

Title: Interpretation of Quantum Theory: Lecture 24

Date: Mar 31, 2005 02:15 PM

URL: <http://pirsa.org/05030153>

Abstract:

"Heat death" analogy

Qu.

$$\text{Born, } \langle \hat{\Omega} \rangle = \text{Tr}(\hat{\rho} \hat{\Omega})$$

quantum noise

Nonlocality $\rightarrow$ Signals

Statistics β
(indep. of prepn.)

Class

(Global thermal equil.)

Boltz. $P \propto e^{-E/kT}$

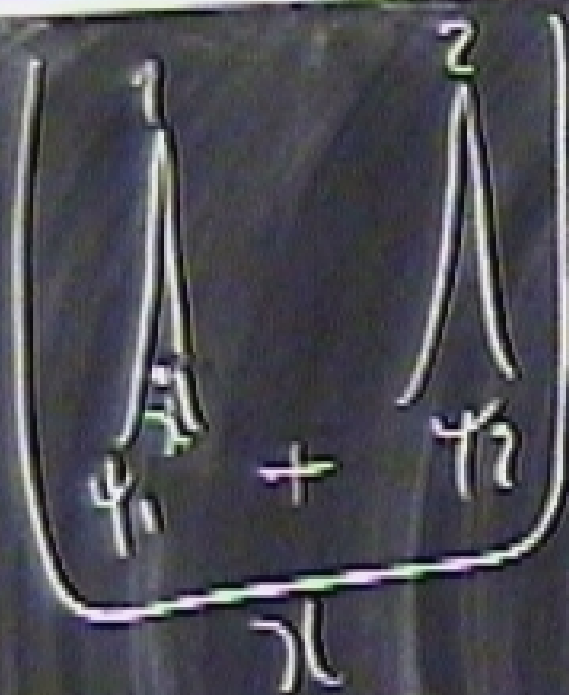
Thermal noise

Heat $\rightarrow$ work

Statistics α
(indep. of prepn.)

$$\left(\begin{array}{c} 1 \\ \psi_1 \end{array} + \begin{array}{c} 2 \\ \psi_2 \end{array} \right)$$

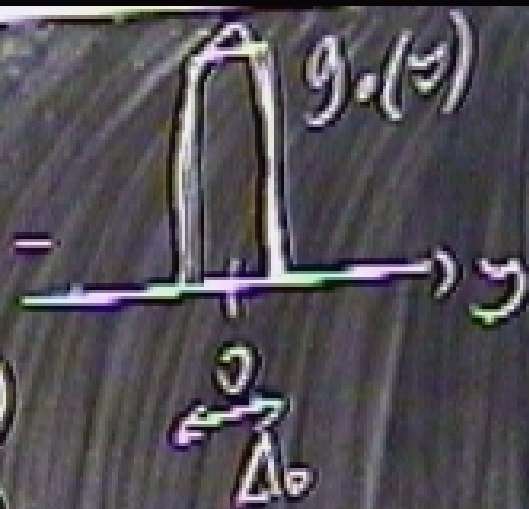
ψ



$$\hat{H} = a \hat{x} \hat{p}$$

$$(\psi_1(x) + \psi_2(x)) g_0(x)$$

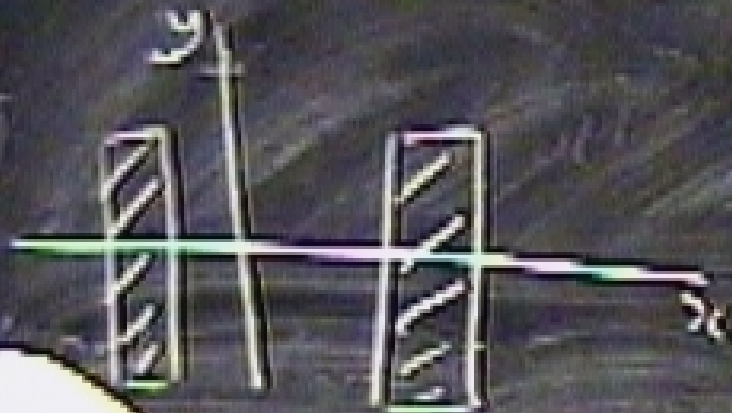
$$\rightarrow \psi_1(x) g_0(x - a x_1 t) + \psi_2(x) g_0(x - a x_2 t)$$



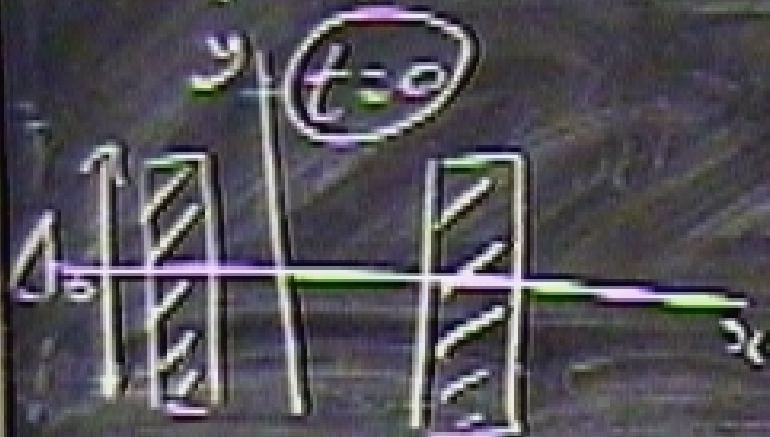
$$|\psi_x|^2 = |\psi_1(x)|^2 |g_-(\omega - \alpha x_0 t)|^2 + |\psi_2(x)|^2 |g_-(\omega - \alpha x_0 t)|^2$$



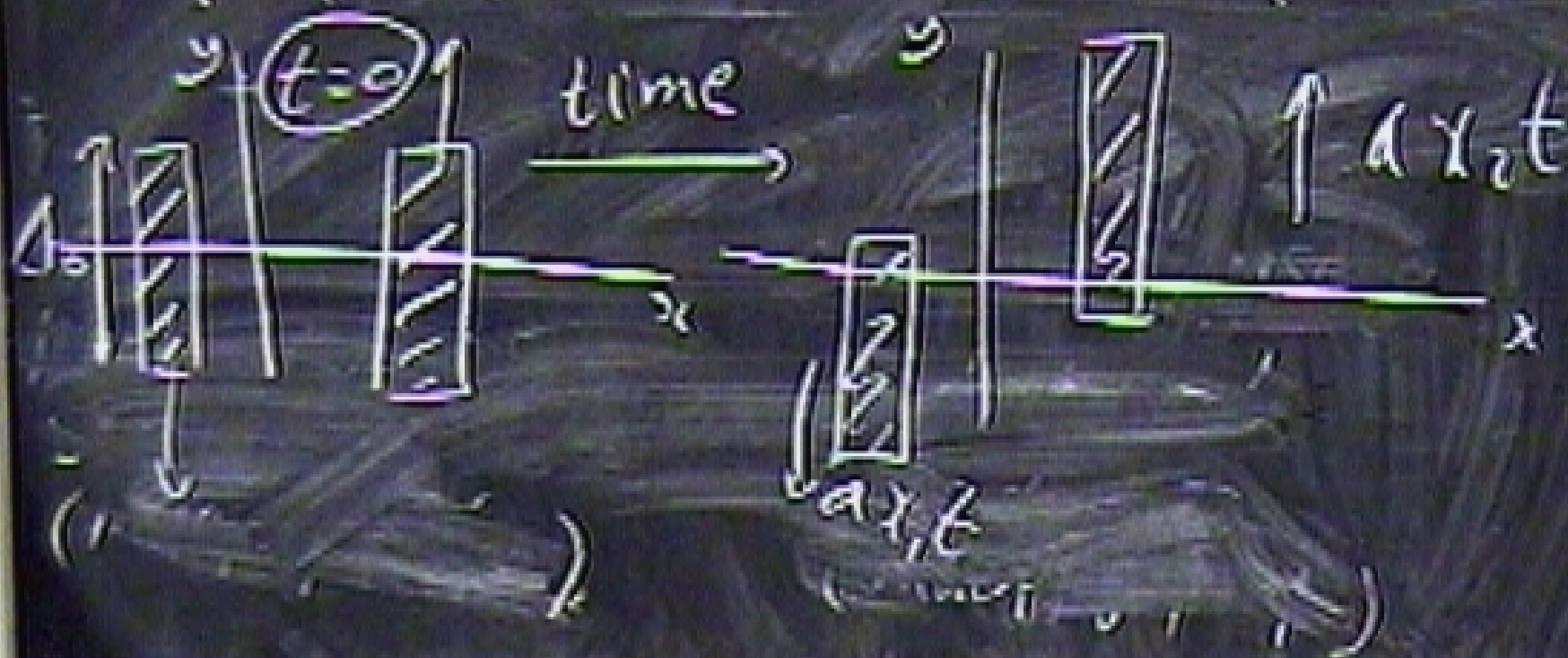
$$|\psi_x|^2 = |\psi_1(x)|^2 |g_1(x - x_1(t))|^2 + |\psi_2(x)|^2 |g_2(x - x_2(t))|^2$$



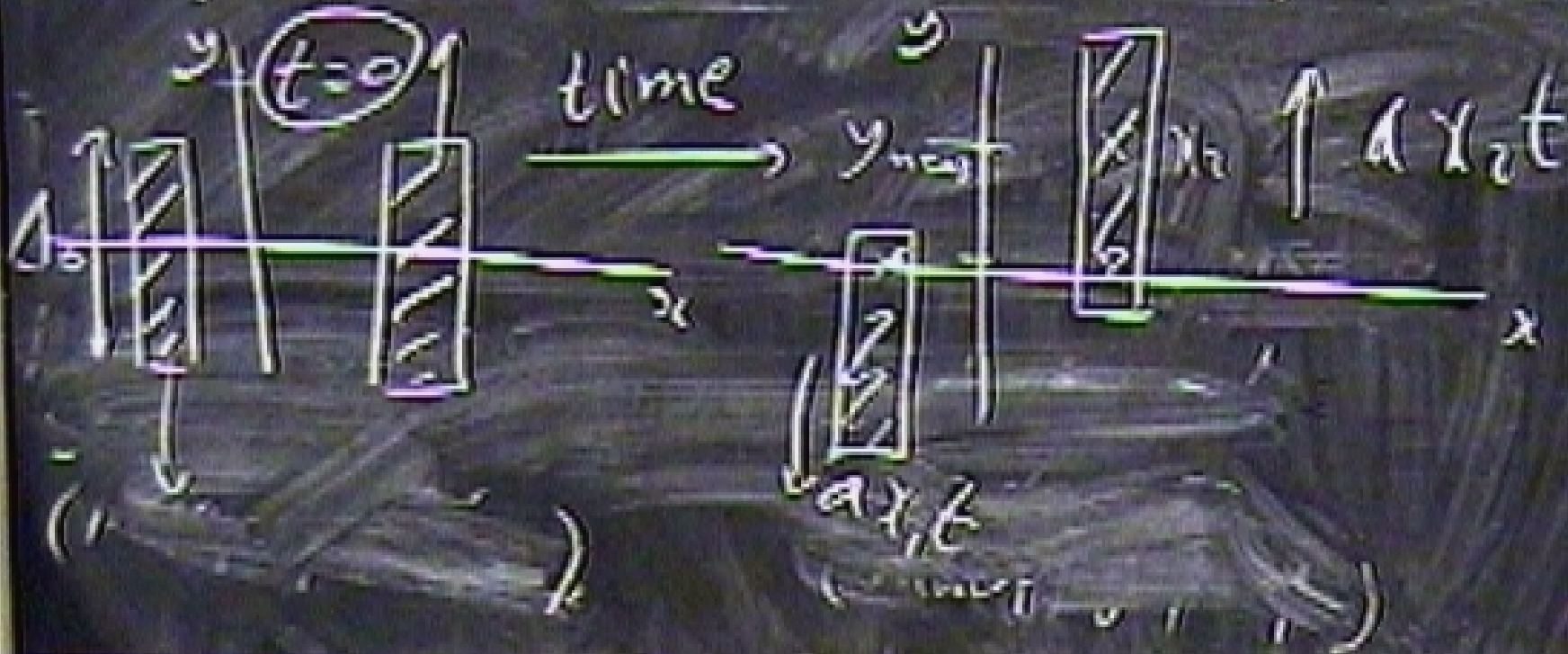
$$|\psi_x|^2 = |\psi_1(x)|^2 |g - (g - \alpha x_1 t)|^2 + |\psi_2(x)|^2 |g - (g - \alpha x_2 t)|^2$$



$$|\psi_x|^2 = |\psi_1(x)|^2 |g_1(x - a x_1 t)|^2 + |\psi_2(x)|^2 |g_2(x - a x_2 t)|^2$$

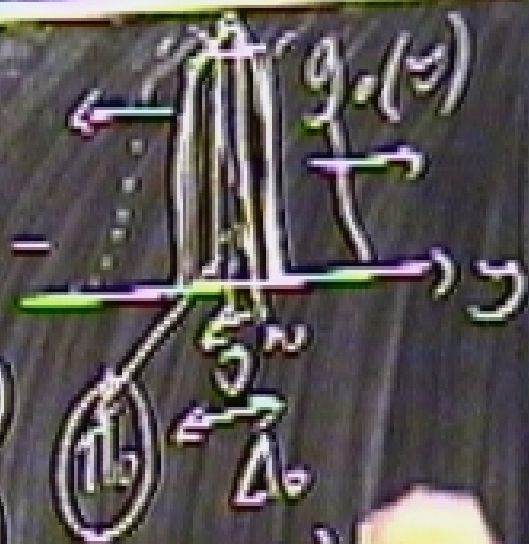


$$|\psi(x)|^2 = |\psi_1(x)|^2 |g_1(x - a x_1 t)|^2 + |\psi_2(x)|^2 |g_2(x - a x_2 t)|^2$$



$$\left(\begin{array}{c} 1 \\ \psi_1 \end{array} + \begin{array}{c} 2 \\ \psi_2 \end{array} \right)$$

