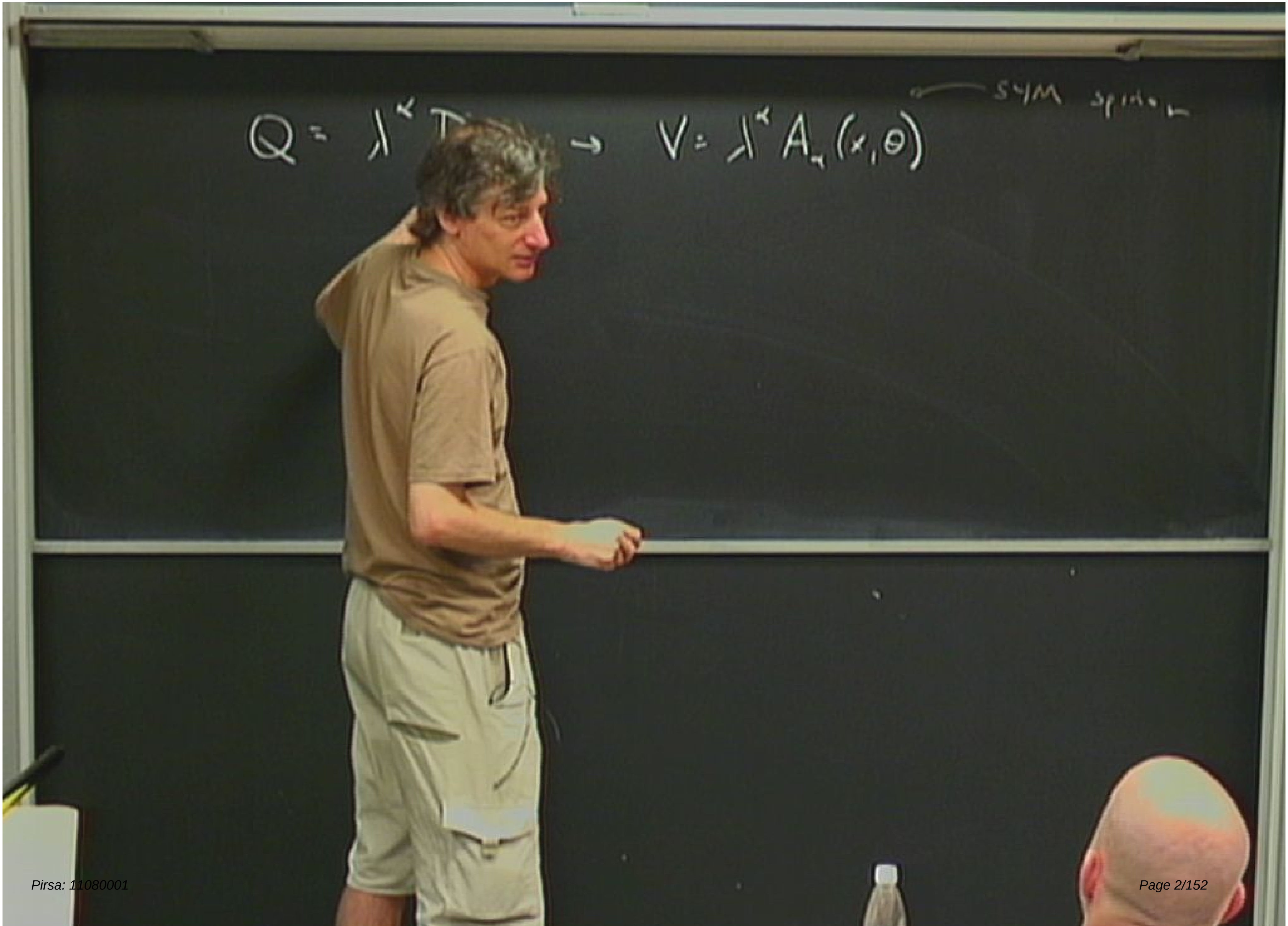
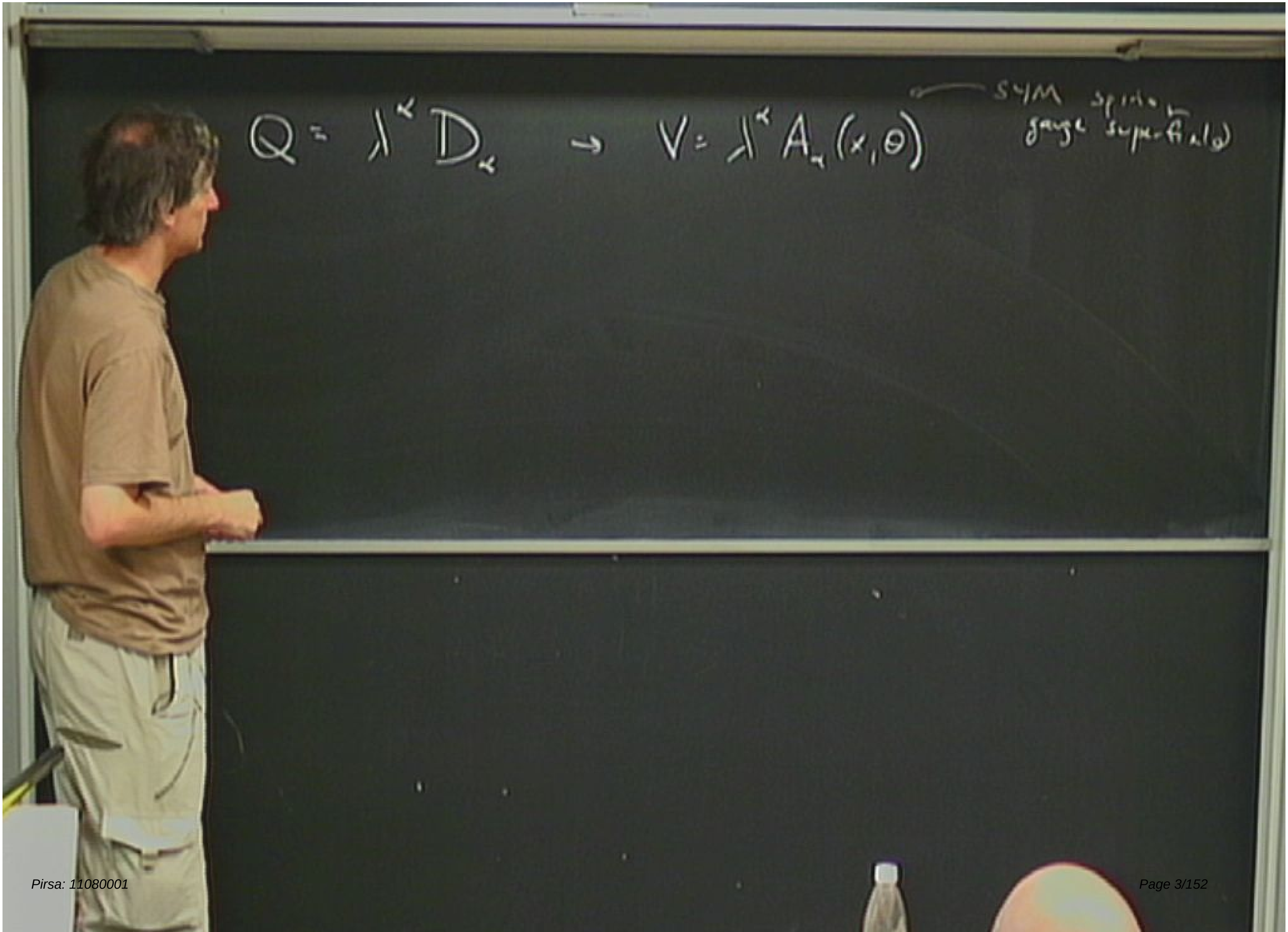
Title: Introduction to Pure Spinor Formalism of the Superstring - Lecture 2

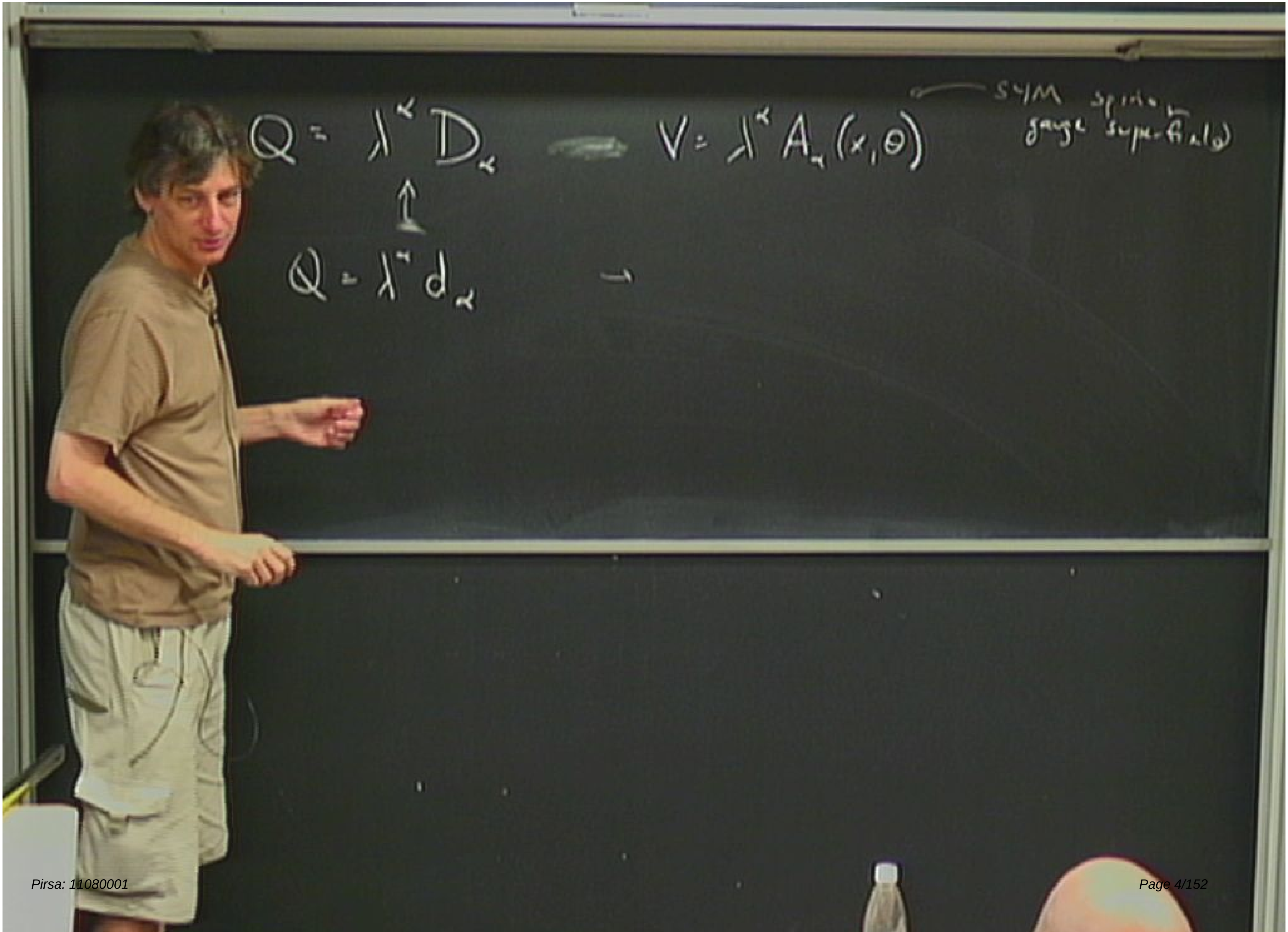
Date: Aug 25, 2011 10:30 AM

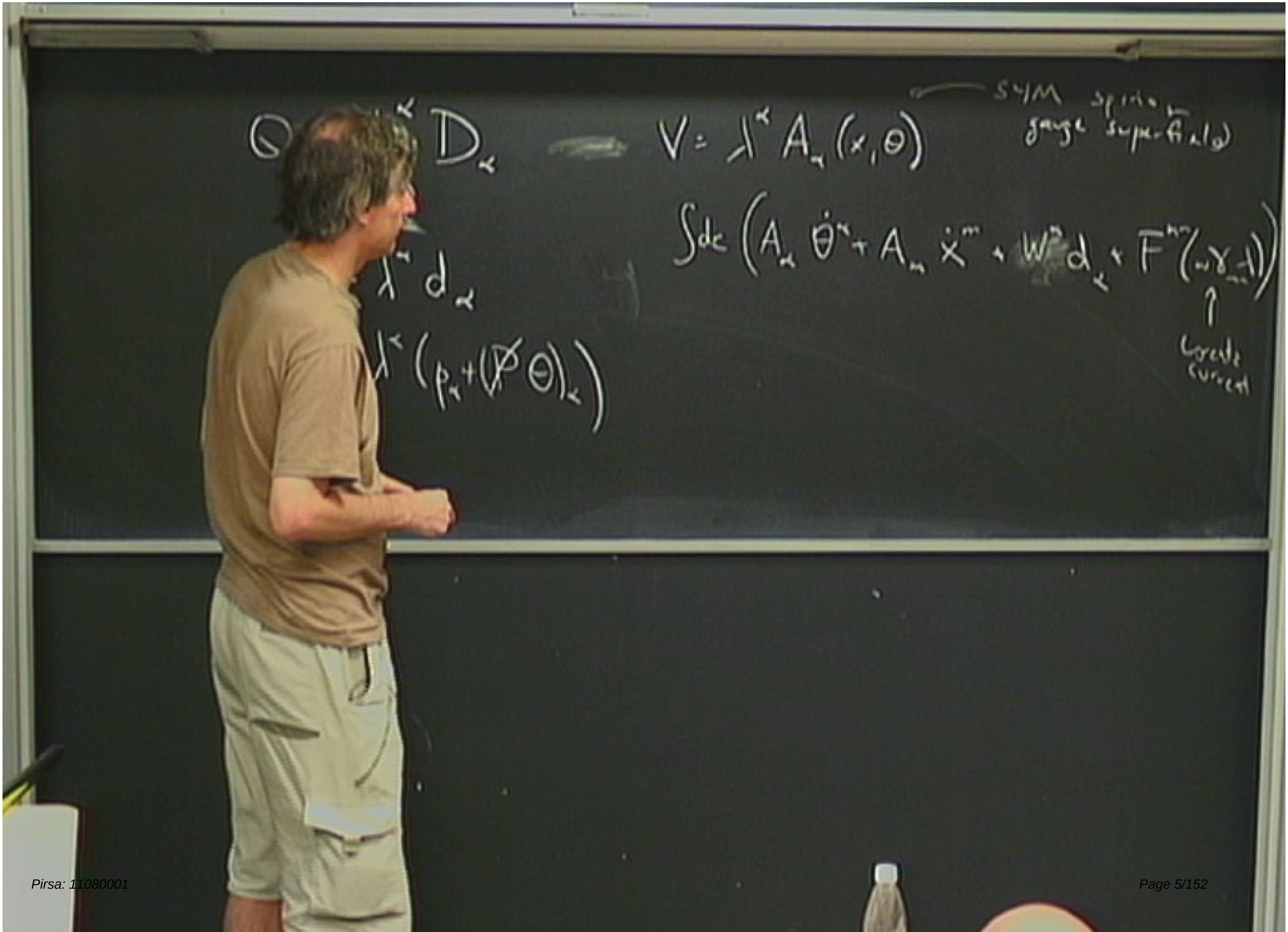
URL: http://pirsa.org/11080001

Abstract: Superstring in flat and AdS_5xS^5 backgrounds

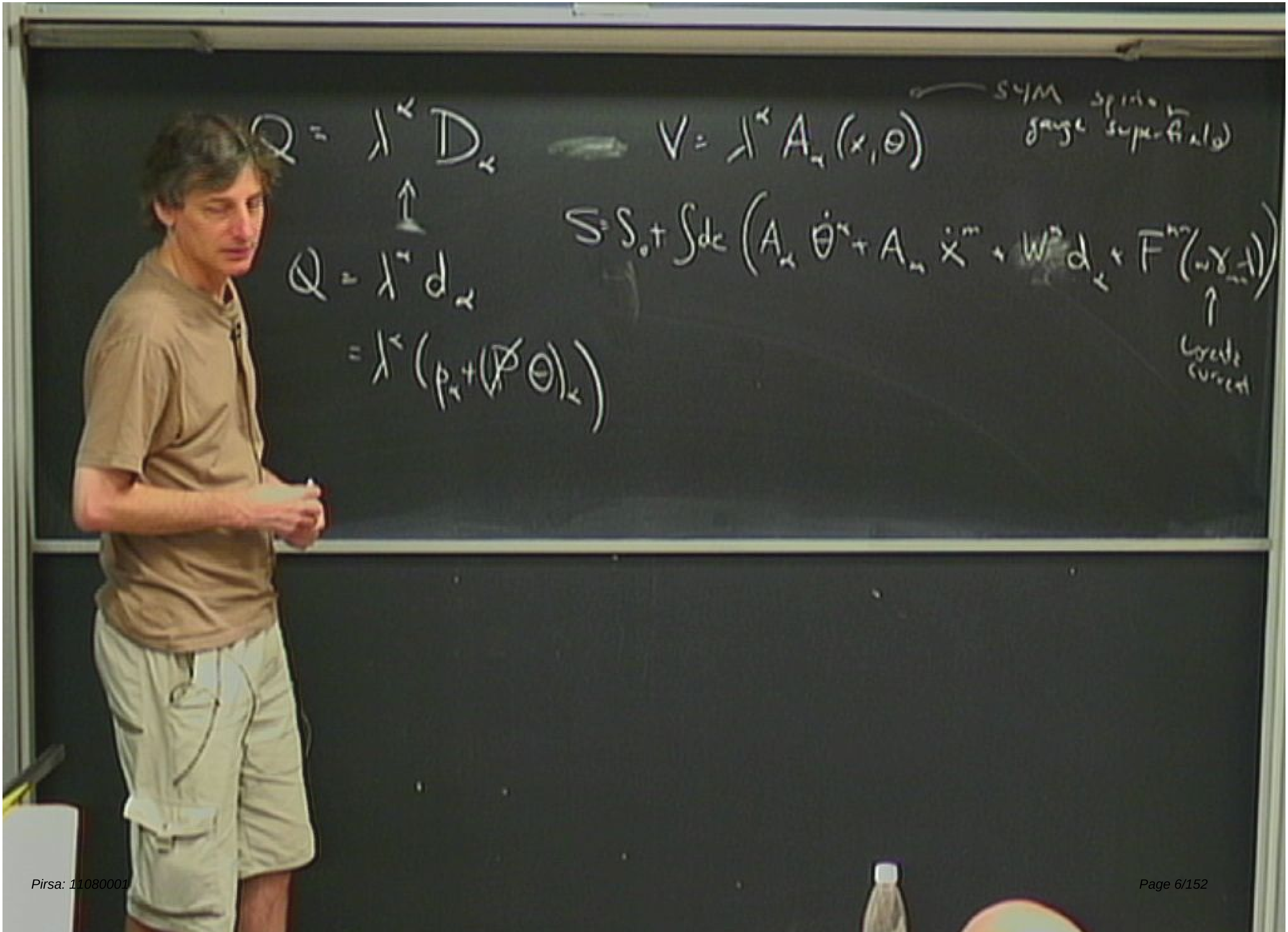

Q = λ^α D → V = λ^α A_α(x, θ)
SYM spinor

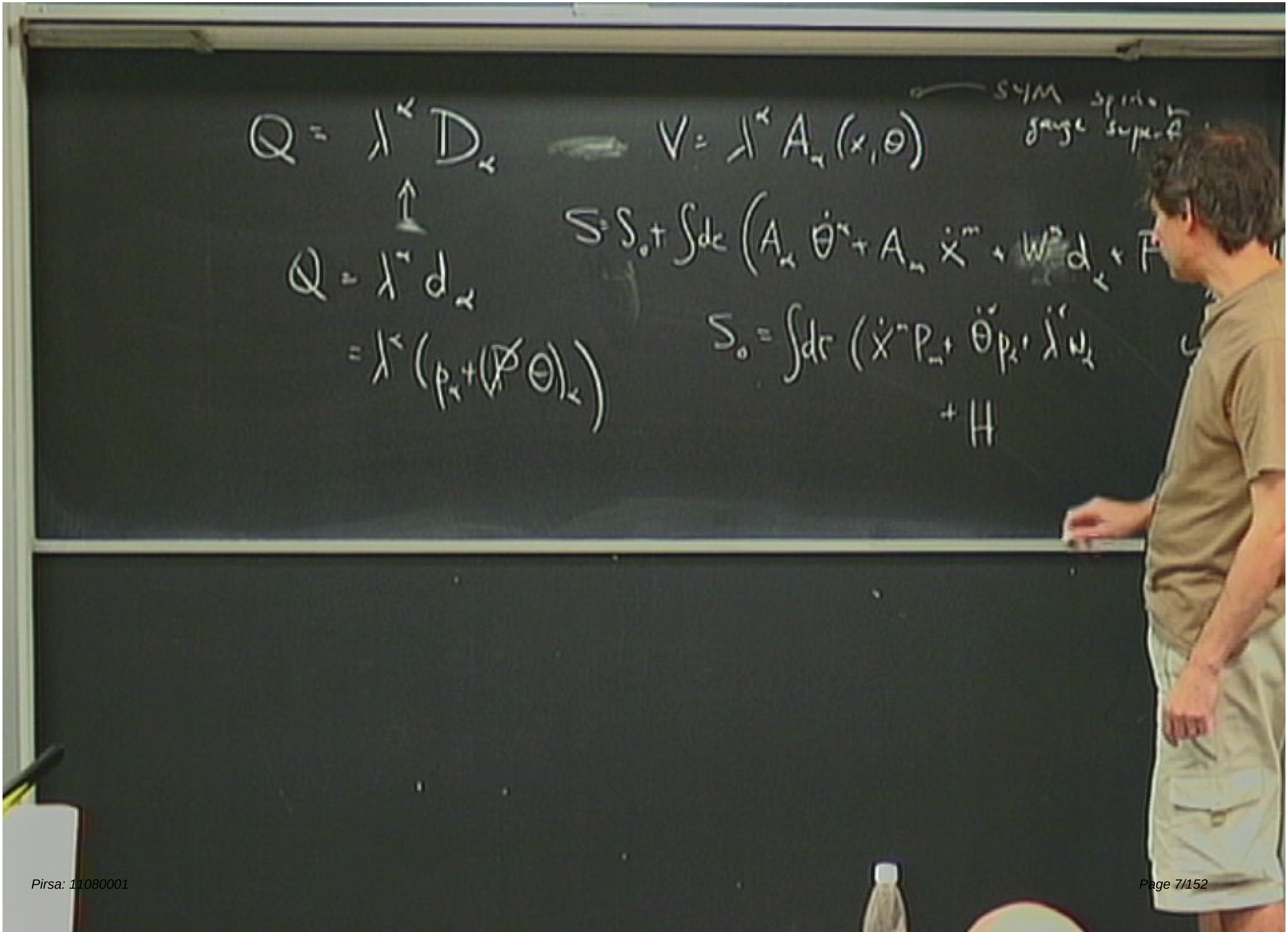

$Q = \lambda^\alpha D_\alpha \rightarrow V = \lambda^\alpha A_\alpha(x,\theta)$
SYM spinor
gauge superfield

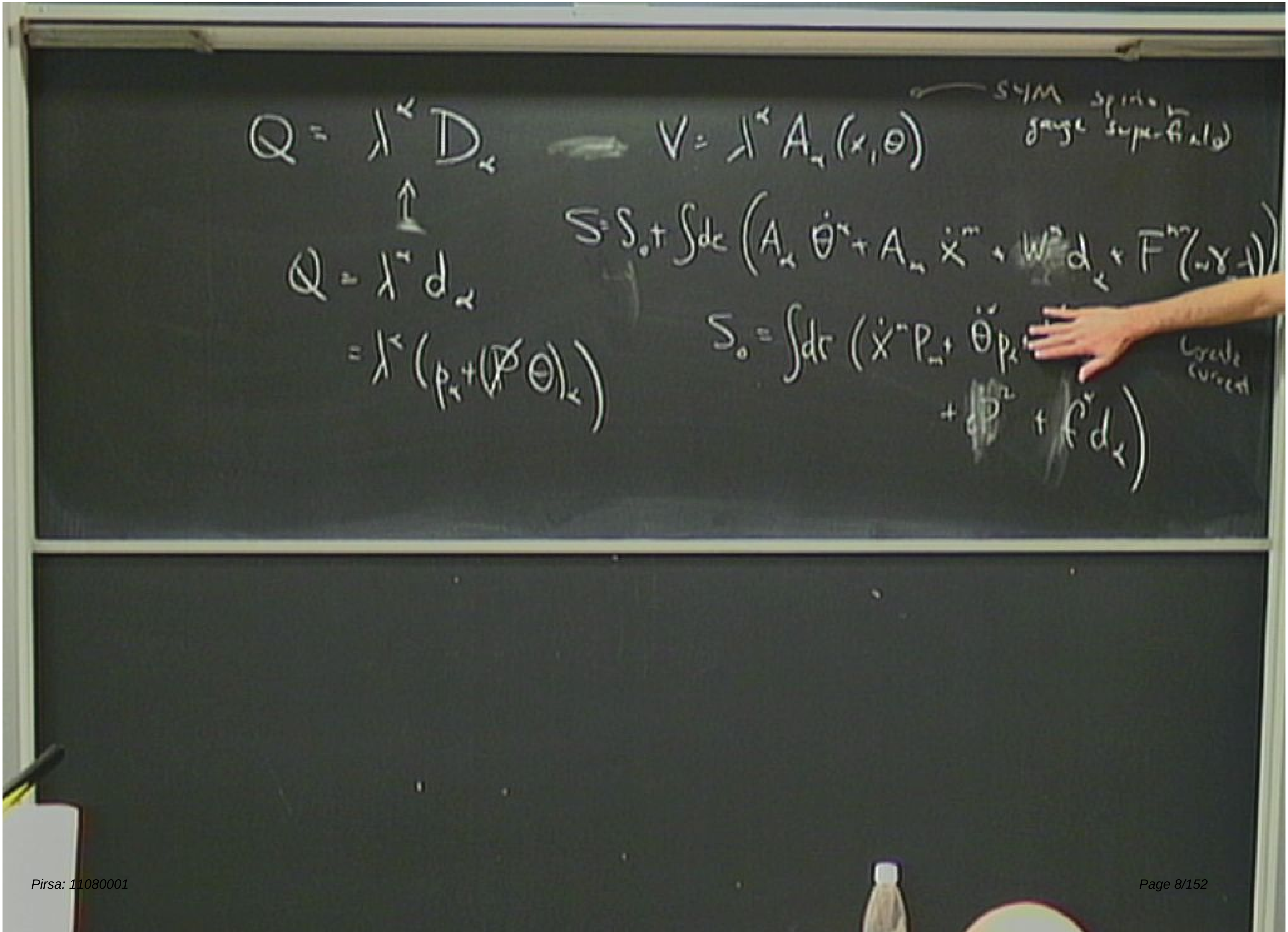

Q = λ^α D_α
V = λ^α A_α(x,θ)
SYM spinor
gauge superfield
Q = λ^α d_α



D_α
V = λ^α A_α(x, θ)
SYM spinor gauge superfield
∫dτ (A_α θ̇^α + A_m ẋ^m + W^α d_α + F^mn (...))
λ^α d_α
λ^α (p_α + (∂̸θ)_α)
Lorentz current


$Q = \lambda^\alpha D_\alpha$
$V = \lambda^\alpha A_\alpha(x,\theta)$
SYM
gauge
$S = S_0 + \int d\tau \left(A_\alpha \dot{\theta}^\alpha + A_m \dot{x}^m + W^\alpha d_\alpha + F^{mn} \right)$
current
$Q = \lambda^\alpha d_\alpha$
$= \lambda^\alpha \left(p_\alpha + (\not{\partial}\theta)_\alpha \right)$


Q = λ^α D_α
V = λ^α A_α(x, θ)
SYM spinor
gauge super
Q = λ^α d_α
= λ^α (p_α + (γ̸ θ)_α)
S = S_0 + ∫dτ (A_α θ̇^α + A_m ẋ^m + W^α d_α + F
S_0 = ∫dτ (ẋ^m P_m + θ̇^α p_α + λ̇^α w_α
+ H


Q = λ^α D_α
V = λ^α A_α(x, θ)
SYM
gauge super-field
Q = λ^α d_α
= λ^α (p_α + (∂̸θ)_α)
S = S_0 + ∫dτ (A_α θ̇^α + A_m ẋ^m + W^α d_α + F^{mn}
S_0 = ∫dτ (ẋ^m P_m + θ̇ p_α
+ f^α d_α)
current

$$Q = \lambda^\alpha D_\alpha \qquad V = \lambda^\alpha A_\alpha(x,\theta)$$

SYM spinor gauge superfield

$$\uparrow$$

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha\left(p_\alpha + (\not{P}\theta)_\alpha\right)$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn}(w\gamma_{mn}\lambda)\right)$$

$$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta^\alpha p_\alpha + \dot\lambda^\alpha w_\alpha + P^2 + \not{P}^\alpha d_\alpha\right)$$

Lorentz current

$$Q = \lambda^\alpha D_\alpha \qquad V = \lambda^\alpha A_\alpha(x,\theta)$$

← SYM spinor gauge superfield

↑

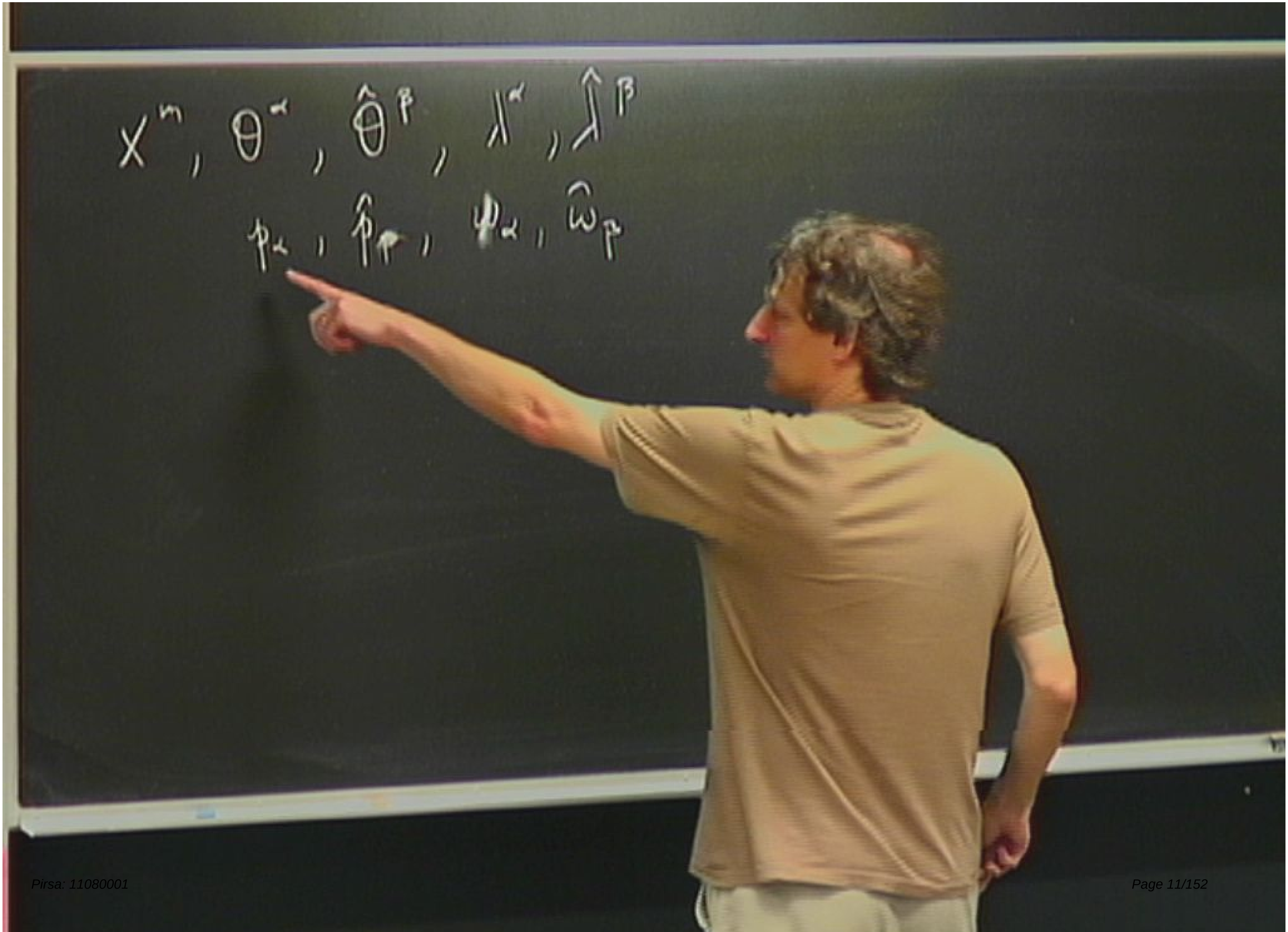
$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha \left(p_\alpha + (\not{\partial}\theta)_\alpha\right)$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot{\theta}^\alpha + A_m \dot{x}^m + W^\alpha d_\alpha + F^{mn}(w\gamma_{mn}\lambda)\right)$$

