

Brane Inflation and (P)reheating

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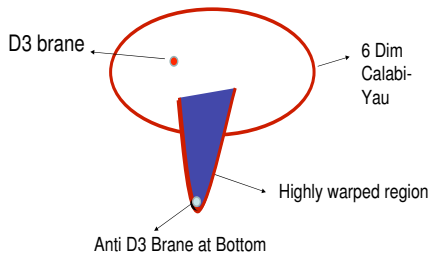
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Brane Inflation in String Theory

- Summary of present status of **Inflation** a la **KKLMMT**
- Type IIB String theory compactified on CY-3 fold, with fluxes
- All moduli stabilized by **KKLT** mechanism
- Internal geometry has a throat, anti-D3 brane placed at the tip
- D3-brane is placed in the compact CY

KKLMMT framework



The KKLMMT Model

Planck Sensitivity

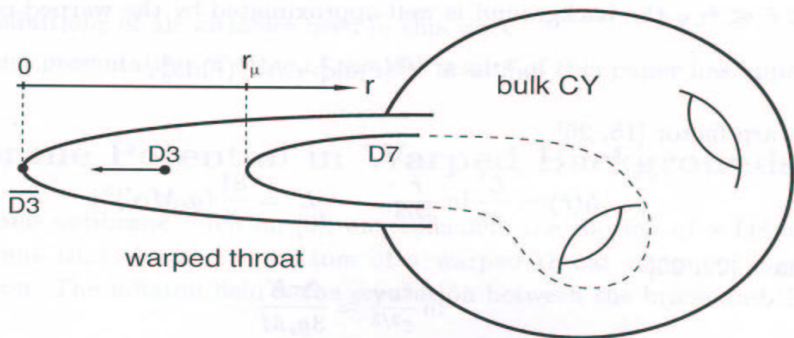
- Inflation is sensitive to Planck scale Physics: Planck-suppressed operators generically make critical contributions to the dynamics.
- This provides remarkable opportunity to probe aspects of ultraviolet completion of gravity (**String Theory**) through observations. To make meaningful use of this connection we should
- compute Planck-suppressed contributions to inflation action in String Theory
- look for what kind of inflation is natural in String Theory
- It turns out that for small inflaton excursions, $\Delta\phi \leq M_{Pl}$ one must control corrections with \mathcal{O}_Δ with $\Delta \leq 6$ and for large field excursions $\Delta\phi \gg M_{Pl}$ we need to control infinite series of corrections with arbitrary large Δ .

- We should carefully examine Planck-suppressed contributions to inflaton potential in String theory.
- Contributions to inflaton potential arise from integrating out massive fields. In String Theory massive fields include the stabilized moduli.
- Potential for inflaton by KKLMNT:

$$V(\phi) = D \left[1 + \frac{1}{3} \left(\frac{\phi}{M_{pl}} \right)^2 - \frac{3D}{16\pi^2\phi^4} \right]$$

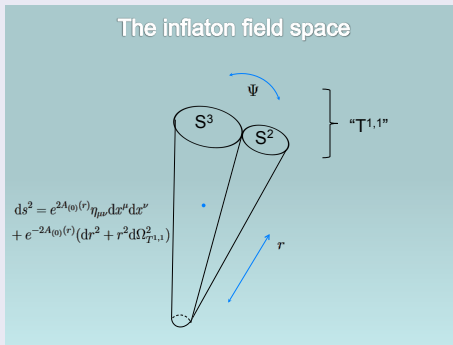
- $D \sim 2a_0^4 T_3$.
- Slow roll parameter η comes out to be $2/3$!

- New proposal like forcing the D3- brane to move deep inside the throat (BDKMS 2007; SP, Tsujikawa, Sami 2007).



- Forcing the D3-brane inside and dragging the D7-brane inside puts severe constraints
- Leads to a potential involving two fields (inflaton and **volume modulus**)
- Effective single field model (**fixing the volume modulus at instantaneous minimum**) yields only eight e-folds.
- Two fields inflation analysis, with dynamics stabilizing the volume modulus, was a better bet.
- Everything was fine but the tilt of the spectrum and COBE normalization for the amplitude could not be satisfied simultaneously.
- However, Cline and Hoi, with extra throats, claim the model to work.

Proposal of BDKKM 2008, 2009, 2010, compactification effects in UV



- Compute the Inflaton potential taking the contributions from Coulomb Interaction, curvature couplings, couplings to moduli in Kahler and in Super potential.

