D3/D7-brane inflation revisited

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Work in progress with R. Kallosh, A. Krause, A. Linde, D. Lüst, M. Zagermann

and hep-th/0404087, hep-th/0508043 (with M. Berg and B. Körs)

Motivation

- Important problem in string phenomenology: Derive (semi)realistic, consistent and controllable models for inflation in string theory

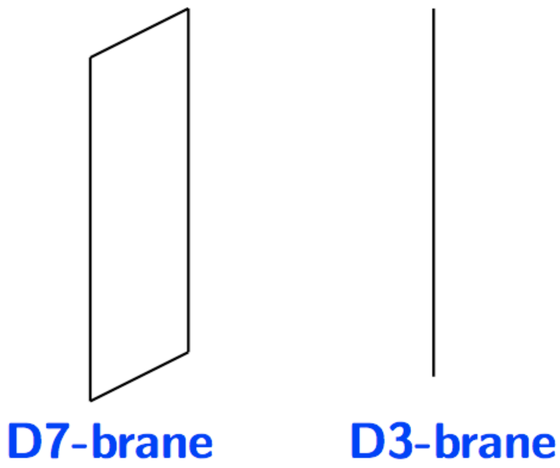
- Prime example: D3/D7 inflation (relatively good control: basic model has $\mathcal{N} = 2$ and only mild warping)

[Dasgupta, Herdeiro, Hirano, Kallosh]

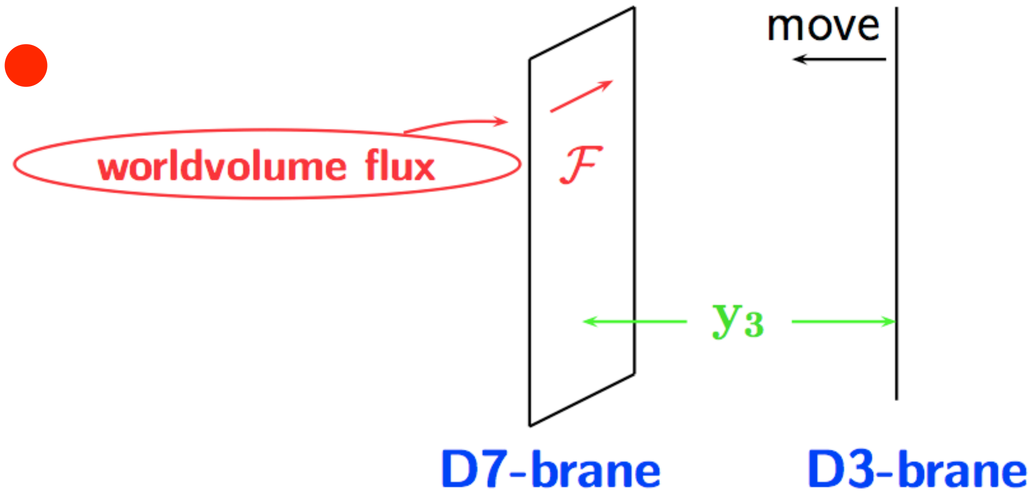
Overview

- Review of D3/D7 inflation
- Why should it be revisited?
- 1-loop corrections to Kähler potential and D7-brane gauge couplings in the D3/D7-system
- Insights for inflation
- Conclusion

D3/D7 inflation: Basic idea

- 

  If the branes are mutually BPS, there is no interbrane force

- 

  Non-selfdual worldvolume fluxes break supersymmetry and lead to a potential for y_3

[Pictures: thanks to M. Zagermann]

A compactified example

[Dasgupta, Herdeiro, Hirano, Kallosh]

- Type IIB orientifold on $\mathbb{R}^{1,3} \times K3 \times T^2/\mathbb{Z}_2$

  (T-dual to the models discussed by
  [Antoniadis, Bachas, Fabre, Partouche, Taylor]
  cf. also [Bianchi, Sagnotti; Gimon, Polchinski])

  $\Omega(-1)^{F_L} I_2$

- Leads to $\mathcal{N} = 2$ supergravity in 4D

- Local D3/D7-pair:

