New Physics From Maximal Supergravity

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Dall'Agata, Inverso, M.T. 1209.0760;
Gallerati, Samtleben, M.T. 1410.0711

Motivations

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

↓ Spontaneous compactification to D=4

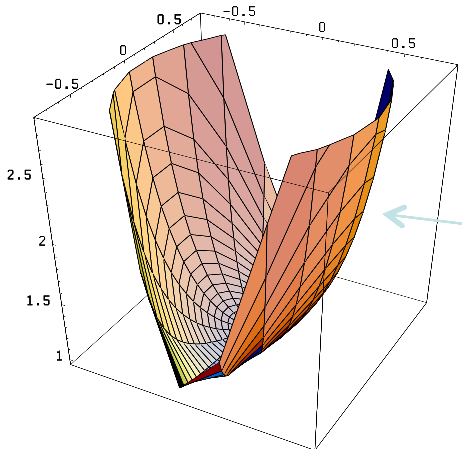
Effective description of our universe

(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 $M^{1,3} \times M$, 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 $\longrightarrow$ **Gauged SUGRA vacua**

$\longleftarrow$ **?**

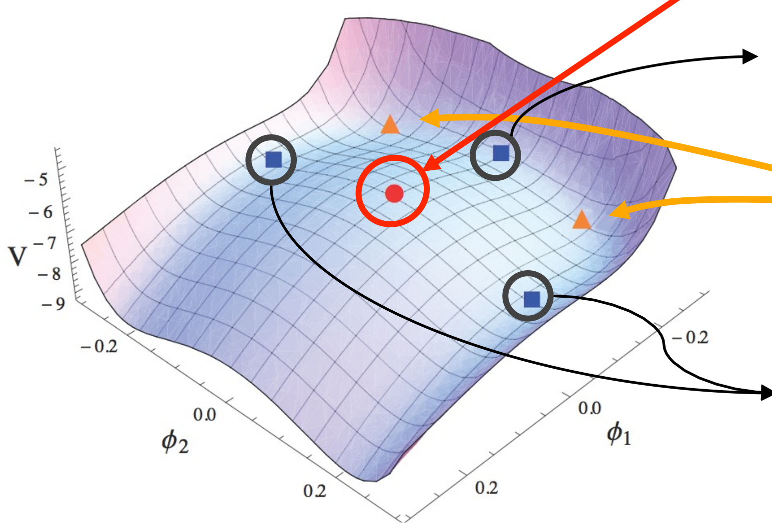
The Maximal D=4 SUGRA

- M-theory (D=11) on $\mathbf{M}^{1,3} \times \mathbf{T}^7$ $\Rightarrow$ Ungauged D=4 N=8 SUGRA global (on-shell) symmetry $G=E_{7(7)}$

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

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

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

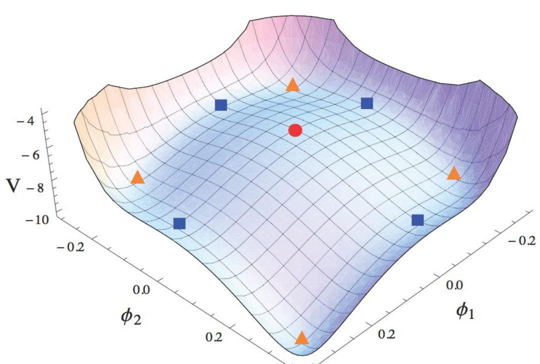
all physically equivalent in the absence of minimal couplings

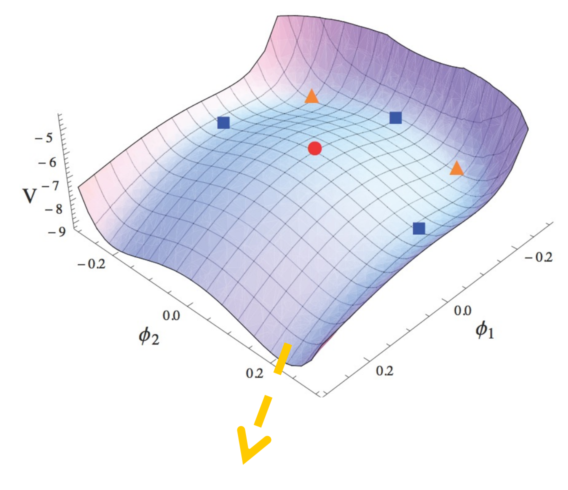
- Constructed a class of physically inequivalent theories by gauging SO(8) in a different frame [Dall'Agata, Inverso, M.T. 1209.0760]

