Title: PSI 2019/2020 - Quantum Matter Part 1 - Lecture 1

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Collection: PSI 2019/2020 - Quantum Matter Part 1

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QUANTUM MATTER

- Emergence
  - Symmetry Breaking
  - Order
  - Emergent Symmetries
  - Emergent Laws : 2nd Law of Th.
- Quantum Correlations

QUANTUM MATTER

- **Emergence**
  - Symmetry Breaking
  - Order
  - Emergent Symmetries
  - Emergent Laws: 2nd Law of Th.

$N \to \infty$

\# of bodies

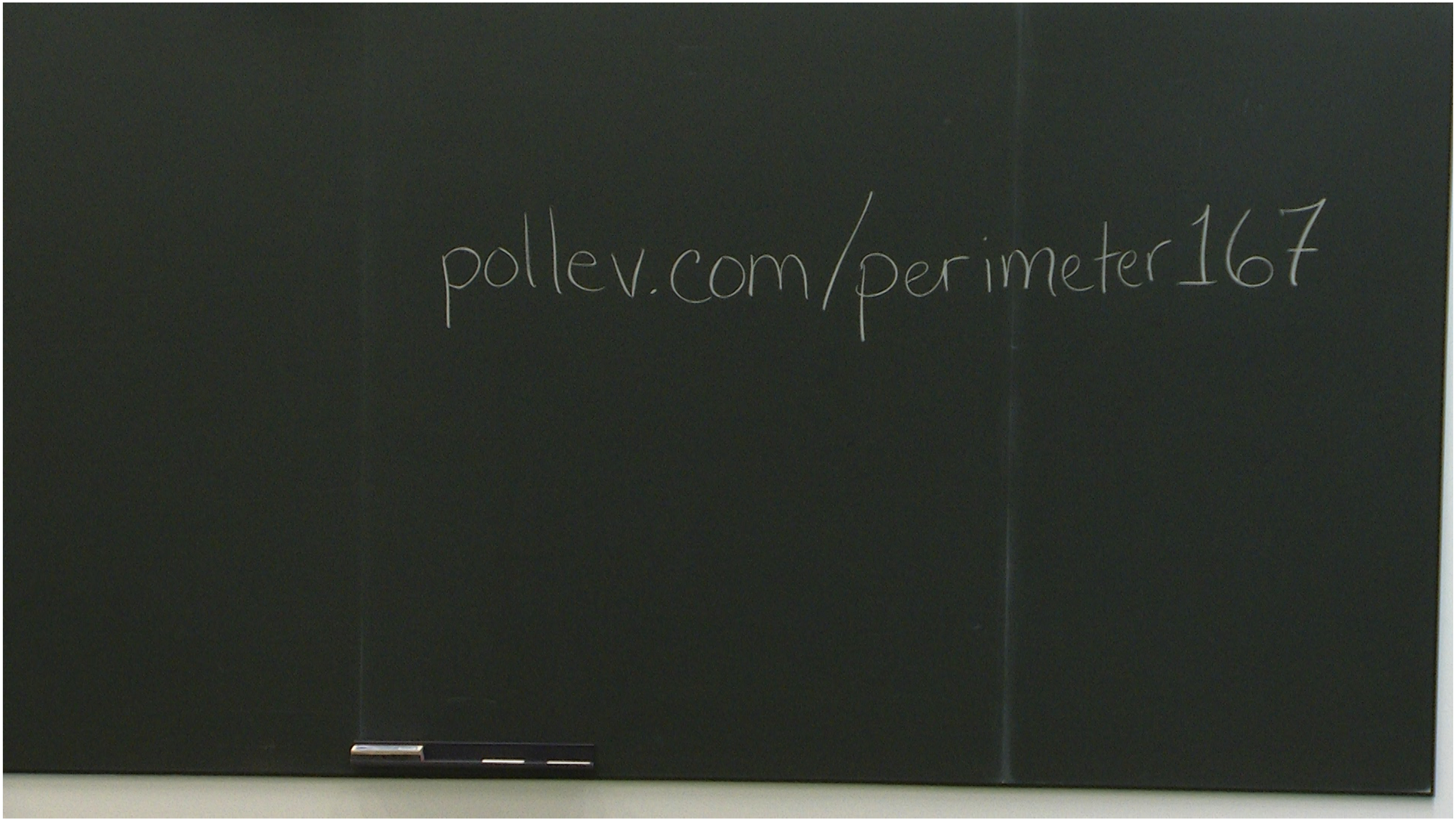
- **Quantum Correlations**
  - Coherence / Decoherence
  - Entanglement
  - Quantum Chaos / Scrambling
  - Quantum Spin Liquids

