

Does String Theory have stable de Sitter vacua ?

Ioşif Bena

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Johan Blåbäck, Alex Buchel, Oscar Dias, Mariana Graña, Nicholas Kovensky, Severin Lüst, Stefano Massai, Ruben Minasian, Andrea Puhm, **Ander Retolaza**, Raffeale Savelli, David Turton, Bert Vercnocke, Thomas Van Riet



John
Templeton
Foundation



Huge fine-tuning in laws of physics:

10^{-120} cosmological constant,

10^{-24} electroweak,

10^{-10} inflation

Symmetry explanations (SUSY)

increasingly **excluded** by LHC data

Anthropic explanation if $\gg 10^{120}$

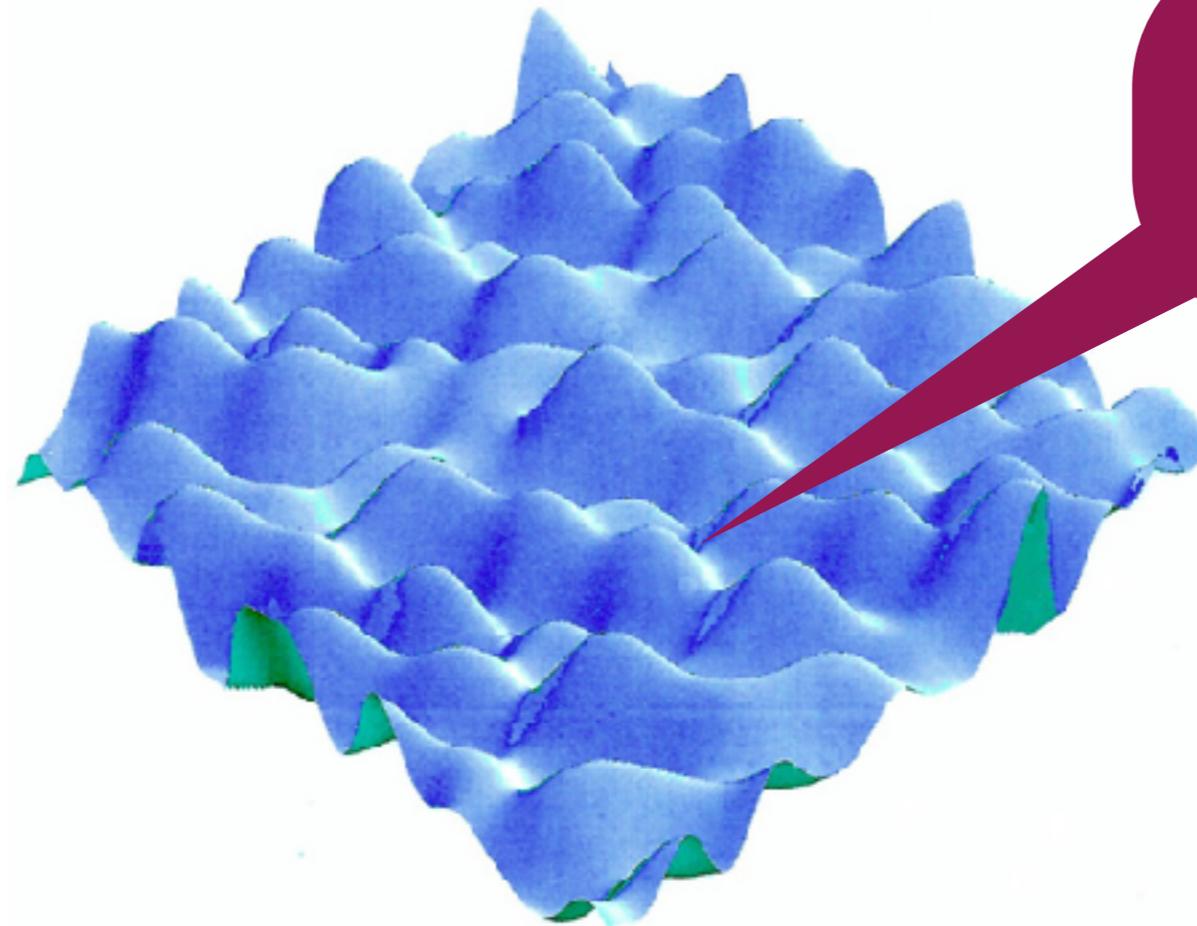
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String Theory has 10^{500} possible compactifications to 4D

Multiverse



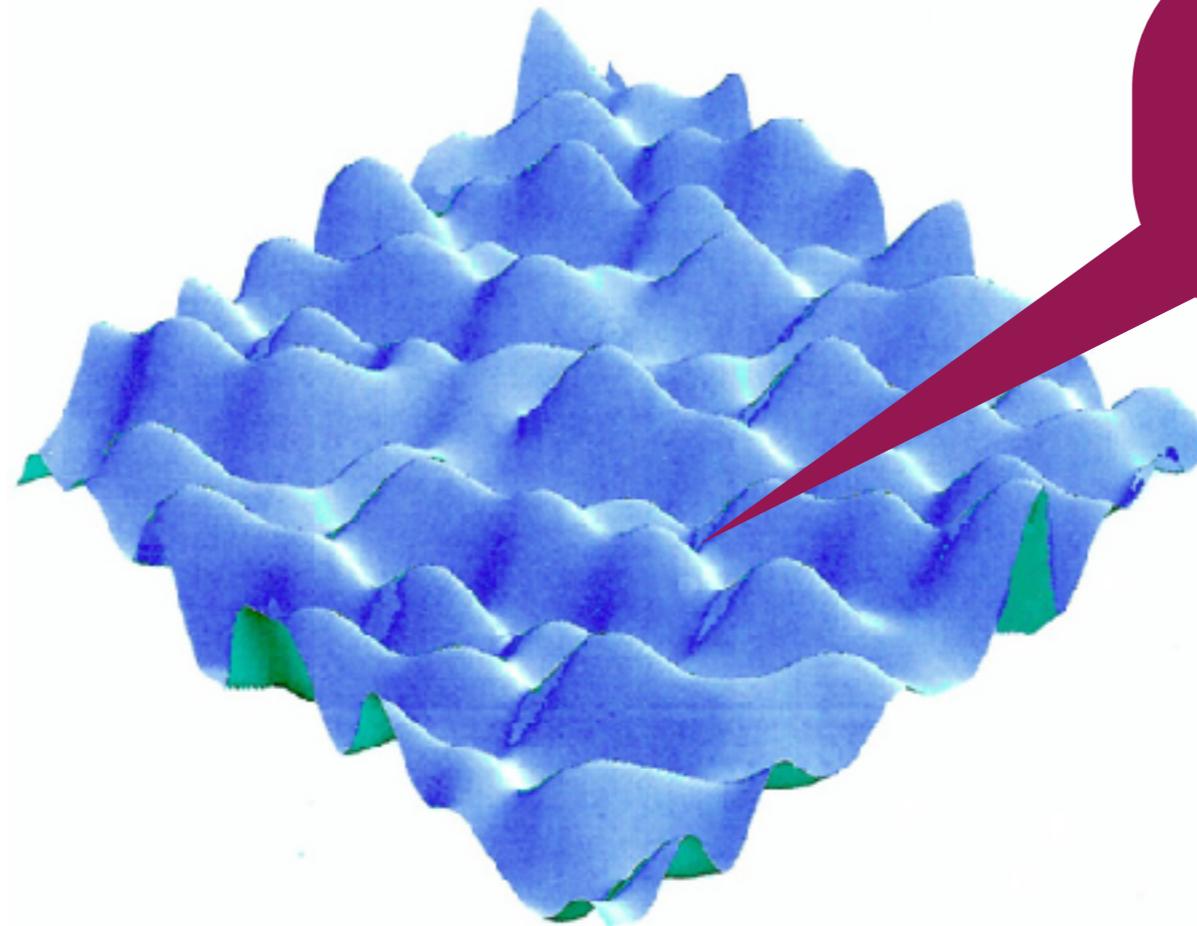
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New paradigm: fundamental laws of physics do not come from a deeper underlying theory, but are environmental variables determined by where we happen to be in the multiverse.

String Cosmology - Standard Lore

Compactify to **4D** on **6D manifold** (Calabi-Yau)

Lots of unphysical **massless scalars** (moduli)

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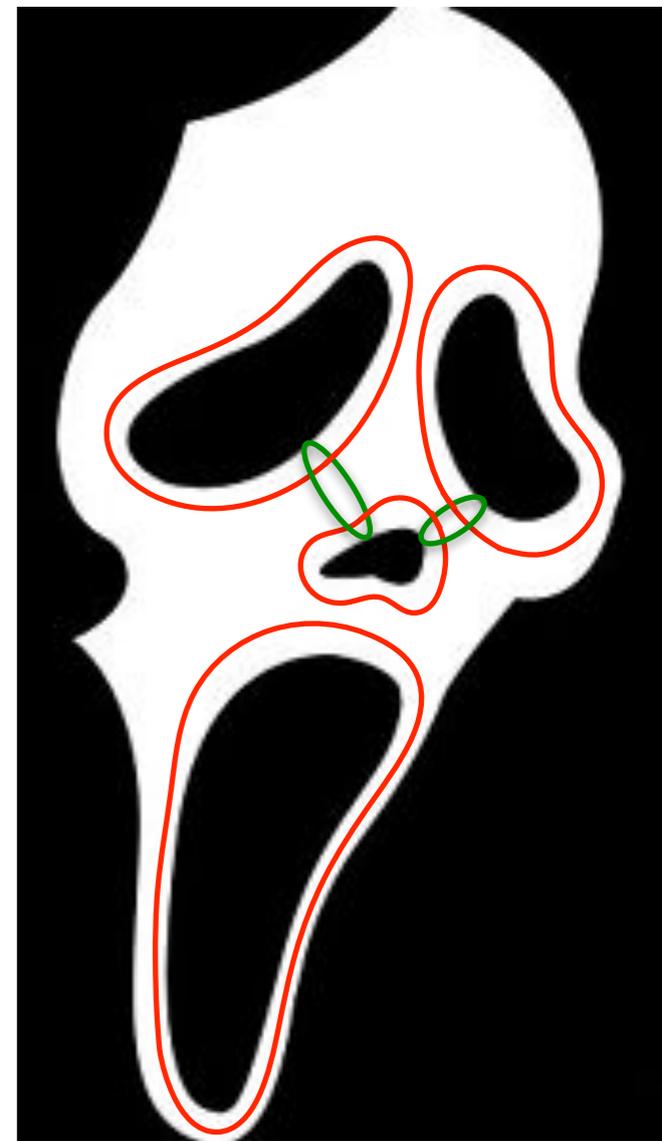


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(negative cosmological constant)



