

COSMOLOGY FROM CONFINEMENT

Extreme Universe Colloquium, Jan 2022

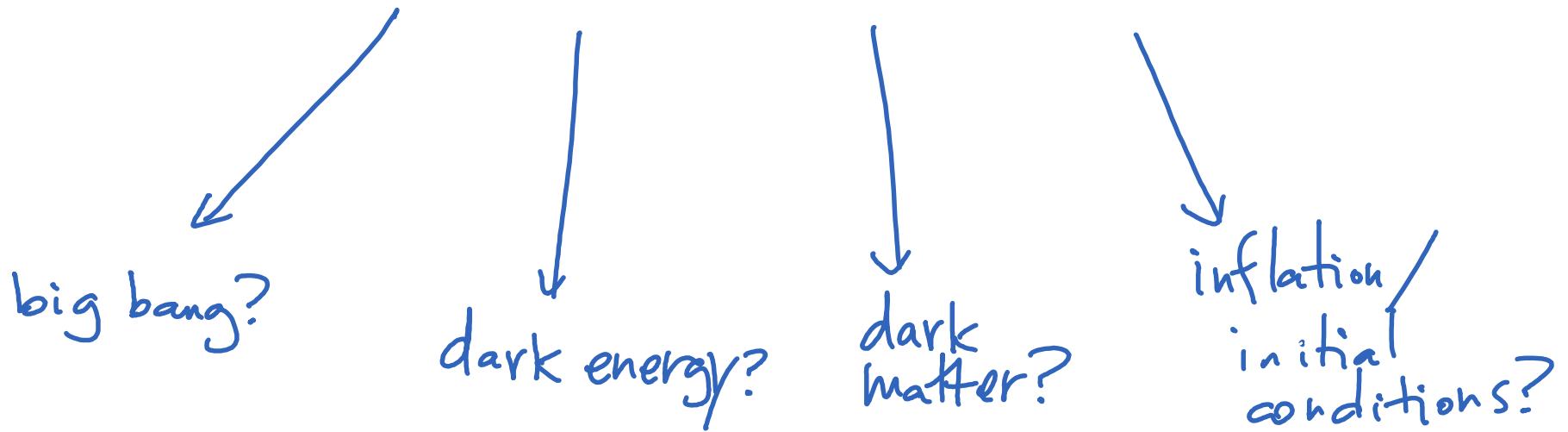
Mark Van Raamsdonk (UBC)

1810.10601 w Cooper, Rozali, Swingle, Waddell, Wakeham

2008.02259 , 2102.05057 , in progress w. Swingle
Simidzija
Antonelli

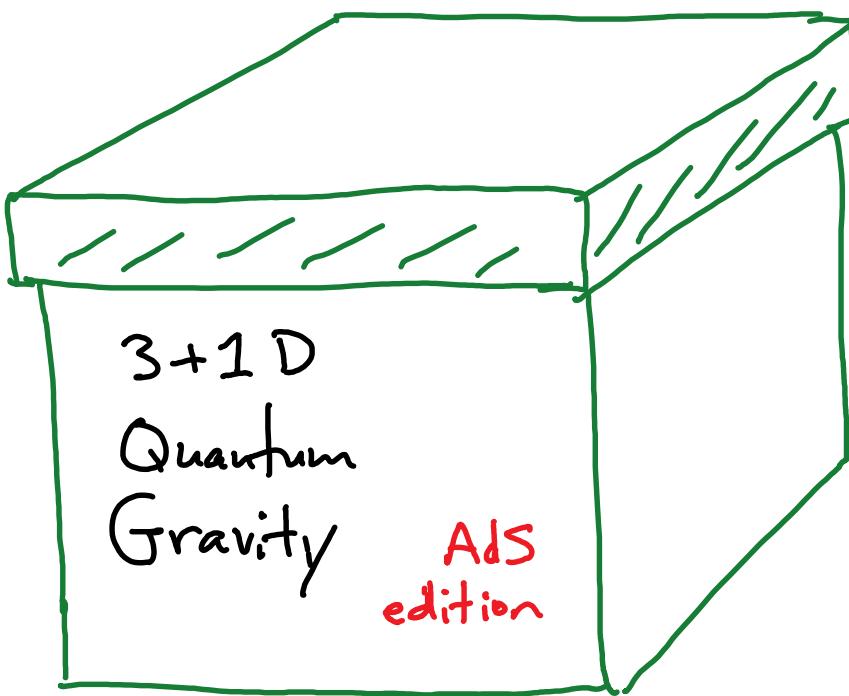
Can we come up with microscopic
quantum gravity models of cosmology?

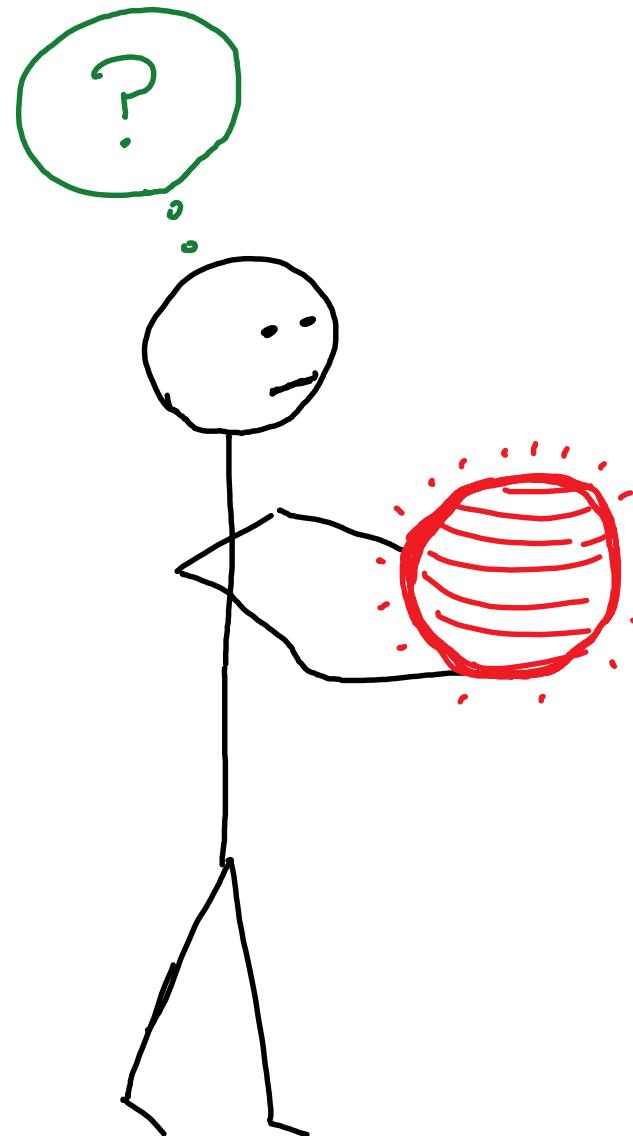
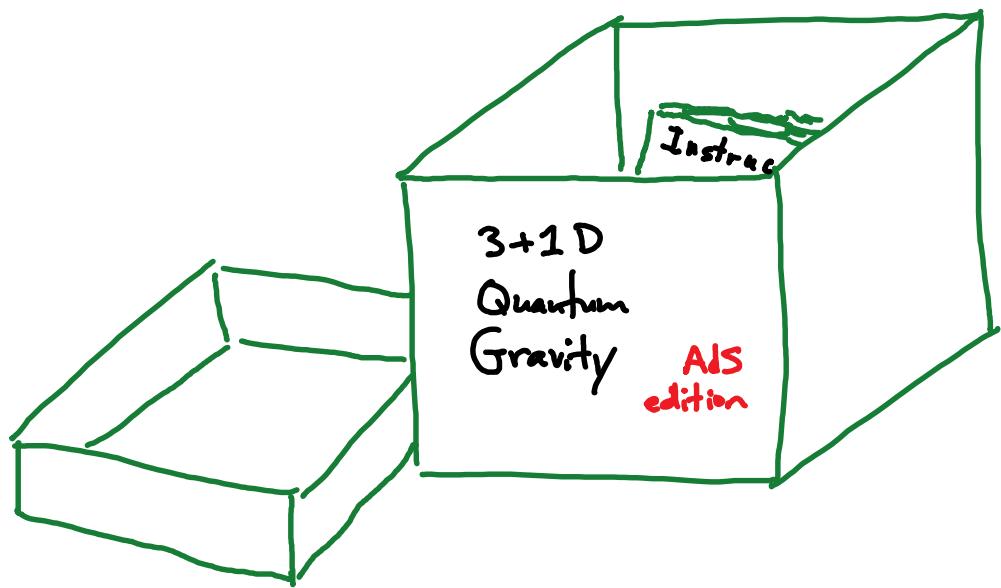
Can we come up with microscopic
quantum gravity models of cosmology?



Our best model for quantum gravity:
the AdS/CFT correspondence

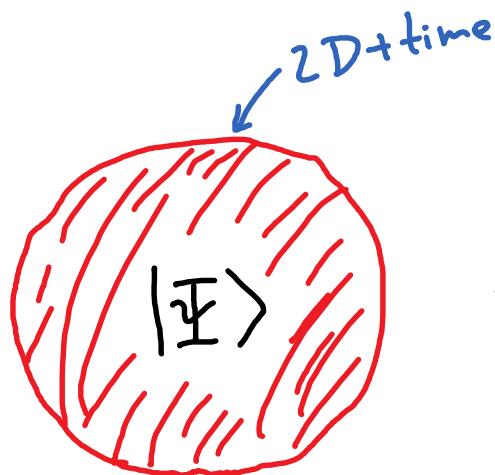
The AdS/CFT approach to quantum gravity:





3+1D AdS quantum gravity

Basic operation



$$i\hbar \frac{d|\Psi\rangle}{dt} = H |\Psi\rangle$$

Non-gravitational
quantum system
(often: CFT)

INSTRUCTIONS

$M_{|\Psi\rangle}$

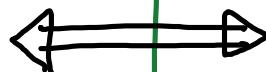
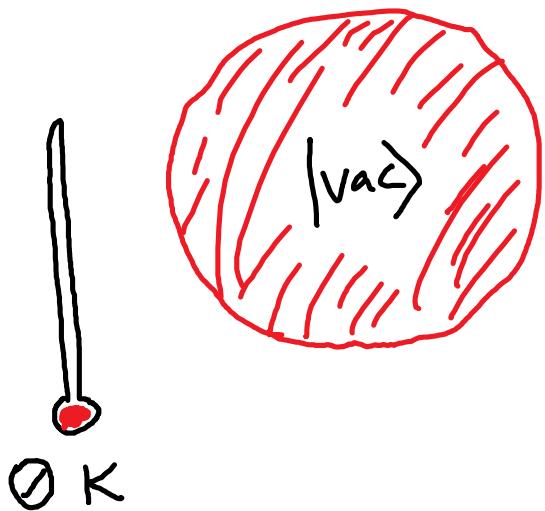
Higher-dimensional
(quantum) gravitational
system

(certain spacetimes)

3D+time

3+1D AdS quantum gravity

INSTRUCTIONS



Anti-de-Sitter
Spacetime
"AdS"

3+1D AdS quantum gravity

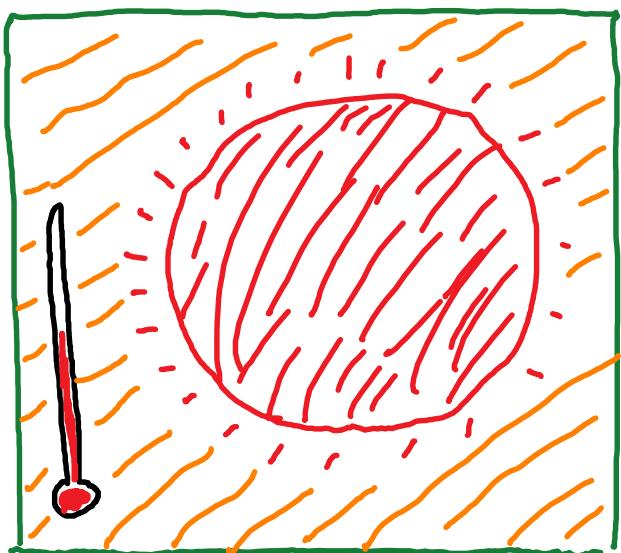
INSTRUCTIONS



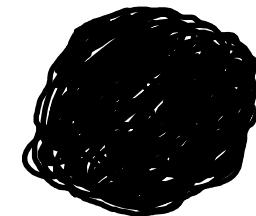
AdS
+ gravitational
waves

3+1D AdS quantum gravity

INSTRUCTIONS



$$T > \frac{1}{R}$$



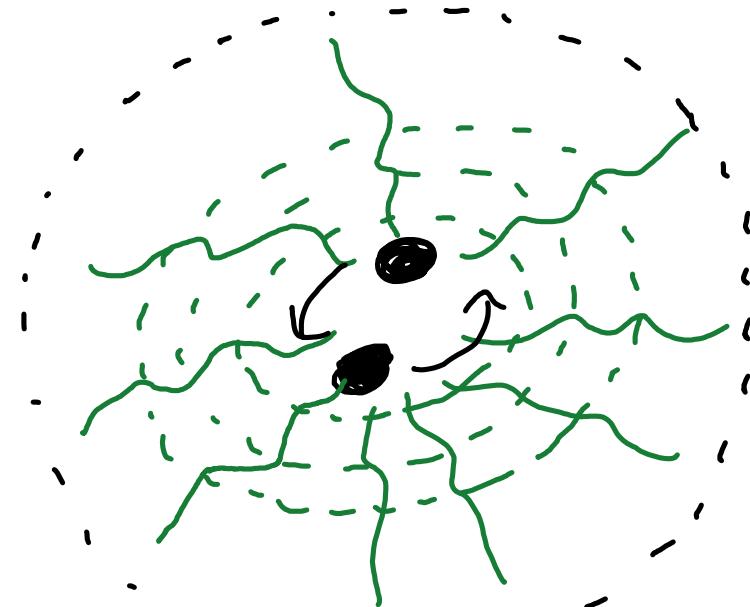
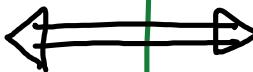
Black hole in AdS

3+1D AdS quantum gravity

INSTRUCTIONS



$|E(t)\rangle$



$M_{|E\rangle}$

Lots of recent progress understanding $|E\rangle \rightarrow M, \text{black}$

holes, etc... \rightarrow quantum information theory is crucial!

