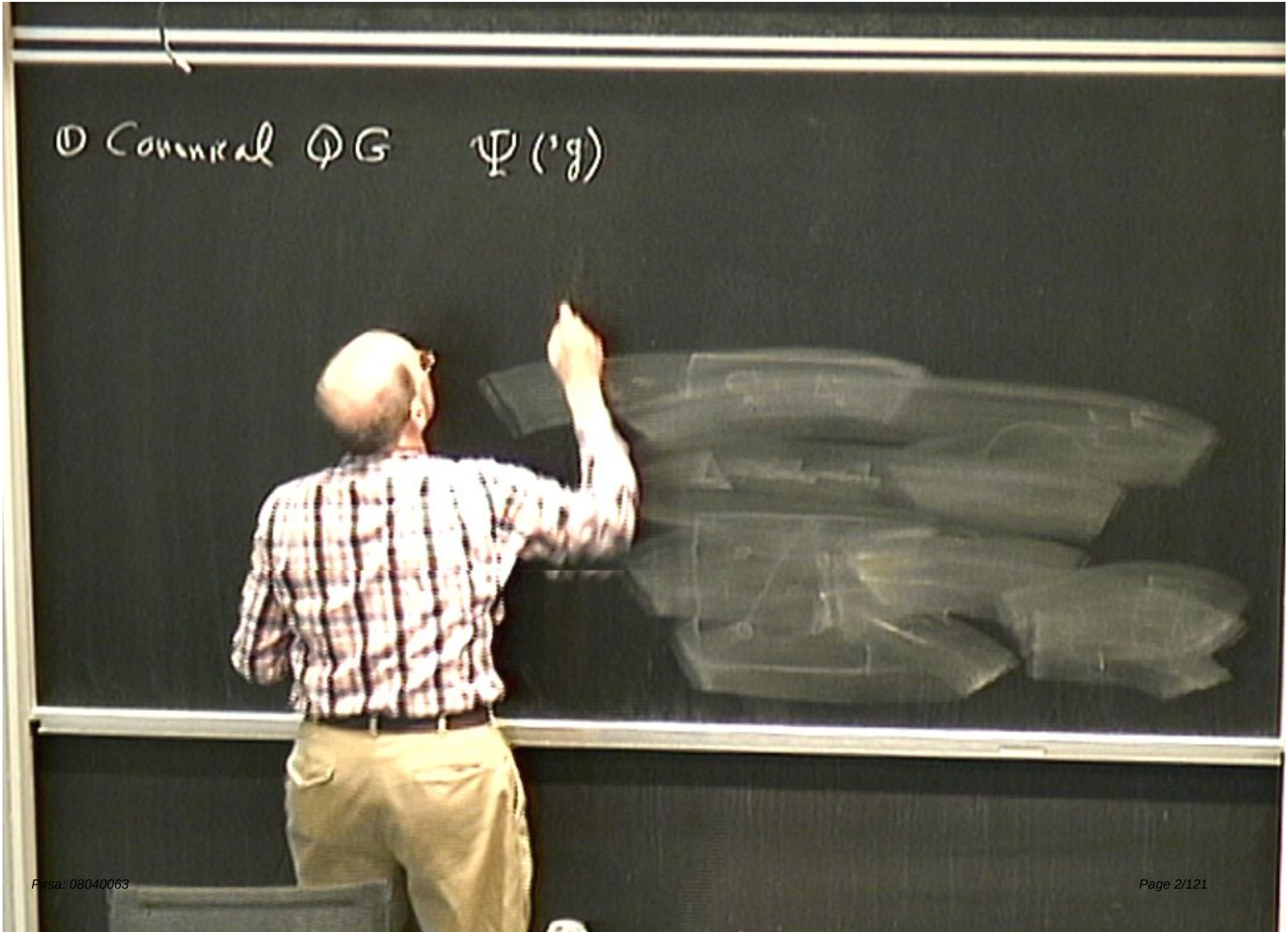
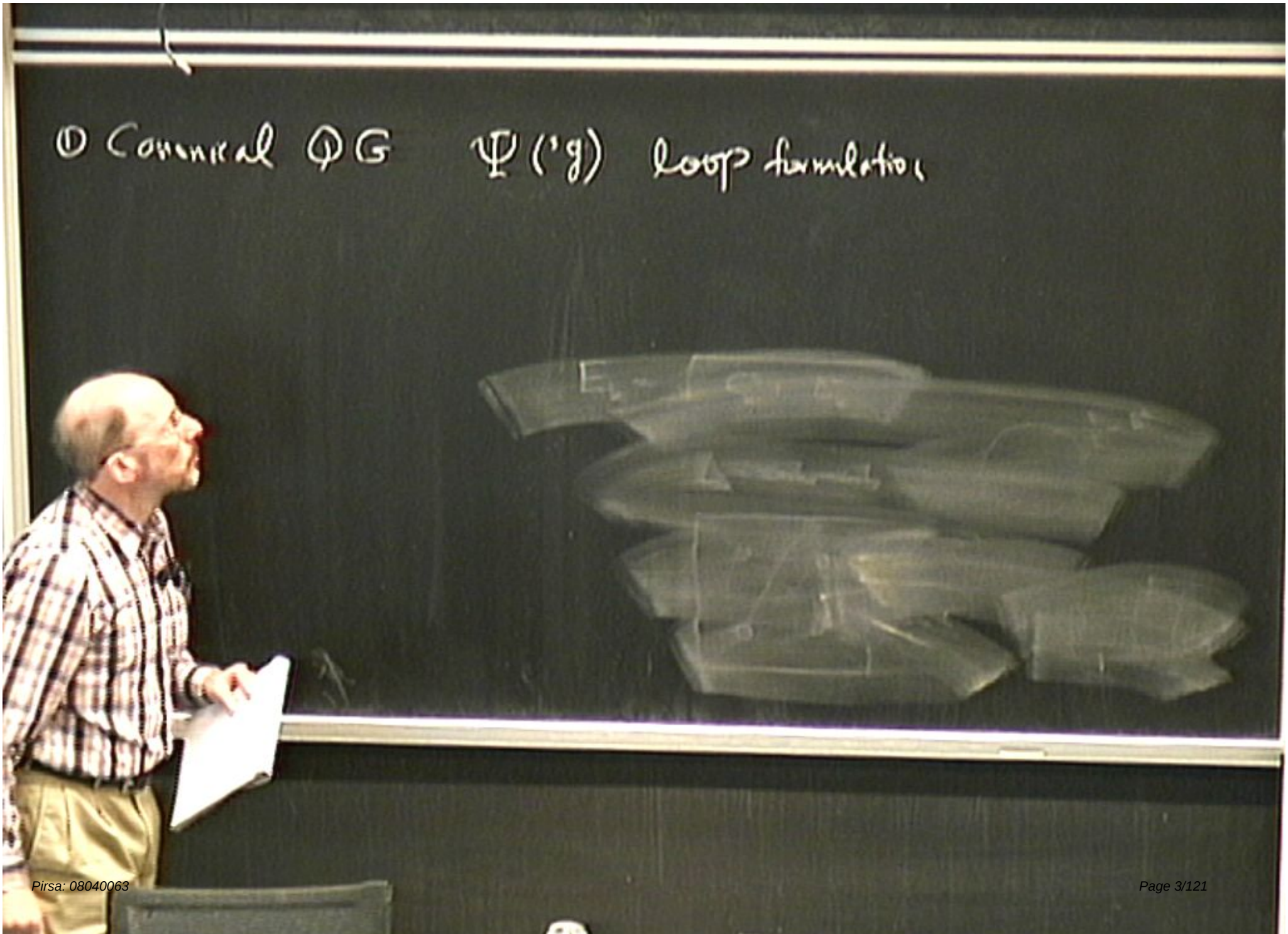
Title: Special Topics in Physics - Lecture 14A

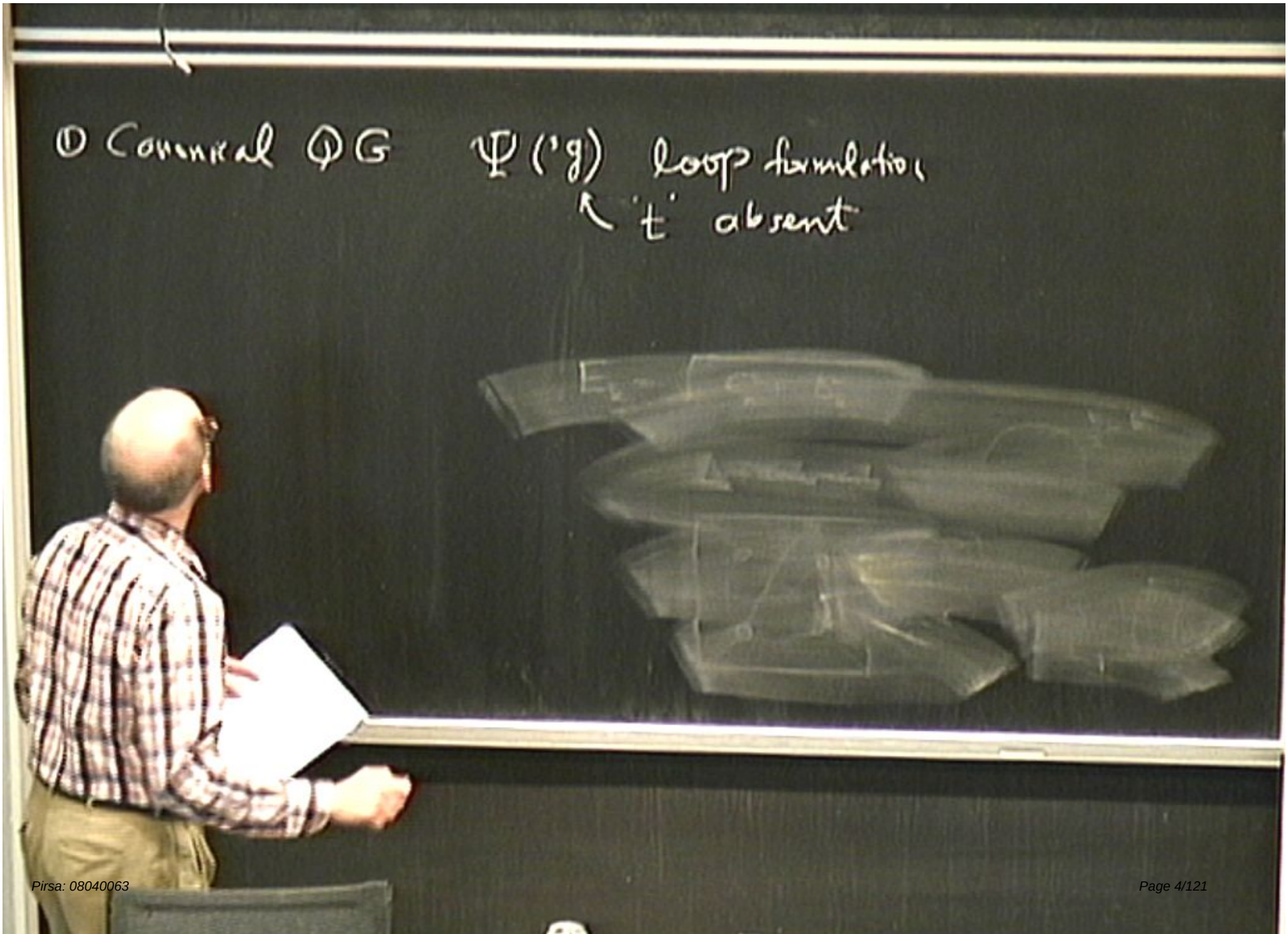
Date: Apr 23, 2008 07:00 PM

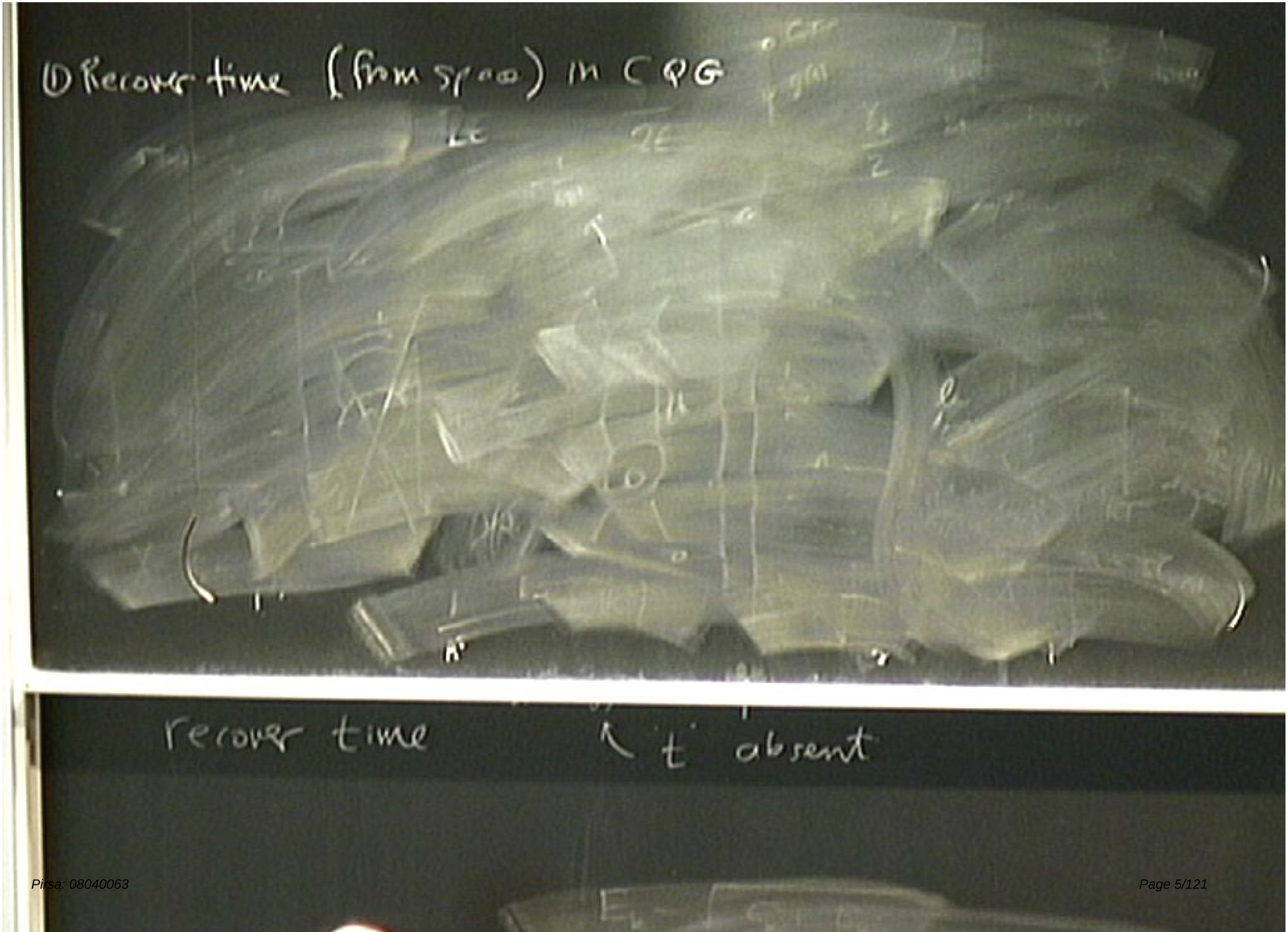
URL: http://pirsa.org/08040063

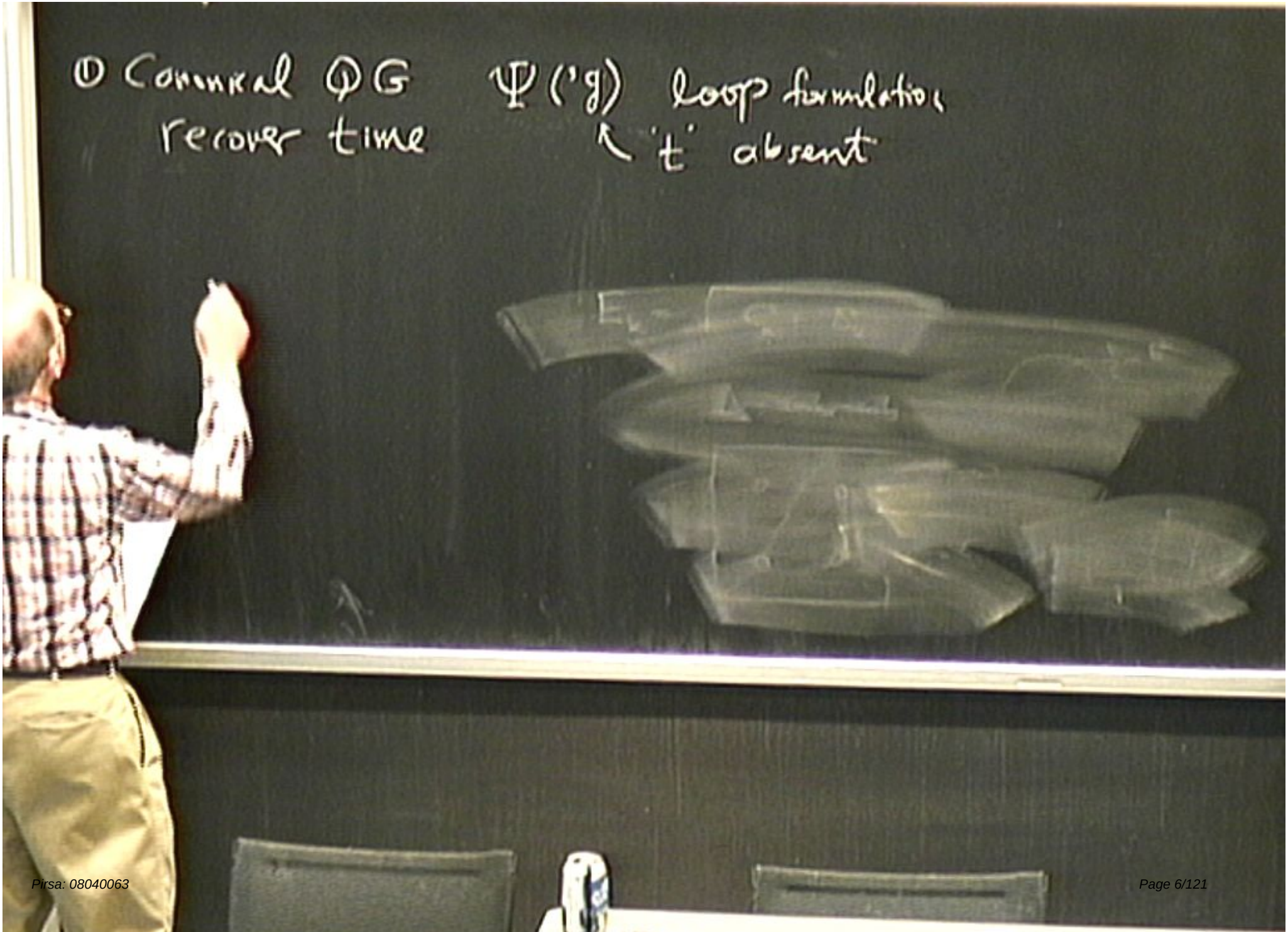
Abstract: The Problem of Time in Quantum Gravity and Cosmology

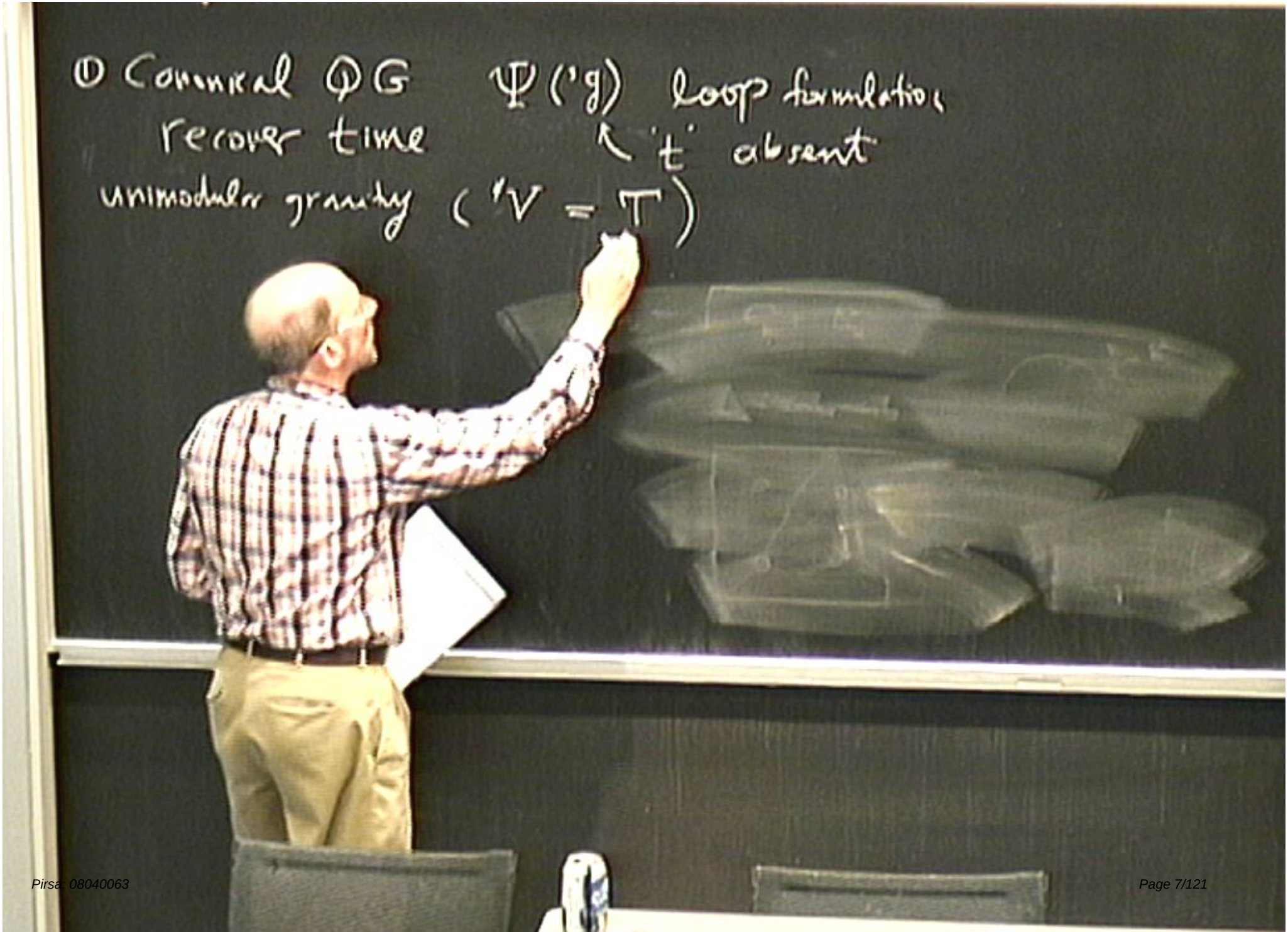

D Canonical QG
Ψ('g)

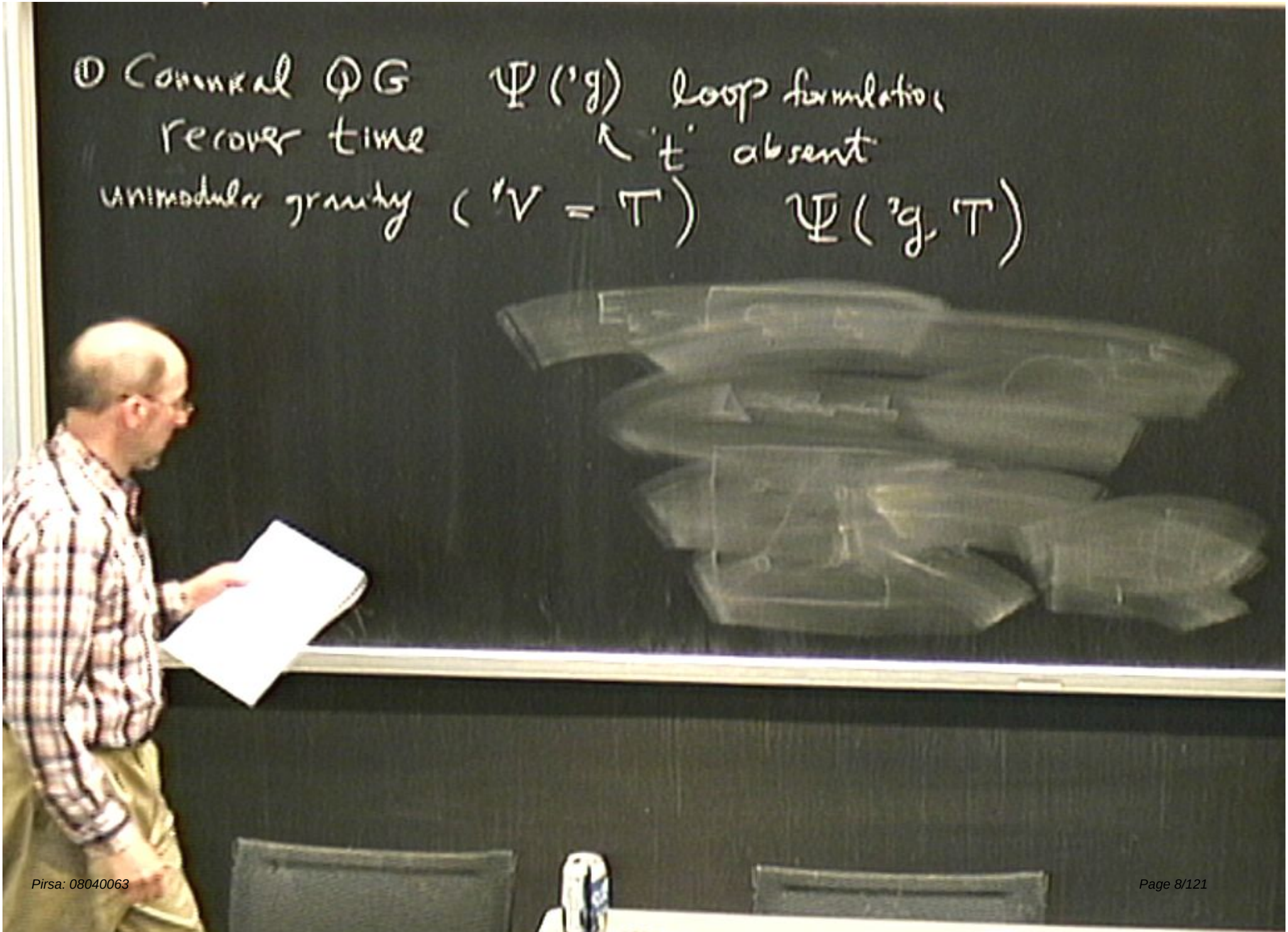

① Canonical QG
Ψ('g) loop formulation

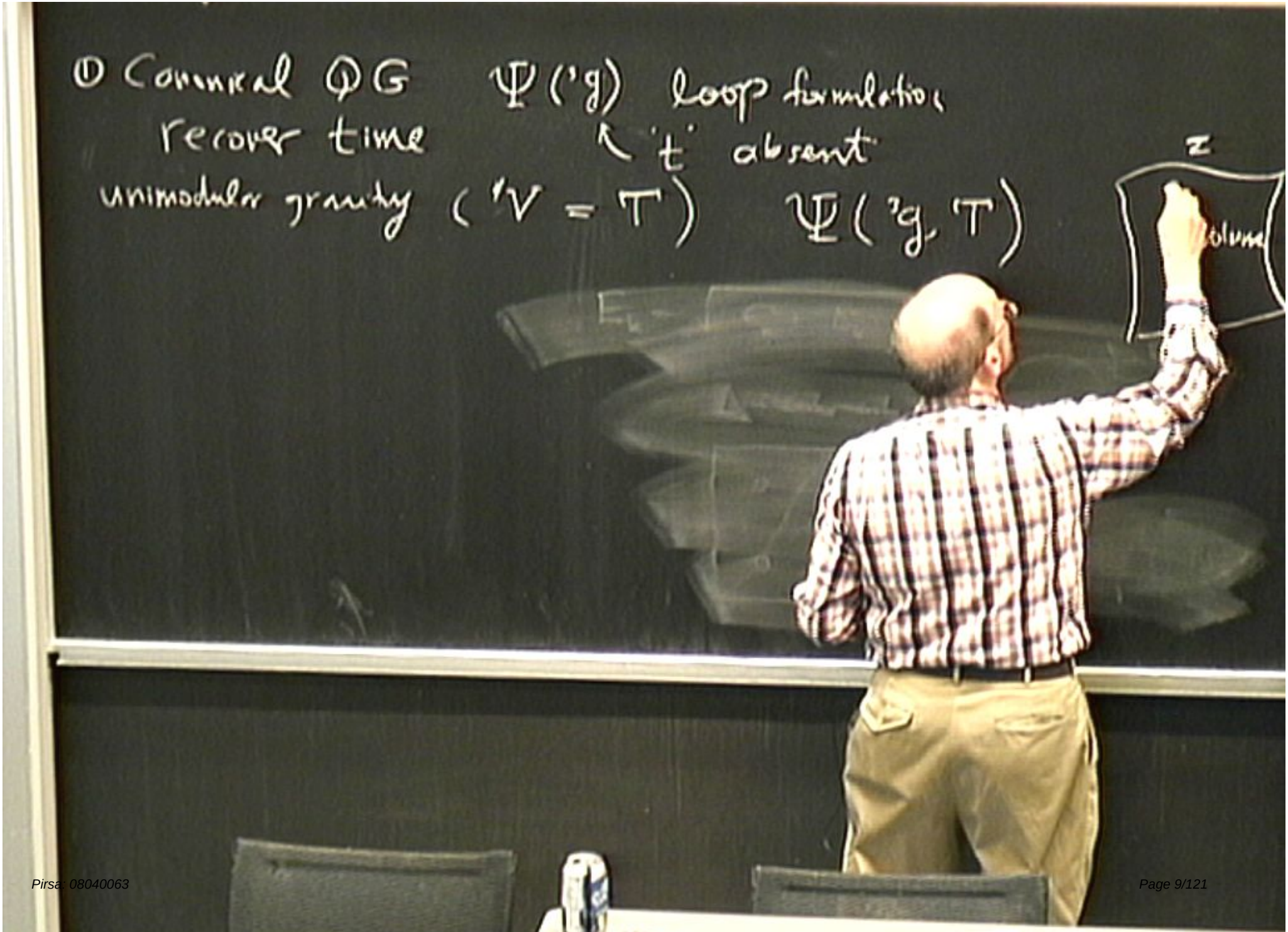

① Canonical QG
Ψ('g) loop formulation
↖ 't' absent

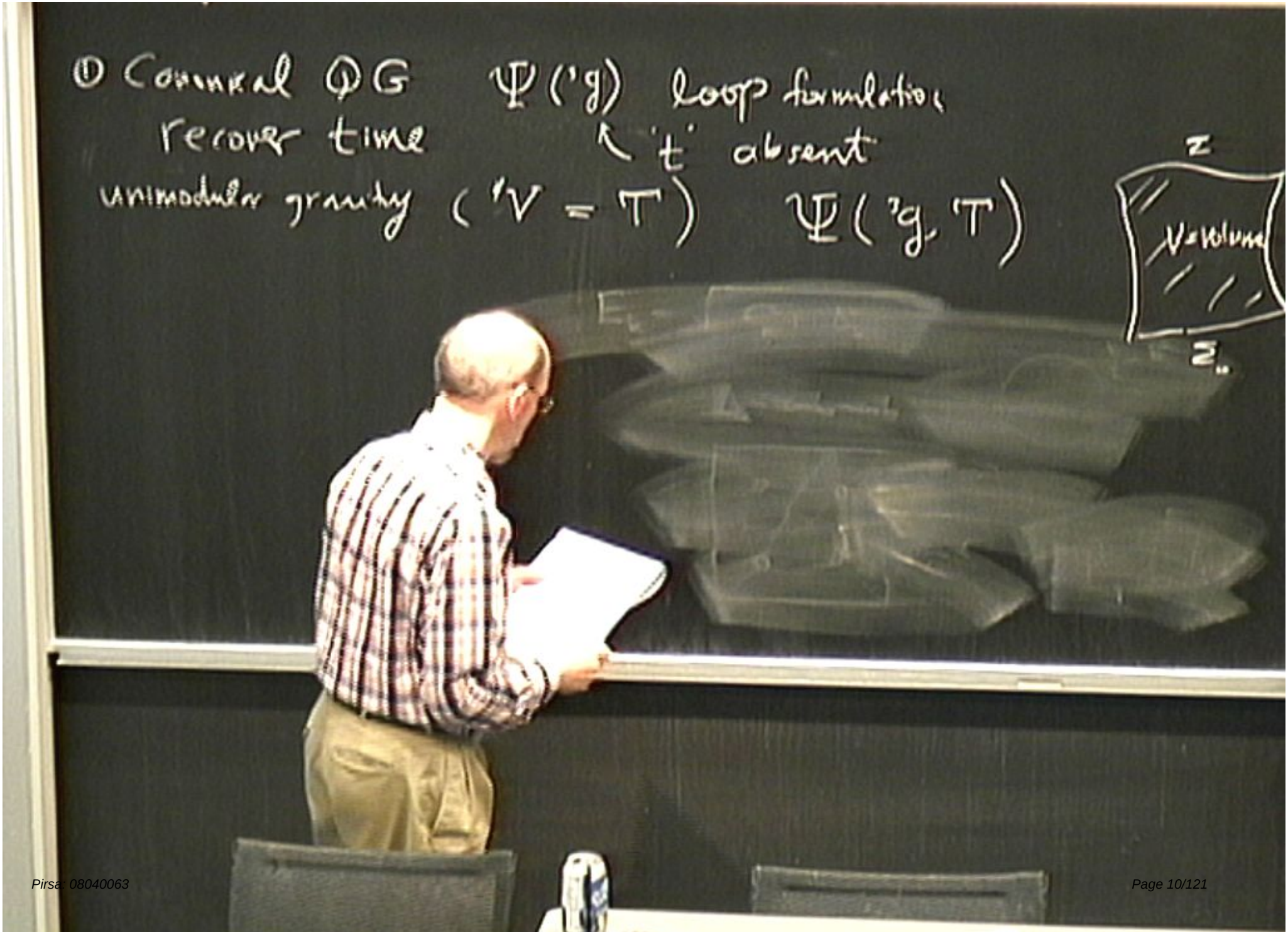

① Recover time (from space) in CQG
recover time
↖ 't' absent

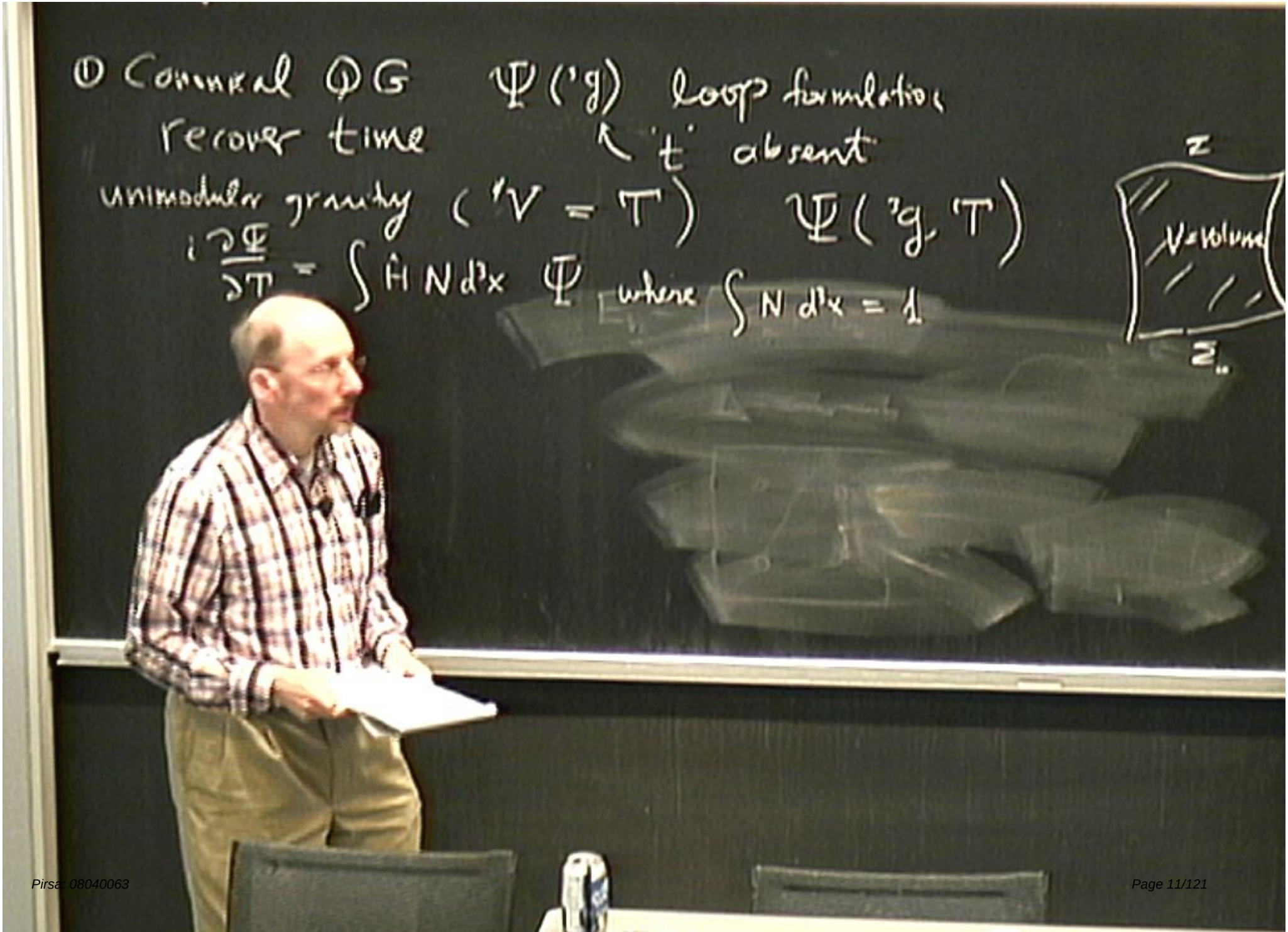

① Covariant QG
recover time
Ψ('g) loop formulation
't' absent

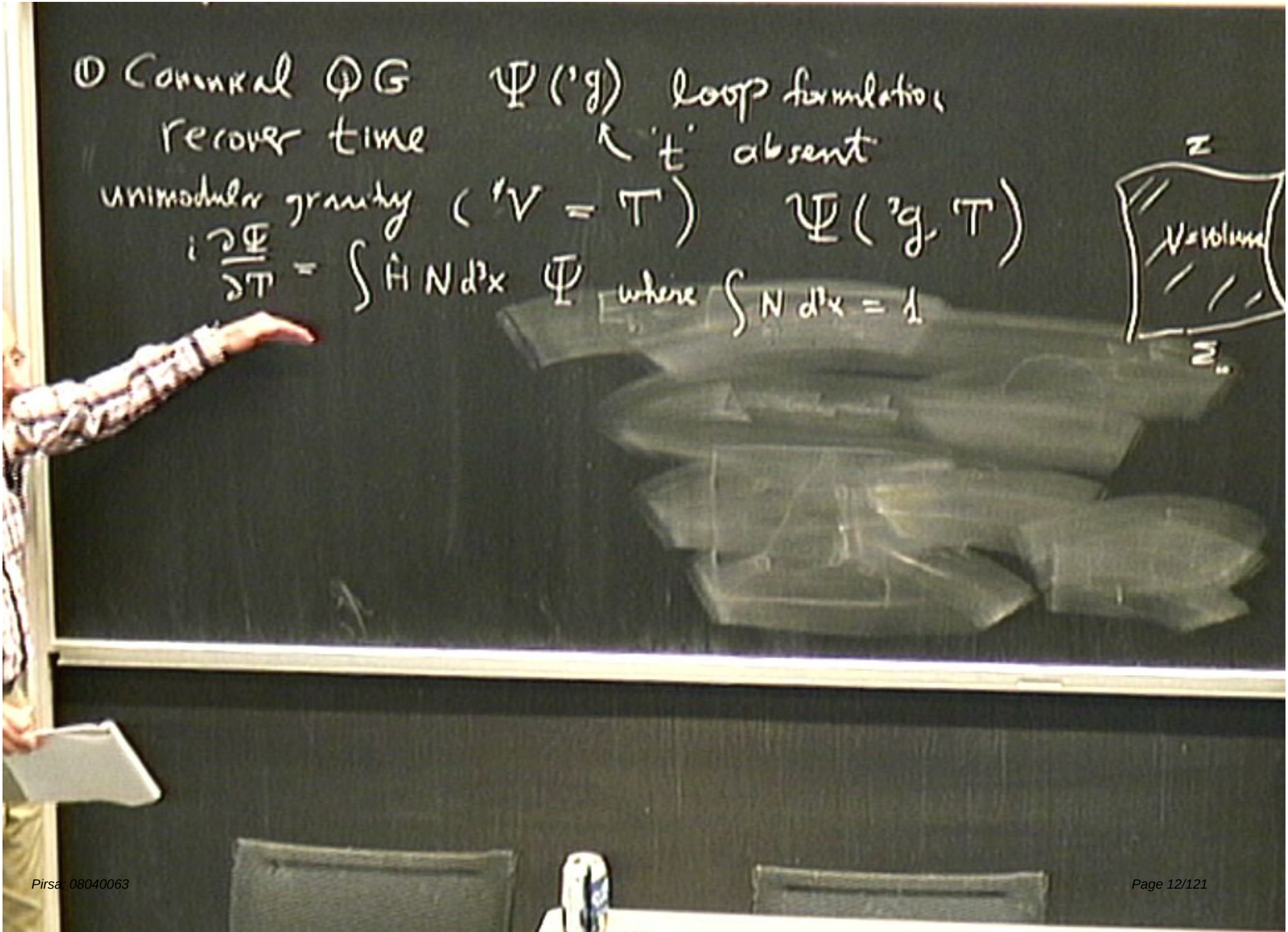

① Canonical QG Ψ('g) loop formulation
recover time
't' absent
unimodular gravity ('V = T)


① Canonical QG Ψ('g) loop formulation
recover time ↖ 't' absent
unimodular gravity ('V = T) Ψ('g, T)


① Canonical QG Ψ('g) loop formulation
recover time ↖ 't' absent
unimodular gravity ('V = T) Ψ('g, T)
z


① Canonical QG Ψ('g) loop formulation
recover time
't' absent
unimodular gravity ('V = T) Ψ('g, T)
Z
V = volume
Z


