SCAPEZILLA : the backreaction of anti-branes in flux compactifications

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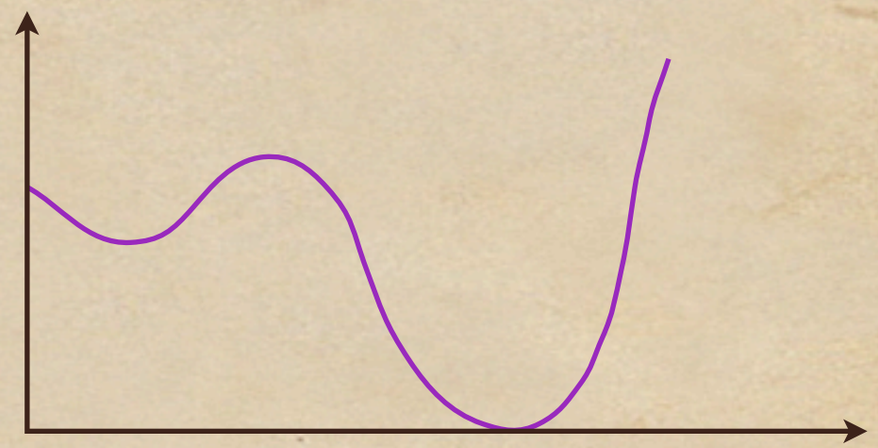
Metastable vacua



- Exist in gauge theories
- N=1 SQCD

Intriligator, Seiberg, Shih

- Lots of other theories

everybody and their brother

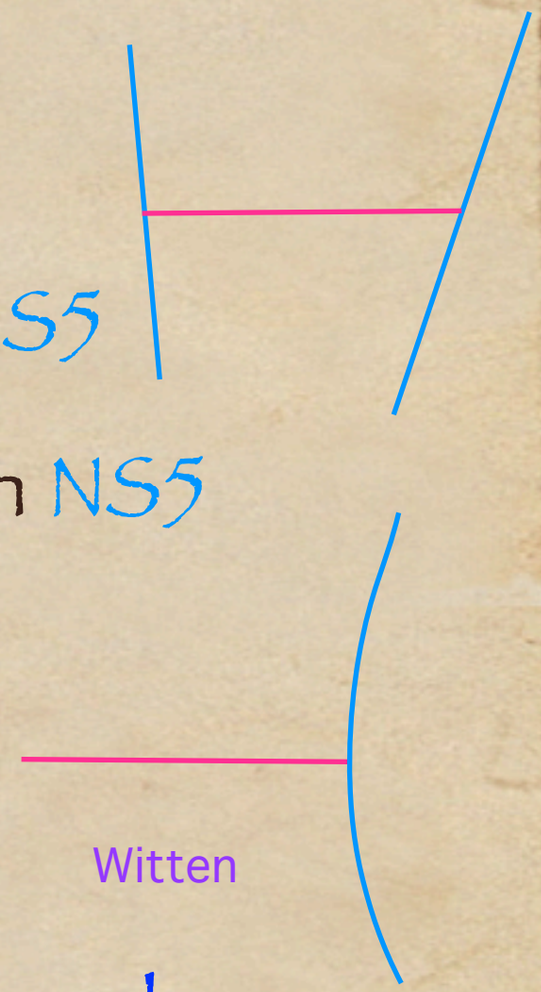
- No type IIA realizations of metastable vacua

Bena, Gorbatov, Hellerman, Seiberg, Shih

- Why ?

No IIA brane realization

- N=1 engineered with D4 + NS5
- D4 ends on 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 Witten

