Title: Introduction to quantum foundations (Part 1B)

Date: Aug 27, 2007 10:30 AM

URL: http://pirsa.org/07080039

Abstract:

5. Two Choices Yield Four Strategies

We must choose between:

(Dynamics): We propose new dynamical laws that evolve a superposition into a (proper) mixture.

(ExtraValues) We ascribe to certain quantities values beyond those prescribed by the eigenvalue-eigenstate link.

"We only know the macrorealm *appears* definite" prompts another choice:

(DefMac): We secure a definite macrorealm; and expect a 'classical psychophysics' to account for experience.

(DefApp): We allow an indefinite macrorealm, but secure that it *appears* definite—and so expect some 'quantum psychophysics'.

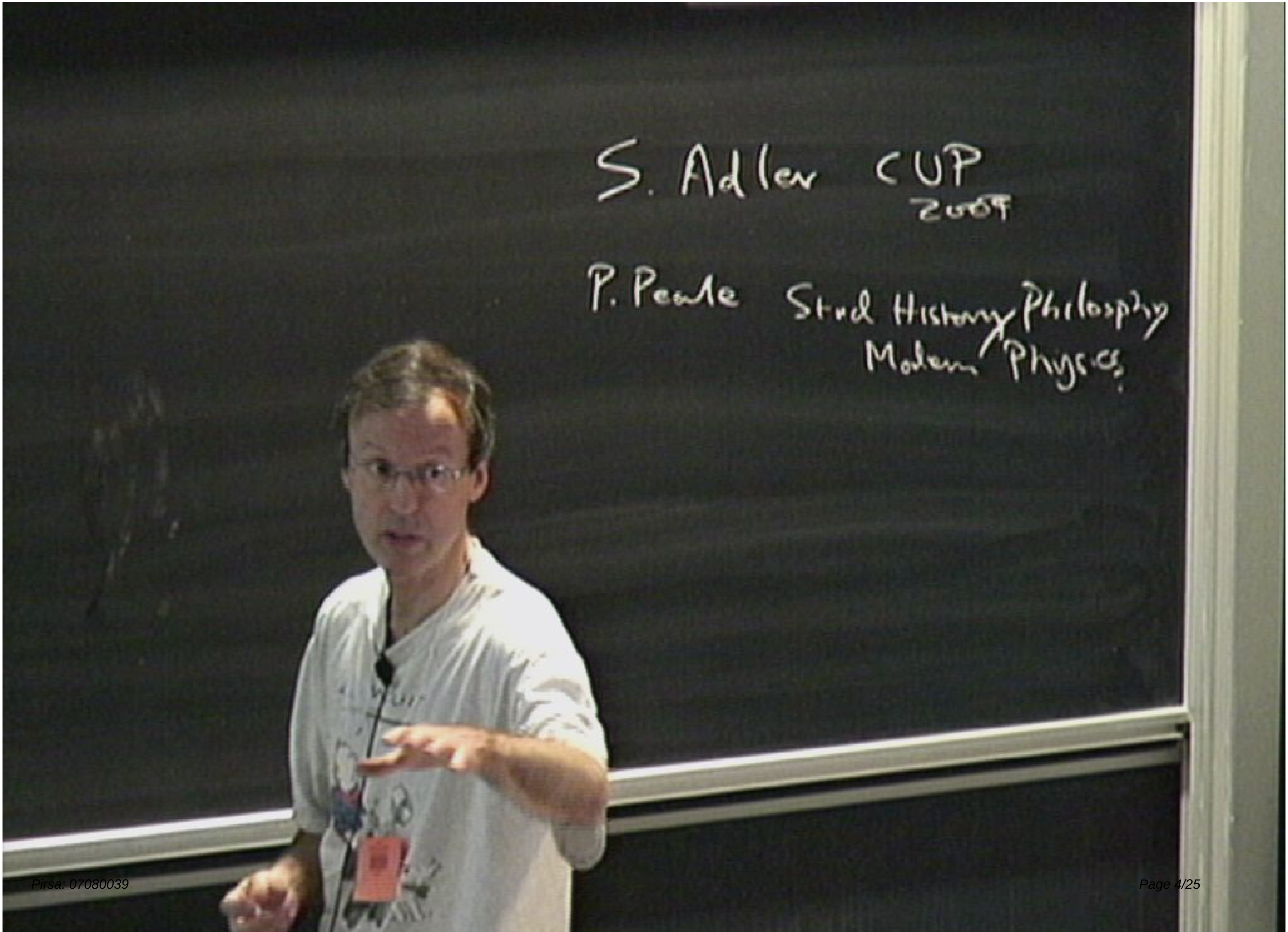
Hence, four strategies:

(Dynamics) and (DefMac):
Models of the 'collapse of the wave-packet' by e.g. Gisin, Ghirardi, Rimini, Weber, Pearle, Percival, Penrose.

(Dynamics) and (DefApp):
Consciousness collapses the wave-packet; e.g. Wigner, Stapp.

(ExtraValues) and (DefMac):
The pilot-wave interpretations of de Broglie and Bohm.

