Holography and Scale Separated AdS vacua

Fien Apers

University of Oxford

Based on **2211.04187** + work in progress with Miguel Montero and Irene Valenzuela

(See also 2202.09330 with Joe Conlon, Sirui Ning and Filippo Revello)

Outline

1. Introduction
2. DGKT vacua
3. Large-N scalings
4. Singularity probed by D-branes

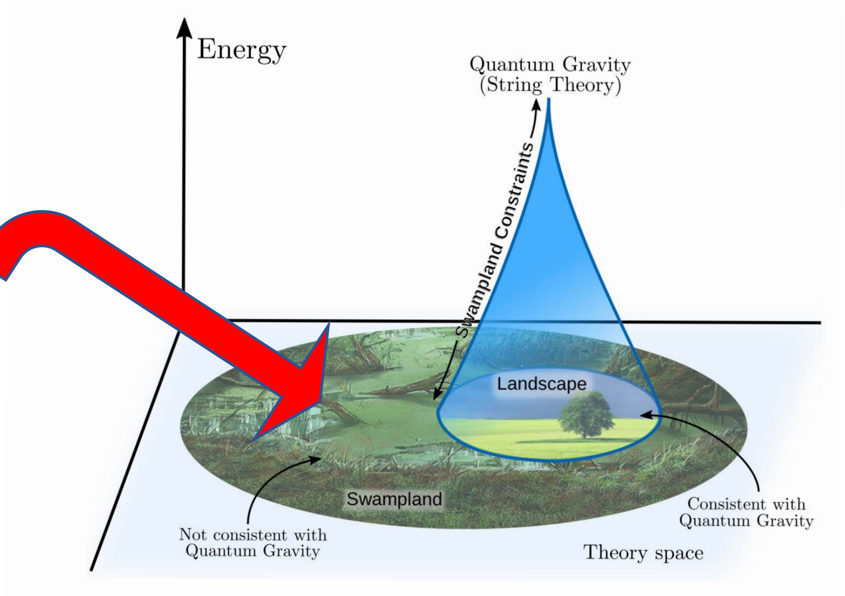
Introduction

- Scale separated AdS vacua do have

$$\frac{L_{extra\,dimensions}}{L_{AdS}} = \frac{L_{KK}}{L_{AdS}} \ll 1$$

- *Question*: are AdS vacua with (parametric) scale separation in the landscape or in the swampland? [Lust, Palti, Vafa 2019]

Scale-separated AdS vacua?



Introduction

- *Question*: Do there exist CFT duals for scale separated AdS vacua?

There are no known CFTs with a large gap in the spectrum of single trace primaries.

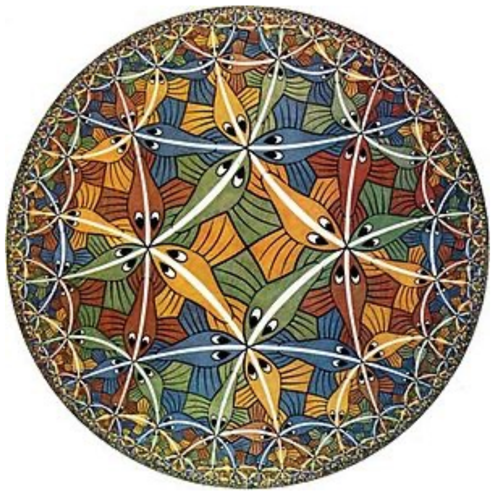
Introduction

- In the best understood AdS/CFT examples, we have

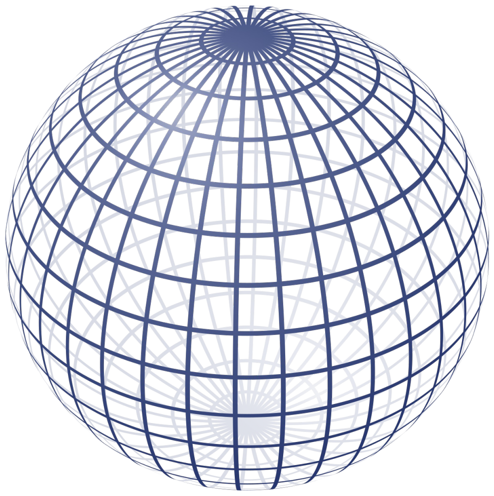
$$L_{extra\ dimensions} \approx L_{AdS}$$

- Example: $\boldsymbol{AdS_5 \times S_5 (/\mathbb{Z}_k)}$ dual to $\mathcal{N} = 4$ SYM
- **N D3-branes** probing flat space or a conical singularity

AdS_5



$\times$



S_5 or $S_5/\mathbb{Z}_k$

Same size!

