

Title: Summer Undergraduate Research Talks - 2010

Date: Aug 17, 2010 11:00 AM

URL: <http://pirsa.org/10080027>

Abstract:

ρ_0

$$U_\epsilon(\rho) = e^{-itH} \rho e^{itH}$$

ρ_0

$$U_e(\rho) = e^{-itH} \rho e^{itH}$$

ρ_0

$$\rho(t) = e^{-itH} \rho e^{itH}$$

$$\rho(t) = \rho_t$$

ρ_0

$$U_\epsilon(\rho) = e^{-itH} \rho e^{itH}$$

$$U_\epsilon(\rho_t) = \rho_t$$

ρ_0

$$U_\epsilon(\rho) = e^{-i\epsilon H} \rho e^{i\epsilon H}$$

$$U_\epsilon(\rho_\pm) = \rho_\pm$$

$$\lim_{\epsilon \rightarrow 0} \|U_\epsilon(\rho_0) - \rho_\pm\| = 0$$

ρ_0

$$U_\epsilon(\rho) = e^{-i\epsilon H} \rho e^{i\epsilon H}$$

$$U_\epsilon(\rho_\pm) = \rho_\pm$$

$$\lim_{\epsilon \rightarrow 0} \|U_\epsilon(\rho_0) - \rho_\pm\| = 0$$

$$\lim_{\epsilon \rightarrow 0} \|U_\epsilon(\rho_0) - U_\epsilon(\rho_\pm)\| = 0$$

ρ_0

$$U_t(\rho) = e^{-itH} \rho e^{itH}$$

$$U_t(\rho_t) = \rho_t$$

$$\lim_{t \rightarrow 0} \|U_t(\rho_0) - \rho_t\| = 0$$

$$\lim_{t \rightarrow \infty} \|U_t(\rho_0) - U_t(\rho_t)\|$$

ρ_0

$$U_\epsilon(\rho) = e^{-itH} \rho e^{itH}$$

$$U_\epsilon(\rho_t) = \rho_t \quad \forall t$$

$$\|\rho_0 - \rho_t\| = 0$$

$$\lim_{t \rightarrow \infty} \|U_t(\rho_0) - U_t(\rho_t)\|$$

ρ_0

$$U_\epsilon(\rho) = e^{-i\epsilon H} \rho e^{i\epsilon H}$$

$$U_\epsilon(\rho_\tau) = \rho_\tau \quad \forall \tau$$

$$\lim_{\epsilon \rightarrow 0} \|U_\epsilon(\rho_0) - \rho_\epsilon\| = 0$$

$$\lim_{\epsilon \rightarrow \infty} \|U_\epsilon(\rho_0) - U_\epsilon(\rho_\tau)\| = 0$$

$$\lim_{\epsilon \rightarrow \infty} \|U_\epsilon(\rho - \rho_\tau)\| = 0$$

$$U_t(\rho) = e^{-itH} \rho e^{itH}$$

$$U_t(\rho_t) = \rho_t \quad \forall t$$

$$\lim_{t \rightarrow 0} \|U_t(\rho_0) - \rho_t\| = 0$$

$$\lim_{t \rightarrow \infty} \|U_t(\rho_0) - U_t(\rho_t)\| = 0$$

$$\lim_{t \rightarrow \infty} \|U_t(\rho_0 - \rho_t)\| = 0$$

→ ~~lim~~
T → $\| \text{Po-} \int f \|$



$$\begin{aligned} \rightarrow \lim_{T \rightarrow \infty} \|p_0 - p_T\| &= 0 \\ &= \end{aligned}$$

$$\rightarrow \lim_{T \rightarrow \infty} \|p_0 - p_T\| = 0$$

$$\|f_0 - p_T\| = 0$$

$$\rightarrow \lim_{T \rightarrow \infty} \|p_0 - p_T\| = 0$$

$$\|p_0 - p_e\| = 0$$

$$\rightarrow \lim_{T \rightarrow \infty} \|p_0 - p_T\| = 0$$

$$\|p_0 - p_e\| = 0$$

$$A = A^+$$

$$\rightarrow \lim_{T \rightarrow \infty} \|p_0 - p_T\| = 0$$

H)

$$\|p_0 - p_e\| = 0$$

$$A = A^+$$

$$\langle A \rangle = \text{Tr} [U_\epsilon(p_0) A]$$
$$= \sum$$

$$\rightarrow \lim_{T \rightarrow \infty} \|\rho_0 - \rho_T\| = 0$$

$$\|\rho_0 - \rho_e\| = 0$$

$$A = A^\dagger$$

$$\langle A \rangle = \text{Tr} [U_e(\rho_0) A]$$

$$= \sum_{nm} \text{Tr} (e^{it(E_n - E_m)})$$

$$\langle n | \rho_0 | m \rangle \langle m | A | n \rangle$$

$$\rightarrow \lim_{T \rightarrow \infty} \|\rho_0 - \rho_T\| = 0$$

$$\|\rho_0 - \rho_e\| = 0$$

$$A = A^\dagger$$

$$\text{Tr} [U_\varepsilon(\varphi_0) A]$$

$$= \sum_{n,m} \text{Tr} (e^{it(E_n - E_m)})$$

$$\{|n\rangle\langle n| \rho_0 |m\rangle\langle m| A\}$$

$$= \sum_n \text{Tr} [|n\rangle\langle n| \rho_0 |n\rangle\langle n| A]$$

$$\rightarrow \lim_{T \rightarrow \infty} \|\rho_0 - \rho_T\| = 0$$

$$\|\rho_0 - \rho_T\| = 0$$

$$A = A^\dagger$$

$$\langle A \rangle = \text{Tr} [U_e(\varphi_0) A]$$

$$= \sum_{nm} \text{Tr} (e^{it(E_n - E_m)})$$

$$\{ |n\rangle\langle n| \rho_0 |m\rangle\langle m| A \}$$

$$\sum_{nm} \text{Tr} [|n\rangle\langle n| \rho_0 |n\rangle\langle n| A]$$

$$\rightarrow \lim_{T \rightarrow \infty} \|\rho_0 - \rho_T\| = 0$$

$$\|\rho_0 - \rho_T\| = 0$$

$$A = A^\dagger$$

$$\langle A(t) \rangle = \text{Tr} [U_\epsilon(\rho_0) A]$$

$$= \sum_{n,m} \text{Tr} \left(e^{it(E_n - E_m)} \right)$$

$$|n\rangle\langle n| \rho_0 |m\rangle\langle m| A$$

$$= \sum_{n,m} \text{Tr} \left[|n\rangle\langle n| \rho_0 |n\rangle\langle n| A \right]$$

$$\sum_{n \times m} \text{Tr} \left(e^{it(E_n - E_m)} |n\rangle\langle n| \rho_0 |m\rangle\langle m| A \right)$$

$$\rightarrow \lim_{T \rightarrow 0} \|\rho_0 - \rho_T\| = 0$$

$$\|\rho_0 - \rho_e\| = 0$$

$$A = A^\dagger$$

$$\langle A \rangle = \text{Tr} [U_e(\rho_0) A]$$

$$= \sum_{n,m} \text{Tr} (e^{it(E_n - E_m)})$$

$$|n\rangle\langle n| \rho_0 |m\rangle\langle m| A$$

$$= \sum_{n,m} \text{Tr} [|n\rangle\langle n| \rho_0 |n\rangle\langle n| A]$$

$$\sum_{n,m} \text{Tr} (e^{it(E_n - E_m)} |n\rangle\langle n| \rho_0 |m\rangle\langle m| A)$$

$$\rightarrow \lim_{T \rightarrow \infty} \|\rho_0 - \rho_T\| = 0$$

$$\|\rho_0 - \rho_e\| = 0$$

$$A = A^\dagger$$

$$\langle A \rangle = \text{Tr} [\rho_0 A]$$

$$= \sum_{n,m} \text{Tr} (e^{it(E_n - E_m)} |n\rangle\langle n| \rho_0 |m\rangle\langle m| A)$$

$$\rightarrow \sum_{n,m} \text{Tr} [|n\rangle\langle n| \rho_0 |n\rangle\langle n| A]$$

$$\sum_{n,m} \text{Tr} (e^{it(E_n - E_m)} |n\rangle\langle n| \rho_0 |m\rangle\langle m| A)$$

$\lim_{T \rightarrow \Delta}$

$$\langle A(t) \rangle = \sum_k \text{Tr} \left[\right]$$

$$\langle A(t) \rangle = \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| A]$$

$\lim_{T \rightarrow \infty} \langle A(t) \rangle = 0$

$$\lim_{T \rightarrow \infty} \langle A(t) \rangle = \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| A]$$



$$\langle A(t) \rangle \stackrel{?}{=} \sum_n \text{Tr} \left[|n\rangle \langle n| \rho_0 |n\rangle \langle n| A \right] = \frac{\lim_{T \rightarrow \infty} \int_0^T dt \langle A(t) \rangle}{T}$$

$$\lim_{T \rightarrow \infty} \langle A(t) \rangle \stackrel{?}{=} \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| A] = \lim_{T \rightarrow \infty} \frac{\int_0^T dt \langle A(t) \rangle}{T}$$

$A = \rho_0 \Rightarrow$ *meant echo*

$$S(t) \equiv \text{Tr} [\rho_0 \rho_0] = 1$$

$$\lim_{T \rightarrow \infty} \langle A(t) \rangle \stackrel{?}{=} \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| A] = \frac{\lim_{T \rightarrow \infty} \int_0^T dt \langle A(t) \rangle}{T}$$

$A = \rho_0 \Rightarrow$ Loschmidt echo $\rho_0 = |\psi(0)\rangle \langle \psi(0)|$

$$f(t) \equiv \text{Tr} [U_t(\rho_0) \rho_0] = |\langle \psi(0) | \psi(t) \rangle|^2$$

$$\lim_{T \rightarrow \infty} \langle A(t) \rangle \stackrel{?}{=} \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| A] = \frac{\lim_{T \rightarrow \infty} \int_0^T dt \langle A(t) \rangle}{T}$$