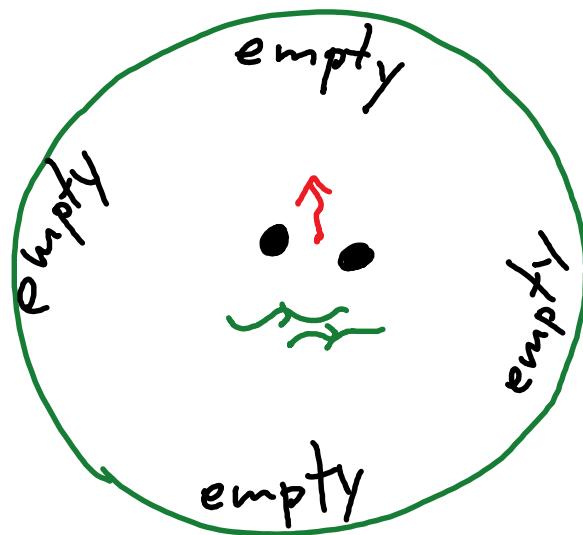
But can we use AdS/CFT to describe cosmology?

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I will describe some ideas...
not a complete story!

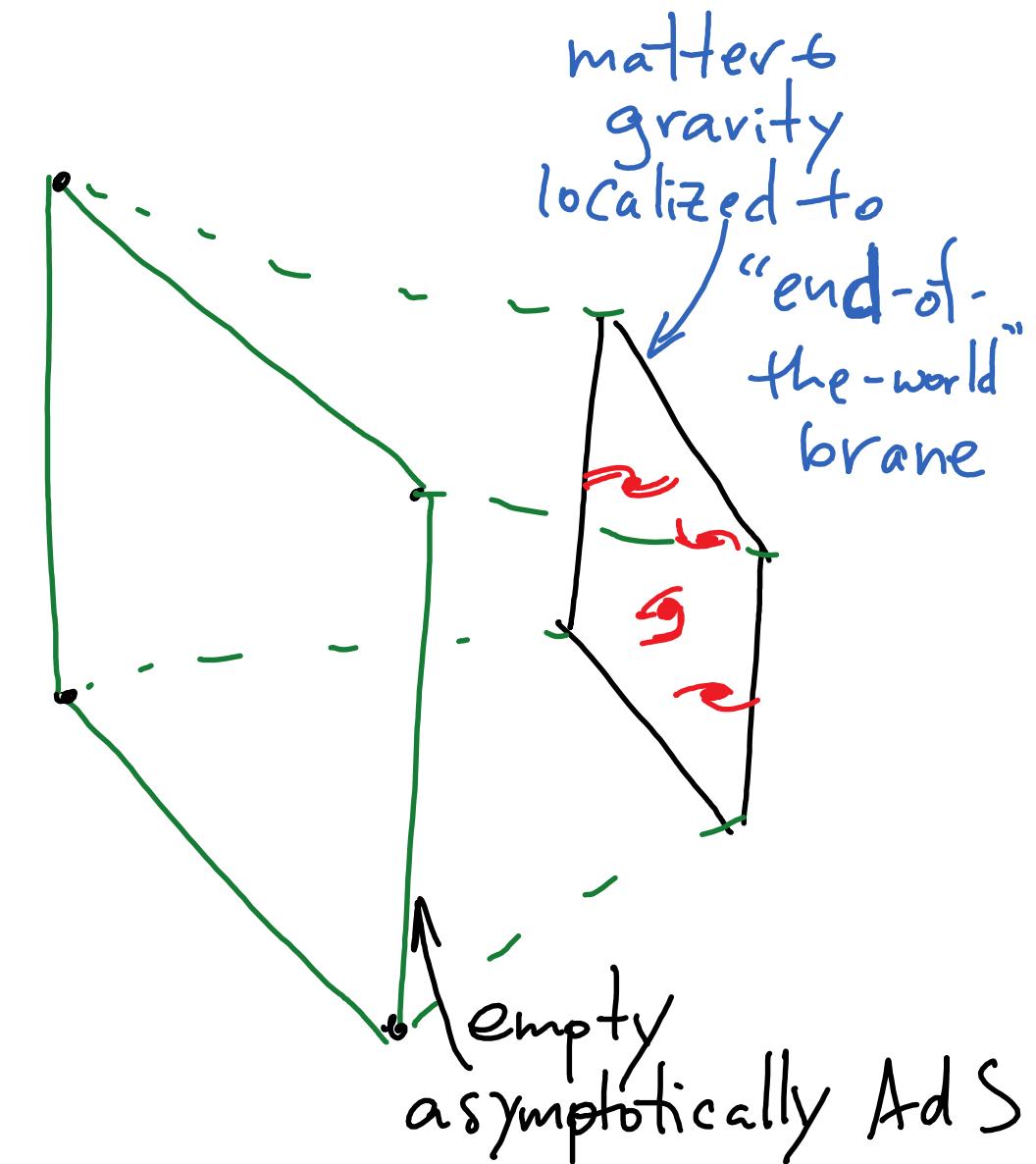
But can we use AdS/CFT to describe cosmology?

major issue : AdS/CFT models describe universes
that are asymptotically empty (negatively
curved)



cosmology : Spacetime uniformly filled with stuff!

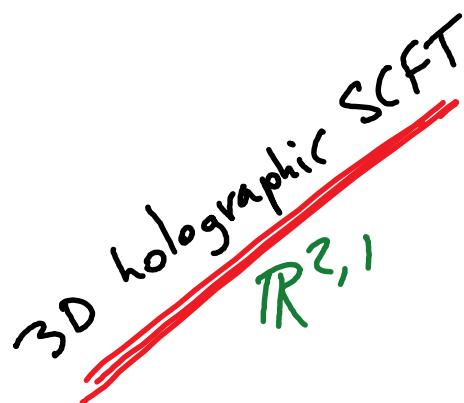
One idea: put cosmology on a brane
(Randall, Sundrum)



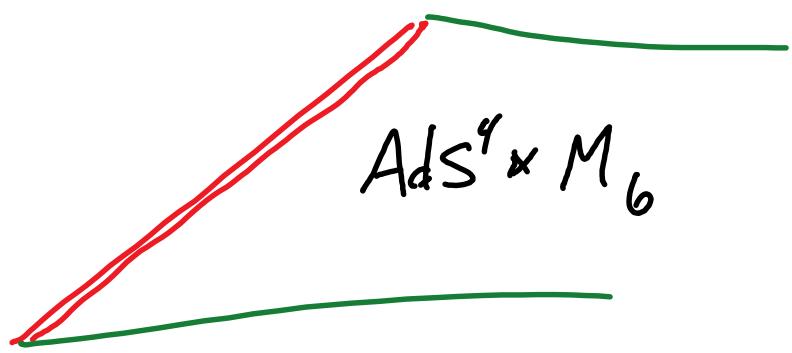
How can we localize gravity to a brane?

How can we localize gravity to a brane?

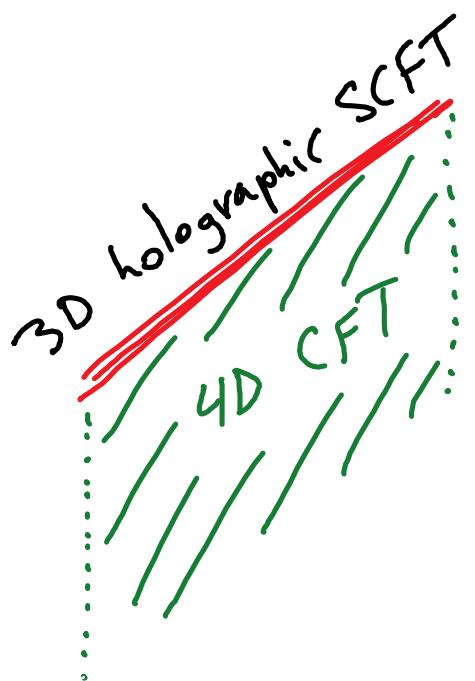
Start with a holographic 3D CFT:



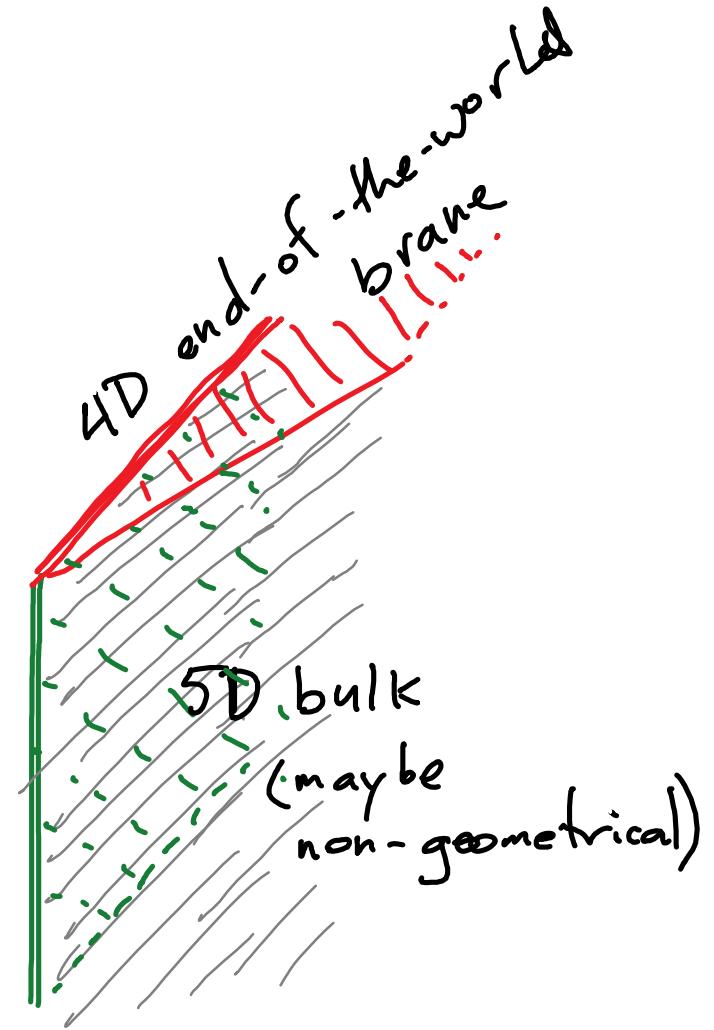
dual
to



Couple to higher dimensional
theory with $C_{4D} \ll C_{3D}$



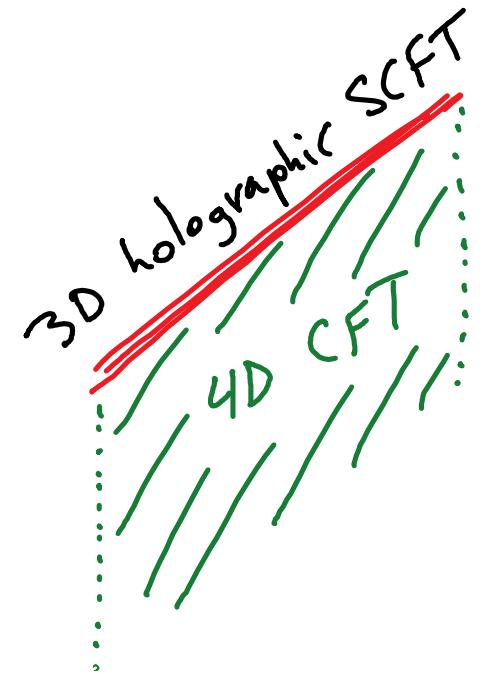
dual to
(Karch, Randall,
Takayanagi, ...)



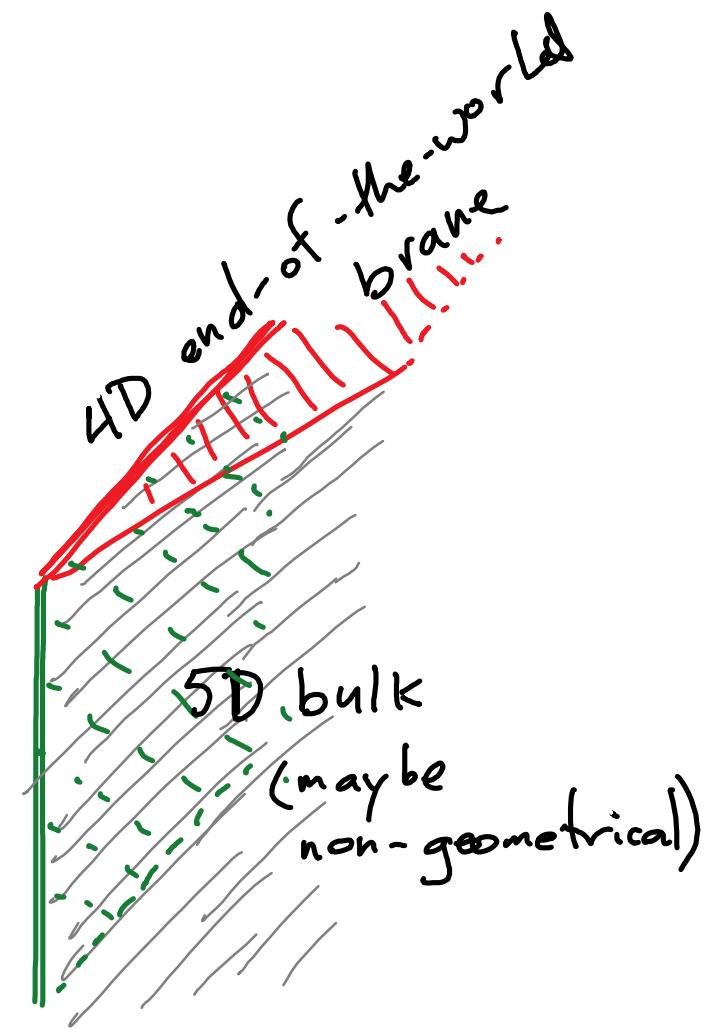
4D CFT is small perturbation, so physics of

ETW brane still approximately 4D gravity.

