SUSY Breaking on DGKT Domain Walls

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In collaboration with Miguel Montero
[2412.00189]

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DGKT is a proposed 4d N=1 AdS vacuum from massive IIA which has **scale separation**

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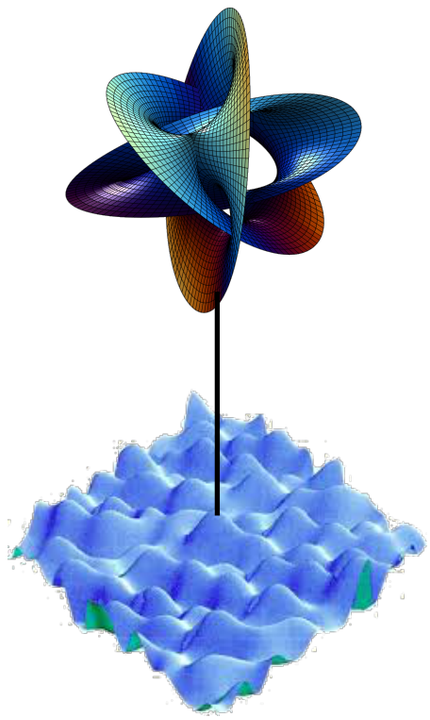
which will be shaped by the SUSY breaking on its domain walls

AdS Scale Separation

All string theory examples are of the form $AdS_d \times X_n$



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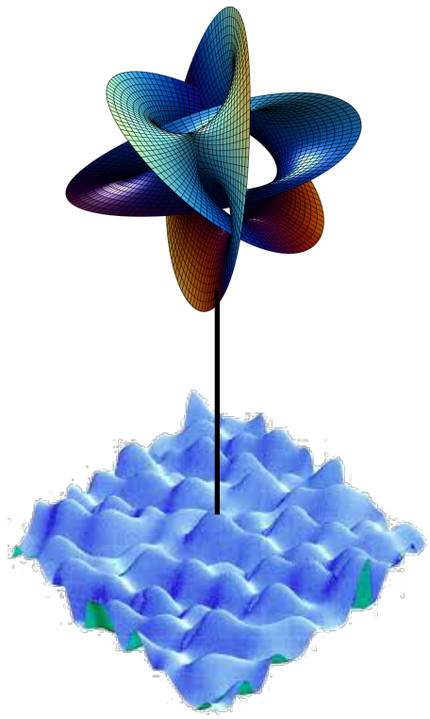

Internal space l_{KK}

AdS space l_{AdS}

Can we have small extra dimensions in AdS vacua? $l_{AdS} \gg l_{KK}$

Otherwise, it does not describe low dimensional physics

AdS Scale Separation in $d \geq 4$

All proposed candidates for scale-separated (stable) vacua from the bulk perspective are 4d N=1: DGKT, KKLT, …

Not known CFT dual yet, under debate whether they are consistent top-down string constructions,…

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Let's try to shed some light on this debate!

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Result: DGKT is in tension with WGC for domain walls

and any other N=1 4d AdS vacuum without parity symmetries

Reason:

Too little SUSY to guarantee domain walls to remain BPS at quantum level

Quantum corrections will render all membranes non-BPS

DGKT vacuum

[De Wolfe, Giryavets, Kachru, Taylor '05]

[Camara, Ibanez, Uranga '05]

4d N=1 AdS vacuum arising from compactifying massive Type IIA on a CY3 with O6-planes and fluxes for

$$F_0, F_4, H_3 \quad \Rightarrow \quad \text{AdS4xCY3}$$

There is one **unconstrained flux** that does not appear on the tadpole:

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By solving the 4d eoms, one finds a family of AdS vacua with

$$V_0 \sim N^{9/2}$$

$$m_{\rm KK}^{-2} \sim L_{\rm KK}^2 \sim N^{7/2} \quad \Rightarrow \quad \left(\frac{\ell_{AdS}}{L_{KK}}\right)^2 \sim N$$

So this solution is **scale-separated** in the large N limit.

DGKT vacuum

The consistency of the solution is not clear because we only solved **4d equations of motion** (zero mode of 10d eoms on CY3)

Lot of recent progress, everything seems fine so far, but no conclusive answer.

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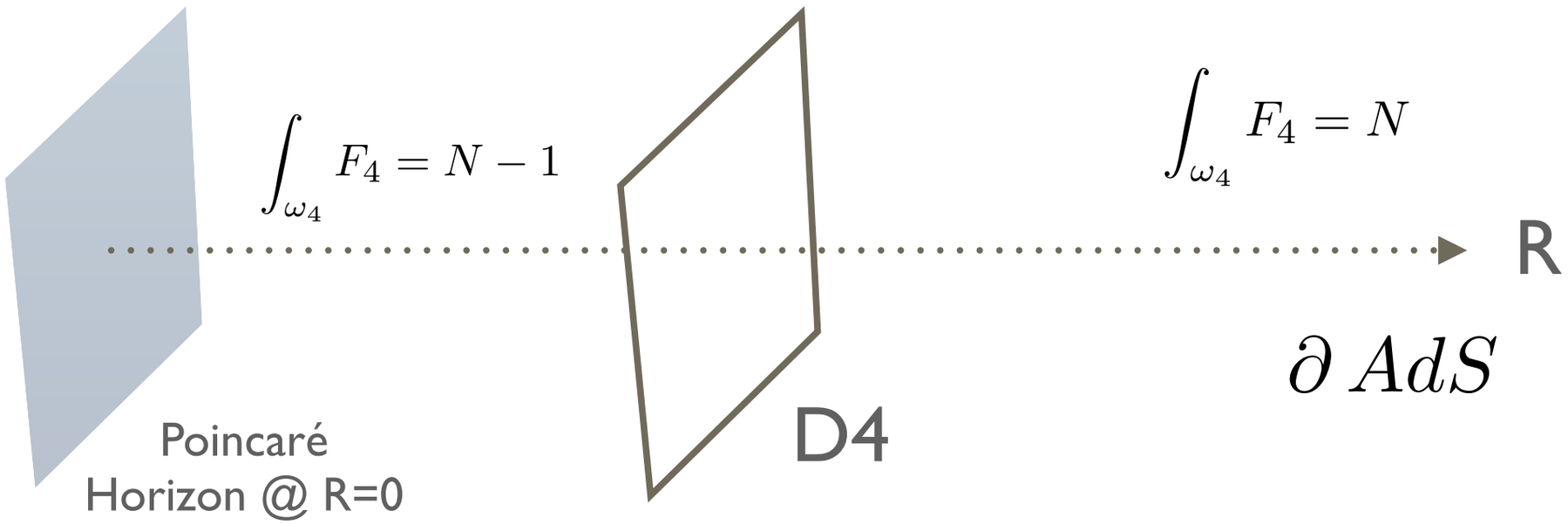
We will assume everything is OK, and study the fate of branes on DGKT vacuum, to perform a non-perturbative consistency check

(i.e. whether it is protected against non-perturbative brane instabilities)

[Montero, Valenzuela '24]

Test of DGKT vacuum

Consider a D4-brane wrapping a holomorphic 2-cycle dual to the large N flux $\int_{\omega_4} F_4 = N$



Dynamics governed by $V(R) = (T - q)\frac{R^3}{\ell^3_{AdS}}$

Three options:

1) $T = Q$

2) $T < Q$

3) $T > Q$

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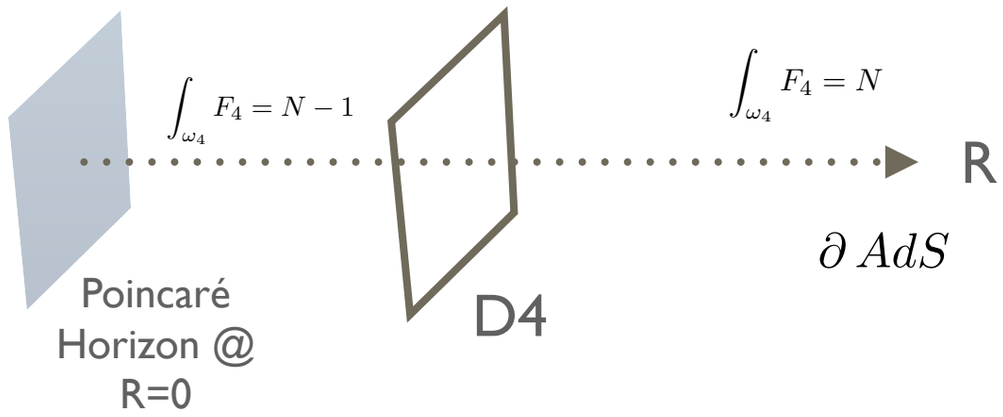

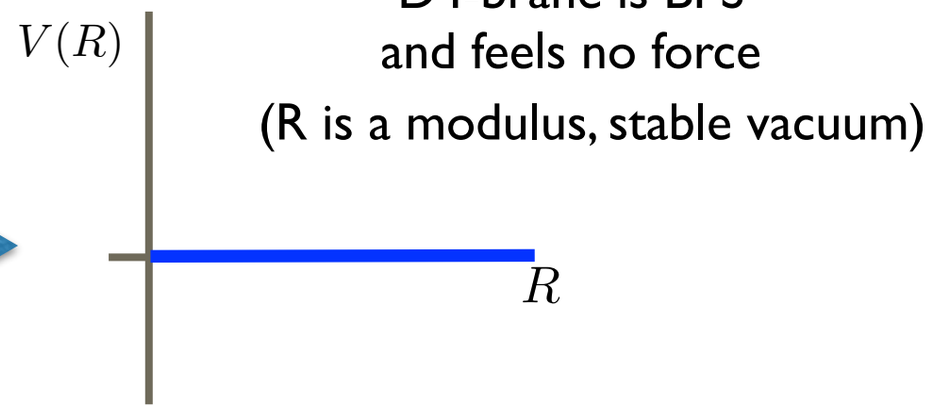

D4-brane is BPS
and feels no force
(R is a modulus, stable vacuum)

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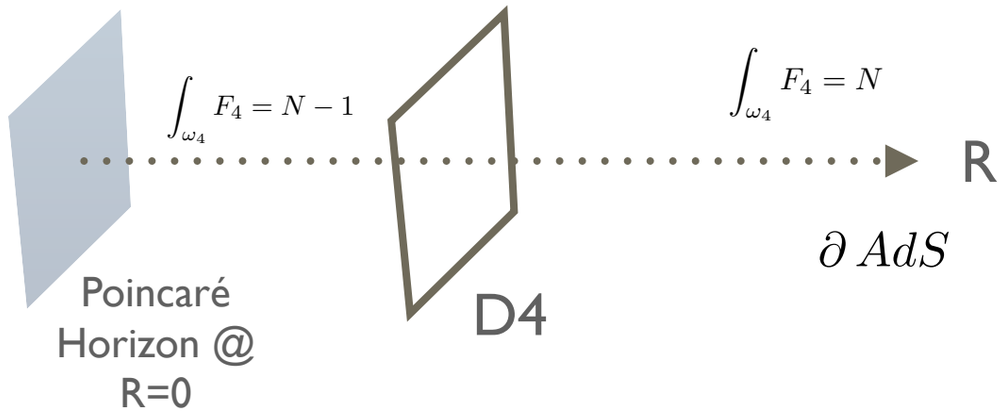

