Title: Quantum Information Lecture - 230308

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Collection: Quantum Information (2022/2023)

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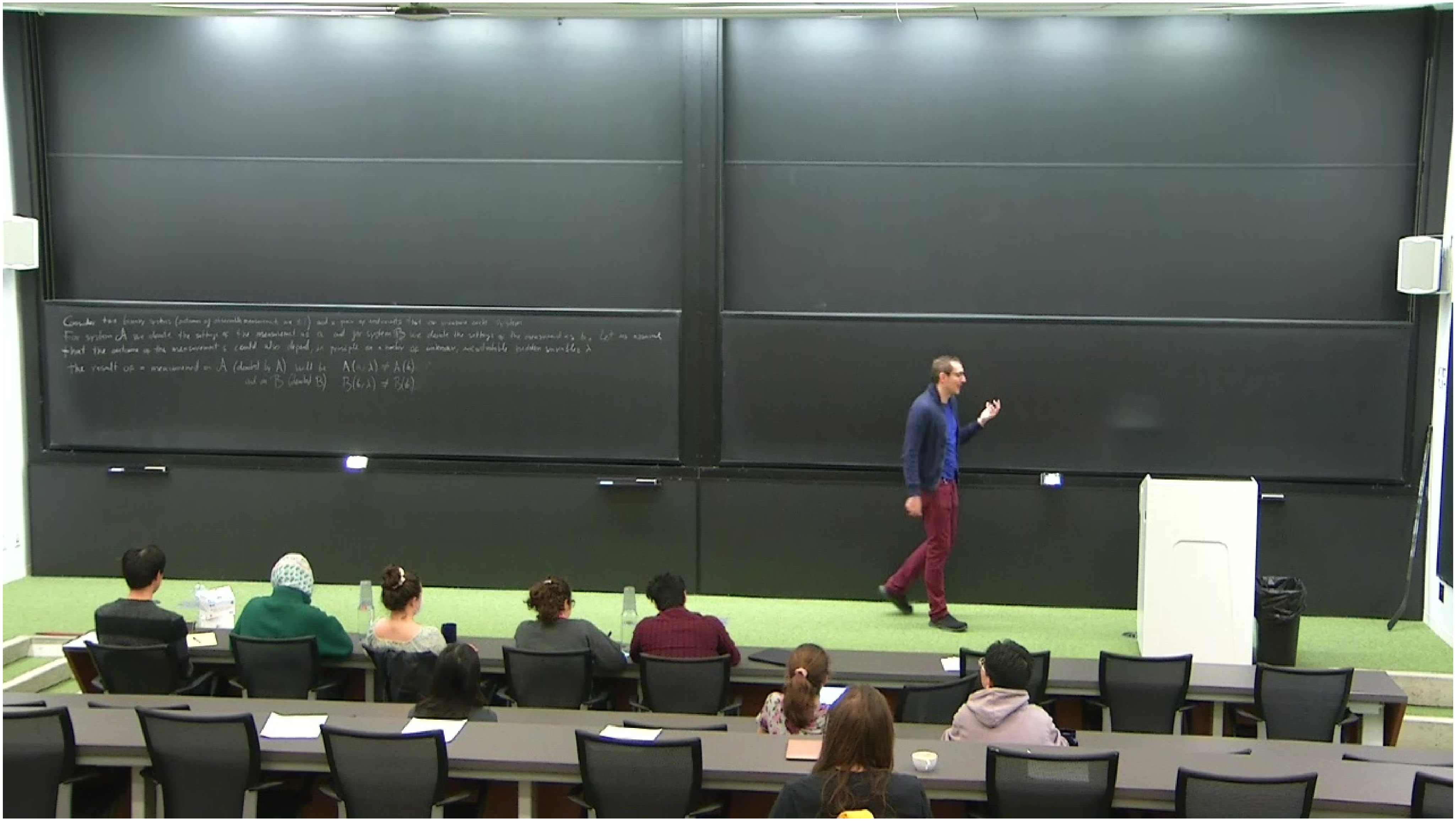
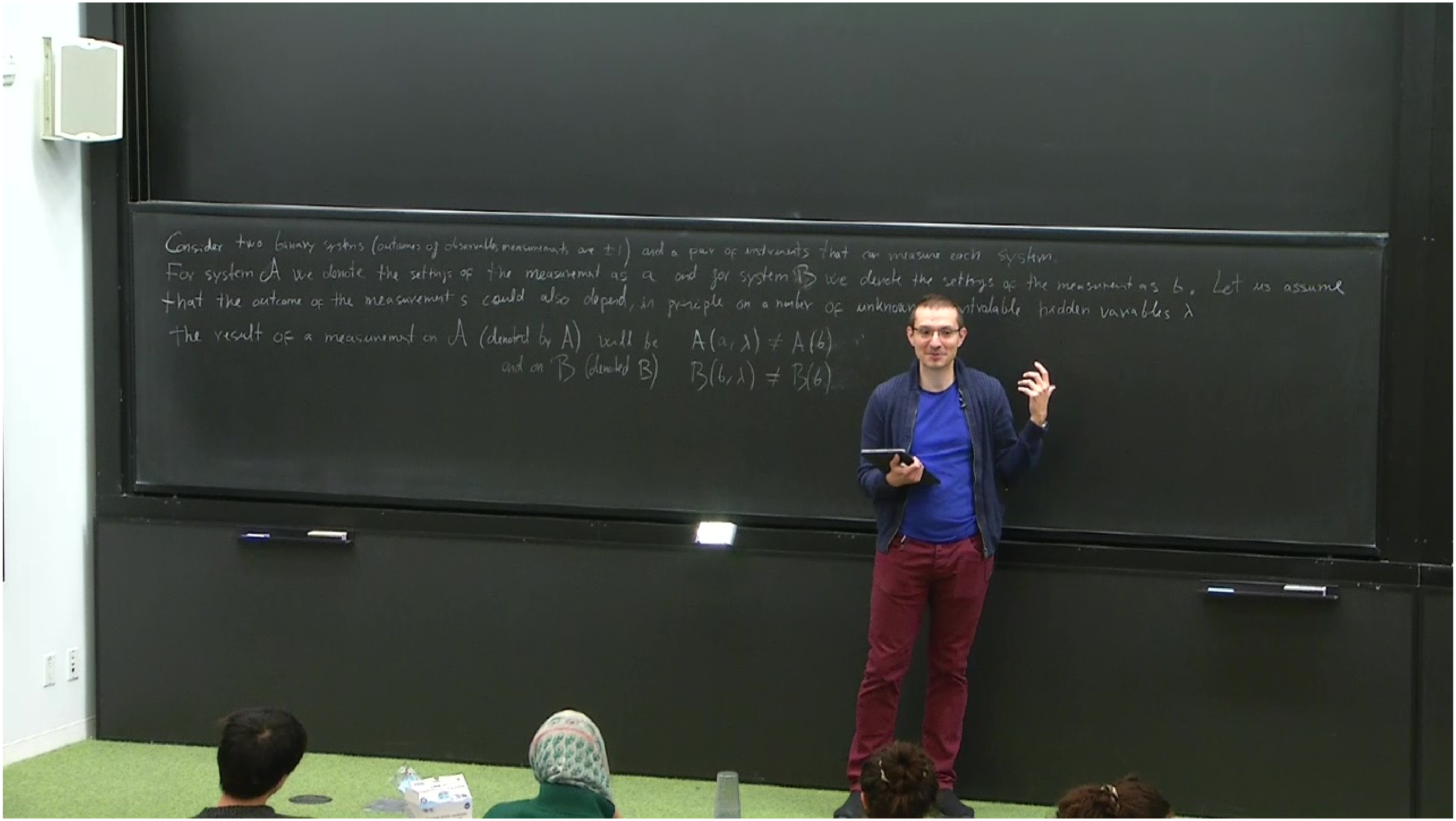
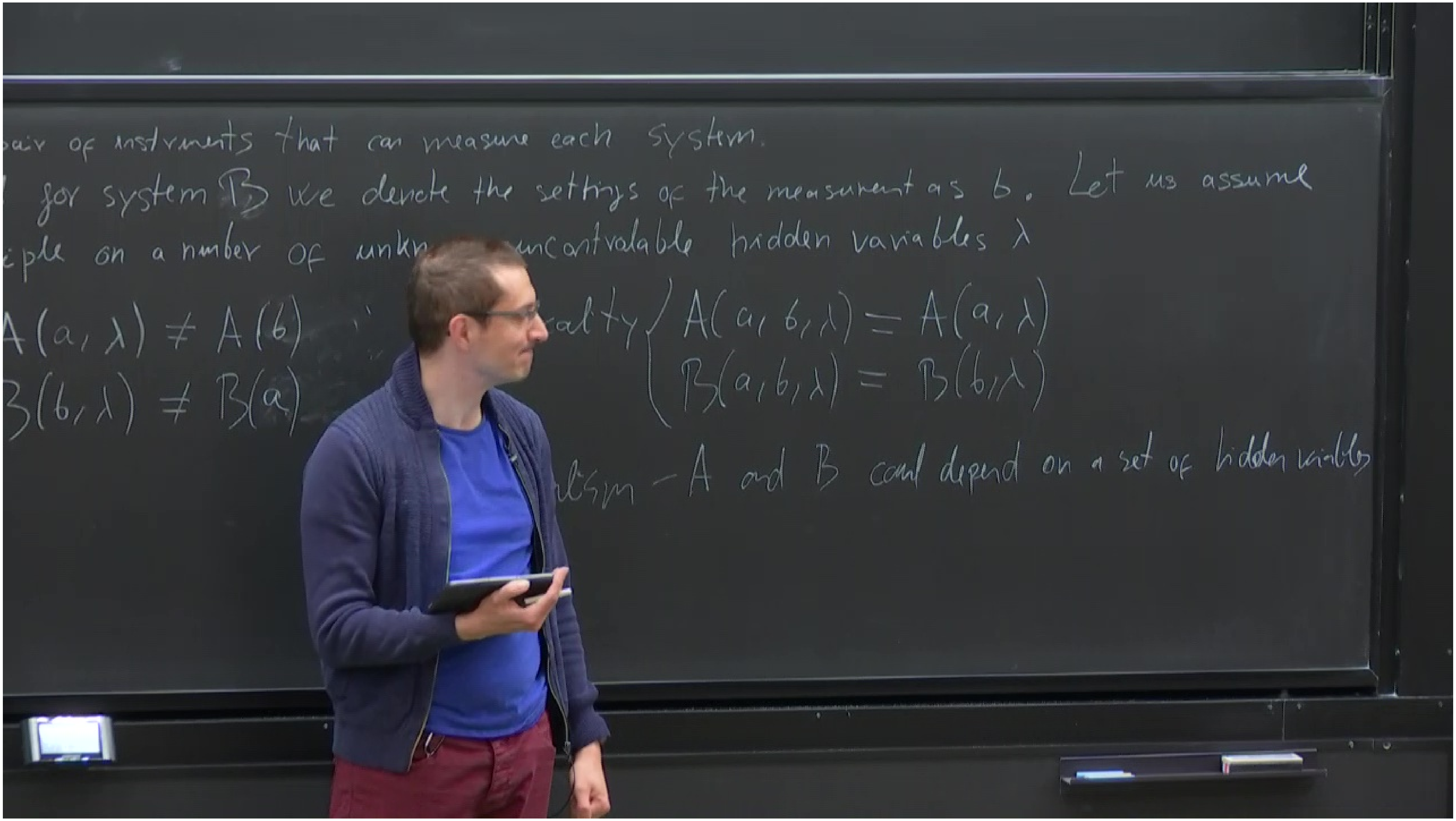



