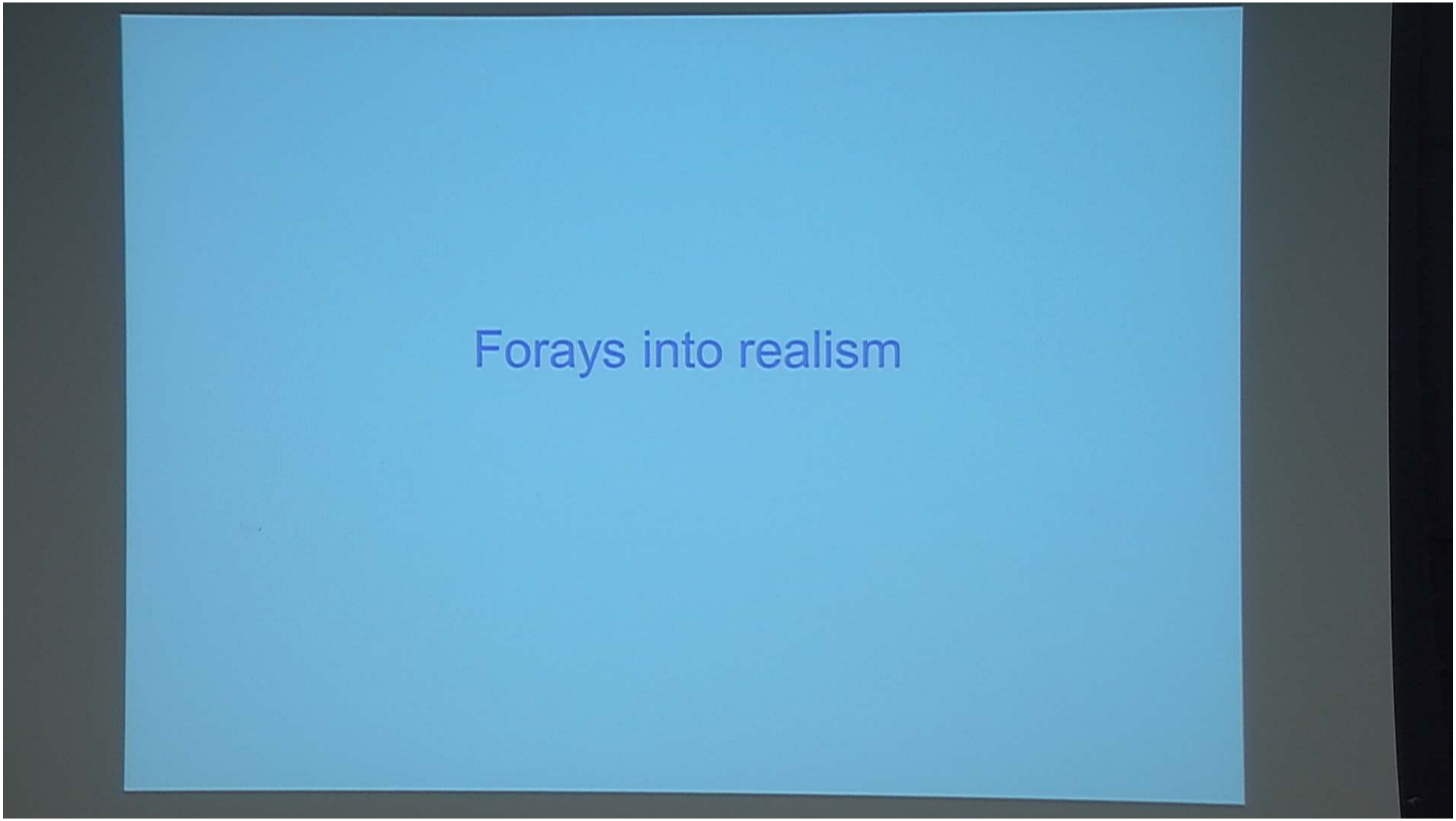
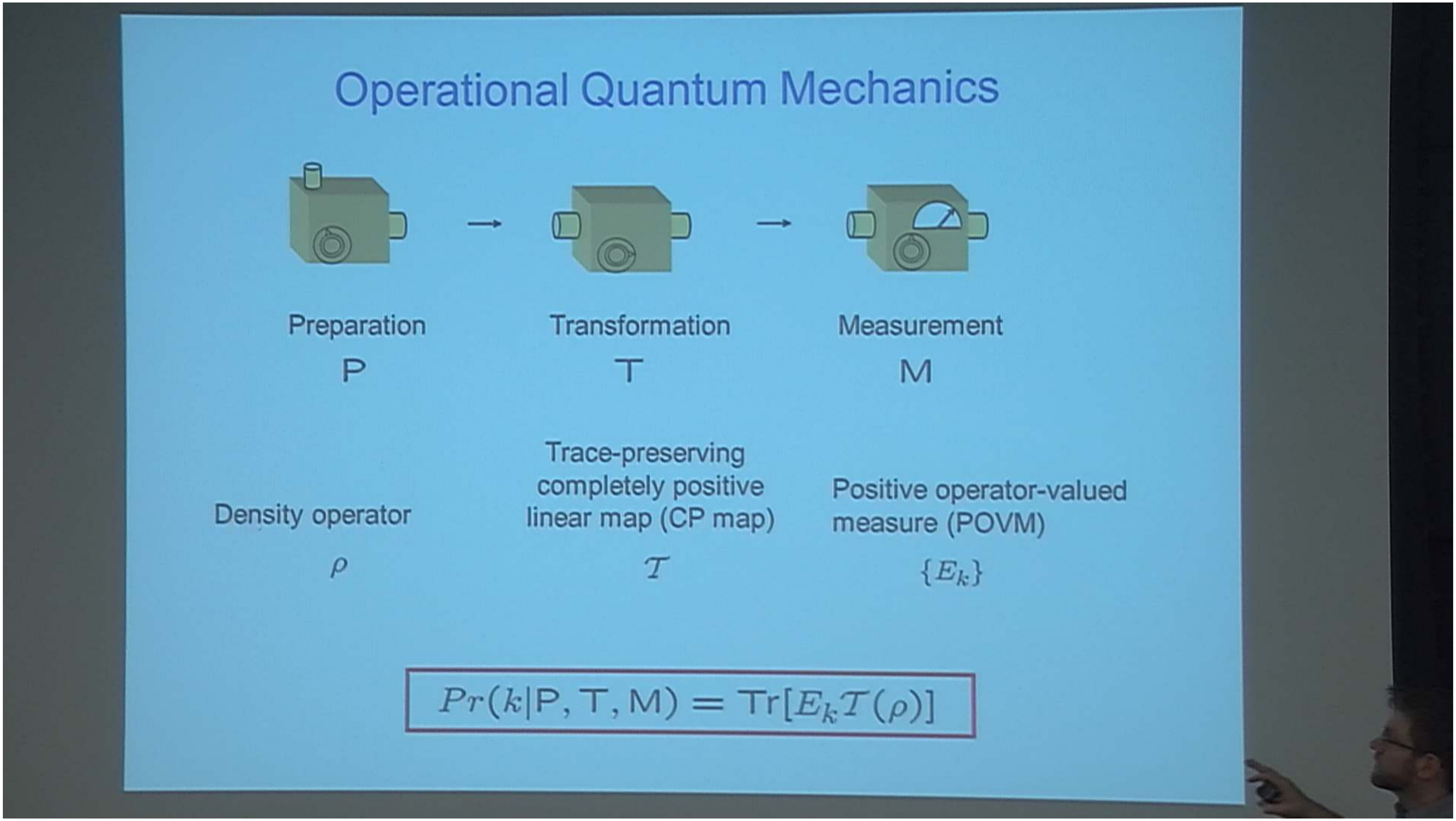
Title: 12/13 PSI - Found Quantum Mechanics Lecture 6

