Bariloche
15/01/2018

Flatfolds

Gianguido Dall'Agata

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Flatfolds

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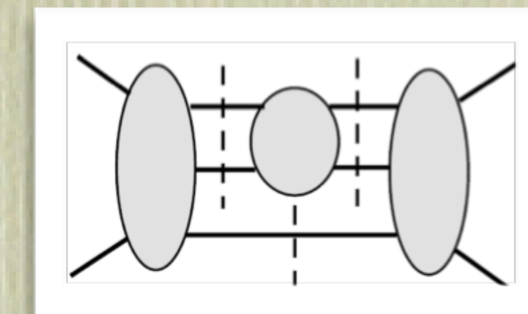
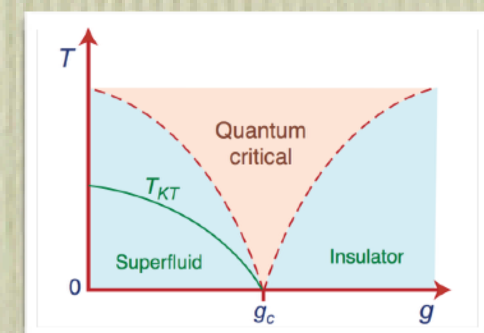
together with:
G. Inverso and P. Spezzati in progress

Focus on N=8 Supergravity with NEW results on

Finiteness (?)

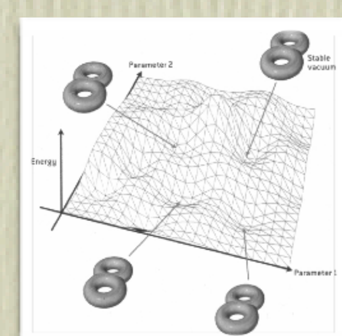


New Minkowski vacua

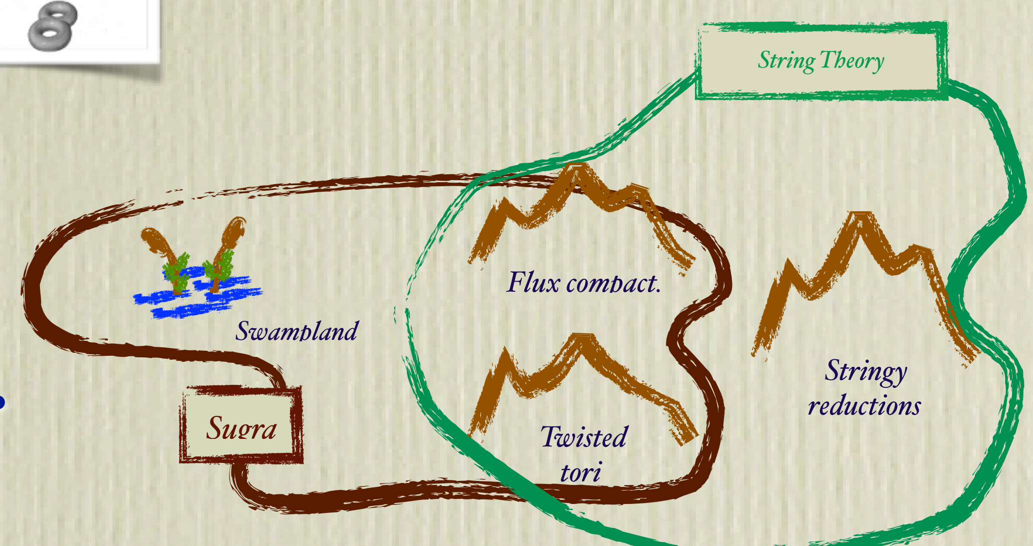


AdS/CMT applications

dS vacua in N>1
(and eventually string theory)



And, of course, the landscape...



The N=8 Landscape

- The problem is well defined for maximally supersymmetric theories:
    - **912** possible fluxes in total
    - fluxes-gaugings map fully worked out
    - full **classification** of gaugings and vacua in progress with **new** techniques

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Which gauge groups and which G_{res}?

Ex.(Gell-Mann, Nicolai):
SU(3) x U(1) with 48 fermions

The N=8 Landscape

- *The problem is well defined for maximally supersymmetric theories:*
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  - *fluxes-gaugings map fully worked out*
  - *full **classification** of gaugings and vacua in progress with **new** techniques*

Which gauge groups and which G_{res}?

Ex.(Gell-Mann, Nicolai): SU(3) x U(1) with 48 fermions

de Sitter?

distribution of c.c.?

Our progress:

i) Structure of the theory

a. New classes of gaugings G.D., Inverso, Trigiante

b. Full classification of parameter space G.D., Inverso, Marrani

c. New susy-breaking patterns Catino, G.D., Inverso, Zwirner

d. **1-loop finiteness** G.D., Zwirner

Our progress:

ii) Structure of the Landscape

a. *Many new **AdS**, **Minkowski** and **dS** vacua* G.D., Inverso

b. *Web of connected Minkowski vacua!* Catino, G.D., Inverso, Zwirner

c. *New uplifts to M-theory* G.D., Baron; G.D., inverso,Spezzati

The Moduli Space of Minkowski Vacua

Cremmer–Scherk–Schwarz from the d=4 perspective:

$$\mathrm{U}(1) \ltimes T^{27} \ \textit{gauging} \quad \left\{ \begin{array}{rcl} [X_0, X^I] & = & Q^I{}_J\, X^J \\ [X^I, X^J] & = & 0 \end{array} \right.$$

- ***Minkowski vacua with* N=0,2,4,6**
- *Gravitino masses 2 x M_i*
- *Overall sliding scale, but M_i/M_j fixed*