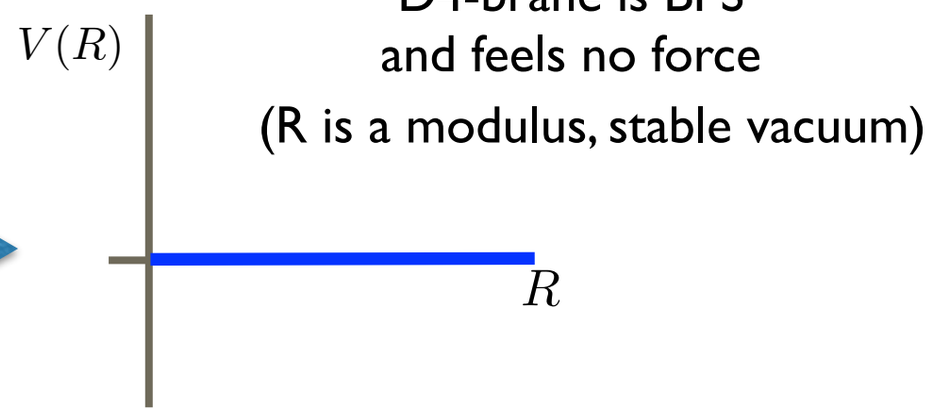

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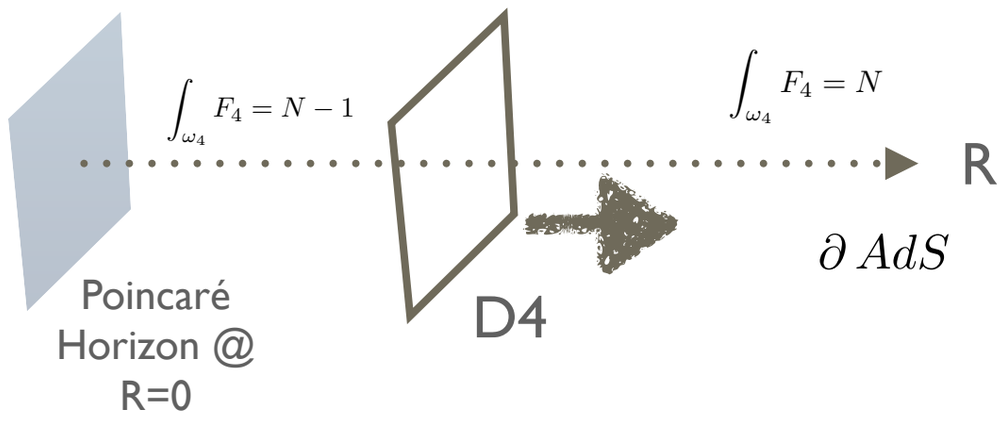

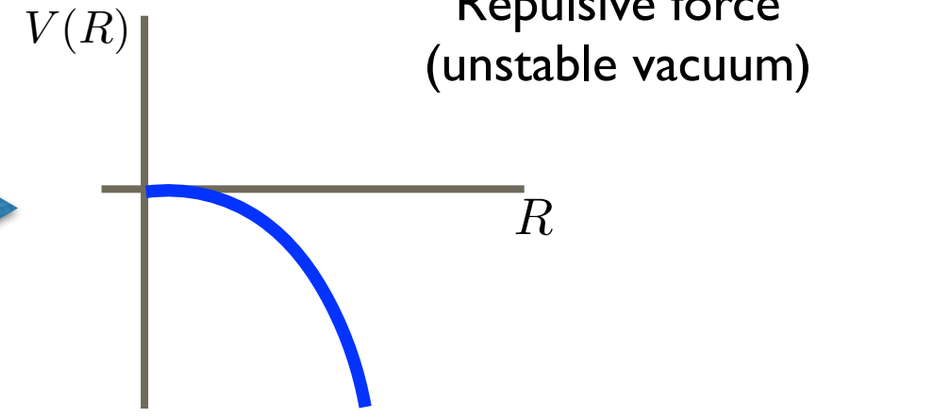

Repulsive force
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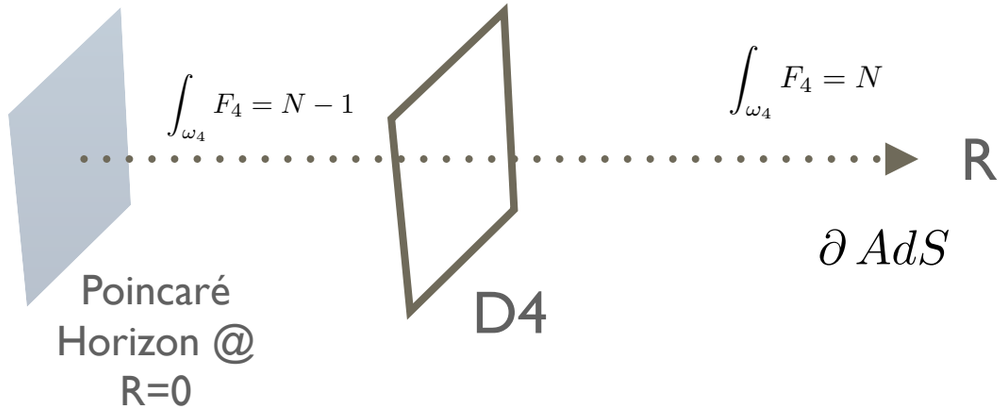

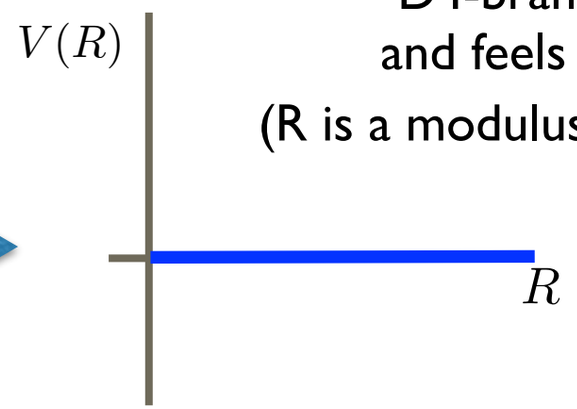

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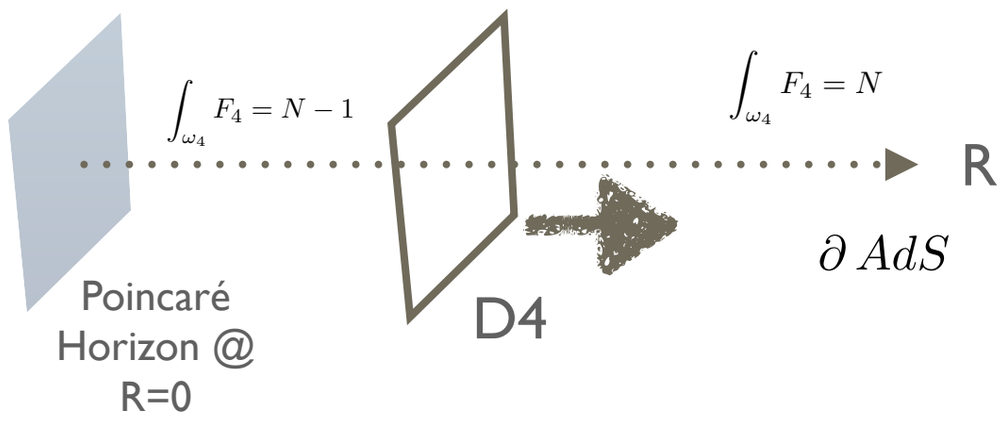

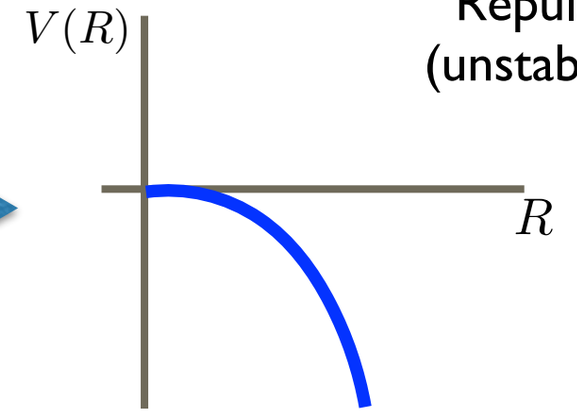

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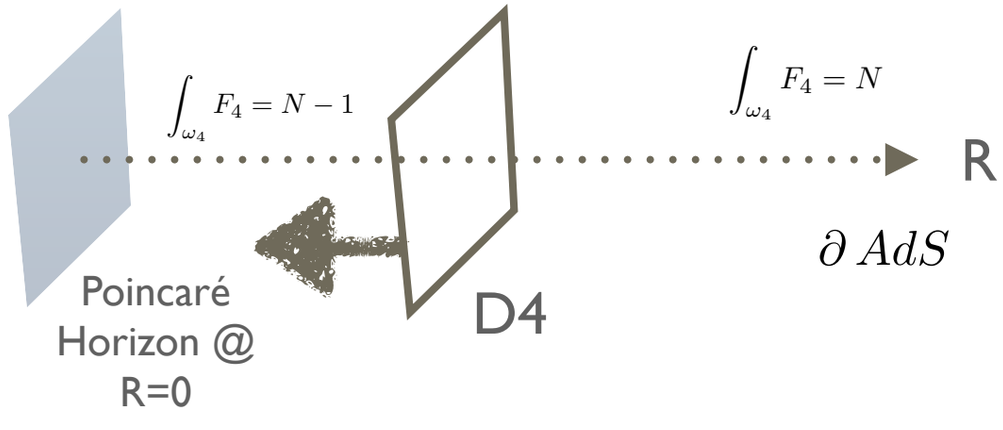

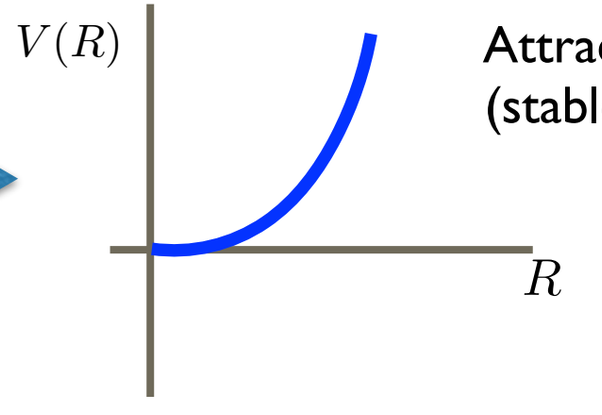

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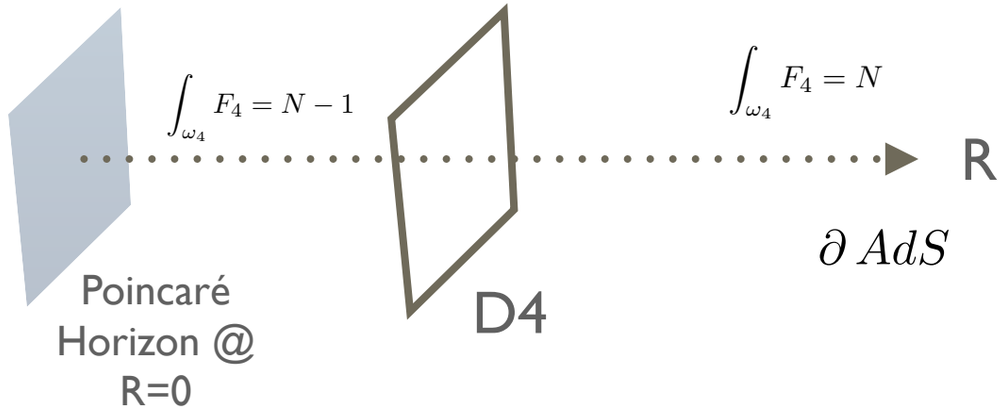

