New Physics From Maximal Supergravity

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The VII Round Table Italy-Russia@Dubna,

Dubna, 24-28 November 2015

Dall'Agata, Inverso, MT, PRL, arXiv:1209.0760;
Gallerati, Samtleben, MT, JHEP, arXiv: 1410.0711;
Work in progress...

Motivations

- Superstring/M-theory (in D=10/11) candidates to quantum theory of gravity

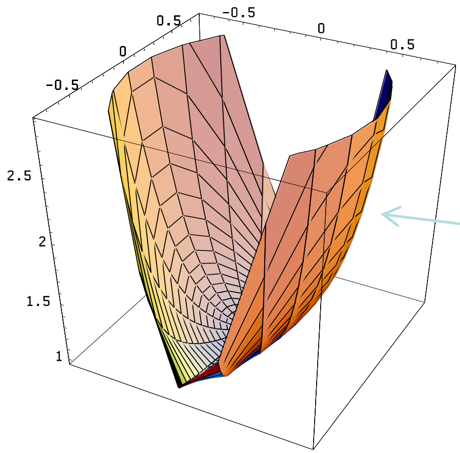
↓ Spontaneous compactification to D=4

Effective description of our universe
(D=4 supergravity)

➢ On $\mathbf{M^{1,3} \times M_{Ricci\ flat}}$, Flux=0 ⇒ Ungauged D=4 SUGRA global symmetry encodes dualities

Plethora of massless scalar fields: physically uninteresting

➢ On $\mathbf{M^{1,3} \times M}$, **Flux $\neq$ 0** $\Rightarrow$ Gauged D=4 SUGRA



Lifting moduli degeneracy

- **Minimal coupl.**
- **Masses**
- **V(ϕ)**

- (Gauged) SUGRAS consistently defined in any dimension

- When originating from string/M-.theory compactif. , *offer unique window on non-pert. low-energy dynamics* (full back-reaction on space-time geometry etc...)

String/M-theory vacua → **Gauged SUGRA vacua**

String/M-theory vacua ← **?** **Gauged SUGRA vacua**

The Maximal D=4 SUGRA

- M-theory (D=11) on $\mathbf{M}^{1,3}$ x$\mathbf{T}^7$ $\Rightarrow$

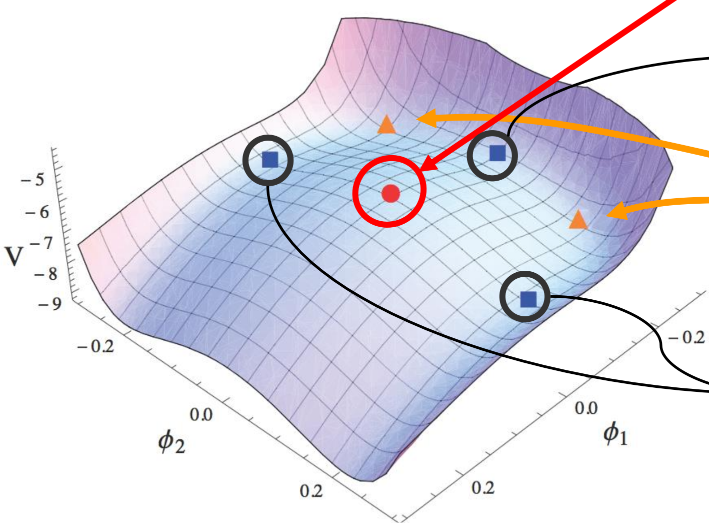
Ungauged D=4 N=8 SUGRA
global (on-shell) symmetry $G=E_{7(7)}$

[Cremmer, Julia, Nucl.Phys. **B159** (1979) 141]

- M-theory on $\mathbf{AdS}_4$ x $\mathbf{S}^7$ $\Rightarrow$

N=8 vacuum of D=4 N=8 SUGRA
with SO(8) gauge group

[De Wit, Nicolai, Nucl.Phys. **B208** (1982) 323]



