# On AdS Scale Separated Vacua

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In collaboration with Miguel Montero
(to appear soon)

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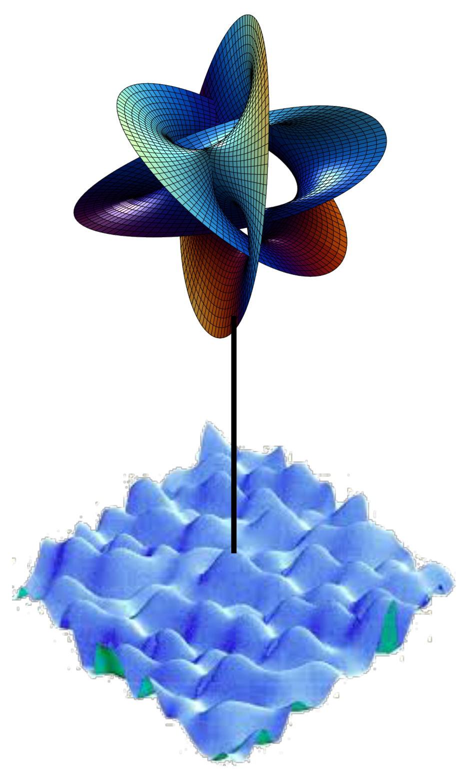
# AdS Scale Separation

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



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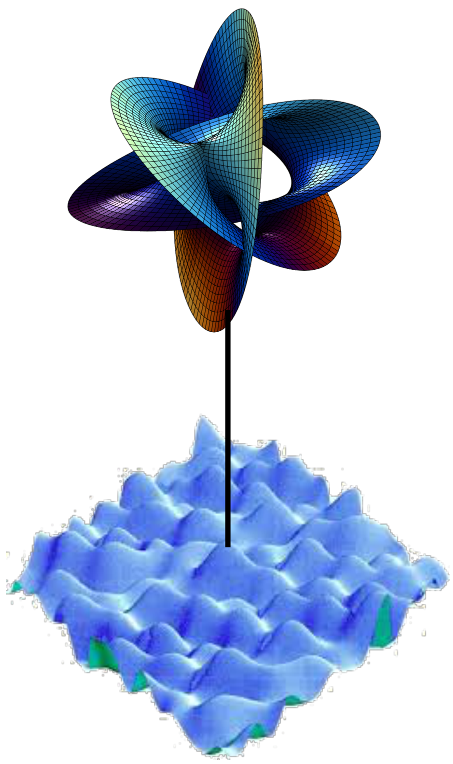

Internal space $l_{KK}$

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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 $d \geq 4$

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All known holographic AdS/CFT examples are not scale-separated

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$$m_{\text{KK}} \sim V_0^\alpha \longrightarrow l_{\text{KK}} \sim l_{AdS}^{-2\alpha}$$

If $\alpha \geq \frac{1}{2}$ no scale separation

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e.g. Scalar potential dominated by Casimir energies [De Luca et al '22]

$$V_{\text{Casimir}} \sim \frac{1}{l^d} \sim m_{KK}^d \qquad \longrightarrow \qquad l_{AdS} \sim l_{KK}^{d/2} \gg l_{KK} \quad \text{for} \quad d > 2$$

$$l_{AdS} \sim V^{-1/2}$$

At the very least, they have non-perturbative bubble of nothing instabilities

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- Bubble of nothing instabilities: always topologically allowed by Cobordism conjecture (absence of global symmetries) [Witten'81] [Garcia-Etxebarria et al'20]
- Brane nucleation due to the Weak Gravity Conjecture (if there are fluxes in the internal dimensions) [Ooguri-Vafa'18]

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In all examples, they correspond to Kaluza-Klein modes

$\longrightarrow$ no scale separation

[Polchinski,Silverstein '09]

[Alday,Perlmutter '19]

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# 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

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

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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.

[Andriot, Apers, Casas, Castellano, Collins, Cribiori, Dall'Agata, De Luca, Emelin, Farakos, Graña, Herraez, Hoter, Ibañez, Junghans, Lust (x2), Marchesano, Marconnet, Montella, Morittu, Ning, Palti, Plauschinn, Prieto, Quirant, Revello, Shiu, Shukla, Tomasiello, Tonioni, Toulikas, Tringas, Tsimpis, Vafa, Van Hemelryck, Van Riet, Walcher, Wiesner, Wrasse, Xu, Yau, Zatti,…]

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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 'ongoing]

# Test of DGKT vacuum

Consider a D4-brane wrapping a holomorphic 2-cycle dual to the large N flux

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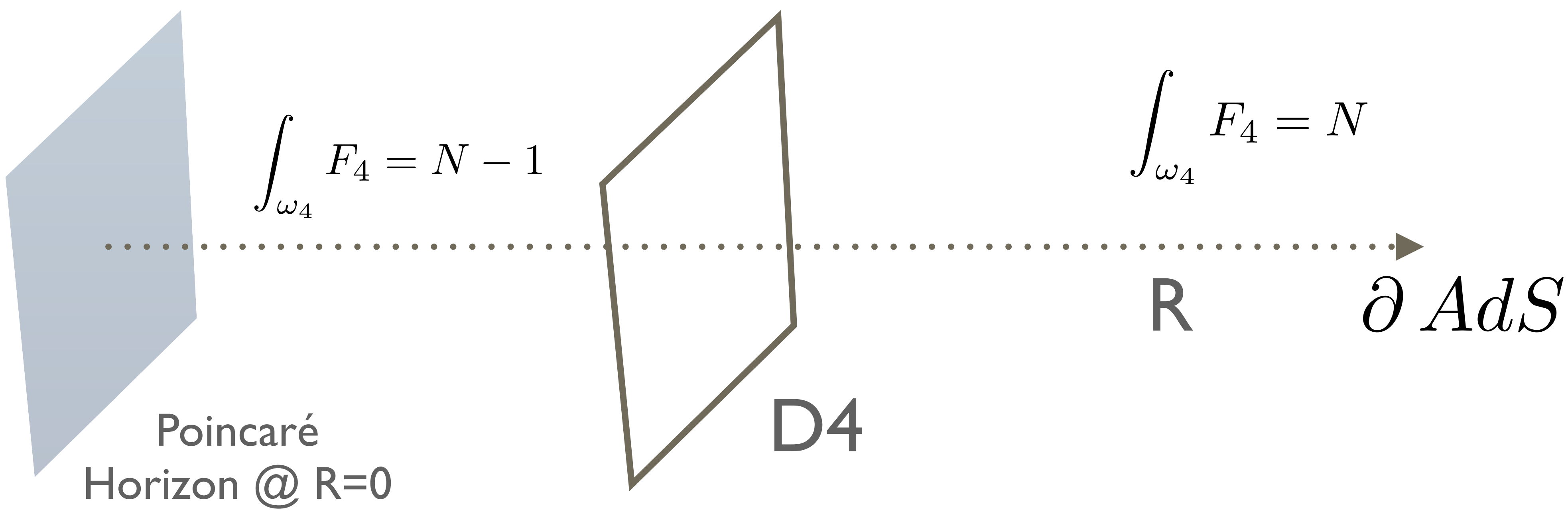

