Title: Foundations of Quantum Mechanics #4

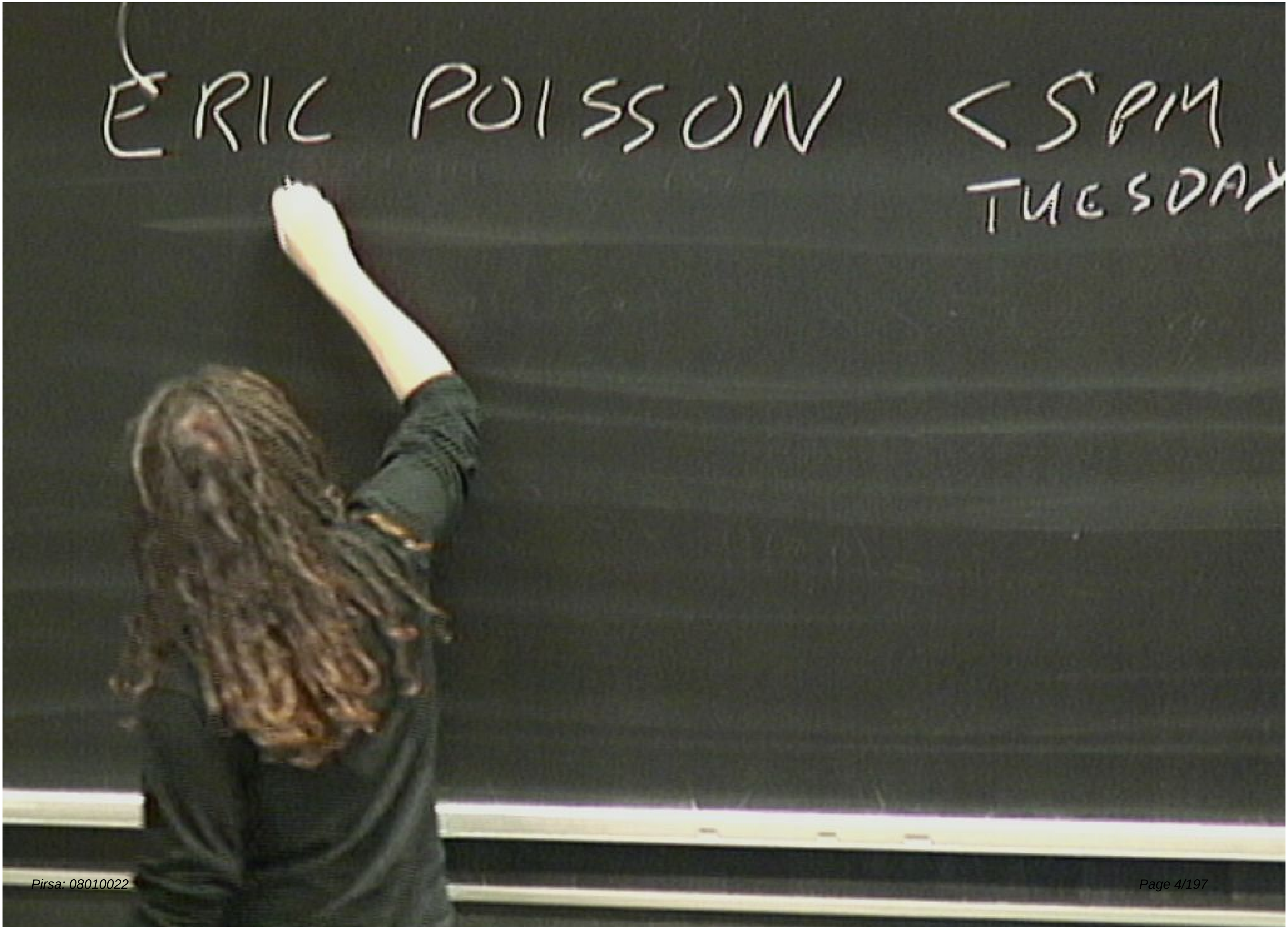
Date: Jan 17, 2008 06:30 PM

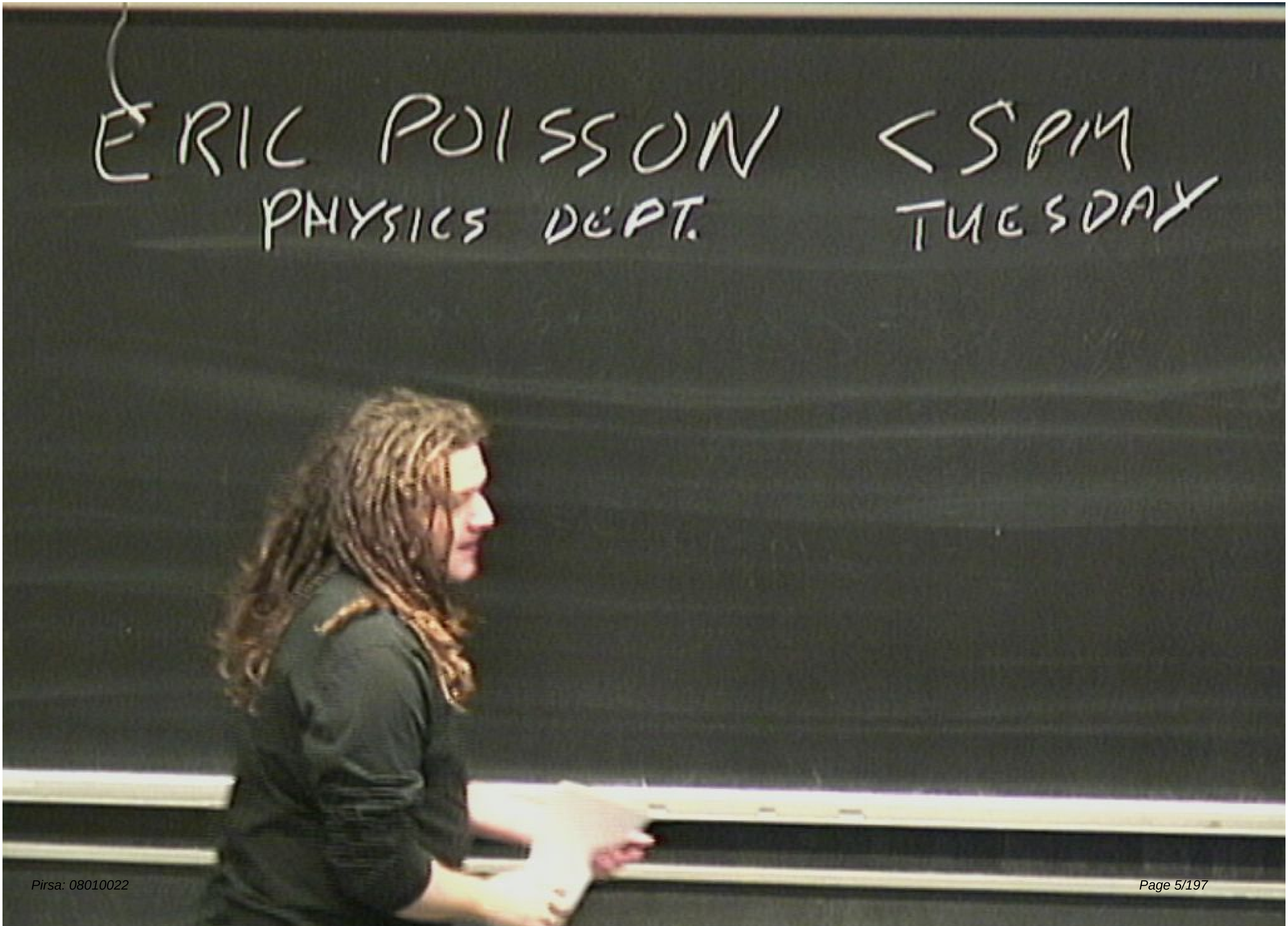
URL: http://pirsa.org/08010022

Abstract: Interferometry, measurement and interpretation. Beyond the quanta.

Interpretation, Reformulation or Replacement?

- Is it enough to attempt to just *interpret* quantum theory?
- Reformulate it?
- Replace it?


ERIC POISSON < 5PM
TUESDAY


ERIC POISSON < 5PM
PHYSICS DEPT.
TUESDAY

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Many worlds.

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

- Preferred basis. Hilbert spaces do not prefer any particular basis, yet for the Everettian interpretation to succeed, our perceptions must divide in a particular basis. Generally considered to be solved by decoherence.

