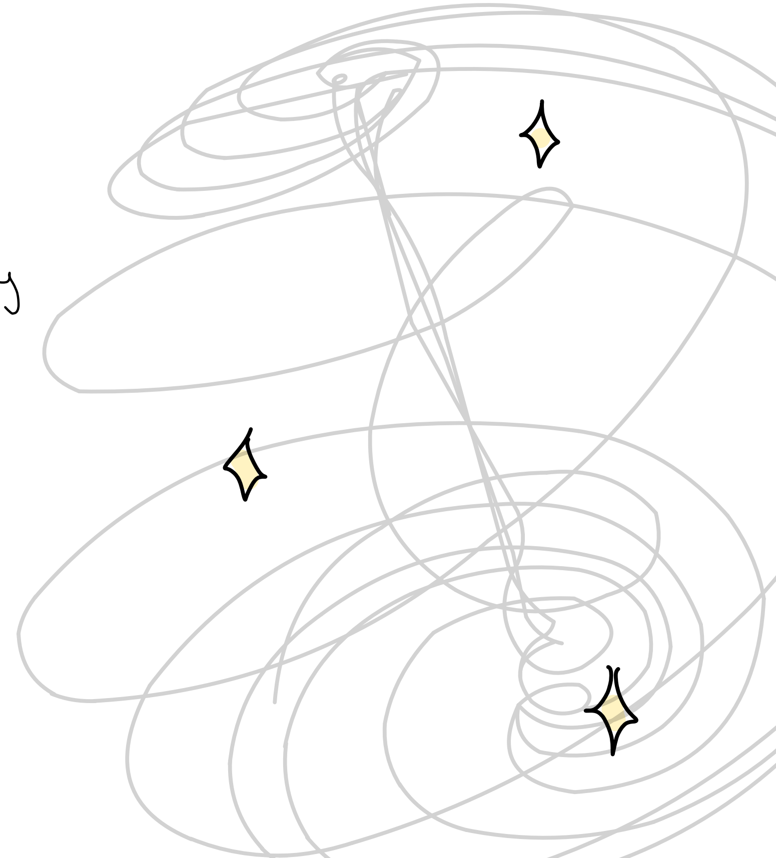
Higgs Centre Workshop Celestial Sphere: holography, CFT & amplitudes

Fun with Celestial Dressings

⟶ Harbingers of Chaos, Heralds of Symmetry

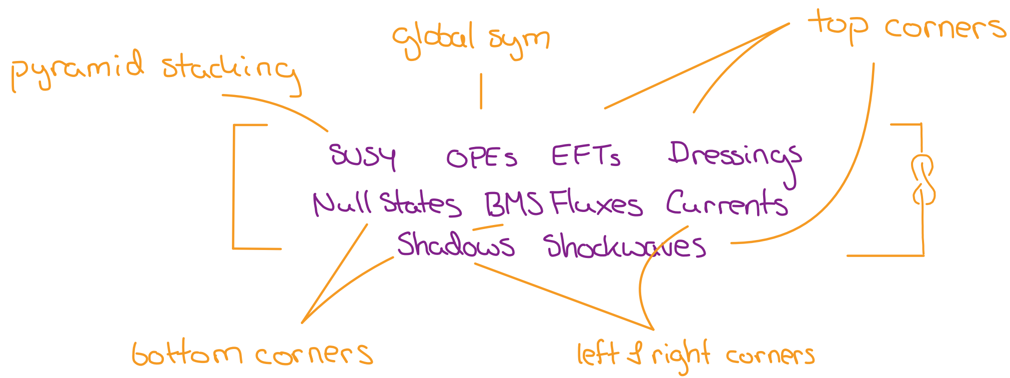


Sabrina Gonzalez Pasterski, PCTS

2012.03850 + upcoming w/ H. Verlinde

The soft sector of phase space encodes a lot!

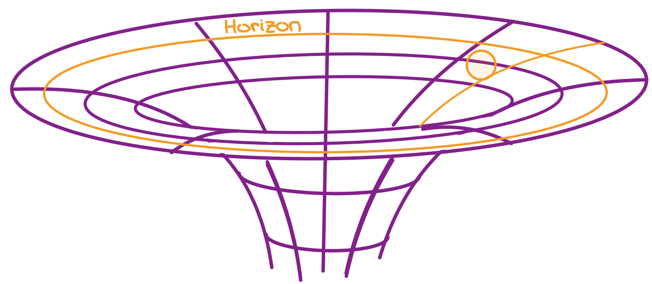
Yesterday / @ Corfu: Celestial Diamonds



We have seen how a systematic treatment of global primary descendants connects the stories of null states, conformally soft dressings, and celestial EFTs.

