Dualities and scale-separated AdS_3 vacua

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September 9, 2025

Talk at EISA Corfu

LEHIGH UNIVERSITY

Based on

Fotis Farakos, G. T, [2502.08215]

Zheng Miao, Muthusamy Rajaguru, G. T, Timm Wrase [2509.XXXXX]

G. T, Timm Wrase [2509.XXXXX]

Scale separation

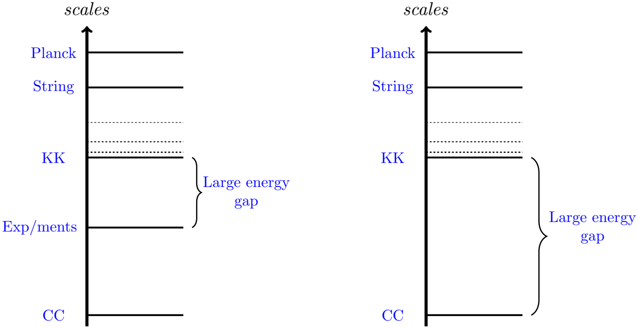


Figure: Schematic illustration of the hierarchy of scales in compactifications

$$\frac{\langle V \rangle}{m_{\mathsf{KK}}^2} \sim \frac{L_{\mathsf{KK}}^2}{L_\Lambda^2} \ll 1$$

Condition to estimate the existence of a *large energy gap* between the extra-dimensional states of the fields and the vacuum energy of the EFT.

Scale separated 4D constructions

- First explicit construction by **D**eWolfe,**G**iryavets,**K**achru,**T**aylor '05; **C**amara, **F**ont, **I**banez '05

  "Parametric scale-separated classical 4d AdS solution from IIA "

  see earlier related constructions: Behrndt, Cvetic '04; Derendinger, Kounas, Petropoulos, Zwirner '04

- Attempts followed to better understand DGKT:
  Acharya, Caviezel, Koerber, Ihl, D. Lüst, Petrini, Solard, Saracco, Tomasiello, Tsimpis, Van Riet, Wrase, Zagermann... (2005–2019)
  using dualities, 10D perspective, more general compactification spaces.

- Early criticism: McOrist, Sethi '12 regarding smearing of local sources etc.

Recent developments

- Parametric scale-separated classical **AdS**$_3$ from IIA Farakos, G.T, Van Riet '20; Van Hemelryck '22;
- Progress on **localization** Junghans '20, '23, Marchesano, Tomasiello, Quirant '20, Emelin, Farakos, G.T '21, Andriot, GT '23, Emelin '24
- Progress in **M-theory** Cribiori, Junghans, Van Hemelryck, Van Riet, Wrase '21; Van Hemelryck '24
- Scale-separated **AdS**$_3$ solutions from **IIB** Arboleya, Guarino, Morittu '24; Van Hemelryck '25
- **Anisotropic** scale-separated 3d and 4d solutions Carrasco, Coudarchet, Marchesano, Prieto '23, Farakos, Morittu, G.T '23; G.T '23 Farakos, G.T. '25
- Scale separation in **arbitrary dimensions** G.T, Wrase '25
- **CFT study**: Conformal dimensions, brane limits etc Apers, Conlon, Montero, Ning, Revello, Valenzuela, Van Riet, Wrase '20-'25

