M-theory origin of $N=8$ gauged supergravities

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Plan of the Talk

1 Exceptional Generalised Geometry and Exceptional Field Theories

2 Embedding of gauged supergravities in EGG and EFT

3 Uplifting the $SO(3) \times SO(3)$ critical point of $SO(4,4)$

4 Conclusions and perspectives
Exceptional Generalised Geometry and Exceptional Field Theories

Embedding of gauged supergravities in EGG and EFT

Uplifting the $SO(3) \times SO(3)$ critical point of $SO(4,4)$

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4 Conclusions and perspectives
$E_{d(d)} \times \mathbb{R}^+$ Generalised Geometry (EGG)

- $E_{d(d)} \times \mathbb{R}^+$ Generalised Geometry $\equiv$ Reformulation of 11D SUGRA where ...

- Geometric Interpretation of the Bosonic Sector
  $g_{MN}, A_{MNP}, \tilde{A}_{N_1 \ldots N_6}$ encoded in the "Generalised metric"

- Generalised Tangent Bundle ($E_{d(d)} \times \mathbb{R}^+$ structure)
  $E = v + w + \sigma + \tau \in TM \oplus \Lambda^2 T^* M \oplus \Lambda^5 T^* M \oplus (T^* M \otimes \Lambda^7 T^* M)$

- Generalised Lie Derivative
  $L_E E' = \mathcal{L}_v v' + (\mathcal{L}_v w' - i_v dw) + (\mathcal{L}_v \sigma' - i_v d\sigma - w' \wedge dw) + (\mathcal{L}_v \tau' - j\sigma' \wedge dw - jw' \wedge d\sigma)$

Nice (unified) mathematical structure
\( E_{d(d)} \times \mathbb{R}^+ \) **Generalised Geometry (EGG)**

- **Generalised Geometry** = Reformulation of 11D SUGRA where ...

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  \( g_{MN}, A_{MNP}, \tilde{A}_{N_1...N_6} \) encoded in the “Generalised metric”

- Generalised Tangent Bundle \((E_{d(d)} \times \mathbb{R}^+ \text{ structure})\)
  
  \[
  E = v + w + \sigma + \tau \quad \in \quad TM \oplus \Lambda^2 T^*M \oplus \Lambda^5 T^*M \oplus (T^*M \otimes \Lambda^7 T^*M)
  \]

- Generalised Lie Derivative
  
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**Nice (unified) mathematical structure**
7 \rightarrow 56 + \text{“section condition”}
\partial m_8 \rightarrow \partial m, \partial m_n \rightarrow 0

\delta \xi V^M = \xi^P \partial_P V^M - 12 P_{(adj)}^{M N P Q} \partial_P \xi^Q V^N + \frac{\omega}{2} \partial_P \xi^P V^M ,

These transformations define the generalised fluxes, $F_{AB}^C$, via

$$\delta E_A E_B = F_{AB}^C E_C .$$

$F_{AB}^C = X_{AB}^C + D_{AB}^C, \quad (912 + 56)$

the structure constants $X_{ABC}$ automatically satisfy the 4D maximal supergravity relations of the embedding tensor

$$P_{(adj)}^{C D E} X_{AD}^E = X_{AB}^C , \quad X_A [BC] = X_{AB}^B = X_{(ABC)} = X_{BA} B = 0,$$

section conditions,

$$\Omega^{MN} \partial_M A \partial_N B = 0, \quad [t_\alpha]^{MN} \partial_M A \partial_N B = 0, \quad [t_\alpha]^{MN} \partial_M \partial_N A = 0 ,$$
N=8 Supergravity in 4D

Field content: \( e^a_\mu \ U = \begin{pmatrix} u^{ij}_{I\bar{J}} & v^{ij}_{I\bar{J}} \\ v^{ij}_{I\bar{J}} & u^{ij}_{I\bar{J}} \end{pmatrix} \subset E_7/SU(8) \quad A^a_\mu \quad \psi^A_\mu \quad \chi_{ABC} \)