When $M_1 = M_2 = M_3 = M_4 : CSO(2,6)$

G.D., INVERSO

First *Minkowski* vacuum from a *semisimple* group

$$SO^*(8) \simeq SO(6,2)_{c=1} \to SU(4) \times U(1) \quad \mathcal{N} = 0$$

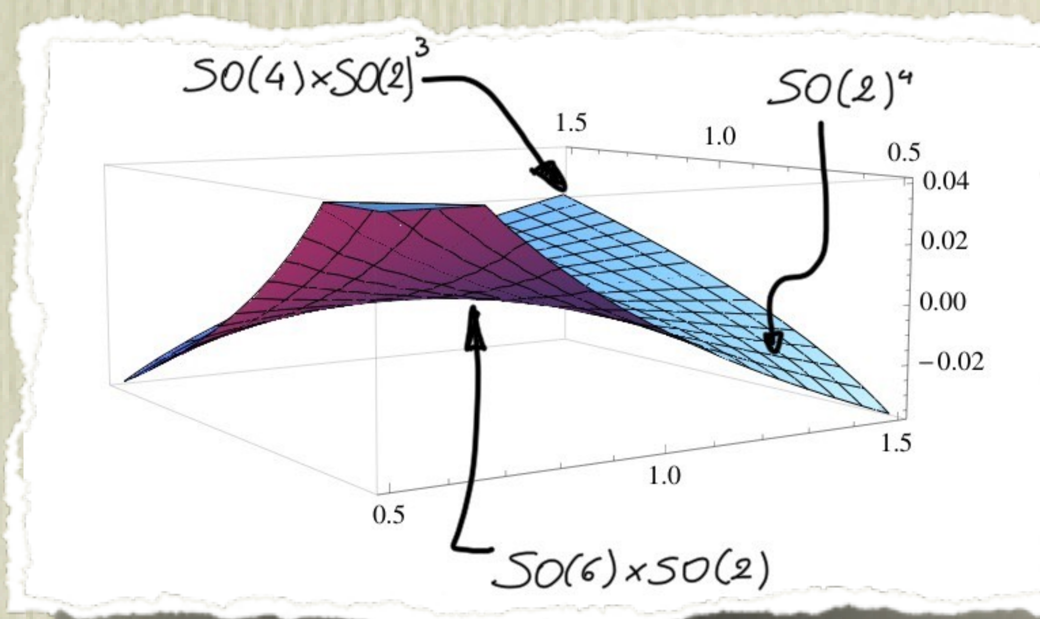
spin	m^2 (SO(6) representation, U(1) charge)
2	$0_{(\mathbf{1},0)}$
$\frac{3}{2}$	$\frac{1}{8}_{(\mathbf{4},1)}$, $\frac{1}{8}_{(\bar{\mathbf{4}},-1)}$
1	$0_{(\mathbf{1},0)}$, $0_{(\mathbf{15},0)}$, $\frac{1}{2}_{(\mathbf{6},2)}$, $\frac{1}{2}_{(\mathbf{6},-2)}$
$\frac{1}{2}$	$0_{(\mathbf{4},1)}$, $0_{(\bar{\mathbf{4}},-1)}$, $\frac{1}{8}_{(\mathbf{20},1)}$, $\frac{1}{8}_{(\overline{\mathbf{20}},-1)}$, $\frac{9}{8}_{(\mathbf{4},-3)}$, $\frac{9}{8}_{(\bar{\mathbf{4}},+3)}$
0	$0_{(\mathbf{1},0)}$, $0_{(\mathbf{15},0)}$, $0_{(\mathbf{6},2)}$, $0_{(\mathbf{6},-2)}$, $0_{(\mathbf{20'},0)}$, $\frac{1}{2}_{(\mathbf{10},-2)}$, $\frac{1}{2}_{(\overline{\mathbf{10}},2)}$, $2_{(\mathbf{1},4)}$, $2_{(\mathbf{1},-4)}$

Mass spectrum *in* $SU(4) \times U(1)$ *irrepses*

Moduli space: $\left[\frac{\mathrm{SU}(1,1)}{\mathrm{U}(1)}\right]^3$

x_i, e_i

Vacuum stability
depends on $\langle x_i \rangle, \langle e_i \rangle$



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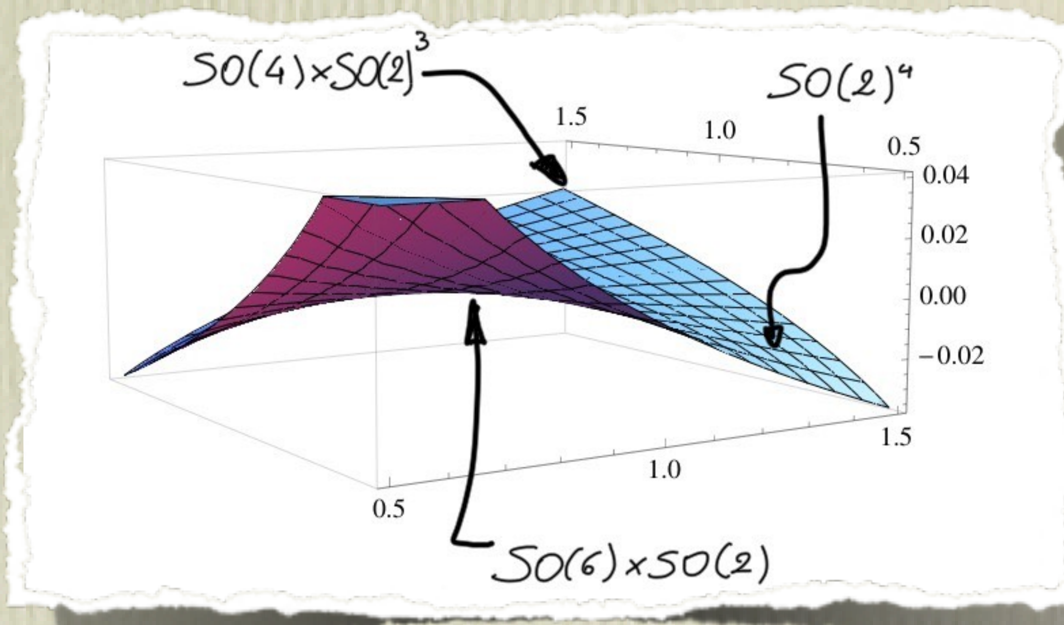
Goldstones