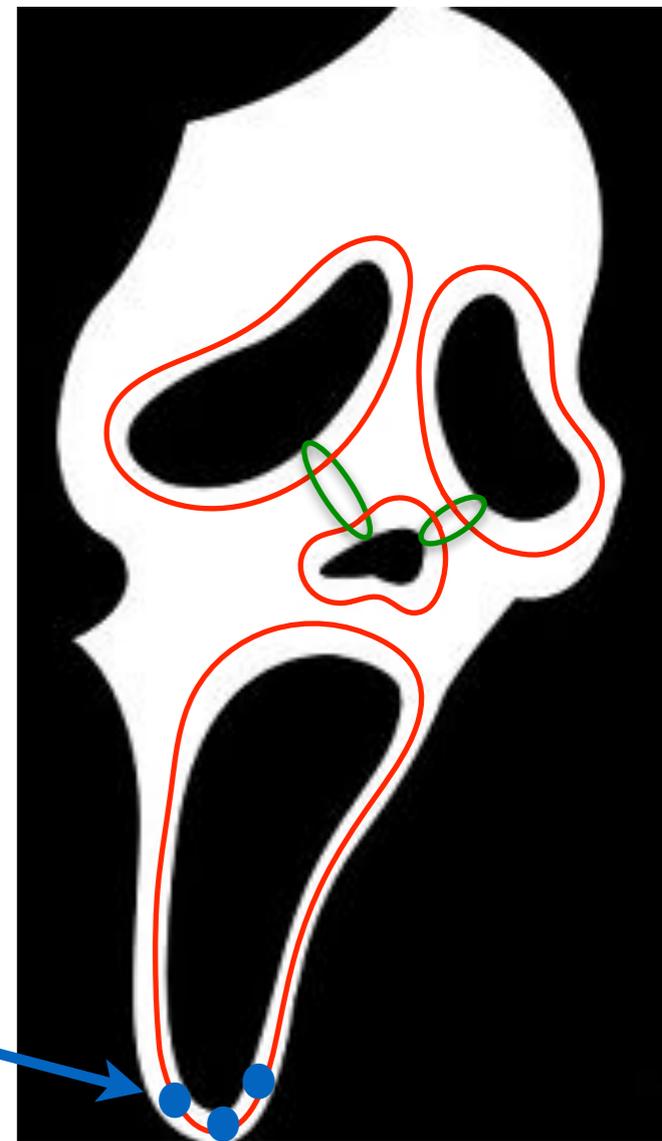
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anti-D3 down **long throats** \rightarrow **redshift** \rightarrow very-small **energy** \rightarrow lift **AdS** to **dS** KKLT, ~ 2500 others



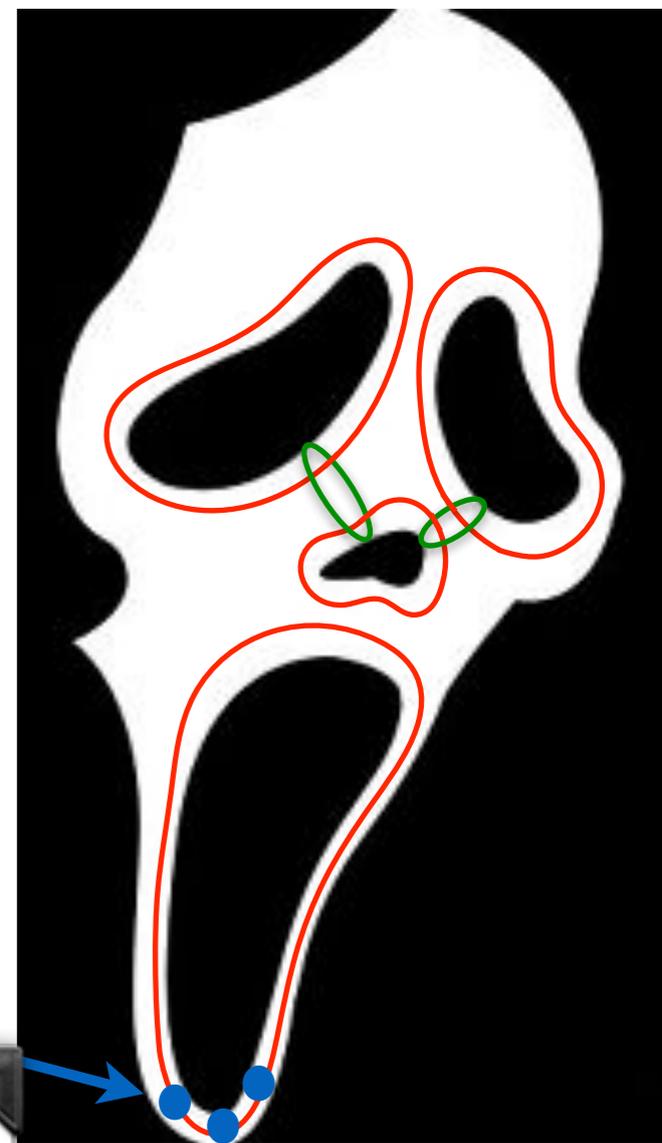
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THE LANDSCAPE

3 stages of de Sitter construction

KKLT, LVS, etc

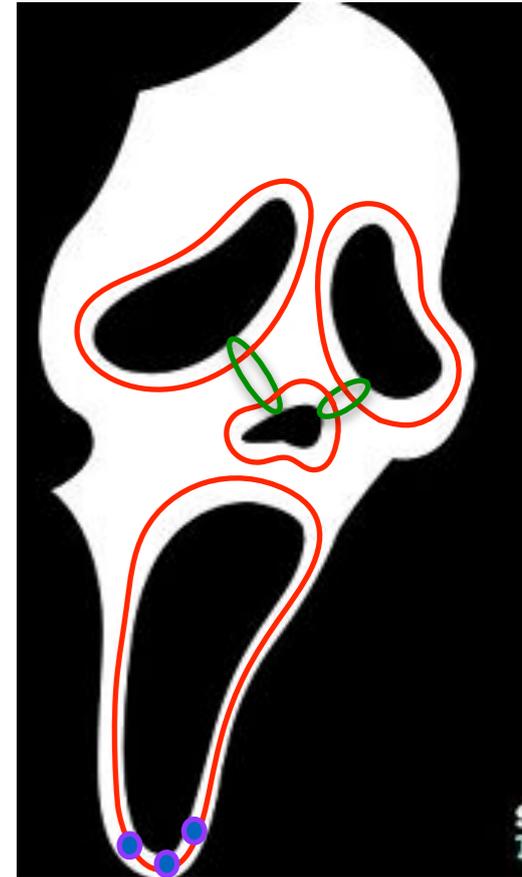
CY moduli:

- **Complex-structure** (twisting shape)
- **Kähler** (volume, breathing mode)

1. Fix **Complex-structure** moduli: **fluxes** on topologically-nontrivial 3-cycles

2. Fix **Kähler** moduli: **D3 instantons** or gaugino condensation (**confinement**) on D7 branes

3. Add **antibranes**: uplift cosmological const.



The problem

Steps 1,2,3: **low-energy effective field theory**
using String-Theory-derived **ingredients**

The problem

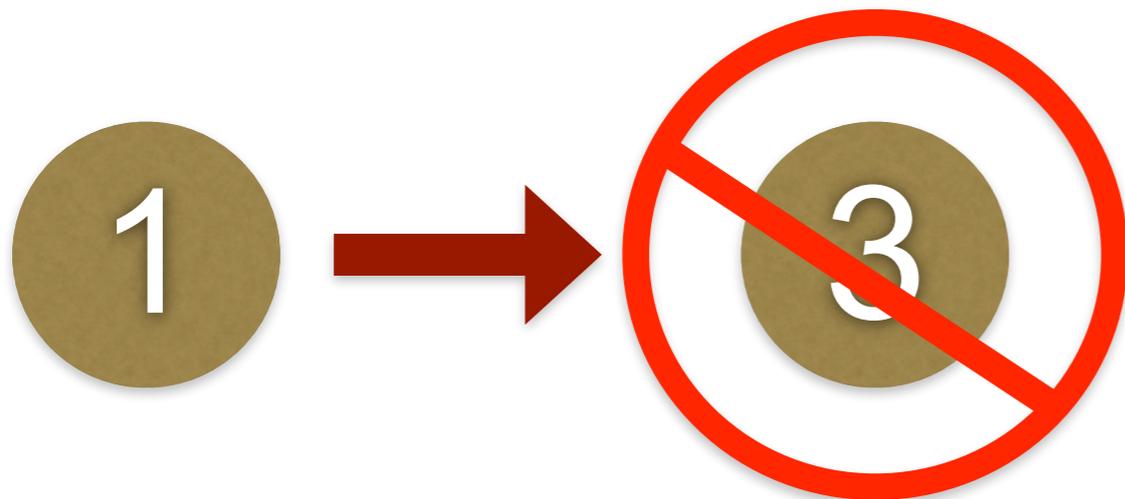
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Nontrivial interactions in String Theory

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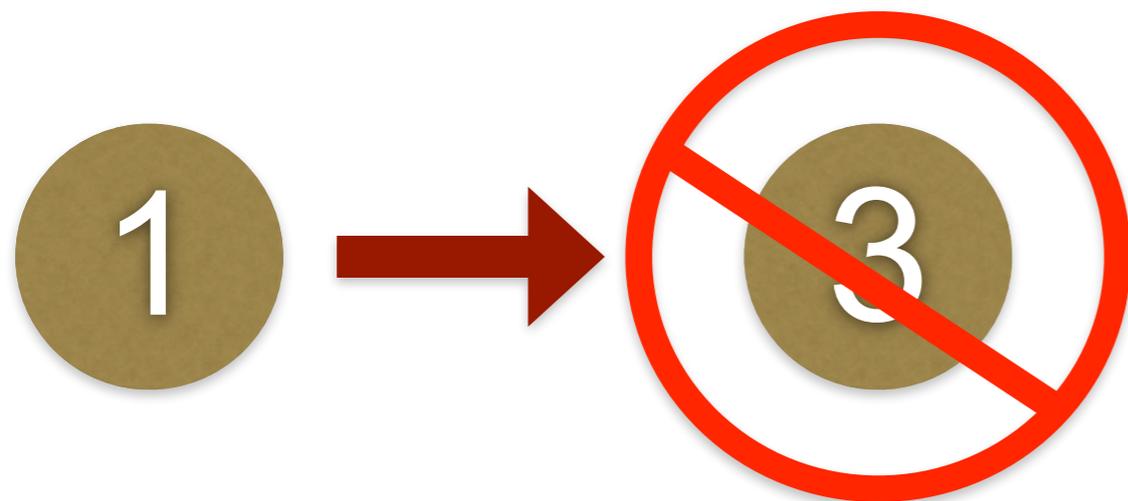


