Flux vacua from gauged supergravities

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with G. Dibitetto and D. Roest :   arXiv:1102.0239
                                     arXiv:1104.3587
                                     arXiv:11xx.xxxx   *(...in progress)*

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)

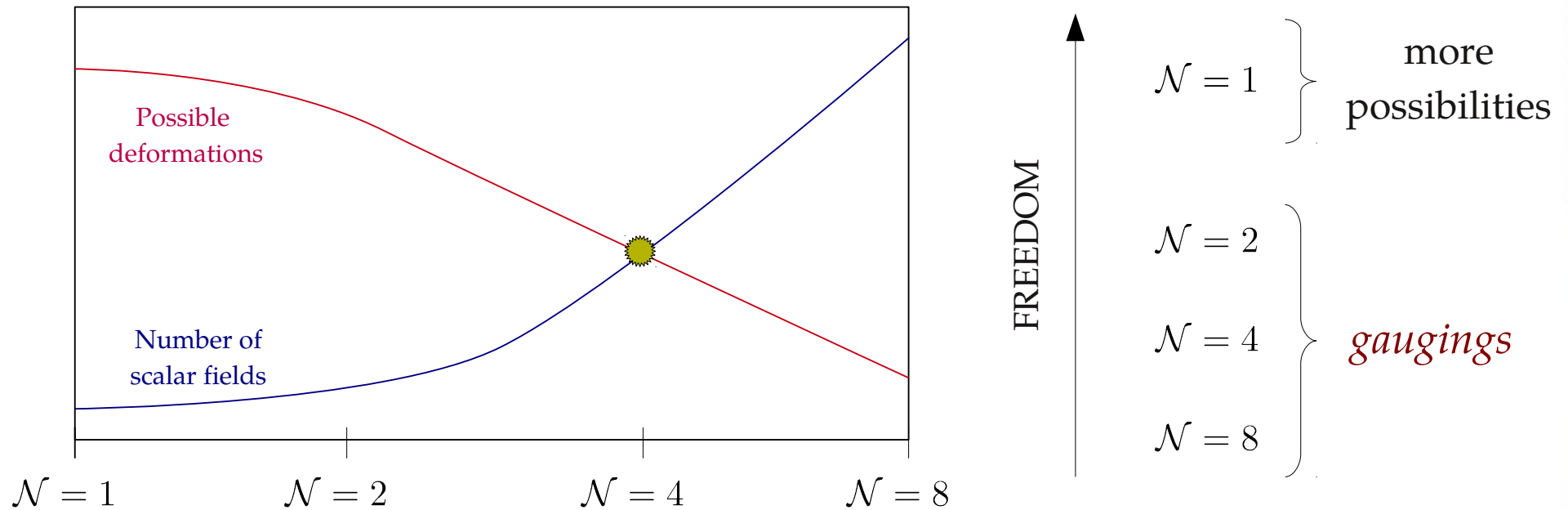Linking strings to observations ➡ Mechanisms to stabilise moduli !!

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

➤ Moduli VEVs $\langle \phi \rangle = \phi_0$ determine 4d physics
$\begin{cases} \Lambda_{c.c} \equiv V(\phi_0) \\ g_s \text{ and } \mathrm{Vol}_{int} \\ \text{fermi masses} \end{cases}$

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

➤ Supersymmetry dictates what deformations are allowed

Possible deformations

Number of scalar fields

$\mathcal{N} = 1$ $\mathcal{N} = 2$ $\mathcal{N} = 4$ $\mathcal{N} = 8$

FREEDOM

$\mathcal{N} = 1$ }   more possibilities

$\mathcal{N} = 2$

$\mathcal{N} = 4$ }   *gaugings*

$\mathcal{N} = 8$

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

➤ Gauged supergravities can be systematically studied

embedding tensor formalism

[Nicolai, Samtleben '00]

[de Wit, Samtleben, Trigiante '02 '05 '07]

[Schon, Weidner '06]

The embedding tensor formalism (I)

➢ Reducing 10d supergravities down to 4d yields *ungauged* supergravities with global symmetry G ⟹ duality group in 4d

