Joint seminar on cosmology and astroparticle physics
Tõravere, 26-27 February 2007

Topics in String Cosmology

(How to get accelerated expansion)

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Standard cosmology, accelerated expansion

- *Ad hoc*: Inflaton potential, value of cosmological constant

Fundamental string / M-theory

↑ ↓

„Phenomenological models"

↑ ↓

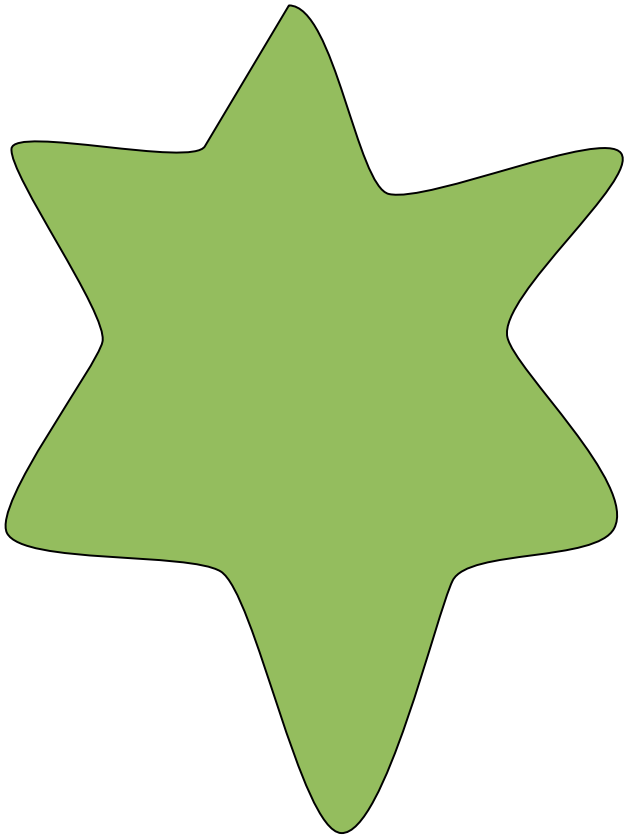
Observations, experiments

Web of String Theories

M-theory
D=11 N=1 sugra

D=11

Het E8xE8 strings
N=1 sugra + SYM E8xE8



IIA strings
IIA sugra

Het SO(32) strings
N=1 sugra + SYM SO(32)

IIB strings
IIB sugra

D=10

I strings
N=1 sugra + SYM SO(32)

Type II String Theory

$$S_{NS\text{-}NS} = \frac{1}{\kappa_{10}^2} \int d^{10}x \sqrt{-g}\, e^{-2\Phi} \left(R + 4(\partial\Phi)^2 - \frac{1}{2}|H_3|^2 \right)$$

$$S_{R\text{-}R} = -\frac{1}{4\kappa_{10}^2} \int d^{10}x \begin{cases} |F_2|^2 + |F_4|^2, & IIA \\ |F_1|^2 + |F_3|^2 + \frac{1}{2}|F_5|^2, & IIB \end{cases} \qquad F_6 = *F_4, \quad F_8 = *F_2, \quad F_5 = *F_5$$

- Dp-branes: dynamical (p + 1)-dimensional objects (with p spatial dimensions)
- F_n couples to the Dp-brane with p = n−2

To obtain a 4D observable world

- Compactification
- Braneworld large extra dimensions

No-go theorem

Compactifications of 10, 11 dim SUGRA on

- Time-independent
- Compact
- Smooth

internal space do not yield de Sitter vacua.

(Gibbons 1987, Maldacena, NuneZ 2001)

How to derive a scalar potential that leads to accelerated expansion?

- Potential induced by compactification
  - With fluxes
  - Time-dependent hyperbolic manifold
  - Time-dependent singular manifold
- Brane-antibrane potential

A simple model

$$S^{(d+m)} = \frac{1}{\kappa^{(d+m)}} \int \mathrm{d}^d x\, \mathrm{d}^m y\, \sqrt{-g} \left(R - \frac{1}{2\, m!}\, (F_m)^2 \right) \qquad F_m = b\, \mathrm{Vol}_{\mathrm{int}}$$

Compactify on a maximally symmetric space

$$\mathrm{d}s^2 = \tilde{g}_{\mu\nu}(x)\, \mathrm{d}x^\mu\, \mathrm{d}x^\nu + \hat{g}_{mn}(x,y)\, \mathrm{d}y^m\, \mathrm{d}y^n \qquad \hat{g}_{mn} = e^{2\beta(x)}\, \hat{\omega}_{mn}(y)$$

