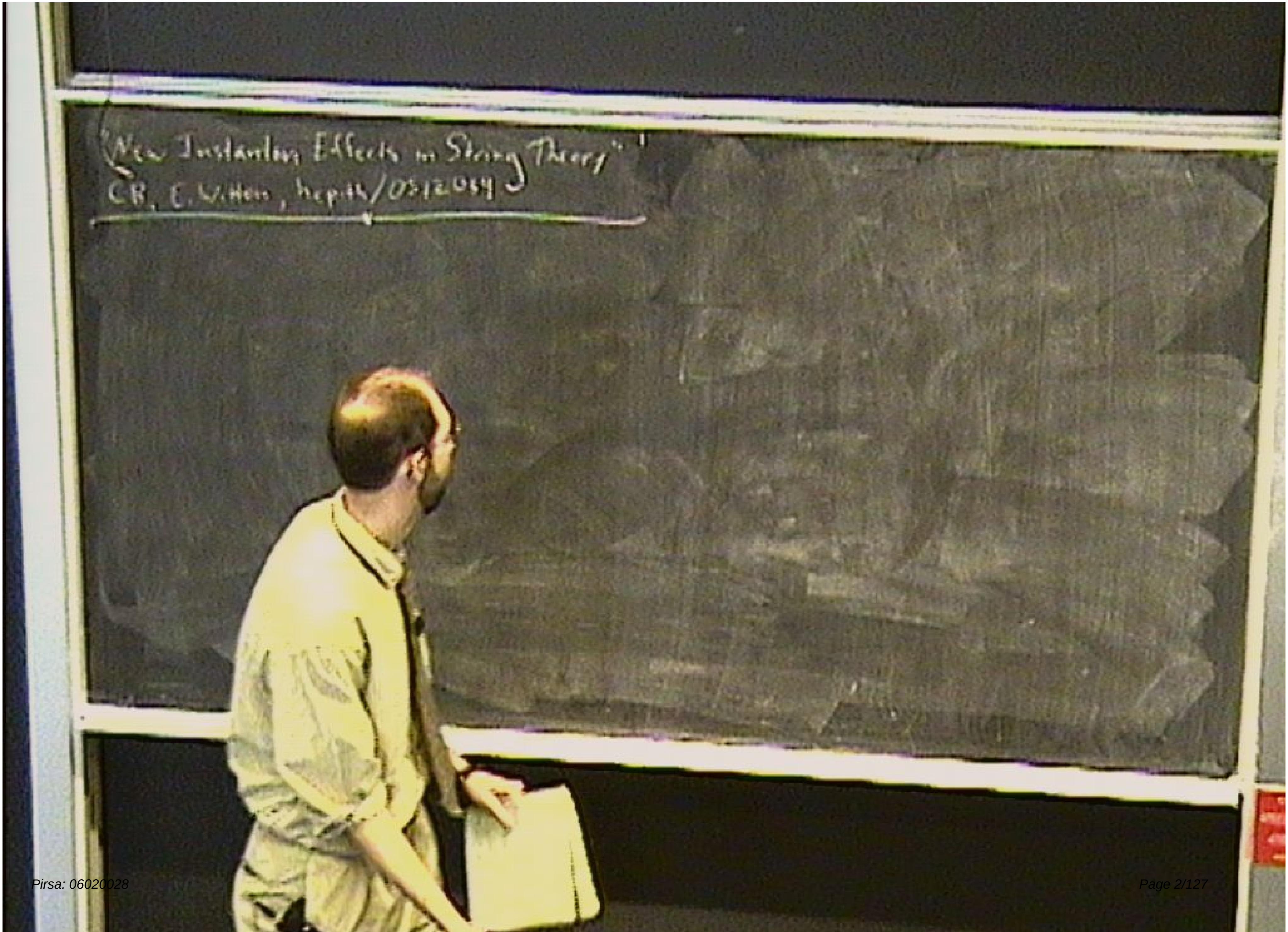
Title: New instanton effects in string theory

Date: Feb 14, 2006 02:00 PM

URL: http://pirsa.org/06020028

Abstract:


"New Instanton Effects in String Theory"
CB, E. Witten, hep-th/0512039

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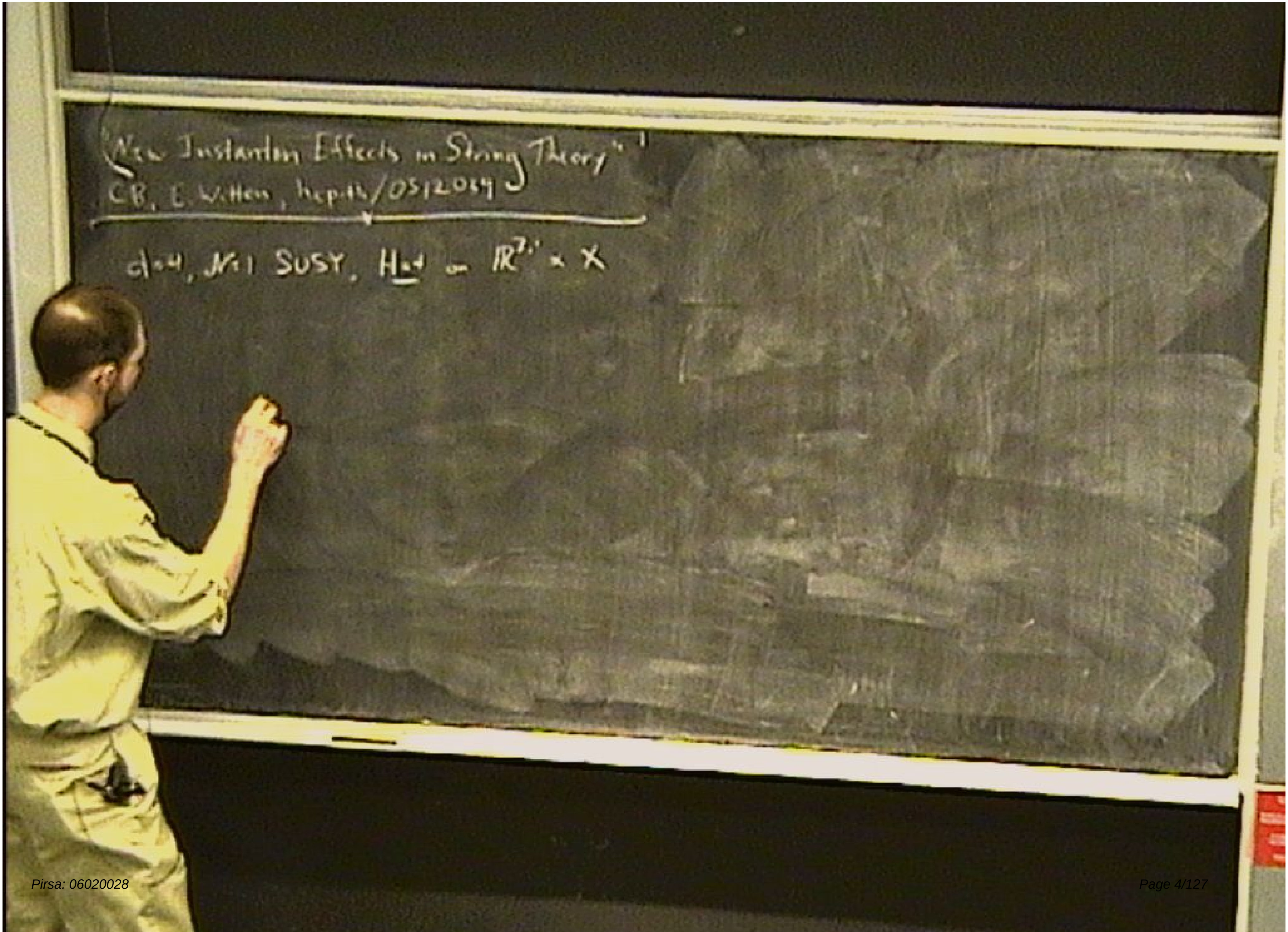
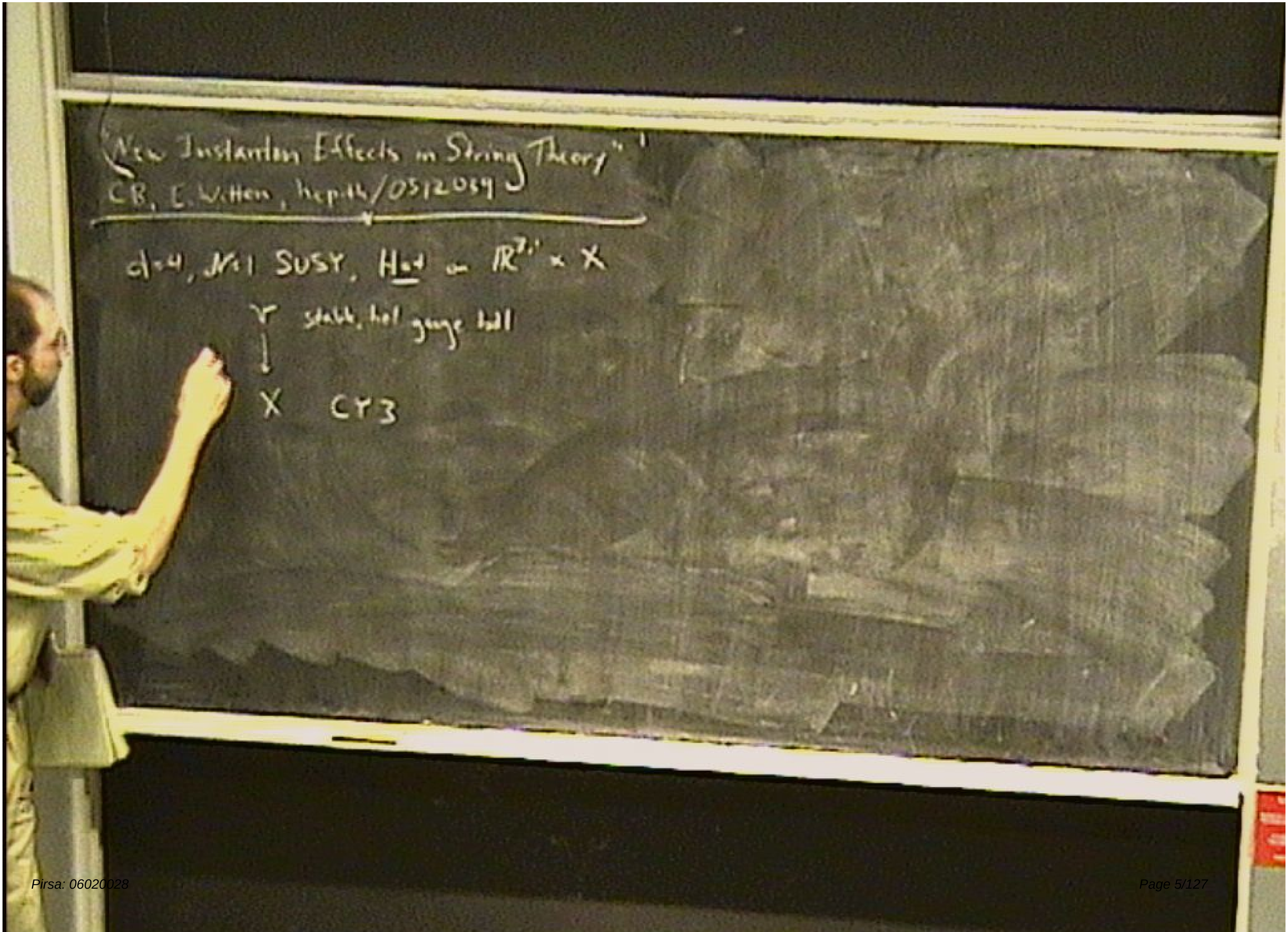
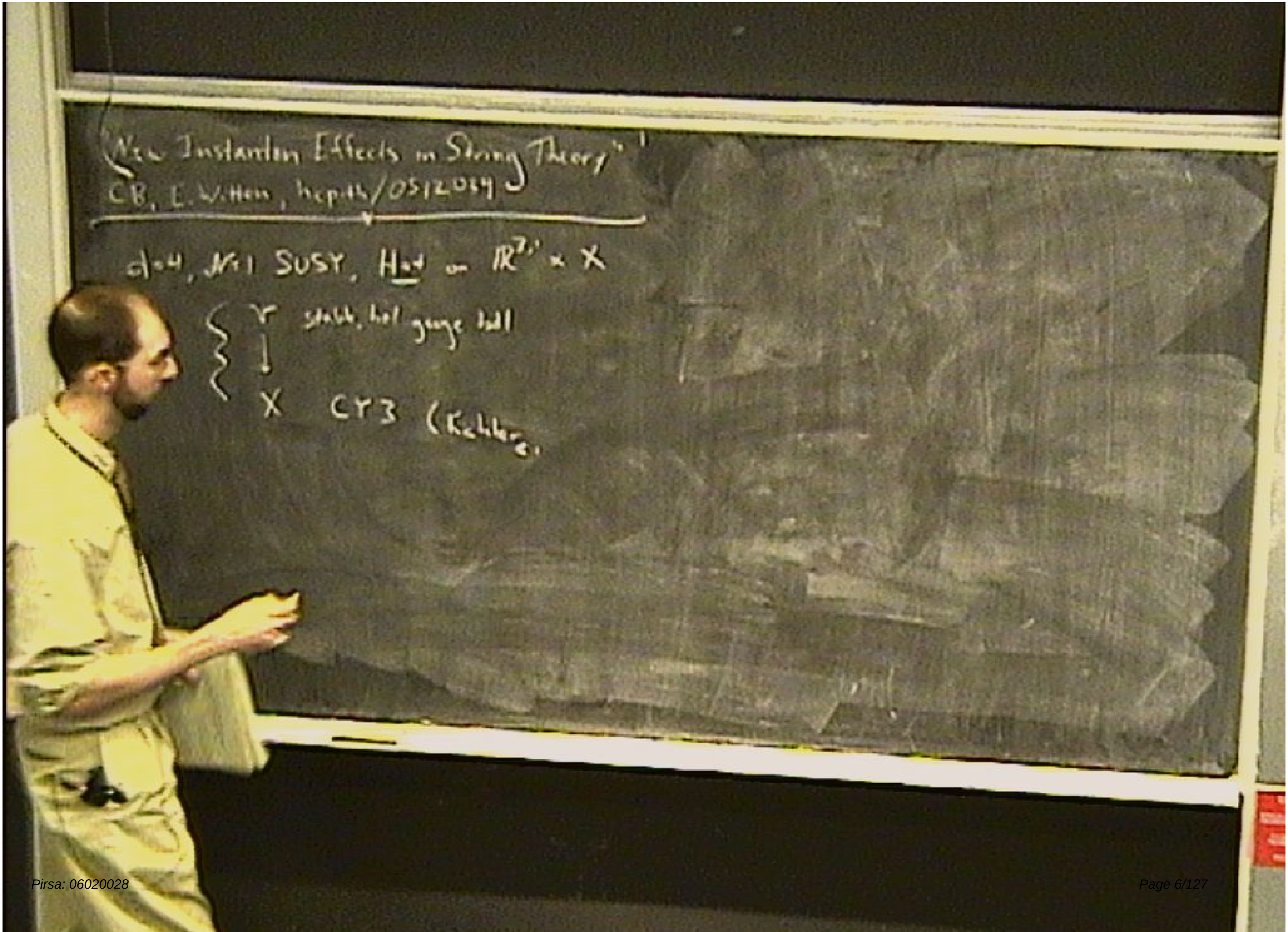
$d=4$, $\mathcal{N}=1$ SUSY


"New Instanton Effects in String Theory"
CB, E. Witten, hep-th/0512059
d=4, N=1 SUSY, Het on $\mathbb{R}^{3,1} \times X$


"New Instanton Effects in String Theory" 1
CB, E. Witten, hep-th/0512039
d=4, N=1 SUSY, Het on $\mathbb{R}^{3,1} \times X$
V stable, hol gauge bdl
X CY3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$d=4$, $\mathcal{N}=1$ SUSY, Het on $\mathbb{R}^{3,1} \times X$

$$\left\{ \begin{array}{ll} V & \text{stable, hol gauge bdl (cplx str)} \\ \downarrow & \\ X & CY3 \ (\text{Kähler}, \text{cplx str}) \end{array} \right.$$

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$d=4$, $\mathcal{N}=1$ SUSY, Het on $\mathbb{R}^{3,1} \times X$

$$\left\{ \begin{array}{ll} V & \text{stable, hol gauge bdl (cplx str)} \\ \downarrow & \\ X & \text{CY3} \quad (\text{Kahler}_{c}, \text{cplx str}) \end{array} \right.$$

$\mathcal{M}_{cl}$ = classical moduli space of (X, V)

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$d=4$, $\mathcal{N}=1$ SUSY, Het on $\mathbb{R}^{3,1} \times X$

$\left\{ \begin{array}{ll} \mathcal{V} & \text{stable, hol gauge bdl (cplx str)} \\ \downarrow & \\ X & \text{CY3 (Kahler}_{\epsilon}\text{, cplx str)} \end{array} \right.$

$\mathcal{M}_{[\epsilon, J]}$ = (classical) moduli space of $(\gamma, \mathcal{V})$

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$$\left\{ \begin{array}{ll} V & \text{stable, hol gauge bdl (cplx str)} \\ \downarrow & \\ X & \text{CY3 (Kähler, cplx str)} \end{array} \right.$$

$\mathcal{M}_{(cl)}$ = (classical) moduli space of (X, V)

$$S_{eff} = \int d^4x \, d^2\theta \, W(\Phi^i)$$

singlet χ sf

"New Instanton Effects in String Theory" 1

C.B., E. Witten, hep-th/0512059

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V stable, hol gauge bdl (cplx str)

$\downarrow$

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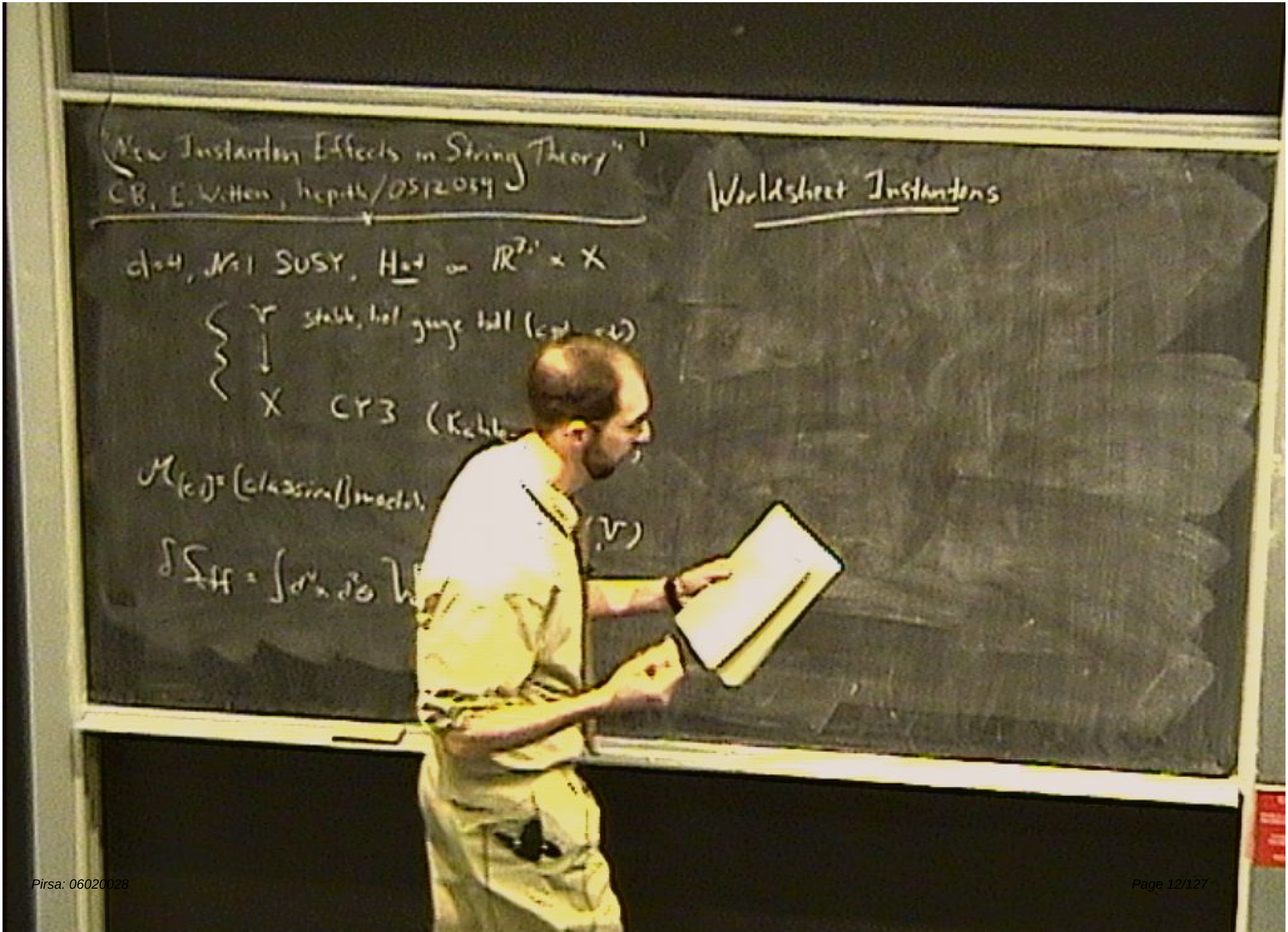

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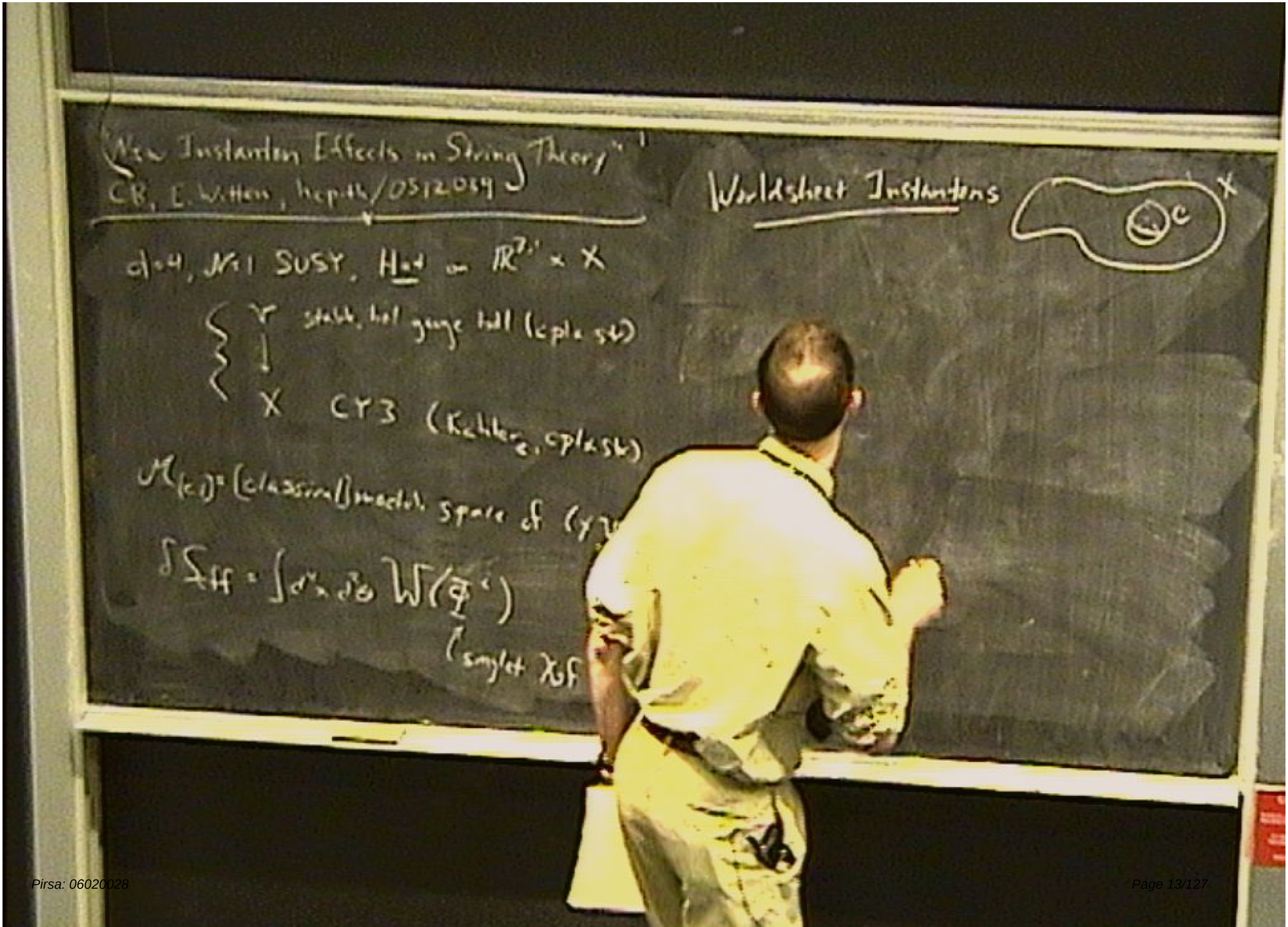
Worldsheet Instantons
SUSY
CY3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singlet
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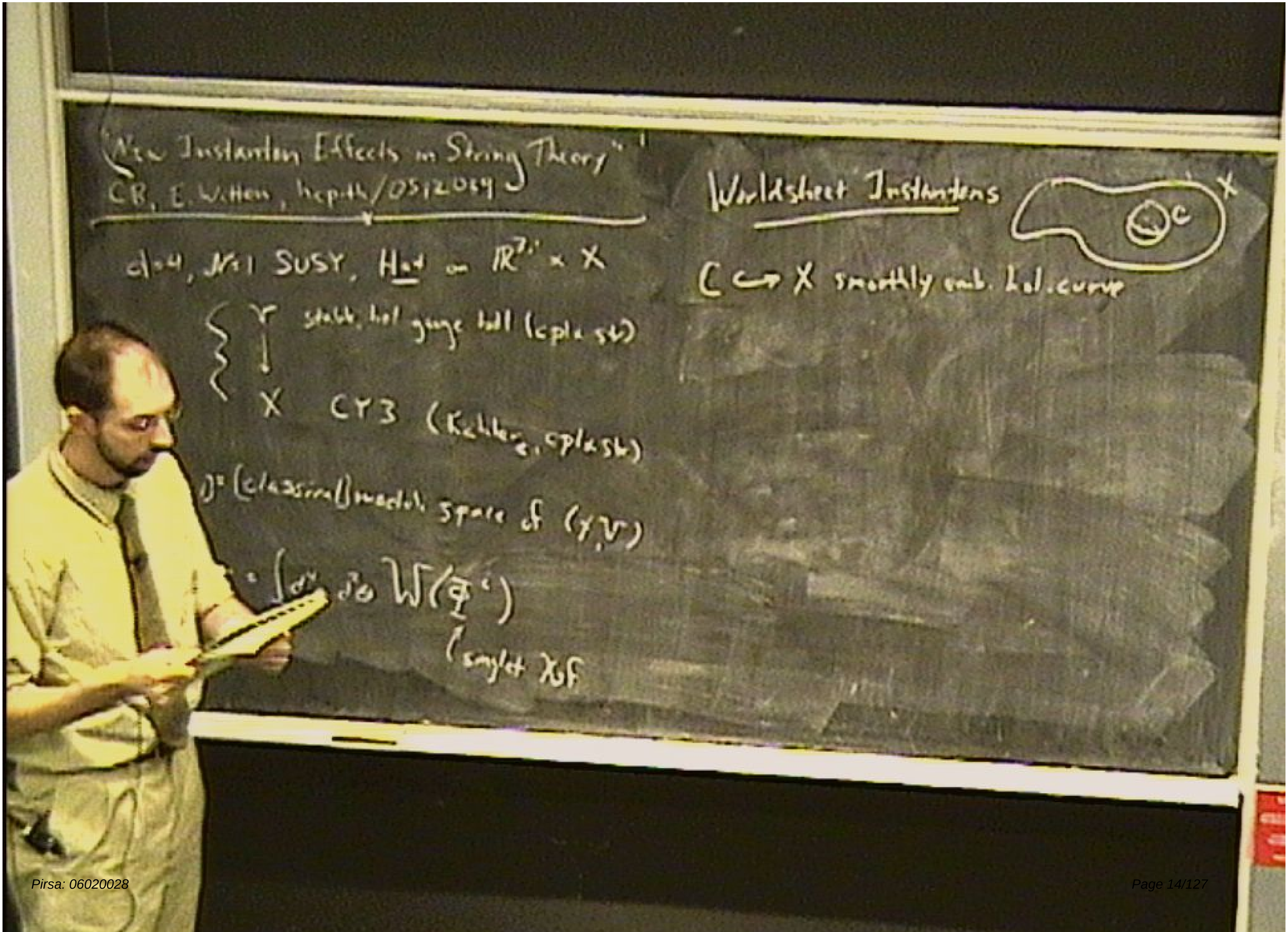
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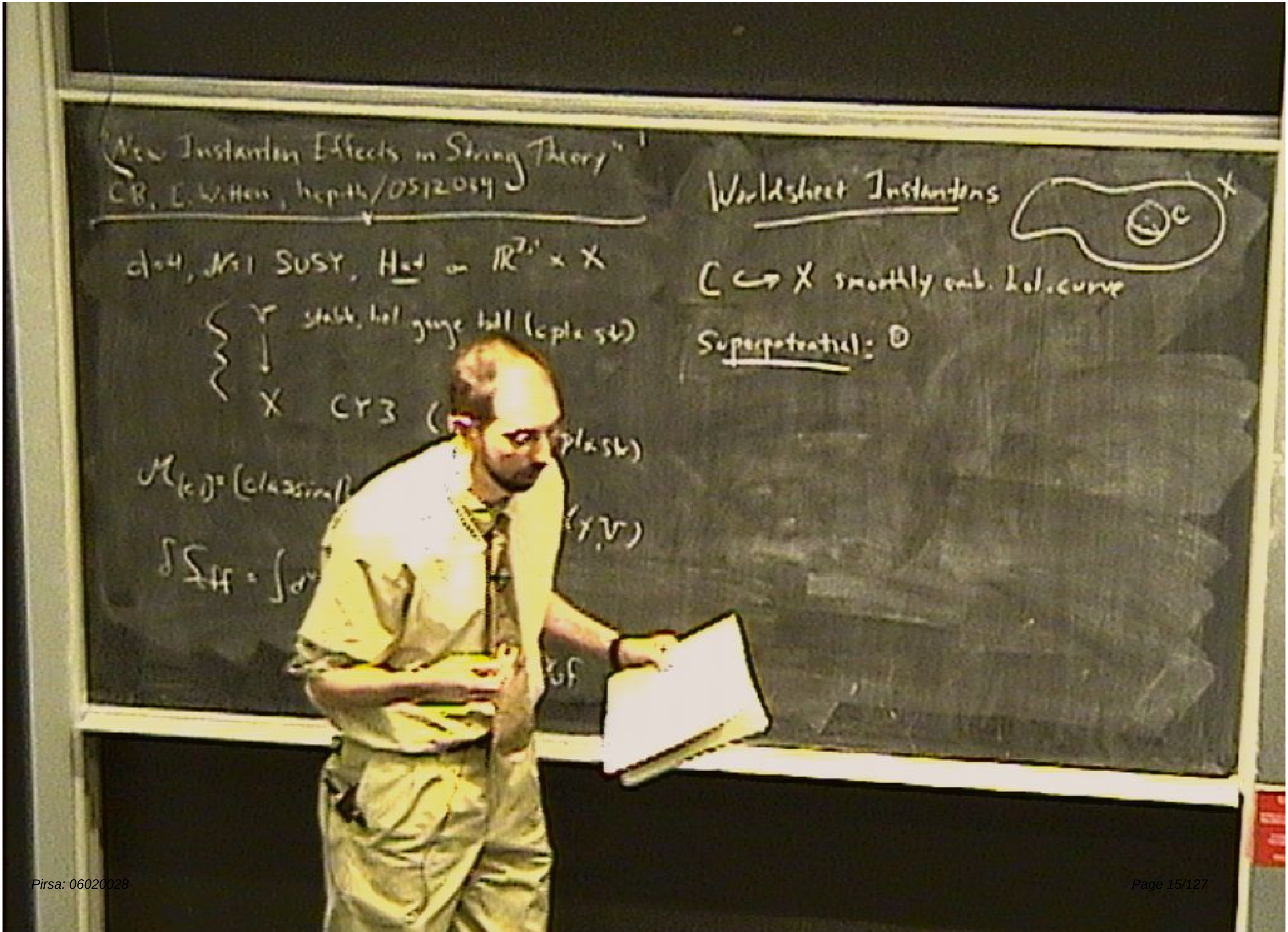
Worldsheet Instantons
C ↪ X smoothly emb. hol. curve
C
X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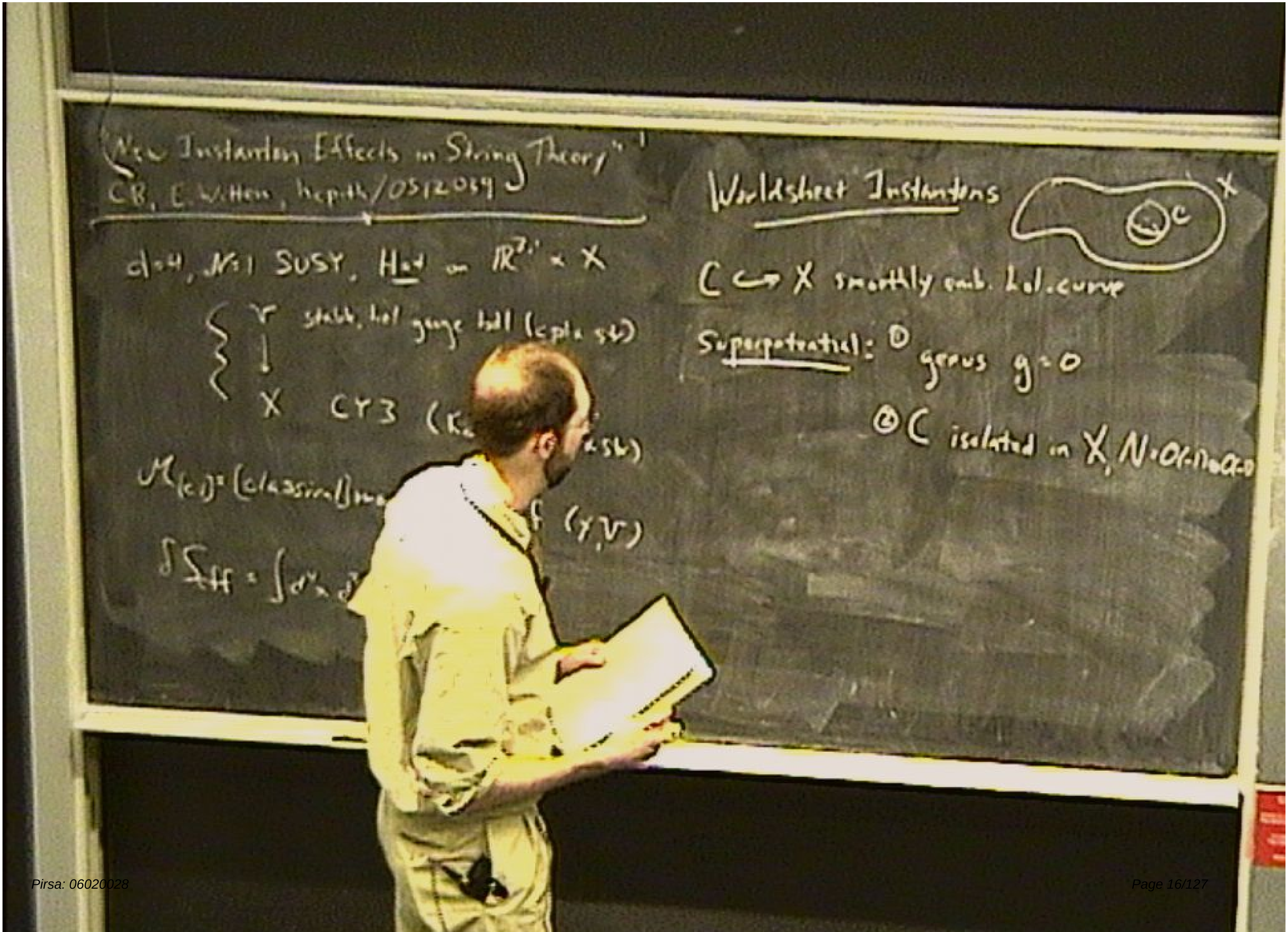
Superpotential: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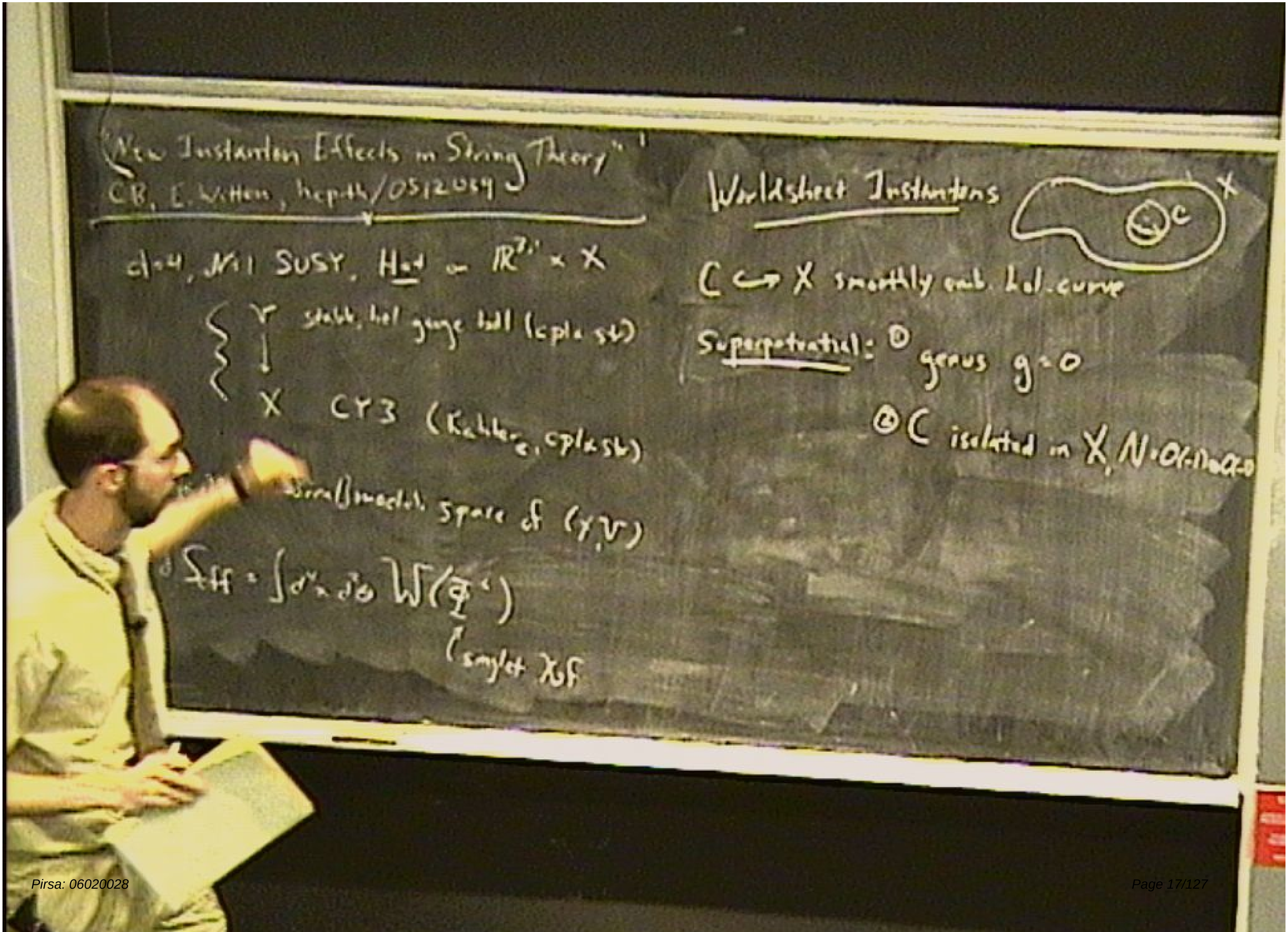
Superpotential: ① genus g=0
② C isolated in X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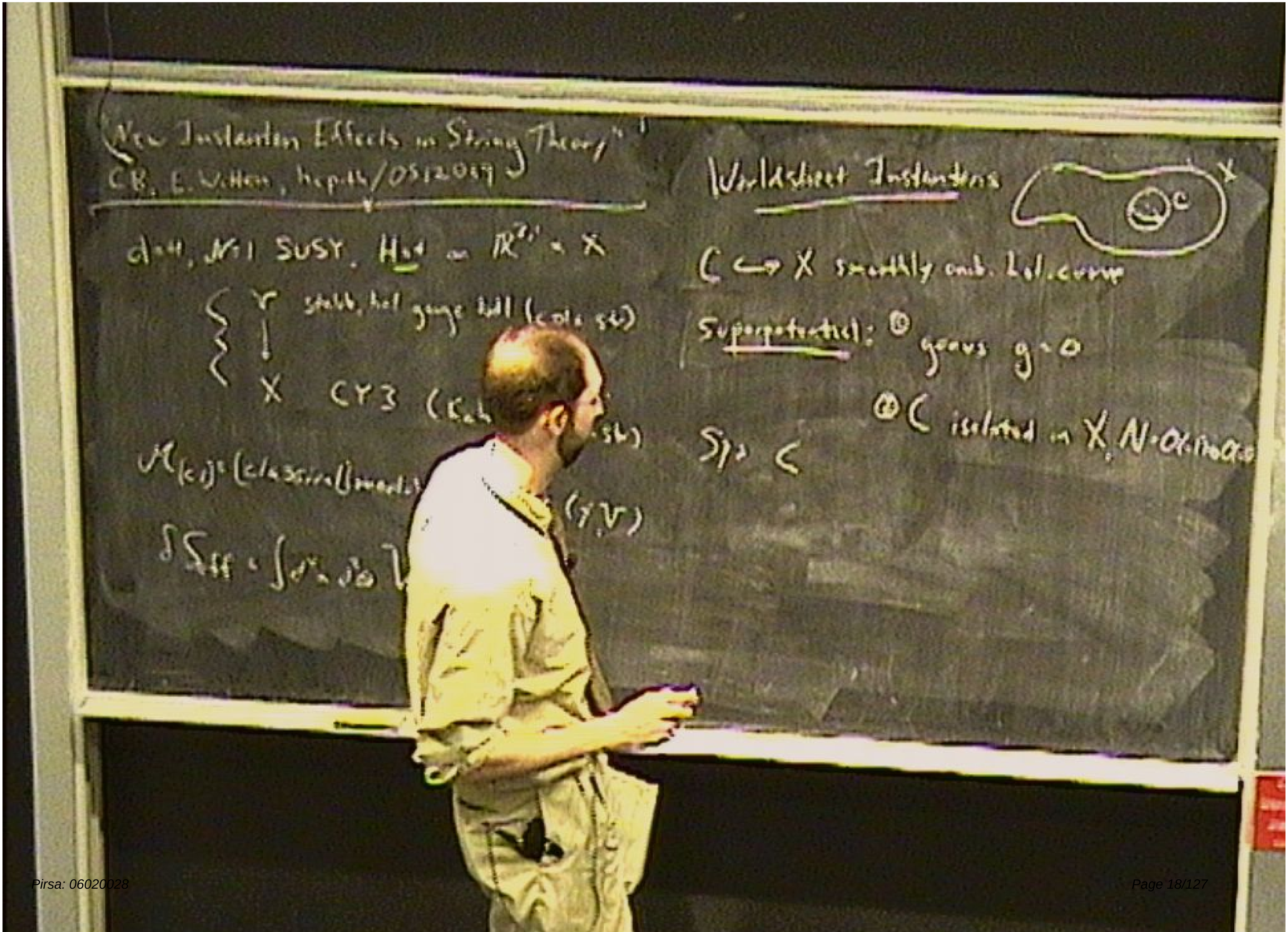
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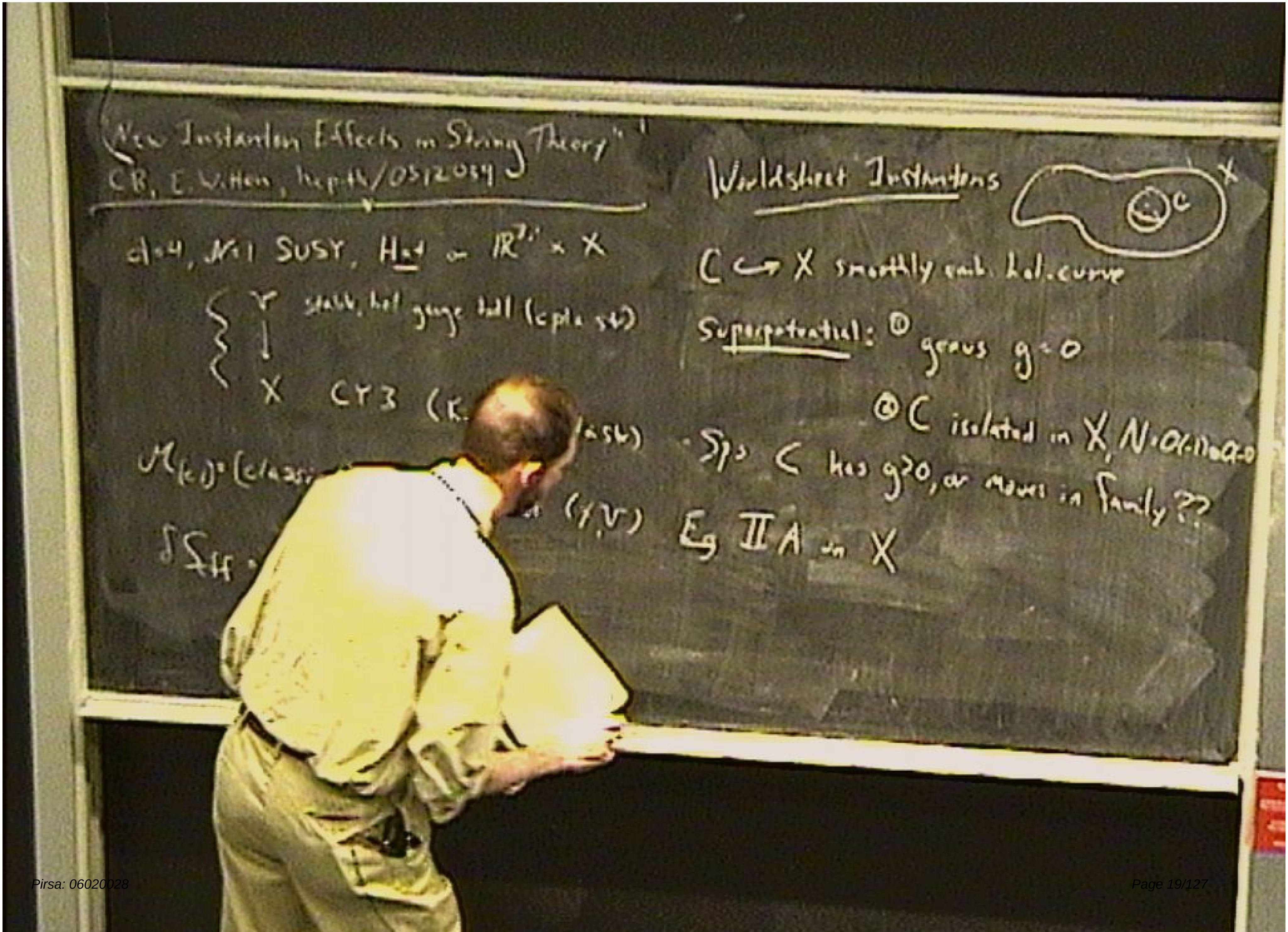
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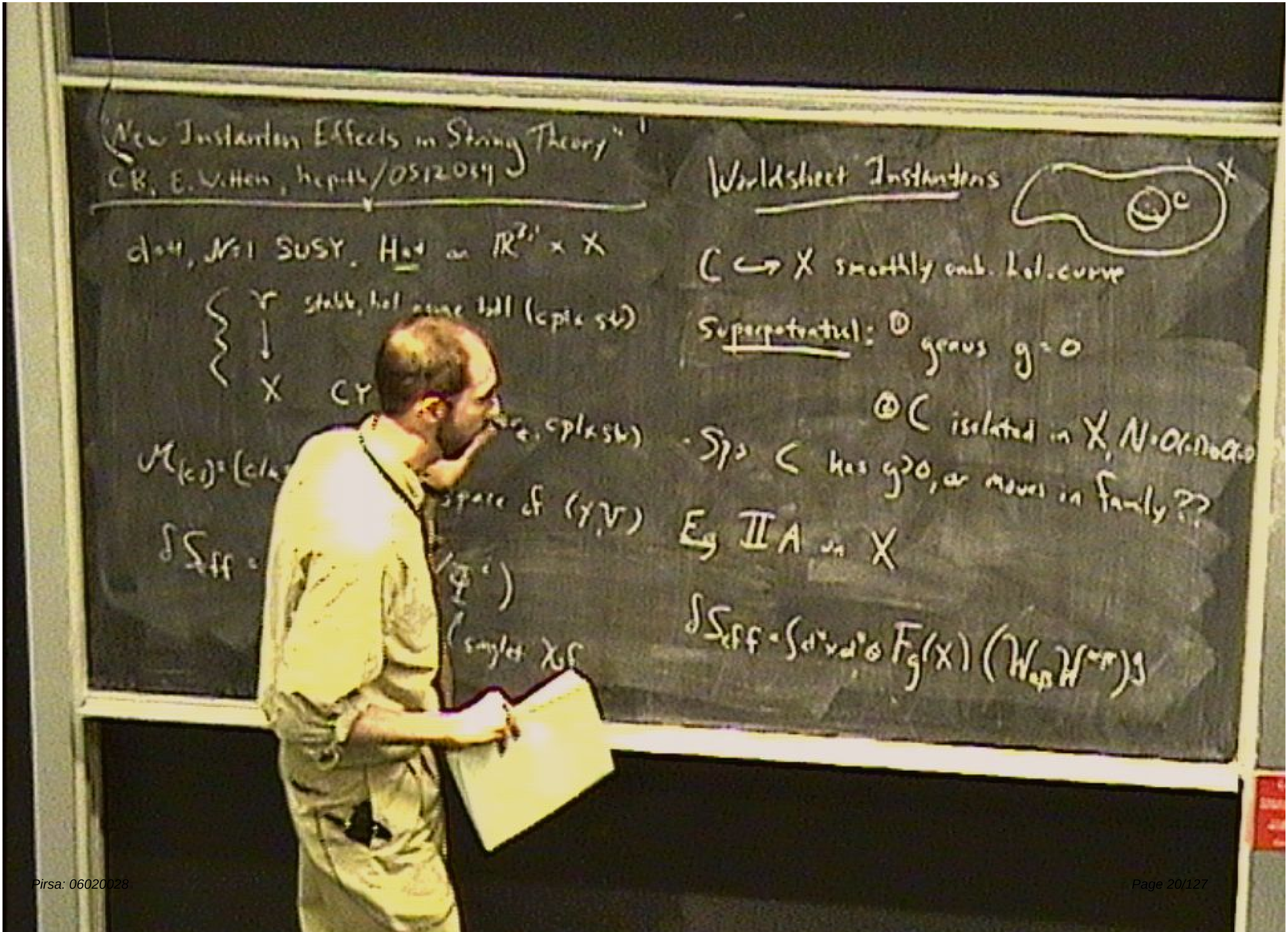
Superpotential: ① genus g=0
② C isolated in X, N=O(-1)⊕O(-1)
Sps C has g>0, or moves in family??
Eg IIA on X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"New Instanton Effects in String Theory" [1]
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$d=4$, $\mathcal{N}=1$ SUSY, Het on $\mathbb{R}^{3,1}\times X$

