Connecting vacua

of half-maximal supergravities :

a type IIA example

Adolfo Guarino

University of Groningen

27th Nordic Network Meeting on "Strings, Fields and Branes"

25 March 2011, Copenhagen

with G. Dibitetto and D. Roest : arXiv:1102.0239

The footprint of extra dimensions

- Four dimensional supergravity theories appear when compactifying string theory

- Fluctuations of the internal space around a fixed geometry translates into massless 4d scalar fields known as ``*moduli*''

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

Deviations from GR !!

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

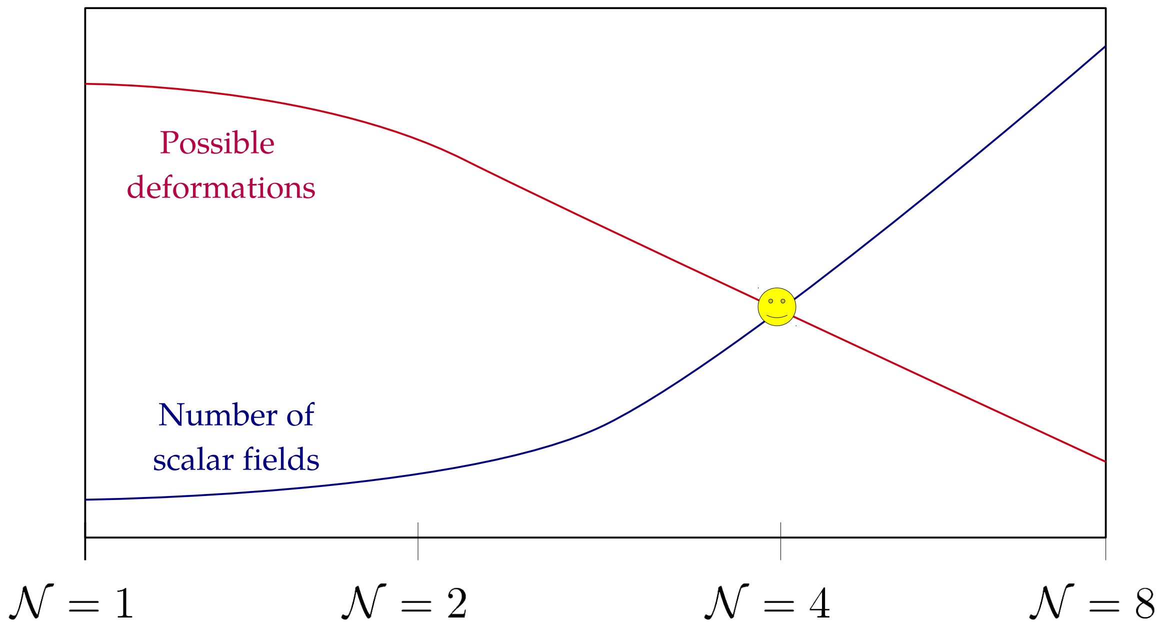
Linking strings to observations → Mechanisms to stabilise moduli !!

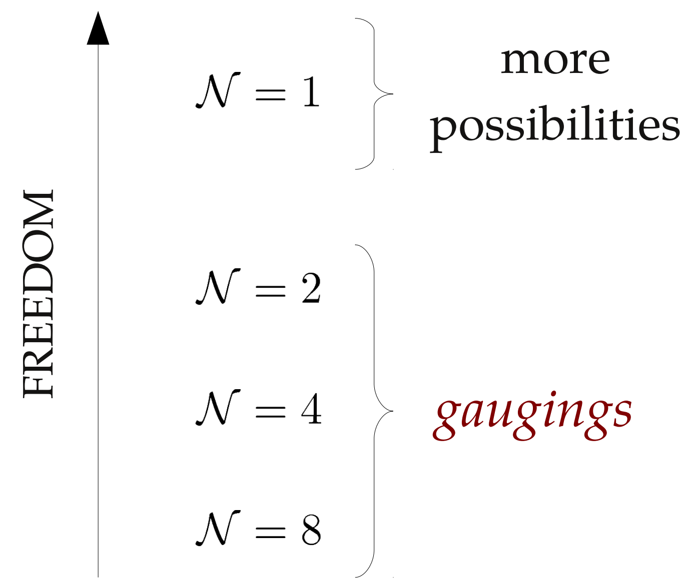
$$V(\phi) = m_{ij}^2 \, \phi^i \phi^j + \ldots$$

