Slow scrambling in extremal BTZ and microstate geometries

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Black hole microstates

- Black holes carry entropy

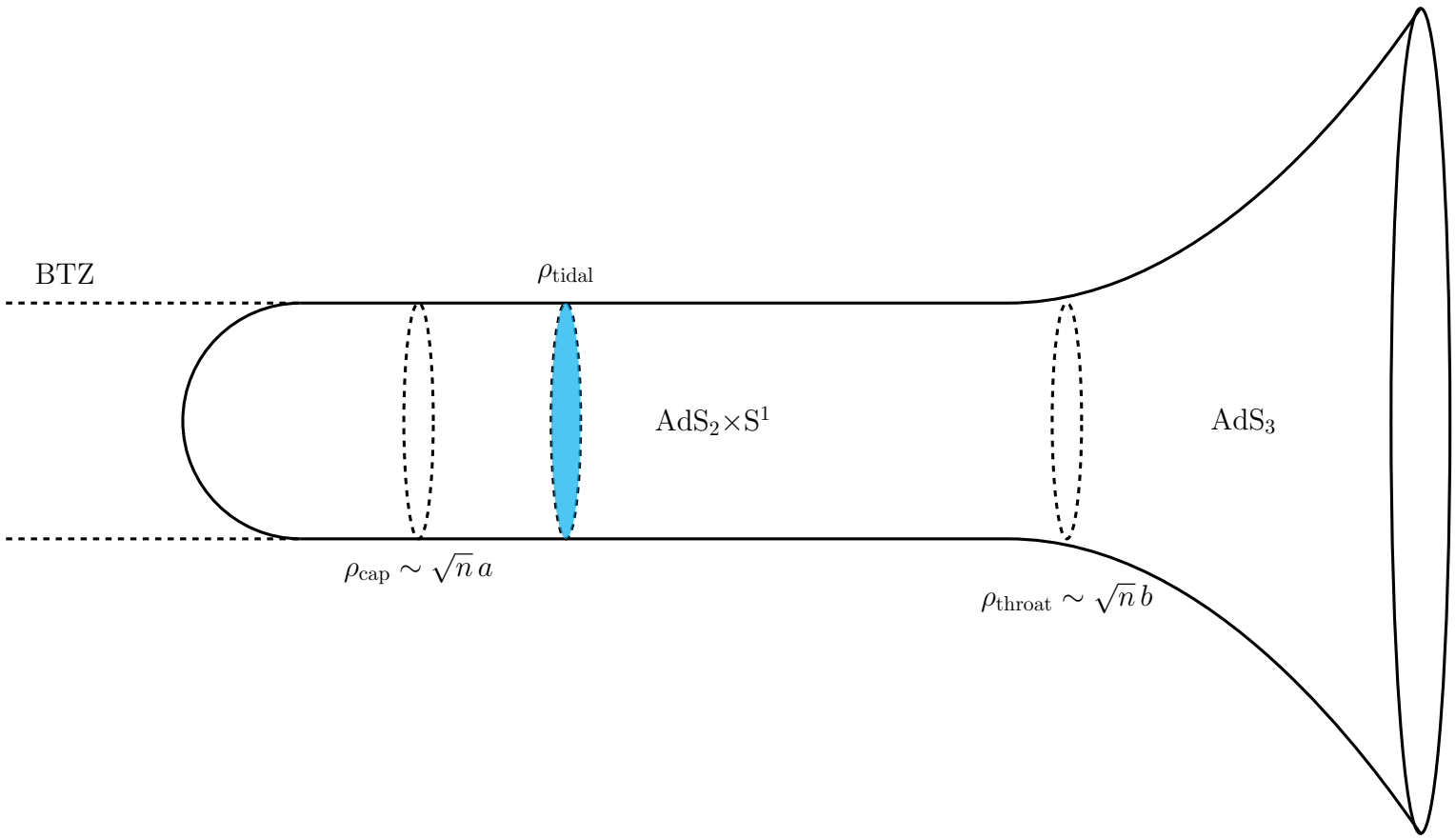
$$S = A/4G_N$$

- In statistical mechanics, entropy measures the number of microstates of a system

$$S = \log \Omega$$

- In the context of string theory, some geometries corresponding to certain microstates have been identified.