Bena, Graña, Kuperstein, Massai

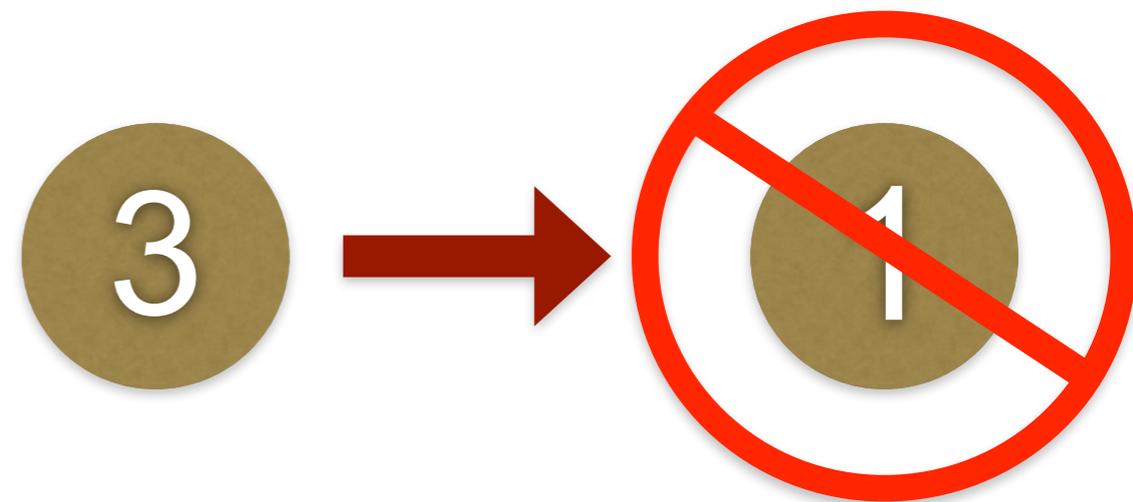
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Bena, Dudaş, Graña, S. Lüst
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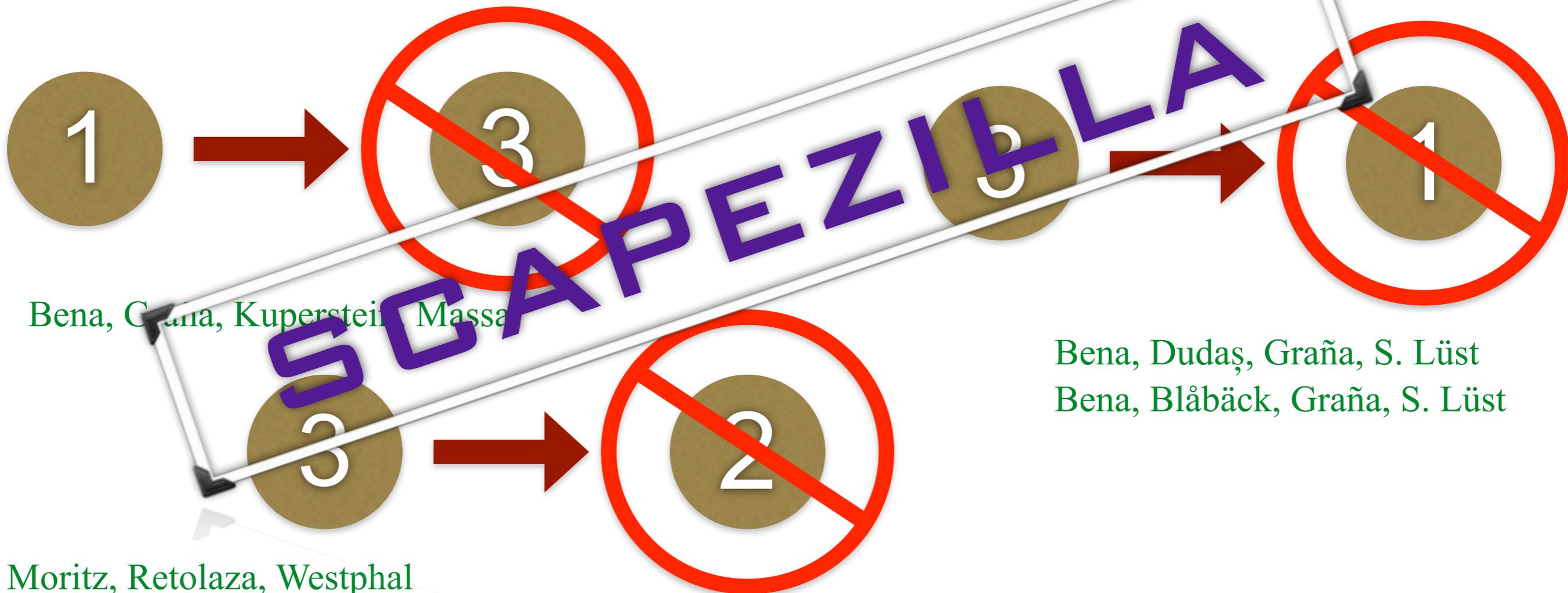
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Bena, Graña, Kuperstein, Massa

Bena, Dudaş, Graña, S. Lüst
Bena, Blåbäck, Graña, S. Lüst

Moritz, Retolaza, Westphal
Bena, Graña, Kovensky, Retolaza + in progress

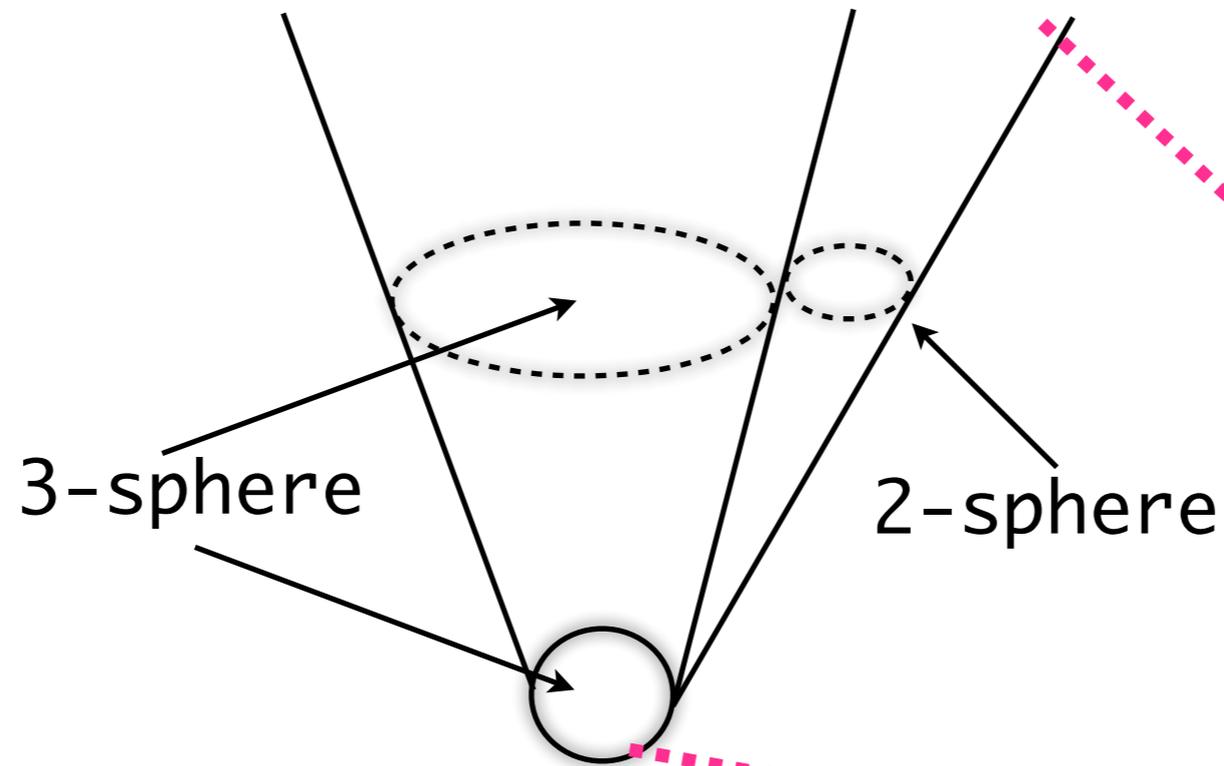


The calculations

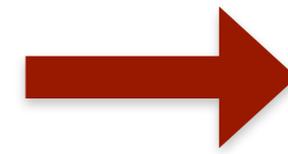


Klebanov-Strassler geometry

Bena, Graña, Kuperstein, Massai



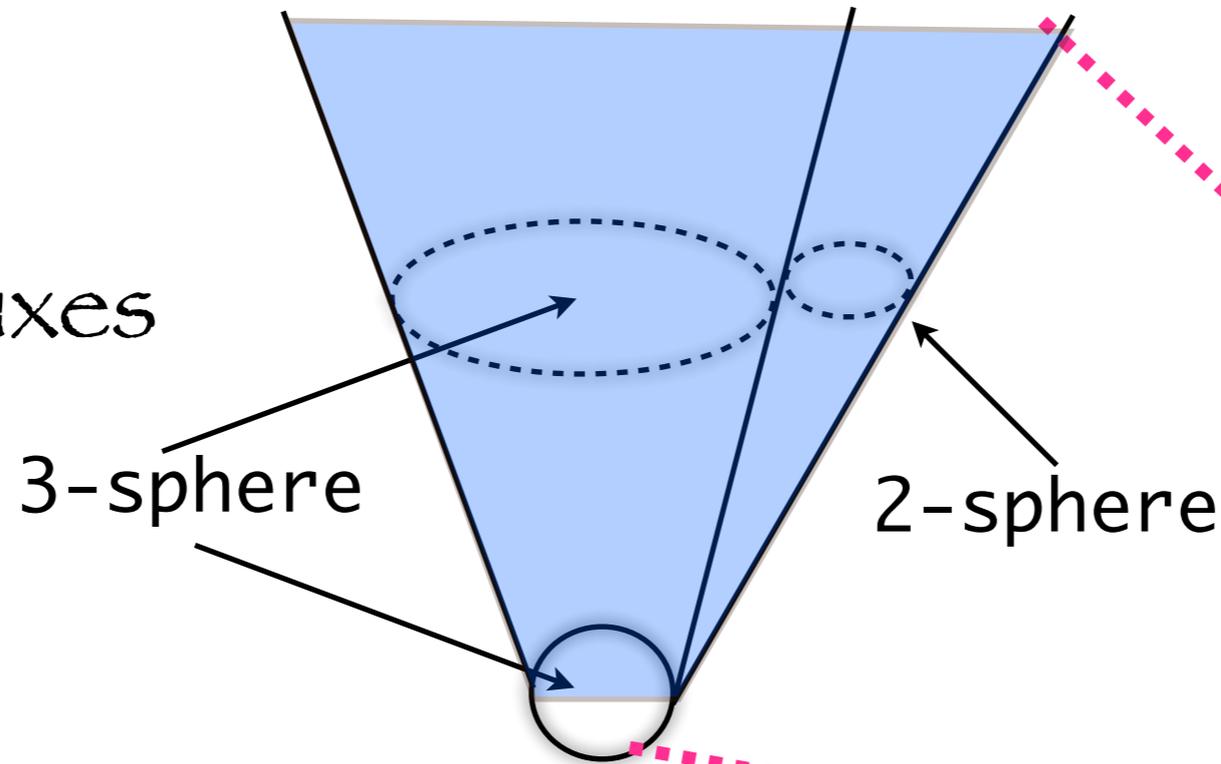
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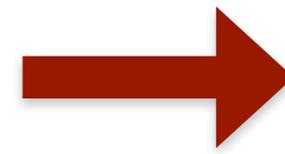
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D3 charge
dissolved in fluxes



The calculations



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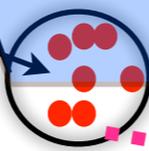
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$D3$ charge
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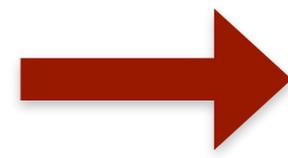
3-sphere

