Title: Emergent State-Dependence in Holographic Models of Black Holes

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Abstract:

State Dependence in Holographic Models of Black Holes

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Motivation

- Information tranfer through weak interactions
  [Giddings etal]

- Coupling between entangled CFTs dual to AdS - Schwarzschild wormhole allows to glean information from behind the horizon
  [Gao, Jafferis & Wall; Stanford & Maldacena;..]

- Interaction (in addition to entanglement) between the dual CFT and its thermofield double (through heat bath) may avoid firewalls/information paradoxes [Chowdhury,…]

- State-dependent operators
  [Papadodimas & Raju]

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  [Papadodimas & Raju]

Bulk Model

Consistent truncation of N=8 SUGRA to gravity in AdS_4 coupled to an $m^2 = -2$ scalar with potential

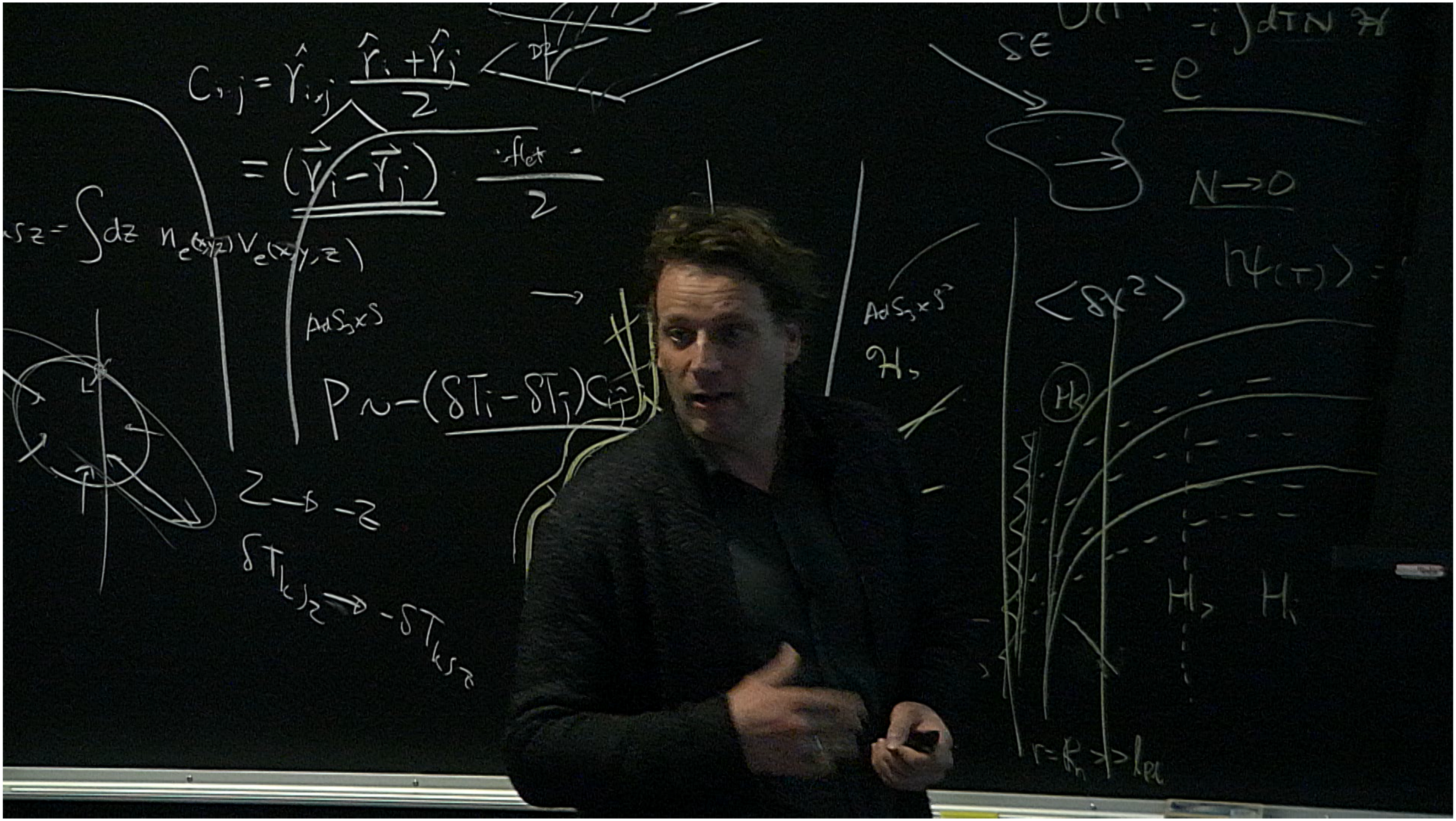
$$V(\phi) = -2 - \cosh(\sqrt{2}\phi)$$

In all asymptotically AdS solutions, the scalar falls off like

$$\phi = \frac{\alpha}{r} + \frac{\beta}{r^2}$$

Consider designer gravity boundary conditions:
[TH & Horowitz]

$$\beta(\alpha)$$



Dual Description

The 3D dual is ABJM theory, which has 8 scalars. With $\beta = 0$ boundary conditions the bulk scalar is dual to the $\Delta = 1$ operator

$$\mathcal{O} = Tr(\phi_1^2 - \phi_2^2)$$

Designer gravity boundary conditions correspond to adding a multi-trace interaction $W(\mathcal{O})$ such that

$$\beta = \frac{\delta W}{\delta \alpha}$$

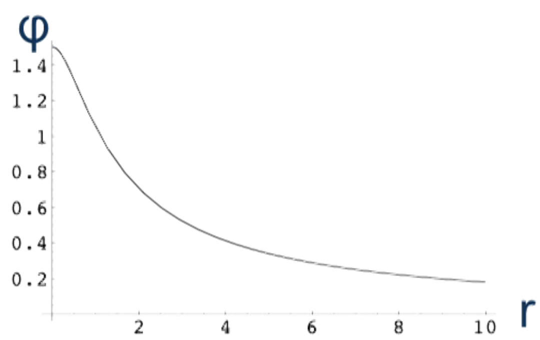
Vacuum structure: bulk

$$\beta_{bc}(\alpha) = -c_1\alpha^2 + c_2\alpha^3$$

Solitons?

$$ds^2 = -h(r)e^{-2\chi(r)}dt^2 + h^{-1}(r)dr^2 + r^2 d\Omega$$

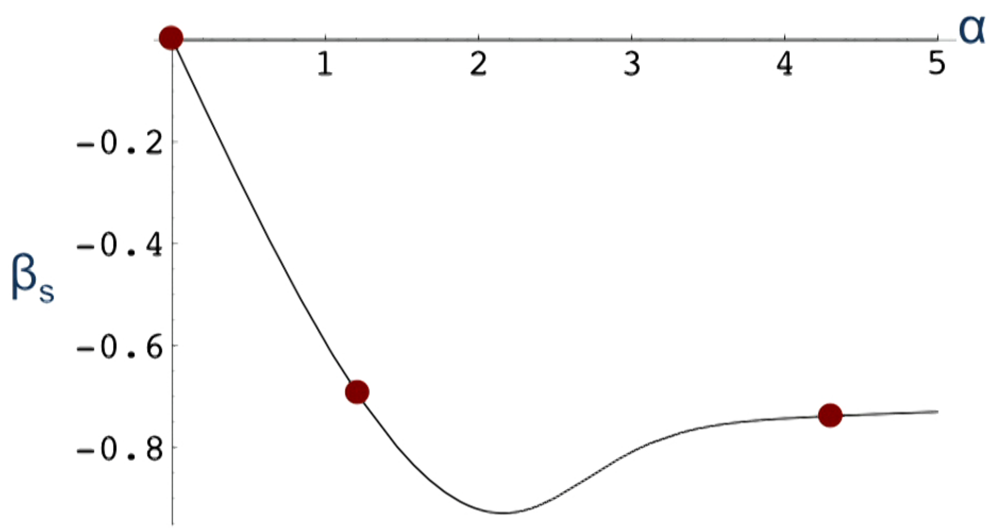
Regularity at origin: h=1, h'=φ'=χ'=0



φ(0) --> (α,β)