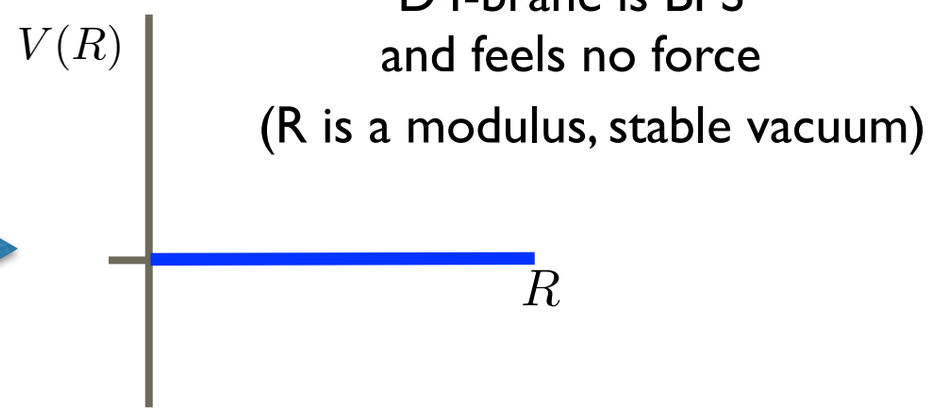

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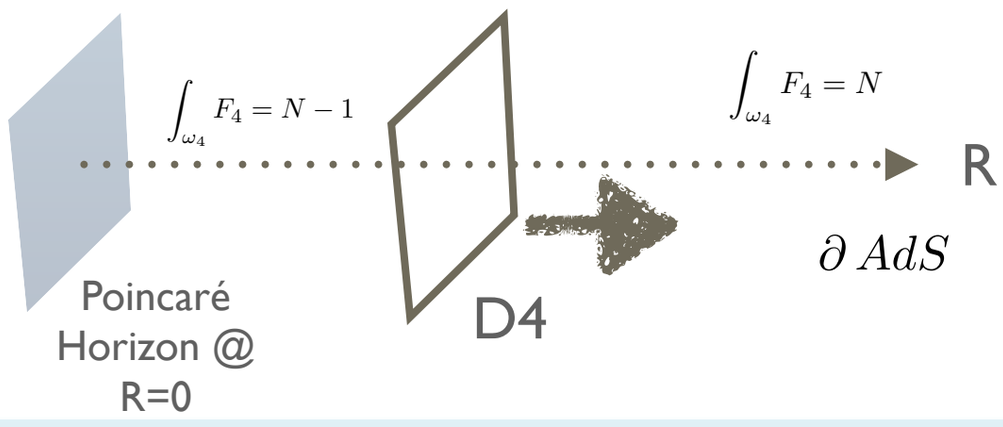

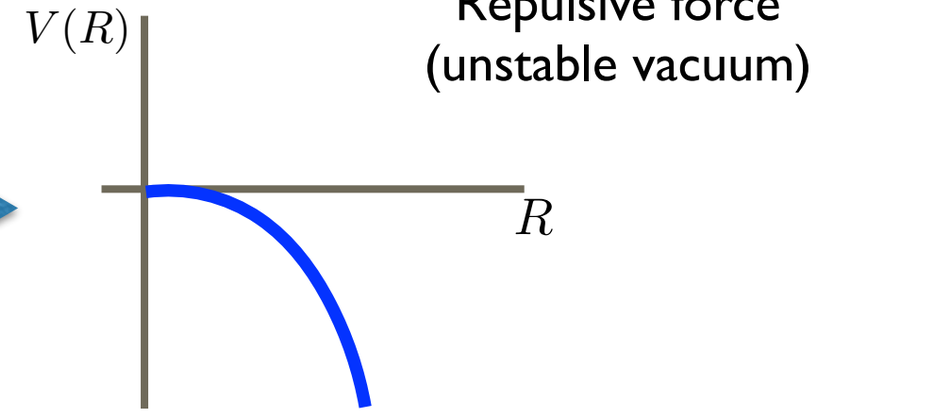

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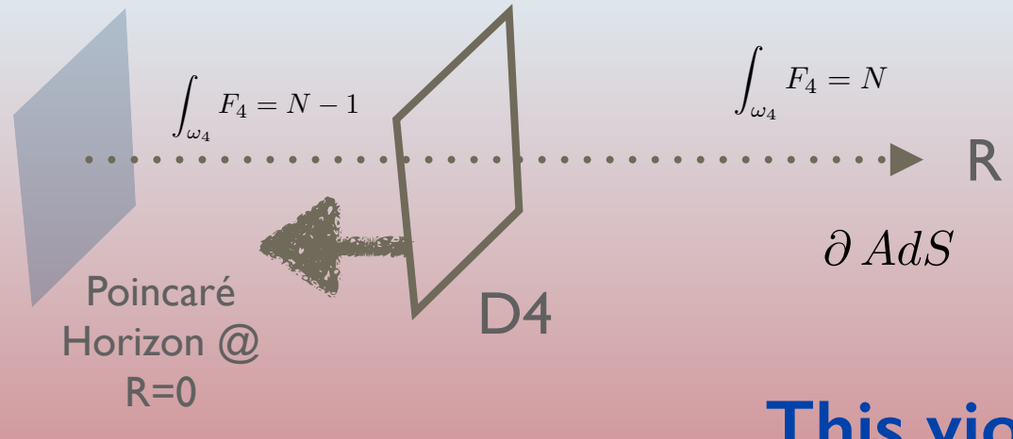

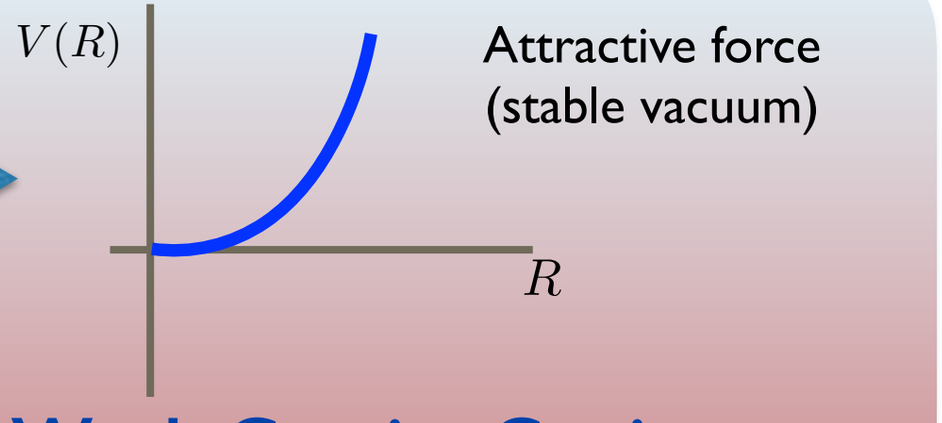

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This violates Weak Gravity Conjecture

Expectation from WGC

Given a p-form gauge field, WGC requires:

$\exists$ (p-1)-brane with $\frac{T}{Q} \leq \left.\frac{T}{Q}\right|_{BH}$ (in Planck units) [Arkani-Hamed et al.'06]

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For codim-1 branes, there is no BH extremality bound

Instead, WGC defined in terms of repulsive force condition:

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[Lee et al'18] [Heidenreich et al'19] [Gendler'20]
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Consider an AdS vacuum supported by fluxes in the internal dimensions:

WGC: $T \leq Q$

(tension) $\leq$ (charge)

Implication: non-SUSY AdS vacua with internal fluxes are mestastable

[Ooguri, Vafa'18]

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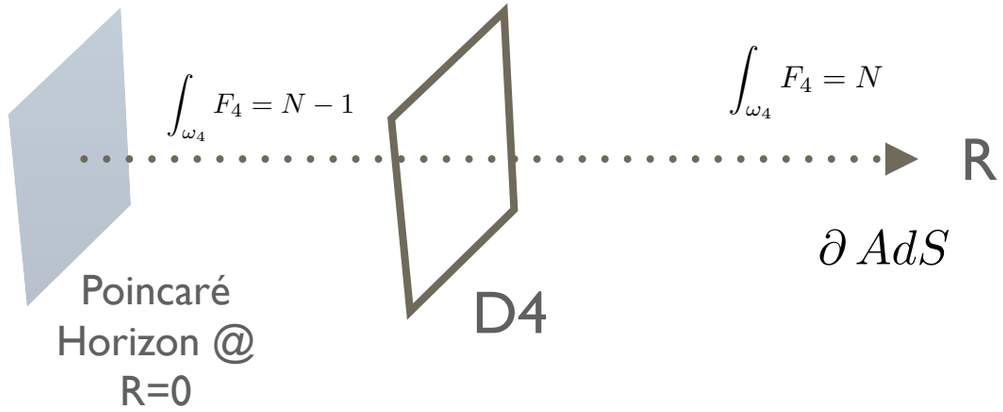

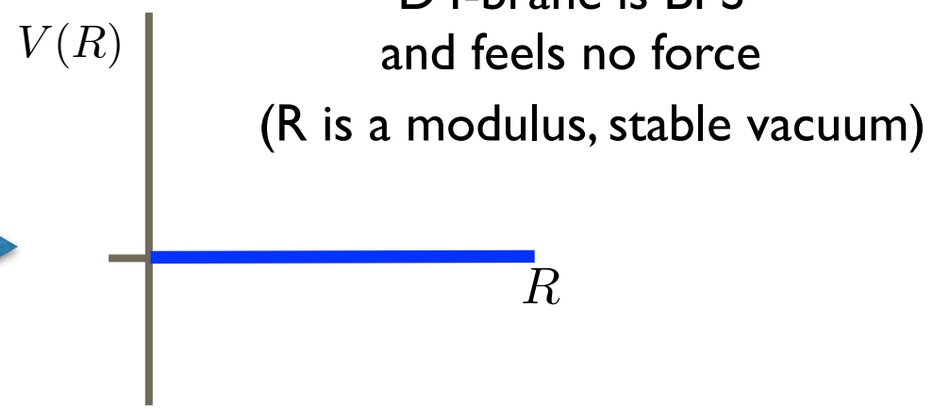

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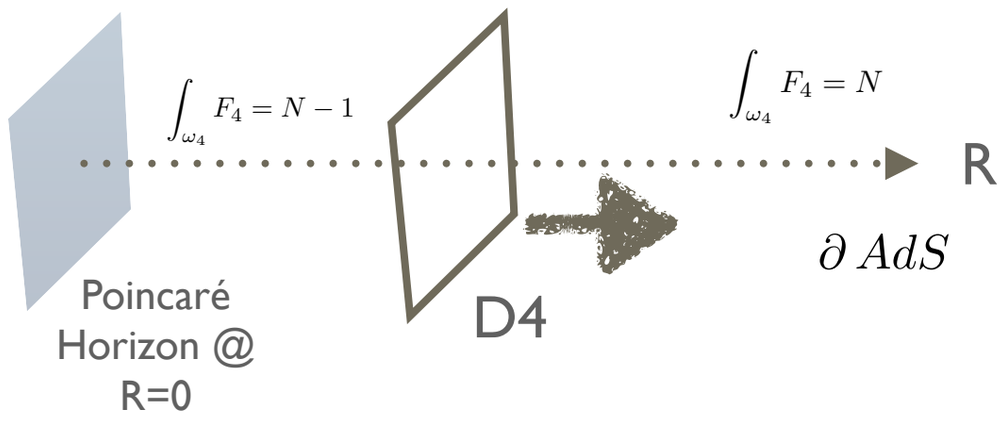

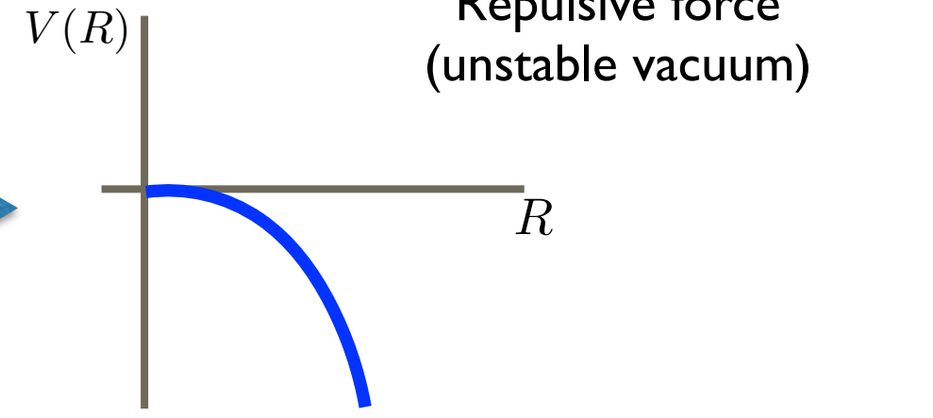

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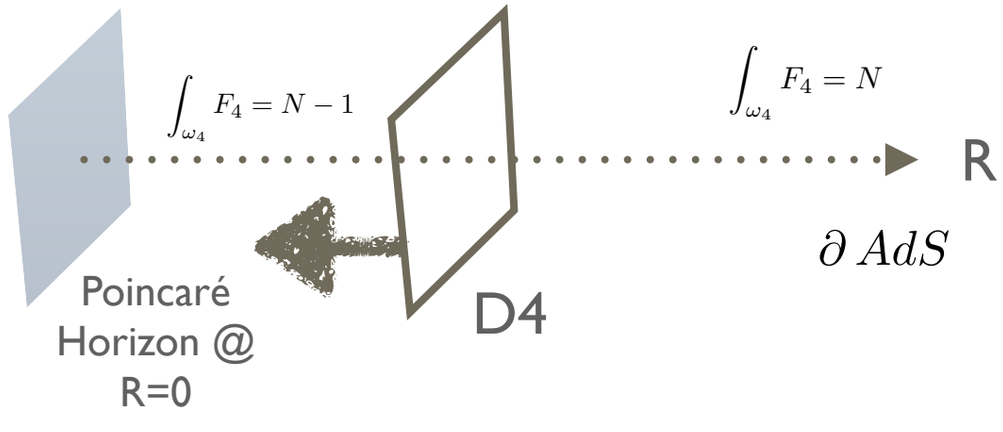