$$\hat{H} = a \hat{x} \hat{p}_y$$

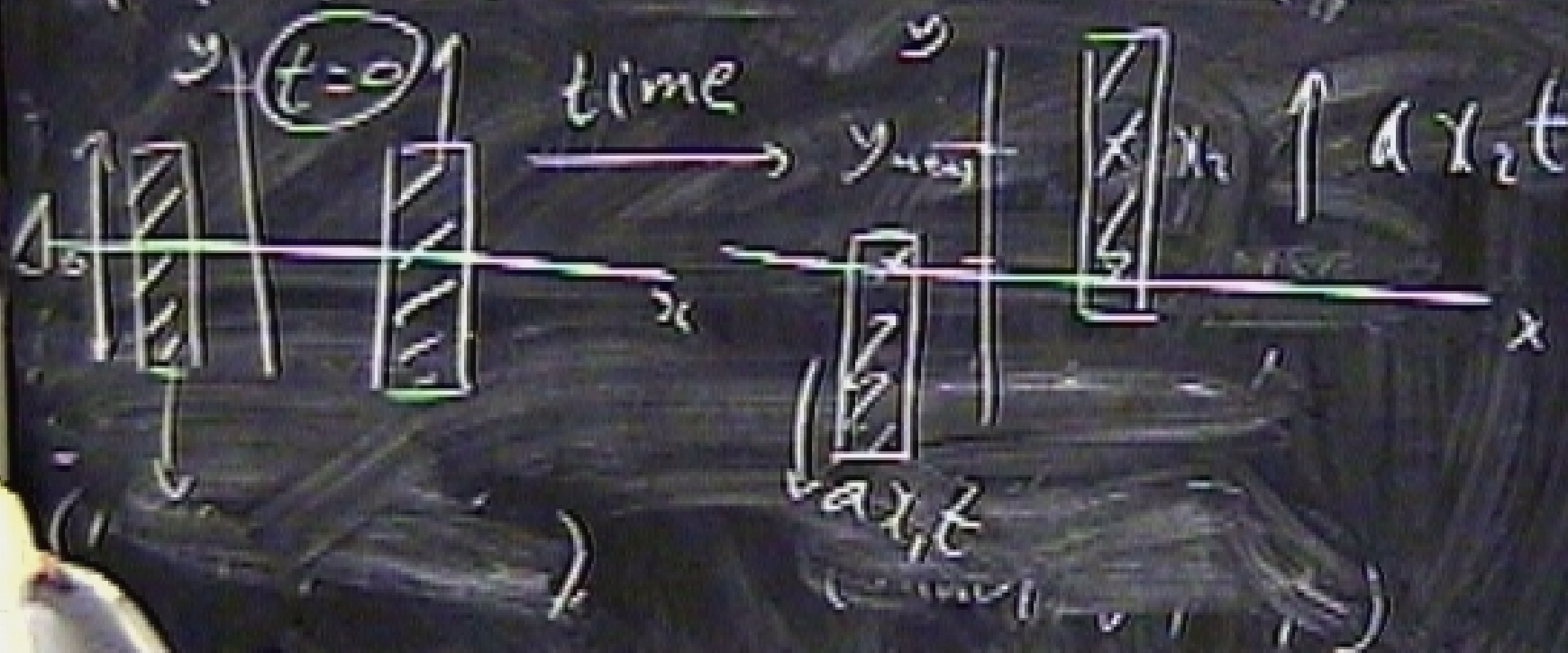


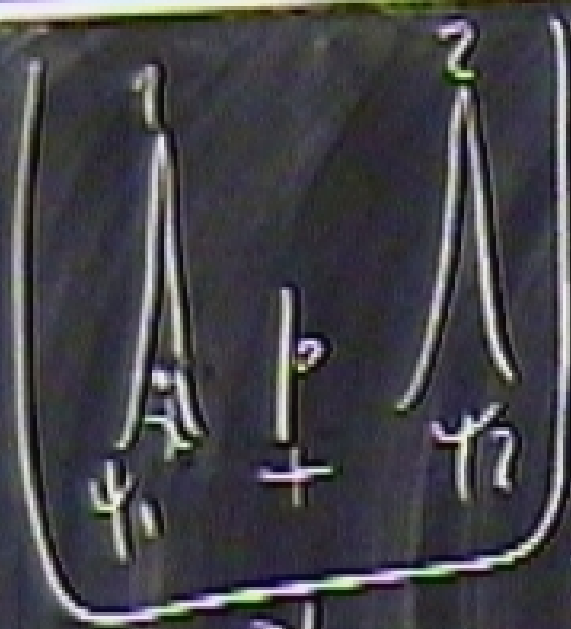
$$(\psi_1(x) + \psi_2(x)) g_0(y)$$

$$\rightarrow \psi_1(x) g_0(y - a x_1 t) + \psi_2(x) g_0(y - a x_2 t)$$

$$P_0(x, y) = |\psi_1(x) + \psi_2(x)|^2 \times \pi_0(y)$$

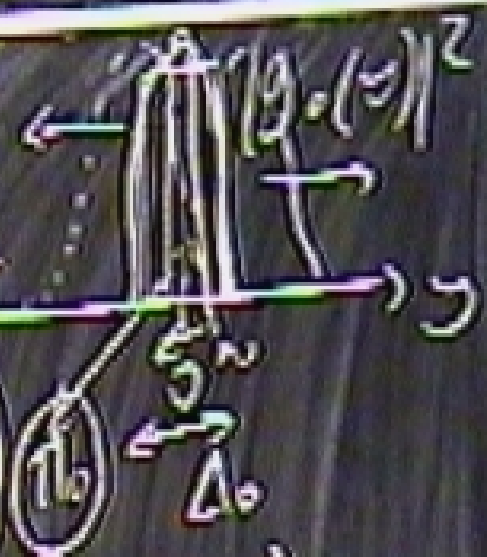
$$P = |\psi_1(x)|^2 |\tilde{\psi}_1(x - a\lambda_1 t)|^2 + |\psi_2(x)|^2 |\tilde{\psi}_2(x - a\lambda_2 t)|^2$$





$$\hat{H} = a \hat{x} \hat{p}_y$$

$$\left(\frac{\psi_1(x) + \psi_2(x)}{2} g_0(y) \right)$$



$$P_0(x, y) = |\psi_1(x) + \psi_2(x)|^2 \times \pi_0(y)$$

$$\psi_1(x) g_0(y - ax_1 t) + \psi_2(x) g_0(y - ax_2 t)$$

$$t < \frac{\Delta_0}{a}$$

$$m_A \uparrow$$

$$A \text{ --- --- --- } B$$

$$\sigma_A = \pm 1$$

$$m_B \rightarrow$$

$$\sigma_B = \pm 1$$



$$\sigma_A = \pm 1$$

$$\sigma_B = \pm 1$$

$$\langle \sigma_A \sigma_B \rangle = -m_A \cdot m_B$$

$$m_A, m_B$$



$$\sigma_A = \pm 1$$

$$\sigma_B = \pm 1$$

$$\langle \sigma_A \sigma_B \rangle = -m_A m_B$$

$$m_A, m_B, 1 \rightarrow \sigma_A, \sigma_B$$



$$\langle \sigma_A \sigma_B \rangle = -m_A m_B$$

$$m_A, m_B, 1 \rightarrow \sigma_A, \sigma_B$$

Proof (1)

$$\begin{aligned} \sigma_A &= \sigma_A(m_A, m_B, 1) \\ \sigma_B &= \sigma_B(m_A, m_B, 1) \end{aligned}$$

$$\langle \sigma_A \sigma_B \rangle = \int dA P_A(A) \sigma_A \sigma_B$$

$$\sigma_A = \pm 1$$

$$\langle \sigma_A \sigma_B \rangle =$$

$$\sigma_B =$$

$$m_A, m_B, T$$

$$P_A(A)$$

$$\sigma_A(\mu_A, \mu_B, T)$$

$$\sigma_B(\mu_A, \mu_B, T)$$

$$m_A \uparrow \quad \langle \sigma_A \sigma_B \rangle_{\text{stat}} = \int dA P_A(A) \sigma_A \sigma_B = - m_A \cdot m_B$$

$\xrightarrow{\quad B \quad}$

$$\sigma_A = \pm 1$$

$$1:1 \quad \langle \sigma_A \sigma_B \rangle = - m_A \cdot m_B \quad \sigma_B = \pm 1 \quad 1:1$$

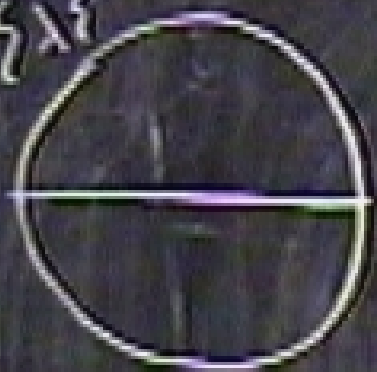
$$m_A, m_B, 1 \longrightarrow \sigma_A, \sigma_B$$

$$P_A(A)$$

$$\left. \begin{aligned} \sigma_A &= \sigma_A(x_A, x_B, 1) \\ \sigma_B &= \sigma_B(x_A, x_B, 1) \end{aligned} \right\}$$

$$P(\lambda) \neq P_{\pi}(\lambda)$$

$\{ \lambda \}$

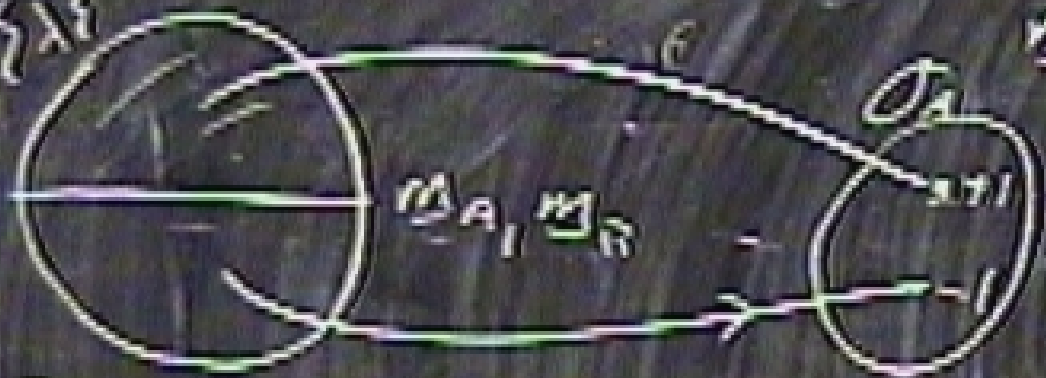


$$\underline{w}_A, \underline{w}_B$$

$$\underline{w}_A, \underline{w}_B$$

$$P_1(\lambda) \neq P_2(\lambda)$$

$\{\lambda\}$

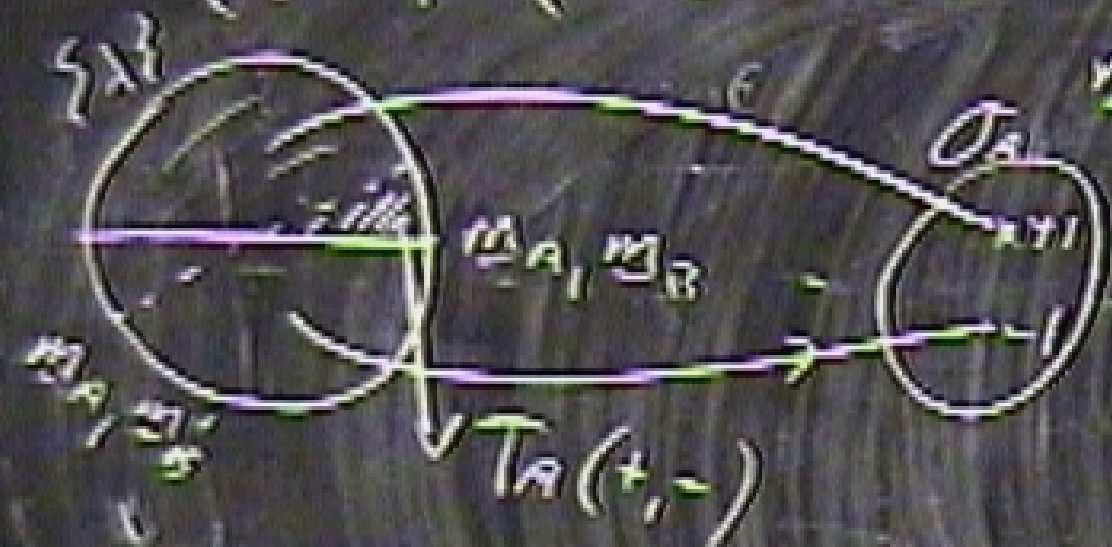


M_A, M_B
 M_A, M_B

$$P(\lambda) \neq P_{2T}(\lambda)$$

$$\underline{m}_A, \underline{m}_B$$

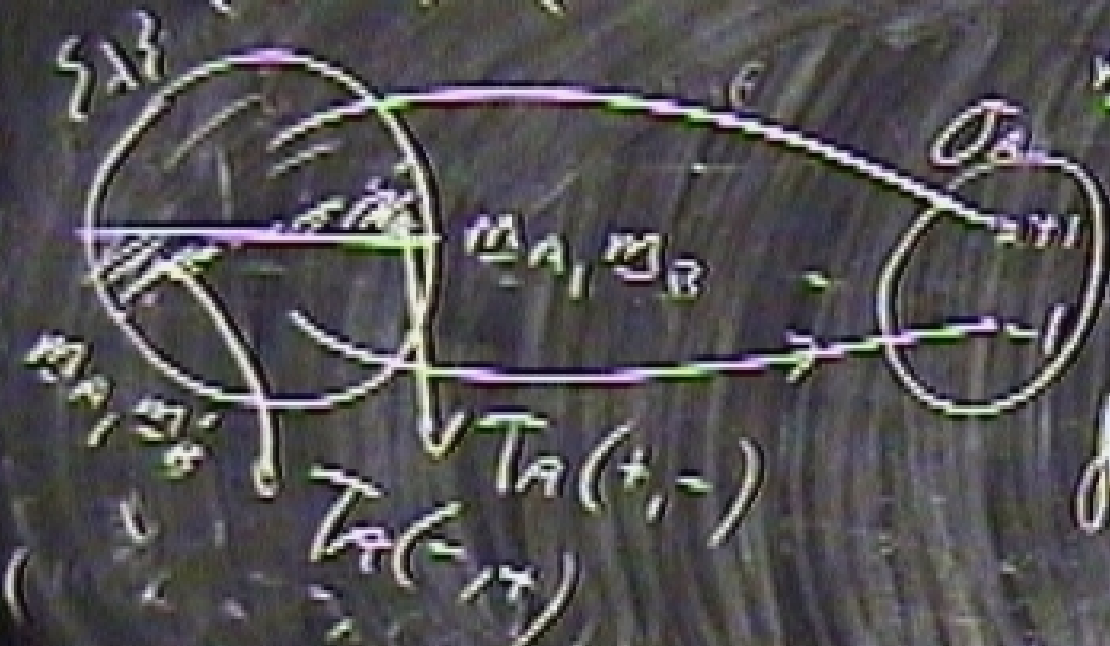
$$\underline{m}_A, \underline{m}_B$$



$$P(\lambda) \neq P_{RT}(\lambda)$$

$$\underline{m}_A, \underline{m}_B$$

$$\underline{m}_A, \underline{m}_B$$

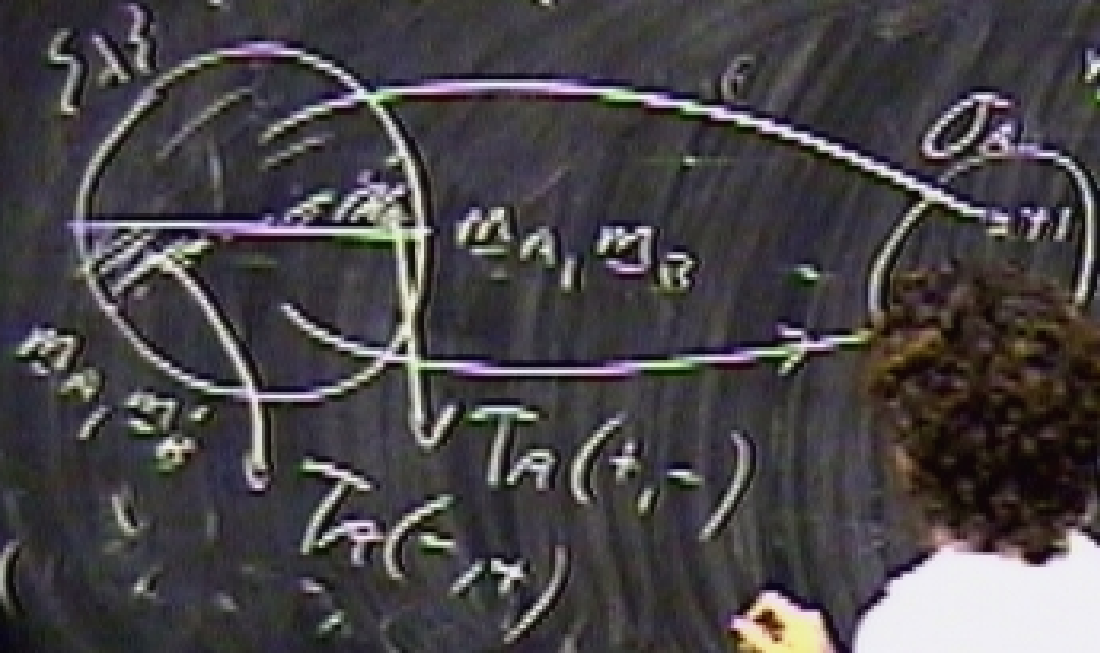


$$dM_{RT} = f_{RT} d\lambda$$

$$P(\lambda) \neq P_{RT}(\lambda)$$

$$\underline{m}_A, \underline{m}'_B$$

$$\underline{m}_A, \underline{m}'_B$$



$$dm = p d\lambda$$

$$M_{RT} = \oint_{RT} p d\lambda$$

Non-additive expectations

Non-additive excitations

$$[\hat{n}_1, \hat{n}_2] \neq 0$$

Non-additive excitations

$$[\hat{n}_1, \hat{n}_2] \neq 0$$

$$\{\hat{n}_1, \hat{n}_2\}$$

Non-additive excitations

$$[\hat{n}_1, \hat{n}_2] \neq 0$$

$$\hat{n}_1, \hat{n}_2, \alpha_1 \hat{n}_1 + \alpha_2 \hat{n}_2$$

Non-additive expectations

$$[\hat{A}_1, \hat{A}_2] \neq 0$$

$$\langle \alpha_1 \hat{A}_1 + \alpha_2 \hat{A}_2 \rangle = \alpha_1 \langle \hat{A}_1 \rangle + \alpha_2 \langle \hat{A}_2 \rangle$$

$$P(\lambda) = \delta(\lambda - \lambda_0)$$

Von N.
1932

Bell
1966

$$P(\lambda) = \delta(\lambda - \lambda_0)$$

Von Neumann
1932

Bell
1966

Spin-1/2



$$P(\lambda) = \delta(\lambda - \lambda_0)$$

Von Neumann
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Bell
1966

Spin-1/2

$$m_s \cdot \vec{\sigma} = \frac{1}{\sqrt{2}} m_1 \cdot \vec{\sigma}_1 + \frac{1}{\sqrt{2}} m_2 \cdot \vec{\sigma}_2$$



