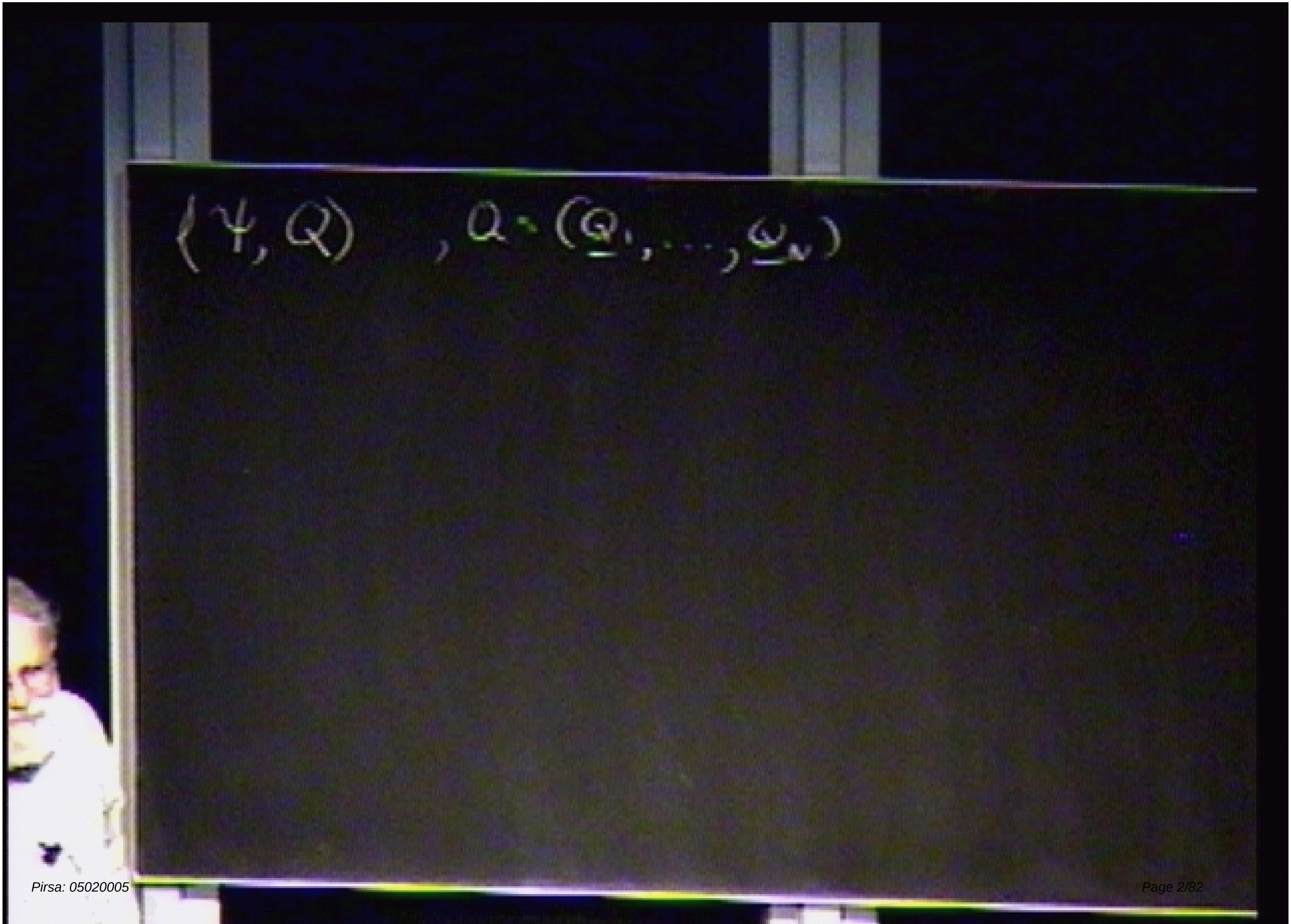
Title: Interpretation of Quantum Theory: Lecture 10

Date: Feb 03, 2005 02:15 PM

URL: http://pirsa.org/05020005

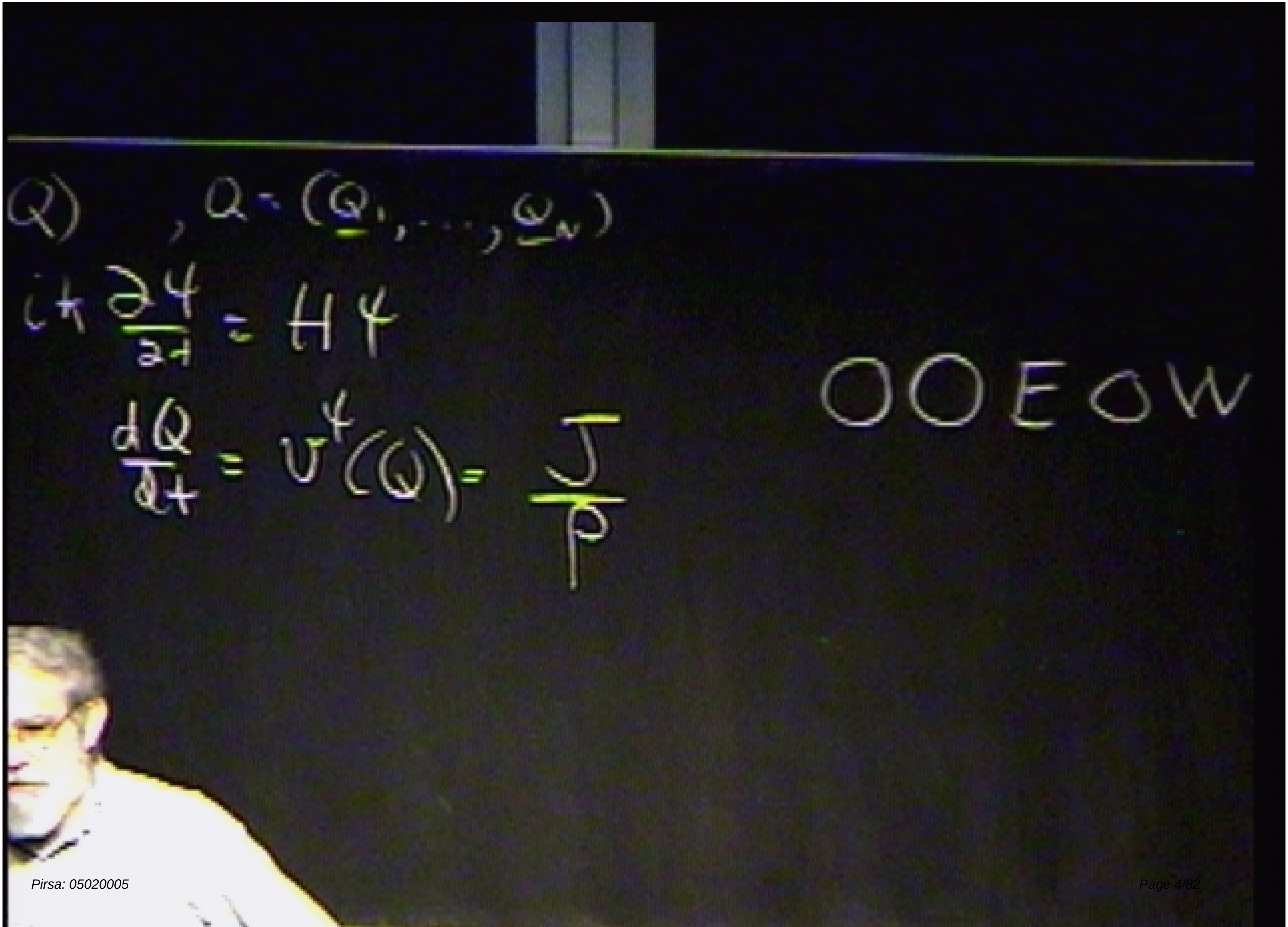
Abstract:


(ψ, Q) , $Q = (\underline{Q}_1, \ldots, \underline{Q}_N)$

$$(\psi, Q) \quad , Q = (\underline{Q}_1, \ldots, \underline{Q}_N)$$

$$i\hbar \frac{\partial \psi}{\partial t} = H\psi$$

$$\frac{dQ}{dt} = v^{\psi}$$


Q) , $Q = (Q_1, \ldots, Q_N)$
$i\hbar \frac{\partial \psi}{\partial t} = H\psi$
$\frac{dQ}{dt} = v^{\psi}(Q) = \frac{J}{\rho}$
OOEOW

$$(\psi, Q) \quad , Q = (Q_1, \ldots, Q_N)$$

$$i\hbar \frac{\partial \psi}{\partial t} = H\psi$$

$$\frac{dQ}{dt} = v^{\psi}(Q) = \frac{J}{\rho}$$

OOE

$$\frac{\partial \rho}{\partial t} + \mathrm{div}(J) = 0$$

$, Q = (Q_1, \ldots, Q_N)$

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OOEOW

BM ~ OQT

$, Q = (\underline{Q}_1, \ldots, \underline{Q}_N)$

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$$\ldots \mathrm{div}(J) = 0$$

OOEOW

BM ~ OQT

- ops as obs
- collapse of the wf

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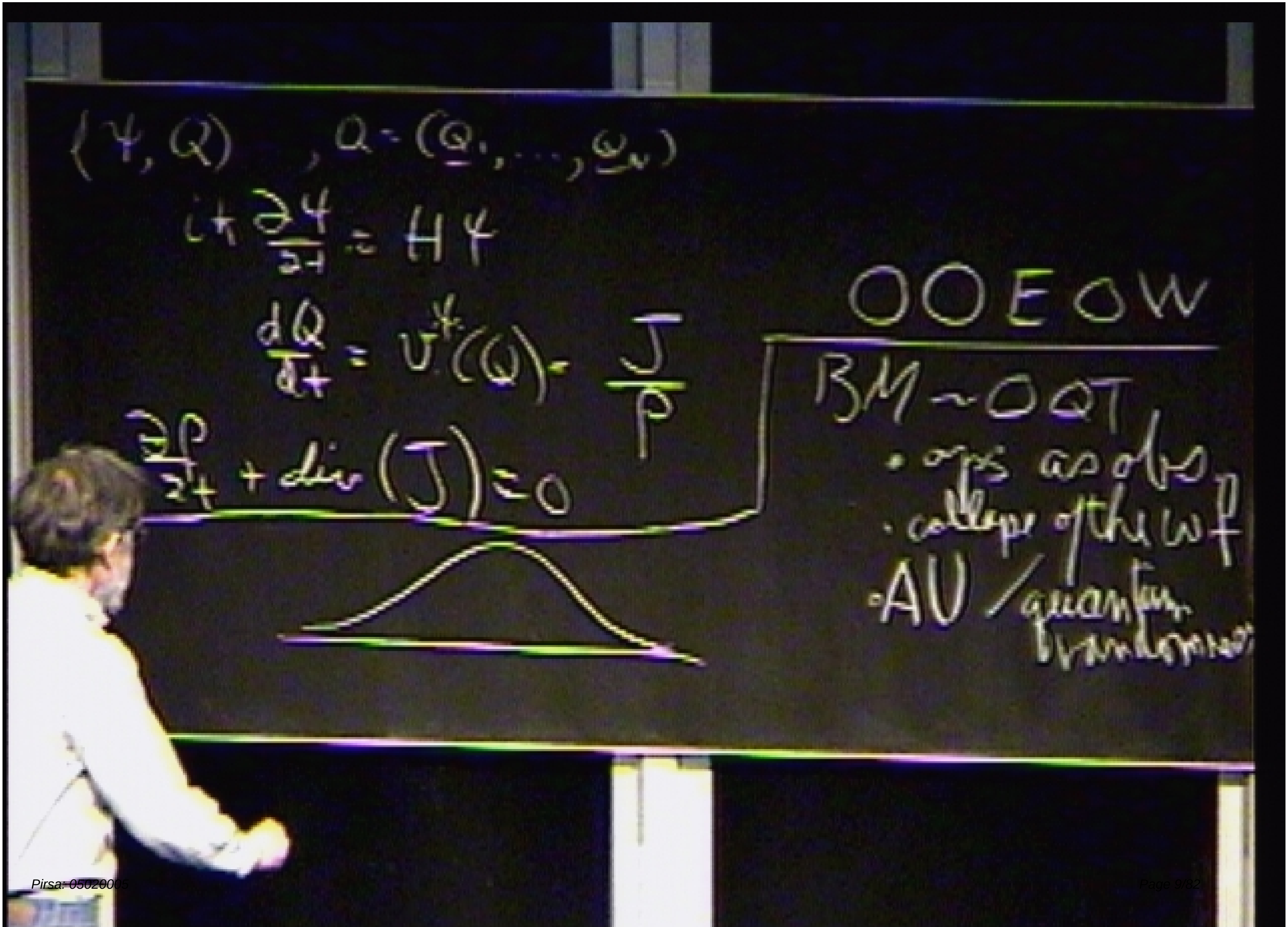
OOEOW

BM ~ OQT
- ops as obs
- collapse of the wf
- AU / quantum randomness


(ψ, Q) , Q = (Q1, ..., QN)
iħ ∂ψ/∂t = Hψ
dQ/dt = v^ψ(Q) = J/ρ
∂ρ/∂t + div (J) = 0
OOEOW
BM ~ OQT
• ops as obs
• collapse of the wf
• AU / quantum randomness

$$\rho = |\psi(q)|^2$$

$$\rho = |\psi(q)|^2 \qquad \psi \longrightarrow \rho^{\psi}$$

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$$(\rho^{\psi_t}) \qquad (\rho^{\psi})$$

$$\rho = |\psi(q)|^2 \qquad \psi \longrightarrow \rho^{\psi}$$

$$\left(\rho^{\psi_t}\right) = \left(\rho^{\psi}\right)_t$$

$\underline{\rho = |\psi(q)|^2}$ $\quad \psi \longrightarrow \rho^\psi$ is equivariant

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If Q_t is $|\psi_t(q)|^2$ distributed at one time t

the – ______ any time

$\rho = |\psi(q)|^2$ $\quad \psi \longrightarrow \rho^\psi$ is equivariant

$$\left(\rho^{\psi_t}\right) = \left(\rho^\psi\right)_t$$

If Q_t is $|\psi_t(q)|^2$ distributed at one time t

then ________ any time

$\frac{dQ}{dt} = v$ $\quad \frac{\partial \rho}{\partial t} + \operatorname{div}(\rho v) = 0$

$\rho = |\psi(q)|^2$ $\quad \psi \longrightarrow \rho^{\psi}$ is equivariant

$$(\rho^{\psi_t}) = (\rho^{\psi})_t$$

If Q_t is $|\psi_t(q)|^2$ distributed at one time t

then ______ any time

$\frac{dQ}{dt} = v$ $\qquad \frac{\partial \rho_t}{\partial t} + \mathrm{div}(\rho_t v_t) = 0$

