Title: Classical and Quantum Chaos 2021/2022 - Lecture 14

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Collection: Classical and Quantum Chaos 2021/2022

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Signatures of quantum chaos –

– in Eigenspectra – Level-spacing statistics, SFF

– in Eigenstates –

– in Quantum dynamics – OTOC, entanglement dynamics

Entanglement in Random States – DN Page, PRL 1993

Let $|\psi^{AB}\rangle \in \mathcal{H}^A \otimes \mathcal{H}^B$ be pure random state

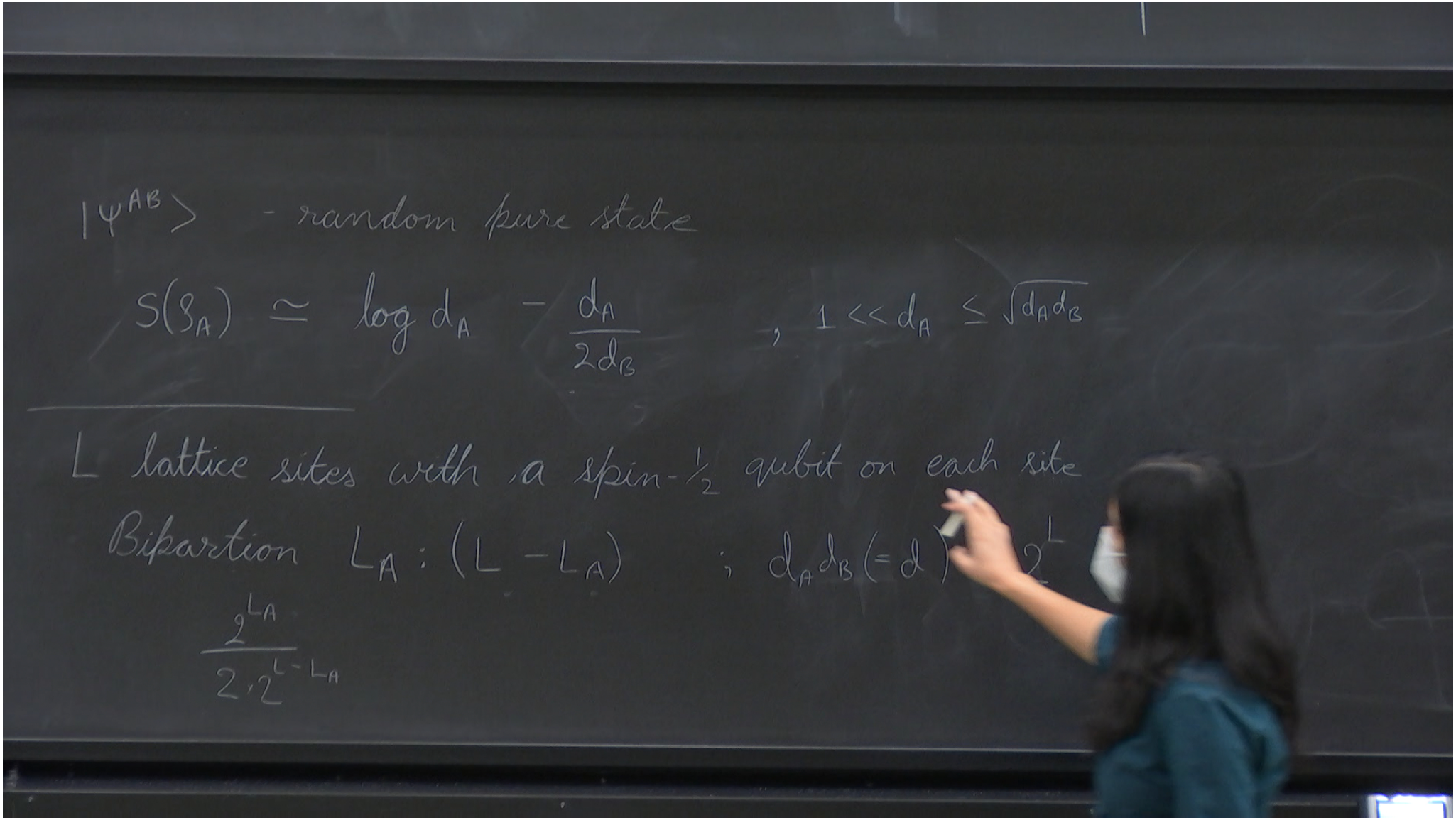
$\dim(\mathcal{H}_A) = d_A$, $\dim(\mathcal{H}_B) = d_B$; $\dim(\mathcal{H}_A \otimes \mathcal{H}_B) = d_A d_B$

WLOG, $d_A \leq d_B$

$\rho_A = Tr_B(|\psi^{AB}\rangle\langle\psi^{AB}|)$

Entanglement $(|\psi^{AB}\rangle) = S(\rho_A) = -Tr(\rho_A \log \rho_A)$

$S_{max}(\rho_A) = \log d_A$


$|\psi^{AB}\rangle$ - random pure state
$S(\rho_A) \simeq \log d_A - \frac{d_A}{2d_B}$, $1 \ll d_A \leq \sqrt{d_A d_B}$
L lattice sites with a spin-$\frac{1}{2}$ qubit on each site
Bipartion $L_A : (L - L_A)$; $d_A d_B (= d)$
$\frac{2^{L_A}}{2 \cdot 2^{L - L_A}}$