Mass spectrum *in*
$SU(4) \times U(1)$*irrepses*

Moduli space: $\left[\dfrac{\mathrm{SU}(1,1)}{\mathrm{U}(1)}\right]^3$
x_i, e_i



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Would-be Goldstones

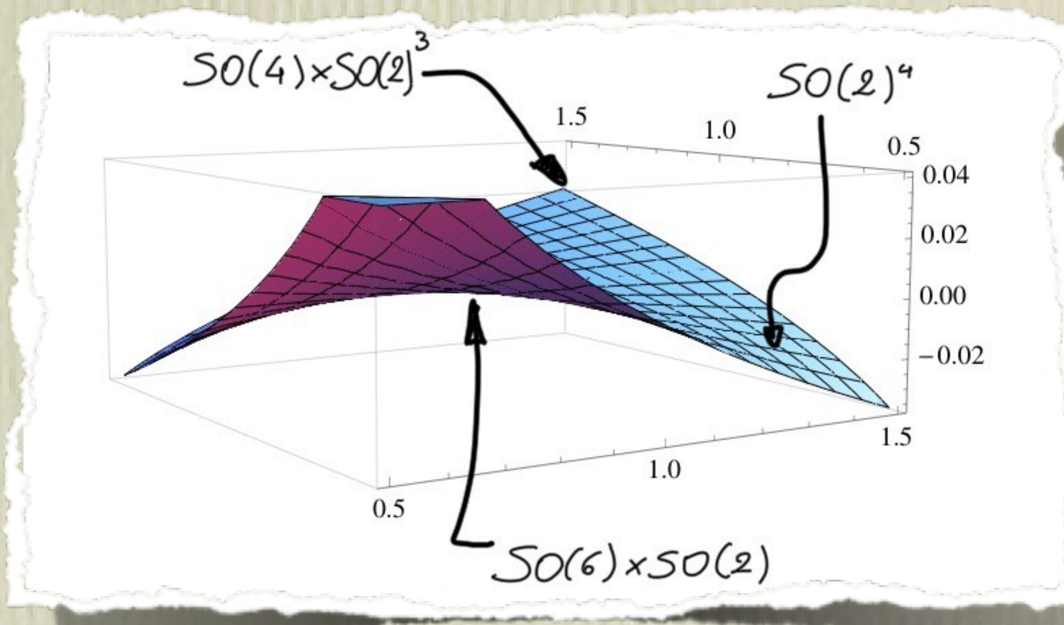
Mass spectrum *in* $SU(4) \times U(1)$ *irrepses*

Moduli space: $\left[\dfrac{\mathrm{SU}(1,1)}{\mathrm{U}(1)}\right]^3$

x_i, e_i

Vacuum stability

depends on $\langle x_i \rangle, \langle e_i \rangle$



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0	$0_{(\mathbf{1},0)}$, $0_{(\mathbf{15},0)}$, $0_{(\mathbf{6},2)}$, $0_{(\mathbf{6},-2)}$, $\boxed{0_{(\mathbf{20'},0)}}$, $\frac{1}{2}_{(\mathbf{10}$

Moduli

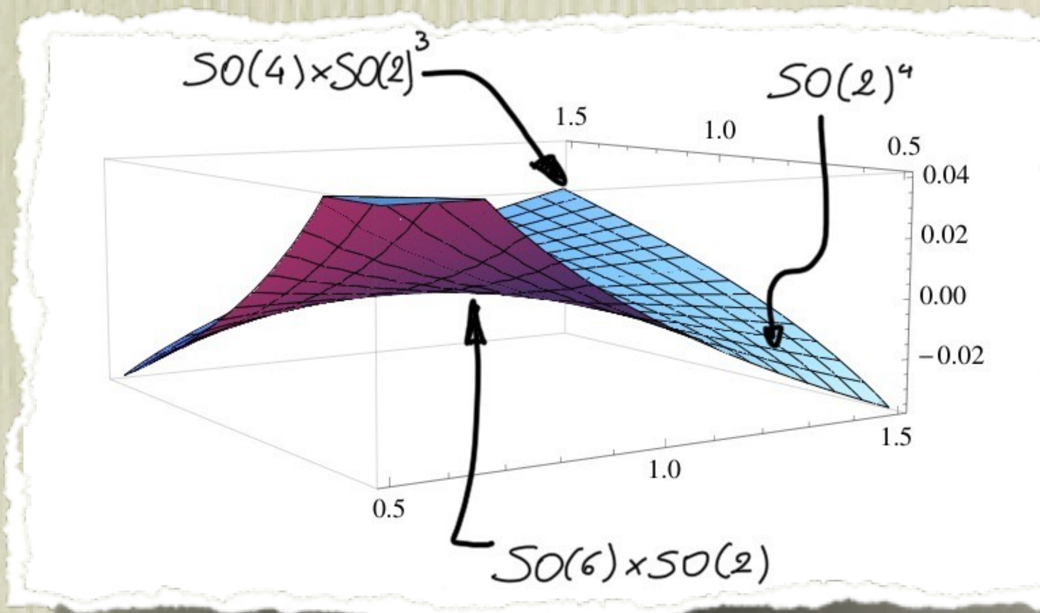
Mass spectrum *in* $SU(4) \times U(1)$ *irrepses*