(ExtraValues) and (DefApp):
The 'many worlds' interpretation of Everett et al.
The quantum state of the universe Ψ is a superposition of states corresponding to many different definite macrorealms.
And all these definite macrorealms are actual.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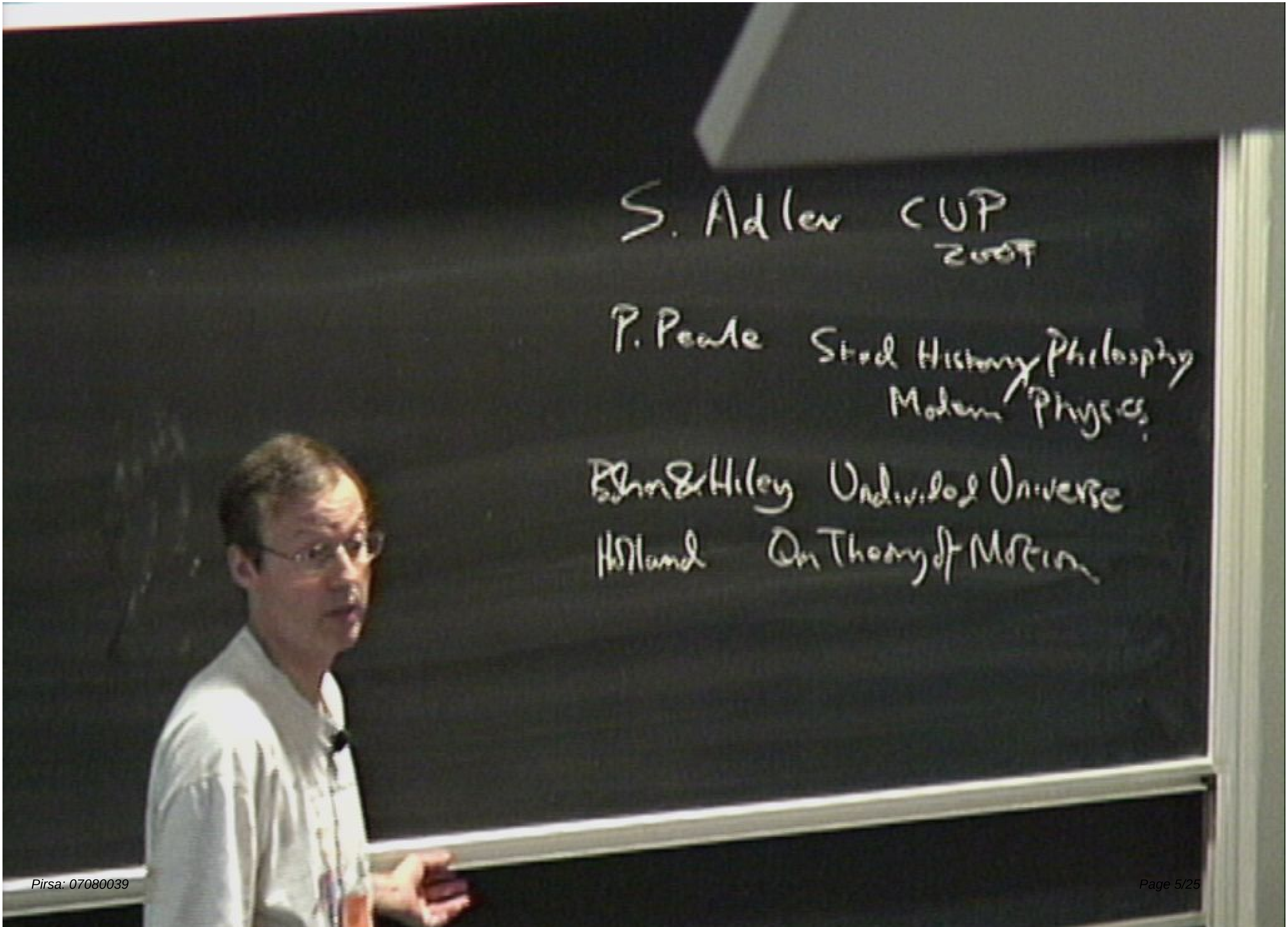
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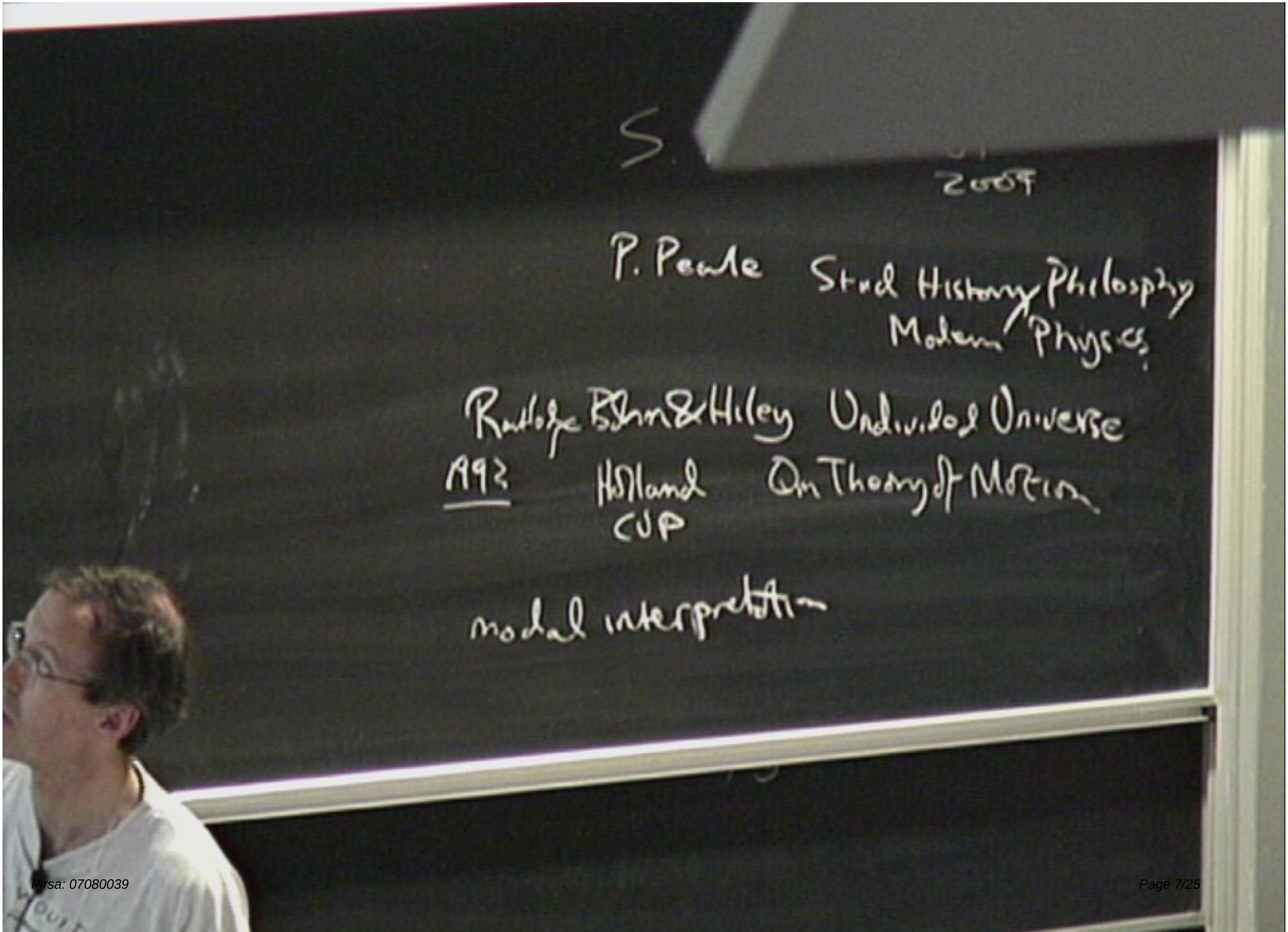
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modal interpretation

