

Anti-D3 branes in Klebanov- Strassler and metastable vacua

Iosif Bena, Nick Halmagyi, Mariana Graña,
Gregory Giecold, Francesco Orsi

Crete Conference On Gauge Theories And The Structure Of Spacetime

Metastable vacua

- ◆ Exist in gauge theories

- ◆ $N=1$ SQCD

Intriligator, Seiberg, Shih

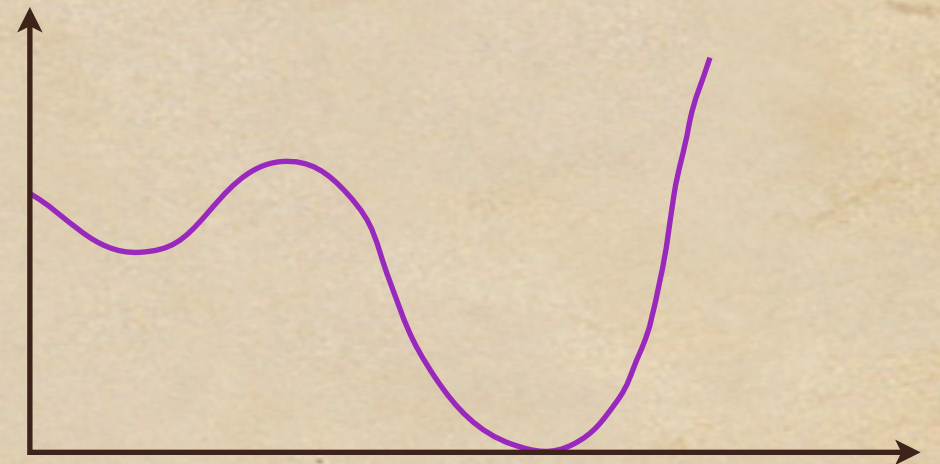
- ◆ Lots of other theories

everybody and their brother

- ◆ No **type IIA realizations** of metastable vacua

Bena, Gorbatov, Hellerman, Seiberg, Shih

- ◆ Why?



No IIA brane realization

- ◆ $N=1$ engineered with $D4 + NS5$
- ◆ $D4$ ends on $\text{codimension } 2$ line inside $NS5$
- ◆ End of $D4$ branes sources $\log$ mode on $NS5$
- ◆ $NS5$ brane bending
 - $\Leftrightarrow$ Log running of $N=1$ coupling constant
- ◆ Tiny IR perturbation $\Rightarrow \log \Rightarrow UV$ messed up

