Title: A talk about Nothing

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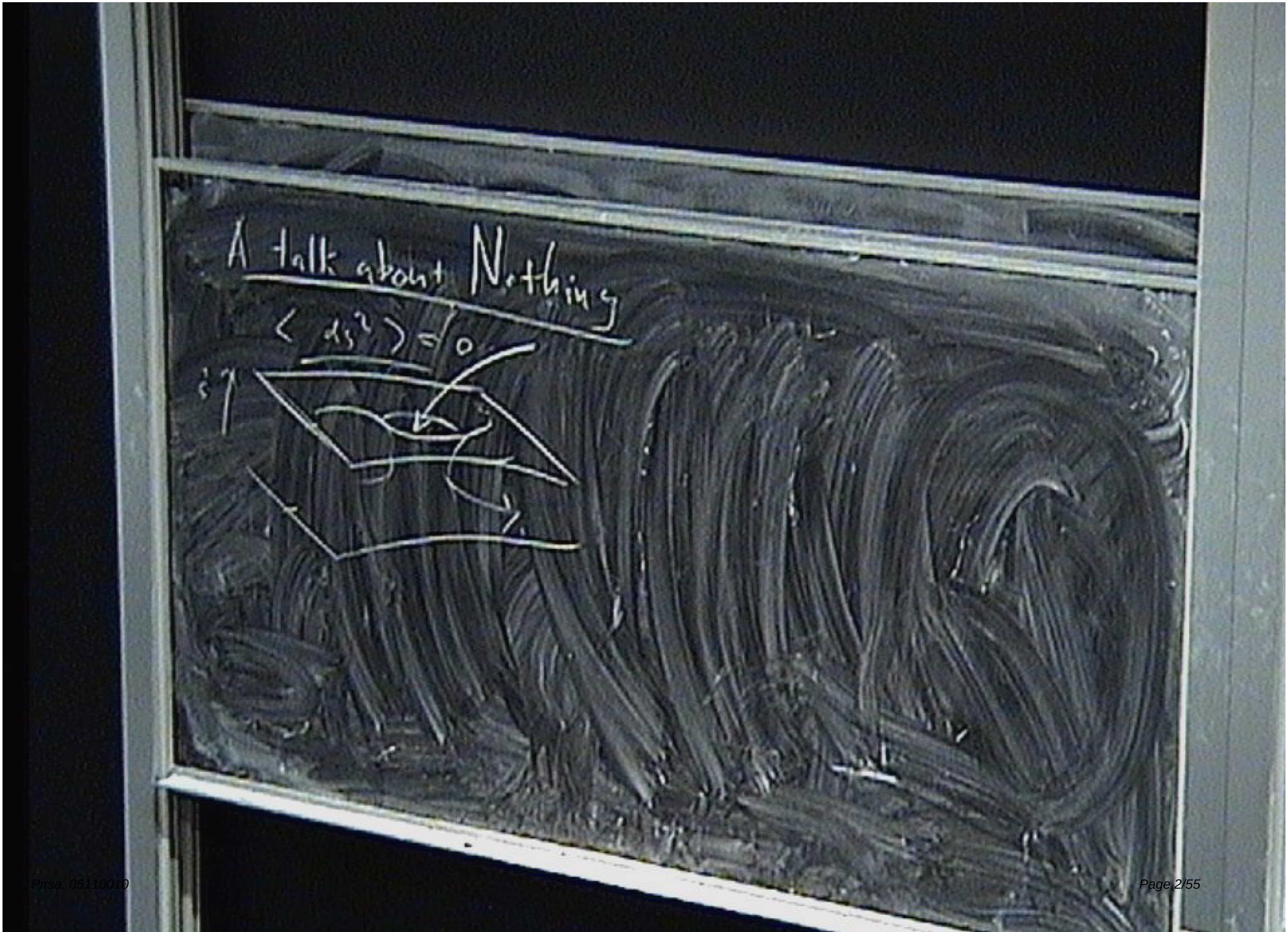
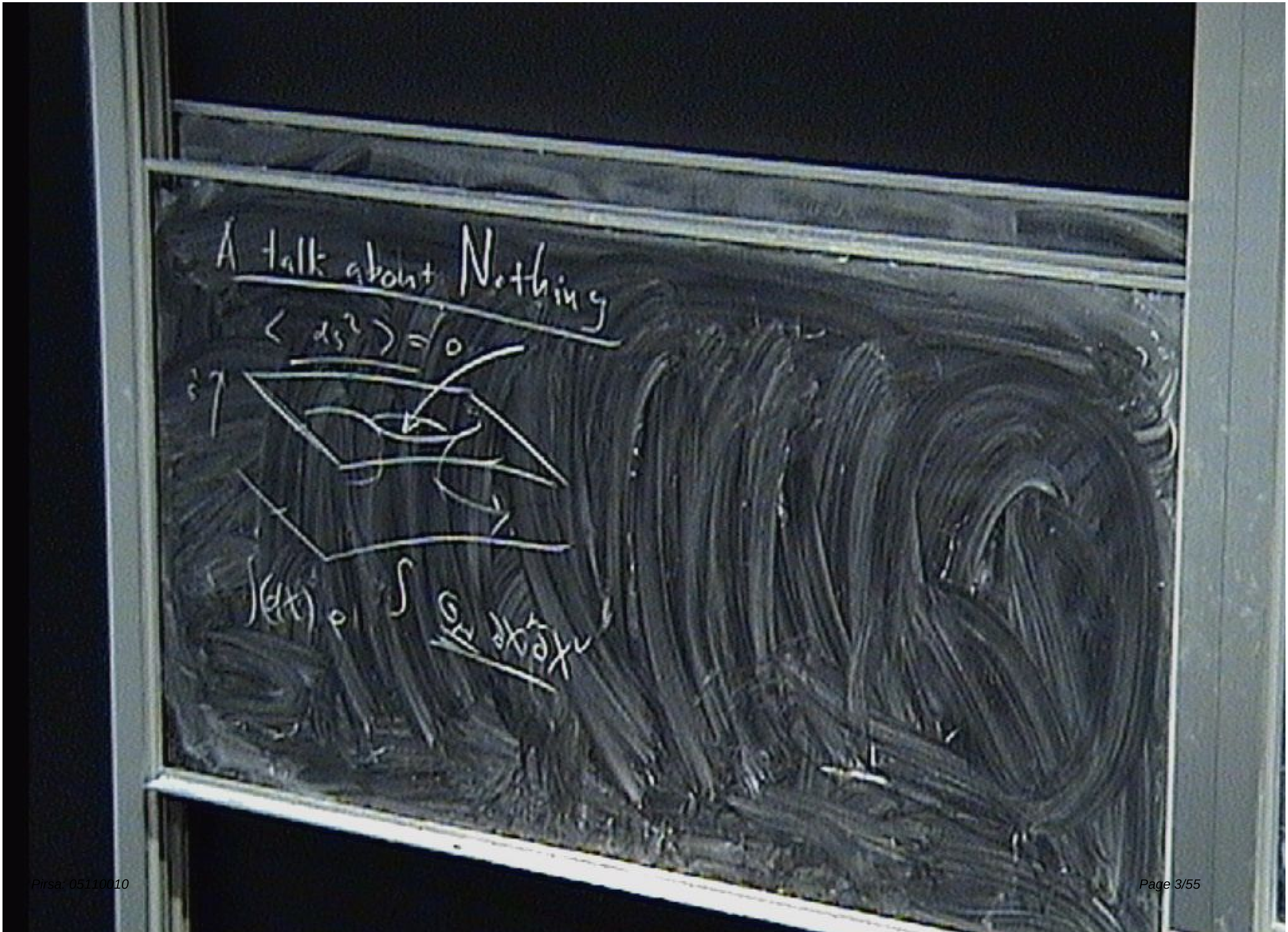
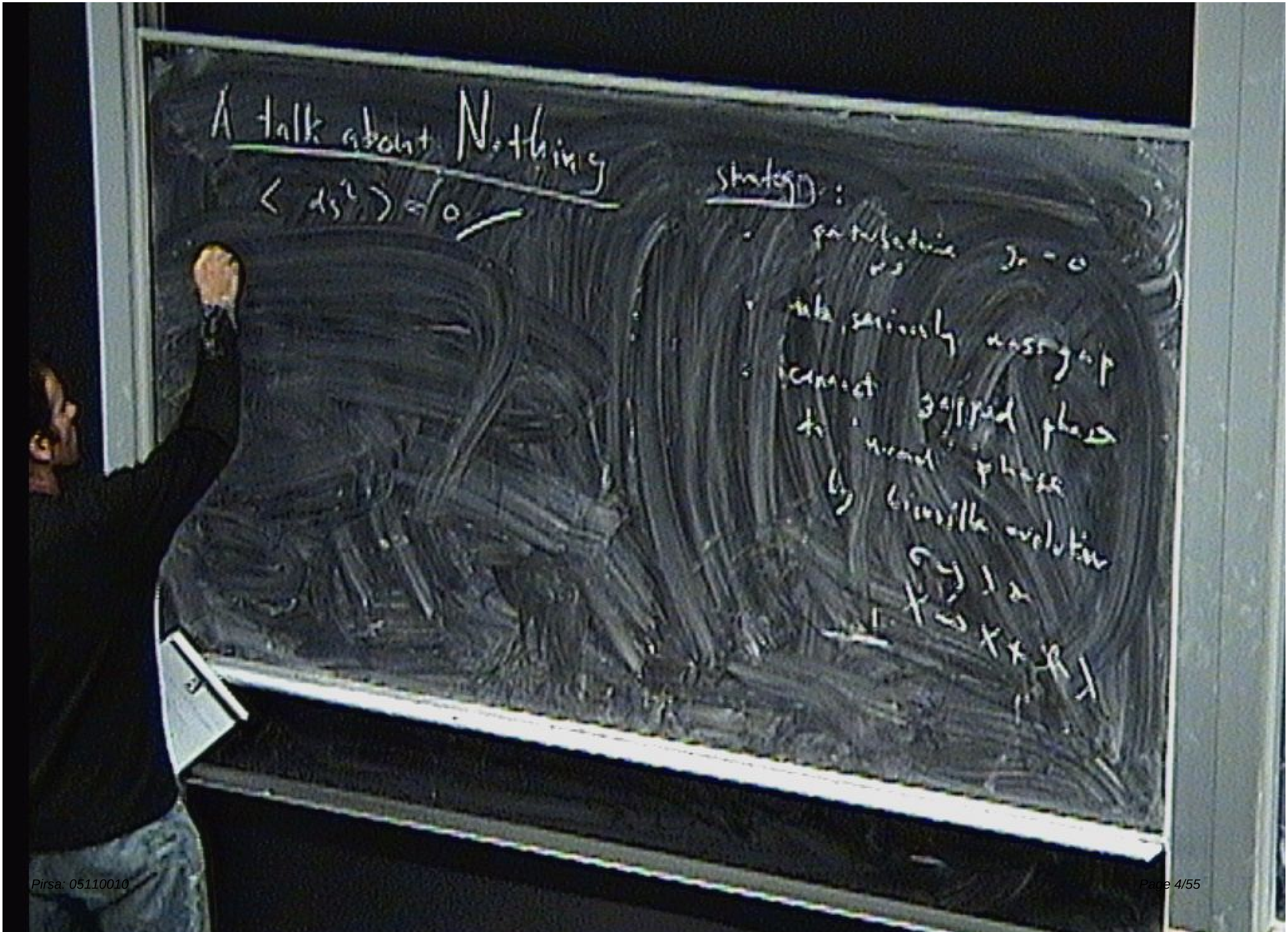
Abstract:


A talk about Nothing


A talk about Nothing


A talk about Nothing
strategy:

A talk about Nothing

$\langle ds^2 \rangle = 0$

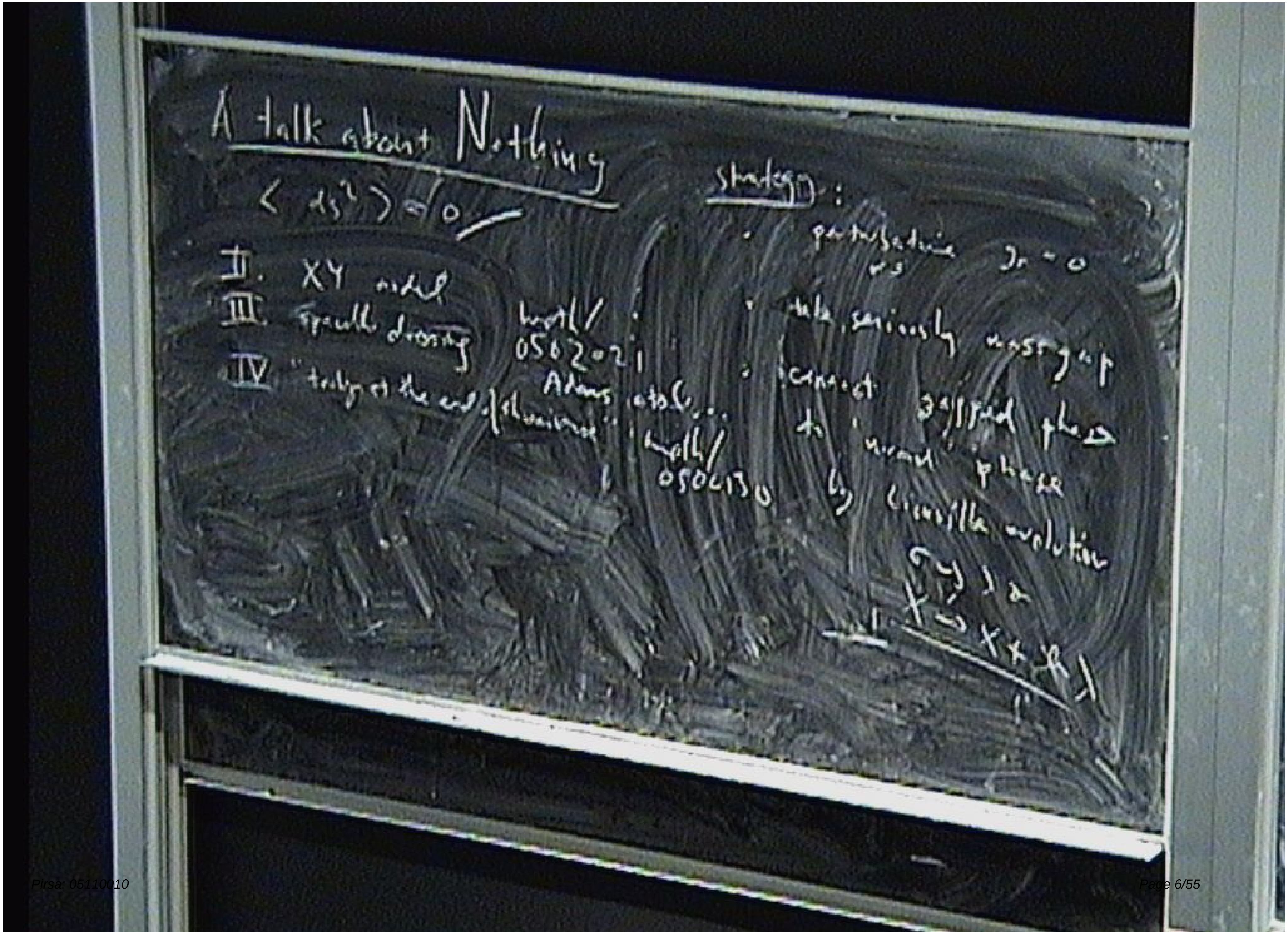
II. XY model

III.

strategy:

- perturbation $g_s \to 0$
- take seriously mass gap
- connect gapped phase to normal phase by Liouville evolution

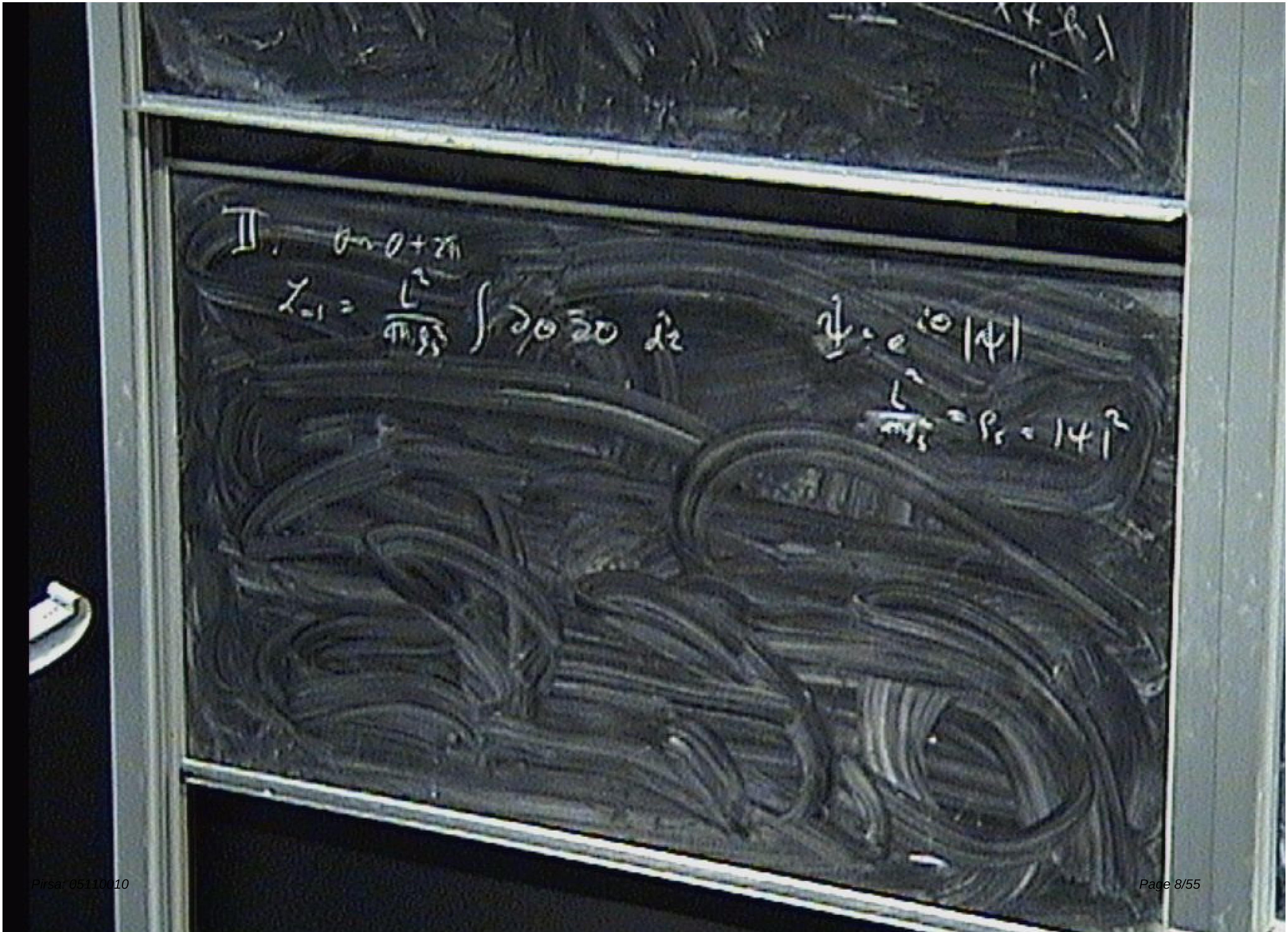
$X \to X + \ldots$



A talk about Nothing
⟨ds²⟩ ≠ 0
II. XY model
III. Spatially dressing
IV. "tachyons at the end of the universe"
0502021
Adams et al...
0504130
Strategy:
perturbative
take seriously mass gap
connect gapped phase
to normal phase
by Liouville evolution

II. $\theta \sim \theta + 2\pi$

$$Z_{-1} = \frac{L^2}{4\pi g_s^2} \int \partial\theta \, \bar{\partial}\theta \, d^2 z$$


II, θ → θ + 2π
L_eff = ℓ²/(4π g_s) ∫ ∂θ ∂̄θ d²z
ψ = e^{iθ} |ψ|
ℓ²/(4π g_s) = ρ_s = |ψ|²

II. $\theta \to \theta + 2\pi$

$$\mathcal{L}_{w1} = \frac{L^2}{4\pi g_s^2} \int \partial\theta\, \bar{\partial}\theta \, d^2z$$

$$\mathcal{O}_{nm} = \exp i(n\theta + m\tilde{\theta})$$

$$\psi = e^{i\theta} |\psi|$$

$$\frac{\hat{L}}{4\pi g_s^2} = \rho_s = |\psi|^2$$

$$\theta = \theta_L + \theta_R \qquad \bar{\partial}\theta_L = 0$$

$$\tilde{\theta} = \theta_L - \theta_R \qquad \partial\theta_R = 0$$

II. $\theta \to \theta + 2\pi$

$$\mathcal{L}_{m1} = \frac{L^2}{4\pi g_s^2}\int \partial\theta\,\bar{\partial}\theta\, d^2z \qquad \Psi = e^{i\theta}|\Psi|$$

$$\mathcal{O}_{nm} = \exp i(n\theta + m\tilde{\theta}) \qquad \frac{L^2}{4\pi g_s^2} = \rho_s = |\Psi|^2$$

$$\alpha'/g_s^2 = 1 \qquad \Delta_{nm} = \left(\frac{n}{L}\right)^2 + (mL)^2$$

$$\theta = \theta_L + \theta_R \qquad \bar{\partial}\theta_L = 0$$

$$\tilde{\theta} = \theta_L - \theta_R \qquad \partial\theta_R = 0$$

if $L < L_c = \sqrt{2}\,\ell_s$, $\Delta_{0,\pm 1} = L^2 < 1$

II. $\theta \to \theta + 2\pi$

$$\mathcal{L}_{m1} = \frac{L^2}{4\pi g_s^2}\int \partial\theta\,\bar\partial\theta\, d^2z \qquad \psi = e^{i\theta}|\psi|$$

$$\mathcal{O}_{nm} = \exp i(n\theta + m\tilde\theta) \qquad \frac{L^2}{4\pi g_s^2} = \rho_s = |\psi|^2$$

$1/g_s^2 \gg 1$

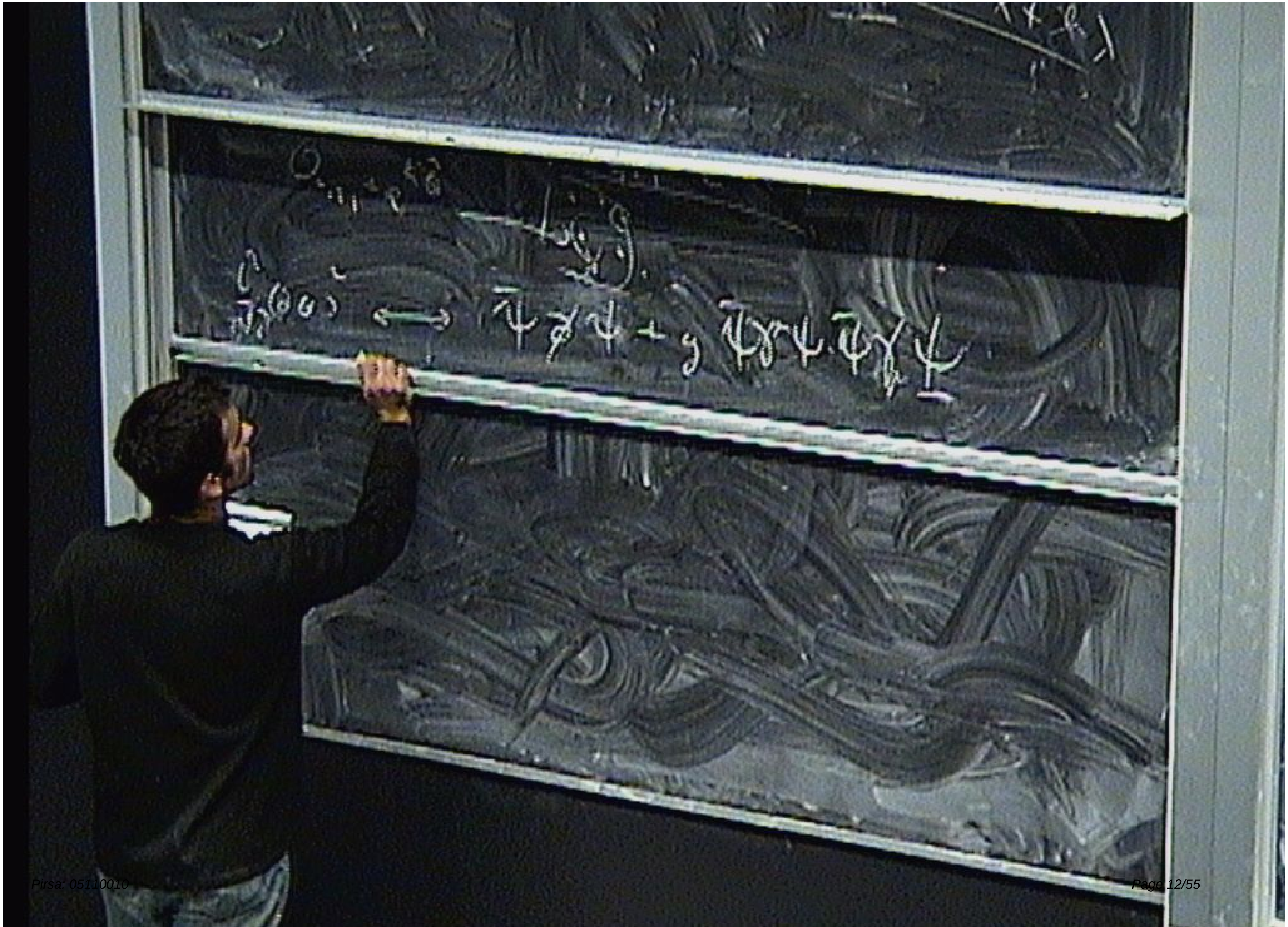
$$\Delta_{nm} = \left(\frac{n}{L}\right)^2 + (mL)^2$$