① Canonical QG Ψ('g) loop formulation
recover time ↖ 't' absent
unimodular gravity ('V = T) Ψ('g, T)
$i\frac{\partial \Psi}{\partial T} = \int \hat{H} N d^3x \, \Psi$ where $\int N d^3x = 1$
z
V=volume
z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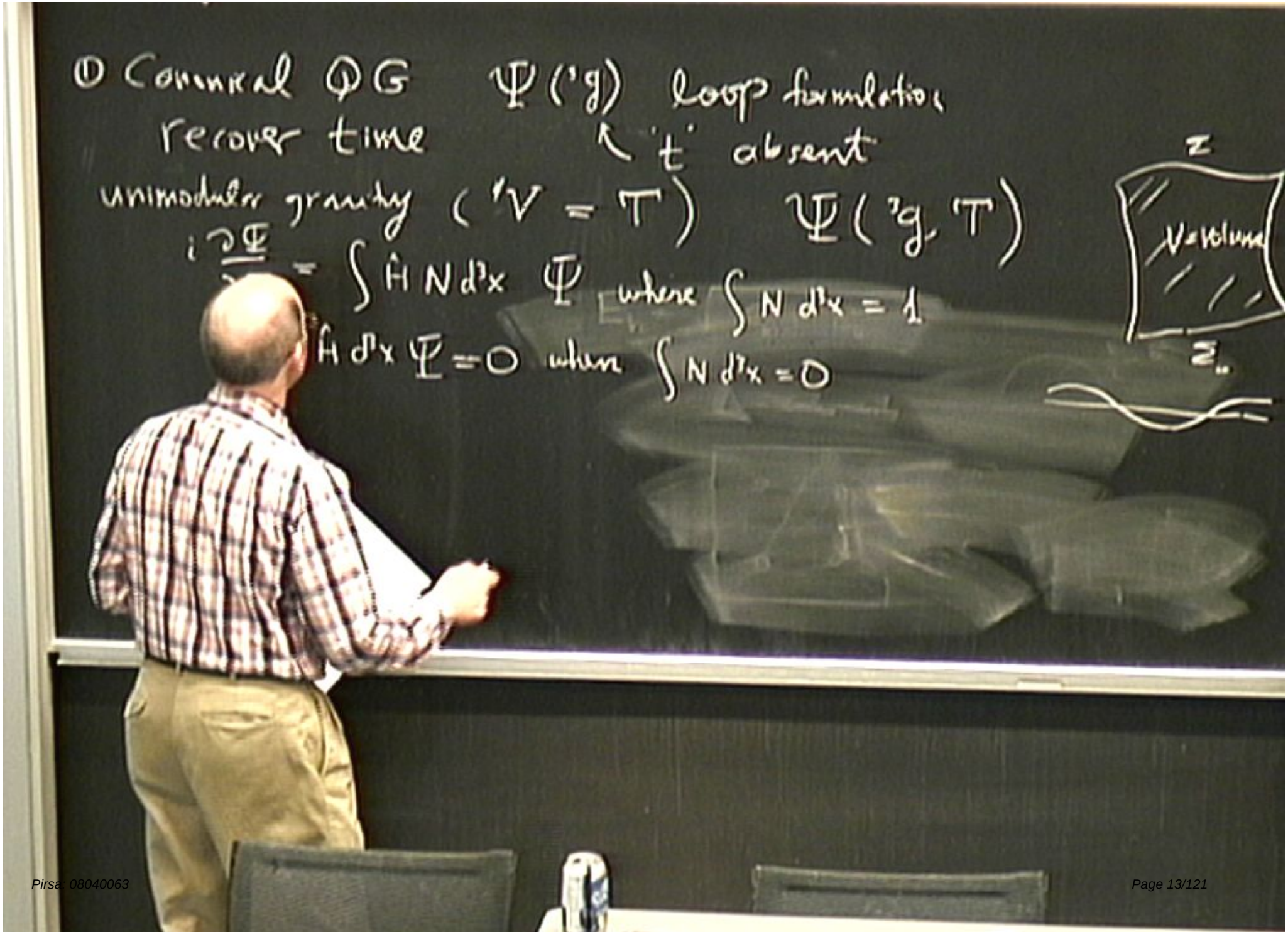
Σ
V = volume
Σ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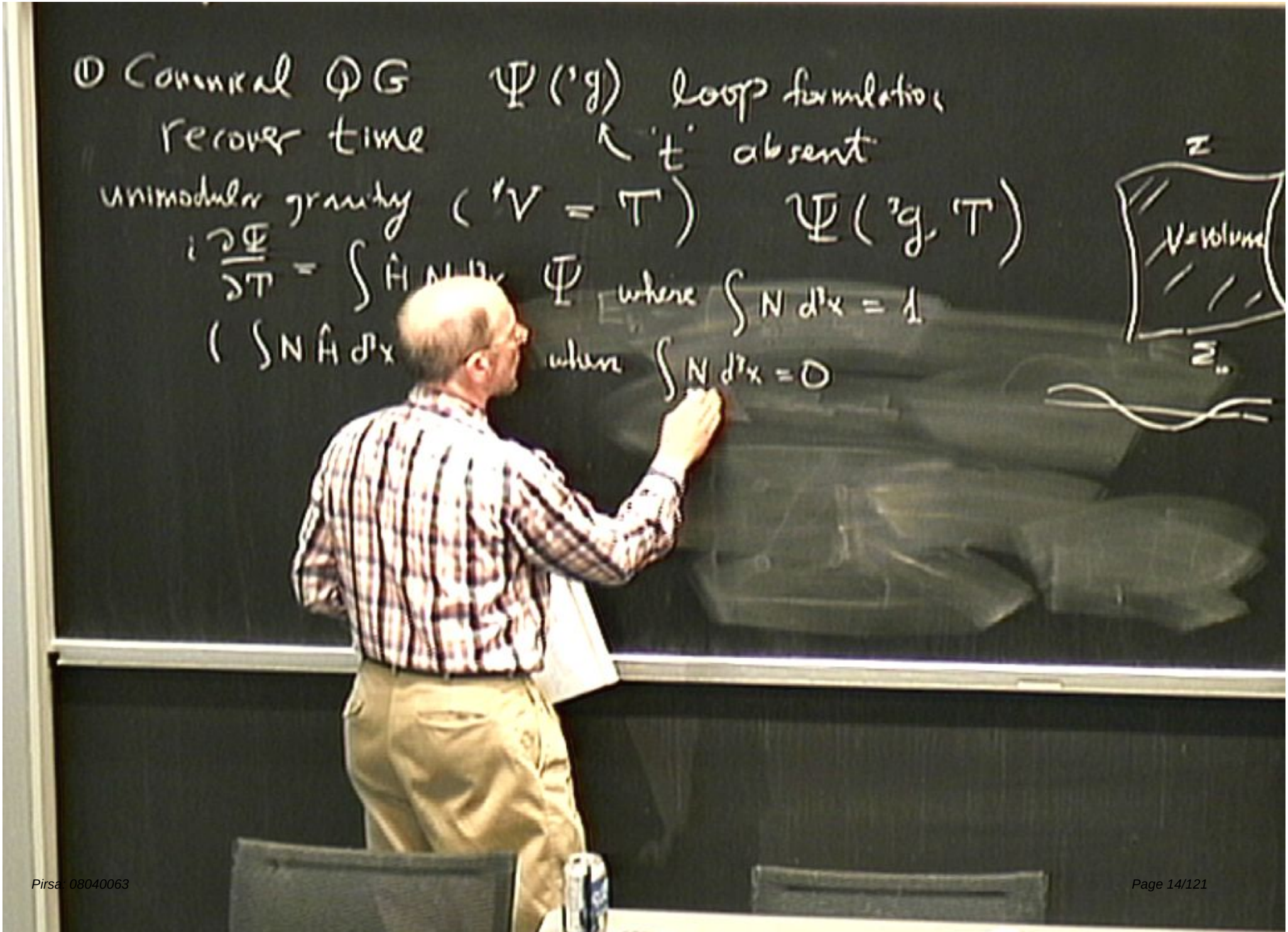
$\int \hat{H} d^3x \Psi = 0$ when $\int N d^3x = 0$
Z
V = volume
$Z_{..}$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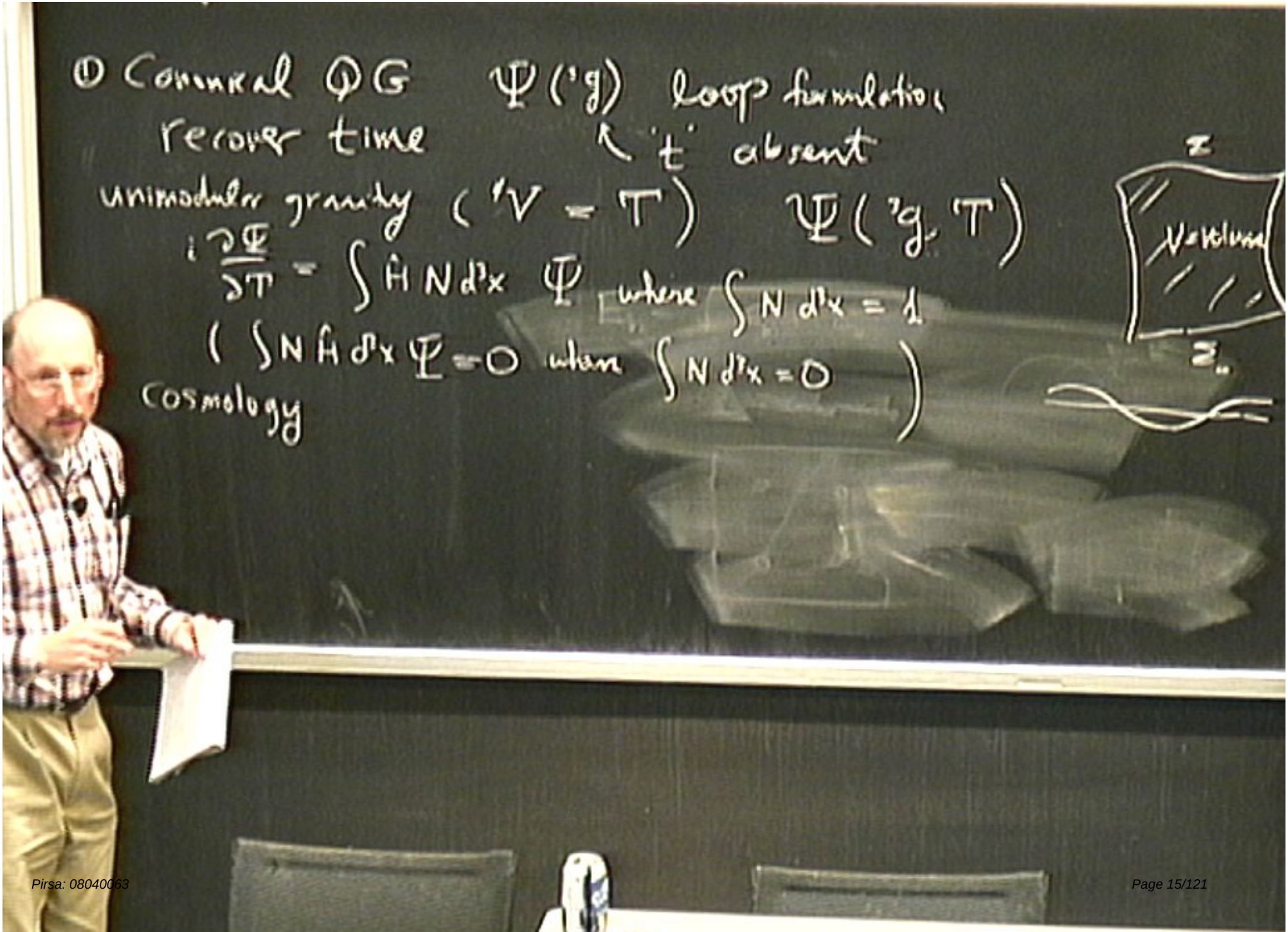
$\left(\int N \hat{H} d^3x \right.$ when $\int N d^3x = 0$
z
V = volume
z_0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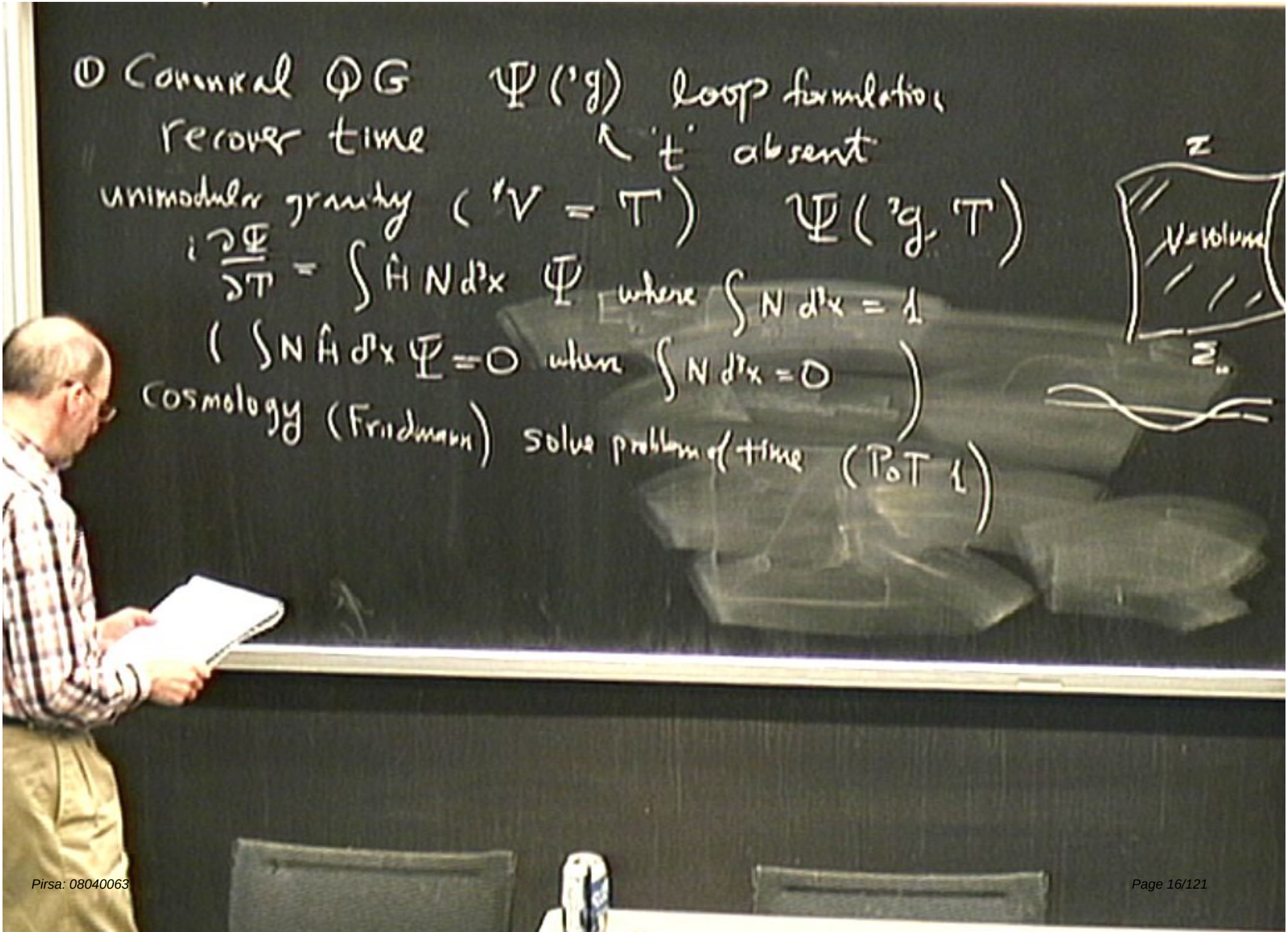
($\int N \hat{H} d^3x \, \Psi = 0$ when $\int N d^3x = 0$)
Cosmology
Σ
Volume
Σ_0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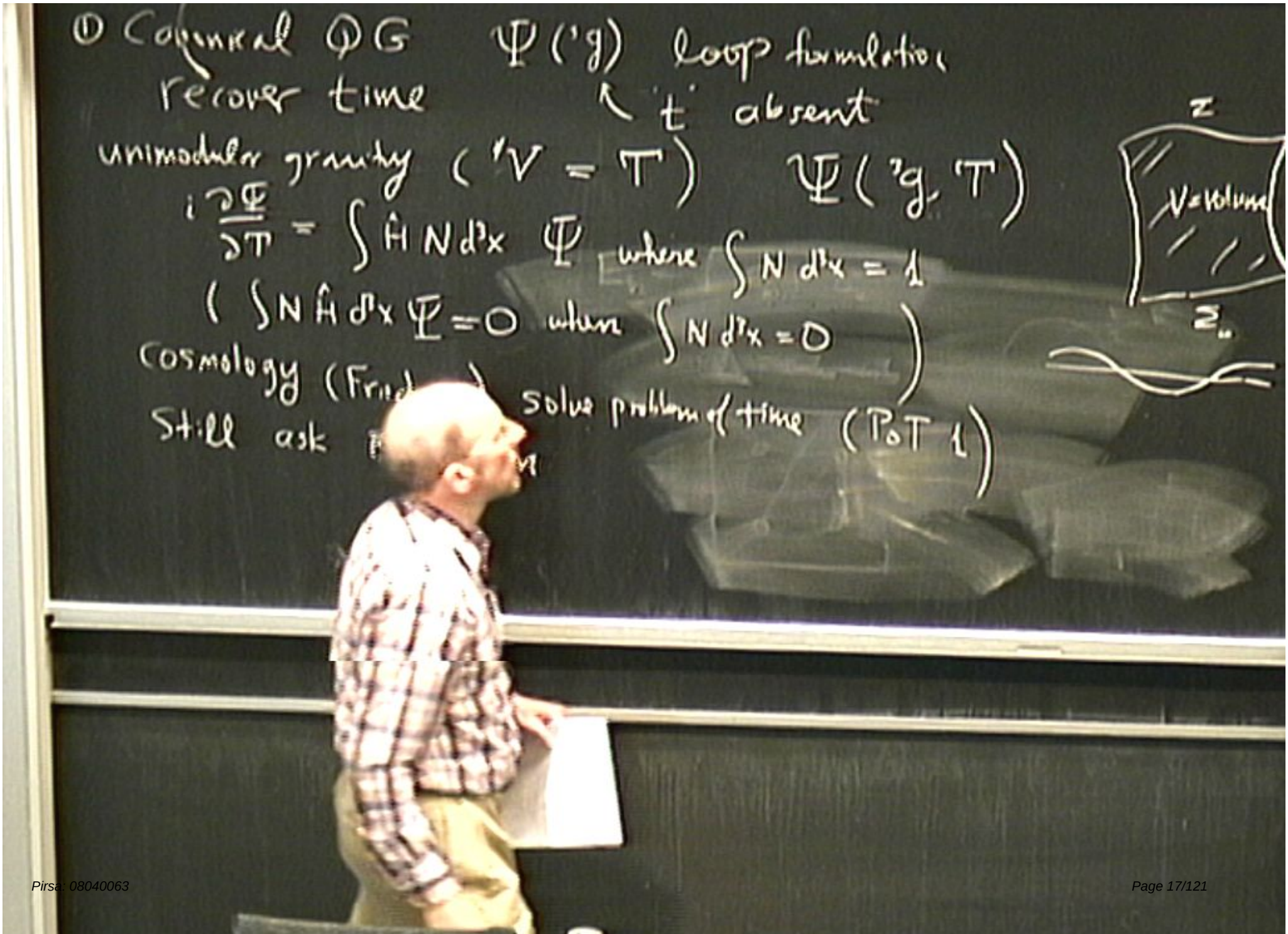
Cosmology (Friedmann) solve problem of time (PoT 1)
z
V = volume
z_0


① Canonical QG Ψ('g) loop formulation
recover time
↖ t absent
unimodular gravity ('V = T) Ψ('g, T)
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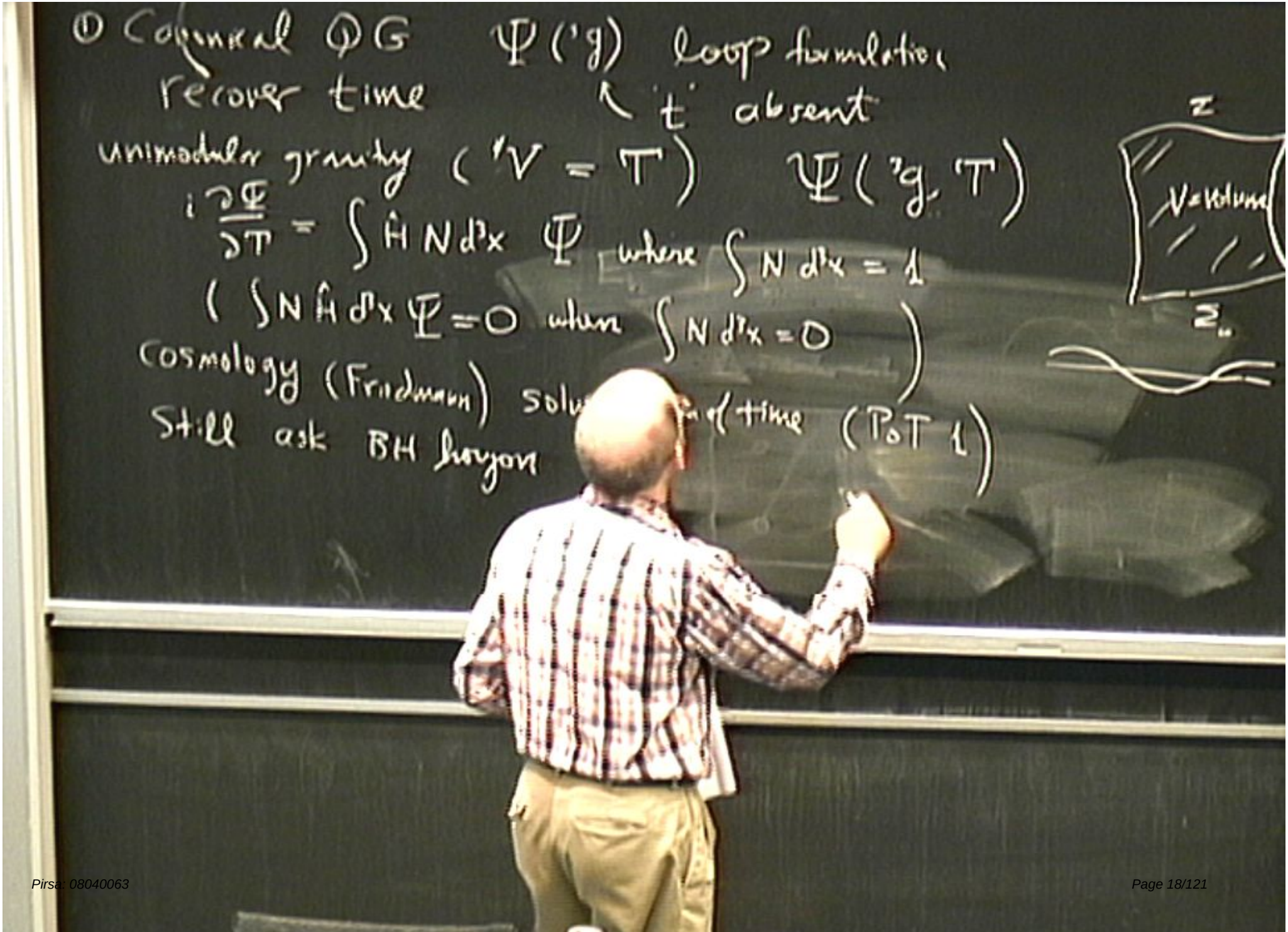
$\left(\int N \hat{H} d^3x \Psi = 0 \text{ when } \int N d^3x = 0 \right)$
Cosmology (Fri
Solve problem of time (PoT 1)
Still ask
V = volume
Σ


① Canonical QG Ψ('g) loop formulation
recover time
t absent
unimodular gravity ('V = T) Ψ('g, T)
i ∂Ψ/∂T = ∫ Ĥ N d³x Ψ where ∫ N d³x = 1
(∫ N Ĥ d³x Ψ = 0 when ∫ N d³x = 0)
Cosmology (Friedmann) Solu of time (PoT 1)
Still ask BH horizon
Σ
V = volume
Σ₀

① Canonical QG $\Psi('g)$ loop formulation

recover time ↖ t absent

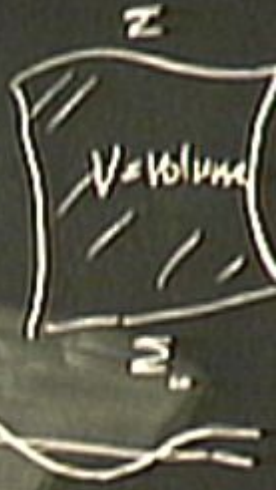
unimodular gravity ($'V = T$) $\Psi('g, T)$

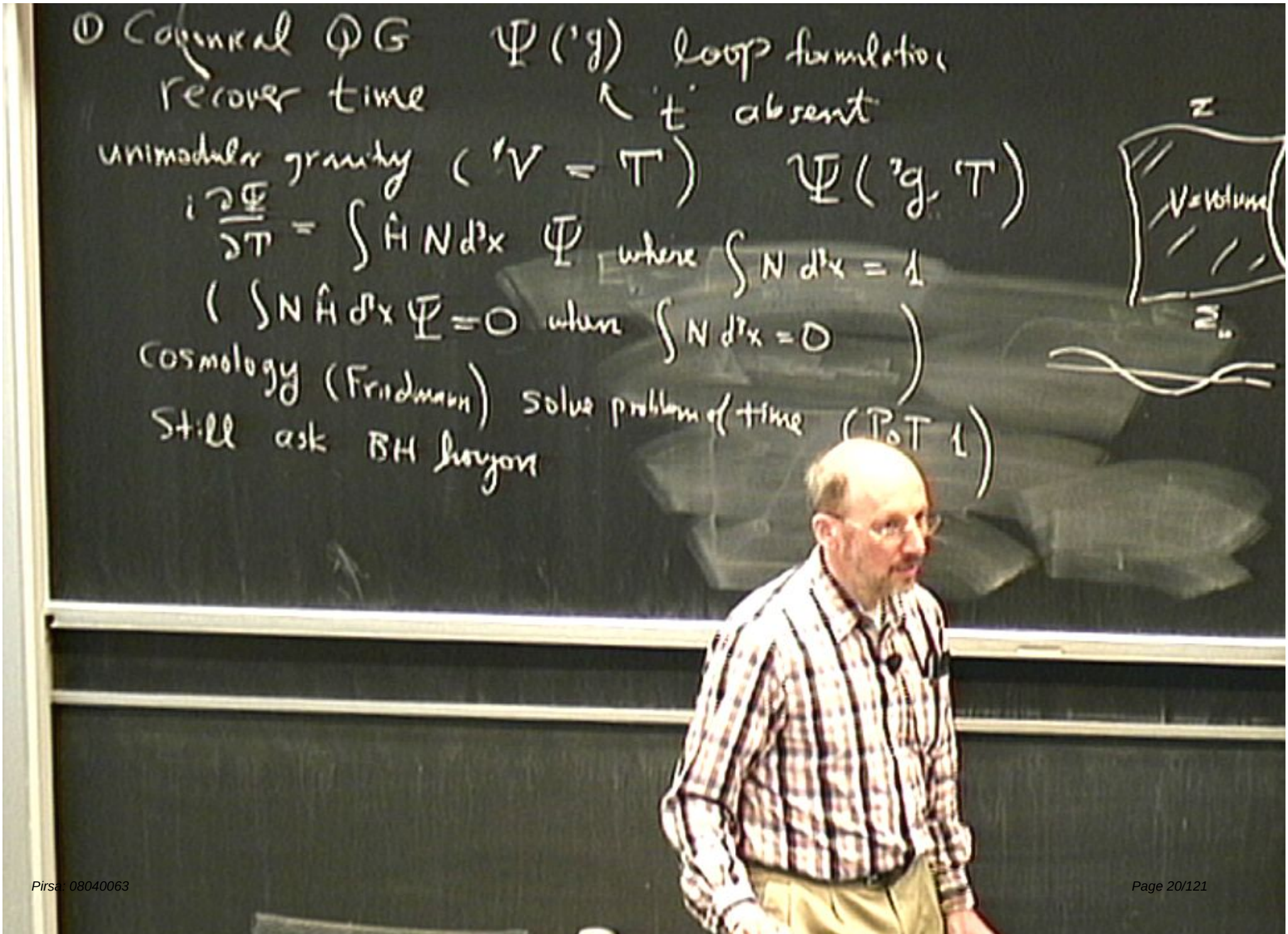
$$i\frac{\partial \Psi}{\partial T} = \int \hat{H} N d^3x \, \Psi \quad \text{where} \int N d^3x = 1$$

$$\left(\int N \hat{H} d^3x \, \Psi = 0 \quad \text{when} \int N d^3x = 0 \right)$$

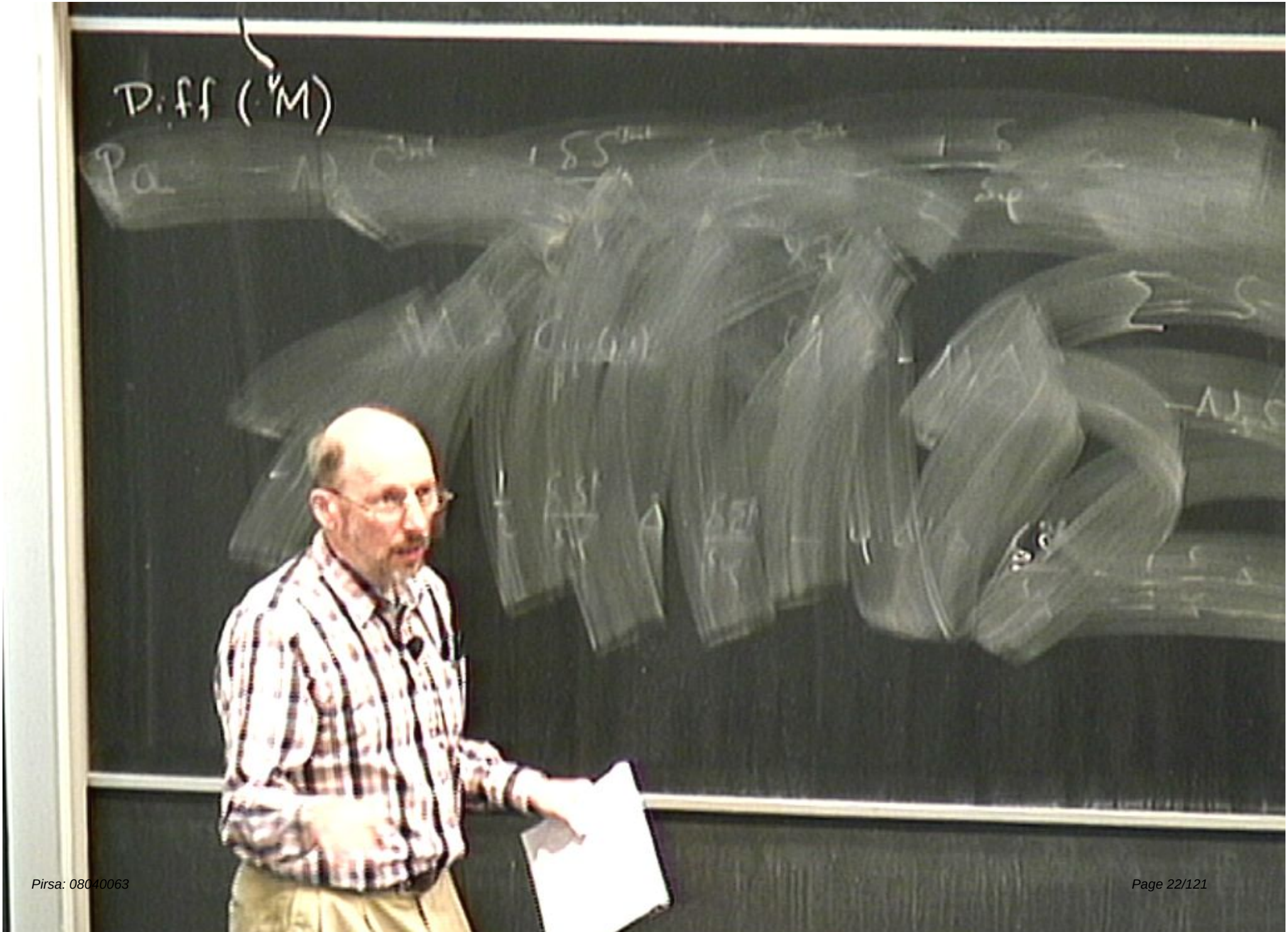
Cosmology (Friedmann) Solve problem of time (PoT 1)

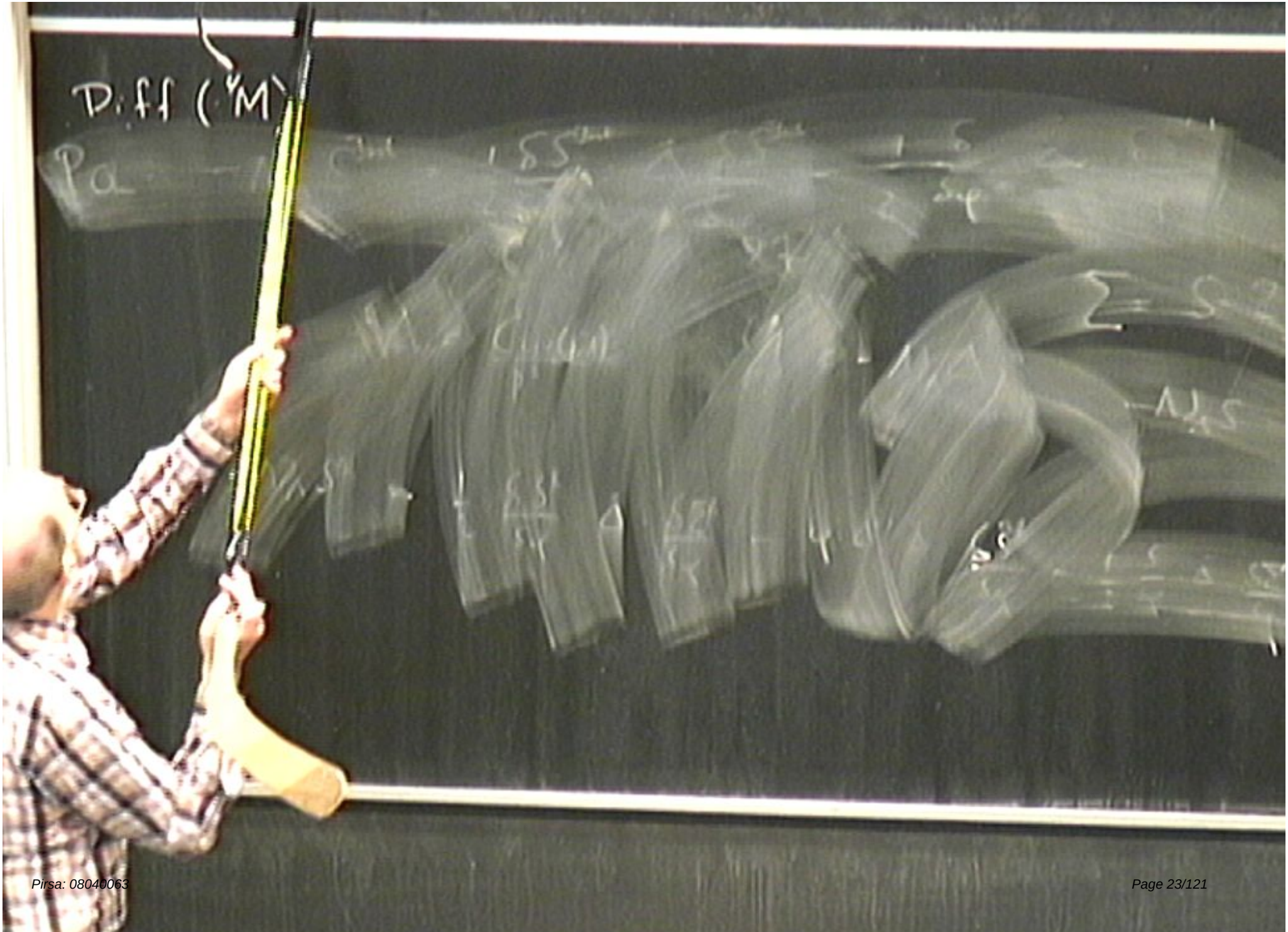
Still ask BH horizon




① Canonical QG Ψ('g) loop formulation
recover time ↖ t' absent
unimodular gravity ('V = T) Ψ('g, T)
$i\frac{\partial \Psi}{\partial T} = \int \hat{H} N d^3x \, \Psi$ where $\int N d^3x = 1$
($\int N \hat{H} d^3x \, \Psi = 0$ when $\int N d^3x = 0$)
Cosmology (Friedmann) Solve problem of time (PoT 1)
Still ask BH horizon
Σ
V = volume

$\sqrt{-g} - 1$


Diff (M)


Diff (M)

Diff ('M)

① Canonical QG $\Psi('g)$ loop formulation

recover time ↖ 't' absent

unimodular gravity ('V = T) $\Psi($ $T)$

$i\frac{\partial \Psi}{\partial T} = \int \hat{H} N d^3x \, \Psi$ where $\int N d^3x$

($\int N \hat{H} d^3x \, \Psi = 0$ when $\int N d^3x =$

Cosmology (Friedmann) Solve problem of th

Still ask BH horizon

Diff (M)

① Canonical QG $\Psi('g)$ loop formulation

recover time ↖ 't' about

unimodular gravity ($'V = T$)

$$i\frac{\partial \Psi}{\partial T} = \int \hat{H} N d^3x \, \Psi$$

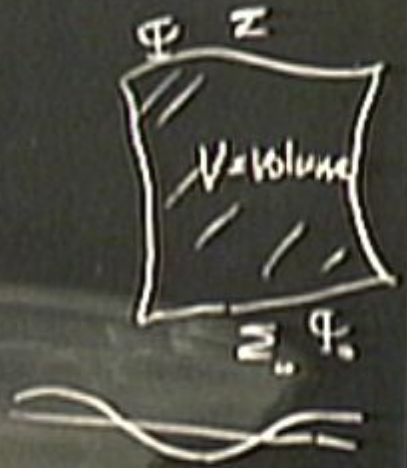
where $\int$ = 1

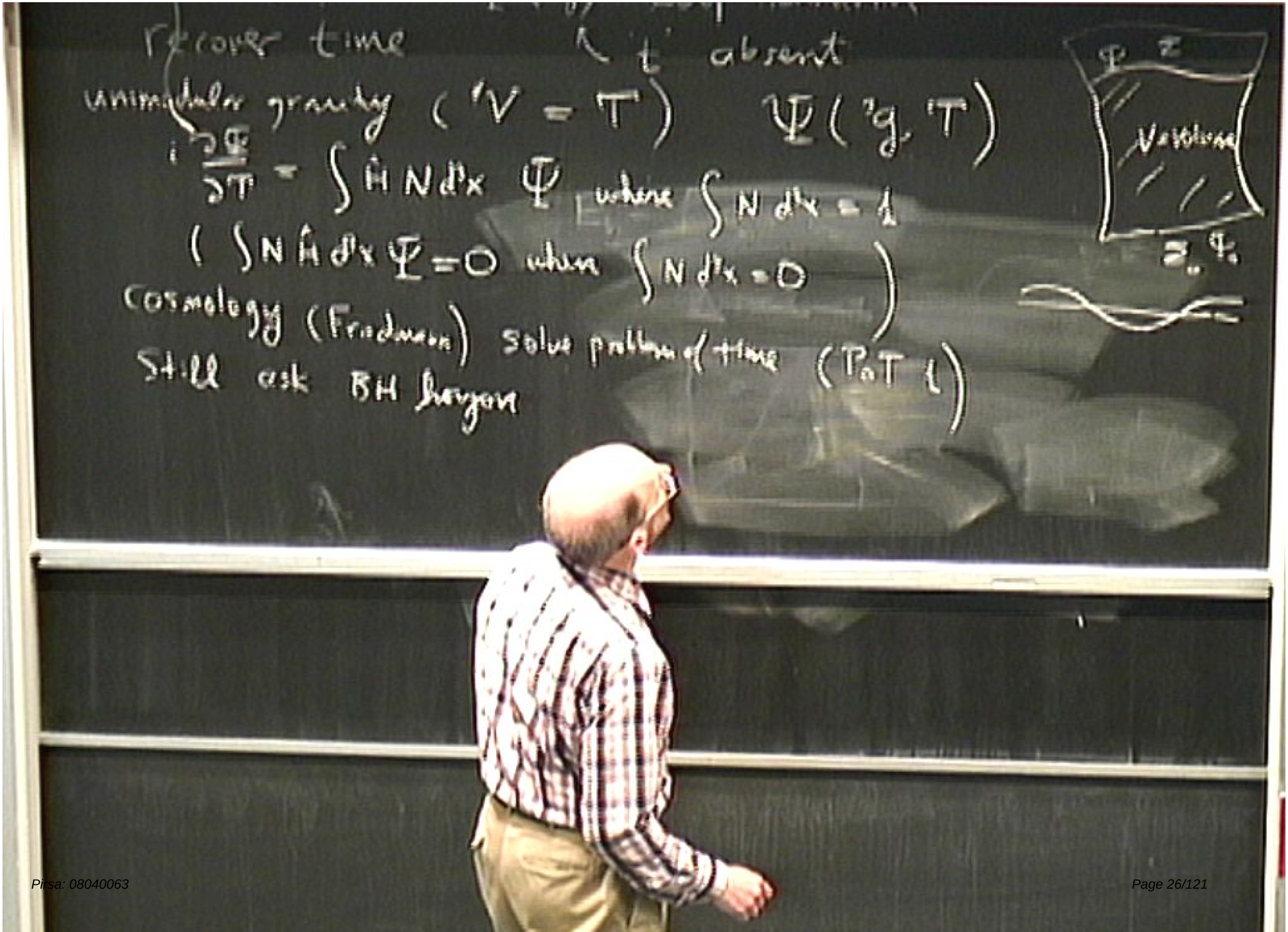
($\int N \hat{H} d^3x \, \Psi = 0$ when $\int N$)

