COMMENTS ON PARAMETRIC SCALE SEPARATION AND HOLOGRAPHY. (1)

Let's consider string compactifications of the form

$$AdS \times M.$$

To obtain a semi-realistic cosmology, we want

$$\mathcal{L}(AdS) \gg \mathcal{L}(M). \quad \equiv \text{scale separation}.$$

But this is not as simple as it seems.

Swampland perspectives.

We can rewrite the scale separation condition as

$$\frac{m_{KK}}{|\Lambda|^{1/2}} \gg 1.$$

We expect towers of states to become light when moving large distances in field space. Therefore, also when we are moving in metric field space, and have $\Lambda \to 0$, we expect a tower to become light.

- AdS Distance Conjecture (Lust, Palti, Vafa 2019).

$$m_{KK} \sim |\Lambda|^{\alpha}$$

α is a positive $O(1)$ number.

- Based on SUSY examples, it seems most natural that

$$\frac{m_{KK}}{|\Lambda|^{1/2}} \approx O(1),$$

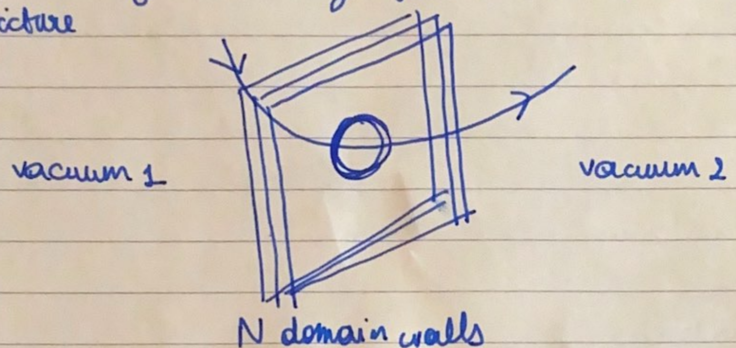
excluding scale sep. in AdS vacua. This is the strong AdS distance conjecture.

②

- There is one suggested way around it [Buratti, Calderon, Mininno, Uranga 2020]. If there is a discrete $\mathbb{Z}_N$ symmetry for domain walls in the theory, with N large, then this ratio gets enhanced

$$\frac{m_{KK}}{|\Lambda|^{1/2}} \sim \sqrt{N},$$

this way allowing for scale separation. (PARAMETRIC).
Picture



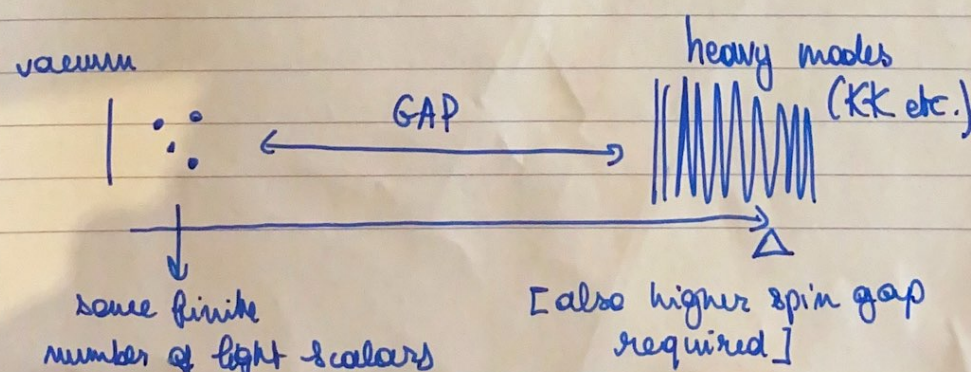
'Vacua separated by N such domain walls are equivalent!'

