D3-/D7-Brane Inflation Revisited

Marco Zagermann

Max-Planck-Institute for Physics, Munich

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Madison, August 26, 2008

M. Haack, R. Kallosh, A. Krause, A. Linde, D. Lüst, M.Z., arXiv:0804.3961

Outline

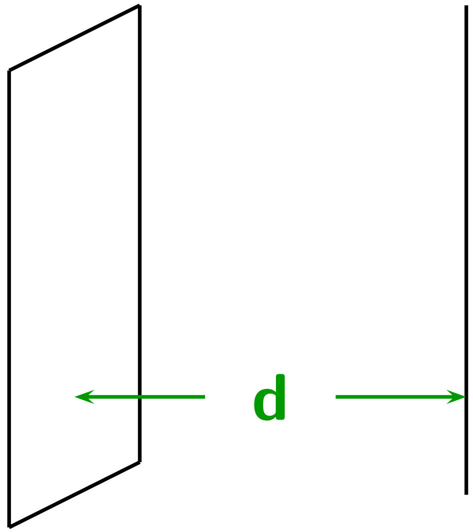
1. Review of D3/D7-brane inflation

2. Why should it be revisited?

3. Our results

4. Conclusions

1. Review of D3/D7-brane inflation

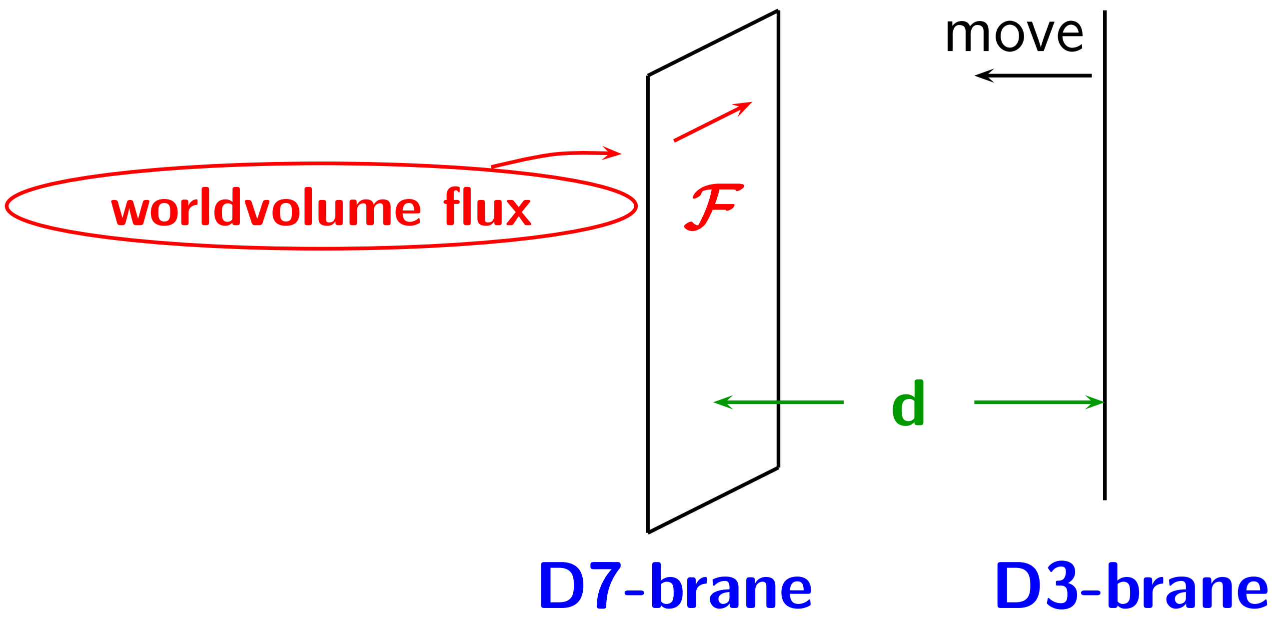


When branes are mutually supersymmetric

⇒ No interbrane force

⇒ Flat potential for interbrane distance: $V(d) = \text{const.}$

1. Review of D3/D7-brane inflation



Certain worldvolume fluxes break SUSY

$\Rightarrow$ Nontrivial potential: $V(d) \neq$ const.