Warped compactification on $\mathbf{S}^7$

Warped compactification on $\mathbf{S}^7$
with torsion

Compactification on $\mathbf{S}^7$
with torsion

- Lagrangian of the ungauged theory not unique, depends on the *symplectic frame*

$$S.F. \;\leftrightarrow\; \text{electric vectors } A^{\lambda}_{\mu} \hookrightarrow \{A^{\Lambda}_{\mu},\, A_{\Lambda\,\mu}\}$$

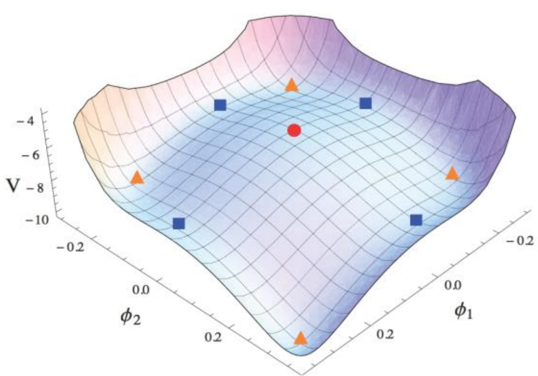
all physically equivalent in the absence of minimal couplings

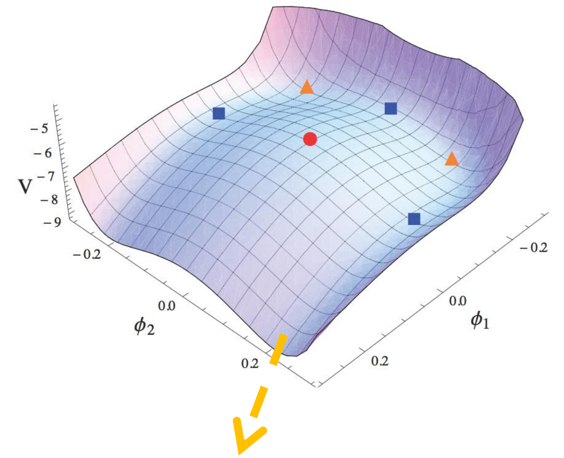
- Constructed a class of physically inequivalent theories by gauging SO(8) in a different frame [Dall'Agata, Inverso, M.T. 1209.0760]

$$(\cos(\omega)\, A_{\mu} + \sin(\omega)\, \tilde{A}_{\mu})\; T^{[SO(8)]}$$

Original C.-J. Sympl. frame

- Original dW-N model is a singular limit ($\omega \to 0$) in which several vacua disappear!





• Analogous construction used to generalize other gaugings [SO(p,q), p+q=8 and contractions thereof]

• Intense study of vacua of the new models, with different residual symmetries

Dall'Agata, Inverso, 1112.3345
Borghese, Guarino, Roest, 1209.3003
Borghese, Dibitetto, Guarino, Roest, Varela, 1211.5335;
Borghese, Guarino, Roest, 1302.6057

•Problematic D=11 uplift [de Wit, Nicolai 0801.1294, Godazgar, Godazgar, Hohm, Nicolai, Samtleben, 1406.3235]

•Omega-rotated ISO(7) from massive Type IIA [Guarino, Jafferis, Varela, 1504.08009]

Our results: All N>2 AdS_4 vacua of maximal supergravity

[Gallerati, Samtleben, M.T. 1410.0711]

- Only three 1-parameter classes

known	N=8 (ω)	$\hookrightarrow$	$SO(8)_\omega$ - model
New	N=4 (ϕ)	$\hookrightarrow$	$[SO(1,1)\times SO(6)]\ltimes N^{12}$–model $SO(1,7)_\omega$–model
New	N=3 (ϕ)	$\hookrightarrow$	$ISO(7)$–model $SO(1,7)_\omega$–model $SO(8)_\omega$–model

- First instances of 2 < N < 8 AdS vacua in the maximal theory
- They disappear in the $\omega \rightarrow 0$ limit
- SO(4) residual symmetry

Ungauged (extended) Supergravities

- Scalar fields (described by a non-lin. Sigma-model) are non-minimally coupled to the vector ones

$$\frac{1}{g^2} F \wedge {}^*F + \theta\, F \wedge F \;\longrightarrow\; -I(\phi)_{\Lambda\Sigma}\, F^\Lambda \wedge {}^*F^\Sigma + R(\phi)_{\Lambda\Sigma}\, F^\Lambda \wedge F^\Sigma$$