Holographic perspectives

- Best understood examples like $AdS_5 \times S^5$ do not have scale separation.
- At best partial scale separation:

$$\begin{array}{ccccc} AdS_3 & \times & S^3 & \times & T^4 \\ \downarrow & & \downarrow & & \downarrow \\ \text{large} & & \text{large} & & \text{small} \end{array}$$

- Does holography require AdS × Large?
- CFT perspective: single trace spectrum



<u>DGKT vacua</u> (DeWolfe, Giryavets, Kachru, Taylor 2005)

They achieve parametric scale separation in AdS_4-vacua using only very simple ingredients. (No quantum ingredients)

- compactification of massive IIA on a Calabi-Yau

$$AdS_4 \times CY_6.$$

- Moduli stabilisation by fluxes:

$$\underbrace{F_4}_{\text{Unbounded}},\ \underbrace{H_3,\ F_0}_{\text{Bounded}}$$

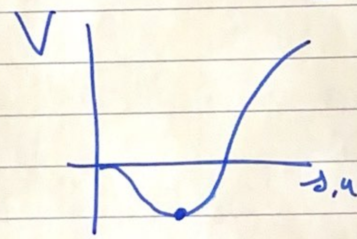
F_4 → Unbounded, $|F_4| \sim N$

H_3, F_0 → Tadpole: O6-planes. Bounded

$$V = \frac{1}{s^3}\left[\frac{A_{F_4}}{u \cdot s} + \frac{A_{F_0}\, u^3}{s} + \frac{A_{H_3} \cdot s}{u^3} - A_{O6}\right]$$

u = volume modulus

s = 4d dilaton



- minimal $\mathcal{N}=1$ SUSY
- parametric control: $\mathcal{V} \sim u^3 \sim N^{3/2}$

[α' + string loop corrections]. $e^{\phi} \sim s^{-1} u^{\frac{1}{2}} \sim N^{-3/4}$.

- scale separation, parametric:

$$\frac{m_{KK}}{|\Lambda|^{1/2}} \sim \sqrt{N}.$$

- only no full understanding of intersecting O6-planes.

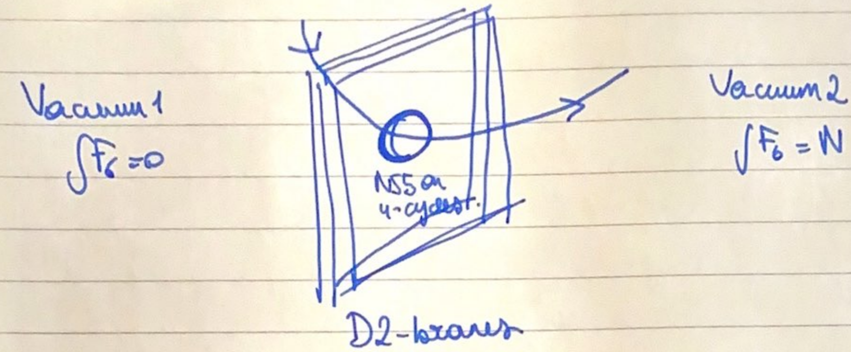
(4)

Discrete symmetries in DGKT-vacua

Dimensional reduction of the 10D Chern-Simons term

$$B_2 \wedge F_4 \wedge F_4 \rightarrow N \phi F_4$$

where ϕ is a B_2-axion.



Light spectrum of the DGKT vacua

$$\Delta = \frac{3}{2} + \sqrt{\frac{9}{4} + m^2 R^2_{AdS}}.$$

- Operators dual to volume moduli and dilaton have

$$\Delta = 10, 6, 6, 6 \ldots$$

- The corresponding axions have ($\mathcal{N}=1$ multiplets)

$$\Delta = 11, 5, 5, 5, \ldots$$

- No a priori reason for $\mathbb{Z}$ conformal dimensions with only minimal SUSY.
- This property is independent of the flux numbers and the CY geometry.

[See FA, Conlon, Montero, Ning, Revello, Wrase, Van Riet 2022].

Shift Symmetries

[Bonifacio, Hinterbichler, Joyce, Rosen 2018]

There are extensions of the ordinary constant shift symmetries for massless scalar fields:

$$\phi \to \phi + c.$$

A free field in AdS_D has a level-k polynomial shift symmetry

$$\phi \to \phi + c_{\mu_1 \dots \mu_k} X^{\mu_1} \dots X^{\mu_k} \big|_{AdS}$$

where X^{μ_i} are embedding flat space coordinates and c is a symmetric traceless tensor iff