A well-understood compactified version

Dasgupta, Herdeiro, Hirano, Kallosh, 2002

IIB string theory on $\mathbb{R}^{1,3} \times \mathbf{K3} \times \mathbf{T}^2/\mathbb{Z}_2$

The $\mathbb{Z}_2$ orientifold operation involves :

$\boxed{x^i \longrightarrow -x^i}$ **(torus coordinates)**

$\Rightarrow$ $\mathbf{T}^2/\mathbb{Z}_2 \cong$ 

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3-form flux $\mathbf{G_3} = \mathbf{F_3} + \mathbf{SH_3}$

$\Rightarrow \mathcal{N} = 2 \rightarrow \mathcal{N} = 1$ (Partial SUSY-breaking)

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	$\mathbb{R}^{1,3}$	K3	$\mathbf{T}^2/\mathbb{Z}_2$
D7	X	X	
D3	X		
$\mathcal{F}$		X	

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D7, D3 } Provide inflaton $d = |y_3 - y_7| \overset{y_7=0}{=} |y_3|$
(= interbrane distance on $\mathrm{T}^2/\mathbb{Z}_2$)

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D7	X	X	
D3	X		
$\mathcal{F}$		X	

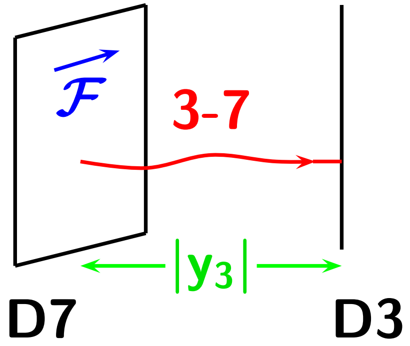
D7, D3 → **Provide inflaton $d = |y_3 - y_7| \overset{y_7=0}{=} |y_3|$ (= interbrane distance on $\mathrm{T}^2/\mathbb{Z}_2$)**

$\mathcal{F}$ → **Fayet-Iliopoulos D-term**
Breaks SUSY: $\mathcal{N} = 1 \rightarrow \mathcal{N} = 0$

⇒ **Bose-Fermi mass splittings for D3-D7 string states:**

Scalars: $\mathbf{M}_{\pm}^2 \sim |\mathbf{y}_3|^2 \pm \mathbf{f}(\mathcal{F})$

Fermions: $\mathbf{M}^2 \sim |\mathbf{y}_3|^2$



$\Rightarrow$ **Bose-Fermi mass splittings for D3-D7 string states:**

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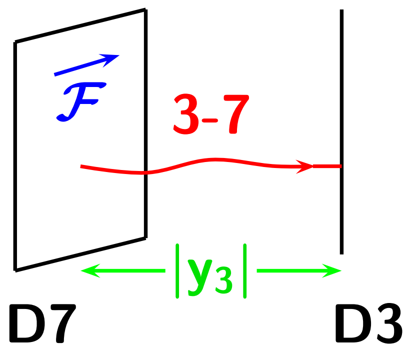


(i) Coleman-Weinberg correction to V_D:

$$V = V_D + \frac{1}{64\pi^2} \mathrm{STr}\left(\mathcal{M}^4(y_3) \log \frac{\mathcal{M}^2(y_3)}{\Lambda_{UV}^2}\right)$$