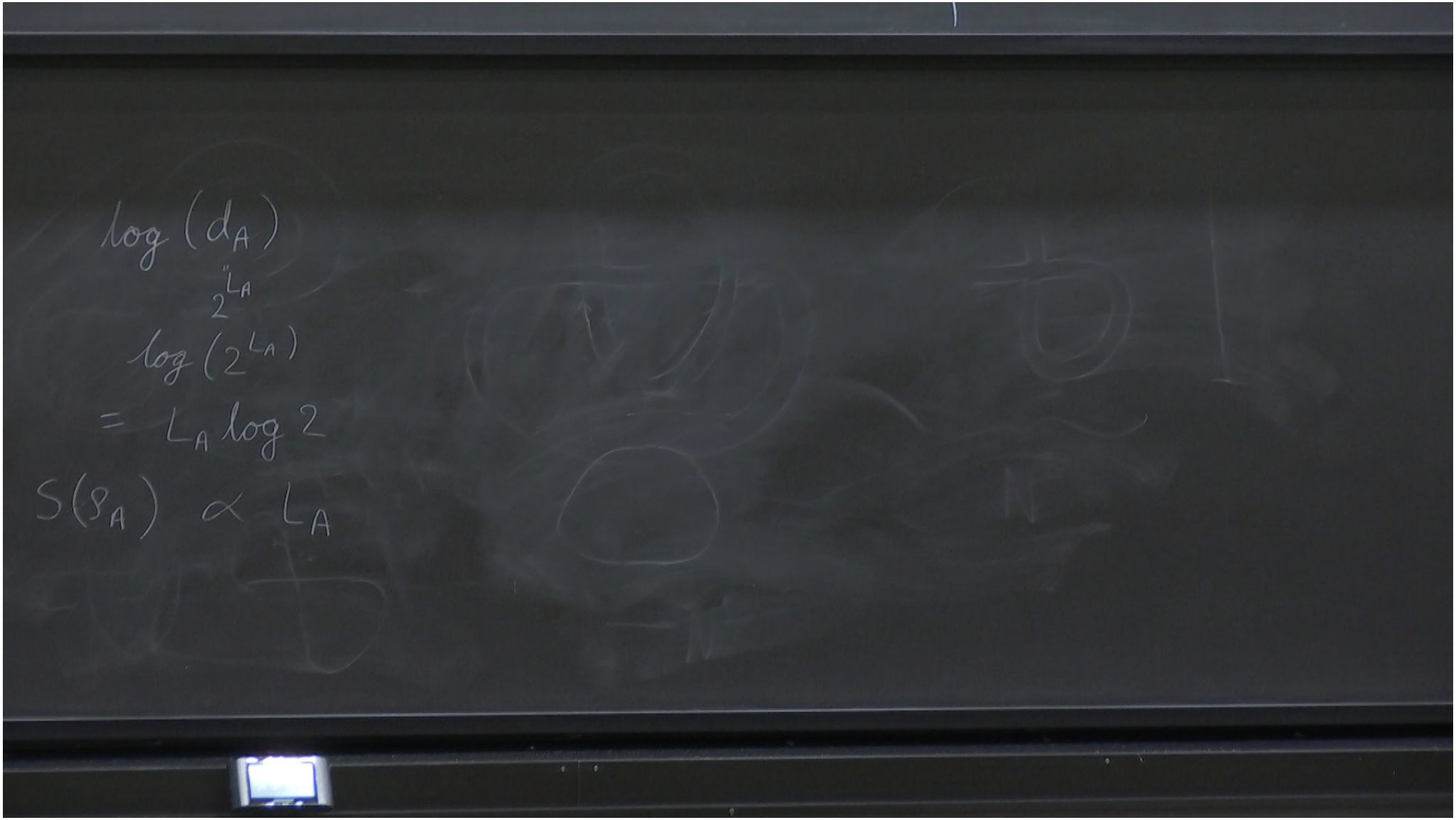
$|\psi^{AB}\rangle$ - random pure state

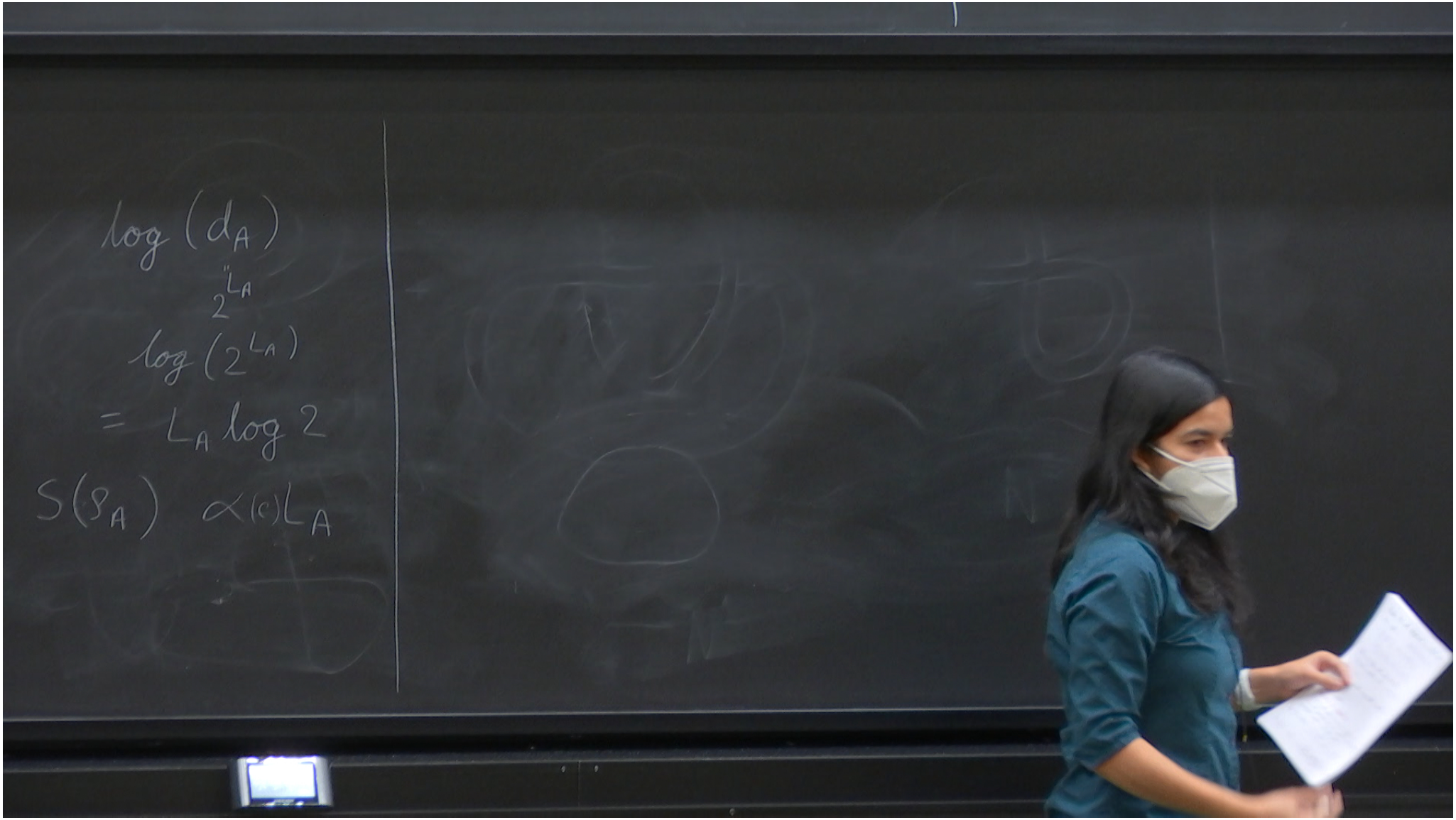
$$S(\rho_A) \simeq \log d_A - \frac{d_A}{2d_B} \quad , \quad 1 \ll d_A \leq \sqrt{d_A d_B}$$