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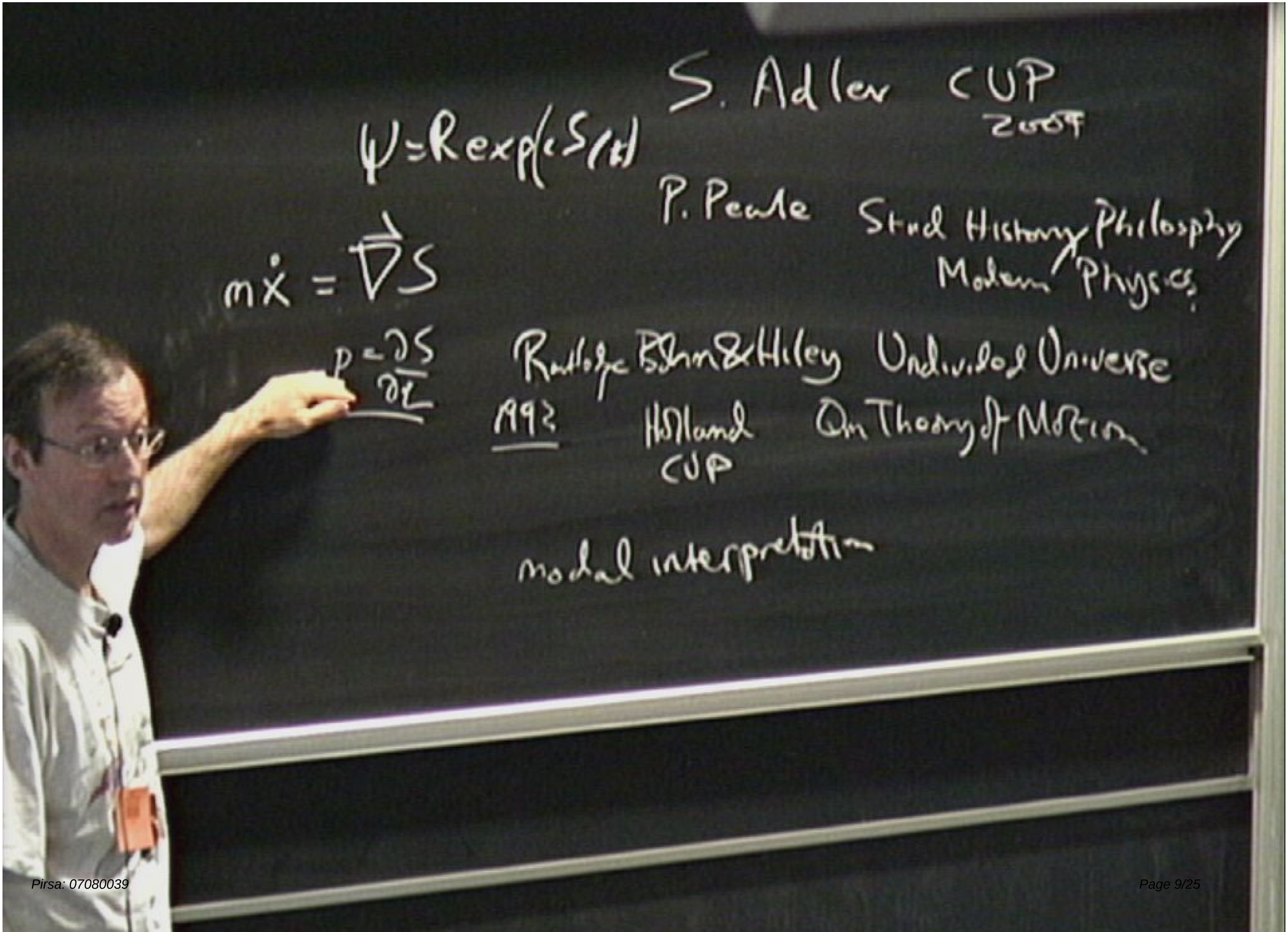
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ψ = R exp(iS/ħ)
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mẋ = ∇S
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Holland On Theory of Motion
CUP
modal interpretation

S. Adler CUP 2004

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$m\dot{x} = \vec{\nabla} S$

$p = \frac{\partial S}{\partial x}$

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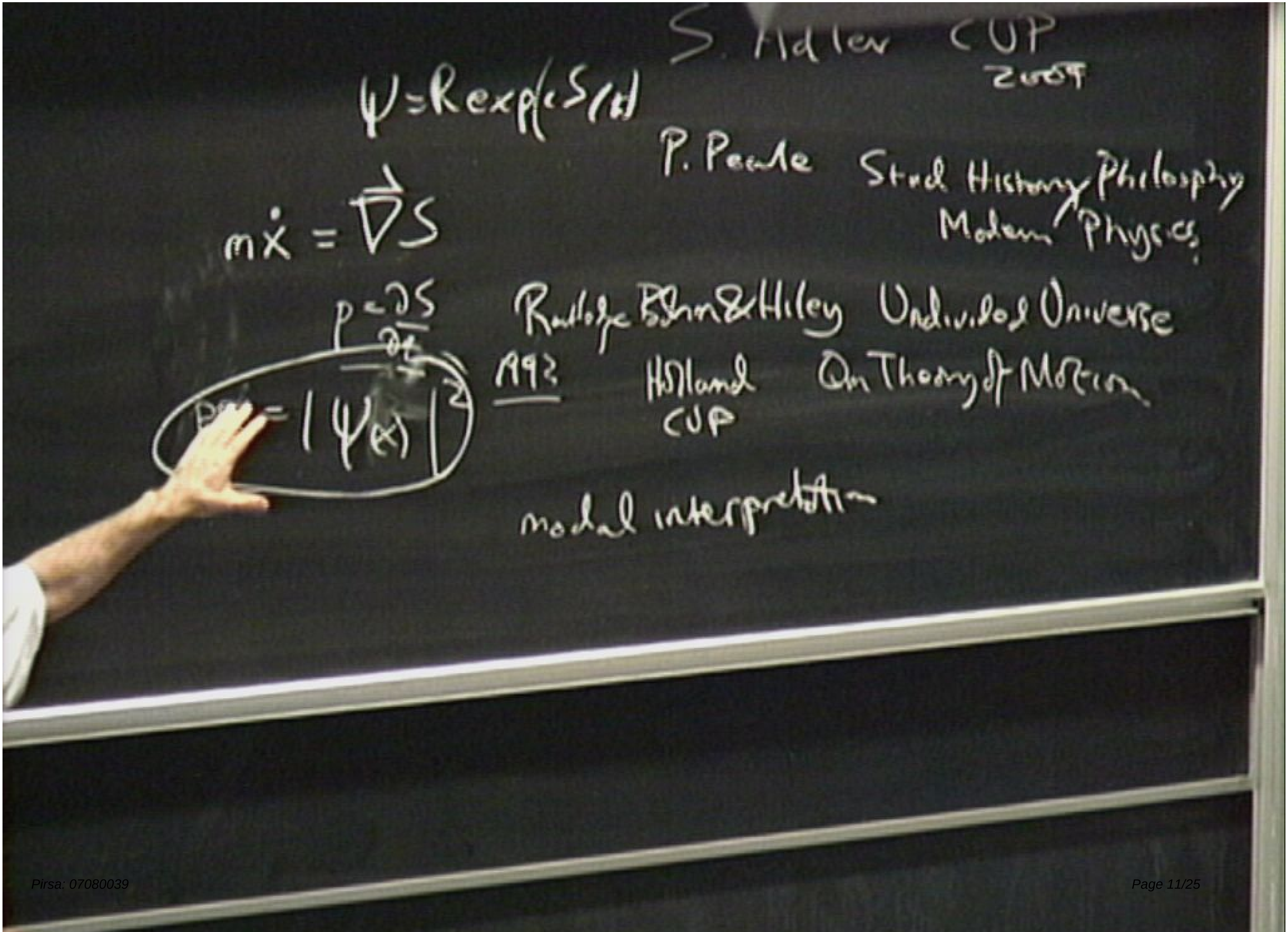
pr

