Title: Quantum Information and holography

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Collection: Quantum Information and holography (2021/2022)

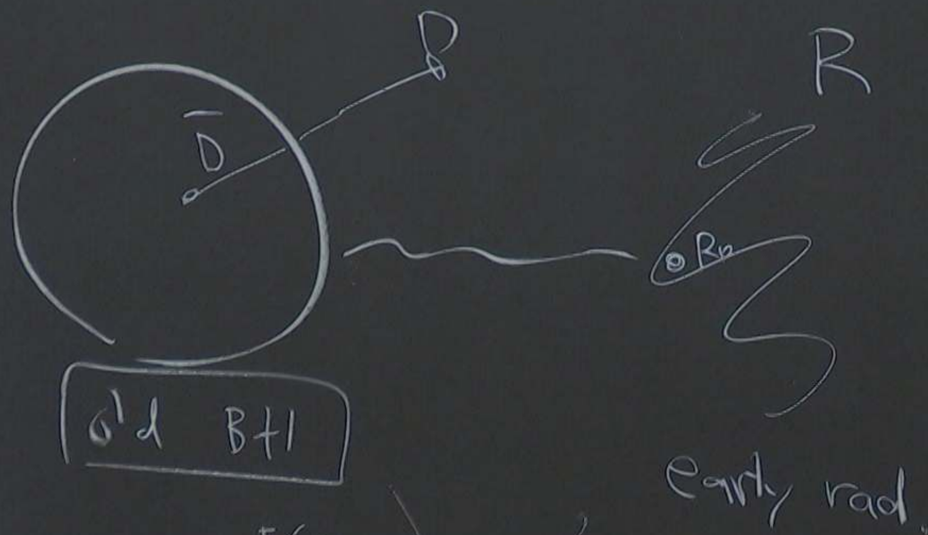
Date: April 27, 2022 - 9:00 AM

URL: https://pirsa.org/22040054

Abstract: Topics will include (but are not limited to):
- Quantum error correction in quantum gravity and condensed matter
- Quantum information scrambling and black hole information
- Physics of random tensor networks and random unitary circuits

Firewall puzzle (review) for old BH

$R \qquad \bar{D} = R_D\ ?$



$$I(D,R) \neq \max$$

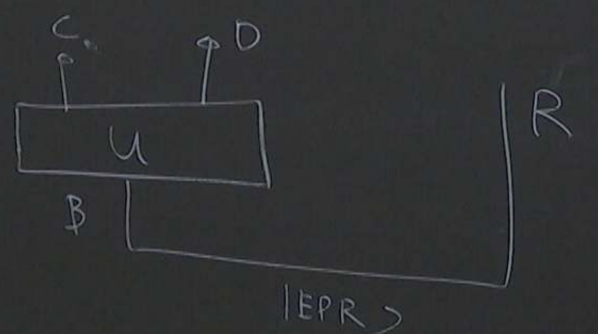
$$I(D,\bar{D}) = \max$$

Firewall puzzle for typical state (young BH)
(microstate)

$\exists$ Firewall for almost all $|\psi_{BH}\rangle$ (Marolf-Polchinski)

Reconstruction of interior op

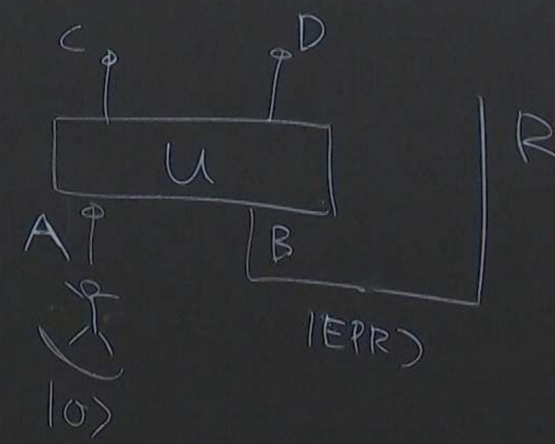
Without an observer ...