$A = \rho_0 \Rightarrow$ Loschmidt echo $\rho_0 = |\psi(0)\rangle \langle \psi(0)|$

$$L(t) \equiv \text{Tr} [\mathcal{U}_t(\rho_0) \rho_0] = |\langle \psi(0) | \psi(t) \rangle|^2$$

$$\lim_{T \rightarrow \infty} \langle A(t) \rangle \stackrel{?}{=} \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| A] = \frac{\lim_{T \rightarrow \infty} \int_0^T dt \langle A(t) \rangle}{T}$$

$A = \rho_0 \Rightarrow$ Loschmidt echo $\rho_0 = |\psi(0)\rangle \langle \psi(0)|$

$$S(t) \equiv \text{Tr} [U(\rho_0) \rho_0] = |\langle \psi(0) | \psi(t) \rangle|^2$$

$$|\psi(0)\rangle = \sum_n c_n |E_n\rangle$$

$$\bar{\rho}(t) = \sum_n |c_n|^2$$

$$\lim_{T \rightarrow \infty} \langle A(t) \rangle \stackrel{?}{=} \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| A] = \frac{\lim_{T \rightarrow \infty} \int_0^T dt \langle A(t) \rangle}{T}$$

$A = \rho_0 \Rightarrow$ Loschmidt echo $\rho_0 = |\psi(0)\rangle \langle \psi(0)|$

$$\mathcal{L}(t) \equiv \text{Tr} [U_t(\rho_0) \rho_0] = |\langle \psi(0) | \psi(t) \rangle|^2$$

$$|\psi(0)\rangle = \sum_n c_n |E_n\rangle$$

$$\mathcal{L}(t) = \sum_n |c_n|^4 = \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| \rho_0]$$

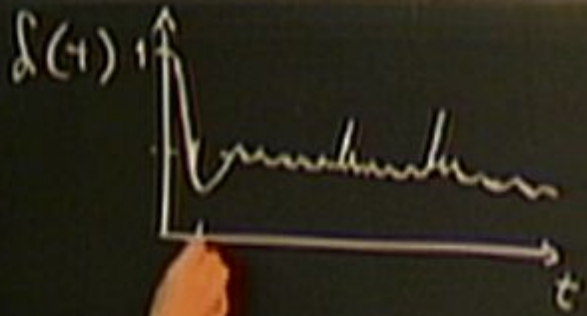
$$\lim_{T \rightarrow \infty} \langle A(t) \rangle \stackrel{?}{=} \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| A] = \frac{\lim_{T \rightarrow \infty} \int_0^T dt \langle A(t) \rangle}{T}$$

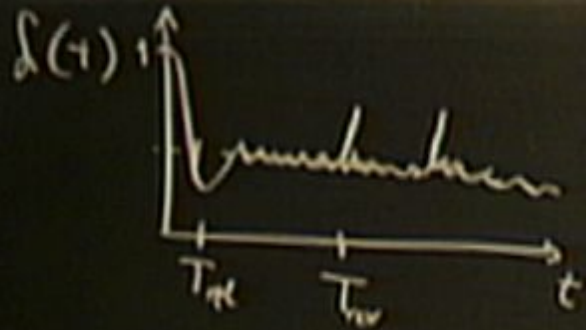
$A = \rho_0 \Rightarrow$ Loschmidt echo $\rho_0 = |\psi(0)\rangle \langle \psi(0)|$

$$f(t) \equiv \text{Tr} [U(\rho_0) \rho_0] = |\langle \psi(0) | \psi(t) \rangle|^2$$

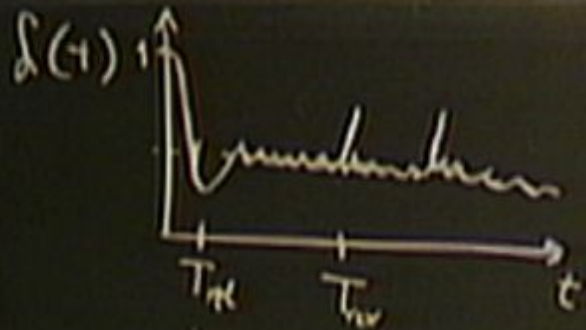
$$|\psi(0)\rangle = \sum_n c_n |E_n\rangle$$

$$\bar{f}(t) = \sum_n |c_n|^4 = \sum_n \text{Tr} [|n\rangle \langle n| \rho_0 |n\rangle \langle n| \rho_0]$$





A hand-drawn sketch of a signal pulse. The pulse is a single, slightly curved line that starts at a point, rises to a peak, and then falls back to the baseline. Below the pulse, the duration is labeled T_{me} .

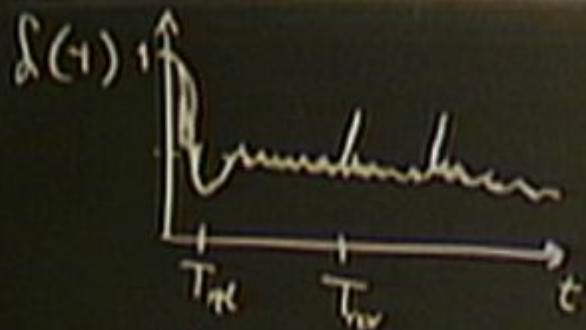


T_{rec}

$$T_{Hd} \sim \frac{1}{\epsilon_{max} - \epsilon_{min}}$$

$$T_{rec} \sim \mathcal{O}(e^N)$$

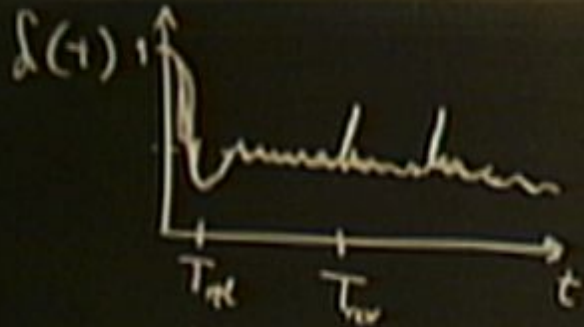
T_{rev}



$$T_H \sim \frac{1}{\text{bandwidth}}$$

$$T_m \sim \mathcal{O}(e^N)$$

$$T_W \sim \frac{N}{\dots}$$

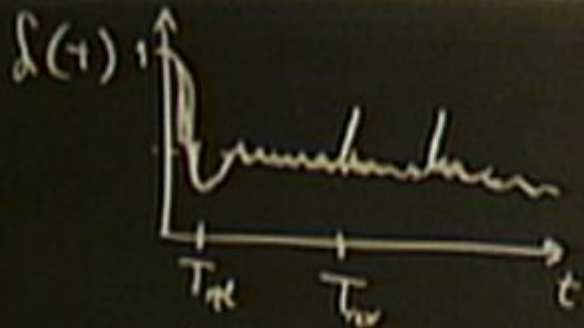


T_{rev}

$$T_{rel} \sim \frac{1}{\epsilon_{max} - \epsilon_{min}}$$

$$T_{rel} \sim \mathcal{O}(e^N)$$

$$T_{rev} \sim \frac{N}{D}$$



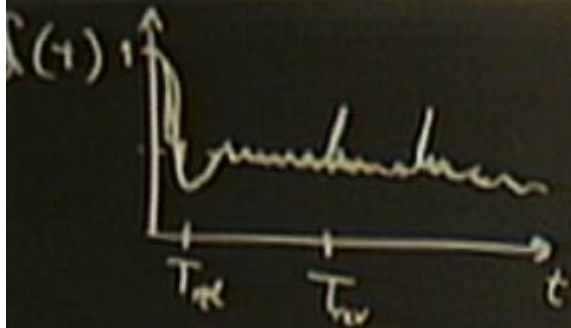
T_{rel}

$$T_{rel} \sim \frac{1}{\epsilon_{max} - \epsilon_{min}}$$

$$T_{rel} \sim O(e^N)$$

$$T_{rev} \sim \frac{N}{D}$$

$$H_t^x = \frac{1}{2} \sum_{j=1}^N (1-\gamma) \sigma_j^x \sigma_{j+1}^x + (1-\gamma) \sigma_j^y \sigma_j^y - \frac{\gamma}{2} \sum_j \sigma_j^z$$



$$T_{\text{diel}} \sim \frac{1}{E_{\text{exc}} - E_{\text{em}}}$$

$$T_{\text{rev}} \sim \mathcal{O}(e^N)$$

$$T_{\text{rev}} \sim \frac{N}{D}$$

T_{rec}

$$H = -\frac{1}{2} \sum_{j=1}^N ((1-\gamma) \sigma_j^x \sigma_{j+1}^x + (1-\gamma) \sigma_j^y \sigma_{j+1}^y) - \frac{\hbar}{2} \sum_j \sigma_j^z$$

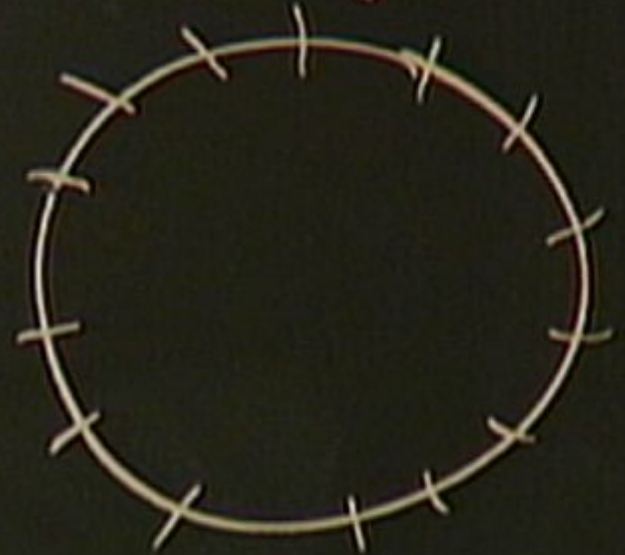
$N+1=1$



$$H = -\frac{1}{5} \sum_{j=1}^N (1-\gamma) \sigma_j^x \sigma_{j+1}^x + (1-\gamma) \sigma_j^y \sigma_j^y$$

