Nothing

~~Nothing~~

Something

Do we live on the End of the World?

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Based on [2411.05912] w/ Tony Padilla and Paul Saffin

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Nothing

Nothing

sike…

“You only realise the importance of someone when they are gone.”

This talk

1. What is Nothing?

2. How to get a dS_4 universe from Nothing

Witten’s Bubble of Nothing

[Witten ‘81]

Witten's Bubble of Nothing

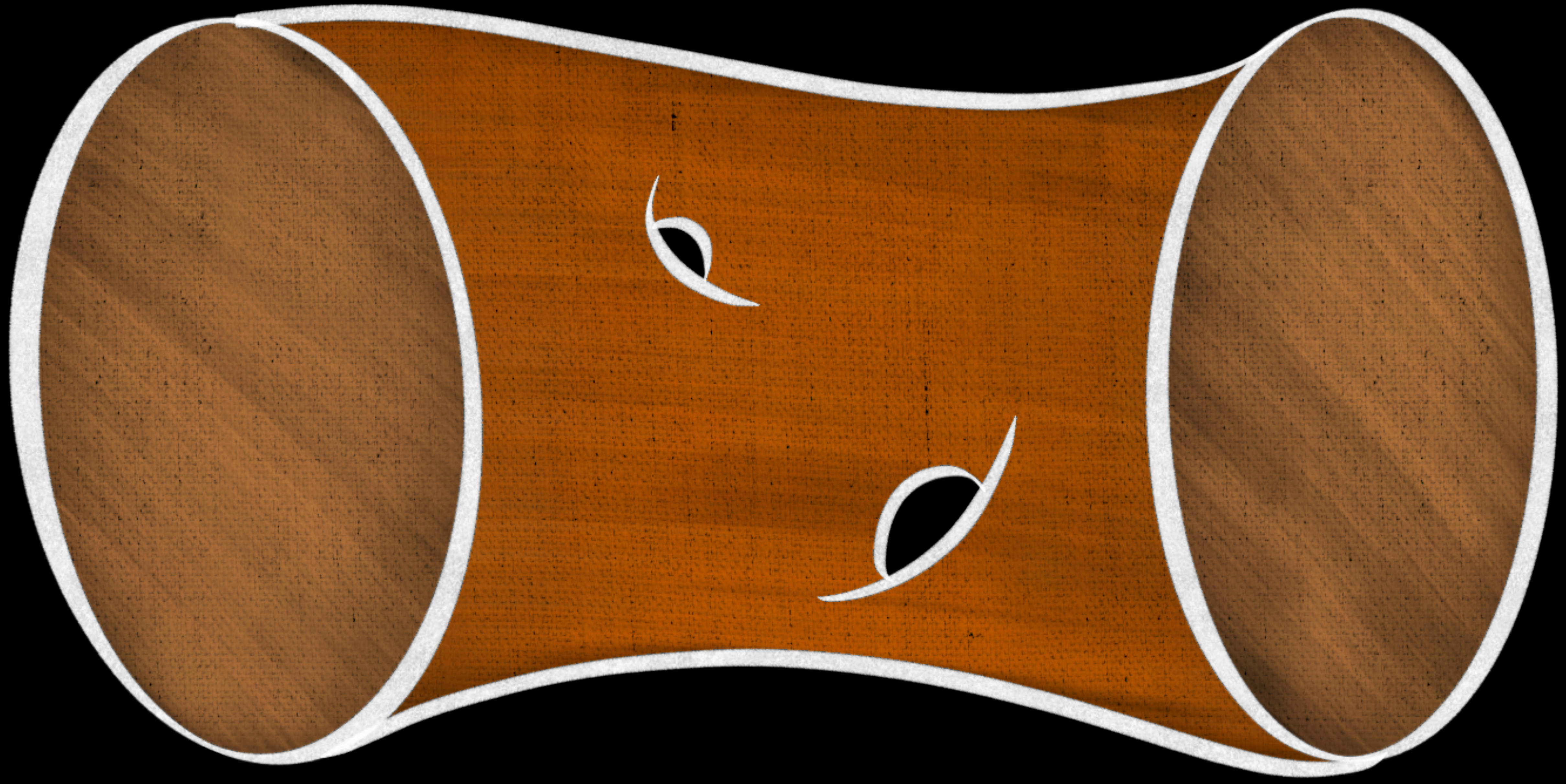
[Witten '81]

Witten's Bubble of Nothing

[Witten '81]

Nothing as a Cobordism

$\mathscr{M}$



$\mathscr{N}$

$$\partial \mathscr{W} = \mathscr{M} \sqcup \mathscr{N}$$

Nothing as a Cobordism

Nothing as a Cobordism

Cobordism Conjecture

Non-vanishing cobordism groups $\Omega_k \neq [\varnothing]$ give rise to $(D-k-1)$-form global symmetries, with cobordism invariants as preserved global charges

All cobordism classes in Quantum Gravity must vanish

$$\Omega_k^{\mathrm{QG}} = [\varnothing]$$

[McNamara, Vafa '19]

What QG is trying to tell us

1. Nothing is *always* an allowed configuration

    ⇝ *we should properly understand what 'nothing' is!*

2. ETW branes better be in the spectrum of extended objects

    ⇝ *can they act as braneworlds?*

Bubbles of Something

Bubbles of Something

Compute the gravitational instanton following standard Coleman-de Luccia

$$S_E = -\frac{1}{2\kappa^2}\int_{\mathrm{AdS}_5} \mathrm{d}^5x\sqrt{g}\left(R + \frac{12}{\ell^2}\right) - \frac{1}{\kappa^2}\int_{\mathrm{ETW}} \mathrm{d}^4\xi\sqrt{h}\left(K - \kappa^2\sigma\right)$$

Make an $O(5)$-symmetric ansatz and solve Israel junction condition

$$\mathrm{d}s^2 = \mathrm{d}r^2 + \ell^2\sinh^2\left(\frac{r}{\ell}\right)\mathrm{d}\Omega_4^2 \quad \rightsquigarrow \quad \sigma = \frac{3}{\kappa^2\ell}\coth\left(\frac{r_0}{\ell}\right)$$