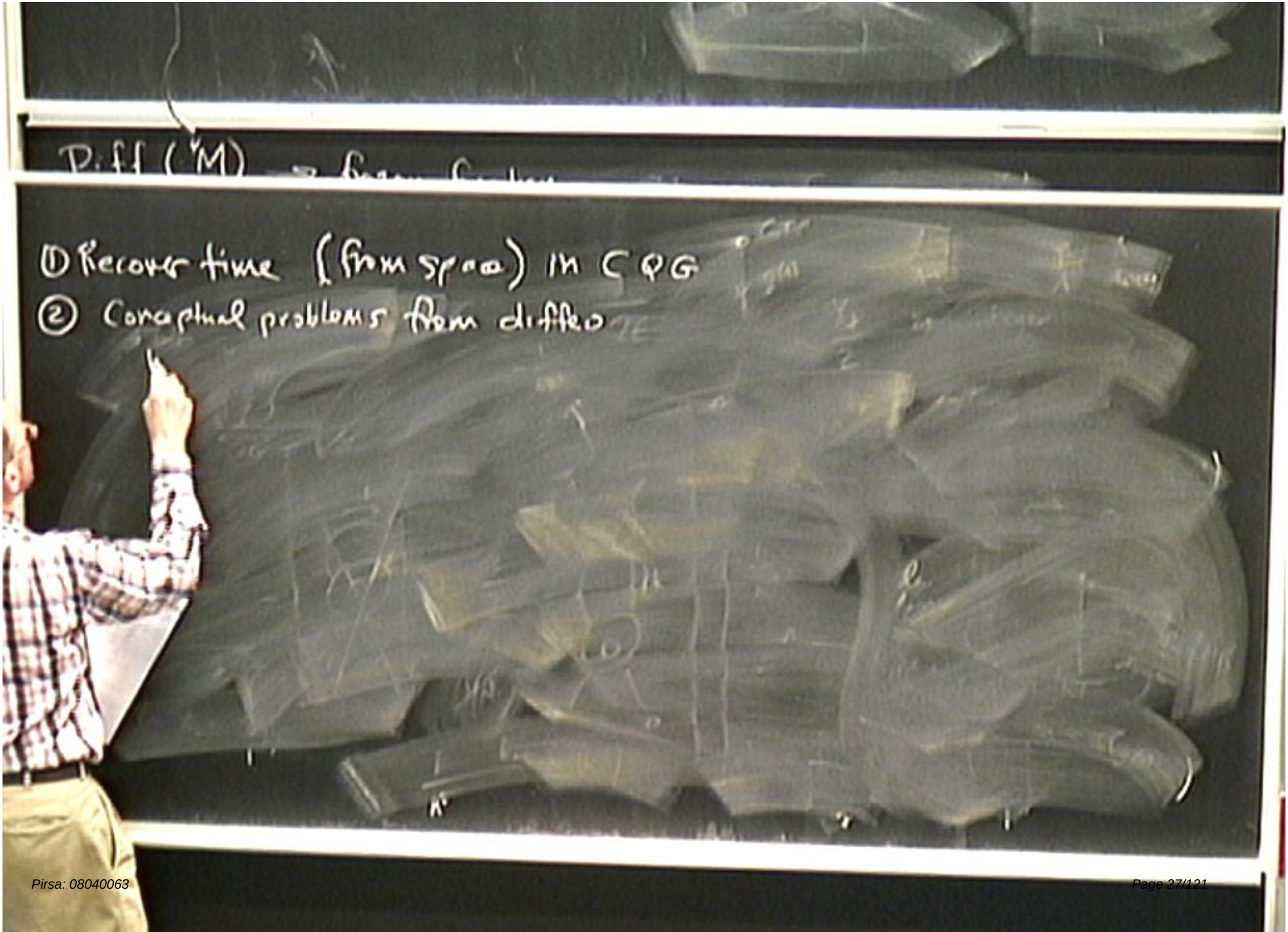
Cosmology (Friedmann) Solve problem

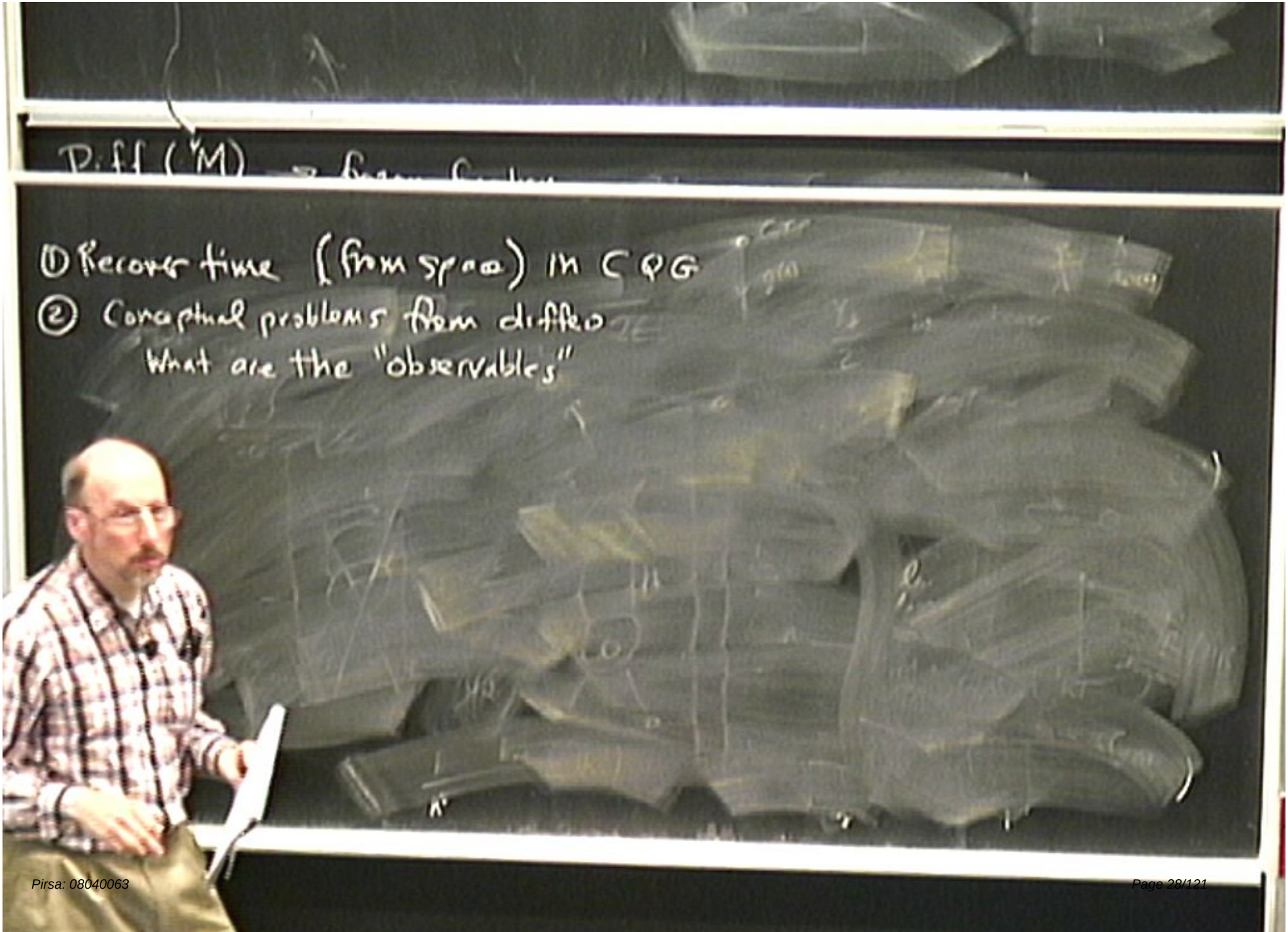
Still ask BH baryon

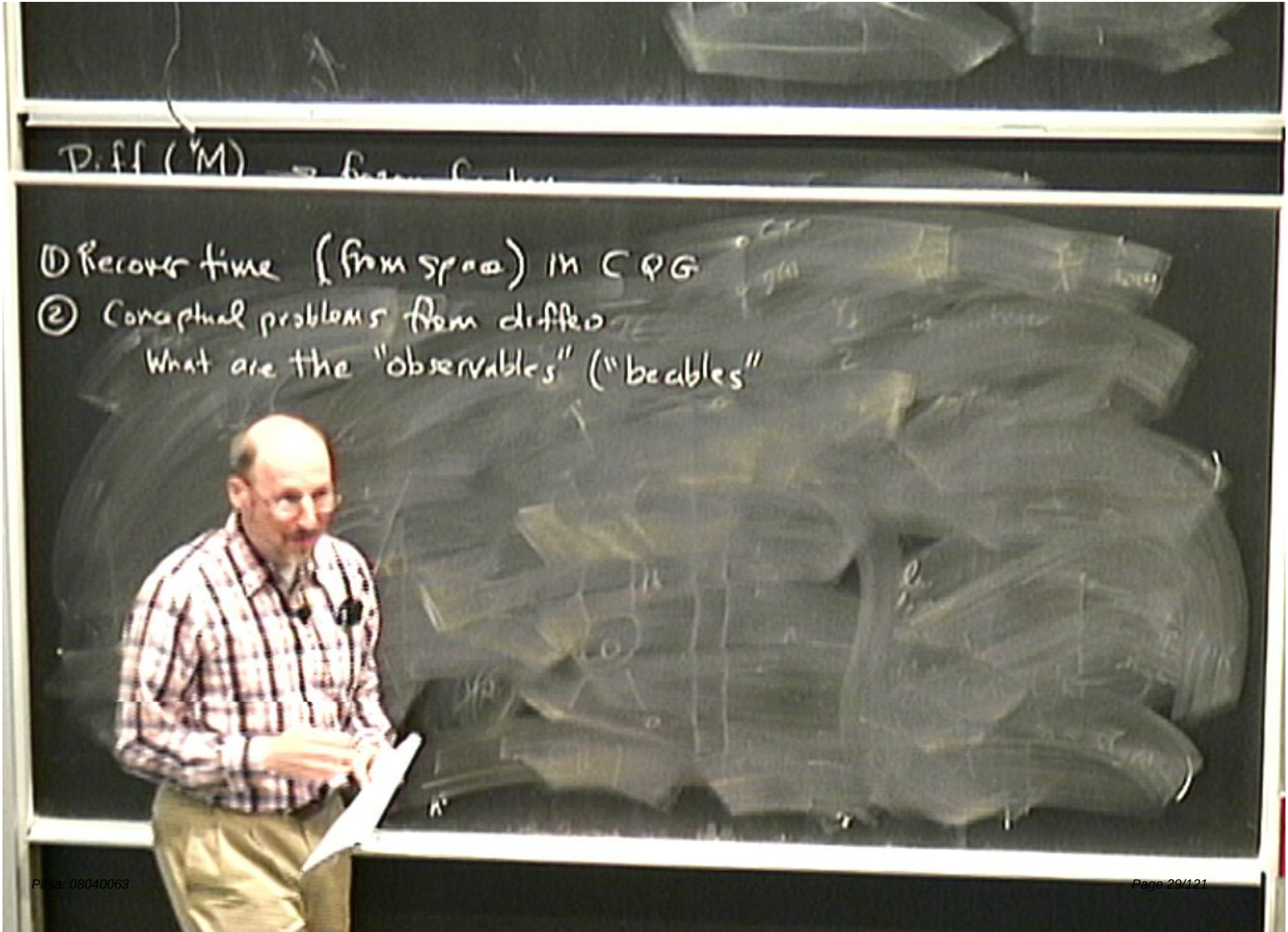
$$\int dv(y)\, e^{is(y)}\, \Psi_n(y)$$




recover time
t absent
unimodular gravity (⁴V = T)
Ψ(³g, T)
i ∂Ψ/∂T = ∫ Ĥ N d³x Ψ where ∫ N d³x = 1
(∫ N Ĥ d³x Ψ = 0 when ∫ N d³x = 0)
Cosmology (Friedmann) solve problem of time (PoT 1)
Still ask BH horizon
N×Volume


Diff (M)
① Recover time (from space) in CQG
② Conceptual problems from diffeo


Diff (M)
① Recover time (from space) in CQG
② Conceptual problems from diffeo
What are the "observables"


Diff (M)
① Recover time (from space) in CQG
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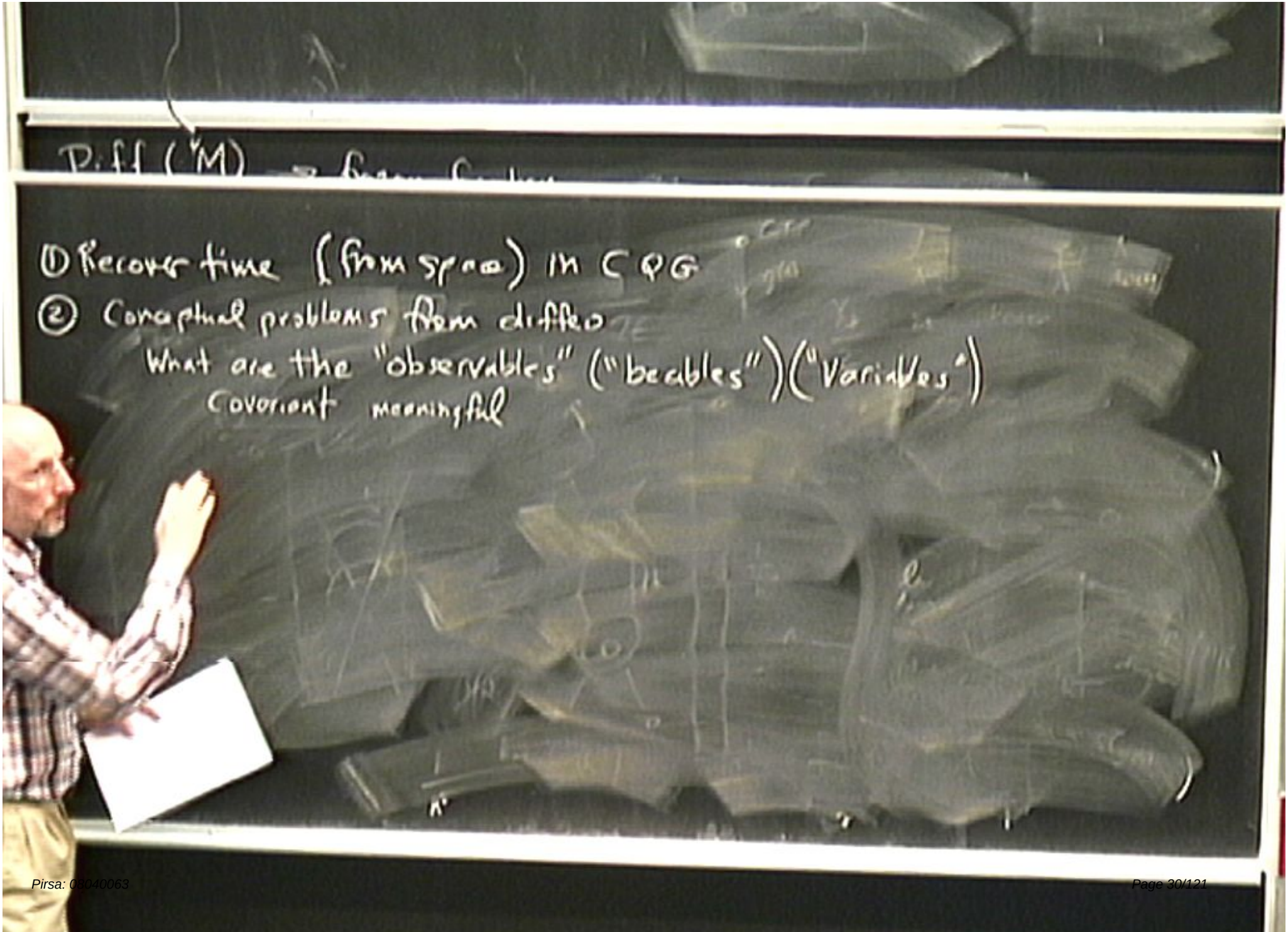
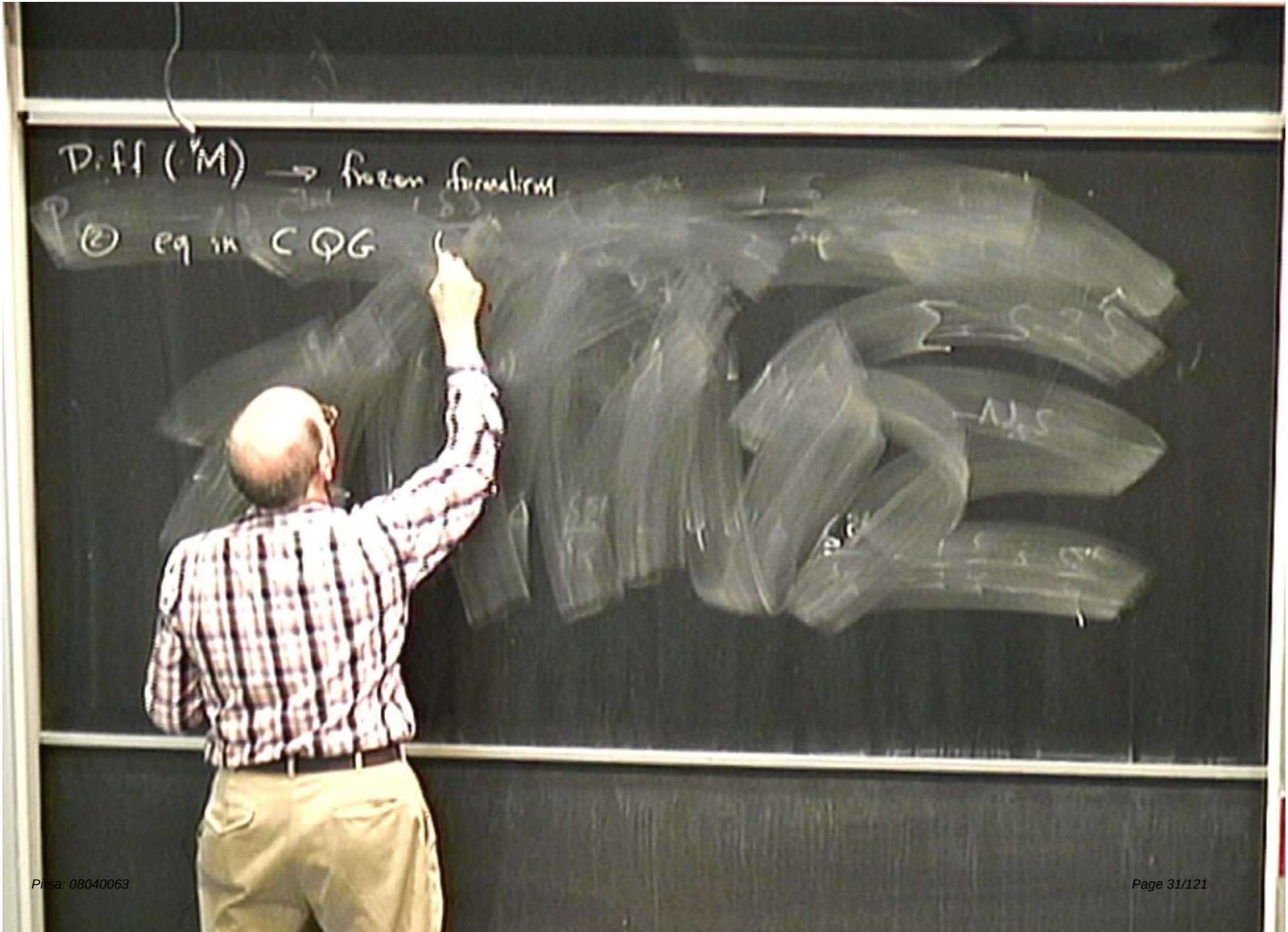
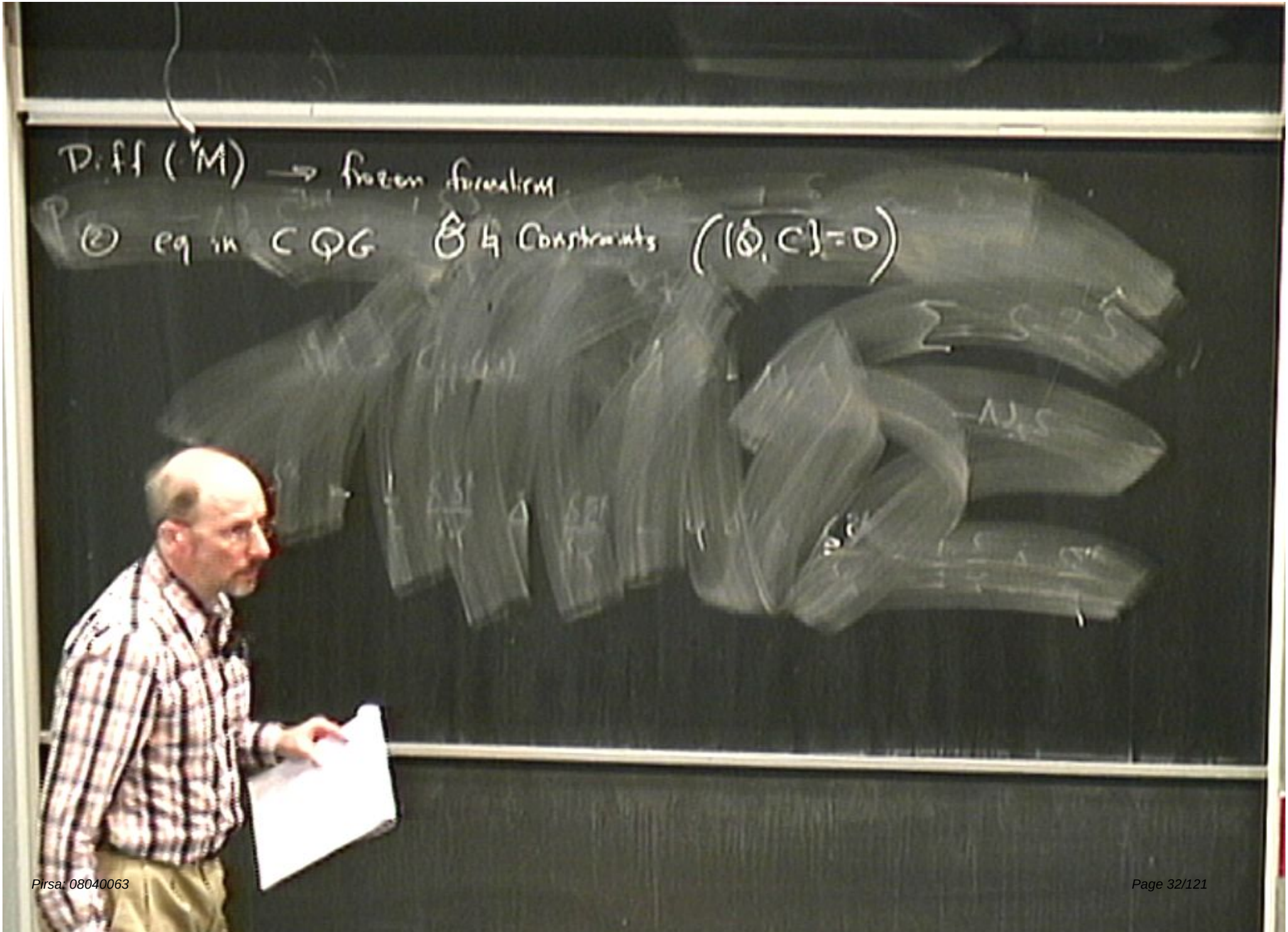
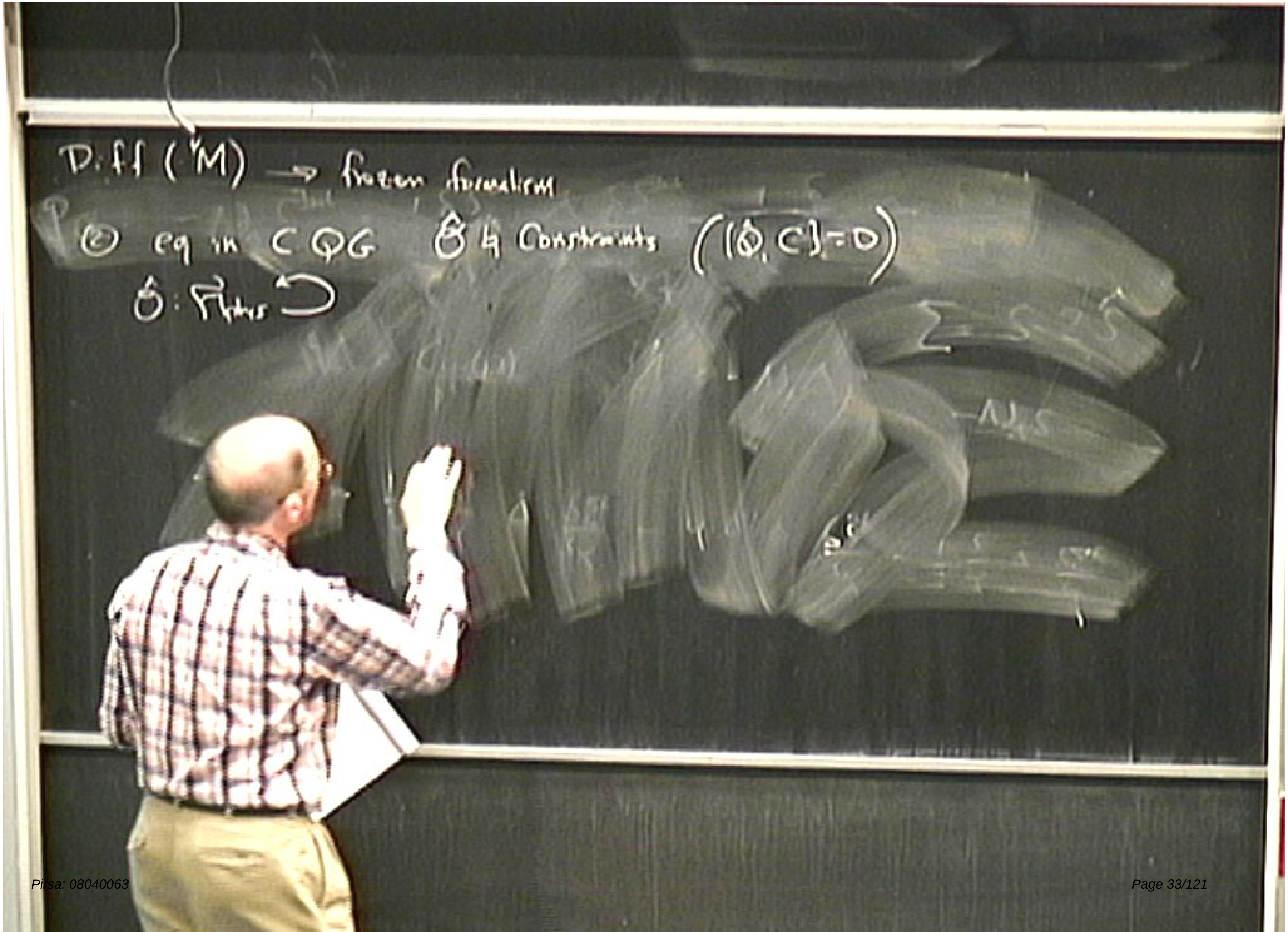
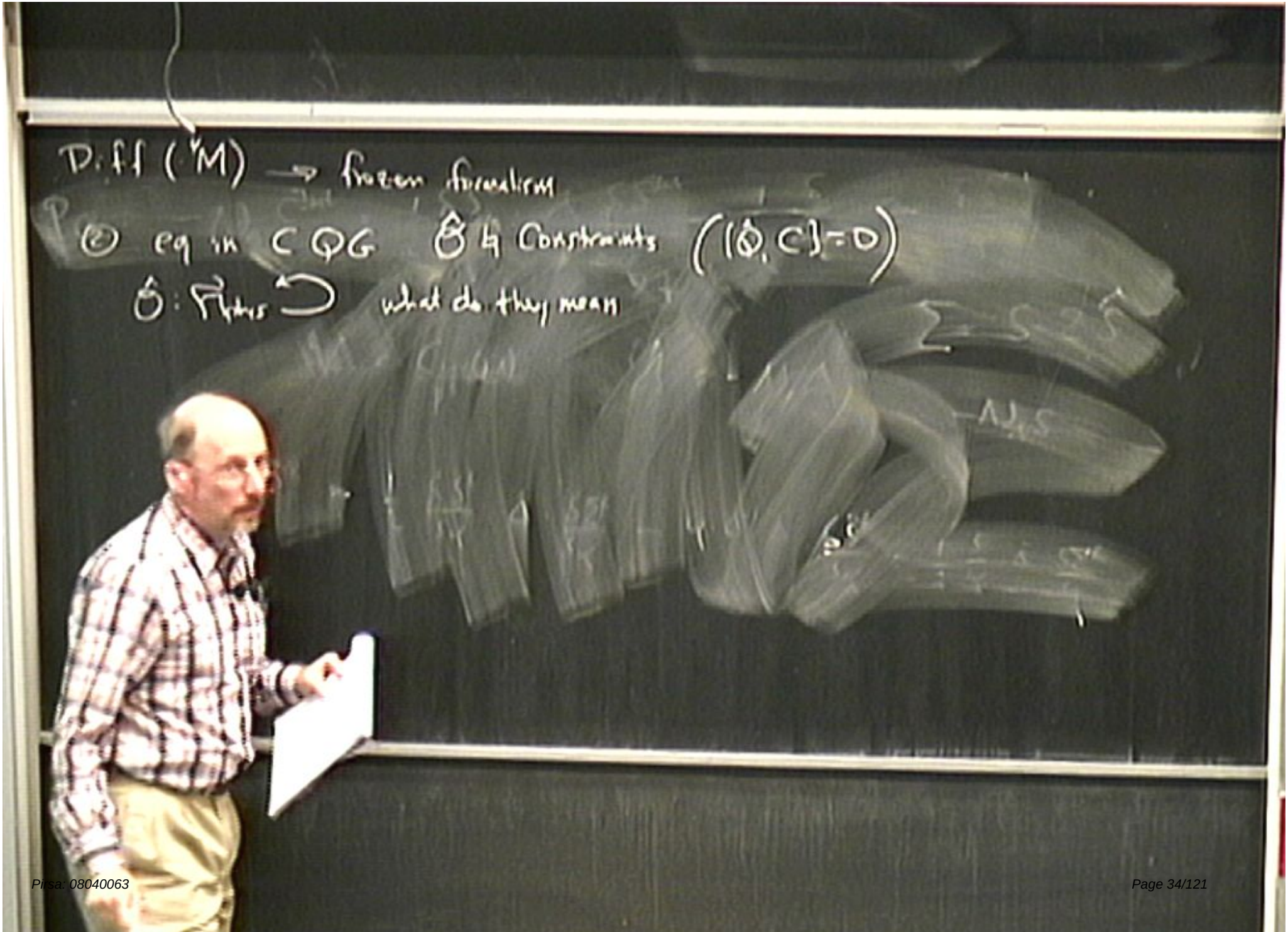
What are the "observables" ("beables"

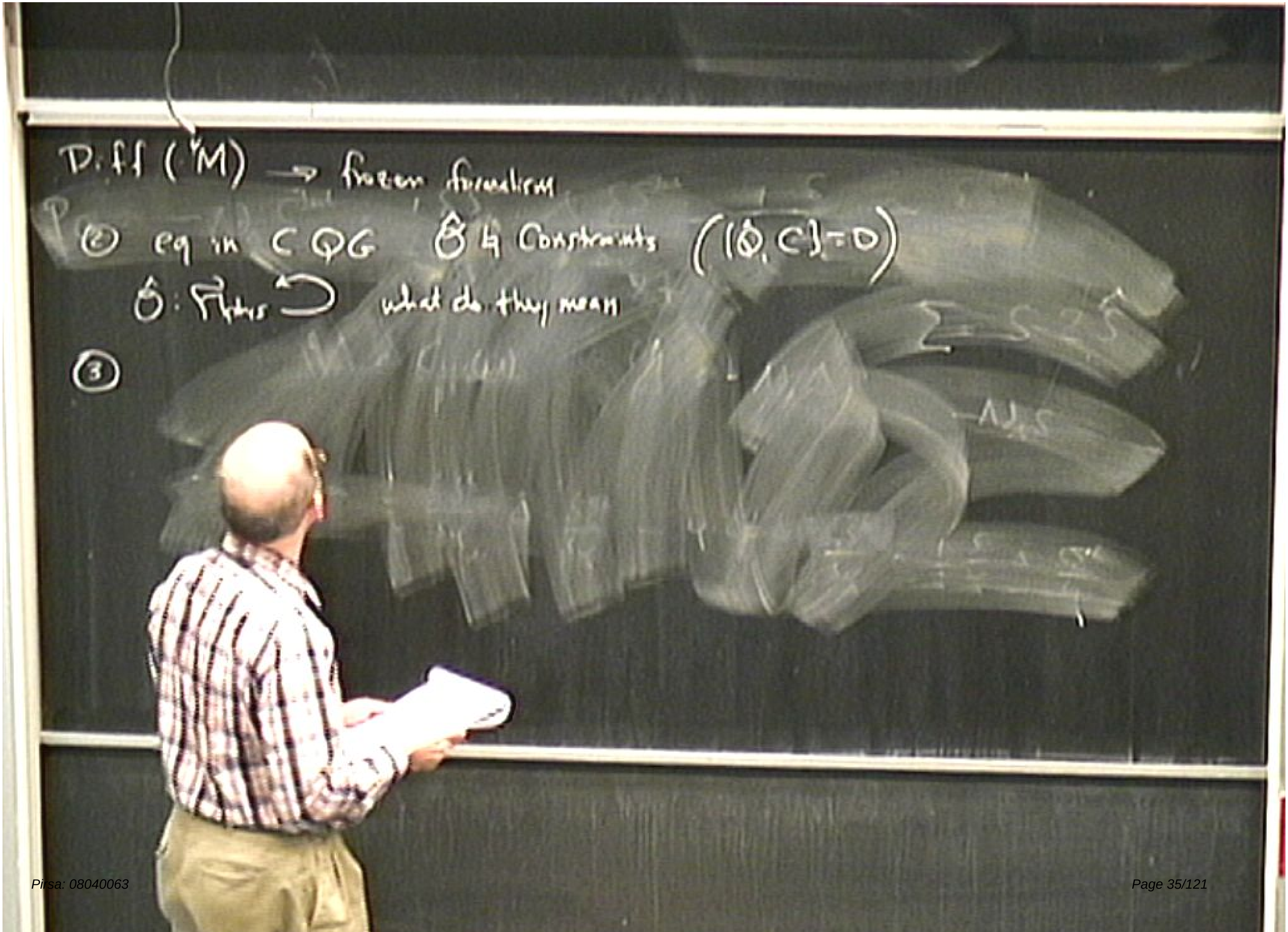

Diff (M)
① Recover time (from space) in CQG
② Conceptual problems from diffeo
What are the "observables" ("beables")("VariAbles")
Covariant meaningful

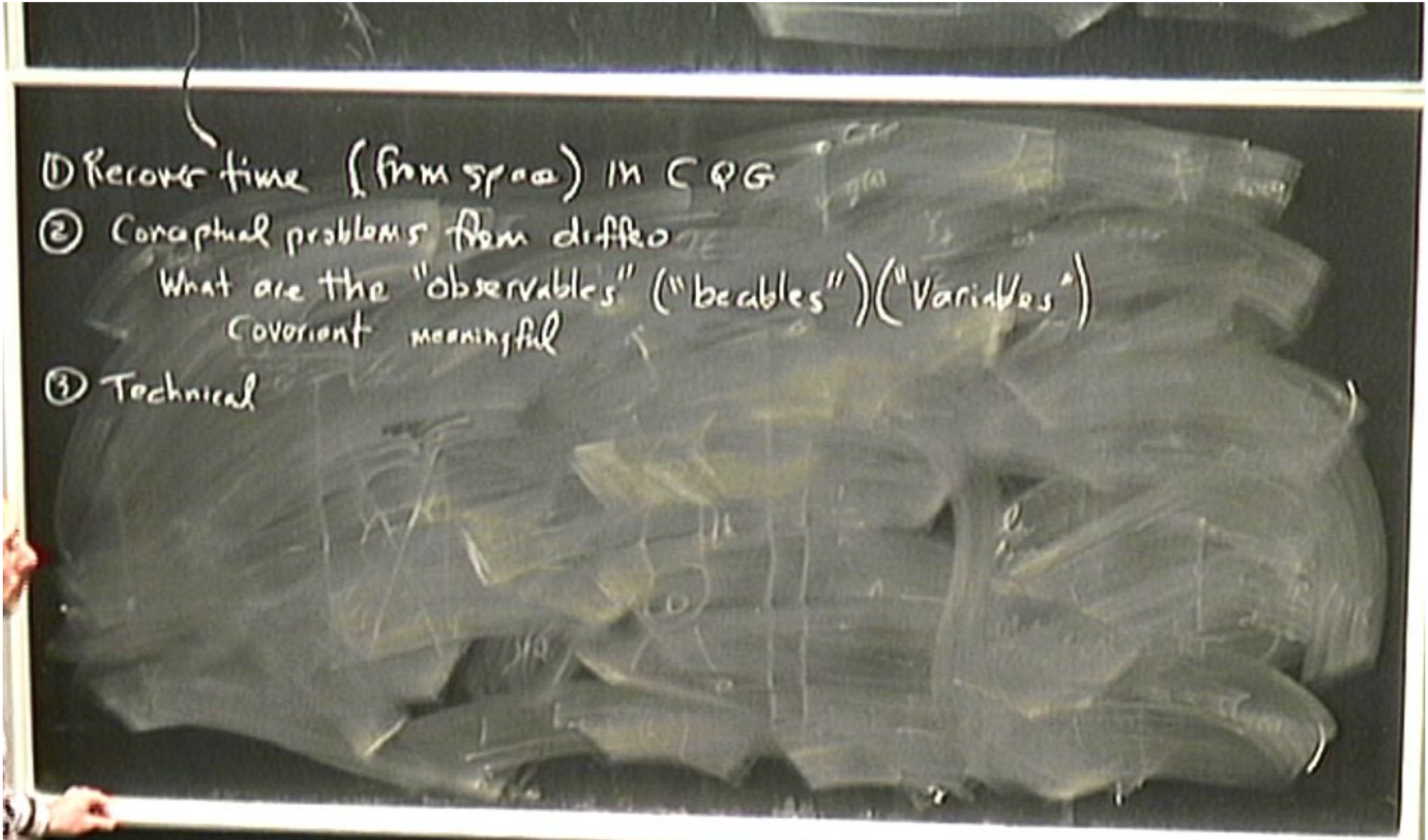

Diff (M) → frozen formalism
② eq in CQG


Diff (M) → frozen formalism
② eq in CQG & 4 Constraints ([Φ, C]=D)


Diff (⁴M) → frozen formalism
eq in CQG
Constraints ([Ô, C] = 0)
Ô : Physics


Diff (M) → frozen formalism
eq in CQG & 4 Constraints ([Φ, C]=0)
Φ: Fluxes
what do they mean


Diff (4M) → frozen formalism
② eq in CQG Ô & Constraints ([Ô, C] = 0)
Ô : Physics what do they mean
③


① Recover time (from space) in CQG
② Conceptual problems from diffeo
What are the "observables" ("beables") ("VariaBles")
covariant meaningful
③ Technical

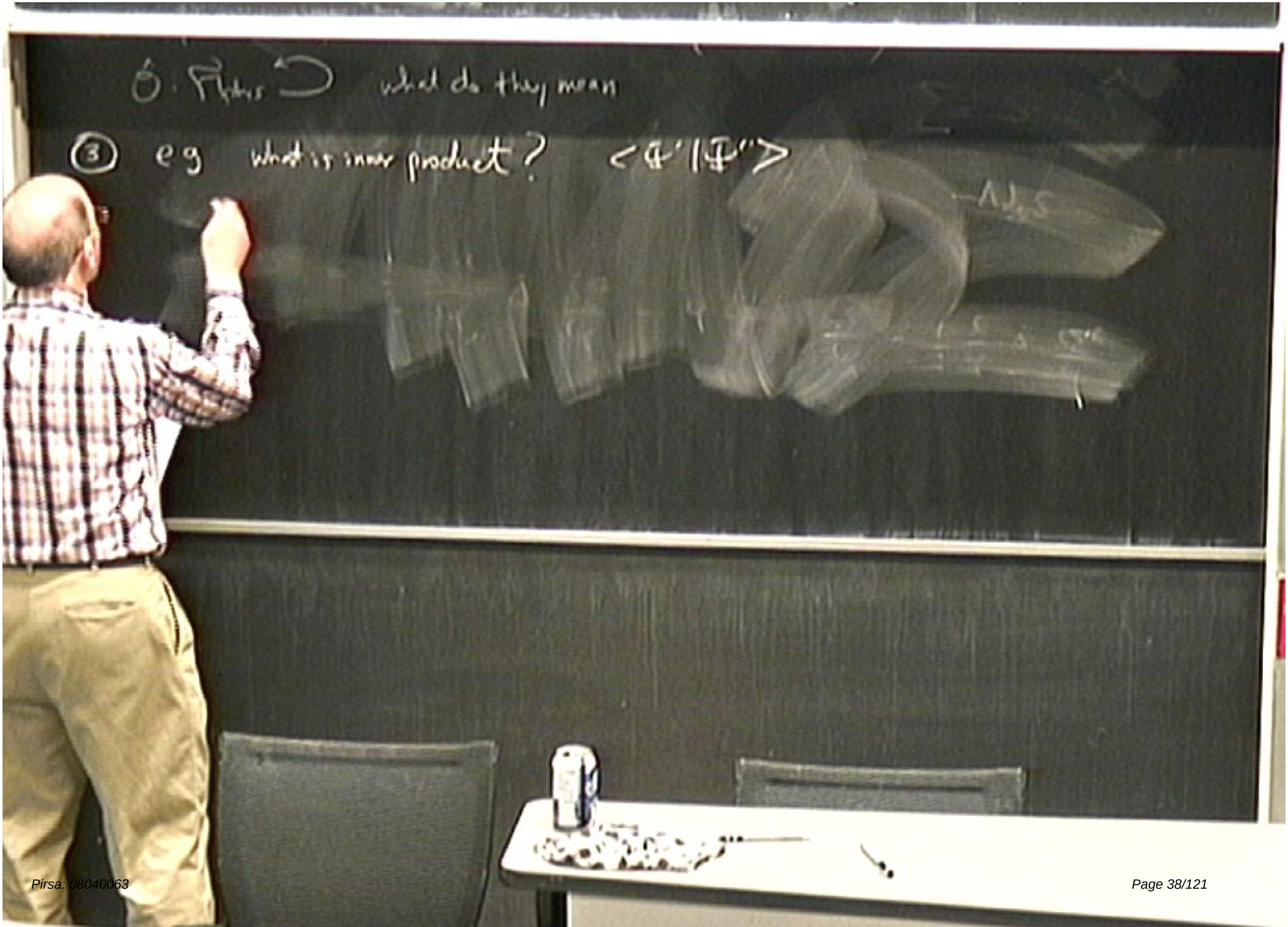
① Recover time (from space) in CQG

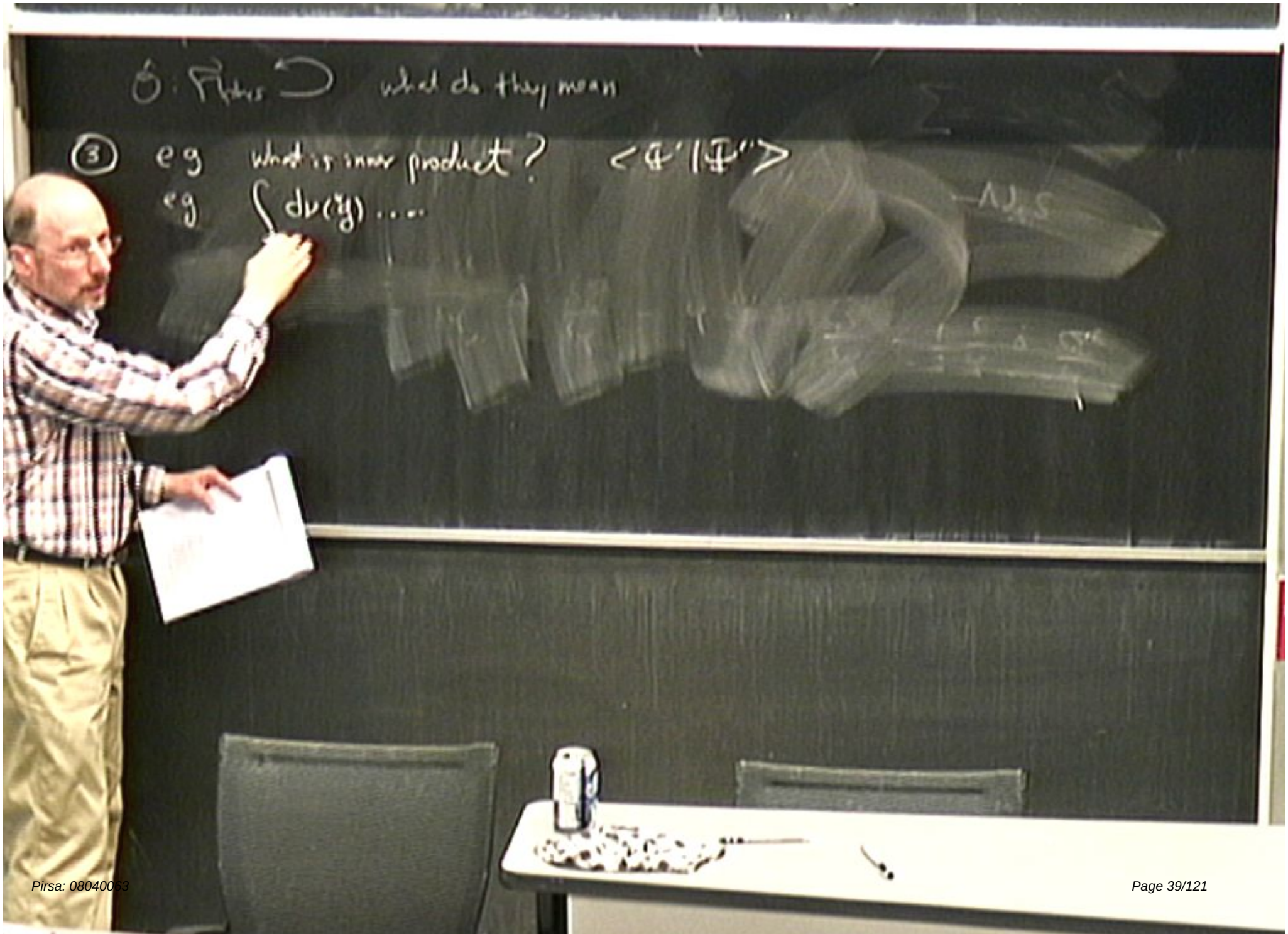
② Conceptual problems from diffeo
What are the "observables" ("beables") ("variables")
Covariant meaningful

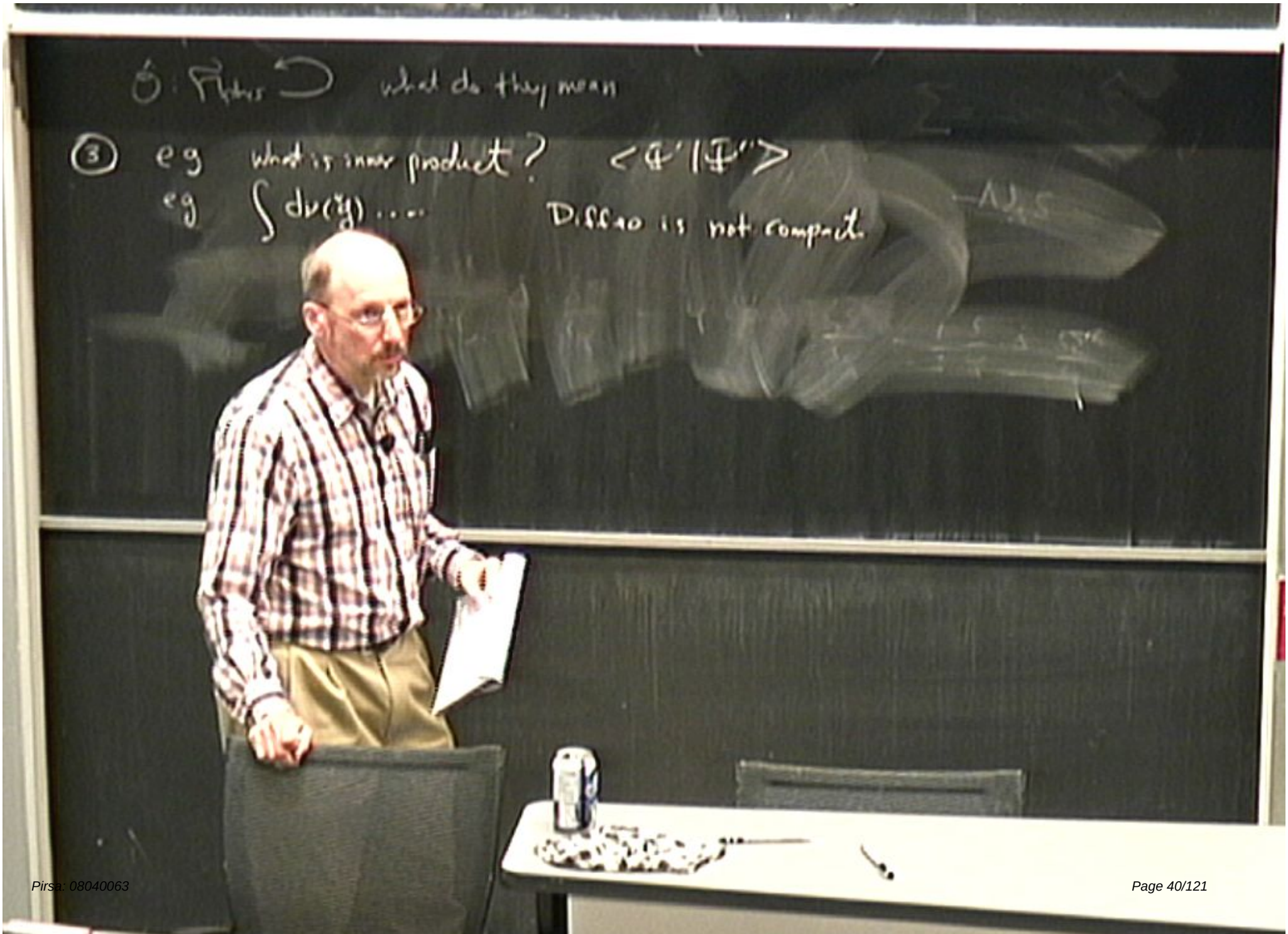
③ Technical problems from diff (e.g. Vol(O,gg) = 0)

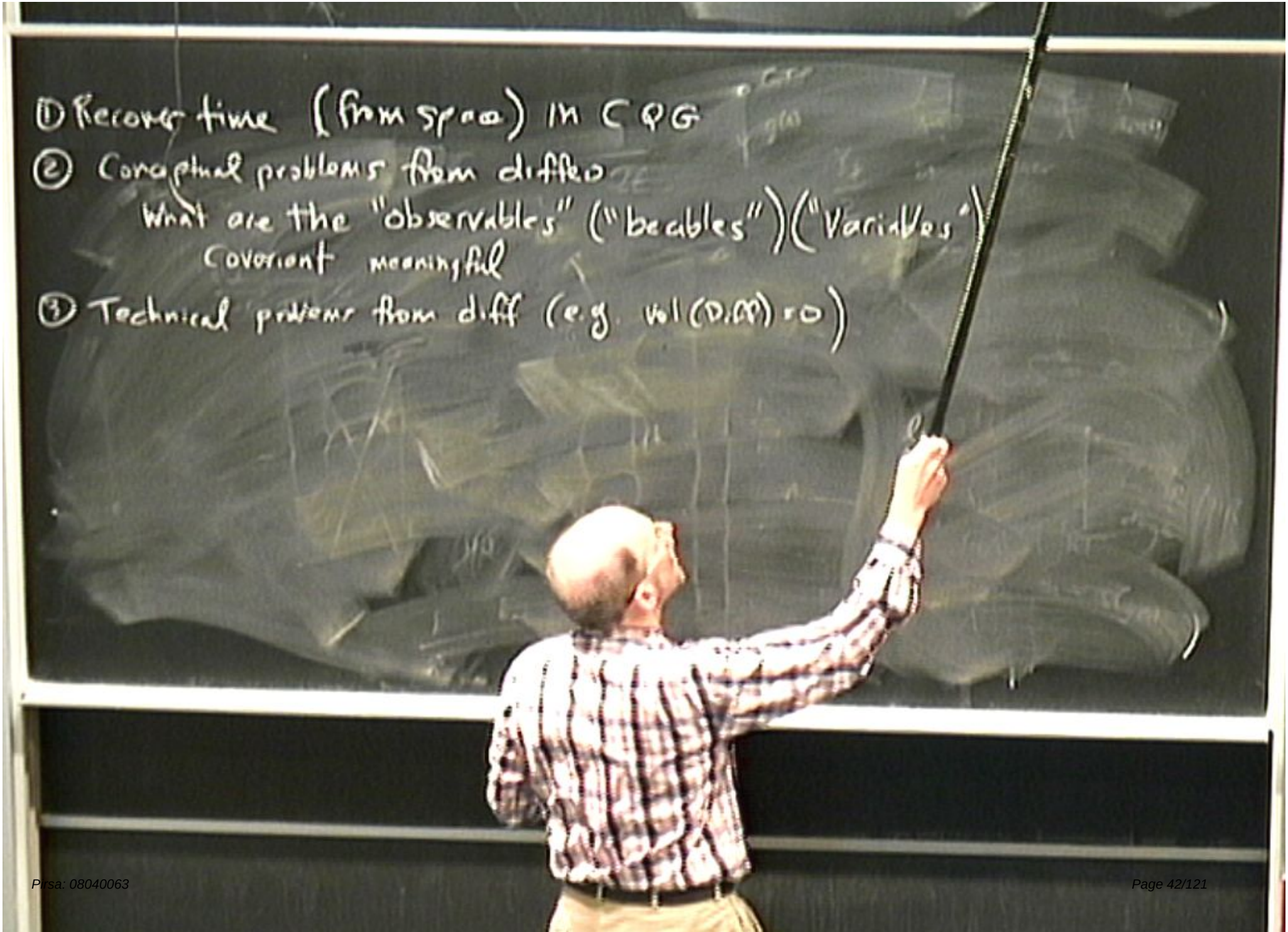
6. Fluxes ⊃ what do they mean

③


what do they mean
③ eg what is inner product?


what do they mean
(3) eg what is inner product? $\langle \Psi' | \Psi'' \rangle$
eg $\int dv(\vec{y}) \ldots$


what do they mean
(3) eg what is inner product? <Ψ'|Ψ''>
eg ∫ dv(y) ....
Diff₀ is not compact.