Introduction

Similarly, we get

- $\mathbf{AdS_4}\times\boldsymbol{M^7}$ (M-theory) in the near-horizon geometry of N M2-branes probing a conical singularity
- $\mathbf{AdS_7}\times\boldsymbol{M^4}$ (M-theory) in the near-horizon geometry of N M5-branes probing a conical singularity

where $L(\mathrm{AdS}) = L(\mathrm{M})$ in all these examples

Can we use holography for phenomenologically more interesting vacua? For AdS vacua with scale separation?

Introduction

Scale separated AdS vacua in string theory:

KKLT *[Kachru, Kallosh, Linde, Trivedi 2003]*

LVS *[Balasubramanian, Berglund, Conlon, Quevedo 2005]*

IIB, fluxes and non-perturbative effects

DGKT *[DeWolfe, Giryavets, Kachru, Taylor 2005]*

IIA, fluxes only

Introduction

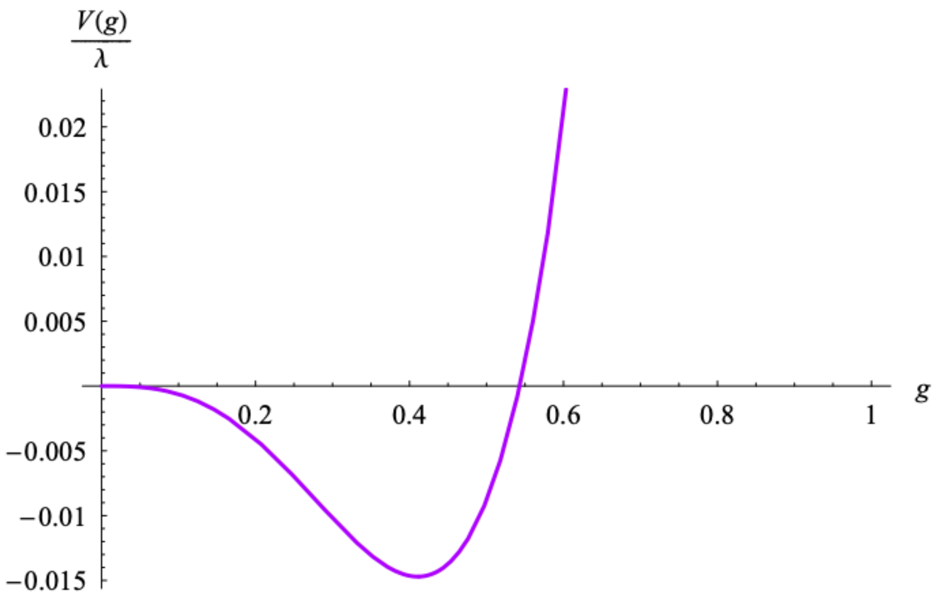
- This talk: what can we learn about the holographic dual and the holographic brane set-up from the scalar potential in the DGKT EFT, and possibly other AdS EFTs as well?

$$\boldsymbol{V_{EFT}} \rightarrow \textbf{D-brane dual}$$

1. Large N-scalings *[2211.04187]*
2. Singularity probed by the D-branes *[ongoing work with M. Montero and I. Valenzuela]*

DGKT vacua

- 4d, $\mathcal{N} = 1$ SUSY AdS vacua by compactifying 10d massive IIA on a CY
- Moduli Stabilization by fluxes: unbounded $\boldsymbol{F_4 \sim N}$ and bounded F_0, H_3
- O6 –planes needed for tadpole cancellation