different $UV \Leftrightarrow$ not vacua of the same theory

What about AdS-CFT

$\exists$ *asmpt-AdS₄*

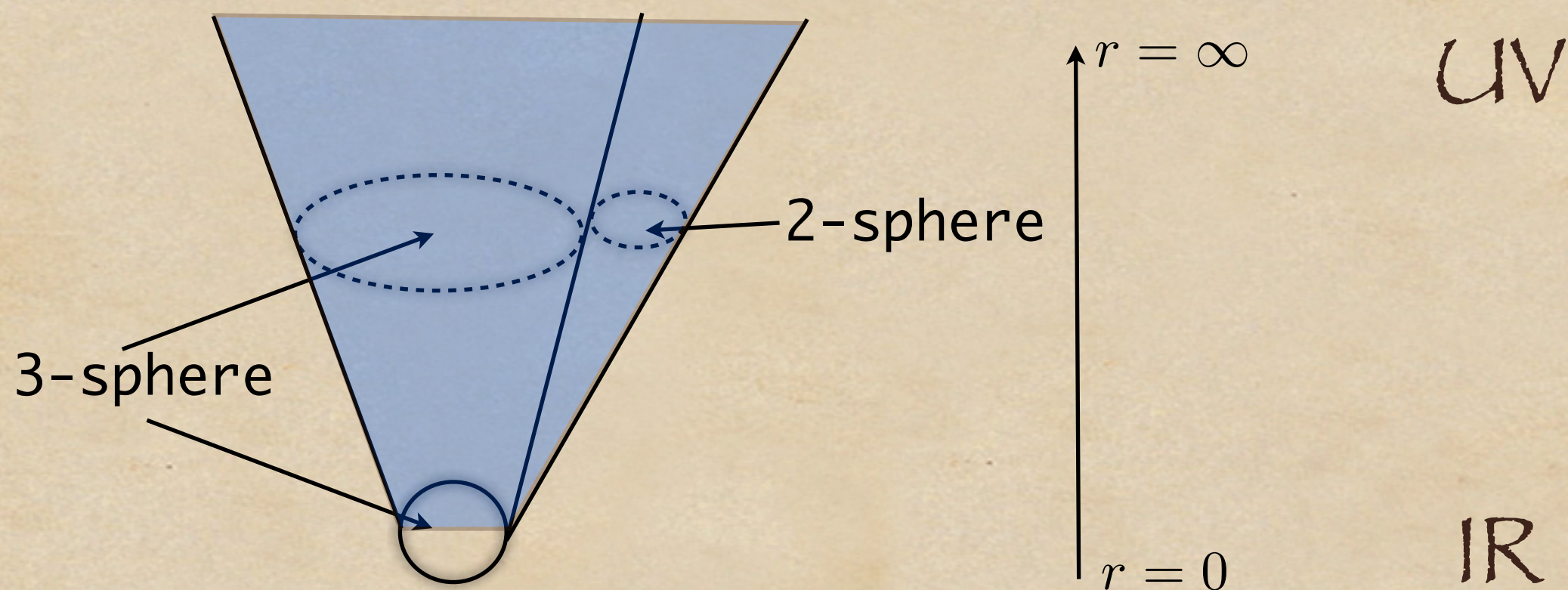
Maldacena Nastase

- ◆ No *asmpt-AdS₅* metastable solutions
- ◆ One candidate:

Kachru Pearson Verlinde

 - ◆ Anti-D3 branes in Klebanov Strassler
 - ◆ Codimension 6 $\Rightarrow$ modes $\sim 1/r^4$
 - ◆ Normalizable $\Rightarrow$ metastable vacuum