V stable, hol gauge bdl (cplx str)
$\downarrow$
X CY3 (Kähler, cplx str)

$\mathcal{M}_{(X,V)}$ = (classical) moduli space of (X,V)

$$\delta S_{eff} = \int d^4x\, d^2\theta\, W(\Phi^i)$$

(Φ^i singlet χsf)

Worldsheet Instantons

$C \hookrightarrow X$ smoothly emb. hol. curve

Superpotential: ① genus $g=0$

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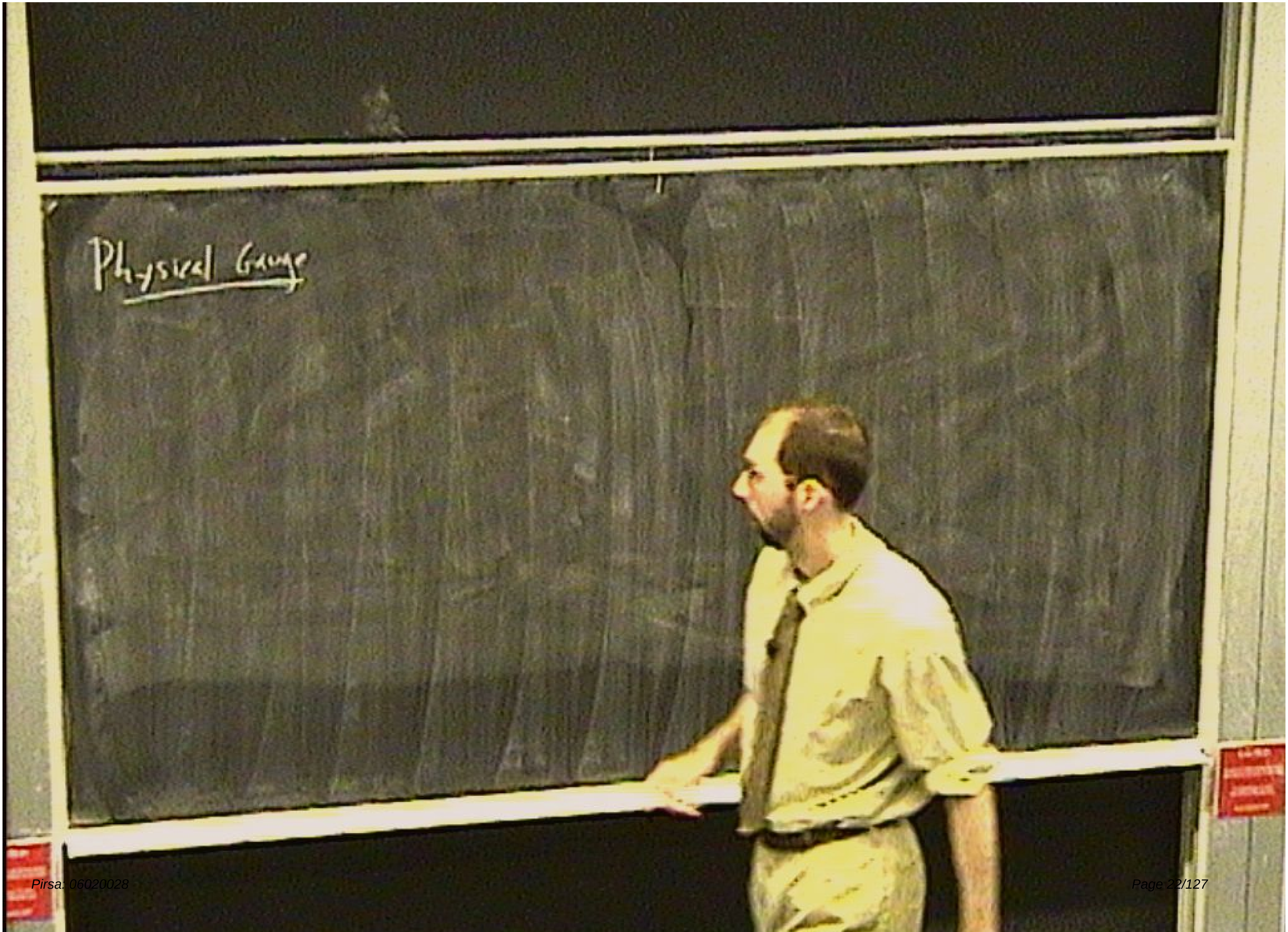
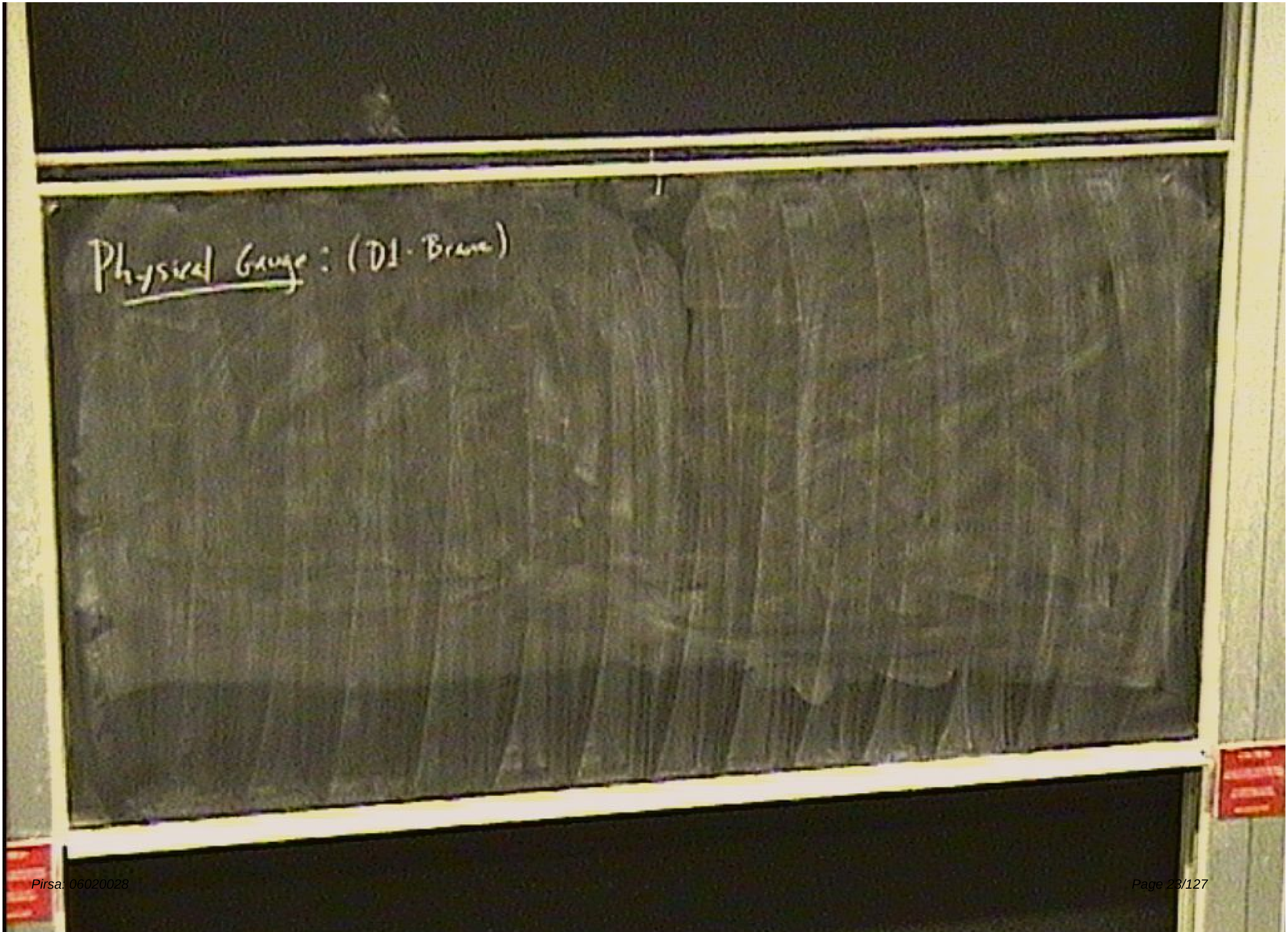
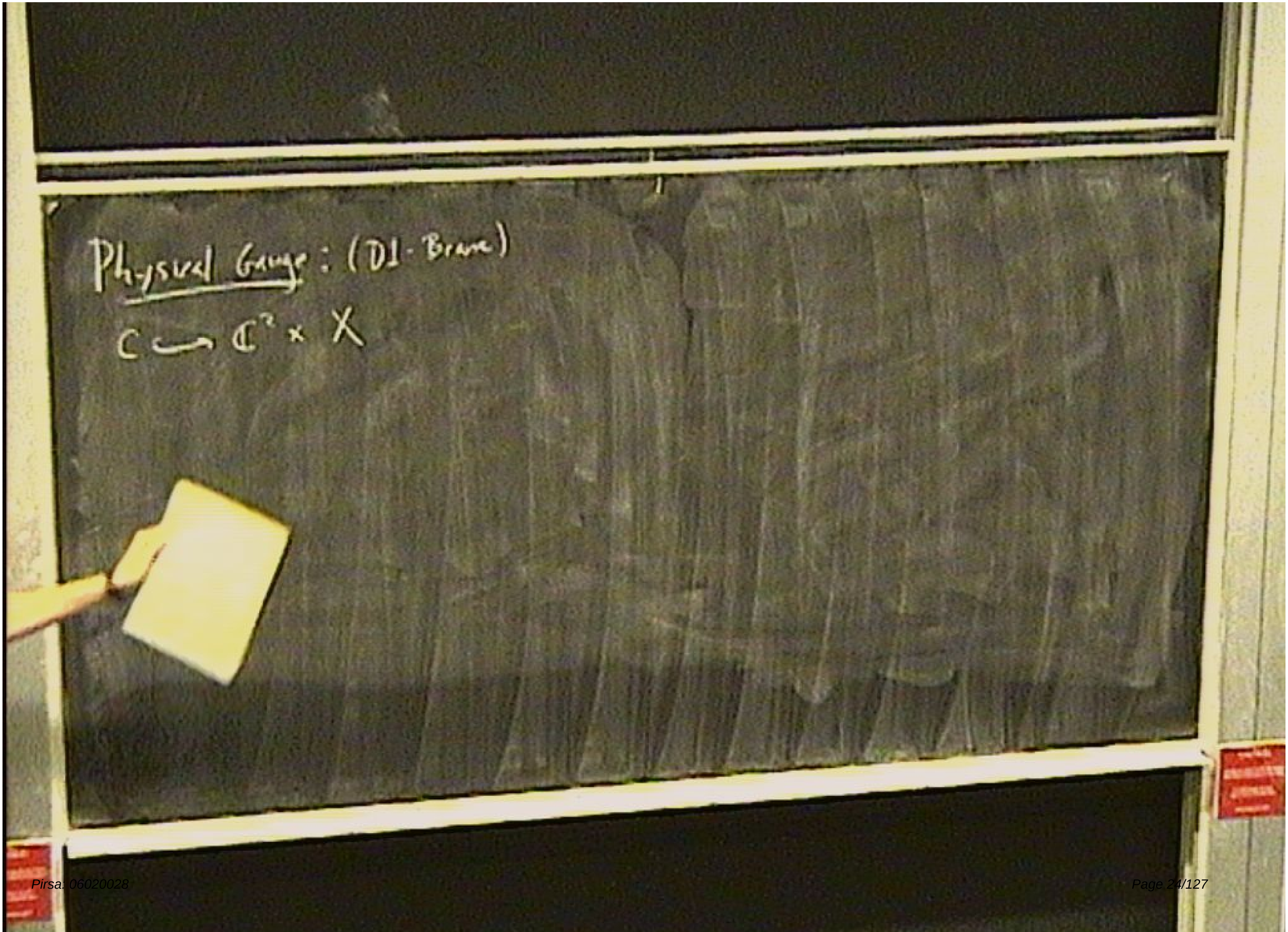
• Sp: C has $g>0$, or moves in family??

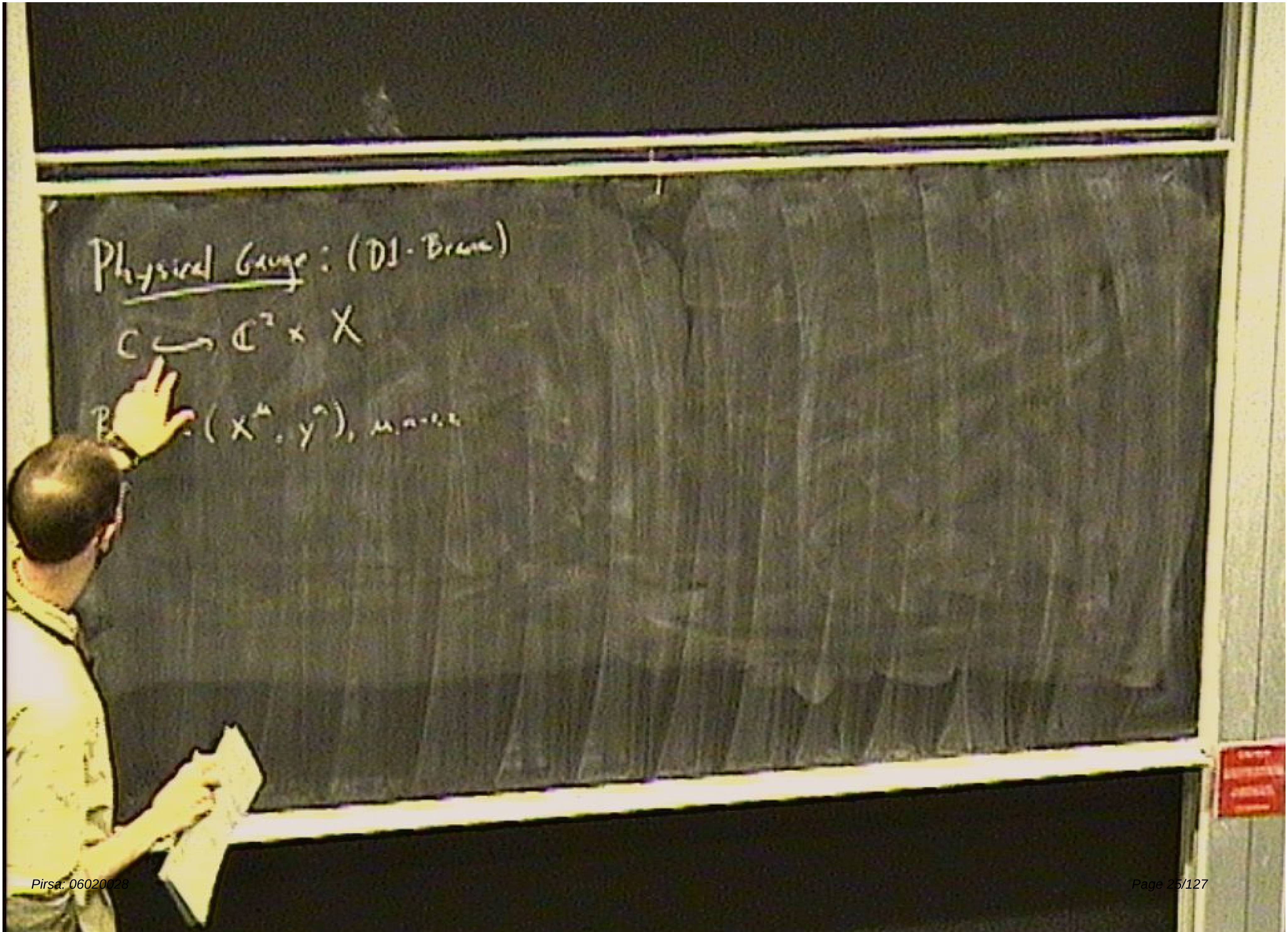
E_g IIA on X

$$\delta S_{eff} = \int d^4x\, d^2\theta\, F_g(X)\,(W_{\alpha\beta}W^{\alpha\beta})^g$$


Physical Gauge


Physical Gauge: (D1-Brane)


Physical Gauge: (D1-Brane)
C ↪ ℂ² × X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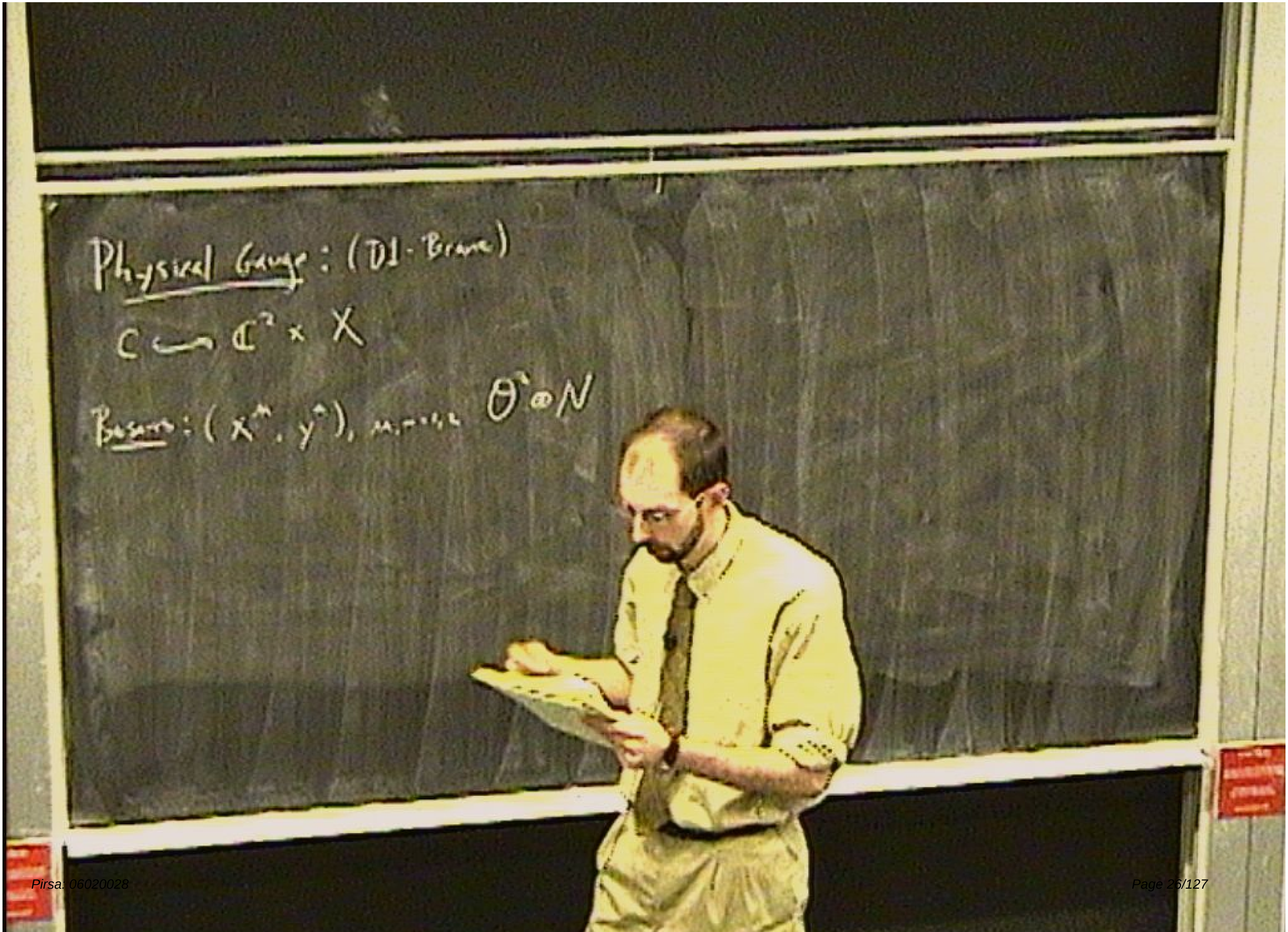

Physical Gauge: (D1-Brane)
$C \hookrightarrow \mathbb{C}^2 \times X$
$\mathcal{O}^2 \oplus N$
Bosons: (x^μ, y^a), $\mu,\nu=1,2$

Physical Gauge: (D1-Brane)

$$C \hookrightarrow \mathbb{C}^2 \times X$$

Bosons: (x^μ, y^n), $\mu, n = 1,2$ $\quad \mathcal{O}^2 \oplus N$

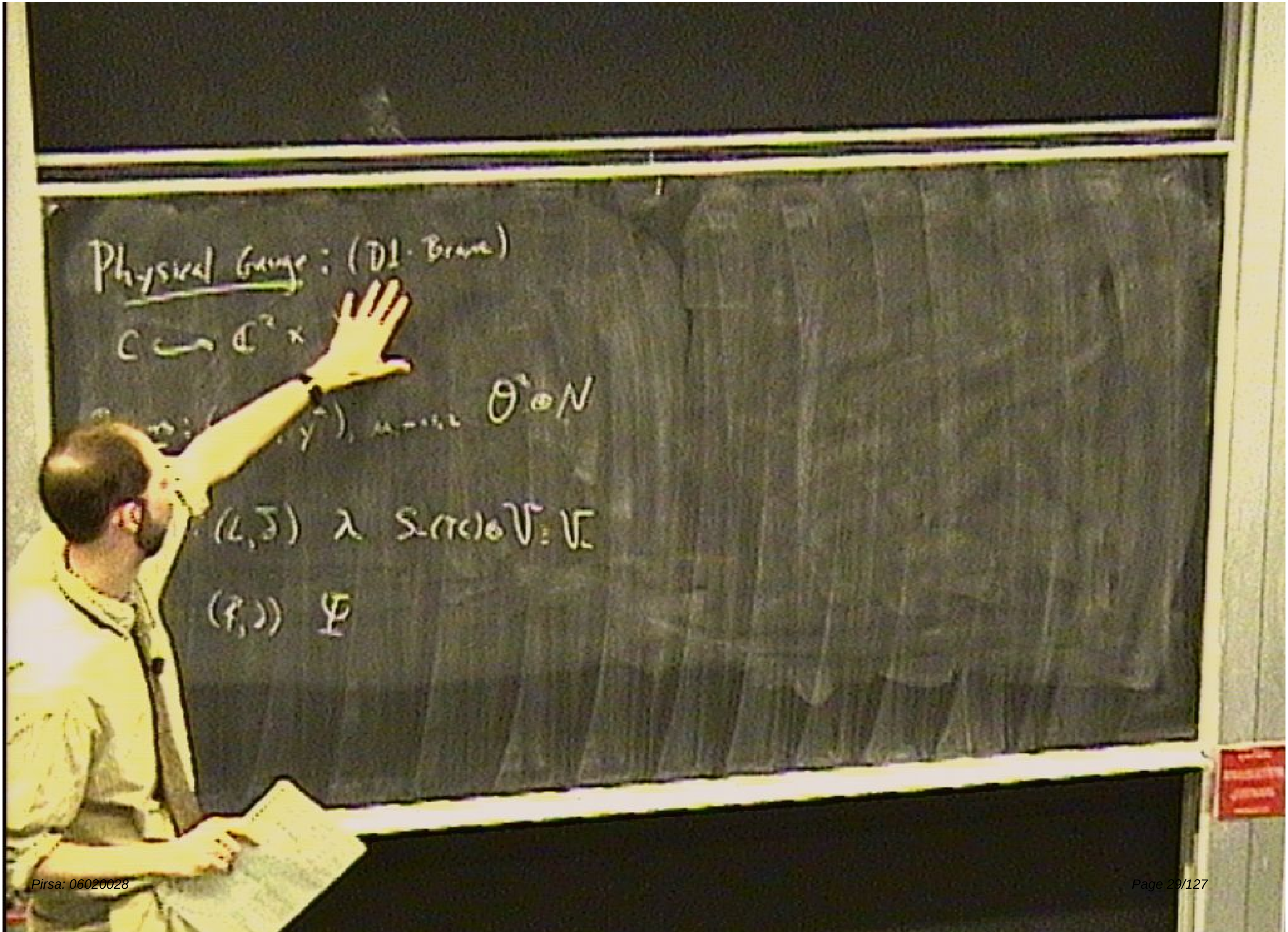
Fermions: $(L, \bar{S})$ λ

Physical Gauge: (D1-Brane)

$C \hookrightarrow \mathbb{C}^2 \times X$

…: (X^μ, y^n), $\mu, n = 0,1,2$ $\mathcal{O}^2 \oplus N$

…ermions: $(\zeta, \bar{\zeta})$ λ $S_-(TC) \otimes V = V_C$


Physical Gauge : (D1 · Brane)

Physical Gauge: (D1-Brane)

$C \hookrightarrow \mathbb{C}^2 \times X$

$\mathcal{O}^2 \oplus N$

Bosons: (X^μ, y^m), $\mu, m = 1,2$

Fermions: $(\iota, \bar{\jmath})$ λ $S_-(TC) \otimes V = V_-$

$(\rho,))$ Ψ $S_+(TC) \otimes S_+(\mathcal{O}^2 \oplus N)$

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Worldsheet Instantons

$C \hookrightarrow X$ smoothly emb. hol. curve

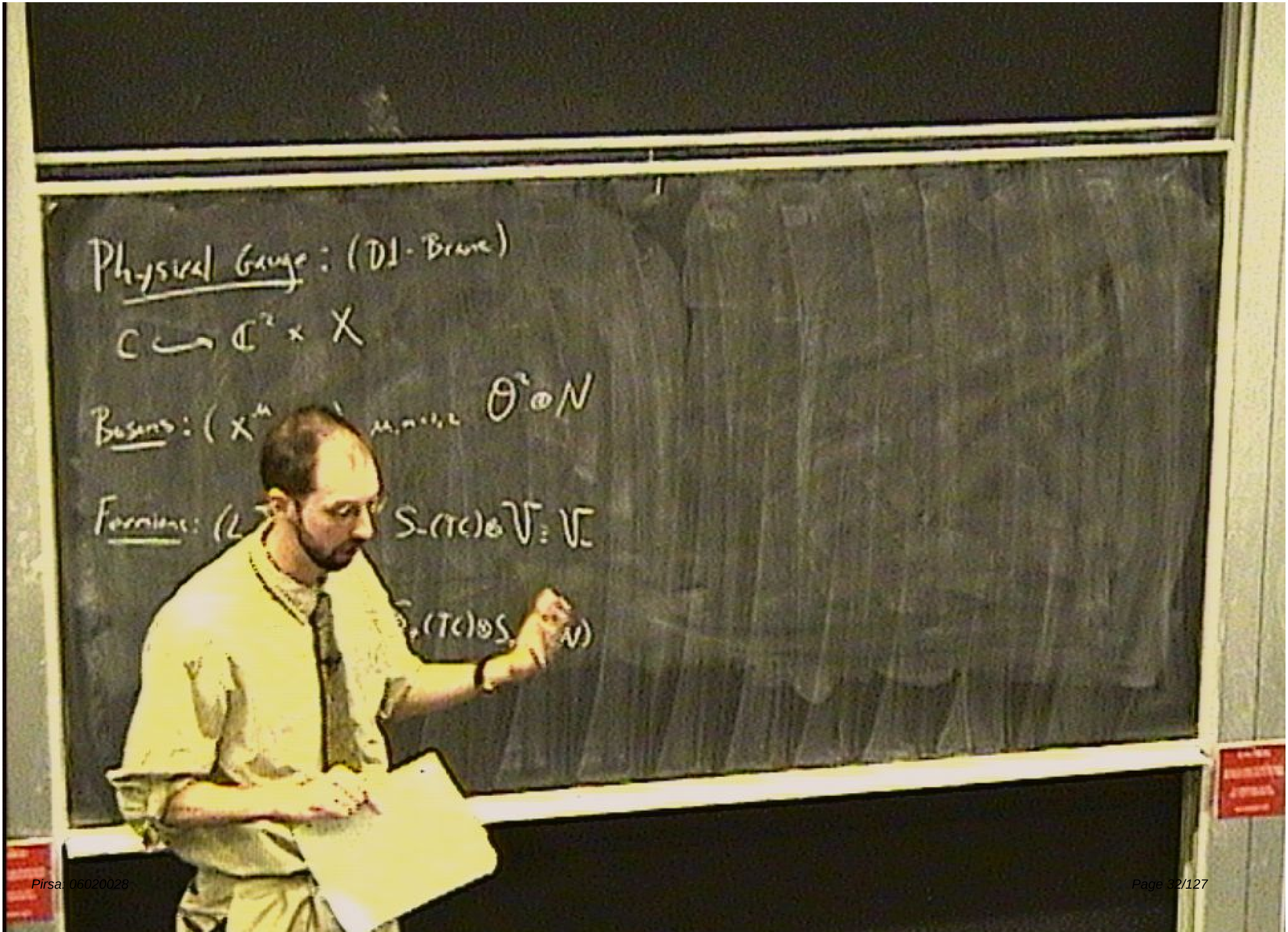
Superpotential: ① genus $g=0$

② C isolated in X, $N=\mathcal{O}(-1)\oplus\mathcal{O}(-1)$

• Sps C has $g>0$, or moves in family??

Eg IIA on X

$$\delta S_{eff} = \int d^4x\, d^2\theta\, F_g(X)\,(W_{\alpha\beta}W^{\alpha\beta})^g$$


Physical Gauge : (D1-Brane)
C ↪ ℂ² × X
Bosons:
θ² ⊗ N
Fermions:
S₋(TC) ⊗ V = V₋
(TC) ⊗ S

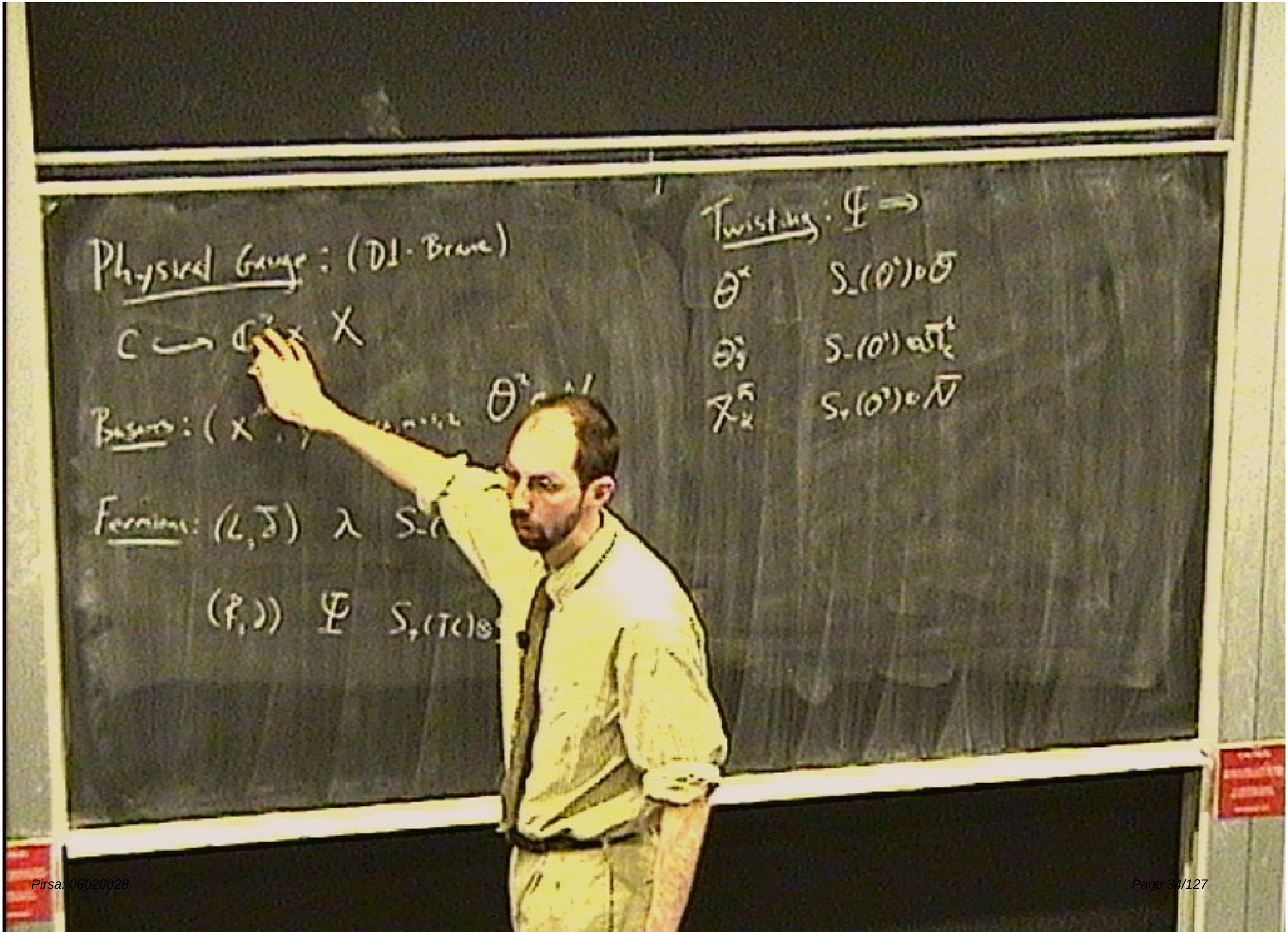
Physical Gauge: (D1-Brane)

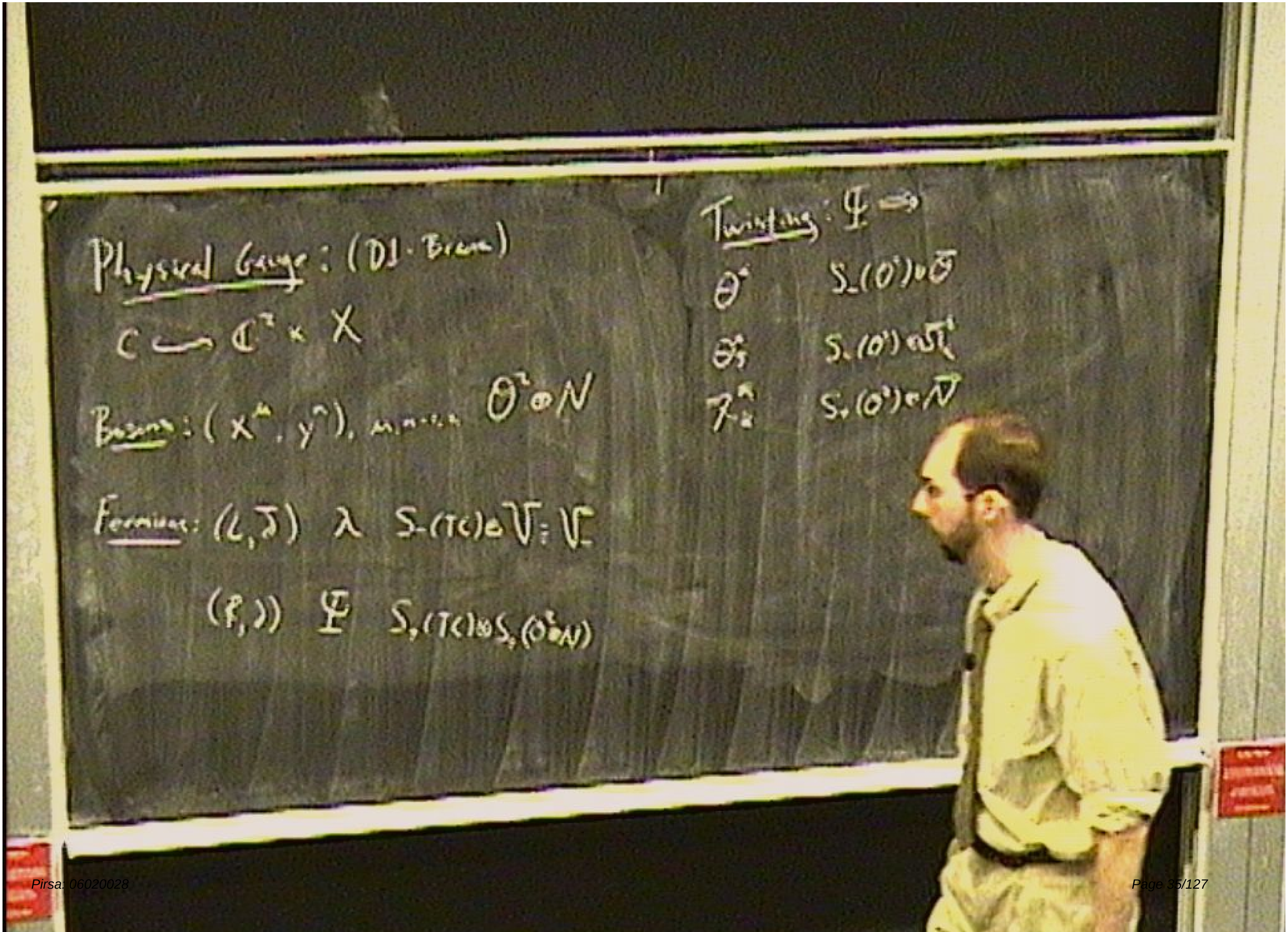
$C \hookrightarrow \mathbb{C}^2 \times X$

