Title: Towards Microscopic Models of Big Bang Cosmology

Speakers: Mark Van Raamsdonk

Series: Quantum Fields and Strings

Date: September 29, 2020 - 2:30 PM

URL: http://pirsa.org/20090021

Abstract: In this talk, we review an approach to describing cosmological physics using ordinary AdS/CFT, where the cosmological physics is the effective description of an end-of-the-world brane which cuts off the second asymptotic region of a two-sided black hole. The worldvolume geometry of the brane is an FRW big-bang/big-crunch spacetime. Infavorable circumstances, the brane acts as a Randall-Sundrum Planck brane so that gravity localizes. We describe a microscopic construction for such an end-of-the-world brane with localized gravity in AdS/CFT, starting from N=4 SYM theory. We suggest specific microscopic states of N=4 SYM theory that may encode the physics in a four-dimensional cosmological spacetime.


# Towards Microscopic Models of Big Bang Cosmology

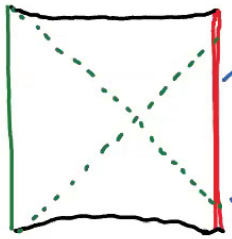
Mark Van Raamsdonk, UBC

Perimeter Institute, Sept. 2020

1810.10601 w Cooper, Rozali, Swingle, Waddell, Wakeham
2004.13088 w. Sully, Wakeham
2006.13943 w. Simidzija
2008.02259
+work in progress

# Black hole microstate cosmology: a fantasy

dual to

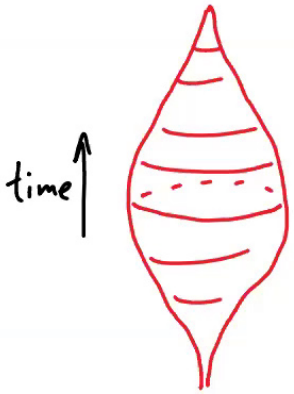


end of the world (ETW) brane = inner boundary of black hole

ETW brane geometry is FRW big bang/big crunch

$|\Psi\rangle_{CFT}$

high-energy state of CFT on $S^3$ or




MVR
Cooper
Rosali
Swingle
Wakeham
Waddell

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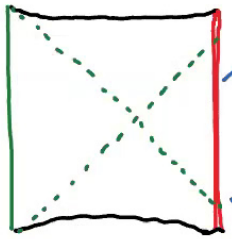

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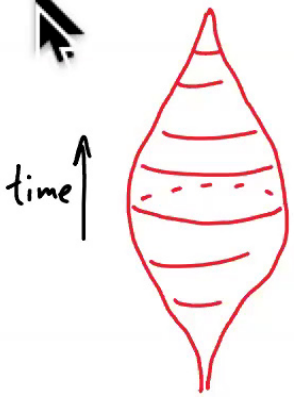


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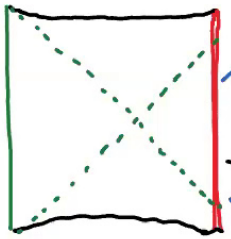


end of the world (ETW) brane = inner boundary of black hole

Planck brane for 2nd asympt. region

ETW brane geometry is FRW big bang/big crunch

$|\Psi\rangle_{CFT}$

high-energy state of CFT on $S^3$ or $\mathbb{R}^3$

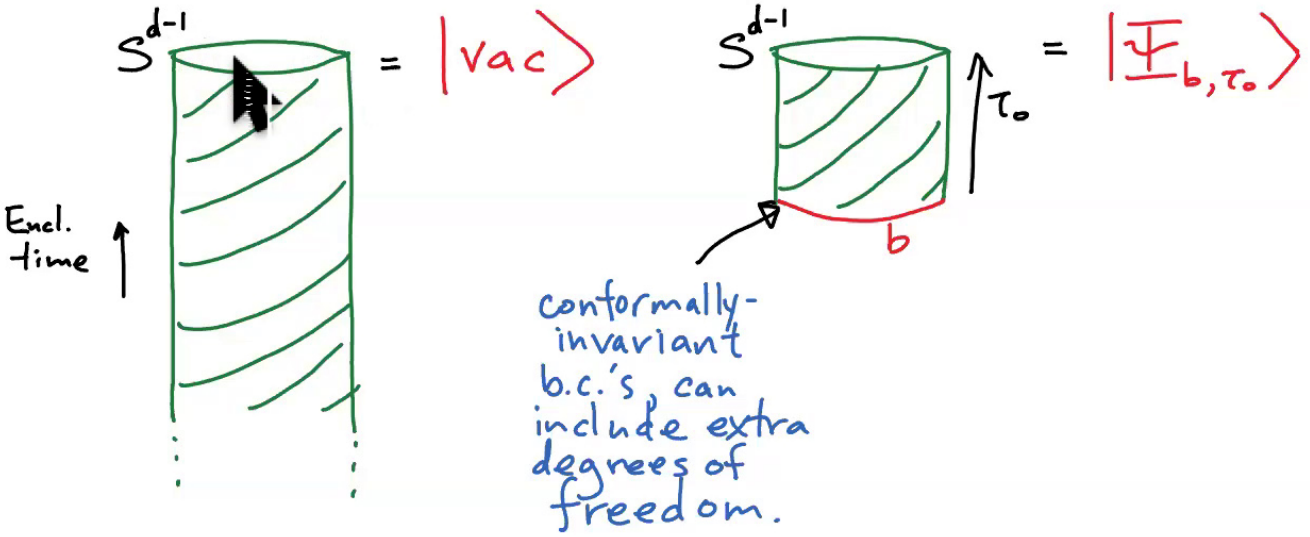

gravity can localize on the ETW brane if it is far enough behind horizon

$\Longrightarrow$ microscopic realization of Randall-Sundrum cosmology?

# What are these states?

Construct using path integral for Euclidean BCFT

(inspired by Kourkoulou/Maldacena)



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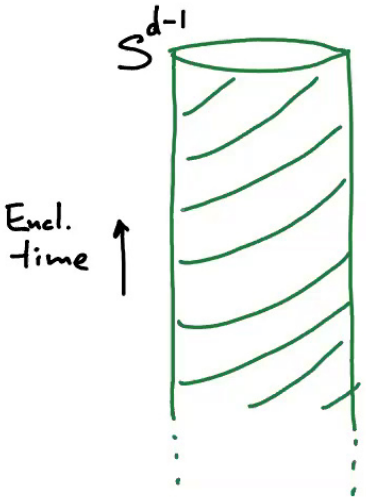
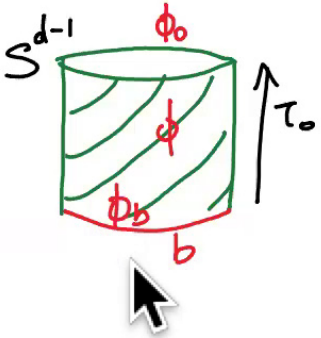



