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De Sitter Horizons and Holography

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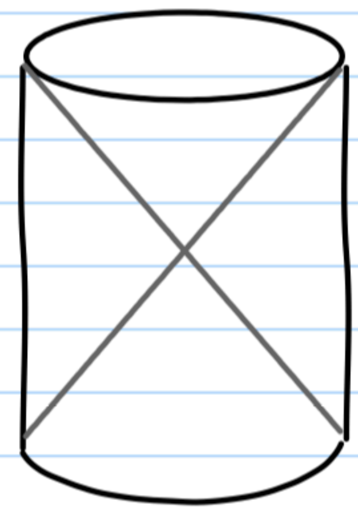
Based on work in collaboration with D. Anninos and D. Hofman

AdS, dS: similar, but different

(from Eva's talk)

More generally, we need a complete framework for the V>0 landscape.

$\Lambda < 0$

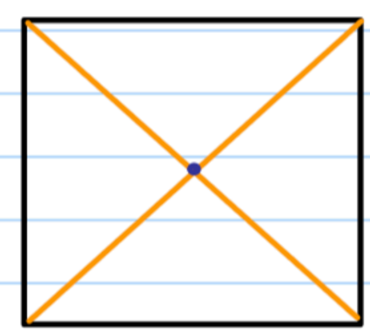


AdS:

observables are conformal field theory (CFT) correlation functions

Timelike boundary at infinity pins fields.

$\Lambda > 0$



dS

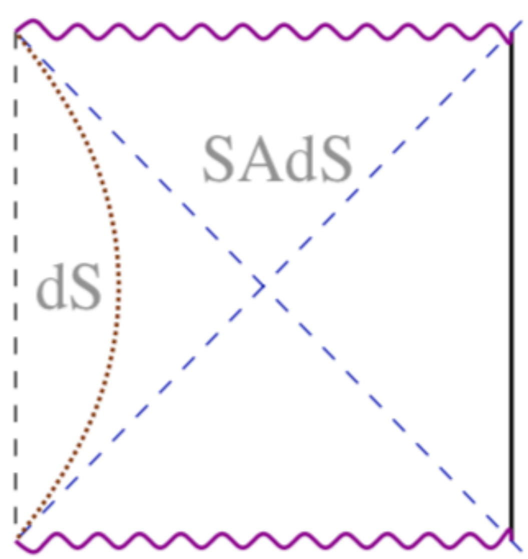
no boundary analogous to the AdS one. (Finite, fluctuating space.)

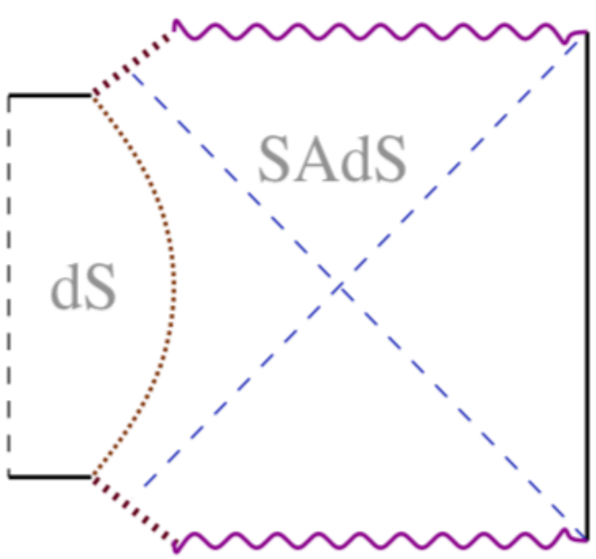
Embedding dS into AdS

- A natural idea would be to try to embed a patch of de Sitter into an AdS geometry.

- This was fostered by [Freivogel, Hubeny, Maloney, Myers, Rangamani, Shenker, 2005].

- But, EoMs + Energy conditions required the dS patch to hide behind the horizon of an AdS Schwarzschild solution.





- But this is for d>2. What about (A)dS$_2$?