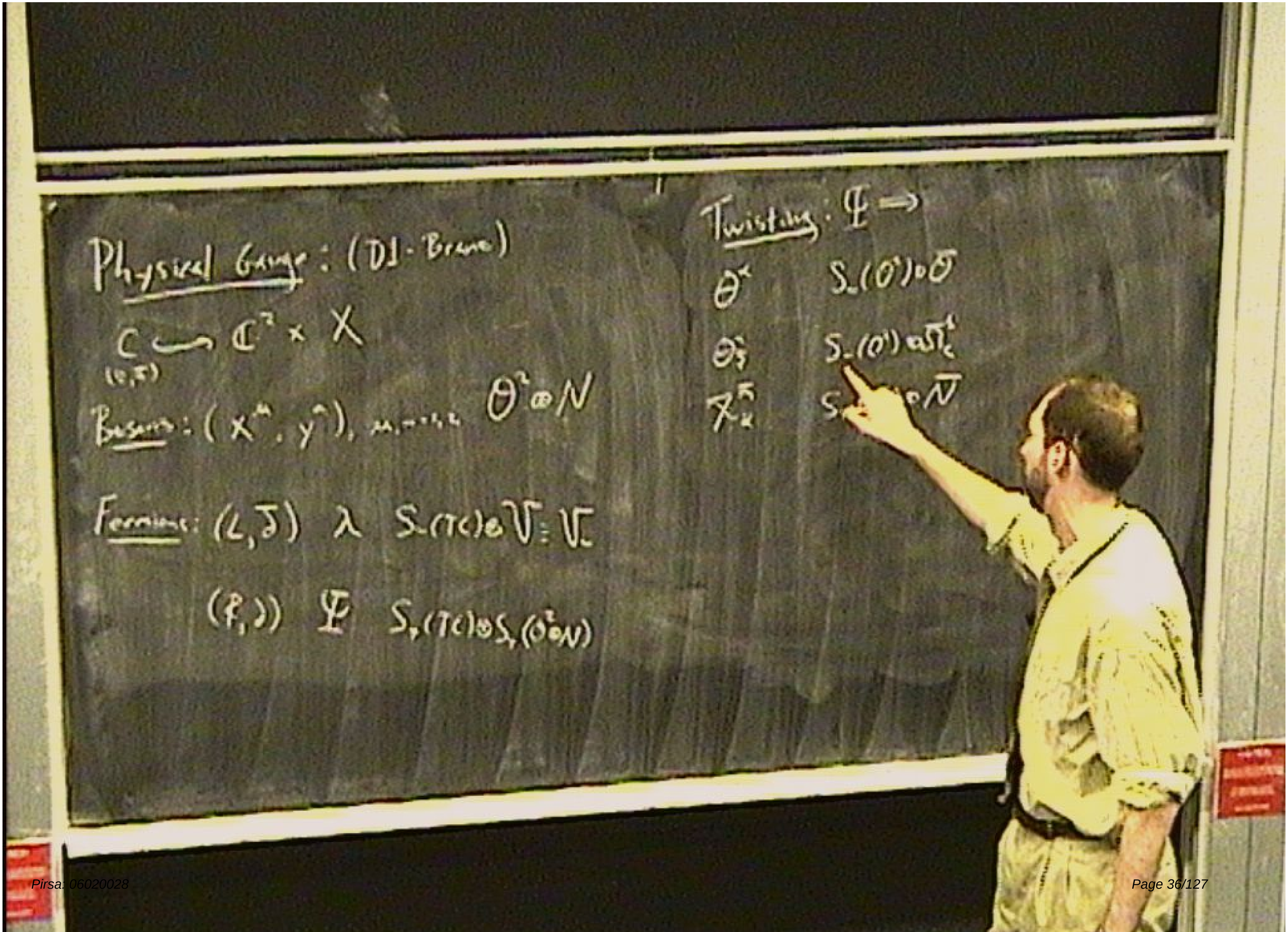
Bosons: (x^μ, y^n), $\mu, n = 1,2$ $\qquad \mathcal{O}^2 \oplus N$

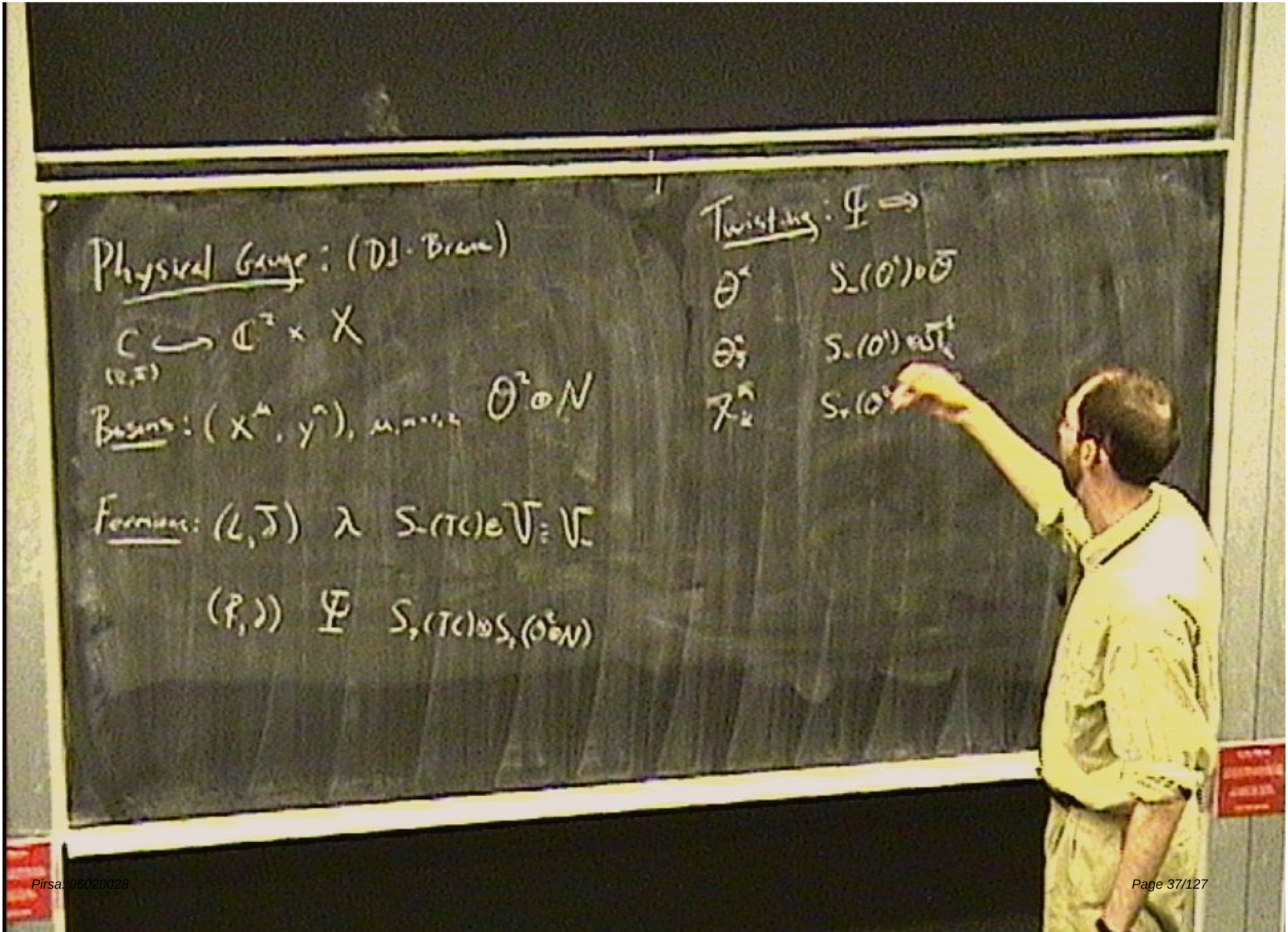
Fermions: $(L, \bar{J})$ $\quad \lambda \quad S_-(TC) \otimes V \cong V_-$

(R, J) $\quad \Psi \quad S_+(TC) \otimes S_+(\mathcal{O}^2 \oplus N)$


Physical Gauge: (D1-Brane)
Bosons:
Fermions:
Twisting:


Physical Gauge: (D1-Brane)
C ↪ ℂ² × X
Bosons: (x^μ, y^n),
O² ⊗ N
Fermions: (L, J) λ S₋(TC) ⊗ V̄ = V̄
(R, J) Ψ S₊(TC) ⊗ S₊(O² ⊗ N)
Twisting: Ψ ⟹
θ⁺ S₋(O¹) ⊗ O
θ̄ S₊(O¹) ⊗ Ω¹
χ̄ S₊(O¹) ⊗ N̄


Physical Gauge: (D1-Brane)
$C \hookrightarrow \mathbb{C}^2 \times X$
$(\theta, \bar{\theta})$
Bosons: (x^μ, y^n), $\mu, n = 1, 2$
$\Theta^2 \otimes N$
Fermions: $(L, \bar{\theta})$ λ $S_-(TC) \otimes V = V_-$
(R, θ) Ψ $S_+(TC) \otimes S_+(\Theta^2 \otimes N)$
Twisting: $\Psi \Longrightarrow$
θ^α $S_-(\Theta^1) \otimes \bar{\Theta}$
$\theta^{\dot{\alpha}}$ $S_-(\Theta^1) \otimes \Omega^1_C$
χ^n S $\otimes \bar{N}$


Physical Gauge: (D1-Brane)
C ↪ ℂ² × X
(z, z̄)
Bosons: (x^μ, y^n), μ, n = 1, 2
O² ⊕ N
Fermions: (L, J̄) λ S₋(TC) ⊗ V = V₋
(R, J) Ψ S₊(TC) ⊗ S₊(O² ⊕ N)
Twisting: Ψ ⇒
θ^α S₋(O¹) ⊗ σ̄
S₋(O¹) ⊗
χ S₊(O

Physical Gauge: (D1 Brane)

$\underset{(z,\bar z)}{C} \hookrightarrow \mathbb{C}^{2} \times X$

Bosons: (x^{m}, y^{n}), $m,n=1,2$ $\quad \Theta^{\circ} \otimes N$

Fermions: $(1,\bar 2)$ λ $S_{-}(TC)\otimes V_{1}\, V_{2}$

$(\bar 2, 1)$ Ψ $S_{+}(TC)\otimes S_{+}(\Theta^{\circ}\otimes N)$

Twisting: $\Psi \longrightarrow$ Q-moduli

θ^{α} $S_{-}(\theta^{\circ})\otimes \bar\sigma$

$\bar\theta^{\dot\alpha}_{i}$ $S_{-}(\theta^{\circ})\otimes \bar\sigma^{i}_{c}$

$\chi^{\bar n}_{\alpha}$ $S_{+}(\theta^{\circ})\otimes \bar N$

Physical Gauge: (D1-Brane)

$C_{(z,\bar z)} \hookrightarrow \mathbb{C}^2 \times X$

Bosons: (x^μ, y^n), $\mu, n = 1,2$ $\quad \mathcal{O}^2 \otimes N$

Fermions: $(L, \bar J)$ $\quad \lambda \quad S_-(TC) \otimes \overline{V} \oplus V$

$(\bar R, J)$ $\quad \Psi \quad S_+(TC) \otimes S_+(\mathcal{O}^2 \otimes N)$

Twisting: $\Psi \Rightarrow$

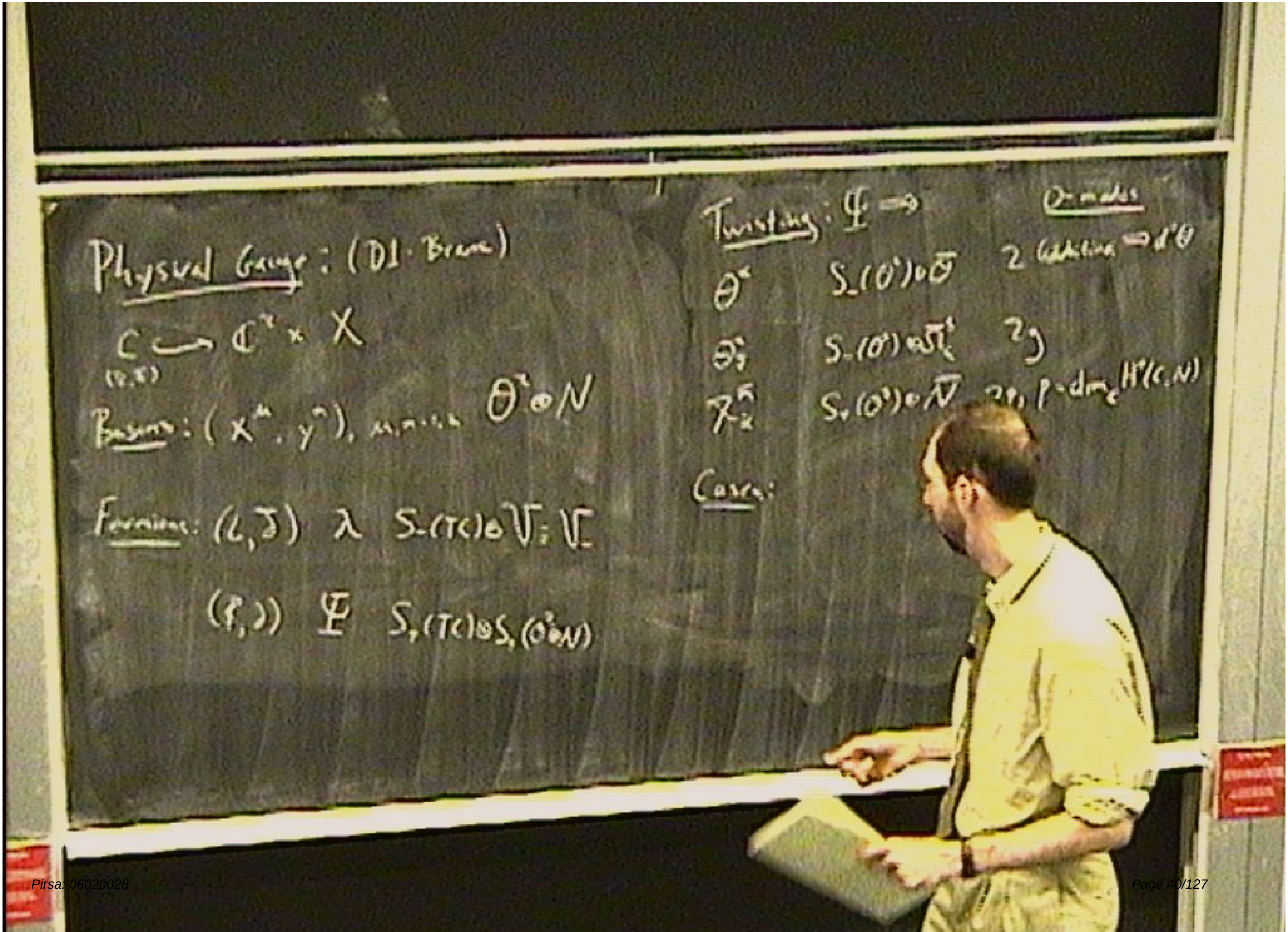
$\theta^\alpha \quad S_-(\mathcal{O}^1) \otimes \overline{\mathcal{O}}$

$\theta^{\dot\alpha}_i \quad S_+(\mathcal{O}^1) \otimes \Omega^1_C$

$\chi^n_{\dot\alpha} \quad S_+(\mathcal{O}^1) \otimes \overline{N}$

Q-modes:

2 Goldstino $\Rightarrow d^2\theta$


Physical Gauge: (D1-Brane)
Bosons:
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Twisting:
0-modes
Cases:

Physical Gauge: (D1-Brane)

$C \hookrightarrow \mathbb{C}^2 \times X$
$(z,\bar{z})$

Bosons: (x^μ, y^m), $m,n=1,2$ $\quad \mathcal{O}^2 \oplus N$

Fermions: $(L,\bar{J})$ $\quad \lambda \quad S_-(TC)\otimes V = V_-$

(R,J) $\quad \Psi \quad S_+(TC)\otimes S_+(\mathcal{O}^2\oplus N)$

Twisting: $\Psi \Rightarrow$ $\qquad$ 0-modes

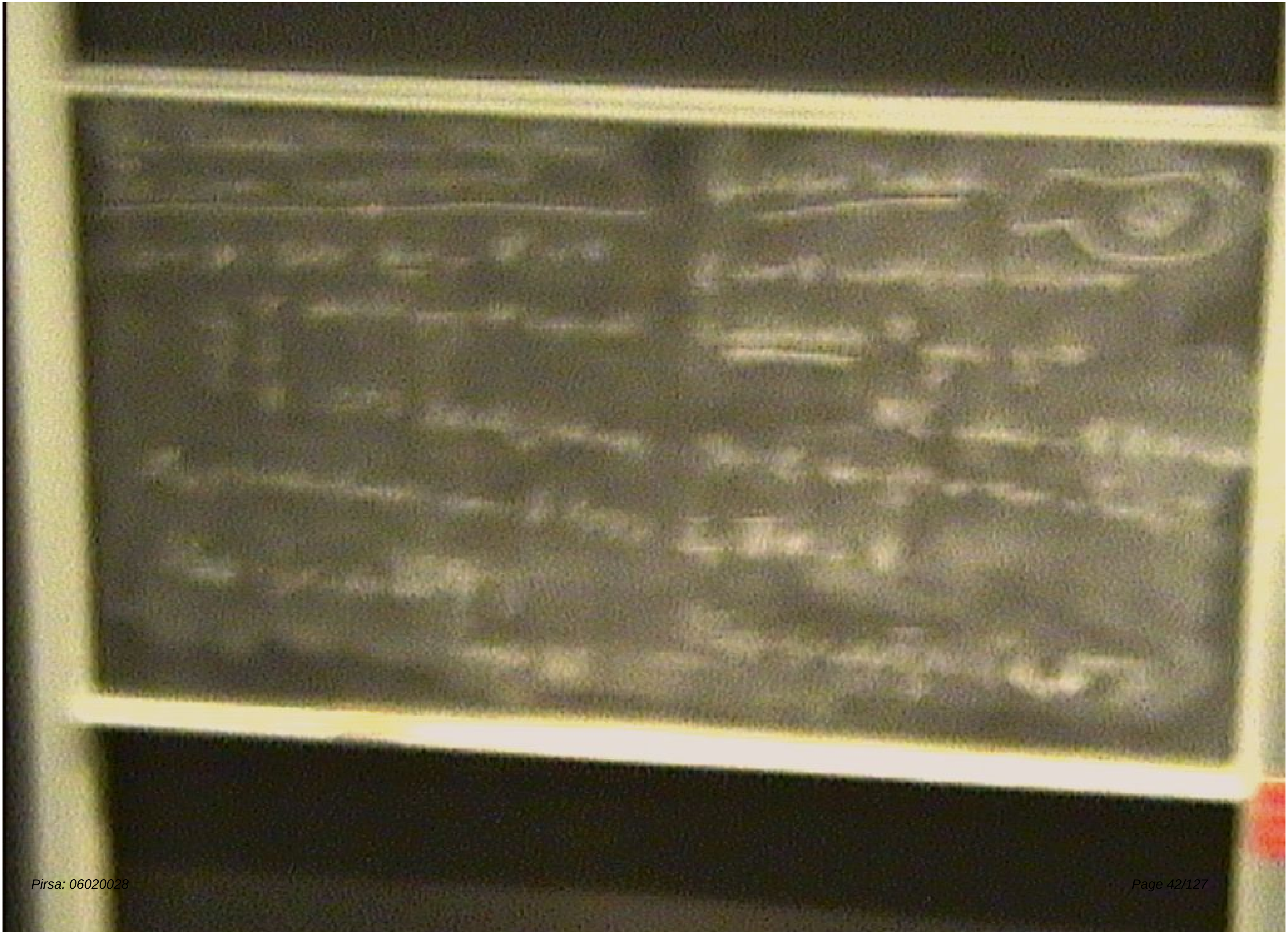
$\theta^\pm \quad S_-(\mathcal{O}^2)\otimes\bar{\mathcal{O}} \quad$ 2 Goldstino $\Rightarrow d^2\theta$

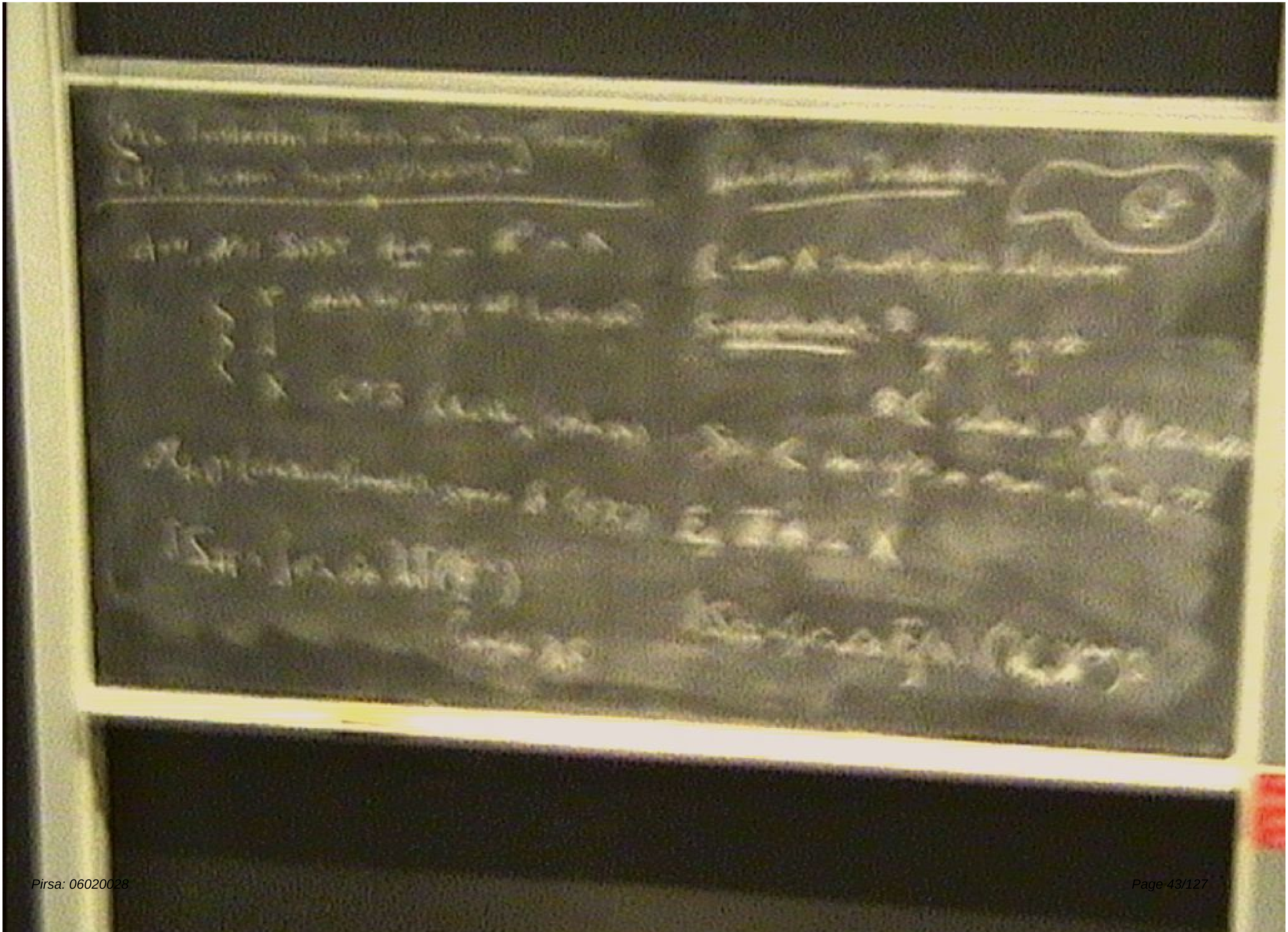
$\bar{\theta}^\pm \quad S_-(\mathcal{O}^2)\otimes\Omega^1_C \quad 2g$

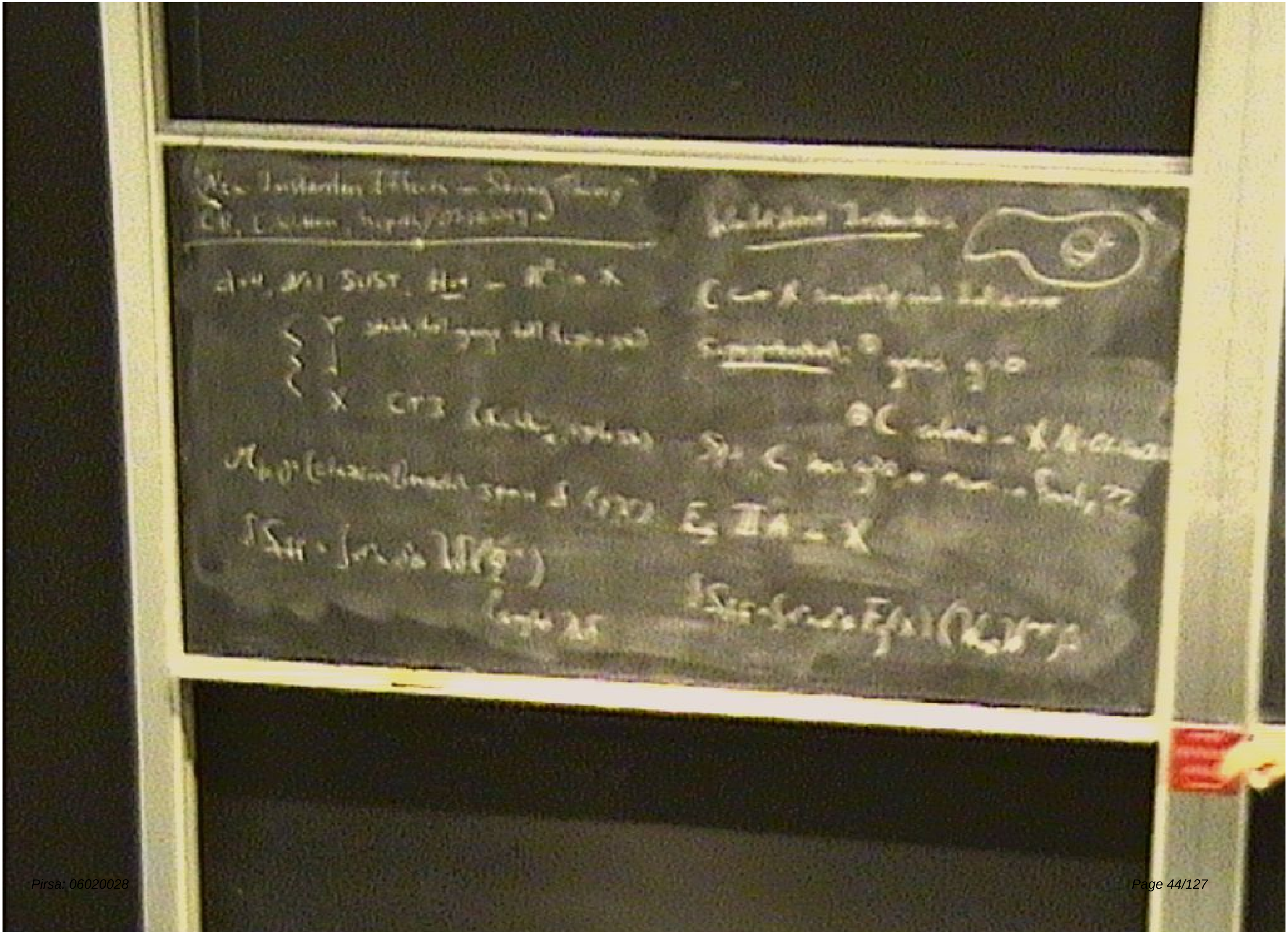
$\chi^\pm \quad S_+(\mathcal{O}^2)\otimes\bar{N} \quad 2p,\ p = \dim_{\mathbb{C}} H^0(C,N)$

Cases: (1) $g=0,\ p=0 \Rightarrow$ Superpotential

(2)






SUSY
CY3

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$$\begin{cases} V & \text{stable, hol. gauge bdl (cplx. str)} \\ \downarrow & \\ X & \text{CY3 (Kähler, cplx str)} \end{cases}$$

$\mathcal{M}_{(k,j)}$ = (classical) moduli space of (X, V)

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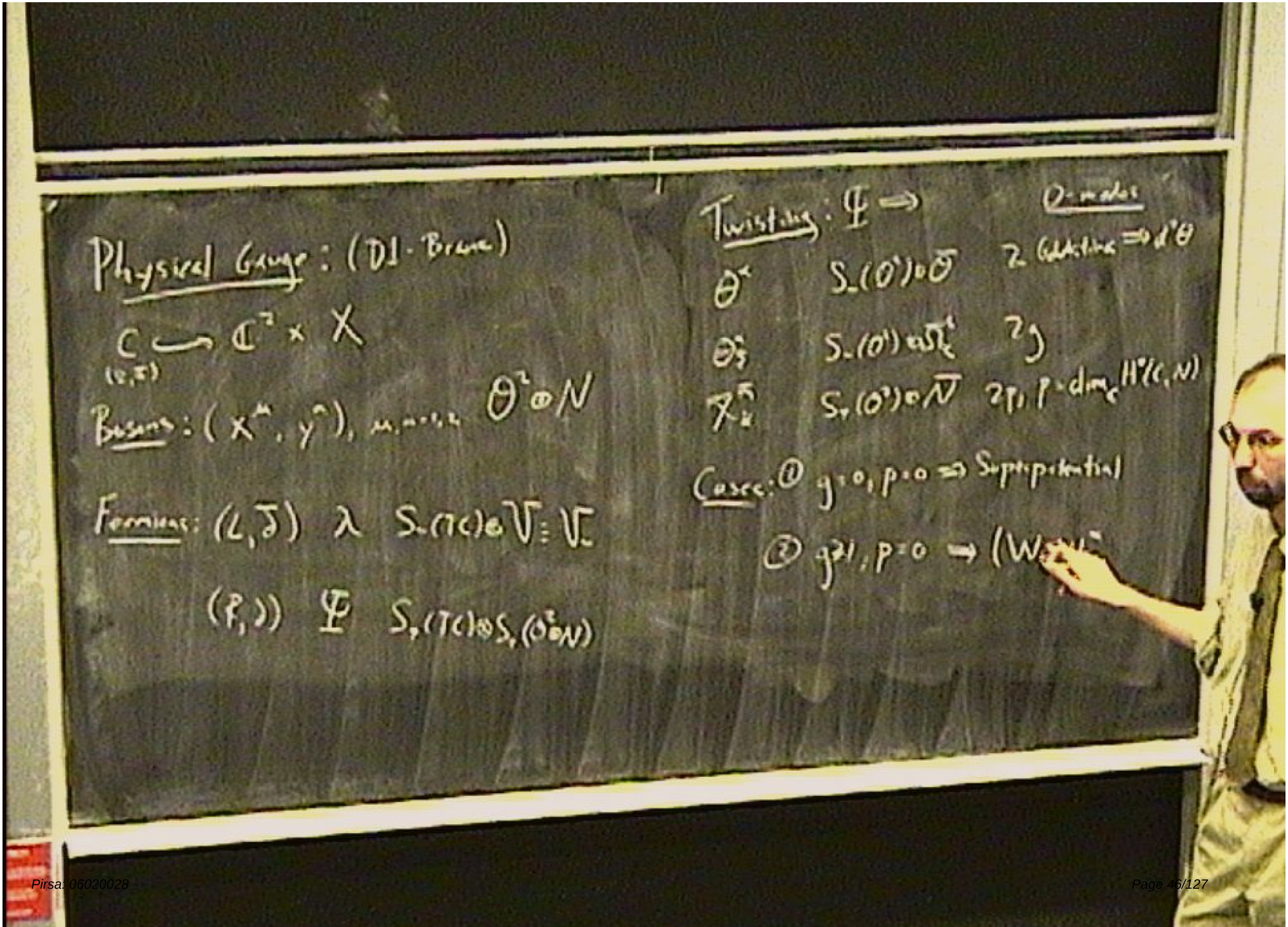

Physical Gauge: (D1-Brane)
$C \hookrightarrow \mathbb{C}^2 \times X$
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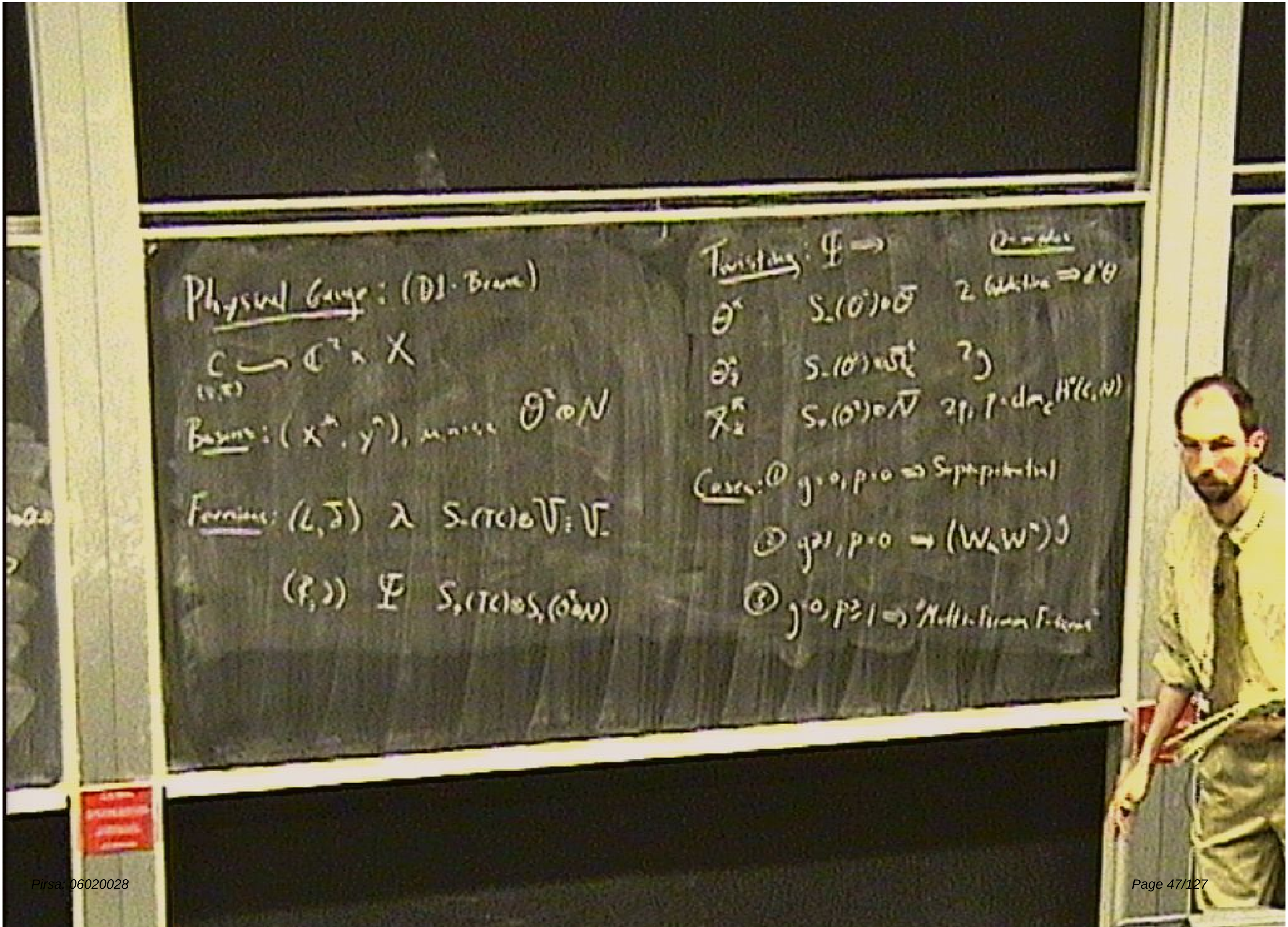
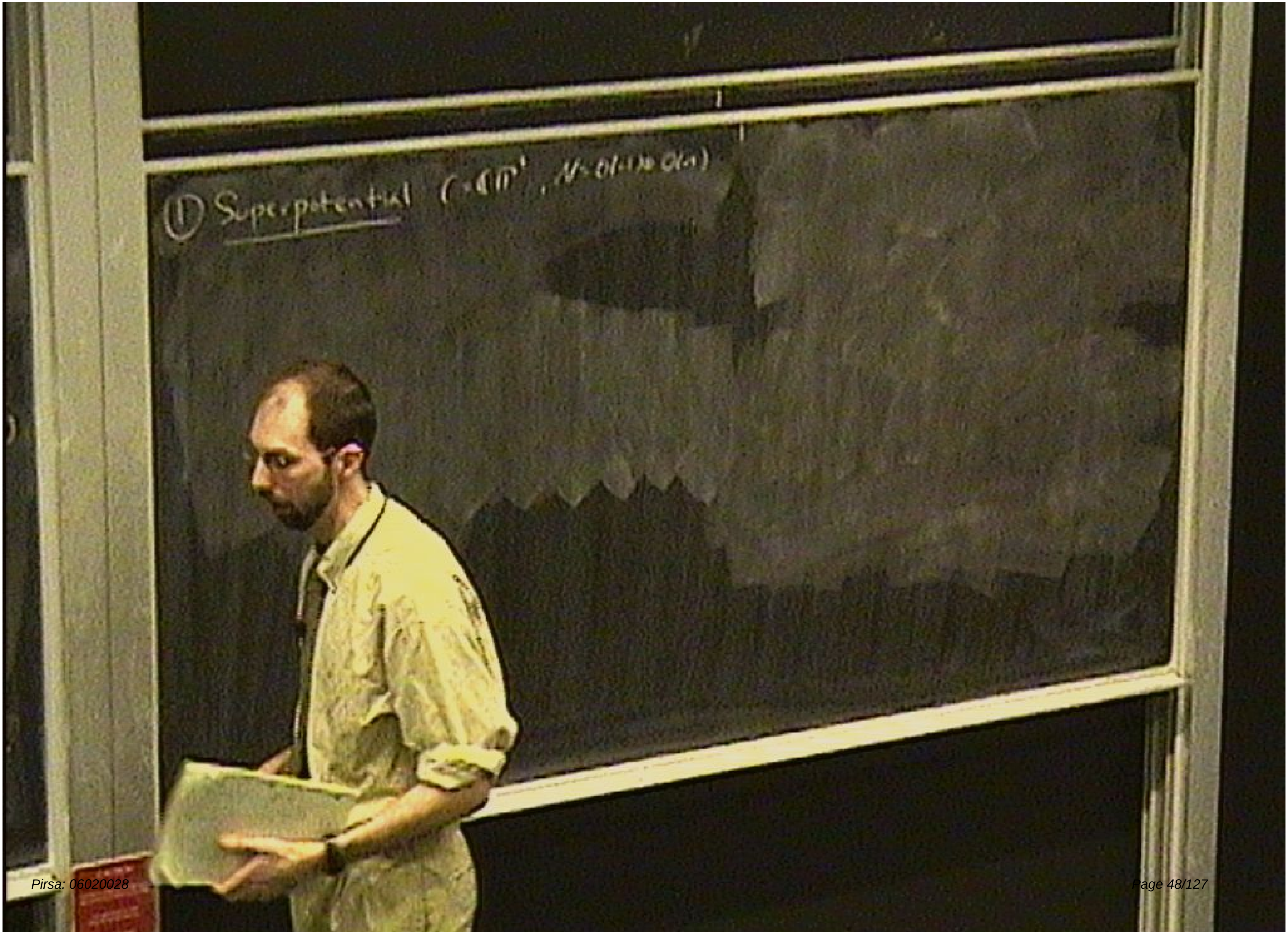
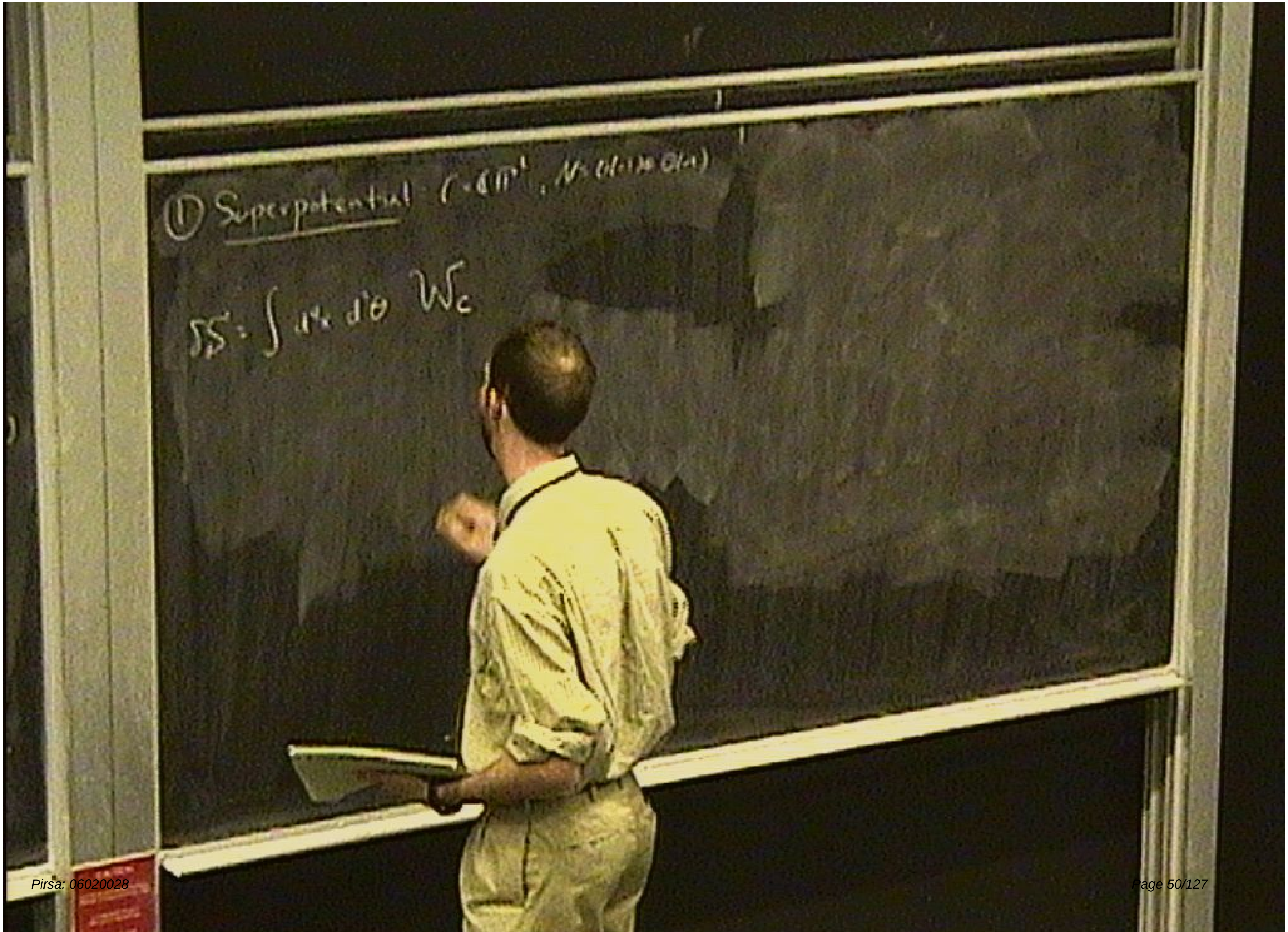
Fermions:
λ
Ψ
Twisting: $\Psi \Rightarrow$
0-modes
$S_-(\Theta^2)\otimes\bar\Theta$
$S_+(\Theta^2)\otimes\bar N$
$p = \dim_{\mathbb{C}} H^0(C,N)$
Cases: ① $g=0, p=0 \Rightarrow$ Superpotential
② $p=0 \Rightarrow$

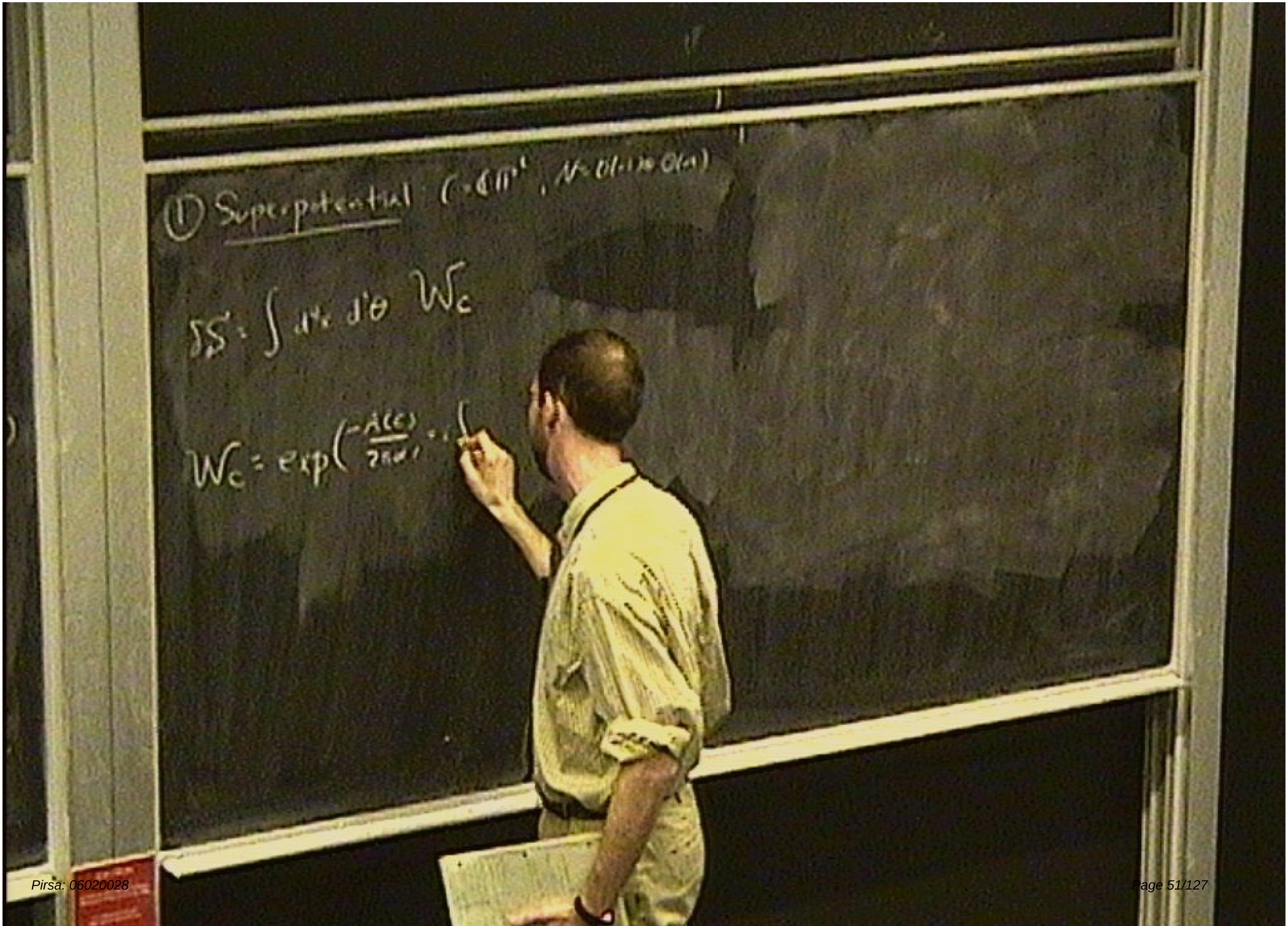

Physical Gauge: (D1-Brane)
Bosons:
Fermions:
Twisting:
Cases:
Superpotential


1 Superpotential

① Superpotential $(\,= \mathbb{CP}^1,\ N = \mathcal{O}(-1) \oplus \mathcal{O}(-1))$