Moduli space: $\left[\dfrac{\mathrm{SU}(1,1)}{\mathrm{U}(1)}\right]^3$

x_i, e_i

Vacuum stability

depends on $\langle x_i \rangle, \langle e_i \rangle$



- SUSY breaking scale depends on $\langle x_i \rangle, \langle e_i \rangle$

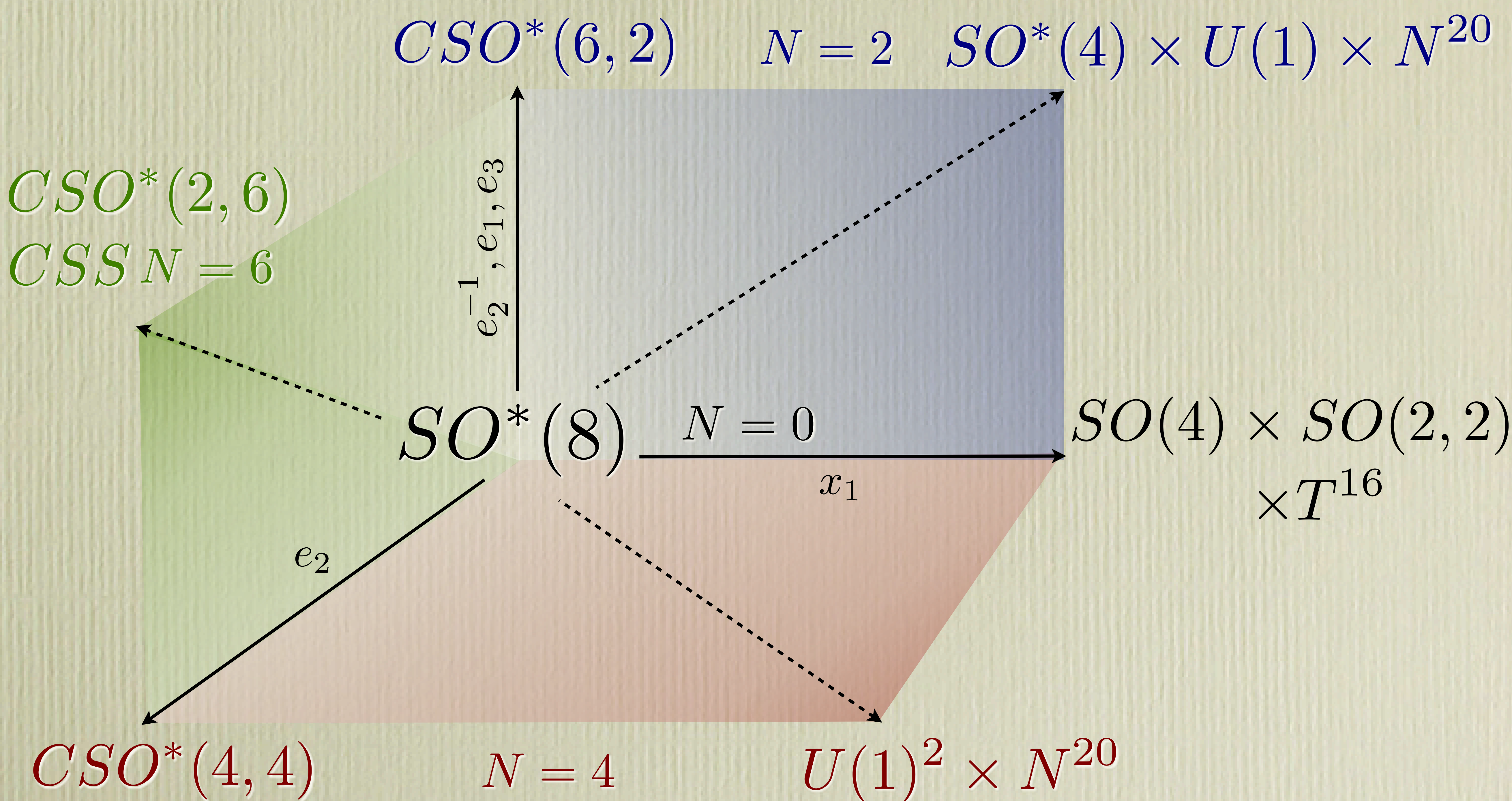
$$\begin{aligned} M_1 &= \frac{e_2 e_3}{e_1} f(x_i)\,, \quad & M_2 &= \frac{e_1 e_3}{e_2} f(x_i)\,, \\ M_3 &= \frac{e_1 e_2}{e_3} f(x_i)\,, \quad & M_4 &= \frac{1}{e_1 e_2 e_3} f(x_i)\,. \end{aligned}$$

$$f(x_i) = \sqrt{\prod_i \frac{1 + x_i^4}{8 x_i}}$$

- Tuning the moduli we can send $M_i \to 0$
- Stable regions of finite volume
- *We reproduce and generalize all CSS susy breaking and mass patterns* Catino, G.D., Inverso, Zwirner