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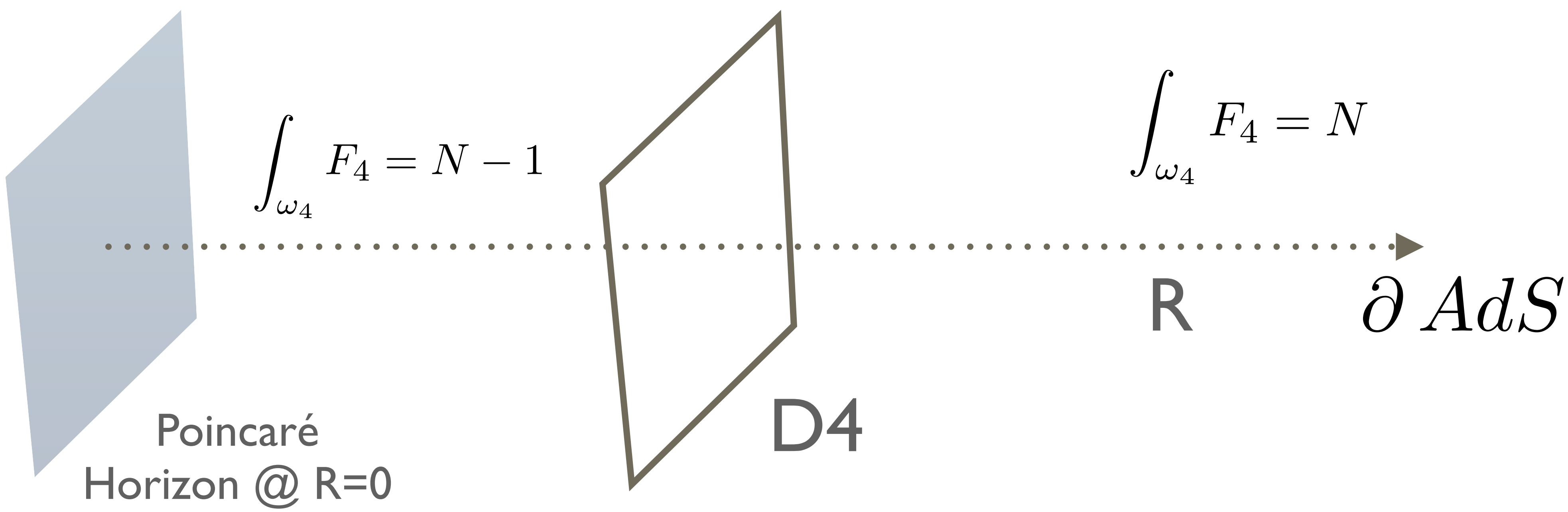


(This is what happens e.g. in $AdS_5 \times S^5$ )

**Case I)** The D4-brane feels no force, so the position of the brane is a modulus and the domain wall is a static solution

⟶ Stable vacuum

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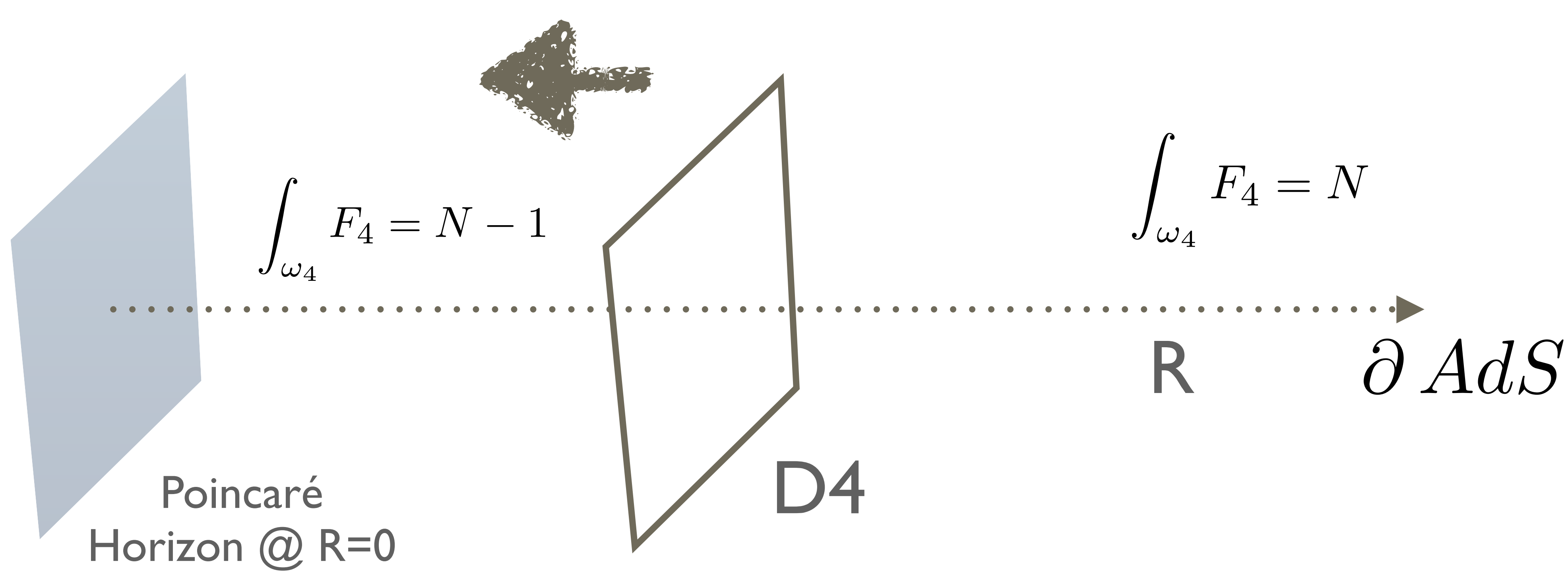