[Maldacena, Turiaci, Yang, '19]
[Cotler, Jensen, Maloney, '19]

A few words on dS_2

- The global metric is described by

$$ds^2_{global} = \frac{-d\tau^2 + d\varphi^2}{\cos^2\tau} \quad , \quad \tau \,\epsilon\, [-\pi/2, \pi/2]$$

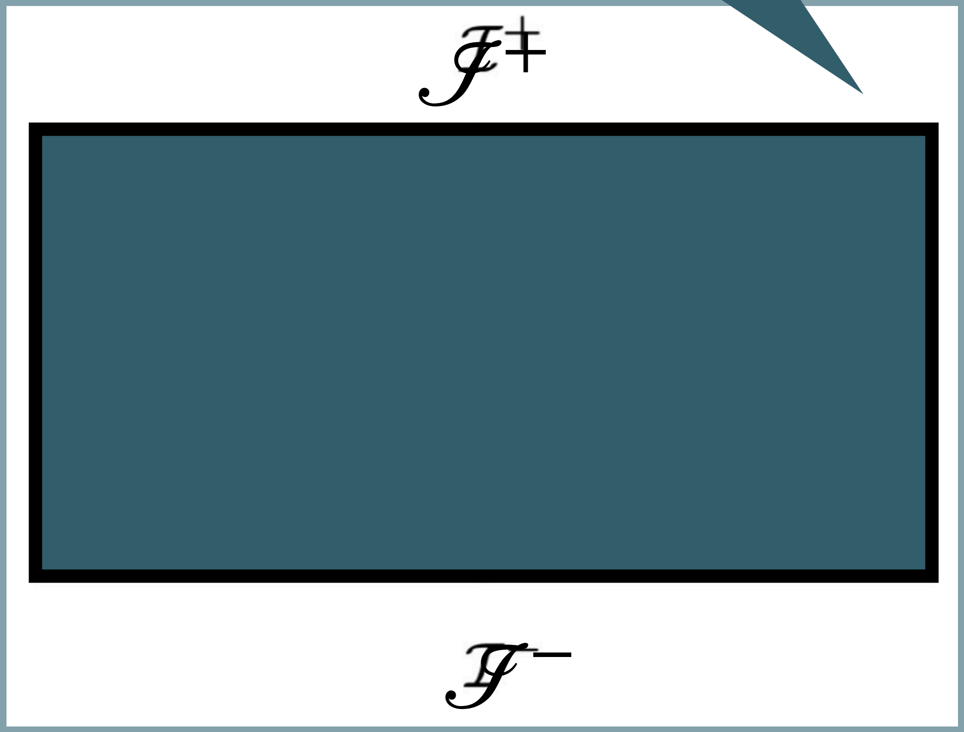
- A single observer only has access to the static patch geometry:

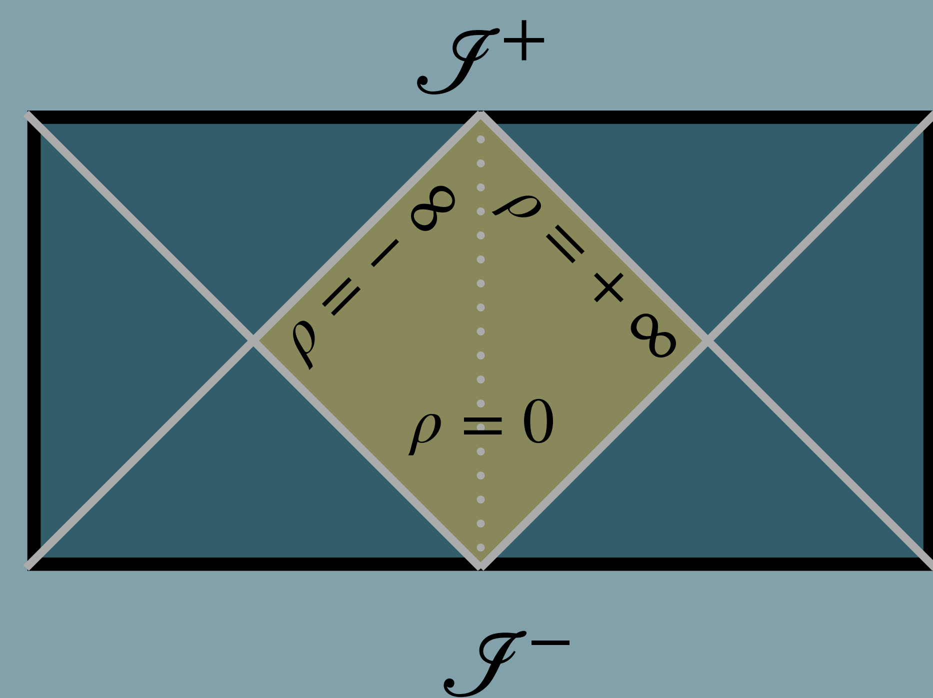
$$ds^2_{static} = \frac{-dt^2 + d\rho^2}{\cosh^2\rho} \quad , \quad \rho \,\epsilon\, [-\infty, \infty]$$

- The patch is always finite.

