Title: Summer Undergraduate Research Talks - 2010

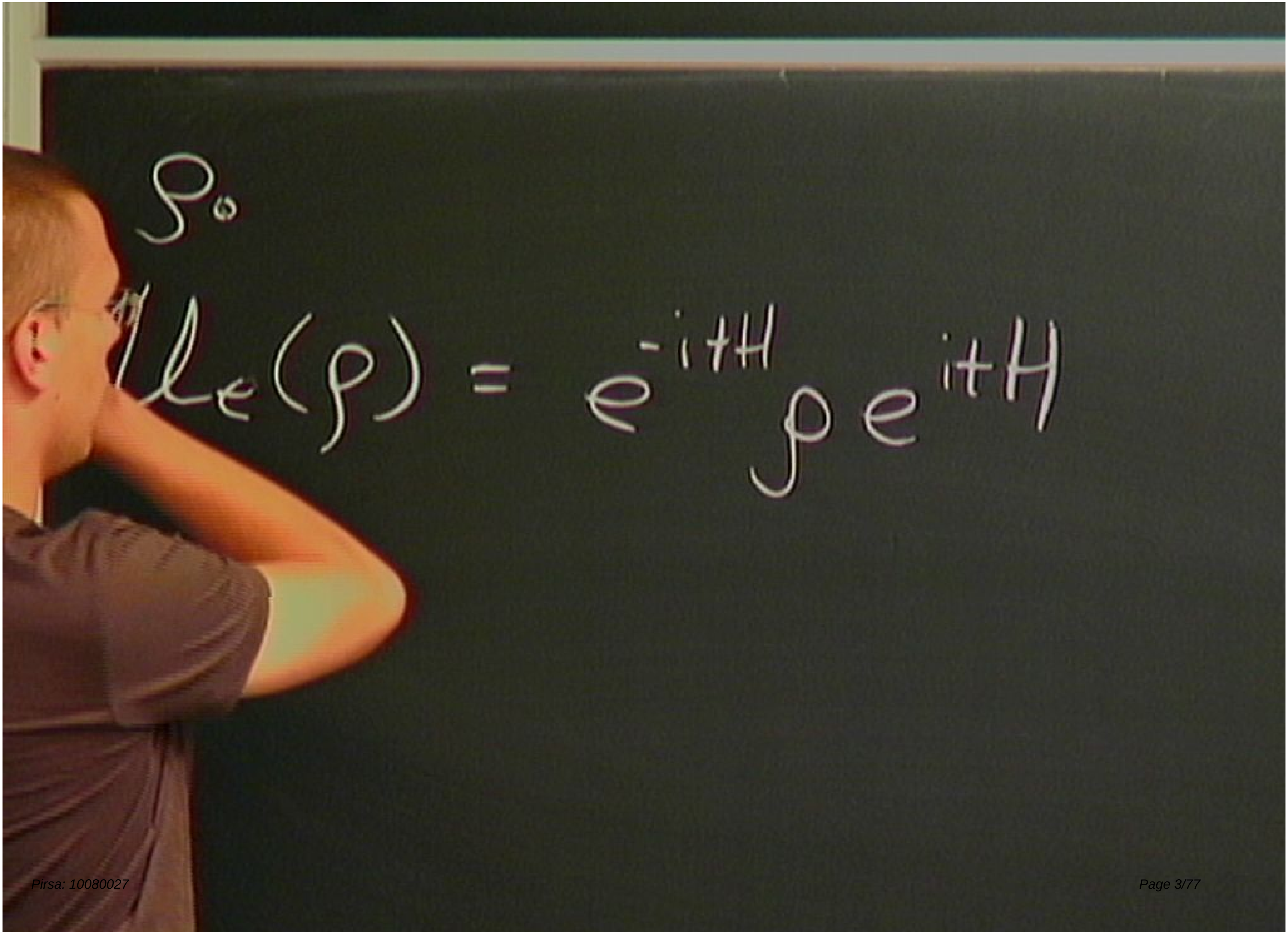
Date: Aug 17, 2010 11:00 AM

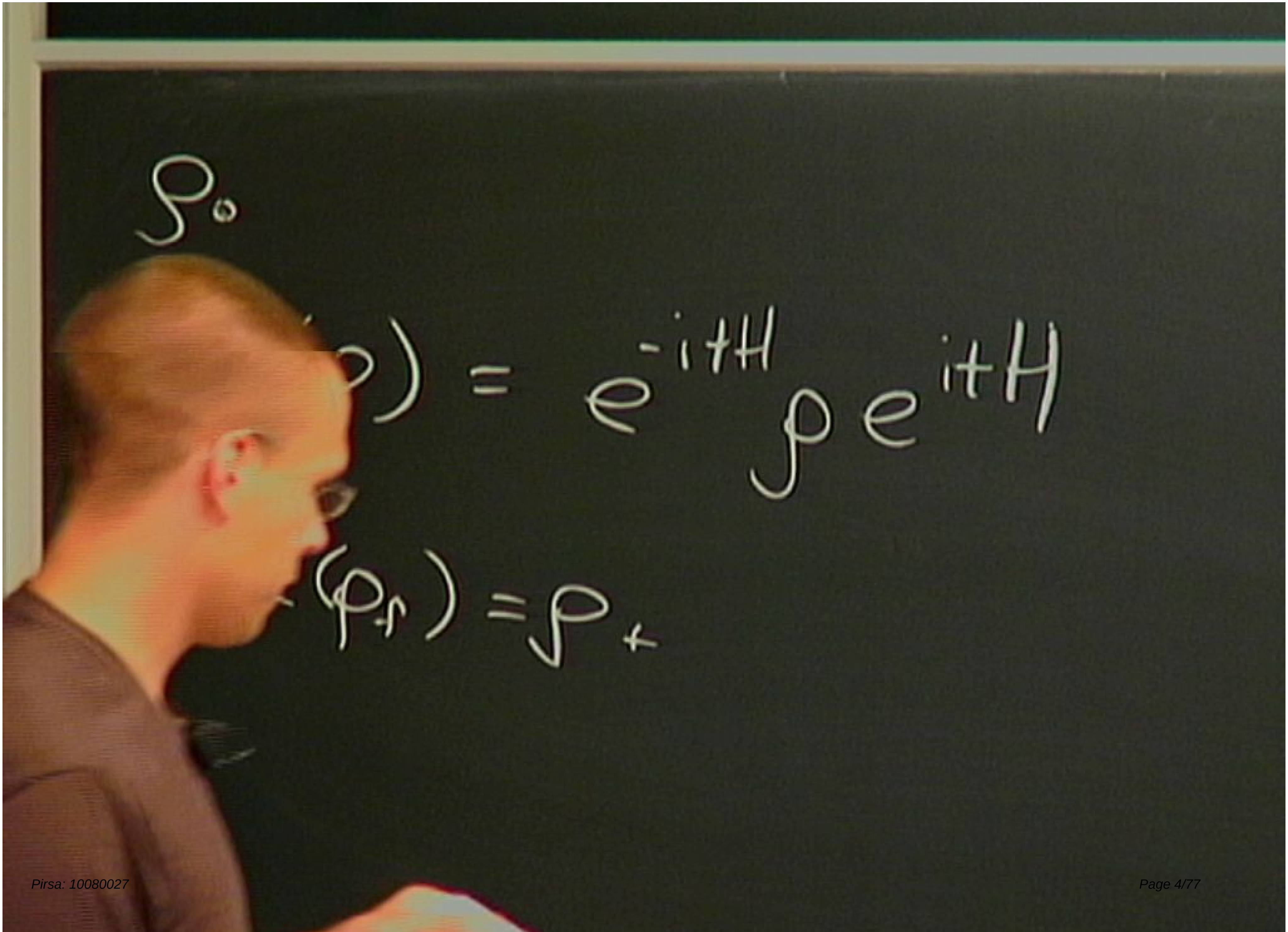
URL: http://pirsa.org/10080027

Abstract:

$$\rho_0$$

$$\mathcal{U}_t(\rho) = e^{-itH}\rho\, e^{itH}$$


ρ_ω
$\mathcal{U}_t(\rho) = e^{-itH}\rho e^{itH}$


ρ_0
$\rho) = e^{-itH} \rho e^{itH}$
$(\rho_f) = \rho_f$

ρ_0

$$\mathcal{U}_t(\rho) = e^{-itH} \rho \, e^{itH}$$

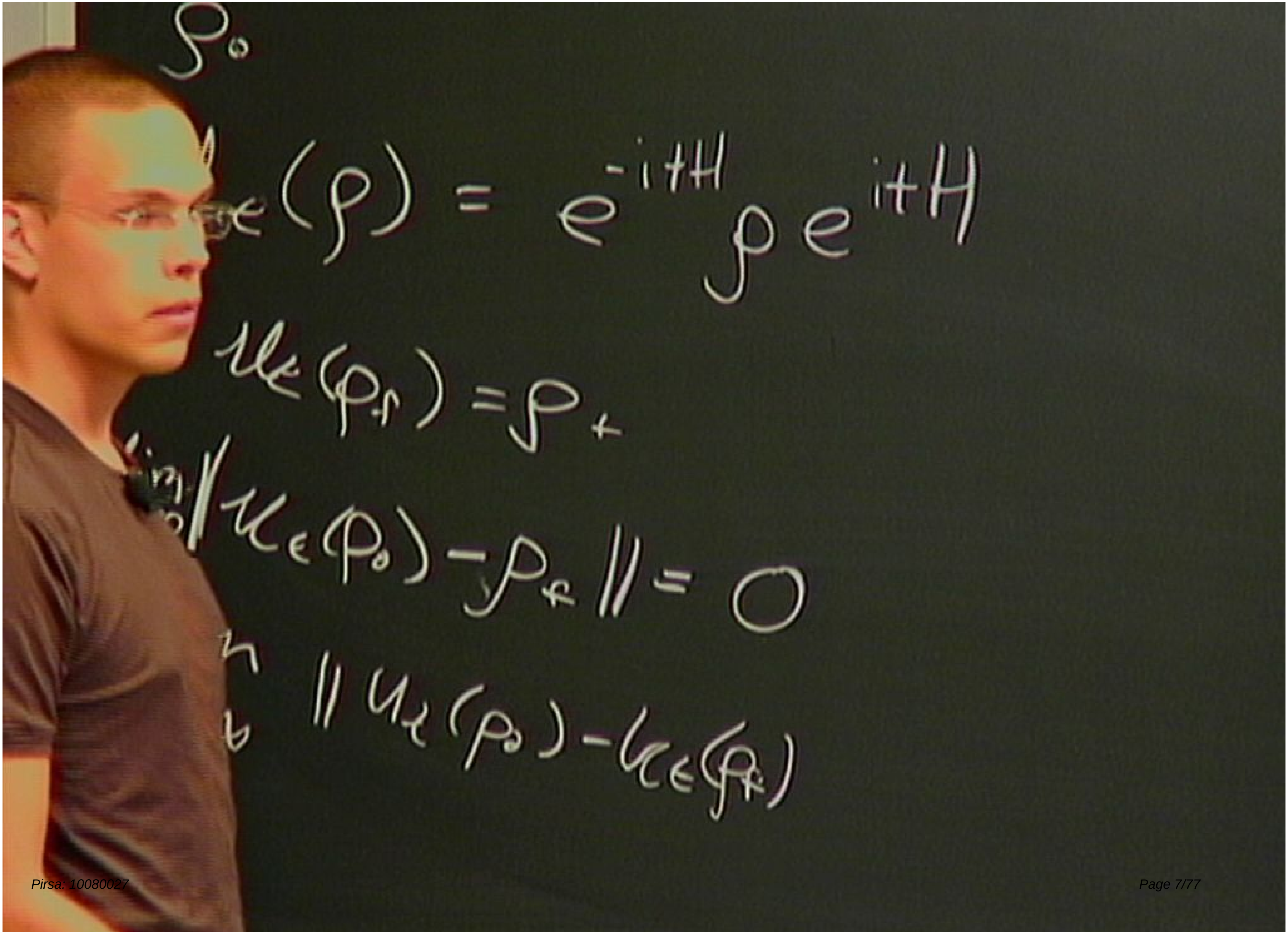
$$\mathcal{U}_t(\rho_f) = \rho_f$$

ρ_0

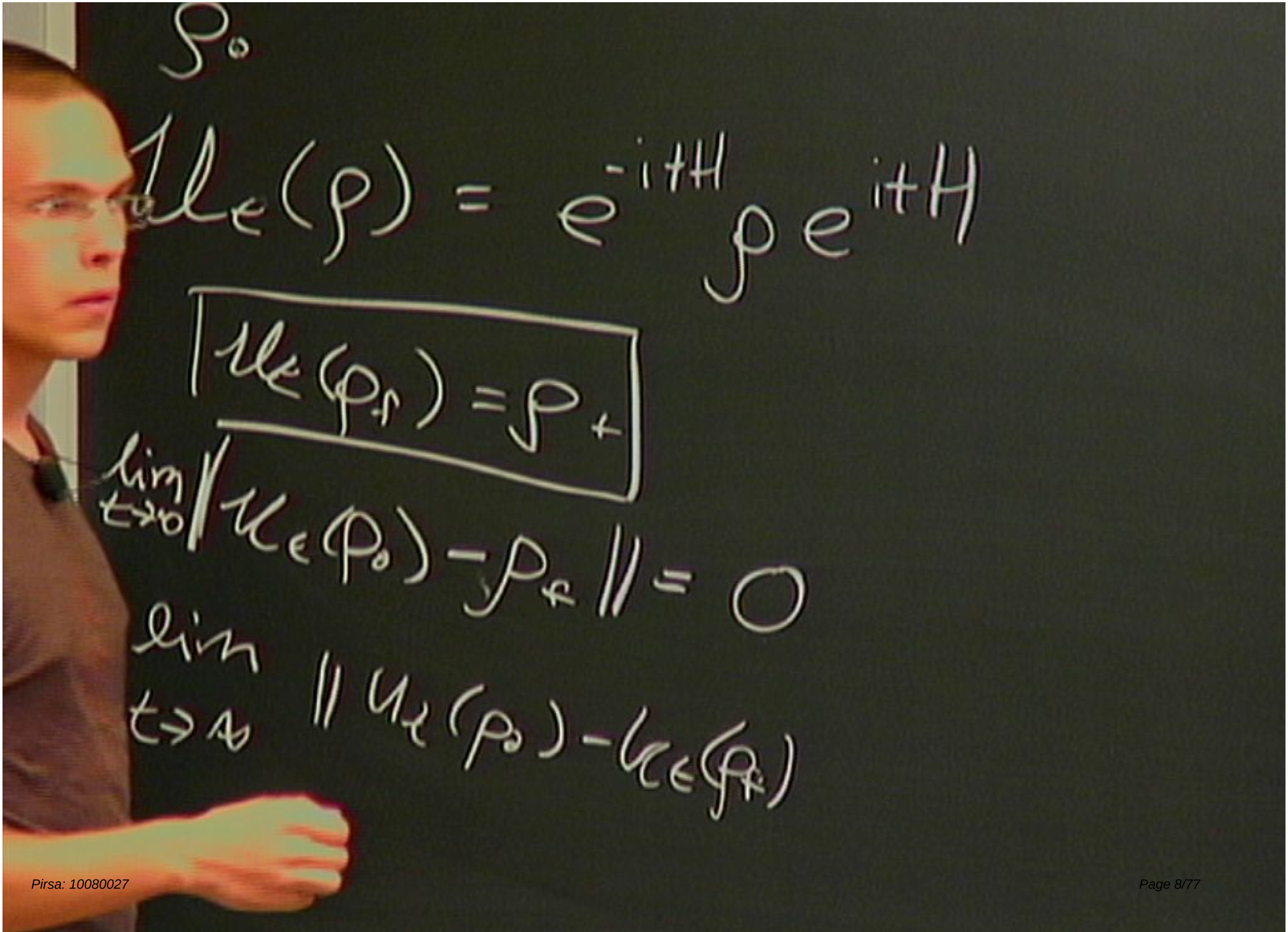
$$\mathcal{U}_t(\rho) = e^{-itH} \rho \, e^{itH}$$

$$\mathcal{U}_t(\rho_f) = \rho_f$$

$$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0) - \rho_f \| = 0$$



ρ_0
$\mathcal{U}_t(\rho) = e^{-itH} \rho e^{itH}$
$\mathcal{U}_t(\rho_f) = \rho_f$
$\lim \| \mathcal{U}_t(\rho_0) - \rho_f \| = 0$
$\| \mathcal{U}_t(\rho_0) - \mathcal{U}_t(\rho_f) \|$


ρ_0
$\mathcal{U}_t(\rho) = e^{-itH} \rho e^{itH}$
$\boxed{\mathcal{U}_t(\rho_f) = \rho_f}$
$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0) - \rho_f \| = 0$
$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0) - \mathcal{U}_t(\rho_f)$

