On type II AdS flux vacua in 3D

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Based on: 2304.14372; 2311.08991; 2407.$\alpha\beta\gamma\delta\epsilon$ [arXiv/hep-th]

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Introduction

Introduction and Motivation

String Theory (ST) comes with:

- Extra-dimensions;
- Supersymmetry;
- Moduli Fields.

From an effective perspective: we do **not observe** them!

Introduction and Motivation

The majority of known SUSY AdS vacua of ST have

$$L_{\mathrm{AdS}}^{-1} \sim m_{\mathrm{KK}} \ :$$

they do **not** exhibit **scale separation**.

Debated SUSY AdS_4 **scale-separated vacua**:

- The KKLT model [Kachru et alii, 2003];
- The DGKT construction [De Wolfe et alii, 2005].

Introduction and Motivation

In particular, **DGKT** classical scale-separated SUSY AdS_4 **vacua** [De Wolfe et alii, 2005]:

- **Setup and ingredients**

  (i) Massive type IIA SUGRA on CY_3 ($\mathbb{T}^6/\mathbb{Z}_3^2$ orientifold);

  (ii) Smeared O6 planes;

  (iii) Unbounded F_4 flux.

- A **criticism**. Smearing approximation.

Our purpose

- Search for **simpler** classical scale-separated AdS flux **vacua** [Farakos et alii, 2021; 2304.14372, 2311.08991];
- Exploit flux and scaling freedom to generate **anisotropies** [2304.14372, 2311.08991];
- Find the most general flux choice allowing for scale-separation [*fundamenta ponentes* in 2407.$\alpha\beta\gamma\delta\epsilon$]?!

AdS_3 flux vacua from IIA orientifolds

Setup and Ingredients [Farakos et alii, 2021]

Massive type IIA SUGRA (in the Einstein frame):

$$S_{\rm IIA} = \frac{1}{2\kappa_{10}^2}\int \mathrm{d}^{10}\mathrm{x}\sqrt{-\mathrm{G}}\Big[R - \frac{1}{2}\partial_M\phi\partial^M\phi - \frac{1}{2}e^{-\phi}|H_3|^2 + \\ - \frac{1}{2}\sum_p e^{\frac{5-p}{2}\phi}|F_p|^2\Big] \quad \text{with } p = 0, 2, 4\,.$$

3D spacetime-filling **O2 planes** and **smeared O6 planes**.

Bianchi identities:

$$\mathrm{d}F_p = H_3 \wedge F_{p-2} + \mu_{\mathrm{O/D}(8-p)}\, J_{p+1} \quad \xrightarrow{\int_{\Sigma_{p+1}}} \quad h_3\, f_{p-2} \sim \mu_{\mathrm{O/D}(8-p)}\,.$$

We can cancel the tadpoles, while F_4 (N) is left **unconstrained**.

Then,

$$\frac{L^2_{\rm KK}}{L^2_{\rm AdS}} \sim N^{-\lambda} \quad \text{for some } \ \lambda > 0,\ N\,\textbf{?}$$

The effective construction

With a **compactification** G2 space [Joyce, 1996],

$$\mathcal{X}_7 = \frac{\mathbb{T}^7}{\mathbb{Z}_2^\alpha \times \mathbb{Z}_2^\beta \times \mathbb{Z}_2^\gamma} \,,$$

we get a **three-dimensional**

$$\mathcal{N} = 16 \ \underset{\text{O2}}{\longrightarrow} \ \mathcal{N} = 8 \ \underset{\text{O6}_\alpha}{\longrightarrow} \ \mathcal{N} = 4 \ \underset{\text{O6}_\beta}{\longrightarrow} \ \mathcal{N} = 2 \ \underset{\text{O6}_\gamma}{\longrightarrow} \ \boxed{\mathcal{N} = 1}$$

supergravity **Lagrangian** [Farakos et alii, 2021; Van Hemelryck, 2022]

$$e^{-1}\mathcal{L} = \tfrac{1}{2} R_3 - \tfrac{1}{4}(\partial x)^2 - \tfrac{1}{4}(\partial y)^2 - \sum_{a=1}^{6} \frac{1+\delta_{ab}}{4\tilde{s}^a\tilde{s}^b}\partial\tilde{s}^a\partial\tilde{s}^b - V(x, y, \tilde{s}^a)$$

$$\text{with} \quad V(x, y, \tilde{s}) = G^{IJ}\partial_I P \partial_J P - 4P^2 \qquad \big(\text{and } L_{\text{AdS}} \sim P^{-1}\big) \ .$$