Date: Jan 14, 2013 11:30 AM

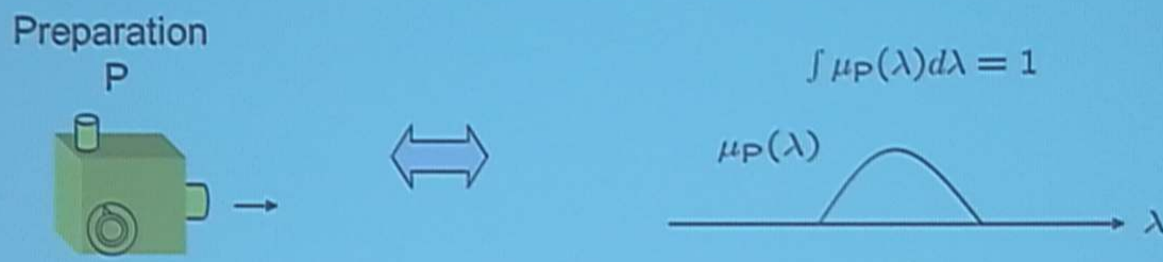
URL: http://pirsa.org/13010073

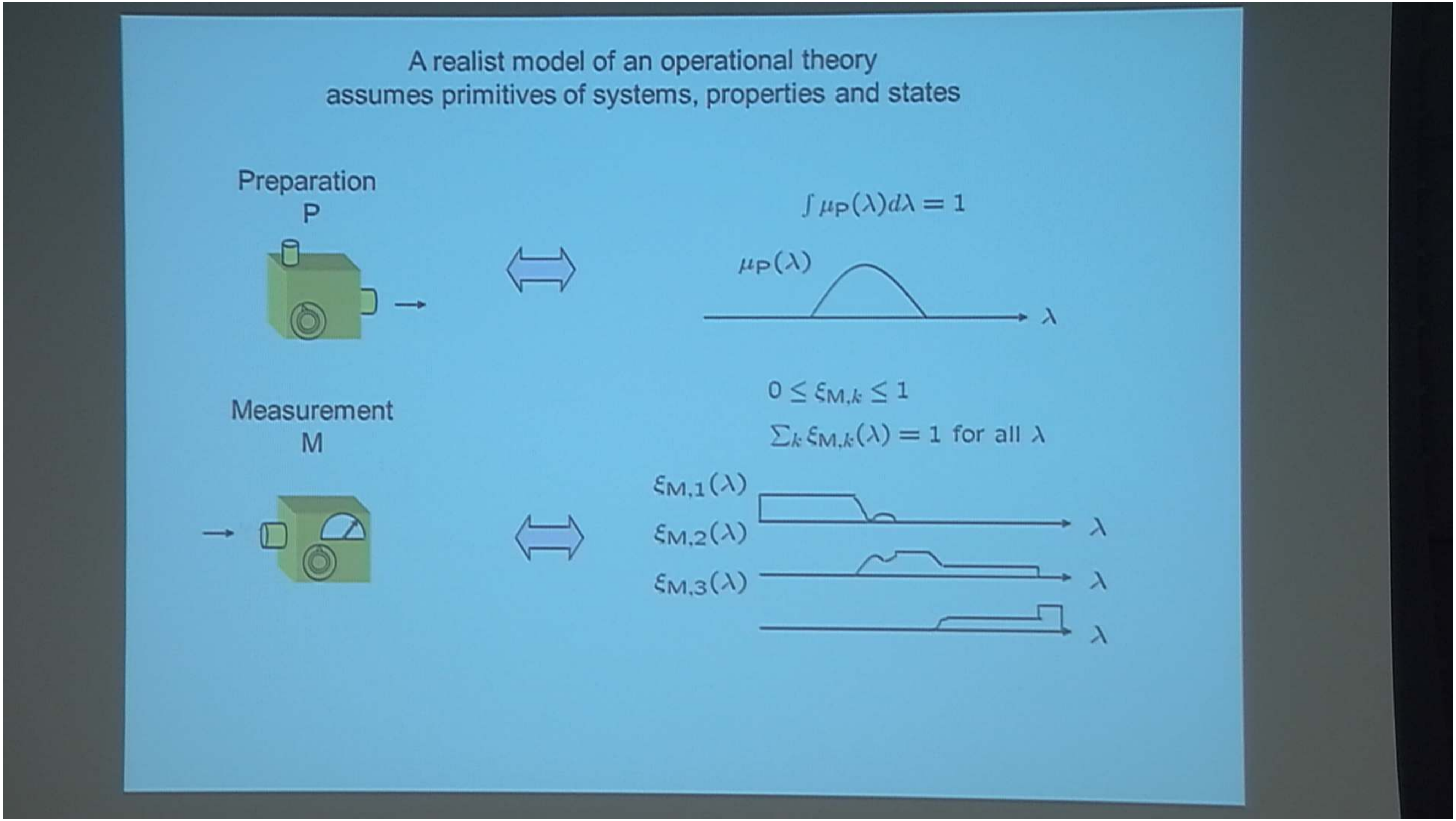
Abstract:

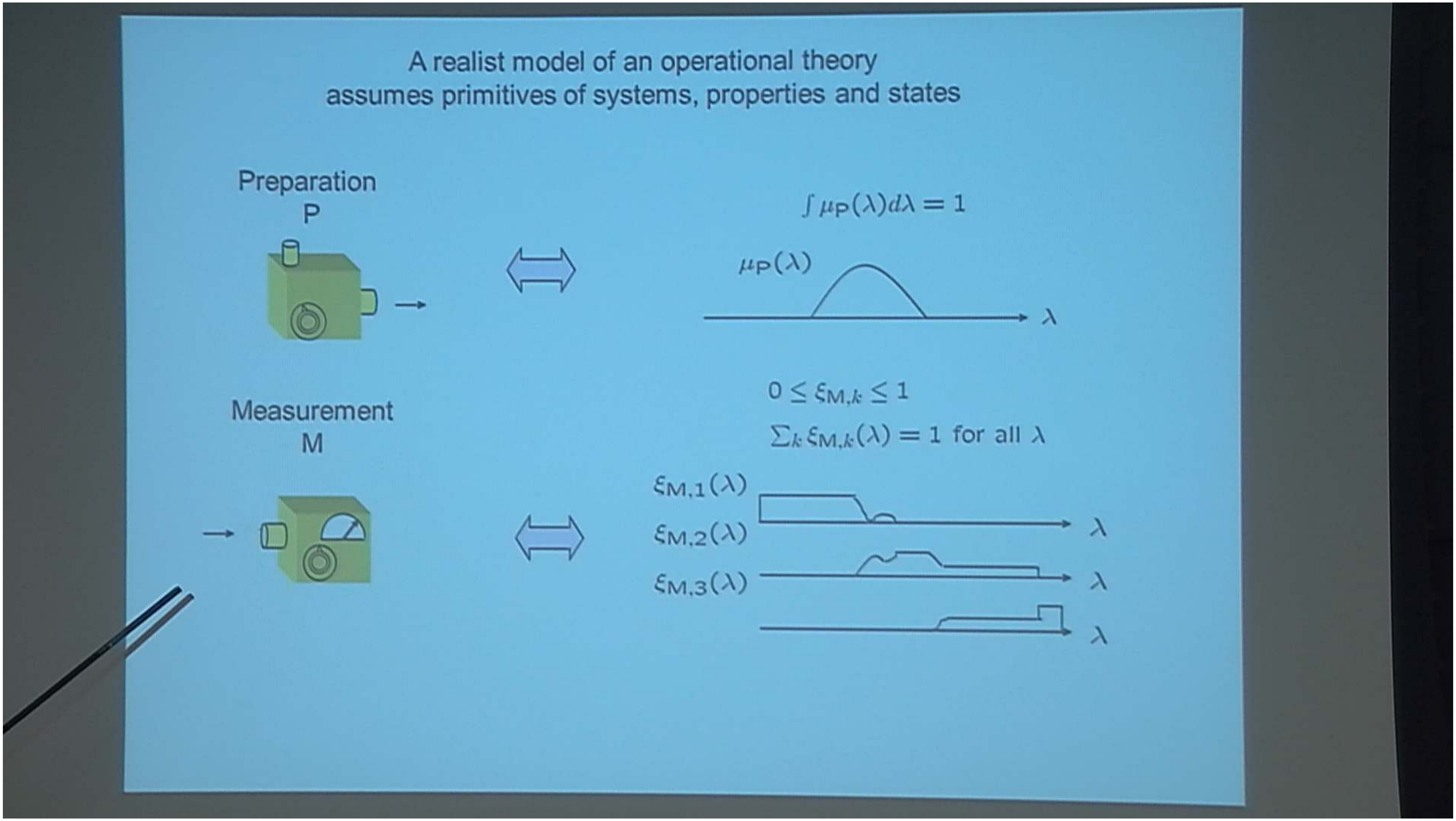

Forays into realism


Operational Quantum Mechanics
Preparation
P
Transformation
T
Measurement
M
Density operator
ρ
Trace-preserving completely positive linear map (CP map)
$\mathcal{T}$
Positive operator-valued measure (POVM)
$\{E_k\}$
$Pr(k|\mathsf{P},\mathsf{T},\mathsf{M}) = \mathrm{Tr}[E_k \mathcal{T}(\rho)]$

A realist model of an operational theory assumes primitives of systems, properties and states




A realist model of an operational theory
assumes primitives of systems, properties and states
Preparation
P
$\int \mu_P(\lambda) d\lambda = 1$
$\mu_P(\lambda)$
λ
Measurement
M
$0 \leq \xi_{M,k} \leq 1$
$\sum_k \xi_{M,k}(\lambda) = 1$ for all λ
$\xi_{M,1}(\lambda)$
$\xi_{M,2}(\lambda)$
$\xi_{M,3}(\lambda)$
λ
λ
λ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$\xi_{M,1}(\lambda)$
$\xi_{M,2}(\lambda)$
$\xi_{M,3}(\lambda)$
λ
λ
λ


P
μP(λ)
λ
Measurement
M
0 ≤ ξM,k ≤ 1
Σk ξM,k(λ) = 1 for all λ
ξM,1(λ)
ξM,2(λ)
ξM,3(λ)
p(k|P, M) = ∫ dλ ξM,k(λ) μP(λ)

A realist model of an operational theory assumes primitives of systems, properties and states

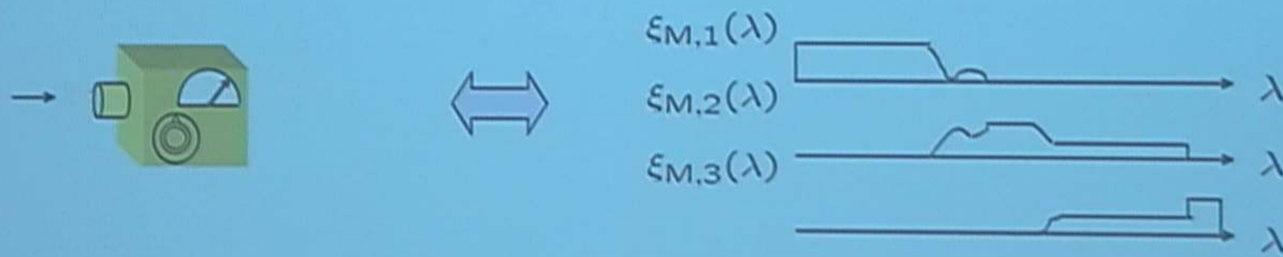
Preparation
P

$\int \mu_{\mathsf{P}}(\lambda) d\lambda = 1$

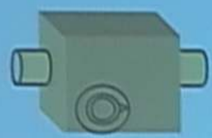
Measurement
M

$0 \leq \xi_{\mathsf{M},k} \leq 1$

$\sum_k \xi_{\mathsf{M},k}(\lambda) = 1$ for all λ

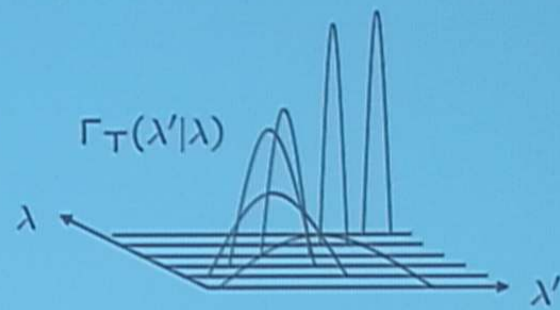


$$p(k|\mathsf{P},\mathsf{M}) = \int d\lambda \, \xi_{\mathsf{M},k}(\lambda) \, \mu_{\mathsf{P}}(\lambda)$$