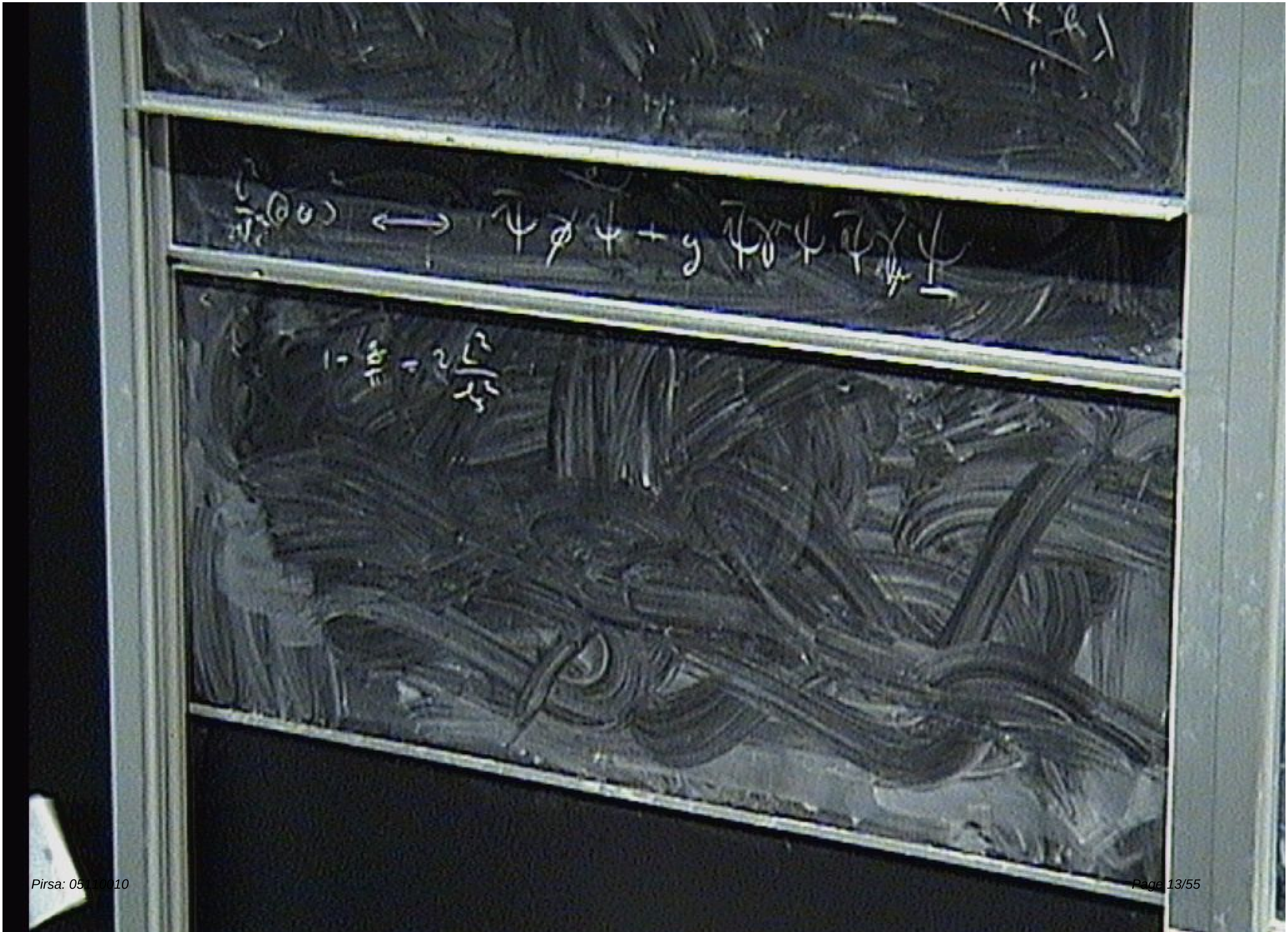
$$\theta = \theta_L + \theta_R \qquad \bar\partial\theta_L = 0$$

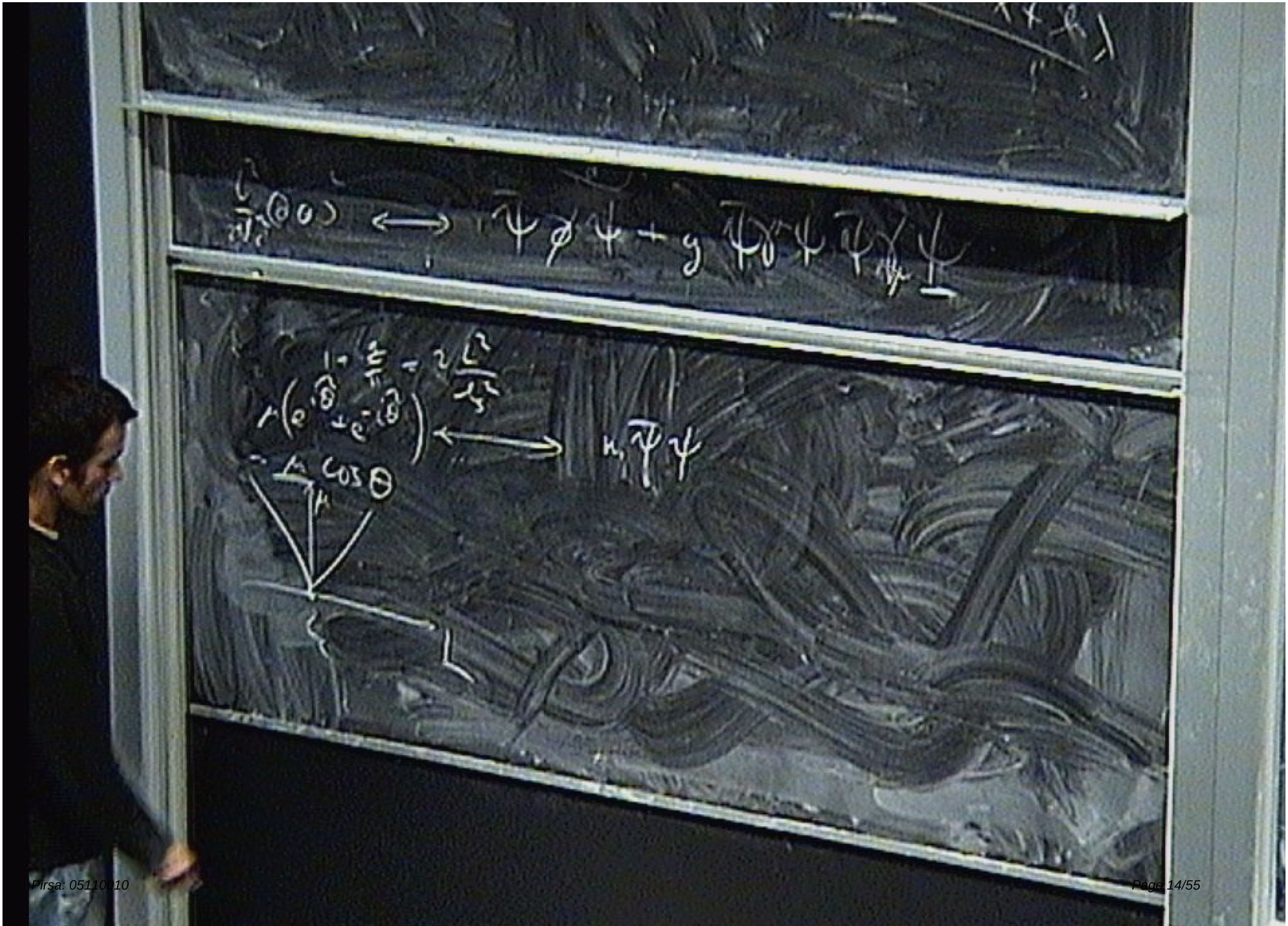
$$\tilde\theta = \theta_L - \theta_R \qquad \partial\theta_R = 0$$

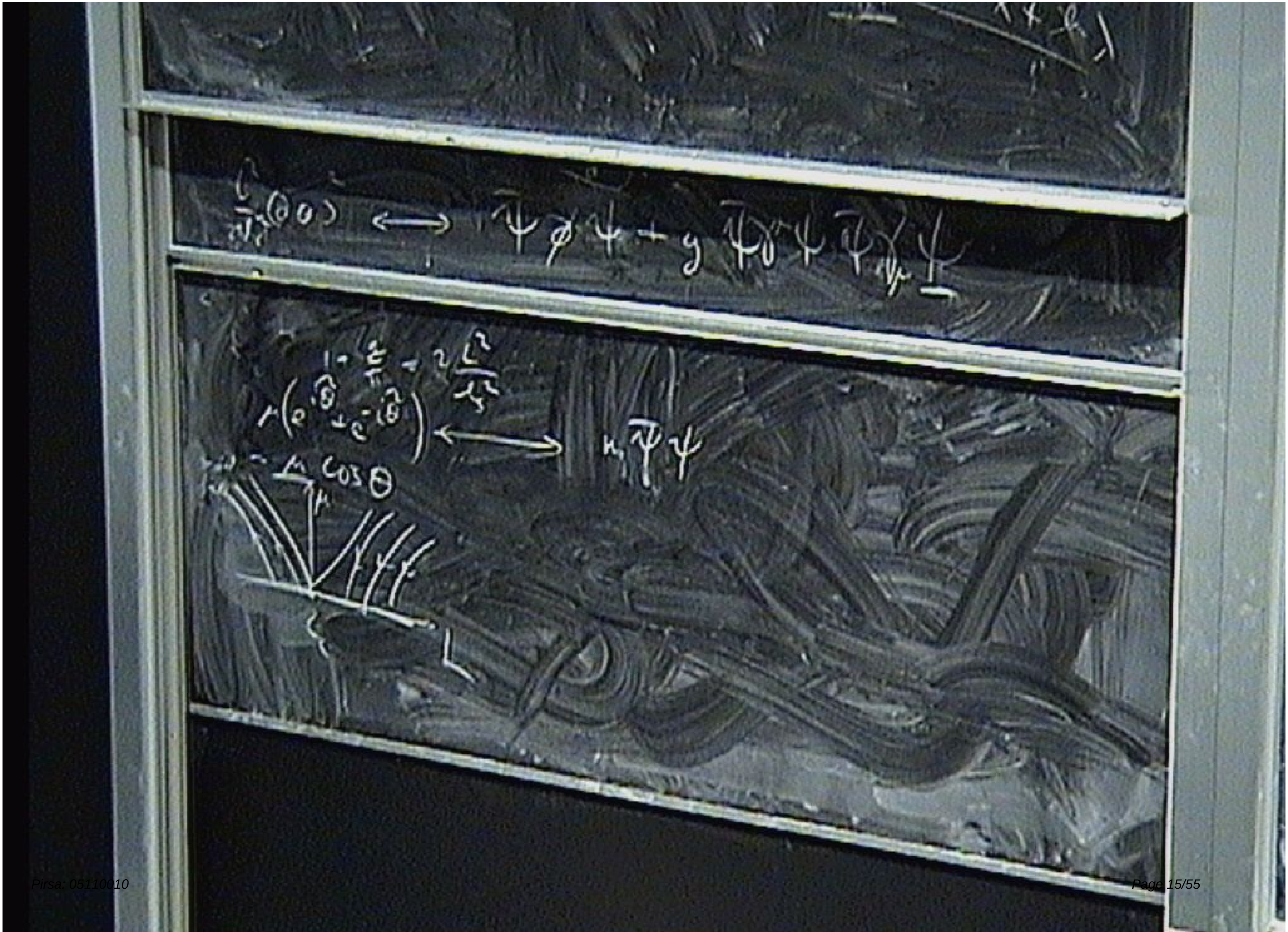
if $L < L_c = \sqrt{2}\, l_s$, $\Delta_{0,\pm1} = L^2 < 1$