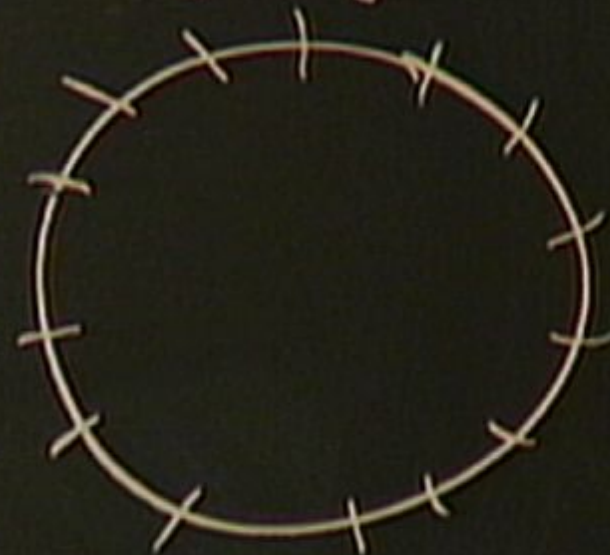
$$-\frac{5}{2} \sum_j \sigma_j^z$$

$$N+1=1$$



$$H = -\frac{1}{5} \sum_{s=1}^N (1-\gamma) \sigma_s^x \sigma_{s+1}^x + (1-\gamma) \sigma_s^y \sigma_{s+1}^y - \frac{h}{2} \sum_s \sigma_s^z$$

$N+1=1$



- $\gamma=1 \Rightarrow$ TFIM
- * Exactly solvable
 - * Phase diagram

$$H = -\frac{1}{5} \sum_{s=1}^N (1-\nu) \sigma_s^x \sigma_{s+1}^x + (1-\nu) \sigma_s^y \sigma_{s+1}^y - \frac{h}{2} \sum_s \sigma_s^z$$

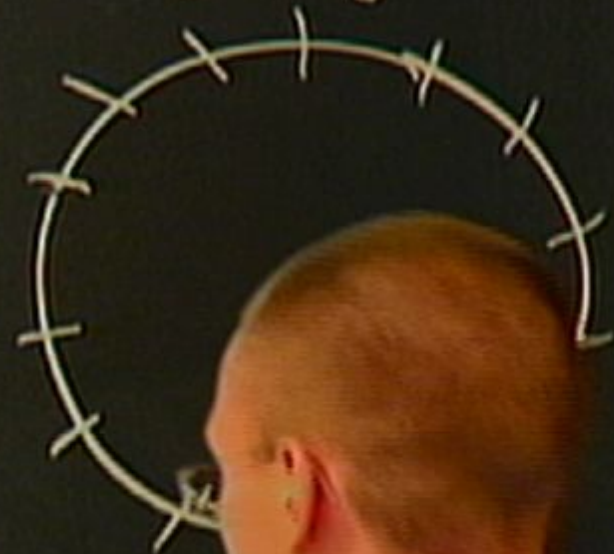
$$N+1=1$$

$\nu=1 \Rightarrow$ TFIM

* Exactly solvable

* Phase diagram

$$H = \sum_k \Lambda_k \eta_k^\dagger \eta_k$$



$$H = -\frac{1}{5} \sum_{s=1}^N (1-\gamma) \sigma_s^x \sigma_{s+1}^x + (1-\gamma) \sigma_s^y \sigma_{s+1}^y - \frac{h}{2} \sum_s \sigma_s^z$$

$$N+1=1$$

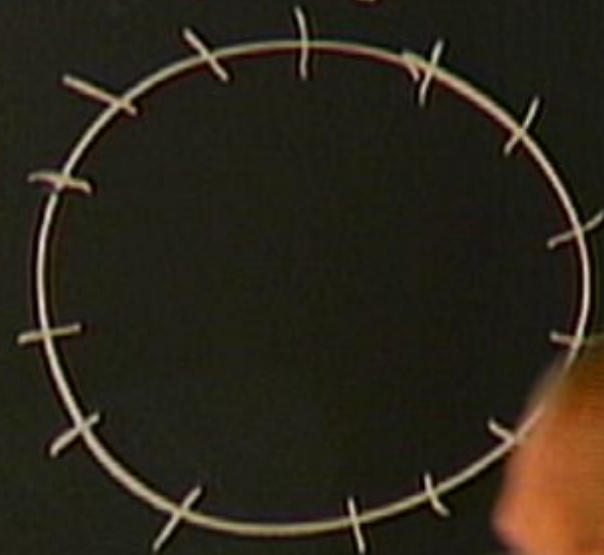
$\gamma=1 \Rightarrow$ TFIM

* Exactly solvable

* Phase diagram

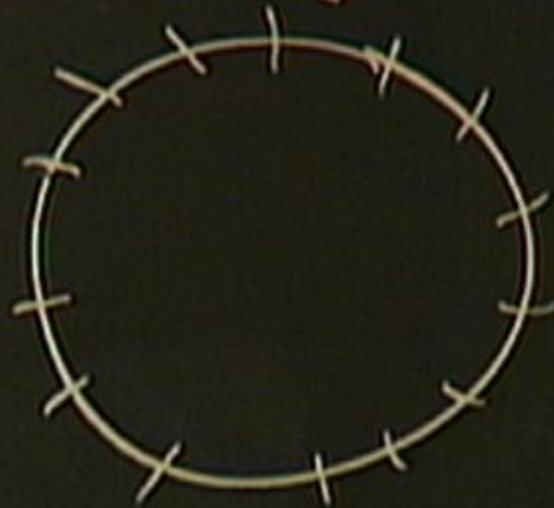
$$H = \sum_k \Lambda_k \eta_k^+ \eta_k$$

$$\{\eta_k^+, \eta_{k'}\} = \delta_{k',k}$$



$$H = -\frac{1}{5} \sum_{\langle j, l \rangle} (1-\nu) \sigma_j^x \sigma_l^x + (1-\nu) \sigma_j^y \sigma_l^y - \frac{h}{2} \sum_j \sigma_j^z$$

