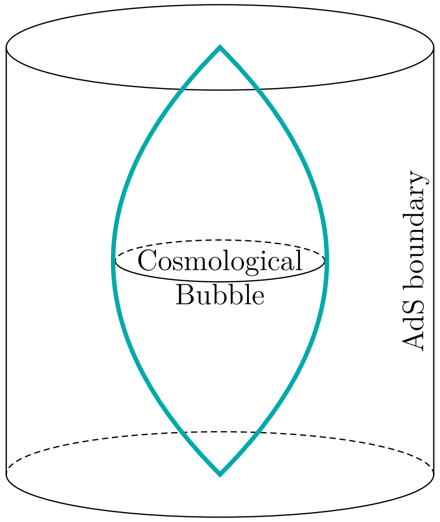
⛩ QIMG 2023 Kyoto ⛩

Bubbles of Cosmology in AdS/CFT

Abhisek Sahu
University of British Columbia



Based on 2306.13143 with Petar Simidzija and Mark van Raamsdonk

Motivation

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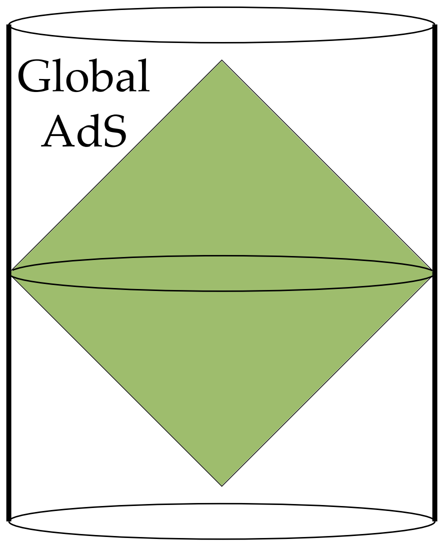

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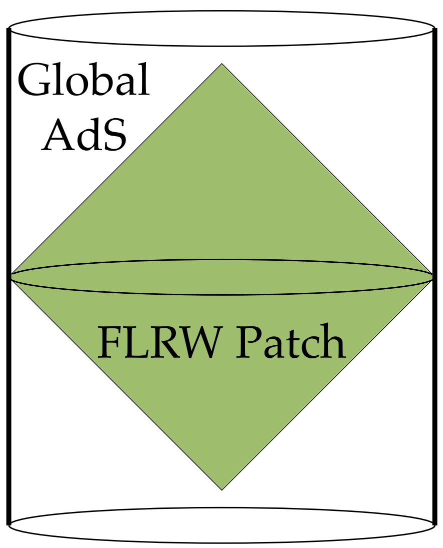

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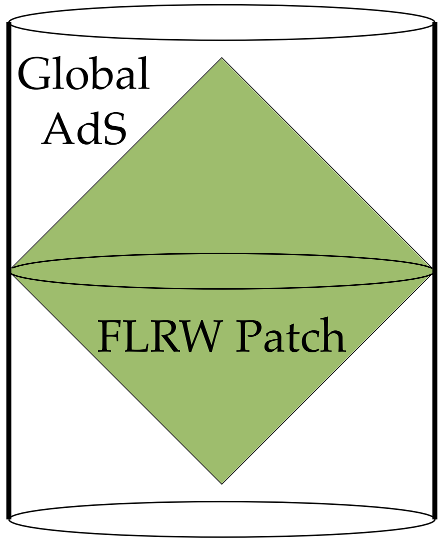

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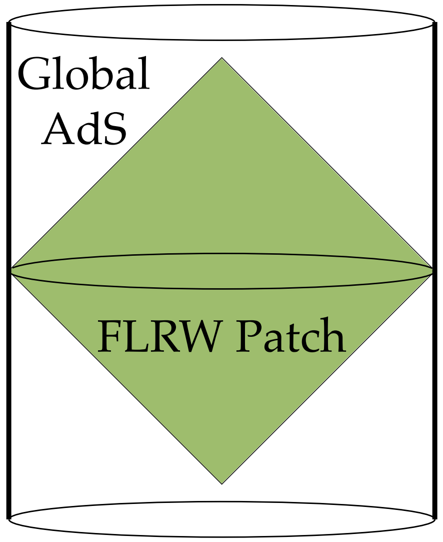

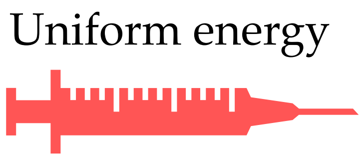

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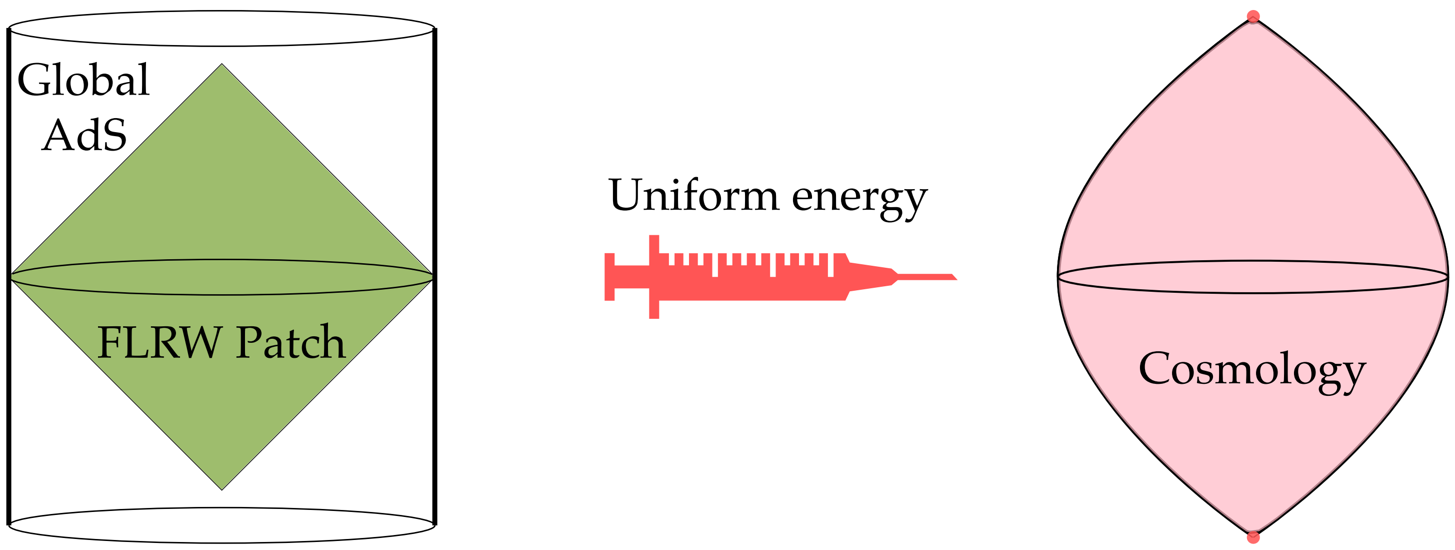

Motivation

Why is it difficult to describe cosmological spacetimes holographically?

The coordinate singularities become big-bang/big-crunch singularities.

Asymptotic boundaries disappear.

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Hint: pump energy uniformly only onto a finite region.

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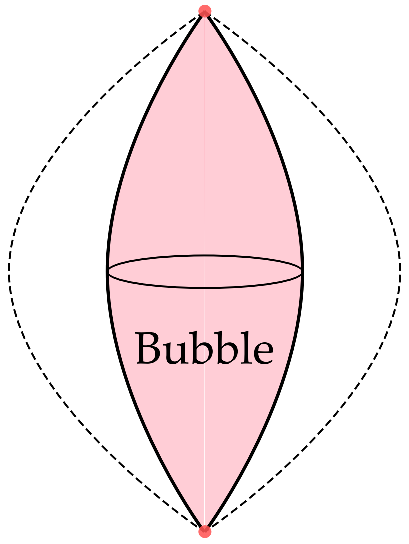

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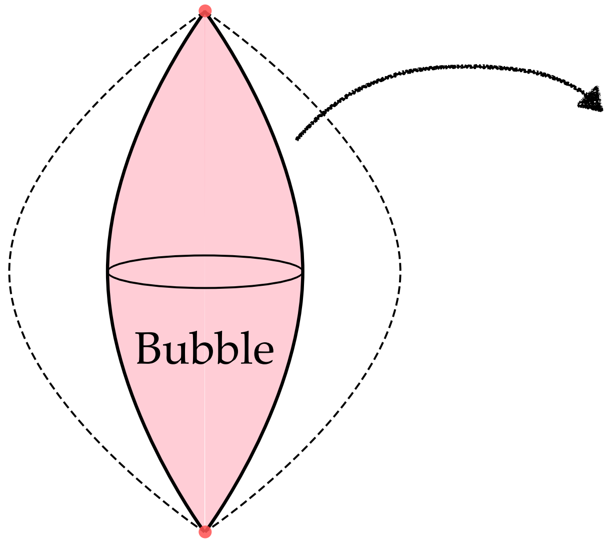

