Title: Holographic Signatures of Cosmological Singularities

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Abstract:

Holographic Signatures of Cosmological Singularities

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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

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

Big Crunch solutions for alternative AdS boundary conditions

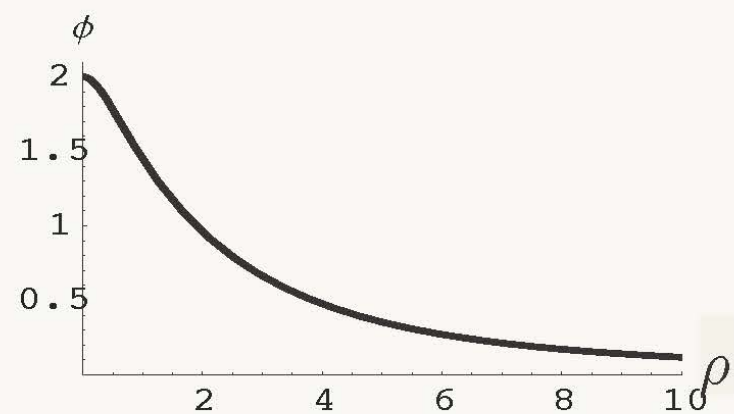
$$\beta(t, \Omega) = f\alpha^2(t, \Omega)$$

Euclidean Construction

First solve the Euclidean Einstein eq with SO(4) symmetry

$$ds^2 = \frac{d\rho^2}{b^2(\rho)} + \rho^2 d\Omega_3$$

This yields Euclidean domain walls



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

Define f by $\beta = f\,\alpha^2$. The restriction to the equator of S^3 defines initial data for a Lorentzian solution.

[Coleman and DeLuccia 1980]

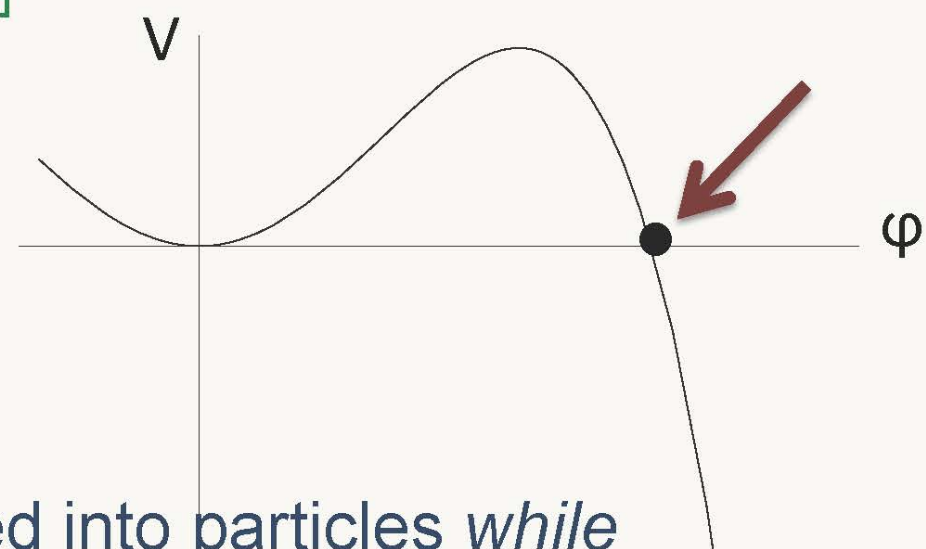
CFT Description

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

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

Boundary conditions $\beta = f\,\alpha^2$ correspond to adding the potential term [Witten; Sever and Shomer, 2002]

$$\frac{f}{3}\int \mathcal{O}^3$$



Most potential energy is converted into particles *while the field rolls down*; no bounce. [Craps, TH, Turok, 2007]

Kasner - AdS

[Englehardt,TH, Horowitz, 2014]