- The static patch has two horizons.

- It appears as a solution in higher dimensions, dS_2 x S^{d-2}, in the so-called Nariai limit.





An action for the centaurs

- In 2d, the Einstein action is topological

$$S_{top} = -\frac{\phi_0}{2}\int d^2x\sqrt{g}R - \phi_0 \int_{\partial\mathcal{M}} du\sqrt{h}\,K$$

- We will consider the following (Euclidean) gravity-dilation action

$$S_E = -\frac{1}{2\kappa}\int d^2x\sqrt{g}\,\big(\phi R + V(\phi)\big) - \frac{1}{\kappa}\int_{\partial\mathcal{M}} du\sqrt{h}\,\phi\,K$$

- It is important that the full dilaton remains positive, so that

$$\phi_{tot} = (\phi_0 + \phi/\kappa) \gg 0$$

- The equations of motion can be simply recasted as

$$R = -V'(\phi)\ \ ,\ \ T^{\phi}_{\mu\nu} = 0\,.$$

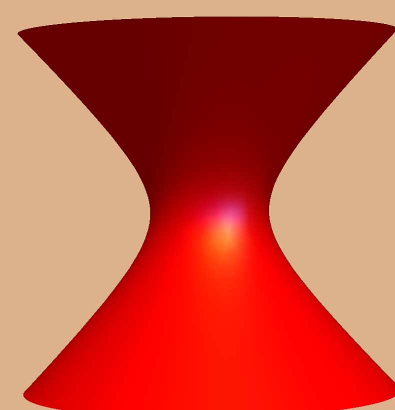
An action for the centaurs II

- The equations of motion can be simple recasted as

$$R = -\,V'(\phi)\ \ ,\ \ T^{\phi}_{\mu\nu} = 0\,.$$

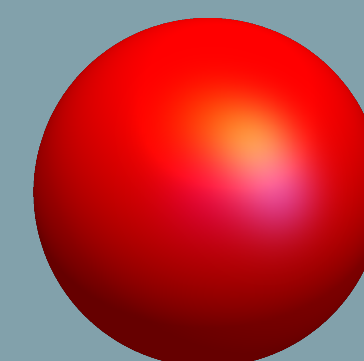
- If the potential is +2ϕ, then the solution is (n)AdS2:

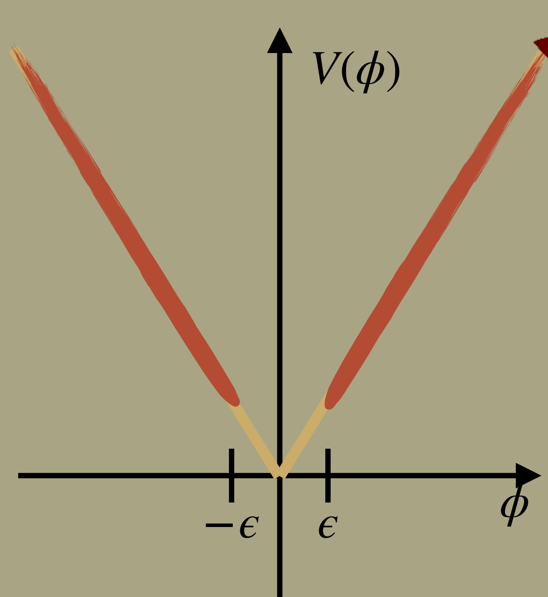
$$\begin{cases} ds^2 = \dfrac{dt^2 + d\rho^2}{\cos^2\rho} \\ \phi = \phi_h \tan\rho \end{cases}$$