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

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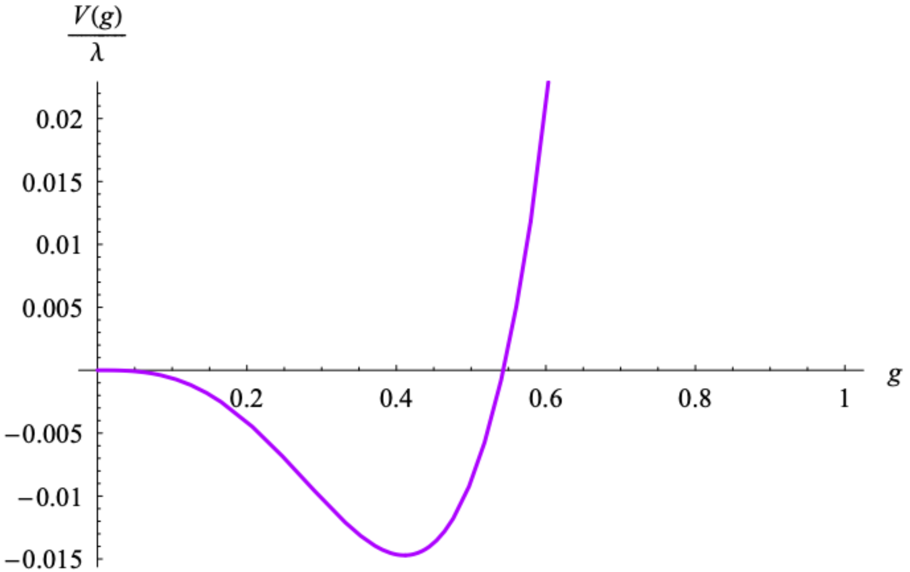

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Parametric control:

- Large volume: $\mathcal{V} \sim \boldsymbol{N^{3/2}}$
- Weak coupling: $e^{\phi} \sim \boldsymbol{N^{-3/4}}$

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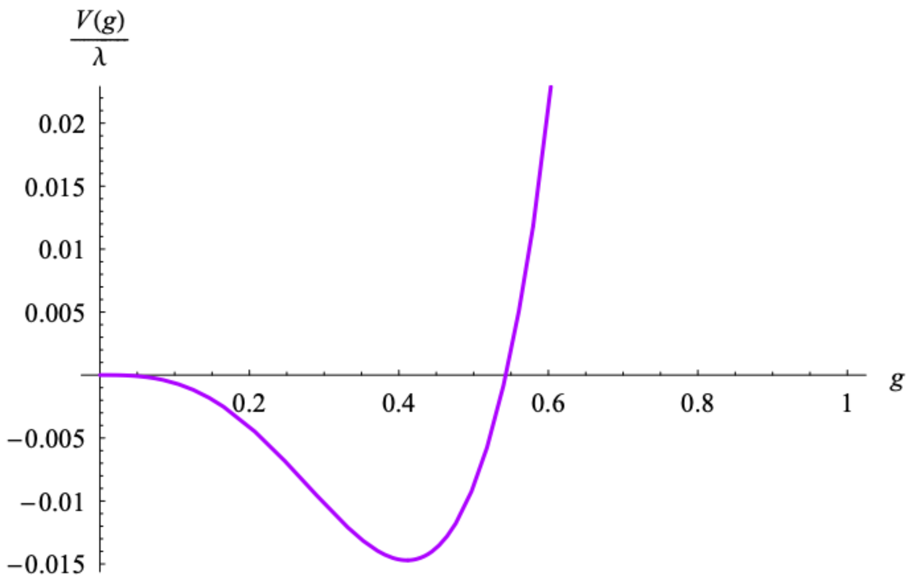

