Walking distances between AdS vacua

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Based on collaborations with:

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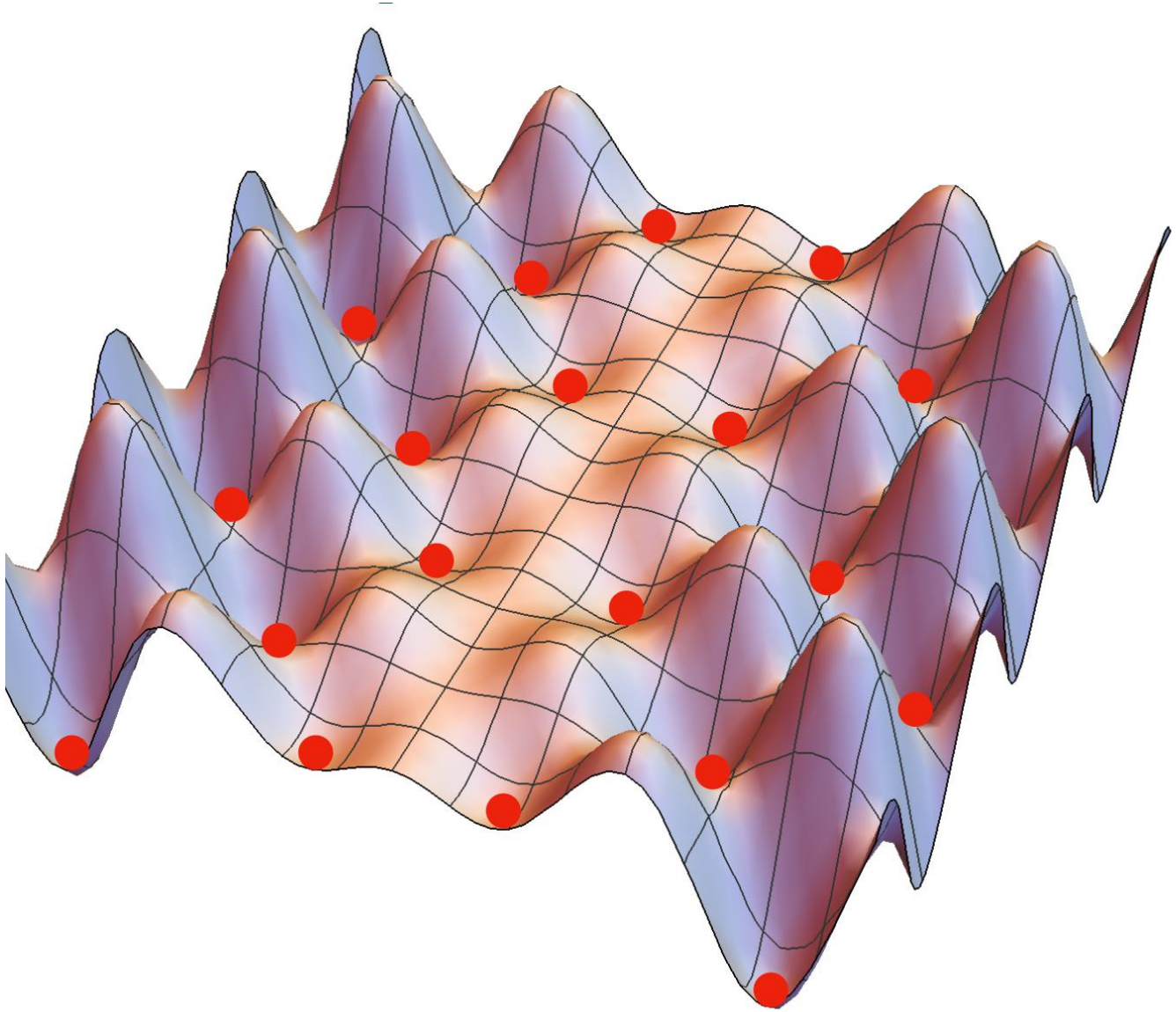
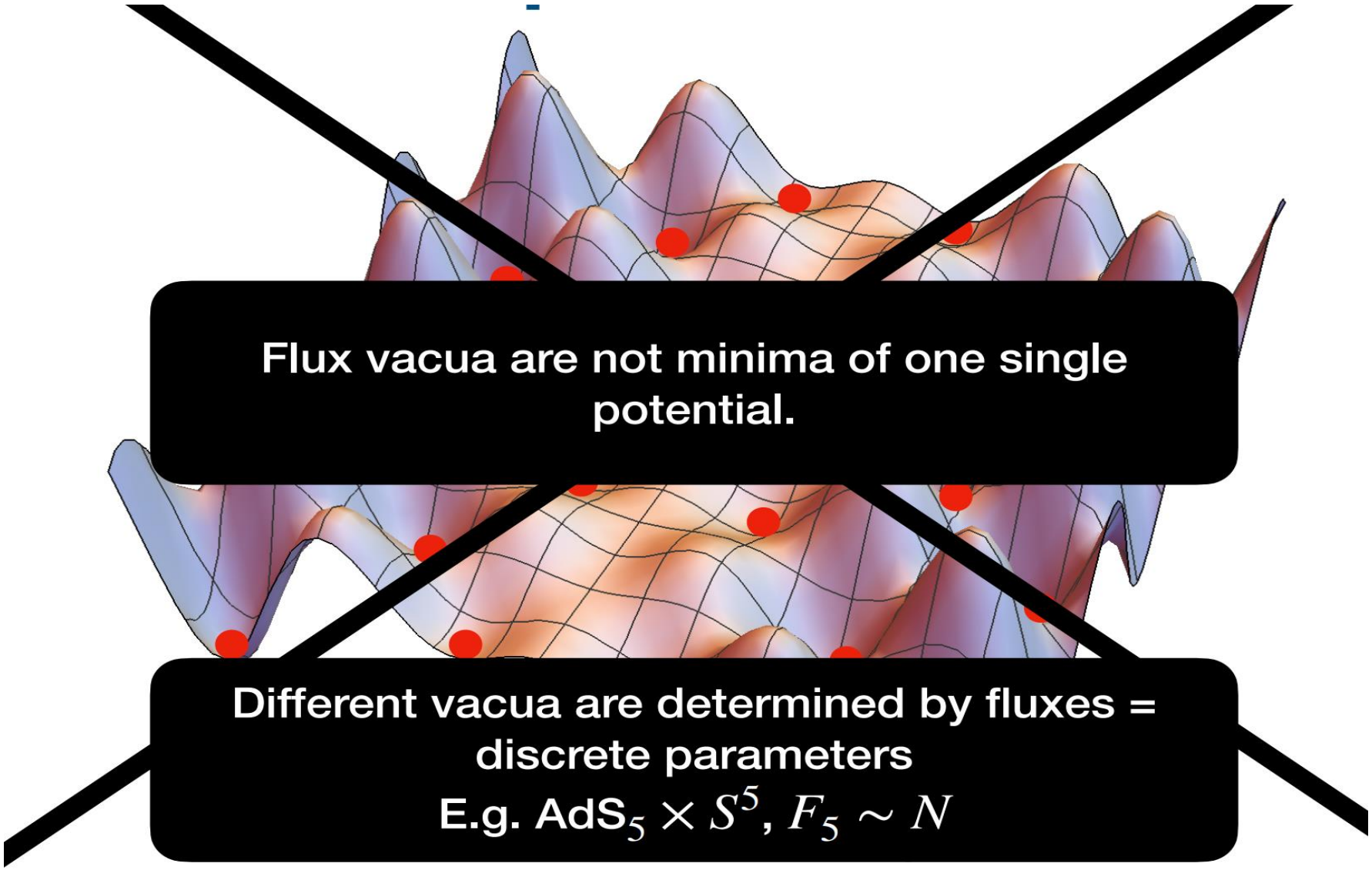
arxiv: 2311.10828, 2212.06169