ρ_0

$$\mathcal{U}_t(\rho) = e^{-itH}\,\rho\, e^{itH}$$

$$\boxed{\mathcal{U}_t(\rho_f) = \rho_f \quad \forall t}$$

$$(\rho_0) - \rho_f \| = 0$$

$$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0) - \mathcal{U}_t(\rho_f) \|$$

$$\rho_0$$

$$\mathcal{U}_t(\rho) = e^{-itH} \rho \, e^{itH}$$

$$\boxed{\mathcal{U}_t(\rho_f) = \rho_f \quad \forall t}$$

$$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0) - \rho_f \| = 0$$

$$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0) - \mathcal{U}_t(\rho_f) \| = 0$$

$$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0 - \rho_f) \| =$$

$$\mathcal{U}_t(\rho) = e^{-itH} \rho\, e^{itH}$$

$$\boxed{\mathcal{U}_t(\rho_f) = \rho_f \quad \forall t}$$

$$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0) - \rho_f \| = 0$$

$$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0) - \mathcal{U}_t(\rho_f) \| = 0$$

$$\lim_{t\to\infty} \| \mathcal{U}_t(\rho_0 - \rho_f) \| = 0$$

$$\Rightarrow \lim_{T \to \infty} \| \rho_0 - \rho_f \|$$

$$\Rightarrow \lim_{T\to\infty} \|\rho_0 - \rho_f\| = 0$$

$$\|$$

$$\Rightarrow \lim_{T\to\infty} \|\rho_0 - \rho_f\| = 0$$

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

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$$\Rightarrow \lim_{T\to\infty} \| \rho_0 - \rho_f \| = 0$$

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

$$A = A^+$$

$$\rightsquigarrow \lim_{T\to\infty} \| \rho_0 - \rho_f \| = 0$$

$$+H$$

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

$$A = A^+$$

$$\langle A(t) \rangle = \mathrm{Tr}\left[\mathcal{U}_t(\rho_0) A \right]$$

$$= \sum$$

$$\Rightarrow \lim_{T\to\infty} \|\rho_0 - \rho_f\| = 0$$

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

$$A = A^+$$

$$\langle A(t)\rangle = \mathrm{Tr}\left[\mathcal{U}_t(\rho_0) A\right]$$

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

$$\Rightarrow \lim_{T\to\infty} \|\rho_0 - \rho_f\| = 0$$

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

$$A = A^{+}$$

$$\mathrm{Tr}\left[\mathcal{U}_t(\rho_0) A\right]$$

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

$$= \sum_n \mathrm{Tr}\left[|n\rangle\langle n|\rho_0|n\rangle\langle n| A\right]$$

$$\sum$$

$$\Rightarrow \lim_{T\to\infty} \|\rho_0 - \rho_f\| = 0$$

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

$$A = A^{\dagger}$$

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

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$$\Rightarrow \lim_{T\to\infty} \|\rho_0 - \rho_f\| = 0$$

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

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

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

$$\Rightarrow \lim_{T\to\infty} \|\rho_0 - \rho_f\| = 0$$

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

$$A = A^+$$

$$\langle A(t)\rangle = \mathrm{Tr}\left[\mathcal{U}_t(\rho_0) A\right]$$

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

$$= \sum_n \mathrm{Tr}\left[|n\rangle\langle n|\rho_0|n\rangle\langle n| A\right]$$

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

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

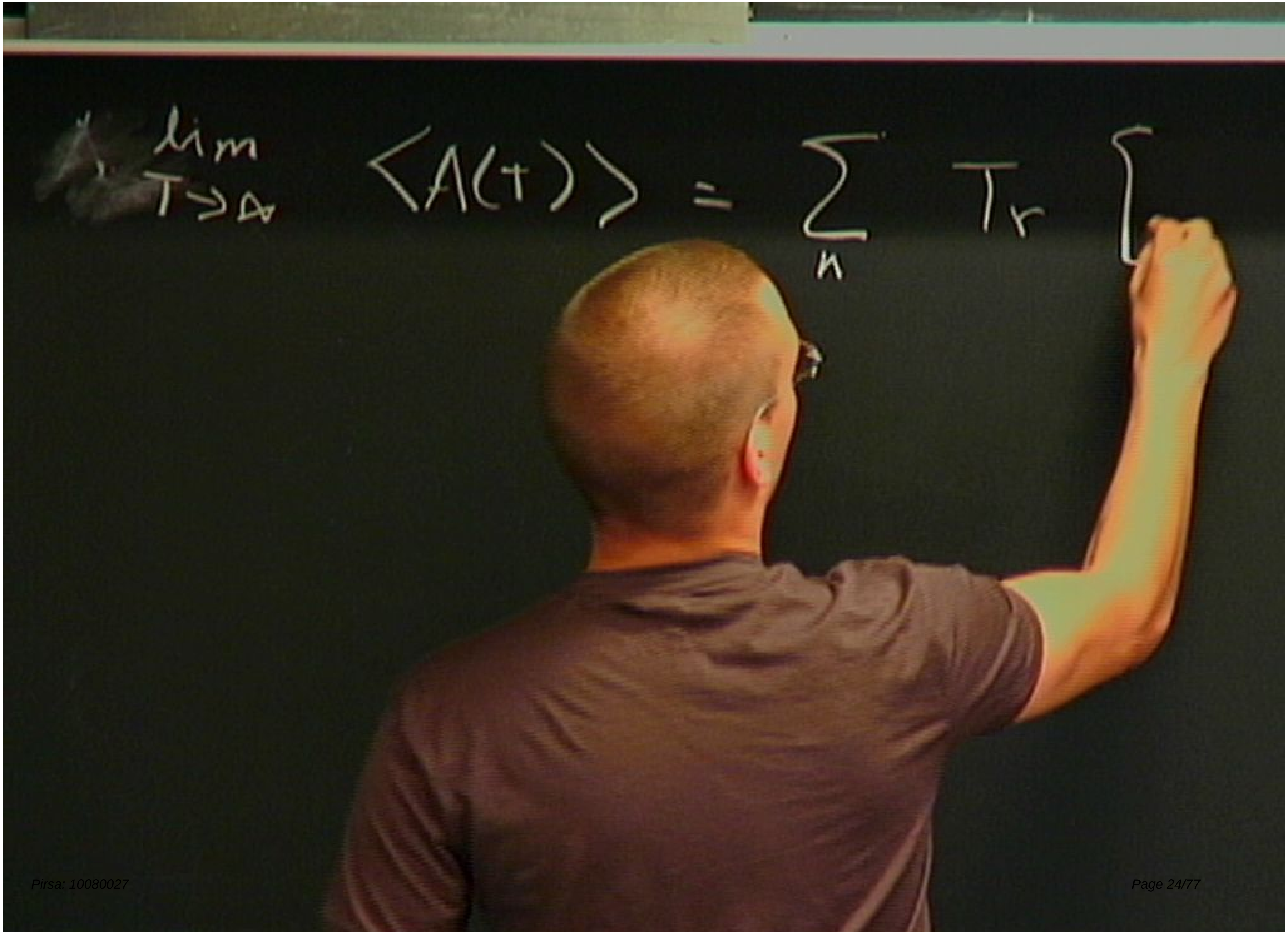
$$A = A^{+}$$

$$\langle A(t)\rangle = Tr\left[\mathcal{U}_t(\rho_0) A\right]$$

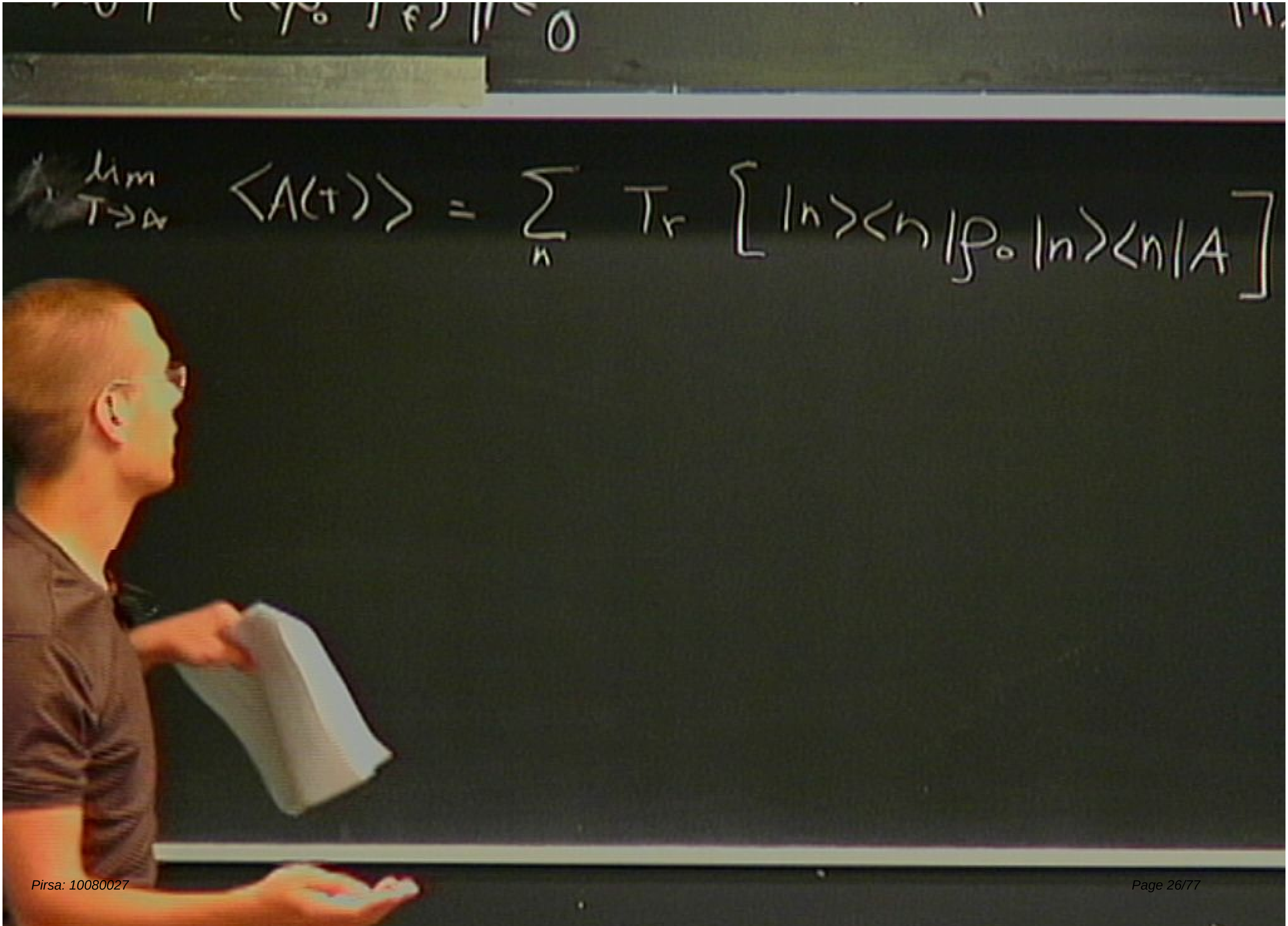
$$= \sum_{n,m} Tr\left(e^{it(E_n - E_m)} |n\rangle\langle n|\rho_0|m\rangle\langle m|A\right)$$

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

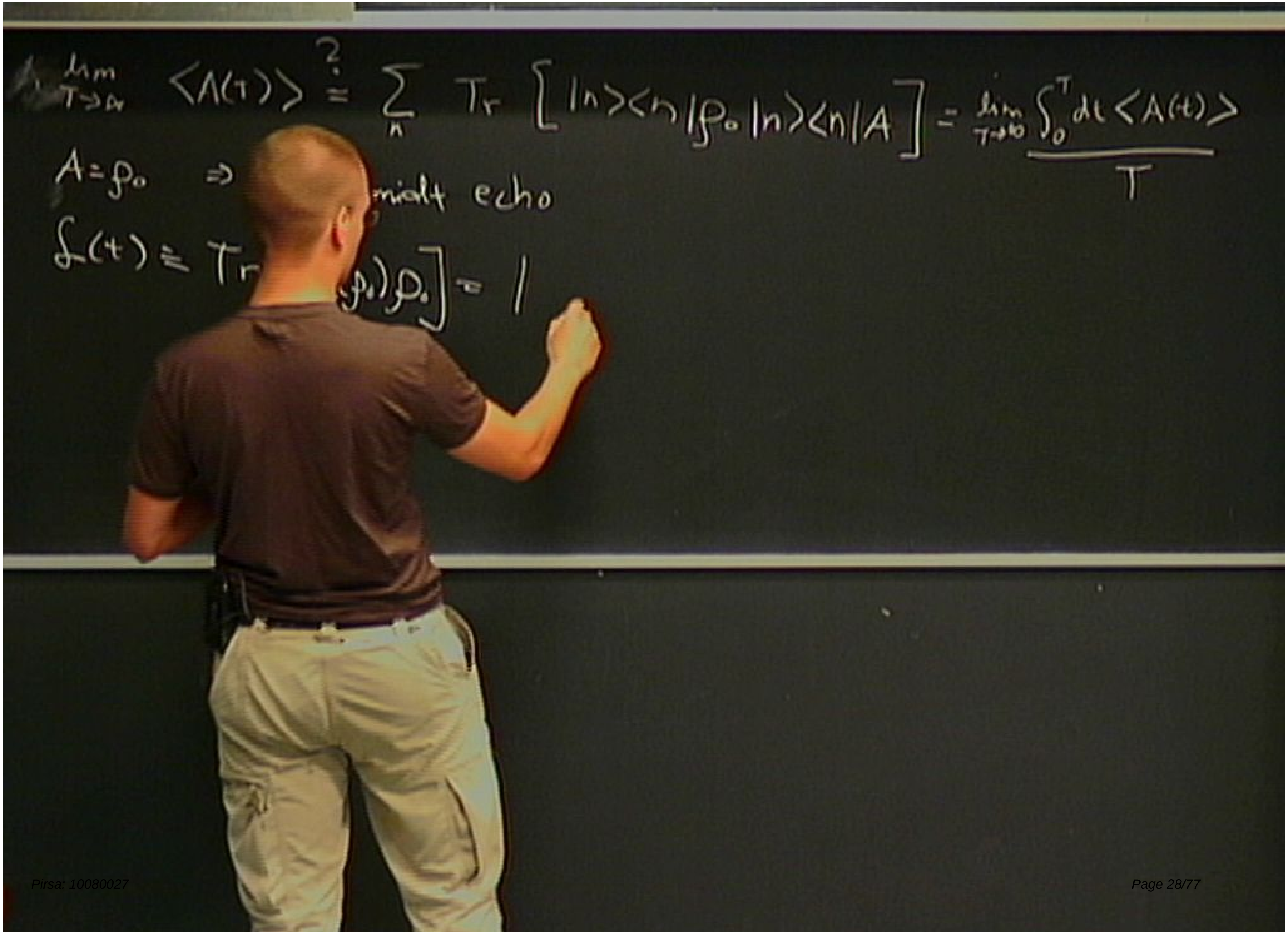
$$\sum_{n\neq m} Tr\left(e^{it(E_m - E_n)} |n\rangle\langle n|\rho_0|m\rangle\langle m|A\right)$$


lim
T→∞
⟨A(t)⟩ = Σ Tr [
n

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


$\lim_{T\to\infty} \langle A(t) \rangle = \sum_n \mathrm{Tr}\left[|n\rangle\langle n| \rho_0 |n\rangle\langle n| A \right]$

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


lim T→∞ ⟨A(t)⟩ ?= Σn Tr [|n⟩⟨n|ρ0|n⟩⟨n|A] = lim T→∞ ∫0T dt ⟨A(t)⟩ / T
A = ρ0 ⇒
echo
= 1