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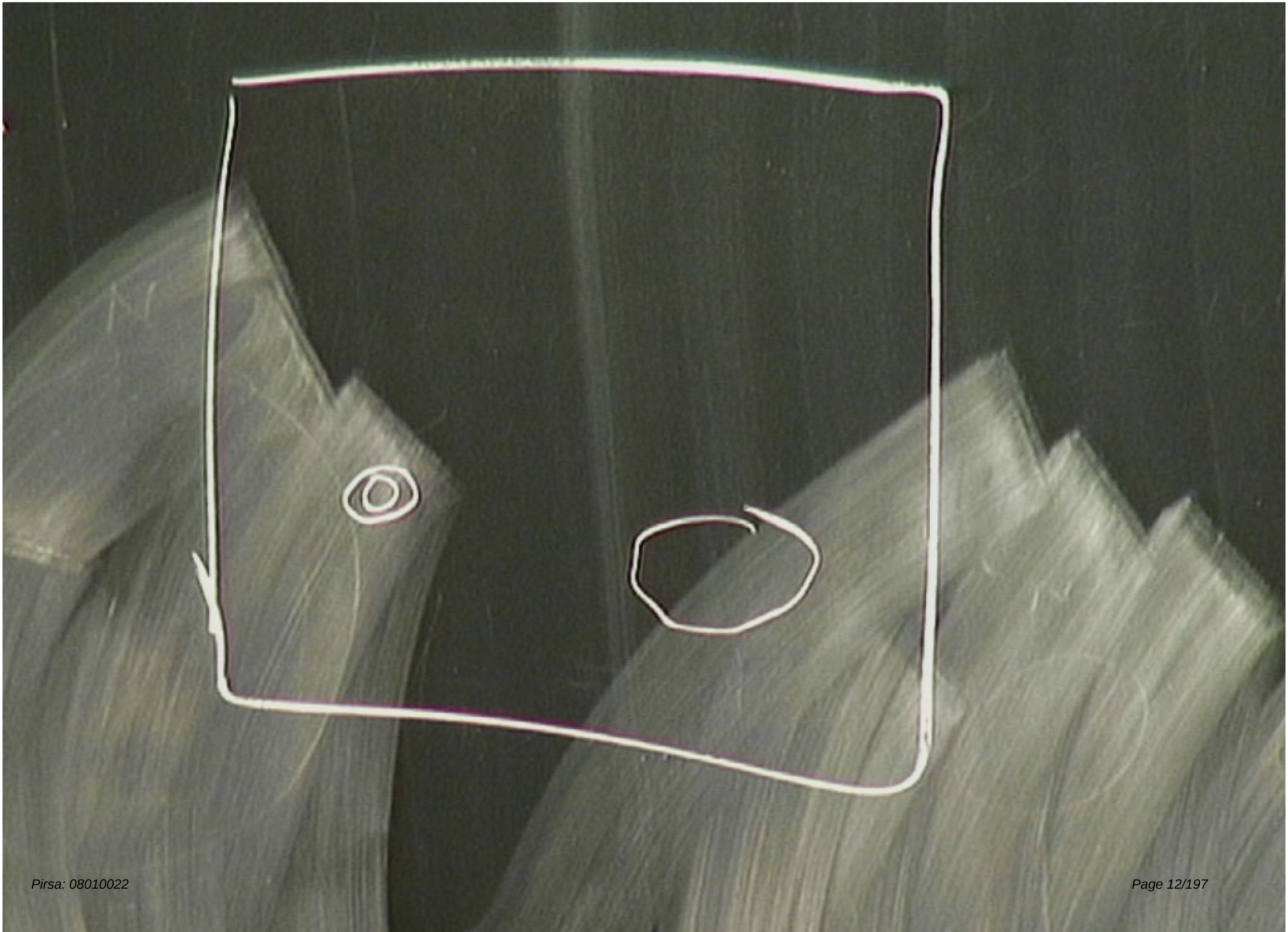
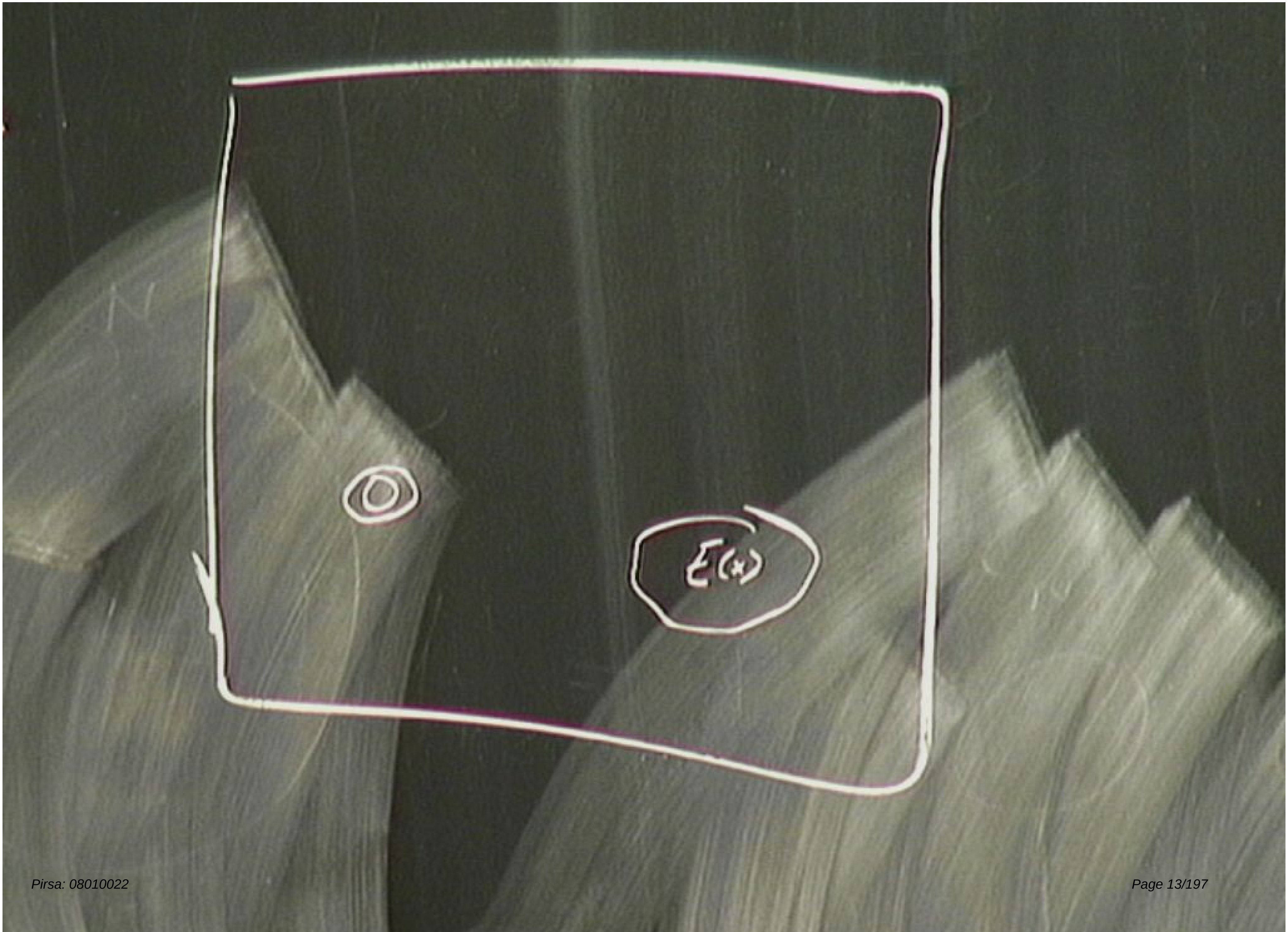
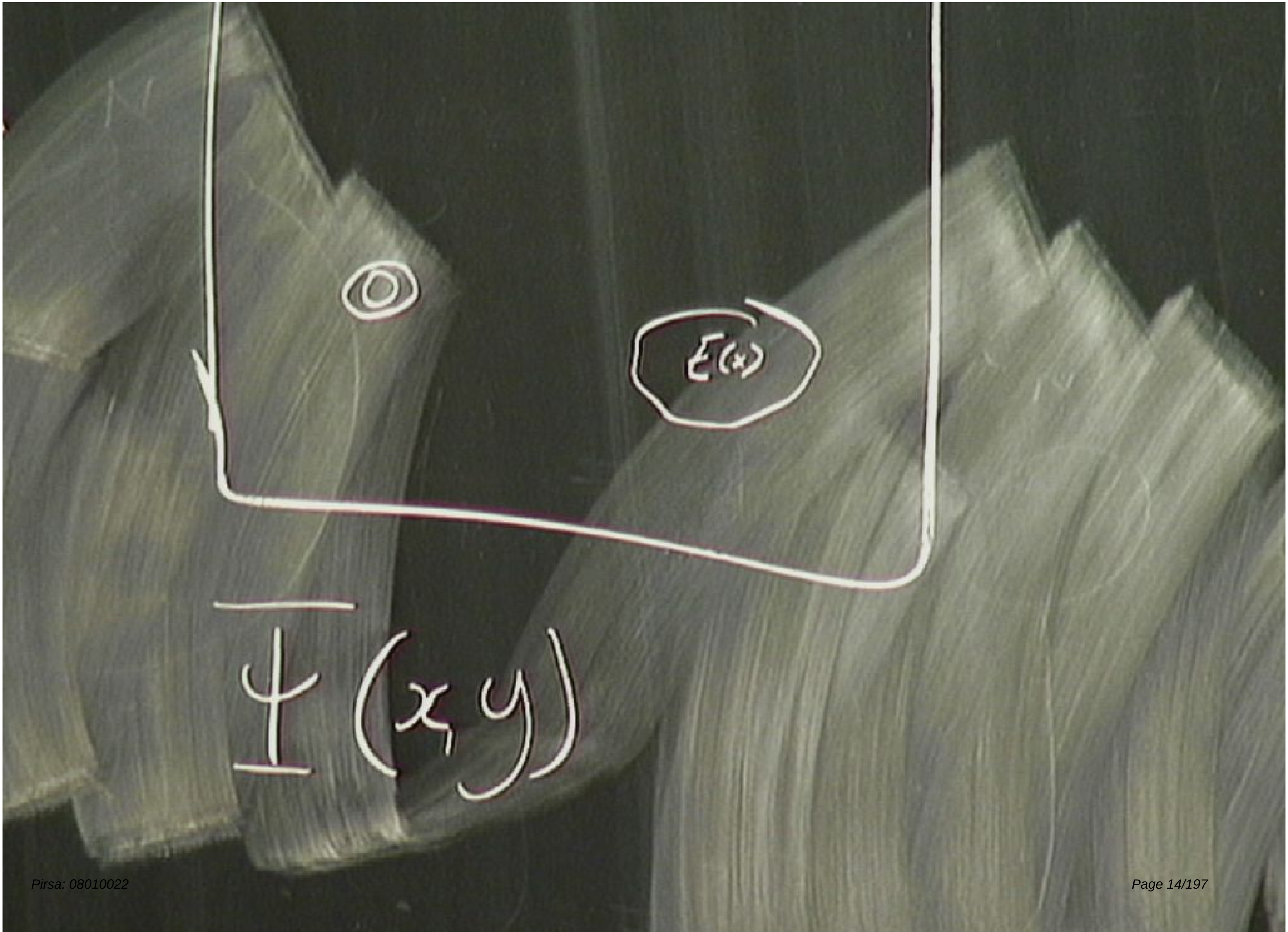
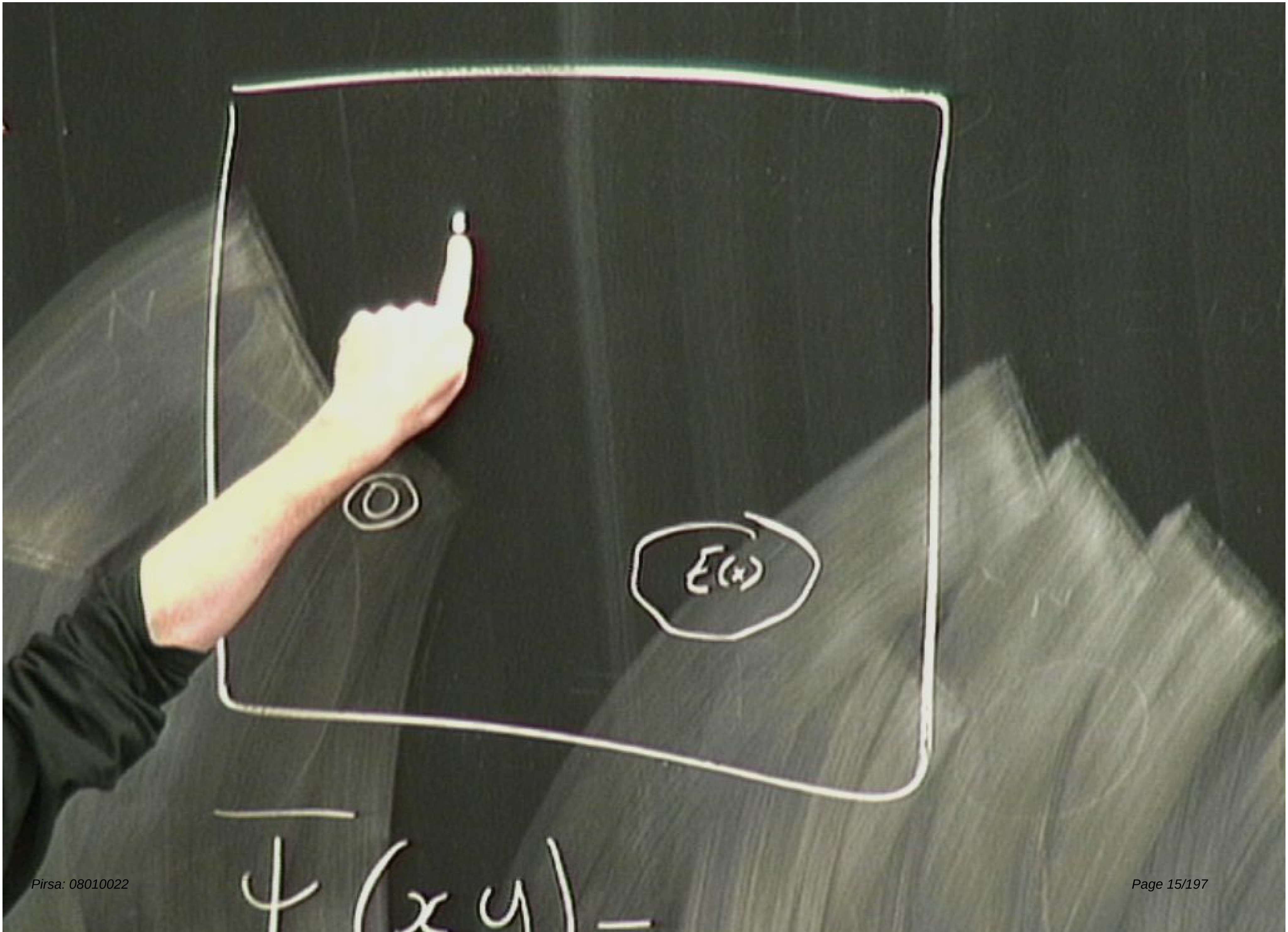
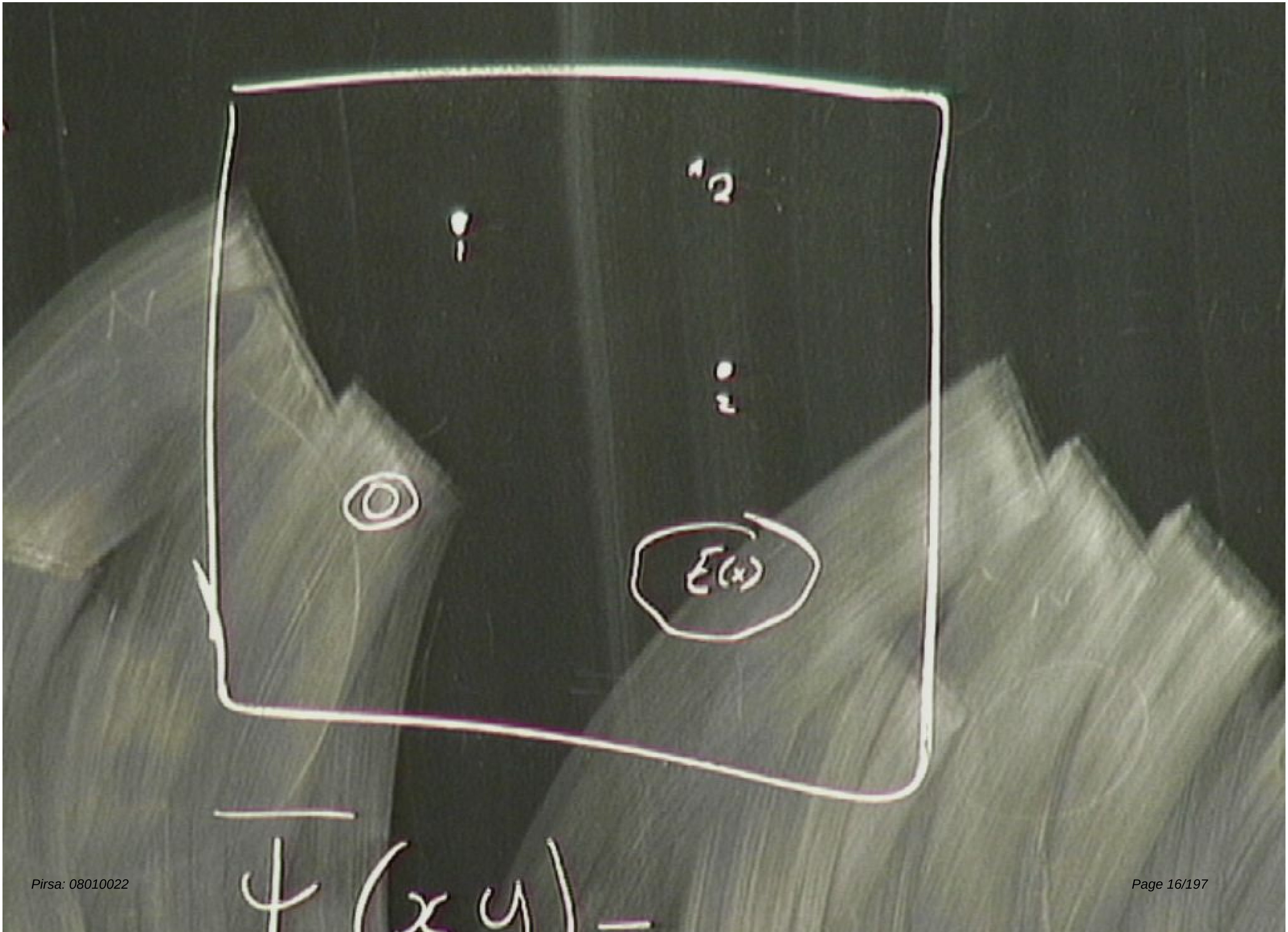
  - Is the wavefunction a local object?

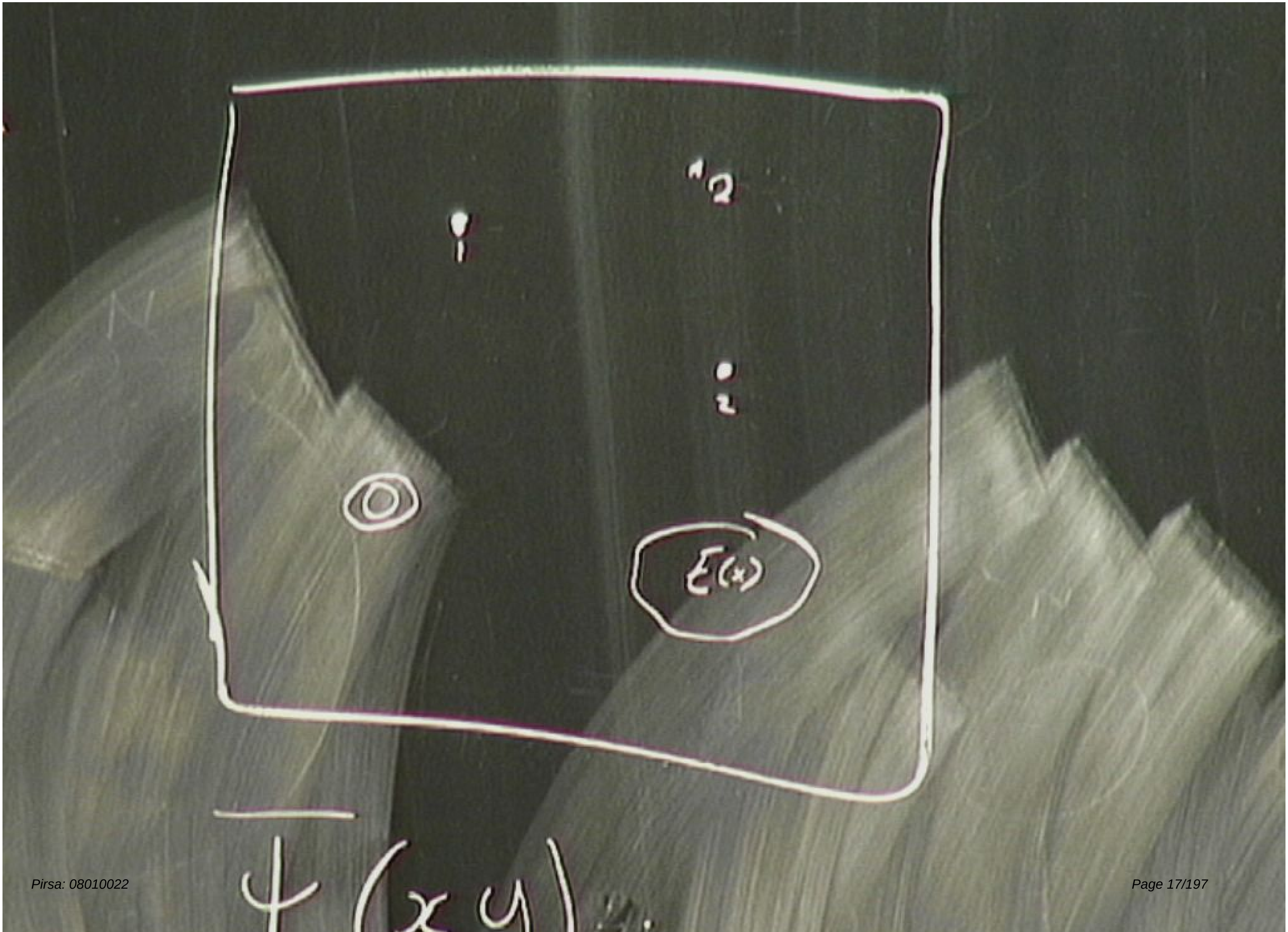





Ψ̄(x, y)


E(x)


1
2
2
E(x)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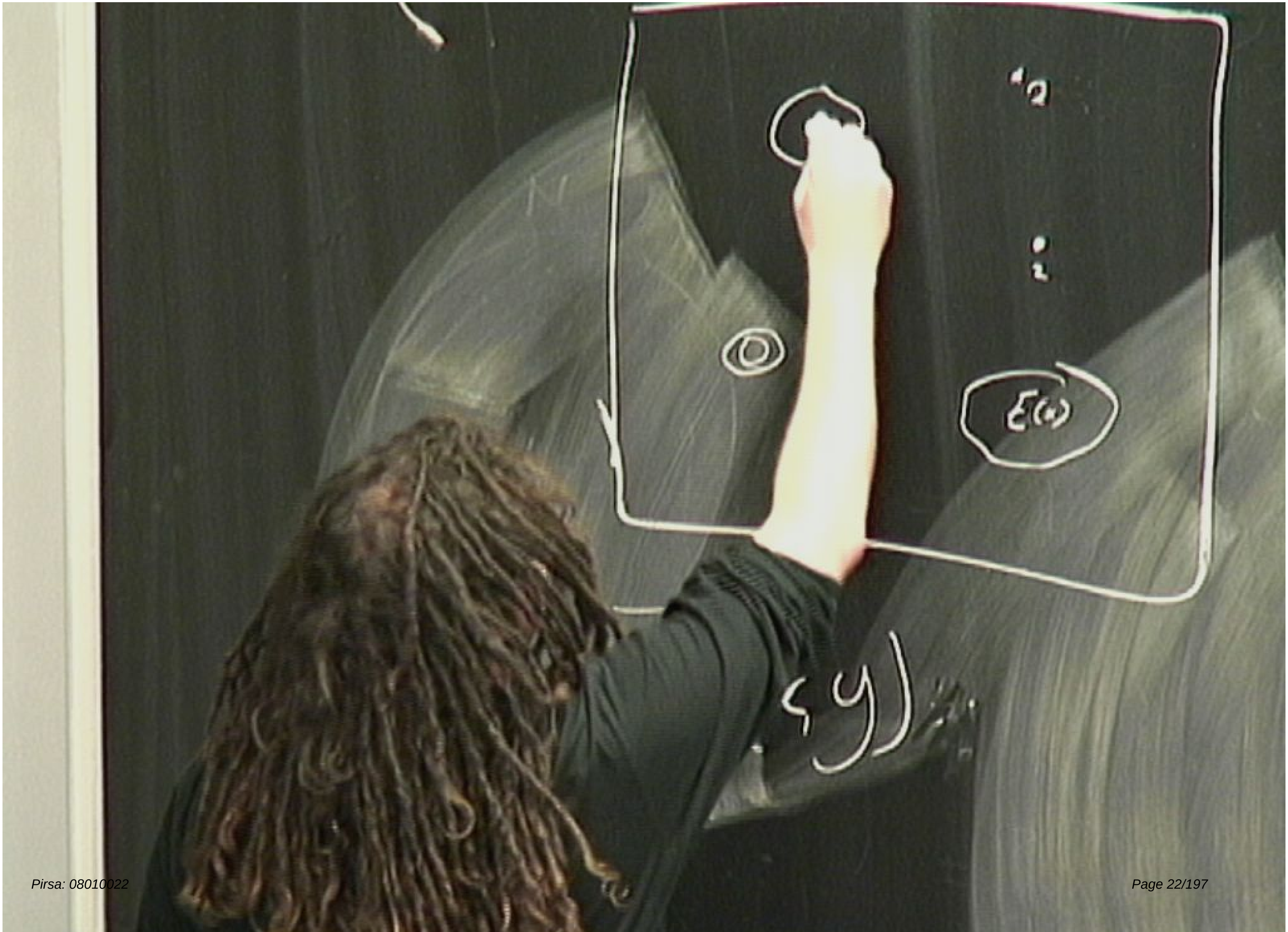

