Equating evaporating black holes to collapsing wave functions

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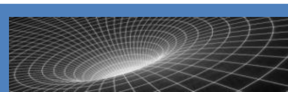
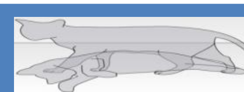
Physically expected similarities between the two scenarios		
Apparent loss of information	Black holes look as if they lose their information by Hawking radiation during their evaporation.	Wave functions lose their information when collapsing to one of the eigenstates, since all information on the original function is lost during a measurement.
Apparent action at a distance	Black holes look as if they act at a distance since they must connect Hawking radiation at infinity to the interior of the black hole in order for the black hole to be able to evaporate after Page time.	Wave functions look as if they act at a distance whenever a collapse takes place since we expect a wave function to collapse all at once for all the points in the universe.
"Decoherence"	Non-observable decoherence when black holes evaporate	Observable decoherence when wave functions collapse.

The general and future goal: Use the apparent correspondence in order to understand the origin of their (similar) mysteries and unique physical behavior.

The simpler and present goal: Use the apparent correspondence in order to obtain the condition for the evolution of a density matrix of the Hartle-Hawking state to one of the superselection sectors.

Constructing the correspondence

1. Choose a model for Hartle-Hawking state and obtain the Hartle-Hawking state density matrix
2. Derive Hartle-Hawking "evolution" equation along a parameter of the theory
3. Choose a model for quantum collapse with similar mathematical properties
4. Equate both evolution rates in theire unitless form and obtain the condition for them to be the same

Model for Hartle-Hawking state

The Hilbert space interpretation for Baby universe considers states as closed 'baby' universes which propagate between distinct asymptotic boundaries.
A state with no-boundaries is a Hartle-Hawking state.
The baby universe Hilbert space can be constructed by acting on a state with no-boundaries with boundary creation operators.

Marolf-Maxfield model (Marolf Maxfield 2020)
Considered a simple 2D topological model of the bulk with asymptotically AdS Hilbert space. Characterize the state **|Z=d⟩** *as* a spacetime with **d** connected components. Define an annihilation operator ***a*** *and* obtained a Hartle-Hawking state as function of a parameter λ :

$$|HH\rangle = e^{\sqrt{\lambda}a^{\dagger}}\,|Z=0\rangle\,.$$

Topological fluctuations can not lead to an observable loss of quantum coherence

Model for spontaneous collapse theory

The Schrödinger equation is supplemented with additional nonlinear terms which localize the wave function in space.

Lindblad equation:
$$\frac{\partial}{\partial t}\rho(t) = -\frac{i}{\hbar}[H,\rho(t)] - \frac{\lambda}{2}[A,[A,\rho(t)]]$$

Lindblad equation leads to an observable decoherence.

Bonifacio model (Bonifacio 1999)
Instead of the continuous unitary evolution of the density matrix, assume a change of the system occurs with a Poisson distribution *as n* random time shifts by τ_0 lead to a total time shift of τ .

$$\frac{\partial}{\partial t}\rho(t) = \frac{1}{\tau_0}\left(exp(-\frac{i}{\hbar}H\tau_0)\rho(t)exp(\frac{i}{\hbar}H\tau_0) - \rho(t)\right)$$

Bonifacio model does not lead to an observable decoherence.

CONCLUSION:

The condition for an evolution of the density matrix of the Hartle-Hawking state in Marolf-Maxfield model to one of the superselection sectors is

$$exp(-iB)\,|Z=n\rangle\,\langle Z=m|\,exp(iB) = \quad (|Z=n+1\rangle\,\langle Z=m| + |Z=n\rangle\,\langle Z=m+1|)$$

where B is a generator of the parameter λ in the theory.