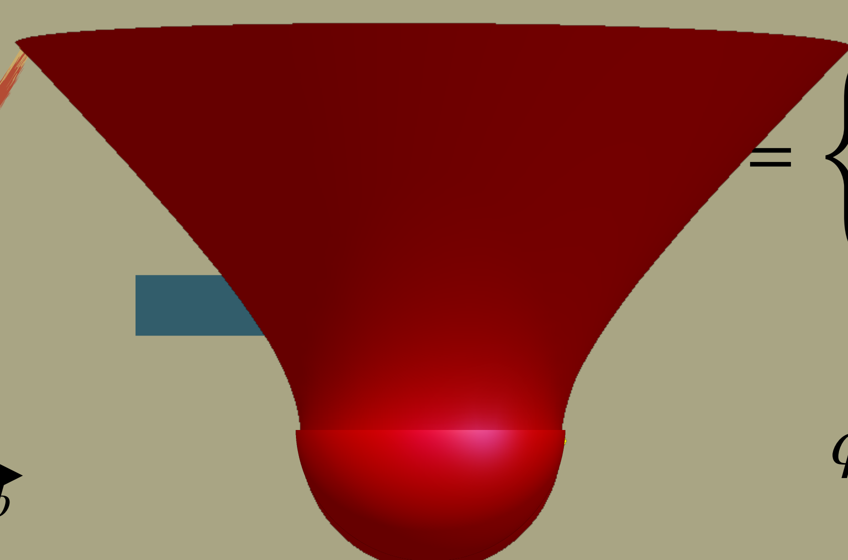


- If the potential is -2ϕ, then the solution is (n)dS2:

$$\begin{cases} ds^2 = \dfrac{dt^2 + d\rho^2}{\cosh^2\rho} \\ \phi = \phi_h \tanh\rho \end{cases}$$





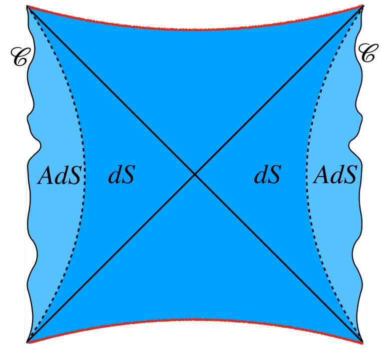


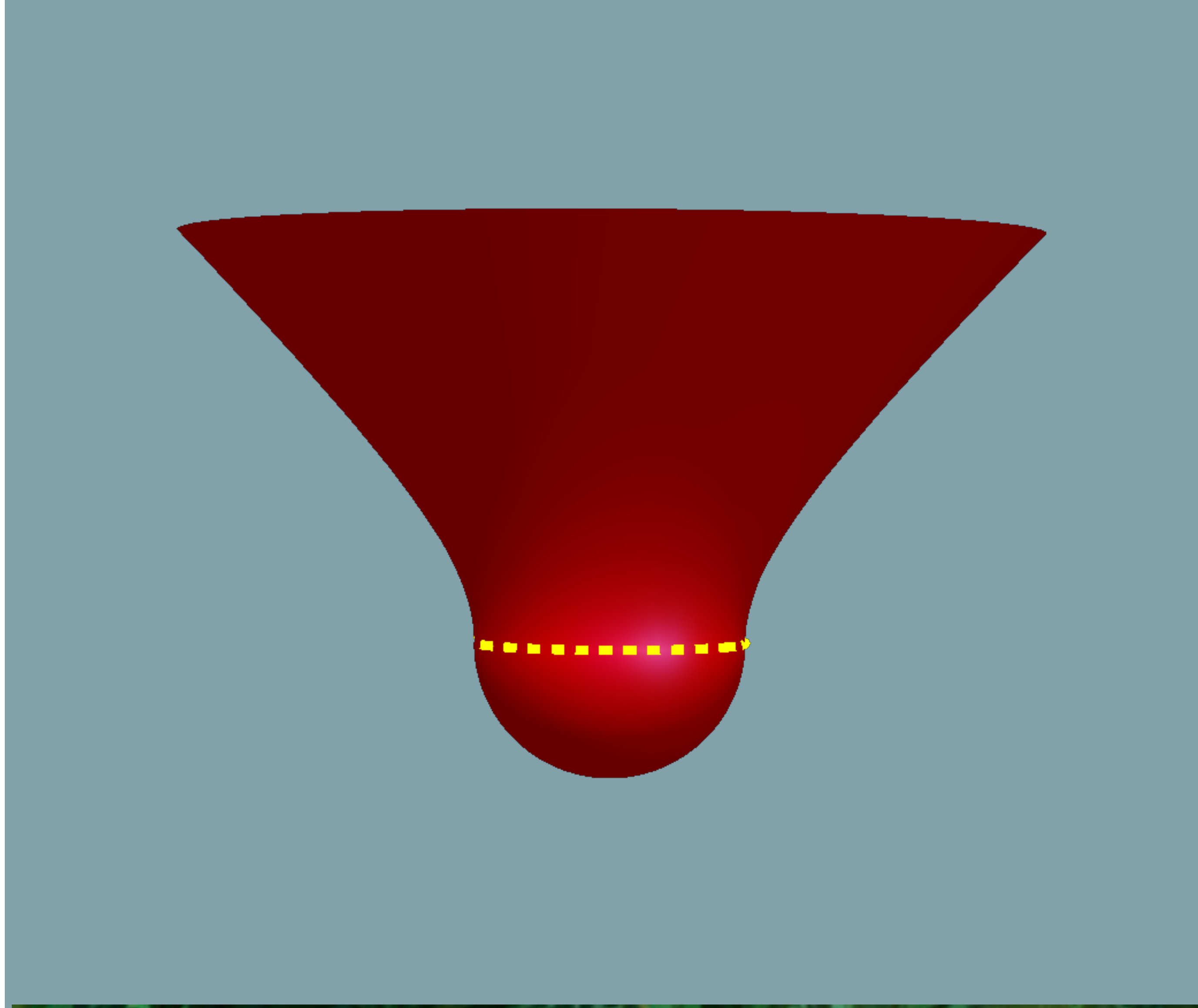
$$= \begin{cases} \cos^{-2}\rho\left(d\rho^2 + d\tau^2\right)\ , & \rho \in (\pi/2, 0)\ , \\ \cosh^{-2}\rho\left(d\rho^2 + d\tau^2\right)\ , & \rho \in (-\infty, 0)\ . \end{cases}$$