- Electric-magnetic duality symmetry of Maxwell equations now must also involve the scalar fields (Gaillard-Zumino)

$G = \mathrm{Isom}(\mathcal{M}_{scal}) \longrightarrow$

- Non-linear action on ϕ
- Linear action $\begin{pmatrix} F_{\mu\nu} \\ G_{\mu\nu} \end{pmatrix} \longrightarrow \mathbf{g} \cdot \begin{pmatrix} F_{\mu\nu} \\ G_{\mu\nu} \end{pmatrix}$

$$\mathbf{g} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \in G \overset{\sigma}{\hookrightarrow} Sp(2\, n_v, R)$$

E/M duality promotes G to ***global sym.*** of f.eqs. E B. ids.

- Smaller symmetry of the action:

$$G_e \subset G$$

Gauging

- Gauging consists in promoting a group $\mathcal{G}$ of G from *global* to *local* symmetry of the action. Different SF allow for different choices for $\mathcal{G}$.

- Local invariance w.r.t. $\mathcal{G}$

$$
\begin{aligned}
\partial_\mu \to D_\mu &= \partial_\mu - A^\lambda_\mu X_\lambda\,, \\
F^\lambda_{\mu\nu} &= \partial_\mu A^\lambda_\nu - \partial_\nu A^\lambda_\mu - f_{\sigma\delta}{}^\lambda A^\sigma_\mu A^\delta_\nu \\
[X_\sigma,\, X_\delta] &= f_{\sigma\delta}{}^\gamma X_\gamma
\end{aligned}
$$

- Description of gauging which is independent of the SF:

$$X_\lambda = E_\lambda{}^\Lambda X_\Lambda + E_{\lambda\Lambda} X^\Lambda = E_\lambda{}^M X_M \in \text{Algebra}(G)$$

E symplectic $2n_v$ x $2n_v$ matrix

- All information about the gauging encoded in a G-tensor: the embedding tensor

$$\text{Alg}(\mathcal{G}) \hookrightarrow \text{Alg}(G) \;\Rightarrow\; X_M = \theta_M{}^\alpha t_\alpha$$

$$\theta_M{}^\alpha \in \mathbf{2n_v} \times \text{Adj}(G)$$

[Cordaro, Frè, Gualtieri, Termonia, M.T. 9804056; Nicolai, Samtleben 0010076; de Wit, Samtleben, M.T. 0311224]

- Restore SUSY of the action:

Fermion shifts: $\delta_{SUSY} f = \ldots N_f \epsilon\,;\ \delta_{SUSY} \psi = \ldots S\epsilon$

Mass terms: $\bar{f}\, N_f\, \psi\,; \quad \bar{\psi}\, S\, \psi\,; \quad \bar{f}\, M\, f$

Scalar potential: $V(\phi) = \sum_f \bar{N}_f N_f - 3\, \bar{S}\, S$

$+\ldots$

$$N_f{}^A = N_f^A(\phi,\theta)\ ,\ \ S_{AB} = S_{AB}(\phi,\theta)$$

$+\ldots$ constraints on θ

$$(X_{MN}{}^P = \theta_M{}^\alpha\, t_{\alpha\, N}{}^P)$$

Linear: $X_{(MNP)} = 0$

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

Locality: $\theta^{\Lambda\,[\alpha}\, \theta_\Lambda{}^{\beta]} = 0$

- Field eq.s formally invariant if we G-transform fields and θ: equivalence between different gauged theories (duality)

$$\forall g \in G\ ;\quad V(\theta,\phi) = V(g\star\theta, g\star\phi)$$

Scalar manifold is homogeneous: $\phi \xrightarrow{G} O$

- Fix $\phi = O$ and search for vacua with given properties by scanning all possible gaugings (condition on θ) [Dall'Agata, Inverso; Dibitetto, Guarino, Roest]

N=8, D=4 SUGRA

32 supercharges

$$\begin{pmatrix} (1)\ g_{\mu\nu} \\ (8)\ \psi_{A\,\mu} \\ (28)\ A^{AB}{}_{\mu} \\ (56)\ \chi^{ABC} \\ (70)\ \phi^{ABCD} \end{pmatrix}$$

