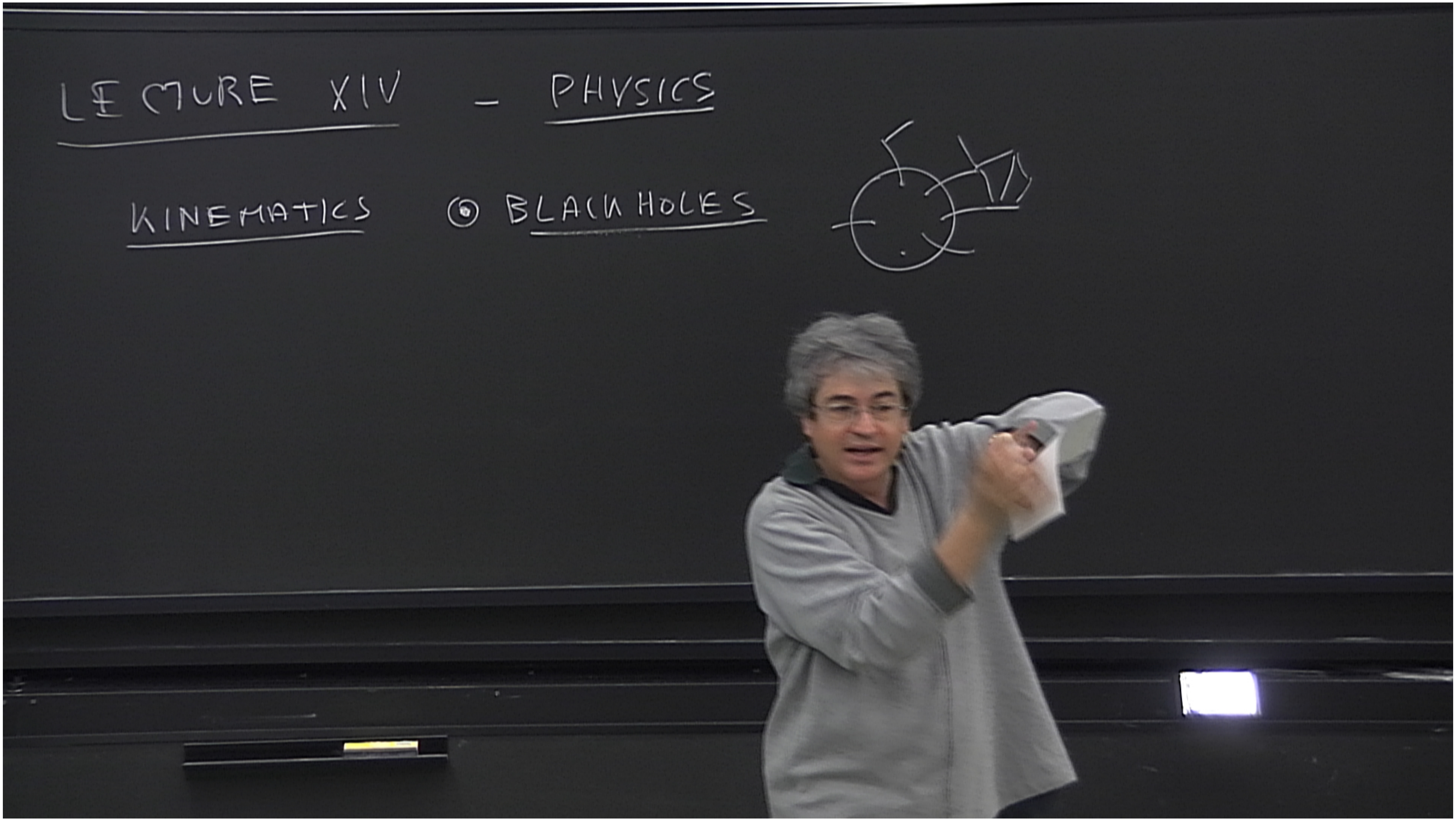
Title: Explorations in Quantum Gravity - Lecture 14

Date: Apr 20, 2012 10:15 AM

URL: http://pirsa.org/12040037

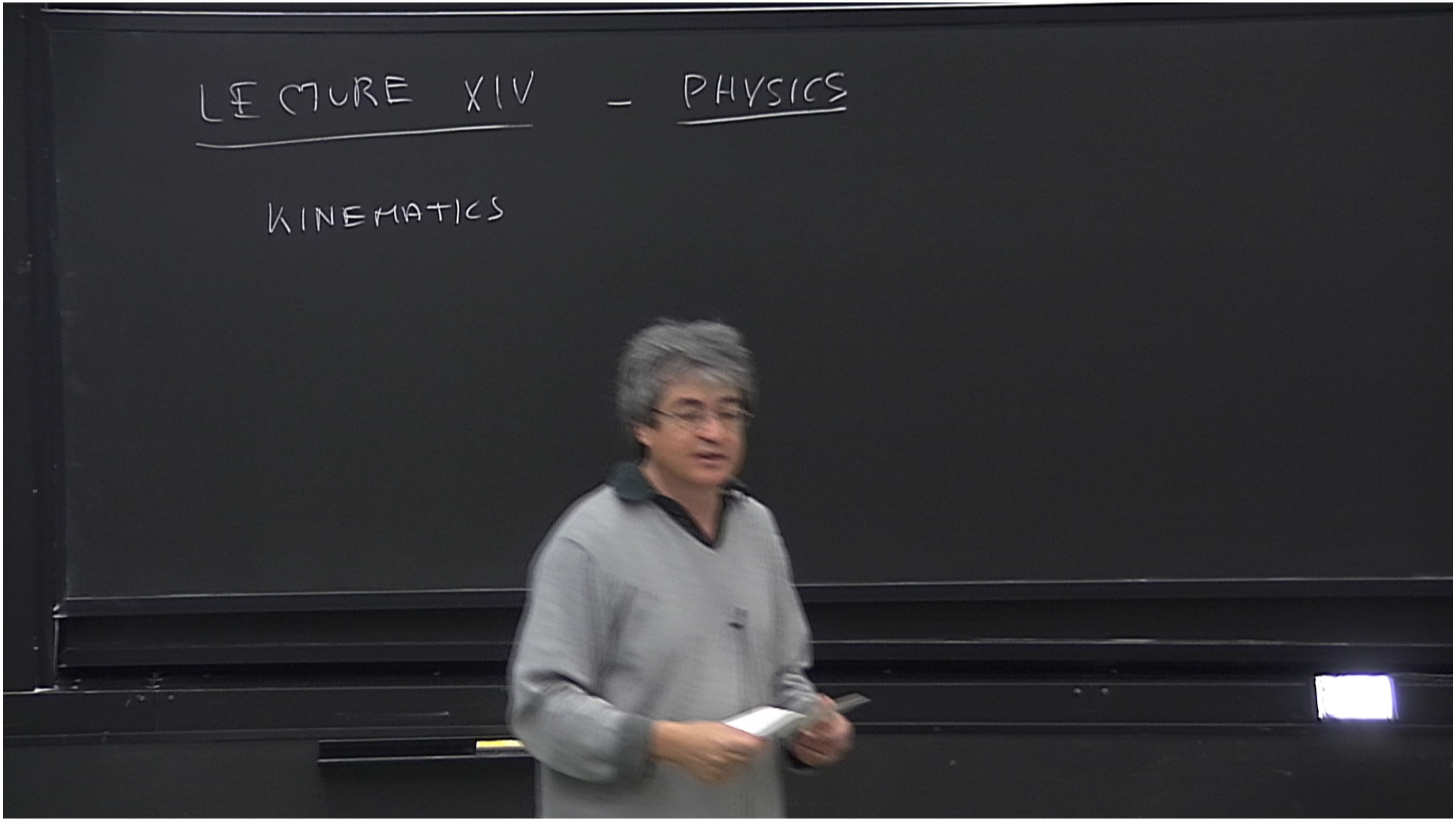
Abstract:

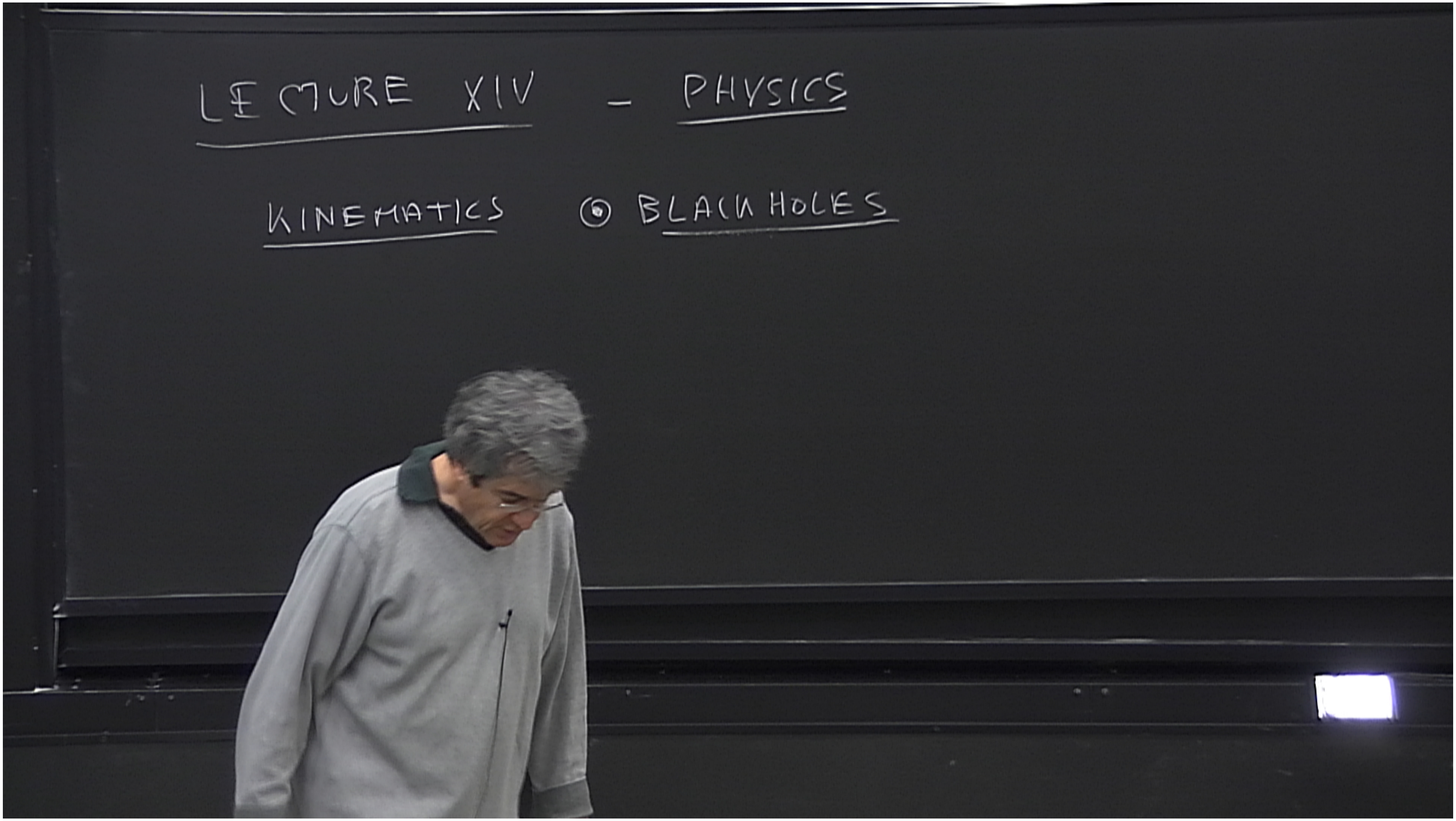


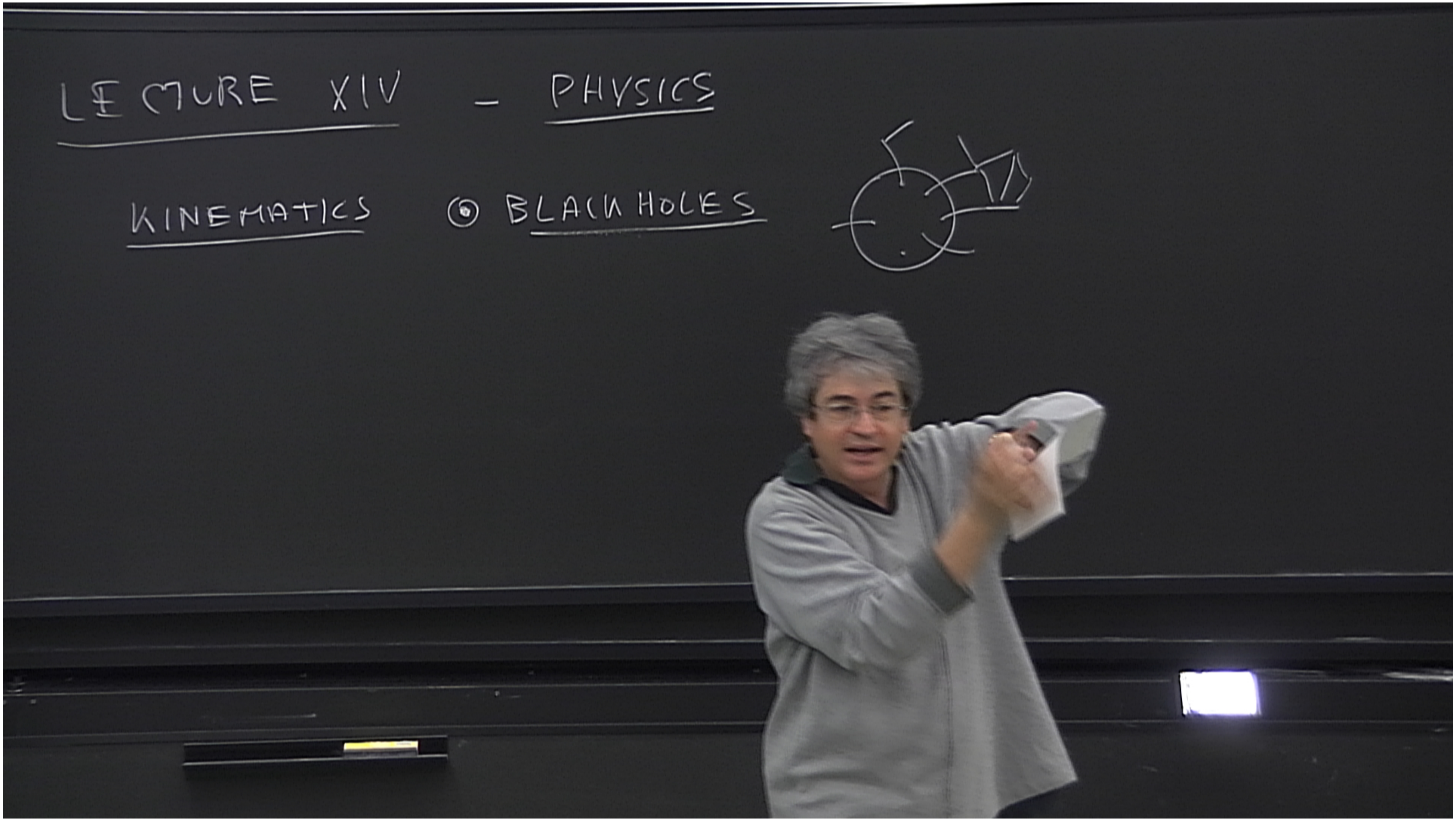
LECTURE XIV – PHYSICS
KINEMATICS
BLACK HOLES

LECTURE XIV

LECTURE XIV - PHYSICS


LECTURE XIV - PHYSICS
KINEMATICS


LECTURE XIV - PHYSICS
KINEMATICS ⊙ BLACK HOLES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KINEMATICS
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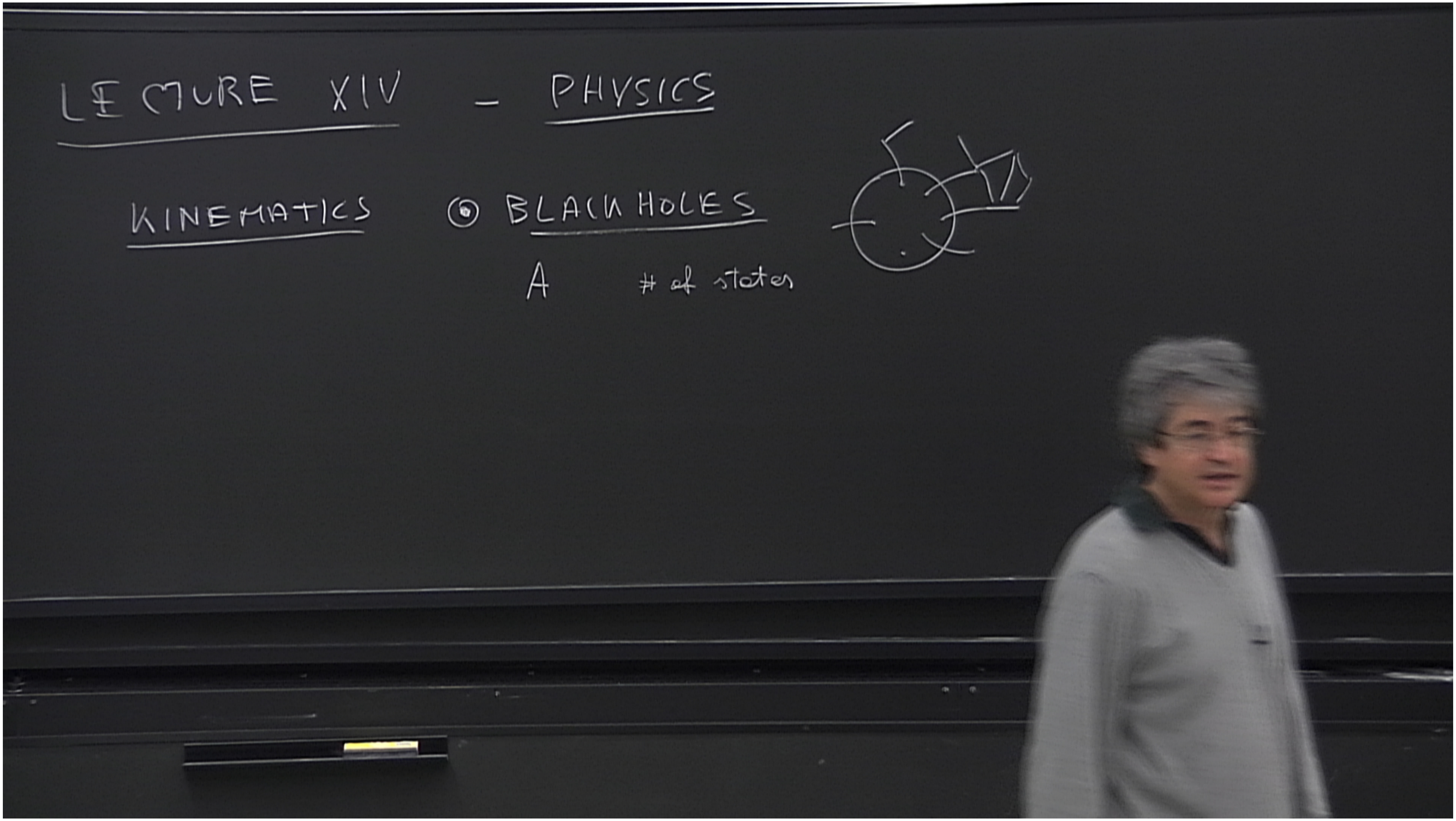

LECTURE XIV - PHYSICS
KINEMATICS
BLACK HOLES
A
# of states

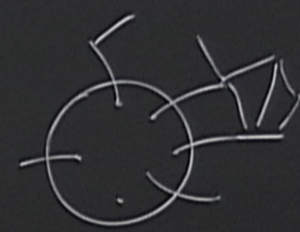
LECTURE XIV – PHYSICS

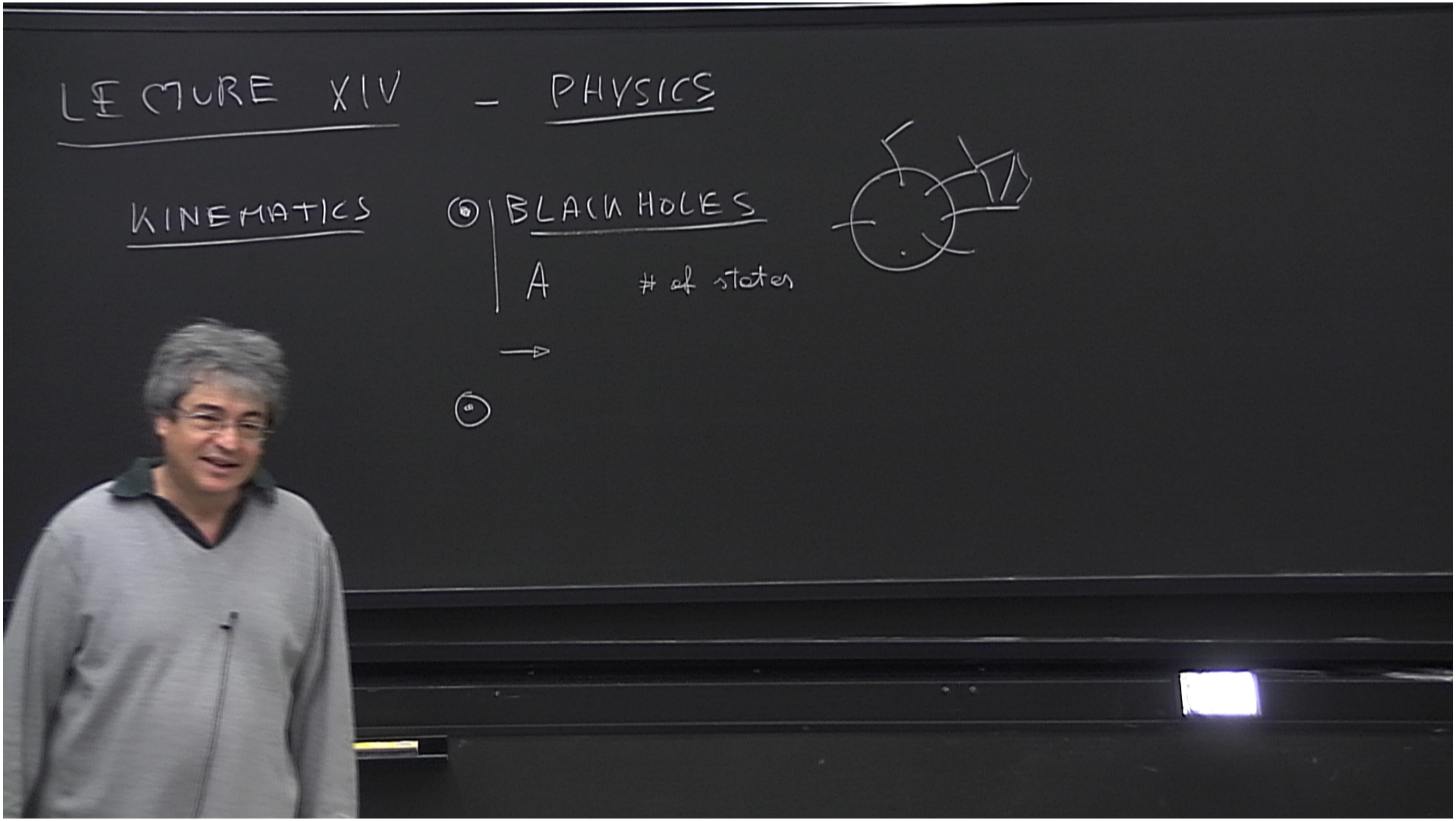
KINEMATICS

⊙ BLACK HOLES

A   # of states

$\longrightarrow$

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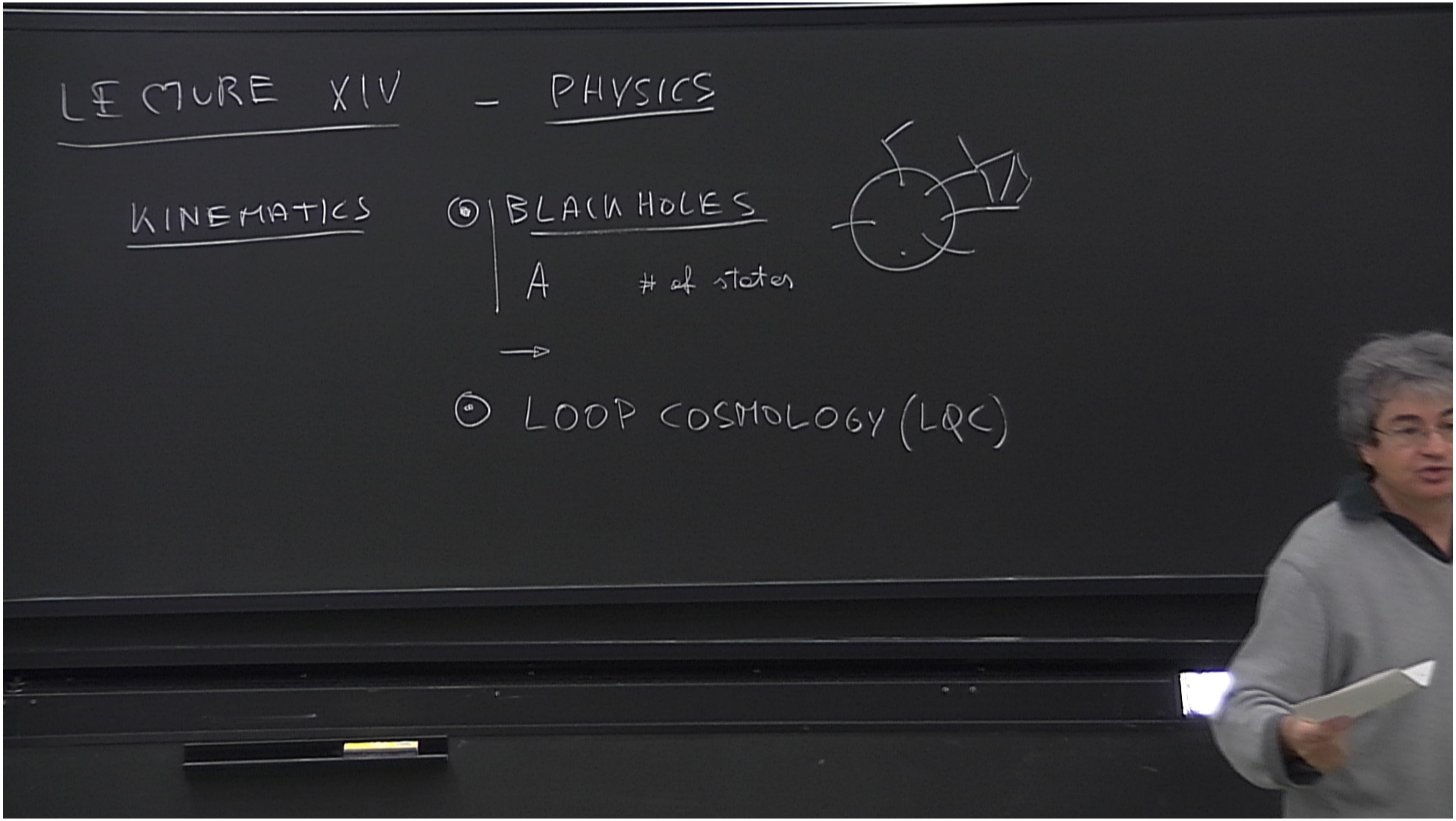
KINEMATICS
BLACK HOLES
A
# of states


LECTURE XIV – PHYSICS
KINEMATICS
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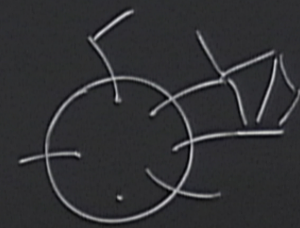
A
# of states
LOOP COSMOLOGY (LQC)

