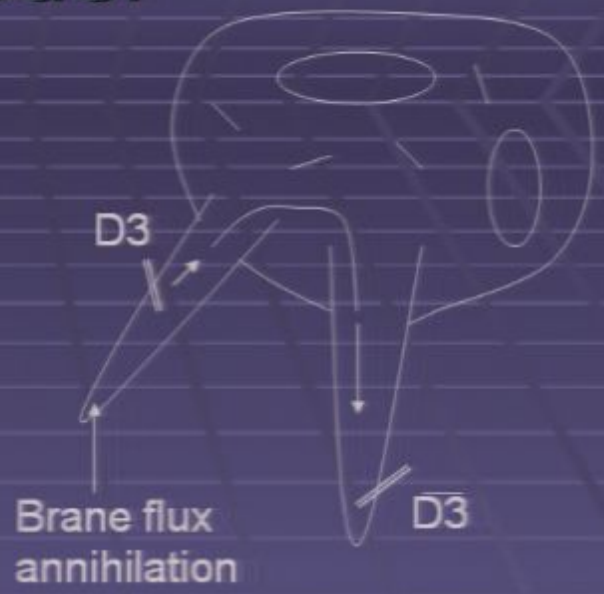

To have eternal inflation, $\beta < 10^{-8}$.
Fine tuning! Moduli stabilization generically gives order 1 $\beta$.

However, there is an even stronger constraint that rules out eternal inflation of this random walk type.

# DBI IR Model

The D3 brane originates at the IR tip of throat B due to brane-flux annihilation.

D3 brane takes its time to travel up to anti-D3 brane in throat A, meanwhile the anti D3 brane inflates due to its tension (exponential inflation).




DBI speed limit important as the upper speed bound prevents the D3 brane from finding and annihilating the anti-D3 brane too soon (i.e. before 55 efolds).

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

r = distance between brane antibrane.

Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$

For slow roll inflation, $0 < \beta < 1/7$.


N = Background D3 brane charge sourcing the warped throat geometry.

$M_p^2 = M_5^8 L^6$

$R^4 \sim \frac{N}{T_3} \sim \frac{N}{\alpha'^2}$

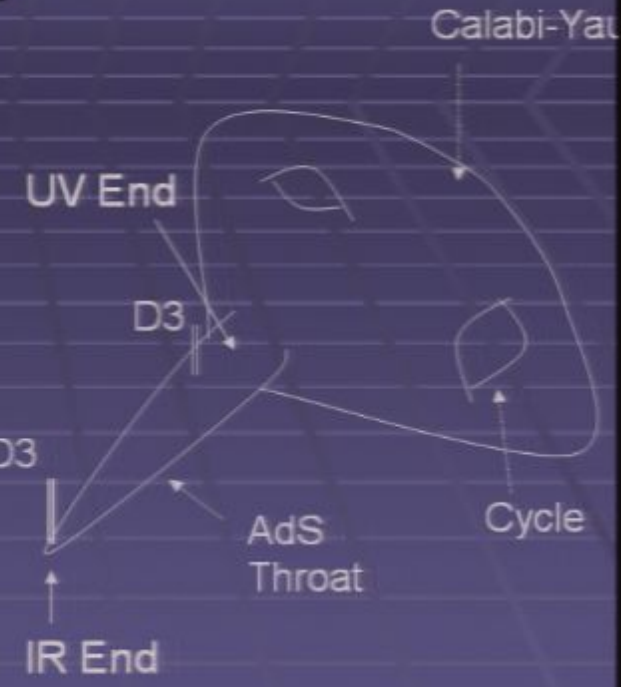
$\phi_c \sim 0.025\, M_p$

# KKLMMT

AdS metric (throat geometry):
$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,
r = distance between brane antibrane.
Inflaton $= \phi = (T_3)^{1/2} r$