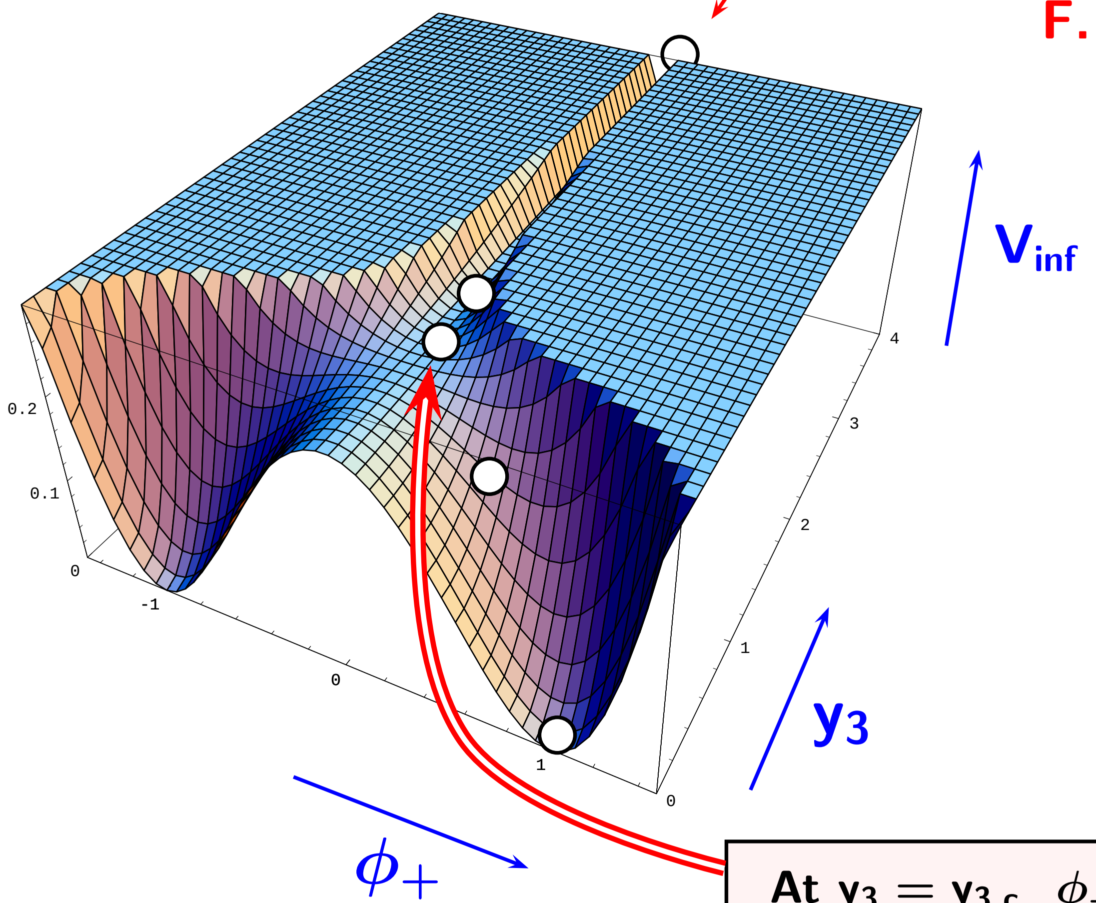
(ii) For $|y_3| > y_{3,c} \equiv \sqrt{|f(\mathcal{F})|}$, all scalars are non-tachyonic

For $|y_3| < y_{3,c}$, one scalar becomes tachyonic

⇒ Hybrid D-term inflation

$$V_{infl}|_{\phi_\pm=0} = \frac{1}{2}g^2\xi^2\left(1 + \frac{g^2}{8\pi^2}\ln\frac{|y_3|^2}{|y_{3,c}|^2}\right)$$

F.I. C.W.



At $y_3 = y_{3,c}$ ϕ_+ becomes tachyonic and condenses

$\phi_\pm$ are charged under $U(1)_D \subset U(1)_{D7} \times U(1)_{D3}$

⇒ **Cosmic strings after inflation!**

Two extreme regimes: Kallosh, Linde (2003)

(A) $g \geq 2 \times 10^{-3} \Rightarrow \boxed{G\mu \cong 2.5 \times 10^{-6}, \quad n_s \cong 0.98}$

(B) $g \ll 2 \times 10^{-3} \Rightarrow \boxed{G\mu \leq 10^{-7}, \quad n_s \cong 1}$

Before WMAP3, $n_s \cong 0.98$ looked very good. $\Rightarrow$ Work on D3/D7-inflation focused on getting rid of the cosmic strings in Regime A, e.g.,

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More recent data: $n_s = 0.96^{+0.014}_{-0.013}$ (WMAP5)
(This value assumes no cosmic strings)

Allowing for ($\sim 10\%$) contribution of cosmic strings to CMB, larger values of n_s (Close to 1) might be possible. $\Rightarrow$ Regime B?

