Moduli Stabilisation & De Sitter Vacua

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Outline

Introduction

Moduli Stabilisation in N=4

Stable De Sitter in N=2

Conclusions

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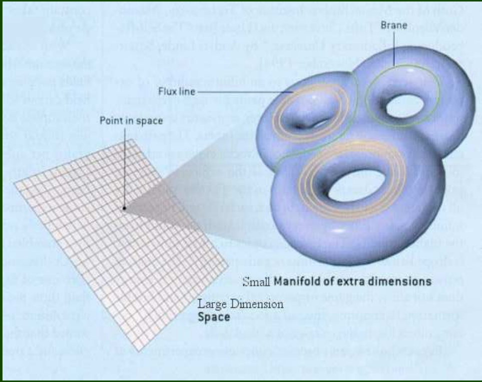
Compactifications

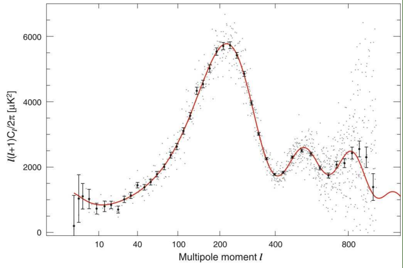


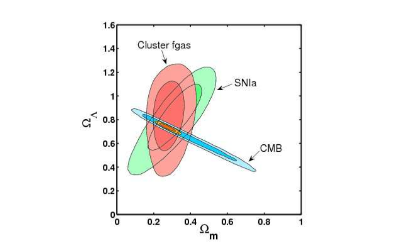
Need for moduli stabilisation!

Cosmology

Challenges for string theory:

- Inflation (1980's - ...)
- Λ-CDM (1990's - ...)





Where is De Sitter in the string theory landscape?

De Sitter in string theory

Focus on extended $N \geq 2$ supergravity: interesting playground with stronger constraints.

Scalar potentials are generated only by gaugings.

Positive and negative results in different flavours of supergravity:

- $N = 4, 8$: unstable dS[1] with $\eta = \mathcal{O}(1)$
- $N = 2$: stable dS[2]

Higher-dimensional origin?

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[1] (Kallosh, Linde, Prokushkin, Shmakova '01, De Roo, Westra, Panda, (Trigiante) '02)

[2] (Fré, Trigiante, Van Proeyen '03)

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N=4 supergravity

Effective theory of type I / heterotic on T^6 or type II / M-theory on $K3 \times T^2$ or with orientifolds.

Key ingredients:

- Supergravity plus n vector multiplets
- Global symmetry $SL(2) \times SO(6, n)$
- Vectors in fundamental rep. of $SO(6, n)$, and into e-m dual under $SL(2)$

gaugings

N=4 gauged supergravity

Possible gaugings classified by parameters[1] $f_{\alpha MNP}$ and $\xi_{\alpha M}$ which are a doublet under $SL(2)$.

Simple gauge group has structure constants and $SL(2)$ angle.

Crucial for moduli stabilisation:

- Gauge group is product of factors $G_1 \times G_2 \times \cdots$
- Factors have different $SL(2)$ angle ("duality or De Roo-Wagemans angles[2]")

If not, the scalar potential has runaway directions.

One needs gaugings at angles.

dS

[1] (Schon, Weidner '06)
[2] (De Roo, Wagemans '85)

De Sitter vacua in N=4

Known De Sitter vacua in[1] $N = 4$:

$$G_1 \times G_2 \,, \quad \text{with } G_i = SO(p_i, 4 - p_i)\,.$$

(Plus some exceptional cases.)

All unstable with $\eta = -2 + \delta\eta < 0$.

No stable De Sitter vacua are expected for $N \geq 4$ - proof[2]?

origin

[1] (De Roo, Westra, Panda, (Trigiante) '02)

[2] (Gomez-Reino, Scrucca, (Covi), (Gross), (Louis), (Palma) '07, '08) - cf. talk by Palma

Gaugings at angles

But where do gaugings at angles come from?

Introduced in supergravity in 1985, but string theory origin was unknown.