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

$$
\begin{array}{|c|}
\hline
\mathcal{N} = 8 \\
G = E_7 \qquad H = SU(8) \\
\hline
\end{array}
$$

$$
\begin{array}{|c|}
\hline
\mathcal{N} = 4 \\
G = SL(2) \times SO(6,6) \\
H = SO(2) \times SO(6) \times SO(6) \\
\hline
\end{array}
$$

➢ Abelian gauge fields $A_\mu^{\mathcal{F}}$ in the fundamental rep. of G

➢ *Gauging* : a subgroup $G_0 \subset G$ is promoted to local symmetry yielding a *gauged* supergravity

$$
\nabla_\mu \longrightarrow \nabla_\mu - g\, A_\mu^{\mathcal{F}}\, \Theta_{\mathcal{F}}{}^{\mathcal{A}}\, t_{\mathcal{A}} \qquad \text{where} \quad \begin{cases} \mathcal{F} \equiv \text{fund} \\ \mathcal{A} \equiv \text{adj} \end{cases} \text{reps of G}
$$

embedding tensor

The embedding tensor formalism (II)

➢ The embedding tensor $\Theta_{\mathcal{F}}{}^{\mathcal{A}}$ encodes any possible deformation of the theory (*gauging*)

$$\mathcal{F} \otimes \mathcal{A} = rep_1 \oplus rep_2 \oplus \dots \qquad \text{of } G$$

➢ Consistency of the *gauging* implies

i) Supersymmetry $\implies$ Linear constraints on Θ (some $\cancel{rep_i}$)

ii) Gauge algebra $\implies$ Quadratic constraints on Θ

➢ The *gauging* also induces a non-trivial scalar potential $V(\Theta, \mathcal{M})$ for the scalar fields $\mathcal{M} = G/H$

➢ *Stringy features (T-S-... dualities) implemented at the supergravity level !!*

A chain of theories in 4d

$$G = E_7$$

e.t comp = 912

vectors = 56

scalars = 133

$$\mathcal{N} = 8$$

$\xrightarrow{SO(3)}$

$$G = SL(2) \times G_2$$

e.t comp = (2,1) + (4,14) + (2,7)

vectors = (4,1)

scalars = (3,1) + (1,14)

$$\mathcal{N} = 2$$

$\mathbb{Z}_2 \downarrow$

$\mathbb{Z}_2 \downarrow$

$$G = SL(2) \times SO(6,6)$$

e.t comp = (2,12) + (2,220)

vectors = (2,12)

scalars = (3,1) + (1,66)

✅

$$\mathcal{N} = 4$$

$\xrightarrow{SO(3)}$

$$G = SL(2) \times SL(2) \times SL(2)$$

e.t comp = (2,2,2) + (2,4,4)

vectors = 0

scalars = (3,1,1) + (1,3,1)+(1,1,3)

$$\mathcal{N} = 1$$

* reps of G

Half-maximal supergravities in 4d

$$G = SL(2) \times SO(6,6)$$

e.t comp = (2,12) + (2,220)
vectors = (2,12)
scalars = (3,1) + (1,66)

$$\mathcal{N} = 4$$

Questions :

➢ Can the whole vacuum structure be charted in $\mathcal{N} = 4$ theories ?

➢ Are there connections in the landscape of vacua ?

Half-maximal : symmetry and fields

➤ Global symmetry (duality) group $\quad\boxed{G = SL(2) \times SO(6,6)}$

➤ 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

$\left.\right\}$ 24 vectors

➤ The scalar sector parameterises $\mathcal{M} = M_{\alpha\beta} \times M_{MN}$

- 1 axion + 1 dilaton in $SL(2)$

- 30 axions + 6 dilatons in $SO(6,6)$

$\left.\right\}$ 38 scalars

$$M_{\alpha\beta} \equiv e^\phi \begin{pmatrix} \chi^2 + e^{-2\phi} & \chi \\ \chi & 1 \end{pmatrix}$$

$$M_{MN} \equiv \begin{pmatrix} G^{-1} & -G^{-1}B \\ BG^{-1} & G - BG^{-1}B \end{pmatrix}$$