- Tiny IR perturbation $\Rightarrow$ log $\Rightarrow$ UV messed up

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

Bena, Gorbatov, Hellerman, Seiberg, Shih

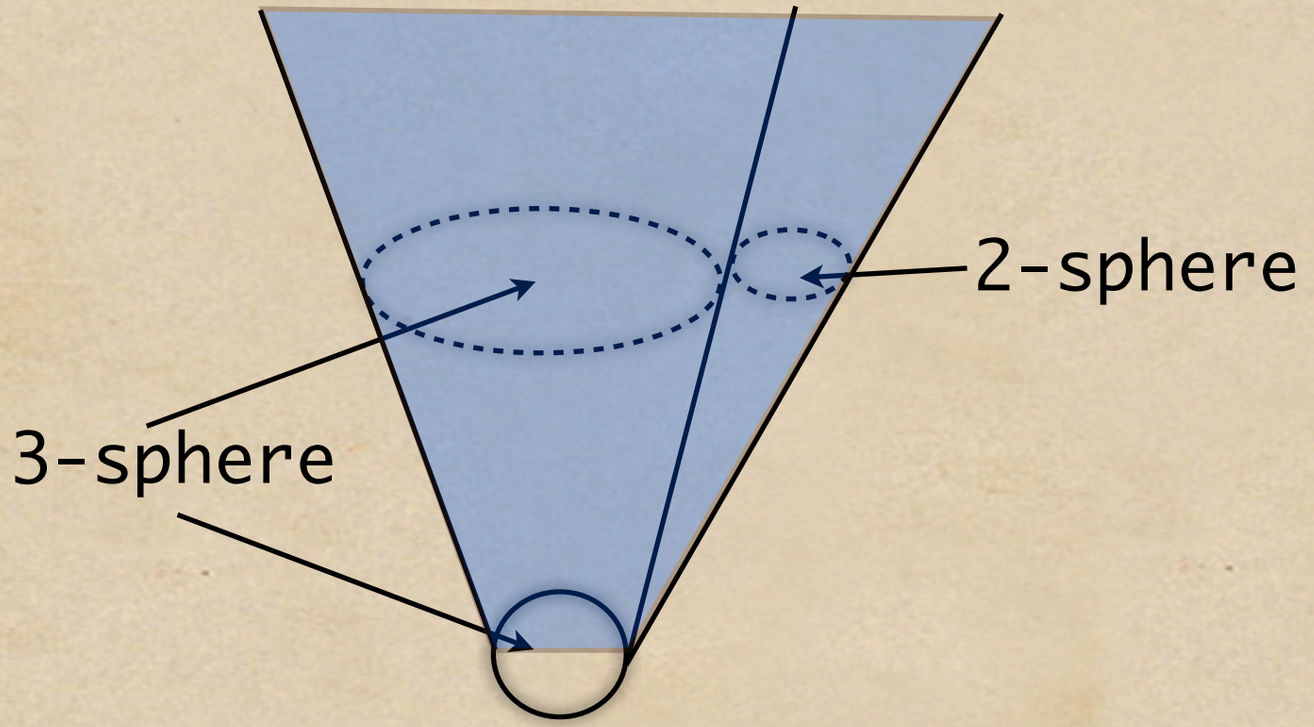
What about AdS-CFT

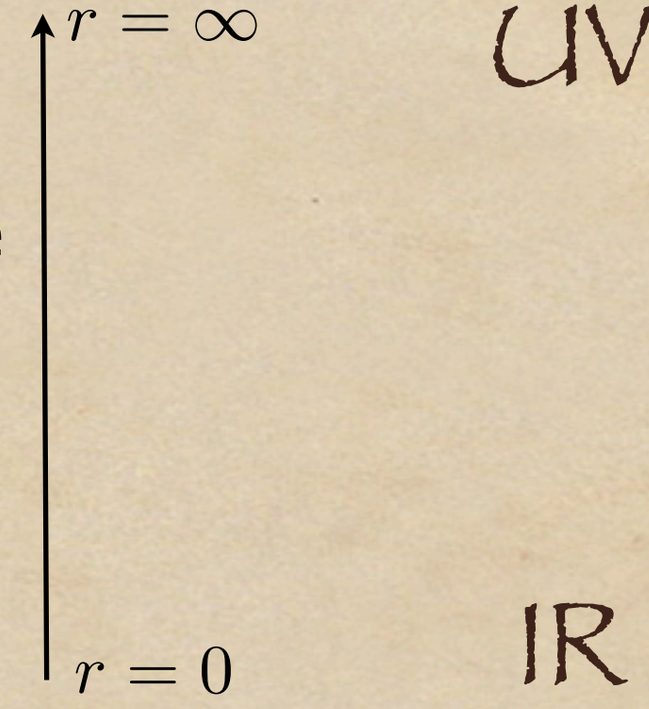
- No *asmpt-AdS$_5$* metastable solutions
- One candidate:

  Kachru Pearson Verlinde

  - Anti-D3 branes in Klebanov Strassler
  - Codimension 6 $\overset{?}{\Rightarrow}$ modes ~ $1/r^4$
  - Normalizable $\Rightarrow$ metastable vacuum
  - Much used in string cosmology

Klebanov-Strassler





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

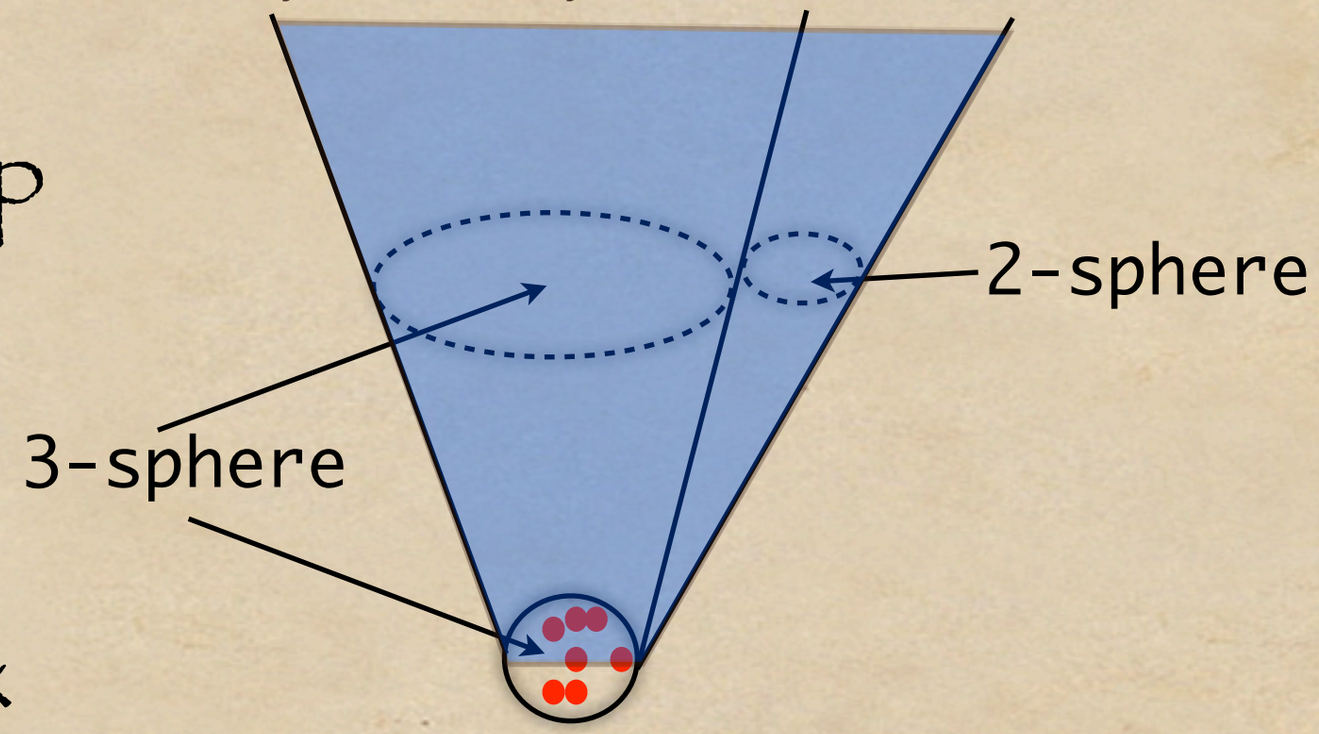
D3 charge dissolved in fluxes

$H_3 \times F_3 \rightarrow F_5$

$F_5 \times F_3 \rightarrow H_3$

Metastable proposal

Add anti-D3 at tip



D3 charge in flux

anti-D3 tunnel and annihilate D3 charge in flux

decay to BPS solution

brane polarization

(Myers effect)

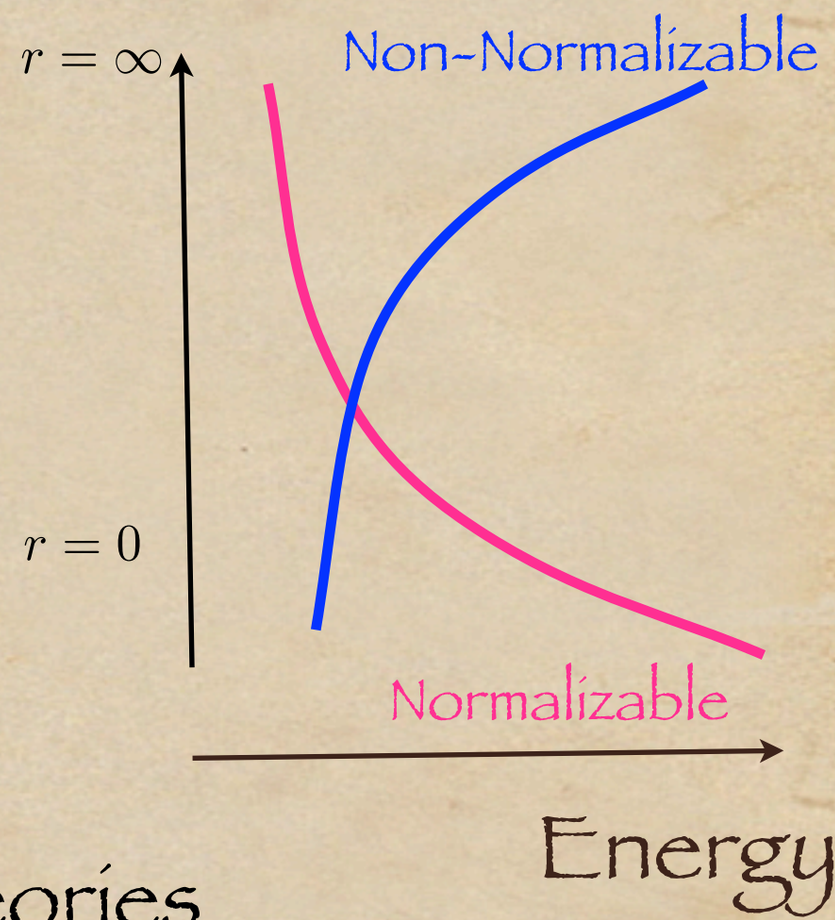
Metastable vacuum

Kachru Pearson Verlinde

AdS-CFT modes

BDHM - BKLT

- Normalizable modes (NM)
  - dual to vevs
  - Finite energy, IR
- Non-normalizable (NNM)
  - deformations of Lagrangian
  - Infinite energy, UV