N=8 (Abelian) Sugra (up to second order in K) \quad \text{de Wit, Freedman 77’}

Full (Abelian) N=8 torus compactification \quad \text{Cremmer, Julia 78’}

\( GL(7, R)_{\text{global}} \times SO(7)_{\text{local}} \rightarrow E_7(7)_{\text{global}} \times SU(8)_{\text{local}} \)

Non Abelian case

Flat groups twisted tori \quad \text{Scherk, Schwarz 79’}

SO(8) gauged Maximal supergravity \quad \text{de Wit, Nicolai 81’}

SO(p,q) and CSO(p,q,r) gauged Maximal supergravity \quad \text{Hull 84’}

New Gauged supergravities \quad \text{Dall’Agata, Inverso, Trigiante 12’}

**Embedding Tensor**

\( X_{MN}^P = \Theta_M^\alpha (t_{\alpha})_N^P \)

\( D_\mu = \partial_\mu - A_\mu^M \Theta_M^\alpha t_\alpha \)

Linear constraints

\( t_{\alpha M}^N \Theta_N^\alpha = 0 , \quad (t_{\beta} t_{\alpha})_M^N \Theta_N^\beta = -\frac{1}{2} \Theta_M^\alpha \)

Quadratic constraint

\( \Theta_M^\alpha \Theta_N^\beta \Omega^{MN} = 0 \)
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**Quadratic constraint**

$\Theta_M^\alpha \Theta_N^\beta \Omega_{MN}^{\alpha \beta} = 0$
Embedding of SUGRAs in EGG and EFT

GENERALISED SCHERK-SCHWARZ REDUCTIONS

\[
\begin{pmatrix}
\tilde{V}^{MN}(x,y) \\
\tilde{V}_M^N(x,y)
\end{pmatrix}
= 
\begin{pmatrix}
\tilde{V}_{AB}^{MN}(x,y) \\
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\end{pmatrix}
= 
\begin{pmatrix}
u_{ab}^{CD}(x) & v_{ab}^{CD}(x) \\
u^{ab} CD(x) & u^{ab} CD(x)
\end{pmatrix}
\begin{pmatrix}
E_{CD}^{MN}(y) \\
E_{CD}^{MN}(y)
\end{pmatrix}
\]

**Embedding tensor of $SO(p, q)$ Gauged Maximal Supergravity**

\[
L_{EAB} E_{CD} = R^{-1} \left( \eta_{CB} E_{AD} - \eta_{DB} E_{AC} - \eta_{CA} E_{BD} + \eta_{DA} E_{BC} \right),
\]

\[
L_{EAB} E^{CD} = R^{-1} \left( \eta_{AE} \delta^C_B E^{ED} - \eta_{BE} \delta^C_A E^{ED} + \eta_{AE} \delta^D_B E^{CE} - \eta_{BE} \delta^D_A E^{CE} \right),
\]

\[
L_{EAB} E_{CD} = 0, \quad L_{EAB} E^{CD} = 0.
\]

\[
L_{E_A} E_B = \chi_{AB}^{C} E_C \quad \chi_{AB}^{C} \equiv SO(p, q) \text{ Embedding tensor}
\]

- $S^n$ are generalised parallelisable Waldram, Lee, Strickland-Constable 14'
- Are Hyperboloids Generalised parallelisable?

Walter H. Baron
M-theory origin of $N=8$ SUGRA
Generalised Scherk-Schwarz reductions

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\begin{pmatrix}
\tilde{V}_{AB}^{MN}(x, y) & \tilde{V}_{AB}^{MN}(x, y)
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Embedding of SUGRAs in EGG and EFT

**Generalised Scherk-Schwarz reductions**

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**Embedding tensor of SO(p, q) Gauged Maximal Supergravity**

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L_{E_{CD}} E_{AB} = R^{-1}(\eta_{CB} E_{AD} - \eta_{DB} E_{AC} - \eta_{CA} E_{BD} + \eta_{DA} E_{BC}),
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\]

\[
L_{E_A} E_{B} = X_{AB}^{C} E_{C}
\]

\[
X_{AB}^{C} \equiv SO(p, q) \text{ Embedding tensor}
\]