Minkowski Vacua

Catino, G.D.,
Inverso, Zwirner



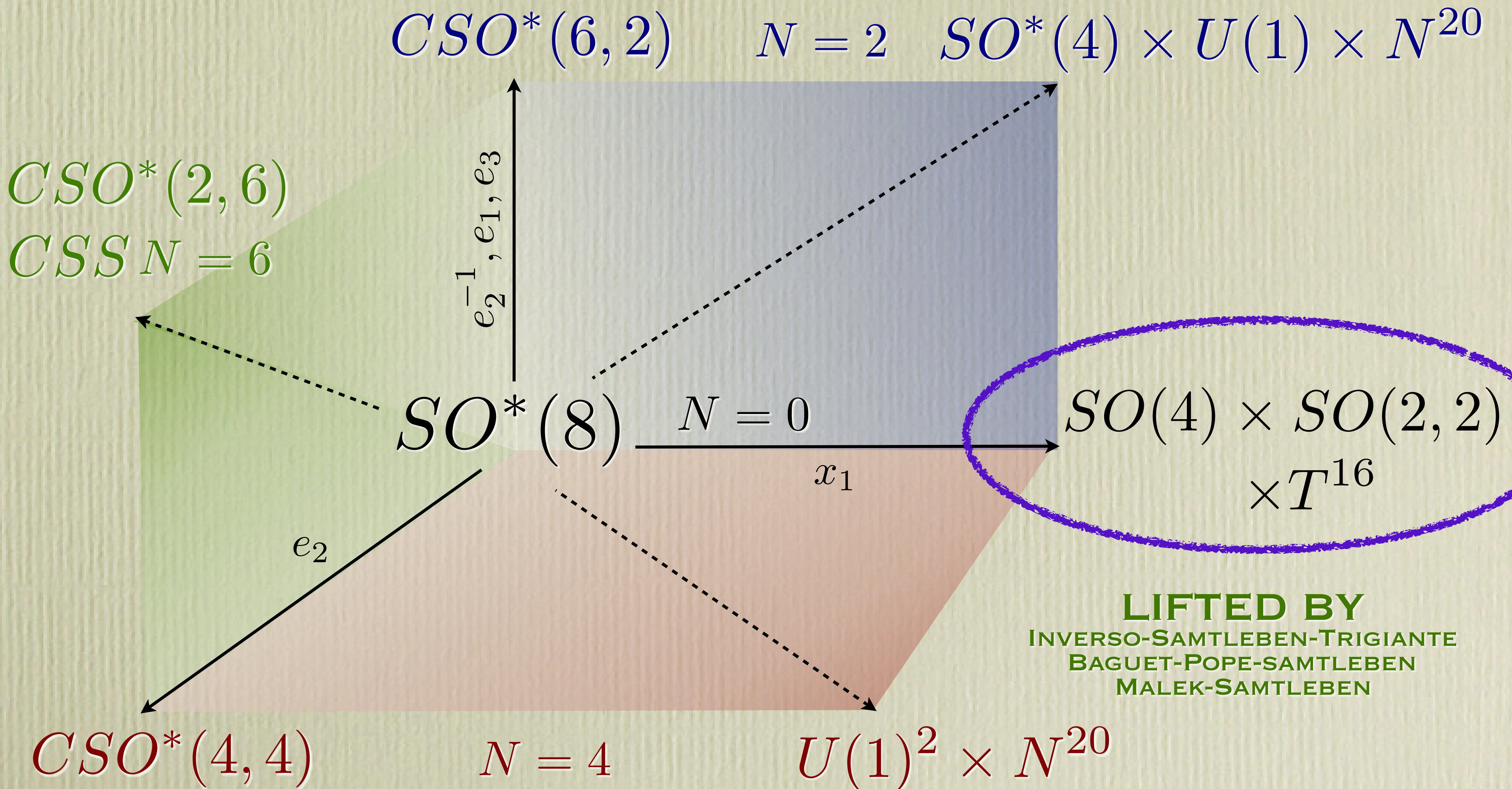
Minkowski Vacua

- *Moduli space fully connected*
- *Can we get odd N?*
- *From kinematics:*
  - **N=7=N=8**
  - **N=5 *forbidden***
  - **N=3** *allowed but restricted*
  - **N=1** *possible*
- *Do we have examples?*

Flatfolds

Flatfolds

Catino, G.D.,
Inverso, Zwirner



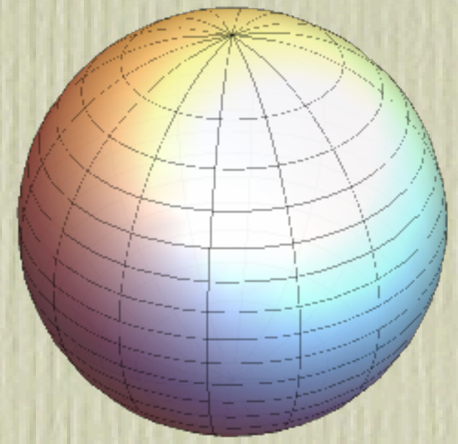
LIFTED BY
Inverso-Samtleben-Trigiante
Baguet-Pope-samtleben
Malek-Samtleben

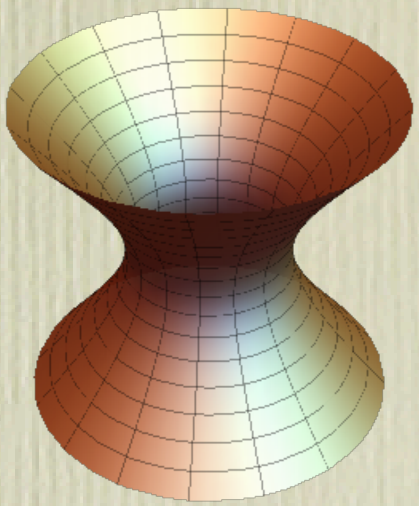
Flatfolds

Inverso-Samtleben-Trigiante
Baguet-Pope-samtleben
Malek-Samtleben

- *The uplift uses the internal manifold* $S^3 \times H^{2,2}$

$$\frac{\mathrm{SO}(4)}{\mathrm{SO}(3)} \times \frac{\mathrm{SO}(2,2)}{\mathrm{SO}(2,1)}$$





- *Trick: describe it as a generalized SS reduction in DFT*
  - *keeps all vectors unlike group manifold reductions*
  - *explicit uplift also of the moduli as geometric deformations*

Focus for simplicity on DFT and type II uplift

$$S_{II} = \int d^{10}x\,\sqrt{-g}\,e^{-2\phi}\left(R + 4(\partial\phi)^2 - \frac{1}{12}H_{MNP}H^{MNP}\right)$$

In the generalized SS truncation to 4d, the metric, vectors, dilaton contain info on 4d supergravity fields and on the internal space (via twist matrices U)