Battye, Garbrecht, Moss (2006); Bevis, Hindmarsh, Kunz, Urrestilla (2007). Cf. also Battye, Garbrecht, Moss, Stoica (2007); Pogosian, Tye, Wasserman, Wyman (2008); Dutta, Kumar, Leblond (2008)

2. Why revisit D3/D7- inflation?

We used $V_{infl}|_{\phi_\pm=0} = \frac{1}{2} g^2 \xi^2 \left(1 + \frac{g^2}{8\pi^2} \ln \frac{|y_3|^2}{|y_{3,c}|^2}\right)$

and assumed $g^2\xi^2 = \text{const.}$

But: $g^2\xi^2$ **depends on Kähler moduli, in particular on Vol(K3).**

⇒ **Moduli stabilization may interfere with inflaton dynamics**

Kachru, Kallosh, Linde, Maldacena, McAllister, Trivedi (2003); McAllister (2005)

Moduli (from $\mathcal{N} = 2$ vector multiplets):

Antoniadis, Bachas, Fabre, Partouche, Taylor; D'Auria, Ferrara, Trigiante

y_3 = D3-position on $T^2/\mathbb{Z}_2$

y_7 = D7-position on $T^2/\mathbb{Z}_2$

U = complex structure of $T^2/\mathbb{Z}_2$

S = axion-dilaton

T = K3 volume modulus

(y_7, U, S) → G_3-flux

T → Non-pert. effects (e.g. gaugino condensation)

$$W = W_{flux} + W_{np} \Rightarrow \boxed{V_F = e^K \left[|\mathcal{D}W|^2 - 3|W|^2 \right]}$$

$W_{np} \sim \exp(-a\, f_{D7})$ (f_{D7} = D7 gauge kin. funct.)

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- $f_{D7}^{(0)} = iT$ $\Rightarrow$ y_3-independent
- $K^{(0)} = K^{(0)}(\text{Im}(y_3), \ldots)$ $\Rightarrow$ $\text{Re}(y_3)$-independent

$\Rightarrow$ **V_F is $\text{Re}(y_3)$-independent (at "leading order")**

$\Rightarrow$ $\text{Re}(y_3) =$ good inflaton candidate? Hsu, Kallosh, Prokushkin (2004)

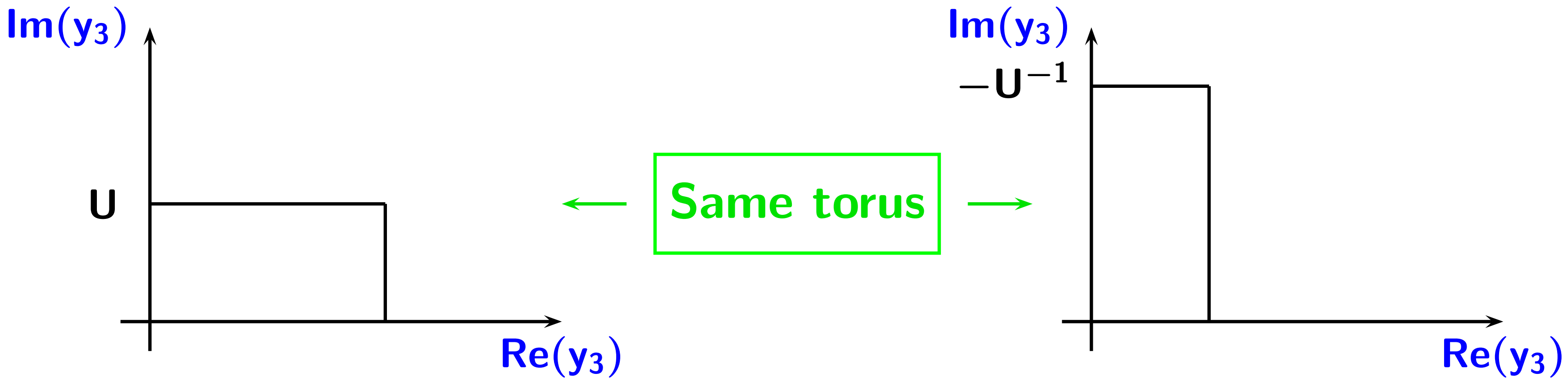
Another example for an inflaton shift symmetry?