- \(S^n\) are generalised parallelisable Walfram, Lee, Strickland-Constable 14’
- Are Hyperboloids Generalised parallelisable?
Embedded of SUGRAs in EGG and EFT

Generalized Vielbein for compact gaugings

- solved in EGG by Waldram, Lee, Strickland-Constable 14'
- solved in EFT by WB 14'

Generalized Vielbein for noncompact gaugings

- solved in EGG by WB, Dall’Agata 14'
- solved in EFT by Hohm, Samtleben 14'
Embedding of SUGRAs in EGG and EFT

\[ E_A = \begin{cases} 
E_{AB} = K_{AB} + S_{AB} + i_k \zeta \\
E^{AB} = P^{AB} + T^{AB} - j \zeta \wedge P^{AB},
\end{cases} \]

with

\[ P^{AB} = dX^A \wedge dX^B, \]

\[ S_{AB} = \ast P_{AB} = \frac{R^{-1}}{(d - 2)!} \epsilon_{ABC_1 \ldots C_{d-1}} X^{C_1} dX^{C_2} \wedge \ldots \wedge dX^{C_{d-1}} \]

\[ T^{AB} = R^{-1} \left( X^A dX^B - X^B dX^A \right) \otimes Vol_H, \]

\[ Vol_H = \frac{R^{-1}}{d!} \epsilon_{C_1 \ldots C_{d+1}} X^{C_1} dX^{C_2} \wedge \ldots \wedge dX^{C_{d+1}}, \]

\[ d\zeta = \frac{d - 1}{R} Vol_H \]

Hyperboloids Generalised parallelizable!

\[ T^{AB} = 0 \iff X^A = X^B = 0, \]

\[ P^{AB} = 0 \iff (X^A)^2 + (X^B)^2 = R^2 \quad A, B = 1, \ldots, 4, \]

\[ P^{AB} = 0 \iff (X^A)^2 - (X^B)^2 = R^2 \quad A = 1, \ldots, 4; \quad B = 5, \ldots, 8, \]

\[ P^{AB} \neq 0 \quad \text{for} \quad A, B = 5, \ldots, 8. \]
Non linear uplift ansatze (WB, Dall’Agata 14’)

**Nonlinear Metric Ansatz**

\[
\Delta^{-1} g^{mn} = \frac{1}{2} K^{m}_{AB} K^{n}_{CD} \left( u^{AB}_{ab} - i v^{ab}_{AB} \right) \left( u^{CD}_{ab} + i v^{ab}_{CD} \right)
\]

**Nonlinear Flux Ansatz**

\[
A_{mnp} = \frac{\sqrt{2}}{4} \Delta \ g_{pq} \ K^{AB}_{mn} K^{q}_{CD} \left( u^{AB}_{ab} + i v^{ab}_{AB} \right) \left( u^{CD}_{ab} + i v^{ab}_{CD} \right)
\]

\(K^{m}_{AB} \): Killing vectors

\(K^{m}_{mn} = R^{-1} \eta^{AC} \eta^{BD} \ ^{\circ}g_{mp} \ ^{\circ}\nabla_n K^p_{CD}\)

Tests:

- In \(SO(8)\) \(\Rightarrow\) \(SO(8), SO(7), G2, SU(4), SO(3) \times SO(3)\)
- In \(SO(5, 3)\) \(\Rightarrow\) \(SO(5) \times SO(3)\)
- In \(SO(4, 4)\) \(\Rightarrow\) \(SO(4) \times SO(4), SO(3) \times SO(3)\)
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\[ A_{mnp} = \frac{\sqrt{2}}{4} \Delta g_{pq} K_{mn}^{AB} K_{q}^{CD} \left( u_{ab}^{AB} + i v_{ab}^{AB} \right) \left( u_{ab}^{CD} + i v_{ab}^{CD} \right) \]

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The $SO(3) \times SO(3)$ invariant critical points of $SO(4,4)$ gauged supergravity (Dall’Agata, Inverso 12') can be obtained by truncating the scalar manifold to a 2d sector.