Space-time	Internal space
macroscopic	compact
d-dim	m-dim

$$\hat{R}_{mn}(\hat{\omega}) = k_1\, (m-1)\, \hat{\omega}_{mn}(y)$$

$$\int \mathrm{d}^m y\, \sqrt{-\hat{\omega}(y)} = 1$$

Effective action in 4D

$$S^{(4)} = \int \mathrm{d}^4 x \sqrt{-g} \left(\frac{1}{2} R - (\partial\phi)^2 - 2V(\phi) \right) \qquad V(\phi) = -\, k_1\, e^{-2c\phi} + \frac{\tilde{b}^2}{2} e^{-\frac{6}{c}\phi}$$

$$c = \sqrt{\tfrac{m+2}{m}} \qquad b^2 =: 4\, \tilde{b}^2 \left(\frac{4}{m\,(m-1)} \right)^{-3/c^2} \qquad \beta(x) = \frac{2}{m\, c}\, \phi(x) + \frac{1}{m+2} \ln \left(\frac{m(m-1)}{4} \right)$$

FRW cosmology of the model

- Acceleration: transient, eternal or eternally cyclic going to zero asymptotically (not good enough for inflation)

- Runaway potential

- Modulus not stabilized, spontaneous decompactification

(L. Järv, T. Mohaupt, F. Saueressig 2004)

Moduli trapping

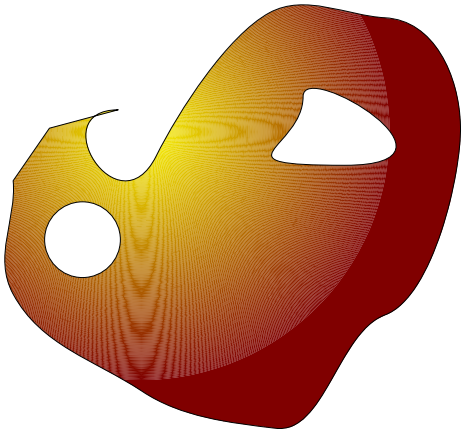
- Fluxes
- Non-perturbative effects

(S. Kachru, R. Kallosh, A. Linde, S. Trivedi 2003)

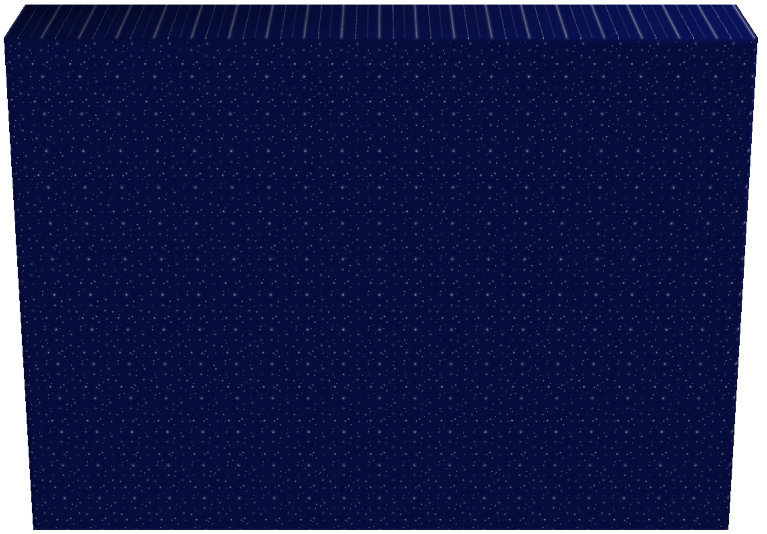
- ESP's (extra species points, enhanced symmetry points)

(M. Brändle, A. Lukas 2002,
L. Järv, T. Mohaupt, F. Saueressig 2003,
L. Kofman, A. Linde, X. Liu, A. Maloney, L. McAllister, E. Silverstein 2004)

Internal space (microscopic)



Spacetime (macroscopic)



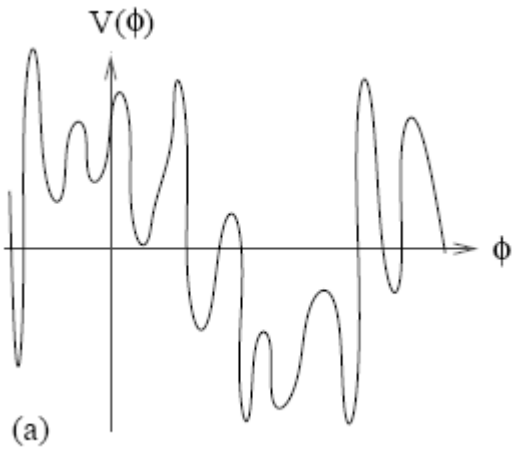
Moduli –
parameters describing the internal geometry and topology

Fluxes in the internal space

Scalar fields in spacetime (with a potential)

Cosmological constant – minimum of the potential

String theory landscape



Live in a local positive minimum
- Metastable, but long lifetime
- Eternal inflation