ALDAZABAL-BARON-MARQUÉS-NÚÑEZ
GEISSBÜHLER

$$g_{\mu\nu} = e^{4\gamma\varphi(x)}g_{\mu\nu}(x) \quad e^{\phi} = \rho^2(y)e^{\varphi(x)}$$

$$\mathcal{H}_{MN} = U_M{}^A(y)M_{AB}(x)U_N{}^B(y)$$

$$\mathcal{A}_\mu^M = U^{-1}{}_A{}^M(y)\,A_\mu^A(x)$$

$$M_{AB}(x) \in \frac{\mathrm{SO}(6,6)}{\mathrm{SO}(6)\times\mathrm{SO}(6)}$$

The Ansatz is consistent iff the twist matrices satisfy

$$\mathcal{J}_{D[A} U^{-1}_{B}{}^{M} U^{-1}_{C]}{}^{N} \partial_M U_N{}^D = f_{ABC}$$

$$\rho^{-1} \partial_M \rho = -\gamma U^{-1}_{A}{}^{N} \partial_N U_M{}^A$$

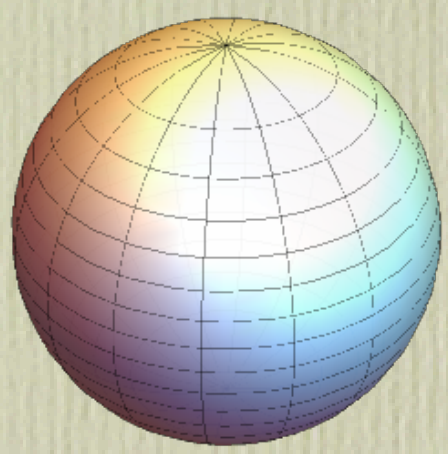
where $\mathcal{J}$ is the O(d,d) metric and f are structure constants

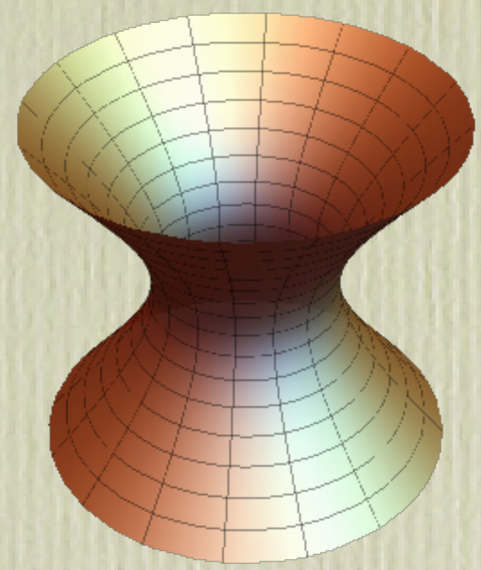
If U depends only on the physical coordinates then we have a type II background

On $S^3 \times H^{2,2}$ one can write down U as a function of the Killing vectors

Flatfolds

- *We then looked at the squashings of the internal space*





- *This simply follows from the vevs of the scalars*

$$\langle \mathcal{H} \rangle (y) = U_M{}^A(y) \langle M_{AB} \rangle U_N{}^B(y)$$

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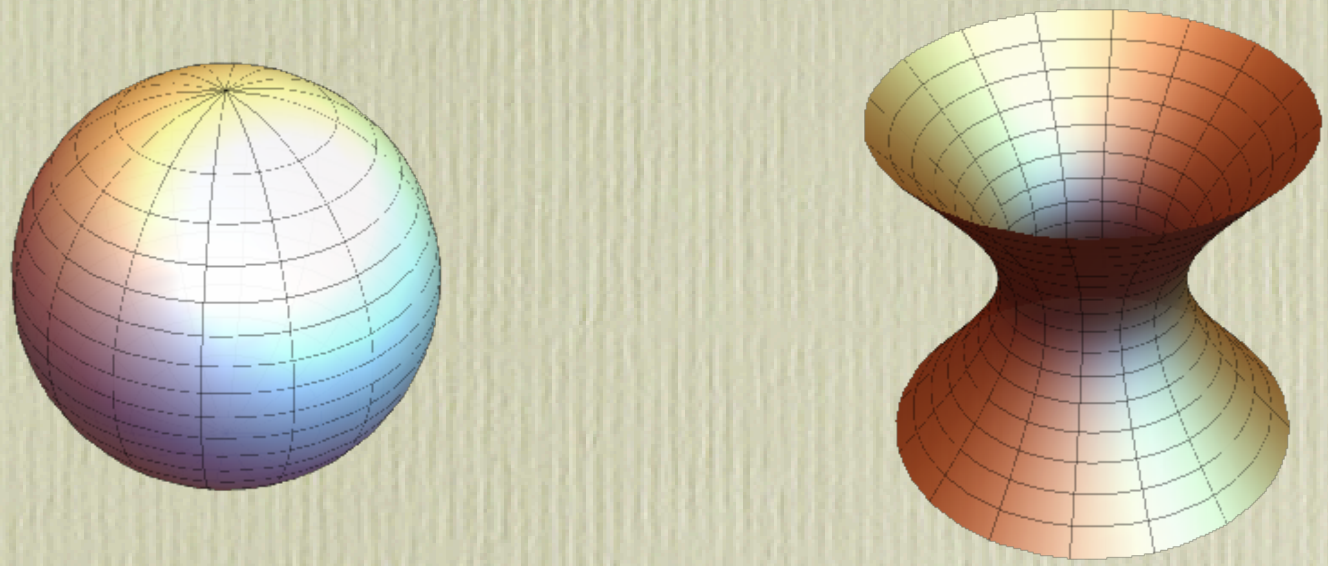

- *This simply follows from the vevs of the scalars*

$$\langle \mathcal{H} \rangle (y) = U_M{}^A(y) \langle M_{AB} \rangle U_N{}^B(y)$$

- *We follow the deformation to the boundary of the moduli space*

$$\hat{U}_M{}^A(y) = g_M{}^P \; J_P{}^N \; U_N{}^B(y')L_B{}^A(\langle\phi_4\rangle)$$

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Vev sent to boundary

Flatfolds

- *We follow the deformation to the boundary of the moduli space*

$$\hat{U}_M{}^A(y) = g_M{}^P \, J_P{}^N \, U_N{}^B(y') L_B{}^A(\langle \phi_4 \rangle)$$

Vev sent to boundary

Jacobian of the coordinate change

- *We follow the deformation to the **boundary** of the **moduli space***

$$\hat{U}_M{}^A(y) = g_M{}^P \, J_P{}^N \, U_N{}^B(y') L_B{}^A(\langle\phi_4\rangle)$$