- **Idea:** Classify all possible corrections starting with infinite throat geometry and study all perturbations in UV consistent with sugra eqn of motion. Check which of these affect inflaton potential. Then classify possible corrections that can appear in true compactification.
- **Tool:** Ads/CFT allows to write arbitrary contribution to Inflaton Lagrangian, encompassing all above effects, in terms of supergravity contributions.
- From this most general solution one can read off the potential taking the help of matching between sugra G-flux modes and CFT operators **cf Ceresole, D'Agata, D'Auria 1999)**

Result

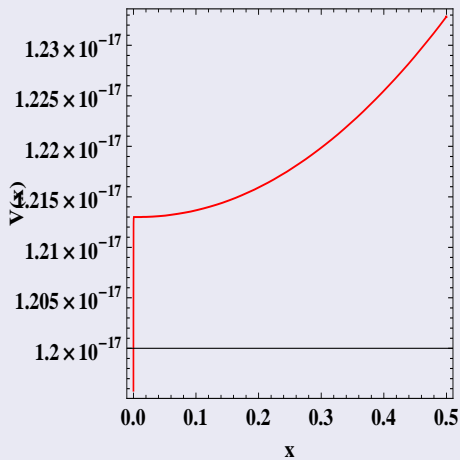
- The potential

$$V(\phi, \Psi) = D\left[1 + \frac{1}{3} \left(\frac{\phi}{M_{pl}}\right)^2 - \frac{3D}{16\pi^2\phi^4} + \sum_i b_i \phi^{\Delta_i} h_i(\Psi)\right]$$

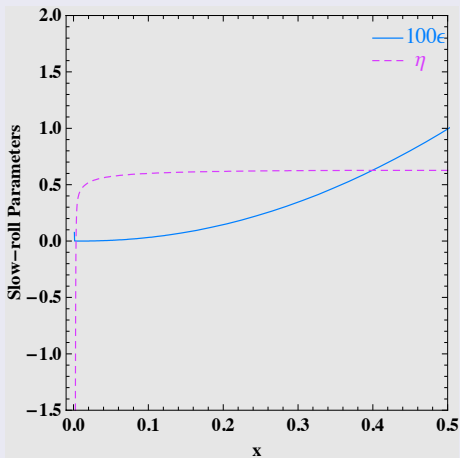
- $\Delta_i = 1, 3/2, 5/2, \dots$ **724 terms for $\Delta < 4!$**
- Inflation dynamics involves evolution of all 6 fields
- Single field Inflation by taking Ψ arbitrary constants **Ali, Chingagbam, Panda, Sami 2008; Ali, Deshamukhya, Panda, Sami 2010**
- Since small field inflation, kept only few terms.
- Keeping the extra term $C_{3/2}\phi^{3/2}$ turns out to satisfy all the ingredients we need to satisfy observational constraints but for highly fine tuned value of $C_{3/2}$ and initial value of inflaton.

- If we keep terms upto $\Delta = 5/2$, fine tuning reduces by order of three and we can have a range of values for each of the parameters to yield a model satisfying all the observational constraints.

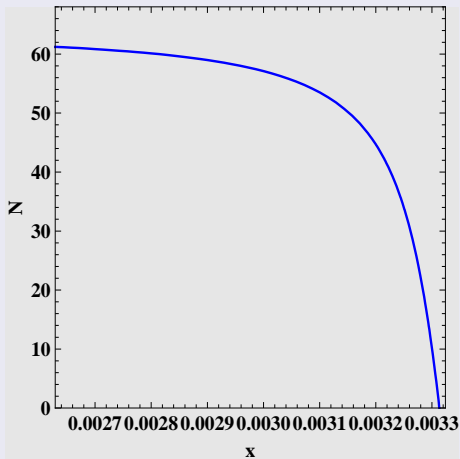
Potential



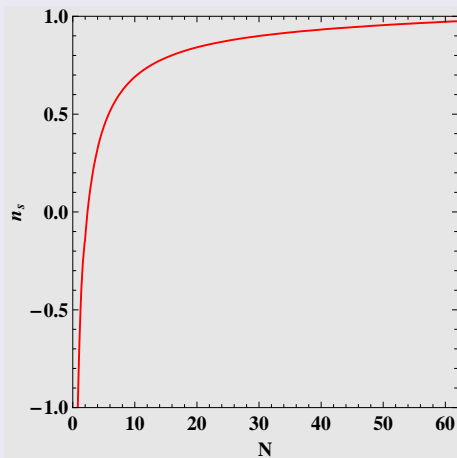
Slow roll parameters



e-folding



spectral index



Reheating Panda, Sami and Thongkool 2010

- In standard reheating the field approaches and inevitably overshoots the minimum, it oscillates around the minimum on a time scale short compared to Hubble time.
- The field decays to other lighter fields (to which it is coupled), dampening the oscillations.
- As the decay product thermalize, the universe is reheated. The highly non-adiabatic reheating process increases the entropy within the inflating patch by many orders of magnitude.
- Thus "Inflation" should include Reheating.

