Fluxbrane Inflation

Sebastian Kraus

Institute for Theoretical Physics
Heidelberg University

String Phenomenology 2012
Cambridge, June 26, 2012

Based on A. Hebecker, S. K., D. Lüst, S. Steinfurt, T. Weigand [arXiv:1104.5016]
and A. Hebecker, S. K., M. Küntzler, D. Lüst, T. Weigand (to appear)

Motivation

- Inflation is one of the crucial concepts in modern cosmology
- Challenge (from particle physics point of view): look for scalar potentials $V(\varphi)$ ($\varphi \equiv$ 'inflaton') which satisfy

$$\boxed{\epsilon = \left(\frac{V'}{V}\right)^2 \ll 1, \quad |\eta| = \frac{1}{2}\left|\frac{V''}{V}\right| \ll 1}$$

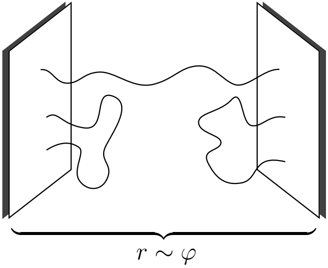
('single-field slow-roll inflation')

Motivation

- Inflation is one of the crucial concepts in modern cosmology
- Challenge (from particle physics point of view): look for scalar potentials $V(\varphi)$ ($\varphi \equiv$ 'inflaton') which satisfy

$$\boxed{\epsilon = \left(\frac{V'}{V}\right)^2 \ll 1, \quad |\eta| = \frac{1}{2}\left|\frac{V''}{V}\right| \ll 1}$$ ('single-field slow-roll inflation')

- Many attempts to construct models of inflation in string theory
- In this talk: Brane Inflation [Dvali, Tye, '98]



Motivation

- Inflation is one of the crucial concepts in modern cosmology
- Challenge (from particle physics point of view): look for scalar potentials $V(\varphi)$ ($\varphi \equiv$ 'inflaton') which satisfy

$$\boxed{\epsilon = \left(\frac{V'}{V}\right)^2 \ll 1, \quad |\eta| = \frac{1}{2}\left|\frac{V''}{V}\right| \ll 1} \quad \text{('single-field slow-roll inflation')}$$

- Many attempts to construct models of inflation in string theory
- In this talk: Brane Inflation [Dvali, Tye, '98]
- Famous examples:
  - Brane-/Antibrane inflation [Burgess et al., '01; KKLMMT, '03]
  - D3/D7 inflation with ~~SUSY~~ flux on D7 [Dasgupta et al., '02; Haack et al., '08]
  - ...
- Proposals suffer from η-problem generically:

$$|\eta| \sim \left(\frac{L}{r}\right)^{d_\perp} \gg 1$$

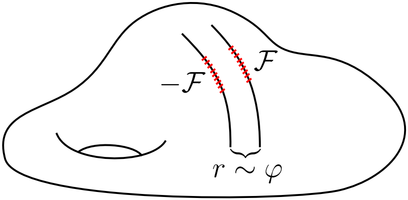
($\mathcal{V} = L^6$, $r =$ brane separation, $d_\perp =$ codimension)

Outline

Fluxbrane Inflation

Fluxbrane Inflation: [Hebecker, SK, Lüst, Steinfurt, Weigand, '11]

- Idea: Inflaton = relative deformation modulus of two D7-branes with flux



Fluxbrane Inflation

Fluxbrane Inflation: [Hebecker, SK, Lüst, Steinfurt, Weigand, '11]

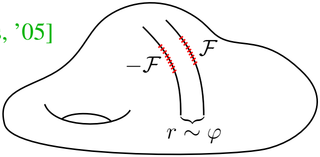
- Idea: Inflaton = relative deformation modulus of two D7-branes with flux

$$V(\varphi) = \frac{g_{YM}^2 \xi^2}{2} \left(1 + \alpha \, \frac{g_{YM}^2}{16\pi^2} \, \log\left(\frac{\varphi}{\varphi_0}\right)\right)$$

$$g_{YM}^2 = \frac{2\pi}{\mathcal{V}_{D7}}, \quad \xi = \frac{1}{4\pi}\frac{\int_{D7} J \wedge \mathcal{F}}{\mathcal{V}},$$

[Jockers, Louis, '05]

$$\alpha = \left(-2\int_{D7} \mathcal{F} \wedge \mathcal{F} + \frac{g_{YM}^2}{2\pi}\left(\int_{D7} J \wedge \mathcal{F}\right)^2\right)$$