Couple to higher dimensional
theory with $C_{4D} \ll C_{3D}$

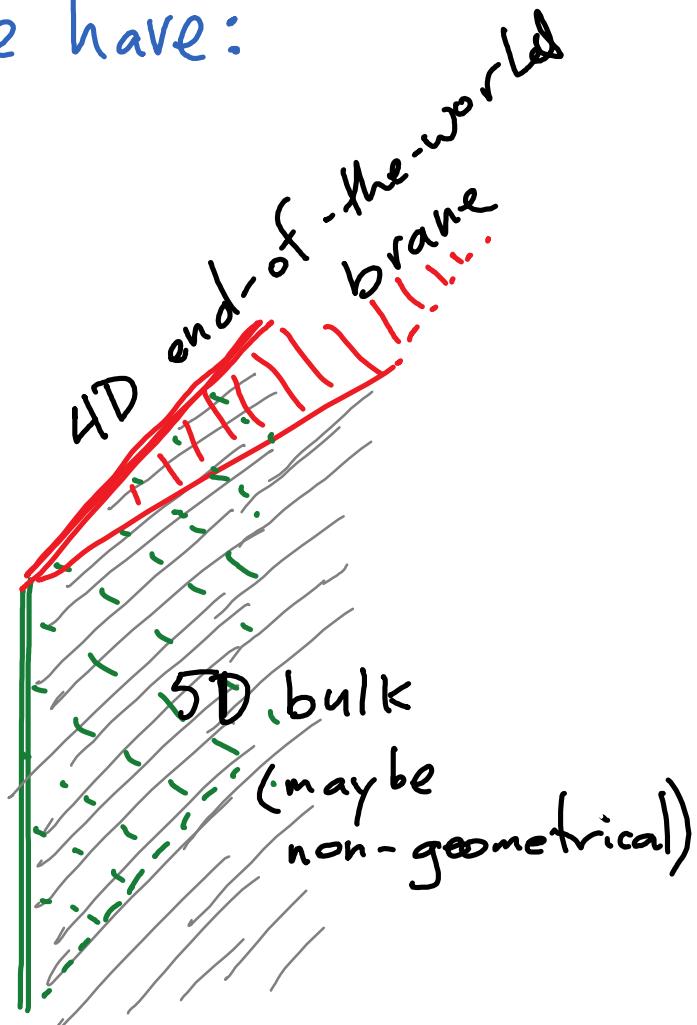


dual to



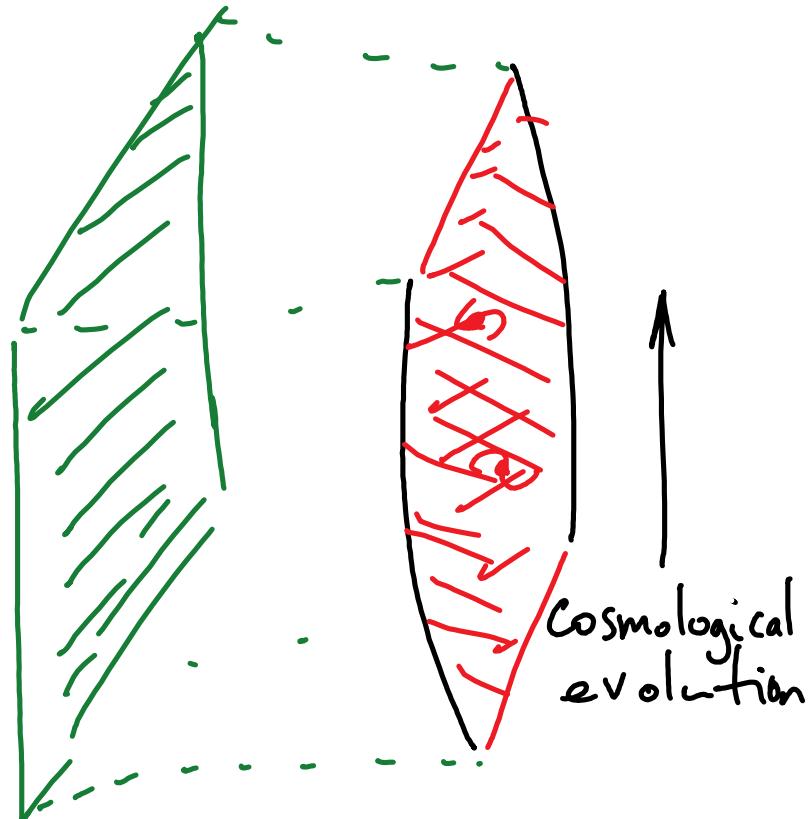
4D CFT is small perturbation, so physics of
ETW brane still approximately 4D gravity.
* microscopic examples based on $N=4$ SYM well understood *

so far,
we have:



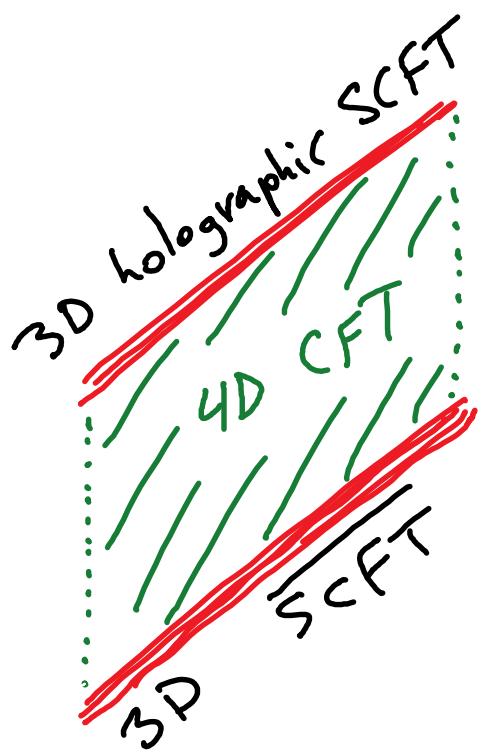
static geometry

we want:



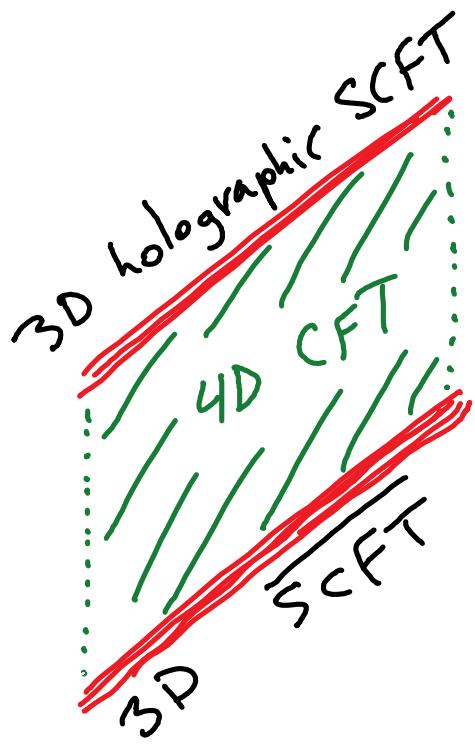
Next step:

Couple to the mirror image SCFT via a 4D CFT
with $C_{4D} \ll C_{3D}$ (break susY)

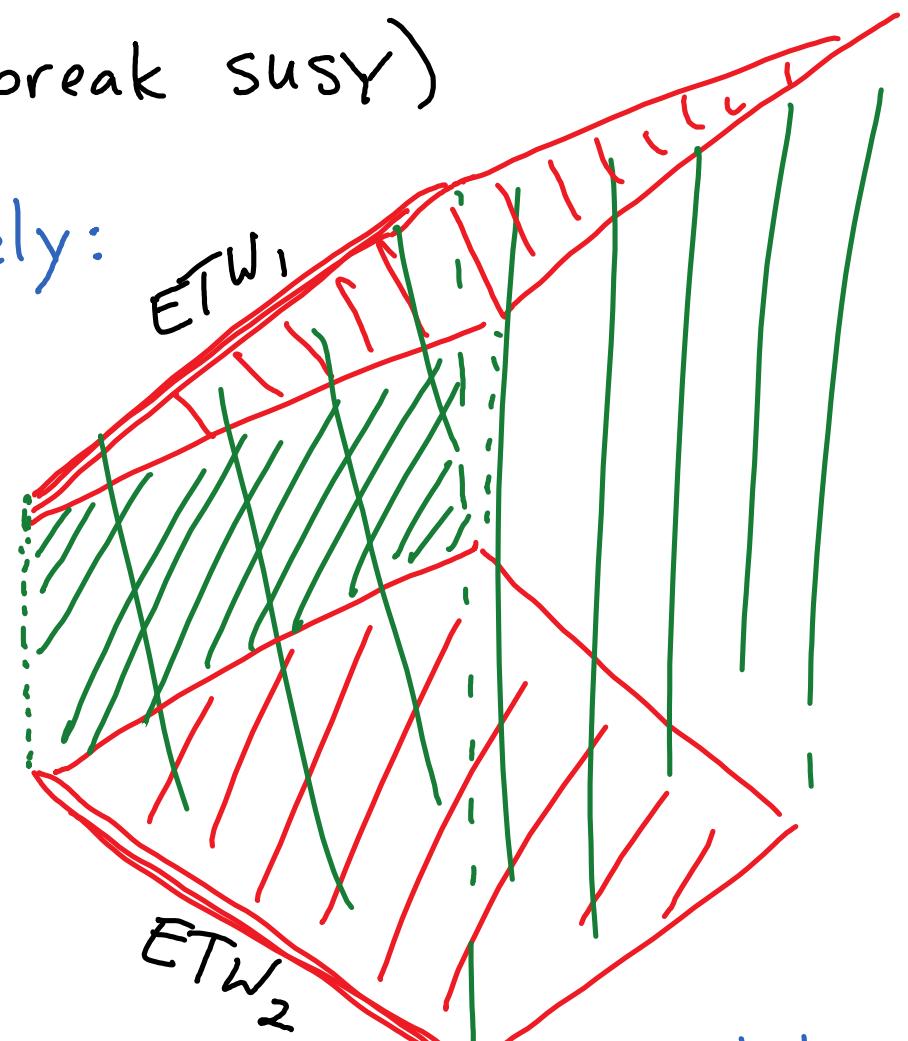


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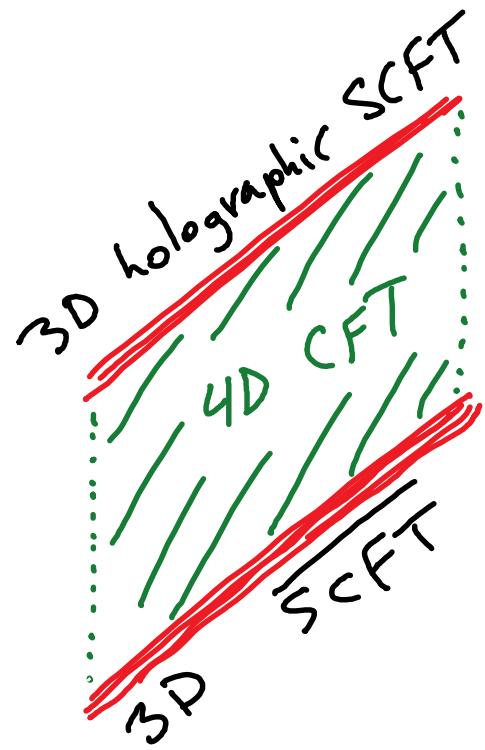


Naively:

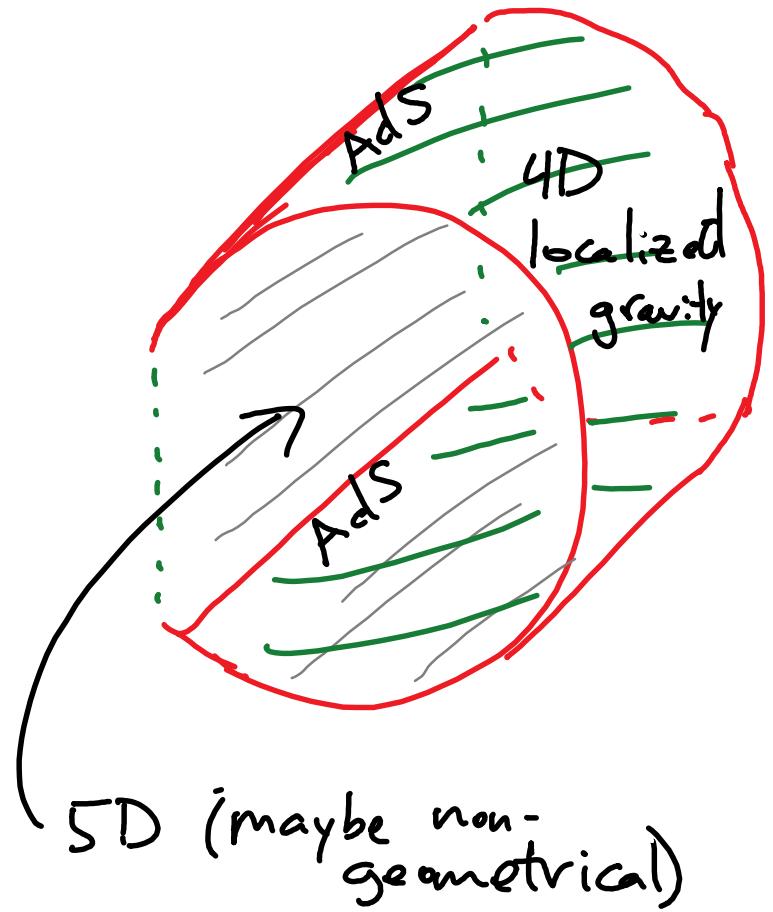


but this can be unstable...