$$\phi = \begin{cases} -\phi_h \tan\rho\ , & \rho \in (\pi/2, 0)\,, \\ -\phi_h \tanh\rho\ , & \rho \in (-\infty, 0)\,. \end{cases}$$

Properties of the centaur

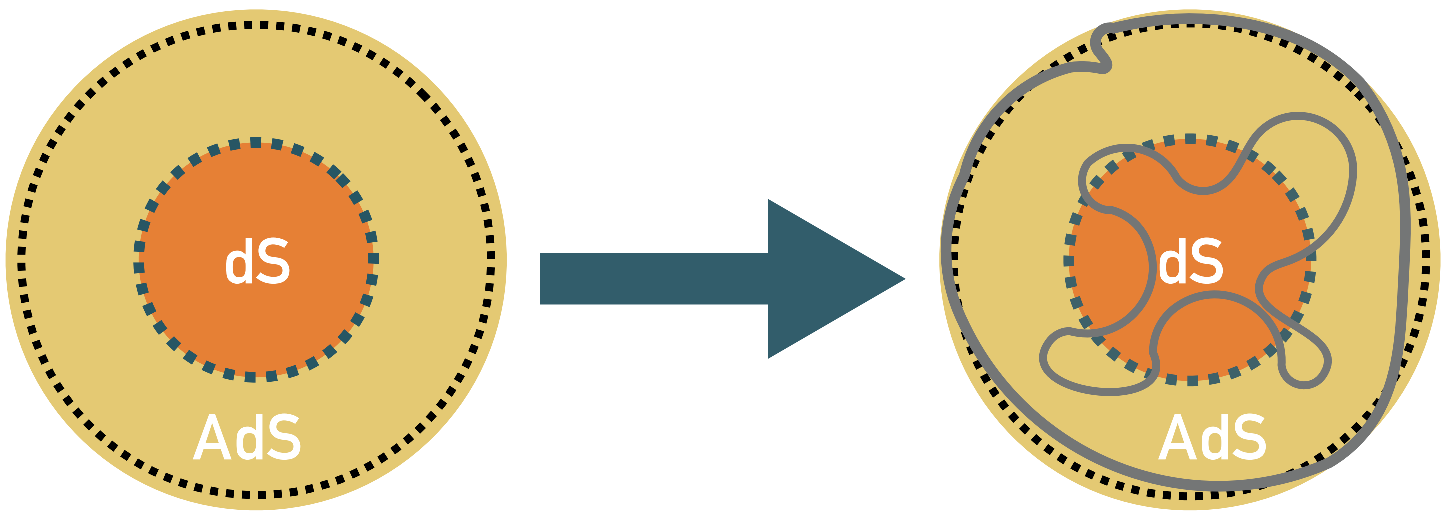
- It is a smooth, differentiable geometry that interpolates between AdS and dS.
- It has the conformal boundary of AdS but deep in the infrared it goes to the static patch of dS.
- The dilaton grows monotonically, so there is no violation of the (higher dimensional) NEC.
- We can also build the Lorentzian centaur via an analogue Hartle-Hawking mechanism.