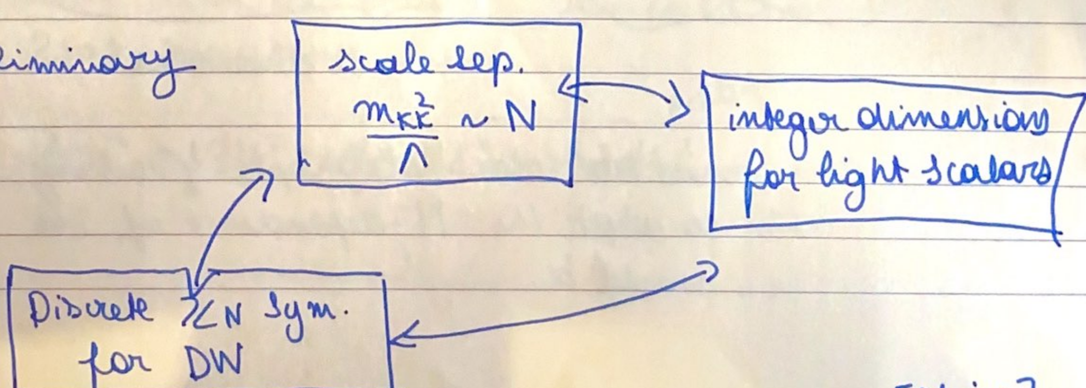
$$m_\phi^2 = \frac{k(k+D-1)}{R^2_{AdS}}.$$

Equivalently, $\Delta_\phi = k + D - 1$.

$\Rightarrow$ There must be polynomial shift symmetries of different levels k ($k = 2, 3, 7, 8$) in the DGKT vacua.

For example, the $k=2$ symmetry is responsible for the $\Delta = 5$ axions and is related to the $N \phi F_4$ scalar Stückelberg coupling.

Preliminary



[w.i.p.]

<u>Question</u>: what are holographic implications of $\mathbb{Z}_N$ symmetries for domain walls in AdS?

<u>The DGKT central charge</u>

From the AdS perspective, we learn that the holographic central charge should scale like

$$c \sim N^{9/2},$$

because $V(\phi)|_{\text{minimum}} \sim N^{-9/2}$.

<u>Question</u>: How to explain from CFT perspective?

In between: BRANE DUAL.

Flux-domain wall correspondence
(see Kounnas, Lust, Petropoulos, Tsimpis 2008).

F_n-flux $\longleftrightarrow$ Domain wall from wrapped D(8-n)-brane.

in DGKT: F_4-flux $\Leftrightarrow$ 3 sets of D4-branes wrapped on 2-cycles.

	x^0	x^1	x^2	r	y^1	y^2	y^3	y^4	y^5	y^6
D4	⊗	⊗	⊗		⊗	⊗				
D4	⊗	⊗	⊗				⊗	⊗		
D4	⊗	⊗	⊗						⊗	⊗

AdS_4 (x^0 to r) — internal dimensions (y^1 to y^6).

Although these branes are (non-holographic / running dilaton), let's see what the N-dependence of the near-horizon would be.

By applying the sugra harmonic superposition rules, we find that

$$ds^2_{\text{near-horizon}} = \alpha' \left(N^{3/2} ds_{A_4}^2 + N^{1/2} ds_6^2 \right)$$
$$= l_{p,4}^2 \left(\underline{\underline{N^{9/2}}} ds_4^2 + N^{7/2} ds_6^2 \right)$$

correctly reproducing the scalings of the string coupling $g_s \sim N^{-3/4}$, $\nu \sim N^{3/2}$ and the central charge $c \sim N^{9/2}$.

→ At leading order in large N, these D4-domain walls must be the brane dual somehow?

This works similarly in other large N holographic set-ups like N D3-branes, or D1-D5 set-up etc.

Question microscopic counting of degrees of freedom on these intersecting D4-branes?

extra What is the background geometry?

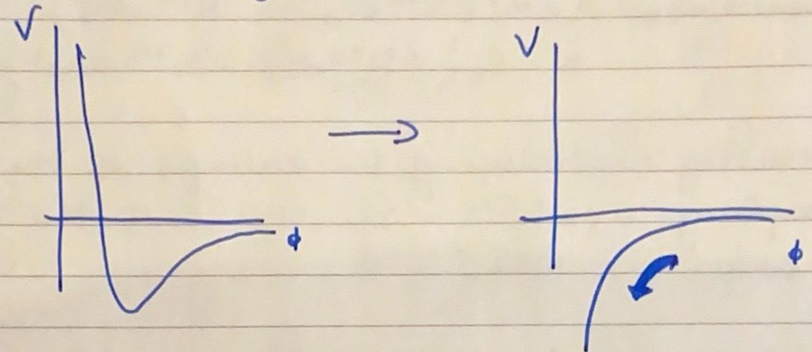
We can summarize the presence of the other ingredients (F_0, H_3, O6) with the following running geometry:

$$ds_{10}^2 = dr^2 + r^{-\frac{10}{9}} dx_\mu dx^\mu + r^{\frac{2}{3}} ds_6^2$$
$$(e^\phi \sim r^{-1}).$$

