

Do Black Holes Create Polyamory?

1506.07133 w/ Grudka, Hall, Horodecki^{⊗2}, Smolin

1401.1523
(JHEP)

An alternative Amps experiment
w/ B. Unruh

0902.2361
(ask for v2)

Fundamental information
Destruction w/ B. Reznik

J. Oppenheim (University College London)



Jonathan Oppenheim

@postquantum

I thought they were the same thing?

Graeme Smith @quantum_graeme

#Quantum Info people: @Harvard seeks postdoc candidates good at both black hole physics and philosophy.

cfa.harvard.edu/events/2016/BH...

RETWEET

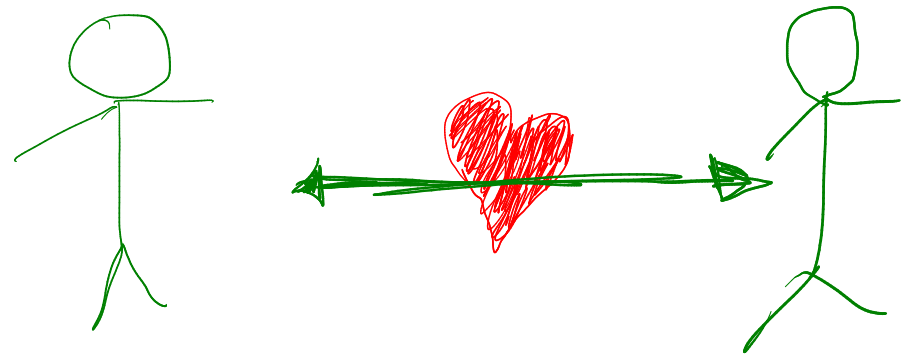
1

LIKES

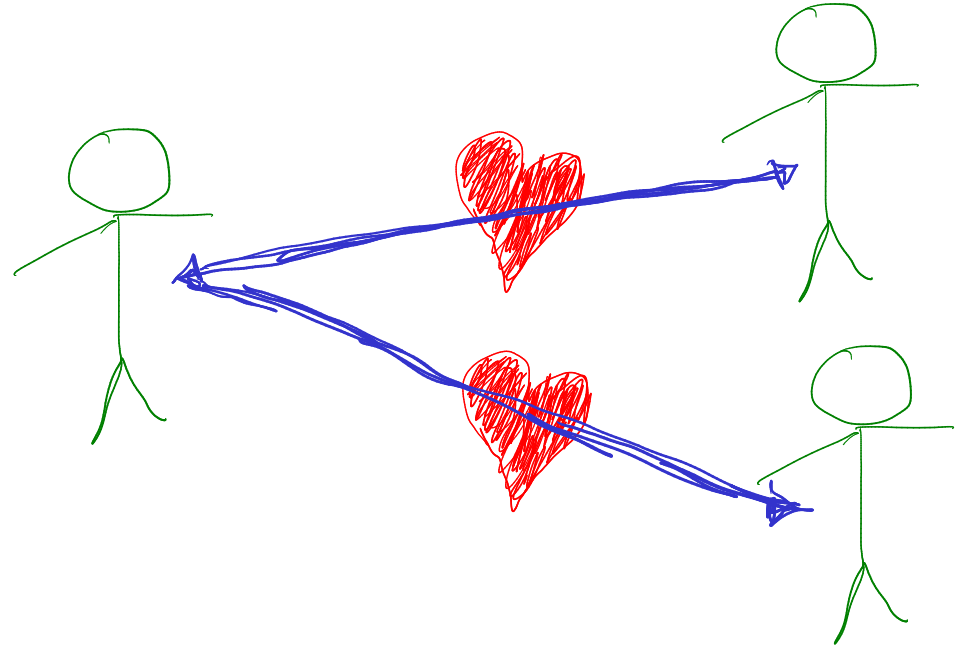
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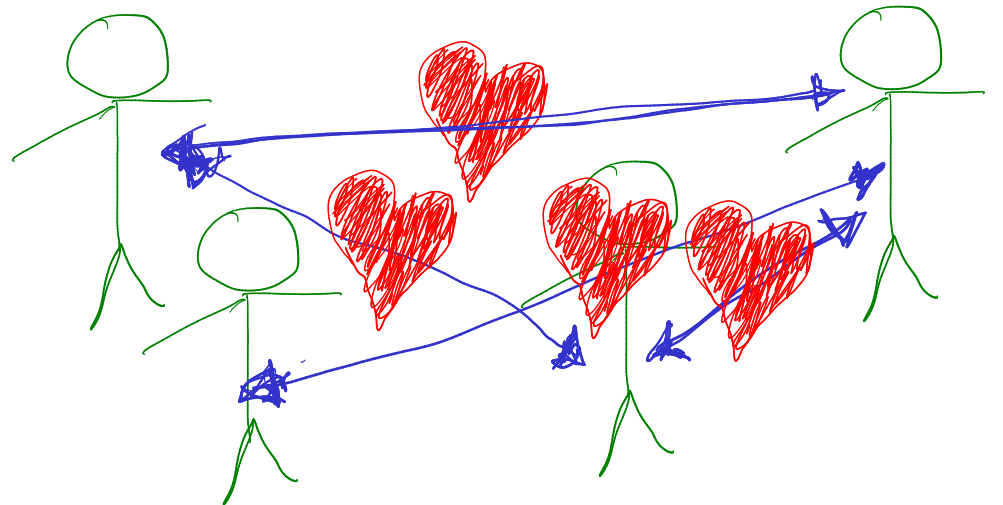
Monogamy



Polygamy



Polyamory



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Fundamental information
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Almheiri, Marolf, Polchinski, Sully JHEP 2013:2 (2013)

Horowitz, Maldacena JHEP 402 08 (2004)

Preskill, Lloyd JHEP 08 126 (2014)

Of Course Not!

- Black hole information problem v2
- Monogamy
- Black holes destroy information or create polyamory
- But we can choose it to be Polyamory "in time"

take home messages

- 1) local / planck scale modification
to quantum theory
+
entanglement
=
long distance modification
to causal structure
- 2) Entanglement in time

Quantum Information meets Quantum Gravity

• no cloning!

$$\langle \psi \rangle |0\rangle \rightarrow \langle \psi \rangle | \psi \rangle$$

• entanglement is monogamous

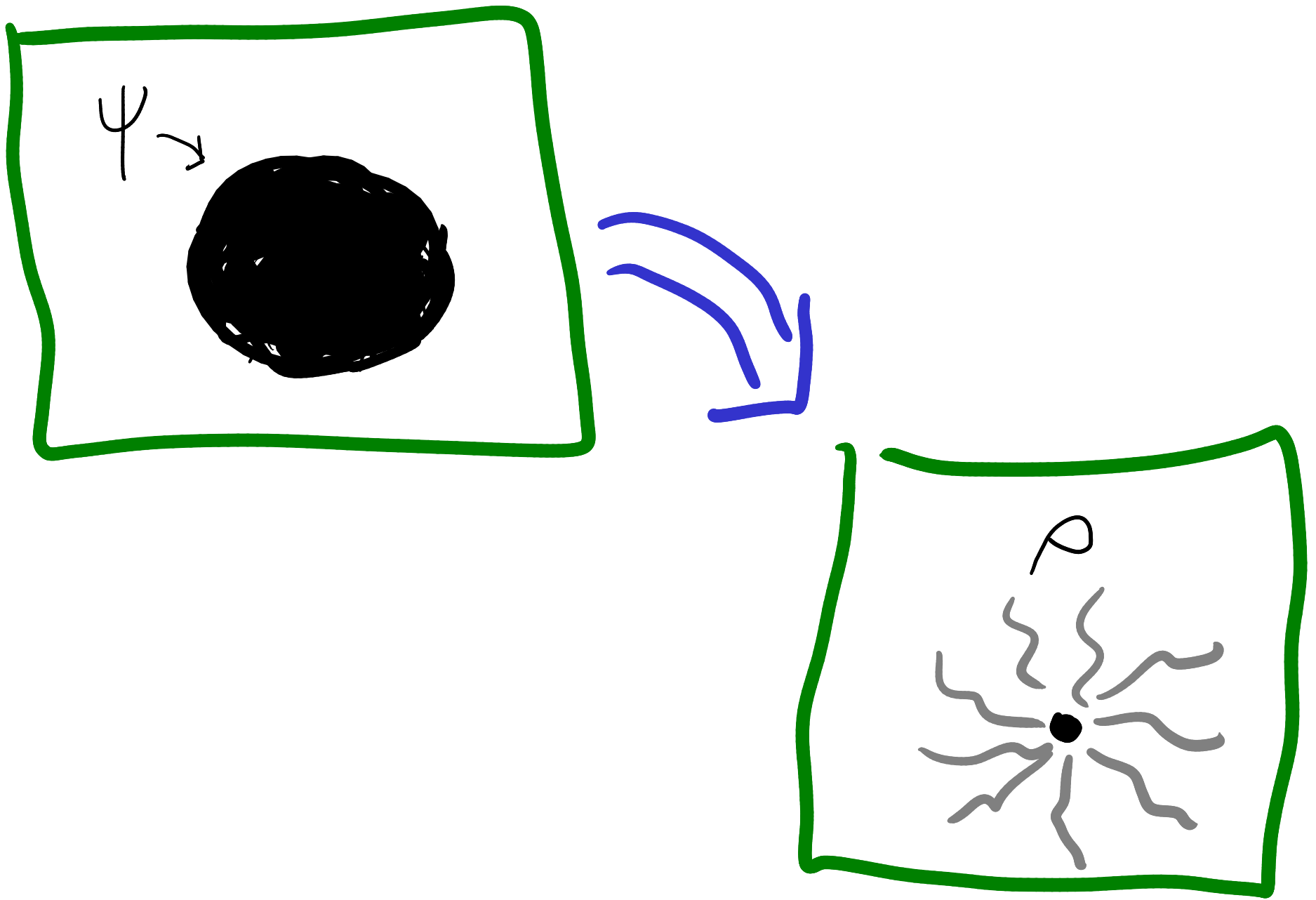
$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}} [|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle]_{AB}$$