modal interpretation


S. Adler CUP
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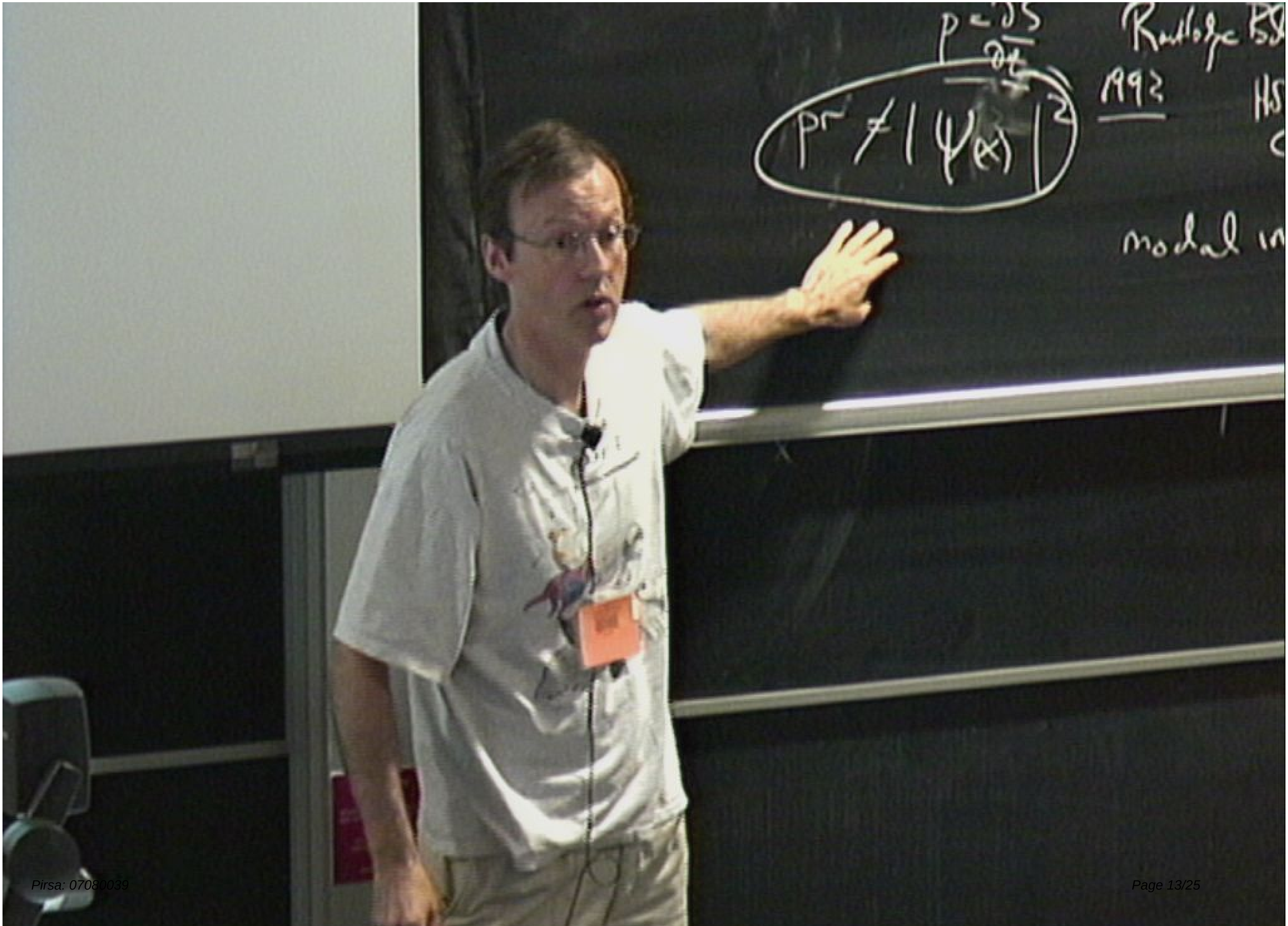
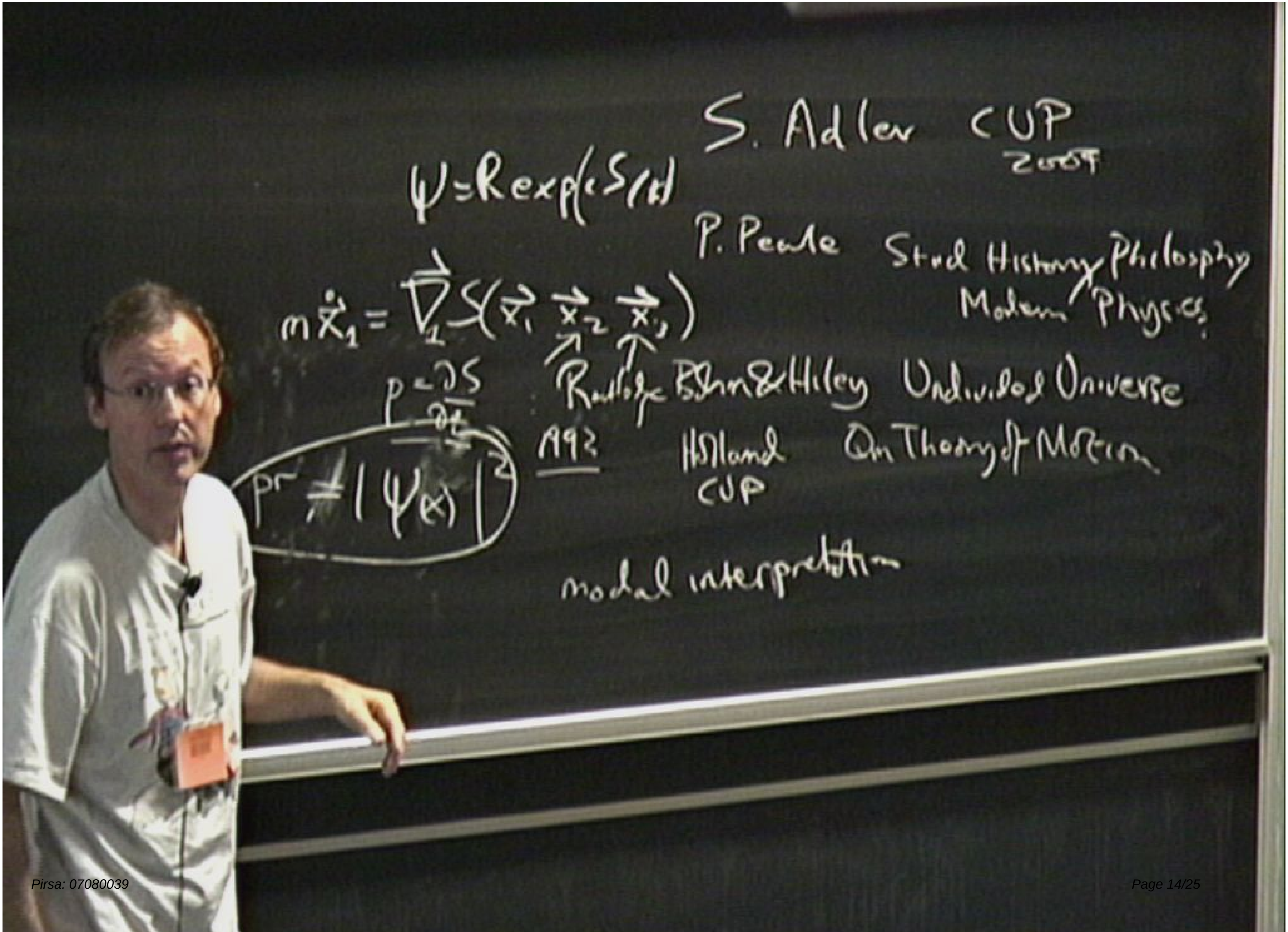
$p^{r} = |\psi(x)|^2$

