What if information is really destroyed by black holes – i.e., ends up in a baby universe?

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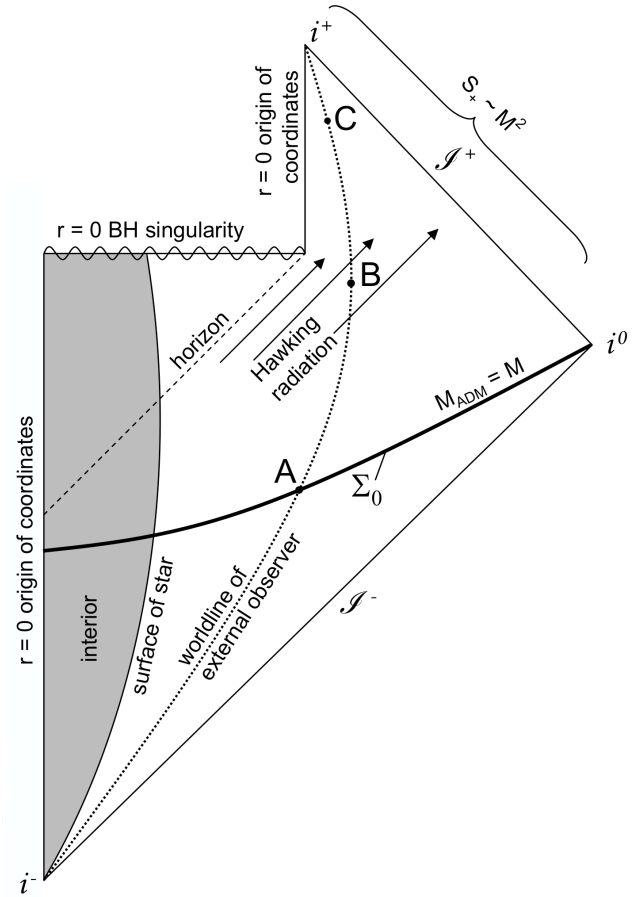
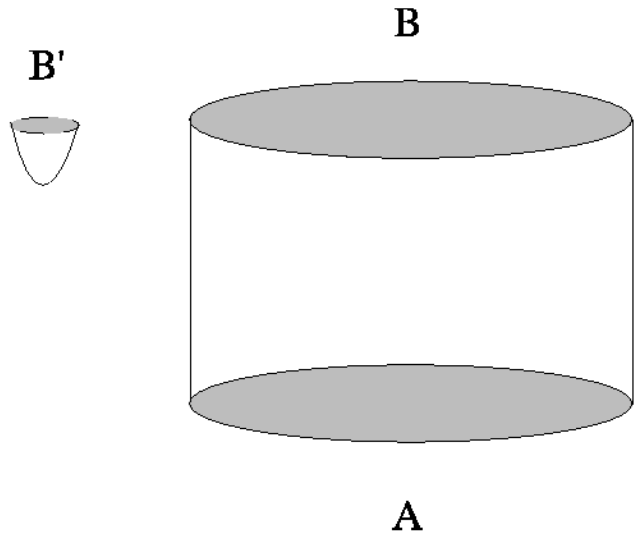
Gone forever?

Suppose: no remnants, not encoded in Hawking radiation.
Information leaves our universe and ends up somewhere else.