LECTURE XIV – PHYSICS

KINEMATICS

⊙ BLACK HOLES



A # of states

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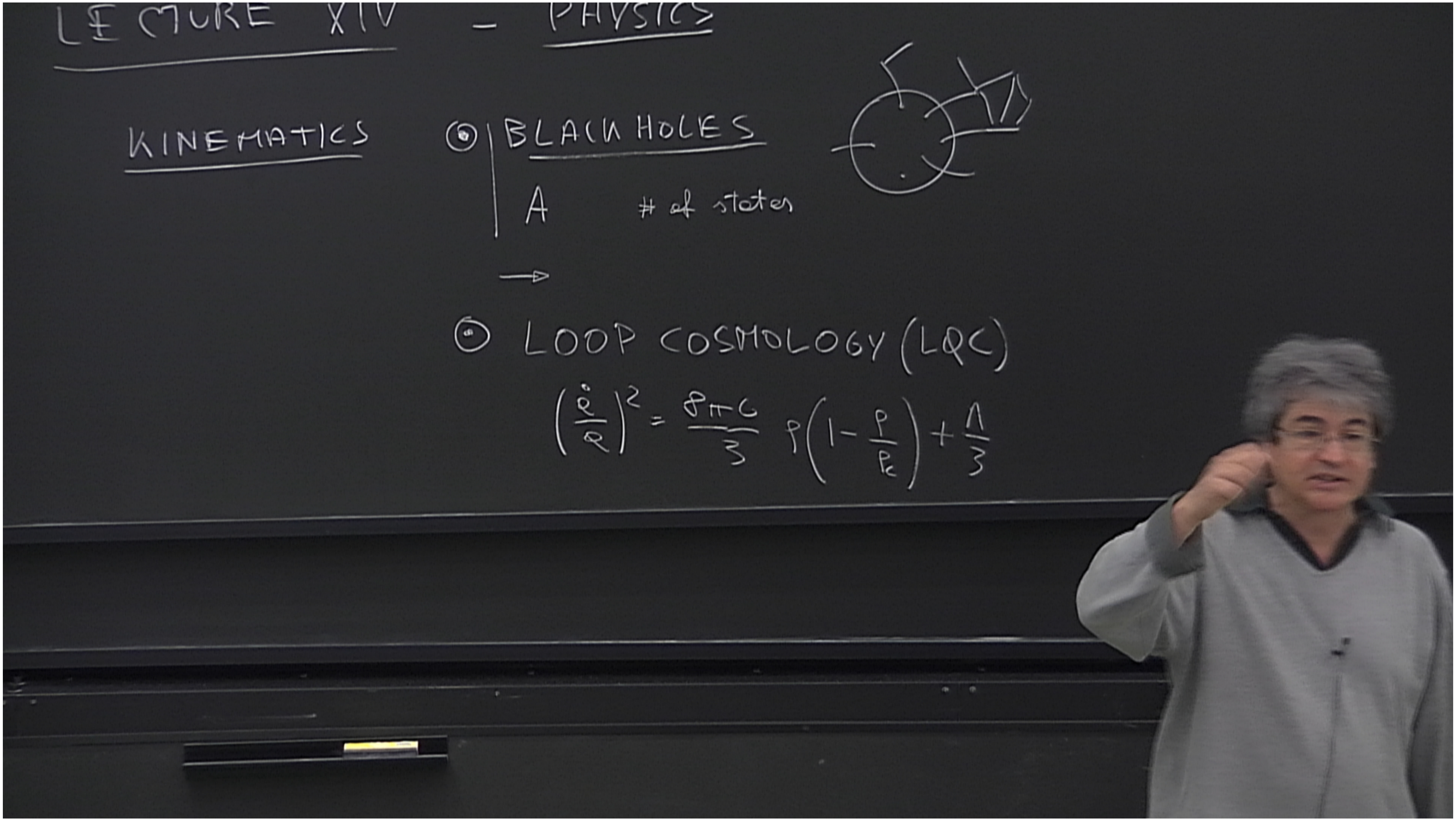
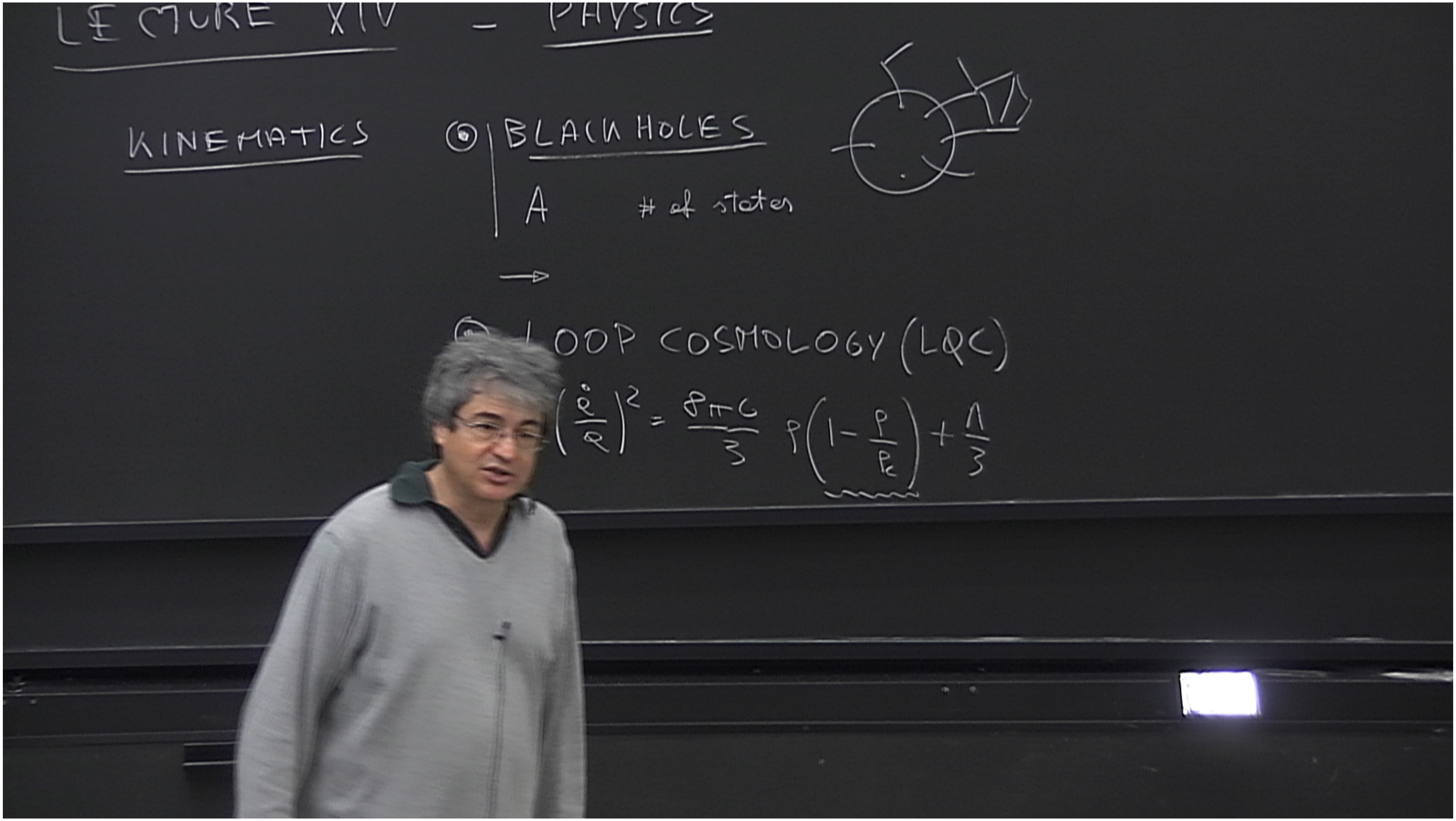
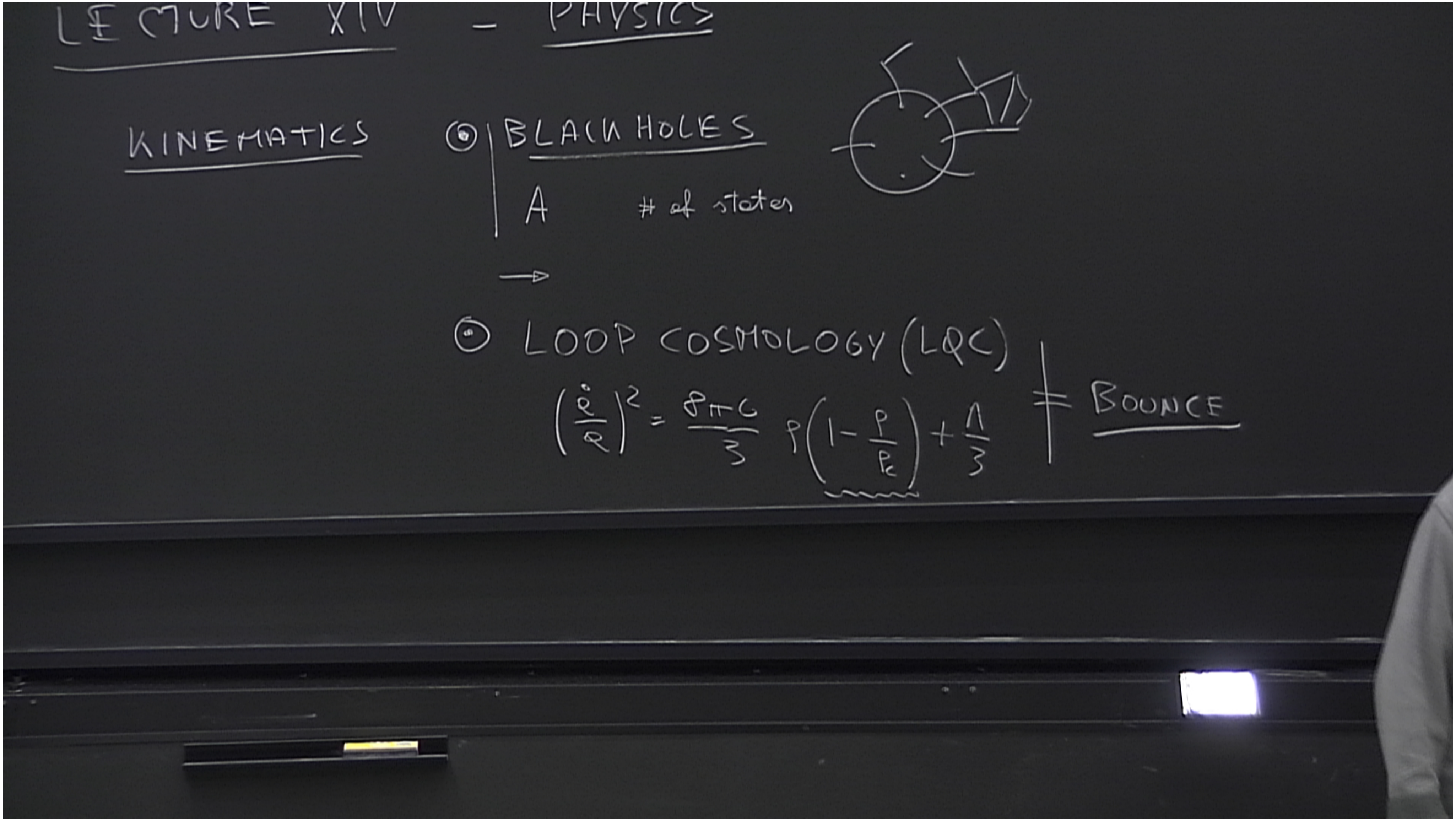
⊙ LOOP COSMOLOGY (LQC)

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho + \frac{\Lambda}{3}$$


LECTURE XIV - PHYSICS
KINEMATICS
BLACK HOLES
A # of states
LOOP COSMOLOGY (LQC)
$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho\left(1-\frac{\rho}{\rho_c}\right)+\frac{\Lambda}{3}$


LECTURE XIV – PHYSICS
KINEMATICS
BLACK HOLES
A # of states
LOOP COSMOLOGY (LQC)
$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho\left(1-\frac{\rho}{\rho_c}\right)+\frac{\Lambda}{3}$

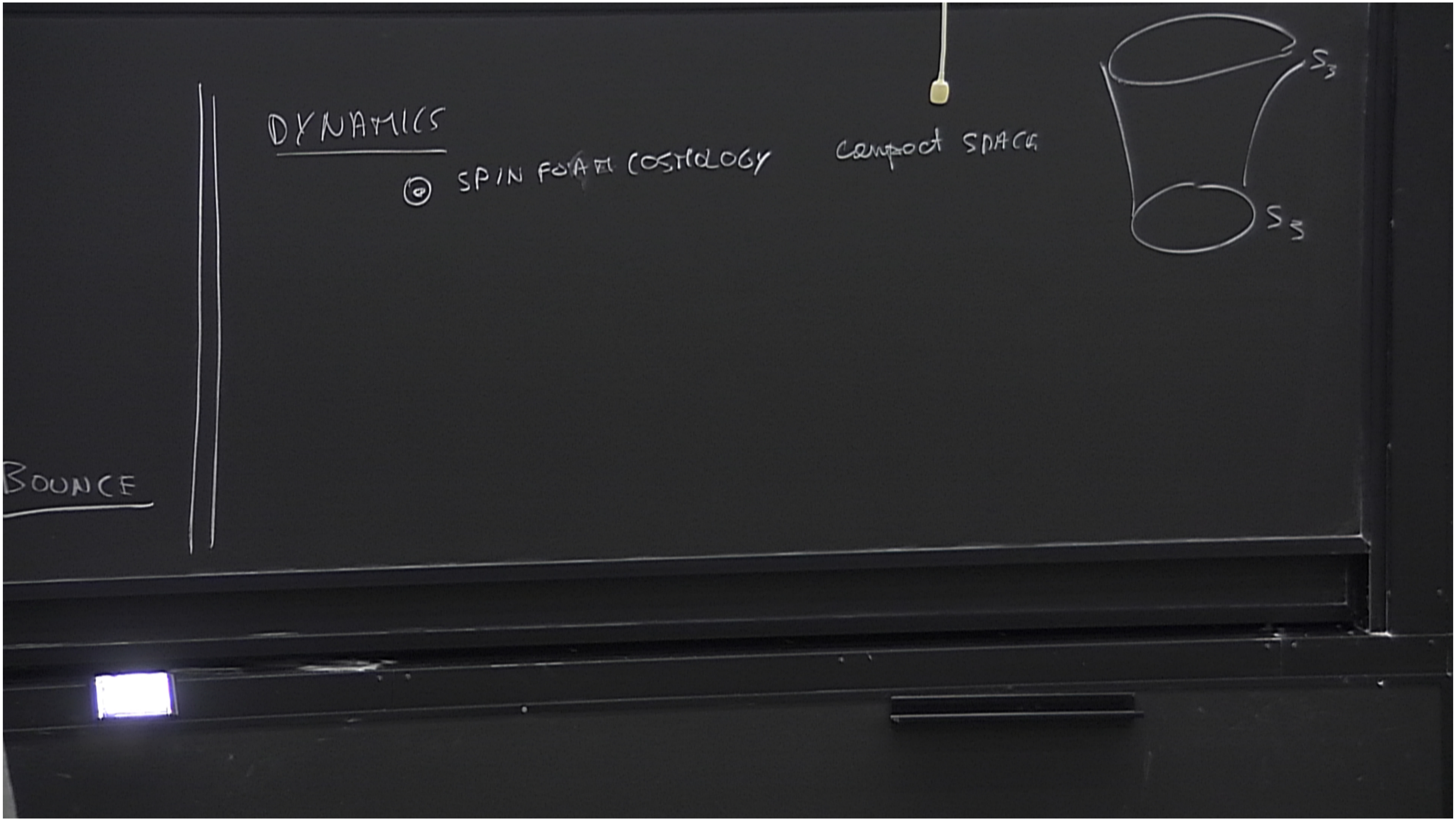

LECTURE XIV – PHYSICS
KINEMATICS
BLACK HOLES
A # of states
LOOP COSMOLOGY (LQC)
$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho\left(1-\frac{\rho}{\rho_c}\right)+\frac{\Lambda}{3}$
BOUNCE