- Moduli VEVs $\langle \phi \rangle = \phi_0$ determine 4d physics
  - $\Lambda_{c.c} \equiv V(\phi_0)$
  - g_s and Vol_{int}
  - fermi masses

How to deform massless theories to have $V(\phi) \neq 0$?

- Supersymmetry dictates what deformations are allowed





gaugings = part of the global symmetry is promoted to local (*gauge*)

Questions :

- Can the whole vacuum structure be charted in $\mathcal{N}=4$ theories ?
- Are there connections in the landscape of vacua ?

Half-maximal supergravities

- $\mathcal{N}=4$ supergravities are commonly found in string reductions
- Global symmetry group $G = SL(2) \times SO(6,6)$
- Field content = supergravity multiplet + six vector multiplets
- Vectors $A_\mu^{\alpha M}$ in the fundamental of G

  $\alpha = +,-$ is an electric-magnetic $SL(2)$ index
  $M = 1,...,12$ is an $SO(6,6)$ index
  } 24 vectors

- The scalar sector parameterises the coset space $\mathcal{M} = G/H$ where H is the maximal compact subgroup of G

  - 1 axion + 1 dilaton in SL(2)
  - 30 axions + 6 dilatons in SO(6,6)

  } 38 scalars

Gaugings and scalar potential

[Schon, Weidner '06]

- A subgroup $G_0 \subset SL(2) \times SO(6,6)$ is promoted to local (*gauged*)

- *Gaugings* are classified by the embedding tensor parameters

$$\xi_{\alpha M} \in (\mathbf{2}, \mathbf{12}) \qquad \text{and} \qquad f_{\alpha MNP} \in (\mathbf{2}, \mathbf{220})$$

- Supersymmetry + gauge invariance determine the scalar potential

$$V(\Phi) = \sum_{\text{terms}} f\, f\ \Phi^{\text{high degree}} + \xi\, \xi\ \Phi^{\text{high degree}}$$

Quadratic in the emb. tens. parameters !!

The SO(3) truncation

- Keeping SO(3)-invariant fields and embedding tensor parameters
  - global symmetry $G = SL(2) \times SO(2,2)$
  - $\xi_{\alpha M} = 0$
  - scalar coset = 3 complex scalars = STU – models !!

[Derendinger, Kounnas, Petropoulos, Zwirner '04]

- The *gaugings* $G_0 \subset G$ and the scalar potential $V(S,T,U)$ are specified by the embedding tensor parameters $f_{\alpha MNP}$

gaugings

$$A_\mu = A_\mu^{\alpha M}\, T_{\alpha M}$$

$$[T_{\alpha M}, T_{\beta N}] = f_{\alpha\, MN}{}^P\; T_{\beta P}$$

→

Quadratic Constraints

$$\epsilon^{\alpha\beta}\, f_{\alpha MNR}\, f_{\beta PQ}{}^R = 0$$

$$f_{\alpha R[MN}\, f_{\beta PQ]}{}^R = 0$$

- String embedding as type II orientifold reductions

generalised fluxes = $f_{\alpha MNP}$

[Dibitetto, Linares, Roest '10]

We would like to . . .