modal interpretation


p = ∂S/∂q
p ≠ |ψ(x)|²
1992


S. Adler CUP
2004
$\psi = R\exp(iS/\hbar)$
P. Pearle Stud History Philosophy Modern Physics
$m\dot{\vec{x}}_1 = \vec{\nabla}_1 S(\vec{x}_1, \vec{x}_2, \vec{x}_3)$
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Bohm & Hiley Undivided Universe
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$p^r \neq |\psi(x)|^2$
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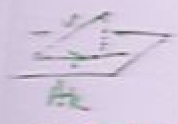
The Projection Postulate: "collapse of the wave packet"

① "Orthodoxy" (von Neumann, Heisenberg; not Bohr) says

<u>If</u> you measure a quantity on a system that is in v, and you get a_k corresponding to subspace A_k

<u>then</u> the state immediately after measurement is <u>not</u> v, but



the projection of v onto A_k
(divided by its own length: "renormalized")

② Indeterminism & Chances

ⓐ can collapse onto any A_k for which $P_{A_k}(v) \neq 0$
ⓑ does so with Born probability $\|P_{A_k}(v)\|^2$

③ Justification?

ⓐ Why should a unitary evolution of a composite induce a Proj Post evolution of a component?
(In fact, at first sight suitable unitaries seem to — they give mathematically right mixtures
But actually, not interpretatively right
They need to be ignorance-interpretable
But they are only improper mixtures

But ...

ⓑ Empirically successful: in particular
PP ⇒ an immediately repeated measurement is certain to yield again whatever a_k was first got

and

ⓒ Mathematically natural
It makes an operational definition of commensurability of P_A, P_B
equivalent to: $[P_A, P_B] = 0$

and ...

Mixtures

① Given two probability distributions pr_1 and pr_2, a convex combination

$$pr(\ ) := \lambda\, pr_1(\ ) + \mu\, pr_2(\ ) \qquad \lambda+\mu=1 \quad \lambda,\mu>0$$

is itself a probability distribution.

Generally: $pr := \sum_i \lambda_i pr_i$ is a prob^y distrib^n if $\sum \lambda_i = 1$, $\lambda_i > 0$

② Physical idea: "ignorance interpretation"

Think of a large ensemble of systems, of which a proportion λ_i are described by pr_i

(Classically, a pure state is a trivial pr_i; i.e. it assigns 1 or 0 to every event A
dispersion-free
(width, spread

But in QT: the pr_i are given by vectors v_i)

③ Improper mixtures

Given an ensemble of composite systems, in some state (maybe mixed) which determines states for component systems:-

If a component's state is an ignorance-mixture then the composite state must be "
(viz. at least as regards this component)

. QT, a pure composite state in general determines mixtures as the states of components

