An Outsider's perspective on information recovery in de Sitter space

Sergio Ernesto Aguilar Gutierrez

KU LEUVEN

Based on **2210.12176** with

Lars Aalsma (ASU)& Watse Sybesma (IcelandU)

and **WIP** with

Juan Hernandez (VUB), Mikhail Khramtsov (VUB, UPenn)& Maria Knysh (VUB)

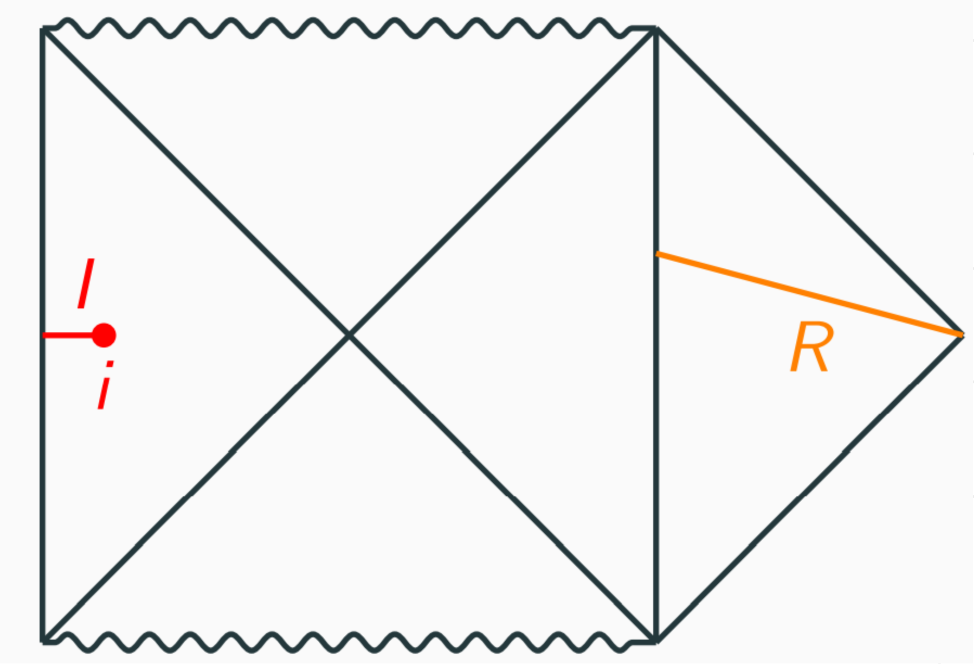
Motivation

- Exciting developments for reproducing the Page curve for BH evaporation.

- **Island rule** [Penington '19], [Almheiri, Engelhardt, Marolf, Maxfield '19]

$$S(R) = \text{Min} \underset{\partial I}{\text{Ext}} \left[S_{\text{gen}}(R \cup I) \right],$$

$$S_{\text{gen}}(R \cup I) = \frac{A(\partial I)}{4G_N} + S_{\text{vN}}(R \cup I).$$