1) build all the consistent SO(3)-invariant gaugings specified by $f_{\alpha MNP}$
by solving the quadratic constraints

$$\epsilon\, f\, f = 0 \qquad \text{and} \qquad f\, f = 0$$

2) compute all the SO(3)-invariant extrema of the f-induced scalar potential $V(f\,,\,\Phi)$ by solving the extremisation conditions

$$\left.\frac{\partial V}{\partial \Phi}\right|_{\Phi_0} = 0 \qquad \text{with} \qquad \Phi \equiv (\,S\,,\,T\,,\,U\,)$$

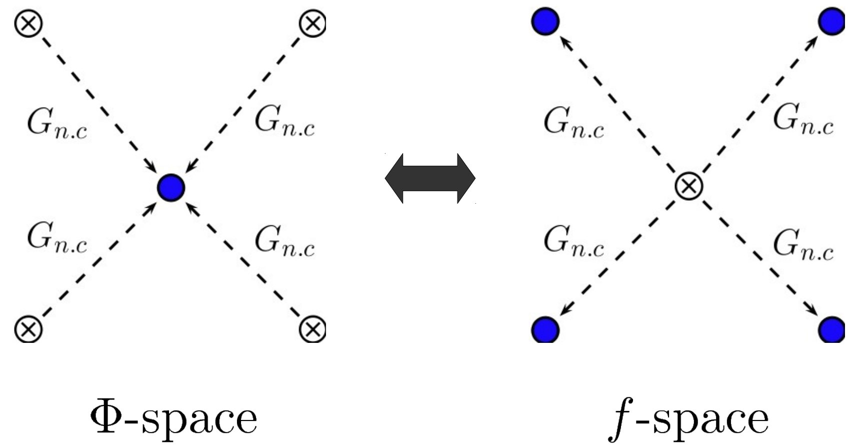
3) check stability of these extrema with respect to fluctuations of all the 38 scalars of half-maximal supergravity

4) identify the gauge group G_0 underlying all the different solutions

. . . but is this doable ?

Strategy and tools

- Idea : use the global symmetry group (non-compact part) to bring any field solution back to the origin !!



- At the origin everything is simply quadratic in the $f_{\alpha MNP}$ parameters

computing the vacua structure	=	solving a quadratic ideal $I = \langle\, \partial_\Phi V|_{\Phi_0} \;,\; \epsilon\, f\, f \;,\; f\, f\,\rangle$

- Algebraic Geometry algorithms : GTZ prime decomposition , . . .

[*Singular* project, 97]

$$I = J_1 \cap J_2 \cap \ldots \cap J_n$$

Splitting of the landscape into n disconnected pieces !!

An example : type IIA with metric fluxes

- Testing the method with type IIA orientifold models including gauge fluxes and a metric flux [Dall'Agata, Villadoro, Zwirner '09]

$$\left(F_{p=0,2,4,6} \quad , \quad H_3 \right) \quad + \quad \omega \quad \subset \quad f_{\alpha MNP}$$

Q.C. of *gaugings* = B.I. + tadpoles cancellation

- Subset of embedding tensor components closed under $G_{n.c}$
  - Fields can still be set at the origin without lost of generality
  - Stability with respect to fluctuations around the origin can be computed

[Borghese, Roest '10]

- Vacua structure of these type IIA orientifolds

16 AdS_4 critical points + Mink of dim=1 → GKP after three T-dualities

[Giddings, Kachru, Polchinski '02]