The soft sector of phase space encodes a lot!

Today: Revisit the HPS proposal, then merge w/ celestial perspective.



Let us now see how this merges with questions one can ask about how interesting bulk processes are encoded in CCFT.

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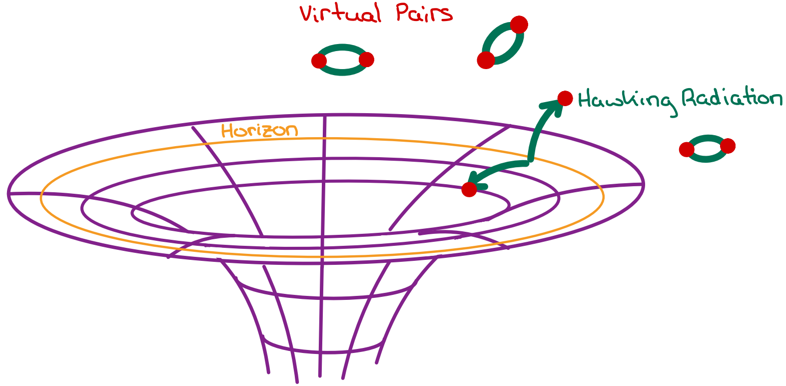

The CCFT currents correspond to symmetry enhancements in the bulk. These ∞-ly many symmetries should also constrain black hole evaporation.

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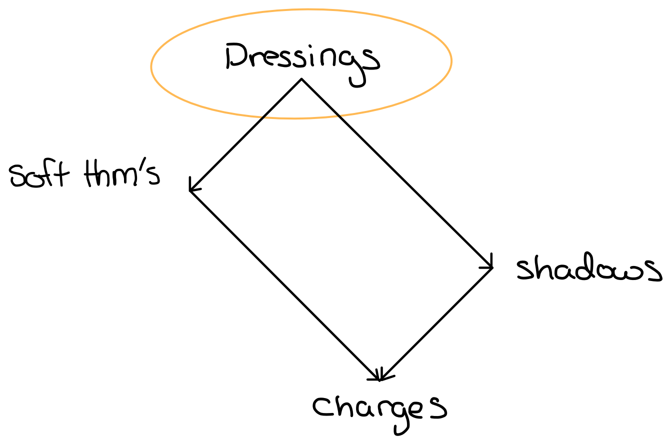
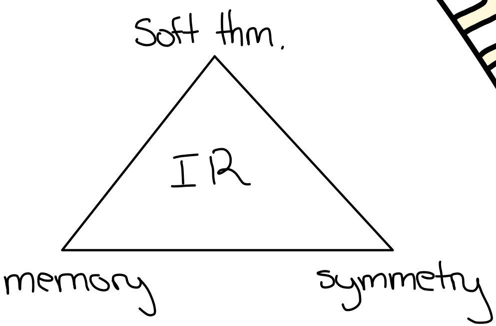
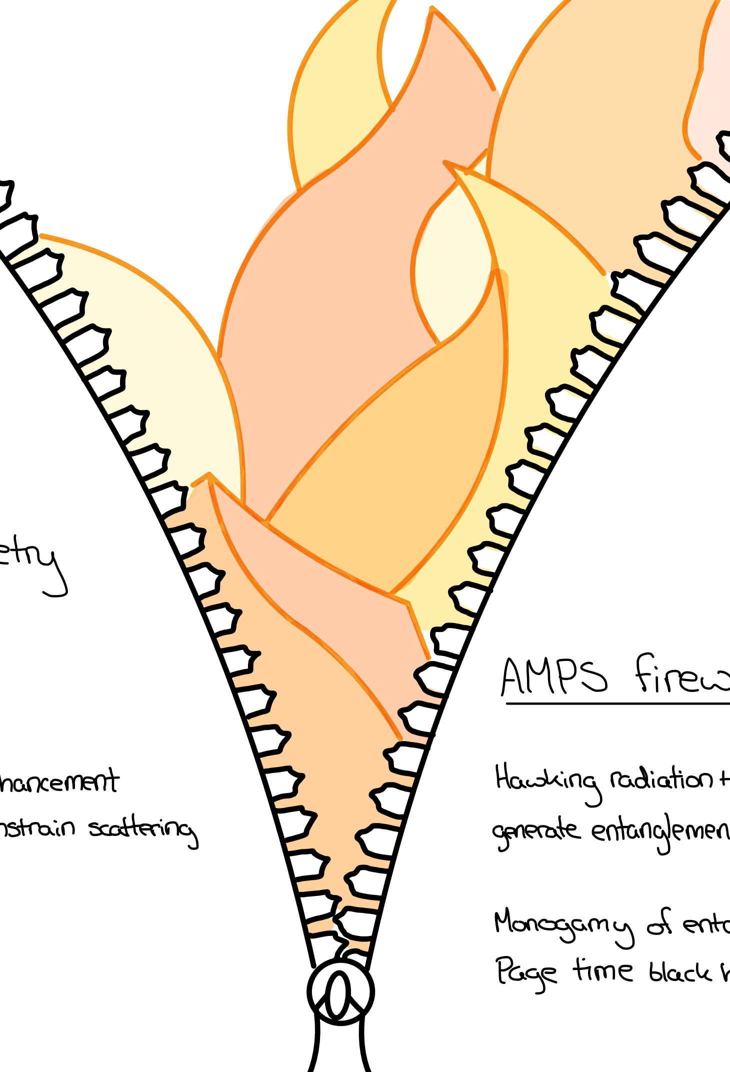