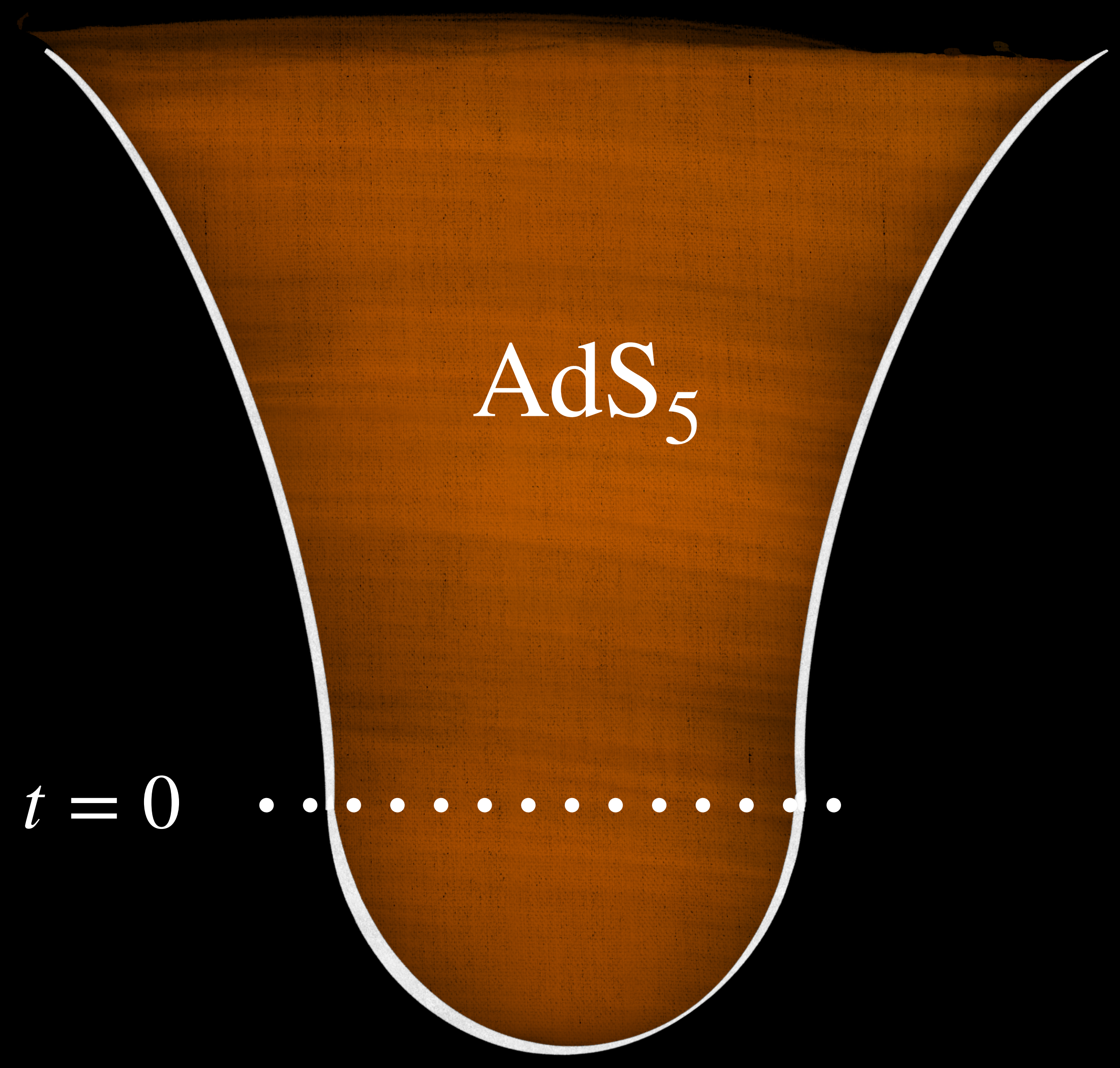
Bubbles of Something

Attach this to the Lorentzian solution at "$t = 0$"

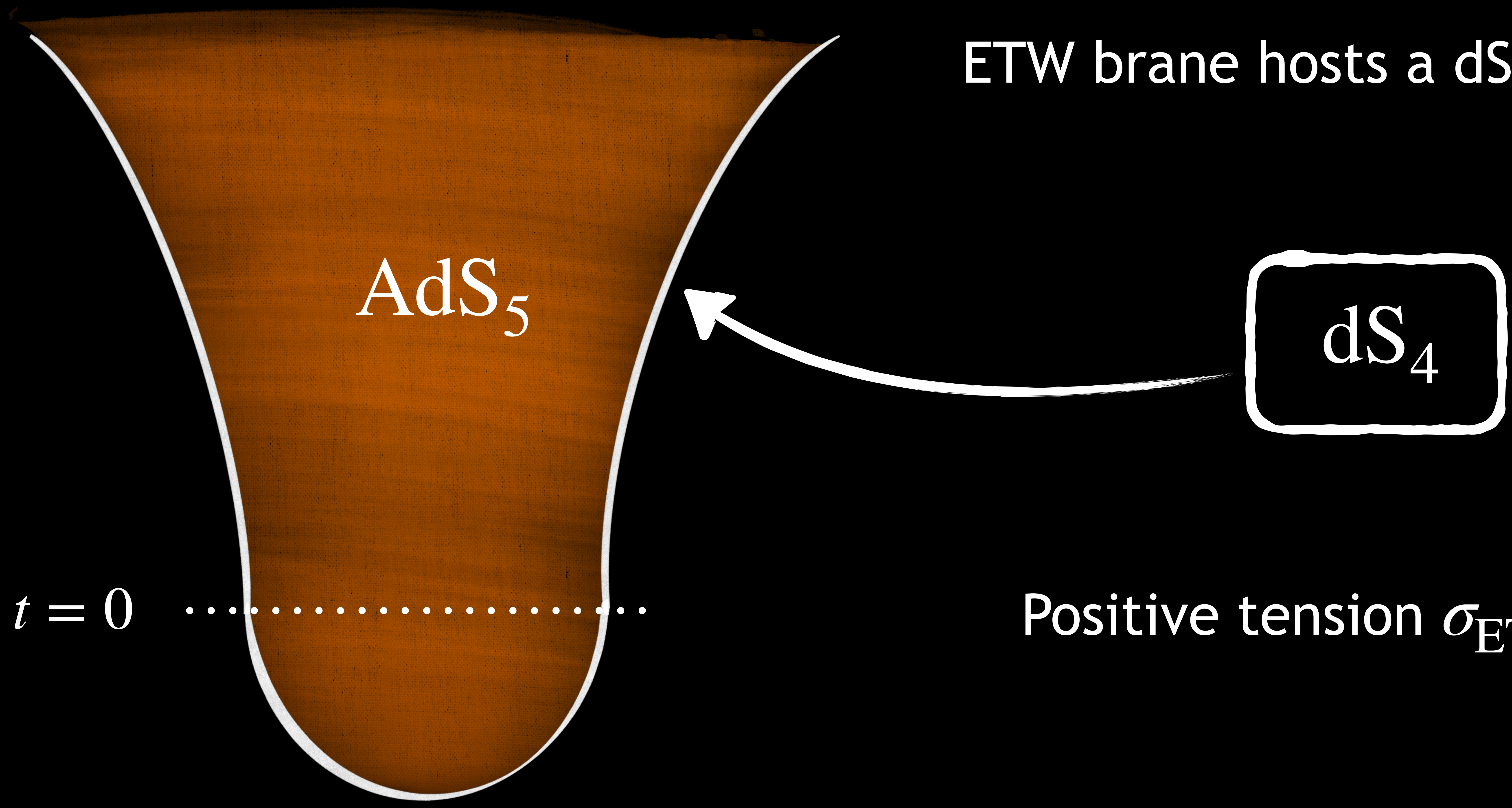
$$ds^2 = dr^2 + \left(\frac{\sinh(r/\ell)}{\sinh(r_0/\ell)}\right)^2 \left[-dt^2 + H_0^{-2}\cosh(H_0 t)d\Omega_3^2\right]$$

Hubble constant on the bubble is

$$H_0 \sim \ell^{-1} e^{-r_0/\ell} \ll \ell^{-1}$$



Bubbles of Something



ETW brane hosts a dS universe!

Positive tension $\sigma_{\mathrm{ETW}} > 0$

Searching for dS

Landscape approach

No-go theorems

Swampland constraints

20+ years of attempts

Domain wall approach

Apparently straightforward

Abundance

QG $\rightsquigarrow$ ETW branes!