Our scope

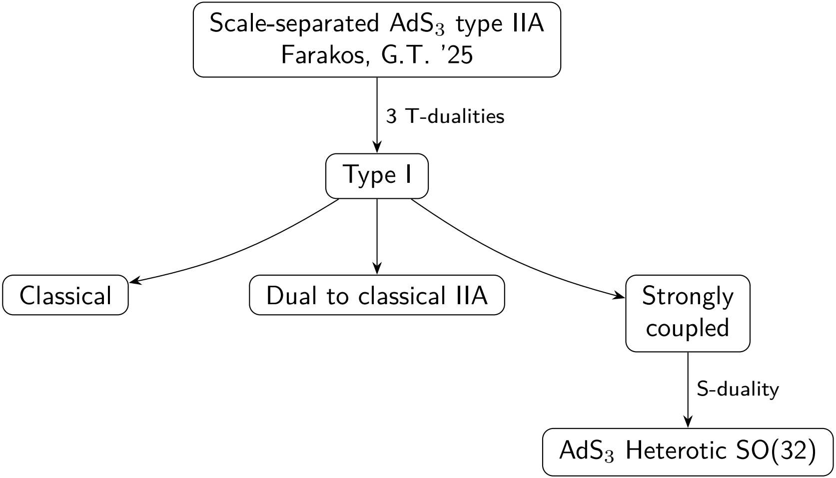
Starting point

- Classical scale-separated AdS_3 vacua from massive IIA
- Dual conformal dimensions with interesting behavior
- Constructed with fluxes and smeared sources O2/D2, O6/D6
- Parametrically controlled solution due to unbounded F_4 flux

Scope

- Perform dualities and study the dual and other families of vacua

New scale separated solutions



massive IIA

Toroidal orbifold

This the the **associative 3-form** of G2

$$\Phi = e^{127} - e^{347} - e^{567} + e^{136} - e^{235} + e^{145} + e^{246}\,,$$

with $\Phi = \sum_i^7 s^i \Phi_i$. In this example we have **G2-holonomy**:

$$d\Phi = 0\,, \qquad d\Psi = 0\,.$$

The internal space is a **seven-torus** modded out by orbifold group $\Gamma = \{\Theta_\alpha, \Theta_\beta, \Theta_\gamma\}$, see [Joyce '96]:

$$X_7 = \frac{T^7}{\mathbb{Z}_2 \times \mathbb{Z}_2 \times \mathbb{Z}_2}$$

For our orbifold group Γ we use the following $\mathbb{Z}_2$ involutions

$$\begin{aligned}
\Theta_\alpha &: (y^1, \dots, y^7) \to (-y^1, -y^2, -y^3, -y^4, y^5, y^6, y^7)\,,\\
\Theta_\beta &: (y^1, \dots, y^7) \to (-y^1, -y^2, y^3, y^4, -y^5, -y^6, y^7)\,,\\
\Theta_\gamma &: (y^1, \dots, y^7) \to (-y^1, y^2, -y^3, y^4, -y^5, y^6, -y^7)\,,
\end{aligned}$$

O2/O6-planes

- Consider O2 plane and require their orbifold image to be a physical object:

$$\sigma_{\text{O2}} : y^i \to -y^i \,, \qquad \sigma_{\text{O6}_i} : \sigma_{\text{O2}}\Gamma$$

	y^1	y^2	y^3	y^4	y^5	y^6	y^7
O6_α	$\otimes$	$\otimes$	$\otimes$	$\otimes$	–	–	–
O6_β	$\otimes$	$\otimes$	–	–	$\otimes$	$\otimes$	–
O6_γ	$\otimes$	–	$\otimes$	–	$\otimes$	–	$\otimes$
$\text{O6}_{\alpha\beta}$	–	–	$\otimes$	$\otimes$	$\otimes$	$\otimes$	–
$\text{O6}_{\beta\gamma}$	–	$\otimes$	$\otimes$	–	–	$\otimes$	$\otimes$
$\text{O6}_{\gamma\alpha}$	–	$\otimes$	–	$\otimes$	$\otimes$	–	$\otimes$
$\text{O6}_{\alpha\beta\gamma}$	$\otimes$	–	–	$\otimes$	–	$\otimes$	$\otimes$