- Different NNM ⇒ different theories
- Same NNM ⇒ different vacua, same theory

metastable ⇔ NNM=0

Big Question

Anti-D3 ⇒ normalizable or non-normalizable modes?

- Fluxes ⇒ KS field ~ 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 ⇒ non-normalizable
- every dual of non-conformal 4D theory ⇒ log modes

Big Implications if NNM

- No AdS-CFT metastable 4D vacua
- String cosmology/landscape:

anti-D3 down long KS throats →

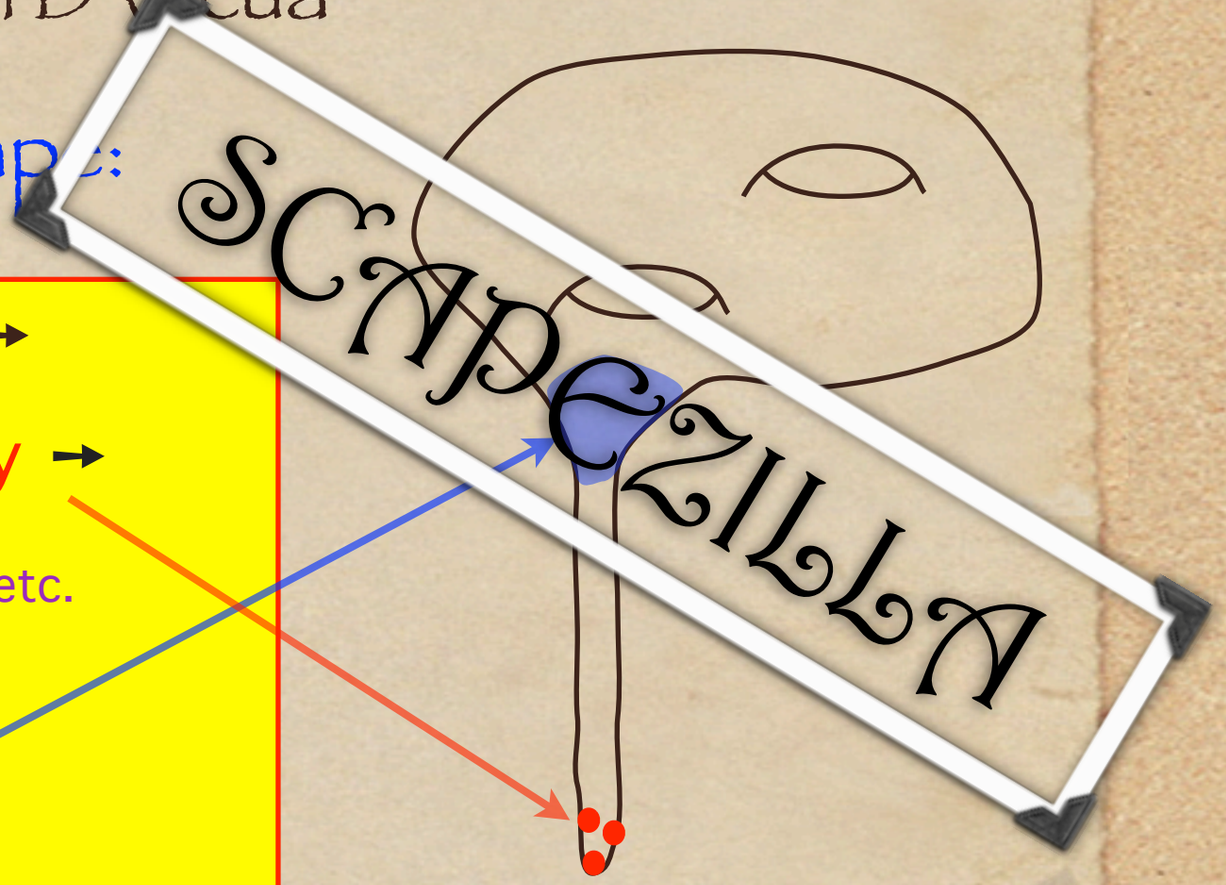
redshift → tunably-small energy →

lift AdS to dS KKLT, etc.

anti-D3 non-normalizable

energy not tunably-small

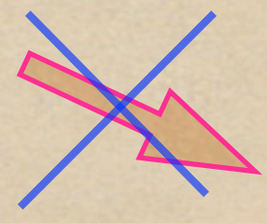
moduli stabilization messed up



$$V = \frac{aAe^{-a\sigma}}{2\sigma^2}\left(\frac{1}{3}\sigma aAe^{-a\sigma} + W_0 + Ae^{-a\sigma}\right) + \frac{D}{\sigma^3} \quad \begin{matrix} \to 3\times 10^{-9} \\ \to \sim 1 \end{matrix}$$

