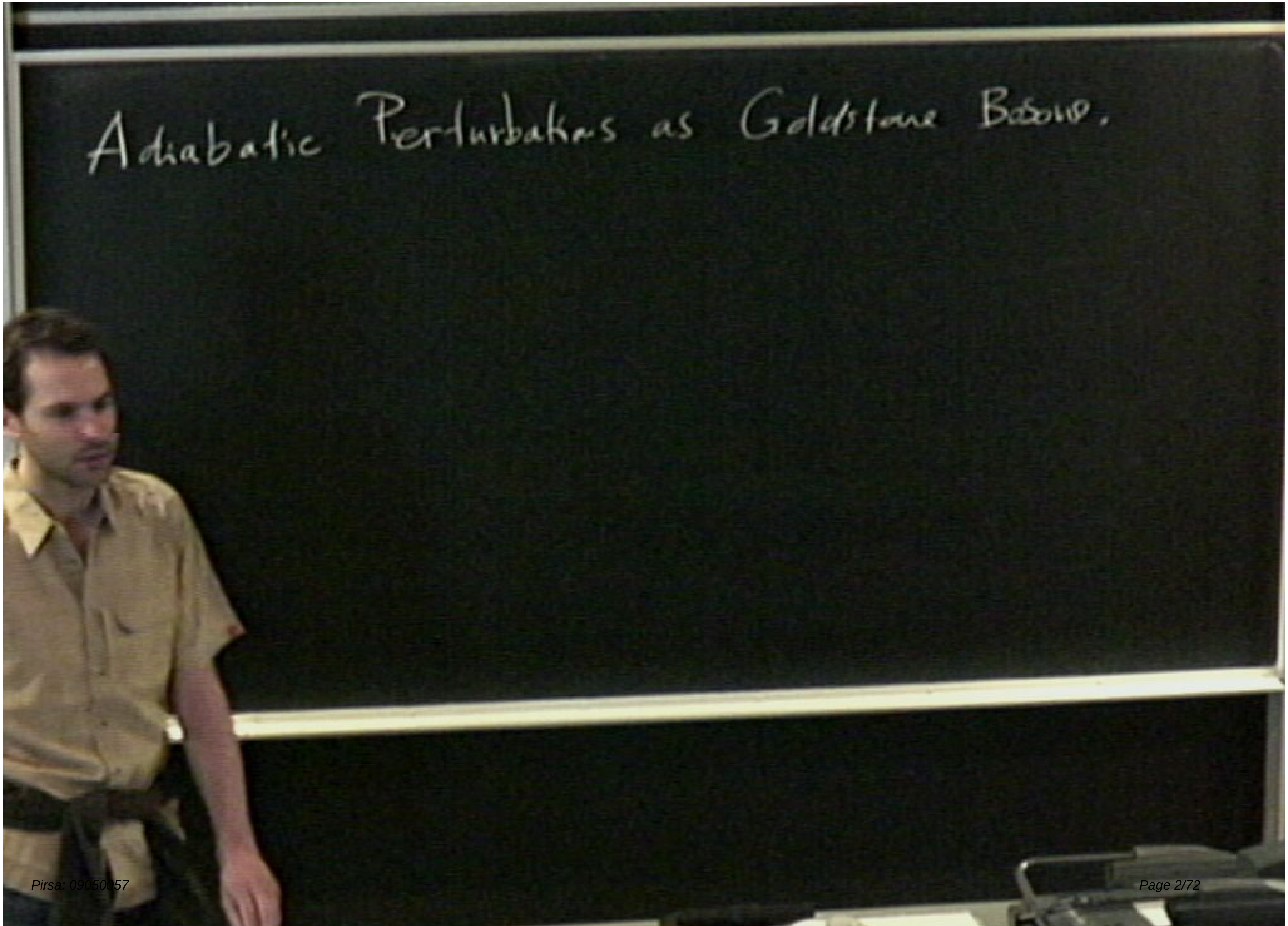
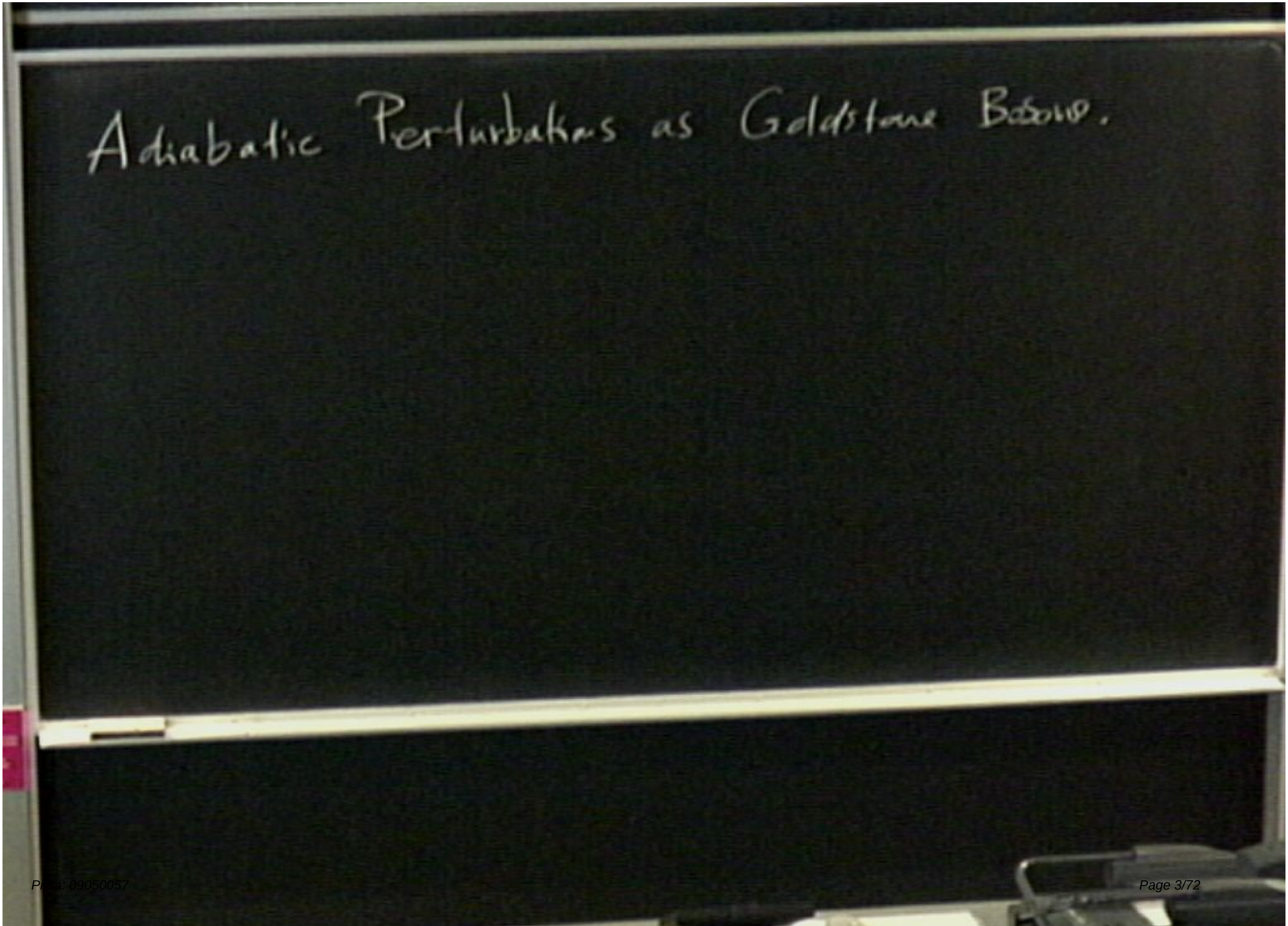
Title: Adiabatic perturbations as Goldstone bosons

Date: May 21, 2009 11:30 AM

URL: http://pirsa.org/09050057

Abstract: TBA


Adiabatic Perturbations as Goldstone Bosons.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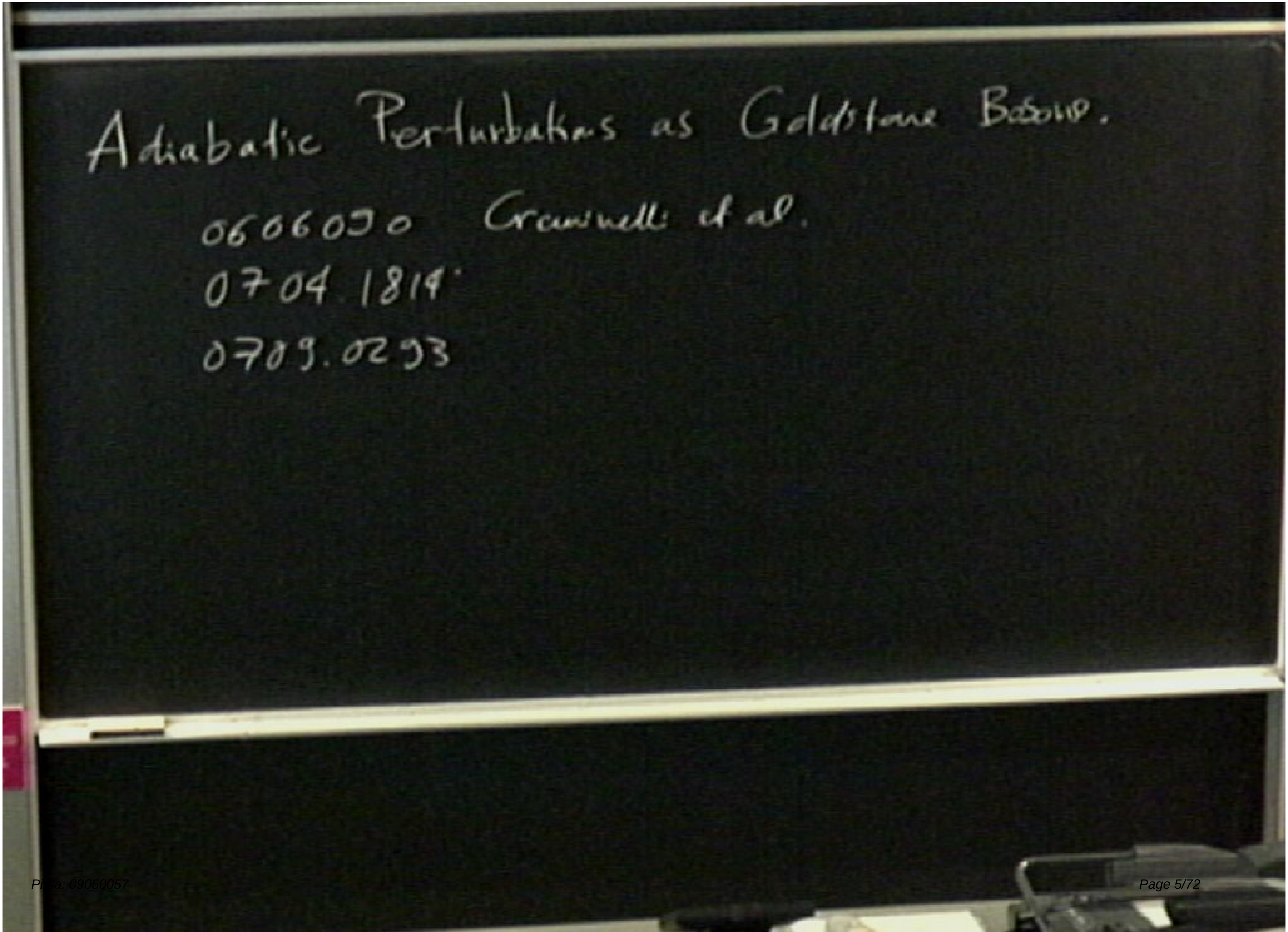
0606090 Creminelli et al.


Adiabatic Perturbations as Goldstone Bosons.
0606090 Creminelli et al.
0704.1814
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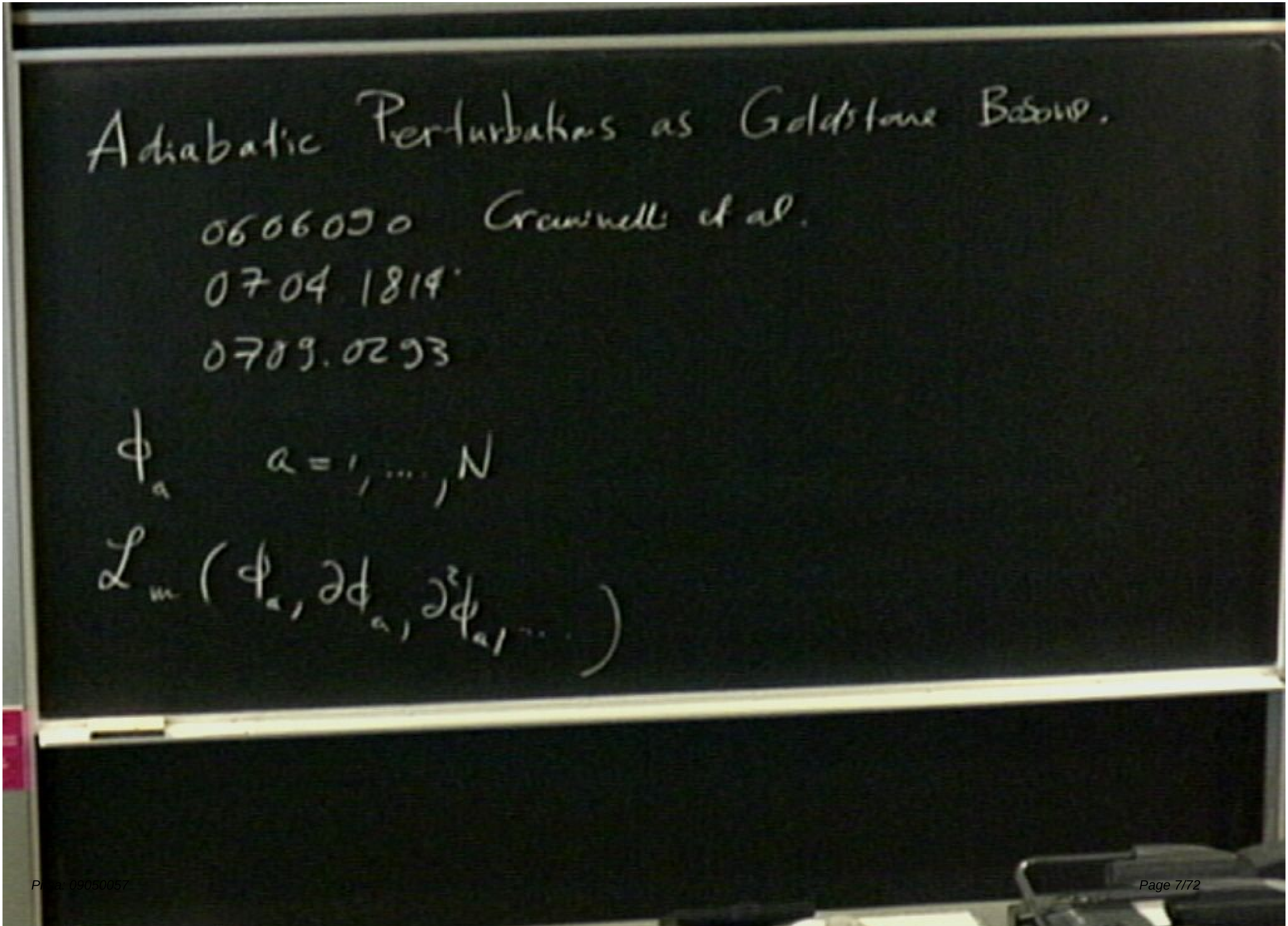
$\phi_a \quad a = 1, \ldots, N$


Adiabatic Perturbations as Goldstone Bosons.
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0709.0293
ϕ_a $a = 1, \dots, N$
$\mathcal{L}_m(\phi_a, \partial\phi_a, \partial^2\phi_a, \dots)$

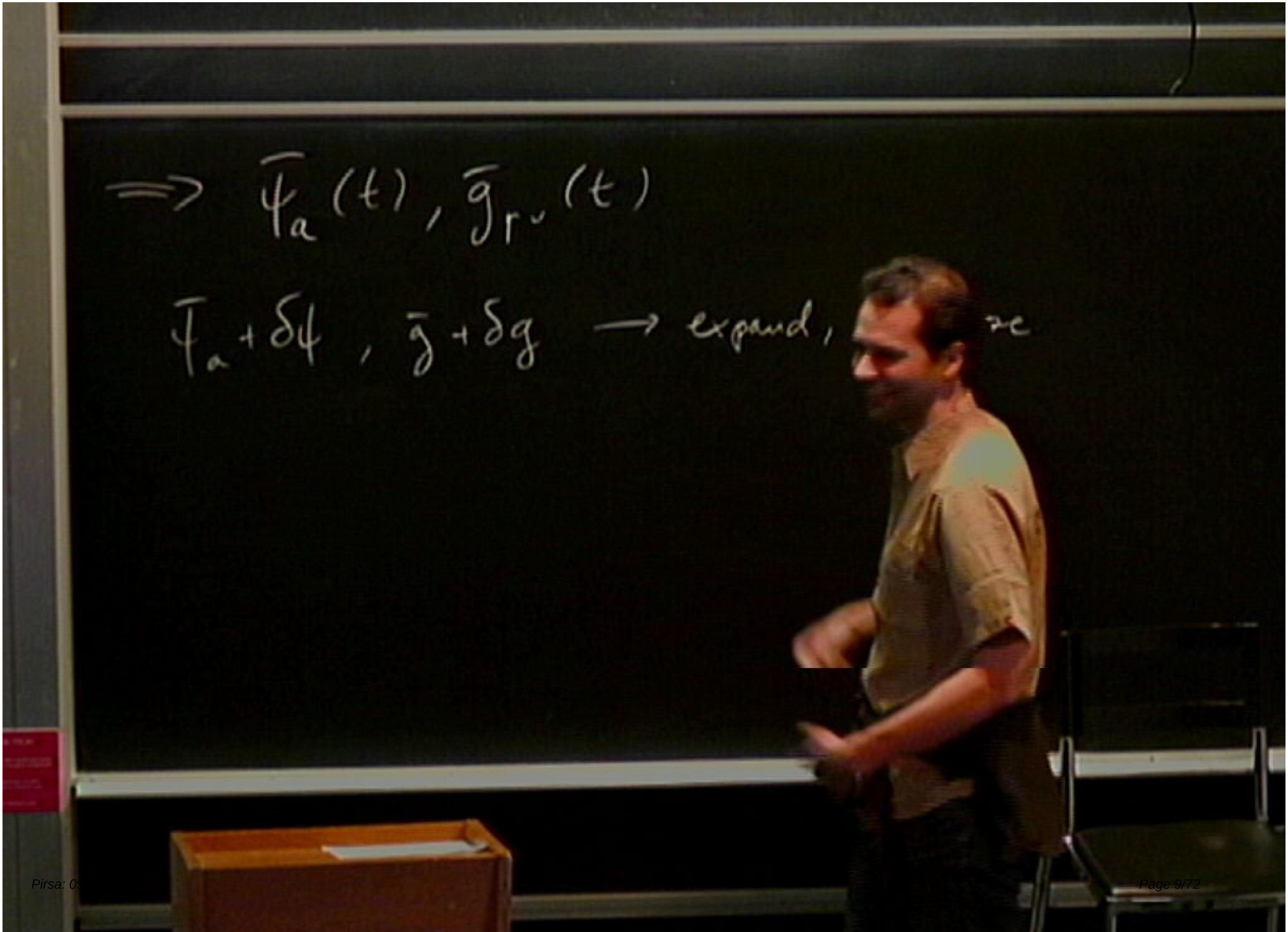
0606090 Creminelli et al.