Possible behaviors in a QMB system?

Entanglement QMB

Q. Phase Transitions

Equilibrium, Scrambling, Chaos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LOCAL QUANTUM SYSTEM

- Mathematical Consistency $\quad i = 1, \ldots\ldots, N$

Q. System $(\mathcal{H}, H)$

$\mathcal{H}_i$ local Hilbert space

$\mathcal{H}_i \simeq \mathbb{C}^d$ d-level system

$\ldots, N$

$\mathbb{C}^d$ ← prime number

al Hilbert
pace

$\mathbb{C}^{d_i}$

d-level system

$\mathcal{H}_i$

$d = d_i \Rightarrow \dim \mathcal{H} = d^N$

QUANTUM SYSTEM

...thematical Consistency $i = 1, \ldots, N$

$(\mathcal{H}, H)$

$\mathcal{H}_i$ local Hilbert space

$\boxed{TPS}$ $\mathcal{H}_i \simeq \mathbb{C}^{d_i}$ d-level system

$\mathcal{H}_N = \bigotimes_{i=1}^{N} \mathcal{H}_i$ $d = d_i \Rightarrow \dim \mathcal{H} = d^N$

$\mathbb{C}^{d}$ ← prim... num...

$\mathcal{B}(\mathcal{H})$

prime number

Hermitean Bounded Operators

$$\mathcal{H}_\infty = \lim_{N\to\infty} \mathcal{H}_N$$

$$= \lim_{N\to\infty} \bigotimes_{i=1}^{N} \mathcal{H}_i$$

$$|\Phi\rangle = \prod_{i=1}^{N} |\Phi_i\rangle \; ; \; |\Psi\rangle$$ product states

$$\bigotimes_{i=1}^{N}$$

$$\langle\phi|\psi\rangle = \lim_{N\to\infty} \prod_{i=1}^{N} \langle\psi_i|\phi_i\rangle$$

$|\Phi\rangle$ reference state $= \bigotimes_i^N |\Phi_i\rangle$

$$|\varphi\rangle = \prod_{i \in I_\varphi} |\varphi_i\rangle \otimes \prod_{l \in \bar{I}_\varphi} |\varphi_l\rangle$$