Half-maximal : *gaugings* and scalar potential

➤ 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

$$V \;=\; \frac{1}{64}\, f_{\alpha MNP}\, f_{\beta QRS} M^{\alpha\beta} \left[\frac{1}{3}\, M^{MQ}\, M^{NR}\, M^{PS} + \left(\frac{2}{3}\, \eta^{MQ} - M^{MQ} \right) \eta^{NR} \eta^{PS} \right] -$$
$$-\; \frac{1}{144}\, f_{\alpha MNP}\, f_{\beta QRS}\, \epsilon^{\alpha\beta}\, M^{MNPQRS} + \frac{3}{64}\, \xi^M_\alpha\, \xi^N_\beta\, M^{\alpha\beta}\, M_{MN}$$

To keep in mind : V is quadratic in the emb. tens. parameters

➤ 464 e.t. components + 38 scalars = TOO MUCH !!

The $SO(3)$ truncation

➤ Keeping only fields and embedding tensor components invariant under the action of a subgroup $SO(3) \subset SO(6,6)$

$$G = SL(2) \times SO(6,6)$$

e.t comp = (2,12) + (2,220)
vectors = (2,12)
scalars = (3,1) + (1,66)

$$\mathcal{N} = 4$$

$$\xrightarrow{SO(3)}$$

$$G = SL(2) \times SL(2) \times SL(2)$$

e.t comp = (2,2,2) + (2,4,4)
vectors = 0
scalars = (3,1,1) + (1,3,1)+(1,1,3)

$$\mathcal{N} = 1$$

➤ R-symmetry group :

$$SU(4) \supset SO(3)$$

$$4 \longrightarrow 1 + 3$$

The SO(3) truncation : fields and *gaugings*

➤ **Symmetry and fields :** [Derendinger, Kounnas, Petropoulos, Zwirner '04]

- global symmetry $G = SL(2)_S \times SL(2)_T \times SL(2)_U$

- $A_\mu^{\alpha M} = 0$ and $\xi_{\alpha M} = 0$

- scalar coset = 3 complex scalars = STU – models !!

$$S \equiv \chi + i\, e^{-\phi} \quad , \quad T \equiv \chi_1 + i\, e^{-\varphi_1} \quad \text{and} \quad U \equiv \chi_2 + i\, e^{-\varphi_2}$$

$$\underbrace{\phantom{S \equiv \chi + i\, e^{-\phi}}}_{\text{SL}(2)} \qquad \underbrace{\phantom{T \equiv \chi_1 + i\, e^{-\varphi_1} \quad \text{and} \quad U \equiv \chi_2 + i\, e^{-\varphi_2}}}_{\text{SO(6,6)}}$$

➤ The *gaugings* $G_0 \subset G$ and the scalar potential $V(S,T,U)$ are specified by the embedding tensor

$$\boxed{f_{\alpha MNP} = 40 \text{ components}}$$

The SO(3) truncation : *gaugings* from fluxes

➤ String embedding as flux compactification

$$f_{\alpha MNP} = \text{generalised fluxes}$$

Example: SO(3) truncation $\Longleftrightarrow$ type II orientifolds of $\mathbb{T}^6/\mathbb{Z}_2 \times \mathbb{Z}_2$

➤ Type IIB fluxes and embedding tensor

$$f_{+mnp} = \tilde{F}'_{mnp} \quad , \quad f_{+mn}{}^p = Q'_{mn}{}^p \quad , \quad f_+{}^{mn}{}_p = Q^{mn}{}_p \quad , \quad f_+{}^{mnp} = \tilde{F}^{mnp} \quad ,$$

$$f_{-mnp} = \tilde{H}'_{mnp} \quad , \quad f_{-mn}{}^p = P'_{mn}{}^p \quad , \quad f_-{}^{mn}{}_p = P^{mn}{}_p \quad , \quad f_-{}^{mnp} = \tilde{H}^{mnp} \quad ,$$

