AdS scale separation and the distance conjecture

2212.06169 with Gary Shiu, Flavio Tonioni and Thomas Van Riet

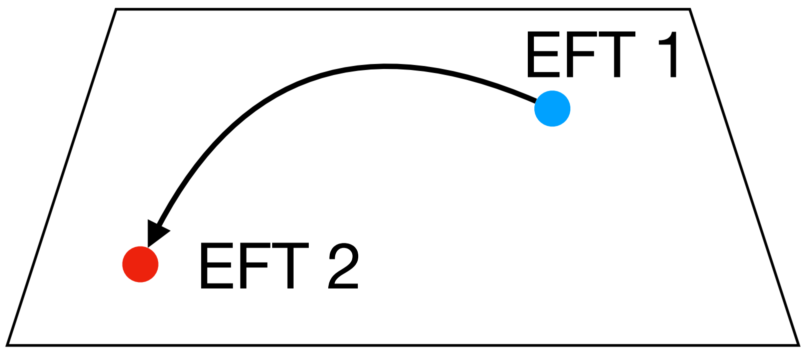
String Phenomenology 2023

KU LEUVEN

fwo Opening new horizons

AdS distance conjecture

[Lüst, Palti, Vafa, 2019]



Metric space

AdS distance conjecture:

$$m_{tw} = m_0 |\Lambda|^\alpha \text{ for } \Lambda \to 0$$

Inspired from the swampland distance conjecture

Strong version for SUSY AdS: $\alpha = \frac{1}{2}$

→ Forbids scale separation with KK tower

$$m_{tw} \propto 1/L_{KK}, \quad \Lambda \propto L_{\text{AdS}}^{-2}, \qquad \Longrightarrow \qquad L_{KK} \sim L_{\text{AdS}}$$

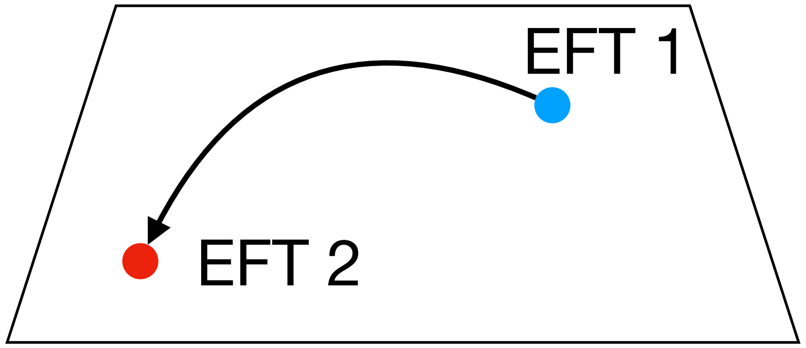
Remarks:

1. Λ is determined by quantised fluxes, not a continuous quantity

2. Counterexamples to strong ADC are known: DGKT

AdS distance conjecture

[Lüst, Palti, Vafa, 2019]



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Can we go beyond the notion of AdS distance and use the ordinary distance conjecture instead?

Scale-separated vacua in mIIA

On orbifolded $\mathbb{T}^6$/Calabi-Yau

[DeWolfe, Kachru, Giryavets, Taylor, 2005]
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$$H_3 = 2m\,\mathrm{Re}\Omega$$

$$g_s F_0 = 5m$$

$$g_s F_2 = 0$$

$$g_s F_4 = \frac{3}{2} m J \wedge J$$

$$g_s F_6 = 0$$

$$dJ = 0$$

$$d\mathrm{Im}\Omega = 0$$

$$dF_2 = H \wedge F_0 + j_{O6}$$

$$L_{AdS}^{-2} = m^2$$

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n is the F_4 flux quantum and labels the flux vacua

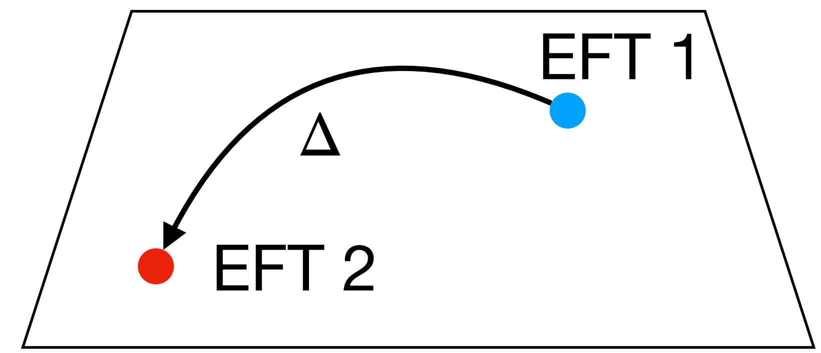
(Refined) Swampland distance conjecture

[Ooguri, Vafa, 2006], [Kläwer, Palti, 2016]

$$K = -\frac{1}{2} g_{ij} \partial_\mu \Phi^i \partial^\mu \Phi^j$$

$m_{tw} = m_0 e^{-\alpha\Delta}$ for $\Delta \to \infty$

$$\Delta = \int ds \frac{1}{M_{Pl}} \sqrt{g_{ij} \frac{d\Phi^i}{ds} \frac{d\Phi^j}{ds}}$$