$$P(\lambda) = \delta(\lambda - \lambda_0)$$

Von Neumann
1932

Bell
1966

Spin-1/2



$$P(\lambda) = \delta(\lambda - \lambda_0)$$

$$O(m\lambda) = \pm 1$$

Von Neumann
1932

Bell
1966

Spin = 1/2



$$\rho(\lambda) = \delta(\lambda - \lambda_0)$$

Von Neumann
1932

Bell
1966

Spin-1/2

$$\begin{aligned} \vec{m}_3 &= \frac{1}{\sqrt{2}} (\vec{m}_1 + \vec{m}_2) \\ \langle \dots \rangle &= \frac{1}{\sqrt{2}} (\langle \dots \rangle + \frac{1}{\sqrt{2}} \langle \dots \rangle) \end{aligned}$$

$$\begin{aligned} \sigma(m, \lambda) &= \pm 1 \\ \langle \sigma \rangle &= \sigma(m, \lambda) \\ \vec{m}_3 &= \frac{1}{\sqrt{2}} (\vec{m}_1 + \vec{m}_2) \end{aligned}$$



$$P(\lambda) = \delta(\lambda - \lambda_0)$$

Von Neumann
1932

Bell
1966

Spin = 1/2

$$\sigma(\vec{m}, \lambda) = \pm 1$$

$$\langle \sigma \rangle = \sigma(\vec{m}, \lambda)$$

$$\vec{m}_3 = \frac{1}{\sqrt{2}}(\vec{m}_1 + \vec{m}_2)$$

$$\vec{m}_3 \cdot \vec{e}_3 = \frac{1}{\sqrt{2}}(\vec{m}_1 \cdot \vec{e}_3 + \vec{m}_2 \cdot \vec{e}_3)$$

$$P(\lambda) = \delta(\lambda - \lambda_0)$$

Von Neumann
1932

Bell
1966

Spin-1/2

$$\sigma(\vec{m}, \lambda) = \pm 1$$

$$\langle \sigma \rangle = \sigma(\vec{m}, \lambda)$$

$$\vec{m}_3 = \frac{1}{\sqrt{2}}(\vec{m}_1 + \vec{m}_2)$$


$$\vec{m}_3 \cdot \vec{\sigma} = \frac{1}{\sqrt{2}} \vec{m}_1 \cdot \vec{\sigma} + \frac{1}{\sqrt{2}} \vec{m}_2 \cdot \vec{\sigma}$$

$$\langle \sigma(\vec{m}_3, \lambda) \rangle = \frac{1}{\sqrt{2}} \langle \sigma(\vec{m}_1, \lambda) \rangle + \frac{1}{\sqrt{2}} \langle \sigma(\vec{m}_2, \lambda) \rangle$$

$$\langle \sigma(\vec{m}_3, \lambda) \rangle = \frac{1}{\sqrt{2}} \langle \sigma(\vec{m}_1, \lambda) \rangle + \frac{1}{\sqrt{2}} \langle \sigma(\vec{m}_2, \lambda) \rangle$$

$$P(\lambda) = \delta(\lambda - \lambda_0)$$

Von Neumann
1932

Bell
1966

Spin-1/2

$$\sigma(\vec{m}, \lambda) = \pm 1$$

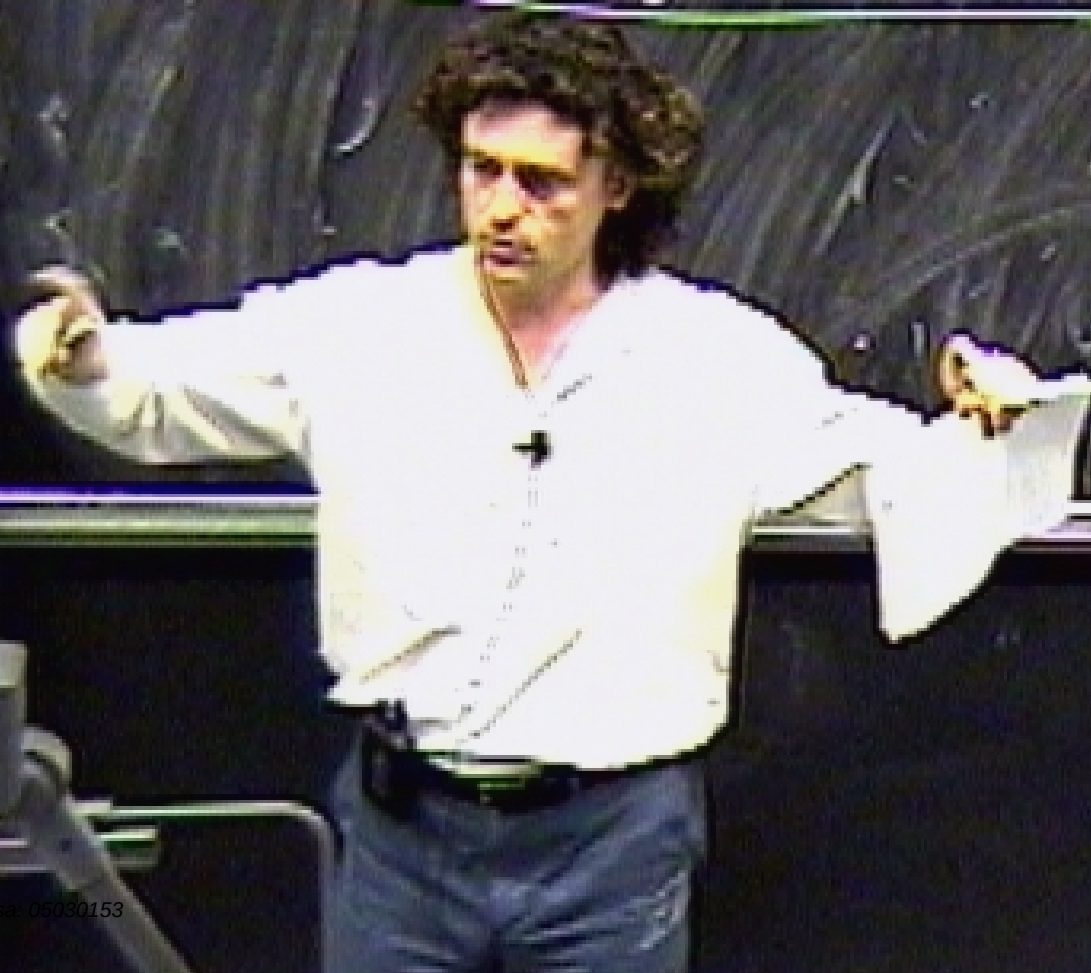
$$\langle \sigma \rangle = \sigma(\vec{m}, \lambda)$$

$$\vec{m}_3 = \frac{1}{\sqrt{2}}(\vec{m}_1 + \vec{m}_2)$$


$$\langle \sigma(\vec{m}_3, \lambda) \rangle = \frac{1}{\sqrt{2}} \langle \sigma(\vec{m}_1, \lambda) + \sigma(\vec{m}_2, \lambda) \rangle$$

$$\rho(\lambda) \neq \rho_{\pi\tau}(\lambda)$$

$$\langle \sigma \rangle \neq \frac{1}{\sqrt{2}} \langle \dots \rangle + \frac{1}{\sqrt{2}} \langle \dots \rangle$$



$$\rho(\lambda) \neq \rho_{\pi\tau}(\lambda)$$

$$\langle 0 \rangle \neq \frac{1}{\sqrt{2}} \langle \dots \rangle + \frac{1}{\sqrt{2}} \langle \dots \rangle$$

$$\langle \alpha_1 \Omega_1 + \alpha_2 \Omega_2 + \dots \rangle = \alpha_1 \langle \Omega_1 \rangle + \dots$$

Ballentine
Rev. Mod. Phys. 70, 70 (1998)

$$\langle m \cdot \hat{\sigma} \rangle = m \cdot P$$

$\Leftrightarrow$ Add. args.

$$m_1, m_2, m_3$$



$$m = \sum_i c_i m_i$$

$$m \cdot \hat{\sigma} = \sum_i c_i (m_i \cdot \hat{\sigma})$$

$$\text{Tr}(\hat{\rho} m \cdot \hat{\sigma})$$

$$= m \cdot P$$

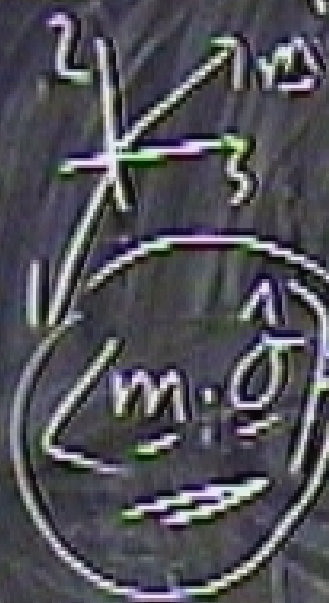
$$\downarrow \text{Tr}(\hat{\rho} \hat{\sigma})$$

$$\langle \underline{m} \cdot \hat{\sigma} \rangle = \underline{m} \cdot \underline{P}$$

$\Leftrightarrow$ Add. args.

$$\underline{m}_1, \underline{m}_2, \underline{m}_3$$

$$\underline{m} = \sum_i c_i \underline{m}_i$$



$$\langle \underline{m} \cdot \hat{\sigma} \rangle = \sum_i c_i \langle \underline{m}_i \cdot \hat{\sigma} \rangle$$

$$\text{Tr}(\hat{\rho} \underline{m} \cdot \hat{\sigma}) = \underline{m} \cdot \underline{P}$$

$$\downarrow \text{Tr}(\hat{\rho} \hat{\sigma})$$

photons
→

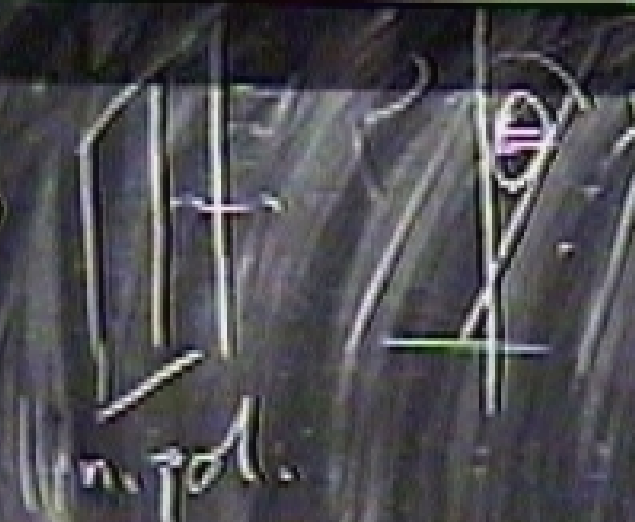


→ trans. prob.

$$P^{\perp}(\theta)$$

$$= \cos^2 \theta$$

photons

trans. prob.
 $P^+(\theta)$

$$= \cos^2 \theta$$

$\sigma = \frac{1}{2} \sigma_T$ $\rightarrow$ pol. Hel / Lin to axis
 $\theta = 0$

$$p^+(\theta) = \frac{1}{2} \left(1 + \langle \sigma(\underline{x}, y) \rangle \right)$$

$$\rho^+(\theta) = \frac{1}{2} (1 + \langle \sigma(\underline{m}, 1) \rangle)$$

$$\rho_{\pi}^+ = \frac{1}{2} (1 + \underline{m} \cdot \underline{p}) = \frac{1}{2} (1 + p \cos 2\theta)$$

$$P^+(\theta) = \frac{1}{2} (1 + \langle \sigma(\vec{m}, 1) \rangle)$$

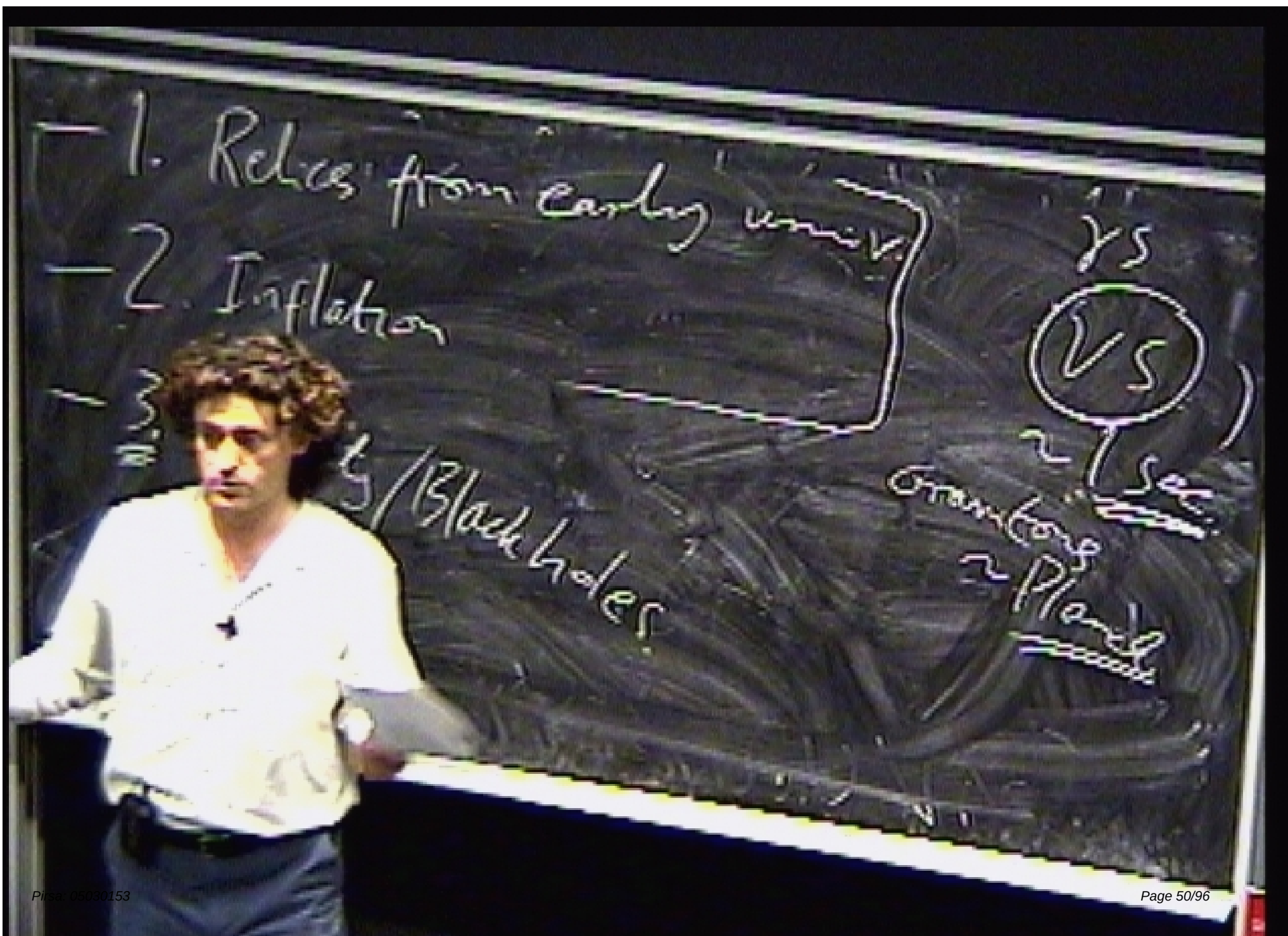
$$P_A^+ = \frac{1}{2} (1 + \vec{m} \cdot \vec{P}) = \frac{1}{2} (1 + P \cos \theta)$$

$= \cos^2 \frac{\theta}{2}$ if $P=1$

- 1. Relics from early universe
- 2. Inflation
- 3.

