Title: Interpretation of Quantum Theory: Lecture 14

Date: Feb 17, 2005 02:15 PM

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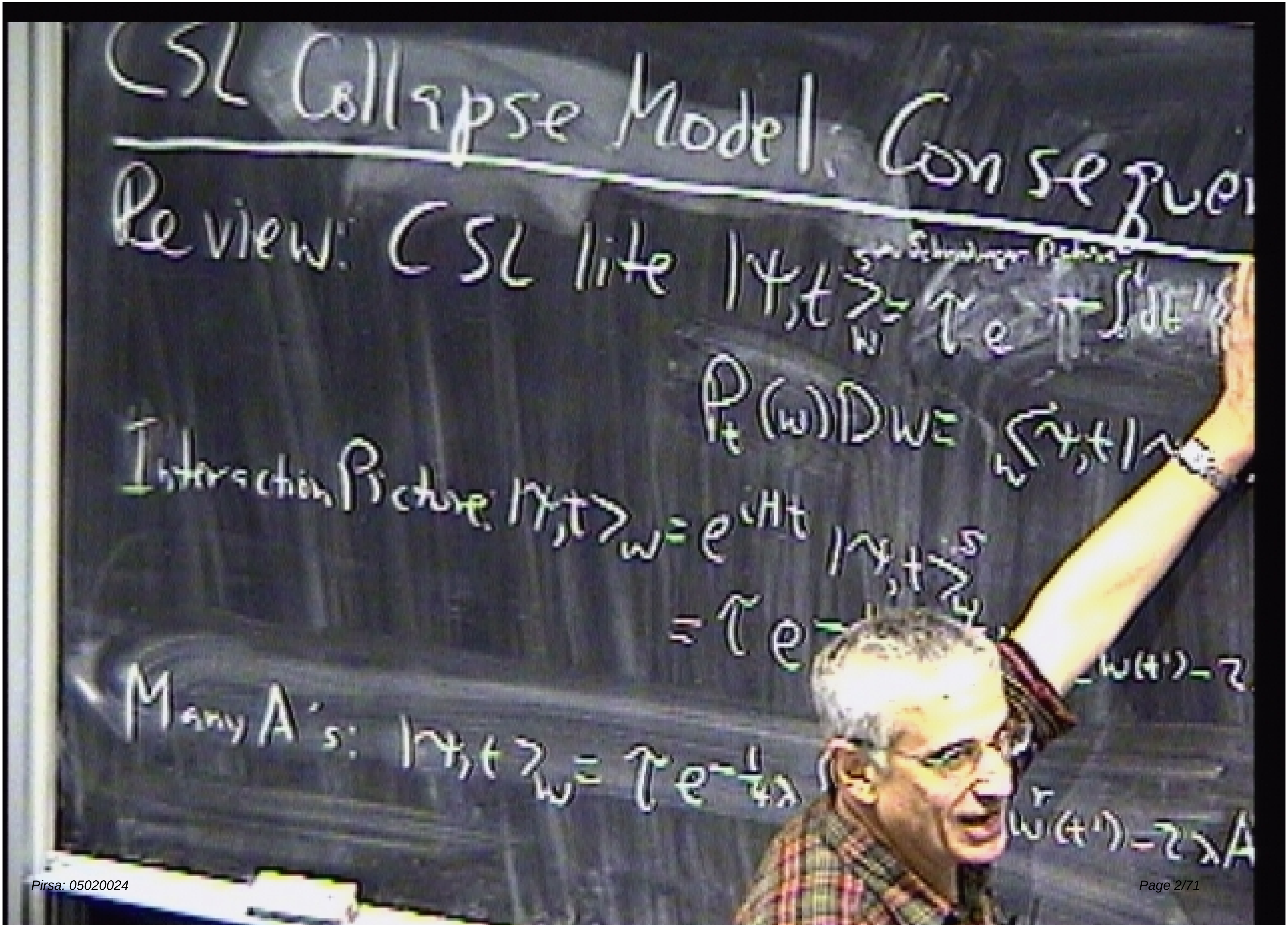
Abstract:


CSL Collapse Model: Consequen
Review: CSL lite
Interaction Picture
Many A's:

el: Consequences

in Schrödinger Picture

$$|\psi,t\rangle_w = \mathcal{T} e^{-\int^t dt' \{ iH(t') \frac{1}{4\lambda}[w(t')-2\lambda A]^2\}}$$

$$P_t(w)Dw = {}_w\langle\psi,t|\psi,t\rangle_w \, Dw$$

$$|\psi,0\rangle = \sum_n (\alpha_n)|a_n\rangle$$

$$|\psi,t\rangle_w$$

$$e^{-\frac{1}{4\lambda}\int_0^t dt' [w(t')-2\lambda A(t')]^2}|\psi\rangle$$

$$A(t') = e^{iHt'} A e^{iHt}$$

$$\frac{1}{4\lambda}\int_0^t dt' \sum_n [w^n(t')-2\lambda A^n(t')]^2 |\varphi\rangle$$

CSL Collapse Model: Consequences

Review: CSL lite $|\psi,t\rangle^{\text{non-Schrödinger Picture}}_w = \mathcal{T} e^{-\int_0^t dt' \frac{1}{4\lambda}[w(t')-2\lambda A]^2}$ [illegible]

$$P_t(w)Dw = {}_w\langle\psi,t|\psi,t\rangle_w Dw$$

Interaction Picture: $|\psi,t\rangle_w = e^{iHt}|\psi,t\rangle^S_w$

$$= \mathcal{T} e^{-\frac{1}{4\lambda}\int_0^t dt' [w(t')-2\lambda A(t')]^2}|\psi\rangle$$

$A(t') = e^{iHt'}$ [illegible]

Many A's: $|\psi,t\rangle_w = \mathcal{T} e^{-\frac{1}{4\lambda}\int_0^t dt' \sum_n [w^n(t')-2\lambda A^n(t')]^2}|\psi\rangle$

...onsequences

gen. Schrödinger Picture:

$$|\psi,t\rangle_w^S = T e^{-\int dt' \{ iH(t') + \frac{1}{4\lambda}[w(t')-2\lambda A]^2\}}$$

$$(w)Dw = {}_w\langle\psi,t|\psi,t\rangle_w \, Dw$$

$$|\psi,0\rangle = \sum_n \alpha_n |a_n\rangle$$

$$\prod_{t_i} \frac{dw_i}{\sqrt{2\pi\lambda dt}}$$

$$t \quad |\psi,t\rangle_w^S$$

$$e^{-\frac{1}{4\lambda}\int_0^t dt' [w(t')-2\lambda A(t')]^2} |\psi\rangle$$

$$A(t') = e^{iHt'} A e^{iHt}$$

$$\lambda \int_0^t dt' \sum_r [w^r(t')-2\lambda A^r(t')]^2 |\psi\rangle$$

CSL Collapse Model: Consequences

Review: CSL lite $|\psi,t\rangle_w = \mathcal{T} e^{-\int_0^t dt' \frac{1}{4\lambda}[w(t')-2\lambda A]^2} |\psi,0\rangle$

$$P_t(w)Dw = {}_w\langle\psi,t|\psi,t\rangle_w \, Dw$$

$$Dw = \prod_{t_i} \frac{dw_{t_i}}{\sqrt{2\pi\lambda/dt}} \qquad |\psi,0\rangle = \sum c_n |a_n\rangle$$

Interaction Picture: $|\psi,t\rangle_w = e^{iHt} |\psi,t\rangle_w^S$

$$= \mathcal{T} e^{-\frac{1}{4\lambda}\int_0^t dt' [w(t')-2\lambda A(t')]^2} |\psi\rangle$$

$$A(t') = e^{iHt'} A e^{-iHt'}$$

Many A's: $|\psi,t\rangle_w = \mathcal{T} e^{-\frac{1}{4\lambda}\int_0^t dt' \sum_\alpha [w^\alpha(t')-2\lambda A^\alpha(t')]^2} |\psi\rangle$

$$\ldots |\varphi\rangle$$

Density matrix: $\rho(t) = \int P_t(\omega)\, D\omega\, |\psi, t\rangle_\omega \frac{{}_\omega\langle \psi, t|}{P_t(\omega)} = \int D\omega\, |\psi, t\rangle_\omega \ldots$

$$\rho(t) = \int D\omega\, e^{-\frac{1}{4\lambda}\int^t dt' [\omega(t') - 2\lambda A(t')]^2}\, |\psi\rangle\langle\psi|\, e^{-\frac{1}{4\lambda}\int_0^t dt' [\omega(t') - 2\lambda A(t')]^2}$$

$$\int \frac{d\omega}{\sqrt{2\pi\lambda/dt}}\, e^{-\frac{1}{4\lambda}dt[\omega - 2\lambda A]^2} \cdot e^{-\frac{1}{4\lambda}dt[\omega - 2\lambda A]^2} = e^{-\frac{\lambda}{2}dt[A_L - A_R]^2}$$

$$\boxed{\rho(t) = e^{-\frac{\lambda}{2}\int_0^t dt' [A_L(t') - A_R(t')]^2}\, \rho(0)}$$

$$\frac{d\rho}{dt}(t) = -\frac{\lambda}{2}[A(t),[A(t),\rho(t)]] = -\frac{\lambda}{2}\left[A^2(t)\rho + \rho A^2(t) - 2A(t)\rho A(t)\right]$$

Density matrix: $\rho(t) = \int P_t(w)\, Dw\, |\psi_t$

$\rho(t) = \int Dw\, \tilde{e}^{-\frac{1}{4\lambda}\int_0^t dt' [w(t') - 2\lambda A(t')]^2}$

$|\psi\rangle\langle\psi| \tilde{e}_R$

$\int \frac{dw}{\sqrt{2\pi\lambda/dt}}\, e^{-\frac{1}{4\lambda} dt [w - 2\lambda A]^2}$ $e^{-\frac{1}{4\lambda} dt [w - 2\lambda A]}$

$$\boxed{\rho(t) = e^{-\frac{\lambda}{2}\int_0^t dt' [A_L(t') - A_R(t')]^2} \rho(0)}$$

$\frac{d\rho}{dt}(t) = -\frac{\lambda}{2}[A(t), [A(t), \rho(t)]] = -\frac{\lambda}{2}[A$

$$P_t(w)\,\mathcal{D}w\,|\psi,t\rangle_w\,{}_w\langle\psi,t|$$

$$\frac{\quad}{P_t(w)} = \int \mathcal{D}w\,|\psi,t\rangle_w\,{}_w\langle\psi,t|$$

$$-2\lambda A(t')]^2$$

$$|\psi\rangle\langle\psi|\,[e_R^{-\frac{1}{4\lambda}\int_0^t dt''[w(t'')-2\lambda A(t'')]^2}$$

$$e^{-\frac{1}{4\lambda}dt[w-2\lambda A]^2}$$

$$= e^{-\frac{\lambda}{2}dt[A_L - A_R]^2}$$

$$\boxed{-A_R(t')]^2\;\rho(0))}$$

$$),\rho(t)]] = -\frac{\lambda}{2}[A^2(t)\rho + \rho A^2(t) - 2A(t)\rho A(t)]$$

$\ldots \lambda A(t')]\,|\psi\rangle$

Density matrix: $\rho(t) \equiv \int \boxed{P_t(\omega)\, D\omega}\, \dfrac{|\psi, t\rangle_\omega \; {}_\omega\langle \psi, t|}{P_t(\omega)} = \int D\omega\, |\psi\rangle\langle\psi| \ldots$

$$\rho(t) = \int D\omega\, N e^{-\frac{1}{4\lambda}\int_0^t dt' [\omega(t') - 2\lambda A(t')]^2}$$

$$|\psi\rangle\langle\psi| \left[e^{-\frac{1}{4\lambda}\int_0^t dt' [\omega(t') - 2\lambda A(t')]^2} \right]$$

$$\int \frac{d\omega}{\sqrt{2\pi\lambda dt}}\, e^{-\frac{1}{4\lambda} dt [\omega - 2\lambda A]^2} \cdot e^{-\frac{1}{4\lambda} dt [\omega - 2\lambda A]^2} = e^{-\frac{\lambda}{2} dt [A_L - A_R]^2}$$

$$\boxed{\rho(t) = e^{-\frac{\lambda}{2}\int_0^t dt' [A_L(t') - A_R(t')]^2}\, \rho(0)}$$

$$\frac{d\rho}{dt}(t) = -\frac{\lambda}{2}[A(t),[A(t), \rho(t)]] = -\frac{\lambda}{2}\left[A^2(t)\rho + \rho A^2(t) - 2A(t)\rho A(t)\right]$$

<u>CSL</u>: $|\psi,t\rangle_w = \mathcal{T} e^{-\frac{1}{4\lambda}\int_0^t dt' \int d\mathbf{x}\,[w(\mathbf{x},t') - 2\lambda A(\mathbf{x},t')]^2} |\psi,0\rangle$

$$A(\mathbf{x},t) \equiv e^{iHt} \underbrace{\frac{1}{(\pi a^2)^{3/4}} \int d\mathbf{z}\, e^{-\frac{(\mathbf{x}-\mathbf{z})^2}{2a^2}} \frac{M(\mathbf{z})}{m_0}}_{A(\mathbf{x})} e^{-iHt} \qquad M(\mathbf{z}) = \sum m_\alpha \xi_\alpha^\dagger(\mathbf{z}) \xi_\alpha(\mathbf{z})$$

<u>Prob</u>: $P_t(w) Dw = {}_w\langle\psi,t|\psi,t\rangle_w \qquad Dw \equiv \prod_{\mathbf{x},t'=0}^{t} \frac{dw(\mathbf{x},t')}{\sqrt{2\pi\lambda/dt\,d\mathbf{x}}}$

(a)

CSL: $|\psi, t\rangle_w = \mathcal{T} e^{-\frac{1}{4\lambda}\int_0^t dt' \int d \ldots}$

$A(\vec{x}, t) \equiv e^{iHt} \left[\underbrace{\frac{1}{(\pi a^2)^{3/4}} \int d\vec{z}\, e^{-\ldots}}_{A(\vec{x} \ldots} \right.$

Prob: $P_t(w)Dw = {}_w\langle \psi, t | \psi, t \rangle_w$

(a)

CSL: $|\psi, t\rangle_w = \mathcal{T} e^{-\frac{1}{4\lambda}\int_0^t dt' \int d$

$$A(\vec{x}, t) \equiv e^{iHt} \Big[\underbrace{\frac{1}{(\pi a^2)^{3/4}} \int d\vec{z}\, e^{-}}_{A(\vec{x}}$$