L lattice sites with a spin-$\frac{1}{2}$ qubit on each site

Bipartion $L_A : (L - L_A)$; $d_A d_B (= d) = 2^L$

$$\frac{2^{L_A}}{2 \cdot 2^{L - L_A}}$$


$\log(d_A)$
2^{L_A}
$\log(2^{L_A})$
$= L_A \log 2$
$S(\rho_A) \propto L_A$


log (d_A)
2^{L_A}
log (2^{L_A})
= L_A log 2
S(ρ_A) ∝ (c) L_A

arXiv: 1909.09654

XXZ model :-

$$\hat{H} = \sum_{i=1}^{L} \left[\frac{1}{2} \left(\hat{S}_i^{+} \hat{S}_{i+1}^{-} + H.C. \right) + \Delta \hat{S}_i^{z} \hat{S}_{i+1}^{z} \right]$$

$$+ \lambda \sum_{i=1}^{L} \left[\frac{1}{2} \left(\hat{S}_i^{+} \hat{S}_{i+2}^{-} + H.C. \right) + \frac{1}{2} \hat{S}_i^{z} \hat{S}_{i+1}^{z} \right]$$

* $\lambda = 0 \Rightarrow$ integrable

$$\frac{2^{L_A}}{2 \cdot 2^{L-L_A}}$$

$\lambda \neq 0$ non-integrable

$\lambda = 1$, Zero magnetization sector

$$\bar{S}_{ran}\left(L_A, \frac{L_A}{L}\right) = L_A \log 2 + \frac{\frac{L_A}{L} + \log\left(1 - \frac{L_A}{L}\right)}{2} - \frac{1}{2} \frac{\binom{2L_A}{L_A}}{\binom{L}{L/2}}$$

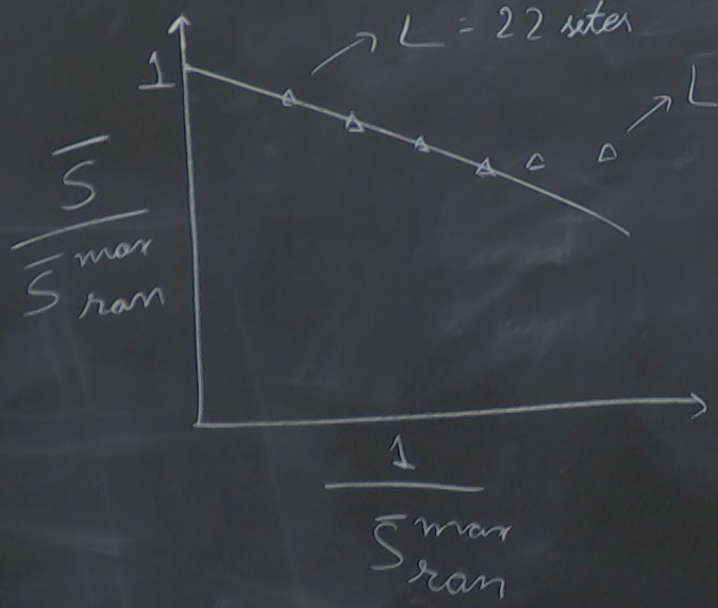
$$\frac{1}{2 \cdot 2^{L-L_A}}$$

$\lambda \neq 0$ non-integrable

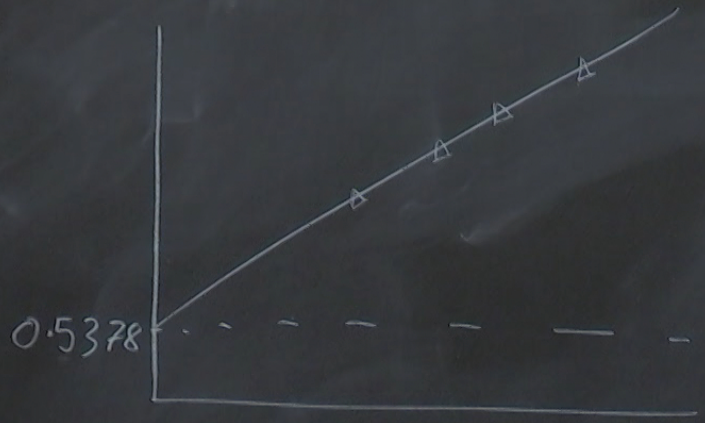
$= 1$, Zero magnetization sector $(M^z = 0)$