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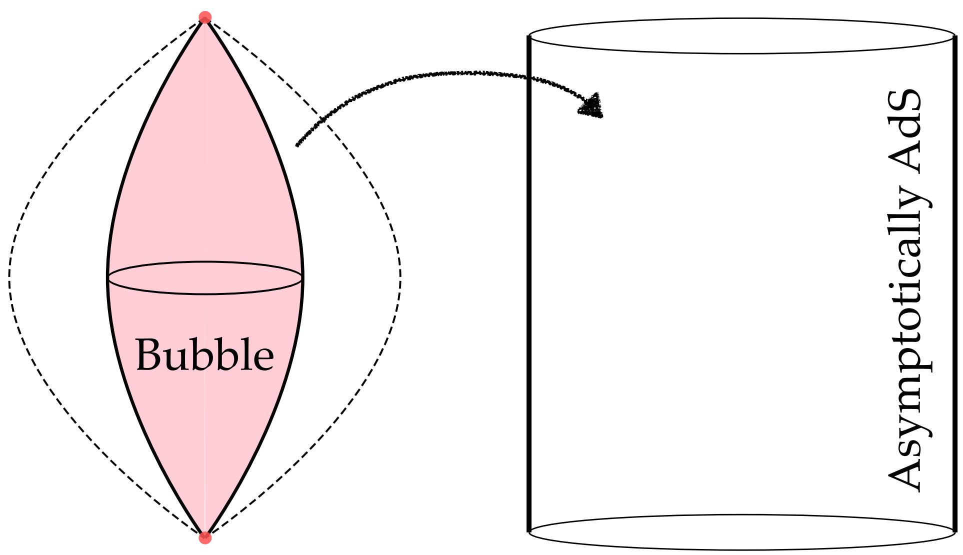

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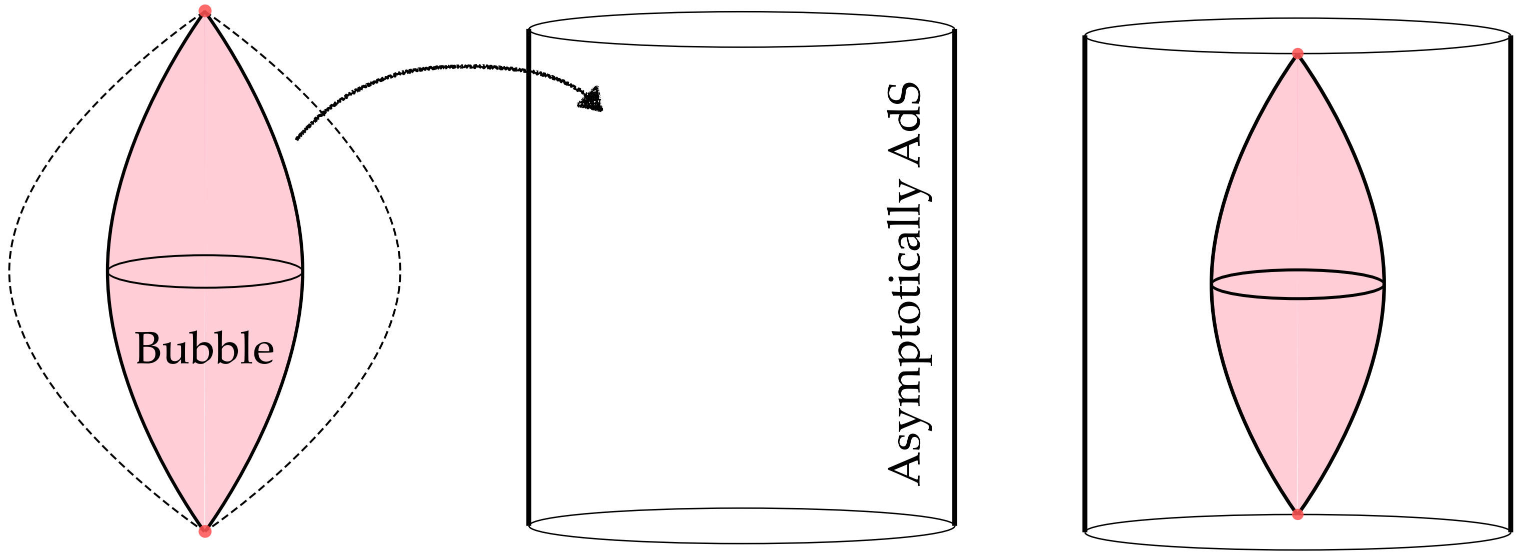

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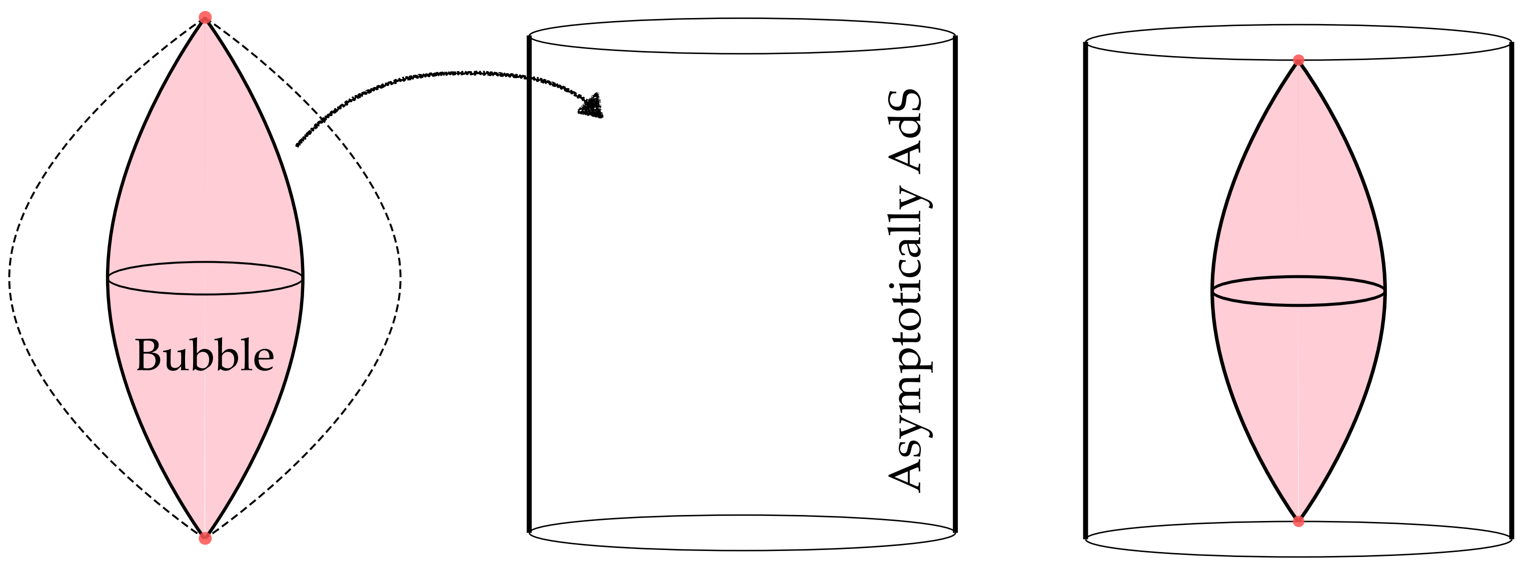

The gravitational picture is a finite bubble of the cosmological spacetime, embedded in an asymptotically AdS spacetime.

How do we construct these bubble spacetimes?

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Do these geometries have a holographic dual?

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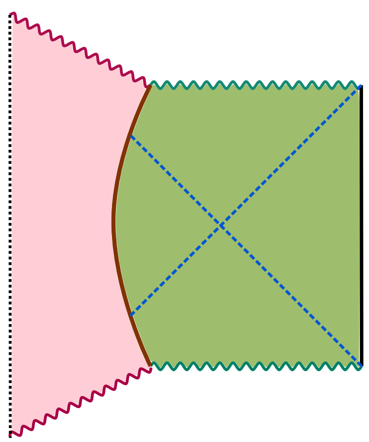
Do these geometries have a holographic dual?

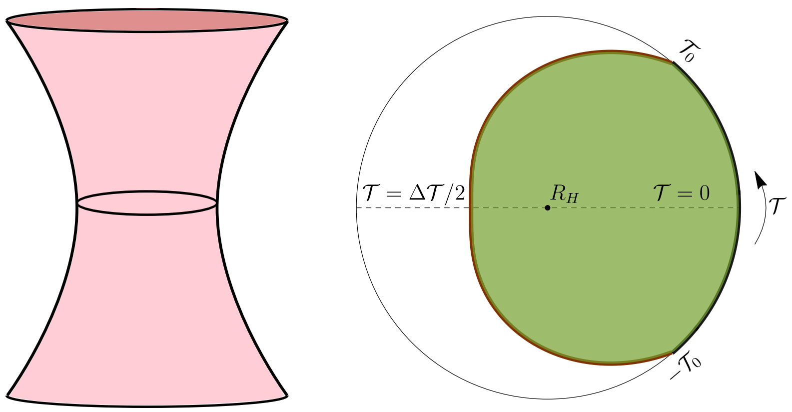
What happens in the limit when the size of the bubble is infinity?