$= |vac\rangle$

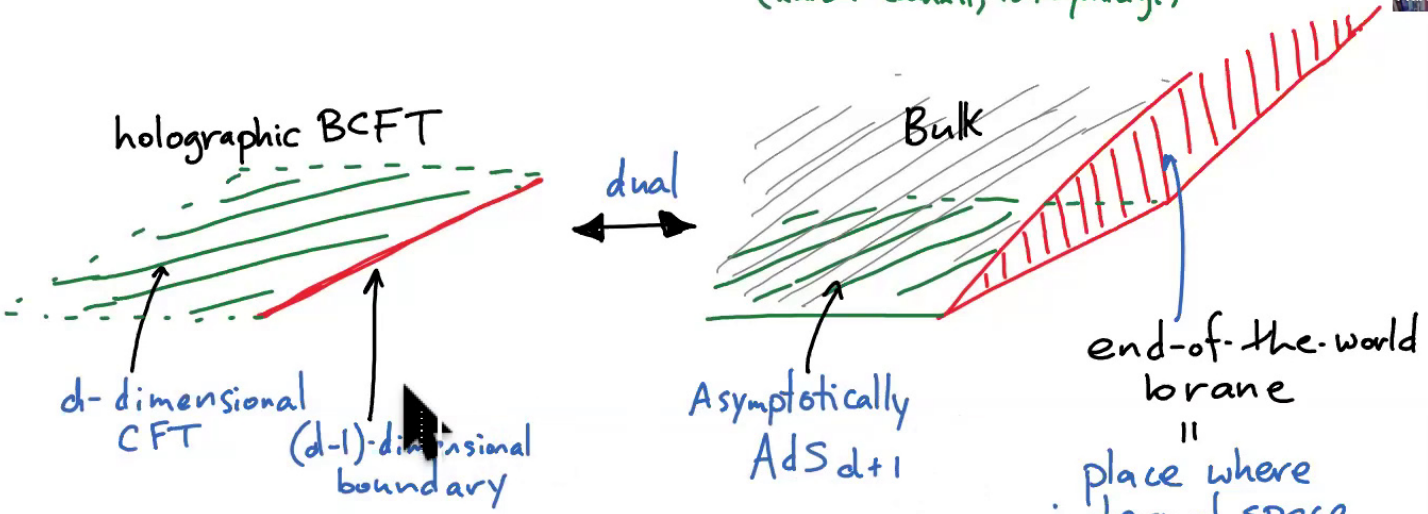



$= |\Psi_{b,\tau_0}\rangle$

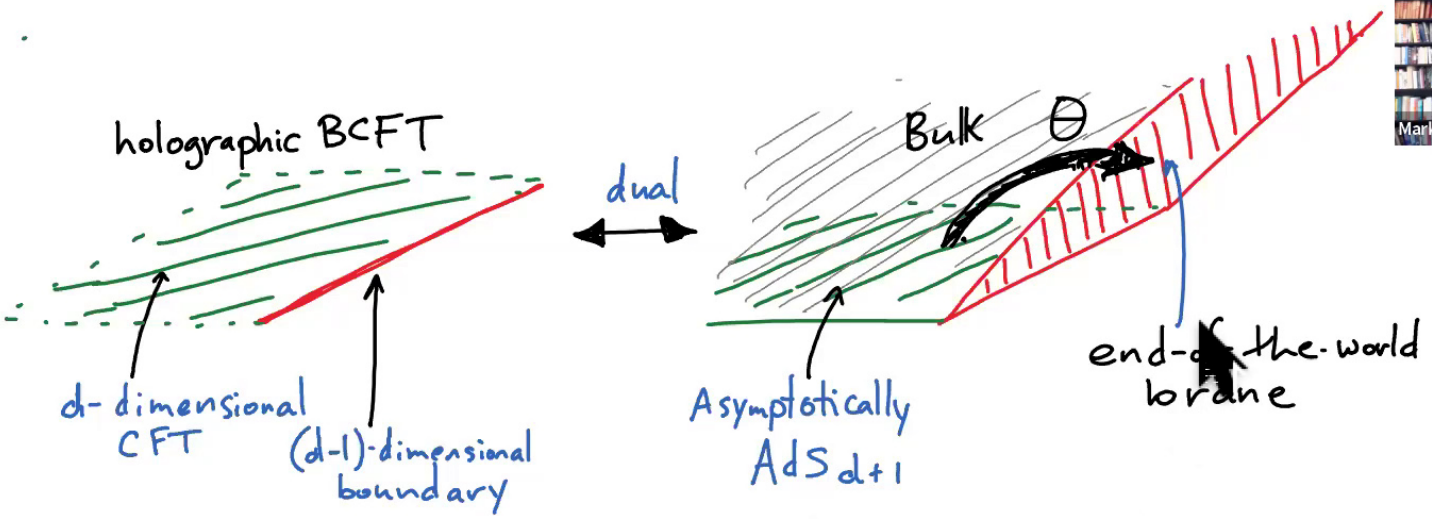
$$\Psi_{b,\tau_0}[\phi_0] = \int_{\phi(\tau_0)=\phi_0} [d\phi][d\phi_b]\, e^{-S_{BCFT}}$$

# Understanding the gravity dual for $|\Psi_{b,\tau_0}\rangle$

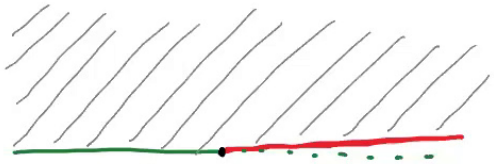
(Karch-Randall, Takayanagi)




bottom-up approach: model ETW brane via codim. 1 object w. tension $T$, couplings to bulk fields.



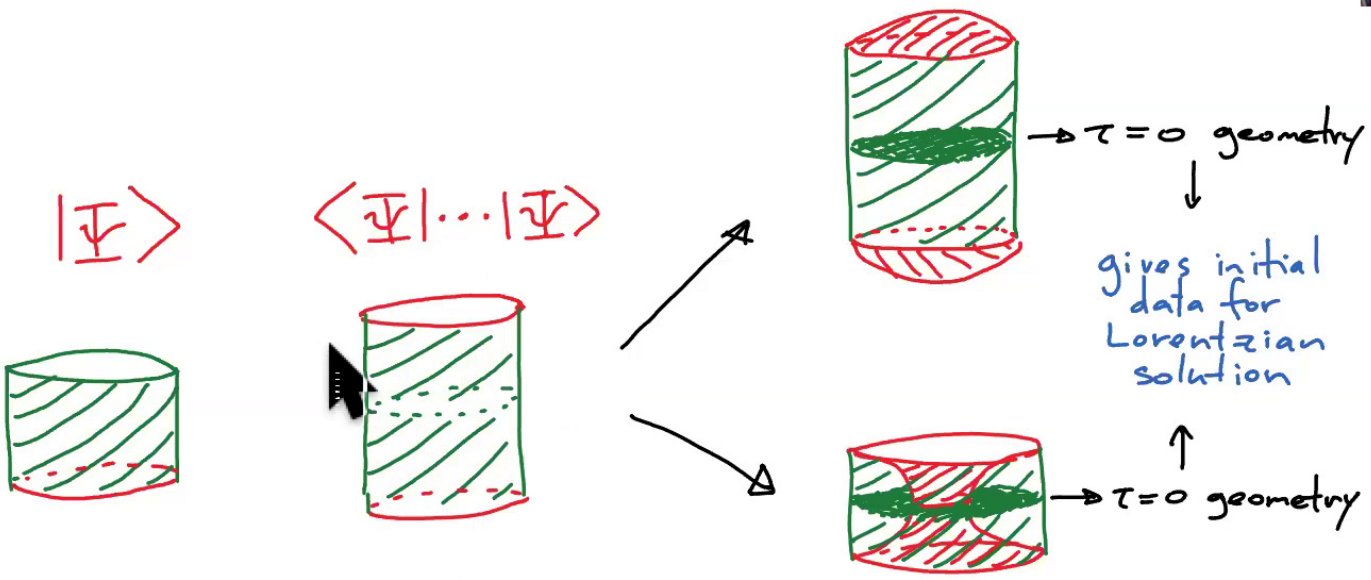

Takayanagi: move boundary d.o.f. $\Rightarrow$ larger tension $\Rightarrow$ larger angle $\theta$