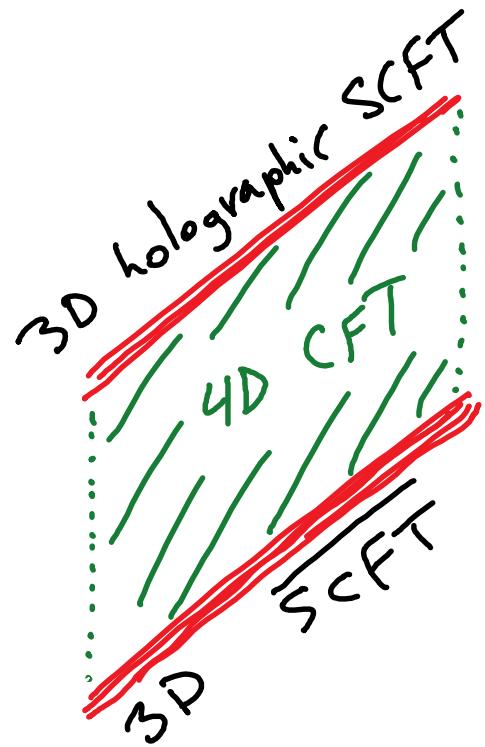
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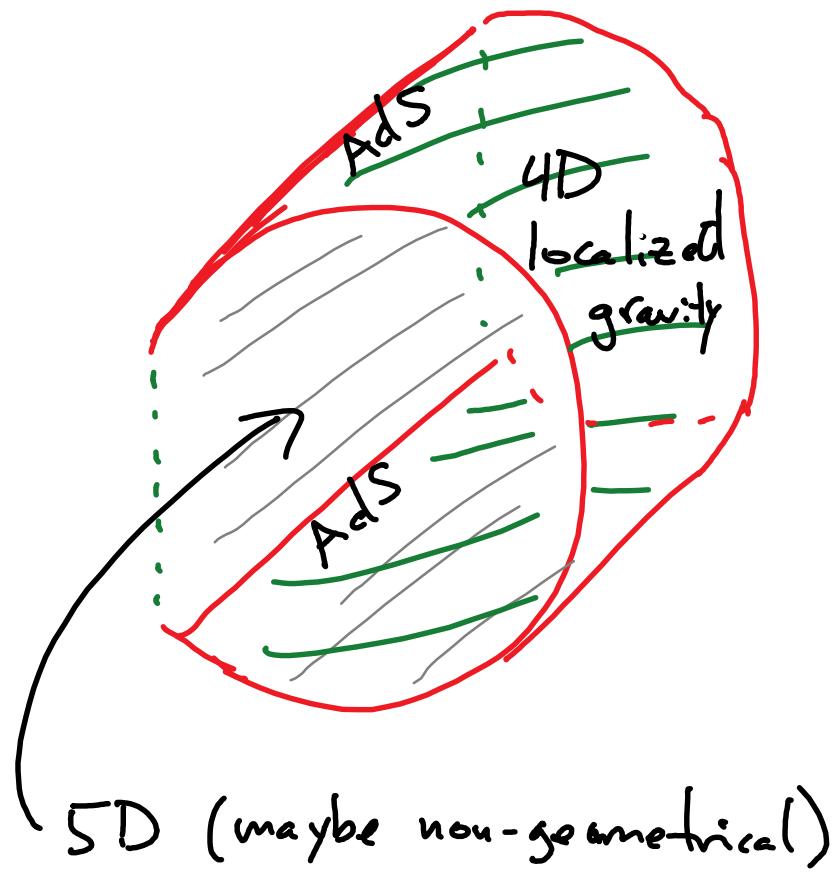
more generic?



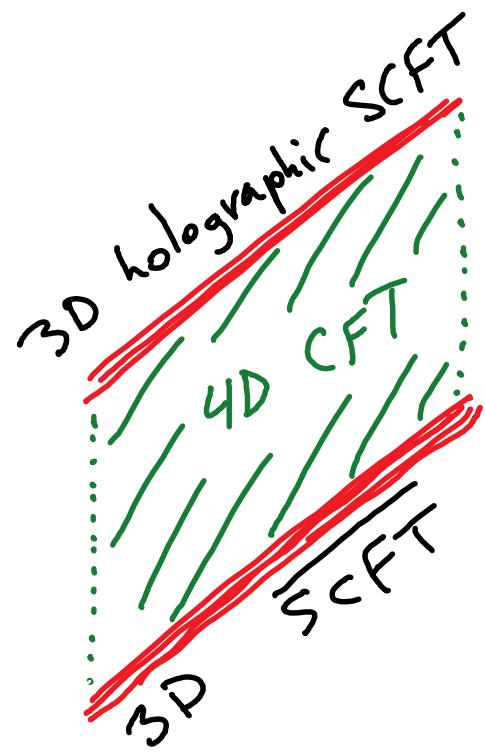
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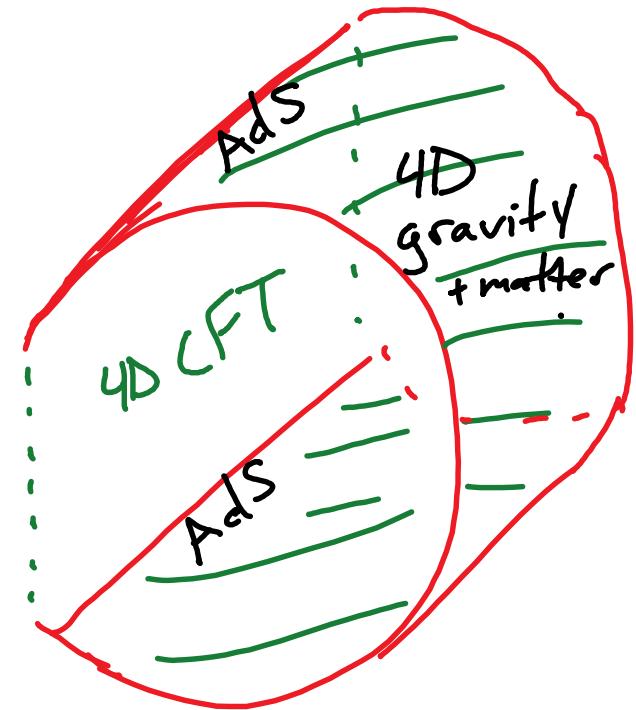
→
 same cases:
 dual to



Why: generic expectation is that 3D IR physics is gapped/confining → radial direction has finite extent.
 also: physics of branes/antibranes in string theory



→
Same cases:
dual to

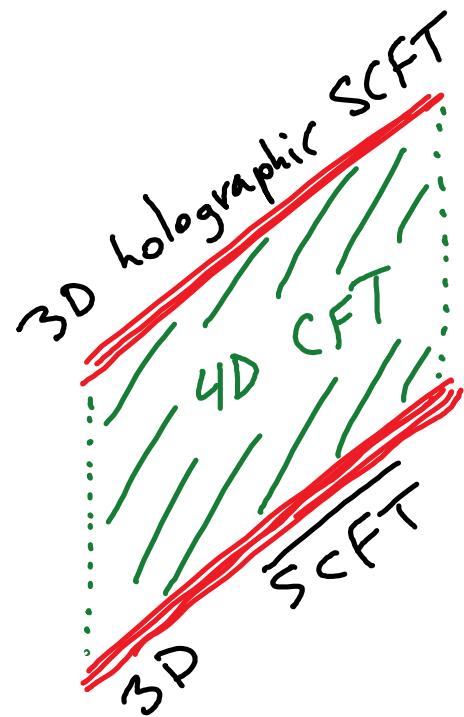


$C_{3D} \gg C_{4D}$: gravity localized to brane?

Effective description of gravitational physics:

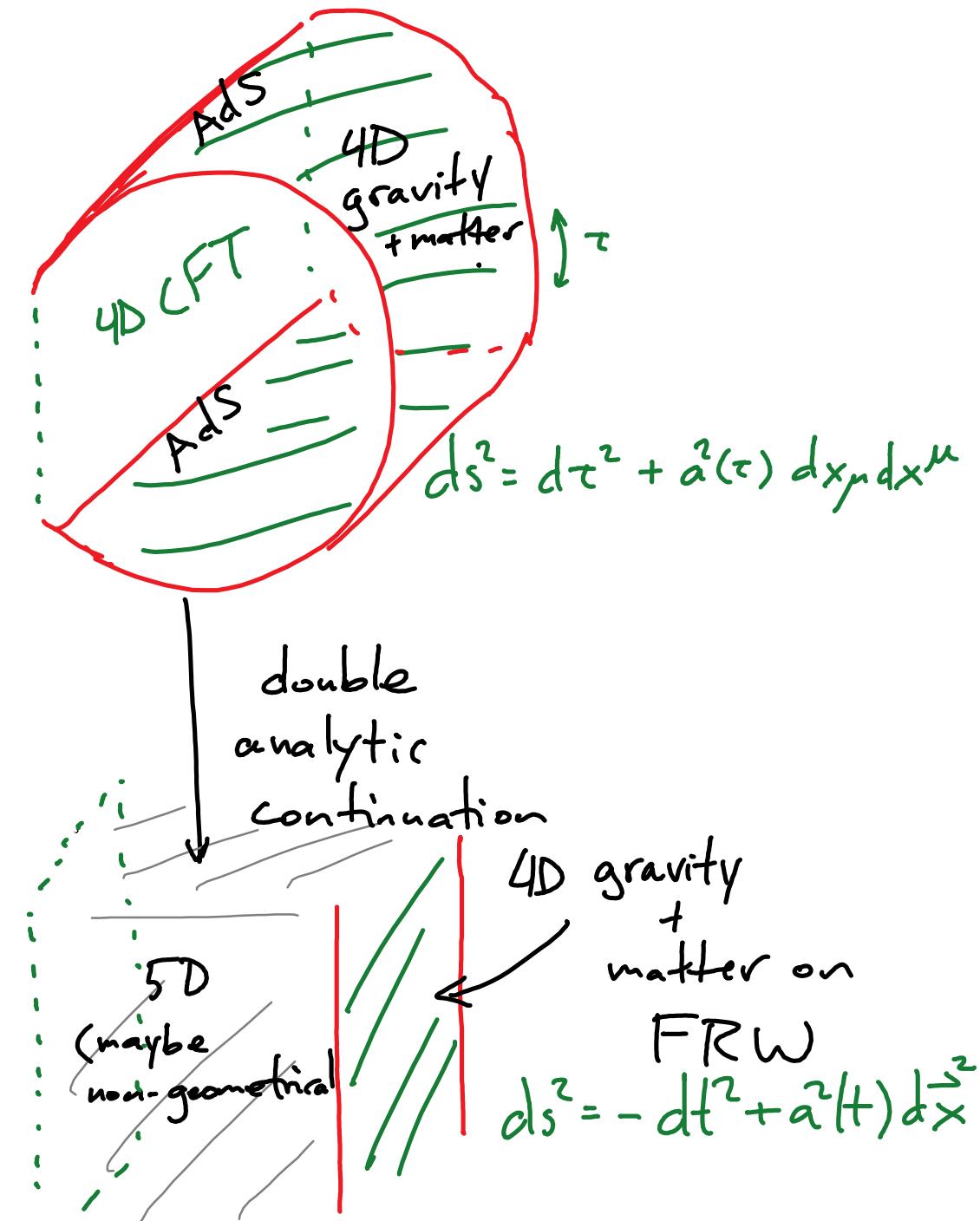
4D gravity + matter (dual of 3D SCFT)

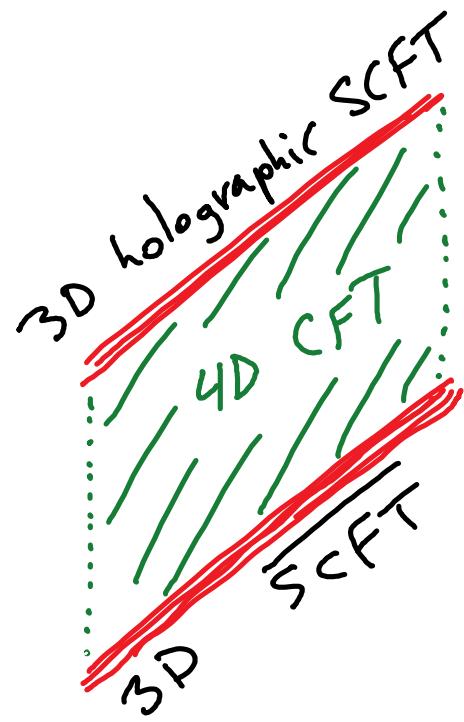
on $ds^2 = d\tau^2 + a^2(\tau) [-dz^2 + dx^2 + dy^2]$