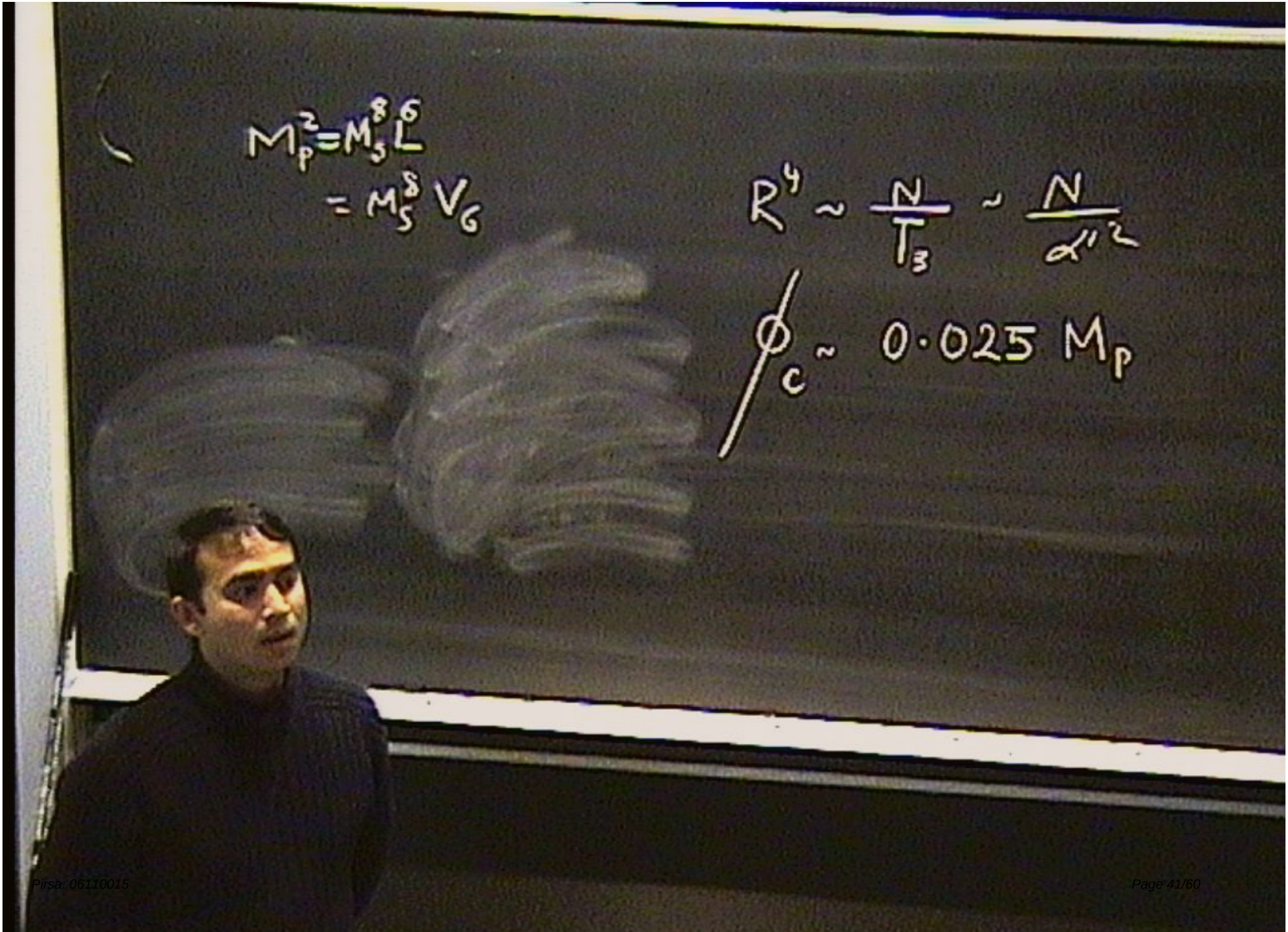
Inflaton Potential :
$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$




For slow roll inflation, $0 < \beta < 1/7$.

N = Background D3 brane charge sourcing the warped throat geometry.