$N+1=1$



$\nu=1 \Rightarrow$ TFIM

* Exactly solvable

* Phase diagram

$$H = \sum_k \Lambda_k \eta_k^+ \eta_k$$



$$\{\eta_k^+, \eta_{k'}\} = \delta_{k',k}$$

$$\{\eta_k, \eta_{k'}\} = 0$$

* Exactly solvable

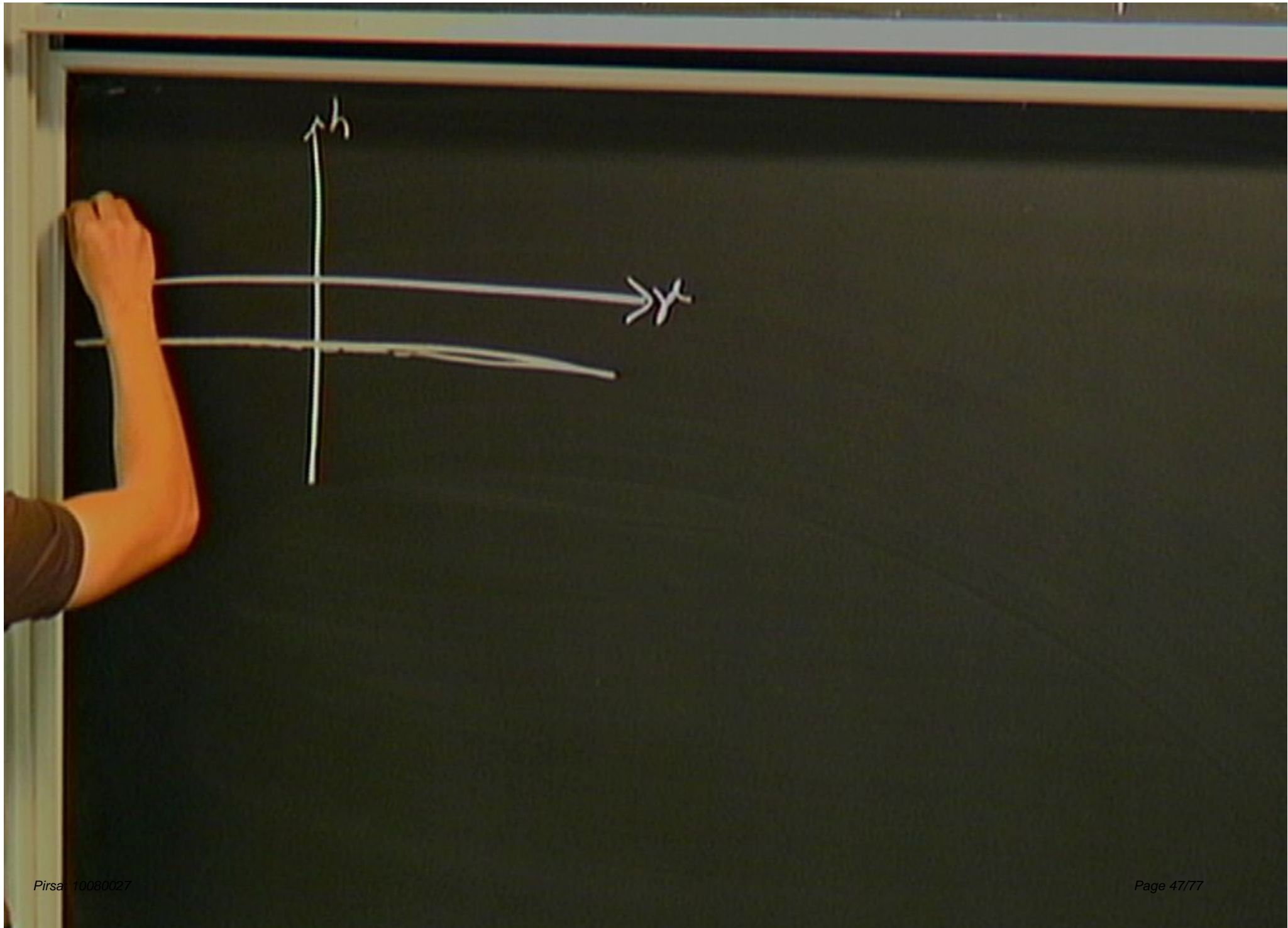
* Phase diagram

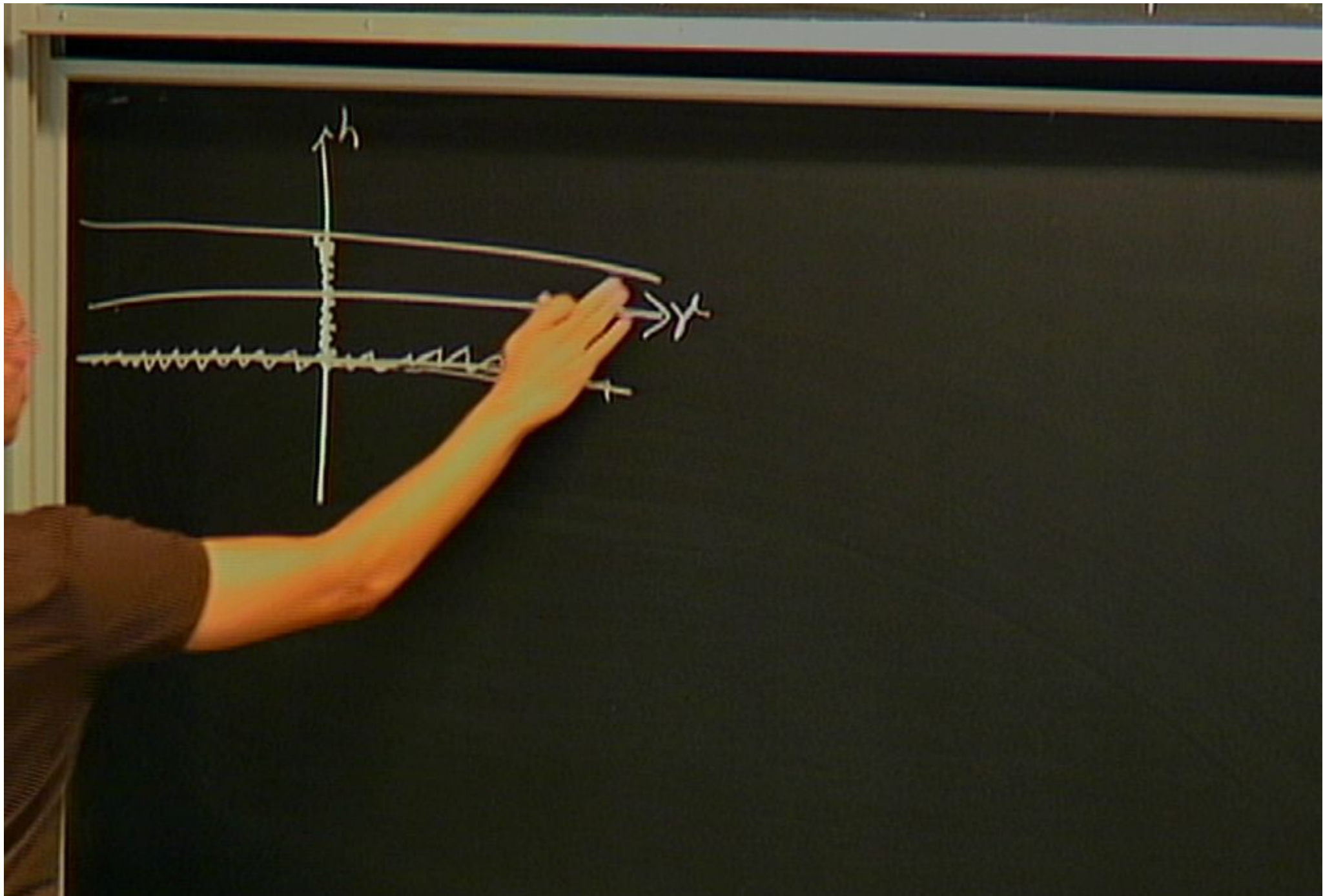
$$H = \sum_k \Lambda_k \eta_k^\dagger \eta_k$$

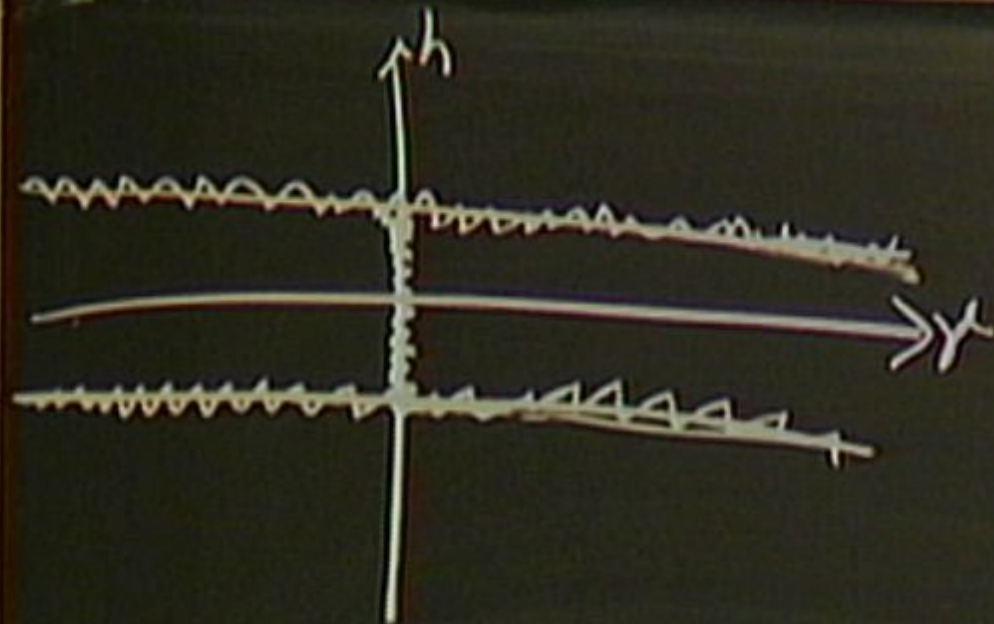
$$\{\eta_k^\dagger, \eta_{k'}\} = \delta_{k,k'}$$