Consider two binary systems (outcomes of observables measurements are ± 1) and a pair of instruments that can measure each system.
For system A we denote the settings of the measurement as a and for system B we denote the settings of the measurement as b. Let us assume
that the outcome of the measurements could also depend, in principle on a number of unknown hidden variables λ
the result of a measurement on A (denoted by A) will be $A(a,\lambda) \neq A(b)$
and on B (denoted B) $B(b,\lambda) \neq B(b)$


pair of instruments that can measure each system.
for system B we denote the settings of the measurement as b. Let us assume
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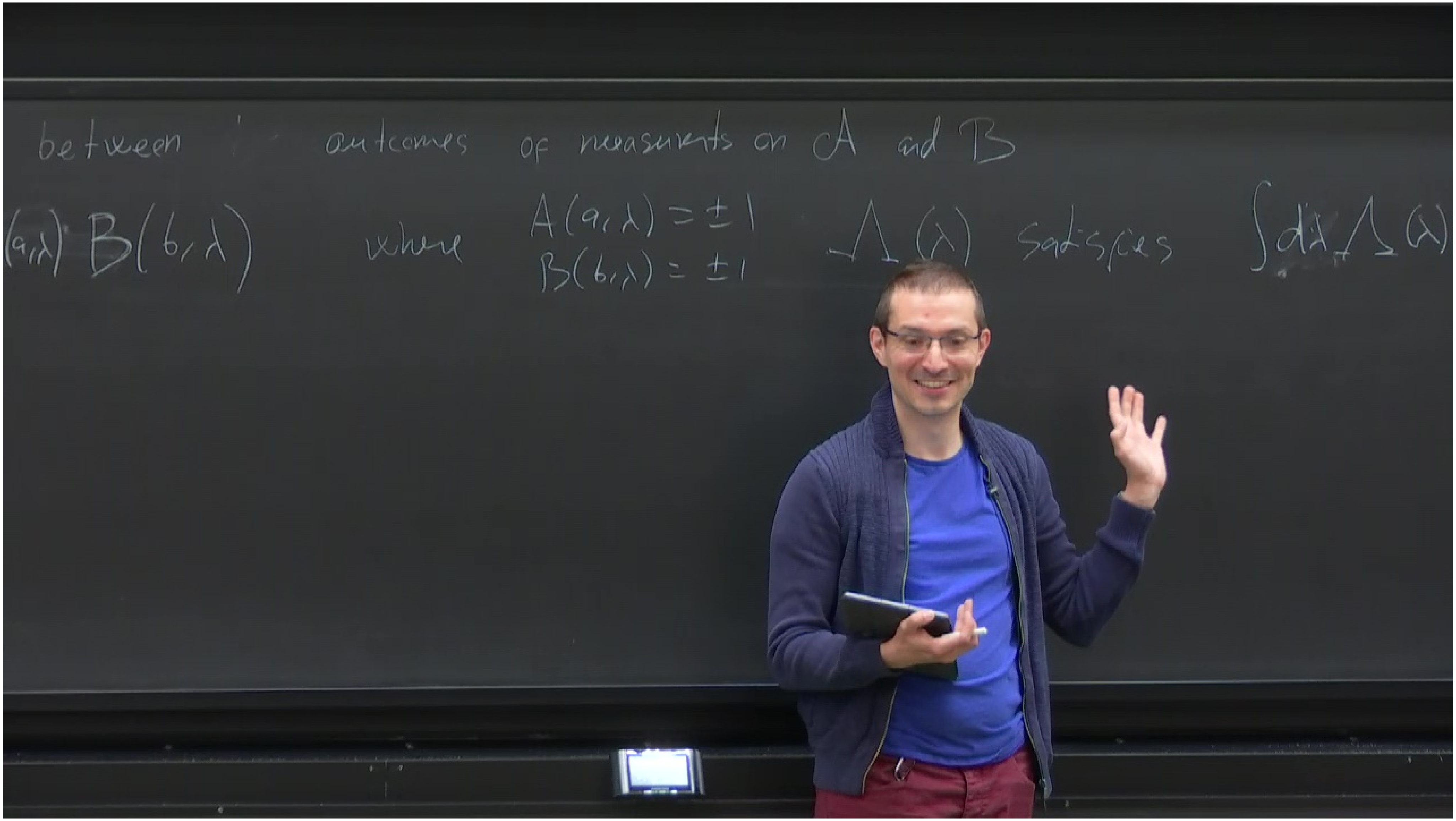
uncontrolable hidden variables λ
A(a, λ) ≠ A(b)
B(b, λ) ≠ B(a)
ality
A(a, b, λ) = A(a, λ)
B(a, b, λ) = B(b, λ)
alism - A and B could depend on a set of hidden variables