On/Off scale separation [2304.14372]

Flux Choices and **Quantization**:

$$H_3 = \sum_{i=1}^{7} h_3^i \Phi_i \,, \qquad F_4 = \sum_{i=1}^{7} f_{4,f}^i \Psi_i + \sum_{i=1}^{7} f_{4,q}^i \Psi_i \,,$$

with e.g. $f_{4,f}^i = (2\pi)^3 N^i$, $N^i \in \mathbb{Z}$.

In particular, in [2304.14372]

$$h_3 = h(1,1,1,1,1,1,0)\,;$$

$$f_{4,f} \sim N(-1,-1,-1,-1,-1,5,0)\,, \quad f_{4,q} \sim N^{1+7\lambda}(0,0,0,0,0,0,-1)\,.$$

Then, we can create **anisotropies** within $\mathbb{T}^7$:

$$\{r_i^2\}_{i=1,3,5,7} \;\propto\; N^{\frac{35}{8}\lambda}\,; \qquad \{r_i^2\}_{i=2,4,6} \;\propto\; N^{-\frac{5}{8}\lambda}\,.$$

On/Off scale separation [2304.14372]

In addition, since $L_{\rm AdS}^{-2} \sim \langle V \rangle \sim P^{-2}$,

$$\{r_i^2\}_{i=1,3,5,7}: \quad \frac{L_{{\rm KK},i}^2}{L_{\rm AdS}^2} \sim N^{-1}\,,$$

$$\{r_i^2\}_{i=2,4,6}: \quad \frac{L_{{\rm KK},i}^2}{L_{\rm AdS}^2} \sim N^{-1-7\lambda}\,,$$

so that

- Large volume, weak coupling, **scale-separation**: $\lambda > -\frac{1}{7}$;
- Large volume, weak coupling, isotropic **scale-separation**: $\lambda = 0$;
- Large volume, weak coupling, **no scale-separation**: $\lambda = -\frac{1}{7}$.

Remarkably, all closed-string moduli are **stabilized**.

. . . Appetizing a generalization . . .

A crash course on half-maximal 3D SUGRA [Deger et alii, 2019]

$$e^{-1}\mathcal{L} = -\frac{1}{4}\,R - \frac{1}{32}\,D_\mu M\,D^\mu M^{-1} - \,V + \dots$$

with

$$\mathcal{V}(\phi) \in \mathcal{M}_{\mathrm{scal}} = \frac{\mathrm{SO}(8,8)}{\mathrm{SO}(8)\times\mathrm{SO}(8)} \qquad \text{and} \qquad M = \mathcal{V}\,\mathcal{V}^T\,.$$

We define

$$D_\mu M = \partial_\mu M - 2\,g\,A_\mu \cdot \Theta\;T \cdot M\;,$$

where the **embedding tensor** is

$$\Theta_{MN|PQ} \quad \equiv \quad \theta_{[ABCD]} \quad \oplus \quad \theta_{(AB)} \quad \oplus \quad \theta \qquad (\text{with } M = 1,\dots,8,\overline{1},\dots,\overline{8}),$$

satisfying **quadratic constraints** (QC)

$$\Theta_{MN|PQ}\,\left(T^{PQ}\right)_R{}^S\Theta_{ST|UV} + \dots = 0\;.$$

Type IIA with an O2 plane [2407.$\alpha\beta\gamma\delta\epsilon$]

With an **O2 plane**

	AdS$_3$			$\mathbb{T}^7$						
	x^0	x^1	x^2	y^1	y^2	y^3	y^4	y^5	y^6	y^7
	$\times$	$\times$	$\times$							

acting as σ_{O2} : $y^m \longrightarrow -y^m$ (for $m = 1, \ldots, 7$),

Fields	$e_n{}^p$	C_1	Φ	C_3	B_2	B_6	C_5
$\mathcal{O}_{\mathbb{Z}_2} = \Omega_P \cdot \sigma_{\text{O2}}$	$+$	$+$	$+$	$-$	$-$	$+$	$+$