- 1. Relics from early universe
- 2. Inflation
- 3. Gravitational waves

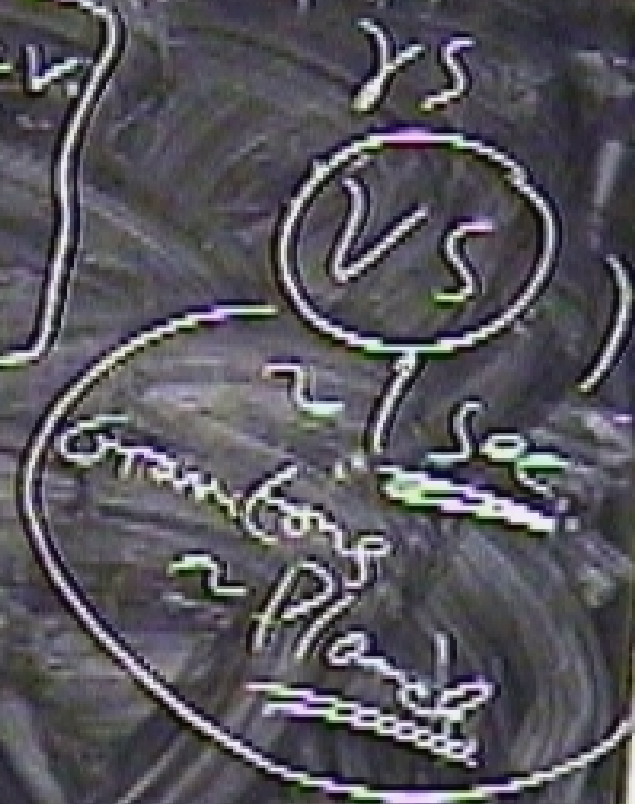
- 1. Relics from early universe
- 2. Inflation
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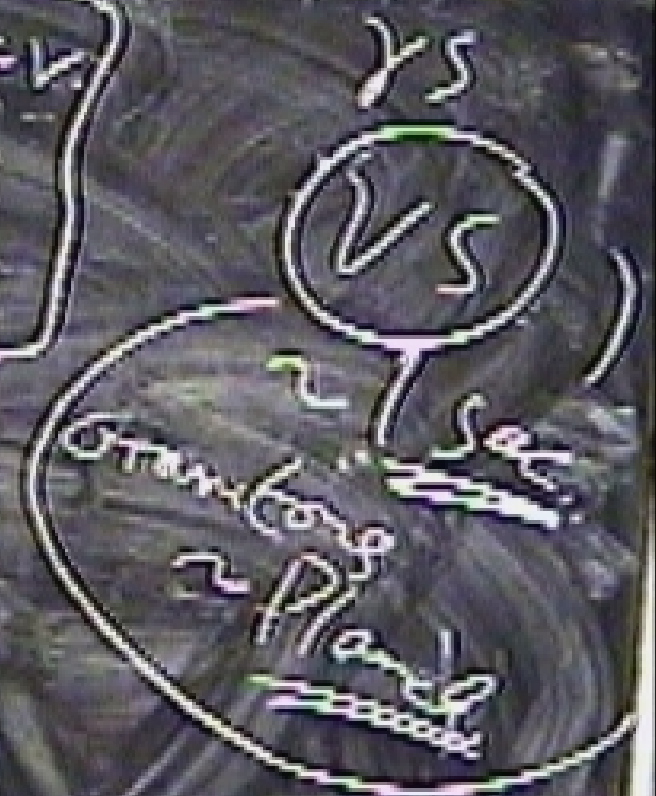
- 1. Relics from early universe

- 2. Inflation

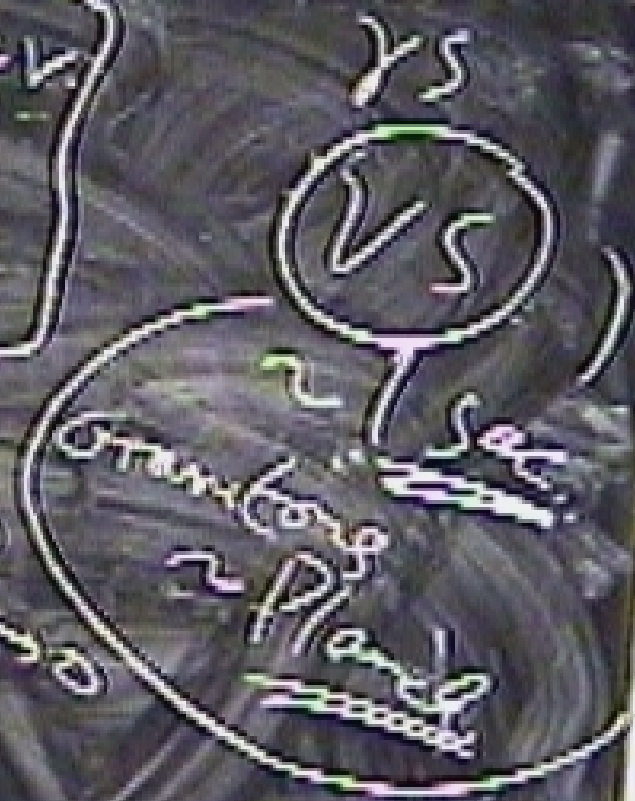
- 3. Gravitational waves / Black holes



- 1. Relics from early universe
- 2. Inflation $a(t) \sim t^{1/2}$
- 3. Gravitational waves / Black holes



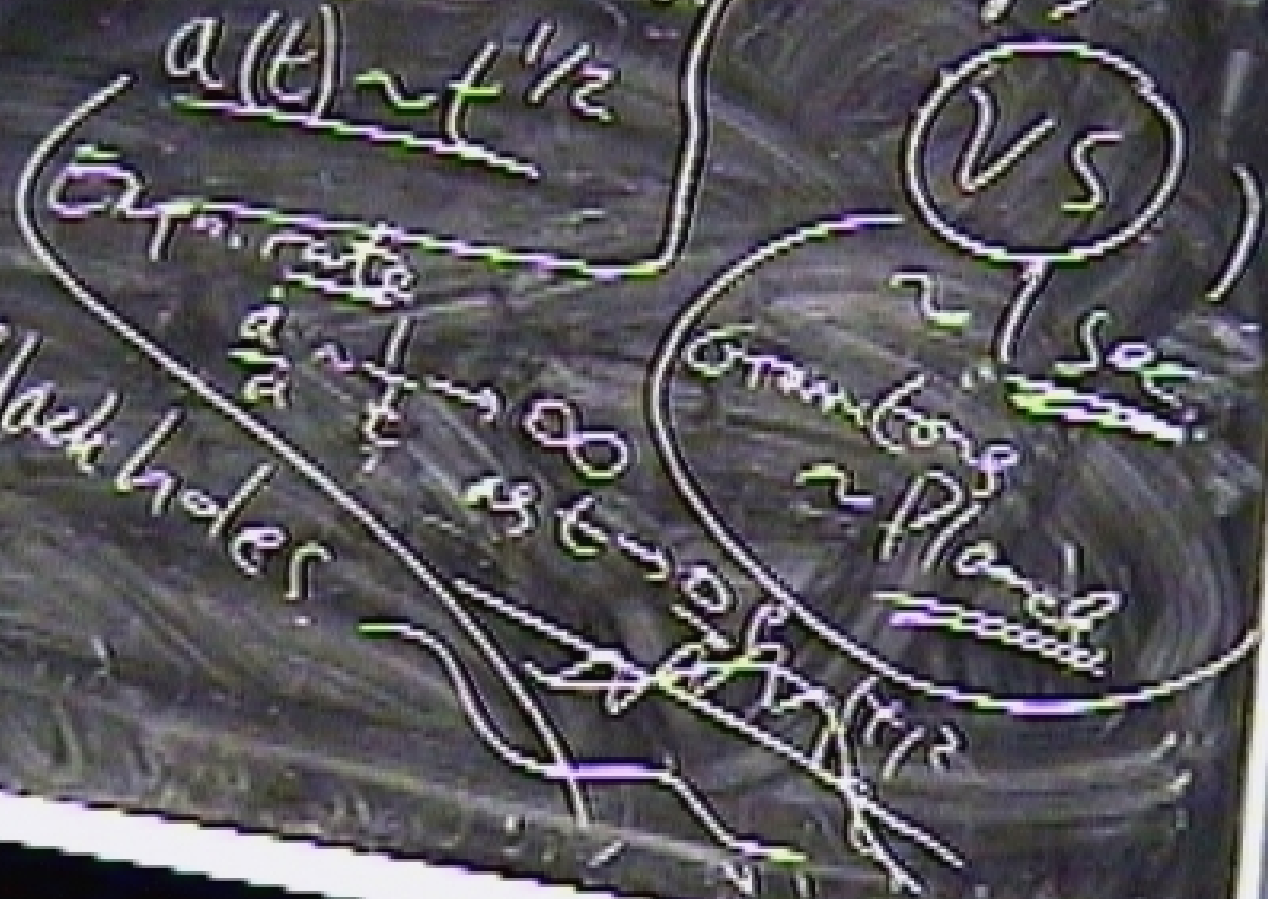
- 1. Relics from early universe
- 2. Inflation $a(t) \sim t^{1/2}$
- 3. $\dot{a}/a \rightarrow \infty$ as $t \rightarrow 0$
- 4. Gravitational waves / Black holes



- 1. Relics from early universe

- 2. Inflation $a(t) \sim t^{1/2}$

- 3. Gravitational waves / Black holes



1. Relics from early univ.

2. Inflation

$$a(t) \sim t^{1/2}$$

Exp. rate

Gravit/Black holes

$$\frac{\dot{a}}{a} \sim \frac{1}{t}$$

$$a \sim t^{1/2}$$

AV
101

γ s

VS

Gravitons

$\sim$ Planck

- How does gravity fit w. Q.T. (?)

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- Perhaps grav. disturbs qu. eq.?

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Hawking 76 (PRD)

Far past

Hawking 76 (PRD)

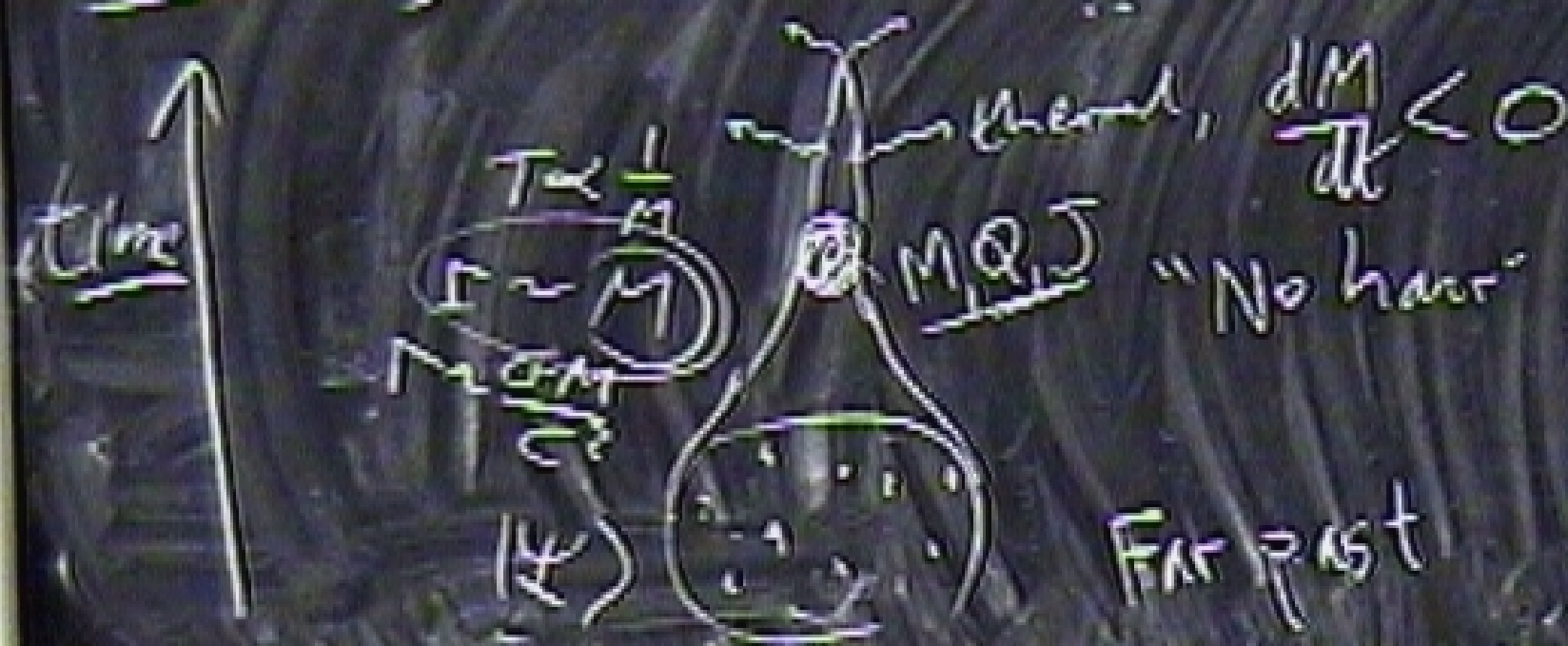
time ↑



Fat part

Hawking 76 (PRD)

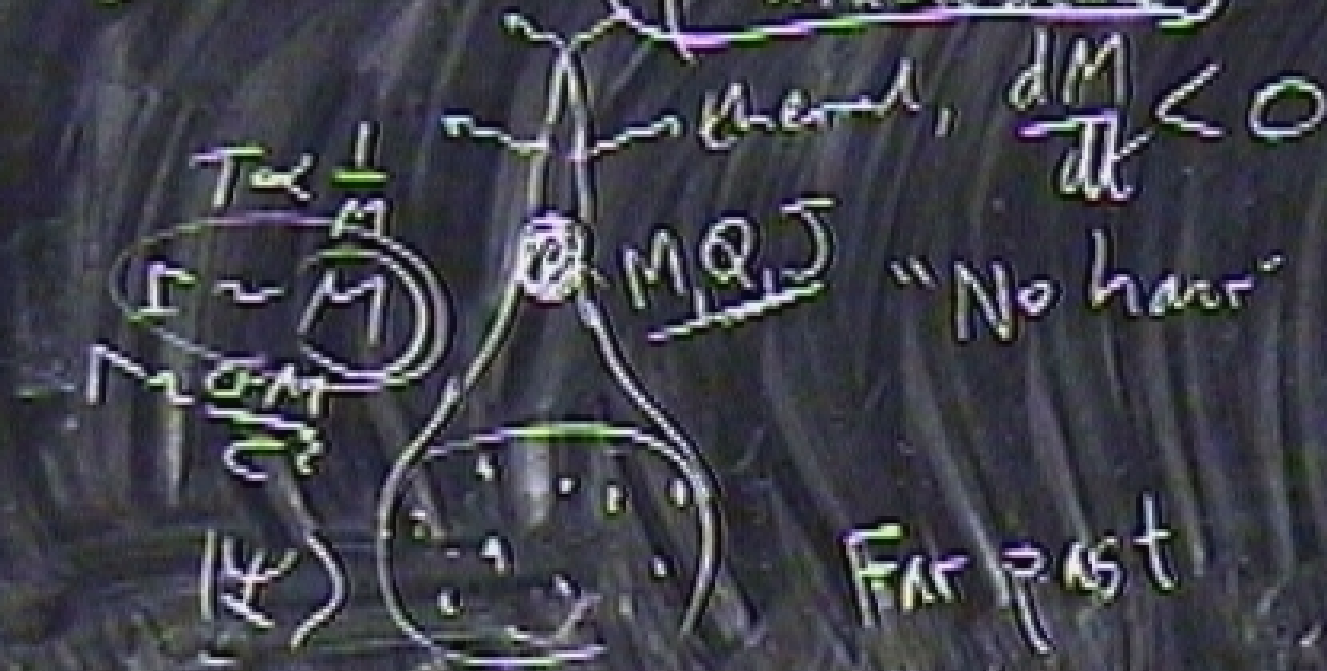
Far future, Ch. rad.