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

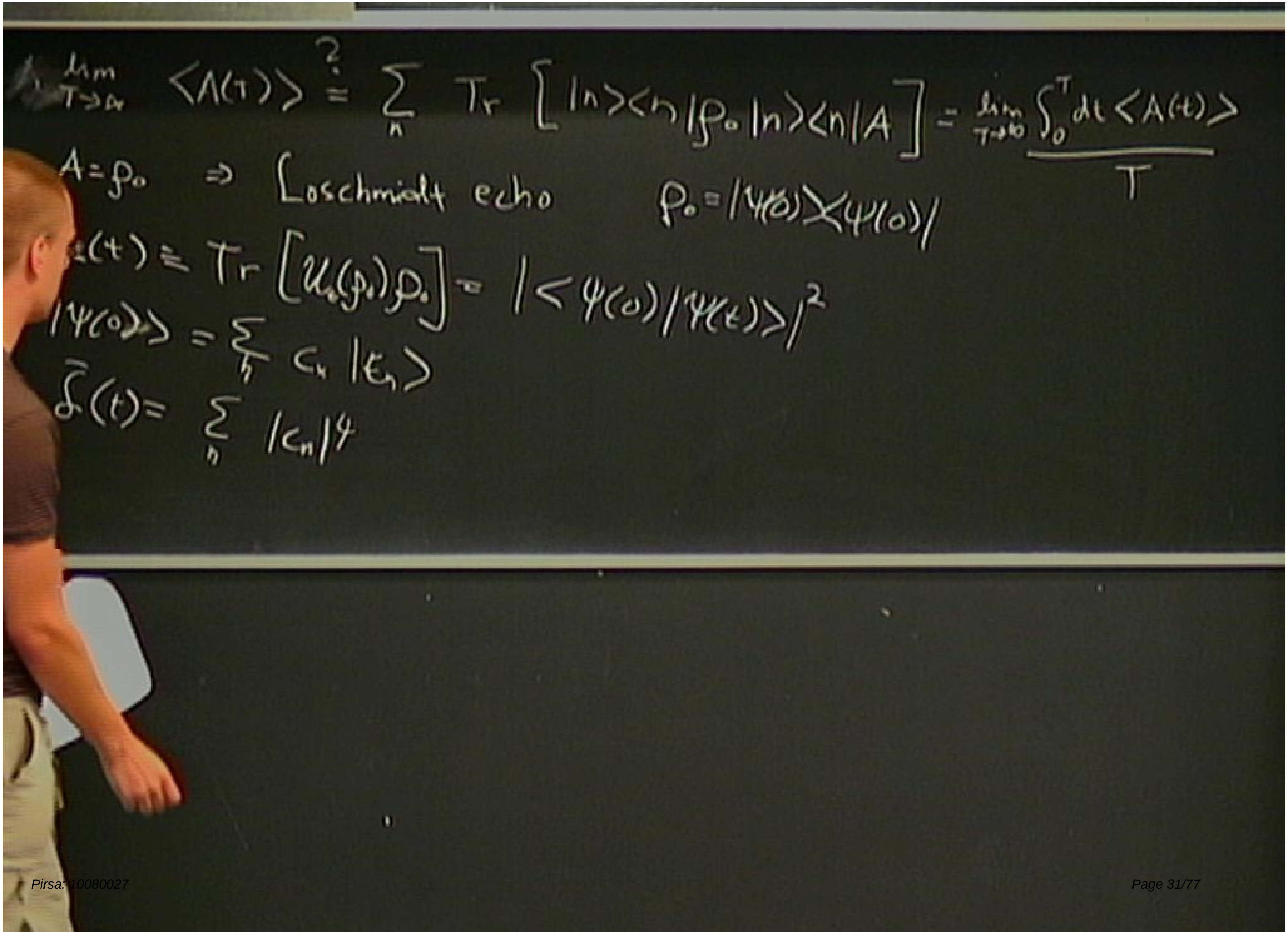
$A=\rho_0 \Rightarrow$ Loschmidt echo $\qquad \rho_0 = |\psi(0)\rangle\langle\psi(0)|$

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

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

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

$$f_L(t) \doteq \mathrm{Tr}\left[\mathcal{U}_t(\rho_0)\rho_0\right] = |\langle\psi(0)|\psi(t)\rangle|^2$$


$\lim_{T\to\infty} \langle A(t)\rangle \overset{?}{=} \sum_n \mathrm{Tr}\left[|n\rangle\langle n|\rho_0|n\rangle\langle n|A\right] = \lim_{T\to\infty} \frac{\int_0^T dt \langle A(t)\rangle}{T}$
$A=\rho_0 \Rightarrow$ Loschmidt echo $\rho_0 = |\psi(0)\rangle\langle\psi(0)|$
$\mathcal{L}(t) = \mathrm{Tr}\left[\mathcal{U}_t(\rho_0)\rho_0\right] = |\langle\psi(0)|\psi(t)\rangle|^2$
$|\psi(0)\rangle = \sum_n c_n |E_n\rangle$
$\bar{\mathcal{L}}(t) = \sum_n |c_n|^4$

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

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

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

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

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

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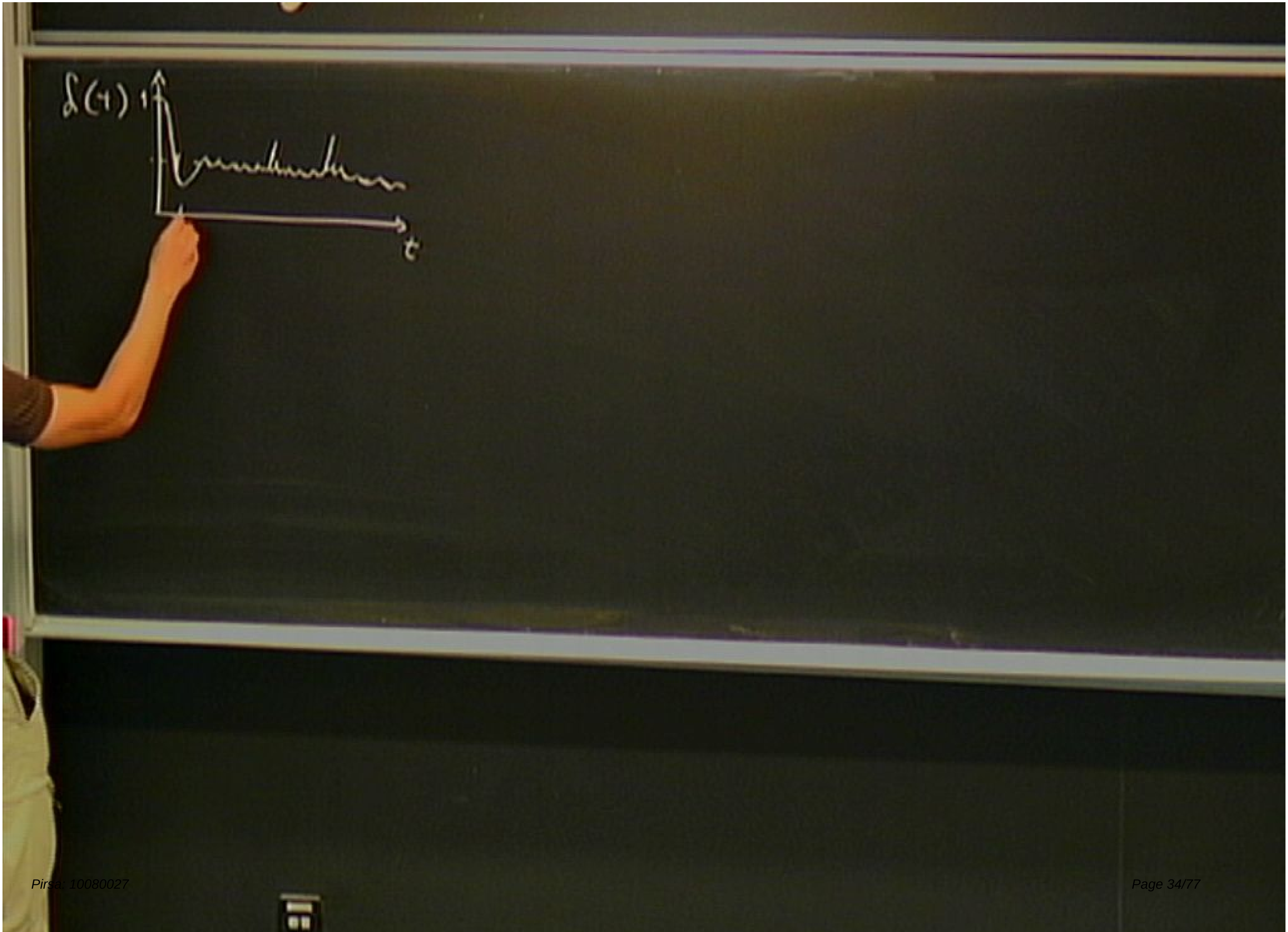
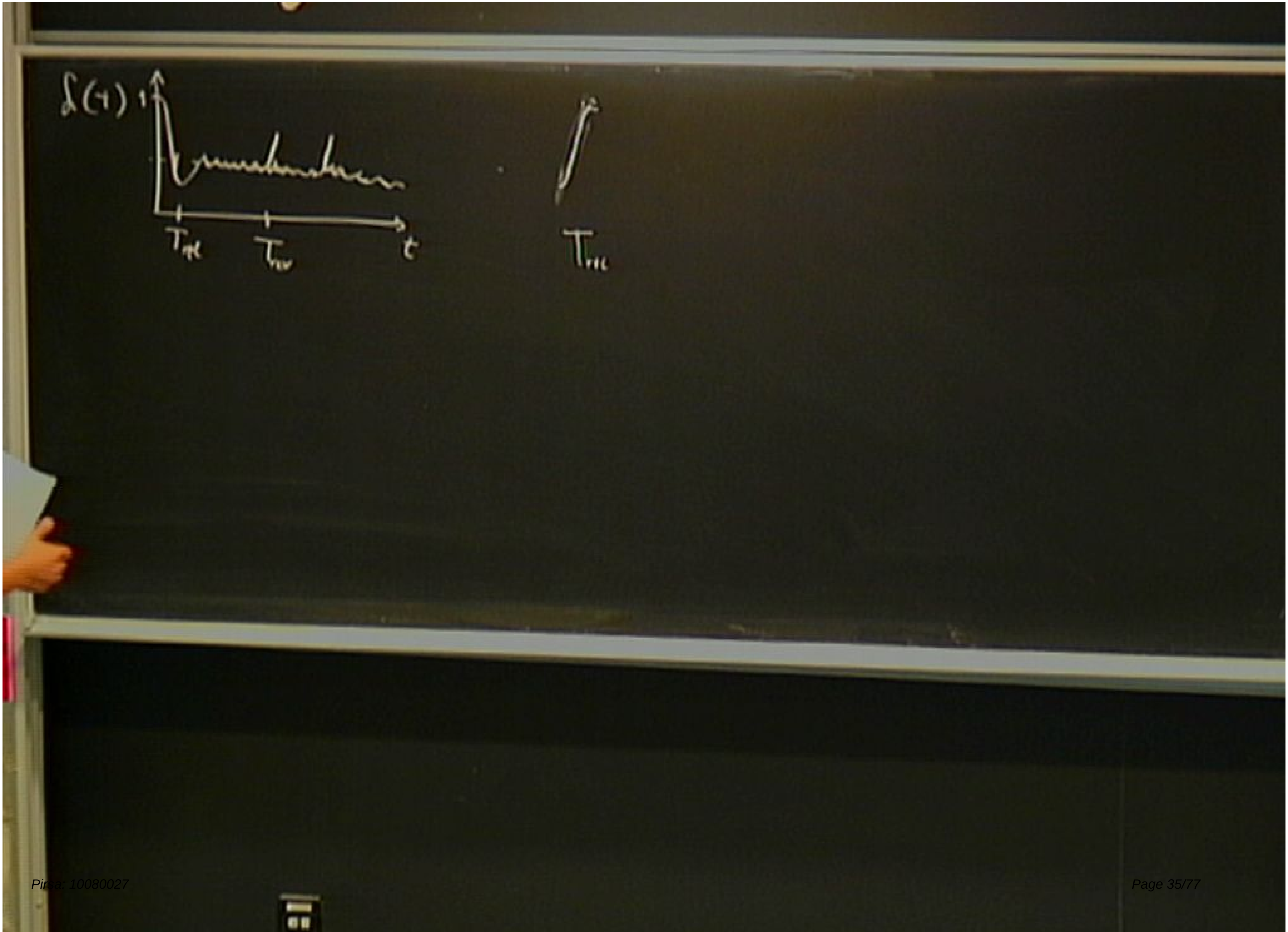
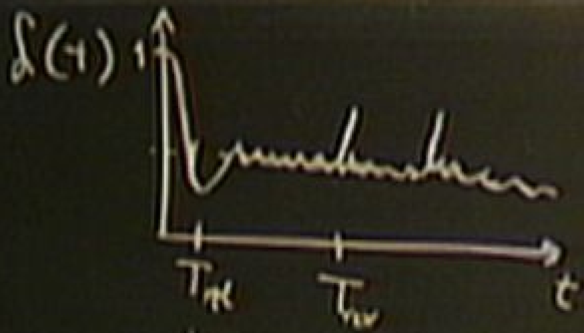
$$\bar{f}_L(t) = \sum_n |c_n|^4 = \sum_n \mathrm{Tr}\left[|n\rangle\langle n|\rho_0|n\rangle\langle n|\rho_0\right]$$


t

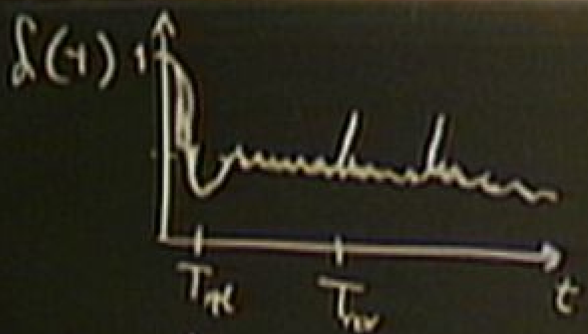

f(t)
1
T_rel
T_rev
t
T_rel



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

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

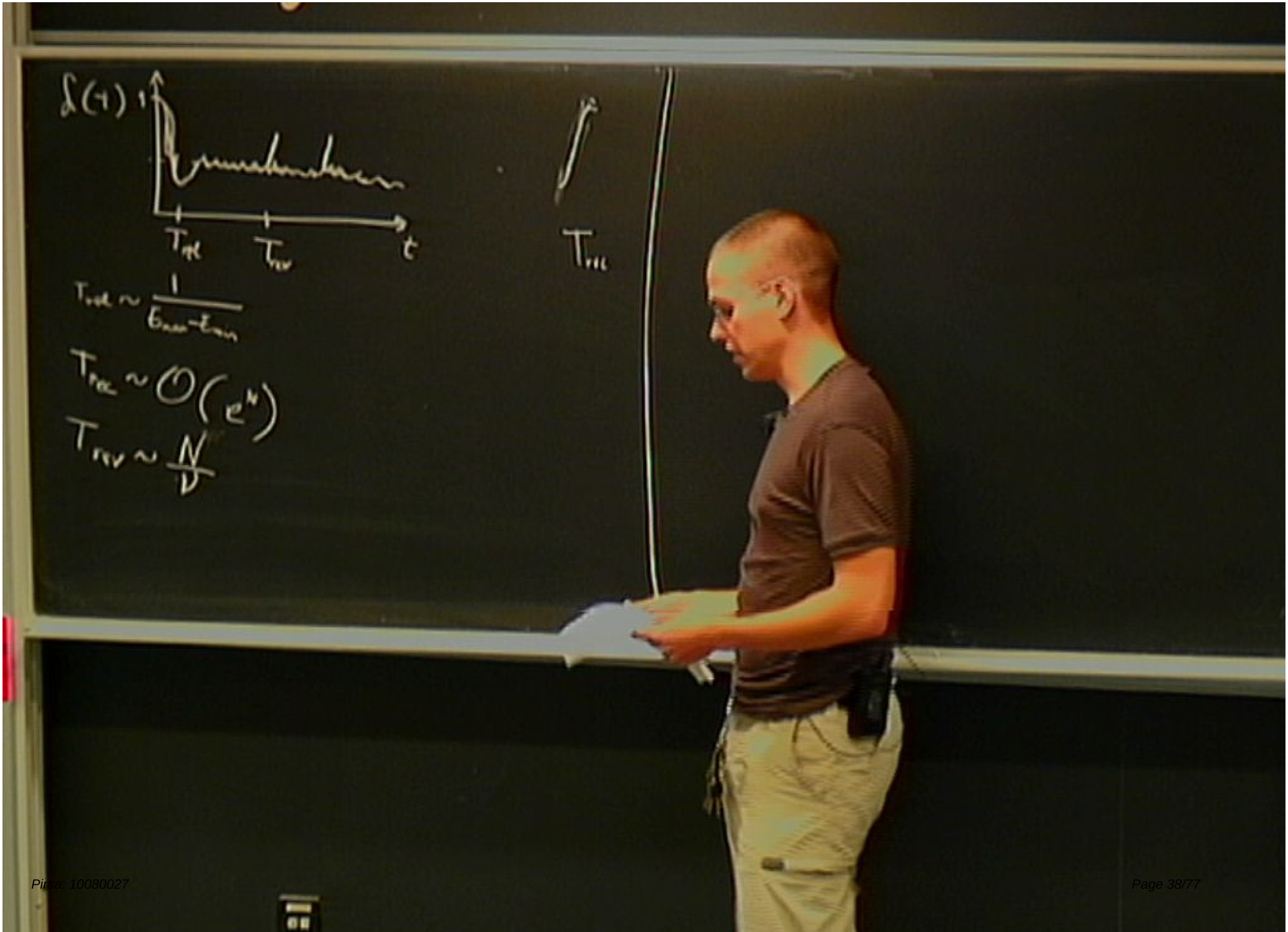
T_{rev}

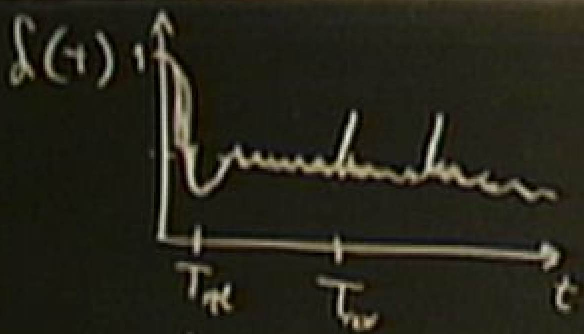


$$T_{rel} \sim \frac{1}{E_{max} - E_{min}}$$

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

$$T_{rev} \sim \underline{N}$$


f(t)
T_rel
T_rev
t
T_rel ~ 1/(E_max - E_min)
T_rec ~ O(e^N)
T_rev ~ N/D
T_rec

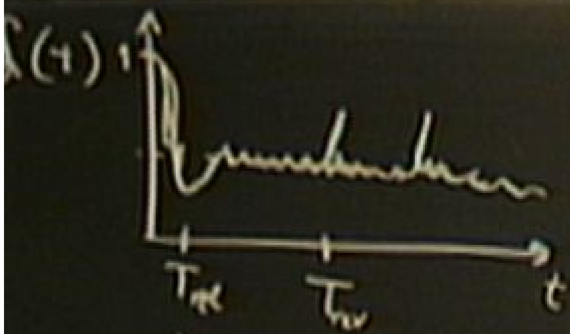


$T_{rel} \sim \frac{1}{E_{max}-E_{min}}$

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

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

$$H = -\frac{1}{4}\sum_{j=1}^{N} (1+\gamma)\sigma_j^x\sigma_{j+1}^x + (1-\gamma)\sigma_j^y\sigma_{j+1}^y - \frac{h}{2}\sum_j \sigma_j^z$$