2-sphere

Add $\text{anti-}D3$ probe at tip
breaks susy



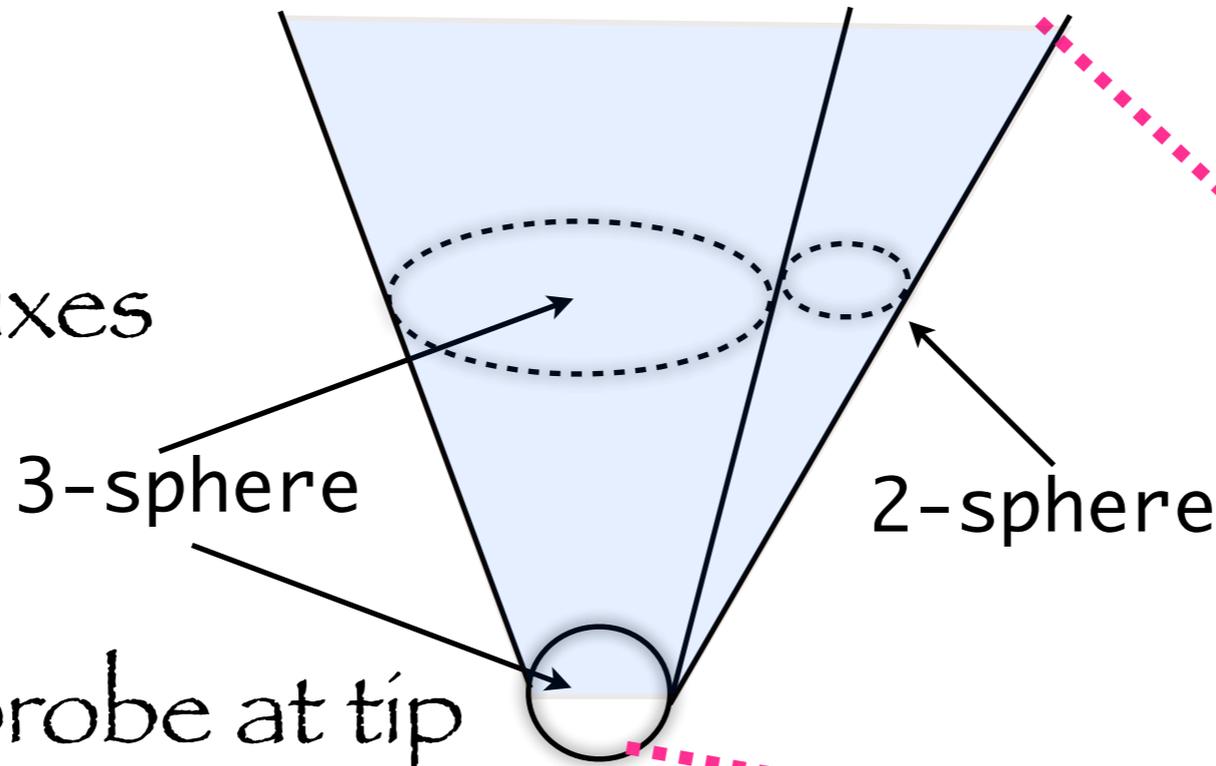
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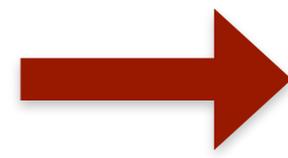


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$\text{anti-}D3$ tunnel and annihilate $D3$ charge in flux
decay to susy solution



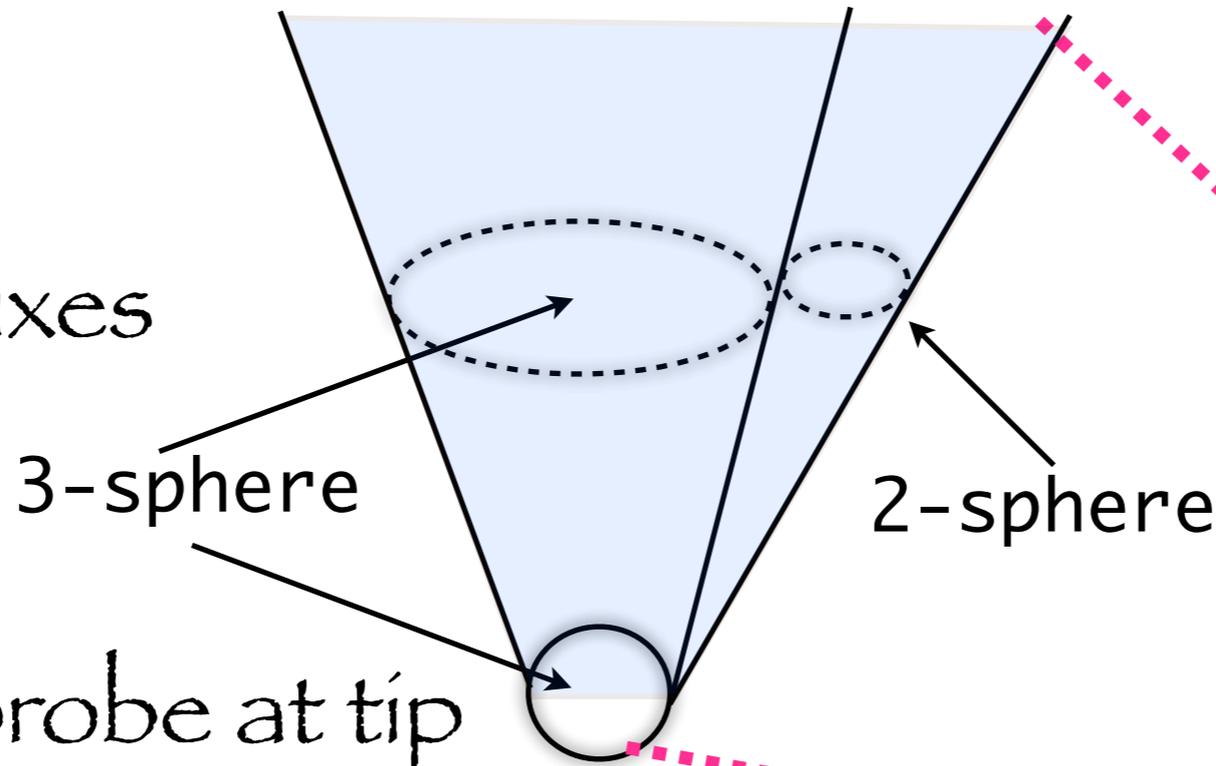
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Kachru Pearson Verlinde

Maldacena Năstase (similar)

Ignoring backreaction \Rightarrow **Metastable**

2 possibilities

- Fluxes \Rightarrow KS field $\sim \log r$
- **Log running** of coupling constant of dual theory

$$\frac{1}{g_1^2} - \frac{1}{g_2^2} \sim \int_{S^2} B_2 \sim \log r$$

- Anti-D3 couple to this field

Intuition \Rightarrow metastability = artifact of probe approx.

Bena, Gorbatov, Hellerman, Seiberg, Shih

Backreaction:

- 1 \Rightarrow **log** affected \Rightarrow **mess up** $\infty \Rightarrow$ **not metastable**
- 2 \Rightarrow **log** unaffected but IR singularity \Rightarrow **tachyon**

Full supergravity backreaction

Bena, Graña, Halmagyi, Kuperstein, Massai, 2009-2014



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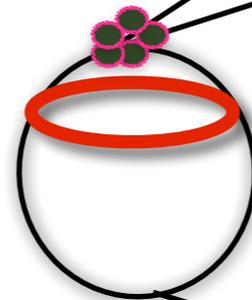
- ◆ Fluxes of KS solution cause anti-D3 branes to polarize
- ◆ 2 main channels
 - ◆ D5 wrapping $S^2 \subset T^{1,1}$
 - ◆ NS5 wrapping $S^2 \subset S^3$



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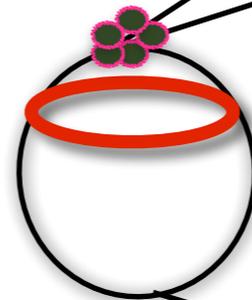


$$V_{\overline{D3} \rightarrow \text{NS5}} = a_4 \frac{\theta^4}{N_{\overline{D3}}} - a_3 \theta^3 + N_{\overline{D3}} a_2 \theta^2$$

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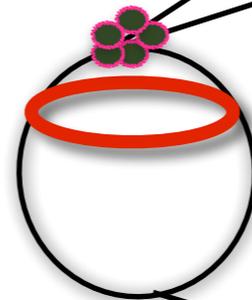
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- ◆ Other directions **negative !**

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anti-D3
tachyonic !!!

Anti-D3 brane perspective ($g_s N_{\text{anti-D3}} \ll 1$)

Bena, Blåbäck, Turton

N anti-D3 branes in fluxes \Rightarrow N=4 SYM + boson & fermion masses:

$(2,1) \Leftrightarrow$ squarks (scalars), $(0,3) \Leftrightarrow$ gauginos Graña

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Flat tree-level potential
(motion on S^3)

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Flat tree-level potential
(motion on S^3)

remains flat to all orders
in perturbation theory !!!

Parke and West '84

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Bena, Graña, Kuperstein, Massai

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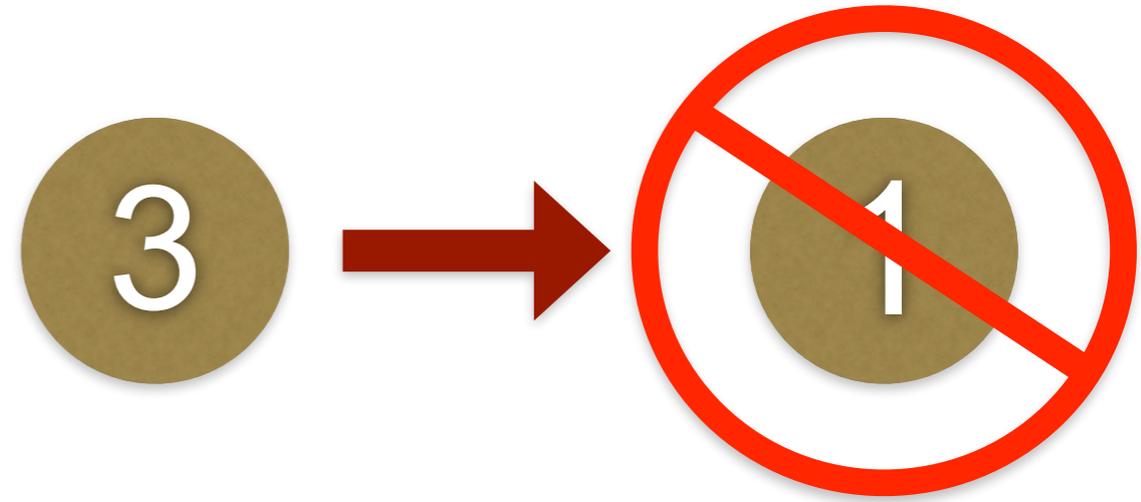
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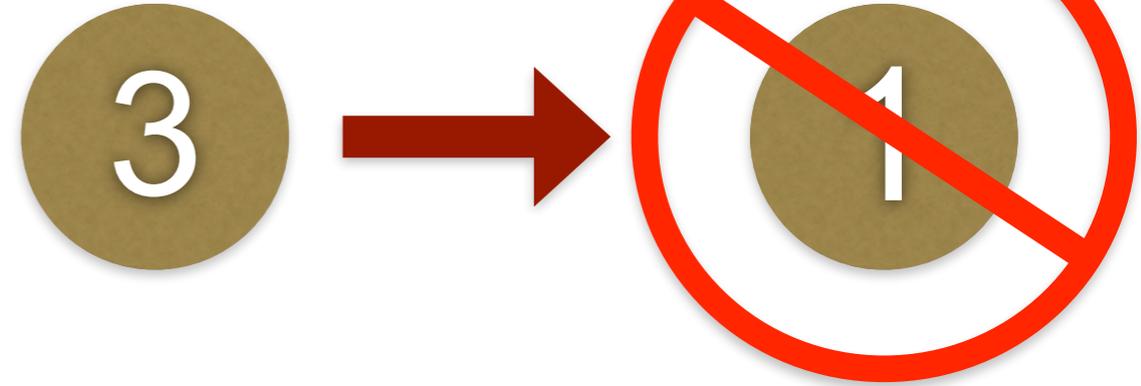
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Brane-brane repelling tachyon always there