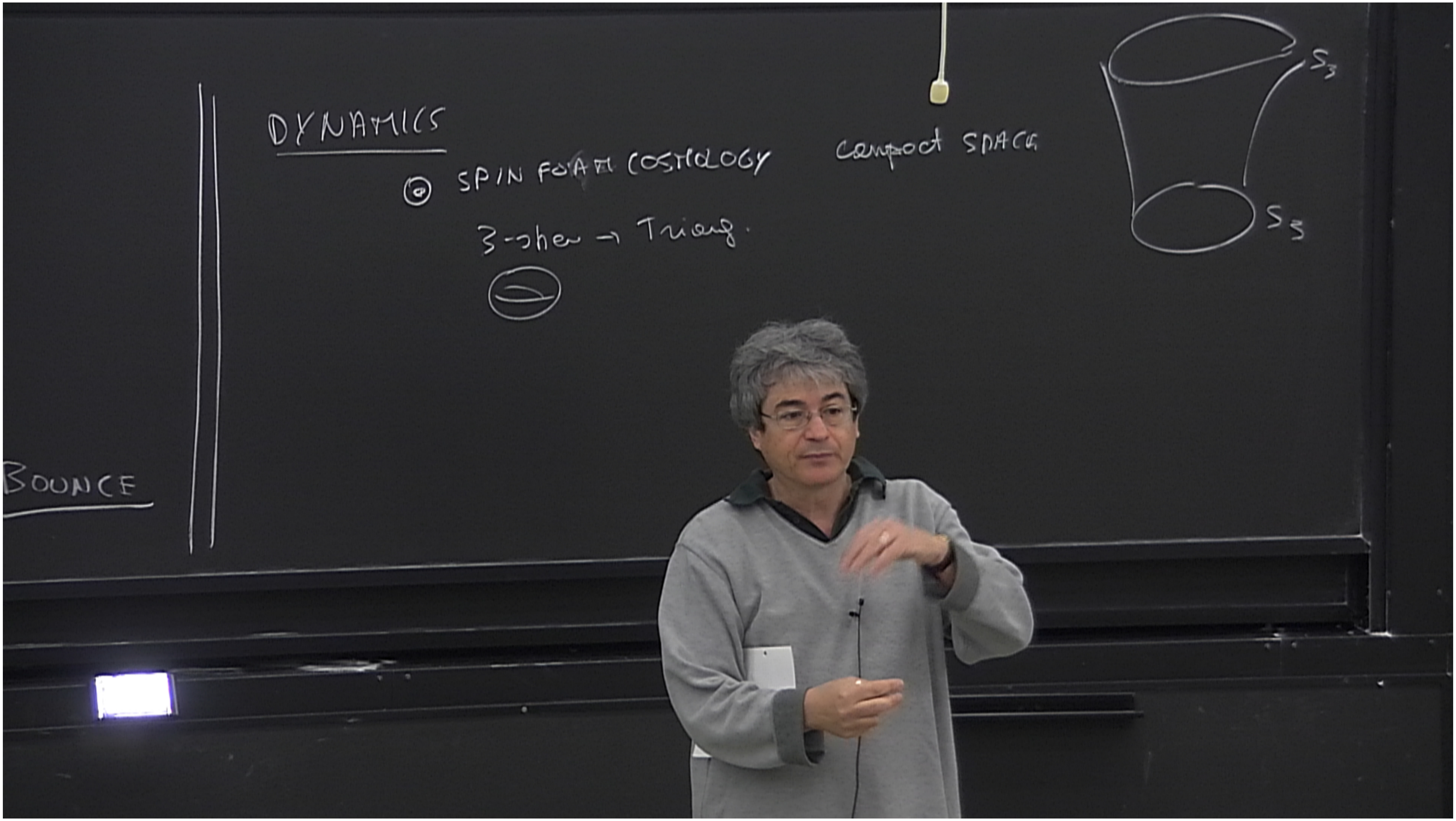

DYNAMICS
BOUNCE

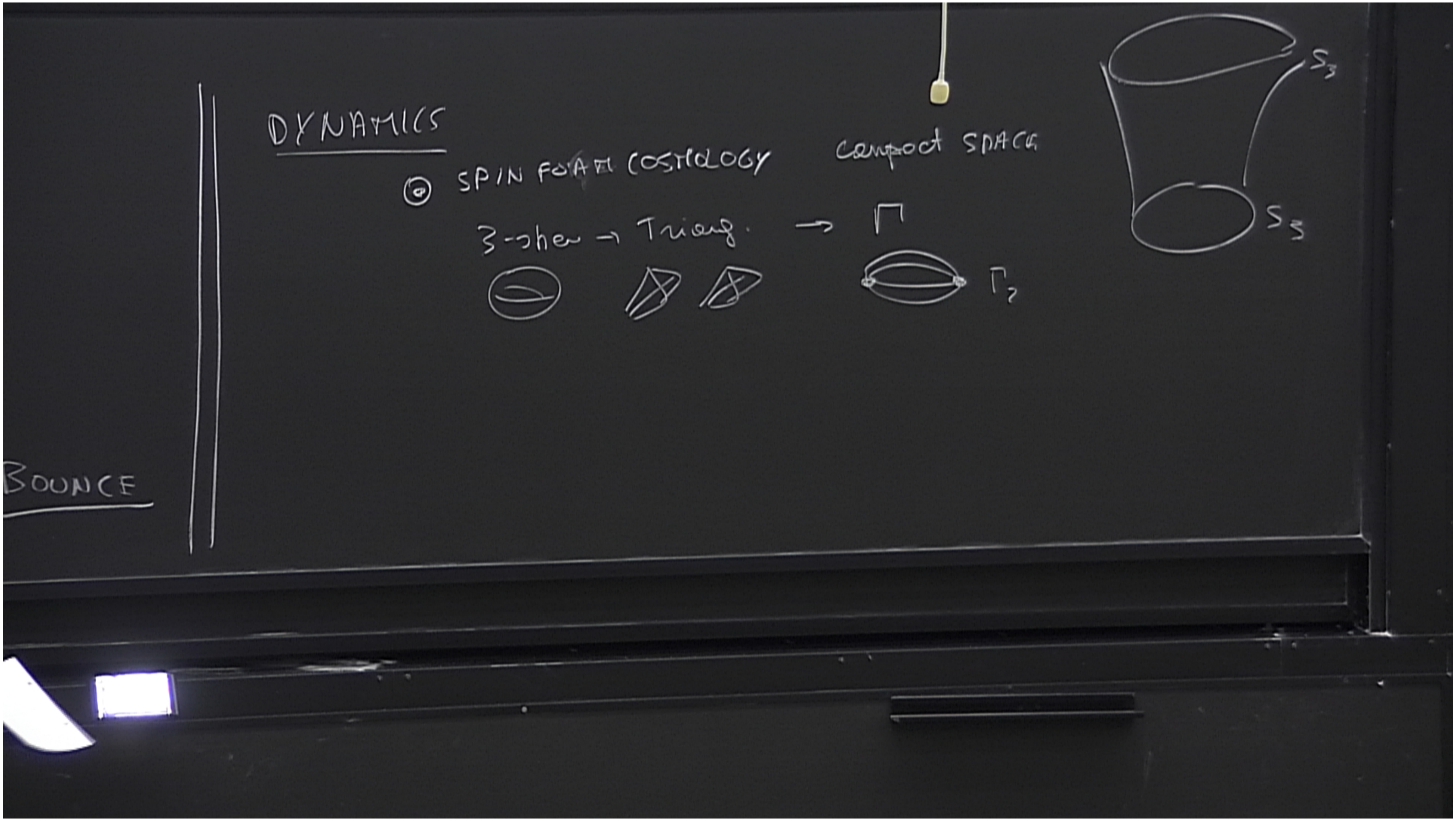
BOUNCE

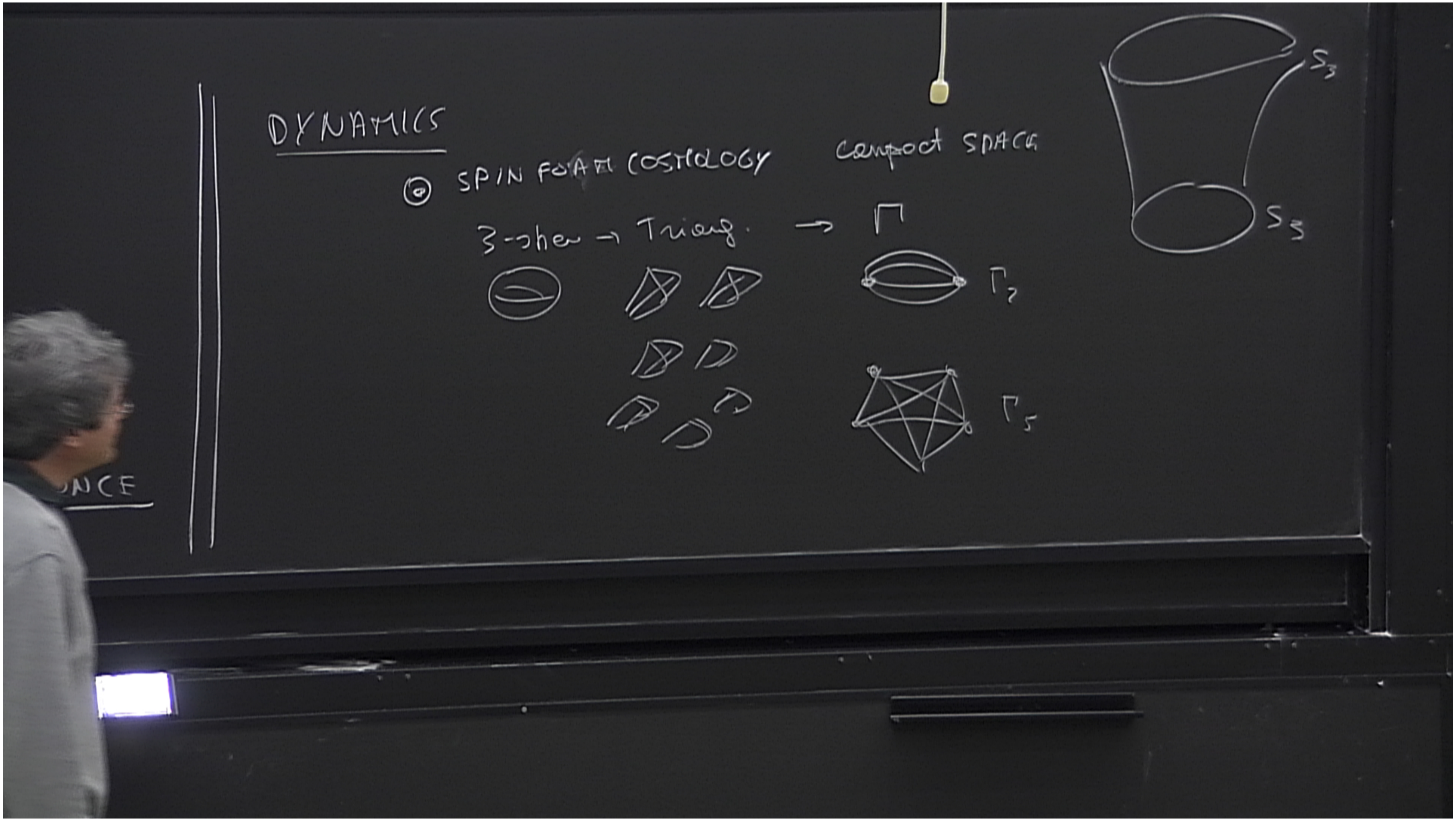
DYNAMICS

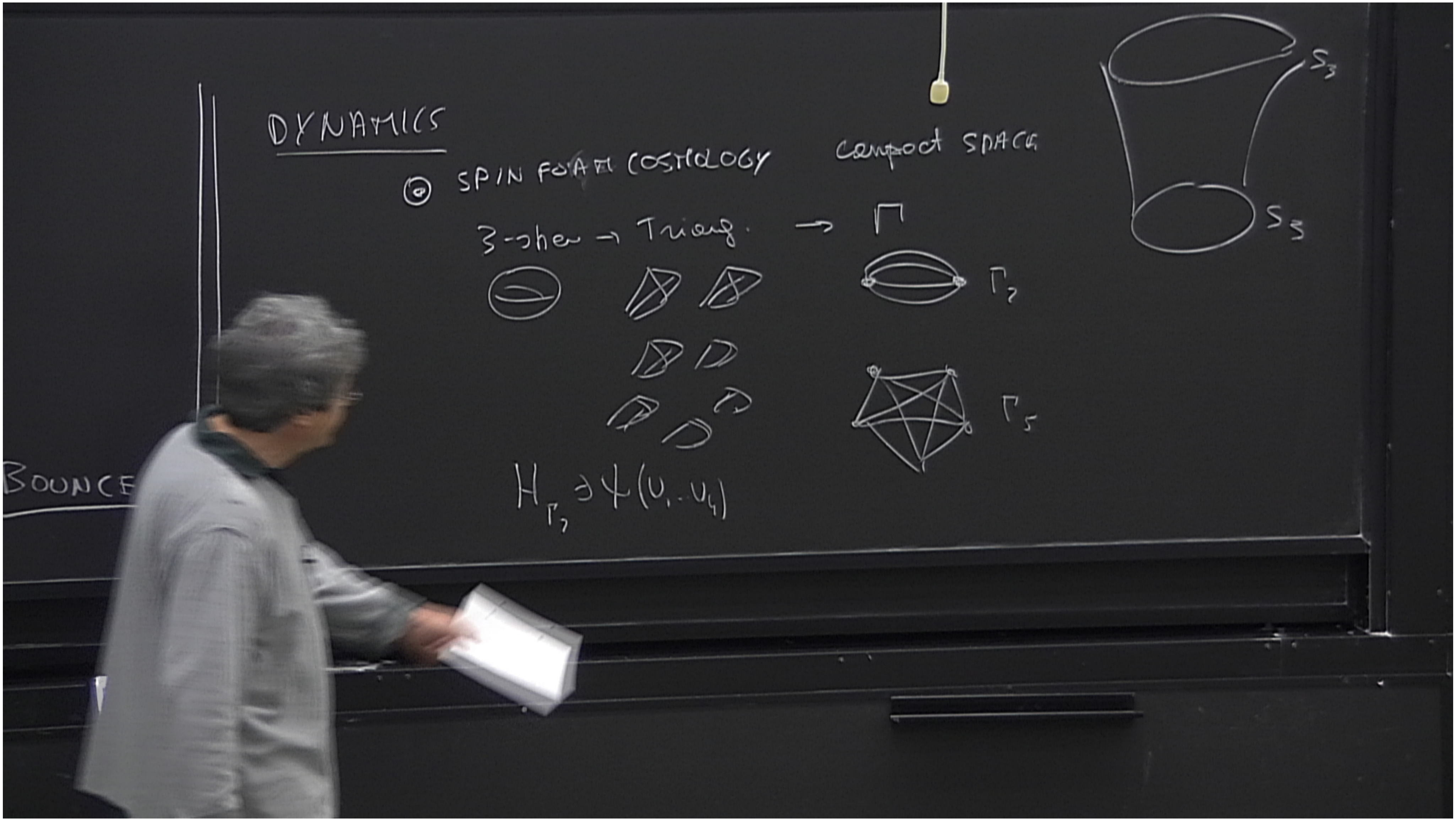
- SPIN FOAM COSMOLOGY

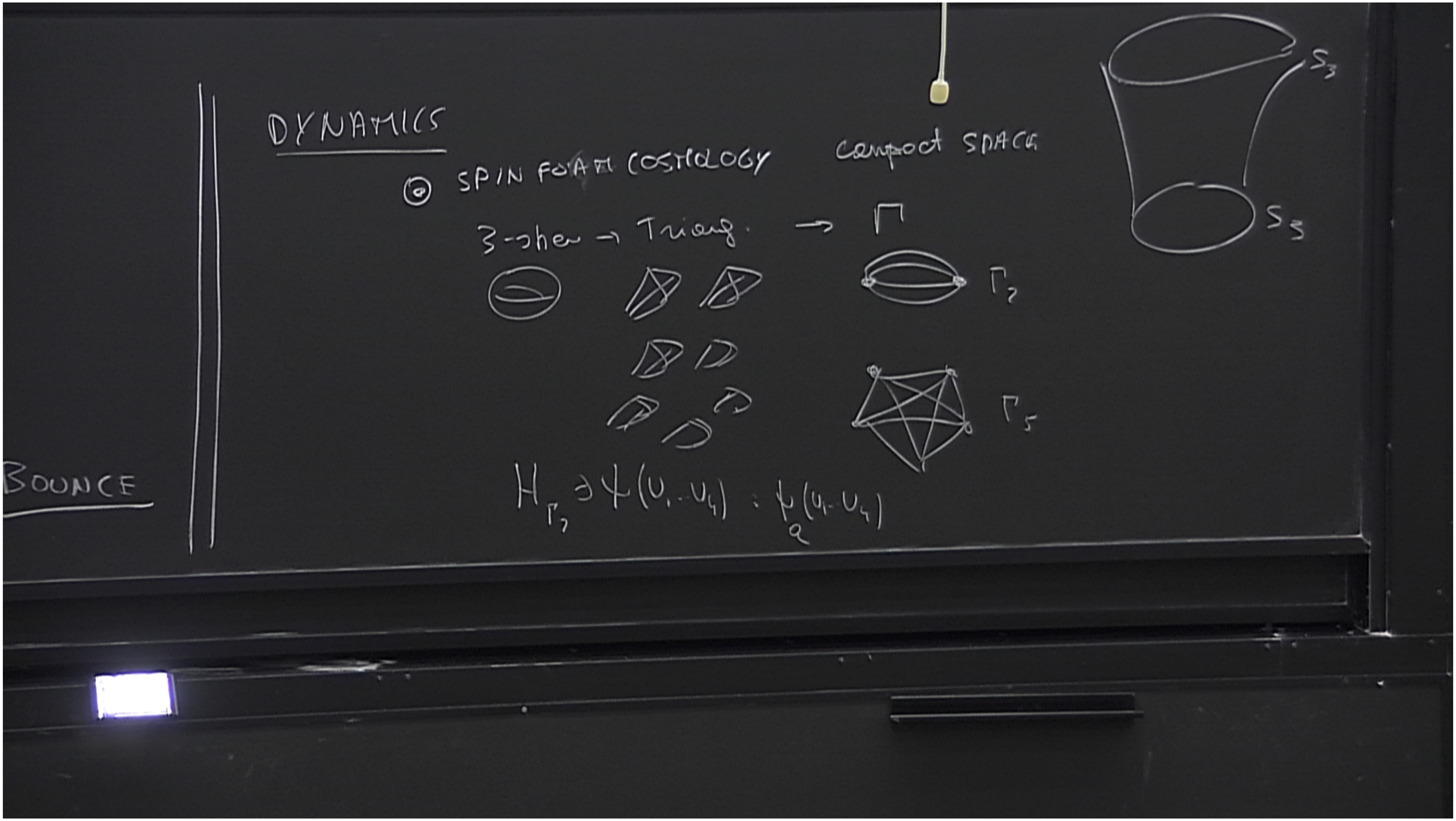

DYNAMICS
SPIN FOAM COSMOLOGY
compact SPACE
S3
S3
BOUNCE

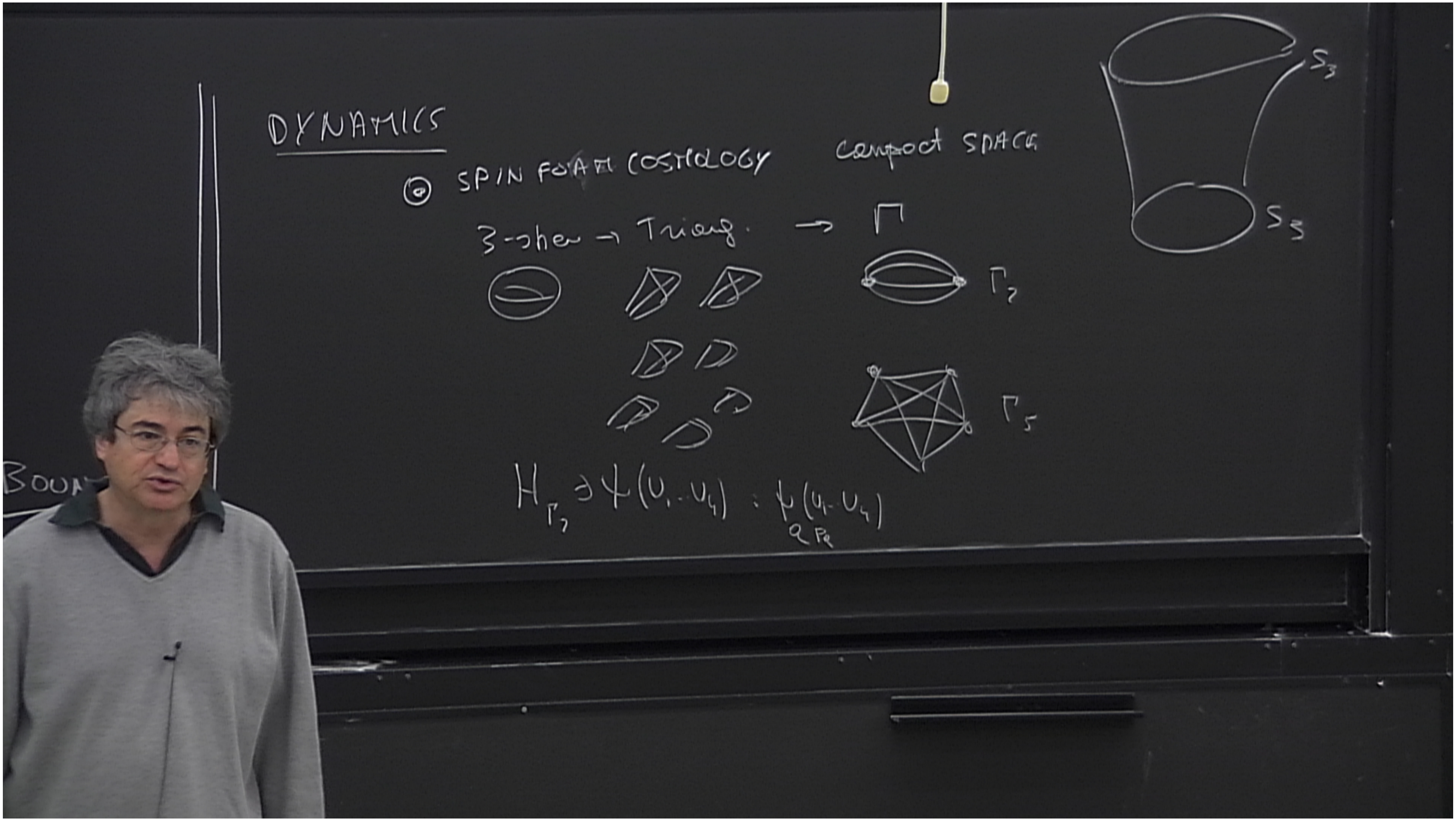

DYNAMICS
SPIN FOAM COSMOLOGY
compact SPACE
3-sphere → Triang.
S_3
S_3
BOUNCE

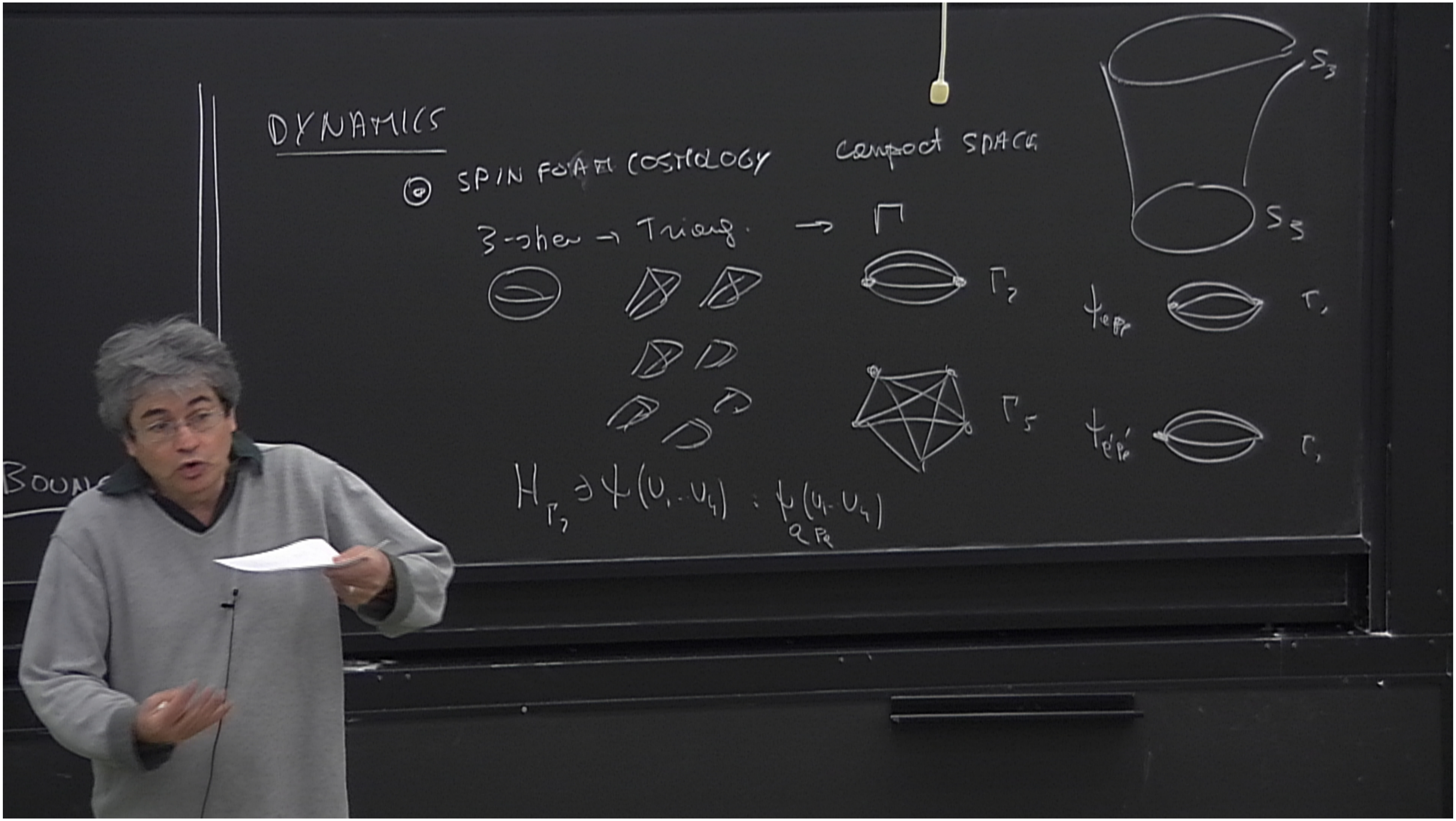

DYNAMICS
SPIN FOAM COSMOLOGY
compact SPACE
3-spher → Triang. → Γ
Γ2
S3
S3
BOUNCE

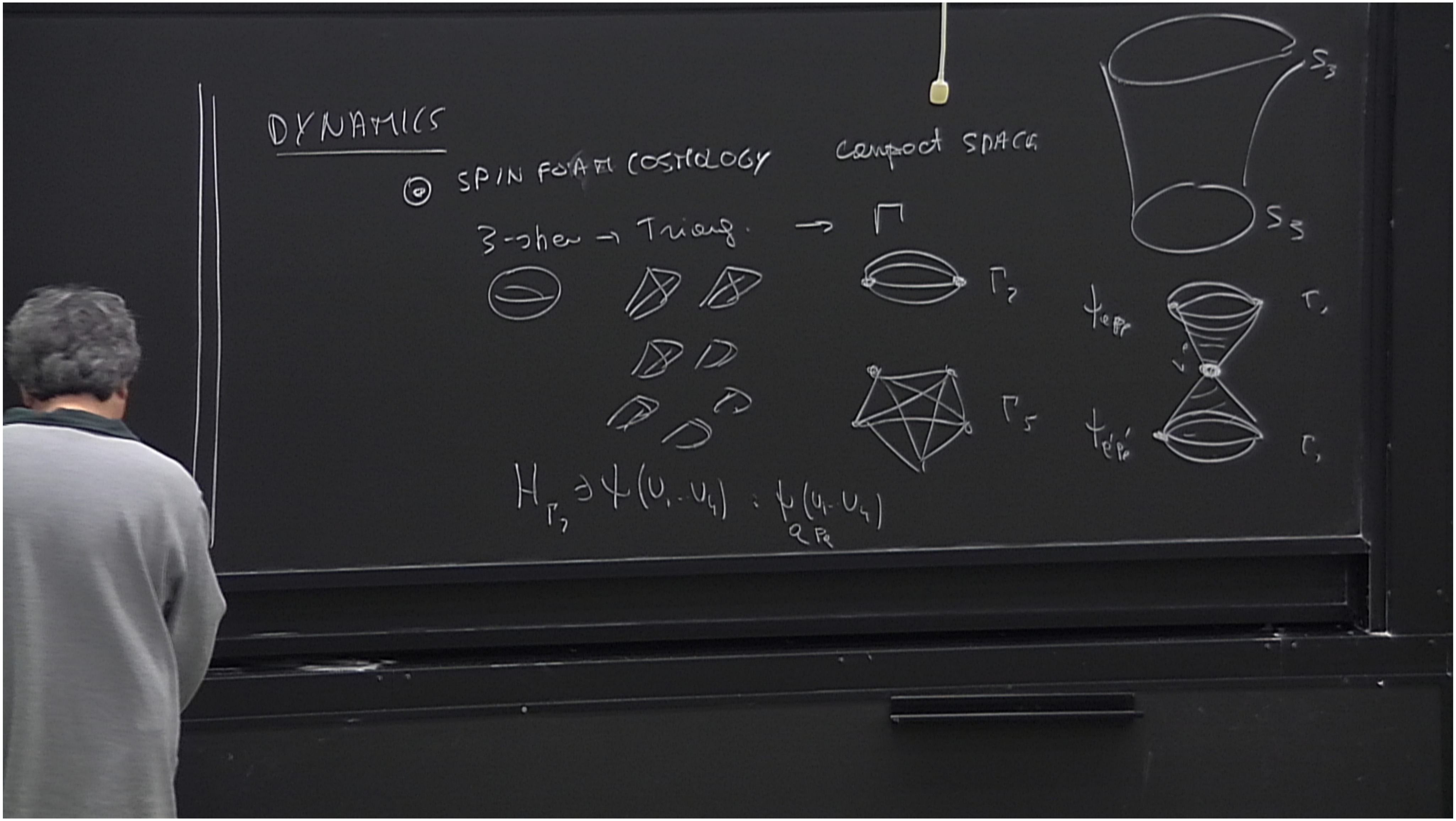

DYNAMICS
SPIN FOAM COSMOLOGY
compact SPACE
3-spher → Triang. → Γ
Γ2
Γ5
S3
S3

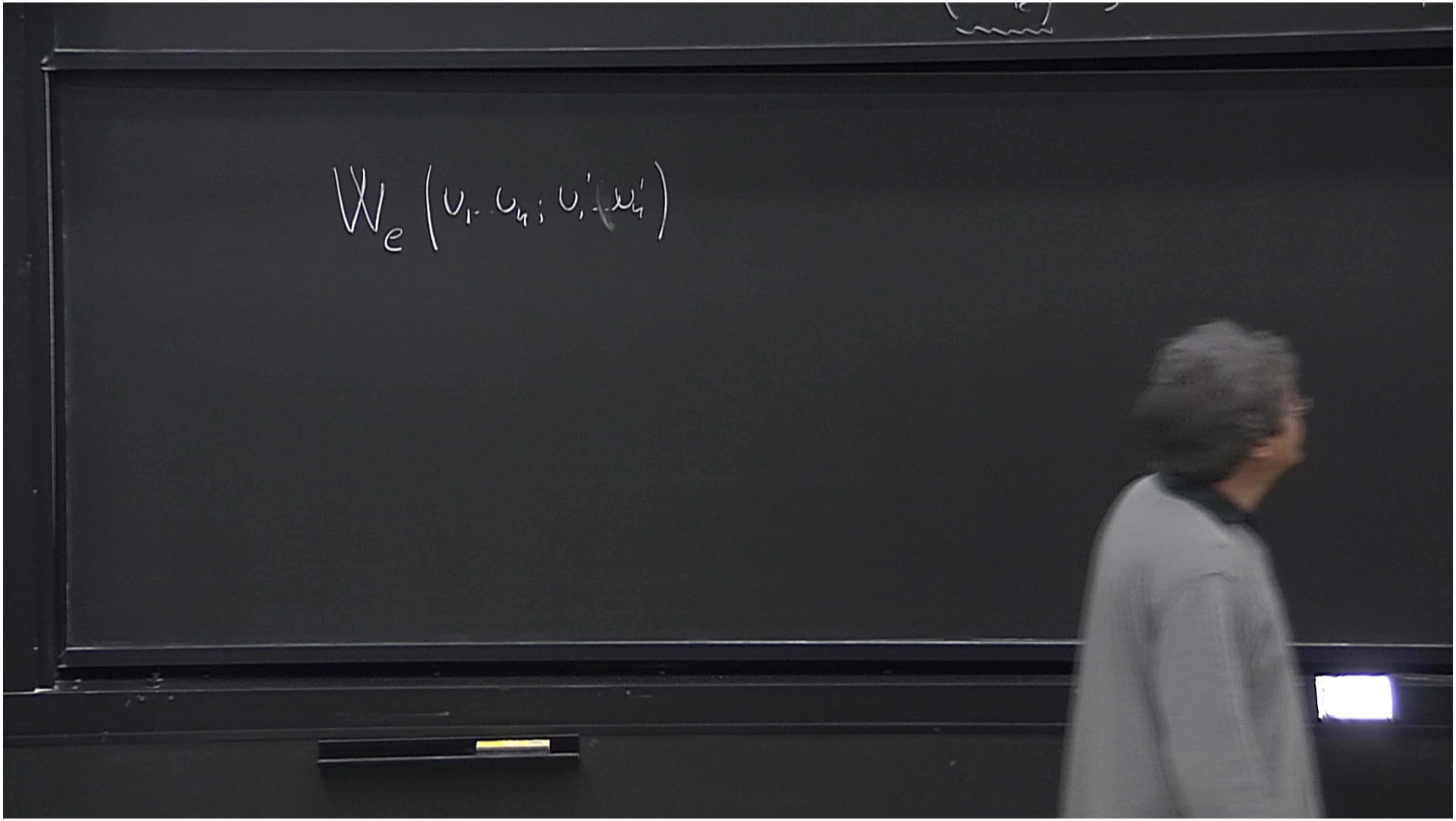

DYNAMICS
SPIN FOAM COSMOLOGY
compact SPACE
3-sphere → Triang. → Γ
Γ_2
Γ_5
S_3
S_3
$H_{\Gamma_2} \ni \psi(v_1 .. v_4)$
BOUNCE

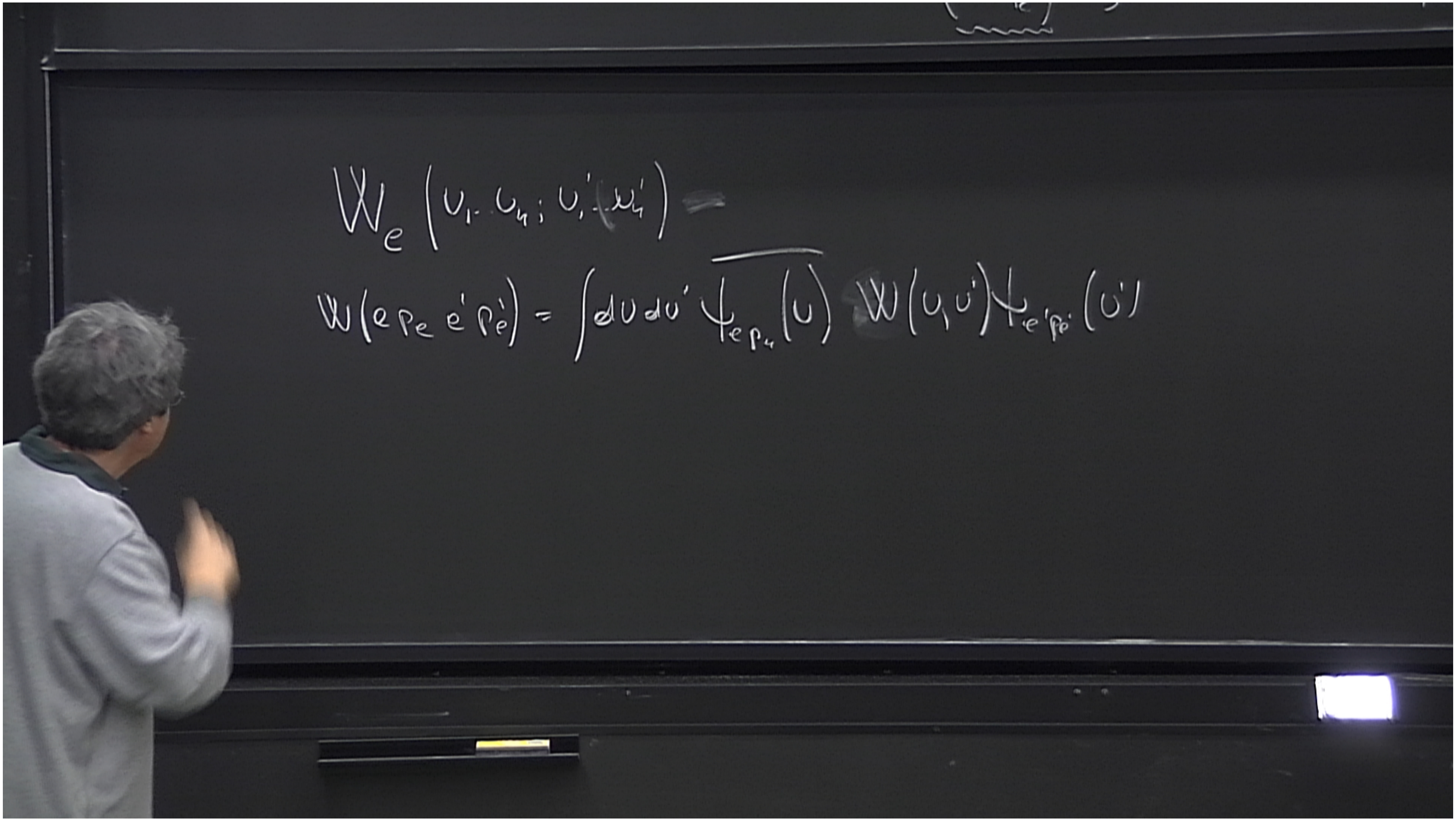

DYNAMICS
SPIN FOAM COSMOLOGY
compact SPACE
3-sphere → Triang. → Γ
Γ_2
Γ_5
S_3
S_3
BOUNCE
$H_{\Gamma_2} \ni \psi(U_1 \ldots U_4) = \psi_a(U_1 \ldots U_4)$