[Dibitetto, Linares, Roest '10]
* index splitting $M = (m \; , \; {}^m)$

➤ Perfect matching with flux-induced superpotential (up to Q.C)

$$W_{flux} = (P_F - P_H\, S) + 3\, T\, (P_Q - P_P\, S) + 3\, T^2 (P_{Q'} - P_{P'}\, S) + T^3\, (P_{F'} - P_{H'}\, S)$$

The SO(3) truncation : *gaugings* consistency

➢ Closure of the gauge algebra = quadratic constraints on $f_{\alpha MNP}$

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 theory :

quadratic constraints $=$ B.I. for gauge fields + vanishing of the flux-induced tadpoles for sources breaking $\mathcal{N} = 4$

Example : Type IIB orientifolds with O3/O7-planes

- (H, F) fluxes : Unconstrained D3-brane flux-induced tadpole
- (H, F, Q) fluxes : Vanishing of D7-brane flux-induced tadpole
- (H, F, Q, P) fluxes : Vanishing of D7 , NS7 and I7 flux-induced tadpoles
- ??

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 !!

Φ-space $\qquad\qquad$ f-space
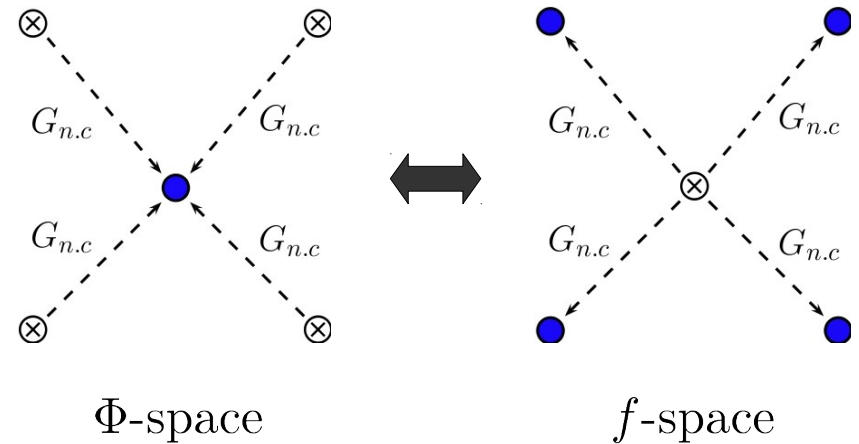
- At the origin everything is **simply quadratic** in the $f_{\alpha MNP}$ parameters

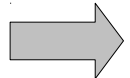$$V(\Phi) = \sum_{\text{terms}} f\, f \;\; \Phi^{\text{high degree}}$$

so then,

$$\boxed{\begin{array}{c}\text{computing the}\\ \text{vacua structure}\end{array}} \;=\; \boxed{\begin{array}{c}\text{multivariate polynomial system}\\[4pt] I = \langle\, \partial_\Phi V\big|_{\Phi_0} \;\;,\;\; \epsilon\, f\, f \;\;,\;\; f\, f \,\rangle\end{array}}$$

$\Longrightarrow$ **Algebraic Geometry** techniques !!

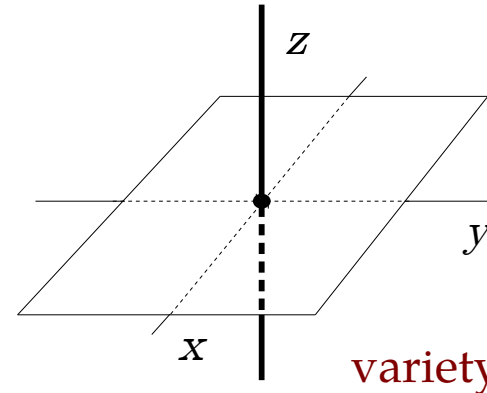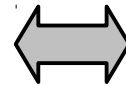[Gray, He, Lukas '06]