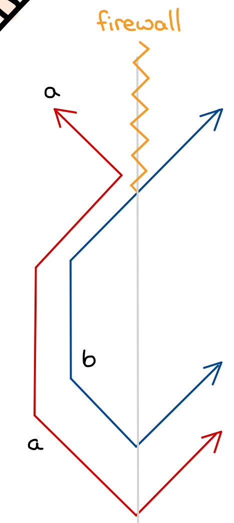
We will see that the dressings capture important aspects of the experience of an infalling observer.



HPS soft hair

IR physics points to an ∞-dim enhancement of Poincaré which should also constrain scattering in the presence of black holes.

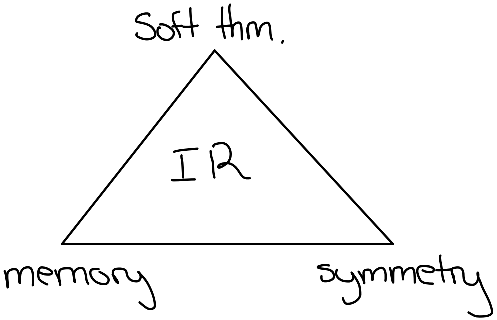




AMPS firewall paradox

Hawking radiation + smooth horizon ⇒ continue to generate entanglement

Monogamy of entanglement ⇒ entropy of post-Page time black hole should decrease.



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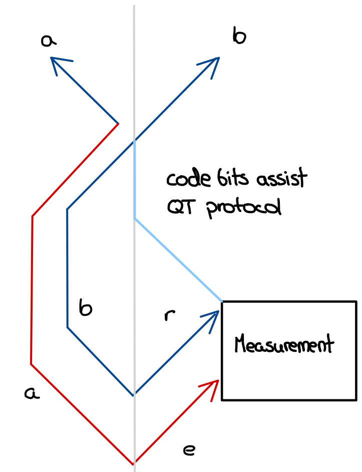

AMPS firewall paradox

Hawking radiation + smooth horizon ⇒ continue to generate entanglement

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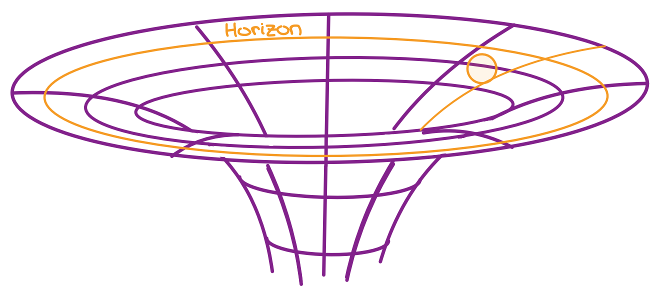
To explore how soft hair affects the experience of an infalling observer we need to

- ▷ understand the soft hair phase space
- ▷ explore the entanglement between an observer & the soft hair
- ▷ motivate that an infaller measures the soft hair
- ▷ demonstrate how to apply existing quantum circuit tech to the HPS paradigm