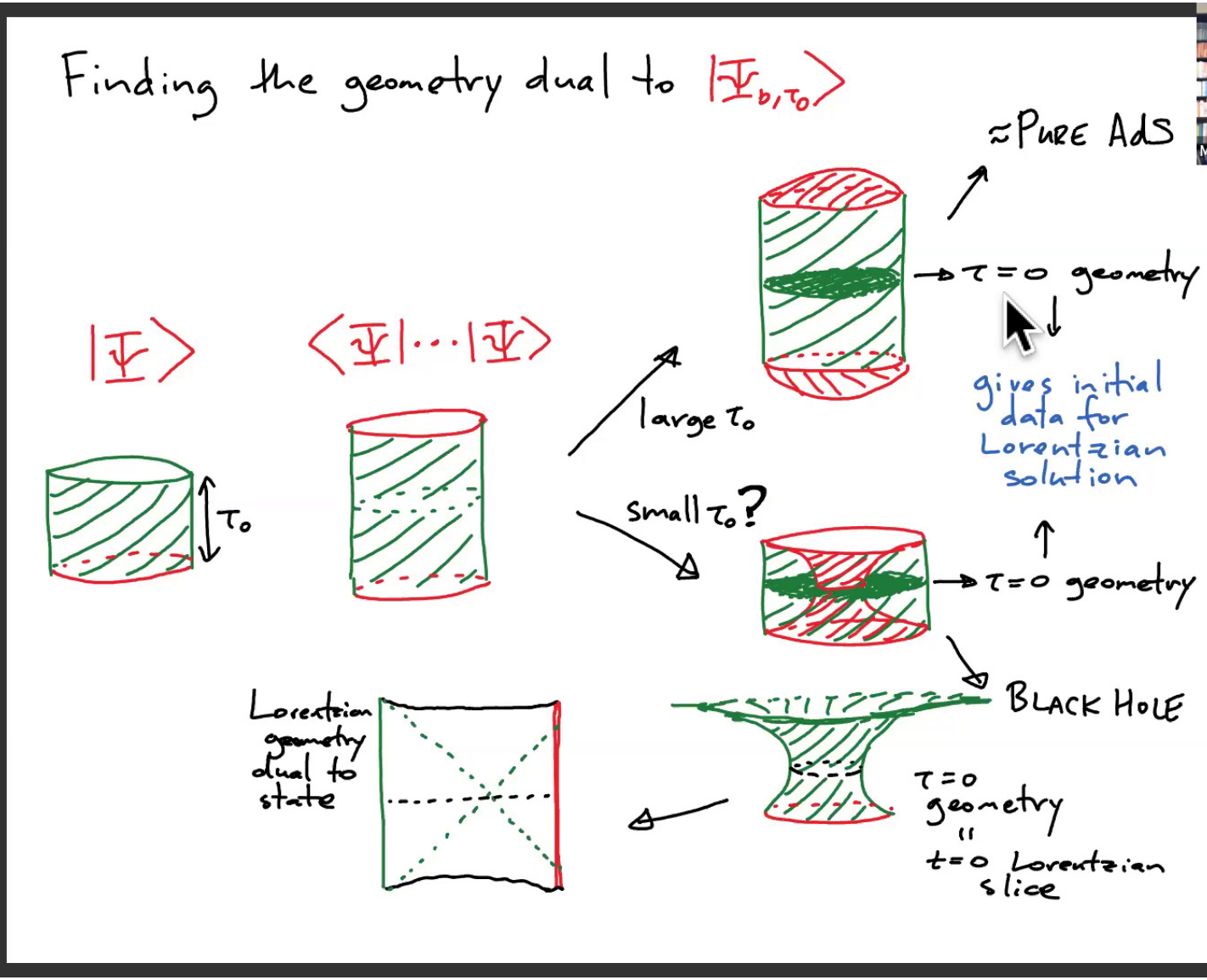


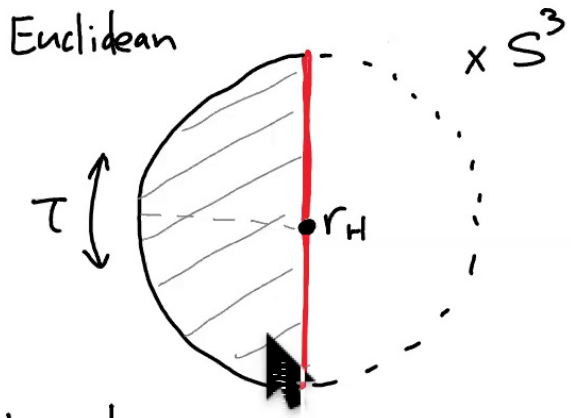
Becomes Randall-Sundrum "Planck brane" + localizes gravity in limit $C_{boundary} \gg C_{bulk}$

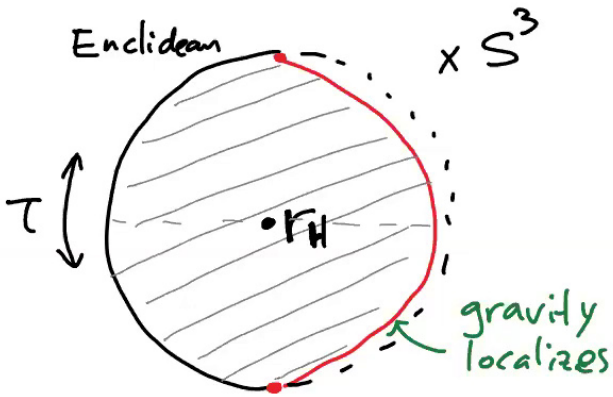
(will check this in microscopic model)

# Finding the geometry dual to $|\Psi_{b,\tau_0}\rangle$

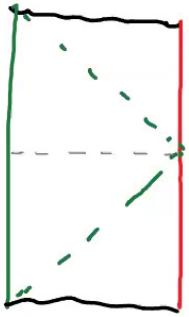




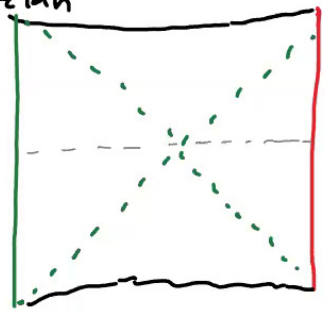




Lorentzian



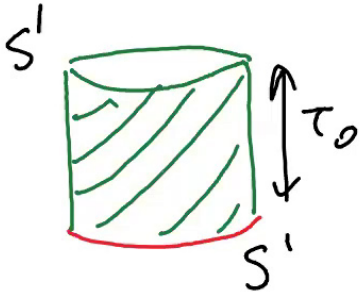
Small # boundary d.o.f. $T \approx 0$

Lorentzian



large # of boundary d.o.f.
(this is what we want)

2D CFT: get exactly this picture



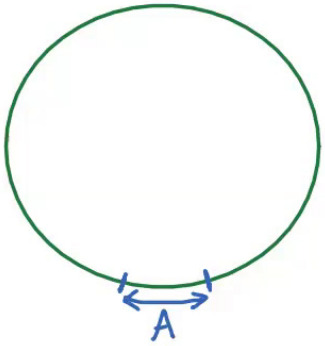

ETW brane approaches 2nd asympt. boundary as $T \to T_c$, $\frac{C_{bound}}{C_{bulk}} \to \infty$