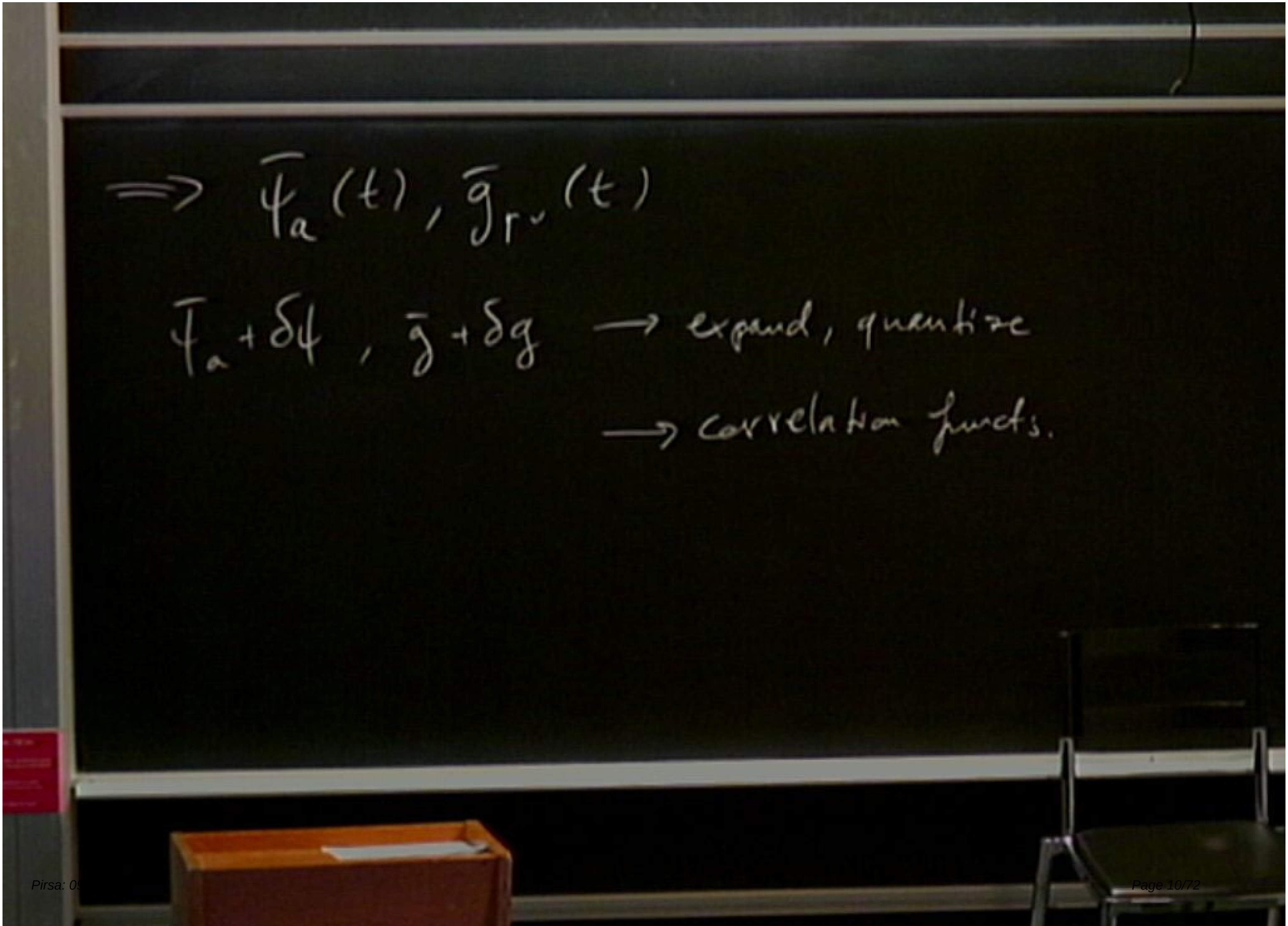
0704.1814

0709.0293

$\phi_a \quad a = 1, \dots, N$

$$\mathcal{L}_m(\phi_a, \partial\phi_a, \partial^2\phi_a, \dots) \longrightarrow T_{\mu\nu}, \quad \frac{\delta \mathcal{L}_m}{\delta \phi_a}, \quad \text{FRW}$$

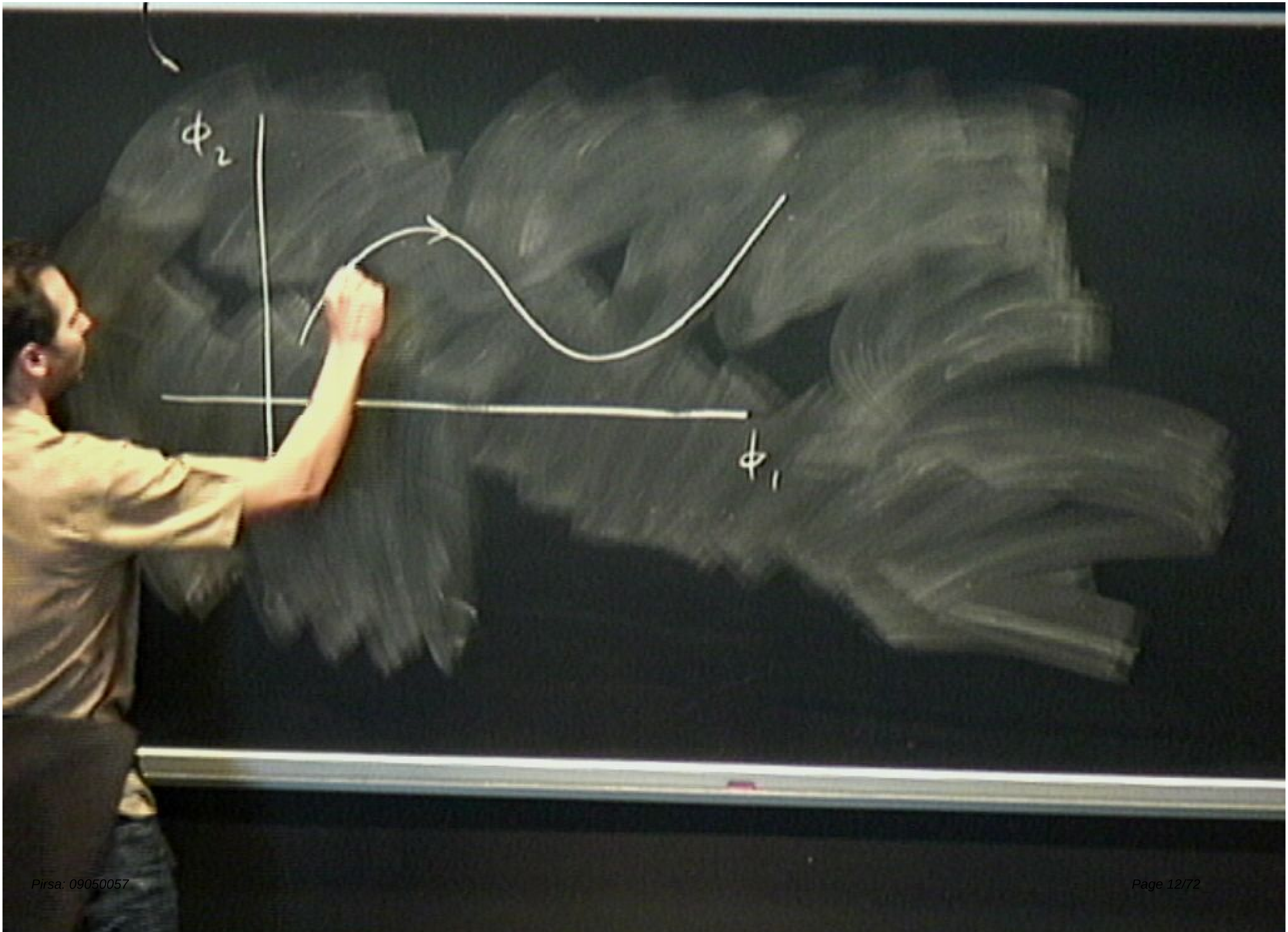

$\Rightarrow \bar{\varphi}_a(t), \bar{g}_{\mu\nu}(t)$
$\bar{\varphi}_a + \delta\varphi, \bar{g} + \delta g \rightarrow$ expand,

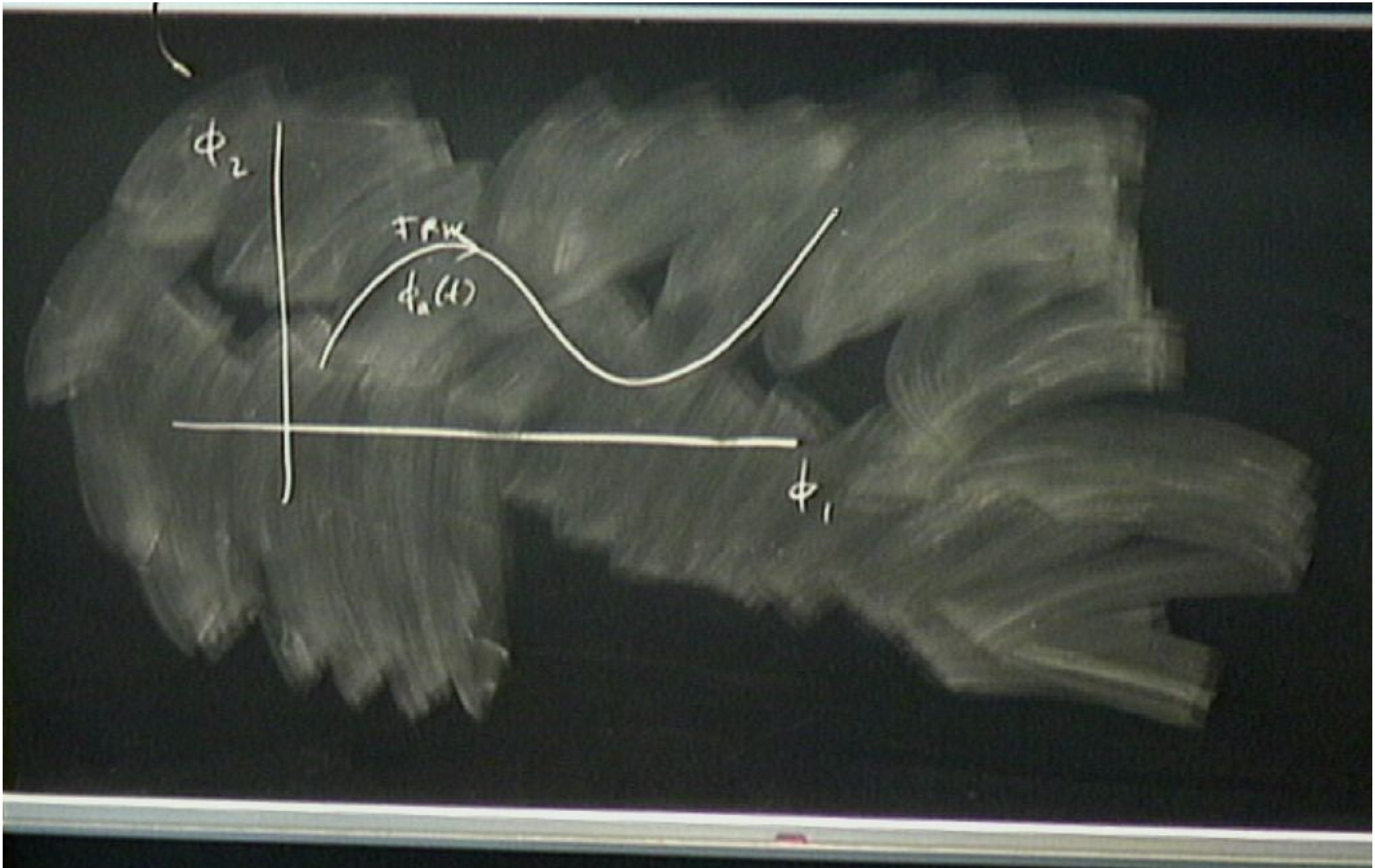

$\Longrightarrow \bar{\varphi}_a(t), \bar{g}_{\mu\nu}(t)$
$\bar{\varphi}_a + \delta\varphi, \bar{g} + \delta g$ → expand, quantize
→ correlation functs.

$$\Longrightarrow \bar{\varphi}_a(t), \bar{g}_{\mu\nu}(t)$$

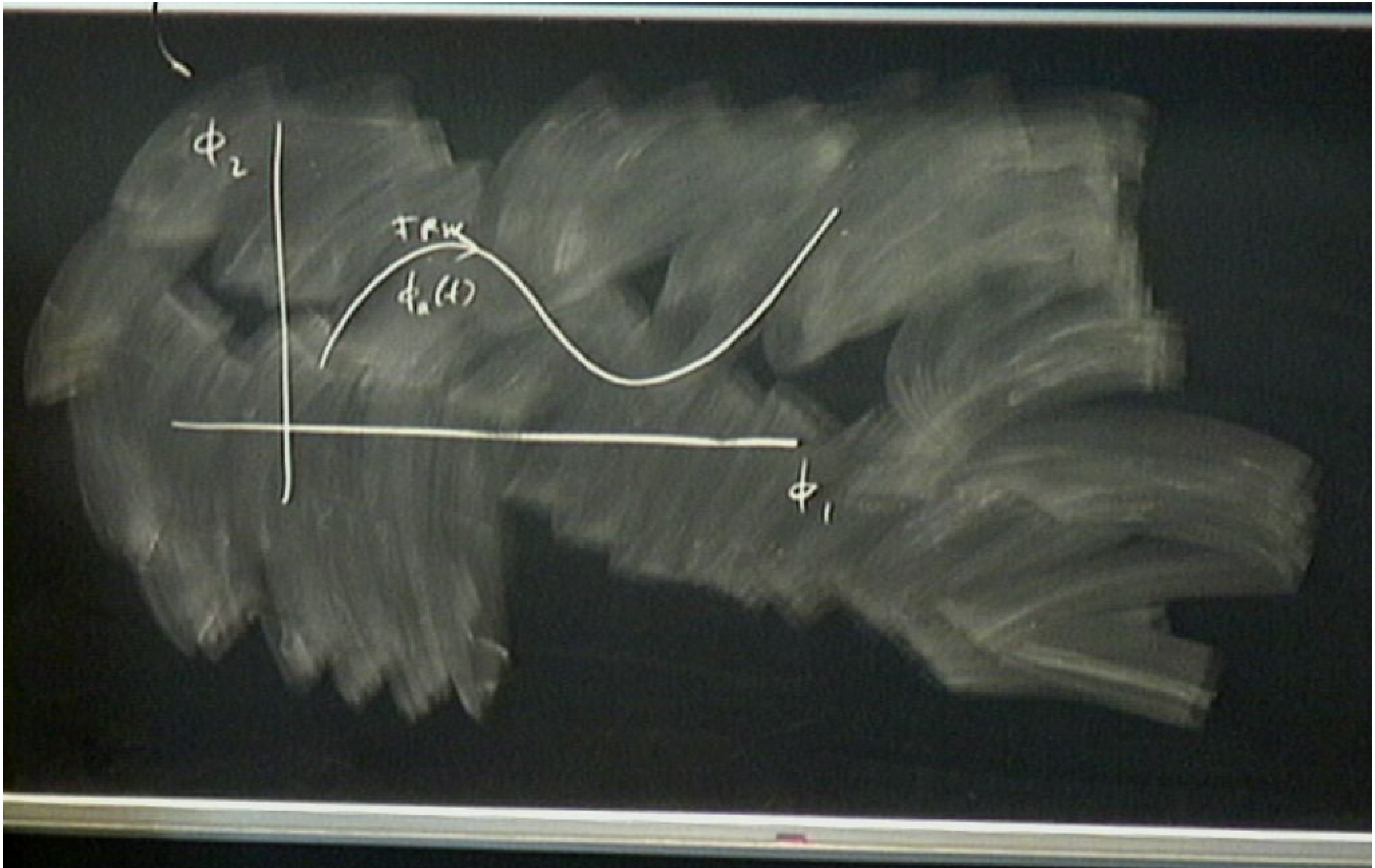
$\bar{\varphi}_a + \delta\varphi$, $\bar{g} + \delta g$ $\longrightarrow$ expand, quantize

$\longrightarrow$ correlation functs.