$$\mathcal{O}_{0,\pm1} = e^{\pm i\tilde\theta}$$







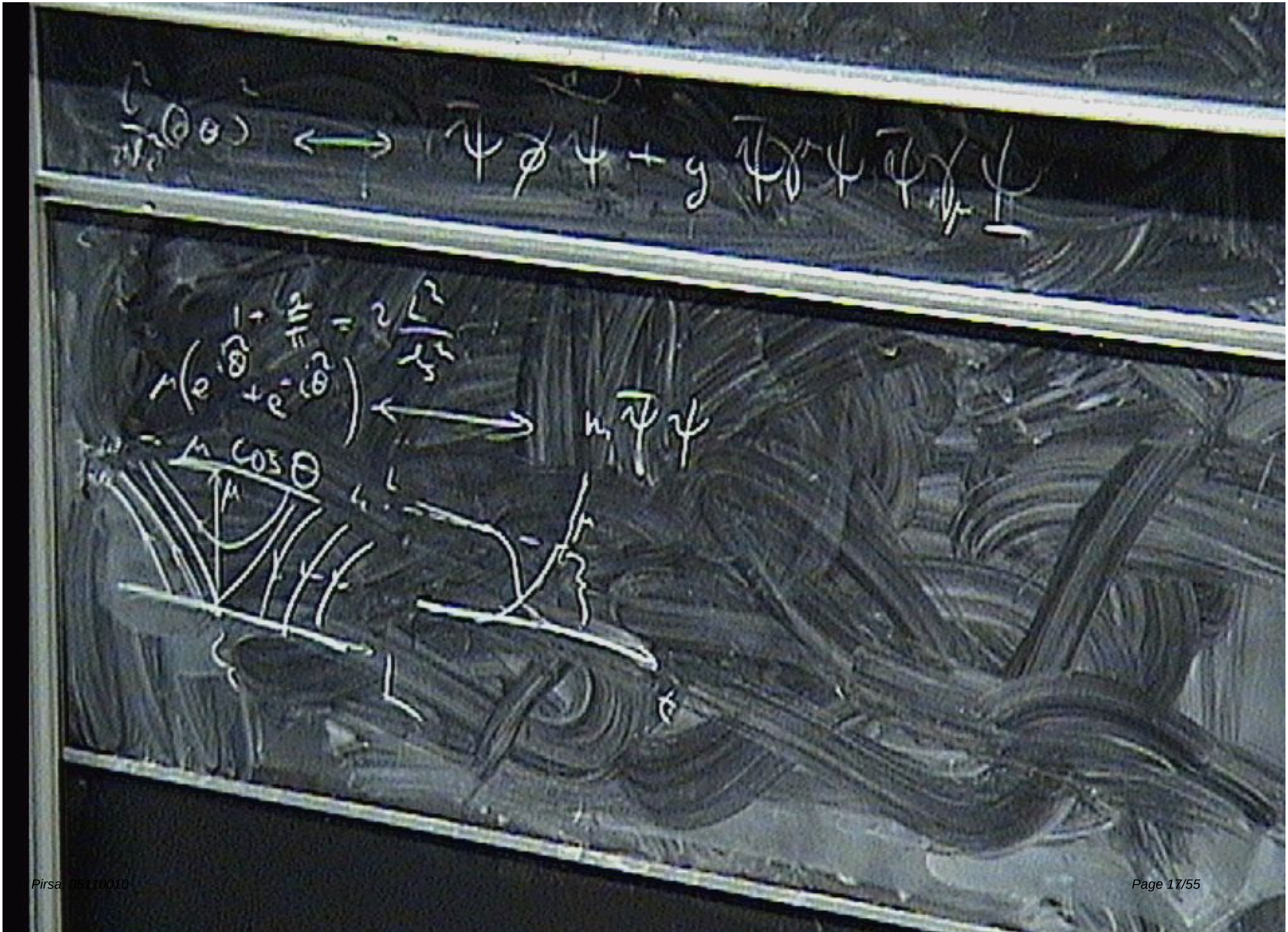


$$\frac{\lambda^2}{2\pi}(\partial\theta)^2 \longleftrightarrow \bar\Psi \not\partial \Psi + g\, \bar\Psi\gamma^\mu\Psi\, \bar\Psi\gamma_\mu\Psi$$

$$1+\frac{g}{\pi} = 2\frac{\lambda^2}{\lambda_s^2}$$

$$\mu\left(e^{i\hat\theta} + e^{-i\hat\theta}\right) \longleftrightarrow m\,\bar\Psi\Psi$$

$$= \mu\cos\theta$$



$\bar\psi \partial\!\!\!/ \psi + g\, \bar\psi\gamma^\mu\psi\, \bar\psi\gamma_\mu\psi$
$m\bar\psi\psi$
$\mu\cos\theta$

$$\frac{L^2}{\pi r_c^2}(\partial\theta)^2 \longleftrightarrow \bar\psi\, \partial\!\!\!/\, \psi + g\, \bar\psi\gamma^\mu\psi\, \bar\psi\gamma_\mu\psi$$

$$1 + \frac{g}{\pi} = 2\frac{L^2}{\lambda_s^2}$$

$$\mu\left(e^{i\hat\theta} + e^{-i\hat\theta}\right) \longleftrightarrow m_1 \bar\psi\psi$$

$$= \mu \cos\theta$$

III RS compactification

IIA on Σ_4

$R_{\mu\nu} = P_{\mu\nu}$

III RS compactification

IIA on Σ_4

$R_{\mu\nu} = R_{\mu\nu}$

$\Rightarrow$ constant [illegible] curvature is a local min

III RS compactification

IIA on Σ_4

$\rho_{\mu\nu} = R_{\mu\nu}$

$\Rightarrow$ constant negative curvature is a local min

$$g_s^{-1}\int \sqrt{g}\, R \qquad V_{eff}\left(\frac{\ell}{R}\right) \sim \frac{1}{\ell_s^{c}}\left(\frac{g_s}{V_\Sigma}\right)^{2/3} (2h-2)$$

III RS compactification

IIA on T_6

$\beta_{\mu\nu} = P_{\mu\nu}$

→ constant eigenvalue curvature is a local min.

$\frac{1}{g_s^2}\int \sqrt{g}\, R$

$$V_{eff}\left(\frac{\Phi}{V}\right) \sim \frac{1}{g_s^2}\left(\left(\frac{g_s}{V_2}\right)\right)^{2/3} \quad (\text{eh}=2)$$

all trends $V_2 \to \infty$, $g_s \to 0$, slowly of $\frac{g_s}{V_2}$ or g_s^2

III RS compactification

IIA on T_6

$R_{\mu\nu} = R_{\mu\nu}$

→ constant system equations is a local min.

$\mathcal{L} = R + \ldots \alpha' R + O(\alpha' R)^2$

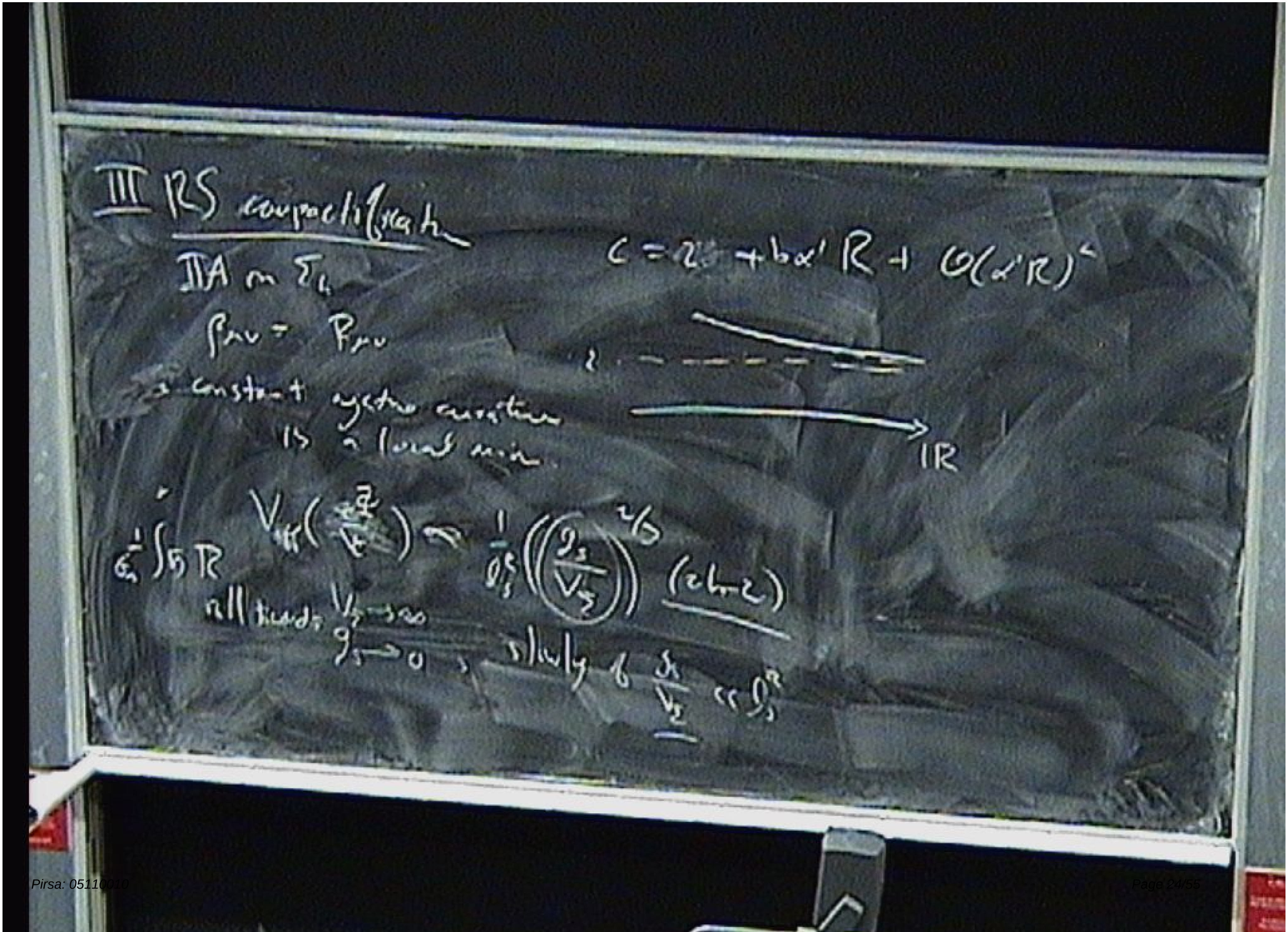
IR

$g_s^{-2} \int R$

$V_{eff}\left(\frac{g_s}{V}\right) \sim \frac{1}{g_s^2}\left(\frac{g_s}{V_4}\right)^{2/3}$ (etc)

all kinds V grows

$g_s \to 0$, likely to $\frac{g_s}{V_2}$ or g_s^2


III RS compactification
IIA on Σ_4
$c = 26 + b\alpha' R + O(\alpha' R)^2$
$R_{\mu\nu} = R_{\mu\nu}$
⇒ constant system curvature is a local min
IR
V_{eff}
$g_s^{-2} \int \sqrt{g} R$
all trends $V_\Sigma \to \infty$
$g_s \to 0$, slowly b/c $\frac{g_s}{V_\Sigma} << g_s^2$

III RS compactification

$$c = 2 + b\alpha' R + O(\alpha' R)^2$$

IIA on Σ_4

$\beta_{\mu\nu} = R_{\mu\nu}$

→ constant negative curvature is a local min

2nd choice of spin structure

$\frac{1}{\alpha'}\int_{\Sigma} R$

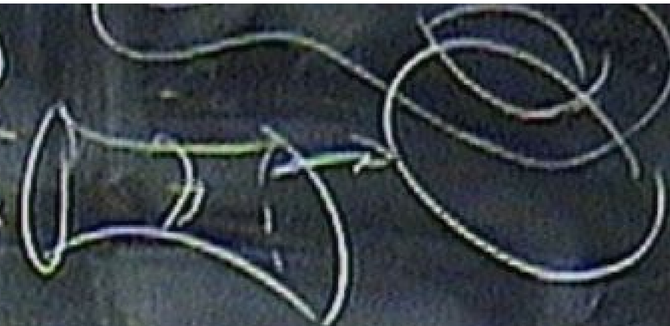
$$V_{\Sigma}\left(\frac{\Sigma}{\epsilon}\right) \sim \frac{1}{g_s^2}\left(\left(\frac{g_s}{V_\Sigma}\right)\right)^{2/3} \quad (\mathrm{ch}=2)$$

all tuneable: $V_\Sigma \to \infty$, $g_s \to 0$, stability of $\frac{g_s}{V_\Sigma} \ll g_s^3$

$\tilde{a}_n$) is R

$g_s^2 \left(\frac{\alpha'}{V_2}\right)$ $(2h-2)$

all tends $V_2 \to \infty$, $g_s \to 0$, slowly so $\frac{\alpha'}{V_2} \ll g_s^2$



$$ds^2 = dx^2 + L(x)^2 d\theta^2$$

$$\frac{dL}{dx} \ll \left(\frac{g_s^2}{V_2}\right)^{1/4}$$

$$\alpha' m^2 = -\frac{1}{2} + \frac{L^2}{2 g_s^4} + \cdots$$

) is R

$g_s^2 \left(\frac{\,}{V_5} \right)$ (ch-2)