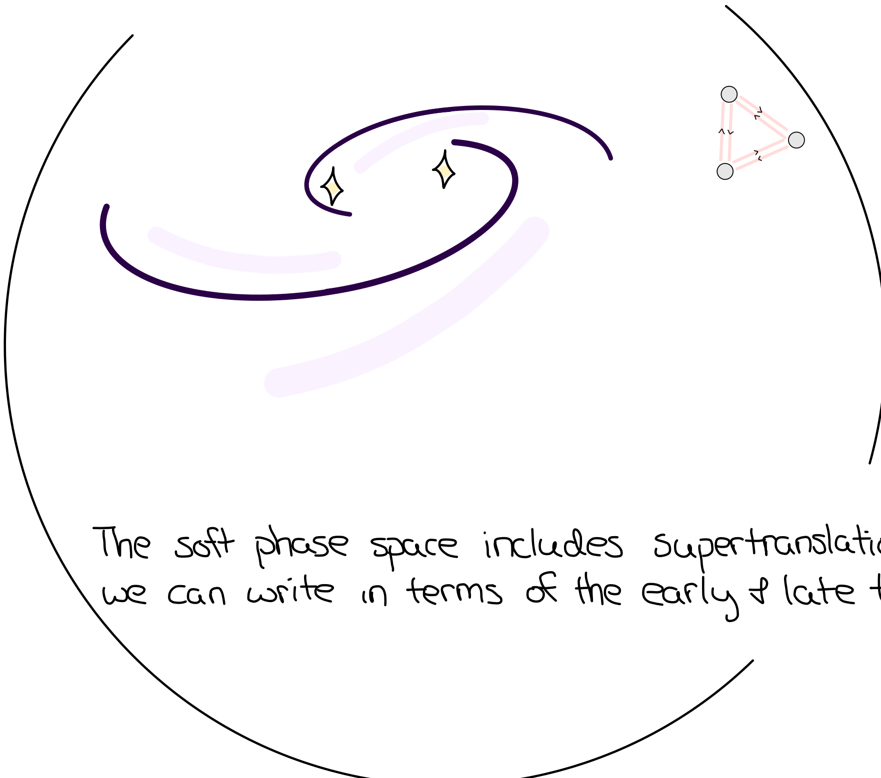


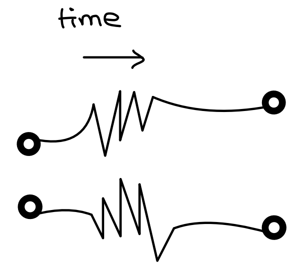
We will want to motivate and then apply the following assertions...

Soft hair degrees of freedom are

1. a classical, measureable feature of the global blackhole spacetime
2. invisible to a strictly asymptotic or near horizon observer
3. can be measured by an observer falling in from infinity
4. are exponentially sensitive probes of infalling matter
5. carry a large amount of entropy
6. are projected into a low entropy state upon measurement by an infaller
7. accumulate more entropy during the Hawking evaporation process.

Scattering processes are accompanied by radiation which induces dynamical vacuum transitions.

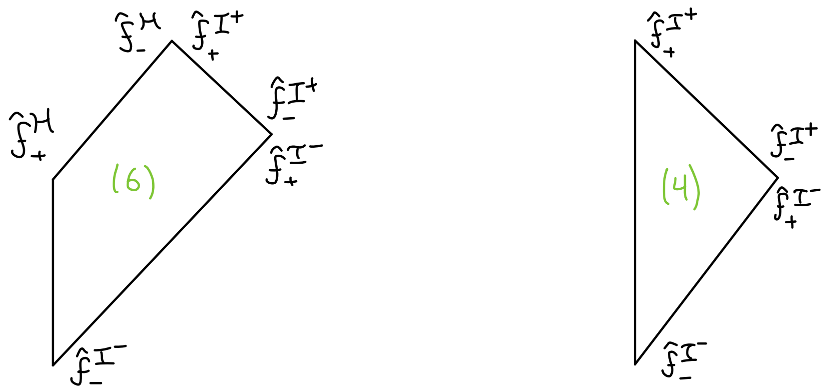




$$\Delta h_{zz} = 2r D_z^2 (\hat{f}_+ - \hat{f}_-)$$

The soft phase space includes supertranslation goldstone/memory modes which we can write in terms of the early & late time vacua.