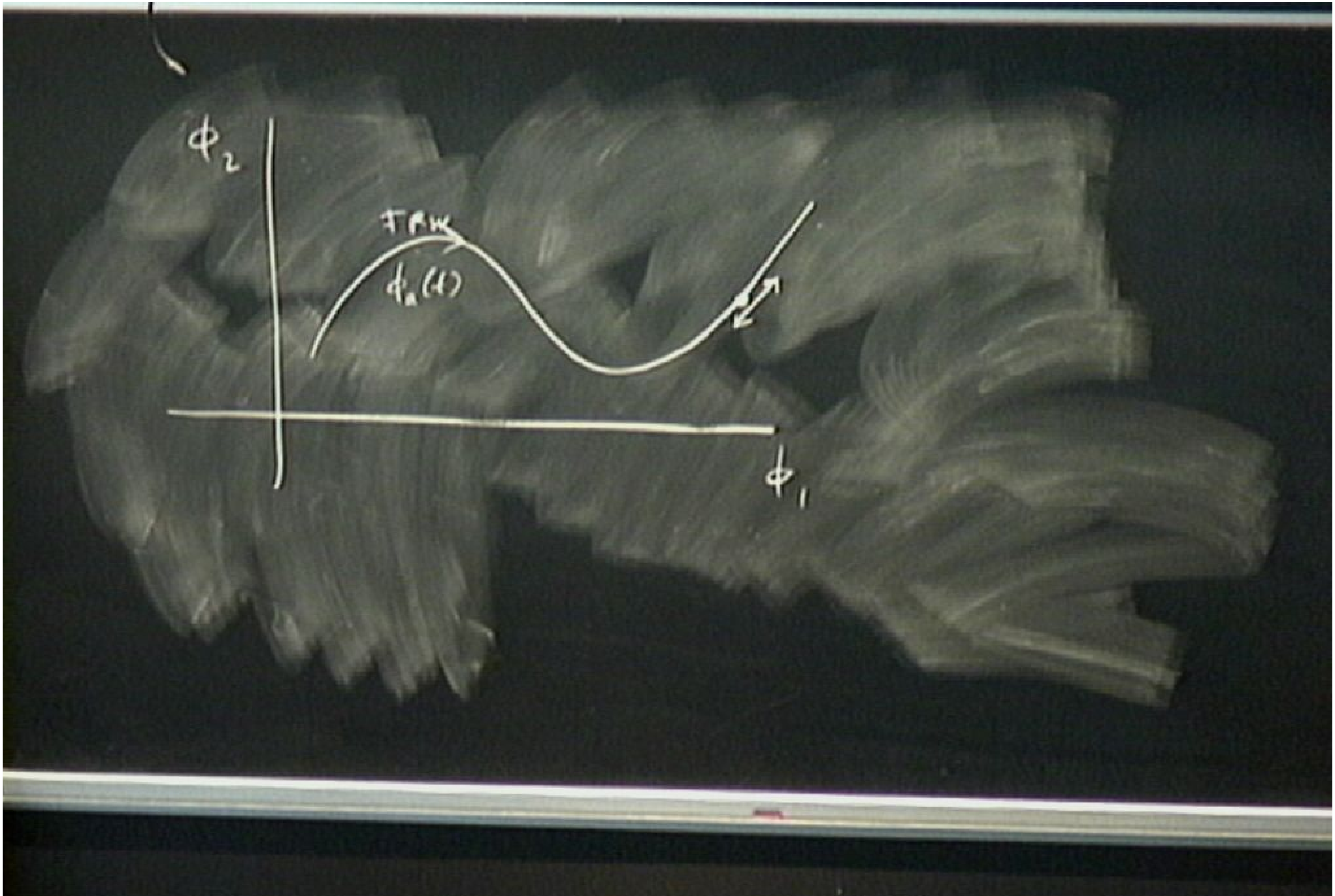

ϕ_2
ϕ_1

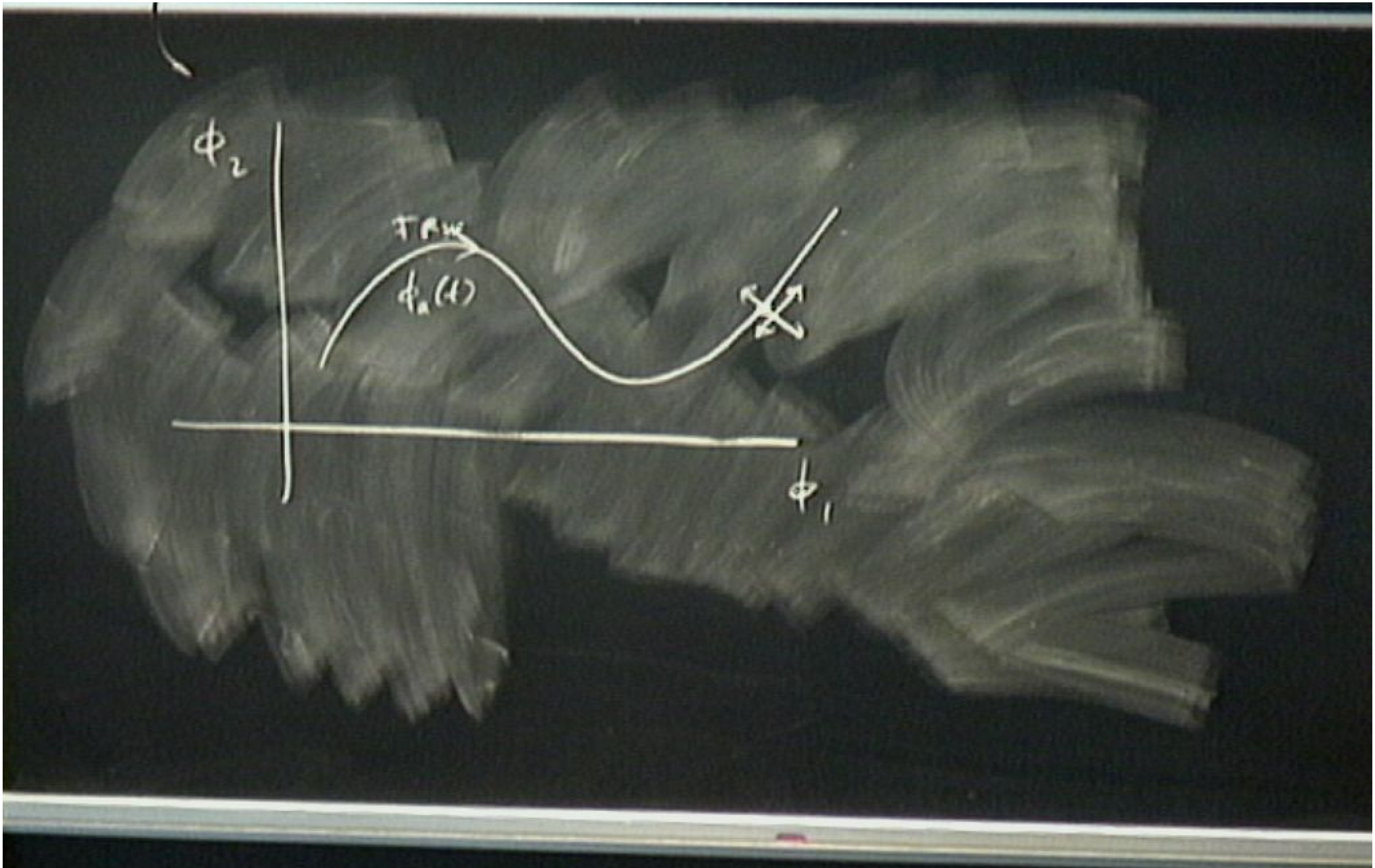


ϕ_2
FRW
ϕ_1

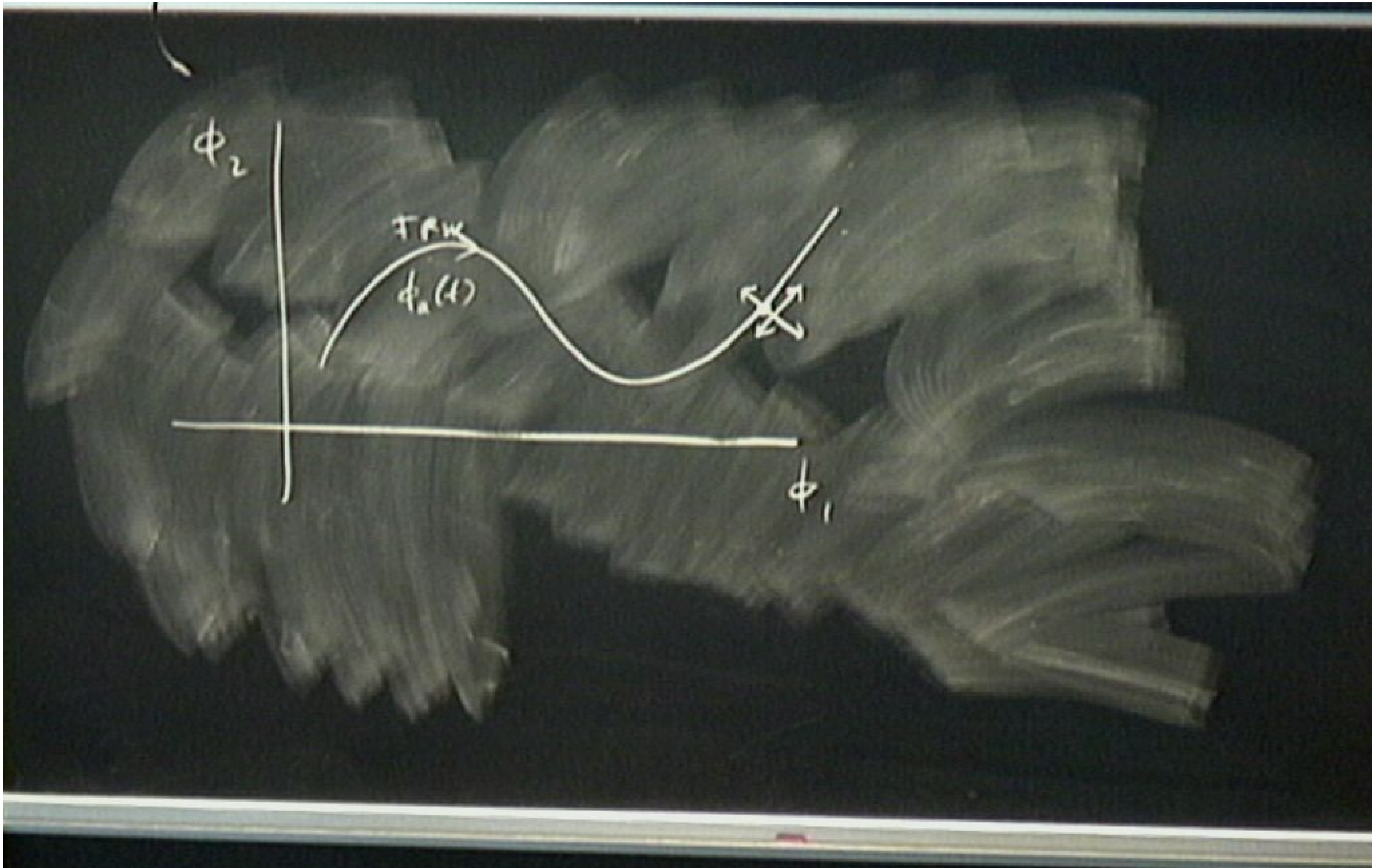


FRW


FRW



ϕ_2
FRW
$\phi_a(t)$
ϕ_1



ϕ_2
FRW
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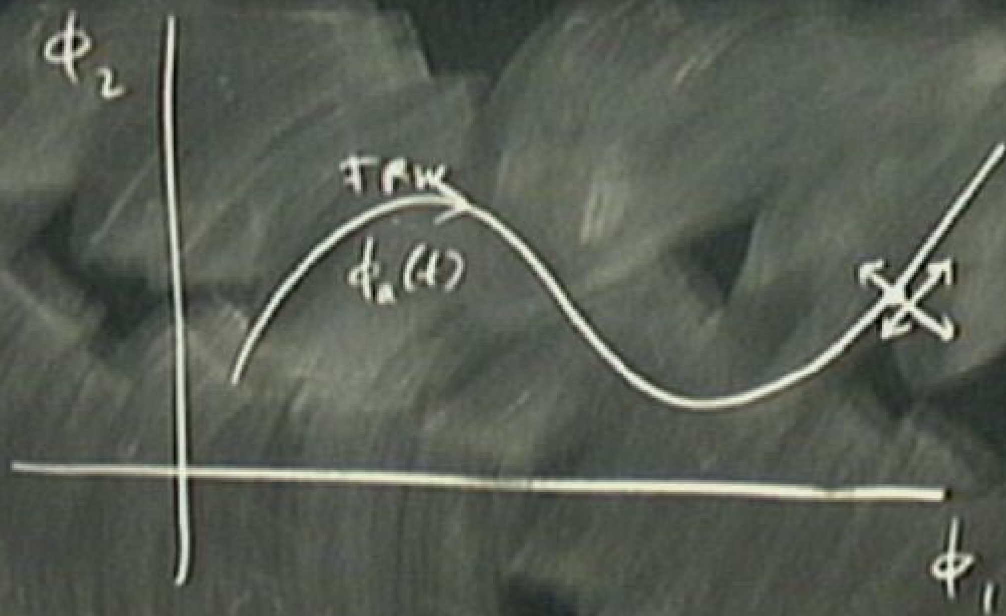
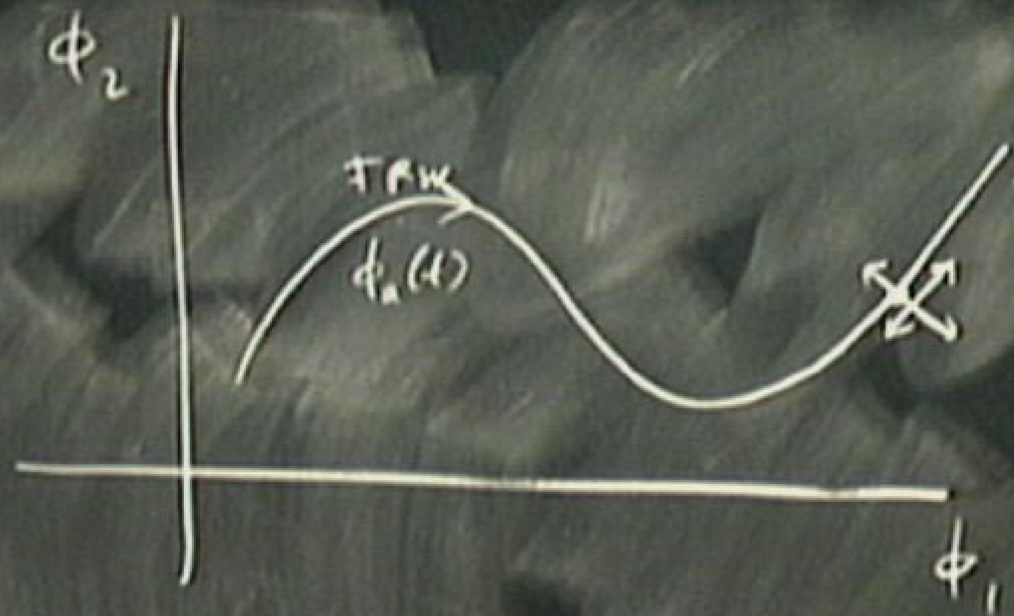


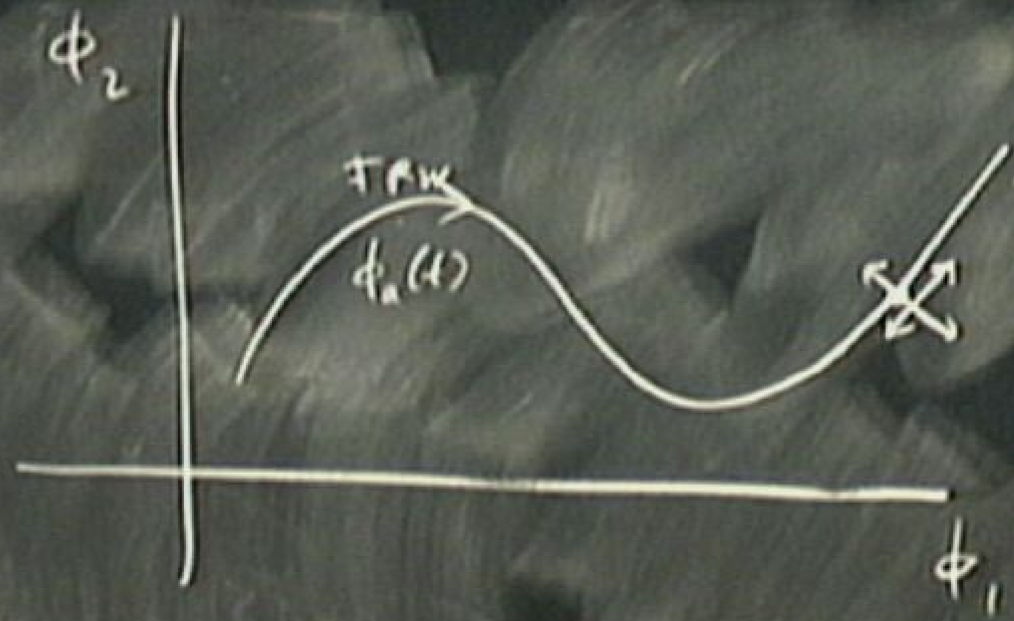
Focus on. Va $\delta\phi_a(x) = \bar{\phi}_a(t + \pi(x)) - \bar{\phi}_a(t)$

$\pi \neq 3.14\ldots$



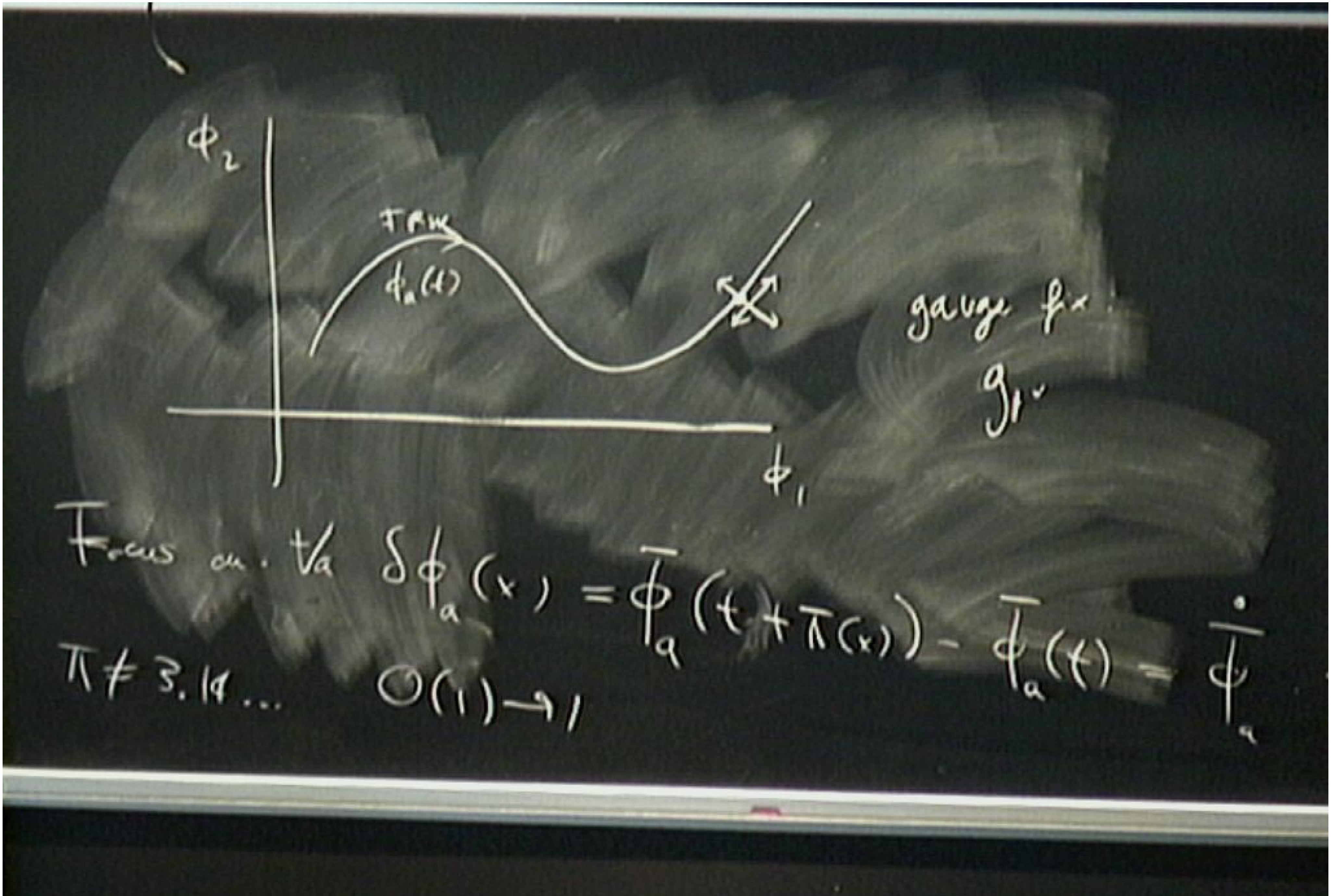
Focus on: Va $\delta\phi_a(x) = \bar{\phi}_a(t+\pi(x)) - \bar{\phi}_a(t) = \dot{\bar{\phi}}_a \cdot$

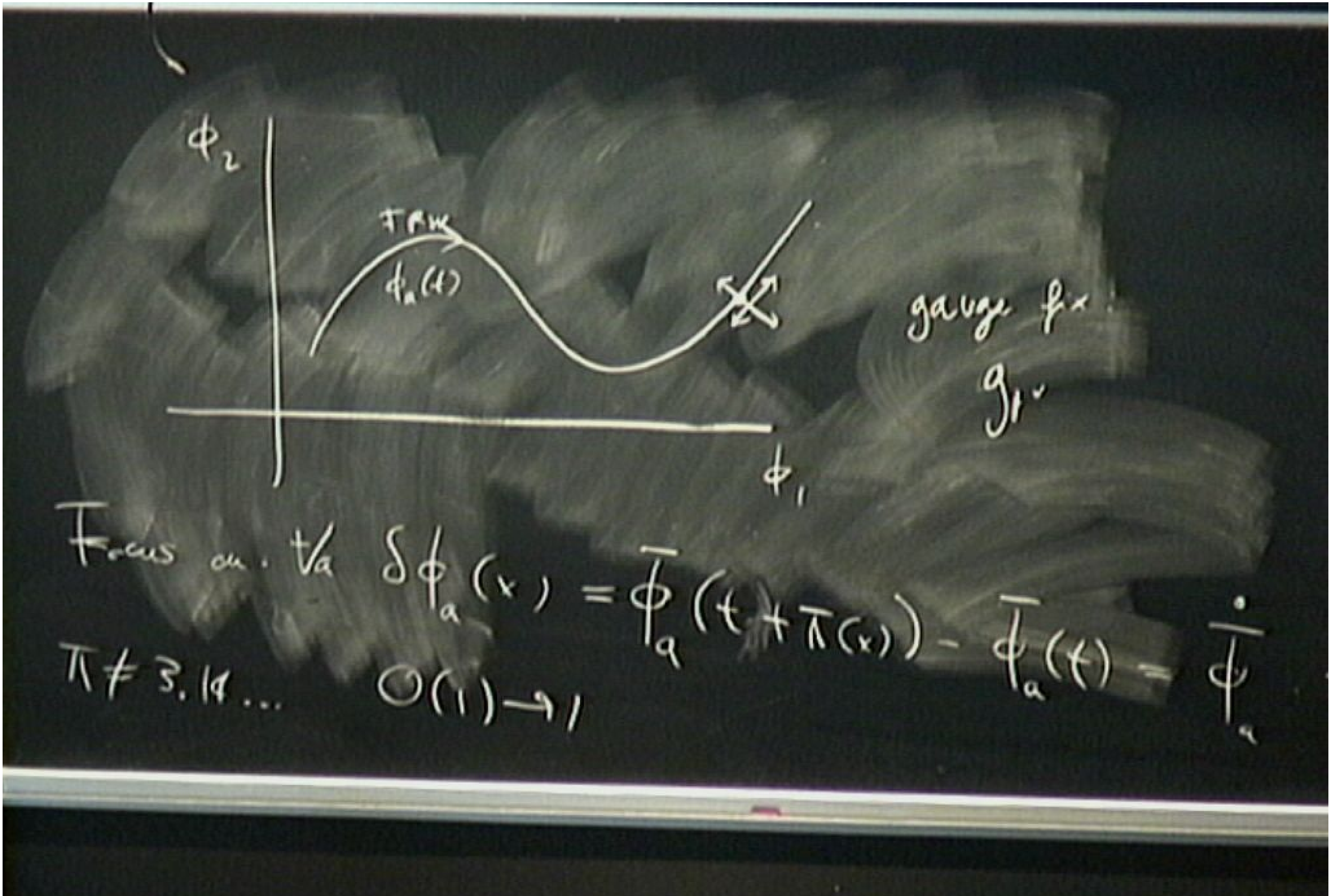
$\pi \neq 3.14\ldots \qquad O(1) \to 1$



Focus on: t/a $\quad \delta\phi_a(x) = \bar{\phi}_a(t+\pi(x)) - \bar{\phi}_a(t) = \dot{\bar{\phi}}_a$