A,B label the **8** of $SU(8)_R$

gravitational

- Scalar fields in non-linear σ-model with target space

$$\mathcal{M}_{scal} = \frac{G}{H} = \frac{E_{7(7)}}{SU(8)}$$

Gaugings defined by $\theta_M{}^\alpha \in \mathbf{56} \times \mathbf{133}$

Linear constraints $\Rightarrow \theta \in \mathbf{912}$ of $E_{7(7)}$

$$\Downarrow$$

At the origin the f. shift tensors are the <u>only</u> SU(8)-irreducible components of θ

$$\theta_M{}^\alpha$$

$$\delta\psi_\mu^A = \cdots + 2\mathcal{D}_\mu\epsilon^A + \sqrt{2}\,A^{AB}\gamma_\mu\epsilon_B \qquad \delta\chi^{ABC} = \cdots - 2\,A_D{}^{ABC}\epsilon^D$$

Searching for N>2 AdS_4 vacua

Bosonic , max. sym. background (fermions=0=vectors, scalars=const.) with N=3 SUSY and negative cosmological constant

$$\epsilon^A = \{\epsilon^\alpha, \epsilon^a\}\ , \quad \alpha = 1,2,3,\ a = 4,\ldots,8$$

Killing spinor eq.s

$$\delta\psi_\mu^\alpha = \mathcal{D}_\mu \epsilon^\alpha + \sqrt{2}\, A^{\alpha\beta}\, \gamma_\mu \epsilon_\beta = 0$$

$$\delta\psi_\mu^a = \sqrt{2}\, A^{a\beta}\, \gamma_\mu \epsilon_\beta = 0$$

$$\delta\chi^{ABC} = -2\, A_\alpha{}^{ABC}\, \epsilon^\alpha = 0$$

And: $R_{\mu\nu}{}^{\rho\sigma} = \frac{2}{3}\Lambda\, \delta_{\mu\nu}^{\rho\sigma}\ ;\ \Lambda = V_0 = V(\theta, \phi = 0) < 0$

SUSY then implies that origin $(\phi = 0)$ is an extremum of V quadratic constraints

+

N=3 susy

$$A_{\alpha\beta} = \sqrt{-\frac{\Lambda}{6}}\,\delta_{\alpha\beta}\ , \quad A_{\alpha a} = 0$$

$$A_{\alpha}{}^{ABC} = 0$$

$\Downarrow$

$\theta(A_{AB}\, , A_A{}^{BCD})$ defines a gauging with the desired vacuum at the origin

<u>Further simplification:</u>

Fermion shifts must be invariant under $SO(3) \subset OSp(4|3)$

Study cases according to the SO(3) representation of the broken SUSYs

Instructive to start with a **kinematic** case-by-case analysis before imposing consistency with the full non-lin. theory (implemented by the ***quadratic constraints***)

Relevant Osp(4/3) irreps. DS(s_{max},E_0, j_0)

[Frè, Gualtieri, Termonia 9909188]

$$\begin{cases} DS(2,\tfrac{3}{2},0) & \text{massless graviton} \\ DS(\tfrac{3}{2},E_0,j_0)_L & \text{long-gravitino} \\ DS(\tfrac{3}{2},j_0+1,j_0)_S & \text{short-gravitino} \\ DS(1,j_0,j_0) & \text{short-vector} \end{cases}$$

$$5 \rightarrow 1+1+1+1+1$$

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

~~$DS(2,\tfrac{3}{2},0)+3\times DS(\tfrac{3}{2},E_0,0)_L+2\times DS(\tfrac{3}{2},1,0)_S+DS(1,1,1)$~~ ~~$\mathcal{N}=5$~~

~~$DS(2,\tfrac{3}{2},0)+2\times DS(\tfrac{3}{2},E_0,0)_L+3\times DS(\tfrac{3}{2},1,0)_S+DS(1,2,2)+DS(1,1,1)$~~

⋮

~~$DS(2,\tfrac{3}{2},0)+DS(\tfrac{3}{2},E_0,0)_L+4\times DS(\tfrac{3}{2},1,0)_S+2\times DS(1,2,2)+DS(1,1,1)$~~