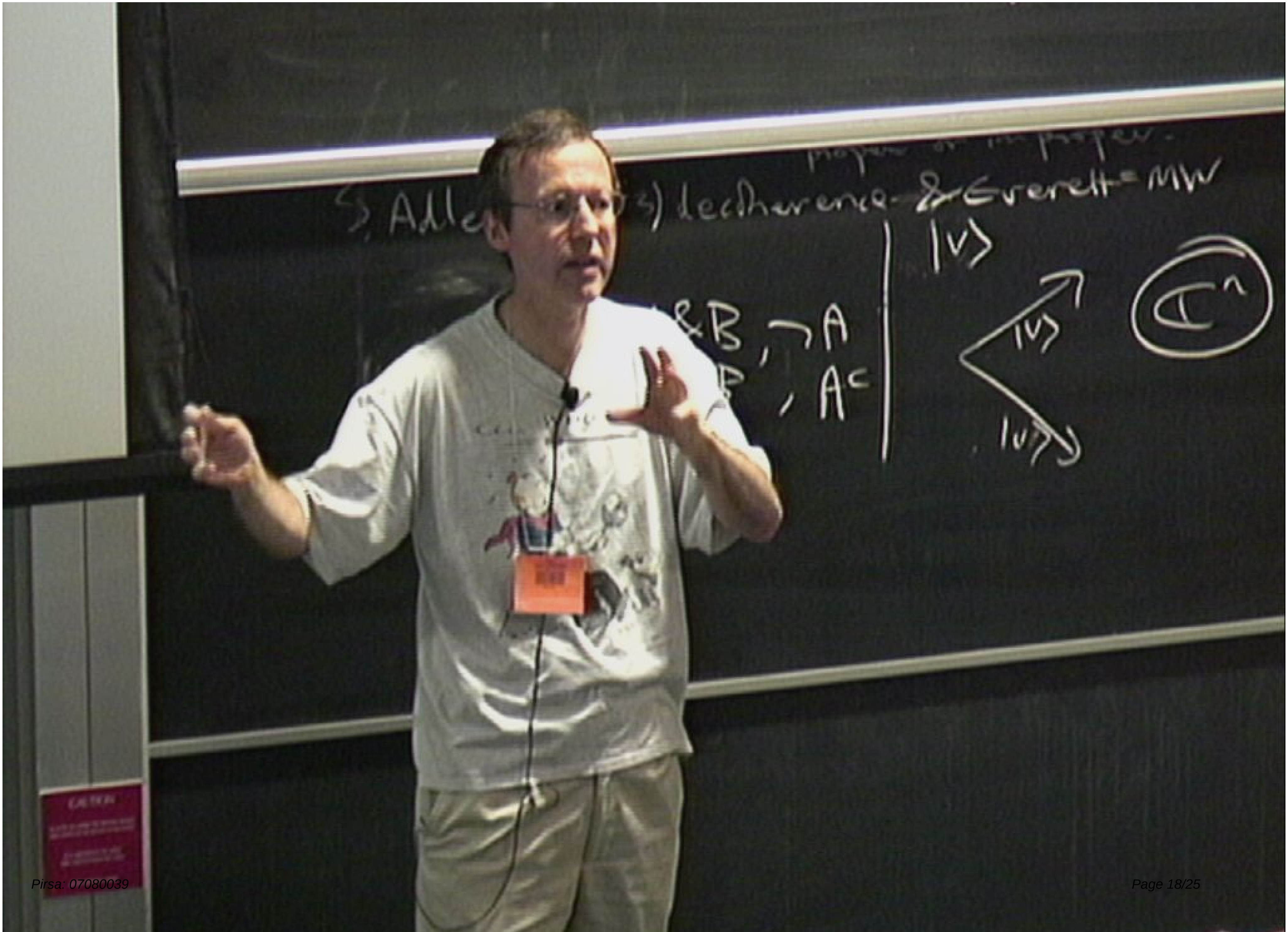
So these can't be ignorance-interpreted.
They are called "improper".

④ Mixtures ≠ Superpositions!

A pure state v, and a quantity Q for which it is a superposition determine a corresponding mixture

$v = \sum_i c_i v_i$ determines $\rho = \sum_i |c_i|^2$ "Being in v_i"
scalars eigenstates

v and ρ fix identical prob^y distrib^{ns} for Q
But not for Q' ... "interference"


decoherence
Everett = MW
|v⟩
¬A
A^c
ℂ^n

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scalars eigenstates
v and ρ fix identical prob distribⁿˢ for Q
But not for Q', which doesn't commute with Q. "interference terms"

The Projection Postulate and Mixtures

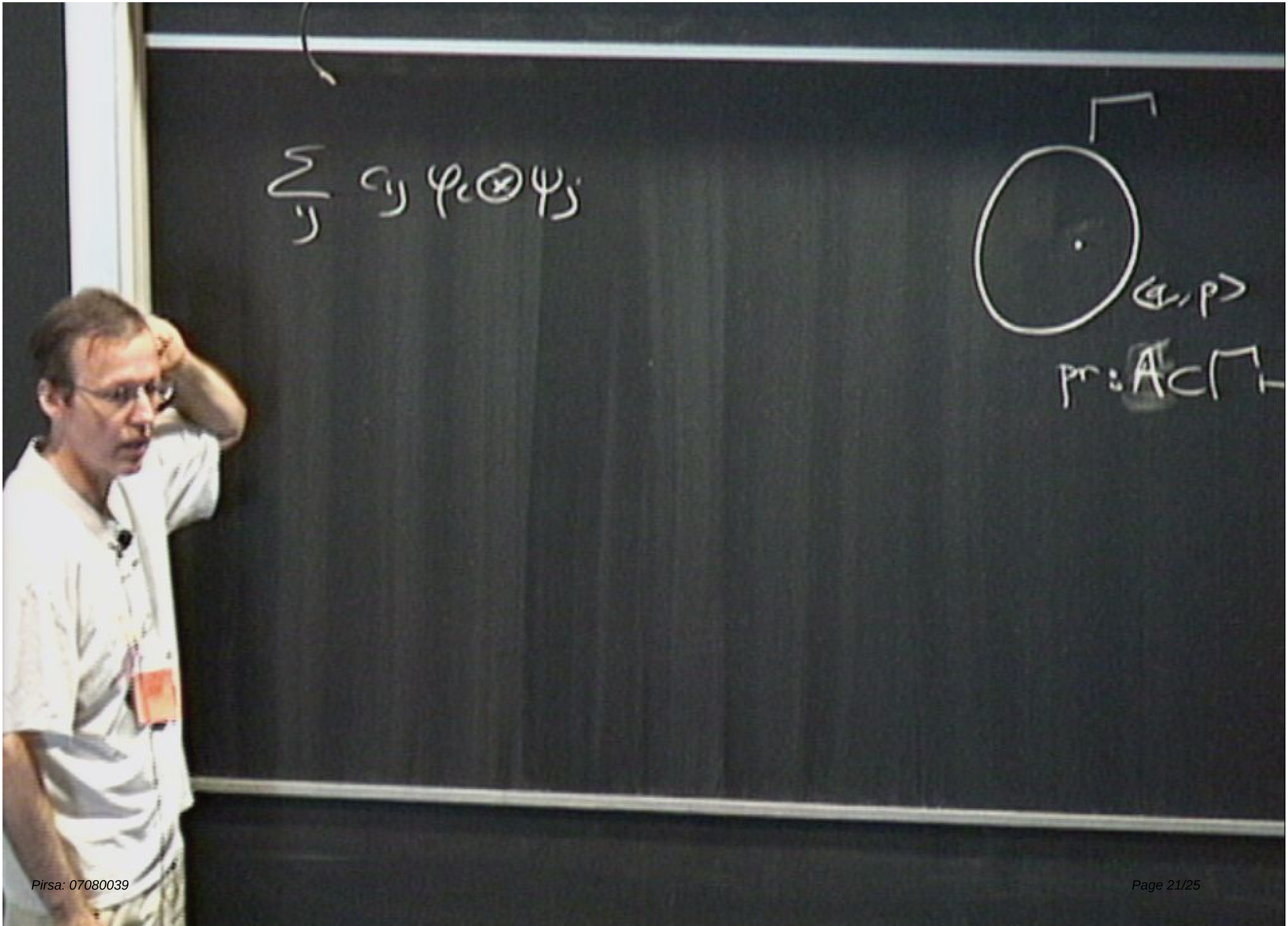
① Assume a proj. post. measmt
of a (for simplicity: maximal) quantity $A = \sum_n a_n P_{u_n}$
on a system in state $v = \sum \lambda_n u_n$
Ask: what is final state?
Selective measmt: one of the u_n
Non-selective measmt:–
Physically: a proper mixture of the u_n with weights $|\lambda_n|^2$
Mathematically: not v! It gives wrong probabilities
for subsequent measmt of B s.t. $[A, B] \neq 0$.