General AdS Bubbles

$AdS_5^+ \longrightarrow AdS_5^-$

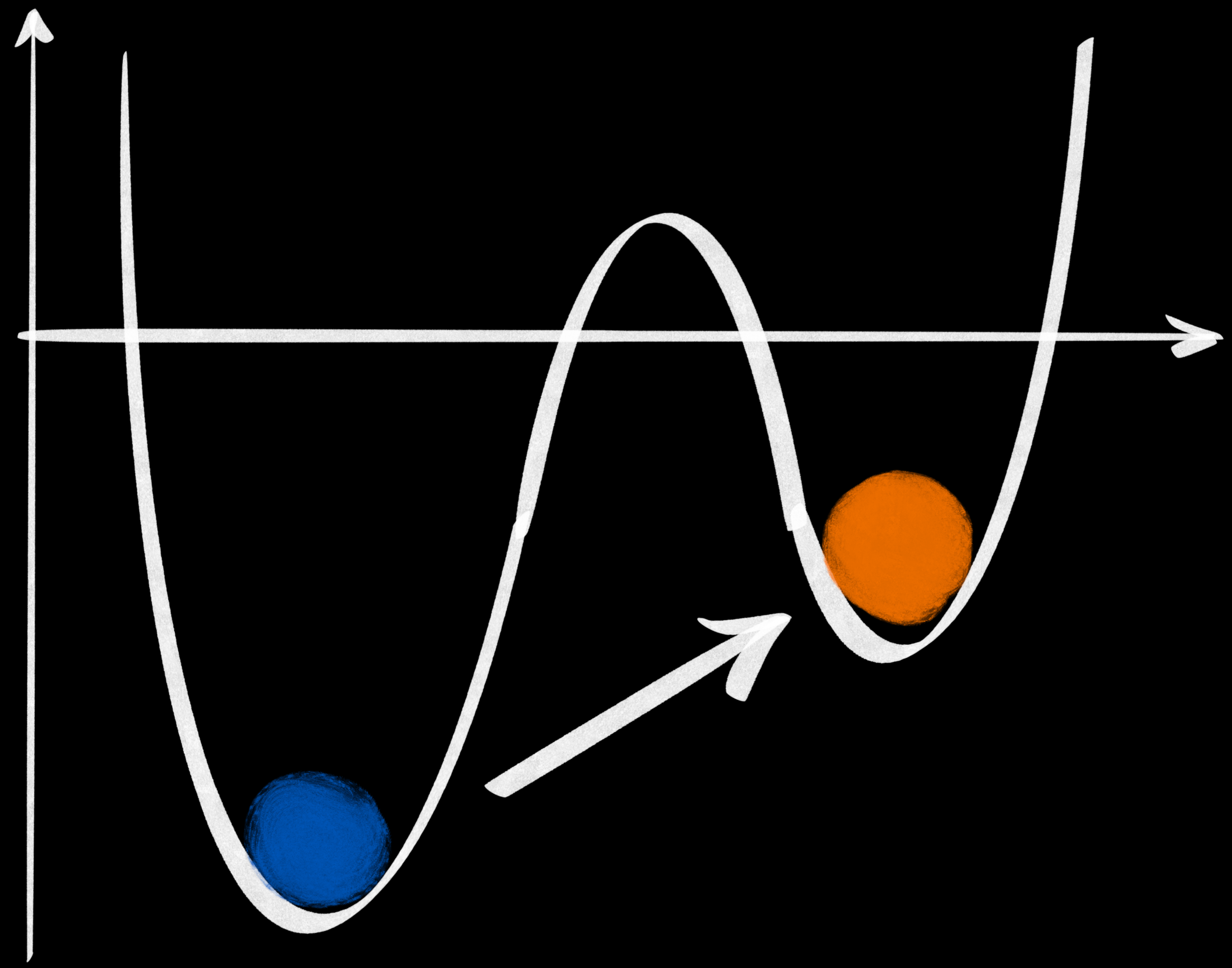
Claim:

Nothing = AdS_5 with $\ell \to 0$

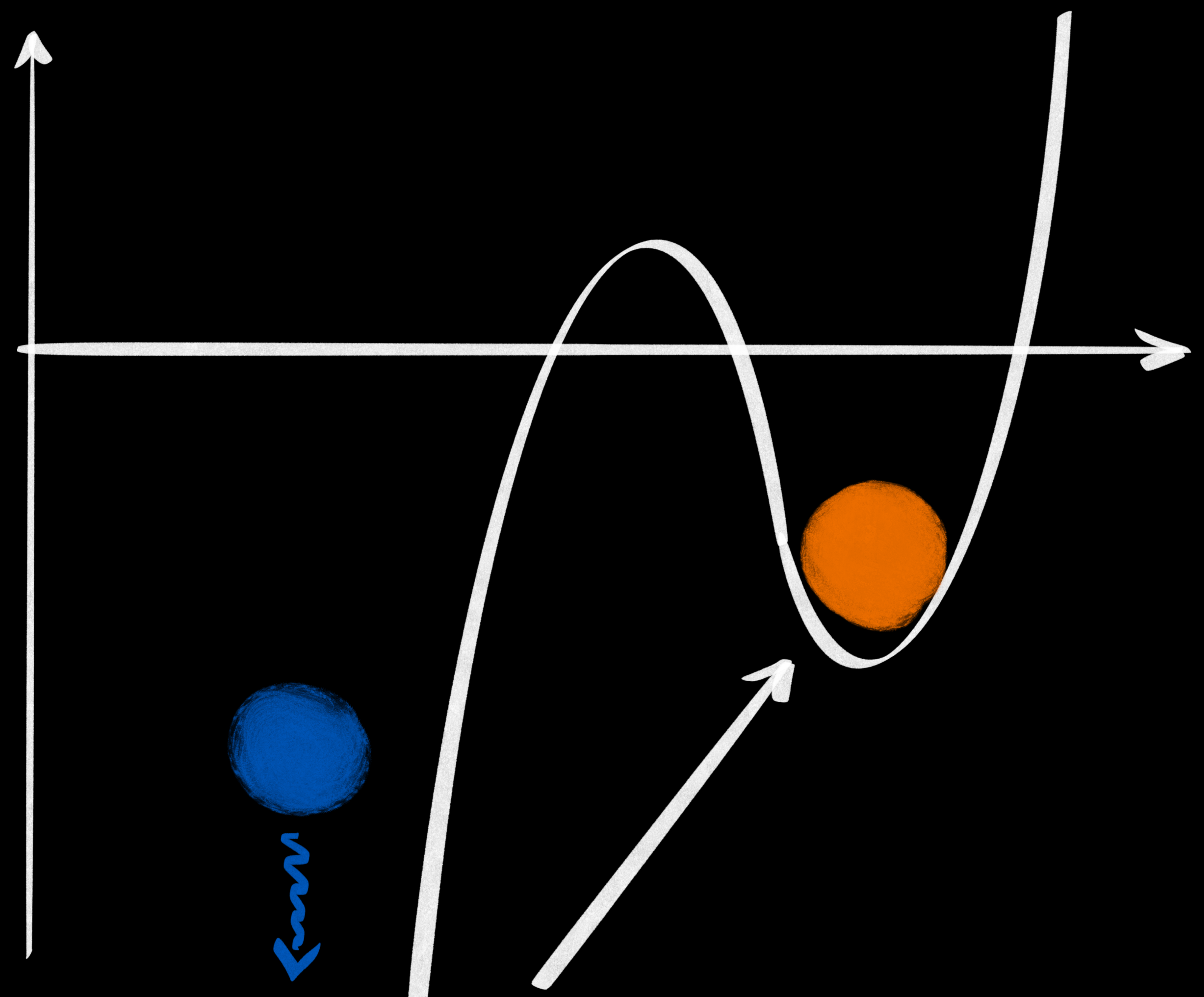
$(\Lambda \to -\infty)$

[Brown, Dahlen '11]