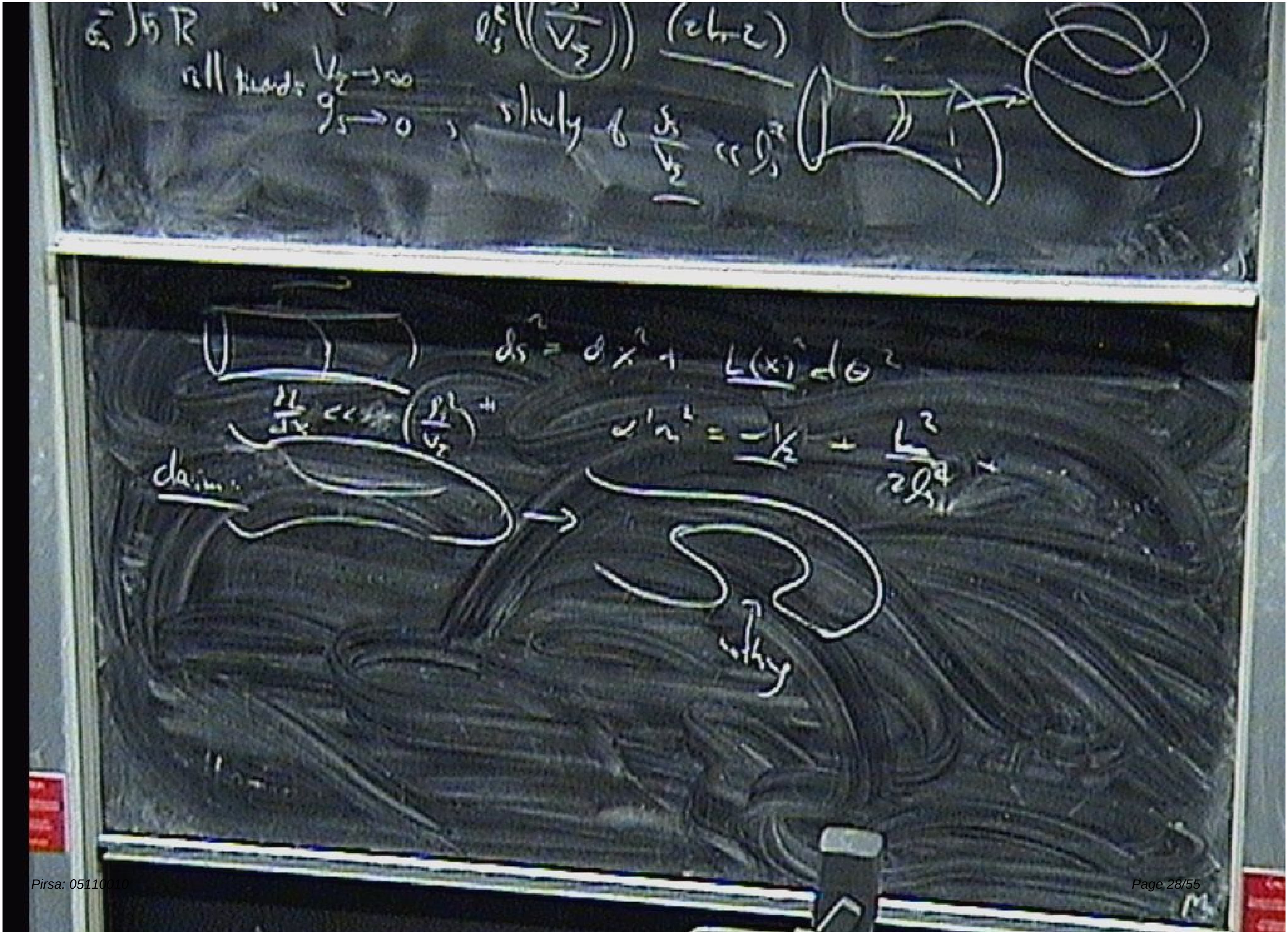
all [illegible]: $V_5 \to \infty$

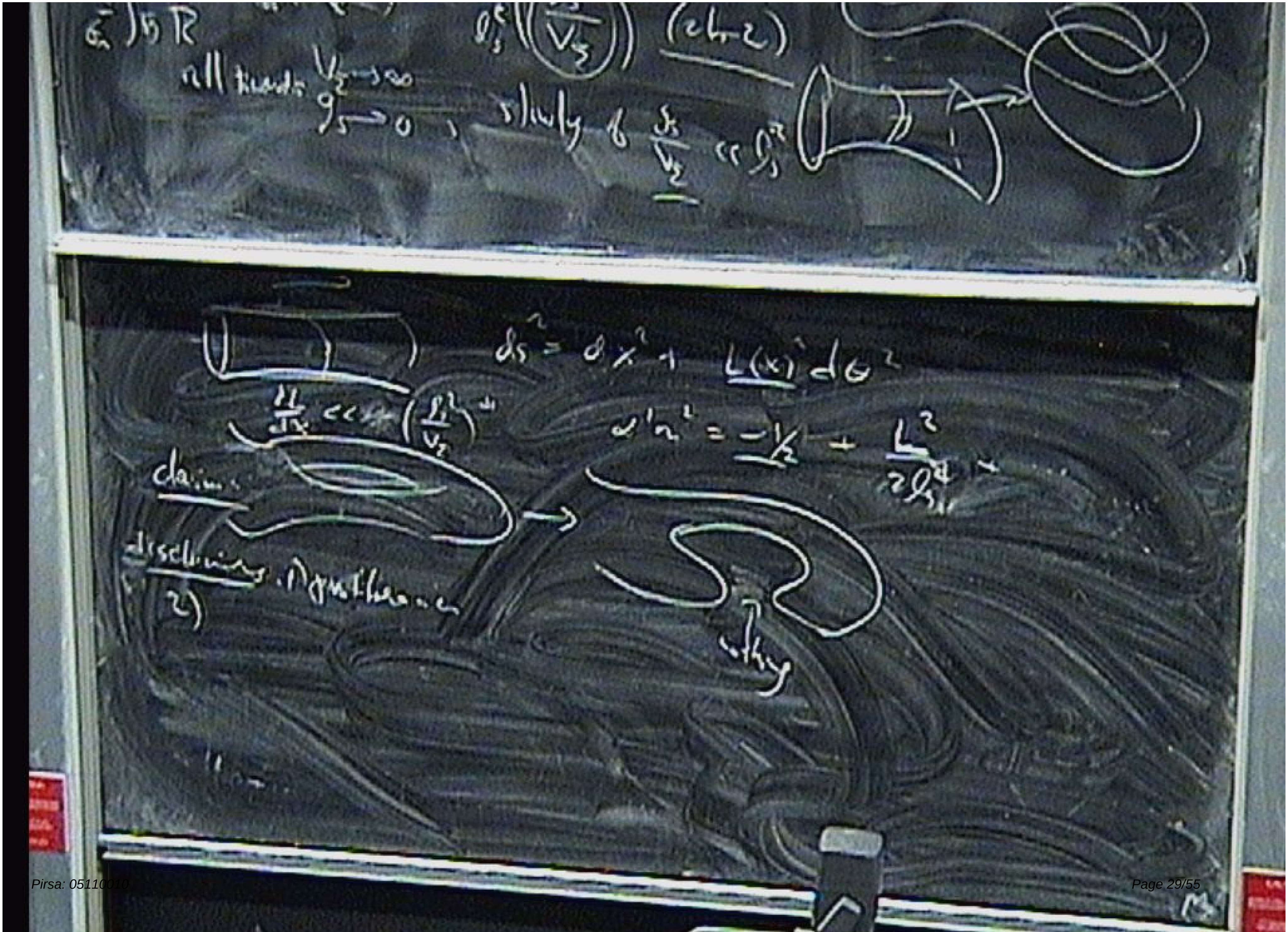
$g_5 \to 0$, slowly b $\frac{g_5}{V_5} \ll \ell_s^3$

$ds^2 = dx^2 + L(x)^2 d\theta^2$

$\frac{dL}{dx} \ll \left(\frac{\ell_s^3}{V_5} \right)^4$

$\alpha' m^2 = -\frac{1}{2} + \frac{L^2}{2\ell_s^4}$


$(2h-2)$
$g_s \to 0$
$ds^2 = dx^2 + L(x)^2 d\theta^2$
$\alpha' m^2 = -\frac{1}{2} + \frac{L^2}{2 l_s^4}$
claim
why


all knots
$ds^2 = dx^2 + L(x)^2 d\theta^2$
claim
why

$\bar{\varepsilon}_s$) is R

$l_s^2 \left(\frac{g_5}{V_5} \right)$ (2h-2)

all times: $V_5 \to \infty$

$g_5 \to 0$, slowly so $\frac{g_5}{V_5} \ll l_s^2$

$ds^2 = dx^2 + L(x)^2 d\theta^2$

$\frac{dL}{dx} \ll \left(\frac{l_s^2}{V_5} \right)^{-1}$

$\alpha' m^2 = -\frac{1}{2} + \frac{L^2}{2 l_s^4} + \dots$

claim:

discharging ...

2) $g_s \to 0$ really 2d type 0

3)

why

σ_n) β R

$g_s^2 \left(\frac{\ell_s}{V_2} \right)$ $(c_h - 2)$

all kinds: $V_2 \to \infty$
$g_s \to 0$, slowly so $\frac{\ell_s}{V_2} \ll g_s^2$

$ds^2 = dx^2 + L(x)^2 d\theta^2$

$\frac{dL}{dx} \ll e^{..} \left(\frac{g_s^2}{V_2} \right)^{-1}$

$\alpha' m^2 = -\frac{1}{2} + \frac{L^2}{2 g_s^4}$

claim:

why

disclaimers: 1) ...

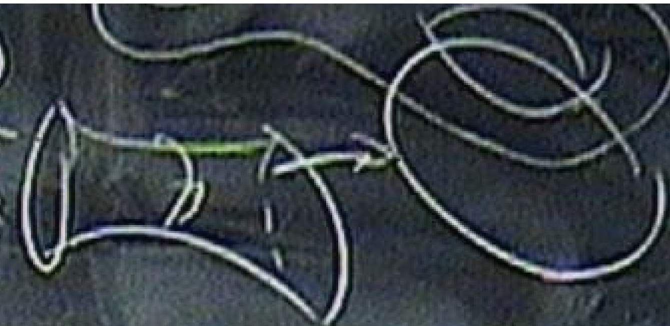
2) $g_s \to 0$ really 2d type 0

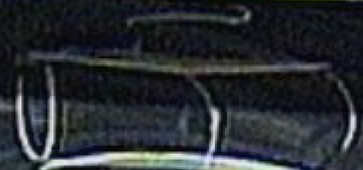
3) $\mathrm{tr}(-1)^F = \chi(\Sigma_h) = 2 - 2h$

$\bar{\sigma}_1) \Sigma R$ $\quad g_s^2 \left(\frac{\alpha'}{V_\Sigma}\right)$ $(2h-2)$

all bounds $V_\Sigma \to \infty$

$g_s \to 0$, slowly $\frac{g_s}{V_\Sigma} \ll g_s^2$





$ds^2 = dx^2 + L(x)^2 d\theta^2$

$\frac{dL}{dx} \ll \left(\frac{g_s^2}{V_\Sigma}\right)^{1/4}$

$\alpha' m^2 = -\frac{1}{2} + \frac{L^2}{2 g_s^4} + \ldots$

claim:

disclaiming assumptions

2) $g_0 \to 0$ really 2d type 0

3) $\mathrm{tr}(-1)^F = \chi(\Sigma_h) = 2-2h$

nothing really 'disturbing'