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

Provide inflaton $\mathbf{y_3}$
(= interbrane distance on $\mathbf{T^2/\mathbb{Z}_2}$)

Fayet-Iliopoulos D-term

Masses of charged chiral multiplets

- The masses of D3/D7-states depend on position y_3 and $\mathcal{F}$

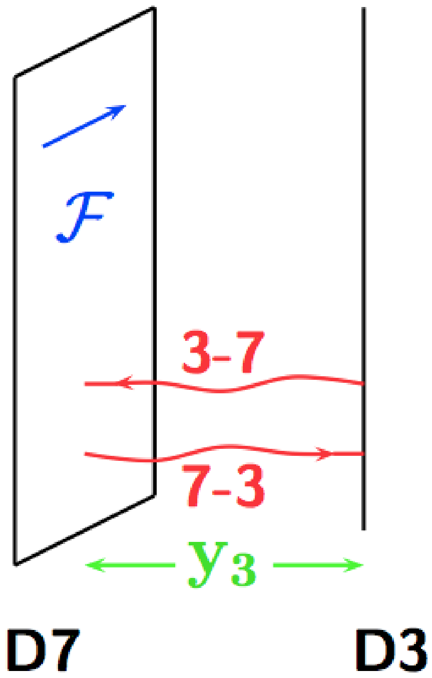
$\arctan(\mathcal{F}_{45}) - \arctan(\mathcal{F}_{67})$

- Scalars $\phi_\pm$: $M_\pm^2 \sim |y_3|^2 \pm \xi(\mathcal{F})$

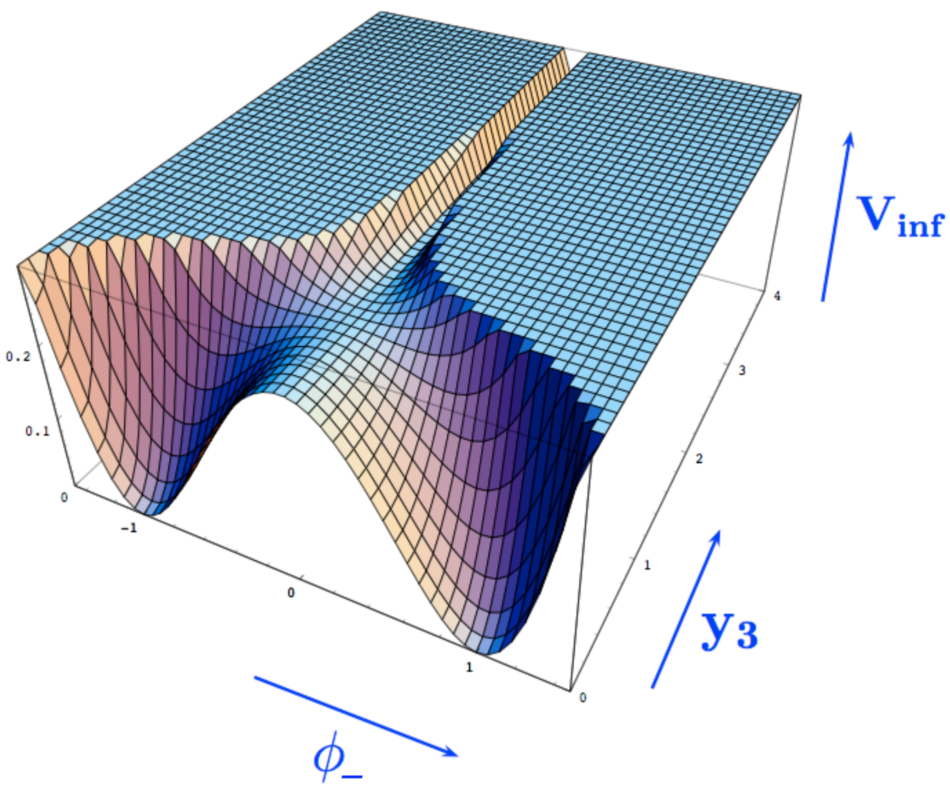
  Fermions: $M^2 \sim |y_3|^2$

- For $|y_3| > |y_{3,c}| = \sqrt{|\xi(\mathcal{F})|}$ all scalars non-tachyonic

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



Hybrid D-term inflation



- $|y_3| > |y_{3,c}| \Rightarrow \langle \phi_\pm \rangle = 0$

One-loop gauge theory effect

F.I.-term

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

Some phenomenology

- Hybrid D-term inflation

$\Longrightarrow$ A priori no supergravity "eta"-problem

- Condensation of ϕ_- spontaneously breaks $U(1)_D$

$\Longrightarrow$ Cosmic string formation after inflation

dimensionless string tension

- $G\mu, n_s$ depend on value of g (coupling of $U(1)_D$)