correlated
pure

$$|\psi\rangle_{ABE} = |\psi\rangle_{AB} |0\rangle_E$$

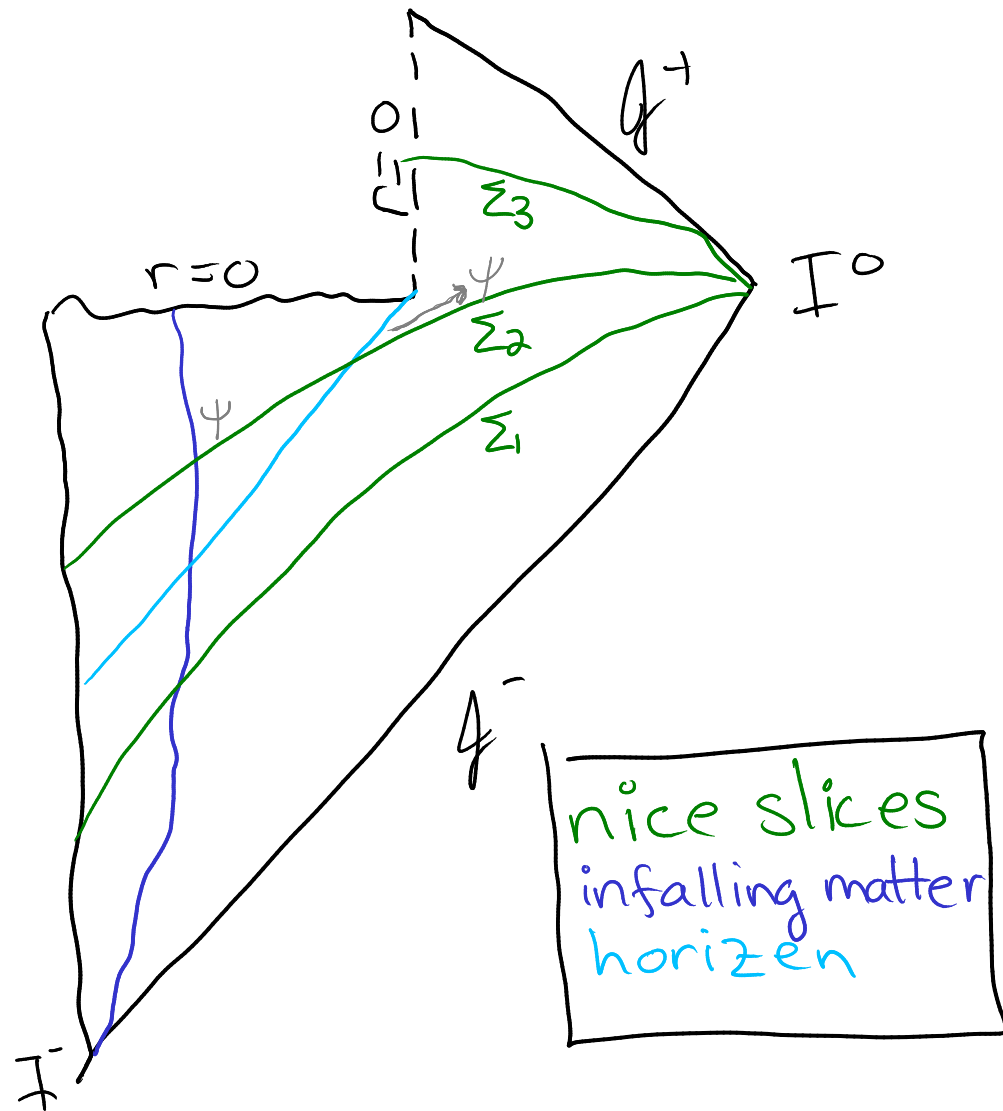
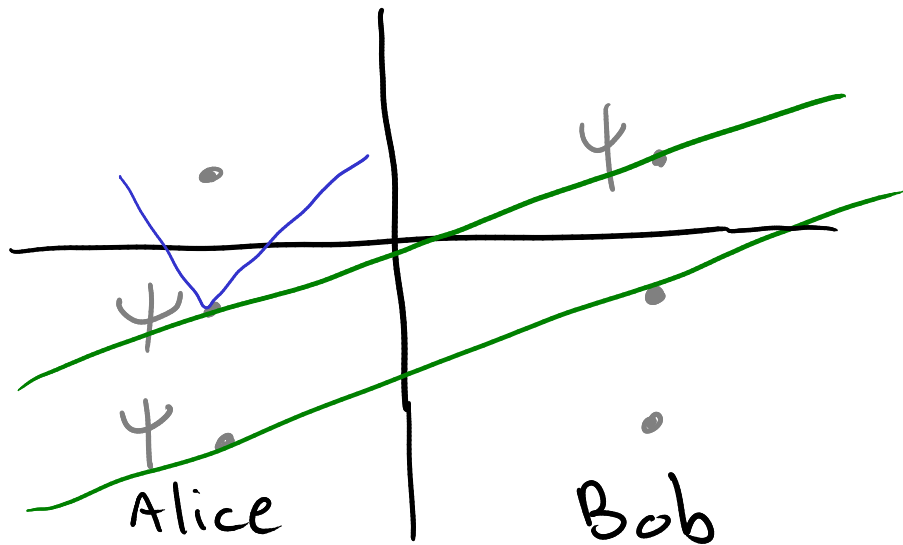
$$\sigma_{\text{classical}} = \frac{1}{2} |\uparrow\uparrow\rangle \langle \uparrow\uparrow|_{AB} + \frac{1}{2} |\downarrow\downarrow\rangle \langle \downarrow\downarrow|_{AB}$$

$$\sigma_{ABE} = \frac{1}{2} |\uparrow\uparrow\uparrow\rangle \langle \uparrow\uparrow\uparrow|_{ABE} + \frac{1}{2} |\downarrow\downarrow\downarrow\rangle \langle \downarrow\downarrow\downarrow|_{ABE}$$



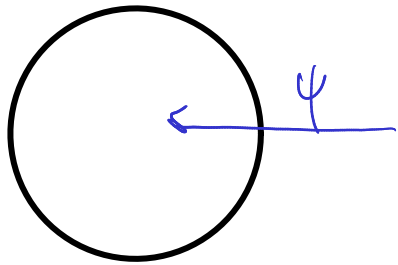
Black hole info loss v1.0

Either information is destroyed in which case, the evolution is non-unitary, or information comes out, in which case it is "cloned", and the evolution must be non-unitary.