**Case 2)** The brane feels an attractive force towards the Poincaré Horizon

⟶ Stable vacuum (not known example in holography yet)

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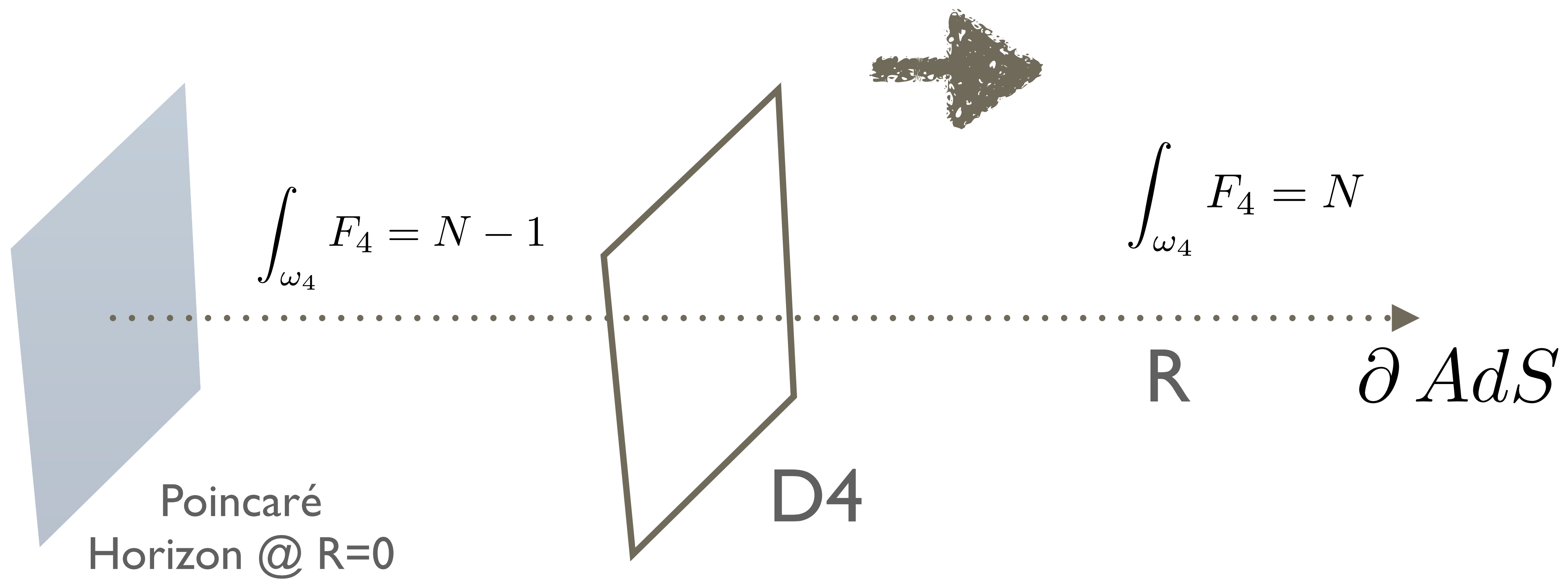


**Case 3)** The brane feels a repulsive force from the Poincaré Horizon

It will discharge the flux $\longrightarrow$ Unstable vacuum

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Consider a D4-brane wrapping a holomorphic 2-cycle dual to the large N flux

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[Arkani-Hamed et al.'06] [Ooguri,Vafa'18]

If the brane satisfies the Weak Gravity Conjecture:

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WGC suggests that non-SUSY AdS vacua with internal fluxes are mestastable due to brane nucleation that discharges the flux

(Case 2 for all branes is not allowed by WGC)

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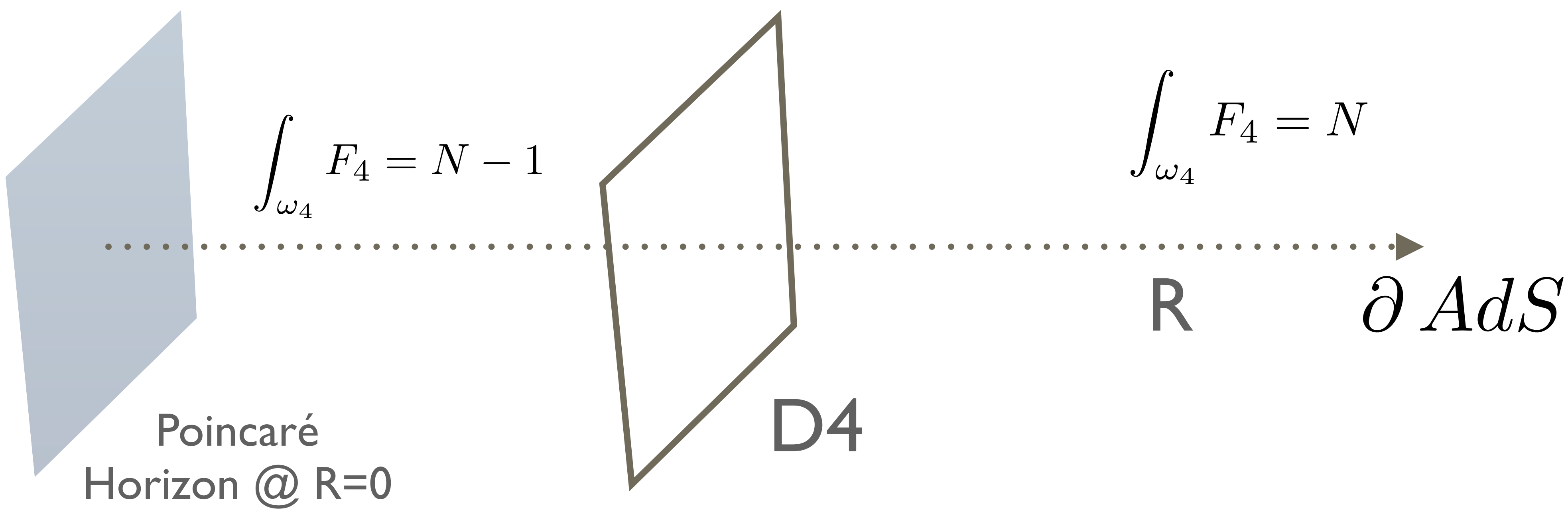