Klebanov-Strassler



$$\frac{1}{4\pi^2\alpha'} \int_{S^3} F^{(3)} = M$$

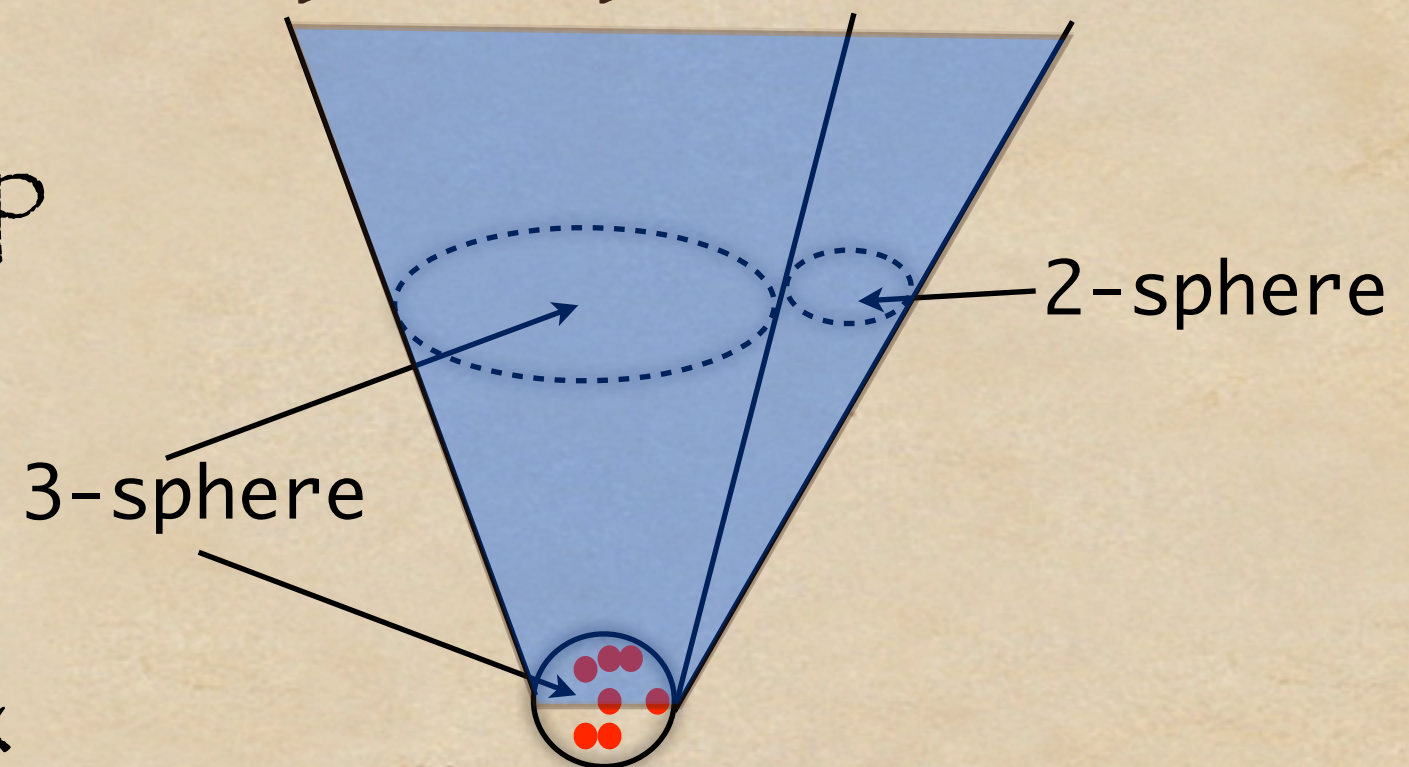
D3 charge dissolved in fluxes

$$F_5 \times F_3 \rightarrow H_3$$

$$H_3 \times F_3 \rightarrow F_5$$

Metastable proposal

Add **anti-D3** at tip



D3 charge in flux

anti-D3 tunnel and annihilate **D3** charge in flux

decay to BPS solution

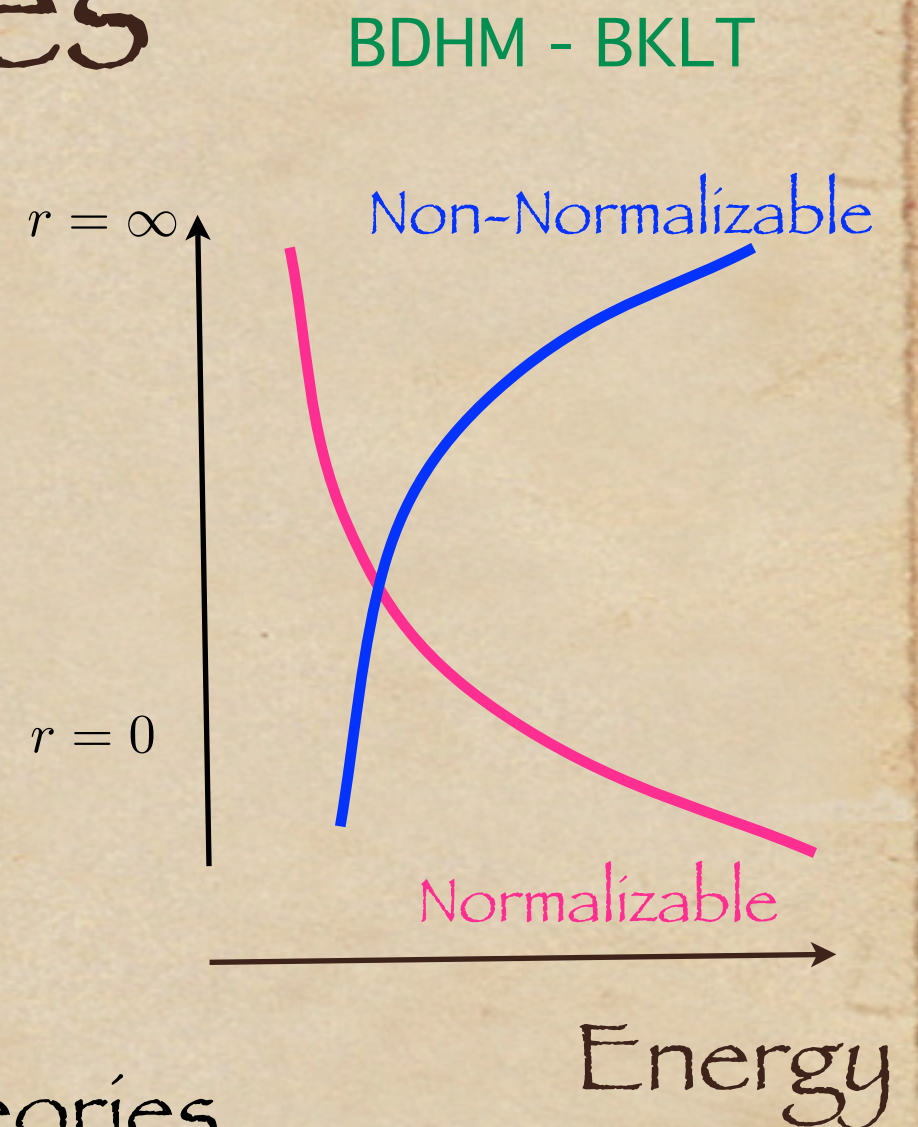
Metastable vacuum

brane polarization
(Myers effect)