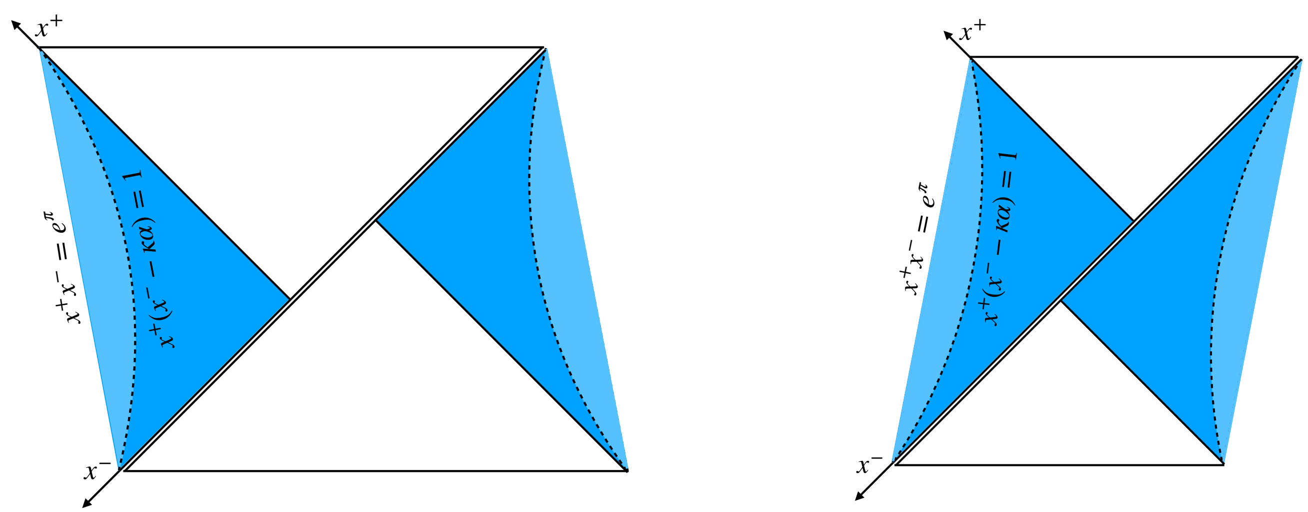


Some holographic experiments

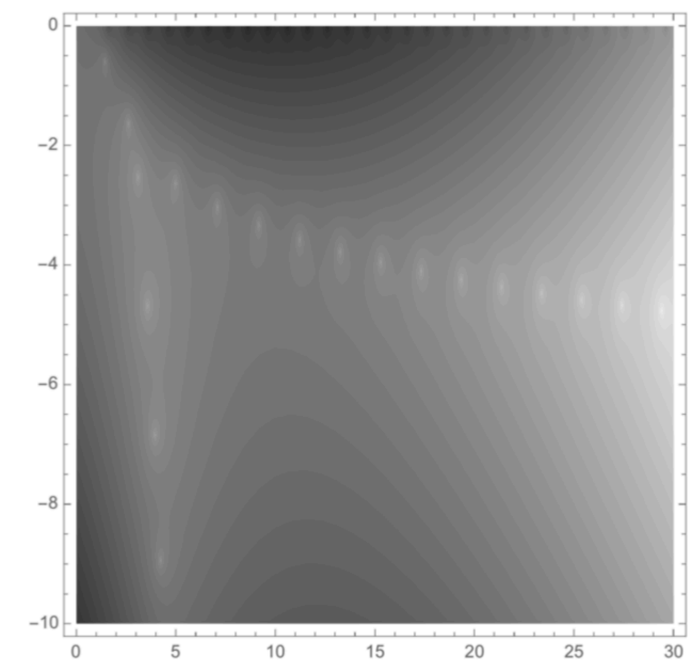
- Perturbative Euclidean deformations



- Shockwave deformations



- Quasinormal modes

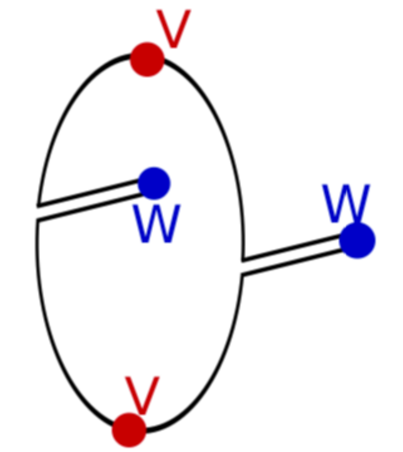


See 1703.04622 and 1811.08153 or ask me later!!

- **Boundary modes and chaos**

The boundary theory

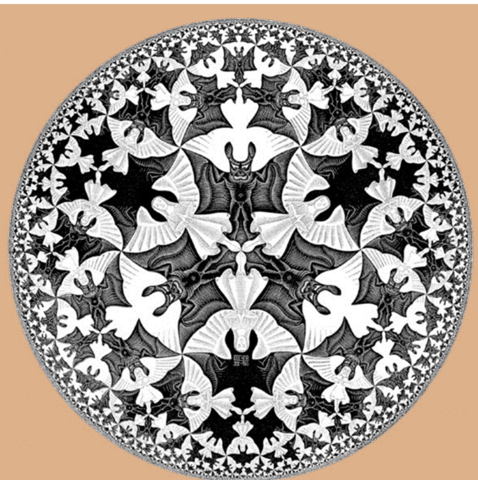
- We still need to fix boundary conditions. The Dirichlet problem defines a curve close to the boundary $\mathscr{C} = \{\tau(u), \rho(u)\}$
$$h(u) = e^{2\omega(\rho(u),\tau(u))}\left((\partial_u\tau(u))^2 + (\partial_u\rho(u))^2\right) \ , \quad \phi_b(u) = \phi(\rho(u), \tau(u))$$
- Evaluating the action we obtain a boundary action