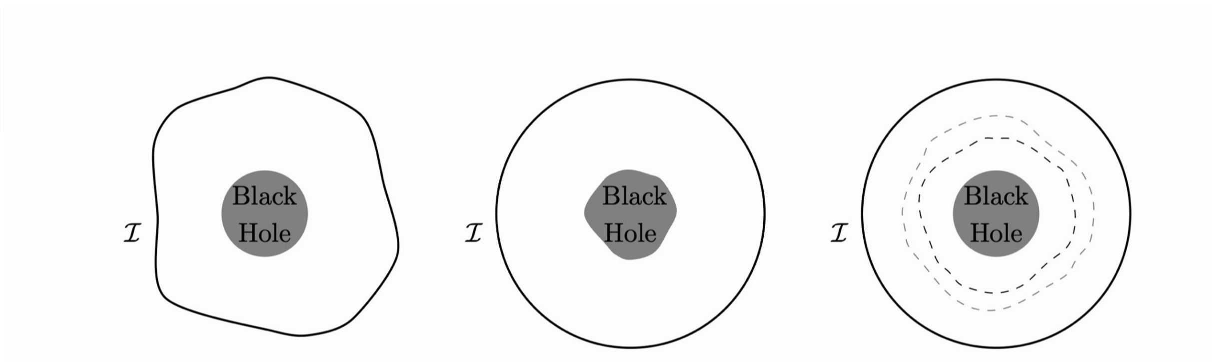
Introducing a horizon enlarges the soft sector of phase space.



(-2) BMS invariance: $\hat{f}^{\mathcal{I}^-}_{\pm} \mapsto \hat{f}^{\mathcal{I}^-}_{\pm} + f, \quad \hat{f}^{\mathcal{I}^+}_{\pm} \mapsto \hat{f}^{\mathcal{I}^+}_{\pm} + f, \quad \hat{f}^{\mathcal{H}}_{\pm} \mapsto \hat{f}^{\mathcal{H}}_{\pm} + f$

(-2) CPT invariance: $\hat{f}^{\mathcal{I}^+}_- = \hat{f}^{\mathcal{I}^-}_+$

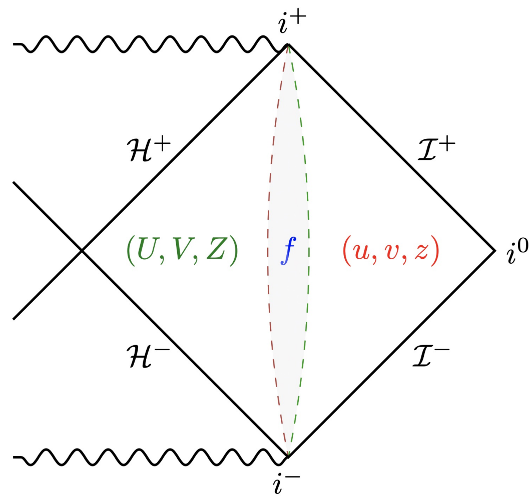
This hair is locally pure gauge but not globally.



By doing a supertranslation one can uniformize either the horizon <u>or</u> the asymptotic hair in one coordinate patch.

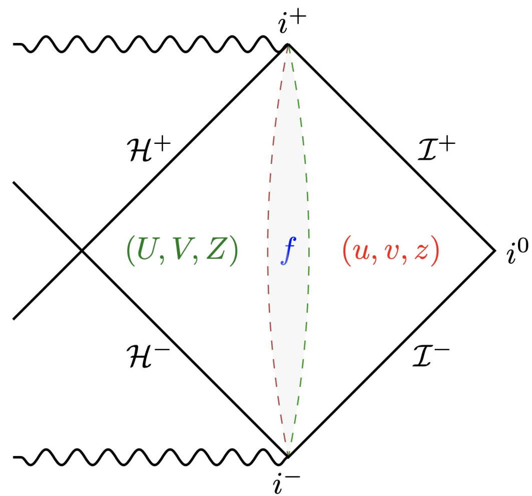
Uniformizing <u>both</u> amounts to encoding the soft hair in a transition function between the near horizon and asymptotic coordinate patches.

$$\frac{V}{4M} = e^{v/4M}\left(1+\frac{f}{4M}\right), \quad \frac{U}{4M} = -e^{-u/4M}\left(1-\frac{f}{4M}-\frac{\gamma}{4M}e^{(u-v)/4M}D^2 f\right), \quad \gamma = \frac{2M}{r}e^{r/2M}$$



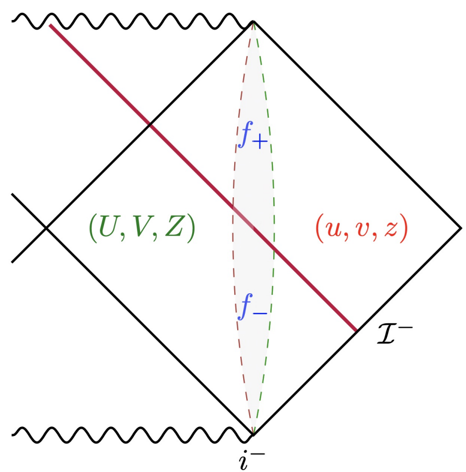
Uniformizing <u>both</u> amounts to encoding the soft hair in a transition function between the near horizon and asymptotic coordinate patches.