Table: Localized positions "-" and the warped directions $\otimes$ for O6-planes

3D effective theory

- Performing a dimensional reduction from massive IIA

$$e^{-1}\mathcal{L} = \frac{1}{2}R_3 - G_{IJ}\partial\varphi^I\partial\varphi^J - V(\varphi^I)\,, \qquad \varphi^I = \upsilon, \phi, \tilde{s}^1, \ldots, \tilde{s}^6$$

with scalar potential

$$V = V_H + V_{F_6} + V_{F_0} + V_{O6}$$

- Scalar potential in 3D supergravity:

$$V = G^{IJ}\partial_I P \partial_J P - 4P^2$$

- The relevant superpotential

$$P = \frac{1}{4\text{vol}(X)^2}\int_X \left(e^{-\frac{\phi}{2}} \star \Phi \wedge H_3 + e^{\frac{\phi}{4}}\Phi \wedge F_4 + e^{\frac{5}{4}\phi} \star F_0\right)\,.$$

Tadpoles

The fluxes H_3 and F_4 are expanded on the Φ_i and Ψ_i basis

$$H_3 = \sum_{i=1}^{7} h^i \Phi_i \,, \qquad F_4 = \sum_{i=1}^{7} f^i \, \Psi_i \,, \qquad F_0 = m_0 \,.$$

- The integrated Bianchi identities

$$0 = \int_{3i} H_3 \wedge F_0 + \int_{3i} \mu_{\mathsf{O6}} J_3$$
$$0 = \int_{7} H_3 \wedge F_4 + \int_{7} \mu_{\mathsf{O2/D2}} J_7$$

- Fluxes ansatz

$$f^i = (-N, -N, -N, -N, -N, -N, +6N)$$
$$h^i = h(1, 1, 1, 1, 1, 1, 1)$$

- Because $h^i f_i = 0$, the tadpole cancellation is satisfied while F_4 flux is unbounded.

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New flux configuration

- Consider the following flux configuration

$$
\begin{aligned}
F_4 =& - N\,(\Psi_2 + \Psi_5 + \Psi_6 + \Psi_7) \\
&+ (Q+G)\Psi_1 + (Q+G)\Psi_3 + (Q-2G)\Psi_4 \\
H_3 =& h\,(\Phi_1 + \Phi_3 + \Phi_4)\ , \\
F_0 =& m_0\,,
\end{aligned}
$$

- The tadpole

$$
0 = \int (F_4^N + F_4^Q + F_4^G) \wedge H_3 + \int (\mu_{O2} + \mu_{D2}) J_7\,,
$$

is satisfied in the following way

$$
\begin{aligned}
&F_4^N \wedge H_3 = 0 \\
&F_4^Q \wedge H_3 = 0 \\
&F_4^G \wedge H_3 = (\mu_{O2} + \mu_{D2}) J_7 \quad \rightarrow \quad 0 = 3Qh + (16 - N_{D2})
\end{aligned}
$$

type I

T-dualizing scale-separated AdS from massive IIA

- T-duality along the directions y_5, y_3, and y_2.

- The F_4 flux and Romans mass become

$$
\begin{aligned}
F_7 &= -\,\mathcal{G} d\eta^1 \wedge \cdots \wedge d\eta^7 \\
F_3 &= +\,N\hat{\Phi}_1 + N\hat{\Phi}_3 + N\hat{\Phi}_4 - \tilde{m}_0\hat{\Phi}_5 \\
&\qquad - (Q+G)\hat{\Phi}_6 - (Q+G)\hat{\Phi}_7 - (Q-2G)\hat{\Phi}_2
\end{aligned}
$$

- The three NSNS fluxes give the following metric fluxes

$$
H_{127} \leftrightarrow -\tau^2_{17} \equiv h\,, \qquad H_{567} \leftrightarrow \tau^5_{67} \equiv -h\,, \qquad H_{136} \leftrightarrow -\tau^3_{16} \equiv h\,,
$$

respect the Maurer-Cartan equation

$$
d\eta^a = -\frac{1}{2}\tau^a_{bc}\eta^b \wedge \eta^c\,,
$$

and η^i are the coordinates of the twisted torus.