Contents

1. Embedding the bubbles



2. Analytic continuation



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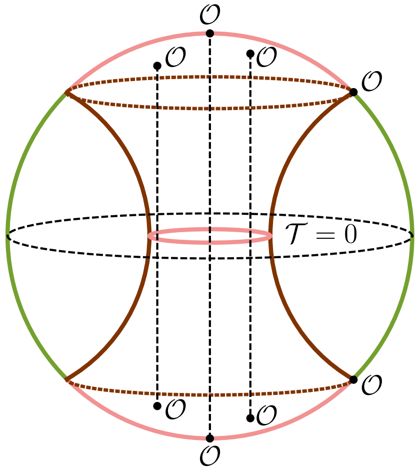
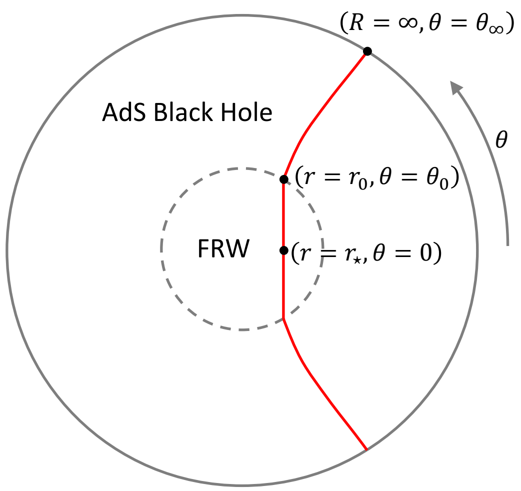
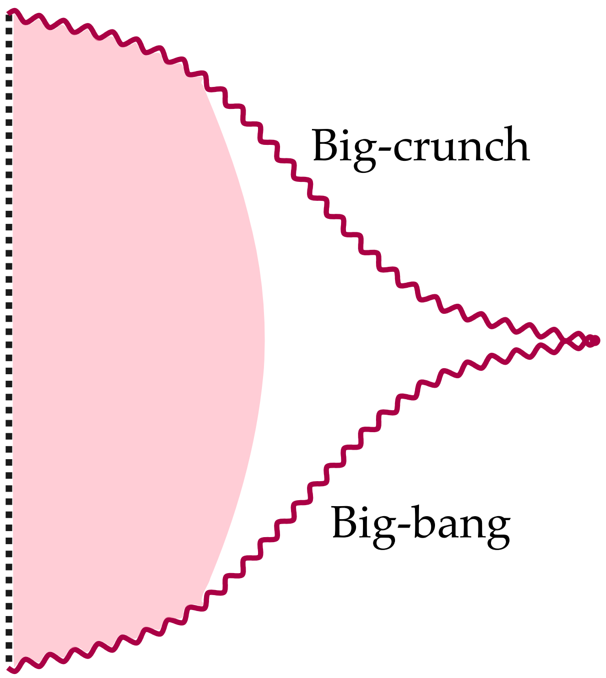


4. Probing the cosmology



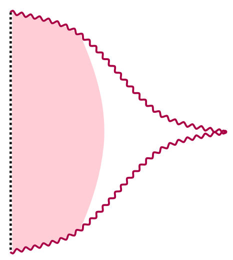
1. Embedding the bubbles

Lorentzian spacetime



Spherical bubble of FLRW cosmology
with $\Lambda < 0$ + ***dust*** + ***radiation***

Lorentzian spacetime



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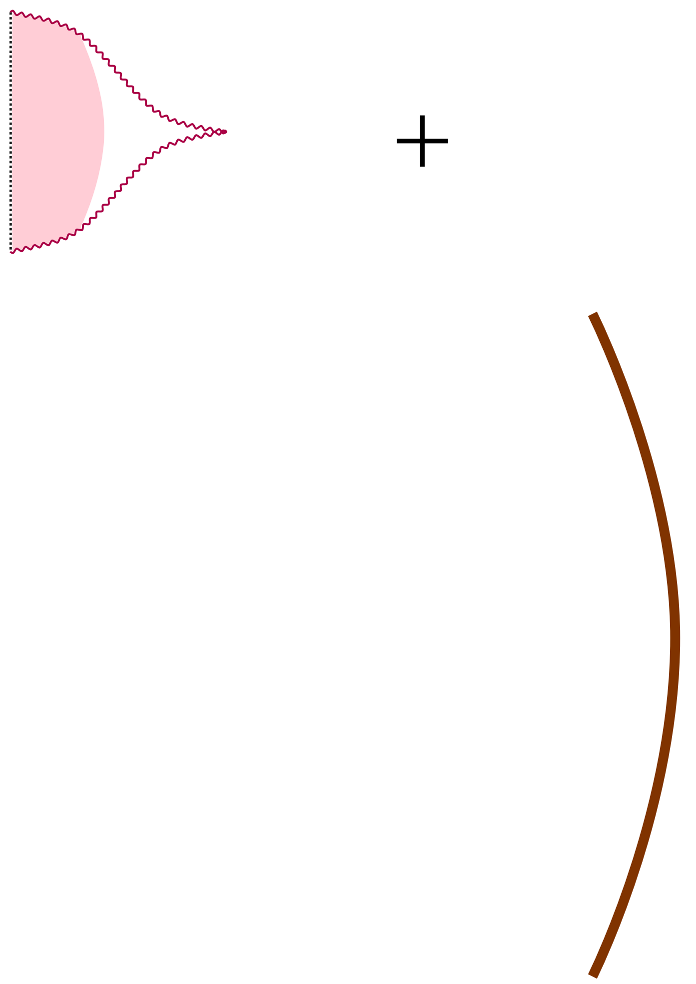
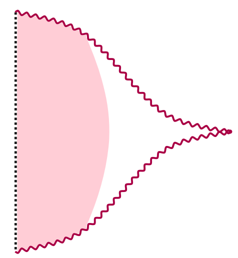
Lorentzian spacetime



Thin spherical domain wall made of pressure-less matter

Lorentzian spacetime



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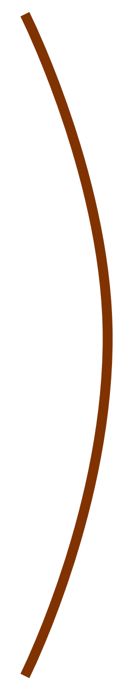

co-moving domain wall
$\Rightarrow$ domain wall size $\propto$ scale factor.

Thin spherical domain wall made of pressure-less matter

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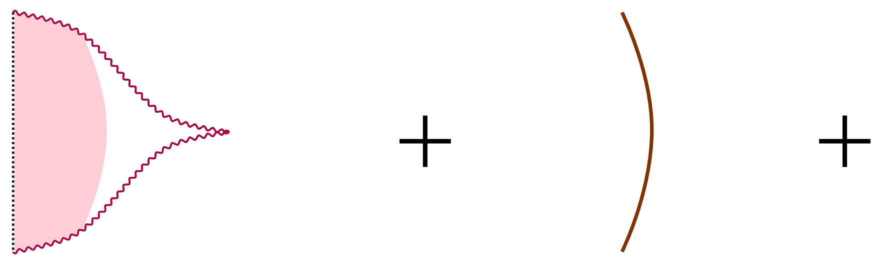

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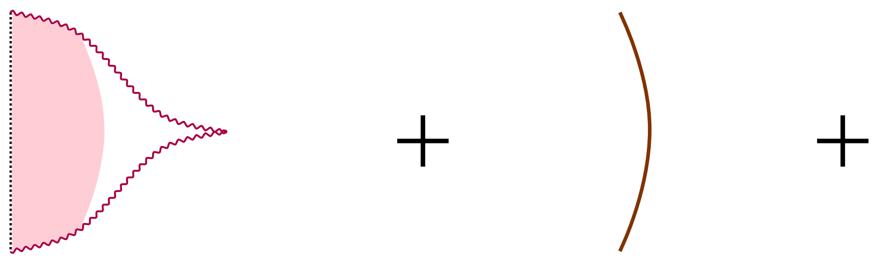
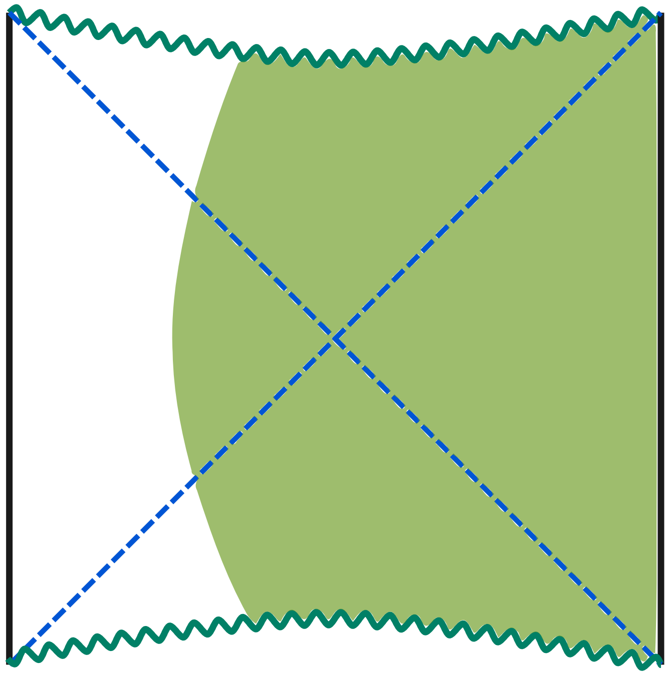
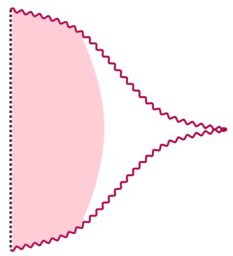
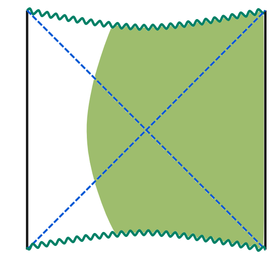




Schwarzschild-AdS black hole exterior

Lorentzian spacetime

 +  +  =

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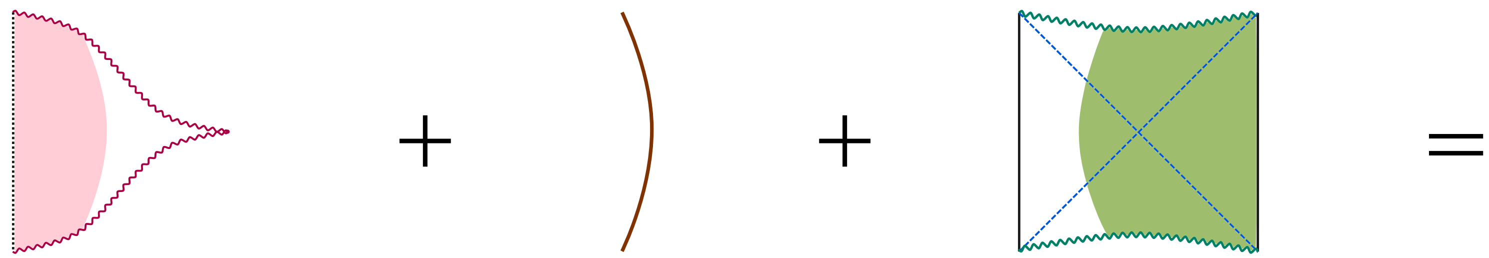