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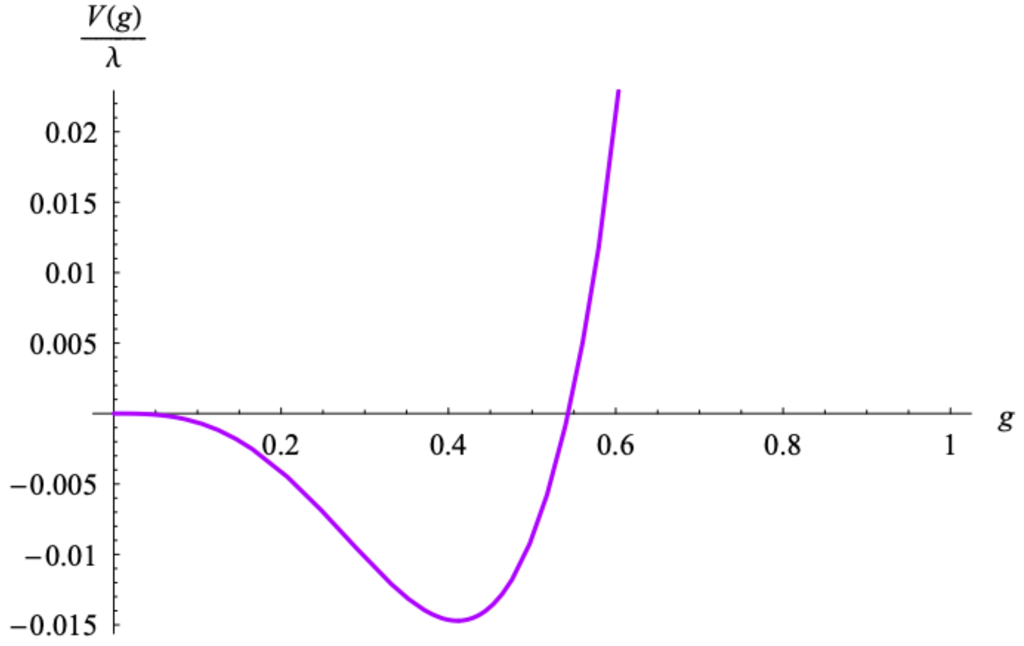
Scale separation:

$$\frac{L_{KK}}{L_{AdS}} \sim \boldsymbol{N^{-1/2}}$$

DGKT vacua



Moduli are stabilized with **particular masses** which are interesting from a holographic perspective:

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

$\Delta_1 = \mathbf{6}$ and $\Delta_2 = \mathbf{10}$

- Universal! Independent of fluxes and choice of Calabi-Yau manifold
- Integer!

Conlon, Ning, Revello 2021 – FA, Montero, Van Riet, Wrase 2022 – FA, Conlon, Ning, Revello 2022

DGKT vacua

Remark: integer conformal dimensions signal the presence of polynomial shift symmetries in the large N-limit:

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

if $\Delta_{\boldsymbol{\phi}} = \boldsymbol{k+3}$.

[Bonifacio, Hinterbichler, Joyce, Rosen 2018],[Blauvelt, Engelbrech, Hinterbichler 2022], [FA 2022]

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Large-N scalings

$$A_{F_4} \sim N^2$$

$$V = \frac{1}{s^3}\left[\underbrace{\frac{A_{F_4}}{us}}_{\text{Unbounded flux}} + \underbrace{\frac{A_{F_0}u^3}{s} + \frac{A_{H_3}s}{u^3}}_{\text{Bounded fluxes}} - A_{O6}\right] \rightarrow$$

D-brane dual?

Essential: **Flux-domain wall correspondence**

Kounnas, Lust, Petropoulus, Tsimpis 2008 –
Cribriori, Gnecchi, Lust, Scalisi 2023