Internal space of the dual type I theory

- The internal space is co-closed G_2

$$d\hat{\Phi} = W_1 \star \hat{\Phi} + W_{27}\,, \qquad d\star\hat{\Phi} = 0\,,$$

- The fluxes satisfy the following conditions

$$dF_7 = 0\,, \qquad dF_3^{\text{closed}} = 0\,, \qquad dF_3^{\text{non-closed}} \neq 0\,,$$

the relevant Bianchi identity is

$$dF_{3,i}^{\text{non-closed}} = \mu_{O5} J_{4,i}\,.$$

- We have already constructed the relevant $\mathcal{N}=1$ 3D supergravity in Emelin, Farakos, G.T. '21

$$P = \frac{1}{4\text{vol}(X)^2}\int_X \left(e^{-\frac{\phi}{2}}F_7 - e^{\frac{\phi}{2}}\star\hat{\Phi}\wedge F_3 + \frac{1}{2}\hat{\Phi}\wedge d\hat{\Phi}\right)\,.$$

Sources in dual type I

$$\begin{pmatrix} \text{O2/D2} & - & - & - & - & - & - & - \\ \text{O6}_\alpha & \times & \times & \times & \times & - & - & - \\ \text{O6}_\beta/\text{D6}_\beta & \times & \times & - & - & \times & \times & - \\ \text{O6}_\gamma/\text{D6}_\gamma & \times & - & \times & - & \times & - & \times \\ \text{O6}_{\alpha\beta} & - & - & \times & \times & \times & \times & - \\ \text{O6}_{\beta\gamma} & - & \times & \times & - & - & \times & \times \\ \text{O6}_{\gamma\alpha}/\text{D6}_{\gamma\alpha} & - & \times & - & \times & \times & - & \times \\ \text{O6}_{\alpha\beta\gamma}/\text{D6}_{\alpha\beta\gamma} & \times & - & - & \times & - & \times & \times \end{pmatrix} \to \begin{pmatrix} \text{O5}'_{\alpha\beta\gamma}/\text{D5}'_{\alpha\beta\gamma} & - & \times & \times & - & \times & - & - \\ \text{O5}_{\beta\gamma} & \times & - & - & \times & \times & - & - \\ \text{O5}_{\gamma\alpha}/\text{D5}_{\gamma\alpha} & \times & - & \times & - & - & \times & - \\ \text{O5}_{\alpha\beta}/\text{D5}_{\alpha\beta} & \times & \times & - & - & - & - & \times \\ \text{O5}_\gamma & - & \times & - & \times & - & \times & - \\ \text{O5}_\alpha & - & - & - & - & \times & \times & \times \\ \text{O5}_\beta/\text{D5}_\beta & - & - & \times & \times & - & - & \times \\ \text{O9/D9} & \times & \times & \times & \times & \times & \times & \times \end{pmatrix}$$

Figure: Mapping of type IIA O-planes/D-branes under three T-dualities.

Supersymmetric solution

Solving the supersymmetric equations $\partial_I P = 0$ for $I = \upsilon, \phi, \tilde{s}^1, \dots, \tilde{s}^6$:

- The *string-frame 3-cycles* are stabilized by fluxes:

$$s^1 = s^3 = s^4 = \left(\frac{4\mathcal{G}^3 Q^3 N}{\tilde{m}_0 (2G - Q)(G+Q)^2 (2G+Q)^3} \right)^{1/4} ,$$

$$s^2 = \frac{4G^2 - Q^2}{2NQ} s^3 , \quad s^5 = \frac{\tilde{m}_0}{2N} s^3 , \quad s^6 = \frac{(G+Q)(2G+Q)}{NQ} \tilde{s}^3 = s^7 .$$