1. Original motivation

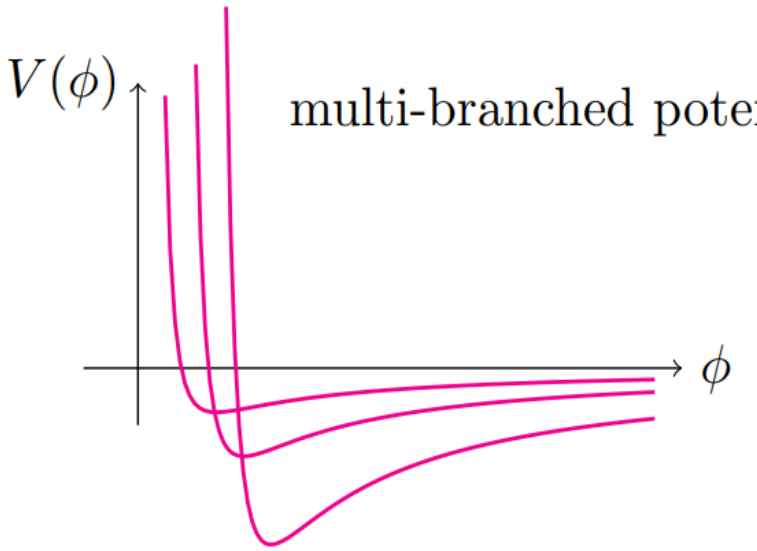
The landscape according to Brian Greene, Brian Cox, Neil deGrasse Tyson,...

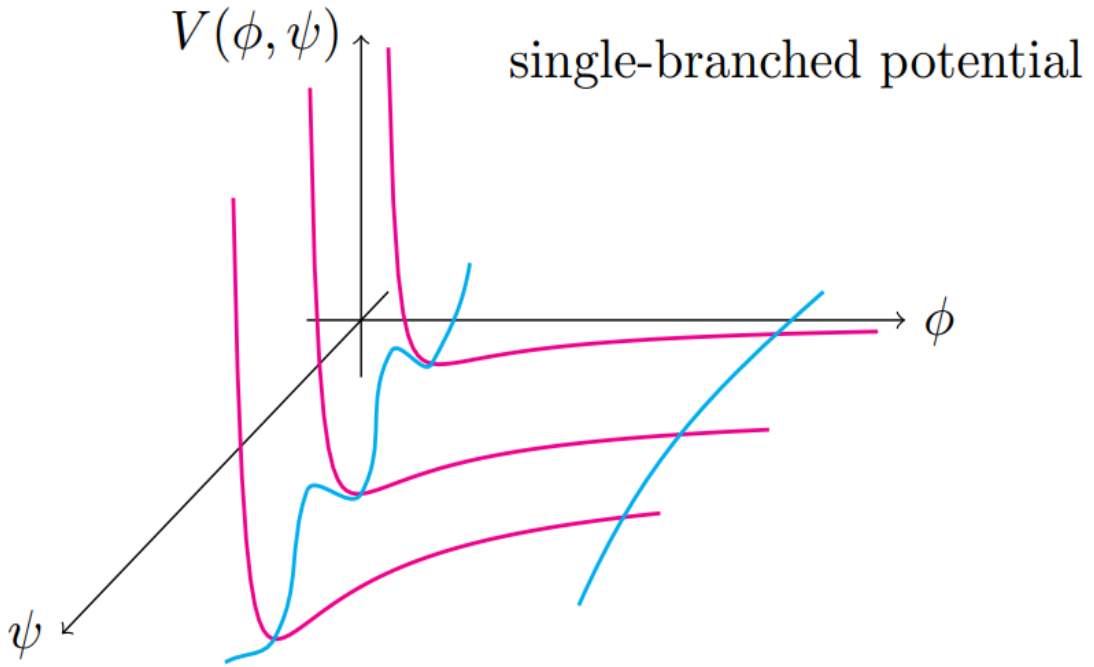


According to researchers:



Can one have a **Reids-type fantasy** for the whole string landscape?





Hopping between flux quanta **continuously**

Very loosely speaking:

1. Cobordism conjecture [McNamara, Vafa]: everything is connected (vacua & theories)

2. Things with different integer data ("topology") connected with more violent processes (hard-thin domain walls?) than things that differ smoothly

3. But in string theory integers are not always integers. Often smooth interpolations possible. Examples:
   - Brane charges can be continuous in a way (Myers effect). Consider a D(p+2) brane wrapping an S^2. WZ action contains:

$$(-1)^p \mu_{p+2} \int \sigma(C_{p+3} + \mathcal{F}_2 \wedge C_{p+1}) \qquad \mathcal{F}_2 = F_2 - B_2 \ ,$$

$$Q(\Psi) = \frac{1}{2\pi} \int_{S^2(\Psi)} \mathcal{F}_2 \ ,$$

Induced Dp charge depends on where the S2 lives in the larger cycle.

- Number of dimensions is not really an integer. Just shrink a certain direction….
- Seiberg duality cascades: rank and flavor “smoothly changes along RG flow”. See the continuous profile of the F_5 field in the Klebanov-Strassler throat solution.
- Topology changing processes do not occur instantly. …
- …..

Why care?

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- …..

Why care?

Anti-de Sitter distance conjecture
[Lust, Palti, Vafa]

for any d-dimensional AdS flux vacuum with cosmological constant Λ_{AdS}, there exists a tower of states with a mass scale m that behaves as

$$\frac{m}{m_{\text{P},d}} \overset{\Lambda_{\text{AdS}}\sim 0}{\sim} |m_{\text{P},d}^{-2}\Lambda_{\text{AdS}}|^{\alpha}, \qquad \text{(I.1)}$$

for a positive constant α, where $m_{\text{P},d}$ is the Planck mass.

Argument **AdS Distance Conjecture** (ADC) from **ordinary *distance conjecture*** *[Ooguri, Vafa]*:

> *At large geodesic distance Δ in field space from the original vacuum, the mass scale m of a tower of modes becomes lighter as*
>
> $$m \sim m_0 \, \mathrm{e}^{-\beta \Delta}$$
>
> *with β an order-one number.*

[Lust, Palti, Vafa], suggested that conjecture also holds for distances travelled in **metric field** and then one finds the ADC.

See also [Basile, Montella, 2023] [Li, Palti, Petri 2023]

The goal is to compute distances between vacua.

Can we interpolate between vacua using scalar fields?

If our fantasy is correct, then yes.