① Recovering time (from space) in CQG
② Conceptual problems from diffeo
What are the "observables" ("beables") ("variables")
covariant meaningful
③ Technical problems from diff (e.g. Vol(O,gg) = 0)

recover time ( ) absent

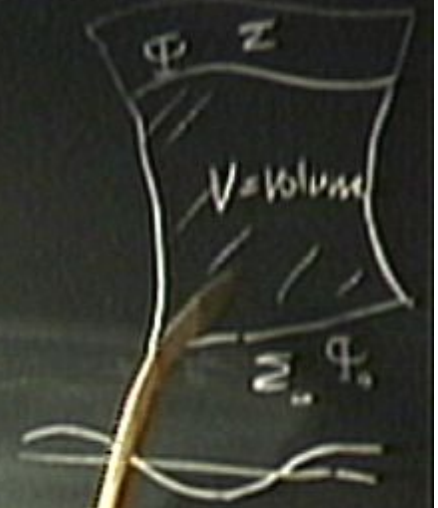
unimodular gravity $\Psi(^3g, {}^3T)$

$i\frac{\partial \Psi}{\partial T} = \int \hat{H} N d^3x \, \Psi$ where $\int N d^3x = 1$

$\left(\int N \hat{H} d^3x \, \Psi = 0 \text{ when } \int N d^3x = 0 \right)$

Cosmology (Friedmann) solve problem of time (PoT 1)

Still ask BH horizon



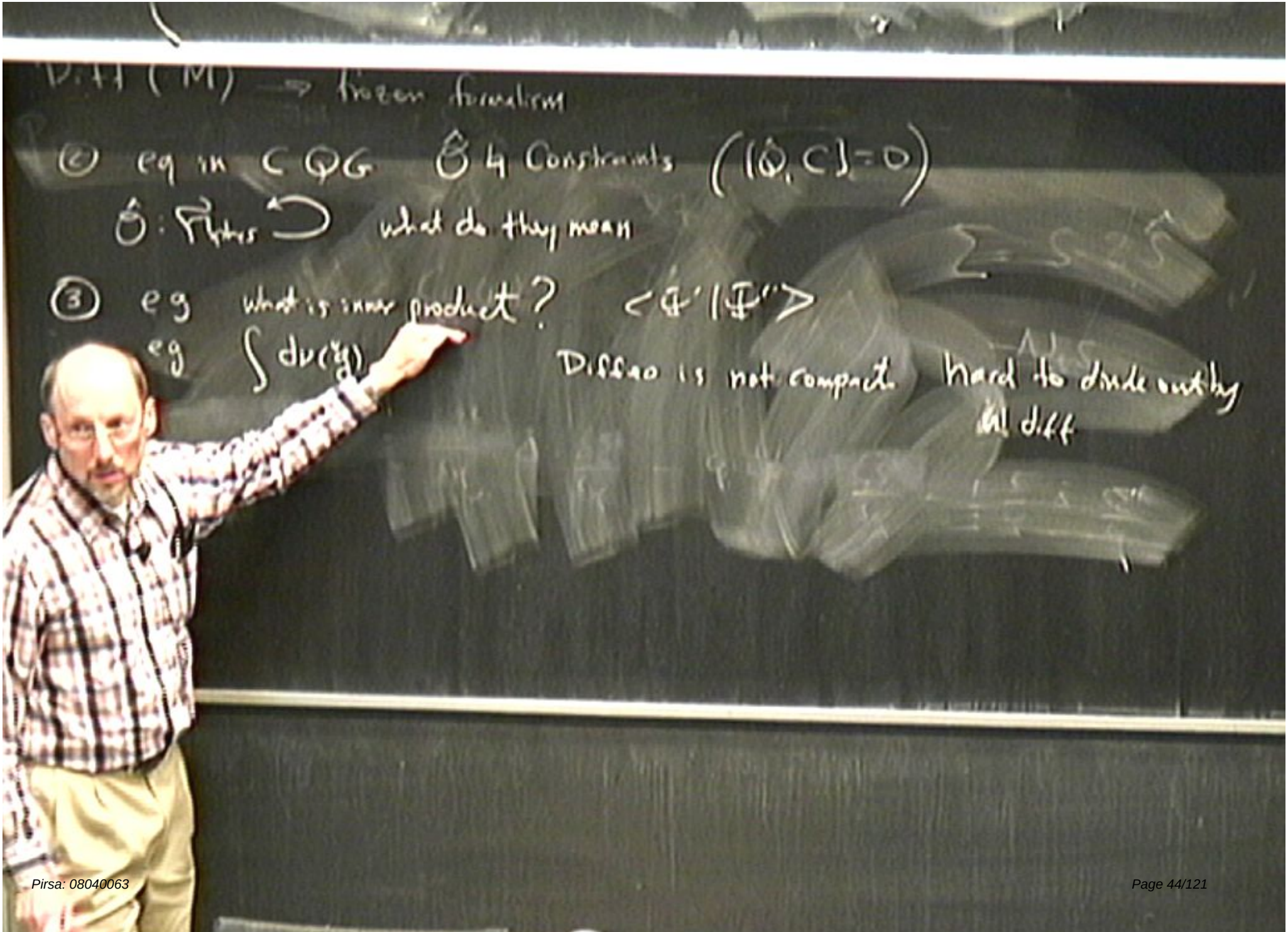
① Recover time (from space) in CQG

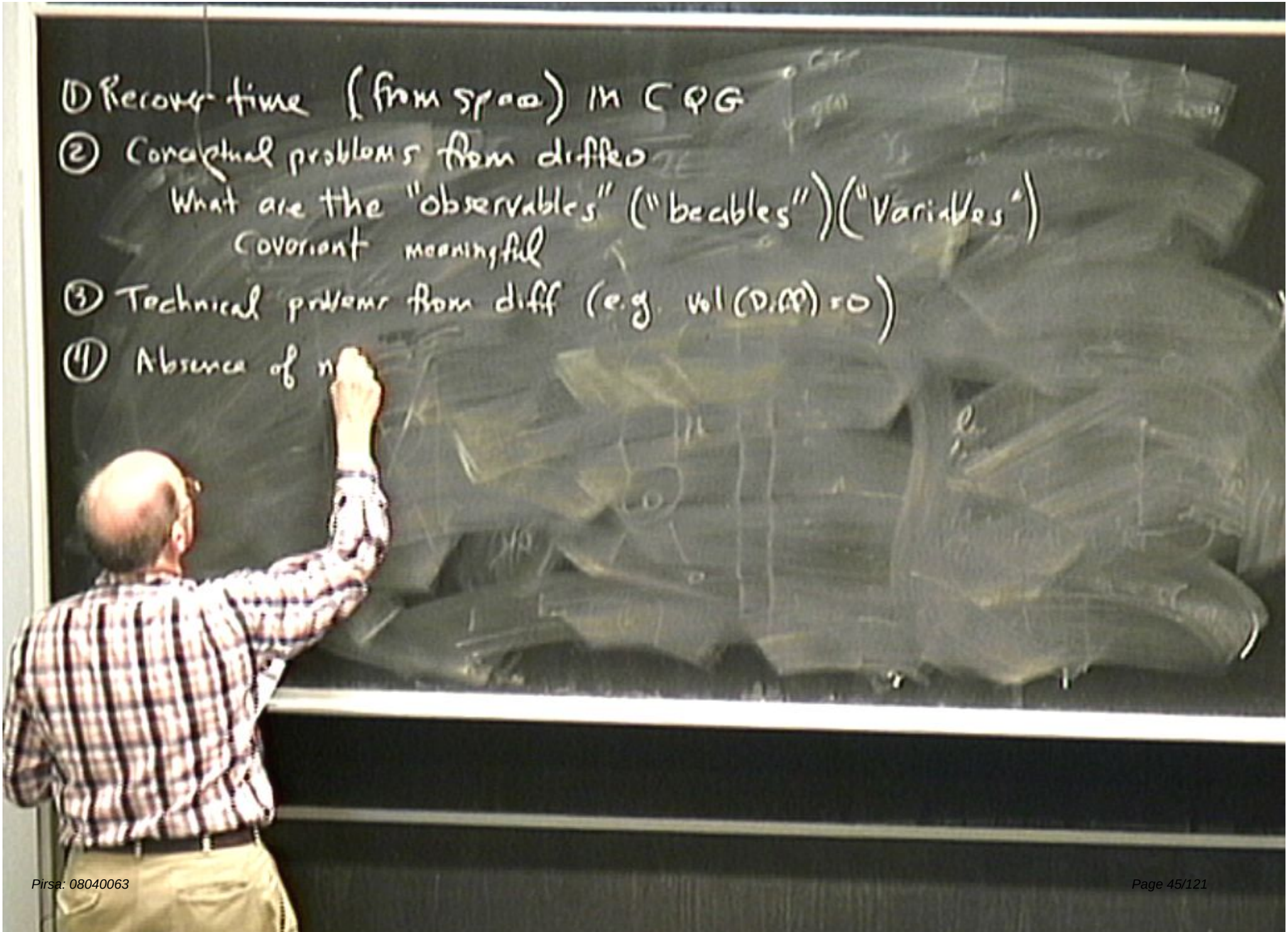
② Conceptual problems from diffeo

What are the "observables" ("beables") ("Variables")

Covariant meaningful

③ Technical problems from diff (e.g. $\mathrm{vol}(\mathrm{Diff}) = \infty$)


Diff(M) ⇒ loop formalism
① eq in CQG & 4 Constraints ([Ô, C] = 0)
Ô: Flows what do they mean
③ eg what is inner product? <Ψ'|Ψ''>
eg ∫ dν(γ)
Diff₀ is not compact hard to divide out by vol diff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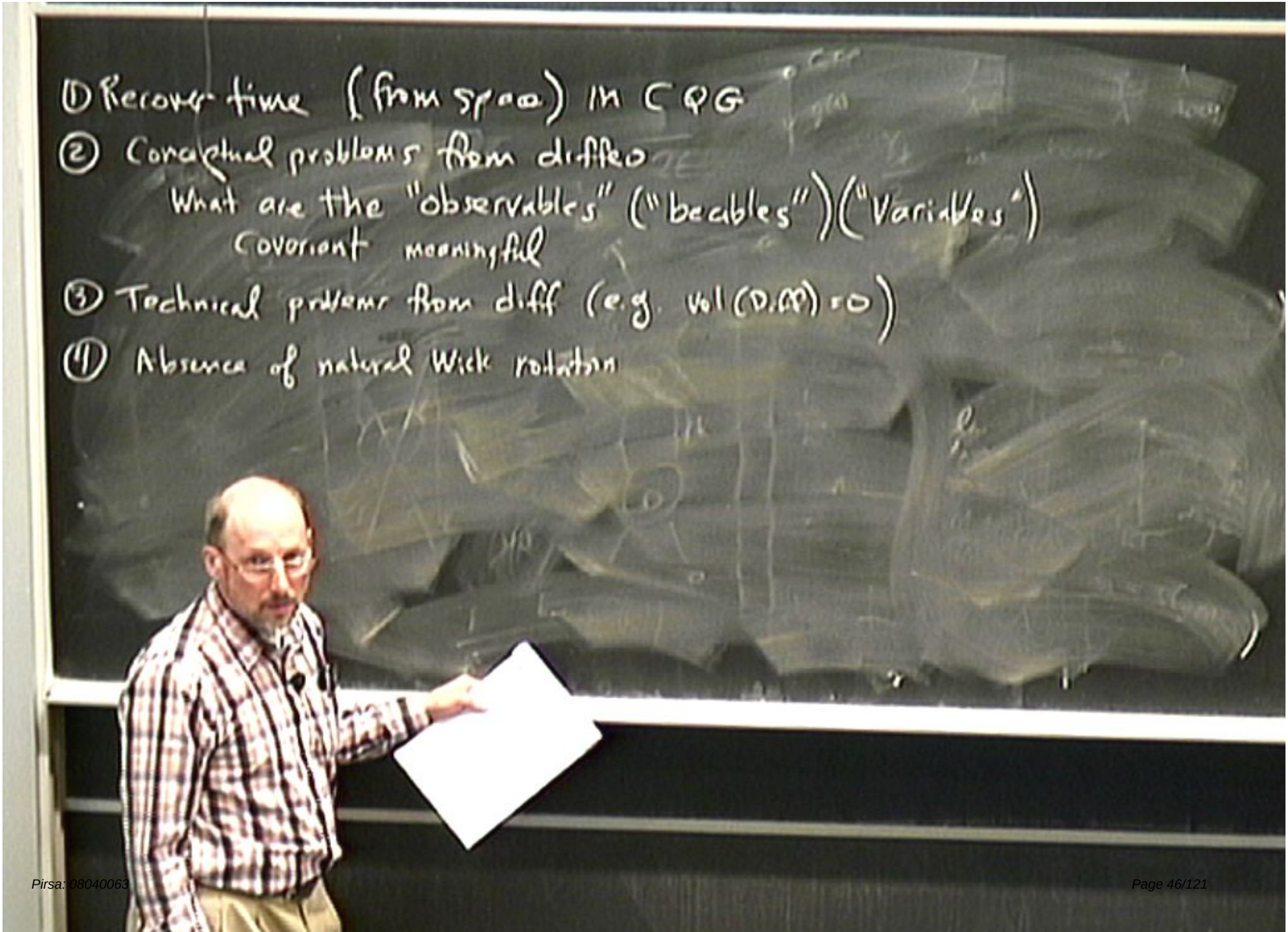
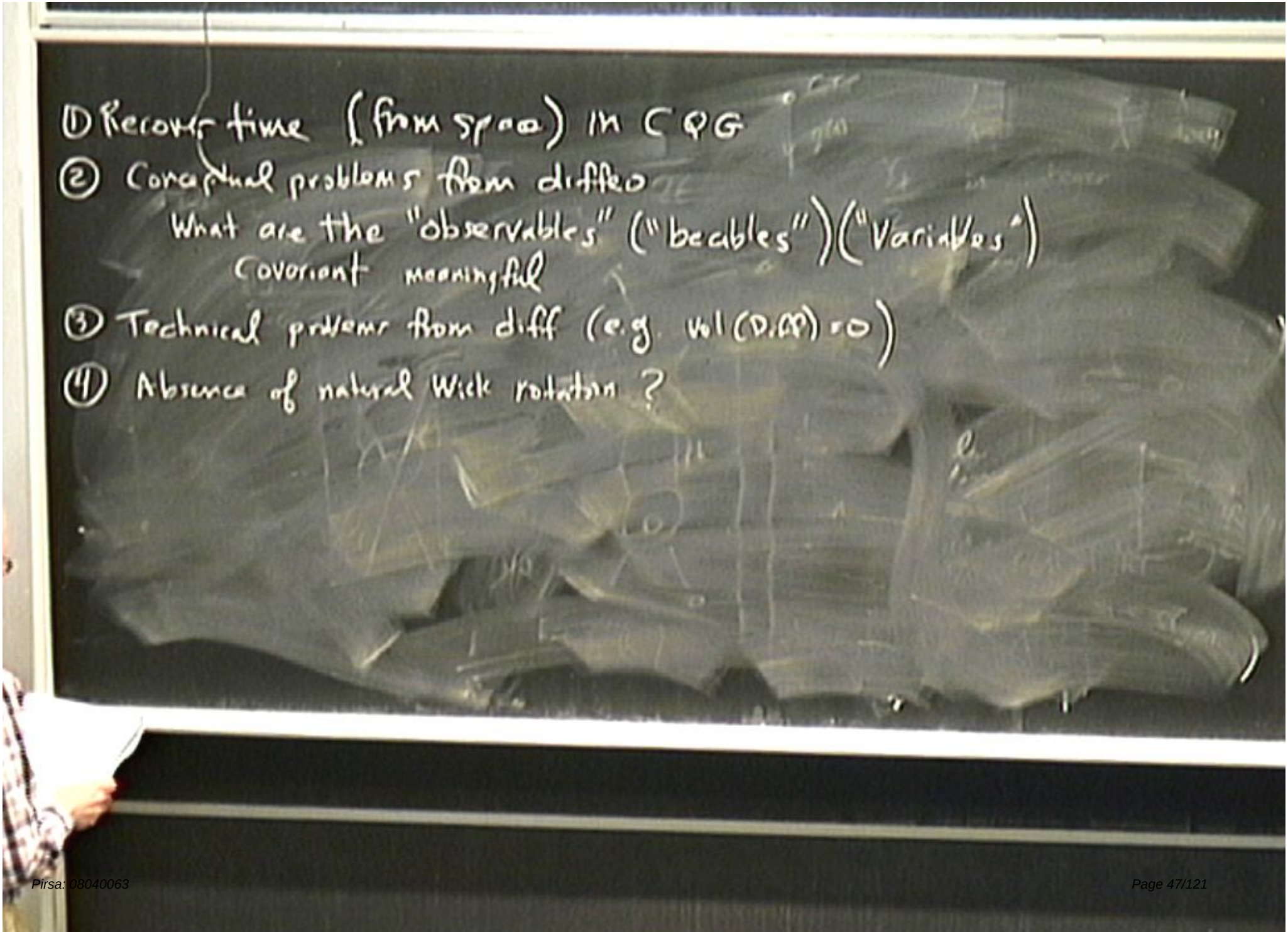
covariant meaningful
③ Technical problems from diff (e.g. Vol(D/Diff) = 0)
④ Absence of


① Recover time (from space) in CQG
② Conceptual problems from diffeo
What are the "observables" ("beables") ("Variables")
covariant meaningful
③ Technical problems from diff (e.g. Vol(Diff) = ∞)
④ Absence of natural Wick rotation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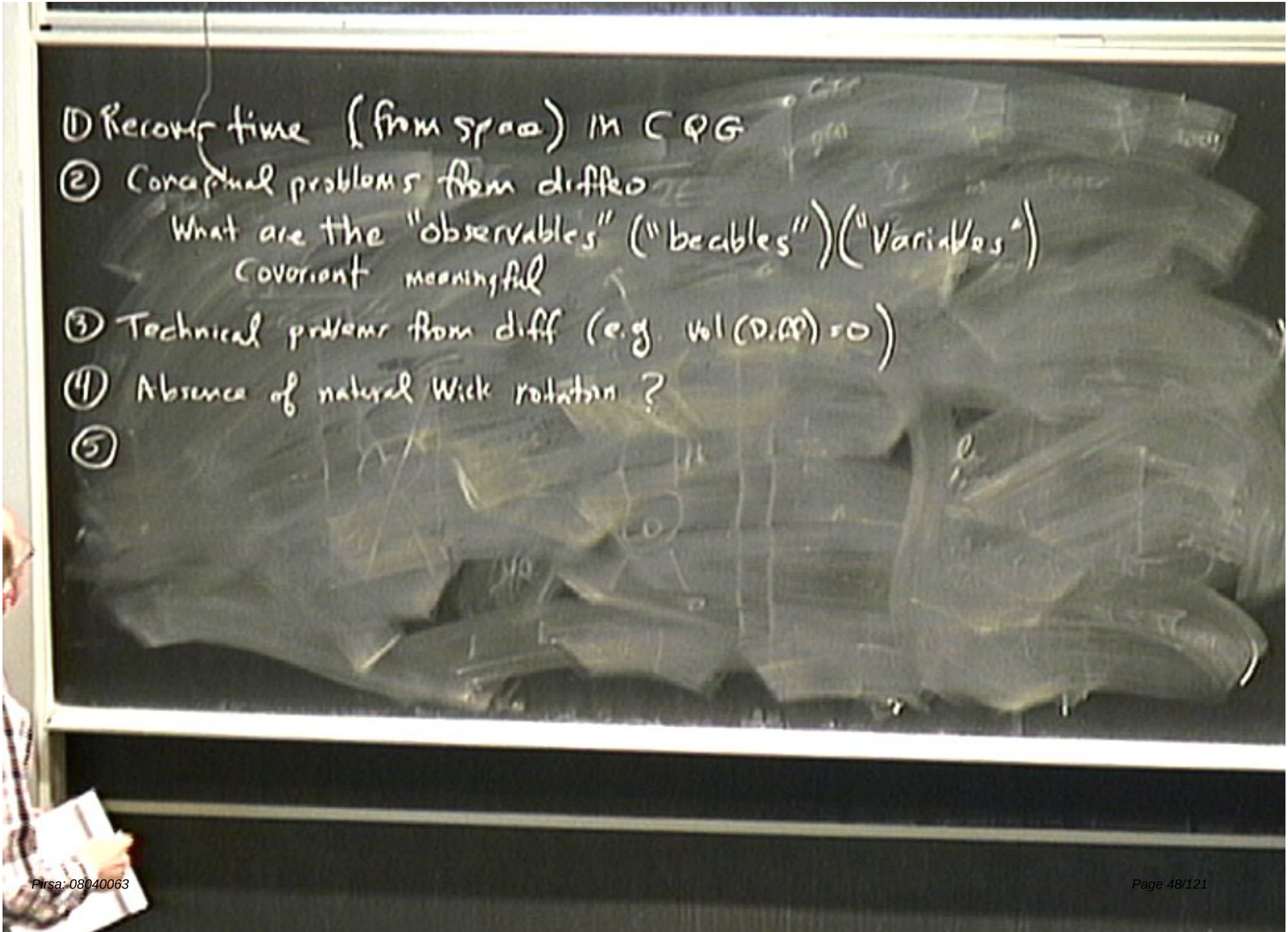
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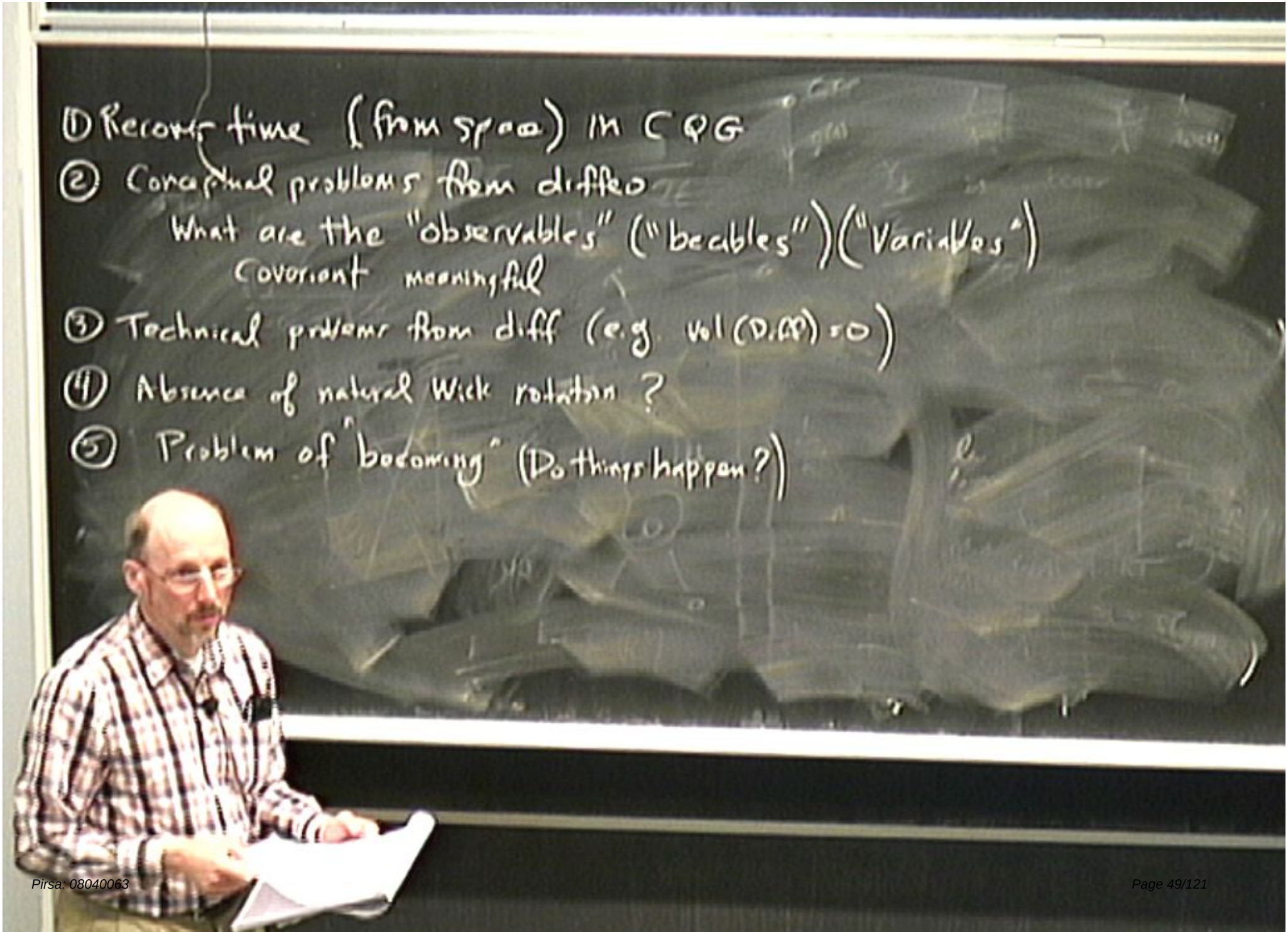
⑤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Covariant meaningful
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④ Absence of natural Wick rotation ?
⑤ Problem of "becoming" (Do things happen ?)

recover time ... absent

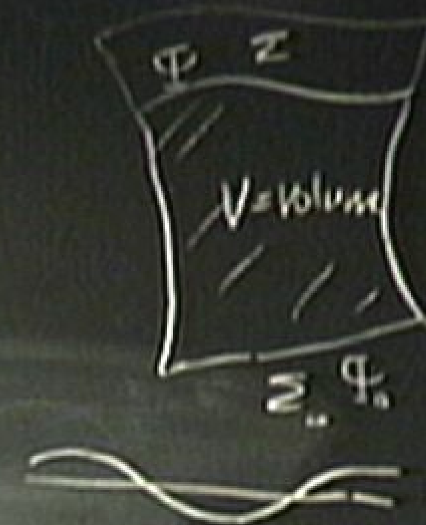
unimodular gravity ... $\Psi({}^3g, T)$

$$i\frac{\partial \Psi}{\partial T} = \int \hat{H} N d^3x \, \Psi \quad \text{where} \int N d^3x = 1$$

$$\left(\int N \hat{H} d^3x \, \Psi = 0 \quad \text{when} \int N d^3x = 0 \right)$$

Cosmology (Friedmann) solve problem of time (PoT 1)

Still ask BH horizon



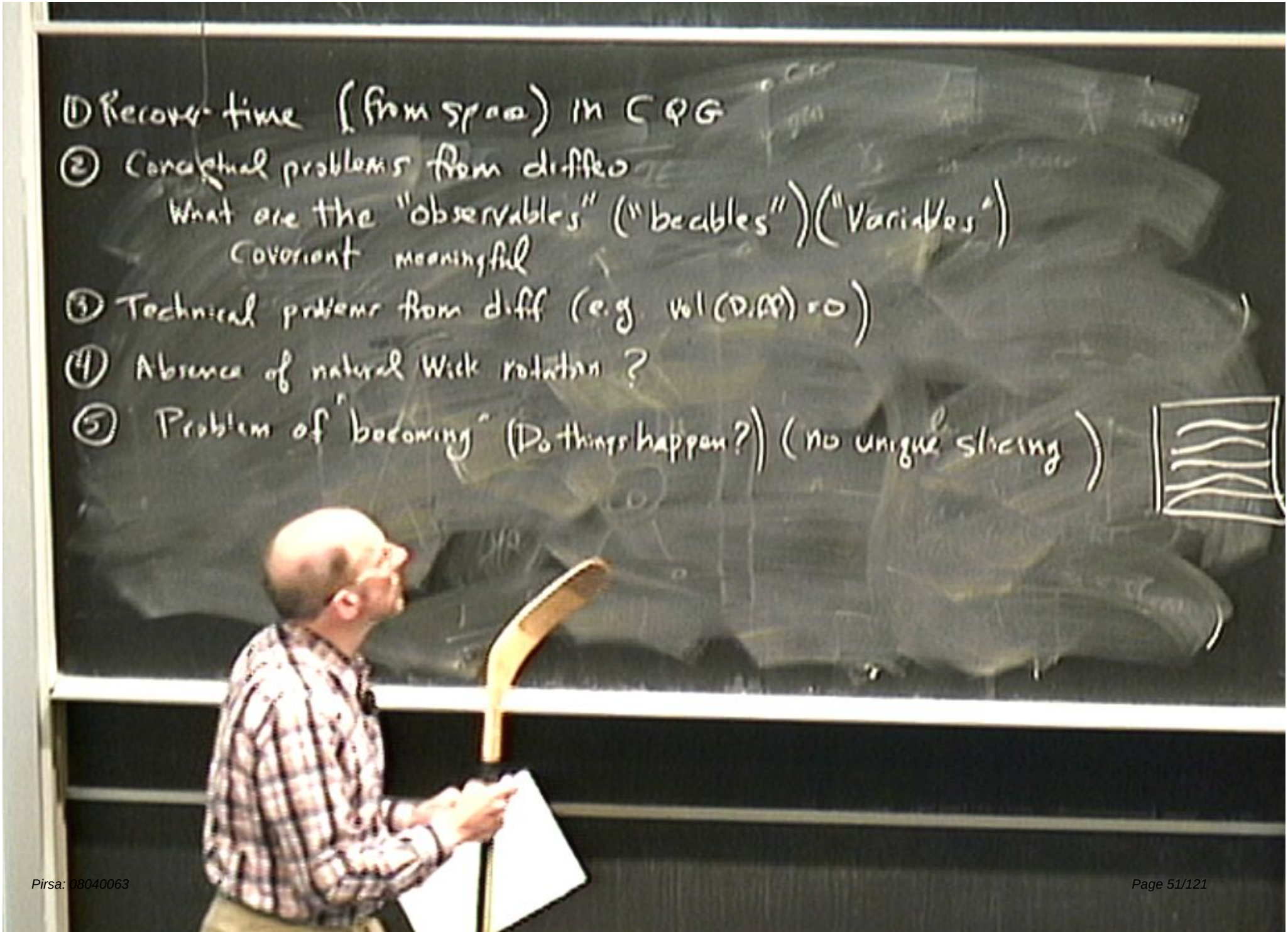
1) Recover time (from space) in CQG

2) Conceptual problems from diffeo

What are the "observables" ("beables") ("Variables")