→ For $\alpha = 1$ we recover the potential of D-term hybrid inflation [Binétruy, Dvali, Halyo, '96]

Fluxbrane Inflation - Phenomenology

- Upshot: Naturally flat potential at *large volume*, also for $r \ll L$:

$$\varphi = \frac{r}{2}\sqrt{\frac{g_s \mathcal{V}_{\text{D7}}}{\mathcal{V}}} \quad \rightarrow \quad \boxed{|\eta| = \frac{n^2}{2\pi}\frac{1}{(rL)^2} \ll 1}$$

$$\mathcal{V} = L^6, \ \mathcal{V}_{\text{D7}} = L^4,$$

$$n = \#\ \text{flux quanta}$$

Fluxbrane Inflation - Phenomenology

- Upshot: Naturally flat potential at *large volume*, also for $r \ll L$:

$$\varphi = \frac{r}{2}\sqrt{\frac{g_s \mathcal{V}_{\mathrm{D7}}}{\mathcal{V}}} \quad \rightarrow \quad \boxed{|\eta| = \frac{n^2}{2\pi}\frac{1}{(rL)^2} \ll 1} \qquad \mathcal{V} = L^6,\ \mathcal{V}_{\mathrm{D7}} = L^4,\quad n = \#\ \text{flux quanta}$$

- Spectral index

$$n_s \simeq 1 - \frac{1}{N} \simeq 0.983 \quad \left(\text{WMAP7: } n_s = 0.968, \quad \checkmark \text{ at } 2\sigma\right)$$

$N = \#$ e-foldings

Fluxbrane Inflation - Phenomenology

- Upshot: Naturally flat potential at *large volume*, also for $r \ll L$:

$$\varphi = \frac{r}{2}\sqrt{\frac{g_s \mathcal{V}_{\mathrm{D7}}}{\mathcal{V}}} \quad \rightarrow \quad \boxed{|\eta| = \frac{n^2}{2\pi}\frac{1}{(rL)^2} \ll 1} \qquad \mathcal{V} = L^6,\ \mathcal{V}_{\mathrm{D7}} = L^4,\quad n = \#\text{ flux quanta}$$

- Spectral index

$$n_s \simeq 1 - \frac{1}{N} \simeq 0.983 \quad \left(\text{WMAP7: } n_s = 0.968, \quad \checkmark \text{ at } 2\sigma\right)$$

$N = \#$ e-foldings

- Amplitude of curvature perturbations $\left(\text{WMAP7: } \frac{V^{3/2}}{V'} = 5.4 \times 10^{-4}\right)$

$$\rightarrow L \simeq 10, \qquad \mathcal{V} \simeq 10^6$$

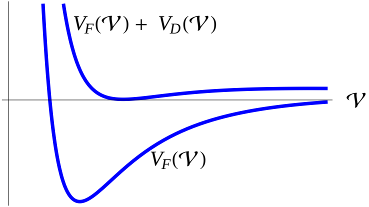
for *isotropic* compactification manifold

Moduli Stabilisation - Isotropic Large Volume Scenario

Moduli stabilisation in *isotropic* large volume model with D-term uplift
[Balasubramanian, Berglund, Conlon, Quevedo, Suruliz, '05]
[Cremades, Garcia del Moral, Quevedo, Suruliz, '07]

- $\mathcal{V} \sim \tau_b^{3/2} - \tau_s^{3/2}, \qquad \tau_b \gg \tau_s$
- Stabilisation through interplay between $\delta K_{\alpha'} \sim \frac{\tilde{\xi}}{\mathcal{V}}$ and $\delta W_{\text{NP}} \sim e^{-a\tau_s}$
- Leading order F- and D-term potential (τ_s integrated out)

$$V_F(\mathcal{V}) \sim \frac{W_0^2}{\mathcal{V}^3}\left(\tilde{\xi} - \log^{3/2}\left(\frac{\mathcal{V}}{W_0}\right)\right), \qquad V_D(\mathcal{V}) \sim \frac{n^2}{\mathcal{V}^2}$$



Moduli Stabilisation - Isotropic Large Volume Scenario

Moduli stabilisation in *isotropic* large volume model with *D*-term uplift
[Balasubramanian, Berglund, Conlon, Quevedo, Suruliz, '05]
[Cremades, Garcia del Moral, Quevedo, Suruliz, '07]