Rest of this talk:

1. argue the fantasy is correct

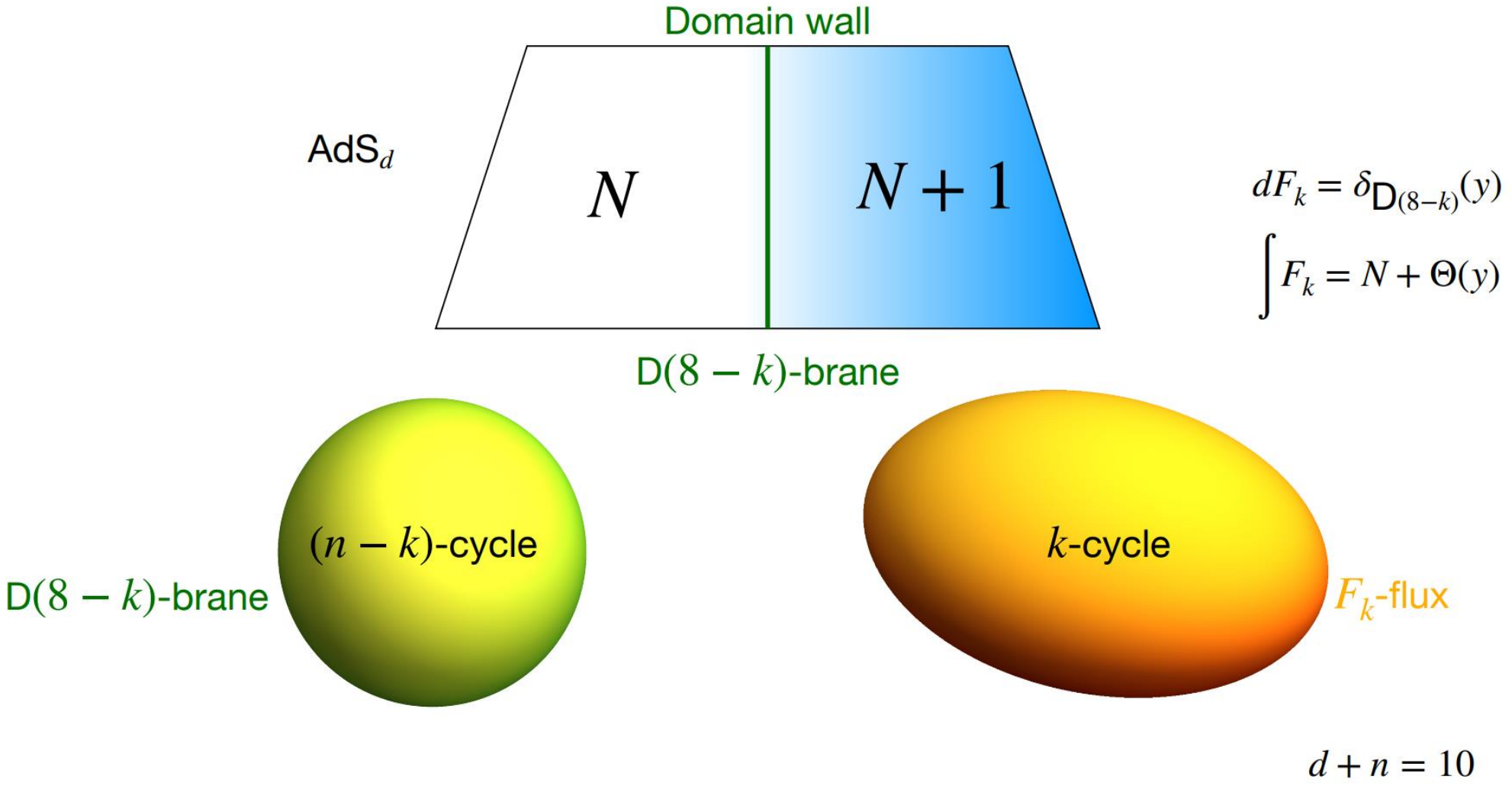
2. Show the distance conjecture is nicely obeyed.

Requires field excursions of “heavy scalars”. Are we ok with this?

2. Proving the fantasy

How to change flux quanta?

1. Thin domain walls

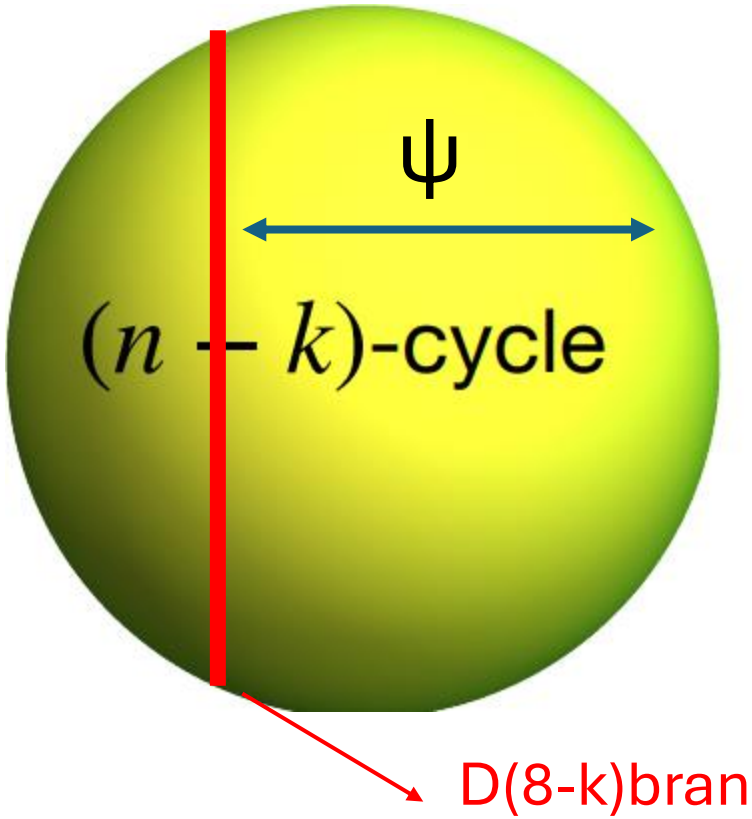


$$dF_k = \delta_{\mathrm{D}(8-k)}(y)$$

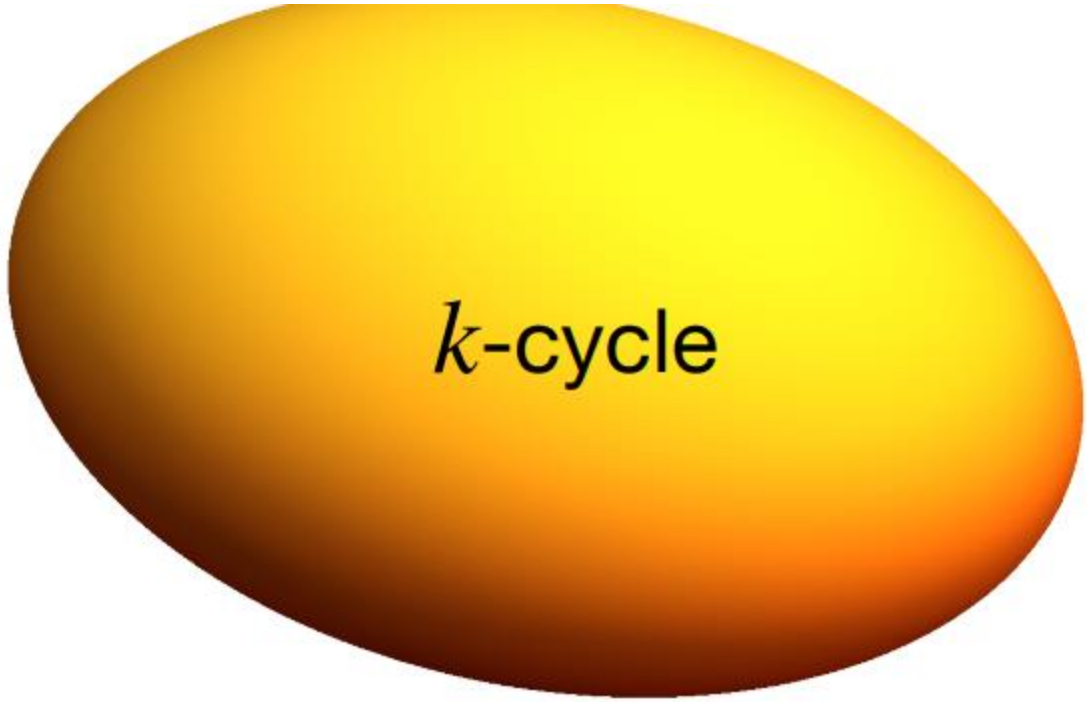
$$\int F_k = N + \Theta(y)$$

$$d + n = 10$$

Co-dimension one = crucial. Always co-dimension one non-compact space? Imagine the D(8-k) brane is co-dimension one **inside** the (n-k)-cycle (instead of wrapping the whole n-k cycle):