$$\langle\psi|\varphi\rangle = \prod_{i \in I} \langle\varphi_i$$

$$|I| < R$$

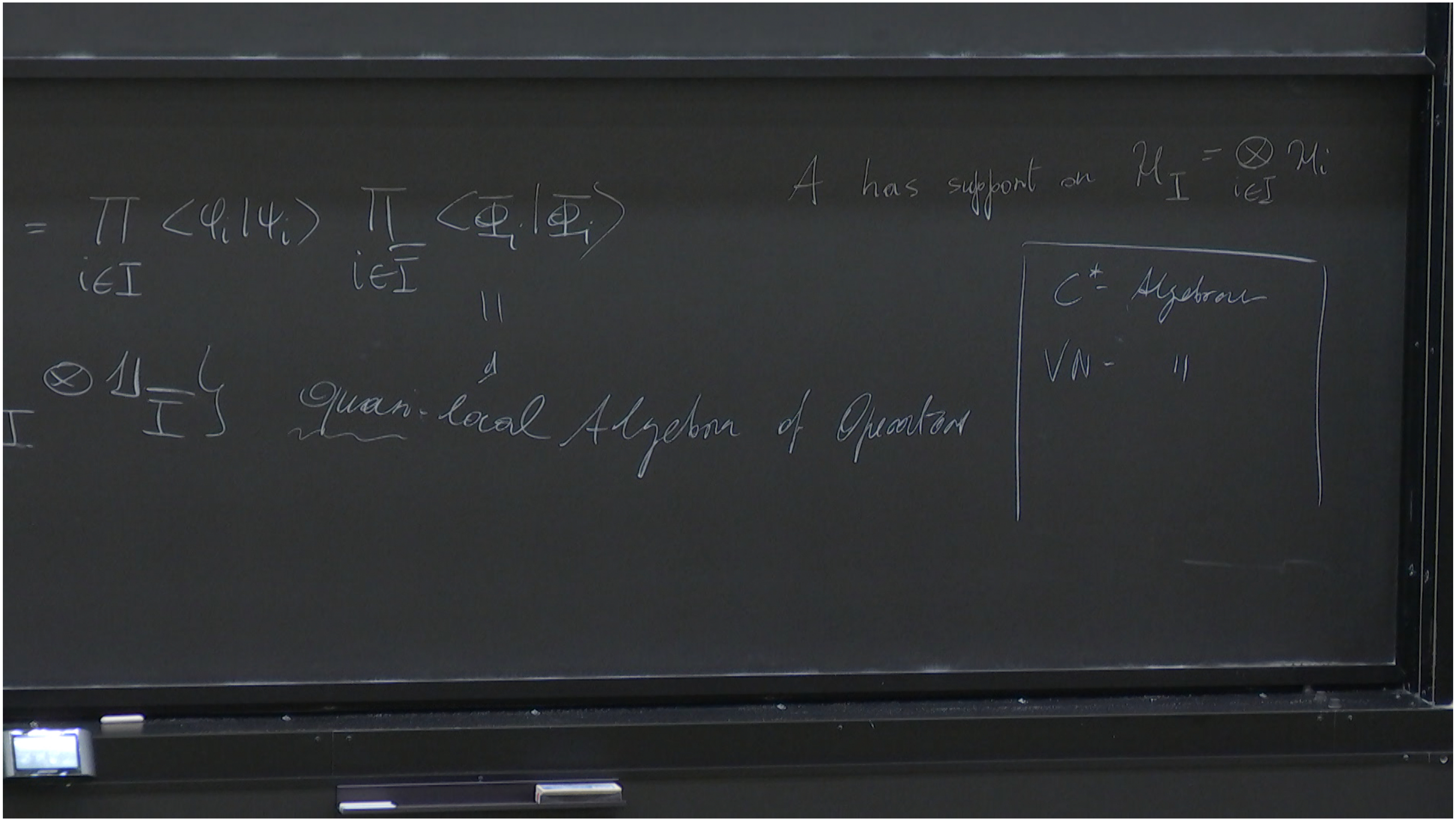
$|\Phi\rangle$ reference state $= \bigotimes_i^N |\Phi_i\rangle$

$$|\varphi\rangle = \prod_{i \in I_\varphi} |\varphi_i\rangle \otimes \prod_{l \in \bar{I}_\varphi} |\varphi_l\rangle$$

$$\langle\psi|\varphi\rangle = \prod_{i \in I} \langle\varphi_i|\psi_i\rangle$$

$$|I| < R$$

$$\mathcal{A} = \{ A = \tilde{A}_I \otimes \mathbb{1}_{\bar{I}} \}$$ qu


A has support on $\mathcal{H}_I = \bigotimes_{i\in I} \mathcal{H}_i$
$= \prod_{i\in I} \langle \varphi_i | \psi_i \rangle \prod_{i\in \bar{I}} \langle \Phi_i | \Phi_i \rangle$
$= 1$
$I \otimes \mathbb{1}_{\bar{I}} \}$ quasi-local Algebra of Operators
C*- Algebra
VN - "

$$H = \sum_{i=1}^{N} \frac{p_i^2}{2m_i} + \sum_{i,j} k_0 \frac{e_i e_j}{|x_i - x_j|}$$