Cf. E. Silverstein's talk

Two problems:

(i) g_s-corrections generically depend on y_3

(ii) $\mathrm{Re}(y_3)$ vs. $\mathrm{Im}(y_3)$ is purely conventional!
($SL(2,\mathbb{Z})$ symmetry)



(i) + (ii) are related:

$f_{D7}^{(0)}, K^{(0)}$ break $SL(2,\mathbb{Z})$ because 1-loop corrections are only partially included

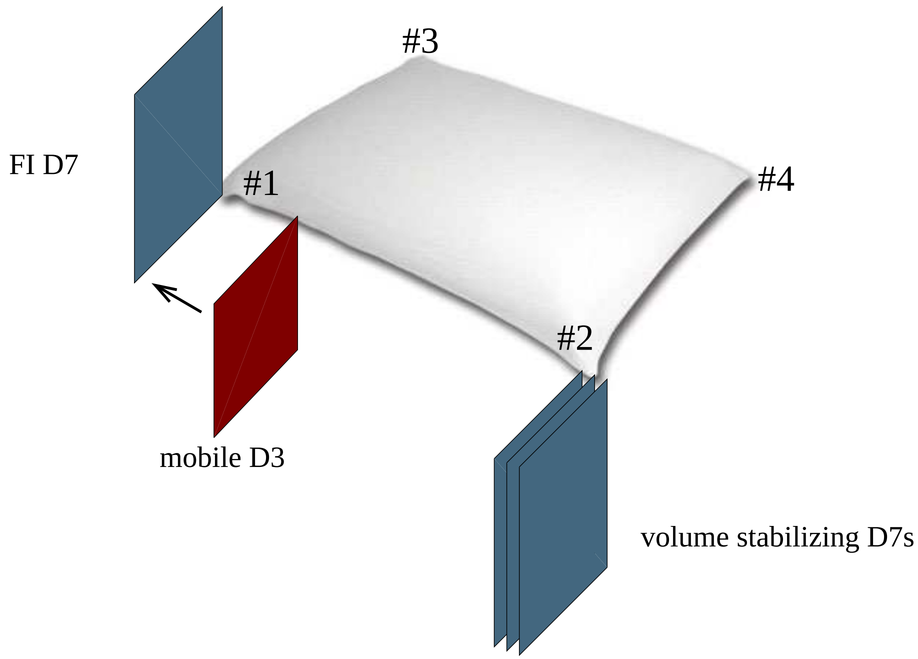
Full 1-loop correction restores $SL(2,\mathbb{Z})$ but breaks shift symmetry

3. Results

Bachas, Fabre; Antoniadis, Bachas, Fabre, Partouche, Taylor, Berg, Haack, Körs; Baumann, Dymarsky, Klebanov, Maldacena, McAllister, Murugan; Burgess, Cline, Dasgupta, Firouzjahi; Haack, Kallosh, Krause, Linde, Lüst, M.Z.

- $f_{D7} \sim iT - \frac{2}{\pi^2}\ln\vartheta_1(y_3, U) + \frac{3}{\pi}\ln\eta(U)$ **(holomorphic)**
- $K \sim -i\ln[\underbrace{\ldots}_{\text{leading term}} + c(U - \bar{U})\mathcal{E}(y_3, y_7, U)]$
- **1-loop corrections restore $SL(2,\mathbb{Z})$ for gauge coupling and Kähler potential but break shift symmetry**
- **Can study cosmological consequences of shift symmetry breaking**

A simple small field setup:

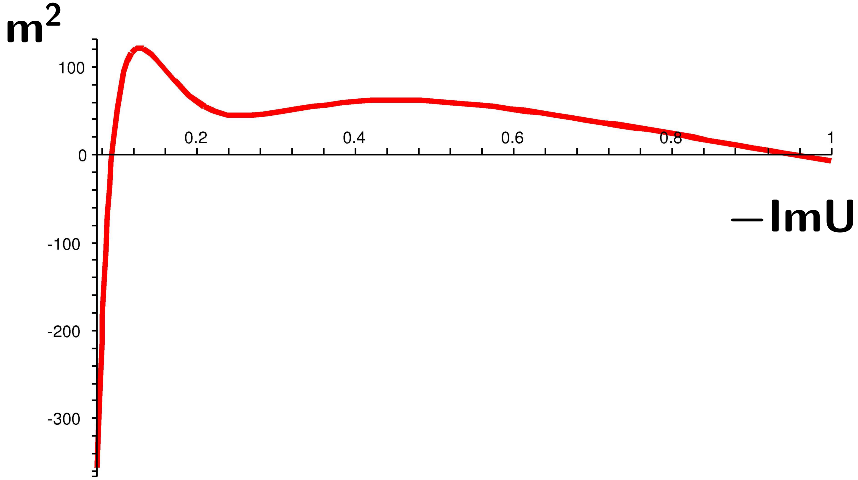


Expand moduli stabilization potential for small inflaton $\phi = \mathrm{Re}(y_3)$