Hawking 76 (PRD)

For future th. rad.
mixed state

time ↑



Pure-to-mixed transition
 $\rho_{in} = |\psi\rangle\langle\psi| \xrightarrow{U} \rho_{out} \text{ (mixed)}$

Pure-to-mixed transition

$$\beta_{in} = \frac{1}{2} \left(\pm 1 \right) \longrightarrow \beta_{out} \text{ (mixed)} \quad \left(\frac{U_1}{U_2} \right)$$

~~no retrodiction~~

Pure-to-mixed transition

$$\rho_{in} = |\psi\rangle\langle\psi| \xrightarrow{\quad} \rho_{out} \text{ (mixed)}$$

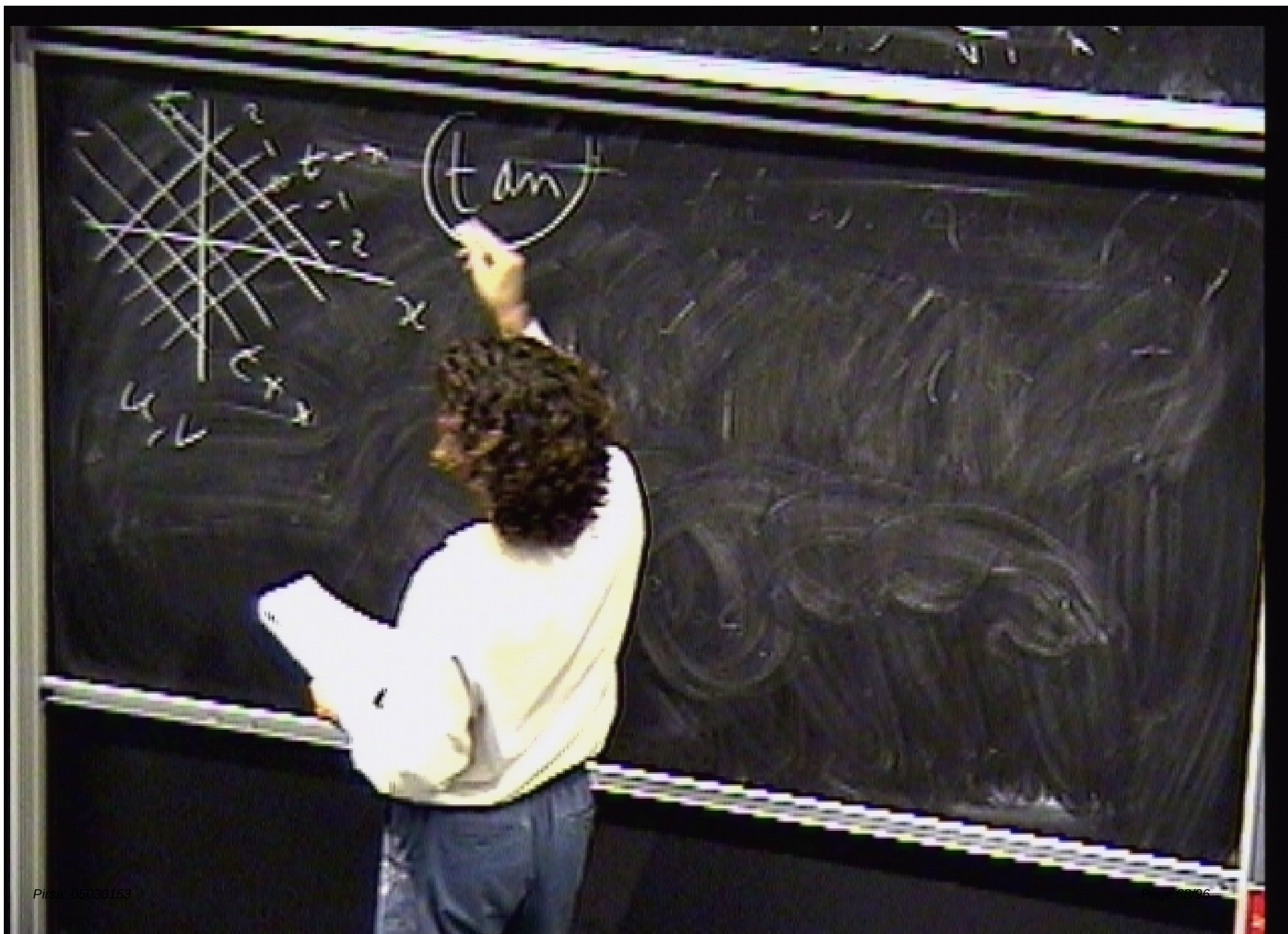
no retrodiction
= "info. loss"

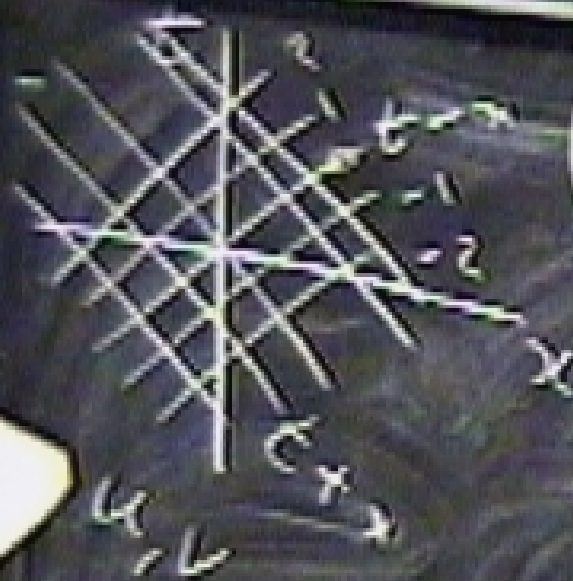
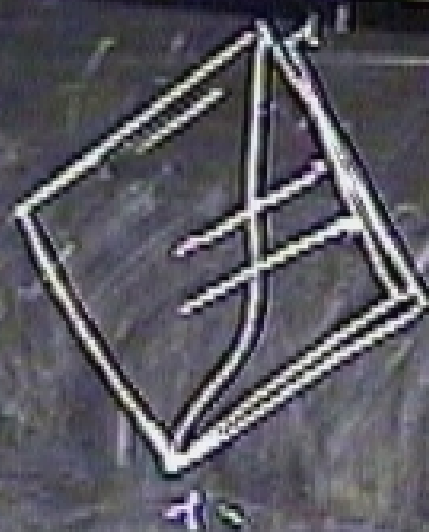
Pure to mixed transition

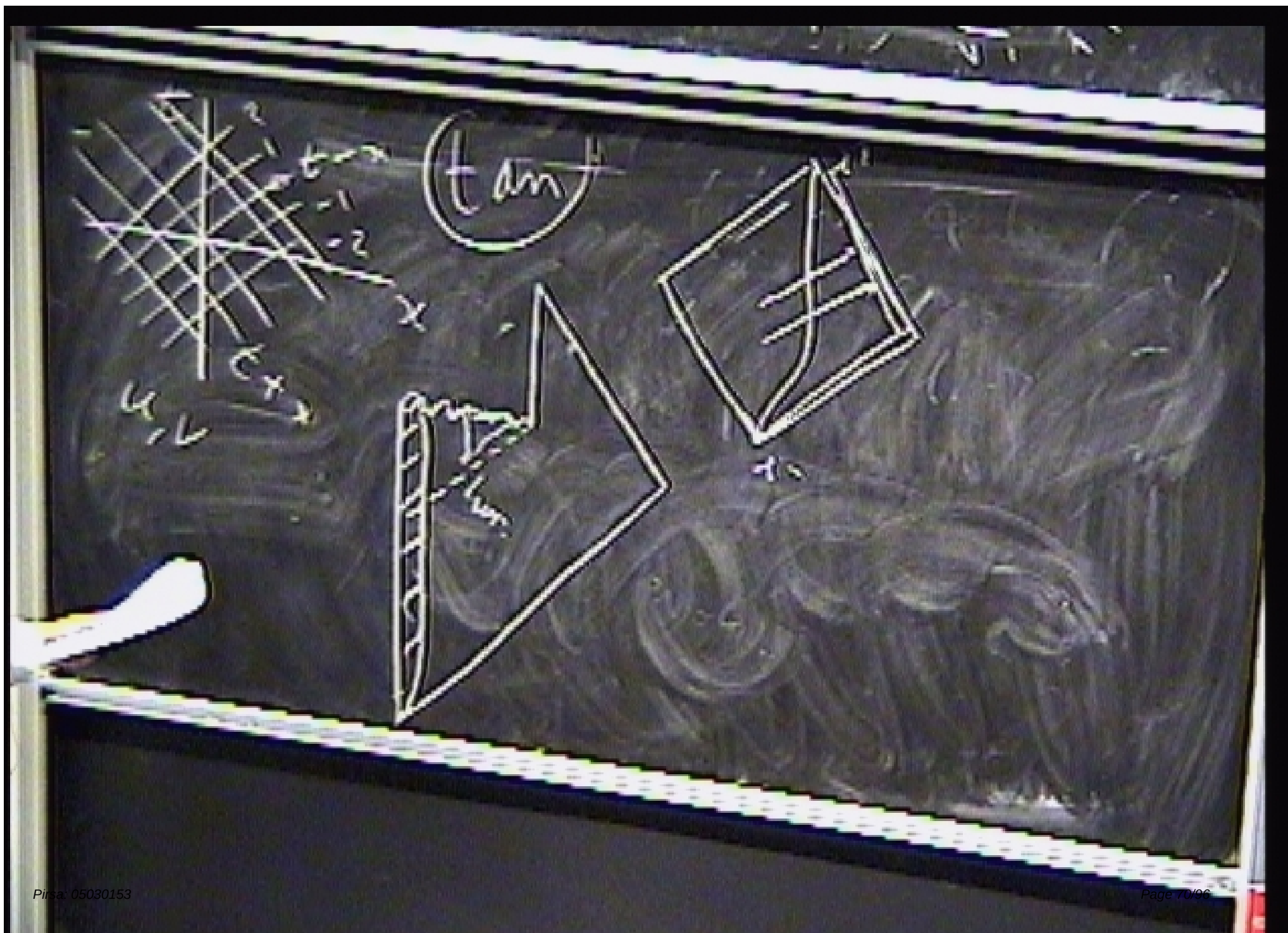
$\rho_{in} = |\psi\rangle\langle\psi| \longrightarrow \rho_{out} \text{ (mixed)}$