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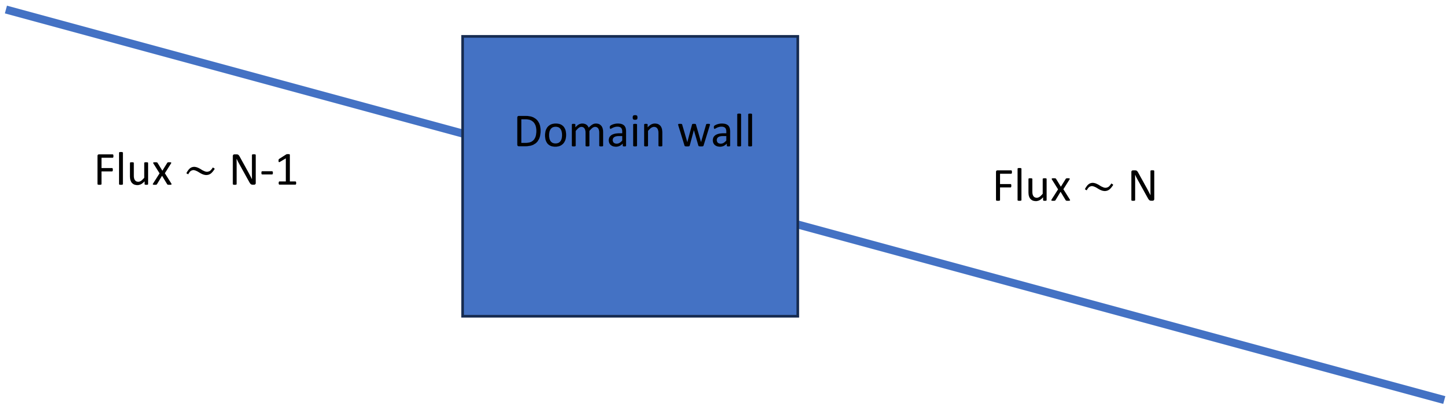
N units of F_n-flux in d dimensions $\leftrightarrow$ N domain walls consisting of D(8-n)-branes wrapped on (6-n-d)-cycles



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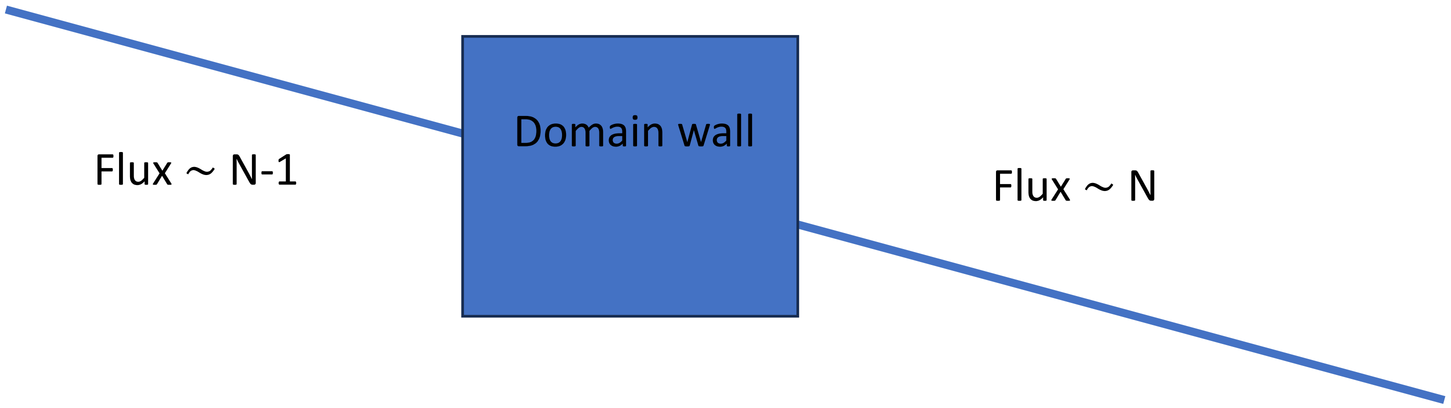
Here:
N units of F_4-flux $\rightarrow$ N D4-branes wrapped on 2-cycles

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



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	t	x^1	x^2	x	y_1	y_2	y_3	y_4	y_5	y_6
N_1 **D4**	$\otimes$	$\otimes$	$\otimes$		$\otimes$	$\otimes$				
N_2 **D4**	$\otimes$	$\otimes$	$\otimes$				$\otimes$	$\otimes$		
N_3 **D4**	$\otimes$	$\otimes$	$\otimes$						$\otimes$	$\otimes$

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Large-N scalings from scalar potential:

$$c \sim R_{AdS}^2 \sim V^{-1} \sim N^{9/2}$$

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Large-N scalings from SUGRA harmonic superposition rule in the near-horizon limit of the D4-branes

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Large-N scalings from SUGRA harmonic superposition rule in the near-horizon limit of the D4-branes

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Non-trivial match!