$SS = \int$

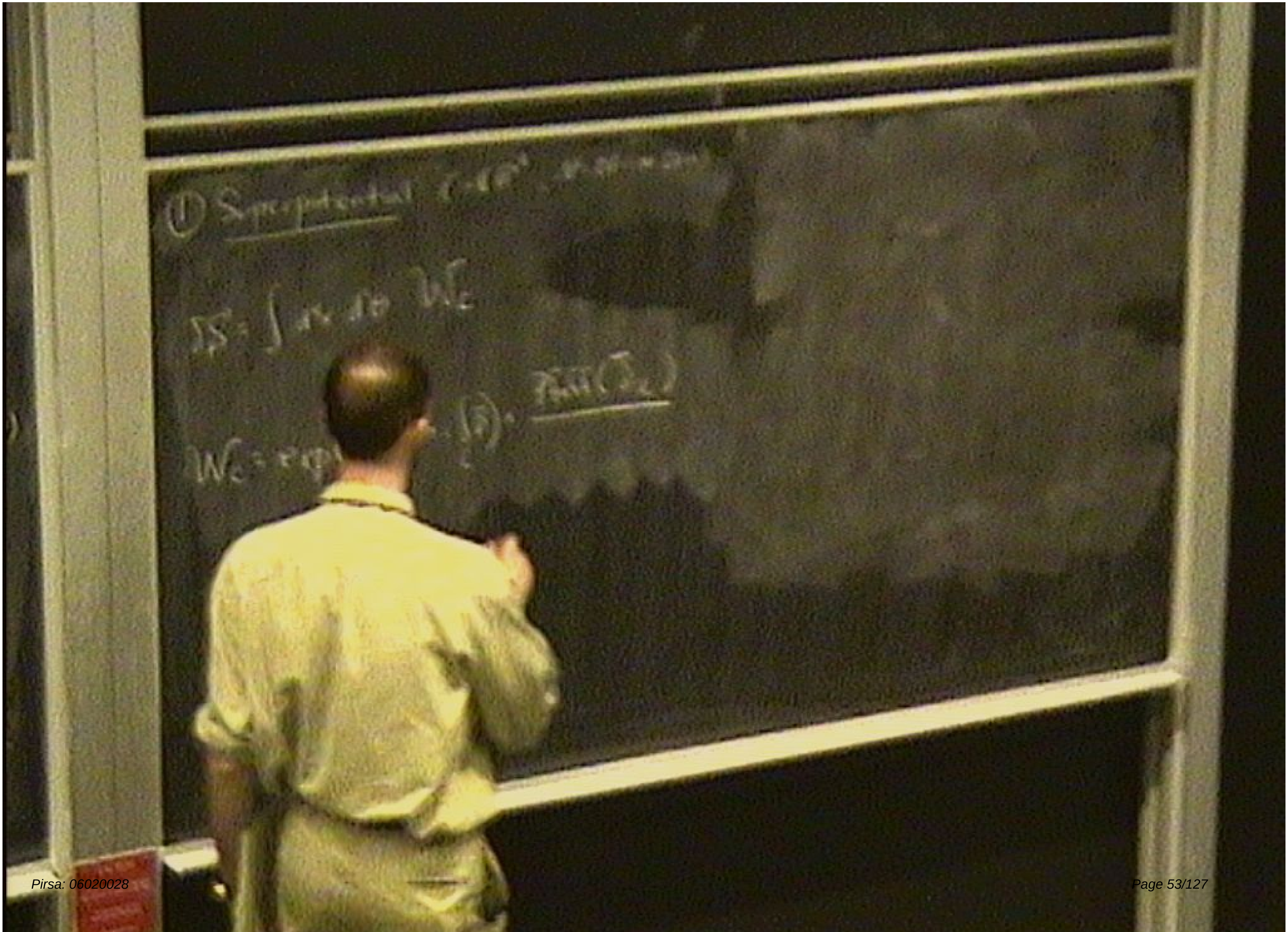

① Superpotential
δS = ∫ d⁴x d²θ W_c

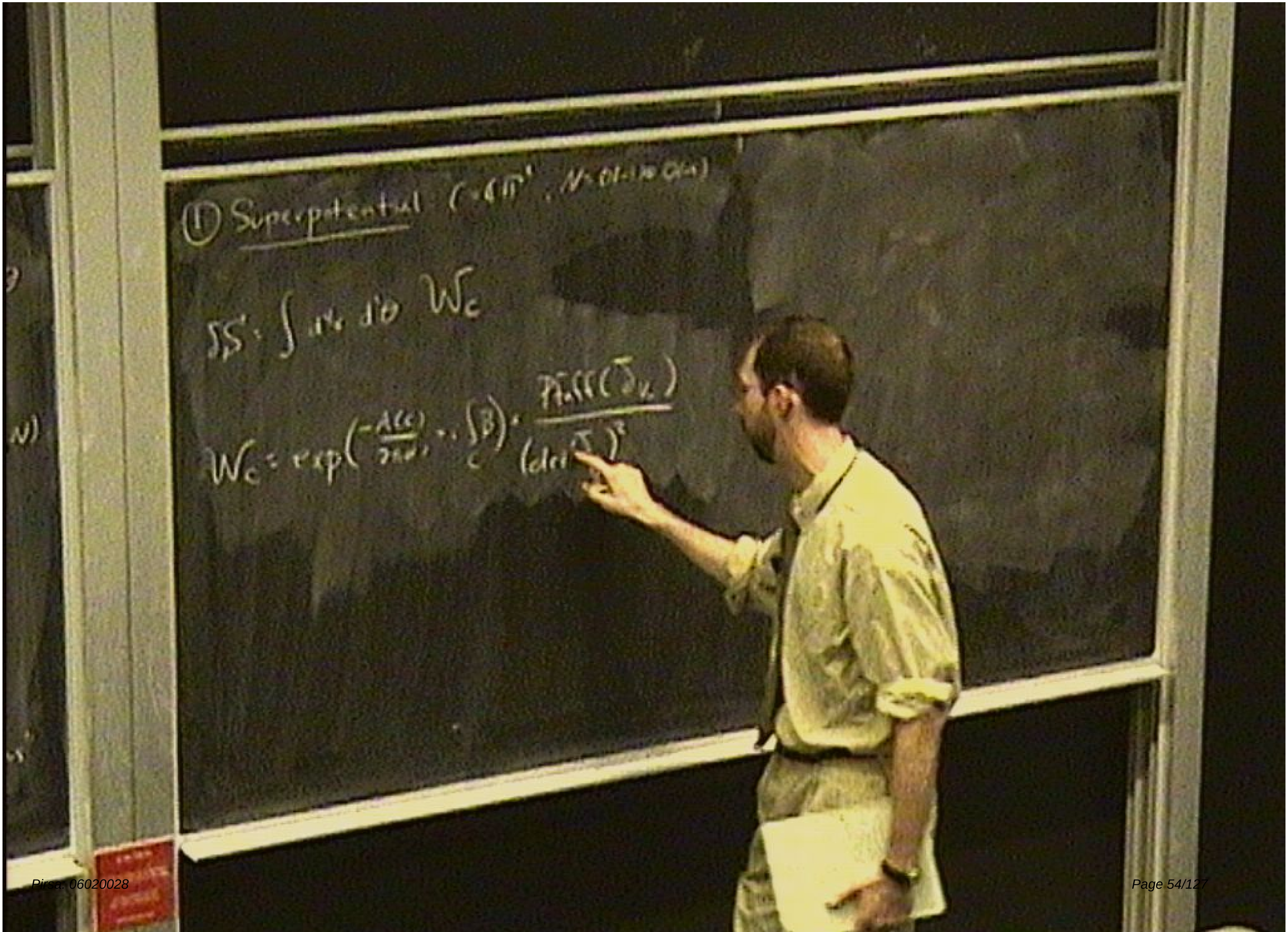

① Superpotential
$\delta S = \int d^4x \, d^2\theta \, W_c$
$W_c = \exp\left(-\frac{A(c)}{2\pi\alpha'}\right.$

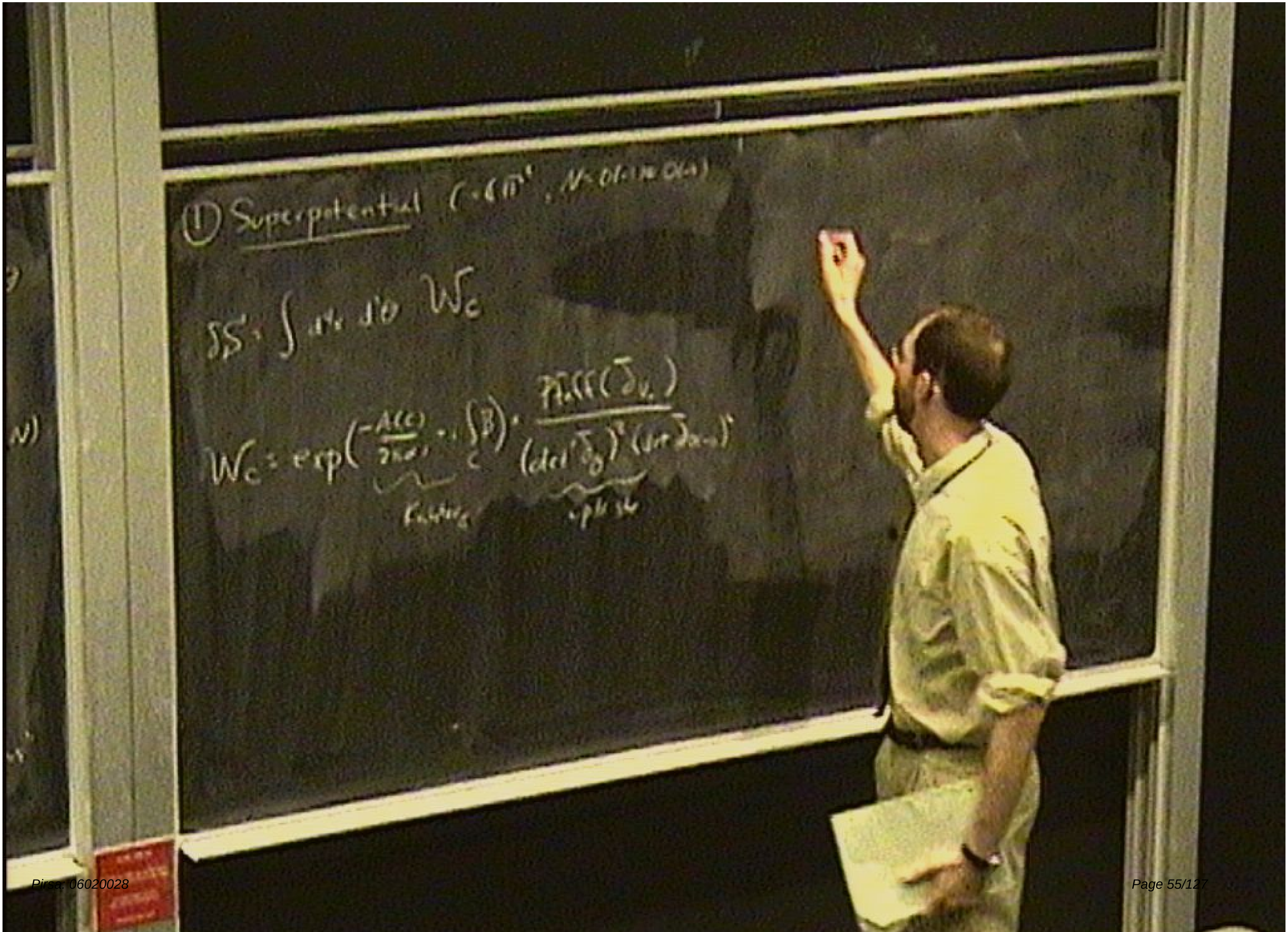
(1) Superpotential ($\times \mathbb{CP}^1$, $\mathcal{N}=(1,1)\to(0,1)$)

$$\delta S = \int d^4x\, d^2\theta\; W_c$$

$$W_c = \exp\left(-\frac{A(c)}{2\pi\alpha'} + i\int_c B\right)$$




Superpotential


① Superpotential
$\delta S = \int d^4x\, d^2\theta\ W_C$
$W_C = \exp\left(-\frac{A(C)}{2\pi\alpha'} + i\int_C B\right) \cdot \frac{\mathrm{Pfaff}(\bar\partial_{V_+})}{(\det'\bar\partial_0)^2\,(\det\bar\partial_{\dots})^{1/2}}$

"D-Instanton Effects in String Theory"

hep-th/0...

4d $N=1$ SUSY, $M^4 = \mathbb{R}^4 \times X$

$\left\{ \begin{array}{l} \text{IIA} \quad \text{gauge} \\ \text{I} \\ X \quad CY3 \ (\text{Kähler, cplx str}) \end{array} \right.$

$\mathcal{M}_{inst}$ = (classical) moduli space of $(\ldots)$

$\delta S_{eff} = \int d^4x\, d^2\theta\, W(\Phi^i)$

complex str

Worldsheet Instantons

$C \subset X$ ... holomorphic

Superpotential: (1) genus $g=0$

(2) C isolated in X, $N=\ldots$

Sps C has $g>0$, or moves in family ??

Eg IIA on X

$\delta S_{eff} = \int d^4x\, d^2\theta\, F_g(t) \, (W_{\alpha\beta}W^{\alpha\beta})^g$

Physical Gauge: (D1-Brane)

$C_{(z,\bar z)} \hookrightarrow \mathbb{C}^2 \times X$

Bosons: (x^μ, y^n), $\mu, n = 1,2$ $\quad \Theta^1 \oplus N$

Fermions: $(L,\bar\partial)$ λ $S_-(TC)\otimes \mathcal{V} = \mathcal{V}_C$

(R,∂) Ψ $S_+(TC)\otimes S_+(\Theta^1 \oplus N)$

Twisting: $\Psi \Rightarrow$ 0-modes

Θ^α $\quad S_-(\Theta^1)\otimes\bar\Theta$ $\quad$ 2 (additive $\Rightarrow d^2\theta$)

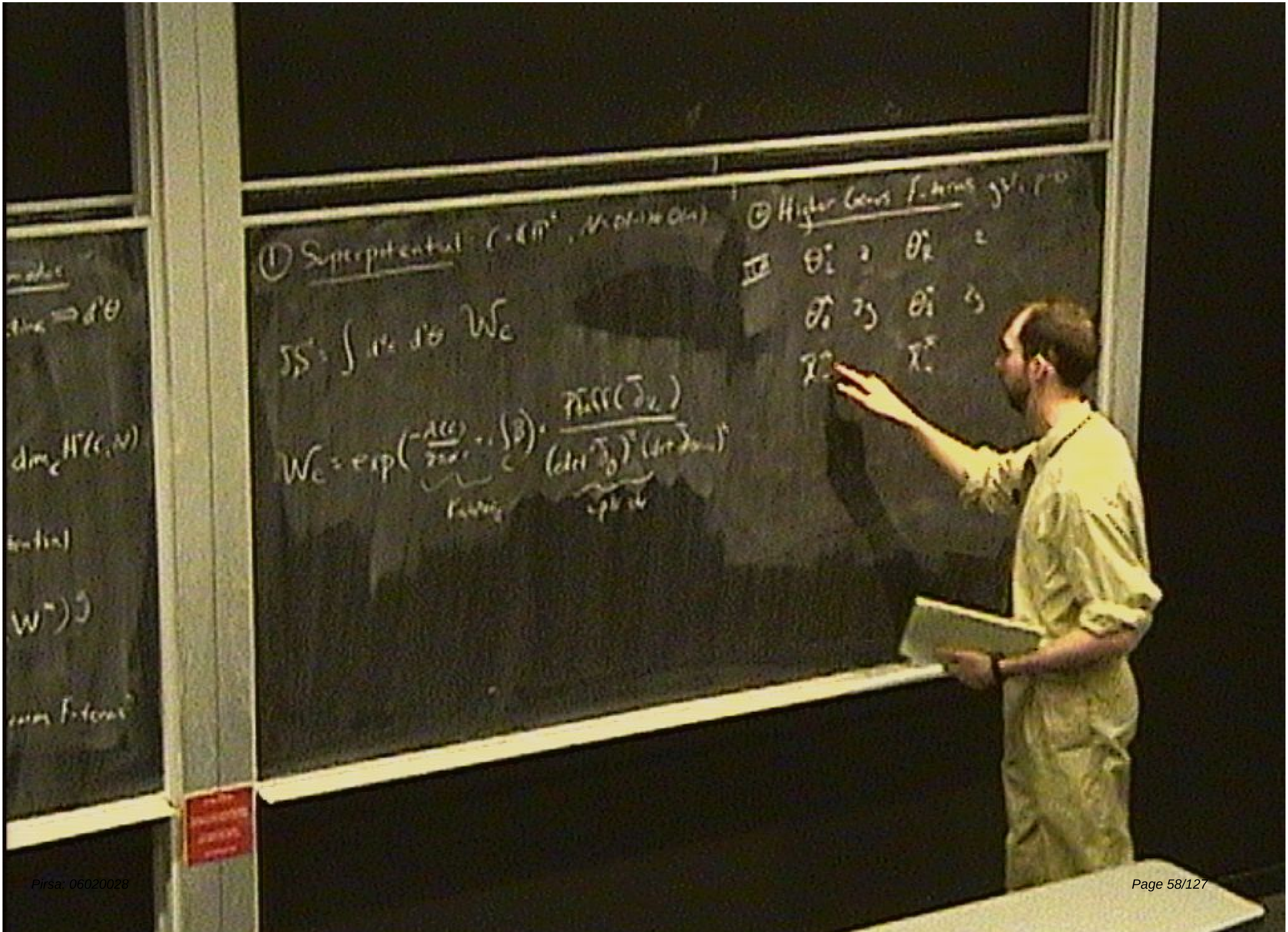
$\bar\Theta_{\bar z}^{\dot\alpha}$ $\quad S_-(\Theta^1)\otimes \Omega_C^1$ $\quad$?g

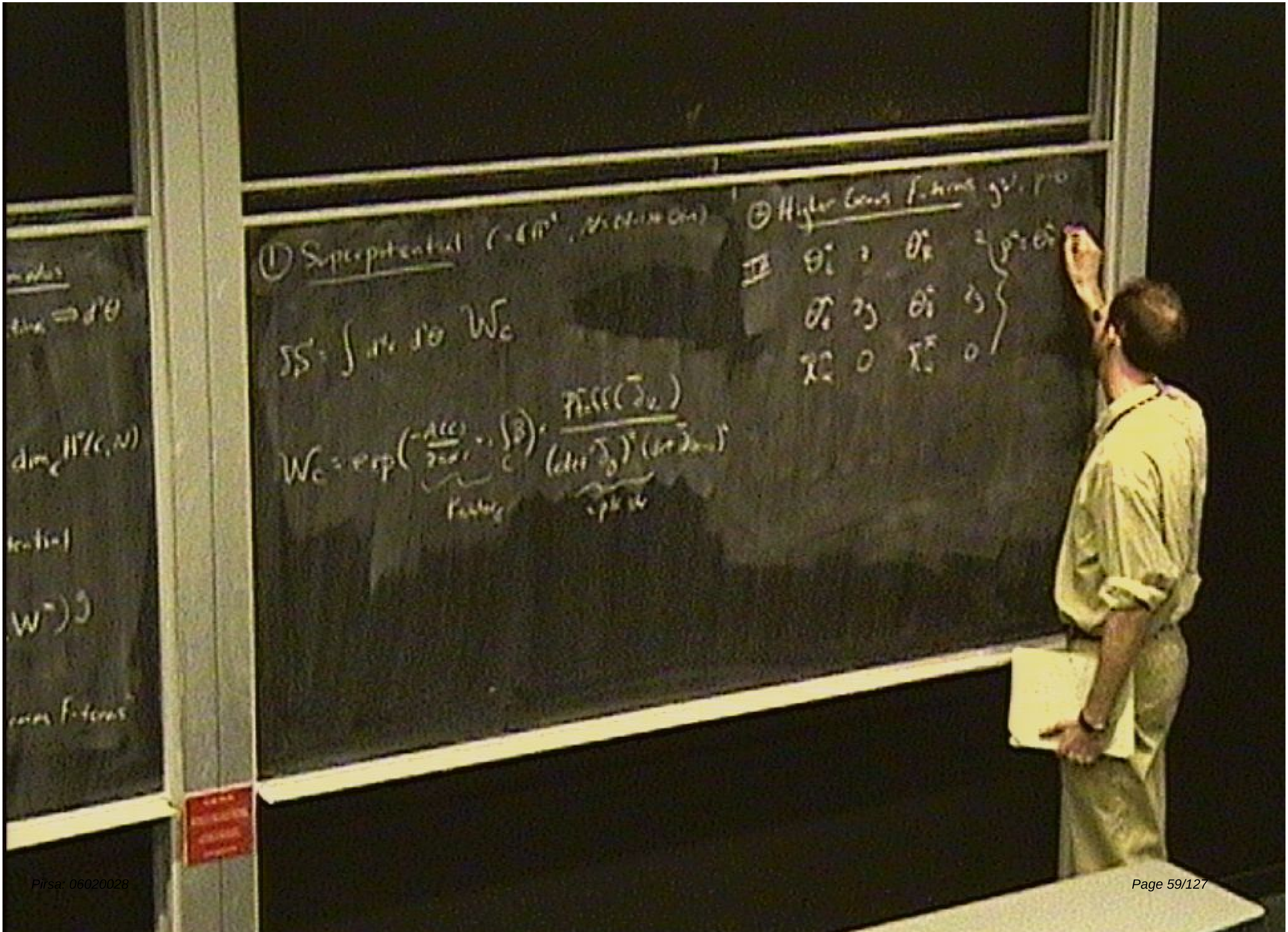
$\chi_{\bar z}^{\bar n}$ $\quad S_+(\Theta^1)\otimes \bar N$ $\quad$ 2p, $p = \dim_{\mathbb{C}} H^0(C,N)$

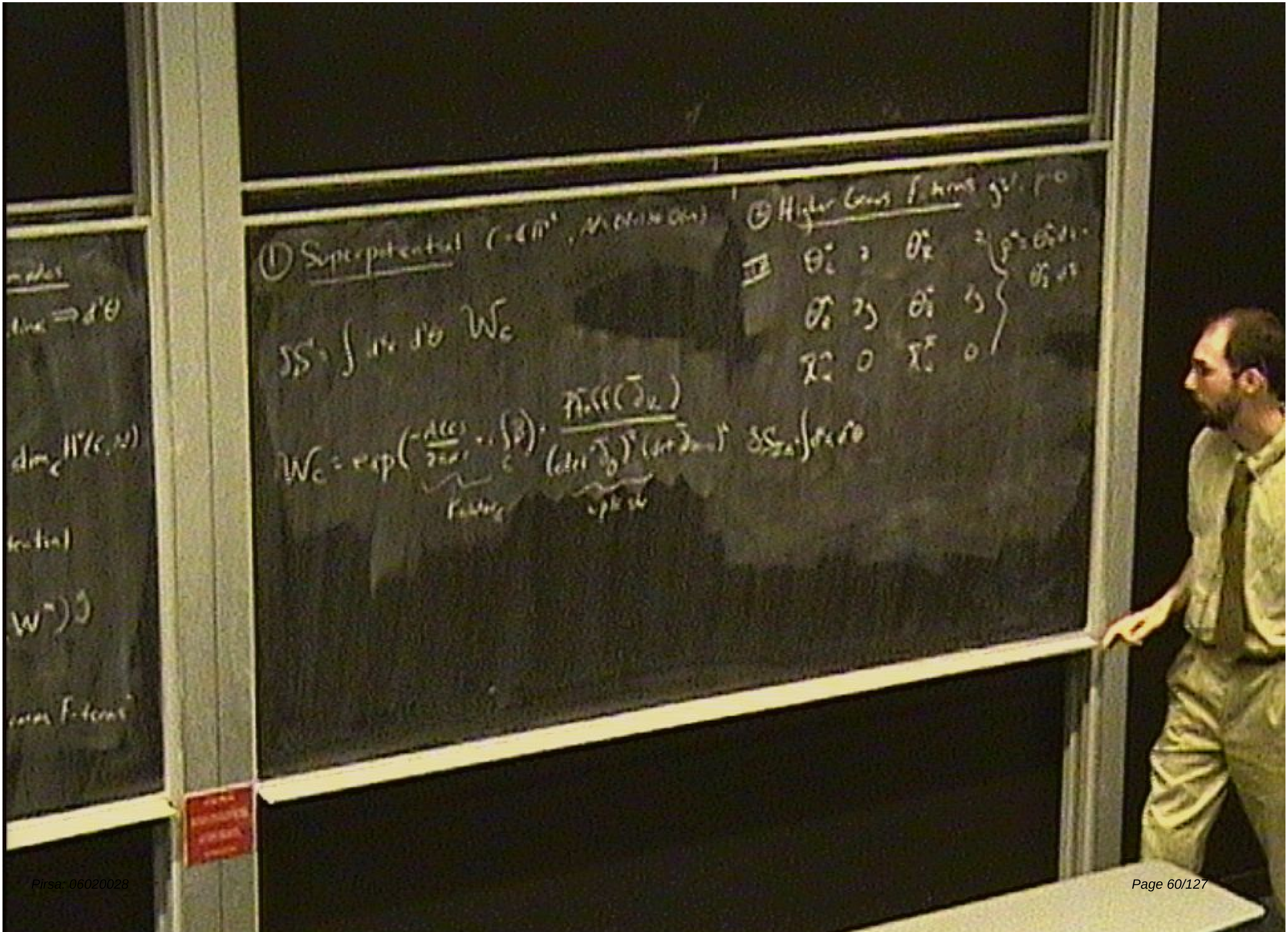
Cases: ① $g=0, p=0 \Rightarrow$ Superpotential

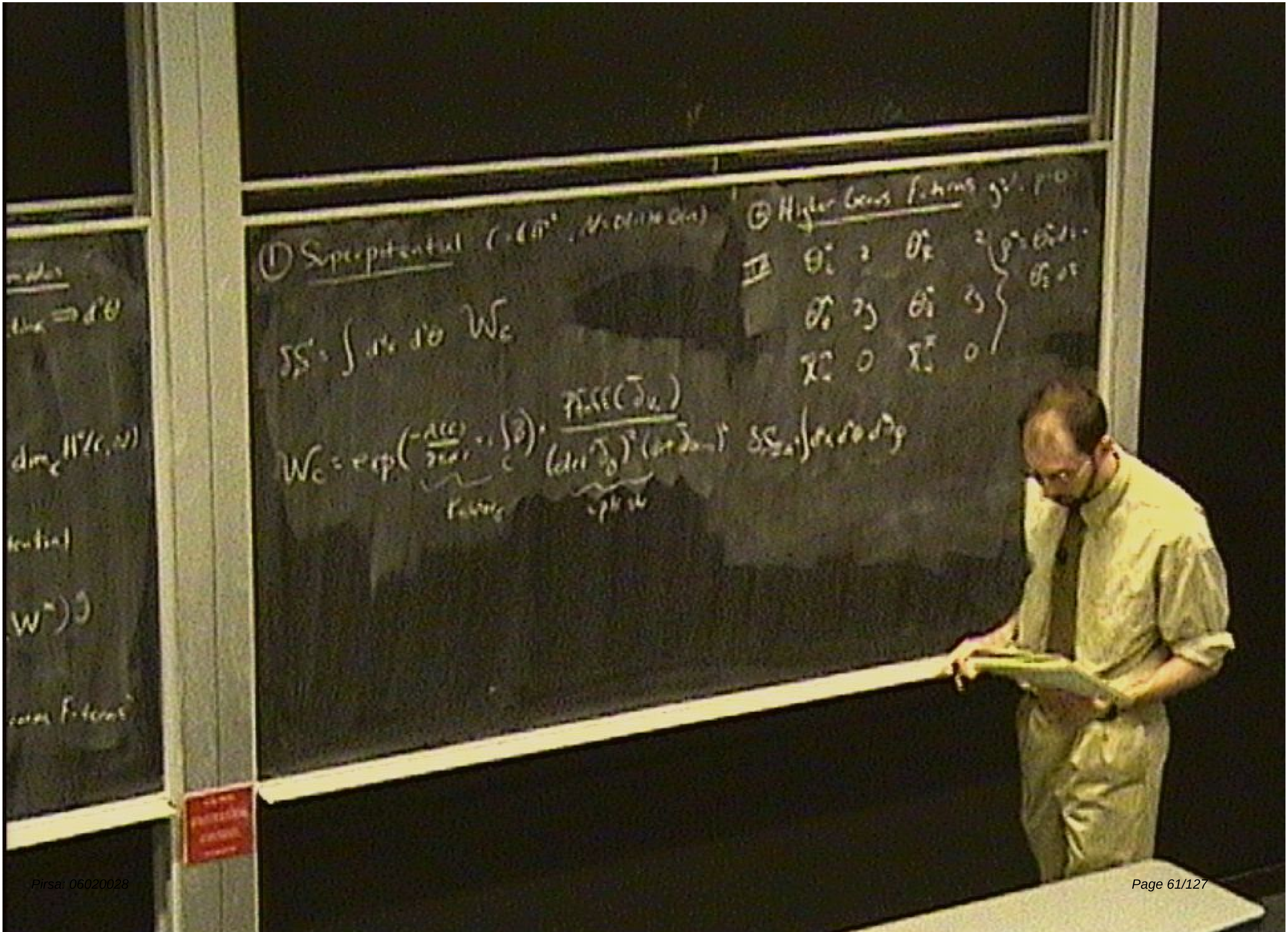
② $g \geq 1, p=0 \Rightarrow (W_\alpha W^\alpha) g$

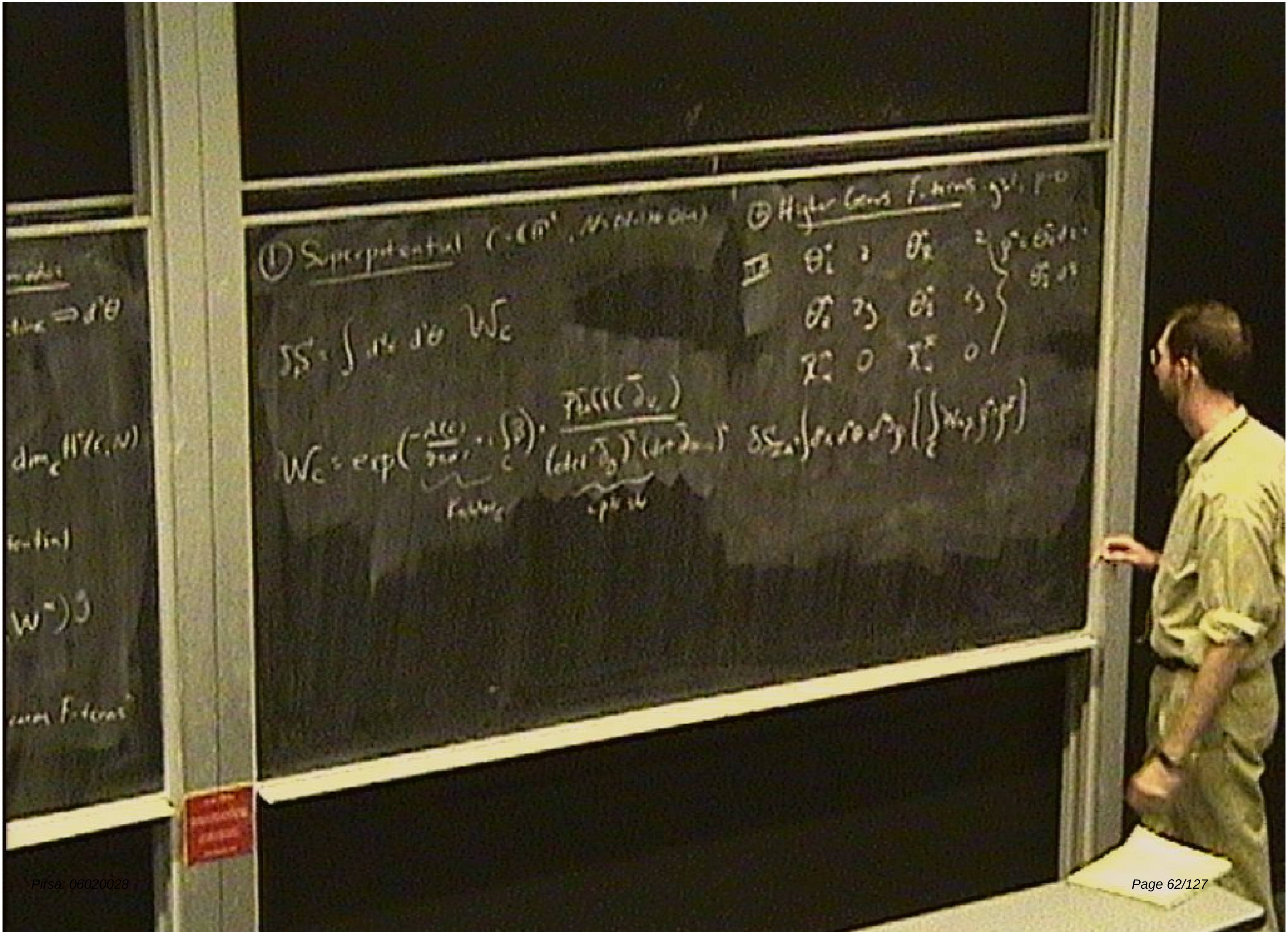
③ $g=0, p\geq 1 \Rightarrow$ "Multi-Fermion F-terms"

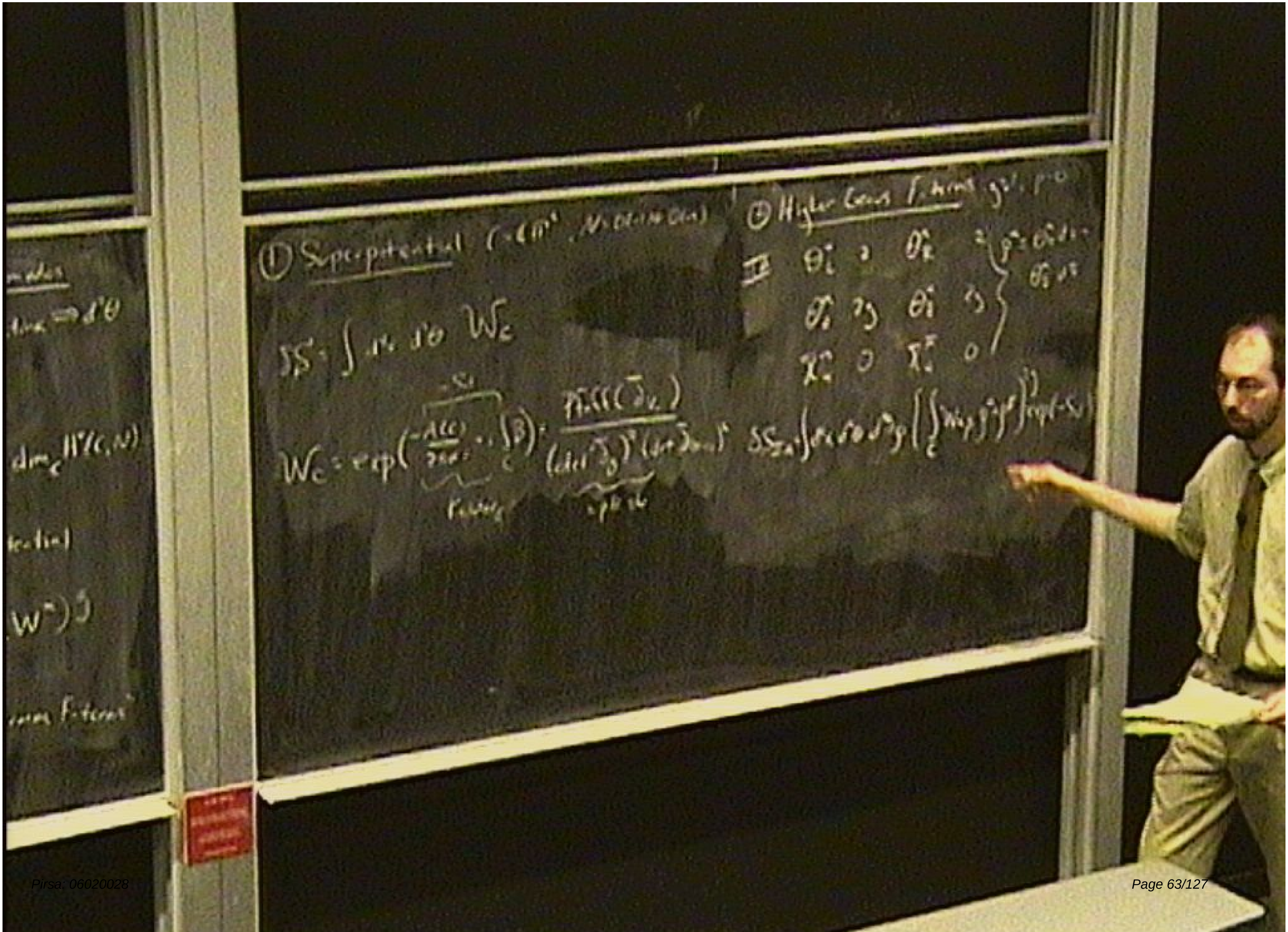

① Superpotential
② Higher Genus F-terms


① Superpotential
② Higher Genus F-terms


① Superpotential
Higher Genus F-terms


Superpotential
Higher Genus F-terms


① Superpotential
② Higher Genus F-terms



① Superpotential
② Higher Genus F-terms

New Instanton Effects in String Theory

(K. B., E. Witten, hep-th/05[illegible])

$d=4$, $N=1$ SUSY, Het on $\mathbb{R}^4 \times X$

X CY3 ([illegible])

$\delta S_{eff} = \int d^4x\, d^2\theta\, W(\Phi^i)$

Worldsheet Instantons

C [illegible]

Simplification: genus $g=0$

C [illegible] X [illegible]

$E_8 \times$ [illegible] X

$\delta S_{eff} = \int d^4x\, d^2\theta\, F(\ldots)$ [illegible]

(1) Superpotential : $C = \mathbb{CP}^1$, $N = O(-1) \oplus O(-1)$

$$\delta S' = \int d^4x\, d^2\theta\; W_C$$

$$W_C = \exp\Big(\overbrace{\underbrace{-\frac{A(C)}{2\pi\alpha'}}_{\text{Kähler}} + i\int_C B}^{-S_{cl}}\Big)\cdot \underbrace{\frac{\mathrm{Pfaff}(\bar\partial_{V_-})}{(\det'\bar\partial_0)^2\,(\det\bar\partial_{N(-1)})^2}}_{\text{cplx str}}$$

(2) Higher Genus F-terms $g \geq 1$, $\beta \neq 0$

IIA				
$\theta^{\dot\alpha}_L$	2	$\theta^{\dot\alpha}_R$	2
θ^{α}_L	2g	θ^{α}_R	2g
χ^{α}_L	0	$\chi^{\bar\alpha}_R$	0

$\rho^{\alpha} = \theta^{\alpha}_L d\sigma$, $\theta^{\alpha}_R\, d\bar\sigma$

$$\delta S_{IIA} = \int d^4x\, d^4\theta\, d^{4g}\rho \left(\int_C W_{\alpha\beta}\,\rho^\alpha \rho^\beta\right)^{2g} \exp(-S_{cl})$$

$$\delta S_{Het} =$$

(1) Superpotential : $C = \mathbb{T}^3$, $N = O(-1) \oplus O(-1)$

$$\delta S' = \int d^4x \, d^2\theta \; W_C$$

$$W_C = \exp\Big(\overbrace{\underbrace{-\frac{A(C)}{2\pi\alpha'}}_{\text{Kahler}} + i\int_C B}^{-S_{cl}} \Big) \cdot \underbrace{\frac{\mathrm{Pfaff}(\bar{\partial}_{V_-})}{(\det' \bar{\partial}_0)^{2} (\det \bar{\partial}_{O(-1)})^{2}}}_{\text{upl. str}}$$

(2) Higher Genus F-terms $g \geq 1$, $p = 0$

IIA	θ^{α}_{L}	2	$\theta^{\hat\alpha}_{R}$	2
	$\theta^{\dot\alpha}_{L}$	$2g$	$\theta^{\hat{\dot\alpha}}_{R}$	$2g$
	$\chi^{\dot\alpha}_{L}$	0	$\chi^{\hat{\dot\alpha}}_{L}$	0

$\rho^{\alpha} = \theta^{\hat\alpha}_{L} \pm \ldots$

$\theta^{\alpha}_{L} \ldots$

$$\delta S'_{IIA} = \int d^4x \, d^2\theta \, d^2\rho \, \Big(\Big[\int_C W_{\alpha\beta}\, \rho^{\alpha} \rho^{\beta} \Big]^{2g} \exp(-S_{cl}) \Big)$$

$$\delta S'_{Het} = \int d^4x \, d^2\theta \, d^{2g}\theta_L$$

① Superpotential : $C \in \tilde{H}^{2}$, $\mathcal{N} = O(-1) \oplus O(-1)$

$$\delta S' = \int d^4x \, d^2\theta \; W_C$$

$$W_C = \exp\Big(\overbrace{-\frac{A(C)}{2\pi\alpha'}}^{-S_0}\!\!\!\!\!\!\!\!\underbrace{\phantom{-\frac{A(C)}{2\pi\alpha'}}}_{\text{Kähler}} + i\int_C B \Big) \cdot \underbrace{\frac{\mathrm{Pfaff}(\bar\partial_{V_-})}{(\det{}' \bar\partial_0)^2 (\det \bar\partial_{O(-1)})^2}}_{\text{cplx str}}$$

② Higher Genus F-terms $g \geq 1$, $p \geq 0$

IIA: Θ^{α}_{L} 2 $\quad \Theta^{\alpha}_{R}$ 2 $\quad \rho^{\alpha} = \Theta^{\alpha}_{L} d\bar z + \bar\Theta^{\alpha}_{j} dz$

$\bar\Theta^{\dot\alpha}_{L}$ 2g $\quad \bar\Theta^{\dot\alpha}_{R}$ 2g

$\chi^{\dot\alpha}_{L}$ 0 $\quad \chi^{\dot\alpha}_{R}$ 0

$$\delta S_{IIA} = \int d^4x \, d^2\theta \, d^{2g}\rho \left(\int_C W_{\alpha\beta} \rho^\alpha \rho^\beta \right)^{2g} \exp(-S_0)$$

$$\delta S_{Het} = \int d^4x \, d^2\theta \, d^{2g}\theta_+ \int_C \mathrm{Tr}(W_{\alpha} g^2)$$

(1) Superpotential : $C = \mathbb{CP}^1$, $N = O(-1) \oplus O(-1)$

$$\delta_p S = \int d^4x\, d^2\theta\, W_C$$

$$W_C = \exp\Big(\overbrace{-\underbrace{\frac{A(C)}{2\pi\alpha'}}_{\text{Kahler}} + i\int_C B}^{-S_{cl}}\Big) \cdot \underbrace{\frac{\mathrm{Pfaff}(\bar\partial_{V_-})}{(\det' \bar\partial_0)^2 (\det \bar\partial_{\mathcal{O}(-1)})^2}}_{\text{cplx str}}$$

(2) Higher Genus F-terms $g \geq 1$, $\mu = 0$

IIA

θ_L^α	2	θ_R^α	2
$\theta_L^{\dot\alpha}$	2g	$\theta_R^{\dot\alpha}$	2g
$\bar\chi_L^{\dot\alpha}$	0	$\bar\chi_R^{\dot\alpha}$	0

$\rho^\alpha = \theta_L^\alpha d\theta$
$\theta_R^\alpha\, d^2\theta$

$$\delta S_{IIA} = \int d^4x\, d^2\theta\, d^{2g}\rho \left(\left(\int_C W_{\alpha\beta}\, \rho^\alpha \rho^\beta\right)^{2g} \exp(-S_{cl})\right)$$

$$\delta S_{Het} = \int d^4x\, d^2\theta\, d^{2g}\theta_L \left(\left(\int_C \mathrm{Tr}(W_{\alpha\beta}\, \gamma^{\alpha\beta})\, \theta_L\right)^{2g}\right)$$

"New Instanton Effects in String Theory"
CB, E. Witten, hep-th/0512039

$d=4$, $\mathcal{N}=1$ SUSY, Het on $\mathbb{R}^{3,1}\times X$

V stable, hol gauge bdl (cplx str)
$\downarrow$
X CY3 (Kähler, cplx str)

$\mathcal{M}_{(X,V)}$ = (classical) moduli space of (X,V)

$$\delta S_{eff} = \int d^4x\, d^2\theta\, W(\Phi^i)$$

singlet flds

Worldsheet Instantons

$C \hookrightarrow X$ smoothly emb. hol. curve

Superpotential: ① genus $g=0$

② C isolated in X, $N=\mathcal{O}(-1)\oplus\mathcal{O}(-1)$

· Sp? C has $g>0$, or moves in family??