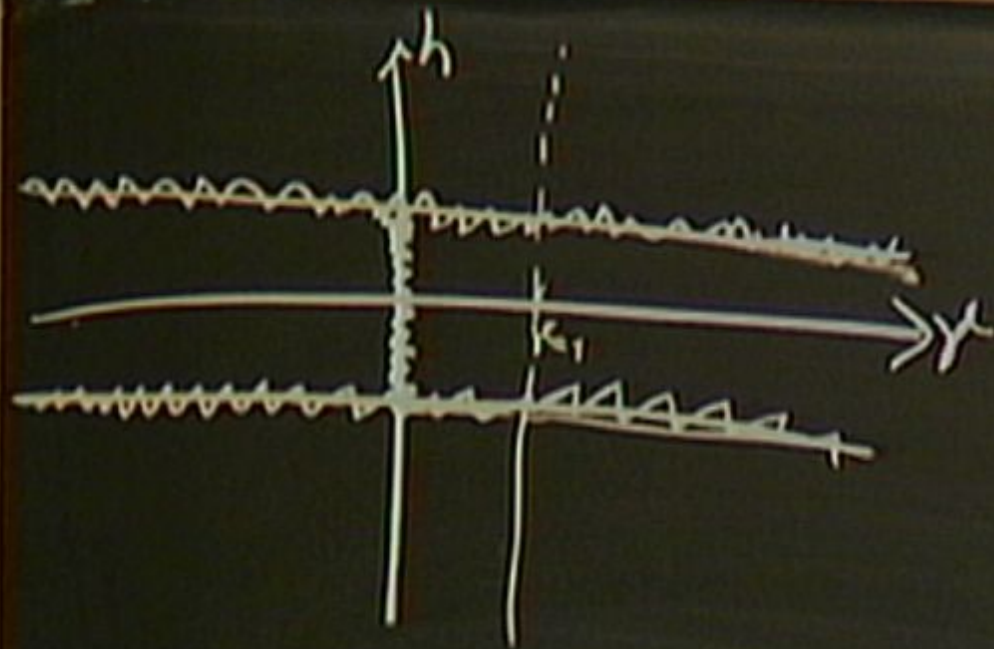
$$\{\eta_k, \eta_{k'}\} = 0$$

$$\Lambda_k = \sqrt{(h + \gamma \cos k)^2 + \gamma^2 \sin^2 k}$$







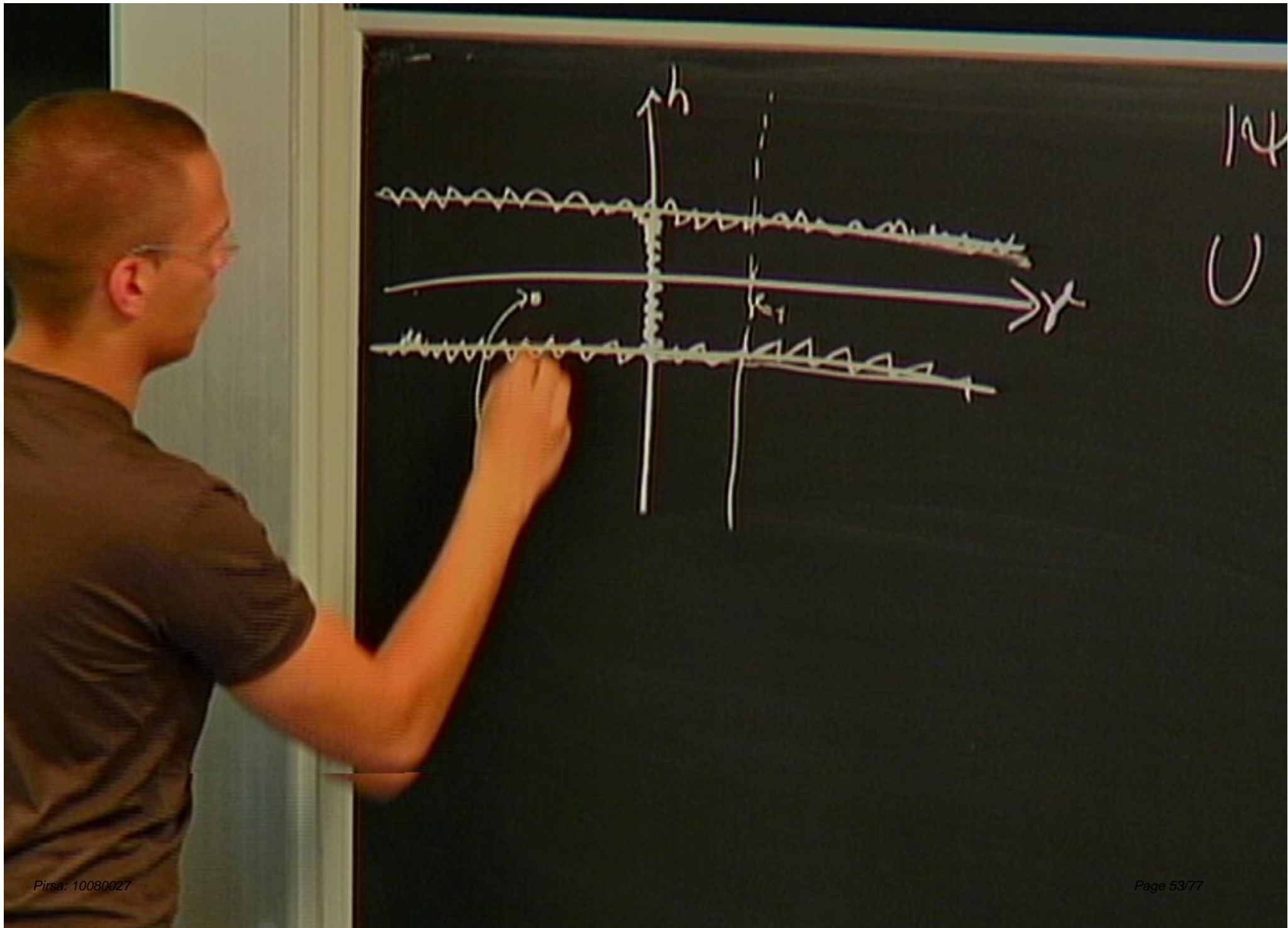


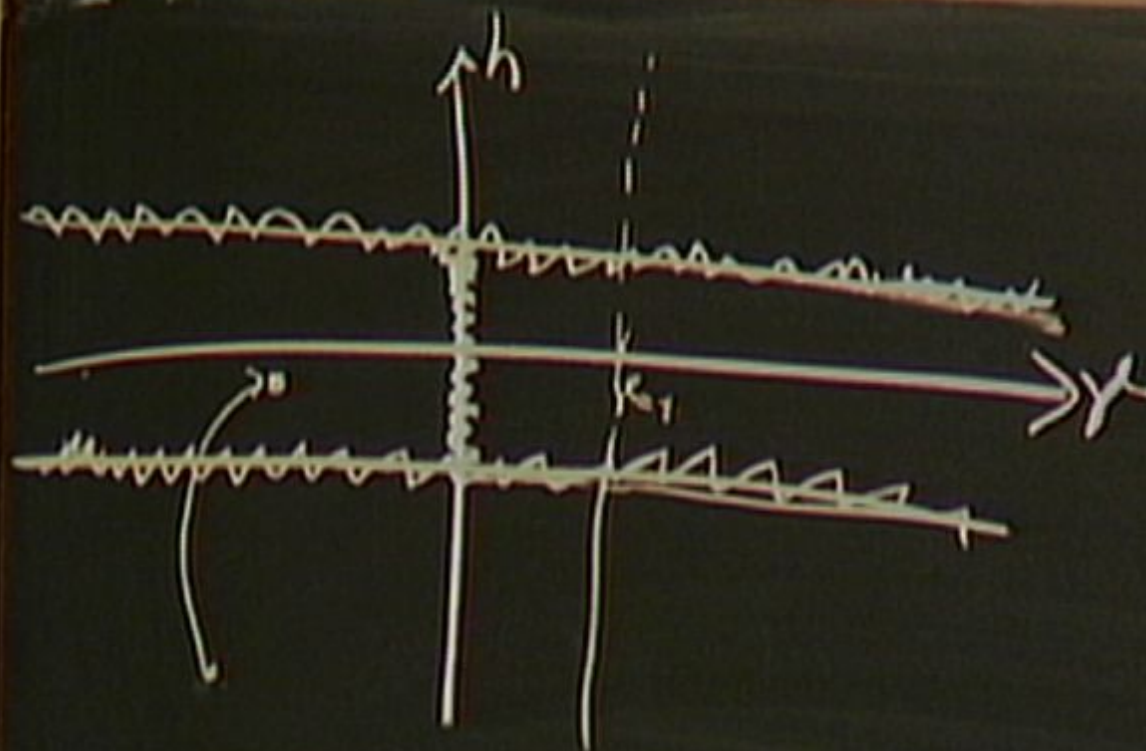
$$|\Psi(0)\rangle = |\text{GS}(h_1, \gamma_1)\rangle$$

$$U = e^{-itH_2}$$

$$|\Psi(0)\rangle = |\text{GS}(h_1, \gamma_1)\rangle$$

$$U = e^{-itH_2(h_2, \gamma_2)}$$





14
U

$$|\Psi(0)\rangle = |\text{GS}(h_1, \gamma_1)\rangle$$

$$U = e^{-itH_2(h_2, \gamma_2)}$$

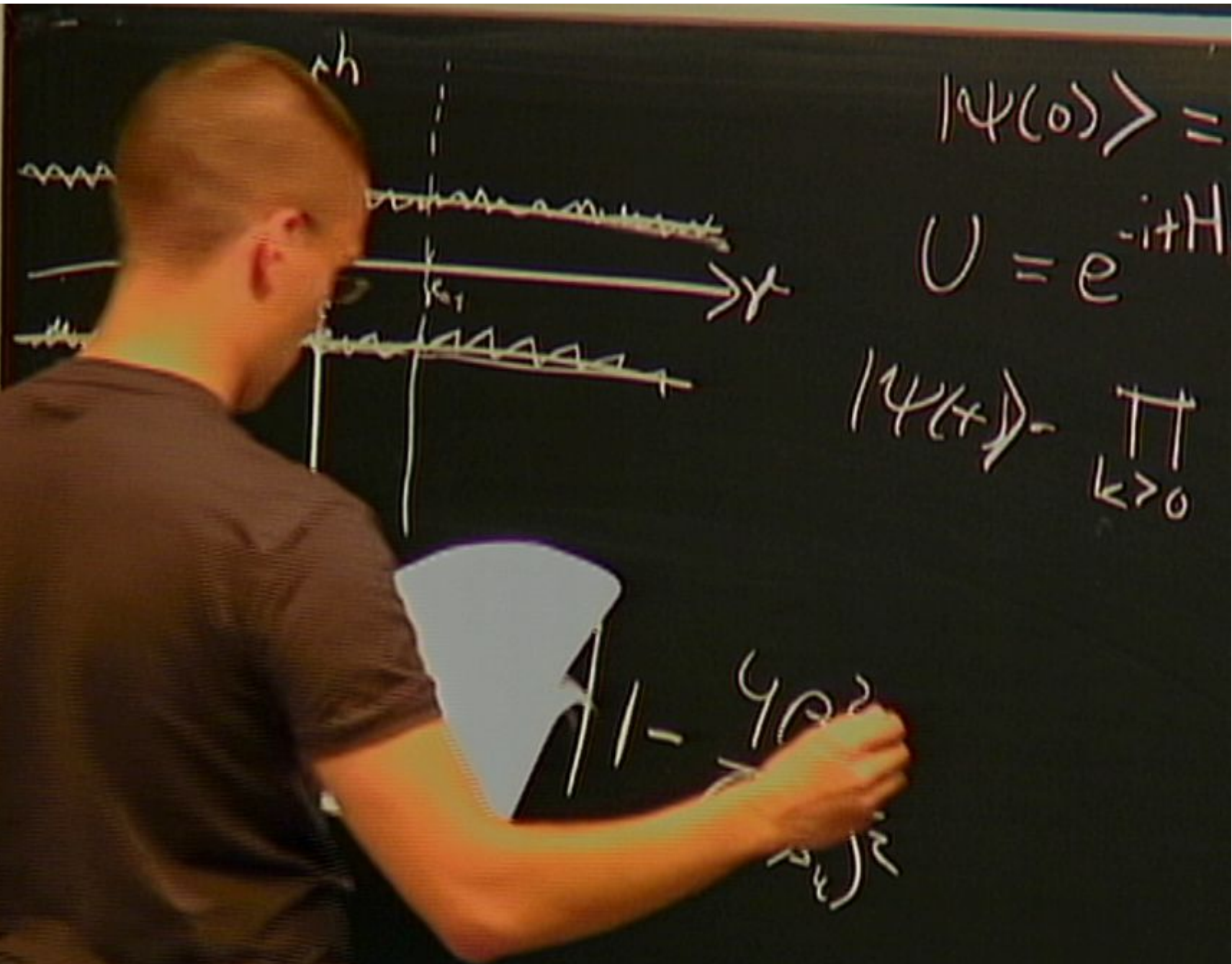
$$|\Psi(t)\rangle = \prod_{k>0} \frac{1}{\sqrt{1+\beta_k^2}} \left(1 + \beta_k e^{-it2\Lambda_k} \eta_k^+ \eta_k^+ \right) |0_k\rangle$$

$$|\Psi(0)\rangle = |\text{GS}(h_1, \gamma_1)\rangle$$

$$k = \frac{2\pi n}{N}$$

$$U = e^{-itH_2(h_2, \gamma_2)}$$

$$|\Psi(t)\rangle = \prod_{k>0} \frac{1}{\sqrt{1+\beta_k^2}} \left(1 - \beta_k e^{-it2\Lambda_k} \eta_k^+ \gamma_k^+ \right) |0_k\rangle$$