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

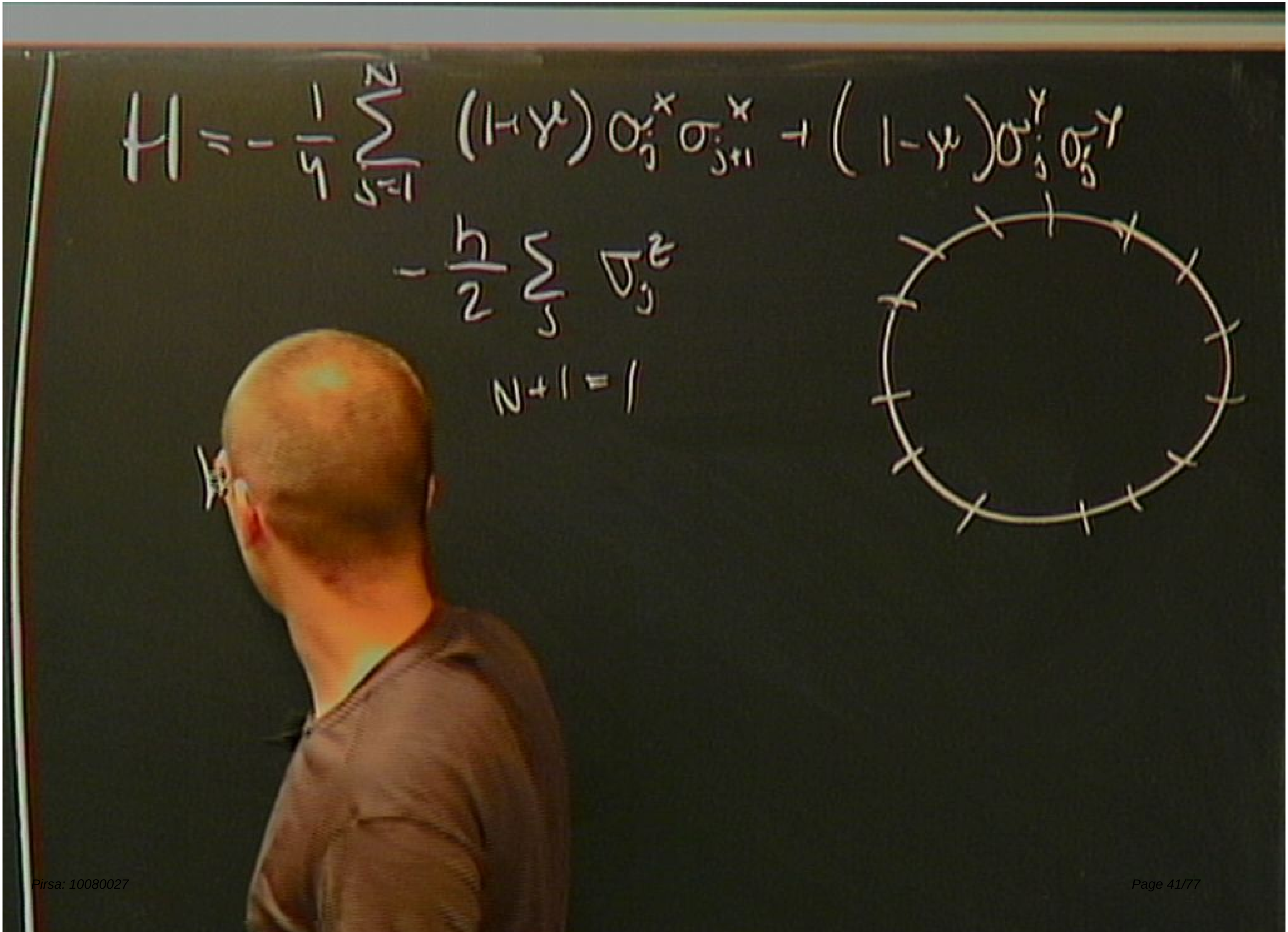
$T_{rec} \sim \mathcal{O}(e^{N})$

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

T_{rec}

$$H = -\frac{1}{4}\sum_{j=1}^{N} (1+\gamma)\sigma_j^x\sigma_{j+1}^x + (1-\gamma)\sigma_j^y\sigma_{j+1}^y - \frac{h}{2}\sum_j \sigma_j^z$$

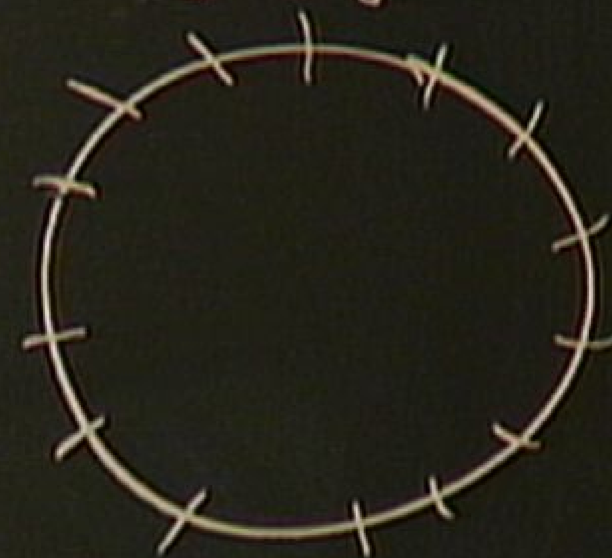
$N+1 = 1$


$H = -\frac{1}{4}\sum_{j=1}^{N} (1+\gamma)\sigma_j^x\sigma_{j+1}^x + (1-\gamma)\sigma_j^y\sigma_j^y$
$-\frac{h}{2}\sum_j \sigma_j^z$
$N+1 = 1$

$$H = -\frac{1}{4}\sum_{j=1}^{N} (1+\gamma)\,\sigma_j^x \sigma_{j+1}^x + (1-\gamma)\,\sigma_j^y \sigma_j^y$$

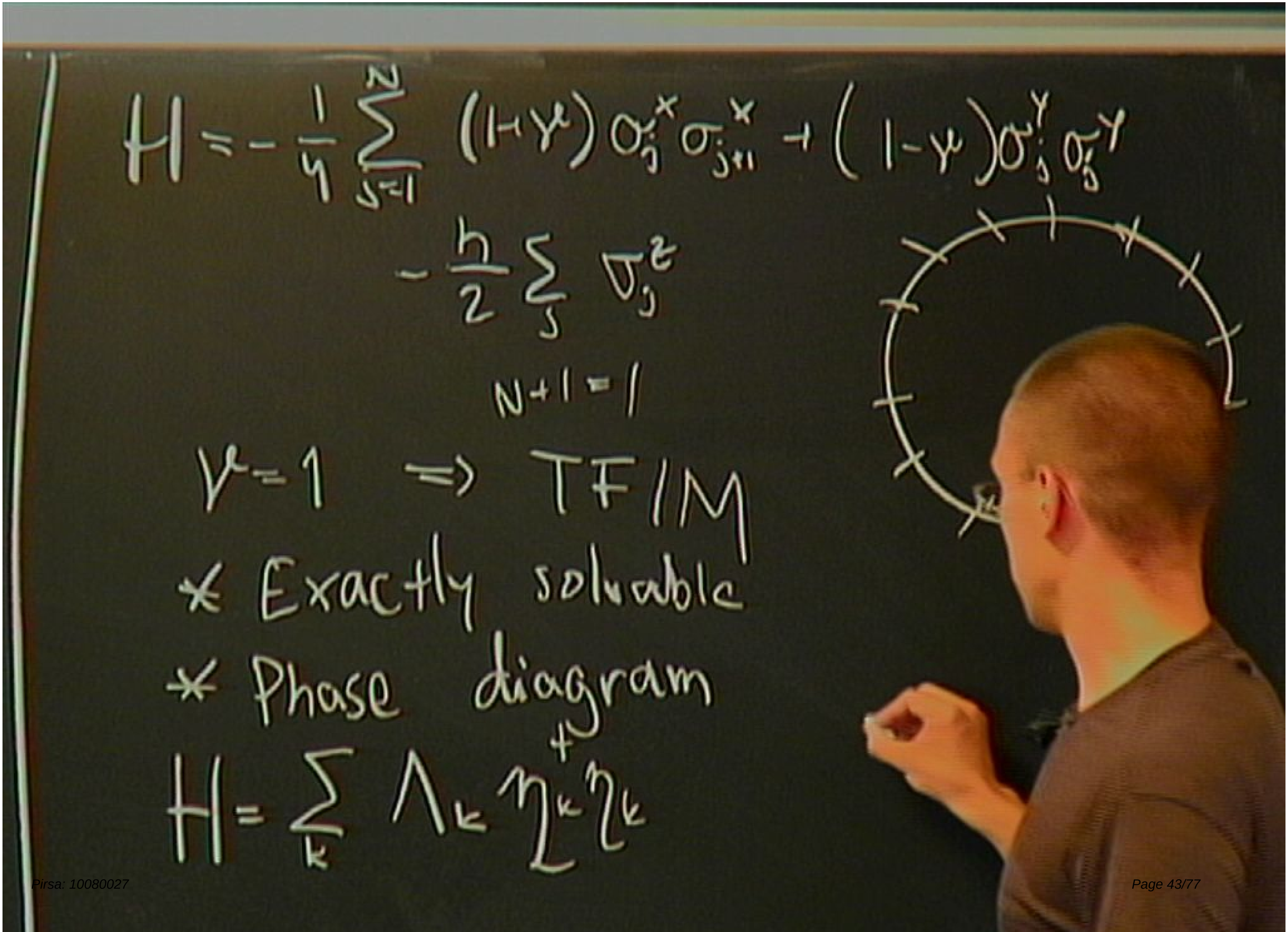
$$-\frac{h}{2}\sum_j \sigma_j^z$$

$$N+1 = 1$$



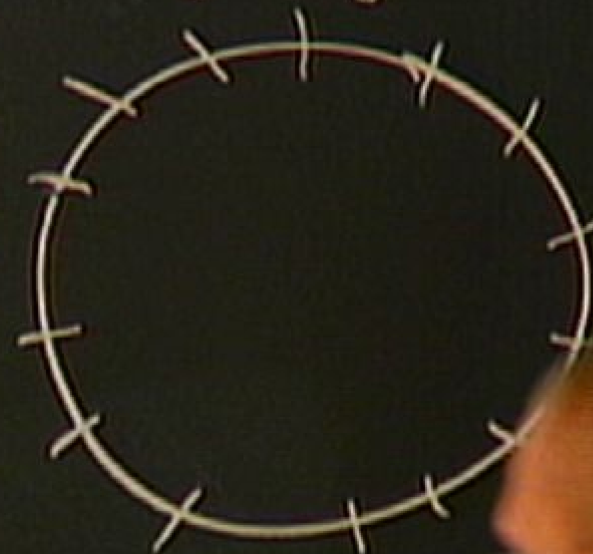
$\gamma = 1 \Rightarrow$ TFIM

* Exactly solvable
* Phase diagram


$H = -\frac{1}{4}\sum_{j=1}^{N} (1+\gamma)\sigma_j^x \sigma_{j+1}^x + (1-\gamma)\sigma_j^y \sigma_{j+1}^y$
$-\frac{h}{2}\sum_j \sigma_j^z$
$N+1=1$
$\gamma = 1 \Rightarrow$ TFIM
* Exactly solvable
* Phase diagram
$H = \sum_k \Lambda_k \eta_k^\dagger \eta_k$

$$H = -\frac{1}{4}\sum_{j=1}^{N} \left((1+\gamma)\sigma_j^x \sigma_{j+1}^x + (1-\gamma)\sigma_j^y \sigma_j^y\right)$$

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



$$N+1 = 1$$

$\gamma = 1 \Rightarrow$ TFIM

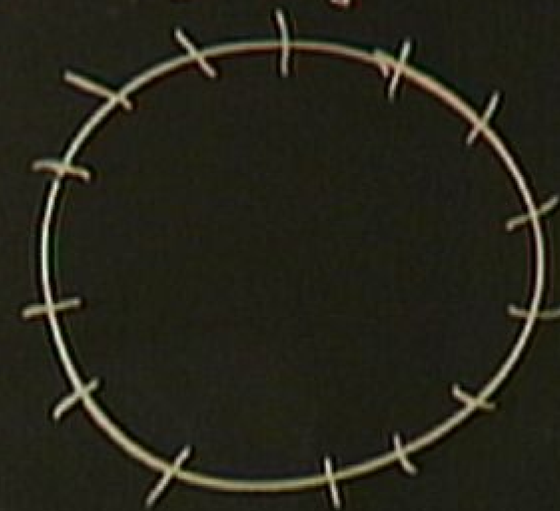
* Exactly solvable
* Phase diagram

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

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

$$H = -\frac{1}{4}\sum_{j=1}^{N} (1+\gamma)\sigma_j^x\sigma_{j+1}^x + (1-\gamma)\sigma_j^y\sigma_j^y$$

