Scale-separated Type IIA AdS_3 vacua and O6-plane backreaction

George Tringas

School of Applied Mathematical and Physical Sciences,
National Technical University of Athens

Talk based on: F. Farakos, G. T, T. Van Riet, [2005.05246]
M. Emelin, F. Farakos, G. T, [2202.13431]

June 28, 2022
SUSY 2022, Ioannina

Outline

Motivation-Goal

Construct EFTs with Einstein gravity from string theory.

$\downarrow$

An elementary starting point is the construction of vacua.

Einstein equations at the vacuum:

$$S = \int d^{\mathrm{d}}x \sqrt{-g}\left(\frac{1}{2}R + \cdots + V(\phi)\right) \xrightarrow[\Lambda \equiv \mathrm{V}(\phi^0)]{\nabla_\phi V|_{\phi^0}=0} R_{mn} - \frac{1}{2}R g_{mn} + \Lambda g_{mn} = 0 \quad (1)$$

In this analysis we are looking for consistent AdS vacua:

$$\Lambda < 0 \quad (2)$$

We want to construct such vacua from string theory and check their consistency.

Goal

Three-dimensional EFTs cannot physically describe our Universe

$$M_{10} = M_3 \times X^7 \ : \ \ 10d \text{ Type IIA supergravity} \to 3d \text{ EFT}$$

however they can provide us with information about the existence of EFTs with "good" properties from string theory

Setup similar to the 4d O. DeWolfe, A. Giryavets, S. Kachru, W. Taylor, [0505160]

Our goal is to find AdS_3 vacua with :

- Stabilize the massless scalars $\rightarrow$ Introduce fluxes
- Make the extra dimensions not detectable: Scale separation $\frac{L_{KK}^2}{L_\Lambda^2} \rightarrow 0$
- Quantized fluxes (Requirement for string theory origin)
- No tachyons
- Classical string theory regime – (Weak coupling & Large internal volume)

Swampland

Effective field theory space:

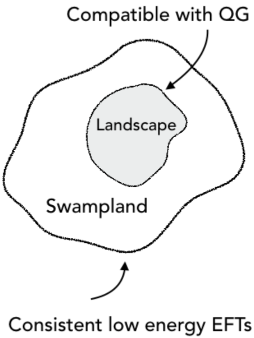
- Swampland: Consistent EFTs that **cannot** be UV-completed to quantum gravity.
- Landscape: Consistent EFTs that **can** be UV-completed to guantum gravity

AdS Conjectures

- D. Luest, E. Palti, C. Vafa [1906.05225] SUSY $\Lambda \to 0$ then light KK modes, H. Ooguri, C. Vafa [1610.01533] non-SUSY develops instabilities

One can study such conjectures in 3d too!

- 3d constructions are simpler than 4d
- The validity of possible AdS_3 vacua can be checked with CFT_2 which is better understood. see F. Apers, M. Montero, T. Van Riet, T. Wrase, [2202.00682].



Type IIA setup

The bosonic Type IIA action (n=even) in the Einstein frame has the form

$$S_{\mathrm{IIA}} = \frac{1}{2\kappa_{10}^2}\int \mathrm{d}^{10}X\sqrt{-G}\Big(R_{10} - \frac{1}{2}\partial_M\phi\partial^M\phi - \frac{1}{2}e^{-\phi}|H_3|^2 - \frac{1}{2}\sum\nolimits_n e^{\frac{5-n}{2}\phi}|F_n|^2\Big)$$

D-branes,O-planes effective action: Span $p+1$ dimensions of the 10d space and wrap internal cycles.

$$S_{\mathrm{D}p/\mathrm{O}p} = -T_{\mathrm{D}p/\mathrm{O}p}\int \mathrm{d}^{10}X\, e^{-\phi}\sqrt{-\det\left(g_{p+1}\right)}\delta^{(9-p)}(y) + CS\,, \tag{3}$$

We use the so called **smeared approximation** and replace the singular function that appears in the EoM with a regular one:

$$\delta_{9-p} \rightarrow j_{9-p}\,,$$

Smearing local sources is a simplification to obtain explicit flux compactifications.