Euclidean distance $d(i,j)$

V_N volume for N-particles $\sim O(N)$

$E_N \sim O(N^2)$

$$\mathcal{E}_N = \frac{E_N}{V_N} \xrightarrow{N\to\infty} \infty$$

Euclidean distance

$d(i,j)$

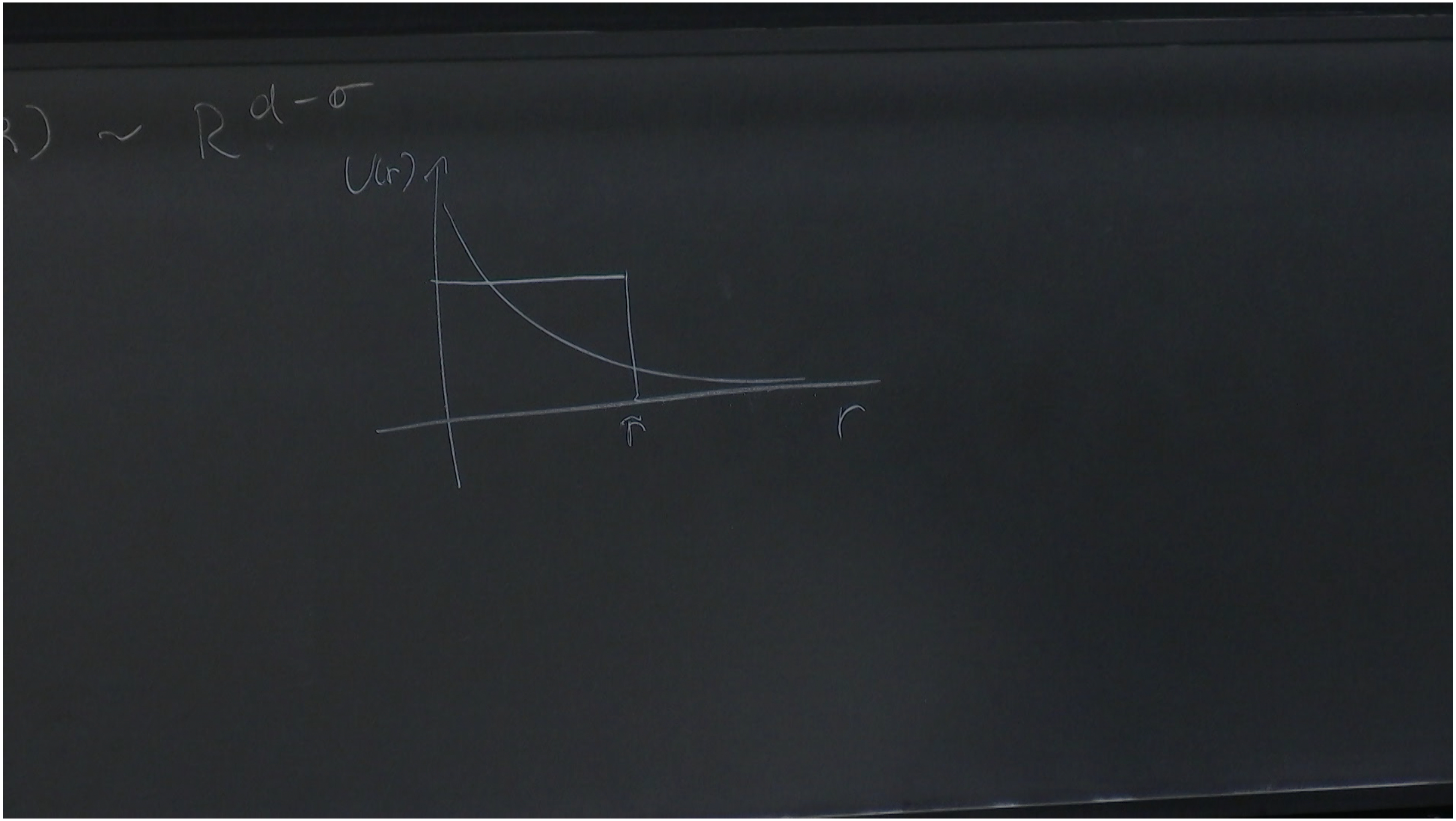
$\rho(\vec{r}) = \rho \qquad U(\vec{r}) = \frac{A}{r}$