$\rho_t = |\psi_t|^2 \qquad v = \frac{J}{\rho}$

system × apparatus

$$\Psi$$

system $\times$ apparatus

$t = 0 \qquad \Psi, Q \qquad \text{dist } Q = |\Psi(q)|^2$

system × apparatus

$t = 0 \qquad \Psi, \; Q \qquad \text{dist } Q = |\Psi(q)|^2$

$t = T \qquad \Psi_T, \; Q_T \qquad \text{dist } Q_T = |\Psi_T(q)|^2$

system × apparatus

$t=0 \quad \Psi, Q \qquad \text{dist } Q = |\Psi(q)|^2$

$t=T \quad \Psi_T, Q_T \qquad \text{dist } Q_T = |\Psi_T(q)|^2$

BM ~ OQT modulo $\underline{\underline{NI = C}}$

system × apparatus

$t=0$ Ψ, Q dist $Q \sim |\Psi(q)|^2$

$t=T$ Ψ_T, Q_T dist $Q_T = |\Psi_T(q)|^2$

BM ~ OQT modulo $|\Psi|^2 = \rho$ quantum equilibrium

the problem of QE

QEH $\rho = |\Psi|^2$

system $\times$ apparatus

$t=0$ $\quad \Psi, Q$ $\quad$ dist $Q = |\Psi(q)|^2$

$t=T$ $\quad \Psi_T, Q_T$ $\quad$ dist $Q_T = |\Psi_T(q)|^2$

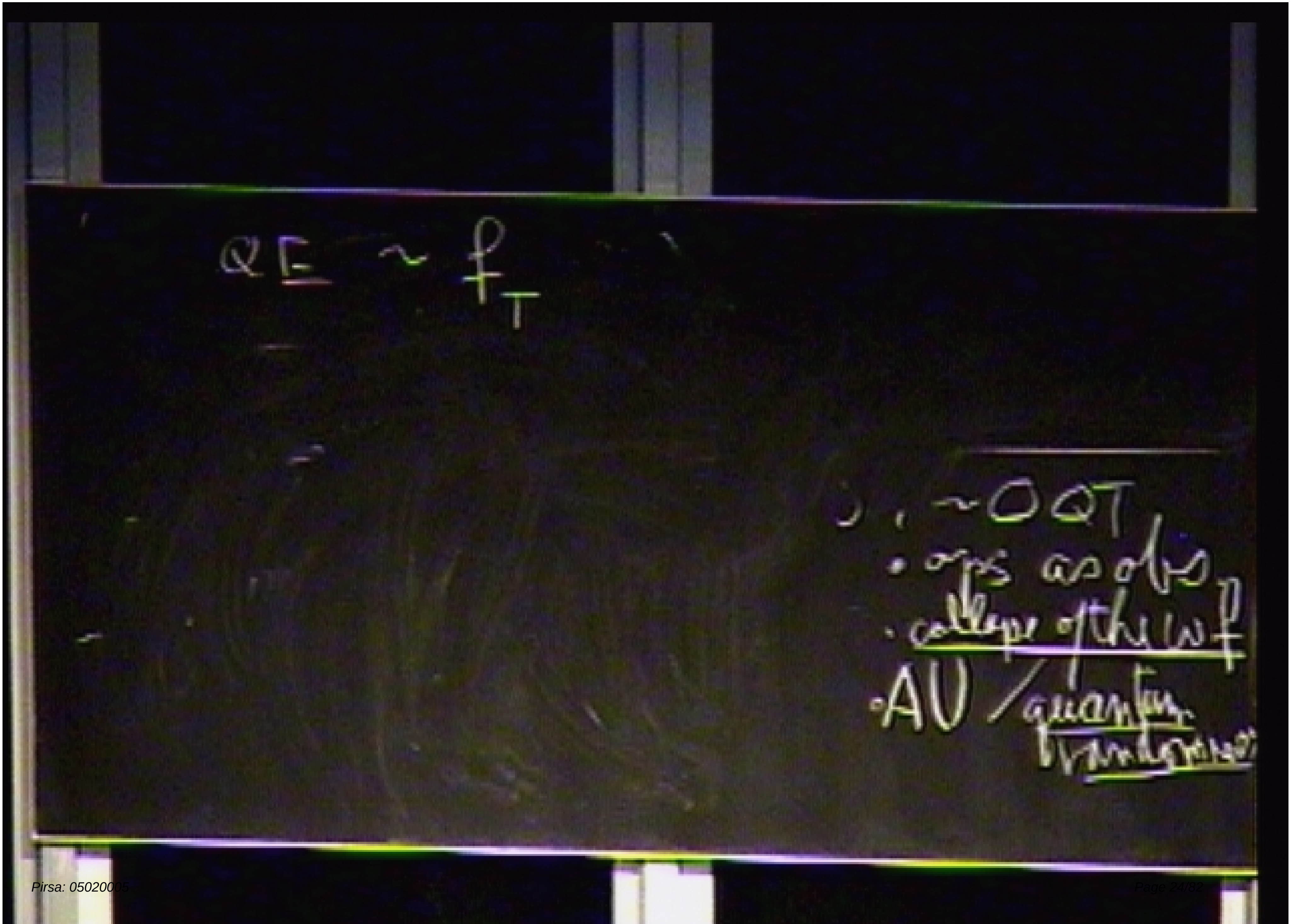
BM ~ OQT modulo $|\Psi|^2 = \rho$ quantum equilibrium

the problem of QE

QEH $\quad \rho = |\Psi|^2$

: what does it mean?

: why should it be true?


QE ~ f_T
~ OQT
• ops as obs
• collapse of the wf
• AU / quantum

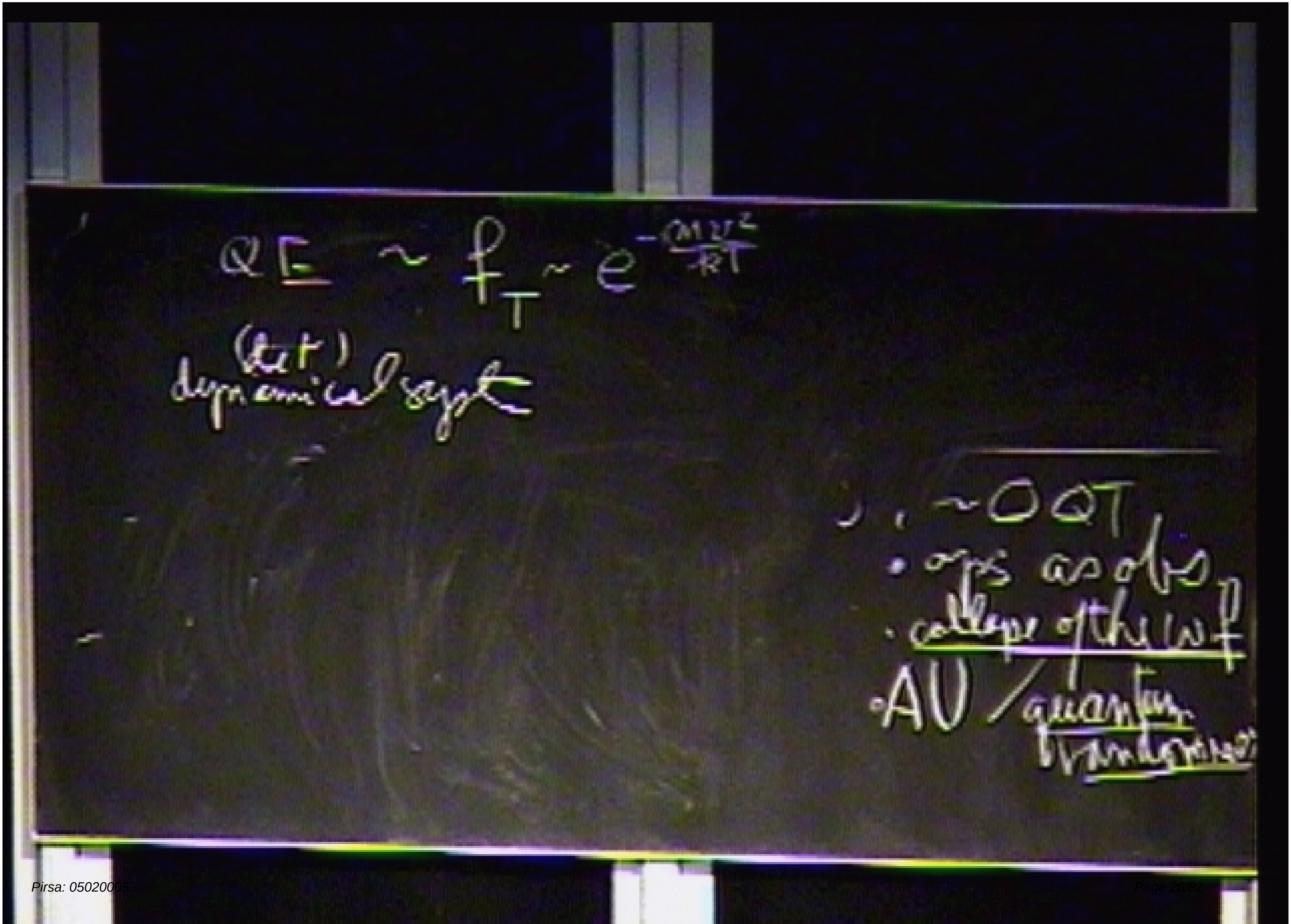
$$QE \sim f_T \sim e^{-\frac{cmv^2}{kT}}$$