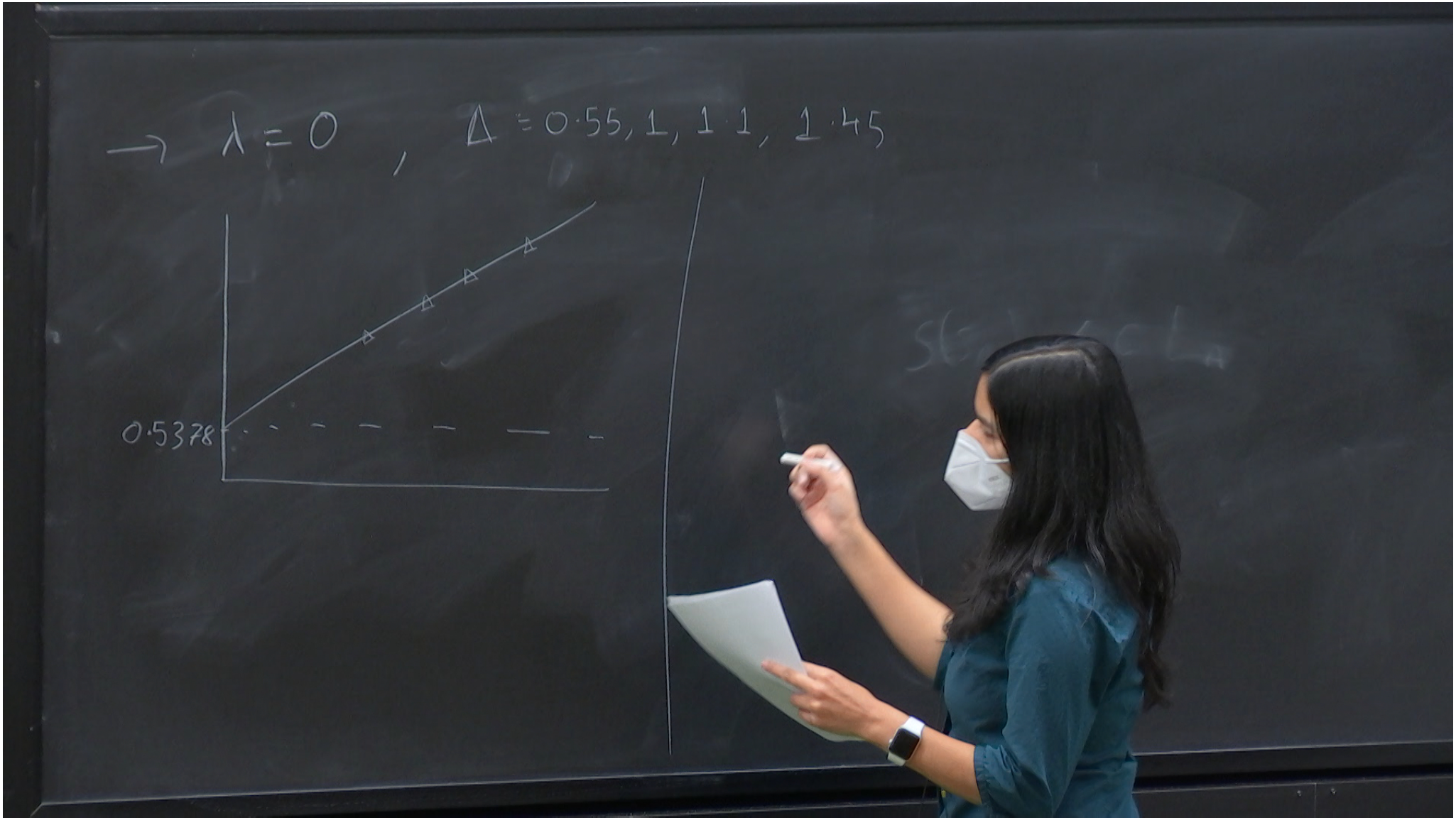
$$\bar{S}_{ran}\left(L_A, \frac{L_A}{L}\right) = L_A \log 2 + \frac{\frac{L_A}{L} + \log\left(1 - \frac{L_A}{L}\right)}{2} - \frac{1}{2} \frac{\binom{2L_A}{L_A}}{\binom{L}{L/2}}$$