Ψ measures position of the brane. “Open string modulus”

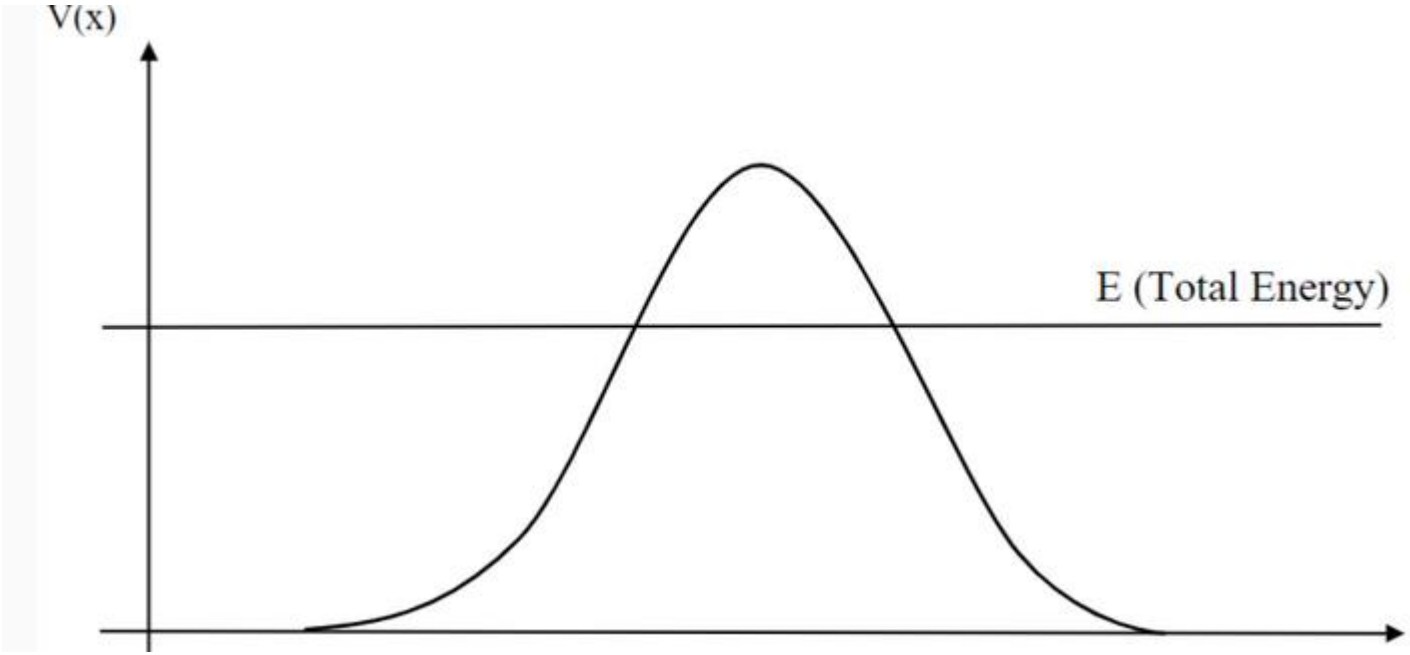


As Ψ runs from left to right the flux will change. But the brane is now space-filling.

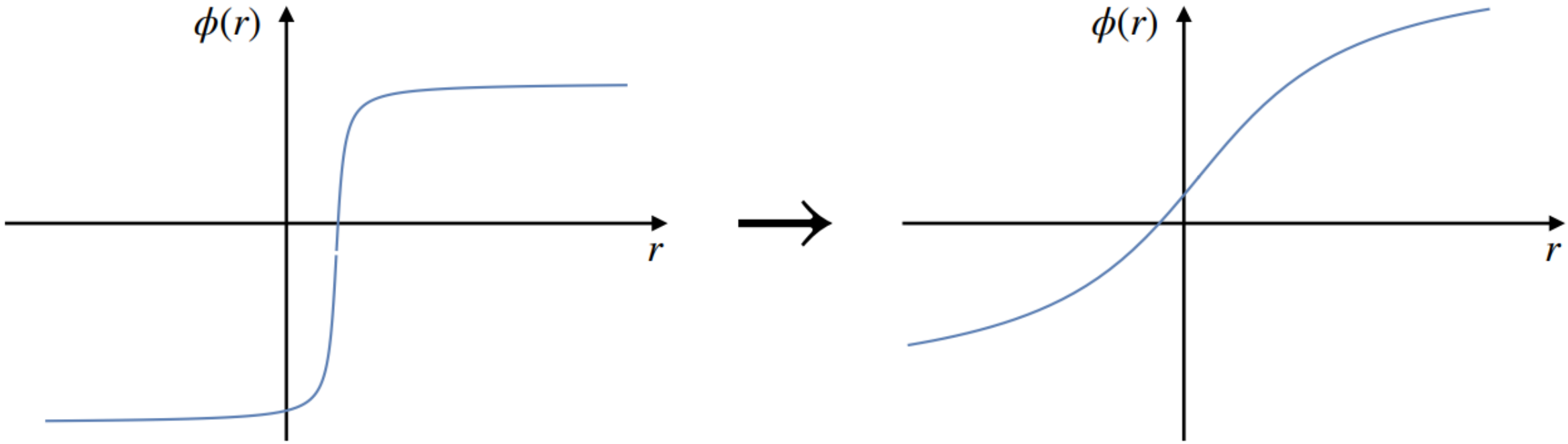
Example: 4d vacuum with F_4 flux inside extra-dimension. Dual 2-cycle wrapped by a D4 brane is a domain wall changing fluxes. Now wrap contractible 1-cycle inside 2-cycle. When the D4 brane pinches off it is gone on both sides. The flux transition will have taken place.

$$\mathrm{d}F_4 = Q_{\mathrm{D4}}\,\delta(y, z^1, z^2, z^3, z^4)\,\mathrm{d}y \wedge \epsilon_4\,, \qquad \Rightarrow \qquad F_4 = [N + Q_{\mathrm{D4}}\theta(y)]\,\epsilon_4\,,$$

This process costs energy: the on-shell action for a motion over the bump equals the tension of a D4 brane wrapping the whole 2-cycle.