↑ Lorentz current

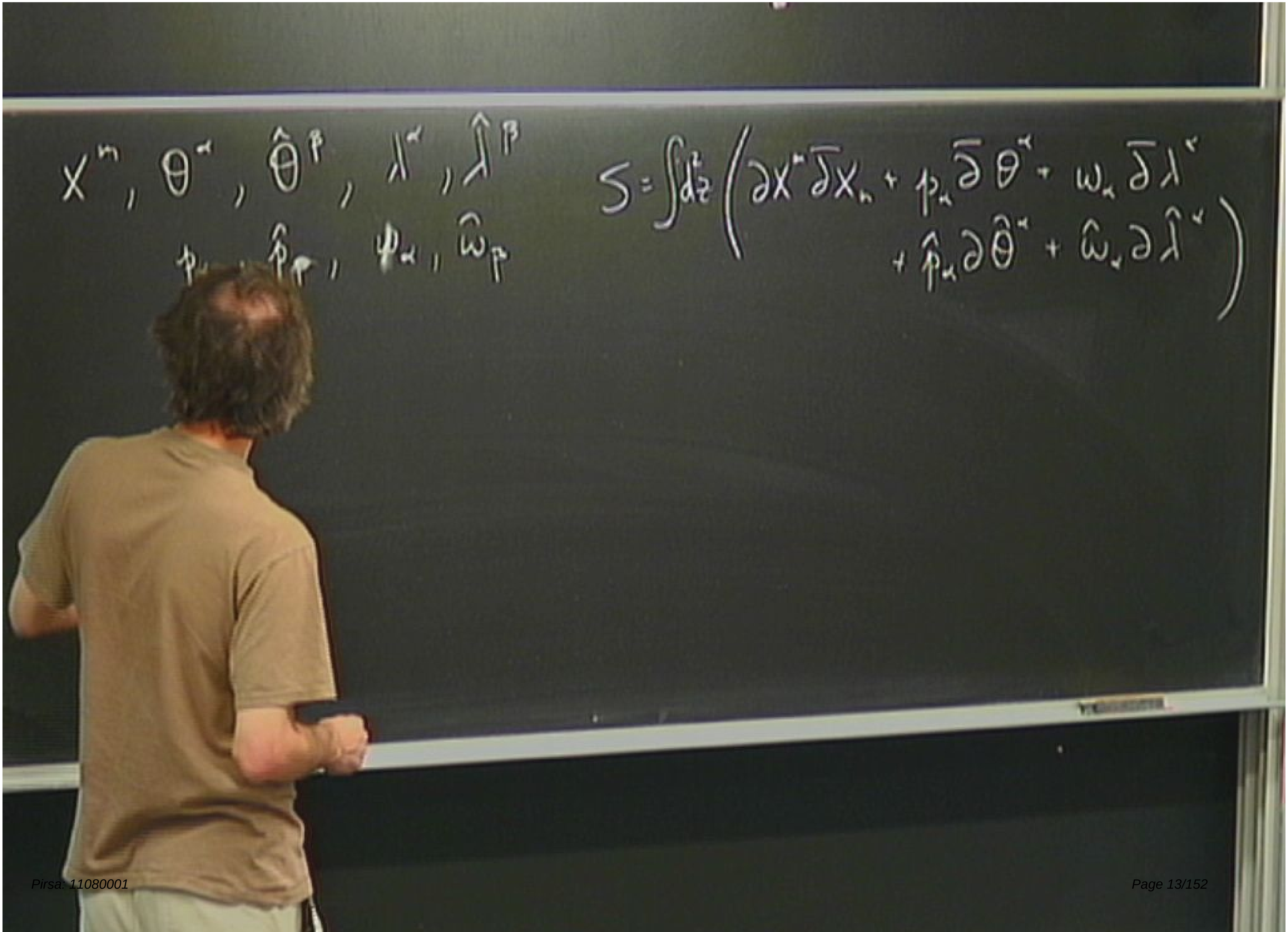
$$S_0 = \int d\tau \left(\dot{x}^m P_m + \dot{\theta}^\alpha p_\alpha + \dot{\lambda}^\alpha w_\alpha + P^2 + \ldots\right)$$


X^m, θ^α, θ̂^β, λ^α, λ̂^β
p_α, p̂_β, w_α, ŵ_β

$$X^m, \quad \theta^\alpha, \quad \hat{\theta}^\beta, \quad \lambda^\alpha, \quad \hat{\lambda}^\beta$$

$$p_\alpha, \quad \hat{p}_\beta, \quad w_\alpha, \quad \hat{w}_\beta$$

$$S = \int d^2z \left(\partial X^m \bar{\partial} X_m + p_\alpha \bar{\partial} \theta^\alpha + w_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_\alpha \partial \hat{\theta}^\alpha + \hat{w}_\alpha \partial \hat{\lambda}^\alpha \right)$$


$X^m, \theta^\alpha, \hat{\theta}^\beta, \lambda^\alpha, \hat{\lambda}^\beta$
$p_\alpha, \hat{p}_\beta, w_\alpha, \hat{w}_\beta$
$S = \int d^2z \left(\partial X^m \bar{\partial} X_m + p_\alpha \bar{\partial} \theta^\alpha + w_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_\alpha \partial \hat{\theta}^\alpha + \hat{w}_\alpha \partial \hat{\lambda}^\alpha \right)$

$X^m, \ \theta^\alpha, \ \hat\theta^{\hat\beta}, \ \lambda^\alpha, \ \hat\lambda^{\hat\beta}$

$p_\alpha, \ \hat p_{\hat\alpha}, \ w_\alpha, \ \hat w_{\hat\beta}$

$$S = \int d^2z \left(\partial X^m \bar\partial X_m + p_\alpha \bar\partial \theta^\alpha + w_\alpha \bar\partial \lambda^\alpha + \hat p_{\hat\alpha} \partial \hat\theta^{\hat\alpha} + \hat w_{\hat\alpha} \partial \hat\lambda^{\hat\alpha} \right)$$

$$Q = \int dz \, \lambda^\alpha d_\alpha \qquad d_\alpha = p_\alpha + (\partial \not{X} \theta)_\alpha + (\theta \gamma \partial\theta)(\gamma \theta)_\alpha$$

$$\hat Q = \int d\bar z \, \hat\lambda^{\hat\alpha} \hat d_{\hat\alpha}$$

$$x^m,\ \theta^\alpha,\ \hat\theta^\beta,\ \lambda^\alpha,\ \hat\lambda^\beta$$

$$p_\alpha,\ \hat p_\beta,\ w_\alpha,\ \hat\omega_\beta$$

$$S = \int d^2z \left(\partial x^m \bar\partial x_m + p_\alpha \bar\partial \theta^\alpha + \omega_\alpha \bar\partial \lambda^\alpha + \hat p_\alpha \partial \hat\theta^\alpha + \hat\omega_\alpha \partial \hat\lambda^\alpha \right)$$

$$Q = \int dz\ \lambda^\alpha d_\alpha \qquad d_\alpha = p_\alpha + (\theta \gamma^m \theta)/_2 + (\theta \gamma^m \partial\theta)(\gamma_m \theta)_\alpha$$

$$\hat Q = \int d\bar z\ \hat\lambda^\alpha \hat d_\alpha \qquad d_\alpha(y) d_\beta(z) \to \frac{1}{y-z} \Pi^m \gamma_{m\alpha\beta}$$

$$\Pi^m = \partial x^m + \theta \gamma^m \partial \theta$$

$$Q = \lambda^\alpha D_\alpha \quad \longleftarrow \quad V = \lambda^\alpha A_\alpha(x,\theta)$$

SYM spinor gauge superfield

$$\uparrow$$

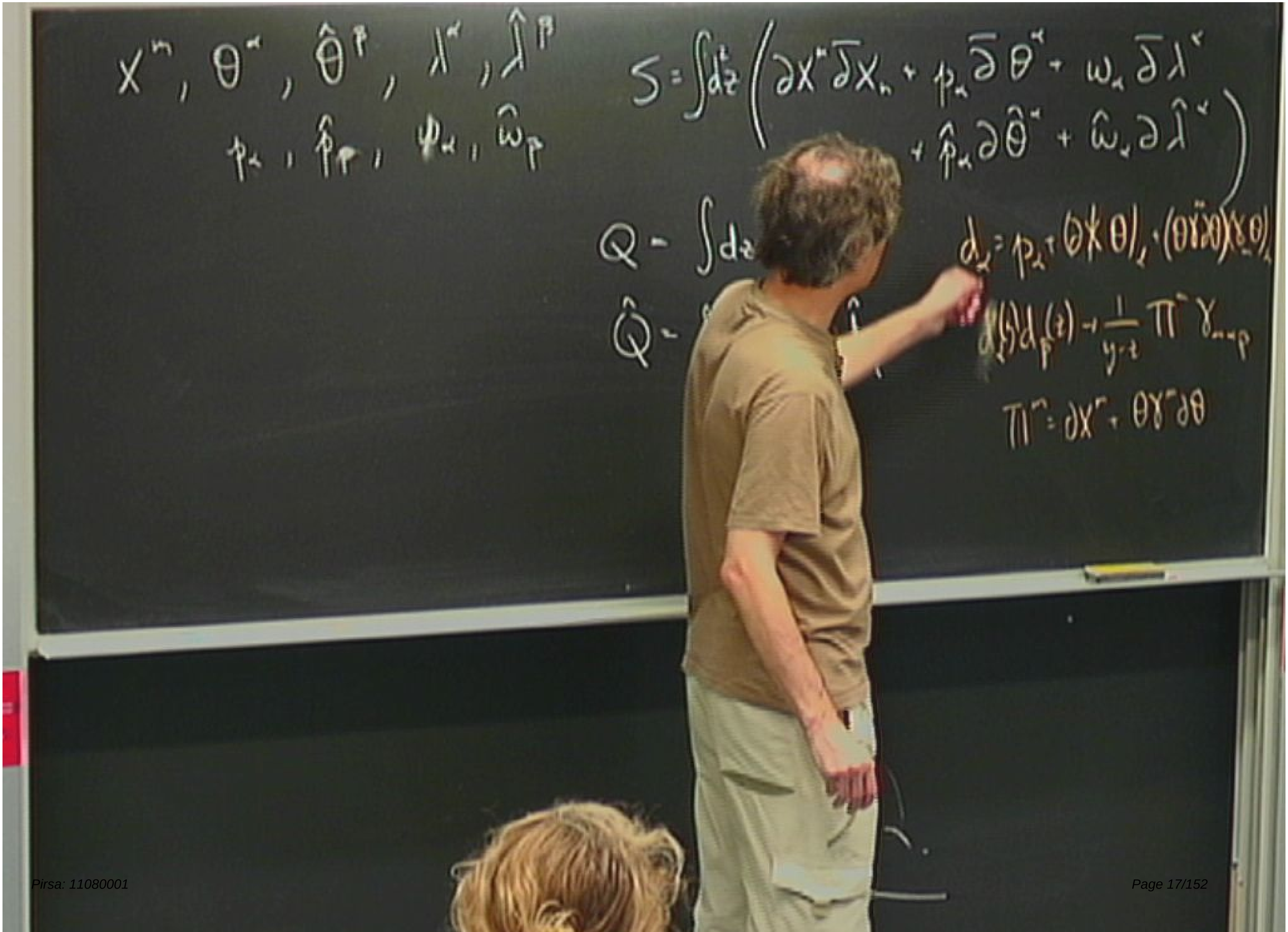
$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha \left(p_\alpha + (\not{\partial}\theta)_\alpha\right)$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot{\theta}^\alpha + A_m \dot{x}^m + W^\alpha d_\alpha + F^{mn}(w\gamma_{mn}\lambda)\right)$$

$\uparrow$ Lorentz current

$$S_0 = \int d\tau \left(\dot{x}^m P_m + \dot{\theta}^\alpha p_\alpha + \dot{\lambda}^\alpha w_\alpha + P^2 + \dot{\theta}^\alpha d_\alpha\right)$$


X^m, θ^α, θ̂^β, λ^α, λ̂^β
p_α, p̂_β, w_α, ŵ_β
S = ∫d²z (∂X^m ∂̄X_m + p_α ∂̄θ^α + w_α ∂̄λ^α + p̂_α ∂θ̂^α + ŵ_α ∂λ̂^α)
Q =
Q̂ =
Π^m = ∂X^m + θγ^m∂θ

$X^m, \theta^\alpha, \hat\theta^{\hat\beta}, \lambda^\alpha, \hat\lambda^{\hat\beta}$

$p_\alpha, \hat p_{\hat\alpha}, w_\alpha, \hat w_{\hat\beta}$

$$S = \int d^2z \left(\partial X^m \bar\partial X_m + p_\alpha \bar\partial \theta^\alpha + w_\alpha \bar\partial \lambda^\alpha + \hat p_\alpha \partial \hat\theta^\alpha + \hat w_\alpha \partial \hat\lambda^\alpha \right)$$

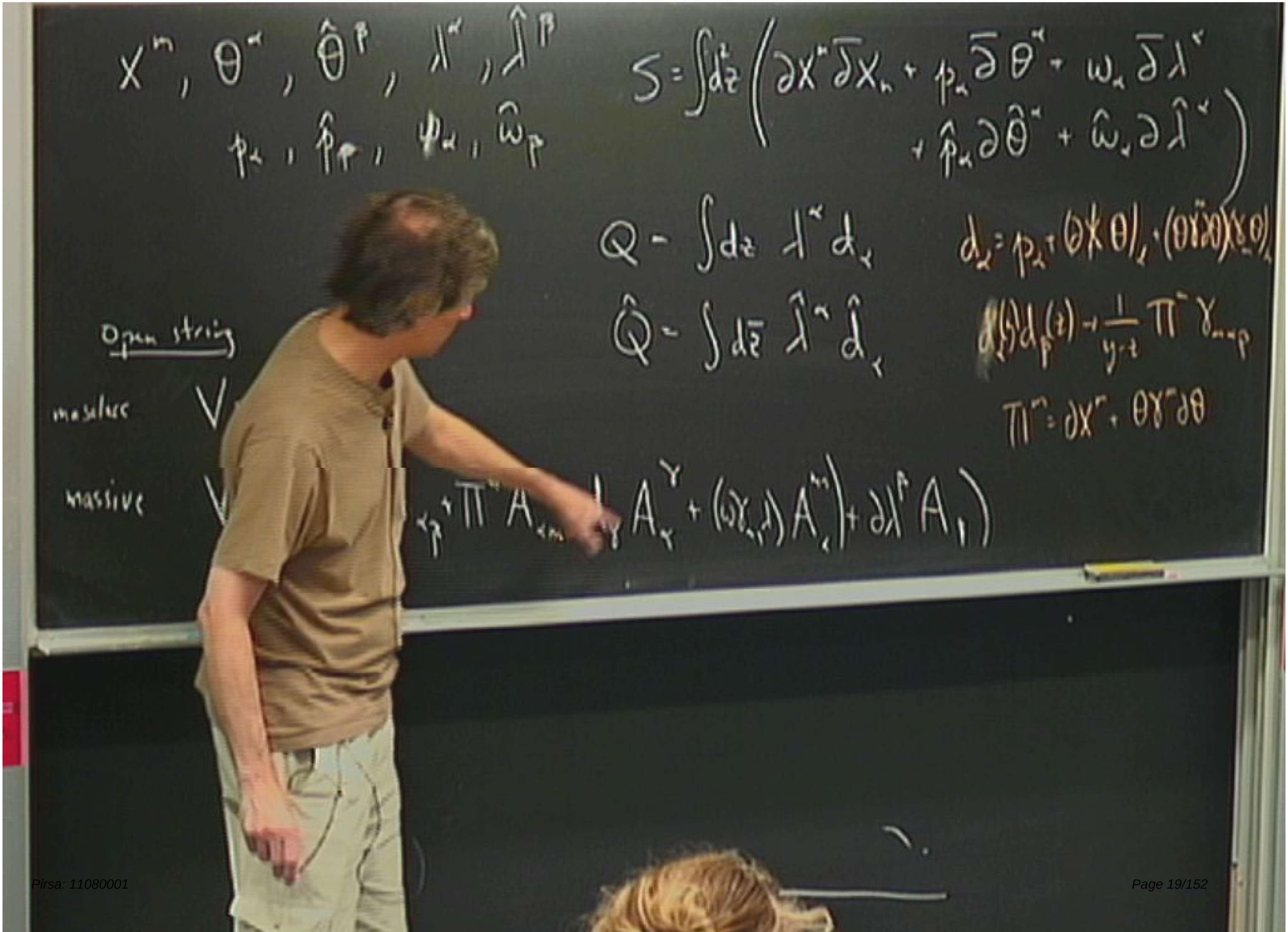
$$Q = \int dz\, \lambda^\alpha d_\alpha \qquad d_\alpha = p_\alpha + (\partial X^m \gamma_m \theta)_\alpha + (\theta \gamma^m \partial\theta)(\gamma_m \theta)_\alpha$$

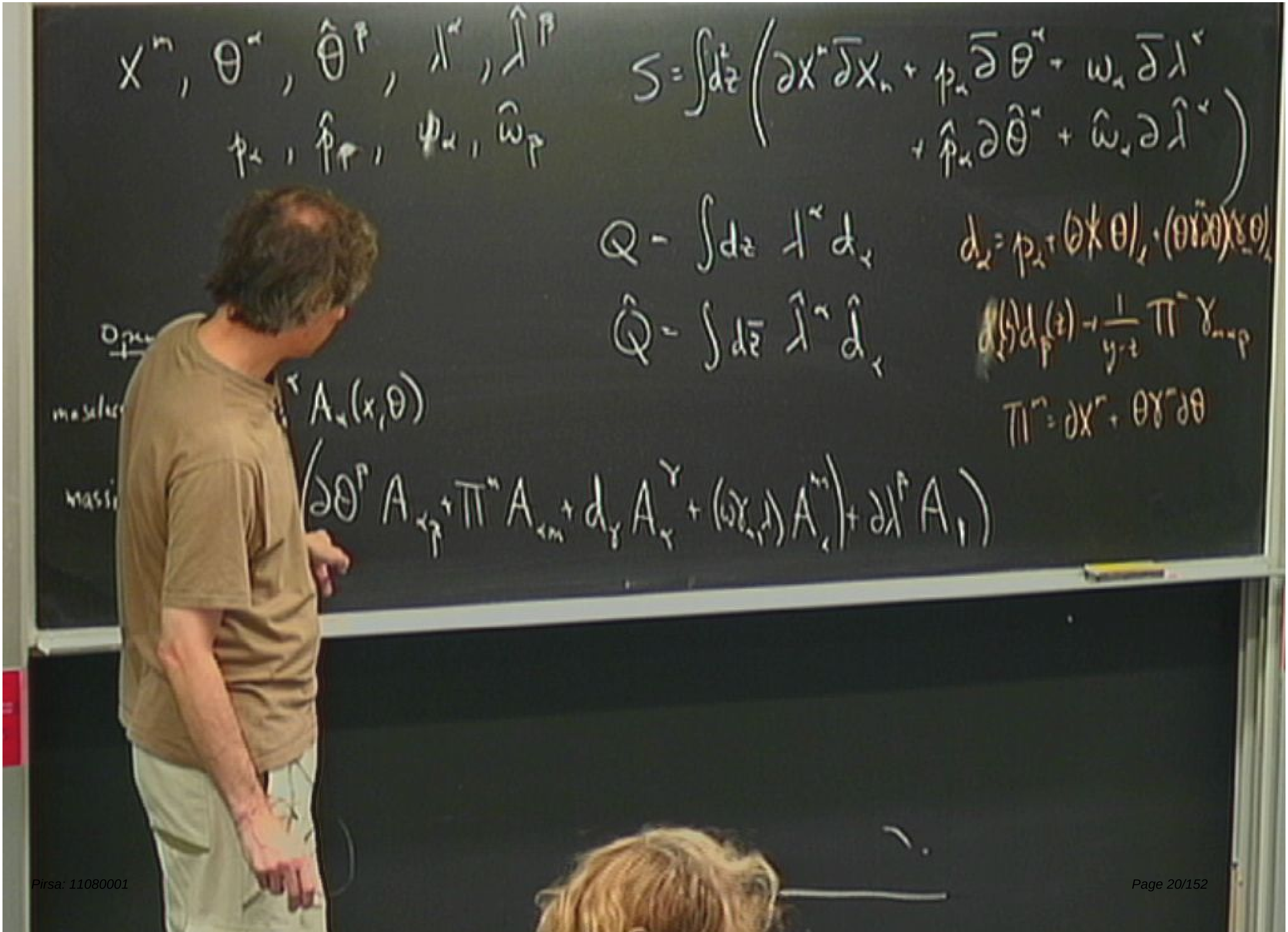
$$\hat Q = \int d\bar z\, \hat\lambda^\alpha \hat d_\alpha \qquad d_\alpha(y) d_\beta(z) \to \frac{1}{y-z} \Pi^m \gamma_{m\alpha\beta}$$

$$\Pi^m = \partial X^m + \theta \gamma^m \partial \theta$$

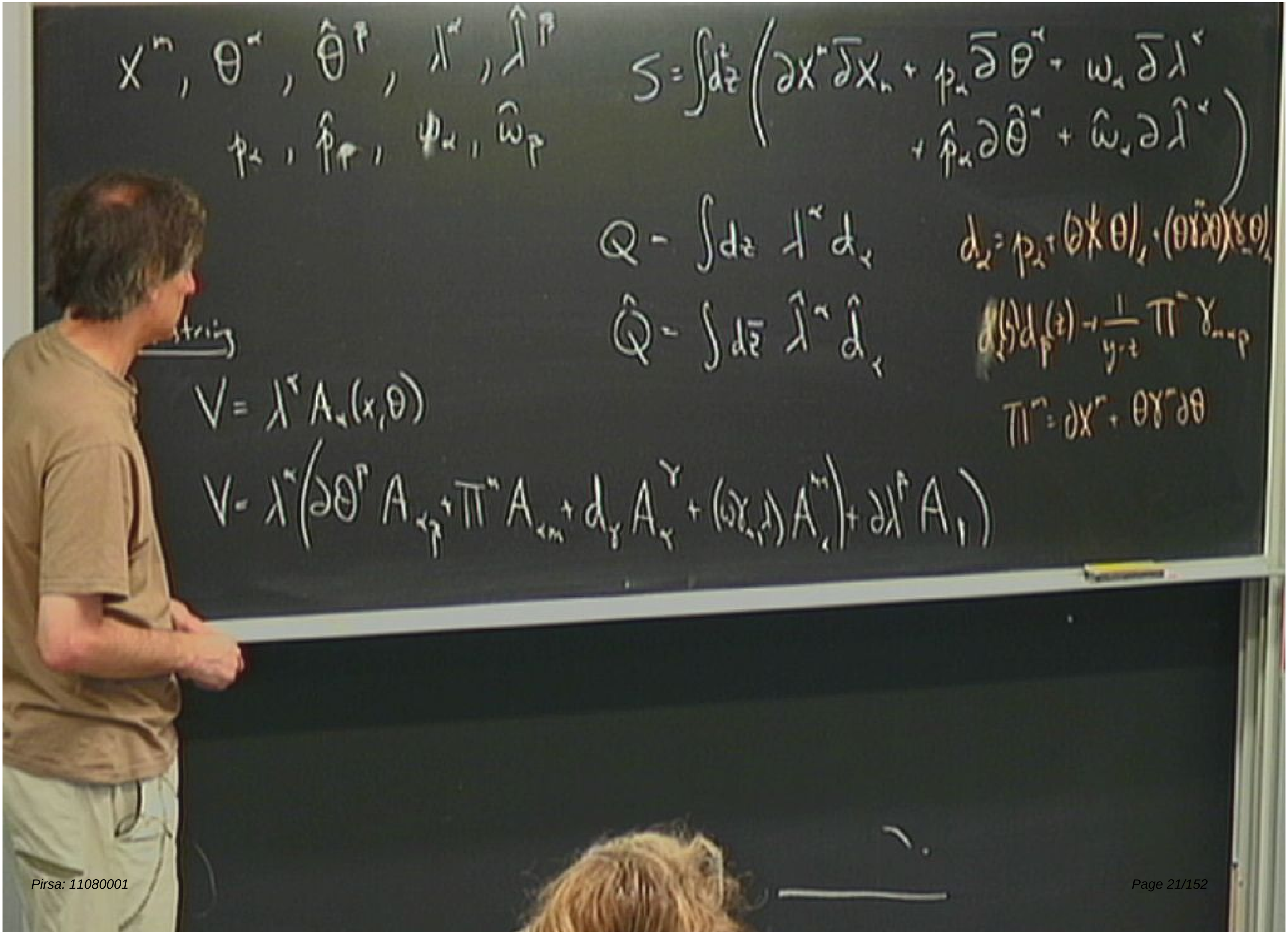
massless $\quad V = \lambda^\alpha A_\alpha(x,\theta)$

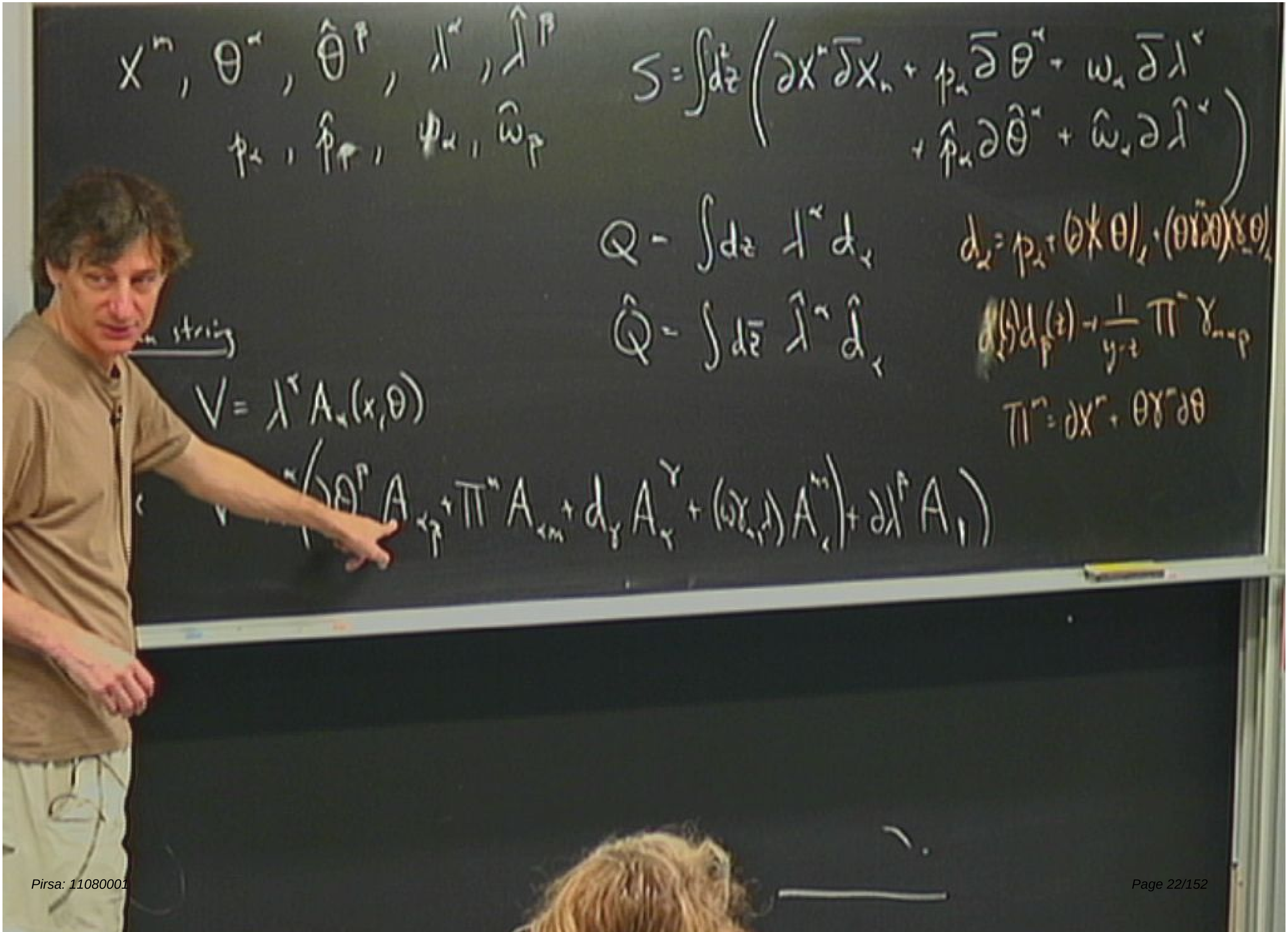
massive


Open string
massless
massive



x^m, θ^α, θ̂^β, λ^α, λ̂^β
p_α, p̂_β, w_α, ŵ_β
S = ∫d²z (∂x^m ∂̄x_m + p_α ∂̄θ^α + w_α ∂̄λ^α + p̂_α ∂θ̂^α + ŵ_α ∂λ̂^α)
Q = ∫dz λ^α d_α
Q̂ = ∫dz̄ λ̂^α d̂_α
Π^m = ∂x^m + θγ^m∂θ


$x^m, \theta^\alpha, \hat\theta^{\hat\alpha}, \lambda^\alpha, \hat\lambda^{\hat\alpha}$
$p_\alpha, \hat p_{\hat\alpha}, w_\alpha, \hat w_{\hat\alpha}$
$S = \int d^2z \left(\partial x^m \bar\partial x_m + p_\alpha \bar\partial \theta^\alpha + w_\alpha \bar\partial \lambda^\alpha + \hat p_\alpha \partial \hat\theta^\alpha + \hat w_\alpha \partial \hat\lambda^\alpha \right)$
$Q = \int dz\, \lambda^\alpha d_\alpha$
$\hat Q = \int d\bar z\, \hat\lambda^\alpha \hat d_\alpha$
$V = \lambda^\alpha A_\alpha(x,\theta)$
$V = \lambda^\alpha \left(\partial\theta^\beta A_{\alpha\beta} + \Pi^m A_{\alpha m} + d_\gamma A_\alpha^\gamma + (\omega\gamma_{mn}\lambda) A_\alpha^{mn} \right) + \partial\lambda^\beta A_\beta$
$\Pi^m = \partial x^m + \theta\gamma^m\partial\theta$


$X^m, \theta^\alpha, \hat\theta^\beta, \lambda^\alpha, \hat\lambda^\beta$
$p_\alpha, \hat p_\beta, w_\alpha, \hat w_\beta$
$S = \int d^2z \left(\partial X^m \bar\partial X_m + p_\alpha \bar\partial \theta^\alpha + w_\alpha \bar\partial \lambda^\alpha + \hat p_\alpha \partial \hat\theta^\alpha + \hat w_\alpha \partial \hat\lambda^\alpha \right)$
$Q = \int dz\, \lambda^\alpha d_\alpha$
$\hat Q = \int d\bar z\, \hat\lambda^\alpha \hat d_\alpha$
$\Pi^m = \partial X^m + \theta\gamma^m\partial\theta$
$V = \lambda^\alpha A_\alpha(x,\theta)$

$X^m, \theta^\alpha, \hat\theta^{\hat\beta}, \lambda^\alpha, \hat\lambda^{\hat\beta}$

$p_\alpha, \hat p_{\hat\alpha}, w_\alpha, \hat w_{\hat\beta}$

$$S = \int d^2z \left(\partial X^m \bar\partial X_m + p_\alpha \bar\partial \theta^\alpha + w_\alpha \bar\partial \lambda^\alpha + \hat p_\alpha \partial \hat\theta^\alpha + \hat w_\alpha \partial \hat\lambda^\alpha \right)$$

w_α

$$Q = \int dz\, \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + (\theta \gamma^m \theta)_\alpha + (\theta\gamma^m \partial\theta)(\gamma_m \theta)_\alpha$$

$$\hat Q = \int d\bar z\, \hat\lambda^\alpha \hat d_\alpha$$

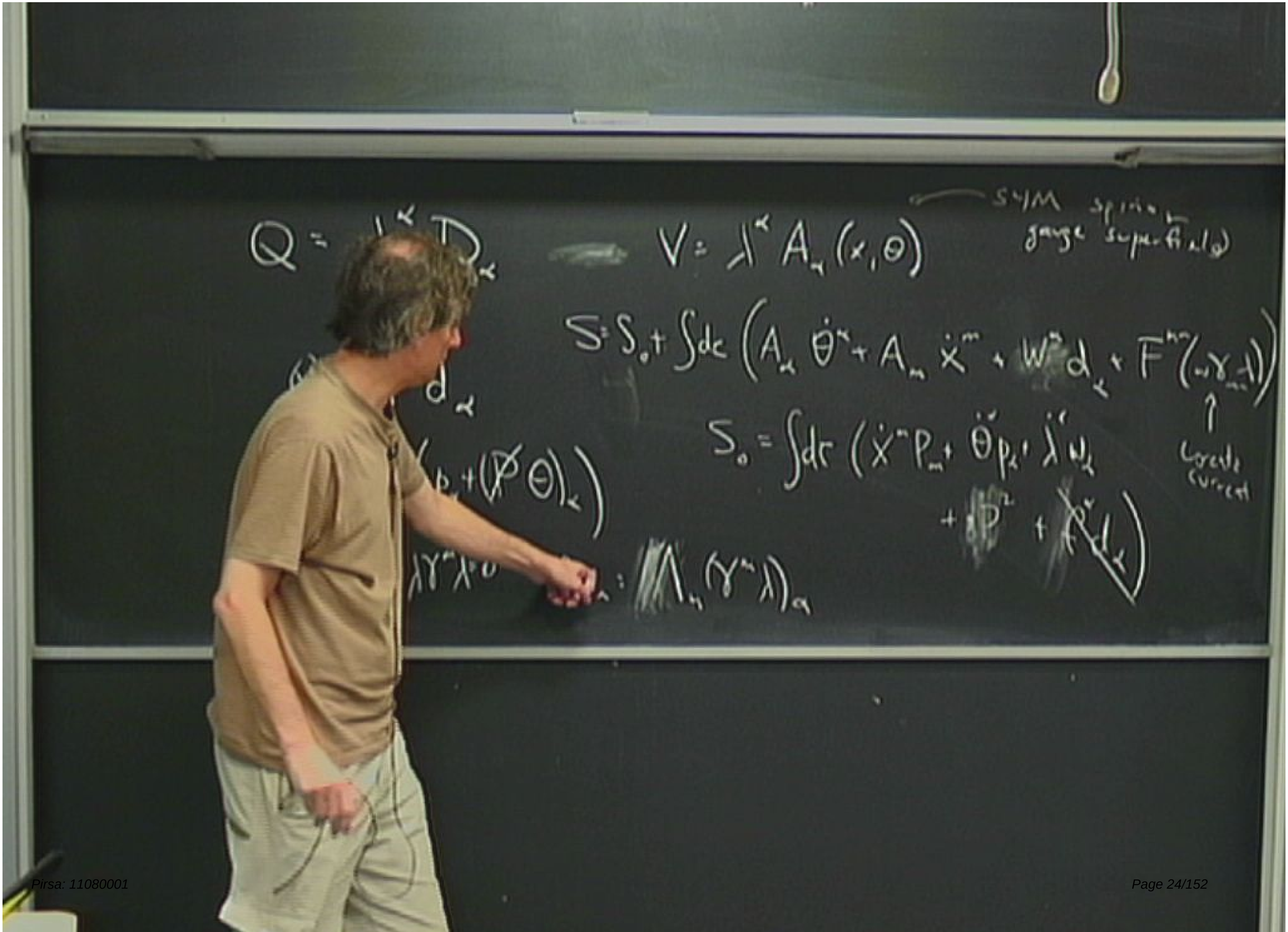
$$d_\alpha(y) d_\beta(z) \to \frac{1}{y-z} \Pi^m \gamma_{m\alpha\beta}$$

$$\Pi^m = \partial X^m + \theta \gamma^m \partial \theta$$

Open string

massless $V = \lambda^\alpha A_\alpha(x,\theta)$

massive $V = \lambda^\alpha \left(\partial\theta^\beta A^{(\partial)}_{\alpha\beta} + \Pi^m A_{\alpha m} + d_\gamma A_\alpha^\gamma + (w\gamma_{mn}\lambda) A_\alpha^{mn} \right) + \partial\lambda^\beta A_\beta$


SYM spinor gauge superfield(s)
Lorentz current

SYM spinor gauge superfield

$$Q = \lambda^\alpha D_\alpha \quad V = \lambda^\alpha A_\alpha(x,\theta)$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn} (\omega \gamma_{mn} \lambda) \right)$$