Basics of Algebraic Geometry

➤ Algebraic Geometry studies multivariate polynomial system and their link to geometry

$$I = \langle P_1 , P_2 \rangle$$

$$
\begin{aligned}
P_1(x,y,z) &= x\,z \\
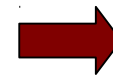P_2(x,y,z) &= y\,z
\end{aligned}
$$

$\Longleftrightarrow$

algebraic system

variety

➤ GTZ prime decomposition (analogous to integers dec. $30 = 2 \times 3 \times 5$)

$$I = J_1 \cap J_2 \quad \text{where} \quad \begin{cases} J_1 = \langle z \rangle \longrightarrow xy\text{-plane} \\ J_2 = \langle x , y \rangle \longrightarrow z\text{-axis} \end{cases}$$

$\Longrightarrow$

$$\boxed{J_1 \cap J_2 \;\longleftrightarrow\; V(J_1) \cup V(J_2)}$$

algebra-geometry dictionary

➤ Applying the above procedure to our problem involving fluxes

$$I = \langle\, \partial_\Phi V|_{\Phi_0} \;,\; \epsilon\,f\,f \;,\; f\,f \,\rangle$$

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

$\Longrightarrow$

Splitting of the landscape into n disconnected pieces !!

[*Singular* project, 97]

An example : type IIA with metric fluxes

➤ Testing the method with type IIA orientifold models including gauge fluxes and a metric flux

[Dall'Agatta, 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
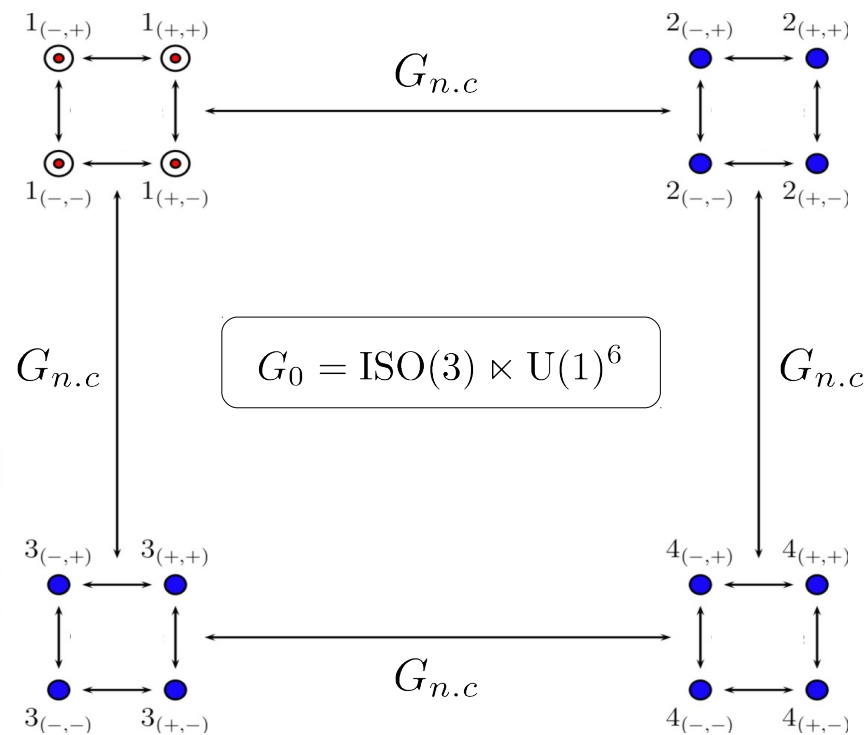
[Giddings, Kachru, Polchinski '02]

The 16 critical points

➤ An AdS$_4$ landscape

$$16 = 4 + 4 + 4 + 4$$

➤ Extra vanishing of ALL the flux-induced tadpoles !!

$1_{(\pm,\pm)}$	$2_{(\pm,\pm)}$	$3_{(\pm,\pm)}$	$4_{(\pm,\pm)}$
$\mathcal{N} = 1$ 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 and correspond to $\omega \equiv SU(2) \times SU(2)$

[Caviezel, Koerber, Körs, Lüst, Tsimpis/Wrase, Zagermann '08, '08]

➤ Unique *gauging*

$$G_0 = \mathrm{ISO}(3) \ltimes \mathrm{U}(1)^6$$

Unique theory

with 4 different vacua !!