$\pi \neq 3.14\ldots \qquad O(1) \to 1$


φ₂
FRW
φa(t)
gauge fix
gμν
φ₁
Focus on. t/a δφa(x) = φ̄a(t + π(x)) - φ̄a(t) = φ̄̇a
π ≠ 3.14... O(1) → 1


ϕ2
FRW
ϕa(t)
gauge fix
gμν
ϕ1
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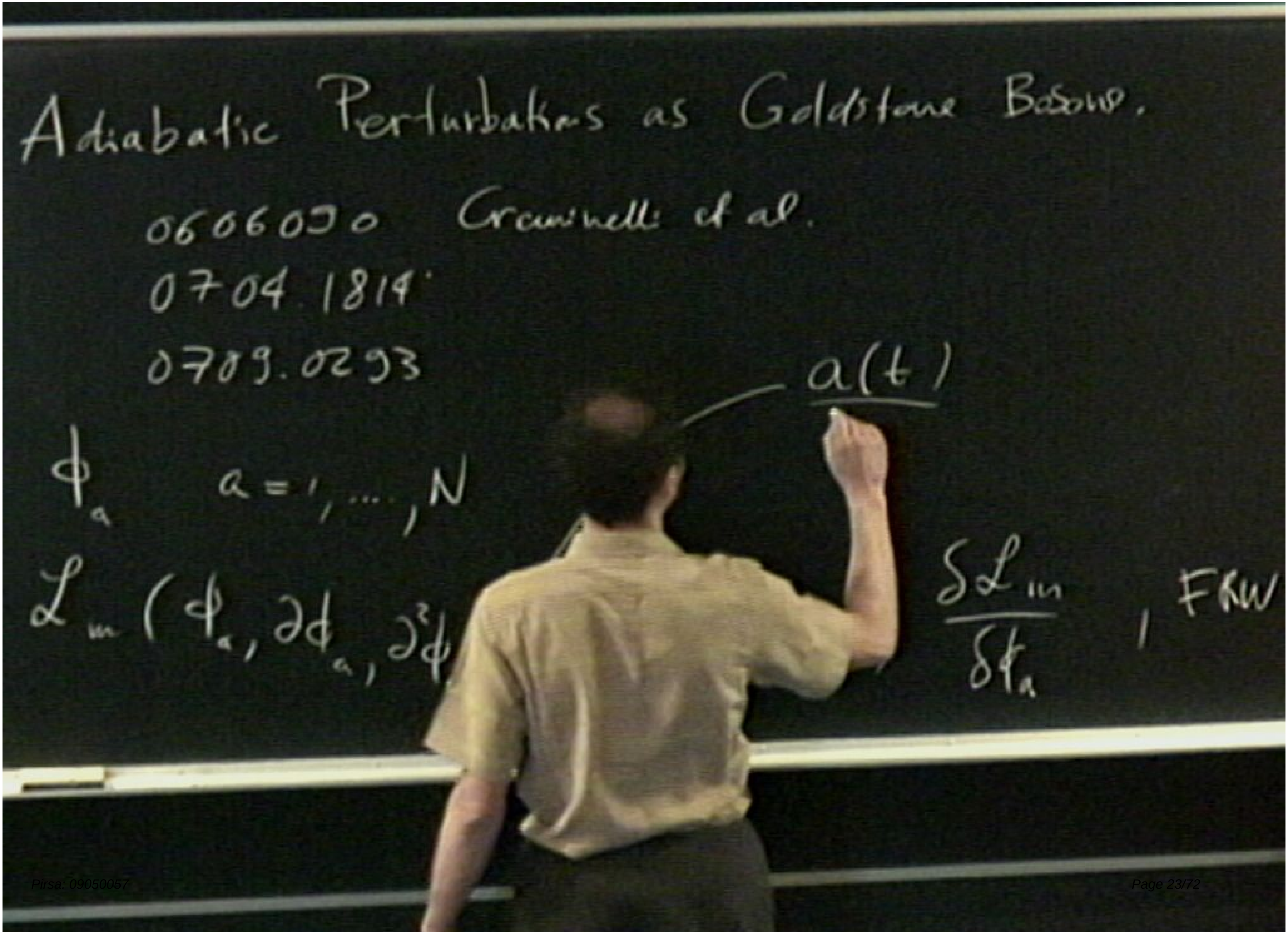
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a(t)
φ_a a = 1, ..., N
L_m(φ_a, ∂φ_a, ∂²φ
δL_m / δφ_a
, FRW

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$a(t)$

$\phi_a \quad a = 1, \dots, N$

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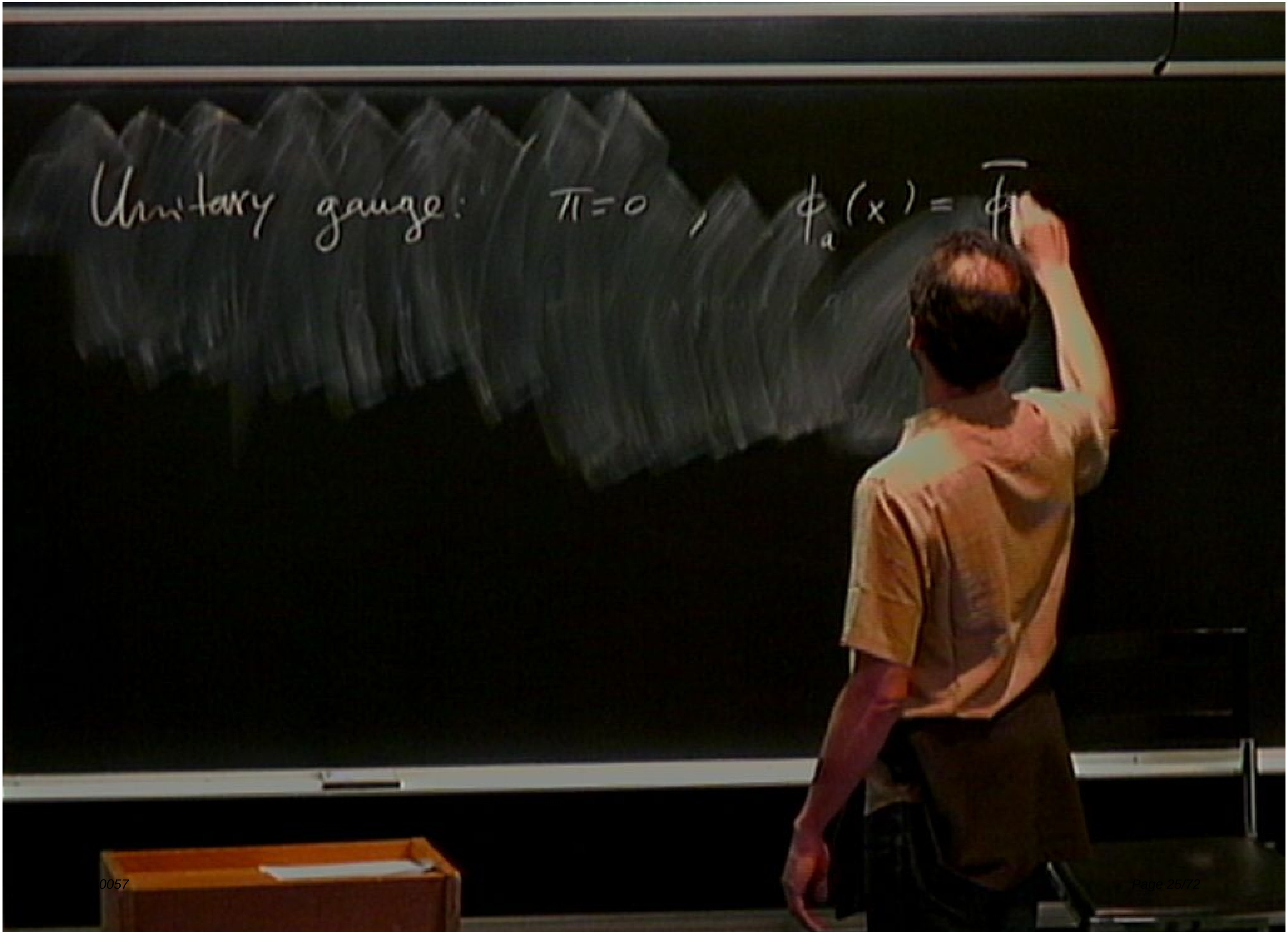
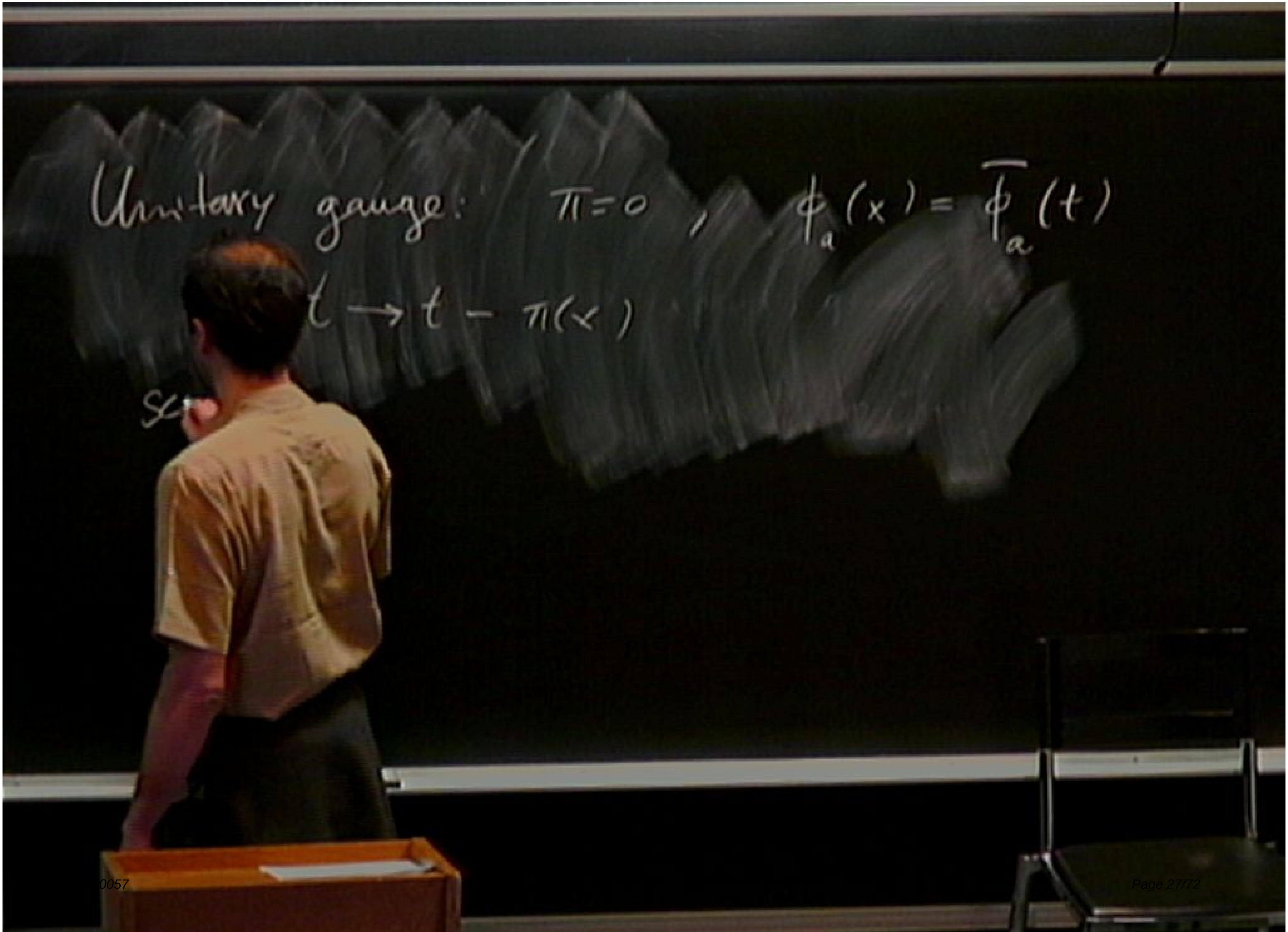

Unitary gauge: π = 0 , φa(x) =

Unitary gauge: $\pi = 0$, $\phi_a(x) = \bar{\phi}_a(t)$



Unitary gauge: $\pi = 0$, $\phi_a(x) = \bar{\phi}_a(t)$
$t \to t - \pi(x)$

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scalar mode in the metric

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scalar mode in the metric

2) Spatial diffs: $x^i \to x^i + \xi^i(t, x)$

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$$\boxed{t \to t - \pi(x)}$$

scalar mode in the metric

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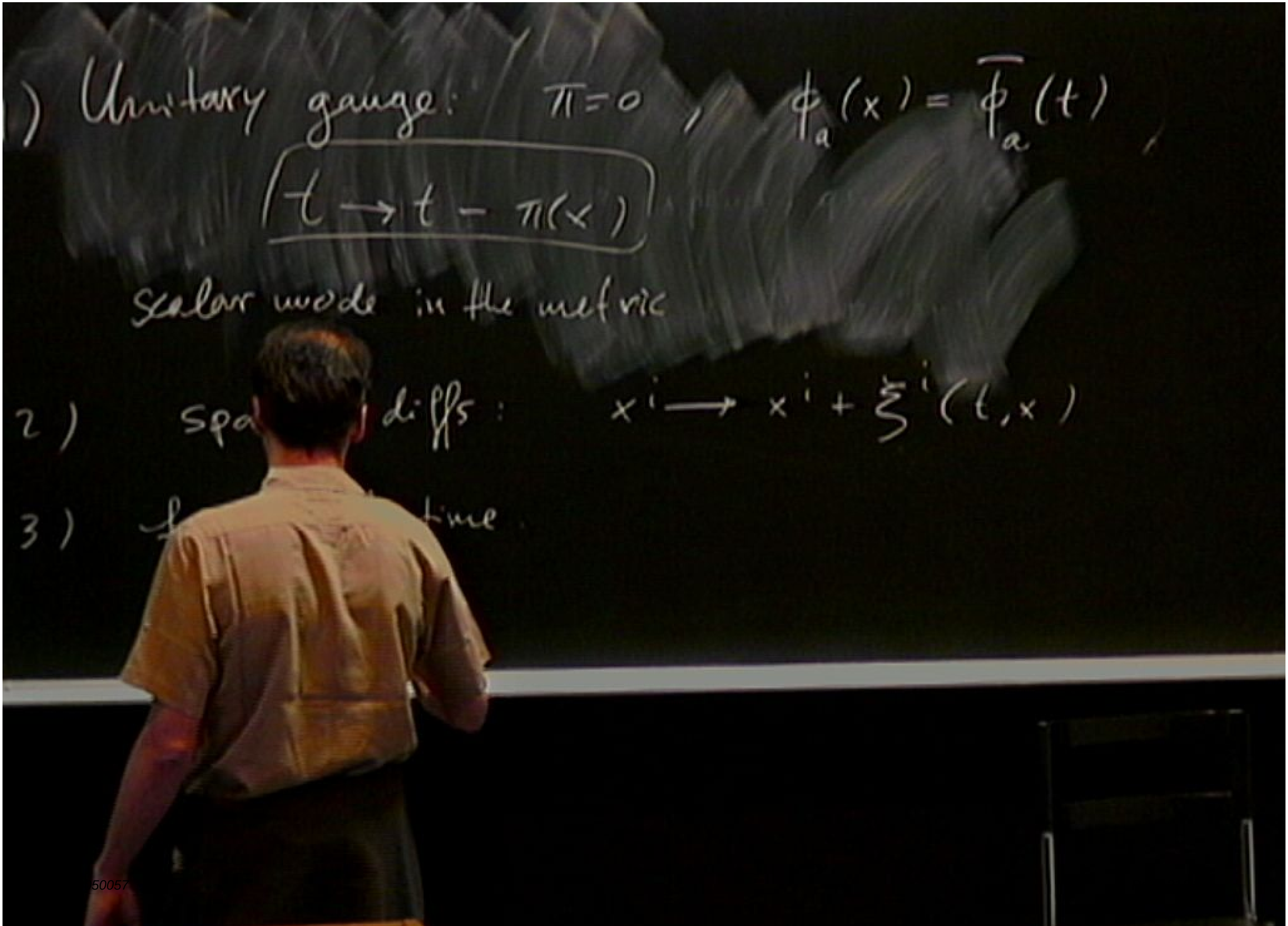
3) functions of time.