From G2-manifold to Toroidal orbifold

A G2-manifold (Ricci flat) is characterized by the **fundamental three-form**

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

We choose the internal manifold X_7 to be a **seven-torus** with the orbifold Γ:

$$X_7 = \frac{T^7}{\mathbb{Z}_2 \times \mathbb{Z}_2 \times \mathbb{Z}_2} \tag{4}$$

with specific $\mathbb{Z}_2$ involutions and periodically identified coordinates

$$y^m \sim y^m + 2\pi r^m \tag{5}$$

The vielbein of the torus $e^m = r^m \mathrm{d}y^m$

$$\Phi = s^i \Phi_i \,, \qquad s^1 \Phi_1 = e^{127} \;\rightarrow\; s^1 = r^1 r^2 r^7 \;, \text{ etc.} \tag{6}$$

where the s^i are the **metric/structure moduli** related to the seven-torus **radii** r^m.

Allowed sources and EFT spectrum

Field content

- O2/D2 & O6/D6 planes and branes
- Fluxes: F_0 , $F_4 = f^i \Psi_i$, $H_3 = h^i \Phi_i$
- Moduli: x , y, $\tilde{s}^i$, i=1,...6.
- Remaining supercharges : **32** $\xrightarrow{\Gamma \text{ orbifold}}$ **4** $\xrightarrow{\text{O2-plane}}$ **2** real

The 3d bosonic effective action has the form

$$e^{-1}\mathcal{L}_{EFT} = \tfrac{1}{2}R_3 - \tfrac{1}{4}(\partial x)^2 - \tfrac{1}{4}(\partial y)^2 - \tfrac{1}{4}\text{vol}(\tilde{X}_7)^{-1}\int_7 \Phi_i \wedge \tilde{\star}\Phi_j \partial\tilde{s}^i \partial\tilde{s}^j - V$$

The dimensionally reduced scalar potential is reproduced by $V = G^{IJ}\partial_I P \partial_J P - 4P^2$ using the following superpotential

$$P = \frac{e^y}{8}\left[e^{\frac{x}{\sqrt{7}}}\int \star\Phi \wedge H_3\, \text{vol}(X_7)^{-\frac{4}{7}} + e^{-\frac{x}{\sqrt{7}}}\int \Phi \wedge F_4\, \text{vol}(X_7)^{-\frac{3}{7}}\right] + \frac{F_0}{8}\, e^{\frac{1}{2}y - \frac{\sqrt{7}}{2}x}$$

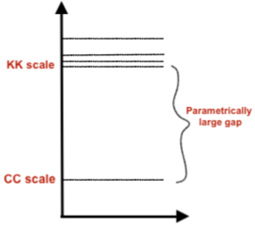
AdS & Indication for parametric scale separation

Minimizing the potential one finds AdS vacuum

$$\langle V \rangle = -\frac{1}{4}|F_4|^2 e^{6\phi} e^{-22\beta\upsilon} < 0\,.$$

Parametric scale separation for **large values** of F_4 flux

$$\frac{L^2_{KK}}{L^2_{\Lambda}} \sim e^{2\phi} e^{-6\beta\upsilon} \times |F_4|^2 \sim f_4^{-1}$$



$\Rightarrow$ However the flux of F_4 (f_4^i) is bounded by the tadpole cancellation conditions:

$$dF_6 = H_3 \wedge F_4 + \mu_{\mathrm{O2/D2}} j_7 \quad \rightarrow \quad h_{3i} f_4^i = -\mu_{\mathrm{O2/D2}}$$

Specific flux ansatz : $f_4^i = (-f, -f, -f, -f, -f, -f, +6f)\,, \quad h_3 = h$

Explicit SUSY AdS vacua with Scale Separation

We solve the supersymmetric equations for $\langle \tilde{s}^\alpha \rangle = \sigma$

$$\partial_i P = 0 \,, \quad \text{for} \quad i = x, y, \tilde{s}^a \tag{7}$$

- Stabilized moduli

$$\text{for} \quad 0.51 \approx \frac{h}{f} e^{\frac{2x}{\sqrt{7}}} \,, \quad 3.43 \approx \frac{m}{f} e^{-\frac{y}{2} - \frac{5x}{2\sqrt{7}}} \,, \quad \langle \tilde{s}^\alpha \rangle = \sigma \approx 1.32 \ldots \tag{8}$$

- Parametric Scale-separation: $L_{KK}^2 / L_\Lambda^2 \sim f^{-1}$
- Parametric Large volume and weak coupling

$$g_s = e^\phi \sim f^{-\frac{3}{4}} \,, \quad \text{vol}(X_7) = e^{7\beta u} \sim f^{\frac{49}{16}} \tag{9}$$

- The fluxes can be quantized and we have no tachyons.