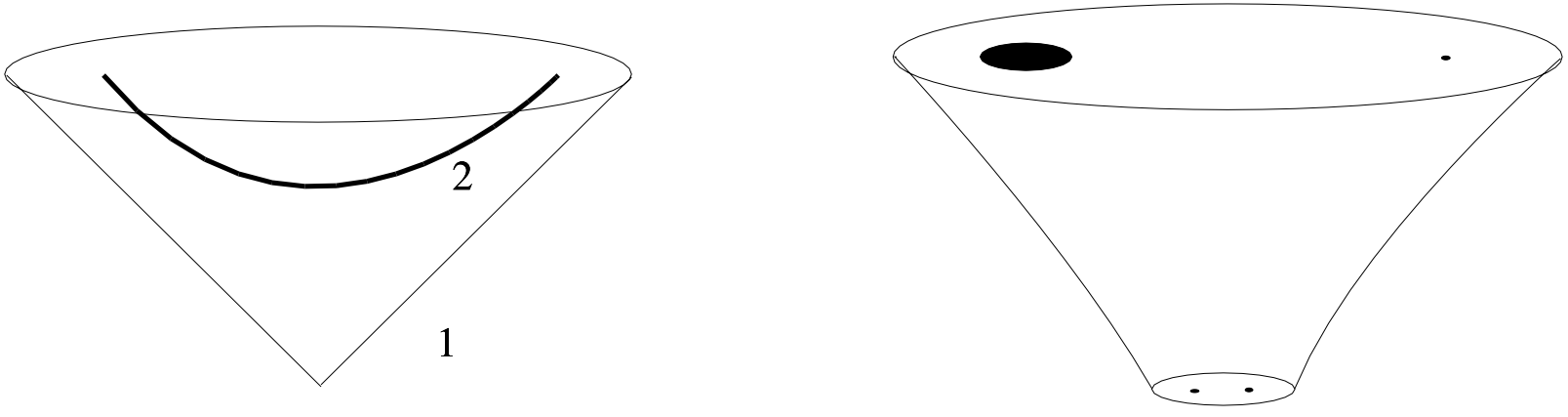




But, wavefunction evolution: $A \to B \cup B'$ is unitary.

Pure to Mixed state evolution

Violations of energy conservation? Suggested by Banks, Peskin, Susskind 1984 – studied dynamical systems with pure to mixed evolution.

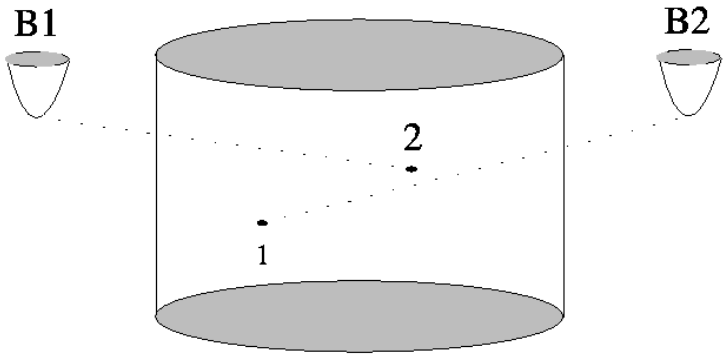


Happens all the time: correlations with dof that have left our local region → partial trace on density matrix. Pure → Mixed.

Decoherence and wavefunction collapse.

Cluster decomposition 1

Black hole processes at spacelike separated points 1 & 2 may display acausal correlations (Susskind 1994). Generic consequence of topology change?



Trace over B1 and B2 states leads to density matrix with 1-2 correlations.

But correlations are typically exponentially small.

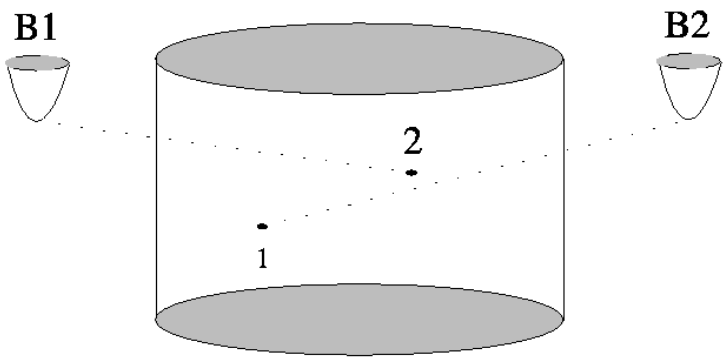
$$\rho = \sum_{B1B2} S(1|1'B1)S^*(1|1''B1)\, S(2|2'B2)S^*(2|2''B2)$$

$$\pm\ S(1|1'B1)S^*(2|2''B1)\, S(2|2'B2)S^*(1|1''B2)$$

Cluster decomposition 2

pure state:

$$|12\rangle\langle 12| \;\rightarrow\; \sum_{\mathrm{f,f'}} S(12|f)\; S^*(12|f')\; |f\rangle\langle f'|$$



$f = 1', 2'; B1, B2 \quad f' = 1'', 2''; B1, B2$

Trace over B1 and B2 states leads to density matrix with 1-2 correlations.

$$\rho \;=\; \sum_{B1B2} S(1|1'B1)S^*(1|1''B1)\; S(2|2'B2)S^*(2|2''B2)$$

$$\pm\; S(1|1'B1)S^*(2|2''B1)\; S(2|2'B2)S^*(1|1''B2)$$

AdS/CFT

Information loss to baby universes would imply pure to mixed evolution in the parent universe. But there does not seem to be any evidence of non-unitary development in the boundary CFT.

If the parent and baby universes are both described by the CFT, then the latter would have to exhibit scattering processes in which some subset of degrees of freedom largely decouple from (stop interacting with) the rest of the universe after scattering.

OK, suppose it comes back out... (unitarity)

There exist classical initial data in GR with entropy much larger than a black hole of equal ADM mass.

If BH evaporation is unitary, such configurations would have to be excised from the Hilbert space of quantum gravity. There are not enough Hawking radiation states for a 1-1 map.

Sorkin, Wald & Zhang 1981
Hsu & Reeb 2007,2008