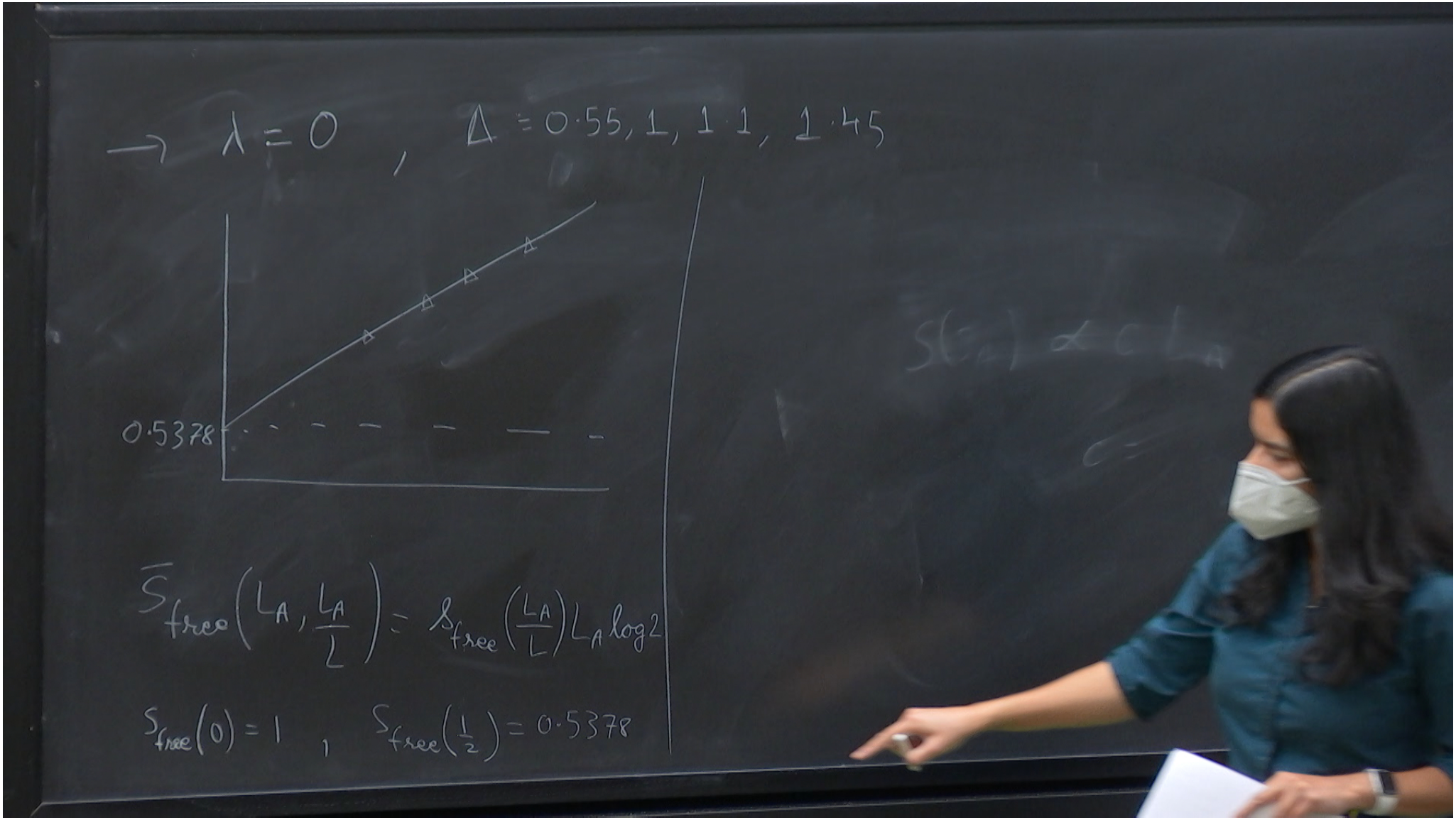
Av. EE in all eigenstates for $M^z = 0$



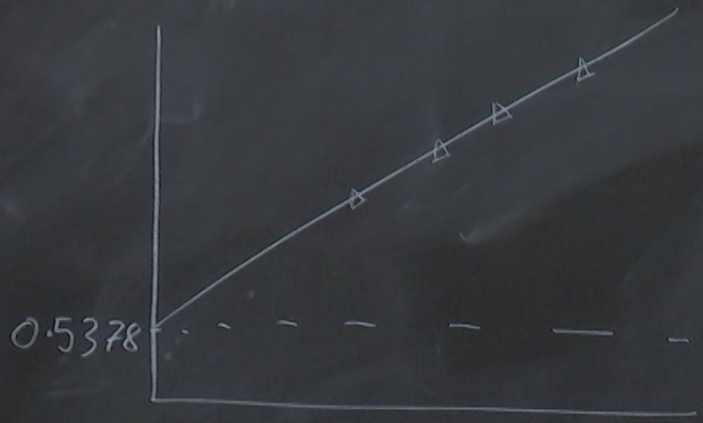
→ $\lambda = 0$, Δ




λ = 0 , Δ = 0·55, 1, 1·1, 1·45
0·5378


$\rightarrow \lambda = 0$, $\Delta = 0.55, 1, 1.1, 1.45$
0.5378
$\bar{S}_{free}\left(L_A, \frac{L_A}{L}\right) = s_{free}\left(\frac{L_A}{L}\right) L_A \log 2$
$S_{free}(0) = 1$, $S_{free}\left(\frac{1}{2}\right) = 0.5378$