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

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

[Kallosh, Linde]

Reasons to revisit D3/D7 inflation

- Taking into account stabilization of moduli (in particular of the volume) could change the story [cf. also McAllister]

  (e.g.: what is the inflaton candidate?)

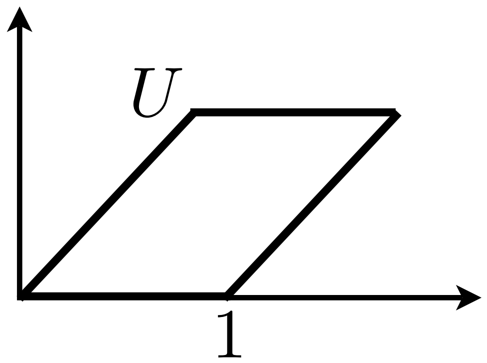
- Inflaton range was not carefully discussed in the literature until now

Moduli

- (Abelian) Vector multiplet scalars:

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

$$y_3^i = y_{3,1}^i + U y_{3,2}^i \ , \quad y_7^r = y_{7,1}^r + U y_{7,2}^r$$



$$U = \frac{g_{12}}{g_{11}} + i\frac{\sqrt{\det g}}{g_{11}}$$

$$S = C_{(0)} - ie^{-\phi} + \tfrac{1}{2}\sum_r y_{7,2}^r y_7^r$$

$$T = C_{(4)} - i\mathcal{V}_{K3}^{(0)} + \tfrac{1}{2}\sum_i y_{3,2}^i y_3^i$$

Only depends on $\mathrm{Im}(y_3)$!

- $$K^{(0)} = -\ln\Big[(S-\bar{S})(T-\bar{T})(U-\bar{U}) - \tfrac{1}{2}(S-\bar{S})(y_3-\bar{y}_3)^2 - \tfrac{1}{2}(T-\bar{T})(y_7-\bar{y}_7)^2\Big]$$

Moduli stabilization

- Assume: 3-form Fluxes break supersymmetry to $\mathcal{N} = 1$

- Fluxes and non-perturbative effects (e.g. gaugino condensation on D7) lead to superpotential

  $W = W_{\rm flux} + W_{\rm np}$

  $\sim e^{-a f_{\rm D7}}$ $\quad f_{\rm D7}$: D7 gauge kinetic function

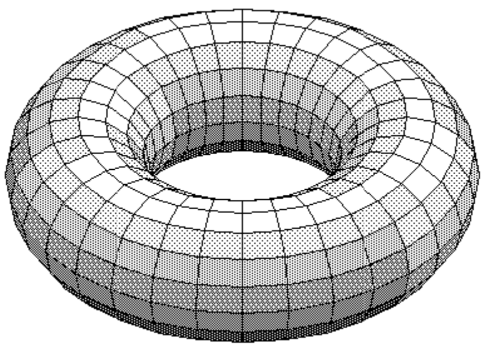
- At leading order: $f_{\rm D7} = iT$ (independent of y_3)

  $W_{\rm flux}$ independent of y_3, $K^{(0)}$ independent of $\mathrm{Re}(y_3)$

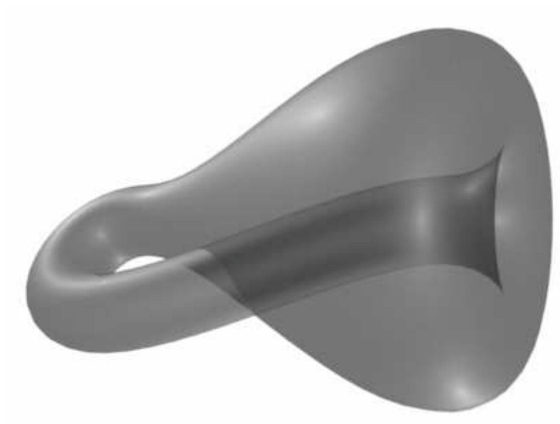
  $\Longrightarrow \mathrm{Re}(y_3)$ good inflaton candidate?