Vacuum structure: bulk

$$\beta_{bc}(\alpha) = -c_1\alpha^2 + c_2\alpha^3$$

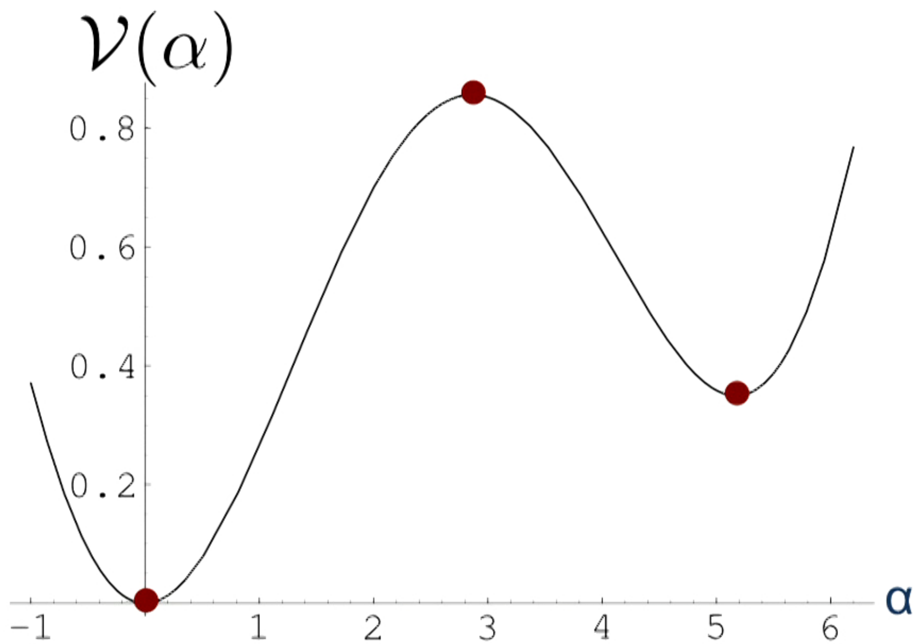


Solitons: $\beta_s(\alpha) = \beta_{bc}(\alpha)$

$$M = \mathrm{Vol}(S^2)\,[M_0 + \alpha\beta + W]$$

Vacuum structure: dual

$$\mathcal{V}(\alpha) = -\int_0^{\alpha} \beta_s(\tilde{\alpha})d\tilde{\alpha} + W(\alpha)$$



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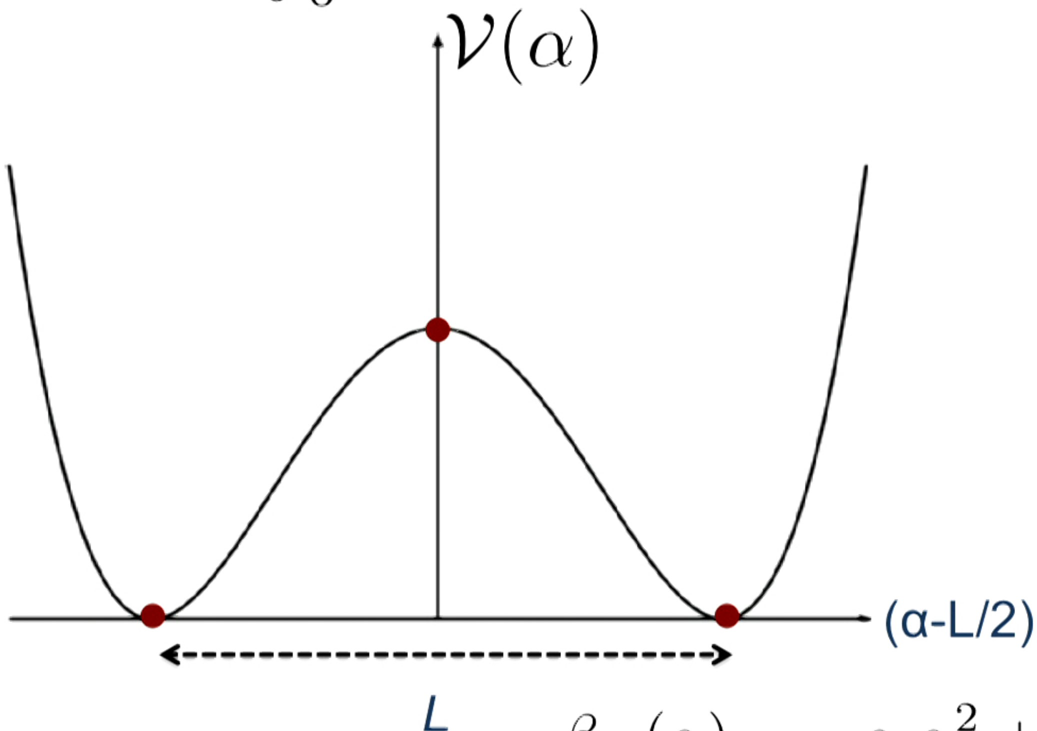