$I(D,R) = 2n_D$

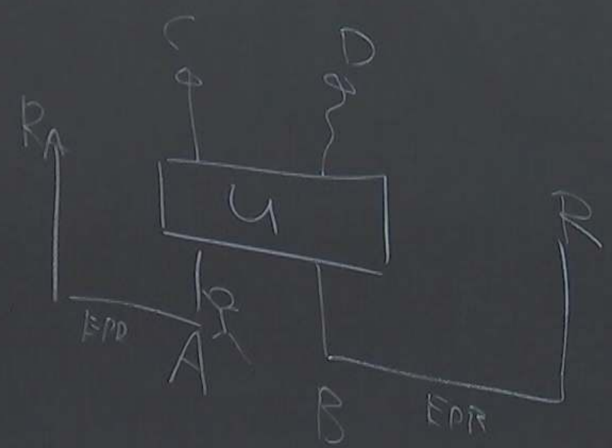
"$\bar{D}$" should be found on R.

With infalling observer ...



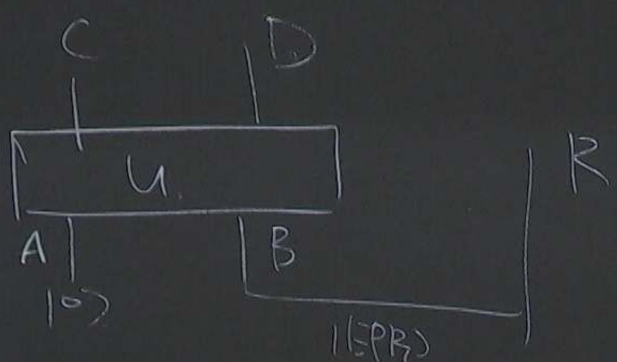
$I(D, C) \simeq 2n_D$ nearly max ($n_A > 2n_D$)

$\rightarrow \bar{D}$ can be found on C (remaining BH).



$I(D, C) \simeq 2n_D$ $(n_A > n_D)$

Minimal surface



$n_C = n - n_D$

$n_B = n - n_A$

$n - n_D, \ n - n_A + n_D$

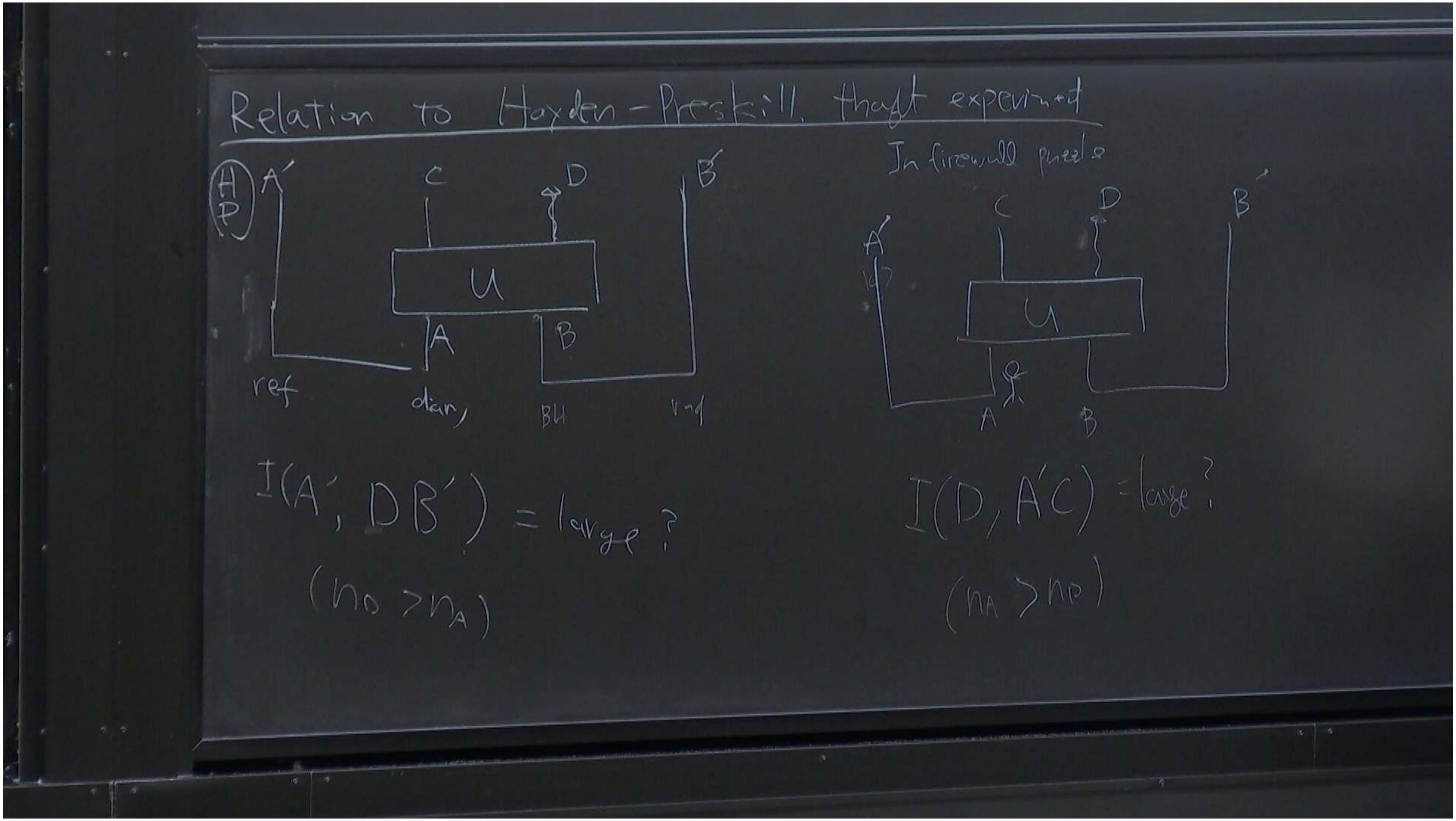
$$I(C,D) = S_C + \underbrace{S_D}_{n_D} - S_{CD}$$