Lifting to maximal supergravity ?

$$G = E_7$$

e.t comp = 912

vectors = 56

scalars = 133

$$\mathcal{N} = 8$$

$\uparrow$ $\mathbb{Z}_2$

$$G = SL(2) \times SO(6,6)$$

e.t comp = (2,12) + (2,220)

vectors = (2,12)

scalars = (3,1) + (1,66)

$$\mathcal{N} = 4$$

Question :

➢ Is the vanishing of ALL the flux-induced tadpoles enough for the geometric IIA solutions to lift to a maximal supergravity theory?

When half- becomes maximal supergravity (I)

➤ See the maximal theory with the half-maximal *''glasses''* and then modding out by a $\mathbb{Z}_2$ orientifold

$$E_7 \quad \supset \quad SL(2) \times SO(6,6)$$

$$\text{vectors}: \quad 56 \quad \longrightarrow \quad (2,12) + (1,32)$$

$$\text{scalars}: \quad 133 \quad \longrightarrow \quad (3,1) + (1,66) + (2,32')$$

$$\text{e.t}: \quad 912 \quad \longrightarrow \quad \underbrace{(2,12)}_{X} + \underbrace{(2,220)}_{\xi_{\alpha M}} + \underbrace{(1,352')}_{f_{\alpha MNP}} + (3,32)$$

$$\begin{array}{ccccc}
rep & \equiv & bos\ (B) & \to & even \\
rep & \equiv & \underbrace{fermi\ (F)}_{SO(6,6)} & \to & odd
\end{array} \right\} \mathbb{Z}_2$$

➤ Gauge algebra of the maximal theory with embedding tensor $X(f,\xi)$

$$\begin{array}{rcl}
[A_B, A_B] & = & X_{BB}{}^B\, A_B \quad + \quad X_{BB}{}^F\, A_F \\
[A_B, A_F] & = & X_{BF}{}^B\, A_B \quad + \quad X_{BF}{}^F\, A_F \\
[A_F, A_F] & = & X_{FF}{}^B\, A_B \quad + \quad X_{FF}{}^F\, A_F
\end{array} \right\} \quad \text{Jacobi identities} = QC_{\mathcal{N}=8}$$

➤ Components with an odd number of fermionic indices projected out !!

When half- becomes maximal supergravity (II)

➤ For a half-maximal to be embeddable in a maximal theory

$$QC_{\mathcal{N}=8} \;\; = \;\; QC_{\mathcal{N}=4} \;\; + \;\; \text{extra conditions for the lifting}$$

➤ The extra conditions are

$$\underbrace{f_{\alpha MNP}\, f_{\beta}{}^{MNP} = 0}_{(3,1)} \qquad \text{and} \qquad \underbrace{\epsilon^{\alpha\beta}\, f_{\alpha[MNP}\, f_{\beta QRS]}\,\big|_{\text{SD}} = 0}_{(1,462')}$$

➤ Type IIB : flux-induced tadpoles for dual sources ?

$$\underbrace{H_3 \wedge F_3}_{\text{}} \subset (1, 462') \qquad \Longrightarrow \qquad \text{which objects fill the rep ?}$$

D3-brane tadpole

An example : lifting of geometric type IIA

➤ All the 16 geom. IIA solutions
  lift to maximal supergravity

➤ Fake SUSY becomes SUSY

$$SU(8) \;\rightarrow\; SU(4) \;\times\; SU(4)$$

$$\underbrace{} \qquad \underbrace{} \qquad \underbrace{}$$

$\mathcal{N} = 8$ $\mathcal{N} = 4$ $\mathcal{N} = 4$

SUSY   SUSY   FAKE

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

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

➤ Computing the mass of the 70 scalars ⟹ ~~SUSY~~ and stable minimum !!