Eg IIA on X

$$\delta S_{eff} = \int d^4x\, d^2\theta\, F_g(X)\,(W_{\alpha\beta}W^{\alpha\beta})^g$$

① Superpotential ($C \in H^{3}$, $N = 0 (-1) \oplus 0(-1)$)

$$\delta S' = \int d^4x\, d^2\theta\, W_C$$

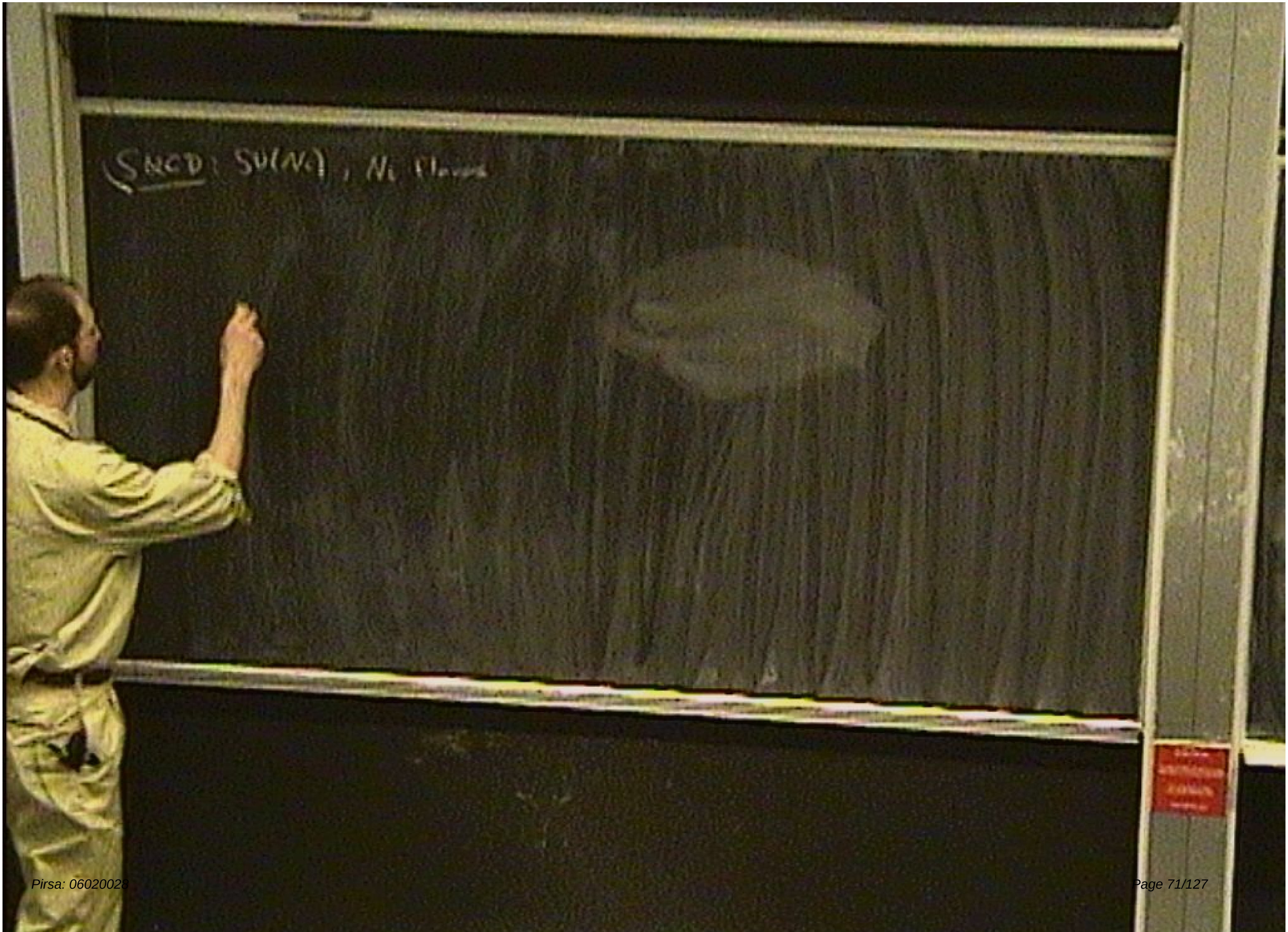
$$W_C = \exp\Big(\overbrace{\underbrace{-\frac{A(C)}{2\pi\alpha'}}_{\text{Kahler}_{G}} + i\int_C B}^{-S_{cl}}\Big) \cdot \underbrace{\frac{\mathrm{Pfaff}(\bar{\partial}_{V_-})}{(\det{}'\bar{\partial}_0)^2\,(\det \bar{\partial}_{\mathrm{Dirac}})^{\frac{1}{2}}}}_{\text{1-loop det}}$$

② Higher Genus F-terms $g \geq 1$, $p \geq 0$

IIA				
θ^{+}_{L}	2	θ^{+}_{R}	2	$\rho^{\pm} = \theta^{\pm}_{L} + \theta^{\pm}_{R}$
θ^{-}_{L}	2g	θ^{-}_{R}	2g	$\theta^{\pm}_{L} - \theta^{\pm}_{R}$
χ^{-}_{a}	0	χ^{+}_{a}	0	

$$\delta S_{IIA} = \int d^4x\, d^4\theta\, d^{4g}\rho \left[\int_C W_{\alpha\beta}\, \rho^{\alpha}\rho^{\beta}\right]^{2g} \exp(-S_{cl})$$

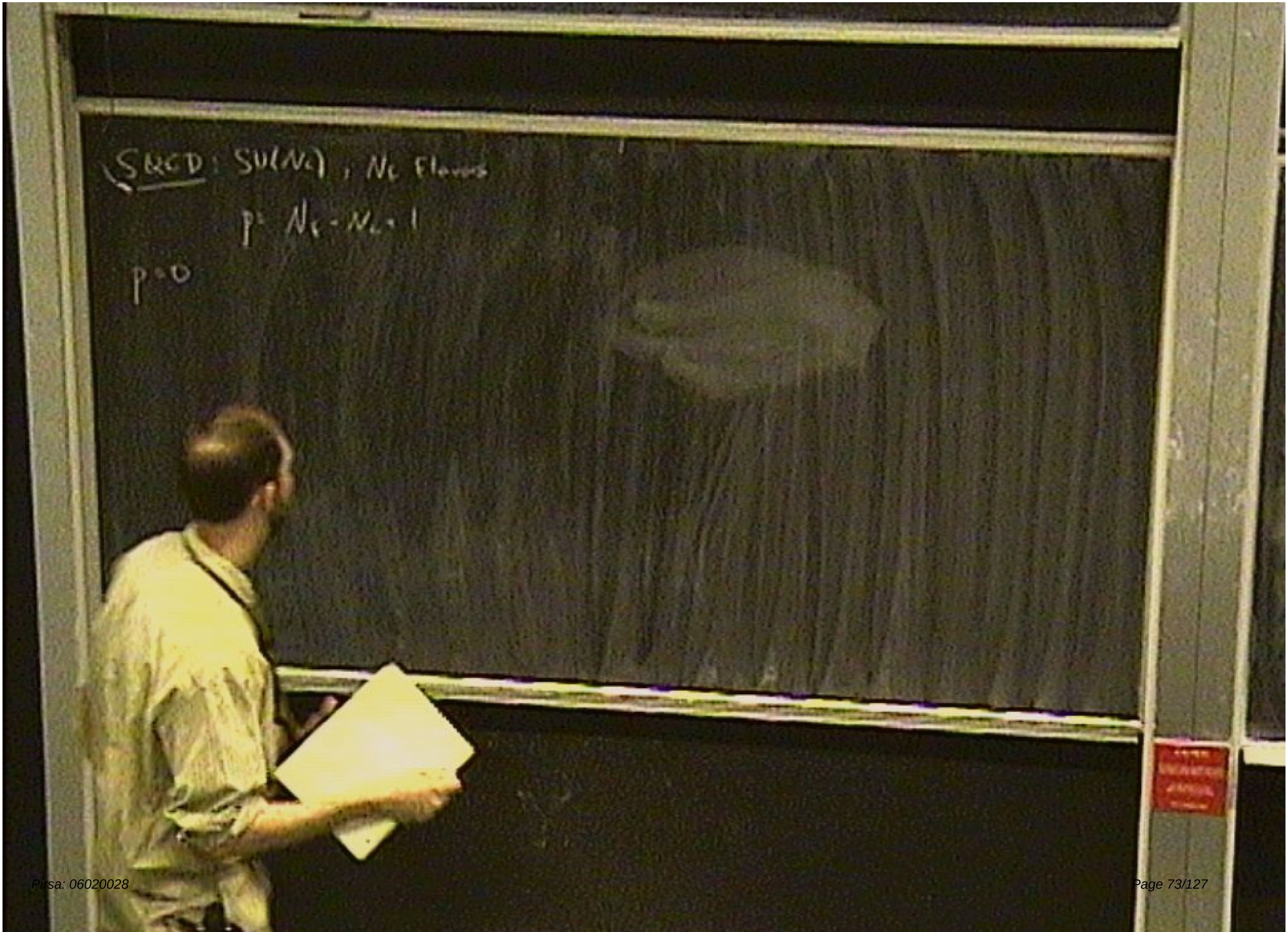
$$\delta S_{Het} = \int d^4x\, d^4\theta\, d^{4g}\theta_R \left[\int_C \mathrm{Tr}(W_{\alpha\beta}\, \theta^{\alpha}_R \theta^{\beta}_R)\right]^{2g}$$

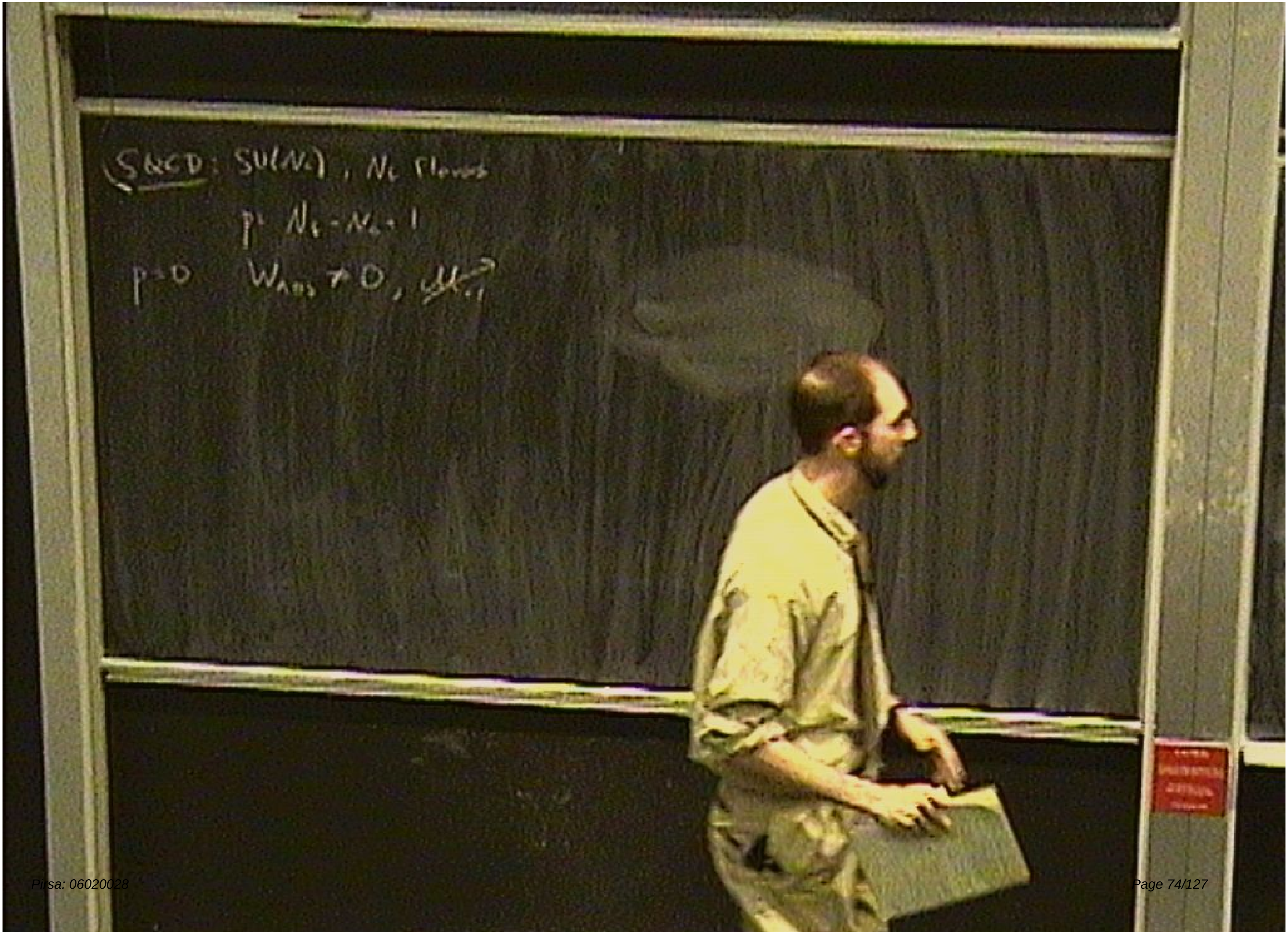

SQCD: SU(Nc), Nf

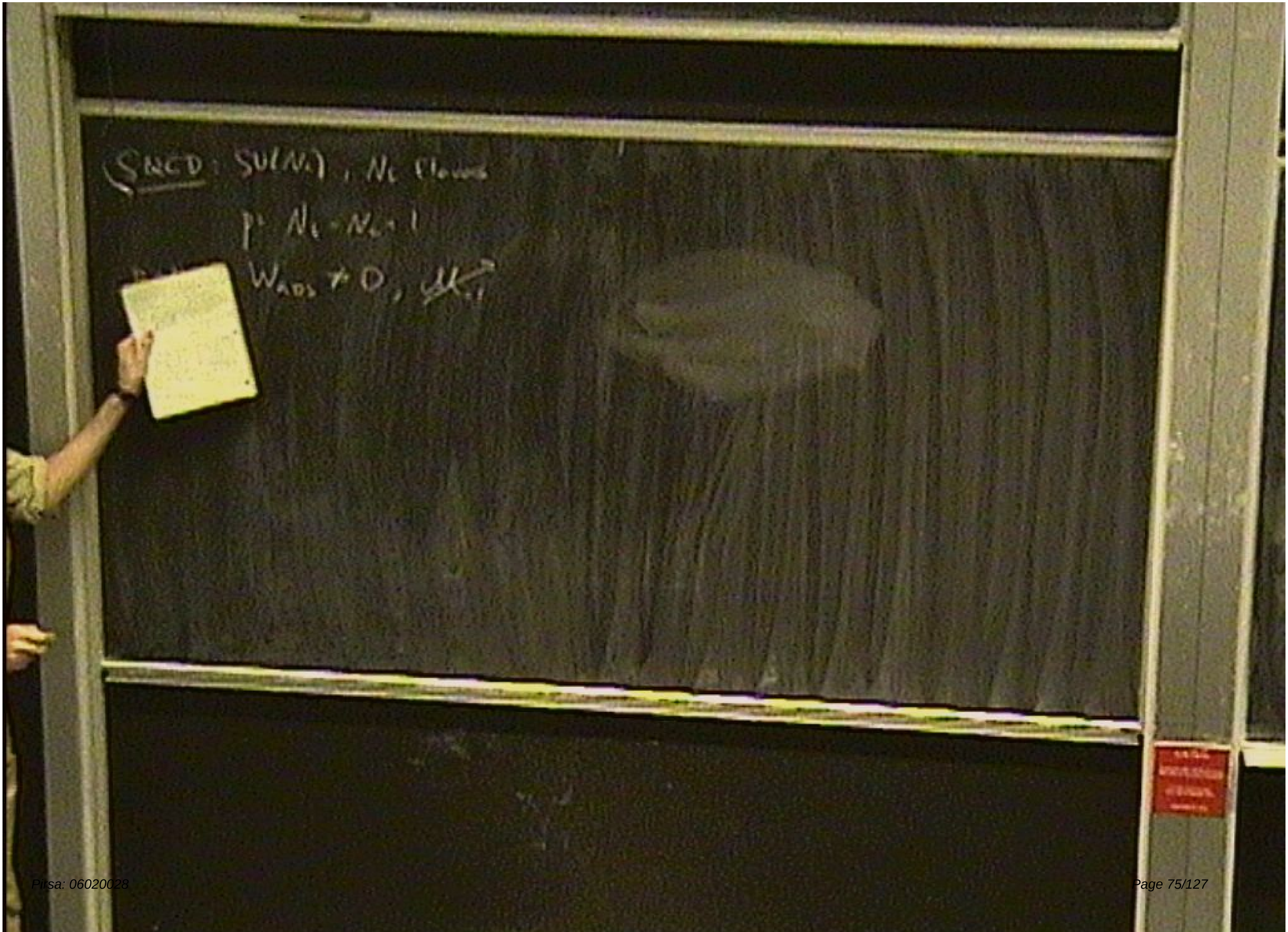
SQCD : $SU(N)$, N_f flavors

$p = N_f - N - 1$

$p = 0$


SQCD: SU(Nc), Nf flavors
p = Nf − Nc − 1
p = 0


SQCD: SU(Nc), Nf flavors
p = Nf - Nc + 1
p < 0 W_ADS ≠ 0,


SQCD: SU(Nc), Nf flavors
Nf = Nc - 1
W_ADS ≠ 0,

SQCD: $SU(N_c)$, N_f flavors

$p = N_f - N_c + 1$

$p = 0$ $\quad W_{ADS} \neq 0$, $\mathcal{M}$

$p = 1$

SQCD: $SU(N_c)$, N_f flavors

$p = N_f - N_c - 1$

$p = 0$ $\quad W_{ADS} \neq 0$, $\cancel{\mathcal{M}_{cl}}$

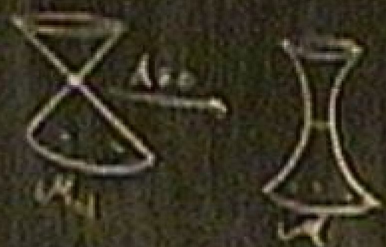
$p = 1$ $\quad$ Cplx str deformation of $\mathcal{M}_{cl}$

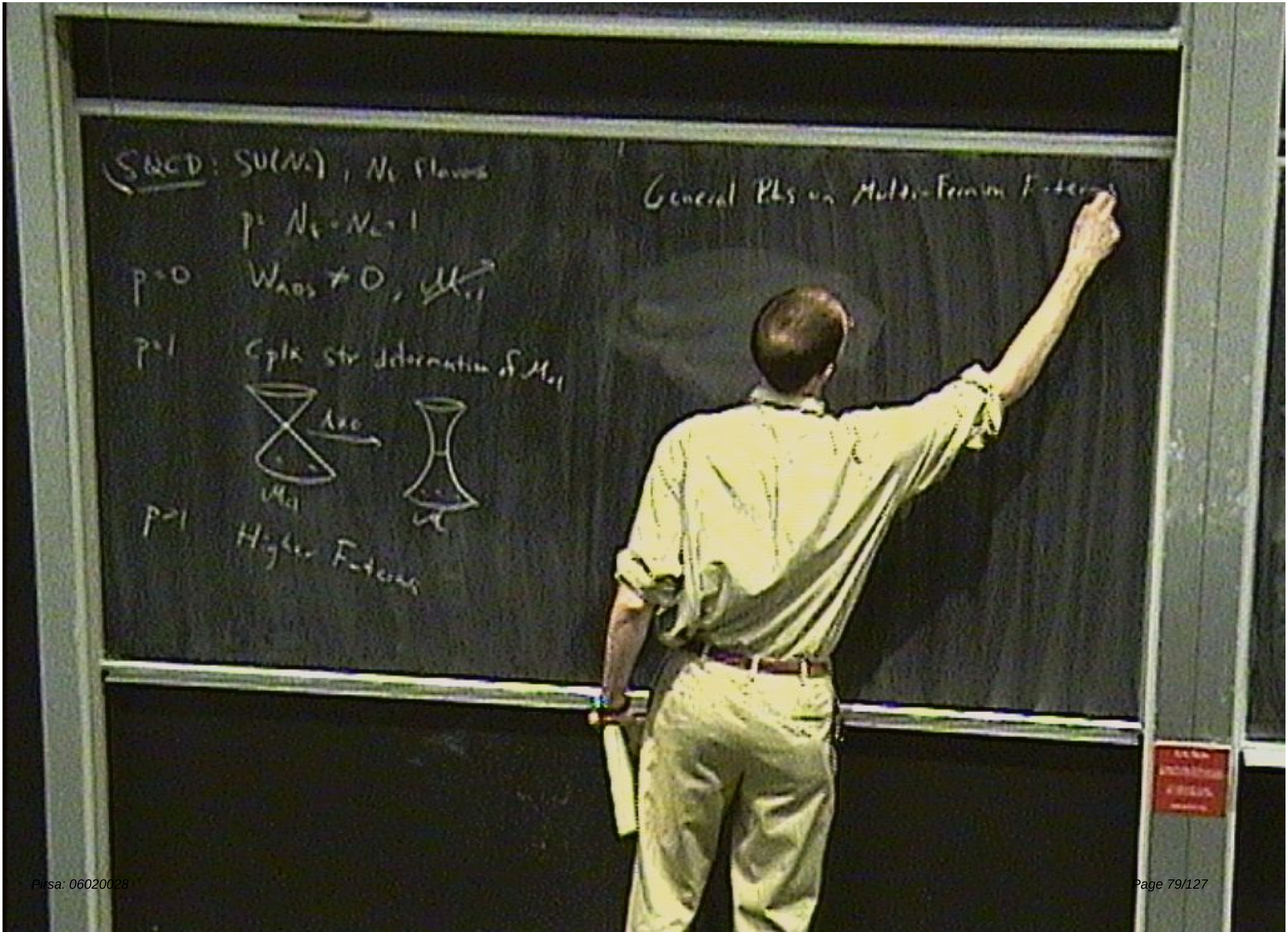
SQCD: $SU(N_c)$, N_f flavors

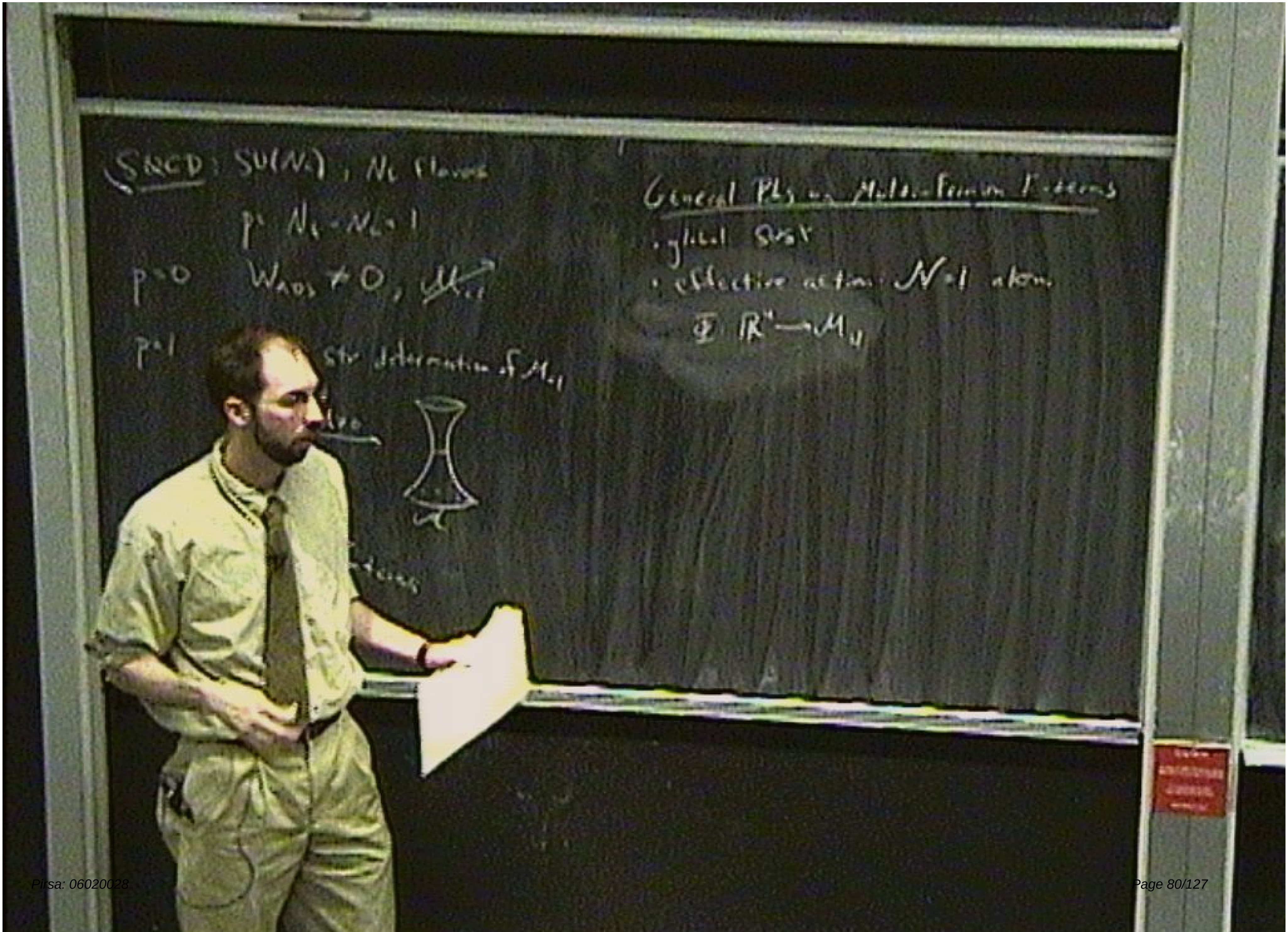
$p = N_f - N_c + 1$

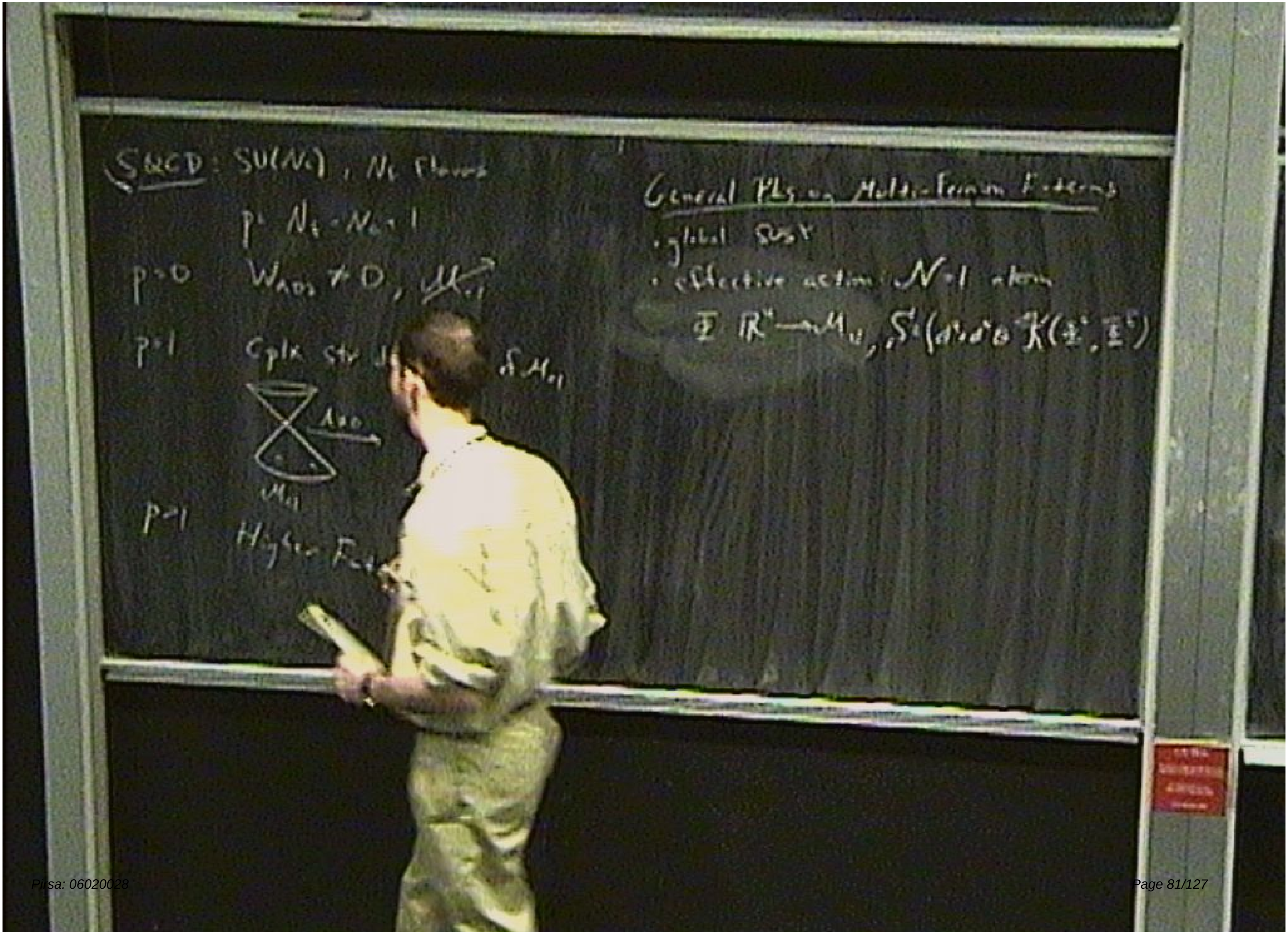
$p=0$ $W_{ADS} \neq 0$, $\mathcal{M}_{cl}$

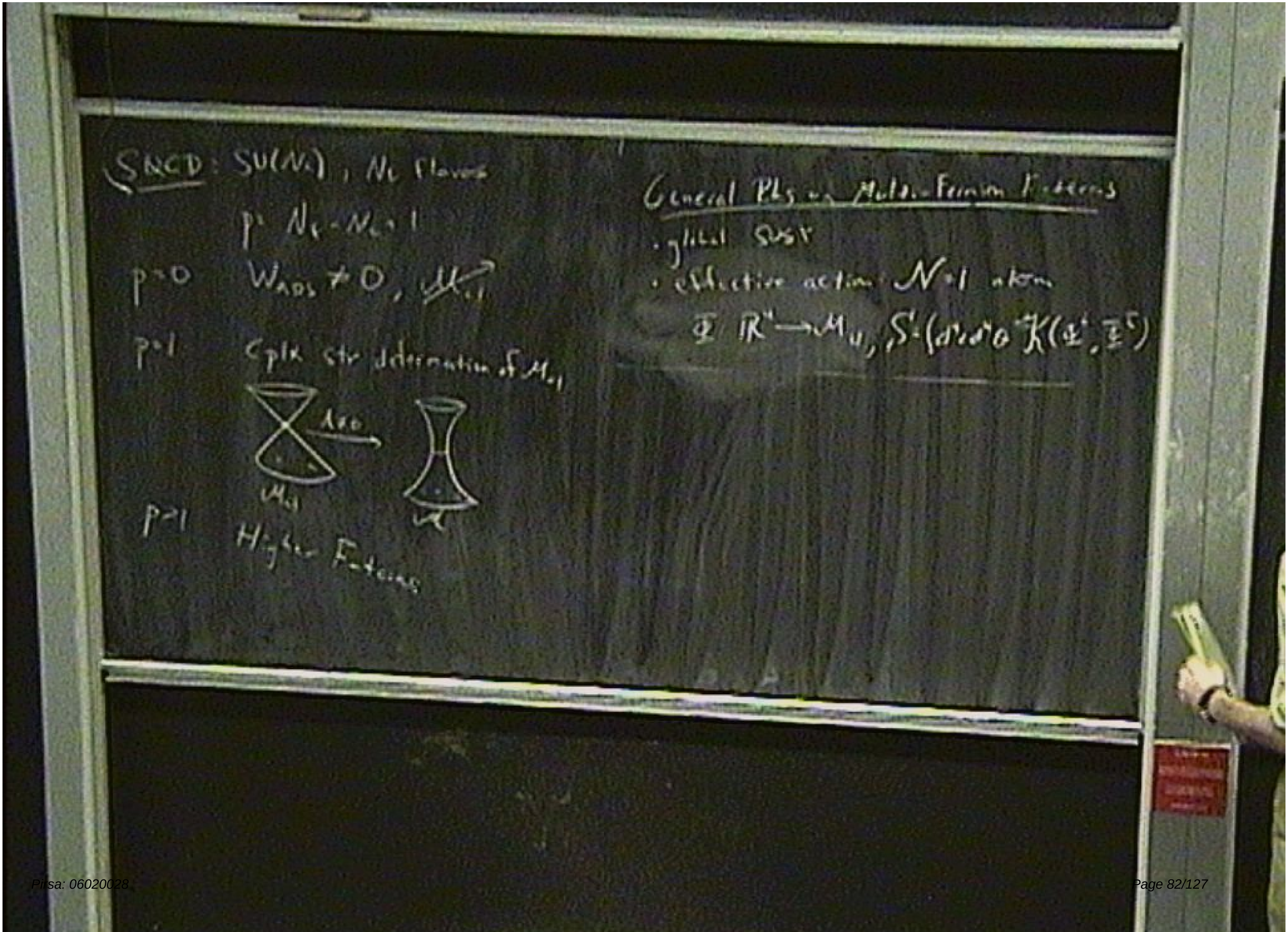
$p=1$ Cplx str deformation of $\mathcal{M}_{cl}$

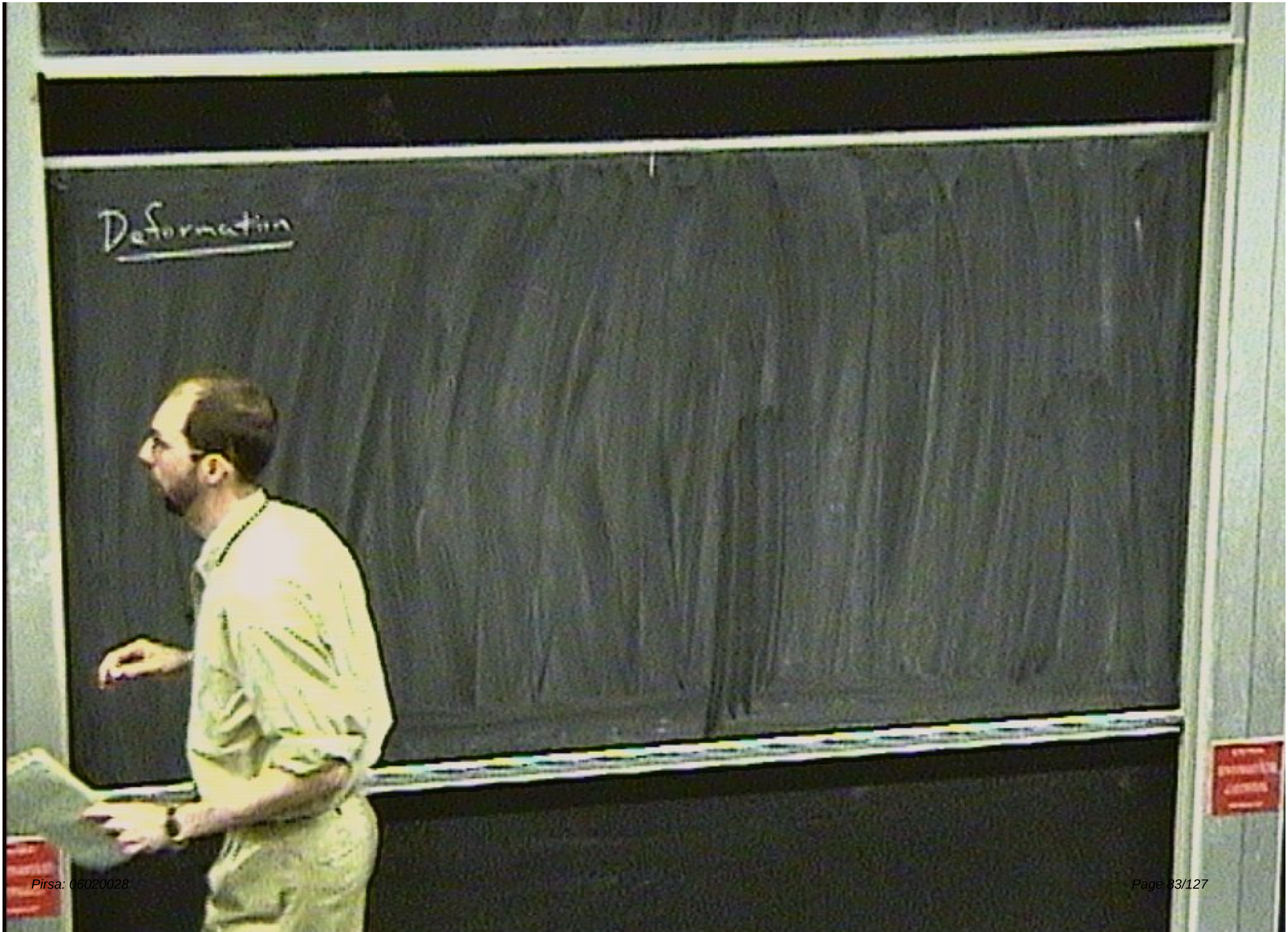


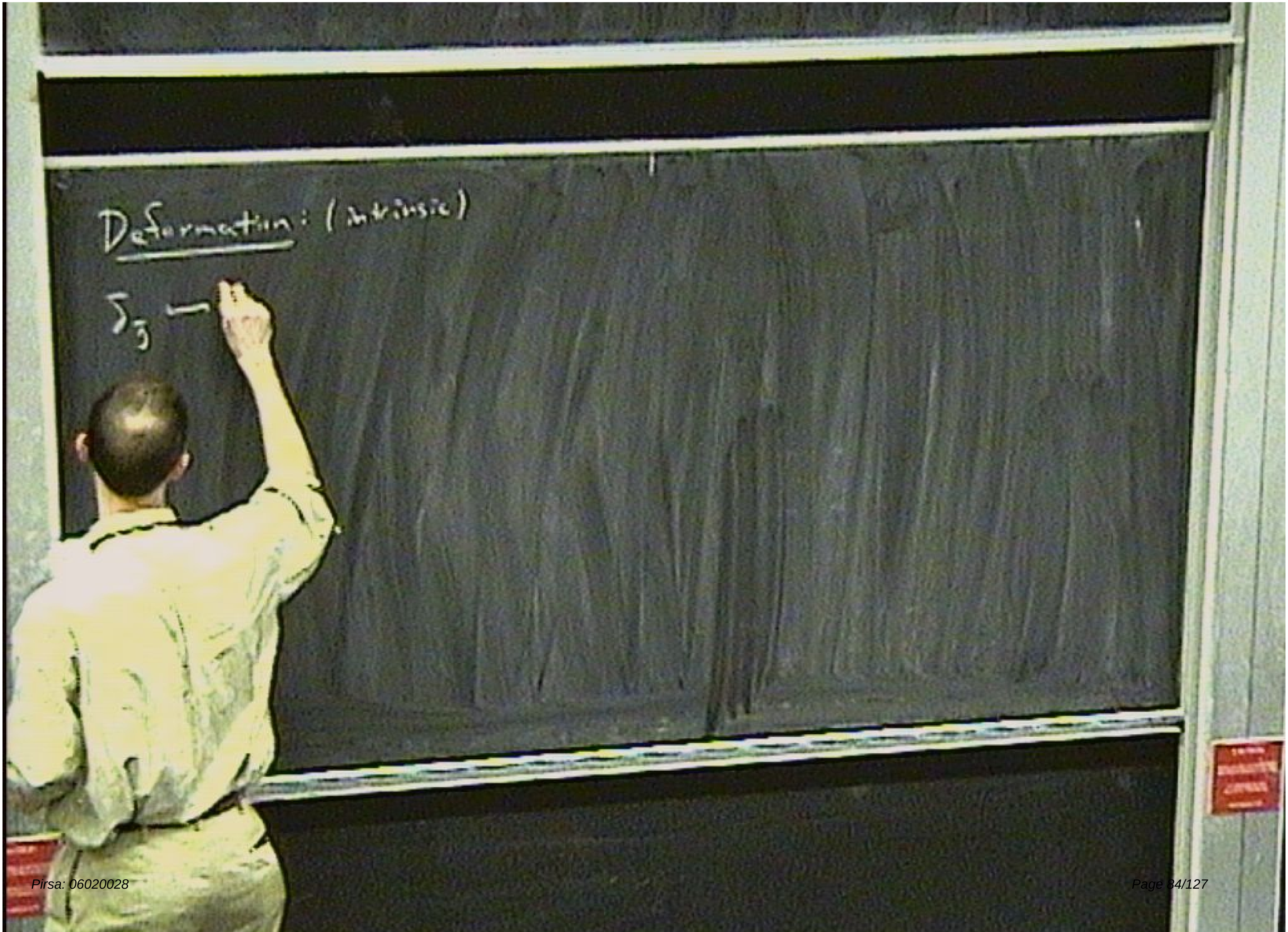

SQCD: SU(Nc), Nf flavors
General Pbs on Multi-Fermion F-terms
p=0 W_ADS ≠ 0,
p=1 Cplx str deformation of
Higher F-terms


SQCD: SU(Nc), Nf flavors
p=0
p=1
global SUSY
effective action


SQCD: SU(Nc), Nf flavors
p = Nf − Nc + 1
Cplx str
Higher
global SUSY
effective action: N=1 atom


SQCD: SU(Nc), Nf flavors
p = Nf - Nc + 1
p=0 WADS ≠ 0
p=1 Cplx str deformation of Mcl
Λ≠0
Mcl
p>1 Higher
global SUSY
effective action


Deformation


Deformation: (intrinsic)
$\Sigma_3 \longrightarrow$

Deformation: (intrinsic)

$$\bar\partial_{\bar j} \longrightarrow \bar\partial_{\bar j} + \omega_{\bar j}^{i}\, \partial_i\,, \quad [\omega] \in H^1_{\bar\partial}(M, T_M)$$

Deformation: (intrinsic)

$$\partial_{\bar j} \longrightarrow \partial_{\bar j} + \omega^{i}_{\bar j}\,\partial_i\,,\quad [\omega]\in H^{1}_{\bar\partial}(\mathcal{M}, T\mathcal{M})$$

$$\Rightarrow d\phi^{i} \longrightarrow d\phi^{i} - \omega^{i}_{\bar j}\, d\phi^{\bar j}$$

$$\Rightarrow g_{i\bar k}\, d\phi^{i}\, d\phi^{\bar k} \longrightarrow g_{i\bar k}\left(d\phi^{i} - \omega^{i}_{\bar j}\, d\phi^{\bar j}\right) d\phi^{\bar k}$$