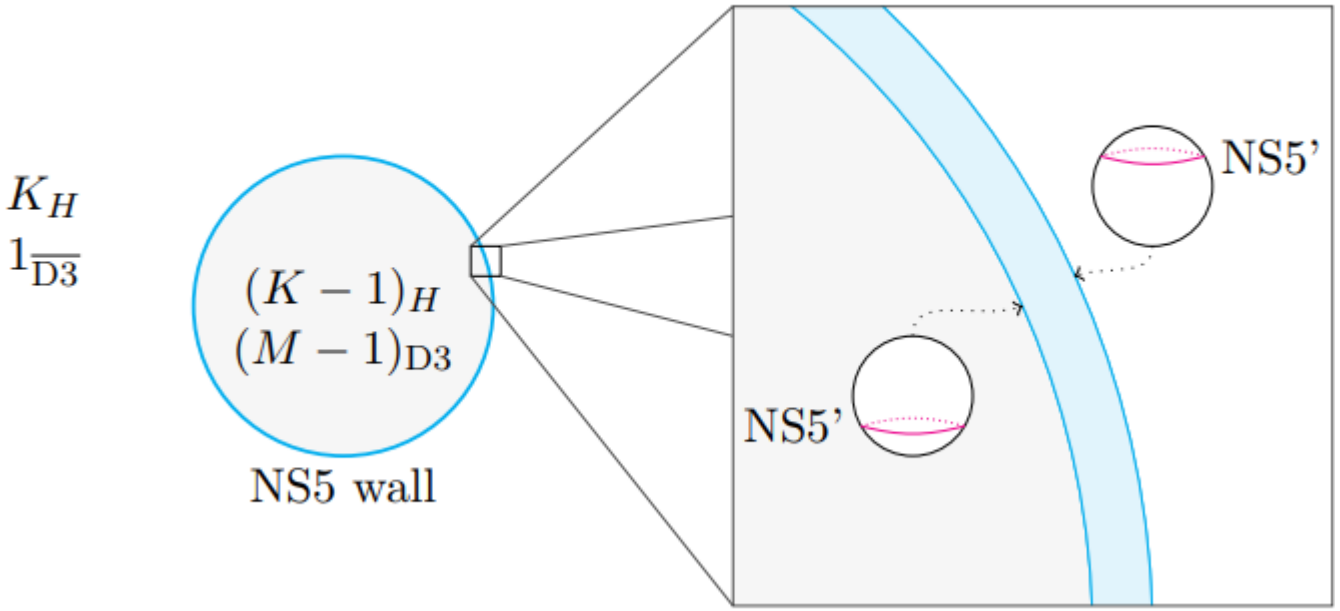
Thin vs thick domain walls? Depends on the UV cut-off? CDL vs BT



This works for many flux vacua we care about

1. IIA flux vacua “a la DGKT” (See also [Camara et al, Derendinger et al 2004])

2. IIB flux vacua: 3-form fluxes can be changed by 5-branes wrapping contractible two cycles inside Poincare dual 3-cycles. But tadpole complicates things and in the same process D3 branes are created. At the heart of brane-flux decay process of KPV 2002:



Freed-Witten effect; an NS5-brane wrapping a cycle filled with M units of F3-flux has M D3-branes attached to it. These D3-branes really puff into the NS5’-branes. So the H-flux changes here happen both inside the 3-cycle and inside 4d space and the two discharges are identical

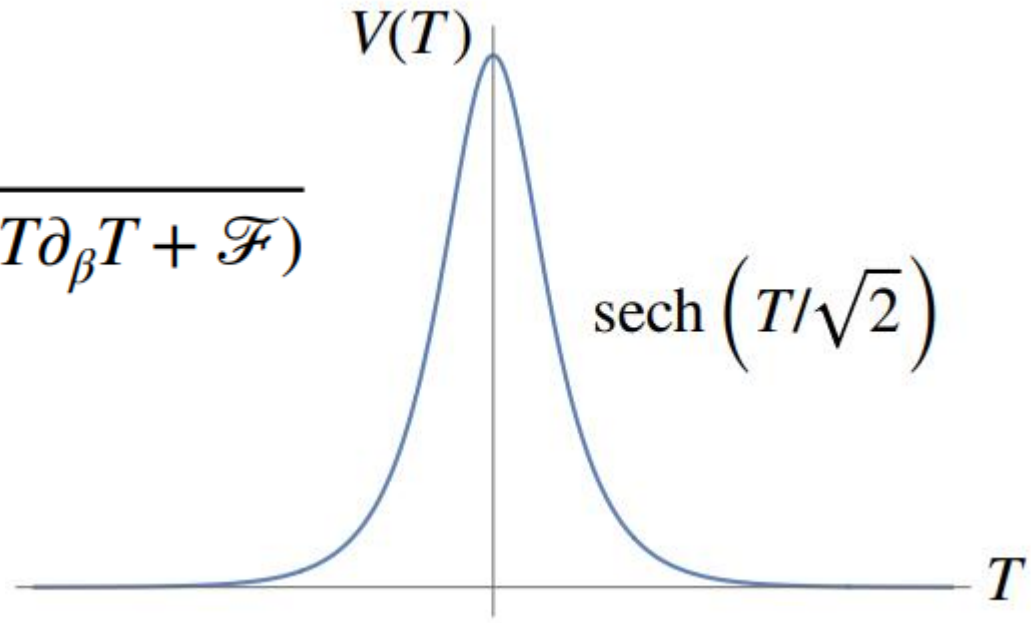
But what about other vacua, more of interest to holography? Say $AdS_5 \times S^5$

We seem to lack the right kind of branes?

→There is yet another way, that relies on the "unstable D-branes" in type II string theory: Dp branes with even p in IIB, odd p in IIA. [Sen 1998-1999].

These branes have a tachyon T in the spectrum.

$$S = -\tilde{\mu}_p \int_{\Sigma_{1,p}} d^{p+1}\xi \, e^{-\Phi} \, V(T) \sqrt{-\det(g_{\alpha\beta} + \partial_\alpha T \partial_\beta T + \mathcal{F})}$$



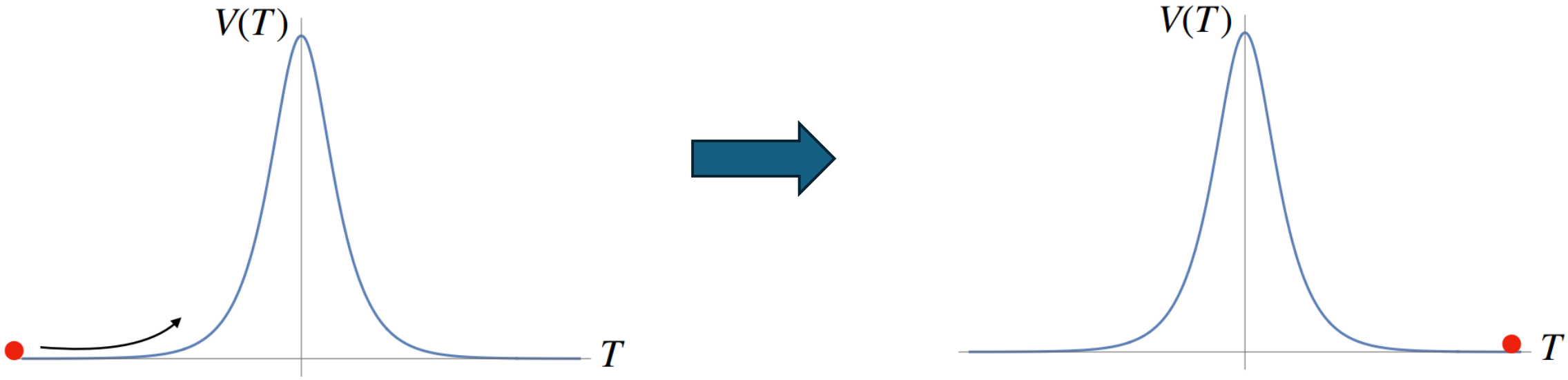
- Tachyon condensation occurs at infinite T values. There the brane disappears.

