

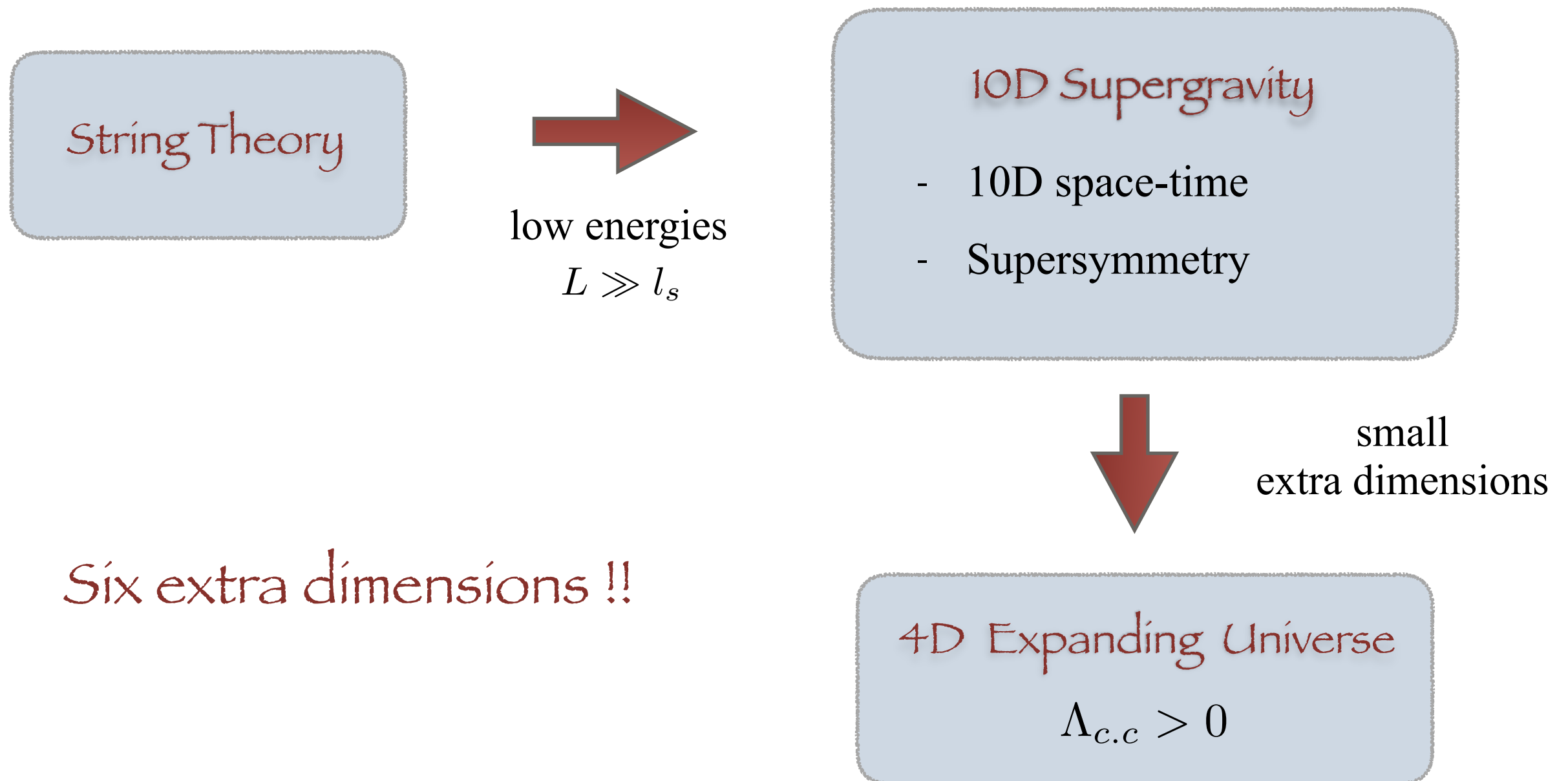
Expanding Universes from String Theory



Based on work in collaboration with Gianluca Inverso

Linking strings to the real world

- ❖ String theory provides a framework where to describe General Relativity and Quantum Field Theory
- ❖ The fundamental building blocks are tiny vibrating strings with $l_s \sim 10^{-33}$ cm



The footprint of the extra dimensions

- ❖ Fluctuations of the extra dimensions (size and shape) translate into a set of **massless** 4D scalar fields known as “**moduli fields**”

$$\mathcal{L} = R - \frac{1}{2} \partial_\mu \phi_i \partial^\mu \phi^i$$



Deviations
from GR !!