- In present case, the effective potential belongs to the class of non-oscillatory models .
- Conventional reheating does not work, try **Instant preheating**
- Inflaton interacts with another scalar field which has a Yukawa type interaction with a Fermi field:
- $L_{int} = -1/2g^2(\phi - v)^2\chi^2 - h\bar{\psi}\psi\chi$, $v = \phi_{end}$.
- Preheating commences when effective mass $m_\chi = g|\phi - v|$ starts changing non-adiabatically:
- $|\dot{m}_\chi| \gtrsim m_\chi^2$ or $|\dot{\phi}| \gtrsim g(\phi - v)^2$
- **Condition for particle production satisfied if**
- $|\phi| \lesssim |\phi_{prod}| = v - \sqrt{\frac{|\dot{\phi}|}{g}}$

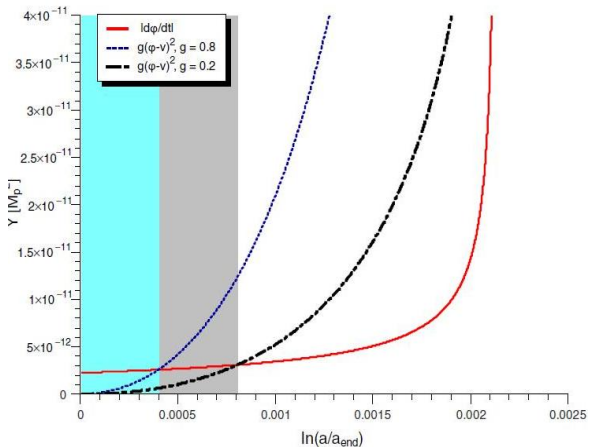


Figure: Post-inflationary evolution of $g(\phi - v)^2$ and $|\dot{\phi}|$, Violation of adiabatic condition takes place in the shaded region.

- We find for generic values of g preheating takes place instantaneously.
- Lower limit on g is fixed such that non-adiabatic process ends before we reach singularity.
- Momentum of particles is estimated by $k_p \sim \delta t^{-1} \sim \frac{|\dot{\phi}|}{|\phi|}$
- Occupation number (finite value during δt) :

$$N_k \sim \exp(-\pi k^2/k_p^2)$$
- Number density : $n_\chi \simeq k_p^3$ which leads to

$$\rho_\chi = m_\chi n_\chi \left(\frac{a_{end}}{a}\right)^3.$$

- Assuming that the energy of χ particles, produced after inflation, is thermalized instantaneously giving rise to radiation energy density:
- $\rho_\chi = \rho_r \Rightarrow$
- Reheating temperature T : $10^{10} \text{ GeV} \lesssim T \lesssim 10^{11} \text{ GeV}$ for permissible values of range of g .
- Decay rate of χ particles to fermions : $\Gamma_{\bar{\psi}\psi} = h^2 m_\chi / 8\pi$ must be larger than the expansion rate of the universe, to make the back reaction of χ particles on the background evolution negligible \Rightarrow Lower bound on h .
- This, along with generic values of parameters g leads to the region in parameter space (h, g) :

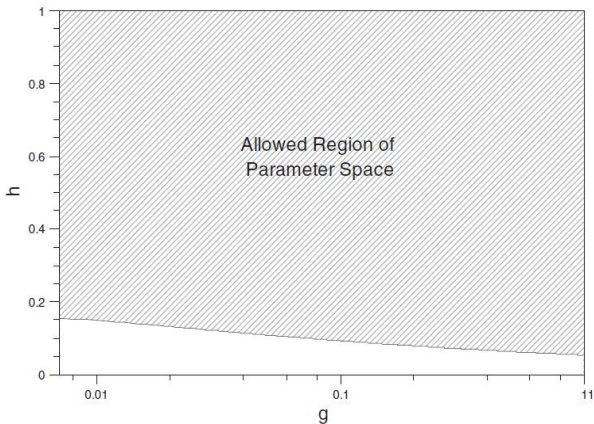


Figure: shaded regions $0.006 \lesssim g \lesssim 1$ and $0.053 \lesssim h \lesssim 1$ lead to successful instant heating,

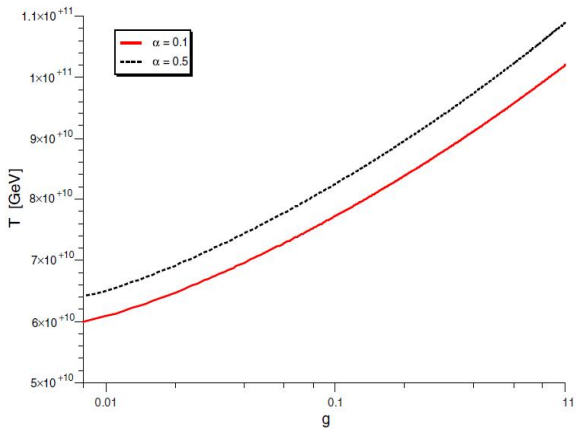


Figure: Reheating temp vs g ; $T \simeq \rho_X^{1/4}$ varies between $6 \times 10^{10} - 1.1 \times 10^{11}$ Gev

- To conclude, there is fair control over Brane inflation model building that includes Reheating which is consistent with observations.



Thank You