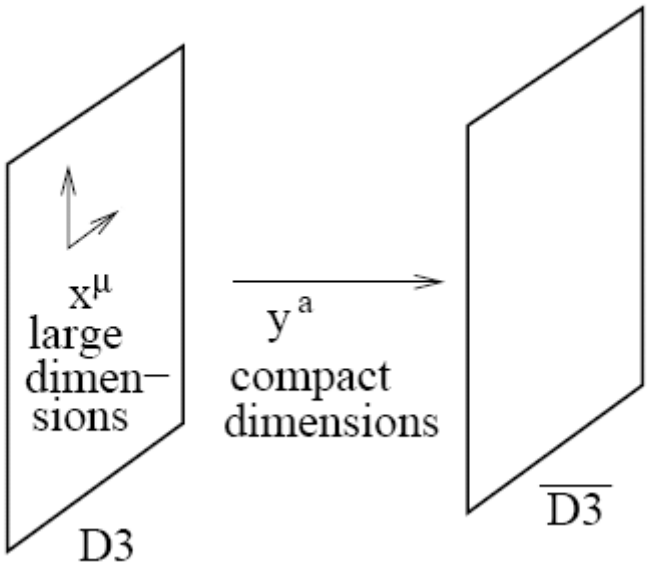
Number of different „vacua"
- e.g. in Calabi-Yau compactifications of type IIb string theory: 10^{500}
(M. Douglas 2003)

What to do?
- Statistics, anthropic selection
- Dynamical mechanism?

Brane and antibrane

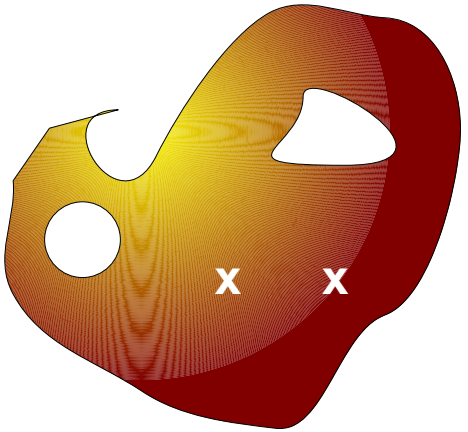
$$\tau_p = \frac{M_s^{p+1}}{(2\pi)^p g_s}$$

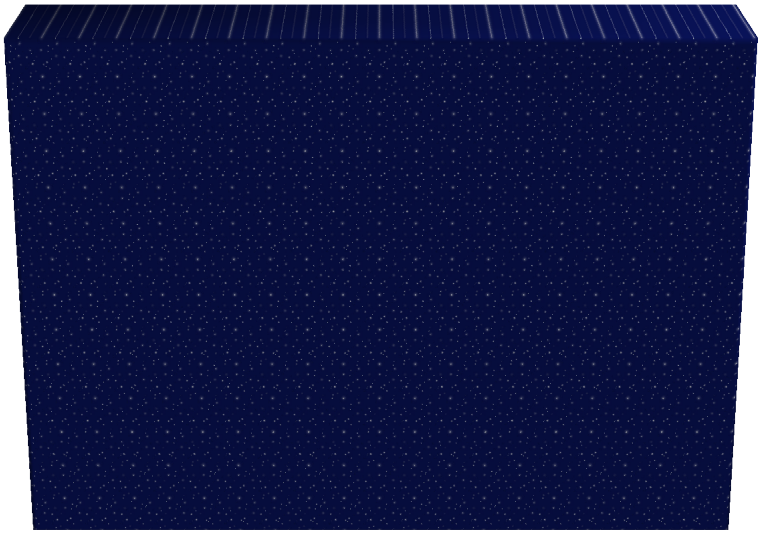
$$\mu_p = g_s \tau_p$$



$$V_{\rm tot} = \frac{G_{10}}{\frac{1}{4}\pi^2 r^4}\left(-\tau_3^2 \pm \frac{\mu_3^2}{g_s^2}\right) \begin{cases} \text{upper sign for D3-D3} \\ \text{lower sign for D3-}\overline{\text{D3}} \end{cases} \qquad G_{10} = (2\pi)^6 g_s^2/(8M_s^8)$$

Brane inflation





D3 brane and antibrane

Separated in internal space, but fill the 4D spacetime

For small velocities large separation

$$\phi = \sqrt{\tau_3}|\vec{y} - \vec{\tilde{y}}|$$

$$c = \frac{4}{\pi^2} G_{10} \tau_3^4$$

$$\mathcal{L} = \frac{1}{2}\dot{\phi}^2 + 2\left(\tau_3 - \frac{c}{\phi^4}\right)$$

At close sepration brane and antibrane annihilate

Unfortunately not slow roll

Various models

- Warped brane-antibrane inflation

S. Kachru, R. Kallosh, A. Linde, J. M. Maldacena, L. McAllisterm S. P. Trivedi 2003

- Superpotential corrections
- Tuning the length of the throat
- Multibrane inflation

- DBI inflation (D-celeration), fast roll

E. Silverstein, D. Tong, M. Alishahiha 2004

- Shift symmetry, D3-D7 inflation

K. Dasgupta, C. Herdeiro, S. Hirano and R. Kallosh 2002
J. P. Hsu and R. Kallosh 2004

- Racetrack and Kähler moduli inflation

J. J. Blanco-Pillado 2004