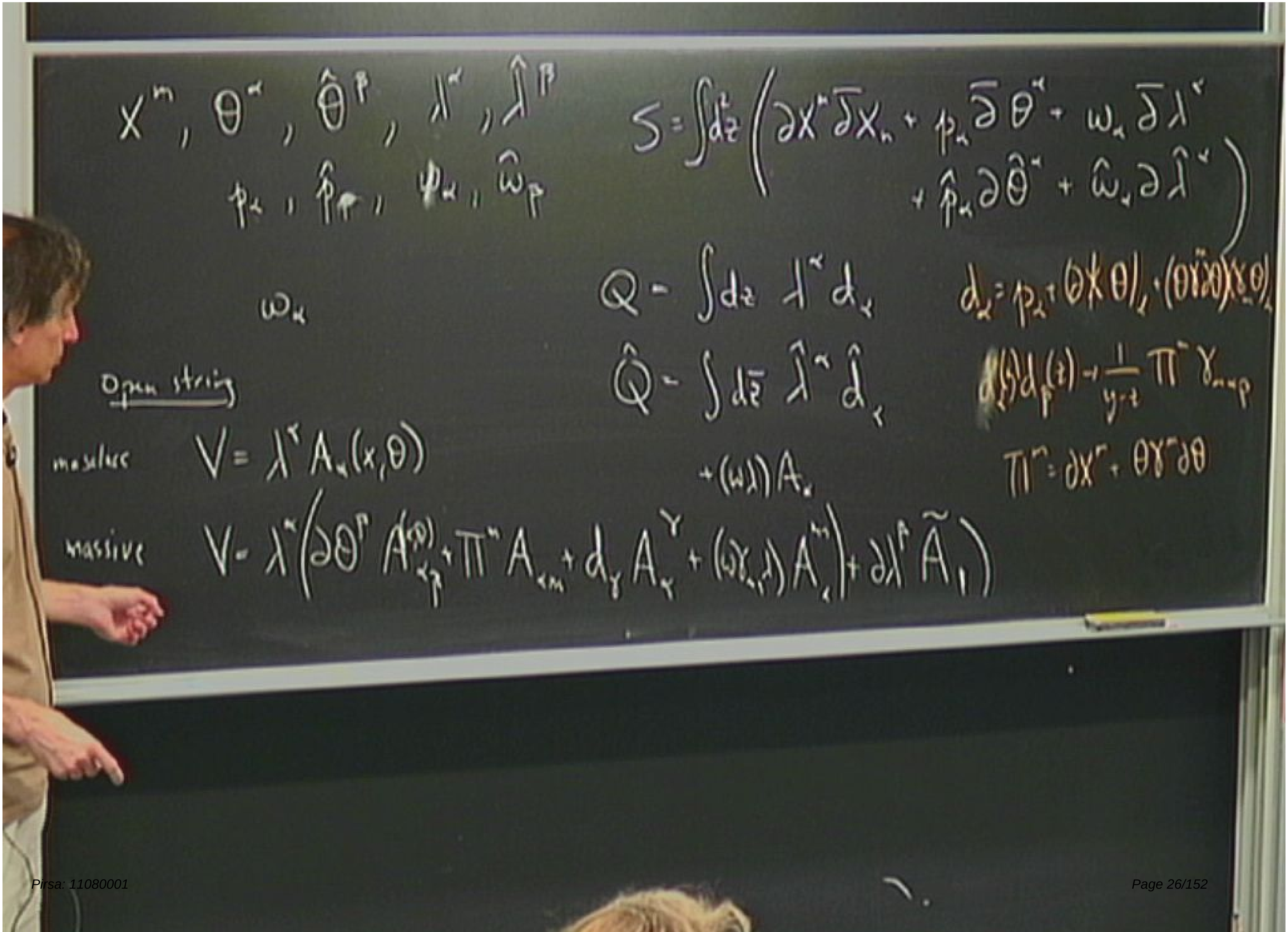
Lorentz current

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha \left(p_\alpha + (\not{P}\theta)_\alpha \right)$$

$$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta p_\alpha + \dot\lambda^\alpha \omega_\alpha + P^2 + \dot\theta^\alpha d_\alpha \right)$$

$$\lambda \gamma^m \lambda = 0 \quad \delta\omega_\alpha = \Lambda_m (\gamma^m \lambda)_\alpha \to (\omega \gamma^{mn} \lambda), \; \omega_\alpha \lambda^\alpha$$


X^m, θ^α, θ̂^β, λ^α, λ̂^β
p_α, p̂_α, ω_α, ω̂_β
S = ∫d²z (∂X^m ∂̄X_m + p_α ∂̄θ^α + ω_α ∂̄λ^α + p̂_α ∂θ̂^α + ω̂_α ∂λ̂^α)
Q = ∫dz λ^α d_α
Q̂ = ∫dz̄ λ̂^α d̂_α
d_α = p_α + (θγ^m θ)...
d_α(y) d_β(z) → 1/(y−z) Π^m γ_mαβ
Π^m = ∂X^m + θγ^m ∂θ
Open string
massless
V = λ^α A_α(x, θ)
+ (ωλ) A_α
massive
V = λ^α (∂θ^β A_αβ + Π^m A_αm + d_γ A_α^γ + (ωγ_mn λ) A_α^mn) + ∂λ^β Ã_β

$X^m, \theta^\alpha, \hat\theta^\beta, \lambda^\alpha, \hat\lambda^\beta$

$p_\alpha, \hat p_\beta, w_\alpha, \hat w_\beta$

$$S = \int d^2z \left(\partial X^m \bar\partial X_m + p_\alpha \bar\partial \theta^\alpha + w_\alpha \bar\partial \lambda^\alpha + \hat p_\alpha \partial \hat\theta^\alpha + \hat w_\alpha \partial \hat\lambda^\alpha \right)$$

w_α

$$Q = \int dz\, \lambda^\alpha d_\alpha \qquad d_\alpha = p_\alpha + (\theta \gamma^m \theta)_\alpha + (\theta \gamma^m \partial\theta)(\gamma_m \theta)_\alpha$$

$$\hat Q = \int d\bar z\, \hat\lambda^\alpha \hat d_\alpha \qquad d_\alpha(y) d_\beta(z) \to \frac{1}{y-z} \Pi^m \gamma_{m\alpha\beta}$$

Open string

massless $V = \lambda^\alpha A_\alpha(x, \theta)$

$+ (w\lambda) A_\alpha$

$$\Pi^m = \partial X^m + \theta \gamma^m \partial \theta$$

massive $V = \lambda^\alpha \left(\partial\theta^\beta A^{(\theta)}_{\alpha\beta} + \Pi^m A_{\alpha m} + d_\gamma A^\gamma_\alpha + (w\gamma_{mn}\lambda) A^{mn}_\alpha \right) + \partial\lambda^\beta \tilde A_\beta \Big), \; QV = 0 +$

$$X^m,\ \theta^\alpha,\ \hat\theta^\beta,\ \lambda^\alpha,\ \hat\lambda^\beta$$
$$p_\alpha,\ \hat p_\beta,\ \omega_\alpha,\ \hat\omega_\beta$$

$$S = \int d^2z \left(\partial x^m \bar\partial x_m + p_\alpha \bar\partial \theta^\alpha + \omega_\alpha \bar\partial \lambda^\alpha + \hat p_\alpha \partial \hat\theta^\alpha + \hat\omega_\alpha \partial \hat\lambda^\alpha \right)$$

ω_α

$$Q = \int dz\ \lambda^\alpha d_\alpha \qquad d_\alpha = p_\alpha + (\theta \gamma \theta)_\alpha + (\theta \ldots$$

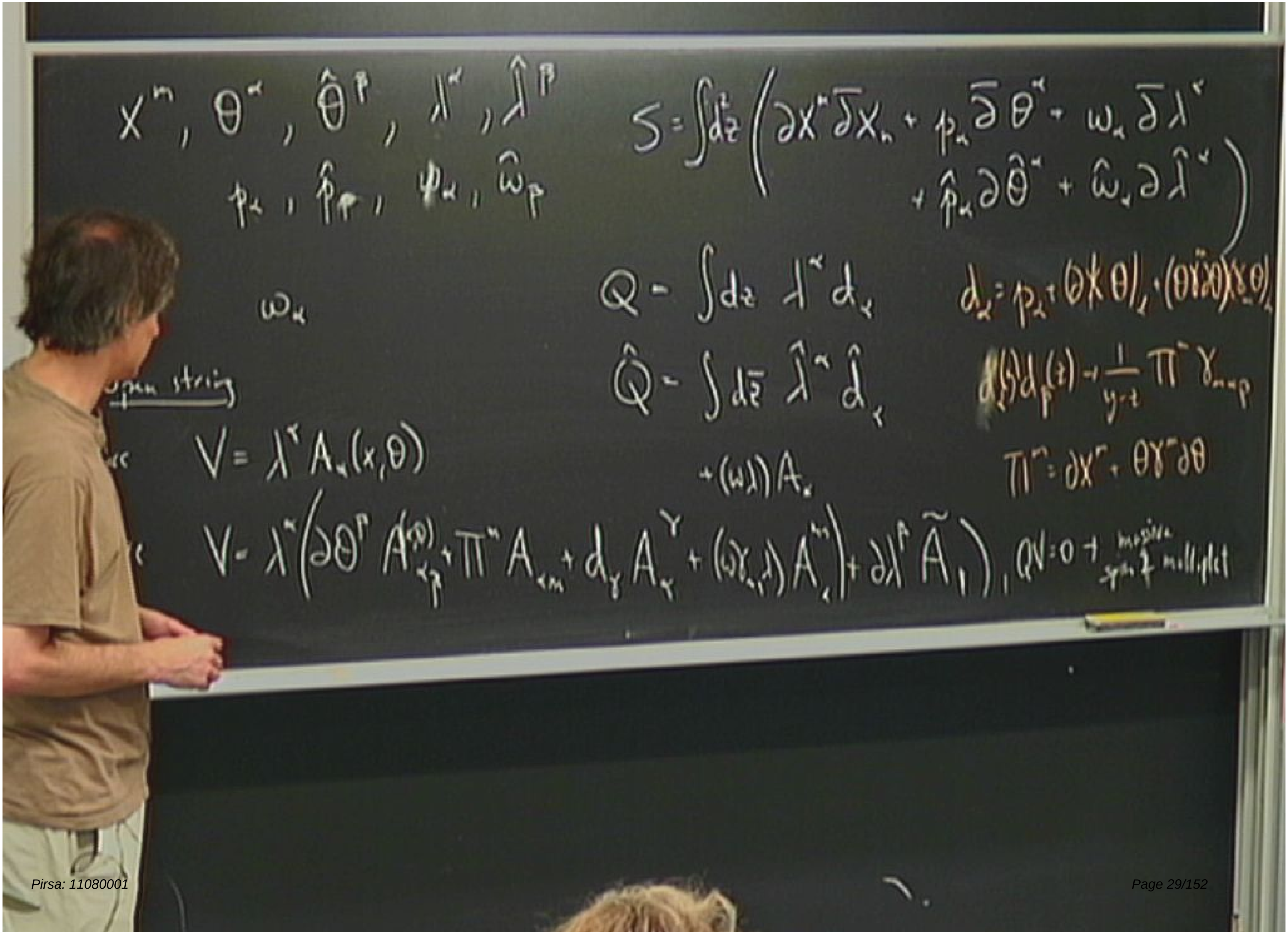
$$\hat Q = \int d\bar z\ \hat\lambda^\alpha \hat d_\alpha \qquad d_\alpha(y) d_\beta(z) \to \frac{1}{y-z} \Pi^m \gamma_{m\alpha\beta}$$

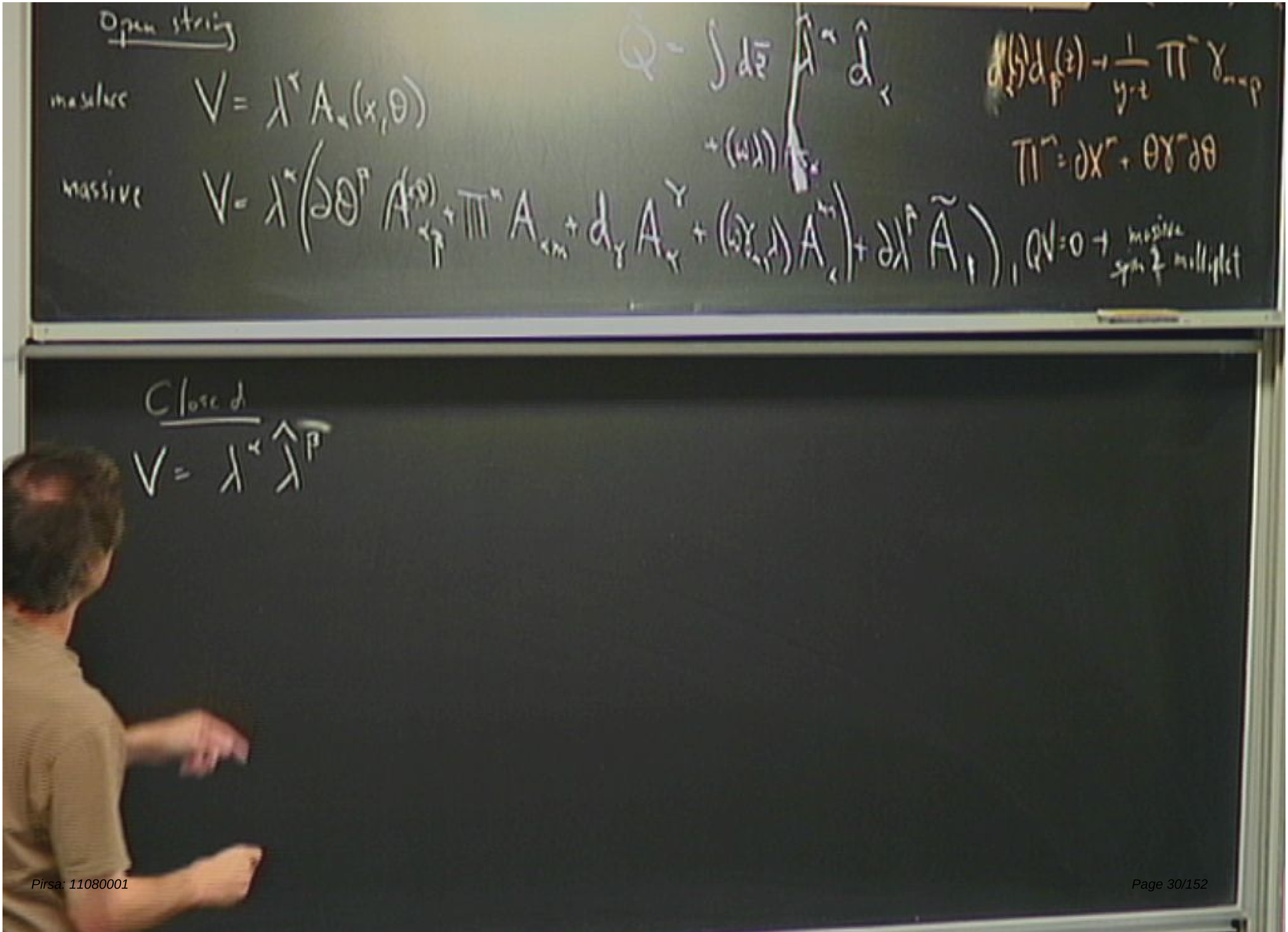
$$\Pi^m = \partial x^m + \theta \gamma^m \partial \theta$$

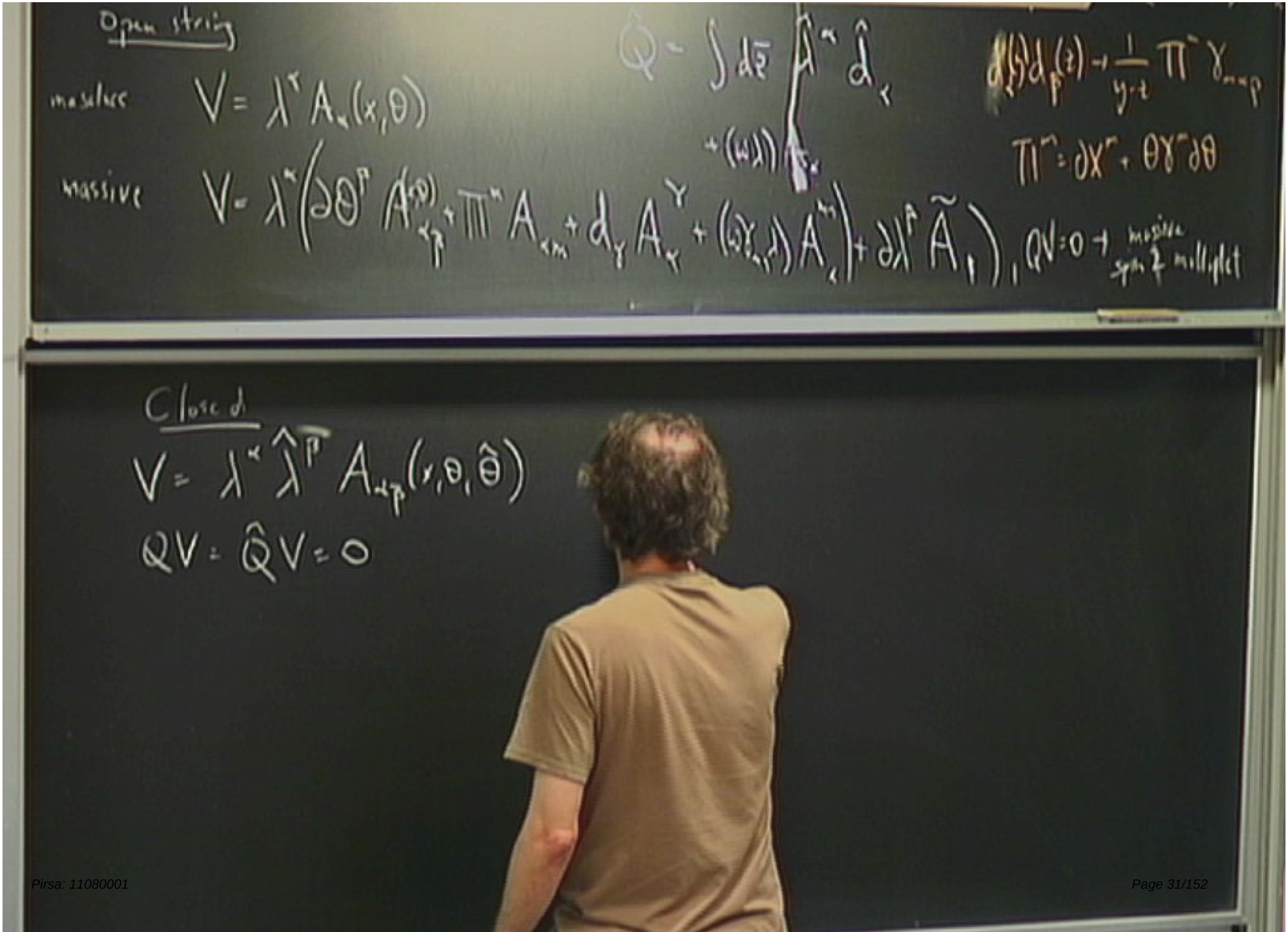
Open string

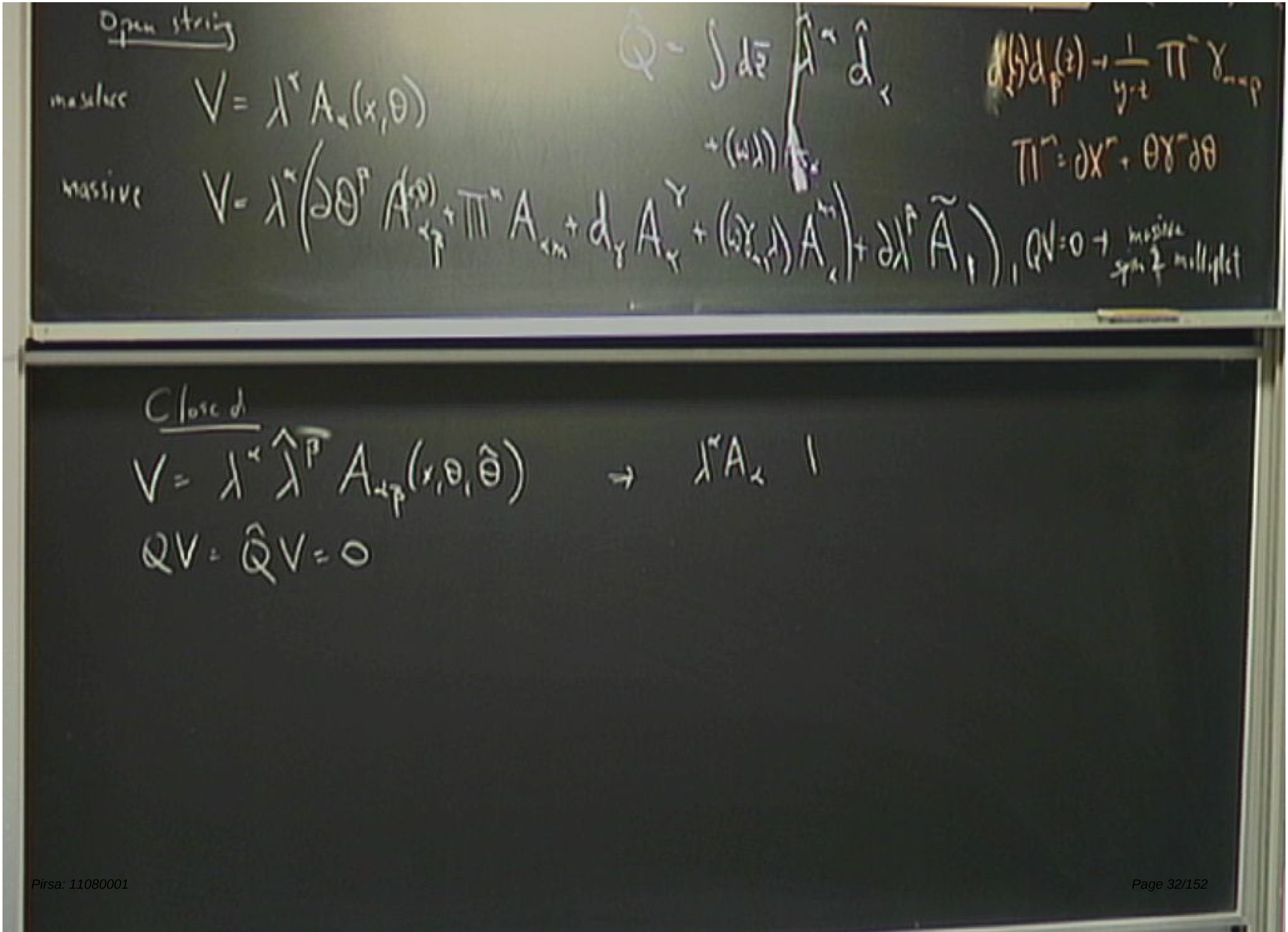
massless $\quad V = \lambda^\alpha A_\alpha(x,\theta) \qquad + (\omega\lambda) A_\alpha$

massive $\quad V = \lambda^\alpha \left(\partial\theta^\beta A^{(\beta)}_{\alpha\beta} + \Pi^m A_{\alpha m} + d_\gamma A_\alpha^\gamma + (\omega \gamma_{\ldots} \lambda) A_\alpha^{mn} \right) + \partial\lambda^\beta \tilde A_\beta \Big),\ QV = 0 \to$ massive spin 2 multiplet


$X^m, \theta^\alpha, \hat\theta^\beta, \lambda^\alpha, \hat\lambda^\beta$
$p_\alpha, \hat p_\beta, \omega_\alpha, \hat\omega_\beta$
$S = \int d^2z \left(\partial X^m \bar\partial X_m + p_\alpha \bar\partial \theta^\alpha + \omega_\alpha \bar\partial \lambda^\alpha + \hat p_\alpha \partial \hat\theta^\alpha + \hat\omega_\alpha \partial \hat\lambda^\alpha\right)$
ω_α
$Q = \int dz\, \lambda^\alpha d_\alpha$
$\hat Q = \int d\bar z\, \hat\lambda^\alpha \hat d_\alpha$
$\Pi^m = \partial X^m + \theta\gamma^m\partial\theta$
open string
$V = \lambda^\alpha A_\alpha(x,\theta)$
$+(\omega\lambda)A_\alpha$
$QV = 0$


Open string
massless V = λ^α A_α(x,θ)
massive
QV = 0 → massive spin 2 multiplet
Π^m = ∂X^m + θγ^m∂θ
Closed
V = λ^α λ̂^β


Open string
massless
massive
Closed
QV = Q̂V = 0
QV = 0 → massive spin 2 multiplet


Open string
massless $V = \lambda^\alpha A_\alpha(x,\theta)$
massive $V = \lambda^\alpha\left(\partial\theta^\beta A_{\alpha\beta}(x,\theta) + \Pi^m A_{\alpha m} + d_\gamma A_\alpha^\gamma + (\omega\gamma_{mn}\lambda) A_\alpha^{mn}\right) + \partial\lambda^\beta \tilde{A}_\beta)$, $QV = 0 \to$ massive spin 2 multiplet
$\hat{Q} = \int d\bar{z}\, \hat{\lambda}^\alpha \hat{d}_\alpha$
$+ (w\lambda)$
$d_\alpha(y) d_\beta(z) \to \frac{1}{y-z} \Pi^m \gamma_{m\alpha\beta}$
$\Pi^m = \partial X^m + \theta\gamma^m\partial\theta$
Closed
$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x,\theta,\hat{\theta}) \to \lambda^\alpha A_\alpha$
$QV = \hat{Q}V = 0$

Open string

$$\hat{Q} = \int d\bar{z}\, \hat{\lambda}^{\alpha} \hat{d}_{\alpha} + (\hat{w}\hat{\lambda})\ldots$$

$$d_{\alpha}(y) d_{\beta}(z) \to \frac{1}{y-z} \Pi^{m} \gamma_{m\,\alpha\beta}$$

$$\Pi^{m} = \partial X^{m} + \theta \gamma^{m} \partial \theta$$

massless $V = \lambda^{\alpha} A_{\alpha}(x,\theta)$

massive $V = \lambda^{\alpha}\left(\partial\theta^{\beta} A_{\alpha\beta}(x,\theta) + \Pi^{m} A_{\alpha m} + d_{\gamma} A_{\alpha}^{\gamma} + (w \gamma_{mn} \lambda) A_{\alpha}^{mn}\right) + \partial\lambda^{\beta} \tilde{A}_{\beta}$, $QV = 0 \to$ massive spin 2 multiplet

Closed

$$V = \lambda^{\alpha} \hat{\lambda}^{\beta} A_{\alpha\beta}(x,\theta,\hat{\theta}) \quad \to \quad \lambda^{\alpha} \hat{\lambda}^{\beta} \left(A_{\alpha} \text{ "}\times\text{" } \hat{A}_{\beta}\right)$$

$$QV = \hat{Q}V = 0$$

$$A_\alpha(x,\theta) = a_m(\gamma^m\theta)_\alpha + (\theta\gamma^{mnp}\theta)(\gamma_{mnp}\chi)_\alpha + \ldots$$

$$Q = \lambda^\alpha D_\alpha \qquad V = \lambda^\alpha A_\alpha(x,\theta)$$

← SYM spinor gauge superfield

$$\uparrow$$

$$Q = \lambda^\alpha d_\alpha = \lambda^\alpha\left(p_\alpha + (\not{\partial}\theta)_\alpha\right)$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot{x}^m + W^\alpha d_\alpha + F^{mn}(w\gamma_{mn}\lambda)\right)$$

↑ Lorentz current

$$S_0 = \int d\tau \left(\dot{x}^m P_m + \dot\theta p_\alpha + \dot\lambda w_\alpha + P^2 + \ldots\right)$$

$$\lambda\gamma^m\lambda = 0 \qquad \delta w_\alpha = \Lambda_m(\gamma^m\lambda)_\alpha \to (w\gamma^{mn}\lambda),\ w_\alpha\lambda^\alpha$$

Closed

$$V = \lambda^{\alpha} \hat{\lambda}^{\beta} A_{\alpha\beta}(x, \theta, \hat{\theta}) \quad \Rightarrow \quad \lambda^{\alpha} \hat{\lambda}^{\beta} \left(A_{\alpha} \cdots \hat{A}_{\beta} \right)$$

$$QV = \hat{Q}V = 0 \qquad = \lambda^{\alpha} \hat{\lambda}^{\beta} \left(a_m \hat{a}_n (\gamma^m \theta)_{\alpha} (\gamma^n \hat{\theta})_{\beta} \right.$$

Closed

$$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x, \theta, \hat{\theta}) \quad \rightarrow \quad \lambda^\alpha \hat{\lambda}^\beta \left(A_\alpha \; \hat{A}_\beta \right)$$

$$QV = \hat{Q}V = 0 \qquad = \lambda^\alpha \hat{\lambda}^\beta \Big(a_m \hat{a}_n (\gamma^m \theta)_\alpha (\gamma^n \hat{\theta})_\beta$$

$$a_m \hat{\chi}^\gamma (\gamma^m \theta)_\alpha (\gamma^n \theta)_\gamma (\gamma_n \theta)_\beta$$

$$+ \chi a_n$$

$$+ \chi \hat{\chi}$$

$$A_\alpha(x,\theta) = a_m(\gamma^m\theta)_\alpha + (\gamma_n\theta)_\alpha(\chi\gamma^n\theta) + \ldots$$

$$Q = \lambda^\alpha D_\alpha \qquad V = \lambda^\alpha A_\alpha(x,\theta)$$

SYM spinor gauge superfield

$$\uparrow$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn}(\omega\gamma_{mn}\lambda) \right)$$

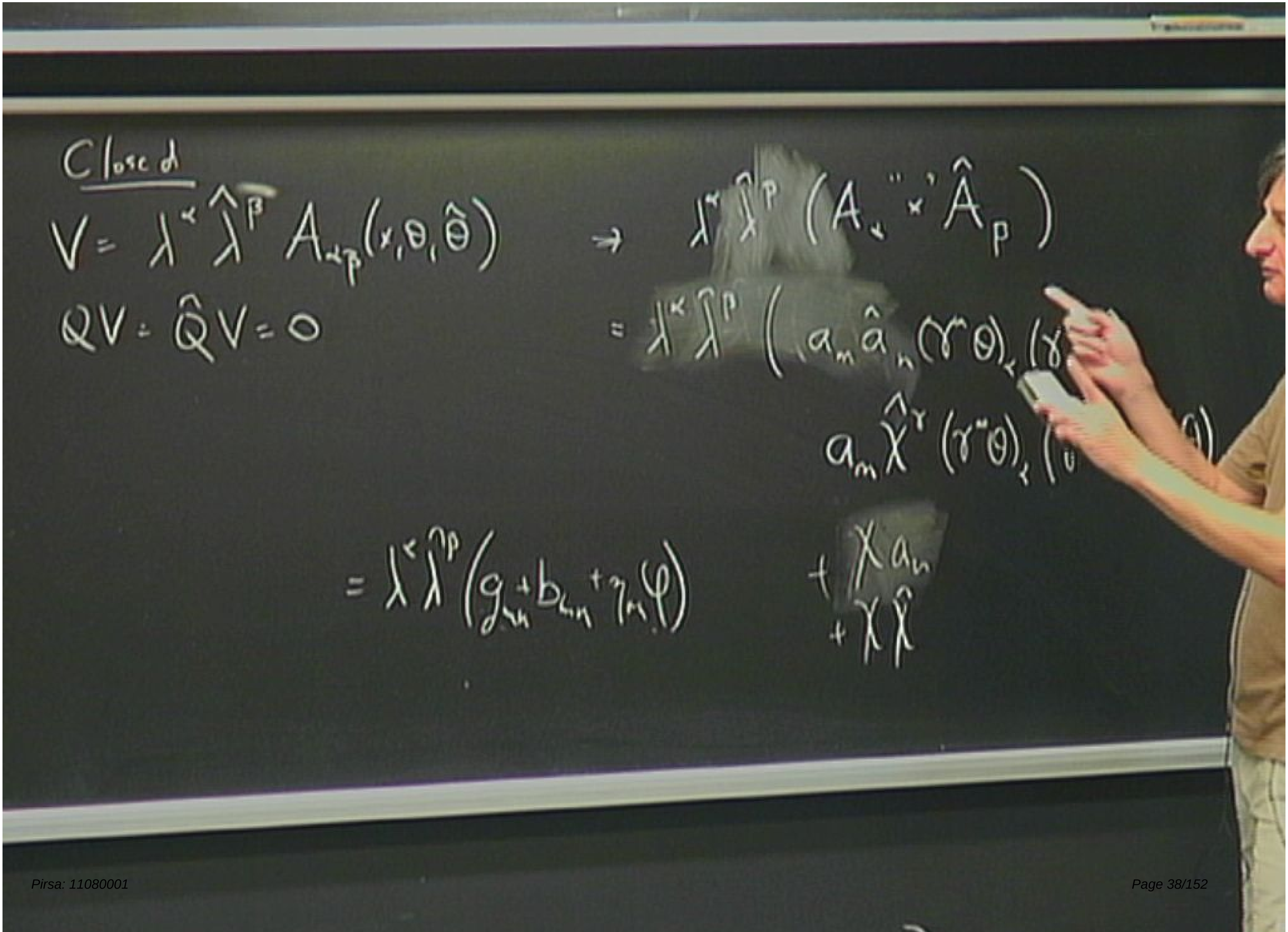
$$Q = \lambda^\alpha d_\alpha$$

Lorentz current

$$= \lambda^\alpha \left(p_\alpha + (\not{P}\theta)_\alpha \right)$$

$$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta^\alpha p_\alpha + \dot\lambda^\alpha w_\alpha + P^2 + \dot\theta^\alpha d_\alpha \right)$$

$$\lambda\gamma^m\lambda = 0 \qquad \delta w_\alpha = \Lambda_m(\gamma^m\lambda)_\alpha \to (\omega\gamma^{mn}\lambda),\ \omega_\alpha\lambda^\alpha$$


Closed
V = λ^α λ̂^β A_αβ(x, θ, θ̂)
QV = Q̂V = 0
= λ^α λ̂^β (g_mn + b_mn + η_m φ)
+ λ λ̂

Closed

$$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x,\theta,\hat{\theta}) \quad \Rightarrow \quad \lambda^\alpha \hat{\lambda}^\beta \left(A_\alpha^{(x)} \times \hat{A}_\beta^{(x)} \right)$$

$$QV = \hat{Q}V = 0$$

$$= \lambda^\alpha \hat{\lambda}^\beta \Big(a_m \hat{a}_n (\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\beta$$

$$a_m \hat{\chi}^\gamma (\gamma^m\theta)_\alpha (\gamma^n\theta)_\gamma (\gamma_n\theta)_\beta$$

$$= \lambda^\alpha \hat{\lambda}^\beta \Big[(g_{mn} + b_{mn} + \eta_{mn}\varphi)(\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\beta$$