$M_p^2 = M_5^8 L^6$
$= M_5^8 V_6$
$R^4 \sim \frac{N}{T_3} \sim \frac{N}{\alpha'^2}$
$\phi_c \sim 0.025\, M_p$

# KKLMMT

AdS metric (throat geometry):

$ds^2 = h(r)^2 (-dt^2 + a(t)^2 \vec{dx}^2) + h(r)^{-2} dr^2$ ,

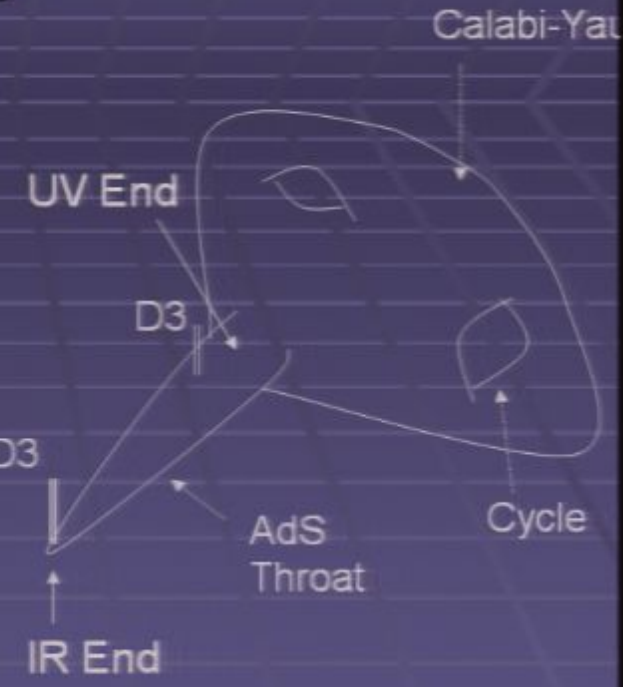
r = distance between brane antibrane.

Inflaton $= \phi = (T_3)^{1/2} r$

Inflaton Potential :

$V(\phi) = V_K + V_A + V_{D\bar{D}}$

$$= \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2}{27} \frac{\phi_A^4}{N} \left(1 - \frac{\phi_A^4}{N\phi^4}\right)$$




For slow roll inflation, $0 < \beta < 1/7$.

N = Background D3 brane charge sourcing the warped throat geometry.

# DBI Model

Models with large inflaton mass, $\beta >> 1$. Brane moves relativistically.

$$S = -\int d^4x\, a^3(t) \left[ T(\phi) \left\{ 1 - v(\phi)^2 / T(\phi) \right\}^{1/2} + V(\phi) - T(\phi) \right],$$

$$T(\phi) = T_3\, h(\phi)^4,$$

$$V(\phi) = \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2 \phi_A^4}{27N} \left( 1 - \frac{\phi_A^4 (\gamma+1)^2}{N\phi^4 4\gamma} \right)$$

# DBI Model

Models with large inflaton mass, $\beta >> 1$. Brane moves relativistically.

$$S = -\int d^4x\, a^3(t) \left[ T(\phi) \left\{ 1 - v(\phi)^2 / T(\phi) \right\}^{1/2} + V(\phi) - T(\phi) \right],$$

$$T(\phi) = T_3\, h(\phi)^4,$$

$$V(\phi) = \tfrac{1}{2} \beta H^2 \phi^2 + \frac{64\pi^2 \phi_A^4}{27N} \left( 1 - \frac{\phi_A^4 (\gamma+1)^2}{N \phi^4 4\gamma} \right)$$

# DBI UV Model

Using the Hamilton-Jacobi approach, the equations of motion of the inflaton field are :

$V(\phi) = 3 M_P^2 H(\phi)^2 - T_3 h(\phi)^4(\gamma(\phi) - 1)$,

$\gamma(\phi) = [1 + 4 M_P^4 T_3^{-1} h(\phi)^{-4} H'(\phi)^2]^{1/2}$,

$$\dot{\phi} = \frac{-2 M_P^2 H'(\phi)}{\gamma(\phi)}$$

For ultrarelativistic motion, $\beta >> 1$, and one gets the following behavior : $H(\phi) \sim \phi$, $\dot{\phi} \sim -\phi^2$, $a(t) \sim t^{1/\varepsilon}$ (powerlaw inflation).