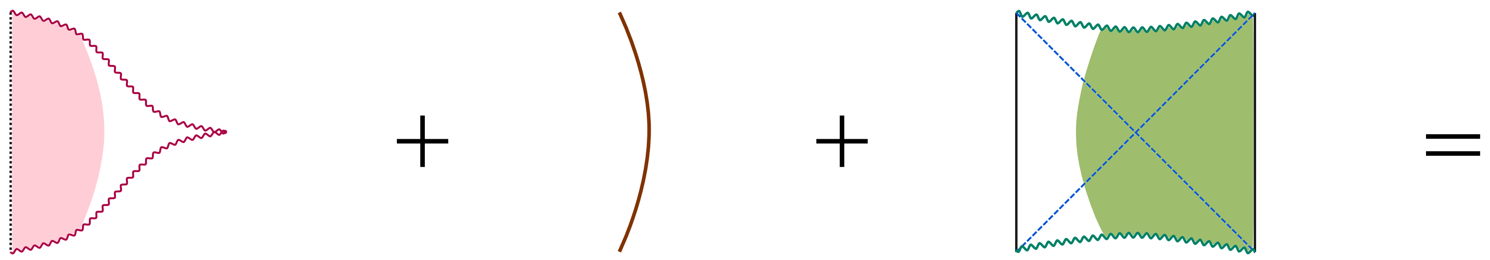
Using Junction conditions

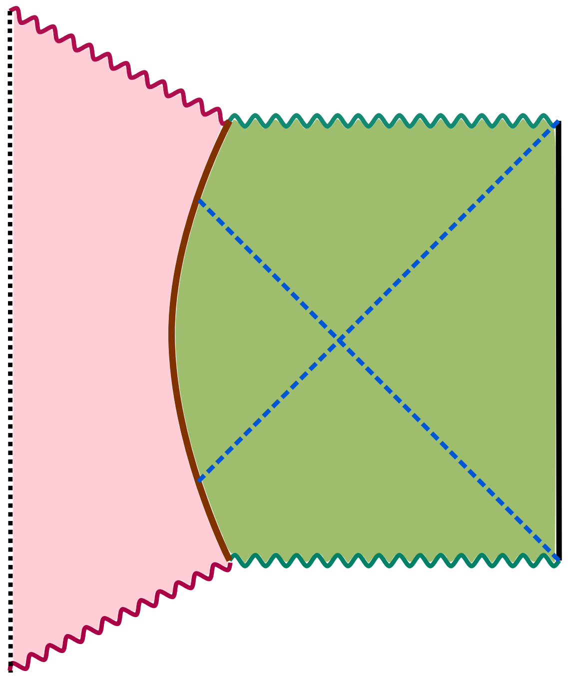
$$[K_{ab}] = S_{ab} - \frac{S}{2}h_{ab}$$

$$[h_{ab}] = 0$$

[Israel 1965]

Lorentzian spacetime





Using Junction conditions

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`Bubble of cosmology' spacetime

[Israel 1965]

Bag of gold?

[Wheeler 1964]

Bag of gold?

Does the bubble contain more information than the black hole can hide?

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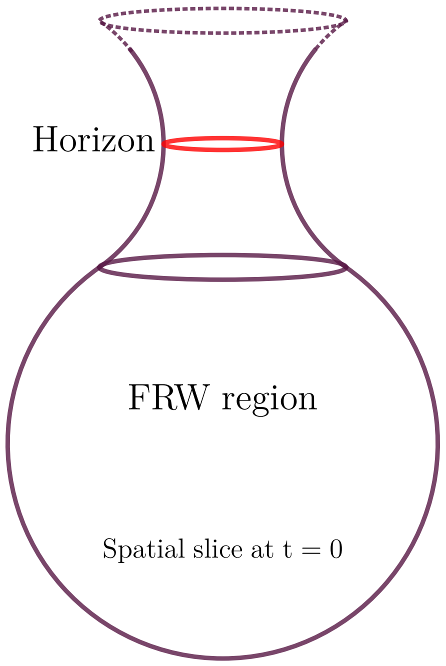

[Wheeler 1964]

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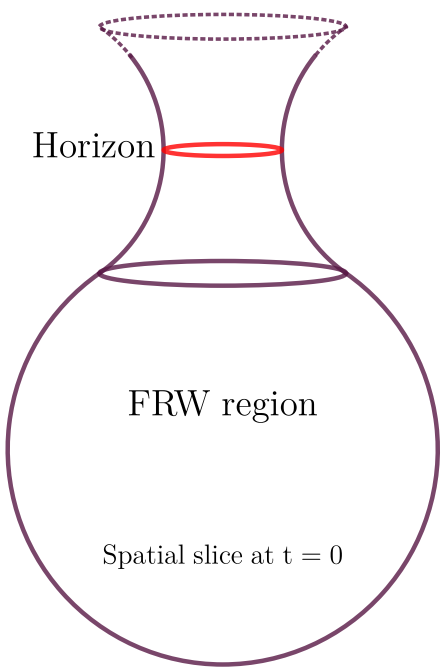

The black hole entropy exceeds the (radiation) entropy in the bubble for all $K < 0$ cosmologies. A puzzle arises for $K = 0$ bubbles parametrically larger than the cosmological scale by a factor of ℓ_{AdS}/ℓ_{Planck}.

[Wheeler 1964]

2. Analytic continuation

Continuation

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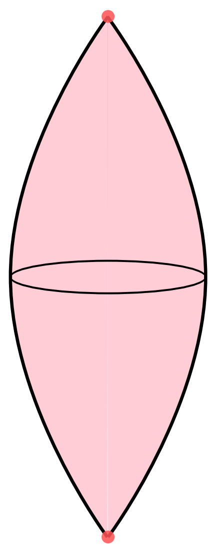
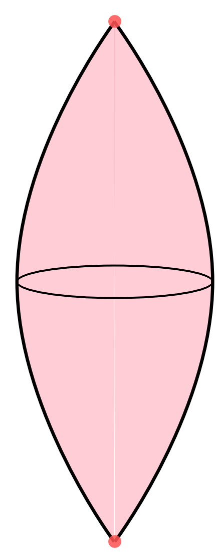


Lorentzian $\Lambda < 0$ cosmology

Continuation



Lorentzian $\Lambda < 0$ cosmology

$t \to i\tau$

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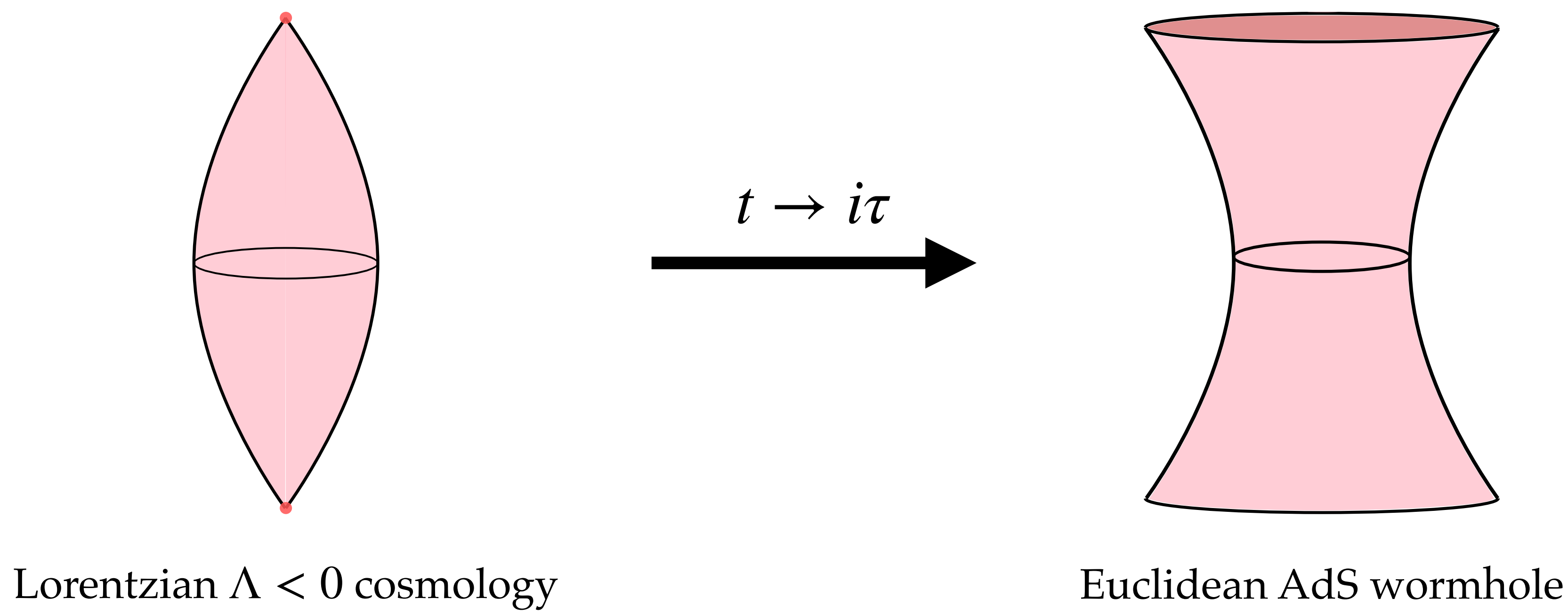
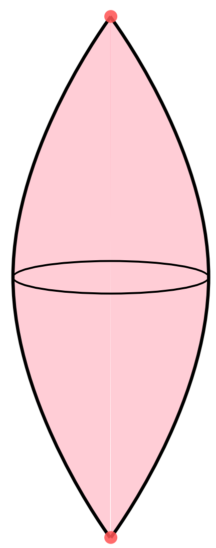