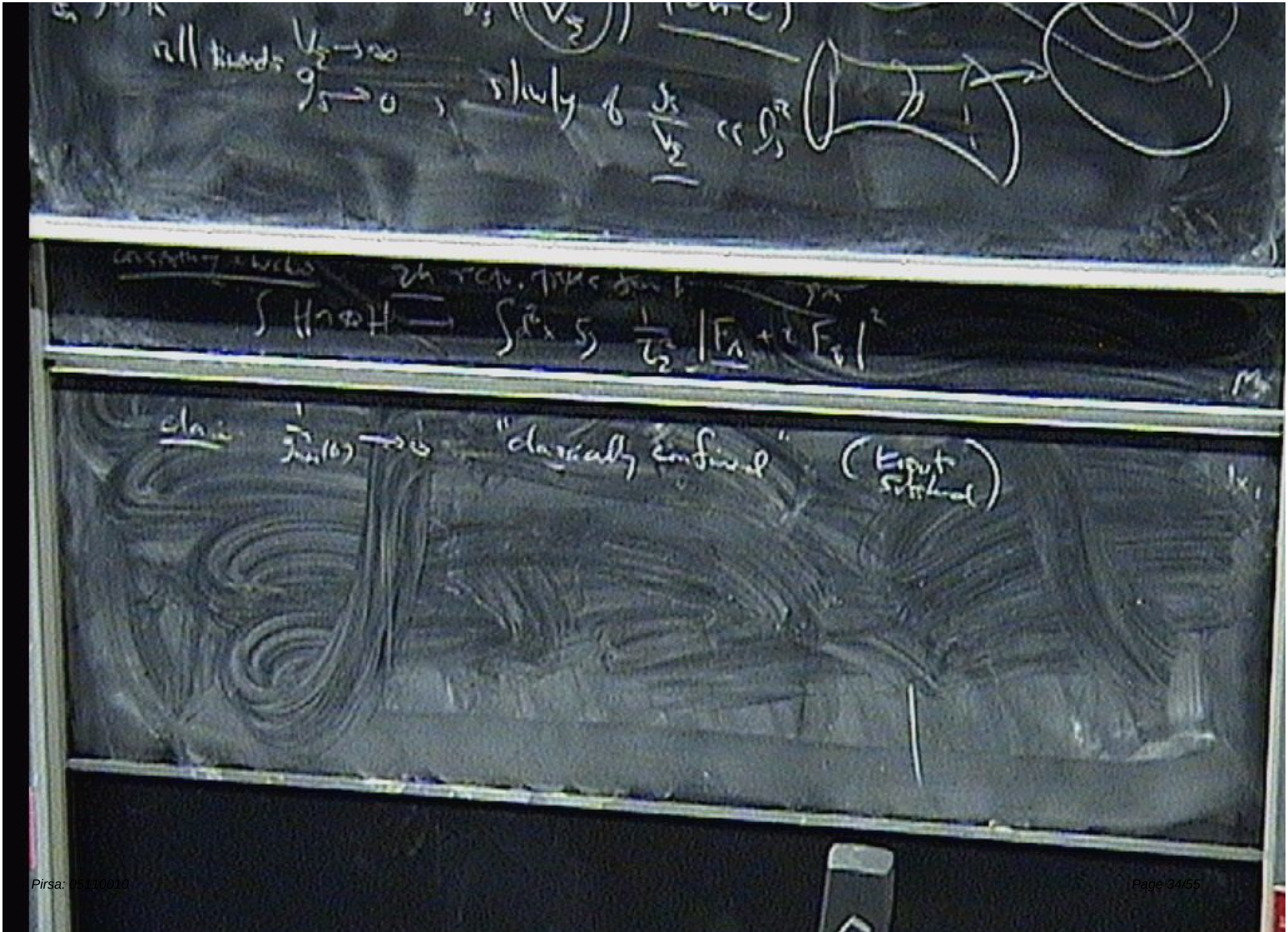
all tends $V_2 \to \infty$

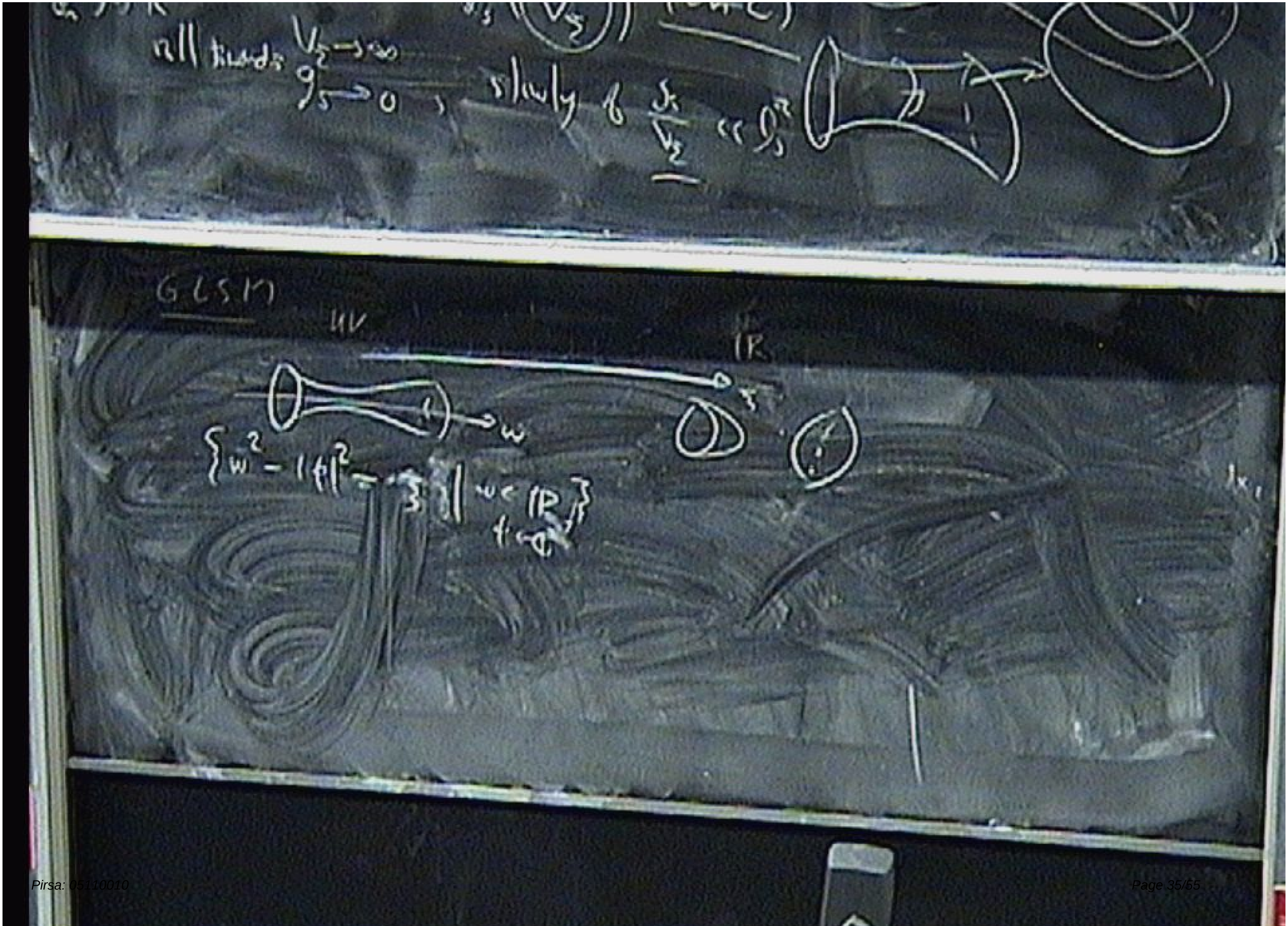
$g_s \to 0$, slowly $\frac{g_s}{V_2} \ll g_s^2$

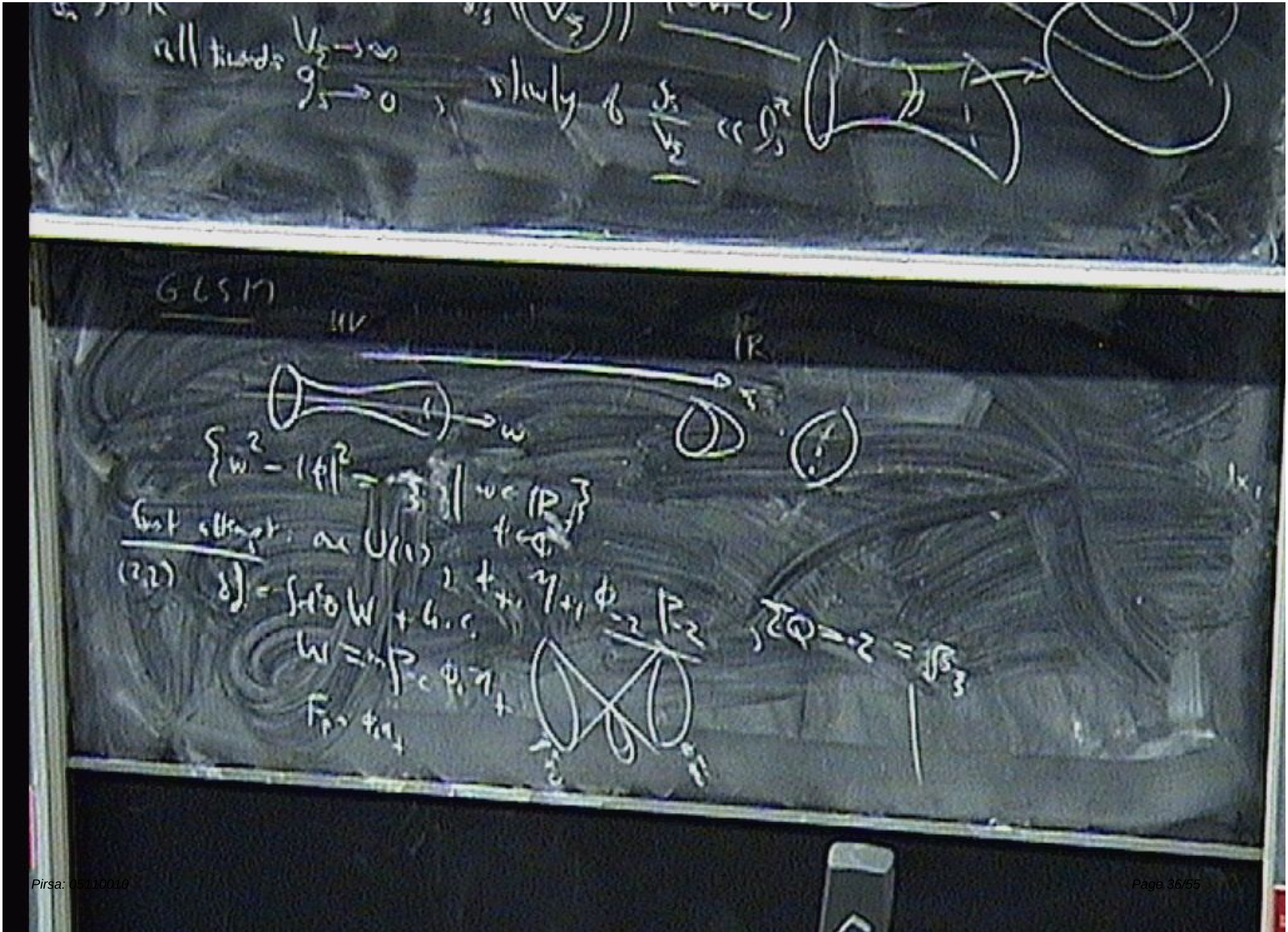
$(-1)^{\ldots} = \chi(\Sigma_1) = 2-2\ldots$

Consistency checks: ... twisted strike ...

$$\int H \wedge * H \longrightarrow \int d^4x \, \Sigma \, \frac{1}{\tau_2} \left| F_1 + \tau F_2 \right|^2$$


all kinds
slowly
claim
"classically confined"


all kinds
GLSM
UV
IR



all kinds
slowly
GLSM
UV
IR
first attempt

all kinds $V_2 \to \infty$

$g_s \to 0$, slowly s.t. $\frac{g_s}{V_2} \ll g_s^2$

GLSM

UV

$\mathbb{P}_1$

$\{ |w|^2 - |\phi|^2 = \zeta \} \quad w \in \mathbb{P}$

first attempt: one $U(1)$

(2,2) $\quad \delta \mathcal{J} = \int d^2\theta \, W + h.c.$

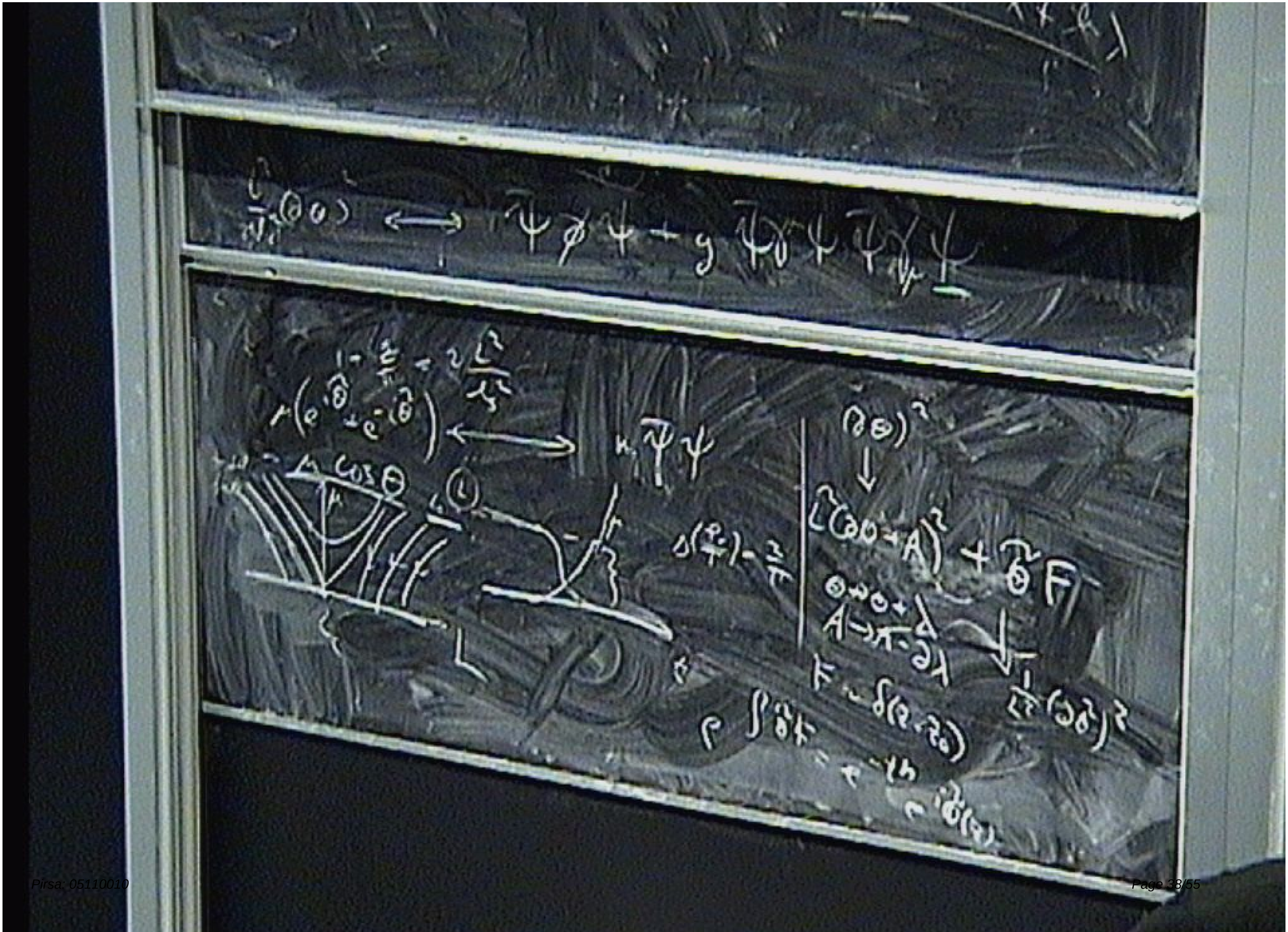
$W = \mathbb{P}_{-2} \, \phi_+ \, \eta_+$