Prob: $P_t(w)\, Dw \equiv {}_w\langle \psi, t | \psi, t\rangle_w$

(a)

$$dt' \int d\vec{x}' \left[w(\vec{x}',t') - 2\lambda A(\vec{x}',t') \right]^2 |\psi\rangle$$

$$\left[\int d\vec{z}\, e^{-\frac{(\vec{x}-\vec{z})^2}{2a^2}} \frac{M(\vec{z})}{m_0} \right] e^{-iHt} \qquad M(\vec{z}) = \sum m_\alpha \psi_\alpha^\dagger(\vec{z}) \psi_\alpha(\vec{z})$$

$$A(\vec{x})$$

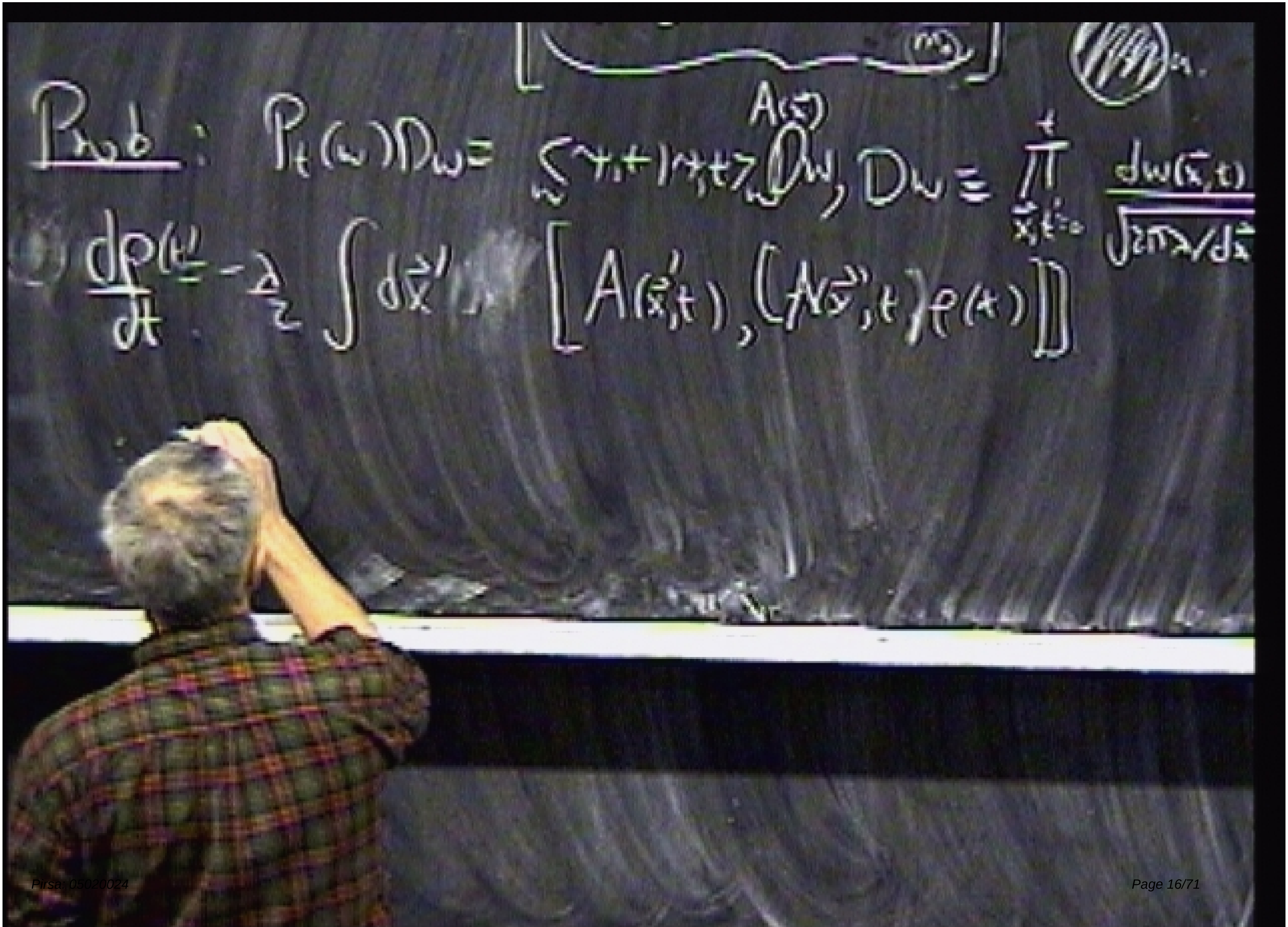
$$,t\rangle_w \qquad Dw \equiv \prod_{\vec{x},t'=0}^{t} \frac{dw(\vec{x},t)}{\sqrt{2\pi\lambda/d\vec{x}\,dt}}$$

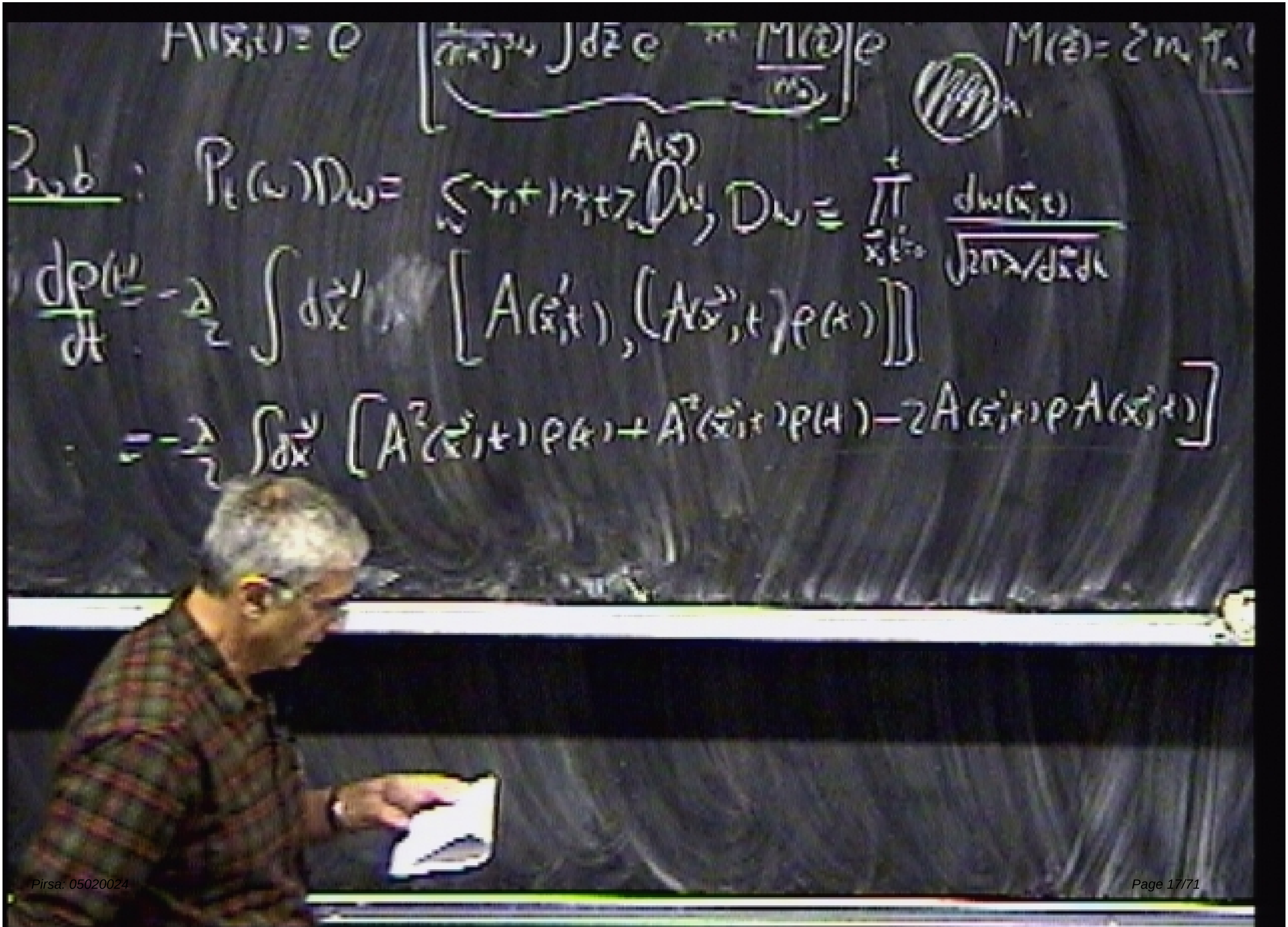
CSL: $|\psi,t\rangle_w = \mathcal{T}\, e^{-\frac{1}{4\lambda}\int_0^t dt' \int dx\, [w(x,t') - 2\lambda A(x,t')]^2} |\psi\rangle$

$$A(x,t) = e^{iHt}\Big[\underbrace{\frac{1}{(\pi a^2)^{3/4}} \int dz\, e^{-\frac{(x-z)^2}{2a^2}} \frac{M(z)}{m_0}}_{A(z)}\Big] e^{-iHt} \qquad M(z) = \sum m_\alpha \psi^\dagger_\alpha(z)\psi_\alpha(z)$$

Prob: $P_t(w)\, Dw = {}_w\langle\psi,t|\psi,t\rangle_w \qquad Dw = \prod_{x,t'}^{t} \frac{dw(x,t)}{\sqrt{2\pi\lambda/dt\,dx}}$

1


Prob :


$M(\vec{z}) = \sum m_n$
Prob: $P_t(\omega)D\omega$
$\frac{d\rho(t)}{dt} = -\frac{\lambda}{2}\int d\vec{x}' \left[A(\vec{x}',t),\left[A(\vec{x}',t),\rho(t)\right]\right]$
$= -\frac{\lambda}{2}\int d\vec{x}' \left[A^2(\vec{x}',t)\rho(t) + A^2(\vec{x}',t)\rho(t) - 2A(\vec{x}',t)\rho A(\vec{x}',t)\right]$

$$A(\vec{x},t) = e \left[\underbrace{\frac{1}{(\pi r_c^2)^{3/4}} \int d\vec{z}\, e^{\cdots} \frac{M(\vec{z})}{m_0} e}_{A(\vec{z})} \right] \qquad M(\vec{z}) = \sum m_n f_n$$

Prob: $P_t(w) Dw = \langle \psi, t | \psi, t \rangle Dw, \quad Dw = \prod_{\vec{x}, t=0}^{t} \frac{dw(\vec{x},t)}{\sqrt{2\pi\lambda / d\vec{x}\, dt}}$

$$\frac{d\rho(t)}{dt} = -\frac{\lambda}{2} \int d\vec{x}' \left[A(\vec{x}',t), [A(\vec{x}',t), \rho(t)] \right]$$

$$= -\frac{\lambda}{2} \int d\vec{x}' \left[A^2(\vec{x}',t) \rho(t) + A^2(\vec{x}',t) \rho(t) - 2A(\vec{x}',t) \rho A(\vec{x}',t) \right]$$

$$= \mathcal{T} e^{-\frac{1}{4\lambda}\int_0^t dt' \int d\vec{x}' \left[w(\vec{x}',t') - 2\lambda A(\vec{x}',t') \right]^2} |\psi\rangle$$

$$e^{iHt}\left[\underbrace{\frac{1}{(\pi a^2)^{3/4}} \int d\vec{z}\, e^{-\frac{(\vec{x}-\vec{z})^2}{2a^2}} \frac{M(\vec{z})}{m_0}}_{A(\vec{x})} \right] e^{-iHt} \qquad M(\vec{z}) = \sum m_\alpha \boxed{\xi_\alpha^\dagger(\vec{z})\xi_\alpha(\vec{z})}$$

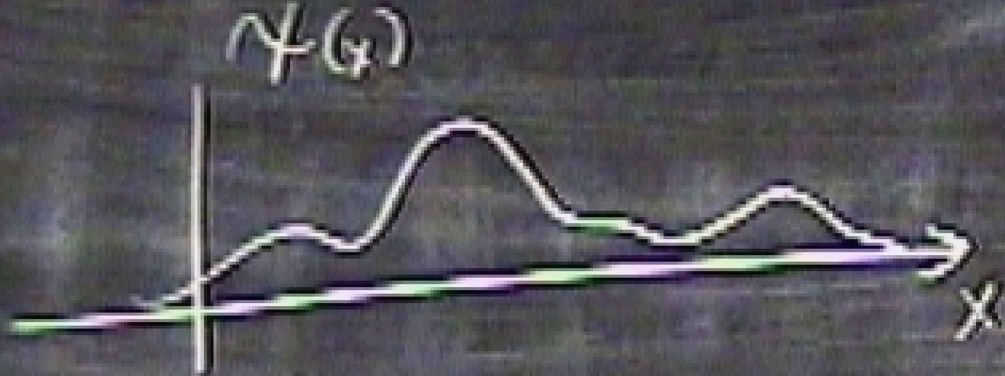
$$a = 10^{-5}\,\mathrm{cm}$$

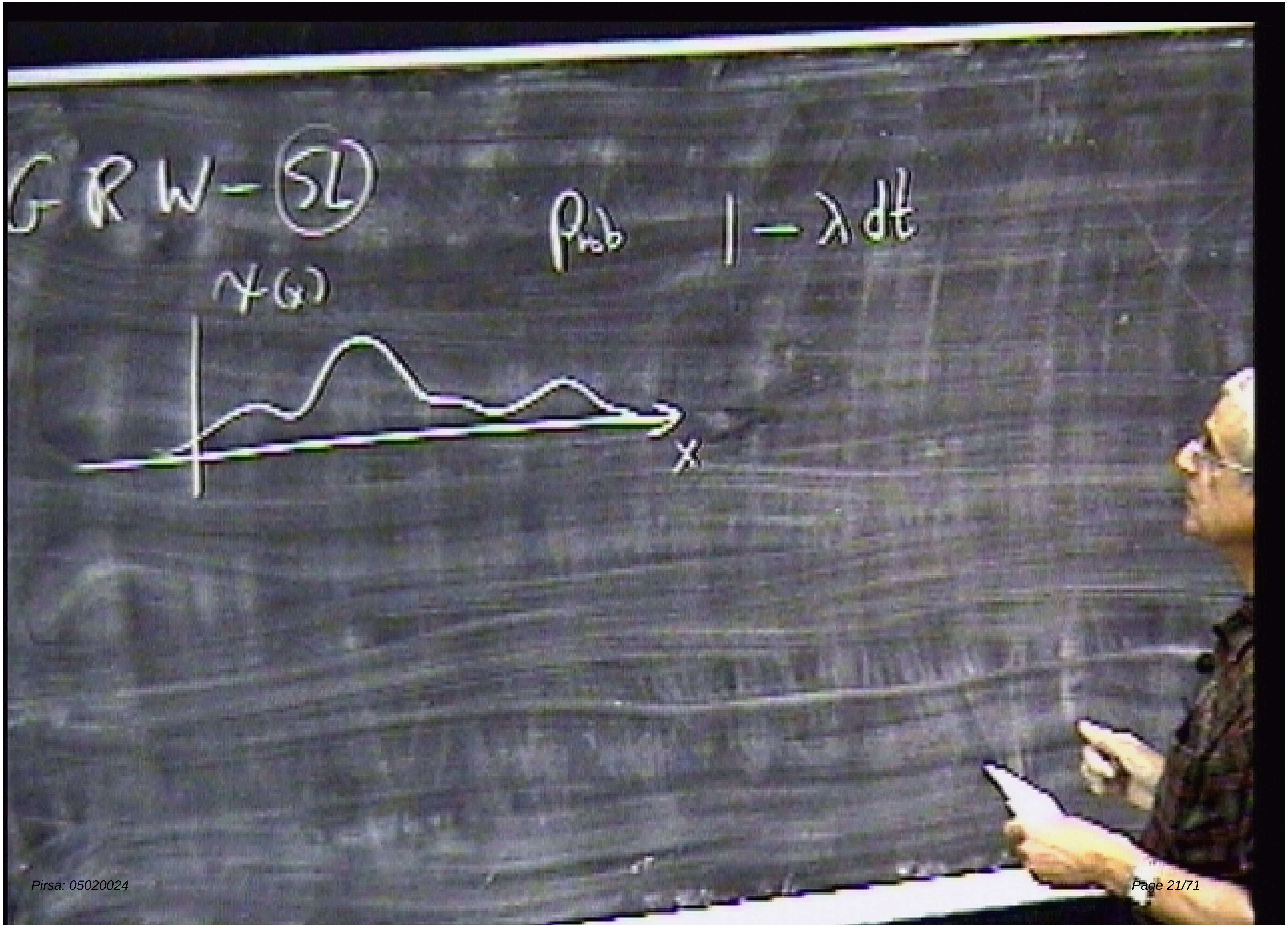
$$\mathcal{D}w = \langle \psi,t|\psi,t\rangle Dw, \quad Dw \equiv \prod_{\vec{x},t=0}^{t} \frac{dw(\vec{x},t)}{\sqrt{2\pi\lambda / d\vec{x}\,dt}} \qquad \lambda = 10^{-16}\,\mathrm{sec}^{-1}$$