Transformation

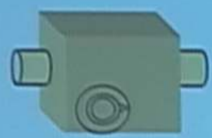
T



$\Gamma_{\mathsf{T}}(\lambda'|\lambda) \geq 0$ for all λ

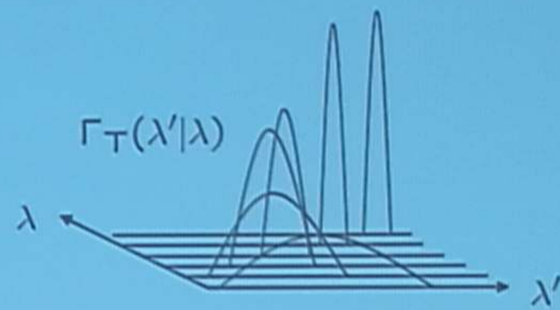
$\int \Gamma_{\mathsf{T}}(\lambda'|\lambda) d\lambda' = 1$ for all λ

$$p(k|\mathsf{P},\mathsf{T},\mathsf{M}) = \int d\lambda' \, \xi_{\mathsf{M},k}(\lambda') \; \int d\lambda \Gamma_{\mathsf{T}}(\lambda'|\lambda) \mu_{\mathsf{P}}(\lambda)$$



Transformation

T



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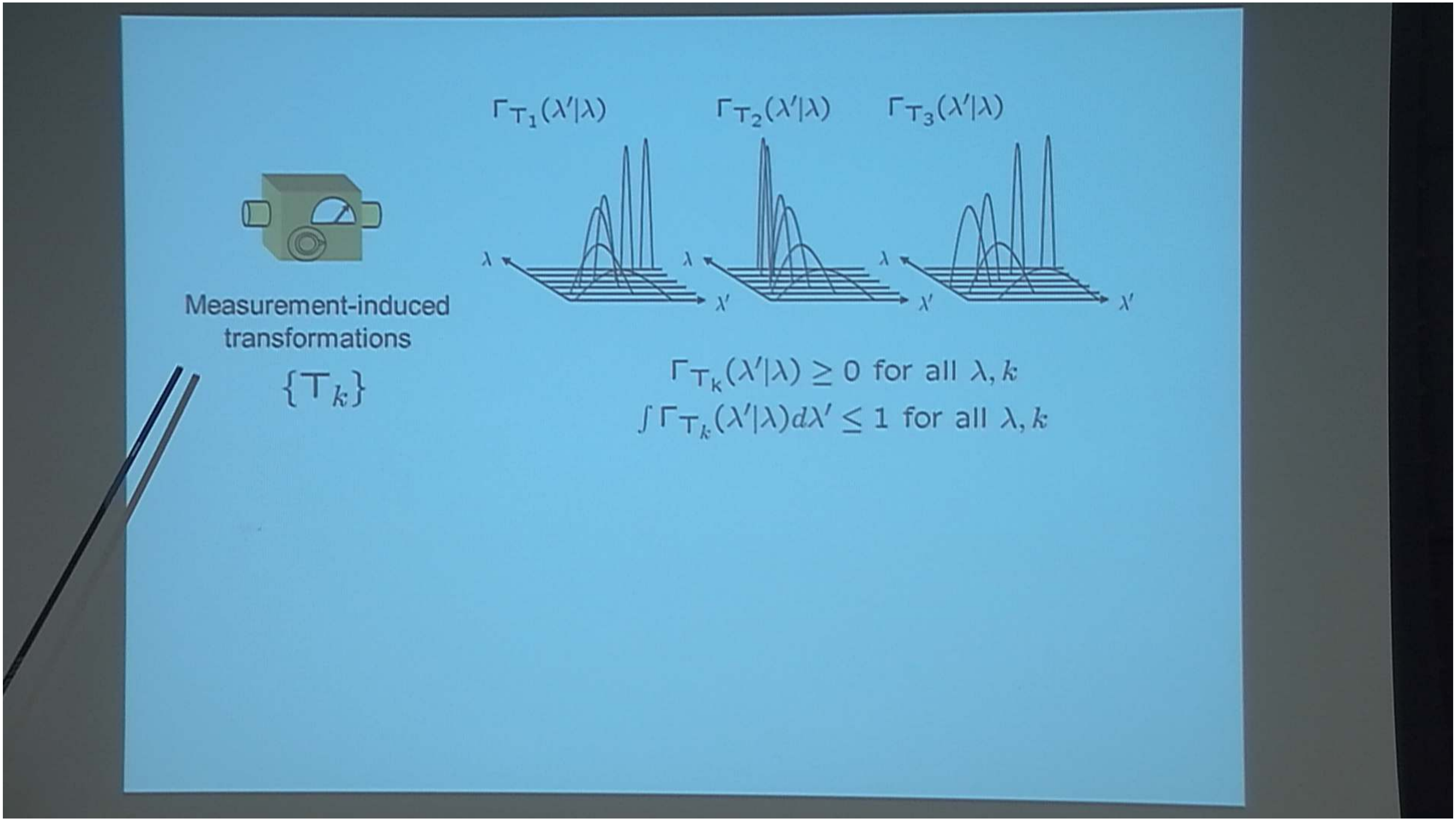
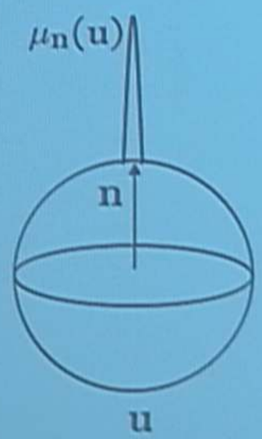

$\Gamma_{T_1}(\lambda'|\lambda)$
$\Gamma_{T_2}(\lambda'|\lambda)$
$\Gamma_{T_3}(\lambda'|\lambda)$
λ
λ'
Measurement-induced transformations
$\{T_k\}$
$\Gamma_{T_k}(\lambda'|\lambda) \geq 0$ for all λ, k
$\int \Gamma_{T_k}(\lambda'|\lambda) d\lambda' \leq 1$ for all λ, k

Recasting the “orthodox” interpretation as a realist model

(for pure states and projective measurements in a 2d Hilbert space)