General AdS Bubbles



General AdS Bubbles



General AdS Bubbles

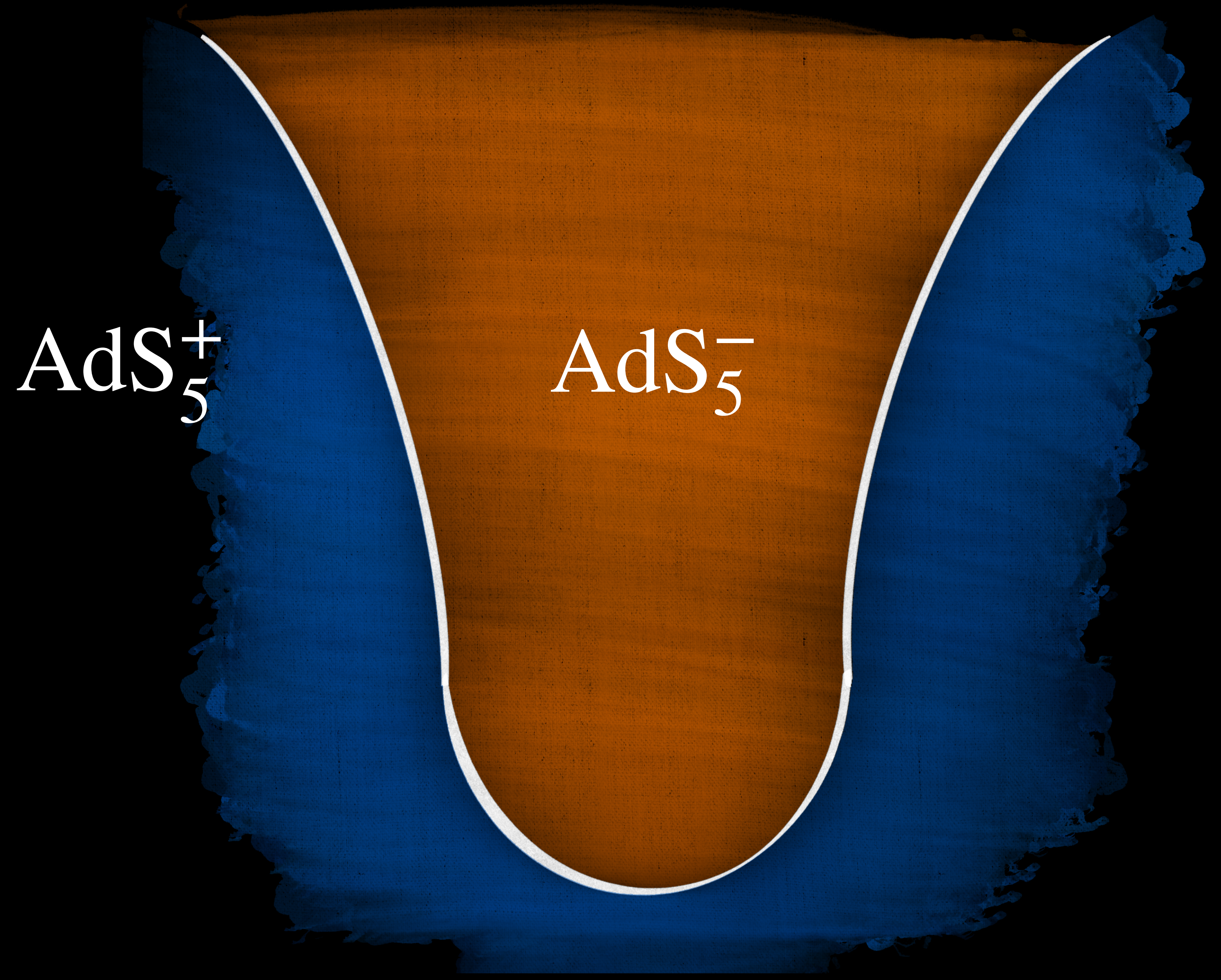
Exactly the same as before, but now subject to a gluing condition

$$\ell_- \sinh\left(\frac{r_-}{\ell_-}\right) = \ell_+ \sinh\left(\frac{r_+}{\ell_+}\right)$$