~ OQT

• ops as obs

• collapse of the wf

• AU / quantum transformations


QE ~ f_T ~ e^{-mv²/kT}
dynamical syst
~ OQT
• ops as obs
• collapse of the w.f
• AU / quantum

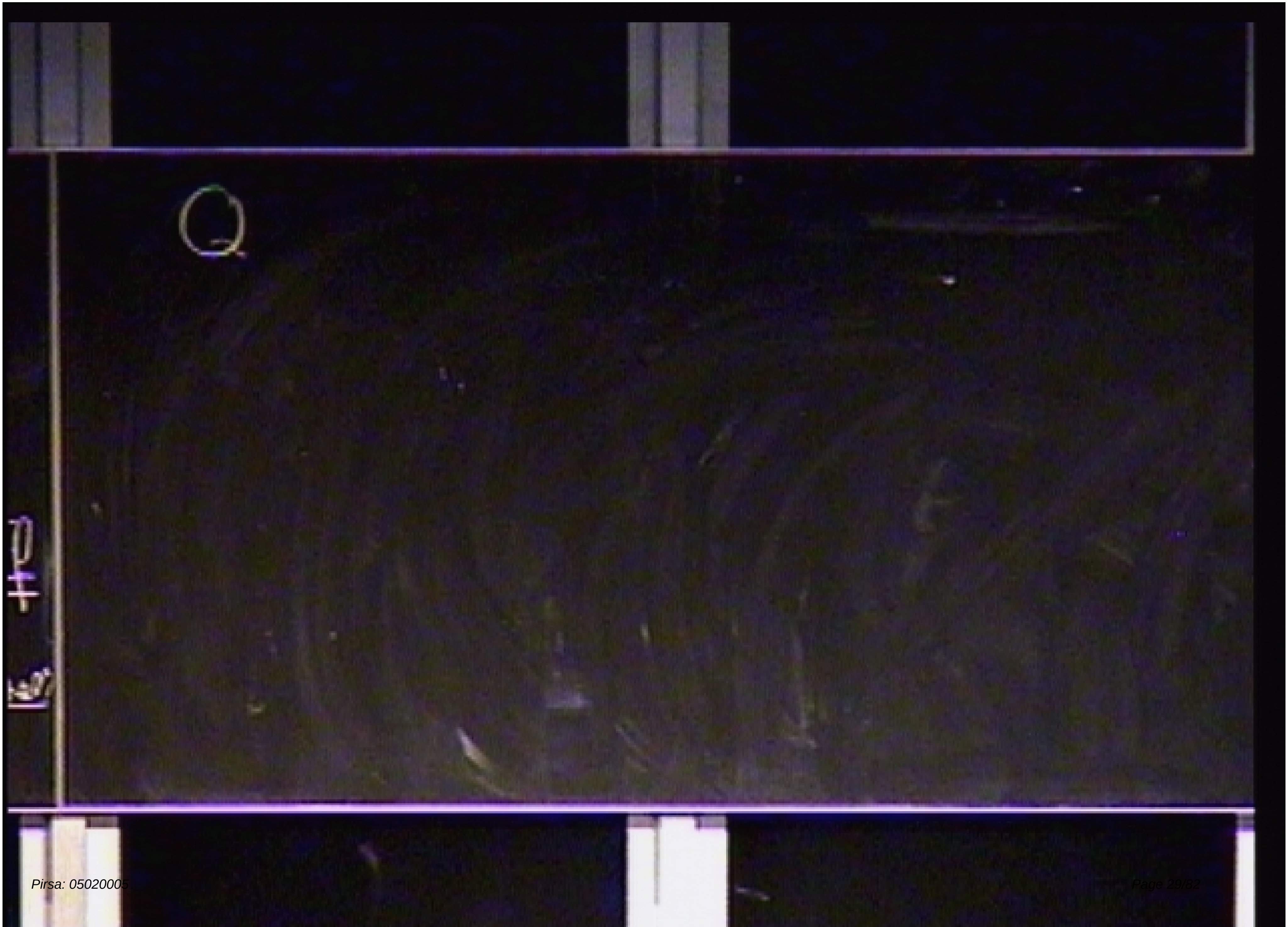
$QE \sim f_T \sim e^{-\frac{(M)v^2}{kT}}$

(det)
dynamical syst $\longrightarrow$ random behavior
governed by
i.e. (a) Stationary Prob.

: ~OQT
: ops as obs
: collapse of the w.f.

AU / quantum randomness


Q


Q

$$Q = (X, Y)$$

subsystem env.

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subsystem env.

$q = (x, y)$

$$\Psi(q), X, Y$$

$Q = (X, Y)$

subsystem   env.

$q = (x, y)$

$\Psi(q),\ X,\ y$

$\psi(x) = \Psi(x, Y)$

$Q = (X, Y)$

subsystem env.

$q = (x, y)$

$$\Psi(q), X, Y$$

$$\frac{dX}{dt} = v^{\Psi}(X)$$

conditional wave function $\psi(x) = \Psi(x, Y)$

$$Q = (X, Y)$$

subsystem env.

$$q = (x, y)$$

$$\frac{\Psi(q), X, Y}{\frac{dX}{dt} = v^{\Psi}(X) \quad [\text{HW}]}$$

conditional wave function $\psi(x) = \Psi(x, Y)$

$Q = (X, Y)$

subsystem — env.

$q = (x, y)$

$\Psi(q), X, Y$

conditional wave function $\psi(x) = \Psi(x, Y)$

$\frac{dX}{dt} = v^{\psi}(X)$

[HW]

Q's

Ψ_0

$\mathbb{P}$

$Q = (X, Y)$

subsystem   env.

$q = (x, y)$

$\Psi(q), X, Y$

conditional wave function $\psi(x) = \Psi(x, Y)$

$\frac{dX}{dt} = v^{\psi}(X)$

[HW]

Ψ Q's Ψ_0

$\mathbb{P}(X_t \in dx \mid Y_t)$

$Q = (X, Y)$

subsystem $\quad$ env.

$q = (x, y)$

$\Psi(q), X, Y$

conditional wave function $\quad \psi(x) = \Psi(x, Y)$

$\frac{dX}{dt} = v^{\psi}(X)$

$\mathbb{P}(X_t \in dx \mid Y_t) = [HW] = |\psi_t(x)|^2 dx$

Ψ's

Ψ_0

$\psi_t(x) = \Psi_t$

BM ~ OQT modulo $|\Psi| = c$

the problem of QE

QEH

$\rho = |\psi|^2$

: what does it mean?