$$S_{bdy} = \frac{\tilde{\phi}_b}{\kappa}\int du \left(\frac{1}{2}\left(\partial_u\tau(u)\right)^2 - Sch\left[\tau(u), u\right]\right) \ .$$
- The clock close to the boundary of the centaur geometries is that of the hyperbolic cylinder instead of the hyperbolic disk.
- Expanding around the saddle τ=u, we obtain an effective action for the fluctuations τ=u+$\delta\tau$(u):
$$S_{fluct} = \frac{\tilde{\phi}_b}{2\kappa}\int du \left(\left(\partial_u^2\delta\tau(u)\right)^2 + \left(\partial_u\delta\tau(u)\right)^2\right) \ .$$



Out-of-time ordered correlators

- Now we will add some matter perturbations and compute the out-of-time ordered correlator for these geometries:

$$F(t) \equiv \langle V(\pi/2)W(it)V(-\pi/2)W(-\pi+it)\rangle_c$$

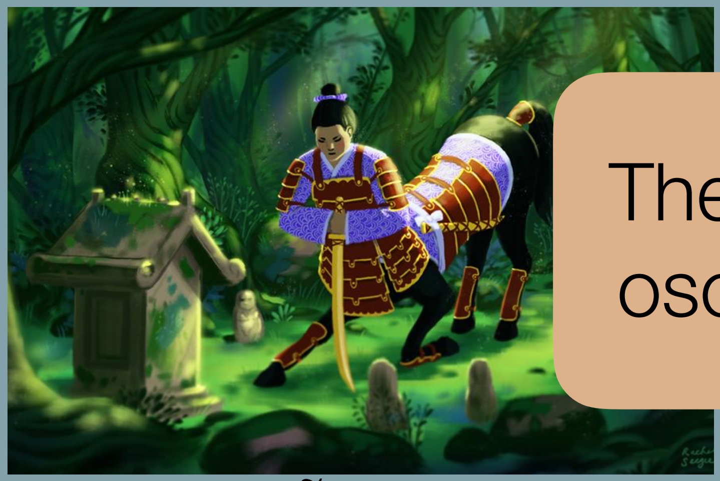


The AdS$_2$ case is maximally chaotic!!