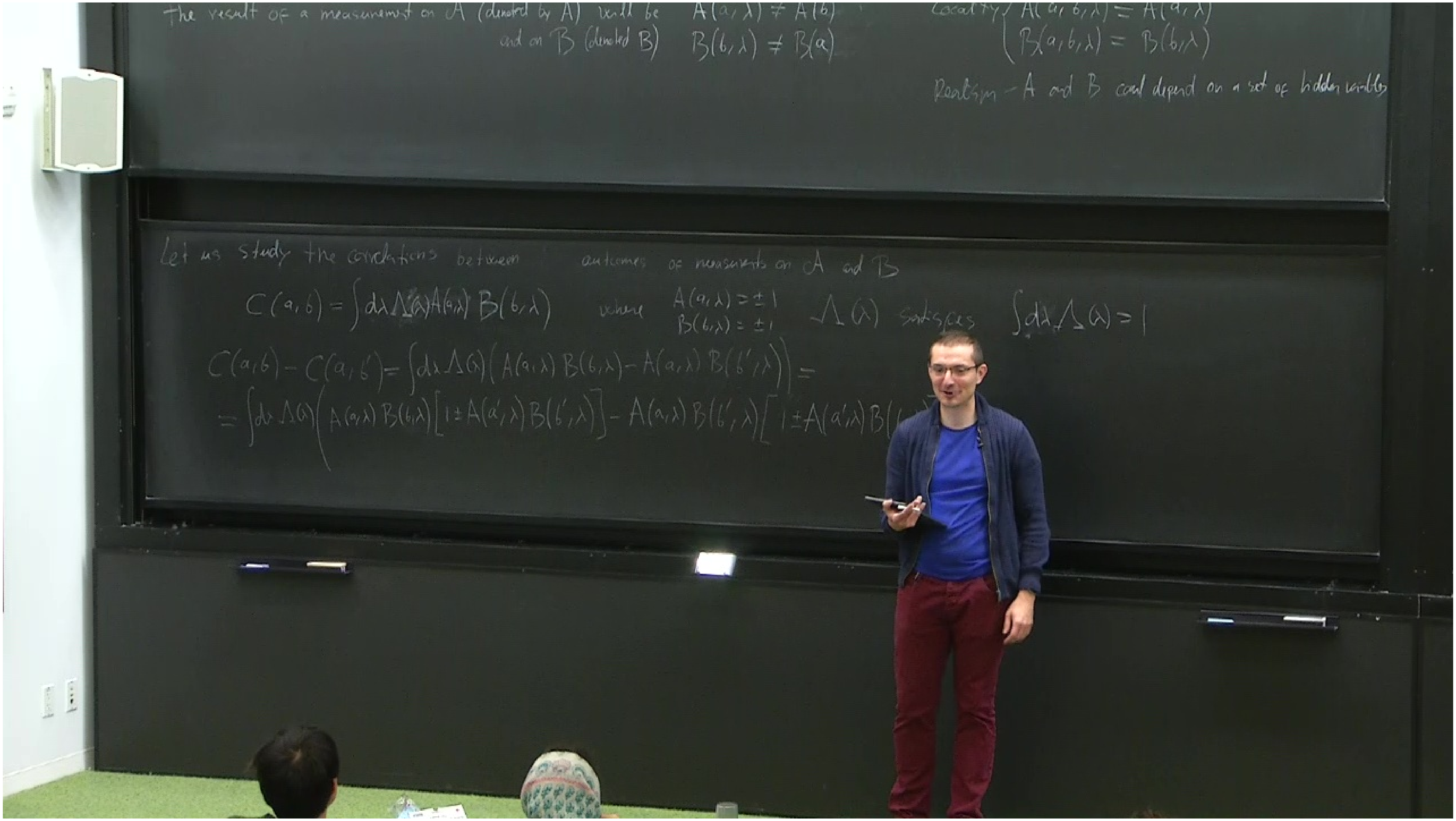
Let us study the correlations between outcomes of measure

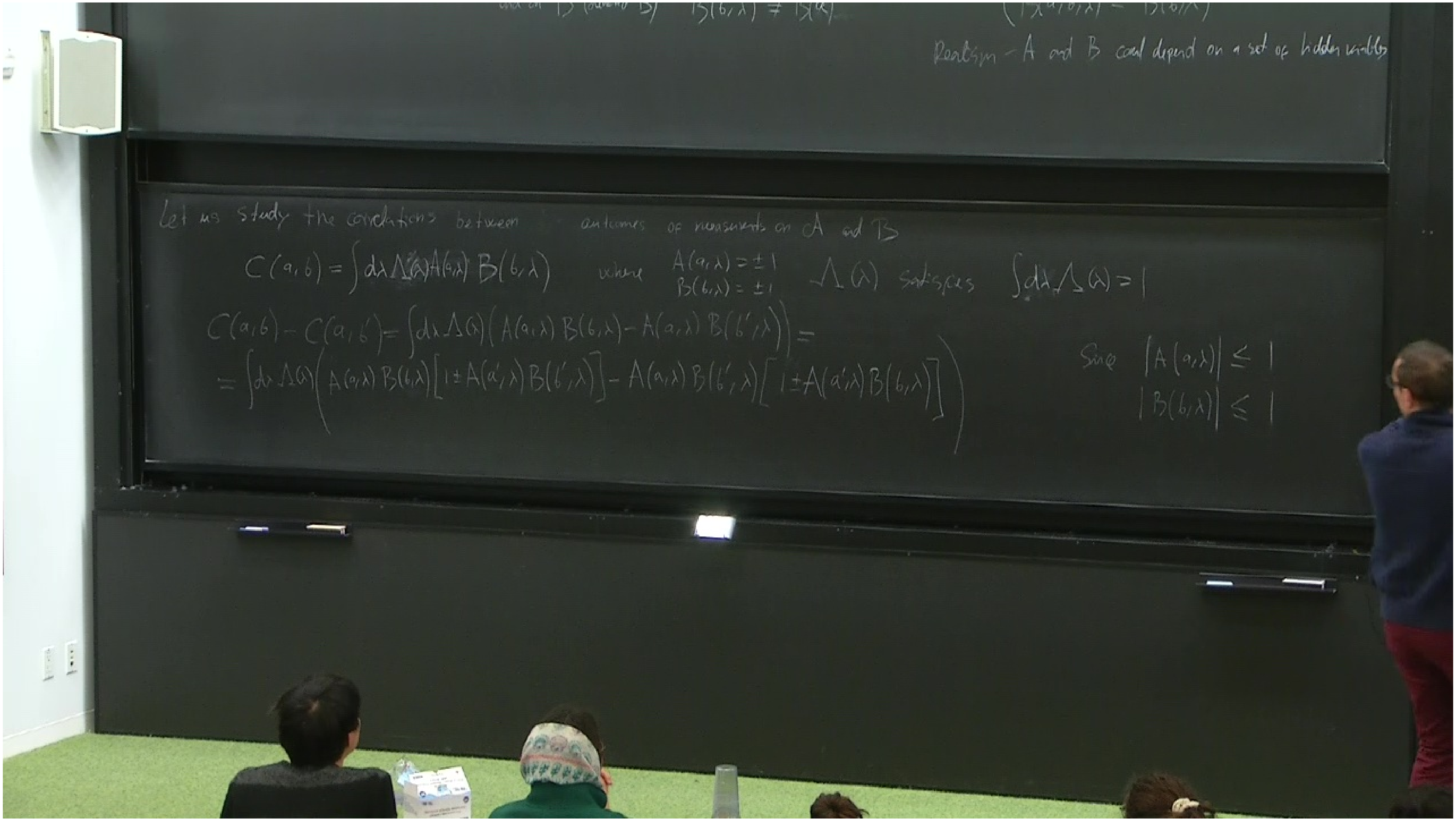
$$C(a,b) = \int d\lambda\, \Lambda(\lambda) A(a,\lambda)\, B(b,\lambda)$$