Covariant meaningful

3) Technical problems from diff (e.g. vol(Diff) = 0)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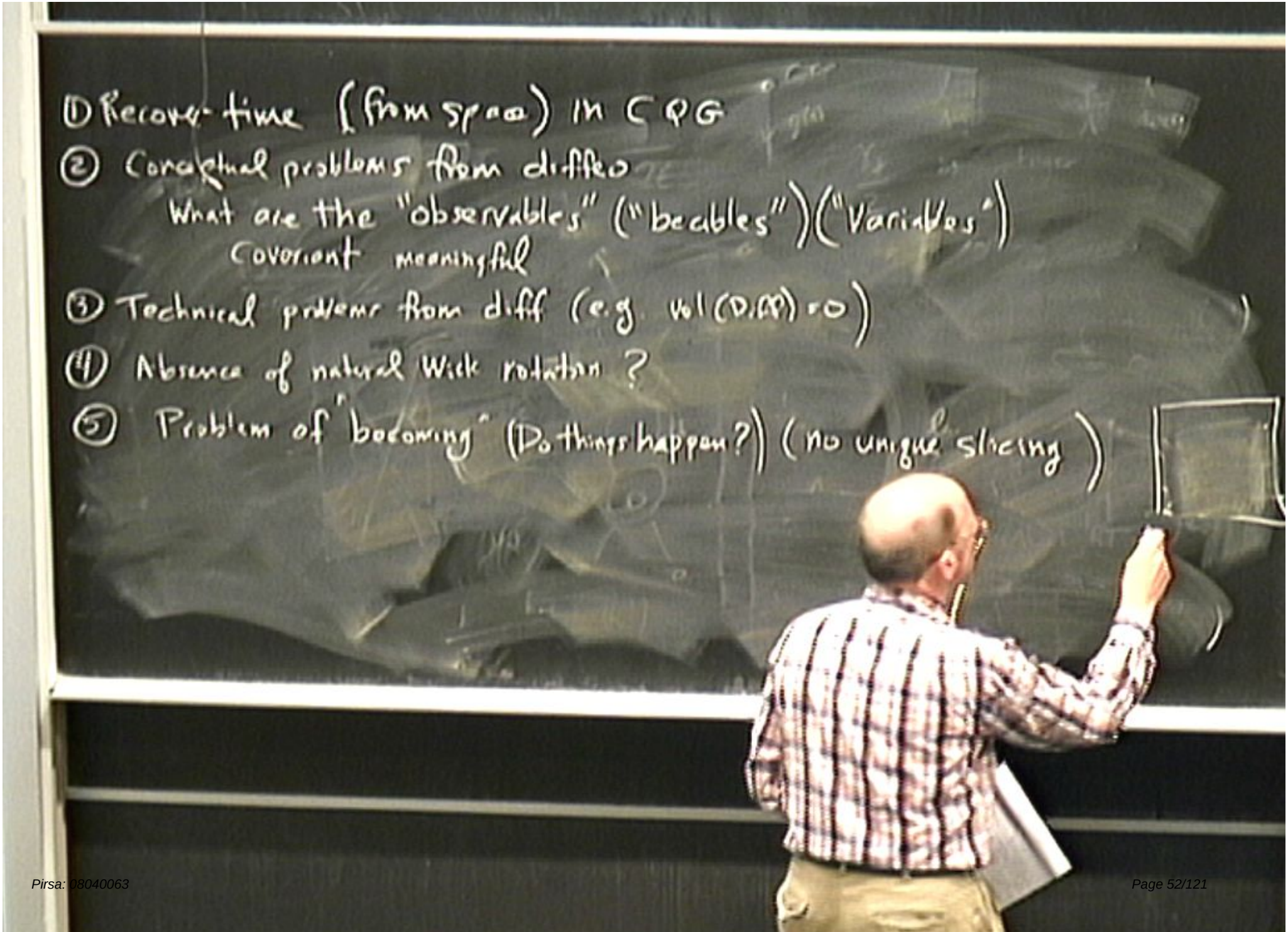
① Recover time (from spacetime) in CQG
② Conceptual problems from diffeo
What are the "observables" ("beables") ("VariaBles")
Covariant meaningful
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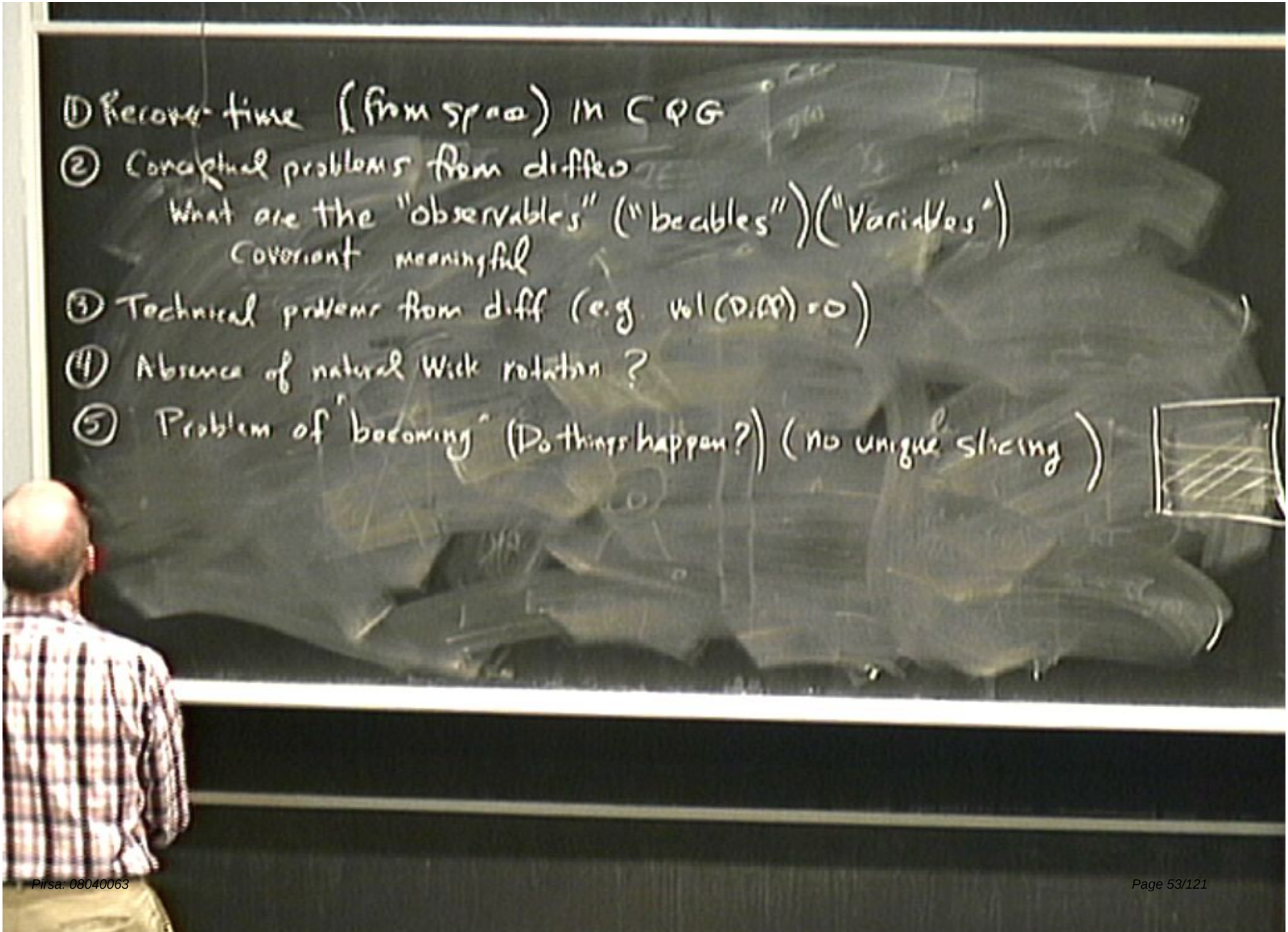
① Recover time (from sp⊂⊃) in CQG
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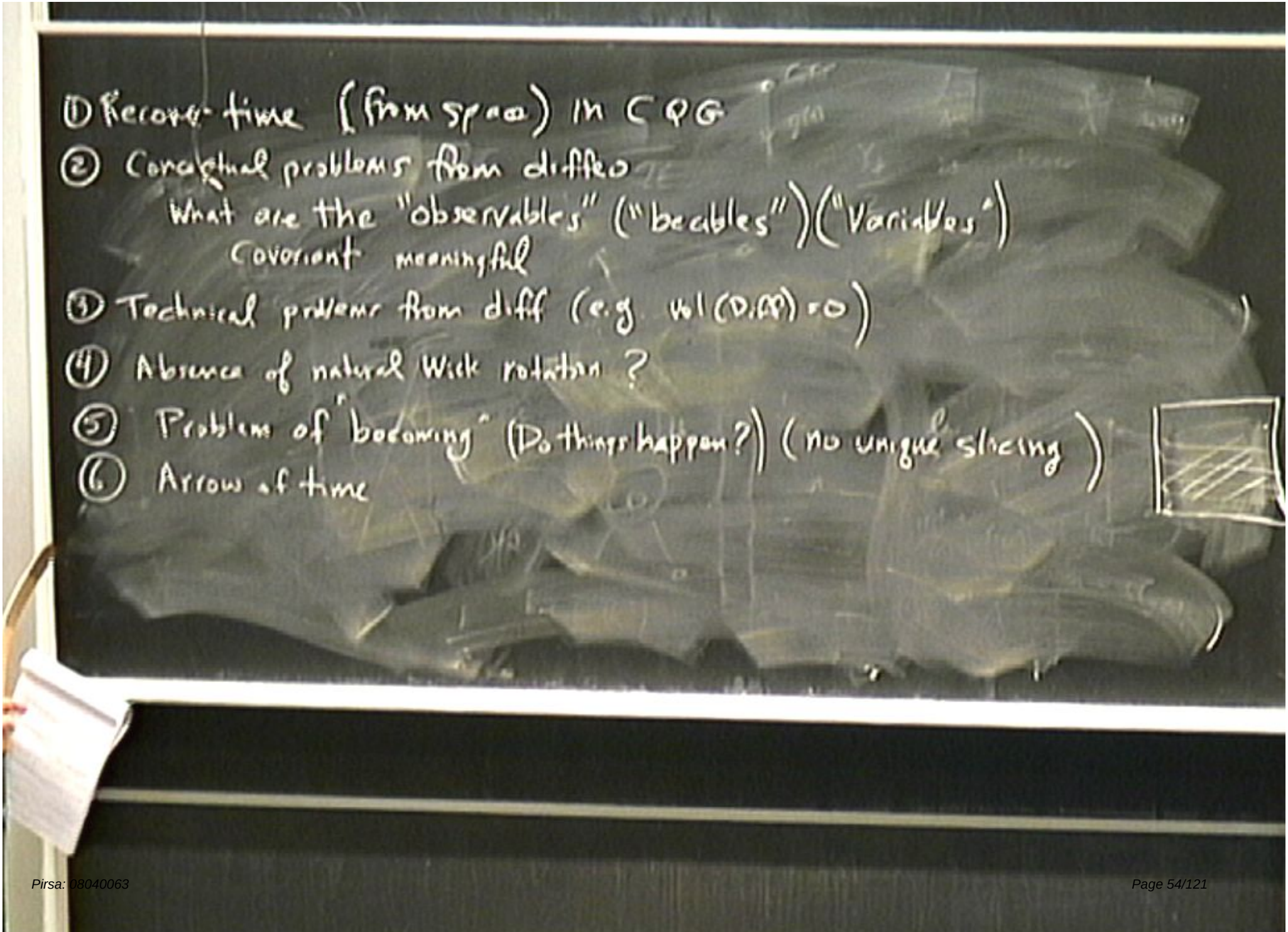
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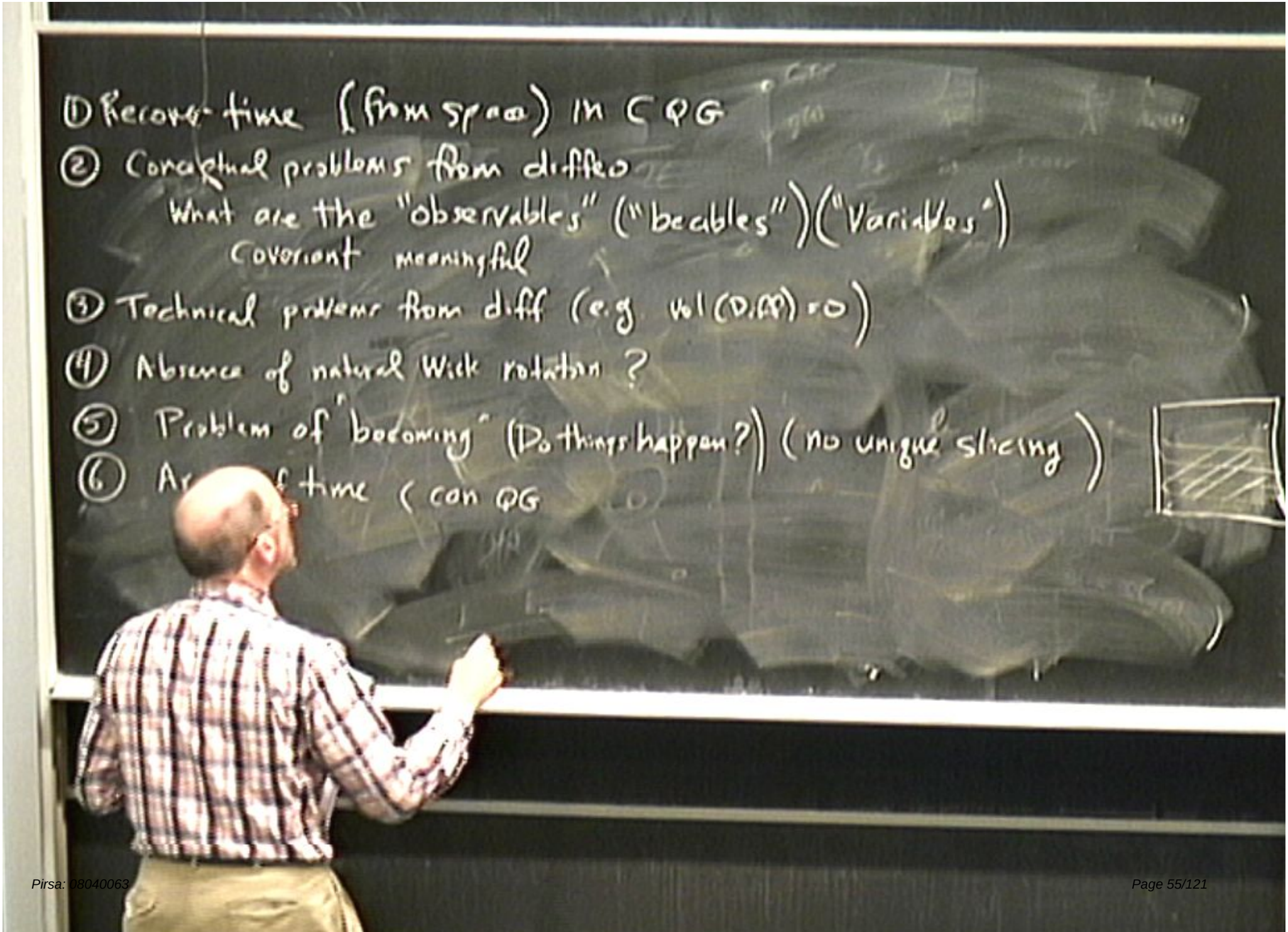
⑤ Problem of "becoming" (Do things happen?) (no unique slicing)
⑥ Arrow of time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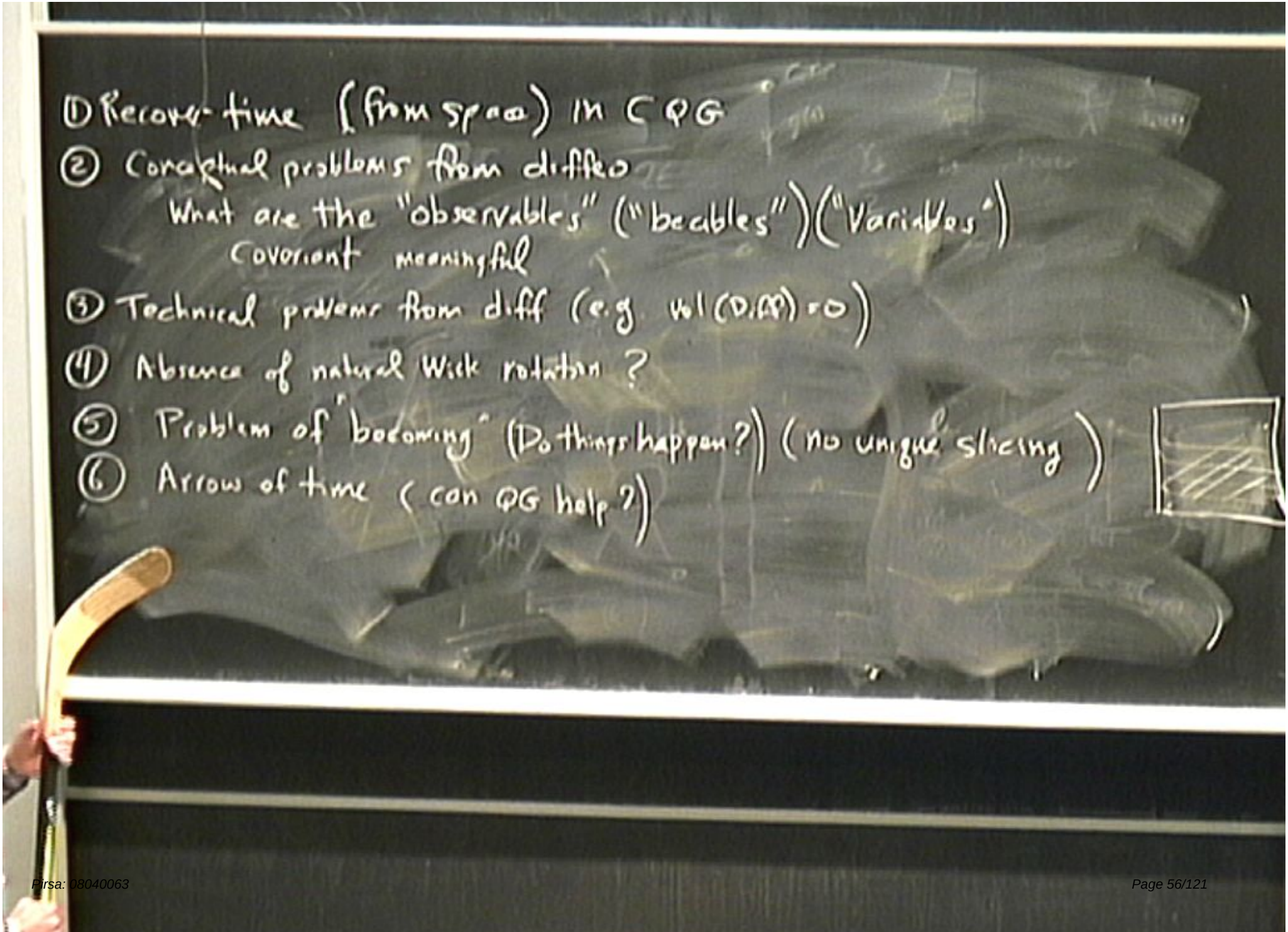
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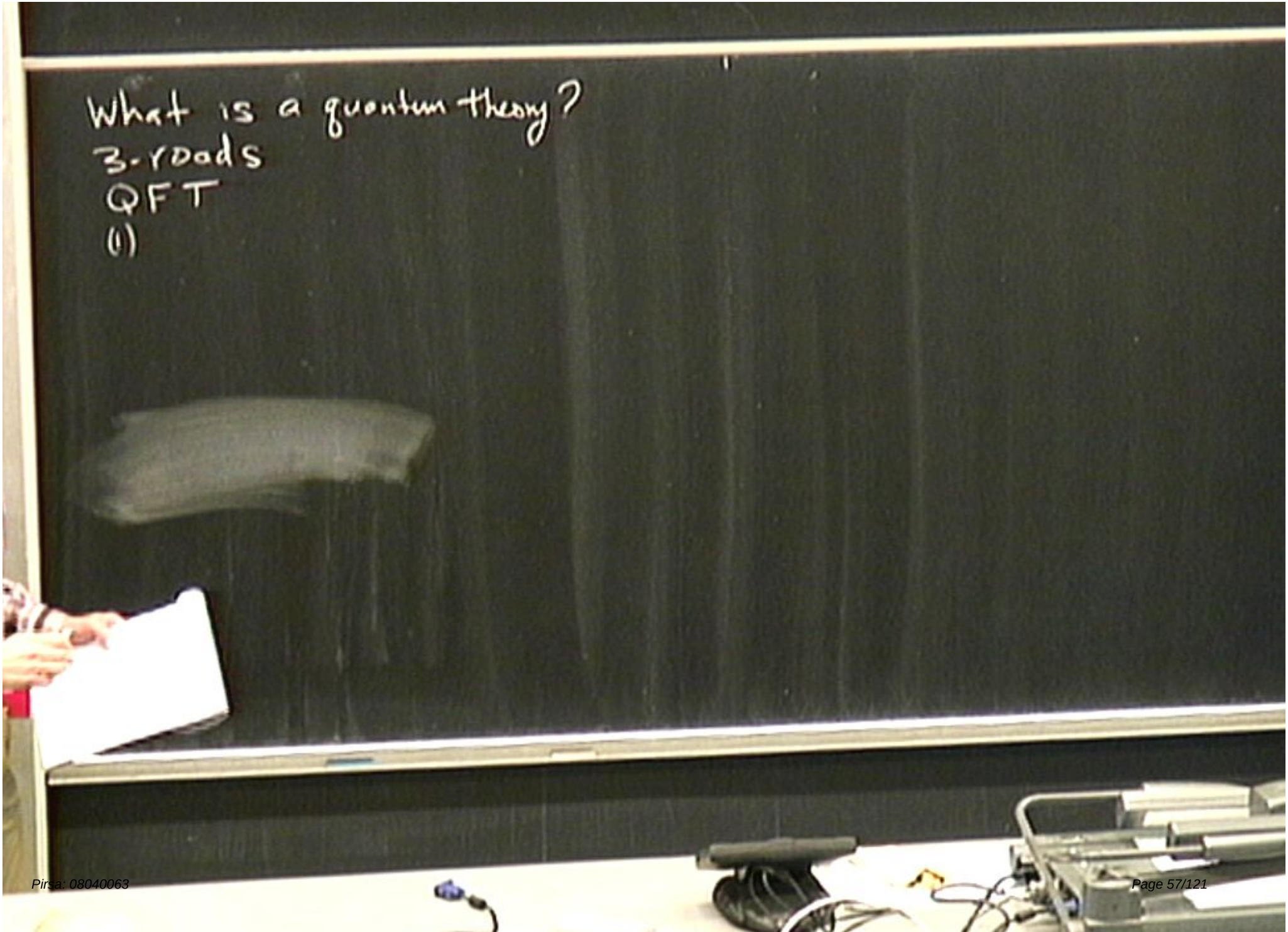
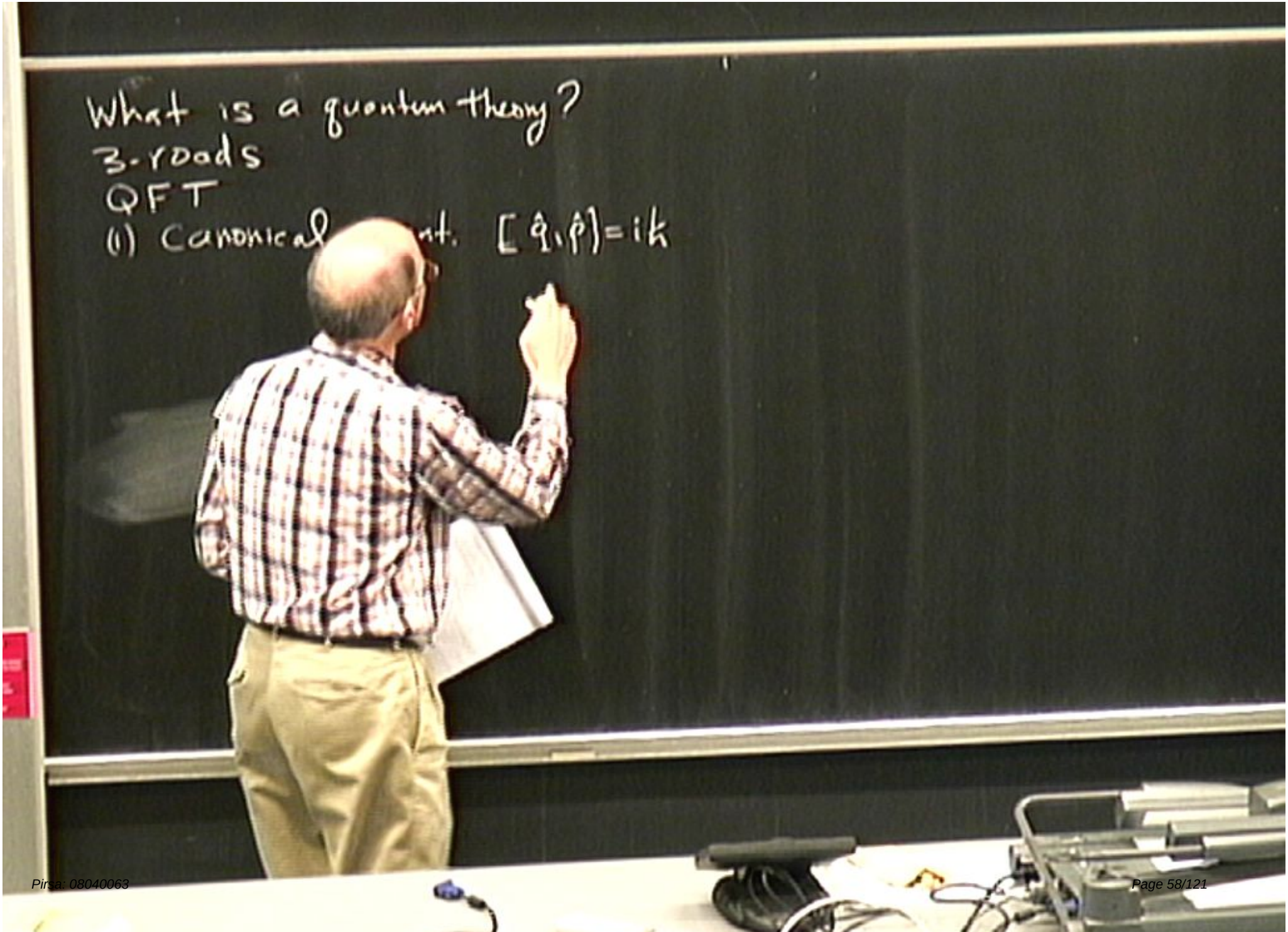

What is a quantum theory?
3-roads
QFT
(1)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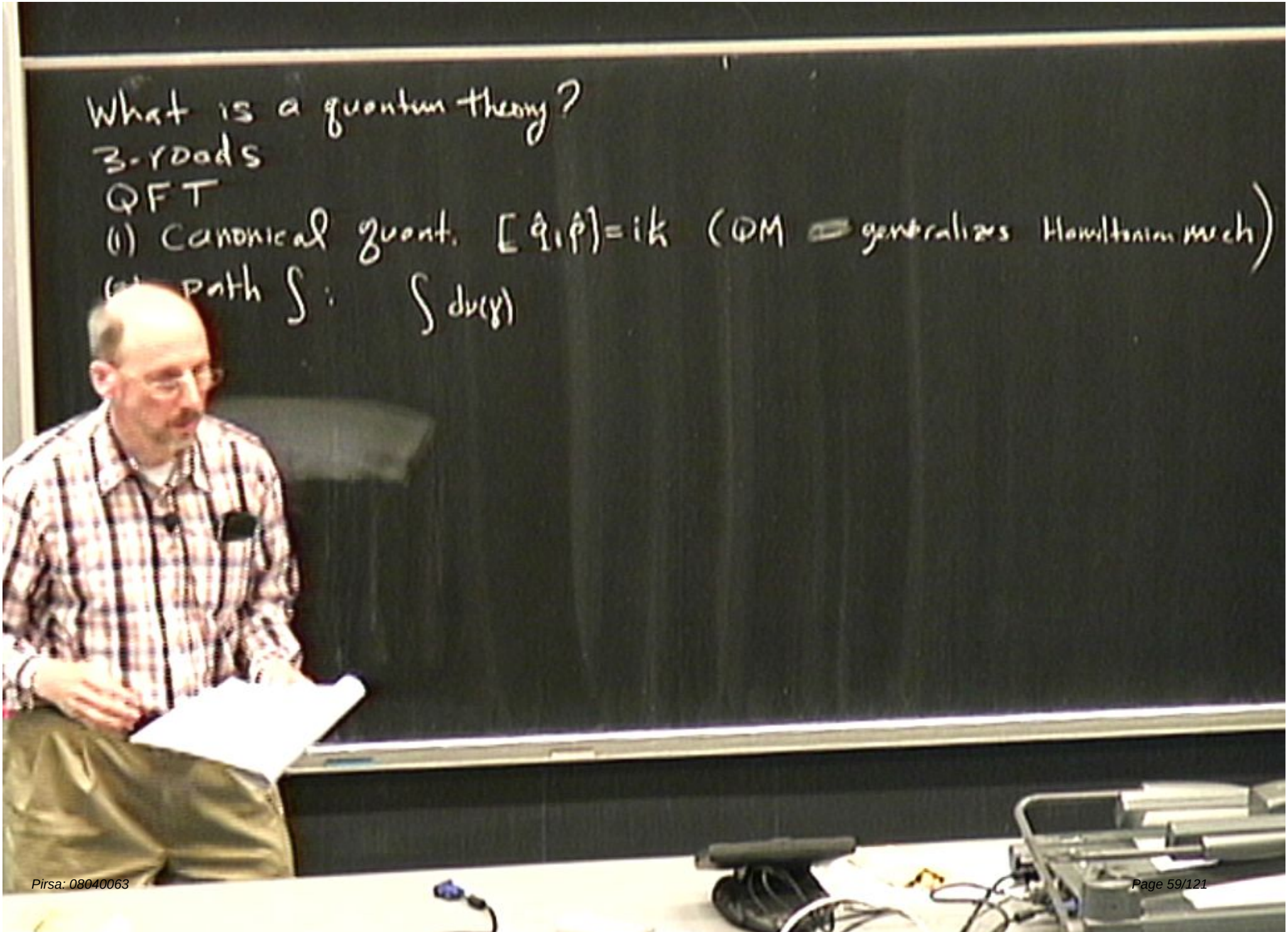
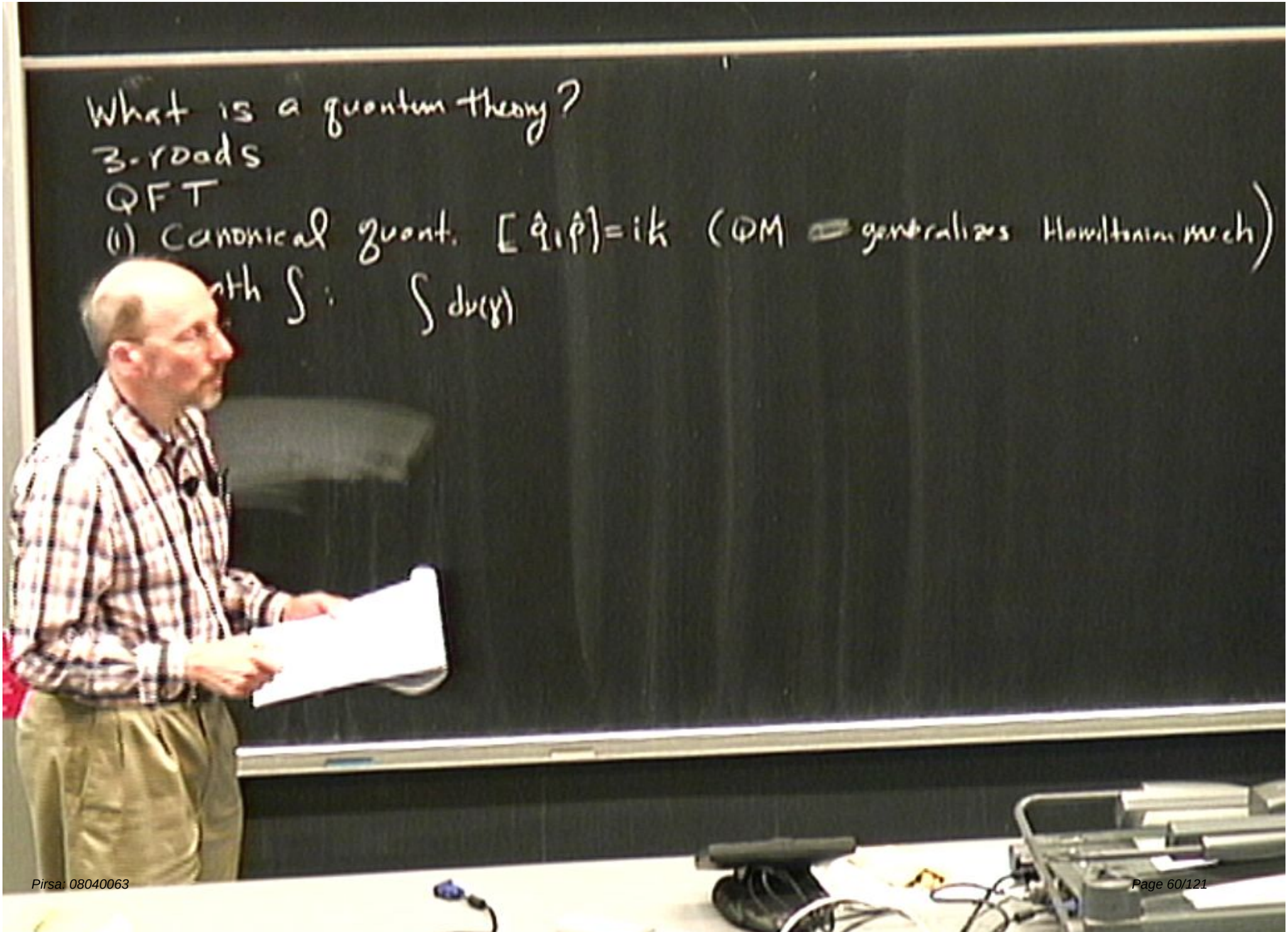
3-roads
QFT
(1) Canonical
nt. [q̂, p̂] = ik


What is a quantum theory?
3 roads
QFT
(i) Canonical quant. $[\hat{q}, \hat{p}] = ik$ (QM → generalizes Hamiltonian mech)
(ii) Path $\int$: $\int d\nu(\gamma)$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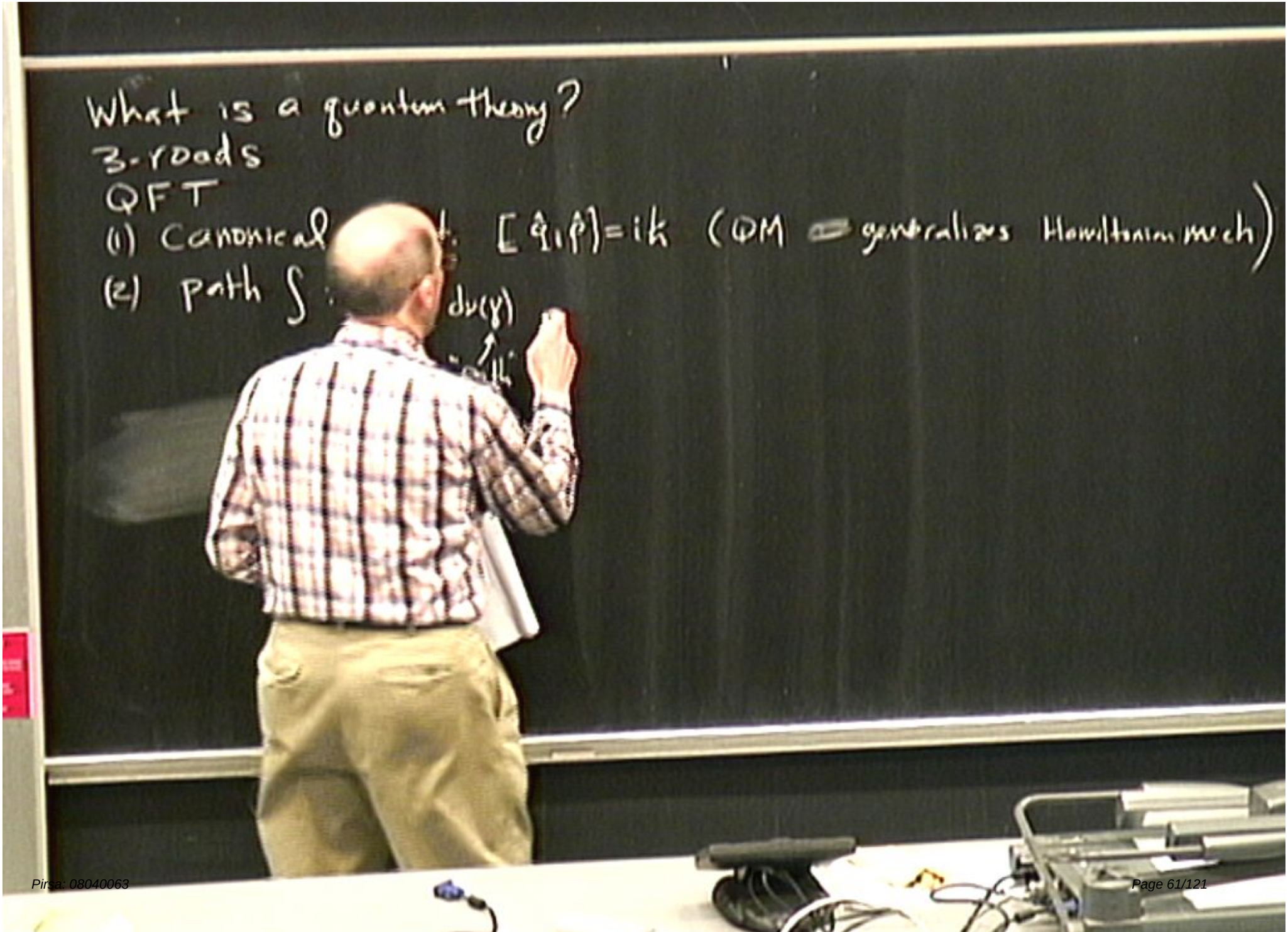
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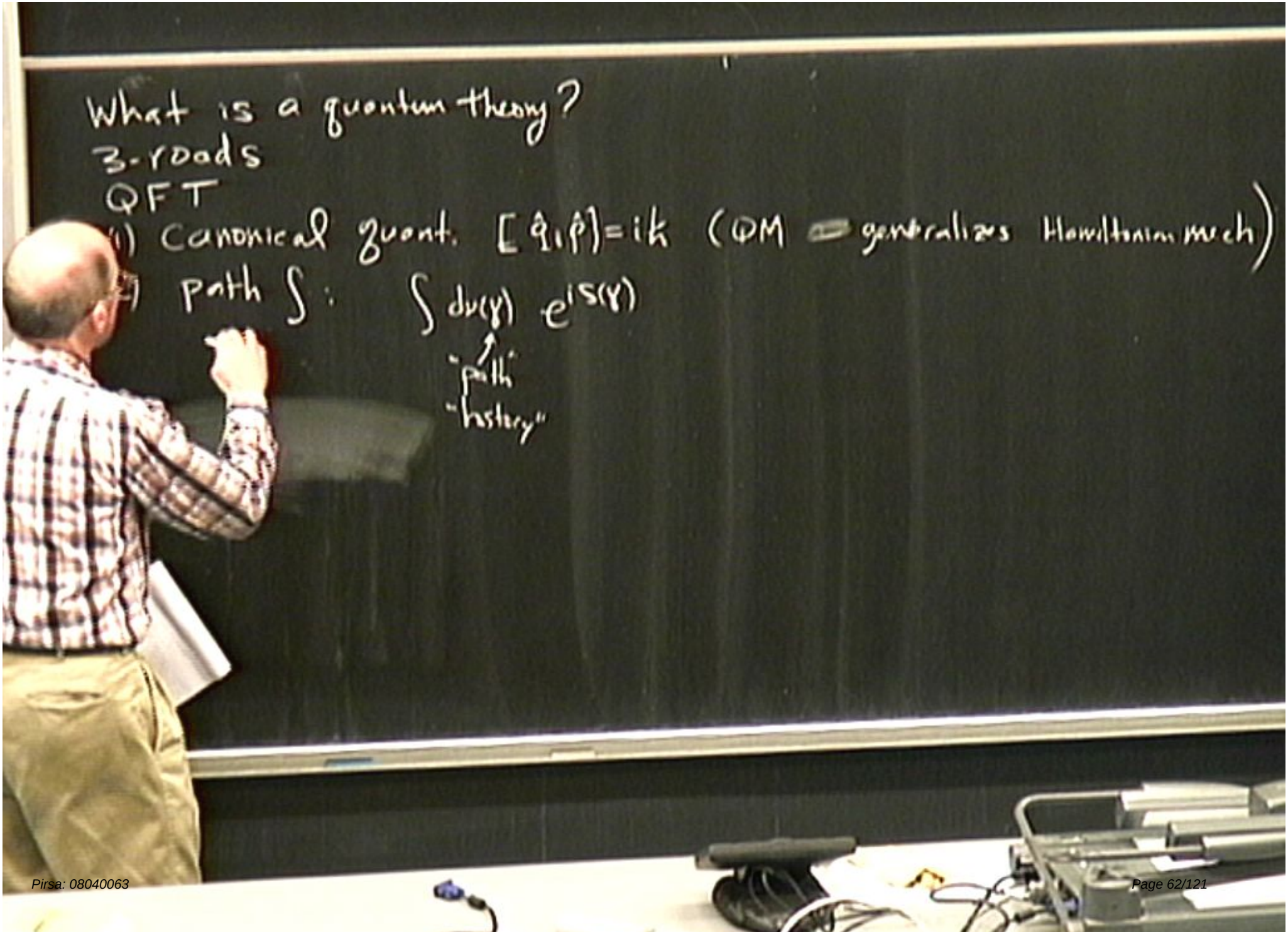
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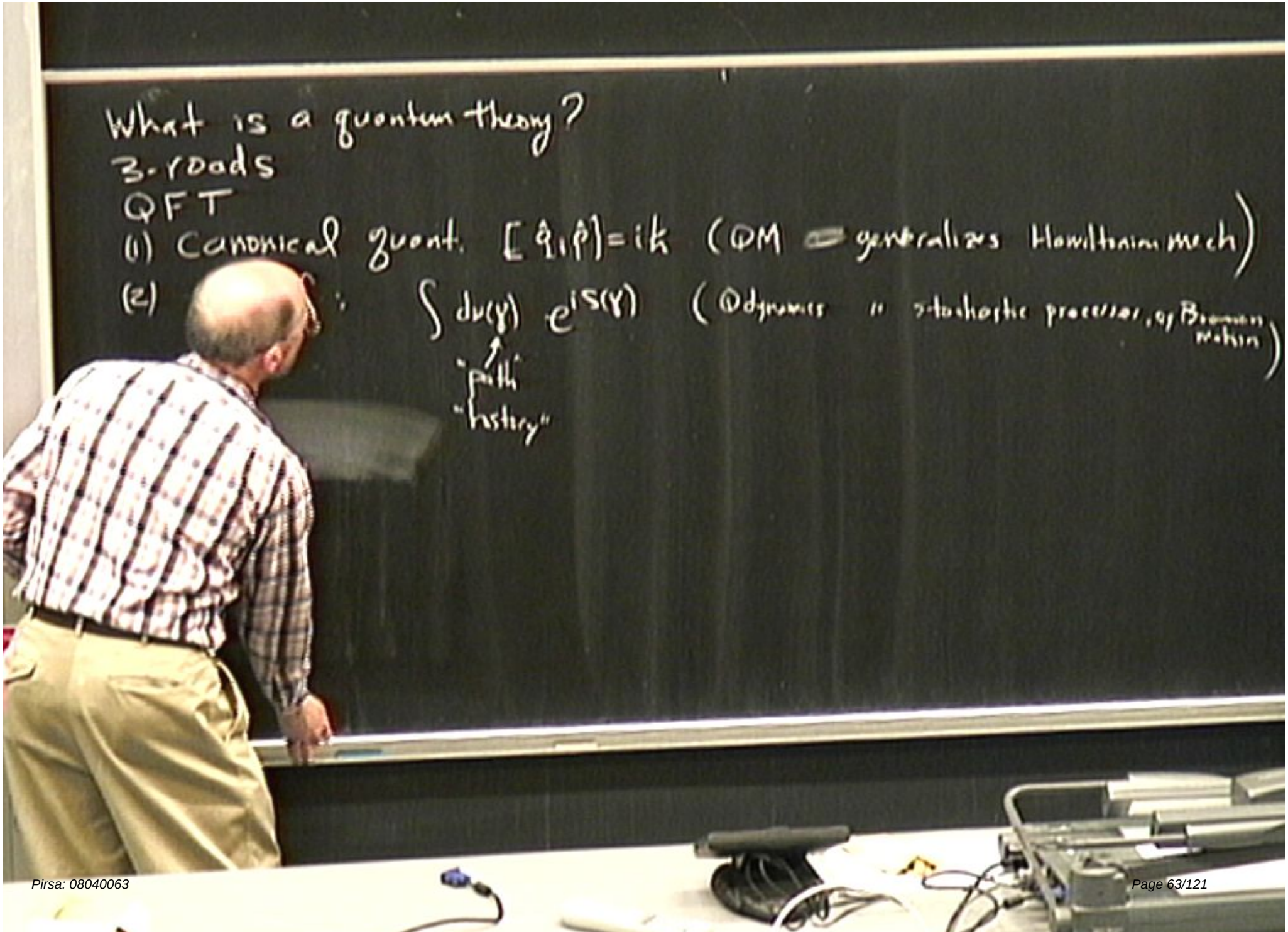
"path"
"history"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(1) Canonical quant. $[\hat{q},\hat{p}]=ik$ (QM generalizes Hamiltonian mech)
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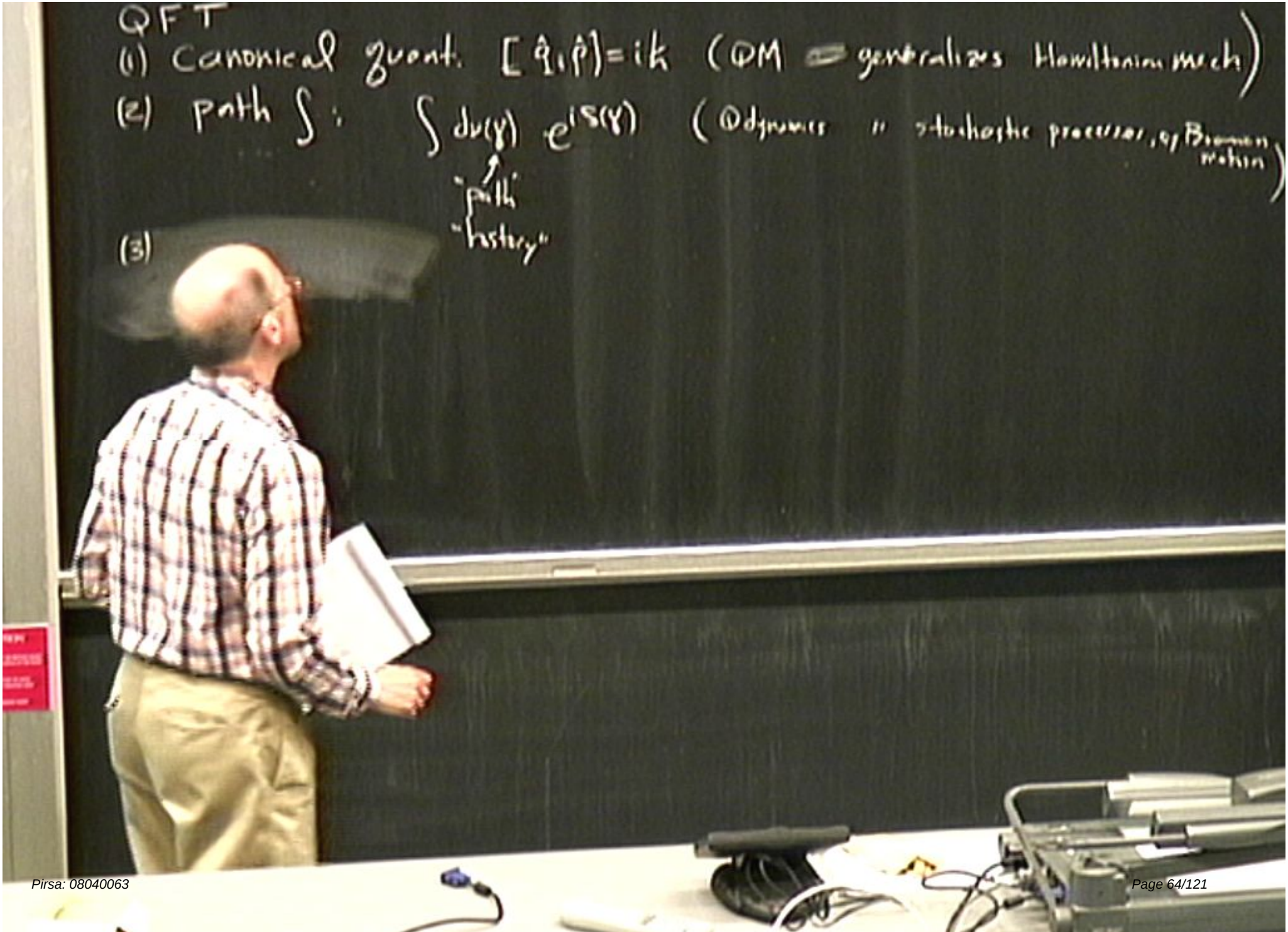
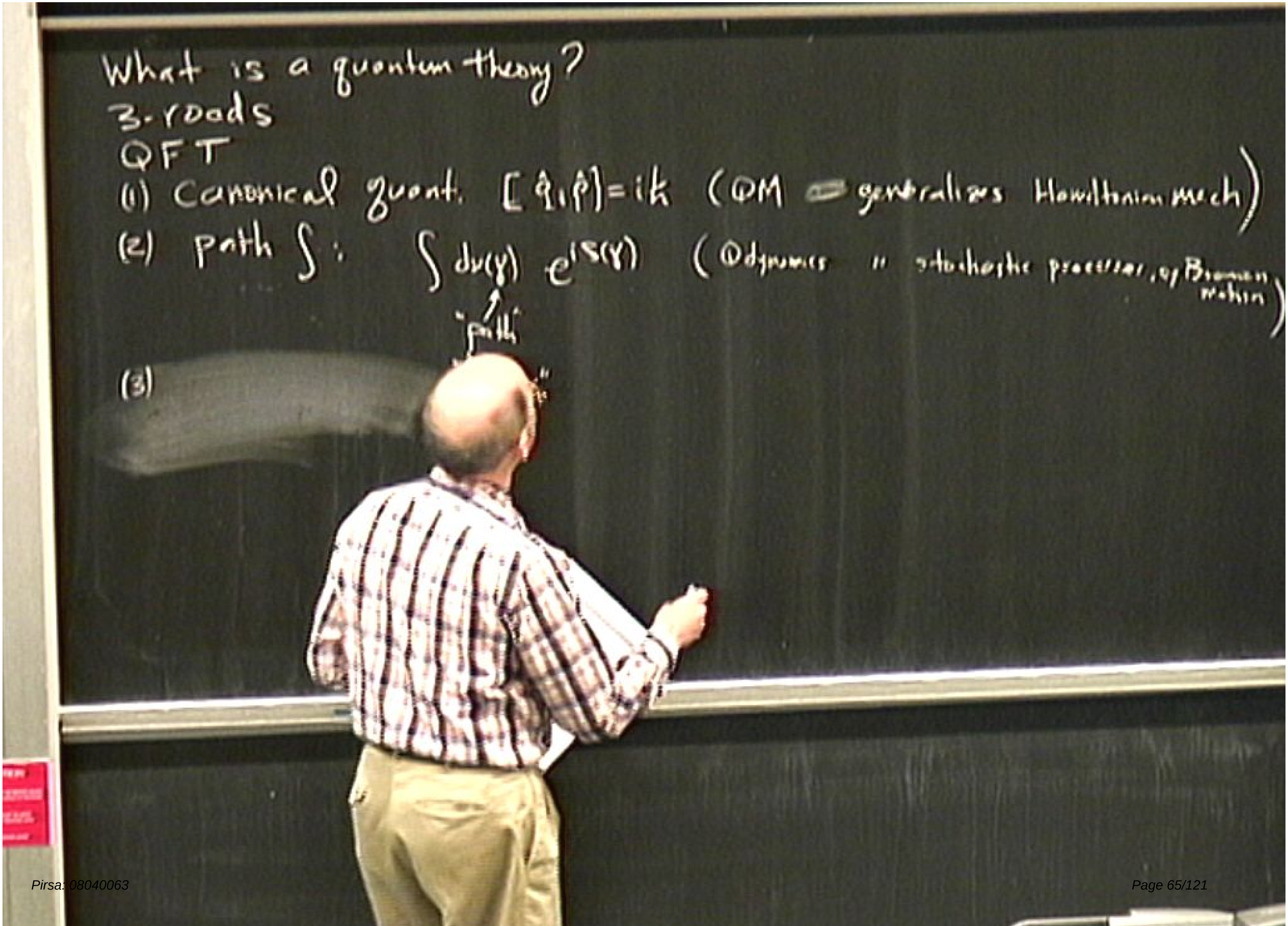
"path"
"history"