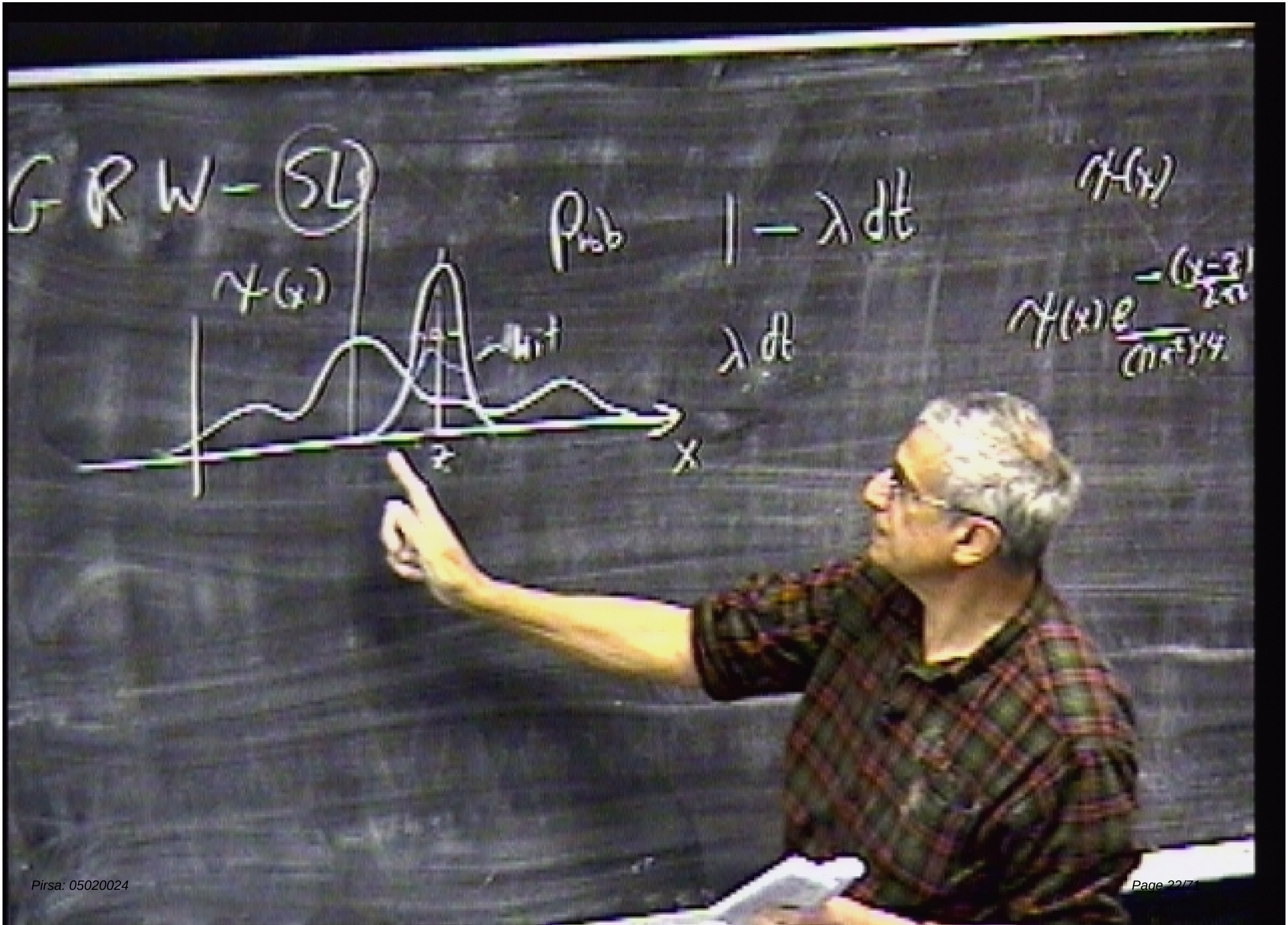
$$d\vec{x}' \left[A(\vec{x}',t), \left(A(\vec{x}',t)\rho(t) \right) \right]$$

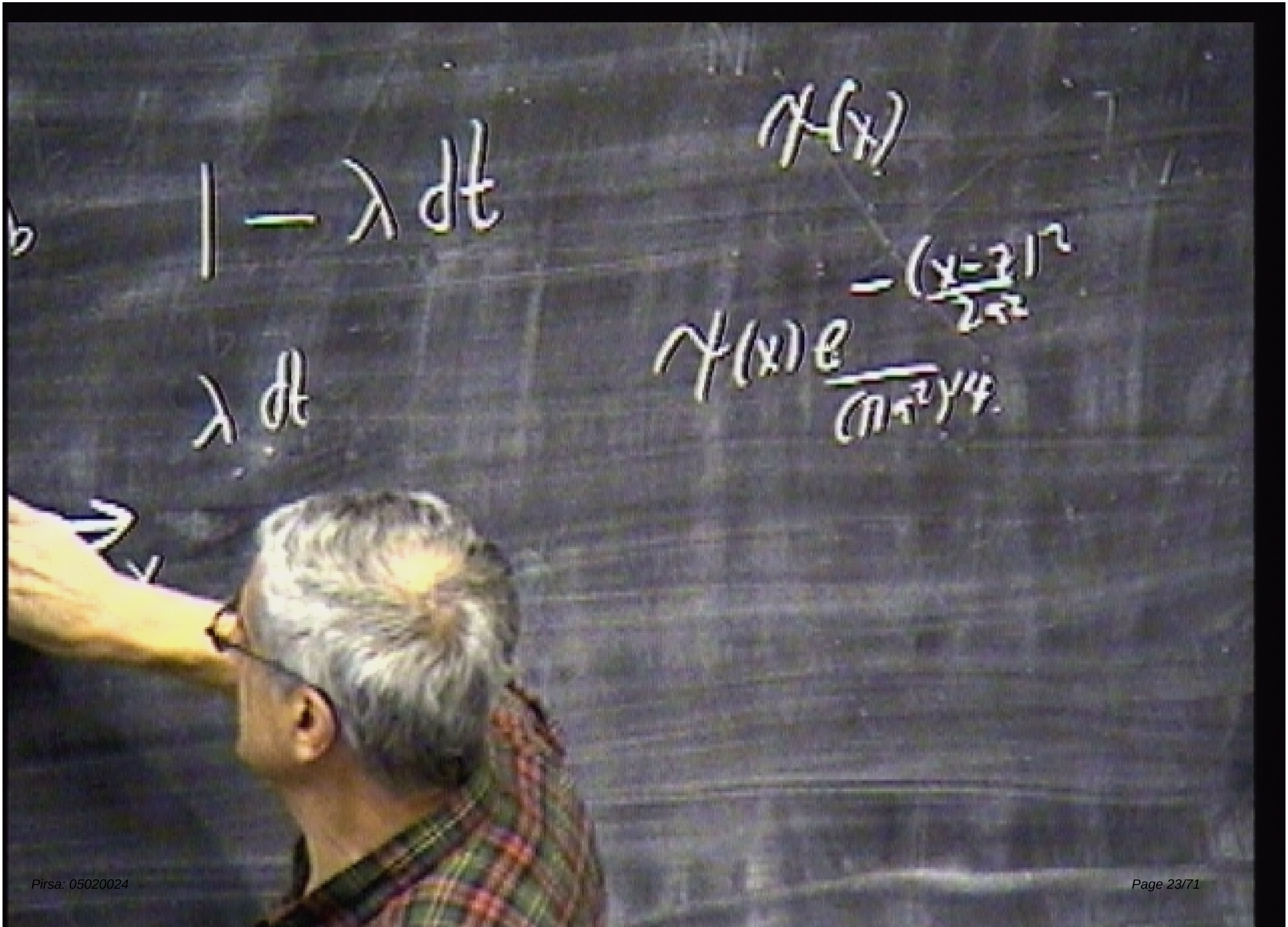
$$\left[A^2(\vec{x}',t)\rho(t) + A^2(\vec{x}',t)\rho(t) - 2A(\vec{x}',t)\rho A(\vec{x}',t) \right]$$

GRW - SL

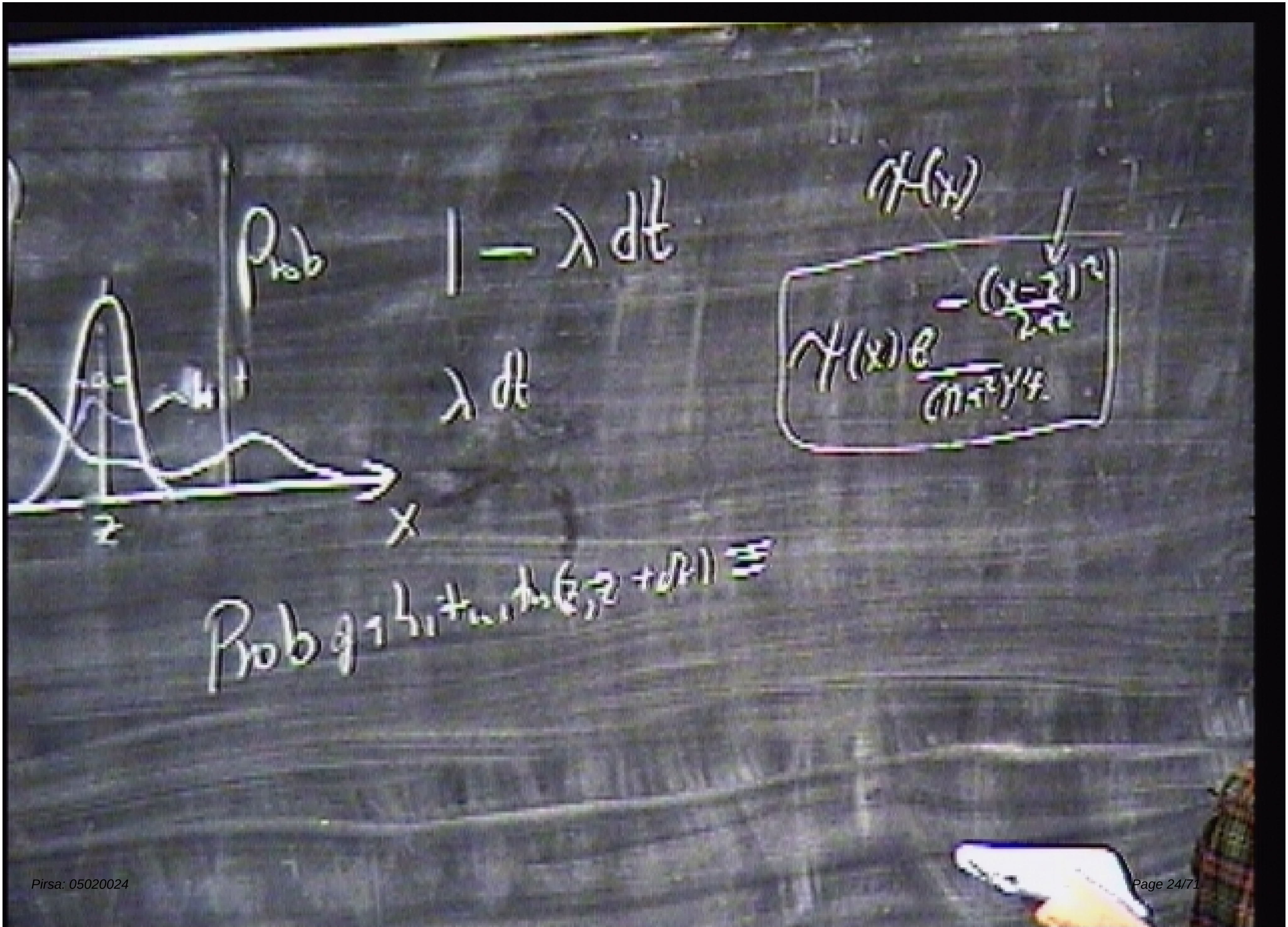


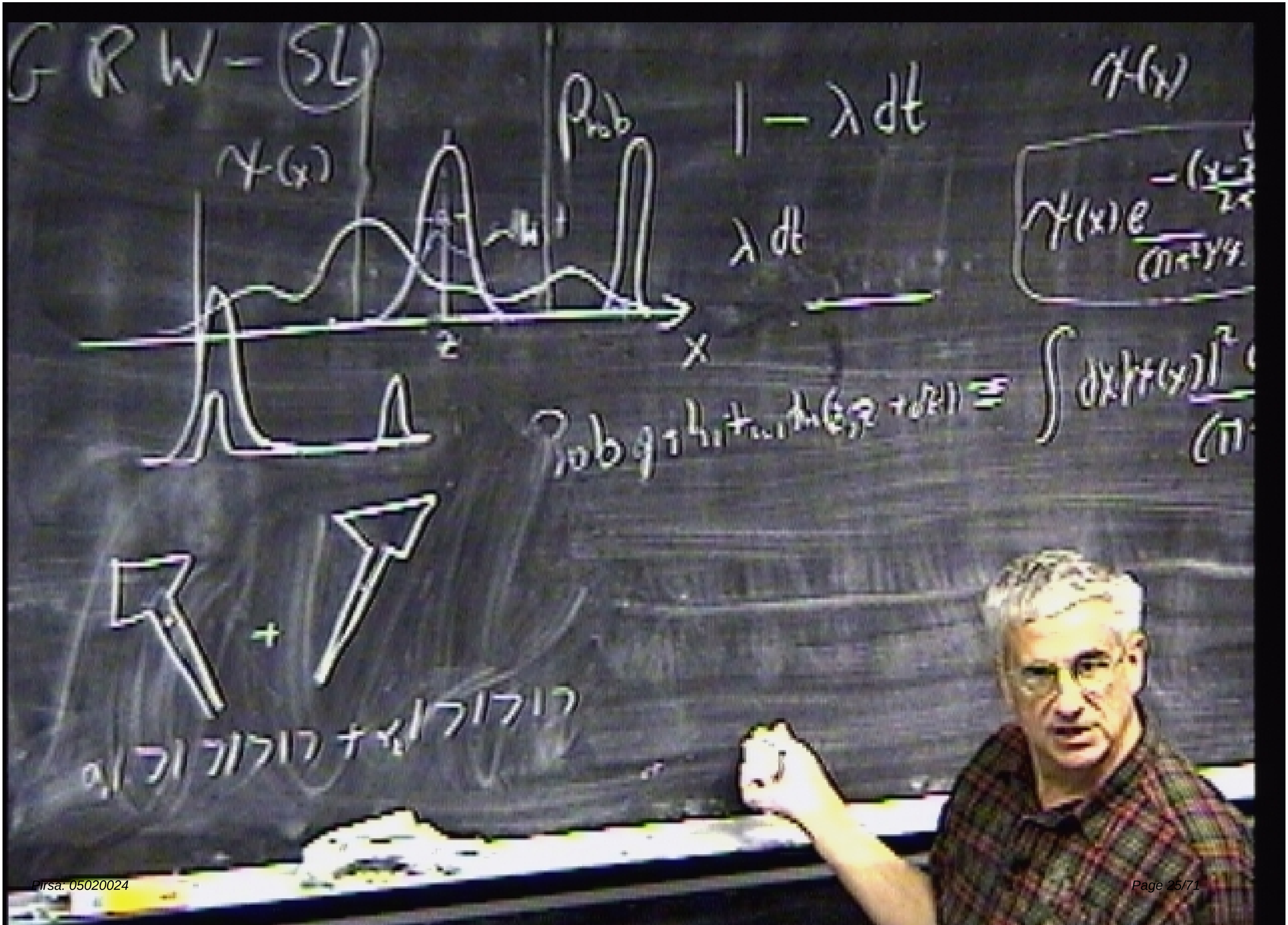

GRW-SL
Prob
1 − λdt
ψ(x)
x


GRW - SL
1 − λdt
λdt
ψ(x)
X



$1 - \lambda\, dt$
$\lambda\, dt$
$\psi(x)$
$\psi(x)\dfrac{e^{-\frac{(x-z)^2}{2\sigma^2}}}{(\pi\sigma^2)^{1/4}}$