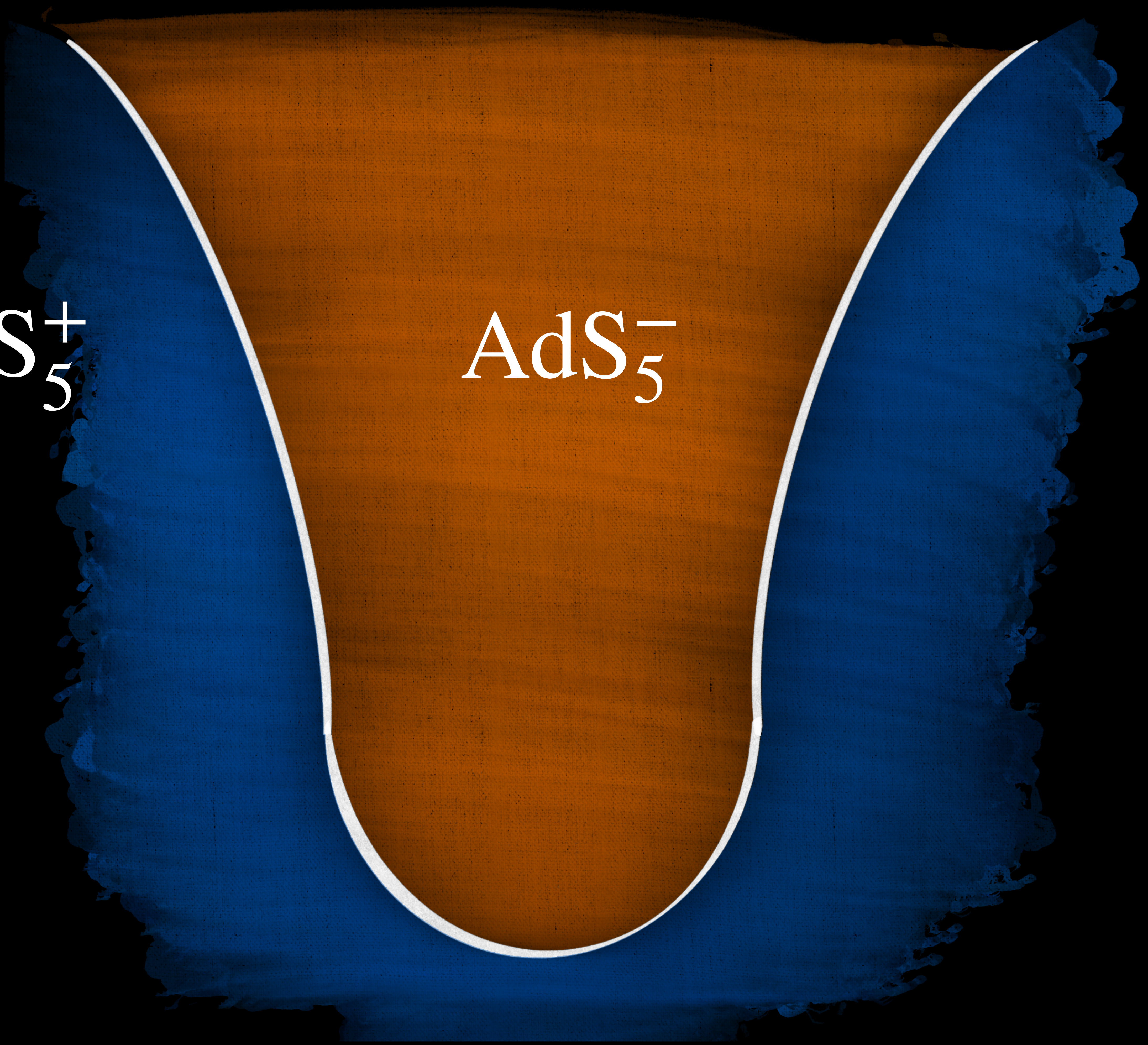
and tension

$$\sigma = \frac{3}{\kappa^2}\left[\frac{1}{\ell_-}\coth\left(\frac{r_-}{\ell_-}\right) - \frac{1}{\ell_+}\coth\left(\frac{r_+}{\ell_+}\right)\right]$$

that is negative for up-tunneling.



General AdS Bubbles



Oh no! Tension diverges!

$$\boxed{\sigma = \sigma_{\mathrm{ETW}} - \frac{3}{\kappa^2 \ell_+} + \mathcal{O}(\ell_+)}$$

ℓ_+: AdS length scale ($\to 0$)

$\sigma_{\mathrm{ETW}} > 0$: Tension of the ETW brane from before

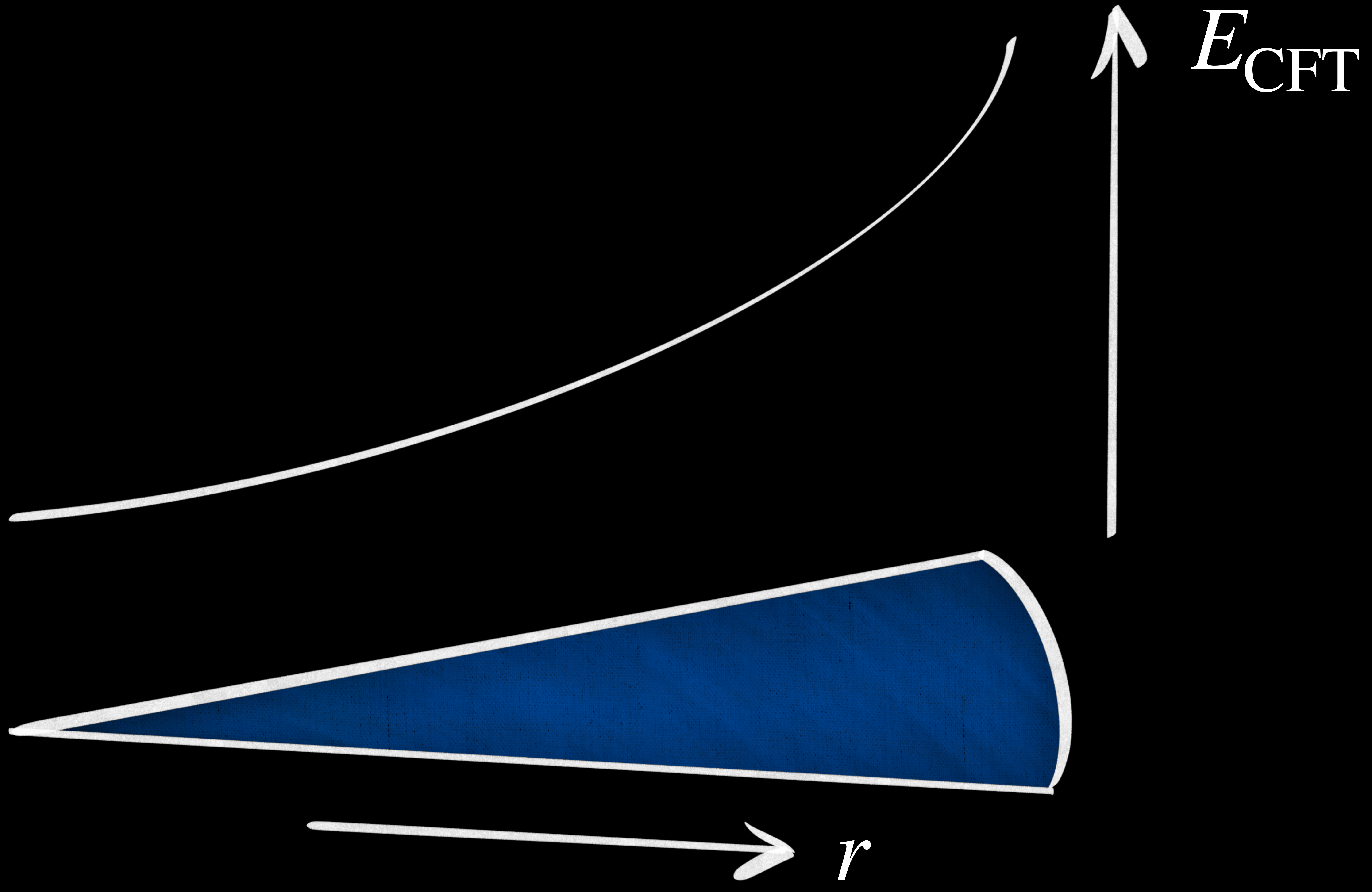
What is going on?