QFT
(1) Canonical quant. $[\hat{q},\hat{p}]=ik$ (QM ⊂ generalizes Hamiltonian mech)
(2) path $\int$: $\int dv(\gamma)\, e^{iS(\gamma)}$ (@dynamics = stochastic processes, eg Brownian motion)
"path"
"history"
(3)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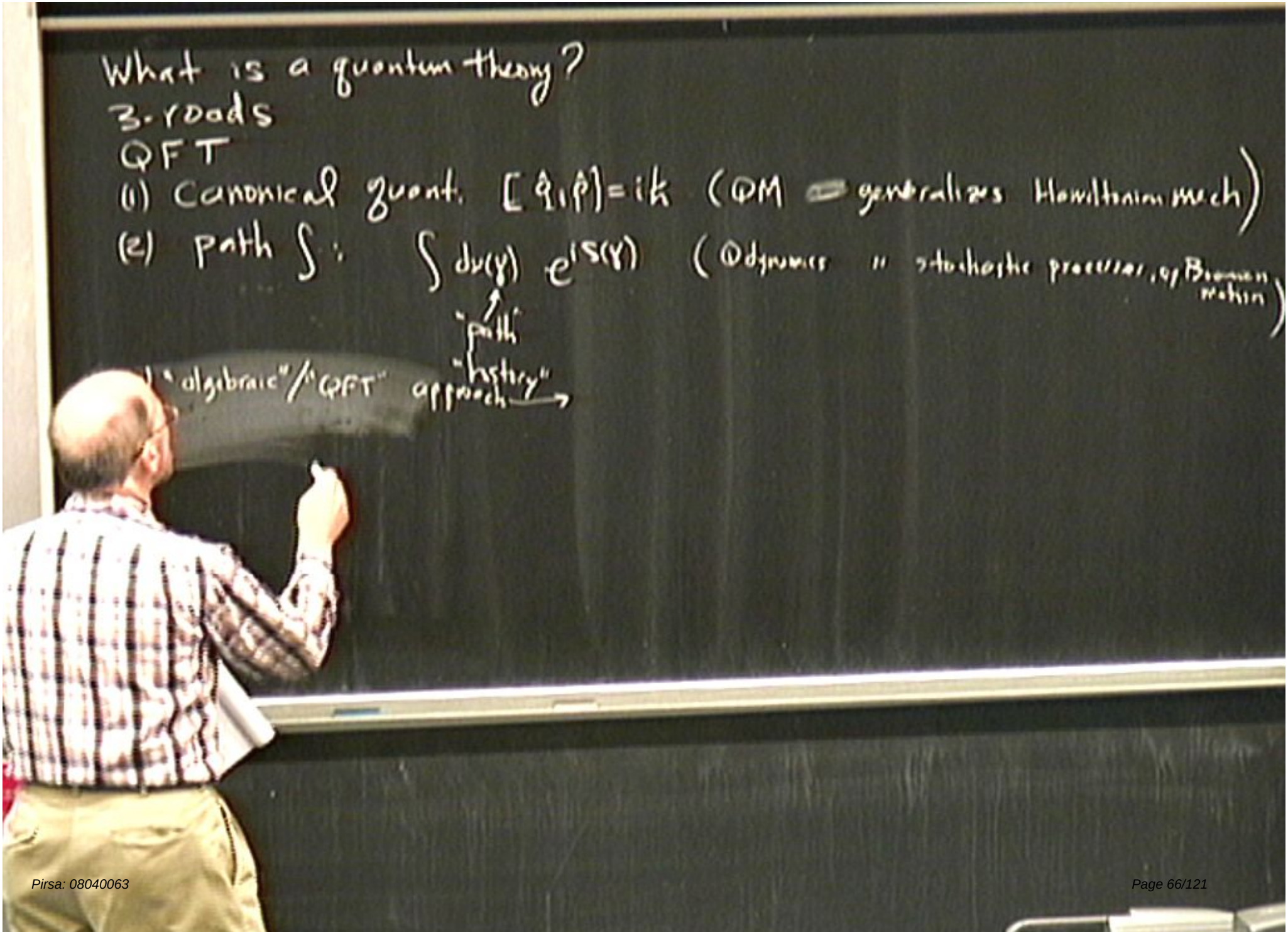
(3)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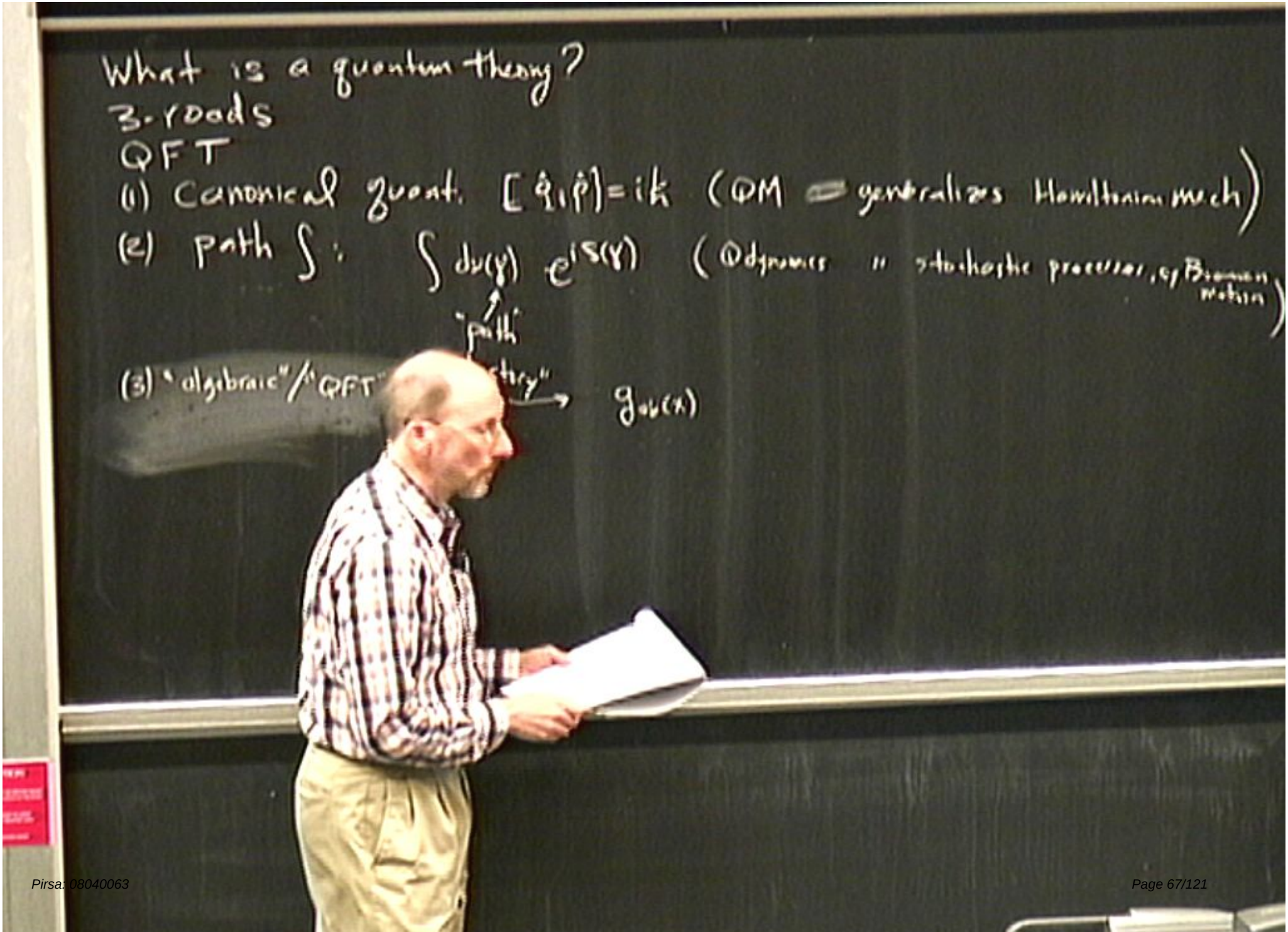
"path"
"history"
"algebraic"/"QFT" approach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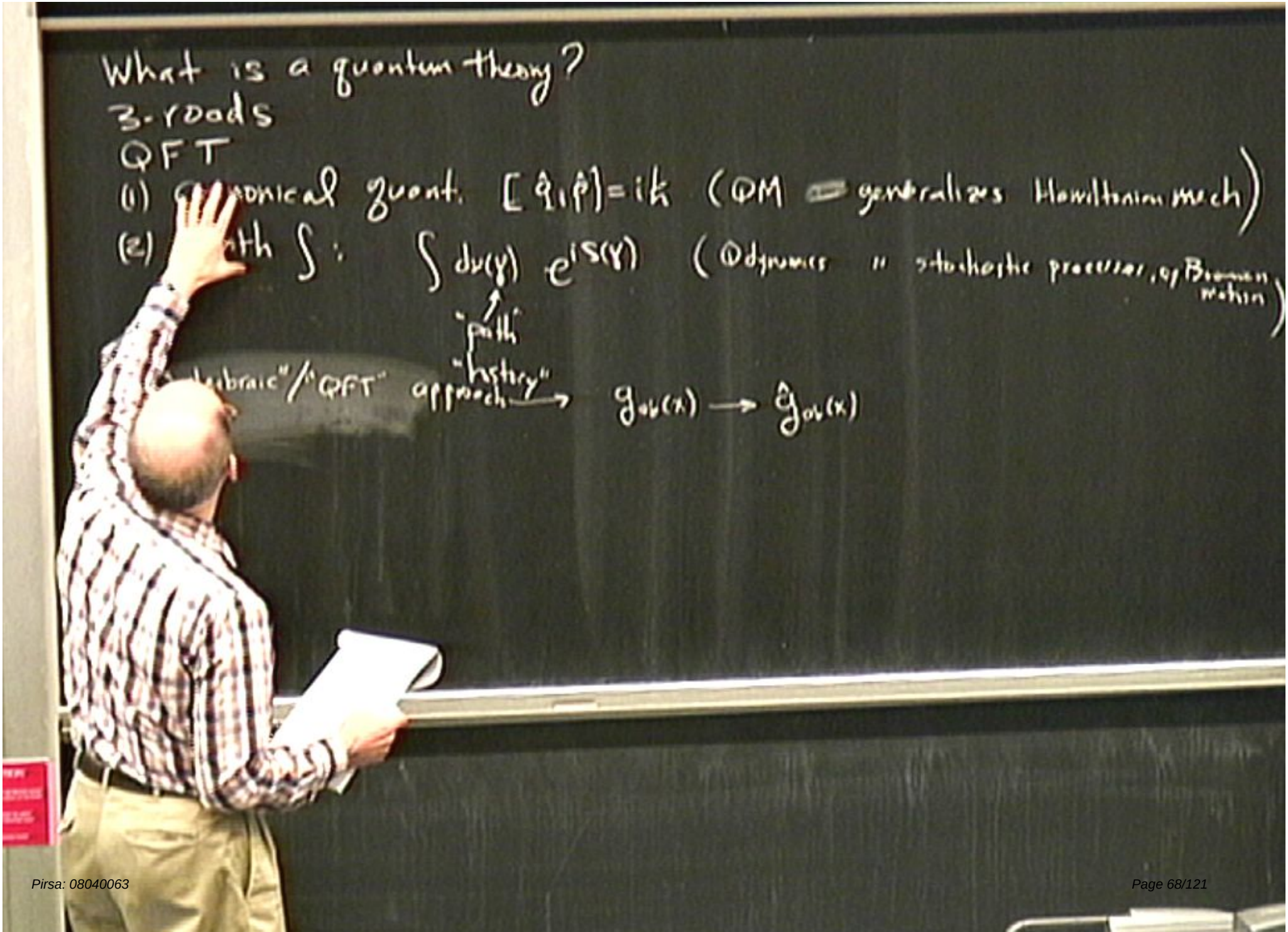
"path"
(3) "algebraic"/"QFT"
$g_{\mu\nu}(x)$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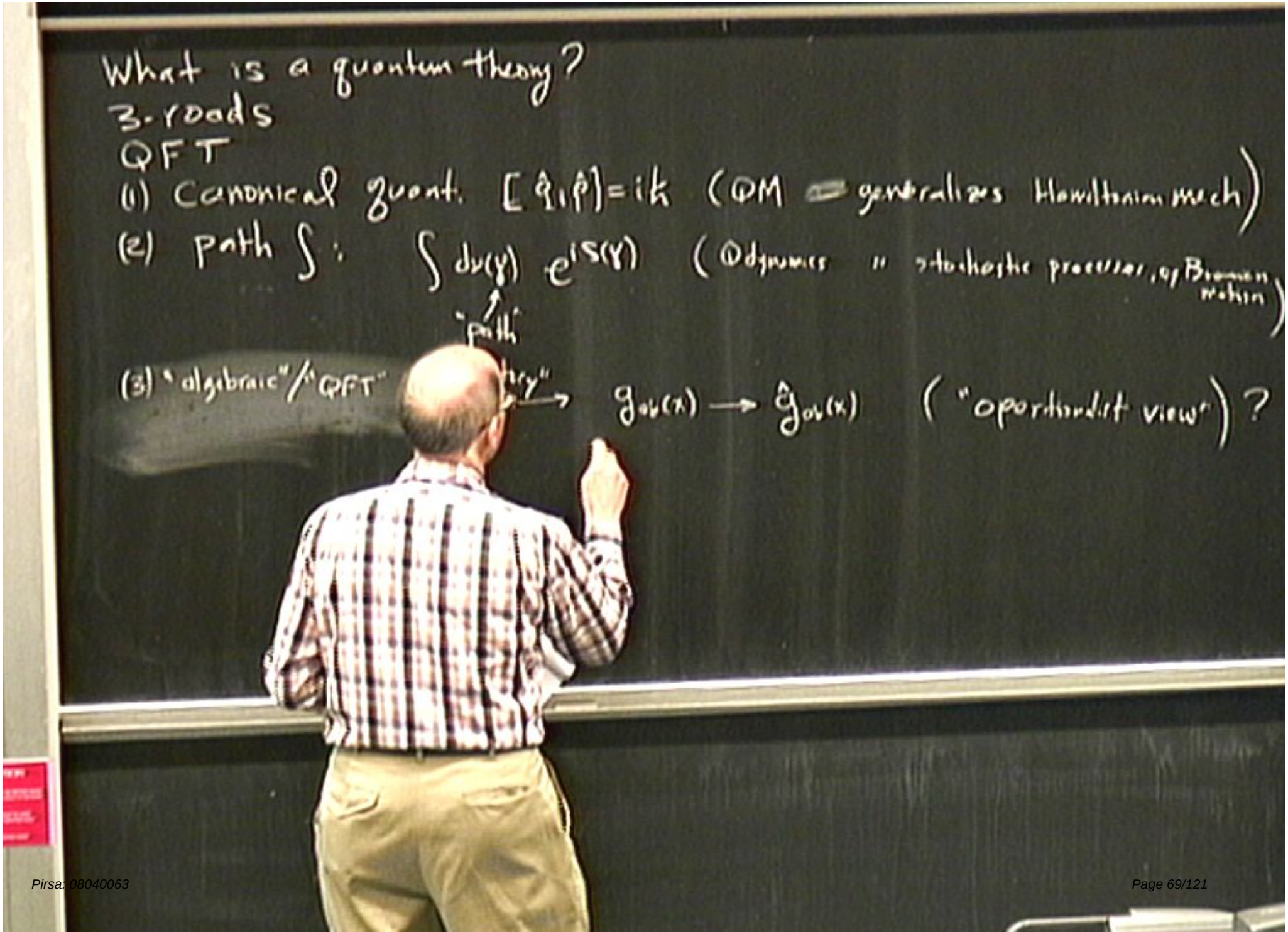
"path"
"history"
algebraic"/"QFT" approach
$g_{\mu\nu}(x) \longrightarrow \hat{g}_{\mu\nu}(x)$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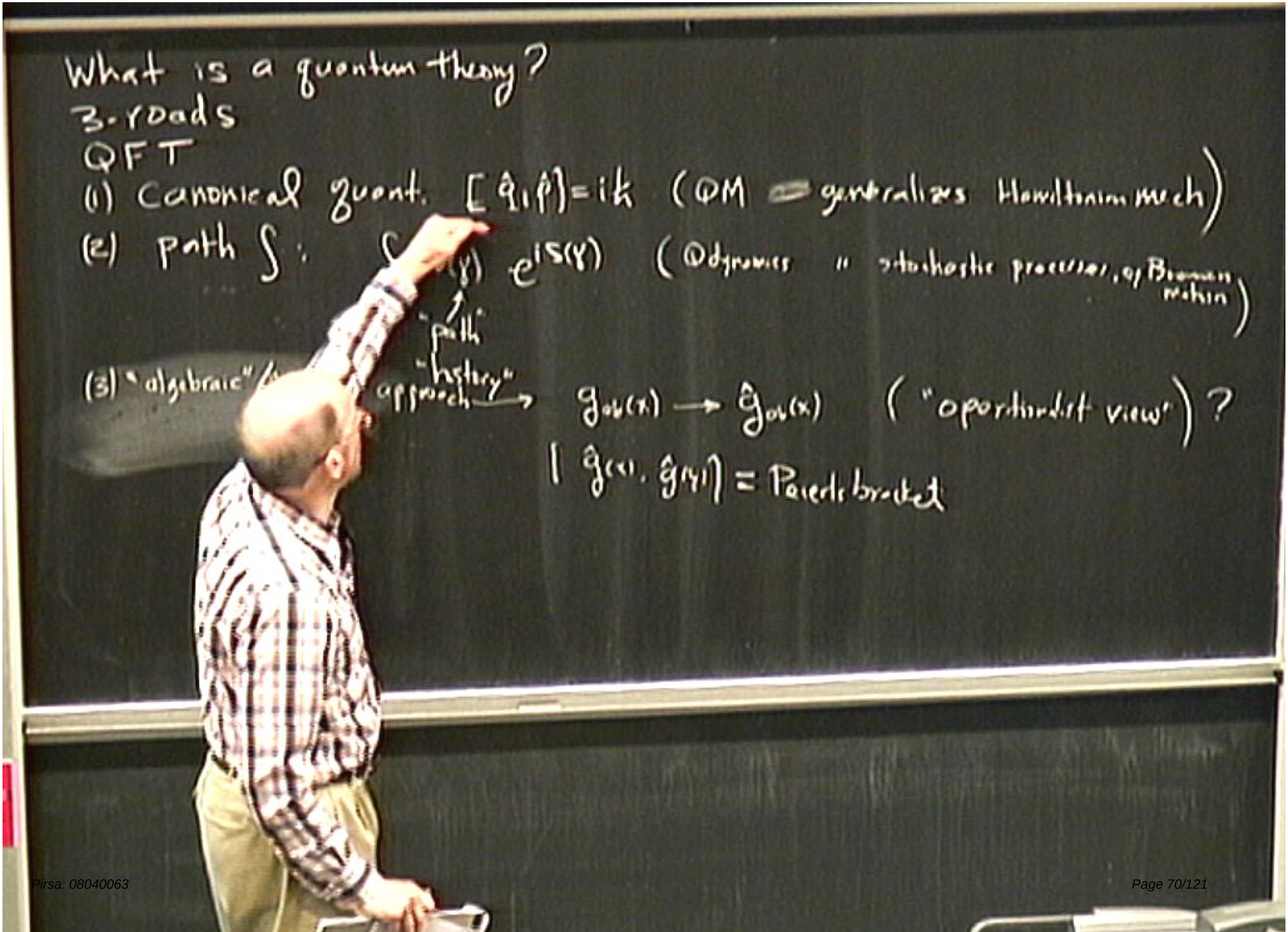
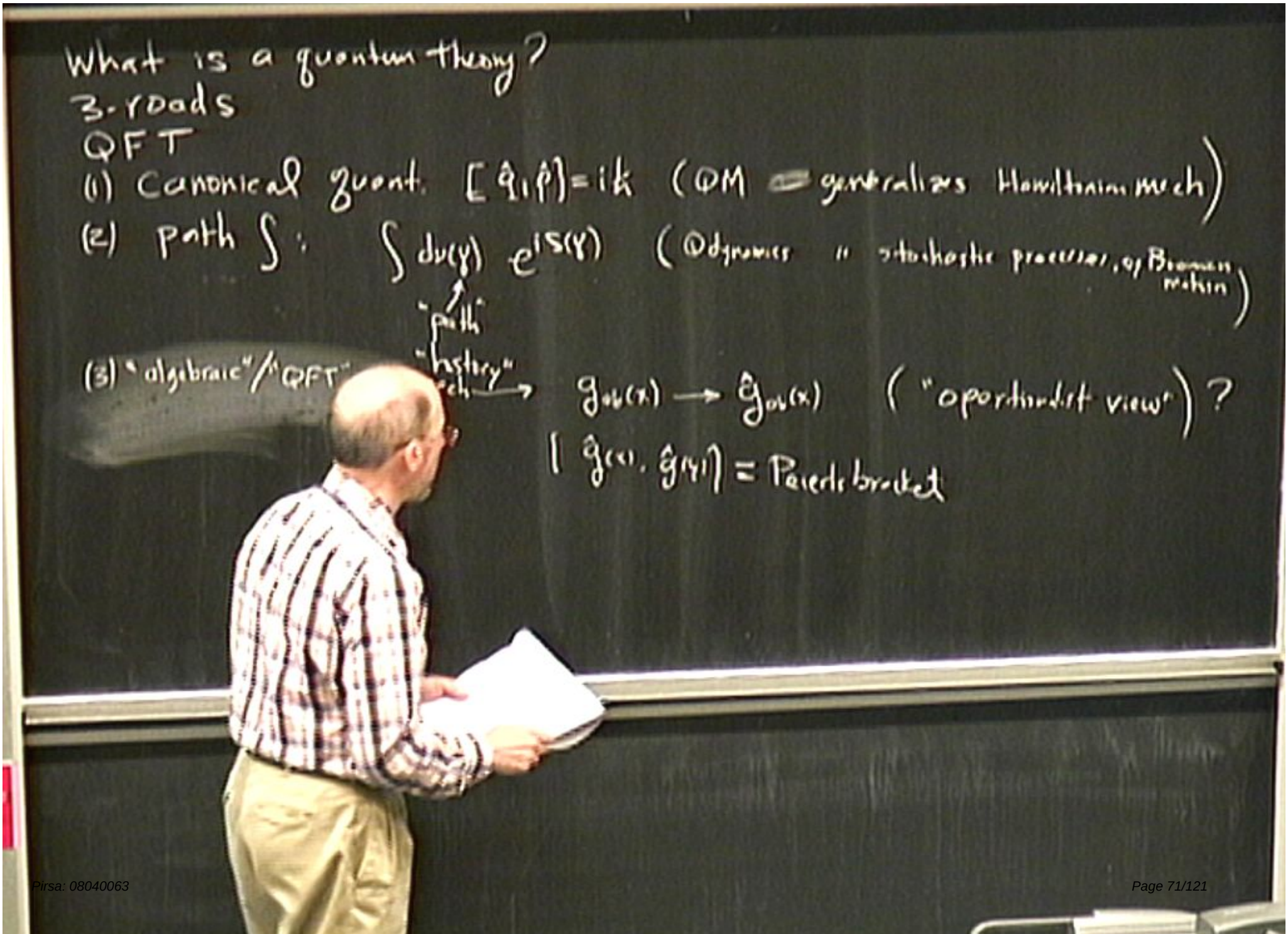
"path"
(3) "algebraic"/"QFT" "theory" $g_{ab}(x) \longrightarrow \hat{g}_{ab}(x)$ ("operational view")?


What is a quantum theory?
3 roads
QFT
(1) Canonical quant. [q, p] = iħ (QM generalizes Hamiltonian mech)
(2) path ∫ : e^{iS(γ)} (dynamics stochastic processes, e.g. Brownian motion)
"path"
"history"
(3) "algebraic" approach → g_{ab}(x) → ĝ_{ab}(x) ("operator view") ?
[ĝ(x), ĝ(y)] = Peierls bracket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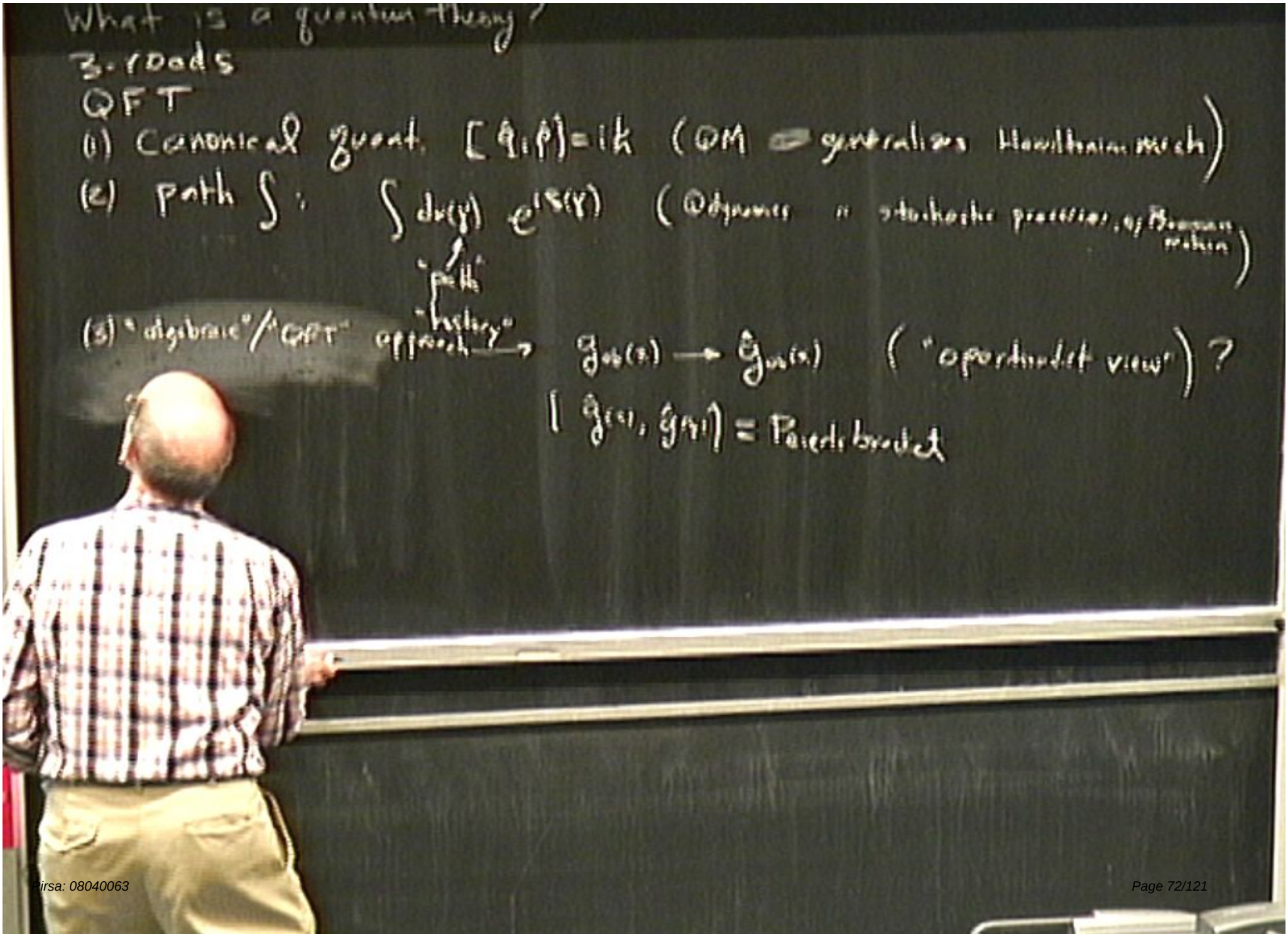
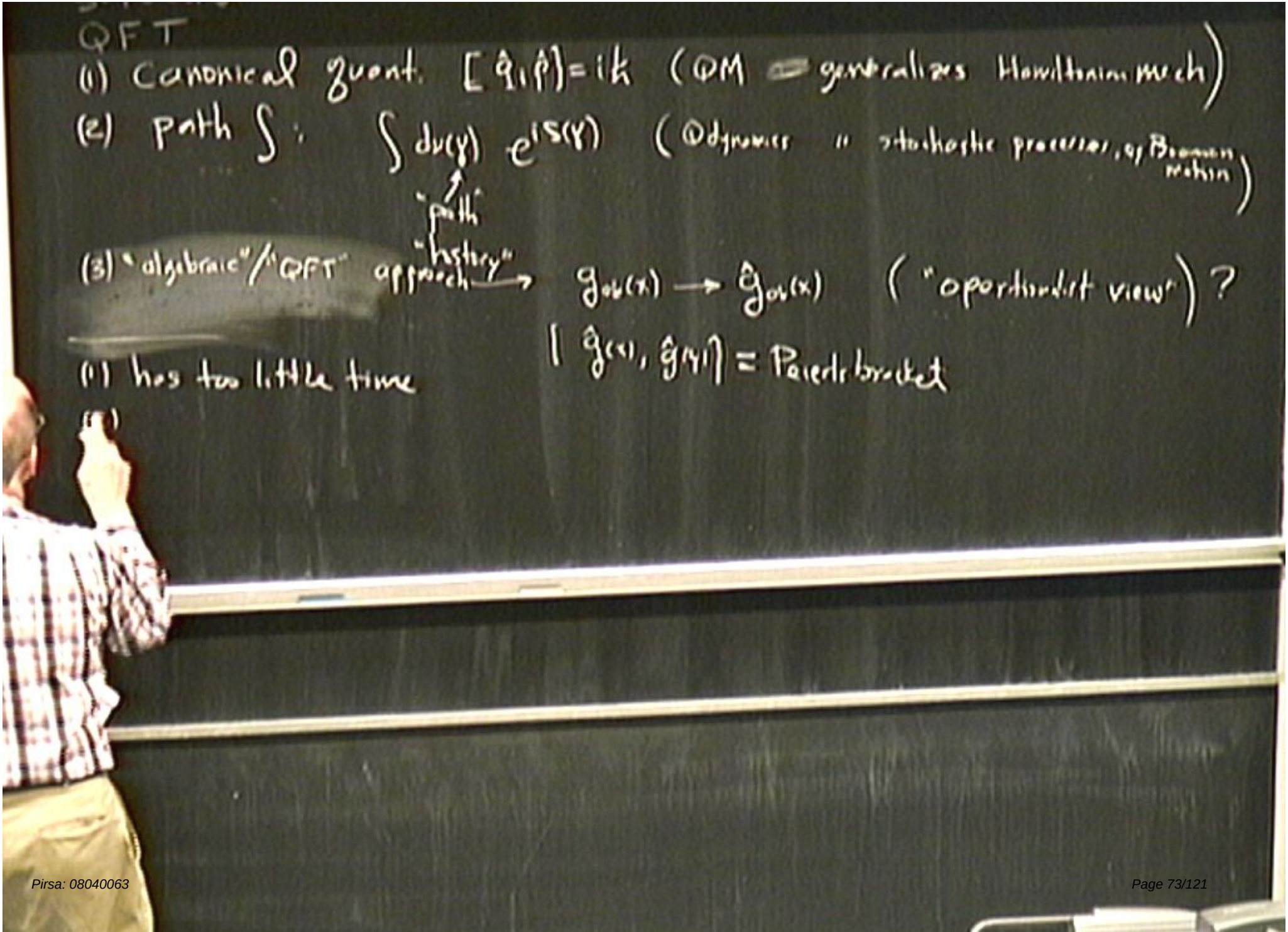
(2) Path $\int$: $\int dv(\gamma)\, e^{iS(\gamma)}$ (Dynamics = stochastic processes, eg Brownian motion)
"path"
"history"
(3) "algebraic"/"QFT"
$g_{\mu\nu}(x) \longrightarrow \hat{g}_{\mu\nu}(x)$ ("operator-valued view")?
$[\hat{g}(x), \hat{g}(y)] =$ Poisson bracket


What is a quantum theory?
3 roads
QFT
(1) Canonical quant. [q,p] = ik (QM = generalized Hamiltonian mech)
(2) path ∫: ∫ dx(t) e^{iS(x)} (dynamics = stochastic processes, of Brownian motion)
"path"
"history"
(3) "algebraic"/"QFT" approach → g_ab(x) → ĝ_ab(x) ("operator-valued view")?
[ĝ(x), ĝ(y)] = Poisson bracket


QFT
(1) Canonical quant. $[\hat{q}, \hat{p}] = ik$ (QM generalizes Hamiltonian mech)
(2) Path $\int$: $\int dv(\gamma)\, e^{iS(\gamma)}$ ("path" "history" (Dynamics = stochastic processes, eg Brownian motion))
(3) "algebraic"/"QFT" approach → $g_{ov(x)} \to \hat{g}_{ov(x)}$ ("operadic view")?
$[\hat{g}(x), \hat{g}(y)] =$ Poisson bracket
(1) has too little time

3 roads
QFT

(1) Canonical quant. $[\hat{q}, \hat{p}] = ik$ (QM ⊃ generalizes Hamiltonian mech)

(2) path $\int$: $\int dv(\gamma)\, e^{iS(\gamma)}$ ("path" "history") (Dynamics = stochastic processes, eg Brownian motion)

(3) "algebraic"/"QFT" approach → $g_{ab}(x) \longrightarrow \hat{g}_{ab}(x)$ ("operational view")?

$[\hat{g}(x), \hat{g}(y)] =$ Poisson bracket

(1) has too little time
(3) " " much time
(2) just right

QFT

(1) Canonical quant. $[\hat{q}, \hat{p}] = ik$ (QM ⊃ generalizes Hamiltonian mech)

(2) path $\int$: $\int d\nu(\gamma)\, e^{iS(\gamma)}$ (Dynamics = stochastic processes, eg Brownian motion)

"path"

"history"

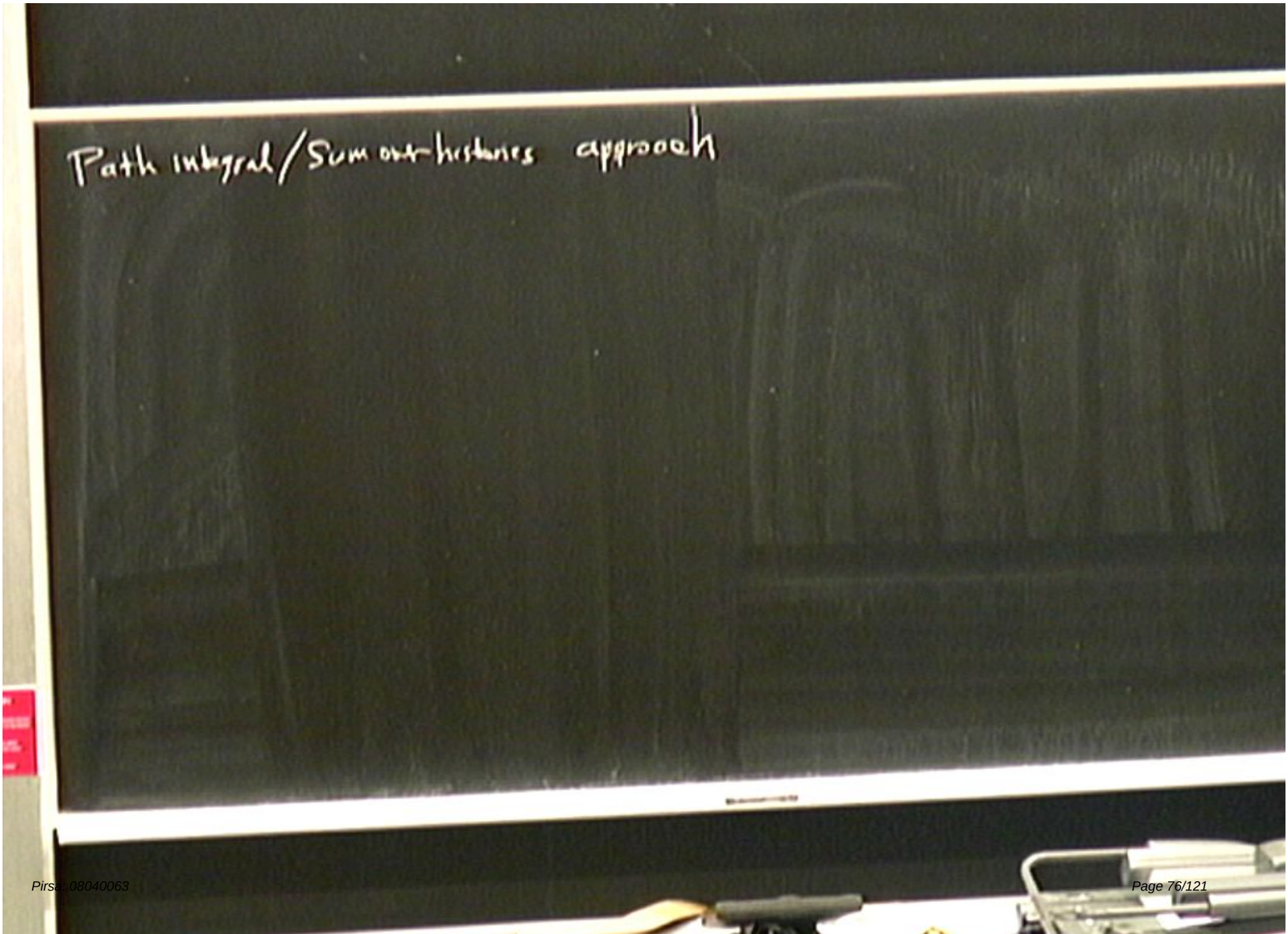
(3) "algebraic"/"QFT" approach → $g_{ab}(x) \longrightarrow \hat{g}_{ab}(x)$ ("operational view")?

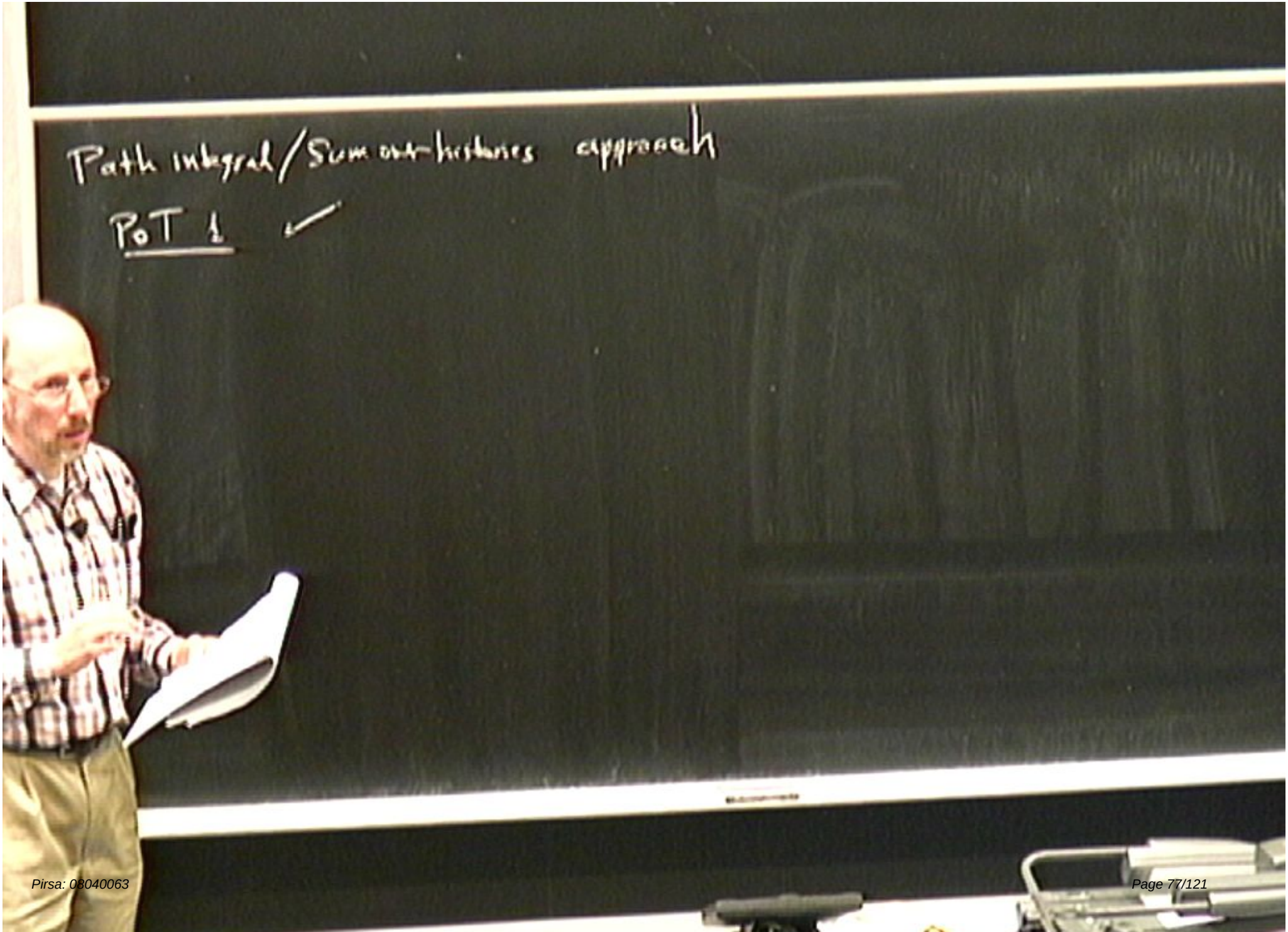
$[\hat{g}(x), \hat{g}(y)] =$ Poisson bracket

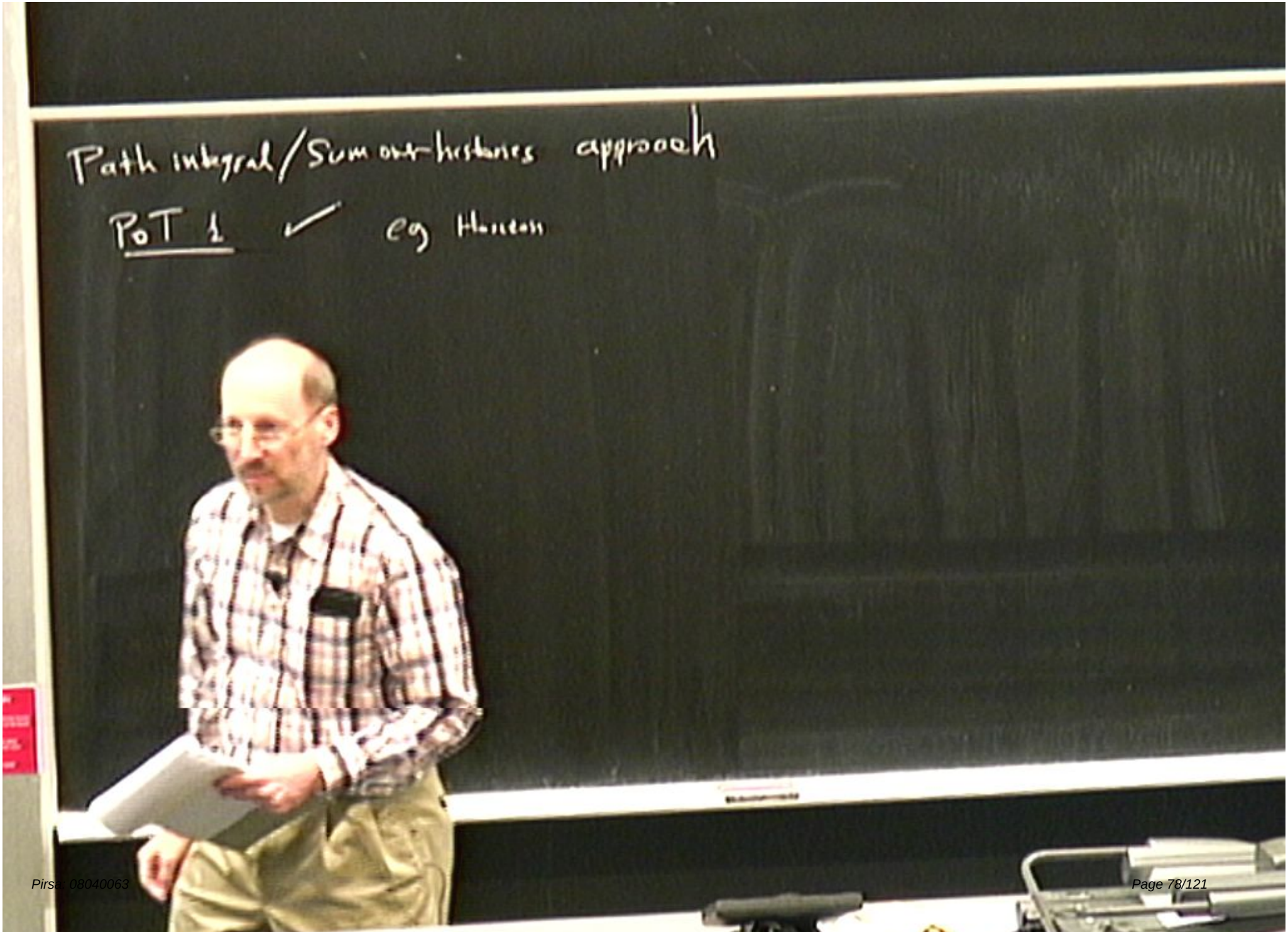
(1) has too little time

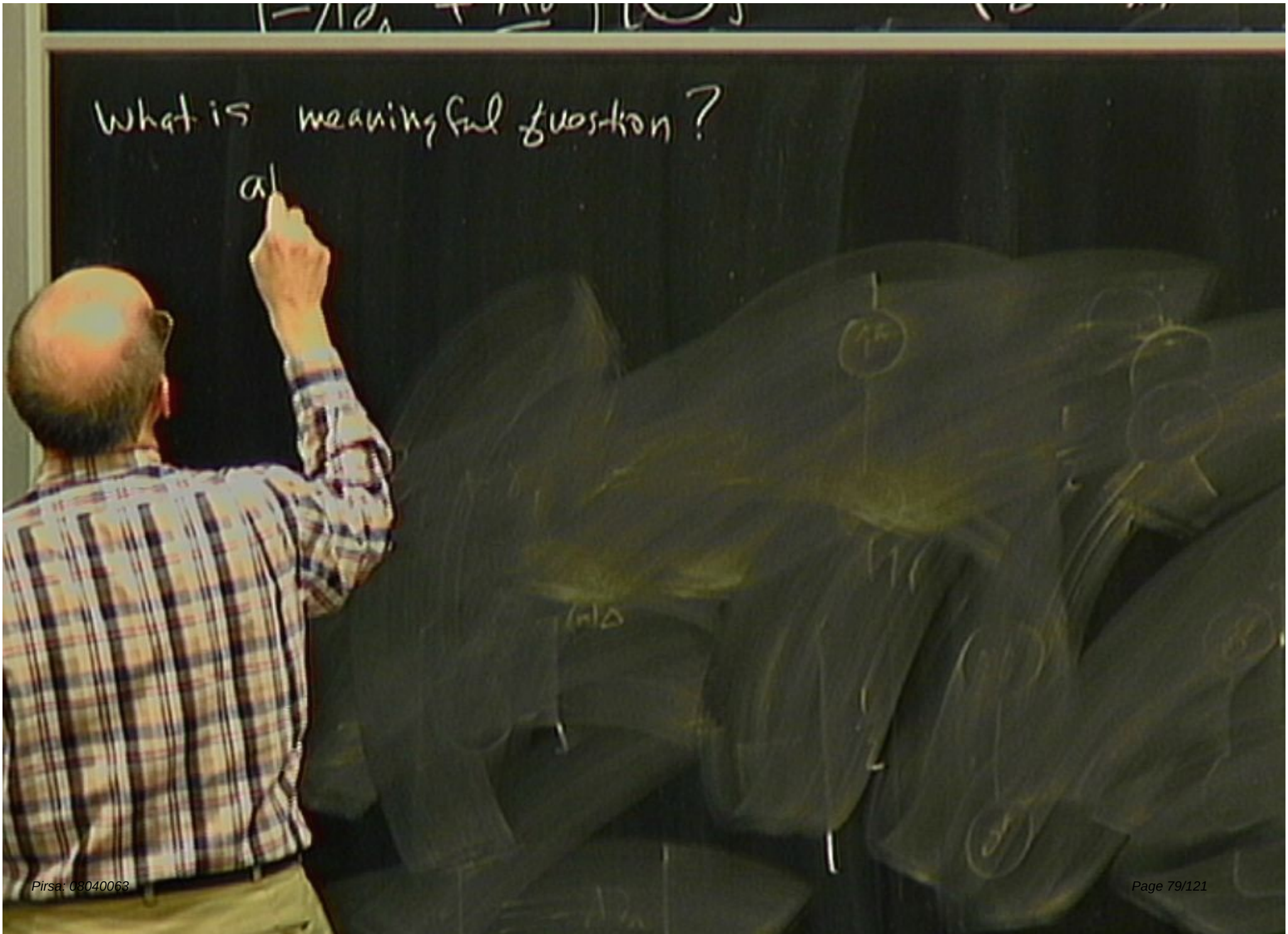
(2) " " much time (eg no top change)