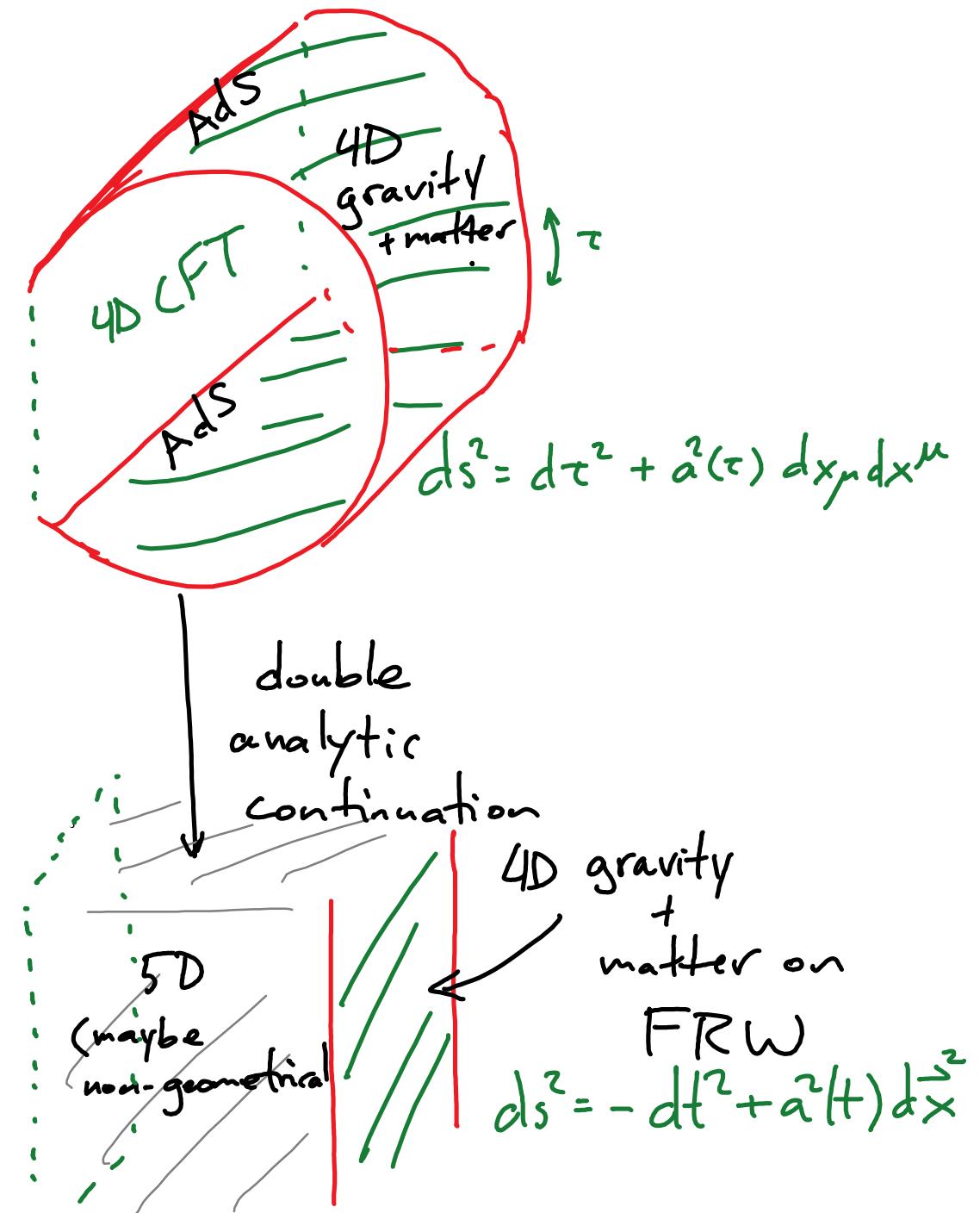
Some cases:
dual to

This connected
brane geometry is
related by analytic
continuation to a
cosmological spacetime
(Maldacena - Maoz)



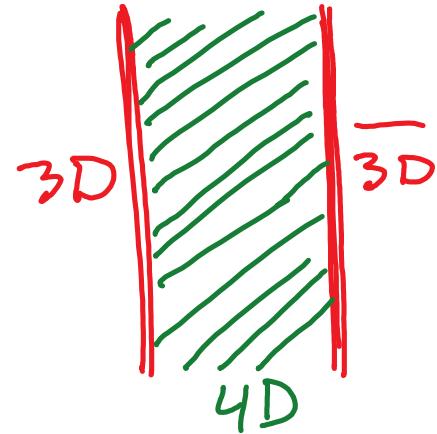


Some cases:
dual to



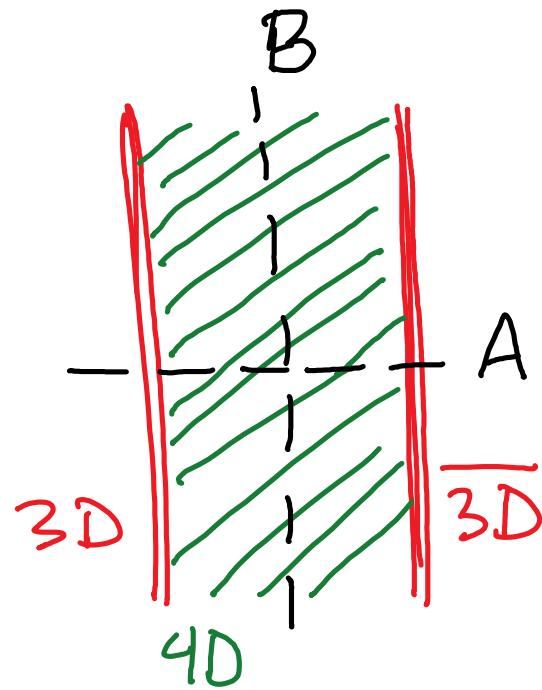
What is this
dual to?

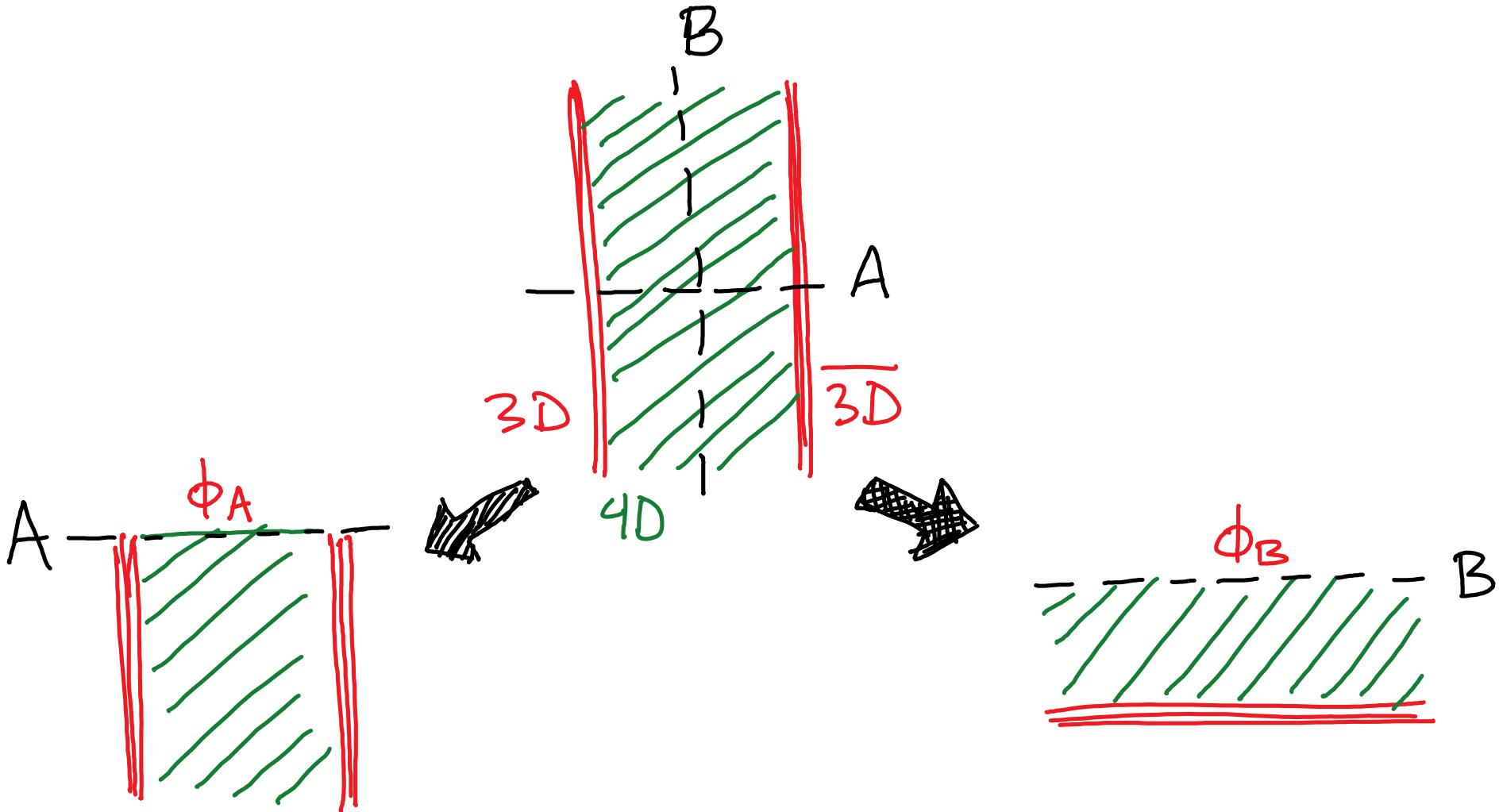
Consider the
Euclidean version
of our theory:



$$Z = \{ [d\phi_{4D}] [d\phi_{3D}] \} e^{-S_{EUC}}$$

We can slice path
integral in different
ways to define states:





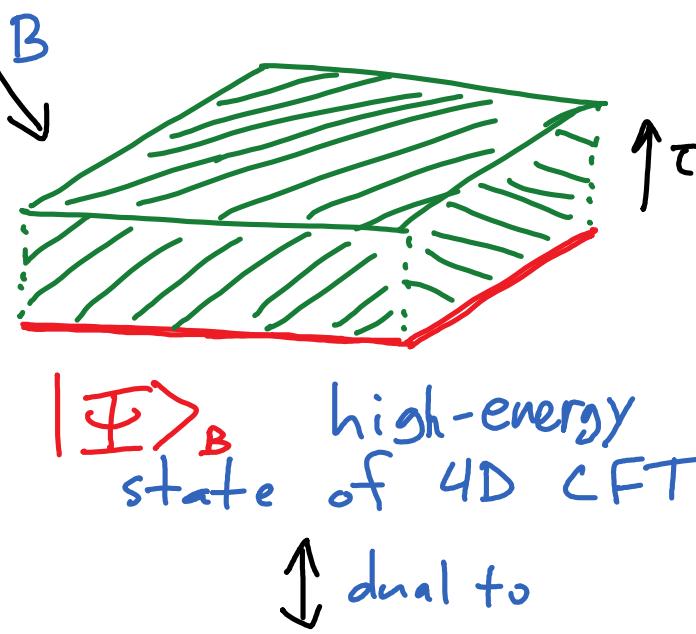
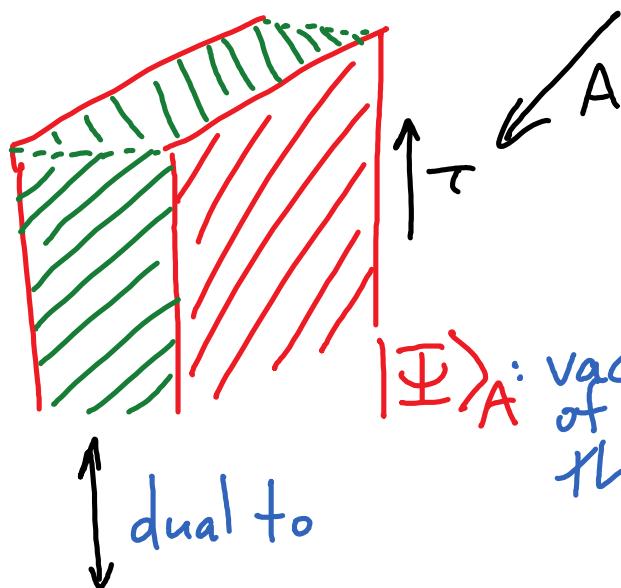
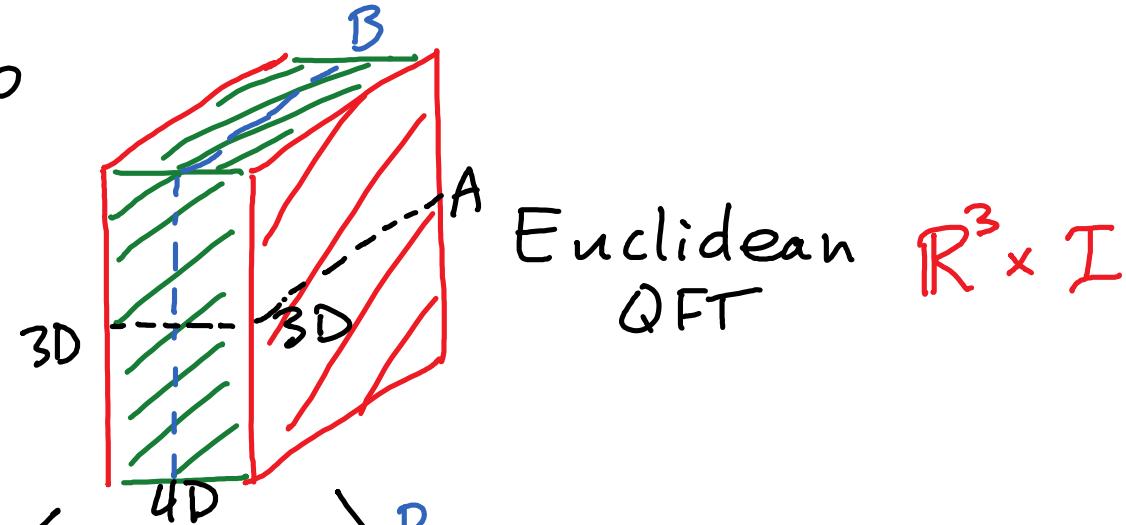
$$\Psi(\phi_A) = \int [d\phi] e^{-S_{\text{Euc}}}$$