Contrast with geometry for 'holographic' branes like D3-branes. Conical singularity or flat spacetime

$$ds_{10}^2 = dr^2 + dx_\mu dx^\mu + r^2 ds_6^2.$$

How to compute ξ from EFT? → Consider flux potential and delete unbounded flux, compute flow (attractor) along the resulting runaway potential



[w.i.p. with Montero, Valenzuela].

<u>Scale-separation in AdS_3?</u>

Use CFT_2-technology? I.e. modular bootstrap?

[Farakos-Tringas-Van Riet 2020]:

- compactification of massive IIA on a G2 holonomy manifold
- $F_4 \sim N$ unbounded flux
- Bounded H_3, F_0
- O6-planes.
- $\mathcal{N}=1$ AdS_3.

Despite very similar ingredients as the DGKT vacua, holographic properties are different.

- there are no $\mathbb{Z}_N$ symmetries for domain walls [these are, as well as the axions, projected out by the orientifold].
- the entire light spectrum consists of irrational conformal dimensions

Turn the F_4-flux into domain walls:

	x^0	x^1	x^2	y^1	y^2	y^3	y^4	y^5	y^6	y^7
D4s	⊗	⊗		⊗	⊗					⊗
	⊗	⊗				⊗	⊗			⊗
	⊗	⊗						⊗	⊗	⊗
	⊗	⊗		⊗		⊗			⊗	
	⊗	⊗			⊗	⊗		⊗		
	⊗	⊗		⊗			⊗	⊗		
	⊗	⊗			⊗		⊗		⊗	

(x^0, x^1, x^2: AdS_7; $y^1, \dots, y^7$: internal)

then $ds_{NH}^2 = \alpha' \left(N^{7/2} ds_{A_3}^2 + N^{1/2} ds_7^2 \right)$

$= \ell_{p,3}^2 \left(N^{14} ds_3^2 + N^{11} ds_7^2 \right)$

$\Rightarrow c \sim N^7$ while from the flux potential $c \sim N^4$.
This is the only known large N-example where the large-N-scalings from the dual domain walls don't match with the fluxes.

[Geometry is $ds_{10}^2 = dr^2 + r^{-4/3} dx_\mu dx^\mu + r^{2/3} ds_7^2$]

extra **Scale separation in massless IIA**
[Gribiori, Junghans, Van Hemelryck, Van Riet, Wrase 21]

- T-dualise × 2 to get a new IIA solution on Iwasawa manifold

$$F_4 \to \left.\begin{matrix} F_6 \\ F_2 \end{matrix}\right\} \text{unbounded}$$

$$F_0 \to F_2$$

$$H_3 \to \text{curvature}$$

- in certain anisotropic scaling limit: parametric control and scale separation

	x^0	x^1	x^2	r	y_1	y_2	y_3	y_4	y_5	y_6
D2	⊗	⊗	⊗							
D6	⊗	⊗	⊗		⊗	⊗	⊗	⊗		
D6	⊗	⊗	⊗		⊗	⊗			⊗	⊗

- Brane dual gives the correct scalings.
- Singularity probed by D2 and D6:

$$ds_{10}^2 = dr^2 + r^{-\frac{10}{9}} dx_\mu dx^\mu + r^{-\frac{2}{3}} ds^2_{y_1 y_2} + r^{\frac{2}{3}} ds^2_{y_3 \dots y_6}$$

$$e^\phi \sim r^{-5/3}$$

- Uplift to M-theory is conical (pure geometry)

$$ds_{11}^2 = dr^2 + dx_\mu dx^\mu + r^2 ds_7^2$$

There is some unbounded flux absorbed into geometry however.

- there are integer conformal dimensions and the F_2-fluxes generate discrete symmetries for domain walls.