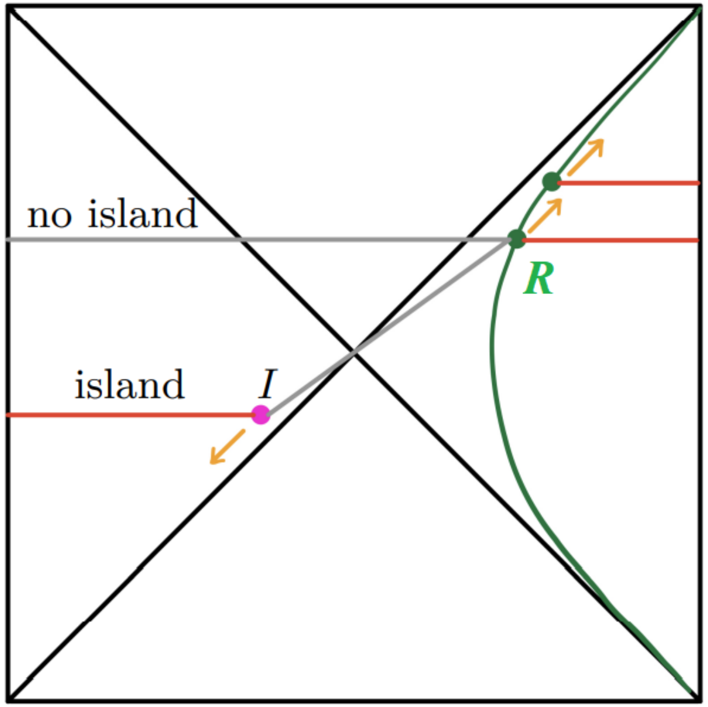


- Non-perturbative transitions.

- Islands are agnostic about the spacetime background.

→ What do they teach us about cosmological horizons?

  - **However,** extremal surfaces on the apparent horizon violate basic consistency principles [Shaghoulian '21] and go backwards in time [Sybesma '20].



- There is a way around it [Aalsma, Sybesma, '21] at the cost of a large backreaction.

Is there a sense of controlled information recovery in dS space?

Two-Dimensional gravity model

$$I = \frac{1}{2\kappa^2}\int \mathrm{d}^d x\,\sqrt{-g}\,\Phi\left(\mathbf{R}-\frac{2}{l^2}\right) + (\text{bdy term}) + (\text{matter})$$

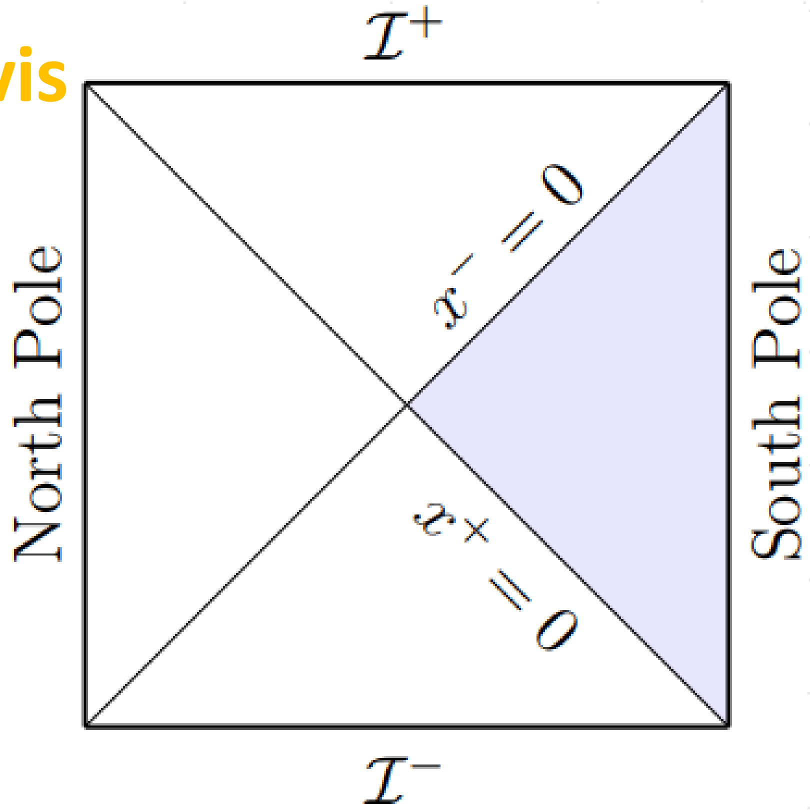
In presence of quantum matter in the **Bunch-Davis state**:

$$\mathrm{d}s^2 = -\Omega_{\mathrm{dS}}^{-2}(x^\pm)\mathrm{d}x^+\mathrm{d}x^-,$$

$$\langle T_{\pm\pm}(x^\pm)\rangle_{\mathrm{BD}} = 0,$$

$$\langle T_\pm(x^\pm)\rangle_{\mathrm{BD}} = \frac{c\,g_\pm}{24\pi l^2},$$

$$\Phi_{\mathrm{dS}}(x^\pm).$$

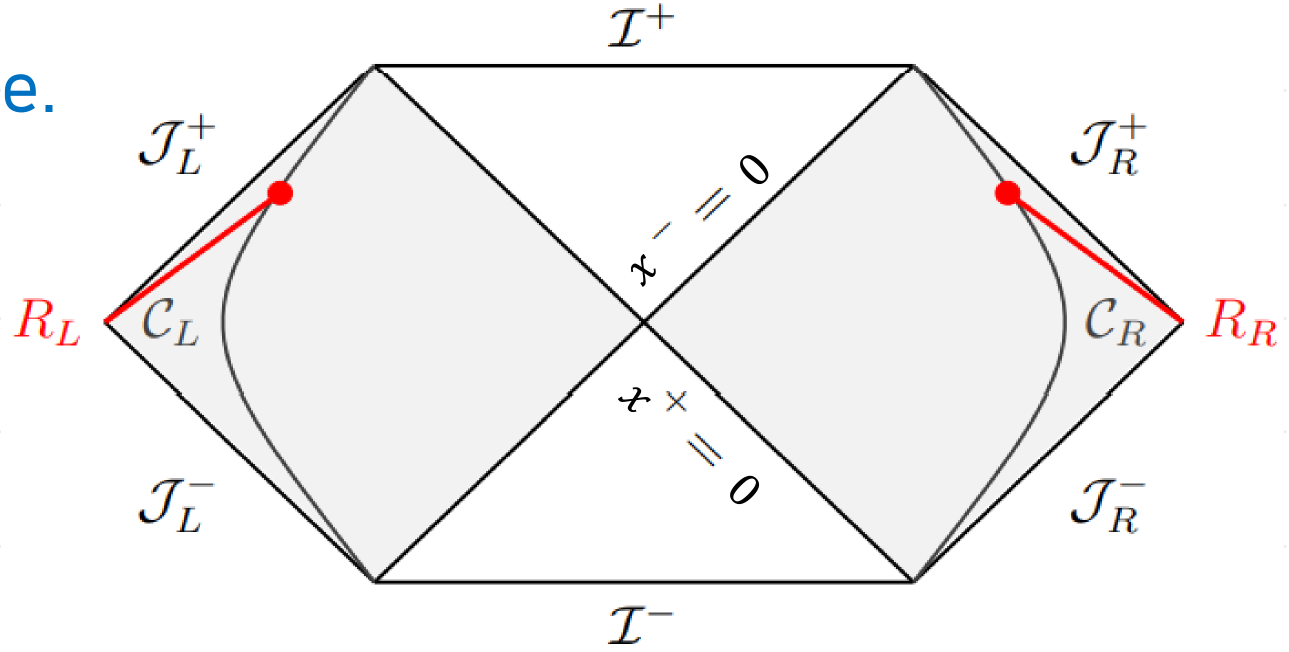


The Outsider's perspective model

- **Problem**: No asymptotic non-gravitational regions in dS space.
- **Proposal**: Glue Rindler wedges.