Closed

$$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x,\theta,\hat{\theta}) \rightarrow \lambda^\alpha \hat{\lambda}^\beta \left(A(x) \times \hat{A}_\beta(x) \right)$$

$$QV = \hat{Q}V = 0$$

$$= \lambda^\alpha \hat{\lambda}^\beta \Big(a_m \hat{a}_n (\gamma^m \theta)_\alpha (\gamma^n \hat{\theta})_\beta$$

$$a_m \hat{\chi}^\gamma (\gamma^m \theta)_\alpha (\gamma^n \hat{\theta})_\gamma (\gamma_n \theta)_\beta + \ldots$$

$$+ \chi \hat{a} + \chi \hat{\chi}$$

$$= \lambda^\alpha \hat{\lambda}^\beta \Big[(g_{mn} + b_{mn} + \eta_{mn} \varphi)(\gamma^m \theta)_\alpha (\gamma^n \hat{\theta})_\beta$$

$$+ \psi_m^\gamma (\gamma^m \theta)_\alpha (\gamma^n \hat{\theta})_\gamma (\gamma_n \hat{\theta})_\beta + \hat{\psi} + \ldots$$

Closed

$$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x, \theta, \hat{\theta}) \quad \Rightarrow \quad \lambda^\alpha \hat{\lambda}^\beta \left(A_\alpha(x) \star \hat{A}_\beta(x) \right)$$

$$QV = \hat{Q}V = 0$$

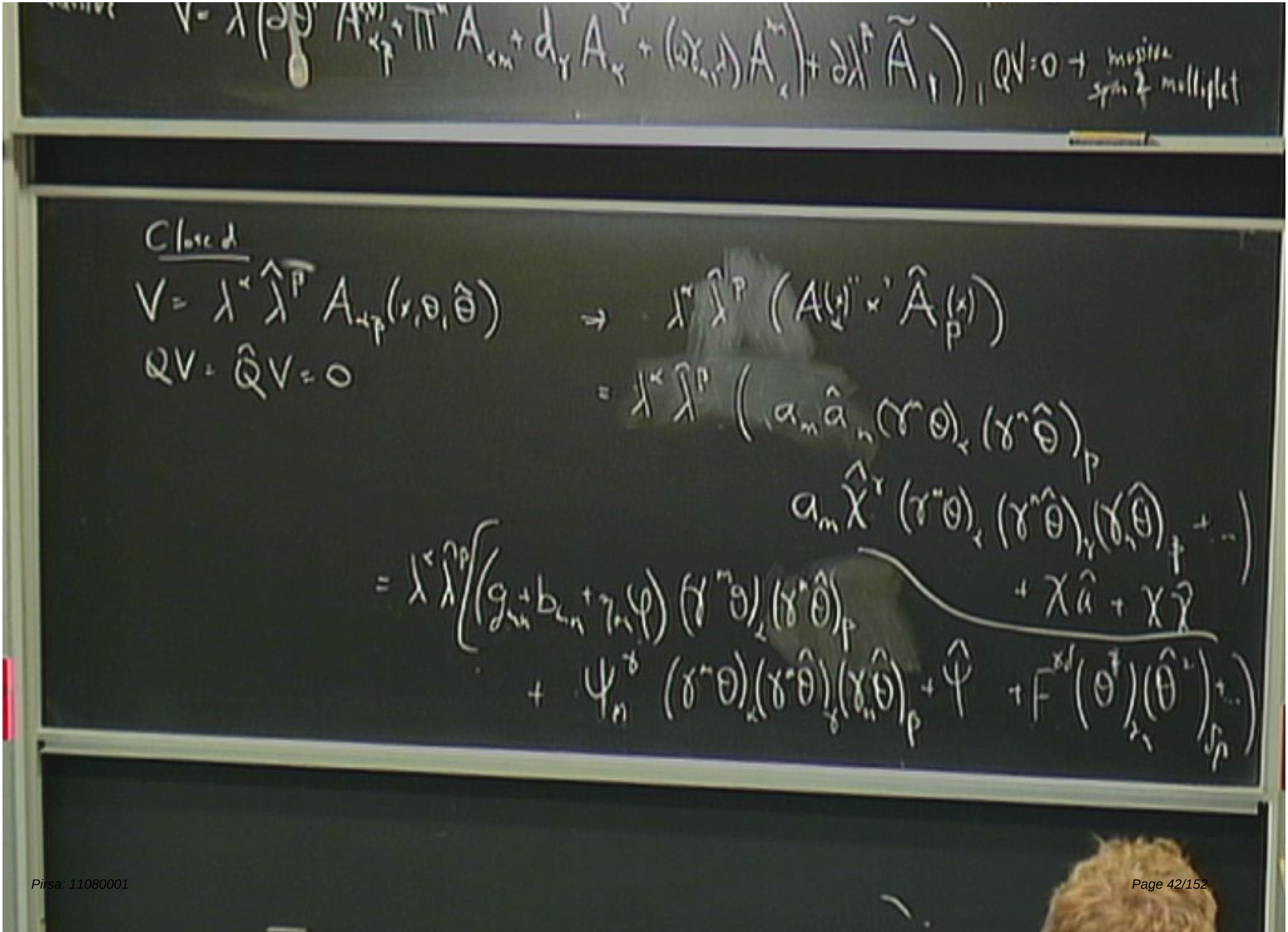
$$= \lambda^\alpha \hat{\lambda}^\beta \Big(a_m \hat{a}_n (\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\beta$$

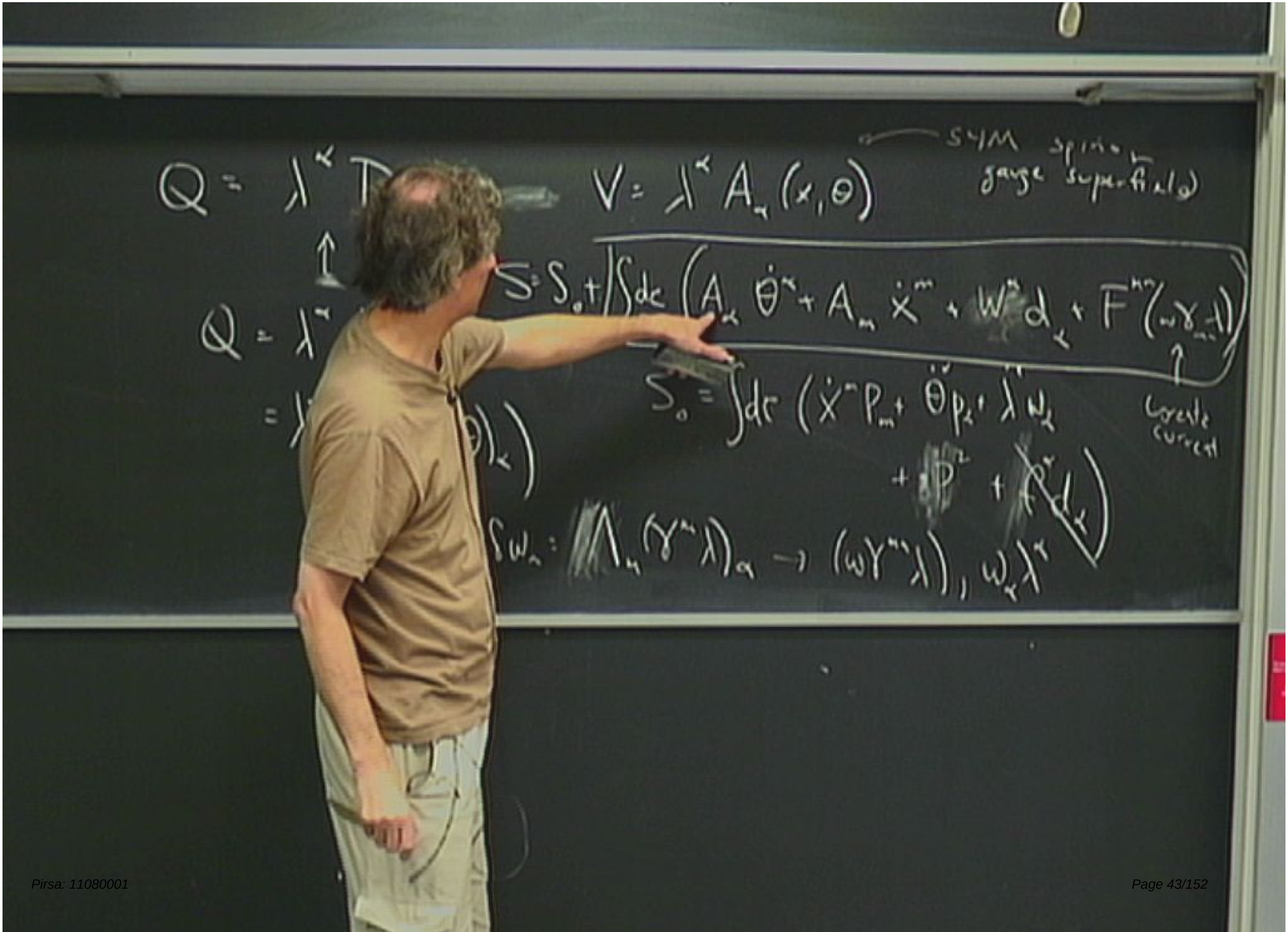
$$a_m \hat{\chi}^\gamma (\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\gamma (\gamma_n\hat{\theta})_\beta + \ldots \Big)$$

$$+ \chi\hat{a} + \chi\hat{\chi}$$

$$= \lambda^\alpha \hat{\lambda}^\beta \Big((g_{mn} + b_{mn} + \eta_{mn}\varphi)(\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\beta + \hat{\varphi} + F^{\gamma\delta}(\theta^\alpha)_{\gamma\alpha} (\hat{\theta}^\nu)_{\delta\beta} + \ldots$$

$$+ \psi_m^\gamma (\gamma^m\theta)_\alpha (\gamma^n\theta)_\gamma (\gamma_n\hat{\theta})_\beta \Big)$$


Closed
$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x,\theta,\hat{\theta})$
$QV = \hat{Q}V = 0$
$QV = 0 \rightarrow$ massive spin 2 multiplet


SYM spinor
gauge superfield
current

$$A_\alpha(x,\theta) = a_m(\gamma^m\theta)_\alpha + (\gamma_n\theta)_\alpha(\chi\gamma^n\theta) + \ldots$$

SYM spinor gauge superfield

$$Q = \lambda^\alpha D_\alpha \qquad V = \lambda^\alpha A_\alpha(x,\theta)$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn}(\omega\gamma_{mn}\lambda)\right)$$

Lorentz current

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha\left(p_\alpha + (\not P\theta)_\alpha\right)$$

$$S_0 = \int d\tau\left(\dot x^m P_m + \dot\theta p_\alpha + \dot\lambda \omega_\alpha + P^2 + \dot\theta^\alpha d_\alpha\right)$$

$$\lambda\gamma^m\lambda = 0 \qquad \delta\omega_\alpha = \Lambda_m(\gamma^m\lambda)_\alpha \rightarrow (\omega\gamma^{mn}\lambda),\ \omega_\alpha\lambda^\alpha$$

$$S = S_0 + \int dz\, d\bar{z} \left(G_{MN} + B_{MN} \right.$$

$M = m, \alpha, \hat{z}$

$Q = \lambda^\alpha D_\alpha$ — $V = \lambda^\alpha A_\alpha(x,\theta)$ ← SYM spinor gauge superfield

$\uparrow$

$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn}(\omega\gamma_{mn}\lambda) \right)$

$\uparrow$ Lorentz current

$Q = \lambda^\alpha d_\alpha$

$= \lambda^\alpha \left(p_\alpha + (\not{P}\theta)_\alpha \right)$

$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta p_\alpha + \dot\lambda w_\alpha + P^2 + \not{P}^\alpha d_\alpha \right)$

$\lambda\gamma^m\lambda = 0$ $\quad \delta w_\alpha = \Lambda_m (\gamma^m \lambda)_\alpha \rightarrow (\omega\gamma^{mn}\lambda),\ \omega_\alpha\lambda^\alpha$

$$S = S_0 + \int dz\, d\bar{z} \left(G_{MN}(x,\theta,\hat{\theta}) + B_{MN}(x,\theta,\hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$$

$M = m, \alpha, \hat{\alpha}$

$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$

SYM spinor gauge superfield

$$Q = \lambda^\alpha D_\alpha \qquad V = \lambda^\alpha A_\alpha(x,\theta)$$

$$\uparrow$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn}(\omega \gamma_{mn} \lambda) \right)$$

$$Q = \lambda^\alpha d_\alpha$$

$$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta p_\alpha + \lambda w_\alpha + P^2 + \cancel{P^\alpha d_\alpha} \right)$$

Lorentz current

$$= \lambda^\alpha \left(p_\alpha + (\not P \theta)_\alpha \right)$$

$$\lambda \gamma^m \lambda = 0 \qquad \delta w_\alpha = \Lambda_m (\gamma^m \lambda)_\alpha \rightarrow (\omega \gamma^{mn} \lambda),\ \omega_\alpha \lambda^\alpha$$

$$S = S_0 + \int dz\, d\bar{z} \left(G_{MN}(x,\theta,\hat{\theta}) + B_{MN}(x,\theta,\hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$$

$$+ E_M{}^{\hat{\alpha}}\, \partial Y^M \hat{d}_{\hat{\alpha}} + E_M^{\alpha}\, d_\alpha \bar{\partial} Y^M$$

$M = m, \alpha, \hat{\alpha}$

$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$

SYM spinor gauge superfield

$$Q = \lambda^\alpha D_\alpha \qquad V = \lambda^\alpha A_\alpha(x,\theta)$$

$$\uparrow$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn} (w \gamma_{mn} \lambda) \right)$$

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha \left(p_\alpha + (\not{P}\theta)_\alpha \right)$$

$$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta p_\alpha + \dot\lambda w_\alpha + P^2 + \not{P}^\alpha d_\alpha \right)$$

Lorentz current

$$\lambda \gamma^m \lambda = 0 \qquad \delta w_\alpha = \Lambda_m (\gamma^m \lambda)_\alpha \to (w \gamma^{mn} \lambda),\ w_\alpha \lambda^\alpha$$

$$S = S_0 + \int dz\, d\bar{z} \Big(G_{MN}(x,\theta,\hat{\theta}) + B_{MN}(x,\theta,\hat{\theta}) \Big) \partial Y^M \bar{\partial} Y^N$$

$$+ \; E_M{}^{\hat{\alpha}} \, \partial Y^M \hat{d}_{\hat{\alpha}} + E_M^{\alpha} d_\alpha \bar{\partial} Y^M$$

$$+ \; F^{\alpha\hat{\alpha}}(x,\theta,\hat{\theta})\, d_\alpha \hat{d}_{\hat{\alpha}}$$

$M = m, \alpha, \hat{\alpha}$

$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$

$$S = S_0 + \int dz\, d\bar{z} \Big(\big(G_{MN}(x,\theta,\hat{\theta}) + B_{MN}(x,\theta,\hat{\theta})\big)\, \partial Y^M \bar{\partial} Y^N$$

$M = m, \alpha, \hat{\alpha}$

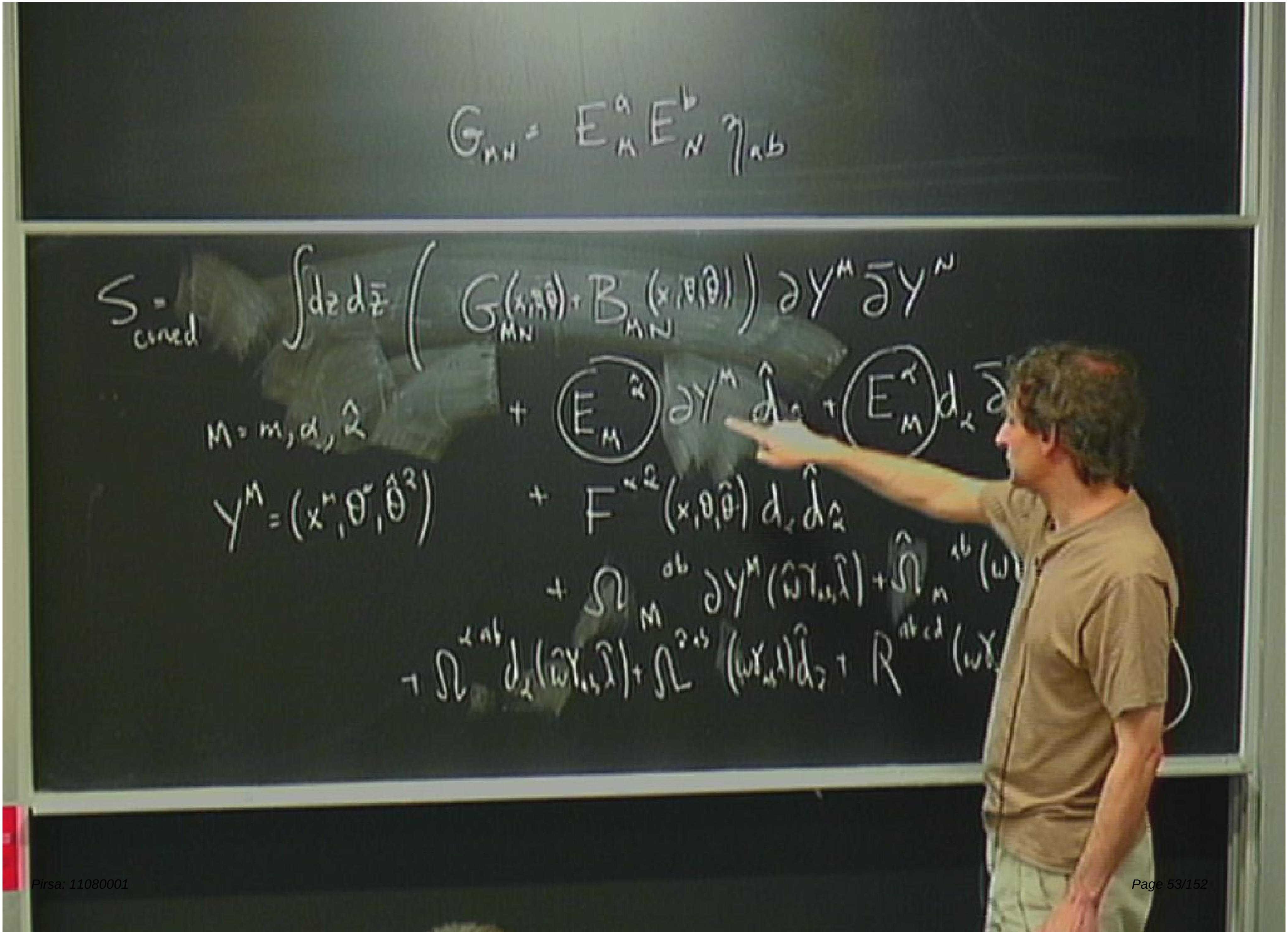
$$+ E_M{}^{\hat{\alpha}}\, \partial Y^M \hat{d}_{\hat{\alpha}} + E_M^{\alpha}\, d_\alpha \bar{\partial} Y^M$$

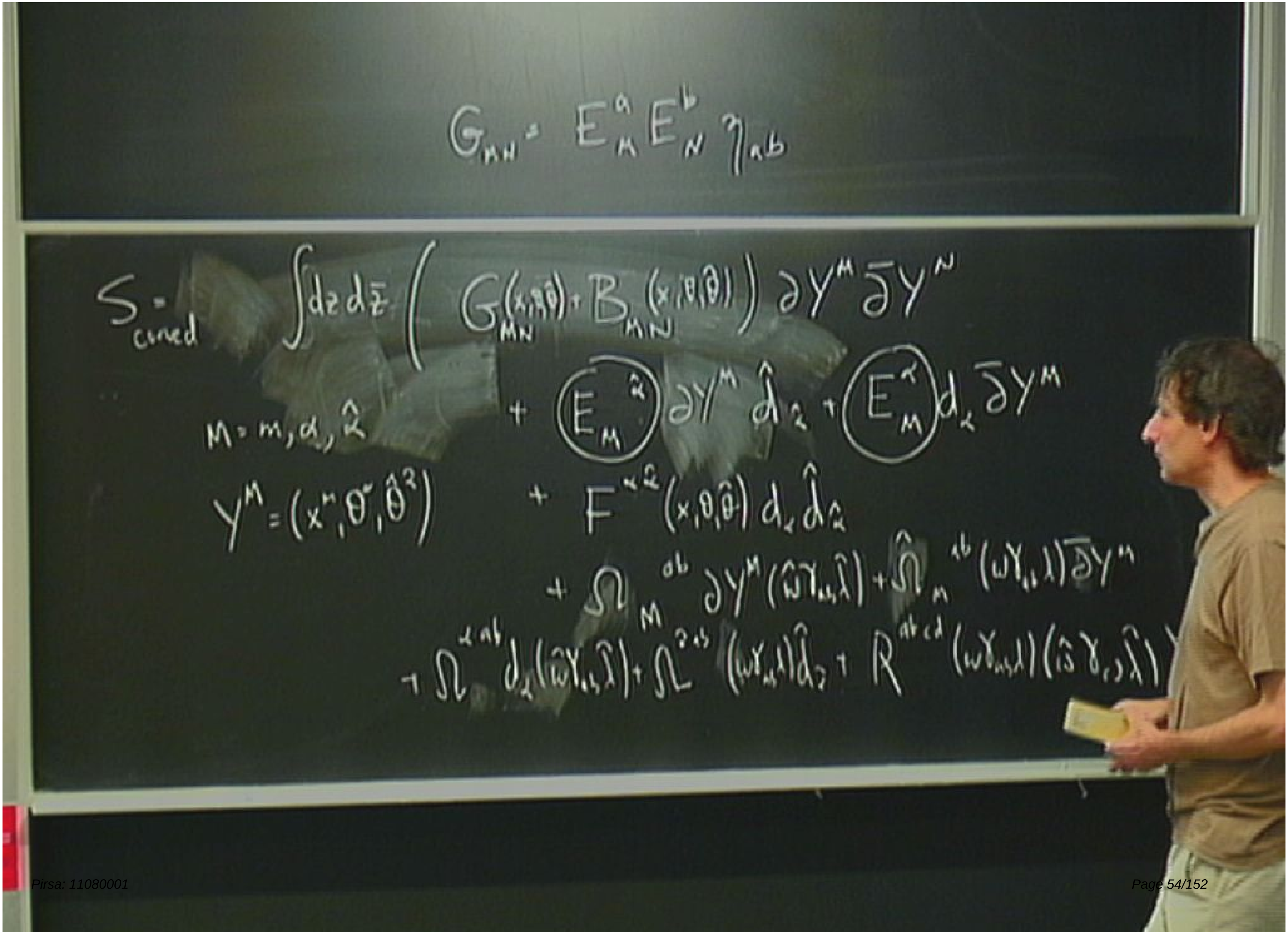
$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$

$$+ F^{\alpha\hat{\alpha}}(x,\theta,\hat{\theta})\, d_\alpha \hat{d}_{\hat{\alpha}}$$

$$+ \Omega_M{}^{ab}\, \partial Y^M (\hat{\omega}\gamma_{ab}\hat{\lambda}) + \hat{\Omega}_M{}^{ab} (\omega\gamma_{ab}\lambda) \bar{\partial} Y^M$$

$$+ \Omega^{\alpha ab} d_\alpha (\hat{\omega}\gamma_{ab}\hat{\lambda}) + \Omega^{\hat{\alpha} ab} (\omega\gamma_{ab}\lambda) \hat{d}_{\hat{\alpha}} + R^{abcd} (\omega\gamma_{ab}\lambda)(\hat{\omega}\gamma_{cd}\hat{\lambda}) \Big)$$


$G_{MN} = E^a_M E^b_N \eta_{ab}$
$S_{cured} = \int dz\, d\bar{z} \left(G_{MN}(x,\theta,\hat{\theta}) + B_{MN}(x,\theta,\hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$
$+ E_M^{\hat{\alpha}} \partial Y^M \hat{d}_{\hat{\alpha}} + E_M^{\alpha} d_\alpha \bar{\partial}$
$M = m, \alpha, \hat{\alpha}$
$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$
$+ F^{\alpha\hat{\alpha}}(x,\theta,\hat{\theta})\, d_\alpha \hat{d}_{\hat{\alpha}}$
$+ \Omega_M{}^{ab} \partial Y^M (\hat{\omega}\gamma_{ab}\hat{\lambda}) + \hat{\Omega}_M{}^{ab} (\omega$
$+ \Omega^{\alpha ab} d_\alpha (\hat{\omega}\gamma_{ab}\hat{\lambda}) + \Omega^{\hat{\alpha} ab} (\omega\gamma_{ab}\lambda) \hat{d}_{\hat{\alpha}} + R^{abcd} (\omega\gamma$


G_MN = E_M^a E_N^b η_ab
S_curved = ∫dz dz̄ ((G_MN(x,θ,θ̂) + B_MN(x,θ,θ̂)) ∂Y^M ∂̄Y^N
+ E_M^α̂ ∂Y^M d̂_α̂ + E_M^α d_α ∂̄Y^M
M = m, α, α̂
Y^M = (x^m, θ^α, θ̂^α̂)
+ F^αα̂(x,θ,θ̂) d_α d̂_α̂

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$S_{\text{cored}} = \int dz\, d\bar{z} \Big(\left(G_{MN}(x,\theta,\hat\theta) + B_{MN}(x,\theta,\hat\theta)\right) \partial Y^M \bar\partial Y^N$$

$$+ E_M^{\hat\alpha} \partial Y^M \hat d_{\hat\alpha} + E_M^{\alpha} d_\alpha \bar\partial Y^M$$

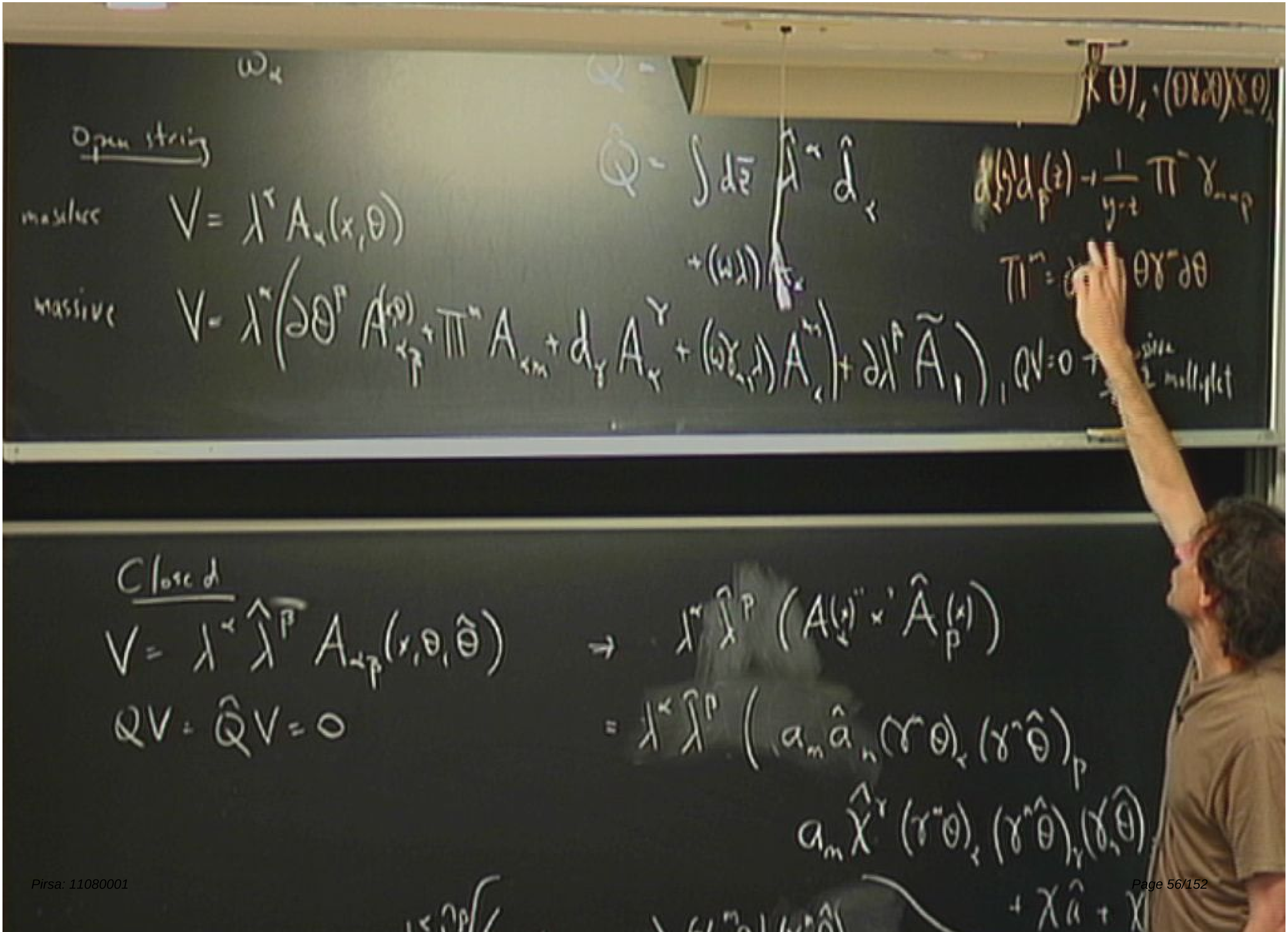
$$+ F^{\alpha\hat\alpha}(x,\theta,\hat\theta)\, d_\alpha \hat d_{\hat\alpha}$$

$$+ \Omega_M{}^{ab} \partial Y^M (\hat\omega \gamma_{ab} \hat\lambda) + \hat\Omega_M{}^{ab} (\omega\gamma_{ab}\lambda) \bar\partial Y^M$$

$$+ \Omega^{\alpha ab} d_\alpha (\hat\omega \gamma_{ab} \hat\lambda) + \Omega^{\hat\alpha ab} (\omega\gamma_{ab}\lambda) \hat d_{\hat\alpha} + R^{abcd} (\omega\gamma_{ab}\lambda)(\hat\omega\gamma_{cd}\hat\lambda) \Big)$$

$$M = m, \alpha, \hat\alpha$$

$$Y^M = (x^m, \theta^\alpha, \hat\theta^{\hat\alpha})$$


Open string
massless
V = λ^α A_α(x,θ)
massive
QV = 0
multiplet
Closed
V = λ^α λ̂^β A_αβ(x,θ,θ̂)
QV = Q̂V = 0

$$V = \lambda(\partial\theta\, A^{m}_{\alpha\beta} + \ldots A_{\alpha m} + d_\gamma A_\alpha + (\hat{\gamma}_{m}\lambda)\hat{A}_\alpha) + \partial\hat{\lambda}^{\beta}\hat{A}_\beta), \quad QV = 0 \to \text{massive spin 2 multiplet}$$

Closed

$$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x,\theta,\hat{\theta}) \quad \to \quad \lambda^\alpha \hat{\lambda}^\beta (A_\alpha(x) \times \hat{A}_\beta(x))$$

$$QV = \hat{Q}V = 0 \qquad = \lambda^\alpha \hat{\lambda}^\beta \big(a_m \hat{a}_n (\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\beta$$

$$\boxed{\lambda\gamma^m\lambda = \hat{\lambda}\gamma^m\hat{\lambda} = 0} \qquad a_m \hat{\chi}^\gamma (\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\gamma (\gamma_n\hat{\theta})_\beta + \ldots \big)$$

$$+ \chi\hat{a} + \chi\hat{\chi}$$

$$= \lambda^\alpha \hat{\lambda}^\beta \Big((g_{mn} + b_{mn} + \eta_{mn}\varphi)(\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\beta + \hat{\psi} + F^{\gamma\delta}(\theta^\dagger)_{\gamma\alpha}(\hat{\theta}^2)_{\delta\beta} + \ldots$$

$$+ \psi^\gamma_n (\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\gamma (\gamma_m\hat{\theta})_\beta \Big)$$

ω_α $\quad Q = \ldots$ $\quad \ldots\gamma\theta)_\alpha + (\theta\gamma\theta)(\gamma\theta)_\alpha$

Open string

$$\hat{Q} = \int d\bar{z}\, \hat{\lambda}^\alpha \hat{d}_\alpha \quad + (w\lambda)\ldots$$

$$d_\alpha(y)\, d_\beta(z) \to \frac{1}{y-z}\, \Pi^m \gamma_{m\alpha\beta}$$

$$\Pi^m = \partial x^m + \theta\gamma^m\partial\theta$$

massless $\quad V = \lambda^\alpha A_\alpha(x,\theta)$

massive $\quad V = \lambda^\alpha\left(\partial\theta^\beta A^{(\theta)}_{\alpha\beta} + \Pi^m A_{\alpha m} + d_\gamma A^\gamma_\alpha + (w\gamma_{mn}\lambda) A^{mn}_\alpha\right) + \partial\lambda^\beta \tilde{A}_\beta$, $\quad QV = 0 \to$ massive spin 2 multiplet