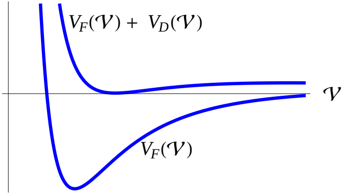
- $\mathcal{V} \sim \tau_b^{3/2} - \tau_s^{3/2}, \qquad \tau_b \gg \tau_s$
- Stabilisation through interplay between $\delta K_{\alpha'} \sim \frac{\tilde{\xi}}{\mathcal{V}}$ and $\delta W_{\text{NP}} \sim e^{-a\tau_s}$
- Leading order *F*- and *D*-term potential (τ_s integrated out)

$$V_F(\mathcal{V}) \sim \frac{W_0^2}{\mathcal{V}^3}\left(\tilde{\xi} - \log^{3/2}\left(\frac{\mathcal{V}}{W_0}\right)\right), \qquad V_D(\mathcal{V}) \sim \frac{n^2}{\mathcal{V}^2}$$

$\rightarrow$ Requires large W_0

- Issues (in *isotropic* model):
  - For $\mathcal{V} \simeq 10^6$ violation of D3-tadpole constraint
  - Parametrically $m_{3/2} \gg m_{\text{KK}}$
    [Discussion with Conlon, Quevedo, ...]
  - Overproduction of cosmic strings, $\xi > \xi_{\text{crit.}}$

$\rightarrow$ Consider *anisotropic* model



Moduli Stabilisation - Anisotropic Large Volume Scenario

Moduli stabilisation in *anisotropic* large volume model
[Cicoli, Conlon, Quevedo, '08]

- We consider

$$\mathcal{V} = \frac{1}{3!}\kappa_{111}t_1^3 + \frac{1}{2}\kappa_{122}t_1t_2^2 + \frac{1}{3!}\kappa_{sss}t_s^3, \qquad t_1 \gg t_2 \gg t_s$$

- Ratio $x \equiv t_1/t_2$ fixed by interplay between δK_{g_s} [Berg et al., '05] and D-term

$$\delta V_{g_s} \sim \frac{W_0^2}{\mathcal{V}^3\mathcal{V}^{1/3}}\,x^2, \qquad V_D \sim \frac{n^2}{\mathcal{V}^2}\frac{1}{x}$$

Moduli Stabilisation - Anisotropic Large Volume Scenario

Moduli stabilisation in *anisotropic* large volume model
[Cicoli, Conlon, Quevedo, '08]

- We consider

$$\mathcal{V} = \frac{1}{3!}\kappa_{111}t_1^3 + \frac{1}{2}\kappa_{122}t_1t_2^2 + \frac{1}{3!}\kappa_{sss}t_s^3, \qquad t_1 \gg t_2 \gg t_s$$

- Ratio $x \equiv t_1/t_2$ fixed by interplay between δK_{g_s} [Berg et al., '05] and D-term

$$\delta V_{g_s} \sim \frac{W_0^2}{\mathcal{V}^3\mathcal{V}^{1/3}}\, x^2, \qquad V_D \sim \frac{n^2}{\mathcal{V}^2}\frac{1}{x}$$

- Upshot: [Hebecker, SK, Küntzler, Lüst, Weigand, '12]
  - Allows for smaller W_0 (compared to isotropic model)
  - D3-tadpole constraint can be satisfied
  - $m_{3/2} \ll m_{\mathrm{KK}}$
  - Cosmic string bound satisfied

Conclusions & Further Issues

Fluxbrane Inflation:

- Model of stringy D-term hybrid inflation
- Attractive phenomenology (large volume, n_s, cosmic strings)
- Stabilisation of Kähler moduli in anisotropic large volume scenario
- Uplift via D-term possible

Conclusions & Further Issues

Fluxbrane Inflation:

- Model of stringy D-term hybrid inflation
- Attractive phenomenology (large volume, n_s, cosmic strings)
- Stabilisation of Kähler moduli in anisotropic large volume scenario
- Uplift via D-term possible

Next step: investigate higher order inflaton mass corrections

Brane modulus (= inflaton) enters:

- Superpotential $W \to$ Flux choice
  [work with M. Arends, A. Hebecker, K. Heimpel, C. Schick, T. Weigand]
- Kähler potential $K = -\log\left(S + \overline{S} - k\left(\varphi, \overline{\varphi}\right)\right)$ [Jockers, Louis, '04, '05]
  $\to$ Shift-symmetries (e.g. $K3 \times K3$)
- String loop corrections $\delta K_{g_s}\left(\varphi, \overline{\varphi}\right)$ [Berg, Haack, Körs, Pajer, '05, '07]