$$ds^2 = -\Omega^{-2}_{\text{Rindler}}(x^{\pm})dx^{+}dx^{-},$$

$$\Phi_{\text{Rindler}}(x^{\pm}).$$



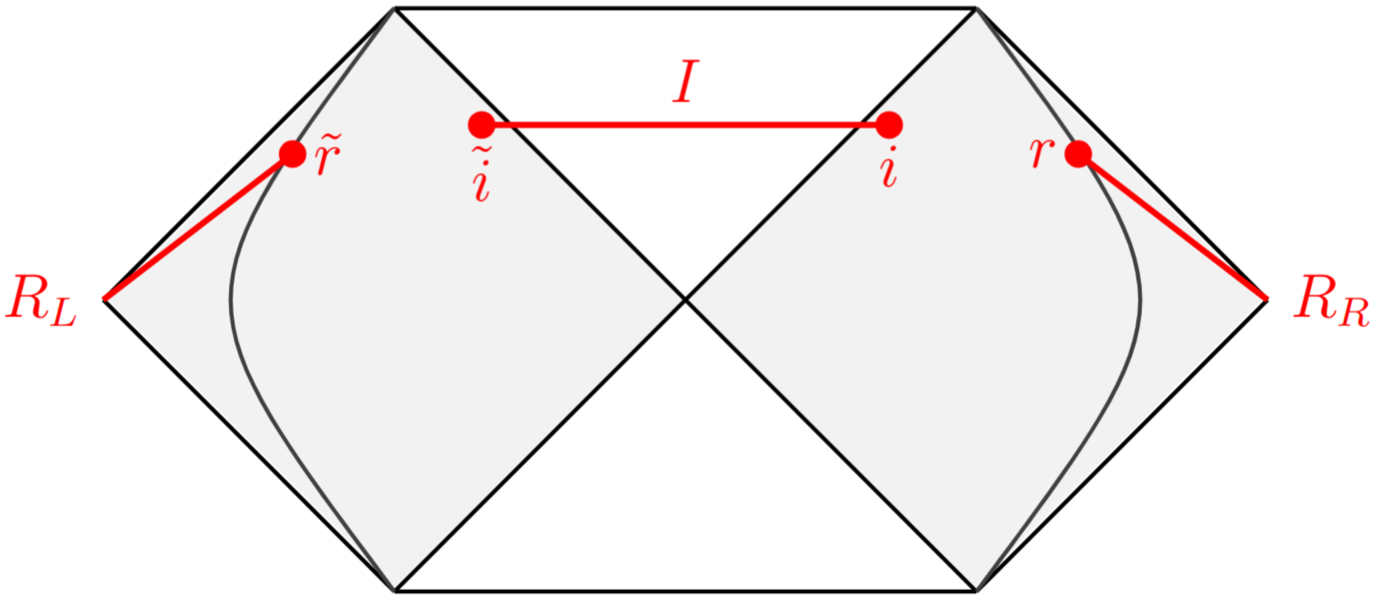
  - **Junction conditions:**

$$[\Phi]_{x^{-}=0} = 0\,,$$

$$\kappa^2 T_{ab}n^a n^b + [n^a \nabla_a \Phi]_{x^{-}=0}\delta(x^{-}) = 0$$

Searching for Islands

$$S_{\text{gen}}(R_L \cup R_R \cup I) = \frac{2\pi}{\kappa^2}\Phi\left(x_i^{\pm}\right) + \frac{c}{6}\log\left[-\frac{(x_i^+ - x_r^+)(x_i^- - x_r^-)}{\epsilon_i\,\epsilon_r\,\Omega(x_i^{\pm})\Omega(x_r^{\pm})}\right] + (i \leftrightarrow \tilde{\imath},\, r \leftrightarrow \tilde{r}).$$