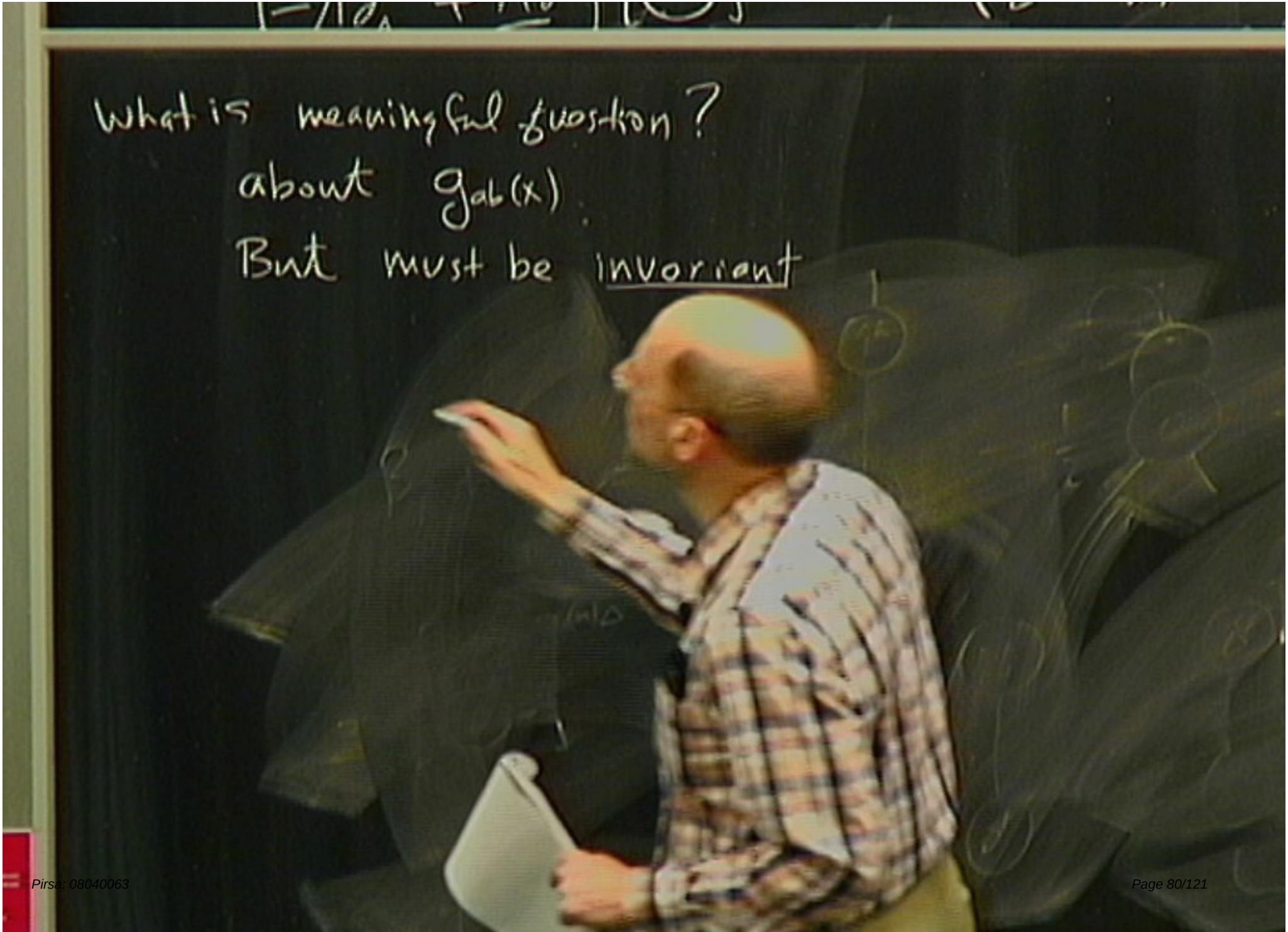
(3) just right

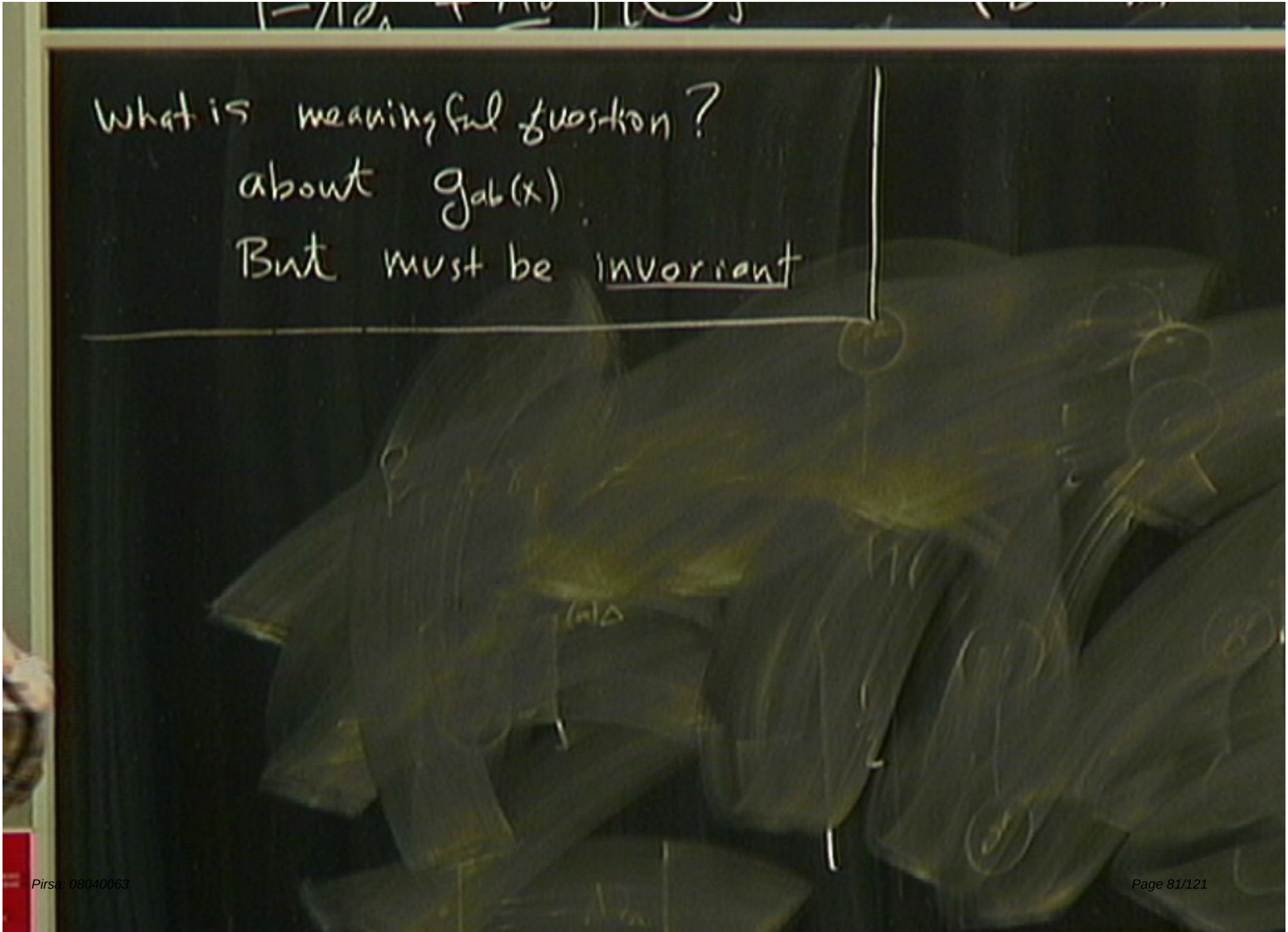

Path integral / Sum over histories approach


Path integral / Sum over histories approach
PoT 1


Path integral / Sum over histories approach
PoT 1
eg Hawkes


What is meaningful question?


What is meaningful question?
about $g_{ab}(x)$
But must be invariant


What is meaningful question?
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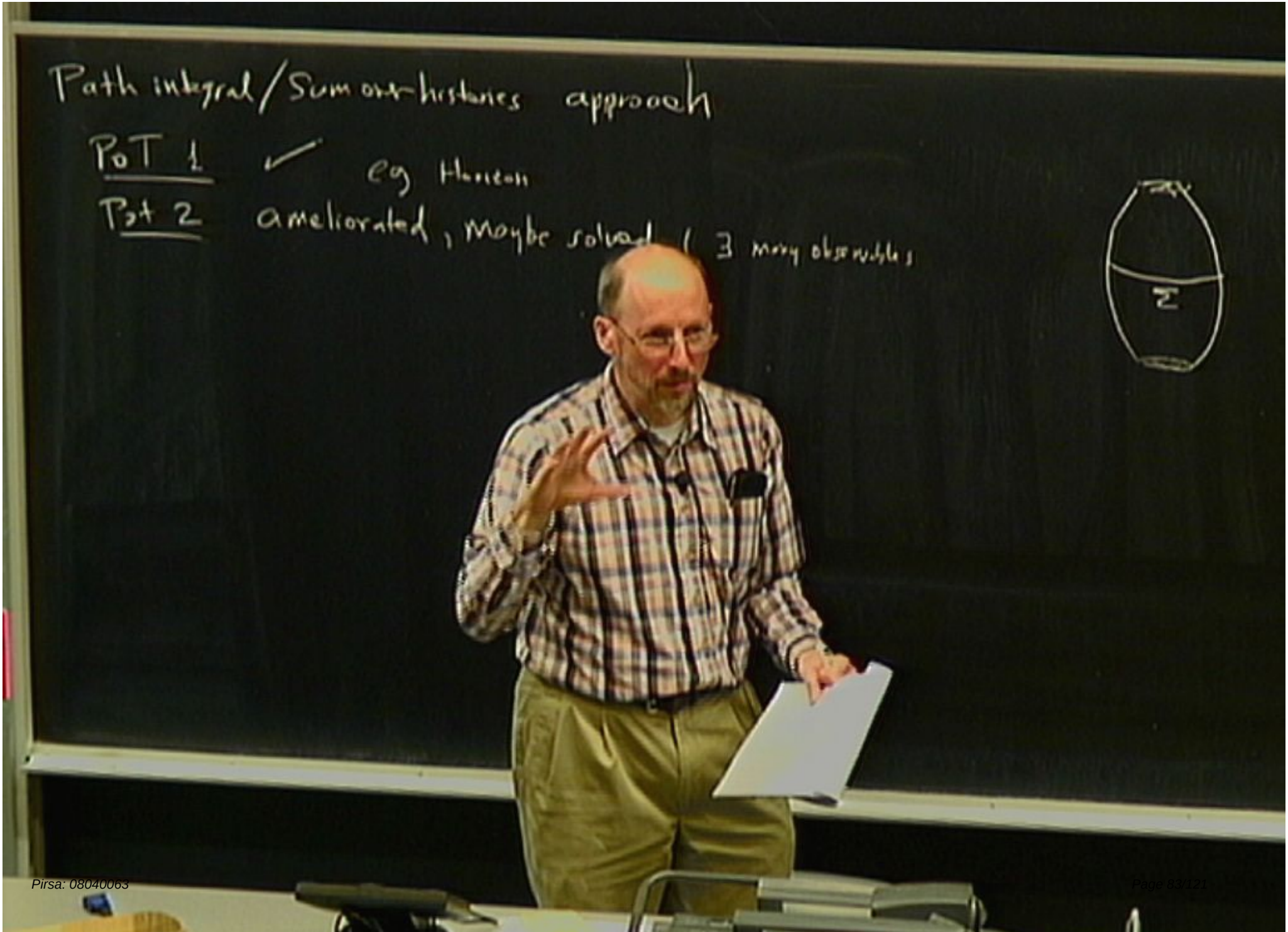
But must be invariant

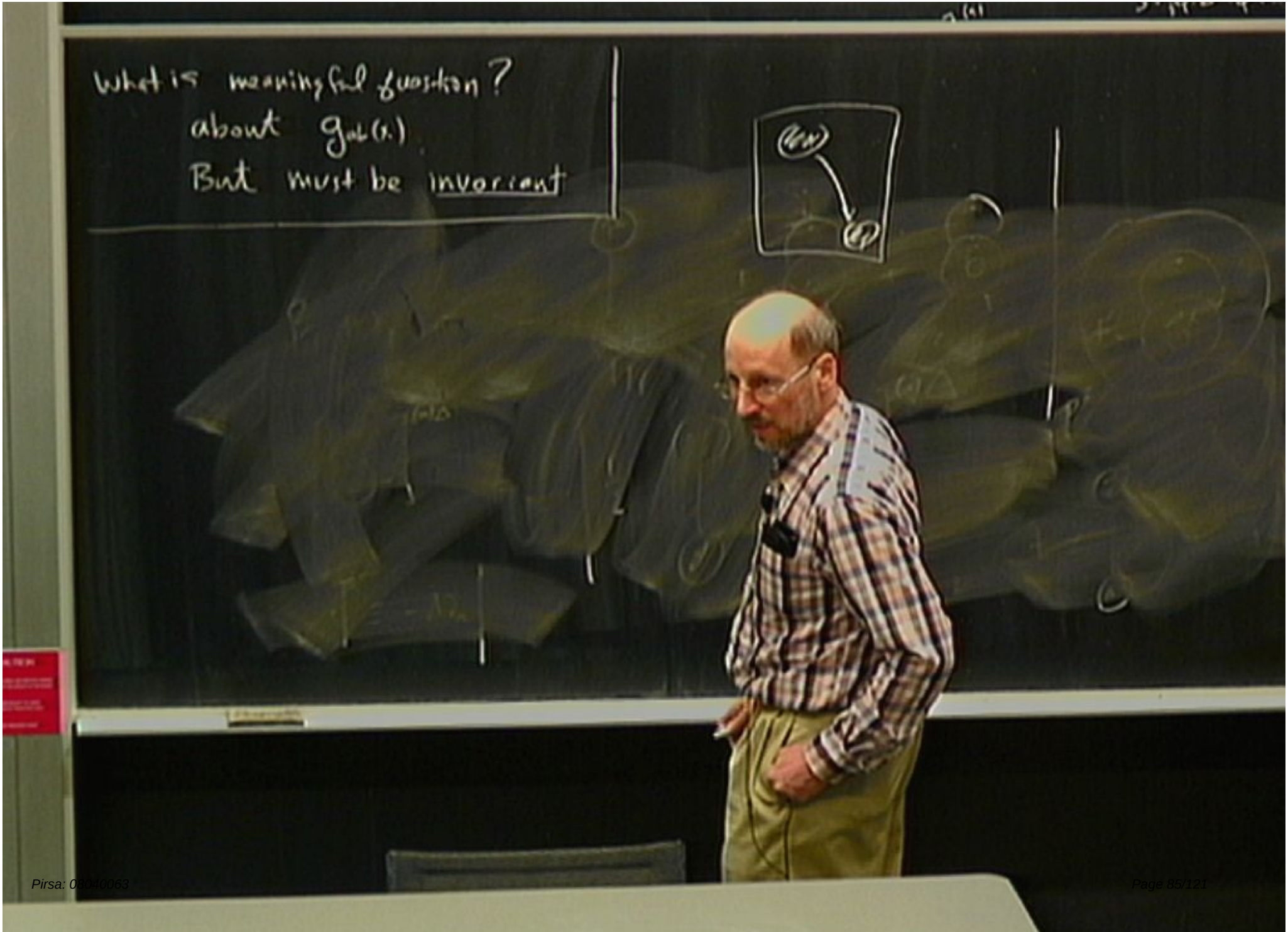
Path integral / Sum over-histories approach

PoT 1 ↙ eg Horton

PoT 2 ameliorated


Path integral / Sum over histories approach
PoT 1
eg Horizon
PoT 2
ameliorated, Maybe solved (3 many observables)
Z


Path integral / Sum over histories approach
PoT 1
eg Heisen
PoT 2
ameliorated, Maybe solved
Σ
bigger Σ


What is meaningful question?
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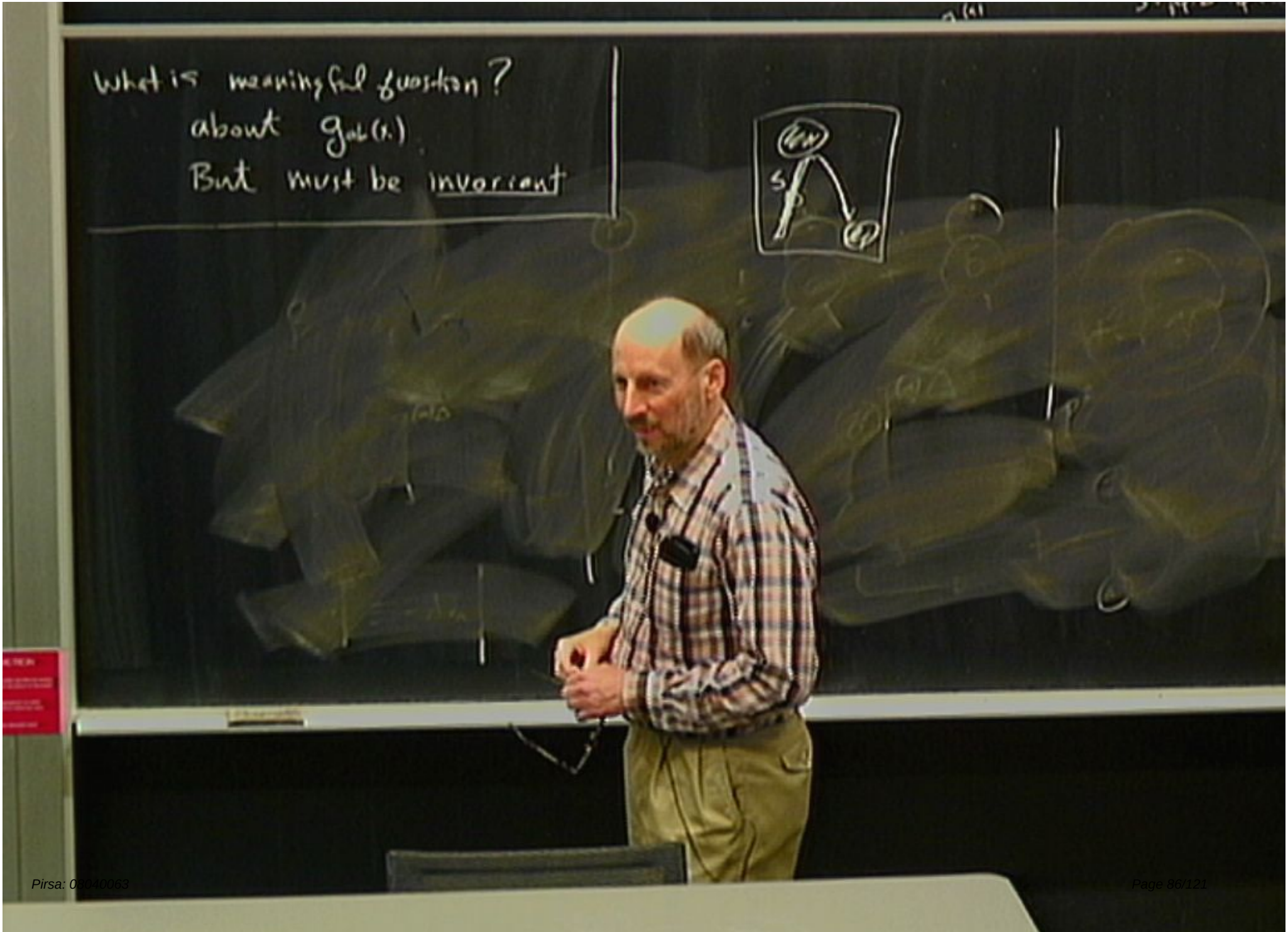
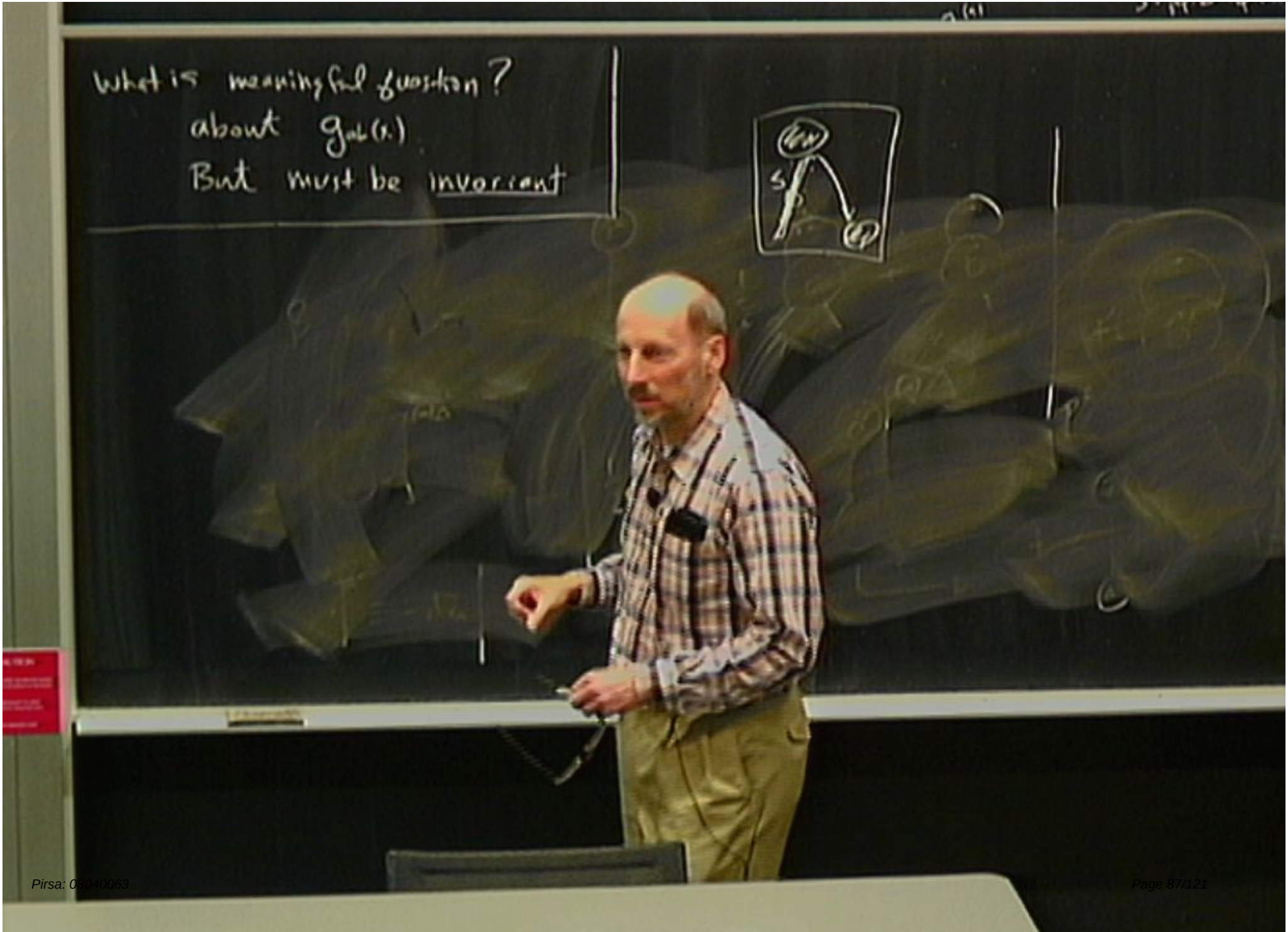
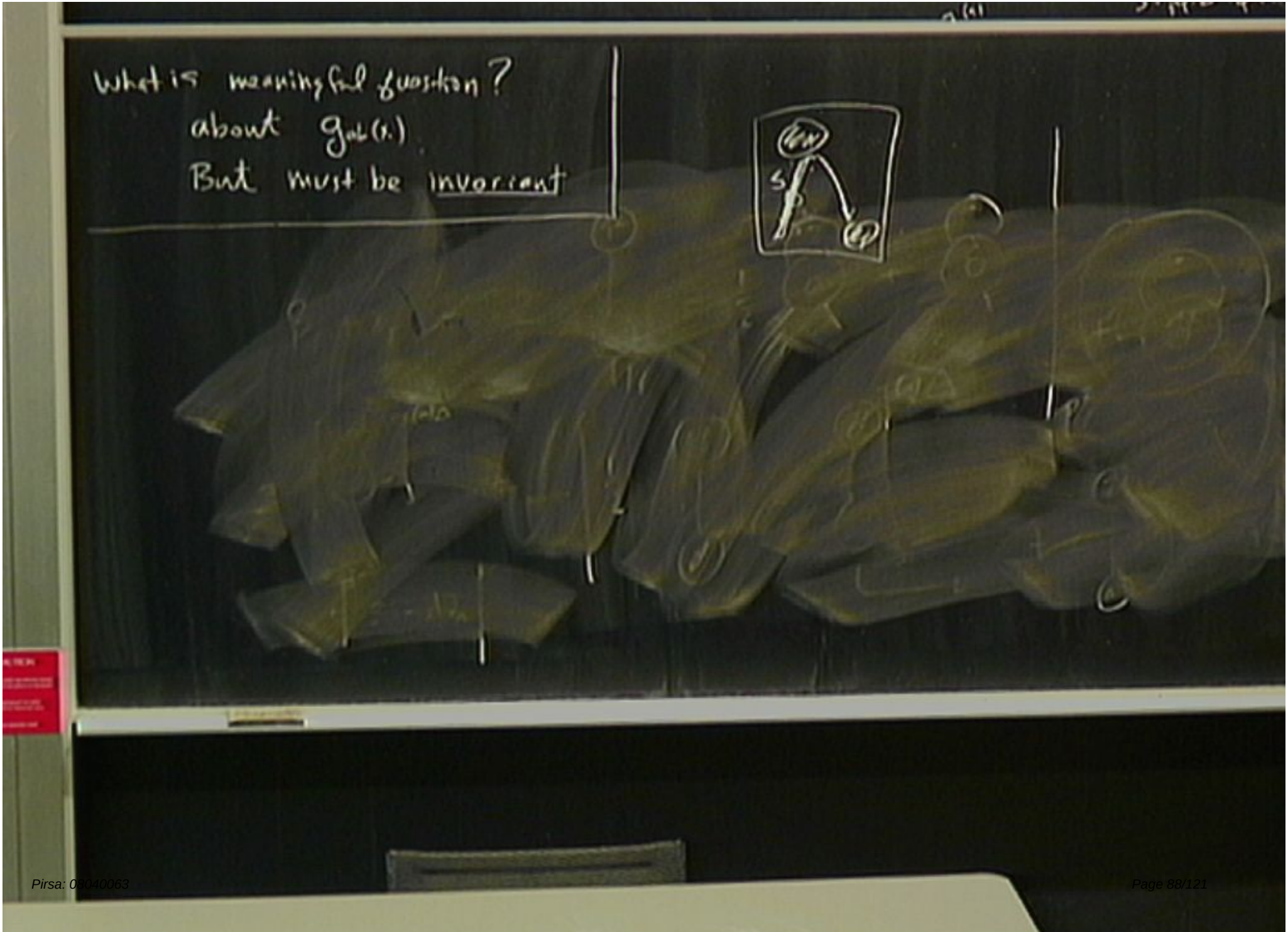

What is meaningful question?
about $g_{\mu\nu}(x)$
But must be invariant


What is meaningful question?
about $g_{\mu\nu}(x)$
But must be invariant


What is meaningful question?
about $g_{\mu\nu}(x)$
But must be invariant

Path integral / Sum over histories approach

PoT 1 ✓ eg Horizon

PoT 2 ameliorated, Maybe solved (3 new observables, enough?)

PoT 3

Path integral / Sum over histories approach

PoT 1 ✓ eg Hawking

PoT 2 ameliorated, Maybe solved (3 many observables, enough?)

PoT 3 ?

Example: Sudarsky & Sorkin "Large fluctuation..."

Wond[illegible]bries [illegible]

biggest Σ

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Example: Sudarsky & Sorkin "Large fluctuation..."

Want histories formulation "free standing" not just propagator Ψ

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Free P.I.

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Example: Sudarsky & Sorkin "Large fluctuation..."

Wont histories formulation "free standing" not just propagator Ψ

Free P.I. from Ψ.

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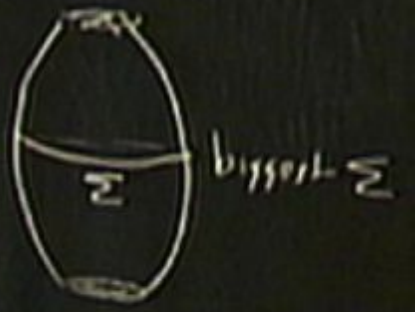

Example: Sudarsky & Sorkin "Large fluctuation..."

Want histories formulation "free standing" not just propagator Ψ

Free P.I. from Ψ.

decoherent histories, quantum-meaning

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Example: Sudarsky & Sorkin "Large fluctuation..."

Want histories formulation "free standing" not just propagator Ψ

Free P.I. from Ψ.

decoherent histories, quantum measure

What is a quantal reality? (See anthropic remark)

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Pot 3 ?

biggest Σ

Example: Sudarsky & Sorkin "Large fluctuation..."

Want histories formulation "free standing" not just propagator Ψ

Free P.I. from Ψ.

decoherent histories, quantum measure

What is a quantal reality? (See anthropomorphic comment)

What is gravitational

Path integral / Sum over histories approach

PoT 1 ✓ eg Hartle

PoT 2 ameliorated, Maybe solved (3 many observables, enough?)

PoT 3 ?

Example: Sudarsky & Sorkin "Large fluctuation..."

Want histories formulation "free standing" not just propagator Ψ

Free P.I. from Ψ.

decoherent histories, quantum-measure

What is a quantal reality? (See anthropomorphic remark)

What is gravitational decoherence for?

(2) just right

Path integral / Sum over histories approach

PoT 1 ✓ eg Hawking

PoT 2 ameliorated, maybe solved (3 many observables, enough?)

PoT 3 ?

Example: Sudarsky & Sorkin "Large fluctuation..."

Want histories formulation "free standing" not just perturbative Ψ

Free P.I. from Ψ.

decoherent histories, quantum measure

What is a quantal reality? (See anthropomorphic comment)

* What is gravitational decoherence for? (How write it down?)