Closed

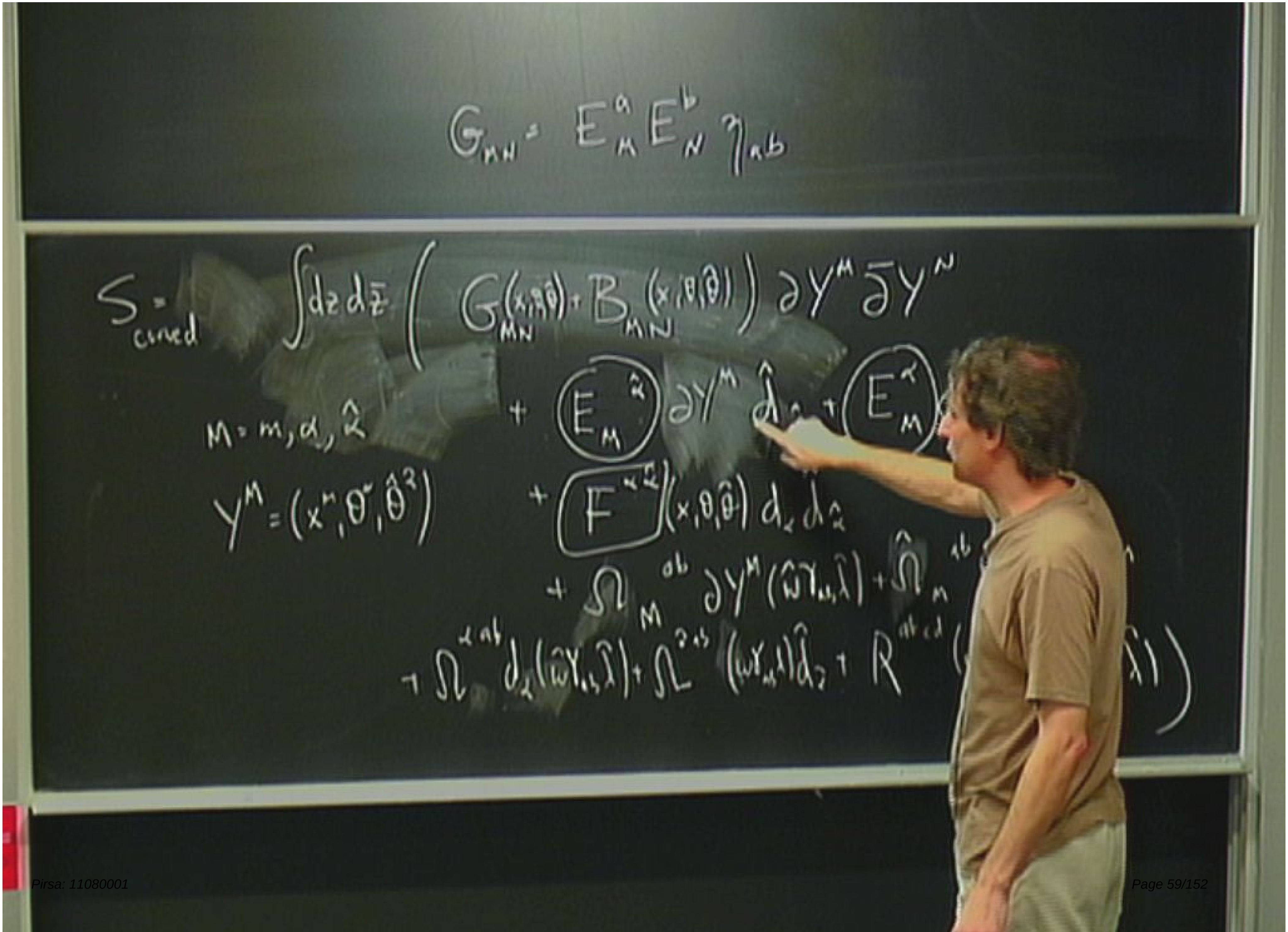
$$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x,\theta,\hat{\theta}) \quad \to \quad \lambda^\alpha\hat{\lambda}^\beta \left(A^{(x)}_\alpha \times \hat{A}^{(x)}_\beta\right)$$

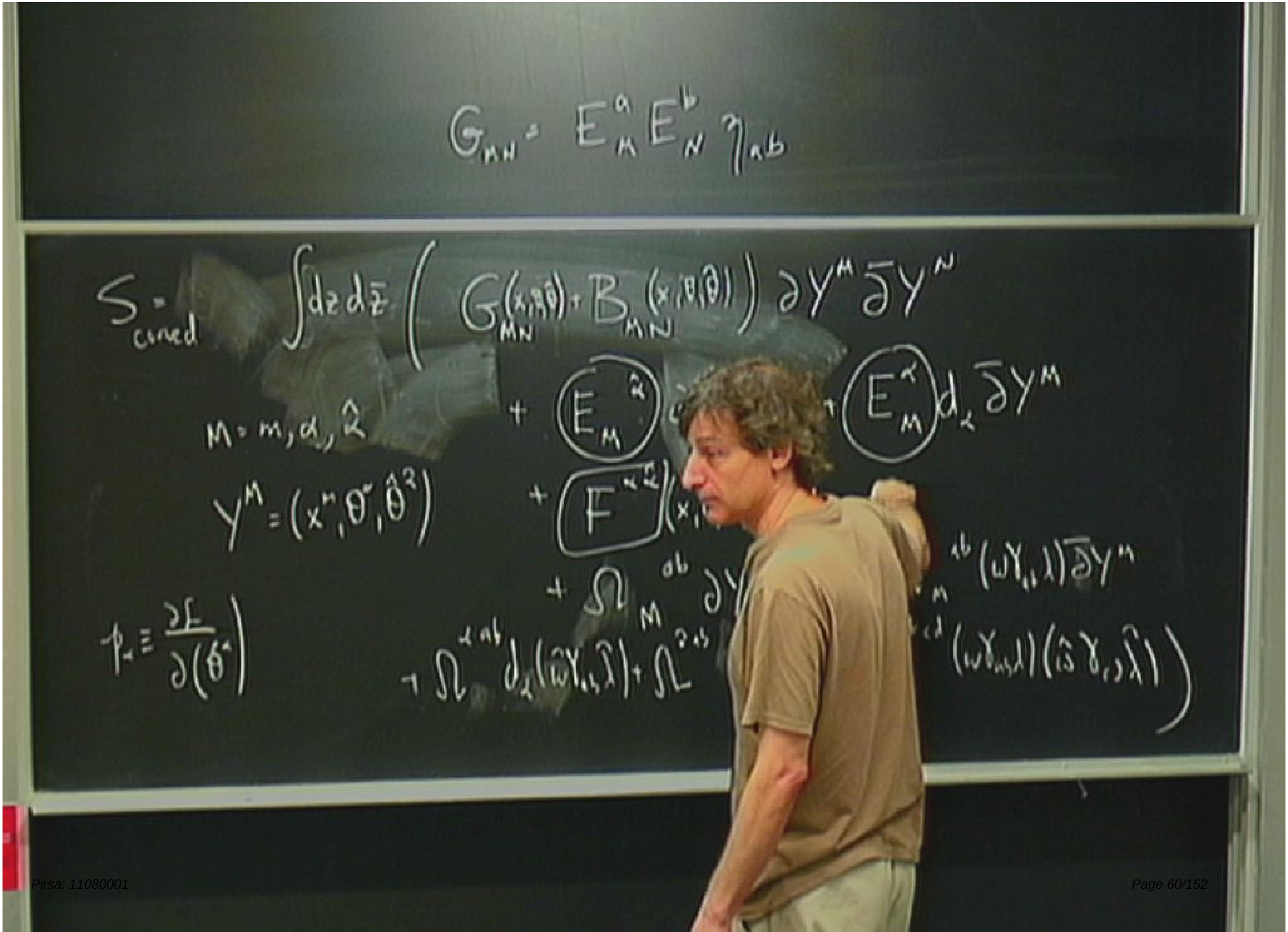
$$QV = \hat{Q}V = 0 \qquad = \lambda^\alpha\hat{\lambda}^\beta\left(a_m \hat{a}_n (\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\beta\right.$$

$$\left. a_m \hat{\chi}^\gamma (\gamma^m\theta)_\alpha (\gamma^n\hat{\theta})_\gamma (\gamma_n\hat{\theta})_\beta + \ldots\right)$$

$$+ \chi\hat{a} + \chi\hat{\chi}$$

$$\boxed{\lambda\gamma^m\lambda = \hat{\lambda}\gamma^m\hat{\lambda} = 0}$$


$G_{MN} = E_M^a E_N^b \eta_{ab}$
$S_{\text{curved}} = \int dz\, d\bar{z} \Big((G_{MN}(x,\theta,\hat{\theta}) + B_{MN}(x,\theta,\hat{\theta}))\, \partial Y^M \bar{\partial} Y^N$
$+ E_M^{\hat{\alpha}}\, \partial Y^M \hat{d}_{\hat{\alpha}} + E_M^{\alpha}$
$M = m, \alpha, \hat{\alpha}$
$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$
$+ F^{\alpha\hat{\alpha}}(x,\theta,\hat{\theta})\, d_\alpha \hat{d}_{\hat{\alpha}}$
$+ \Omega_M^{ab}\, \partial Y^M (\hat{\omega}\gamma_{ab}\hat{\lambda}) + \hat{\Omega}_M^{ab}$
$+ \Omega^{\alpha ab} d_\alpha (\hat{\omega}\gamma_{ab}\hat{\lambda}) + \Omega^{\hat{\alpha} ab} (\omega\gamma_{ab}\lambda) \hat{d}_{\hat{\alpha}} + R^{abcd}$


$G_{MN} = E^a_M E^b_N \eta_{ab}$
$S_{cined} = \int dz\, d\bar{z} \Big((G_{MN}(x,\theta,\hat{\theta}) + B_{MN}(x,\theta,\hat{\theta}))\, \partial Y^M \bar{\partial} Y^N$
$M = m, \alpha, \hat{\alpha}$
$+ E_M^{\hat{\alpha}}$
$E_M^{\alpha} d_\alpha \bar{\partial} Y^M$
$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$
$+ F^{\alpha\hat{\alpha}}$
$(w\gamma_{ab}\lambda)\bar{\partial} Y^M$
$+ \Omega_M^{ab}\, \partial Y$
$p_\alpha = \frac{\partial L}{\partial(\dot{\theta}^\alpha)}$
$+ \Omega^{\alpha ab} d_\alpha (\hat{w}\gamma_{ab}\hat{\lambda}) + \Omega^{ab}$
$(w\gamma_{ab}\lambda)(\hat{w}\gamma_{cd}\hat{\lambda}) \Big)$

Closed

$$V = \lambda^\alpha \hat\lambda^\beta A_{\alpha\beta}(x,\theta,\hat\theta) \quad \to \quad \lambda^\alpha \hat\lambda^\beta \left(A_\alpha(x) \cdot \hat A_\beta(x) \right)$$

$$QV = \hat Q V = 0 \qquad = \lambda^\alpha \hat\lambda^\beta \Big(a_m \hat a_n (\gamma^m\theta)_\alpha (\gamma^n\hat\theta)_\beta$$

$$a_m \hat\chi^\gamma (\gamma^m\theta)_\alpha (\gamma^n\hat\theta)_\gamma (\gamma_n\hat\theta)_\beta + \dots \Big)$$

$$\boxed{\lambda\gamma^m\lambda = \hat\lambda\gamma^m\hat\lambda = 0}$$

$$+ \chi\hat a + \chi\hat\chi$$

$$\{Q, \hat Q\} = 0 \qquad = \lambda^\alpha \hat\lambda^\beta \Big((g_{mn} + b_{mn} + \eta_{mn}\varphi)(\gamma^m\theta)_\alpha (\gamma^n\hat\theta)_\beta$$

$$Q^2 = \hat Q^2 = 0 \qquad + \psi_n^\gamma (\gamma^m\theta)_\alpha (\gamma^n\hat\theta)_\gamma (\gamma_m\theta)_\beta + \hat\psi + F^{\gamma\delta} (\theta^\dagger)_{\gamma\alpha} (\hat\theta^2)_{\delta\beta} + \dots \Big)$$

Closed

$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x,\theta,\hat\theta) \rightarrow \lambda^\alpha \hat\lambda^\beta (A_\alpha(x) \times \hat{A}_\beta(x))$

$QV = \hat{Q}V = 0$ $\quad = \lambda^\alpha \hat\lambda^\beta (a_m \hat{a}_n (\gamma^m\theta)_\alpha (\gamma^n\hat\theta)_\beta$

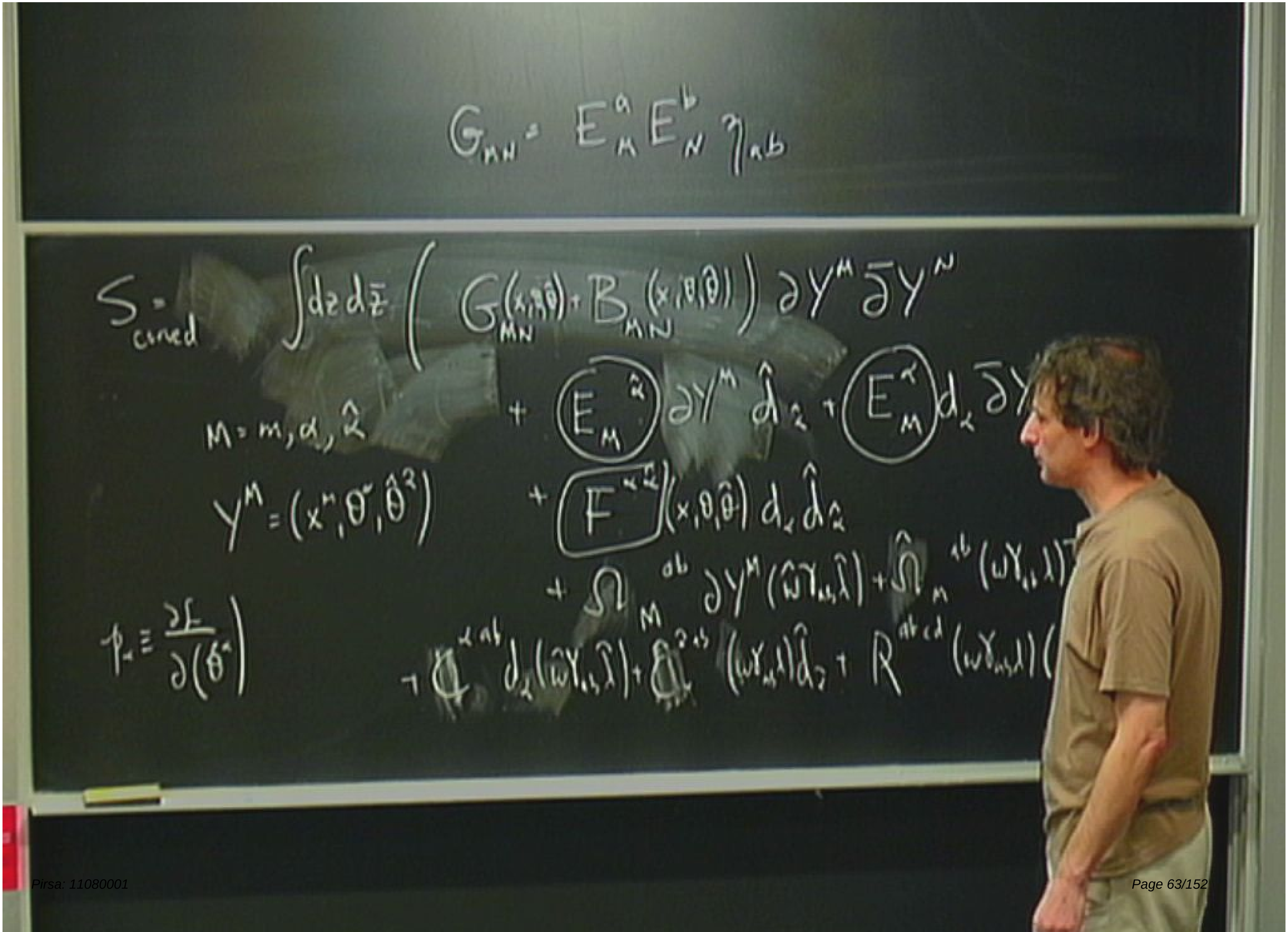
$a_m \hat\chi^\gamma (\gamma^m\theta)_\alpha (\gamma^n\hat\theta)_\gamma (\gamma_n\hat\theta)_\beta + \ldots)$

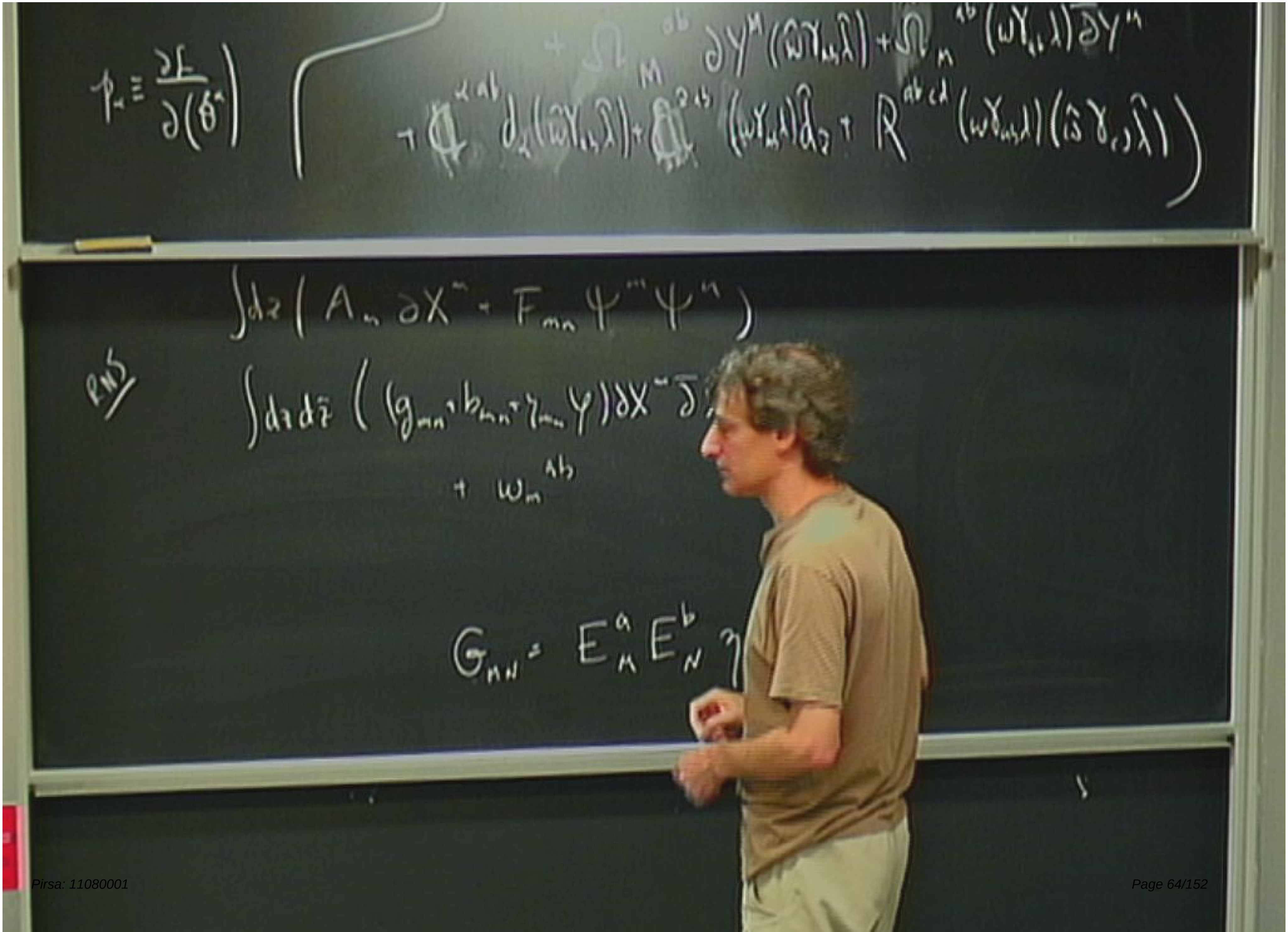
$\boxed{\lambda\gamma^m\lambda = \hat\lambda\gamma^m\hat\lambda = 0}$

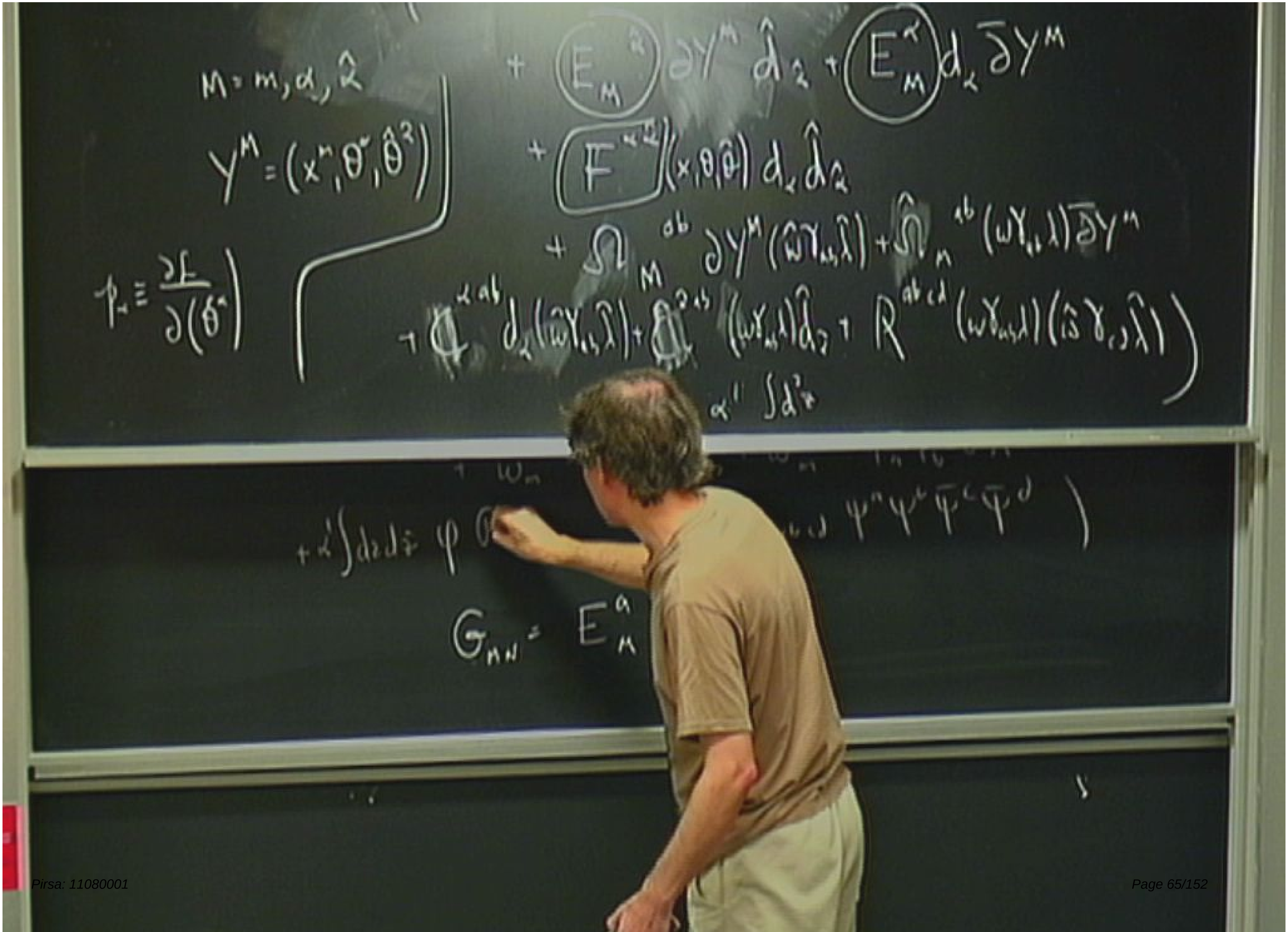
$+ \chi\hat{a} + \chi\hat\chi$

$\{Q, \hat{Q}\} = 0$ $\quad = \lambda^\alpha \hat\lambda^\beta ((g_{mn} + b_{mn} + \eta_{mn}\varphi)(\gamma^m\theta)_\alpha(\gamma^n\hat\theta)_\beta + \hat\varphi + F^{\alpha\beta}(\theta^\gamma)_{\gamma\alpha}(\hat\theta^\delta)_{\delta\beta} + \ldots$

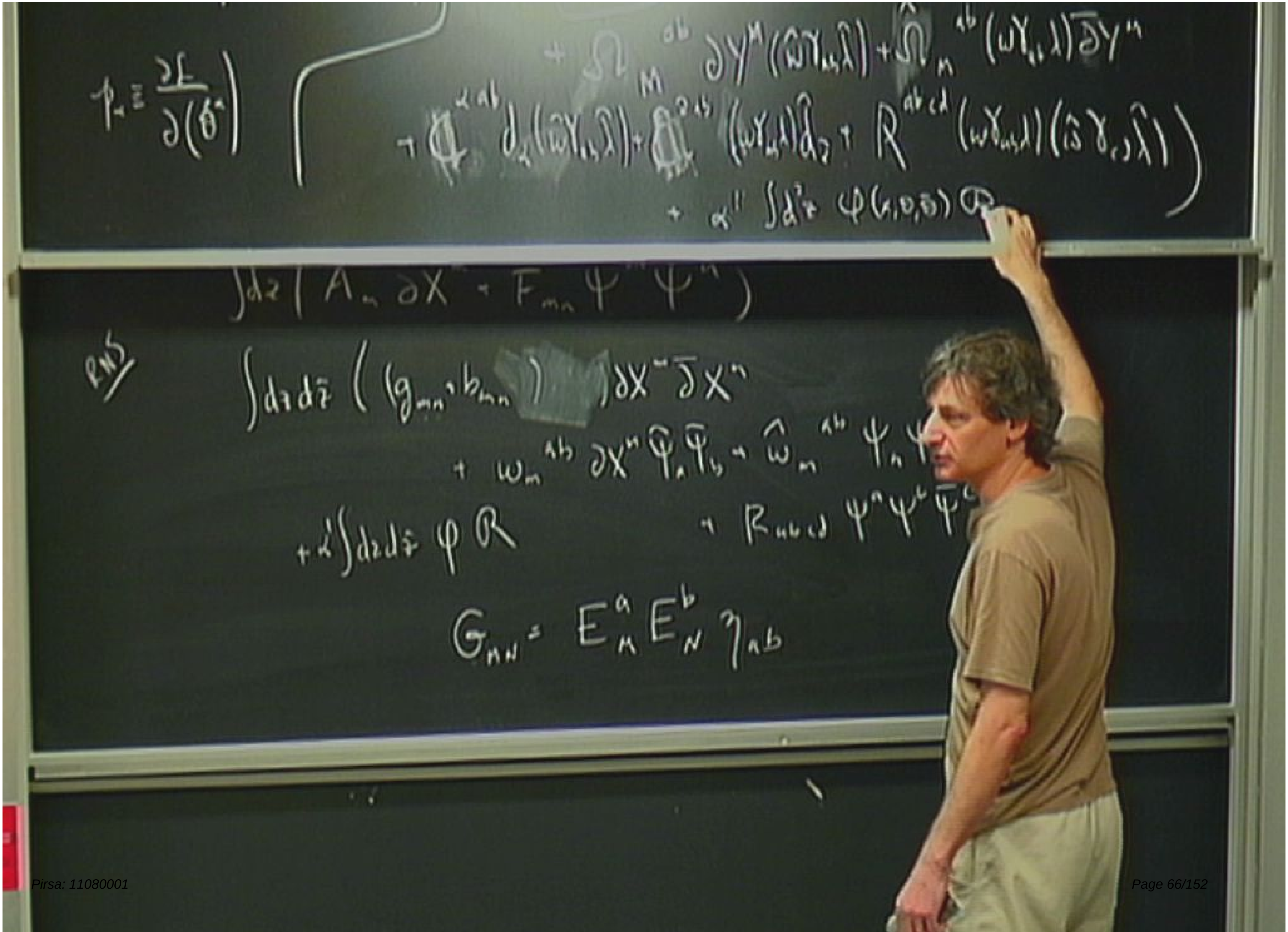
$Q^2 = \hat{Q}^2 = 0$ $\quad + \psi_n^\gamma (\gamma^m\theta)_\alpha (\gamma^n\hat\theta)_\gamma (\gamma_m\hat\theta)_\beta$

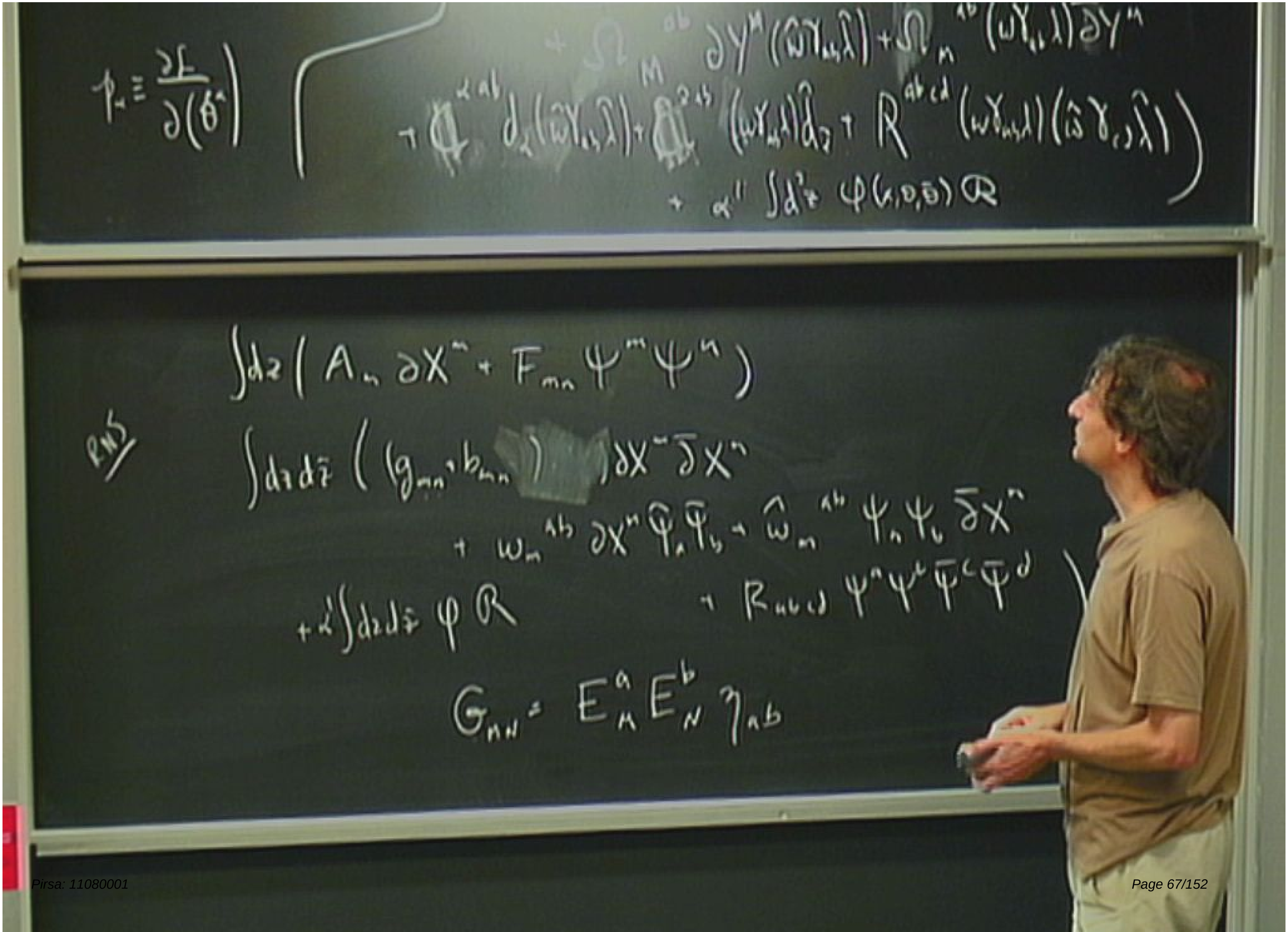

G_MN = E_M^a E_N^b η_ab
S = ∫dz dz̄ (G_MN(x,θ,θ̂) + B_MN(x,θ,θ̂)) ∂Y^M ∂̄Y^N
M = m, α, α̂
Y^M = (x^m, θ^α, θ̂^α̂)
+ F^αα̂ (x,θ,θ̂) d_α d̂_α̂
p_α = ∂L / ∂(∂θ^α)


p_α ≡ ∂L/∂(∂θ^α)
∫dz (A_m ∂X^m - F_mn ψ^m ψ^n)
RNS
∫dz dz̄ ((g_mn + b_mn + γ_mn ψ) ∂X^m ∂̄X^n
+ ω_m^ab
G_MN = E^a_M E^b_N η



M = m, α, α̂
Y^M = (x^m, θ^α, θ̂^α̂)
p_α ≡ ∂L / ∂(θ^α)
+ E_M^α̂ ∂Y^M d̂_α̂ + E_M^α d_α ∂̄Y^M
+ F^{αα̂}(x, θ, θ̂) d_α d̂_α̂
G_MN = E_M^a


RNS
$G_{MN} = E^a_M E^b_N \eta_{ab}$


∫dz (A_m ∂X^m + F_mn ψ^m ψ^n)
∫dz dz̄ ((g_mn + b_mn) ∂X^m ∂̄X^n
+ ω_m^ab ∂X^m ψ̄_a ψ̄_b + ω̂_m^ab ψ_a ψ_b ∂̄X^m
+ R_abcd ψ^a ψ^b ψ̄^c ψ̄^d)
+ α' ∫dz dz̄ φ R
G_MN = E^a_M E^b_N η_ab

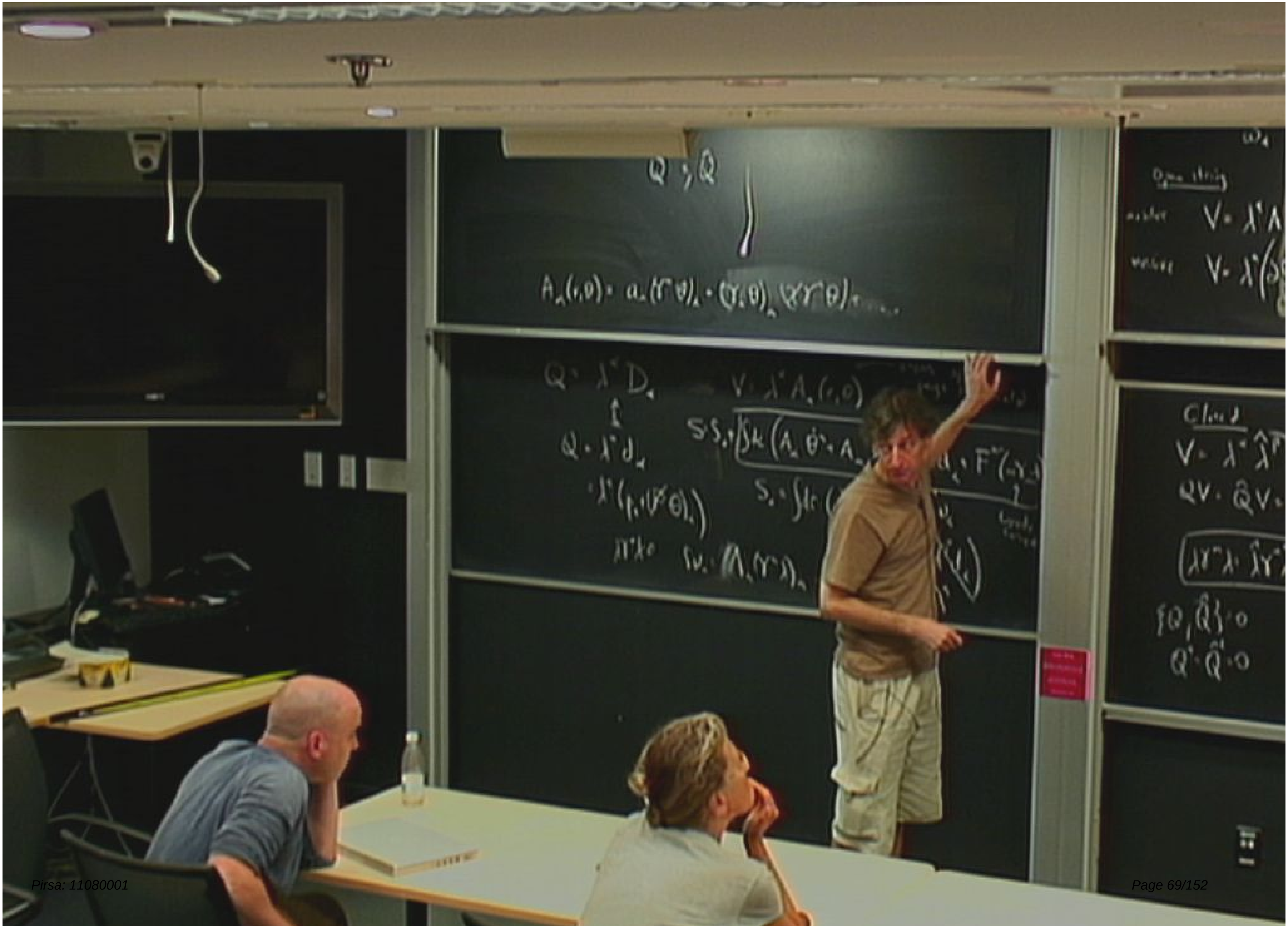
$$p_\alpha \equiv \frac{\partial \mathcal{L}}{\partial(\theta^\alpha)}$$