Early times → Hawking saddle

$$S_{\text{gen}}(R_L \cup R_R \cup I) = S_{\text{vN}}(R) \sim \frac{c}{3l}t\,,$$

Late times → Rindler island saddle

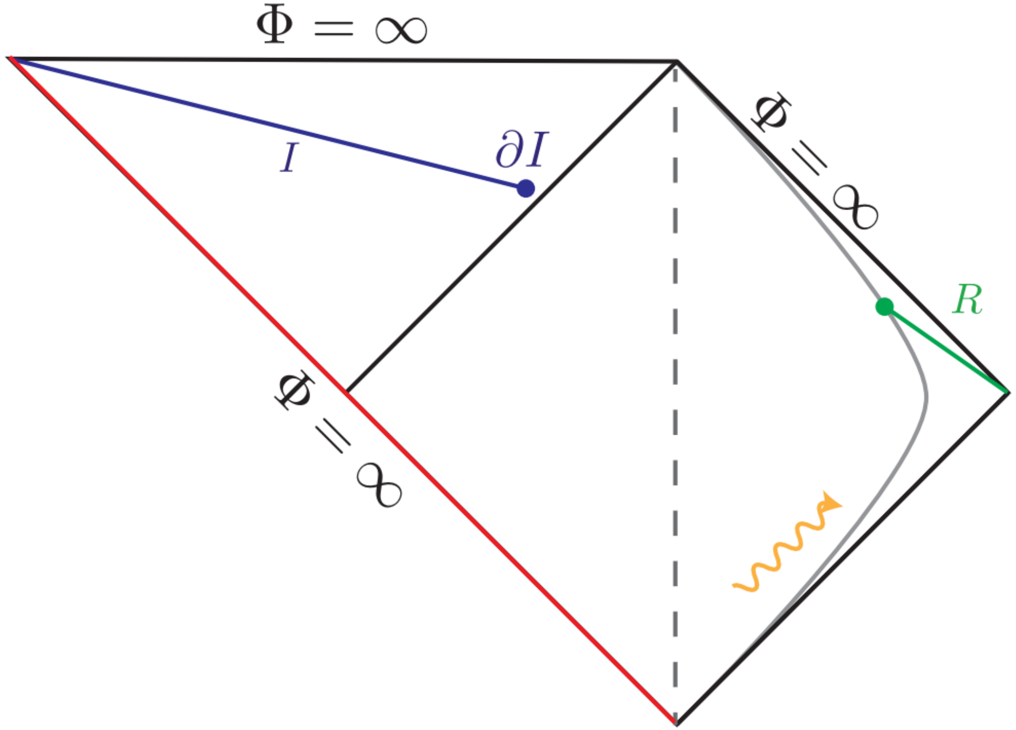
$$S_{\text{gen}}(R_L \cup R_R \cup I) = 2S_{\text{dS}}\,.$$

Breaking Thermal Equilibrium

- **Unruh-de Sitter state** [Aalsma , Parikh, van der Schaar '19]

$$\langle T_{++}(x^+)\rangle = -\frac{c}{48\pi(x^+)^2}, \quad \langle T_{--}(x^-)\rangle = 0.$$

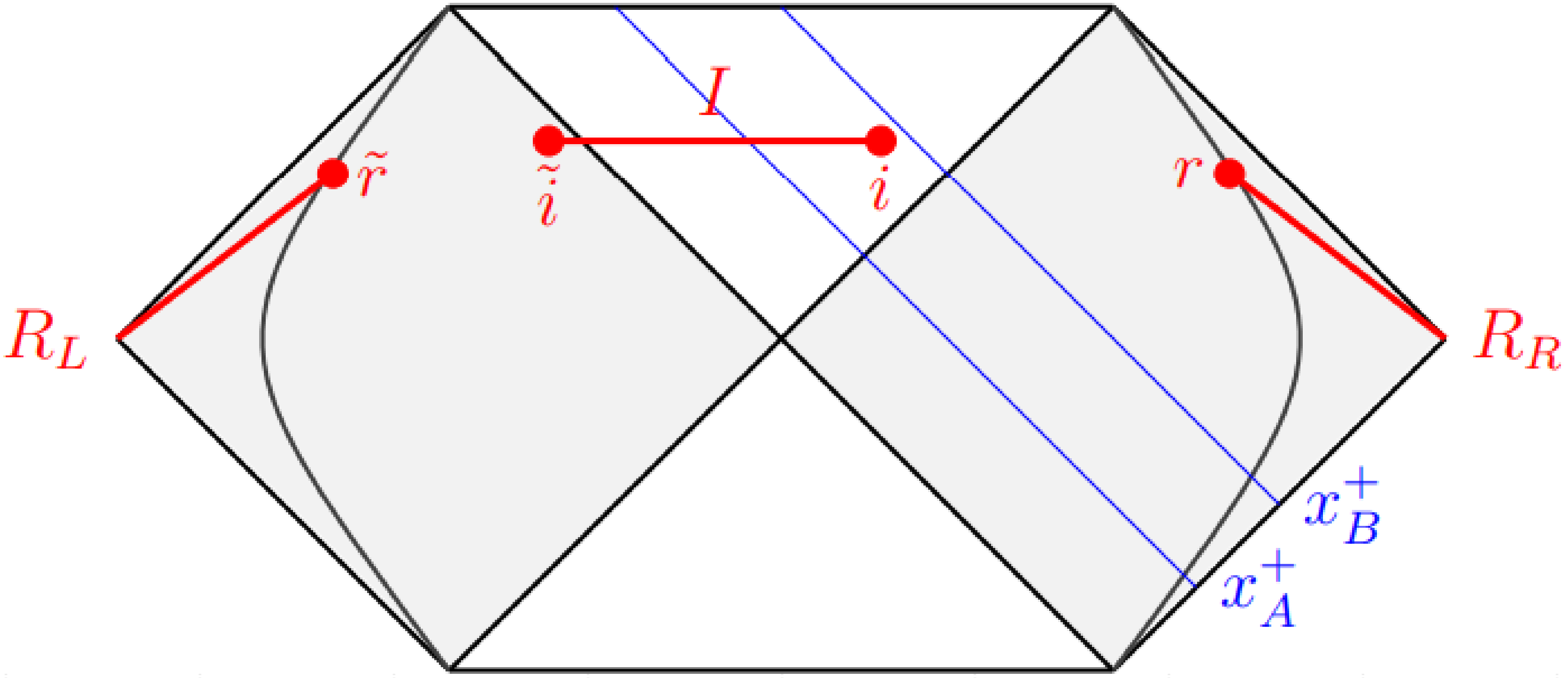
- However, curiosity comes with a **price** [Aalsma, Sybesma '21]