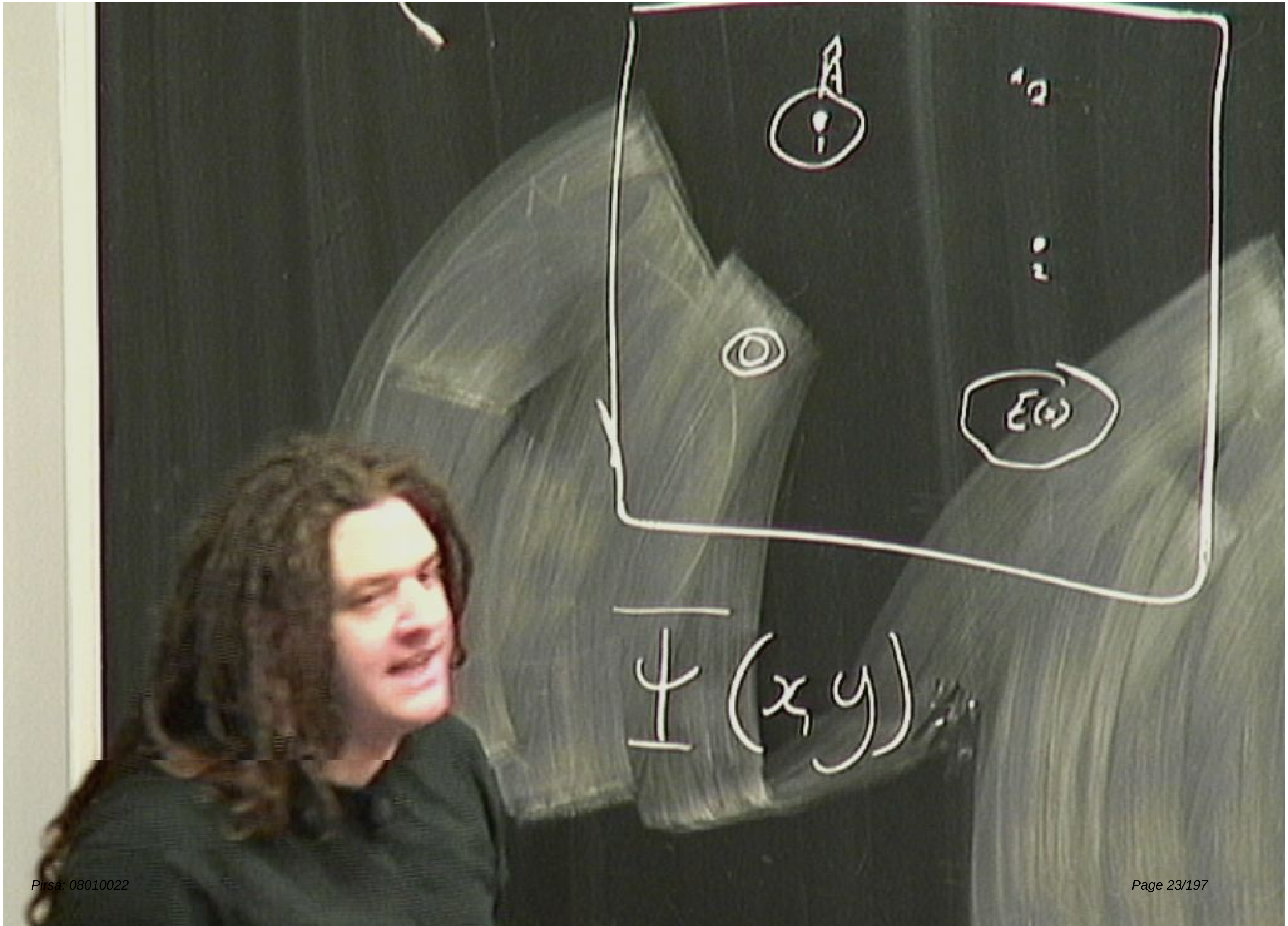
Ψ(x, y)

Hidden Variables

- Original quantum theory! De Broglie, 1924-1927.
  - Wave *or* particle?
  - Wave *and* particle!

$$\psi(x,t)=|\psi(x,t)|e^{iS(x,t)}$$

For a plane wave $A e^{ikx}$ so $p=\hbar k=\hbar\nabla S(x,t)$

$$m\dot{x}=\hbar\nabla S(x,t) \qquad P(x|t=t_0)=|\psi(x,t_0)|^2$$

Conservation equation $\frac{\partial P(x,t)}{\partial t}+\nabla J=0$

$$J(x,t)=\frac{\psi^*(x,t)\hbar\nabla\psi(x,t)-\psi(x,t)\hbar\nabla\psi^*(x,t)}{2im}=\frac{P(x,t)\hbar\nabla S(x,t)}{m}=P(x,t)\dot{x}$$

Hidden Variables

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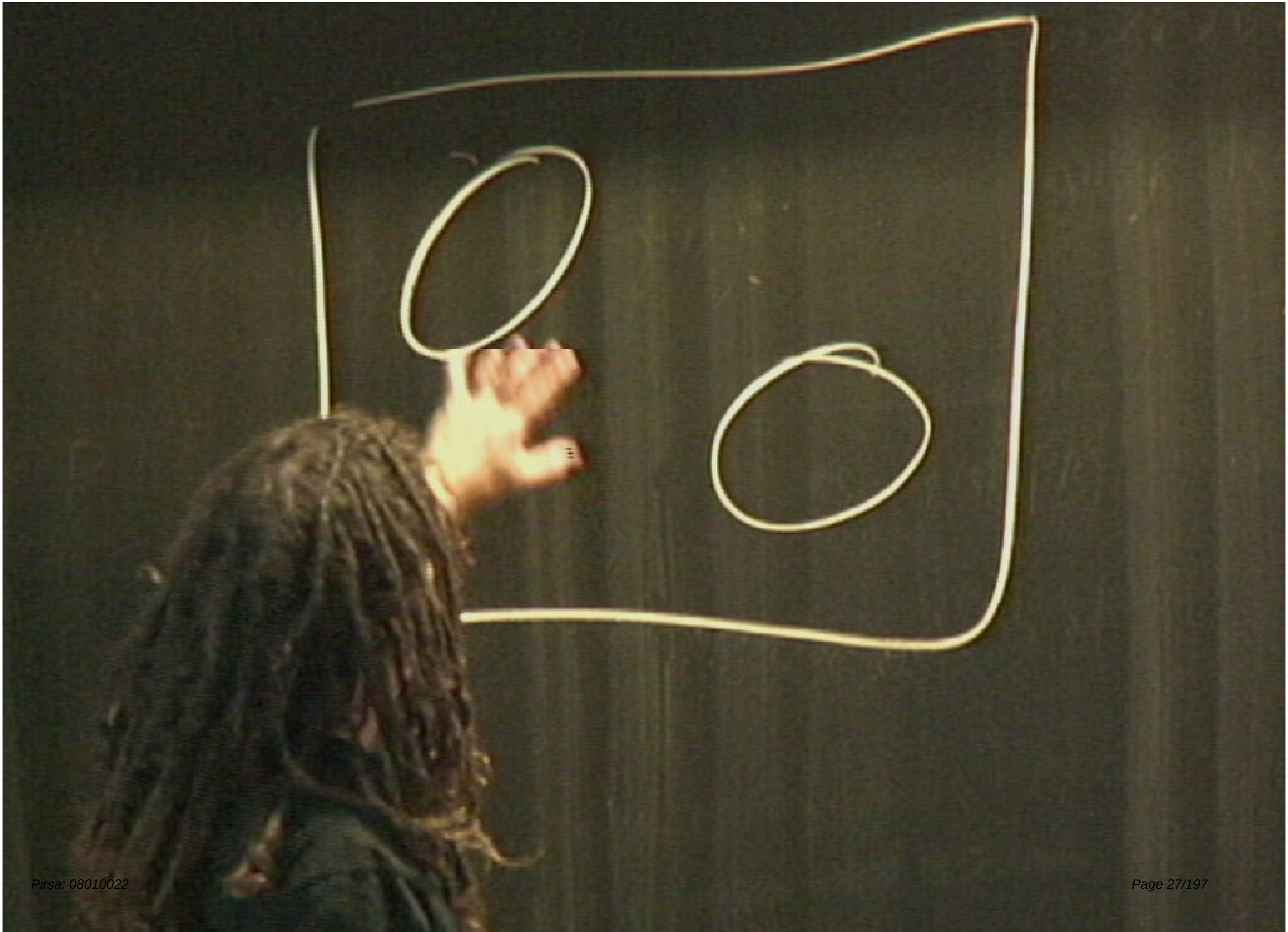
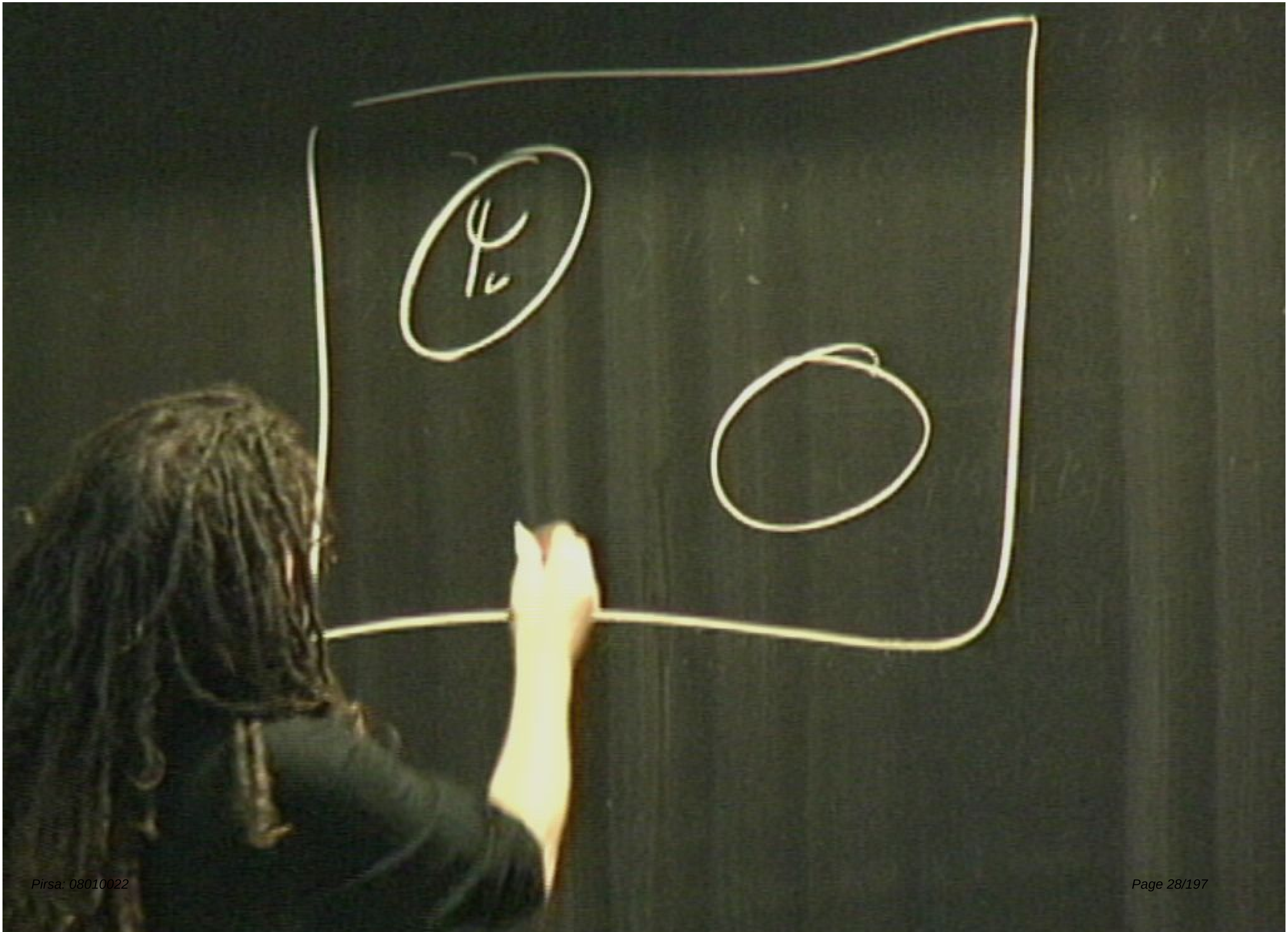
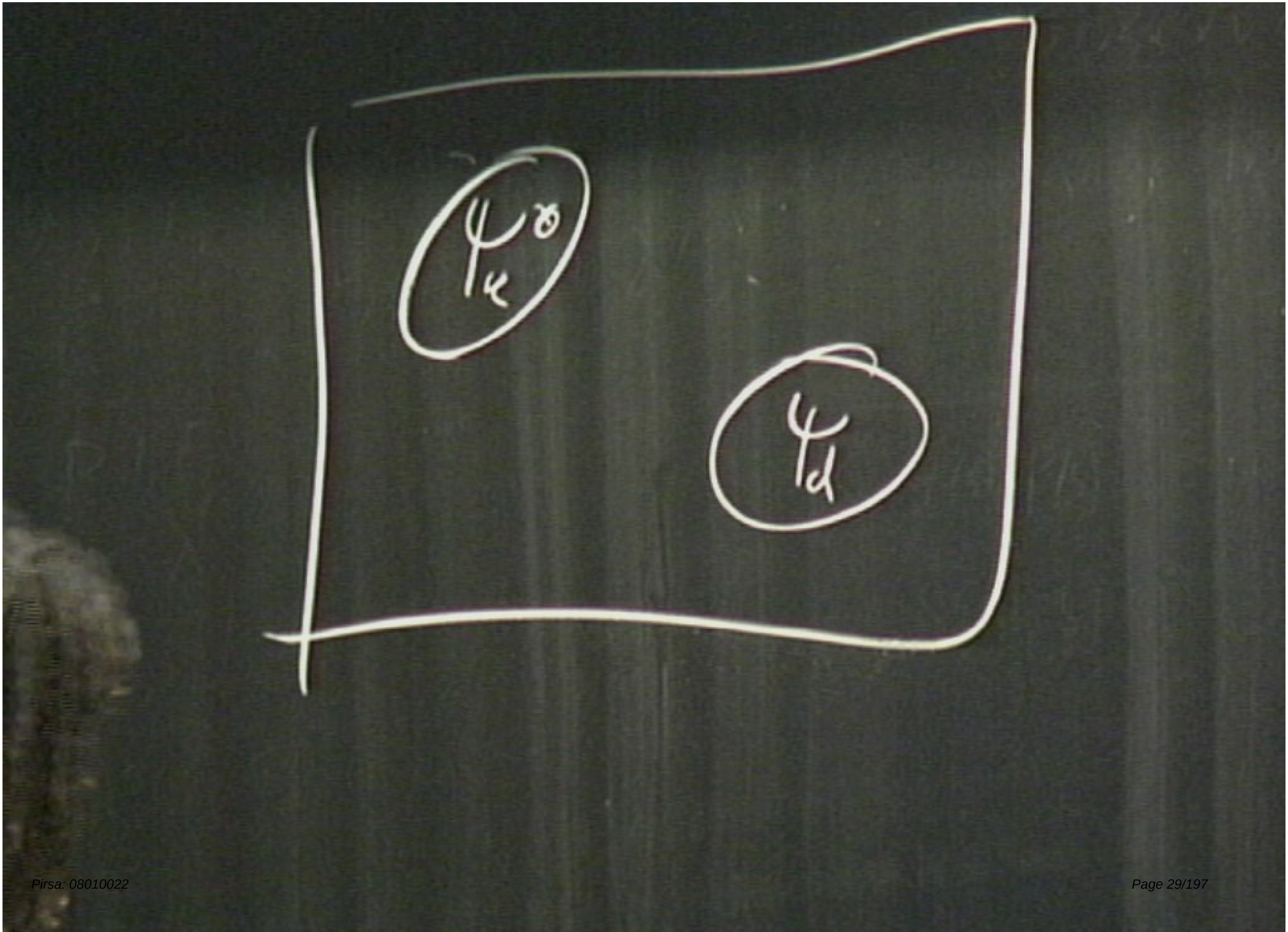
If, at some position x' $\quad |\psi_u(x',t)|\approx 0$ or $|\psi_d(x',t)|\approx 0$

then $\begin{matrix}|\psi(x',t)|\approx|\psi_u(x',t)| \\ S(x',t)\approx S_u(x',t)\end{matrix}$ or $\begin{matrix}|\psi(x',t)|\approx|\psi_d(x',t)| \\ S(x',t)\approx S_d(x',t)\end{matrix}$