Higher-dimensional origin: orientifold reductions

Key ingredients[1] : massive IIA with NS-NS flux and O6-planes.

model

[1] (D.R. '09, Dall'Agata, Villadoro, Zwirner '09)

Gaugings at angles

Simple set-up gives rise to nilpotent gauge groups[1]:

$$G_1 \times G_2 \,, \quad \text{with } G_i = CSO(1,0,3)\,.$$

Triple group contracted versions of $SO(p_i, 4 - p_i)$.

Moduli stabilised in Minkowski vacuum.

No-go theorem: (massive) IIA compactifications with gauge fluxes and O6-planes cannot lead to dS[2].

dS

[1] (D.R., '09)

[2] (Hertzberg, Kachru, Taylor, Tegmark '07) - cf. talk by Zagermann

Uplift to De Sitter?

In $N = 4$ flux compactifications one can also include geometric fluxes. Can these be used[1] to 'undo' the group contraction?

$$CSO(1,0,3) \to CSO(p,2-p,2) \to ISO(p,3-p) \to SO(p,4-p)\,.$$

First $N = 4$ flux compactification to dS?

Connection with $N = 1$ compactification on $SU(2) \times SU(2)$ group manifold[2], leading to unstable De Sitter. Includes the same fluxes as $N = 4$, but has more O6-planes and hence weaker quadratic constraints.

If nothing else: use non-geometric fluxes.

[1] (Dibitetto, Linares, DR, work in progress)
[2] (Caviezel, Koerber, Körs, Lüst, Wrase, Zagermann '08)

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Stable De Sitter in N=2

In $N \geq 4$ all known dS vacua have $\eta < 0$.

In contrast, there are a few, mysterious examples known of stable dS[1] in $N = 2$.

Additional complications in $N = 2$: hypermultiplets, more general scalar manifolds, ...

Crucial ingredients:

- Non-compact gaugings
- Gaugings at angles
- Fayet-Iliopoulos parameters / non-trivial hypersector

Higher-dimensional origin or relation to $N > 2$ unknown.

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[1] (Fre, Trigiante, Van Proeyen '02)

Example

Five vector multiplets and two hyper multiplets.

Scalar manifold chosen to be G/H with

$$G = \underbrace{SL(2) \times SO(2,4)}_{\text{vector}} \times \underbrace{SO(4,2)}_{\text{hyper}} .$$

Gauge group chosen to be

$$SO(2,1) \times SO(3) ,$$

with different duality angles, and both factors acting on both $SO(2,4)$ and $SO(4,2)$ parts of scalar manifold.

Relation to $N = 4$

There is a simple relation[2] between unstable dS in $N = 4$ and stable dS in $N = 2$: one can perform a $\mathbb{Z}_2$ or $\mathbb{Z}_2{}^2$truncation that projects out the unstable directions in $N = 4$ moduli space.

Leads to known models plus more.

Three-step procedure towards stable dS in string theory:

$$
\begin{array}{lccc}
 & \underline{N=4} & & \underline{N=2} \\
\text{dS:} & SO(3,1)^2 & \rightarrow & SO(2,1)\times SO(3) \\
 & \uparrow & & \\
\text{Mink:} & CSO(1,0,3)^2 & &
\end{array}
$$

[2] (work in progress)

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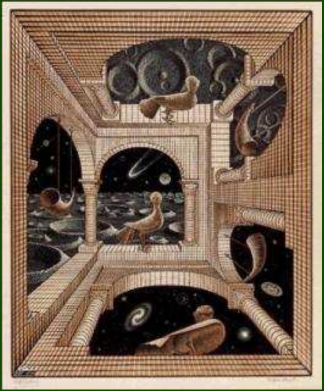
Conclusions

- Moduli stabilisation and De Sitter in extended supergravity
- Higher-dimensional origin for gaugings at angles
- Possibility for dS in $N = 4$?
- Relation to stable dS in $N = 2$?
- String theory embedding of dS in extended supergravity?
- Inflation?



Thanks for your attention!