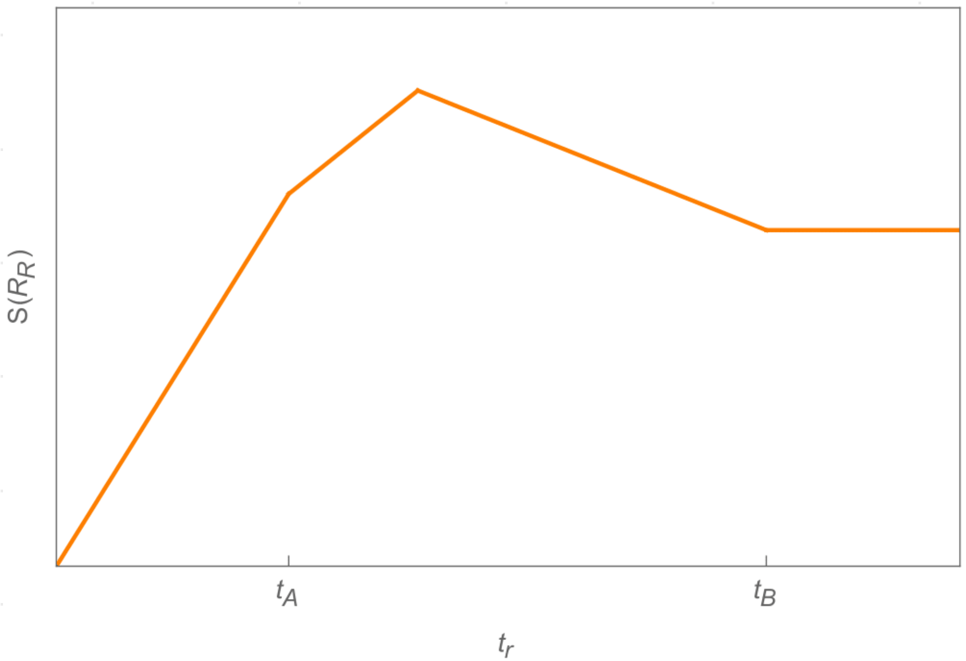
Information recovery

Without destroying the observer.