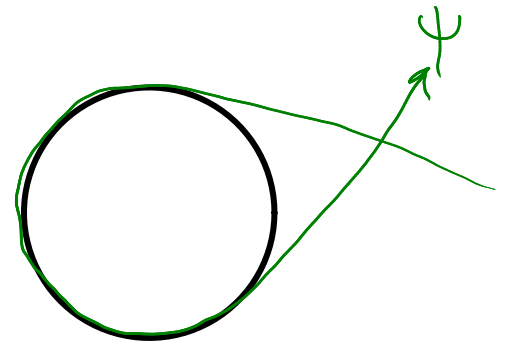


Black hole complementarity

One way out is to reject the idea that there exists a simultaneous description of the inside and outside of the black hole.



infalling observer

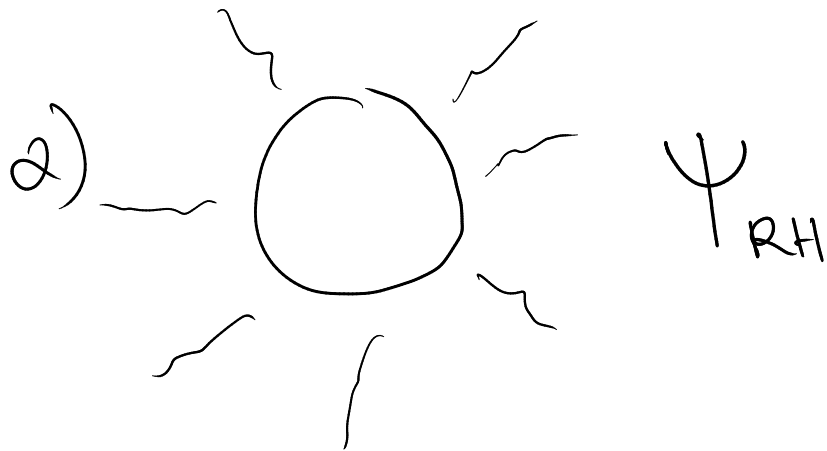
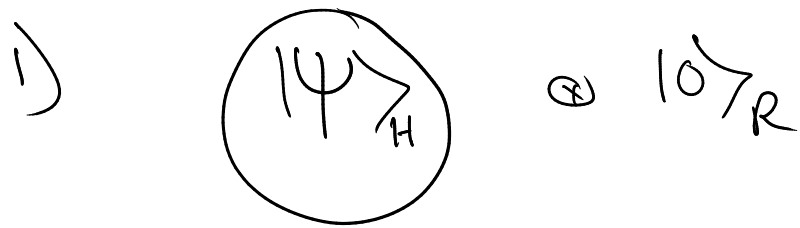


outside observer

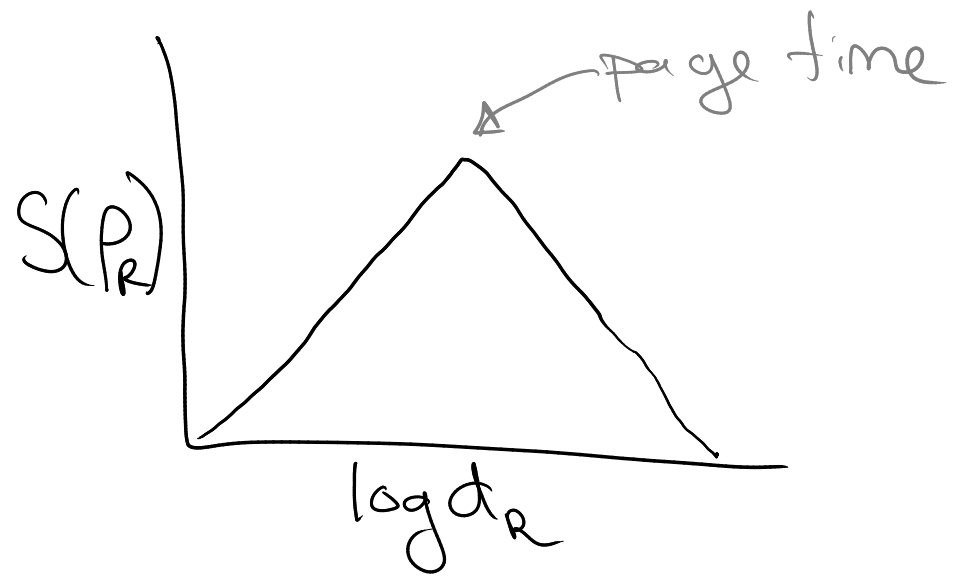
there is only a contradiction if the outside observer can collect the outgoing radiation to recover ψ and then jump into the black hole to get ψ

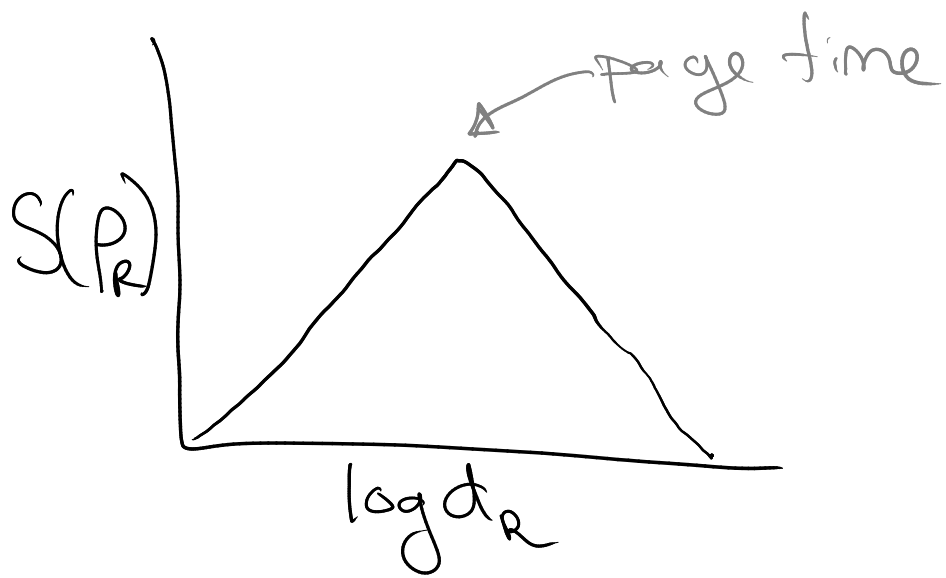
Black hole information problem v2

AMPS: Almheiri, Marolf, Polchinski, Sully
or modification due to J.O., Unruh (2014)



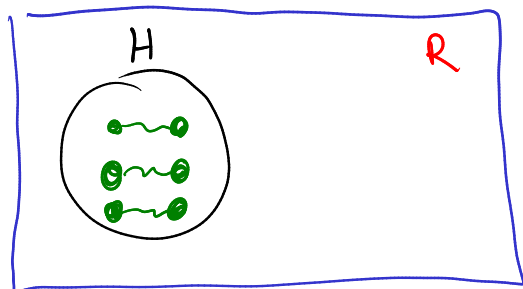
3) After the page time, each subsequent emitted photon B is entangled with R



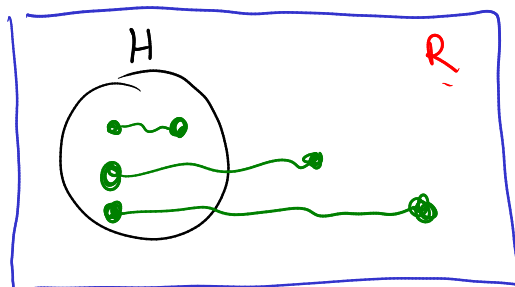


After which each late time photon is entangled with an early time one.

①

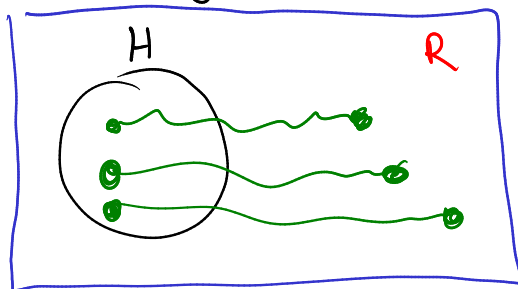


②

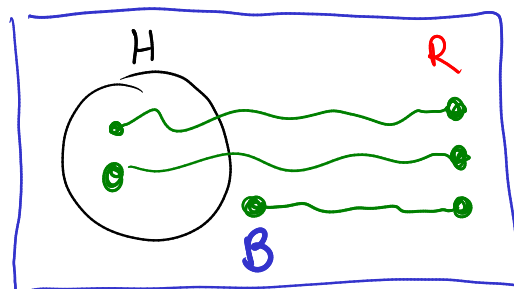


Page Time

③

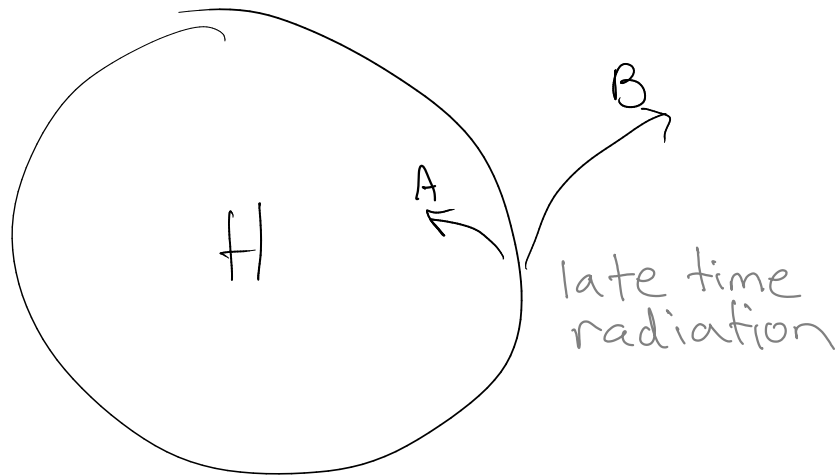


④



BR entangled (unitarity)