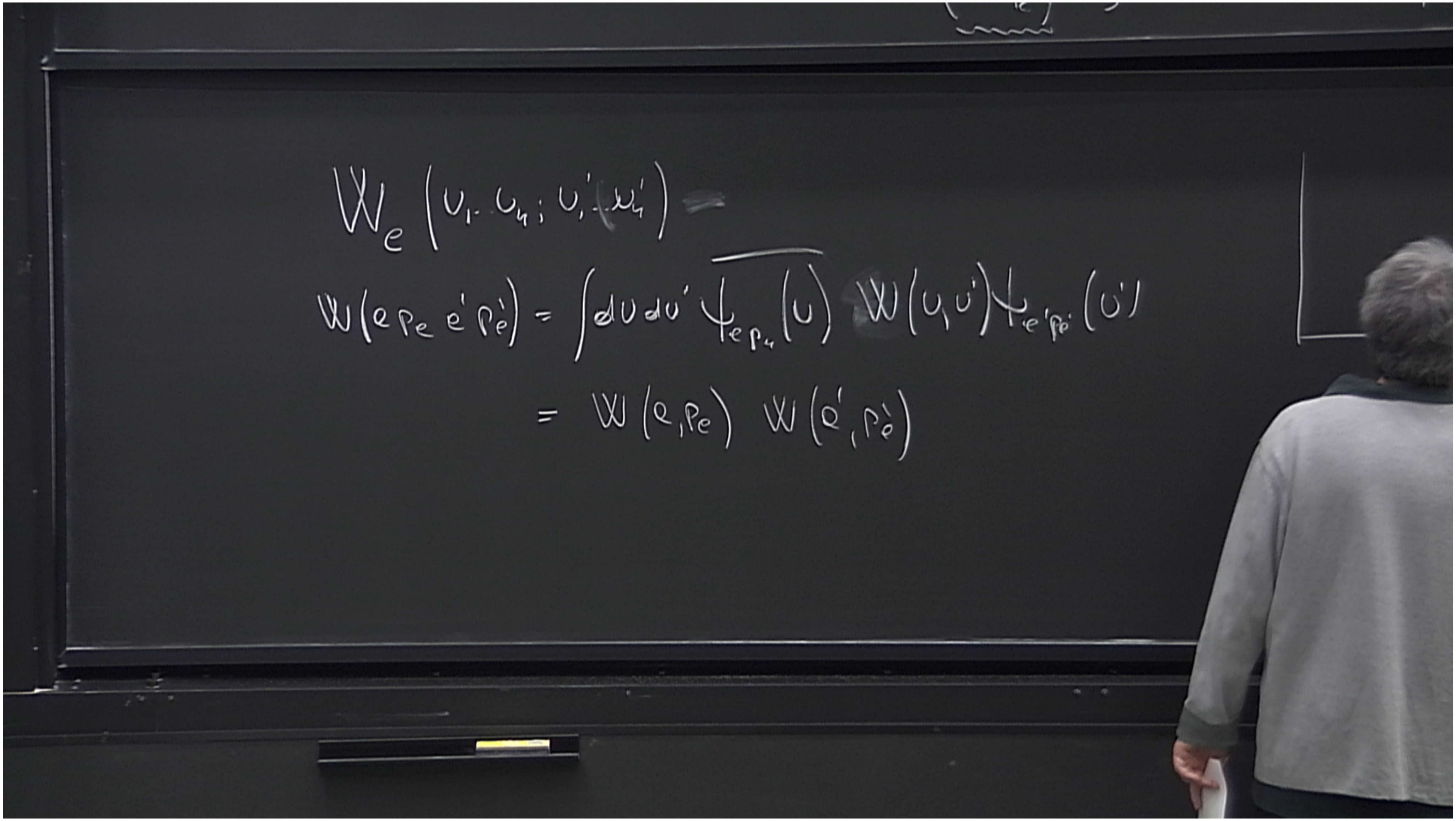

DYNAMICS
SPIN FOAM COSMOLOGY
compact SPACE
S_3
S_3
Γ_2
Γ_5


DYNAMICS
SPIN FOAM COSMOLOGY
compact SPACE
3-sphere → Triang. → Γ
S3
Γ2
Γ5

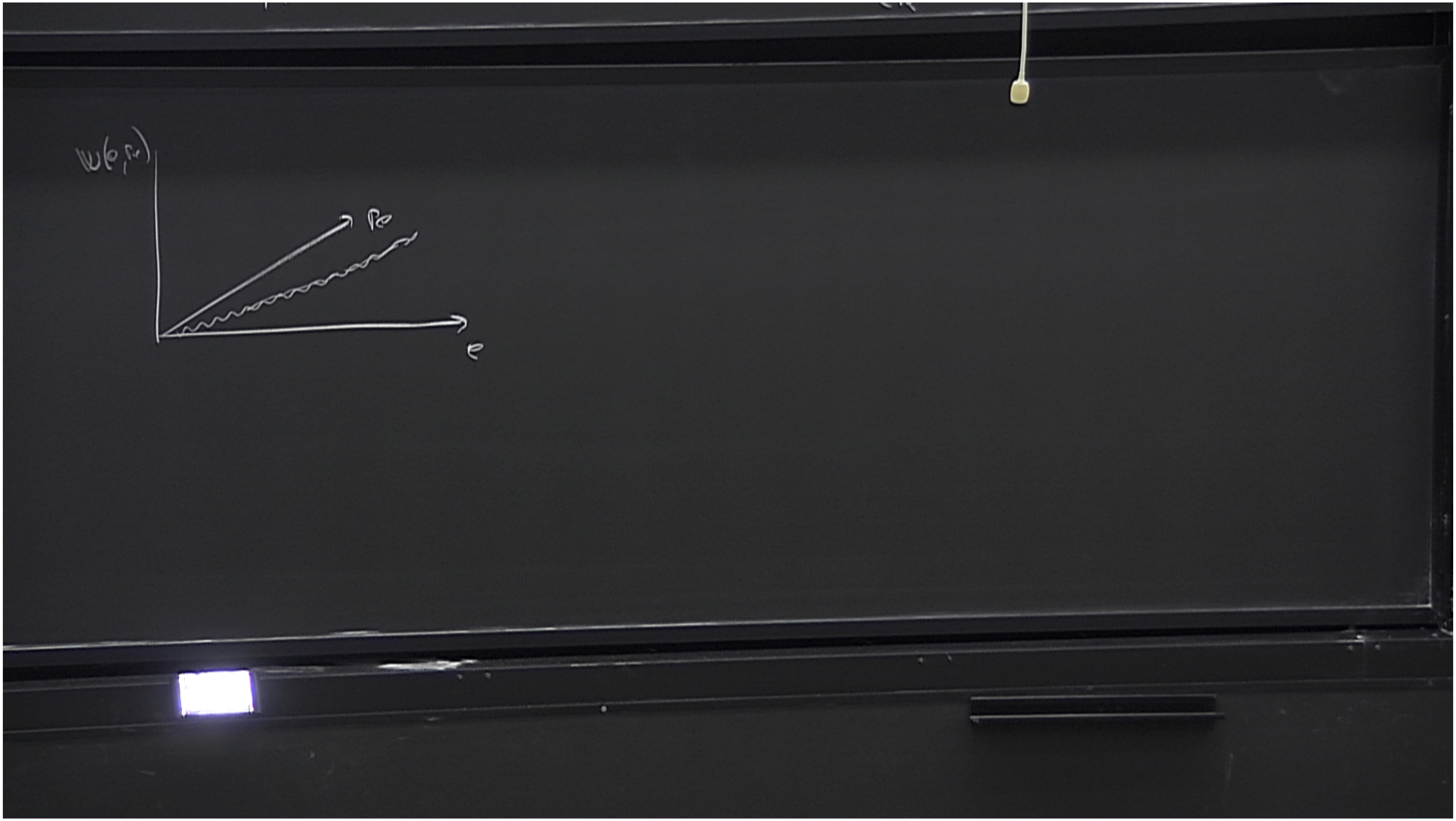

DYNAMICS
SPIN FOAM COSMOLOGY
compact SPACE
3-sphere → Triang. → Γ
Γ2
Γ5
S3
S3

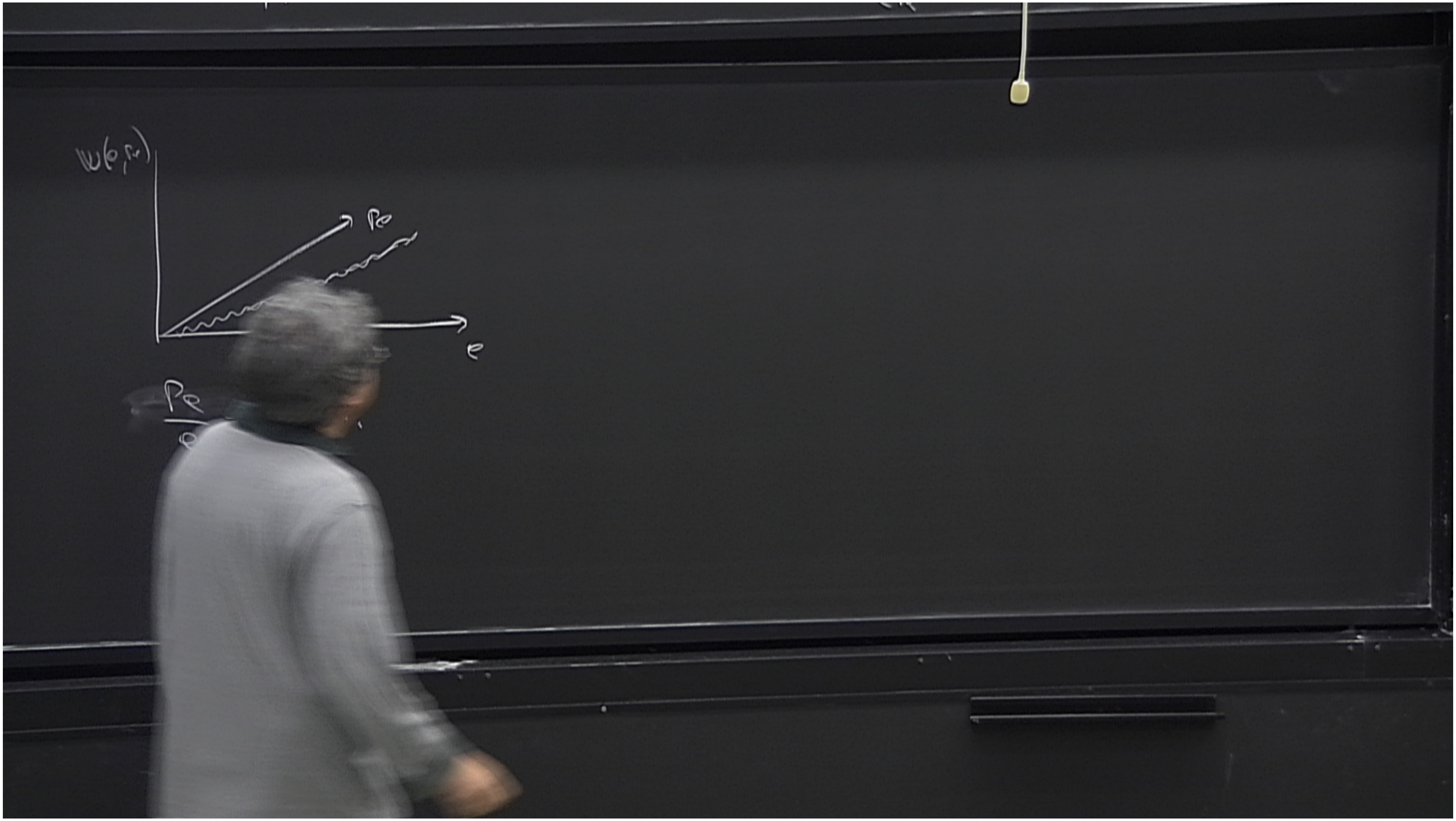

$W_e(u_1 \dots u_n ; u_1' \dots u_n')$

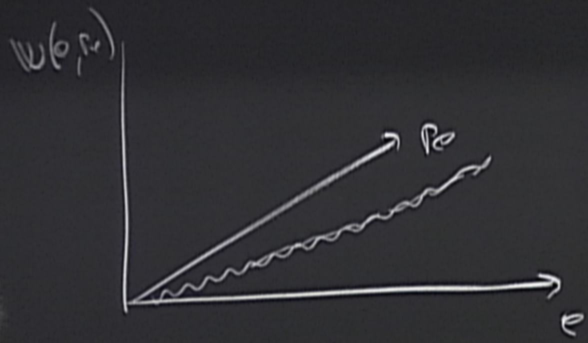

$W_e(u_1 \ldots u_4 ; u_1' \ldots u_4') =$
$W(e\, p_e\, e'\, p_e') = \int du\, du'\, \overline{\psi_{e p_e}(u)}\, W(u, u')\, \psi_{e' p_{e'}}(u')$



$W_e(u_1 \dots u_4 ; u'_1 \dots u'_4)$
$W(e\, p_e\, e'\, p'_e) = \int du\, du'\, \overline{\psi_{e p_4}(u)}\, W(u, u')\, \psi_{e' p'_e}(u')$
$= W(e, p_e)\, W(e', p'_e)$

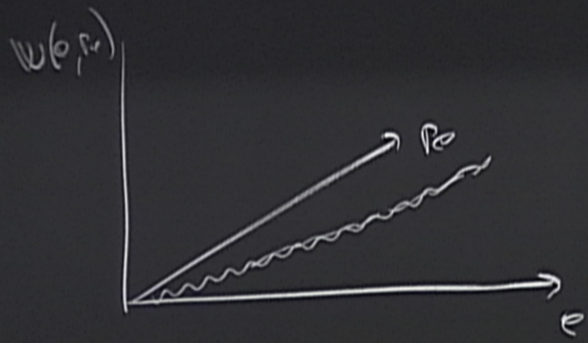






$$\frac{P_\rho}{\rho} = \text{constant.}$$

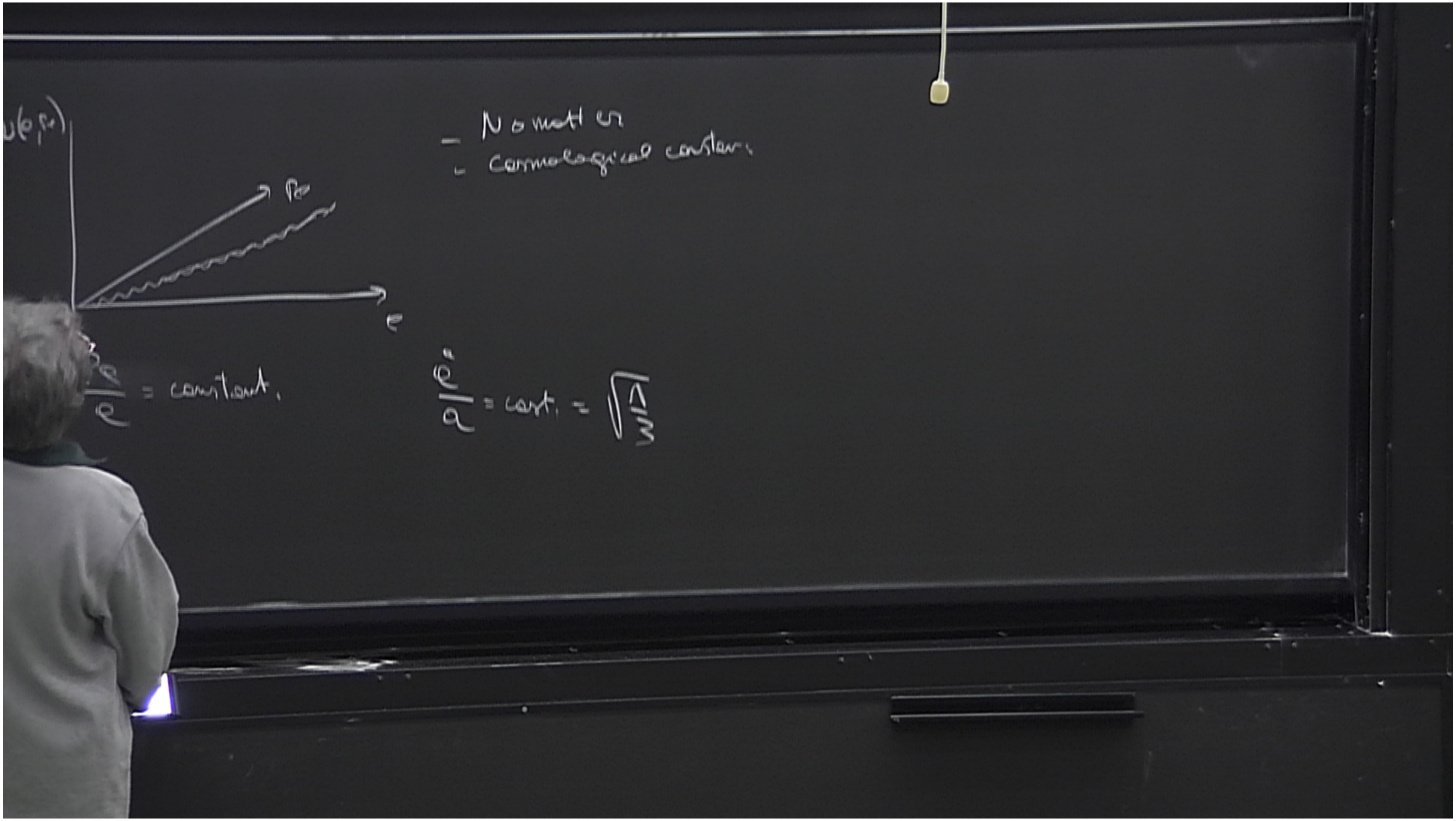
- No matter
- Cosmological constant.



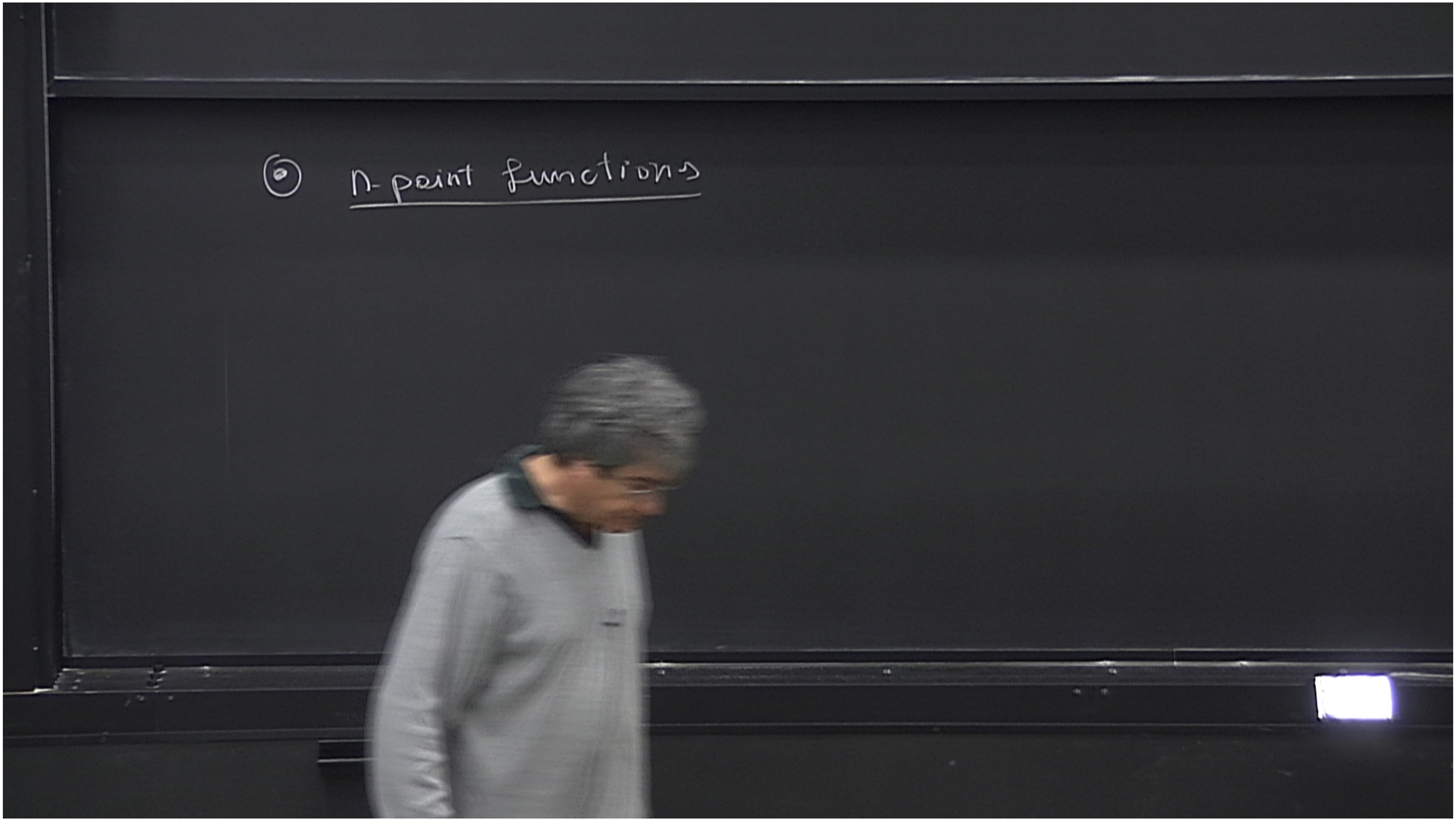
- No matter
- Cosmological constan.

$$\frac{p_e}{e} = \text{constant.}$$

$$\frac{\dot{e}}{a} = \text{cast.} = \sqrt{\frac{\Lambda}{3}}$$

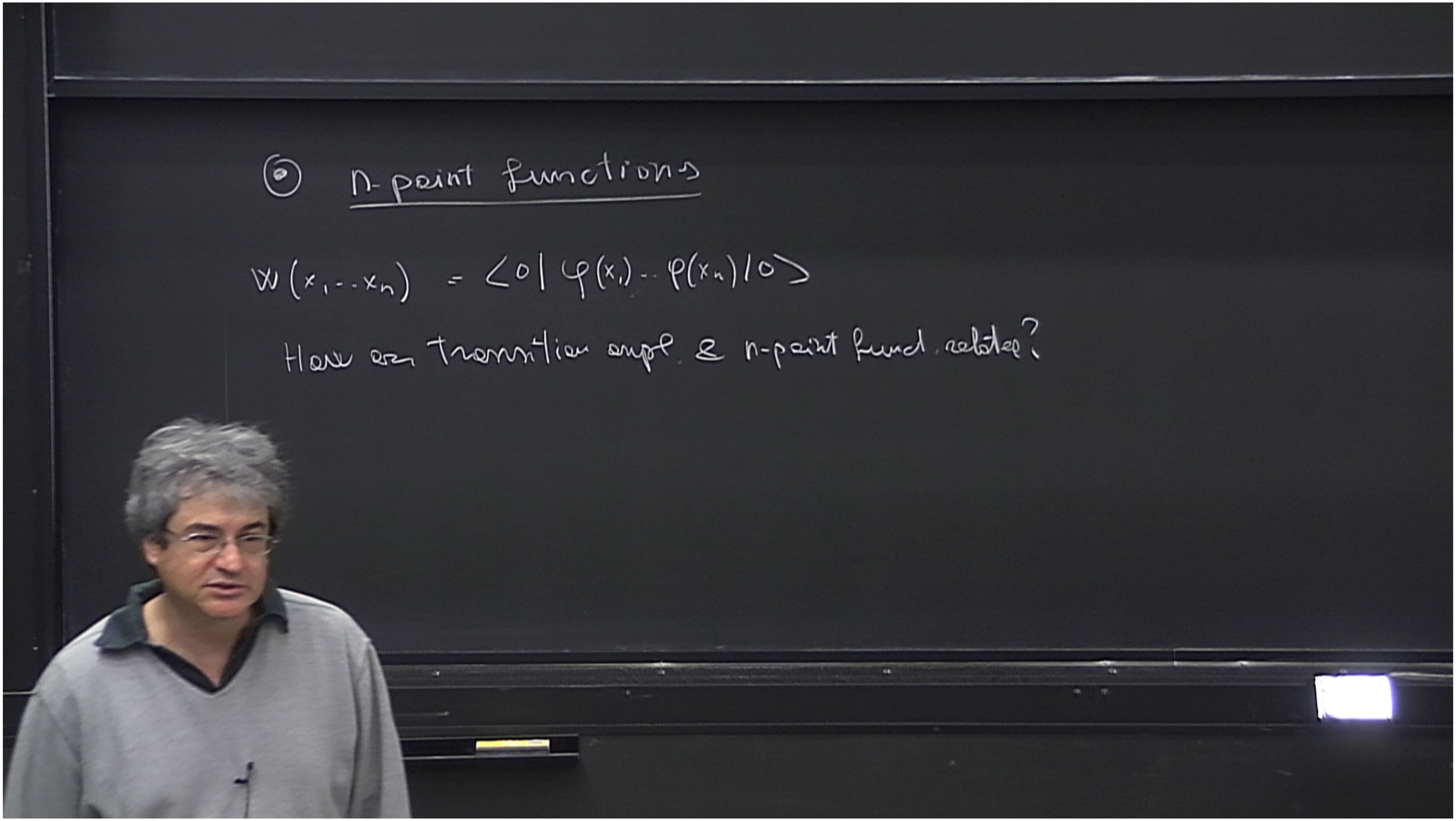


- No matter
- Cosmological constant
$\frac{\dot{a}}{a}$ = const. = $\sqrt{\frac{\Lambda}{3}}$
= constant.


n-point functions

n-point functions

$$W(x_1, \dots x_n) = \langle 0 | \varphi(x_1) \dots \varphi(x_n) | 0 \rangle$$


n-point functions
$W(x_1 \ldots x_n) = \langle 0 | \varphi(x_1) \ldots \varphi(x_n) | 0 \rangle$
How are transition ampl. & n-point funct. related?