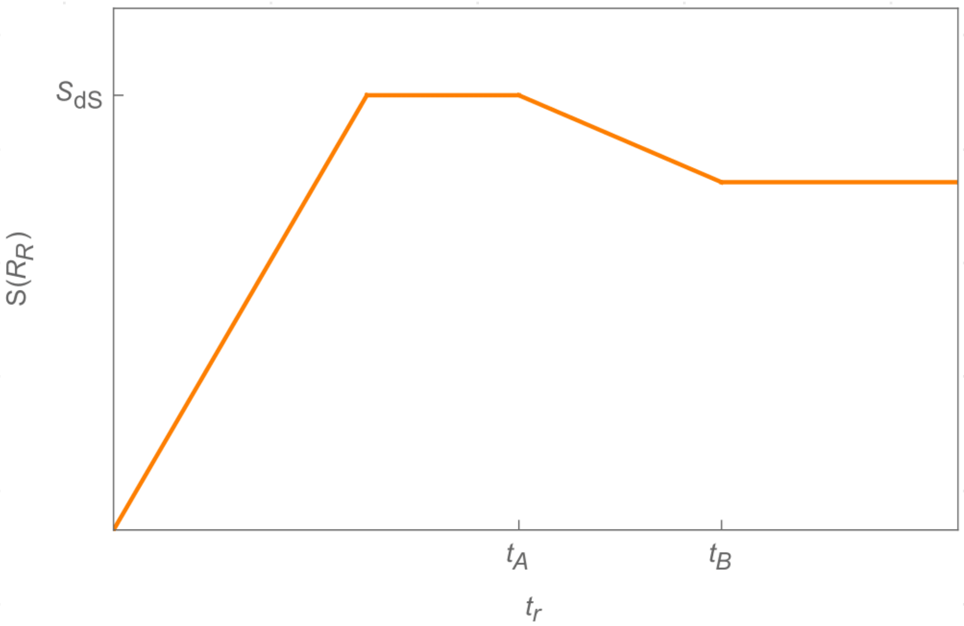
[Aalsma, SEAG, Sybesma '22]