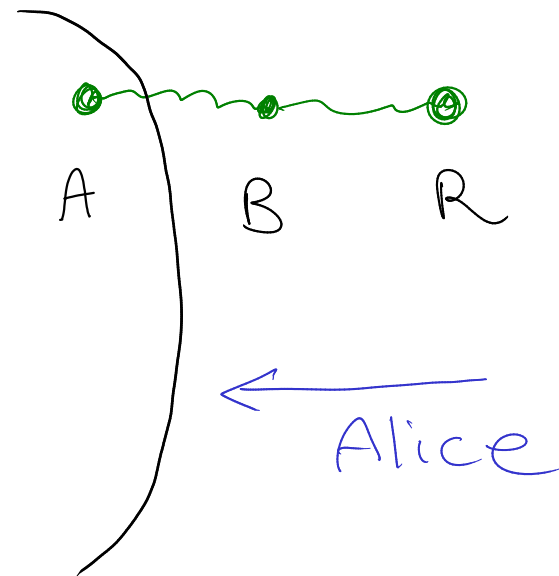
but BA entangled (Hawking pair-creation)



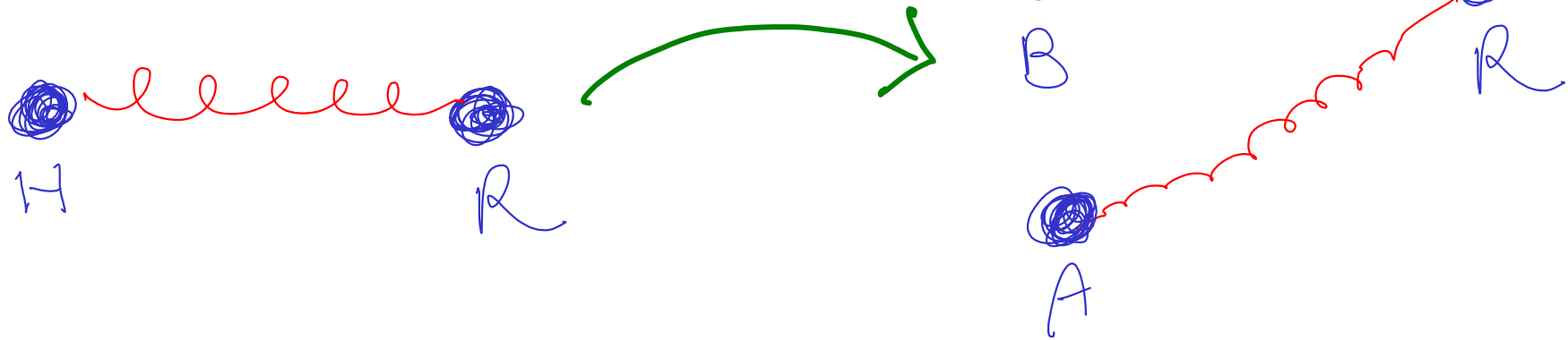
R
early
radiation

Ψ_{BR} max. entangled

Ψ_{BA} max. entangled



Cloning → Polyamory

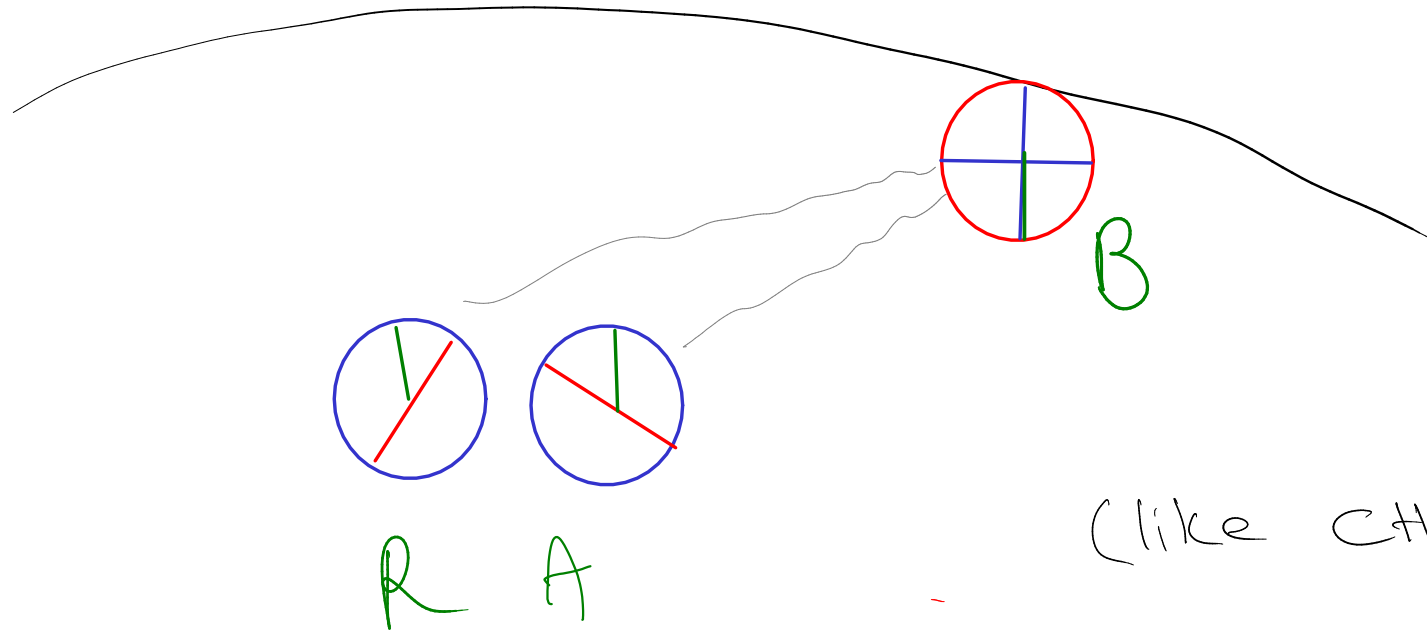


→ tachyons

complementarity can't save us

- 1) Non-monogamy implies info. destruction
 - a) Non-monogamy implies instantaneous signals
 - b) instantaneous signals implies CTC's
 - c) CTC's imply info. destruction