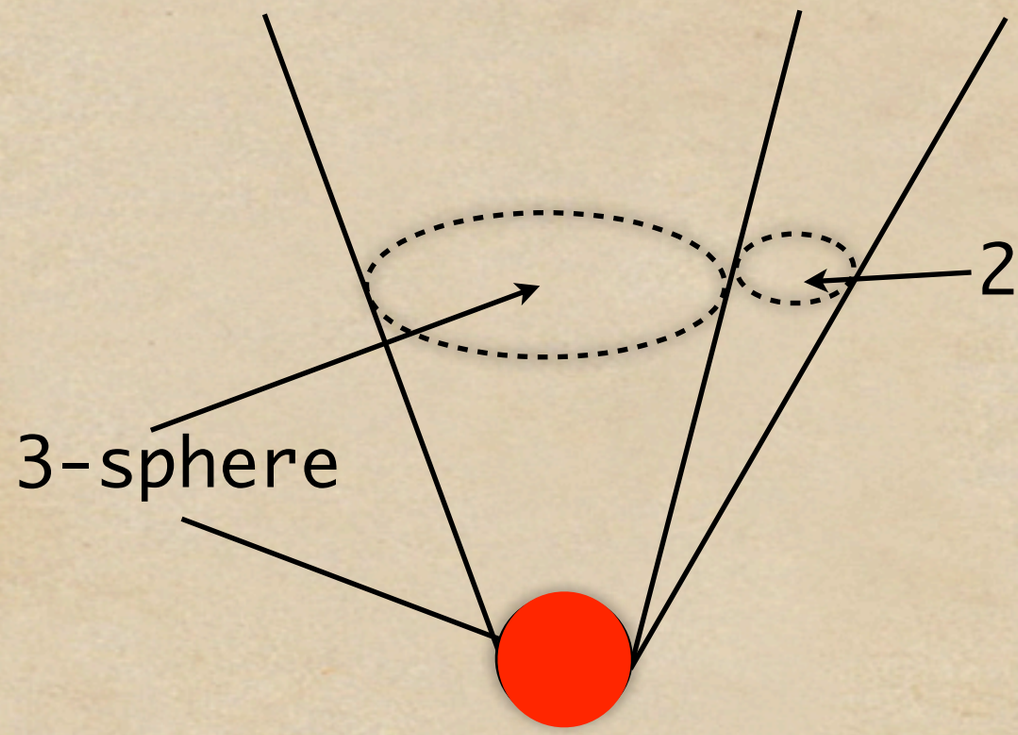
Scape-zilla

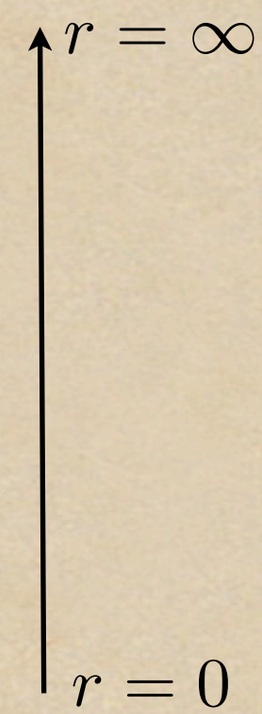
- 4D N=1 gauge theories - log running - generic phenomenon, not restricted to KS
- Same happens in LARGE volume scenarios
- No vacuum uplift by small-energy !
  anti-D3 give O(1) contribution !
- Landscape of AdS vacua



Landscape of dS vacua

Can we find Scapezilla ?





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 ⇒

  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

The Hunting Method

- 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

The hard work

- Implicit solution - 8 nested integrals
- Smart grad students → nested integrals can be simplified:
- ξ - solved in terms of one integral !
- ϕ - 2 or 3 nested integrals !
- Easy to find all mode profiles numerically

The silver bullet !!!

- 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

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 ~ ξ_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

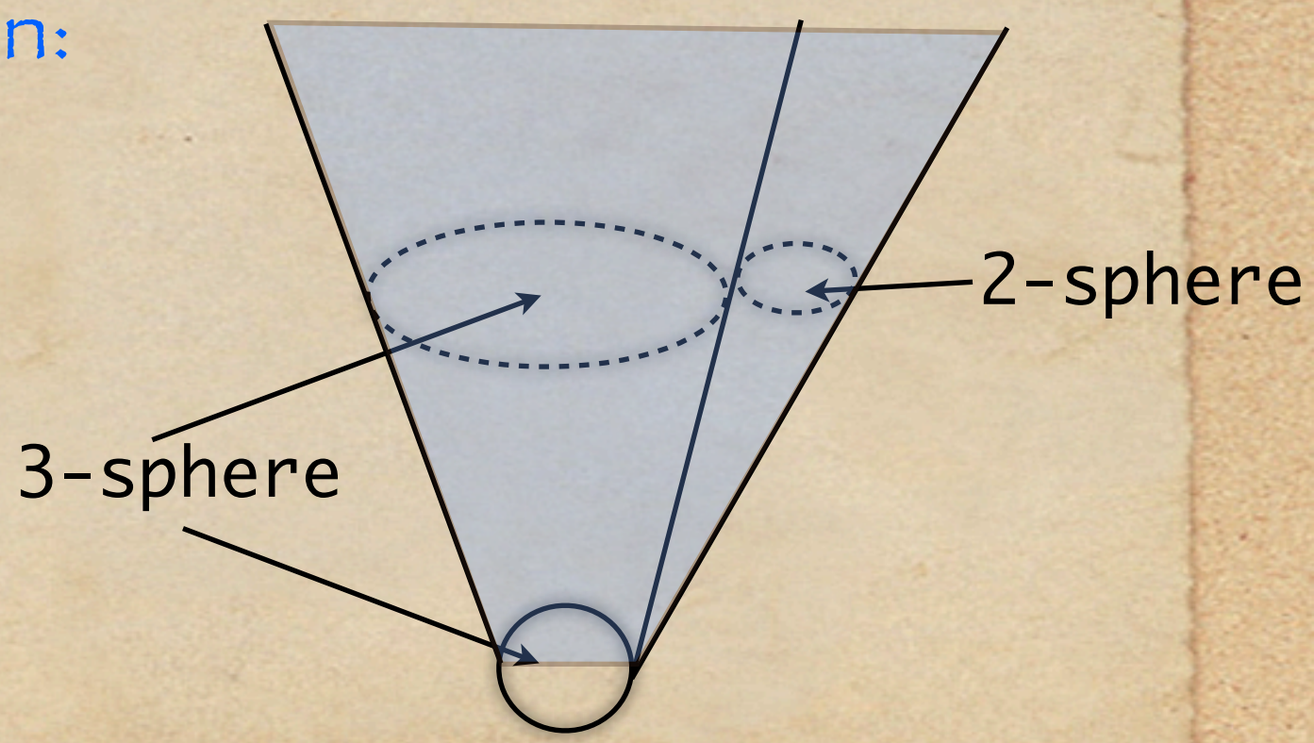
Dymarsky
Klebanov
Seiberg

- AdS can be uplifted to dS
- Landscape of dS vacua alive and frisky
- No Scapezilla

If singularity unphysical:

- anti-D3 sources non-normalizable modes
- IR couplings to log mode (H_3) - mess up UV
- No more dS landscape - SCAPEZILLA

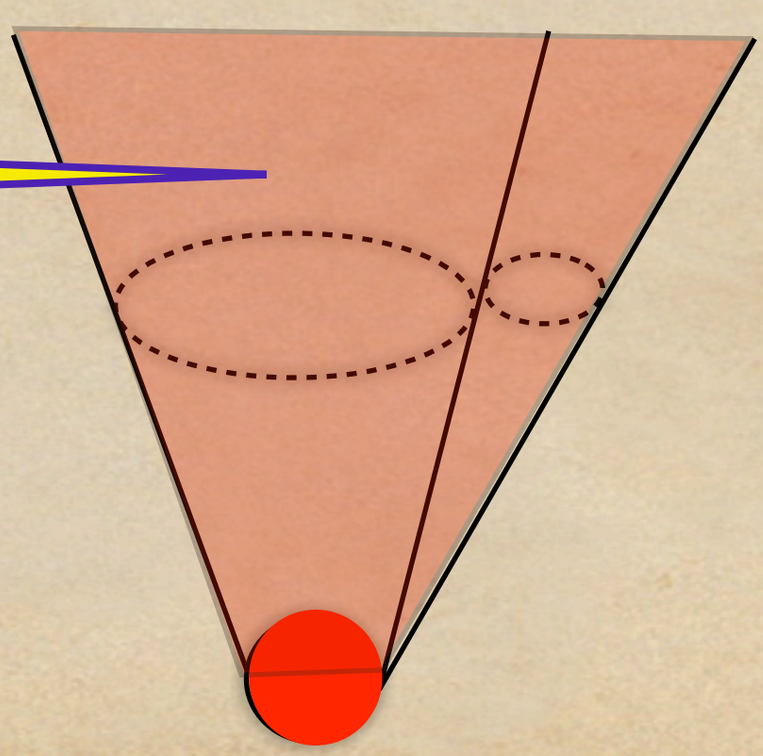
- Reminder -BPS solution:
- $F_5 \times F_3 \rightarrow H_3$
- $H_3 \times F_3 \rightarrow F_5$