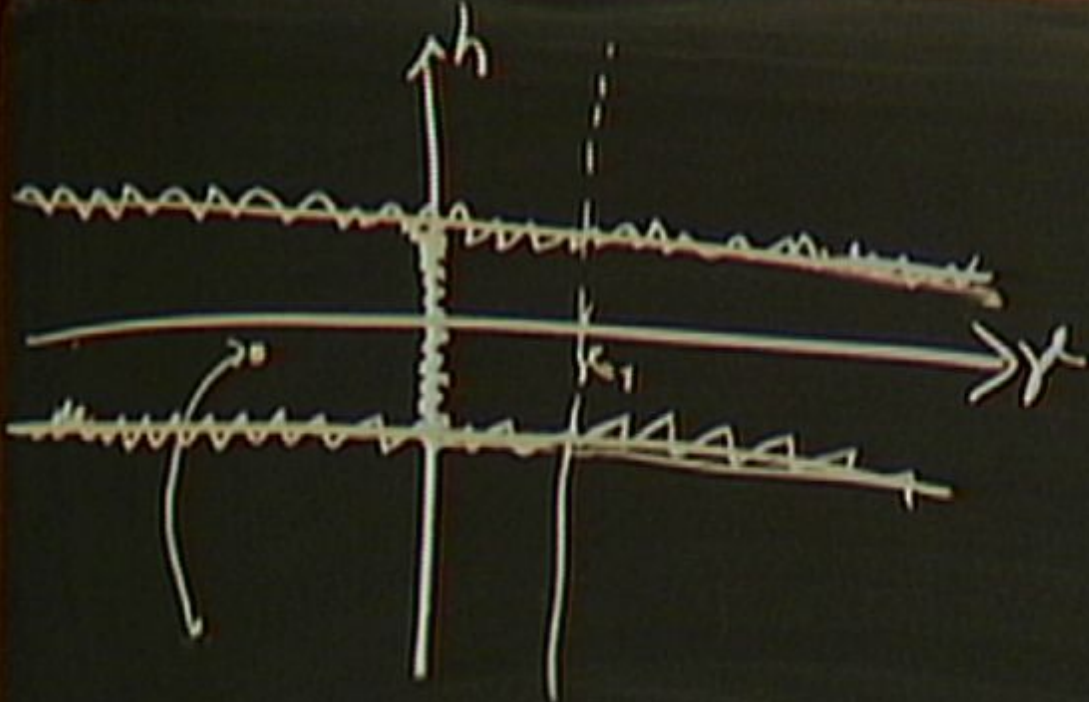
$$|\psi(0)\rangle =$$

$$U = e^{-iHt}$$

$$|\psi(t)\rangle = \int_{k>0} \dots$$

$$1 - \frac{4\alpha^2}{k^2 + \alpha^2}$$

CAUTION
 Do not use chalk for writing on the board.
 Use white markers for writing on the board.
 Pirs: 10080027



$$|\psi(0)\rangle = |0\rangle$$

$$U = e^{-itH_2}(\hbar)$$

$$|\psi(t)\rangle = \prod_{k>0} \sqrt{\dots}$$

$$f(t) = \prod_{k>0} \left| \frac{1}{1 - \frac{4\beta_k^2}{(\beta_k+1)^2} \sin^2(\beta_k t)} \right|$$

$$|\psi(0)\rangle = |GS(h_1, \gamma_1)\rangle$$

$$k = \frac{2\pi n}{N}$$

$$U = e^{-itH_2(h_2, \gamma_2)}$$

$$|\psi(t)\rangle = \prod_{k>0} \frac{1}{\sqrt{1+\beta_k^2}} \left(1 + \beta_k e^{(1\rightarrow 2) - it2\Lambda_k^{(2)} \frac{m_1^+ m_2^+}{\hbar}} \right) |a_k\rangle$$

$$\frac{4\beta_k^2}{(1+\beta_k)^2} \sin^2(\gamma) \Big|$$

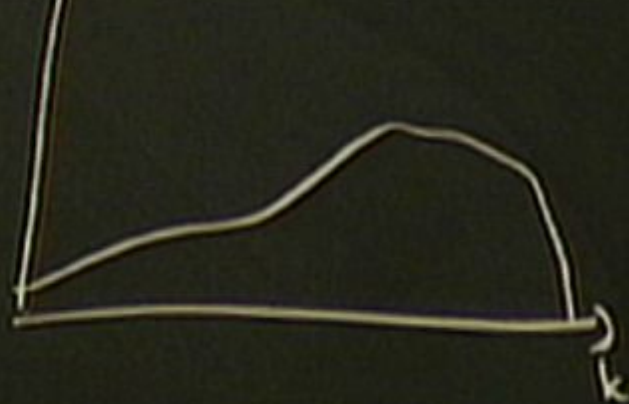
$$|\psi(0)\rangle = |GS(h_1, \gamma_1)\rangle$$

$$k = \frac{2\pi h}{N}$$

$$U = e^{-itH_2(h_2, \gamma_2)}$$

$$|\psi(t)\rangle = \prod_{k>0} \frac{1}{\sqrt{1+\beta_k^2}} \left(1 + \beta_k e^{(i \rightarrow 2) - it 2\Lambda_k^{(2)} \frac{m_1^2 + m_2^2}{\hbar}} \right) |0_k\rangle$$

$$\frac{4\beta_k^2}{(1+\beta_k^2)^2} \sin^2(kx)$$



$$|0\rangle = |GS(h_1, \gamma_1)\rangle$$

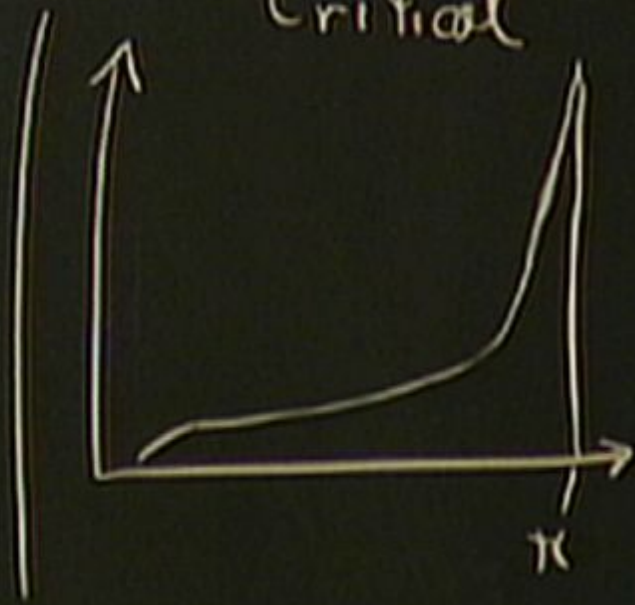
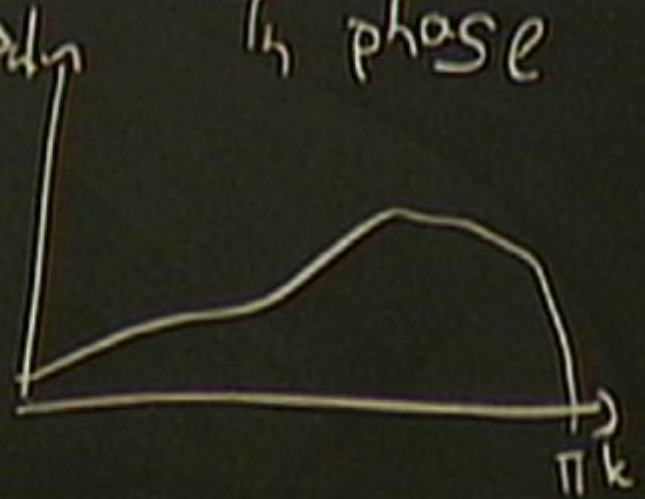
$$k = \frac{2\pi n}{N}$$

$$e^{-itH_2(h_2, \gamma_2)}$$

$$\prod_{k>0} \frac{1}{\sqrt{1+\beta_k^2}} \left(1 + \beta_k e^{i\theta_k} e^{-it2\Lambda_k^{(2)}} \right) |0_k\rangle$$

β_k in phase Critical

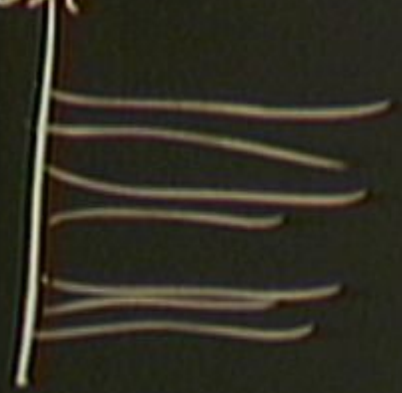
(1x)