Infinite tension stems from infinite volume of AdS

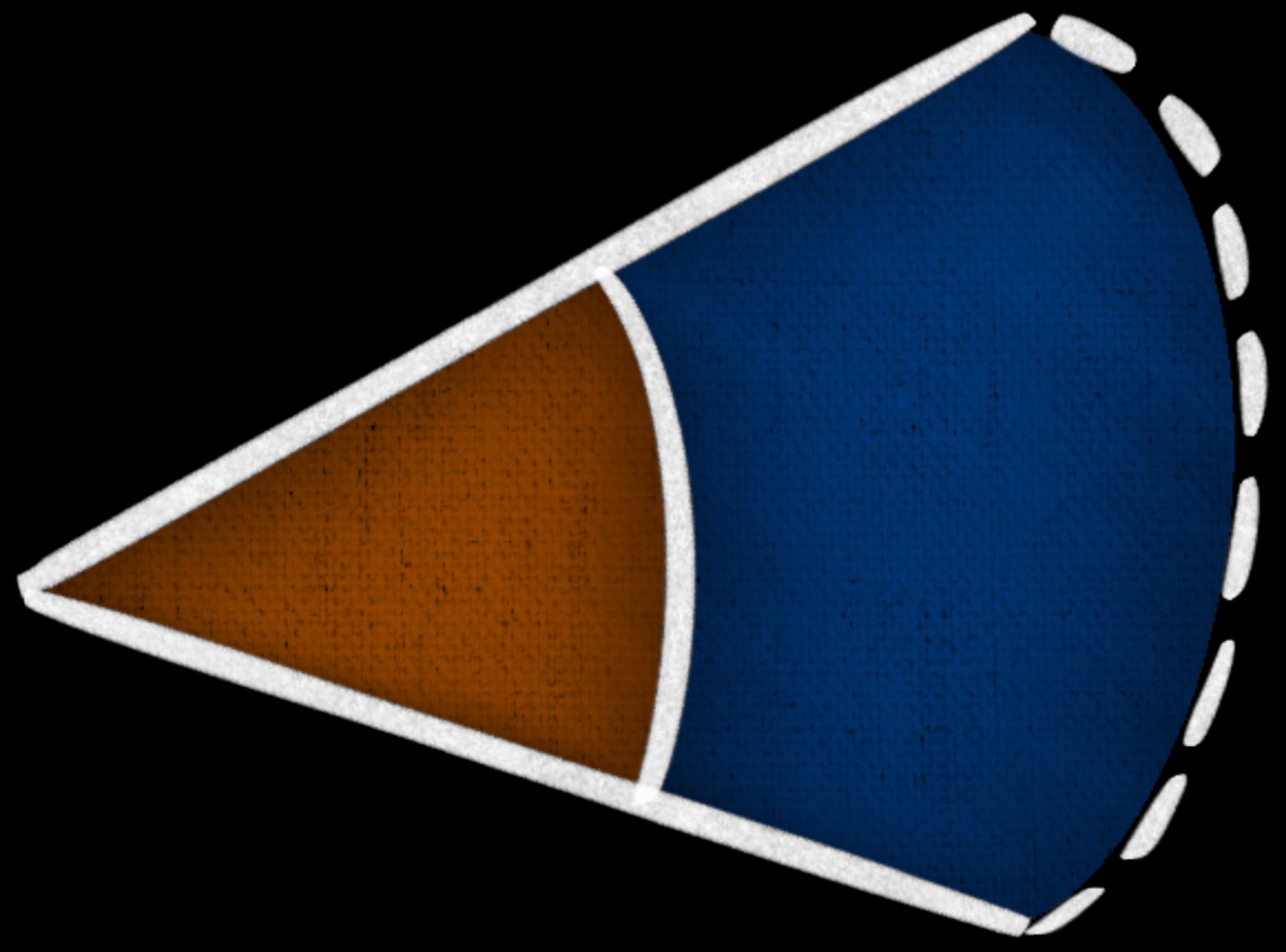
Dual CFT calls for UV renormalization

⇣

Boundary counterterms



Holographic Renormalization



Introduce holographic counterterms
on the conformal boundary

[de Haro, Solodukhin, Skenderis ‘01]   [c.f. Skenderis ‘02, Papadimitriou ‘16]

Holographic Renormalization

To better understand the theory in the limit $r \to \infty$ we rewrite in *Fefferman-Graham* coordinates

$$\mathrm{d}s^2 = \frac{\ell^2}{4\varrho^2}\mathrm{d}\varrho^2 + \frac{\ell^2}{\varrho}\hat{g}_{ij}\mathrm{d}\xi^i\mathrm{d}\xi^j$$

$$\hat{g}_{ij}(\varrho,\xi) = \hat{g}^{(0)}_{ij}(\xi) + \varrho\hat{g}^{(2)}_{ij}(\xi) + \varrho^2\left(\hat{g}^{(4)}_{ij}(\xi) + \log(\varrho)\hat{h}^{(4)}_{ij}(\xi)\right) + \mathcal{O}(\varrho^3)$$

Holographic Renormalization

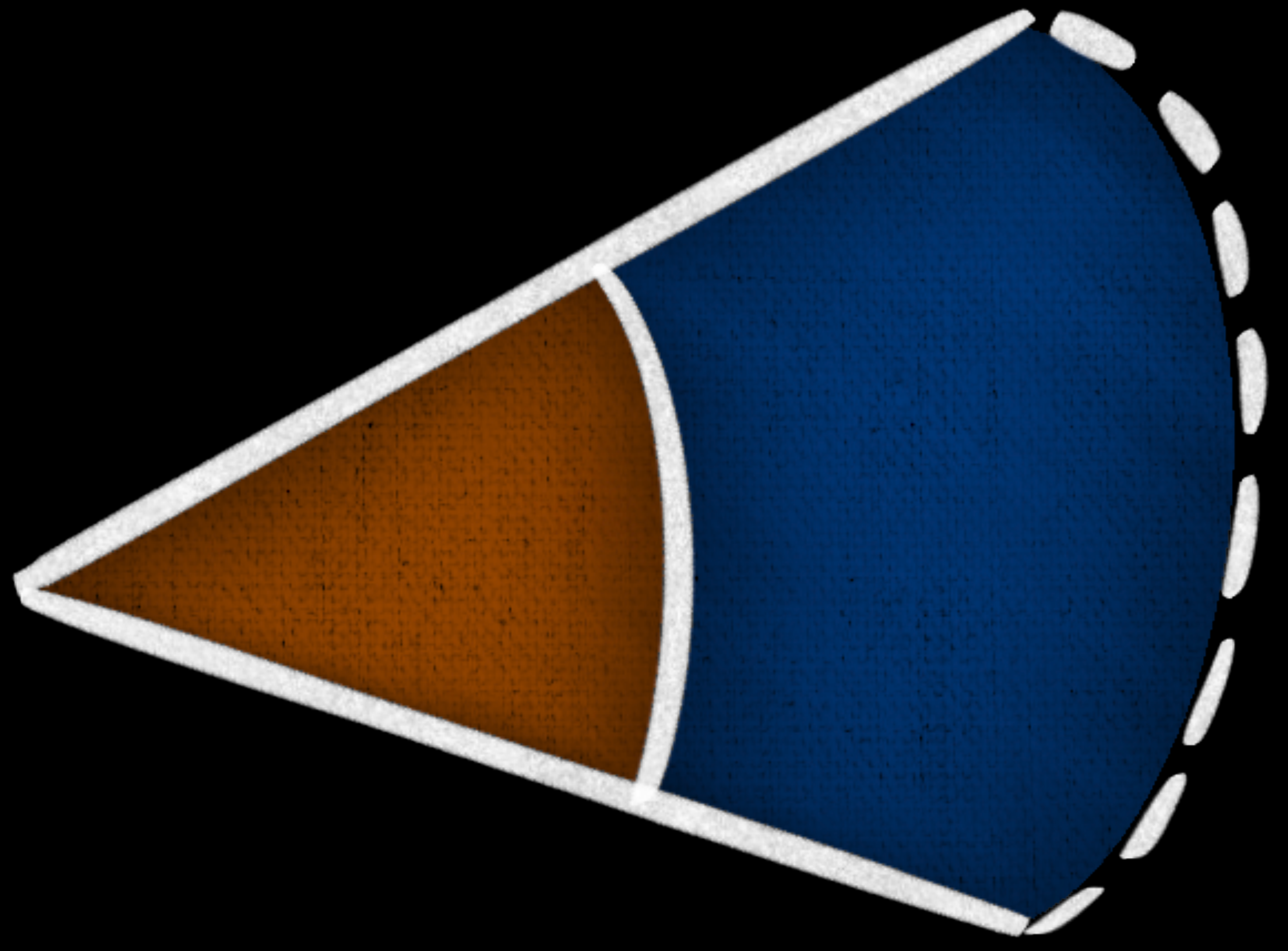
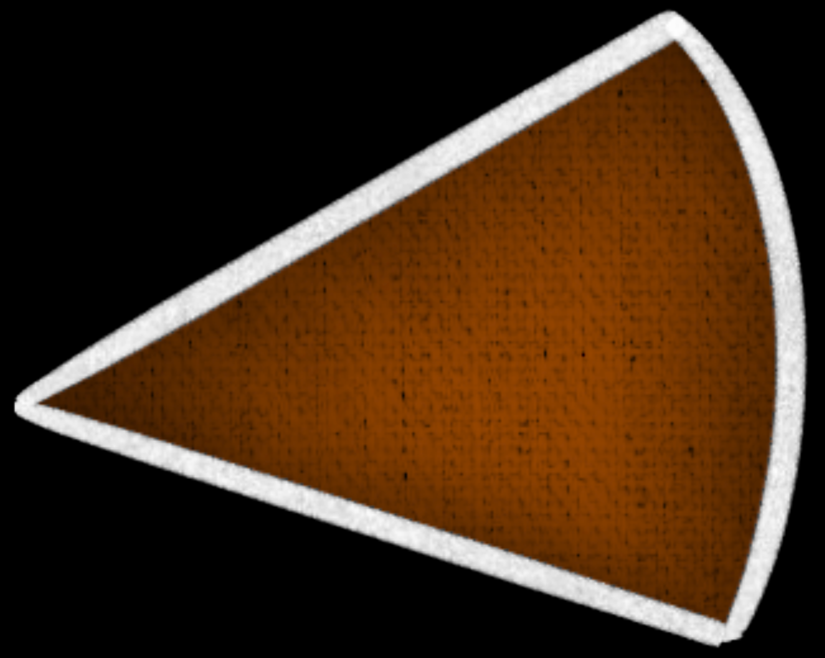
1. Regularise at some $\varrho = \varepsilon \ll 1$

