Moduli Stabilisation and De Sitter in Extended Supergravity [1]

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[1] (D.R., arXiv:0902.0479), (Dibitetto, Linares, D.R., in progress), (D.R., Rosseel, in progress)

Outline

Introduction

Moduli Stabilisation in N=4

Stable De Sitter in N=2

Conclusions

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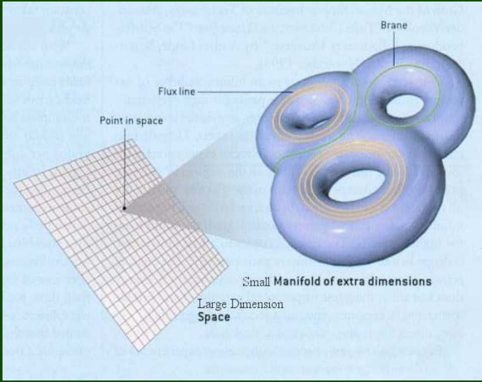
Compactifications

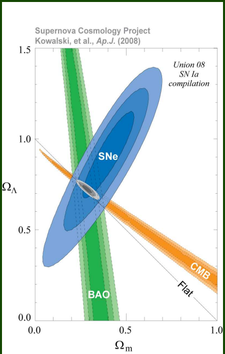


Need for moduli stabilisation!

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:

- $N = 8$: gauge groups $SO(4,4)$ or $SO(5,3)$ with unstable dS[1]
- $N = 4$: gauge groups with unstable dS[2]
- $N = 2$: stable dS[3]
- no-go theorems for stable dS in various theories[4]

Higher-dimensional origin? Relations between models?

[1] (Hull, Warner '85, Kallosh, Linde, Prokushkin, Shmakova '01
[2] (De Roo, Westra, Panda, (Trigiante) '02)
[3] (Fré, Trigiante, Van Proeyen '03)
[4] (De Wit, Van Proeyen, ... '84, '85, Gomez-Reino, Louis, Scrucca,... '07, '08)

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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]")
  ("electric and magnetic gauge factors[3]")

If not, the scalar potential has runaway directions.

One needs gaugings at angles.

dS

[1] (Schon, Weidner '06)
[2] (De Roo, Wagemans '85)
[3] (De Wit, Samtleben, Trigiante '02)

De Sitter vacua in N=4

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

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

(Plus some exceptional cases.)

All unstable. 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)

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 Wrase

Uplift to De Sitter?

In $N = 4$ flux compactifications one can also include geometric fluxes. Can these be used 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?

IIB duality frame

IIB duality frame

Convenient to go to IIB duality frame with O3-plane:
only gauge and non-geometric fluxes[1].

Gauge groups spanned by[2]

- electric: R-R gauge flux F and NS-NS non-geometric flux Q
- magnetic: NS-NS gauge flux H and R-R non-geom. flux P

Gauge fluxes F and H give rise to product of nilpotent groups.

The non-geom. fluxes P and Q enhance this to $SO(p_i, 4 - p_i)$[3].

Only geometric fluxes: no duality frame with $SO(p_i, 4 - p_i)$ gauge groups. The magnetic factor is always nilpotent.

[1] (Shelton, Taylor, Wecht '05)
[2] (Aldazabal, Cámara, Rosabal '08)
[3] (De Carlos, Guarino, Moreno '09, Dibitetto, Linares, D.R., to appear)

Uplift to De Sitter?

None of the known $N = 4$ models with dS follow from compactifications with gauge and/or geometric fluxes. Need to include non-geometric fluxes!

Other models that also allow for dS[1]?

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.

[1] (Dibitetto, Linares, D.R., to appear)
[2] (Caviezel, Koerber, Körs, Lüst, Wrase, Zagermann '08), cf talk by Wrase

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Stable De Sitter in N=2

In $N \geq 4$ all known dS vacua are unstable.

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.

example

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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[1] 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.

Requirement: structure constants be even w.r.t. $\mathbb{Z}_2$.

Leads to known models plus more.

truncations

[1] (D.R., Rosseel, work in progress)

Truncations from $N = 4 \to N = 2$

Truncation 1: global symmetry $SO(6,6) \to SO(2,4) \times SO(4,2)$:

$$SO(3,1) \times SO(3,1) \to SO(2,1)_{\mathrm{H}} \times SO(3)_{\mathrm{H}}\,,$$

$$SO(3,1) \times SO(2,1) \to \begin{cases} SO(2,1)_{\mathrm{H}} \times SO(2)_{\mathrm{H}}\,, \\ SO(2,1) \times SO(3)_{\mathrm{H}}\,, \end{cases}$$

$$SO(2,2) \times SO(2,2) \to SO(2,1) \times SO(2)_{\mathrm{H}} \times SO(1,1)^2_{\mathrm{H}}\,,$$

Truncation 2: global symmetry $SO(6,6) \to SO(2,2) \times SO(4,4)$:

$$SO(3,1) \times SO(2,1) \to SO(2,1)_{\mathrm{H}} \times SO(2)_{\mathrm{H}}\,,$$
$$SO(2,1) \times SO(2,1) \to SO(2,1) \times SO(2)_{\mathrm{H}}\,,$$
$$SU(2,1) \times SO(2,1) \to SO(2,1)_{\mathrm{H}} \times SO(1,1)_{\mathrm{H}}\,, \quad (\text{in the } \mathbf{5} \text{ rep!})\,,$$

Subscript H indicates action on hypersector. Hypersector can be truncated in absence of $SO(1,1)_{\mathrm{H}}$ or $SO(2,1)_H$ factors.

Truncations from $N = 8 \to N = 4$

Global symmetry $E_7 \to SL(2) \times SO(6,6)$:

$$SO(4,4) \to \begin{cases} SO(4) \times SO(4)^{1}\,, \\ SO(3,1) \times SO(3,1)\,, \\ SO(2,2) \times SO(2,2)\,, \end{cases}$$

$$SO(5,3) \to \begin{cases} SO(4) \times SO(3,1)\,, \\ SO(3,1) \times SO(2,2)\,, \end{cases}$$

Leads to a subset of unstable $N = 4$ models with dS[2].

(almost) All $N = 4$ models with dS either come from $N = 8$ or can be truncated to $N = 2$.

[1] (Hull, Warner '86)
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[2] (D.R., Rosseel, to appear)

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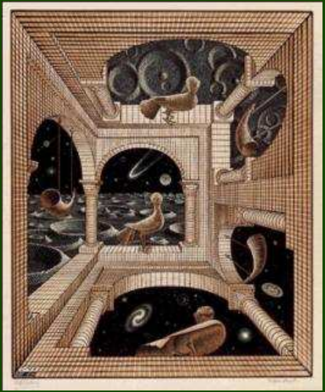
Conclusions

- Moduli stabilisation and De Sitter in extended supergravity
- Higher-dimensional origin for gaugings at angles.
- None of $N = 4$ models from (gauge and geometric) flux compactifications. Need for non-geometric fluxes.
- Web of truncations between dS models in $N = 2, 4, 8$. Higher-N origin of stable dS (and Fayet-Iliopoulos terms) in $N = 2$.
- String theory embedding of dS in extended supergravity?
- Inflation?



Thanks for your attention!