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



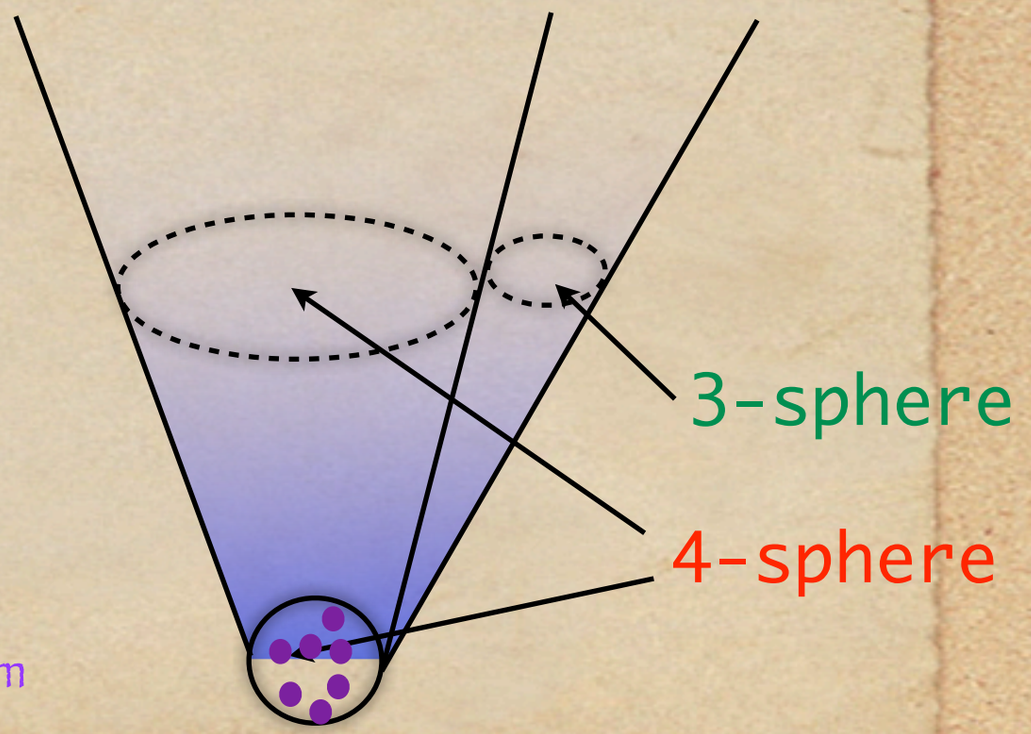
Only physical solution with anti-D3 is anti-KS !!!

Is this generic ?

- Do anti-branes always hate charge dissolved in flux ?
- I hope not ...
- M-theory version of Klebanov-Strassler - CGLP

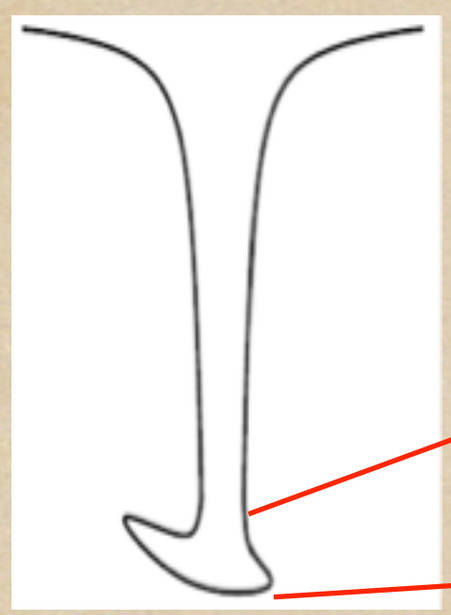
  Cvetic, Gibbons, Lu, Pope
- M2 + transverse 8D Stenzel Space, magnetic F_4 + F_4
- M2 charge in fluxes
- add anti-M2 → metastable

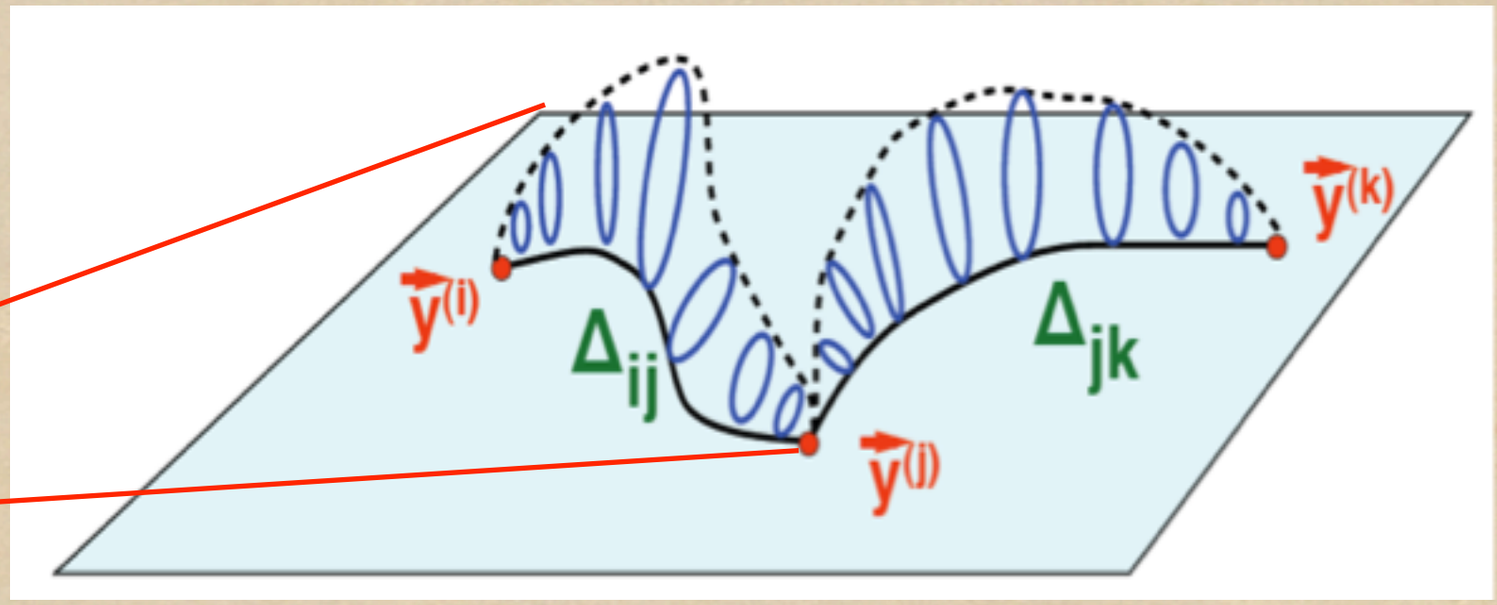
  Klebanov, Pufu
- Perturbative solution = singular !
- Idem for anti-D2 in CGLP, A8
- Insane antibranes Giecold, Orsi, Puhm