$\delta_H \sim H^2/2\pi\dot{\phi}$ = independent of $\phi$ (fixed at $10^{-5}$) → No Eternal Inflation

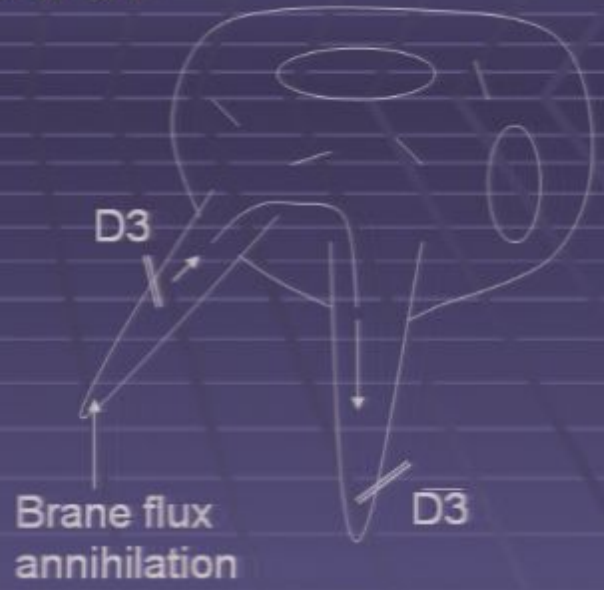
# Intermediate Case

- For $\beta \ll 1$, one gets the KKLMMT scenario. Eternal inflation precluded by the requirement that the throat size should be less than the bulk size.
- For $\beta \gg 1$, gets the DBI scenario. $\delta_H$ fixed at $10^{-5}$. Quantum fluctuations too small to lead to eternal inflation.
- For $\beta \sim 1$, the brane begins in the KKLMMT phase, and evolves to a DBI phase before the end of the inflation. Eternal inflation again precluded by above arguments for KKLMMT and DBI models.

# DBI IR Model

The D3 brane originates at the IR tip of throat B due to brane-flux annihilation.

D3 brane takes its time to travel up to anti-D3 brane in throat A, meanwhile the anti D3 brane inflates due to its tension (exponential inflation).




DBI speed limit important as the upper speed bound prevents the D3 brane from finding and annihilating the anti-D3 brane too soon (i.e. before 55 efolds).

# DBI IR Model (contd)

In this scenario, the spectral index is red. Naively, eternal inflation of random walk type might be possible.

Two relevant scales : $\gamma H$ and $T_3^{1/4} h(\phi)$ .

Hubble at the D3.

String scale at The D3.

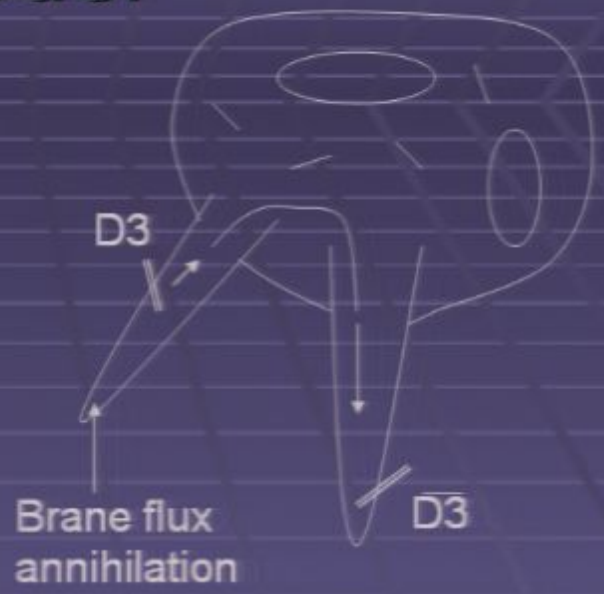
To have a field theory description, the string scale should exceed The Hubble scale.

However, right at the onset of eternal inflation, the Hubble scale exceeds the string scale! No inflation!

# DBI IR Model

The D3 brane originates at the IR tip of throat B due to brane-flux annihilation.

D3 brane takes its time to travel up to anti-D3 brane in throat A, meanwhile the anti D3 brane inflates due to its tension (exponential inflation).




DBI speed limit important as the upper speed bound prevents the D3 brane from finding and annihilating the anti-D3 brane too soon (i.e. before 55 efolds).

# DBI IR Model (contd)

In this scenario, the spectral index is red. Naively, eternal inflation of random walk type might be possible.

Two relevant scales : $\gamma H$ and $T_3^{1/4} h(\phi)$ .

Hubble at the D3.