$$\beta_{bc}(\alpha) = -c_1\alpha^2 + c_2\alpha^3$$

Black Holes

$$ds^2 = -h(r)e^{-2\chi(r)}dt^2 + h^{-1}(r)dr^2 + r^2 d\Omega$$

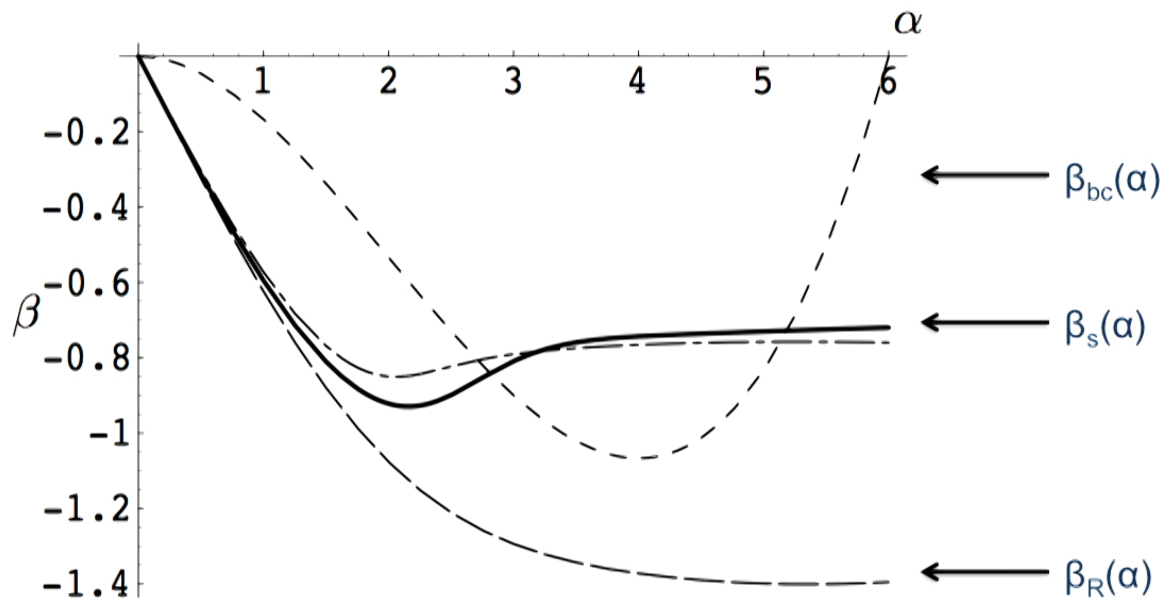
Regularity at horizon:

$$\phi'(R_e) = \frac{V_{,\phi}}{h_{,r}} = \frac{R_e V_{,\phi_e}}{1 - R_e^2 V(\phi_e)}$$

$\varphi(R_e)$ --> (α,β)