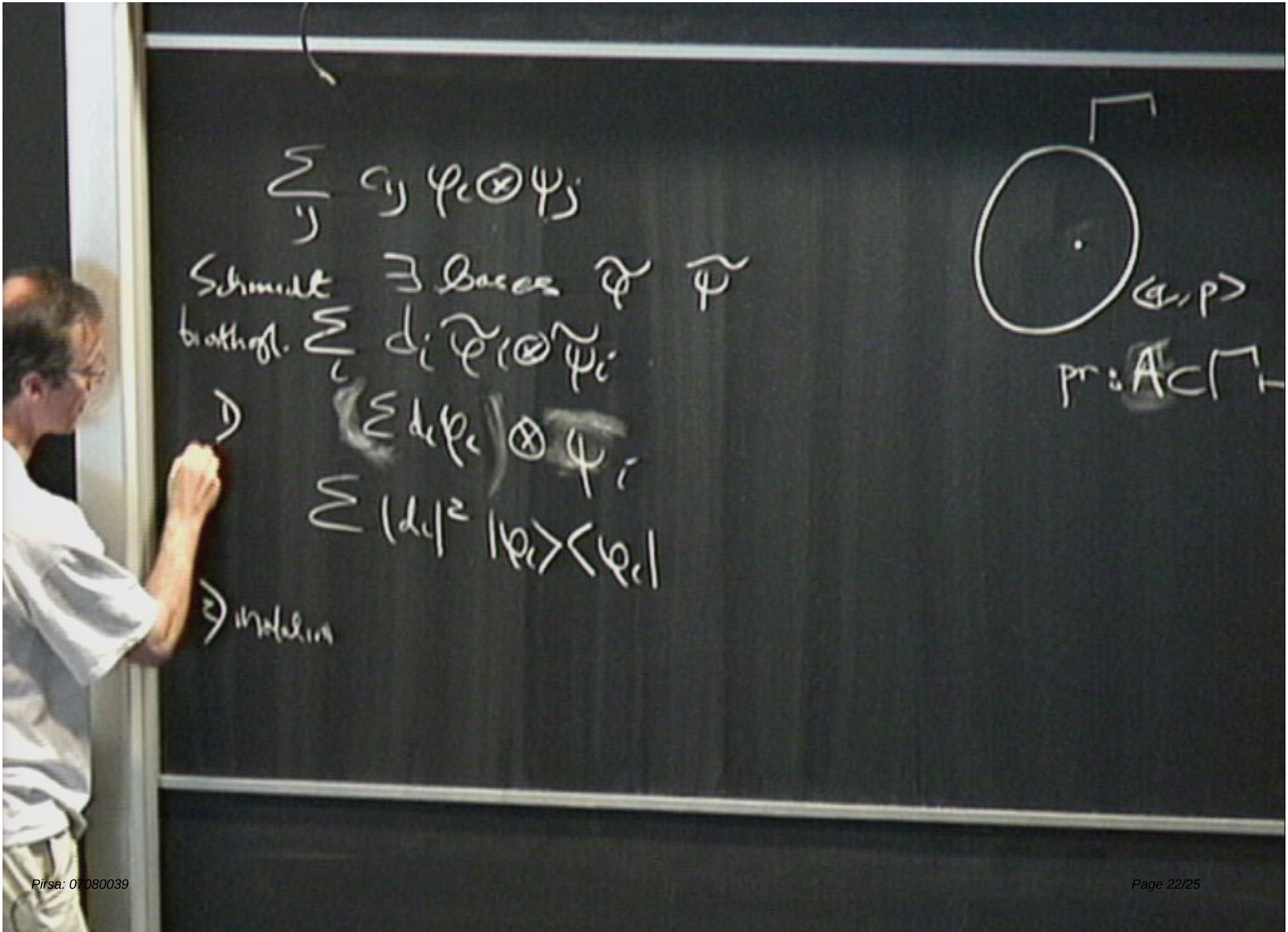
② ⓐ Define trace of any $B: \mathcal{H} \to \mathcal{H}$ relative to orthonormal basis $\{e_i\}$
by: $\mathrm{tr}(B) := \sum_n \langle e_n, B(e_n) \rangle$ in fact, basis-independent
ⓑ tr is a linear functional: $\mathrm{tr}(B + C) = \mathrm{tr}(B) + \mathrm{tr}(C)$
$\mathrm{tr}(\omega B) = \omega\, \mathrm{tr}(B)$ $\forall$ scalars ω
ⓒ prob(get a_k if measure A on state v) $\underset{\text{Born rule}}{=} |\lambda_k|^2 = \mathrm{tr}(P_{[v]} \cdot P_{[u_k]})$
So: the initial state is equally well represented by $P_{[v]}$,
if we use this to calculate Born probabilities.

