

Theoretical constraints on brane inflation and cosmic superstring radiation

arXiv:1105.1784 [hep-th]

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1 CONSTRAINTS ON BRANE INFLATION MODELS

Supergravity constraints

D3/D7 inflation

Brane-antibrane inflation

2 PART II: CONSTRAINTS ON CSS RADIATION

Cosmic superstrings

Allowed radiation

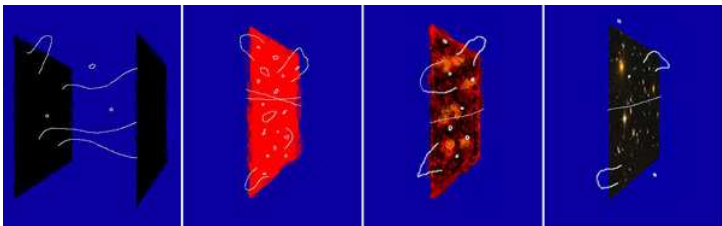
The axionic wavefunction

3 CONCLUSIONS

Supergravity
constraints
D3/D7 inflation
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Cosmic superstrings
Allowed radiation
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Supergravity
constraints
D3/D7 inflation
Brane-antibrane
inflation

- Cosmic superstrings are produced at the end of brane inflation.
- They can have richer networks and radiation modes than cosmic strings, BUT...
- they are subject to consistency conditions on the underlying string theory

Cosmic superstrings
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Supergravity constraints

In consistent supergravity theories,

- 1 Field-independent FI terms are not allowed:
 - Constant $\xi + \text{SUGRA} \Rightarrow$ a continuous global symmetry
Komargodski & Seiberg, 0904.1159; Dienes & Thomas, 0911.0677
 - Forbidden by a folk theorem *Banks & Seiberg, 1011.5120*
- 2 The moduli space cannot be compact *Komargodski & Seiberg, 1002.2228*:
 - *well-defined FZ multiplet \iff exact Kähler form J*
 - *Then, $\int_{\gamma} J \wedge J \wedge J \dots = 0$ for γ compact.*
 - *i.e. exact Kähler form \iff noncompact moduli space*

Note that

- 1 the moduli space can be a discrete set of points
- 2 making the FI term field-dependent will render the moduli space noncompact

Implications for brane inflation

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- D3/D7 is a string embedding of **D-term inflation**, which uses the FI term ξ to break SUSY and start inflation.
- In D3/D7 and $D3/\overline{D3}$, need to stabilize the volume, while allowing the branes to move.
- **Such moduli stabilization cannot be done in a supersymmetric way:** the closed string modulus cannot be larger than the open string one or the SUSY breaking scale

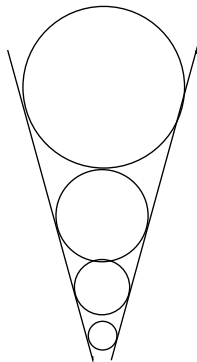


Figure: A compact space fibered by an unfixed modulus

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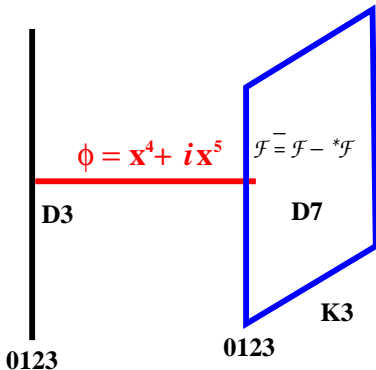
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The NSD flux on the D7 gives a field-dependent FI term via GS mechanism:

$$\xi = \frac{\delta_{GS}}{\text{vol}(K3)}$$

where $s = \text{vol}(K3) + iC_{(4)}$,
s the Kahler modulus.

[Binetruy, Dvali, Kallosh, Van
Proeyen, 0402046; Burgess,
Kallosh, Quevedo, 0309187,
RG, Sakellariadou and Sypsas,
1008.0087]



Constraint on D3/D7

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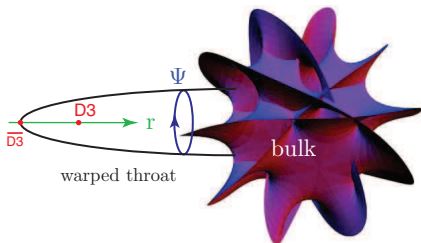
[Binetruy, Dvali, Kallosh, Van Proeyen, 0402046; Burgess, Kallosh, Quevedo, 0309187, RG, Sakellariadou and Sypsas, 1008.0087]

- ✓ ξ is field dependent!
- ✗ But $\text{Vol}(K3)$ must be stabilised above the SUSY scale
- ? Is ξ constant?
- ✓ No – it depends on r :

$$\xi^2 \sim \frac{1}{g^2} \int_{K3} \mathcal{F}^- \wedge \star \mathcal{F}^-$$
$$\xi^2 = \xi^2(r)$$

[Haack et al, 0804.3961];
Dasgupta et al, 0405247; RG,
Sakellariadou and Sypsas,
1105.1784]

Constraint on $D3/\overline{D3}$



[stolen from Baumann and McAllister, 0901.0265]

- No FI term, but the moduli space must be noncompact
- But we want to stabilize the volume!