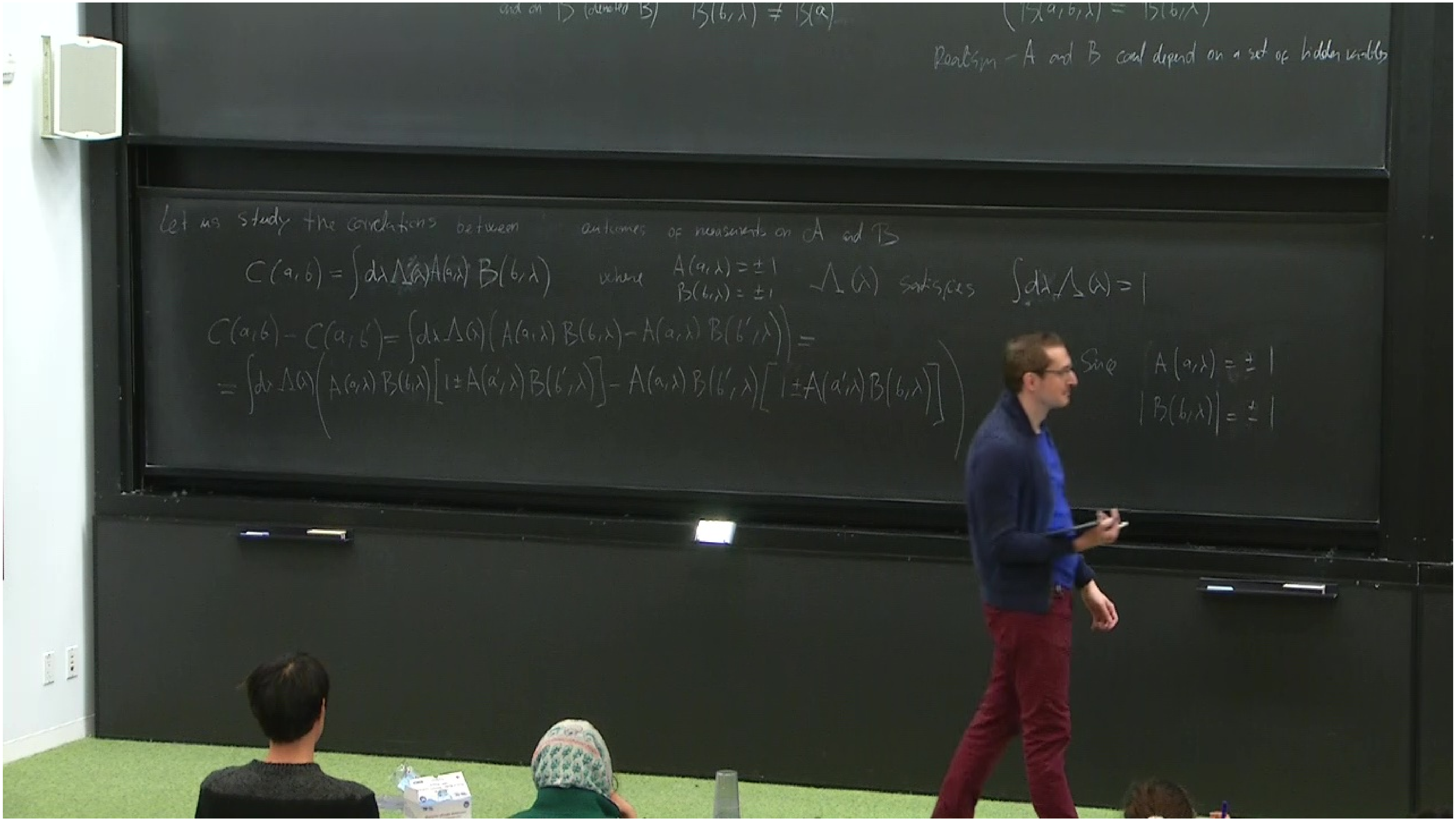
where $A(a,\lambda) =$

$B(b,\lambda) =$


between outcomes of measurements on A and B
(a,λ) B(b,λ) where A(a,λ) = ±1
B(b,λ) = ±1
Λ(λ) satisfies ∫dλ Λ(λ)