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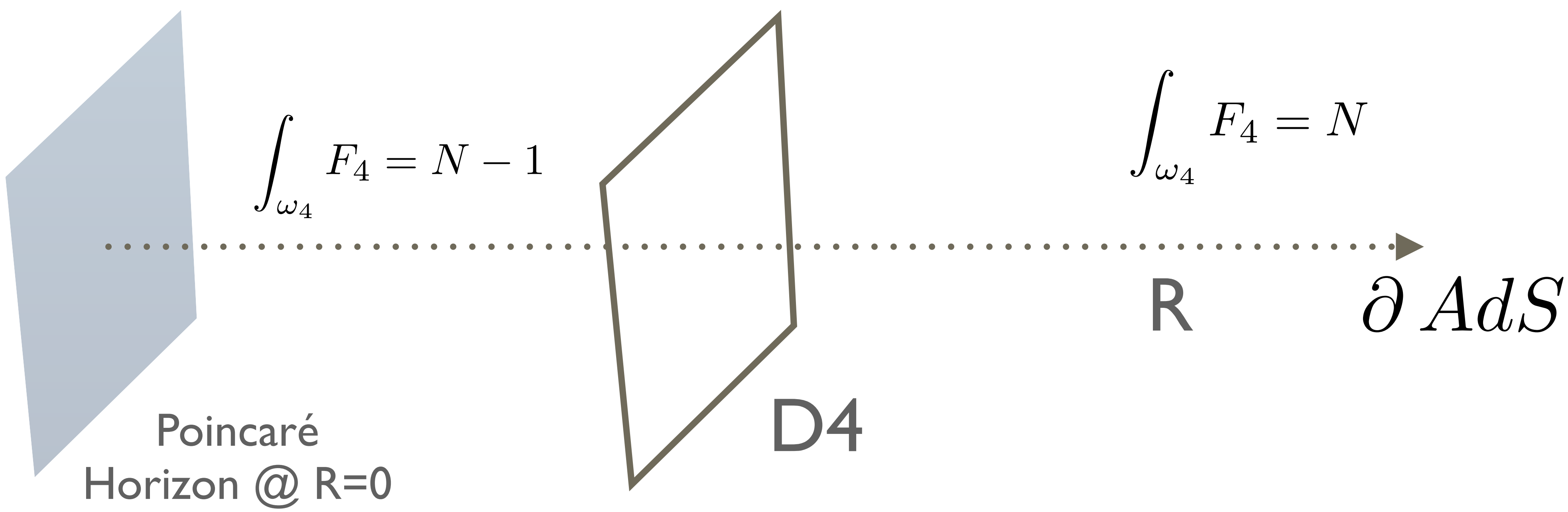


At the classical level, the brane is **BPS**, so the position of the brane is a modulus

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the brane will feel a non-vanishing force

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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 $\longrightarrow$ it has a moduli space

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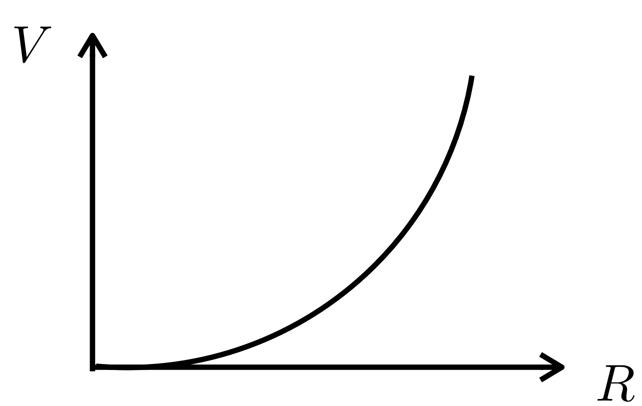


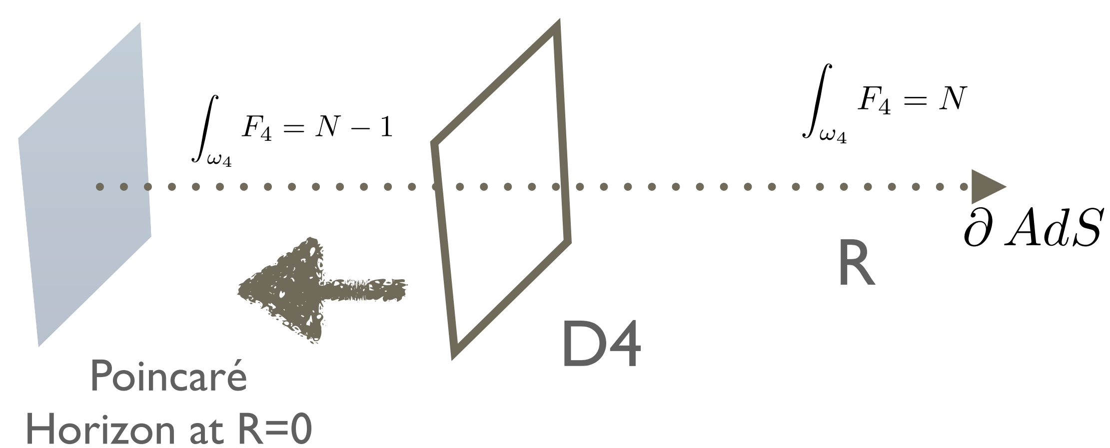

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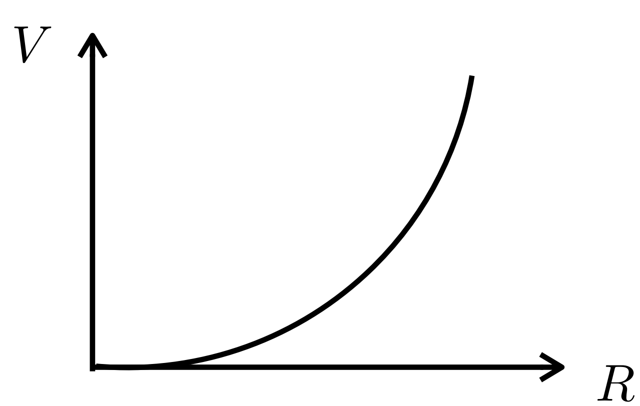


It violates the Weak Gravity Conjecture!!

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Attractive branes can be a hint to construct the CFT dual if it exists (first example of this type ever seen!)