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

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 $\omega \to 0$ 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)

$G = \mathrm{Isom}(\mathcal{M}_{scal})$ ⟶ { Non-linear action on ϕ ; Linear action $\begin{pmatrix} F_{\mu\nu} \\ G_{\mu\nu} \end{pmatrix} \longrightarrow \mathbf{g}.\begin{pmatrix} F_{\mu\nu} \\ G_{\mu\nu} \end{pmatrix}$ }

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

→ 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 $\mathcal{G}$ from *global* to *local* symmetry of the action. Different SF correspond to different choices for $\mathcal{G}$.

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

$$\partial_\mu \to D_\mu = \partial_\mu - A^\lambda_\mu X_\lambda \,, \qquad [X_\sigma, X_\delta] = f_{\sigma\delta}{}^\gamma X_\gamma$$

- 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	$X_{PN}{}^P = 0\,,\ X_{(MNP)} = 0$
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)

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

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

(1) $g_{\mu\nu}$

(8) $\psi_{A\,\mu}$

(28) $A^{AB}{}_{\mu}$

(56) χ^{ABC}

(70) ϕ^{ABCD}

gravitational

A,B : **8** of $SU(8)_R$

- 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 $E_{7(7)}$

36 **420**

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

$$\boxed{\theta_M{}^\alpha} \in \mathbf{912} \to \mathbf{36} + \mathbf{420} + \overline{\mathbf{36}} + \overline{\mathbf{420}}$$

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

Searching for N>2 AdS_4 vacua

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

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

Killing spinor eq.s

$$\delta\psi^\alpha_\mu = 2\mathcal{D}_\mu\epsilon^\alpha + \sqrt{2}\,A^{\alpha\beta}\,\gamma_\mu\epsilon_\beta = 0$$
$$\delta\psi^a_\mu = \sqrt{2}\,A^{a\beta}\,\gamma_\mu\epsilon_\beta = 0$$
$$\delta\chi^{ABC} = -2\,A_\alpha{}^{ABC}\,\epsilon^\alpha = 0$$

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

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

Further simplification:

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]

- $DS(2, \frac{3}{2}, 0)$ massless graviton
- $DS(\frac{3}{2}, E_0, j_0)_L$ long-gravitino
- $DS(\frac{3}{2}, j_0 + 1, j_0)_S$ short-gravitino
- $DS(1, j_0, j_0)$ short-vector

$5 \to 1+1+1+1+1$

$N = 8 \longrightarrow$

- $DS(2,\frac{3}{2},0)+3\times DS(\frac{3}{2},E_0,0)_L+2\times DS(\frac{3}{2},1,0)_S+DS(1,1,1)$ — $N=5$
- $DS(2,\frac{3}{2},0)+2\times DS(\frac{3}{2},E_0,0)_L+3\times DS(\frac{3}{2},1,0)_S+DS(1,2,2)+DS(1,1,1)$
- $DS(2,\frac{3}{2},0)+DS(\frac{3}{2},E_0,0)_L+4\times DS(\frac{3}{2},1,0)_S+2\times DS(1,2,2)+DS(1,1,1)$
- ⋮
- $DS(2,\frac{3}{2},0)+5\times DS(\frac{3}{2},1,0)_S+10\times DS(1,1,1)$ — $N=8$

Quadr. constr. ✗

$5 \to 5$

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

Quadr. constr. ✗

$5 \to 3+1+1$

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

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

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

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

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

Quadr. constr. ✗

$5 \to 2+2+1$

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

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

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

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

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

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

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

Conclusions

- 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 RG flows: $\begin{cases} N=3 & \longrightarrow & N=8 \\ N=3 & \longrightarrow & N=4 \end{cases}$
- Study black hole solutions which asymptote the new AdS vacua
- N=3 vacuum of ISO(7) correspond to $AdS_4 \times S^6$ compact. of massive type IIA

[Guarino, Jafferis, Varela, 1504.08009]