The result of a measurement on A (denoted by A) will be A(a, λ) ≠ A(b)
and on B (denoted B) B(b, λ) ≠ B(a)
Locality A(a, b, λ) = A(a, λ)
B(a, b, λ) = B(b, λ)
Realism - A and B could depend on a set of hidden variables
Let us study the correlations between outcomes of measurements on A and B
C(a, b) = ∫dλ Λ(λ) A(a, λ) B(b, λ) where A(a, λ) = ±1 B(b, λ) = ±1 Λ(λ) satisfies ∫dλ Λ(λ) = 1
C(a, b) - C(a, b') = ∫dλ Λ(λ)(A(a, λ) B(b, λ) - A(a, λ) B(b', λ)) =
= ∫dλ Λ(λ)(A(a, λ) B(b, λ)[1 ± A(a', λ) B(b', λ)] - A(a, λ) B(b', λ)[1 ± A(a', λ) B(


Realism - A and B could depend on a set of hidden variables
Let us study the correlations between outcomes of measurements on A and B
C(a,b) = ∫dλ Λ(λ) A(a,λ) B(b,λ)
where A(a,λ) = ±1
B(b,λ) = ±1
Λ(λ) satisfies ∫dλ Λ(λ) = 1
C(a,b) − C(a,b') = ∫dλ Λ(λ) (A(a,λ) B(b,λ) − A(a,λ) B(b',λ)) =
= ∫dλ Λ(λ) (A(a,λ) B(b,λ) [1 ± A(a',λ) B(b',λ)] − A(a,λ) B(b',λ) [1 ± A(a',λ) B(b,λ)])
Since |A(a,λ)| ≤ 1
|B(b,λ)| ≤ 1


and on B (denoted B) B(b,λ) ≠ B(a)
(B(a,b,λ) = B(b,λ))
Realism - A and B could depend on a set of hidden variables
Let us study the correlations between outcomes of measurements on A and B
C(a,b) = ∫dλ Λ(λ) A(a,λ) B(b,λ) where A(a,λ) = ±1, B(b,λ) = ±1 Λ(λ) satisfies ∫dλ Λ(λ) = 1
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Since |A(a,λ)| = ±1
|B(b,λ)| = ±1

nts that can measure each system.

B we denote the settings of the measurement as b. Let us assume

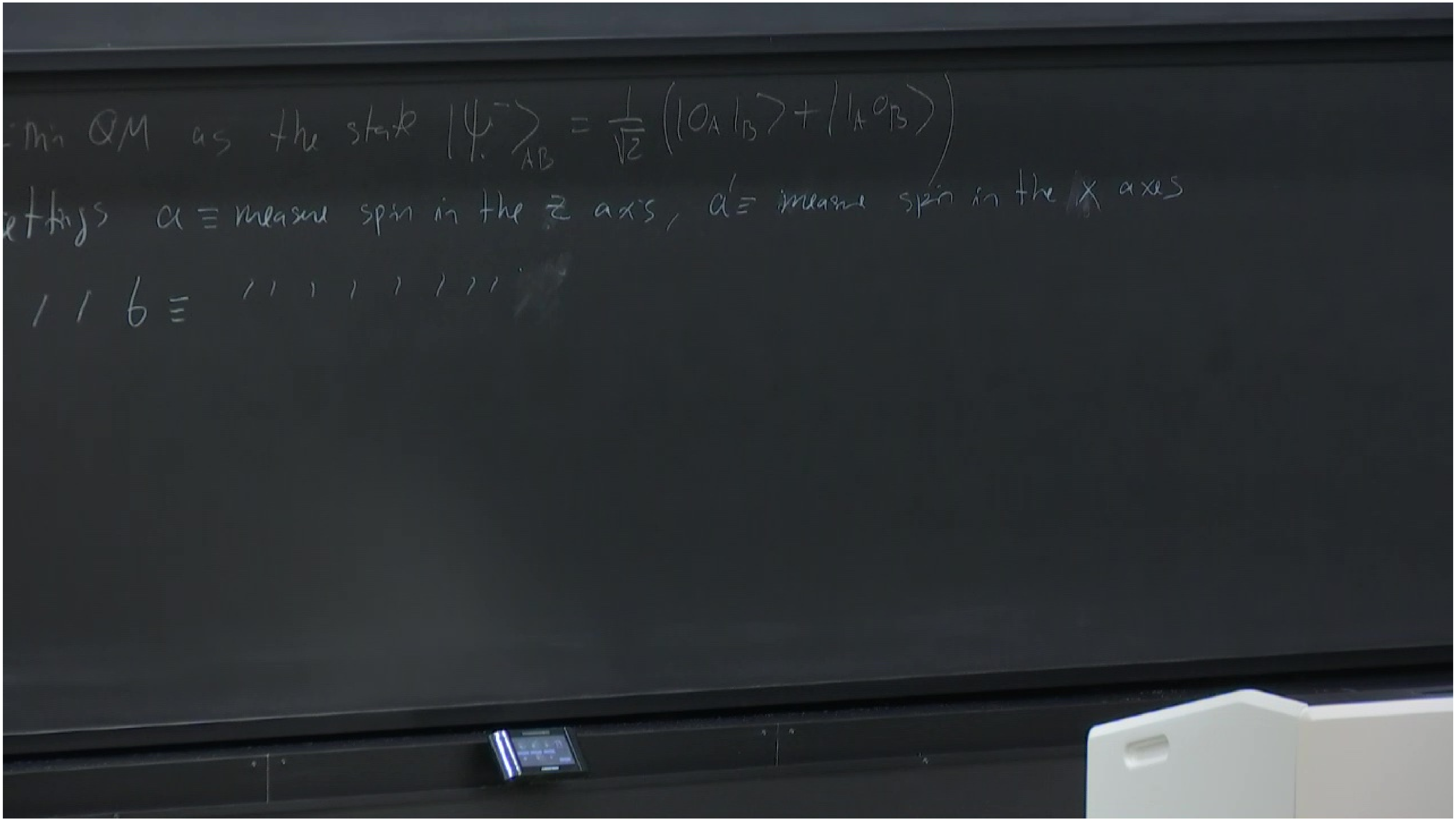
nber of unknown, uncontrolable hidden variables λ