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*Thank you!*

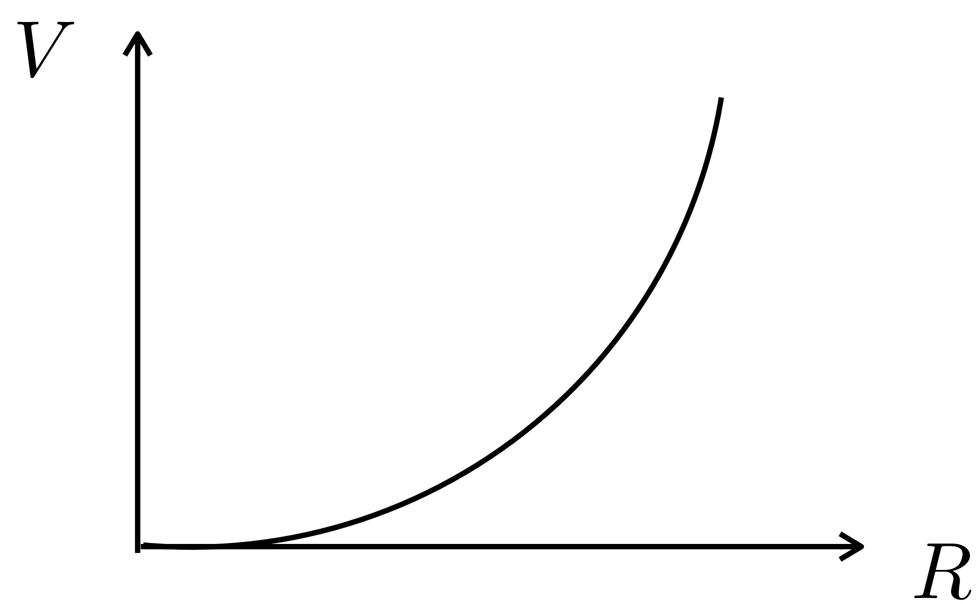
back-up slides

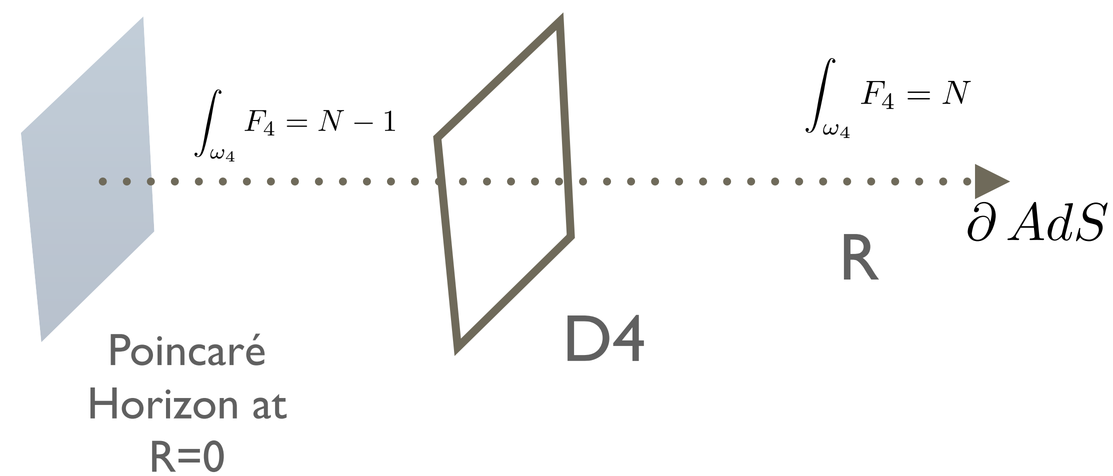
# Worldvolume D4 theory

At the orientifold locus, the worldvolume theory is a pure SU(2) gauge theory

$$S \propto \int d^3\xi \left( \frac{\ell}{2R} |\nabla R|^2 + \frac{1}{2g_{YM}^2} |F|^2 \right)$$

$$V = |W|^2 \sim g_{YM}^6 = \left( \frac{R}{\ell_{AdS}} \right)^3$$ in string units




It forces the position of the brane to

$$R \to 0$$

# Evidence for WGC and SDC

❖ String theory compactifications: Plethora of quantitative tests!

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❖ Using positivity/unitarity bounds: lead to mild versions of the WGC

[Cheung et al'18][Hamada et al'18]…

# Weak Gravity Conjecture

**Weak Gravity conjecture:** [Arkani-Hamed et al'06]

Given a gauge theory coupled to gravity, there must exist an electrically charged state with:

$\mathcal{O}(1)$ *factor (extremality bound of the black holes)*

*mass* $m \leq \gamma_{\rm BH} Q M_p$

*electric charge*

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*mass* → $m$

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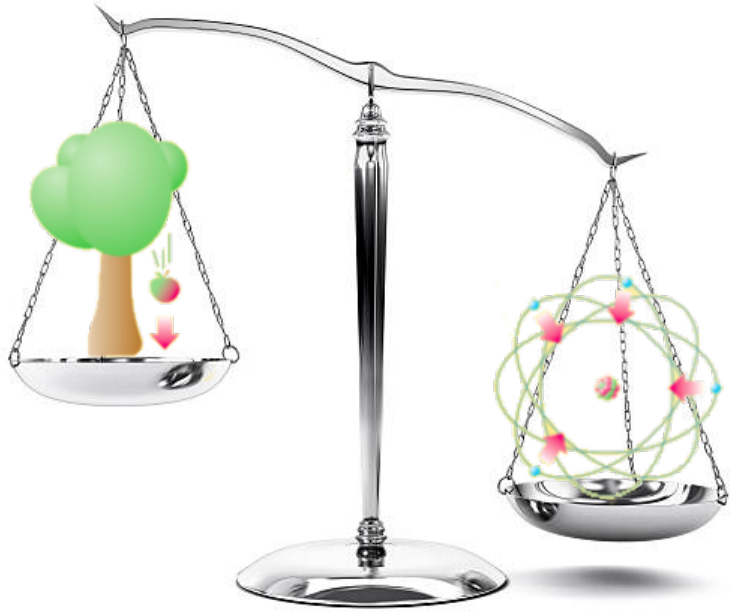
$Q$ → *electric charge*

$q$ → *quantized charge*

$g_{\rm YM}$ → *gauge coupling*

- Independent motivation based on black hole physics
- Plethora of evidence based on string theory, AdS/CFT, scattering amplitudes,…

review: [Harlow et al'22]



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Consider an AdS vacuum supported by fluxes in the internal dimensions:

flux: $f_0 \sim \int_{\Sigma_p} F_p$ → p-form gauge field in the extra dimensions

WGC codimension-one charged brane in AdS

Exact equality only occurs if it is a supersymmetric BPS state

# Cobordism conjecture

The cobordism group of a quantum gravity theory must be trivial:

$$\Omega_k^{QG} = 0$$ [McNamara,Vafa'19]