The 16 critical points

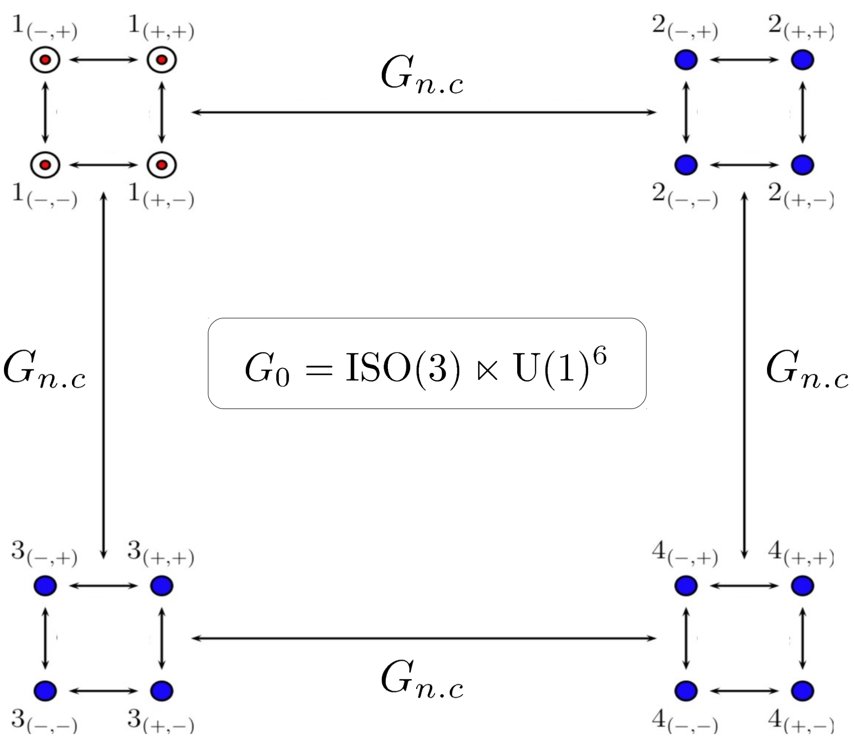
- An AdS$_4$ landscape

  $16 = 4 + 4 + 4 + 4$

- All the solutions are embeddable in $\mathcal{N} = 8$

$1_{(\pm,\pm)}$	$2_{(\pm,\pm)}$	$3_{(\pm,\pm)}$	$4_{(\pm,\pm)}$
$\mathcal{N} = 1$ SUSY & FAKE SUSY	~~SUSY~~	~~SUSY~~	~~SUSY~~
stable	unstable	stable	stable
m^2 = -2/3	m^2 = -4/5	$m^2 > 0$	$m^2 > 0$
V= -1	V= -32/27	V= -8/15	V= -32/27

$(*)\ m^2 \equiv$ lightest mode (B.F. bound $= -3/4$)



- All the solutions are connected
- Unique *gauging*

Unique theory

with 4 different vacua !!

Conclusions

- Some progress towards disentangling the landscape of half-maximal supergravities can still be done without performing statistics of vacua

- The approach relies on the combined use of global symmetries and of algebraic geometry techniques

- As a warming-up, the complete vacua structure of simple type IIA orientifold theories can be worked out revealing some odd features :

  i) stability without supersymmetry
  ii) connections between vacua
  iii) $\mathcal{N} = 8$ embedding of the entire vacua structure

- For the future :

  - Going beyond the geometric limit : non-geometric backgrounds . . .

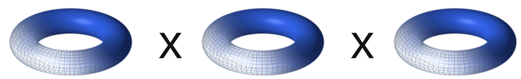
  - Systematic search of de Sitter stable solutions in extended supergravity and also links to Cosmology

Thanks for your attention !!

Extra material . . .

Internal geometries and massless theories . . .

``maximal''

$\mathbb{T}^6 =$ 

$\mathcal{N} = 8$ (70 scalars)

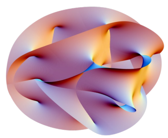
Type II 10d supergravity

``half-maximal''

Orientifolds of $\mathbb{T}^6$

$\mathcal{N} = 4$ (38 scalars)

``minimally extended''

$CY_3 =$ 

$\mathcal{N} = 2$

scalars $\leftrightarrow \left(h^{(1,1)}, h^{(1,2)}\right)$

``minimal''

Orientifolds of CY_3

$\mathcal{N} = 1$ scalars $\leftrightarrow \left(h^{(1,1)}, h^{(1,2)}\right)$

Lower bound on topologically distinct CY_3
30108

Gaugings and their higher-dimensional origin

- Scalars potentials are induced by *``gaugings''* : Part of the global symmetry is promoted to local (*gauge*)

[de Wit, Samtleben, Trigiante '07]
[Schon, Weidner '06]

- $\mathcal{N}=8$: Gauging a subgroup of the global symmetry $G=E_7$

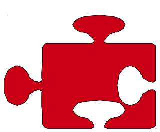
Internal space extension ⟷ Exceptional Generalised Geometry ?