: why should it be true?

$$\psi_t(x) = \Psi_t(x, Y_t)$$

SE

collapse

BM ~ ÖQT modulo

the problem of QE

QEH

$\rho = |\psi|^2$

what does it mean?

why should it be true?

$$\psi_t(x) = \Psi_t(x, Y_t) \quad \begin{cases} \text{SE} \\ \underline{\text{collapse}} \end{cases}$$

$$\psi(x)\,\Phi_0(y)$$

$$\psi_t(x) = \Psi_t(x, Y_t)$$

SE

collapse

$$\psi = \sum c_\alpha \psi_\alpha$$

$$\Psi_0 = \psi(x)\,\Phi_0(y)$$

$$\psi_t(x) = \Psi_t(x, Y_t)$$

SE

collapse

$$\psi = \sum c_\alpha \psi_\alpha$$

$$\Psi_0 = \psi(x)\,\Phi_0(y) \longrightarrow \sum c_\alpha \psi_\alpha(x)\,\Phi_\alpha(y)$$

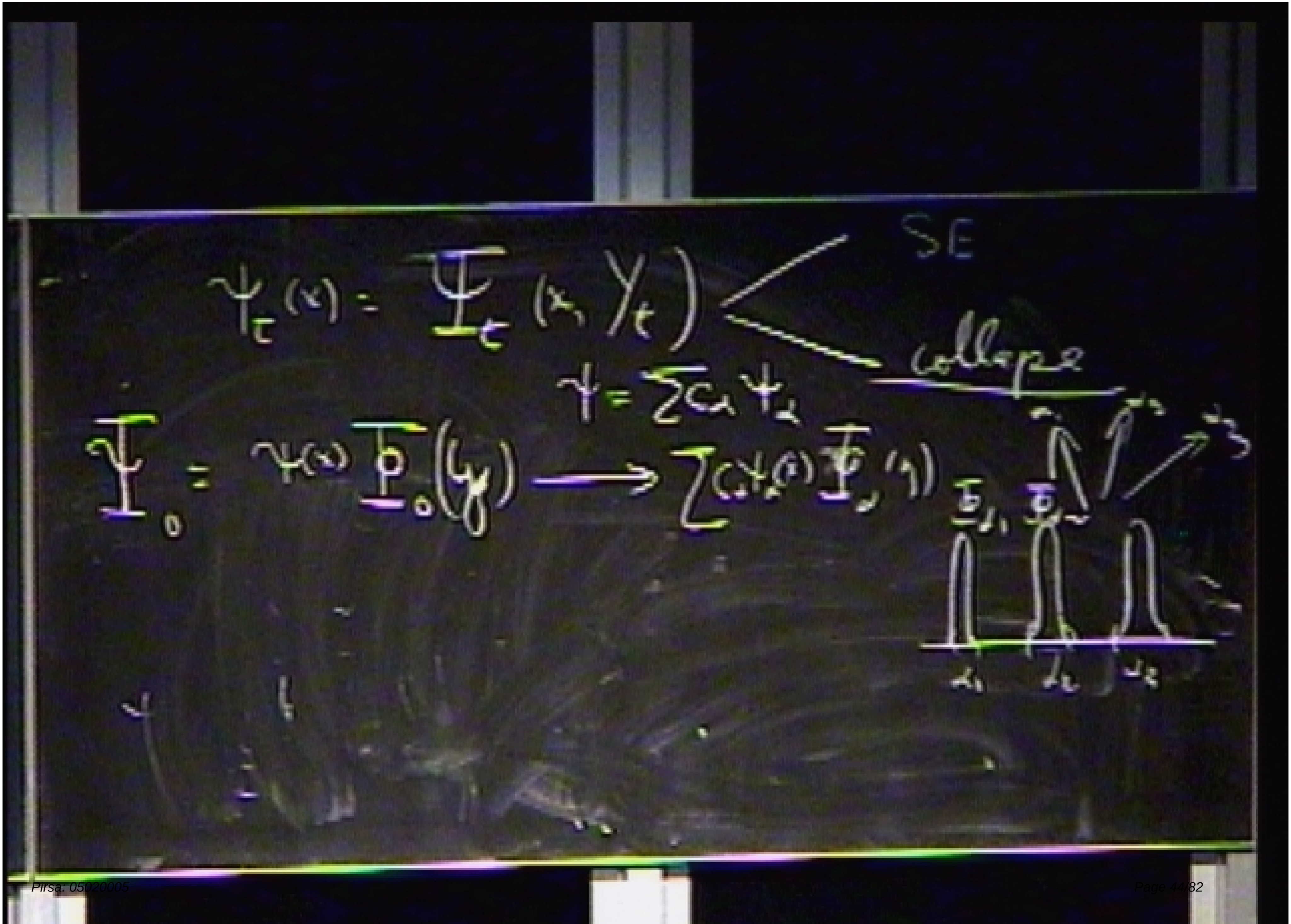
$$\psi_t(x) = \Psi_t(x, Y_t)$$

SE

collapse

$$\psi = \sum c_\alpha \psi_\alpha$$

$$\Psi_0 = \psi(x)\,\Phi_0(y) \longrightarrow \sum c_\alpha \psi_\alpha(x)\,\Phi_\alpha(y)$$

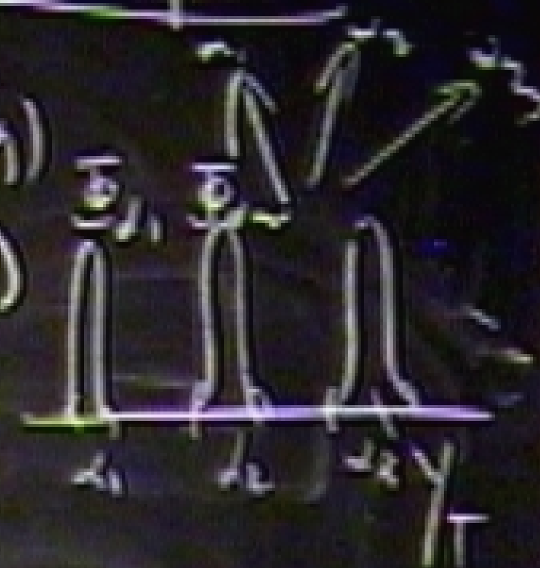

$\psi_t(x) = \Psi_t(x, Y_t)$
SE
collapse
$\psi = \sum c_\alpha \psi_\alpha$
$\Psi_0 = \psi(x)\,\Phi_0(y) \longrightarrow \sum c_\alpha \psi_\alpha(x)\,\Phi_\alpha(y)$
α_1
α_2
α_3

$$\psi_t(x) = \Psi_t(x, Y_t) \;<\; \begin{matrix} \text{SE} \\ \text{collapse} \end{matrix}$$

$$\psi = \sum c_\alpha \psi_\alpha$$

$$\Psi_0 = \psi(x)\,\Phi_0(y) \longrightarrow \underbrace{\sum c_\alpha \psi_\alpha(x)\,\Phi_\alpha(y)}_{\Psi_T(x,y)}$$