$$E_R = \int_0^R \frac{4}{3}\pi r^3 \rho \, \frac{A}{r} \, 4\pi r^2 \rho \, dr = \frac{A}{15}(4\pi)^2 \rho^2 R^5$$

$$V_R = \frac{4}{3}\pi R^3$$

$U = A r^{-\sigma}$ $\qquad \mathcal{E}(R) \sim R^{d-\sigma}$

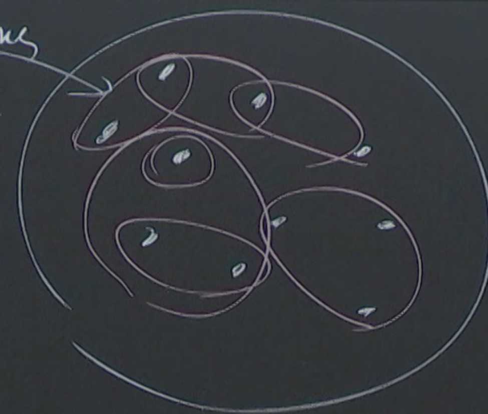
$U \sim e^{-r/D_L}$


~ R d-σ
U(r)
r̄
r

$i \in \Lambda$

$\mathcal{H} = \bigotimes_{i \in \Lambda} \mathcal{H}_i$

links



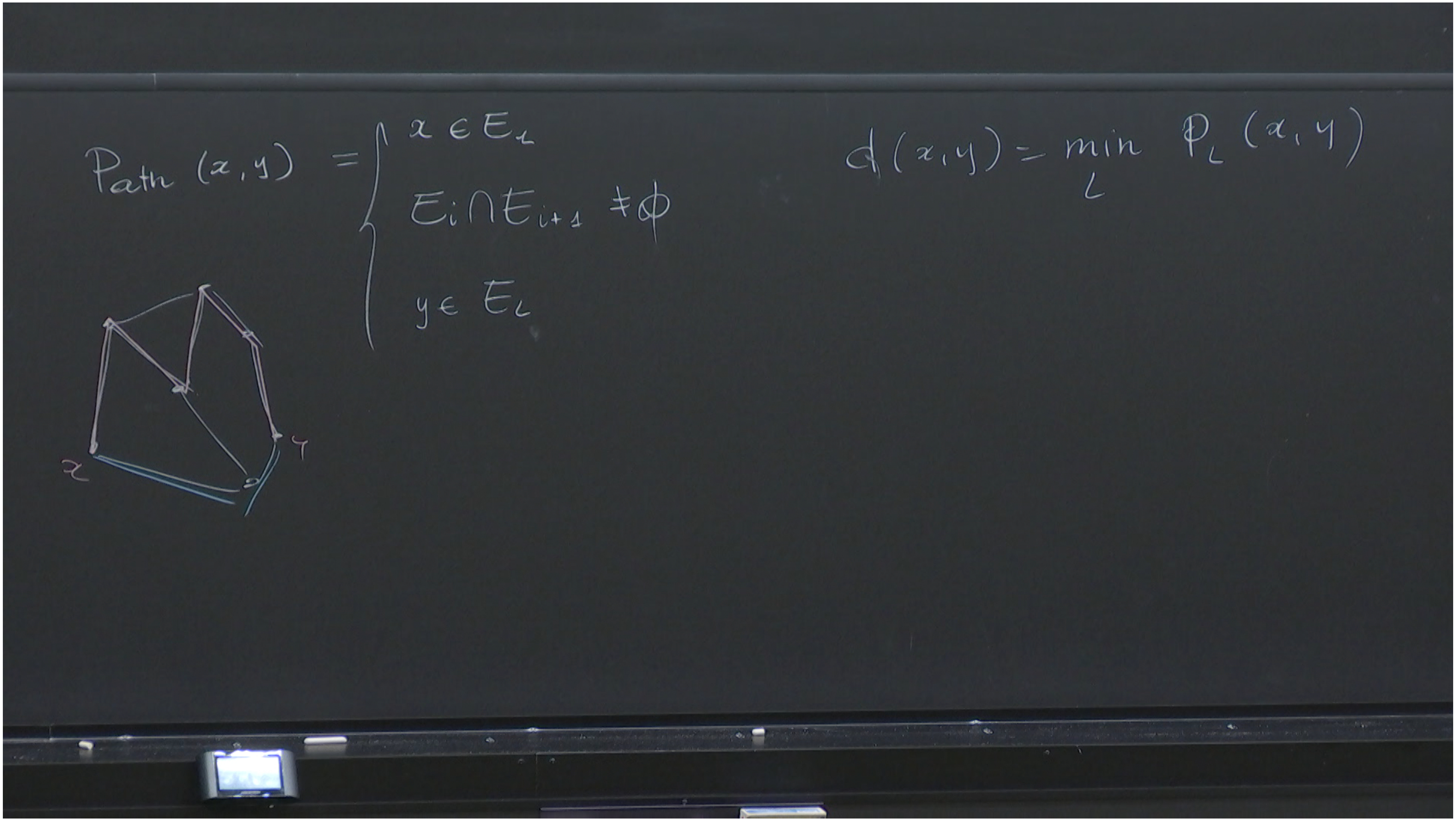
Λ

Power set $\mathcal{P}(\Lambda) \supset E$

edges

(Λ, E) Graph

$E = \{ \bigcirc \}$


$\text{Path}(x,y) = \begin{cases} x \in E_1 \\ E_i \cap E_{i+1} \neq \phi \\ y \in E_L \end{cases}$
$d(x,y) = \min_L P_L(x,y)$
x
y

$\in E_i$

$\cap E_{i+1} \neq \phi$

E_i

$$d(x,y) = \min_{L} P_L(x,y)$$

$$X \subset \Lambda \qquad \operatorname{diam} X = \max_{x,y\in X} d(x,y)$$

$\in E_i$

$\cap E_{i+1} \neq \phi$

E_i

$$d(x,y) = \min_{l} P_l(x,y)$$

$$X \subset \Lambda \qquad \mathrm{diam}\, X = \max_{x,y \in X} d(x,y)$$

$$\Phi : X \subset \Lambda \longrightarrow \Phi_X \in \mathcal{B}(\mathcal{H}_X)$$

$$n\,(x,y) = \begin{cases} x \in E_1 \\ E_i \cap E_{i+1} \neq \phi \\ y \in E_L \end{cases}$$