- But there can be a stable soliton on the unstable brane; a tachyonic "kink" solution behaves exactly like a stable Dp-1 brane!

$$S = -\tilde{\mu}_p \int_{\Sigma_{1,p}} d^{p+1}\xi\, e^{-\Phi}\, V(T) \sqrt{-\det(g_{\alpha\beta} + \partial_\alpha T \partial_\beta T + \mathcal{F})} + \tilde{\mu}_p \int_{\Sigma_{p+1}} C \wedge W(T)\, dT \wedge e^{\mathcal{F}}$$

- $W(T) \sim e^{\mp T/\sqrt{2}}/2$ for $T \to \pm\infty$
- $\tilde{\mu}_p \int_{-\infty}^{\infty} W(T)\, dT = \mu_{p-1}$ $\qquad\qquad$ $\tilde{\mu}_p = \sqrt{2}\,\mu_p$

Our proposal: discharge fluxes by moving in tachyon space.



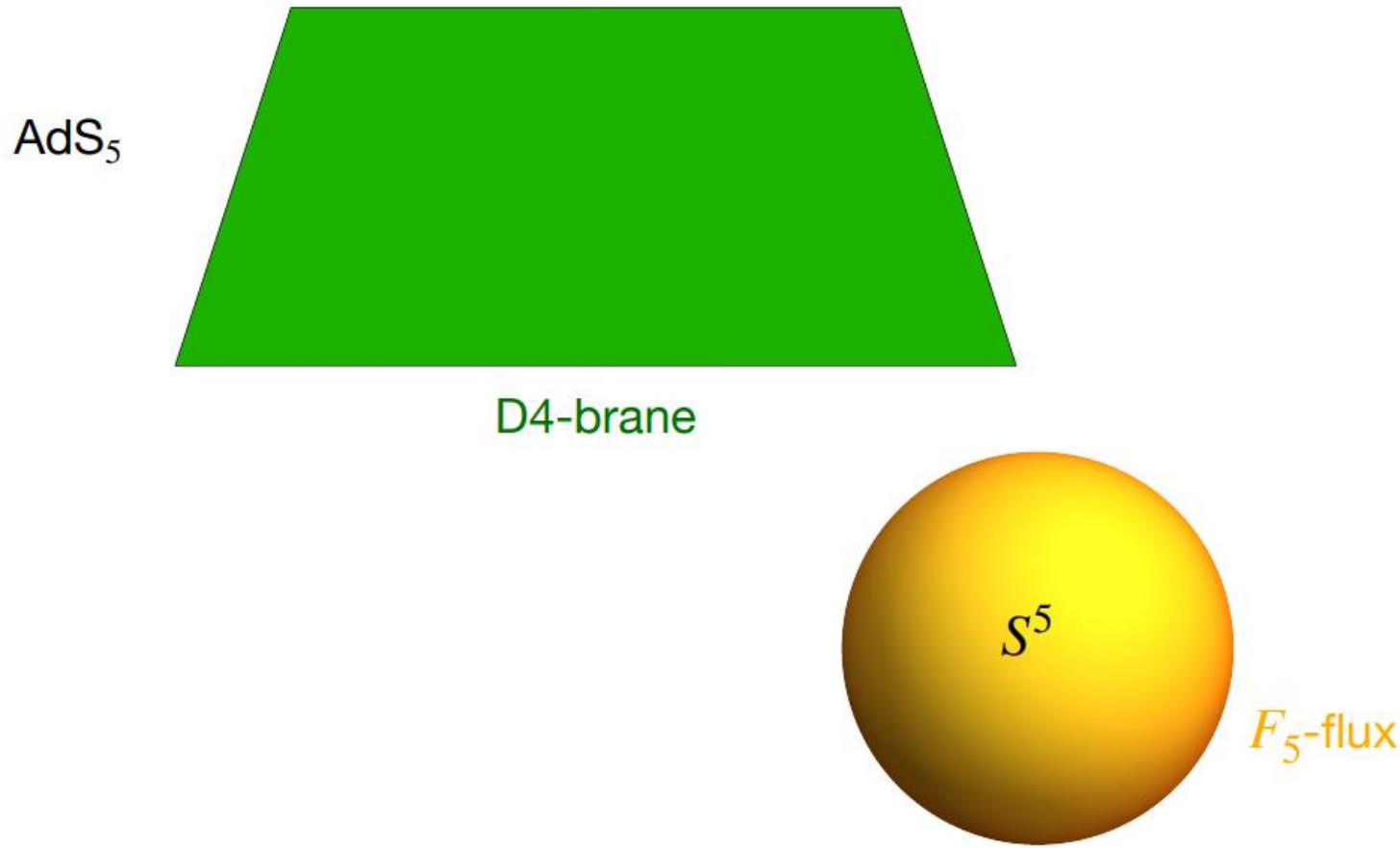
How exactly?

$$dF_k = 2\kappa_{10}^2 \tilde{\mu}_{9-k} W(T)\, dT \wedge \delta(\Sigma_k),$$

$$\int F_k = N + U(T) \text{ with } U(T) = \sqrt{2} \int_{-\infty}^{T} W(S) dS$$

But $U(T = -\infty) = 0$, whereas $U(T = +\infty) = 1$

$AdS_5 \times S^5$ in IIB



Brane not wrapping any cycle

3. Computing distances

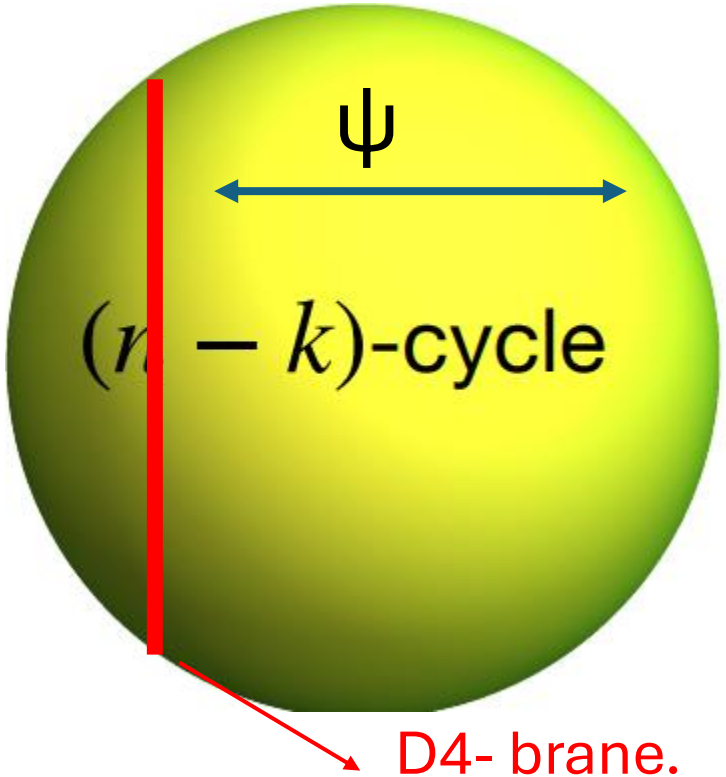
Some of the original claims Ooguri-Vafa 2006:

1. Tower mass scale comes down exponentially with the distance in moduli space
2. At large distances the moduli space metric is negatively curved, most likely hyperbolic.