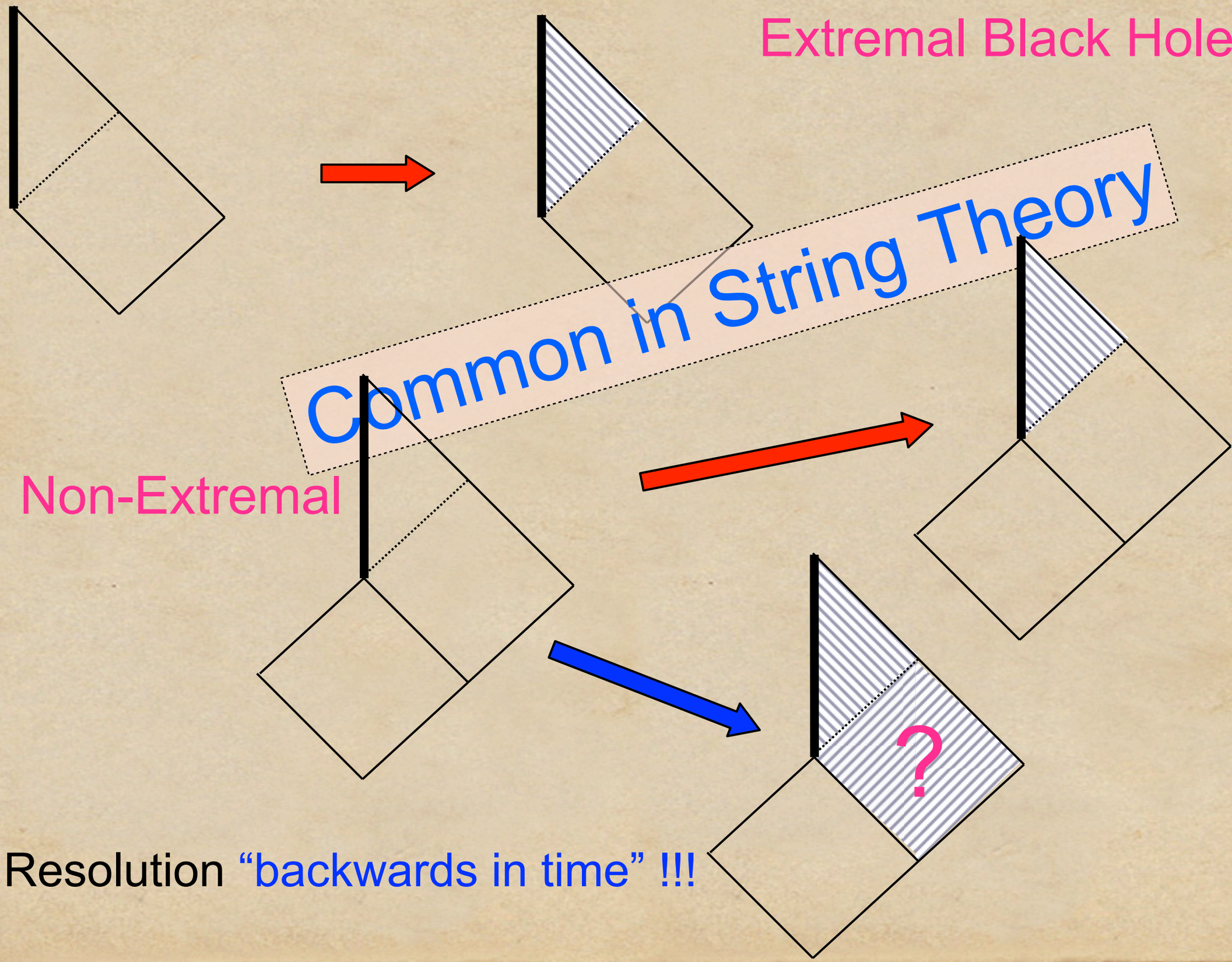
What about non-extremal fuzzballs ?

We have many many many BPS or extremal horizonless microstate geometries (fuzzballs):





Bena, Bobev, Bossard, Dall'Agata, deBoer, Giusto, Niehoff, Ruef, Shigemori, Vasilakis, Warner & friends

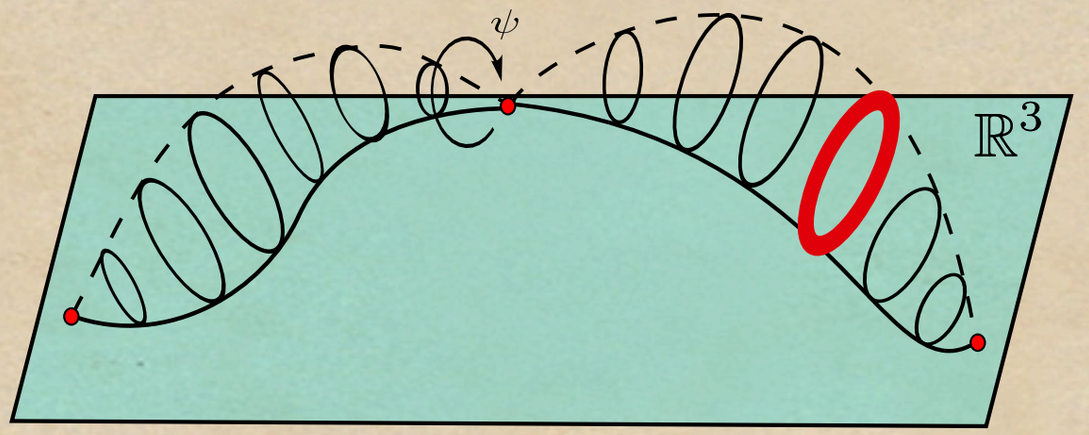


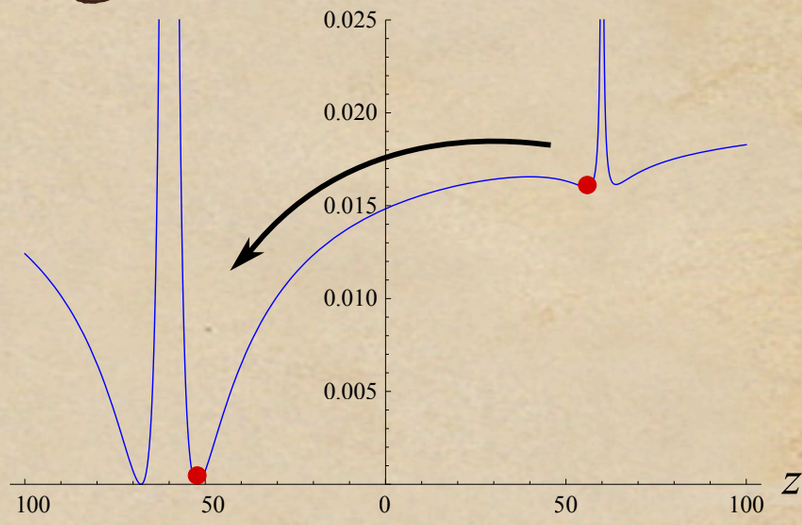
Resolution “backwards in time” !!!