$DS(2,\tfrac{3}{2},0)+5\times DS(\tfrac{3}{2},1,0)_S+10\times DS(1,1,1)$ $\mathcal{N}=8$

Quadr. constr. ✗

$5 \to 5$

$N=8 \longrightarrow$ $DS(2,\frac{3}{2},0)+DS(\frac{3}{2},3,2)_S+2\times DS(1,1,1)$ $N=3$

Quadr. constr. ✗

$5 \to 3+1+1$

$N=8 \longrightarrow$

$DS(2,\frac{3}{2},0)+DS(\frac{3}{2},E_0,1)_L+2\times DS(\frac{3}{2},1,0)_S+$
$DS(1,1,1)$ $N=5$

$DS(2,\frac{3}{2},0)+DS(\frac{3}{2},2,1)_S+2\times DS(\frac{3}{2},1,0)_S+$
$6\times DS(1,1,1)$ $N=5$

$DS(2,\frac{3}{2},0)+2\times DS(\frac{3}{2},E_0,0)_L+DS(\frac{3}{2},2,1)_S$ $N=3$

$DS(2,\frac{3}{2},0)+DS(\frac{3}{2},2,0)_L+DS(\frac{3}{2},2,1)_S+DS(\frac{3}{2},1,0)_S+$
$\times DS(1,2,2)$ $N=4$

Quadr. constr. ✗

$5 \to 2+2+1$

$DS(2,\frac{3}{2},0)+DS(\frac{3}{2},E_0,0)_L+2\times DS(\frac{3}{2},\frac{3}{2},\frac{1}{2})_S+$
$3\times DS(1,1,1)$ $N=3$

$DS(2,\frac{3}{2},0)+DS(\frac{3}{2},1,0)_S+2\times DS(\frac{3}{2},\frac{3}{2},\frac{1}{2})_S+$
$6\times DS(1,1,1)$ $N=4$

Quadr. constr. ✗

Quadratic constraints explicitly solved and found1-parameter families of N=3 and N=4 vacua (besides the N=8 ones)

N=4 (ϕ) $\hookrightarrow \begin{cases} [\mathrm{SO}(1,1)\times \mathrm{SO}(6)]\ltimes N^{12}\text{–model} \\ \mathrm{SO}(1,7)_\omega\text{–model} \end{cases}$

$$N=8 \longrightarrow DS(2,\tfrac{3}{2},0)+DS(\tfrac{3}{2},2,0)_L+DS(\tfrac{3}{2},2,1)_S+DS(\tfrac{3}{2},1,0)_S+ \times DS(1,2,2)$$

N=3 (ϕ) $\hookrightarrow \begin{cases} \mathrm{ISO}(7)\text{–model} \\ \mathrm{SO}(1,7)_\omega\text{–model} \\ \mathrm{SO}(8)_\omega\text{–model} \end{cases}$

$$N=8 \longrightarrow DS(2,\tfrac{3}{2},0)+DS(\tfrac{3}{2},\sqrt{3},0)_L+2\times DS(\tfrac{3}{2},\tfrac{3}{2},\tfrac{1}{2})_S+ 3\times DS(1,1,1)$$

- SO(4) residual symmetry
- Spectra are parameter-independent, the cosmological constant is parameter-dependent

Discussion

- Worked out all AdS vacua of D=4 maximal SUGRA with N>2: only 3 1-parameter families with N=8, 4, 3 respectively

- N=4,3 are first instances of AdS_4 vacua with 2<N<8 in the maximal theory.

- AdS/CFT: vacua dual to D=3 CFT with N=4,3 resp.

- Study DW solutions: $\begin{cases} N=3 \longrightarrow N=8 \\ N=3 \longrightarrow N=4 \end{cases}$

  Partial results for dyonic SO(8) gauging [Pang, Pope, Rong 1506.04270]

- Dual CFT?: Problem with the UV completion of the new dyonic gaugings… [Lee, Strickland-Constable and Waldram,1506.03457]

  Only exception: dyonic ISO(7), consistent truncation of Roman's massive Type IIA [Guarino, Jafferis, Varela, 1504.08009, Pang, Rong, 1508.05376]

Thank You!