a) non-monogamy \rightarrow instantaneous signalling



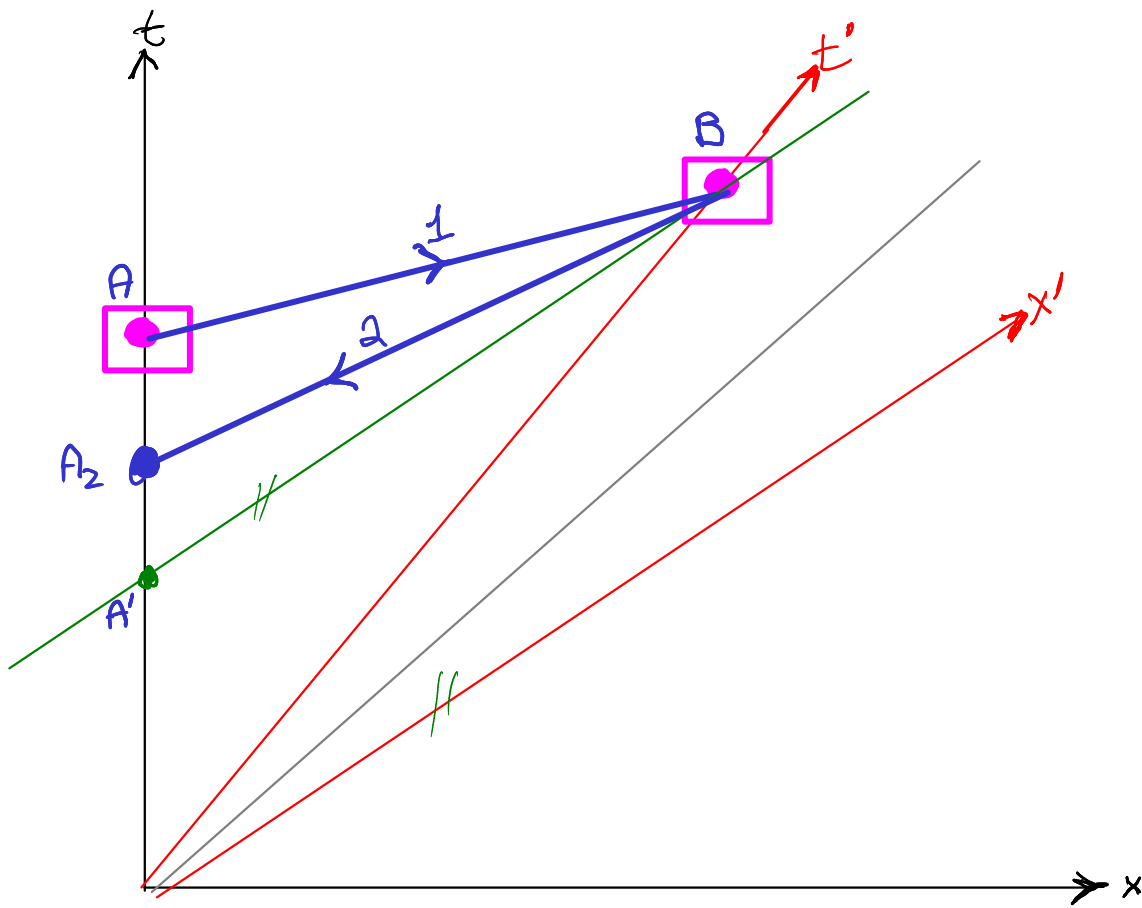
B measure σ_z to send a 0 $\rho_{RA}^0 = \frac{1}{2} |00\rangle\langle 00| + \frac{1}{2} |11\rangle\langle 11|$

measures σ_x to send a 1 $\rho_{RA}^1 = \frac{1}{2} |++\rangle\langle ++| + \frac{1}{2} |--\rangle\langle --|$

ρ_{RA}^0 | ρ_{RA}^1 are distinguishable with $P = 3/4$

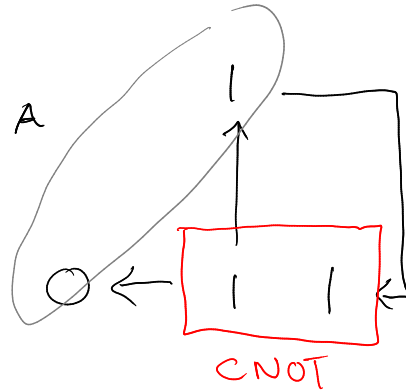
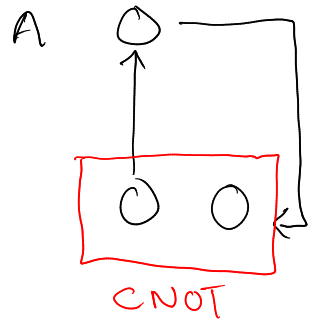
b) Superluminal signalling \rightarrow CTC's

Tolman telephone to your past



c) CTC \rightarrow information loss

Cnot your past controlled on your future



$$|\Phi\rangle_{RA} = \frac{1}{\sqrt{2}} [|00\rangle + |11\rangle]$$

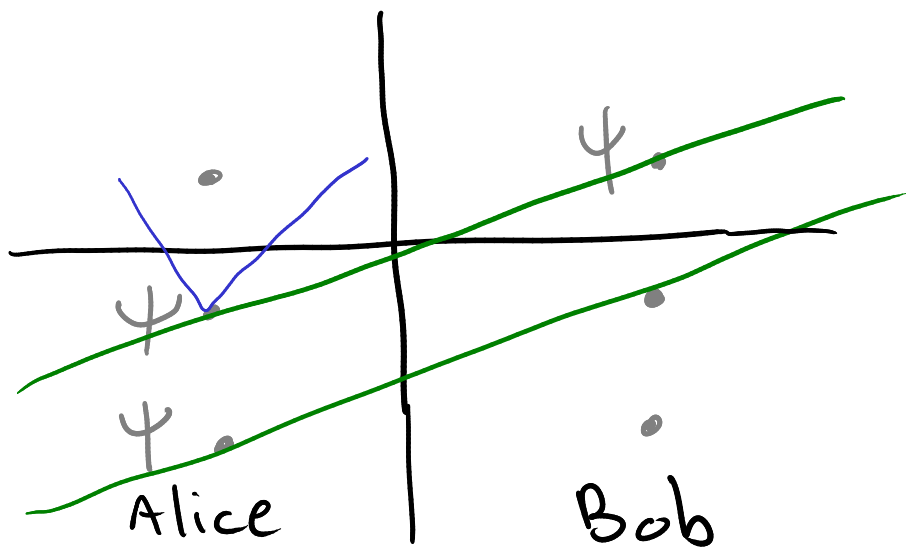
$$\rightarrow \frac{1}{2} \left[\begin{matrix} |0\rangle\langle 0| \\ R \end{matrix} + \begin{matrix} |1\rangle\langle 1| \\ R \end{matrix} \right] \otimes \begin{matrix} |0\rangle\langle 0| \\ A \end{matrix}$$

pure state becomes mixed

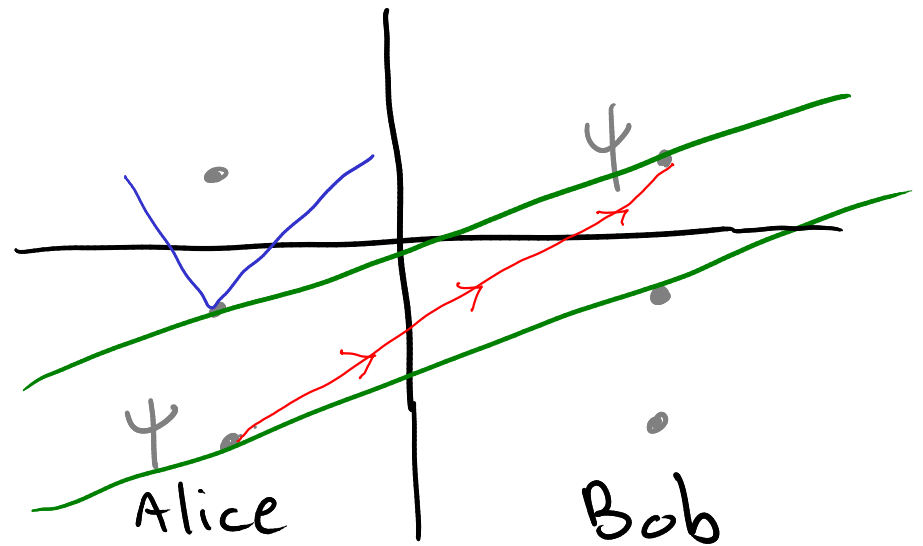
Unitarity \rightarrow polyamory \rightarrow non-unitarity
acausality

But is it polyamory?

polyamory in space vs polyamory in time



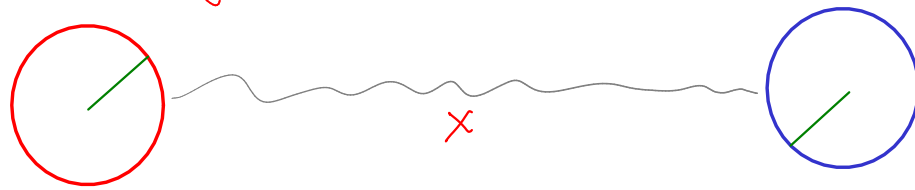
$\Psi \otimes \Psi$
tensor product



$\Psi(t_0) \rightarrow \Psi(t_1)$
temporal product

Entanglement in space $|\Psi\rangle_{AB} = \frac{1}{\sqrt{2}}[|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle]_{AB}$