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scalar mode in the metric
2) diffs : $x^i \to x^i + \xi^i(t, x)$
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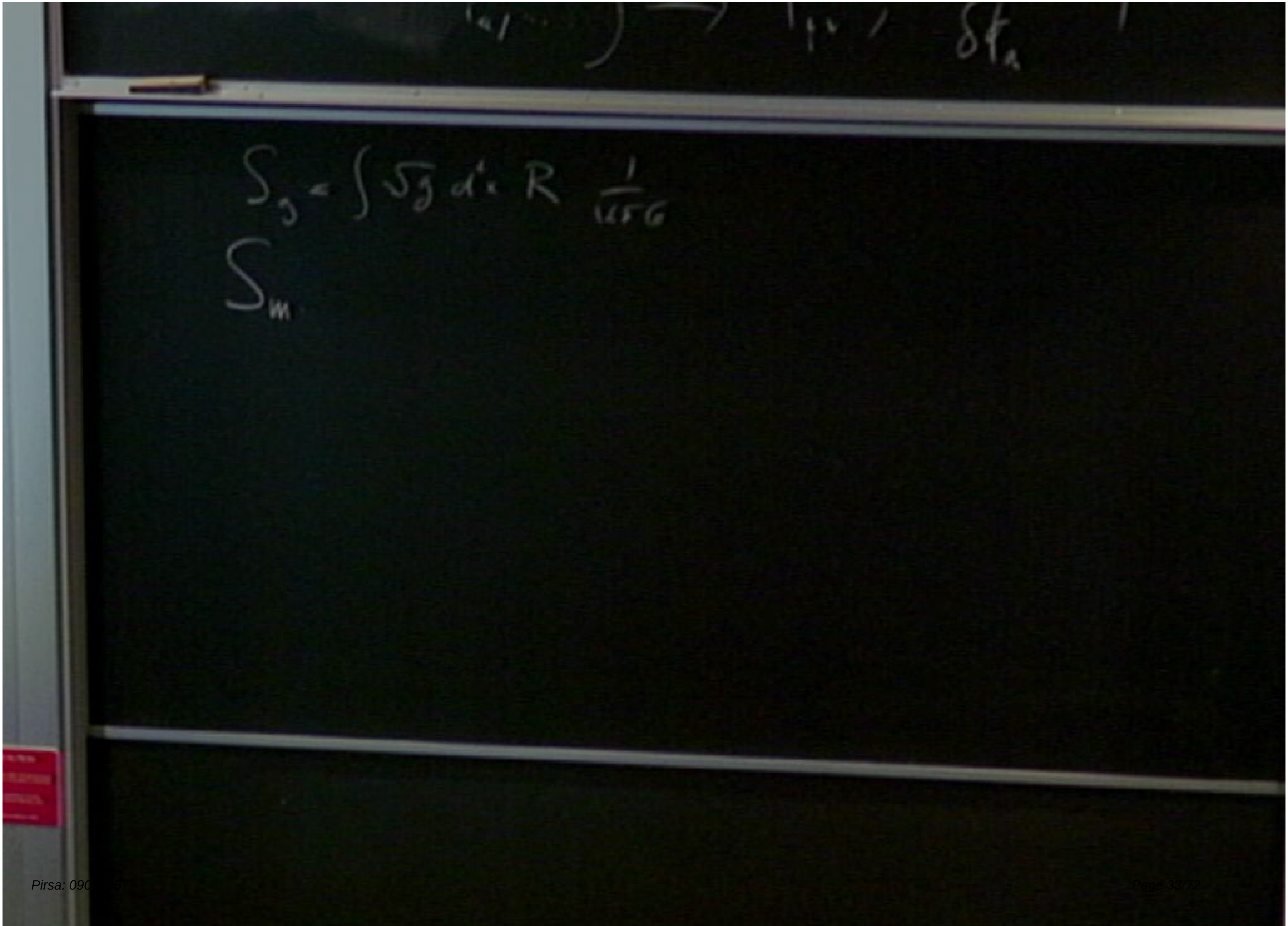
scalar mode in the metric

2) Spatial diffs: $x^i \to x^i + \xi^i(t, x)$

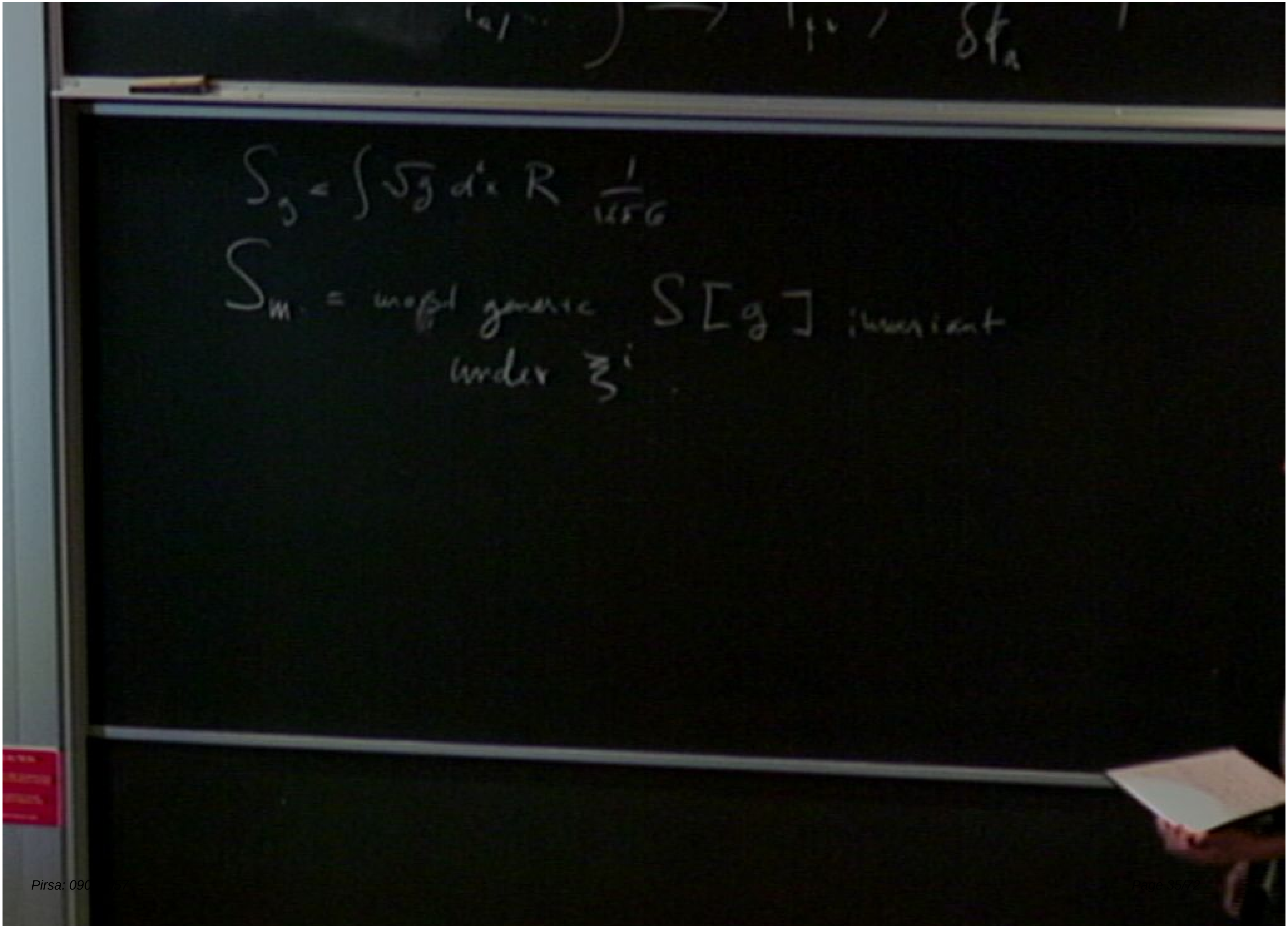
3) functions of time

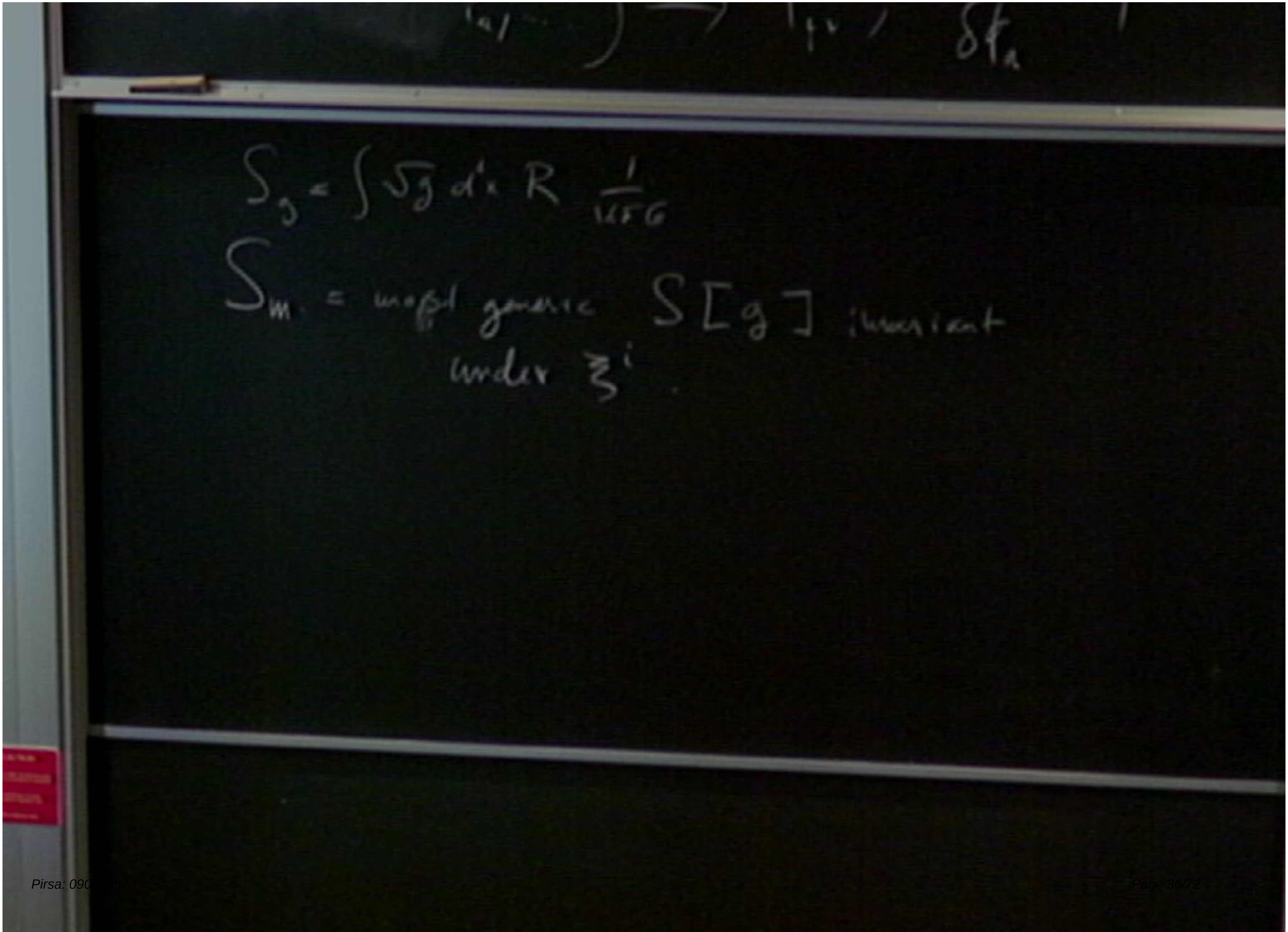
$\bar{\phi}_a(t)$ $\qquad \mathcal{L}(\phi_a, \ldots) \to \mathcal{L}(\phi_a(t), \ldots)$


$S_g = \int \sqrt{g}\, d^4x\, R \frac{1}{16\pi G}$
S_m

$$S_g = \int \sqrt{g}\, d^4x\, R \,\frac{1}{16\pi G}$$

S_m = most generic $S[g]$


S_g = ∫ √g d⁴x R 1/16πG
S_m = most generic S[g] invariant
under ξ^i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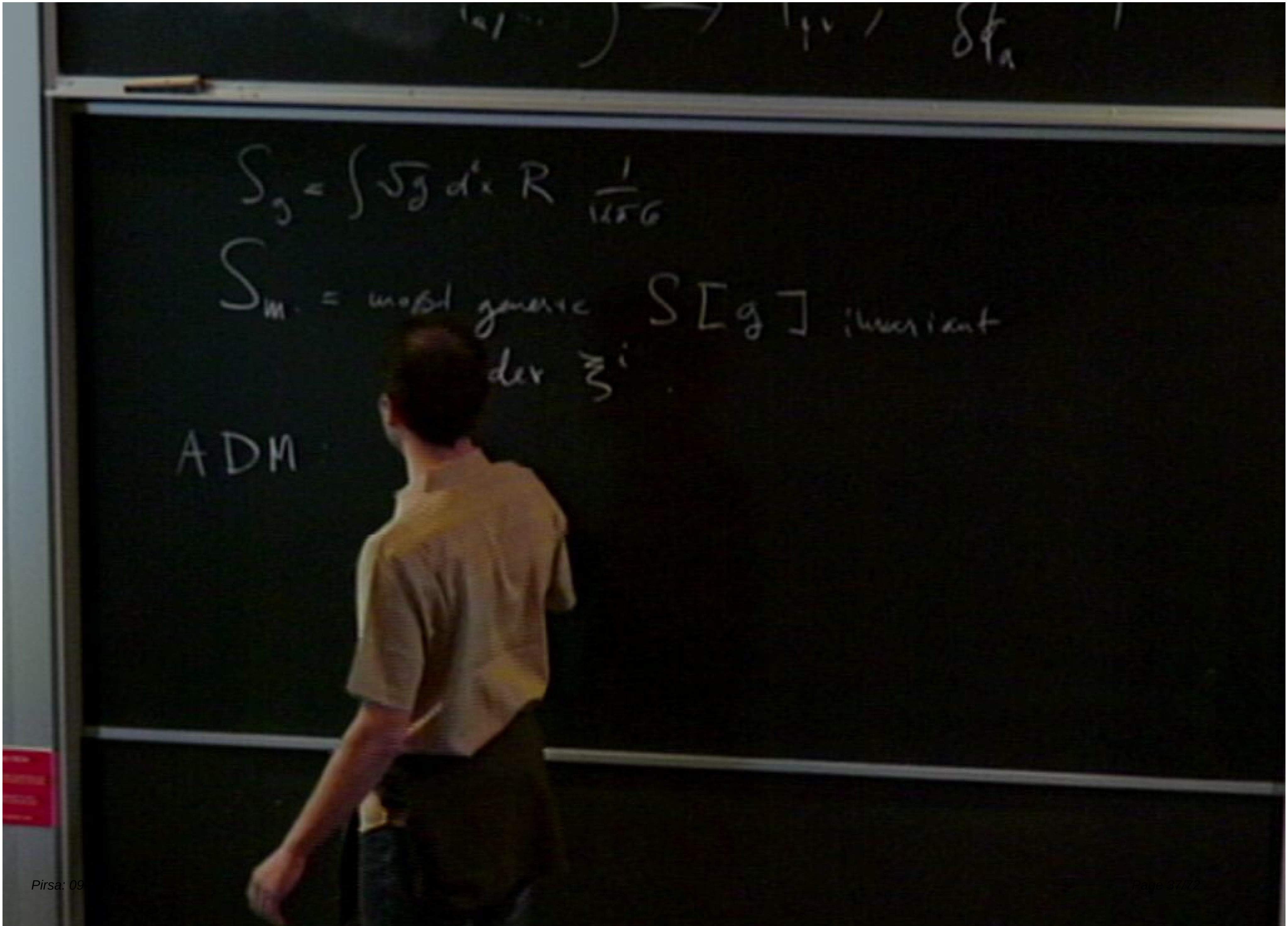
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ADM

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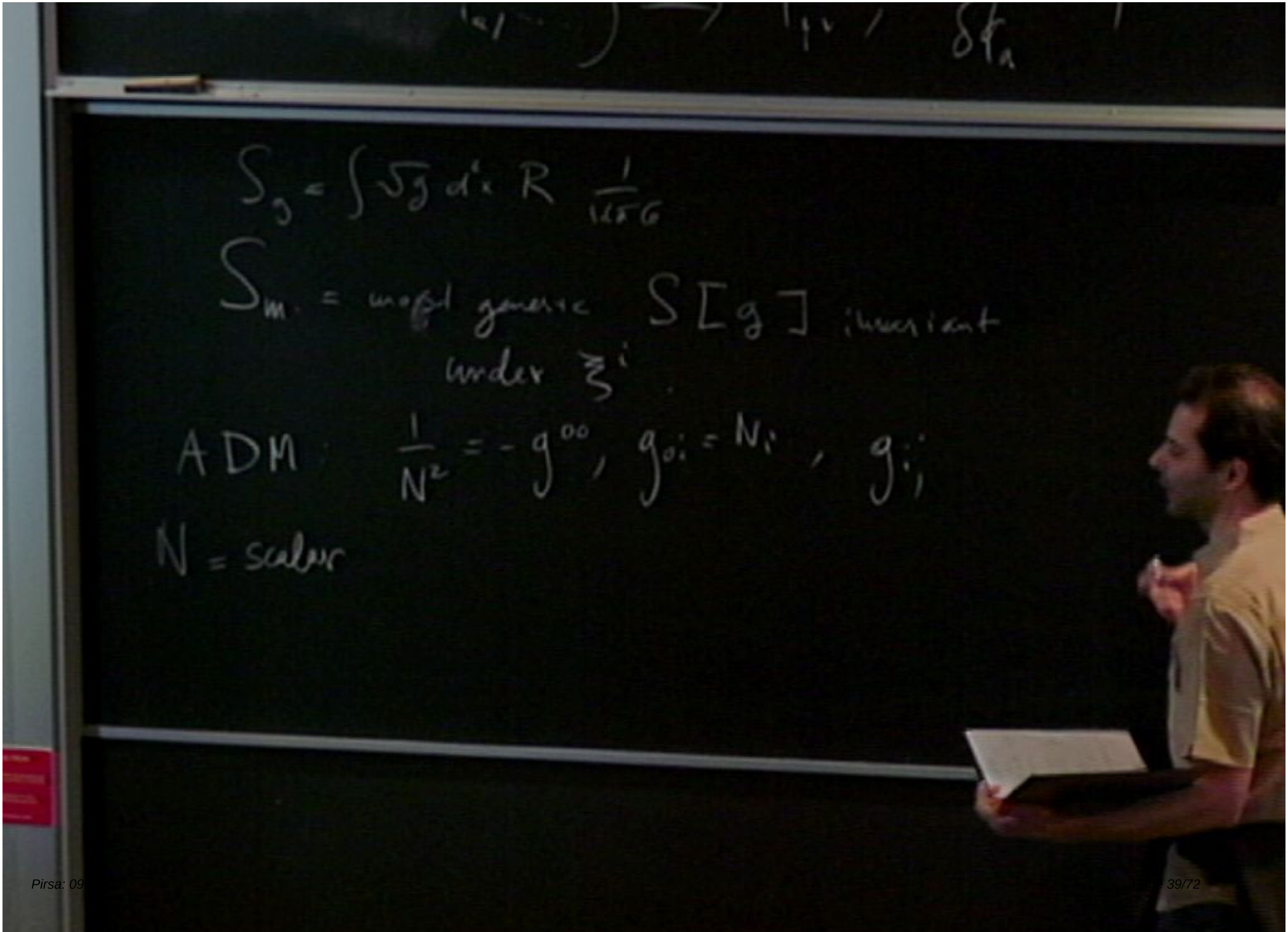
S_g = ∫ √g d⁴x R 1/16πG
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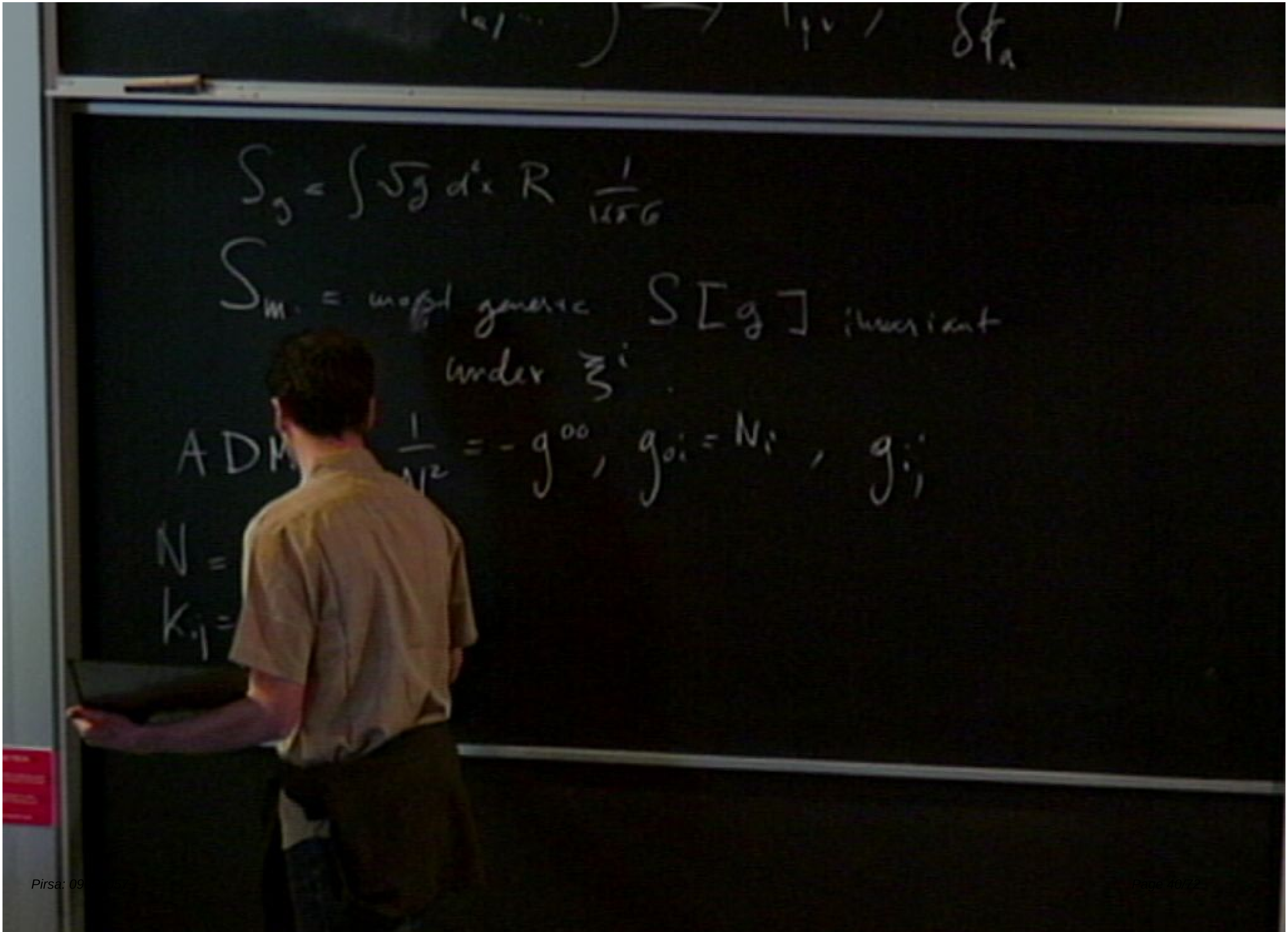
ADM 1/N² = - g^00, g_0i = N_i , g_ij
N = scalar