Prob
1 − λ dt
λ dt
ψ(x)
x
z


GRW-(SL)
Prob
1 − λdt
λdt
x
z

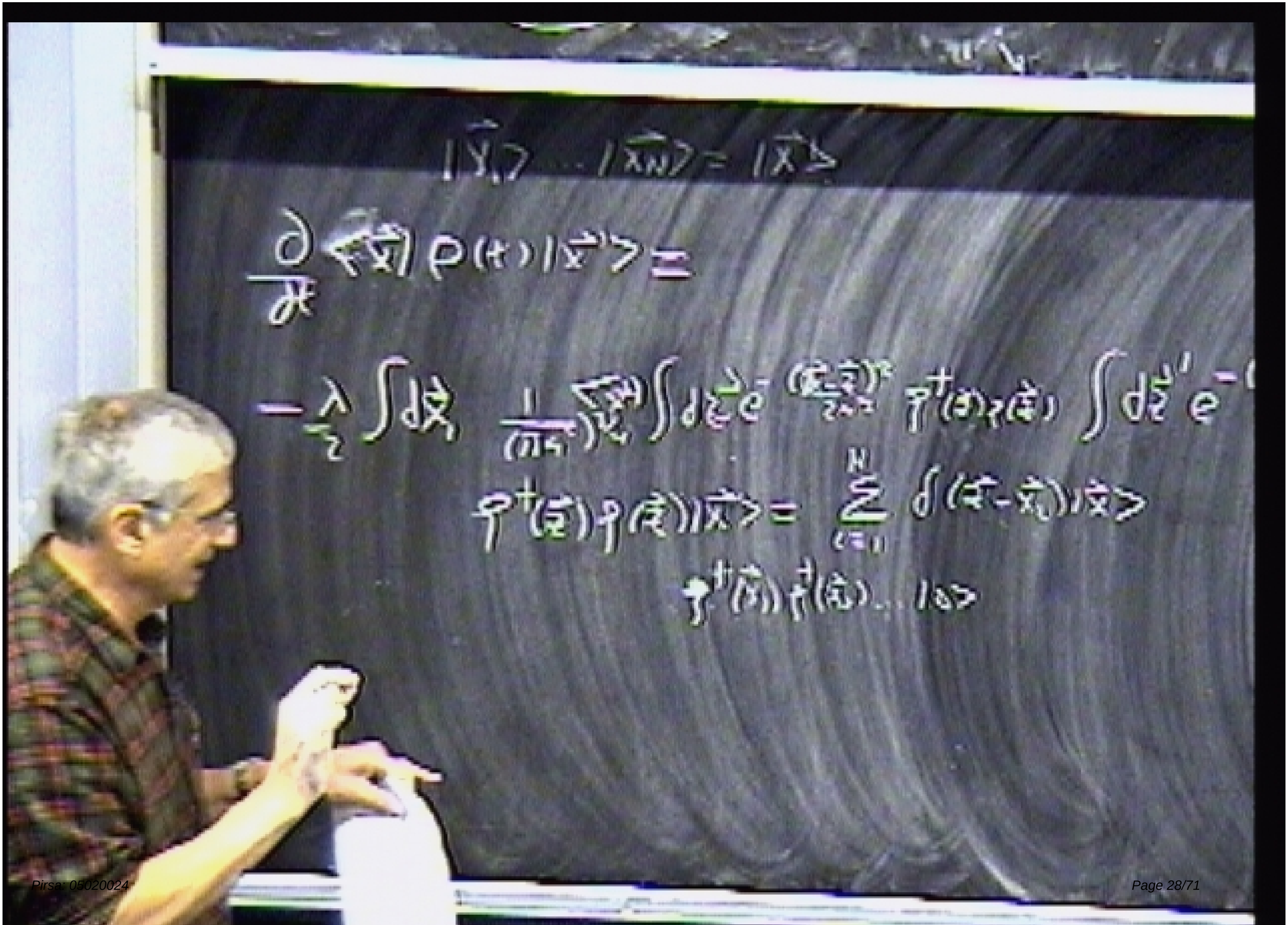
$|\vec{y}_1\rangle \ldots |\vec{x}_N\rangle = |\vec{x}'\rangle$

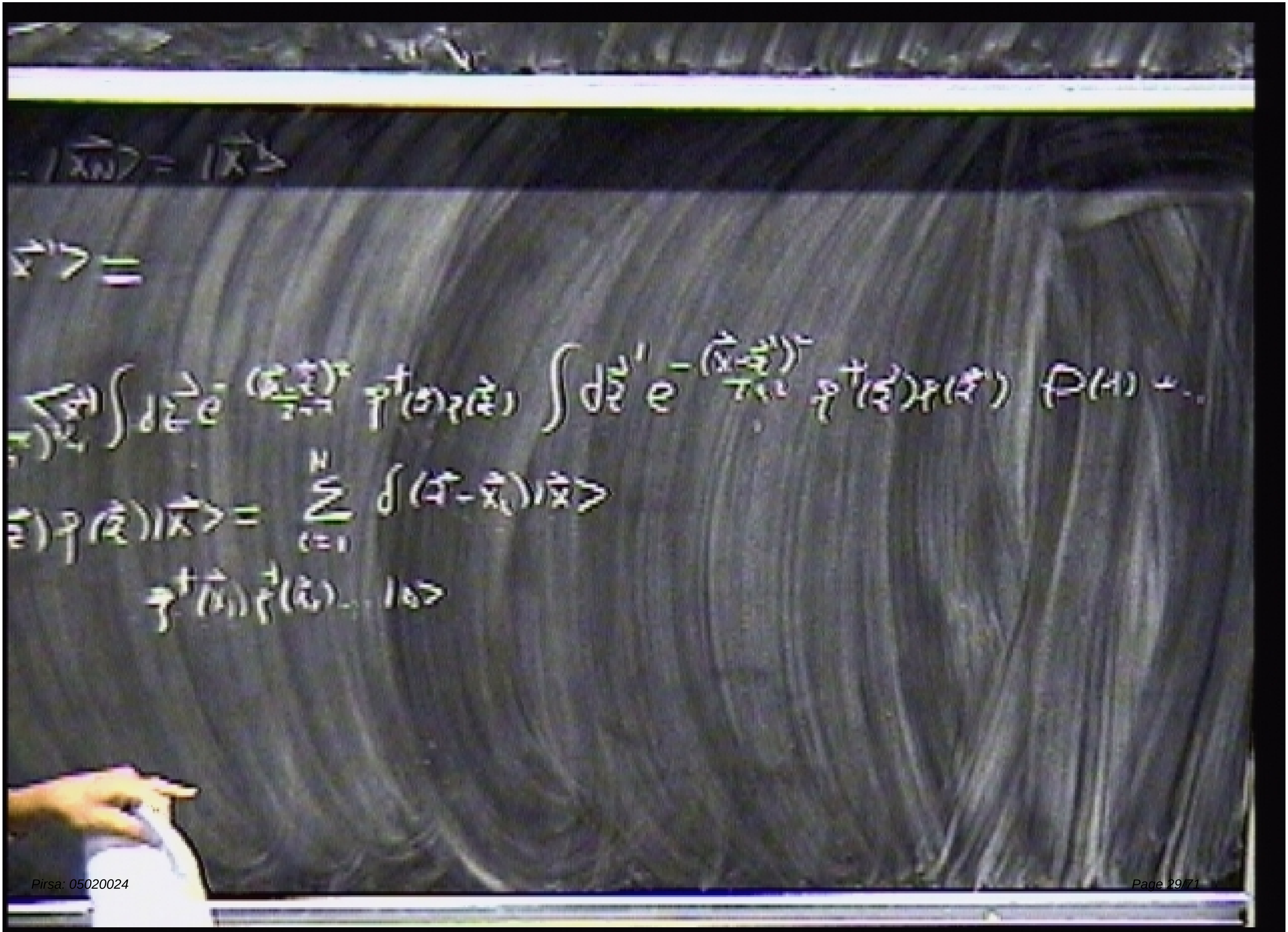
$\frac{\partial}{\partial t} \langle \vec{x} | \rho(t) | \vec{x}' \rangle =$

$$|\vec{x}_1\rangle \ldots |\vec{x}_N\rangle = |\vec{x}\rangle$$

$$\frac{\partial}{\partial t}\langle \vec{x}|\rho(t)|\vec{x}'\rangle =$$

$$-\lambda$$


|x_1> ... |x_N> = |x>
∂/∂t <x|ρ(t)|x'> =
ψ†(z)ψ(z)|x> = Σ_{i=1}^{N} δ(z − x_i)|x>
ψ†(x_1)ψ†(x_2) ... |0>


$|\vec{x}\rangle$
$= \sum_{i=1}^{N} \delta(\vec{x}-\vec{x}_i)|\vec{x}\rangle$
$|0\rangle$

$$\langle \vec{x} | \rho(t) | \vec{x}' \rangle =$$

$$-\frac{\lambda}{2}\int d\vec{x}_i \frac{1}{(\pi r_c^2)^{3/2}} \int d\vec{z}\, e^{-\frac{(\vec{x}_i-\vec{z})^2}{2r_c^2}} \psi^\dagger(\vec{z})\psi(\vec{z}) \int d\vec{z}'\, e^{-\frac{(\vec{x}_i-\vec{z}')^2}{2r_c^2}} \psi^\dagger(\vec{z}')\psi(\vec{z}'$$

$$\psi^\dagger(\vec{z})\psi(\vec{z})|\vec{x}\rangle = \sum_{i=1}^{N} \delta(\vec{z}-\vec{x}_i)|\vec{x}\rangle$$

$$\psi^\dagger(\vec{x}_1)\psi^\dagger(\vec{x}_2)\ldots|0\rangle$$

$$-\frac{\lambda}{2} \int d\vec{z}\, d\vec{z}'\, e^{-\frac{(\vec{x}_i-\vec{z})^2}{2r_c^2}} \sum_{i=1}^{N} \delta(\vec{z}-\vec{x}_i) \sum_{j} \delta(\vec{z}'-\vec{x}_j) \langle \vec{x} | \rho(t)$$

$$\frac{\partial}{\partial t}\langle \vec{x} | \rho(t) | \vec{z}' \rangle =$$

$$-\frac{\lambda}{2}\int d\vec{x}_i \, \frac{1}{(\pi r_c^2)^{3/4}} \int d\vec{z}\, e^{-\frac{(\vec{x}_i-\vec{z})^2}{2r_c^2}} \psi^\dagger(\vec{z})\psi(\vec{z}) \int d\vec{z}''\, \frac{1}{(\pi r_c^2)^{3/4}} e^{-\frac{(\vec{x}_i-\vec{z}'')^2}{2r_c^2}} \psi^\dagger(\vec{z}'')\psi$$

$$\psi^\dagger(\vec{z})\psi(\vec{z})|\vec{x}\rangle = \sum_{i=1}^{N} \delta(\vec{z}-\vec{x}_i)|\vec{x}\rangle$$

$$\psi^\dagger(\vec{x}_1)\psi^\dagger(\vec{x}_2)\ldots|0\rangle$$

$$= -\frac{\lambda}{2}\int d\vec{z}\, d\vec{z}'\, e^{-\frac{(\vec{z}-\vec{z}')^2}{4r_c^2}} \sum_{i=1}^{N} \delta(\vec{z}-\vec{x}_i)\sum_{j} \delta(\vec{z}'-\vec{x}_j)\langle \vec{x}|\rho(t))$$

$$= -\frac{\lambda}{2}$$

$$-\frac{\lambda}{2}\int d\vec{x}_0 \frac{1}{(\pi r^2)^{3}} \int d\vec{z}\, e^{-\frac{(\vec{x}_0-\vec{z})^2}{2r^2}} \psi^\dagger(\vec{z})\psi(\vec{z}) \int d\vec{z}'\, e^{-\frac{(\vec{x}_0-\vec{z}')^2}{2r^2}} \psi^\dagger(\vec{z}')\psi(\vec{z}')$$