The orthodox realist model

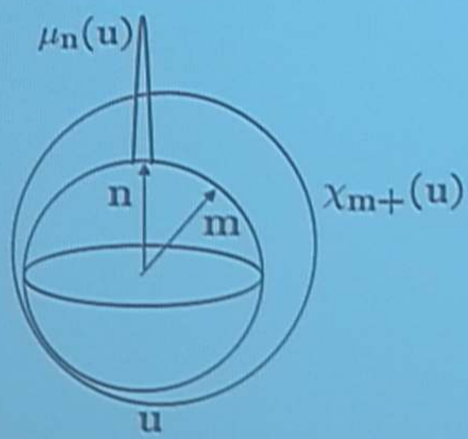
$$|+\mathbf{n}\rangle \leftrightarrow \quad \mu_{\mathbf{n}}(\mathbf{u}) = \delta(\mathbf{u}-\mathbf{n})$$



The orthodox realist model

$$|+\mathbf{n}\rangle \leftrightarrow \quad \mu_{\mathbf{n}}(\mathbf{u}) = \delta(\mathbf{u}-\mathbf{n})$$

$$|+\mathbf{m}\rangle \leftrightarrow \quad \chi_{\mathbf{m}+}(\mathbf{u}) = \frac{1}{2}(1+\mathbf{m}\cdot\mathbf{u})$$



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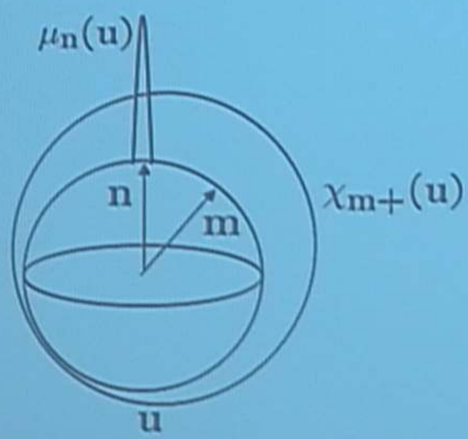
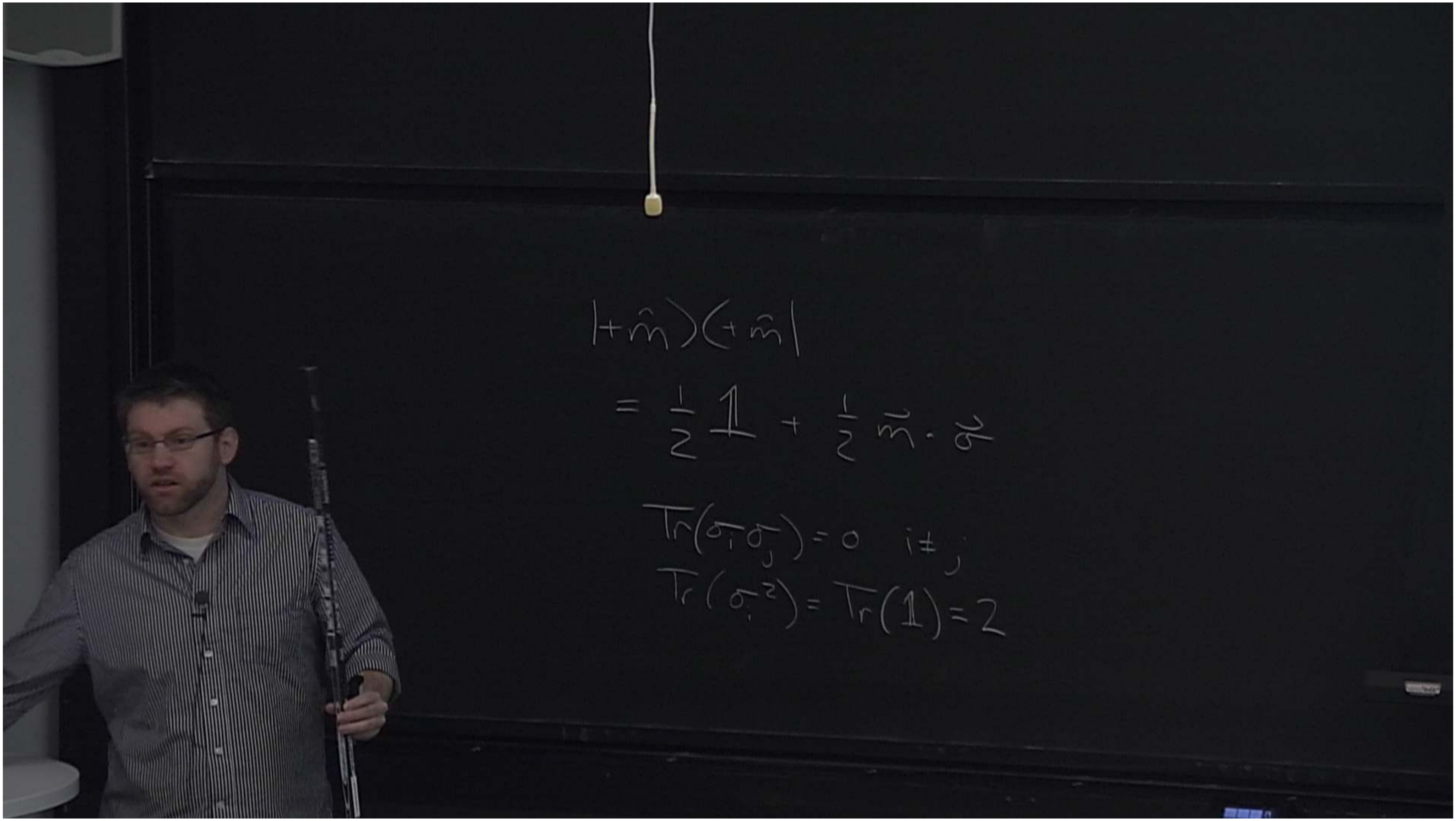
$$\int \mu_{\mathbf{n}}(\mathbf{u})\chi_{\mathbf{m}+}(\mathbf{u})d\mathbf{u} = \frac{1}{2}(1+\mathbf{m}\cdot\mathbf{n})$$
$$= |\langle +\mathbf{m}| + \mathbf{n}\rangle|^2$$




$|+\hat{m}\rangle\langle+\hat{m}|$
$= \frac{1}{2}\mathbb{1} + \frac{1}{2}\vec{m}\cdot\vec{\sigma}$
$\mathrm{Tr}(\sigma_i\sigma_j) = 0 \quad i \neq j$
$\mathrm{Tr}(\sigma_i^2) = \mathrm{Tr}(\mathbb{1}) = 2$

The orthodox realist model

$$|+\mathbf{n}\rangle \leftrightarrow \quad \mu_{\mathbf{n}}(\mathbf{u}) = \delta(\mathbf{u}-\mathbf{n})$$