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



$$N+1 = 1$$

$\gamma = 1 \Rightarrow$ TFIM

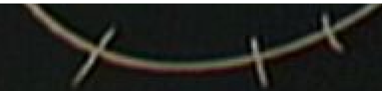
* Exactly solvable
* Phase diagram

$$H = \sum \Lambda_k \eta_k^{\dagger}\eta_k$$

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

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

$$\Lambda_k$$



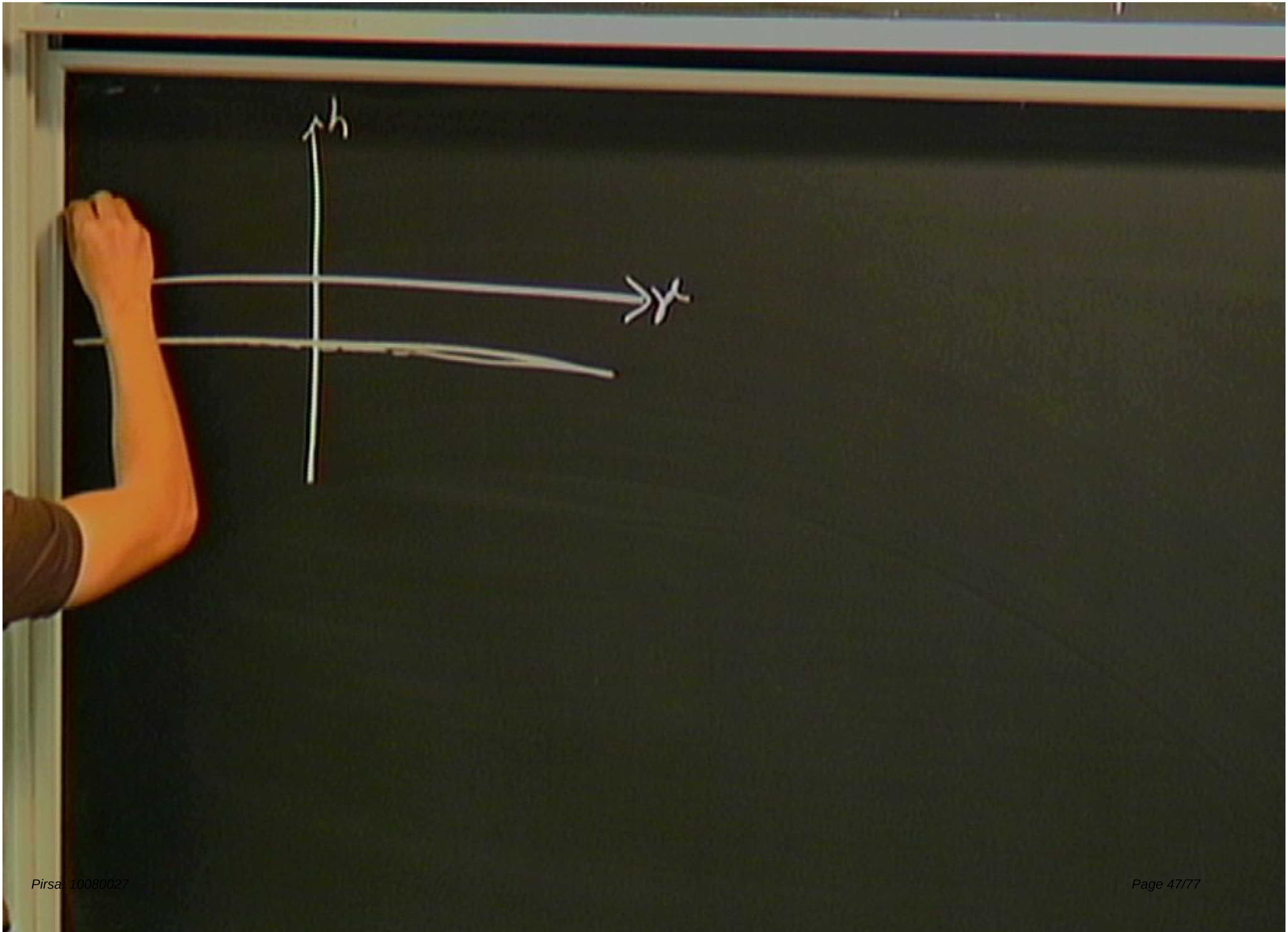
* Exactly solvable
* Phase diagram

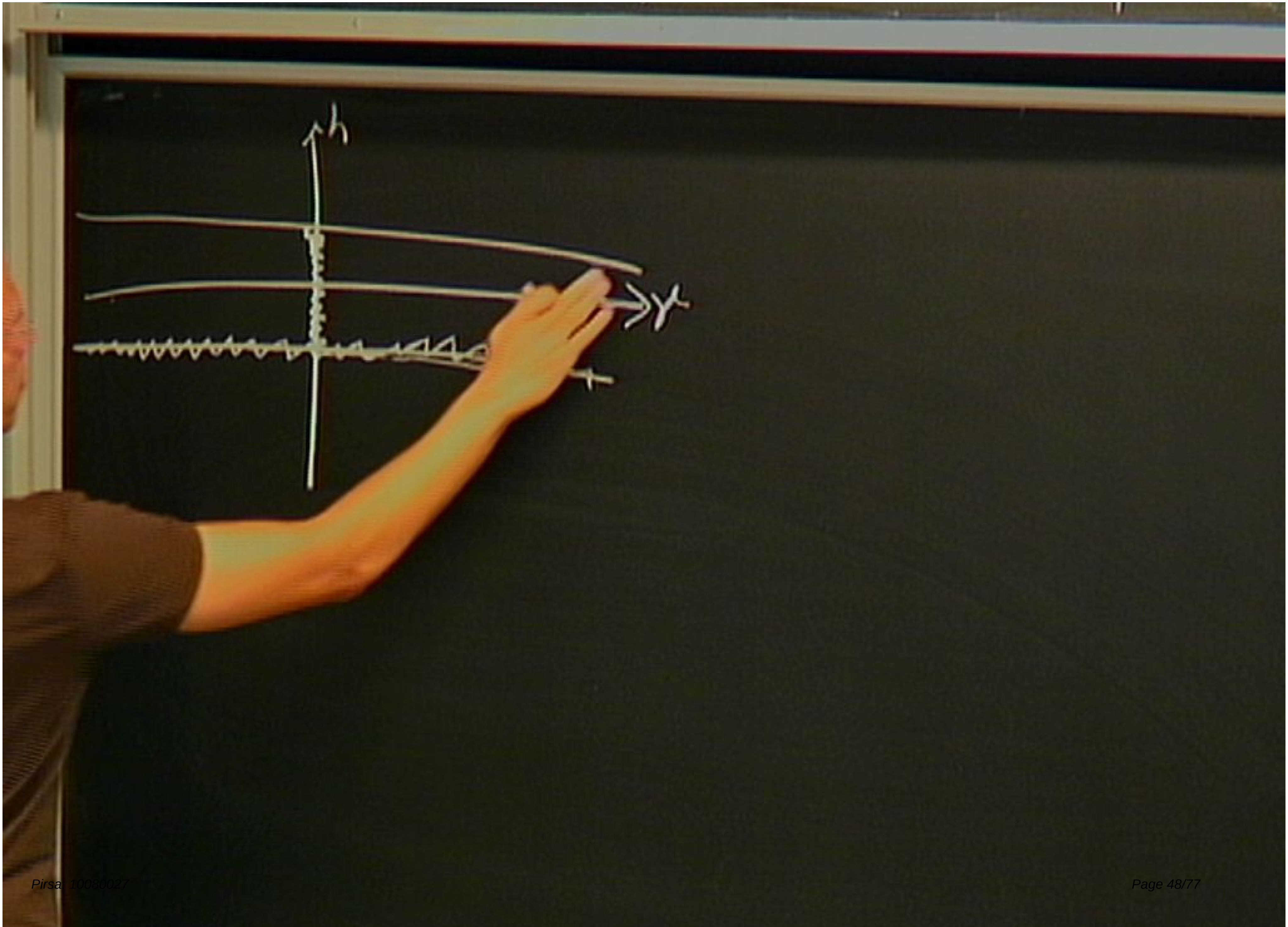
$$H=\sum_k \Lambda_k \eta_k^\dagger \eta_k$$

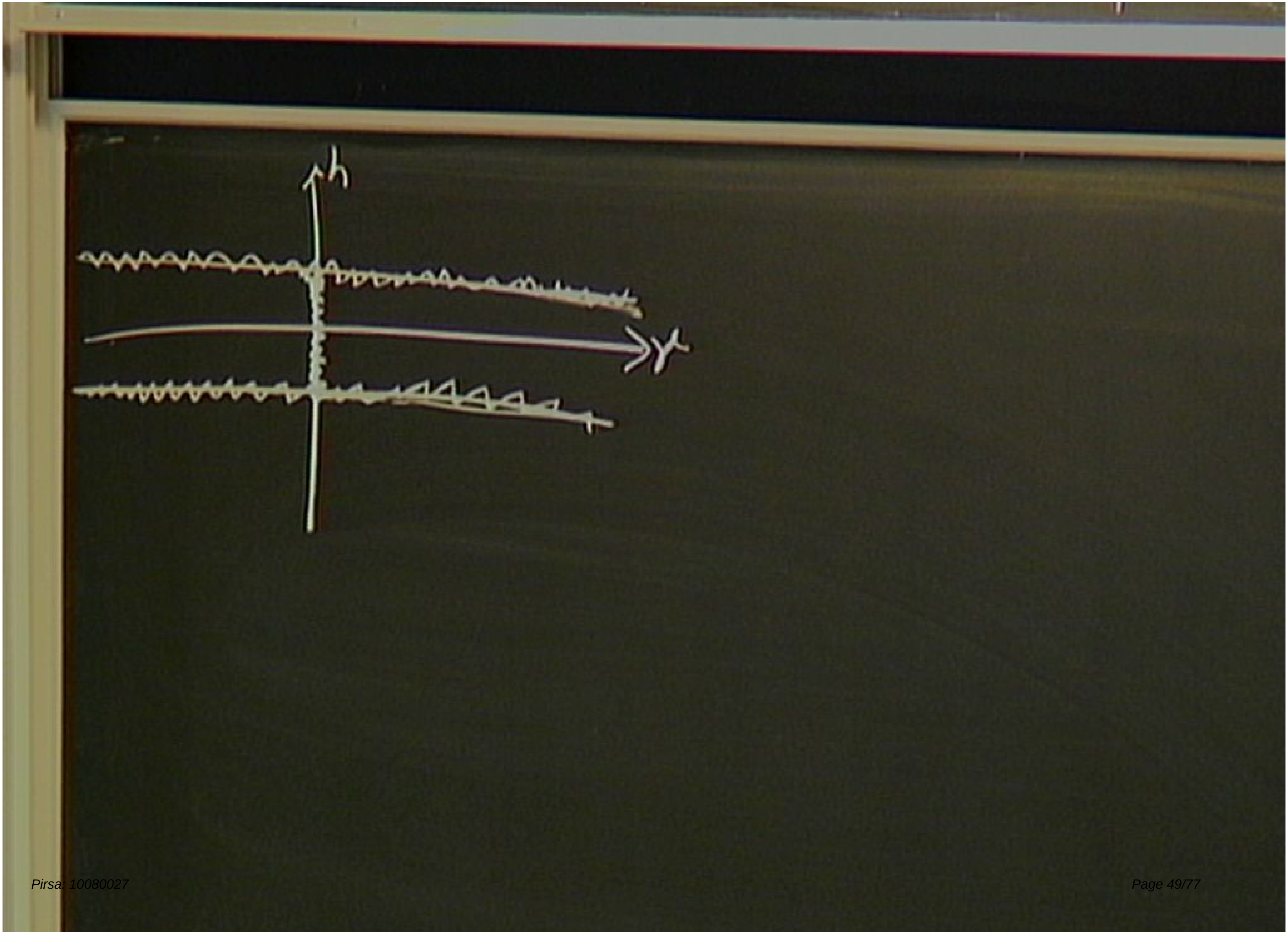
$$\{\eta_k^\dagger, \eta_{k'}\} = \delta_{k'k}$$

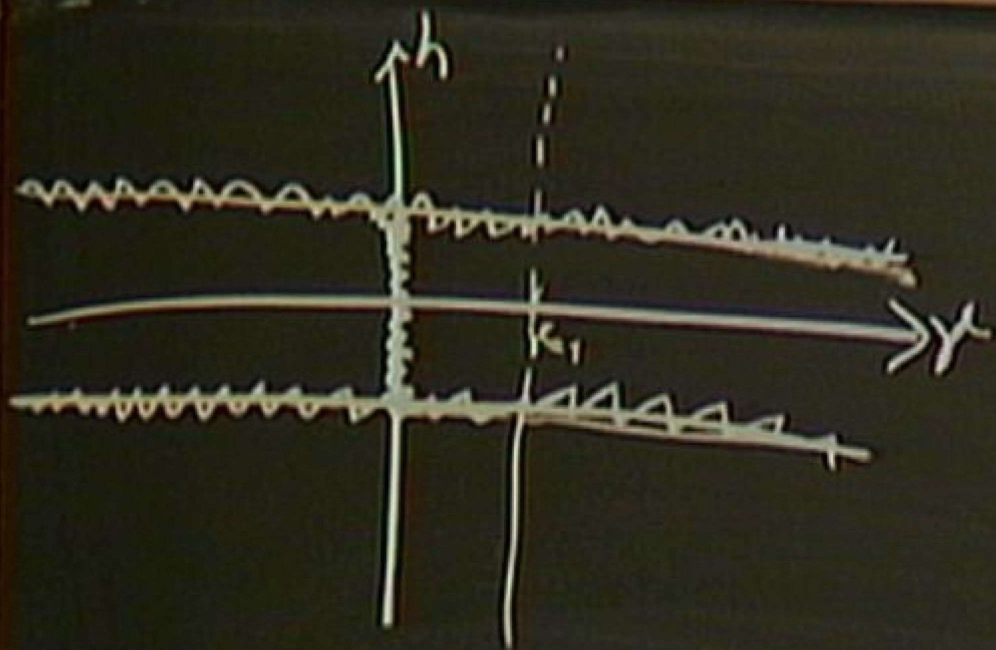
$$\{\eta_k, \eta_{k'}\} = 0$$

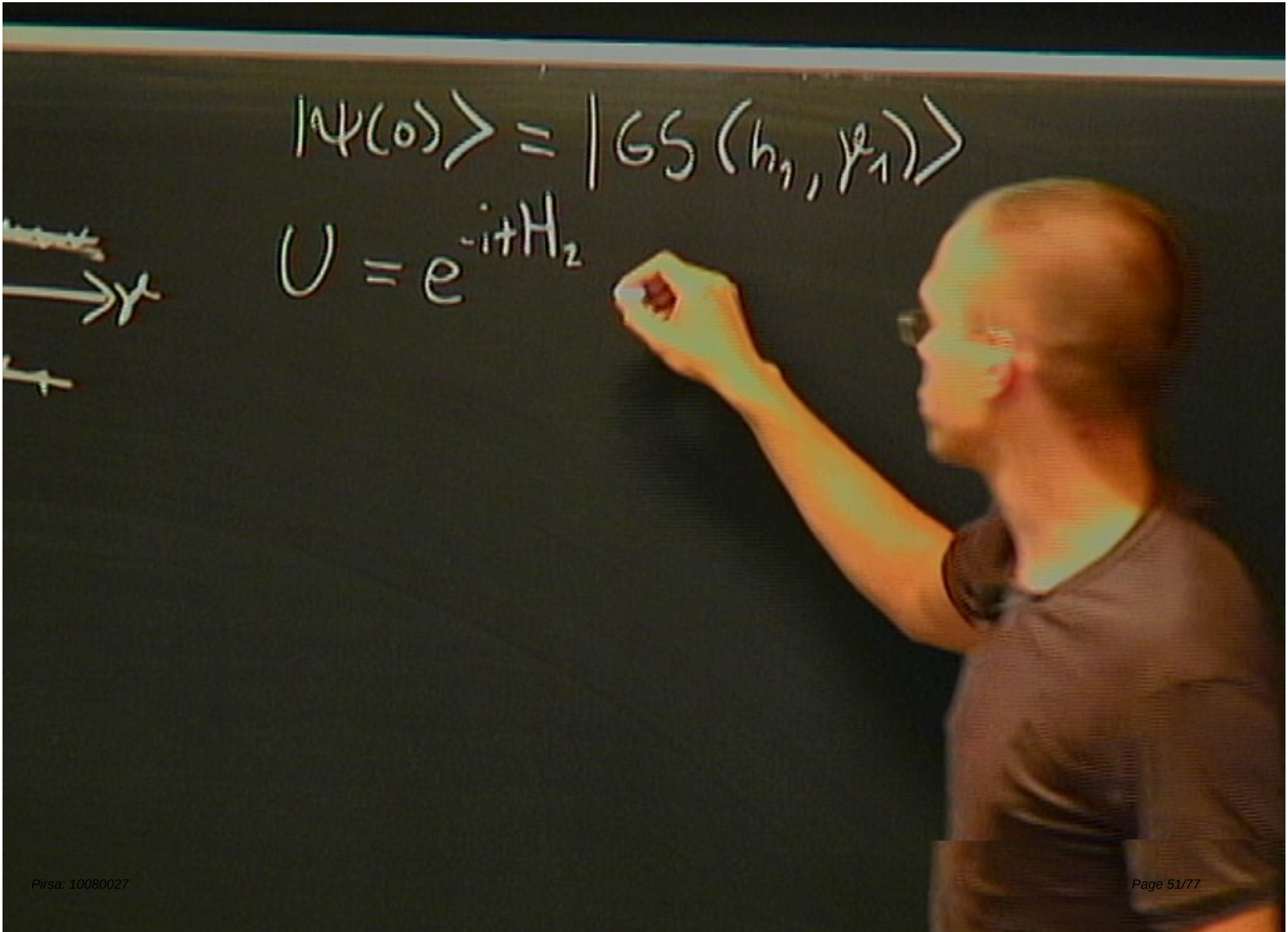
$$\Lambda_k = \sqrt{(h+\cos k)^2 + \gamma^2 \sin^2 k}$$