ψ attra, $\psi_T = \Psi_T(x, Y_t)$



$$\psi_t(x) = \Psi_t(x, Y_t)$$

SE

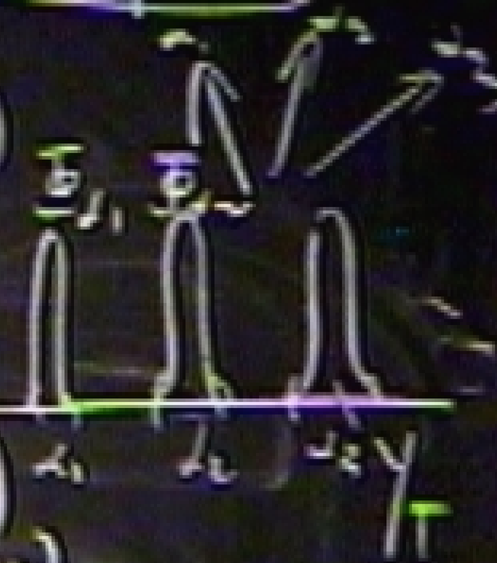
collapse

$$\psi = \sum c_\alpha \psi_\alpha$$

$$\Psi_0 = \psi(x)\,\Phi_0(y) \longrightarrow \underbrace{\sum c_\alpha \psi_\alpha(x)\,\Phi_\alpha(y)}_{\Psi_T(x,y)}$$

ψ attra, $\psi_T = \Psi_T(x, Y_T)$

$$= \sum c_\alpha \psi_\alpha(x)\,\Phi_\alpha(Y_T) \sim \psi_{\alpha_3}(x)$$



$$\psi_t(x) = \Psi_t(x, Y_t)$$

SE

collapse

$$\psi = \sum c_\alpha \psi_\alpha$$

$$\Psi_0 = \psi(x)\,\Phi_0(y) \longrightarrow \underbrace{\sum c_\alpha \psi_\alpha(x)\,\Phi_\alpha(y)}_{\Psi_T(x,y)}$$

ψ attrac, $\psi_T = \Psi_T(x, Y_T)$

$\psi \longrightarrow \psi_\alpha$ with prob $|c_\alpha|^2$ $\quad = \sum c_\alpha \psi_\alpha(x)\,\Phi(Y_T) \sim \psi_{\alpha_3}(x)$

[HW]

1) Nonlocality and HV's.
2) Properties and quant. observables

a. $\hat{v}(Q)$

"Stationary prob."

• ops as obs
• collapse of the w.f.
• AU / quantum transitions

1) Nonlocality and HV's
2) Properties and quantum observables
3) (ψ, X), $(\psi, ?)$

a. $\psi(q)$

Stationary prob.

- ops as obs
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transformations

1) Nonlocality and HV's.
2) Properties and quant. observables;
3) (ψ, X), $(\psi, ?)$

Bell NL arg. 1) EPRB

1) Nonlocality and HV's.
2) Properties and quantum observables
3) (ψ, X), $(\psi, ?)$

Bell NL arg.

1) EPRB: "QM" + locality $\Rightarrow$ HV
2) Bell: "QM"

1) Nonlocality and HV's.
2) Properties and quantum observables
3) (ψ, X), $(\psi, ?)$

Bell NL arg:

1) EPRB: "QM" + locality $\Rightarrow$ HV
2) Bell: "QM" $\Rightarrow$ no HV

1) Nonlocality and HV's.
2) Properties and quantum observables
3) (ψ, X), $(\psi, ?)$

Bell NL arg.

1) EPRB: "QM" + locality ⇒ HV

2) Bell: "QM" ⇒ no HV

"QM" ⇒ NL

Nature is NL

1) Nonlocality and HV's.
2) Properties and quantum observables:
3) (ψ, X), $(\psi, ?)$

Bell NL arg:

"QM" + L ⇒ C

"QM" ⇒ not C

1) EPRB: "QM" + locality ⇒ HV

2) Bell: "QM" ⇒ no HV

"QM" ⇒ NL

Nature is NL

What properties does a Bohmian particle/system have?

What properties does a Bohmian particle/system have?

Do Bohmian particles have only positions?

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Do Bohmian particles have only positions?

Momentum

Spin

Observables

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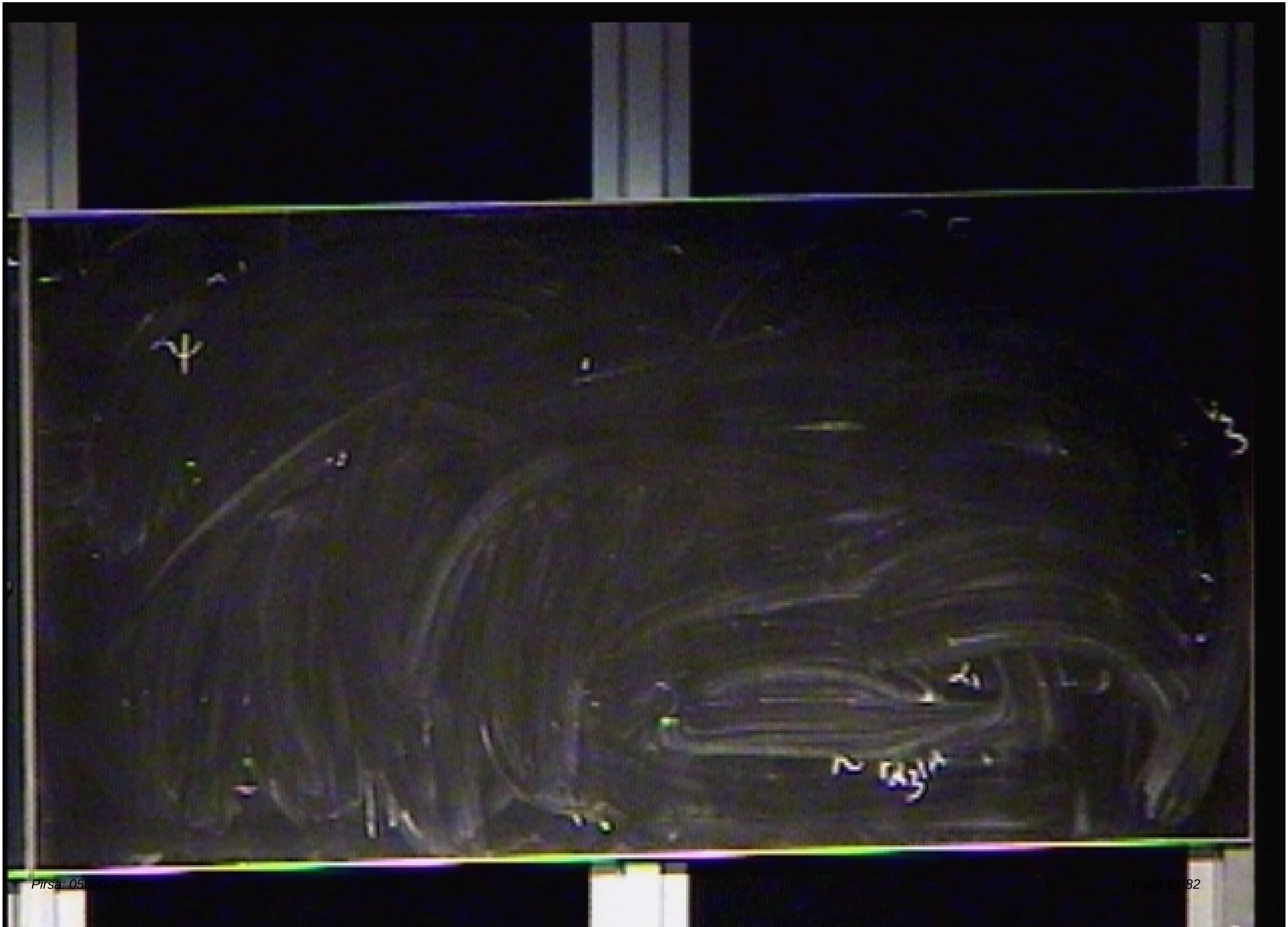