*k : internal dimension*
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to avoid a (D-k-1)-form global symmetry with charges $[M] \in \Omega_k^{QG}$

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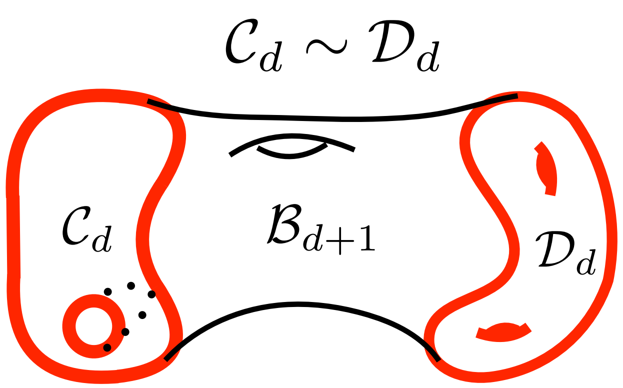

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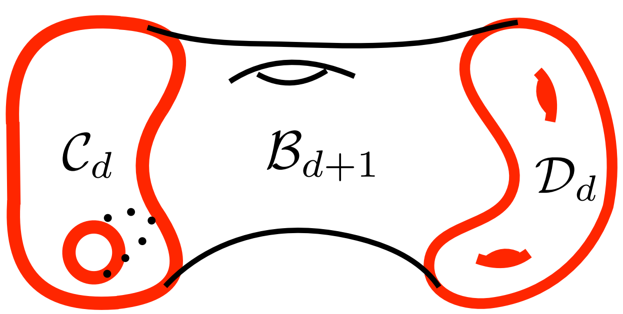
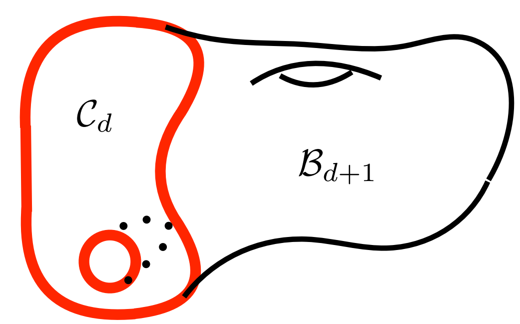
$\mathcal{C}_d \sim \mathcal{D}_d$




$C_d = \partial B_{d+1}$ *(trivial class)*



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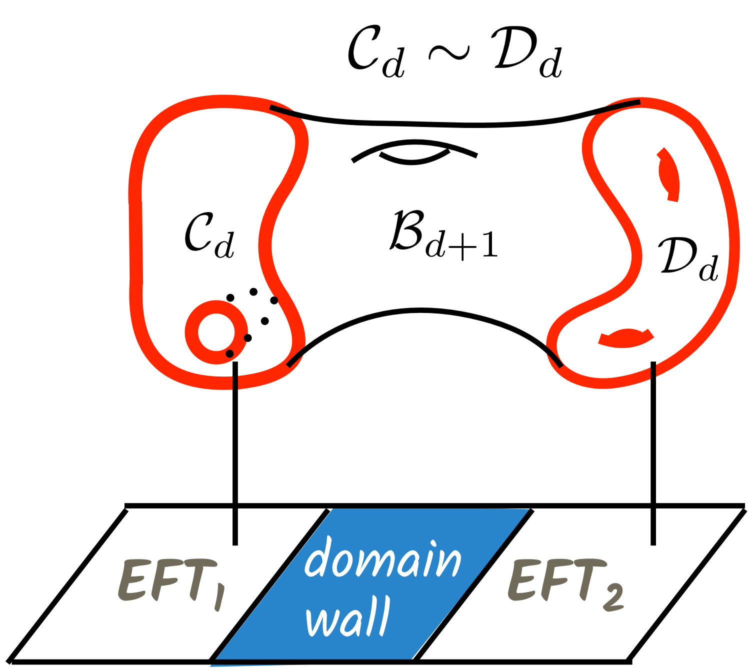