vacuum state of 3D-4D-3D theory

$$\bar{\Psi}(\phi_B) = \int [d\phi] e^{-S}$$

excited state of 4D CFT

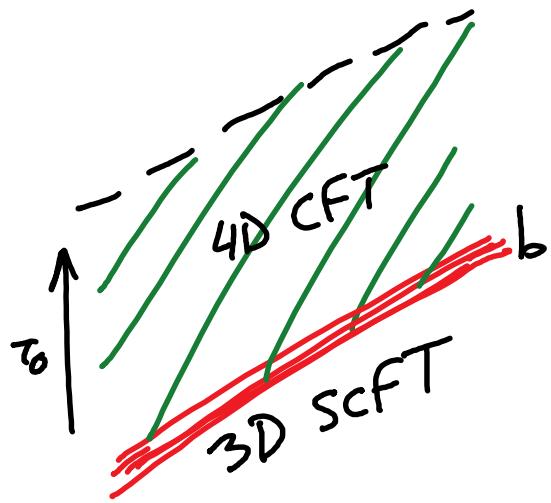
$|\Psi\rangle_A, |\Psi\rangle_B$ dual to
double analytically
continued spacetimes:



$$ds^2 = d\tau^2 + a^2(\tau) dx_\mu dx^\mu$$

$$ds^2 = -dt^2 + a^2(t)dx^2$$

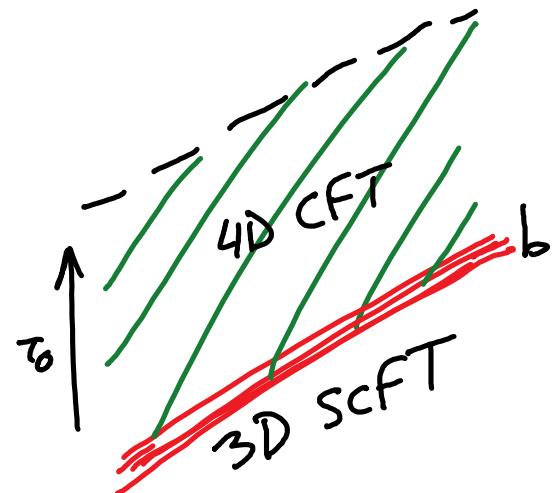
Final picture:



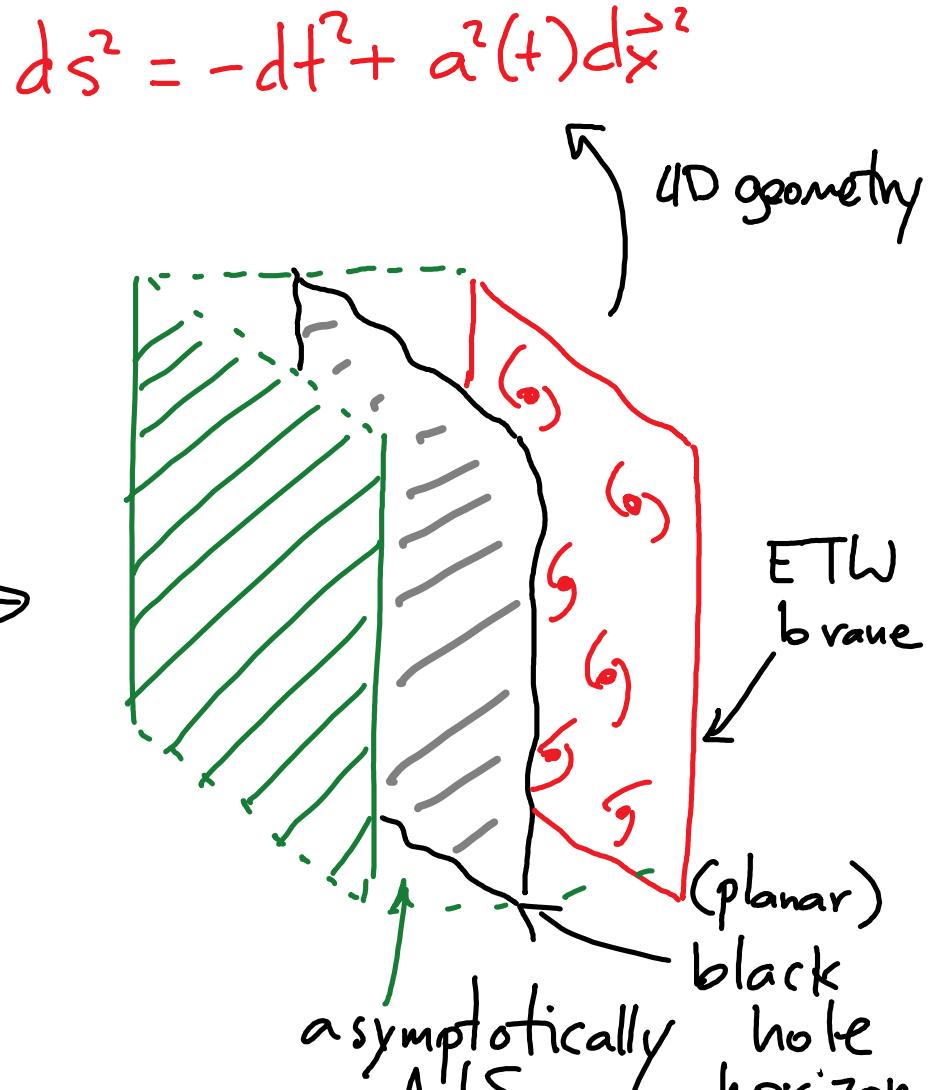
$$|\Xi_{b,\tau_0}\rangle = \left[[d\phi_{3D}] [d\phi_{4D}] \right] e^{-S_{BCFT}}$$

complicated high-energy state \leadsto generally dual to black hole!

Final picture:



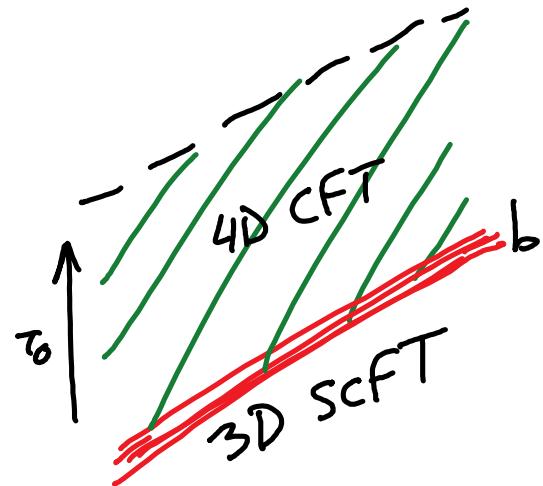
\longleftrightarrow
dual to



$$|\Psi_{b,\tau_0}\rangle = \left[[d\phi_{3D}] [d\phi_{4D}] e^{-S_{BCFT}} \right]$$

complex excited state

Final picture:

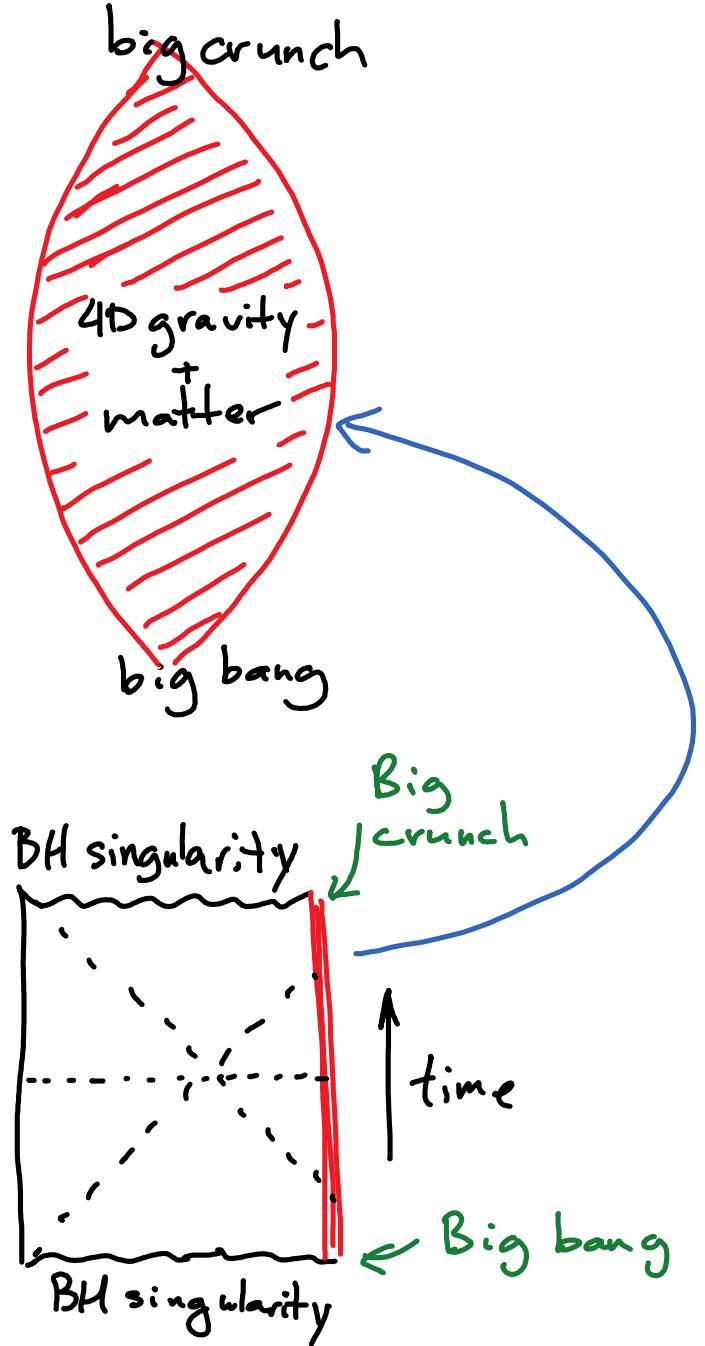


$$|\Psi_{b,\tau_0}\rangle = \int [d\phi_{3D}] [d\phi_{4D}] e^{-S_{BCFT}}$$

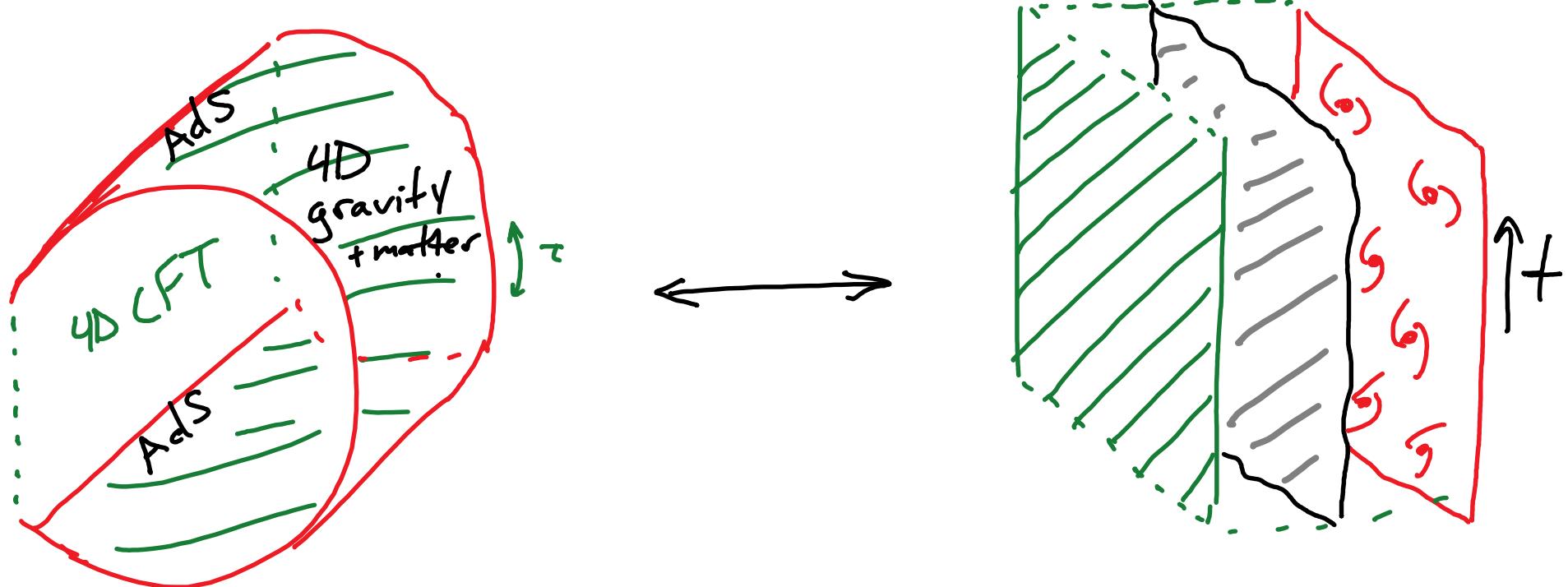
complex excited state

Spacetime
picture:

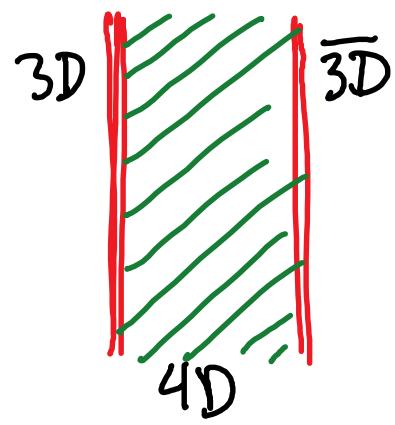
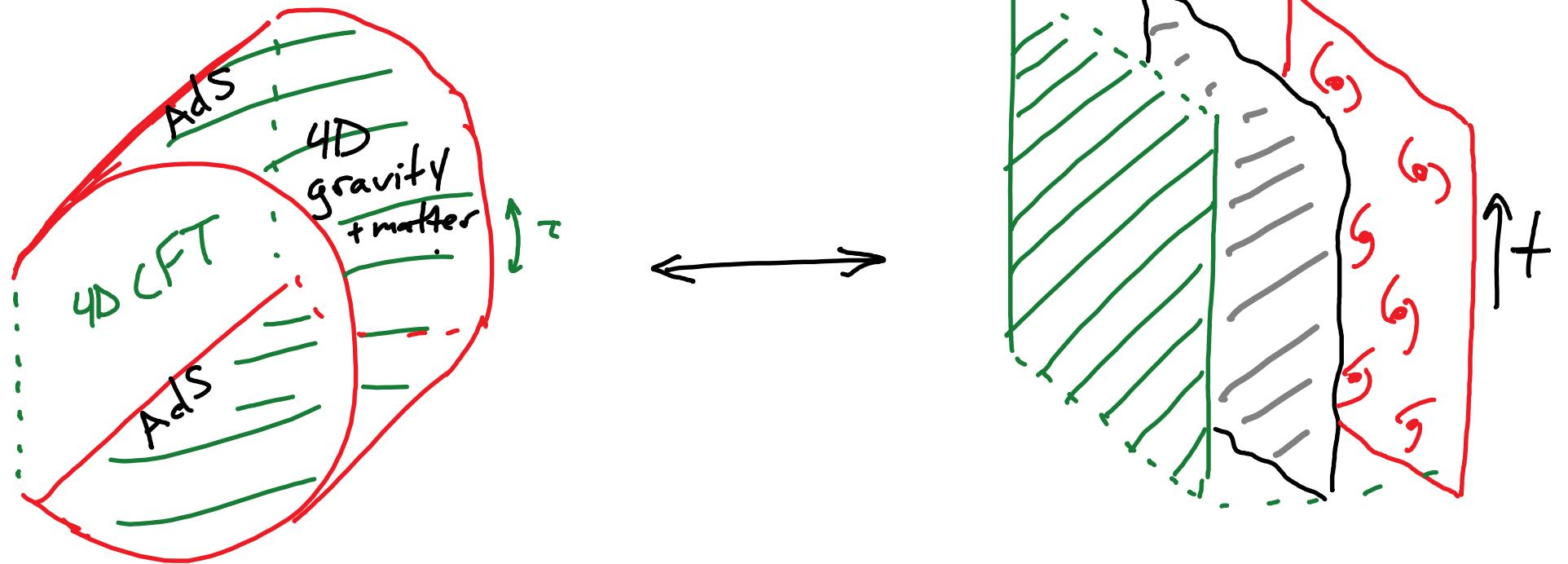
$$ds^2 = -dt^2 + a^2(t)d\vec{x}^2$$



If this works, would give a fully microscopic /
non-perturbative description of 4D cosmological
physics (not necessarily realistic!)



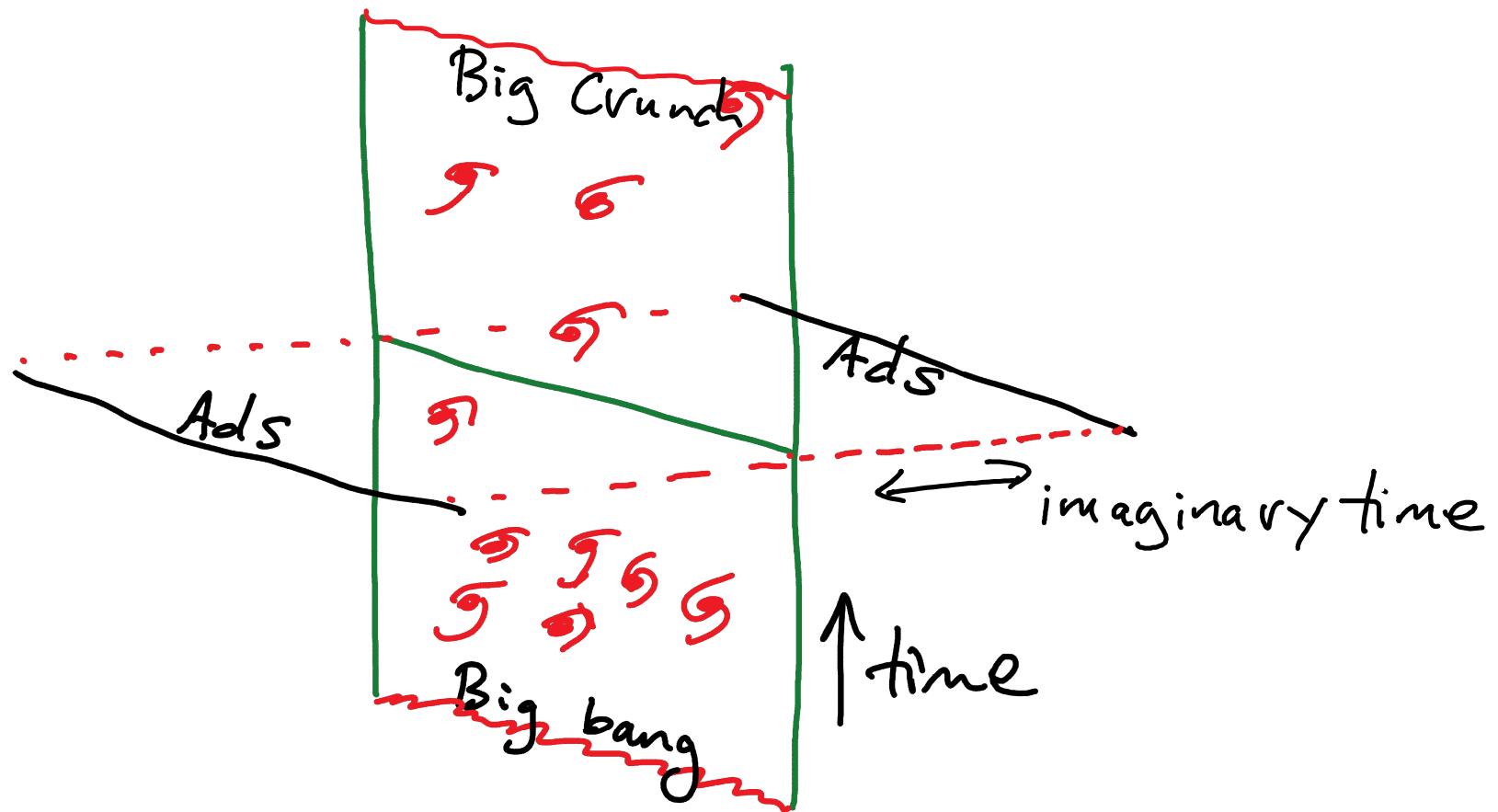
cosmological scale factor evolution, stress-energy, and correlators are analytic continuations of corresponding quantities in geometry dual to vacuum state of confining gauge theory



theoretical input: choice of 3D, 4D CFTs.

- gauge group for effective field theory in cosmology determined by global symmetry of 3D CFT.

Final picture : effective description



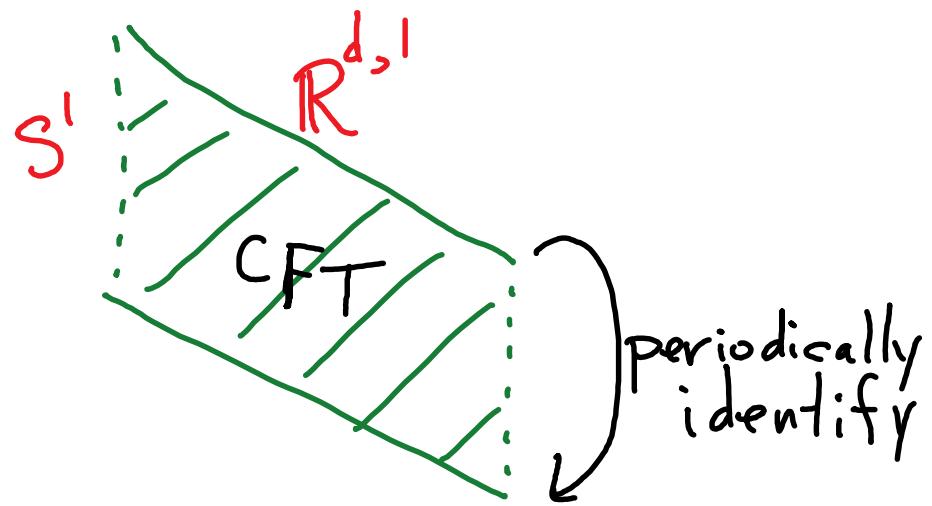
Current directions

- general lessons?
- examples?
- realistic cosmology?

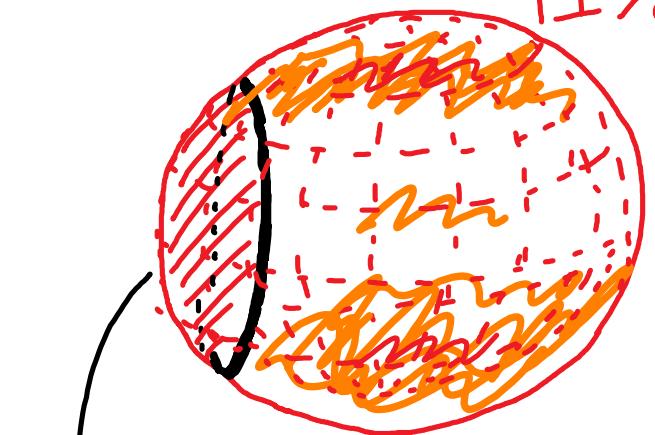
Thanks!

Aside: confining gauge theories in AdS/CFT

Witten '98:



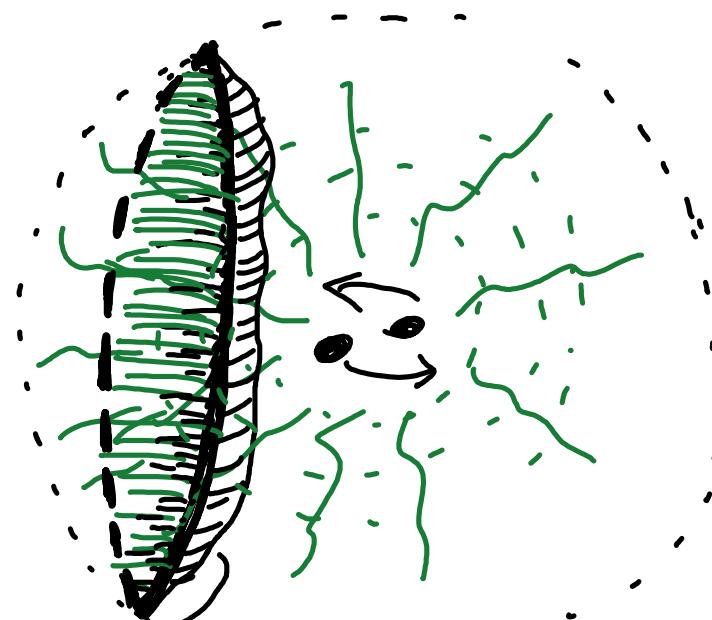
3+1D AdS quantum gravity
The Ryu-Takayanagi formula



Subsystem A

$$\text{entropy } S_A =$$

INSTRUCTIONS

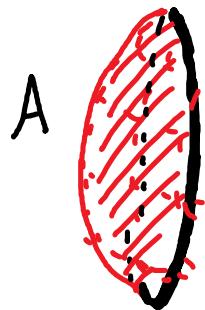


\tilde{A} = extremal area surface
in $M_{\mathcal{H}}$ enclosing boundary
region $\sim A$

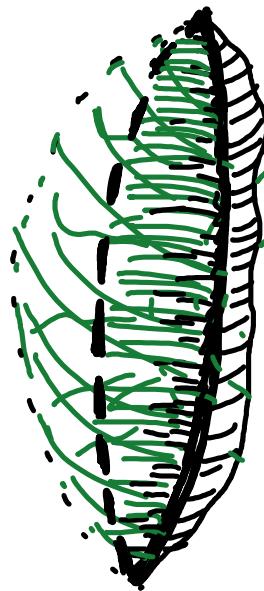
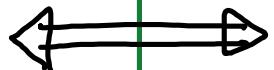
area of \tilde{A} (Planck units)