$\psi \mapsto \psi \otimes \mathbb{I}_0$

$\sim (a_3)^n$

$$\psi \mapsto \psi \otimes \underbrace{\Psi_0}_{\Psi_0} \longrightarrow \Psi_T = U_T \Psi_0$$

$$\psi \mapsto \underbrace{\psi \otimes \Phi_0}_{=\Psi_0} \longrightarrow \Psi_T = U_T \Psi_0$$

$$\psi \mapsto \underbrace{\psi \otimes \Phi_0}_{\Psi_0} \longrightarrow \Psi_T = U_T \Psi_0$$

$$Z = F(Q)$$

$$\psi \mapsto \underbrace{\psi \otimes \Phi_0}_{\Psi_0} \longrightarrow \Psi_T = U_T \Psi_0 \to \rho_{\Psi_T} = |\Psi_T|^2$$

$$\to \rho_{\Psi_0} \circ F^{-1}$$

$$\text{dist } Z = F(Q)$$

$$\psi \mapsto \psi \otimes \Phi_0 \longrightarrow \Psi_T = U_T \Psi_0 \longrightarrow \rho_{\Psi_T} = |\Psi_T|^2$$

$$\underbrace{\psi \otimes \Phi_0}_{\Psi_0} \qquad \longrightarrow \rho_{\Psi_T} \circ F^{-1}$$

$$\text{dist } Z = F(Q_T)$$

$$\psi \to \text{dist } Z$$

$= \mu_\psi$ quadratic

$\sim \text{rigid}$

$$\psi \mapsto \psi \otimes \Phi_0 \longrightarrow \Psi_T = U_T \Psi_0 \to \rho_{\Psi_T} = |\Psi_T|^2$$

$$\underbrace{\qquad}_{= \Psi_0} \qquad \to \rho_{\Psi} \circ F^{-1}$$

$$\text{dist } Z = F(Q_T)$$

$$\psi \to \underset{= \mu_\psi}{\text{dist}} \; Z$$

quadratic

A

$$(\psi, E(dz)\,\psi)$$

$$\psi \mapsto \underbrace{\psi \otimes \Phi_0}_{=\Psi_0} \longrightarrow \Psi_T = U_T \Psi_0 \rightarrow \rho_{\Psi_T} = |\Psi_T|^2$$