h
x


h
r
t


h
r

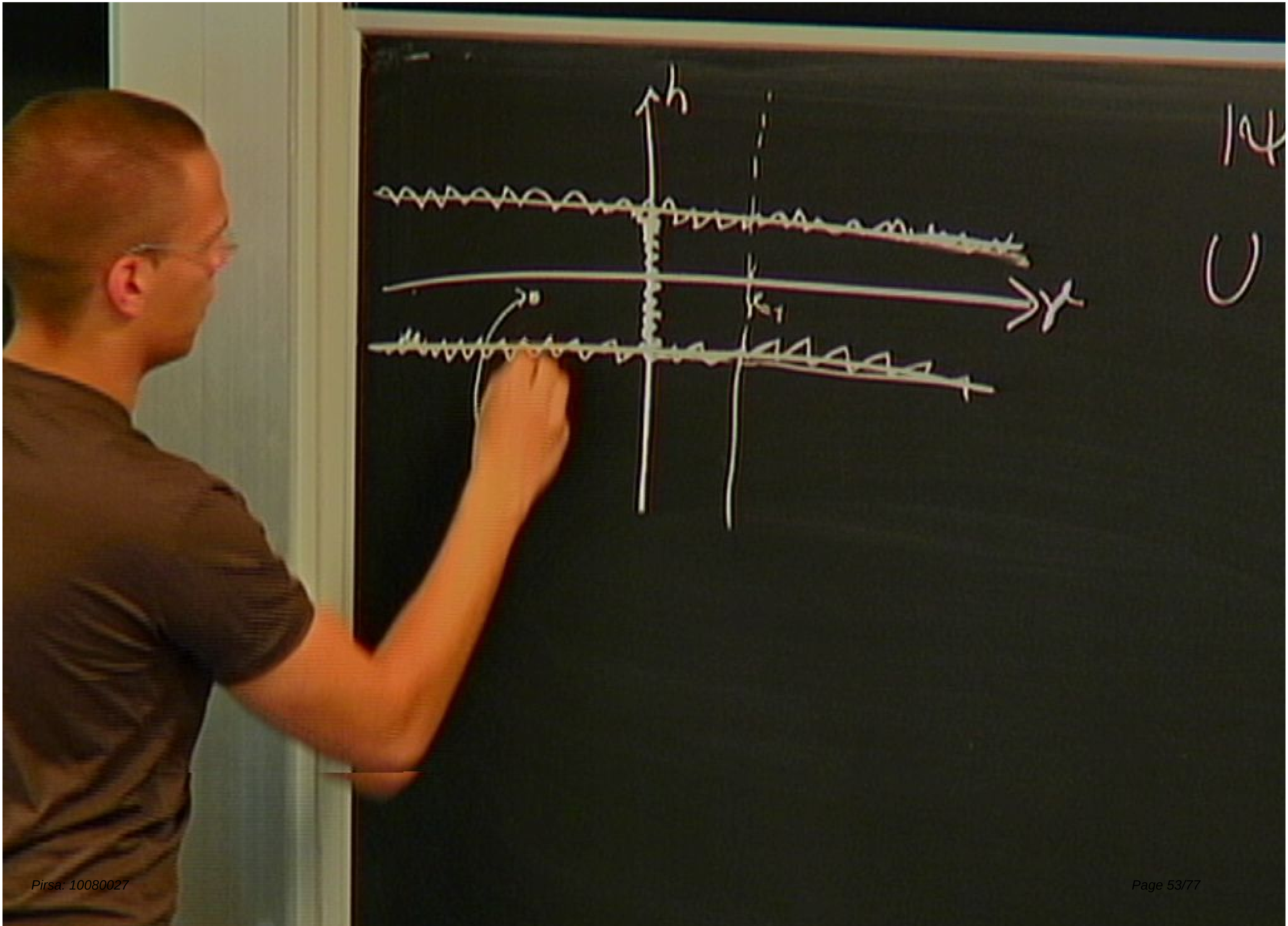

h
k_1

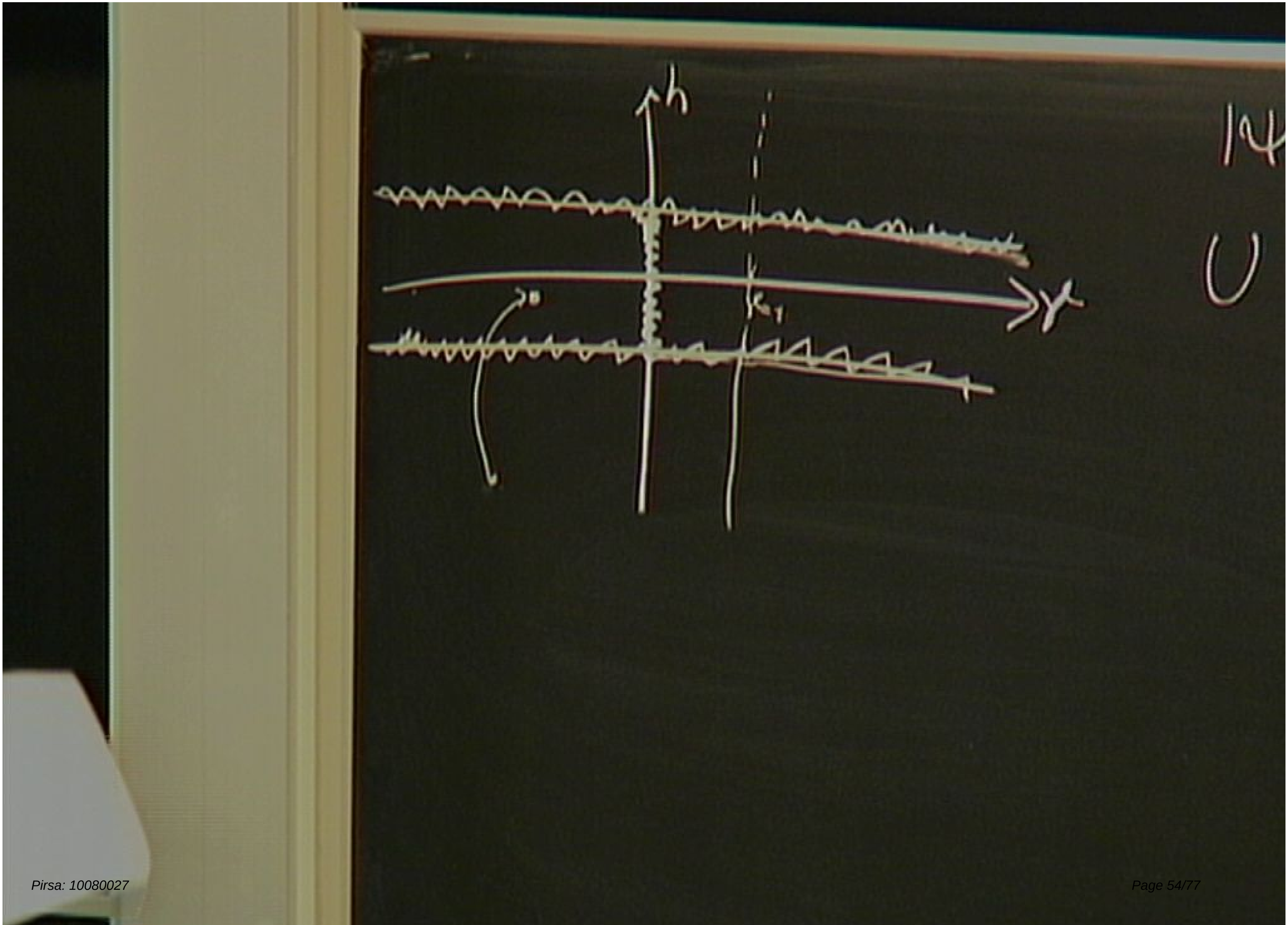

$|\psi(0)\rangle = |GS(h_1, \gamma_1)\rangle$
$U = e^{-itH_2}$

$\Rightarrow \gamma$

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

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




h
x

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

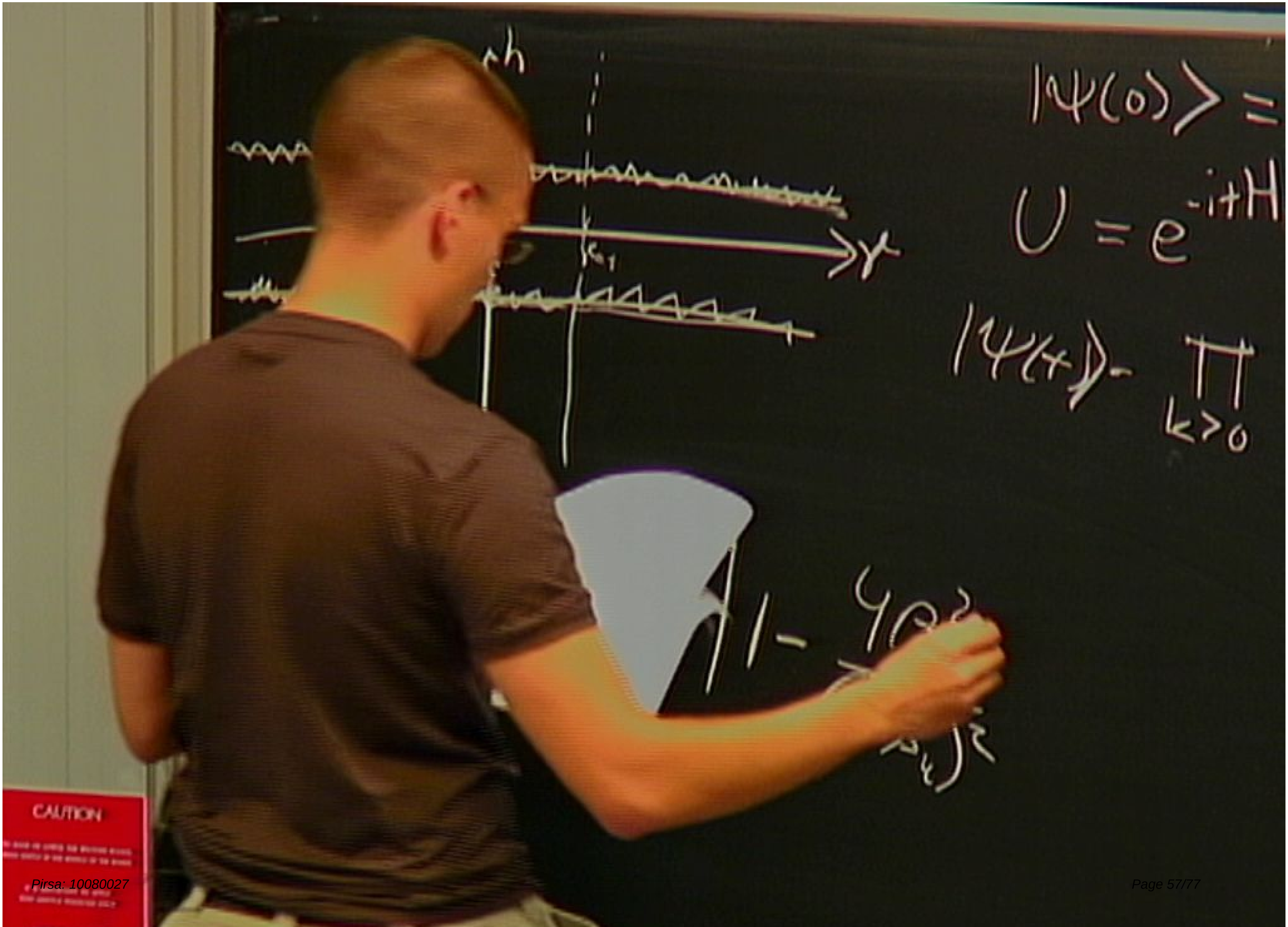
$$U = e^{-itH_2(h_2,\gamma_2)}$$

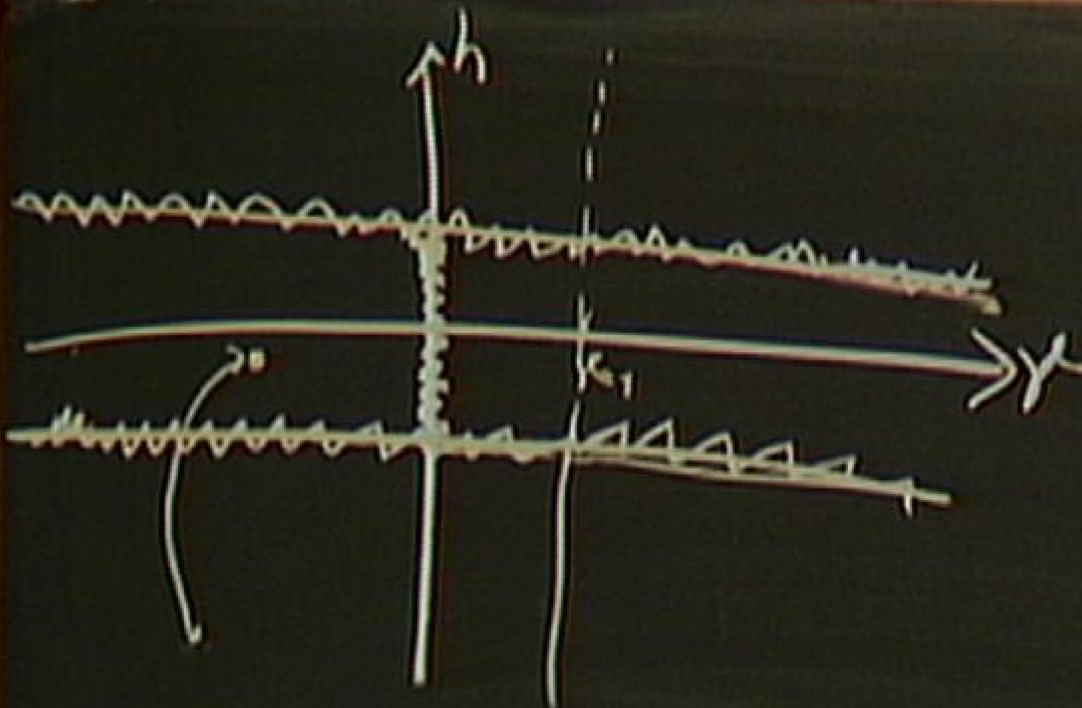
$$|\psi(t)\rangle = \prod_{k>0} \frac{1}{\sqrt{1+\beta_k^2}} \left(1 + \beta_k e^{-it2\Lambda_k} \eta_k^{+} \eta_{-k}^{+}\right) |0_k\rangle$$

$$|\psi(0)\rangle = |GS(h_1, \gamma_1)\rangle \qquad k = \frac{2\pi n}{N}$$

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

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


|ψ(0)> =
U = e^{-itH}
|ψ(t)> = ∏ k>0
CAUTION



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

$$U = e^{-itH_2(h \ldots}$$

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

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

$$|\psi(0)\rangle = |GS(h_1, \gamma_1)\rangle \qquad k = \frac{2\pi n}{N}$$

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

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

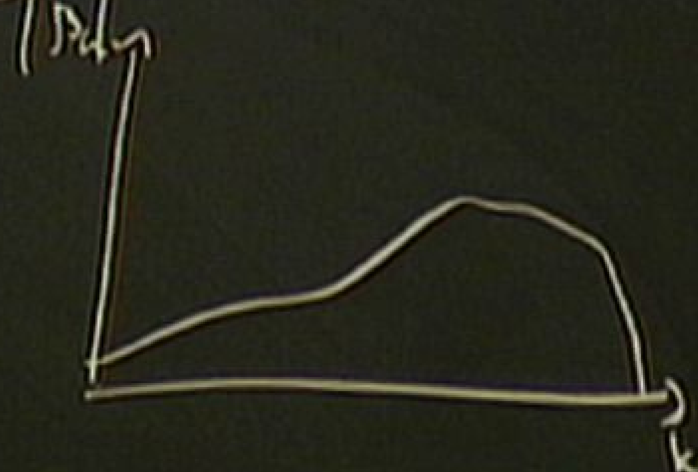
$$\frac{4\beta_k^2}{(1+\beta_k)^2} \sin^2(\Lambda t) \Big|$$

$$|\psi(0)\rangle = |GS(h_1,\gamma_1)\rangle \qquad k = \frac{2\pi n}{N}$$

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

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

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

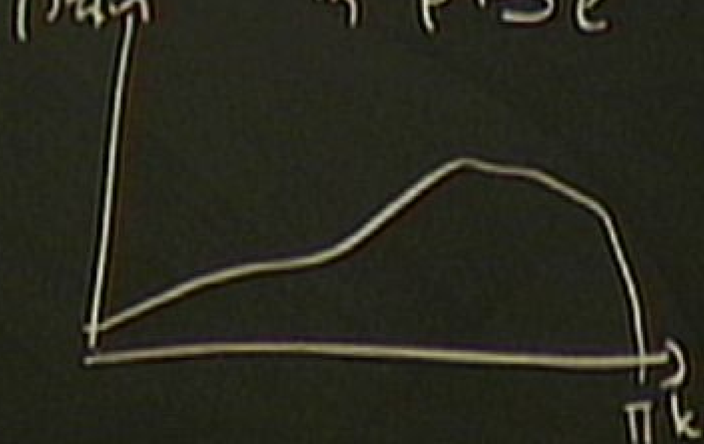


$$\rangle\rangle = |GS(h_1,\gamma_1)\rangle \qquad k = \frac{2\pi n}{N}$$

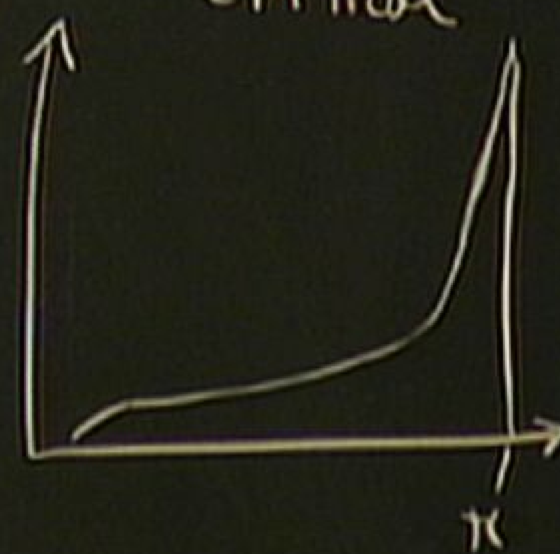
$$e^{-itH_2(h_2,\gamma_2)}$$

$$\prod_{k>0} \frac{1}{\sqrt{1+\beta_k^2}}\left(1 + \beta_k^{(1\to2)}\, e^{-it2\Lambda_k^{(2)}}\, \eta_k^{(2)\dagger}\eta_{-k}^{(2)\dagger}\right)|0_k\rangle$$