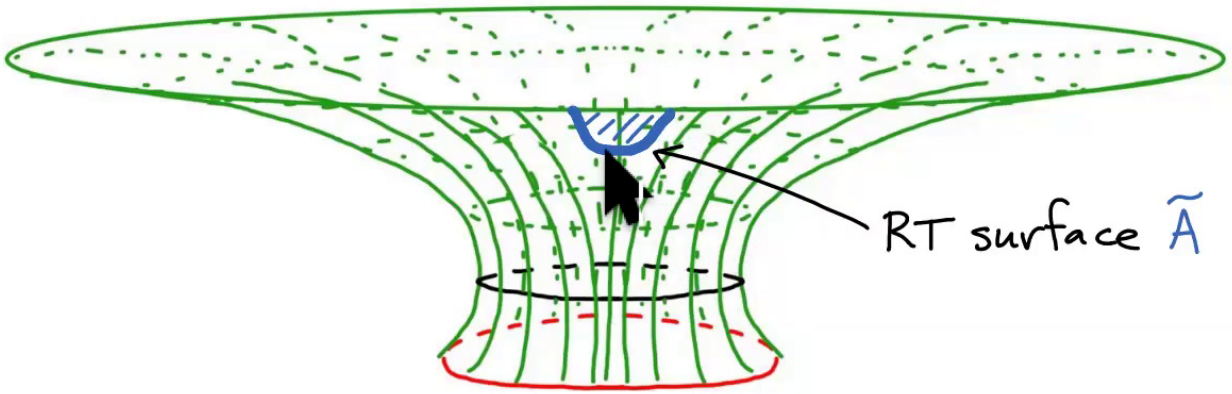
$T$: ETW brane tension

★ can verify by direct CFT calculations ★

Sully, MVR, Wakeham

$t = 0$ entanglement entropy:

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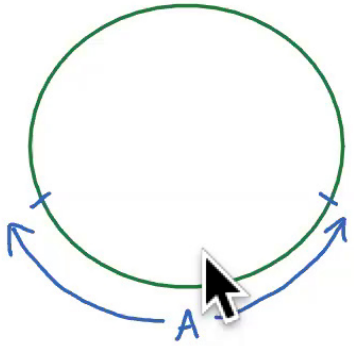
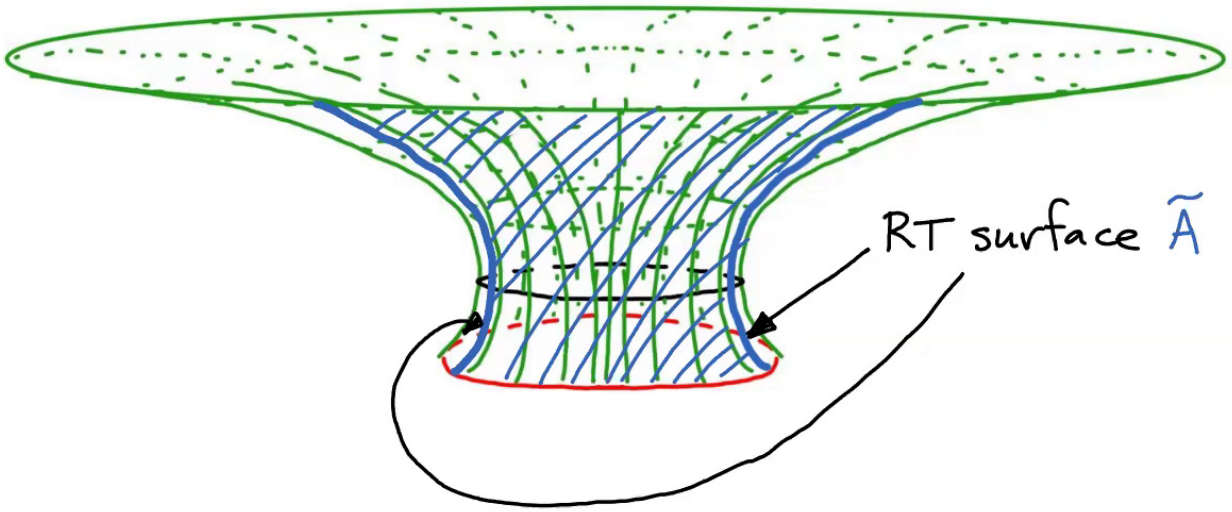
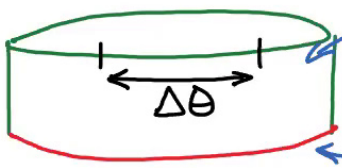


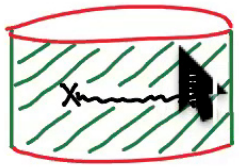




central charge c

boundary entropy log g

$$S = \begin{cases} \dfrac{c}{3}\log\left[\dfrac{4\tau_0}{\pi\epsilon}\sinh\left(\dfrac{\pi\Delta\theta}{4\tau_0}\right)\right] & \sinh\left(\dfrac{\pi\Delta\theta}{4\tau_0}\right) \le \cosh\left(\dfrac{\pi t}{2\tau_0}\right) e^{\frac{6\log g_b}{c}} \\ \dfrac{c}{3}\log\left[\dfrac{4\tau_0}{\epsilon\pi}\cosh\left(\dfrac{\pi t}{2\tau_0}\right)\right] + 2\log g_b & \sinh\left(\dfrac{\pi\Delta\theta}{4\tau_0}\right) \ge \cosh\left(\dfrac{\pi t}{2\tau_0}\right) e^{\frac{6\log g_b}{c}} \end{cases}$$



this gravity result using bottom-up ETW brane w. tension $\frac{2c}{3L^2}\tanh\left(\frac{6\log g}{c}\right)$ is reproduced by CFT replica calculation, assuming vacuum block dominance

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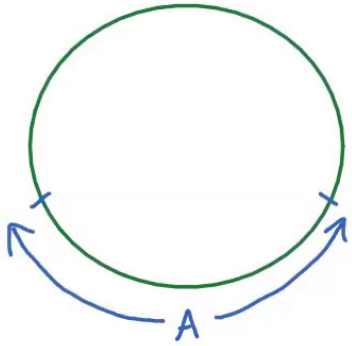