Page curve



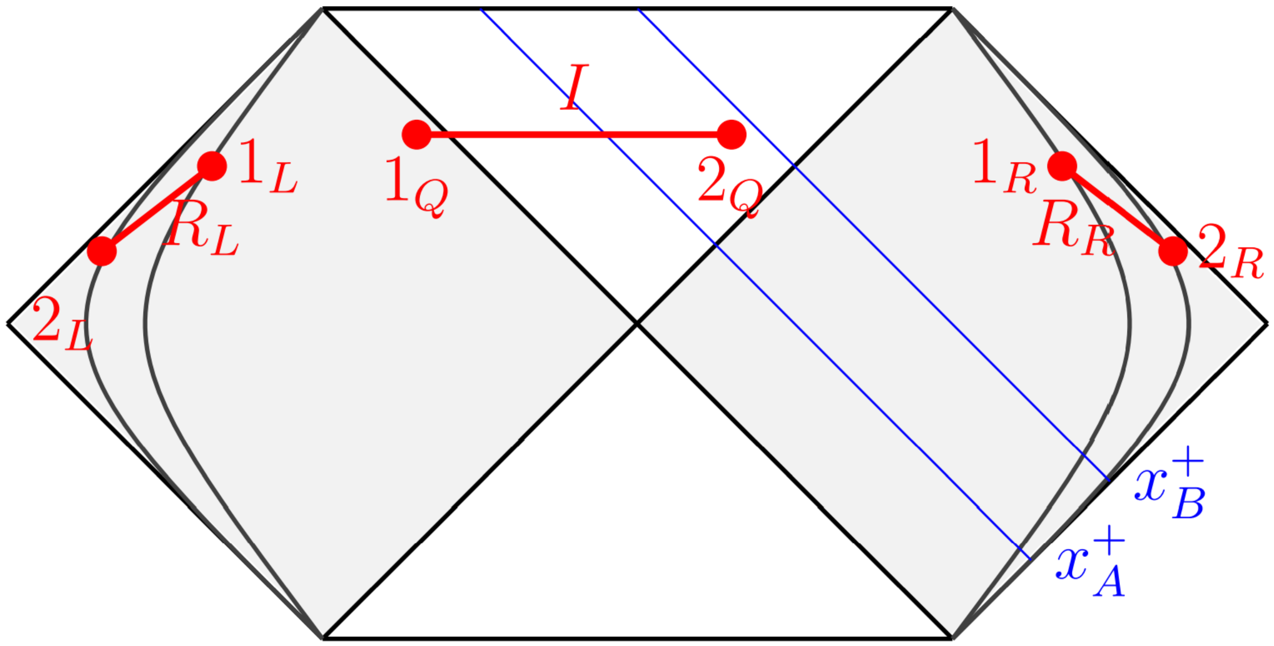
Before saturation time

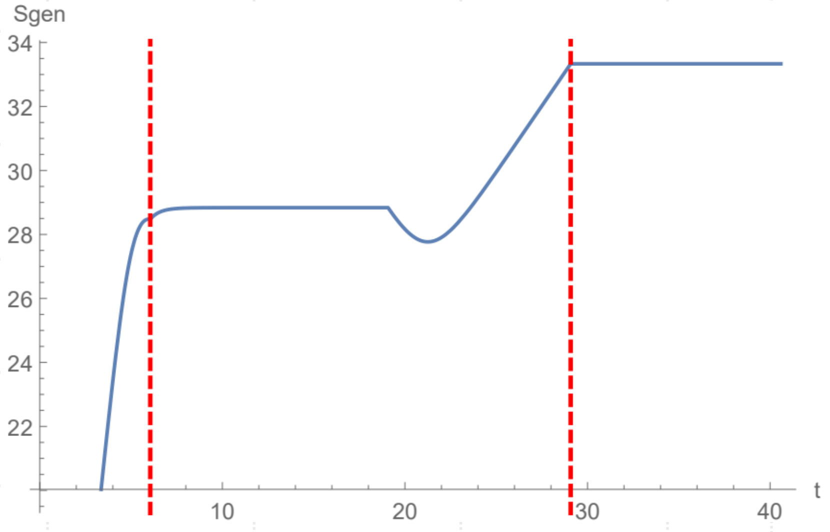


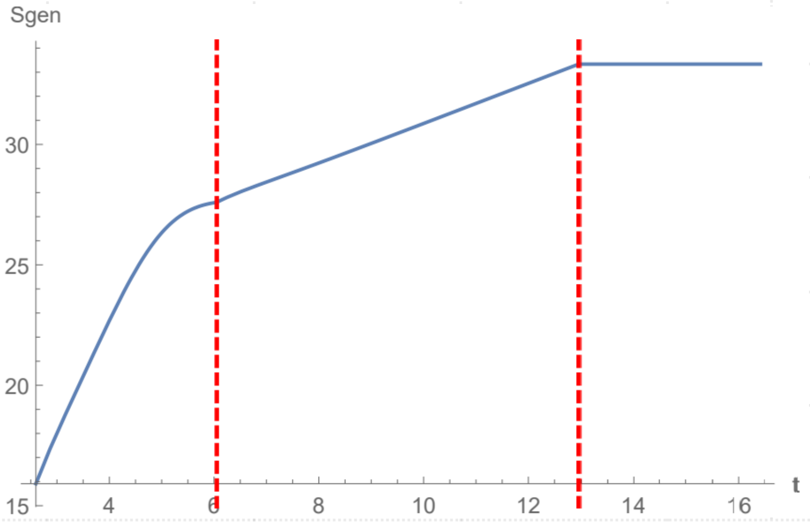
After saturation time

Collecting radiation in finite segments

[SEAG, Hernandez, Khramtsov, Knysh **WIP**]







Summary

- The entanglement wedge of Hawking radiation includes regions behind the horizon, **independent on the background** [Bousso, Penington ‘22].

- The cost for recovering information in dS space is large backreaction, which can be **tamed** with our protocol.

- Entropy is a sensitive to a notion of non-locality present in quantum gravity in the form of islands.

- Are there other low-energy observables that have this property?