Fluxes	$\omega_{mn}{}^p$	F_2	H_1	F_4	H_3	H_7	F_6
$\mathcal{O}_{\mathbb{Z}_2} = \Omega_P \cdot \sigma_{\text{O2}}$	$-$	$-$	$-$	$+$	$+$	$-$	$-$

Then, **group theoretically**:

$$H_3 \equiv \theta^{mnpq}\,, \qquad F_4 \equiv \theta^{mnp8}\,, \qquad F_0 \equiv \theta^{88}\,.$$

Type IIA with an O2 plane [2407.$\alpha\beta\gamma\delta\epsilon$]

Specializing to a $(\mathbb{Z}_2 \times \mathbb{Z}_2) \times \mathbb{Z}_2$ invariant sector, i.e.

$$\mathcal{M}_{\text{scal}} = \left[\frac{\mathrm{SL}(2)}{\mathrm{SO}(2)}\right]^8 \subset \frac{\mathrm{SO}(8,8)}{\mathrm{SO}(8)\times\mathrm{SO}(8)} \quad \oplus \quad \text{other eight scalars} = 0\,,$$

we get the **half-maximal scalar potential**

$$g^{-2}\, V_{\mathcal{N}=8} = \frac{\sigma^4}{32}\left[\sum_{m=1}^{7}\left(\frac{h_m}{\sqrt{s_{(4)}^m}} - f_m\sqrt{s_{(4)}^m}\right)^2\right] + \frac{\sigma^2}{32}\,F_0^2\,\prod_{m=1}^{7} s_m^2\,,$$

together with the **half-maximal QC**

$$F_0\ H_3 = 0 \qquad \Longleftrightarrow \qquad \text{absence of O6/D6}\,.$$

Its vacuum structure: for $F_0 = 0$, $\mathbf{Mkw}_3$ at $s_{(4)}^m = \frac{h_m}{f_m}$.

Adding O6 planes [2407.$\alpha\beta\gamma\delta\epsilon$]

Adding three independent types (1_α, 2_β, 3_γ) of **O6 planes**,

$$\mathcal{N}=16 \underset{\mathrm{O2}}{\longrightarrow} \mathcal{N}=8 \underset{\mathrm{O6}_\alpha}{\longrightarrow} \mathcal{N}=4 \underset{\mathrm{O6}_\beta}{\longrightarrow} \mathcal{N}=2 \underset{\mathrm{O6}_\gamma}{\longrightarrow} \boxed{\mathcal{N}=1}$$

and

$$-F_0\, H_3 = J_{\mathrm{O6/D6}} \neq 0 \ ,$$

so that

$$g^{-2}\, V_{\mathrm{O6}} = \frac{\sigma^3}{16}\, F_0 \sum_{m=1}^{7} \left(h_m\, s^m_{(3)} \sqrt{s^m_{(4)}} \right) \ .$$

Moreover,

$$V_{\mathcal{N}=1} = V_{\mathcal{N}=8} + V_{\mathrm{O6}} \quad \equiv \quad G^{IJ}\partial_I P \partial_J P - 4P^2 \quad \text{in [2304.14372].}$$

Which **fluxes** connect to **interesting phenomenology**?

Conclusions

Concluding Remarks

- We constructed new SUSY AdS_3 vacua with(out) scale-separation while maintaining large volume and weak coupling, respecting flux quantization and stabilizing the closed-string moduli;
- We described a correspondence between stringy orientifold reductions/3D half-maximal supergravity, which seems a florid ground to explore interesting phenomenological questions.

Future directions

Exempli gratia:

- Charting the landscape of (Mkw_3 and AdS_3) vacua of 3D half-maximal supergravity;
- Thanks to the embedding tensor formalism, the most general flux choice giving scale-separation in the setup of [2304.14372, 2311.08991] [In progress, Arboleya, Guarino, Farakos and MM];
- O6-plane backreaction at higher orders [Building on Junghans, 2020];
- Detailed investigation of 3-dimensional de Sitter uplifts [In progress, Farakos et alii];

Thank you for your interest and attention!