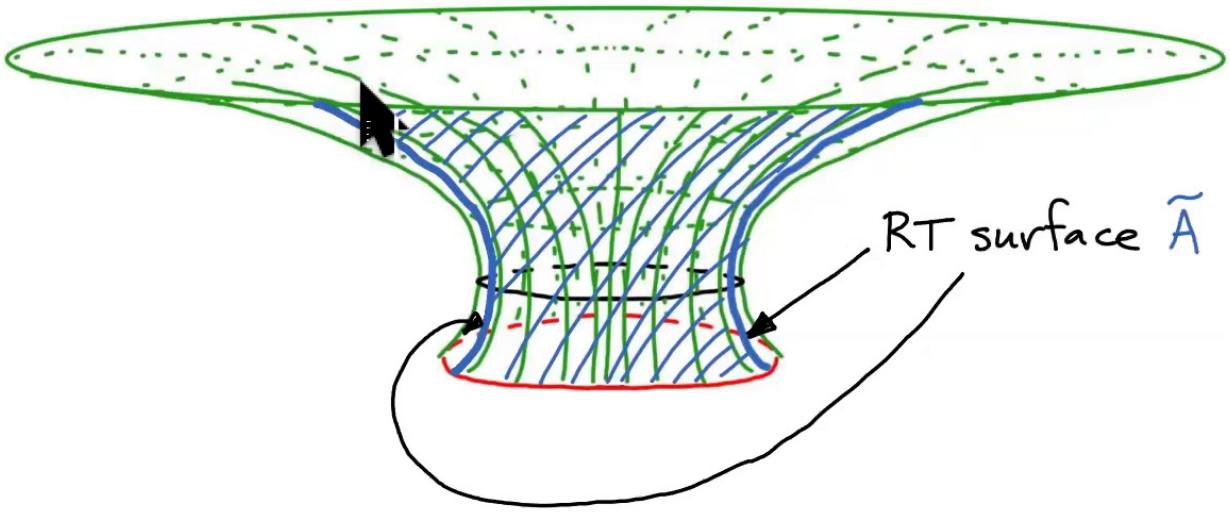


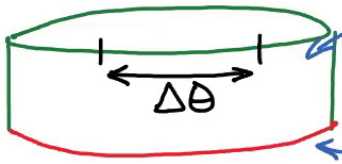


central charge $c$

boundary entropy $\log g$

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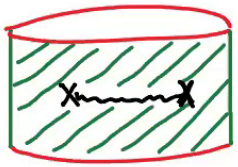

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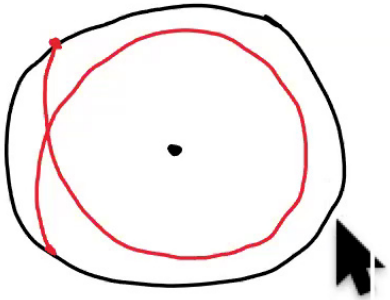
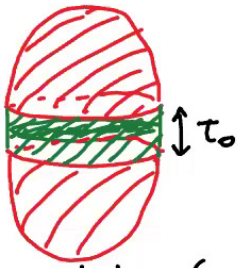
4D situation: simplest bottom-up model does not give black hole solutions with ETW brane far behind horizon.



connected ETW brane solutions w. large tension




only solution for $T > T_*$, small $\tau_0$

this model suggests energy of state remains small even for $\tau_0 \to 0$, contrary to expectation that boundary state $|b\rangle = \lim_{\tau_0 \to 0} |\Psi_{b,\tau_0}\rangle$ is singular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Page 16 of 33

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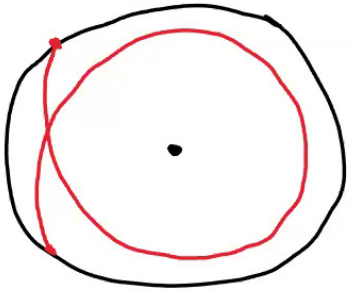

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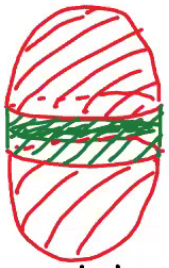


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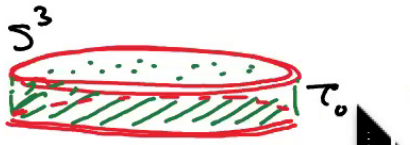
- problem with simple bottom-up model?

  Antonini + Swingle showed problem can be resolved using bottom up model w. changed ETW brane

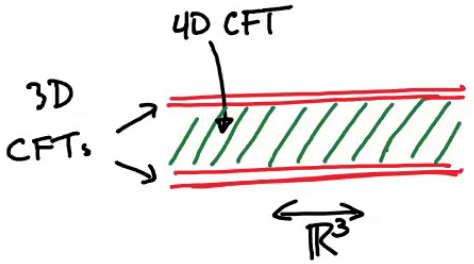
- can we find a microscopic construction?

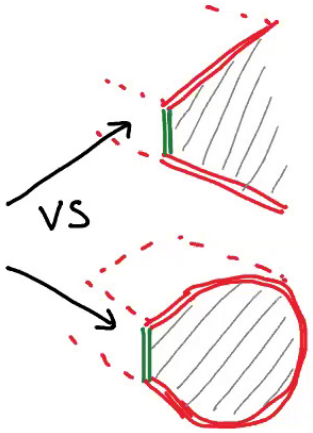
# Field Theory Picture:




Does ETW brane connect for $\tau_0 \to 0$ ?

Study planar limit:




3D CFT in IR

IR 3D theory is gapped

Can we find example w. $C_{3D} \gg C_{4D}$ that is gapped in IR?

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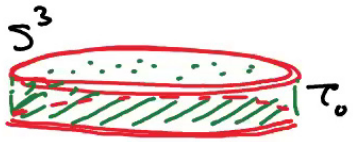


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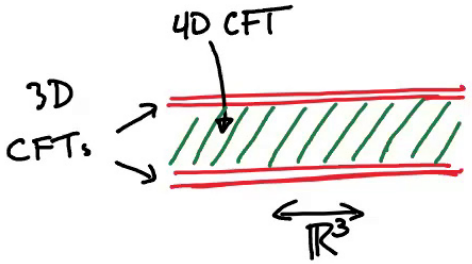


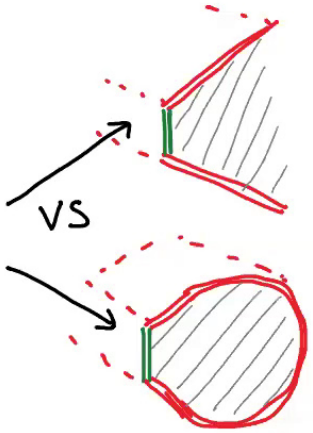


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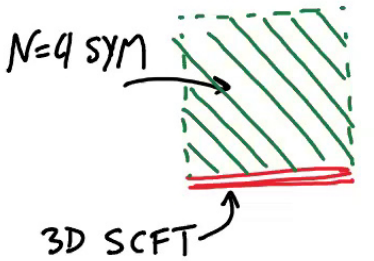
# Microscopic Example


Start w. $\mathcal{N}=4$ SYM theory.

Can introduce boundary w. 3D SCFT

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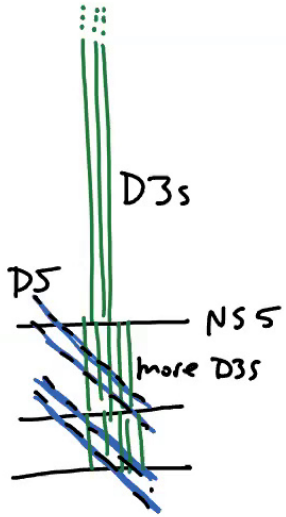


Preserves $\frac{1}{2}$ SUSY, can have arbitrarily large $\frac{C_{bdy}}{C_{bulk}}$

IIB supergravity solutions known explicitly. Estes, d'Hoker, Gutperle
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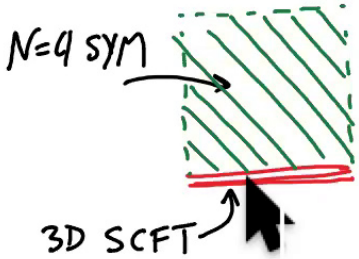