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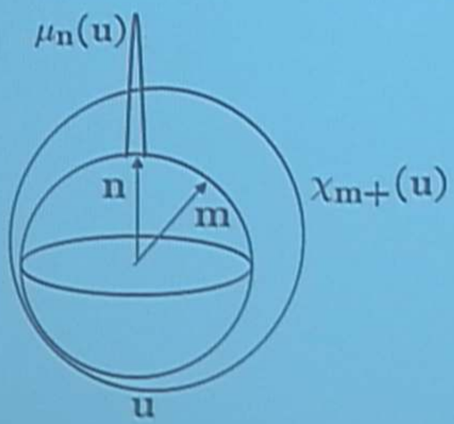
$$= |\langle +\mathbf{m}|+\mathbf{n}\rangle|^2$$



Responses to the measurement problem

1. Deny universality of quantum dynamics
   - Quantum-classical hybrid models
   - Collapse models

2. Deny representational completeness of ψ
   - ψ-ontic hidden variable models (e.g. Bohmian mechanics)
   - ψ-epistemic hidden variable models

3. Deny that there is a unique outcome
   - Everett's relative state interpretation (many worlds)

4. Deny some aspect of classical logic or classical probability theory
   - Quantum logic and quantum Bayesianism

5. Deny some other feature of the realist framework?

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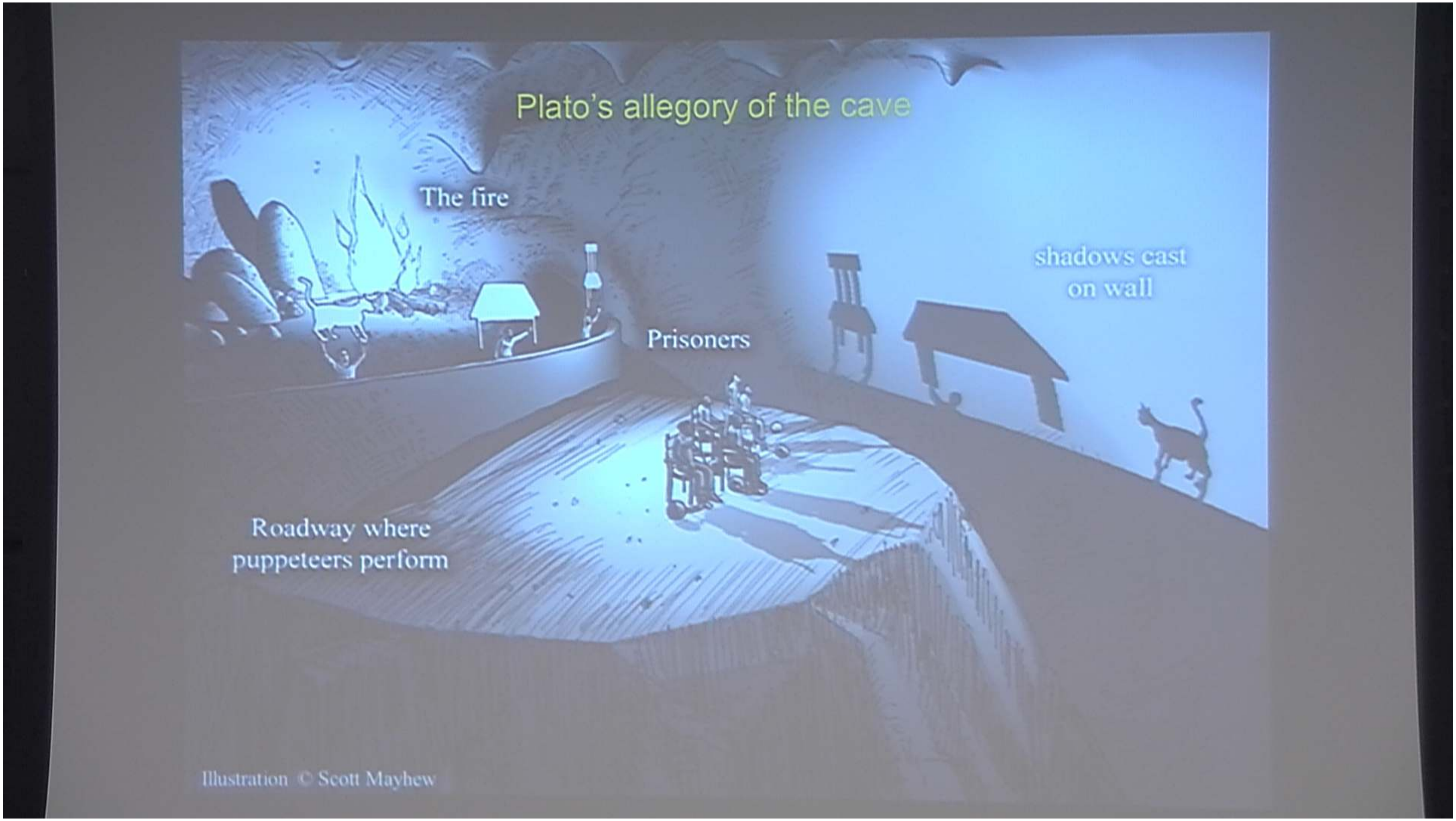
Realism via hidden variables

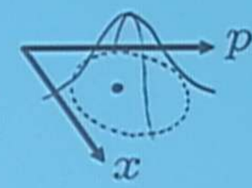

Plato's allegory of the cave
The fire
shadows cast
on wall
Prisoners
Roadway where
puppeteers perform
Illustration © Scott Mayhew

Ontic versus Epistemic

Ontic state = real state of affairs

Epistemic state = state of knowledge

e.g.



Classical case:

Points in phase space are ontic states

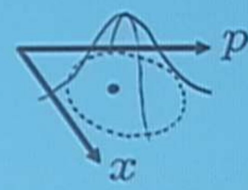
Probability distributions over phase space are epistemic states