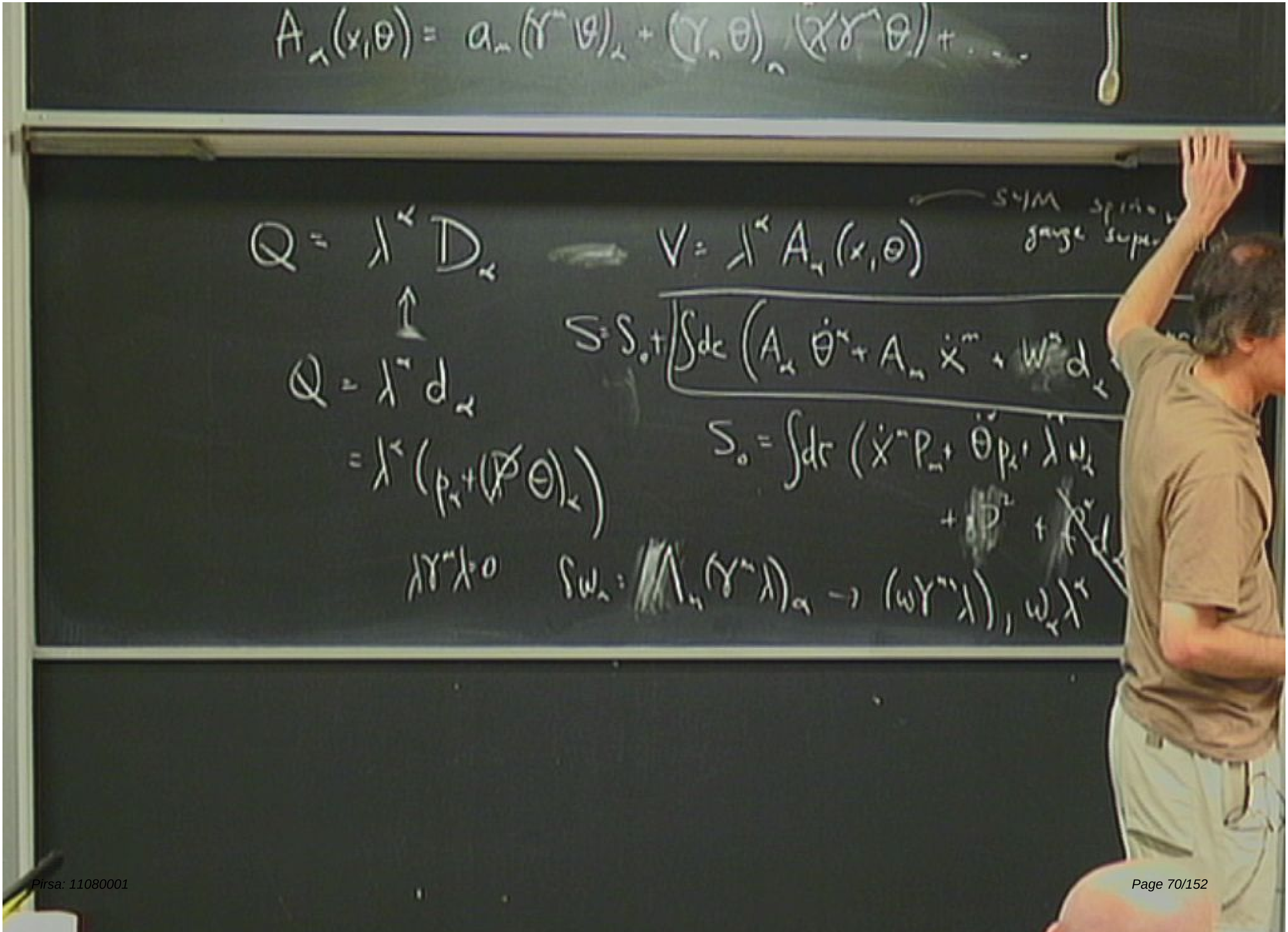
$$\Big(\; + \Omega_M{}^{ab} \partial Y^M (\bar{\omega}\gamma_{ab}\hat{\lambda}) + \Omega_M{}^{ab} (\omega\gamma_{ab}\lambda)\bar{\partial} Y^M$$
$$+ \Phi^{\alpha ab} d_\alpha (\hat{\omega}\gamma_{ab}\hat{\lambda}) + \hat{\Phi}^{\hat{\alpha} ab} (\omega\gamma_{ab}\lambda)\hat{d}_{\hat{\alpha}} + R^{abcd} (\omega\gamma_{ab}\lambda)(\hat{\omega}\gamma_{cd}\hat{\lambda}) \Big)$$
$$+ \alpha' \int d^2z \, \phi(\lambda, D, \bar{D}) \mathcal{R}$$

$$\int dz \left(A_m \partial X^m + F_{mn} \psi^m \psi^n \right)$$

$$\int dz\, d\bar{z} \Big((g_{mn} + b_{mn}) \partial X^m \bar{\partial} X^n$$
$$+ \omega_m{}^{ab} \partial X^m \bar{\psi}_a \bar{\psi}_b + \hat{\omega}_m{}^{ab} \psi_a \psi_b \bar{\partial} X^m$$
$$+ R_{abcd} \psi^a \psi^b \bar{\psi}^c \bar{\psi}^d \Big)$$
$$+ \alpha' \int dz\, d\bar{z} \, \phi \, \mathcal{R}$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$




$A_\alpha(x,\theta) = a_m(\gamma^m\theta)_\alpha + (\gamma_n\theta)_\alpha(\theta\gamma^{n}\theta) + \ldots$
SYM
$Q = \lambda^\alpha D_\alpha$
$V = \lambda^\alpha A_\alpha(x,\theta)$
$S = S_0 + \int d\tau\,(A_\alpha\dot\theta^\alpha + A_m\dot x^m + W^\alpha d_\alpha$
$Q = \lambda^\alpha d_\alpha$
$= \lambda^\alpha(p_\alpha + (\not{P}\theta)_\alpha)$
$S_0 = \int d\tau\,(\dot x^m P_m + \dot\theta p_\alpha + \dot\lambda w_\alpha$
$+ P^2 +$
$\lambda\gamma^m\lambda = 0$
$\delta w_\alpha = \Lambda_m(\gamma^m\lambda)_\alpha \rightarrow (w\gamma^{mn}\lambda),\ w_\alpha\lambda^\alpha$

$$A_\alpha(x,\theta) = a_m(\gamma^m\theta)_\alpha + (\gamma_m\theta)_\alpha(\chi\gamma^m\theta) + \ldots$$

$$Q = \lambda^\alpha D_\alpha \quad \longrightarrow \quad V = \lambda^\alpha A_\alpha(x,\theta)$$

← SYM spinor gauge superfield

$$\uparrow$$

$$Q = \lambda^\alpha d_\alpha$$

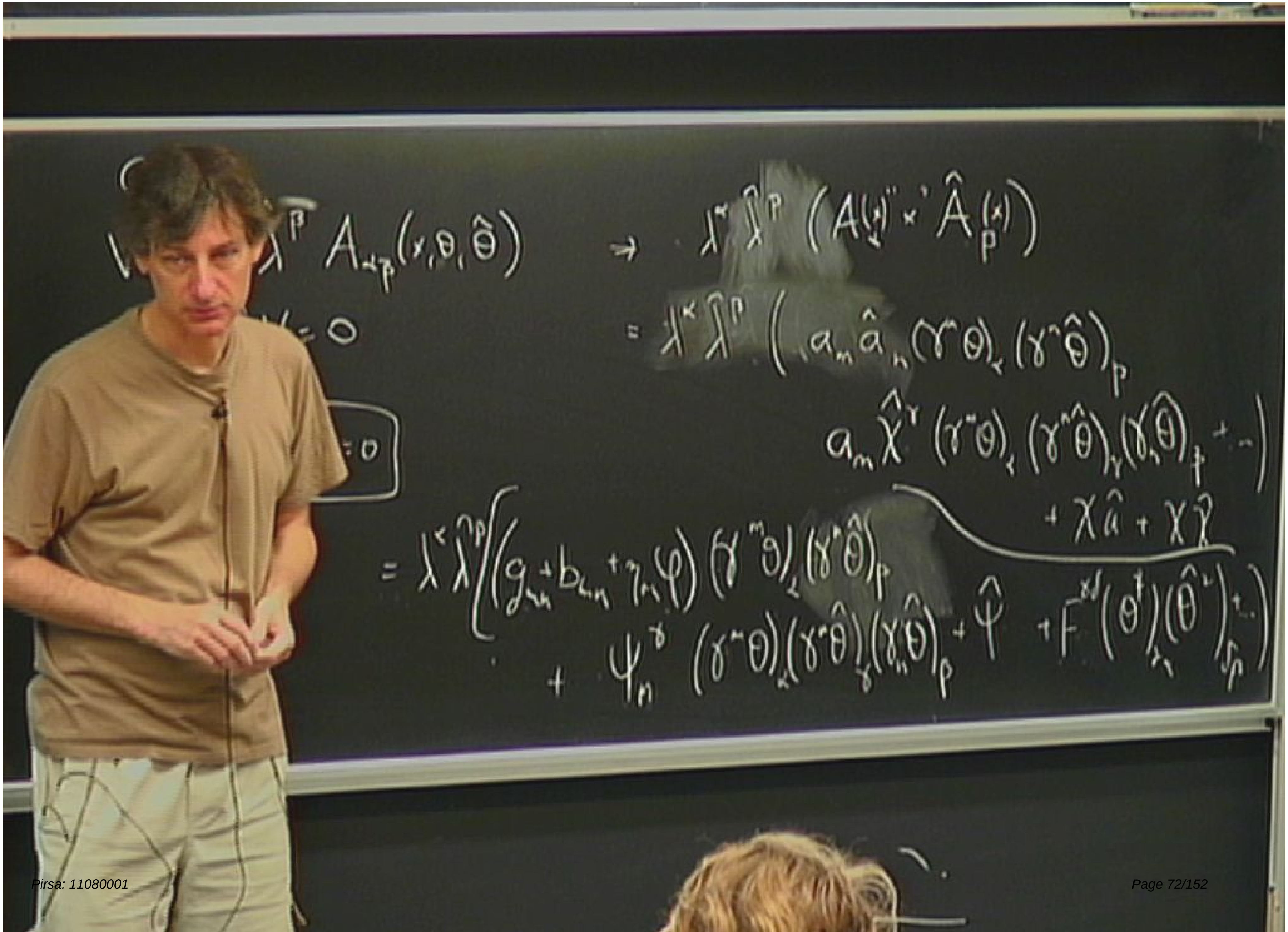
$$= \lambda^\alpha\left(p_\alpha + (\not{P}\theta)_\alpha\right)$$

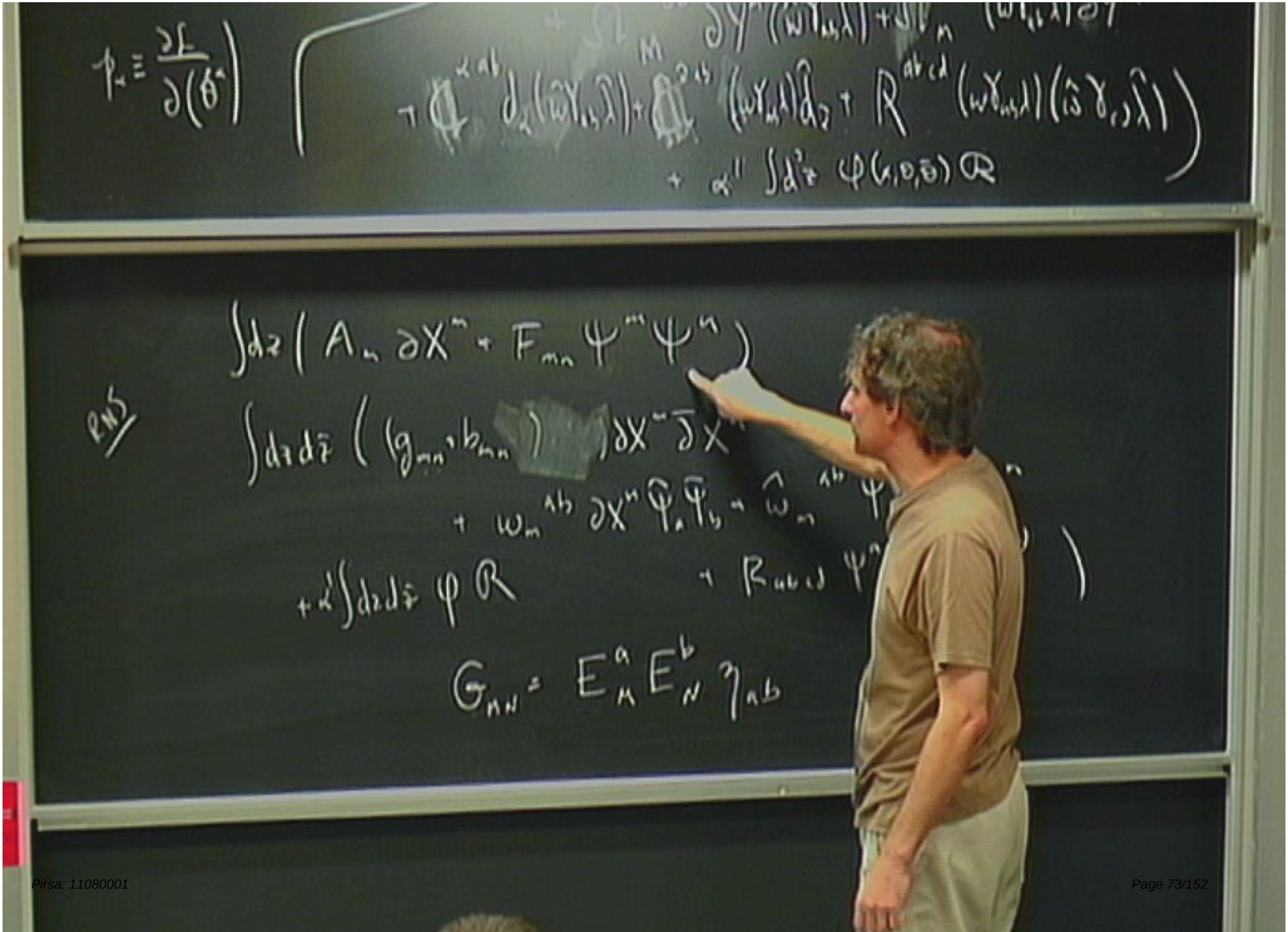
$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn}(\omega\gamma_{mn}\lambda)\right)$$

↑ Lorentz current

$$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta p_\alpha + \dot\lambda \omega_\alpha + P^2 + \not{P}^\alpha d_\alpha\right)$$

$$\lambda\gamma^m\lambda = 0 \qquad \delta\omega_\alpha = \Lambda_m(\gamma^m\lambda)_\alpha \to (\omega\gamma^{mn}\lambda),\ \omega_\alpha\lambda^\alpha$$





$p_\alpha \equiv \frac{\partial \mathcal{L}}{\partial(\dot\theta^\alpha)}$
$+ \alpha' \int d^2z\, \varphi(x,\theta,\bar\theta)\, R$
$\int dz \left(A_m \partial X^m + F_{mn} \psi^m \psi^n \right)$
RNS
$\int dz\, d\bar z \left((g_{mn} + b_{mn}) \partial X^m \bar\partial X^n \right.$
$+ \omega_m{}^{ab} \partial X^m \bar\psi_a \bar\psi_b + \hat\omega_m{}^{ab} \psi$
$+ R_{abcd} \psi$
$+ \alpha' \int dz\, d\bar z\, \varphi R$
$G_{MN} = E^a_M E^b_N \eta_{ab}$

$$p_\alpha \equiv \frac{\partial L}{\partial(\theta^\alpha)}$$

$$\ldots \partial y^m (\bar w \gamma_m \lambda) + \bar\partial \ldots_m (w \gamma \ldots \lambda)\, \partial \ldots$$

$$+ \Phi^{\alpha ab} d_\alpha (\hat w \gamma_{ab} \hat\lambda) + \hat\Phi^{\hat\alpha ab} (w\gamma_{ab}\lambda)\hat d_{\hat\alpha} + R^{abcd}(w\gamma_{ab}\lambda)(\hat w \gamma_{cd}\hat\lambda) \Big)$$

$$+ \alpha' \int d^2 z\, \varphi(x,\theta,\hat\theta)\, \mathcal{R}$$

$$N^{mn} = \psi^m \psi^n$$

$$N^{mn} N^{mn} \to \frac{\mathbb{1}}{(y-t)^2}$$

$$N_1 + N_2 \qquad h_1 = +4, \quad h_2 = -3$$

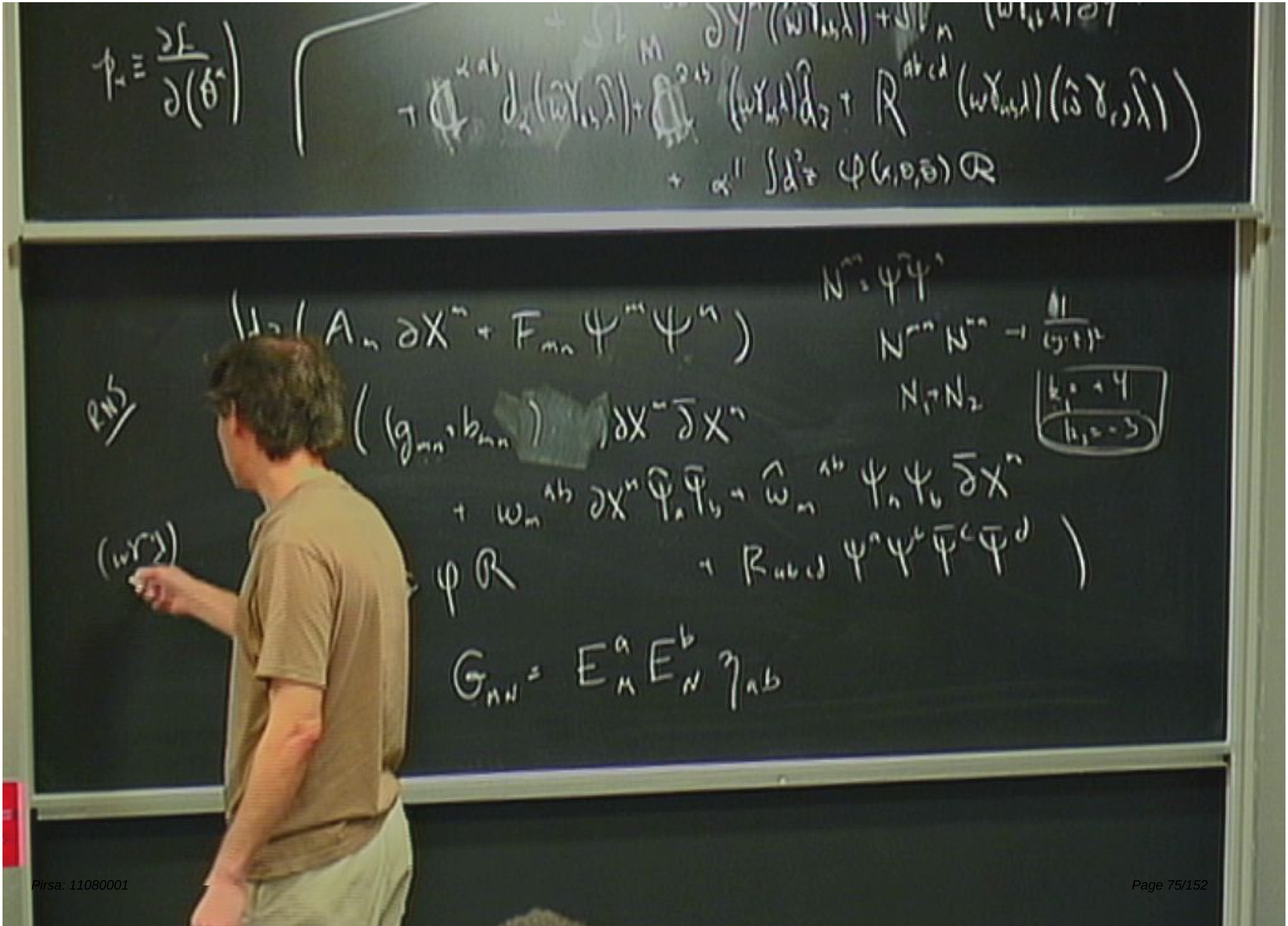
$$\int dz \left(A_m \partial X^m + F_{mn}\psi^m\psi^n \right)$$

RNS

$$\int dz\, d\bar z \Big((g_{mn} + b_{mn}) \partial X^m \bar\partial X^n + \omega_m{}^{ab} \partial X^m \bar\psi_a \bar\psi_b + \hat\omega_m{}^{ab}\psi_a\psi_b \bar\partial X^m + R_{abcd}\psi^a\psi^b\bar\psi^c\bar\psi^d \Big)$$

$$+ \alpha' \int dz\, d\bar z\, \varphi\, \mathcal{R}$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$



RNS
N = ψψ
N N → 1/(z-w)²
N₁ + N₂
h = -3
G_MN = E^a_M E^b_N η_ab

$$p_\alpha \equiv \frac{\partial L}{\partial(\theta^\alpha)}$$

$$+ [illegible]^{\alpha ab}\, d_\alpha (\bar\omega \gamma_{ab} \hat\lambda) + [illegible]^{\alpha ab} (\omega\gamma_{ab}\lambda)\hat d_\alpha + R^{abcd}(\omega\gamma_{ab}\lambda)(\hat\omega\gamma_{cd}\hat\lambda) \Big)$$

$$+ \alpha' \int d^2z\, \varphi(x,\theta,\bar\theta)\, \mathcal{R}$$

$$\int dz \left(A_m \partial X^m + F_{mn} \psi^m \psi^n \right)$$

$N^{mn} = \psi^m \psi^n$

$N^{mn} N^{mn} \to \frac{\#1}{(y-z)^2}$

$N_1 + N_2$

$k_1 = +4$, $k_2 = -3$

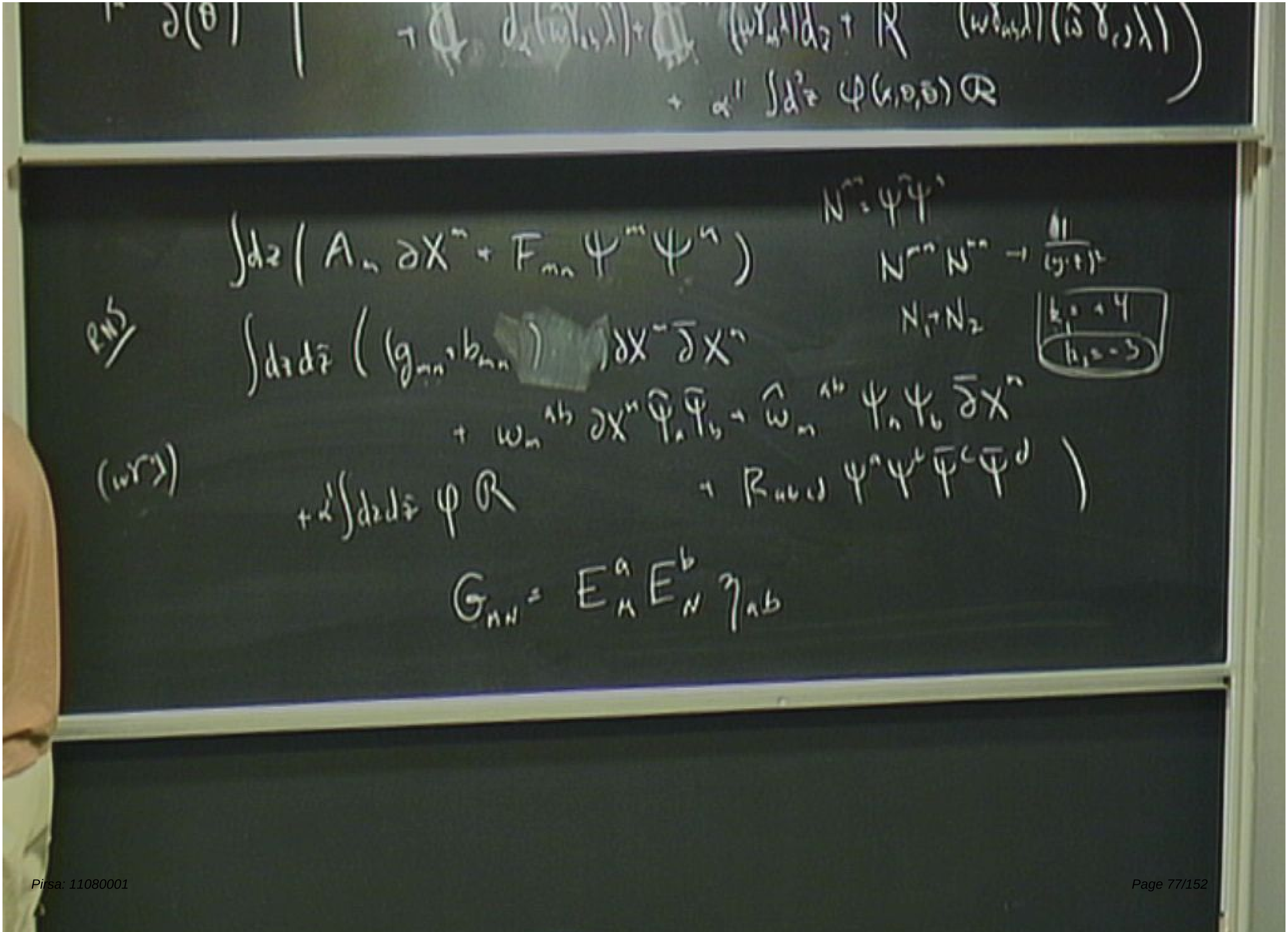
RNS

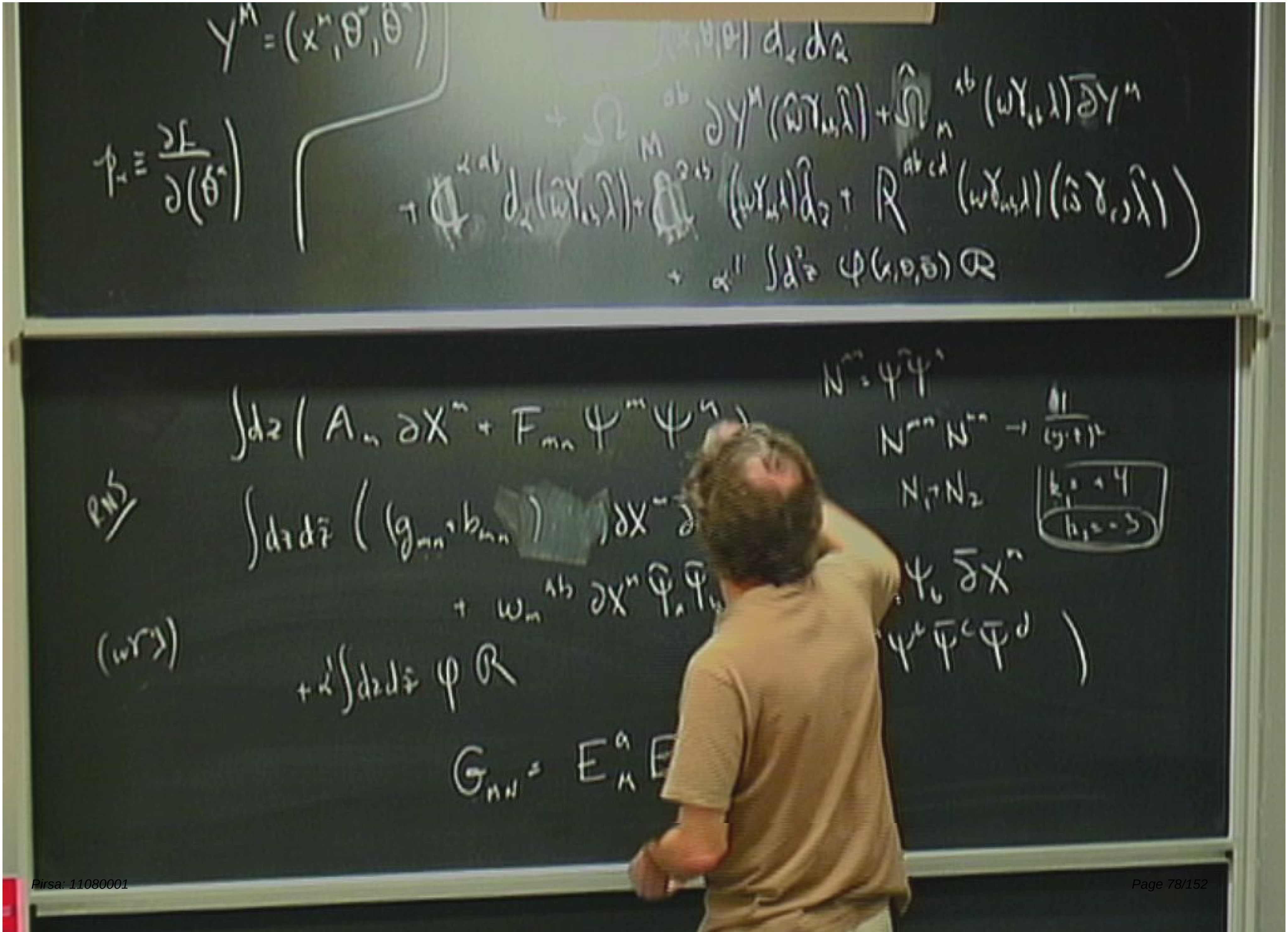
$$\int dz\, d\bar z \Big((g_{mn} + b_{mn}) \partial X^m \bar\partial X^n + \omega_m{}^{ab} \partial X^m \bar\psi_a \bar\psi_b + \hat\omega_m{}^{ab} \psi_a \psi_b \bar\partial X^m + R_{abcd} \psi^a \psi^b \bar\psi^c \bar\psi^d \Big)$$

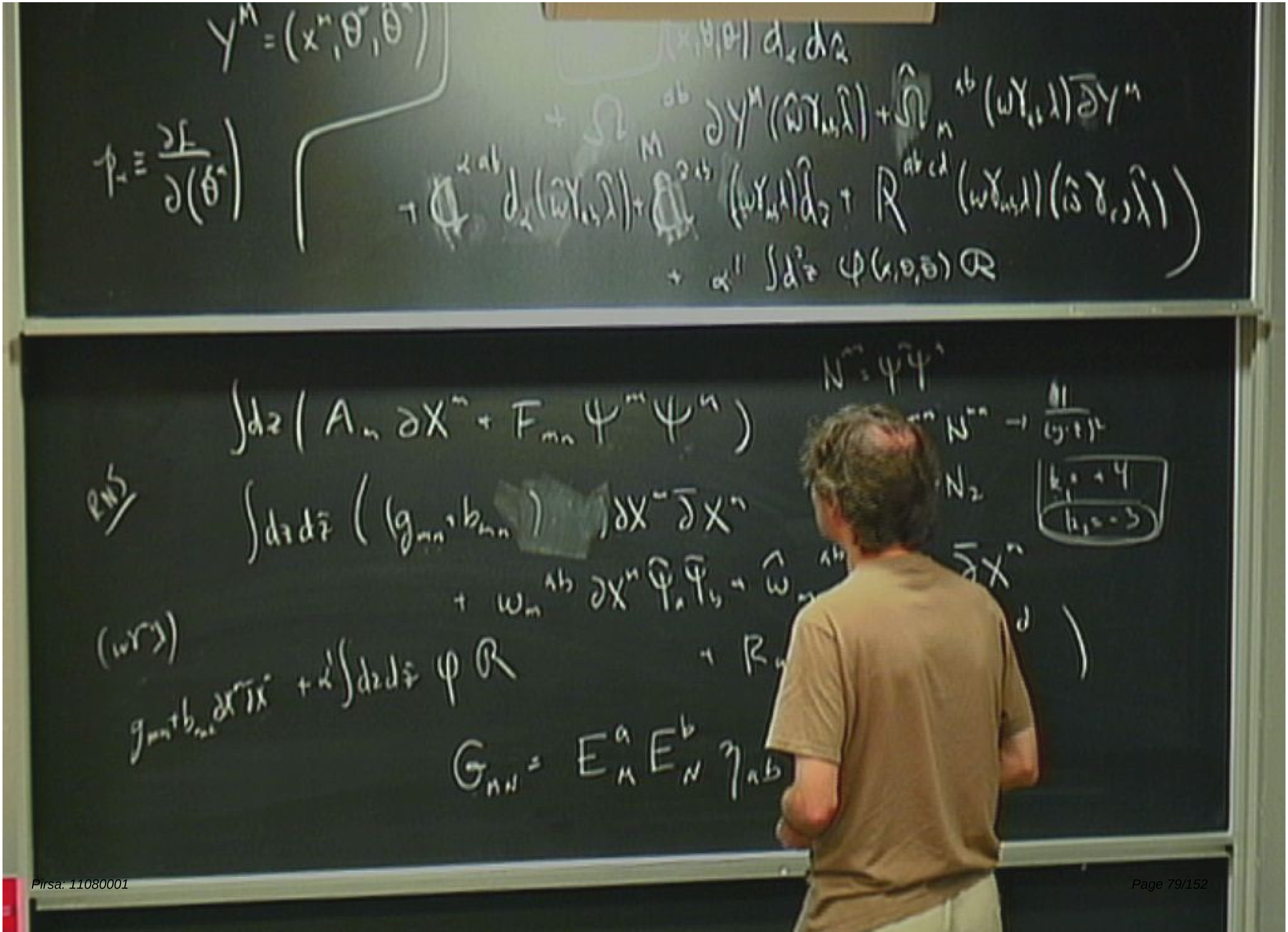
$$+ \alpha' \int dz\, d\bar z\, \varphi\, \mathcal{R}$$