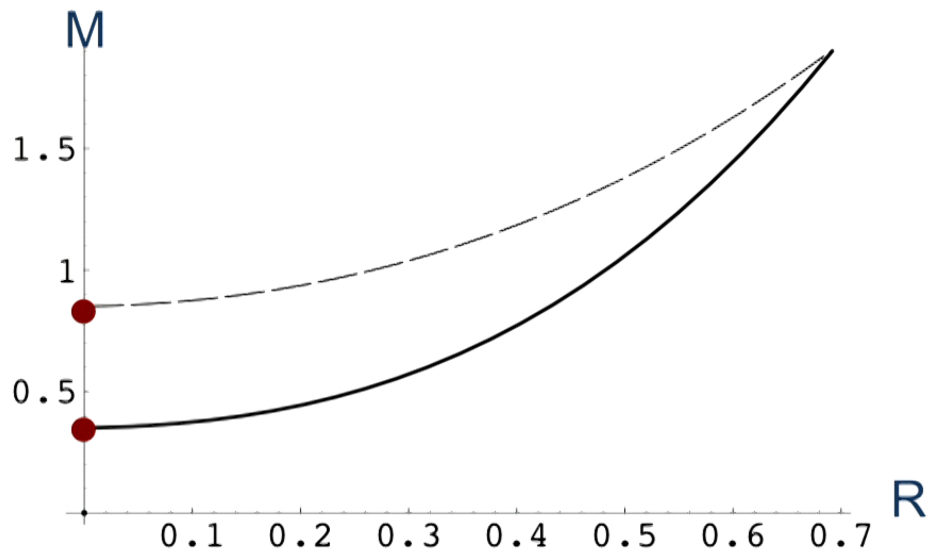
1. Schwarzschild-AdS black holes: $\varphi = 0$ outside horizon
2. Black holes with scalar hair

Black Holes



Black holes with hair: $\beta_R(\alpha) = \beta_{bc}(\alpha)$

Black Holes

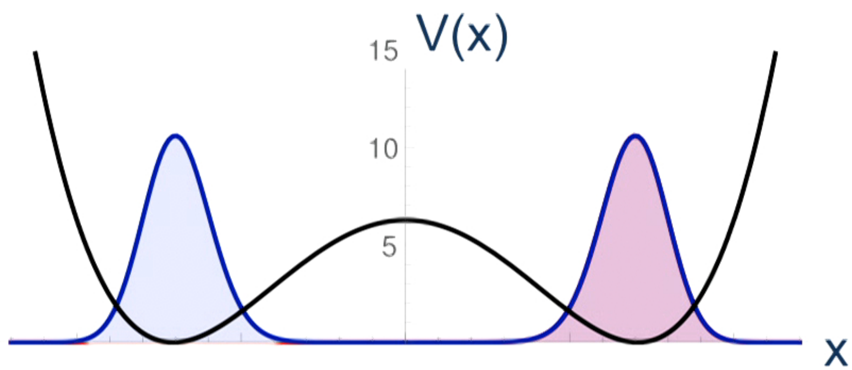


Black holes with hair: $\beta_R(\alpha) = \beta_{bc}(\alpha)$

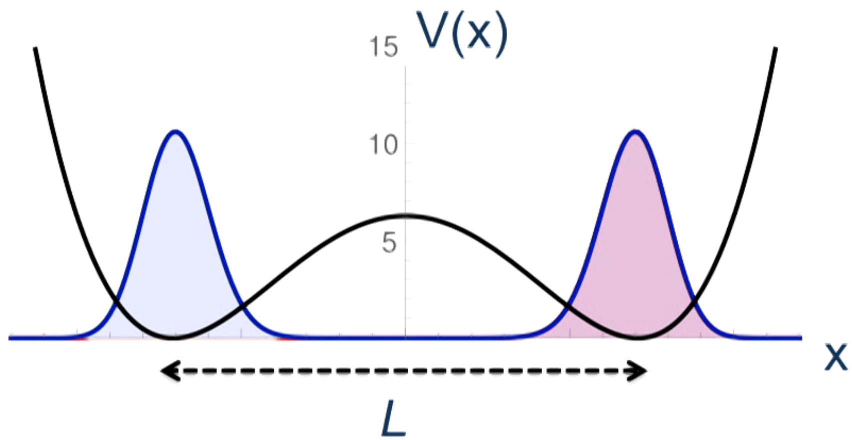
Black Holes: dual description

Black holes with hair: Schwarzschild - AdS inside horizon smoothly glued onto soliton vacuum outside.