massless scalars = long range interactions (precision tests of GR)

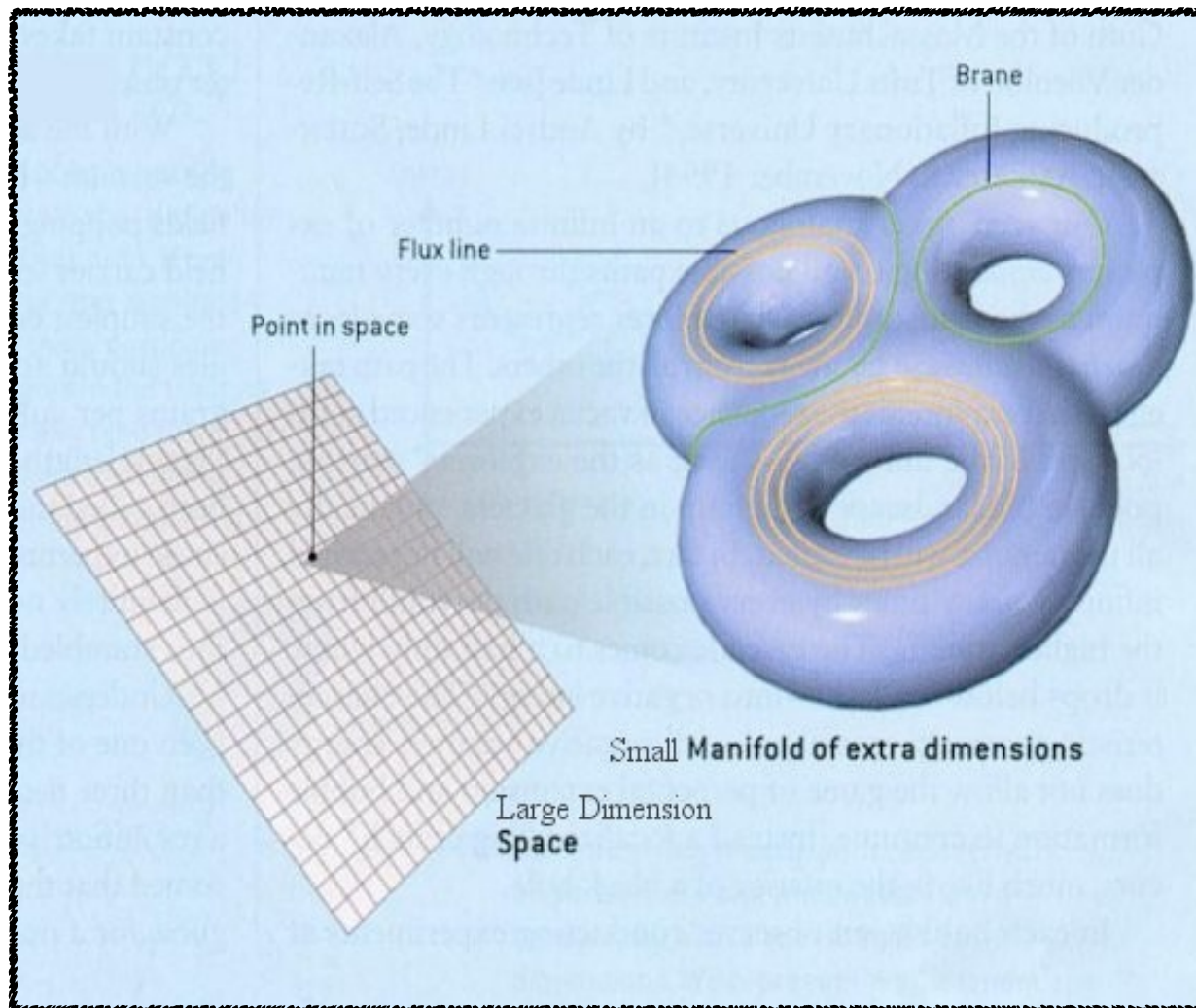
- ❖ String phenomenology \rightarrow Mechanisms for “**moduli stabilisation**”

$$V(\phi) = m_{ij}^2 \phi^i \phi^j + \dots$$

- ❖ The moduli VEVs $\langle \phi^i \rangle = \phi_0^i$ determine the **4D cosmological constant !!**

$$\Lambda_{c.c} \equiv V(\phi_0)$$

Extra dimensions...