Kachru Pearson Verlinde

AdS-CFT modes

- ◆ Normalizable modes (NM)
 - ◆ dual to vevs
 - ◆ Finite energy, IR
- ◆ Non-normalizable (NNM)
 - ◆ deformations of Lagrangian
 - ◆ Infinite energy, UV
- ◆ Different NNM $\Rightarrow$ different theories
- ◆ Same NNM $\Rightarrow$ different vacua, same theory



metastable $\Leftrightarrow$ NNM=0

Big Question

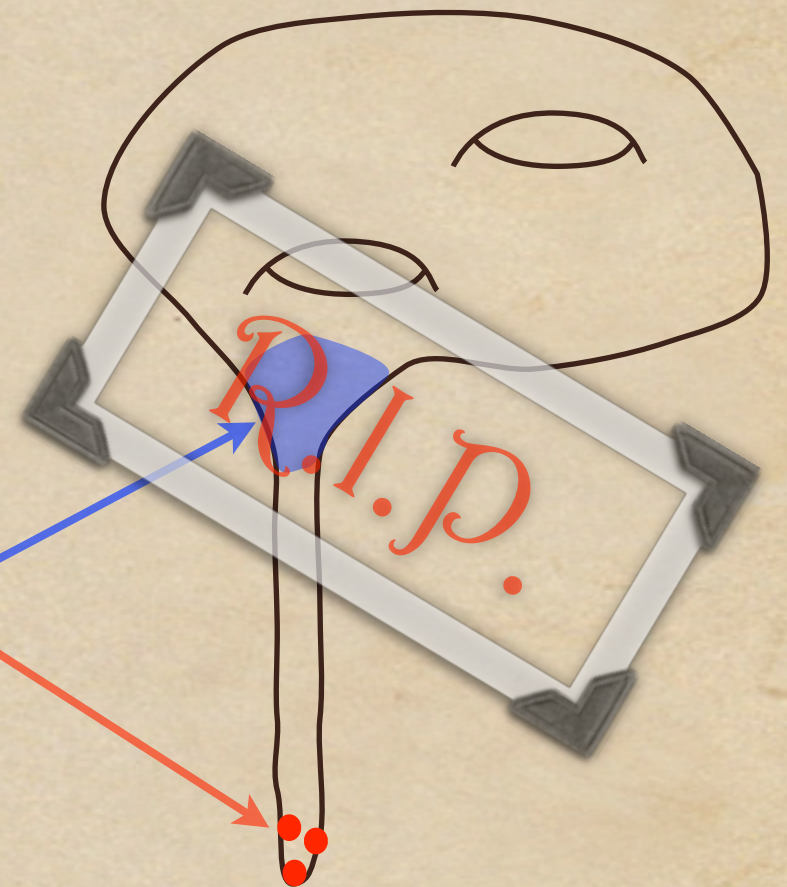
Anti-D3 $\Rightarrow$ normalizable or non-normalizable modes?

- ◆ Fluxes $\Rightarrow$ KS field $\sim \log r$
- ◆ encodes $\log$ running of coupling constant
$$\frac{1}{g_1^2} - \frac{1}{g_2^2} \sim \int_{S^2} B_2 \sim \log r$$
- ◆ Anti-D3 couple to this field
- ◆ IIA intuition: $\log$ messed up, $\Rightarrow$ non-normalizable
- ◆ $\forall$ non-conformal 4D dual has $\log$ modes

Big Implications if NNM

- ◆ anti-D3 SUSY breaking explicit, not spontaneous
- ◆ No AdS-CFT metastable 4D vacua
- ◆ String cosmology/landscape:

anti-D3 down long KS throats →
 redshift → tunably-small energy →
 lift AdS to dS
 KKLT, etc.
 anti-D3 non-normalizable
 energy not tunably-small
 moduli stabilization messed up