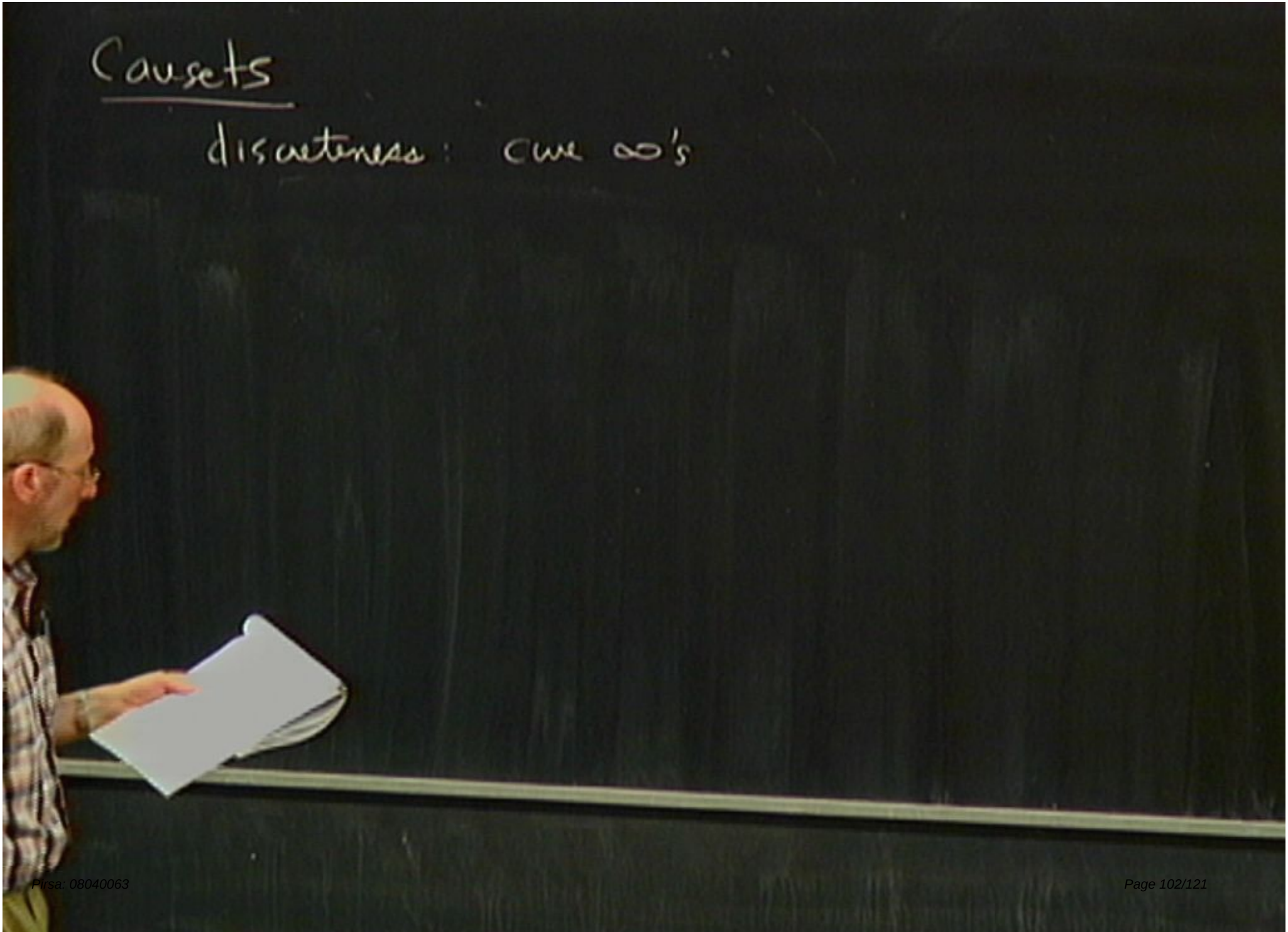
Causets

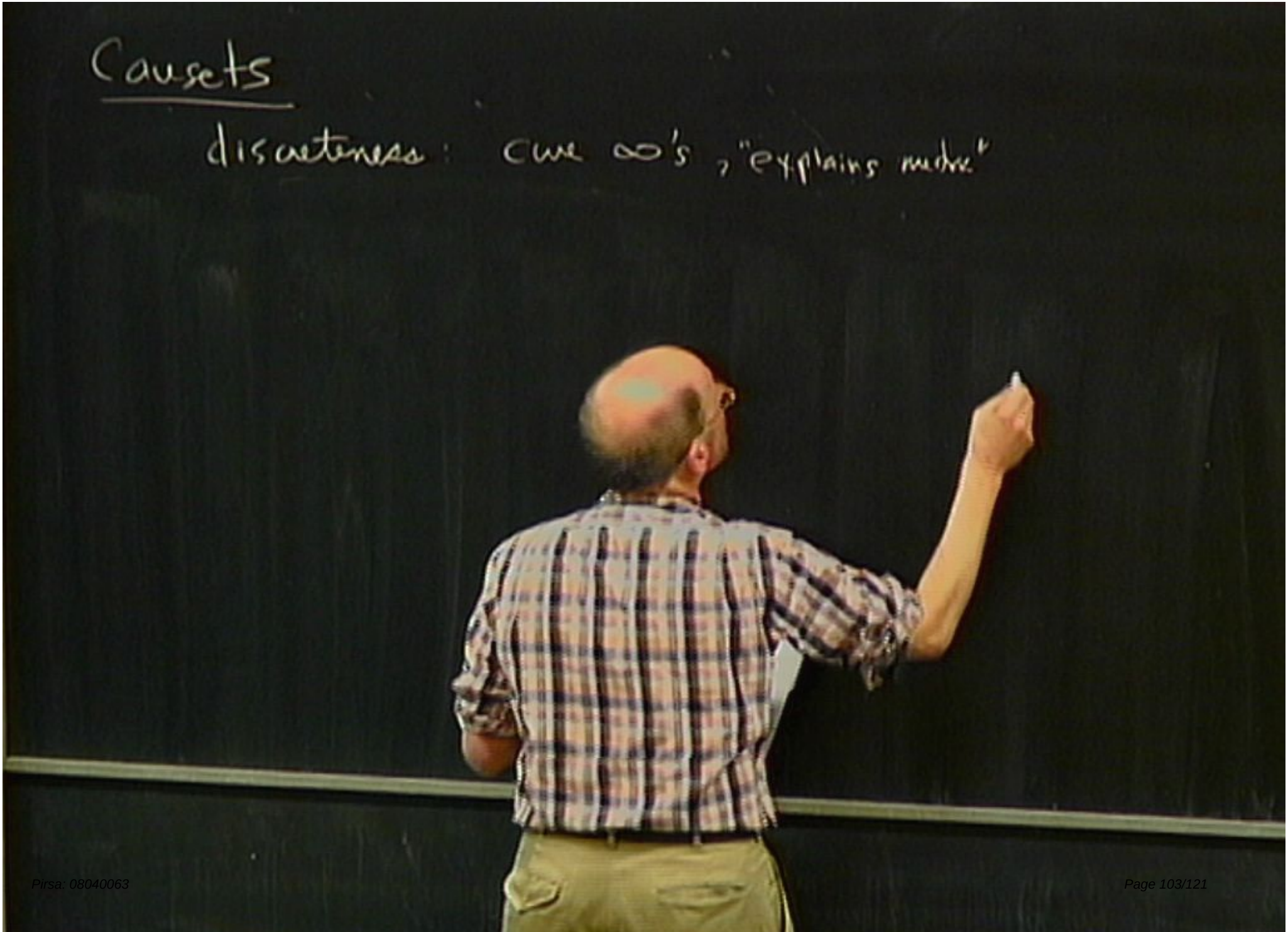
Causets

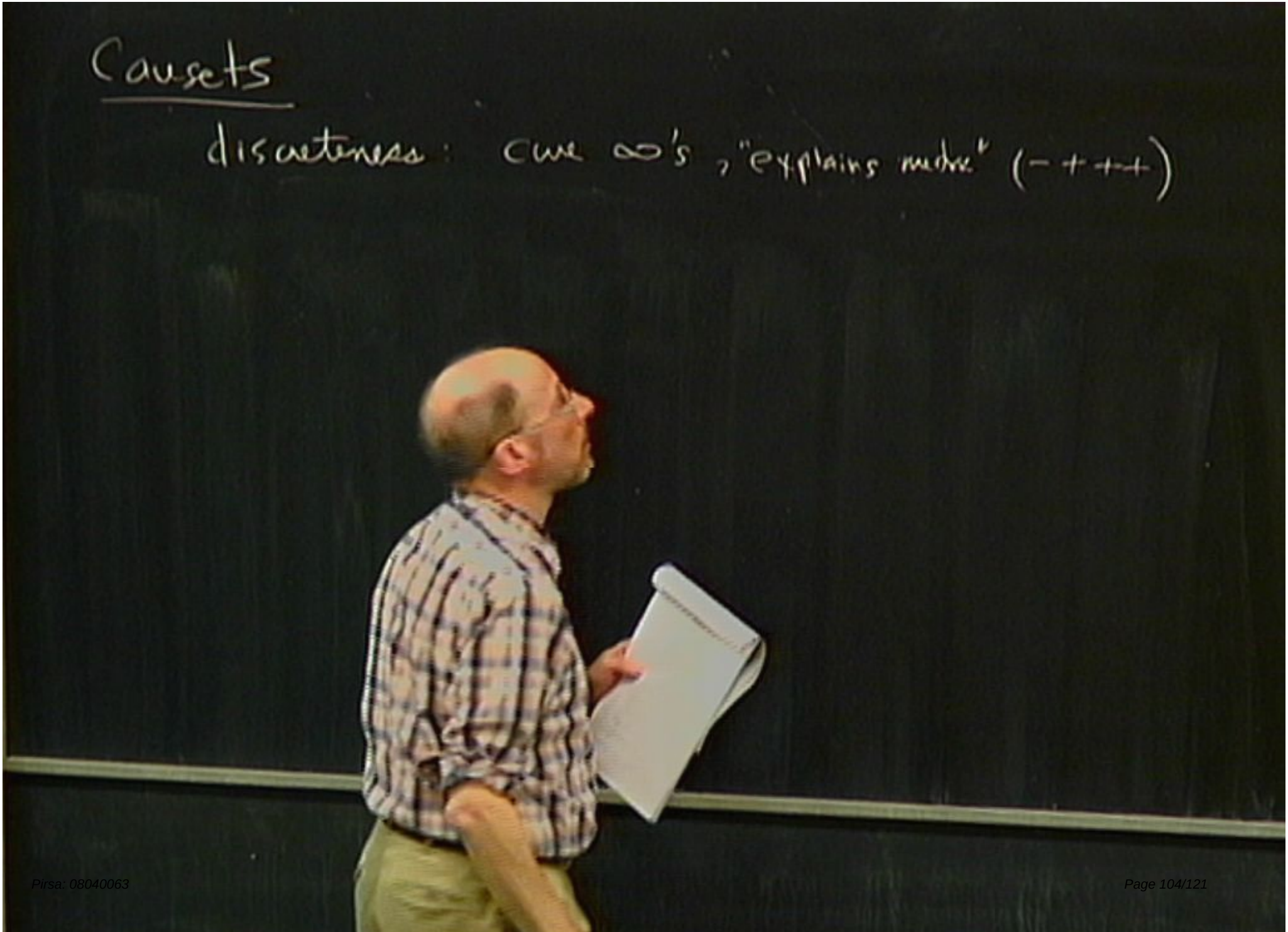
discreteness

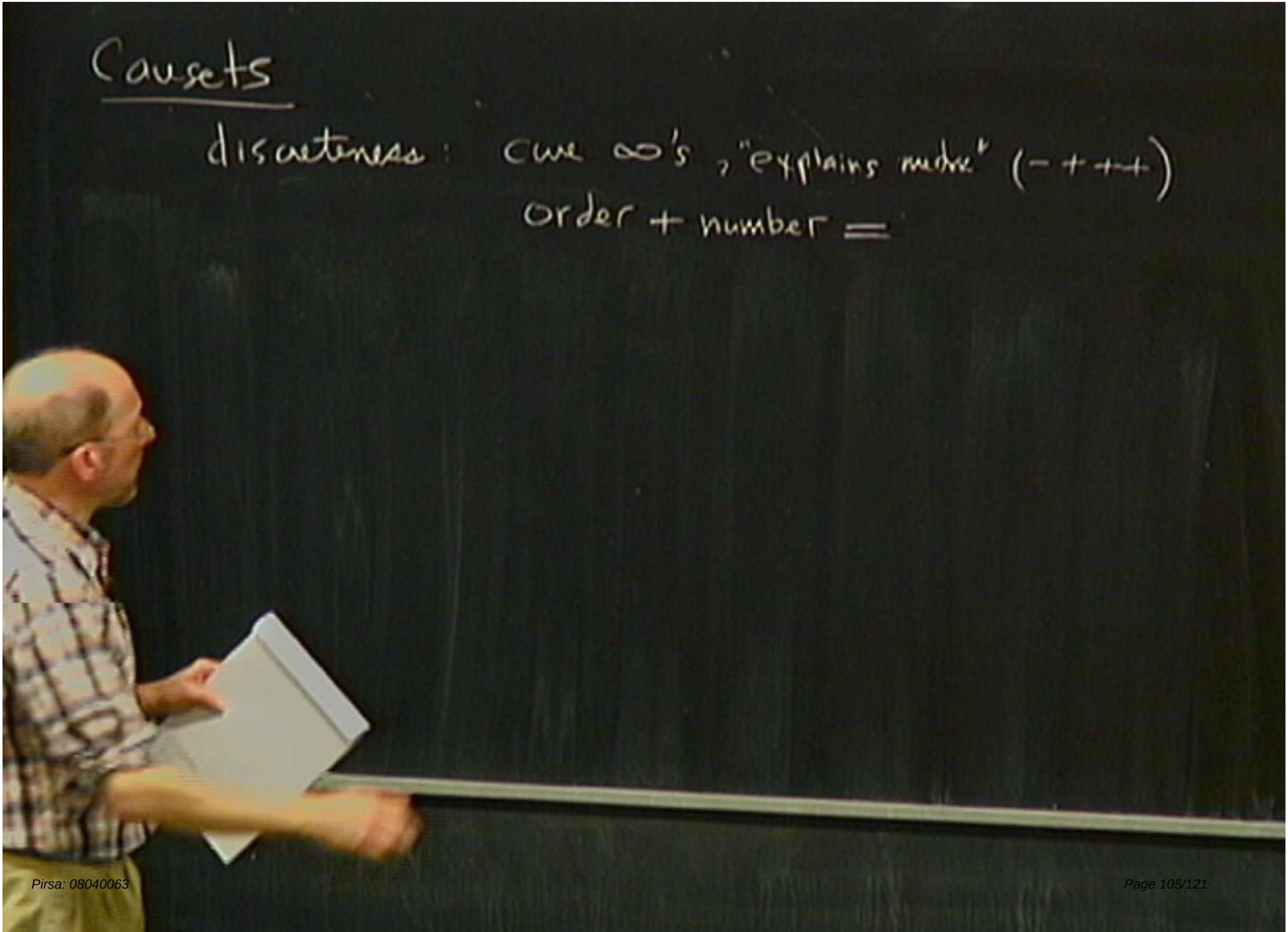
Causets

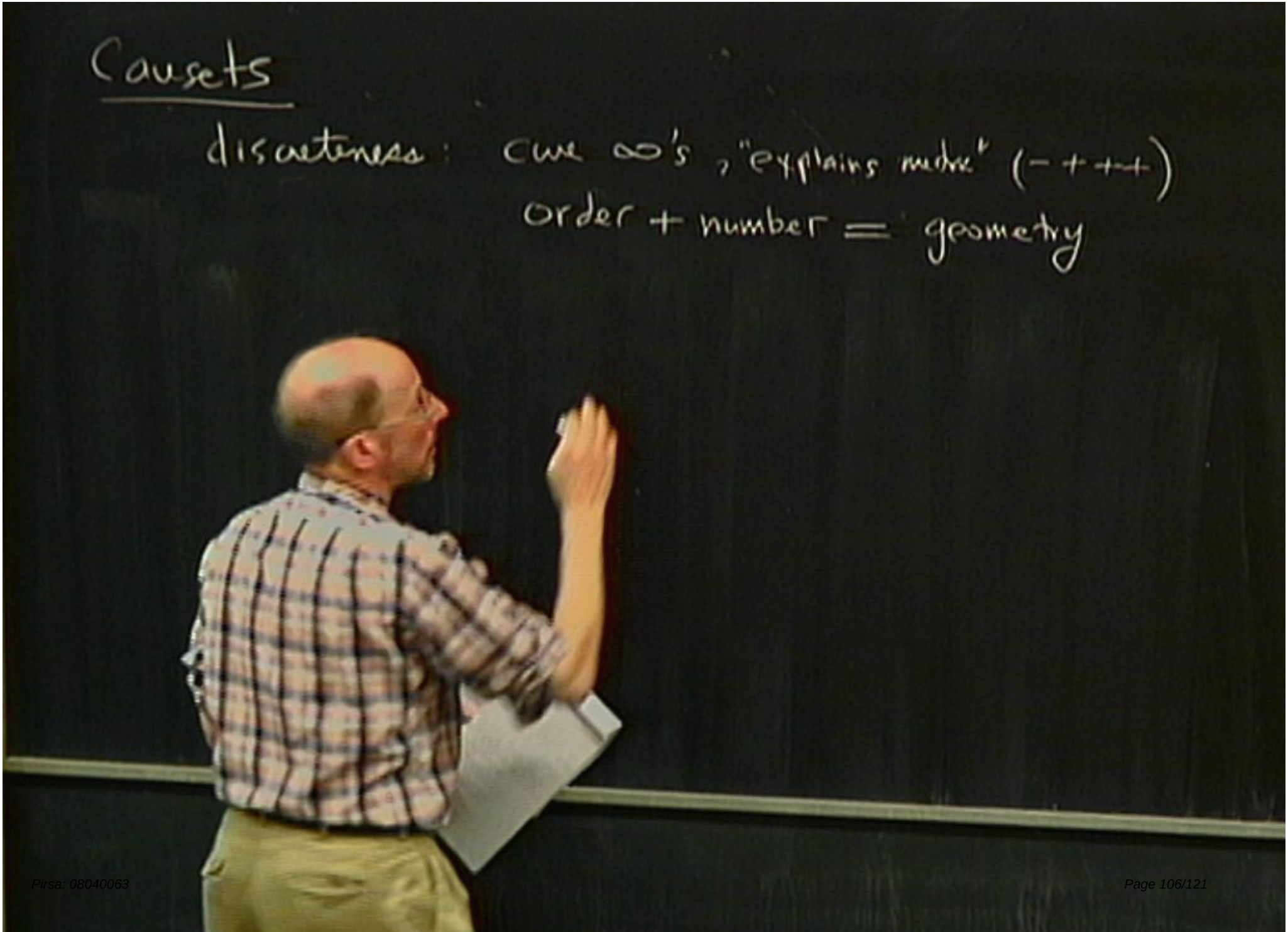
discreteness

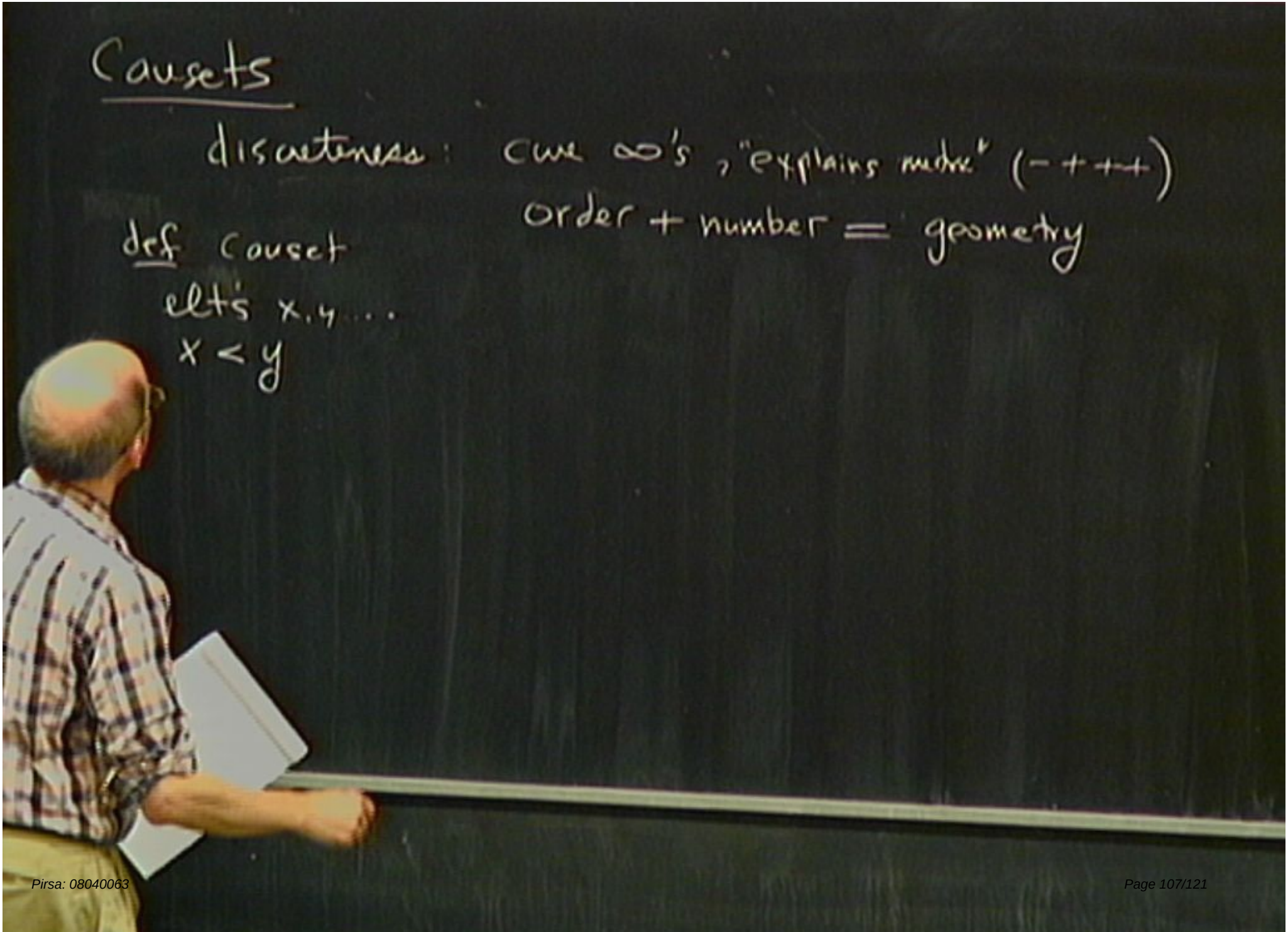

Causets
discreteness : cure ∞'s

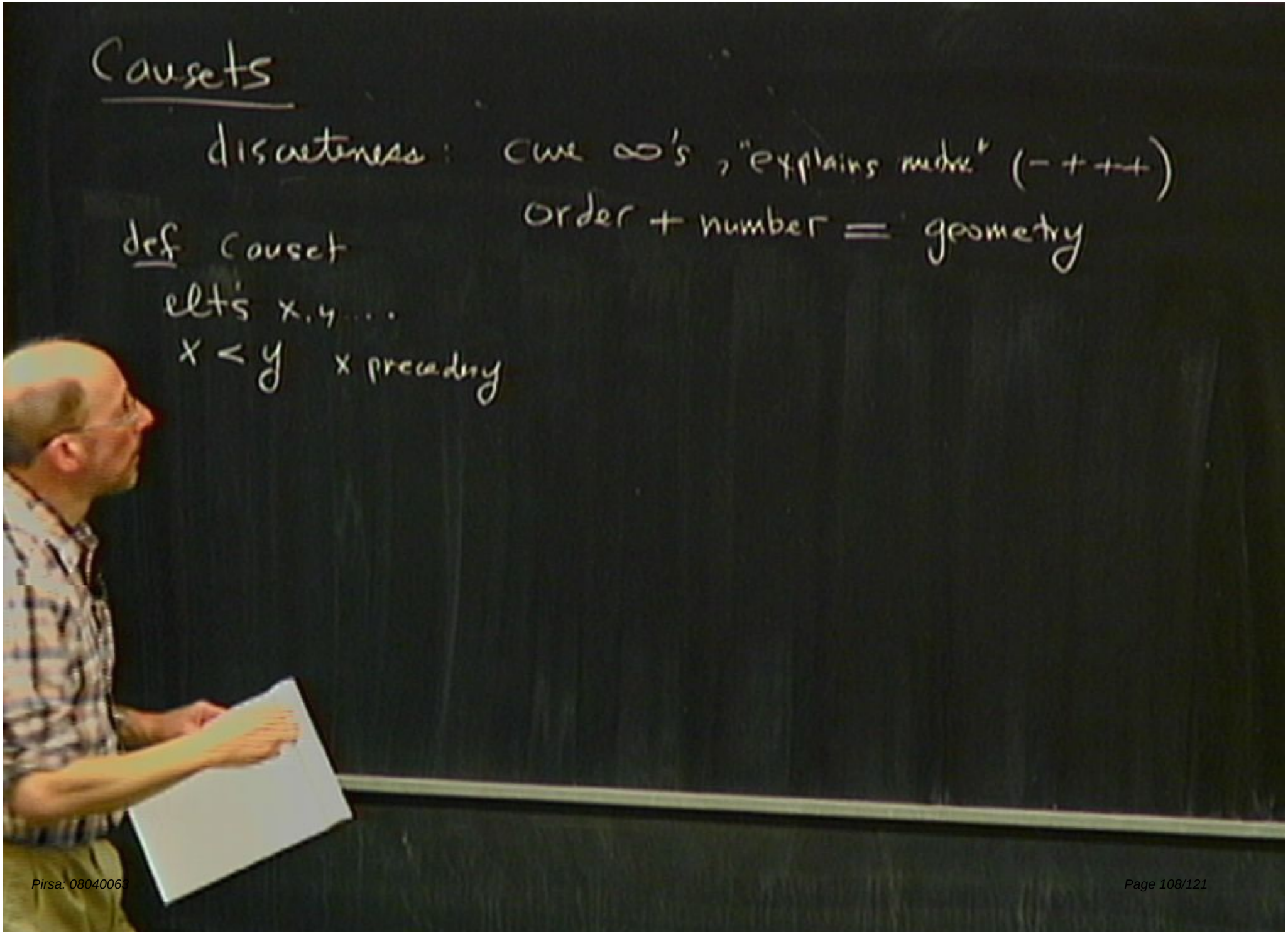

Causets
discreteness: cure ∞'s, "explains mass"


Causets
discreteness: cure ∞'s, "explains matter" (− + + + +)


Causets
discreteness: cure ∞'s, "explains matter" (− + + +)
order + number =


Causets
discreteness: cure ∞'s, "explains mass" (− + + +)
order + number = geometry


Causets
discreteness: cure ∞'s, "explains mass" (− + + +)
order + number = geometry
def Causet
elt's x, y ...
x < y


Causets
discreteness: cure ∞'s, "explains mass" (− + + +)
order + number = geometry
def Causet
elt's x, y ...
x < y x precedes y

Causets

discreteness: cure ∞'s, "explains matter" $(-+++)$

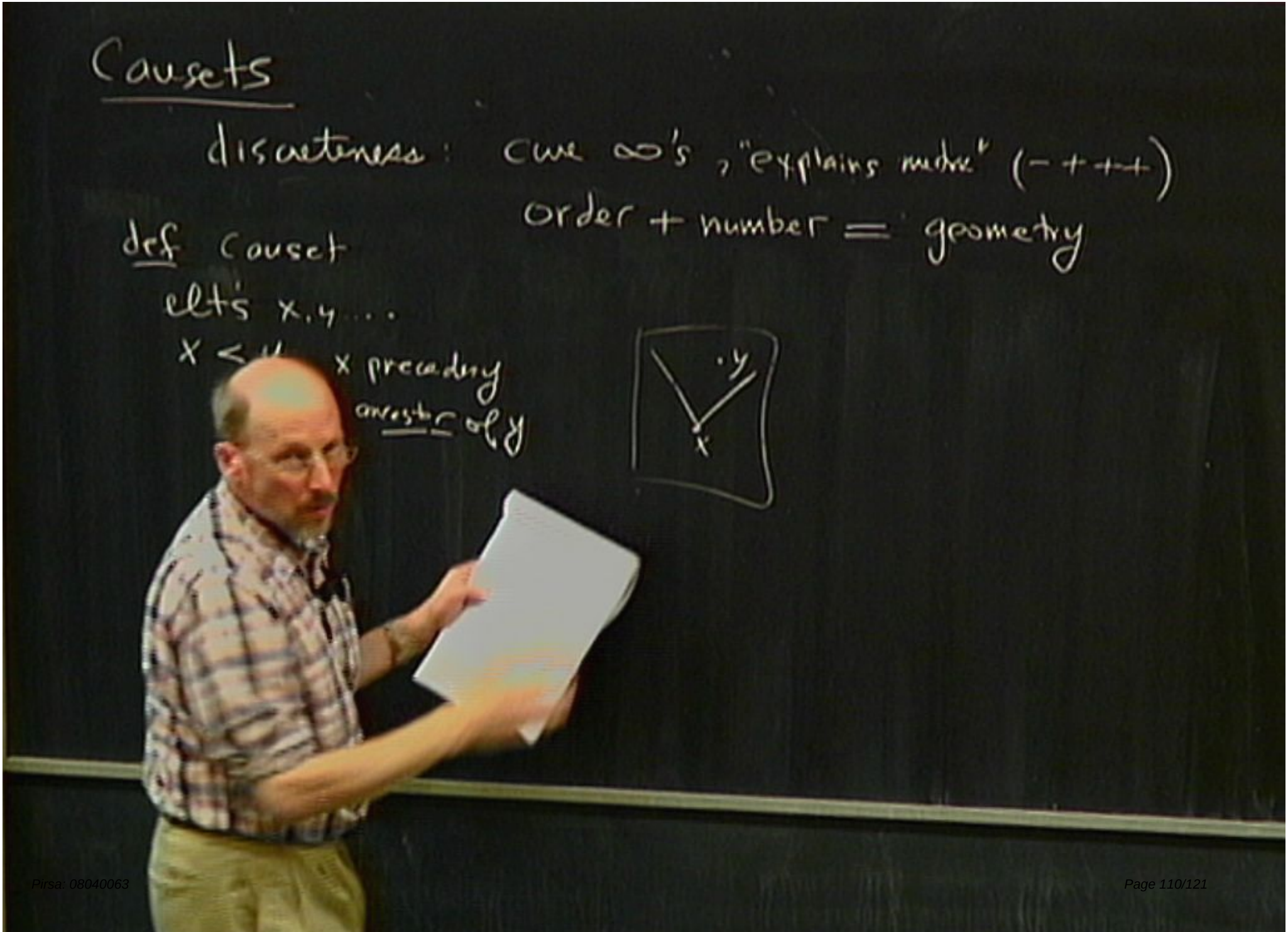
order + number = geometry

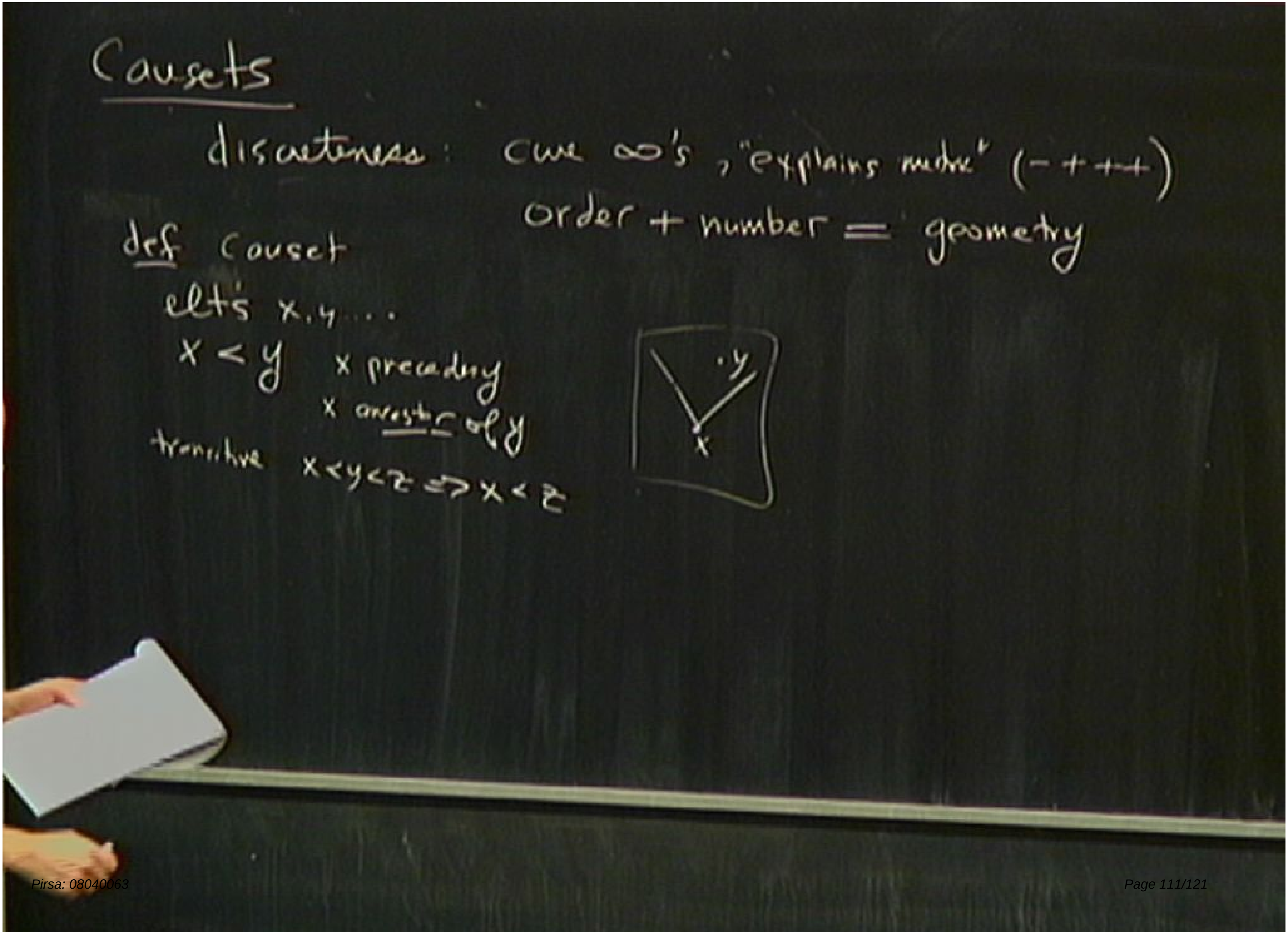
def Causet

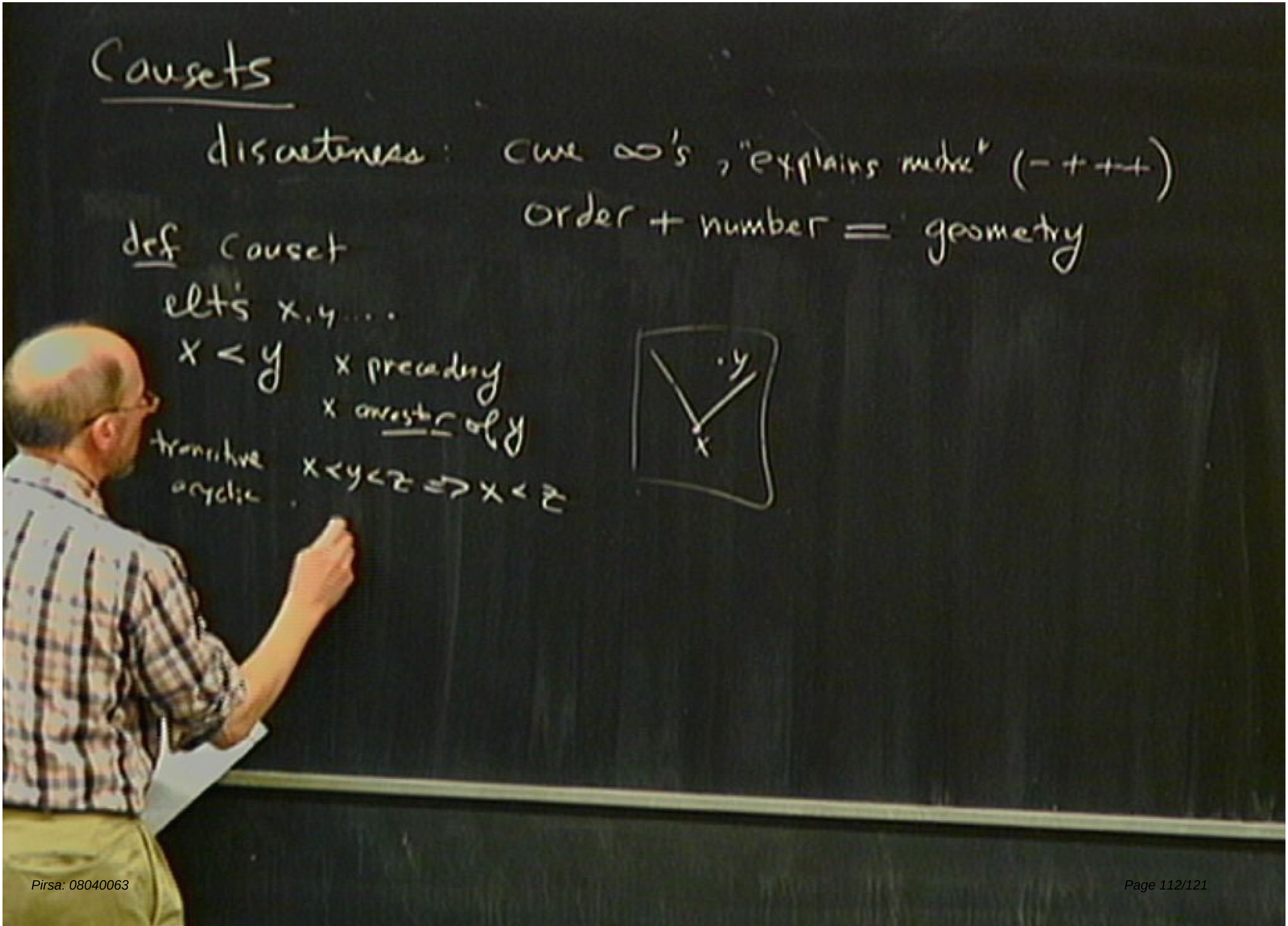
elt's $x, y \ldots$

$x \prec y$ x precedes y

x <u>immediately</u> precedes y


Causets
discreteness: cure ∞'s, "explains nature" (− + + + +)
order + number = geometry
def Causet
elt's x, y ...
x < y
x precedes y
y
x


Causets
discreteness: cure ∞'s, "explains metric" (− + + +)
order + number = geometry
def causet
elt's x, y . . .
x < y
x preceding y
x ancestor of y
transitive x < y < z => x < z
y
x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discreteness: cure ∞'s, "explains metric" (− + + +)
order + number = geometry
def causet
elt's x, y, . . .
x < y
x preceding
x ancestor of y
transitive
acyclic
x < y < z => x < z
y
x

Causets

discreteness: cure ∞'s, "explains metric" $(-+++)$

order + number = geometry

def causet

elt's $x, y, \ldots$

$x < y$ x preceding y

x ancestor of y

transitive $x < y < z \Rightarrow x < z$

acyclic: $x \not< x$

Causets

discreteness: cure ∞'s, "explains metric" $(-+++)$

order + number = geometry

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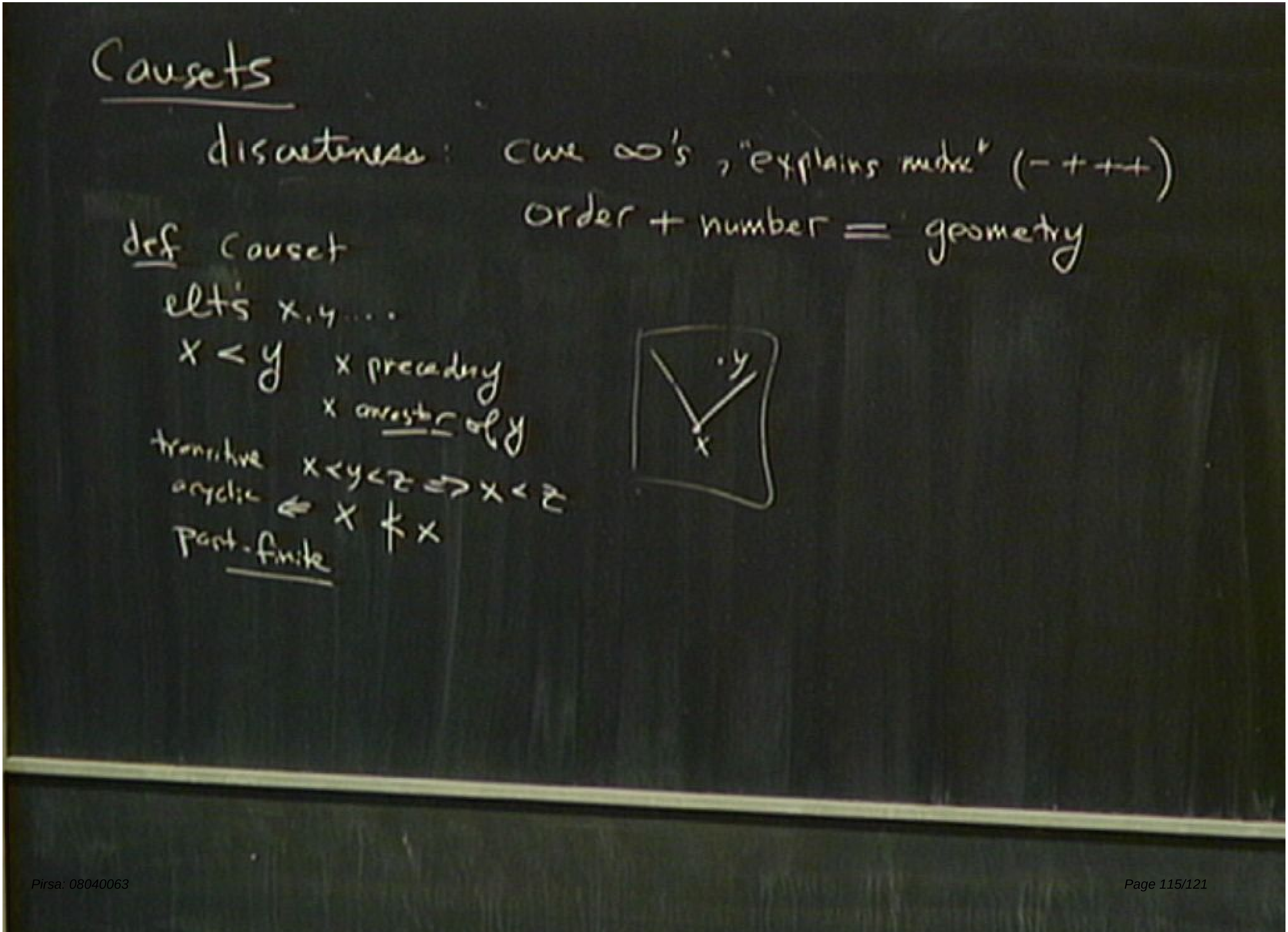

Causets
discreteness: cure ∞'s, "explains metric" (− + + +)
order + number = geometry
def Causet
elt's x, y ....
x < y x preceding
x ancestor of y
transitive x<y<z ⇒ x<z
acyclic ⇐ x ≮ x
past-finite
y
x

Causets

discreteness: cure ∞'s, "explains metric" $(-+++)$

order + number = geometry

def Causet

elt's $x, y \ldots$

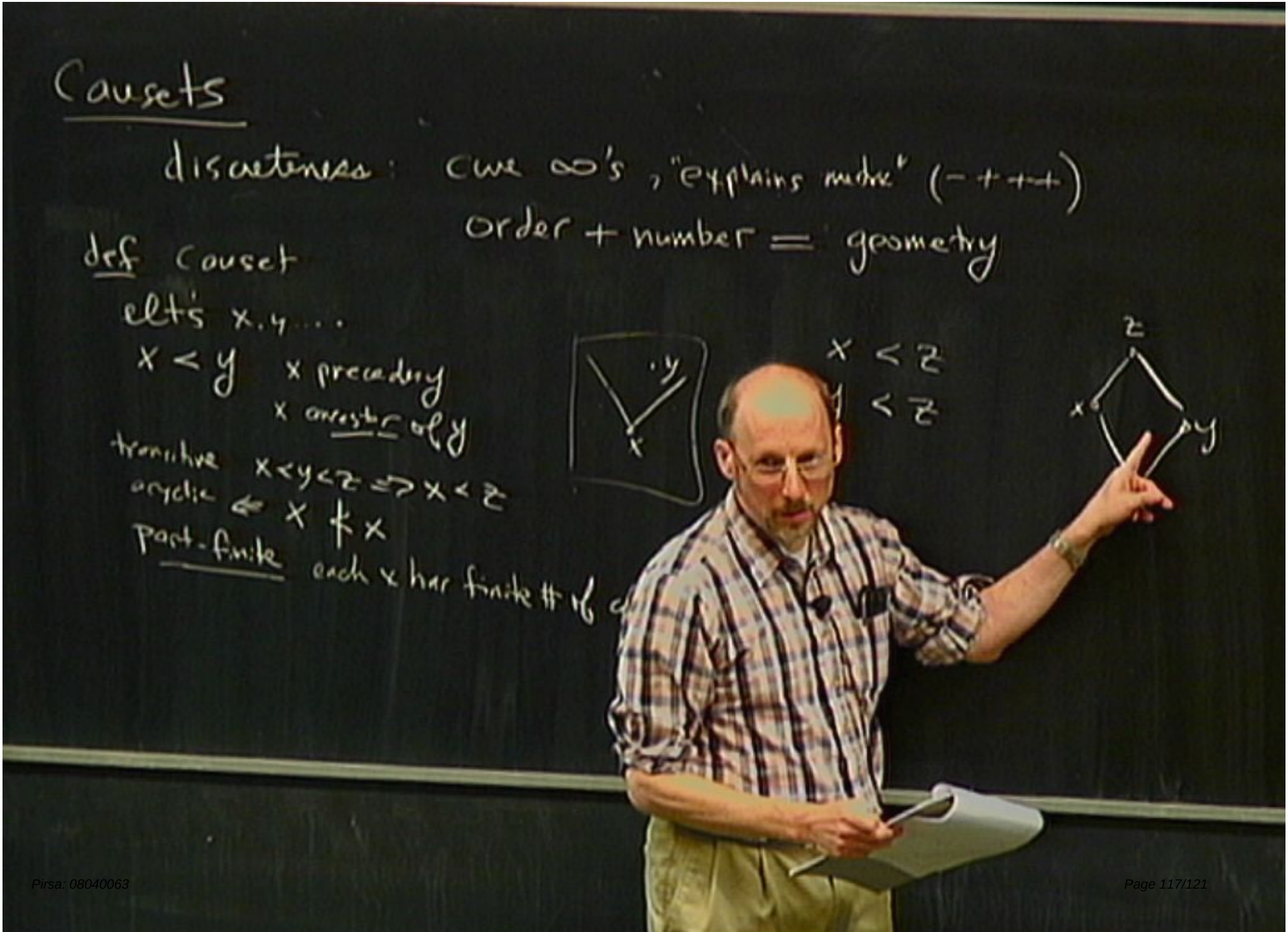
$x \prec y$ x precedes y

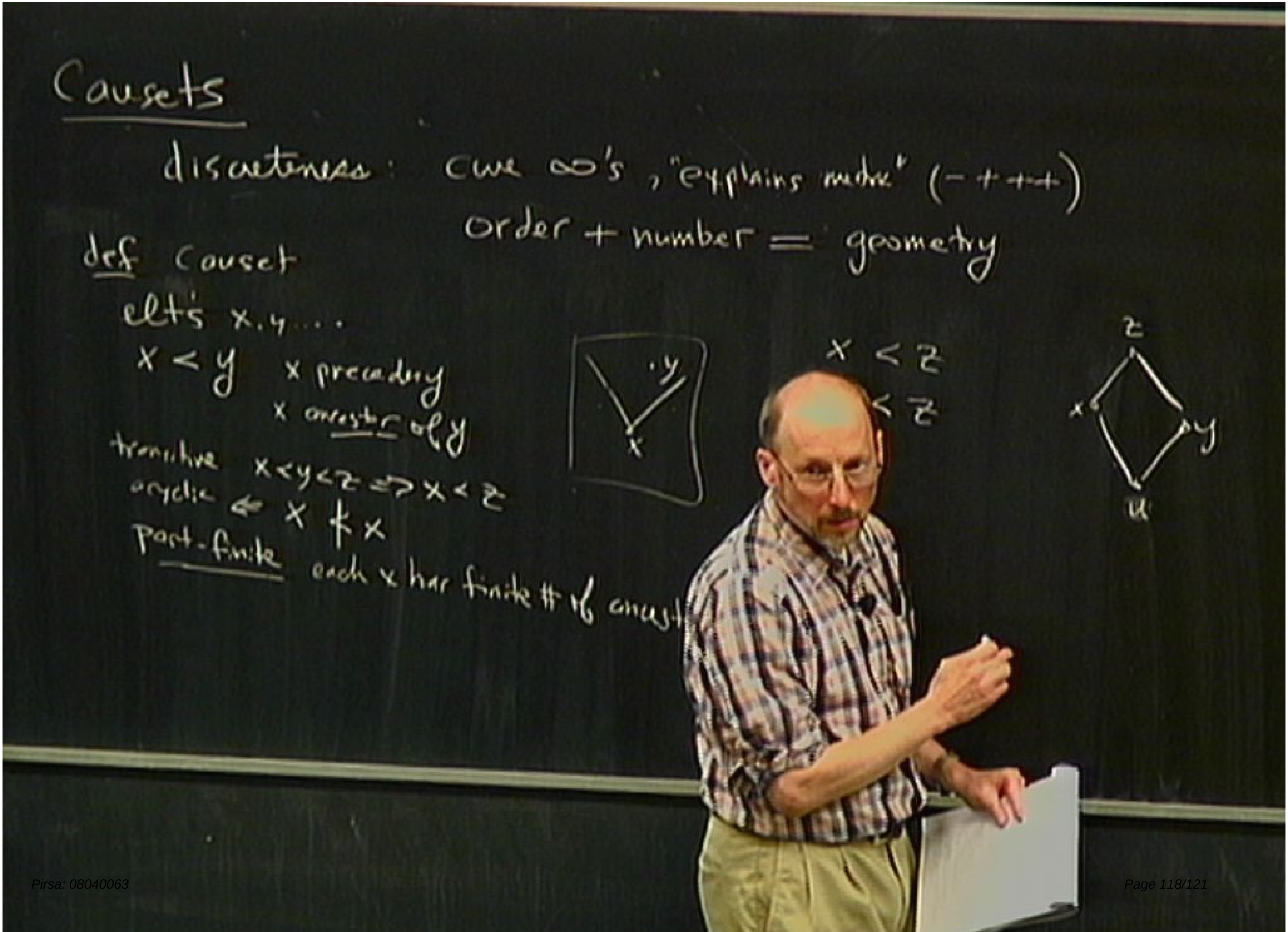
x ancestor of y

transitive $x \prec y \prec z \Rightarrow x \prec z$

acyclic $\Leftarrow x \not\prec x$

part-finite each x has finite # of ancestors


Causets
discreteness: cure ∞'s, "explains mass" (− + + − +)
order + number = geometry
def Causet
elt's x, y, ...
x < y x precedes y
x comes before y
transitive x<y<z ⇒ x<z
acyclic ⇐ x ≠ x
Part. finite each x has finite # of
x < z
< z
z
x
y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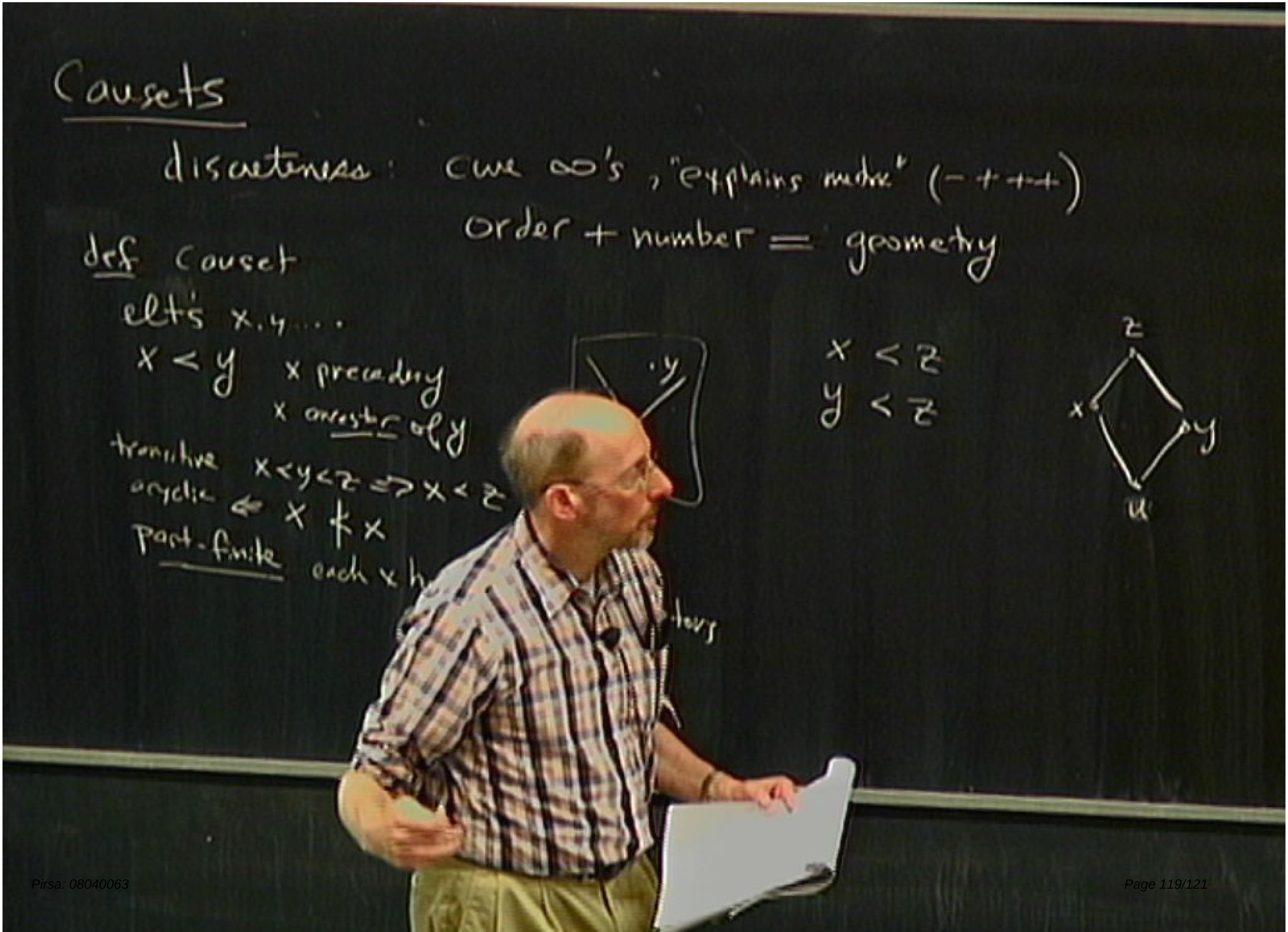
order + number = geometry
def causet
elt's x, y, ...
x < y   x preceding y
x ancestor of y
transitive   x < y < z ⇒ x < z
acyclic ⇐ x ≮ x
past-finite   each x has finite # of
x < z
z
x
y
u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y

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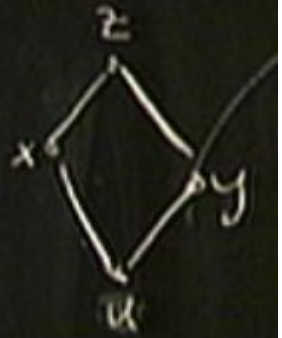
x ancestor of y

$x < z$

$y < z$



transitive $x < y < z \Rightarrow x < z$

acyclic $\Leftarrow x \not< x$

Part.-finite each x has f

Causets

discreteness: cure ∞'s, "explains metric" $(-+++)$

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$x < y$ x precedes y

x ancestor of y

$x < z$

$y < z$

transitive $x < y < z \Rightarrow x < z$

acyclic $\Leftarrow x \not< x$

Past-finite each x has finite # of ancestors