$$S_{fluct} = \frac{\tilde{\phi}_b}{2\kappa}\int du\,\left(\left(\partial_u^2\delta\tau(u)\right)^2 - \left(\partial_u\delta\tau(u)\right)^2\right)$$

compute, compute, compute …

$$F(t) \propto \frac{\kappa\beta}{\tilde{\phi}_b}\exp\frac{2\pi}{\beta}t \qquad \lambda_L = \frac{2\pi}{\beta}$$



The centaurs have oscillatory OTOC!!

$$S_{fluct} = \frac{\tilde{\phi}_b}{2\kappa}\int du\,\left(\left(\partial_u^2\delta\tau(u)\right)^2 + \left(\partial_u\delta\tau(u)\right)^2\right)$$

compute, compute, compute, compute,
compute, compute, compute, compute,
compute, compute, compute, compute …

$$F(t) \propto \frac{\kappa\beta}{\tilde{\phi}_b}\cos\frac{2\pi}{\beta}t$$

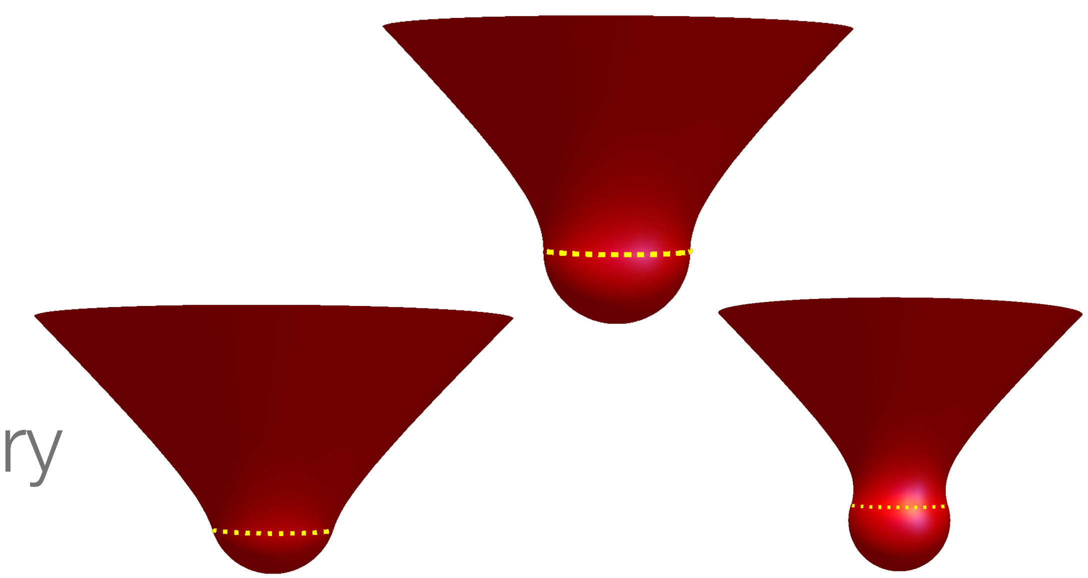
De Sitter horizons and chaos

- We found that dS horizons do not exhibit a chaotic behaviour in their out-of-time-ordered correlator. This is quite striking since the naive argument is that the gravity result is universal for horizons.

- We consider this a distinctive feature of dS horizons rather than a "bug".

- We can even generalise our construction:

- We obtain a generalised Schwarzian theory



$$S_{bdy} = \frac{\phi_b}{\kappa} \int du \left(\frac{\gamma}{2} (\partial_u \tau(u))^2 - Sch\left[\tau(u), u\right] \right)$$

→ Exponential, when $\gamma<0$

→ Power law, when $\gamma=0$

→ Oscillatory, when $\gamma>0$

Questions and future directions

- Can we understand the γ-Schwarzian theory from a quantum mechanical point of view? Is there an SYK-like model that exhibits these features? [T. Anous, J. Sonner; T. Mertens, J. Turiaci; J. Yoon; K. Jensen]

- What about the κ<0 solutions and the non-suppressed fluctuations? How can we make sense of this theory?

- Would it possible to get rid of the AdS part? [e.g.: poster by A. Rolph]

- Are there centaurs in higher dimensions?

- What is the relation between this construction and dS/CFT correspondence? Or the dS/dS correspondence?

Lots to explore…