Consider AdS_5 and no scalar,

$$ds^2 = \frac{1}{z^2}\left(\eta_{\mu\nu}dx^\mu dx^\nu + dz^2\right)$$

Replace $\eta_{\mu\nu}$ with a Ricci flat Kasner metric,

$$ds^2 = -dt^2 + t^{2p_1}dx_1^2 + t^{2p_2}dx_2^2 + t^{2p_3}dx_3^2$$

$$\sum_i p_i = 1 = \sum_i p_i^2$$

Kasner - AdS

[Englehardt,TH, Horowitz, 2014]

$$ds^2 = \frac{H^2 t^2}{z^2}\left(\frac{-dt^2 + t^{2p_1}dx_1^2 + t^{2p_2}dx_2^2 + t^{2p_3}dx_3^2 + dz^2}{H^2 t^2}\right)$$

In terms of τ = ln t:

$$ds^2 = -d\tau^2 + \sum_i e^{-2(1-p_i)H\tau} dy_i^2$$

⟶ anisotropic de Sitter boundary

Dilation symmetry:

$$z \to \lambda z, \quad t \to \lambda t, \quad x_i \to \lambda^{(1-p_i)} x_i$$

Boundary two-point functions

We use spacelike bulk geodesics with endpoints on the boundary to compute two-point functions of CFT operators with large dimension Δ:

$$\langle\psi|\,\mathcal{O}(x)\,\mathcal{O}(x')\,|\psi\rangle = e^{-m\mathcal{L}_{reg}(x,x')}$$

where L_{reg} is the regulated length.

Consider equal-time correlators for two points separated in $x=x_1$ direction only. Symmetries imply we can set t=1, $x_2=x_3=0$

Example: p_1 = -1/4

Geodesic equations can be solved analytically using $w= t^{1/2}$ as the parameter,

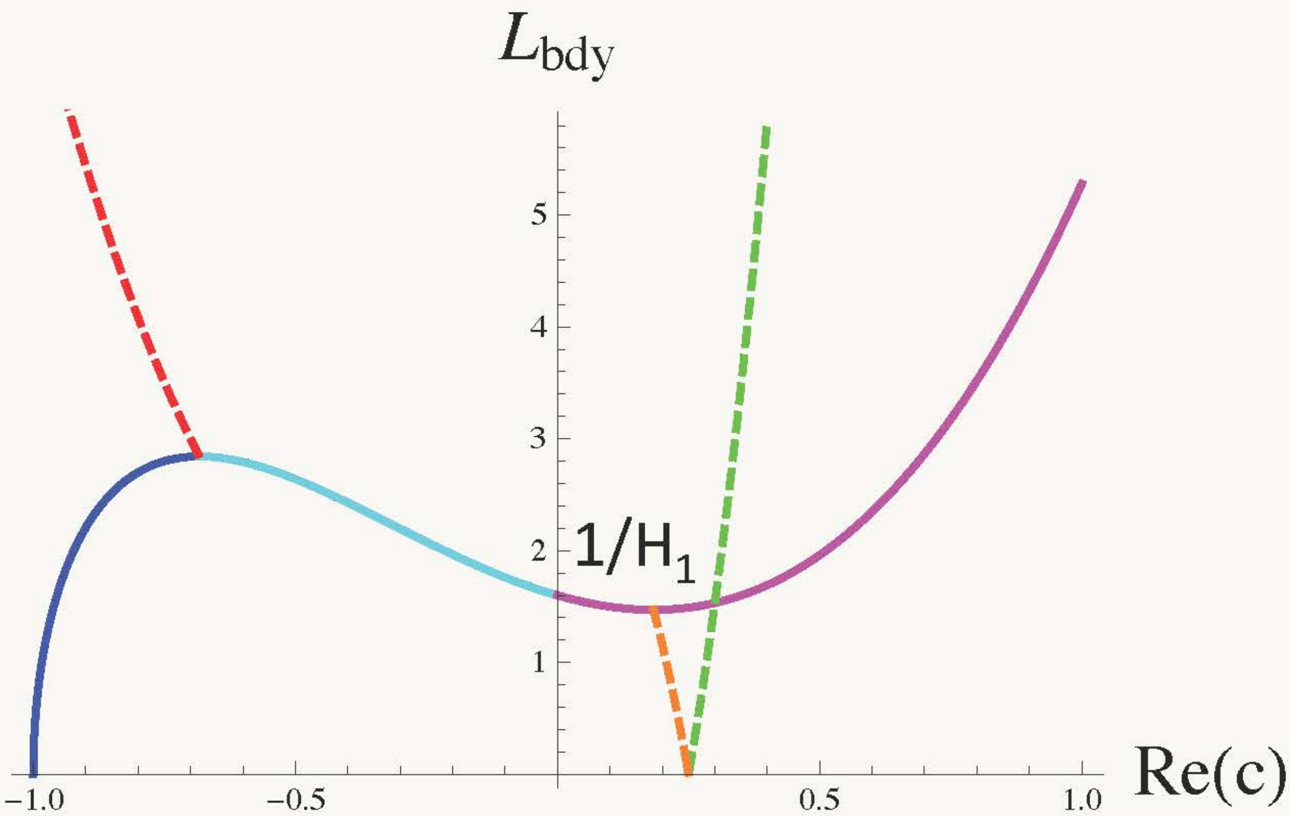
$$x(w) = \frac{4}{15}\sqrt{c+w}(8c^2 - 4cw + 3w^2)$$
$$z(w) = \frac{4}{3}\sqrt{c[w^3 - 1 + 3c(1-w^2)]}$$