This critical point has the following uplift solution in 11D SUGRA (WB, Dall’Agata 14'). $y^i = \{\psi, \theta_1, \phi_1\}$

$$ds^2 = \frac{\alpha^{-1} R^2}{\Delta(y)} \left[ \sum_{i,j=1}^{3} h_{ij}(y) \, dy^i \, dy^j + R_1^2(y) \left( d\theta_2^2 + \sin^2(\theta_2) \, d\theta_3^2 \right) + R_2^2(y) \left( d\phi_2^2 + \sin^2(\phi_2) \, d\phi_3^2 \right) \right],$$

$$A = A^{(1)} \wedge e^4 \wedge e^5 + A^{(2)} \wedge e^6 \wedge e^7, \quad e^4 = R_1 \, d\theta_2, \quad e^5 = R_1 \, \sin \theta_2 \, d\theta_3, \quad e^6 = R_2 \, d\phi_2, \quad e^7 = R_2 \, \sin \phi_2 \, d\phi_3,$$

$$A^{(1)} = -A_0 \left[ \sinh^2(\psi) + \left( 1 + \frac{2}{\sqrt{3}} \right) \cosh^2(\psi) \right] \sin(\theta_1) \cos(\phi_1) \, d\psi$$

$$- A_0 \sinh(\psi) \cosh(\psi) \cos(\theta_1) \cos(\phi_1) \, d\theta_1 + A_0 \left( 1 + \frac{2}{\sqrt{3}} \right) \sinh(\psi) \cosh(\psi) \sin(\theta_1) \sin(\phi_1) \, d\phi_1$$

The 4D metric $\tilde{g}$ describes de Sitter spacetime and therefore $\tilde{R}_{\mu\nu} = 3 R_4^{-2} \tilde{g}_{\mu\nu}$, with $R_4$ the de Sitter radius. The 4-form $F_{\mu\nu\rho\sigma} = f_{FR} \, \epsilon_{\mu\nu\rho\sigma}$, where

$$R_4^2 = \frac{3}{2} \frac{g^2}{V_c} R^2, \quad f_{FR} = \pm \frac{1}{g^2 \sqrt{2}} V_c R^{-1},$$

where $g$ is the coupling constant of the 4-dimensional gauged supergravity theory and $V_c$ is the value of the potential at the critical point.
The $SO(3) \times SO(3)$ invariant critical points of $SO(4,4)$ gauged supergravity (Dall’Agata, Inverso 12’) can be obtained by truncating the scalar manifold to a 2d sector.

This critical point has the following uplift solution in 11D SUGRA (WB, Dall’Agata 14’). $y^i = \{\psi, \theta_1, \phi_1\}$

$$ds_7^2 = \frac{\alpha^{-1} R^2}{\Delta(y)} \left[ \sum_{i,j=1}^{3} h_{ij}(y) dy^i dy^j + R_1^2(y) \left( d\theta_2^2 + \sin^2(\theta_2) d\theta_3^2 \right) + R_2^2(y) \left( d\phi_2^2 + \sin^2(\phi_2) d\phi_3^2 \right) \right],$$

$$A = A^{(1)} \wedge e^4 \wedge e^5 + A^{(2)} \wedge e^6 \wedge e^7, \quad e^4 = R_1 d\theta_2, \quad e^5 = R_1 \sin \theta_2 d\theta_3, \quad e^6 = R_2 d\phi_2, \quad e^7 = R_2 \sin \phi_2 d\phi_3,$$

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Uplifting the $SO(3) \times SO(3)$ critical point

\[
R_1^2 = \frac{4(2\sqrt{3} - 3) \sin^2 \theta_1}{3(\sqrt{3} - 1) + 6 \sin^2 \theta_1 + \tanh^2 \psi[3\sqrt{3}(\sqrt{3} - 1) - (6 - 4\sqrt{3}) \sin^2 \phi_1]} ,
\]

\[
R_2^2 = \frac{4(2\sqrt{3} - 3) \sin^2 \phi_1}{3(\sqrt{3} - 1) + 6 \sin^2(\phi_1) + \coth^2 \psi[3\sqrt{3}(\sqrt{3} - 1) - (6 - 4\sqrt{3}) \sin^2 \theta_1]} ,
\]