Dual toy model description:

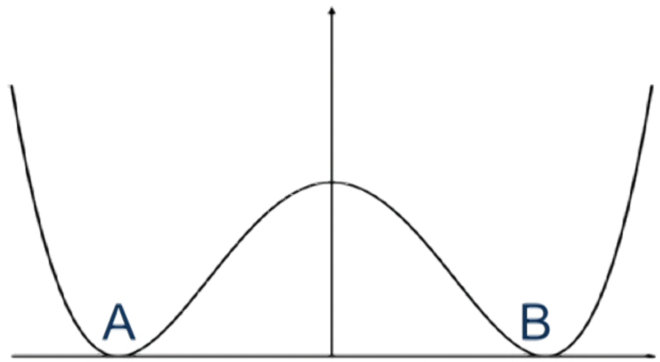


Dual toy model



- Two semi-classical vacua, without introducing a second boundary.
- Non-perturbative interaction $\lambda \sim 1/N^2$
- As the separation L ➔ ∞ : decoupling/cosmic censorship violation

Dual toy model



Perturbatively: Two harmonic oscillators

$$b_R|0\rangle_R = 0, \qquad |n\rangle_R = \frac{1}{\sqrt{n!}}(b_R^+)^n|0\rangle_R$$

No tensor product: $\mathcal{H} \cong \mathcal{F}_R \cong \mathcal{F}_L$

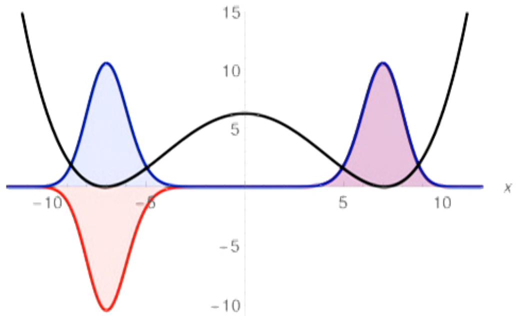
Naively there is a firewall, since vacuum A is a highly excited state from the viewpoint of vacuum B.

Black hole `microstates'

More natural to consider parity based decomposition: $\mathcal{H} = \mathcal{H}^+ \oplus \mathcal{H}^-$

Energy eigenstates:

$$H\Psi_n^\pm = E_n^\pm \Psi_n^\pm$$



Black hole microstates:

$$\mu = \alpha_+ \Psi_0^+ + \alpha_- \Psi_0^-$$

Contain both coarse and fine-grained information, e.g.

$$E_0^- - E_0^+ = \frac{2}{\sqrt{\pi\lambda}} e^{-\frac{1}{6\lambda}} \left[1 + O(\lambda)\right]$$

State-dependence emerges

Many different black hole microstates,

$$\mu = \alpha_+ \Psi_0^+ + \alpha_- \Psi_0^- = \alpha_R \Psi_0^R + \alpha_L \Psi_0^L$$

are mapped to the same doubled state

$$\Psi_{00}^{\mathrm{dbl}} = \begin{cases} \Psi_0^L \otimes \Psi_0^R & \text{if } \alpha_L, \alpha_R \neq 0, \\ 0 & \text{if } \alpha_L = 0 \text{ or } \alpha_R = 0. \end{cases}$$

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- Fine-grained information about original microstate lost.
- Vice versa, since no correlation in the effective tensor product theory distinguishes fine-grained features of microstates, this information must be supplied to match predictions in the full theory

$\longrightarrow$ emergent state-dependence

- In terms of operators, state-dependence can be viewed as the problem to define operators on an overcomplete basis of states [Jafferis]