[Pacheco, Waldram '08 , Grana, Louis, Sim, Waldram '09]
[Aldazabal, Andrés, Cámara, Grana '10]

- $\mathcal{N}=4$: Gauging a subgroup of the global symmetry $G=SL(2)\times SO(6,6)$

Internal space extension ⟷ Doubled/Generalised Geometry ?

[Hitchin '02, Gualtieri '04]
[Hull '04, '06]



pathological
internal spaces

String compactifications including generalised flux backgrounds !!

De Sitter in extended supergravity

- $\mathcal{N} = 8$: unstable dS solutions with $SO(4,4)$ and $SO(5,3)$ gaugings

[Hull, Warner '85]

- $\mathcal{N} = 4$: unstable dS solutions with gaugings at *angles*

[De Roo, Wagemans '85]

i) $G_1 \times G_2$ gaugings with $\begin{cases} G_i = SO(p_i, q_i) \quad , \quad p_i + q_i = 4 \\ G_i = CSO(p_i, q_i, r_i) \quad , \quad p_i + q_i + r_i = 4 \end{cases}$

[De Roo, Westra, Panda, (Trigiante) '02, '03, '06]

ii) $SO(3,1) \ltimes U(1)^6$ gauging

[Dibitetto, A.G, Roest '11]

non-geometric fluxes in string theory !!

[Dibitetto, Linares, Roest '10]

- $\mathcal{N} = 2$: stable dS solutions with $SO(2,1) \times SO(3)$ gauging plus Fayet-Iliopoulos terms

[Fré, Trigiante, Van Proeyen '03]

unclear origin in string theory !!

De Sitter in minimal supergravity

- No-go theorems forbidding dS solutions in $\mathcal{N}=1$ compactifications with magnetic fluxes

$$V_o = -\frac{1}{9}\sum \bar{F}^2 \leq 0 \quad \Longrightarrow \quad \text{AdS !!}$$

[Hertzberg, Kachru, Taylor, Tegmark '07]

- Including **more general fluxes** : (metric + non-geometric)

$$V_o = -\frac{1}{9}\sum \bar{F}^2 + \Delta V_{\text{metric}} + \Delta V_{\text{non-geom}}$$

a) metric fluxes ⟷ unstable dS in type IIA models

[Caviezel, Koerber, Kors, Lust, Wrase, Zagerman '08]

b) non-geometric fluxes ⟷ stable dS in type IIA models

[de Carlos, A.G, Moreno '09, '10]

- Including D-branes to **uplift an AdS** solution

[Kachru, Kallosh, Linde, Trivedi '03]

a) D-terms from D-branes ⟷ stable dS in type IIB models

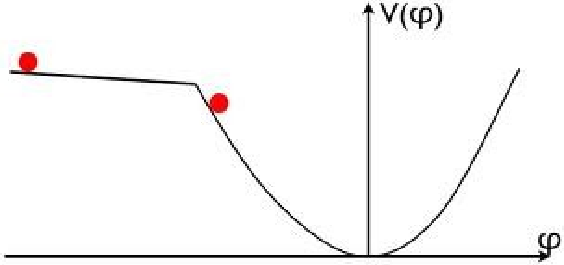
[Burgess, Kallosh, Quevedo '03]

b) non-perturbative effects from D-branes ⟷ stable dS in type IIB

[Achúcarro, de Carlos, Casas, Doplicher '06]

Cosmology from moduli ?

- slow-roll inflation requires an almost flat dS saddle point of $V(\phi)$ from which to start rolling down



$$\eta \equiv M_p^2 \left(\frac{V''}{V} \right) \ll 1$$

- dS saddle points suffering from eta-problem, *i.e.* $\eta \sim \mathcal{O}(1)$

i) gaugings in extended supergravity [Kallosh, Linde, Prokushkin, Shmakova '01]

ii) general fluxes in minimal supergravity [Flauger, Paban, Robbings, Wrase '08] [de Carlos, A.G, Moreno '10]

- dS saddle points with $\eta \ll 1$ in minimal supergravity including non-perturbative effects $\Longrightarrow$ axion inflation !!

[Dimopoulos, Kachru, McGreevy, Wacker '05]