String scale at The D3.

To have a field theory description, the string scale should exceed The Hubble scale.

However, right at the onset of eternal inflation, the Hubble scale exceeds the string scale! No inflation!

# Possibility of Eternal Inflation in Brane Inflation

- In KKLMMT type scenario, it might be possible to have more structure to the potential ( a flat potential extending into the bulk, e.g.) that supports eternal inflation of the random walk type.

- Multithroat brane inflation : Antibranes annihilate with RR flux at the IR tip to produce many mobile branes (which can lead to either KKLMMT or DBI scenarios).

  Brane-flux annihilation is a first order phase transition.

  Eternal inflation proceeds via bubble nucleation.

# DBI IR Model (contd)

In this scenario, the spectral index is red. Naively, eternal inflation of random walk type might be possible.

Two relevant scales : $\gamma H$ and $T_3^{1/4} h(\phi)$ .

Hubble at the D3.

String scale at The D3.

To have a field theory description, the string scale should exceed The Hubble scale.

However, right at the onset of eternal inflation, the Hubble scale exceeds the string scale! No inflation!

# Possibility of Eternal Inflation in Brane Inflation

- In KKLMMT type scenario, it might be possible to have more structure to the potential ( a flat potential extending into the bulk, e.g.) that supports eternal inflation of the random walk type.

- Multithroat brane inflation : Antibranes annihilate with RR flux at the IR tip to produce many mobile branes (which can lead to either KKLMMT or DBI scenarios).

  Brane-flux annihilation is a first order phase transition.

  Eternal inflation proceeds via bubble nucleation.

# Langevin Analysis of DBI Scenario.

- Inflaton classical motion is the classical motion of the brane, and the inflaton quantum fluctuations correspond to the fluctuations of the brane position.
- In DBI set up, the brane moves relativistically.
- Does the usual eternal inflation analysis stay valid?
- Is there a superluminal problem? Do the dS fluctuations add to the already highly relativistic brane motion?
- Does the Langevin analysis need modifications?
- A relativistic Langevin formulation?
- Perhaps yes, perhaps not .... Need more investigation.

$M_p^2 = M_s^8 L^6$

$= M_s^8 V_6$

$V \sim c$

$R^4 \sim \frac{N}{T_3} \sim \frac{N}{\alpha'^2}$

$\phi_c \sim 0.025\, M_p$

# Langevin Analysis of DBI Scenario.

- Inflaton classical motion is the classical motion of the brane, and the inflaton quantum fluctuations correspond to the fluctuations of the brane position.
- In DBI set up, the brane moves relativistically.
- Does the usual eternal inflation analysis stay valid?
- Is there a superluminal problem? Do the dS fluctuations add to the already highly relativistic brane motion?
- Does the Langevin analysis need modifications?
- A relativistic Langevin formulation?
- Perhaps yes, perhaps not .... Need more investigation.

# Langevin Analysis of DBI Scenario.

- Inflaton classical motion is the classical motion of the brane, and the inflaton quantum fluctuations correspond to the fluctuations of the brane position.
- In DBI set up, the brane moves relativistically.
- Does the usual eternal inflation analysis stay valid?
- Is there a superluminal problem? Do the dS fluctuations add to the already highly relativistic brane motion?
- Does the Langevin analysis need modifications?
- A relativistic Langevin formulation?
- Perhaps yes, perhaps not .... Need more investigation.

# Eternal Inflation and Brane Fluctuations

What happens to the brane motion as it gets crumpled ? A fractal brane?

DBI description should break down as the second derivatives of $\phi$ become non-vanishing.

Stringy effects become important.

# Conclusion

- In certain brane inflation models, eternal inflation of random walk type is either highly constrained or precluded.
- Eternal inflation through tunneling will still take place (how to describe tunneling between very different vacua?).
- If future observations select a particular brane inflation model, one might be able to rule out eternal inflation of the random walk type.

# Conclusion (contd)

- New features in stringy inflationary models.
- Langevin analysis of DBI model : is there a superluminal problem?
- Brane dynamics intimately tied with evolution of 4D spacetime during eternal inflation.

- These indicate that a better understanding of stringy physics will aid in better understanding of eternal inflation.
- Thanks!