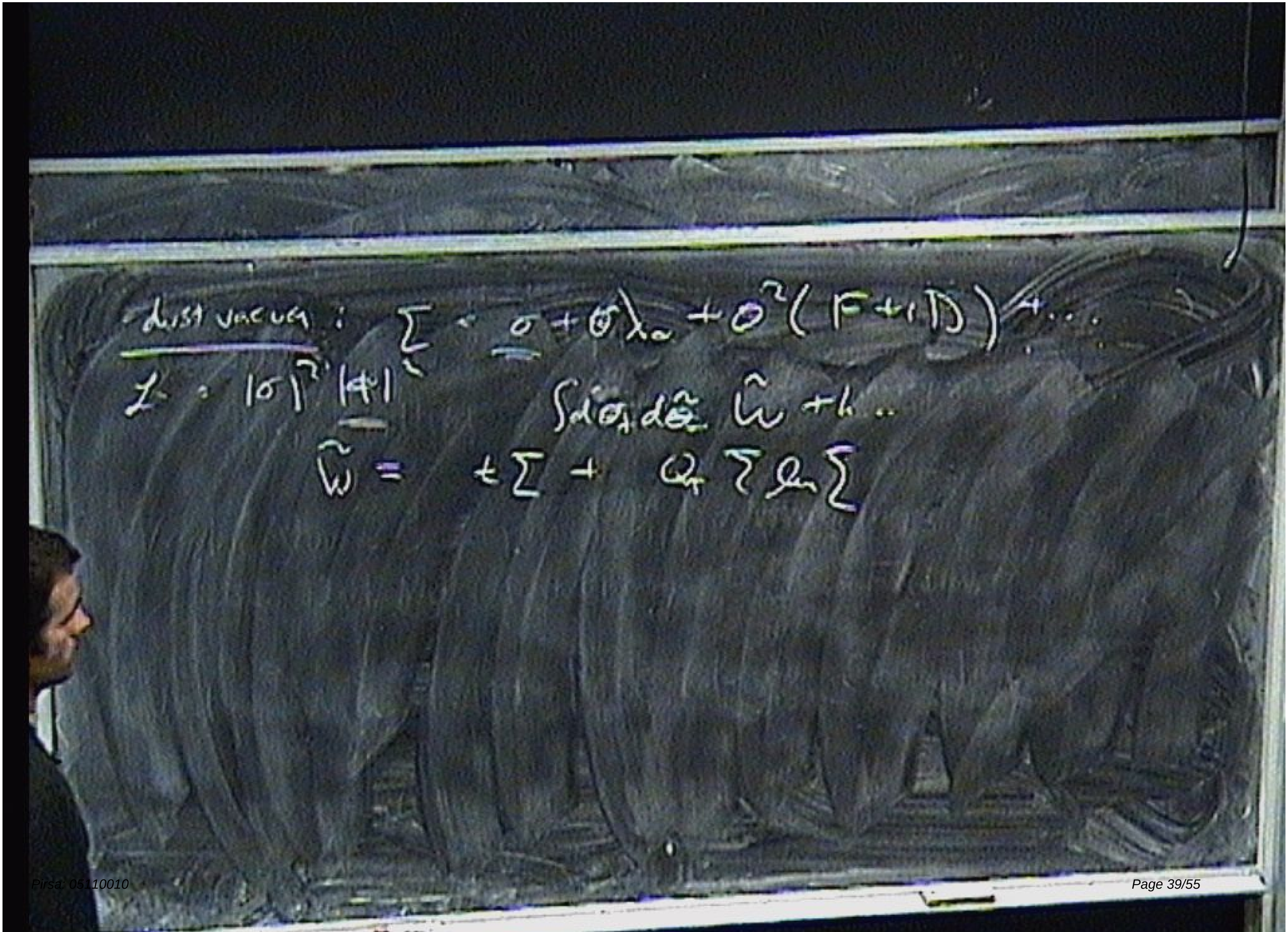
$W = \mathbb{P}(XY - \mu)$

$\phi_{+1} \quad \eta_{+1} \quad \phi_{-2} \quad \mathbb{P}_{-2}$

$\sum Q = -2 = c_1(\beta)$

$\delta \mathcal{J} = \int d\theta_+ \, \bar{\eta}_- \left(\mathbb{P}_{-2} \mathbb{P}_{-2} + \phi_+ \bar{\eta}_+ \eta_+ + \bar{\phi}_+ \eta_+ \right)$




dist vacua : Σ = σ + θλ + θ²(F + iD) + ...
∫dθ dθ̃ W̃ + h.c.
W̃ = tΣ + Q Σ ln Σ

dust vacua : $\Sigma = \sigma + \theta\lambda_\alpha + \theta^2 (F + iD) + \ldots$

$\mathcal{L} = |\sigma|^2 \; |F|^2$

$\int d\theta_+ d\bar{\theta}_- \, \tilde{W} + h.c.$

$\tilde{W} = t\Sigma + Q_r \Sigma \ln \Sigma$

R sym. $\theta_+ \to e^{i\alpha_+}\theta_+$ $\quad \Sigma \to e^{i(\alpha_+ - \alpha_-)}\Sigma$

$\theta_- \to e^{i\alpha_-}\theta_-$

dust vacua : $\Sigma = \sigma + \theta^\alpha \lambda_\alpha + \theta^2 (F + iD) + \ldots$

$Z = |\sigma|^2 |t|^2$

$\int d\theta_+ d\bar\theta_- \, \widehat{W} + h.c.$

$$\widetilde{W} = t\Sigma + Q_T \Sigma \ln \Sigma$$

R sym. $\theta_+ \to e^{i\alpha_+}\theta_+$ $\quad \Sigma \to e^{i(\alpha_+ - \alpha_-)}\Sigma$

$\theta_- \to e^{i\alpha_-}\theta_-$

chiral case. $\sigma \to -\sigma$ $\quad \mathbb{Z}_2 \subset U(1)_{\text{axial}}$ since $Q_T \in 2\mathbb{Z}$

$0 = \widetilde{W}' \iff \sigma = \pm e^{|t|/2}$

dust vacua : $\Sigma = \sigma + \theta \lambda_\alpha + \theta^2 (F + iD) + \ldots$

$\mathcal{L} = |\sigma|^2 |t|^2$

$\int d\theta_+ d\bar{\theta}_- \, \tilde{W} + h.c.$

$$\tilde{W} = t\Sigma + Q_+ \Sigma \ln \Sigma$$

R-sym: $\theta_+ \to e^{i\alpha_+}\theta_+$ $\quad \Sigma \to e^{i(\alpha_+ - \alpha_-)}\Sigma$

$\theta_- \to e^{i\alpha_-}\theta_-$

$\mathbb{Z}_2 \subset U(1)_{\text{axial}}$

chiral ... $\sigma \to -\sigma$ since $Q_+ \in 2\mathbb{Z}$

$0 = \tilde{W} \iff \sigma = \pm e^{-t/2} \longrightarrow$ 9d type 0

$\delta = \pm e^{i(\cdot)/2} \longrightarrow$ 8d typeO

IV. Ind(?)

$$ds^2 = -dt^2 + L^2(t)\,d\Theta^2 + ds_\perp^2$$

$\pm e^{i\ldots/2} \longrightarrow$ 8d type 0

IV. [illegible]

$ds^2 = -dt^2 + L^2(t)\,d\theta^2 + ds_\perp^2$ w/ APBC on θ

$0 = \dot{L}$ closed: $\dot{L} \ll 1$

$\dot{L} > 0$

$Z \sim \int (dX)\, e^{i\int d^2\sigma\, G_{\mu\nu} \partial X^\mu \bar{\partial} X^\nu}$

$\gamma = \pm e^{i\epsilon/2} \longrightarrow$ 8d type 0

IV. [illegible]

$$ds^2 = -dt^2 + L^2(x^1)\, d\theta^2 + d\vec{x}_\perp^{\,2} \quad \text{w/ APBC on } \theta$$

$0 = i^1$ closed: $L \ll 1$

$L \to 0$

$$Z \sim \int (\delta X)\, e^{i\int d^2\sigma \left[G_{\mu\nu}\partial X^\mu \bar\partial X^\nu - \mu e^{\kappa X^0} \cos\tilde\theta \right]}$$

$\pm e^{i(\cdot)/2} \longrightarrow$ 2d tgpe 0

IV. Tachyons

$ds^2 = -dt^2 + L^2(t)\,d\theta^2 + ds_\perp^2$ w/ APBC on θ

$0 = L'$ closed: $L \ll l_s$

$L \to 0$

$$Z \sim \int (\delta X)\, e^{-i\int d^2\sigma \left[G_{\mu\nu}\partial X^\mu \partial X^\nu - \mu e^{\kappa X^0} \cos\tilde\theta \right]}$$

$\Phi(X^0) \sim$

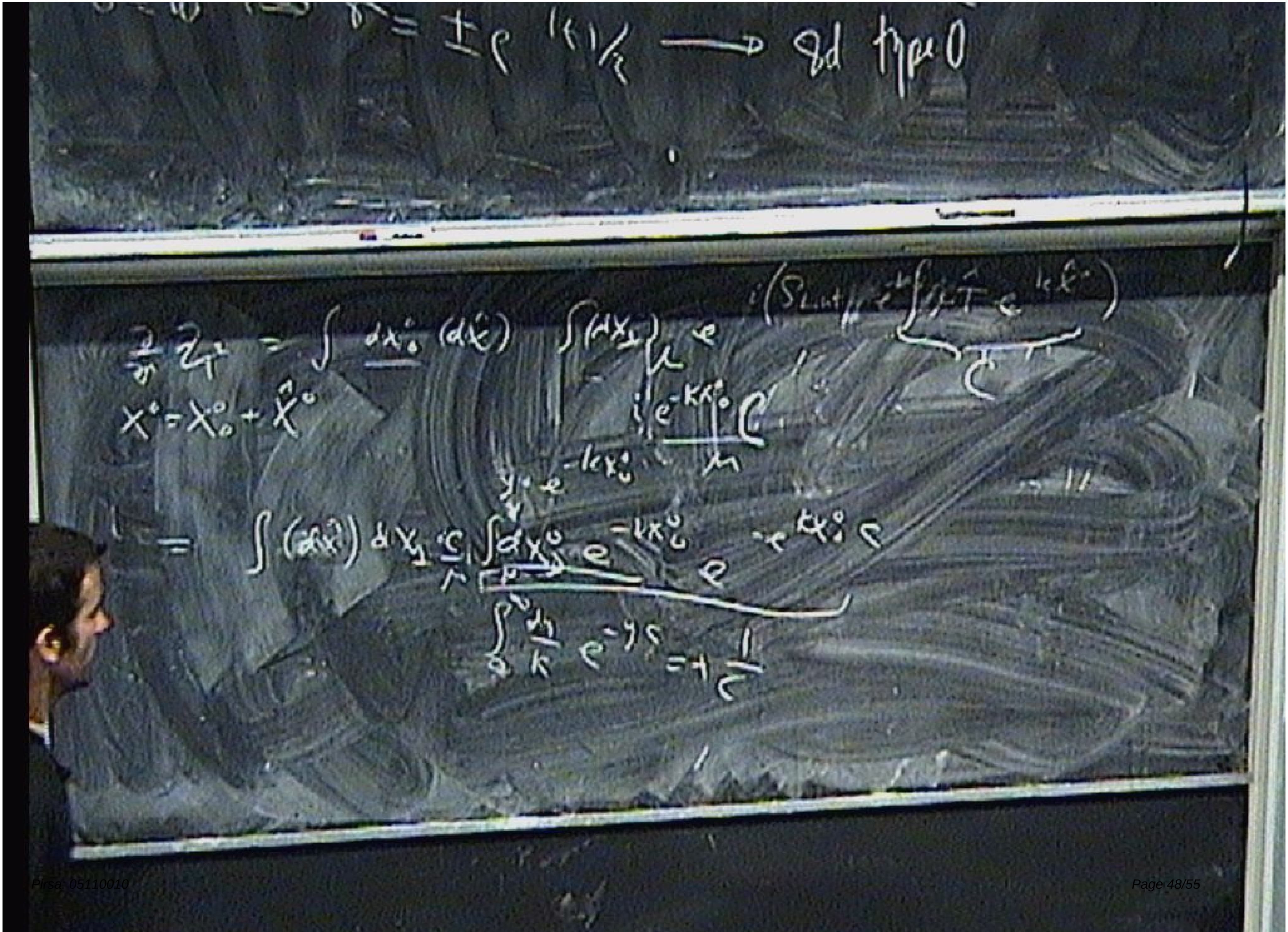
$T(X^0) \sim e^{\kappa t}$

$$= \pm e^{i(\cdot)/\epsilon} \longrightarrow \text{2d top } 0$$

$$\frac{\partial}{\partial \tau} Z_T = \int \underline{dx_0^i}\,(d\hat{x}) \int (dX_\perp)\, \mu \; e^{i\left(S_{\perp,\mu} + \underbrace{\dots\, e^{k\hat{x}^0}}_{\epsilon}\right)}$$

$$i\, e^{-k x_0^0} \frac{C}{m}$$

$$X^0 = X^0_0 + \hat{X}^0$$



$= \pm e^{i(\ )/2} \longrightarrow$ 2d type 0

$\frac{\partial}{\partial \mu} Z_T^2 = \int dx_0^0 \, (d\tilde{x}) \int (dx_1) \, \mu \, e^{i(S_{kin} + \mu \int \tilde{T} e^{kX^0})}$