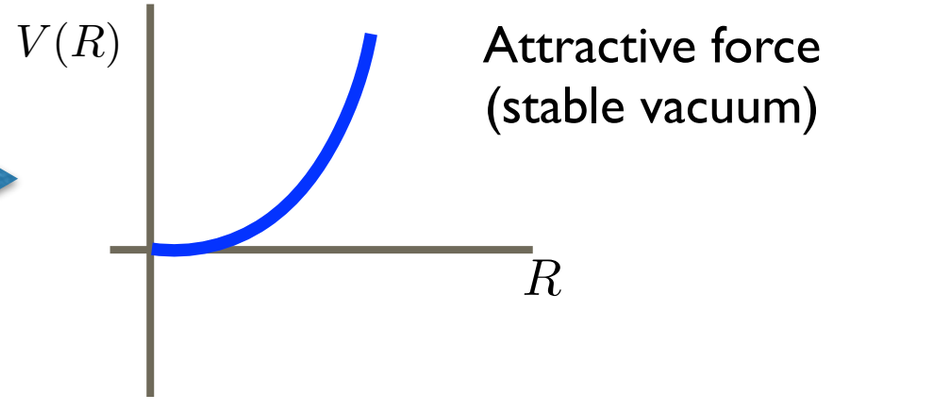

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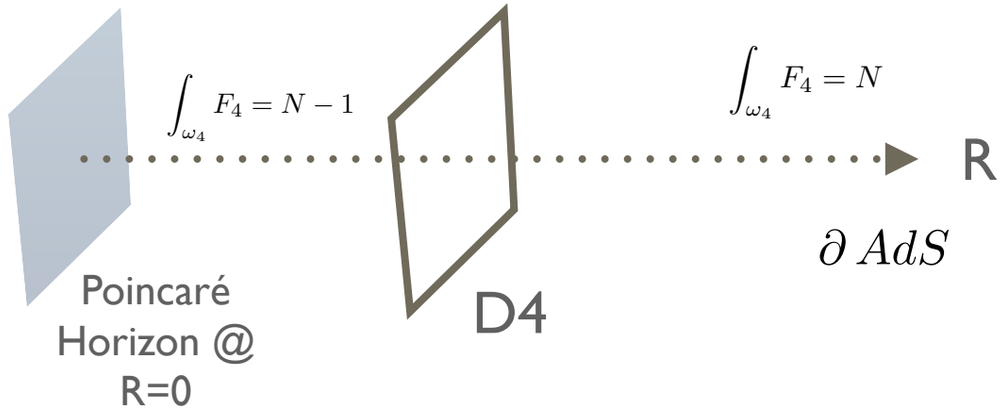

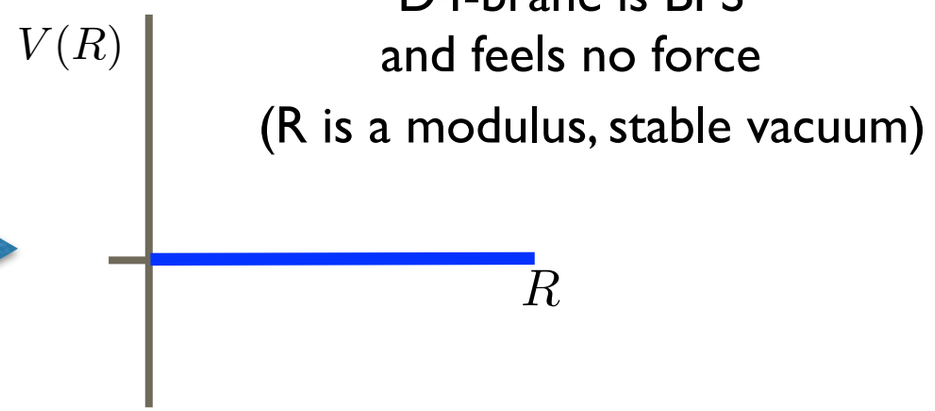

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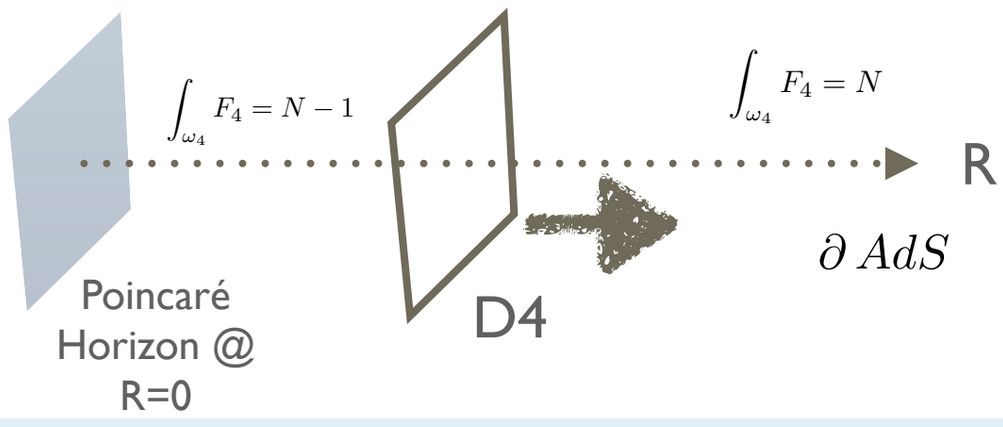

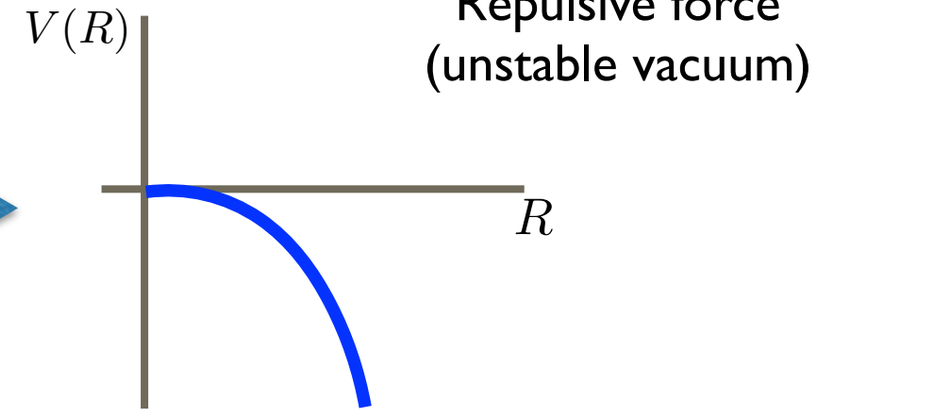

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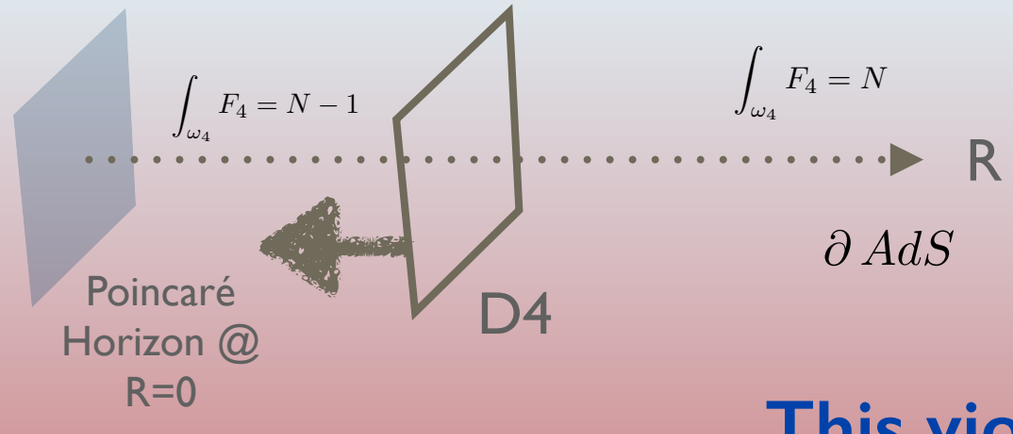

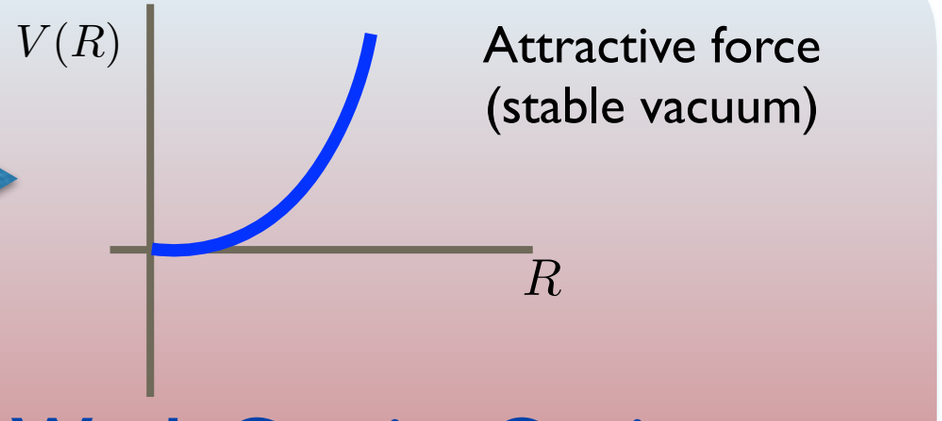

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What is the case of DGKT?

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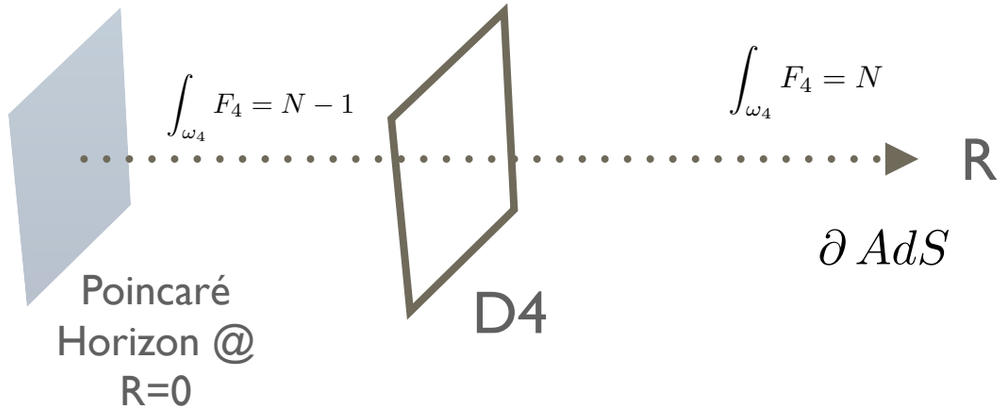