S_g = ∫ √g d^4x R 1/16πG
S_m = most generic S[g] invariant
under ξ^i
ADM 1/N^2 = -g^00, g_0i = N_i , g_ij
N =
K_ij =

$\delta \phi_a$

$$S_g = \int \sqrt{g}\, d^4x\, R\, \frac{1}{16\pi G}$$

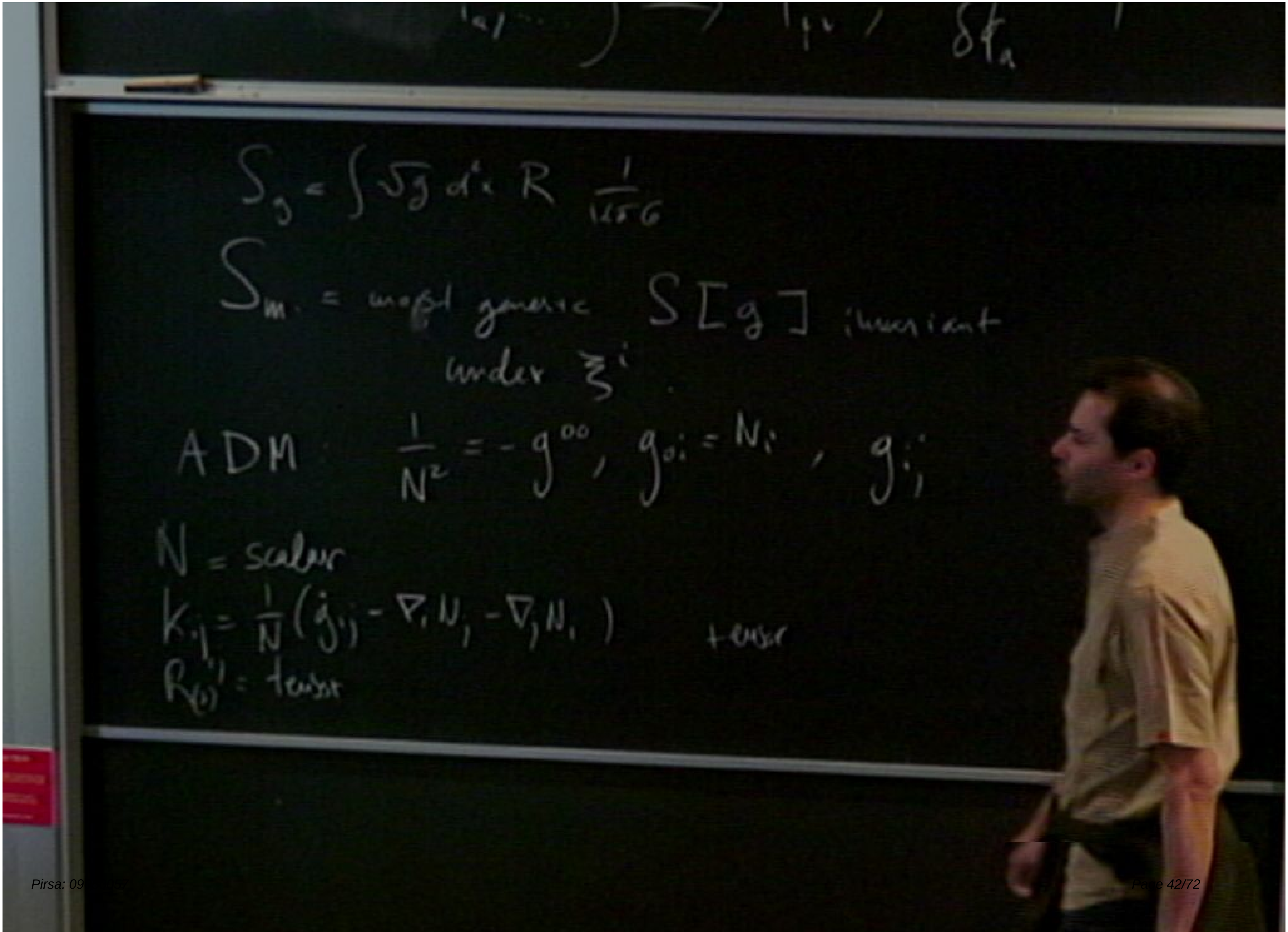
S_m = most generic $S[g]$ invariant under ξ^i

ADM: $\frac{1}{N^2} = -g^{00}$, $g_{0i} = N_i$, g_{ij}

N = scalar

$K_{ij} = \frac{1}{N}\left(\dot{g}_{ij} - \nabla_i N_j - \nabla_j N_i\right)$ tensor

$R_{(3)}^{ij}$ = tensor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ADM 1/N^2 = -g^00, g_0i = N_i, g_ij
N = scalar
K_ij = 1/N (ġ_ij - ∇_i N_j - ∇_j N_i) tensor
R_(3)^ij = tensor

$$S_g = \int \sqrt{g}\, d^4x\, R\, \frac{1}{16\pi G}$$

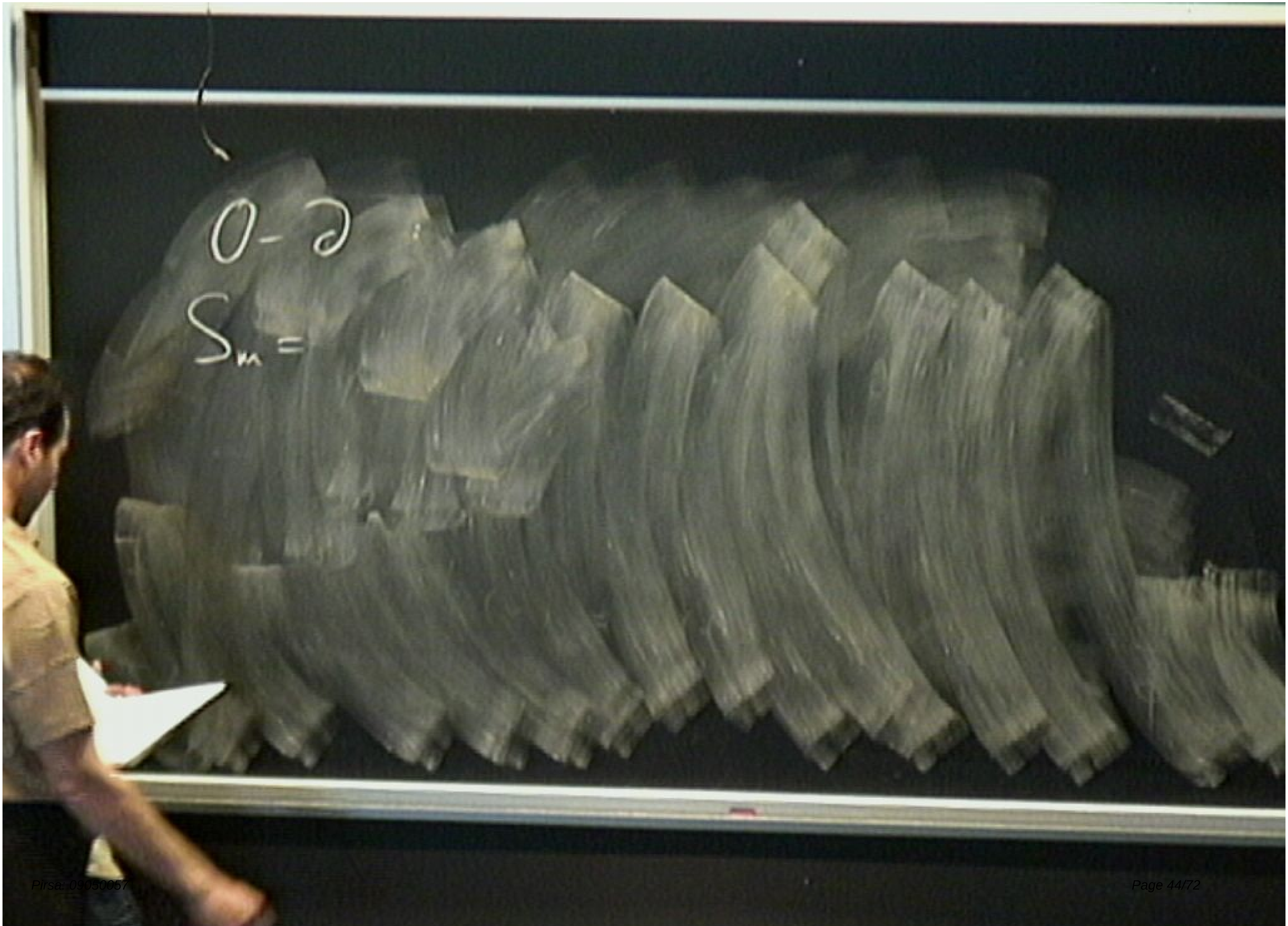
S_m = most generic $S[g]$ invariant under ξ^i

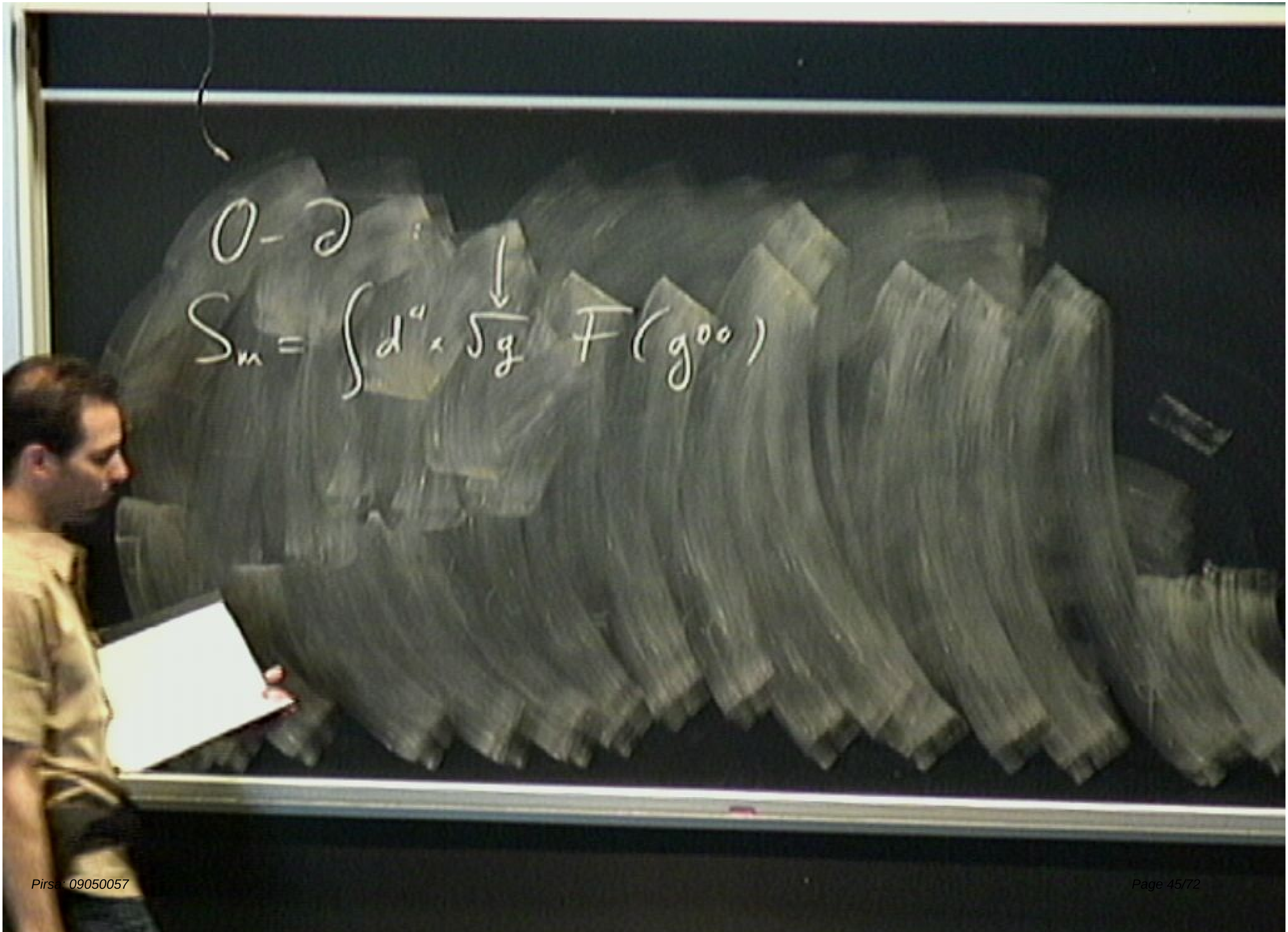
ADM: $\frac{1}{N^2} = -g^{00}$, $g_{0i} = N_i$, g_{ij}

N = scalar   0-derivative

$K_{ij} = \frac{1}{N}(\dot g_{ij} - \nabla_i N_j - \nabla_j N_i)$ tensor   1-derivative

$R_{(3)}{}^{ij}$ = tensor   2-derivative


0- ∂
Sm =

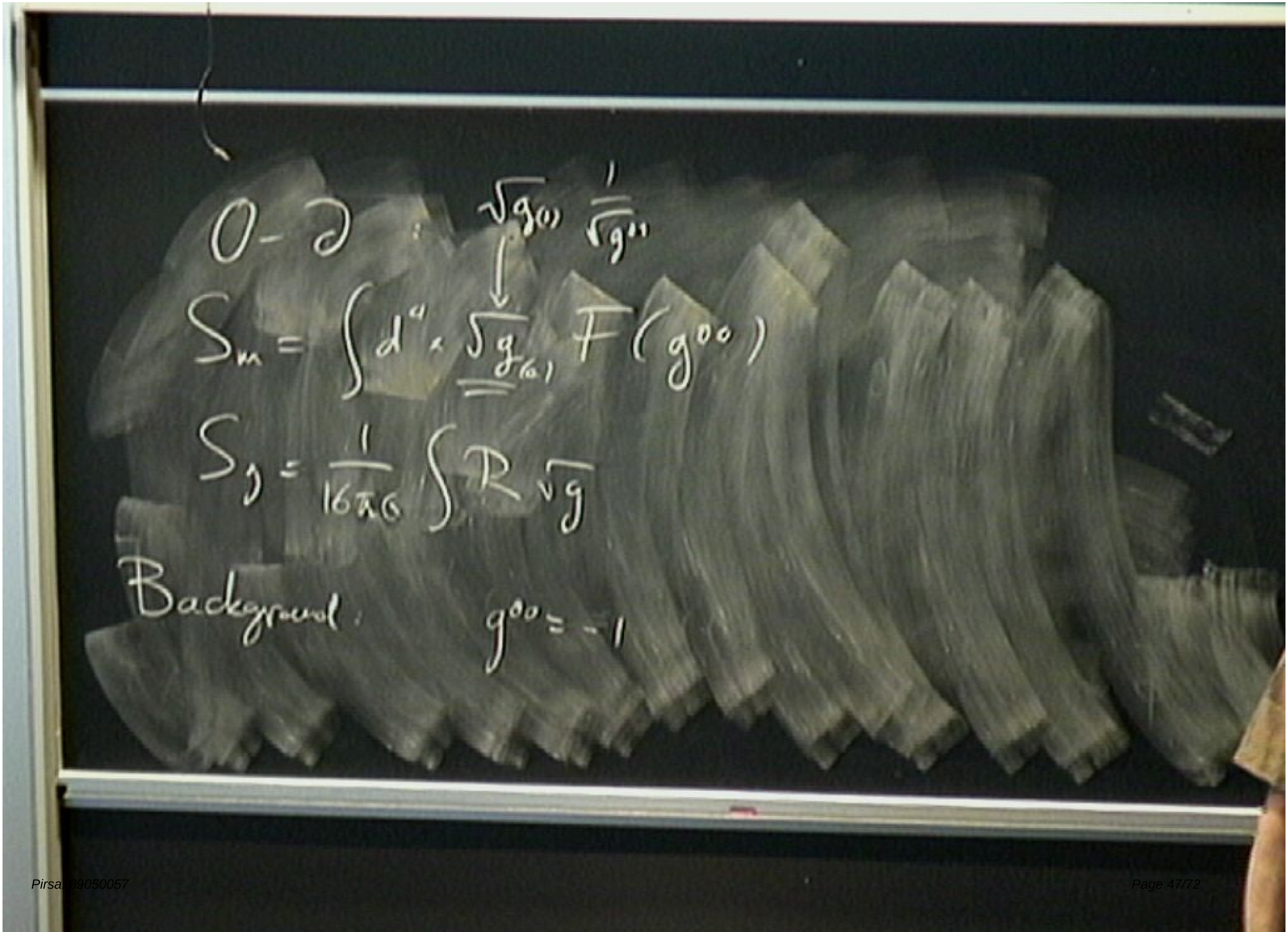

$0-\partial$:
$S_m = \int d^4x \sqrt{g}\, F(g^{00})$

$O-\partial$: $\sqrt{g_{(1)}}\ \frac{1}{\sqrt{g_{11}}}$

$$S_m = \int d^4x \sqrt{g_{(6)}}\, F(g^{00})$$

$$S_g = \frac{1}{16\pi G}\int R\sqrt{g}$$

Background :



O-∂ : $\sqrt{g_{(0)}}$ $\frac{1}{\sqrt{g_{(1)}}}$
$S_m = \int d^4x \sqrt{g_{(0)}} F(g^{00})$
$S_g = \frac{1}{16\pi G} \int R \sqrt{g}$
Background: $g^{00} = -1$

$O - \partial \quad : \quad \sqrt{g_{(0)}} \quad \frac{1}{\sqrt{g^{00}}}$

$$S_m = \int d^4x \, \sqrt{g_{(0)}} \, F(g^{00})$$

$$S_g = \frac{1}{16\pi G} \int R \sqrt{g}$$

Background: $g^{00} = -1$

$$G_{\mu\nu} = 8\pi G \, T_{\mu\nu} = 8\pi G \, \frac{\delta S_m}{\delta g^{\mu\nu}}$$

$0-\partial$: $\sqrt{g_{(0)}}$ $\frac{1}{\sqrt{g_{(1)}}}$

$$S_m = \int d^4x \sqrt{g_{(0)}}\, F(g^{00})$$

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Background:

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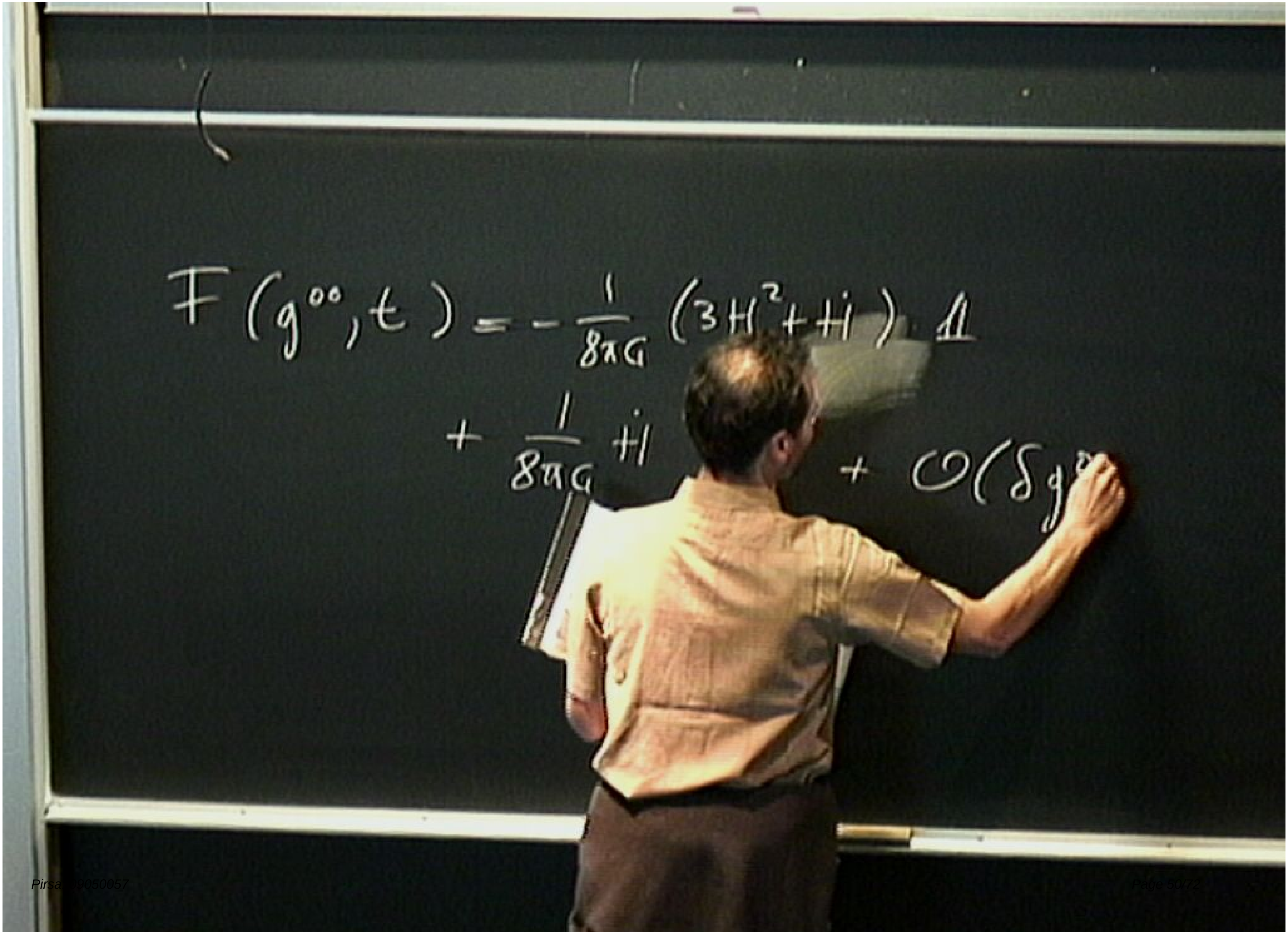

$F(g^{00}, t) = -\frac{1}{8\pi G}(3H^2 + \dot{H})$
$+ \frac{1}{8\pi G}\dot{H}$
$+ \mathcal{O}(\delta g^{0}$

$$F(g^{00}, t) = -\frac{1}{8\pi G}\left(3H^2 + \dot{H}\right) \mathbb{1} + \frac{1}{8\pi G}\dot{H}\, g^{00} + \mathcal{O}(\delta g^{00})$$

$\delta g^{00} = g^{00} + 1$

$\Lambda(t)$

$$F(g^{00}, t) = -\frac{1}{8\pi G}\left(3H^2 + \dot{H}\right) \Lambda$$

$$+ \frac{1}{8\pi G}\dot{H}\; g^{00} + \mathcal{O}(\delta g^{00})^2$$

$c(t)$

$$\delta g^{00} = g^{00} + 1$$

$$F(g^{00}, t) = \underbrace{\left(-\frac{1}{8\pi G}(3H^2 + \dot{H})\right)}_{\Lambda(t)} \Lambda + \underbrace{\left(\frac{1}{8\pi G}\dot{H}\right)}_{c(t)} g^{00} + \mathcal{O}(\delta g^{00})^2$$

$$\mathcal{O}(\delta g^{00})^2 = M^4(t)\, \delta g^{00\,2} + \tilde{M}^4(t)(\delta g^{00})^3 + \ldots$$

$S_g = \int \sqrt{g}\, d^4x\, R \frac{1}{16\pi G}$

S_m = more generic $S[g]$ invariant under ξ^i.

ADM $\frac{1}{N^2} = -g^{00}$, $g_{0i} = N_i$, g_{ij}

N = scalar 0-derivative

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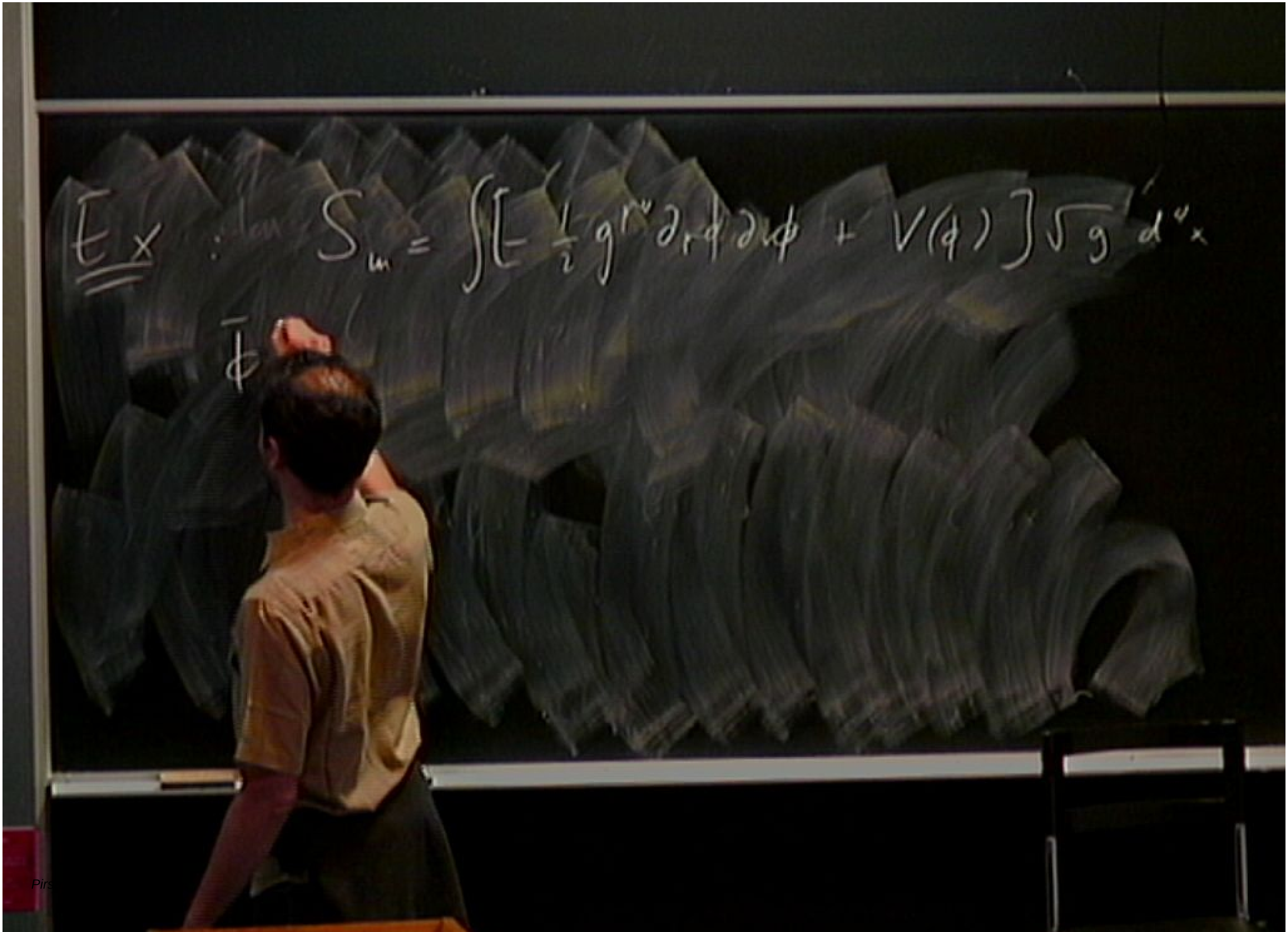

Ex :
$S_m = \int [-\frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi + V(\phi)] \sqrt{g} \, d^4x$
$\bar{\phi}$

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$\bar{\phi}(t)$, $a(t)$

perturb Unitary gauge $\phi(x) = \bar{\phi}(t)$

$$S_m = \int \sqrt{g} \, d^4x \left[-\frac{1}{2} \dot{\bar{\phi}}^2(t) \, g^{00} + V(\bar{\phi}(t)) \right]$$

Ex: $S_m = \int \left[-\frac{1}{2} g^{\mu\nu} \partial_\mu \phi \, \partial_\nu \phi + V(\phi) \right] \sqrt{g} \, d^4x$

$\bar{\phi}(t)$, $a(t)$

perturb   Unitary gauge $\phi(x) = \bar{\phi}(t)$

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$\bar{\phi}(t), \; a(t)$

perturb. Unitary gauge $\phi(x) = \bar{\phi}(t)$

$$S_m = \int \sqrt{g} \, d^4x \left[-\frac{1}{2} \dot{\bar{\phi}}^2(t) \, g^{00} + V(\bar{\phi}(t)) \right]$$

$$\mathcal{O}\left((\delta g^{00})^2 \right) = 0$$

$$\mathcal{L} = P(\phi, X) \qquad X = (\partial\phi)^2$$

$$\rightarrow P\left(\bar{\phi}(t),\ g^{00}\,\dot{\bar{\phi}}^2(t)\right)$$

$$\delta g^{00} = g^{00} + 1$$

$$F(g^{00}, t) = \underbrace{-\frac{1}{8\pi G}(3H^2 + \dot{H})}_{\Lambda(t)} + \underbrace{\frac{1}{8\pi G}\dot{H}}_{c(t)}\, g^{00} + \mathcal{O}(\delta g^{00})^2$$

$$\mathcal{O}(\delta g^{00})^2 = M^4(t)\, \delta g^{00\,2} + \tilde{M}^4(t)(\delta g^{00})^3 + \ldots$$

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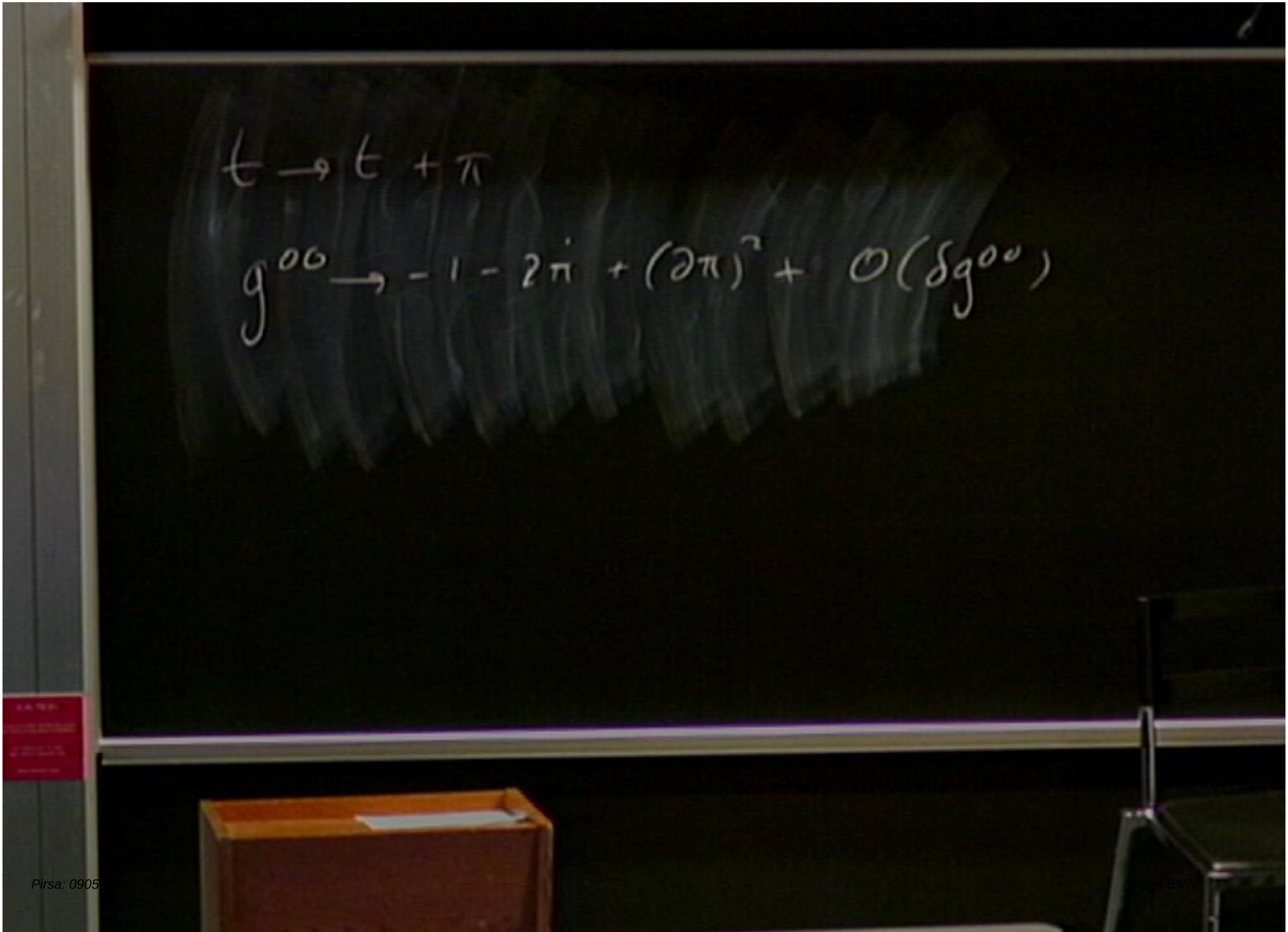
$$\Lambda(t)$$

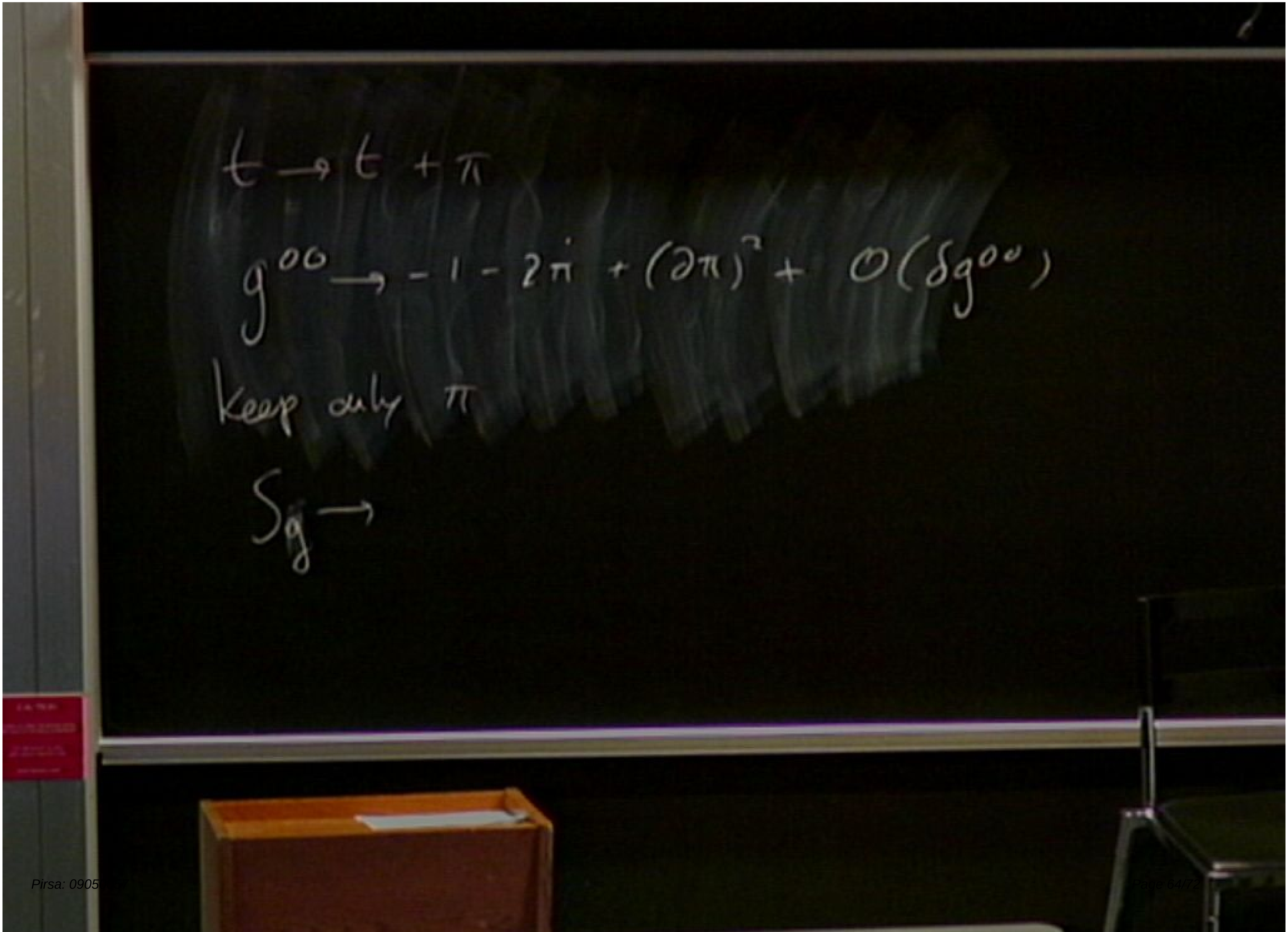
$$F(g^{00}, t) = -\frac{1}{8\pi G}(3H^2 + \dot{H})\,\mathbb{1}$$