Field space

Refined version: from moduli to all fields

For DGKT:

Flux vacua are labeled by flux quantum n

→ Invent a field that interpolates between different flux vacua

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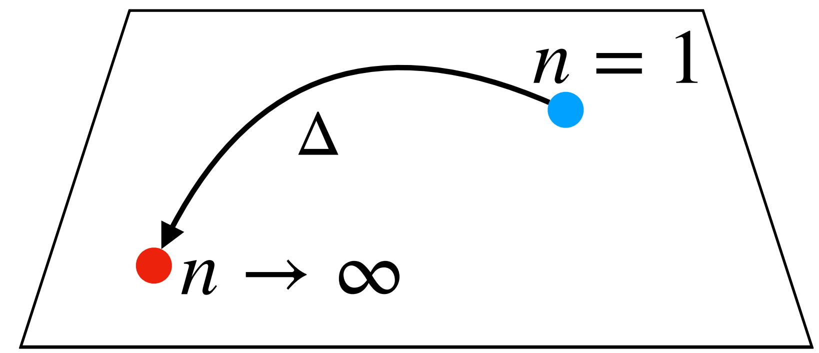

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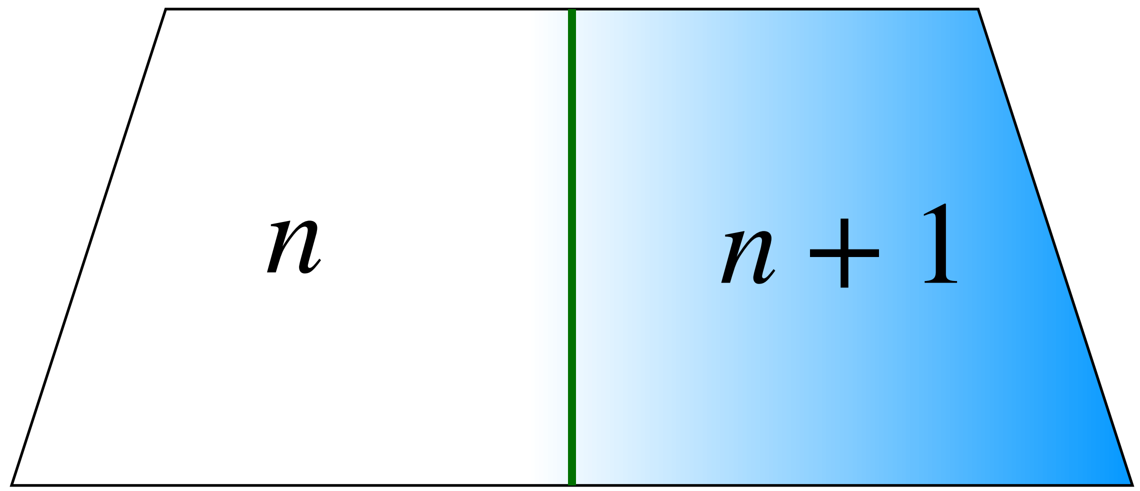
D4 domain wall

[Aharony, Antebi, Berkooz, 2008]