Rescaling of coupling constant

Jacobian of the coordinate change

Vev sent to boundary

Flatfolds

- *We follow the deformation to the boundary of the moduli space*

$$\hat{U}_M{}^A(y) = g_M{}^P\ J_P{}^N\ U_N{}^B(y')L_B{}^A(\langle\phi_4\rangle)$$

- *We then plug the result back in the Ansatz to get the new geometry*

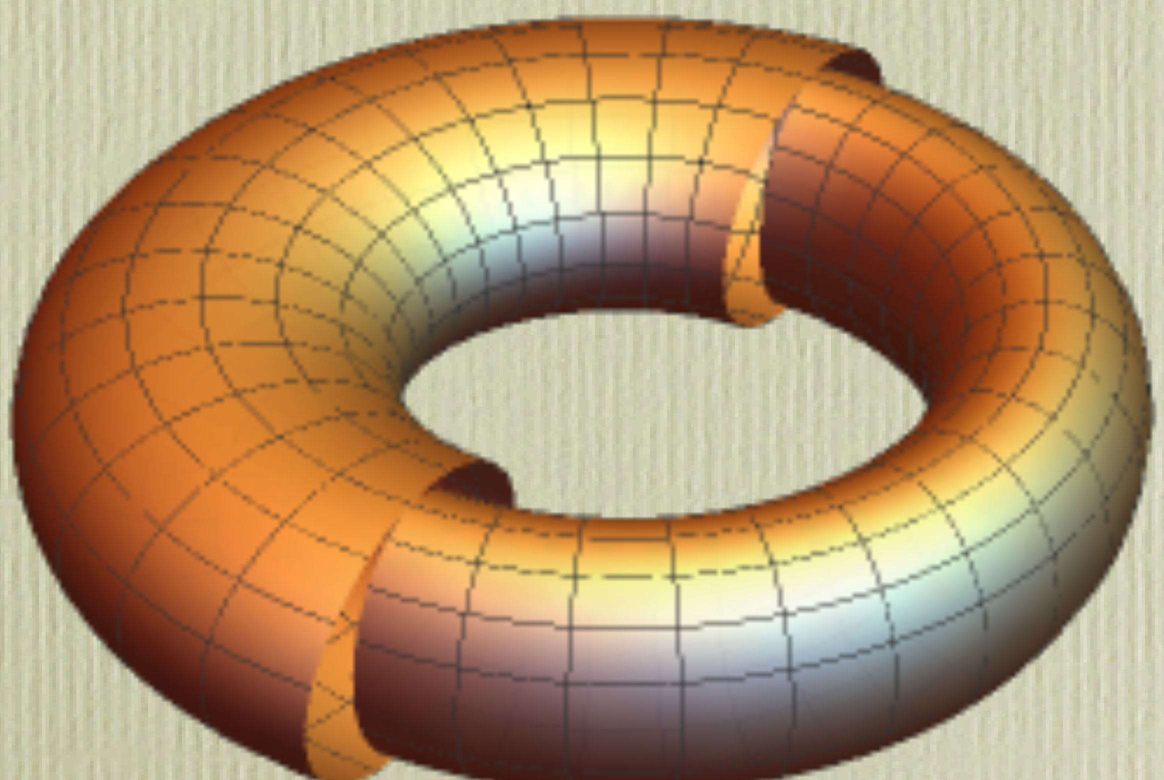
$$\langle\mathcal{H}\rangle(y) = U_M{}^A(y)\langle M_{AB}\rangle U_N{}^B(y)$$

- *We finally look for appropriate boundary conditions to make it compact*

The results are either known solvmanifolds

Graña-Minasian-Petrini-Tomasiello
Andriot

Or simply flat space with non trivial patching via duality



Flat-folds

An example: *lifting 4-parameters CSS*

$$\mathcal{M}_7 = \frac{U(1) \ltimes \mathbb{R}^{24}}{\mathbb{R}^{18}}$$

3 parameters flatgroup from twisted torus

$$e^1 = dy^1 + m_1 y^3 dy^7 \qquad e^2 = dy^2 - m_1 y^1 dy^7$$

$$e^3 = dy^4 + m_2 y^4 dy^7 \qquad e^4 = dy^4 - m_2 y^3 dy^7$$

$$e^5 = dy^5 + m_3 y^6 dy^7 \qquad e^6 = dy^6 - m_3 y^5 dy^7$$

$$e^7 = dy^7$$

Generalized CSS $\quad U_{\underline{A}}{}^{\underline{M}} = \begin{pmatrix} e_a{}^m & 0 \\ 0 & 1 \end{pmatrix}$

An example: *lifting 4-parameters CSS*

$$\mathcal{M}_7 = \frac{U(1) \ltimes \mathbb{R}^{24}}{\mathbb{R}^{18}}$$

The extra twist is non-geometric

$$U_A{}^M = R_A{}^B U_B{}^M \qquad R = \begin{pmatrix} \mathbb{I}_6 & & \\ & \cos(m_4 y^7) & \sin(m_4 y^7) \\ & -\sin(m_4 y^7) & \cos(m_4 y^7) \end{pmatrix}$$

The final result is either a truncation to the massive modes or a true flat-fold, depending on the ***periodicity*** *conditions*

Stability?