$$ds^2 = -\left(1-\frac{2M}{r}\right)du^2 + 2\,du\,dr + r^2\gamma_{AB}\,dz^A dz^B \qquad \xi_f = f\partial_v - \frac{1}{2}D^2 f\,\partial_r + \frac{1}{r}D^A f\,\partial_A$$



Infalling matter will implant soft hair and shift the horizon.

$$T_{vv} = \left[\frac{\mu - \frac{1}{4} D^2 (D^2 + 2) f}{4\pi r^2} + \frac{T^{(1)}}{4\pi r^3} \right] \delta(v - v_0) \qquad \Rightarrow \qquad \delta r_S = 2\mu + \frac{1}{2} D^2 f$$



Supertranslation invariance gives a Ward identity

$$\langle out | Q^+ S - S Q^- | in \rangle = 0$$

where Q^+ splits into $\mathcal{H}$ and $\mathcal{I}^+$ contributions

$$Q^+ = Q^{\mathcal{H}} + Q^{\mathcal{I}^+}$$

and further into soft and hard parts

$$Q^i = Q^i_S + Q^i_H$$

which act on different tensor factors of the Hilbert space.

The hard charges act nontrivially on the matter while the soft charge induces inhomogeneous shifts of the Goldstone mode.

$$Q_S = \frac{1}{16\pi} D^2 (D^2+2)(\hat{f}_+ - \hat{f}_-) \Rightarrow [Q_S(z), \hat{f}_\pm(z')] = i\delta^{(2)}(z-z')$$

One can construct operators invariant under supertranslations by dressing them

$$\mathcal{O}_{dress}(p,z) = \mathcal{O}_p(z) W_p(z), \qquad W_p(z) = e^{-ip\hat{f}(z)}$$

which one can conveniently implement via operator valued coordinates

$$\mathcal{O}_{in,dress}(v,z) = \mathcal{O}_{in}(\hat{v},z), \qquad \hat{v} = v - \hat{f}(z)$$

However because $[\hat{f}_+, \hat{f}_-] \neq 0$ we need to decide where the dressing should be anchored. Defining

$$\hat{v}_\pm = v - \hat{f}_\pm \qquad \hat{u}_\pm = u - \hat{f}_\pm - \gamma e^{(u-v)/4M} D^2 \hat{f}_\pm$$

We see that

$$[\hat{v}_-(z), \hat{u}_+(z')] \simeq \gamma e^{(u-v)/4M} \Lambda, \qquad (D^2+2)\Lambda(z,z') = -16\pi \delta^{(2)}(z-z')$$

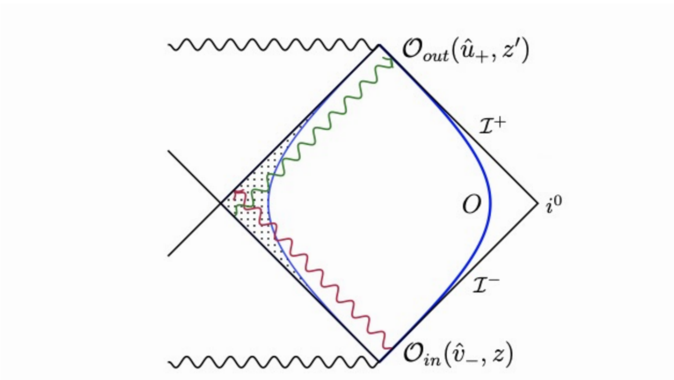
So that the dressings account for the Lyapunov behavior associated to backreaction effects.

$$\frac{\langle [\mathcal{O}_{in}(\hat{v}_-, z, \bar{z}), \mathcal{O}_{out}(\hat{u}_+, z', \bar{z}')]^2 \rangle}{\langle \mathcal{O}_{in}\mathcal{O}_{in}\rangle \langle \mathcal{O}_{out}\mathcal{O}_{out}\rangle} \simeq \gamma^2 p_{in}^2 p_{out}^2 e^{(u-v)/2M} \Lambda(z,z')$$