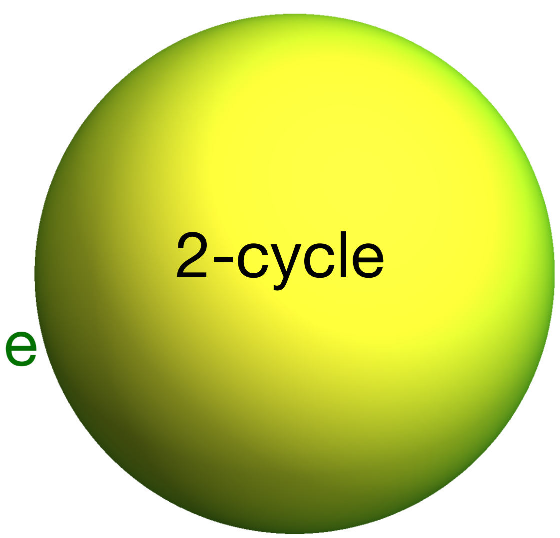
Domain wall

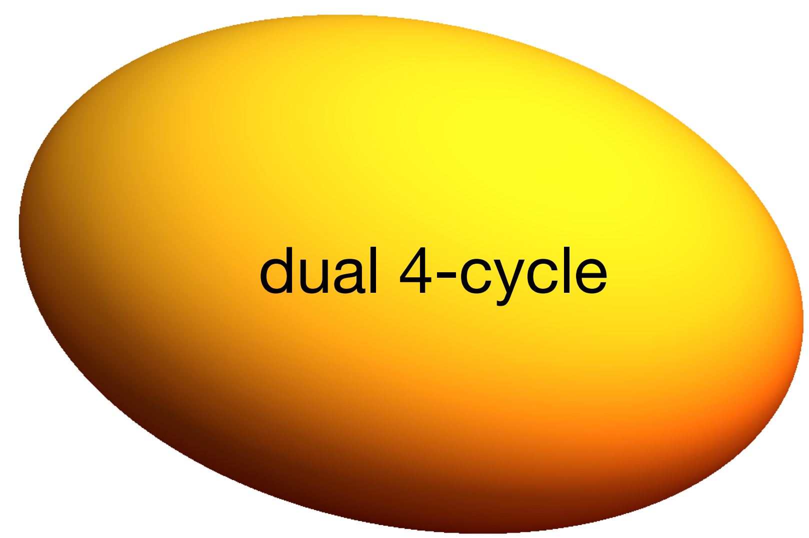


D4-brane

$$dF_4 = \delta_{\mathrm{D4}}(y)$$
$$F_4 = [n + \Theta(y)]\omega_4$$

D4-brane



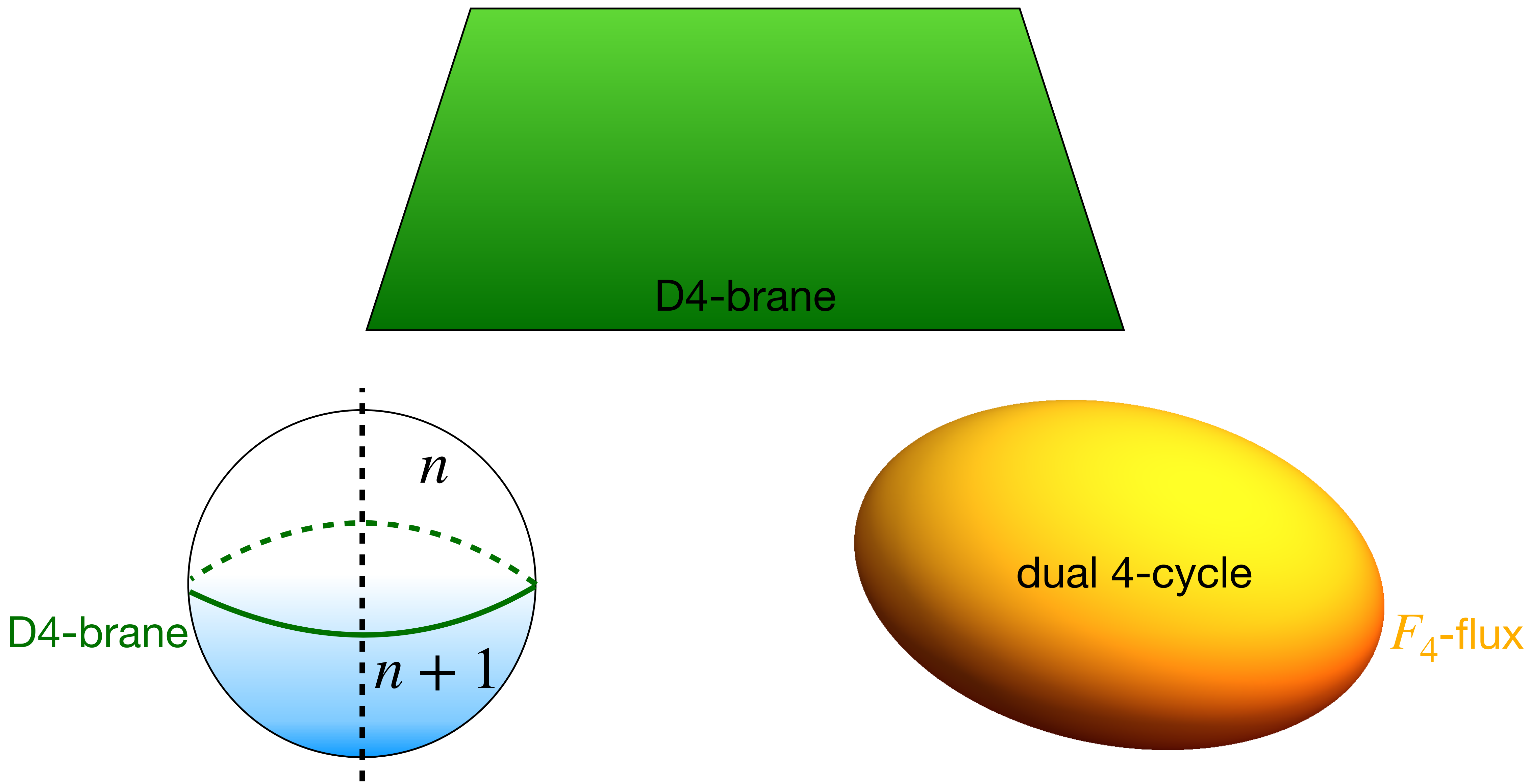


F_4-flux

Put the domain wall in the compact dimensions