Ψ_U



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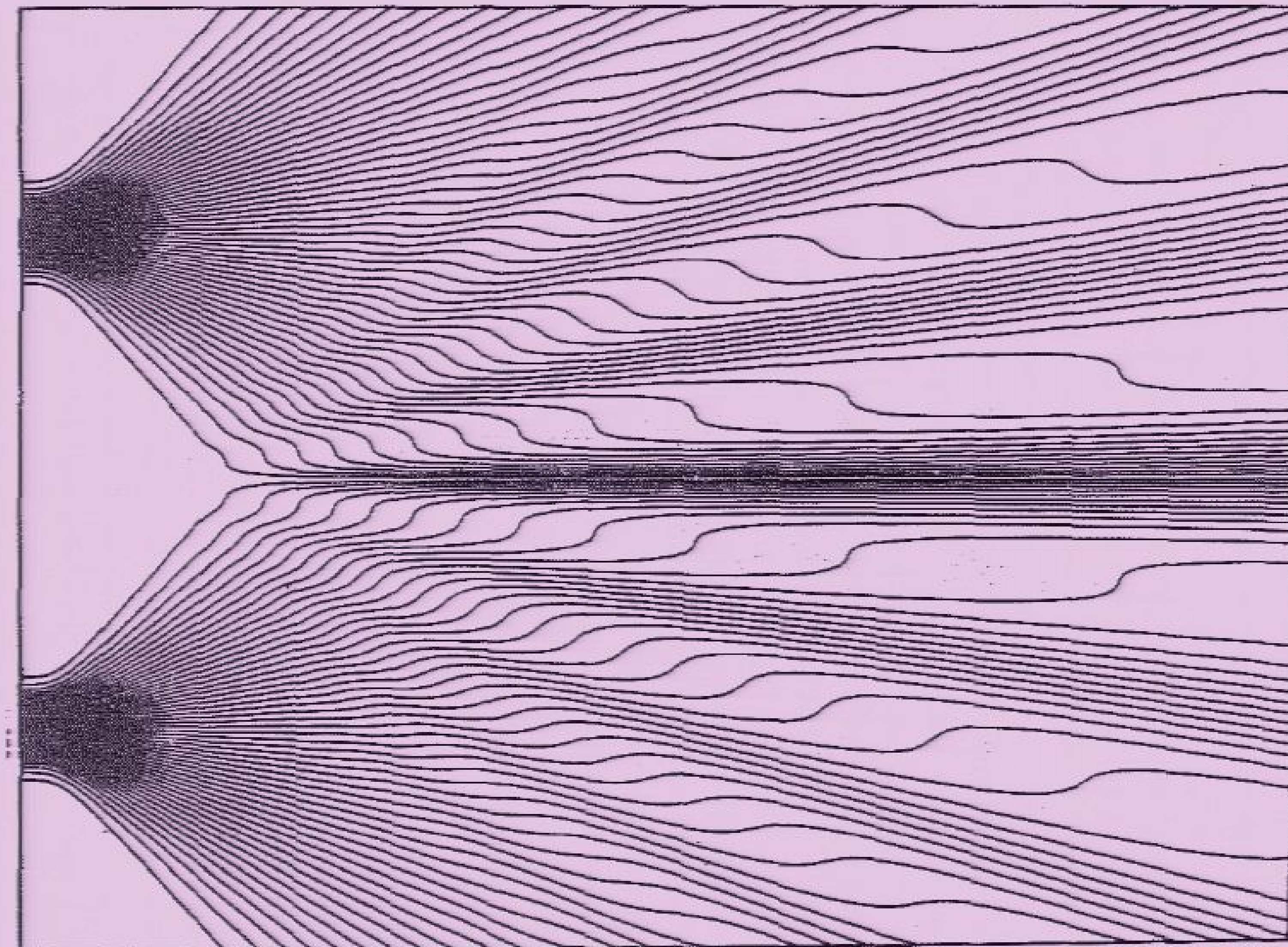

Source: Bohm, Hiley
The Undivided Universe pg. 33

Hidden Variables

With two degrees of freedom:

$$\Psi(x,y,t) = |\Psi(x,y,t)| e^{iS(x,y,t)}$$

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If, at some position y′ $|\Phi_u(y')|\approx 0$ or $|\Phi_d(y')|\approx 0$

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then
$$\Psi(x,y')\approx\psi_u(x)\Phi_u(y')$$
$$\frac{dx}{dt}\approx\frac{\hbar}{m}\frac{\partial}{\partial x}S_{\psi_u}(x)$$

Hidden Variables

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$$S(x,y)=\arctan\left(\frac{|\Psi_u(x,y)|\sin S_u(x,y)+|\Psi_d(x,y)|\sin S_d(x,y)}{|\Psi_u(x,y)|\cos S_u(x,y)+|\Psi_d(x,y)|\cos S_d(x,y)}\right)$$

If, at some position y′ $|\Phi_u(y')|\approx 0$ or $|\Phi_d(y')|\approx 0$

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- Non-equilibrium. Hidden variable theories reproduce quantum mechanics for particular probability distributions over the hidden variable state. This distribution is often referred to as "quantum equilibrium", as it's justifications is similar to thermal equilibrium. The possibility of systems with non-equilibrium distributions would lead to novel experimental results and possibilities.

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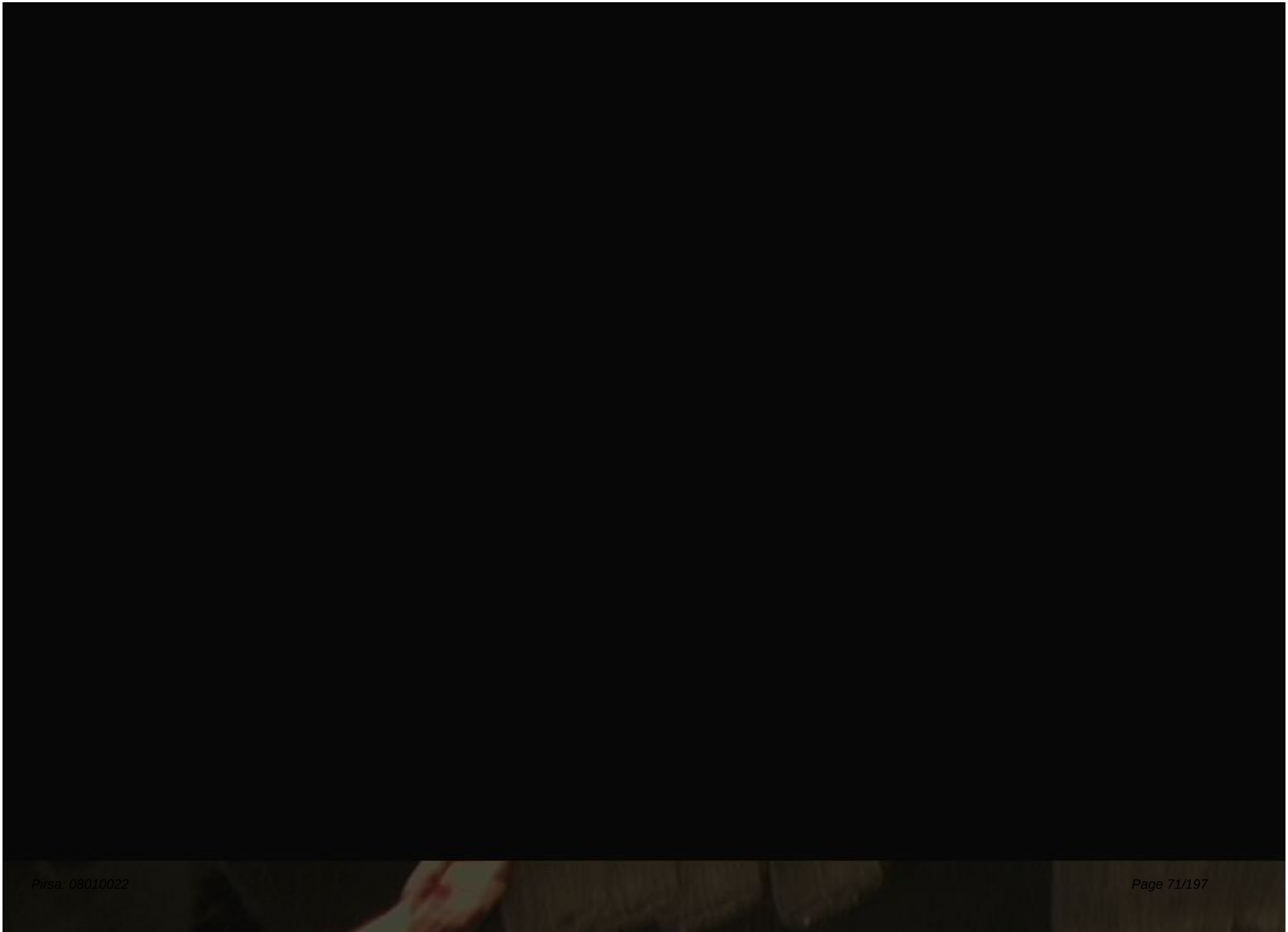
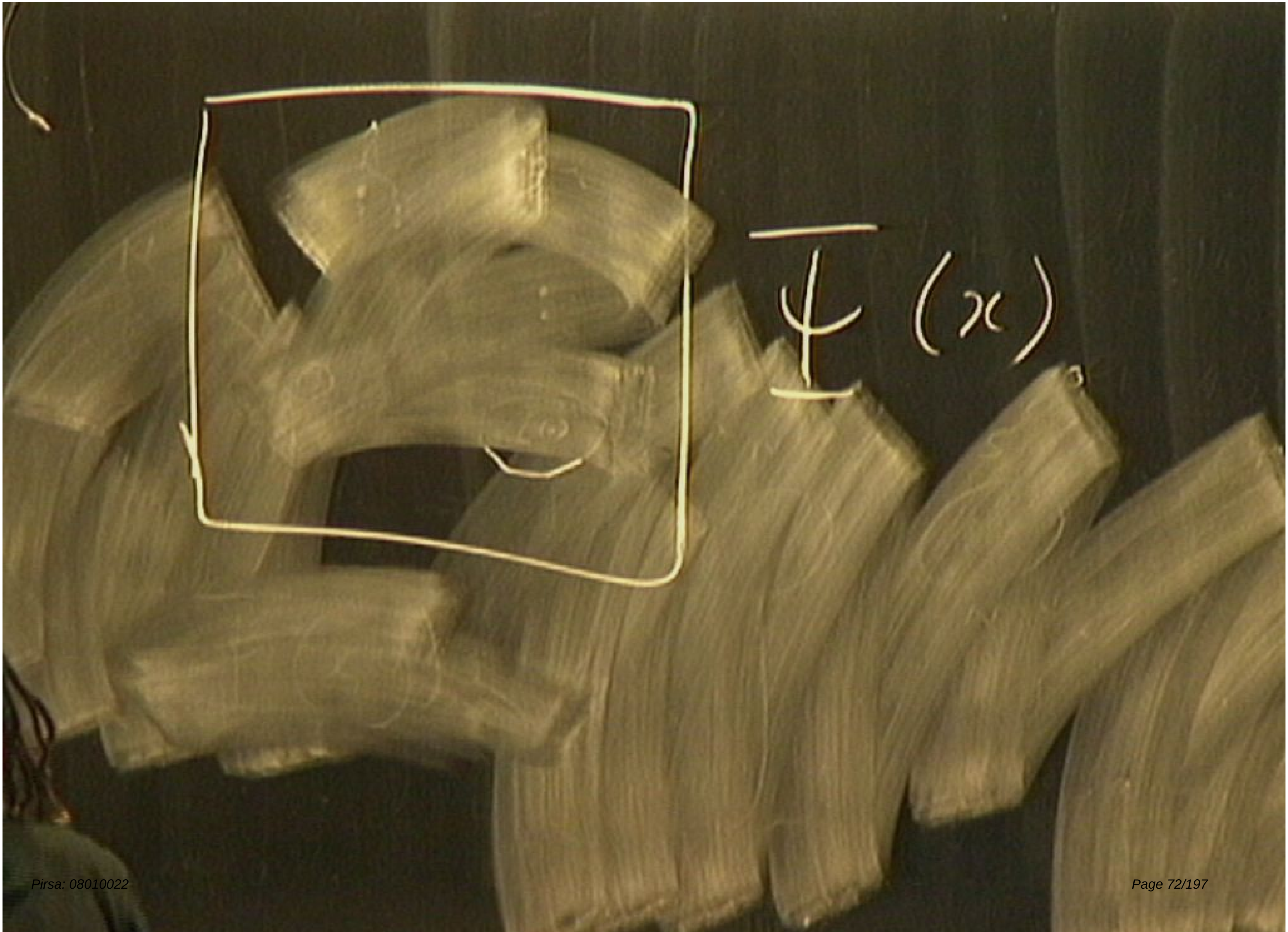
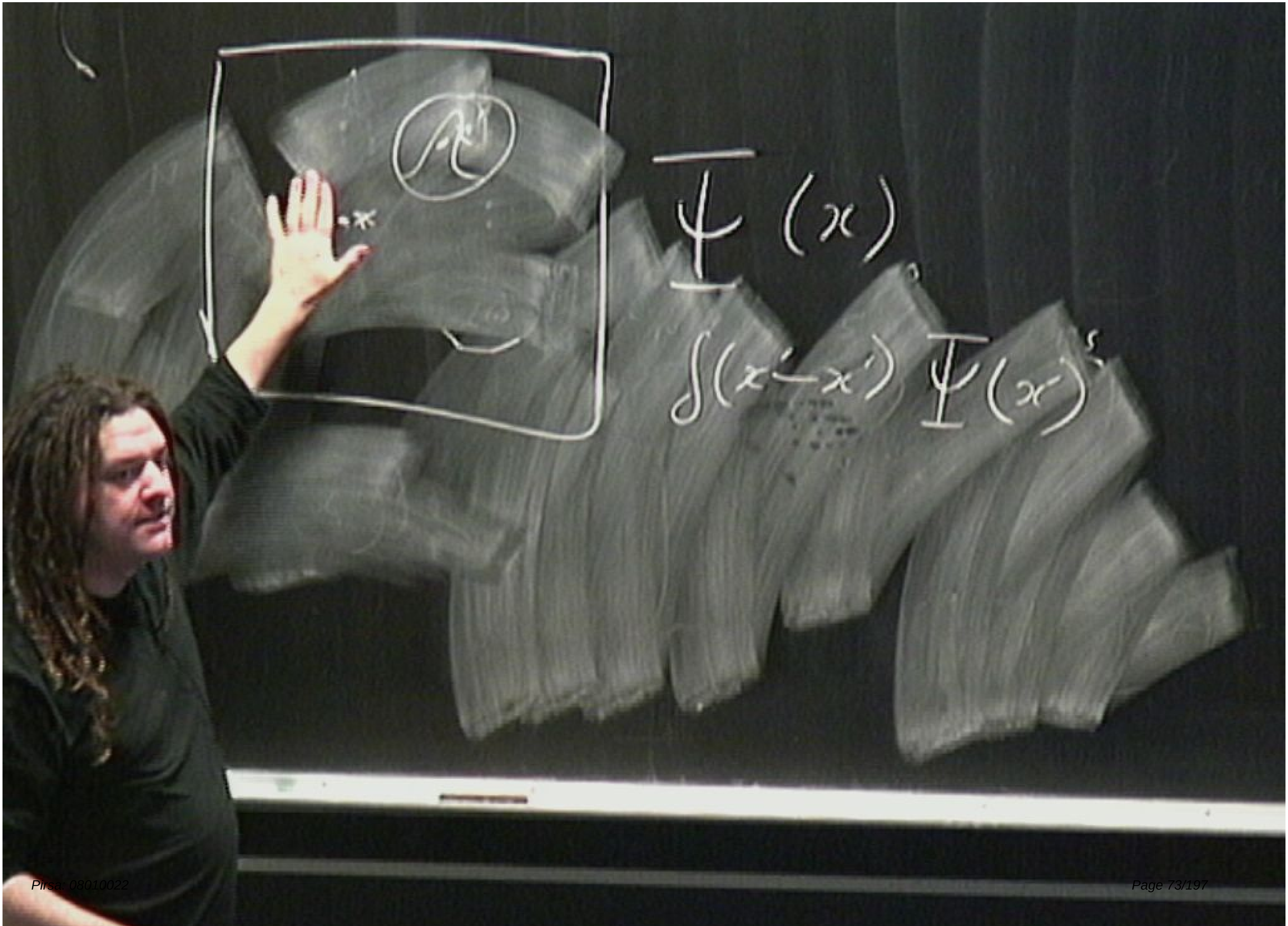
and x' is selected at random with probability: $$P(x') = |N(x')|^2 dx'$$