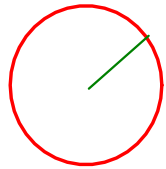
measuring A prepares state on B



then B measures

Entanglement in time $\rho(t_0) = \frac{11}{2}$

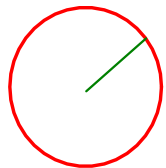
B gets



and measures



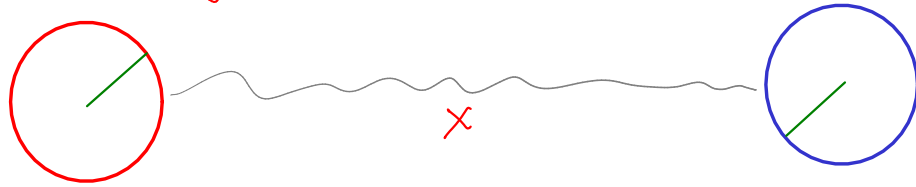
A measures



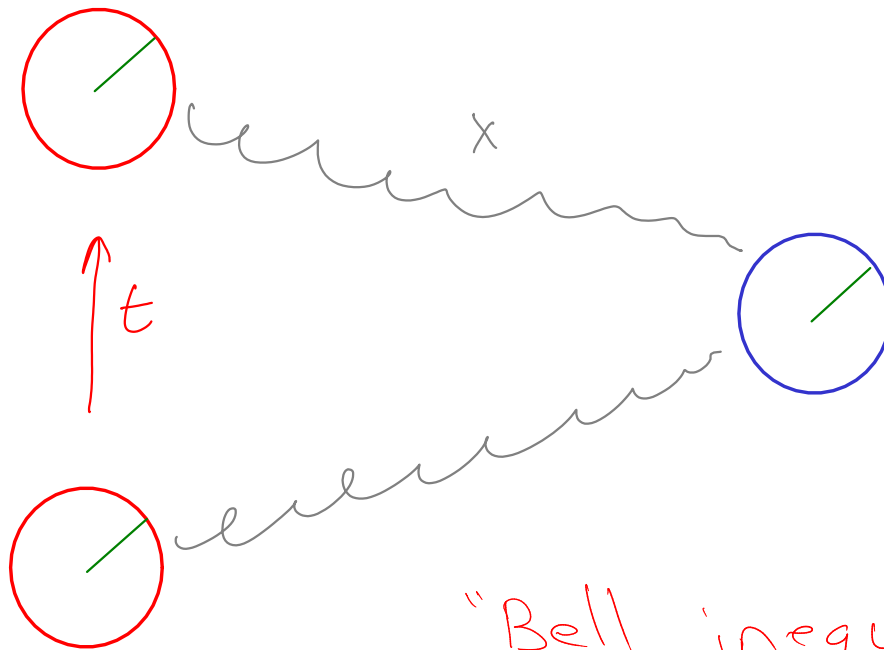
"Bell inequality in time"

Entanglement in space $|\Psi\rangle_{AB} = \frac{1}{\sqrt{2}}[|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle]_{AB}$

measuring A prepares state on B

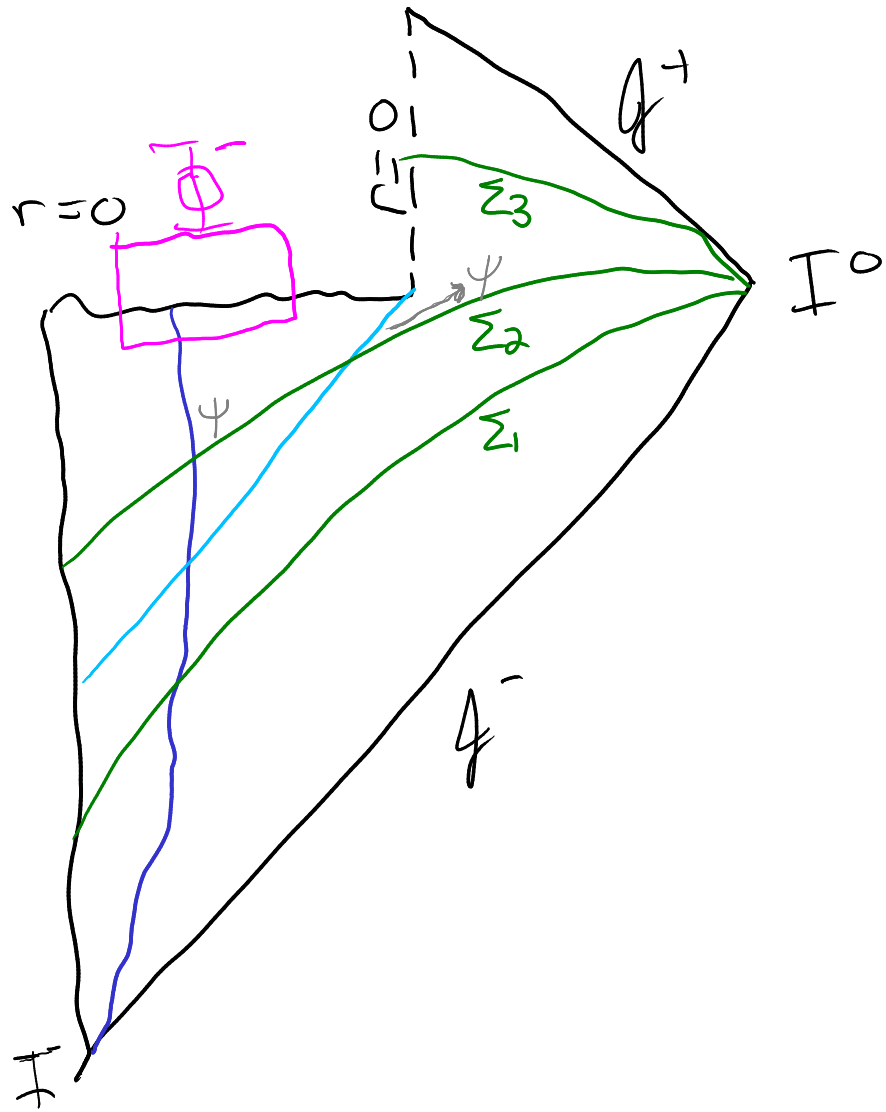


Entanglement in time $\rho(t_0) = \frac{11}{2}$

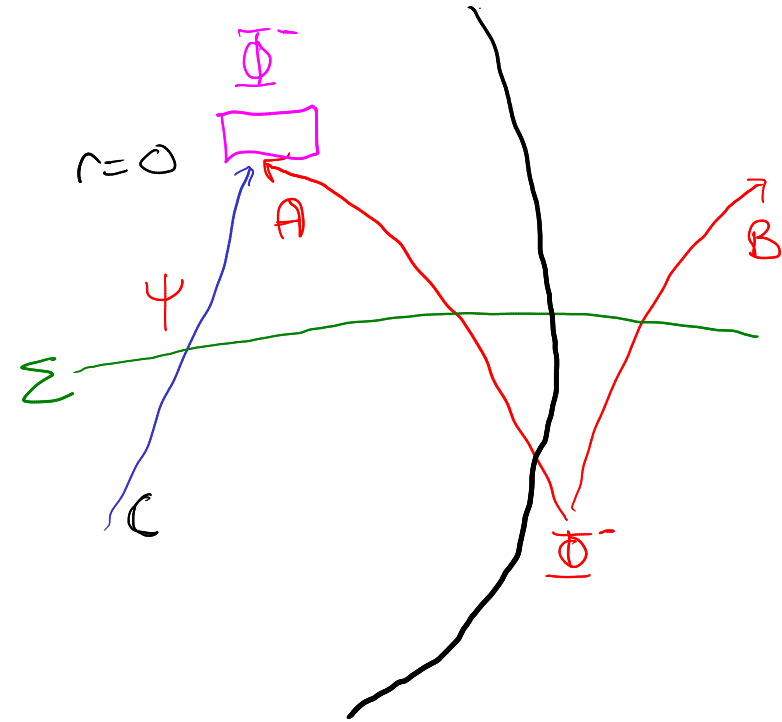


"Bell inequality in time"