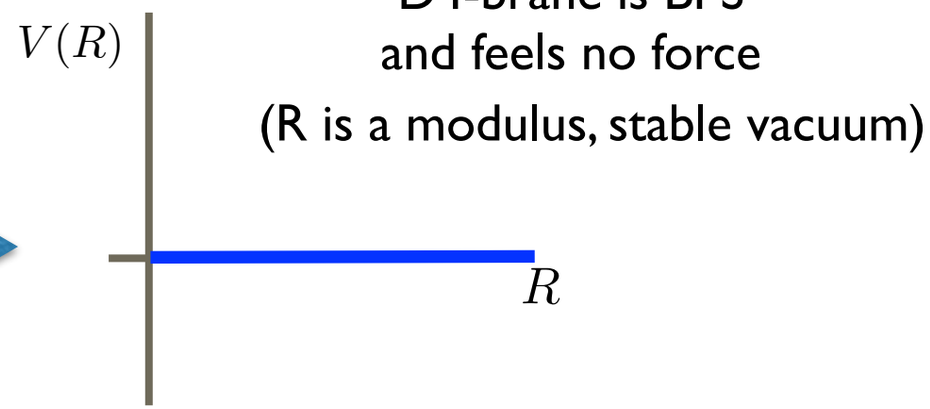

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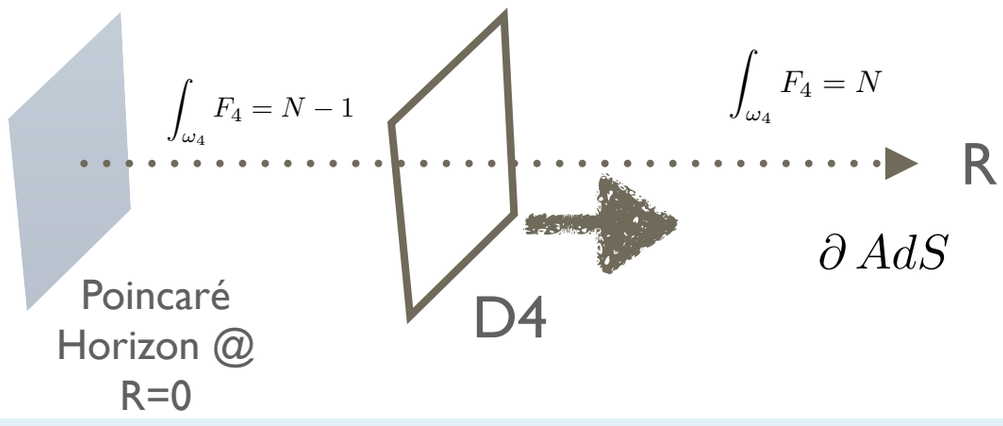

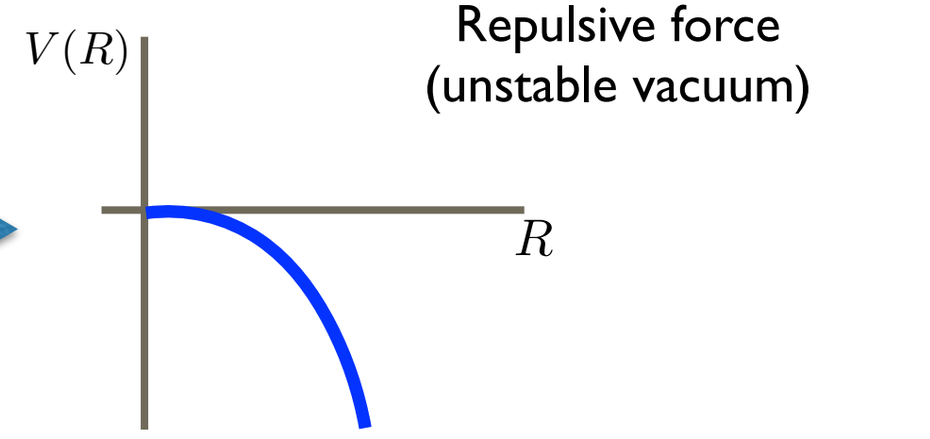

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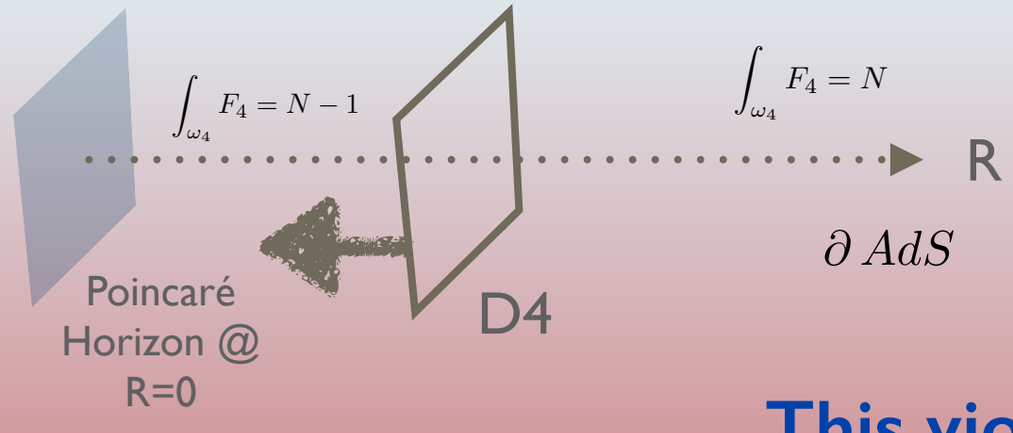

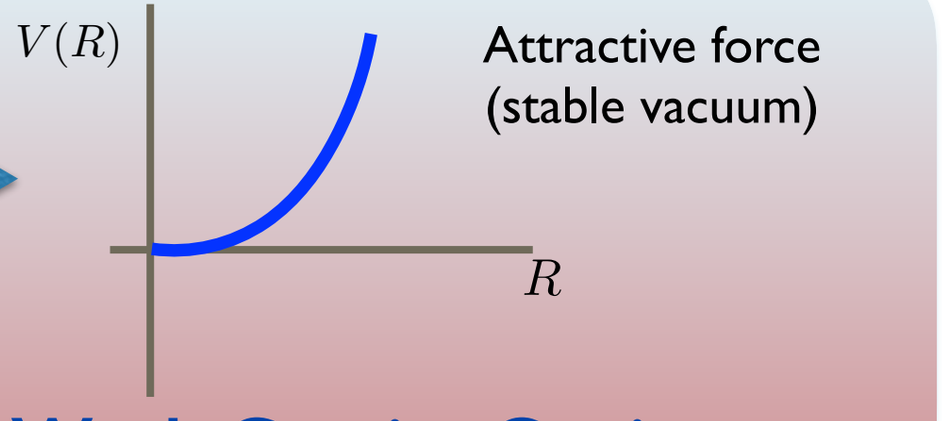

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3d N=1 theories

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e.g. 4d N=1 AdS from M-theory on $AdS_4 \times G_2^{weak}$ with $\int_{G_2^{weak}} G_7 = N$

[Forcella, Zaffaroni '09]

Preserves Pin+ symmetry of M-theory ⟶ it has a moduli space

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By explicit computation, we show that a superpotential is generated

(SUSY is broken spontaneously on the brane)

→ the position of D4-brane is not a modulus

Brane dynamics in DGKT

Consider the original DGKT solution:

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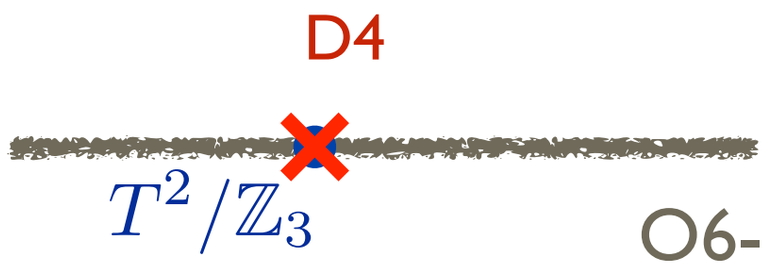
Brane	T	X_1	X_2	R	$\mathrm{Re}(z_1)$	$\mathrm{Im}(z_1)$	$\mathrm{Re}(z_2)$	$\mathrm{Im}(z_2)$	$\mathrm{Re}(z_3)$	$\mathrm{Im}(z_3)$
$D4$	–	–	–	×	–	–	×	×	×	×
$O6$	–	–	–	–	–	×	–	×	–	×

Instanton corrections

Brane on orbifold singularity:



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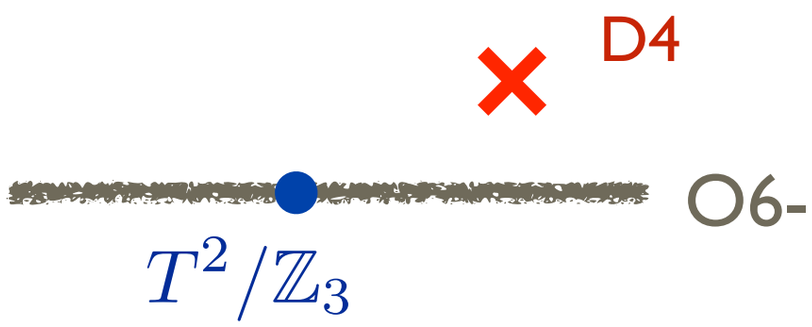

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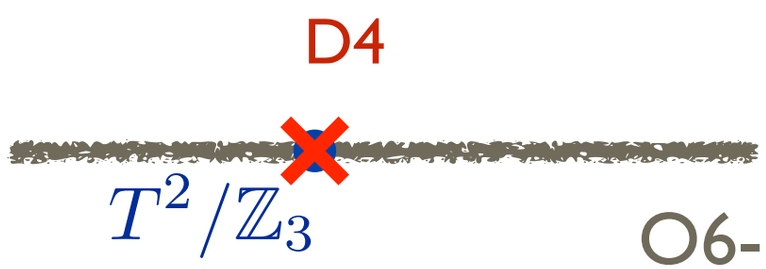

3d N=1 pure SU(2) + scalar for gauge coupling

This **breaks susy spontaneously** [Witten '99]

$$V \sim g_{YM}^6 \sim \left(\frac{R}{\ell_{AdS}}\right)^3 \quad \Rightarrow \quad T > Q$$

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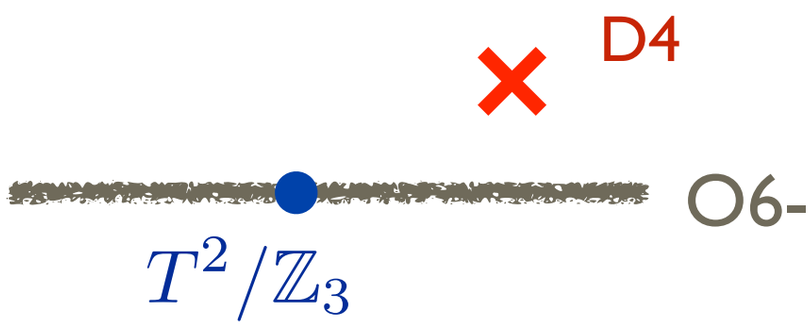

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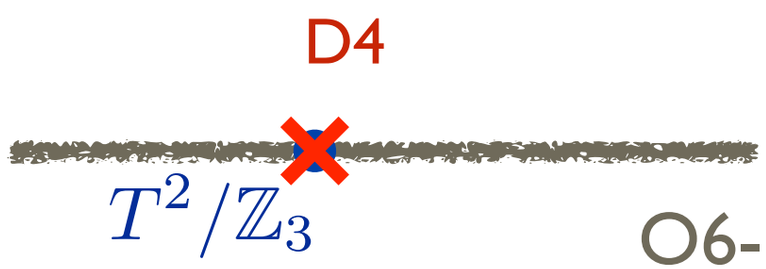

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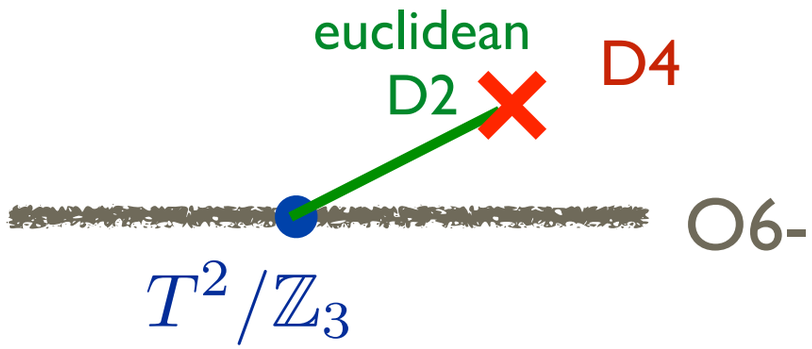