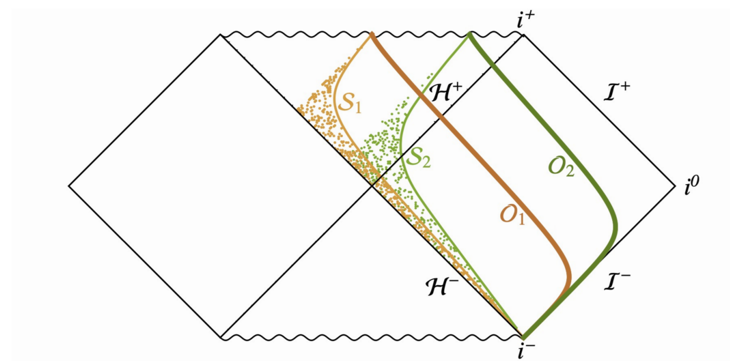
For an infalling trajectory we similarly use

$$\hat{\mathcal{O}}_{in}(\hat{v},z) = e^{-i\omega_{in}\hat{\tau}_-(v,z)}, \qquad \hat{\mathcal{O}}_{out}(\hat{u},z') = e^{-i\omega_{out}\hat{\tau}_+(u,z')}$$

and see that the stretched horizon recedes

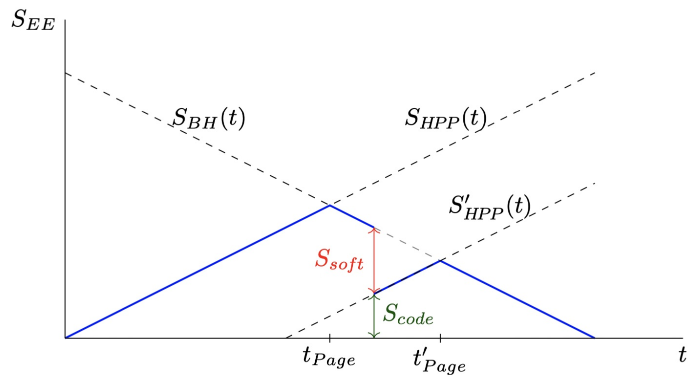


$\longrightarrow$



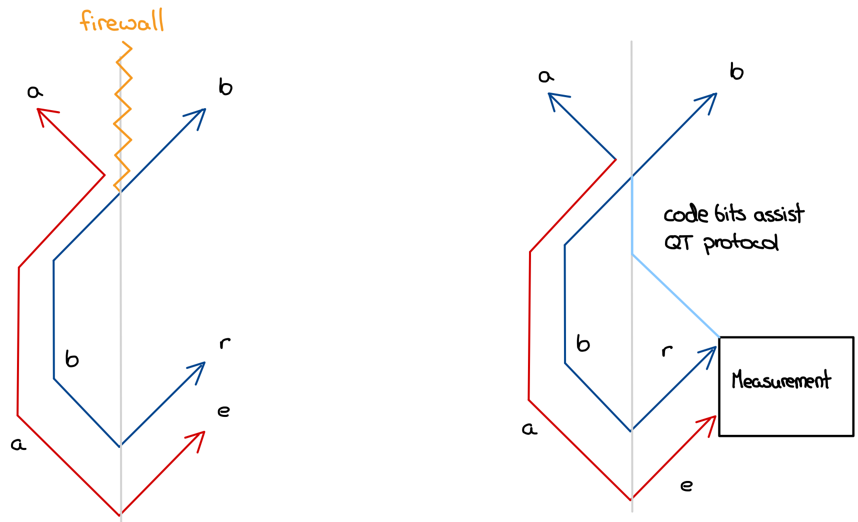
$$\frac{\langle [\mathcal{O}_{in}, \mathcal{O}_{out}]^2 \rangle}{\langle \mathcal{O}_{in}\mathcal{O}_{in}\rangle \langle \mathcal{O}_{out}\mathcal{O}_{out}\rangle} \sim 1$$

Such Lyupanov behavior has been known to catalyze a quantum-to-classical transition



If we think of the observer as making a measurement of f, this reduction in entropy allows for consistent late time evaporation.

One can then use the <u>soft/hard Hilbert space tensor product structure</u> as well as the <u>observer/soft mode entanglement structure</u> to provide an HPS interpretation of quantum teleportation protocols used to avoid firewalls.



Specifically, one can show that the late time radiation is entangled with interior modes rather than the early radiation, so that the horizon remains smooth.

