# Questions for Black Hole evaporation from Quantum Statistical Mechanics

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Black Hole Initiative, May 9th 2017

# Thermally Typical Black Holes

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  - AdS/CFT

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- Black hole radiation is ordinary thermal radiation from this stretched horizon
- Late-time radiation is entangled with early-time radiation (just as in ordinary thermal cooling) so that evolution remains unitary

# Atmosphere of a black hole

# Quantum mechanics of the interior

Penrose diagram for gravitational collapse (Heisenberg picture)

# Black hole complementarity

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- Most obvious interpretation: degrees of freedom on the stretched horizon (holography again)
- The **AMPS paradox** (Almheiri, Marolf, Polchinski, Sully): someone falling into black hole at sufficiently late times can see both copies of the quantum state

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- Natural consequence of no entanglement between interior/exterior
- Some evidence that firewalls are typical in AdS black holes (Marulf/Wolf)

# Why not firewalls?

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- Physics just outside horizon seems perfectly well-behaved (and horizons aren't even local)

# Choice of exterior quantum state

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**Singular on past and future horizons**

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Unruh vacuum – static observers see outgoing radiation at the Hawking temperature. **Singular on past horizon, regular on future**

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Hartle-Hawking "vacuum" – static observers see outgoing and incoming radiation at the Hawking temperature

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**Regular on both horizons**

# Form of horizon singularity

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- “Lenny Susskind has emphasized to me however that one can attempt a “strictly exterior” calculation of the entropy and temperature by arguing that quantum fields outside the horizon have a large backreaction in the Schwarzschild geometry if we put them at a temperature other than $T_H$ … if we are willing to allow large backreaction right at the horizon in the form of a firewall, why shouldn’t we also allow it further out in the atmosphere?” (Harlow, arXiv:1409.1231v4)

# Form of horizon singularity

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- Answer (I take it): we need self-consistency. We must have

$$G_{ab} = 8 \pi G \langle T_{ab} \rangle$$

at least approximately

(There might be *other* quantum objects which deviate from Schwarzschild metric far from horizon, but we're interested in *these* objects)

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- Entropy of a solar-mass black hole: $\sim 10^{77}$ J/K
- Number of (orthogonal) microstates of microstate with entropy S is $\exp(k_B S)$
- So black holes produced through astrophysical collapse processes are *highly atypical* from a statistical-mechanics viewpoint

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- Seal in a box of radiation at just slightly higher temperature
- Continuously expand the box and lower the temperature, keeping it *just above* the black hole temperature
- When you get bored, adjust the temperature to *just below* the black hole temperature
- Continuously contract the box and raise the temperature, keeping it *just below* the black hole temperature

# Typical black hole spacetime?

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- Within-horizon region already unpredictable?
- Further timelike singularities needed to close interior?

# Typical black hole spacetime

- No interior?

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- For *thermally typical* black holes (but not astrophysical ones) it's somewhat mysterious how to fill in the interior *without* firewalls
- Gives some tentative support to interior-reconstruction scenarios that work only in atypical cases