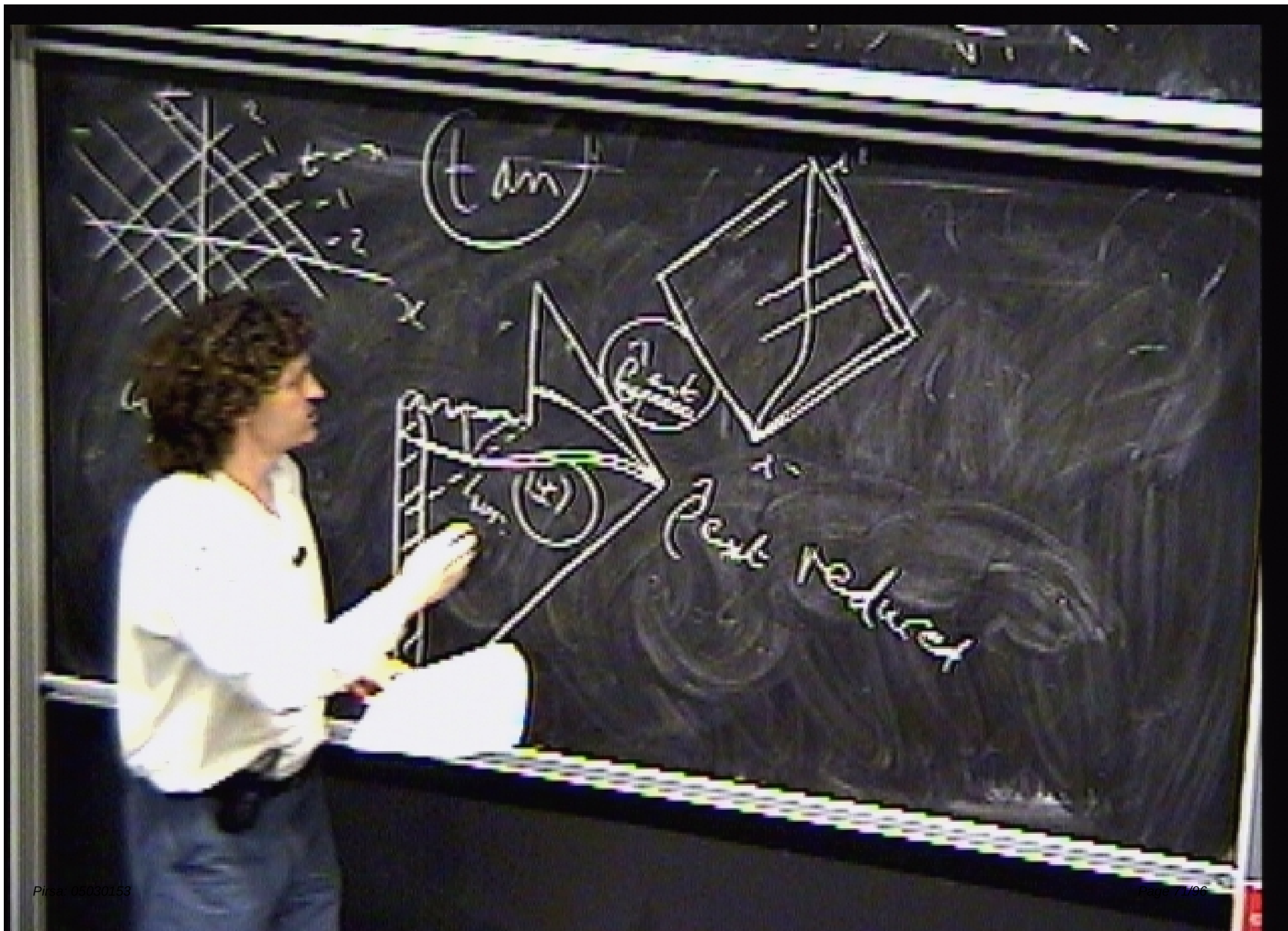
$$\frac{d\rho}{dt} = -i[H, \rho]$$

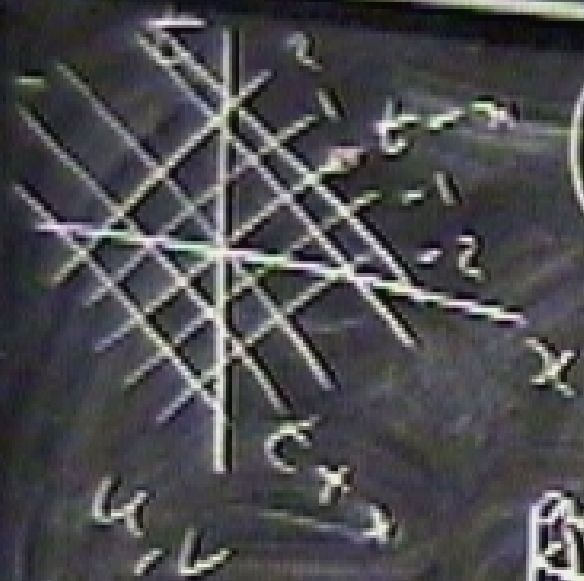
No retrocausality



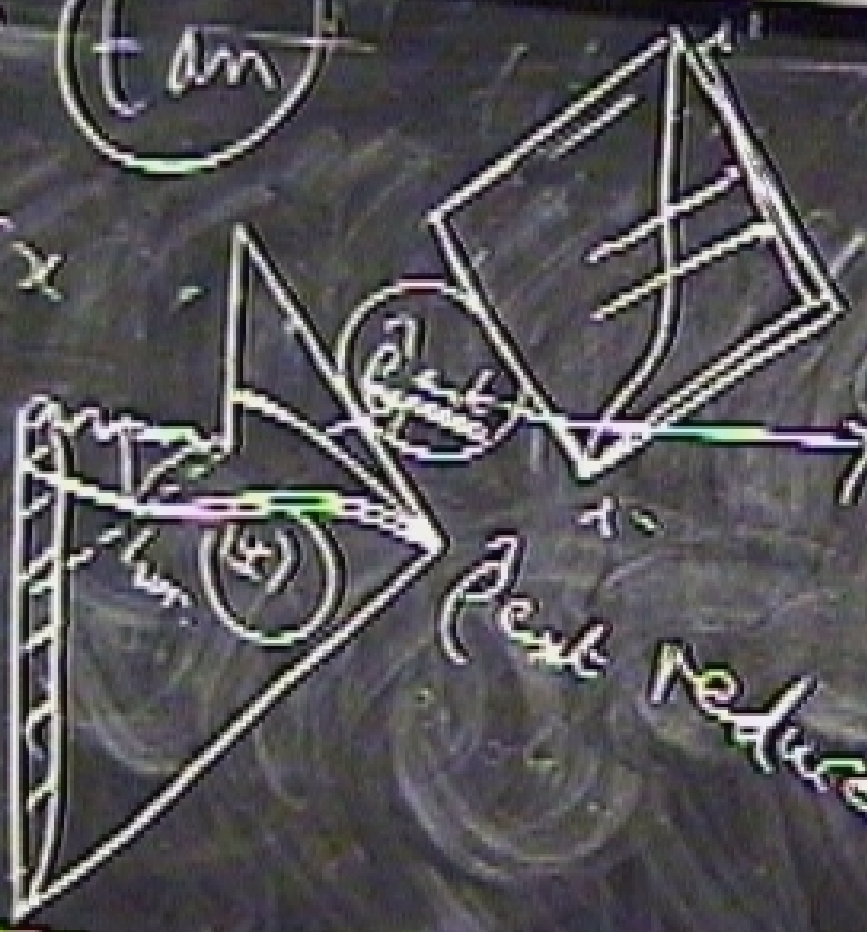

$$\tan$$






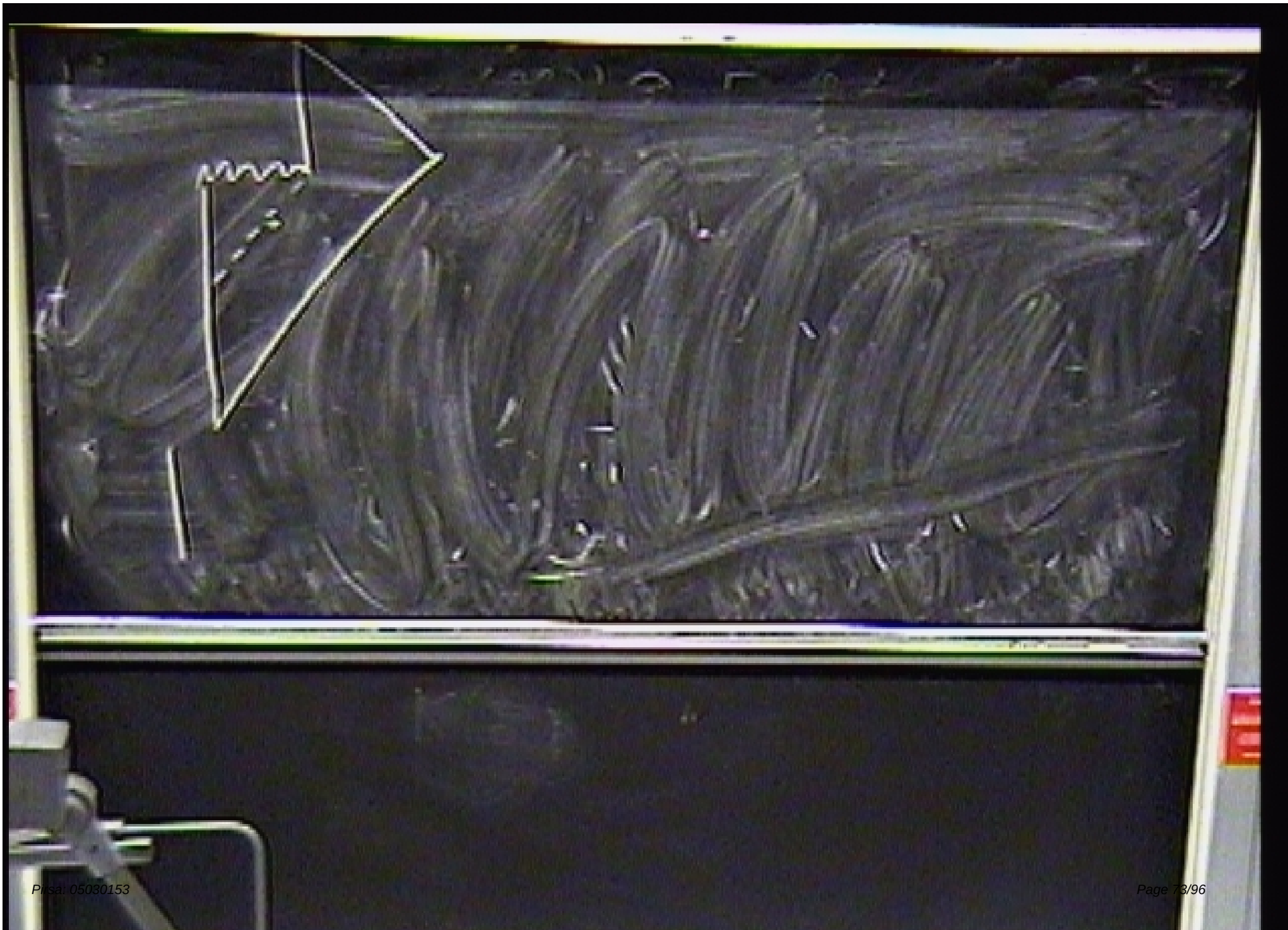


(tan)



tan qu.
None

Reduct



Notice



$$\chi_A \quad \psi(\chi_A, \chi_B) \quad \chi_B$$

$$H = \alpha \gamma \beta$$

None



$$iA \int_{\gamma_1}^{\gamma_2} \psi(x_1, x_2) dx_3$$

$$H = \langle \psi | \rho_3$$

$$\rho_0 = \frac{|\psi_0|^2 \pi_0(\gamma)}{\sum_{\alpha=1}^n |\psi_\alpha|^2}$$

Notice

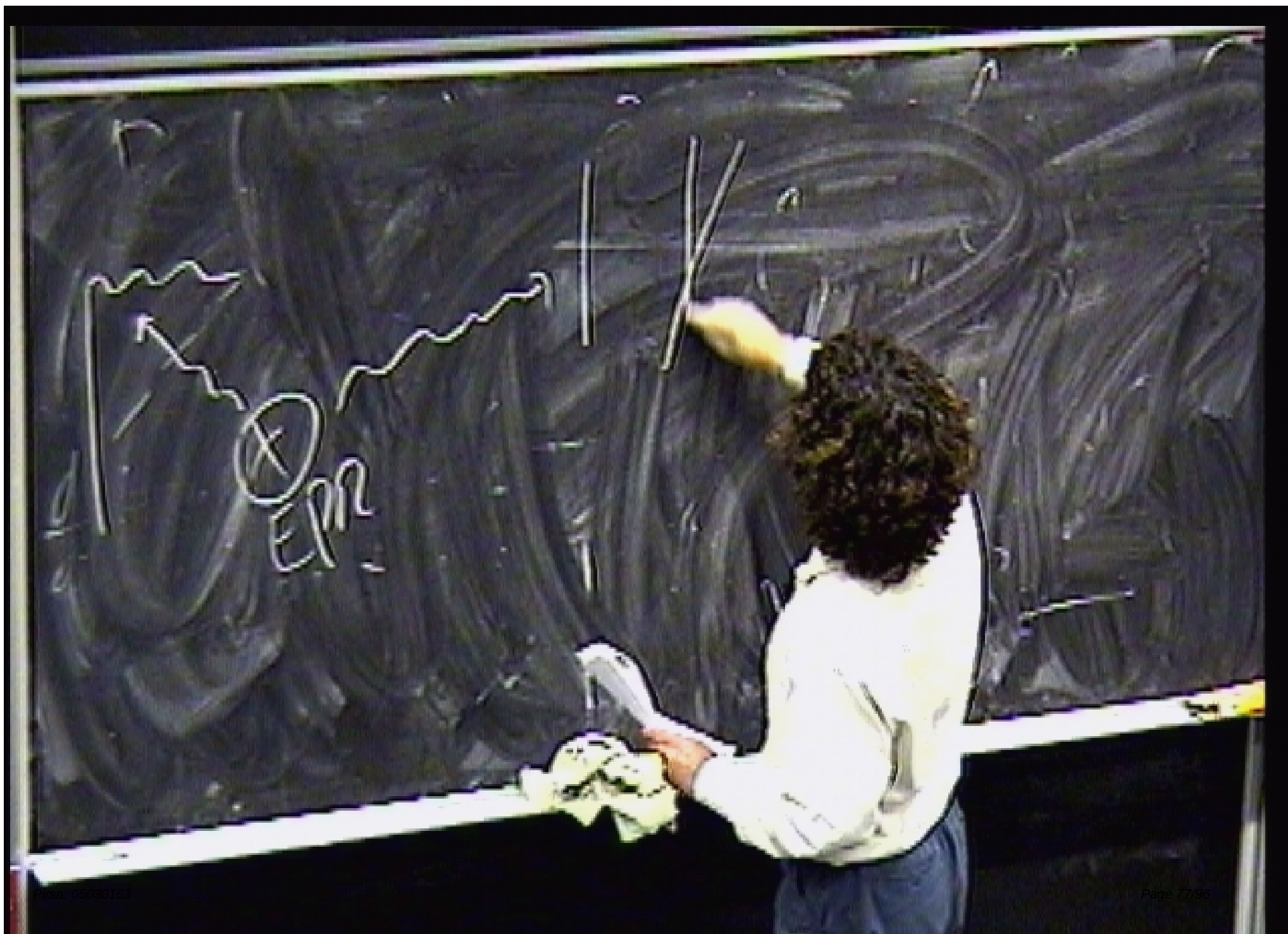


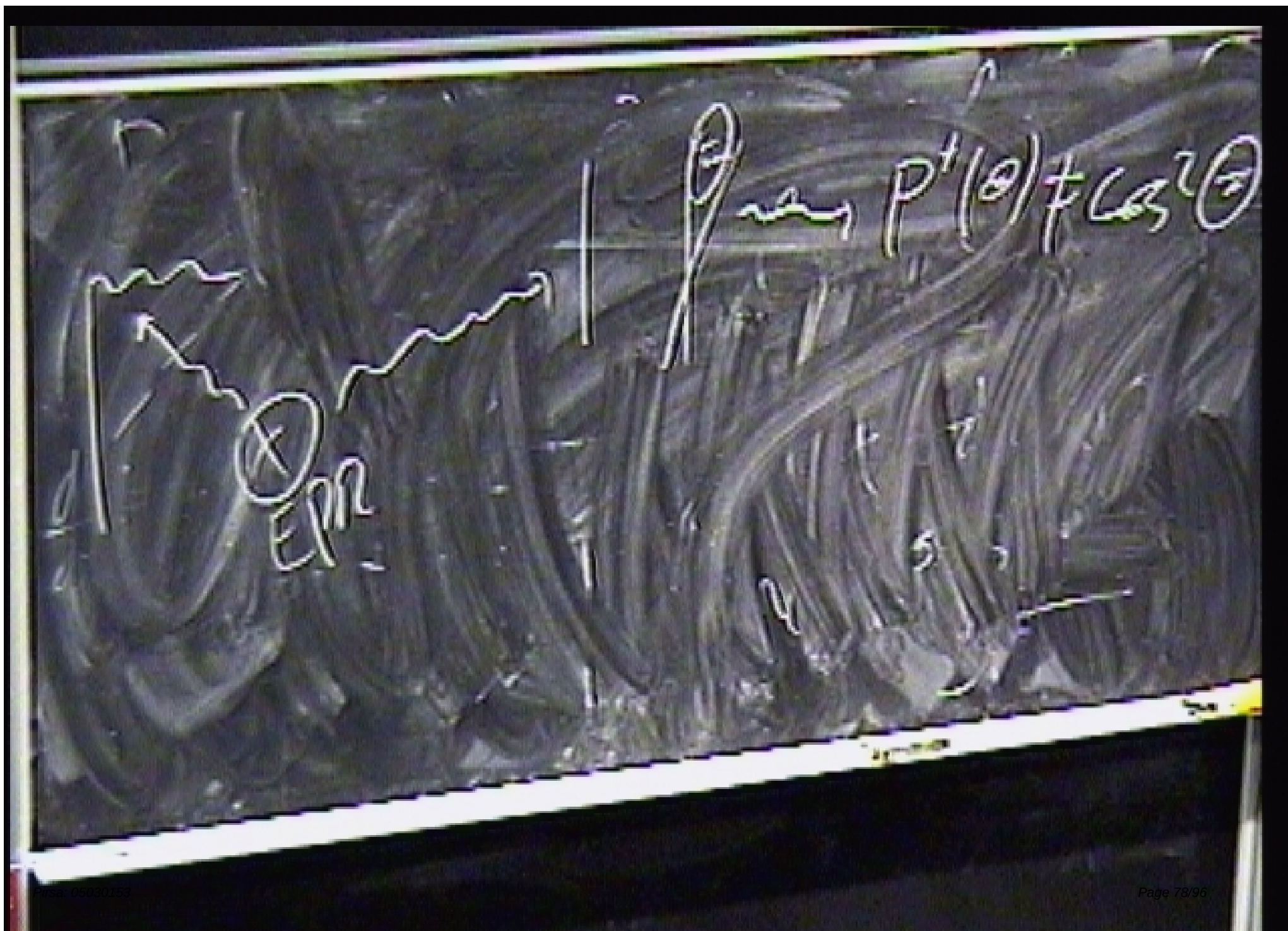
$$\gamma_A \psi(x_1, x_2)$$

$$H = \alpha \gamma \beta_2$$

$$\rho_0 = |\psi_0|^2 \pi_0(\psi)$$

$$D(\gamma_A, \gamma_B, \gamma_C) = \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}}$$



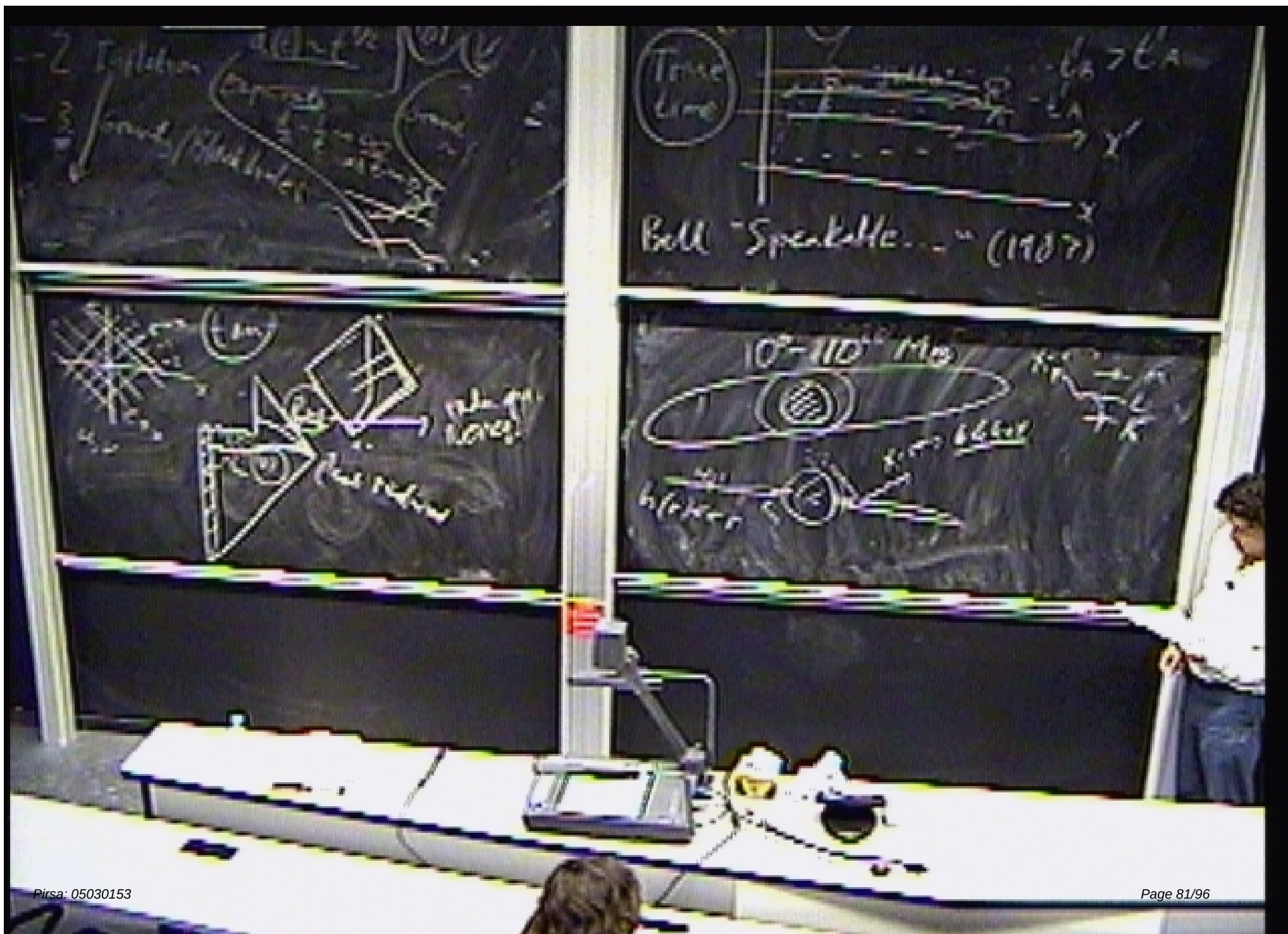


$10^6 - 10^{10} M_{\odot}$

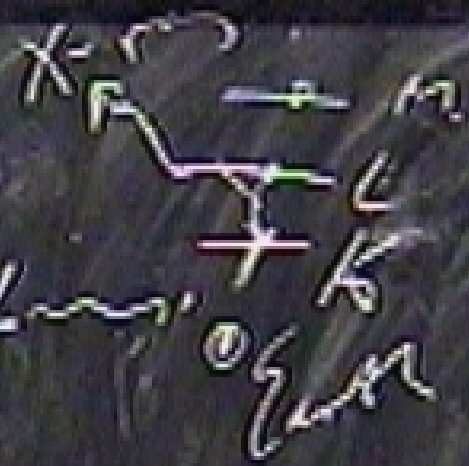


$10^6 - 10^{10} M_{\odot}$





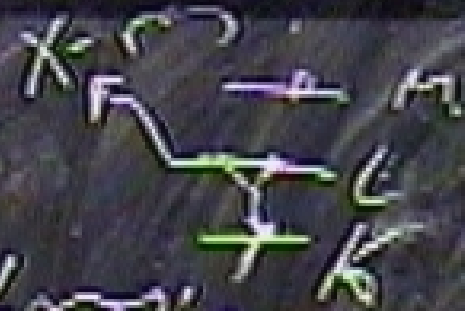
$10^6 - 10^{10} M_{\odot}$



6.4 keV



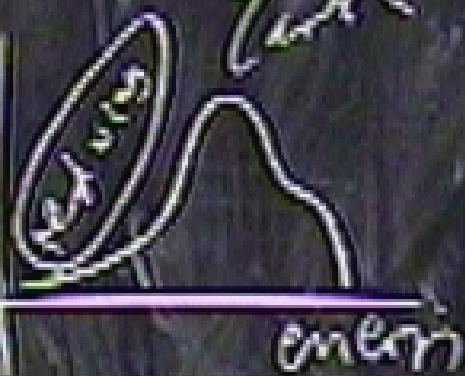
$10^6 - 10^{10} M_{\odot}$



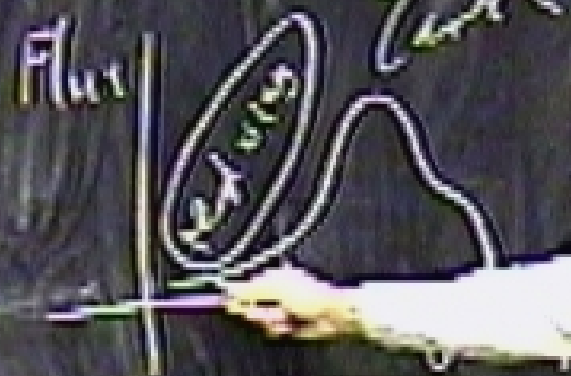
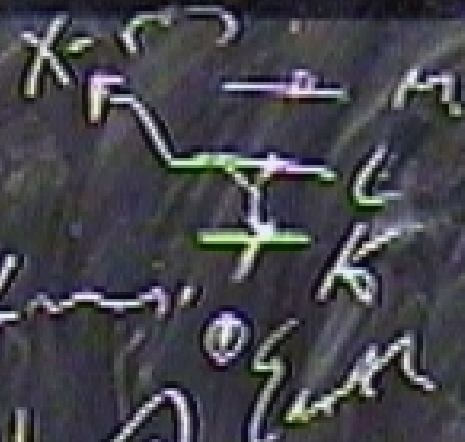
6.44 eV