D4-brane on contractible cycle

[Shiu, Tonioni, VVH, Van Riet, 2022]



Position modulus ψ controls the flux:
at $\psi = 0, \pi, 2\pi, \ldots$ different vacua with flux $n, n+1, n+2, \ldots$

'KPV' in type IIA

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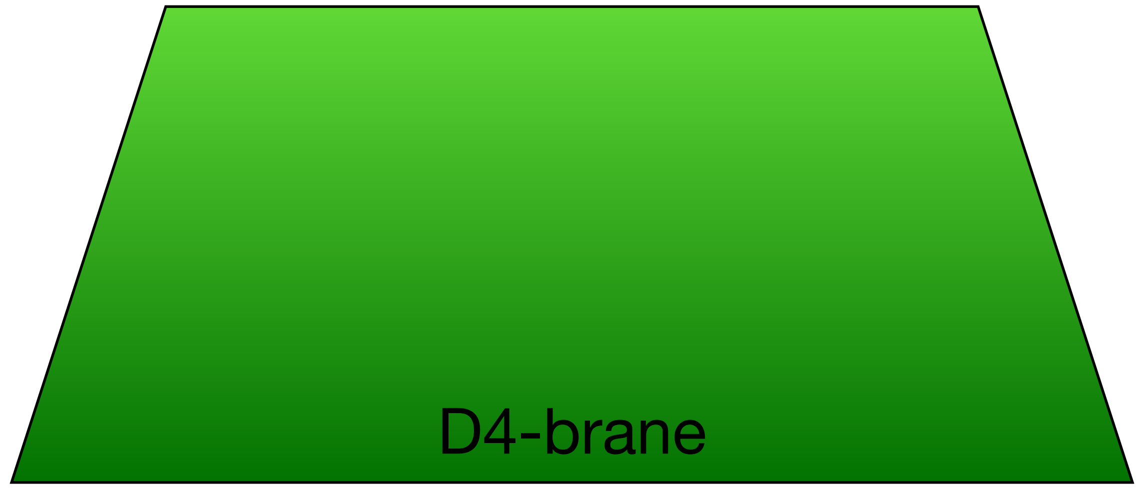