Black hole microstates - *Superstrata*



Classical and Quantum Chaos

- In classical mechanics, a system is chaotic if

$$\frac{\partial q(t)}{\partial q(0)} = \{q(t), p(0)\} \propto e^{\lambda_L t}.$$

  with *Lyapunov exponent* λ_L

Classical and Quantum Chaos

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  with *Lyapunov exponent* λ_L
- In quantum systems, we can use the *commutator squared*

$$C(t) = -\langle [V(0), W(t)]^2 \rangle_\beta$$

  instead.

Classical and Quantum Chaos

For times large compared to the inverse temperature $t \gg \beta$, the normalized commutator squared is given by

$$\hat{C}(t) = 1 - \mathrm{Re}\,\mathrm{OT\hat{O}C}(t)$$

in terms of the *out-of-time-order correlator*

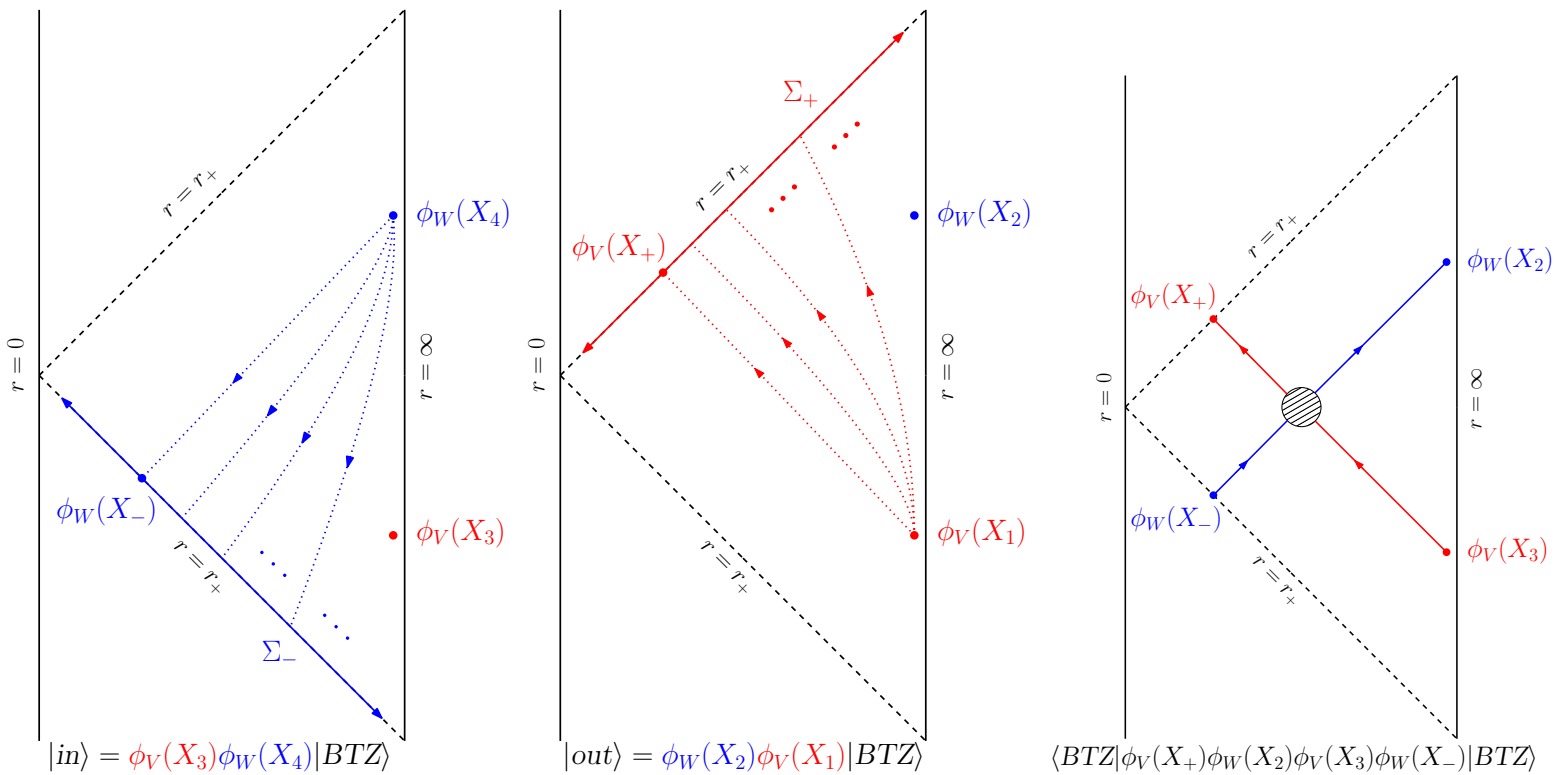
$$\mathrm{OTOC}(t) = \langle V(0)W(t)V(0)W(t)\rangle_\beta$$