$x \sim r$

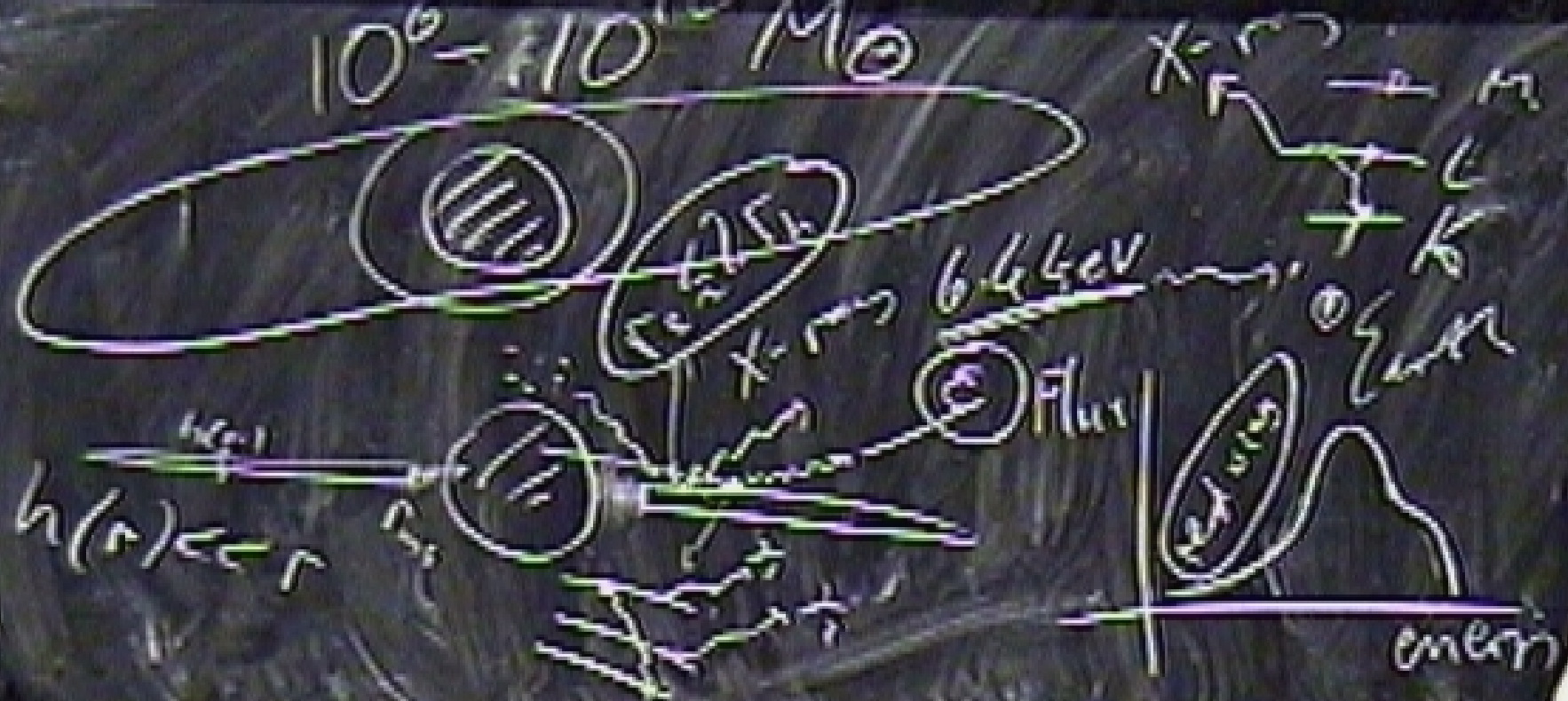
Flux



$10^6 - 10^{10} M_{\odot}$



$10^6 - 10^{10} M_{\odot}$



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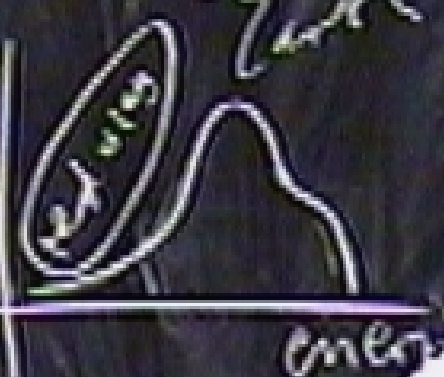
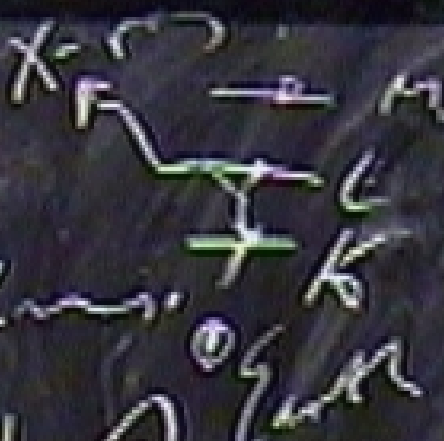
$10^6 - 10^7 M_\odot$