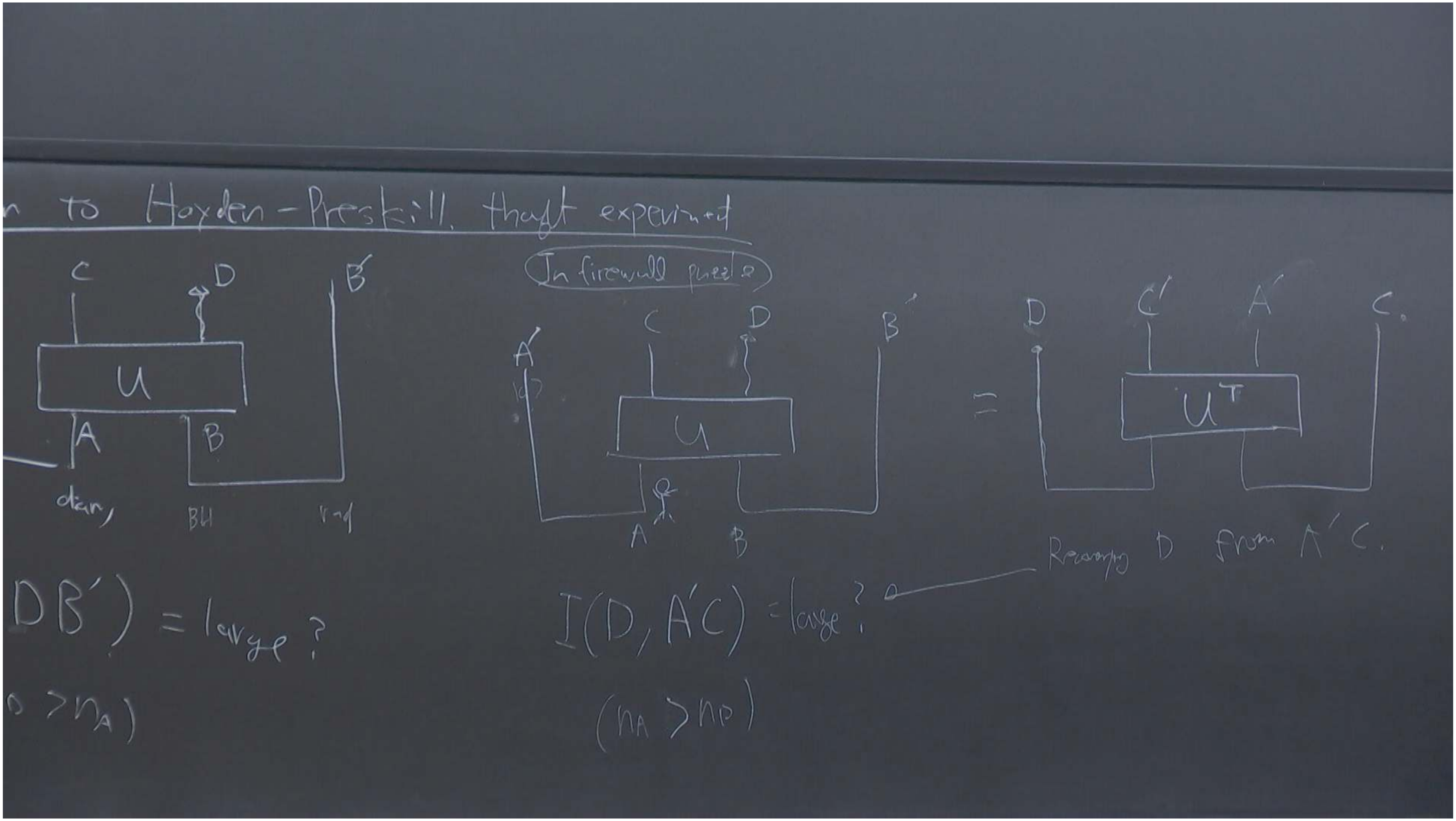
$$S_C = \min(n_C, n_B + n_D)$$

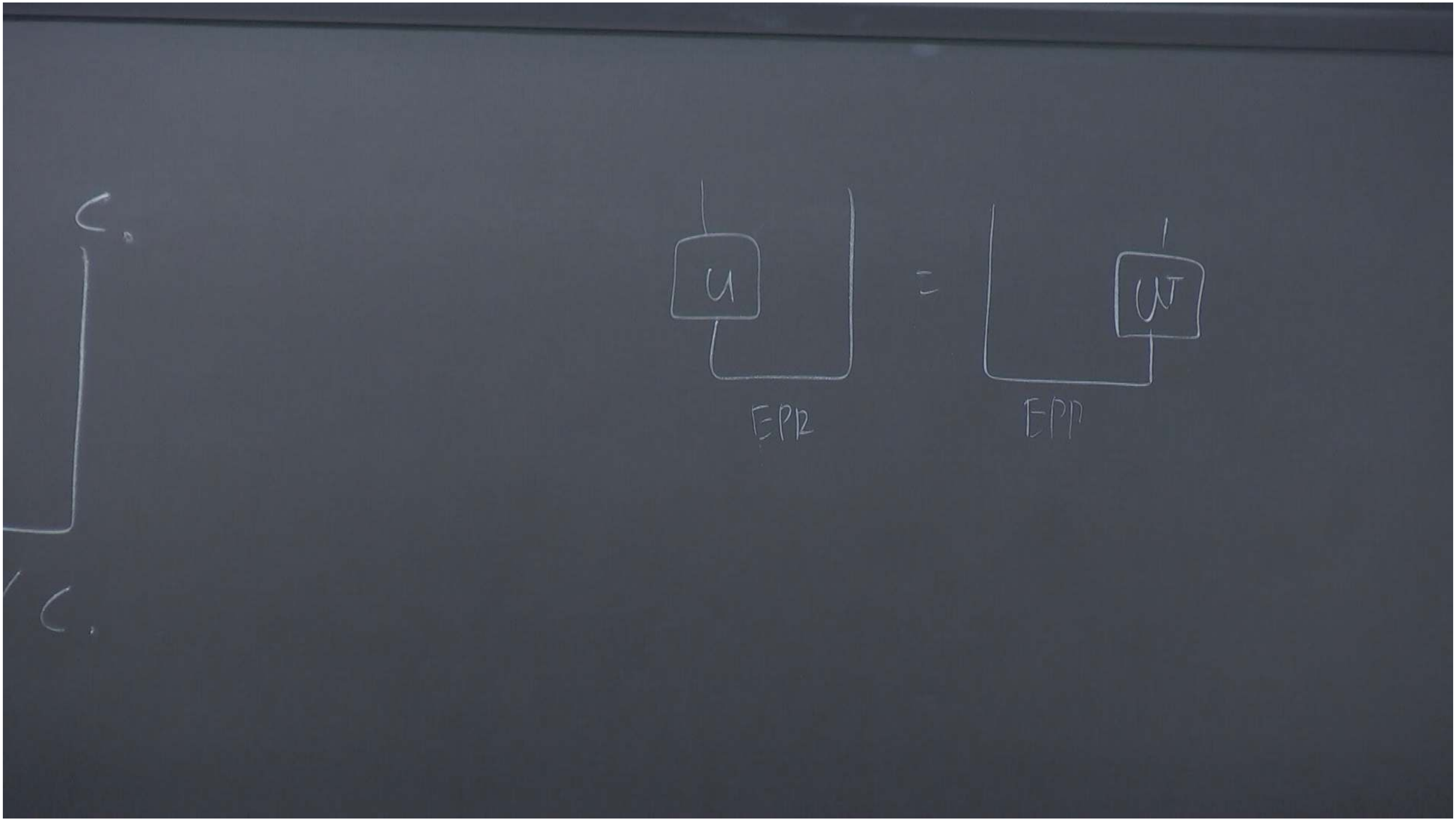
$$S_{CD} = S_R = n_B$$

$$= 2n_D \quad (n_A \geq 2n_D)$$

$$I(D,R) \simeq 0$$


Relation to Hayden-Preskill thought experiment
HP
A'
C
D
B'
U
A
B
ref
diary
BH
rad
I(A'; DB') = large?
(n_D > n_A)
In firewall puzzle
A'
C
D
B'
U
A
B
I(D, A'C) = large?
(n_A > n_D)


to Hayden-Preskill thought experiment
In firewall puzzle
C D B'
U
A B
diary BH rad
DB') = large ?
A' C D B'
U
A B
D C' A' C
U^T
Recovering D from A'C.
I(D, A'C) = large ?
($n_A > n_D$)