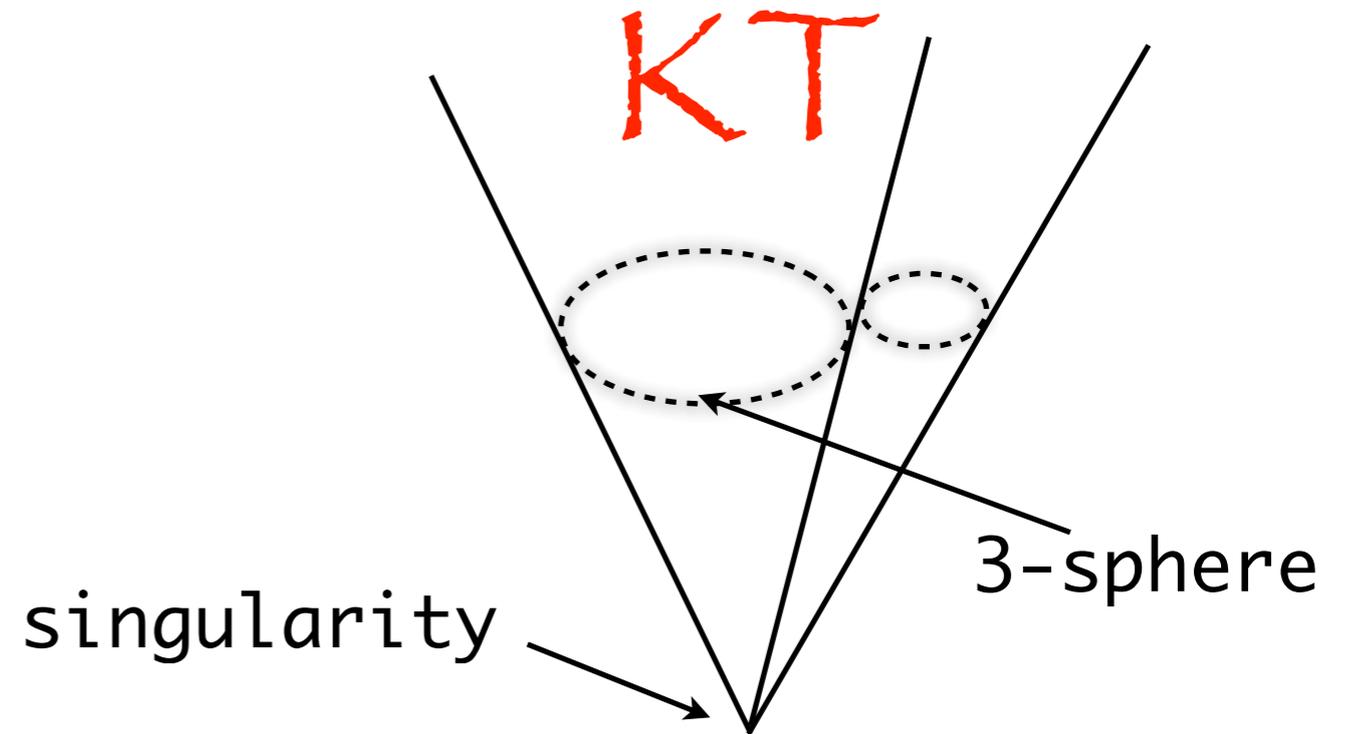
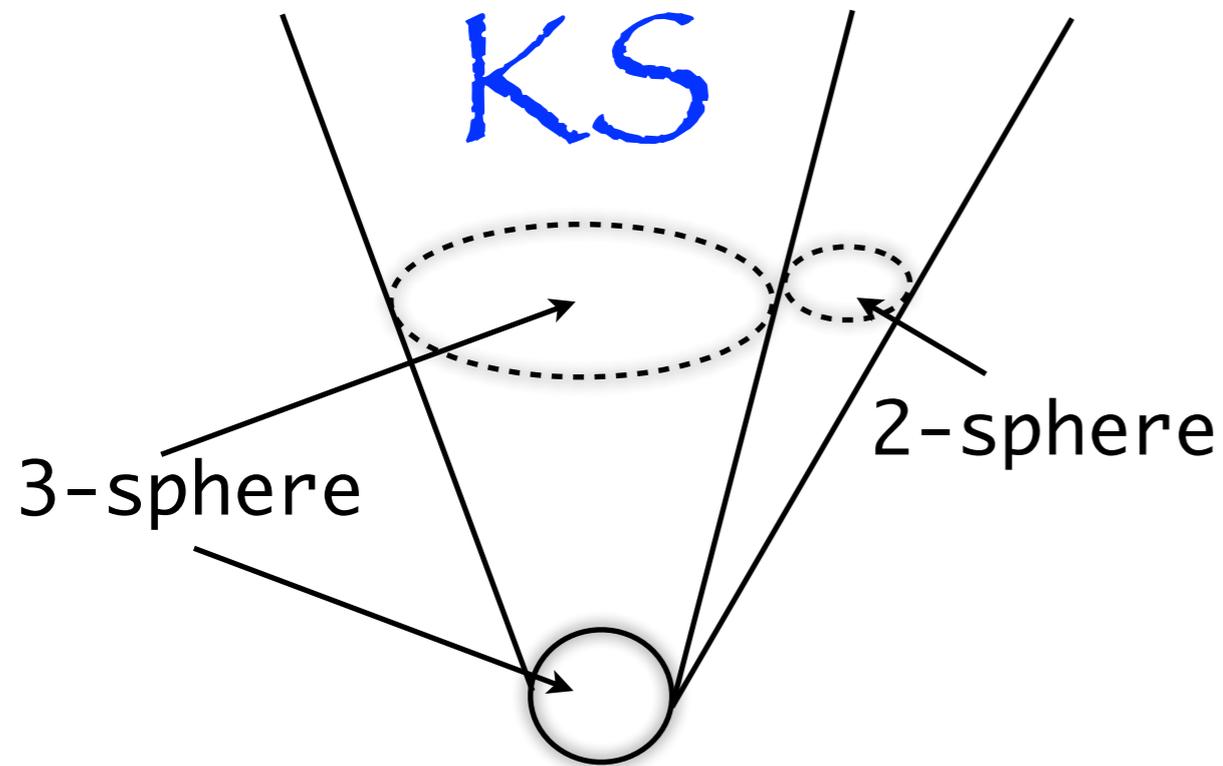
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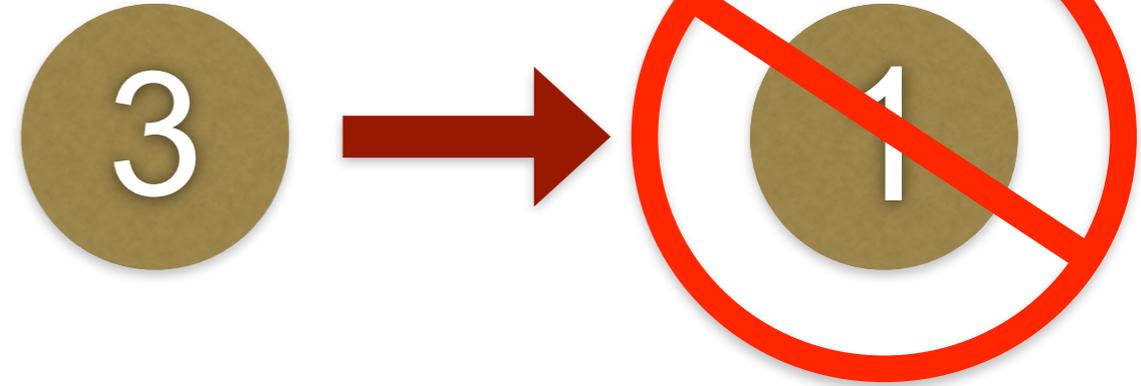


Bena, Dudaş, Graña, S. Lüst
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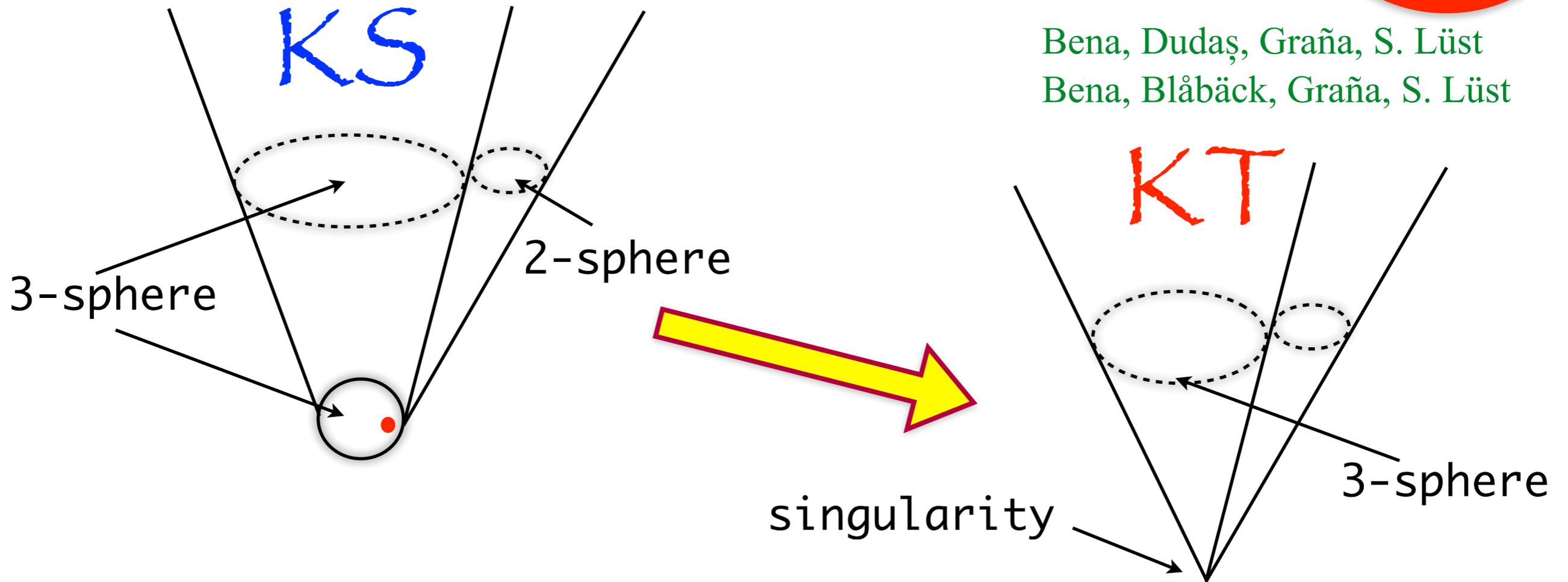


- 3-sphere size = conifold deformation modulus
- Fixed in flux compactification, flat in ∞ KS