$A(b)$

$B(a)$

Locality $\begin{cases} A(a,b,\lambda) = A(a,\lambda) \\ B(a,b,\lambda) = B(b,\lambda) \end{cases}$

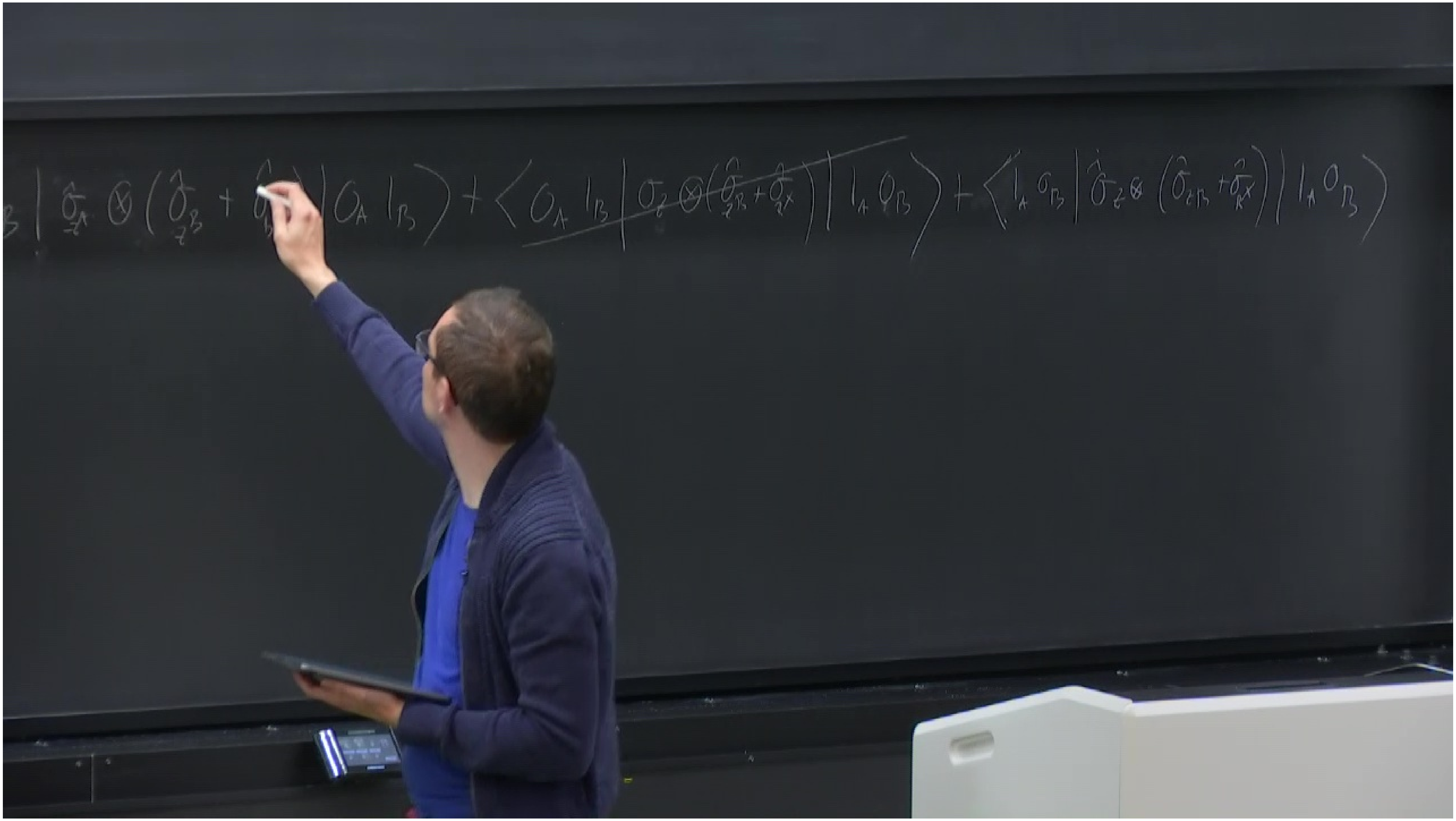
Realism – A and B could depend on a set of hidden variables


in QM as the state |ψ⁻⟩_AB = 1/√2 (|0_A 1_B⟩ + |1_A 0_B⟩)
ettings a ≡ measure spin in the z axis, a' ≡ measure spin in the x axes
b ≡

...in QM as the state $|\psi^-\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|0_A 1_B\rangle + |1_A 0_B\rangle\right)$

...ettings $a \equiv$ measure spin in the z axis, $a' \equiv$ measure spin in the x axes