[Le Diffon, Samtleben, Trigiante '11]

➤ Underlying gaugings in maximal supergravity (28 vectors) ??

(…in progress)

Conclusions

➤ Some progress towards disentangling the landscape of extended 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) connections between vacua
    ii) $\mathcal{N} = 8$ lifting of the entire vacua structure
    iii) stability without supersymmetry

➤ For the future :

  - Beyond the geometric limit : non-geometric backgrounds, dual branes . . .

  - de Sitter in extended supergravity (maybe $\mathcal{N} = 2$) and links to Cosmology

  - Higher dimensional origin of gaugings : DFT, Generalised Geometry . . .

Thanks !!

Extra material . . .

Internal geometries and massless theories . . .

``maximal''

$$\mathbb{T}^6 = \quad \text{x} \quad \text{x}$$

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

Orientifolds of $\mathbb{T}^6$

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

``half-maximal''

Type II 10d

supergravity

``minimally extended''

$$CY_3 =$$

$$\mathcal{N} = 2$$

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

Orientifolds of CY_3

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

``minimal''

Lower bound on
topologically distinct CY_3
30108

Gaugings and their higher-dimensional origin

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

> Internal space extension $\Longleftrightarrow$ Exceptional Generalised Geometry ?

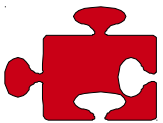[Pacheco, Waldram '08 , Grana, Louis, Sim, Waldram '09]

[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 $\Longleftrightarrow$ Doubled/Generalised Geometry ?

[Hitchin '02, Gualtieri '04]

[Hull '04, '06]

pathological internal spaces

String compactifications including generalised flux backgrounds !!

The SO(3) truncation : fields and *gaugings*

➢ Symmetry and fields :

- global symmetry $\quad G = SL(2)_S \times SL(2)_T \times SL(2)_U$

- $A_\mu^{\alpha M} = 0 \quad$ and $\quad \xi_{\alpha M} = 0$ [Derendinger, Kounnas, Petropoulos, Zwirner '04]

- scalar coset $\;=\;$ 3 complex scalars $\;=\;$ STU – models !!

$$S \equiv \chi + i\, e^{-\phi} \quad , \quad \underbrace{T \equiv \chi_1 + i\, e^{-\varphi_1} \quad \text{and} \quad U \equiv \chi_2 + i\, e^{-\varphi_2}}$$

$$\underbrace{\phantom{S \equiv \chi + i e^{-\phi}}}$$

$$\text{SL(2)} \qquad\qquad\qquad\qquad \text{SO(6,6)}$$

- SO(6,6) : $\quad G = e^{\varphi_2 - \varphi_1} \begin{pmatrix} \chi_2^2 + e^{-2\varphi_2} & -\chi_2 \\ -\chi_2 & 1 \end{pmatrix} \otimes \mathbb{I}_3 \quad , \quad B = \begin{pmatrix} 0 & \chi_1 \\ -\chi_1 & 0 \end{pmatrix} \otimes \mathbb{I}_3$

➢ The *gaugings* $\;G_0 \subset G\;$ and the scalar potential $\;V(S,T,U)\;$ are specified by the embedding tensor

$$f_{\alpha MNP} = 40 \text{ components}$$

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 gauge 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 $\longleftrightarrow$ unstable dS in type IIA models

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

b) non-geometric fluxes $\longleftrightarrow$ 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 $\longleftrightarrow$ stable dS in type IIB models
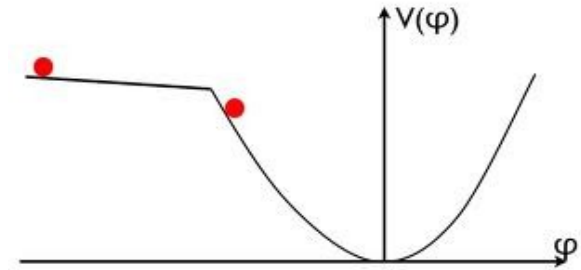
[Burgess, Kallosh, Quevedo '03]

b) non-perturbative effects from D-branes $\longleftrightarrow$ 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]