[Maldacena, Maoz 2004]

Continuation



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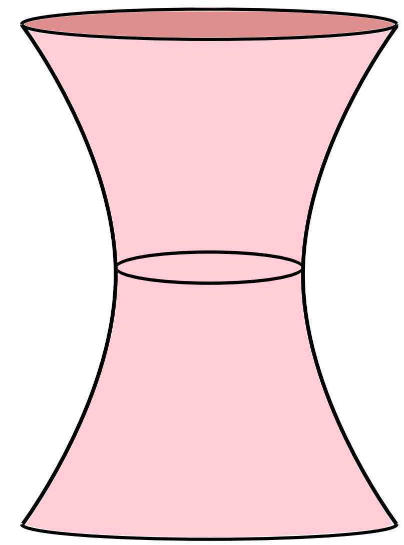
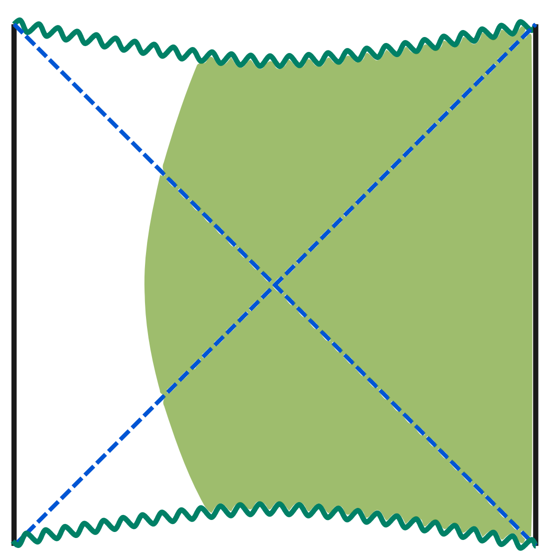


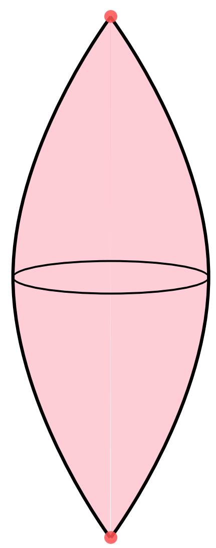
Euclidean AdS wormhole



Lorentzian Schwarzschild AdS black hole

[Maldacena, Maoz 2004]

Continuation



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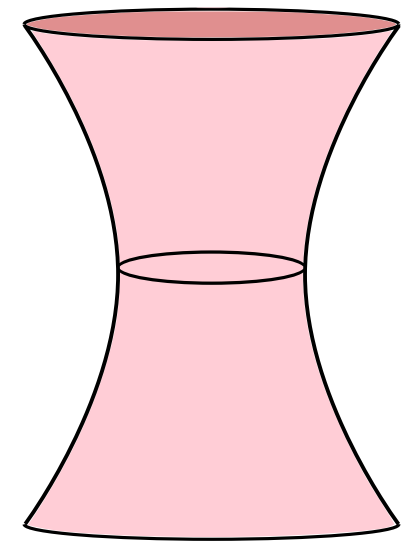

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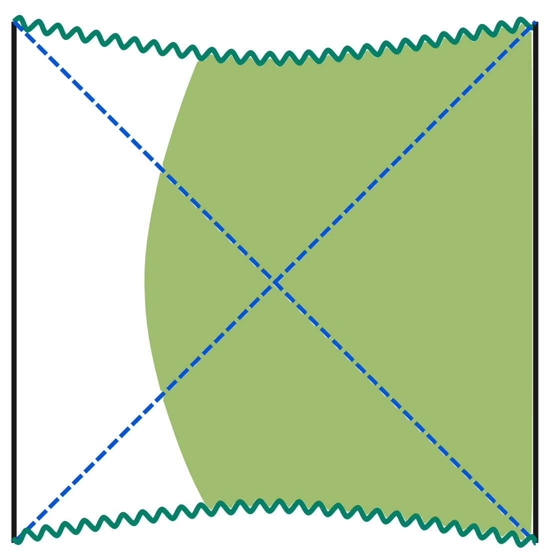

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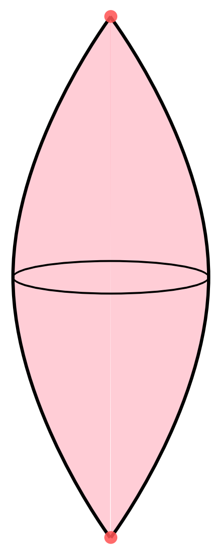

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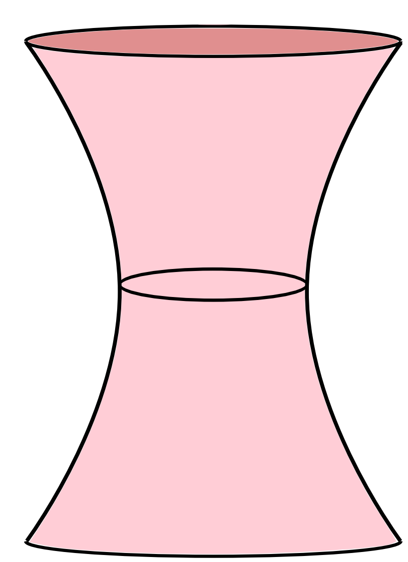

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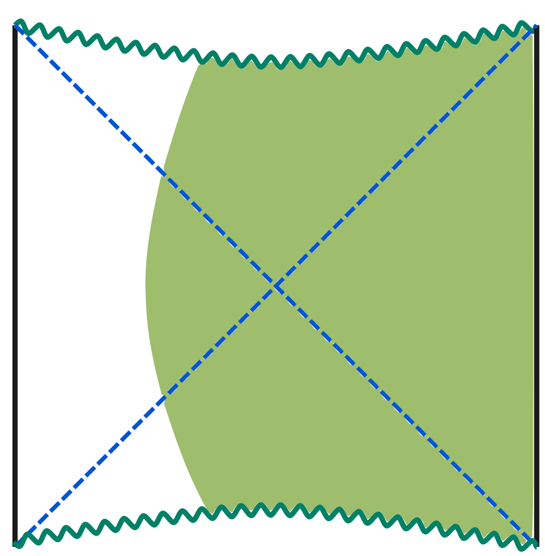

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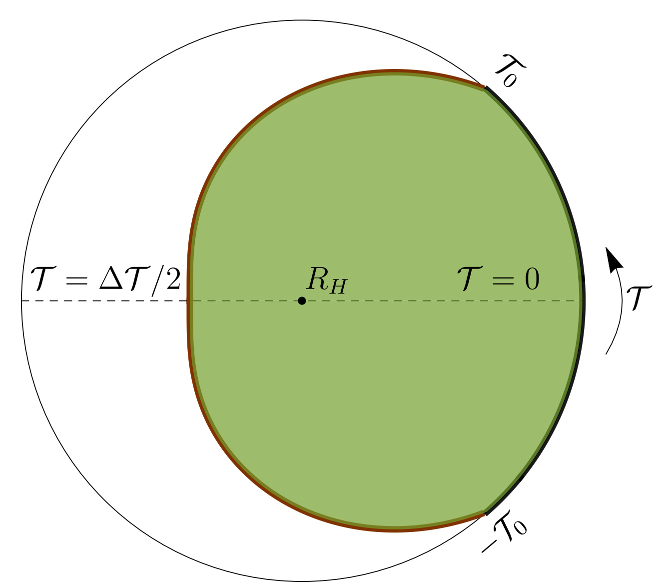

Lorentzian Schwarzschild AdS black hole

Euclidean cigar geometry

[Maldacena, Maoz 2004]