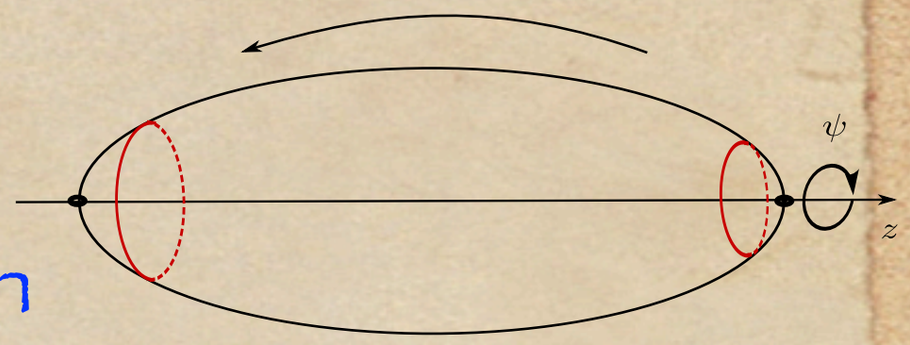
Non-extremal microstates ?

Add metastable supertube wrapping GH fiber:

Bena, Puhm, Vercnocke







Decays via brane-flux annihilation

May be only way to construct stationary non-extremal microstate geometries Gibbons, Warner

Is singularity physical ?

- If not physical:
  - antibranes cannot coexist with charge in fluxes
  - maybe no more dS landscape ☹
  - maybe no systematic way to build non-extremal stationary microstate geometries (fuzzballs) ☹
- 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-CMT without incoming b.c. at black hole
  - Confinement from Klebanov-Tseytlin

Scapezilla not easy to kill

Is singularity physical ?

- Anti-D3 singularity @ first-order backreaction
- May go away at full backreaction Dymarsky

- No intention: Bena, Grana, Kuperstein, Massai

  1. Eliminate IR singularity

  2a. Find full solution in an IR expansion to order τ^{10}

  2b. Examine r.h.s. of nonlinear eq

- Only possible solution with anti-

Anti-M2's as well

Anti-D3's are singular to the bitter end

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 (Dymarsky)

- 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

- Furthermore, anti-M2 and anti-D2 singularities have divergent IR action

GRAVITY DOUBLE WILL KILL YOU & DRINK YOUR BLOOD !!!

Is singularity physical ?

- Singularity indicates new physics
  - Instabilities
  - Polarization:

- Probe anti-D3's polarize into NS5 branes/$S^2 \subset S^3$
  this could resolve singularity à la Polchinski-Strassler
- Smearing wipes out this polarization channel:
- PS has many channels: D5 branes/$S^2 \subset T^{1,1}$ survive smearing
- No smeared anti-D3+D5 $\longrightarrow$ no localized anti-D3+D5 $\not\Rightarrow$
  no localized anti-D3+NS5 branes either !!!

Why Polchinski-Strassler does not save the landscape

revenge on Bousso-Polchinski ☺

Same potential terms as in PS !

Good intuition

$$V(\tau) \sim (2\pi n)\, a_2 \tau^2 - a_3 \tau^3 + \frac{1}{2\pi n} a_4 \tau^4$$

No polarization if:

$$(a_3)^2 < \frac{32}{9} a_2 a_4$$

Long calculation:

$$a_2 = \frac{1}{3p^2}\left(4\lambda_f^2 + 3\lambda_F^2\right), \quad a_3 = \frac{2}{3p}\,\lambda_f\,, \quad a_4 = \frac{1}{8}$$

Could have worked, but it does not !!!

Is singularity physical ?

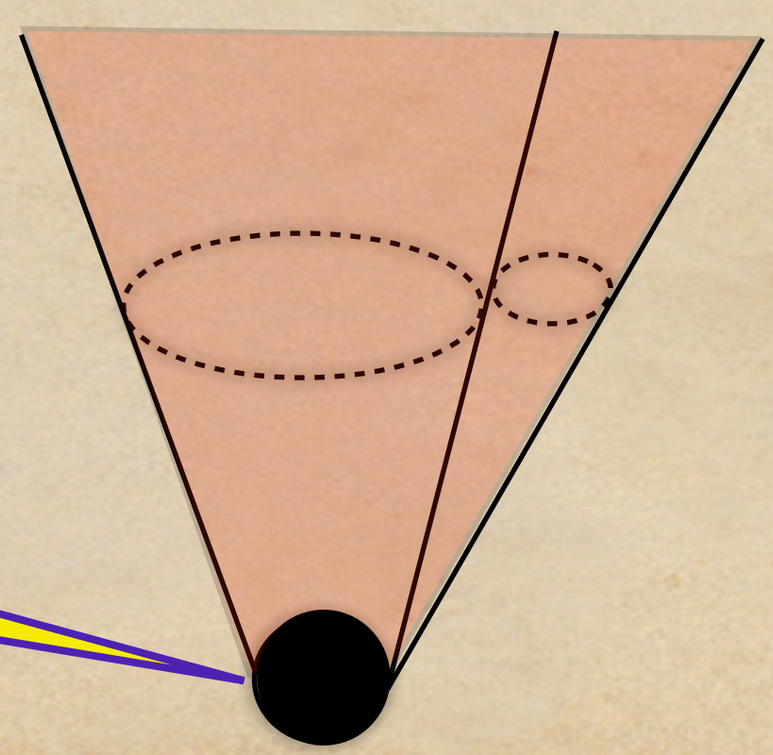
- Maybe we are not smart-enough to understand resolution
- "Good, Bad, Ugly" criterion: Gubser

  Good singularities can be cloaked by horizon
- If physical ⇒ ∃ BH in KS/KT with negative charge