Collapse models

$$\Psi_o(x) \rightarrow \Psi_N(x) = \frac{f(x'-x)}{N(x)} \Psi_o(x')$$




$\bar{\Psi}(x)$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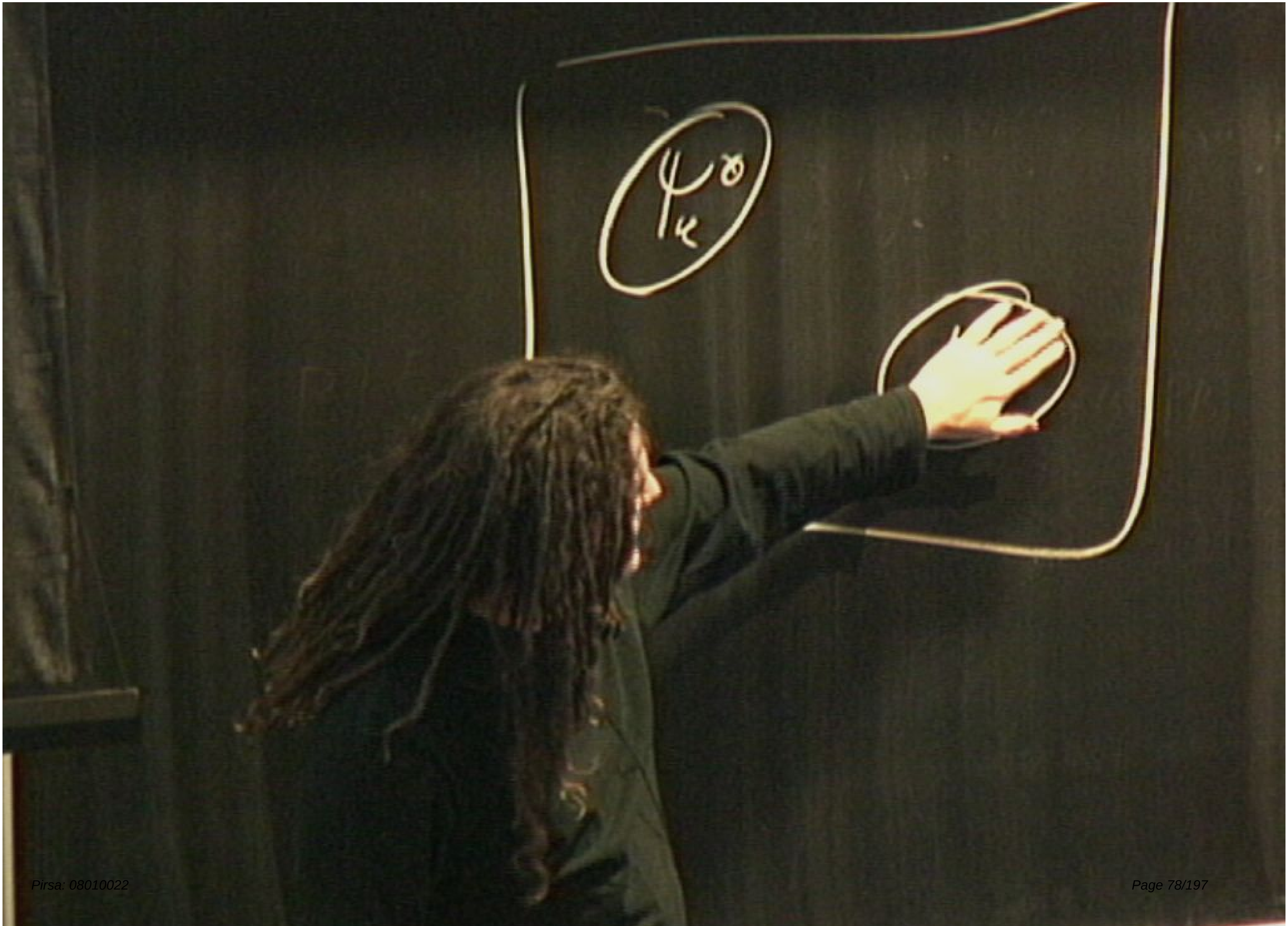

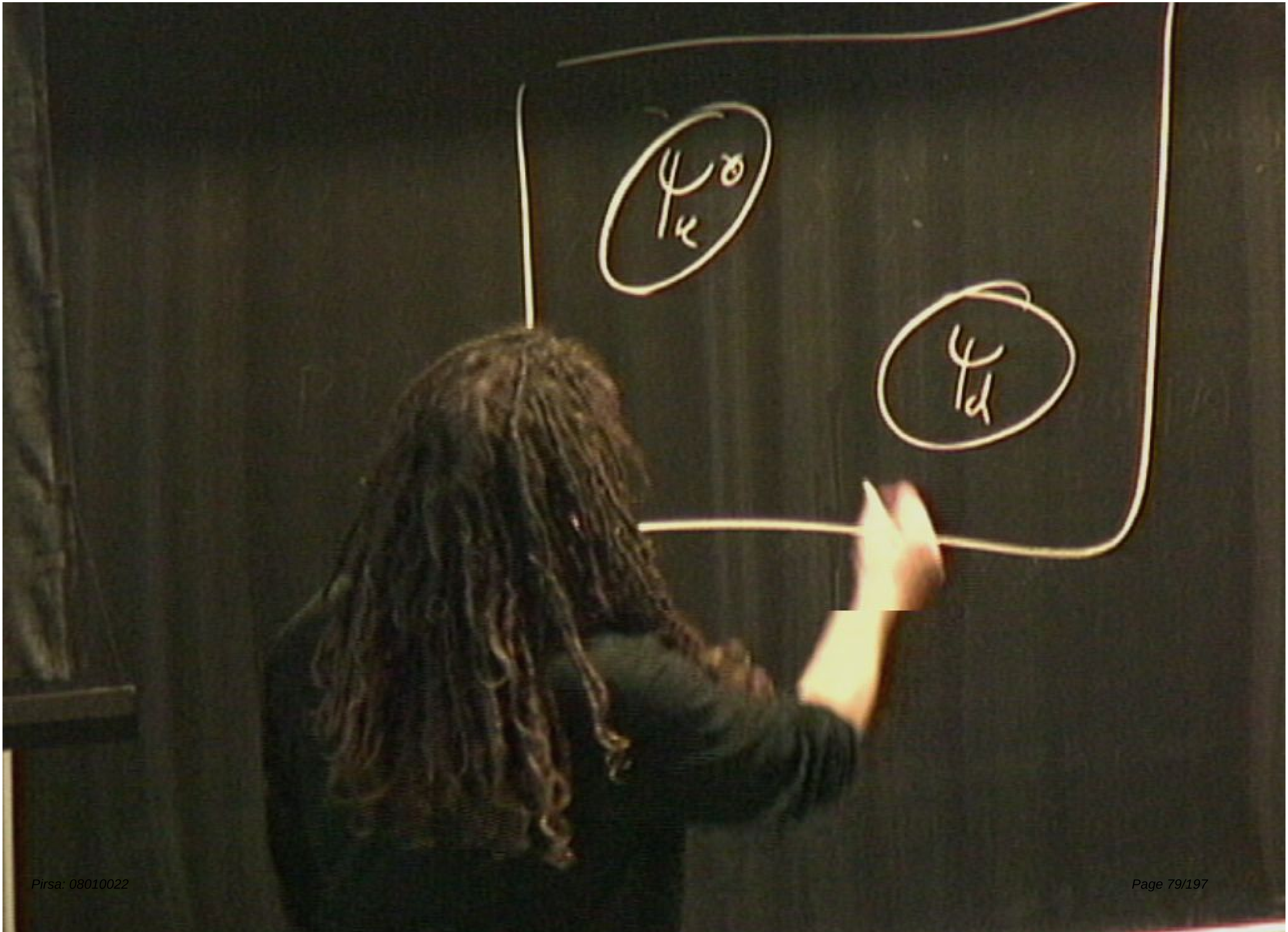

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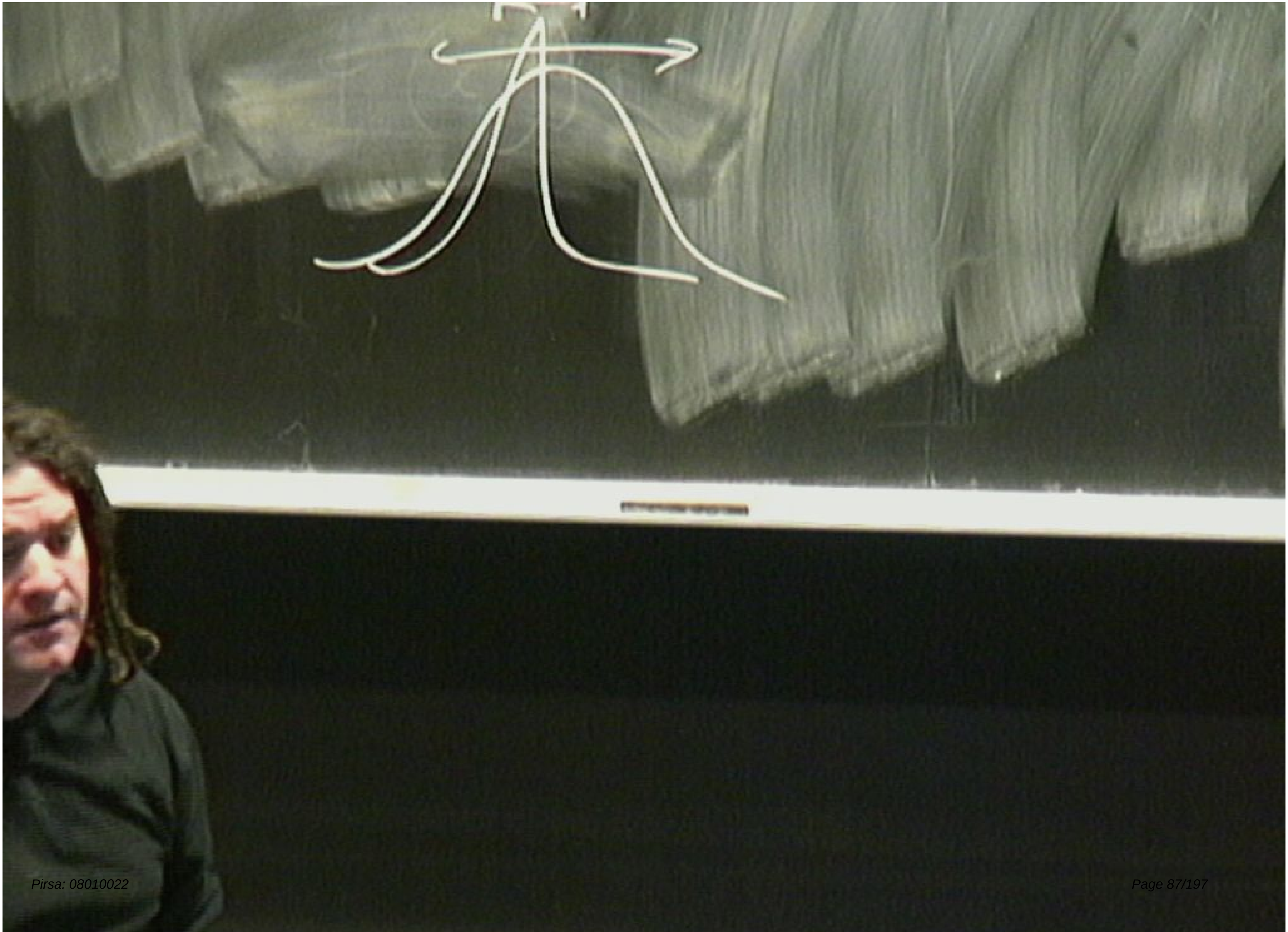