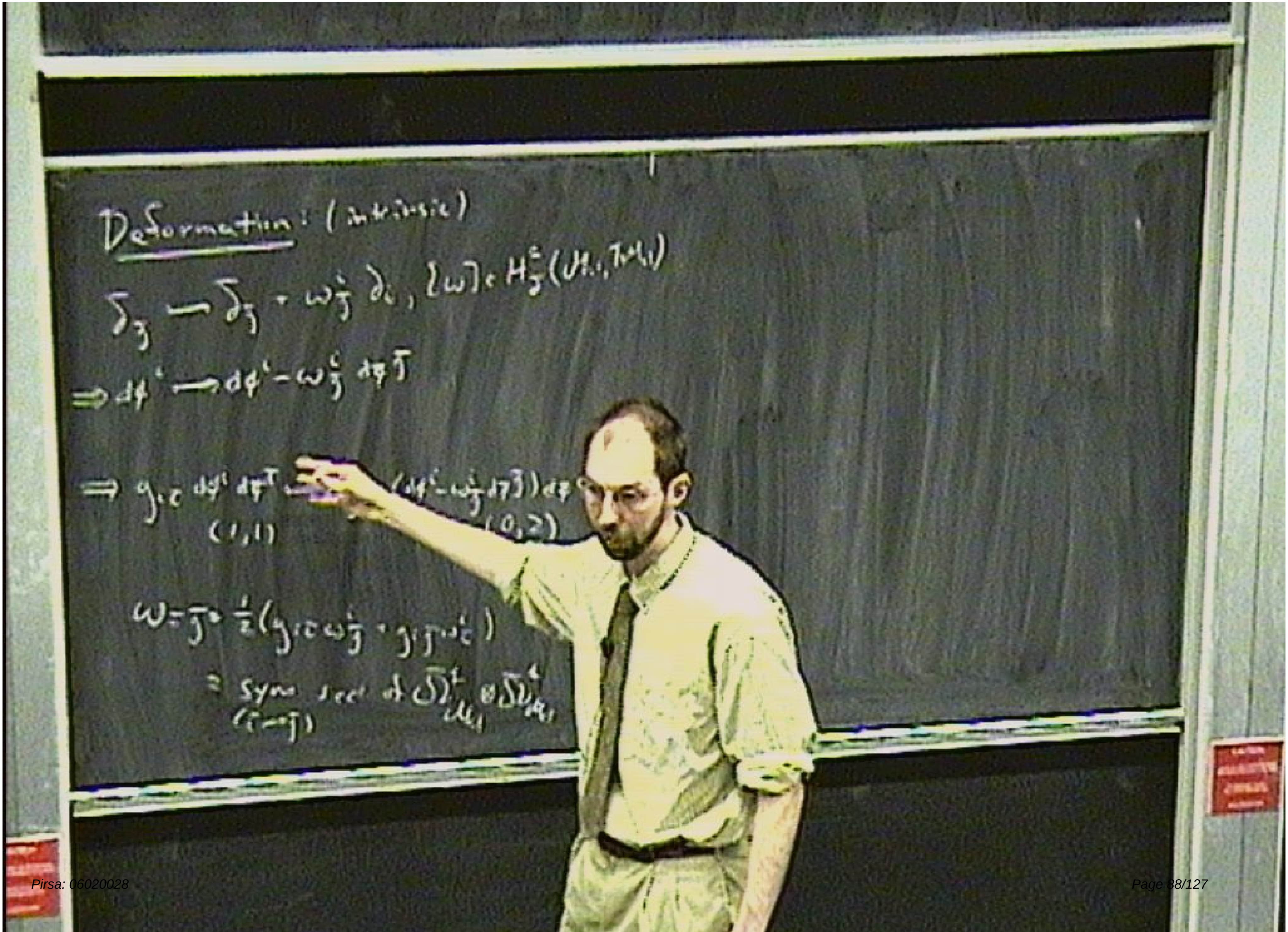
Deformation: (intrinsic)

$$\bar{\partial}_{\bar{j}} \longrightarrow \bar{\partial}_{\bar{j}} + \omega^{i}_{\bar{j}}\, \partial_i \,, \quad [\omega] \in H^{1}_{\bar{\partial}}(\mathcal{M}, T\mathcal{M})$$

$$\Rightarrow d\phi^{i} \longrightarrow d\phi^{i} - \omega^{i}_{\bar{j}}\, d\bar{\phi}^{\bar{j}}$$

$$\Rightarrow g_{i\bar{\imath}}\, d\phi^{i}\, d\bar{\phi}^{\bar{\imath}} \longrightarrow g_{i\bar{\imath}}\,(d\phi^{i} - \omega^{i}_{\bar{j}}\, d\bar{\phi}^{\bar{j}})\, d\bar{\phi}^{\bar{\imath}}$$

(1,1)


Deformation: (intrinsic)
$\bar\partial_{\bar j} \to \bar\partial_{\bar j} + \omega^i_{\bar j}\partial_i$, $[\omega]\in H^1_{\bar\partial}(M, TM)$
$\Rightarrow d\phi^i \to d\phi^i - \omega^i_{\bar j}\, d\phi^{\bar j}$
$\Rightarrow g_{i\bar\imath}\, d\phi^i d\phi^{\bar\imath} \to (d\phi^i - \omega^i_{\bar j} d\phi^{\bar j})\, d\phi^{\bar\imath}$
(1,1)
(0,2)
= sym sect of $\bar\Omega^1_M \otimes \bar\Omega^1_M$
$(\bar\imath \leftrightarrow \bar j)$

Deformation: (intrinsic)

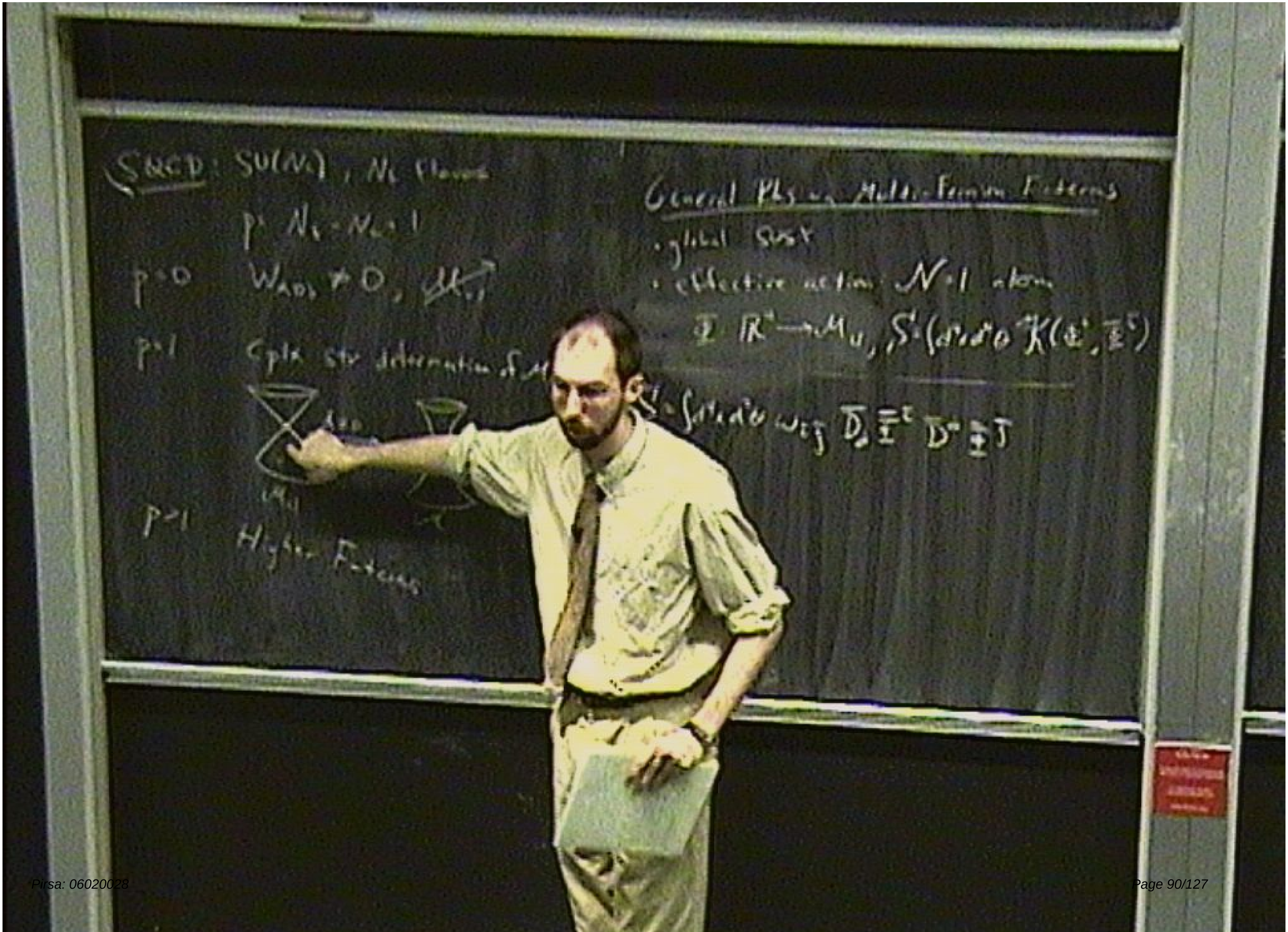
$$\bar\partial_{\bar j} \to \bar\partial_{\bar j} + \omega^i_{\bar j}\, \partial_i\,, \quad [\omega] \in H^1_{\bar\partial}(\mathcal{M}, T\mathcal{M})$$

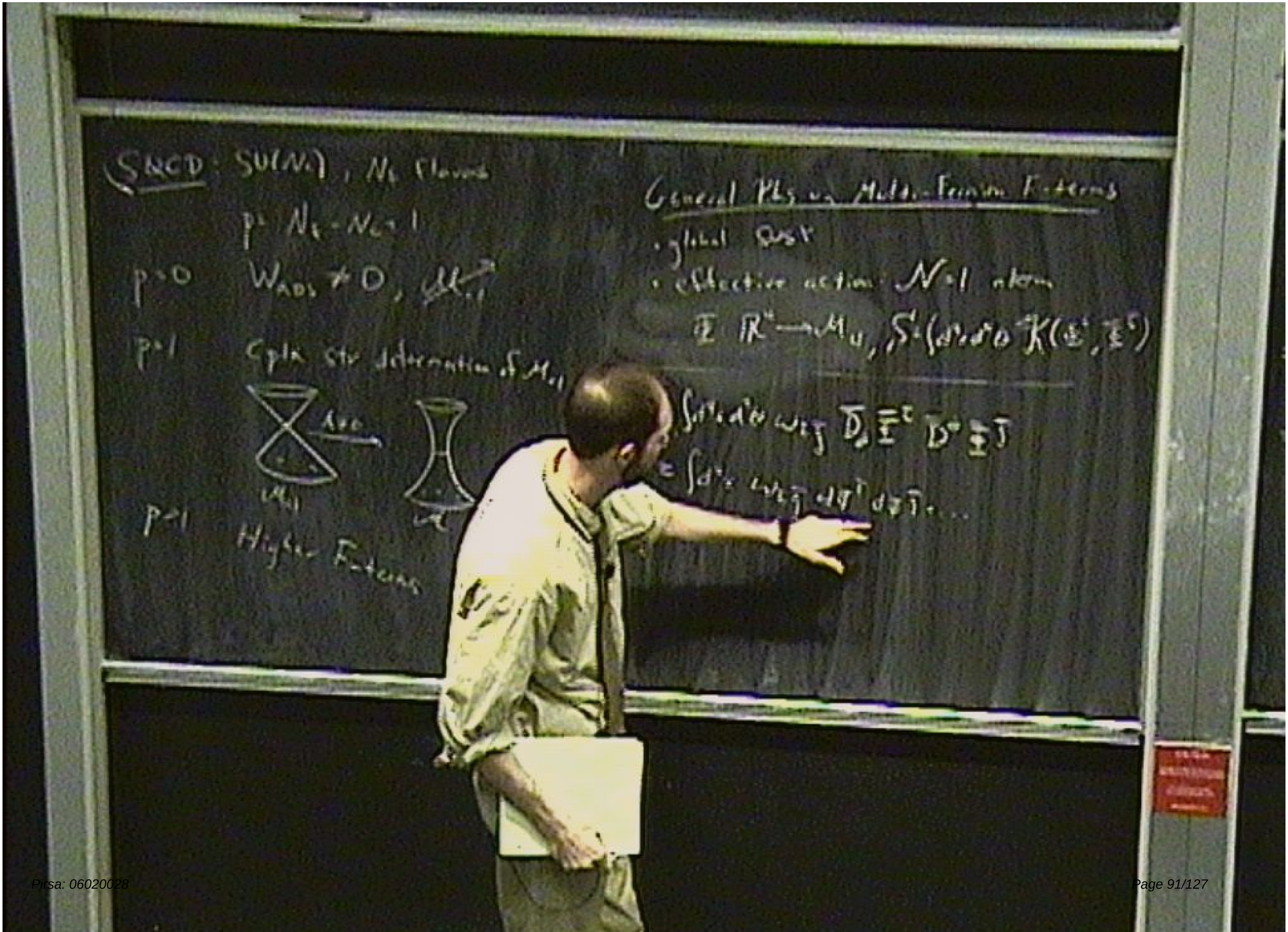
$$\Rightarrow d\phi^i \to d\phi^i - \omega^i_{\bar j}\, d\bar\phi^{\bar j}$$

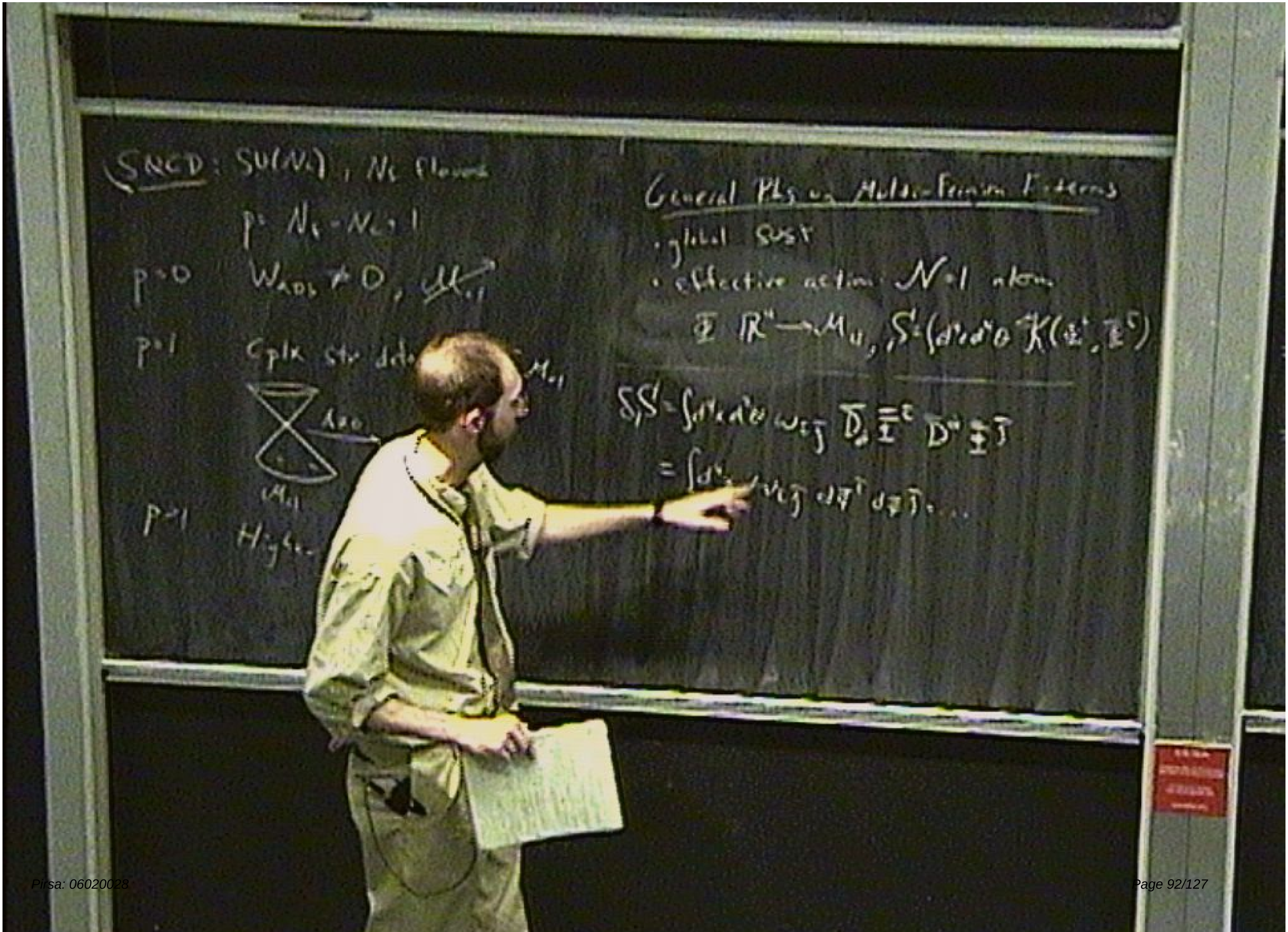
$$\Rightarrow \underset{(1,1)}{g_{i\bar k}\, d\phi^i\, d\bar\phi^{\bar k}} \to \underset{(0,2)}{g_{i\bar k}\,(d\phi^i - \omega^i_{\bar j}\, d\bar\phi^{\bar j})\, d\bar\phi^{\bar k}}$$

$$\omega_{\bar k \bar j} = \tfrac{1}{2}\left(g_{i\bar k}\,\omega^i_{\bar j} + g_{i\bar j}\,\omega^i_{\bar k}\right)$$

$$= \underset{(\bar k \leftrightarrow \bar j)}{\text{sym}}\ \text{sec of}\ \bar\Omega^1_{\mathcal{M}} \otimes \bar\Omega^1_{\mathcal{M}}$$


SQCD: SU(Nc), Nf flavors
global SUSY
effective action


SQCD: SU(Nc), Nf flavors
p = Nf - Nc - 1
p=0
p=1 Split str deformation of
ADS
p>1 Higher F-terms
General Pbs w/ Multi-Fermion F-terms
global SUSY
effective action N=1 atom



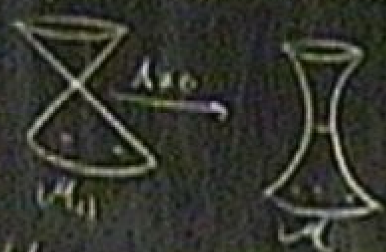
global SUSY
effective action
Cplx str
Higher

SQCD: $SU(N_c)$, N_f flavors

$p = N_f - N_c + 1$

$p=0$ $\quad W_{ADS} \neq 0$, $\mathcal{M}_{cl}$

$p=1$ $\quad$ Cplx str deformation of $\mathcal{M}_{cl}$



$p>1$ $\quad$ Higher F-terms

General Phys w/ Multi-Fermion F-terms

- global SUSY
- effective action $\mathcal{N}=1$ σ-model

$\Phi: \mathbb{R}^4 \to \mathcal{M}_{cl}$, $S = \int d^4x\, d^4\theta\, K(\Phi^i, \bar{\Phi}^{\bar{j}})$

$$\delta S = \int d^4x\, d^4\theta\, \omega_{i\bar{j}}\, \bar{D}_{\dot\alpha} \bar{\Phi}^{\bar{i}}\, \bar{D}^{\dot\alpha} \bar{\Phi}^{\bar{j}}$$

$$= \int d^4x\, \omega_{i\bar{j}}\, \partial\bar{\phi}^{\bar{i}}\, \partial\bar{\phi}^{\bar{j}} + \ldots$$

Deformation: (intrinsic)

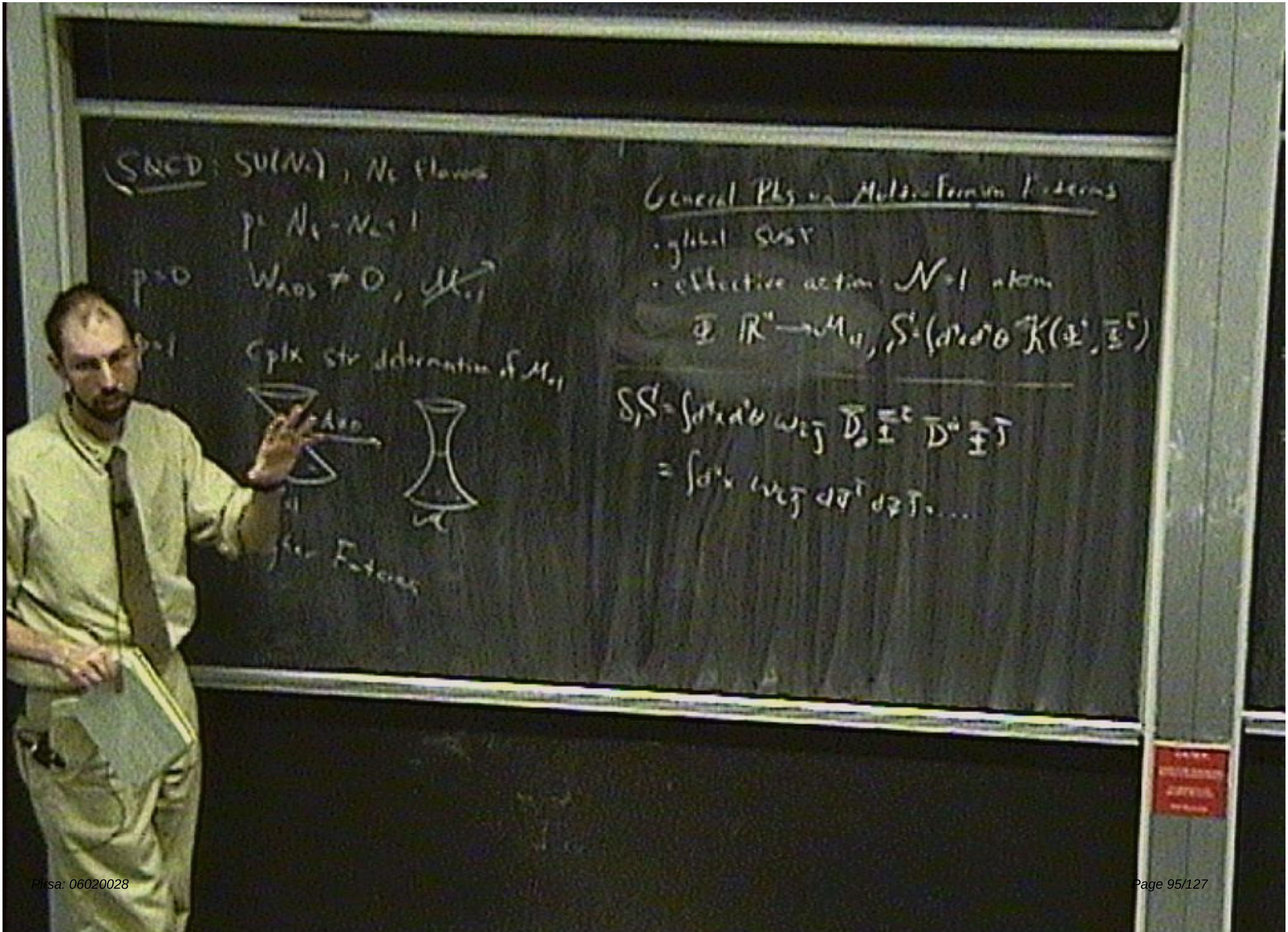
$$\partial_{\bar{j}} \longrightarrow \partial_{\bar{j}} + \omega^{i}_{\bar{j}}\,\partial_i\,, \quad [\omega] \in H^{1}_{\bar{\partial}}(\mathcal{M}_1, T\mathcal{M}_1)$$

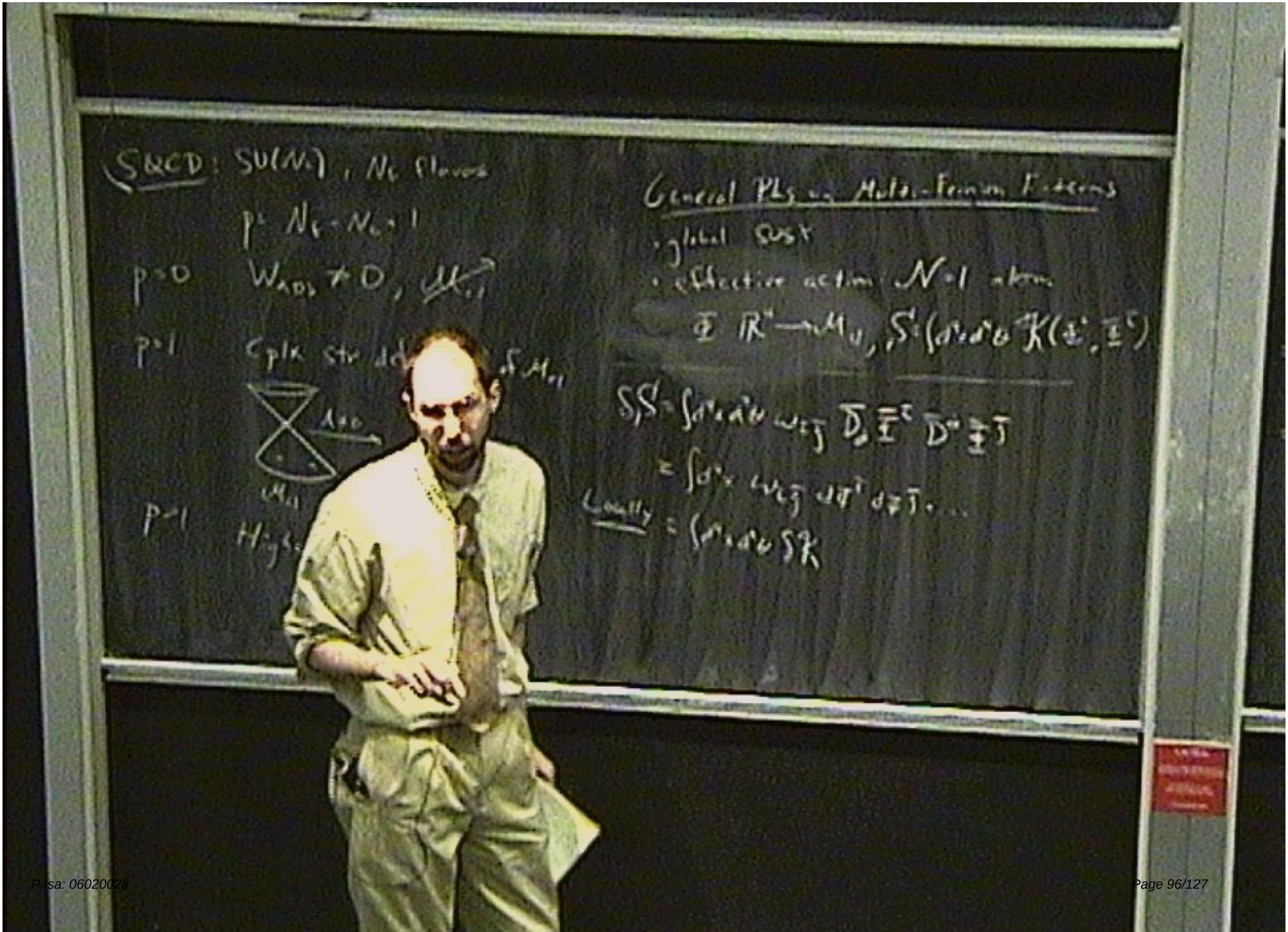
$$\Rightarrow d\phi^{i} \longrightarrow d\phi^{i} - \omega^{i}_{\bar{j}}\,d\bar{\phi}^{\bar{j}}$$

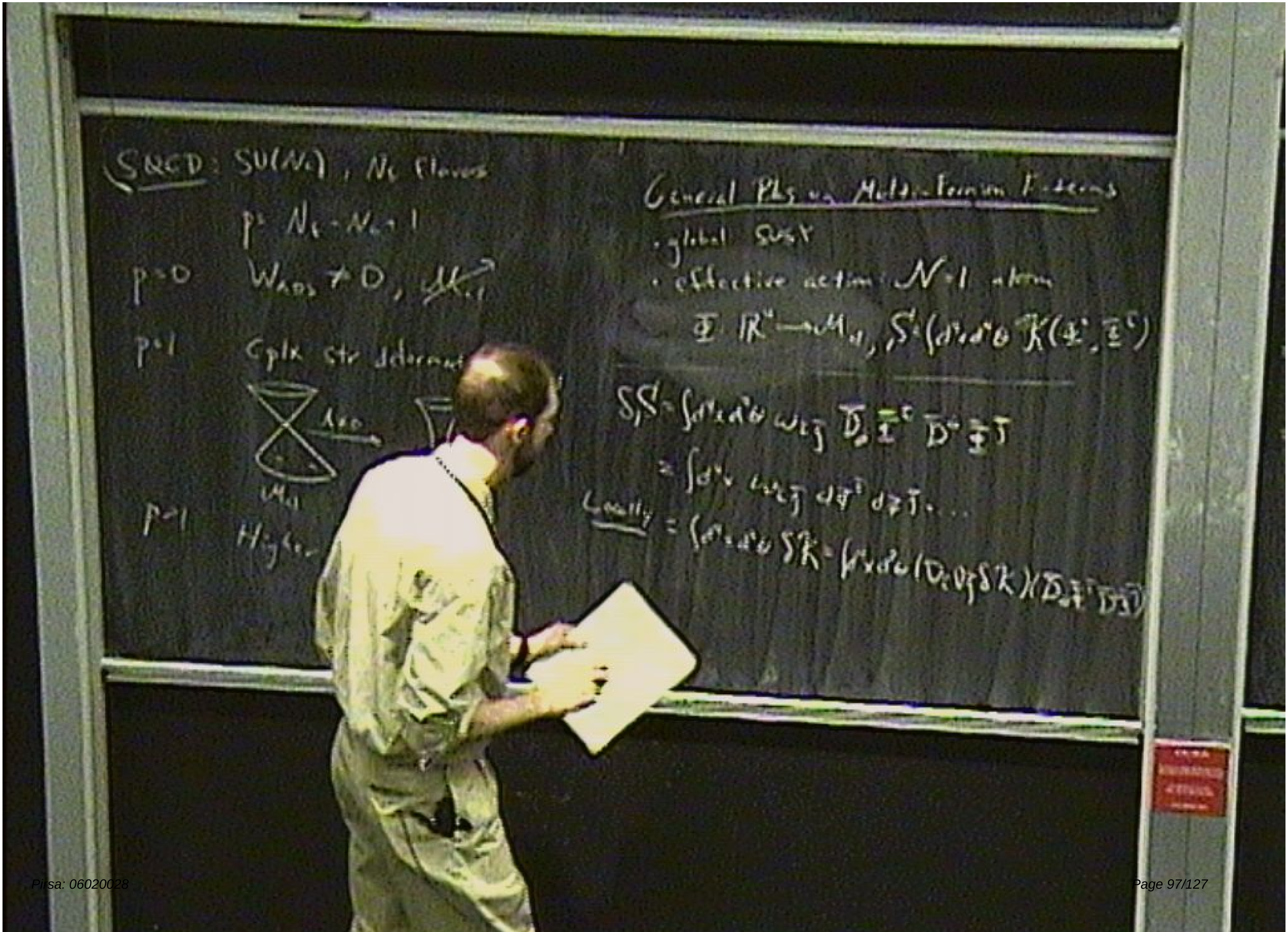
$$\Rightarrow \underset{(1,1)}{g_{i\bar{\imath}}\,d\phi^{i}\,d\bar{\phi}^{\bar{\imath}}} \longrightarrow \underset{(0,2)}{g_{i\bar{\imath}}\,(d\phi^{i} - \omega^{i}_{\bar{j}}\,d\bar{\phi}^{\bar{j}})\,d\bar{\phi}^{\bar{\imath}}}$$

$$\omega_{\bar{\imath}\bar{j}} = \tfrac{1}{2}\left(g_{i\bar{\imath}}\,\omega^{i}_{\bar{j}} + g_{i\bar{j}}\,\omega^{i}_{\bar{\imath}}\right)$$

$$= \underset{(\bar{\imath}\leftrightarrow\bar{j})}{\text{sym}}\ \text{sect of } \bar{\Omega}^{1}_{\mathcal{M}_1} \otimes \bar{\Omega}^{1}_{\mathcal{M}_1}$$


SQCD: SU(Nc), Nf flavors
global SUSY
effective action
Cplx str deformation


SQCD: SU(Nc), Nf flavors
p = Nf - Nc + 1
p=0
p=1
global SUSY
effective action
Locally


SQCD: SU(Nc), Nf flavors
p = Nf − Nc + 1
Cplx str deformation
global SUSY
effective action
Locality

SQCD: $SU(N_c)$, N_f flavors

$p = N_f - N_c + 1$

$p=0$ $\quad W_{ADS} \neq 0$, $\mathcal{M}_{cl}$

$p=1$ $\quad$ Cplx str deformation of $\mathcal{M}_{cl}$

$p>1$ $\quad$ Higher F-terms

General Phys of Multi-fermion F-terms

- global SUSY
- effective action $\mathcal{N}=1$ atom

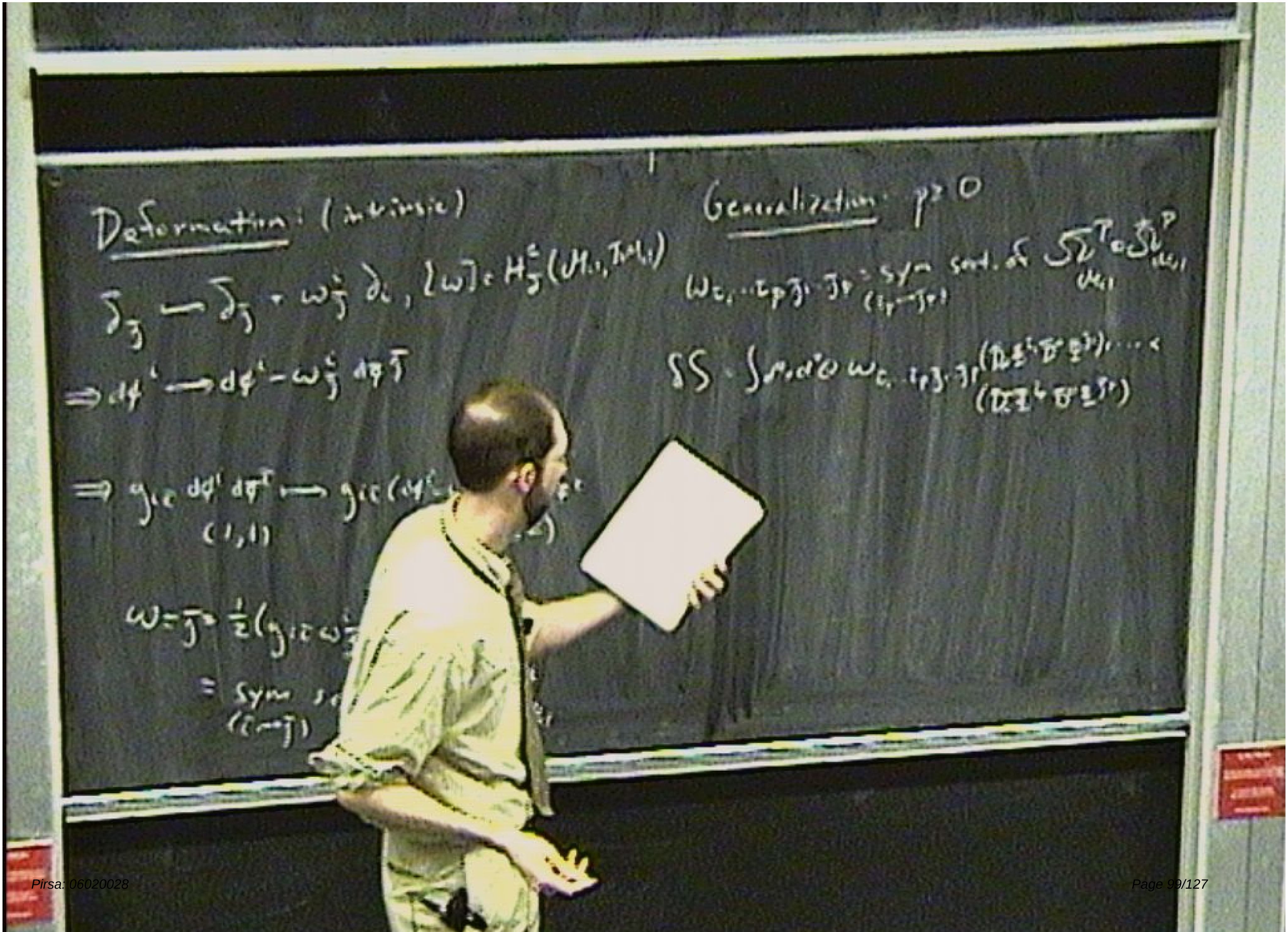
$\Phi: \mathbb{R}^4 \to \mathcal{M}_{cl}$, $S = \int d^4x\, d^4\theta\, K(\Phi^i, \bar{\Phi}^{\bar{j}})$

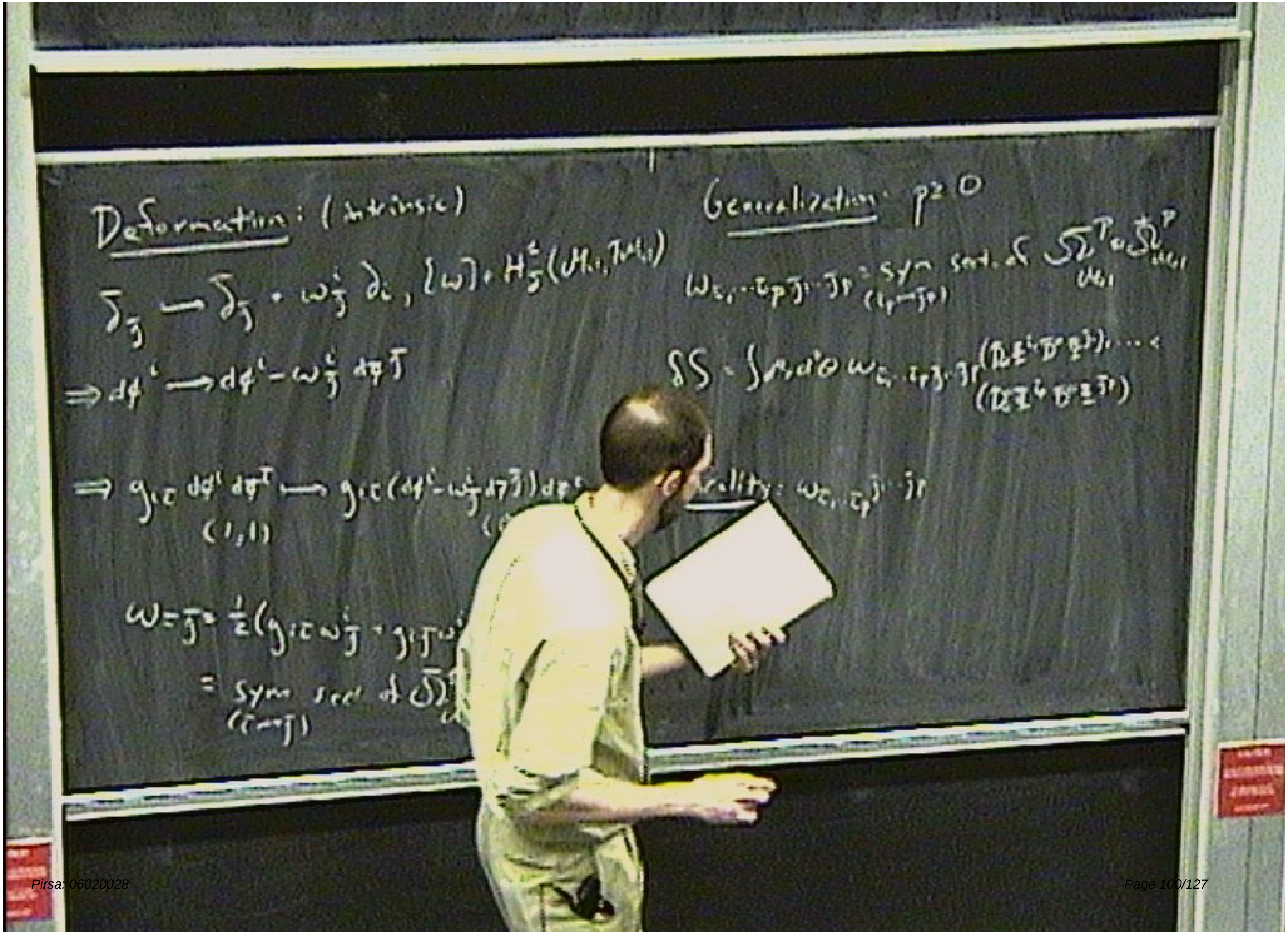
$\delta_1 S = \int d^4x\, d^2\theta\, \omega_{i\bar{j}}\, \bar{D}_{\dot\alpha} \bar{\Phi}^{\bar{j}}\, \bar{D}^{\dot\alpha} \bar{\Phi}^{\bar{j}}$

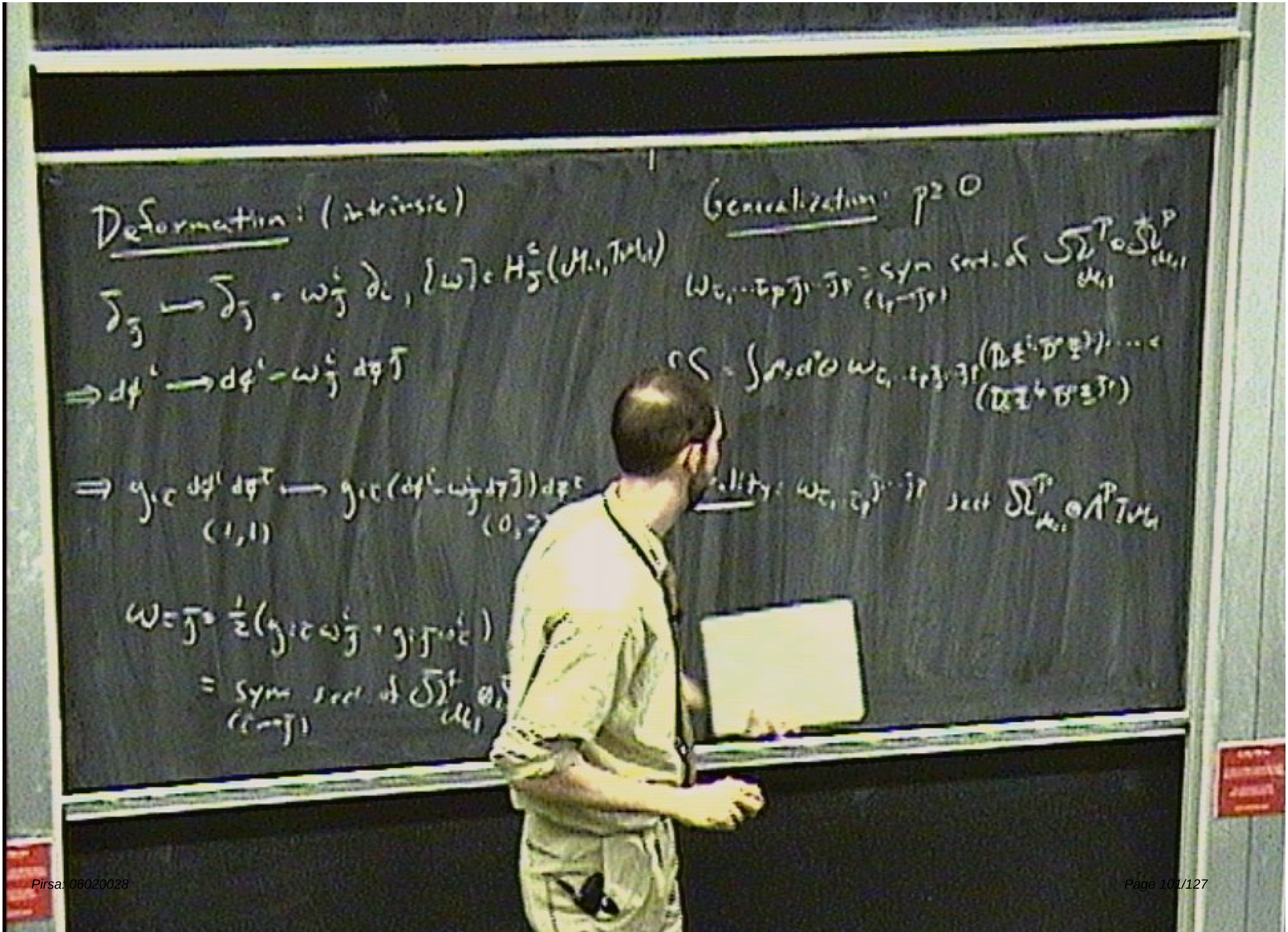
$= \int d^4x\, \omega_{i\bar{j}}\, dz^{\bar{i}}\, dz^{\bar{j}} \ldots$

Locally $= \int d^4x\, d^4\theta\, \delta K = \int d^4x\, d^4\theta\, (\partial_i \partial_{\bar{j}} \delta K)(\bar{D}\bar{\Phi}^{\bar{i}}\, \bar{D}\bar{\Phi}^{\bar{j}})$

Globally $\neq$ — " —


Deformation: (intrinsic)
Generalization: p>0


Deformation: (intrinsic)
Generalization
Sym sect. of
Sym sect of


Deformation: (intrinsic)
Generalization: p ≥ 0
∂_j̄ → ∂_j̄ + ω_j̄^i ∂_i , [ω] ∈ H^1_∂̄(M_1, TM_1)
⇒ dφ^i → dφ^i − ω_j̄^i dφ^j̄
⇒ g_{iī} dφ^i dφ^ī → g_{iī}(dφ^i − ω_j̄^i dφ^j̄) dφ^ī
(1,1)
ω = j̄ ∘ ½(g_{iī} ω_j̄^i + g_{j̄i} ω_ī^i)
= Sym sect of Ω^1_{M_1} ⊗
δS = ∫ d^2σ ω
sect Ω^p_{M_1} ⊗ Λ^p TM_1

Deformation: (intrinsic)

$\bar\partial_{\bar j} \to \bar\partial_{\bar j} + \omega^i_{\bar j}\,\partial_i$, $[\omega] \in H^1_{\bar\partial}(M, T^{1,0}M)$

$\Rightarrow d\phi^i \to d\phi^i - \omega^i_{\bar j}\, d\bar\phi^{\bar j}$

$\Rightarrow \underset{(1,1)}{g_{i\bar\imath}\, d\phi^i d\bar\phi^{\bar\imath}} \to \underset{(0,2)}{g_{i\bar\imath}(d\phi^i - \omega^i_{\bar j} d\bar\phi^{\bar j})\, d\bar\phi^{\bar\imath}}$

$\omega_{\bar\imath\bar j} = \frac{1}{2}(g_{i\bar\imath}\,\omega^i_{\bar j} + g_{i\bar j}\,\omega^i_{\bar\imath})$

$= \underset{(\bar\imath\leftrightarrow\bar j)}{\text{sym}}$ sect. of $\bar\Omega^1_{(M)} \otimes \bar\Omega^1_{(M)}$