$$S_{\mathrm{reg},\varepsilon} = \int_{\varrho=\varepsilon} \mathrm{d}^4\xi \sqrt{-\hat{g}^{(0)}} \left(\underbrace{\varepsilon^{-2} \hat{\mathscr{L}}^{(0)} + \varepsilon^{-1} \hat{\mathscr{L}}^{(2)} - \log(\varepsilon) \hat{\mathscr{L}}^{(4)}} + \mathcal{O}(\varepsilon) \right)$$

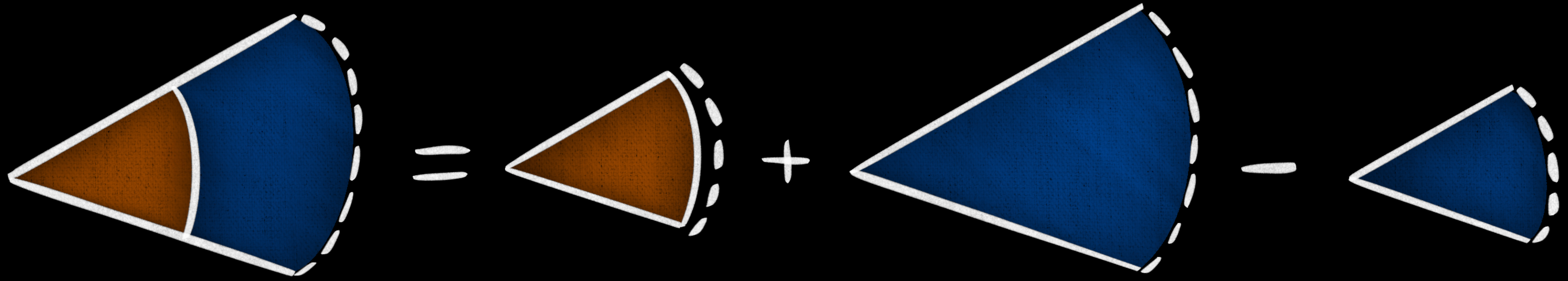
2. Introduce counterterms: $$S_{\mathrm{ct},\varepsilon} = -\,\mathrm{div}\left(S_{\mathrm{reg},\varepsilon} \right)$$

3. Renormalise: $$S_{\mathrm{ren}} = \lim_{\varepsilon \to 0} S_{\mathrm{ren},\varepsilon} = \lim_{\varepsilon \to 0} S_{\mathrm{reg},\varepsilon} + S_{\mathrm{ct},\varepsilon}$$

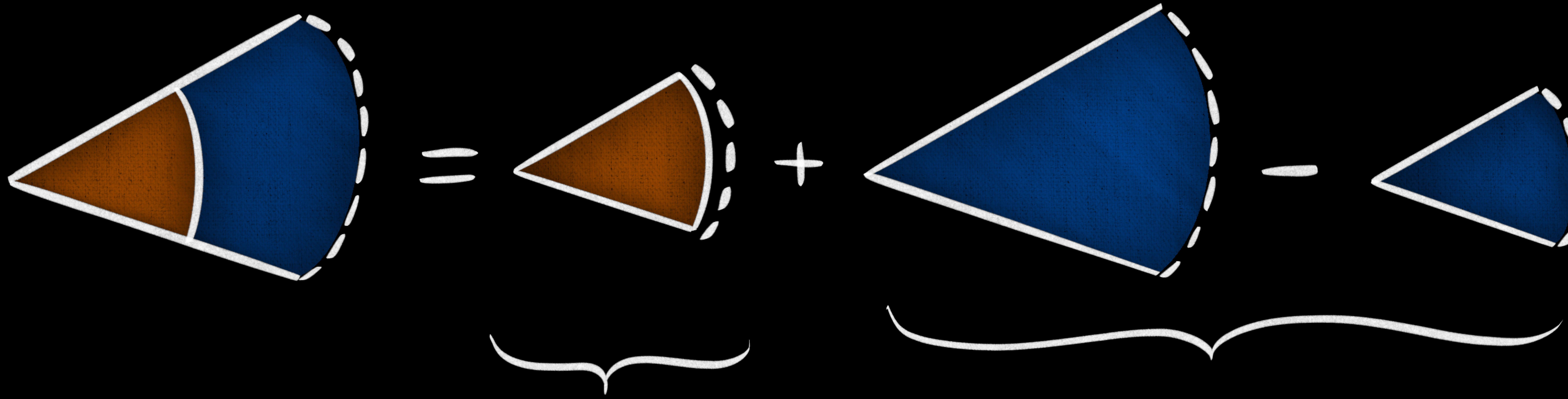
Our claim

$\lim_{\ell_+ \to 0}$  =  σ_{ETW}

Picture proof



Picture proof



$$\lim_{\ell_+ \to 0}$$

$$\sigma + \frac{3}{\kappa^2 \ell_+} = \sigma_{\mathrm{ETW}}$$

$$= 0$$

Symbols proof

$$S_{\text{bubble}} = S_{\text{in}}[-] + S_{\text{bare}}[\text{brane}] + S_{\text{out}}[+]$$

$$\begin{aligned} S_{\text{out}}[+] &= S_{\text{ren}}[+] - S_{\text{reg},\varrho_+}[+] \\ &= S_{\text{ren}}[+] - S_{\text{ren},\varrho_+}[+] + S_{\text{ct},\varrho_+}[+] \end{aligned}$$

$$S_{\text{bubble}} = S_{\text{in}}[-] + \left(S_{\text{bare}}[\text{brane}] + S_{\text{ct},\varrho_+}[+]\right) + S_{\text{ren}}[+] - S_{\text{ren},\varrho_+}[+]$$