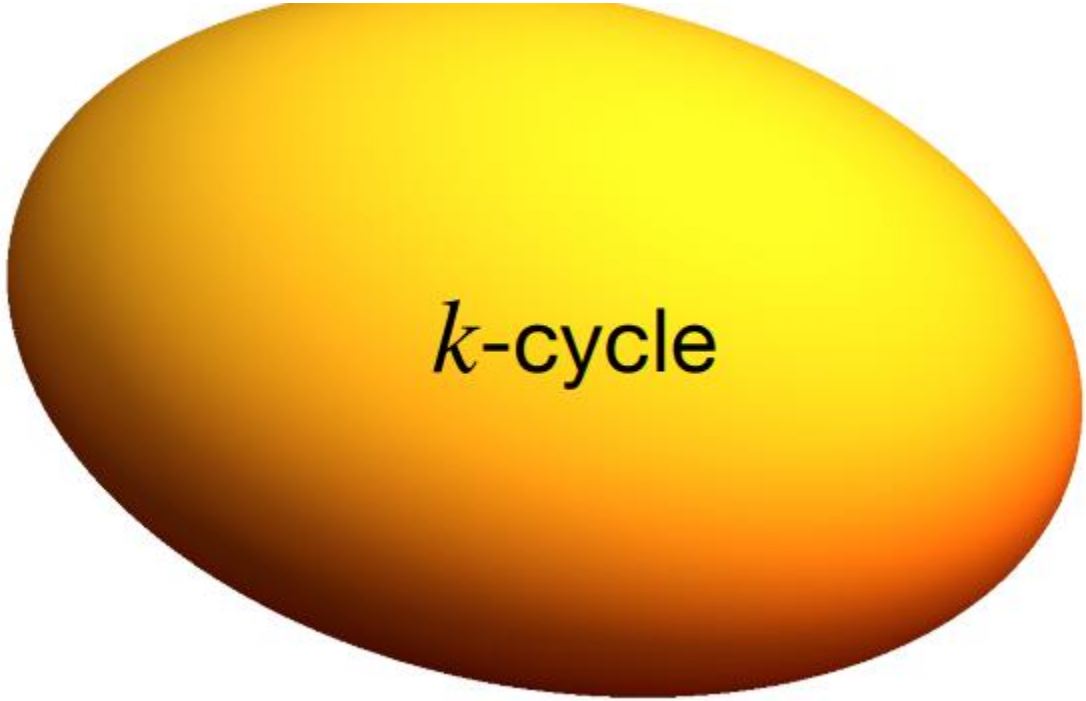
→ We will verify both and this will be consistent with the **WEAK** form of the **AdS distance conjecture**. Not the strong form.

Method 1: Using the space-filling BPS D-branes [2212.06169]

We specify to AdS_4 vacua from IIA orientifold flux reductions



n=6 and k=4.



We discharge the F4 fluxes using D4 branes wrapping a contractible loop on the 2 cycle Poincare-dual to the 4 cycle. Its position Ψ will be our brane modulus.

For every 2-cycle (4-cycle) the local metric looks like:

$$\mathrm{d}s_{10}^2 = g_{\mu\nu}\mathrm{d}x^\mu \mathrm{d}x^\nu + \ell_s^2 L^2 \left[f^2(\psi)\mathrm{d}\varphi^2 + \mathrm{d}\psi^2\right] + \mathrm{d}s_{\Sigma_4}^2 .$$

and contributes to the kinetic term of Ψ the following

$$S_{\mathrm{D4}} = -2\pi\ell_s L\mu_4 \int \mathrm{d}^4x\sqrt{-g_4}\,\mathrm{e}^{-\phi}|f(\psi)|\sqrt{1+\ell_s^2 L^2(\partial\psi)^2}\,,$$

We want to use this to compute the distance travelled between flux vacua with different F_4 flux quanta

$$\Delta = \int_0^1 \mathrm{d}s\,\frac{1}{M_{\mathrm{Pl}}}\sqrt{g_{\alpha\beta}\,\frac{\mathrm{d}\varphi^\alpha}{\mathrm{d}s}\,\frac{\mathrm{d}\varphi^\beta}{\mathrm{d}s}}\,.$$

But in the typical solutions we have multiple 2-cycles. DGKT has three 2-cycles and so characterized by 3 integers: N_1, N_2, N_3.

Changing the N's changes the vacua and thus the value of the stabilized moduli. Hence we compute distances in a field space consisting of:

Ψ, Dilaton ϕ, Kahler moduli σ_i i=1,2,3.

After some simple computation we have:

$$\Delta = \int_0^1 \mathrm{d}s \sqrt{\gamma\, \mathrm{e}^{D-\sum_{j=1}^3 \sigma_j} \sum_{i=1,2,3} \mathrm{e}^{3\sigma_i} |f(\psi_i)| \left(\frac{\mathrm{d}\psi_i}{\mathrm{d}s}\right)^2 + 2\left(\frac{\mathrm{d}D}{\mathrm{d}s}\right)^2 + 2\sum_{i=1,2,3}\left(\frac{\mathrm{d}\sigma_i}{\mathrm{d}s}\right)^2}.$$

D is the 4d dilaton: $D = \phi - \sum_{i=1}^3 \sigma_i,$

After some field redefs this metric can be brought to the hyperbolic form.

Since we know how the KK masses depend on the moduli positions (the vevs) we can verify the distance conjecture and find it to be exactly obeyed with coefficient

$$m \sim m_0 \, \mathrm{e}^{-\beta\Delta} \qquad \text{where} \qquad \beta = \frac{1}{\sqrt{206}} \qquad \Delta = \sqrt{\frac{103}{8}} \log(N)$$

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Method 2: Using the space-filling non-BPS D-branes [2311.10828]

Applies universally to all flux compactifications.

Now field metric includes tachyon. When applied to known examples, hyperbolic metric +distance conjecture obeyed. Eg

a) $AdS_5 \times S^5$: $\beta = \frac{3}{\sqrt{184}}$ $\Delta = \sqrt{\frac{23}{6}}\log(N)$

b) DGKT: $\beta = \frac{1}{\sqrt{126}}$ $\Delta = \sqrt{\frac{63}{8}}\log(N)$

Some thoughts

Was this all valid?