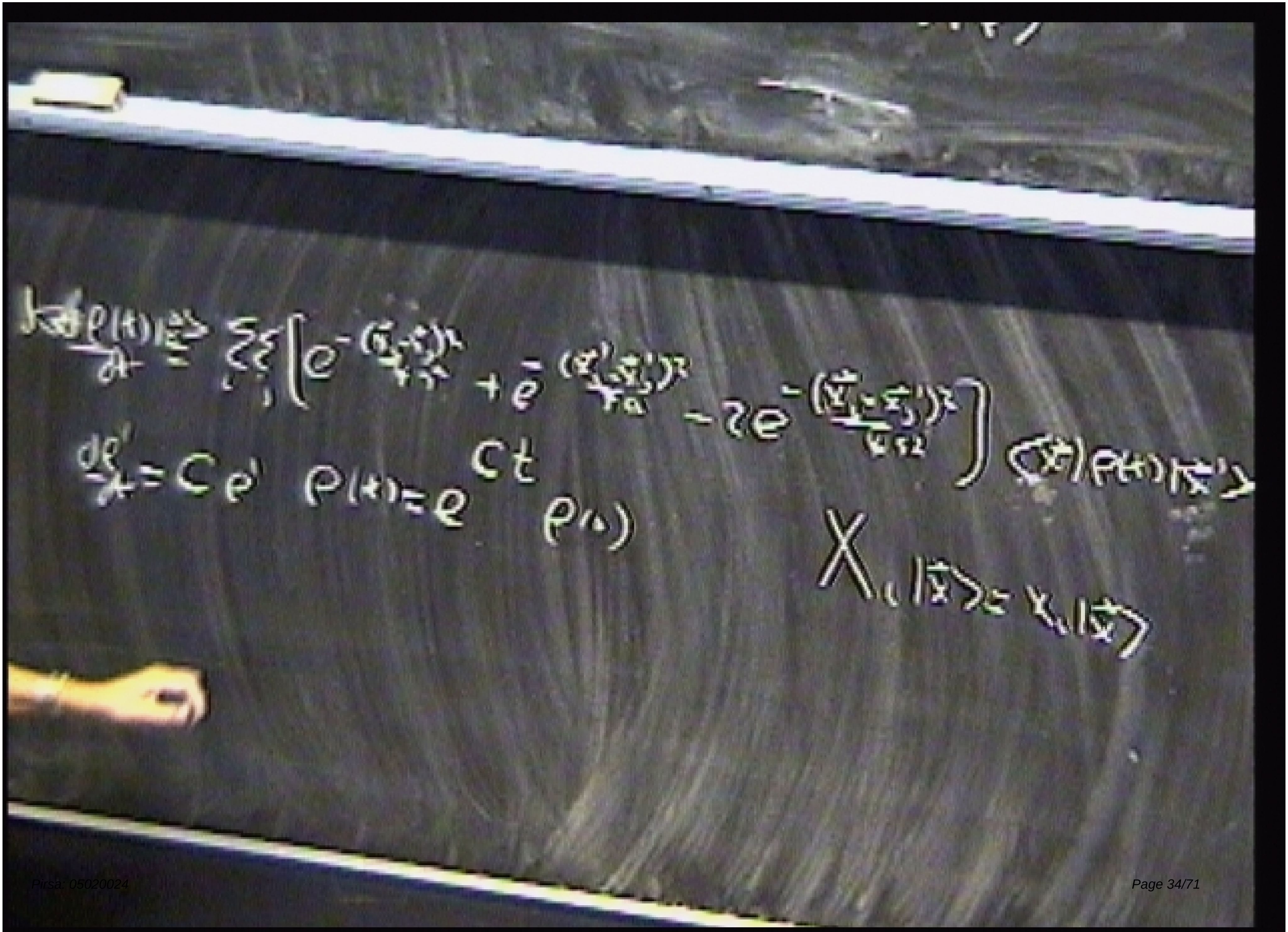
$$\psi^\dagger(\vec{z})\psi(\vec{z})|\vec{x}\rangle = \sum_{i=1}^{N} \delta(\vec{z}-\vec{x}_i)|\vec{x}\rangle$$

$$\psi^\dagger(\vec{x}_1)\psi^\dagger(\vec{x}_2)\ldots|0\rangle$$

$$= -\frac{\lambda}{2}\int d\vec{z}\, d\vec{z}'\, e^{-\frac{(\vec{z}-\vec{z}')^2}{4r^2}} \sum_{i=1}^{N} \delta(\vec{z}-\vec{x}_i)\sum_j \delta(\vec{z}'-\vec{x}_j)\langle\vec{x}|\rho(t)$$

$$= -\frac{\lambda}{2}\sum_{i,j} e^{-\frac{(\vec{x}_i-\vec{x}_j)^2}{4r^2}} \langle\vec{x}|\rho(t)$$

$$\frac{d\rho(t)}{dt} = \sum_i \sum_j \left[e^{-\frac{(x_i - x_j)^2}{4a^2}} + e^{-\frac{(x'_i - x'_j)^2}{4a^2}} - 2e^{-\frac{(x_i - x'_j)^2}{4a^2}} \right] \langle x | \rho(t) | x' \rangle$$


$\frac{d\rho'}{dt} = C\rho'$
$\rho(t) = e^{ct}\rho(0)$
$X_i |x\rangle = x_i |x\rangle$

$$|\psi\rangle = \alpha_1 |1\rangle + \alpha_2 |2\rangle$$

$$\frac{d\rho(t)}{dt} =$$

$$|\psi\rangle = \alpha_1 |1\rangle + \alpha_2 |2\rangle$$

$$\frac{d\rho(t)}{dt} = -\sum_i \lambda \left[1 - e^{-\frac{[\vec{x}_i - \vec{x}_i']^2}{4r^2}} \right] \rho(t)$$

$$|\psi\rangle = \alpha_1|1\rangle + \alpha_2|2\rangle$$

$$\frac{d\rho(t)}{dt} = -\frac{\lambda}{2}\cdot 2\left[1 - e^{-\frac{(\vec{x}_1-\vec{x}_2)^2}{4a^2}}\right]\rho(t)$$

$$\frac{d}{dt}\langle 1|\rho(t)|2\rangle = -\lambda\left[\langle 1|\rho(t)|2\rangle - \langle 1|e^{-\frac{(x_1-x_2)^2}{4a^2}}\rho(t)|2\rangle\right.$$

$$= -\lambda\langle 1|\rho(t)|2\rangle$$

$$\langle 1|\rho(t)|2\rangle = e^{-\lambda t}\alpha_1\alpha_2^*$$

$\alpha_1 |1\rangle + \alpha_2 |2\rangle$

distance >> a

$\lambda t \approx .01 \quad \lambda^{-1} \geq 100\,t = \ldots$

$\geq 2\ldots$

$$- \frac{\lambda}{2} \cdot 2 \left[1 - e^{-\frac{[\bar{X}_1 - \bar{X}_2]^2}{4r^2}} \right] \rho(t)$$

$$\ldots 2\rangle = - \lambda \left[\langle 1|\rho(t)|2\rangle - \langle 1| e^{-\frac{[x_1 - x_2]^2}{4r^2}} \rho(t)|2\rangle. \right.$$