and the overall warp factors are

\[
\Delta^{-9} = \alpha^7 \det h^{-1} \frac{\sin^4 \theta_1}{R_1^4} \frac{\sin^4 \phi_1}{R_2^4} \cosh^6 \psi \sinh^6 \psi
\]

\[
h = (\det M)^{-\frac{1}{2}} M
\]

where

\[
M = \begin{pmatrix}
A B - S_2^2 S_3^2 & -(\Phi_3 B + S_3^2 \Phi_2) S_2 & -\left(\Phi_2 A + S_2^2 \Phi_3\right) S_3 \\
-(\Phi_3 B + S_3^2 \Phi_2) S_3 & \left[\frac{3(2+\sqrt{3})}{4} - \Phi_2 \Phi_3\right] B - S_3^2 \Phi_2 & \left[\frac{3(2+\sqrt{3})}{4} - \Phi_2 \Phi_3\right] A - S_2^2 \Phi_3^2 \\
-(\Phi_2 A + S_2^2 \Phi_3) S_3 & \frac{3(2+\sqrt{3})}{4} S_2 S_3 & \frac{3(2+\sqrt{3})}{4} S_2 S_3
\end{pmatrix},
\]

and

\[
S_2 = \frac{1}{2} \tanh \psi \sin(2\theta_1), \quad S_3 = \frac{1}{2} \coth \psi \sin(2\phi_1),
\]

\[
\Phi_2 = \frac{3}{2} - \sin^2 \theta_1 , \quad \Psi_2 = \frac{3}{2} - \cos^2 \theta_1 ,
\]

\[
\Phi_3 = \frac{3}{2} - \sin^2 \phi_1 , \quad \Psi_3 = \frac{3}{2} - \cos^2 \phi_1 ,
\]

\[
A = \frac{3+\sqrt{3}}{4} + \tanh^2 \psi \left[\frac{3(2+\sqrt{3})}{4} - \Psi_2 \Phi_3\right] , \quad B = \frac{3+\sqrt{3}}{4} + \coth^2 \psi \left[\frac{3(2+\sqrt{3})}{4} - \Psi_3 \Phi_2\right].
\]
Conclusions and perspectives

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- We provided a new ansatz for the full uplift of the vacua of maximal gauged supergravity with non-compact gauge groups $SO(p, q)$ and tested it against the 11-dimensional equations of motion for all the known de Sitter vacua of these models.

- An alternative way of deriving the Uplift ansatze follows from a ground-up approach by using the $SU(8)$ reformulation of 11D SUGRA and SUSY as a organising principle.

- While the construction of the generalised vielbein involves the use of Killing tensors for the space with $(p,q)$ signature, this procedure correctly reproduces euclidean geometries, because the scalar-dependent matrix $M_{AB}(x)$ is positive definite.

- The fact that the final metric depends on the contraction of the generalised vielbeins with a positive definite matrix $M$, implies that at any vacuum the $SO(p, q)$ gauge group is broken to a subgroup of its maximal compact subgroup $SO(p) \times SO(q)$. 
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Conclusions and perspectives

An independent derivation of the CSO(p,q,r) gaugings was proposed by Hohm and Samtleben in the Exceptional Field Theory framework (EFT). Even though the geometrical interpretation of these solutions is not completely clear, these should reduced to ours for \( r = 0 \) because they imposed the section conditions.

The same approach was successfully applied by Hohm and Samtleben to get the uplift formulas of IIB supergravity with compact and non compact gauge group.

After 35 years of work in this longstanding problem we feel confident that today all electric maximal gauged supergravities can be uplifted to 11D Supergravity.

A very interesting problem is to understand if the dyonic gauged supergravities recently proposed by Dall’Agata, Inverso and Trigiante can be uplifted to 11 D Supergravity or some deformation. By simple analysis of the generalised Lie derivatives of the generalised vielbeins one observes that dyonic gaugings need the inclusion of form fluxes in the background. We expect to explore this situation in the future.
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Thank you for your attention!