Large-N scalings

Observation: For 4d scalar potentials with an AdS minimum where the **large-N scalings agree** with those of the near-horizon geometry of N (possibly orthogonally intersecting) D-brane domain walls, there will be at least one modulus with mass such that $\Delta = \mathbf{6}$.

See 2211.04187

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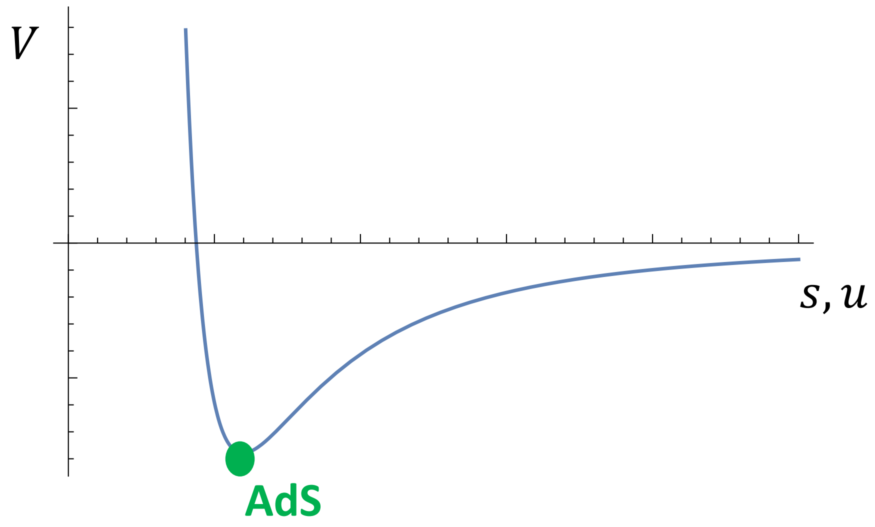
More generally, for d-dimensional AdS vacua, this should be $\Delta = 2(d-1)$.

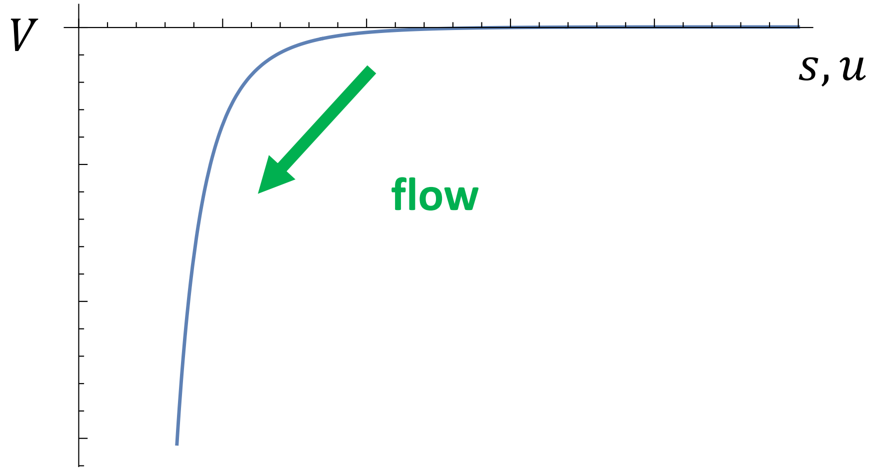
See 2211.04187

Singularity probed by D-branes

- What singularity is probed by the D4-branes in DGKT?
- Delete the unbounded flux from the potential:

$$V = \frac{1}{s^3}\left[\frac{A_{F_4}}{us} + \frac{A_{F_0}u^3}{s} + \frac{A_{H_3}s}{u^3} - A_{O6}\right] \quad \longrightarrow \quad V = \frac{1}{s^3}\left[\cancel{\frac{A_{F_4}}{us}} + \frac{A_{F_0}u^3}{s} + \frac{A_{H_3}s}{u^3} - A_{O6}\right]$$