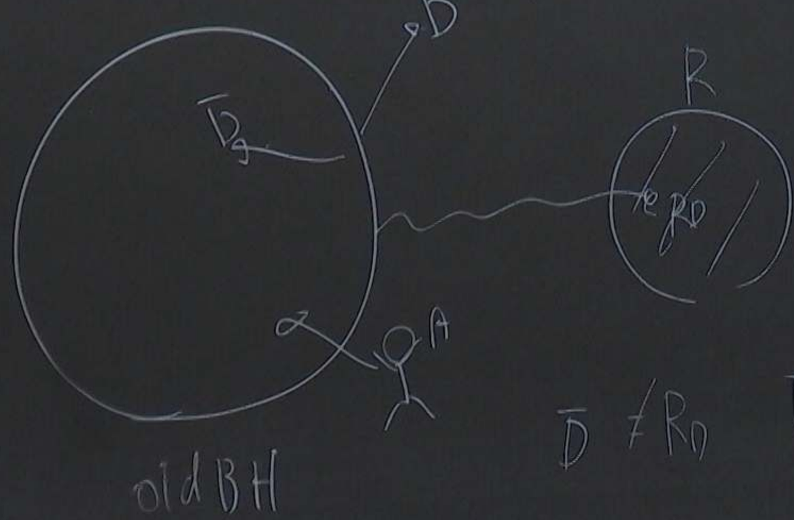

C.
U
=
U^T
EPR
C.

Implications

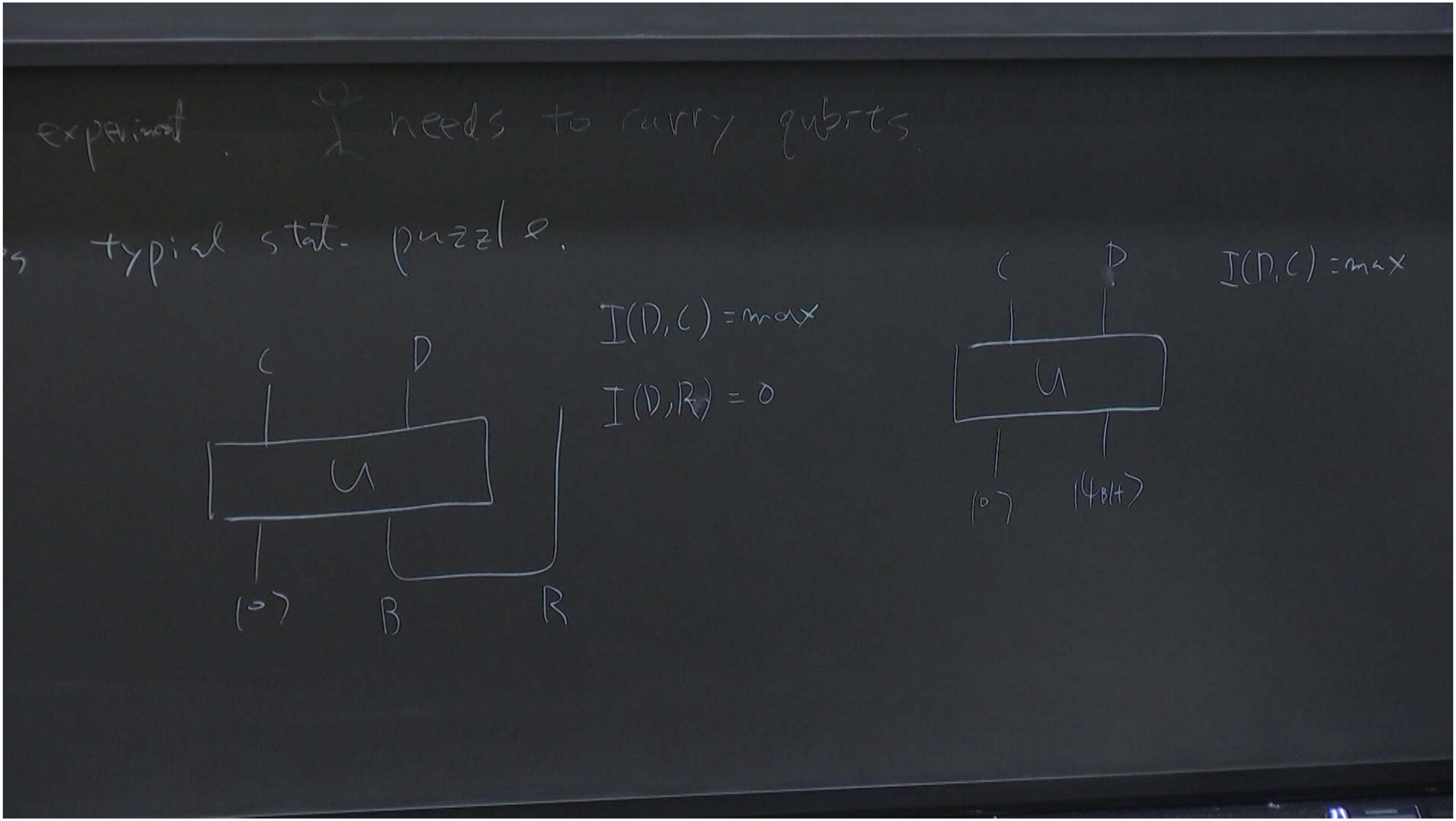
i). Interior mode $\bar{D}$ dynamically changes, and is observer-dependent.

Non-locality is avoided.

(ii)

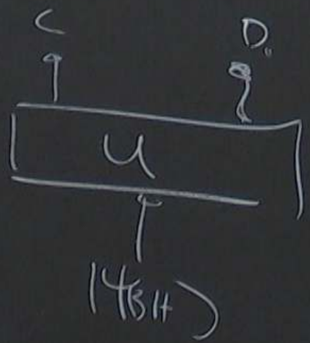


$\bar{D} \neq R_D$ $\bar{D}$ in $C(BH)$


experiment . needs to carry qubits.
typical stat. puzzle.
I(D,C) = max
I(D,R) = 0
C
D
U
|0⟩
B
R
C
D
U
|0⟩
|ψ_B|+⟩
I(D,C) = max

Firewall puzzle for typical state (young BH)
(microstate)

$\exists$ Firewall for almost all $|\psi_{BH}\rangle$ (Marolf-Polchin



$\bar{D}$.

out mode	infalling mode
X_D	$X_{\bar{D}}$
Y_D	$Y_{\bar{D}}$
Z_D	$Z_{\bar{D}}$

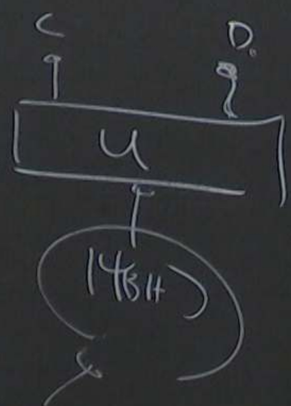
Tate (young BH)

BH) (Marolf - Polchinski)

$X^* \otimes X \, |EPR\rangle = |EPR\rangle$

$\langle X_D^* \otimes X_D \rangle = \langle Y_D^* \otimes Y_D \rangle = \langle Z_D^* \otimes Z_D \rangle \approx 1$

$\exists$ Firewall for almost all $|\psi_{BH}\rangle$ (Marolf-Polchinski)