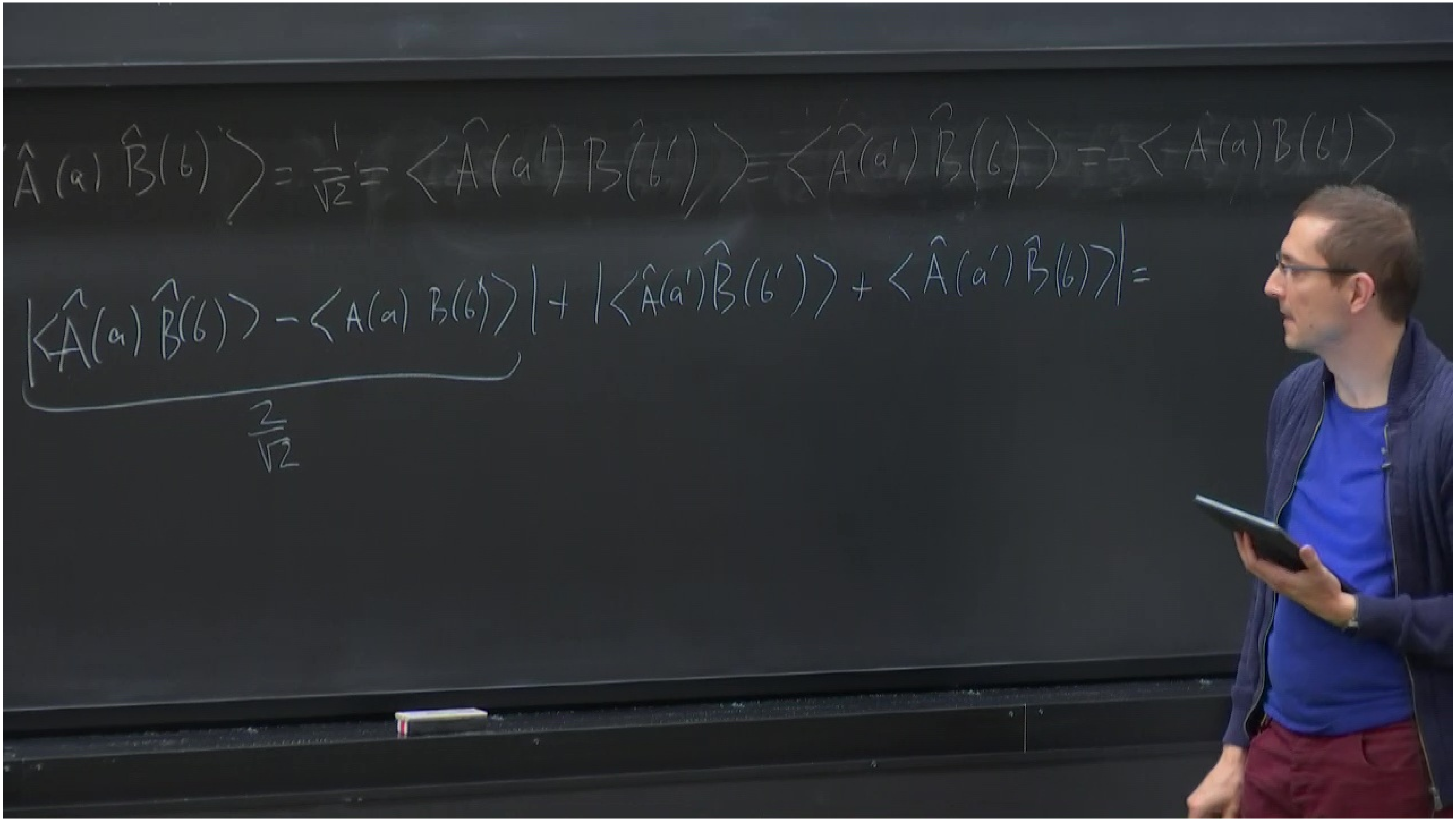
/ / $b \equiv$ measures $\frac{1}{\sqrt{2}}\left(\mathbb{1}_A \otimes \left(\hat{\sigma}_z + \hat{\sigma}_x\right)\right)$, $b' \equiv$ measure $\frac{1}{\sqrt{2}}\left(\mathbb{1}_A \otimes \left(\hat{\sigma}_z - \hat{\sigma}_x\right)\right)$



$\sigma_z|0\rangle = -|0\rangle$

$\frac{\Omega \sigma_z}{2}$

$$\ldots_B| \hat{\sigma}_{zA} \otimes \left(\hat{\sigma}_{zB} + \hat{\sigma}_{Bx} \right) |0_A 1_B\rangle + \cancel{\langle 0_A 1_B | \sigma_z \otimes \left(\hat{\sigma}_{zB} + \hat{\sigma}_{zx} \right) | 1_A 0_B\rangle} + \langle 1_A 0_B | \hat{\sigma}_z \otimes \left(\hat{\sigma}_{zB} + \hat{\sigma}_{Bx} \right) | 1_A 0_B\rangle$$


$\langle \hat{A}(a)\hat{B}(b)\rangle = \frac{1}{\sqrt{2}} = \langle \hat{A}(a')B(b')\rangle = \langle \hat{A}(a')\hat{B}(b)\rangle = -\langle A(a)B(b')\rangle$
$\underbrace{|\langle \hat{A}(a)\hat{B}(b)\rangle - \langle A(a)B(b')\rangle|}_{\frac{2}{\sqrt{2}}} + |\langle \hat{A}(a')\hat{B}(b')\rangle + \langle \hat{A}(a')\hat{B}(b)\rangle| =$

$$\langle \hat{A}(a)\,\hat{B}(b)\rangle = \frac{1}{\sqrt{2}} = \langle \hat{A}(a')\,B(b')\rangle = \langle \hat{A}(a')\,\hat{B}(b)\rangle = -\langle A(a)\,B(b')\rangle$$

$$\underbrace{\left|\langle \hat{A}(a)\,\hat{B}(b)\rangle - \langle A(a)\,B(b')\rangle\right|}_{\frac{2}{\sqrt{2}}} + \underbrace{\left|\langle \hat{A}(a')\hat{B}(b')\rangle + \langle \hat{A}(a')\,\hat{B}(b)\rangle\right|}_{2/\sqrt{2}} = 2\sqrt{2} > 2$$