→ $\lambda = 0$, $\Delta = 0.55, 1, 1.1, 1.45$

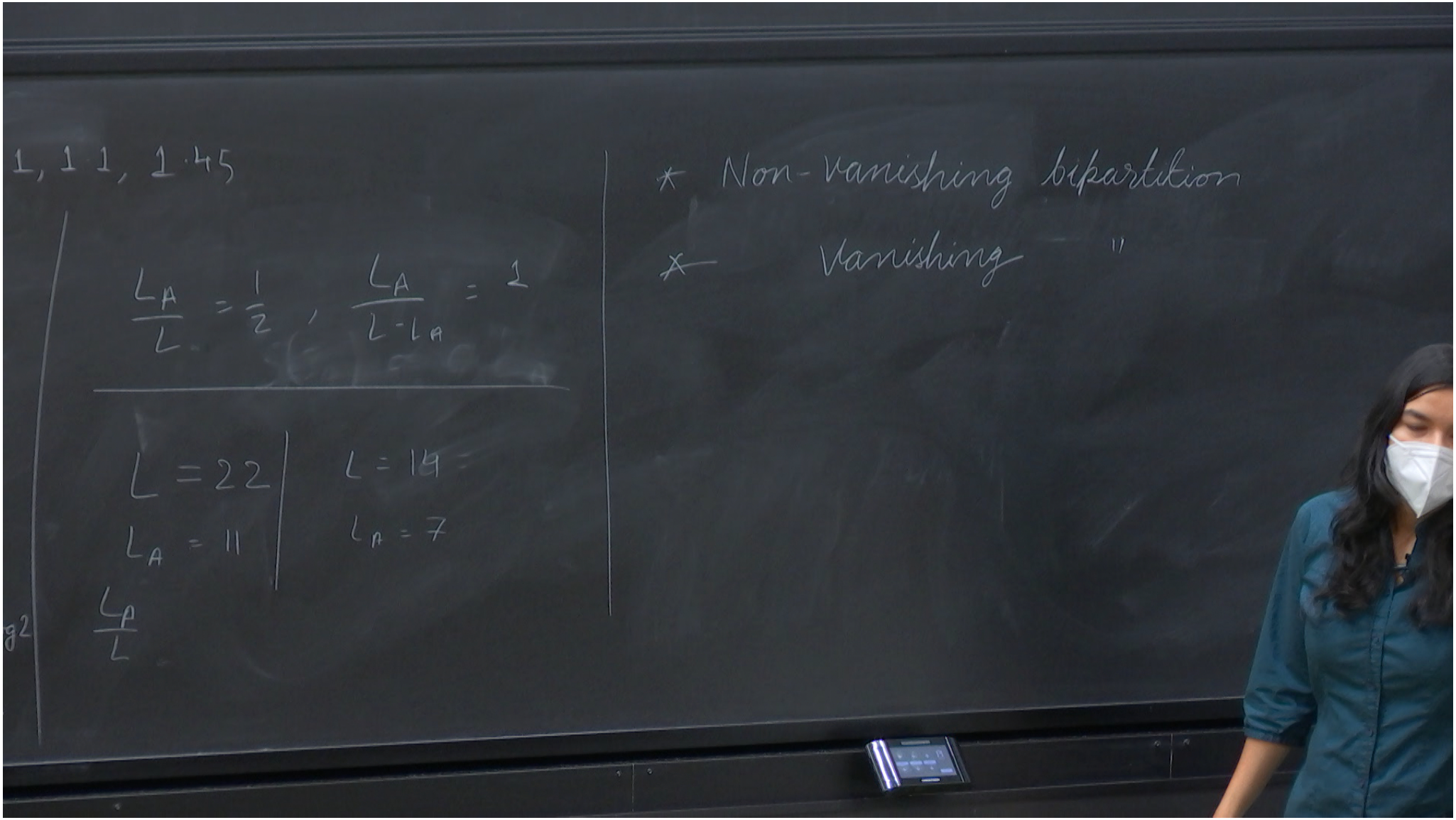


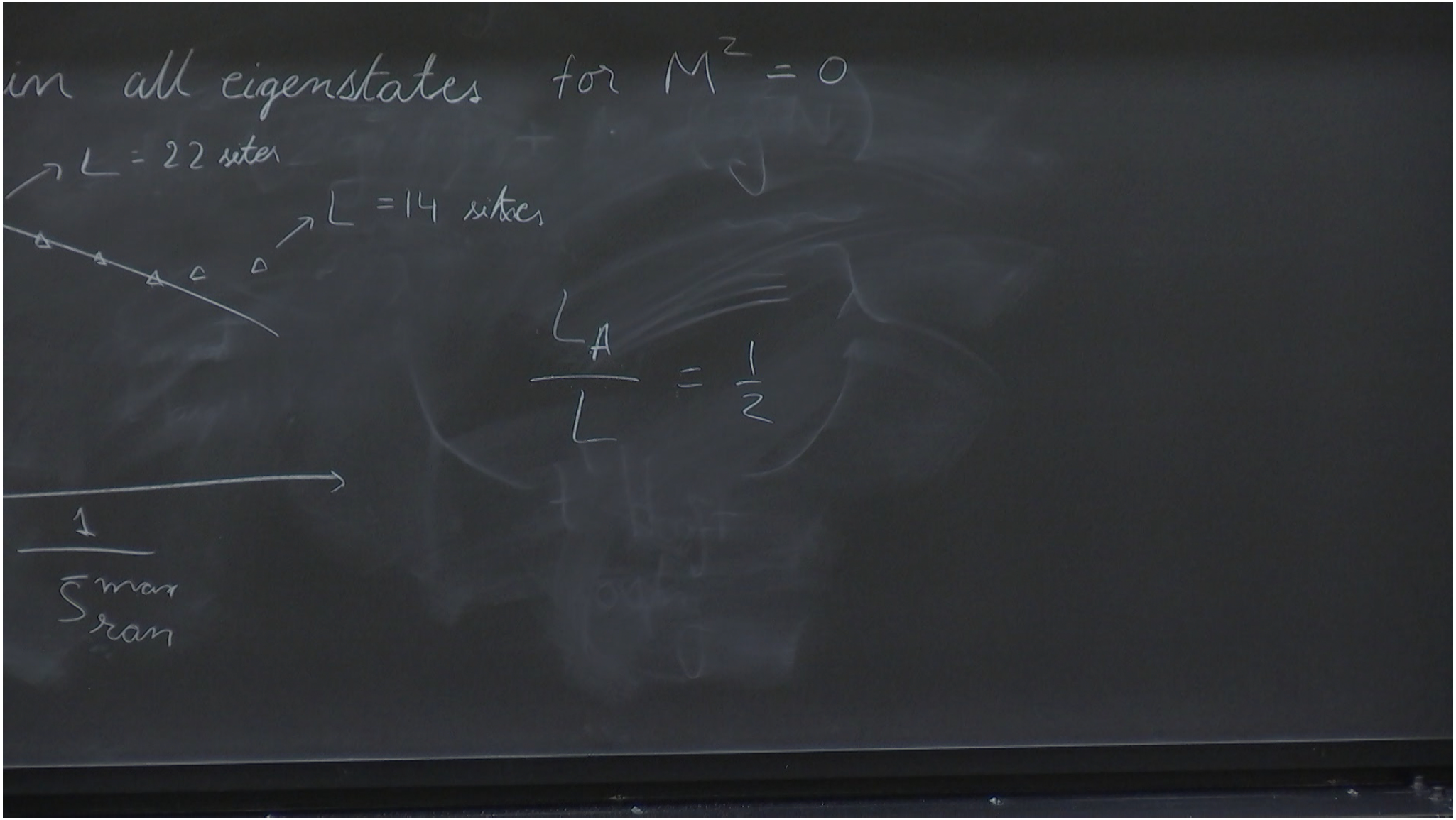
$\frac{L_A}{L} = \frac{1}{2}$, $\frac{L_A}{L - L_A} = 1$