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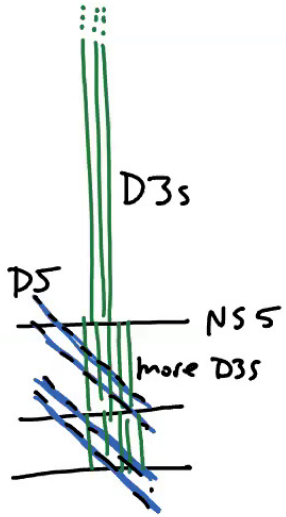


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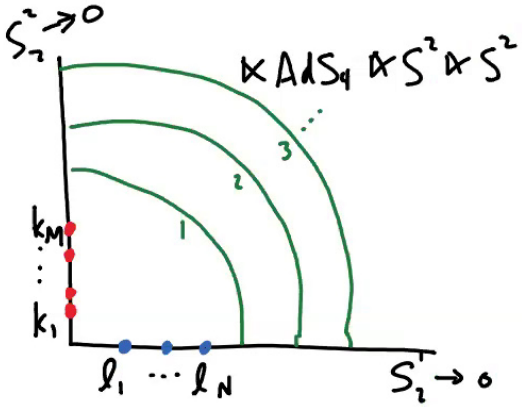
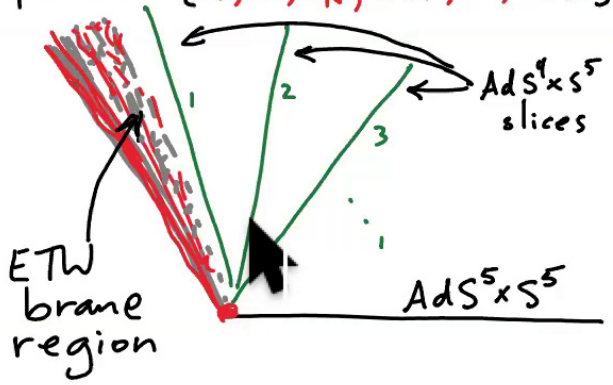
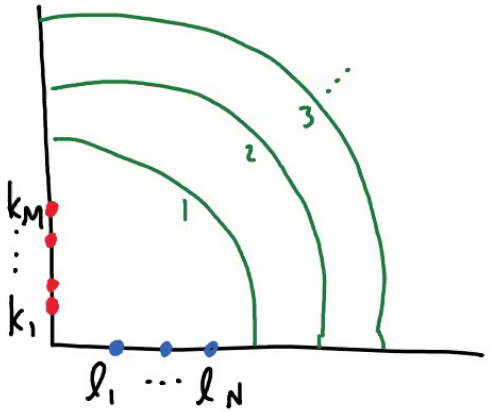
# Gravity duals for $\mathcal{N}=4$ SYM with single ½ susy boundary

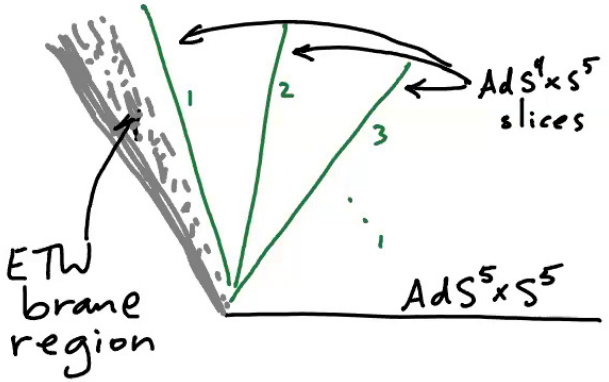
- dual is $AdS^4 \times S^2 \times S^2$ fibered over +ve quadrant of $\mathbb{R}^2$.
- fields expressed in terms of harmonic functions $h_1, h_2$ on quadrant. These are determined by poles $\{\ell_1, \ldots, \ell_N, ik_1, \ldots, ik_M\}$




# Gravity duals for $\mathcal{N}=4$ SYM with single ½ susy boundary



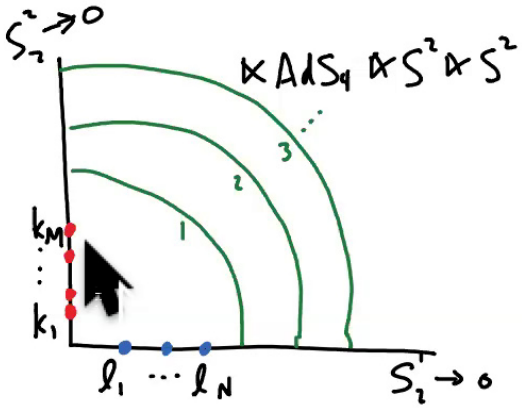



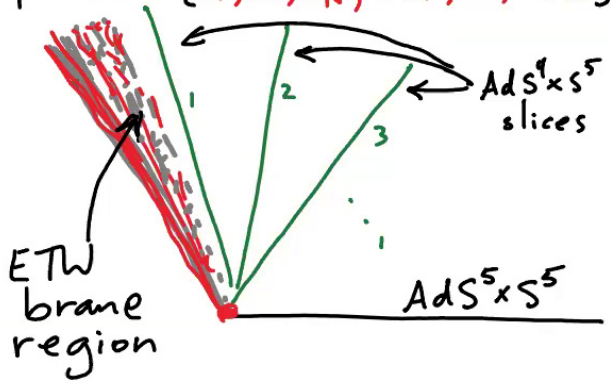

AdS radius determined by $N = \sum_{i=1}^{M} k_i + \sum_{j=1}^{N} \ell_j$

★ With fixed $N$ in limit of large number of poles, ETW brane approaches "missing" boundary and we recover $AdS^5 \times S^5$! ★

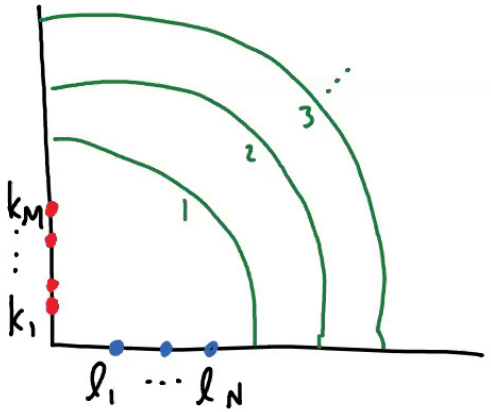
# Gravity duals for $N=4$ SYM with single $\frac{1}{2}$ susy boundary

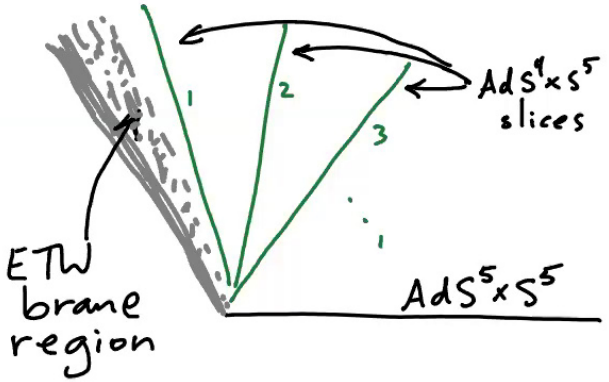
- dual is $AdS^4 \times S^2 \times S^2$ fibered over +ve quadrant of $\mathbb{R}^2$.
- fields expressed in terms of harmonic functions $h_1, h_2$ on quadrant. These are determined by poles $\{\ell_1, \ldots, \ell_N, ik_1, \ldots, ik_M\}$