- Moduli space will be a discrete set of points [Adams et al 1104.3155]
- In this case, there is no flat direction for the inflaton...
- Have to **break** SUSY, then can stabilize volume below this scale [KKLT, KKLMMT]
- Crucial point: volume is not tied to the SUSY scale

- CSS are produced at the end of brane inflation
- Tension is too large in D3/D7 (can make semilocal)
- In D3/ $\overline{D3}$, warping lowers the tension:

$$T_{(p,q)} = \frac{h_I^2}{2\pi\alpha'} \sqrt{\frac{q^2}{g_s^2} + \left(\frac{bM}{\pi}\right)^2 \sin^2\left(\frac{\pi(p - qC_0)}{M}\right)},$$

where $h_I \ll 1$ is the warp factor at the bottom of the throat:

$$ds^2 = h^2(y) \eta_{\mu\nu} dx^\mu dx^\nu + g_{mn} dy^m dy^n$$

[Firouzjahi, Leblond and Tye, hep-th/0603161; also Herzog and Klebanov, hep-th/0111078, Hartnoll and Portugues, hep-th/0405214, Gubser et al, 0405282]

Warped background - radiation

- In flat space, power radiation from RR emission \sim radiation from gravitational wave emission.
- In a warped background ($h \ll 1$), RR/NSNS radiation can be enhanced for D-strings: [\[Firouzjahi, 0710.4609\]](#)

$$\begin{aligned} S_{D,4\text{dim}} &= \frac{M_{\text{P}}^2}{2} \int d^4x \sqrt{-g} \left(R - \frac{\beta g_s}{12} F_3^2 \right) \\ &\quad - \mu_{\text{eff}} \int dt dx \sqrt{-\gamma} + \mu_1 \int dt dx C_2, \\ \frac{P_{\text{RR}}}{P_g} &= \left(\frac{8\Gamma_{\text{RR}}}{\pi\Gamma_g} \right) \frac{g_s}{\beta h^4}, \quad \mu_{\text{eff}} = h^2 \mu_1 g_s^{-1} \\ \beta &= \frac{\int d^6y \sqrt{g_6} h^{-2}(y)}{\int d^6y \sqrt{g_6} h^2(y)}. \end{aligned}$$

What about (p, q) strings??

- The only known consistent compactification of the KS throat is the GKP flux compactification [[Giddings, Kachru, Polchinski, hep-th/0105097](#)]

- GKP involves an orientifold projection

$$\mathcal{O} = (-1)^{F_L} \Omega_p \sigma^*$$

- This acts on the NSNS and RR two-forms as

$$\mathcal{O} B_2 = -\sigma^* B_2 \quad \text{and} \quad \mathcal{O} C_2 = -\sigma^* C_2 ,$$

- σ^* acts on the internal manifold, so $B_{\mu\nu}$ and $C_{\mu\nu}$ are projected out
- \Rightarrow Their zero modes do not appear in the spectrum [[Copeland, Myers, Polchinski, hep-th/0312067](#)]

For a (p, q) string which is actually a *wrapped D3 brane*, RR radiation is possible if there exists a two-cycle $\Omega_2 \in H_-^2$:

$$D_2(x^M) = d_2(x^\mu) + d(x)\Omega_2 + V_1(x) \wedge \alpha_1,$$

- d_2 is projected out
- $d(x)$ (model-dependent axion) is allowed if $\Omega_2 \in H_-^2$ exists
- This does not help the case of a D-string (C_{01}).

Similarly, the decomposition

$$C_4(x^M) = c_4(x^\mu) + c_2(x^\mu) \wedge \Omega_2 + c_1(x^\mu) \wedge \Omega_3 + c(x^\mu) \wedge \Omega_4$$

with $\mathcal{O}C_4 = \sigma^* C_4$ can give rise to RR radiation.

We have seen that

- D-strings and F-strings in warped throat have no NSNS or RR axions
- Two types of model-dep RR axion are possible for (p,q) strings which are wrapped D3 branes

Q: *But what about the proposed enhancement of axionic radiation in the throat?*

- dimensional reduction in a warped geometry is nontrivial
- EOM, including warping and compensating terms, given for the universal Kähler volume modulus and the universal axion a

$$C_4 = aJ \wedge J,$$

where J is the Kähler form ($\sigma^* J = J$)

[Frey, Torroba, Underwood and Douglas, 0810.5768]

- for nonuniversal axions such as $C_4 = c_2(x) \wedge \Omega_2$, only formal expressions can be given, subject to constraints. EOM cannot be written down, so the wavefunction is not known. This would be required to calculate the magnitude of radiation.

- 1 Brane inflation models subject to sugra consistency constraints
- 2 FI term in D-inflation must depend on an unfixed modulus
- 3 D3/D7: $\xi = \xi(r)$, but will this affect inflation?
- 4 D3/ $\overline{D3}$: moduli space cannot be compact;
 - it can be a discrete set of points
 - one can play with the SUSY breaking scale
- 5 Enhancement of axionic radiation does not translate to (p,q) strings:
 - axionic radiation ruled out for F,D strings in a throat
 - RR radiation possible for wrapped D3 branes, but hard to quantify