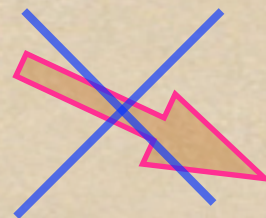


$$V = \frac{aAe^{-a\sigma}}{2\sigma^2} \left(\frac{1}{3}\sigma aAe^{-a\sigma} + W_0 + Ae^{-a\sigma} \right) + \frac{D}{\sigma^3}$$

3×10^{-9}
 ~ 1

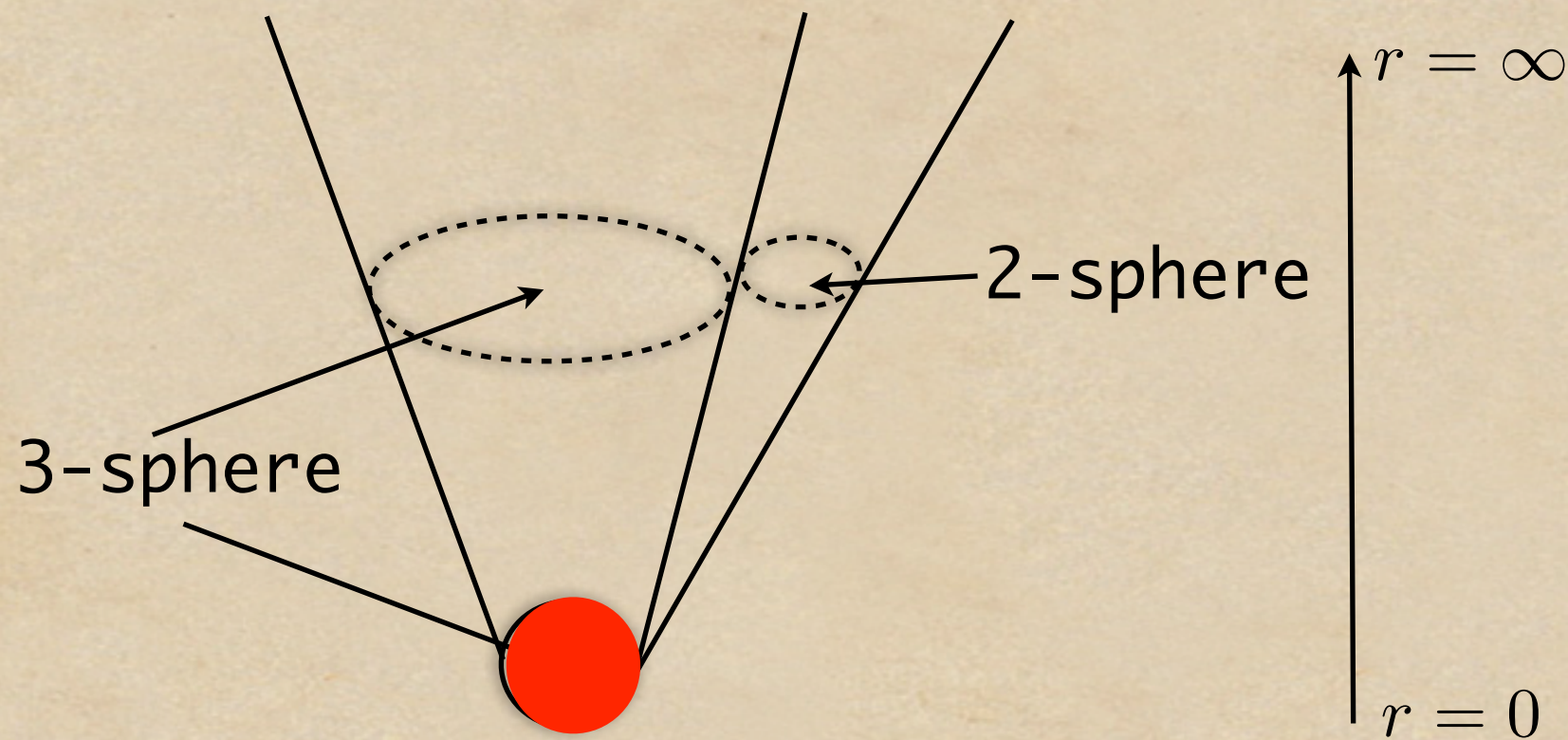
Big Implications

- ◆ 4D $N=1$ gauge theories - log running - generic phenomenon, not restricted to KS
- ◆ Same happens in LARGE volume scenarios
- ◆ No vacuum uplift by small-energy !
anti-D3 give $O(1)$ contribution !
- ◆ Landscape of AdS vacua



Landscape of dS vacua

How can we show this ?