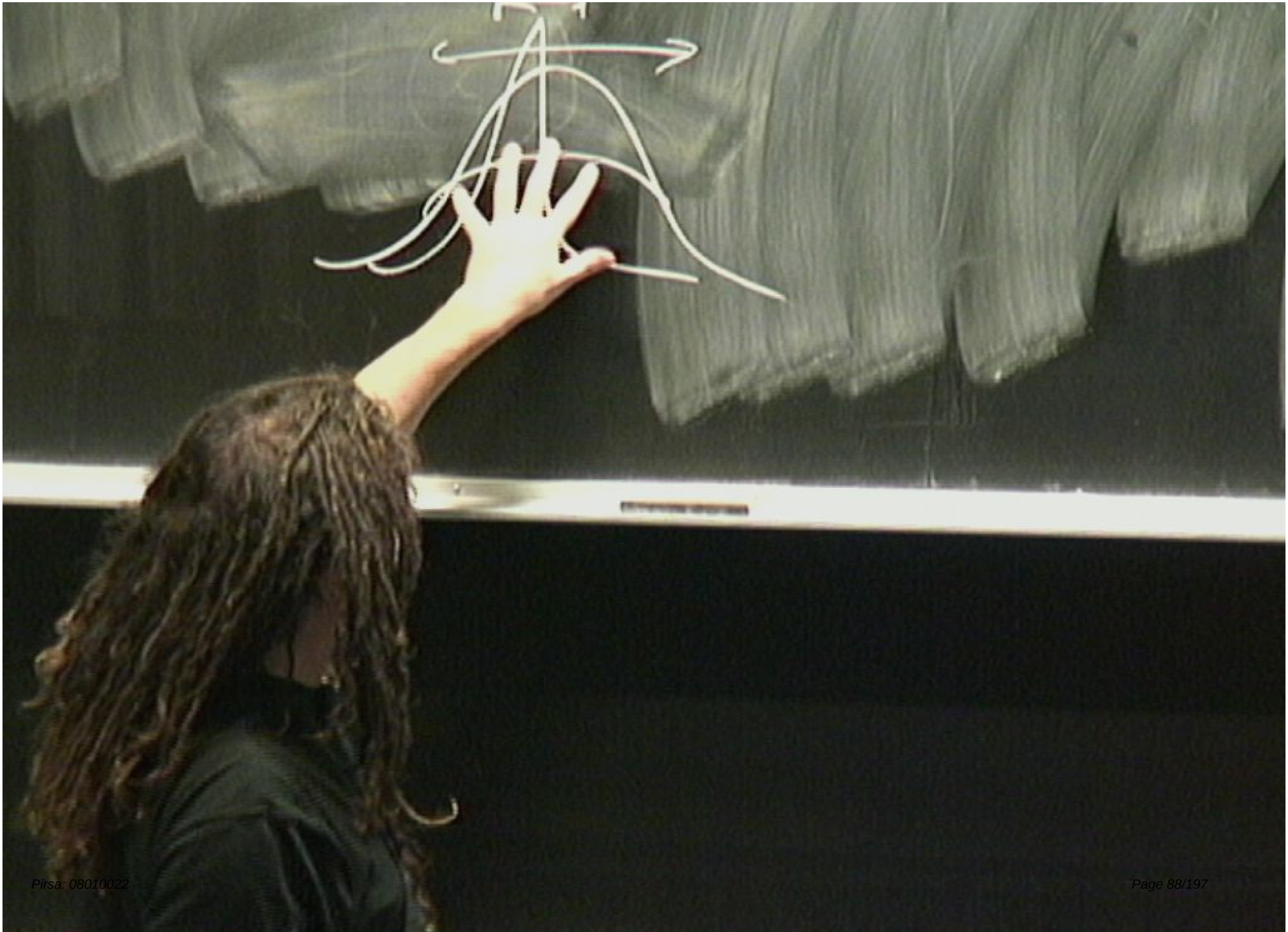

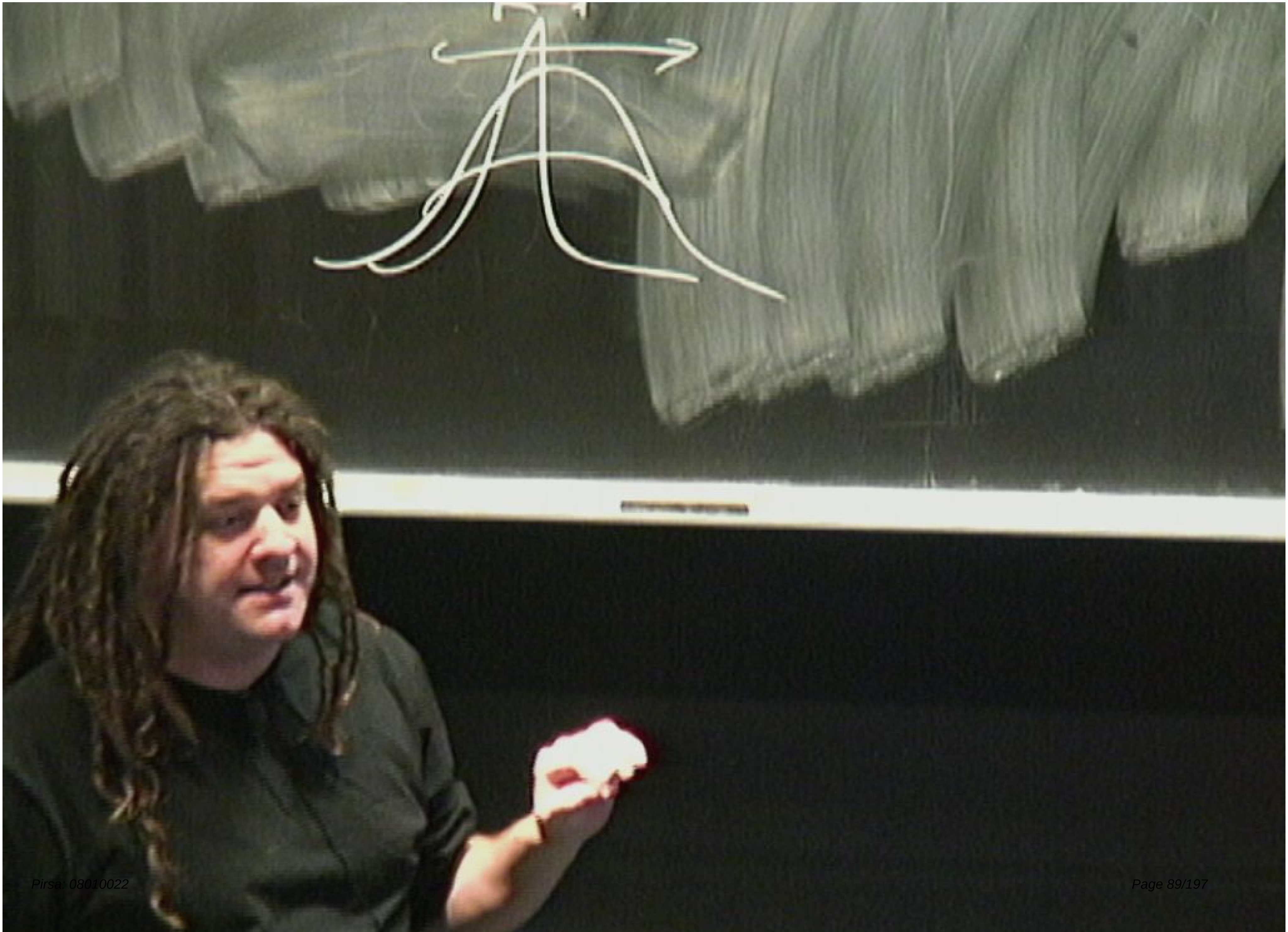

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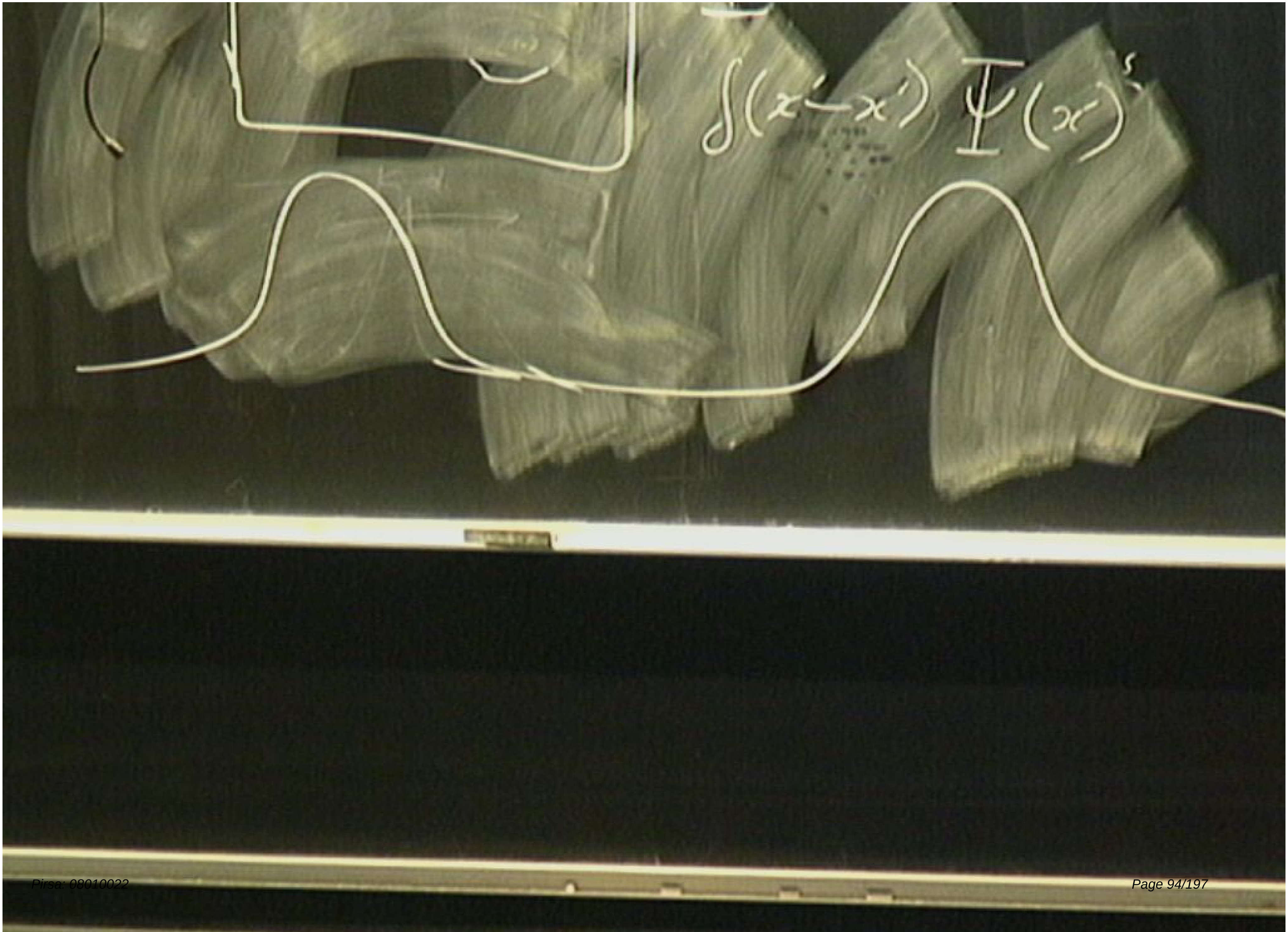
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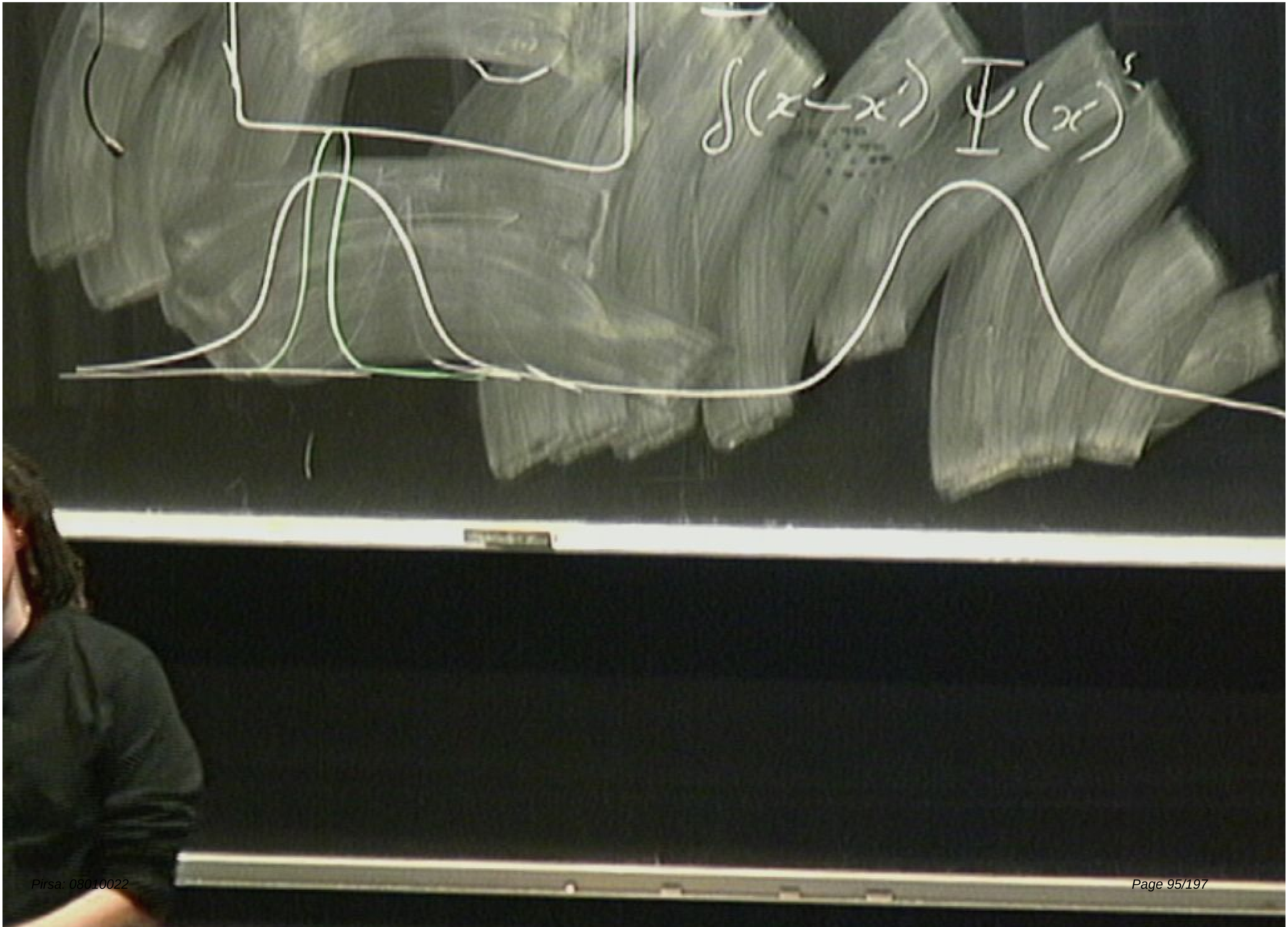
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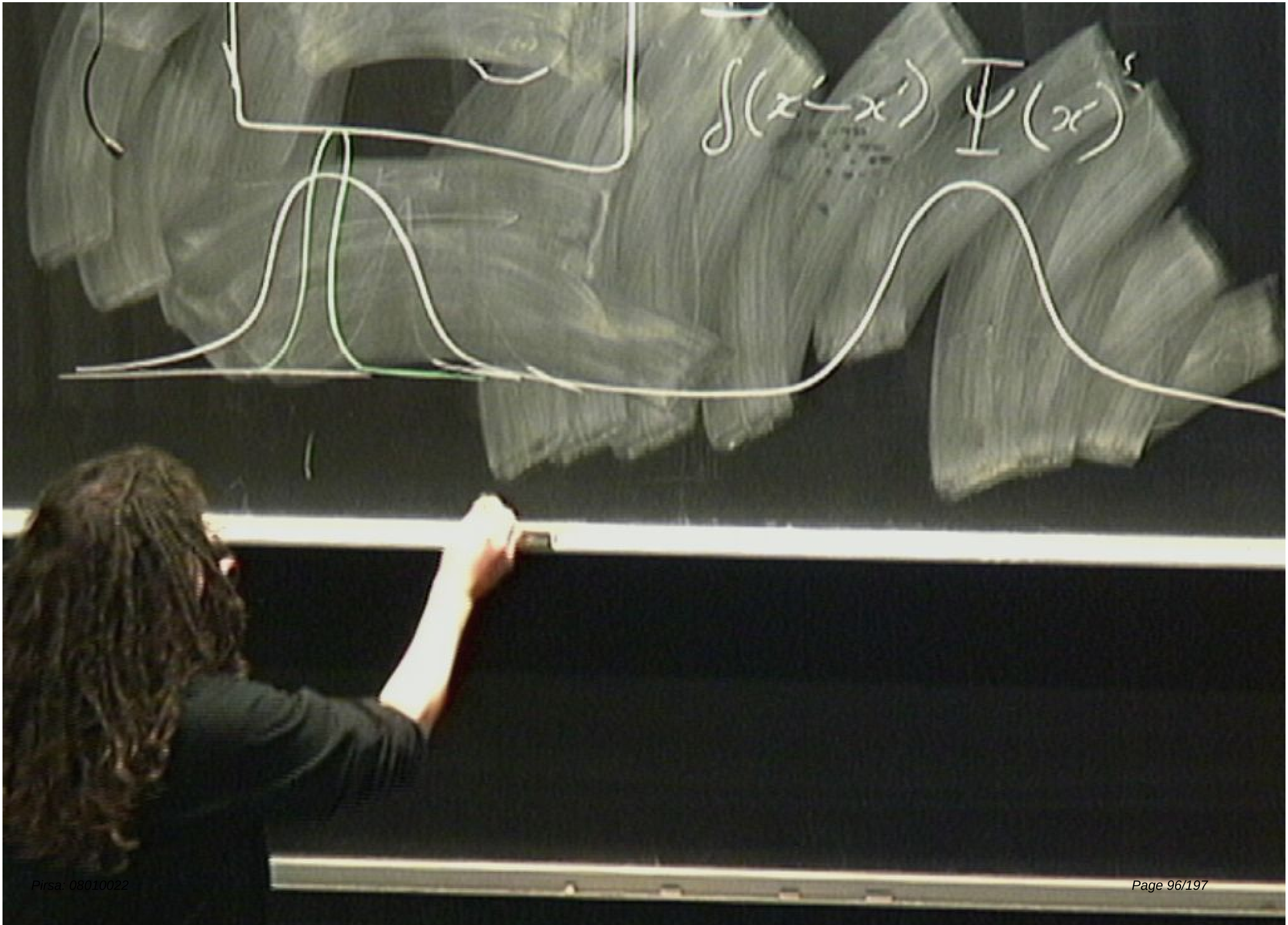
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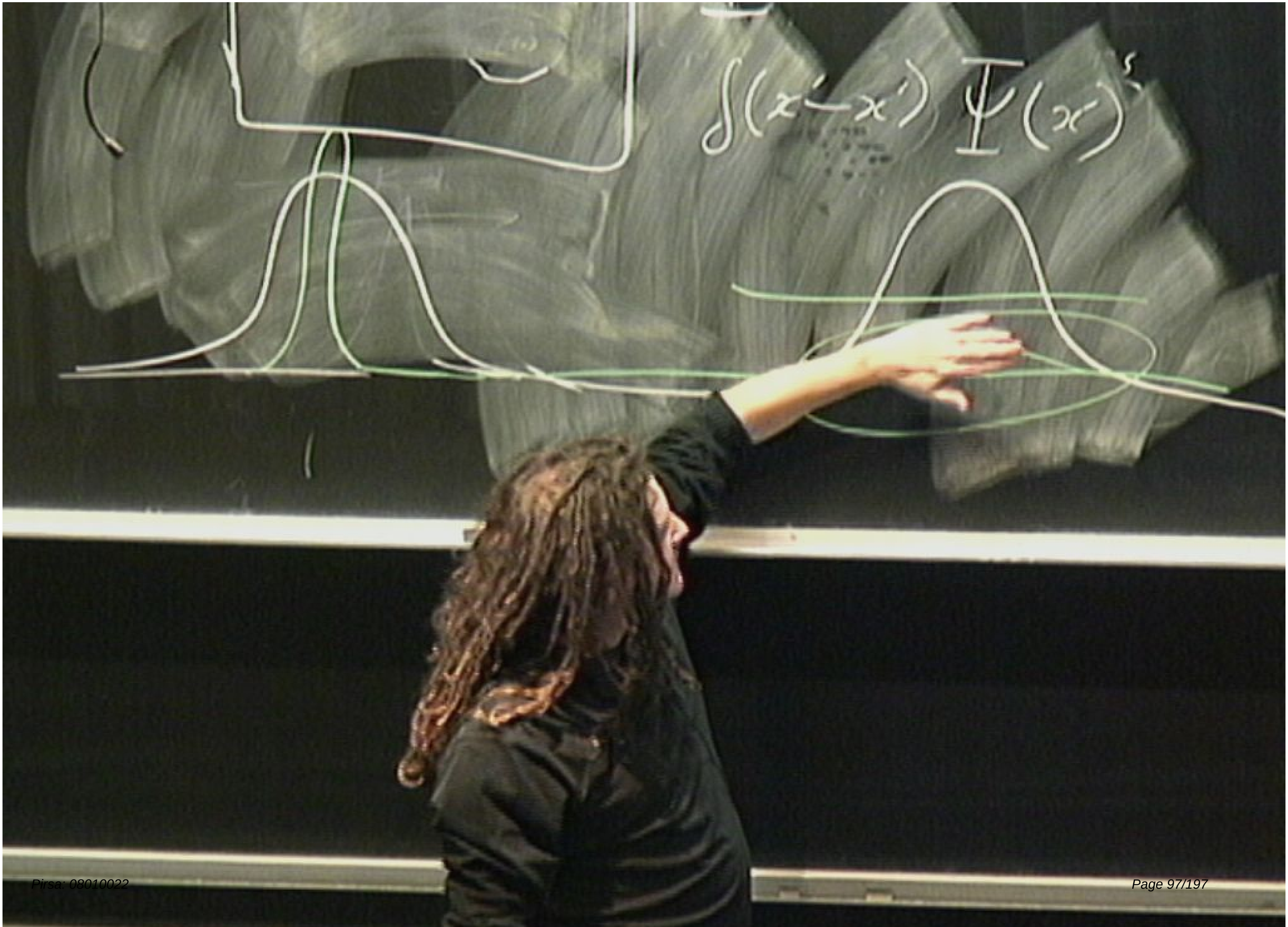
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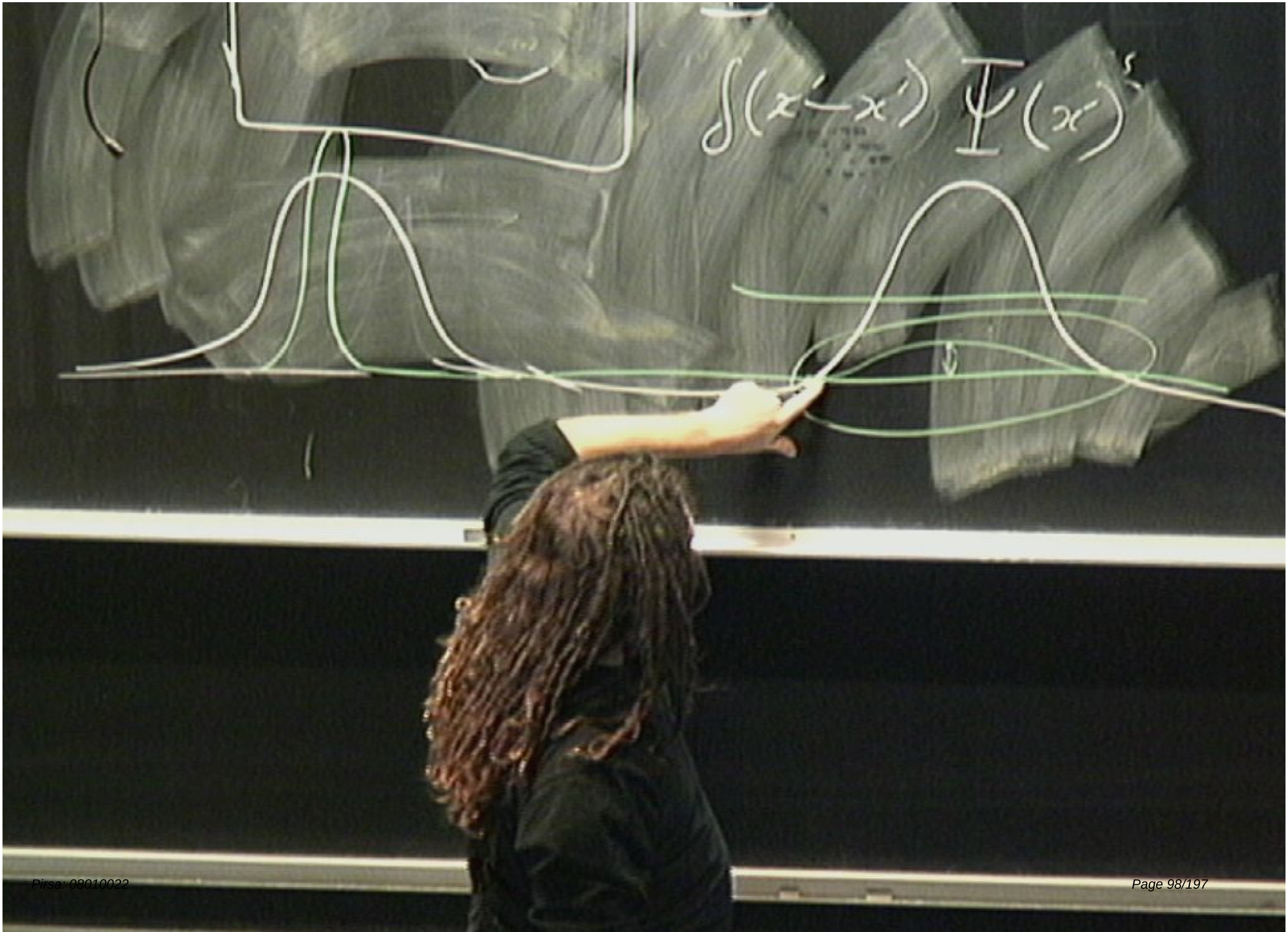
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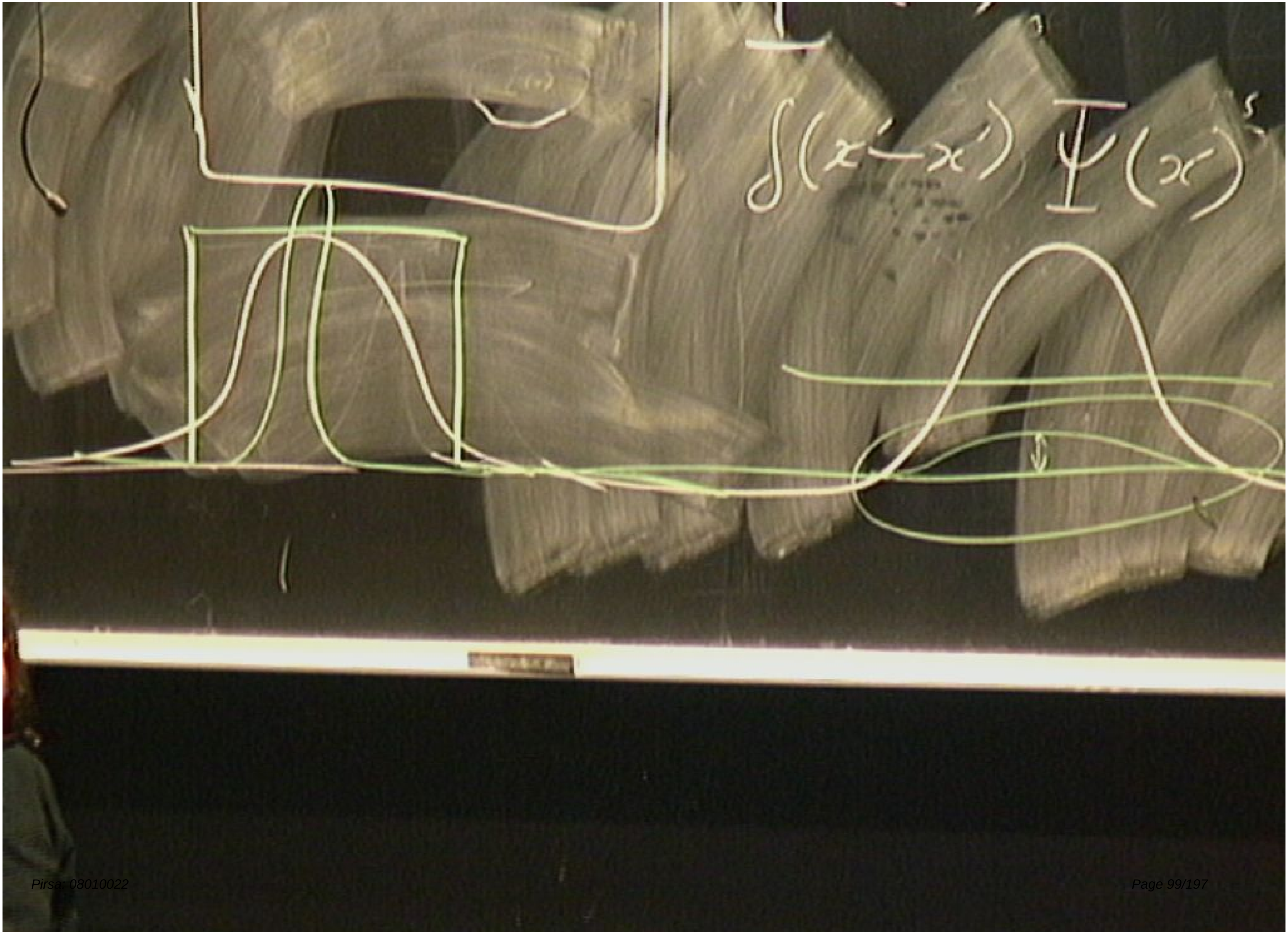
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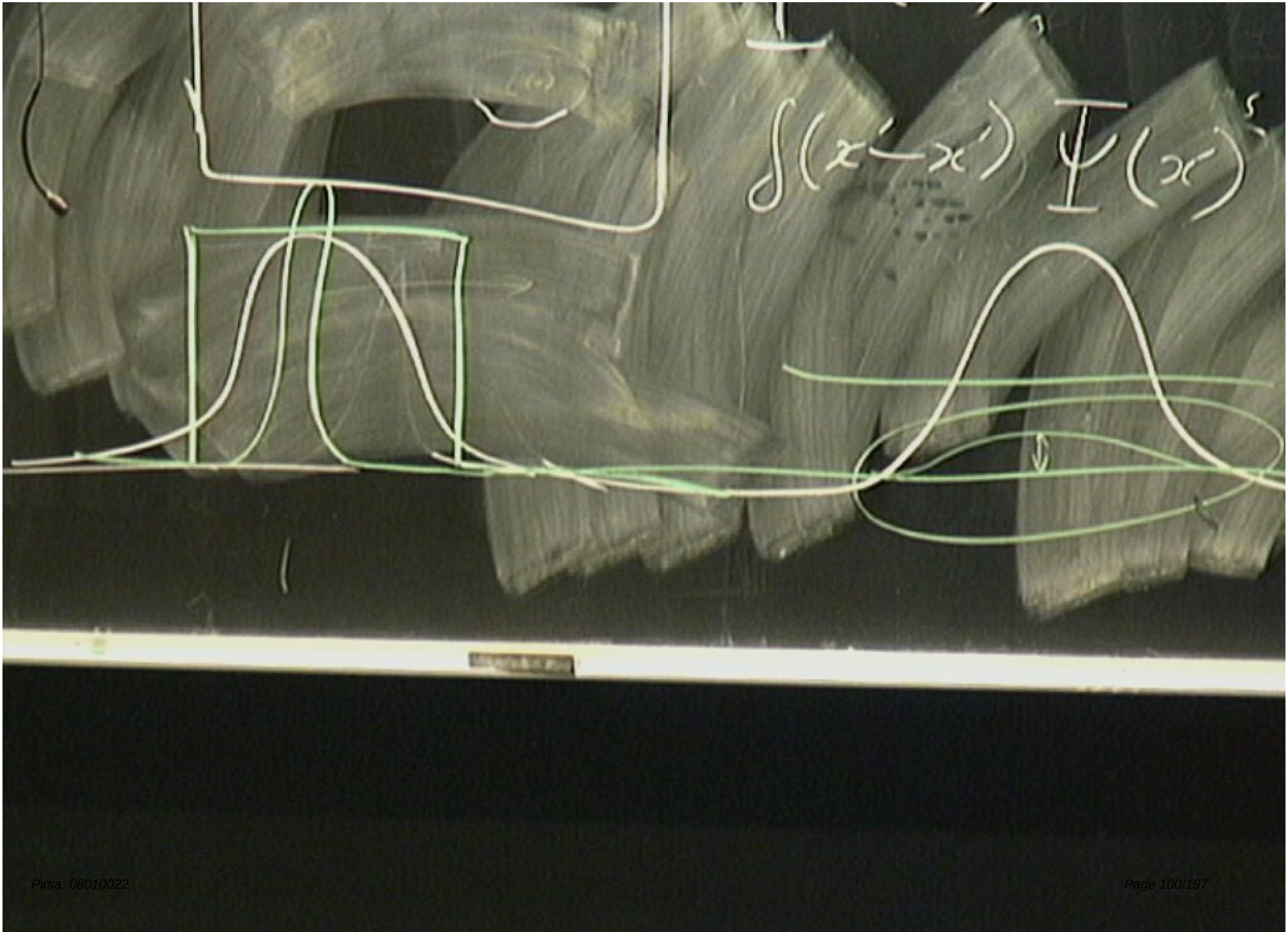
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Ψ epistemic theories