All KS/KT black holes must have positive charge:
Bena, Buchel, Dias

Black hole in Klebanov-Strassler/Tseytlin

Aharony, Buchel, Kerner; Buchel



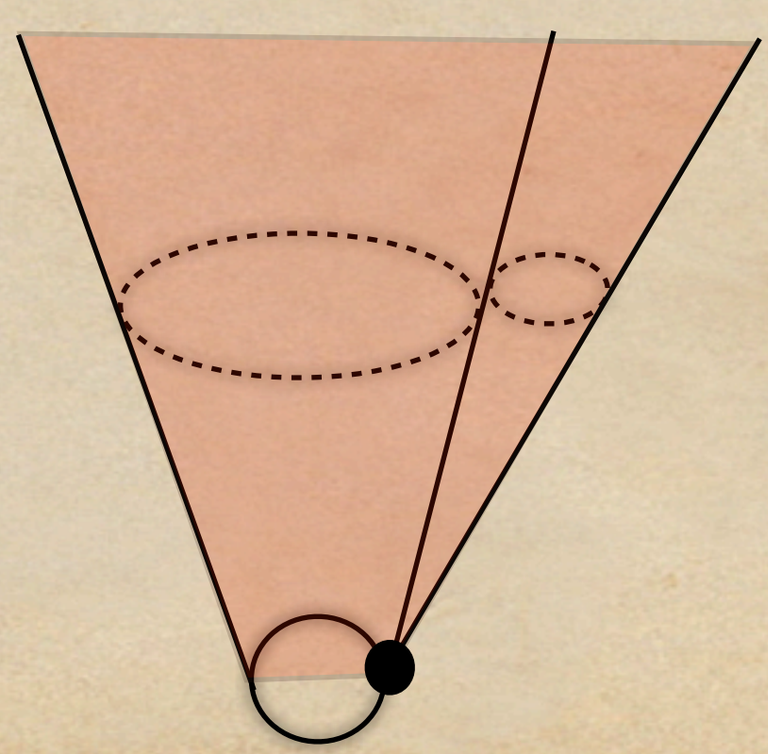
Is singularity physical ?

- Maybe artifact of smearing
- Localized anti-branes may not have this problem
- $\Leftrightarrow$ Localized BH with anti-D3 charge in KS exists

Can be anywhere on S^3
Could be smeared

Smeared BH with negative charge does not exist

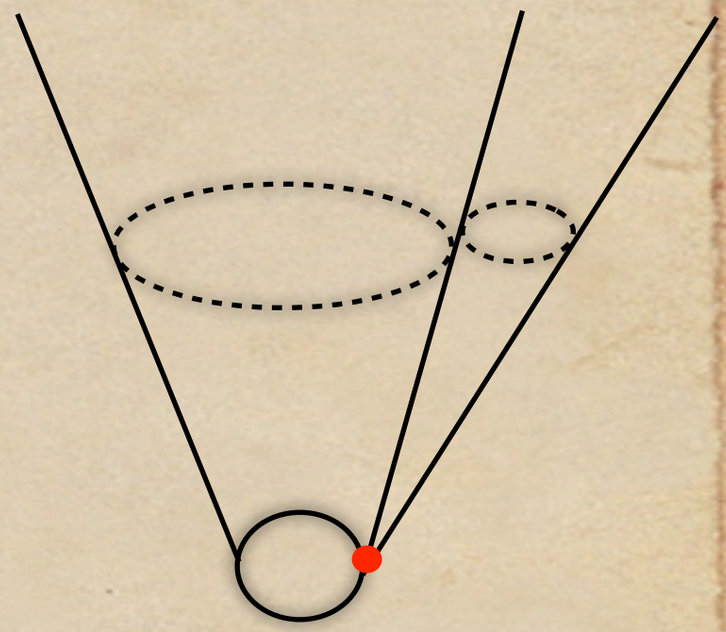
Bena, Buchel, Dias



Is singularity physical ?

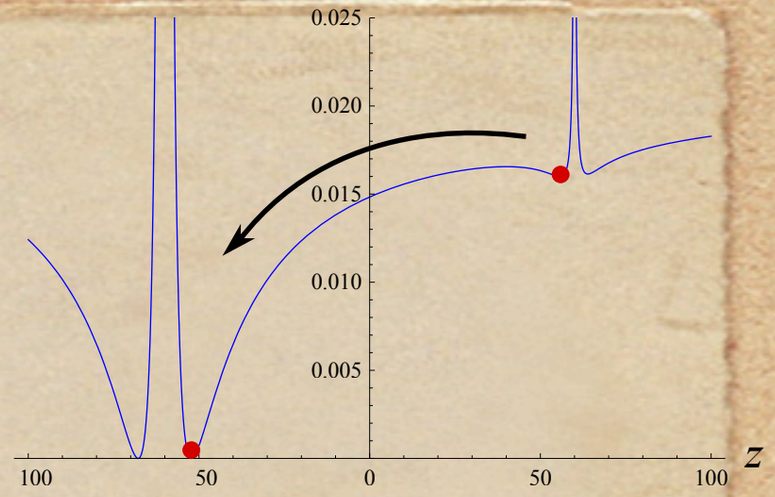
- Nobody could have predicted it a-priori !
- No a-posteriori physical reason for accepting it
- Several highly nontrivial calculations that could have worked either for or against - all worked against

What would help

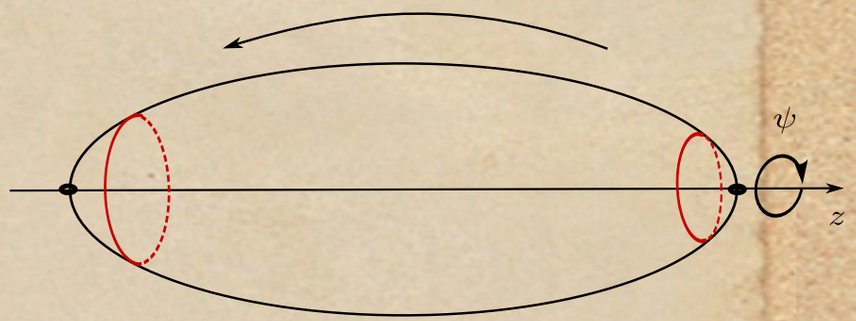


- Localized anti-D3 in KS
- Localized BH in KS
  - Non-BPS solution, 2 variables
  - Separation of scales
- No smeared BH solution → no localized BH solution
  - Is this always true ? If not why ?
- Solution for smeared anti-M2, anti-D2 black holes in CGLP, A8
  - Would confirm whether anti-D3 story is generic or not
  - One variable - shooting or relaxation - straightforward.

What would help



- Metastable supertube solution
  - cannot smear → 2 variables !
  - supertube charges: (-,-) or (+,-)



- Numerics ? ... BlackFold ? ...

Separation of scales ? ... Inverse scattering ? ... Perturbative ?

- first fully-backreacted microstate geometry of a non-extremal BH with macroscopic horizon
- existence of gazillions of microstates - resolve info paradox
- mechanism that keeps them from collapsing into BH

(which nobody else has ☺)

Conclusions

- Probe antibranes uplift AdS to dS
- Probe antibranes give stationary near-extremal fuzzballs
- Backreacted antibranes have singularity
- No reason to accept it. So far all evidence against.

If unphysical:

- A lot of string cosmology and phenomenology to be revisited.
- SCAPEZILLA: AdS landscape ≠ dS landscape
- Find other ways to uplift AdS to dS (Kahler uplifting ? nonperturbative effects ? nothing ?)
- Find other ways to build non-extremal fuzzballs (JMaRT-type centers ? motion on moduli space ? inverse scattering ? numerics ?)