$$= - \lambda \langle 1|\rho(t)|2\rangle$$

$$\ldots|2\rangle = e^{-\lambda t} \alpha_1 \alpha_2^*$$

$$n^2 \lambda t \simeq .01 \qquad \lambda^{-1} \geq 100\, t n^2$$

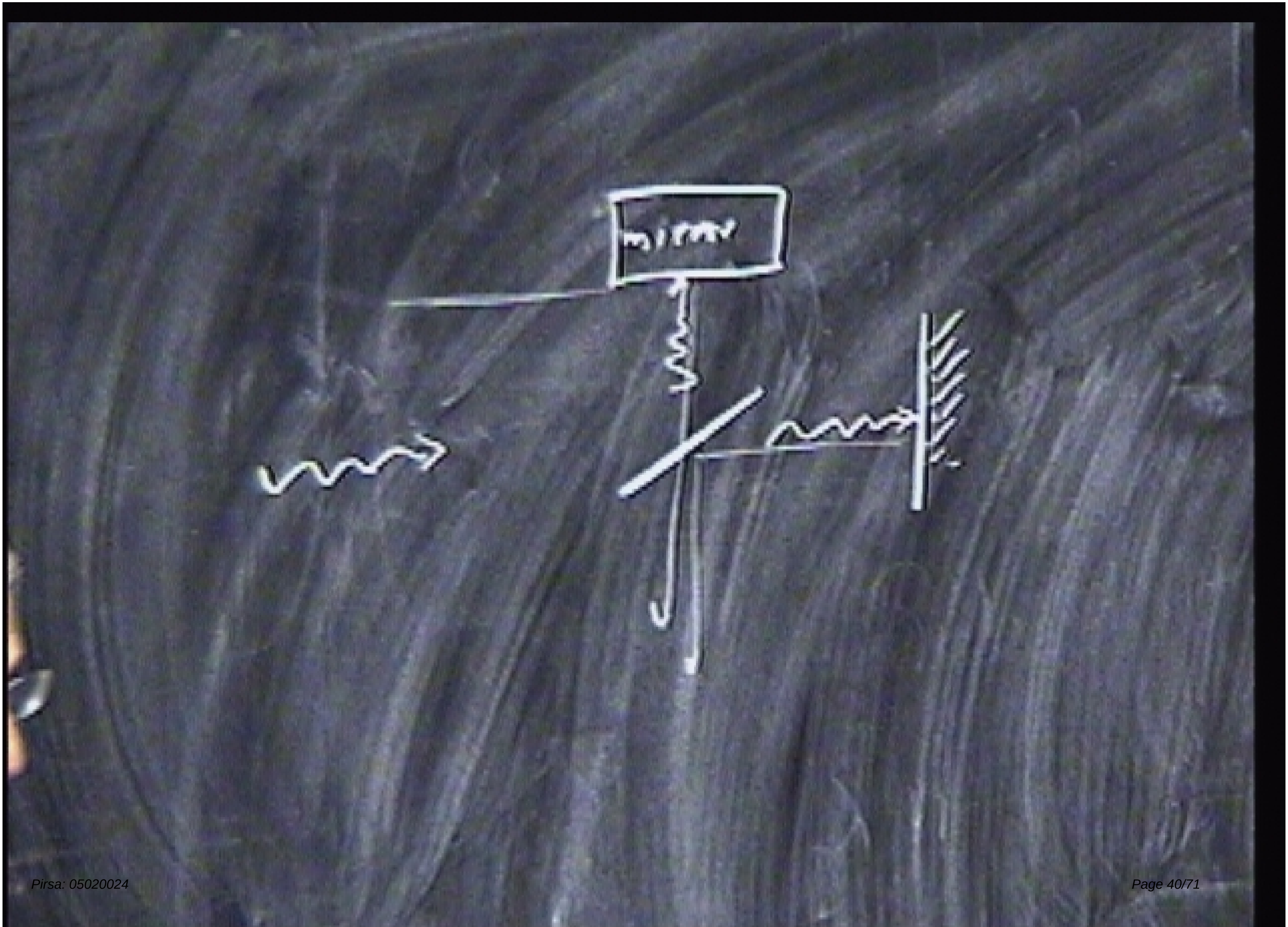
$$.05\,s \qquad 700$$

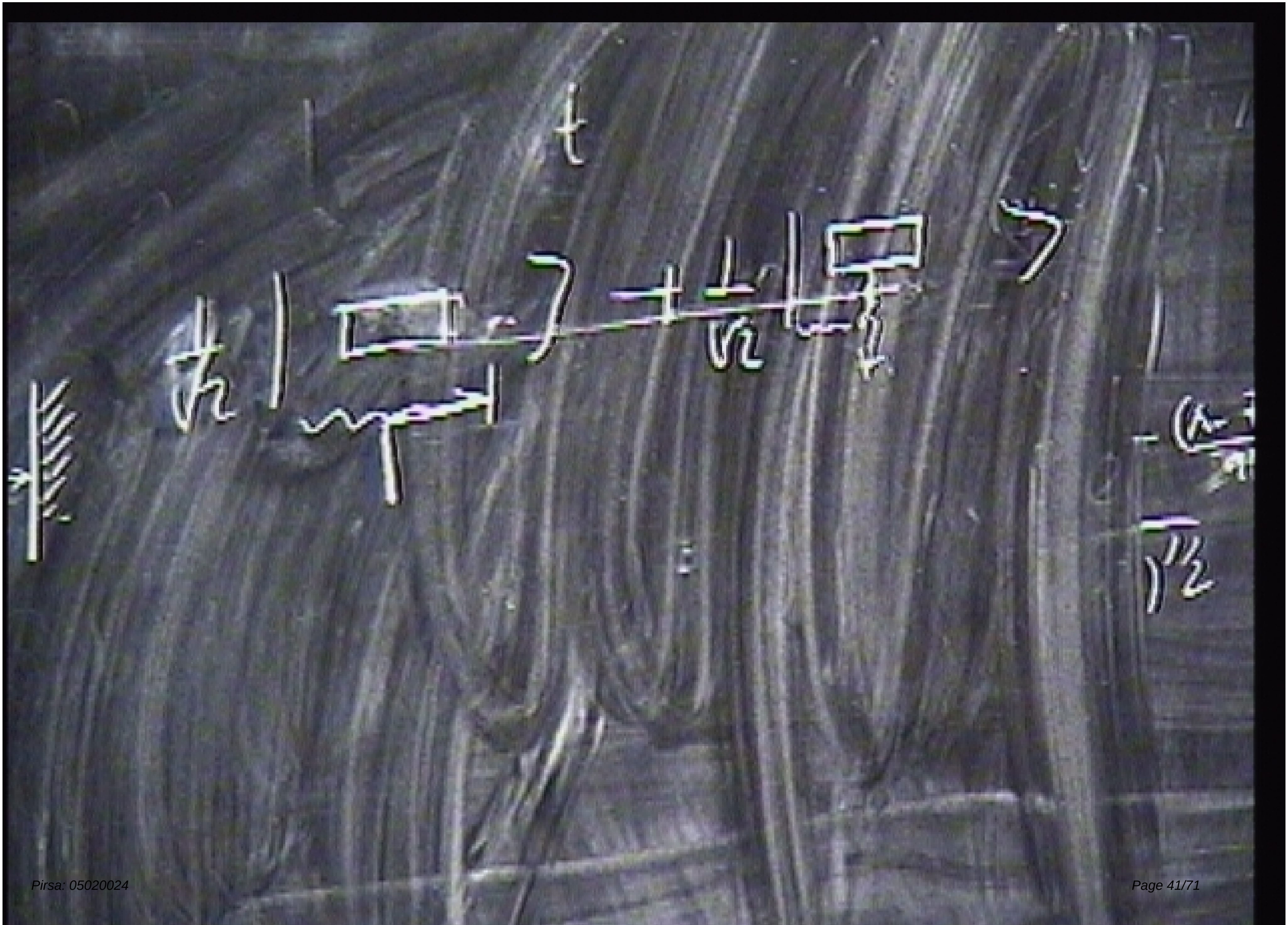
$$\geq 2\ \text{sec}$$

$$\left.\right]^2 \Big] \ \rho(t)$$

$$\boxed{\lambda^{-1} \geq ?\ 5\times 10^{6}}$$

$$\langle n | e^{-\frac{[x_L - x_R]^2}{4 s^2}} \rho(t) | n \rangle .$$


mirror

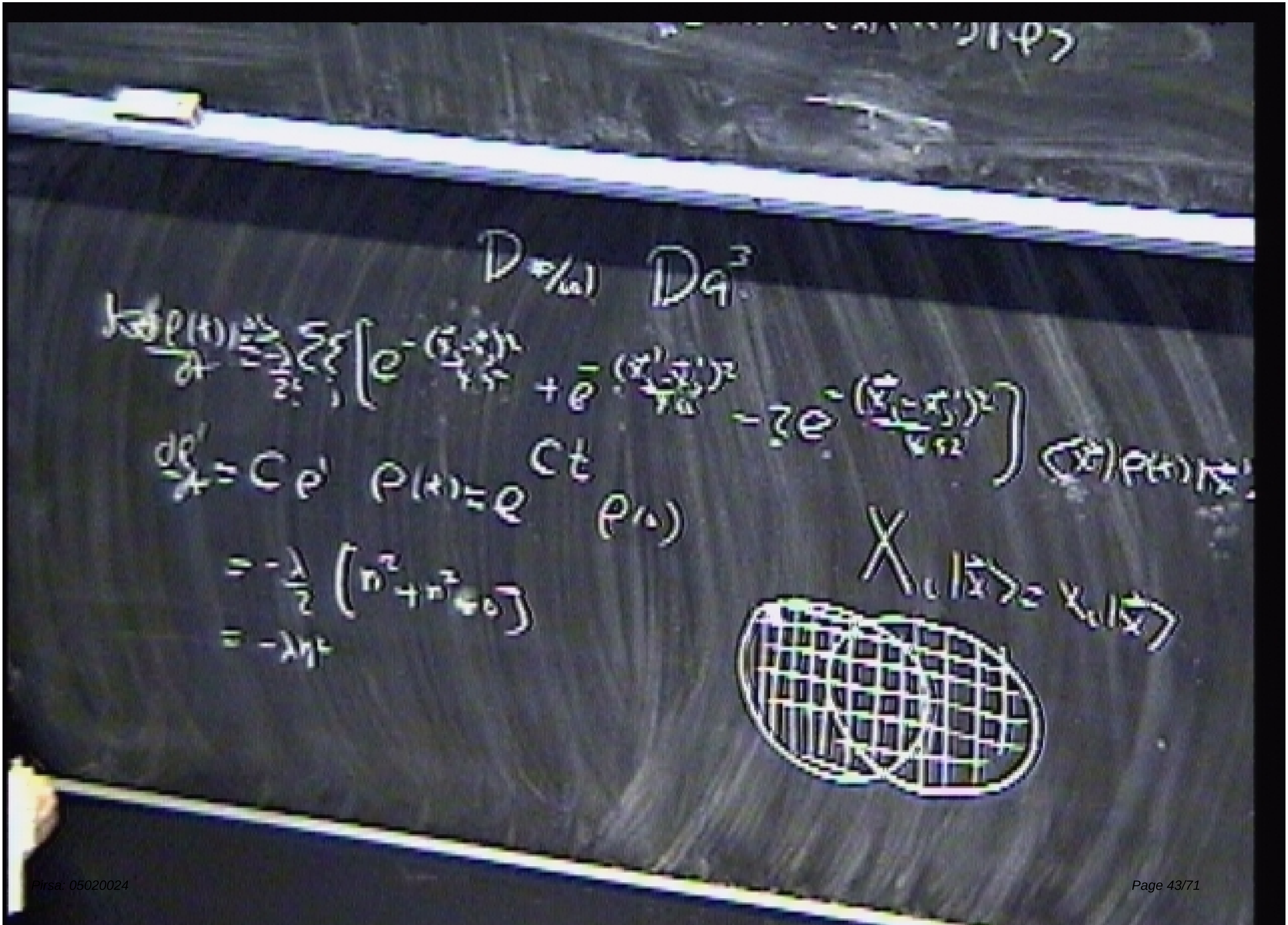

t

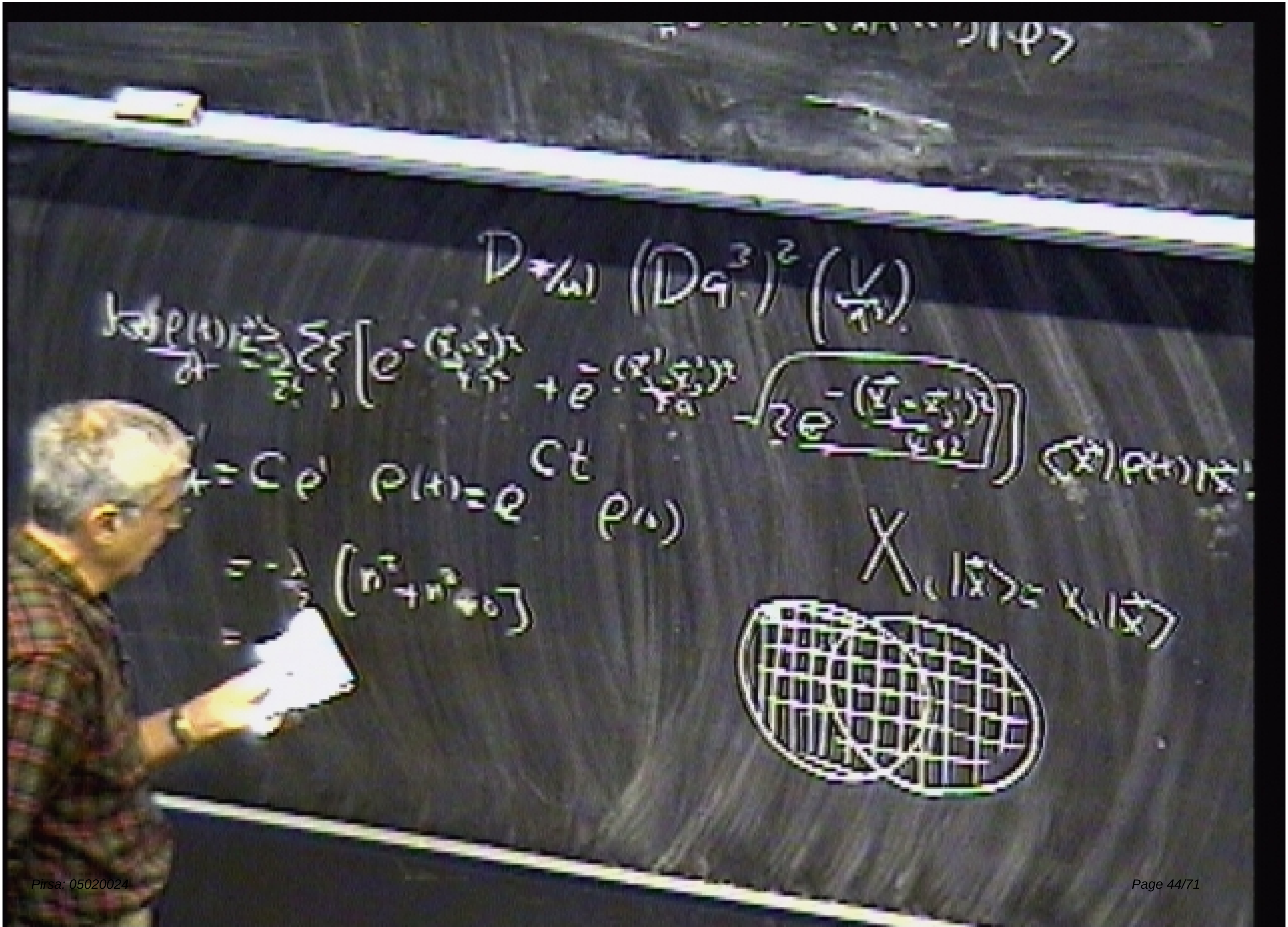
$$e^{-\frac{(\vec{x}_i' - \vec{x}_j')^2}{4\Omega}} - 2e^{-\frac{(\vec{x}_i - \vec{x}_j')^2}{4\Omega}} \Big] \langle \vec{x} | \rho(t) | \vec{x}' \rangle$$

t

$\rho(0)$

$$X_i |\vec{x}\rangle = x_i |\vec{x}\rangle$$


D Dq³
ρ(t) = e^{ct} ρ(0)
= −λn²



$$\rangle\,|\varphi\rangle$$

$$D \approx 1/(\omega) \; (D q^3)^2 \left(\frac{V}{\dots}\right)$$

$$\frac{d\rho(t)}{dt} = \dots \sum_i \sum_j \left[e^{-\frac{(\vec{x}_i - \vec{x}_j)^2}{\dots}} + e^{-\frac{(\vec{x}_i' - \vec{x}_j')^2}{\dots}} - 2 e^{-\frac{(\vec{x}_i - \vec{x}_j')^2}{\dots}} \right] \langle \vec{x} | \rho(t) | \vec{x}' \rangle$$

$$\frac{d\rho'}{dt} = C \rho' \qquad \rho(t) = e^{Ct} \rho(0)$$

$$= -\frac{\lambda}{2} \left[n^2 + n^2 + 0 \right]$$

$$= -\lambda n^2$$

$$X$$

$$X_i |\vec{x}\rangle = x_i |\vec{x}\rangle$$

V

$$|\psi\rangle$$

$$D = \hbar\omega/2\,(Dq^3)^2\left(\frac{V_0}{q^2}\right) - (Dq^3)^2\,\frac{V_0}{q^2}$$

$$\frac{d\rho(t)}{dt} = \frac{\lambda}{2}\sum_i\sum_j\left[e^{-(x_i-x_j)^2/4a^2} + e^{-(x'_i-x'_j)^2/4a^2} - 2e^{-(x_i-x'_j)^2/4a^2}\right]\langle \vec{x}|\rho(t)|\vec{x}'\rangle$$

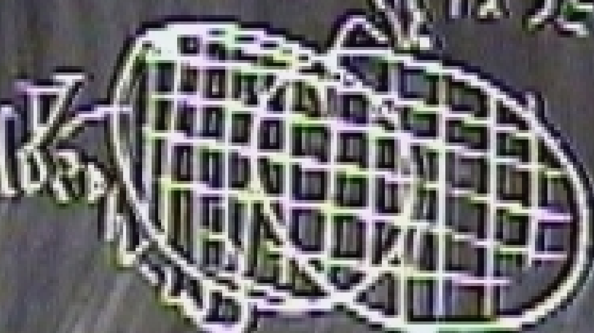
$$\frac{d\rho'}{dt} = C\rho' \qquad \rho(t) = e^{Ct}\rho(0)$$

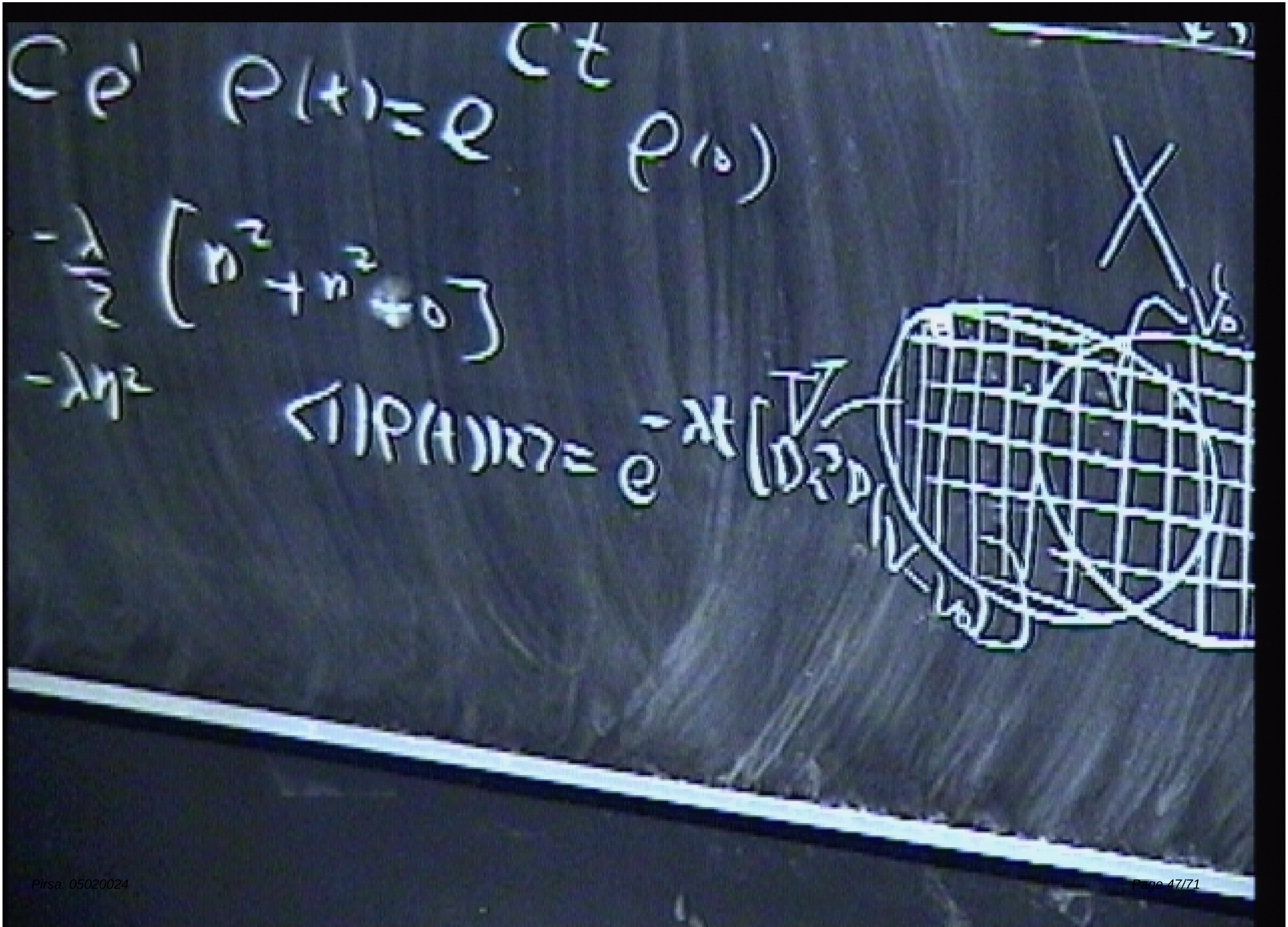
$$= -\frac{\lambda}{2}\left[n^2 + n^2 + 0\right]$$