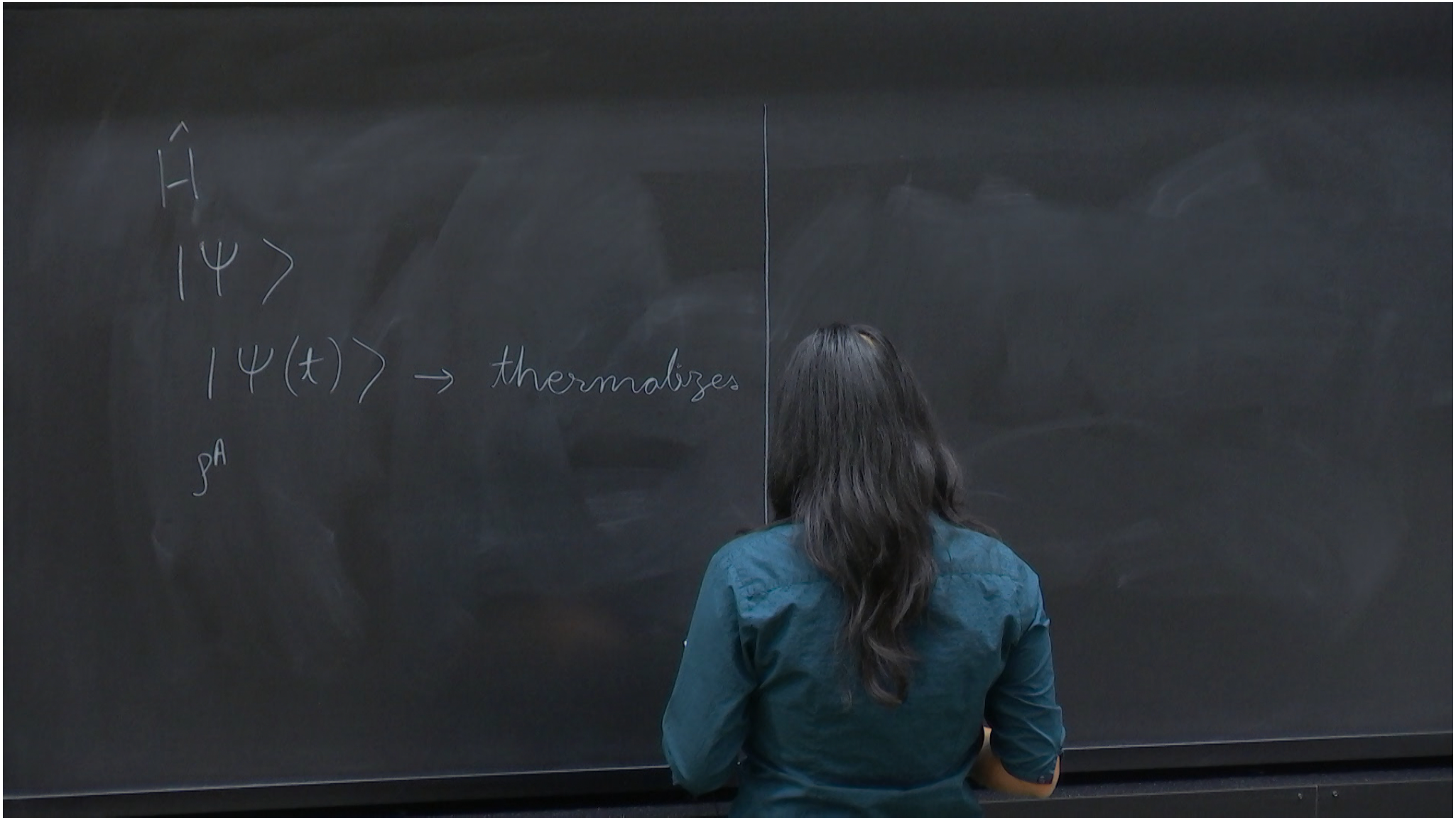
$\bar{S}_{free}\left(L_A, \frac{L_A}{L}\right) = s_{free}\left(\frac{L_A}{L}\right) L_A \log 2$