- The *string coupling*:

$$e^{\phi} = \frac{h}{2(G+Q)} \sqrt{\frac{\tilde{m}_0 \mathcal{G} Q (2G+Q)}{N^3 (2G-Q)}} .$$

- The *vacuum expectation value*:

$$\langle V \rangle = -4P^2 = -\frac{h^6 \tilde{m}_0^4 (Q+2G)^6}{2^{12}(2G-Q)^2 (Q+G)^4} \frac{1}{\mathcal{G}^2 N^6} .$$

Parametric regimes

Parametrically we find the following ratios:

$$\frac{\langle V \rangle}{m^2_{\mathsf{KK},\{1,6,7\}}} \sim \frac{1}{N}\,, \qquad \frac{\langle V \rangle}{m^2_{\mathsf{KK},\{2,3,5\}}} \sim \frac{1}{N^2}\,, \qquad \frac{\langle V \rangle}{m^2_{\mathsf{KK},4}} \sim \frac{G^4}{N^3}\,.$$

Families of solutions

- Classical solution with scale separation:

$$G^{\frac{10}{3}} \ll G^2 N \ll \mathcal{G} \ll G^2 N^3\,.$$

- Weak coupling, a shrinking dual s^5 cycle and scale separation:

$$\mathcal{G} \ll G^2 N \quad \text{and} \quad N^3 \mathcal{G}^{-3} \ll G^2 \ll \mathcal{G} N^{\frac{1}{3}} \quad \text{and} \quad G^4 \ll N^3\,.$$

- Strong coupling, all cycles large and scale separation:

$$G^6 \ll G^2 N^3 \ll \mathcal{G}\,.$$

Conformal dimensions

For the mass eigenvalues we find

$$m^2L^2 = \left\{ \frac{8Q(2G+3Q)}{(2G+Q)^2}, 8, 8, 8, 8, e_1(Q,G), e_2(Q,G), e_3(Q,G) \right\} ,$$

they can be expanded for $G \gg 1$ to reproduce the IIA results

$$e_1(Q,G) = 48 + \frac{35Q^2}{3G^2} + \mathcal{O}\left(G^{-3}\right) ,$$
$$e_2(Q,G) = -\frac{4Q}{G} + \frac{22Q^2}{3G^2} + \mathcal{O}\left(G^{-3}\right) ,$$
$$e_3(Q,G) = \frac{3Q^2}{G^2} + \mathcal{O}\left(G^{-3}\right) .$$

$$\frac{8Q(2G+3Q)}{(2G+Q)^2} = \frac{4Q}{G} + \ldots$$

while finally the conformal dimensions are given by

$$\Delta = 1 + \sqrt{1+m^2L^2}\Big|_{G\to\infty} = \{8,4,4,4,4,2,2,2\} .$$

Heterotic S-dual

We perform the S-duality to the strongly coupled type I solution:

$$F_3 \to H_3\,, \qquad F_7 \to H_7\,, \qquad \phi^{(I)} \to -\phi^{(HET)}\,,$$

and find the superpotential

$$P = \frac{1}{4\mathsf{vol}(X)^2}\int_X \left(e^{-\frac{\phi}{2}}H_7 - e^{\frac{\phi}{2}}\star\hat{\Phi}\wedge H_3 + \frac{1}{2}\hat{\Phi}\wedge d\hat{\Phi}\right)\,.$$

which matches with the superpotential found in de la Ossa–Larfors–Magill–Svanes from 10d heterotic truncation on G_2.

$$dH_{3,i}^{\text{non-closed}} = \mu_{ONS5/NS5}J_{4,i}\,.$$

Conclusion

Summary

- We performed three T-dualities to scale separated AdS_3 from massive type IIA. The dual theories maintain the same characteristic.
- Apart from the dual theory with shrinking cycles, we found classical type I solutions and strong coupling ones.
- The strong coupling type I leads to classical scale separated AdS_3 in Heterotic SO(32) supergravity.

Thank you!