Symbols proof

One can readily compute the holographic counterterms

$$S_{\mathrm{ct},\varrho_+}[+] = -\frac{\ell_+}{\kappa^2}\int \mathrm{d}^4\xi\sqrt{-h}\left[\frac{3}{\ell_+^2}+\frac{1}{4}R+\frac{\ell_+^2\log\varrho_+}{8}\left(R_{ij}R^{ij}-\frac{1}{3}R^2\right)\right]$$

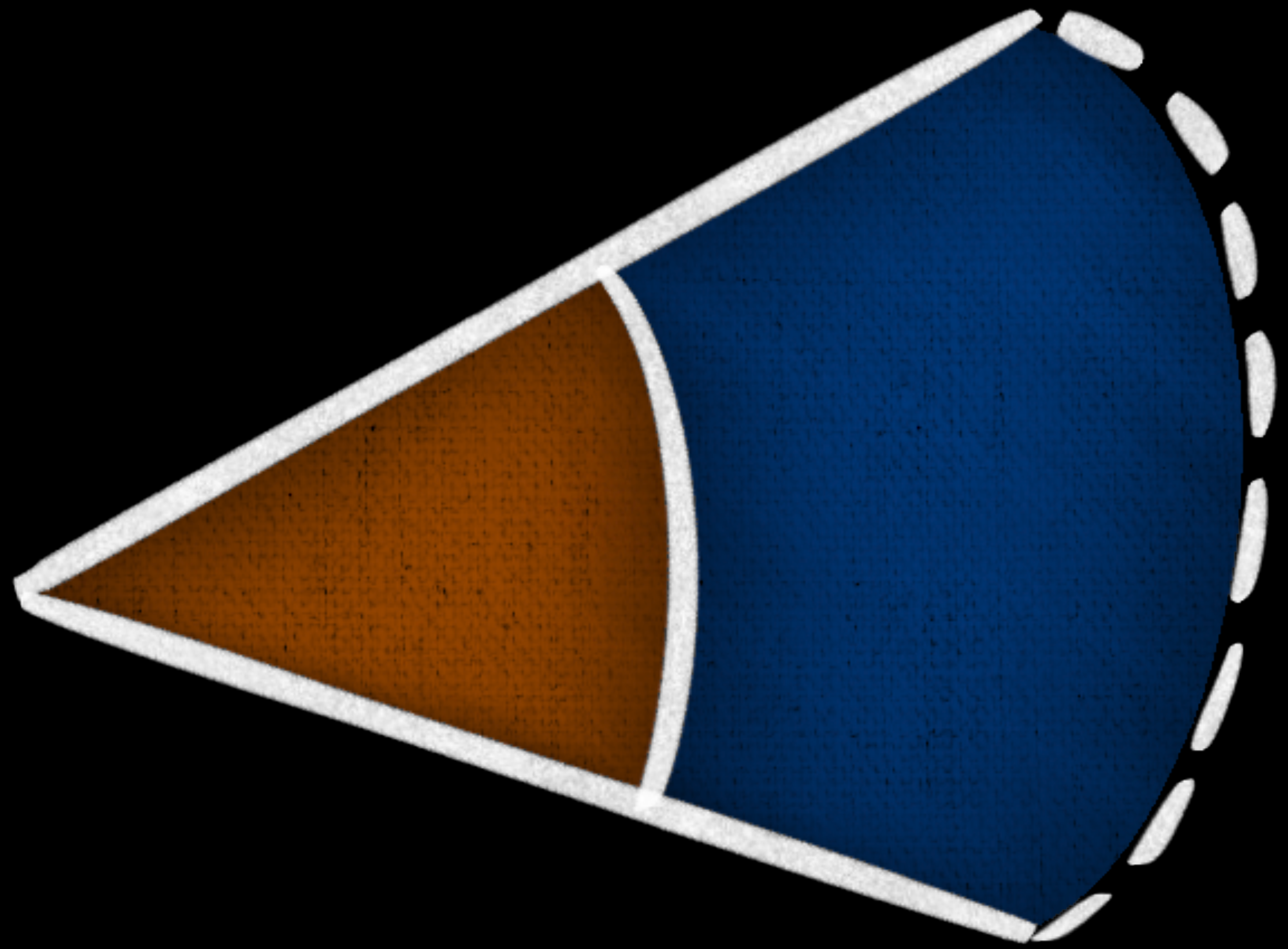
$$-\int \mathrm{d}^4\xi\sqrt{-h}\underbrace{\left[\frac{3}{\kappa^2\ell_+}\right]}_{\sigma_{\mathrm{ct}}}$$

Divergence cancels!

$$\boxed{\sigma = \sigma_{\mathrm{ETW}} - \frac{3}{\kappa^2\ell_+} + \mathcal{O}(\ell_+)}$$

Our claim

$\lim_{\ell_+ \to 0}$



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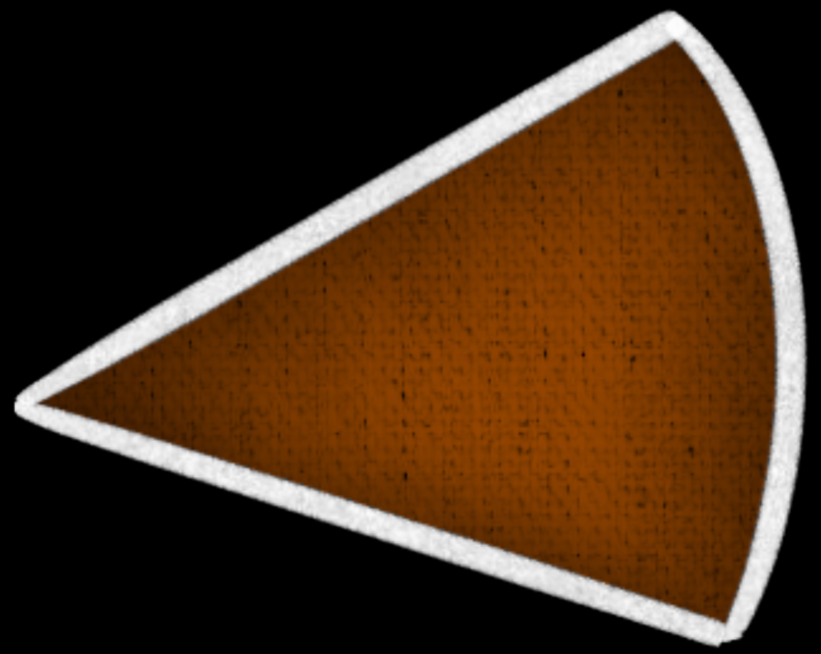

σ_{ETW}

Summary

Two fun take-home lessons

Absence of spacetime is a spacetime

It is *of infinite negative curvature.*

everywhere singular metric.

holographic in nature.

dual "CFT" with $c \to 0$

able to decay.

dS on ETW branes is straightforward

works in d dimensions and to all orders in perturbations

Some ongoing work:

- ⇝ *embedding in Type IIB using topological terms*
- ⇝ *early universe* (cosmologists? 👀)
- ⇝ *Swampland Programme: signs of a "dual AdS Distance Conjecture"?*

Thank you