Singularity probed by the D-branes

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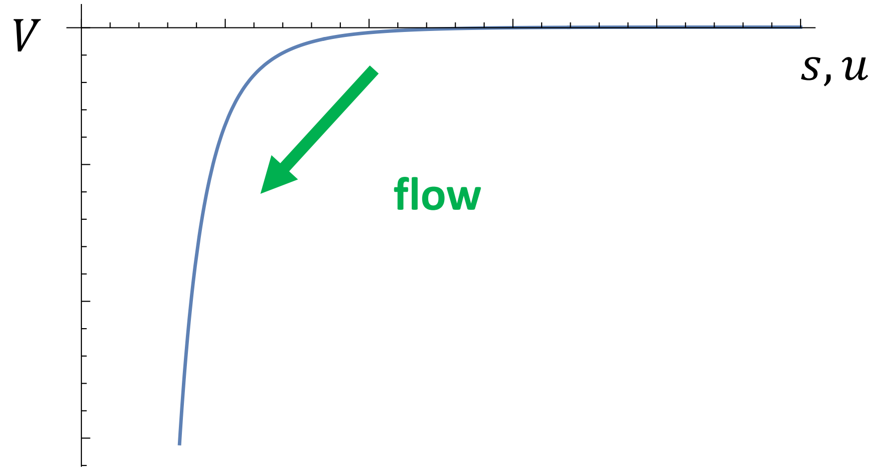


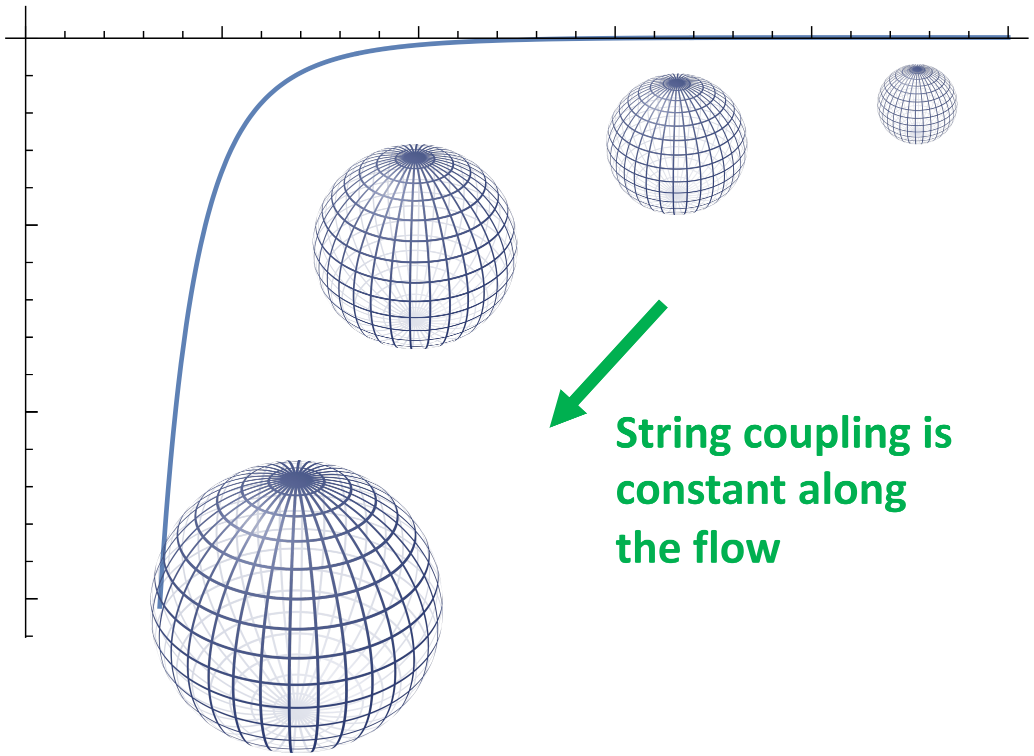
→ Find what geometry the **D4-branes** probe by finding the flow $s(r), u(r), A(r)$ from the 'redidual potential'

$$\boxed{ds^2_{10} = [s(r)]^{-2}\left(dr^2 + e^{2A(r)}dx_n dx^n\right) + [u(r)]d\tilde{s}^2_6.}$$