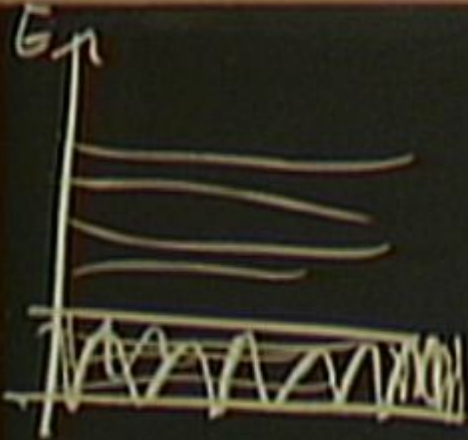


G_n



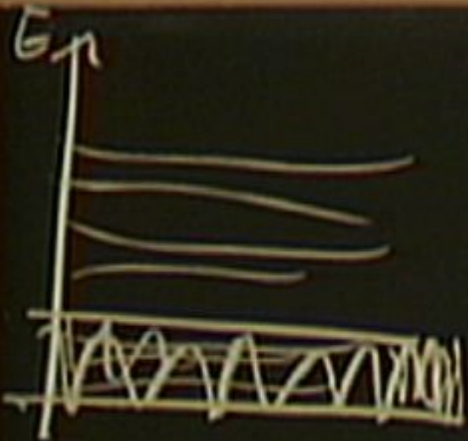
G_n





$$T_{\text{rel}} \sim \frac{N}{E_{\text{max}} - E_{\text{min}}}$$

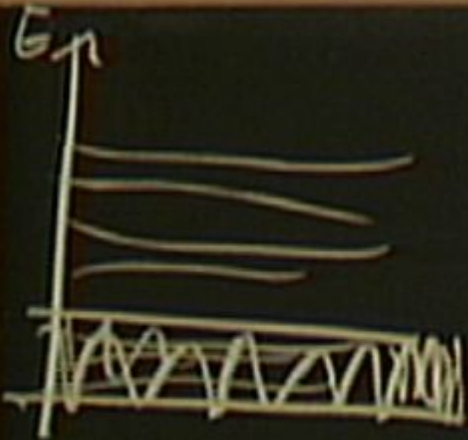
$$T_{\text{rev}} \sim N_{\text{max}}$$



$$T_{\text{rel}} \sim \frac{N}{E_{\text{max}} - E_{\text{min}}}$$

$$T_{\text{rev}} \sim N \left(\max_k \left| \frac{\partial \lambda_k}{\partial k} \right| \right)^2$$

$$\eta_k = \frac{1}{\sqrt{N}} \sum_k e^{i(kx - \lambda_k t)}$$

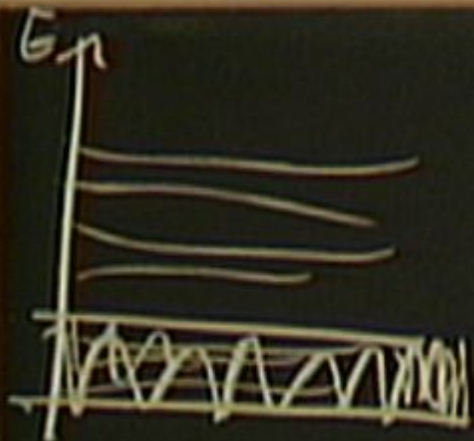


$$T_{\text{rev}} \sim \frac{1}{E_{\text{max}} - E_{\text{min}}}$$

$$T_{\text{rev}} \sim N \left(\max_k \left| \frac{\partial \Lambda_k}{\partial k} \right| \right)^{-1}$$

$$\eta_k = \frac{1}{\sqrt{N}} \sum_k e^{i(kk - \Lambda_k t)} \eta_k$$

$k \rightarrow k + \delta k$ $\Lambda_k \rightarrow \Lambda_{k_0} + \delta \Lambda$



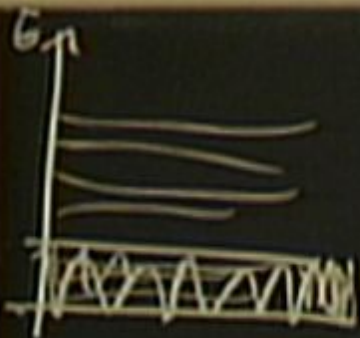
$$T_{\text{rev}} \sim \frac{1}{E_{\text{max}} - E_{\text{min}}}$$

$$T_{\text{rev}} \sim N \left(\max_k \left| \frac{\partial \lambda_k}{\partial k} \right| \right)^{-1}$$

$$\eta_k = \frac{1}{\sqrt{N}} \sum_k e^{i(kx - \lambda_k t)} \eta_k$$

$k \rightarrow k + \delta k \quad \lambda_k \rightarrow \lambda_{k_0} + \delta \lambda$

$$\delta k N - \delta \lambda t = 2\pi n$$



$$T_{rev} \sim \frac{N}{\epsilon_{max} t_{min}}$$

$$T_{rev} \sim N \left(\max_k \left| \frac{\partial \lambda_k}{\partial k} \right| \right)^{-1}$$

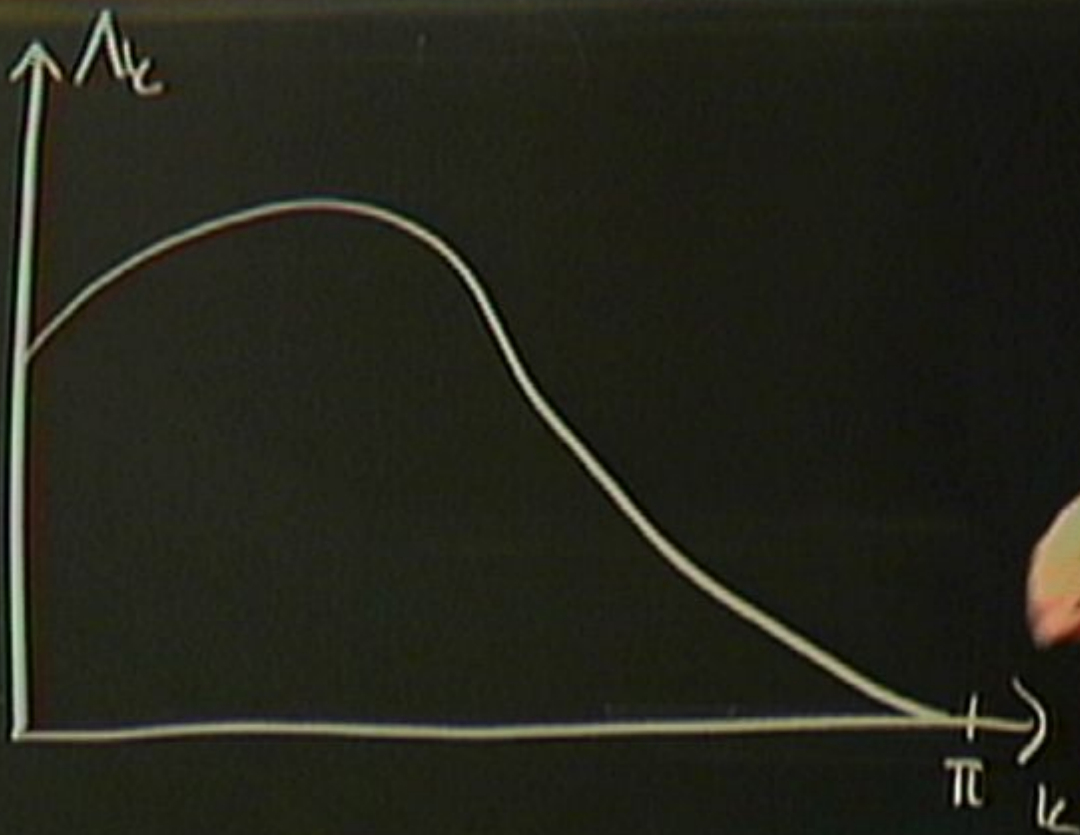
$$\eta_k = \frac{1}{\sqrt{N}} \sum_k e^{i(kk - \lambda_k t)} \eta_k$$

$k \rightarrow k + \delta k \quad \lambda_k \rightarrow \lambda_{k_0} + \delta \lambda$

$$\delta k N - \delta \lambda t = 2\pi n$$

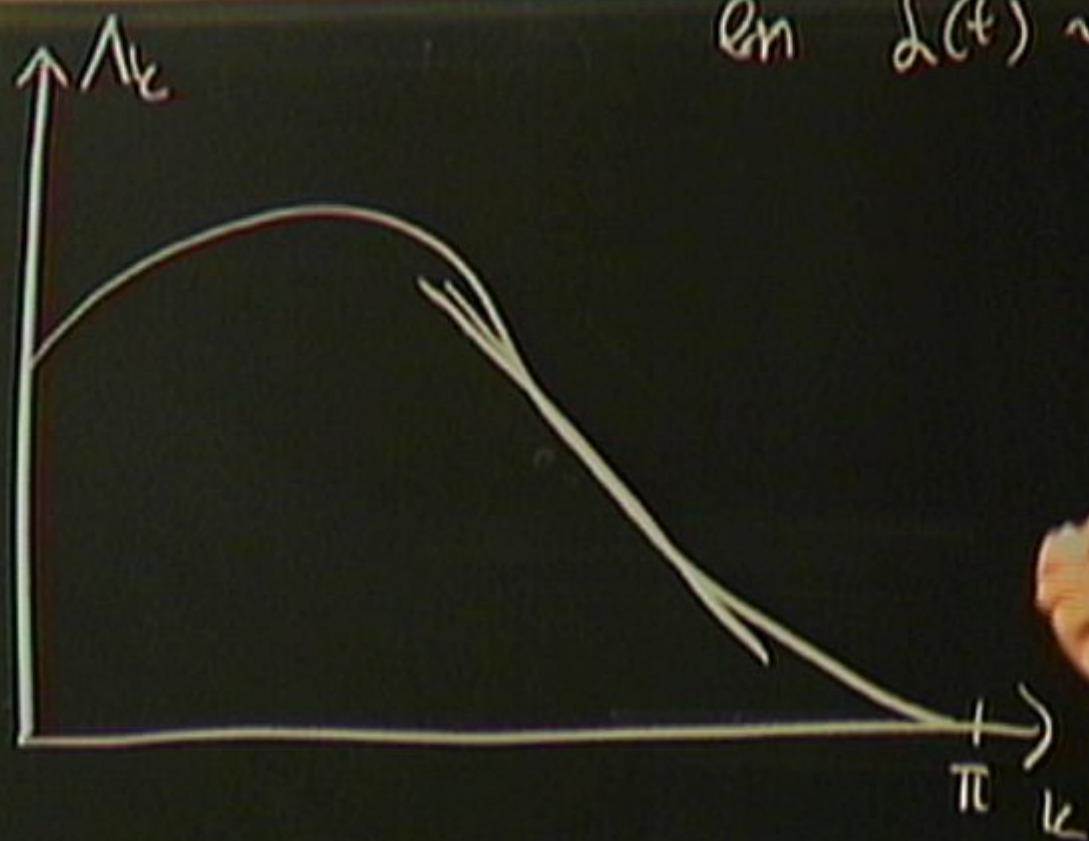
$$t = N \frac{\delta k}{\delta \lambda} \left(\frac{\partial \lambda}{\partial k} \right)^{-1}$$