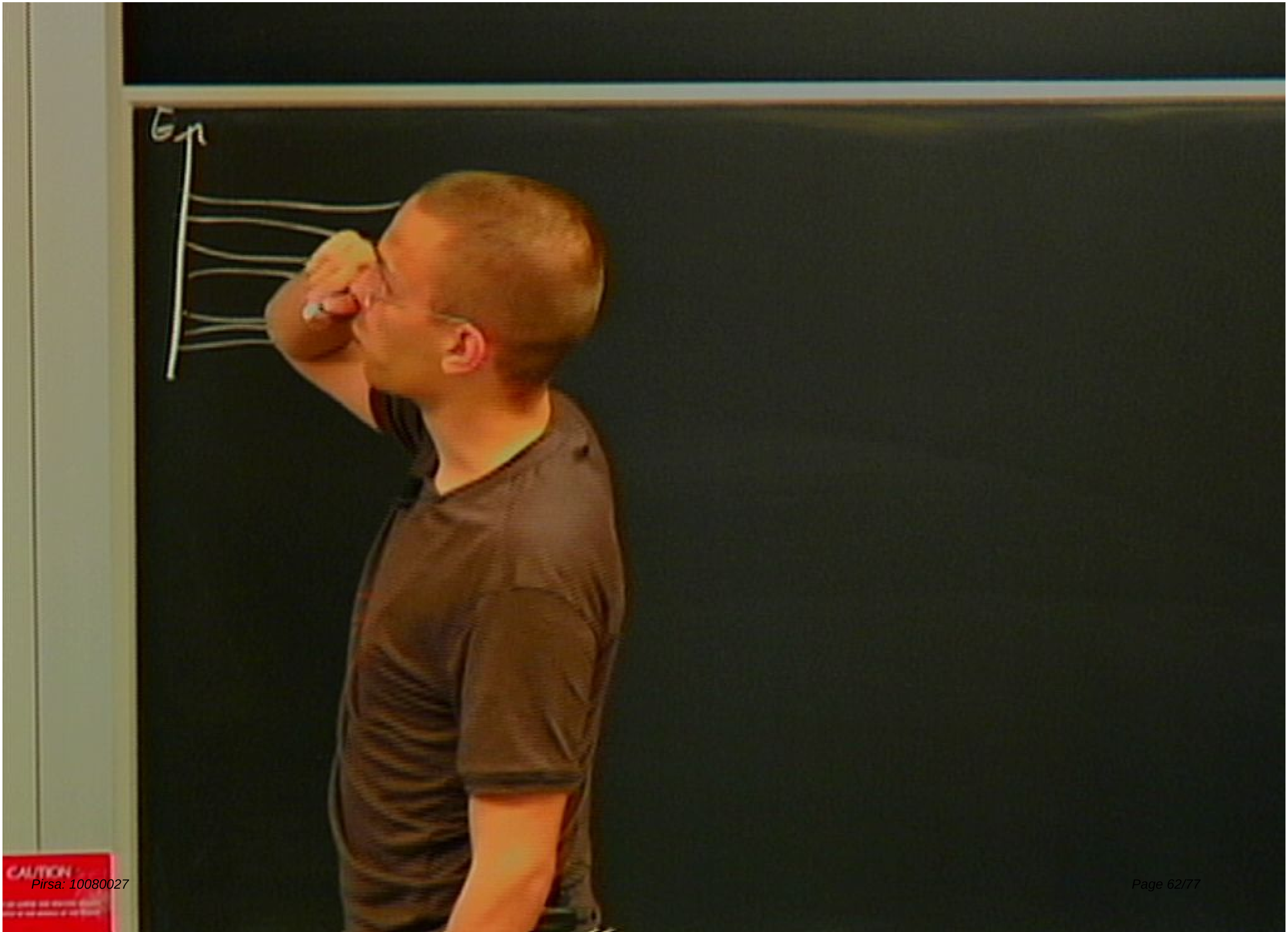
$|\beta_k|$ h phase

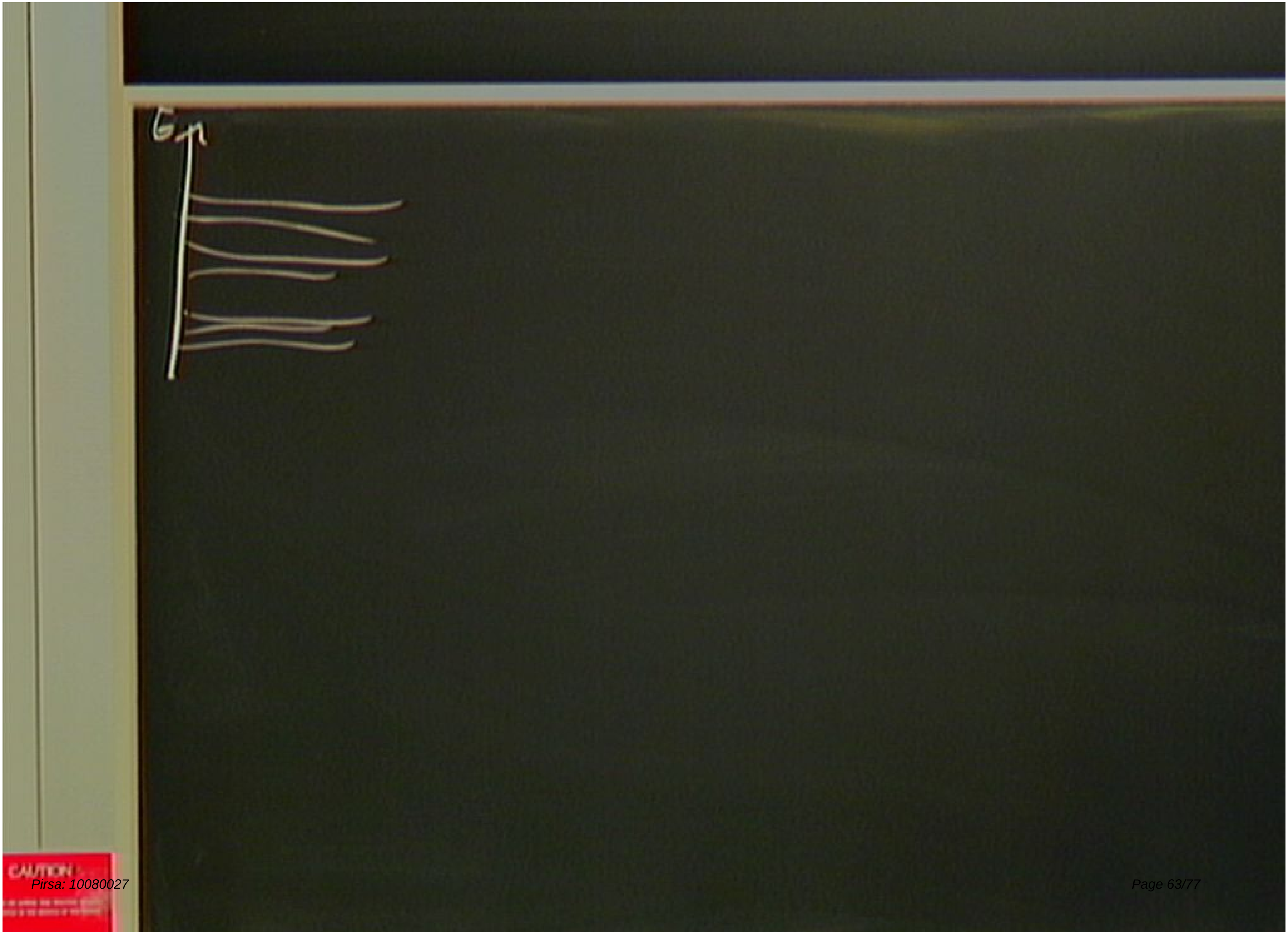


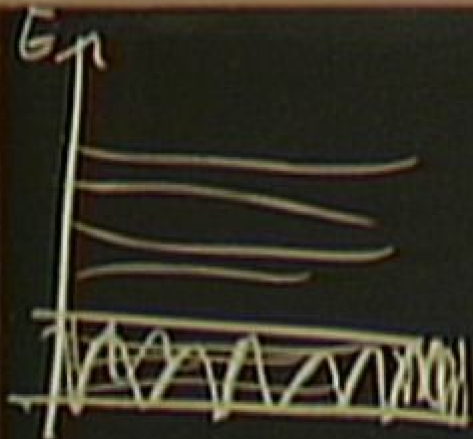
Critical



$(1\gamma)\rangle$

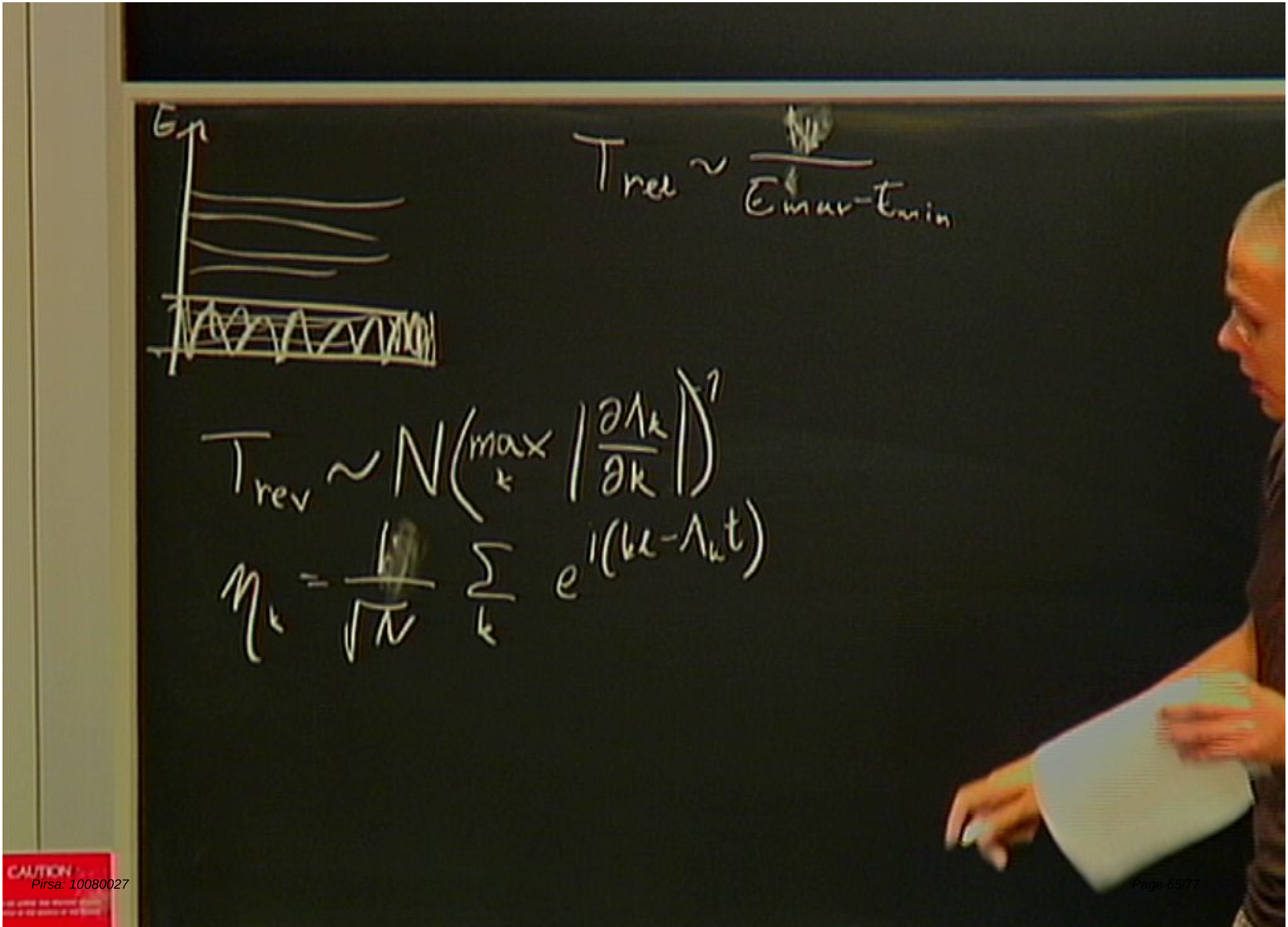

E

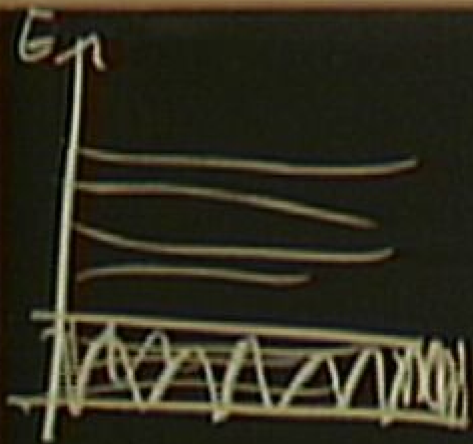

E



$$T_{rel} \sim \frac{N^2}{E_{max} - E_{min}}$$

$$T_{rev} \sim N^{max}$$


E
$T_{rel} \sim \frac{\hbar}{E_{max} - E_{min}}$
$T_{rev} \sim N \left(\max_k \left| \frac{\partial \Lambda_k}{\partial k} \right| \right)^{-1}$
$\eta_k = \frac{1}{\sqrt{N}} \sum_k e^{i(kl - \Lambda_k t)}$

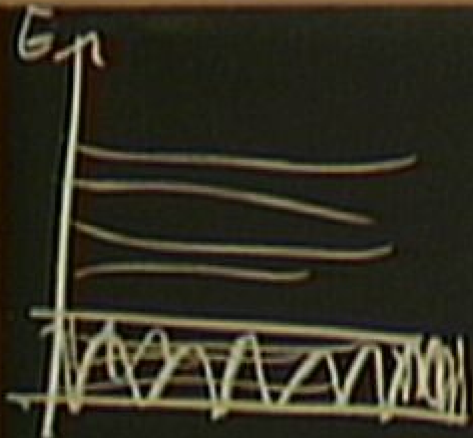


$$T_{rel} \sim \frac{1}{E_{max}-E_{min}}$$

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

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

$$k \to k + \delta k \qquad \Lambda_k \to \Lambda_{k_0} + \delta\Lambda$$



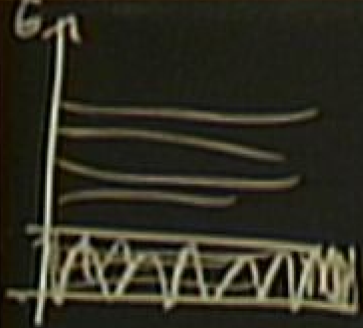
$$T_{rel} \sim \frac{\text{[illegible]}}{E_{max} - E_{min}}$$

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

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

$$k \to k + \delta k \qquad \Lambda_k \to \Lambda_{k_0} + \delta\Lambda$$

$$\delta k \, N - \delta\Lambda \, t = 2\pi n$$



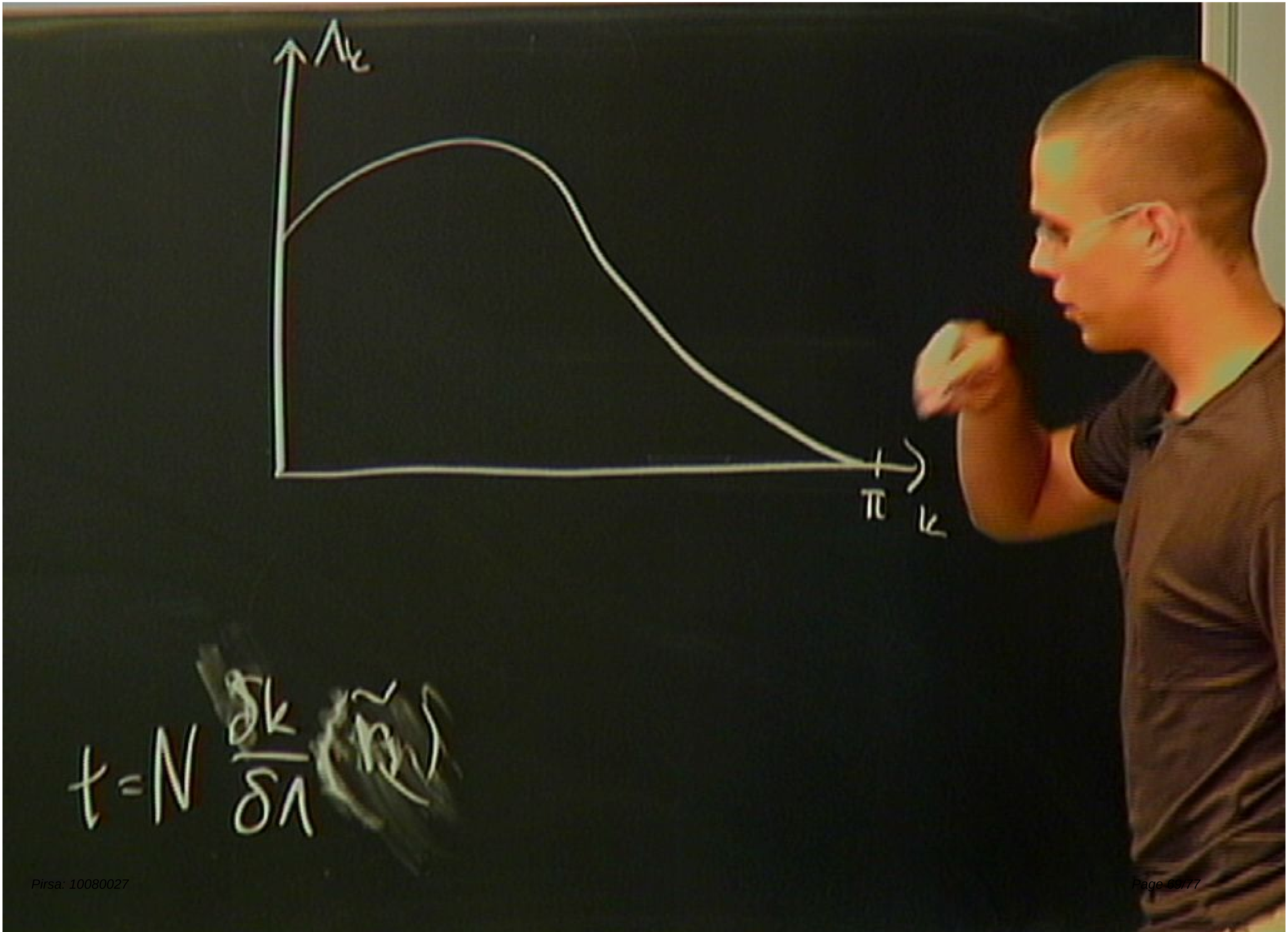
$$T_{rec} \sim \frac{\hbar}{E_{max}-E_{min}}$$