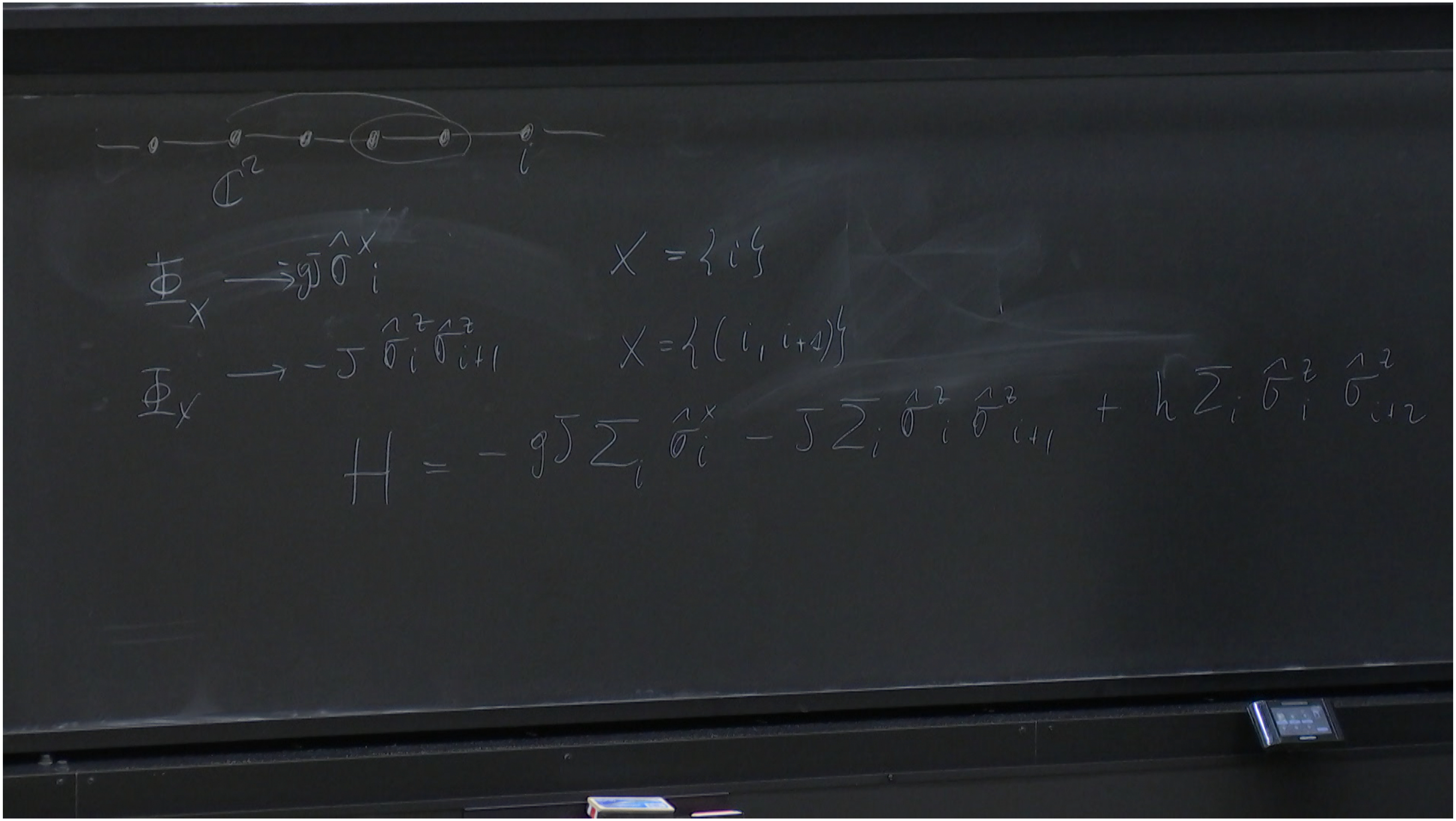
$$d(x,y) = \min_{L} P_L(x,y)$$

$$X \subset \Lambda \qquad \operatorname{diam} X = \max_{x,y \in X} d(x,y)$$

$$\Phi : X \subset \Lambda \longrightarrow \Phi_X \in \mathcal{B}(\mathcal{H}_X)$$

$\neq 0$ only X : $\operatorname{diam} X < \tilde{r}$

$$H = \sum_X \Phi_X \qquad |X| < R$$


$\mathbb{C}^2$
i
$\Phi_X \longrightarrow -gJ\hat{\sigma}^x_i$
$X=\{i\}$
$\Phi_X \longrightarrow -J\hat{\sigma}^z_i\hat{\sigma}^z_{i+1}$
$X=\{(i,i+1)\}$
$H=-gJ\sum_i \hat{\sigma}^x_i - J\sum_i \hat{\sigma}^z_i\hat{\sigma}^z_{i+1} + h\sum_i \hat{\sigma}^z_i\hat{\sigma}^z_{i+2}$