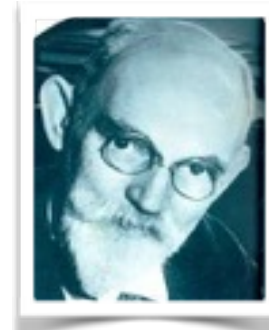
... will be non empty !!

- D-branes
- magnetic fluxes
- funny geometries

...

$$V(\phi) = V_{brane} + V_{flux} + V_{geom}$$

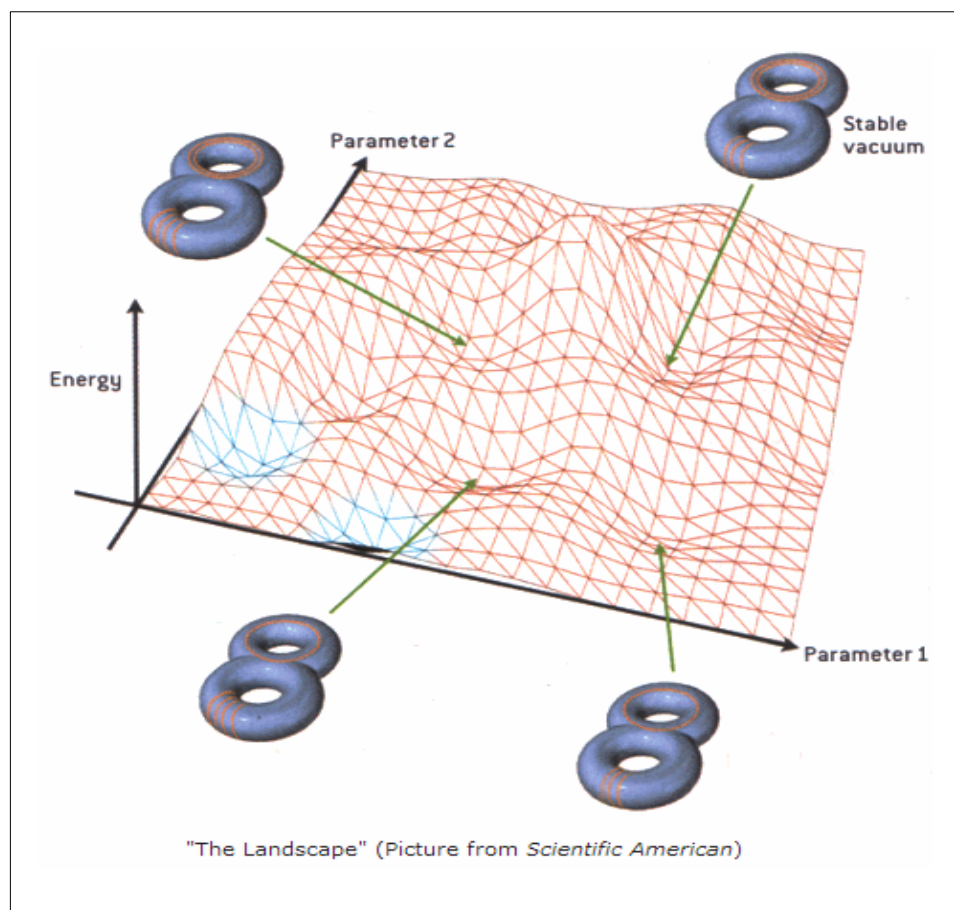
The problem = finding



Willem de Sitter
(1872 – 1934)

❖ Model building :

branes + fluxes + geometries + ... = parameters



$$\Lambda_{c.c} \equiv V(\phi_0) > 0$$

... but where is de Sitter

within the string landscape?

The KKLT mechanism

❖ Ingredients :

- Calabi-Yau manifold (geometry)
- Background fluxes and D-branes
- Non-perturbative effects
- **Anti D3-branes**

❖ Two-step process

- **Step 1 = stabilisation** (*wrong sign !!*)