OTOC from Holography [Ben, Kévin, Marine & Vijay '19]

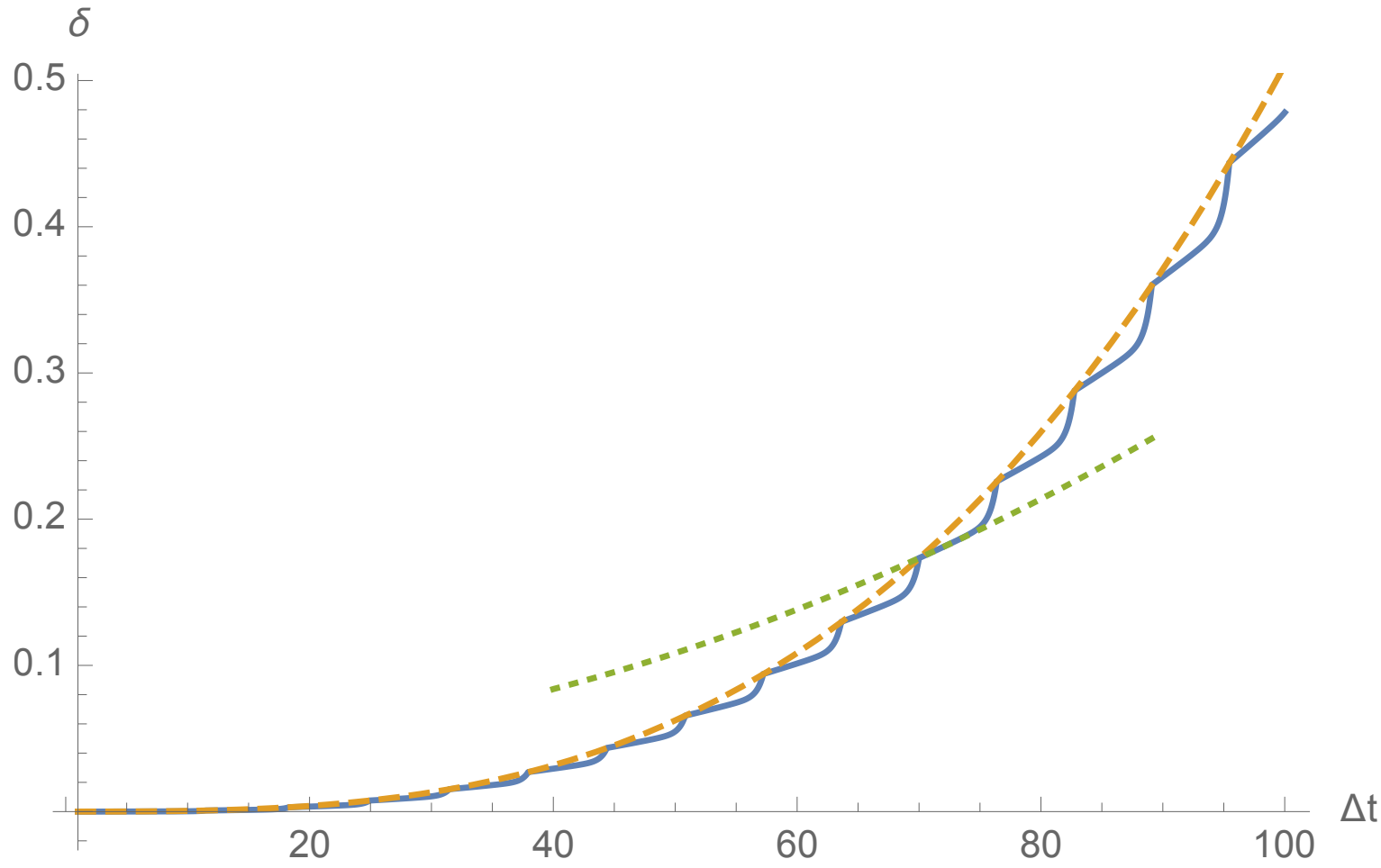
- Think of OTOC as overlap between *in*- and *out*- state