$X^0 = X_0^0 + \tilde{X}^0$

$= \int (d\tilde{x}) \, dx_1 \, \int dx_0^0 \, e^{-kx_0^0} \, e \, e^{kx_0^0} \, e^{iS_{kin}}$

$\int_0^\infty \frac{dy}{k} e^{-yc} = + \frac{1}{kc}$

$= \frac{1}{\mu k} \underbrace{\int (d\tilde{x}) dx_1 \, e^{iS_{kin}}}_{Z_{kin}}$

$= \pm e^{i(\epsilon)/2} \longrightarrow$ 2d type 0

$$\frac{\partial}{\partial \mu} Z_T^2 = \int \frac{dx_0^i}{\;}\,(dx^i) \int (dx_1)_\mu\, e^{i\left(S_{1,\mathrm{int}} + \mu \int \hat{f}\, e^{k\hat{x}^0}\right)}$$

$$X^0 = X_0^0 + \hat{x}^0$$

$$i\, e^{-kx_0^0}\, \frac{\;}{h}$$

$$y = e^{-kx_0^0}$$

$$= \int (dx^i)\, dx_1\, \frac{e}{k} \int dx_0^0\, e^{-kx_0^0}\, e^{-e^{kx_0^0}}\, e^{iS_{\mathrm{int}}}$$

$$\int_0^\infty \frac{dy}{k}\, e^{-y\epsilon} = +\frac{1}{\epsilon}$$

$$= \frac{1}{\mu k} \int (dx^i)\, dx_1\, e^{iS_{\mathrm{int}}}$$

$\gamma = \pm e^{i(\epsilon)/2} \longrightarrow$ 8d type 0

$$\frac{\partial}{\partial \mu} Z_{T^2} = \int dx_0^i \, (d\hat{x}) \int (dx_\perp)_\mu \, e^{i\left(S_{L.c.t} + \mu e^{\ldots} \int \psi \bar{\psi} \, e^{\,k \hat{x}^-}\right)}$$

$$X^0 = X^0_0 + \hat{X}^0$$

$$= \int (d\hat{x}) \, dx_\perp \, \int dx_0^0 \, e^{-kx_0^0} \, e^{\,kx_0^0} \, e^{\,S_{L.c.}}$$

$$= \frac{1}{\mu k} \int (d\hat{x}) \, dx_\perp \, e^{S_{L.c.}} \int \frac{dy}{k} \, e^{-y} \ldots \, T \, V \, Z_{T^2}$$

$$\mu_0 = e^{\hat{x}_*}$$

$$Z_{T^2} = -\frac{1}{k} \ln\left(\frac{r}{r_*}\right) Z_{T^2}$$

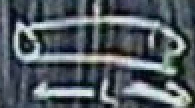
$$X^0 = X^0_0 + \hat{X}^0$$

$$Z_{T^2} = -\frac{1}{K}\ln\left(r/r_K\right) Z_{fer}$$

$\epsilon_i \in \mathbb{R}$ $\quad g_s^2\left(\frac{\cdot}{V_5}\right)$ $\quad (2h-2)$

all kinds: $V_5 \to \infty$, $g_5 \to 0$, slowly s.t. $\frac{g_5}{V_5} \ll g_5^2$

V: other probes

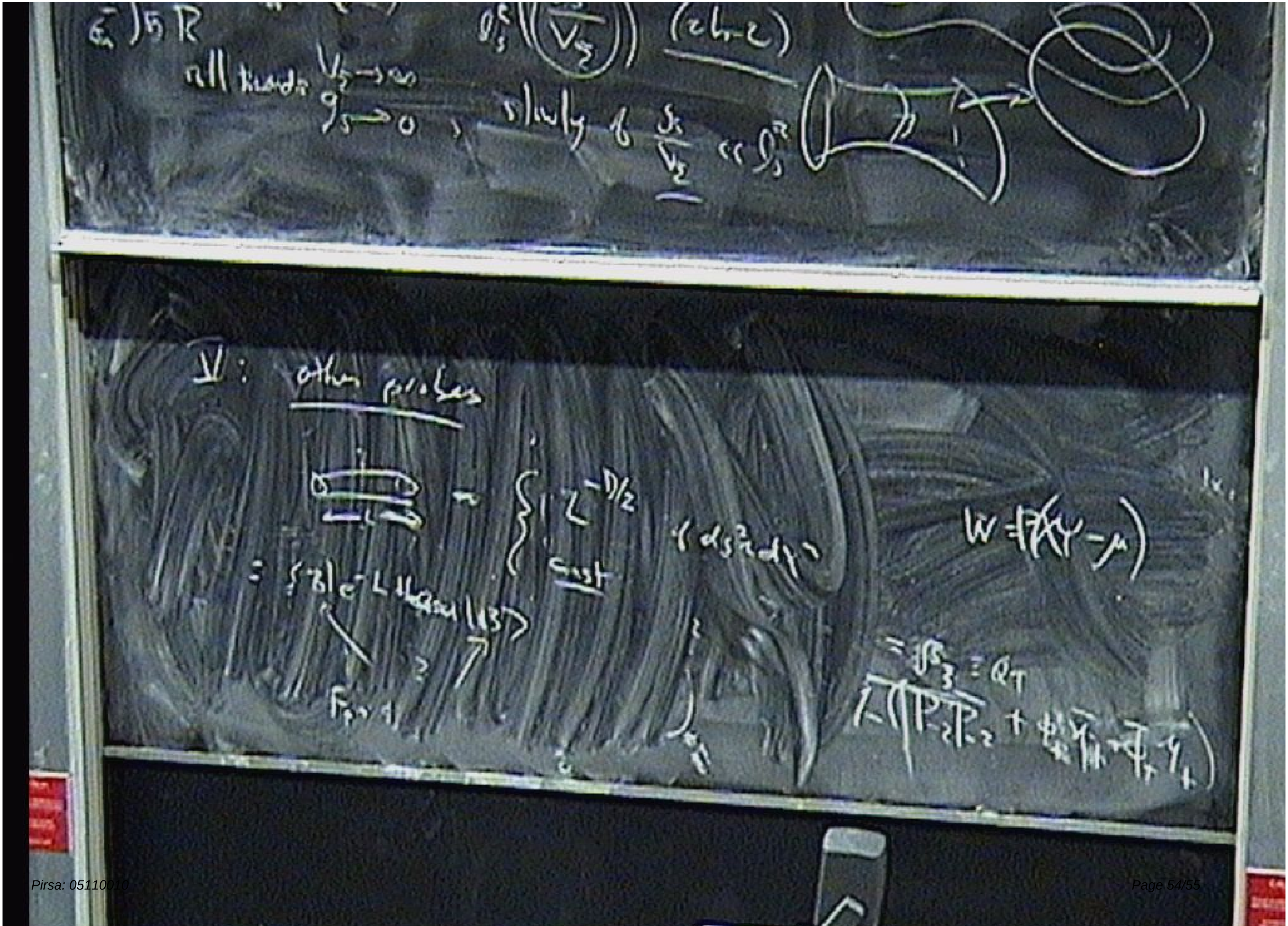


$= \sum_B e^{-L H_{open}} |B\rangle$

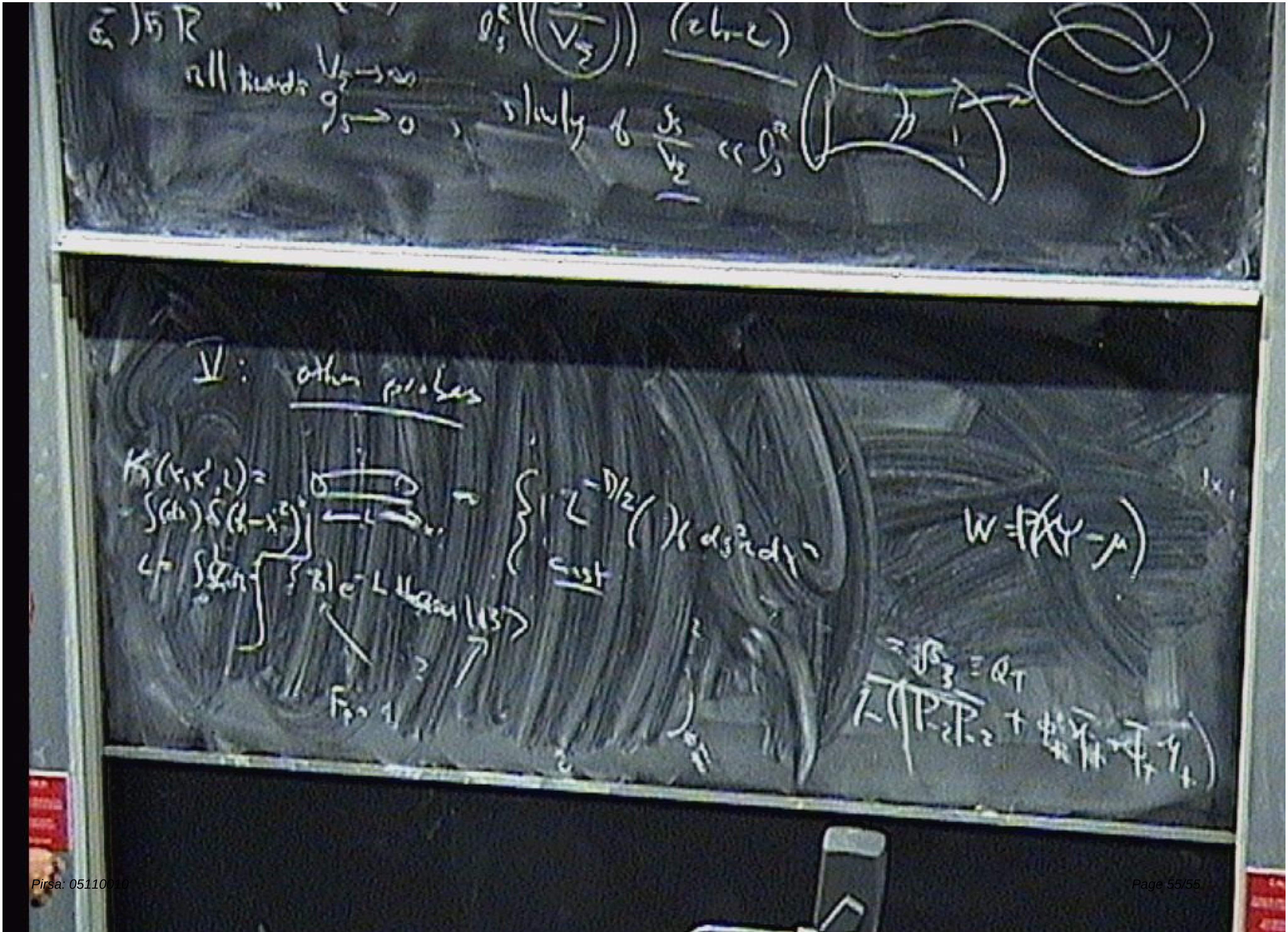
$W = \Phi(XY - \mu)$

$= \int \beta_3 = Q_T$

$L(\bar{\Phi}_{-2}\Phi_{-2} + \phi^{\dagger}_{H}\psi_{H} + \bar{\psi}_{+}\psi_{+})$



all kinds
slowly
other probes


V : other probes
W = Tr(ΛY − μ)