Euclidean picture

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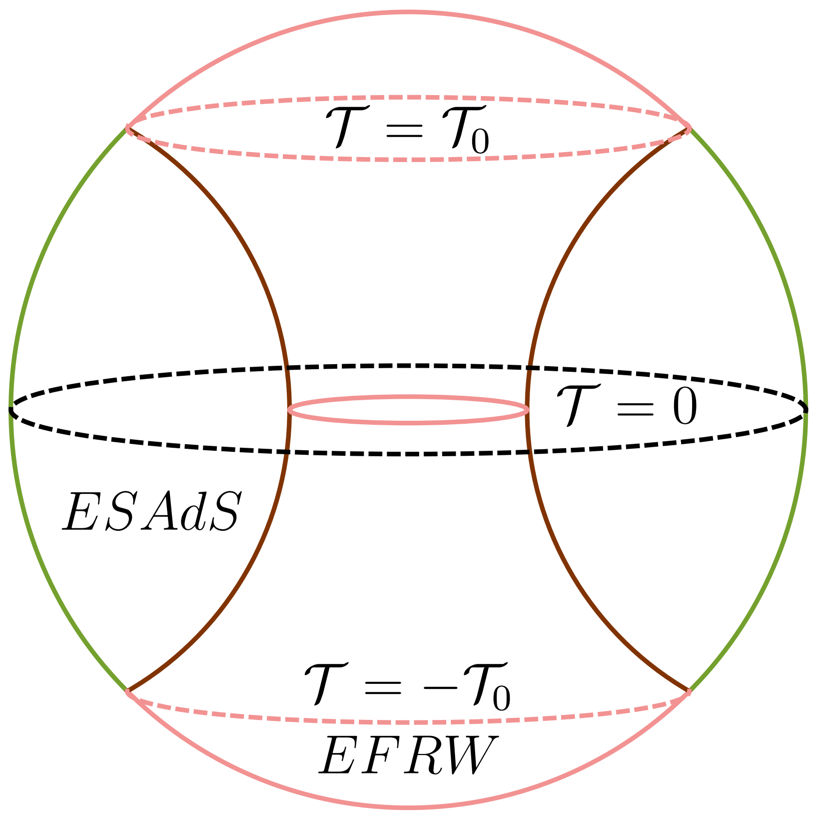
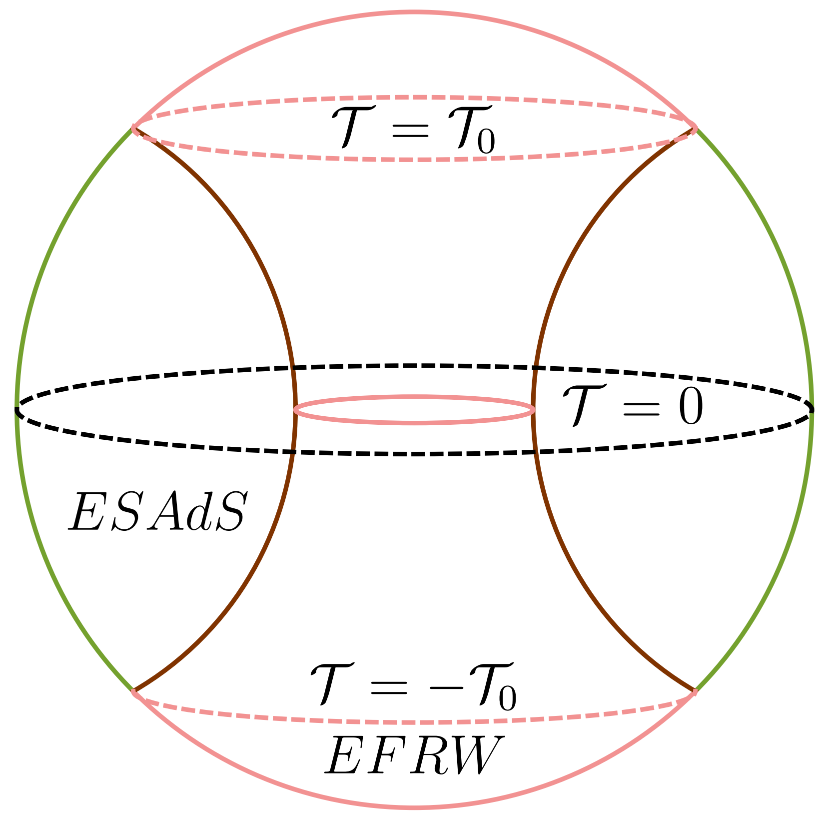


Euclidean picture

The boundary is topologically a ball shaped region with parts from both the Euclidean wormhole as well as the black hole boundaries.



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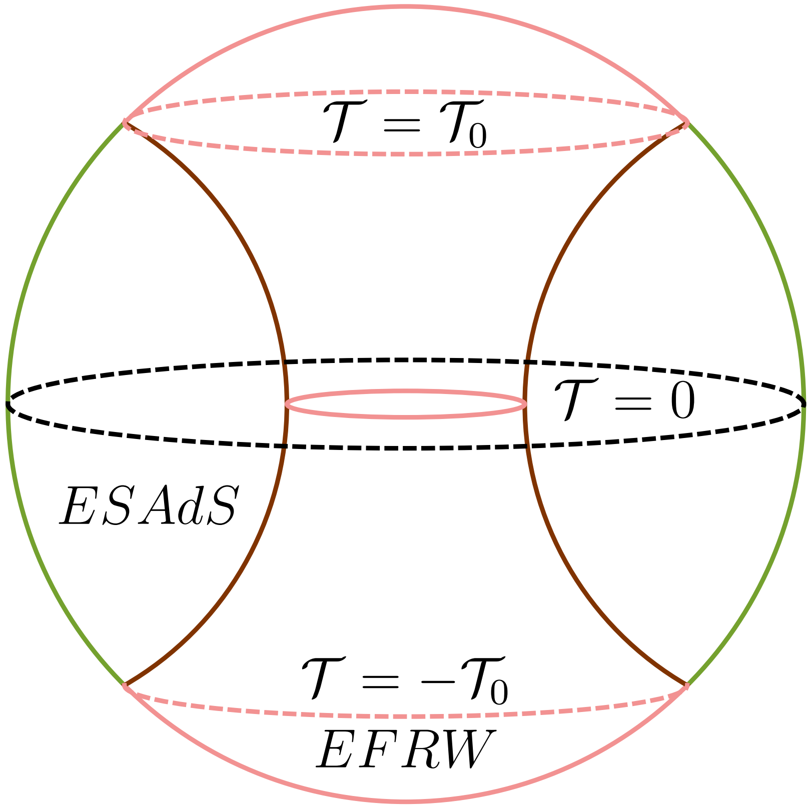

Different from dS bubbles! The domain wall modifies the Euclidean boundary

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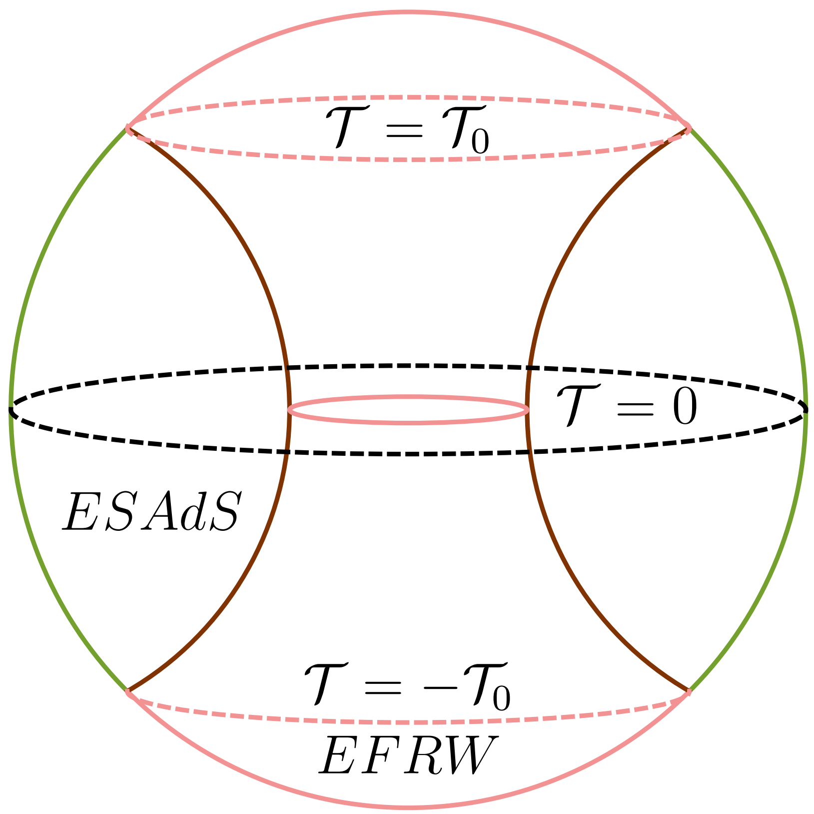

Different from dS bubbles! The domain wall modifies the Euclidean boundary

[Fu, Marolf 2019, Freivogel et al. 2006]

3. Proposing a dual

Dual CFT state

Lorentzian

Euclidian

Dual CFT state

The Euclidean geometry is plausibly the saddle point of a gravitational path integral with the modified boundary conditions produced by the domain wall reaching the asymptotic boundary.

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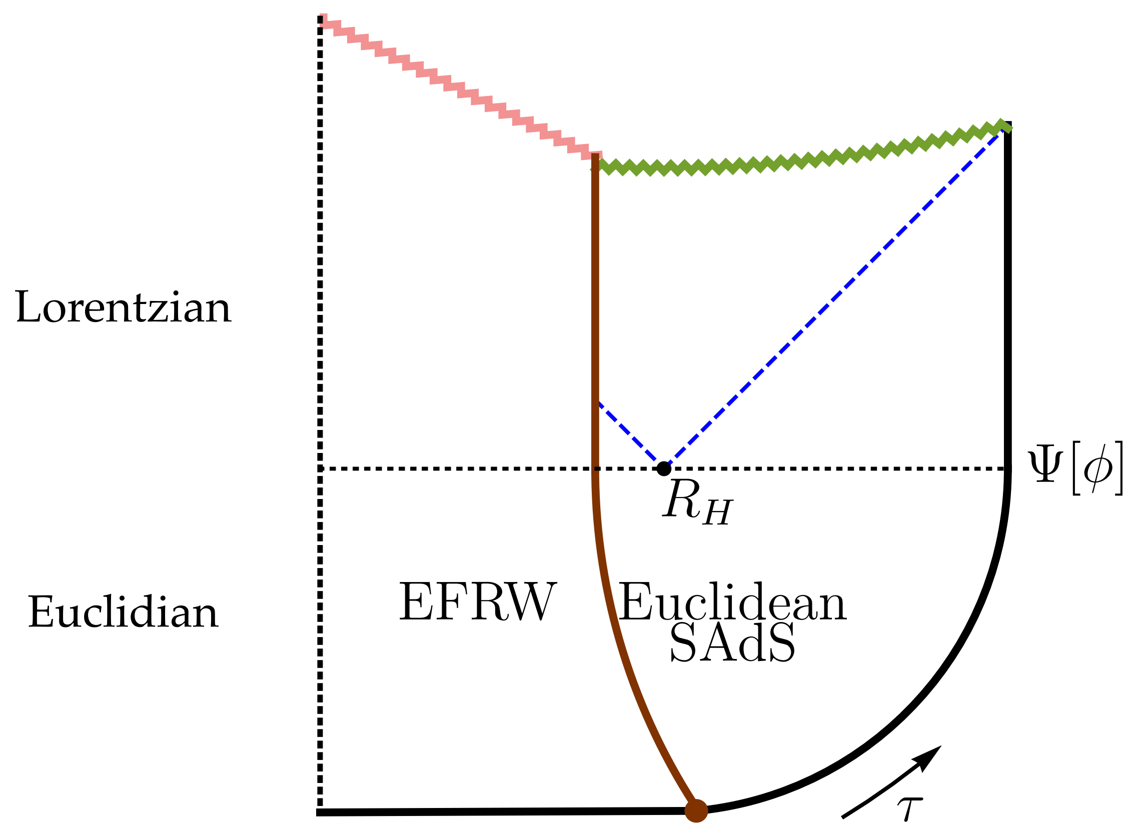