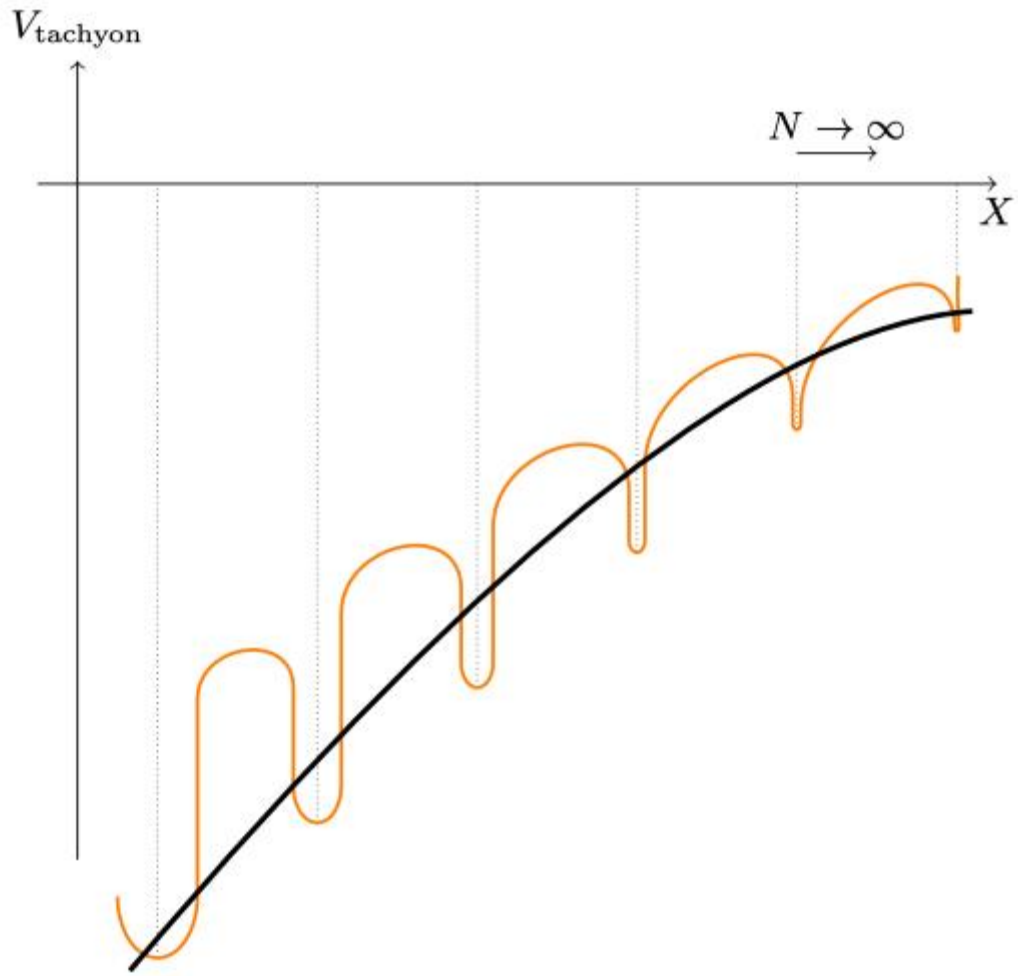
Are the open-string moduli that make the scalar potential single valued, in my EFT?

→ Depends on your cut-off. What is the mass of T?

$$m^2_{tachyon} \sim g^{-1}_{XX}\, \partial^2_X V_{tachyon} \sim m_s^2 \qquad \Longrightarrow \qquad m_{tachyon} \gg m_{KK}$$

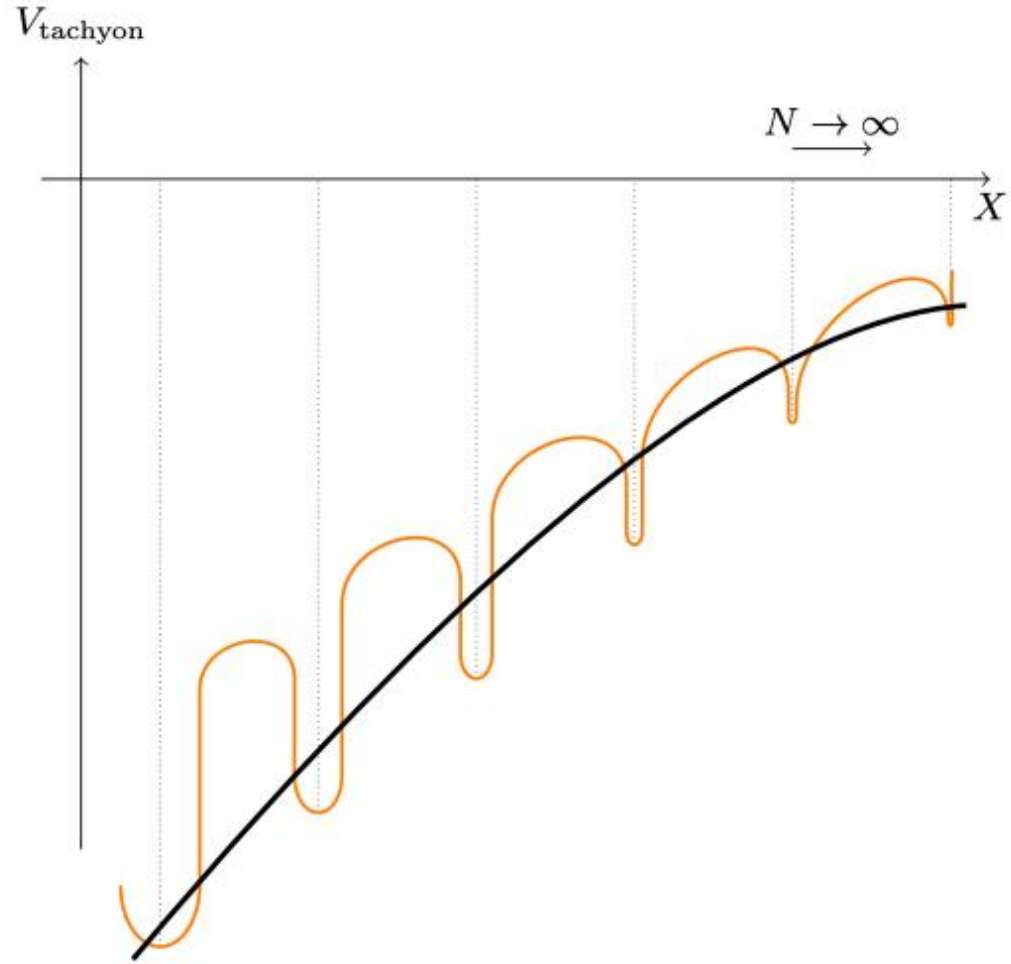
For the other method where one can use space-filling Dp branes we found a mass of the order KK scale.

But be careful: mass is only a measure of the second derivative in the vacuum. Let us draw the potential and its energy scales:


V_{tachyon}
$N \to \infty$
X

Tachyon energy lower than flux energy:

- DGKT in mIIA: $\frac{V_{tachyon}}{V_{flux}} \sim N^{-1/4}$
- $AdS_5 \times S^5$ in IIB: $\frac{V_{tachyon}}{V_{flux}} \sim N^{-3/4}$



In large N-regime, wiggles become smaller and smaller:

→ Small kinetic energy in AdS-units ⇒ like wiggles are not there, like runaway potential

“**Continuous** cobordism conjecture”

If one extends the cobordism conjecture lore to demanding that transitions between vacua can happen continuously then one postdics the unstable Dp branes of string theory.

Then our proposal also implies the existence of extended non-BPS objects with NS5-charge in string theory and non-BPS objects with M2- or M5-charges in M-theory. The idea is again that BPS thin domain walls are described as thick domain walls that lift to space-filling non-BPS branes.

Summary:

- Our understanding of the validity and use of the distance conjecture beyond pure moduli spaces remains incomplete.
- We describe a general method to compute distances between AdS vacua using a valid 10d picture.
- Distance conjecture obeyed for few checked examples although the potential for T or ψ has regions with gradients above the cut-off the EFT “one typically uses”.
- Our results are nicely consistent with the weak AdS distance conjecture since both the cosmological constant and the mass scale depend powerlaw on the flux quanta N.