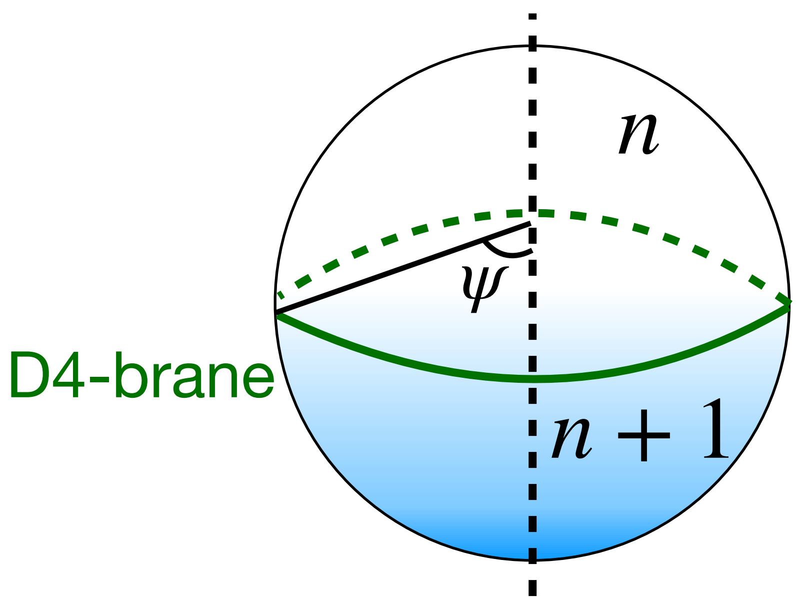

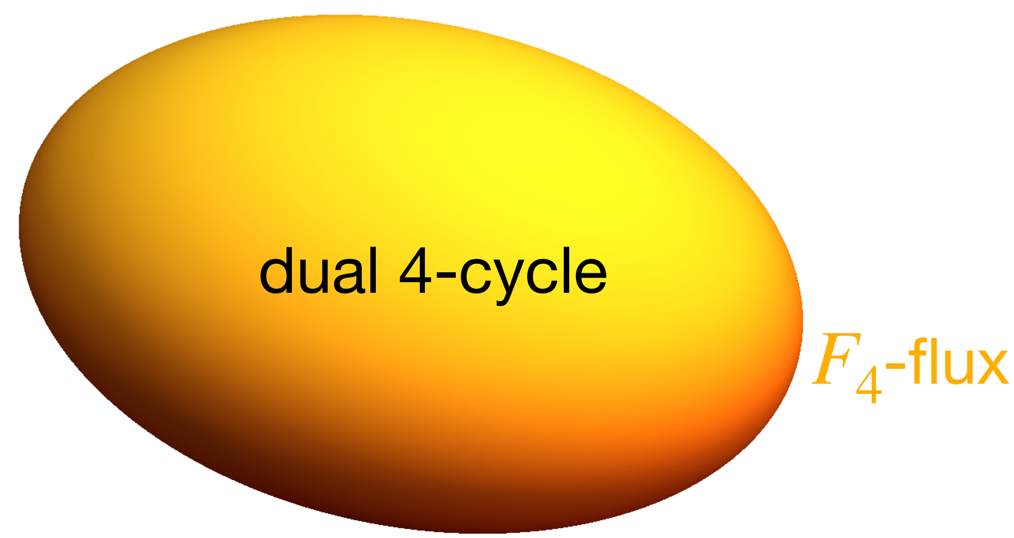

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Field space metric

Start from local metric

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

Metric pulled-back on D4 worldvolume:

$$\mathrm{d}s^2|_{D4} = (g_{\mu\nu} + L^2\partial_\mu\psi\partial_\nu\psi)\mathrm{d}x^\mu \mathrm{d}x^\nu + L^2 f^2(\psi)\mathrm{d}\varphi^2$$

Put in DBI-action and expand

Field metric from DBI: $\dfrac{g_{\psi\psi}}{M_{Pl}^2} = \gamma \mathrm{e}^{\phi} L^3 |f(\psi)|$

Field distance

After field redefinitions:

$$\Delta = \int \mathrm{d}s \sqrt{g_{ab} \frac{\mathrm{d}\varphi^{\mathrm{a}}}{\mathrm{d}s} \frac{\mathrm{d}\varphi^{\mathrm{b}}}{\mathrm{d}s}}$$

$$= \int \mathrm{d}s \sqrt{\frac{8}{z^2} \left[\left(\frac{\mathrm{d}x}{\mathrm{d}s} \right)^2 + \left(\frac{\mathrm{d}z}{\mathrm{d}s} \right)^2 \right] + 6 \left(\frac{\mathrm{d}\sigma}{\mathrm{d}s} \right)^2}$$

$$\frac{\mathrm{d}x}{\mathrm{d}\psi} = \sqrt{3\gamma\,|\,f(\psi)\,|\,/8}, \qquad z = \exp(-D/2) = \exp(-\phi/2)L^{3/2}, \qquad \sigma = \log L$$