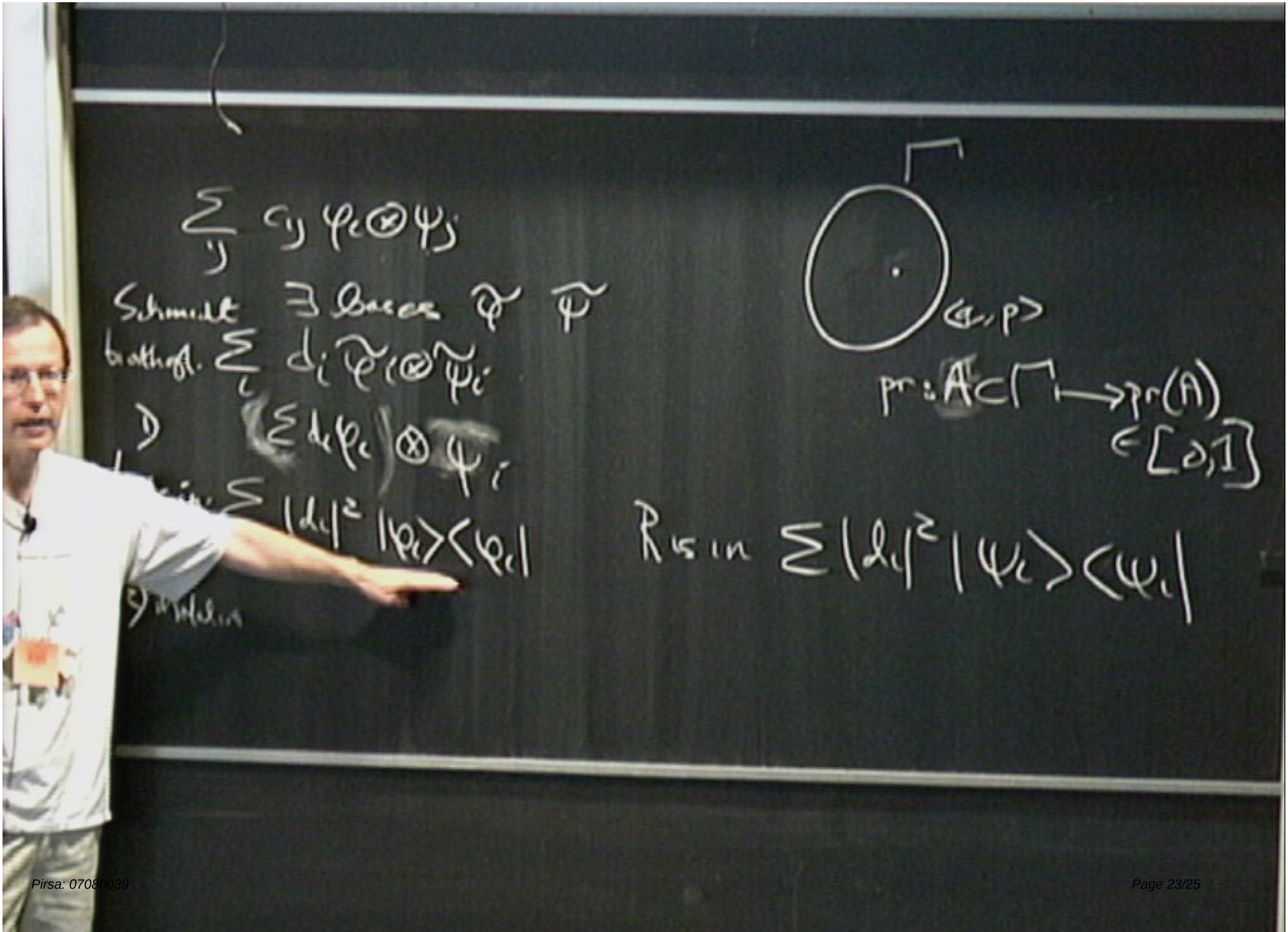
③ Idea
Represent the proper mixture of the u_n, with weights ω_n,
($\sum \omega_n = 1$) by: $W = \sum \omega_n P_{[u_n]}$
and extract probabilities by:
prob(get a_k, if msre A on ensemble) $= \mathrm{tr}(W \cdot P_{[u_k]})$
By linearity of trace, this $= \sum_n \omega_n \cdot$ prob(get a_k, if msre A on u_n)
W is a density matrix (aka: statistical operator)

④ So non-selective proj. post. measmt of A on v yields:–
$P_{[v]} \longrightarrow \sum_n |\lambda_n|^2 P_{[u_n]}$ where $v = \sum \lambda_n u_n$

NB. Final mixture depends on quantity measured
If B has eigenbasis $\{v_n\}$ and $v = \sum \mu_n v_n$,
then measuring B gives:–
$P_{[v]} \longrightarrow \sum |\mu_n|^2 P_{[v_n]}$


$\sum_{ij} c_{ij}\, \varphi_i \otimes \psi_j$
Γ
$\langle q, p \rangle$
$pr: A \subset \Gamma$


$\sum_{ij} c_{ij}\, \varphi_i \otimes \psi_j$
Schmidt $\exists$ bases $\tilde{\varphi}$ $\tilde{\psi}$
biorthog. $\sum_i d_i\, \tilde{\varphi}_i \otimes \tilde{\psi}_i$
1) $\left(\sum d_i \varphi_i\right) \otimes \psi_i$
$\sum |d_i|^2 |\varphi_i\rangle\langle\varphi_i|$
2)
Γ
$\langle q, p\rangle$
pr: $A \subset \Gamma$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$\sum |d_i|^2 |\varphi_i\rangle\langle\varphi_i|$
Γ
$\langle q, p\rangle$
$pr: A \subset \Gamma \longmapsto pr(A)$
$\in [0,1]$
R is in $\sum |d_i|^2 |\psi_i\rangle\langle\psi_i|$

$$\sum_{ij} c_{ij}\, \varphi_i \otimes \psi_j$$

Schmidt $\exists$ bases $\tilde{\varphi}$ $\tilde{\psi}$

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D $\left(\sum d_i \varphi_i\right) \otimes \psi_i$

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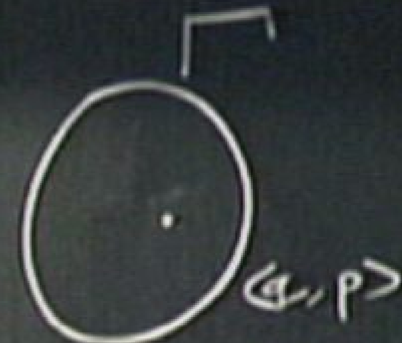
2) Modal interps: Kochen
Dieks 1985–1995
Healey



pr: $A \subset \Gamma \longmapsto pr(A) \in [0,1]$

R is in $\sum |d_i|^2 |\psi_i\rangle\langle\psi_i|$

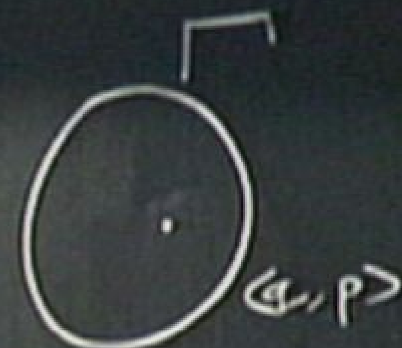
$$\sum_{ij} c_{ij}\, \varphi_i \otimes \psi_j$$

Schmidt $\exists$ bases $\tilde{\varphi}$ $\tilde{\psi}$

biorthogonal. $\sum_i d_i\, \tilde{\varphi}_i \otimes \tilde{\psi}_i$

D $\left(\sum d_i \varphi_i\right) \otimes \psi_i$

L is in: $\sum |d_i|^2\, |\varphi_i\rangle\langle\varphi_i|$



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