# Gravity duals for $\mathcal{N}=4$ SYM with single ½ susy boundary

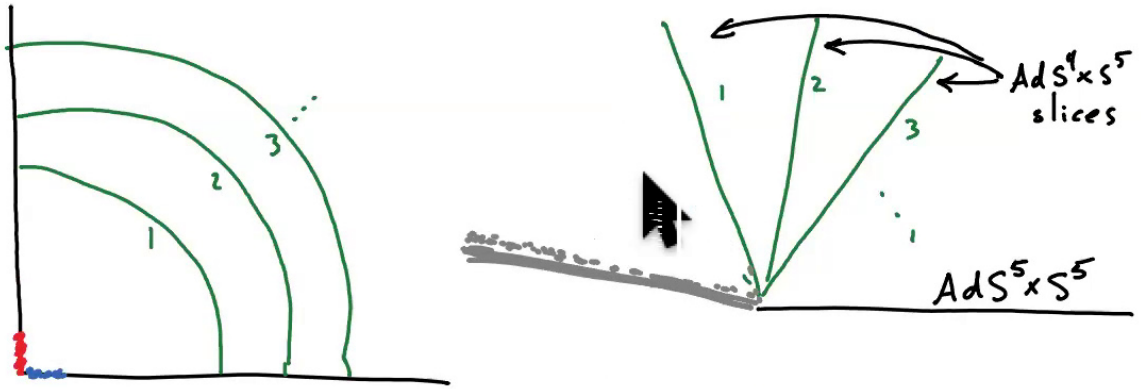



AdS radius determined by $N = \sum_{i=1}^{M} k_i + \sum_{j=1}^{N} \ell_j$

★ With fixed $N$ in limit of large number of poles, ETW brane approaches "missing" boundary and we recover $AdS^5 \times S^5$! ★

# Gravity duals for $\mathcal{N}=4$ SYM with single ½ susy boundary

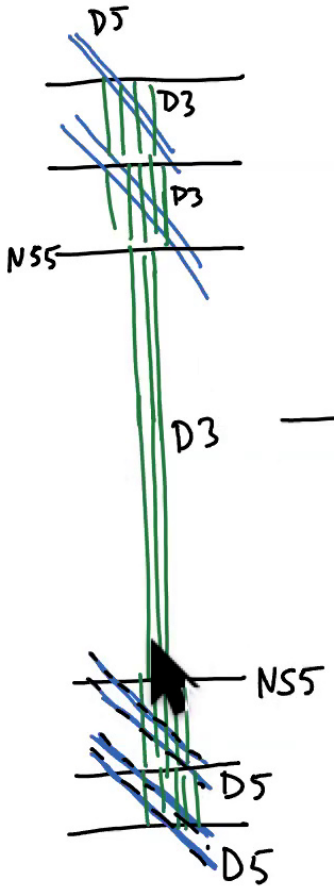



AdS radius determined by $N = \sum_{i=1}^{M} k_i + \sum_{j=1}^{N} \ell_j$

★ With fixed $N$ in limit of large number of poles, ETW brane approaches "missing" boundary and we recover $AdS^5 \times S^5$! ★

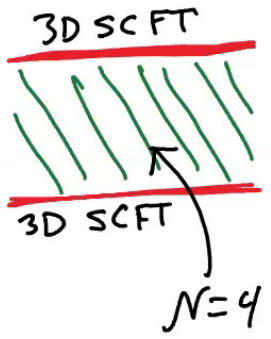
ETW brane becomes a Planck brane w. localized gravity! (large # boundary d.o.f. in this case)

Now add 2nd boundary:

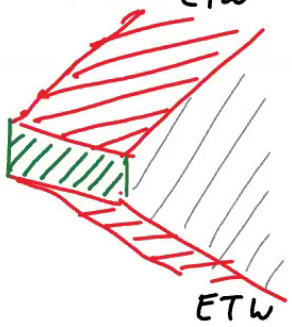



preserves SUSY → flows to 3D SCFT in IR

(deconstructed $\mathcal{N}=4$ SYM theory as angle $\to \pi$ !)

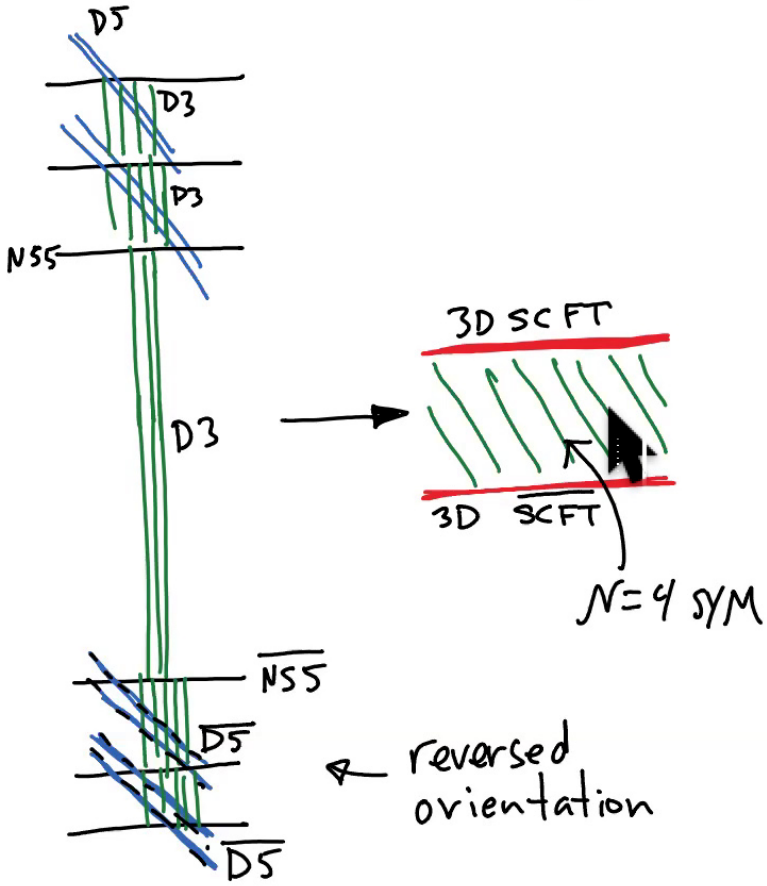



dual to: ETW




NOT WHAT WE WANT

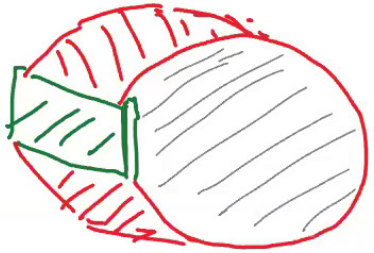
Now add 2nd boundary:

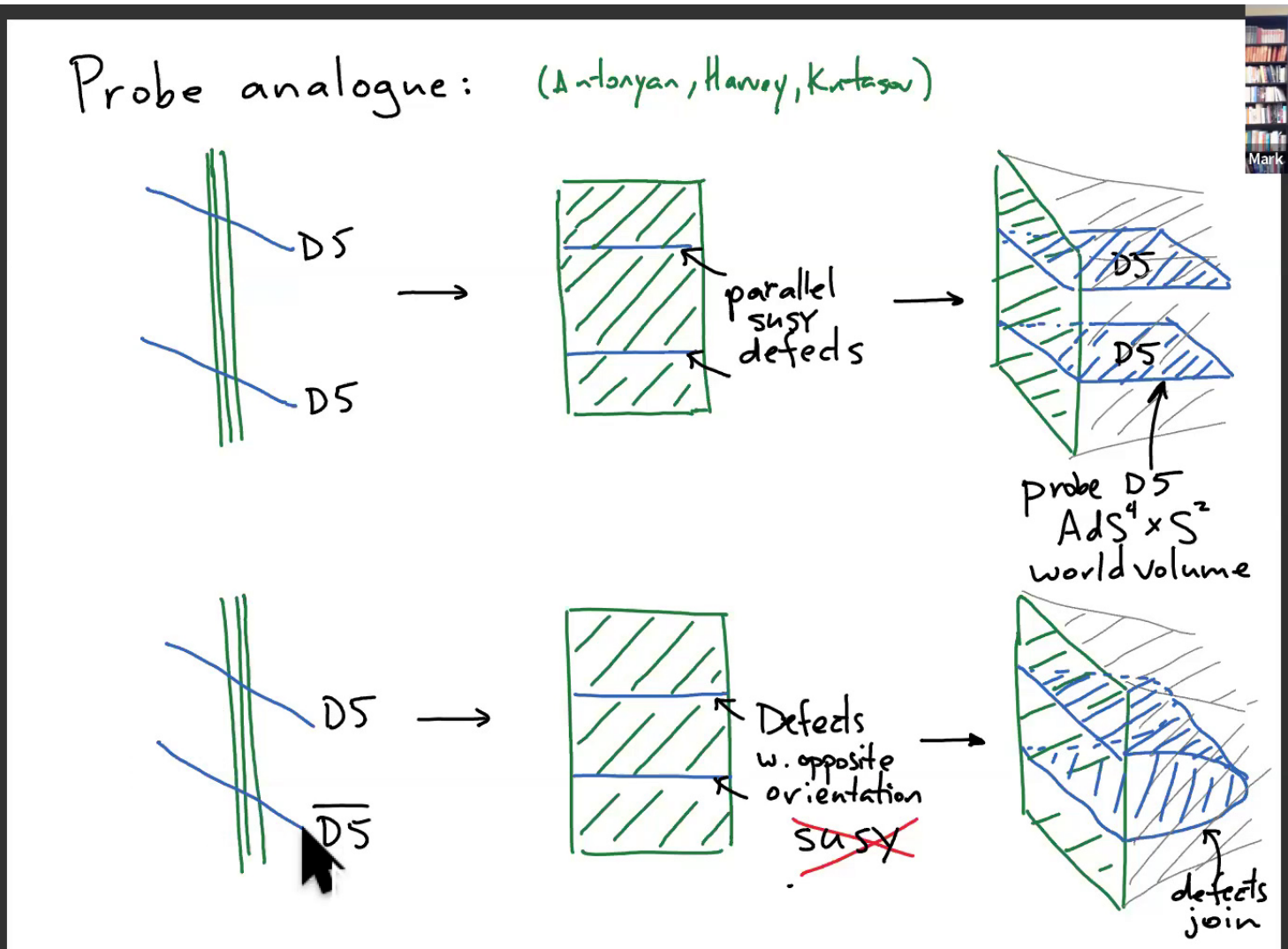



breaks all SUSY

conjecture:

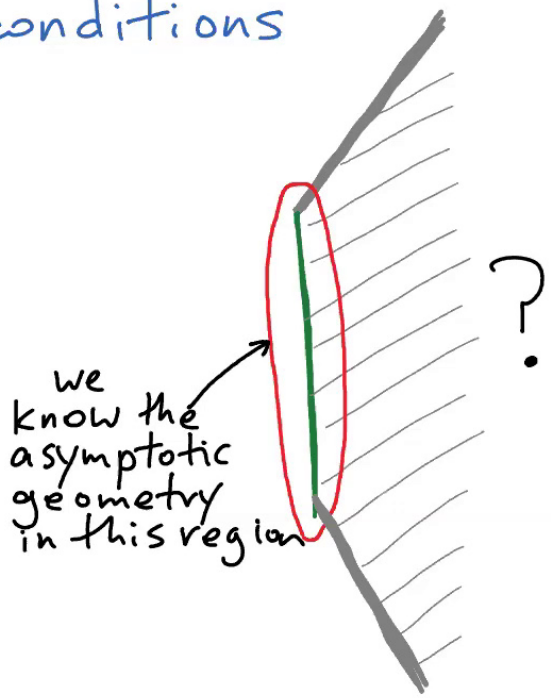
this will lead to gapped theory in IR and connected ETW brane:




Probe analogue: (Antonyan, Harvey, Kutasov)
D5
D5
parallel susy defects
D5
D5
probe D5
$AdS^4 \times S^2$
world volume
D5
$\overline{D5}$
Defects w. opposite orientation
susy
defects join

# How can we tell for sure?

Analyze type IIB supergravity equations with asymptotic behavior corresponding to chosen boundary conditions




probe example suggests that geometry will be $\mathbb{R}^3 \times S^2 \times S^2$ fibered over 3D space, so fields depend non-trivially on 3 coordinates.

Questions:

Is there a connected solution?

Is this the least action solution?

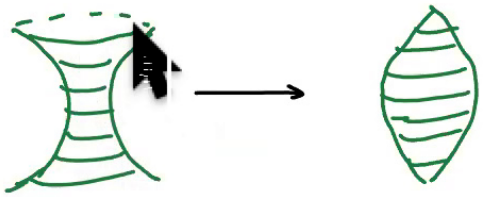
Does gravity localize?

Puzzle (Lin + Maldacena)

What is the effective description of the physics? Euclidean picture would be 4D AdS wormhole. Difficult to construct w. standard effective field theory.

# ASIDE: connection to recent wormhole discussion

Maldacena, Maoz:



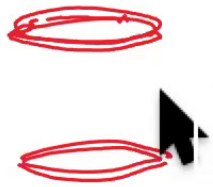
Euclidean wormhole analytically continues to FRW cosmology.

AdS/CFT description in terms of 2 Euclidean CFTs?

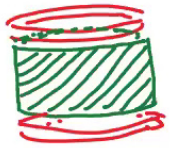
non-factorization of correlators →

- ensemble average? (e.g. Maoz-Maldacena, Saad/Stanford/Stanford)
- interaction between CFTs? (e.g. Betzios, Kiritsis, Papadoulaki)

BHMC suggests general picture:



- start with two holographic CFTs



- couple to auxiliary d.o.f.

" spread these over extra spatial direction to avoid short distance singularities

* Can view as interaction or ensemble avg *

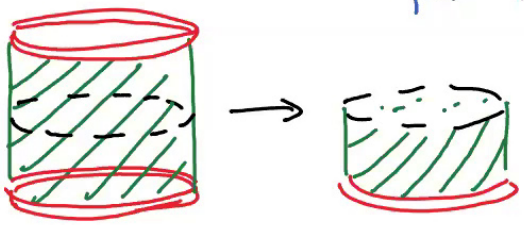
- take $C_{3D} \gg C_{4D}$ so dual description is still approximately 4D gravity

- BUT: want interaction with auxiliary d.o.f. to be strong enough to give connected wormhole.

(e.g. coupling via bifundamentals in our microscopic example)
maybe weak coupling + long RG flow works

Consequence of auxiliary d.o.f. + extra spatial direction

Path integral can be associated w. wavefn. for auxiliary d.o.f.



$|\Psi_{Aux}\rangle$ = a wavefn. of the universe.

Q: does this contain complete information about the dual spacetime?


Thanks!

Page 33 of 33