- Two reasons to reconsider this point:
  - ★ g_s corrections could introduce y_3 dependence, leading higher order corrections from:

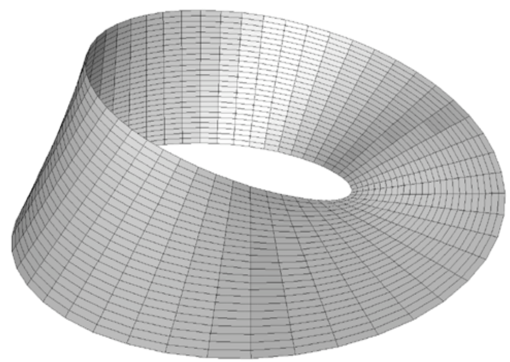
Torus:



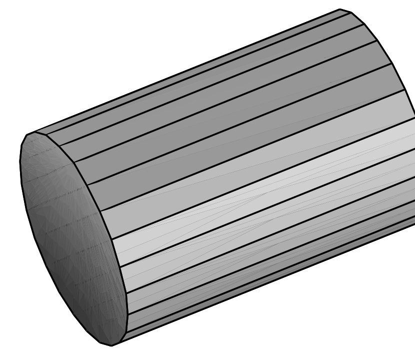
Klein bottle:



Möbius strip:



Annulus:



  - ★ $SL(2,\mathbb{Z})$ symmetry: $U \to -U^{-1}$ mixes real and imaginary part of y_3

- Both problems are actually connected;
  $SL(2,\mathbb{Z})$ is broken by leading order terms

$$f_{\rm D7} = iT \ \& \ K^{(0)}$$

- E.g.: Under $U \to -U^{-1}$
  one has $K^{(0)} \to K^{(0)} + \ln|U|^2 \ (= K^{(0)} + \ln U + \ln \bar{U})$
  only for $y_7 = 0$!

- These points can be addressed qualitatively
  in the case without fluxes

Result for $K3 \times T^2/\mathbb{Z}_2$

[Berg, Haack, Körs; Bachas, Fabre; Antoniadis, Bachas, Dudas; Haack, Kallosh, Krause, Linde, Lüst, Zagermann]

- $$f_{\rm D7} \sim iT - \frac{1}{8\pi^2}\sum_i \ln\vartheta_1(y_3^i, U) + \frac{3}{\pi^2}\ln\eta(U)$$

depends on y_3 holomorphically!

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  leading order   depends on y_3 holomorphically!

- $K = -\ln[\ldots - c(U - \bar{U})\mathcal{E}_2(y_3, y_7, U)]$

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leading order

depends on y_3 holomorphically!

- $$K = -\ln[\ldots - c(U - \bar{U})\mathcal{E}_2(y_3, y_7, U)]$$
- $$\mathcal{E}_2 = \sum_{i,r} [E_2(y_3^i - y_7^r, U) + E_2(y_7^r - y_3^i, U)] + (\text{other } E_2 \text{ terms})$$
- $$E_2(y, U) = \sum_{(n,m)\neq(0,0)} \frac{U_2^2}{|n + mU|^4} \exp\left[2\pi i \frac{y(n + m\bar{U}) - \bar{y}(n + mU)}{U - \bar{U}}\right]$$

Generalized Eisenstein series

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  Generalized Eisenstein series

- 1-loop corrections restore $SL(2,\mathbb{Z})$ invariance of gauge coupling and Kähler potential

Field range

- Is there a flat direction?