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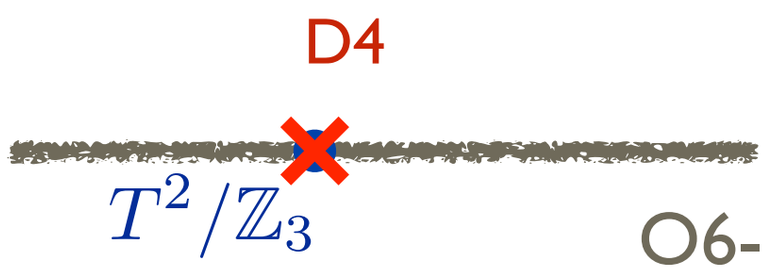

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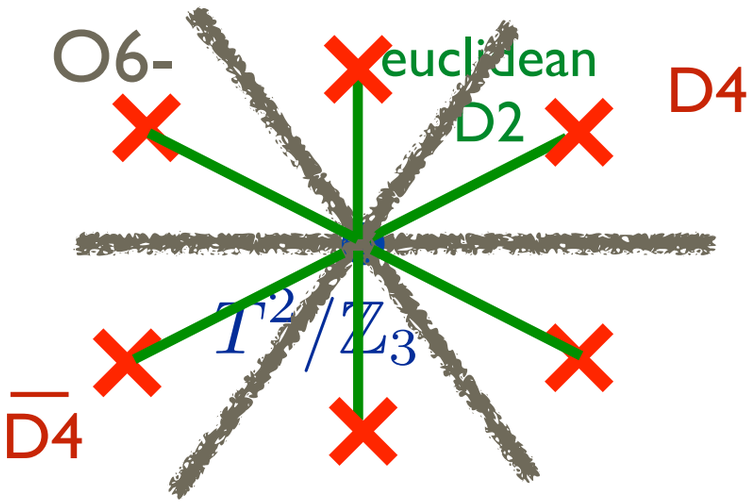

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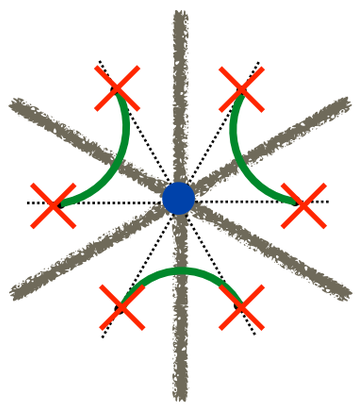
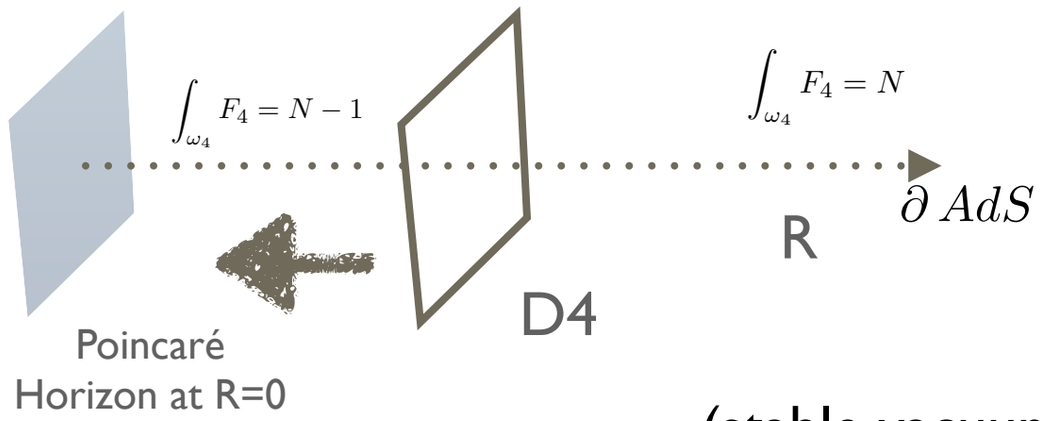


instanton configuration with two fermion zero modes

Result for DGKT vacuum

Assuming the EFT of the DGKT solution is correct:

We find that the brane feels an attractive force $\longrightarrow$ $T > Q$



(stable vacuum)

All branes charged under F4 flux are non-BPS beyond classical level

It violates the Weak Gravity Conjecture!!

General result for 4d N=1 AdS vacua

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WGC implies that the the dual CFT to a holographic AdS vacuum supported by fluxes must have an exact moduli space of deformations

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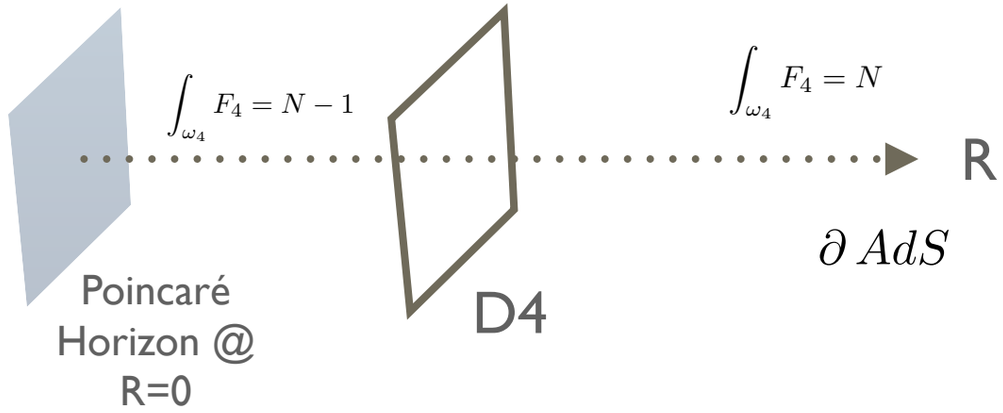

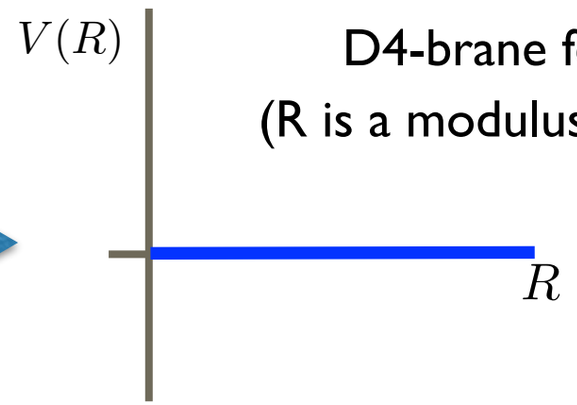

D4-brane feels no force
(R is a modulus, stable vacuum)

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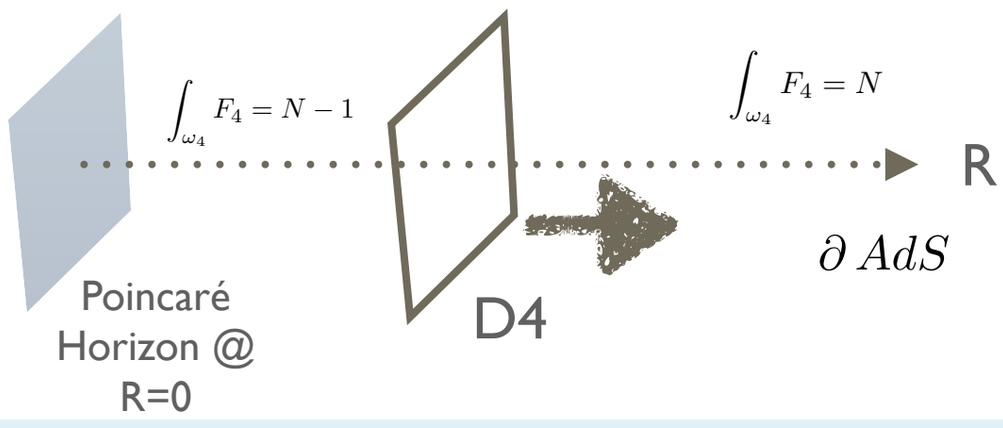

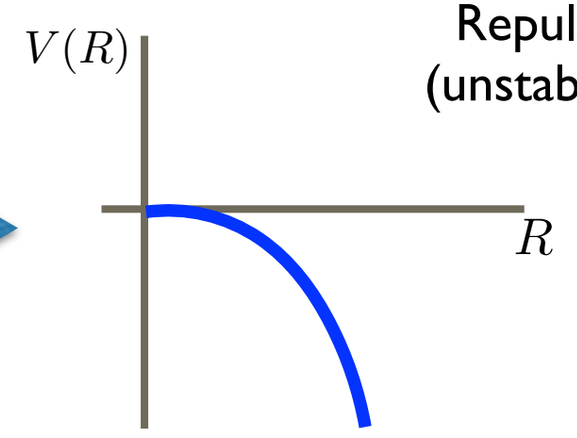

Repulsive force
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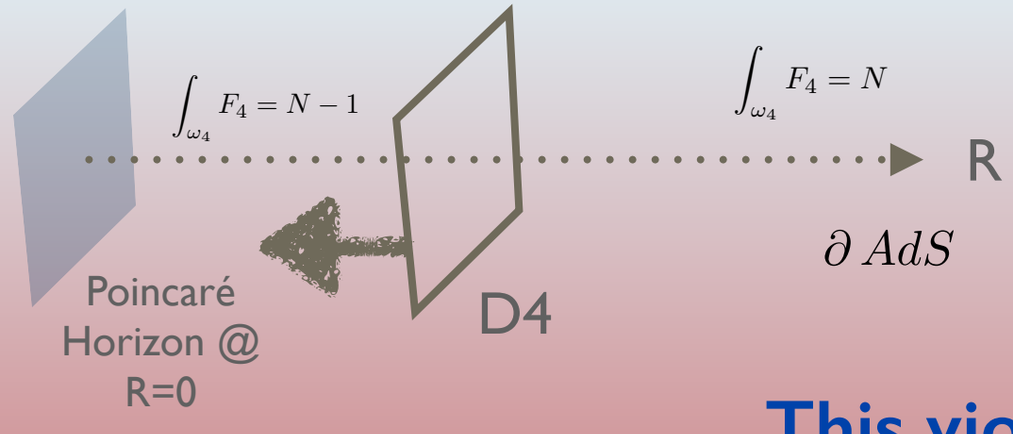

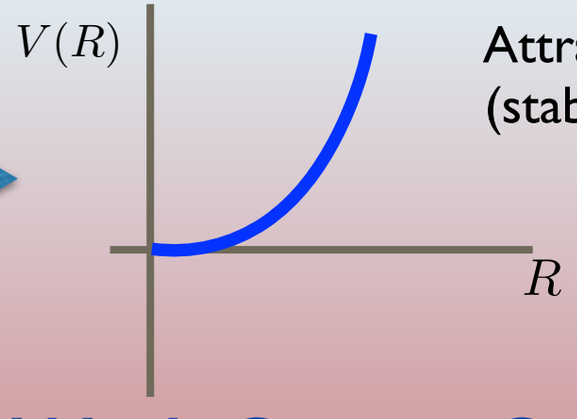

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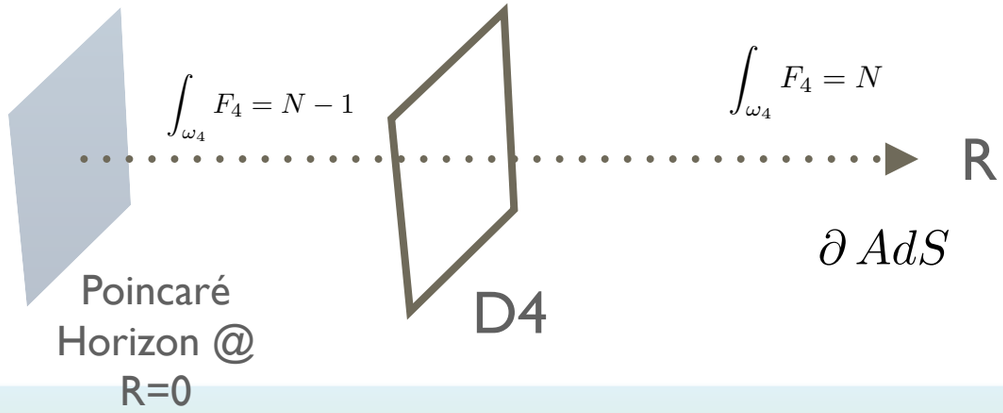