AdS_3/CFT_2: F. Apers, M. Montero, T. Van Riet, T. Wrase, [2202.00682]

- Flipping the sign $f \to -f$ we get non-SUSY vacuum with the same properties
- Stable non-SUSY AdS? Is the instability hidden due to the smearing approx?

Instability using Blons?

In F. Marchesano, D. Prieto, J. Quirant [2110.11370] a system of $D6/D8$ branes was used to study the effects of NLO terms on stability.

It was found that

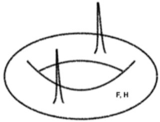
- In the smeared approximation both SUSY and non-SUSY vacua are stable.
- Considering NLO terms the tension and charge got modified. The SUSY was still protected by BPS however the non-SUSY develops instability $T < Q$.

This can be computed also in the non-SUSY AdS_3 setup for the systems $D2/D4$ and $D6/D8$, G. T, [work in progress].

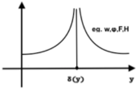
Smearing process

Localized sources:

- The density is locally distributed by singular function $\delta(y)$.
- Strong backreaction
  $\rightarrow$ Non-trivial field profile close to the locii, $F \sim F_0 + 1/r + \ldots$

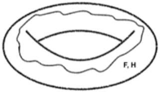


Localized source

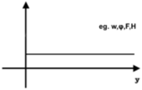


Smeared sources:

- Smeared sources are distributed all over the cycles $j(y)$.
- The fields *ignore* local backreaction : Trivial profile.



Smeared source



We obtained our results using smeared sources. We want to

- Estimate the distance r_0 from the locii where the smeared solution breaks down.
- Find O6-backreaction effects on the fields at NLO order.
- Can be used to test stability?

Study of O6-plane backreaction - Methodology

Follow the steps of 4d DGKT example from D. Junghans [2003.06274]

- Start from a general ansatz for the 10d metric:

$$\mathrm{d}s_{10}^2 = \underbrace{w^2(y) g_{\mu\nu}}_{AdS_3} \mathrm{d}x^\mu \mathrm{d}x^\nu + \underbrace{g_{mn}}_{7d} \mathrm{d}y^m \mathrm{d}y^n \tag{10}$$

- Proper field expansion with the leading term being the smeared field

$$F = F^{(0)} + F^{(1)} + \dots\,, \qquad (1/n^q,\ \ q > 0) \tag{11}$$

- Use the exact + smeared **equations of motion** to calculate the corrections.

The smeared EoMs are invariant under the following scaling of fluxes:

$$F_4^{(0)} \sim n\,,\ \ F_0^{(0)} \sim n^0\,,\ \ H_3^{(0)} \sim n^0\,,\ \ \tau^{(0)} \sim n^{\frac{3}{4}}\,,\ \ w^{(0)} \sim n^{\frac{3}{4}}\,,\ \ g_{mn}^{(0)} \sim n^{\frac{1}{2}}$$

where n can be thought as the VEV of F_4.

Next to leading order equations

- The scaling rate of **next to leading order terms**, is **not uniquely dictated** by the system of equations we have at our disposal. We choose for example

$$g_{mn} = g^{(0)}_{mn} n^{1/2} + g^{(1)}_{mn} n^{-1/2} + \mathcal{O}(n^{-3/2}). \tag{12}$$