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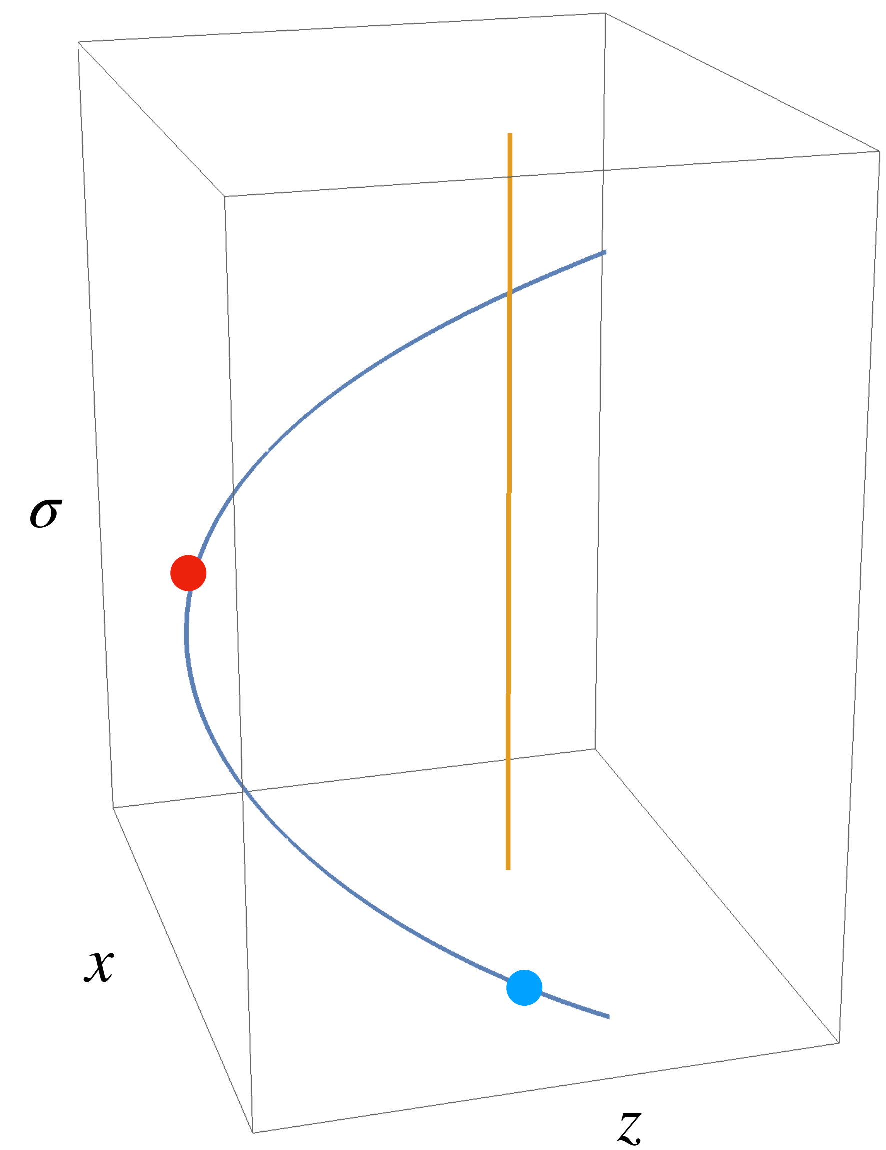
Geodesic distance

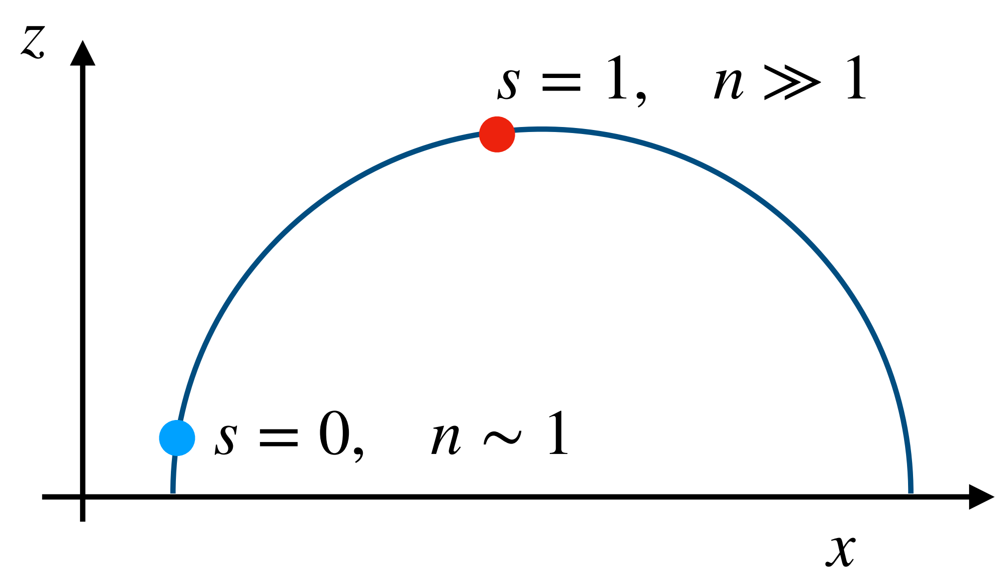
Geodesics on $\mathbb{H}^2 \times \mathbb{R}$ are simple: helices