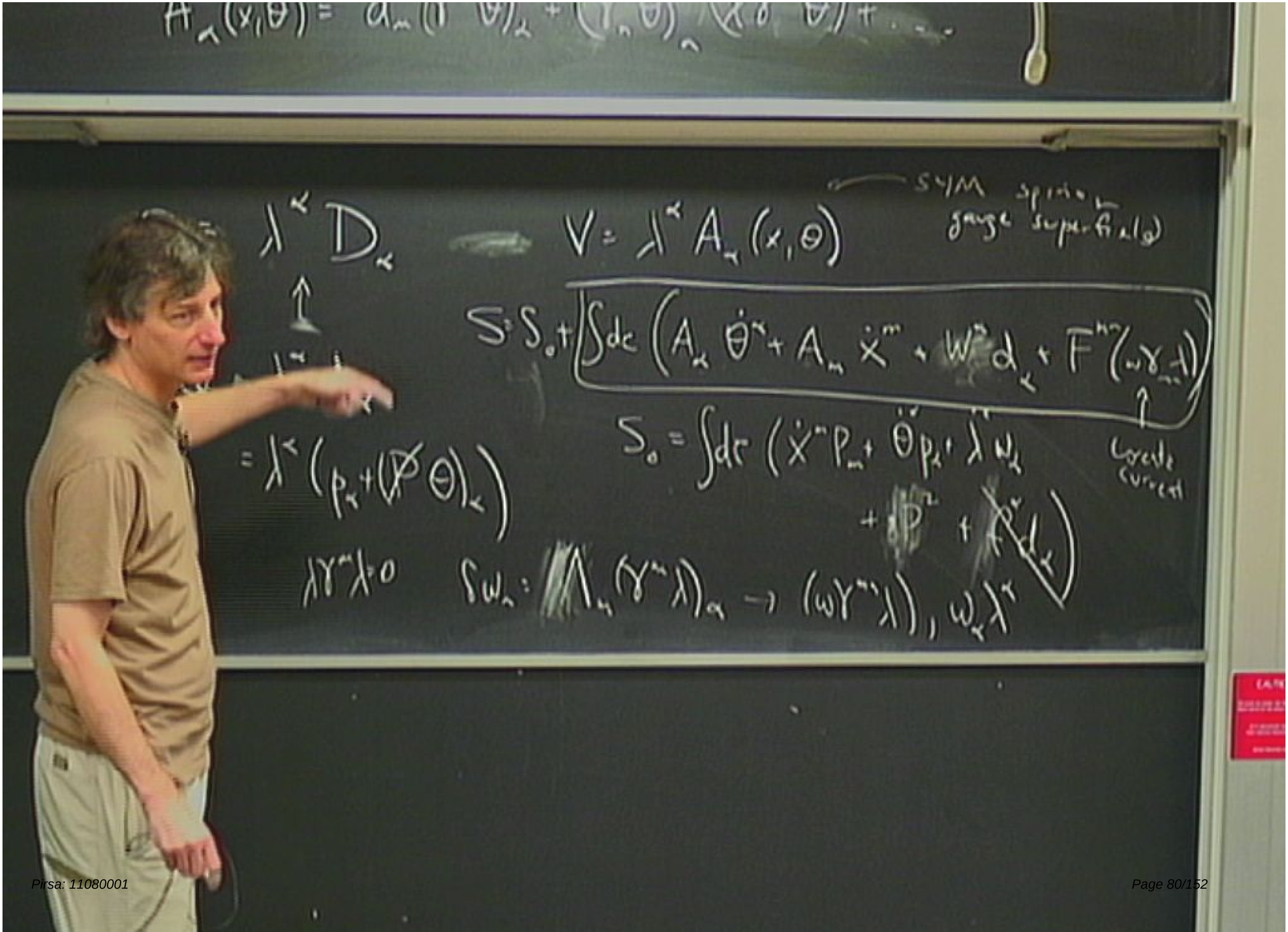
$(w\gamma\lambda)$

$$G_{MN} = E^a_M E^b_N \eta_{ab}$$


+ α'' ∫d²z φ(λ,θ,θ̄) R
∫dz (A_m ∂X^m + F_mn ψ^m ψ^n)
N^mn = ψψ
N^mn N^mn → 1/(y+1)²
N_1 + N_2
RNS
∫dz dz̄ ((g_mn + b_mn) ∂X^m ∂̄X^n
+ ω_m^ab ∂X^m ψ̄_a ψ̄_b + ω̂_m^ab ψ_a ψ_b ∂̄X^m
+ R_abcd ψ^a ψ^b ψ̄^c ψ̄^d)
+ α' ∫dz dz̄ φ R
G_MN = E^a_M E^b_N η_ab


Y^M = (x^m, θ^α, θ̄^α)
p_α ≡ ∂L / ∂(θ^α)
+ α' ∫d²z φ(x,θ,θ̄) R
∫dz (A_m ∂X^m + F_mn ψ^m ψ^n)
N_1 + N_2
∫dz dz̄ ((g_mn + b_mn) ∂X^m
+ ω_m^ab ∂X^m
+ α' ∫dz dz̄ φ R
G_MN = E^a_M


Y^M = (x^m, θ^α, θ̄^α)
∫dz (A_m ∂X^m + F_mn ψ^m ψ^n)
N^mn = ψ^m ψ^n
∫dz dz̄ ((g_mn + b_mn) ∂X^m ∂̄X^n
+ α' ∫dz dz̄ φ R
G_MN = E^a_M E^b_N η_ab


SYM
gauge superfield

$$A_\alpha(x,\theta) = a_m(\gamma^m\theta)_\alpha + (\gamma_m\theta)_\alpha(\lambda\gamma^m\theta) + \ldots$$

$$Q = \lambda^\alpha D_\alpha \qquad V = \lambda^\alpha A_\alpha(x,\theta)$$

← SYM spinor gauge superfield

$$\uparrow$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn}(w\gamma_{mn}\lambda)\right)$$

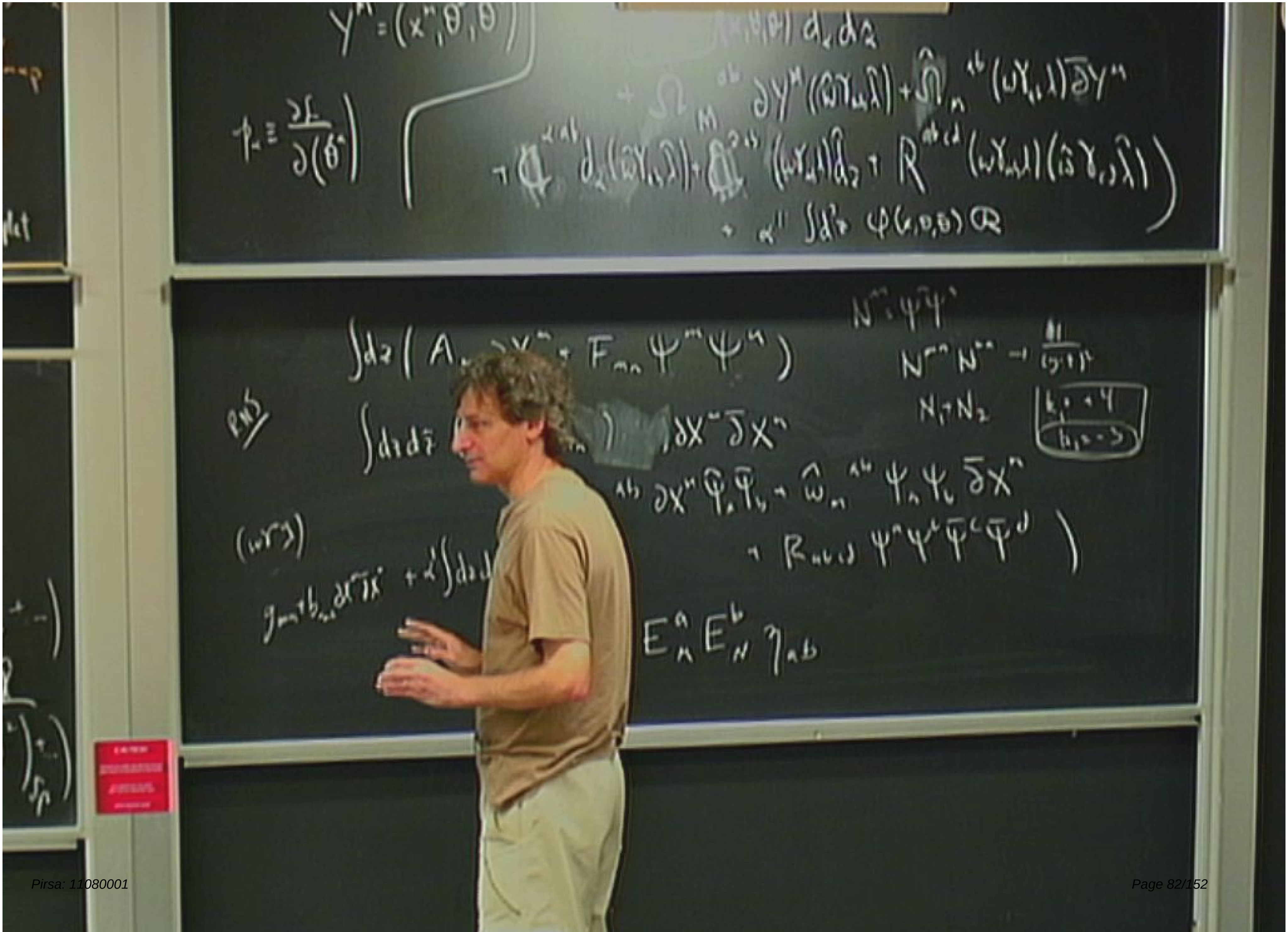
↑ Lorentz current

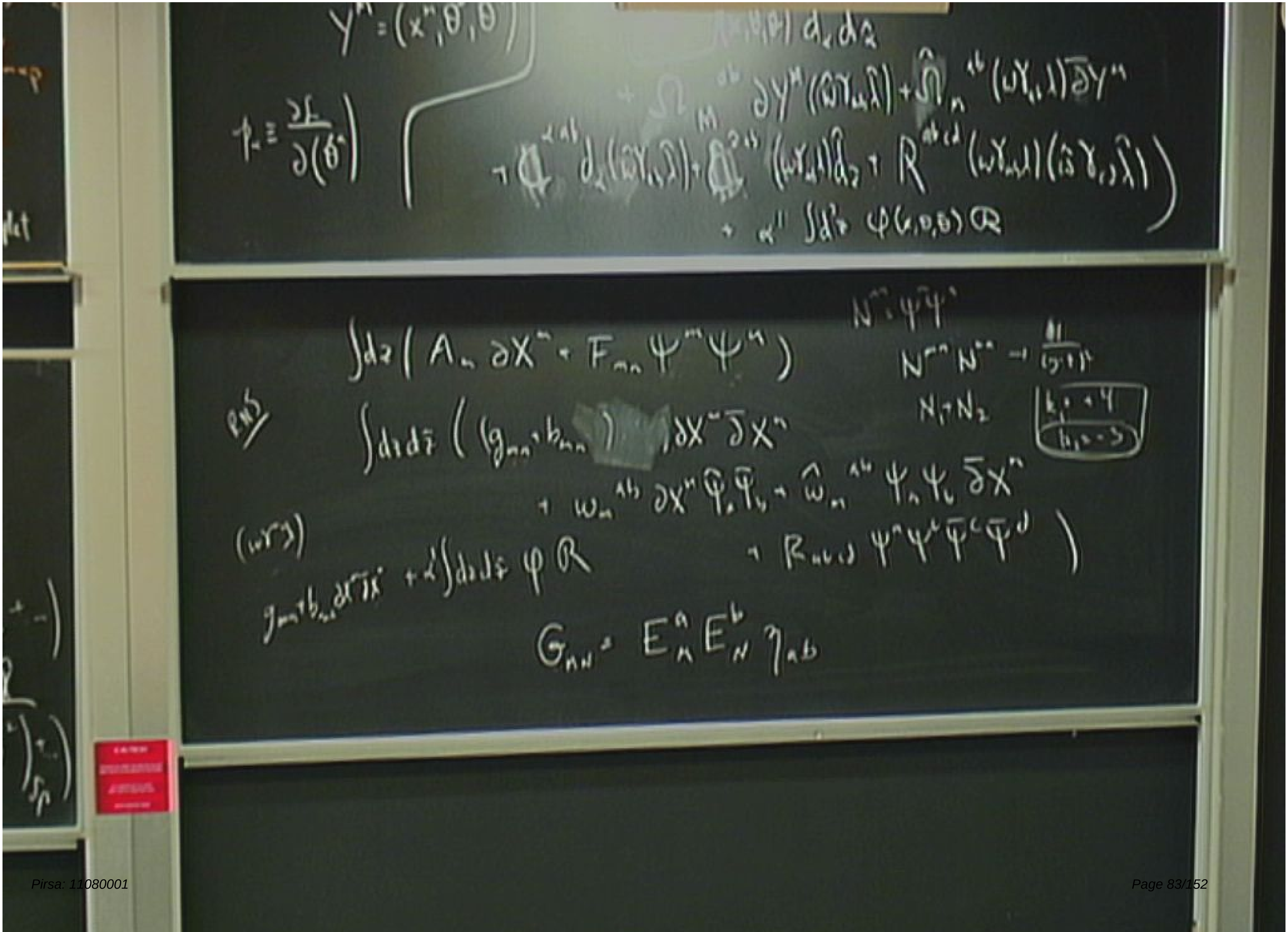
$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha\left(p_\alpha + (\not{P}\theta)_\alpha\right)$$

$$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta p_\alpha + \dot\lambda w_\alpha + P^2 + ~~\lambda^\alpha d_\alpha~~\right)$$

$$\lambda\gamma^m\lambda = 0 \qquad \delta w_\alpha = \Lambda_m(\gamma^m\lambda)_\alpha \to (w\gamma^{mn}\lambda),\ w_\alpha\lambda^\alpha$$

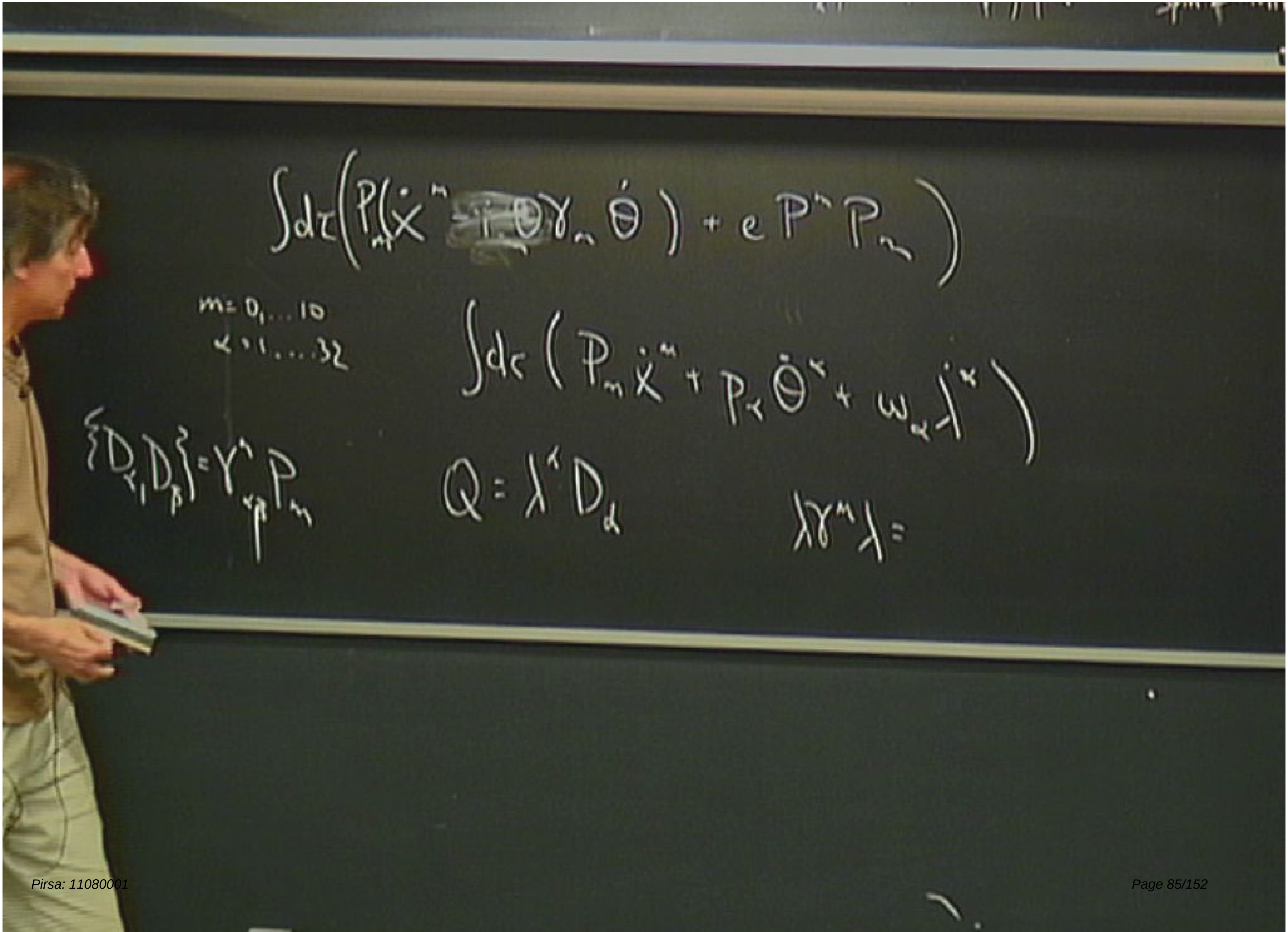


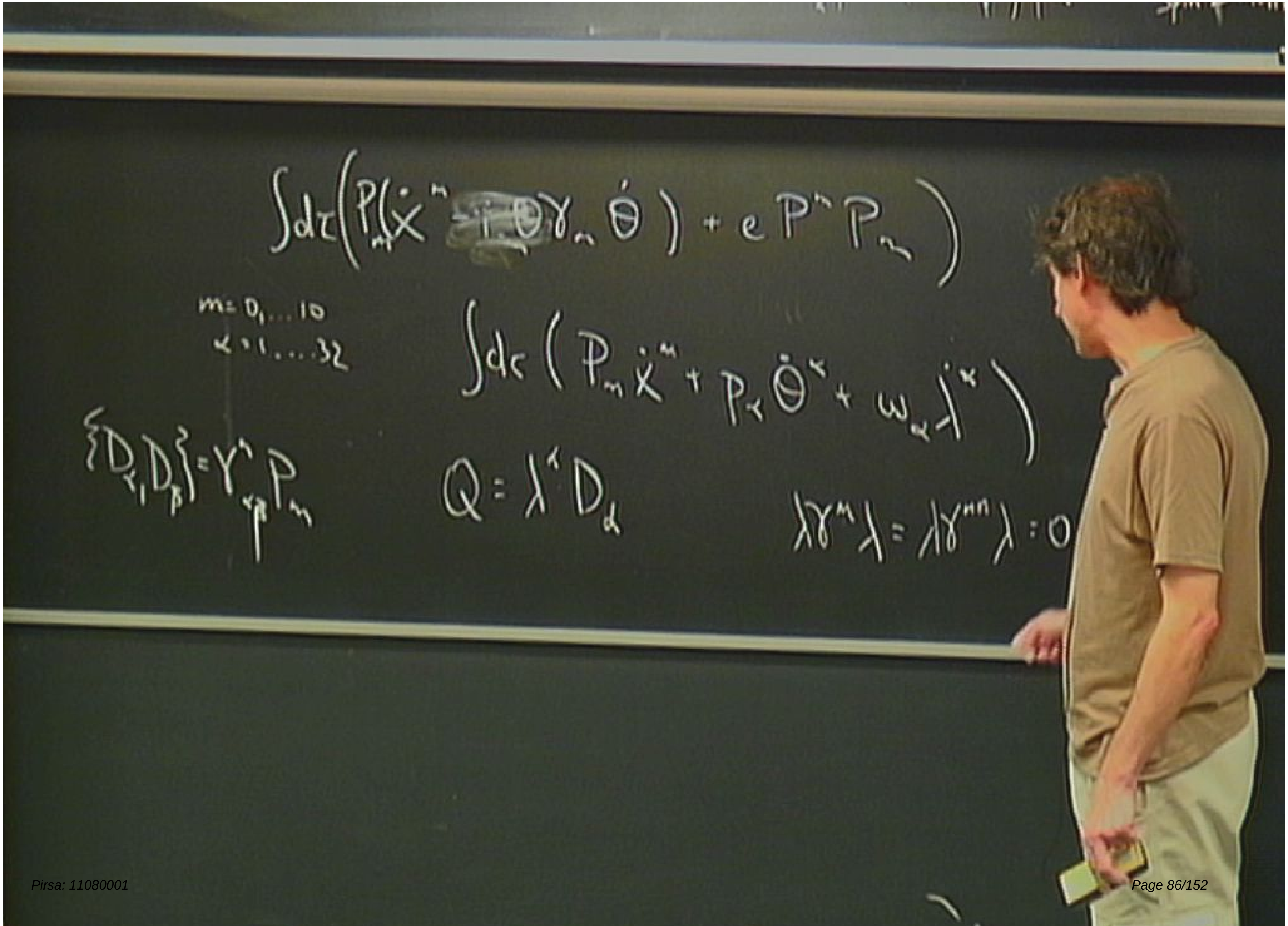


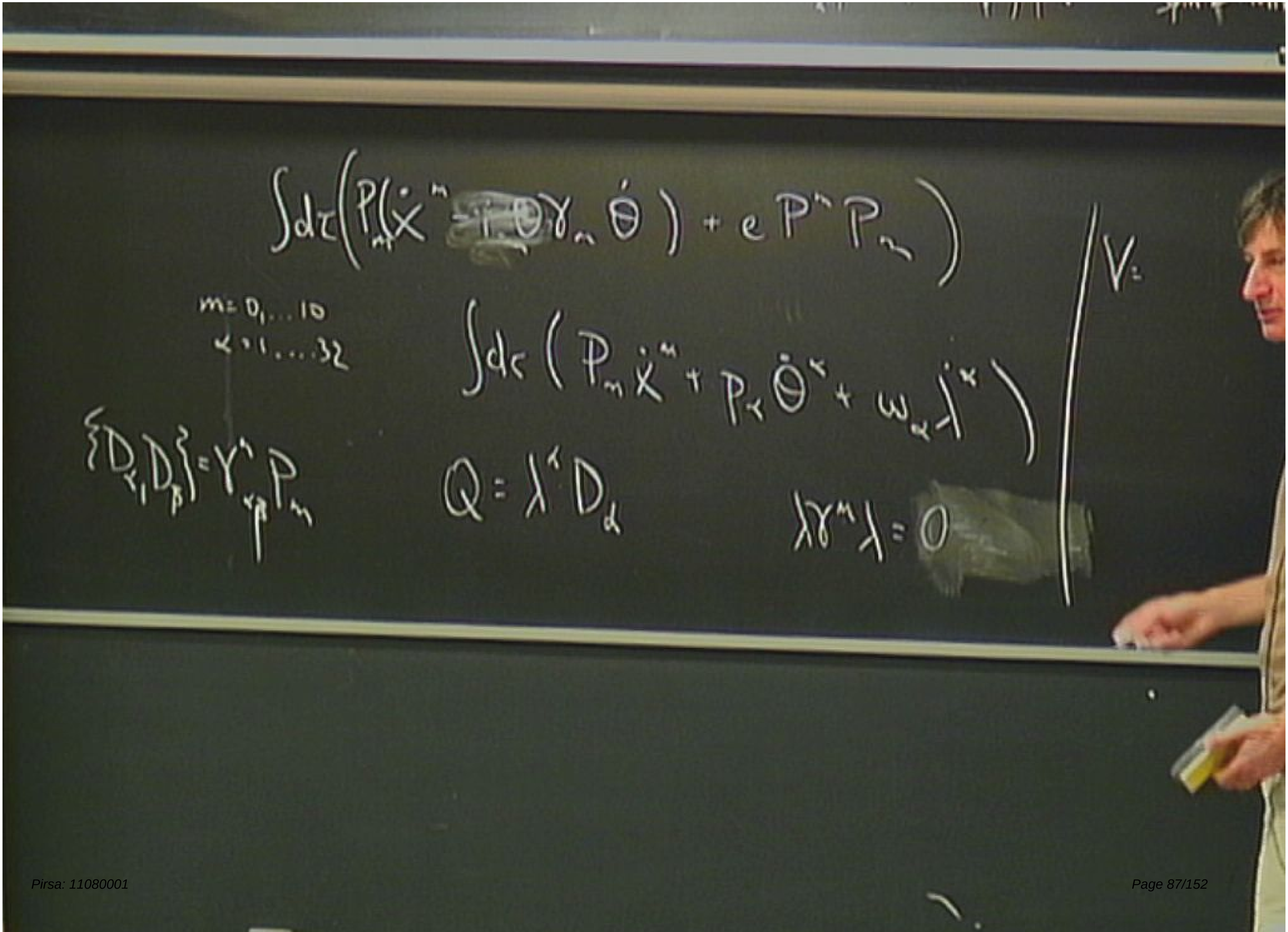
$$\int d\tau \left(P_m (\dot{x}^m - i\theta\gamma_m \dot{\theta}) + e P^m P_m \right)$$

$m = 0, \ldots 10$

$\alpha = 1, \ldots 32$


∫dτ(P_m(ẋ^m − iθγ_m θ̇) + e P^m P_m)
m = 0,…10
α = 1,…32
∫dτ(P_m ẋ^m + p_α θ̇^α + w_α λ̇^α)
{D_α, D_β} = γ^m_αβ P_m
Q = λ^α D_α
λγ^m λ =


$\int d\tau \left(P_m (\dot{X}^m - i \Theta \gamma_m \dot{\Theta}) + e P^m P_m \right)$
$m = 0, \ldots 10$
$\alpha = 1, \ldots 32$
$\int d\tau \left(P_m \dot{X}^m + P_\alpha \dot{\Theta}^\alpha + w_\alpha \dot{\lambda}^\alpha \right)$
$\{D_\alpha, D_\beta\} = \gamma^m_{\alpha\beta} P_m$
$Q = \lambda^\alpha D_\alpha$
$\lambda \gamma^m \lambda = \lambda \gamma^{mn} \lambda = 0$


$\int d\tau \left(P_m (\dot{x}^m - i \theta \gamma_m \dot{\theta}) + e P^m P_m \right)$
$m = 0, \ldots 10$
$\alpha = 1, \ldots 32$
$\int d\tau \left(P_m \dot{x}^m + p_\alpha \dot{\theta}^\alpha + w_\alpha \dot{\lambda}^\alpha \right)$
$\{ D_\alpha, D_\beta \} = \gamma^m_{\alpha\beta} P_m$
$Q = \lambda^\alpha D_\alpha$
$\lambda \gamma^m \lambda = 0$
V:

$$Q = \lambda^\alpha D_\alpha \quad \longleftarrow \quad V = \lambda^\alpha A_\alpha(x,\theta)$$

SYM spinor gauge superfield

$$\uparrow$$

$$Q = \lambda^\alpha d_\alpha$$

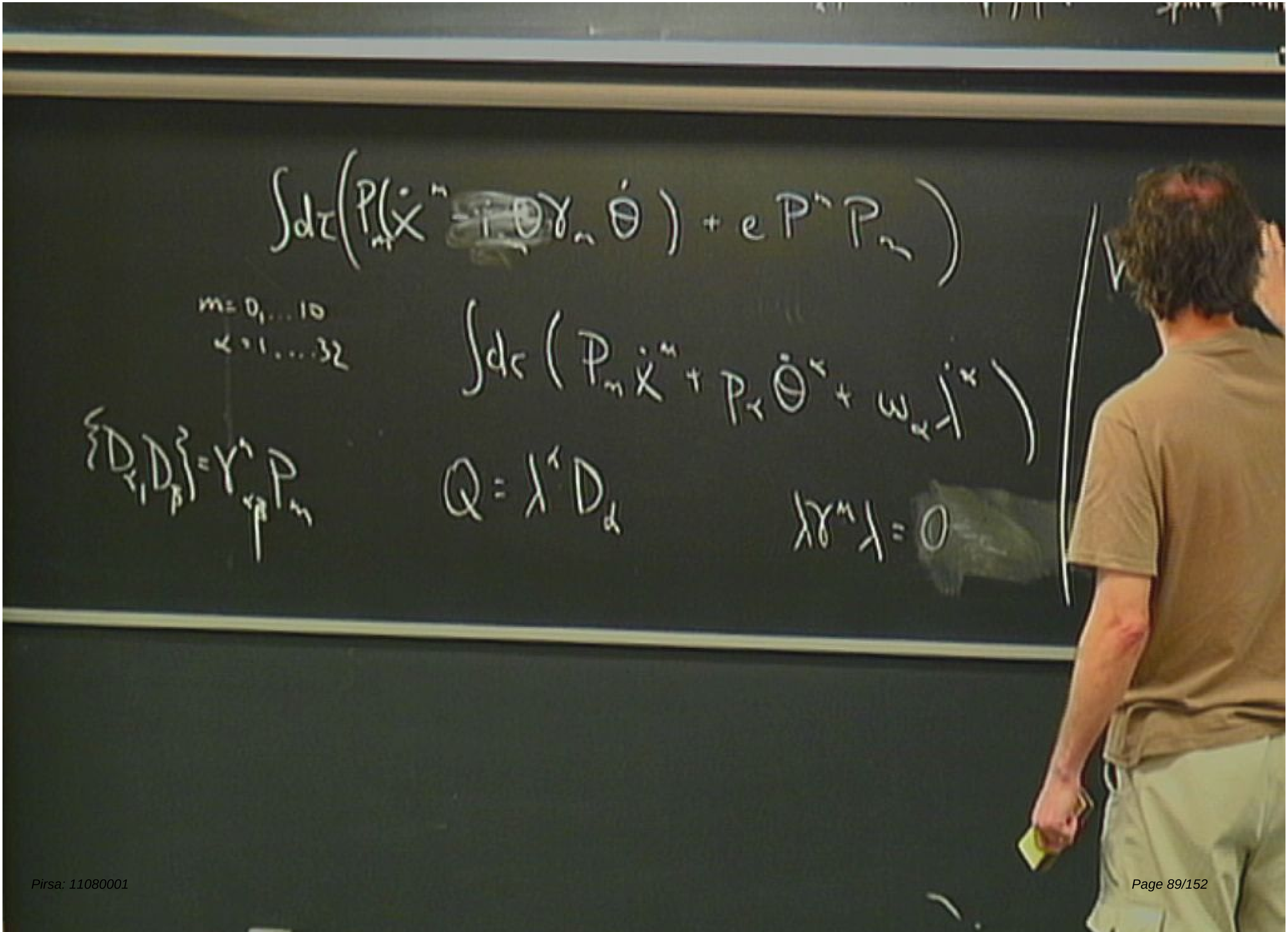
$$= \lambda^\alpha \left(p_\alpha + (\not{P}\theta)_\alpha\right)$$

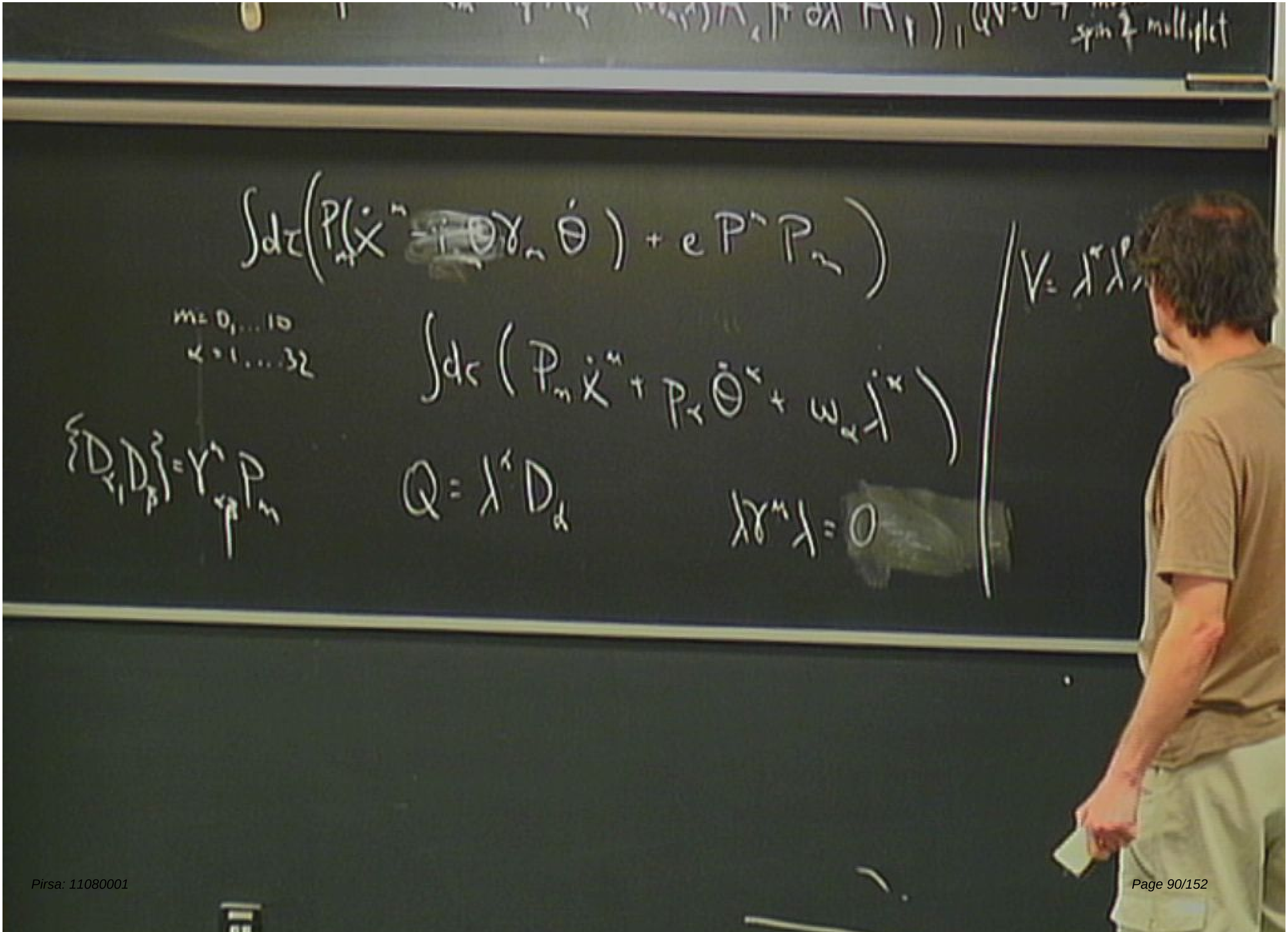
$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn}(w\gamma_{mn}\lambda)\right)$$

$$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta p_\alpha + \dot\lambda w_\alpha + P^2 + \not{P}^\alpha d_\alpha\right)$$