Using the dilaton, Bianchi and Einstein equations we get the NLO expressions:

$$dF_2^{(1)} = 2\mu_6 \sum_i (j_{i,3} - \delta_{i,3}) \tag{13}$$

$$\nabla^2 \tau^{(1)} = -\frac{3}{2}\mu_6 \sum_i (j_{\pi_i} - \delta(\pi_i)) \tag{14}$$

$$\nabla^2 w^{(1)} = \frac{1}{2}\frac{w^{(0)}}{\tau^{(0)}}\mu_6 \sum_i (j_{\pi_i} - \delta(\pi_i)) \tag{15}$$

$$\tau^{(0)} R^{(1)}_{mn} - 3\frac{\tau^{(0)}}{w^{(0)}}\nabla_m \partial_n w^{(1)} - 2\nabla_m \partial_n \tau^{(1)} = \sum_i (\frac{1}{2} g^{(0)}_{mn} - \Pi^{(0)}_{i,mn})(j_{\pi_i} - \delta(\pi_i)) \tag{16}$$

SOLUTION: Consider a single O6-plane localized at y^5, y^6, y^7, wraps y^1, y^2, y^3, y^4

First order corrections

The first order corrections on the RR fields **near the locus** of a *single* O6-plane:

$$F_2^{(1)} = -2 \star_7 (\mathrm{d}\beta(y) \wedge \Psi_3) \tag{17}$$

$$F_4^{(1)} = G^i \Psi_i - 2\beta(y) \sum\nolimits_i h^i \Psi_i \tag{18}$$

$$\vdots$$

for $\beta(\vec{y}) = \frac{1}{4\pi} \frac{r_5 r_6 r_7}{r}$ and $r^2 = (r_5 y_5^2 + r_6 y_6^2 + r_7 y_7^2)$. For the rest of the fields:

$$\tau = \tau^{(0)} n^{3/4} - \frac{3}{8\pi r} n^{-1/4} + \mathcal{O}(n^{-5/4}) \tag{19}$$

$$w = w^{(0)} n^{3/4} + \frac{w^{(0)}}{\tau^{(0)}} \frac{1}{8\pi r} n^{-1/4} + \mathcal{O}(n^{-5/4}) \tag{20}$$

$$\vdots$$

similar for the metric. For distances away from the source the correction becomes negligible.

Potential corrections – Cut off distance

Plugging in the potential the field expansion we find the corrections $V = V^{(0)} + V^{(1)}$

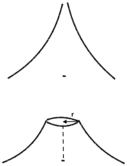
The scaling rate of the smeared/leading order part:

$$V^{(0)} = \frac{1}{(2\pi)^2 \tilde{\mathcal{V}}_7^{(0)1/2} \tau^{(0)2}} \left(\frac{1}{2} \tau^{(0)2} |H_3^{(0)}|^2 + \frac{1}{2} \sum_{p=0,4} |F_p^{(0)}|^2 \right) n^{-17/4}$$
$$- \frac{\mu_6}{(2\pi)^2 \tilde{\mathcal{V}}_7^{(0)3/2}} \sum_i \int \mathrm{vol}_{\pi_i}^{(0)} \wedge \left(\tau^{(0)} w^{(0)3} H_3^{(0)} F_0 \right) n^{-17/4}$$

The first order correction:

$$V^{(1)} \in - \frac{\mu_6}{(2\pi)^2 \tilde{V}_7^{(0)3/2}} \sum_i \int \mathrm{vol}_{\pi_i}^{(0)} \wedge \left(d(3\tau^{(0)} w^{(0)2} w^{(1)} + \tau^{(1)} w^{(0)3}) \wedge F_2^{(1)} \right) n^{-21/4}$$

Requiring the backreaction to be negligible we estimate the *cut off distance* r_0 where the smeared approximation breaks down



$$V^{(0)} \gg V^{(1)} \ \to \ n \gg r_0^{-1} \, .$$

Conclusion slide

- We found three-dimensional AdS vacua in the classical regime with "good" properties:
  - Moduli-stabilization
  - Scale-separation
  - weak coupling – large volume regime
  - Flux-quantization
  - Absence of tachyon
- However the SUSY vacua seems to be ruled out by AdS/CFT.
- We found the NLO corrections to the fields.
- We used a proper expansion to estimate the regions where the smeared approximation breaks down.
- It can be probably shown that the non-SUSY AdS_3 is unstable (Using the NLO correction).

Thank you!