3 fields, 6 integration constants to be fixed by boundary conditions

Only 2 matter for the distance:

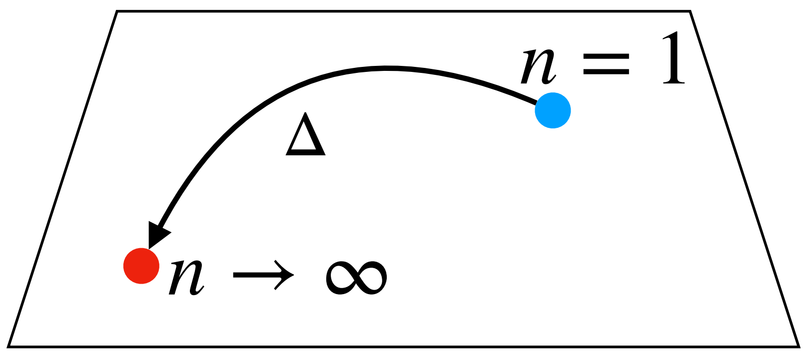
$$\Delta = \sqrt{8d_1^2 + 6d_3^2}$$





The distance conjecture is satisfied!

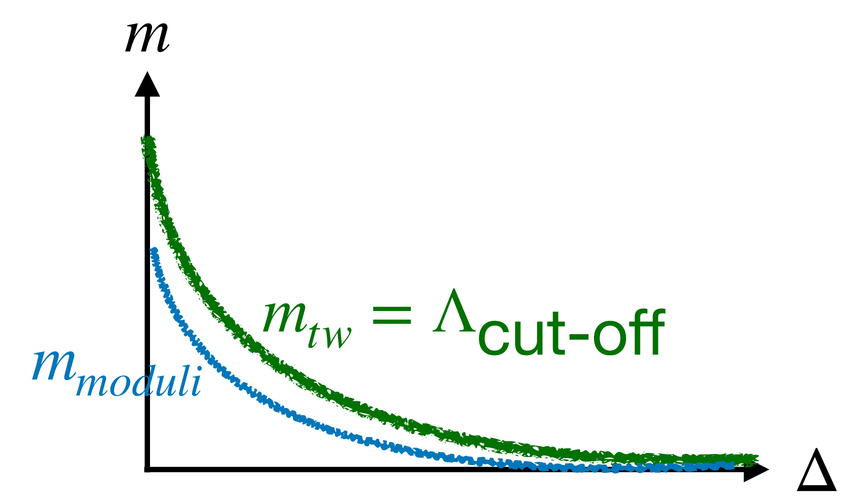
We find $\Delta = \sqrt{\frac{103}{8}} \log n \to$ mass of tower polynomial in n



Field space

For KK-tower:

$$\frac{m_{KK}}{m_0} \sim n^{-1/4} \sim \mathrm{e}^{-\beta\Delta} \implies \beta = 1/\sqrt{206}$$



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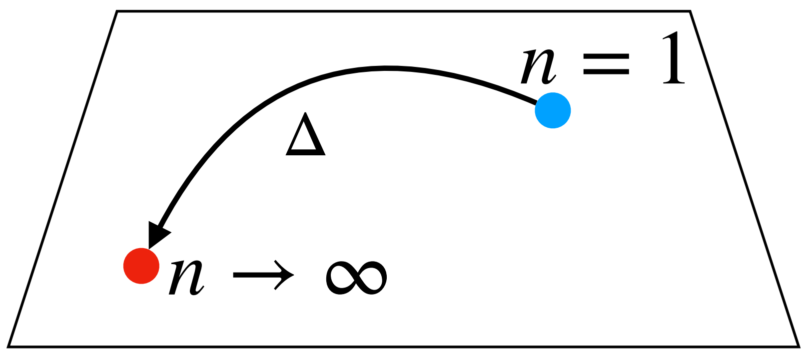

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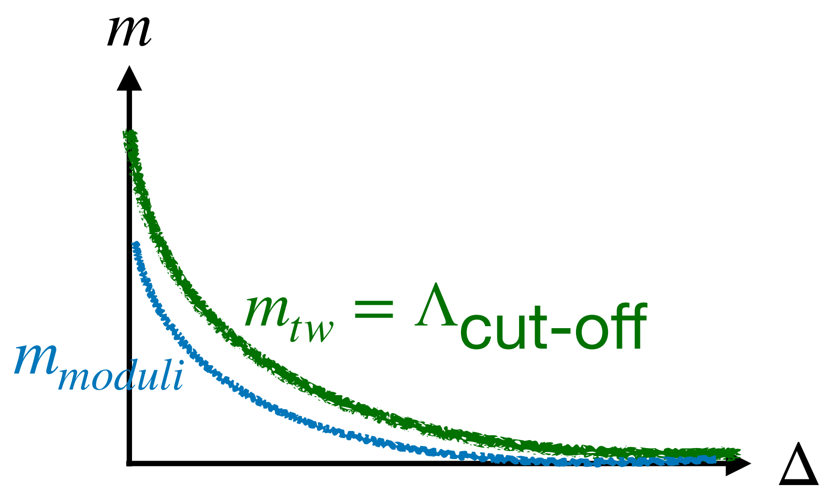