$$\mathrm{OTOC} = \langle \mathrm{out}|\mathrm{in}\rangle$$

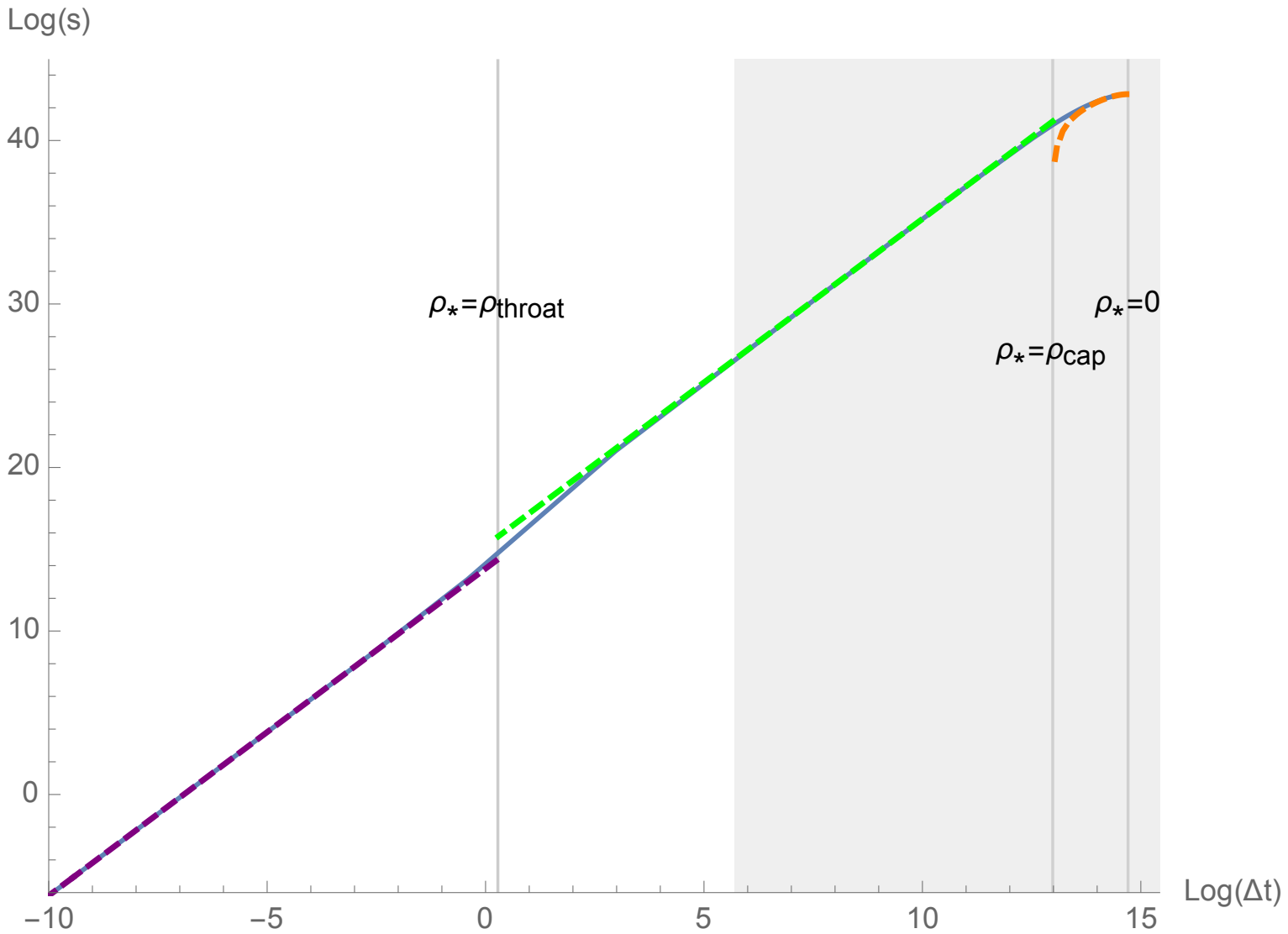
$$|\mathrm{in}\rangle = \phi_V(X_3)\phi_W(X_4)|\psi\rangle \qquad |\mathrm{out}\rangle = \phi_W(X_2)\phi_V(X_1)|\psi\rangle$$



BTZ black holes



Superstrata



Thank you for your attention!