$q(t)$

$W(q\,t;\,q'\,t') = \langle q | e^{iH(t-t')} | q' \rangle$

$q(t)$

$$W(q\,t, q'\,t') = \langle q | e^{iH(t-t')} | q' \rangle$$

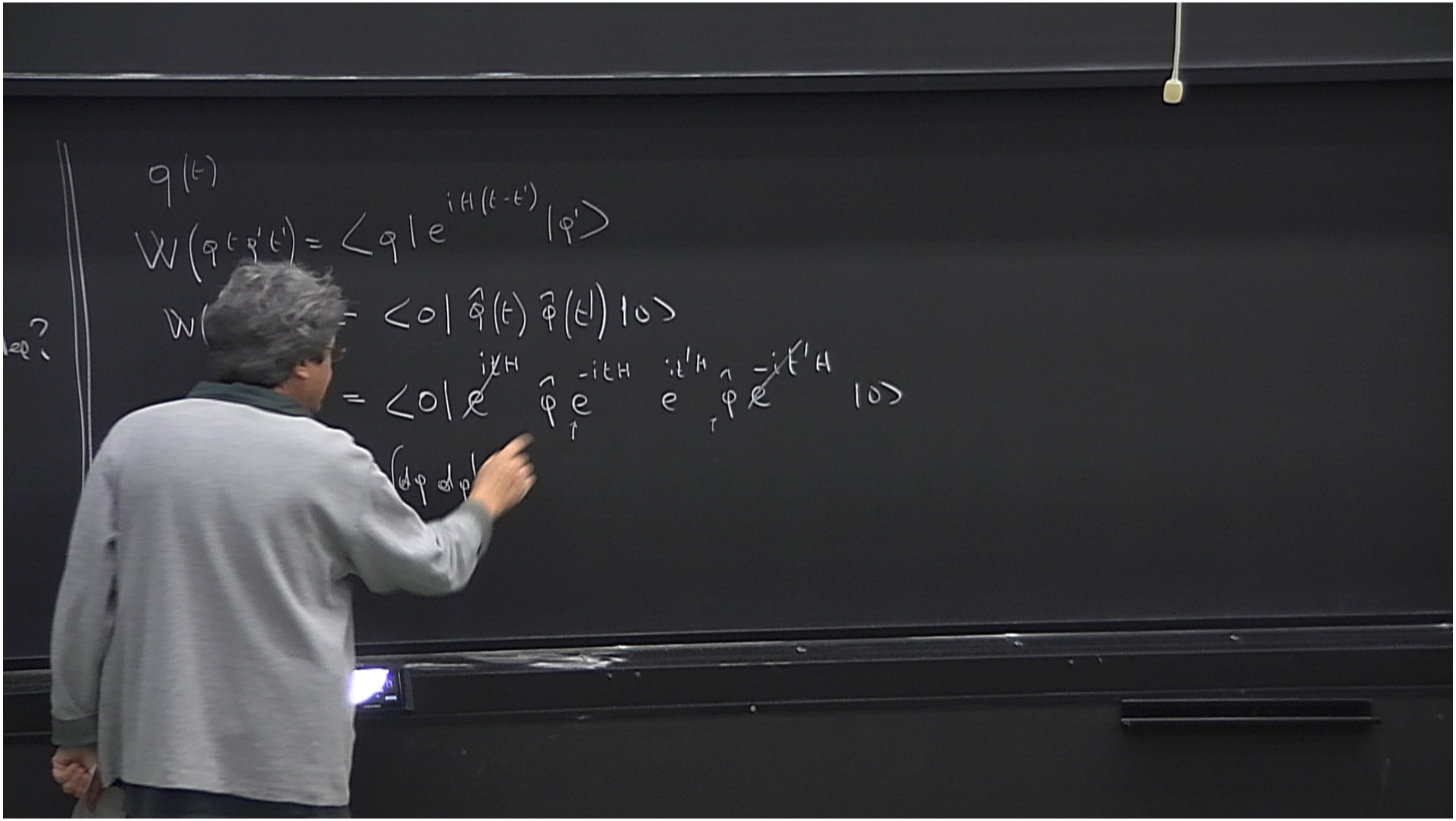
$$W(t, t') = \langle 0 | \hat{q}(t)\, \hat{q}(t') | 0 \rangle$$

$q(t)$

$$W(q\,t;\,q'\,t') = \langle q | e^{iH(t-t')} | q' \rangle$$

$$W(t,t') = \langle 0 | \hat{q}(t)\, \hat{q}(t') | 0 \rangle$$

$$= \langle 0 | \cancel{e^{itH}}\, \hat{q}\, e^{-itH}\, e^{it'H}\, \hat{q}\, \cancel{e^{-it'H}} | 0 \rangle$$



q(t)
W(q t; q' t') = <q| e^{iH(t-t')} |q'>
= <0| q̂(t) q̂(t') |0>
= <0| e^{itH} q̂ e^{-itH} e^{it'H} q̂ e^{-it'H} |0>

$q(t)$

$$W(q\,t;q'\,t') = \langle q | e^{iH(t-t')} | q' \rangle$$

$$W(t,t') = \langle 0 | \hat{q}(t)\, \hat{\varphi}(t') | 0 \rangle$$

$$= \langle 0 | \cancel{e^{itH}}\, \hat{\varphi}\, e^{-itH}\, e^{it'H}\, \hat{\varphi}\, \cancel{e^{-it'H}} | 0 \rangle$$

$$= \int d\varphi\, d\varphi'$$

?

$q(t)$

$$W(q\,t\,q'\,t') = \langle q | e^{iH(t-t')} | q' \rangle$$

ke?

$$W(t,t') = \langle 0 | \hat{q}(t)\, \hat{q}(t') | 0 \rangle$$

$$= \langle 0 | \cancel{e^{itH}}\, \hat{q}\, e^{-itH}\, e^{it'H}\, \hat{q}\, \cancel{e^{-it'H}} | 0 \rangle$$

$$= \int dq\, dq'\, \langle 0 | q \rangle q\, W(q\,t\,q'\,t')$$

ee?

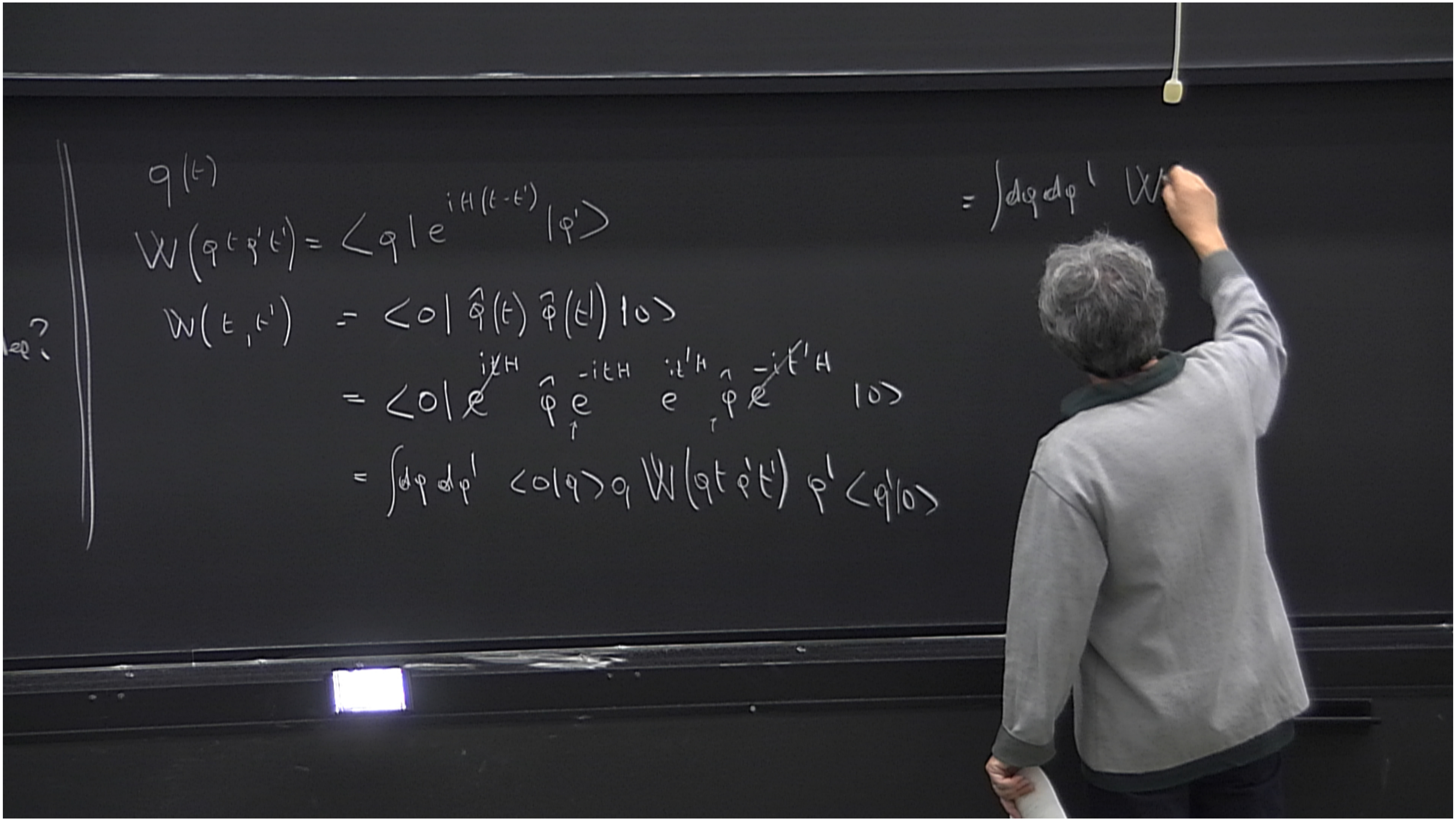
$q(t)$

$$W(q\,t;\,q'\,t') = \langle q | e^{iH(t-t')} | q' \rangle$$

$$W(t, t') = \langle 0 | \hat{q}(t)\, \hat{q}(t') | 0 \rangle$$

$$= \langle 0 | \cancel{e^{itH}}\, \hat{q}\, e^{-itH}\, e^{it'H}\, \hat{q}\, \cancel{e^{-it'H}} | 0 \rangle$$

$$= \int dq\, dq' \, \langle 0 | q \rangle\, q\, W(q\,t\,q'\,t')\, q' \langle q' | 0 \rangle$$


q(t)
W(q t q' t') = <q| e^{iH(t-t')} |q'>
W(t, t') = <0| q̂(t) q̂(t') |0>
= <0| e^{itH} q̂ e^{-itH} e^{it'H} q̂ e^{-it'H} |0>
= ∫dq dq' <0|q> q W(q t q' t') q' <q'|0>
= ∫dq dq' W

$$q(t)$$

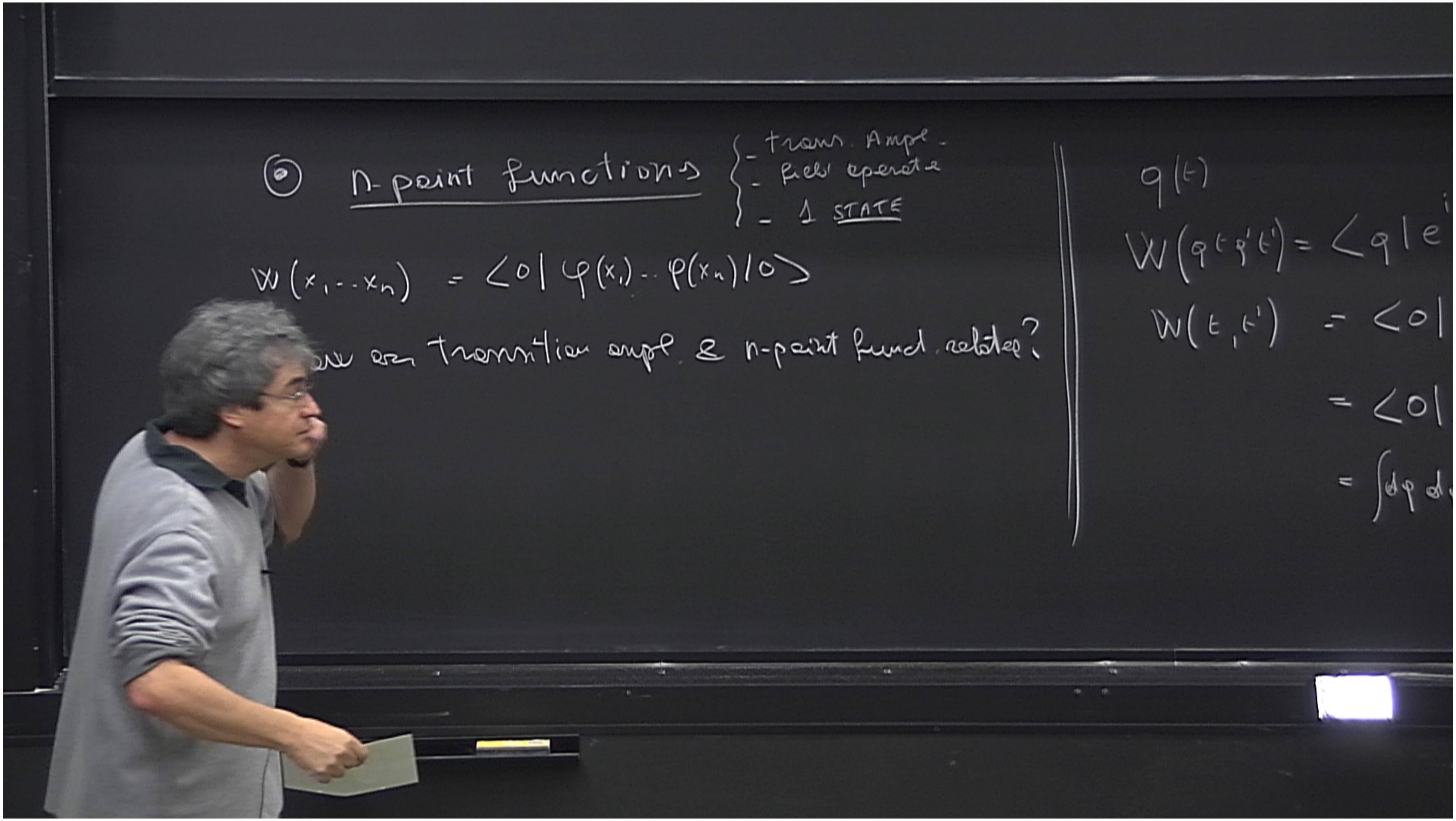
$$W(q\,t\,\varphi'\,t') = \langle q|\, e^{iH(t-t')}\, |\varphi'\rangle$$

$$W(t,t') = \langle 0|\, \hat{q}(t)\, \hat{\varphi}(t')\, |0\rangle$$

$$= \langle 0|\, \cancel{e^{itH}}\, \hat{\varphi}\, e^{-itH}\, e^{it'H}\, \hat{\varphi}\, \cancel{e^{-it'H}}\, |0\rangle$$

$$= \int d\varphi\, d\varphi'\, \langle 0|\varphi\rangle\, \varphi\, W(\varphi\, t\, \varphi'\, t')\, \varphi'\, \langle \varphi'|0\rangle$$

$$= \int d\varphi\, d\varphi'\, W(\varphi\, t\, \varphi'\, t')\, \varphi\, \varphi'\, \bar{\Psi}(\varphi)\, \Psi(\varphi')$$


n-point functions
- trans. Ampl.
- field operator
- 1 STATE
W(x1...xn) = <0| φ(x1)...φ(xn) |0>
transition ampl. & n-point funct. related?
q(t)
W(q t q' t') = <q|e
W(t, t') = <0|
= <0|
= ∫dφ d

③ n-point functions $\begin{cases} \text{- trans. Ampl.} \\ \text{- field operator} \\ \text{- 1 STATE} \end{cases}$

$$W(x_1 \ldots x_n) = \langle 0 | \varphi(x_1) \ldots \varphi(x_n) | 0 \rangle$$

How are transition ampl. & n-point fund. related?