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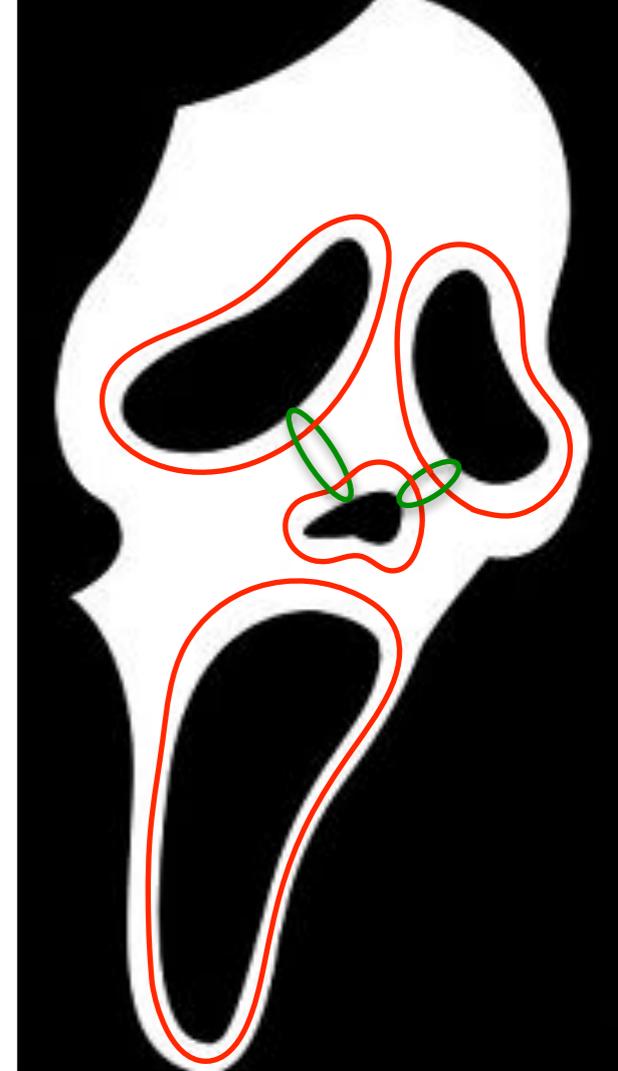


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- add energy $\Rightarrow \infty$ KS + anti-D3 $\rightarrow \infty$ KT

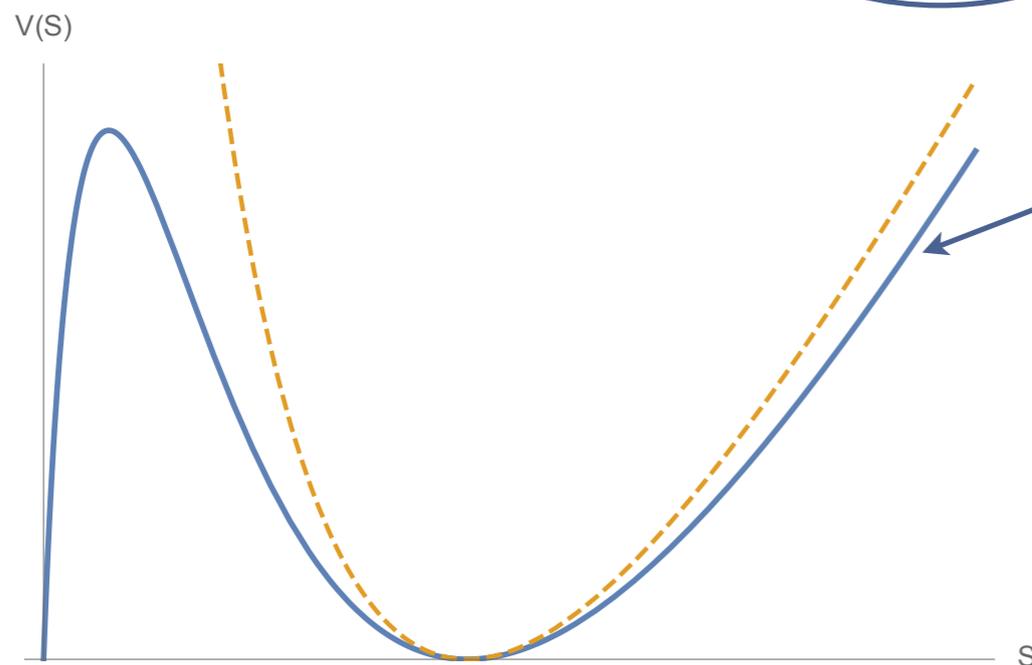
Stabilization in compactification



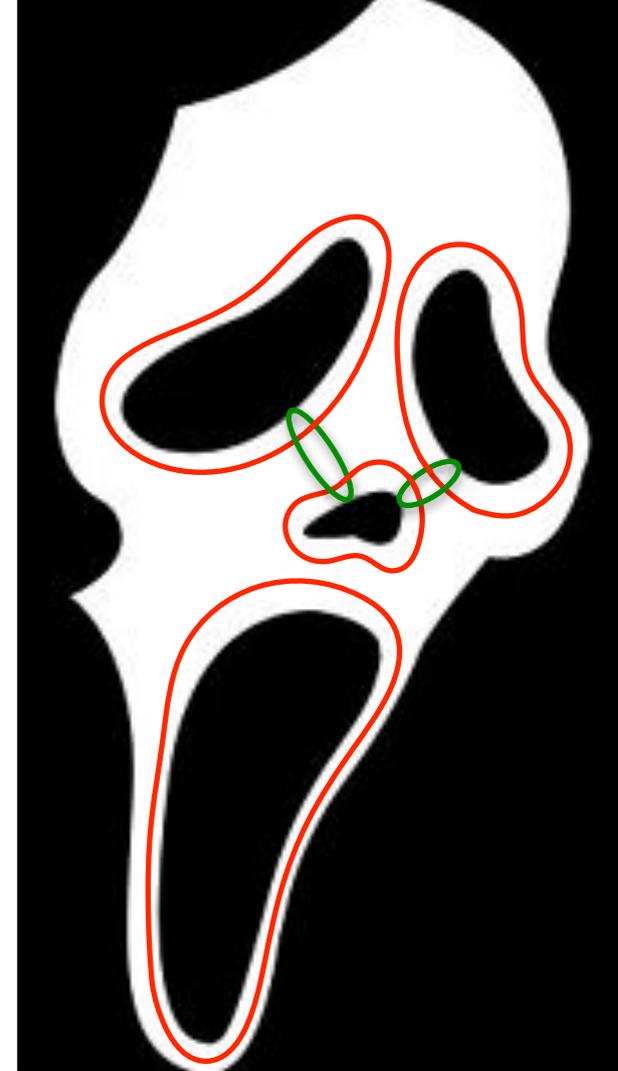
Stabilization in compactification

Douglas, Torroba

$$V_{KS} = \frac{\pi^{3/2}}{\kappa_{10}} \frac{g_s}{(\text{Im } \rho)^3} \left[c \log \frac{\Lambda_0^3}{|S|} + c' \frac{g_s (\alpha' M)^2}{|S|^{4/3}} \right]^{-1} \left| \frac{M}{2\pi i} \log \frac{\Lambda_0^3}{S} + i \frac{K}{g_s} \right|^2$$



Quantum
Correction

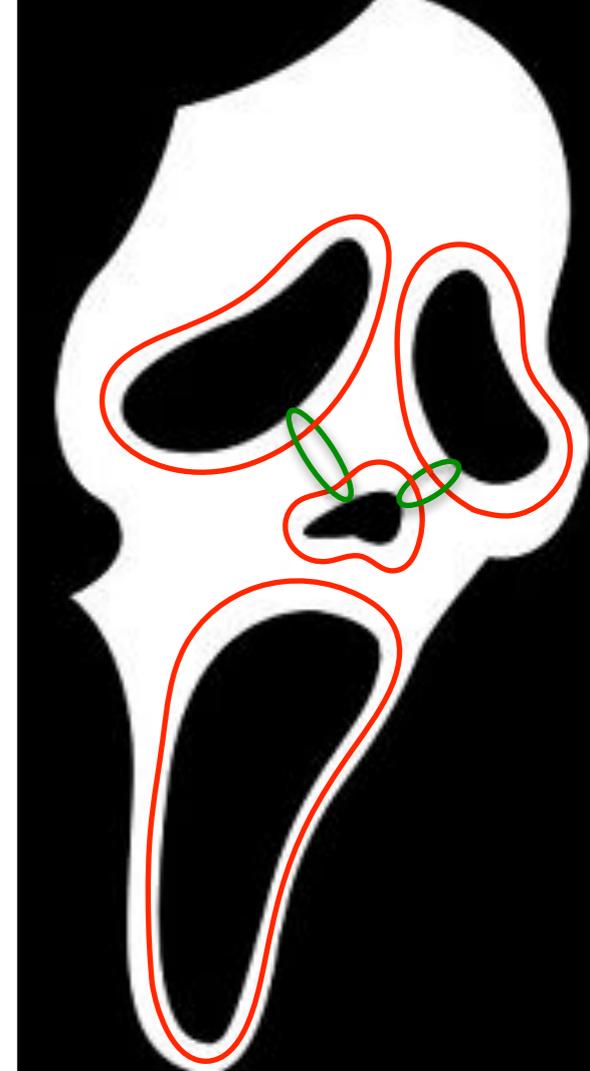
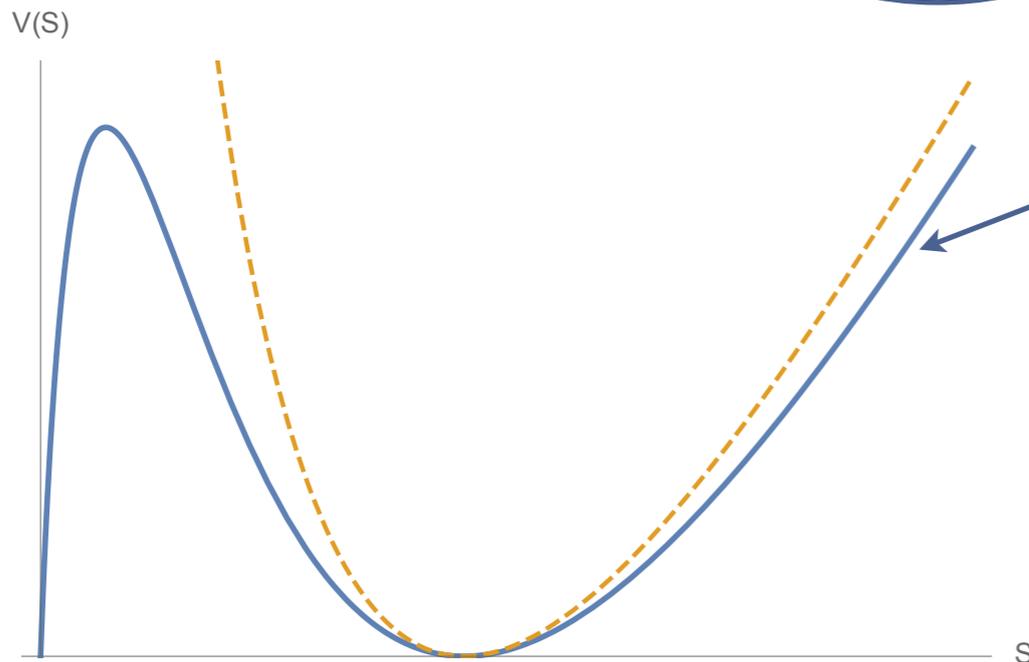