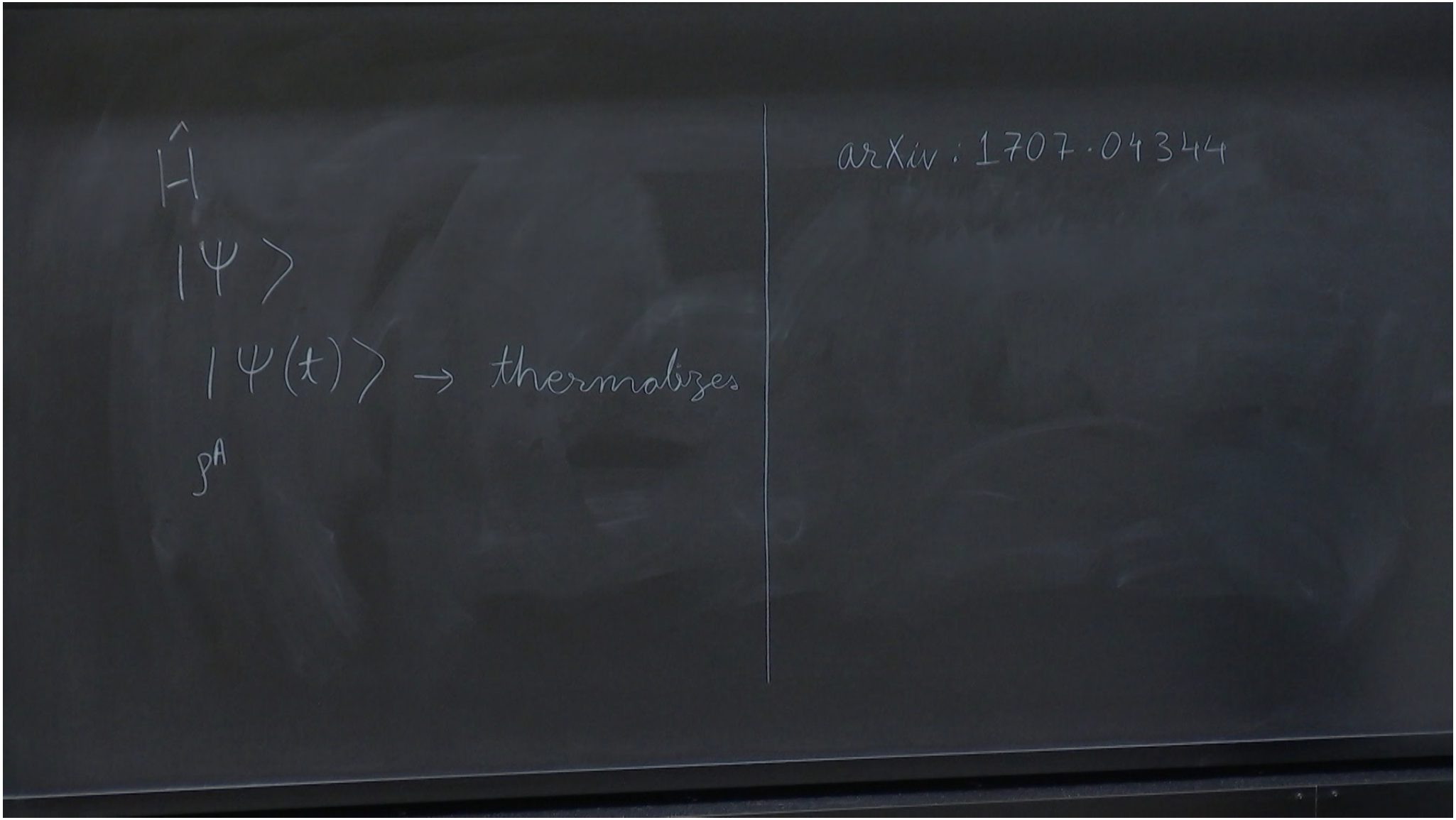
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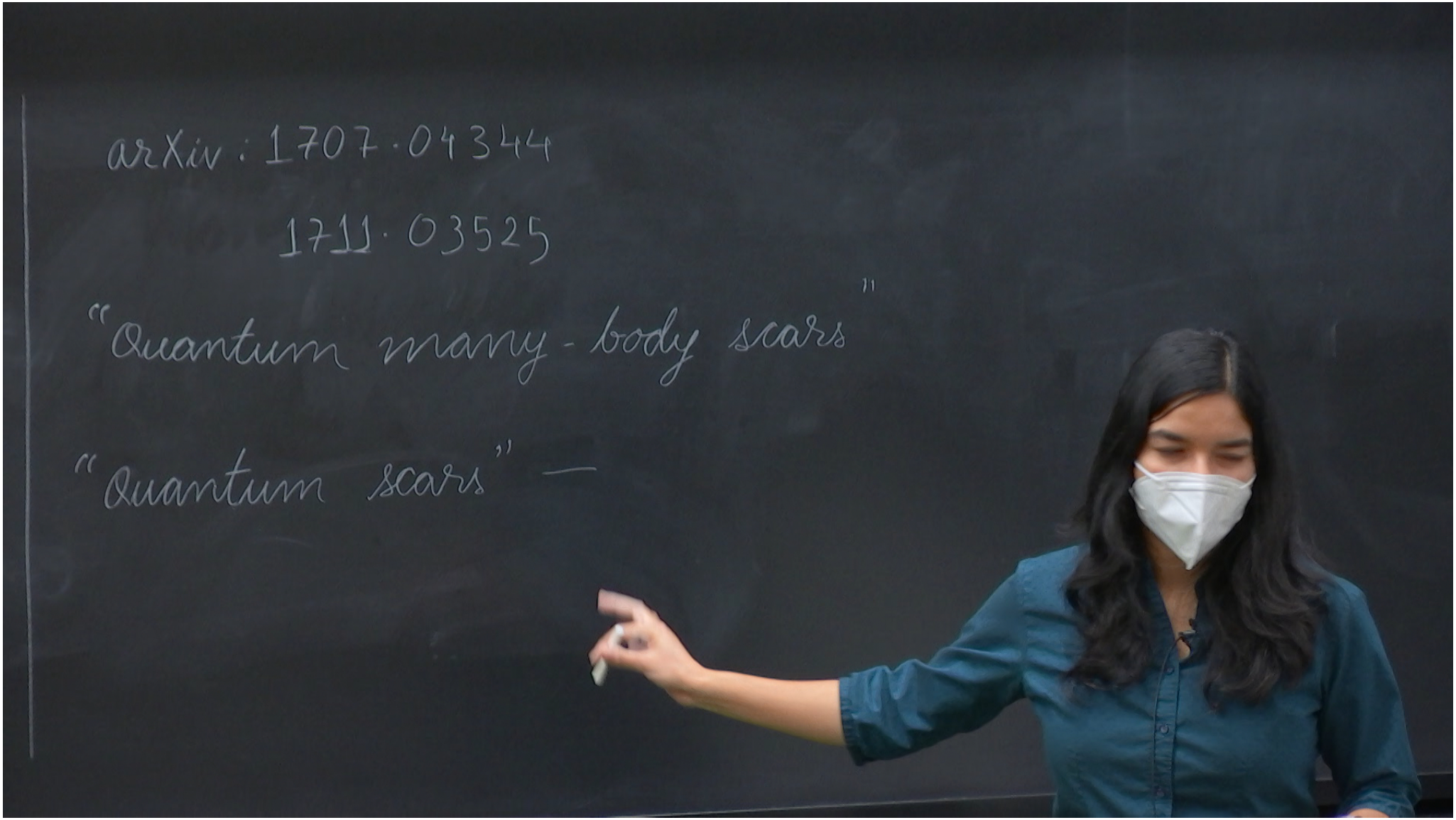
*


1, 1 1, 1·45
$\frac{L_A}{L} = \frac{1}{2}$, $\frac{L_A}{L-L_A} = 1$
$L = 22$
$L_A = 11$
$L = 14$
$L_A = 7$
$\frac{L_A}{L}$
* Non-vanishing bipartition
* Vanishing "


in all eigenstates for $M^2 = 0$
L = 22 sites
L = 14 sites
$\frac{L_A}{L} = \frac{1}{2}$
$\frac{1}{S_{ran}^{max}}$


$\hat{H}$
$|\psi\rangle$
$|\psi(t)\rangle \rightarrow$ thermalizes
ρ_A


$\hat{H}$
$|\Psi\rangle$
$|\Psi(t)\rangle \rightarrow$ thermalizes
ρ_A
arXiv : 1707.043 44


arXiv: 1707.04344
1711.03525
"Quantum many-body scars"
"Quantum scars" —