$$= \int D\varphi \; \varphi(x_1) \ldots \varphi(x_n) \, e^{iS[\varphi]}$$

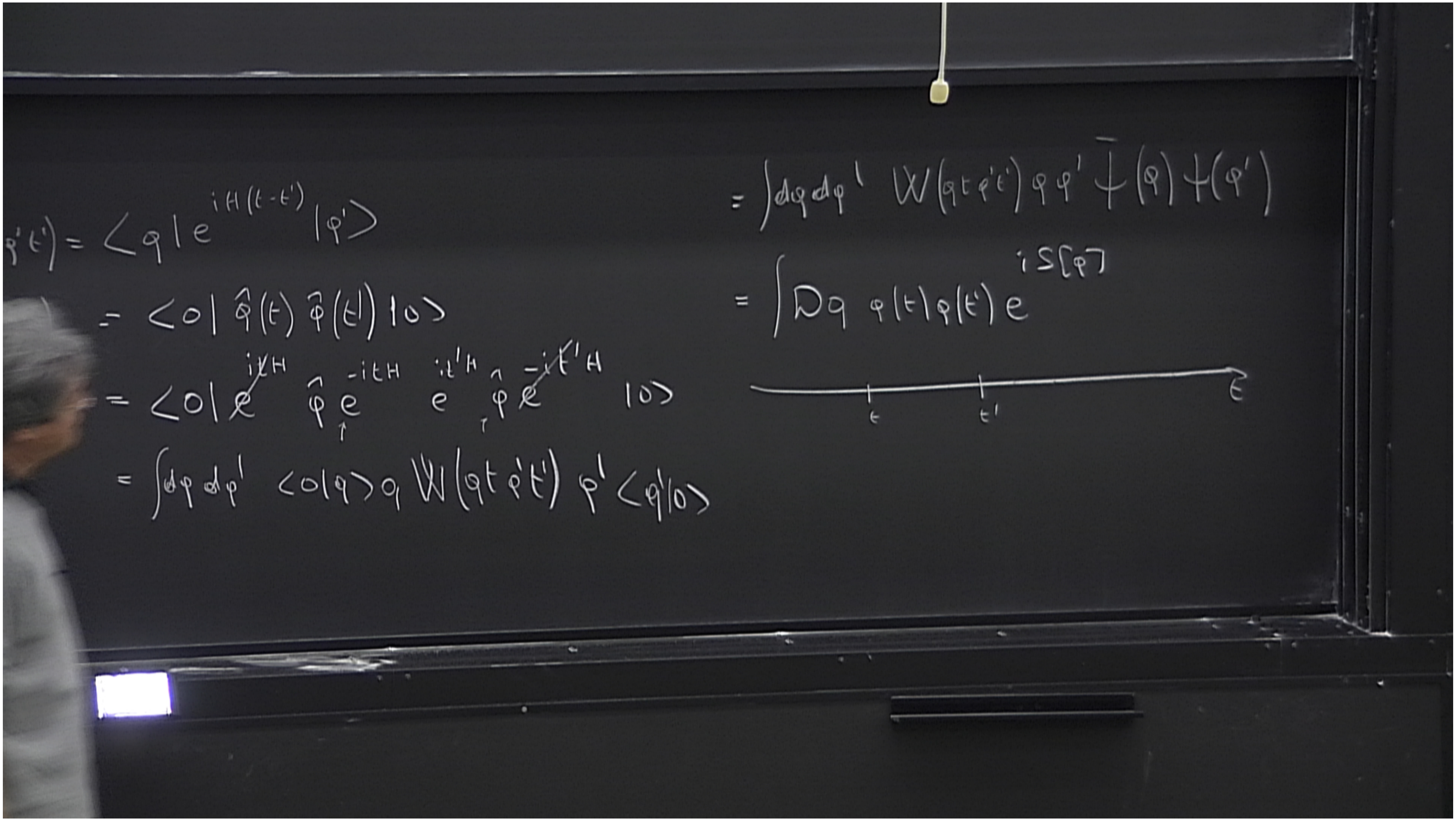
$q(t)$

$W(q\,t, q'\,t') = \langle q | e^{i}$

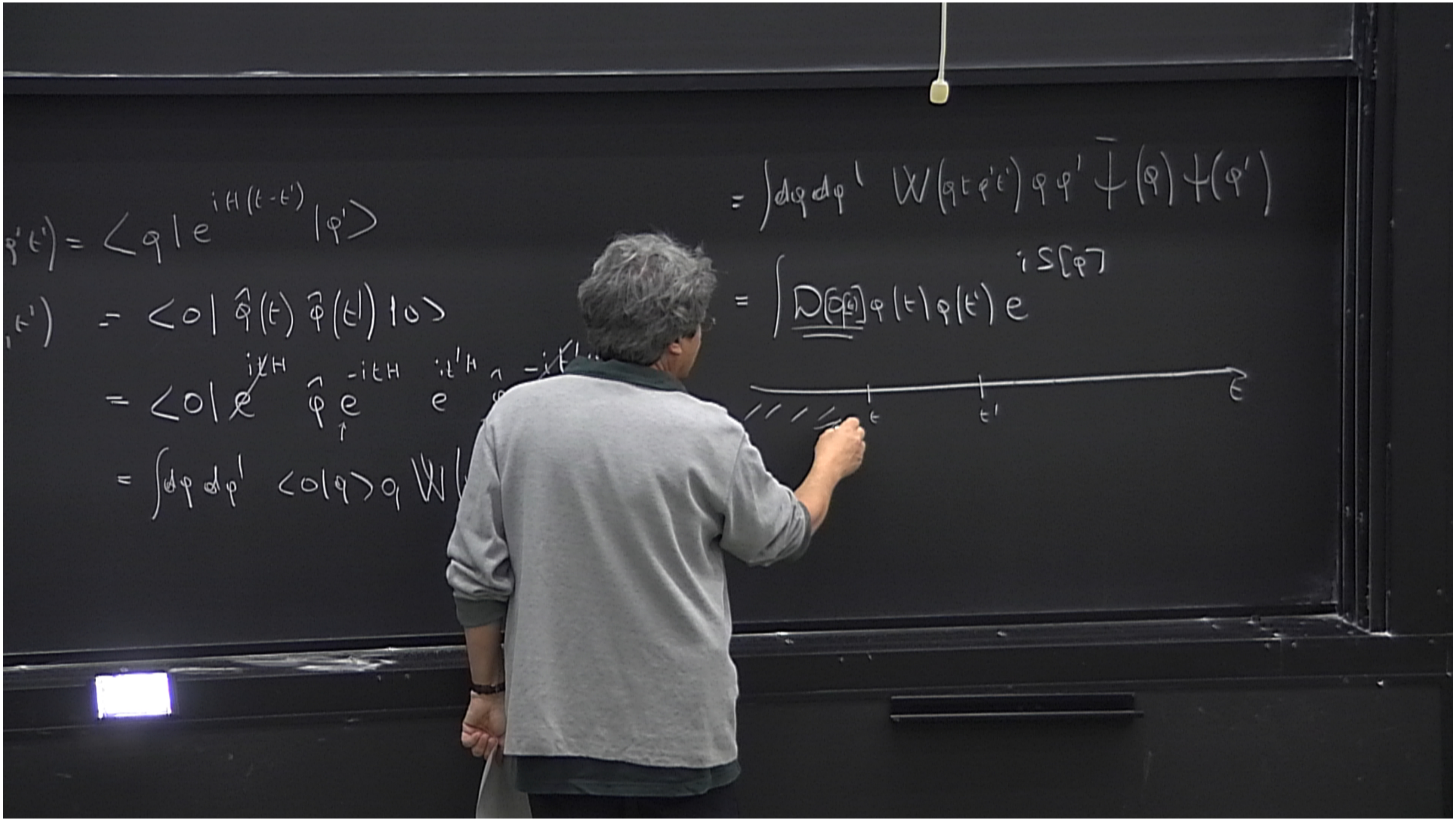
$W(t, t') = \langle 0 |$

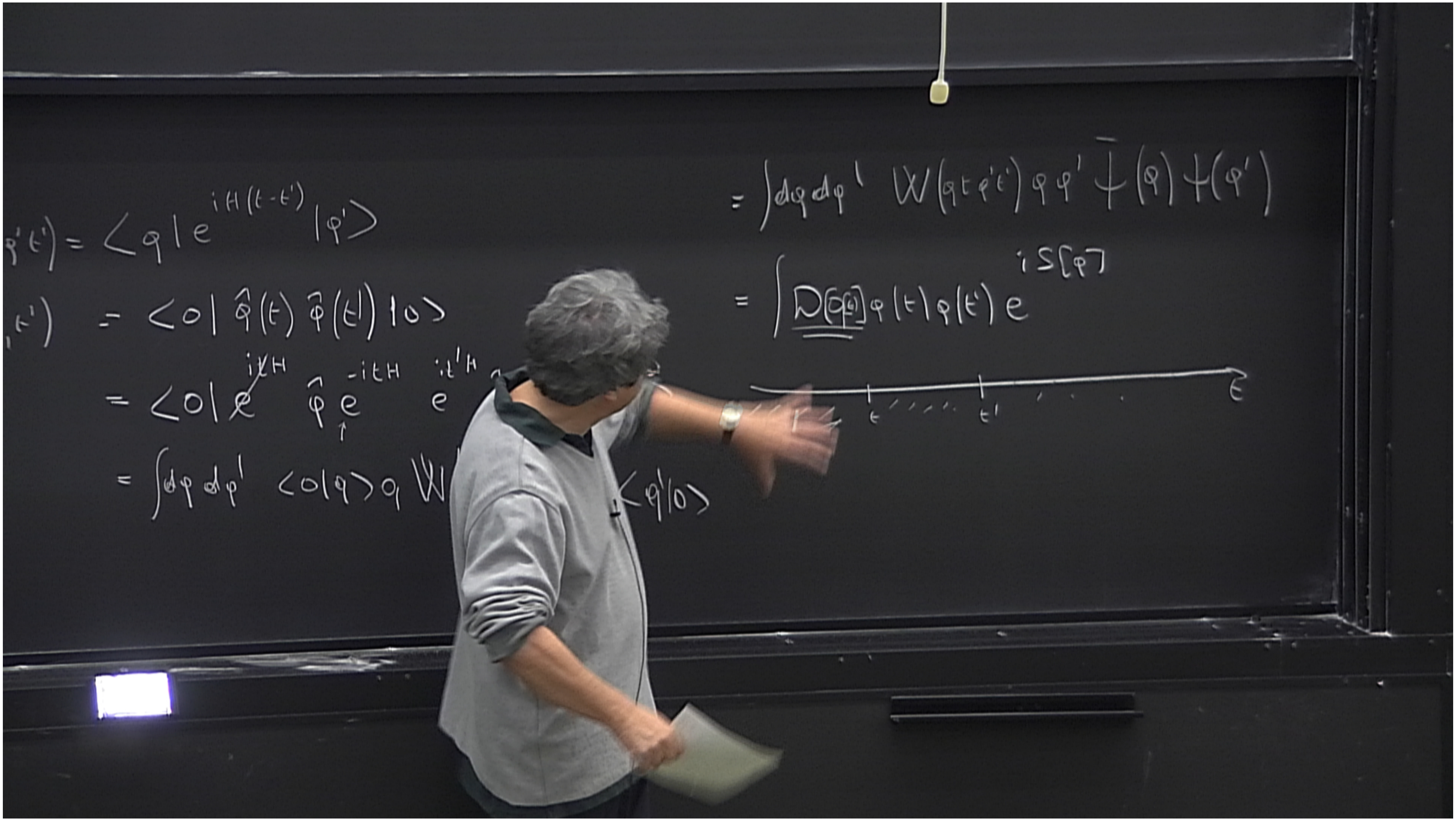
$= \langle 0 |$

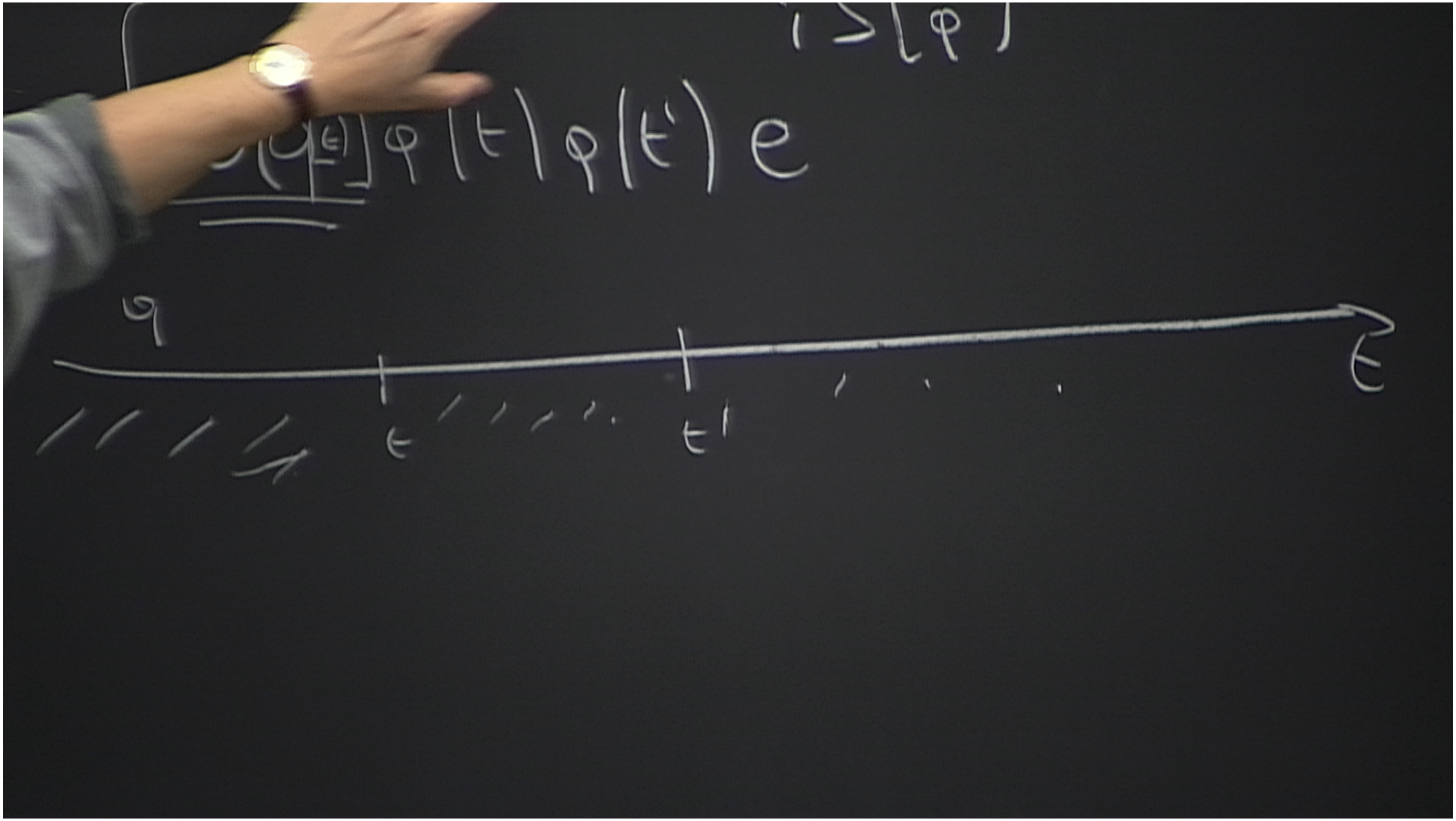
$= \int dq \, d$

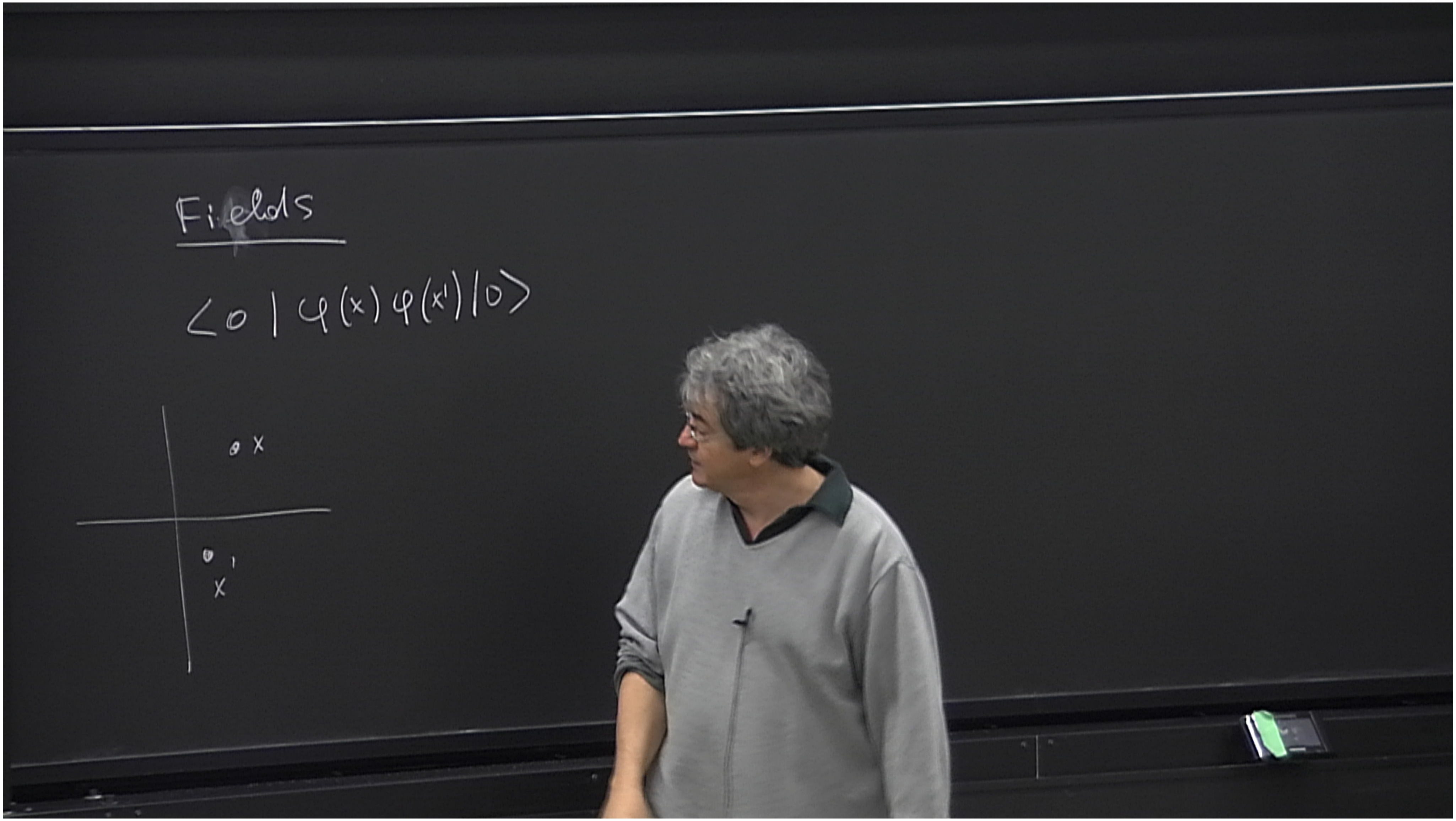


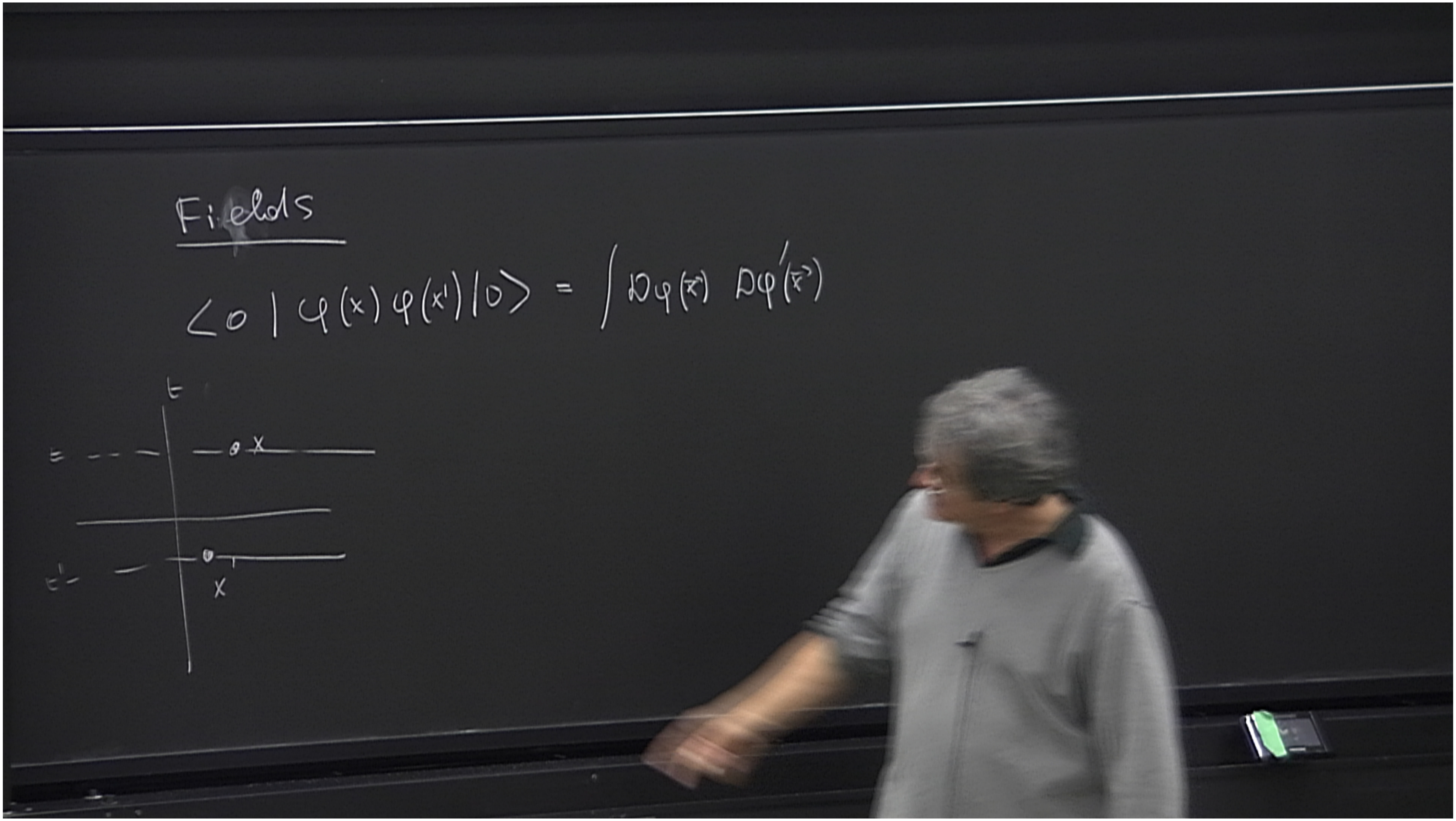
$q' t') = \langle q | e^{iH(t-t')} | q' \rangle$
$= \langle 0 | \hat{q}(t)\, \hat{q}(t') | 0 \rangle$
$= \langle 0 | \cancel{e^{itH}}\, \hat{q}\, e^{-itH}\, e^{it'H}\, \hat{q}\, \cancel{e^{-it'H}} | 0 \rangle$
$= \int dq\, dq'\, \langle 0 | q \rangle\, q\, W(qt\, q't')\, q' \langle q' | 0 \rangle$
$= \int dq\, dq'\, W(qt\, q't')\, q\, q'\, \bar{\psi}(q)\, \psi(q')$
$= \int \mathcal{D}q\, q(t)\, q(t')\, e^{iS[q]}$
t
t'
t

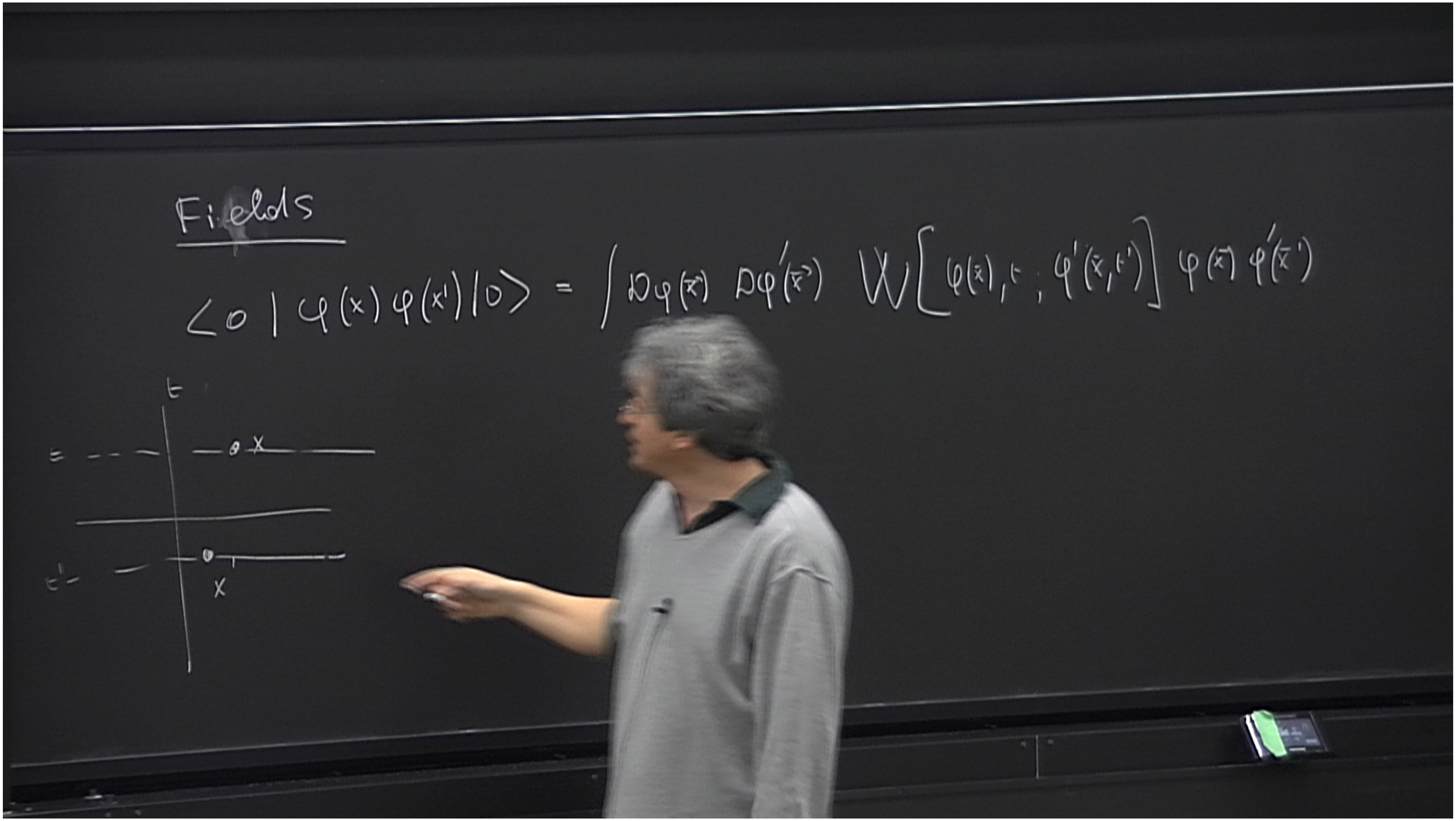


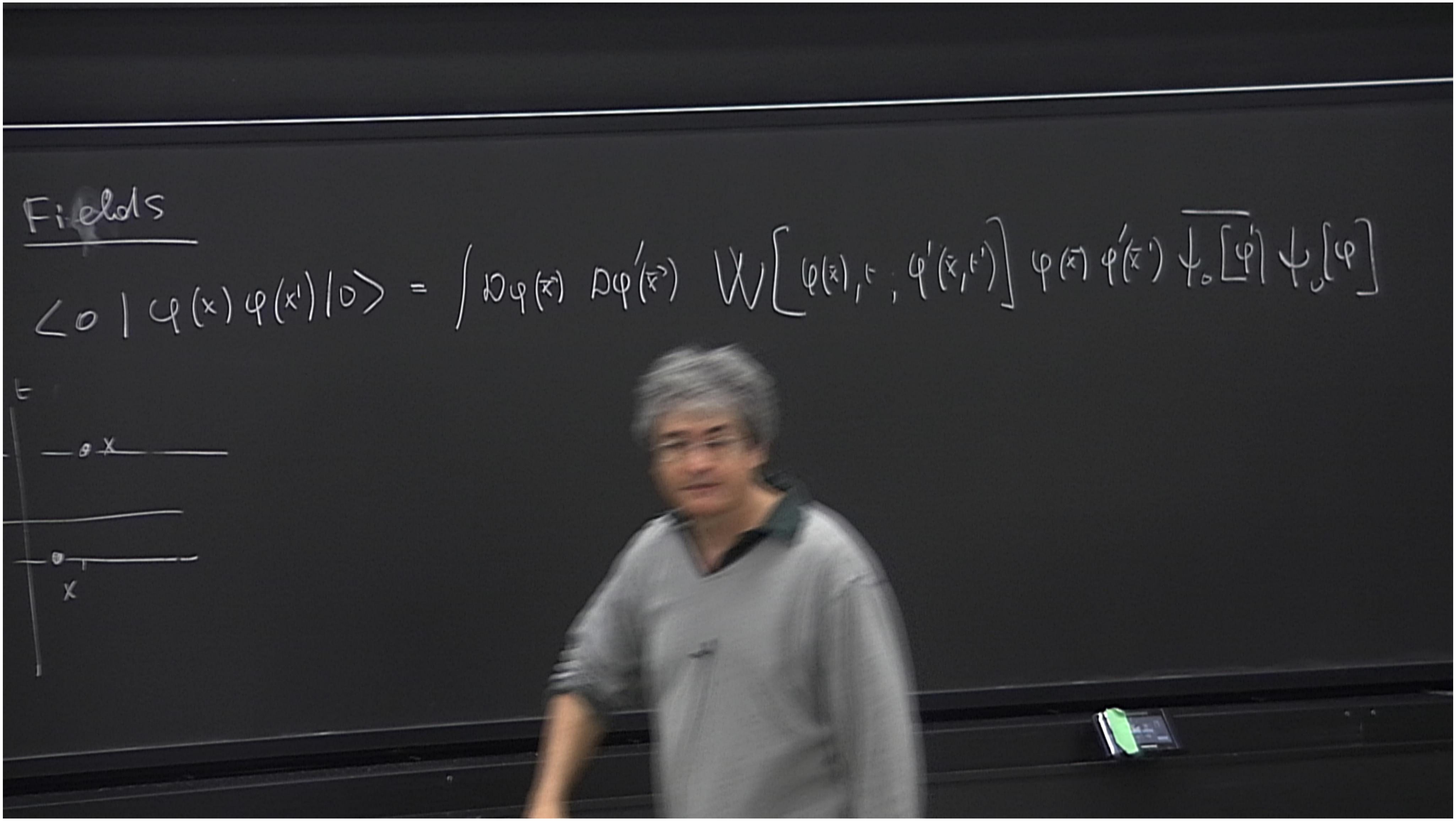

$= \langle q| e^{iH(t-t')} |q'\rangle$
$= \langle 0| \hat{q}(t)\, \hat{q}(t') |0\rangle$
$= \int dq\, dq'\, \langle 0|q\rangle q\, W$
$\langle q'|0\rangle$
$= \int dq\, dq'\, W(q\,t\,q'\,t')\, q\, q'\, \bar{\Psi}(q)\, \Psi(q')$
$= \int D[\varphi]\, \varphi(t)\, \varphi(t')\, e^{iS[\varphi]}$

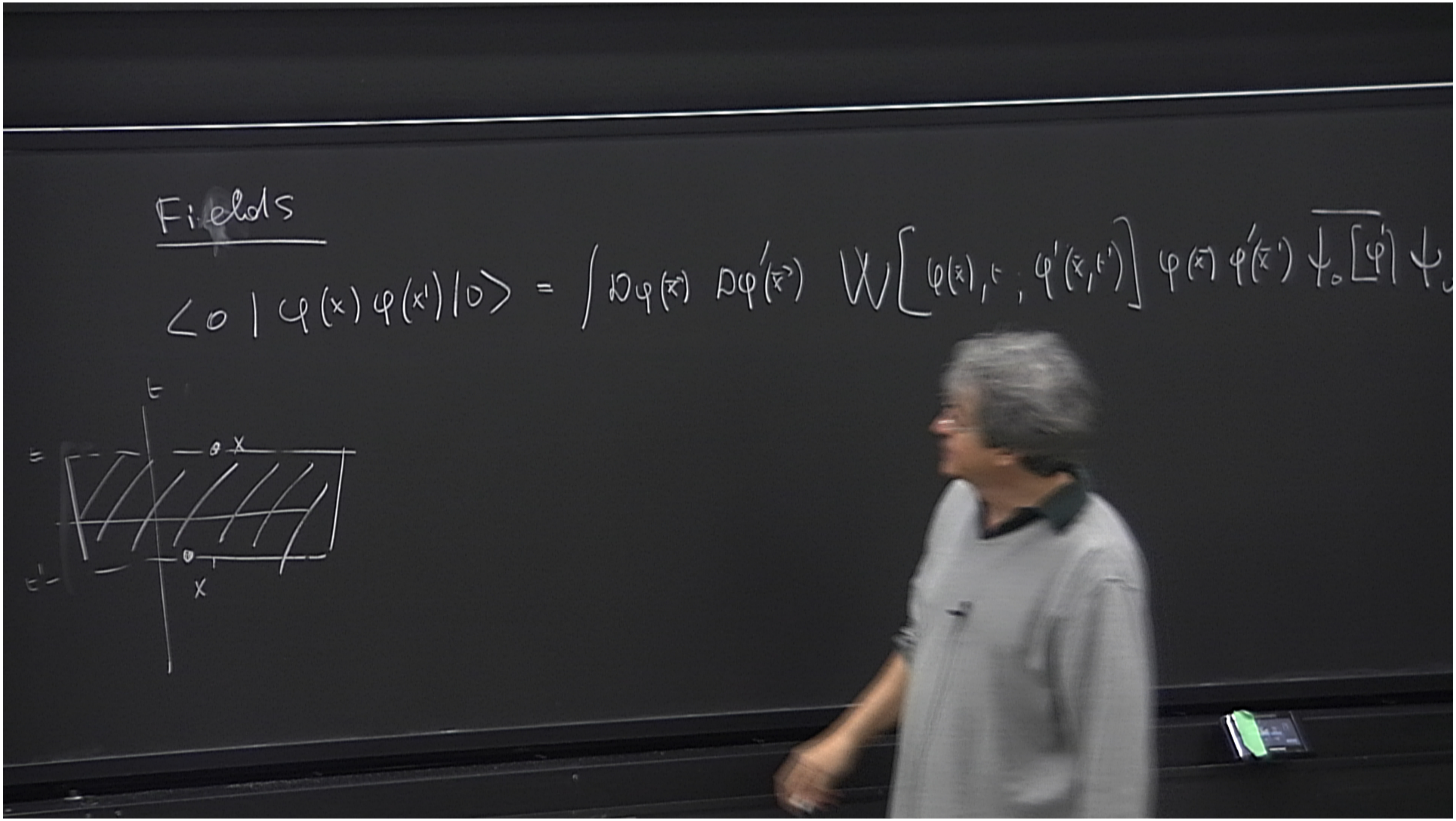

iS[φ]
φ(t) φ(t') e
φ
t
t'
t

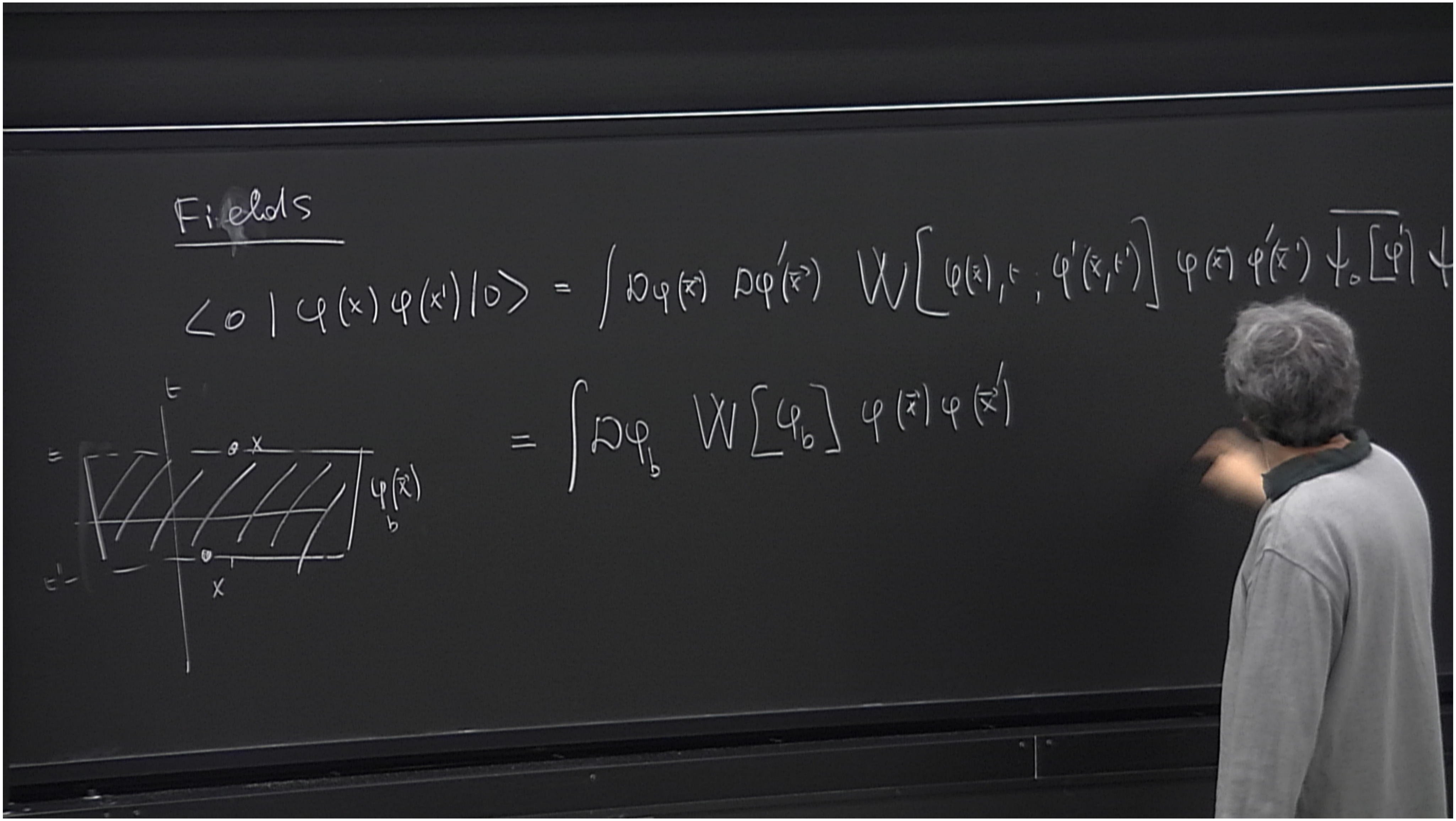

Fields
⟨0| φ(x) φ(x') |0⟩
x
x'

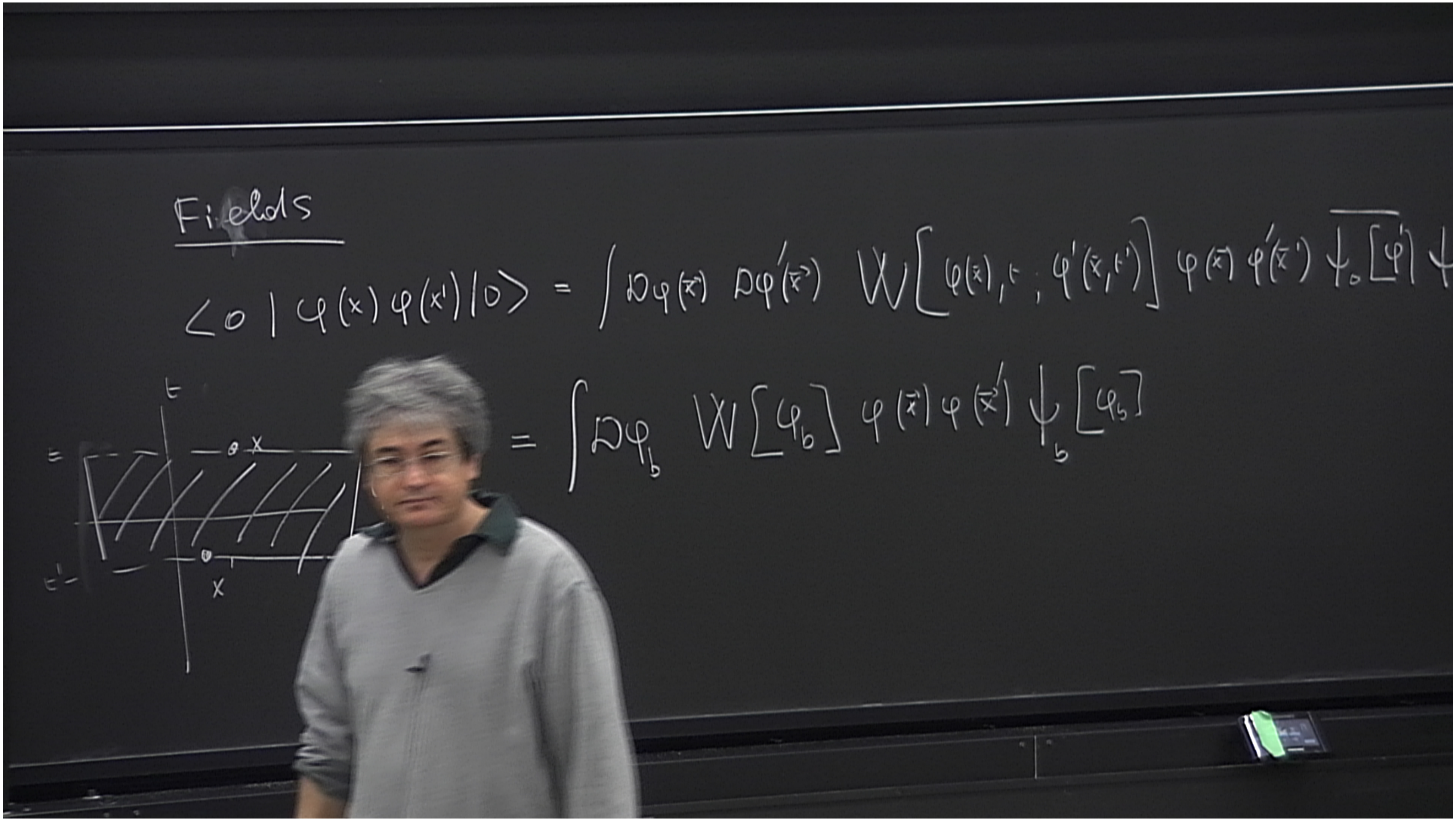

Fields
$\langle 0 | \varphi(x)\varphi(x') | 0 \rangle = \int D\varphi(\vec{x})\; D\varphi'(\vec{x})$
t
t
x
t'
x