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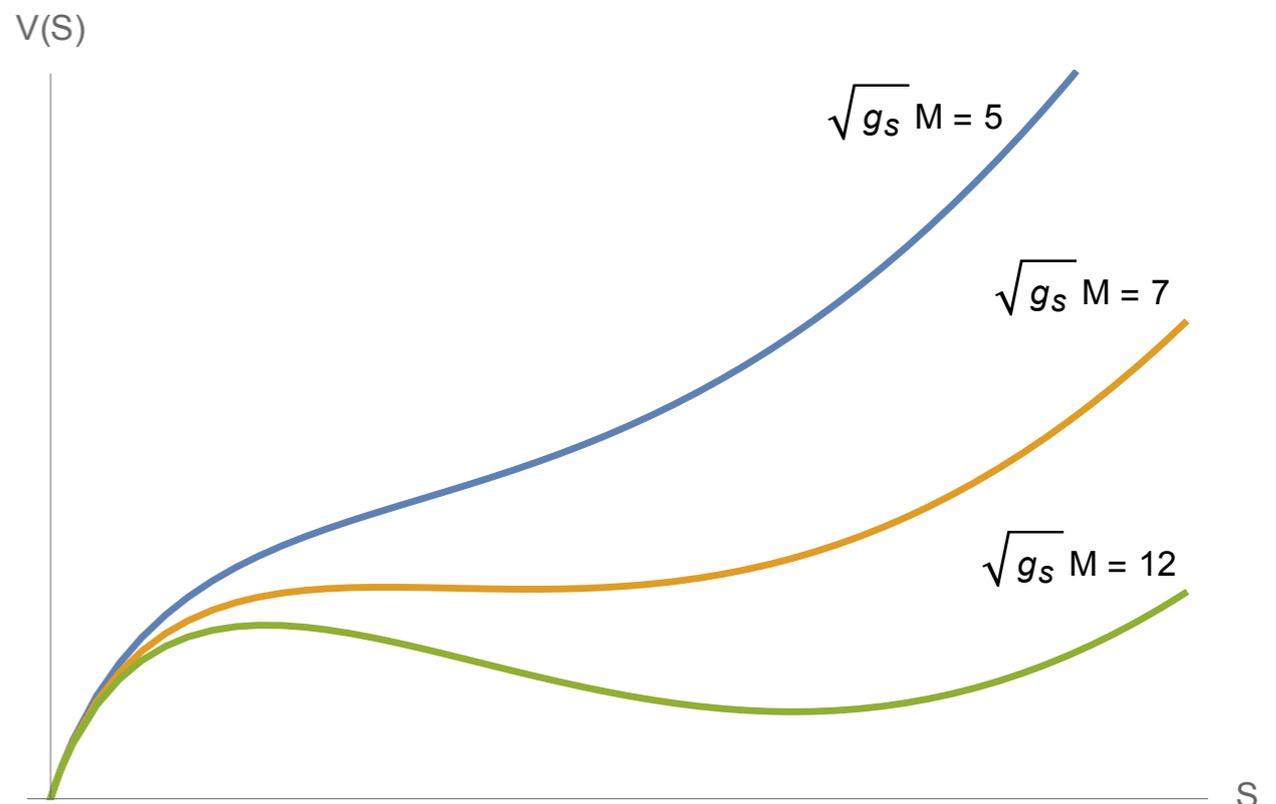
Quantum Correction



Add **single** anti-D3 brane:

$$V_{D3} = \frac{\pi^{1/2}}{\kappa_{10}} \frac{1}{(\text{Im } \rho)^3} \frac{2^{1/3}}{I(\tau)} \frac{|S|^{4/3}}{g_s (\alpha' M)^2}$$

Bena, Dudaş, Graña, S. Lüster



∞ KS throat
stable at large M !!!

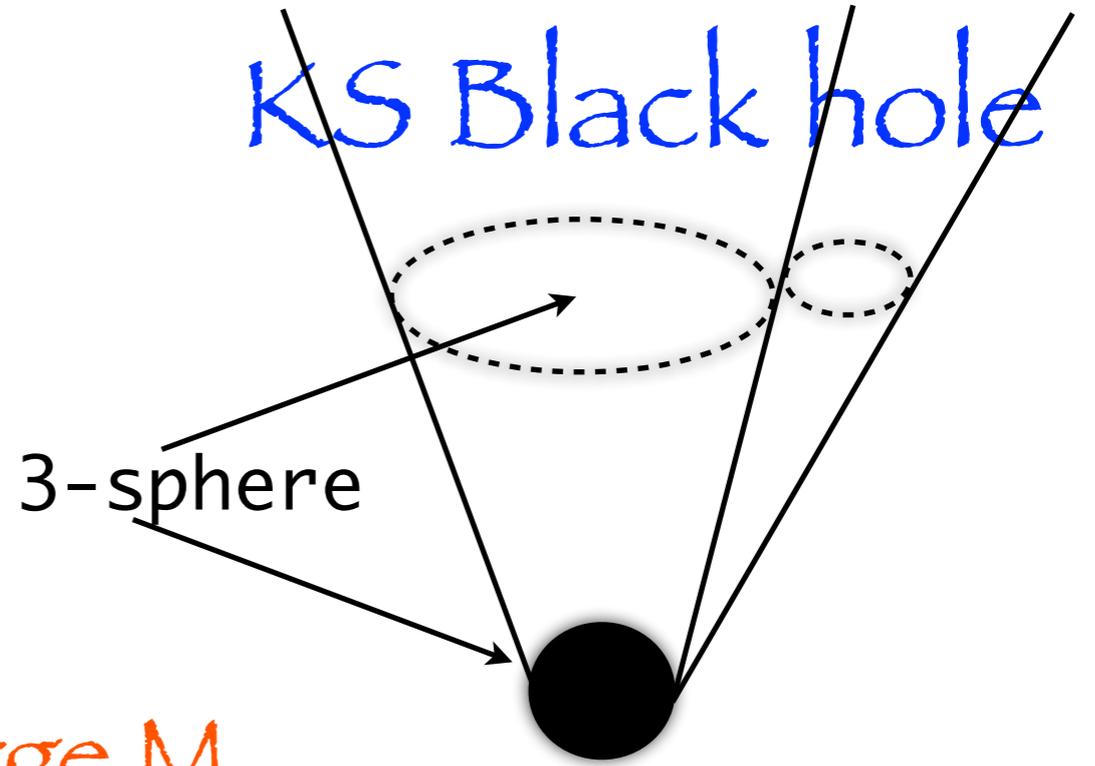
- few anti-D3 OK in ∞ KS at large M
- small BH horizon should also be OK \Rightarrow
- conjecture: \exists KS black hole

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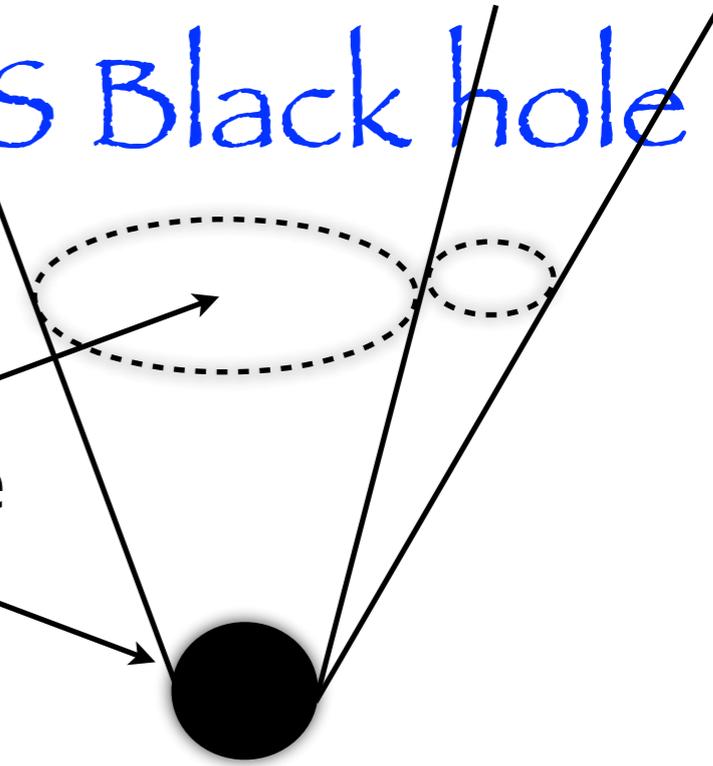
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3-sphere



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- Numerics confirmed!
- Deconfined, broken χ -sym phase of dual theory
- Similar range to metastable antibrane:

Buchel

Bena, Buchel, S. Lüst

$$\sqrt{g_s}M \geq \gamma \sqrt{N_{D3}} \quad \gamma_{D3} \approx 6.8 \quad \gamma_{BH} \approx 4.16$$

Flux compactifications

Runaway mode \leftrightarrow jaw becoming longer and longer

Bena, Dudaş, Graña, S. Lüst

Goes away if $\sqrt{g_s} M \geq 6.8 \sqrt{N_{D3}}$

Long throat (small uplift term)

\Rightarrow D3 charge dissolved in fluxes in the jaw **>500**

But total charge on compact space has to be zero !



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Lost 500 units of charge Master Calabi-Yau has ?
How embarrassing ? How embarrassing !

How to get **-500** units of charge ?

- O3 planes - at most **-32**
- D7 planes on 4-cycle S with huge Euler number: $\chi(S)/24$
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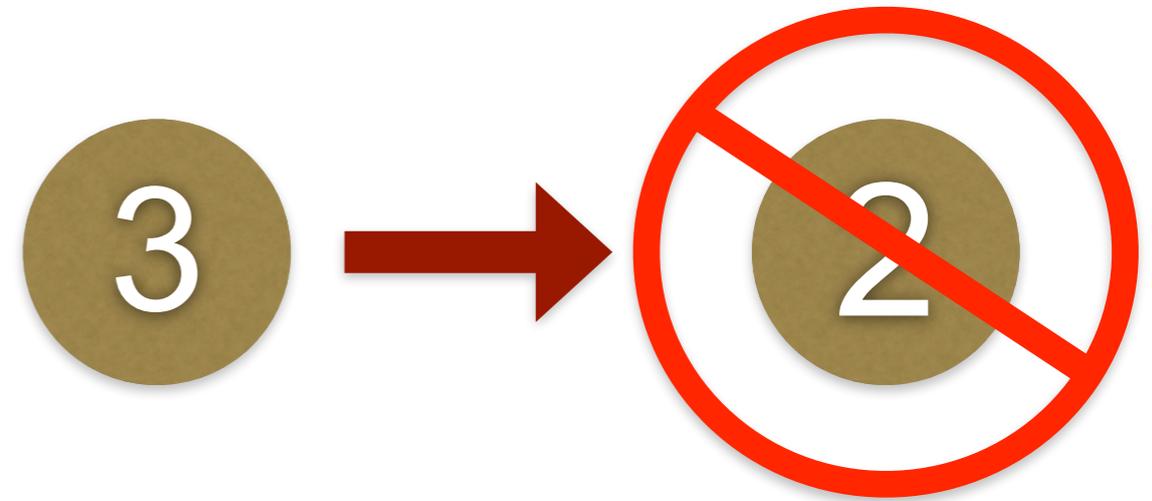
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- **Tadpole** of fluxes that stabilize (3,1) moduli **$> \chi(CY_4)/18$**
- Cannot stabilize all moduli with tadpole **-500**.
- KKLT uplift to get de Sitter does not work ! **Tough luck !**