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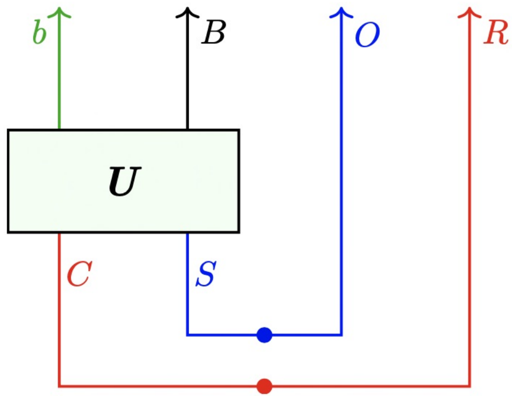

C = code subspace
S = soft hair modes
O = observer
R = early radiation
B = black hole
b = late radiation

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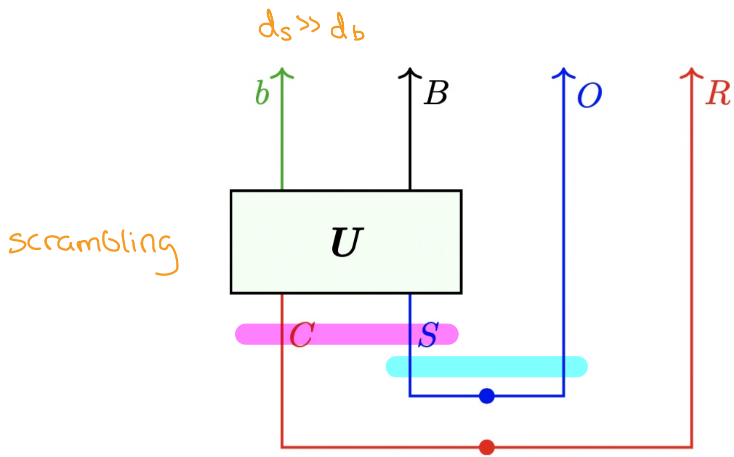

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+ Yoshida's decoupling thm

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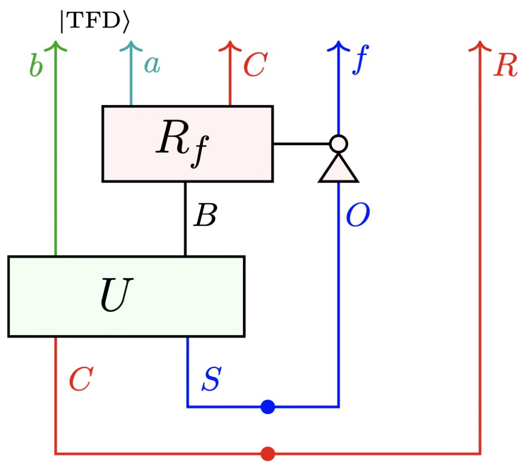

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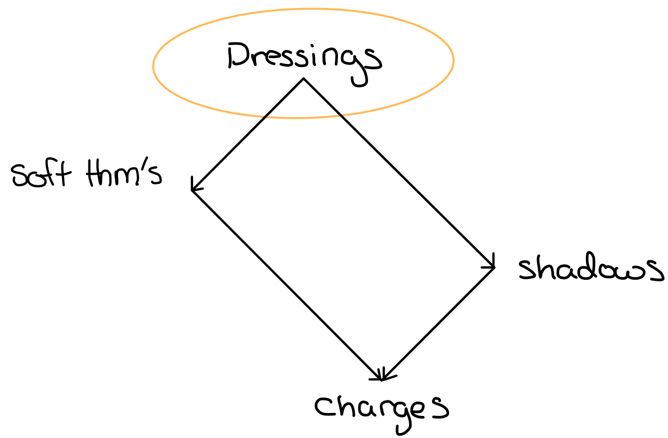
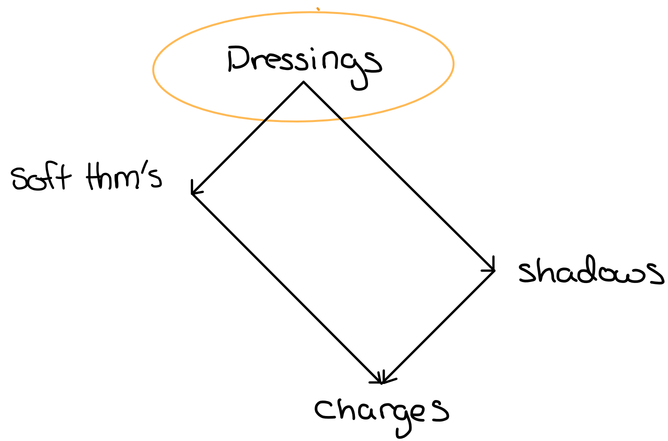
The main takeaway for today is the fact that the dressing modes capture the Lyapunov behavior, they are harbingers of chaos.

However we also know that in celestial CFT these modes live at the top of our celestial diamonds and are heralds of symmetry.



Any bulk process that can be shown to be dominated by the ASG spontaneous symmetry breaking dynamics should be captured by the 2D EFTs for the conformally soft sector.



Thank You!