Smear **anti-D3's**

$$SU(2) \times SU(2) \times \mathbb{Z}_2$$

Solution(τ)

Perturbation theory in anti-D3 number

- ◆ 8 modes satisfying **second-order** eqs.
- ◆ **16** integration constants
- ◆ expanded around **BPS** solution $\Rightarrow$
first-order system:

$$\begin{aligned}\frac{d\xi_a}{d\tau} + \xi_b M^b_a(\phi_0) &= 0, \\ \frac{d\phi_1^a}{d\tau} - M^a_b(\phi_0)\phi_1^b &= G^{ab}\xi_b\end{aligned}$$

Papadopoulos, Tseytlin 2000
Borokhov, Gubser 2002
Kuperstein, Sonnenschein 2003

Ze calcul

- ◆ Solve first 8 equations for ξ . Integration constants X .
- ◆ Use ξ + other 8 eqs. to get ϕ . Integration constants Y

dim Δ	non-norm/norm	int. constant
8	r^4/r^{-8}	Y_4/X_1
7	r^3/r^{-7}	Y_5/X_6
6	r^2/r^{-6}	X_3/Y_3
5	r/r^{-5}	— — —
4	r^0/r^{-4}	$Y_7, Y_8, Y_1/X_5, X_4, X_8$
3	r^{-1}/r^{-3}	$X_2, X_7/Y_6, Y_2$
2	r^{-2}/r^{-2}	— — —

X_2 and $X_7 \sim 1/r$

non-normalizable

Ze force !!!

- ◆ 16 constants ~ 14 physical ones
- ◆ Probe **D3** brane attracted by **anti-D3**'s

- ◆ Force is universal: **KKLMMT**

$$F_r \sim \frac{N_{\overline{D3}}}{r^5}$$

- ◆ We get

$$F_r \sim \frac{X_1}{r^5} + \mathcal{O}\left(\frac{1}{r^{11}}\right)$$

- ◆ Only depends on **1** of the **14** constants !!!
- ◆ Only **force-mode** is **ξ_1**

Ze stratégie

Usual
AdS-CFT

- ◆ Cannot *a-priori* fix *both* NM and NNM
- ◆ *IR physics* (e.g. incoming waves at horizon)
- ◆ Fix relation between NM and NNM $\Rightarrow$ *physics*

- ◆ Cannot *a-priori* decide $NNM=0$
- ◆ Physical IR boundary conditions
- ◆ Nonzero ξ_1
- ◆ Try to see whether NNM can be zero.

Here

Look in the infrared

- ◆ Kill very divergent guys + ξ_1 must be nonzero !!!
- ◆ **Physical divergence**: anti-D3 smeared on S^3
- ◆ Warp factor diverges $\sim \tau^{-1}$
- ◆ **Curvature** diverges: $R \sim F_{(5)}^2 \sim \tau^{-4}$
- ◆ **Another divergence** - no obvious reason

$$H_{(3)}^2 \sim F_{(3)}^2 \sim \tau^{-2}$$

- ◆ Subleading singularity $\sim \xi_1$

Must be there !!!

Everything depends on it !!!

If singularity physical:

- ◆ Anti-D3 in KS is **normalizable**
- ◆ Dual to gauge theory **metastable vacuum**
- ◆ Nice physics - vev's etc.
- ◆ Hunt for gauge theory dual