- de Broglie-Bohm hidden variable models treat the wavefunction as a real entity.

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$f(y'-y)\Phi_u(y,z,...)\approx 0$ or: $f(y'-y)\Phi_d(y,z,...)\approx 0$

so: $\Psi_N(x,y,z...)=\dfrac{\psi_u(x)f(y'-y)\Phi_u(y',z,...)+\psi_d(x)f(y'-y)\Phi_d(y',z,...)}{N(y)\sqrt{2}}$

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$$\tau_{y,z...}\approx\frac{10^{15}s}{10^{23}}=10^{-8}s$$

Collapse models

- Non-conservation of energy. Objective collapse models, that produce localised states, generically violate the conservation of energy, *even on average.*
- Relativistic invariance. Explicit collapse models have generally been non-relativistic. Making a relativistically invariant collapse model presents difficulties. Recent progress has been made for non-interacting systems.
- Empirical predictions. Wavefunction collapse models generically produce situations where different predictions can be made to quantum theory. Experimentally probing these situations are hard, as environmental decoherence must be excluded.
- Tails and signalling Collapse models leave "tails" that include uncollapsed traces of unobserved outcomes. Eliminating these traces leads to violations of no-signalling.
- What is the ontology?
  - Bare theory : Everettian?
  - Flash ontology : moments of experience? What is real is only the event at the moment of the collapse.
  - Matter field : extra structure to the world in addition to the wavefunction