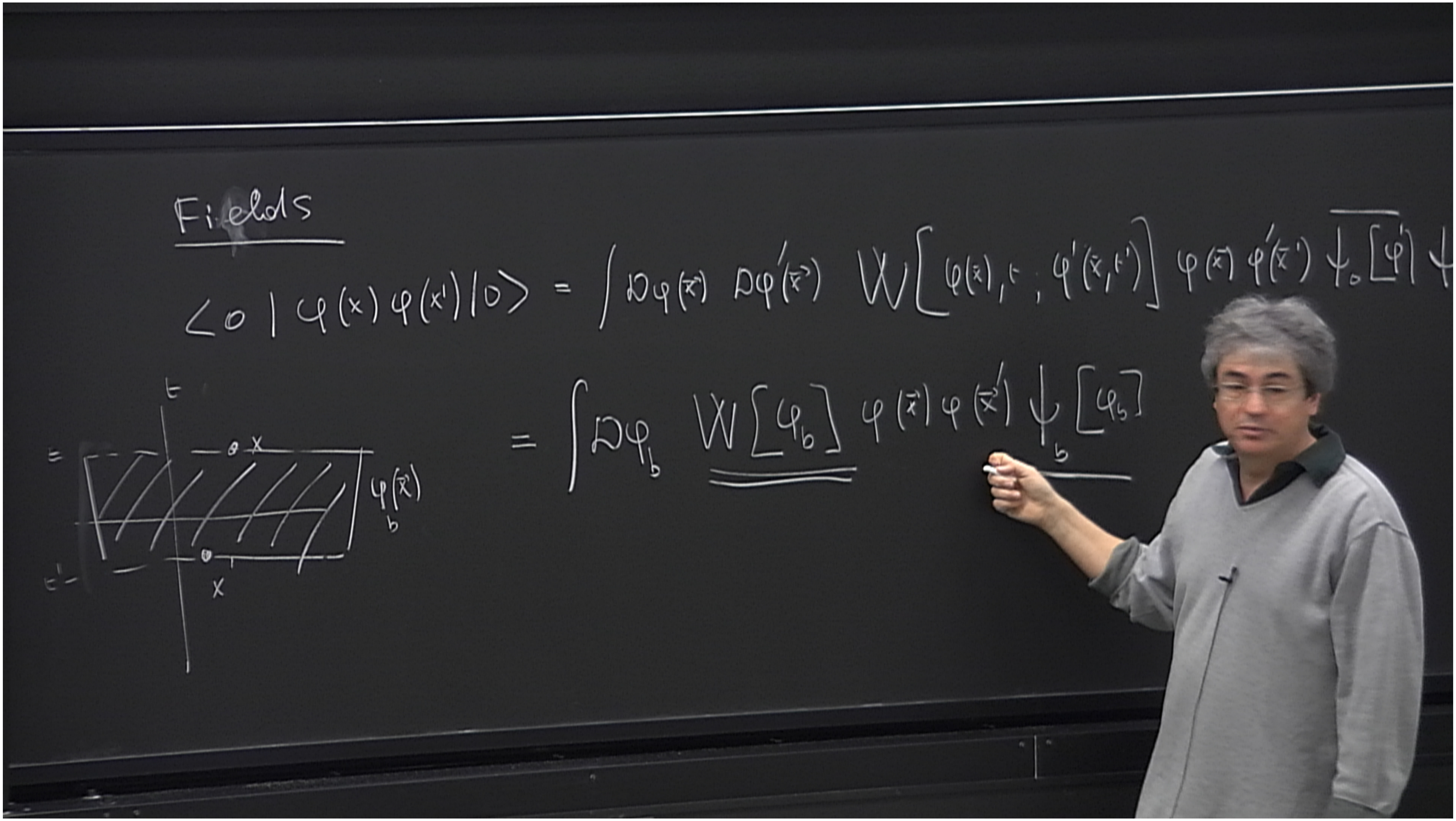

Fields
$\langle 0|\varphi(x)\varphi(x')|0\rangle = \int \mathcal{D}\varphi(\vec{x})\, \mathcal{D}\varphi'(\vec{x}')\, \Psi[\varphi(\vec{x}),t;\varphi'(\vec{x}',t')]\,\varphi(\vec{x})\,\varphi'(\vec{x}')$
t
x
t'
x

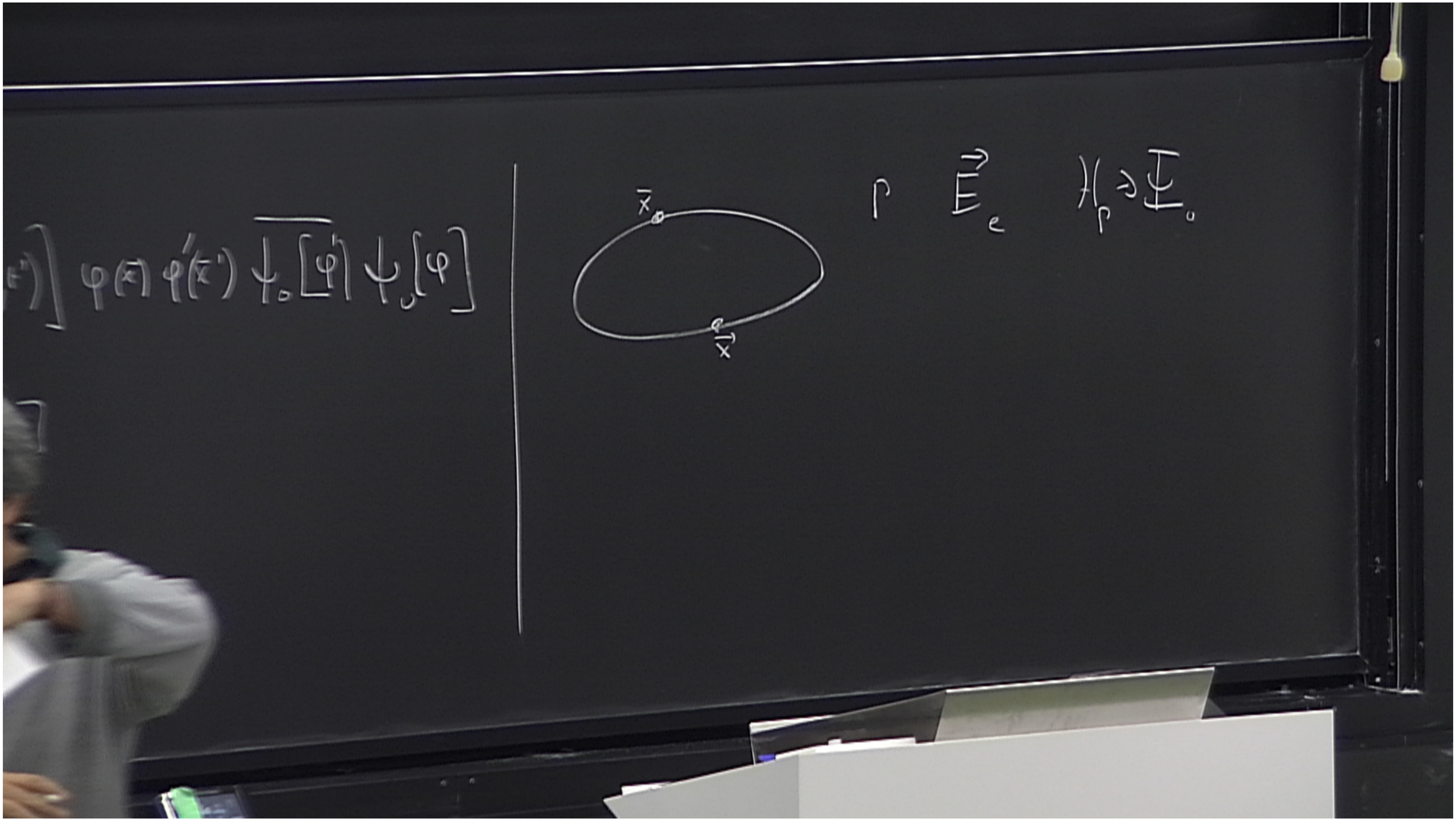

Fields
$\langle 0 | \varphi(x)\varphi(x') | 0 \rangle = \int D\varphi(\vec{x})\, D\varphi'(\vec{x}')\, W[\varphi(\vec{x}),t;\varphi'(\vec{x}',t')]\, \varphi(\vec{x})\, \varphi'(\vec{x}')\, \overline{\psi_0[\varphi']}\, \psi_0[\varphi]$
t
x
x

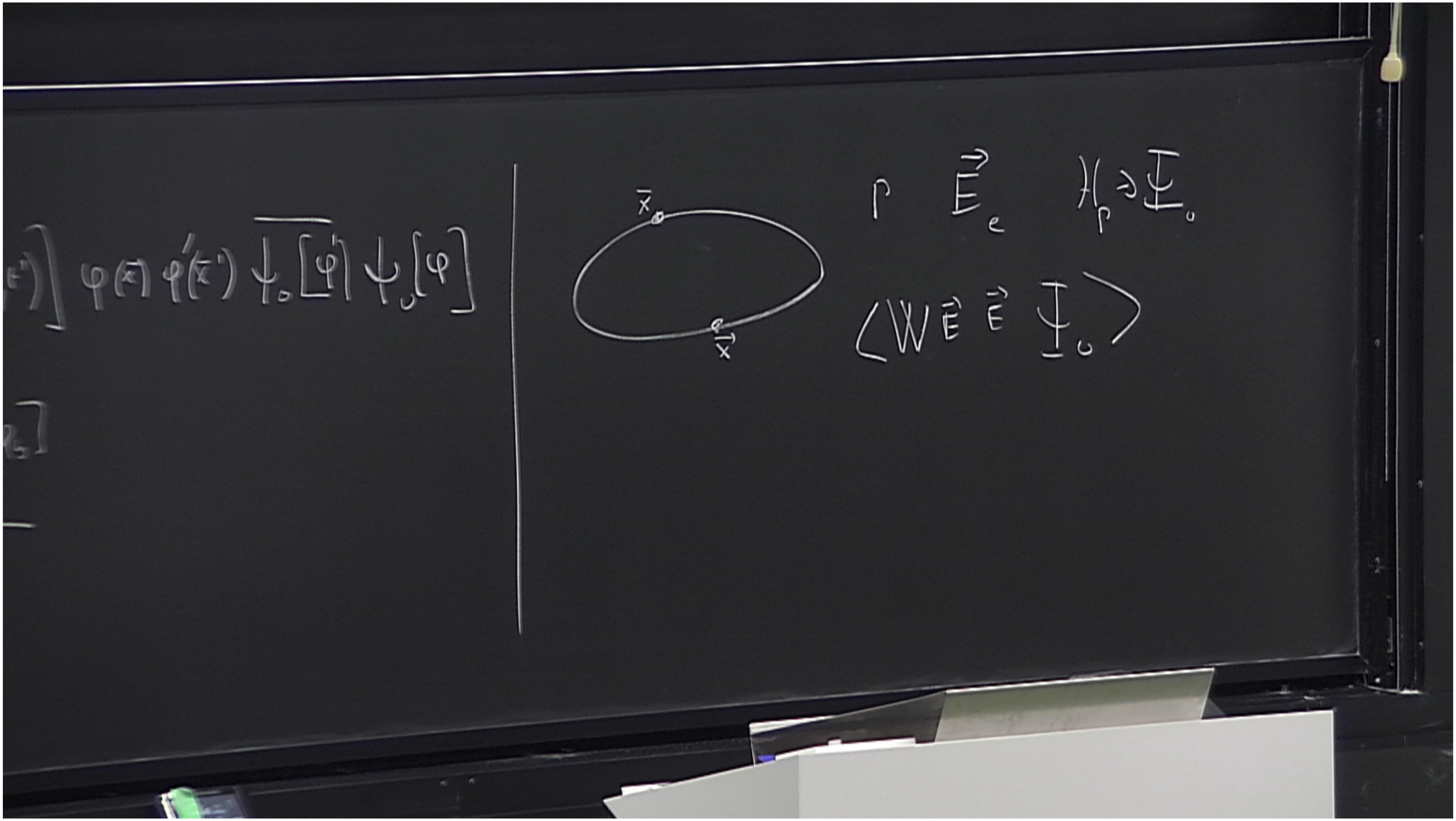

Fields
<0 | φ(x) φ(x') | 0> = ∫ Dφ(x⃗) Dφ'(x⃗') W[φ(x⃗), t ; φ'(x⃗', t')] φ(x⃗) φ'(x⃗') Ψ̄₀[φ'] Ψ
t
x
x
t'

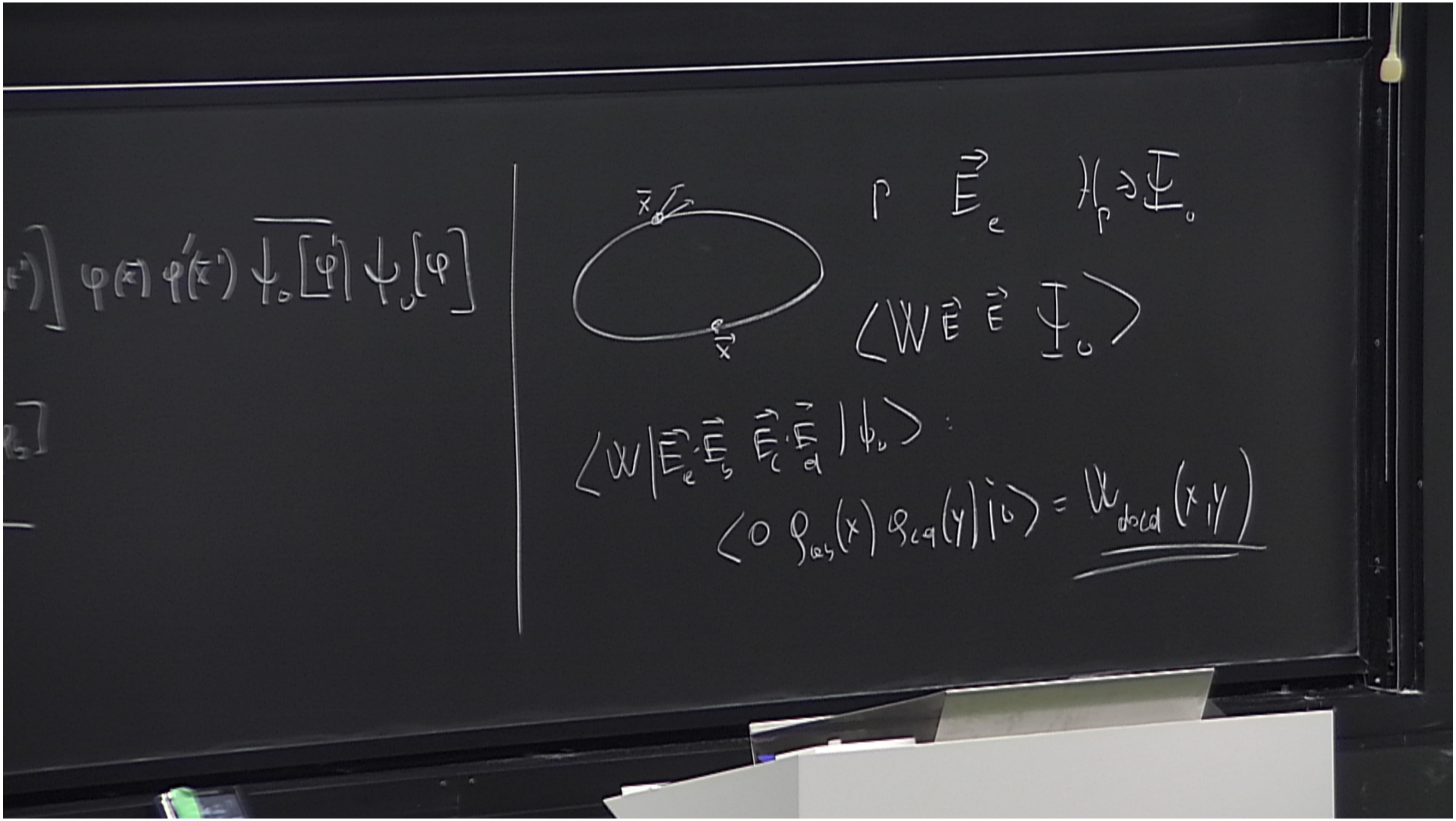

Fields
$\langle 0 | \varphi(x)\varphi(x') | 0 \rangle = \int \mathcal{D}\varphi(\vec{x})\, \mathcal{D}\varphi'(\vec{x})\, W[\varphi(\vec{x}), t; \varphi'(\vec{x}, t')]\, \varphi(\vec{x})\, \varphi'(\vec{x}')\, \Psi_0[\varphi']\, \Psi$
$= \int \mathcal{D}\varphi_b\, W[\varphi_b]\, \varphi(\vec{x})\, \varphi(\vec{x}')$
t
x
$\varphi_b(\vec{x})$
t'
x'


Fields

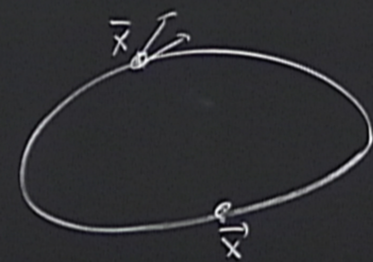

Fields
⟨0| φ(x) φ(x') |0⟩ = ∫ Dφ(x⃗) Dφ'(x⃗') W[φ(x⃗), t ; φ'(x⃗', t')] φ(x⃗) φ'(x⃗') ψ̄₀[φ']
= ∫ Dφ_b W[φ_b] φ(x⃗) φ(x⃗') ψ_b[φ_b]
t
x
t'
x'
φ_b(x⃗)




$\varphi(\vec{x})\,\varphi'(\vec{x}')\,\overline{\Psi_0[\varphi']}\,\Psi_0[\varphi]$
$\vec{x}$
$\vec{x}'$
$\rho \quad \vec{E}_e \quad H_\rho \to \Psi_0$
$\langle W \vec{E}\, \vec{E}\, \Psi_0 \rangle$


⟨W E E Ψ₀⟩
⟨W | E·E E·E | ψ₀⟩
⟨0 φ(x) φ(y) | 0⟩ = W(x, y)

$$\ldots)\Big]\ \varphi(\vec{x})\ \varphi'(\vec{x}')\ \overline{\Psi_0[\varphi']}\ \Psi_0[\varphi]$$



$$\rho \qquad \vec{E}_e \qquad \mathcal{H}_p \ni \Phi_0$$

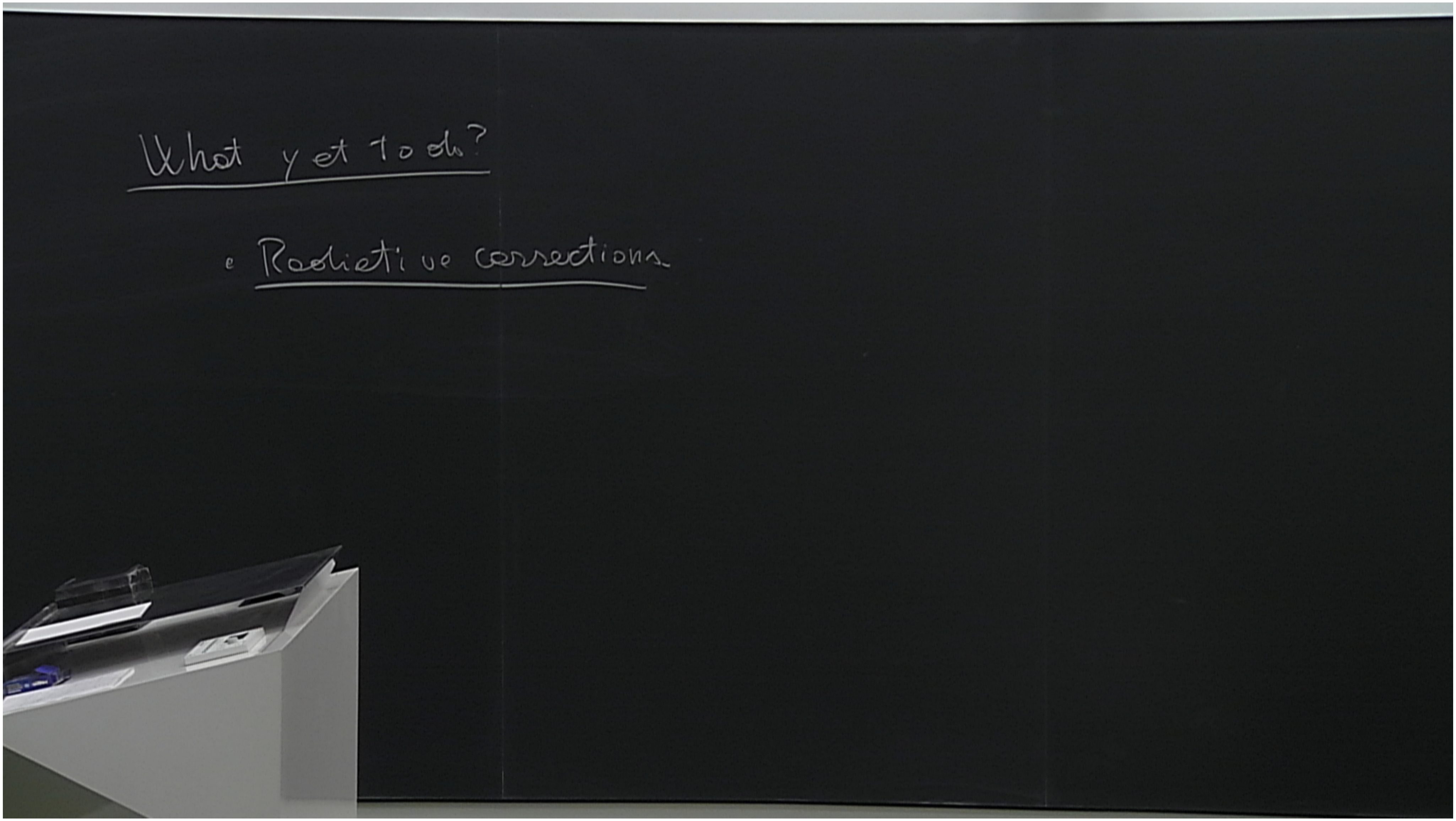
$$\langle W\, \vec{E}\, \vec{E}\, \Phi_0 \rangle$$

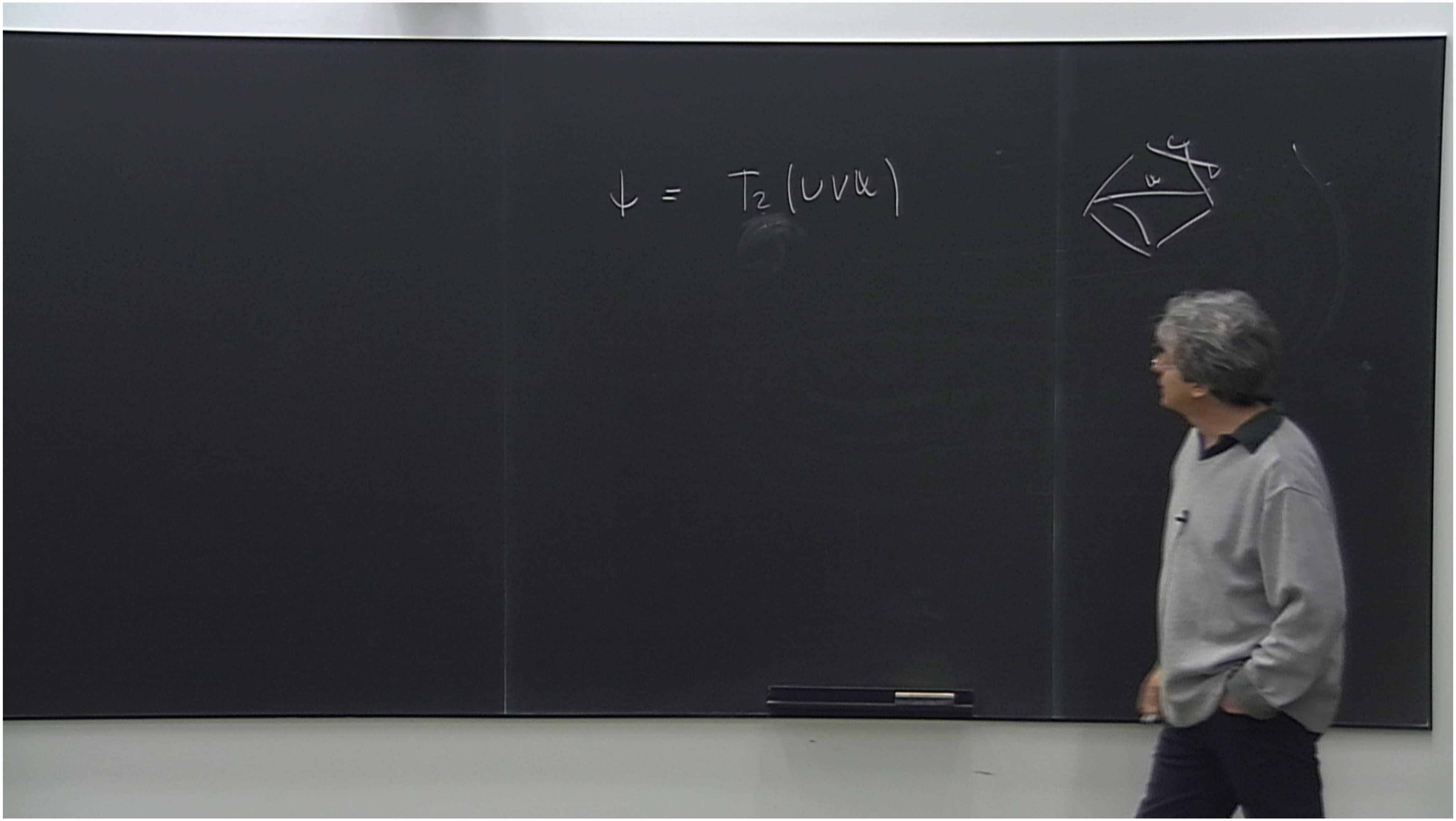
$$\langle W | \vec{E}_e \cdot \vec{E}_b\ \vec{E}_c \cdot \vec{E}_d | \psi_0 \rangle$$