$$= -\lambda n^2$$

$$\langle|\rho(t)|\rangle = e^{-\lambda t}\ldots$$

$$X_i|\vec{x}\rangle = x_i|\vec{x}\rangle$$



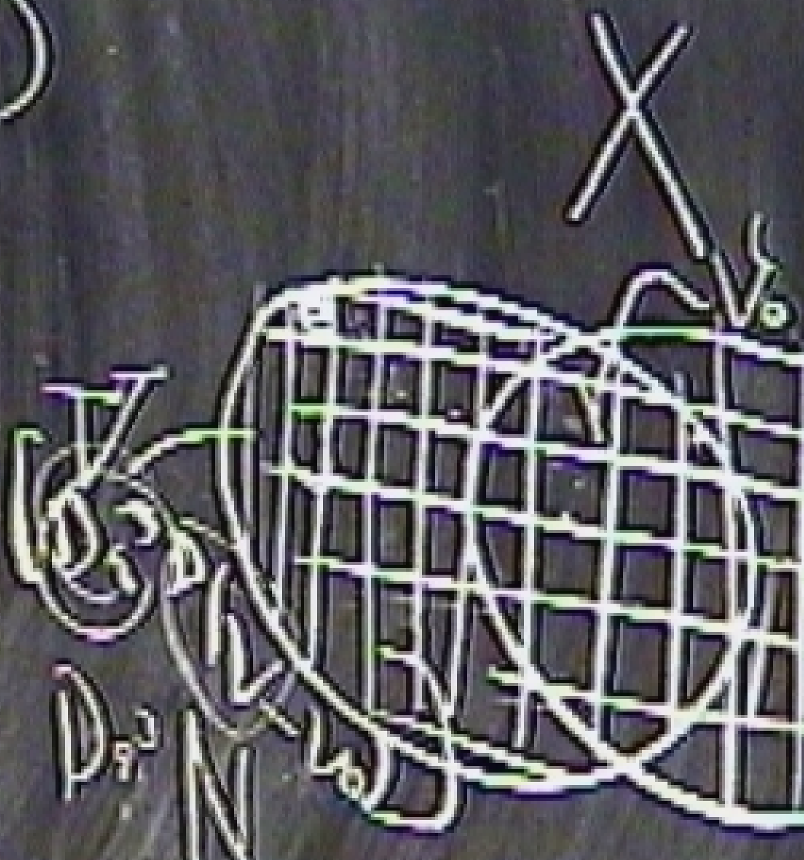

ρ(t) = e^{Ct} ρ(0)
-λ/2 [n^2 + n^2 + 0]
-λn^2
X

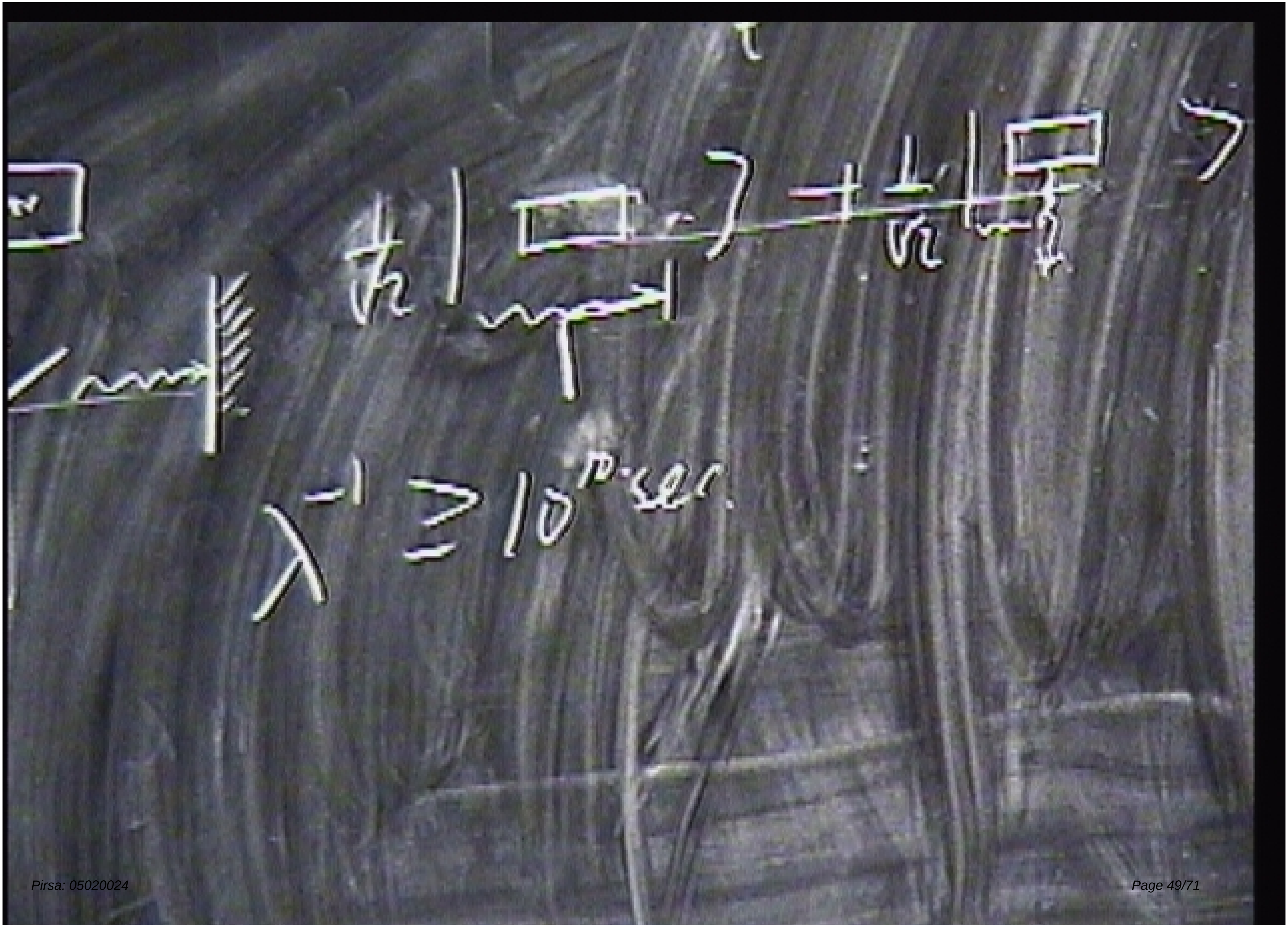
$\mathcal{C}\rho' \quad \rho(t) = e^{\mathcal{C}t}\rho(0)$

$-\frac{\lambda}{2}\left[n^2 + n^2 - 0\right]$

$-\lambda n^2$

$\langle 1|\rho(t)|2\rangle = e^{-\lambda t}$




$\lambda^{-1} \geq 10^{10}$ sec

$$H = \sum_n \frac{p_n^2}{2m} + V$$

$$\rho(\vec{x})|\vec{x}\rangle = \sum_{i=1}^{N} \delta(\vec{x} - \vec{x}_i)|\vec{x}\rangle$$

$$\psi^\dagger(\vec{x}_1)\,\psi^\dagger(\vec{x}_2)\ldots|0\rangle$$

$$\int d^3x\, d^3x'\, e^{-\frac{(\vec{x}-\vec{x}')^2}{\cdots}} \sum_{i=1}^{N} \delta(\vec{x}-\vec{x}_i) \sum_j \delta(\vec{x}'-\vec{x}_j) \langle \vec{x}|\rho(t))$$

$$\sum_{i,j} e^{-\frac{(\vec{x}_i-\vec{x}_j)^2}{\cdots}} \langle \vec{x}|\rho(t))$$

$$H = \sum_n \frac{p_n^2}{2m} + V$$

$$\frac{d}{d\beta} \mathrm{Tr}\, H e$$

$$(\vec{z}))|\vec{x}\rangle = \sum_{i=1}^{N}$$

$$\psi^\dagger(\vec{x}_1)\psi^\dagger(\vec{x}_2)\dots$$

$$= -\frac{\lambda}{2} \int d\vec{z}\, d\vec{z}'\, e^{-\frac{(\vec{z}-\vec{z}')^2}{4\sigma^2}} \sum_{i=1}^{N} \delta(\vec{z}-$$

$$= -\lambda \sum\sum e^{-\frac{(\vec{x}_i-\vec{x}_j)^2}{4\sigma^2}}$$

$$H = \sum_n \frac{p_n^2}{2m} + V$$

$$\frac{d}{dt} \mathrm{Tr}\, H\rho = \frac{d}{dt} \int \langle \vec{x} | H \rho | \vec{x} \rangle$$

$$(\vec{z}))|\vec{x}\rangle = \sum_{i=1}$$

$$\psi^{+}(\vec{x}_1)\psi^{+}(\vec{x}_2)\ldots$$

$$= -\frac{\lambda}{2} \int d\vec{z}\, d\vec{z}'\, e^{-\frac{(\vec{z}-\vec{z}')^2}{4a^2}} \sum_{i=1}^{N} \delta(\vec{z}-$$

$$= -\lambda \sum\sum e^{-\frac{(\vec{x}_i-\vec{x}_j)^2}{4a^2}}$$

$$\frac{P_n^2}{2m} + V$$

$$\frac{d}{dt}\int \langle \vec{x} | H \rho | \vec{x} \rangle P_n \, d\vec{x} = \frac{3}{4} \frac{\lambda \hbar^2}{m a^2} n$$

$$(\vec{z}) | \vec{x} \rangle = \sum_{i=1}$$

$$\psi^\dagger(\vec{x}_1)\psi^\dagger(\vec{x}_2)\ldots|0\rangle$$

$$\vec{z}' \; e^{-\frac{(\vec{z}-\vec{z}')^2}{4a^2}} \quad \sum_{i=1}^{N} \delta(\vec{z}-\vec{x}_i) \sum_j \delta(\vec{z}-\vec{x}_j) \langle \vec{x} | \rho(t)$$

$$e^{-\frac{(\vec{x}_i-\vec{x}_j)^2}{4a^2}} \langle \vec{x} | \rho(t)$$

$$H = \sum_n \frac{p_n^2}{2m} + V$$

$$\frac{d}{dt}\,\mathrm{Tr}\,H\rho = \frac{d}{dt}\int \langle x|H\rho|x\rangle\, dx = \frac{3}{4}\frac{\lambda\hbar^2}{ma^2}\, n$$

$$\frac{d\overline{H}}{dt} = 6\cdot 10^{-44}\ \mathrm{J/sec} \simeq 4\times 10^{-25}\ \mathrm{eV/sec}$$

Frank Avignone

$$H = \sum_n \frac{p_n^2}{2m} + V$$

$$\frac{d}{dt}\,\mathrm{Tr}\,H\rho = \frac{d}{dt}\int \langle \vec{x}|H\rho|\vec{x}\rangle\, d\vec{x} = \frac{3}{4}\frac{\lambda\hbar^2}{m a^2}\, n \qquad \left(\frac{m}{\lambda}\right)$$

$$\frac{d\overline{H}}{dt} = 6\cdot 10^{-44}\ \mathrm{J/sec} \simeq 4\times 10^{-25}\ \mathrm{eV/sec}$$

Frank Avignone

$$H = \sum_n \frac{p_n^2}{2m} + V$$

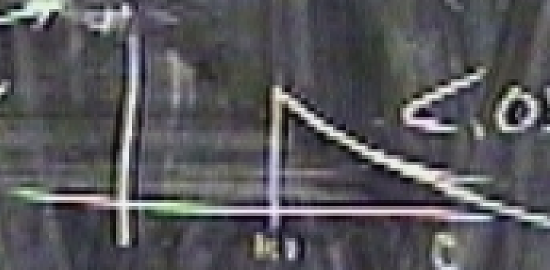
$$\mathrm{Tr}\, H\rho = \frac{d}{dt}\int \langle x | H\rho | x \rangle \, dx = \frac{3}{4}\frac{\lambda\hbar^2}{m^2}\, n$$

$$\frac{d\bar{H}}{dt} = 6\cdot 10^{-44}\ \mathrm{J/sec} = 4\times 10^{-25}\ \mathrm{eV/ke}$$

Frank Avignone

Ge

1111 keV



$\leq .05$ cts/kg

$$\Gamma_\alpha = \frac{\lambda}{2m^2} \langle E_\alpha | \sum_i q_i \vec{X}_i | E_0 \rangle \langle E_0 | \sum_j q_j \vec{X}_j | E_\alpha \rangle$$

$$\Gamma_\alpha = \frac{\lambda}{2\pi^2} \langle E_\alpha | \sum q_i \vec{X}_i | E_0 \rangle \langle E_0 | \sum q_j \vec{X}_j | E_\alpha \rangle$$

$$\sum m_i \vec{X}_i | E_0 \rangle = 0$$

$$\Gamma_\alpha = \frac{\lambda}{2\hbar^2} \langle E_\alpha | \sum g_i \vec{X}_i | E_0 \rangle \langle E_0 | \sum g_j \vec{X}_j | E_\alpha \rangle$$

$$\sum m_i \vec{X}_i \, | E_0 \rangle = 0$$

$$= \frac{\lambda}{2\hbar^2} \left(g - \frac{m}{M_p} \right)^2 \left| \langle E_\alpha | \sum_{i \in \alpha} X_i \, | E_0 \rangle \right|^2$$

$$\Gamma_\alpha = \frac{\lambda}{2\sigma^2} \langle E_\alpha | \sum_i g_i \vec{X}_i | E_0 \rangle \langle E_0 | \sum_j g_j \vec{X}_j | E_\alpha \rangle$$

$$\sum m_i \vec{X}_i \, | E_0 \rangle = 0$$

$$= \frac{\lambda}{2\sigma^2} \left(g - \frac{m}{M_p} \right)^2 \left| \langle E_\alpha | \sum_{e^-} x_i \, | E_0 \rangle \right|^2 \qquad 0 \leq ge$$

$$= \sum_{\alpha} \frac{\lambda}{2\alpha^2} \langle E_\alpha | \sum_i g_i \vec{X}_i | E_0 \rangle \langle E_0 | \sum_j g_j \vec{X}_j | E_\alpha \rangle$$

$$\sum m_i \vec{X}_i \, | E_0 \rangle = 0$$

$$= \frac{\lambda}{2\alpha^2} \left(g - \frac{m}{M} \right)^2 | \langle E_\alpha | \sum_i X_i | E_0 \rangle |^2$$

$$\boxed{0 \le g_e \le 13 \frac{m_e}{m_p}}$$

$$\sum_j \zeta_j \vec{x}_j |E_\alpha\rangle \qquad g_n = \frac{m_n}{m_p} \pm 4 \cdot 10^{-3} \left(\frac{3(m_n - m_p)}{\frac{m_n + m_p}{2}} \right)$$