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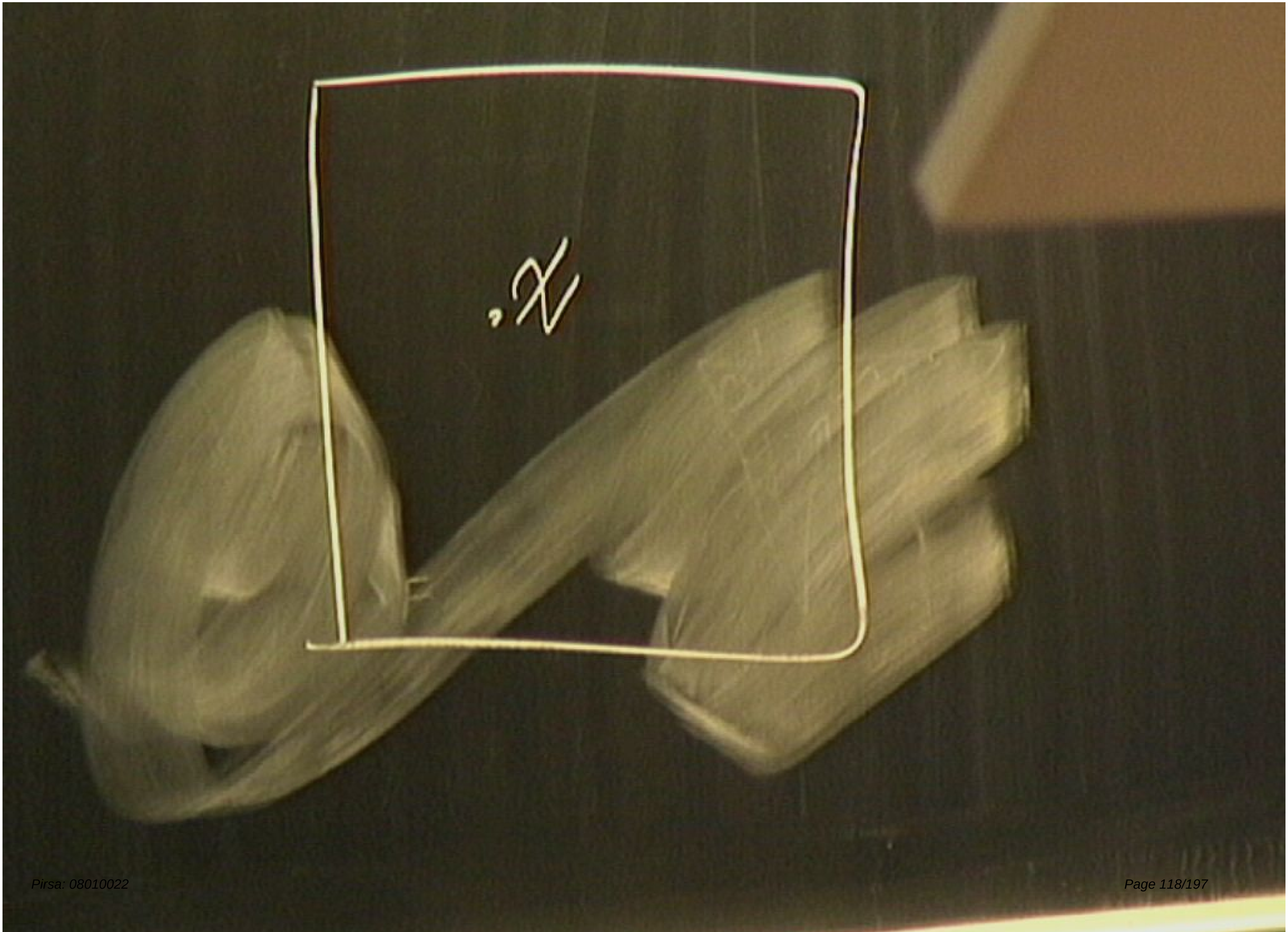
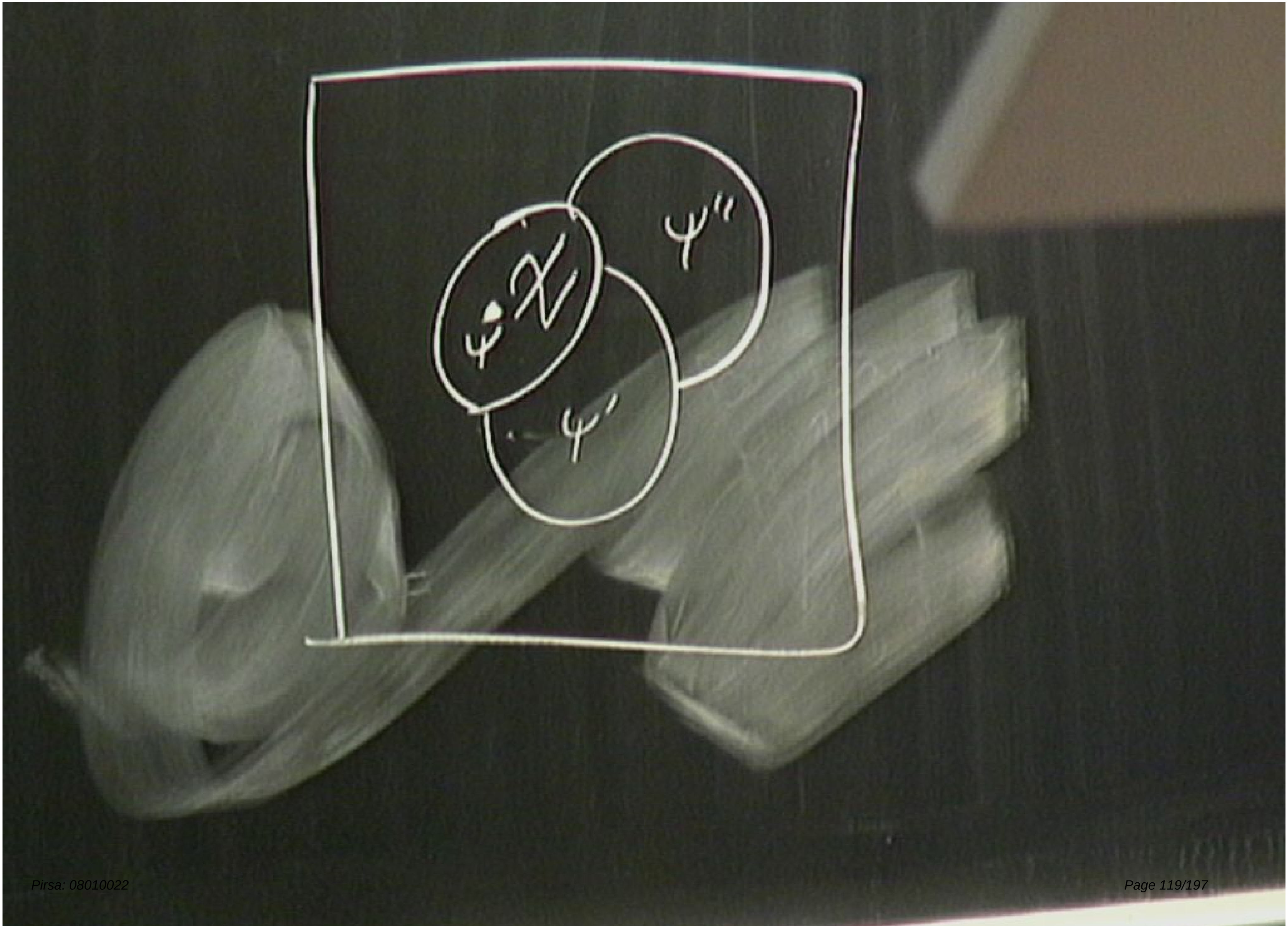
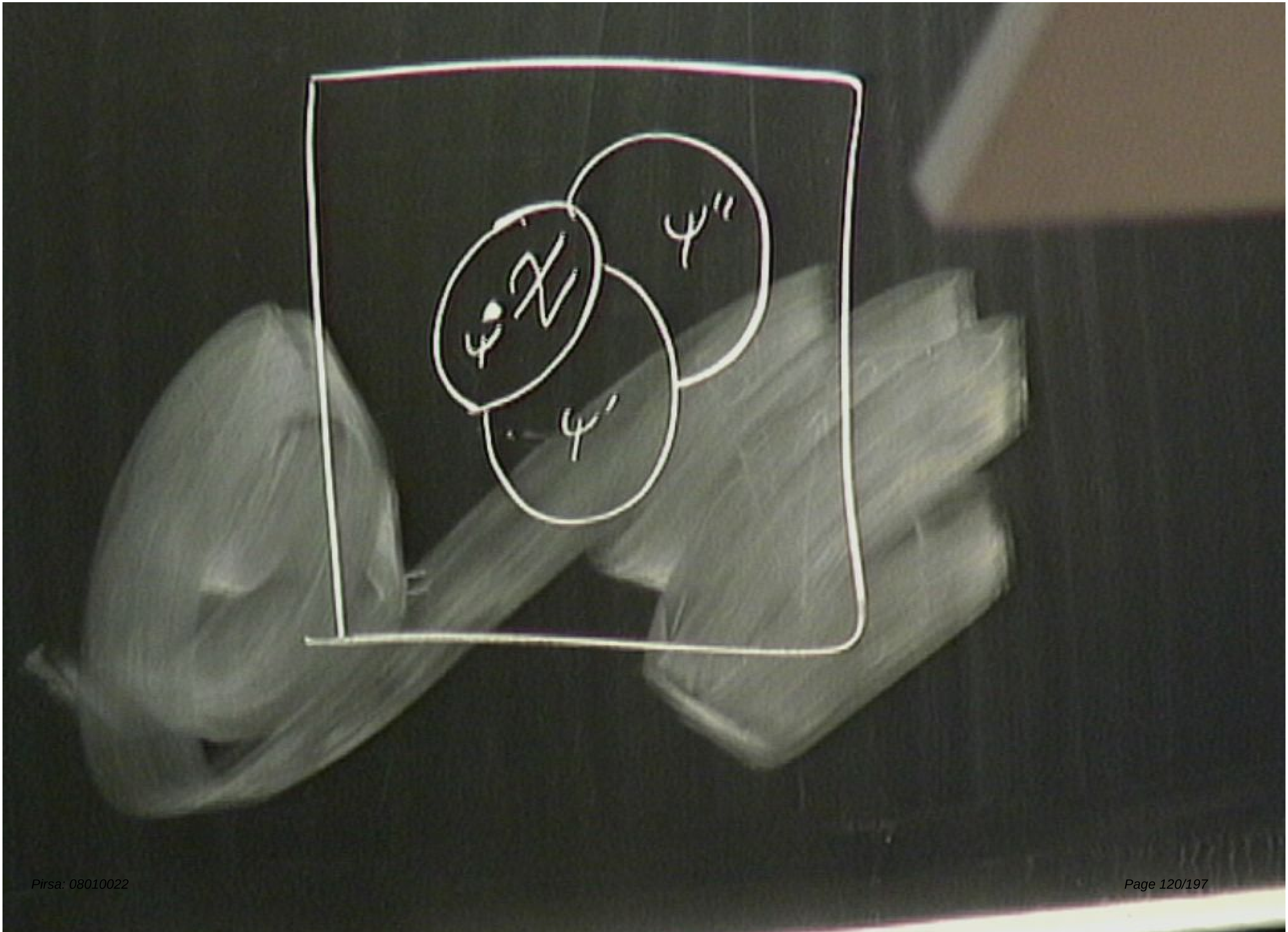

X



ψ''
ψ'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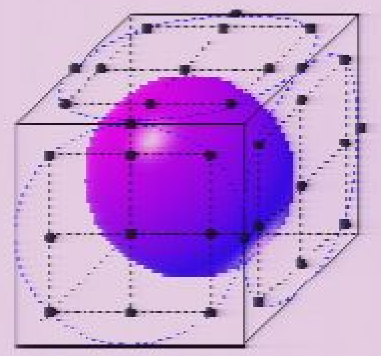

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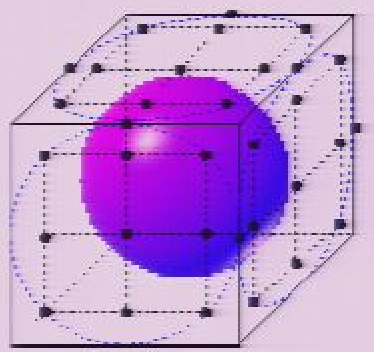

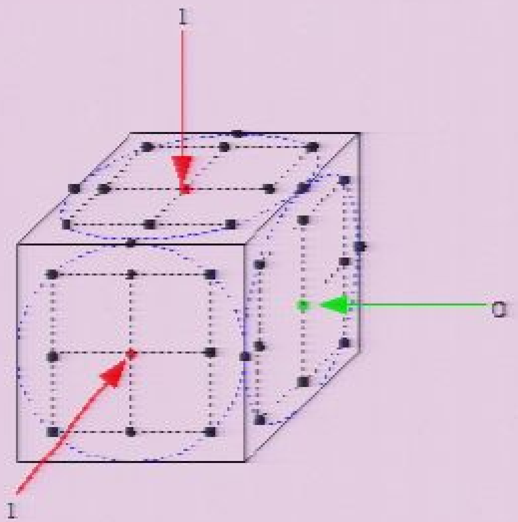

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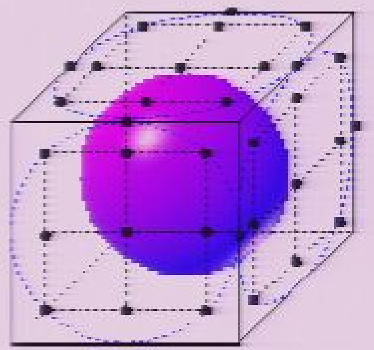

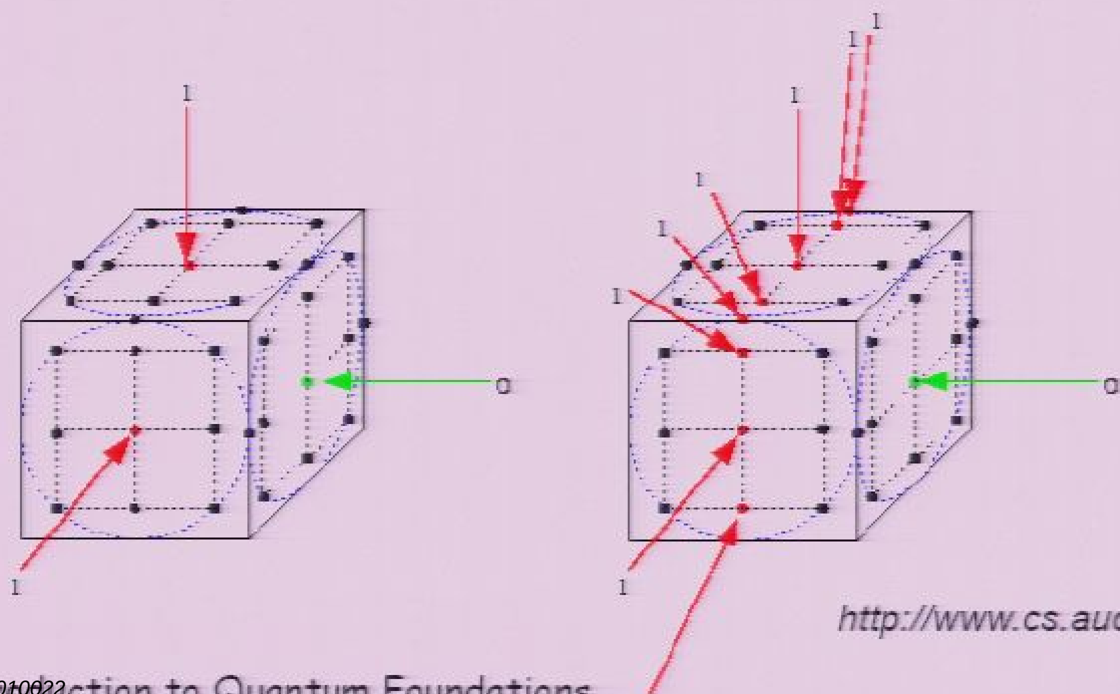

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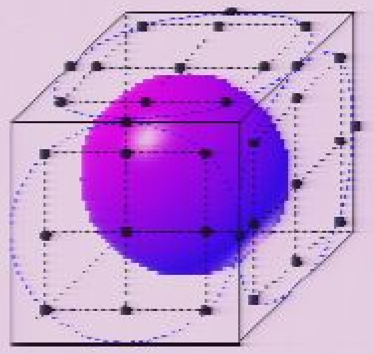

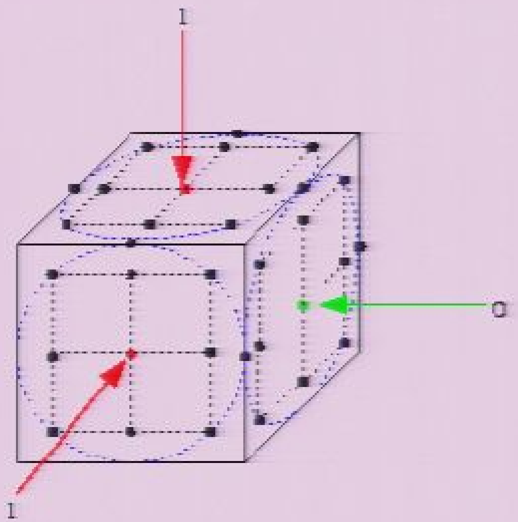

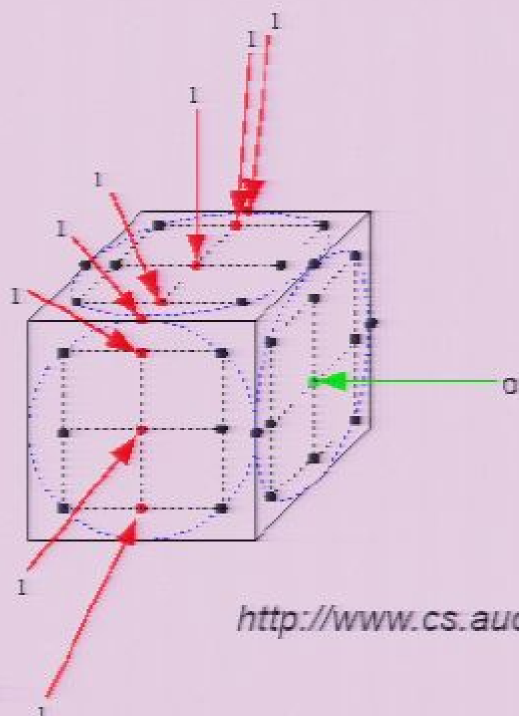

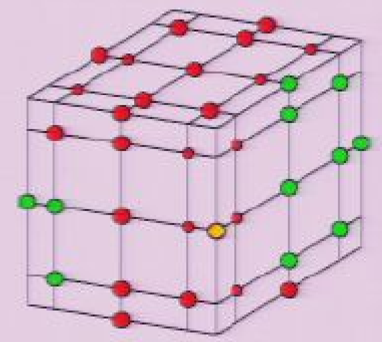

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- "Asking a question" replaces "Making a measurement" but does this help?

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If a consistency condition is met, all normal probability rules can be used.

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Summary

"One way or another, God has played us a nasty trick.
The voice of nature has always been faint,
but in this case it speaks in riddles and mumbles as well."

T. Maudlin "Quantum Non-locality and Relativity"