3+1D AdS quantum gravity

INSTRUCTIONS



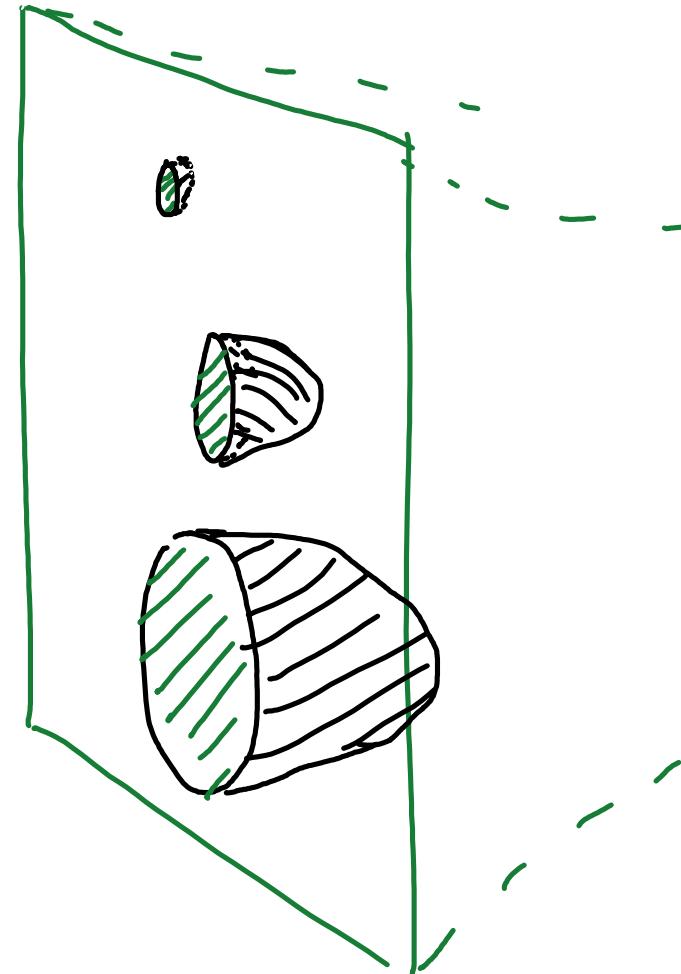
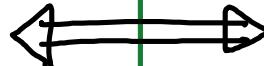
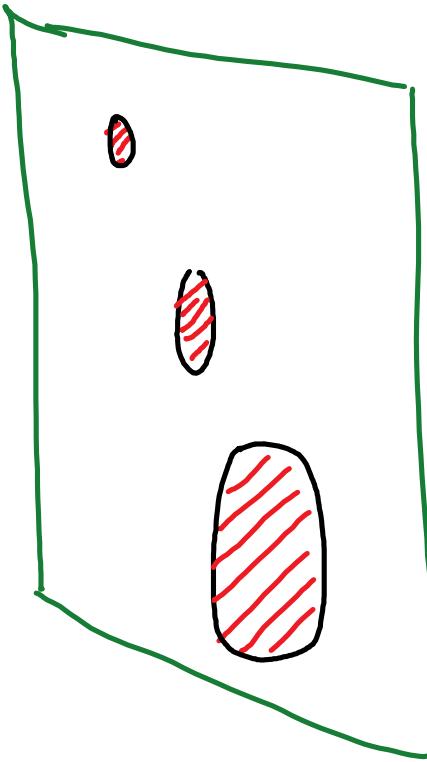
quantum
state of
subsystem



encodes spacetime
subregion

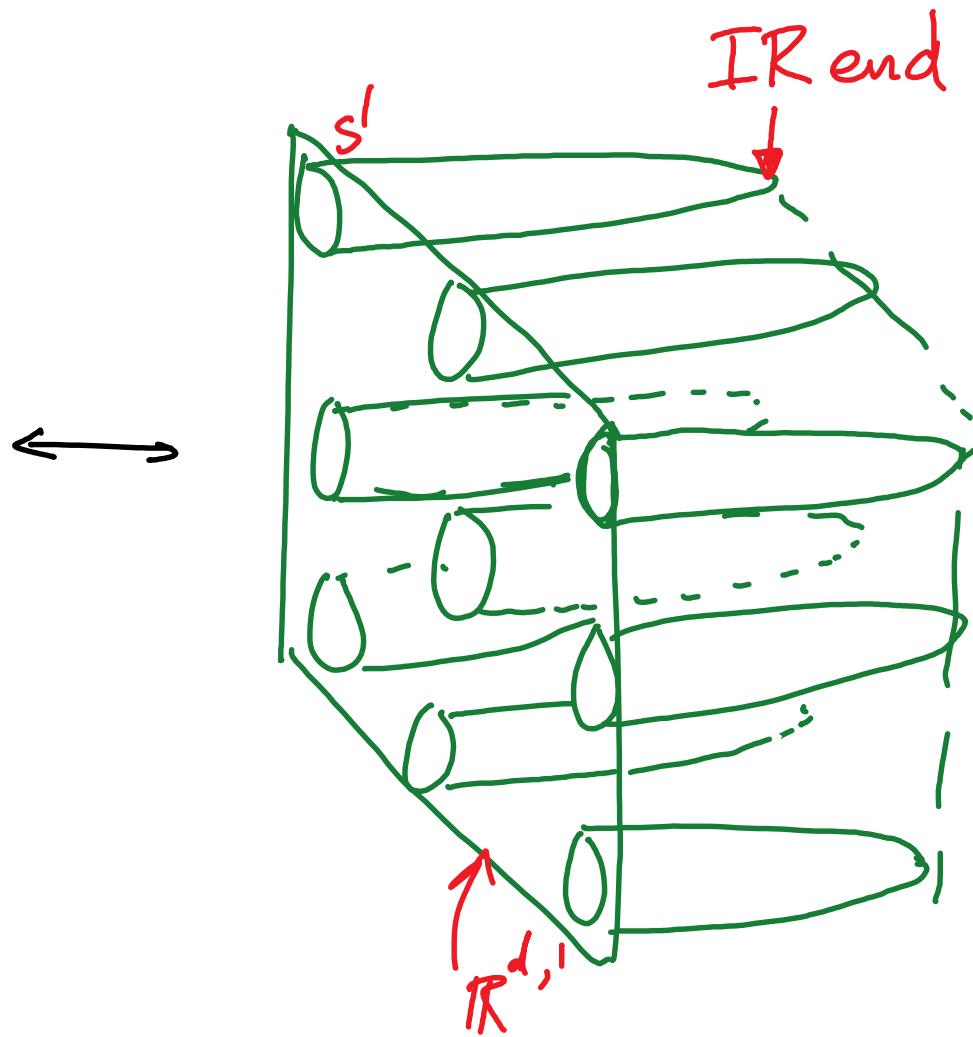
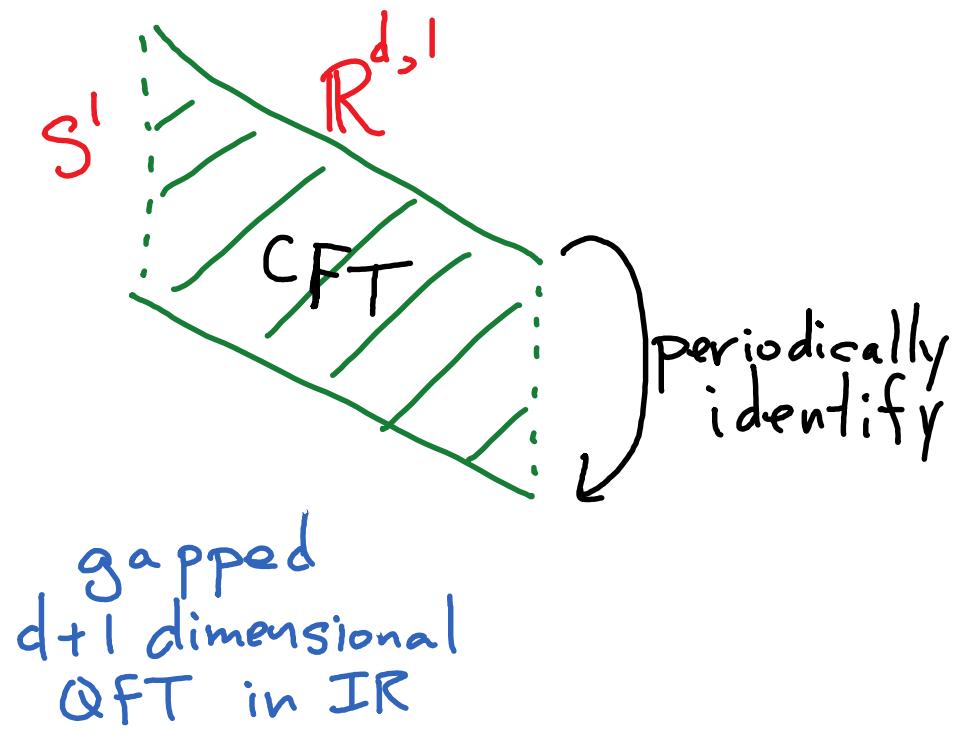
3+1D AdS quantum gravity

INSTRUCTIONS



Aside: confining gauge theories in AdS/CFT

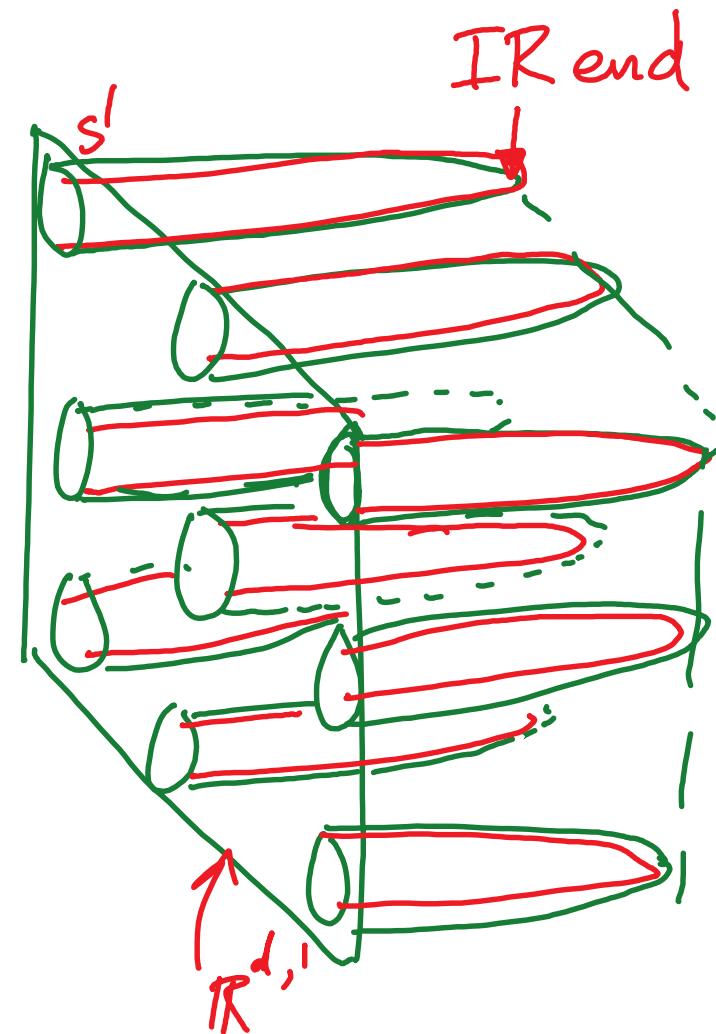
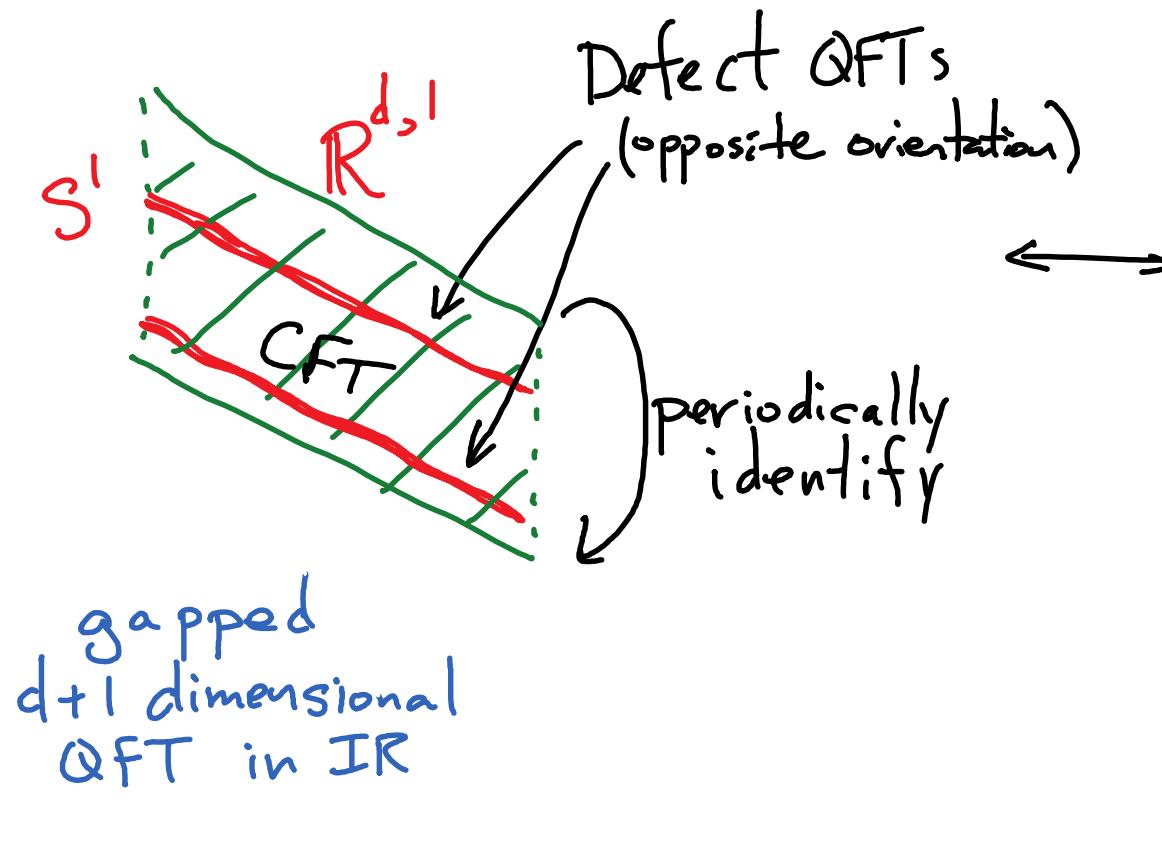
Witten '98:



- compact direction contracts smoothly in the bulk \rightarrow IR end of spacetime

Aside: confining gauge theories in AdS/CFT

Sakai - Sugimoto:



Aside: confining gauge theories in AdS/CFT

Our setup .