The calculations

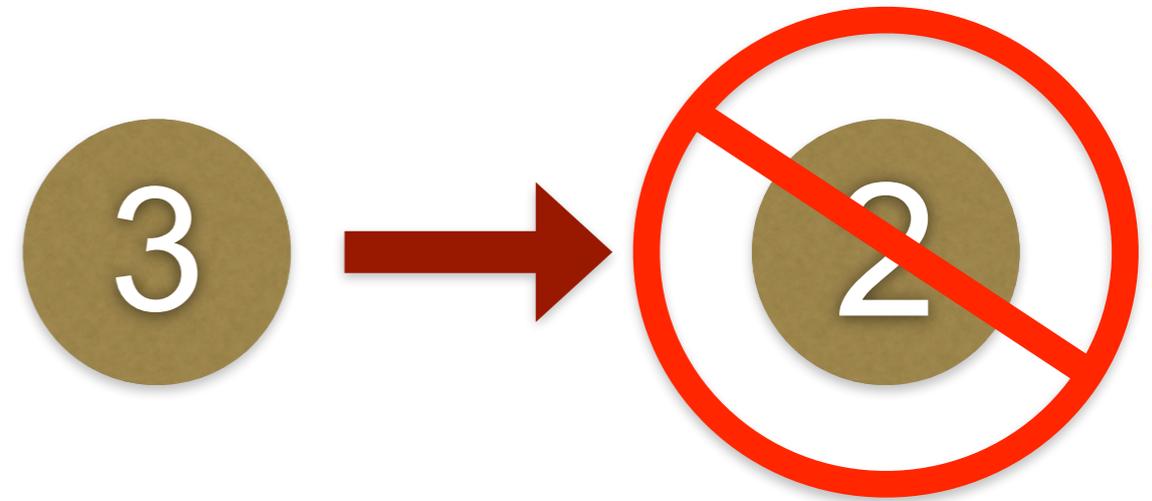
Kähler moduli stabilization



Moritz, Retolaza, Westphal
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in progress

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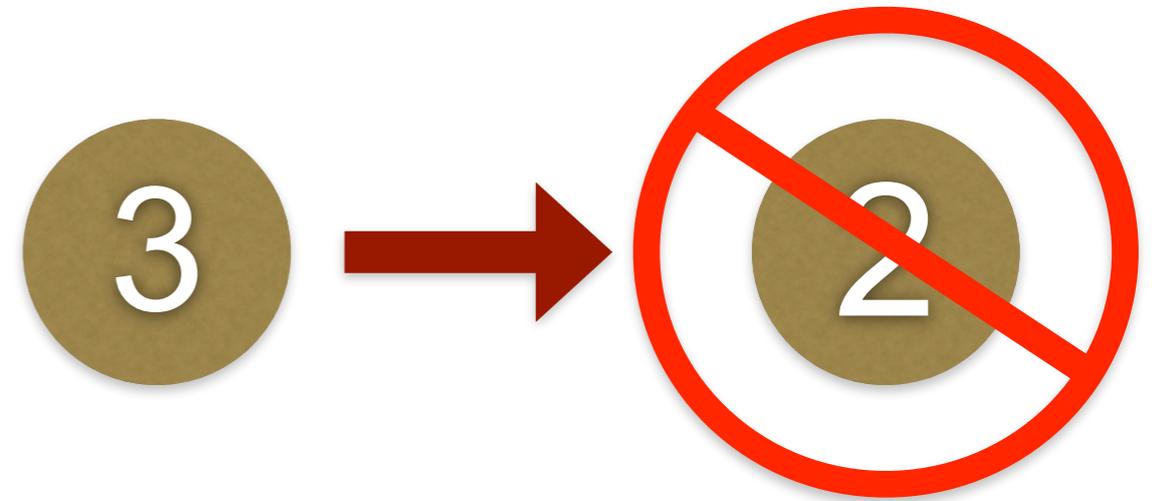
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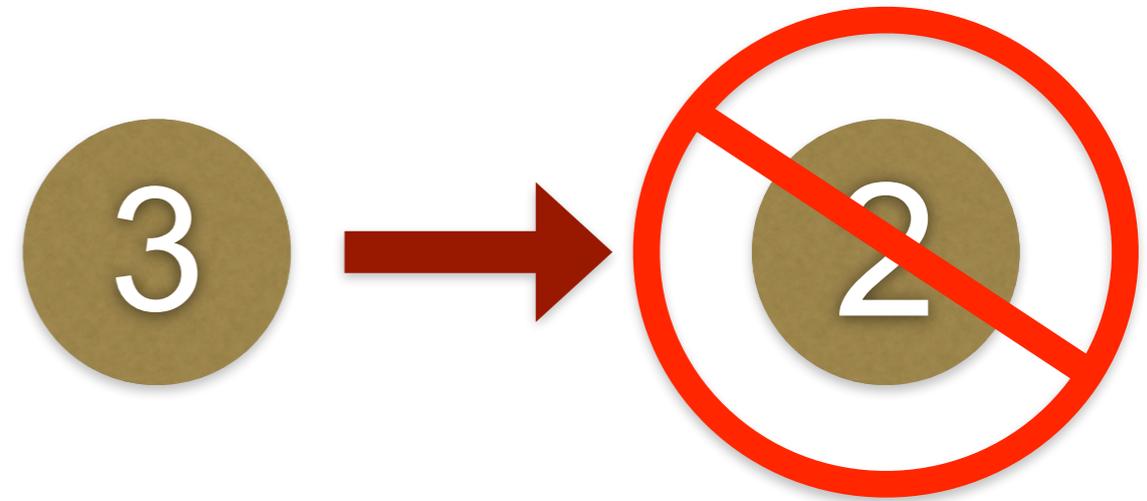
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D7 branes on 4-cycle:

4D massless $N=1$ theory: confinement with
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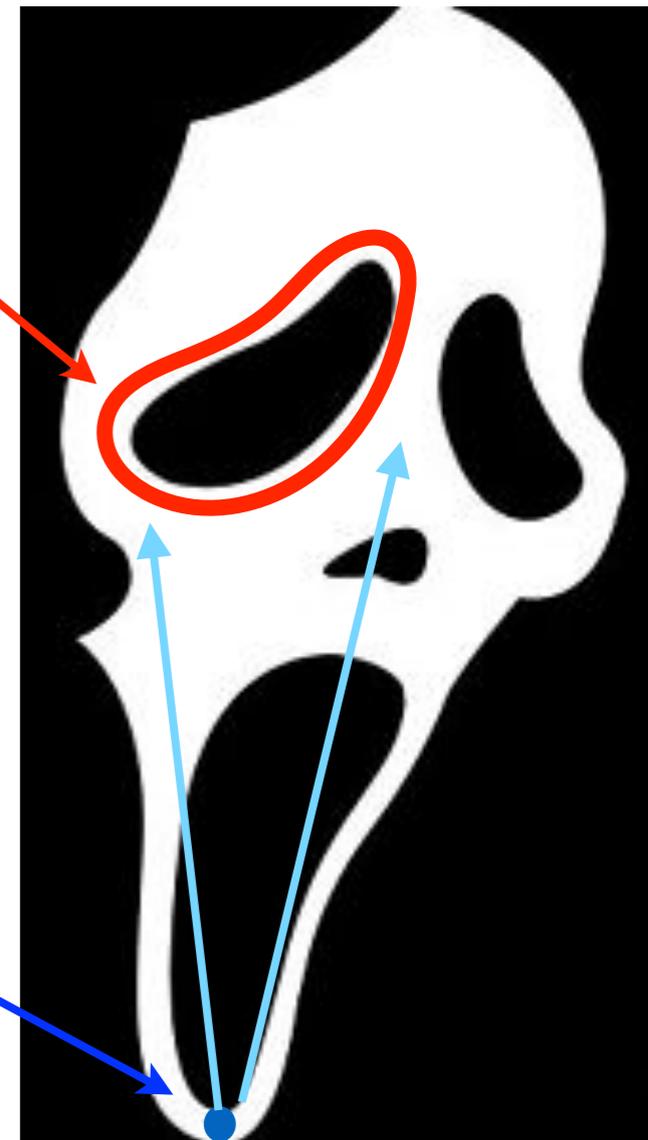
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Anti-D3

induce **fluxes** that make 4D $N=1$ theory **massive**
confines at **scale of the mass**
independent of 4-cycle size - **not stabilized !**



Lesson about “*intuition-based*” claims about validity of de Sitter landscape

- ◆ Crucial to distinguish between **hard calculations** and **wishful thinking** or **moving goalposts**
- ◆ **US \$** versus **Zimbabwe \$**
- ◆ pro-KKLT de Sitter **goalposts** moved from
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 - ◆ “ $g_s N_{\text{anti}D3} \ll 1$ is OK” 2012
 - ◆ “a single anti- $D3$ is OK” 2015
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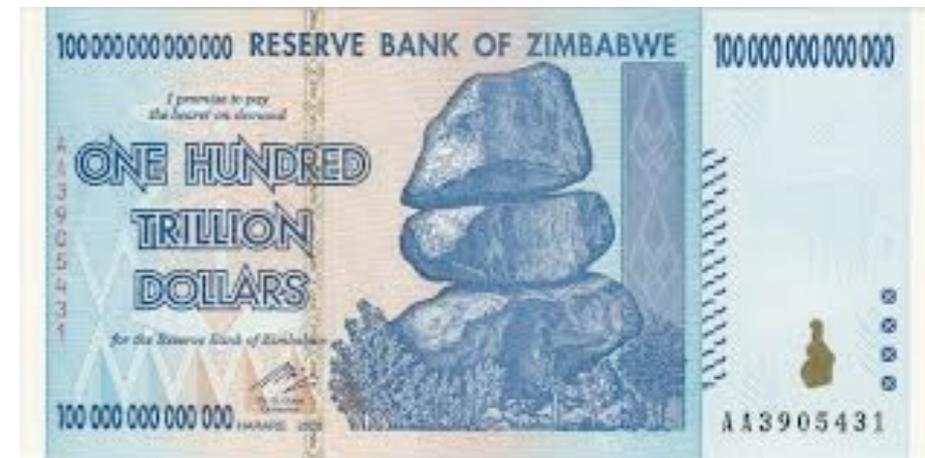
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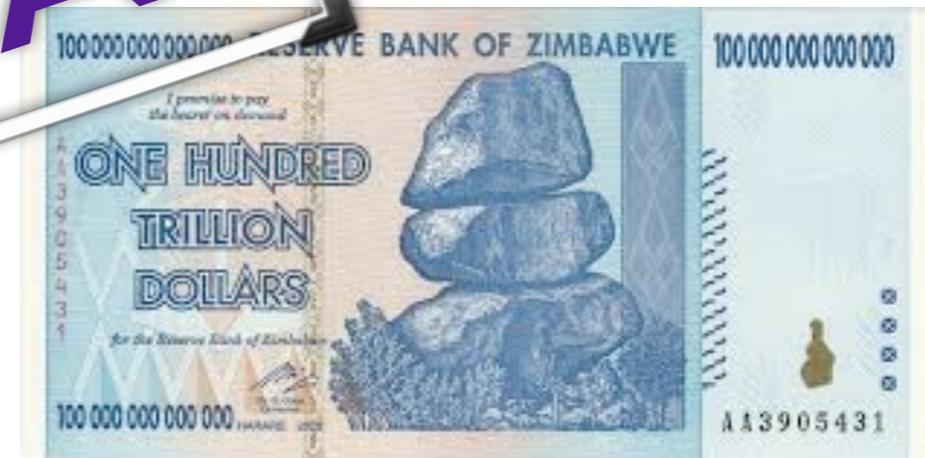
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SCAPEZILLA

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- Back to drawing board in String Cosmology
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Where
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