Tensor Product vs Temporal Product



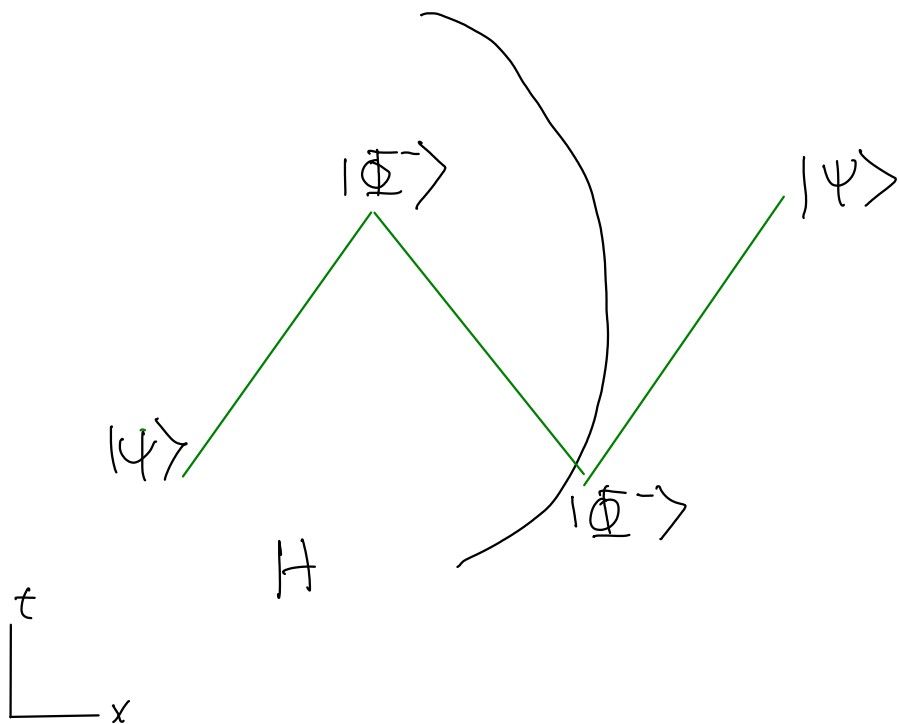
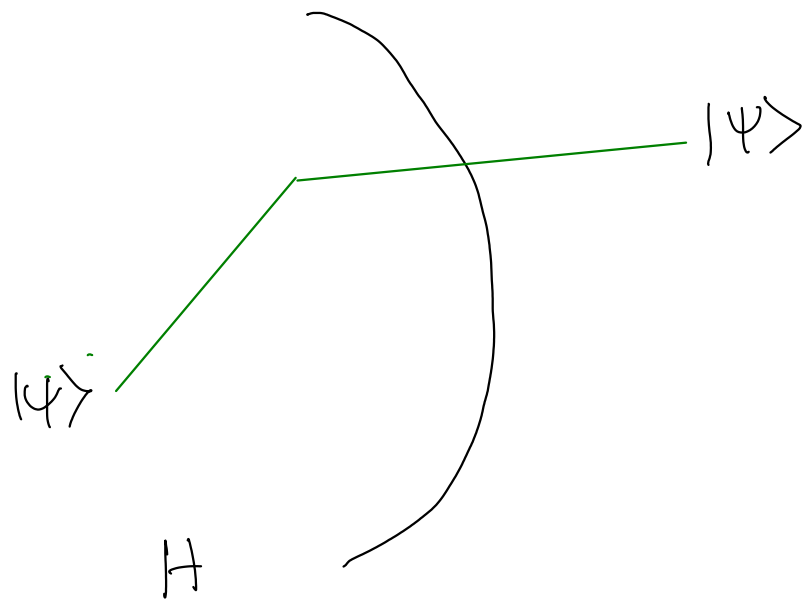
Horowitz Maldacena



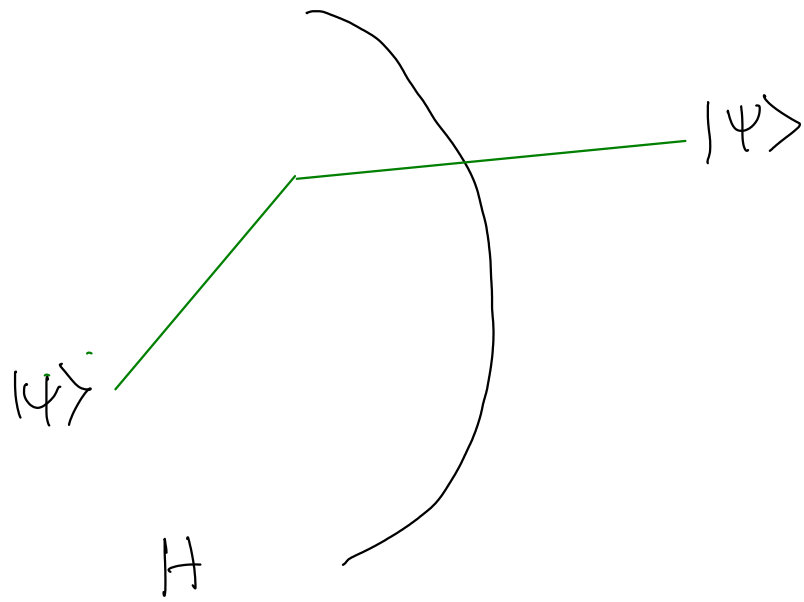
$$|\Psi\rangle_C |\Phi^-\rangle_{AB} = \frac{1}{2} \left[|\Phi^-\rangle_{AC} |\Psi\rangle_B + |\Phi^+\rangle_{AC} |Z\Psi\rangle_B + |\Psi\rangle_{AC} |X\Psi\rangle + |\Psi^+\rangle_{AC} |XZ\Psi\rangle_B \right]$$

$$|\Phi^\pm\rangle = \frac{1}{\sqrt{2}} [|00\rangle \pm |11\rangle]$$

$$|\Psi^\pm\rangle = \frac{1}{\sqrt{2}} [|10\rangle \pm |10\rangle]$$



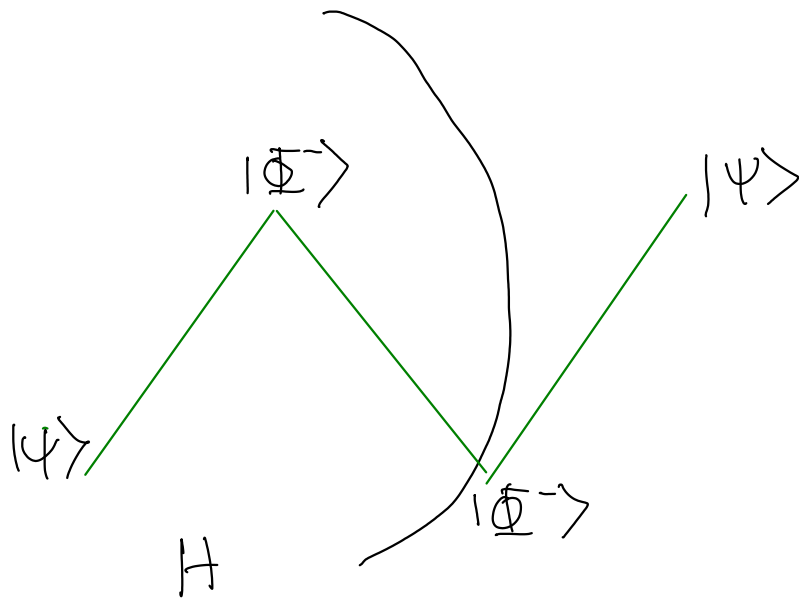
Final State
(Horowitz Maldacena)



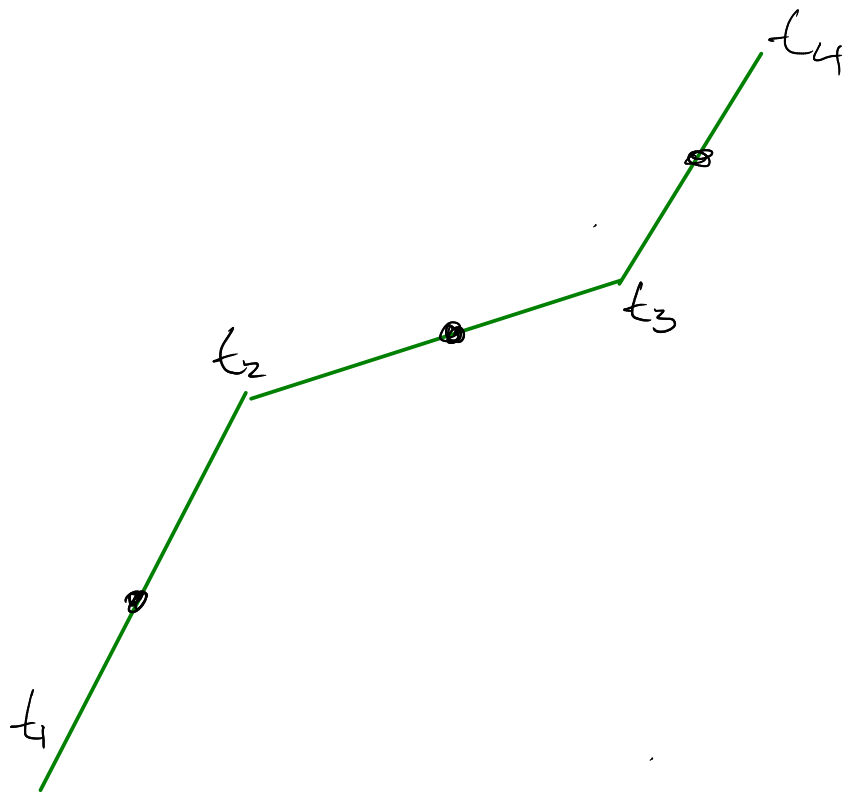
looks like tachyon
in another reference
frame