Quantum corrections

- ***Ungauged*** N=8 supergravity is *finite* up to 4 loops and possibly more, ***Gauging*** **=** ***new couplings*** *(and masses)*

- *What can we say about the* ***finiteness of the quantum theory?***

- *One loop* divergencies controlled by ***supertraces***

$$Str\left(\mathcal{M}^{2k}\right) = \sum_J (-1)^{2J}(2J+1)tr(\mathcal{M}_J)^{2k}$$

- Example: *One loop effective potential*

$$\begin{aligned} V_{eff} &= \frac{1}{64\pi^2}\mathrm{Str}\mathcal{M}^0\Lambda^4\log\frac{\Lambda^2}{\mu^2} + \frac{1}{32\pi^2}\mathrm{Str}\mathcal{M}^2\Lambda^2 - \frac{1}{64\pi^2}\mathrm{Str}\mathcal{M}^4\log\Lambda^2 \\ &+ \frac{1}{64\pi^2}\mathrm{Str}\left(\mathcal{M}^4\log\mathcal{M}^2\right) \end{aligned}$$

- We computed the ***quadratic*** and ***quartic*** supertrace mass formulae for a *generic* N=8 gauged supergravity

- Using: G.D., ZWIRNER

  1. *Critical point condition;*
  2. *Vanishing cosmological constant;*
  3. *Quadratic constraints*

we find that they **vanish**

$$\boxed{Str\ \left(\mathcal{M}^2\right) = Str\ \left(\mathcal{M}^4\right) = 0}$$

Quantum corrections

- As before, the classical potential has regions of marginal stability
- The 1-loop correction to the potential is negative, hence the final vacuum is Anti de Sitter
- *The vevs get further corrections*
- *The vacuum is N=0*
- If no non-susy AdS vacuum can be stable, these manifolds should have *decay modes*?

Summarizing:

Intriguing classical moduli space of Minkowski vacua

First examples of lift for such vacua

*"Infinite" deformations used to generate new vacua and new uplifting manifolds (or **flatfolds**)*

Effective potential negative definite: problem for stability?

What is the uplift of the "Father/Mother" vacuum?

N=8 Multiplet	$\{g_{\mu\nu},$	$\psi_\mu^i,$	$A_\mu^{ij},$	$\chi^{ijk},$	$\phi^{ijkl}\}$
# dofs	1	8	28	56	70

Scalars are coordinates on $\mathcal{M}_{scal} = \frac{\mathrm{E}_{7(7)}}{\mathrm{SU}(8)}$

E$_{7(7)}$ is the ***U-duality group*** in 4 dimensions

U-duality = generalized *electric-magnetic* duality

In 4d we have
electric & *magnetic*
vector fields
Hodge-dual to each other

eoms + BI

$$\begin{cases} dF^\Lambda = 0 \\ dG_\Lambda = d\left(\frac{\partial \mathcal{L}}{\partial F^\Lambda}\right) = 0 \end{cases}$$

The sum of eoms+BI is *invariant under duality transformations*

The Lagrangian is ***not**** *(*according to the rules given previously)*

$$\mathcal{L}_{vec} = \mathcal{I}_{\Lambda\Sigma}(\phi) F^{\Lambda} \wedge \star F^{\Sigma} + \mathcal{R}_{\Lambda\Sigma}(\phi) F^{\Lambda} \wedge F^{\Sigma}$$

Non-minimal couplings transform *under symplectic rotations*

GAILLARD, ZUMINO

$$F^M \longrightarrow S^M{}_N F^N \qquad S = \begin{pmatrix} A & B \\ C & D \end{pmatrix}$$

$$\mathcal{N} = \mathcal{R} + i\mathcal{I} \longrightarrow (C + D\mathcal{N})(A + B\mathcal{N})^{-1}$$

Where $\quad F_{\Lambda} \equiv \dfrac{\delta \mathcal{L}}{\delta F^{\Lambda}} \qquad A_{\mu}^{M} = \{A_{\mu}^{\Lambda}, A_{\mu\,\Lambda}\}$

N=8 gauged supergravity models

- *Choice of duality frame = Choice of* $\mathcal{R}$ *and* $\mathcal{I}$
- *Symmetries of Lagrangian* $\subset \mathrm{E}_{7(7)} \subset \mathrm{Sp}(56, \mathbb{R})$
- *Ungauged models equivalent* De wit

$$\mathrm{GL}(28, \mathbb{R}) \backslash \mathrm{Sp}(56, \mathbb{R}) / \mathrm{E}_{7(7)}$$

local redefinitions of vector fields

(Non-local) Electric-magnetic transformations

redefinition of the coordinates of the scalar manifold

- **Gauging:**
  - make $t_\alpha \in \mathfrak{e}_{7(7)}$ ***local*** using A_μ^M

$$\boxed{\mathfrak{g} \textit{ generated by } \quad X_M = \Theta_M{}^\alpha\, t_\alpha}$$

Nicolai-Samtleben. De Wit-Samtleben-Trigiante

closure: $[X_M, X_N] = -X_{MN}{}^P X_P$

locality: $\Theta_M{}^\alpha \Theta^{M\beta} = 0$

susy: $\Theta \in \mathbf{912}$ of $E_{7(7)}$

Now most non-local transformations are incompatible with the 2-derivative action!

Gauged SUGRA from M-theory (e.g.) on T7. ***912 'Fluxes':***

$\mathbf{1}_{+\mathbf{7}}$	g_7	$(\mathbf{140}+\mathbf{7})_{+\mathbf{3}}$	$\tau^i_{jk}+\delta^i_j\tau_k$	$\mathbf{28}_{-\mathbf{1}}$	$\theta_{(ij)}$
$\mathbf{1}_{-\mathbf{7}}$	$\tilde{g}_7$	$(\mathbf{140}'+\mathbf{7}')_{-3}$	$Q^{jk}_i+\delta^j_iQ^k$	$\mathbf{28}'_{+1}$	$\xi^{(ij)}$
$\mathbf{35}_{-\mathbf{5}}$	h^{ijkl}	$\mathbf{224}_{-1}$	f^i_{jkl}	$\mathbf{21}_{-\mathbf{1}}$	$\theta_{[ij]}$
$\mathbf{35}'_{+5}$	g_{ijkl}	$\mathbf{224}'_{+1}$	R^{jkl}_i	$\mathbf{21}'_{+1}$	$\xi^{[ij]}$

$$\underbrace{\qquad}$$

$$\mathcal{D}_\mu=\partial_\mu+A^M_\mu\,\Theta_M{}^\alpha t_\alpha$$

Geometric

Locally geometric

Geometric on S7 !!