$2^n \; |\psi_{BH(j)}\rangle$

$j = 1, \ldots, 2^n$

$\bar{D}$

outside node	infalling node
X_D	$X_{\bar{D}}$
Y_D	$Y_{\bar{D}}$
Z_D	$Z_{\bar{D}}$

$$\langle X_{\bar{D}}^* \otimes X_D \rangle = \langle Y_{\bar{D}}^* \otimes Y_D \rangle = \langle$$

$$\langle \psi_{BH(j)} | \, X_{\bar{D}}^* \otimes X_D \, | \psi_{BH(j)} \rangle$$

$|\psi_{BH}\rangle$ (Marolf-Polchinski)

$$\langle X_D^* \otimes X_D \rangle = \langle Y_D^* \otimes Y_D \rangle = \langle Z_D^* \otimes Z_D \rangle \approx 1$$

$$\langle \psi_{BH}(j) | X_D^* \otimes X_D | \psi_{BH}(j) \rangle = 1 \quad \text{for all } j,$$

$$\mathrm{Tr}(X_D^* \otimes X_D) = 2^n$$

(microstate)

$X^* \otimes X$

almost all $|\psi_{BH}\rangle$ (Marolf-Polchinski)

$$\langle X_{\bar{D}}^* \otimes X_D\rangle = \langle Y_{\bar{D}}^* \otimes Y_D\rangle = \langle Z_D^* \otimes Z_D\rangle \simeq 1$$

infalling node

$X_{\bar{D}}$

$Y_{\bar{D}}$

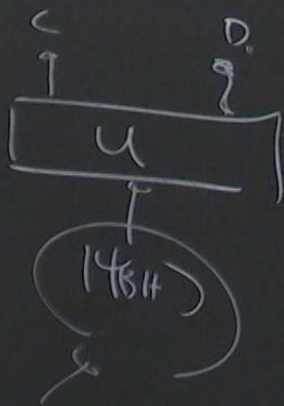
$Z_{\bar{D}}$

$$\langle \psi_{BH}(j)| X_{\bar{D}}^* \otimes X_D |\psi_{BH}(j)\rangle = 1 \quad \text{for all } j,$$

$$\mathrm{Tr}(\underbrace{X_{\bar{D}}^* \otimes X_D}_{U}) = 2^n$$

(microstate)

Firewall for almost all $|\psi_{BH}\rangle$ (Marolf-Polchinski)



2^n $|\psi_{BH}(j)\rangle$

$j = 1, \ldots, 2^n$

$\bar{D}$ outside mode	infalling mode
X_D	$X_{\bar{D}}$
Y_D	$Y_{\bar{D}}$
Z_D	$Z_{\bar{D}}$

or $X_{\bar{D}}(j)$

$$\langle X_{\bar{D}}^* \otimes X_D \rangle = \langle Y_{\bar{D}}^* \otimes Y_D \rangle = \langle Z_D^* \otimes$$

$$\langle \psi_{BH}(j) | X_{\bar{D}}^* \otimes X_D | \psi_{BH}(j) \rangle = 1$$

$$\mathrm{Tr}\big(\underbrace{X_{\bar{D}}^* \otimes X_D}_{0}\big) = 2^n$$

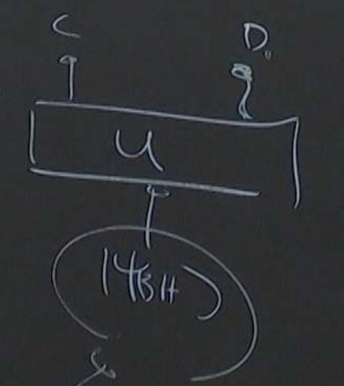
d BH

$\overline{D} = R_D$?

Firewall puzzle for typical state (young B
(microstate)

$\exists$ Firewall for almost all $|\psi_{BH}\rangle$ (Maro

Firewall
or state-dep?



2^n $|\psi_{BH}(j)\rangle$

$j = 1, \cdots, 2^n$

$\overline{D}$

outside mode: X_D, Y_D, Z_D

infalling mode: $X_{\overline{D}}$, $Y_{\overline{D}}$, $Z_{\overline{D}}$

or $X_{\overline{D}}(j)$

$\langle X_D^* \otimes$

$\langle \psi_{BH}(j)| X^*_{\overline{D}}$

$\mathrm{Tr}(X_{\overline{D}}^*$