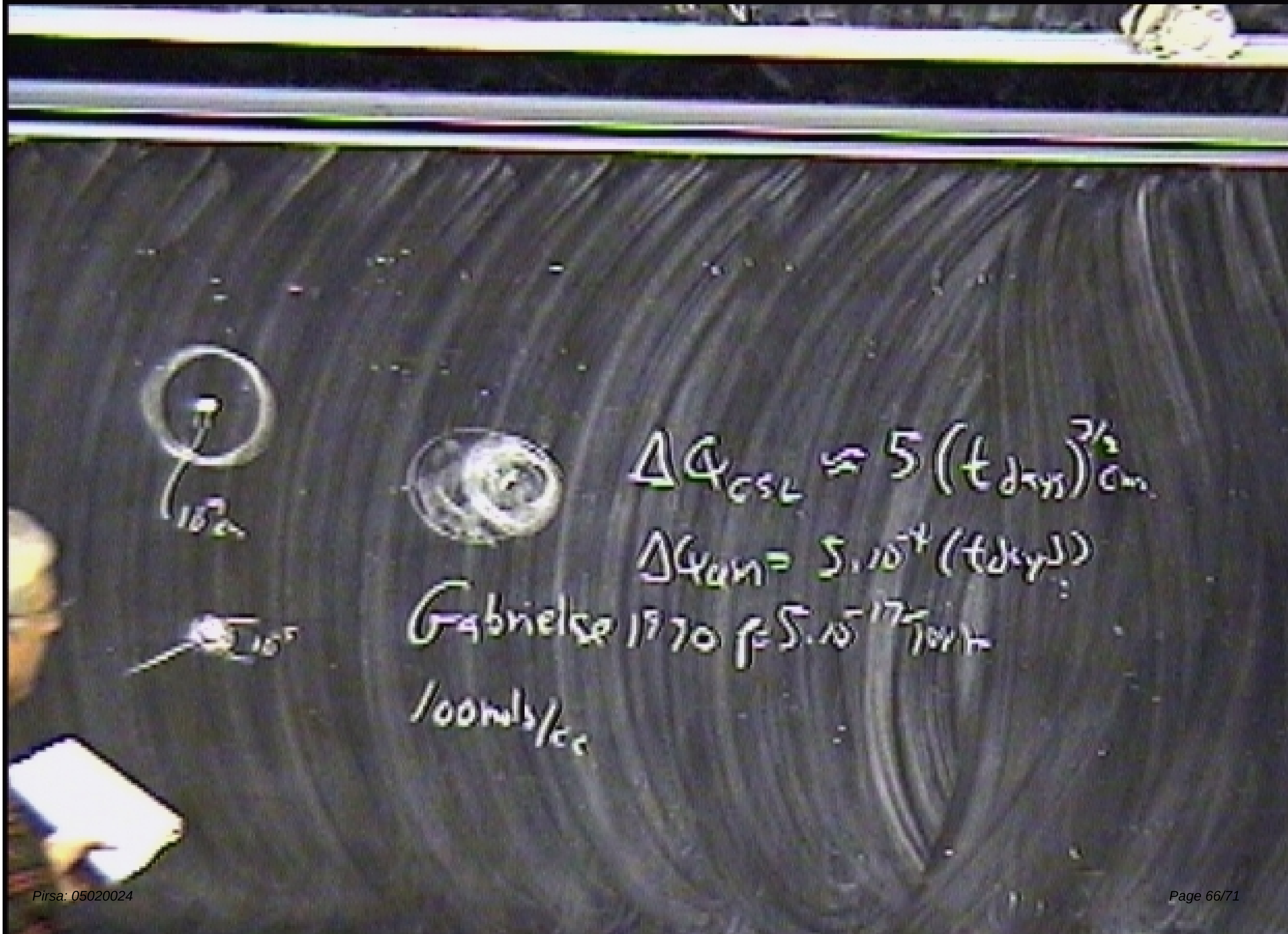
$$\rangle = 0$$

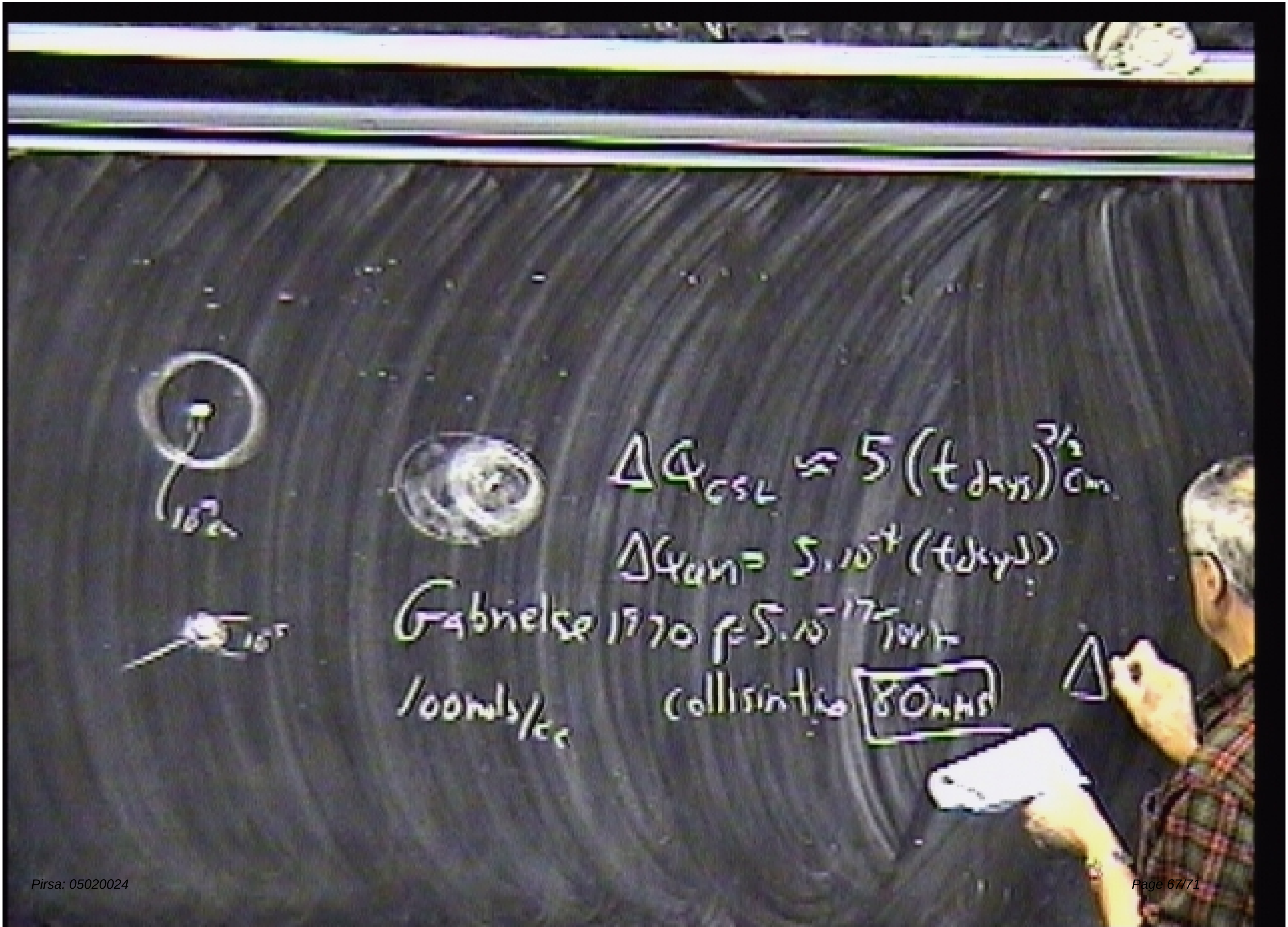
$$|E_0\rangle|^2 \qquad \boxed{0 \leq g_e \leq 13 \frac{m_e}{m_p}}$$

$$\Delta q_{CSL} \approx 5 \left(t_{days}\right)^{7/2} \text{cm}$$

$$\Delta q_{CSL} \approx 5\,(t_{days})^{3/2}\ \text{cm}$$

$$\Delta q_{QM} = 5\cdot 10^{-4}\,(t_{days})$$


ΔqCSL ≈ 5 (tdays)^3/2 cm
ΔqQM = 5·10^-4 (tdays)
Gabrielse 1990 p ≤ 5·10^-17 Torr
100 mols/cc


ΔQ_CSL ≈ 5 (t days)^3/2 cm
ΔQ_QM = 5·10^-4 (t days)
Gabrielse 1990 p=5·10^-17 torr
100 mols/cc
collisions 80 hrs

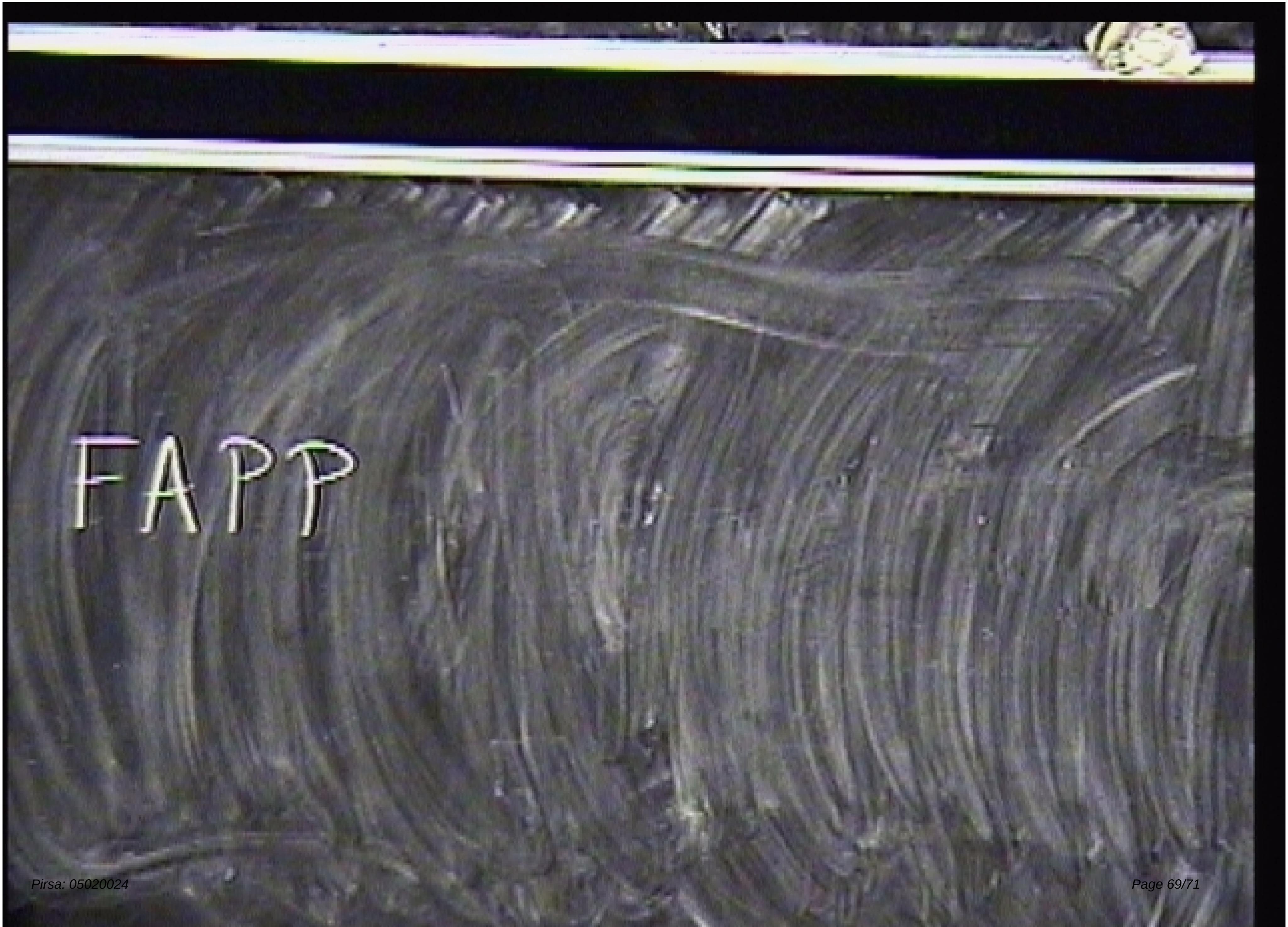
$5\cdot 10^{-5}$

$$\Delta a_{CSL} \approx 5 \left(t_{days}\right)^{3/2} \text{cm}$$

$$\Delta a_{am} = 5\cdot 10^{-4} \left(t_{days}\right)$$

Gabrielse 1990 $p \leq 5\cdot 10^{-17}$ Torr

100 atoms/cc collision time $\boxed{80 \text{ min}}$ $\Delta a_{CSL} \approx 1$ mm.


FAPP

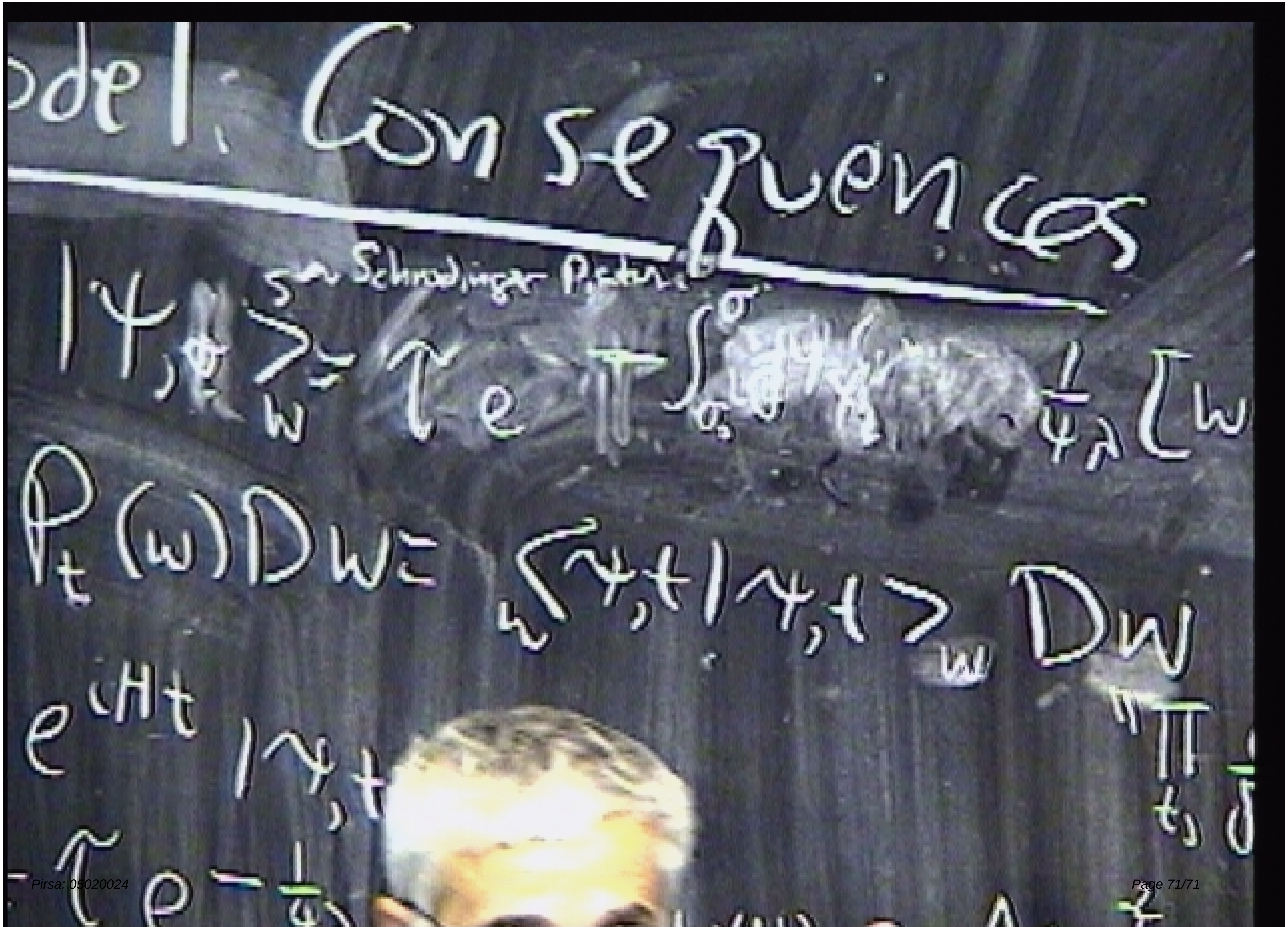
uences

$\frac{1}{\psi_\lambda}[W(\psi) - 2\Lambda]^2 \quad \bar{\Psi}\Psi \quad \Phi$

$\psi, t\rangle_W \; DW$

$= \prod_j \frac{dw_j}{\sqrt{2\pi\lambda/dt}}$

$|\varphi, 0\rangle = \sum_n (\alpha_n)|q_n\rangle$


odel. Consequences
Schrodinger Picture
P_t (w) DW = ⟨ψ,t|ψ,t⟩_w DW
e^{iHt} |ψ,t