Final State
(Horowitz Maldacena)

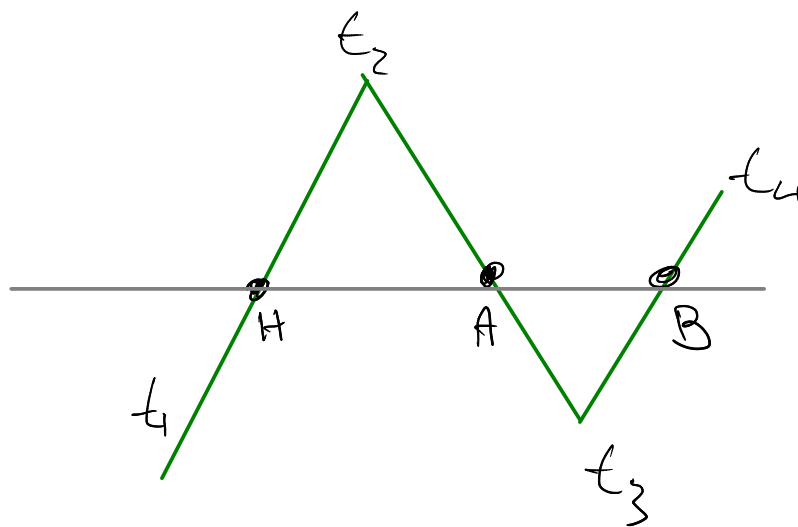
teleportation



t
x



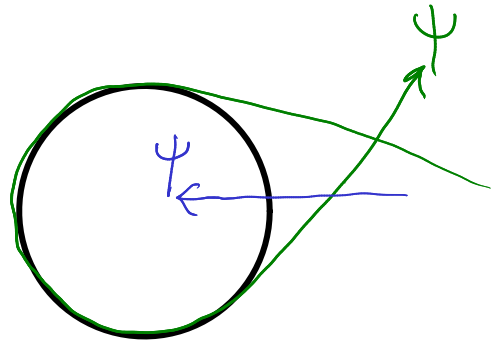
1 particle picture



3 particle picture

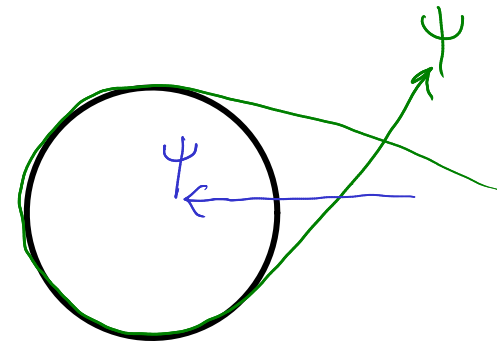
Black hole complementarity

Tensor Product

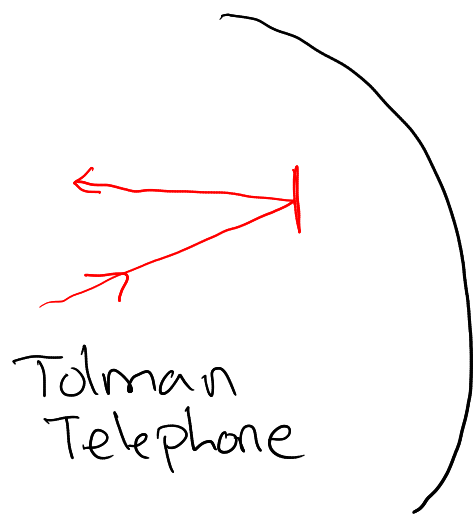


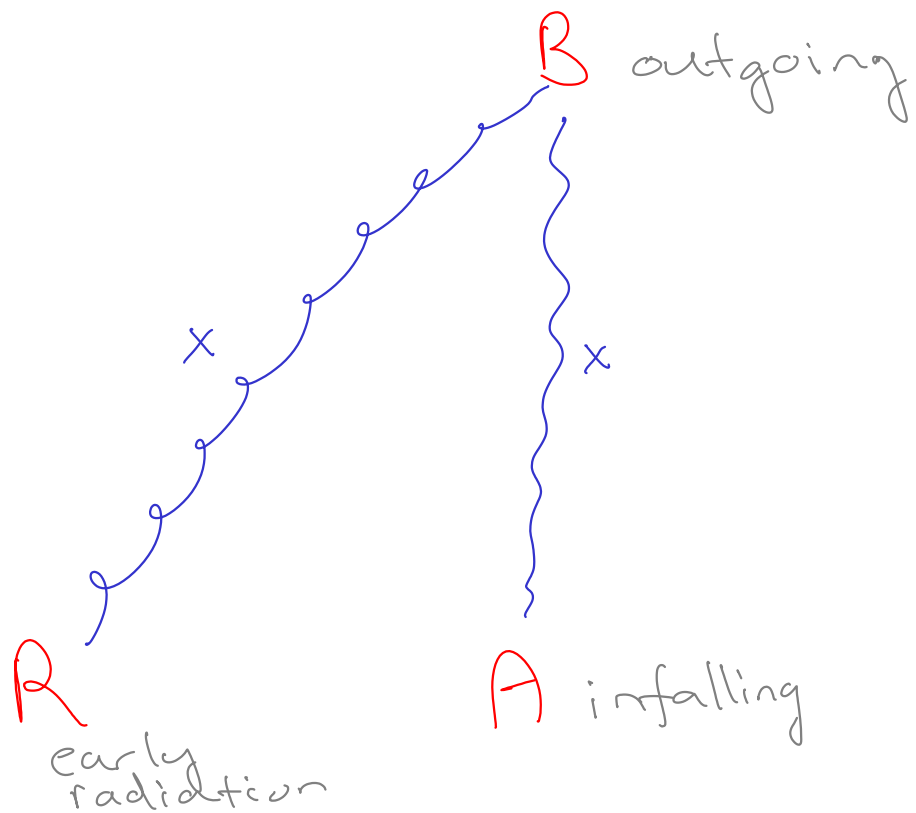
Protected against cloning

Temporal Product



Chronological Protection

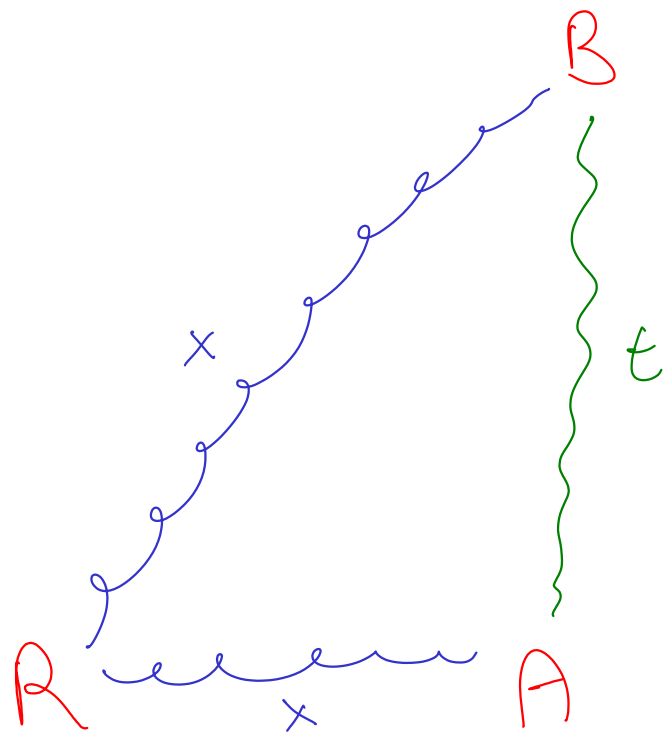




AMPS

polygamy

vs



polyamoury

Conclusion

choose one of:

a) information destruction

b) tensor product \rightarrow polyamory \rightarrow causality breakdown

c) temporal product \rightarrow breakdown of semiclassical causal structure

d) perhaps there is something else?

//