Generalization: $p \geq 0$

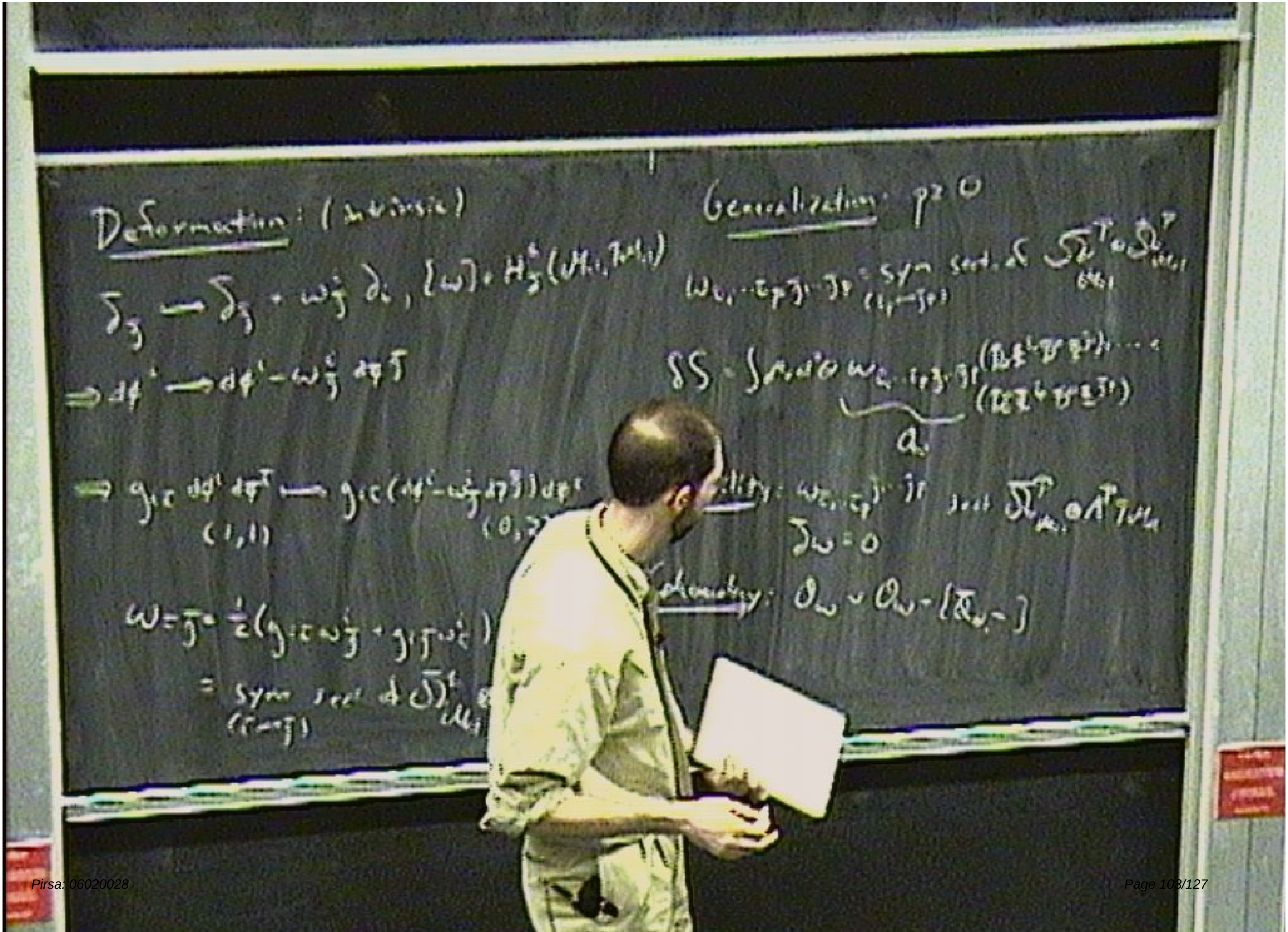
$\omega_{\bar\imath_1\cdots\bar\imath_p \bar j_1\cdots\bar j_p} = \underset{(\bar\imath_p\leftrightarrow\bar j_p)}{\text{sym}}$ sect. of $\bar\Omega^p_{(M)} \otimes \bar\Omega^p_{(M)}$

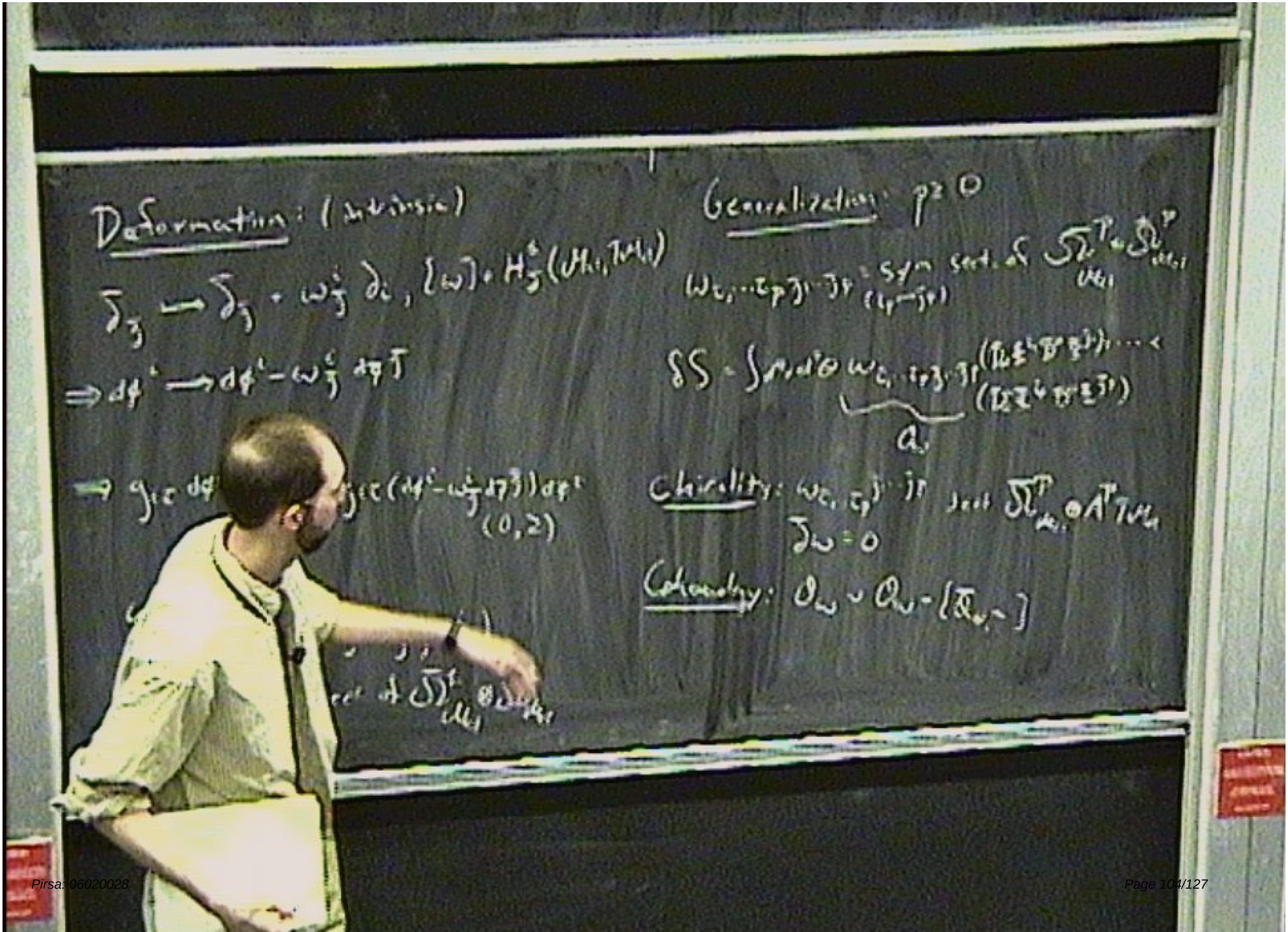
$\delta S = \int d^2\sigma\, d^2\theta\; \omega_{\bar\imath_1\cdots\bar\imath_p\bar j_1\cdots\bar j_p}\,(D_+\bar\Phi^{\bar\imath_1}\cdots D_+\bar\Phi^{\bar\imath_p})\cdots(D_-\bar\Phi^{\bar j_1}\cdots D_-\bar\Phi^{\bar j_p})$

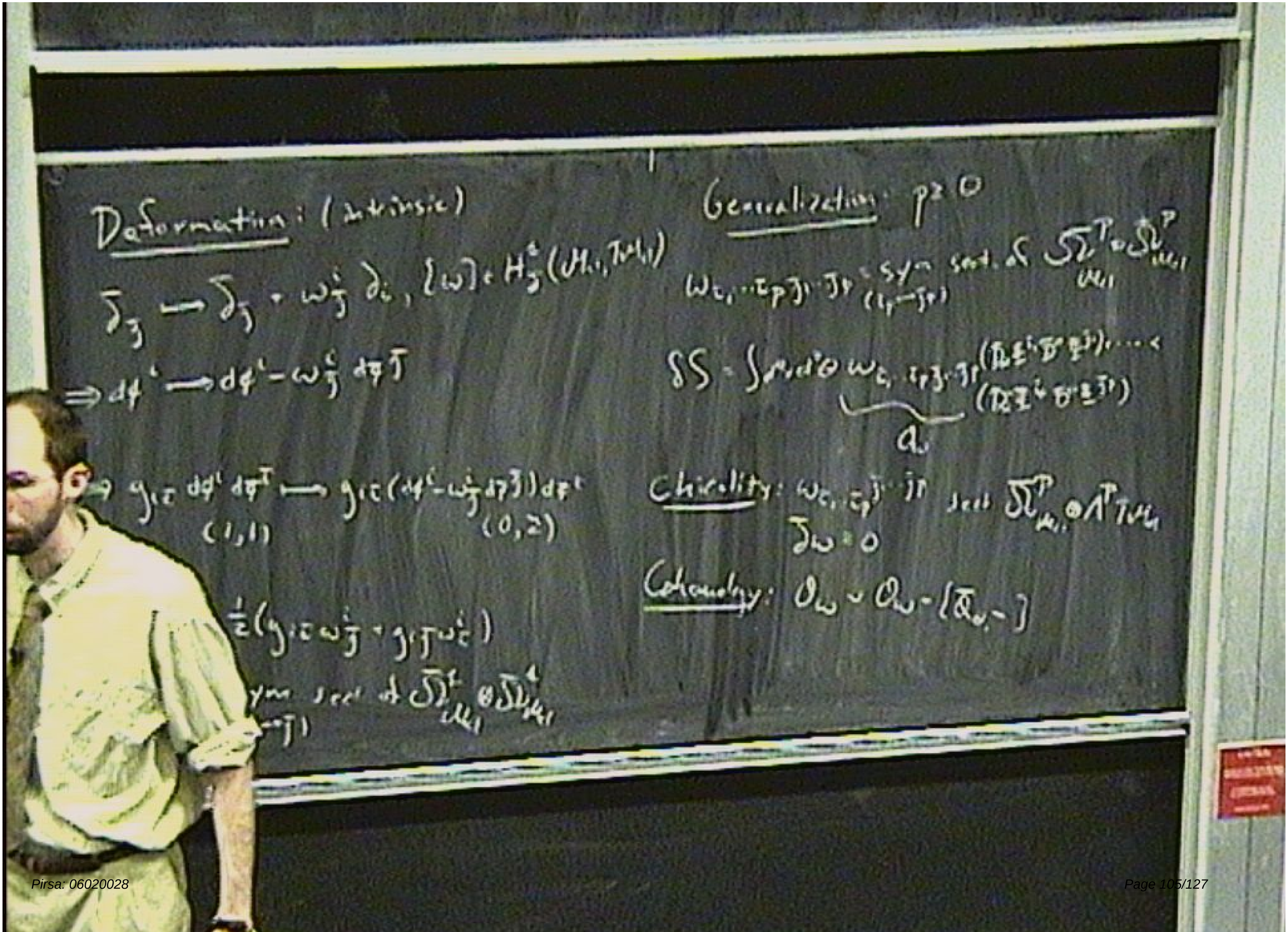
Chirality: $\omega_{\bar\imath_1\cdots\bar\imath_p}{}^{j_1\cdots j_p}$ sect. $\bar\Omega^p_{M} \otimes \Lambda^p T M$

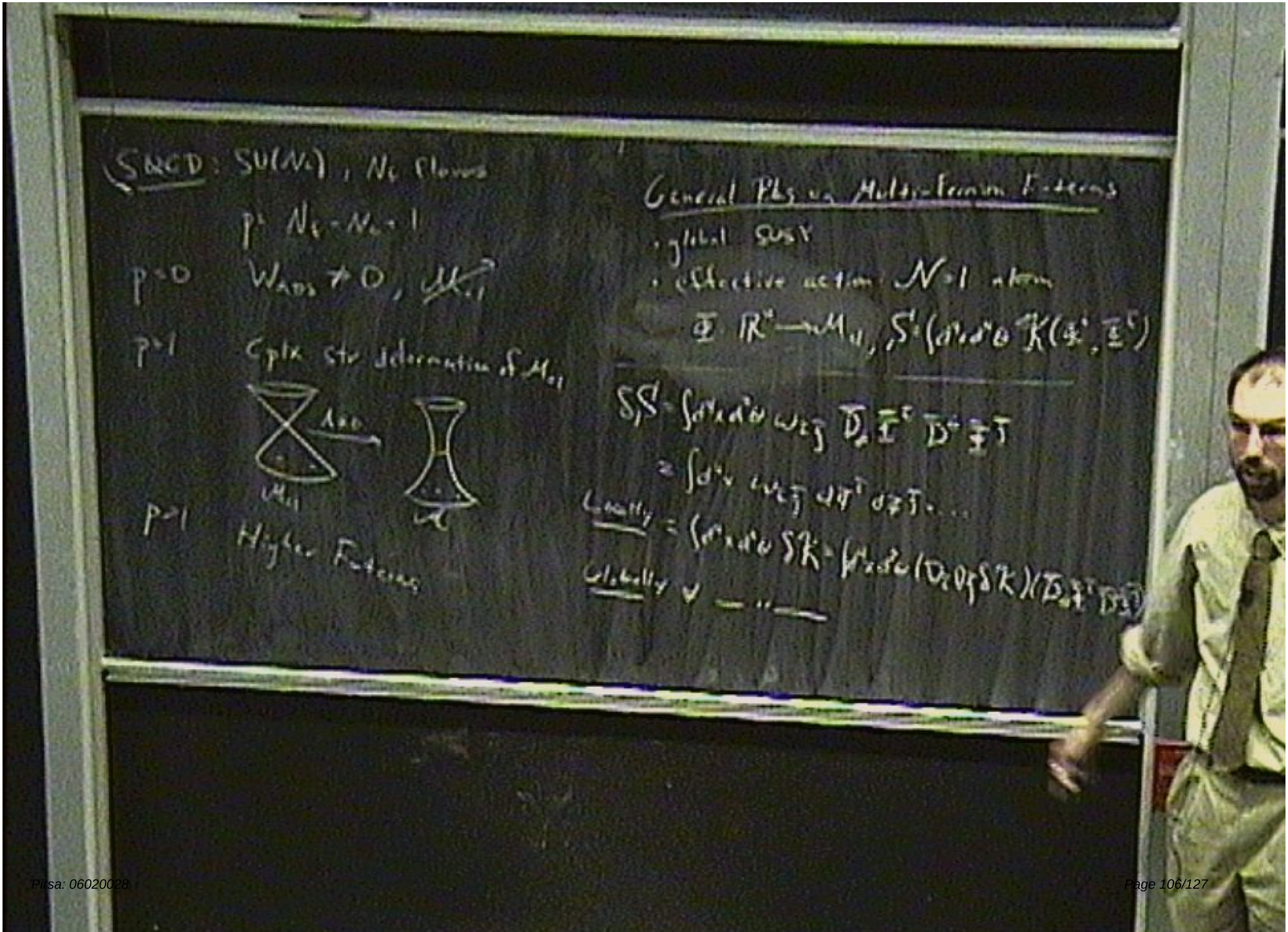
$\bar\partial\omega = 0$

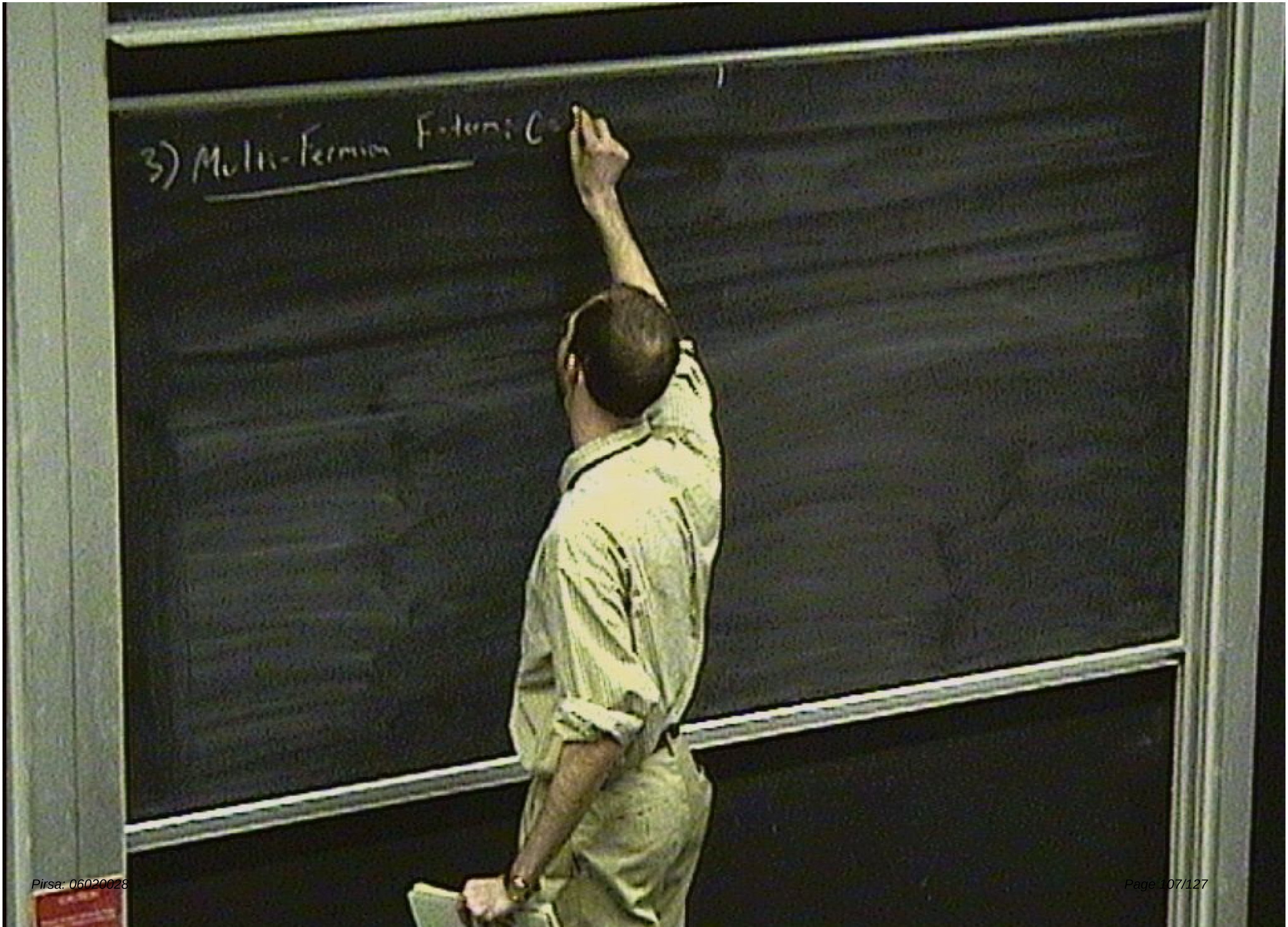
Cohomology:

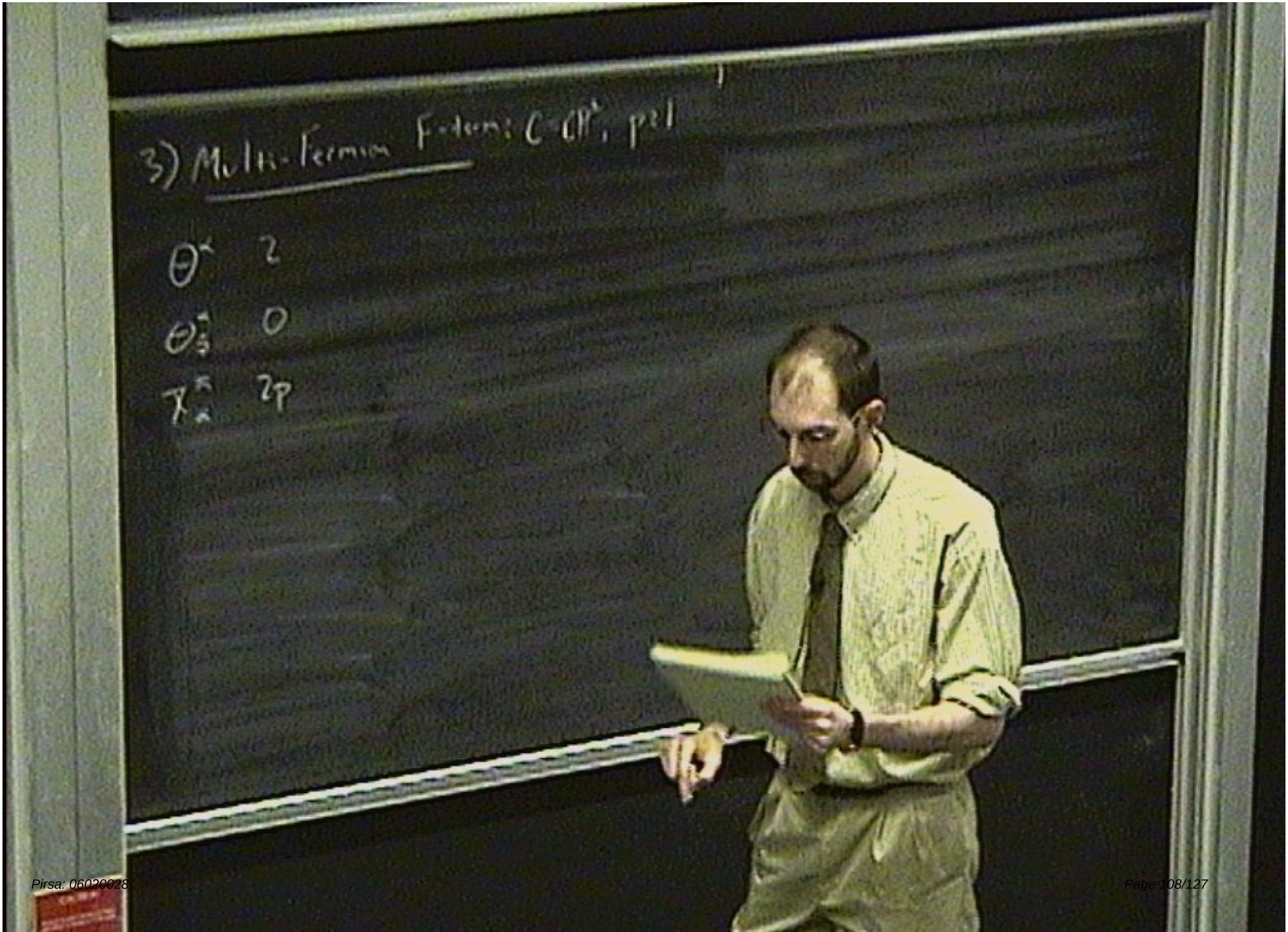

Deformation: (intrinsic)
Generalization: p ≥ 0
Sym
(1,1)
(0,2)
= sym sect of
Cohomology:

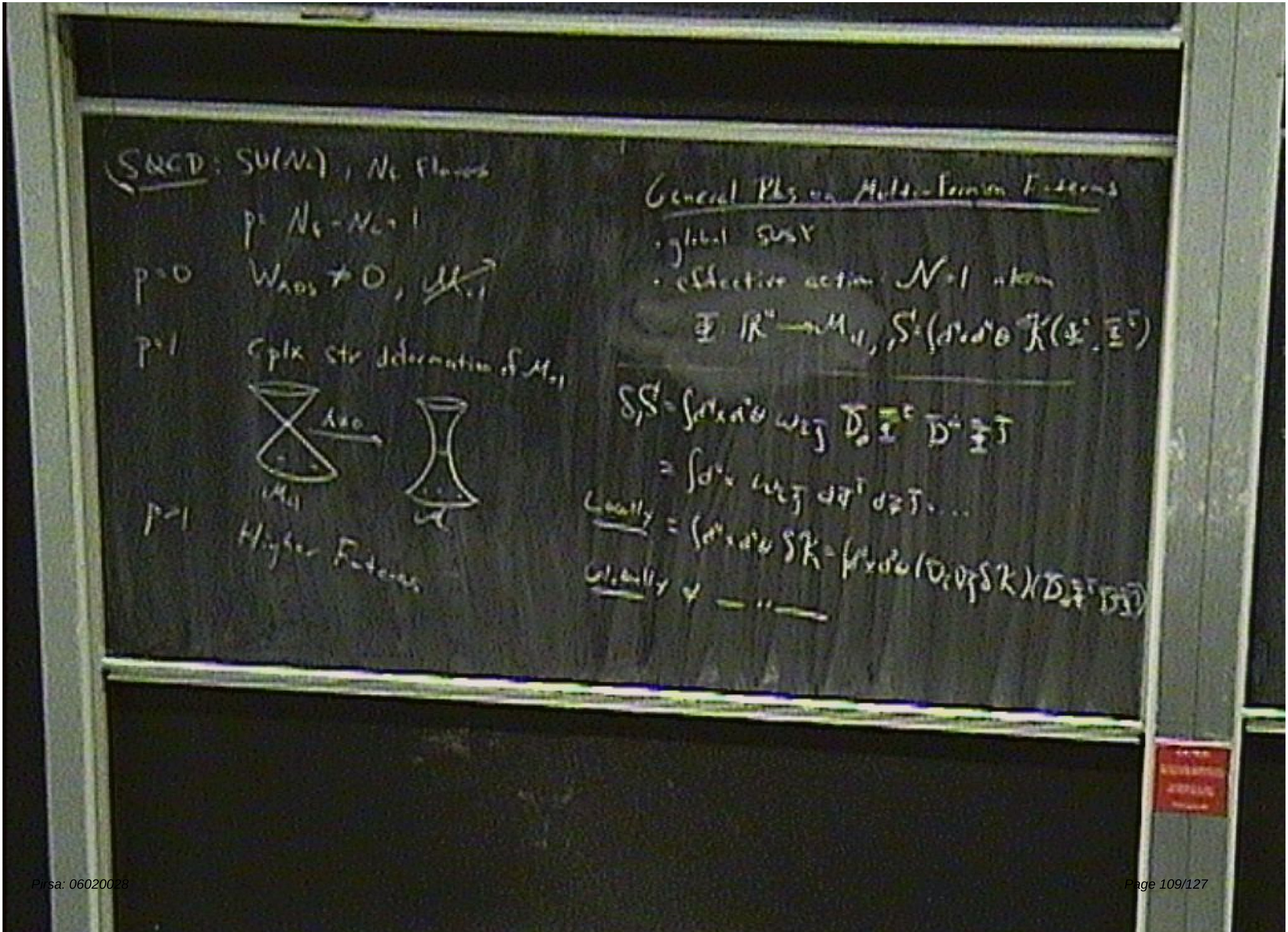

Deformation: (intrinsic)
Generalization:
Chirality:
Cohomology:

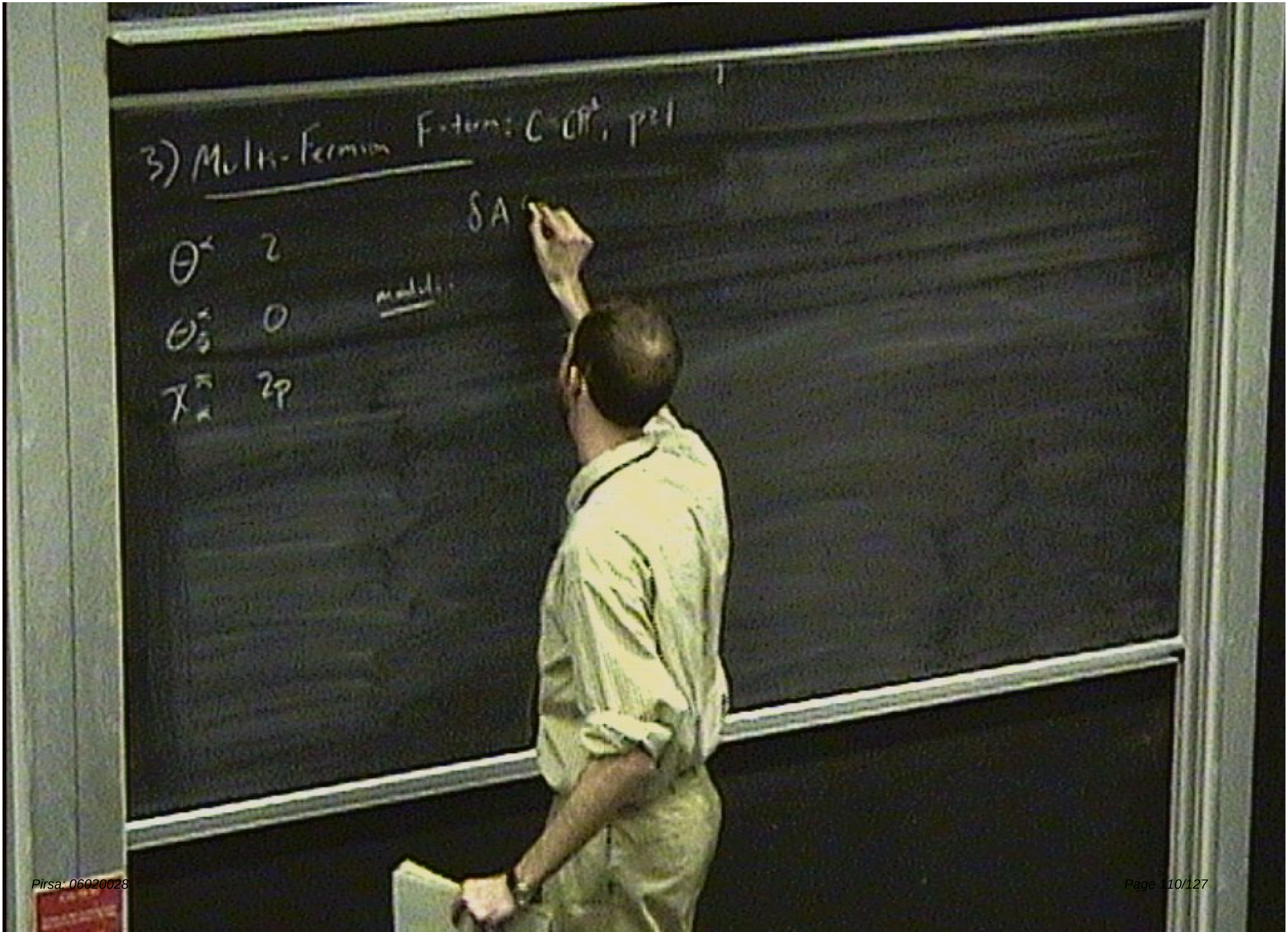

Deformation: (intrinsic)
(1,1)
(0,2)
Generalization:
Chirality:
Cohomology:

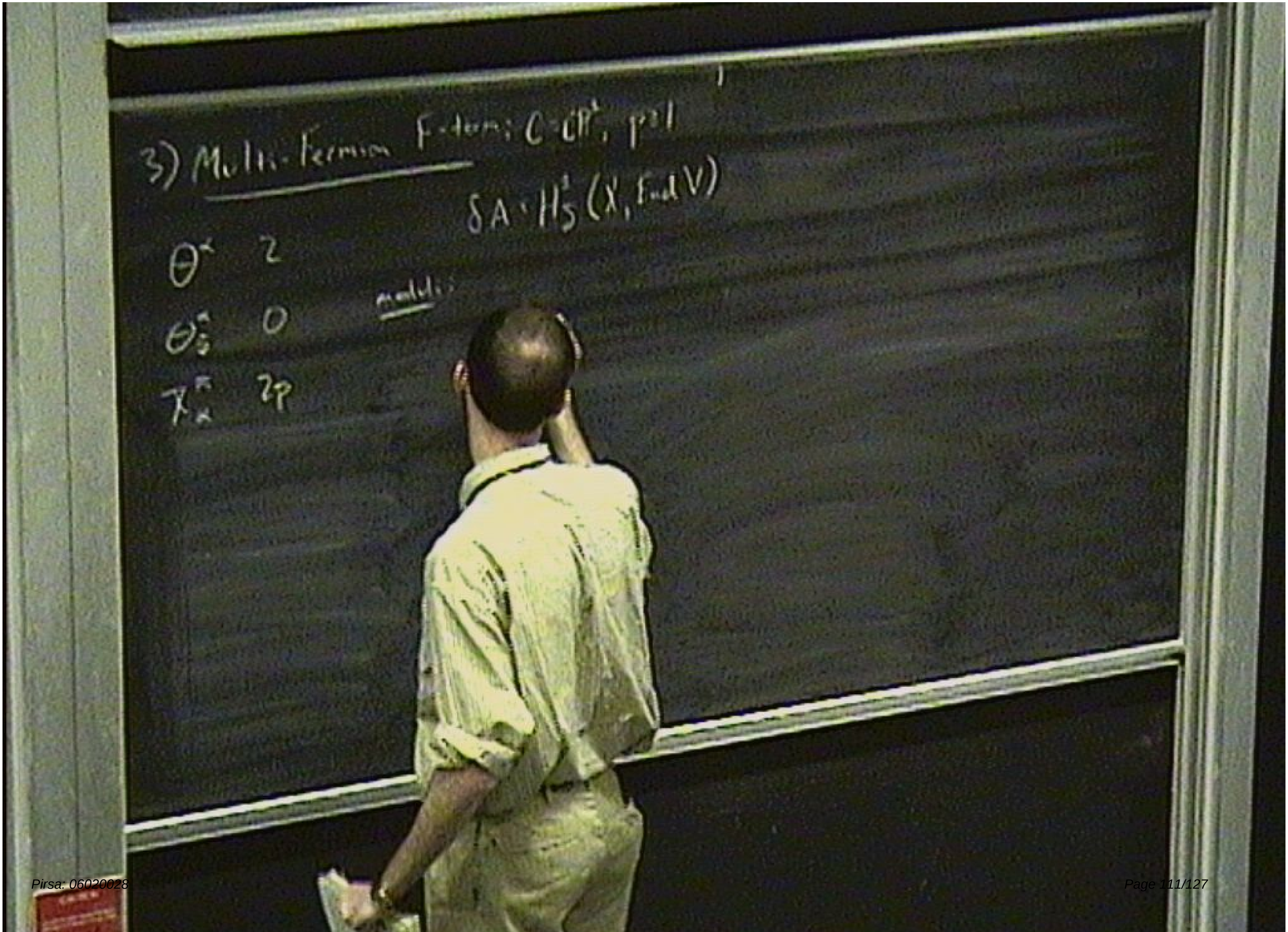

SQCD: SU(Nc), Nf flavors
p = Nf - Nc + 1
p=0
p=1 Cplx str deformation of
p>1 Higher
General
global SUSY
effective action N=1
Locally
Globally

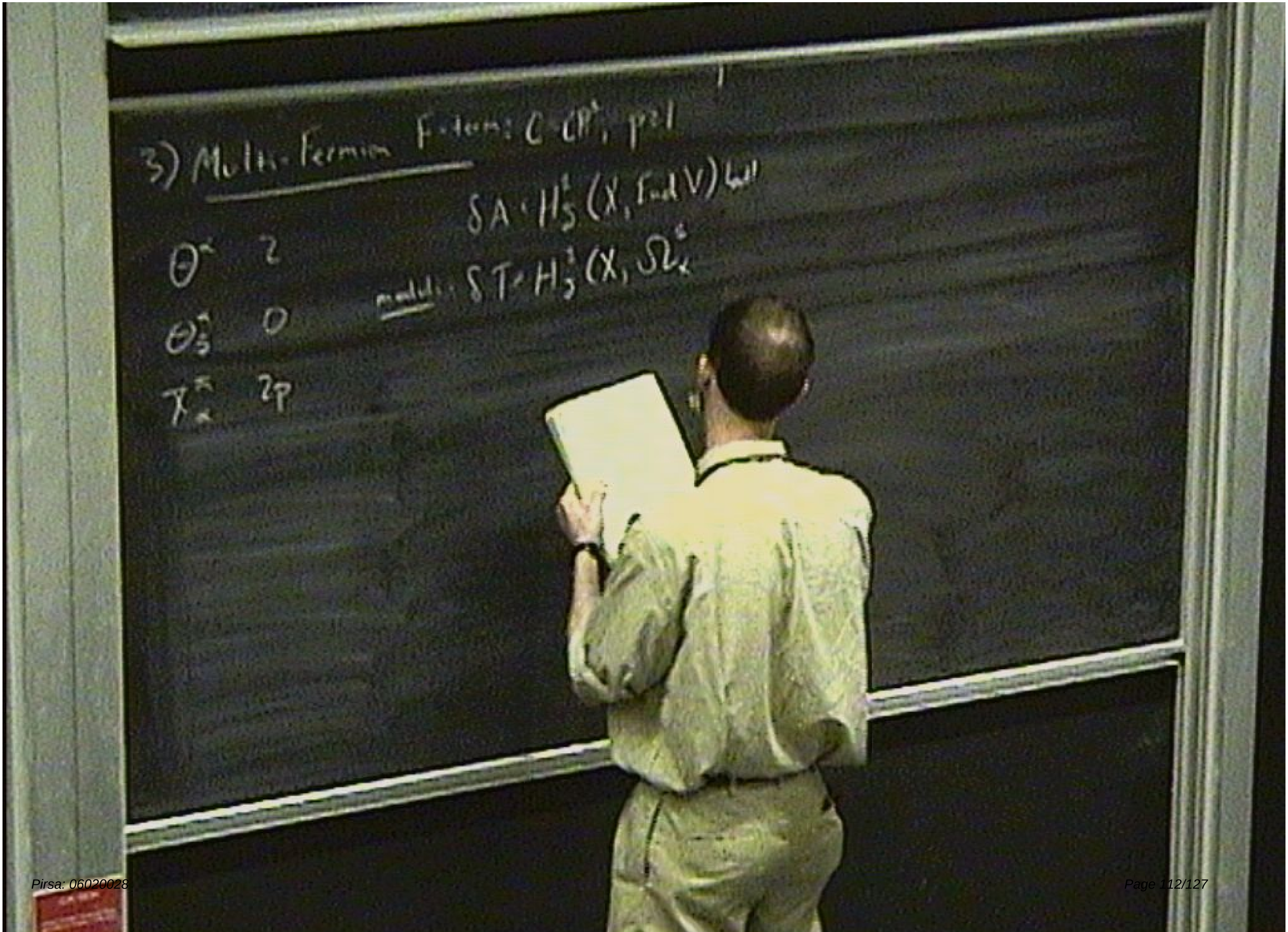

3) Multi-Fermion


3) Multi-Fermion F-term: C=CP¹, p≥1
θ^α 2
θ^α̇ 0
χ^α 2p


SQCD: SU(Nc), Nf Flavors
p = Nf - Nc + 1
p = 0 W_ADS ≠ 0
p = 1 Cplx str deformation of M_cl
p > 1 Higher Fusions
General Phys on Moduli-Fermion Fusions
· global SUSY
· effective action N = 1 atom
Locally
Globally


3) Multi-Fermion
2
0
2p
moduli
δA


3) Multi-Fermion F-term: C = CP^1, p≥1
δA ∈ H^1_S(X, End V)
θ^α 2
θ^α_S 0
moduli
χ^α_α 2p


3) Multi-Fermion
moduli

3) Multi-Fermion F-terms: $C = \mathbb{CP}^1$, $p \geq 1$

$$\delta A \in H^1_{\bar\partial}(X, \mathrm{End}\, V) \text{ bdl}$$

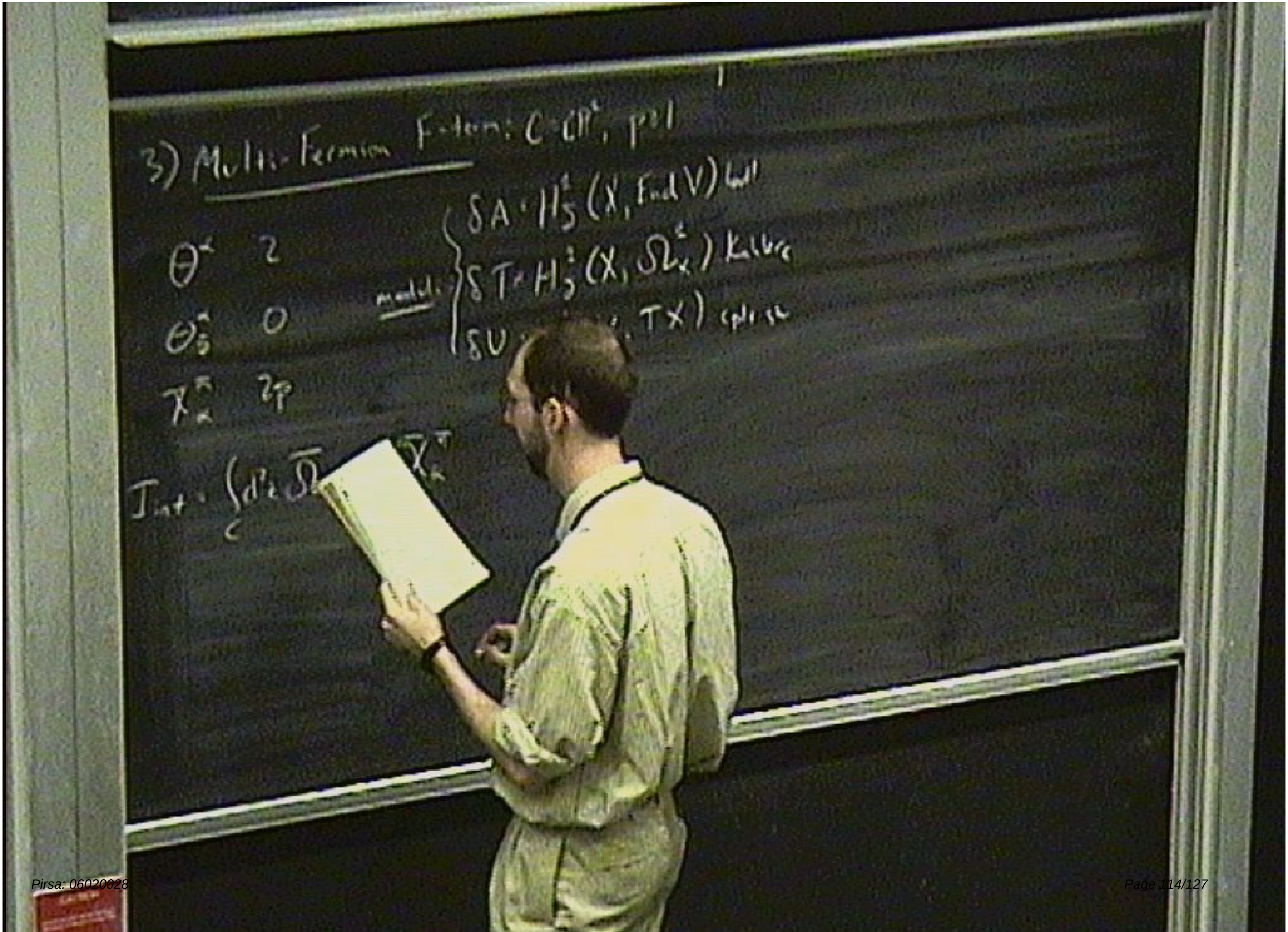
Θ^{ζ} 2

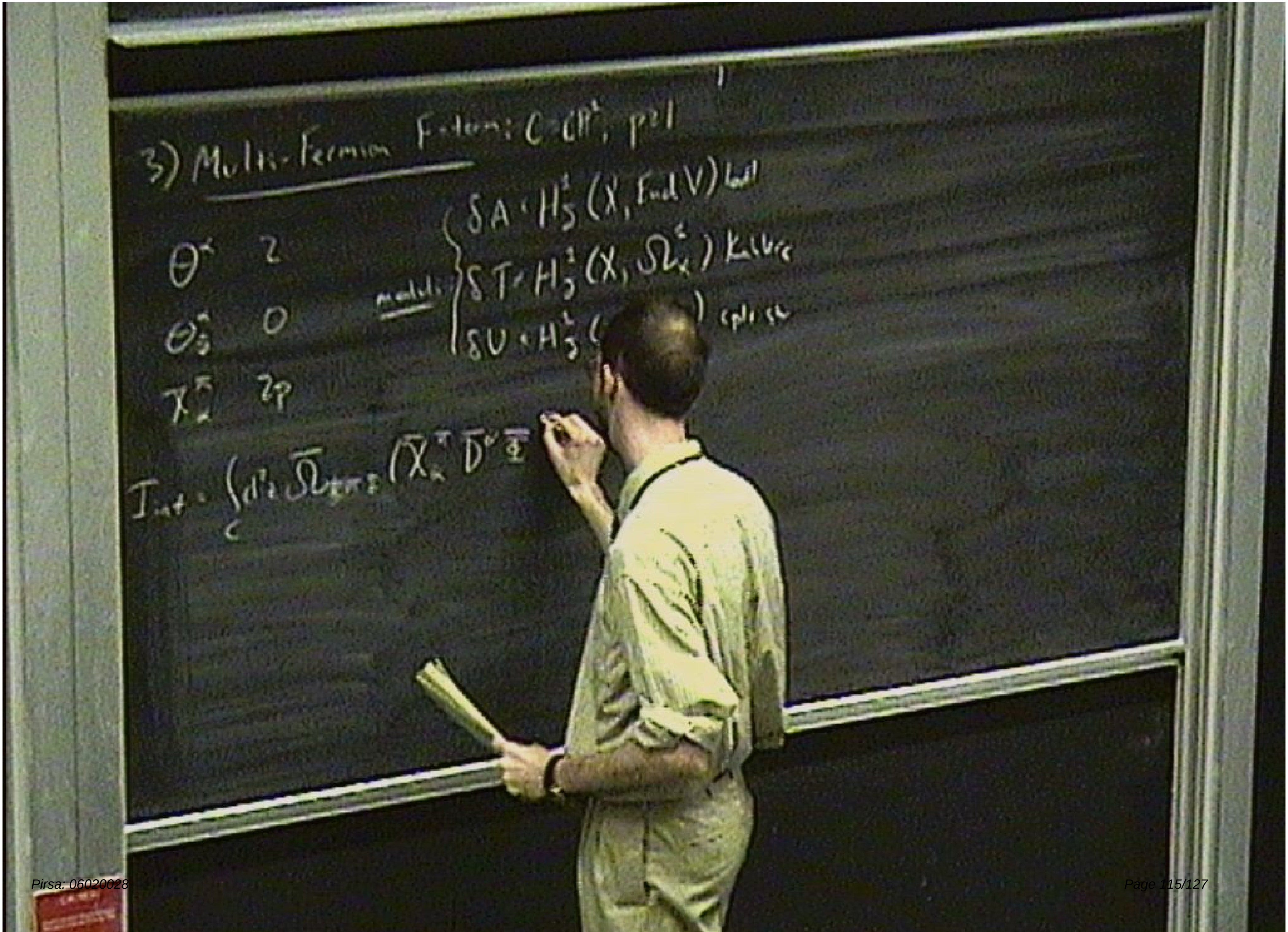
moduli: $\delta T \in H^1_{\bar\partial}(X, \Omega^2_X)$ Kähler