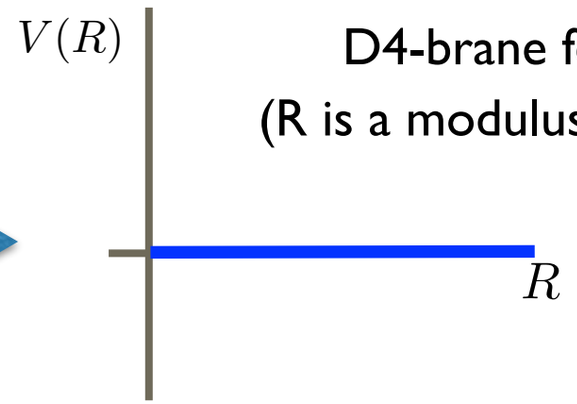

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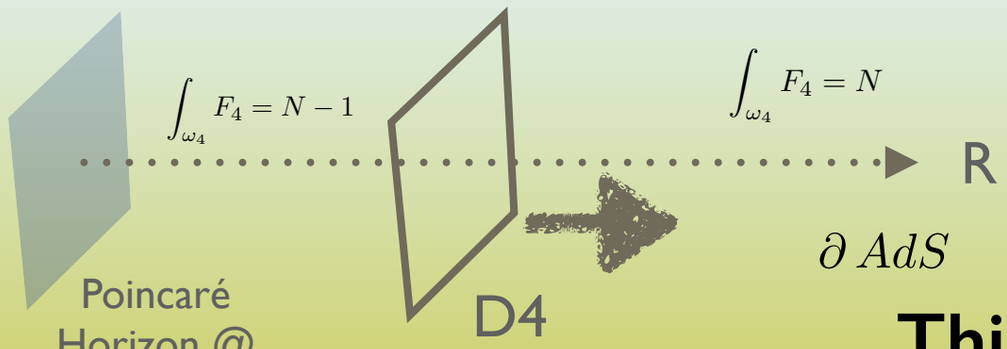

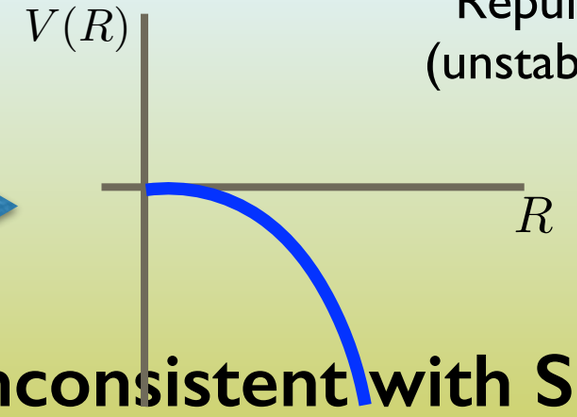

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This is inconsistent with SUSY AdS

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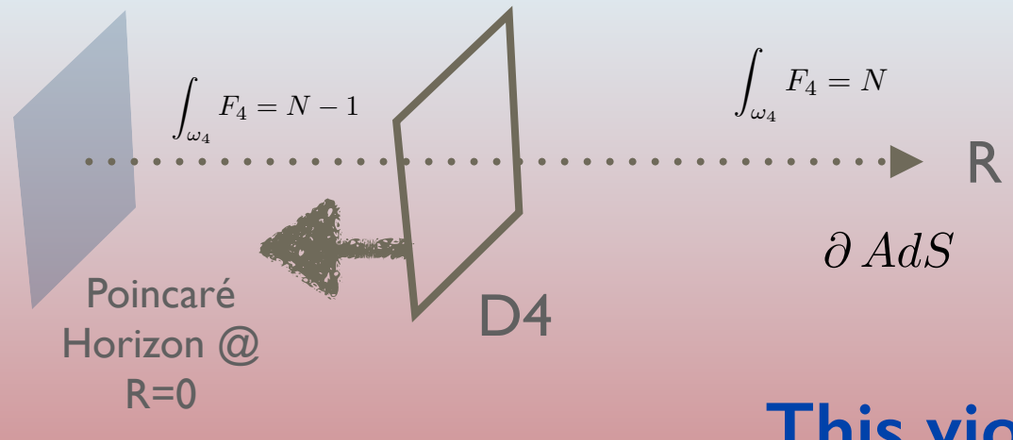

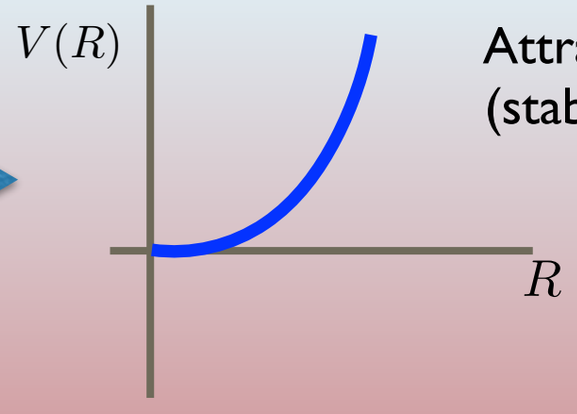

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But no parity symmetry for DGKT, KKLT,? … Are they in the Swampland?

Result

Either DGKT (and similar AdS 4d N=1 vacua) are inconsistent
(i.e., cannot be UV-completed)

or

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[Heidenreich,Lotito'24]

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We don't know for sure which one it is, but both would have profound implications

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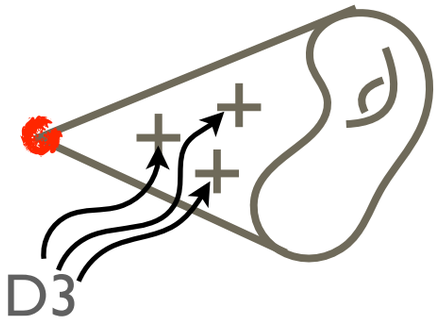
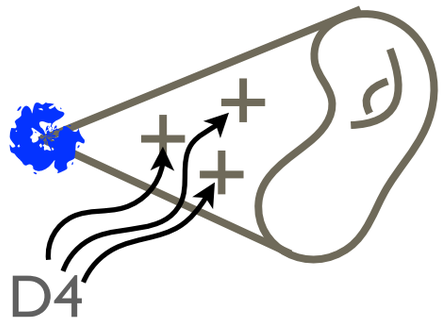


For DGKT → dual to D4 branes probing massive IIA singularity



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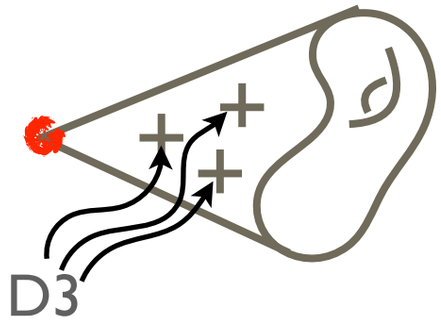
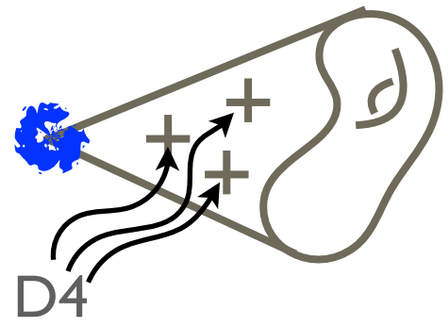


For DGKT → dual to D4 branes probing massive IIA singularity



We will provide the putative geometric singularity in [Apers, Montero, Valenzuela'ongoing]

DGKT brane geometry

If DGKT is correct, this adds to the weirdness of the solution

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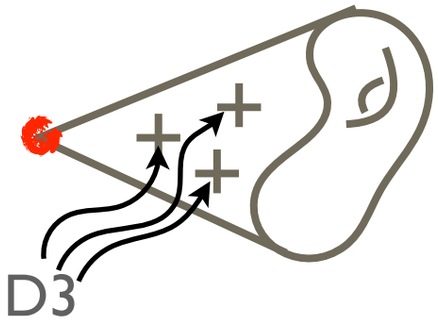

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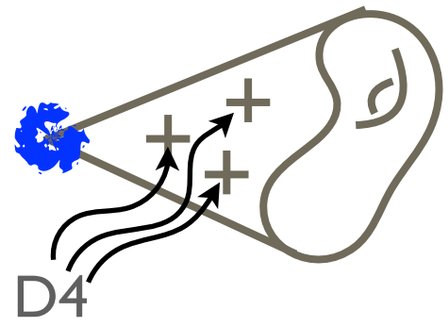

We will provide the putative geometric singularity in [Apers, Montero, Valenzuela'ongoing]

It should imply an enhancement of $\mathcal{N} = 0 \rightarrow \mathcal{N} = 1$ when placing the D4-branes in the singularity

!?

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Question:

How can we be sure that there is no higher order UV effect that breaks SUSY also in the bulk?

Maybe satisfying the F-term eqs. for the zero modes is not enough

Conclusion

Either DGKT (and similar AdS 4d N=1 vacua without parity symmetries) is inconsistent,

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Further ongoing investigation
(in other 4d N=1 setups like Gaiotto-Tomassiello'09)
to shed light on this

[Montero, Sharon, Valenzuela'ongoing]

Conclusion

If we are looking for AdS scale-separated vacua, which is the most promising corner of the landscape?

Non-SUSY	4 supercharges	8 or more supercharges

(4d N=1 theories)

Easier, but unstable

Take e.g. non-SUSY vacuum with

$$V_{\text{Casimir}} \sim \frac{1}{l^d} \sim m_{KK}^d$$

(scale-separated for d>2, but unstable and no unitary CFT dual)

???

Difficult or impossible

KK (BPS) modes are charged under continuous R-symmetry which prevents scale separation

$$m \sim q\, \ell_{AdS}^{-1}$$

$$q = 0, 1, 2, ...$$

[Polchinski,Silverstein '09] [Alday,Perlmutter '19]

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Thank you!

back-up slides

Flux Backtracking DGKT

How can we derive the brane geometry that should generate a given AdS flux vacuum as its near horizon geometry (and the dual CFT as its worldvolume field theory)?

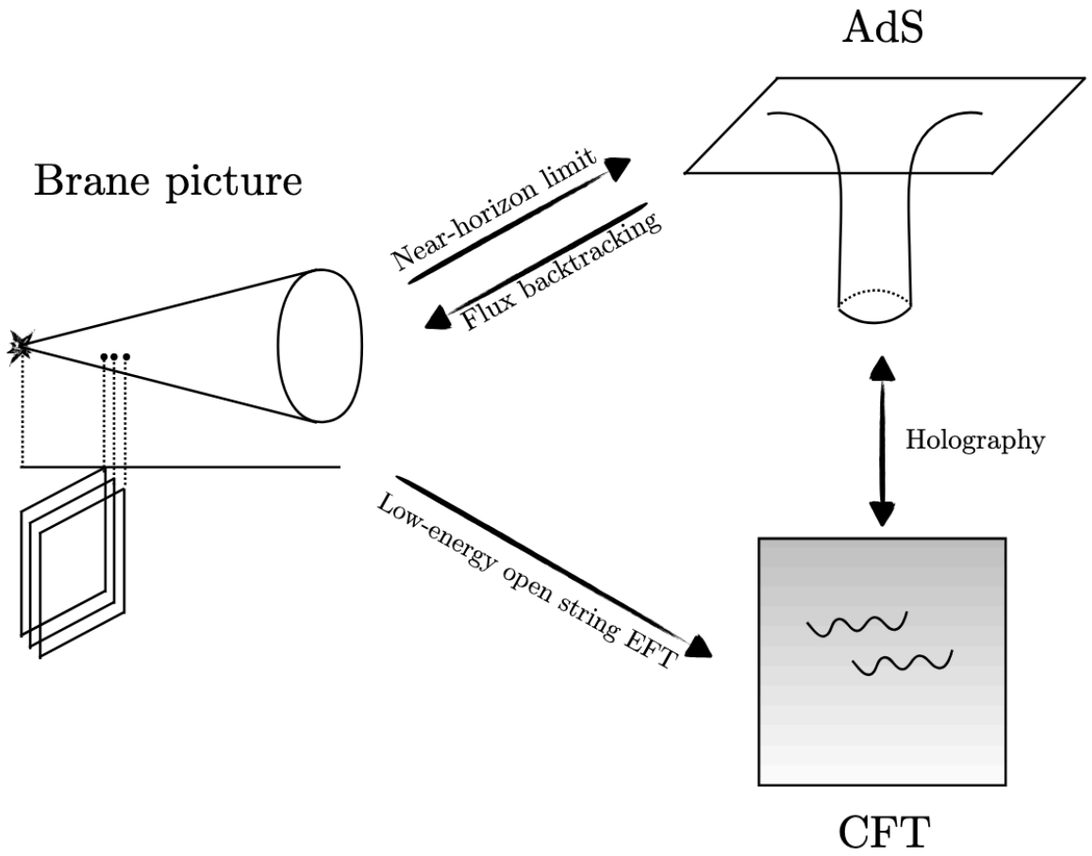
Flux backtracking procedure:

- Start with effective (bulk) flux potential

- Remove some flux (that will then be dualize to the barnes probing the singular geometry)

- Solve the eom for the running solution of the remaining effective potential

- This yields a "dynamical" cobordism yielding the singular geometry where we should place the probe branes



[Apers, Montero, Valenzuela' ongoing]

Flux Backtracking DGKT

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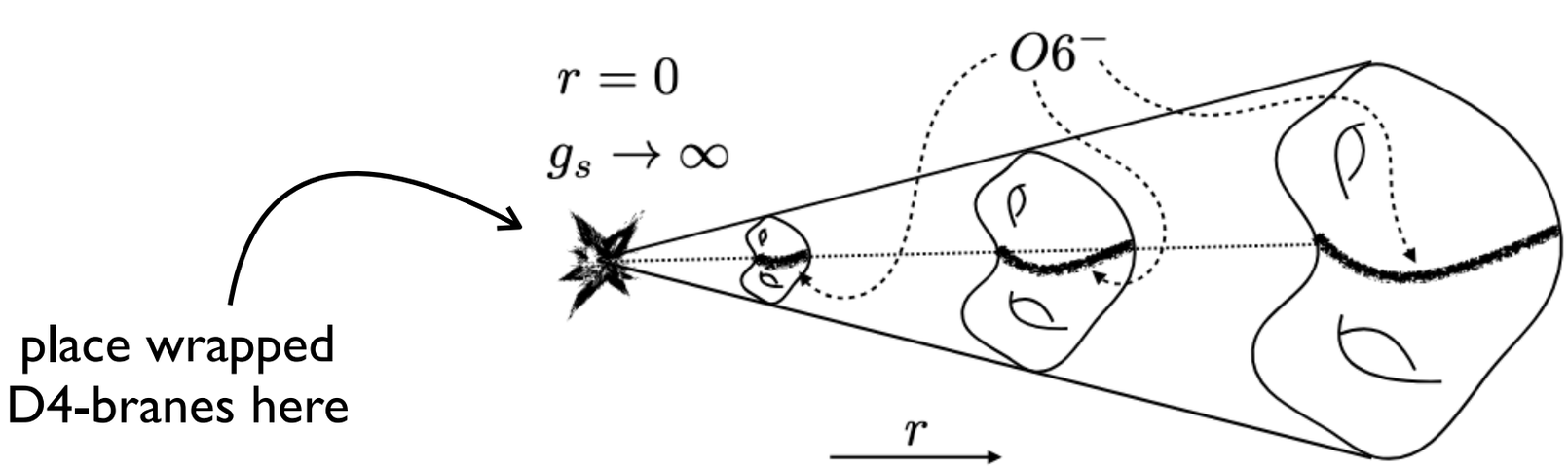
Flux backtracking procedure applied to DGKT:



$$ds_{10}^2 = dy^2 + y^{-10/9} ds_3^2 + y^{2/3} ds_{CY}^2, \quad g_s(y) \sim y^{-1}$$

[Apers, Montero, Valenzuela' ongoing]

Evidence for WGC and SDC

❖ String theory compactifications: Plethora of quantitative tests!

- Systematic approach according to the level of supersymmetry [Grimm, Palti, IV'18] [Grimm,Palti,Li'18]
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❖ Using positivity/unitarity bounds: lead to mild versions of the WGC

[Cheung et al'18][Hamada et al'18]…

Instabilities of non-SUSY vacua

Swampland conjecture: Any non-supersymmetric vacuum is at best metastable

Is there any universal instability that arises when breaking supersymmetry?

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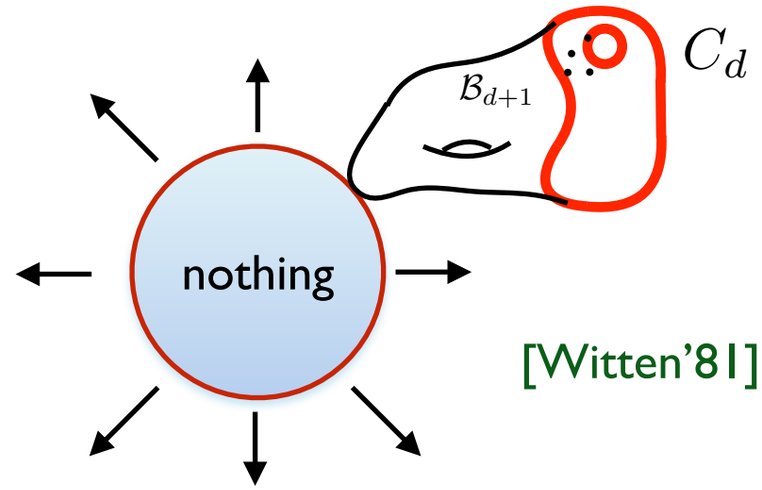

[Witten'81]

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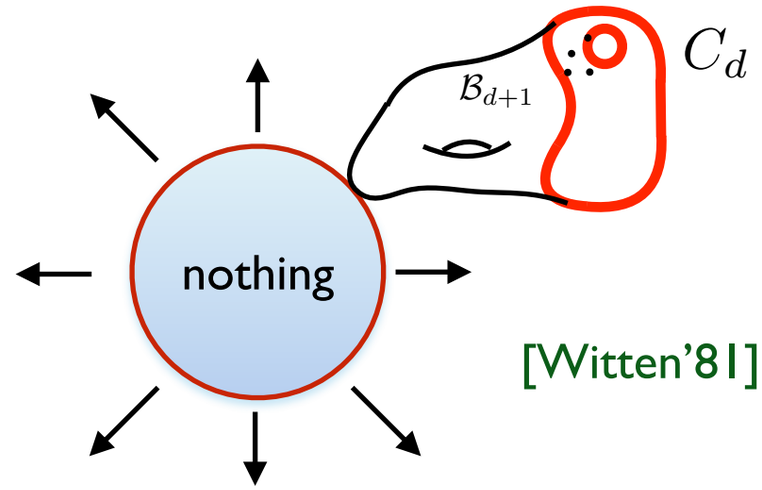

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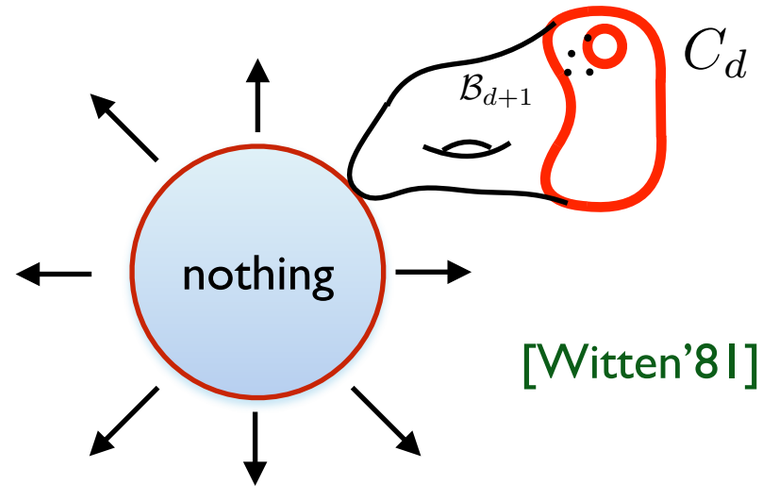

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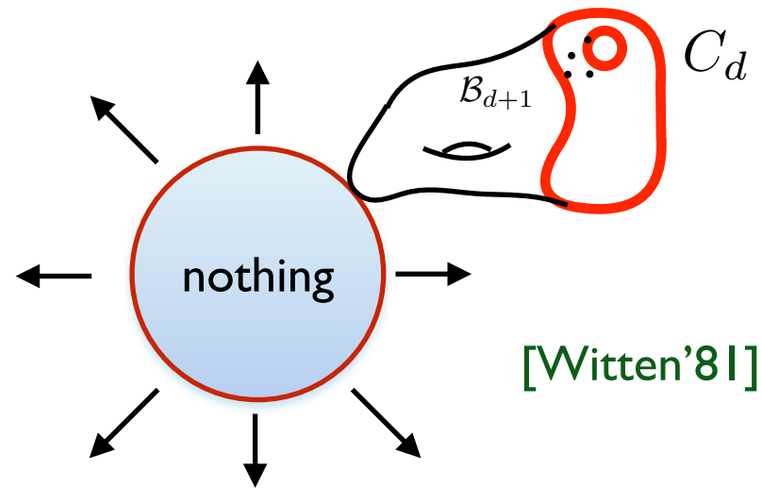

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$\Leftrightarrow$ no topological global charges (cobordism classes)

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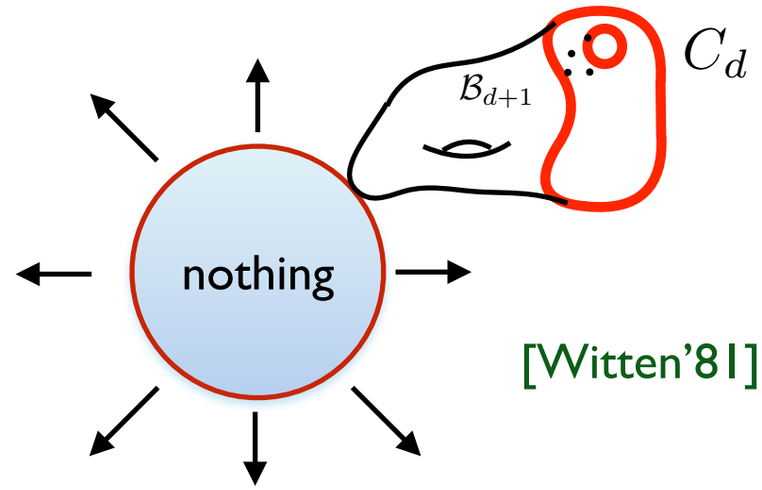

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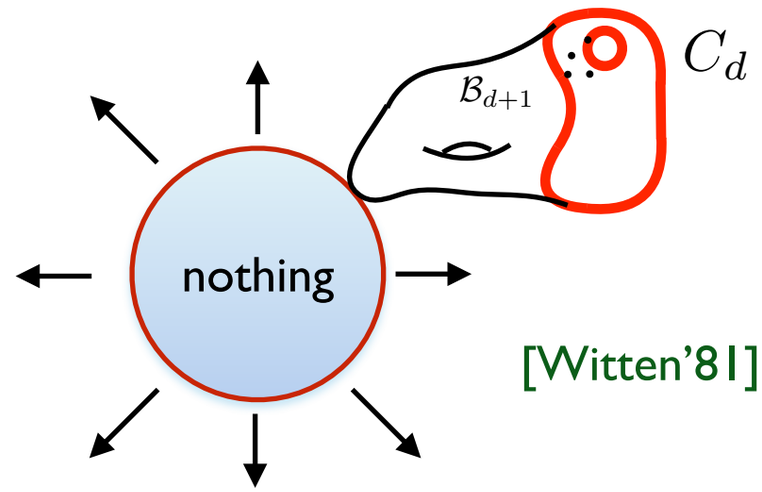

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They will expand and describe a vacuum instability if a certain energy condition (DEC) is violated semiclassically

(which can happen when supersymmetry is broken)