The moduli fields get stabilised in a minimum with $V < 0$

- **Step 2 = uplift to a positive c.c**

Anti D3-branes uplift the minimum to a de Sitter one with $V > 0$

de Sitter Vacua in String Theory

Shamit Kachru,^{1,2} Renata Kallosh,¹ Andrei Linde¹ and Sandip P. Trivedi³

¹Department of Physics, Stanford University, Stanford, CA 94305-4060, USA

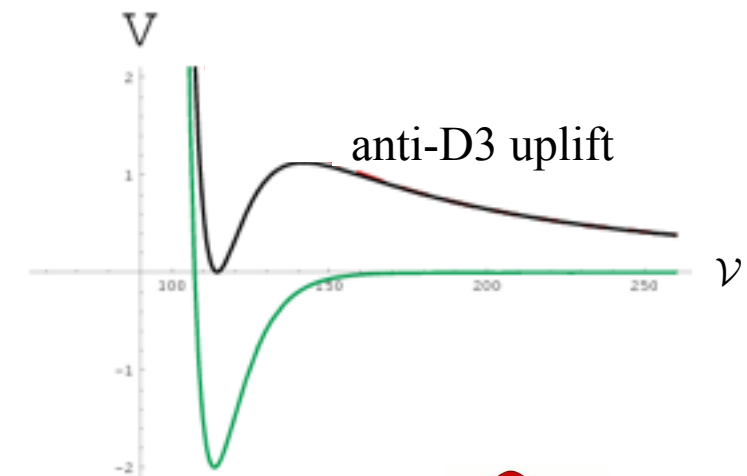
²SLAC, Stanford University, Stanford, CA 94309, USA and

³TIFR, Homi Bhabha Road, Mumbai 400 005, INDIA

We outline the construction of metastable de Sitter vacua of type IIB string theory. Our starting point is highly warped IIB compactifications with nontrivial NS and RR three-form fluxes. By incorporating known corrections to the superpotential from Euclidean D-brane instantons or gaugino condensation, one can make models with all moduli fixed, yielding a supersymmetric AdS vacuum. Inclusion of a small number of $\overline{D3}$ branes in the resulting warped geometry allows one to uplift the AdS minimum and make it a metastable de Sitter ground state. The lifetime of our metastable de Sitter vacua is much greater than the cosmological timescale of 10^{10} years. We also prove, under certain conditions, that the lifetime of dS space in string theory will always be shorter than the recurrence time.

PACS numbers: 11.25.-w, 98.80.-k; SU-ITP-03/01, SLAC-PUB-9630, TIFR/TH/03-03, hep-th/0301240

2188 citations (2003) !!



Anti D3-branes
are controversial !!

Matter fields as an alternative to uplift mechanisms

❖ Ingredients :

- Calabi-Yau manifold (geometry)
- Background fluxes and D-branes
- Non-perturbative effects usually require matter fields M

$$[KKLT] \quad W_{n.p} \sim A e^{-\mathcal{V}^{2/3}} \quad \rightarrow \quad W_{n.p} \sim A(M) e^{-\mathcal{V}^{2/3}} \quad [us]$$

- ❖ Single-step process = *No need for uplift mechanisms or ~~Anti-D3-branes~~ !!*

Single-step moduli stabilisation in a de Sitter minimum $(V > 0)$

Single-step de Sitter vacua from non-perturbative effects with matter

Adolfo Guarino and Gianluca Inverso

Nikhef, Science Park 105, 1098 XG Amsterdam, The Netherlands

A scenario of moduli stabilisation based on the interplay between closed and open string sectors is explored in a bottom-up approach. We study $\mathcal{N} = 1$ effective supergravities inspired by type IIB orientifold constructions that include background fluxes and non-perturbative effects. The former generate the standard flux superpotential for the axiodilaton and complex structure moduli. The latter can be induced by gaugino condensation in a non-Abelian sector of D7-branes and involve the overall Kähler modulus of the compactification as well as matter fields. We analyse the dynamics of this coupled system and show that it is compatible with single-step moduli stabilisation in a metastable de Sitter vacuum. A novelty of the scenario is that the F-term potential suffices to generate a positive cosmological constant and to stabilise all moduli, except for a flat direction that can be either lifted by a mass term or eaten up by an anomalous U(1).

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e-mails: aguarino@nikhef.nl, ginverso@nikhef.nl

(2015)

Summary

- ❖ The fact that our Universe is currently undergoing a phase of accelerated expansion makes the **search for de Sitter vacua** a key step towards linking strings to cosmological data
- ❖ Finding de Sitter in the string landscape remains elusive and most of the examples are based on the **KKLT mechanism : stabilisation ($V < 0$) + uplift**
- ❖ We propose a novel **single-step mechanism of moduli stabilisation** in a de Sitter vacuum that takes into account **matter fields** and avoids the standard problems with the uplift mechanisms (Anti D3-branes)
- ❖ We plan to explore other cosmological implications : moduli inflation, ...

Dank u wel!!