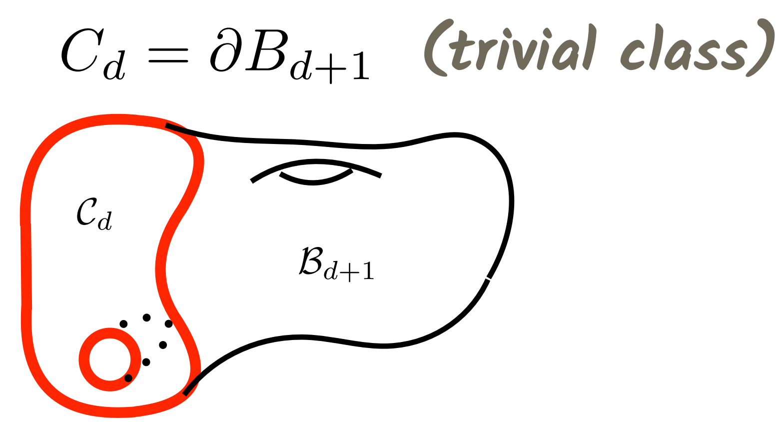

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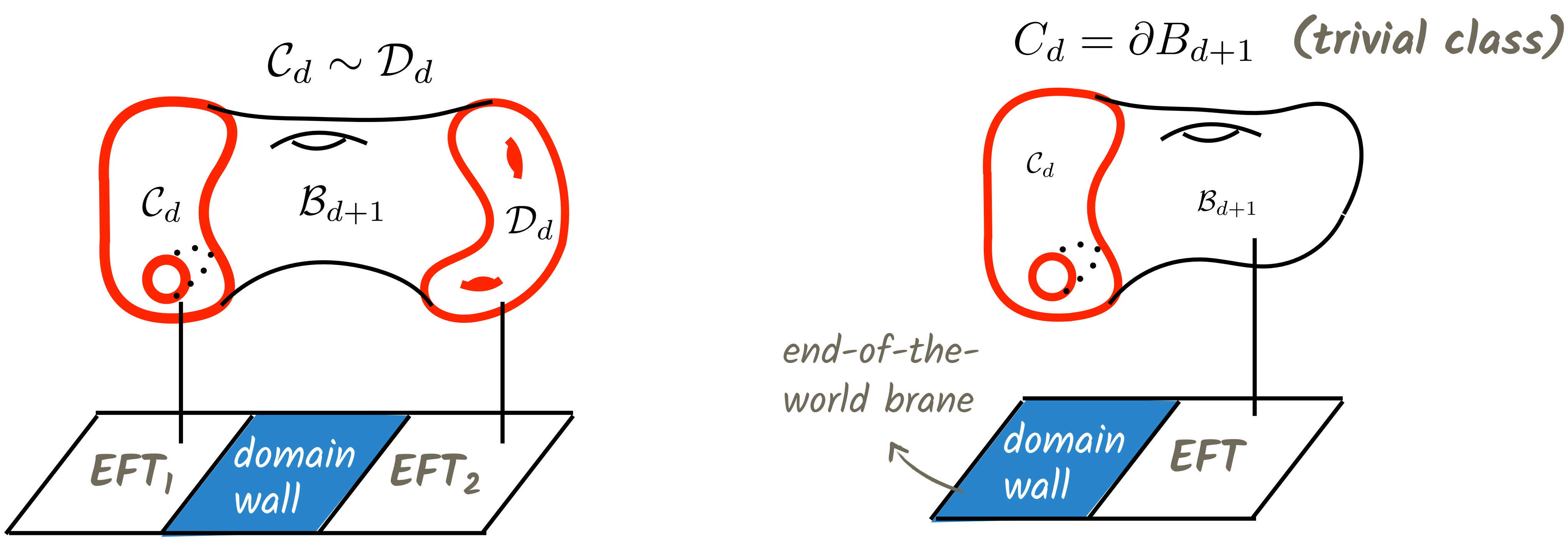

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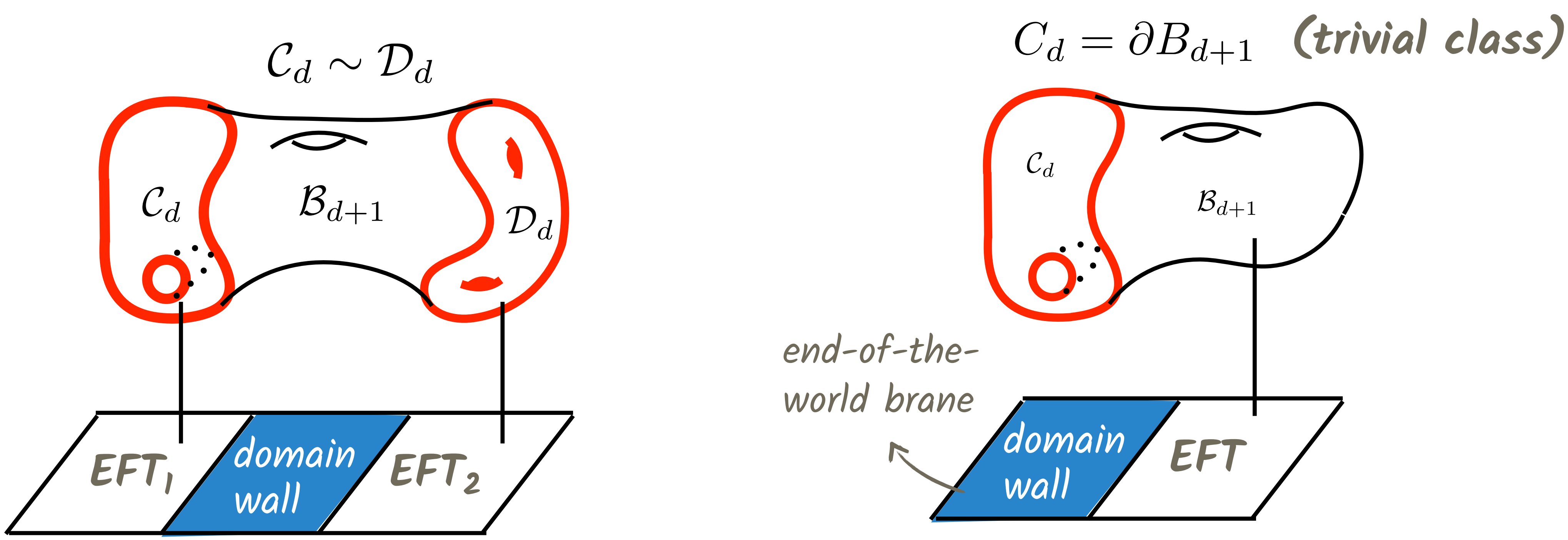


It implies all theories of same dimension are connected by finite energy domain walls, and predicts the existence of new defects in string theory!

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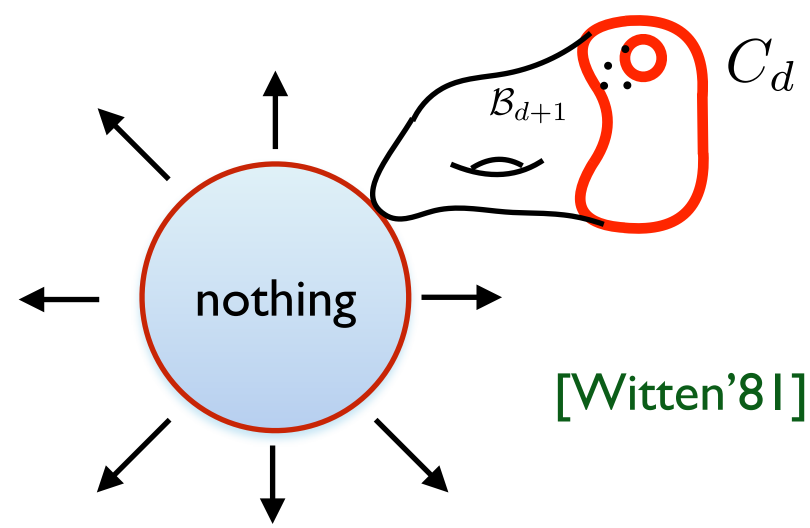
from the vacuum to nothing:

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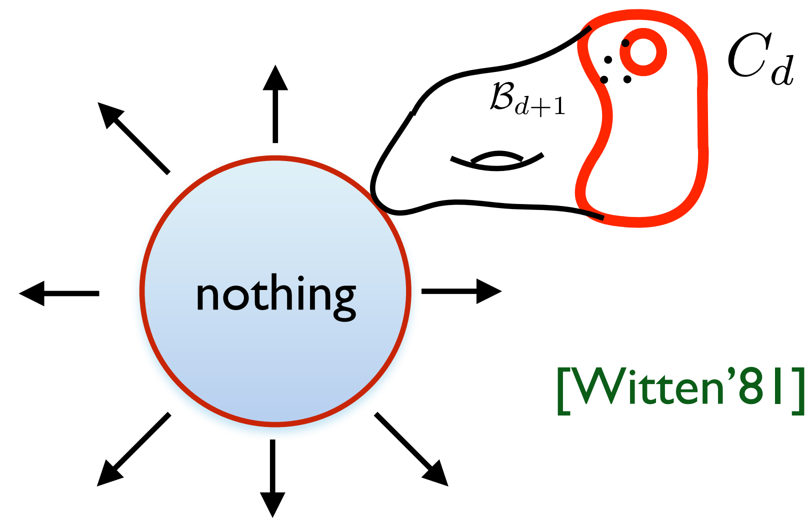


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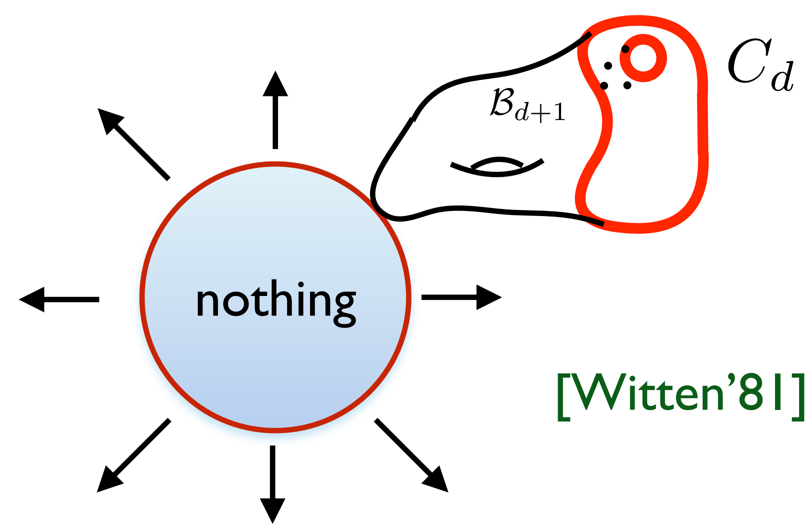


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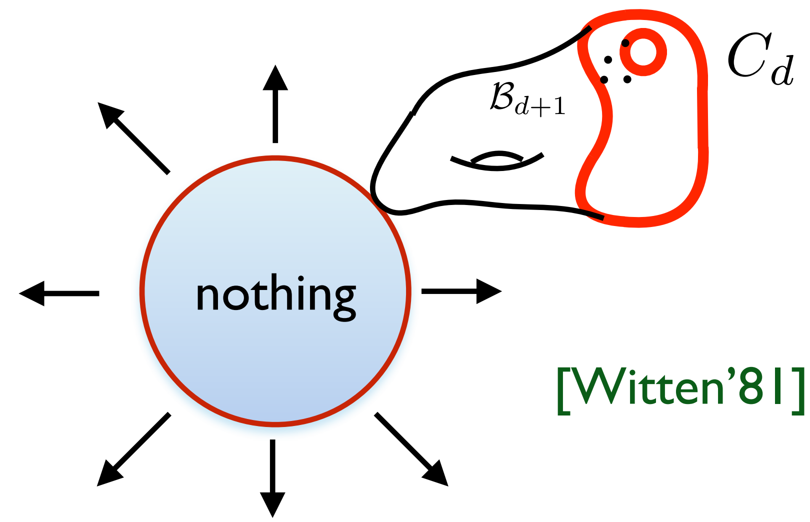


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⟺ no topological global charges (cobordism classes)

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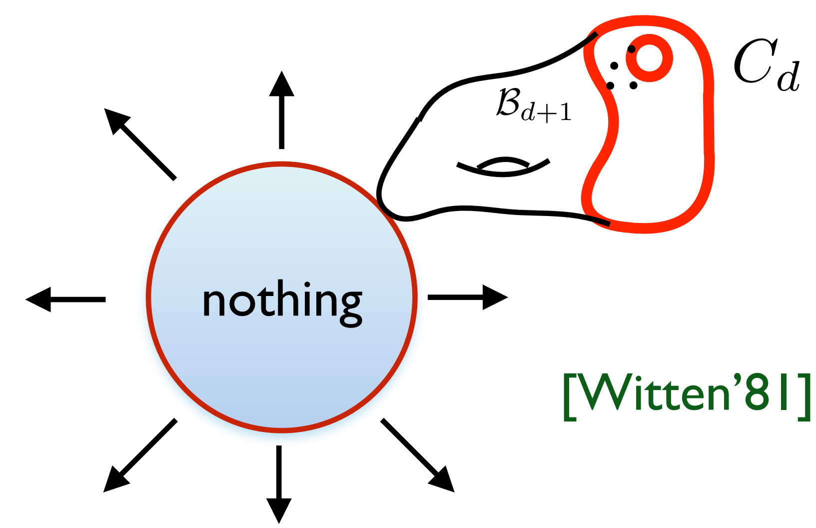


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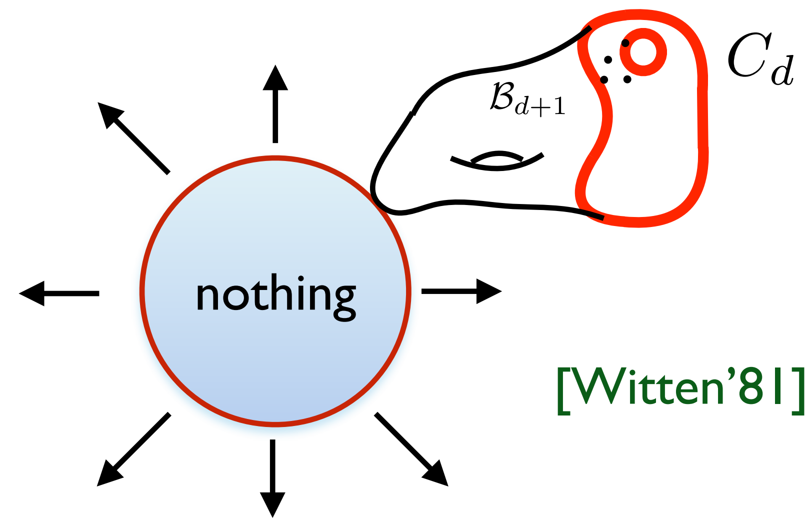


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They will expand and describe a vacuum instability if a certain energy condition (DEC) is violated semiclassically

(which can happen when supersymmetry is broken)