Dymarsky
Klebanov
Seiberg

- ◆ AdS upliftable to dS
- ◆ KKLT, LVS, etc. **alive and frisky**

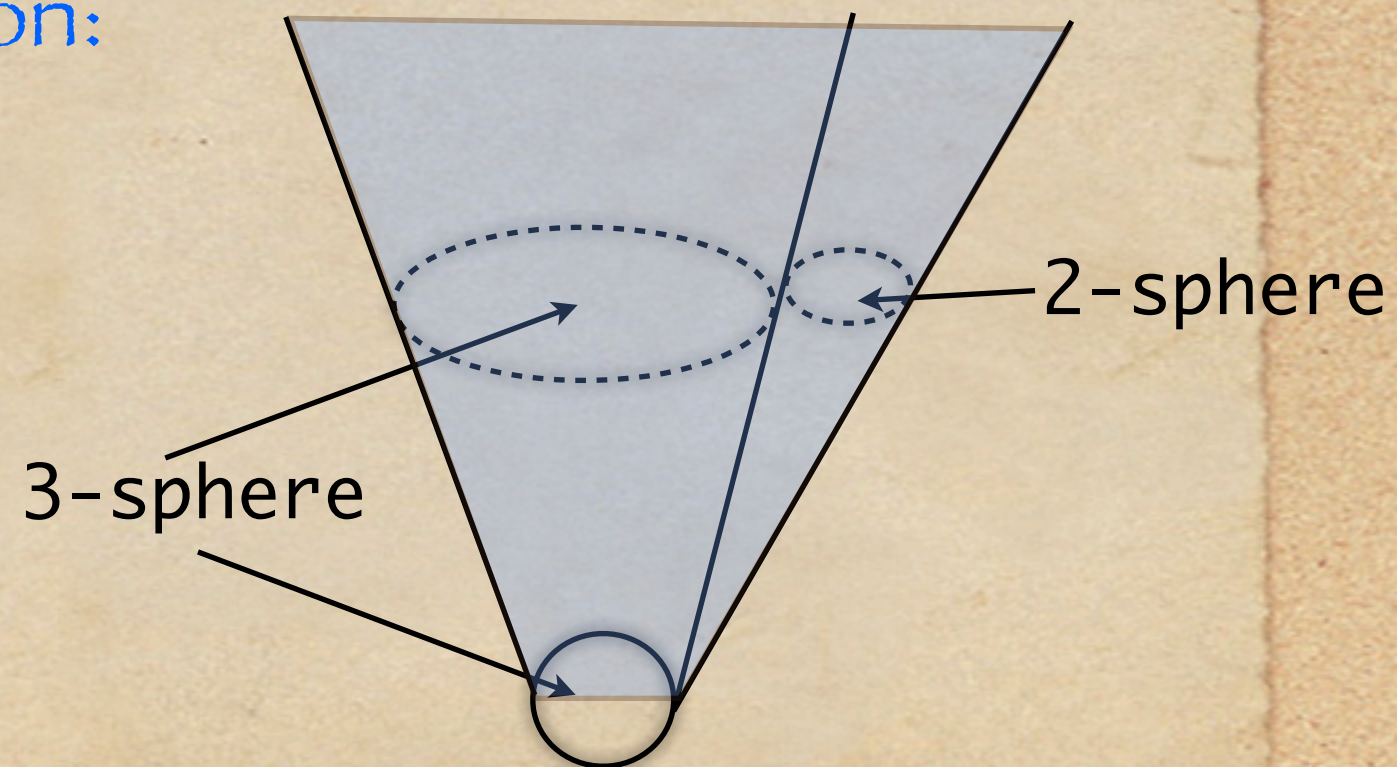
If singularity unphysical:

- ◆ anti-D3 has non-normalizable modes
- ◆ IR coupling to $\log$ mode (H_3) - mess up UV

- ◆ Reminder -BPS solution:

- ◆ $F_5 \times F_3 \rightarrow H_3$

- ◆ $H_3 \times F_3 \rightarrow F_5$

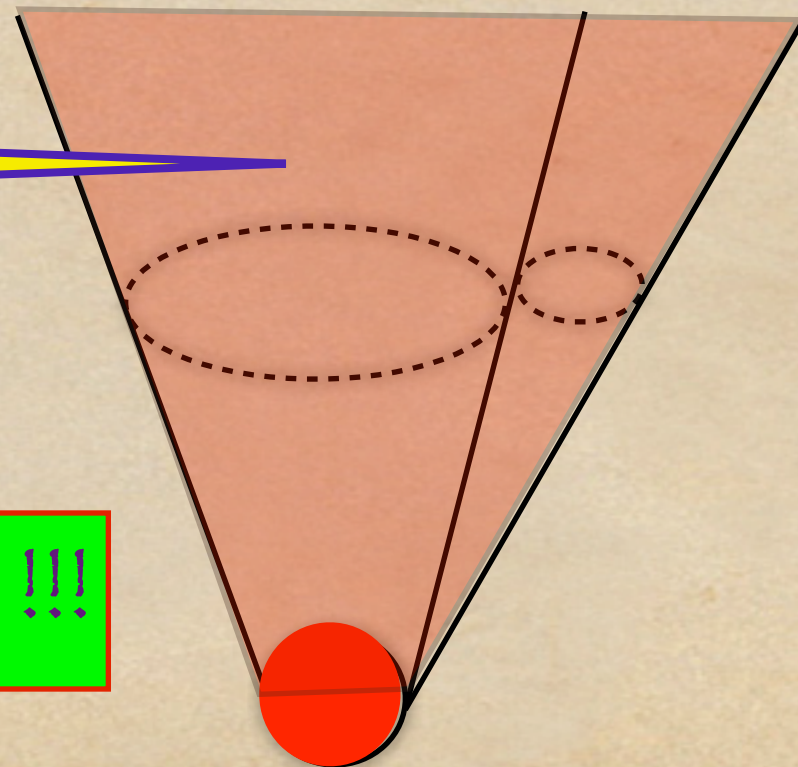


If singularity unphysical:

- ◆ $(-F_5) \times F_3 \rightarrow -H_3$
- ◆ $(-H_3) \times F_3 \rightarrow -F_5$
- ◆ Sign of $D3$ charge dissolved in flux not fixed !!!
- ◆ Only F_3 flux on S^3 fixed.

anti-D3
dissolved in flux

Solution for anti-D3 is anti-KS !!!



Is singularity physical?

- ◆ Fate of dS dependeth on singularity
- ◆ If not physical:
 - ◆ find **new ways** of constructing **deSitter**
 - ◆ maybe **no more landscape**
 - ◆ lots of work needs to be **redone**
 - ◆ brane of **codimension 6** + **fluxes** → **log modes**

So it must be physical !!!

Proof by
wishful thinking

Is singularity physical?

Incorrect AdS-CFT

- ◆ One should a-priori take **only normalizable modes** in UV, and accept **whatever** exists in the IR
- ◆ Maybe, but not in AdS-CFT ☺
- ◆ IR regularity **crucial** to relate **NNM** with **NM**.
Otherwise get **wrong physics**:
 - ◆ AdS-QCD **without** incoming b.c. at black hole
 - ◆ Confinement from Klebanov-Tseytlin

Is singularity physical?

- ◆ Maybe divergence has **brane interpretation**
- ◆ **anti-D3** polarizes into **NS5** branes. Source H_3
- ◆ **Wrong legs**. Also **divergent F_3** and **no D5 brane**

No brane
interpretation

- ◆ **NS5** branes wrap S^2 inside S^3 . Tunnel to BPS solution.
- ◆ Brane-flux annihilation. **Smearing** → **Singularity?**
- ◆ Our singularity **linear** in anti-D3 brane number
- ◆ Brane-flux annihilation **nonlinear** in anti-D3 number.

Is singularity physical?

- ◆ **Integral** of divergent energy density is **finite** !
- ◆ We can be **agnostic** about origin of singularity
- ◆ Accept everything with **finite IR action**
- ◆ After all, **AdS-CFT** relates bulk and boundary **actions**

Klebanov

- ◆ Negative-mass Schwarzschild
- ◆ **Integral** of divergent energy density is **finite**
- ◆ **Must be eliminated** if AdS-CFT is to make any sense

Counter-argument:
Horowitz-Myers

Is singularity physical?

- ◆ Nobody could have predicted it **a-priori**!
- ◆ No **a-posteriori** physical reason for accepting it

One more chance!

Throw to the garbage!

- ◆ Two divergences in the infrared:
- ◆ Smeared anti-D3 $\rightarrow$ **physical**: $R \sim F_{(5)}^2 \sim \tau^{-4}$
- ◆ **Unphysical** + subleading: $H_{(3)}^2 \sim F_{(3)}^2 \sim \tau^{-2}$
- ◆ Leading divergence resolved in string theory.
- ◆ Resolution **may** also cure unphysical divergence.

How can we check this ?

- ◆ MAY CURE $\neq$ WILL CURE
- ◆ ξ_1 needed to attract D3 branes
- ◆ anti-D3 or some brane-attracting piece of junk ?
- ◆ Force by anti-D3 on probe D3 known KKLMMT
- ◆ Does ξ_1 give correct force per anti-D3 number ?

YES

Messy numerical integrals

NO

Physical singularity.
Too much coincidence otherwise

Singularity most likely unphysical

Conclusions

- ◆ IR singularity $\rightarrow$ anti-D3 branes in KS likely source non-normalizable modes
- ◆ Need final nails in coffin: numerics, nonlinear
- ◆ Extend to other systems $\rightarrow$ generic?
- ◆ A lot of string cosmology to be revisited
- ◆ Find new ways of constructing deSitter
- ◆ Find new ways of uplifting AdS to dS
- ◆ AdS landscape $\neq$ dS landscape