At the boundary, t=1, z(1)=0, and L_{bdy}=2x(1).

Boundary separation related to integration constant c

But..

Example: p_1 = -1/4



For fixed real L_{bdy}, 5 complex geodesics

[Englehardt TH, Horowitz, 2014]

Two-point correlator

$$\mathcal{L}_{reg} = \ln\left[-\frac{64}{9}c(1+c)(2c-1)^2\right]$$

- For $c \approx -1$, L_{bdy} is small and $L_{reg} = 2 \ln L_{bdy}$ so at short scales

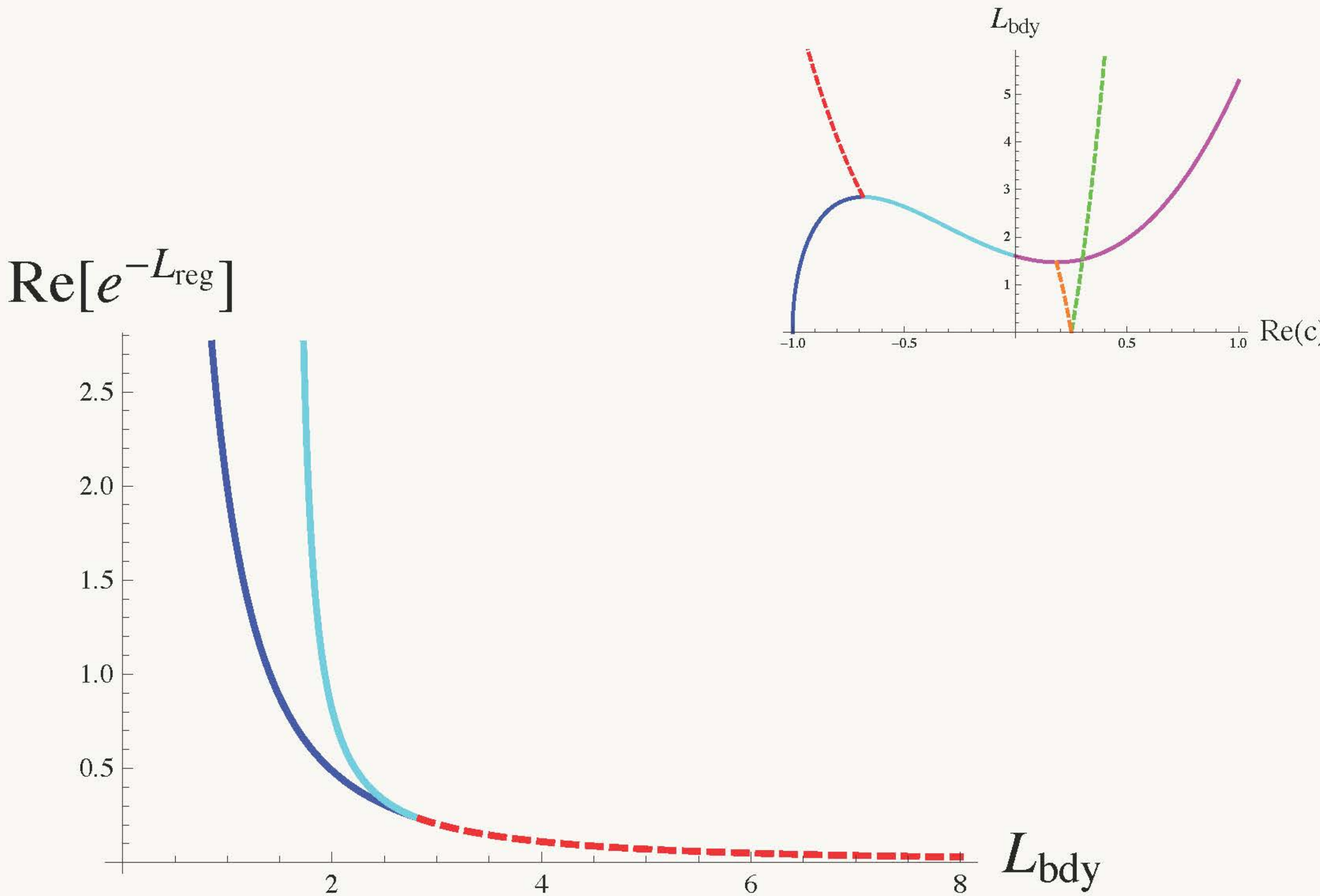
$$\langle \mathcal{O}\mathcal{O} \rangle = \mathcal{L}_{bdy}^{-2\Delta}$$