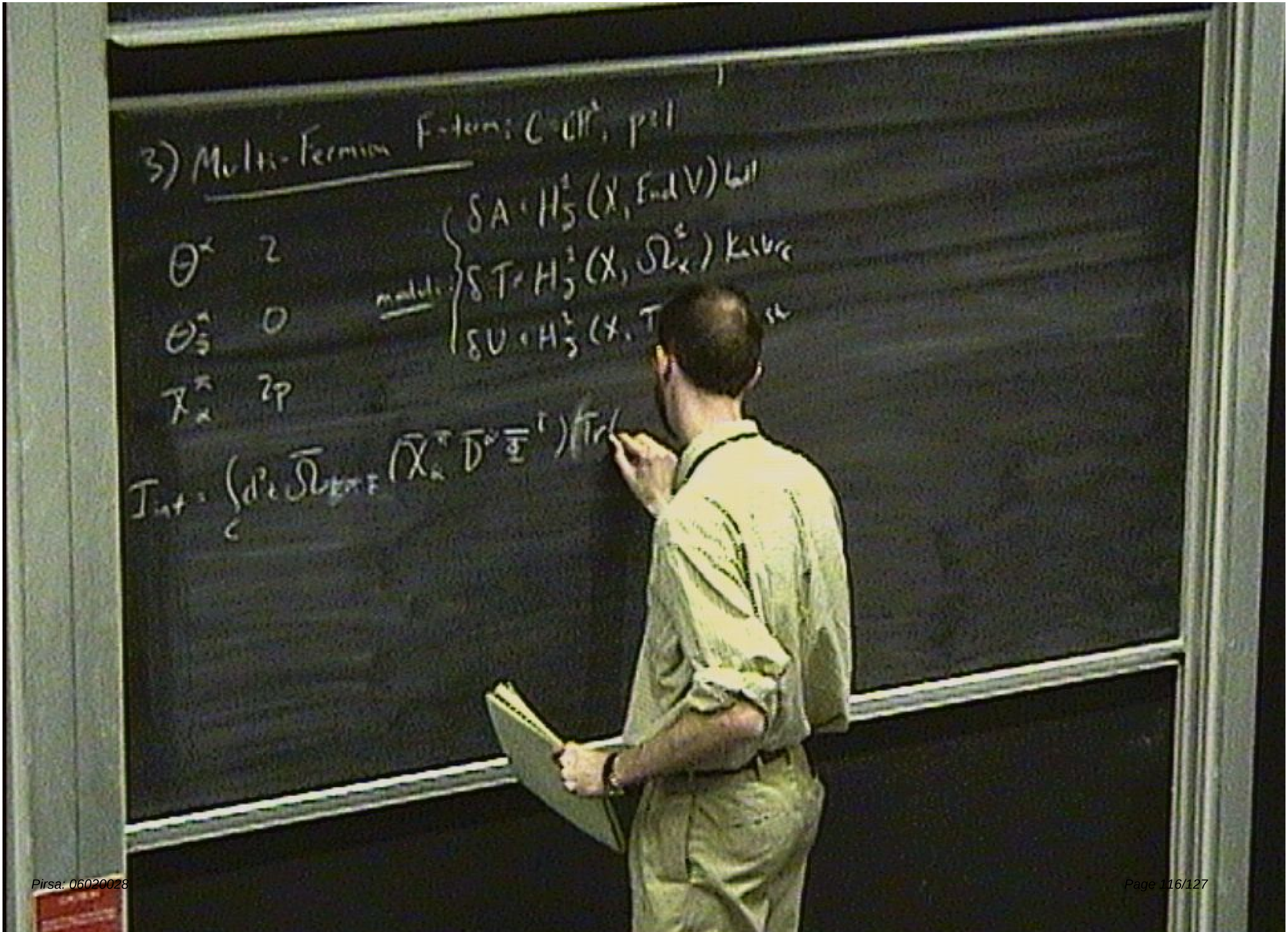
$\Theta^{a}_{\bar a}$ 0

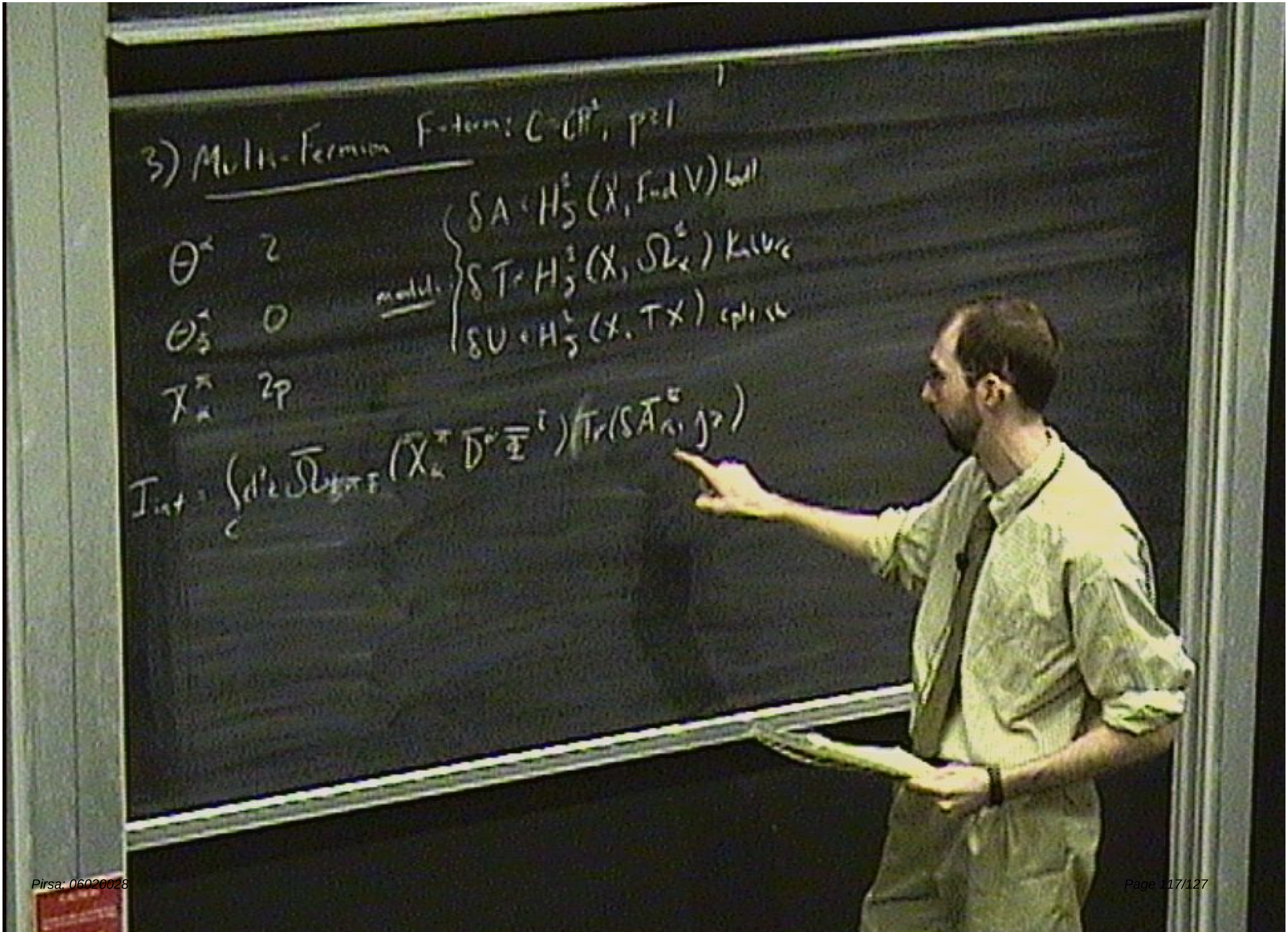
$\delta U \in H^1_{\bar\partial}(X, TX)$ cplx str

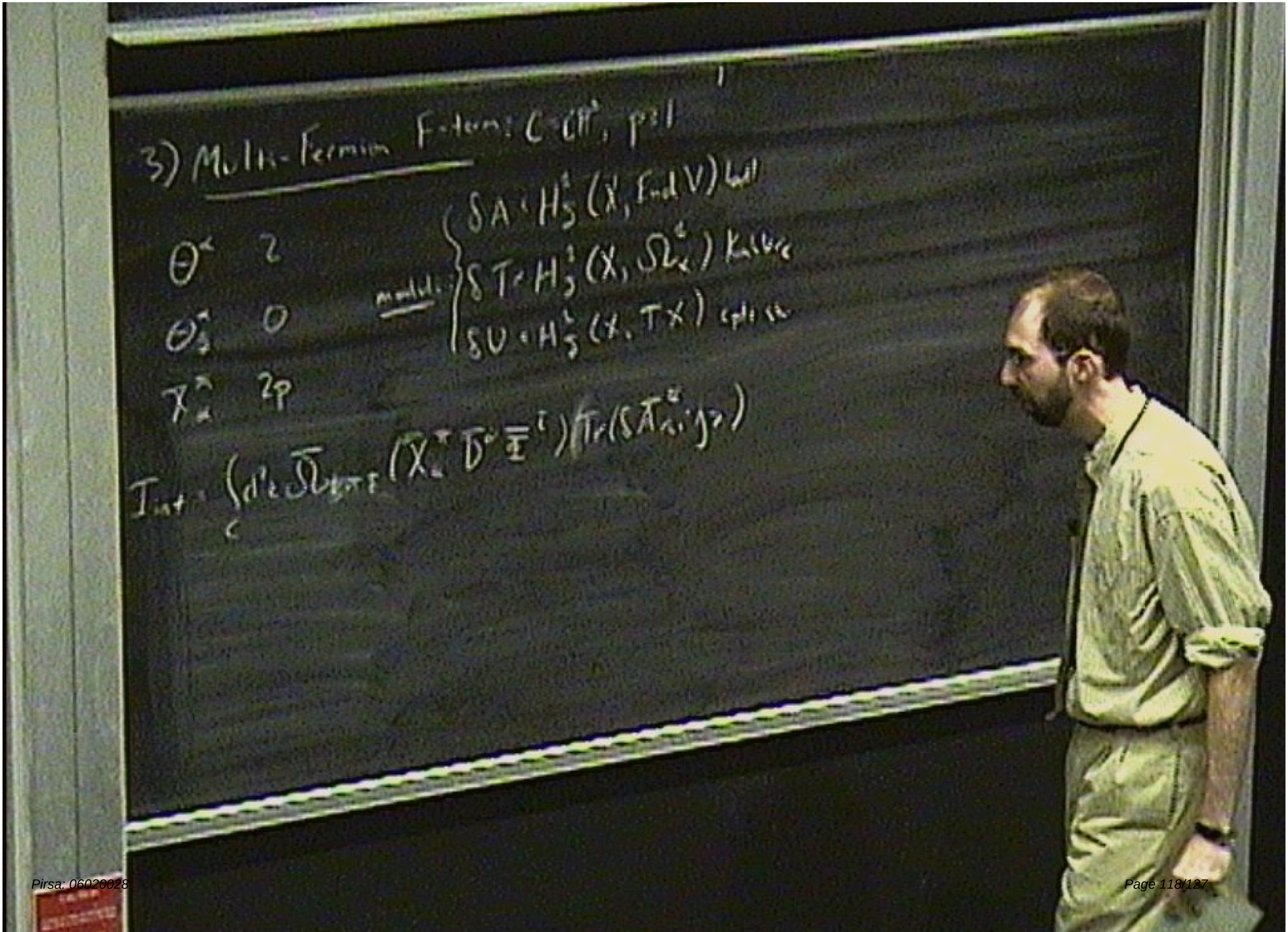
$\chi^{\bar a}_{a}$ 2p

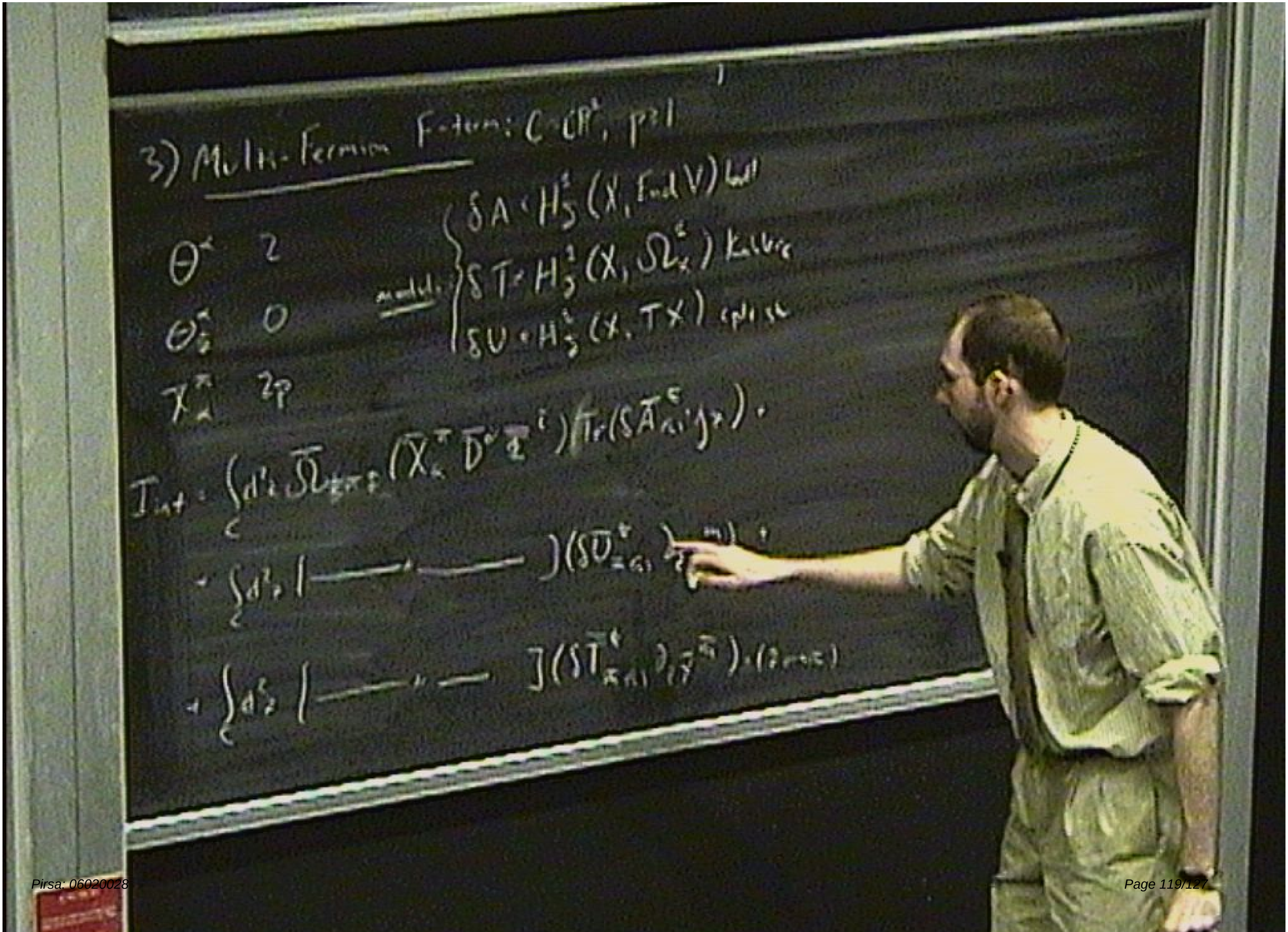

3) Multi-Fermion F-term: C = CP^1, p≥1
moduli
δA ∈ H^1_∂̄(X, End V)
δT ∈ H^1_∂̄(X, Ω^2_X) Kahler
TX) complex
Θ^α 2
Θ^α_∂̄ 0
χ^π_α 2p
I_int = ∫_C d^2z

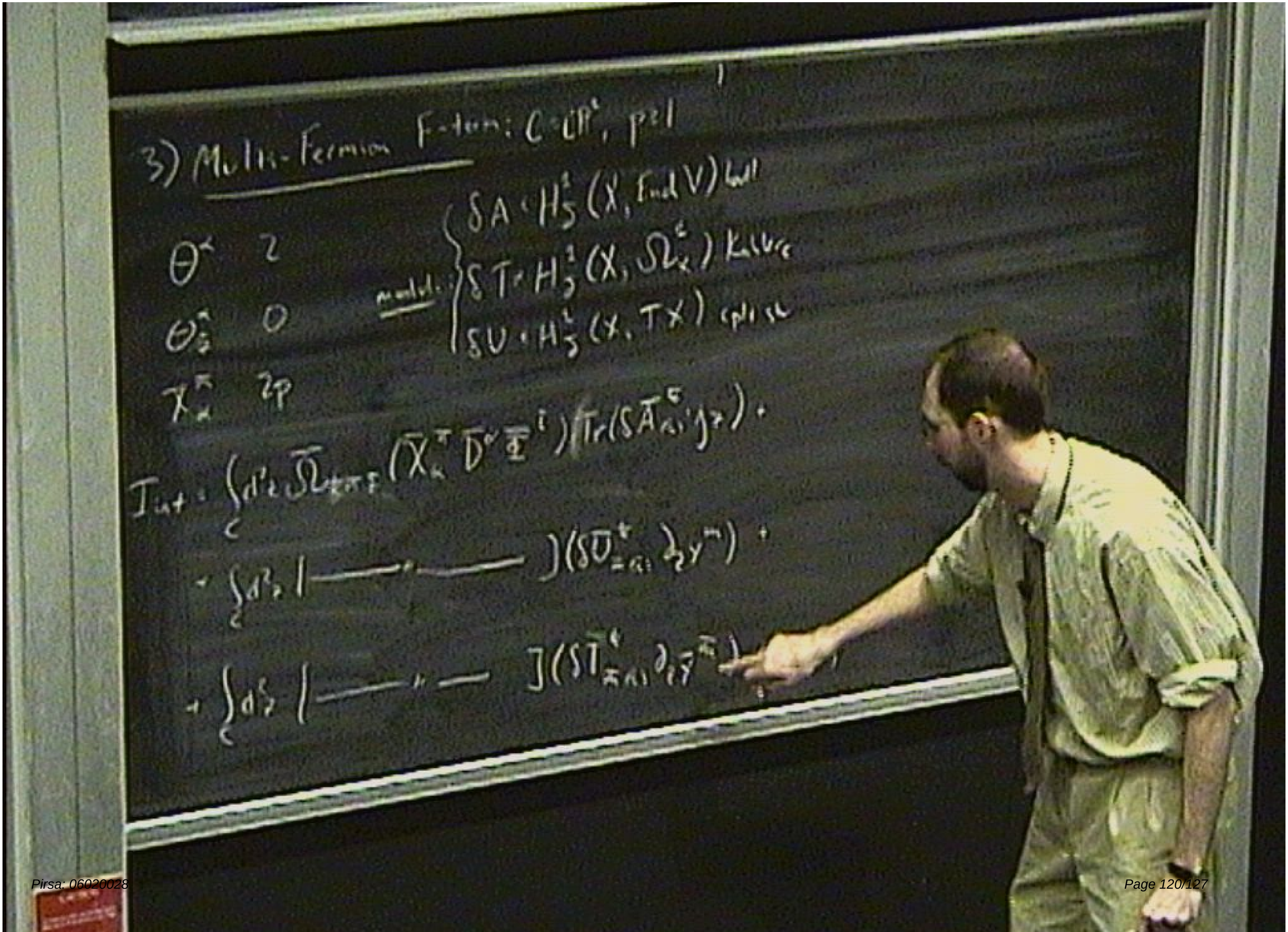

3) Multi-Fermion
moduli

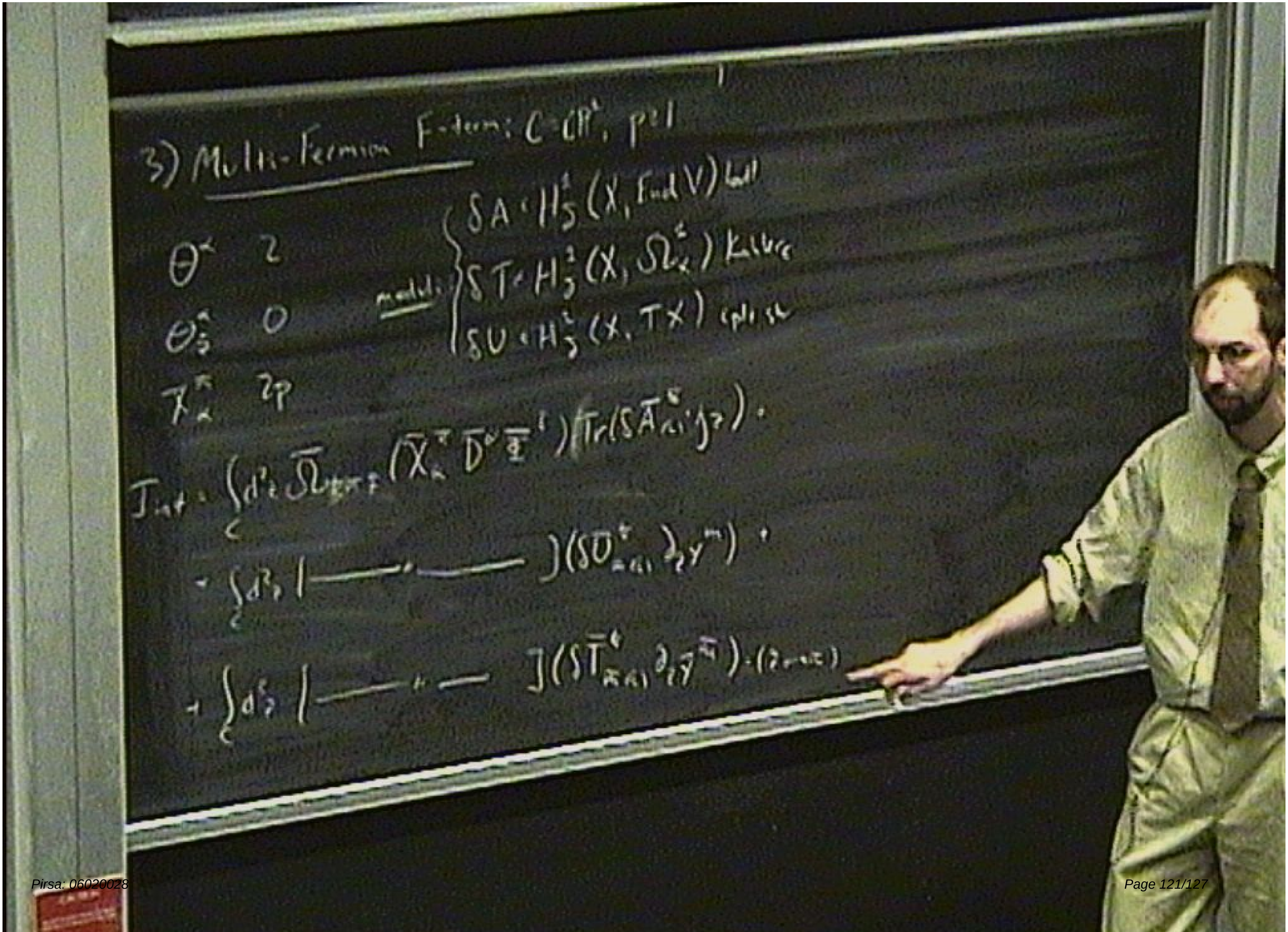

3) Multi-Fermion
moduli


3) Multi-Fermion F-term
moduli


3) Multi-Fermion F-term: C = CP^1, p≥1
δA ∈ H^1(X, End V) bdl
δT ∈ H^1(X, Ω^2_X) Kähler
moduli:
δU ∈ H^1(X, TX) cplx str
θ^α 2
θ̄^α̇ 0
χ^a_α 2p
I_int = ∫_C d^2z


3) Multi-Fermion
moduli


3) Multi-Fermion F-term: C=CP^1, p=1
moduli:
Kähler


3) Multi-Fermion F-term
moduli

3) Multi-Fermion Fixedpt: $C = \mathbb{CP}^1$, $p \geq 1$ $\quad (p=1)$ $\quad \omega \sim \int_{C \times \Sigma} \delta\bar{A}\,\delta\bar{A} \langle j_z j_z \rangle$

$\Theta^\alpha \quad 2$

$\Theta^a_{\bar z} \quad 0$

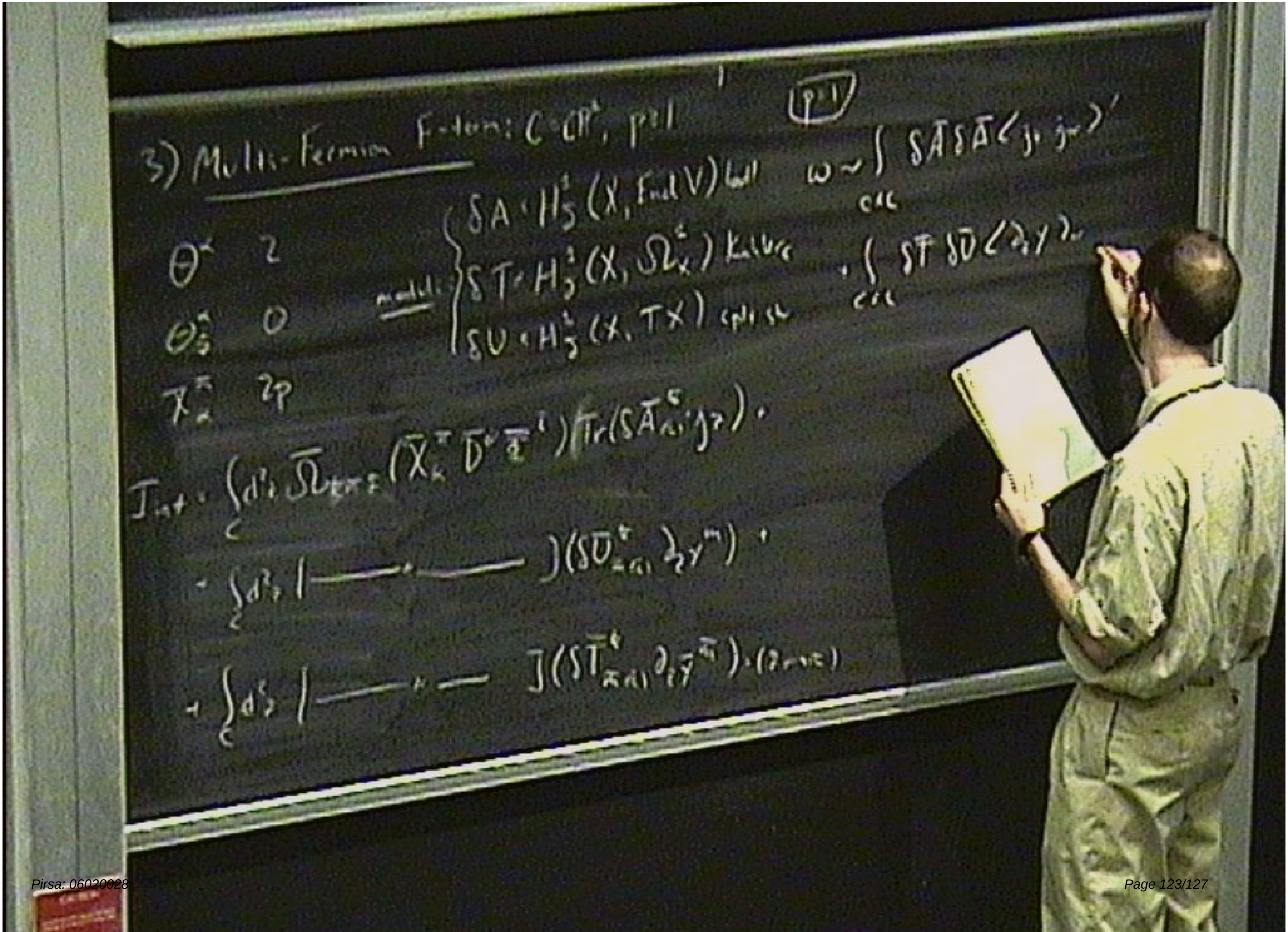
$\chi^{\bar a}_\alpha \quad 2p$

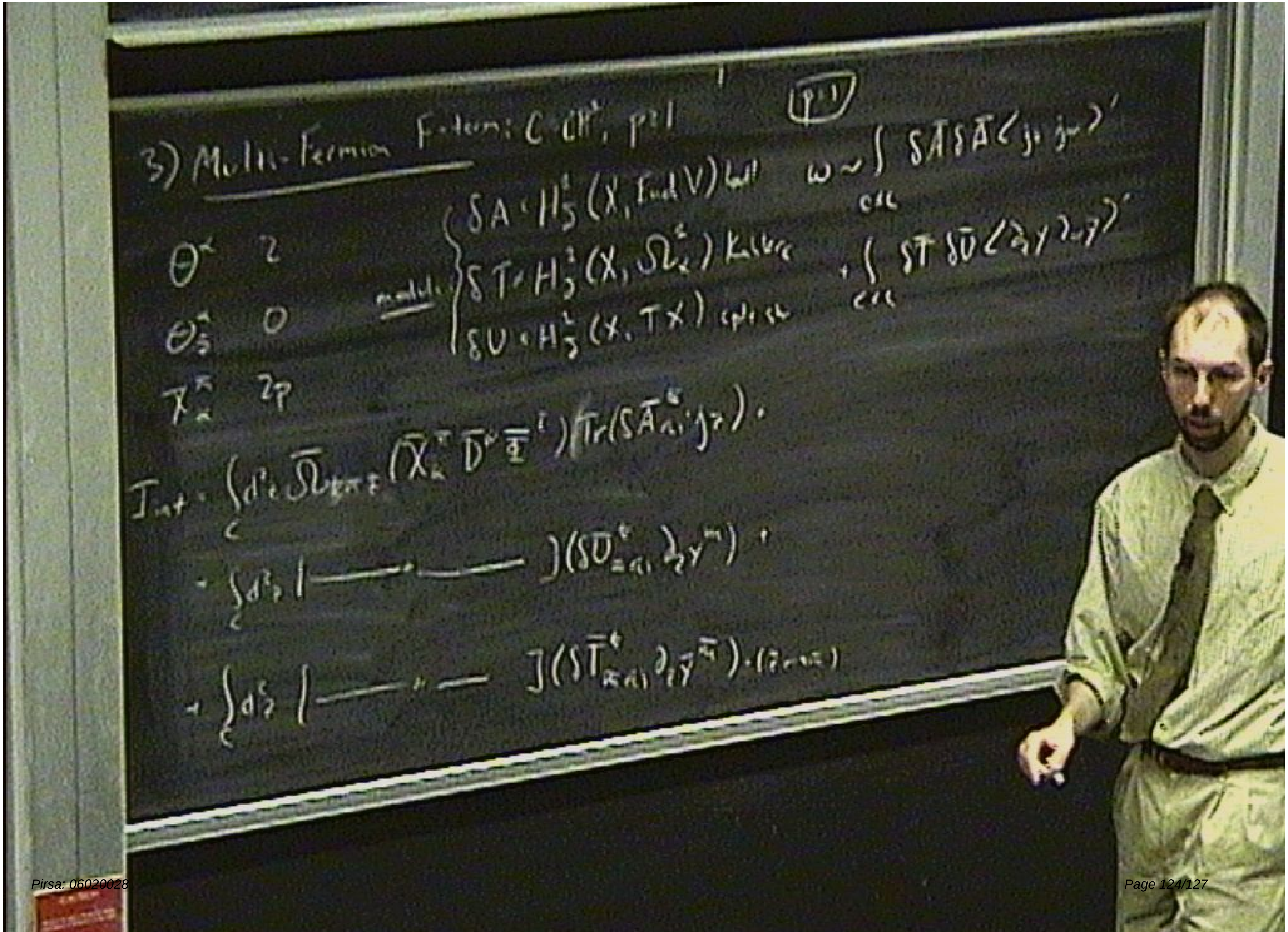
moduli $\begin{cases} \delta A \in H^1_{\bar\partial}(X, \mathrm{End}\,V) \text{ bdl} \\ \delta T \in H^1_{\bar\partial}(X, \Omega^2_X) \text{ Kähler} \\ \delta U \in H^1_{\bar\partial}(X, TX) \text{ cplx str} \end{cases}$

$$J_{int} = \int_C d^2z\, \bar\Omega_{\bar x x \bar z} (\chi^{\bar a}_\alpha \bar D^\alpha \bar\psi^c)(\mathrm{Tr}(\delta\bar A^c_{\bar z(1)} j_z)) +$$

$$+ \int_C d^2z \left[\text{———} + \text{———} \right] (\delta U^a_{\bar z(1)} \partial_z y^m) +$$

$$+ \int_C d^2z \left[\text{———} + \text{———} \right] (\delta T_{\bar z(1)} \partial_z \bar y^{\bar m}) + (z \leftrightarrow \bar z)$$


3) Multi-Fermion
moduli


3) Multi-Fermion
moduli
δA ∈ H^1_∂(X, End V) bdl
δT ∈ H^1_∂(X, Ω^2_X) Kähler
δU ∈ H^1_∂(X, TX) cplx str
ω ~ ∫_C δĀ δĀ
I_int = ∫_C d^2z

3) Multi-Fermion F-term: $C = \mathbb{CP}^1$, $p \geq 1$ $\boxed{p=1}$

θ^{α} 2

$\bar{\theta}^{\dot{\alpha}}_{\dot{5}}$ 0

$\chi^{\bar{m}}_{\alpha}$ 2p

moduli: $\begin{cases} \delta A \in H^1_{\bar{\partial}}(X, \mathrm{End}\,V)\ \text{bundle} \\ \delta T \in H^1_{\bar{\partial}}(X, \Omega^1_X)\ \text{Kähler} \\ \delta U \in H^1_{\bar{\partial}}(X, TX)\ \text{cplx str} \end{cases}$

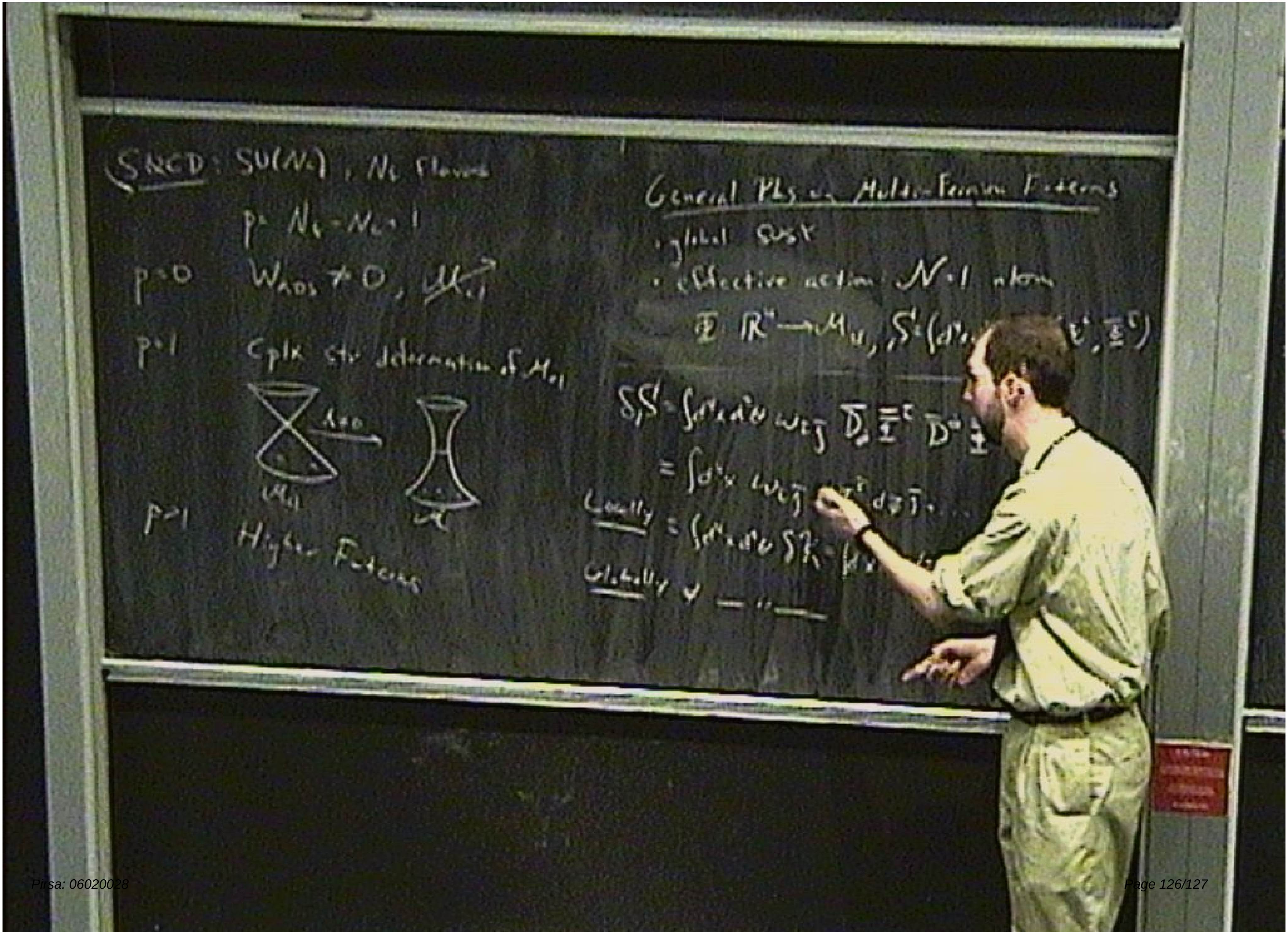
$\omega \sim \int_{C \in \mathcal{C}} \delta\bar{A}\,\delta\bar{A} \langle j_{\bar{z}}\, j_{\bar{z}} \rangle' + \int_{C \in \mathcal{C}} \delta\bar{T}\,\delta\bar{U} \langle \lambda_{\bar{z}} / \lambda_{\bar{z}} \rangle'$

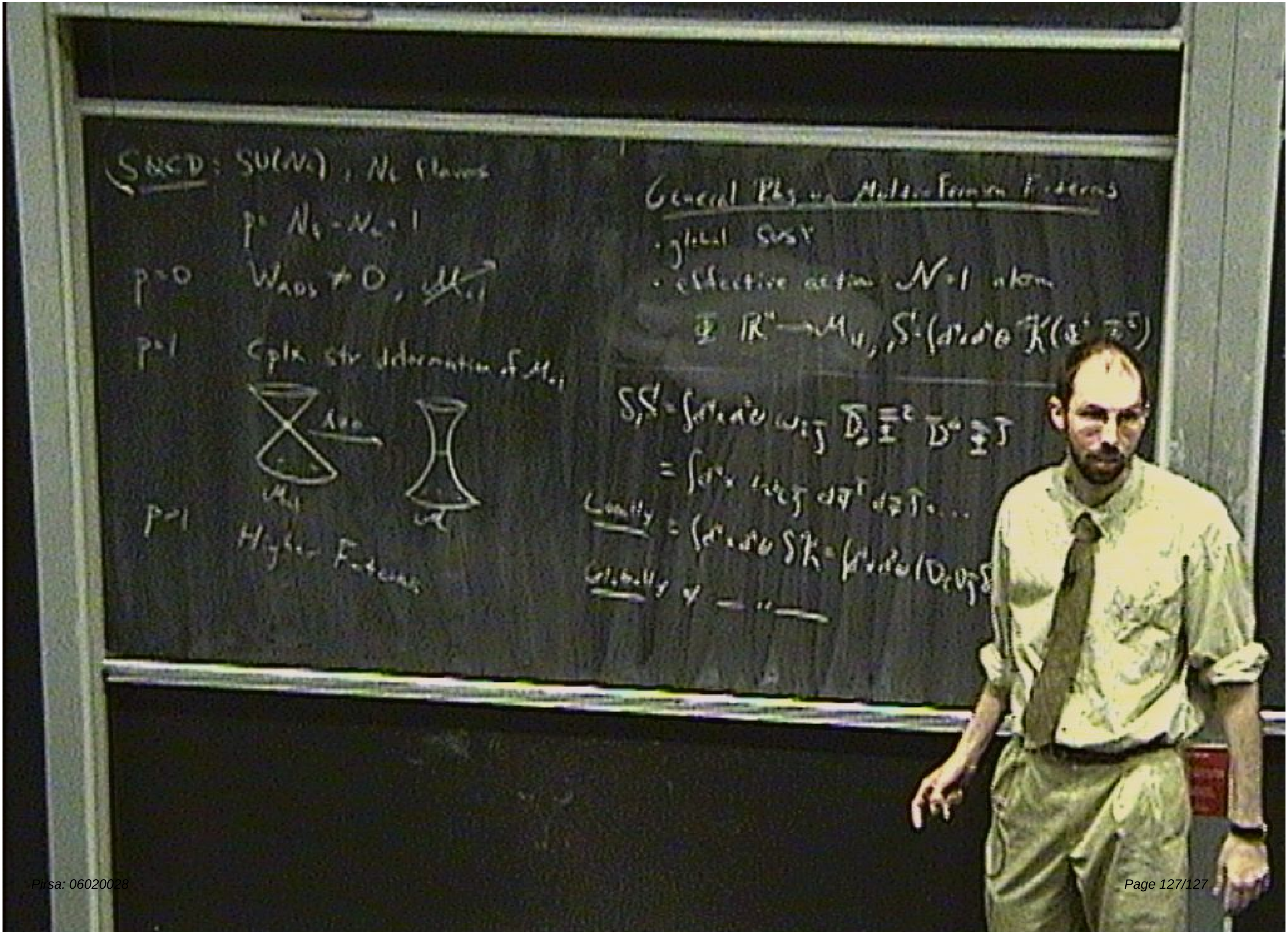
$\delta_{\eta} S = \int \bar{\theta}\,\bar{\theta}\,\omega\ \mathcal{U}_C$

$I_{int} = \int_C d^2z\, \bar{\Omega}_{\bar{z}\bar{\alpha}\bar{\beta}} (\chi^{\bar{\alpha}}_{\bar{z}}\, \bar{D}^{\alpha} \bar{\Xi}^{c}) \mathrm{Tr}(\delta\bar{A}^{c}_{\bar{z}(i)}\, j_{\bar{z}}) +$

$+ \int_C d^2z\, [\ \text{———}\ +\ \text{———}\ ] (\delta\bar{U}^{k}_{\bar{z}(i)}\, \partial_{\bar{z}} y^{m}) +$

$+ \int_C d^2z\, [\ \text{———}\ +\ \text{———}\ ] (\delta\bar{T}^{c}_{\bar{z}(i)}\, \partial_{\bar{z}} \bar{y}^{\bar{m}}) + (\text{3-more})$


SQCD: SU(Nc), Nf flavors
p = Nf - Nc + 1
p=0
p=1
Cplx str deformation of
p>1
global SUSY
effective action
Locally
Globally


SQCD: SU(Nc), Nf flavors
p = Nf - Nc + 1
Cplx str deformation of
Higher F-terms
global SUSY
effective action