[Work in progress]

- What could be maximal range?
- Important because of Lyth bound:

constant of $\mathcal{O}(1/10)$

$$r \leq C\left(\frac{\Delta\phi}{M_P}\right)^2$$

- In literature (square 6-torus, analog of $U = i$):

$$\frac{\Delta\phi}{M_P} \leq \frac{\sqrt{g_s}\alpha'}{L^2}$$

length of torus

- In range of validity ($L/\sqrt{\alpha'} \gg 1, g_s \ll 1$) this implies

$$r \ll 1$$

- Kinetic term of y_3 (for $y_7 = 0$):

$$M_P^2 \frac{\partial_\mu y_3 \partial^\mu \bar{y}_3}{4\mathrm{Im}\,T\mathrm{Im}\,U - 2(\mathrm{Im}\,y_3)^2}$$

$\Longrightarrow$ canonically normalized field:

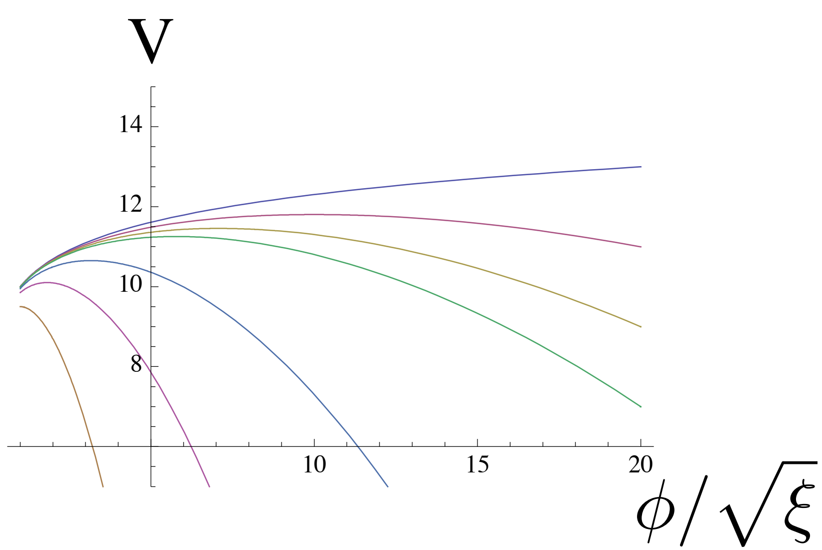
$$y_3^c = \frac{M_P y_3}{\sqrt{2\mathrm{Im}\,T\mathrm{Im}U - (\mathrm{Im}\,y_3)^2}}$$

- $\frac{\Delta \mathrm{Re}\, y_3^c}{M_P} \leq \frac{1+U_1}{\sqrt{U_2}} \frac{\sqrt{g_s}\alpha'}{\sqrt{\mathcal{V}_{K3}^{(0)}}}$, $\frac{\Delta \mathrm{Im}\, y_3^c}{M_P} \leq \sqrt{U_2} \frac{\sqrt{g_s}\alpha'}{\sqrt{\mathcal{V}_{K3}^{(0)}}}$
- Independent of $\mathcal{V}_{T^2/\mathbb{Z}_2}$
- One or the other gets large for $U_2 \ll 1$ or $U_2 \gg 1$

Phenomenology revisited

- For small ϕ

$$V = \frac{g^2\xi^2}{2}\left(1 + \frac{g^2}{4\pi^2}\ln\frac{\phi}{\sqrt{\xi}}\right) \longrightarrow \frac{g^2\xi^2}{2}\left(1 + \frac{g^2}{4\pi^2}\ln\frac{\phi}{\sqrt{\xi}}\right) - \frac{m^2}{2}\phi^2$$

- 

$\Longrightarrow$ V' smaller, $V(\phi \sim \sqrt{\xi})$ almost unchanged

- $\delta \sim \frac{V^{3/2}}{V'}$ $\Longrightarrow$ suppression of cosmic strings relative to inflationary perturbations
- $n_s \sim 0.96$ possible even for $g \ll 2 \times 10^{-3}$

Conclusions

- 1-loop corrections important for D3/D7-inflation (also for $SL(2, \mathbb{Z})$)
- Usual assumption of $\mathrm{Re}\, y_3$ as the inflaton should be reconsidered
- Kinematical field range can be large
- Phenomenology?