- As c -> 0, L_{reg} again diverges while L_{bdy} -> $1/H_1$.
This leads to a pole at horizon size.

- For large L_{bdy} we have $L_{reg} = \ln L_{bdy}^{8/5}$, which yields

$$\langle \mathcal{O}\mathcal{O} \rangle \propto \mathcal{L}_{bdy}^{-2\Delta/H_1}$$

Two-point correlator



[Englehardt TH, Horowitz, 2014]

General Kasner exponents p

[Englehardt,TH, Horowitz, 2015]

- No pole at horizon scale for p≥0
- Always a pole at horizon scale for p<0
- For large boundary separations:

$$\langle \mathcal{O}\left(\bar{x}\right) \mathcal{O}\left(-\bar{x}\right)\rangle \propto \mathcal{L}_{bdy}^{-2\Delta/(1-p)}$$

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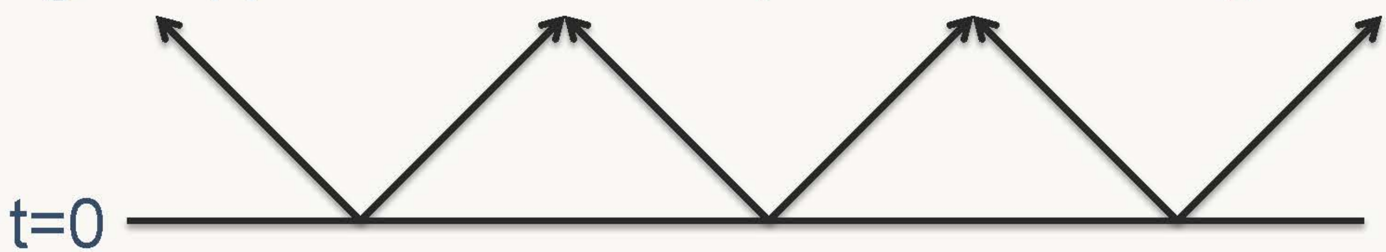
Interpretation of the pole at horizon size??

Conjecture

Anisotropy effectively leads to dimensional reduction near past boundary, down to a 1+1 CFT

The two-point correlator in the geodesic approx. has a pole at horizon size only in the remaining (p<0) direction

Consider a 1+1 CFT after a quantum quench. Correlators of some operators show a large bump at `horizon size' which can be described in terms of EPR pairs of quasi-particles moving in opposite directions [Calabrese & Cardy, 2006]



Further, the entanglement entropy grows and then stabilizes. Is this the case in our system?

Happy Birthday Gary!!