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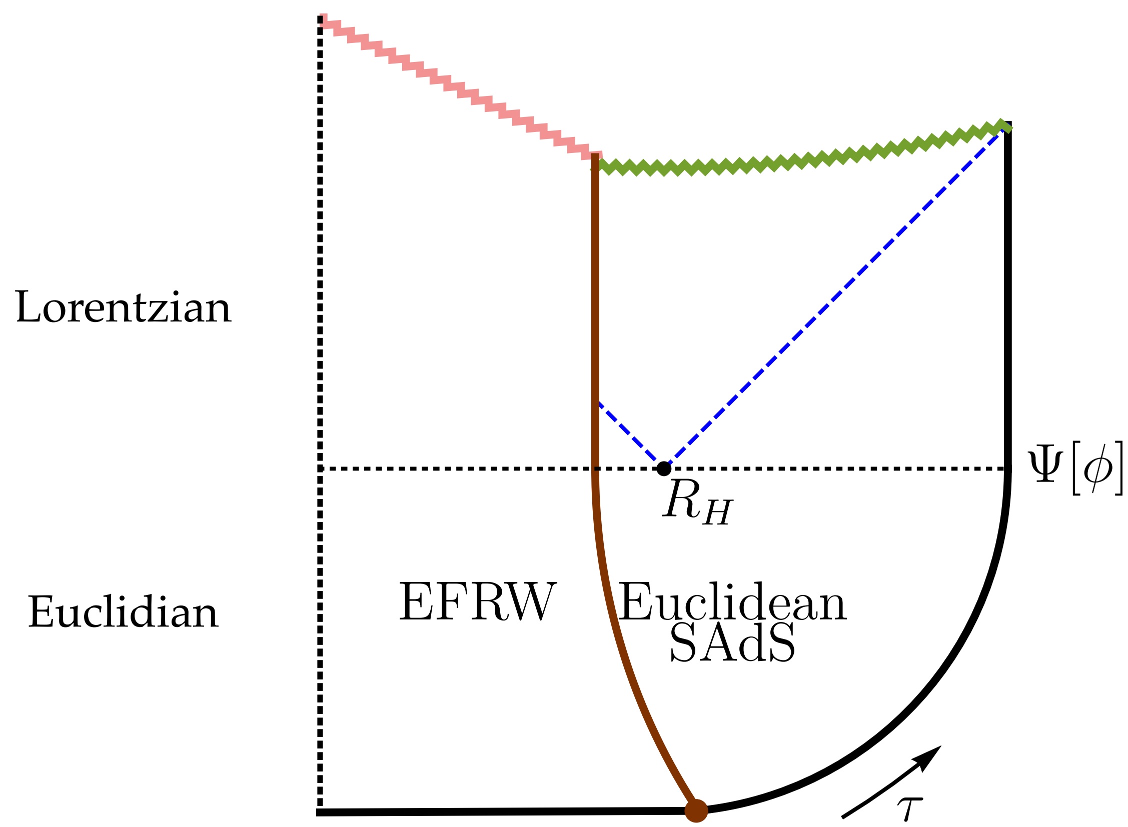
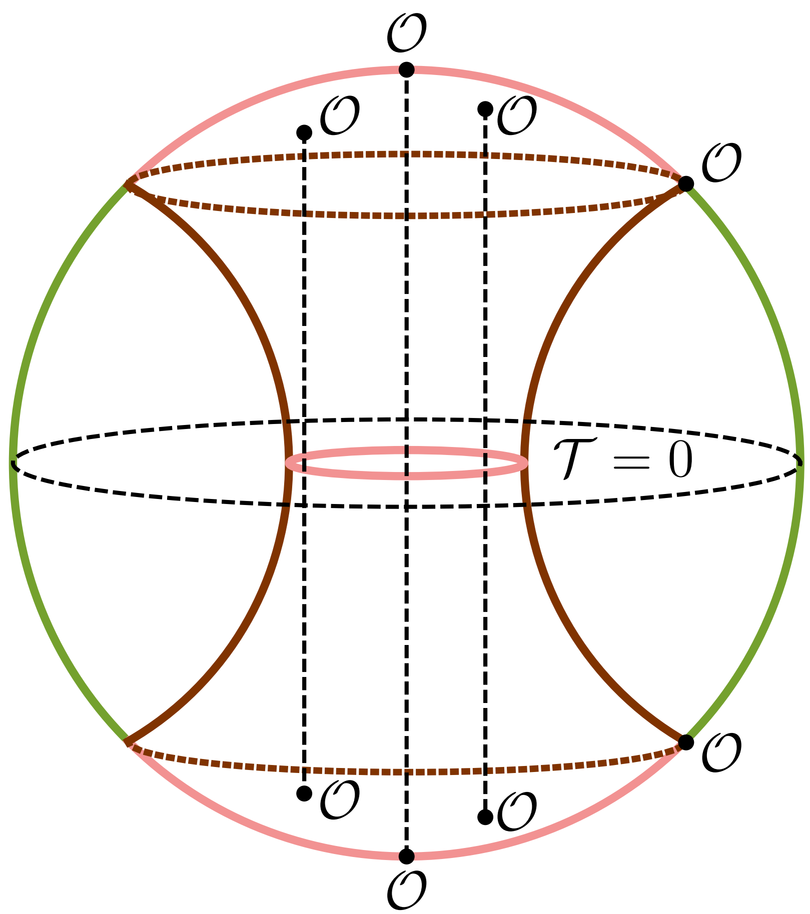


A dual CFT state may be prepared via a Euclidean path integral!

CFT Proposal

CFT Proposal



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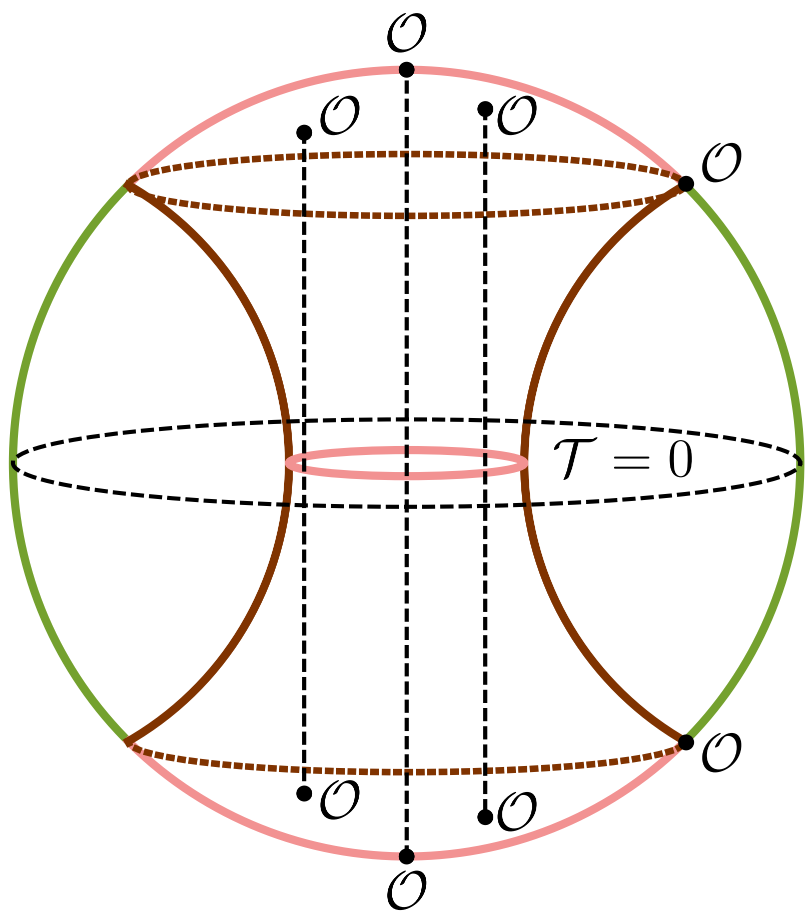