Singularity probed by the D-branes

Example: $AdS_5 \times S_5(T_{1,1})$ in IIB with N units of F_5-flux

Remove the F_5-flux and solve for the flow:



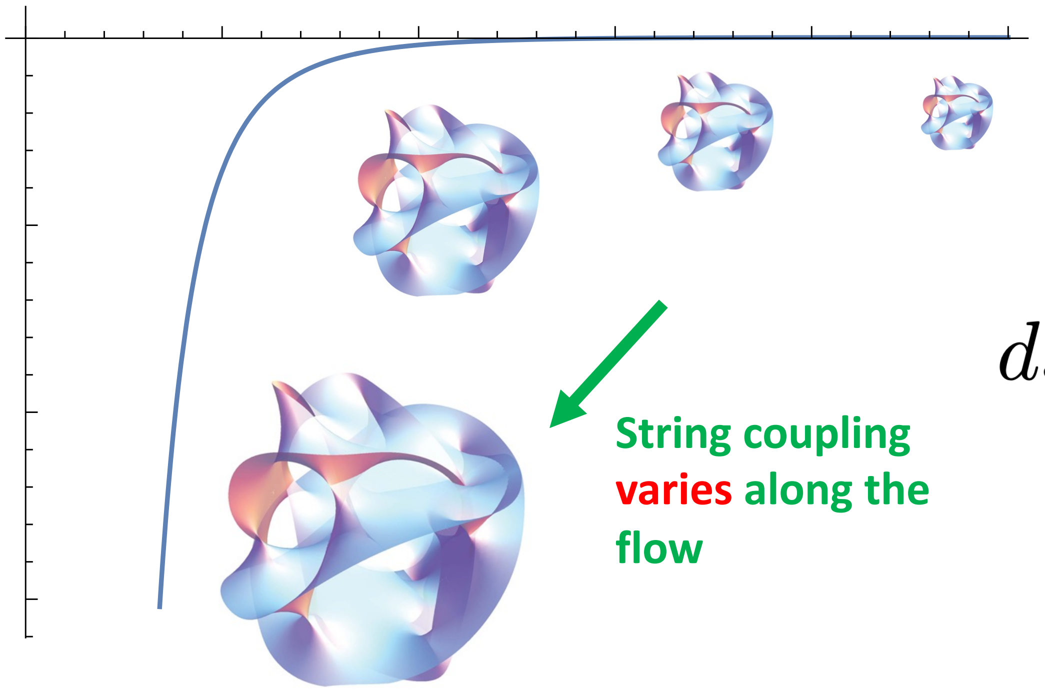
Conical singularity probed by D3-branes:

$$ds^2_{10} = dr^2 + dx_n dx^n + r^2 ds^2_{S_5(T_{1,1})}$$

Singularity probed by the D-branes

DGKT: $AdS_4 \times CY_3$ in massive IIA with N units of F_4-flux

Remove the F_4-flux and solve the flow equations:



String coupling varies along the flow

Non-conical singularity probed by D4-branes:

$$ds^2_{10} = dr^2 + r^{-\frac{10}{9}} dx_n dx^n + r^{\frac{2}{3}} ds^2_{CY}$$

$$e^{\phi} \sim r^{-1}$$

Singularity probed by the D-branes

Comment: after two T-dualities a solution in massless IIA with unbounded F_6-flux and F_2-flux can be obtained which is scale separated as well as strongly coupled and so can be uplifted to M-theory

Cribriori, Junghans Van Hemelryck, Van Riet, Wrase 2021

Conical singularity probed by M2-branes:

$$ds_{11}^2 = dr^2 + dx_n dx^n + r^2 d\tilde{s}_7^2$$

Conclusions

- It is a challenge to understand holography for vacua that look more like the real world.
- A first step would be to do it for scale separated AdS vacua, the **DGKT** vacua.
- Holographically, the DGKT vacua have an interesting light spectrum, consisting fully of **integer conformal dimensions**.
- We can learn a lot about the D-brane dual from the scalar potential.
- Integer conformal dimensions are related to the presence of polynomial shift symmetries and the presence a **pure D-brane dual**.
- The D4-branes in DGKT probe a **non-conical singularity**.