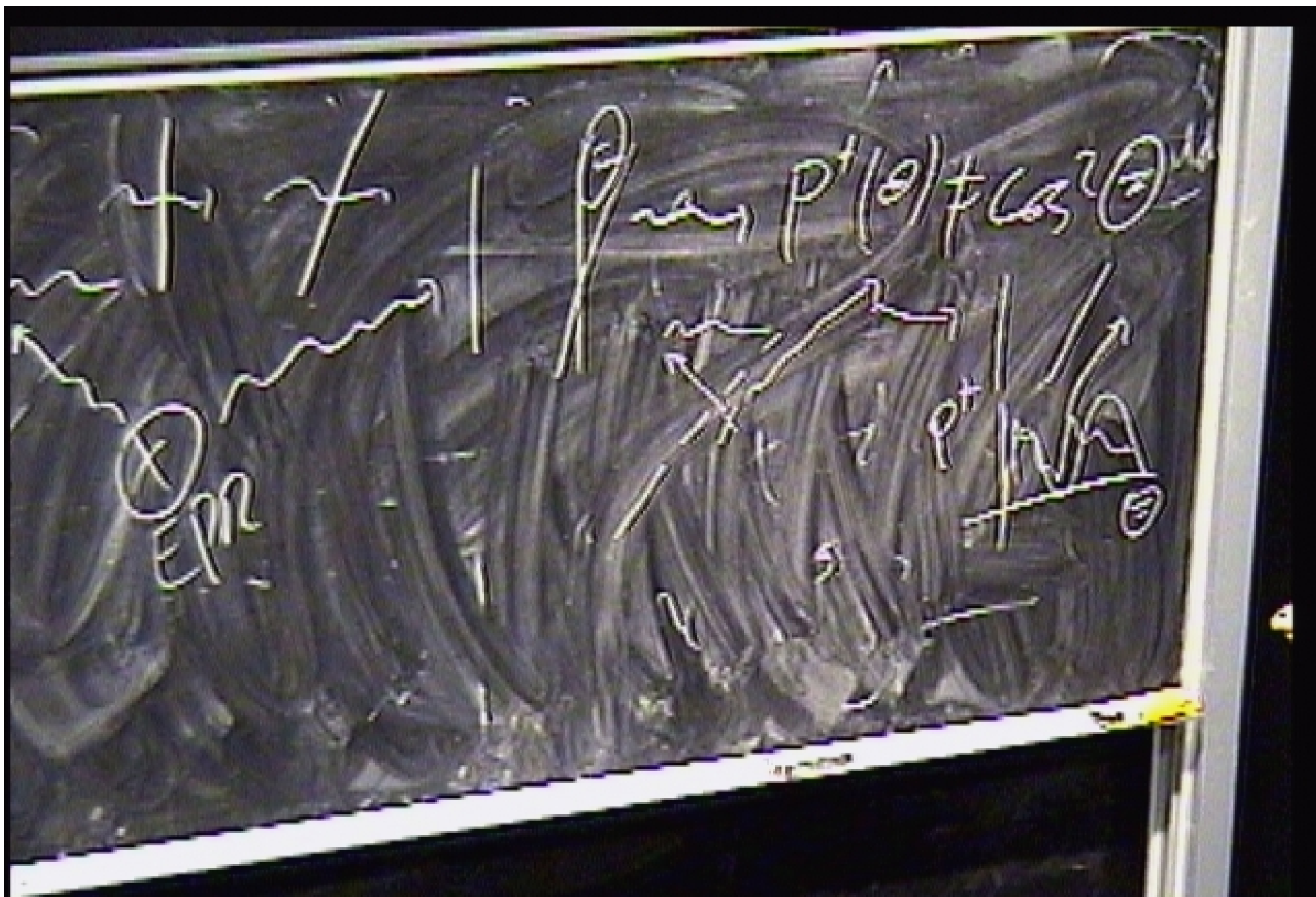


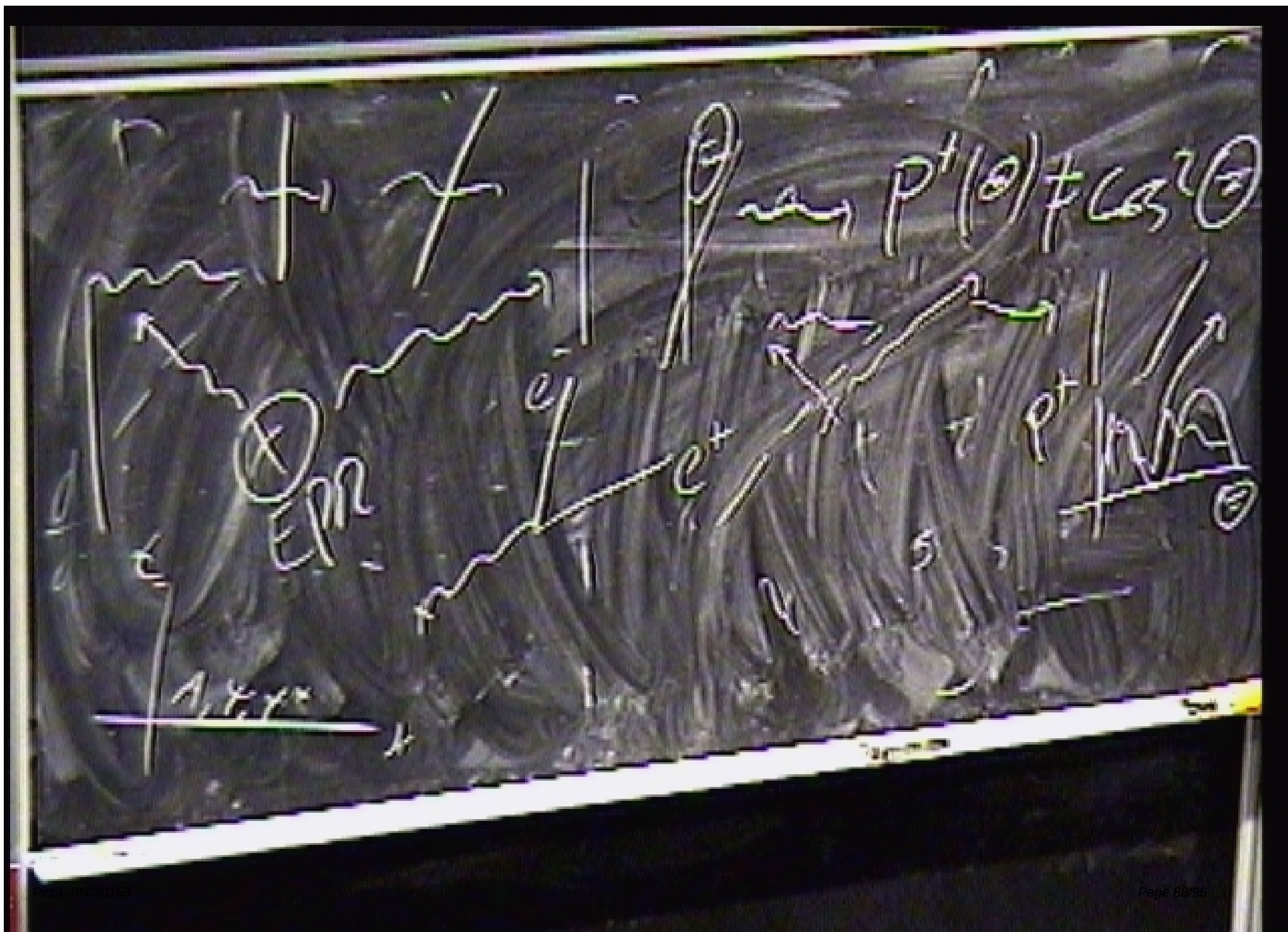
6.4 keV

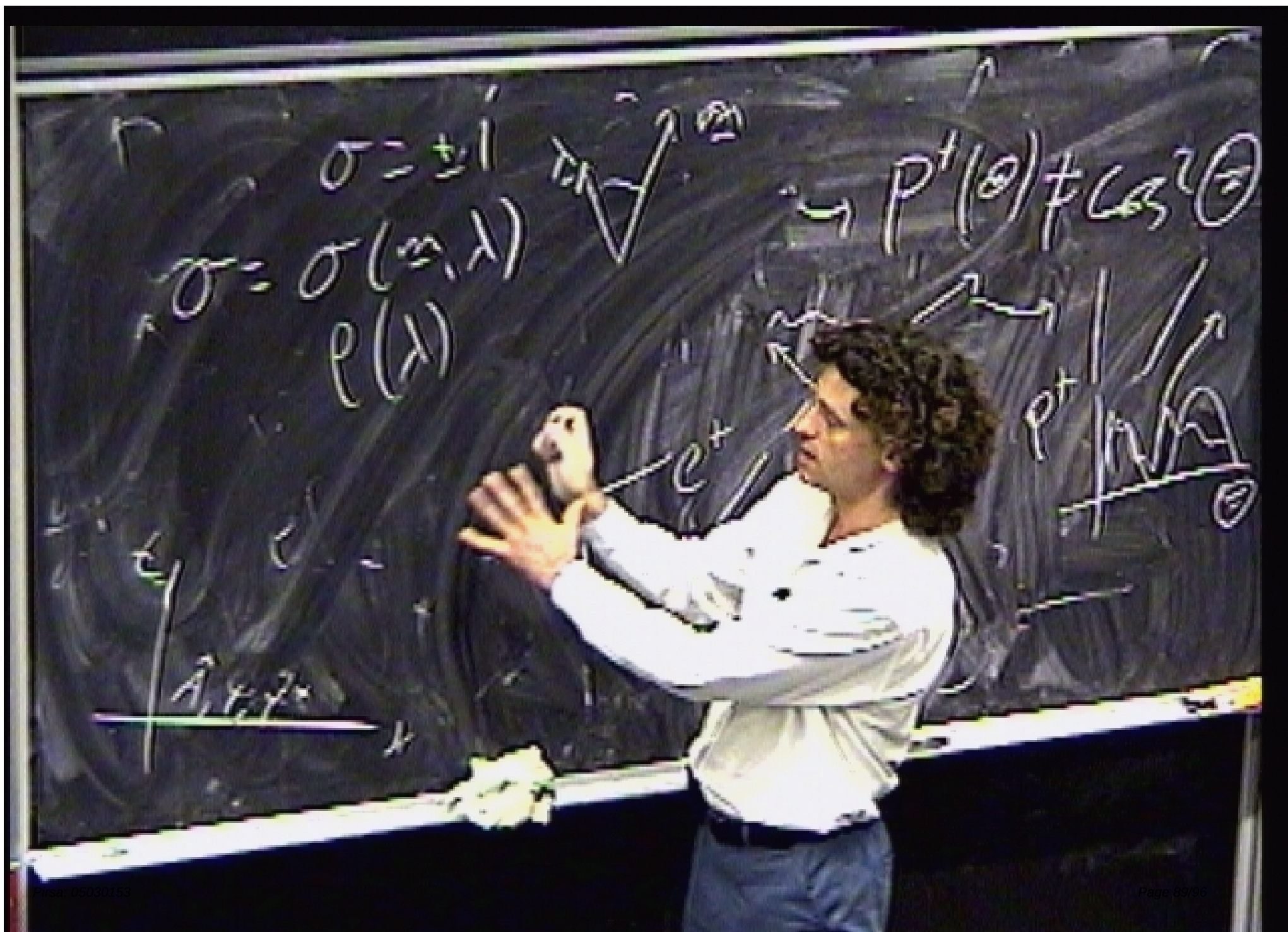
Flux

$h(\nu) \ll r$









$$\sigma = \pm i$$

$$\sigma = \sigma(m, \lambda)$$

$$p(\lambda)$$

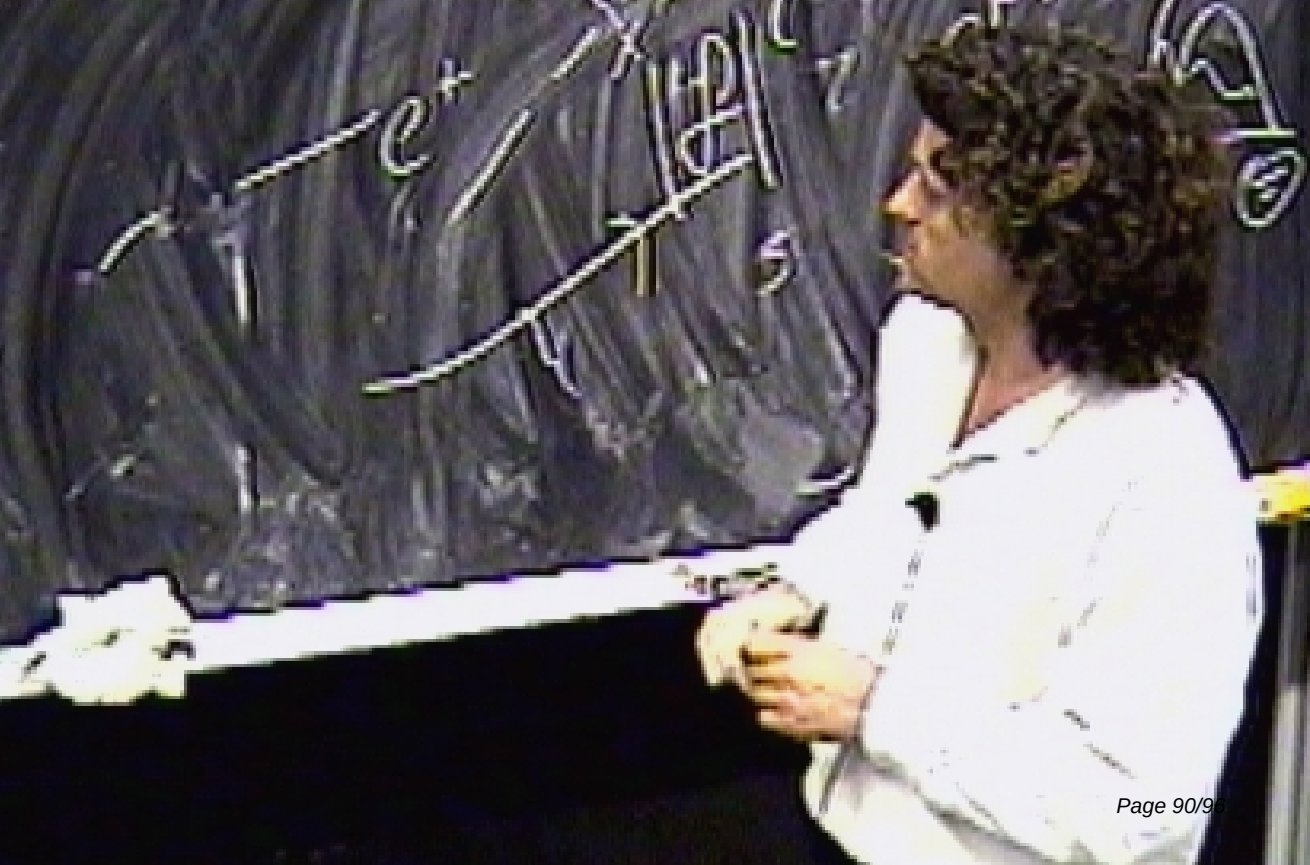


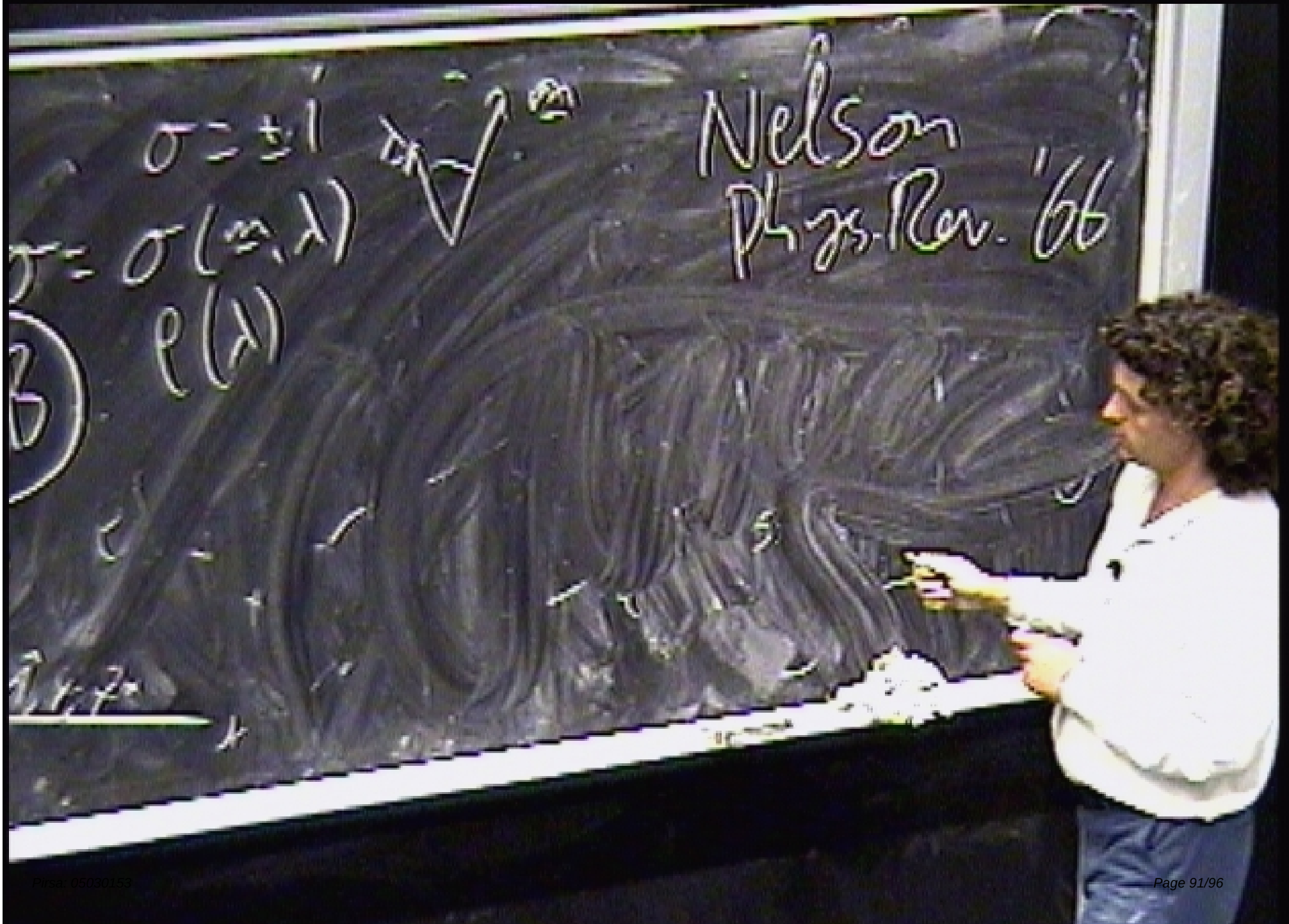
$$P'(\theta) \neq \mathcal{L}^2(\mathbb{R})$$

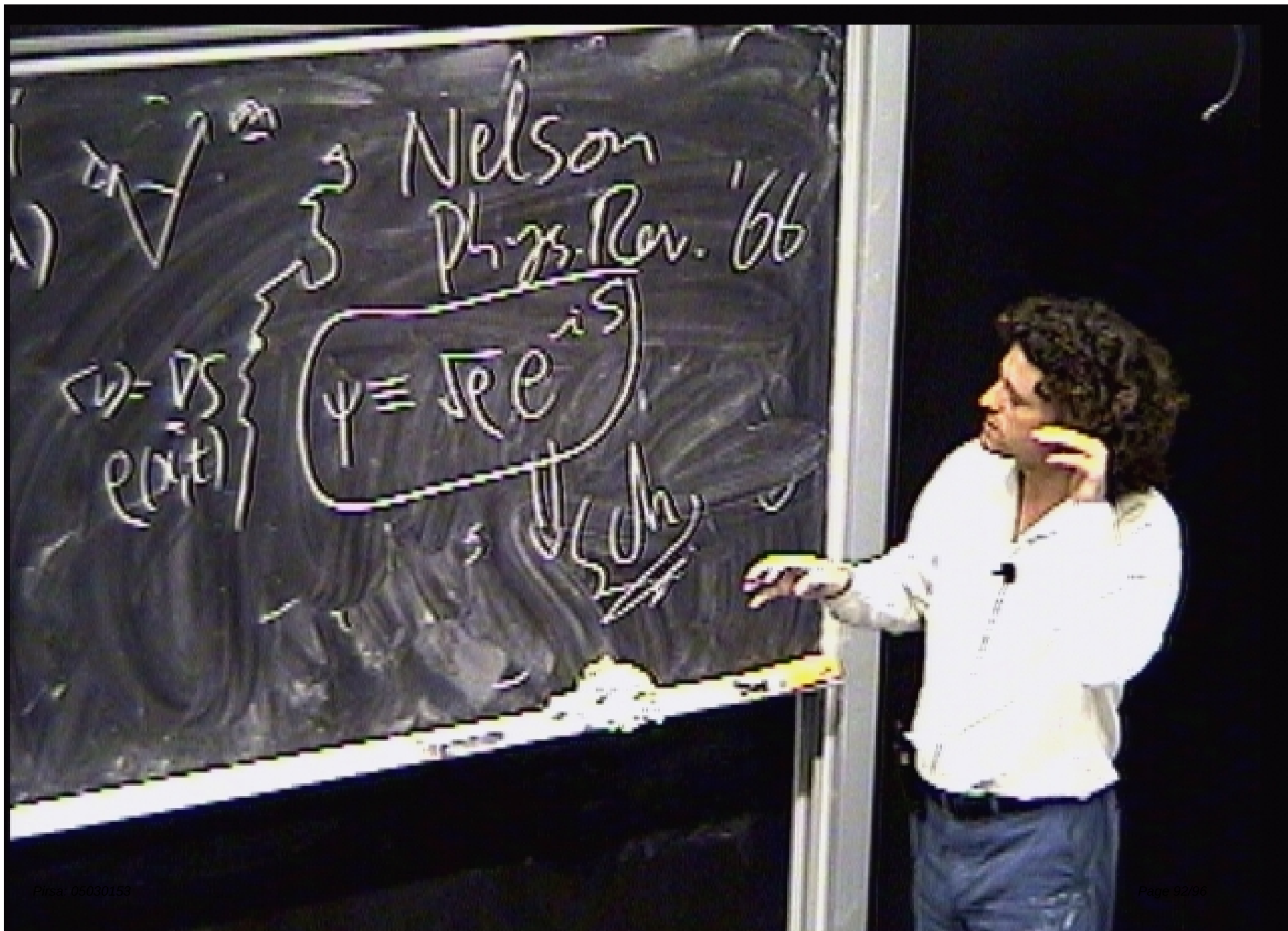
deBB

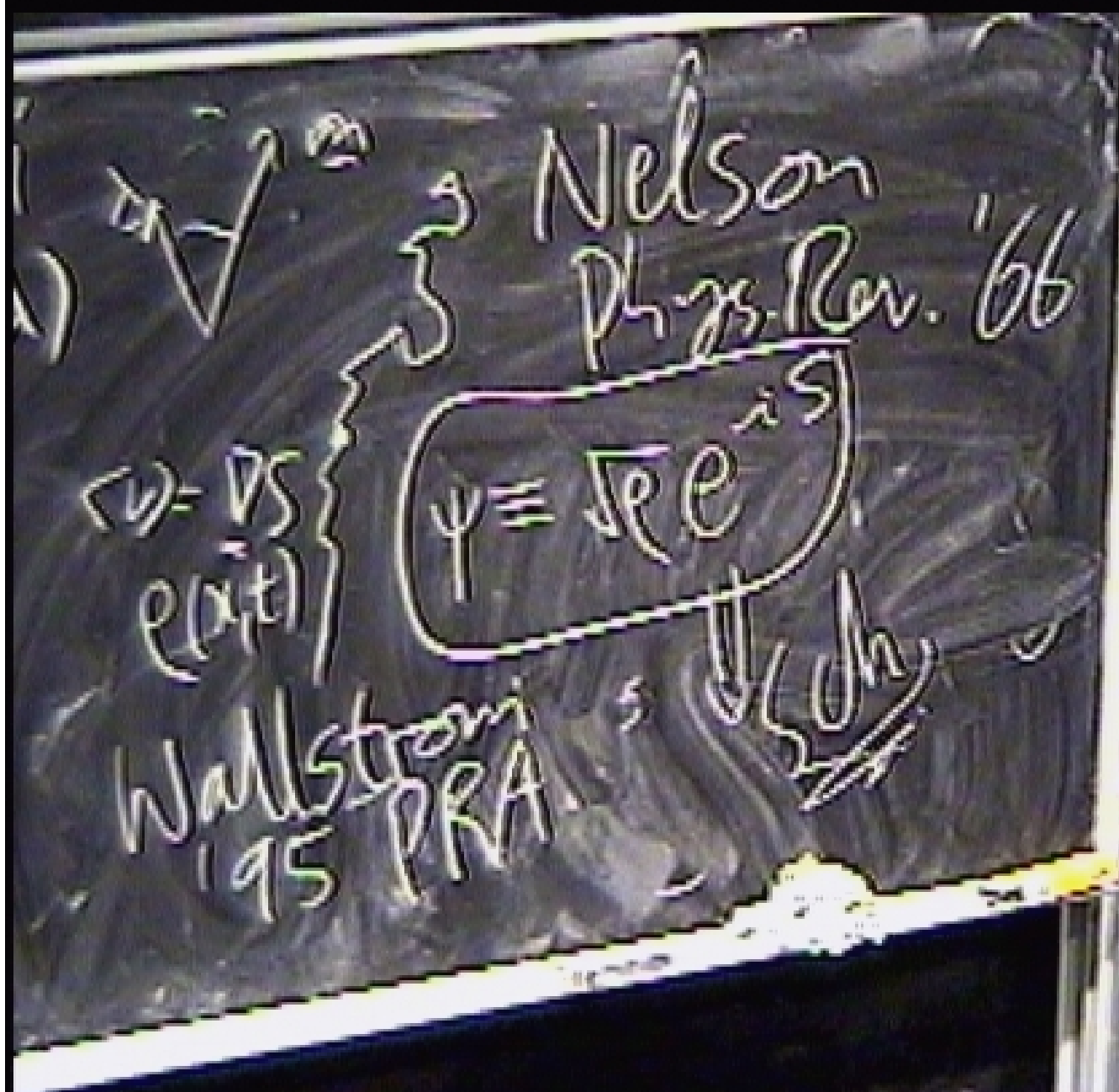


$\hat{A}, \hat{B}, \hat{C}$









$\psi = \psi(x,t)$ } Nelson
 Phys. Rev. '65
 $\psi = \sqrt{\rho} e^{iS}$
 Wallstrom 195 PRA
 $\downarrow$ ψ