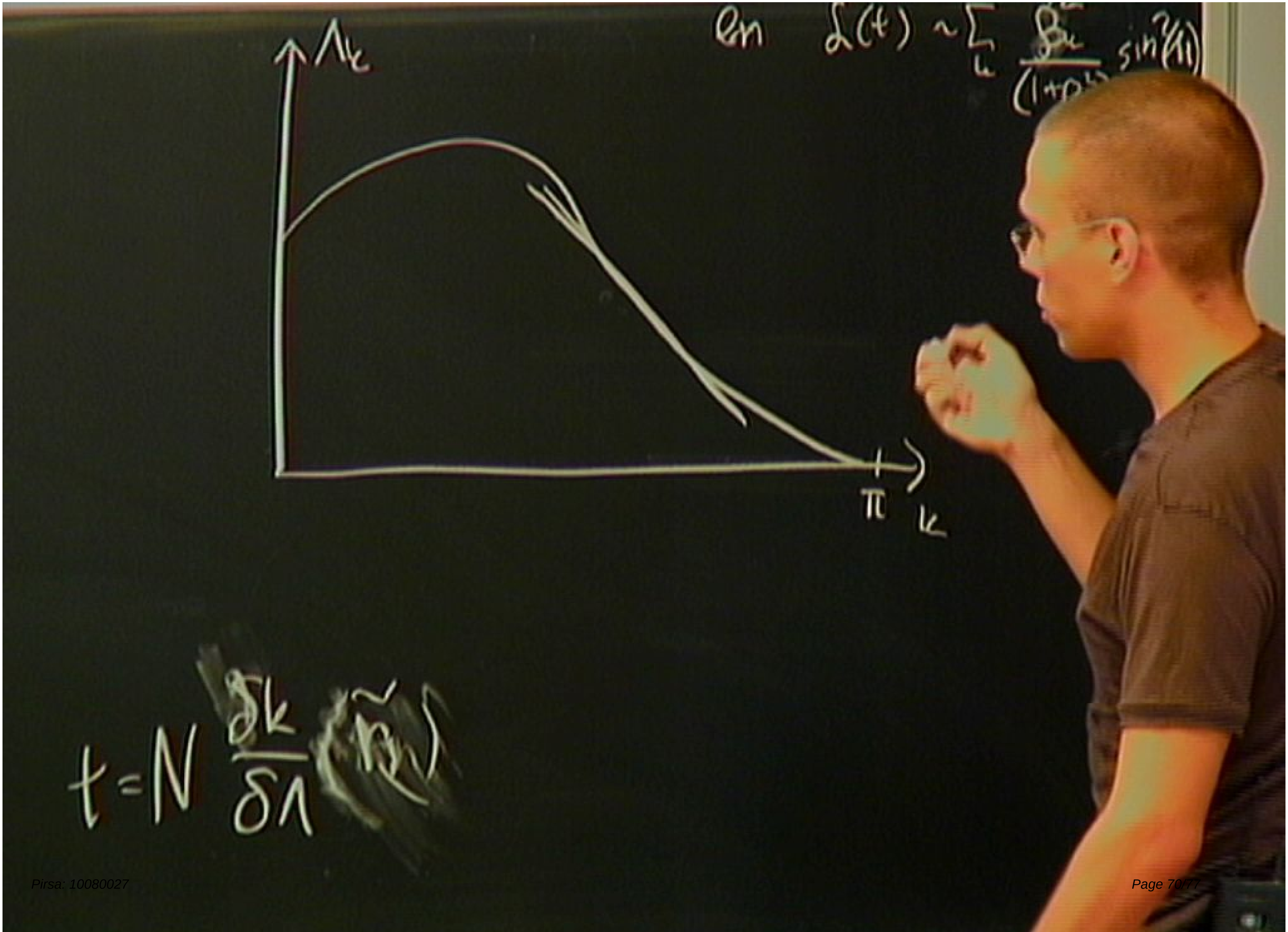
$$T_{rev} \sim N\left(\max_k \left|\frac{\partial \Lambda_k}{\partial k}\right|\right)^{-1}$$

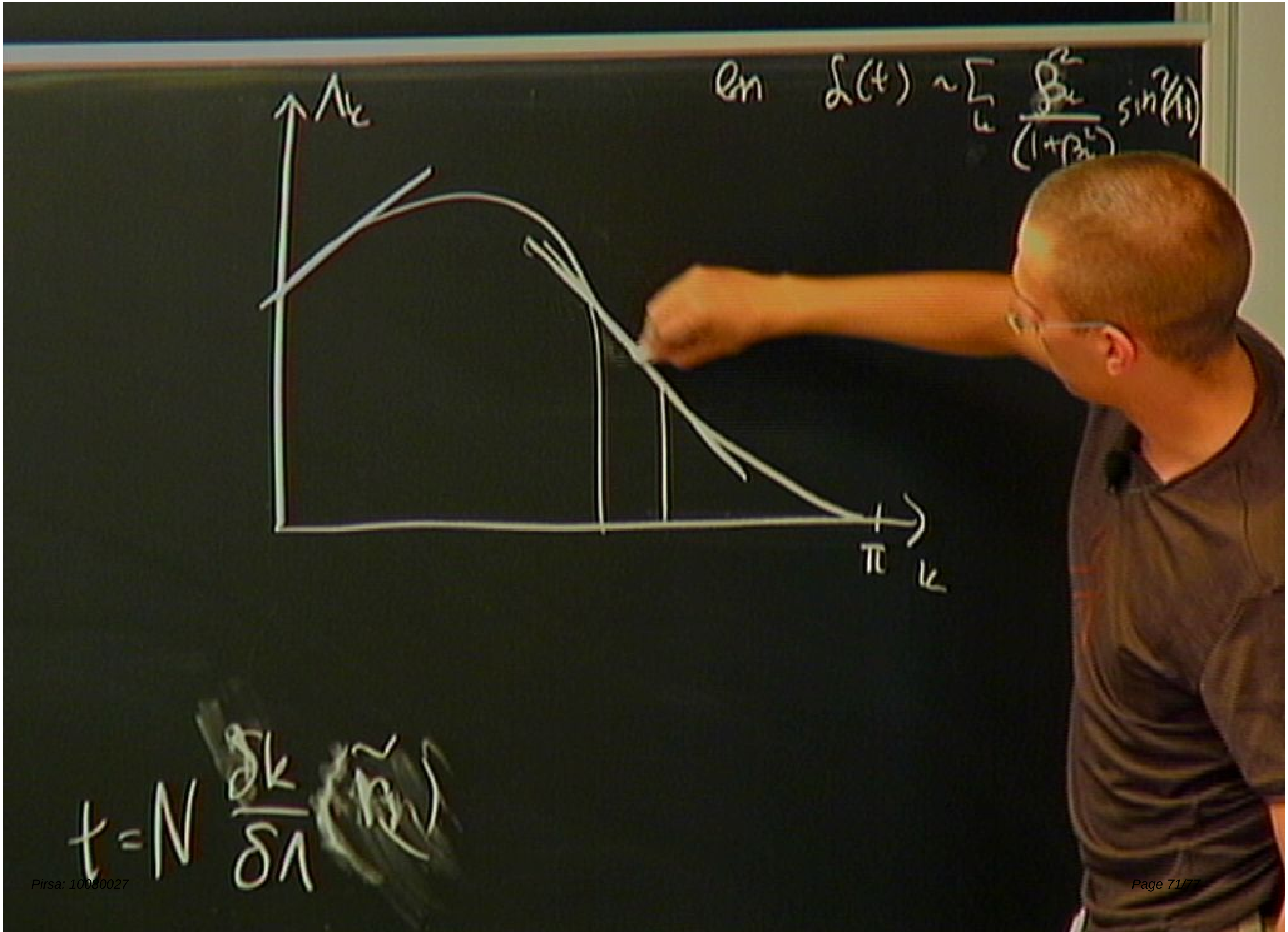
$$\eta_i = \frac{1}{\sqrt{N}} \sum_k e^{i(ki-\Lambda_k t)} \eta^k$$

$$k \to k + \delta k \qquad \Lambda_k \to \Lambda_{k_0} + \delta\Lambda$$

$$\delta k\, N - \delta\Lambda t = 2\pi n \qquad t = N\frac{\delta k}{\delta\Lambda}\,[\text{illegible}]$$


Λ_k
π
k
$t = N \frac{\delta k}{\delta \Lambda}$

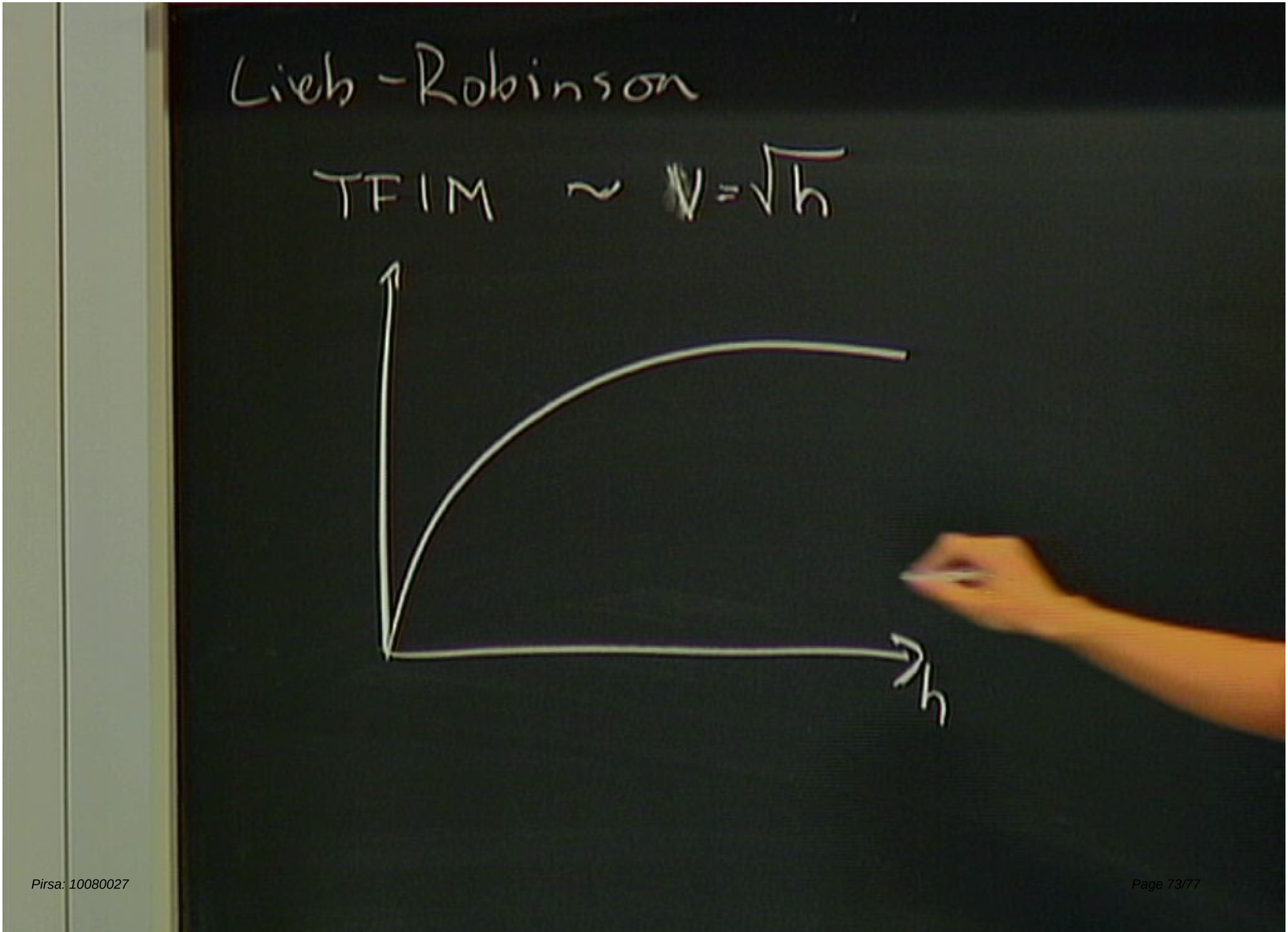

Λ_k
π
k
$t = N \frac{\delta k}{\delta \Lambda}$



en
Λk
π
k
t = N δk/δΛ

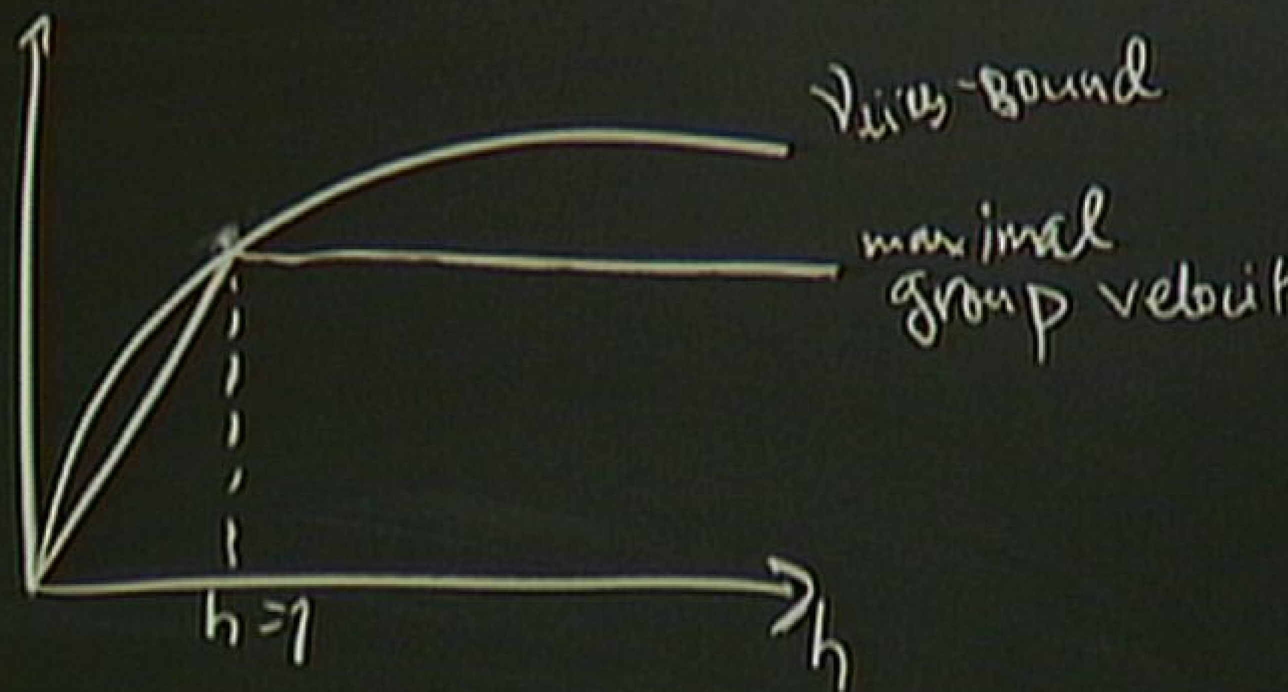
Lieb-Robinson

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


Lieb-Robinson
TFIM ~ V = √h
h

Lieb-Robinson

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



$$U^{+}(t)\,\sigma^x_j\,U(t)$$

l

$$= \sum_l A_l\,\sigma_l^x + A_l^*\,\sigma_l^x$$

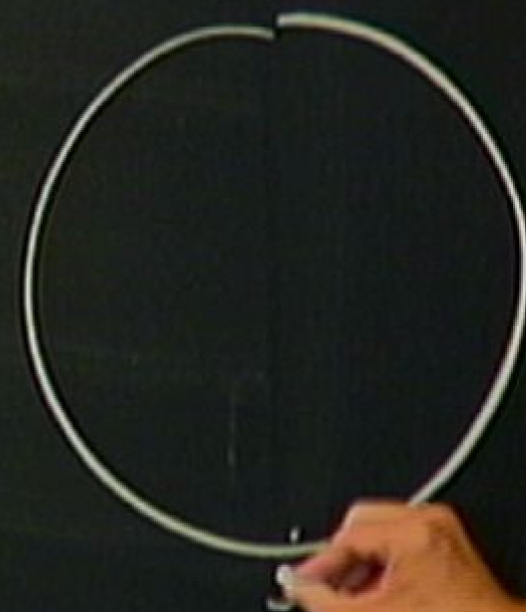
velocit

$$U^\dagger(t)\,\sigma^x\,U(t)$$

$$= \sum_i \underbrace{A_i(t)}\,\sigma_i^x + A^*_i(t)\,\sigma_i^x$$

ℓ

velocit



$$U^{\dagger}(t)\,\sigma_0^x\,U(t)$$

l

$$= \sum_i A_i(t)\,\sigma_i^x + A_i^*(t)\,\sigma_i^x$$

velocit

$\mu \sim \log \mathcal{L}(t)$