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The swampland distance conjecture does not invalidate the EFT!

Summary

1. Interpolating between DGKT flux vacua with D4-brane moduli

2. Field space becomes simple: $\mathbb{H}^2 \times \mathbb{R}$

3. DGKT vacua pass the test of the distance conjecture

Similar for scale-separated AdS$_3$ vacua on G_2-manifolds

[Farakos, Tringas, Van Riet 2020]

Extended to AdS$_3$ models where scale separation can be turned on/off

[Farakos, Morittu, Tringas, 2023]

Go beyond DGKT: Extend to other flux vacua: massless type IIA

[Cribiori, Junghans, VH, Van Riet, Wrase, 2021]

See how it relates with other proposals for AdS distances

[Li, Palti, Petri, 2023]

Thank you!

Field space metric

From DBI-action of the D4-brane

10d metric near D4-brane:

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

DBI expanded:

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

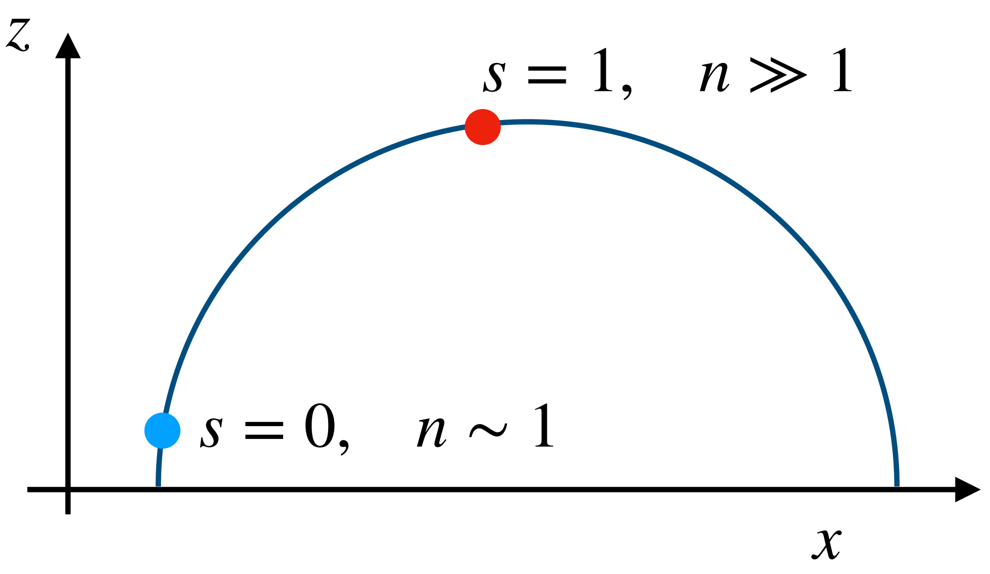
Metric: $\dfrac{g_{\psi\psi}}{M_{Pl}^2} = \gamma \mathrm{e}^{\phi} L^3\,|f(\psi)|$

Geodesic distance

$$x(s) = l\cos[h(s)] + x_0, \qquad z = l\sin[h(s)], \qquad \sigma(s) = d_3 s + d_4 s$$

$$h[s] = 2\arctan\left[\tanh\left(\frac{d_1 s + d_2}{2}\right)\right]$$

$$\Delta = \sqrt{8d_1^2 + 6d_3^2}$$



Integration constants determined by boundary conditions

Comments on energy scales

- Effective mass of D4: $g^{\psi\psi}\partial_\psi^2 V(\psi) \ \sim m_{KK}$
- But $V(\psi)/V_{\text{flux}} \sim n^{-1/2}$: D4-brane energy density becomes parametrically smaller
- KK-modes would shorten distance even further
- Flux unwinding with D4-branes is <u>not</u> a dynamical proces

- 3 four-cycles $\Rightarrow$ 3 F_4-fluxes $\Rightarrow$ 3 D4-branes necessary