CAUTION
 Do not touch the board
 Do not touch the board
 Do not touch the board



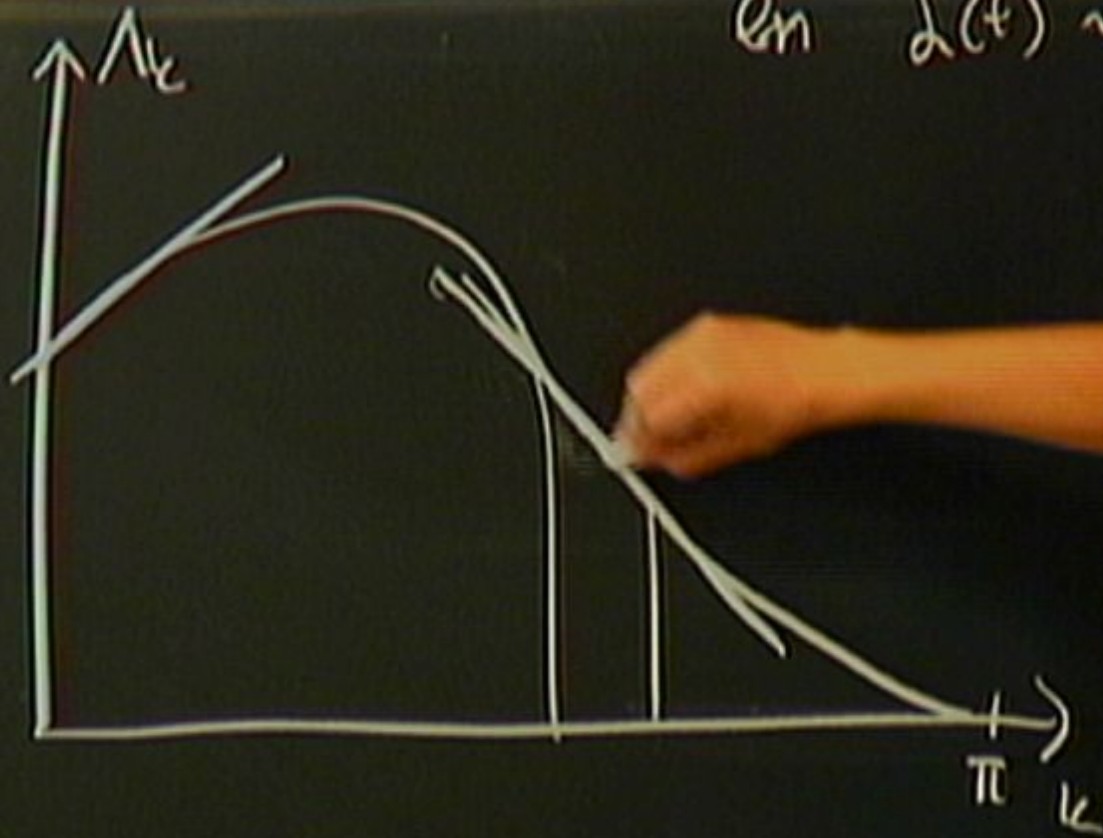
$$t = N \frac{\delta k}{\delta \lambda} (\vec{v}_g)$$

$$\text{en } d(t) \sim \sum_k \frac{\beta_k}{(1+\alpha_k)} \sin^2(kl)$$



$$t = N \frac{\delta k}{\delta \lambda} (\vec{R}_k)$$

$$\text{en } \mathcal{L}(t) \sim \sum_k \frac{\delta_k^2}{(1+\beta_k)} \sin^2(kl)$$



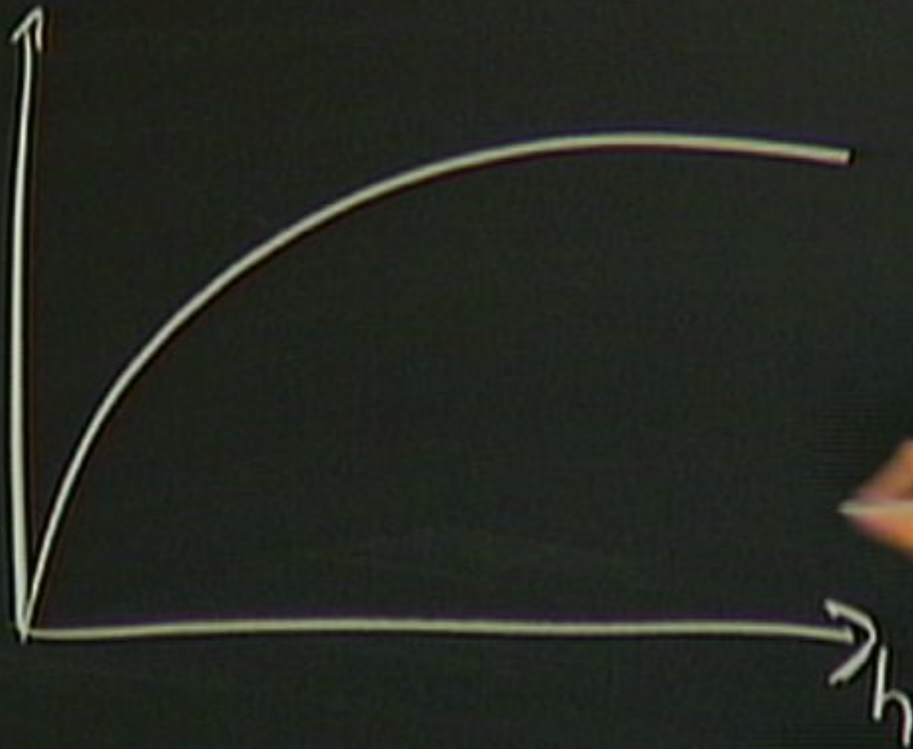
$$t = N \frac{\delta_k}{\delta \lambda} \approx (N \beta_k)$$

Lieb - Robinson

$$\text{TFIM} \sim \nu = \sqrt{h}$$

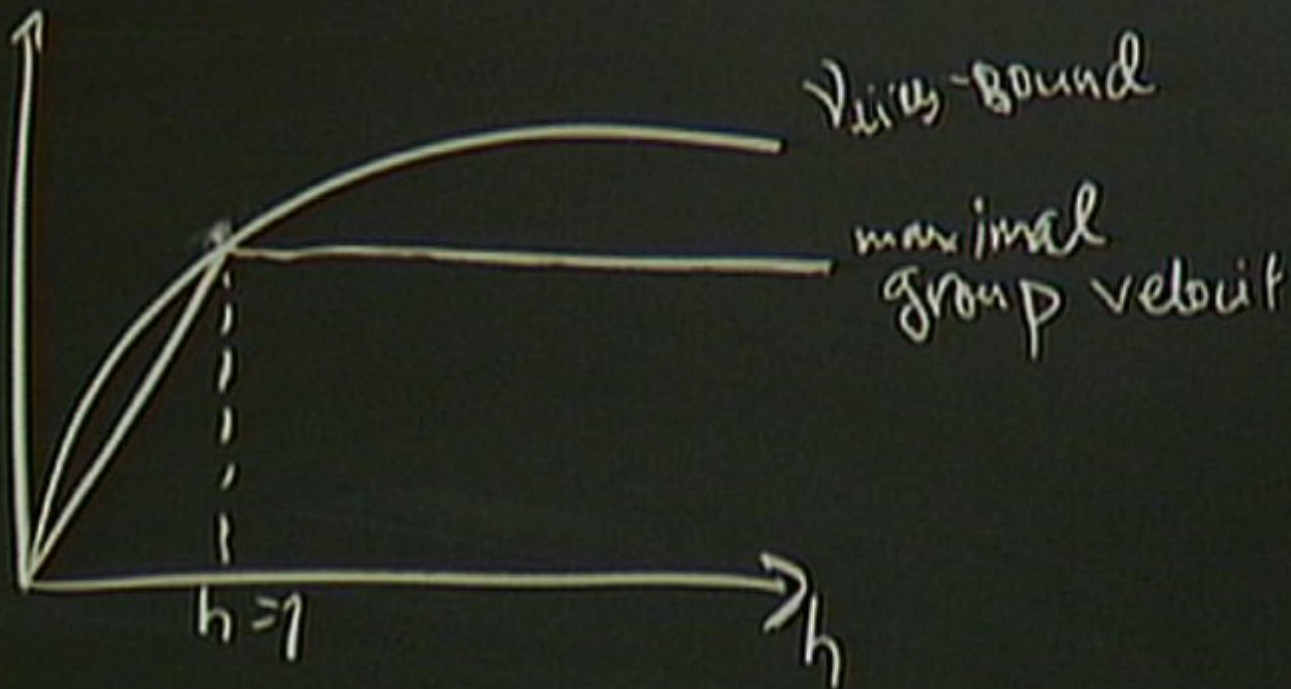
Lieb-Robinson

$$\text{TFIM} \sim v = \sqrt{h}$$



Lieb - Robinson

$$\text{TFIM} \sim v = \sqrt{h}$$



$$U^\dagger(t) \sigma_x U(t)$$

$$= \sum_{\mu} A_{\mu} \sigma_{\mu}^x + A_{\mu}^* \sigma_{\mu}^x$$

about

$$U(t) \sigma_x^* U(t) = \sum_{\lambda} \underbrace{A_{\lambda}(t)}_{\rightarrow \lambda} \sigma_{\lambda}^* + A_{\lambda}(t) \sigma_{\lambda}^*$$

about



$$U(t) \sigma_{\mu}^{\times} U(t)$$

$$= \sum_{\lambda} \underbrace{A_{\lambda}(t) \sigma_{\lambda}^{\times}}_{\rightarrow \mu} + A_{\lambda}(t) \sigma_{\lambda}^{\times}$$

$$\mu \sim \log L(t)$$