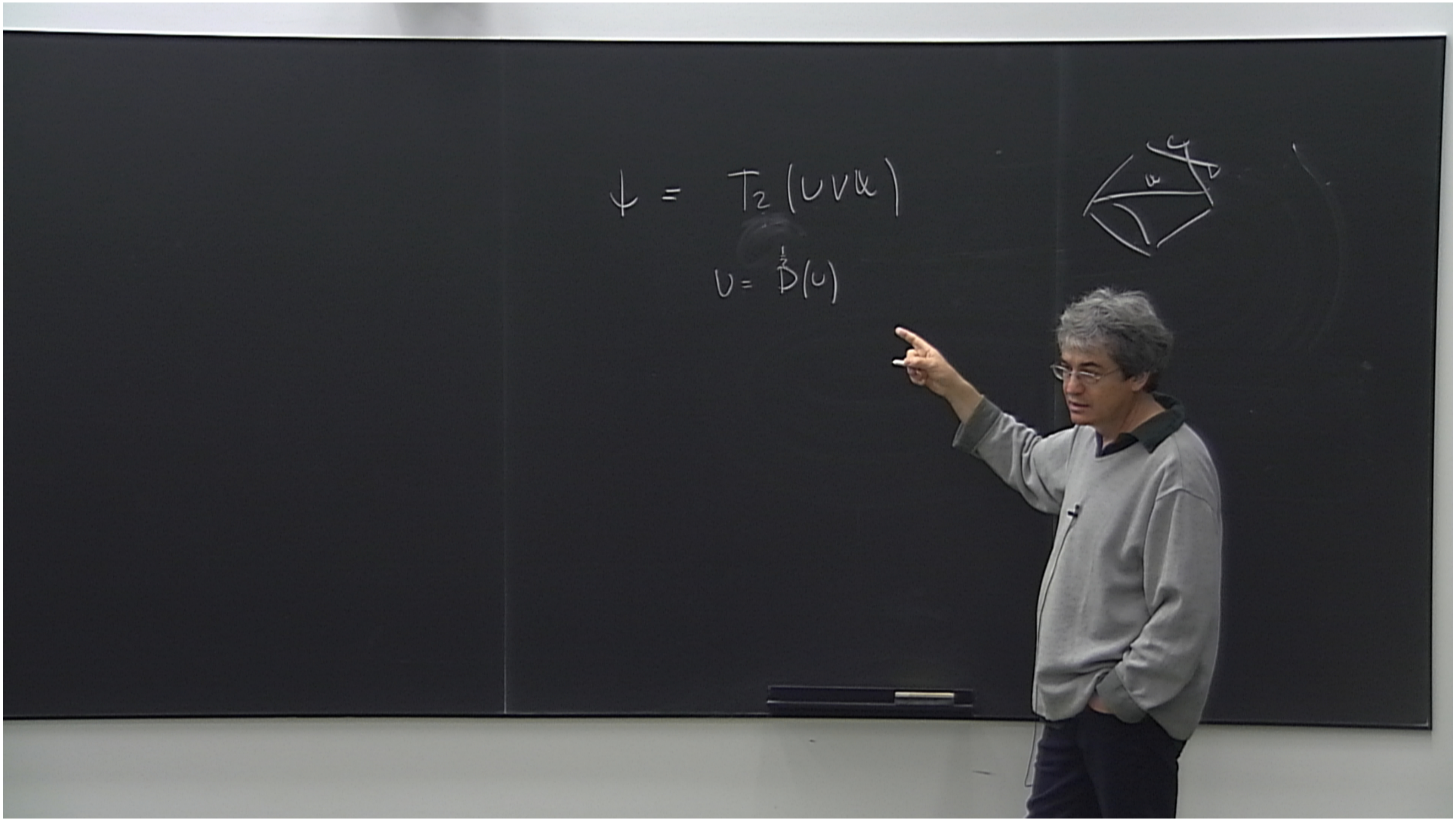
$$\langle 0 |\, \varphi_{ab}(x)\, \varphi_{cd}(y) | 0 \rangle = \underline{\underline{W_{abcd}(x,y)}}$$

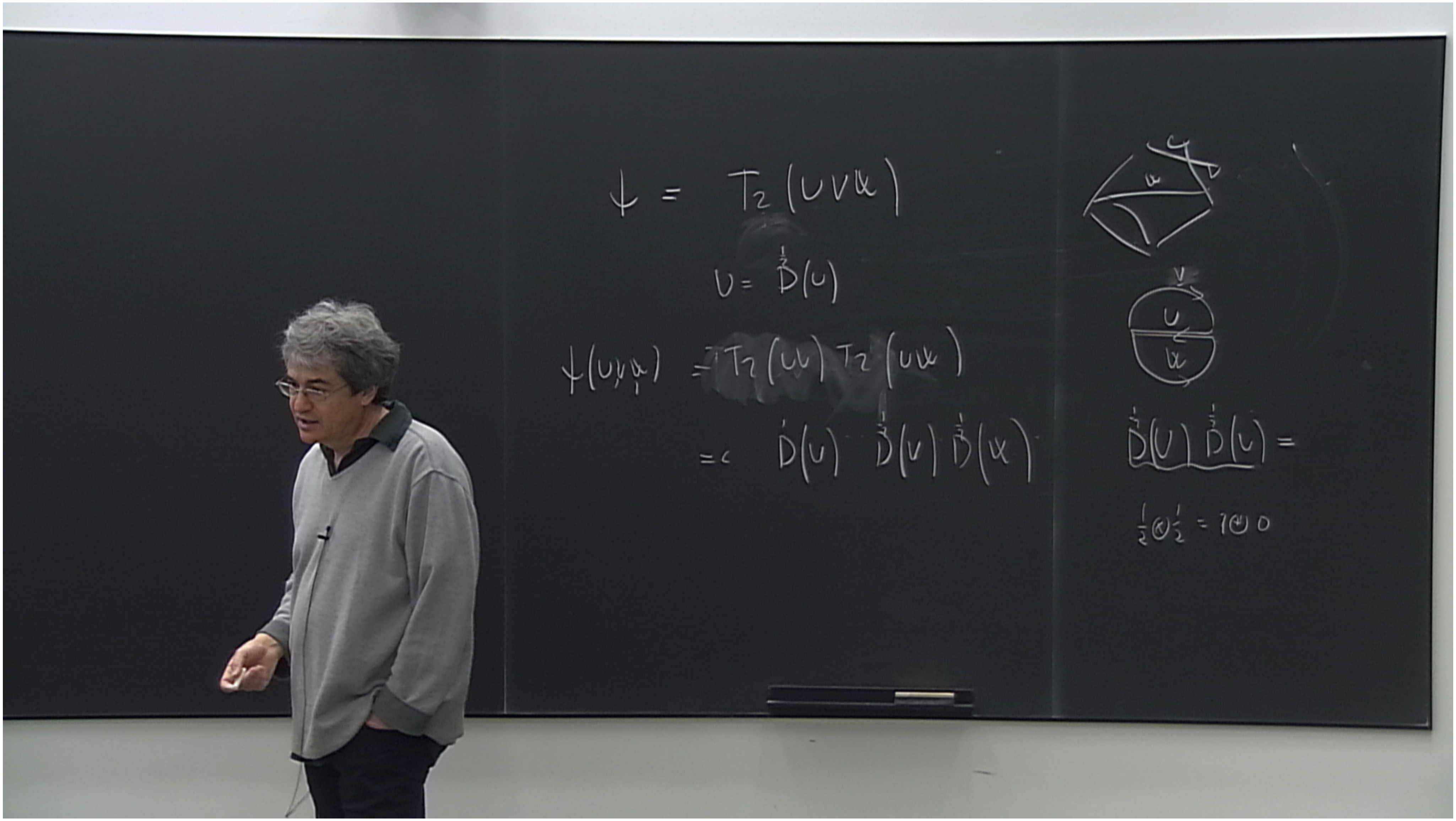
What yet to do?

- Radiative corrections


What yet to do?
• Radiative corrections


ψ = T2 (UVU)


ψ = T₂ (UVU)
V = D^½(U)

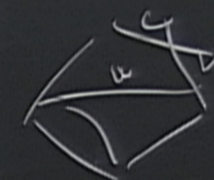


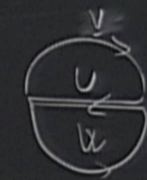
$$\psi = T_2(u\,v\,w)$$

$$v = \overset{\frac{1}{2}}{D}(u)$$

$$\psi(u,v,w) = T_2(uv)\,T_2(uw)$$

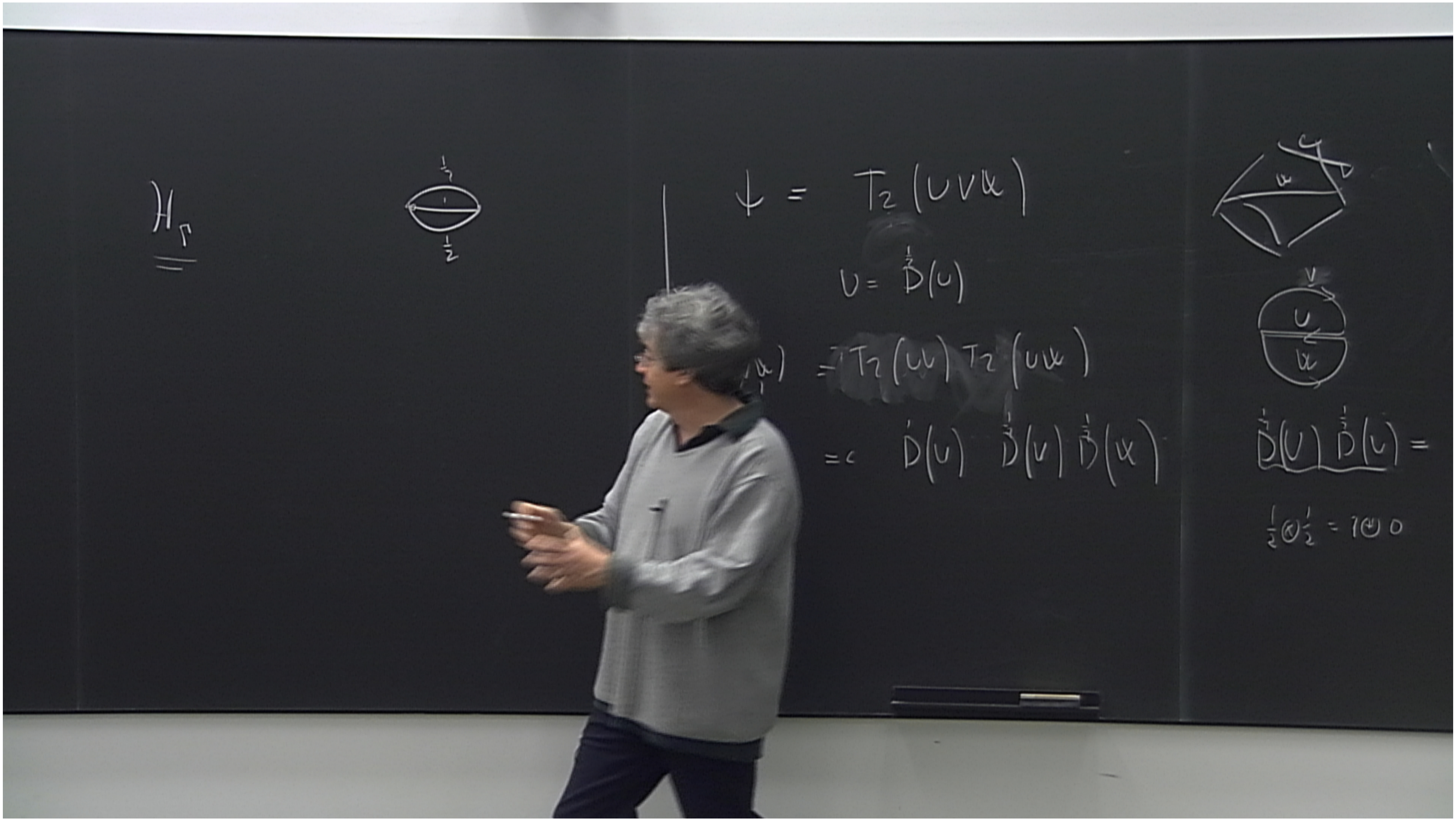
$$= c\;\overset{1}{D}(u)\;\overset{\frac{1}{2}}{D}(v)\;\overset{\frac{1}{2}}{D}(w)$$

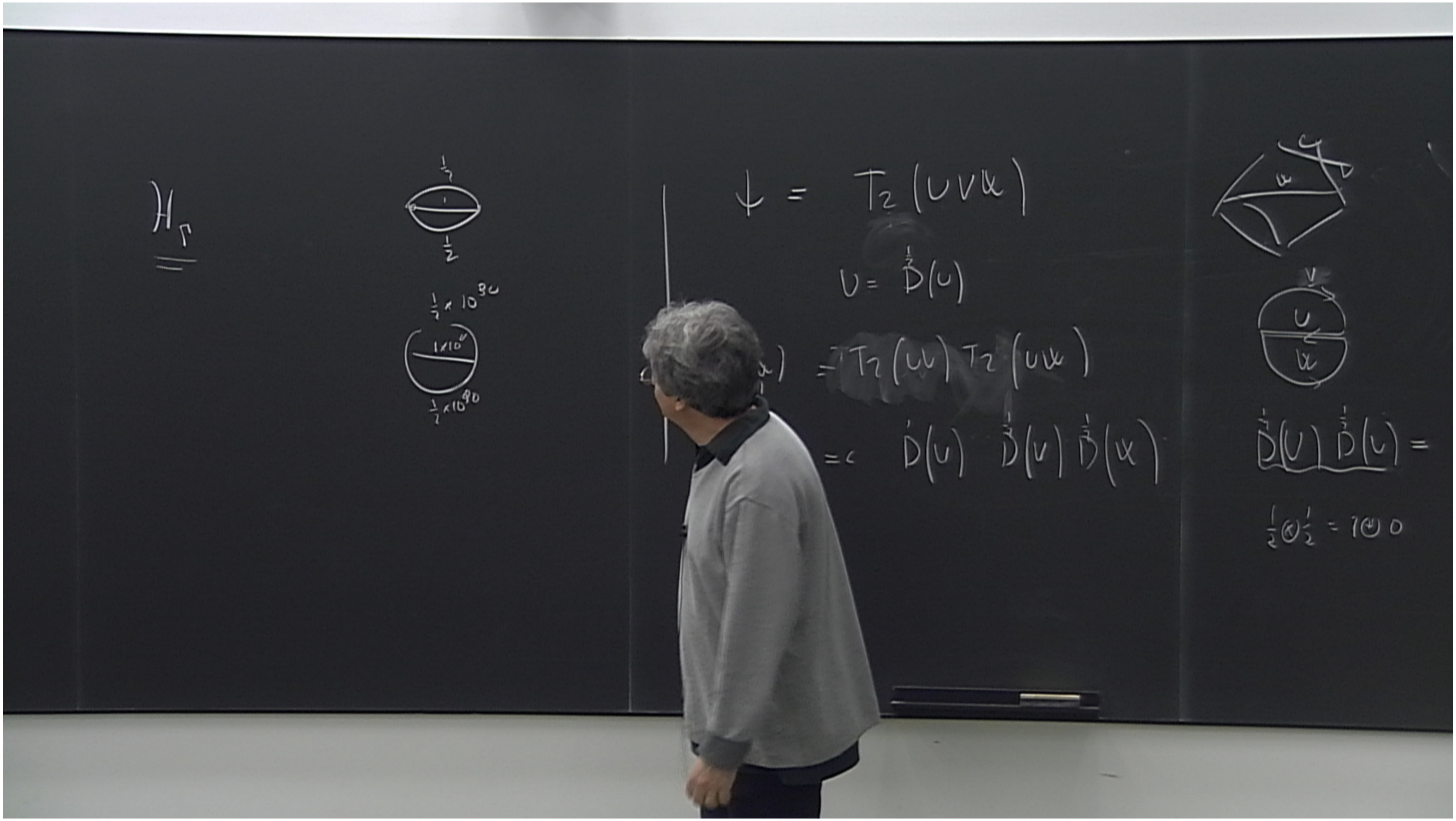




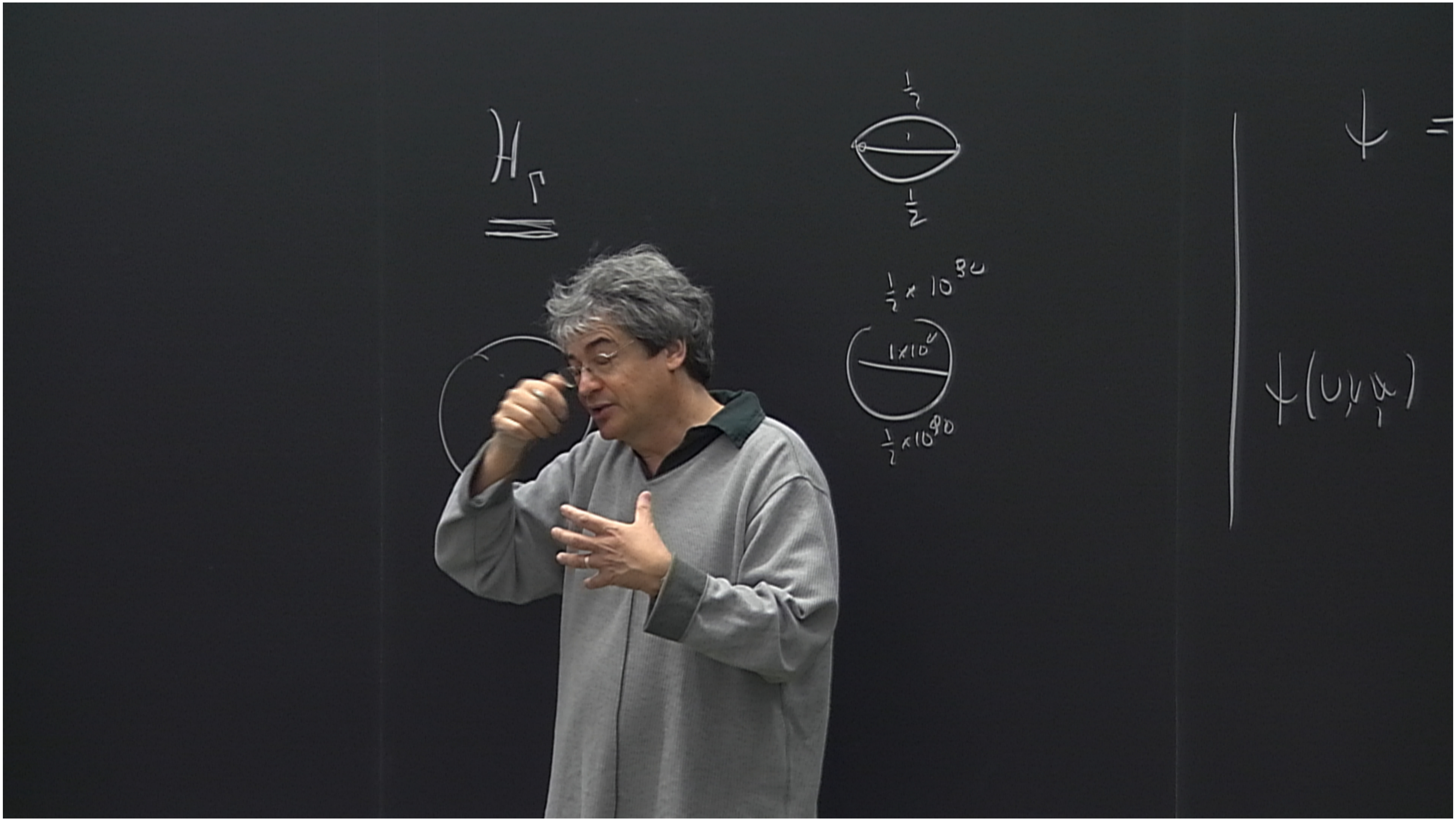
$$\underline{\overset{\frac{1}{2}}{D}(v)\;\overset{\frac{1}{2}}{D}(v)} =$$

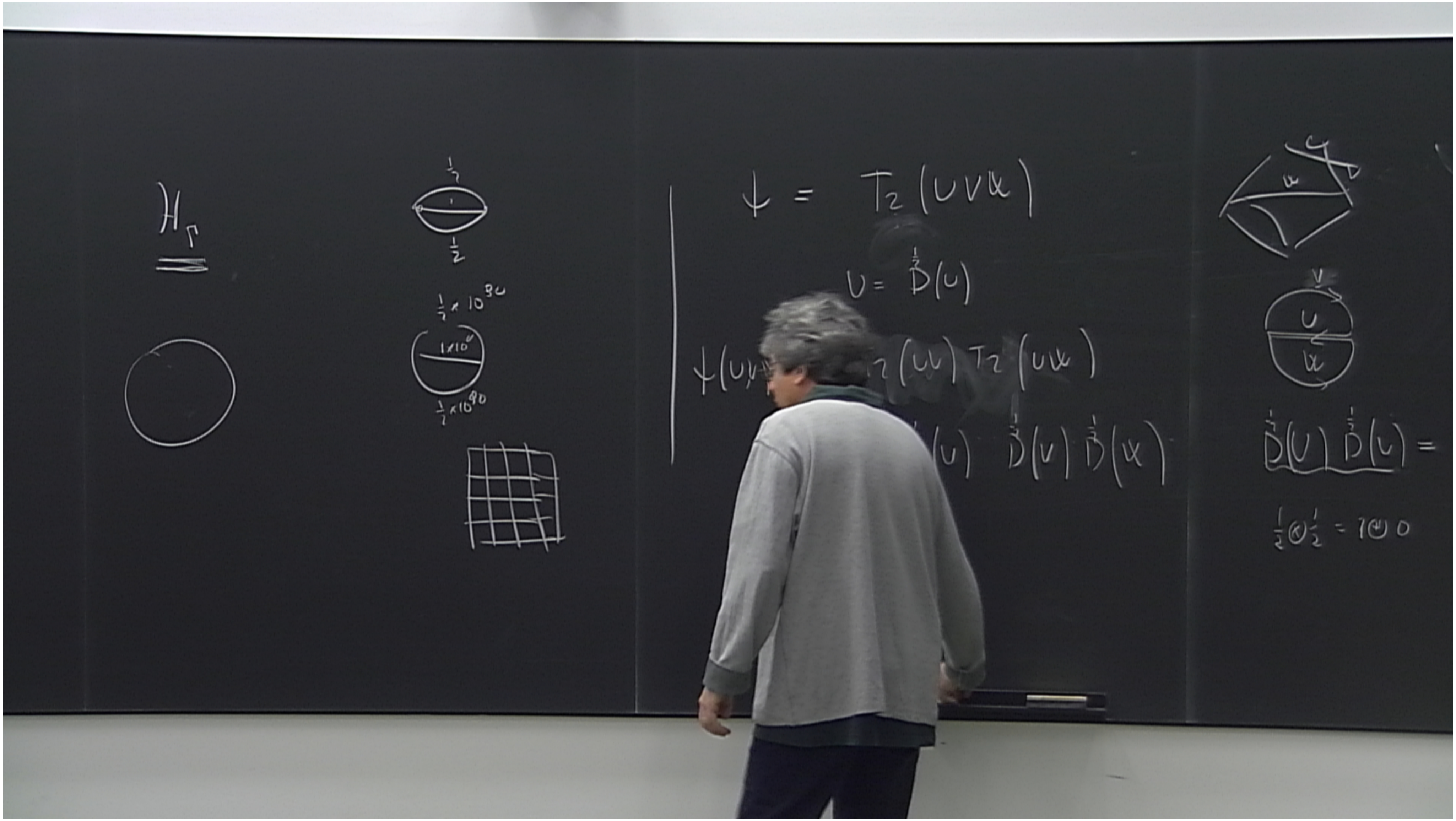
$$\tfrac{1}{2} \otimes \tfrac{1}{2} = 1 \oplus 0$$

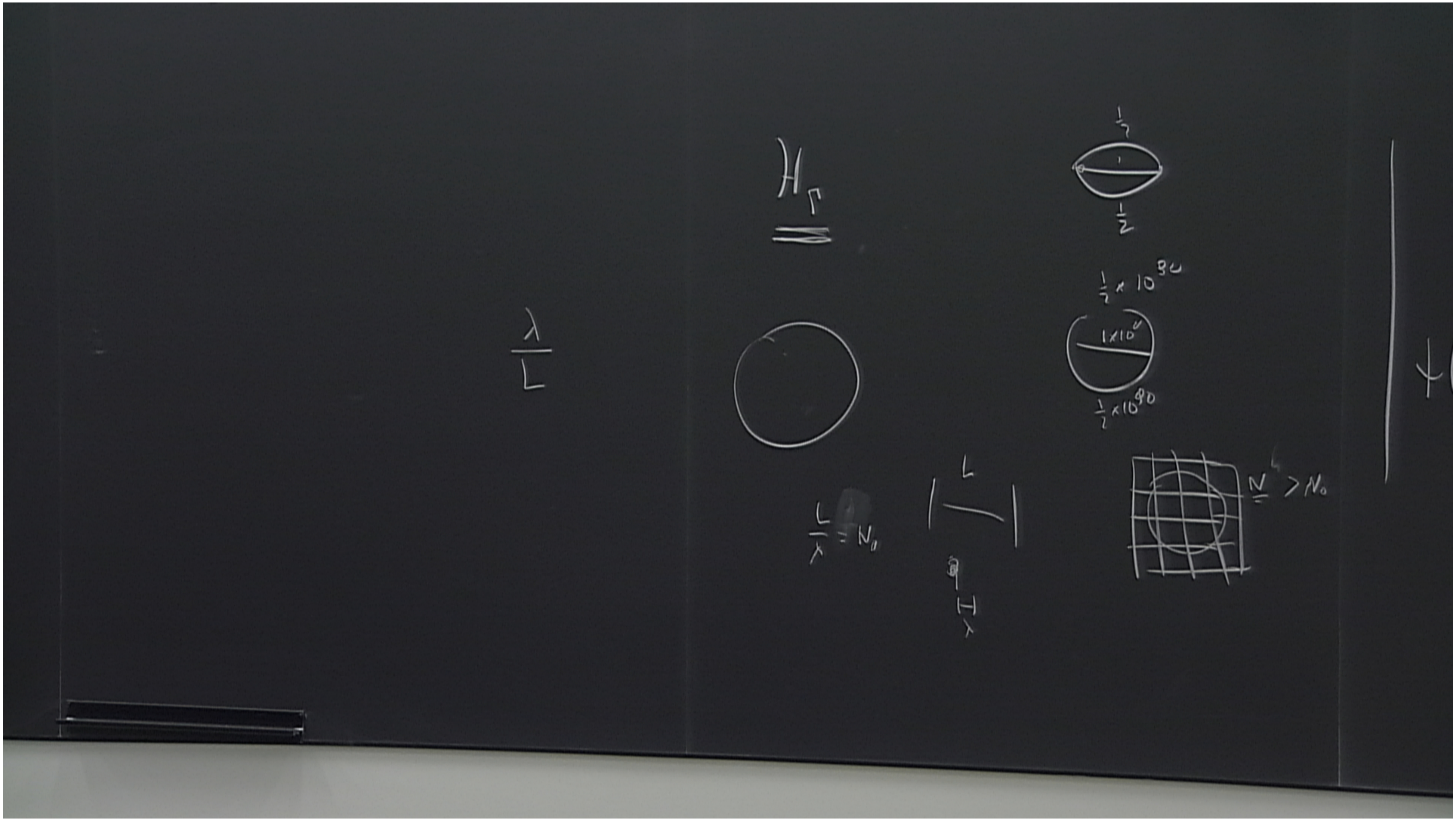




H_Γ
½ × 10^80
½ ⊗ ½ = 1 ⊕ 0


H_Γ
$\frac{1}{2}$
$\frac{1}{2}$
$\frac{1}{2} \times 10^{80}$
1×10^{0}
$\frac{1}{2} \times 10^{80}$
$\psi(u, v, \dots)$


ψ = T₂(uvw)
v = D(v)
D(v) D(v) =
½⊗½ = 1⊕0



λ / L
H_Γ
1/2
1/2 × 10^80
L/λ = N_0
L
N > N_0