$$+ \frac{1}{8\pi G}\dot{H}\, g^{00} + \mathcal{O}(\delta g^{00})^2$$

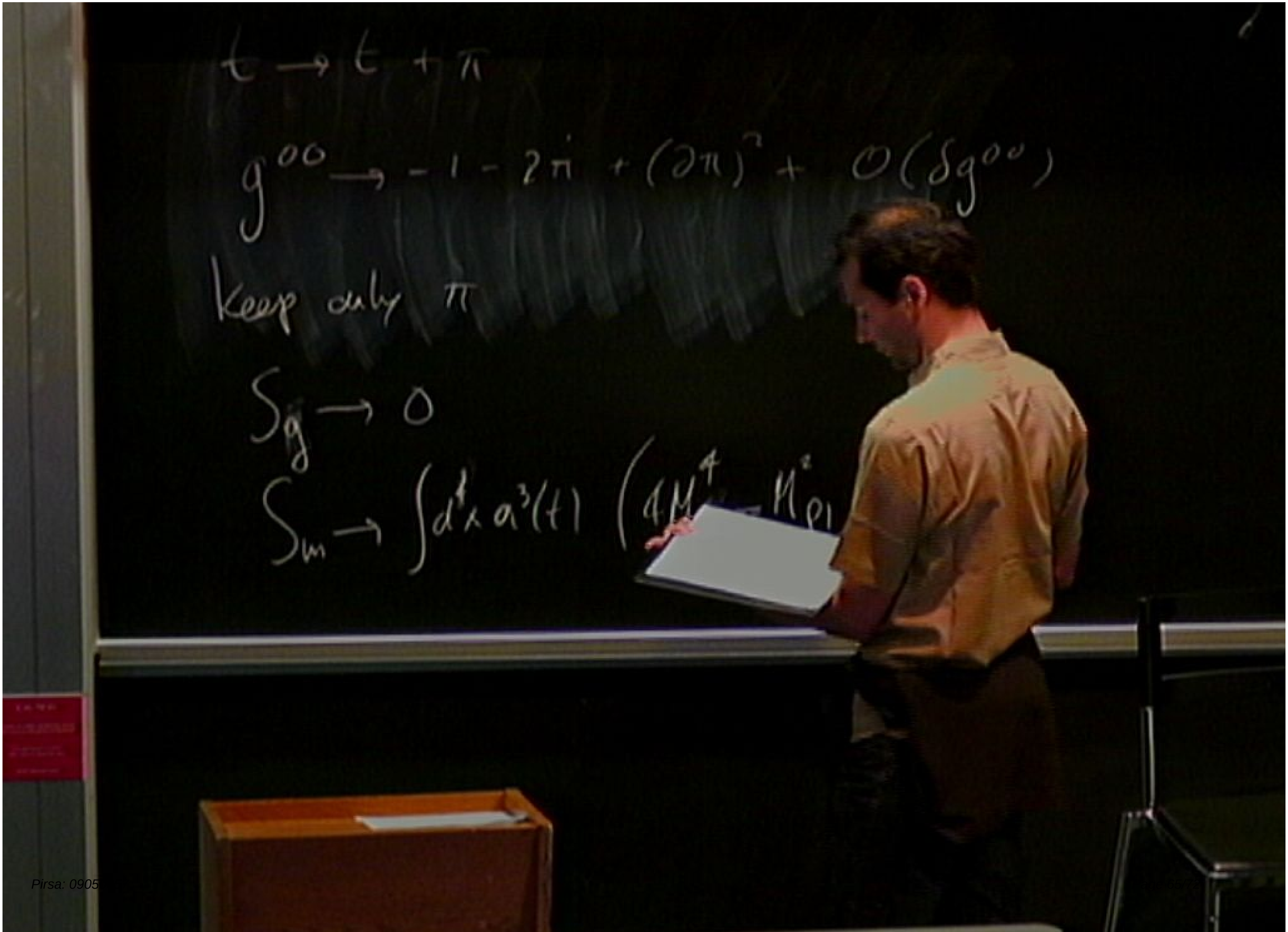
$$c(t)$$

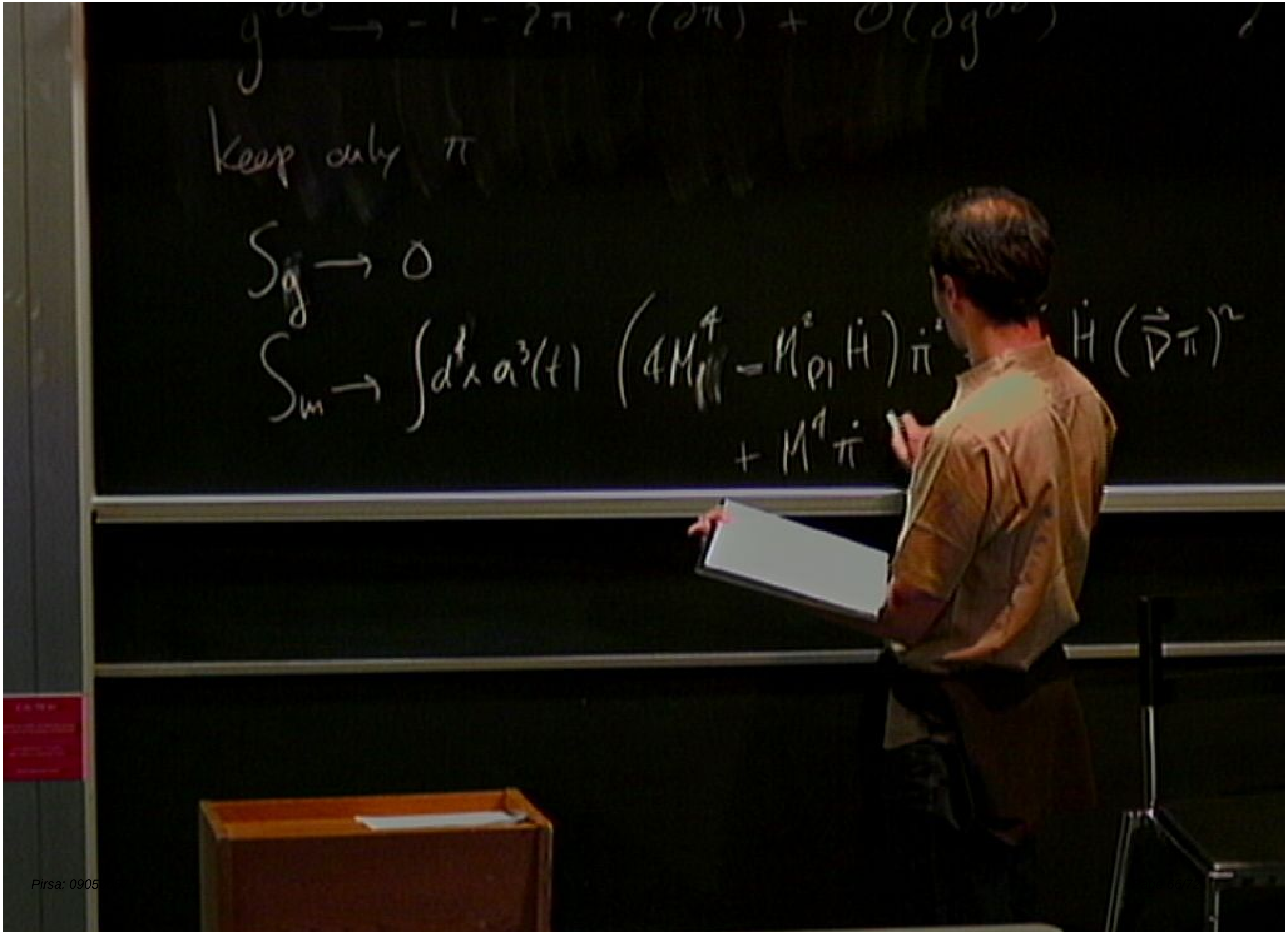
$$\mathcal{O}(\delta g^{00})^2 = M^4(t)\,\delta g^{00\,2} + \tilde{M}^4(t)(\delta g^{00})^3 + \ldots$$


$t \to t + \pi$
$g^{00} \to -1 - 2\dot{\pi} + (\partial\pi)^2 + \mathcal{O}(\delta g^{00})$



$t \to t + \pi$
$g^{00} \to -1 - 2\dot{\pi} + (\partial\pi)^2 + \mathcal{O}(\delta g^{00})$
Keep only π
$S_g \to$


t → t + π
g^00 → −1 − 2π̇ + (∂π)^2 + O(δg^00)
Keep only π
S_g → 0
S_m → ∫d^4x a^3(t) (4M^4 − M_Pl^2

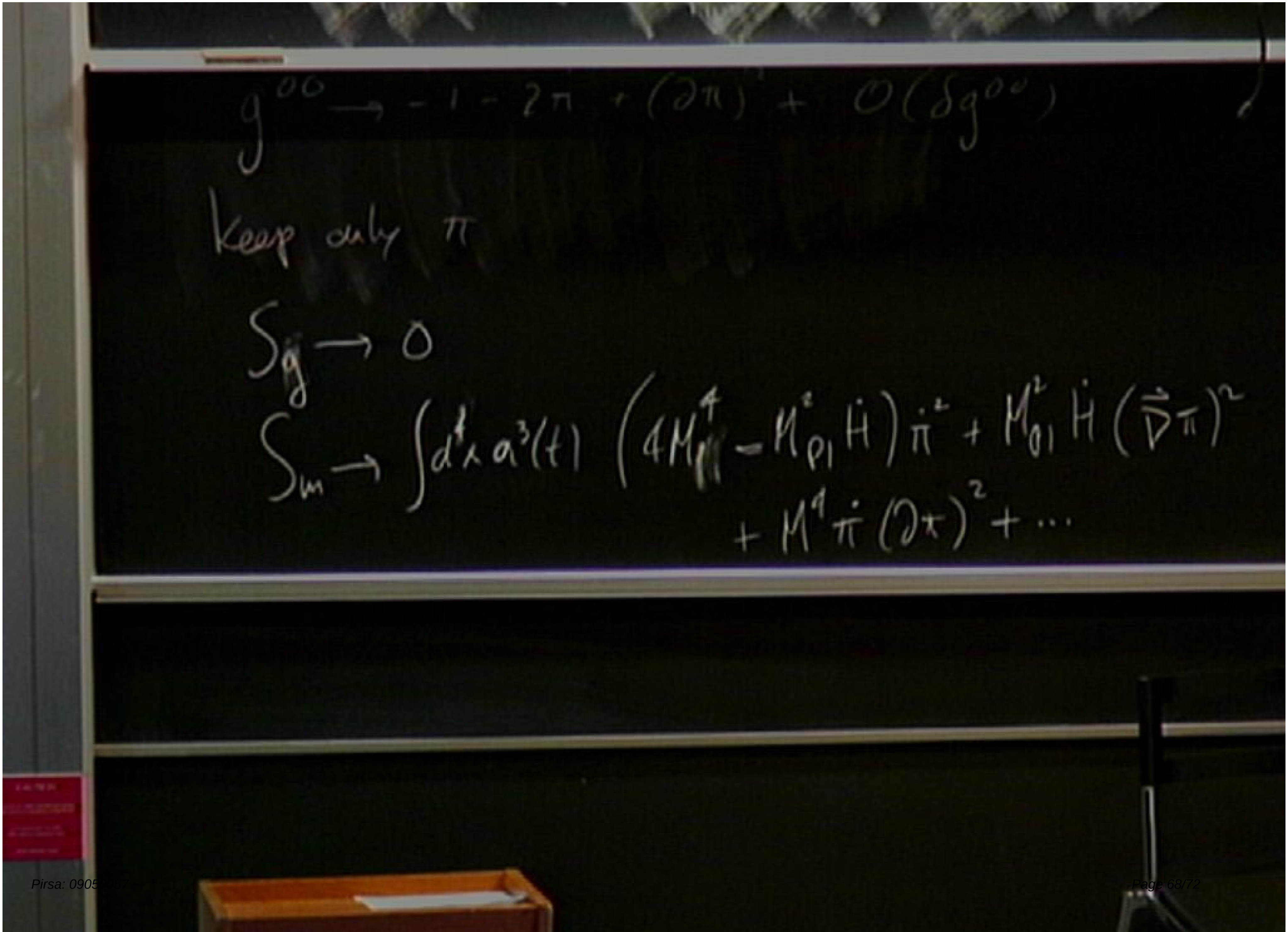

Keep only π
S_g → 0
S_m → ∫d^4x a^3(t) (4M^4 − M_Pl^2 Ḣ) π̇^2
Ḣ (∇π)^2
+ M^4 π̇

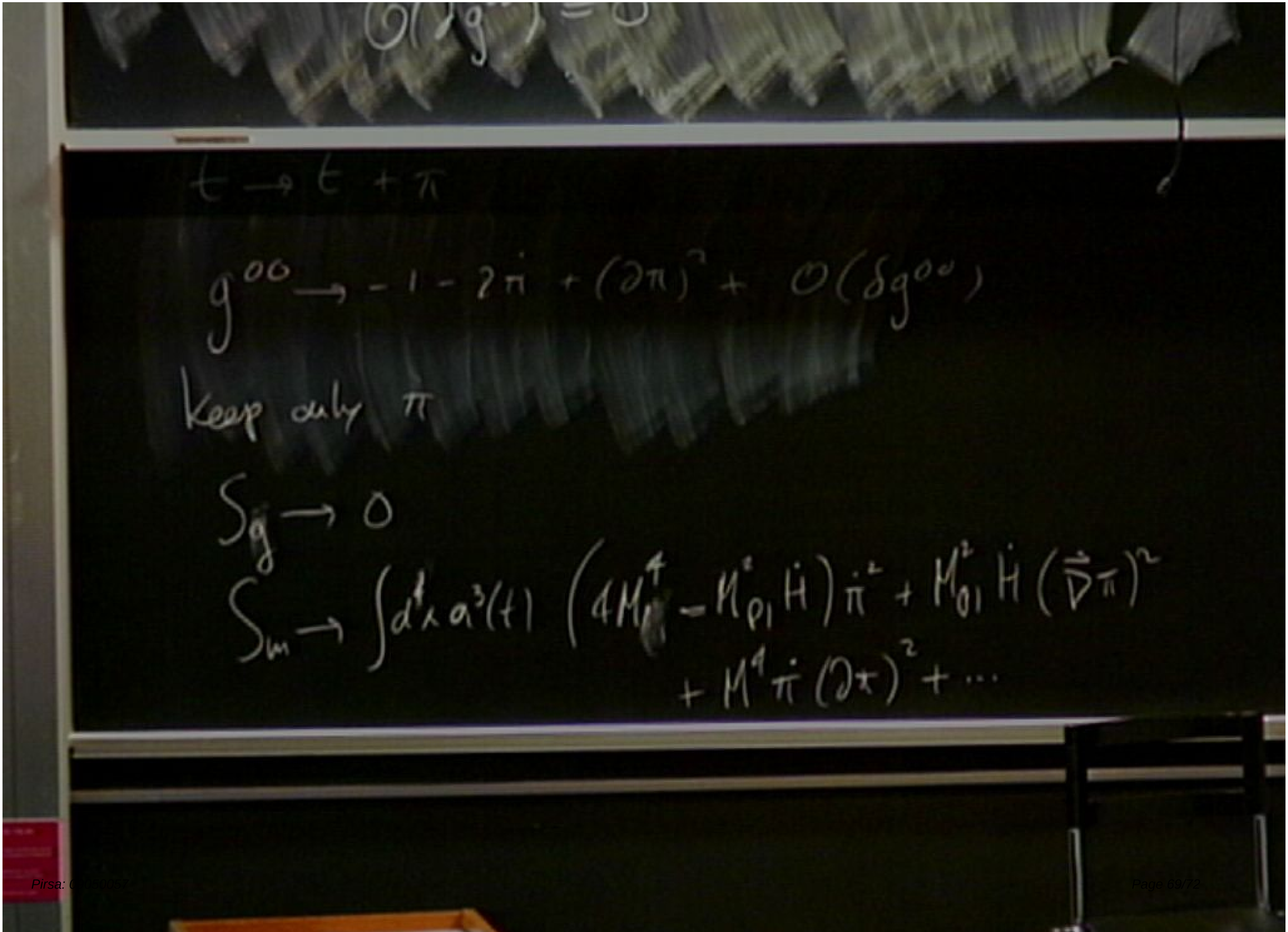
$$g^{00} \to -1 - 2\dot{\pi} + (\partial\pi)^2 + \mathcal{O}(\delta g^{00})$$

Keep only π

$$S_g \to 0$$

$$S_m \to \int d^4x \, a^3(t) \left((4M^4 - M_{Pl}^2 \dot{H})\dot{\pi}^2 + M_{Pl}^2 \dot{H} (\vec{\nabla}\pi)^2 + M^4 \dot{\pi} (\partial\pi)^2 + \dots \right.$$


$g^{00} \to -1 - 2\pi + (\partial\pi)^2 + \mathcal{O}(\delta g^{00})$
Keep only π
$S_g \to 0$
$S_m \to \int d^4x\, a^3(t) \left((4M^4 - M_{Pl}^2 \dot{H}) \dot{\pi}^2 + M_{Pl}^2 \dot{H} (\vec{\nabla}\pi)^2 \right.$
$+ M^4 \dot{\pi} (\partial\pi)^2 + \dots$


$t \to t + \pi$
$g^{00} \to -1 - 2\dot{\pi} + (\partial\pi)^2 + \mathcal{O}(\delta g^{00})$
Keep only π
$S_g \to 0$
$S_m \to \int d^4x\, a^3(t) \left((4M^4 - M_{Pl}^2 \dot{H}) \dot{\pi}^2 + M_{Pl}^2 \dot{H} (\vec{\nabla}\pi)^2 + M^4 \dot{\pi} (\partial\pi)^2 + \dots \right.$

$\mathcal{O}(\delta g^{00}) = 0$

$t \to t + \pi$

$$g^{00} \to -1 - 2\dot{\pi} + (\partial\pi)^2 + \mathcal{O}(\delta g^{00})$$

Keep only π

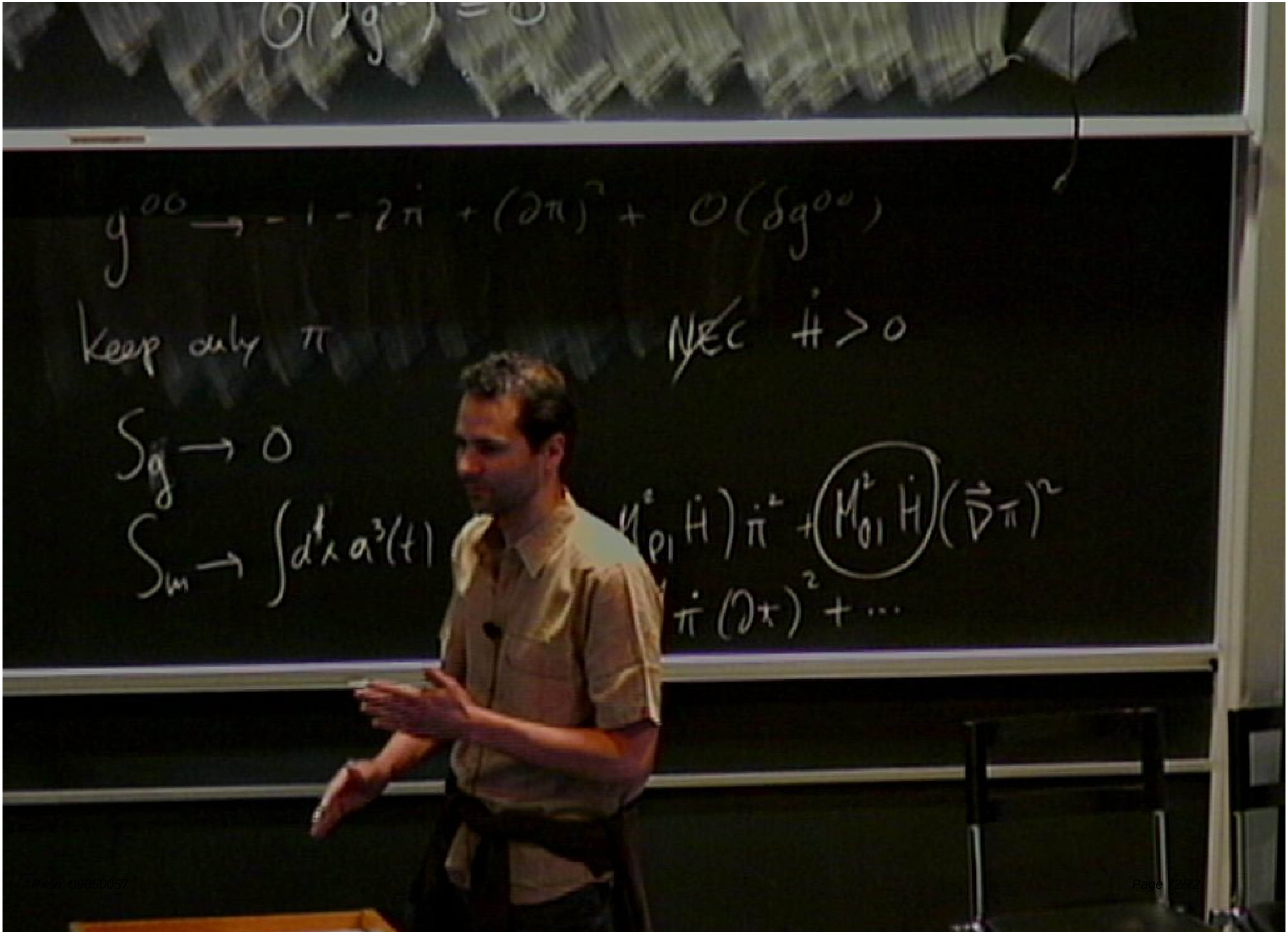
$$S_g \to 0$$

$$S_m \to \int d^4x\, a^3(t) \left((4M^4 - M_{Pl}^2 \dot{H})\dot{\pi}^2 + M_{Pl}^2 \dot{H} (\vec{\nabla}\pi)^2 + M^4 \dot{\pi} (\partial\pi)^2 + \cdots \right)$$

$$M^4 \gg M_{Pl}^2 \dot{H}$$

$$M^4 \dot{\pi}^2 + M_{Pl}^2 \dot{H} \, (\vec{\nabla}\pi)^2$$

$$c_\pi^2 = -\frac{M_{Pl}^2 \dot{H}}{M^4} \ll$$



$g^{00} \rightarrow -1 - 2\dot{\pi} + (\partial\pi)^2 + \mathcal{O}(\delta g^{00})$
Keep only π
NEC $\dot{H} > 0$
$S_g \rightarrow 0$
$S_m \rightarrow \int d^4x\, a^3(t)$
$M_{P1}^2 \dot{H})\dot{\pi}^2 + (M_{P1}^2 \dot{H})(\vec{\nabla}\pi)^2$
$\dot{\pi}(\partial\pi)^2 + \cdots$