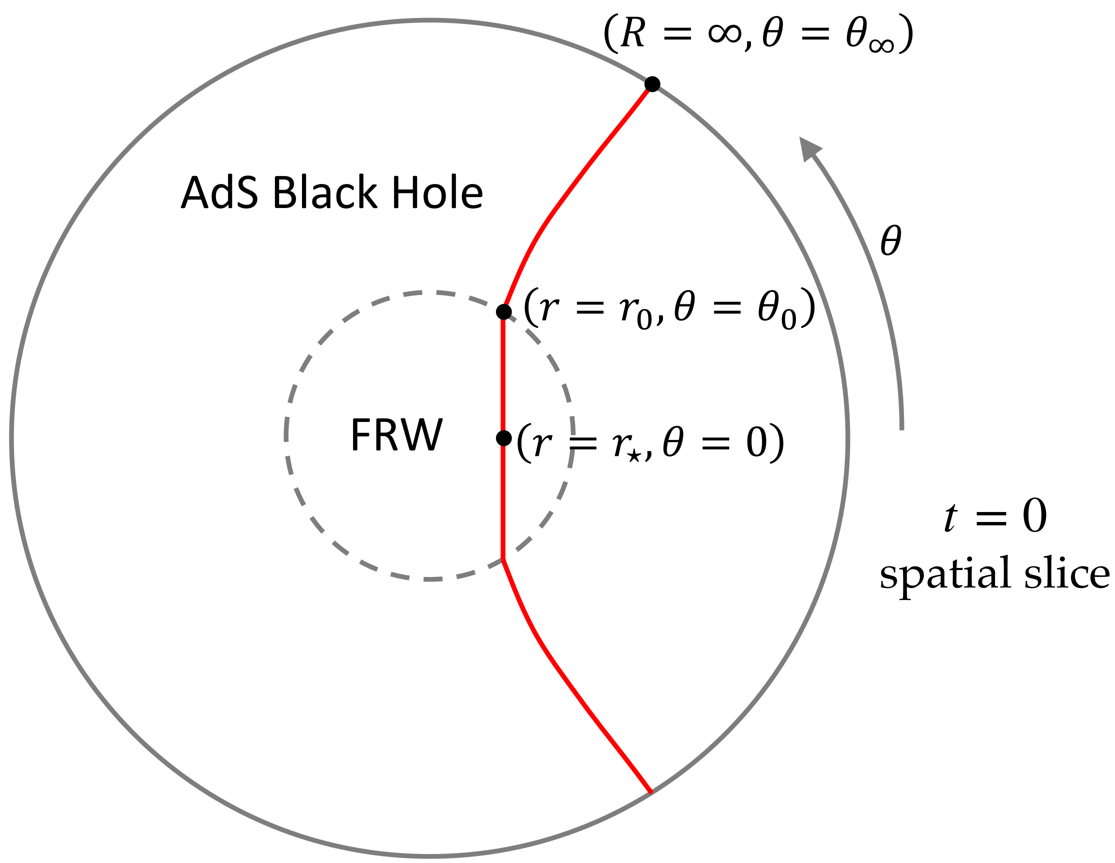
Correlated heavy operator insertions introduce particles traveling on FLRW geodesics. A ring of heavy operators can create the domain wall.

[Sasieta 2022,
Balasubramanian et al. 2022]

4. Probing the cosmology

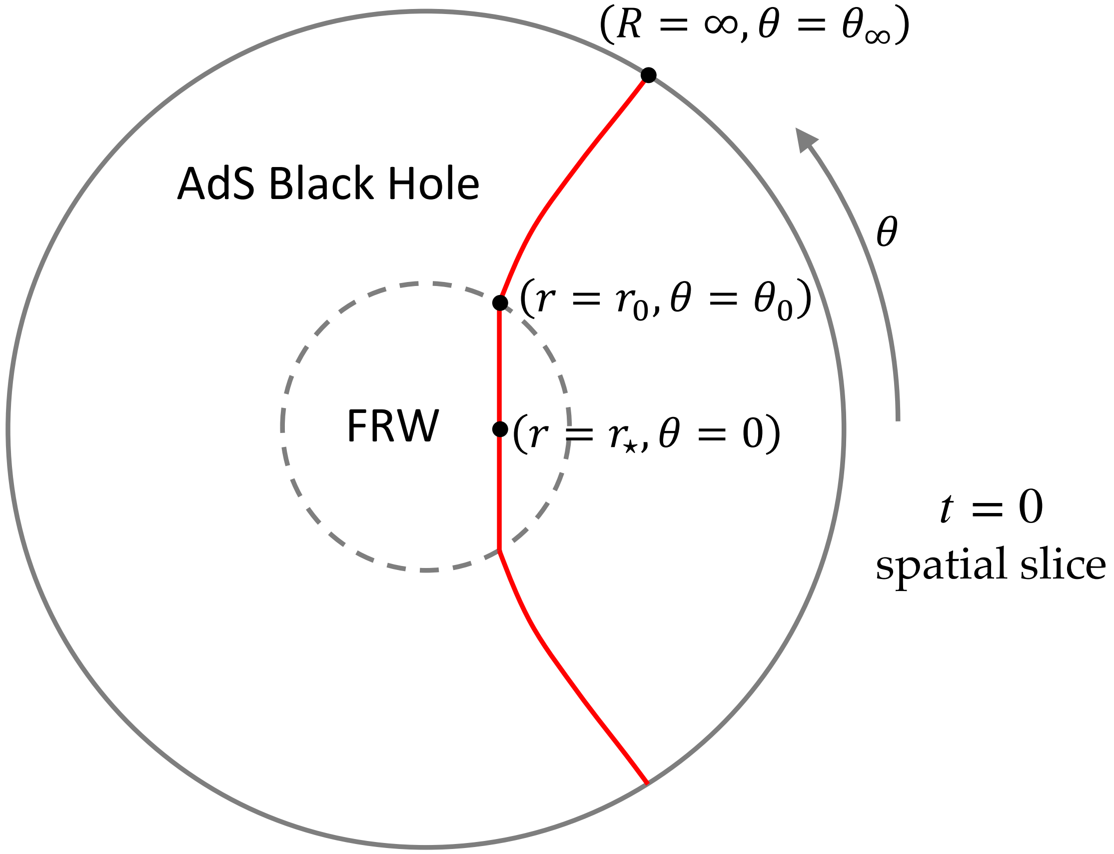
Probing the CFT

Probing the CFT



Probing the CFT

The boundary is homologous to a point in the bulk.



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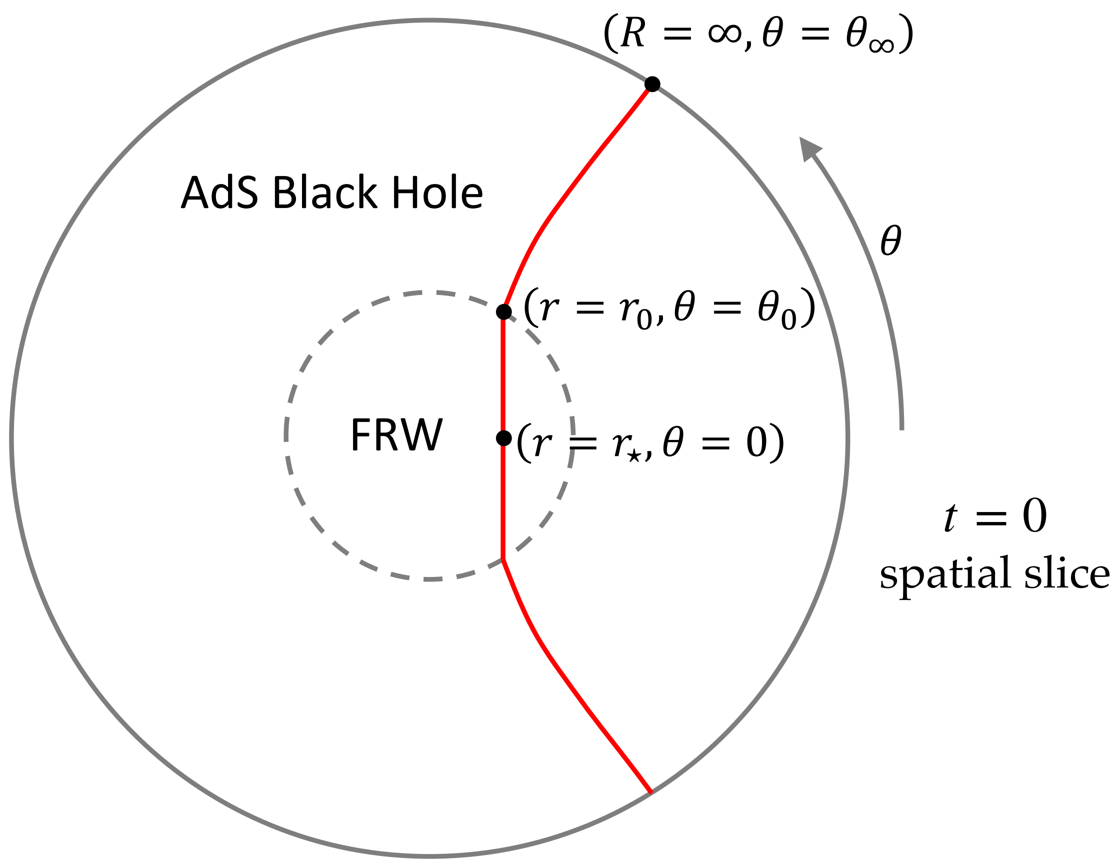

Reconstructing the bubble interior is possible, but difficult if the bubble lies behind the horizon and becomes a "Python's lunch". In other cases the interior can be probed using RT surfaces.

[Ryu, Takayanagi 2006]

Summary

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4. The state is constructed at the time-reversal symmetric slice and no knowledge of the big bang is needed.

5. Further work : exact nature of insertions? Correlation functions?

Thank you ! 🙇🏽‍♂️

Extras

The construction is special to 3+1 spacetime dimensions and generalises the Oppenheimer-Snyder solution.

The solution space is spanned by ρ_M, ρ_R, and R_0.

The density of dust and the mass of the black hole are given by the density of dust and radiation in the cosmology.

$$\rho_S = 2\sqrt{\rho_R}$$
$$\mu = \rho_M R_0^3 + 2\sqrt{\rho_R} R_K'(r_0) R_0^2$$

Parameter regimes with sensible Euclidean continuation (orange and green)