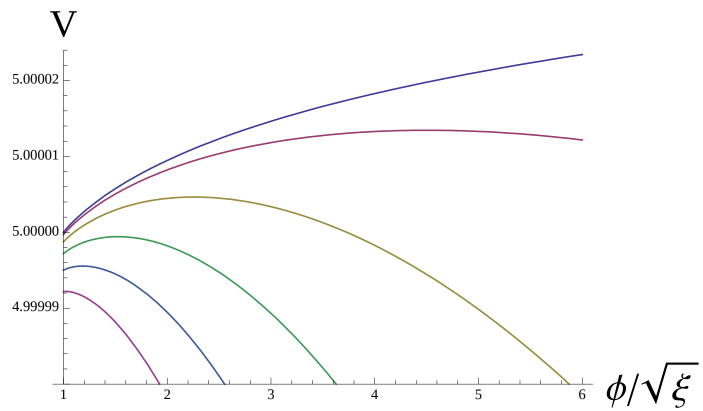
$$\Rightarrow V = V_D + V_{CW} + V_F = V_D + V_{CW} - \frac{m^2}{2}\phi^2 + \mathcal{O}(\phi^4)$$

(Only even powers due to $\mathbb{Z}_2$ projection on $T^2/\mathbb{Z}_2$) Cf. S. Kachru's talk

- $\mathbf{m^2 = m^2(U)}$ ⇒ **tunable**



- **$m^2 = m^2(U)$ ⇒ tunable**
- **$m^2 = 0$ ⇒ $n_s \approx 1$, $\sim 10\%$ cosmic strings**
- **m^2 small but non-zero ⇒ n_s can be lowered with smaller relative cosmic string contribution ⇒ more conventional WMAP5 fits**



$$\delta_S \sim \frac{V^{3/2}}{V'}$$

Other approaches: Seto, Yokoyama (2005); Bastero-Gil, King, Shafi (2006); Brax, van de Bruck, Davis, Davis, Jeannerot, Postma (2006); Jeannerot, Postma (2006); Rocher, Sakellariadou (2006); Davis, Postma (2008)

4. Conclusions

- D3/D7-brane inflation on $K3 \times T^2/\mathbb{Z}_2$ is a very controllable and computable model

- Clarification of the inflaton shift symmetry

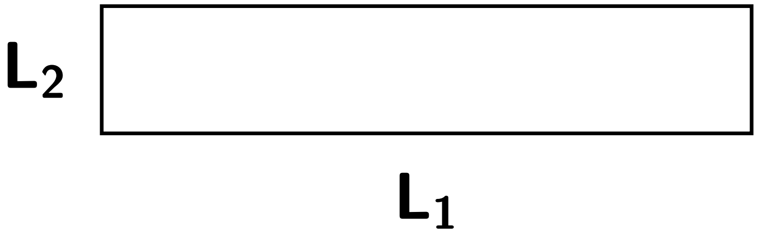
- Studied a setup in which shift symmetry breaking induces small, tuneable mass terms

- $m^2 = 0$ could correspond to CMB fits with $n_s \cong 1$ and 10% cosmic strings, whereas small, non-vanishing m^2 could bring model close to more conventional CMB fits with smaller n_s and negligeable cosmic string contribution. $\Rightarrow$ Certainly room for further work Cf. J. Cline's talk

An interesting observation:

- **Kinematical field range** $\frac{\Delta \mathrm{Re}(y_3)}{M_P} \sim \frac{L_1}{\sqrt{L_1 L_2 \mathrm{Vol}(K3)}} = \sqrt{\frac{L_1}{L_2 \mathrm{Vol}(K3)}}$

  Can be made very large for $L_1 \gg L_2$:



$\Rightarrow$ Complex structure dependence of kinematical field range

$\Rightarrow$ Gravitational waves? (Not for our potential. Modify the setup?)

Cf. e.g. Baumann, McAllister (2007); Becker, Leblond, Shandera (2007); Silverstein, Westphal (2008) and E. Silverstein's talk