$$\rightarrow \rho_{\Psi_T} \circ F^{-1}$$

dist $Z = F(Q_T)$

$\psi \rightarrow$ dist Z $= \mu_\psi$

quadratic

A

$(\psi, E(dz)\psi)$

POVM

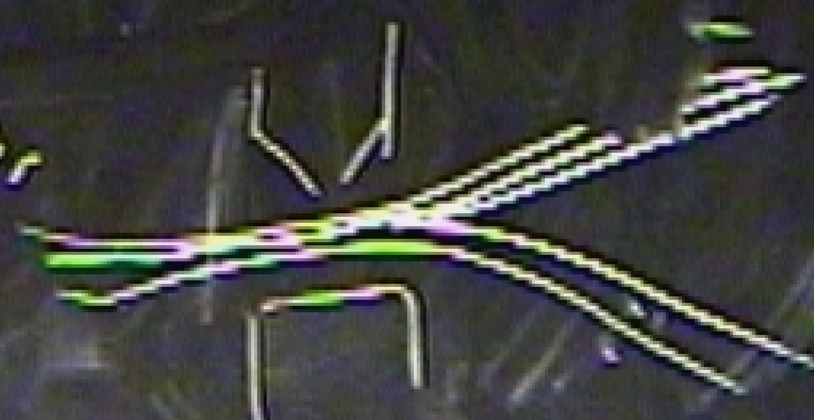
positive operator valued measure

No UV thms

No good - map

$A \mapsto$

Observables

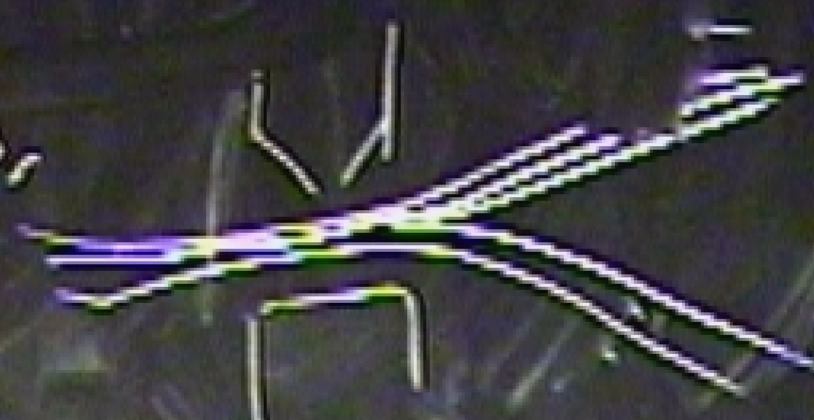


No HV thms

No good map

$$A \mapsto X_A(\omega)$$

Observables,



No HV thms

No good map

$$A \mapsto X_A(\omega)$$

$$\mathcal{E} \to \text{dist}^{n} \; A$$

No HV thms

No good map

$$A \mapsto X_A(\psi)$$

$$\mathcal{E} \to \mathrm{dist}\,\xi^{\psi} \to A$$

$$\mathcal{E}' \to \mathrm{dist}\,\xi^{\psi} \to A$$

No HV thms

No good map

$$A \mapsto X_A(\psi)$$

$$\mathcal{E} \to \text{dist } \xi^\psi \longrightarrow A$$

$$\mathcal{E}' \to \text{dist } \xi^\psi \longrightarrow A$$

$$Z \to \underline{A}$$

No HV thms

No good map

$\boxed{A \cancel{\mapsto} X_1(\cdot)}$

$\mathcal{E} \to \text{dist}\, \xi^{\psi} \longrightarrow A$

$\mathcal{E}' \to \text{dist}\, \xi^{\psi} \longrightarrow A$

$\mathcal{E} \to \underline{A}$

No HV thms

No good map

$\boxed{A \cancel{\mapsto} X_A(\,)}$

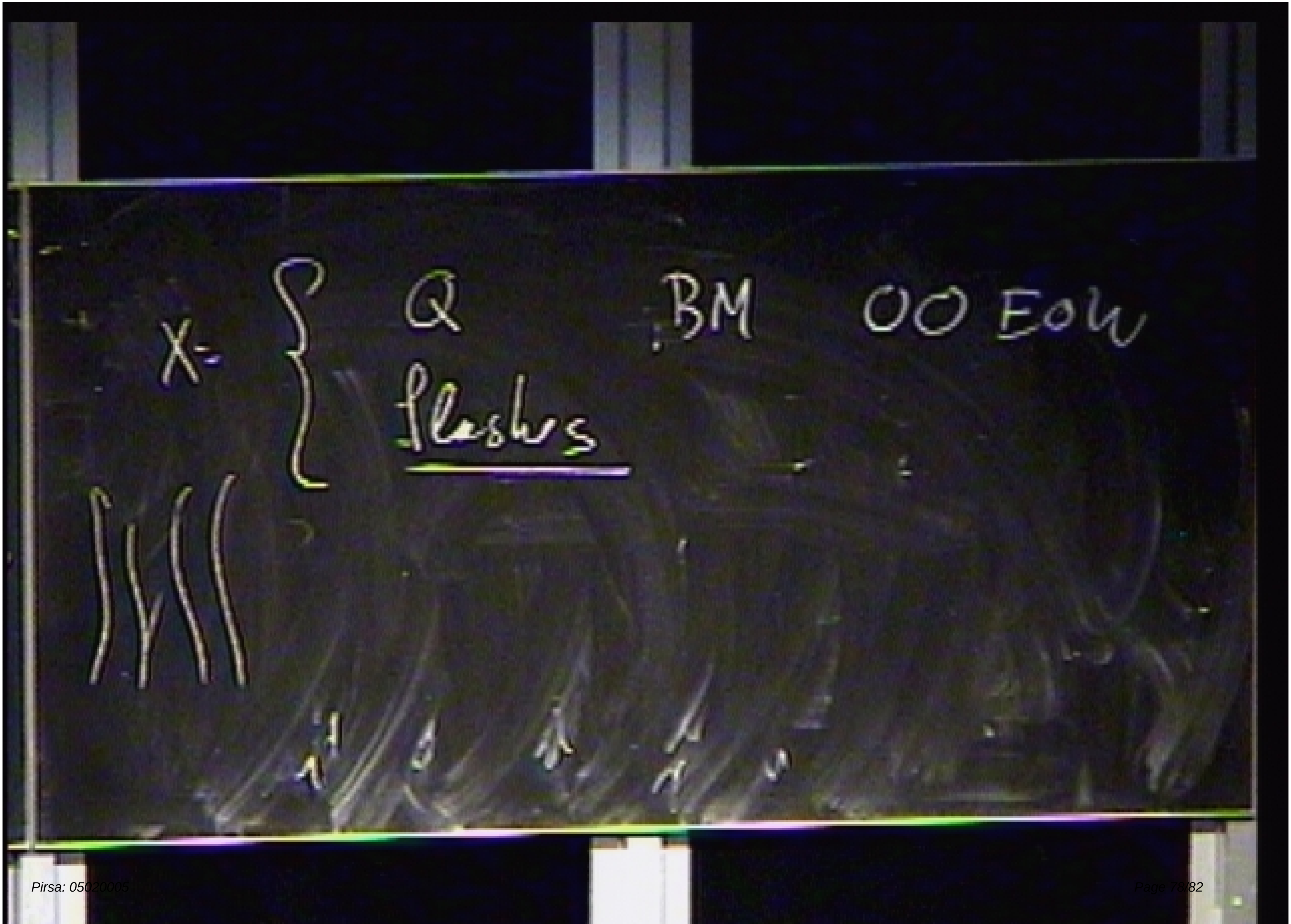
$\mathcal{E} \to A$

Naive realism: about properties

$\mathcal{E} \to \mathrm{dist}\, \xi^{k} \to A$

$\mathcal{E}' \to \mathrm{dist}\, \xi' \to A$

$X = \{$ Q BM OO EoW


X =
Q
flashes
BM
OO EoW

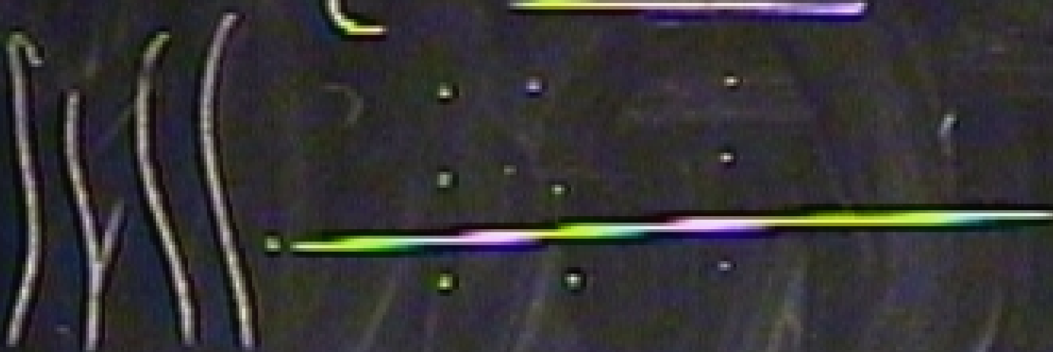
X: { Q BM OO EOW
flashes

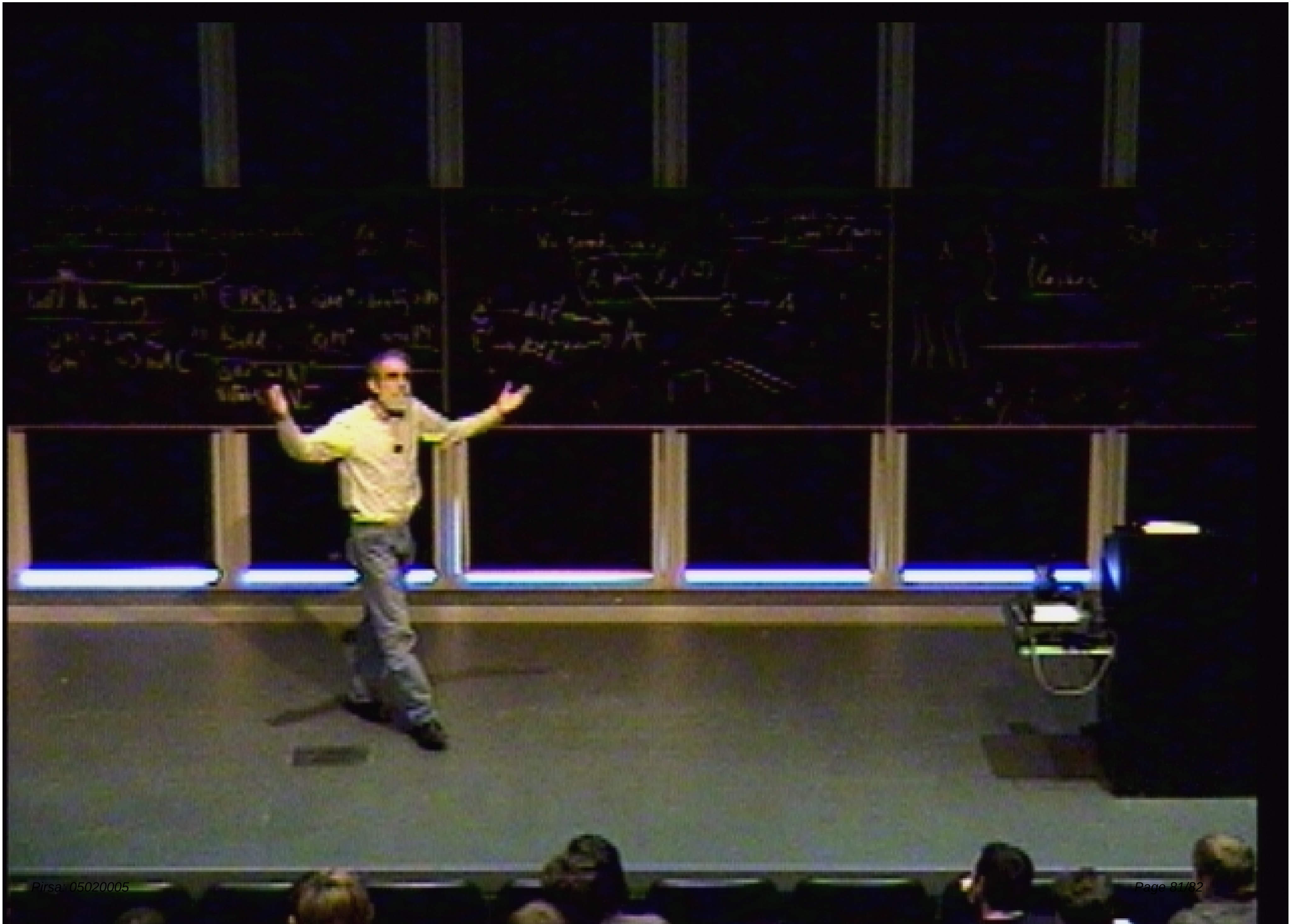
Tumulka

X: { Q · BM · OO EOW

Q flashes · suppress?

Tumulka





No HV thms

Naive Realism

No good map

$\psi(x) = \Psi(x, Y)$

$\boxed{A \mapsto \chi_A(\cdot)}$

$\mathcal{E} \to A$

$\mathcal{E} \to \text{dist } \xi^{\psi} \to A$

$\mathcal{E}' \to \text{dist } \xi^{\psi} \to A$