Ontic versus Epistemic

Ontic state = real state of affairs

Epistemic state = state of knowledge

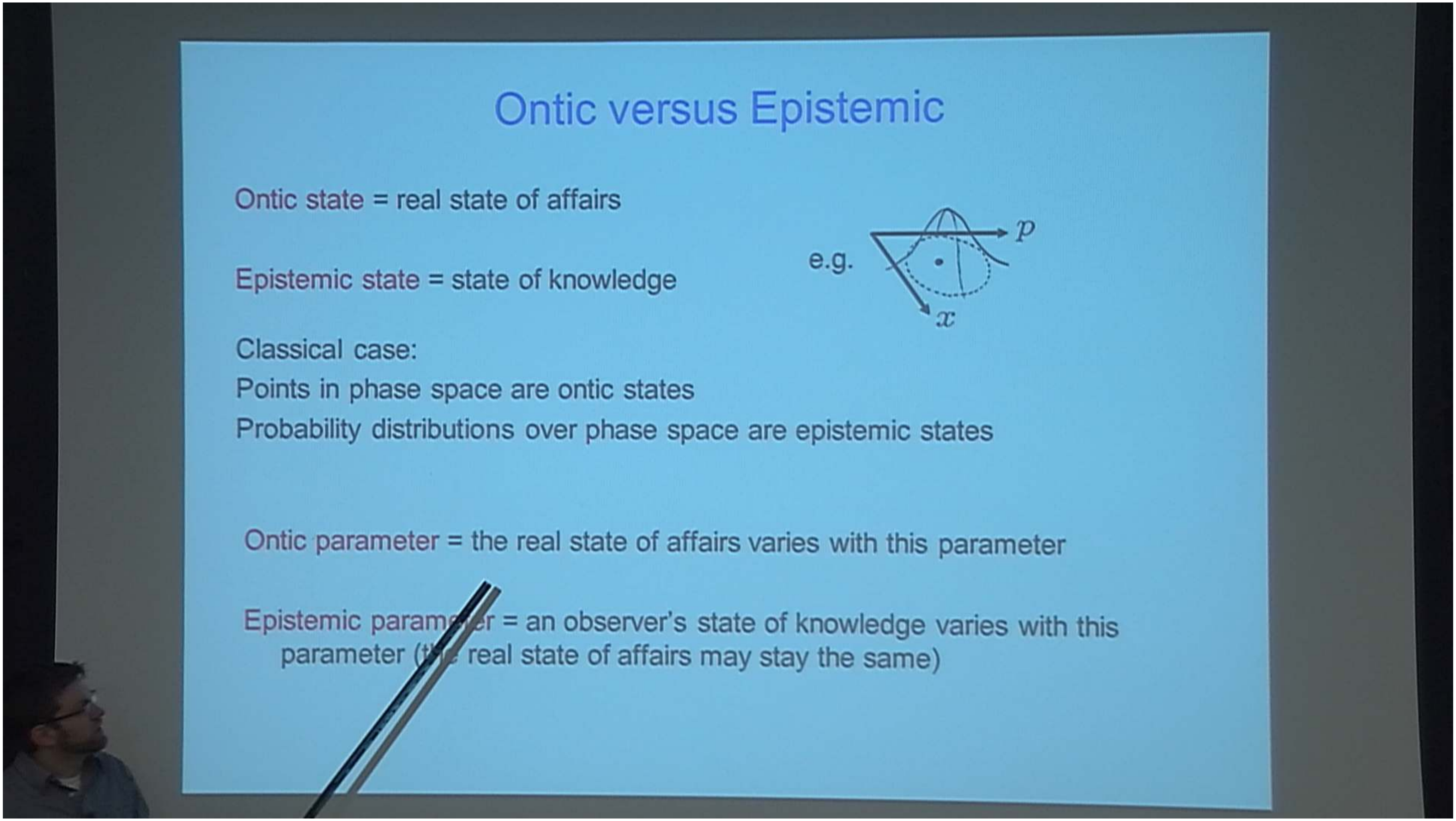
e.g.



Classical case:

Points in phase space are ontic states

Probability distributions over phase space are epistemic states

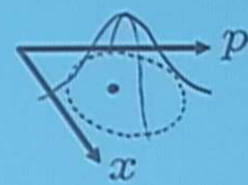


Ontic versus Epistemic
Ontic state = real state of affairs
Epistemic state = state of knowledge
e.g.
p
x
Classical case:
Points in phase space are ontic states
Probability distributions over phase space are epistemic states
Ontic parameter = the real state of affairs varies with this parameter
Epistemic param
r = an observer's state of knowledge varies with this
parameter (t
real state of affairs may stay the same)

Ontic versus Epistemic

Ontic state = real state of affairs

e.g.



Epistemic state = state of knowledge

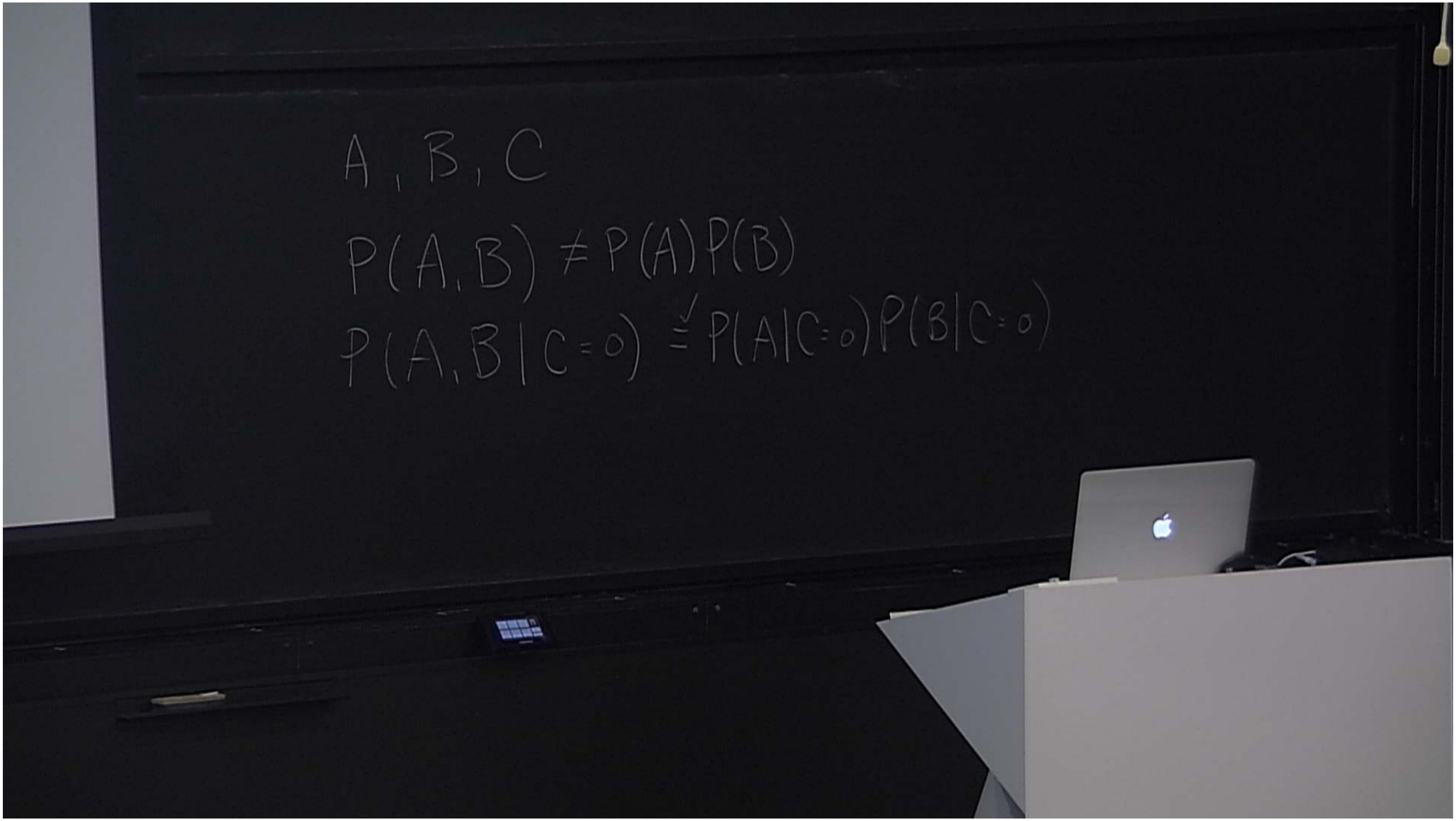
Classical case:

Points in phase space are ontic states

Probability distributions over phase space are epistemic states

Ontic parameter = the real state of affairs varies with this parameter

Epistemic parameter = an observer's state of knowledge varies with this parameter (the real state of affairs may stay the same)


A, B, C
P(A,B) ≠ P(A)P(B)
P(A,B|C=0) =✓ P(A|C=0)P(B|C=0)

Ontic versus Epistemic

Probability

Correlation

Determinism

Causality

A useful distinction among hidden variable models

Let $P_{|\psi_1\rangle}$, $P_{|\psi_2\rangle}$ be preparation procedures for $|\psi_1\rangle, |\psi_2\rangle$

ψ-ontic model: $\forall\ |\psi_1\rangle, |\psi_2\rangle$ distinct

$\mu(\lambda|P_{|\psi_1\rangle})\mu(\lambda|P_{|\psi_2\rangle}) = 0$ for all λ

Variation of ψ entails a variation of the ontic state

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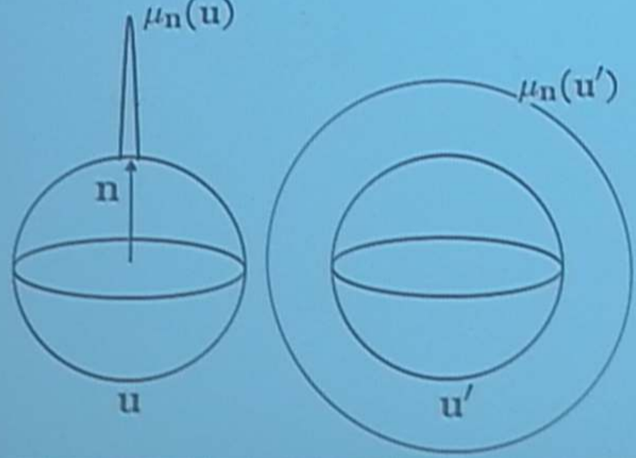
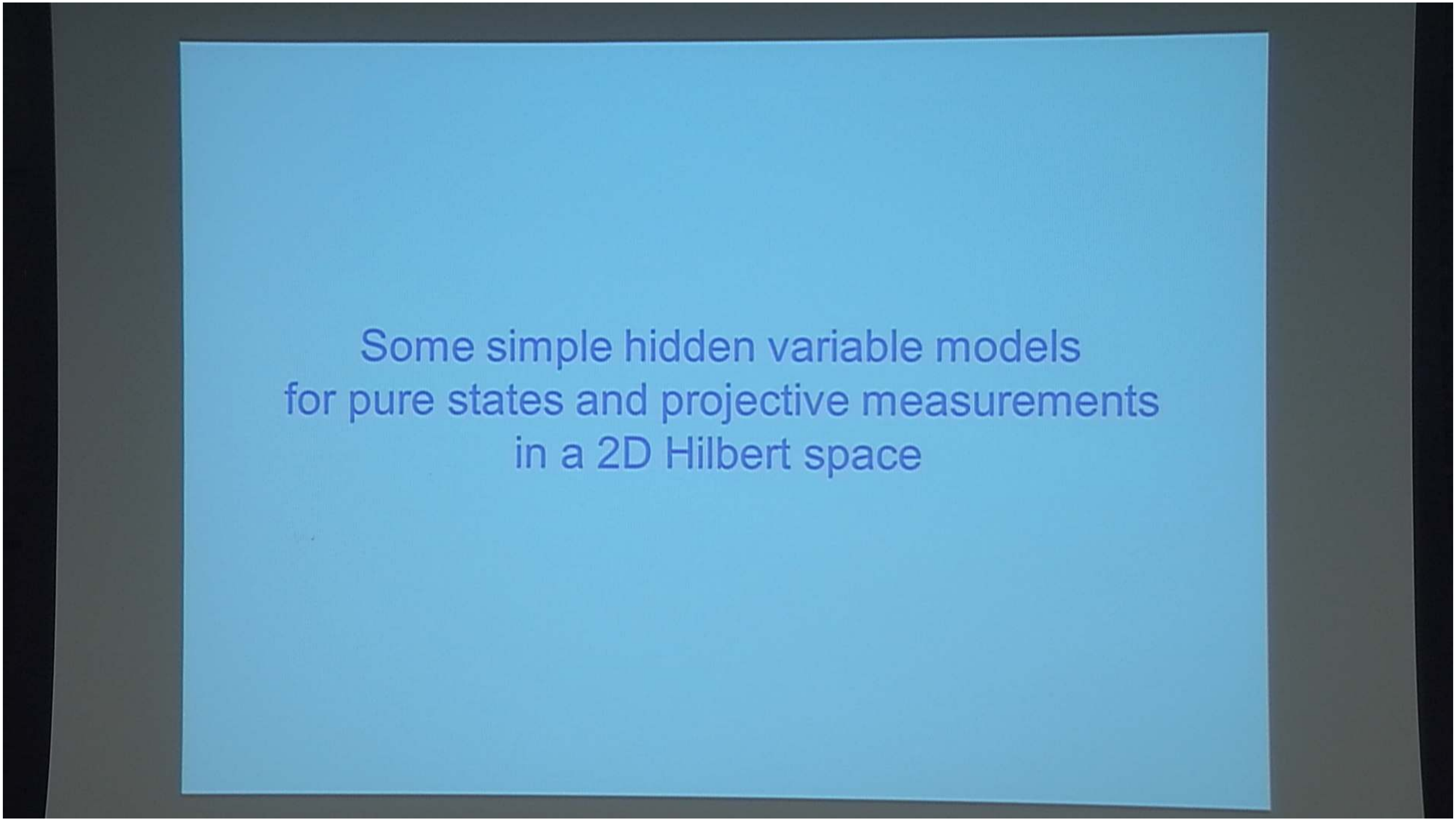
Variation of ψ is consistent with **no** variation of the ontic state

Some simple hidden variable models for pure states and projective measurements in a 2D Hilbert space

The Bell-Mermin model

$$|+\mathbf{n}\rangle \leftrightarrow \quad \mu_{\mathbf{n}}(\mathbf{u},\mathbf{u}') = \frac{1}{4\pi}\delta(\mathbf{u}-\mathbf{n})$$

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for pure states and projective measurements
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