Lorentz current

$$\lambda\gamma^m\lambda = 0 \qquad \delta w_\alpha = \Lambda_m(\gamma^m\lambda)_\alpha \rightarrow (w\gamma^{mn}\lambda),\ w_\alpha\lambda^\alpha$$


∫dτ(P_m(ẋ^m − iθγ_m θ̇) + e P^m P_m)
m = 0,…10
α = 1,…32
∫dτ(P_m ẋ^m + p_α θ̇^α + w_α λ̇^α)
{D_α, D_β} = γ^m_αβ P_m
Q = λ^α D_α
λγ^m λ = 0


$\int d\tau \left(P_m (\dot{x}^m - i\theta\gamma^m \dot{\theta}) + e P^m P_m \right)$
$m = 0, \ldots, 10$
$\alpha = 1, \ldots, 32$
$\int d\tau \left(P_m \dot{x}^m + p_\alpha \dot{\theta}^\alpha + w_\alpha \dot{\lambda}^\alpha \right)$
$\{D_\alpha, D_\beta\} = \gamma^m_{\alpha\beta} P_m$
$Q = \lambda^\alpha D_\alpha$
$\lambda\gamma^m\lambda = 0$
$V = \lambda^\alpha \lambda^\beta$

spin ½ multiplet

$$\int d\tau \left(P_m (\dot{x}^m - i\theta\gamma^m \dot{\theta}) + e P^m P_m \right)$$

$m = 0, \ldots, 10$

$\alpha = 1, \ldots, 32$

$$\int d\tau \left(P_m \dot{x}^m + p_\alpha \dot{\theta}^\alpha + w_\alpha \dot{\lambda}^\alpha \right)$$

$$\{D_\alpha, D_\beta\} = \gamma^m_{\alpha\beta} P_m$$

$$Q = \lambda^\alpha D_\alpha$$

$$\lambda \gamma^m \lambda = 0$$

$$V = \lambda^\alpha \lambda^\beta \lambda^\gamma A_{\alpha\beta\gamma}(x,\theta)$$

$$QV = 0$$

$$\Rightarrow A_{\alpha\beta\gamma} = (\gamma^m\theta)_\alpha (\gamma^n\theta)_\beta (\gamma^p\theta)_\gamma \, b_{mnp} + \ldots$$

$$Q = \lambda^\alpha D_\alpha \qquad V = \lambda^\alpha A_\alpha(x,\theta)$$

← SYM spinor gauge superfield

$$\uparrow$$

$$S = S_0 + \int d\tau \left(A_\alpha \dot\theta^\alpha + A_m \dot x^m + W^\alpha d_\alpha + F^{mn}(w\gamma_{mn}\lambda) \right)$$

↑ Lorentz current

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha \left(p_\alpha + (\not{P}\theta)_\alpha \right)$$

$$S_0 = \int d\tau \left(\dot x^m P_m + \dot\theta p_\alpha + \dot\lambda w_\alpha + \not{P}^2 + \not{\theta}^\alpha d_\alpha \right)$$

$$\lambda\gamma^m\lambda = 0 \qquad \delta w_\alpha = \Lambda_m(\gamma^m\lambda)_\alpha \to (w\gamma^{mn}\lambda),\ w_\alpha\lambda^\alpha$$

$$\int d\tau \left(P_m (\dot{x}^m - [i\,\theta\gamma^m\dot{\theta}]) + e P^m P_m \right)$$

$m = 0, \ldots, 10$

$\alpha = 1, \ldots, 32$

$$\int d\tau \left(P_m \dot{x}^m + p_\alpha \dot{\theta}^\alpha + \omega_\alpha \dot{\lambda}^\alpha \right)$$

$$\{D_\alpha, D_\beta\} = \gamma^m_{\alpha\beta} P_m \qquad Q = \lambda^\alpha D_\alpha \qquad \lambda\gamma^m\lambda = 0$$

$V = \lambda^\alpha \lambda^\beta \lambda^\gamma A_{\alpha\beta\gamma}(x,\theta)$

$QV = 0$

$\rightarrow A_{\alpha\beta\gamma} = (\gamma\theta)_\alpha (\gamma\theta)_\beta (\gamma\theta)_\gamma \, b_{mnp}$

$+ \ldots$

$$\int d\tau \left(P_m(\dot{x}^m - i\,\theta\gamma_m\dot{\theta}) + e P^m P_m \right)$$

$m = 0, \ldots 10$

$\alpha = 1, \ldots 32$

$$\int d\tau \left(P_m \dot{x}^m + p_\alpha \dot{\theta}^\alpha + w_\alpha \dot{\lambda}^\alpha \right)$$

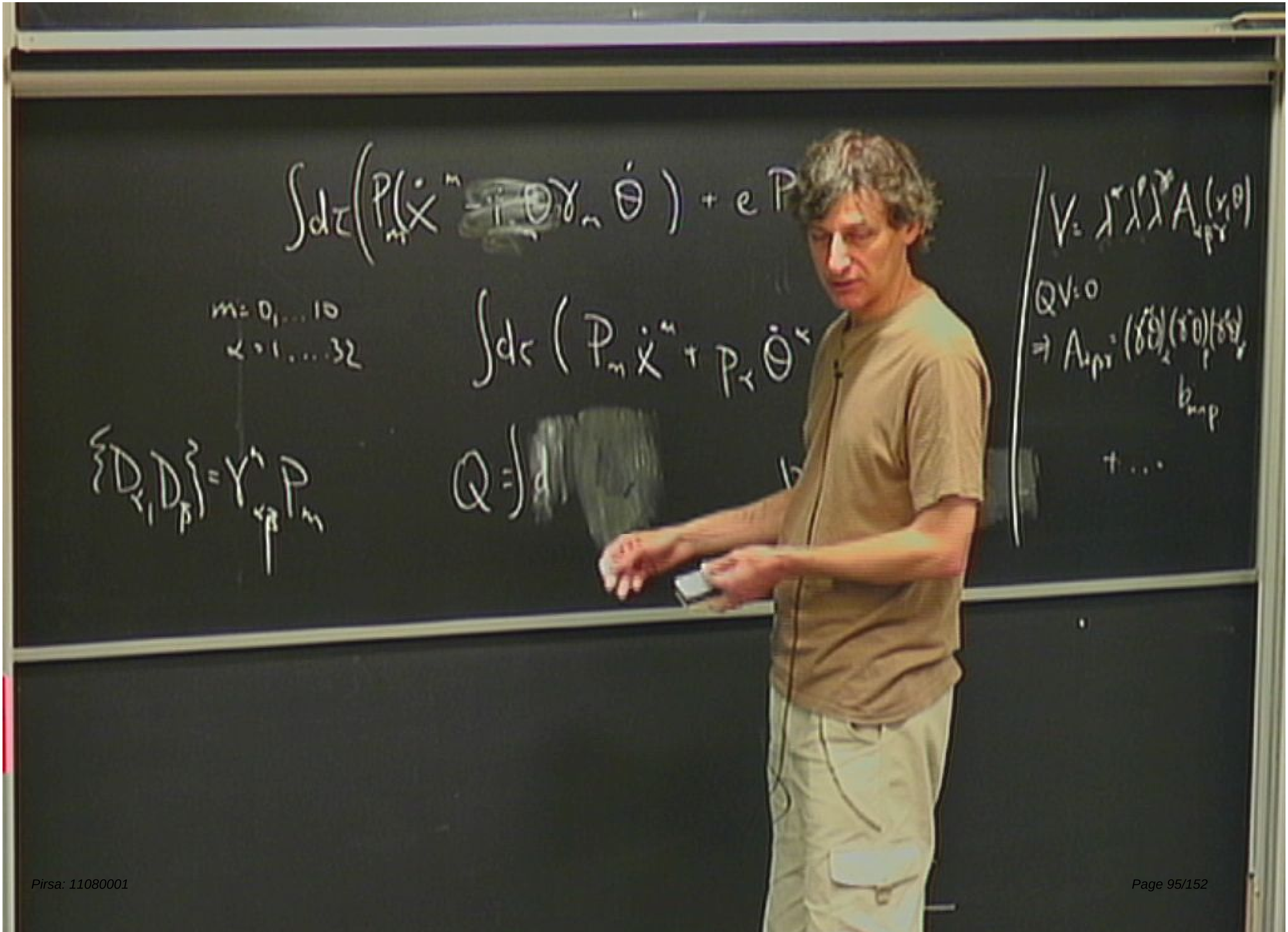
$$\{D_\alpha, D_\beta\} = \gamma^m_{\alpha\beta} P_m \qquad Q = \lambda^\alpha D_\alpha \qquad \lambda\gamma^m\lambda = 0$$

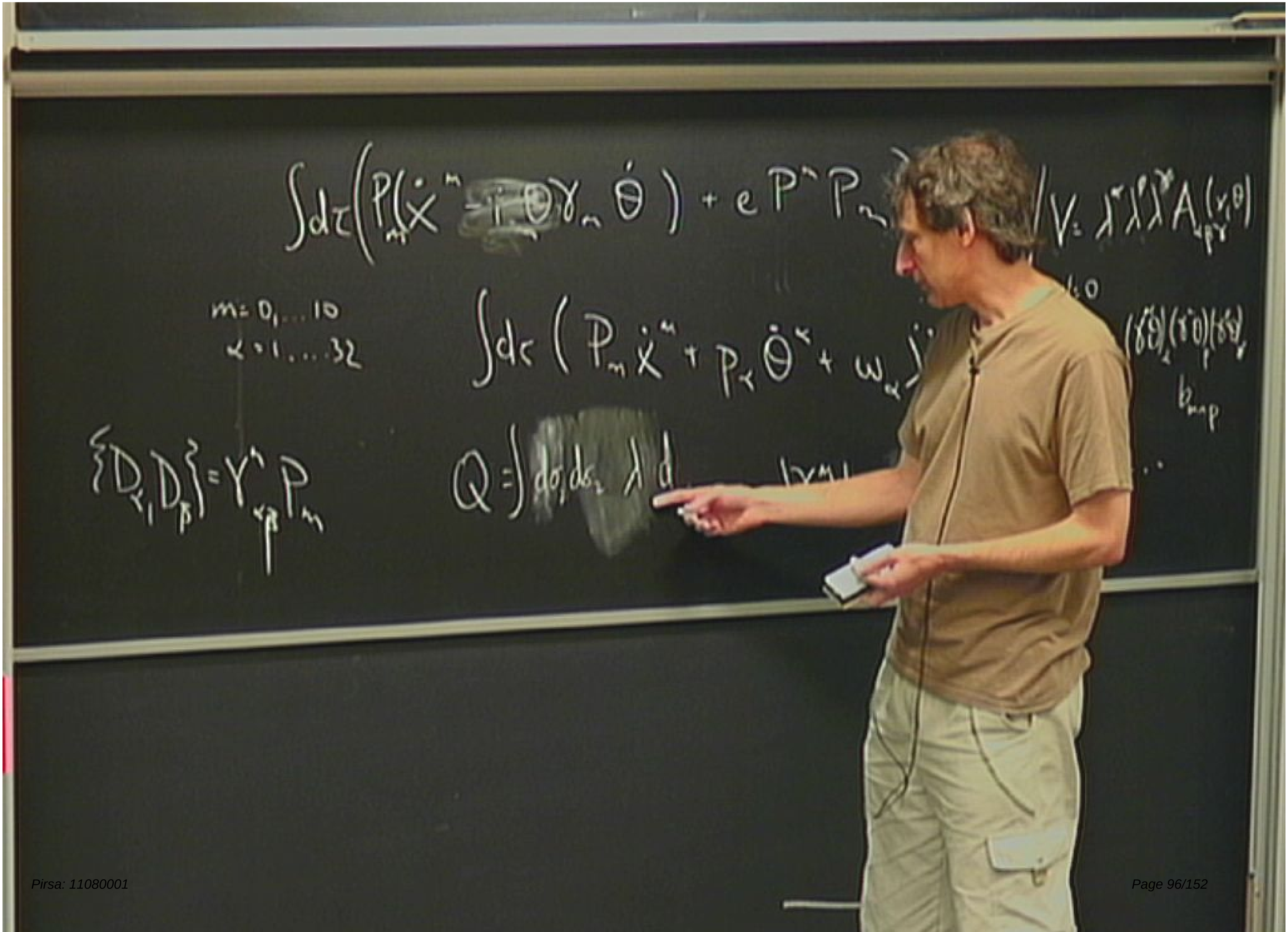
$V = \lambda^\alpha \lambda^\beta \lambda^\gamma A_{\alpha\beta\gamma}(x,\theta)$

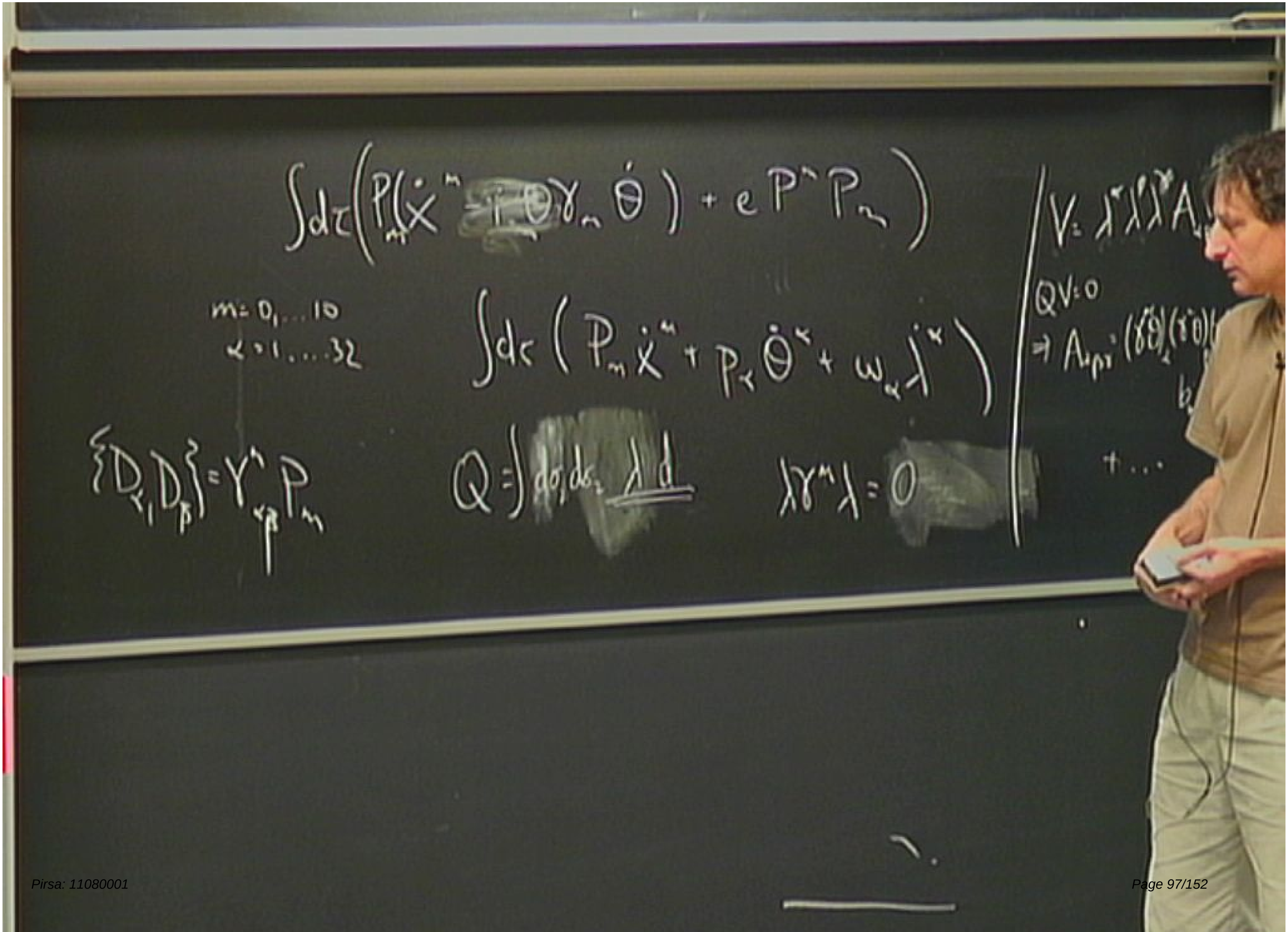
$QV = 0$

$\rightarrow A_{\alpha\beta\gamma} = (\gamma^m\theta)_\alpha (\gamma^n\theta)_\beta (\gamma^p\theta)_\gamma \, b_{mnp}$

$+ \ldots$


m = 0, ..., 10
α = 1, ..., 32
QV = 0


m = 0, ..., 10
α = 1, ..., 32


m = 0, ... 10
α = 1, ... 32
QV = 0
+ ...

$$\int d\tau \left(P_m (\dot{x}^m - i\,\theta \gamma_m \dot{\theta}) + e P^m P_m \right)$$

$m = 0, \ldots 10$

$\alpha = 1, \ldots 32$

$$\int d\tau \left(P_m \dot{x}^m + p_\alpha \dot{\theta}^\alpha + \omega_\alpha \dot{\lambda}^\alpha \right)$$

$$\{D_\alpha, D_\beta\} = \gamma^m_{\alpha\beta} P_m$$

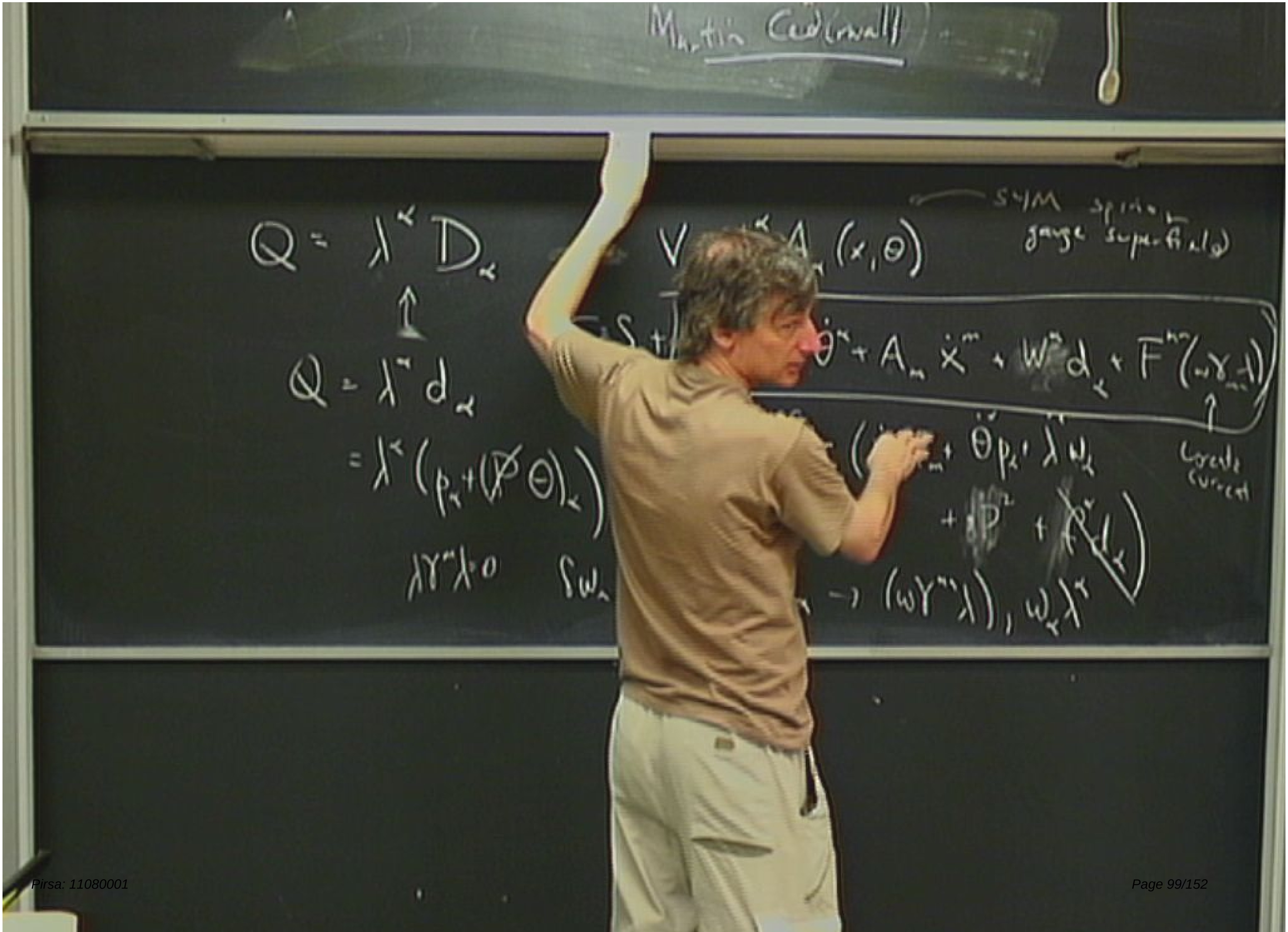
$$Q = \int d\sigma_1 d\sigma_2 \, \lambda^\alpha d_\alpha \qquad \lambda \gamma^m \lambda = 0$$

$V = \lambda^\alpha \lambda^\beta \lambda^\gamma A_{\alpha\beta\gamma}(x,\theta)$

$QV = 0$

$\rightarrow A_{\alpha\beta\gamma} = (\gamma\theta)_\alpha (\gamma\theta)_\beta (\gamma\theta)_\gamma \, b_{mnp}$

$+ \ldots$



Martin Cederwall
SYM

$\langle \varphi Q \varphi \rangle$

$$\int d\tau \left(P_m (\dot{x}^m - i\theta\gamma^m \dot{\theta}) + e P^m P_m \right)$$

$m = 0, \ldots, 10$

$\alpha = 1, \ldots, 32$

$$\int d\tau \left(P_m \dot{x}^m + p_\alpha \dot{\theta}^\alpha + \omega_\alpha \dot{\lambda}^\alpha \right)$$

$$\{D_\alpha, D_\beta\} = \gamma^m_{\alpha\beta} P_m$$

$$Q = \int d\sigma_1 d\sigma_2 \, \lambda^\alpha d_\alpha \qquad \lambda\gamma^m\lambda = 0$$

$V = \lambda^\alpha \lambda^\beta \lambda^\gamma A_{\alpha\beta\gamma}(x,\theta)$

$QV = 0$

$\Rightarrow A_{\alpha\beta\gamma} = (\gamma\theta)_\alpha (\gamma\theta)_\beta (\gamma\theta)_\gamma \, b_{mnp}$

$+ \ldots$

$$\langle \varphi Q \varphi' \ldots \varphi^3 \rangle \qquad \int d\tau \left(P_m (\dot{X}^m - i\bar{\theta}\gamma^m \dot{\theta}) + e P^m P_m \right)$$

$m = 0, \ldots, 10$

$\alpha = 1, \ldots, 32$

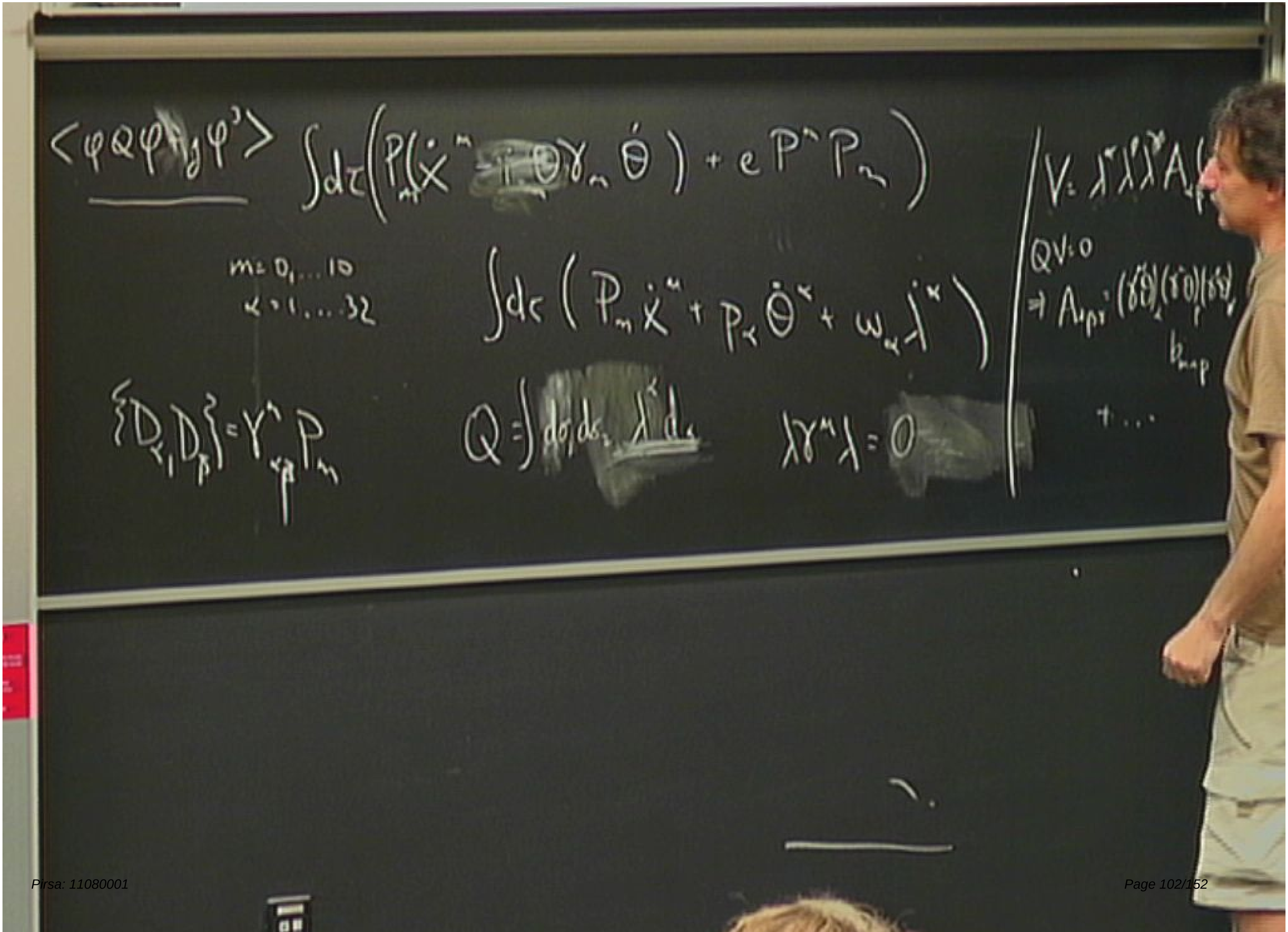
$$\int d\tau \left(P_m \dot{X}^m + p_\alpha \dot{\theta}^\alpha + w_\alpha \dot{\lambda}^\alpha \right)$$

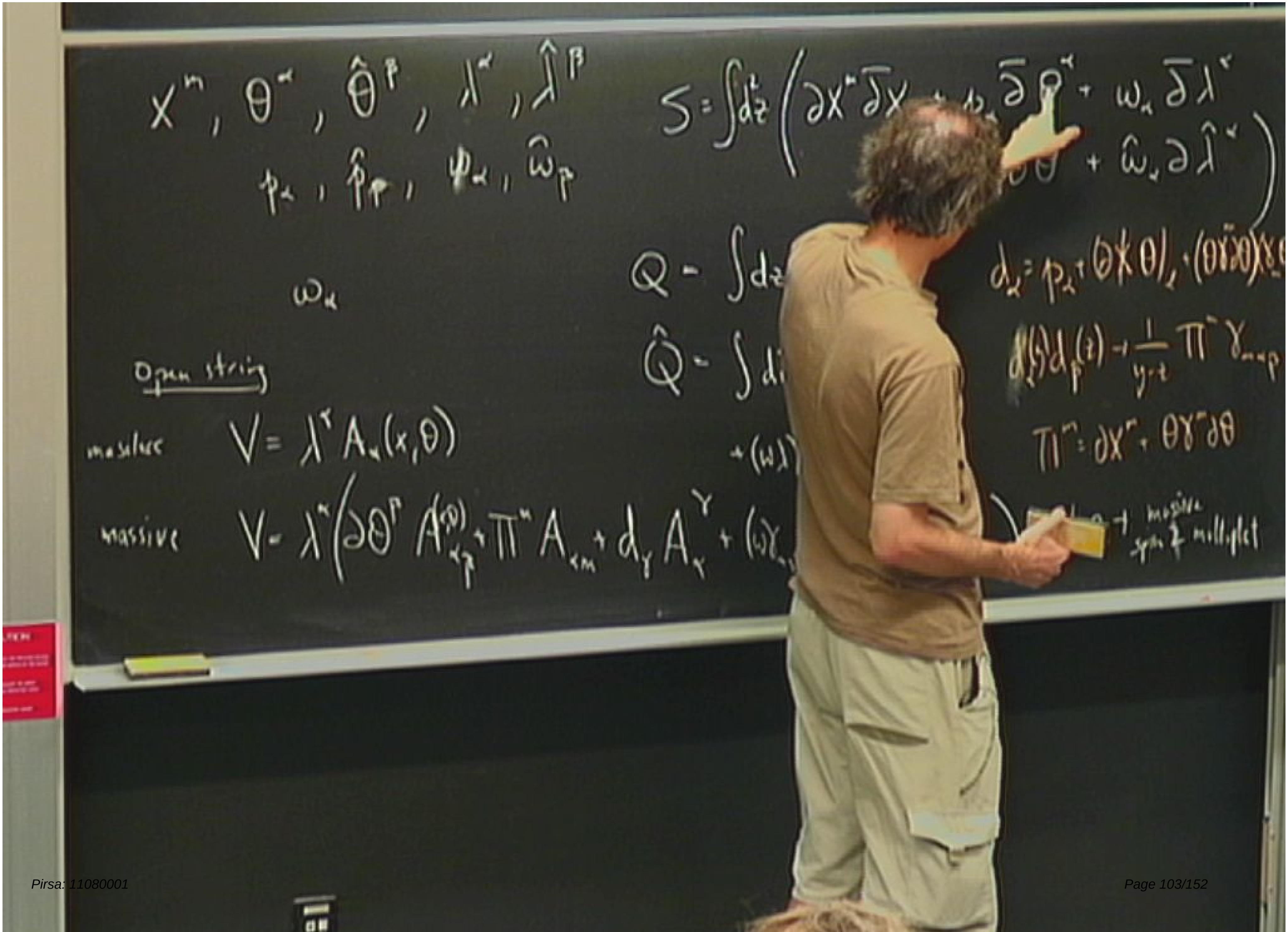
$$\{D_\alpha, D_\beta\} = \gamma^m_{\alpha\beta} P_m \qquad Q = \int d\sigma_1 d\sigma_2\, \lambda^\alpha d_\alpha \qquad \lambda\gamma^m\lambda = 0$$

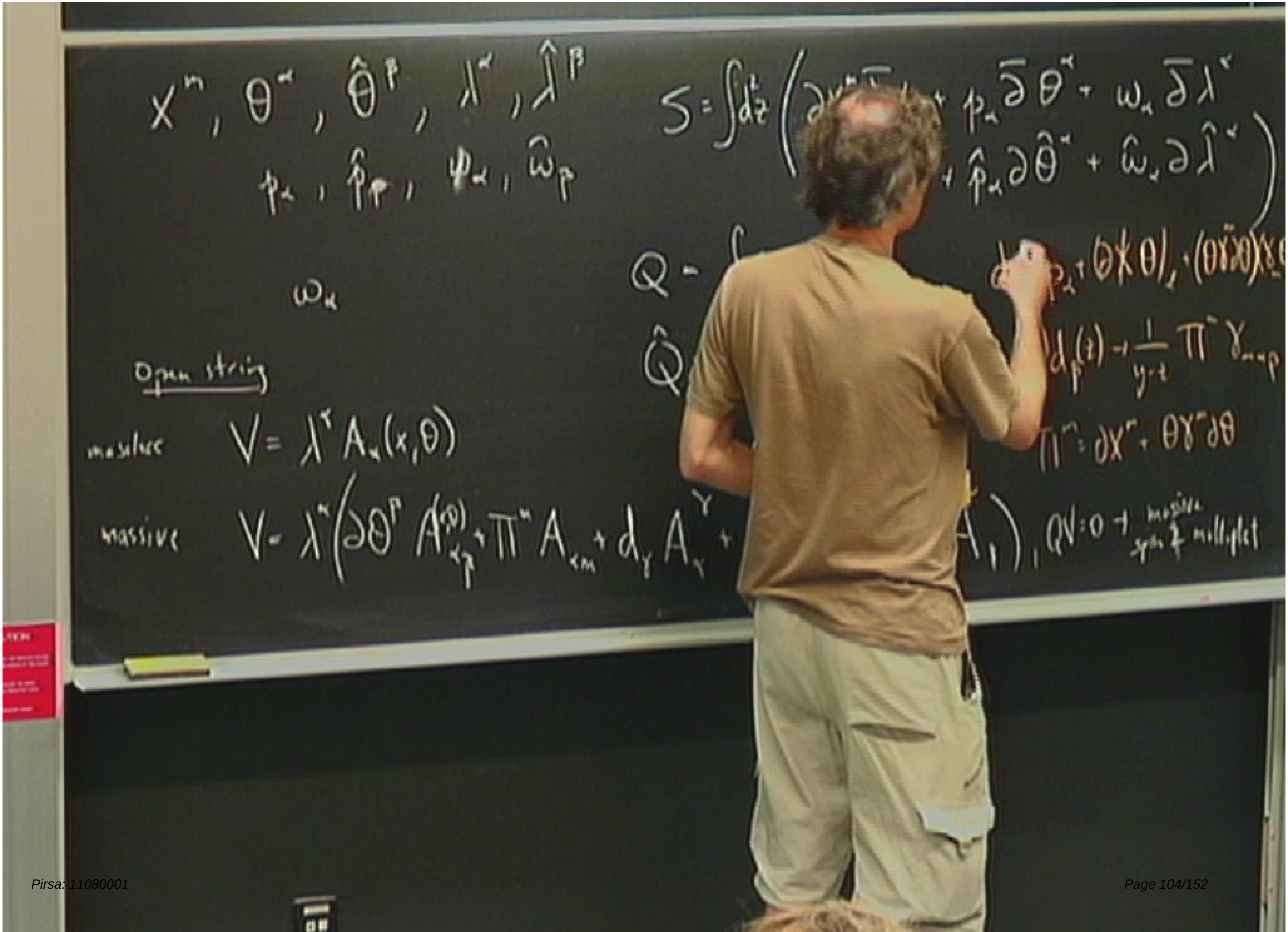
$$V = \lambda^\alpha \lambda^\beta \lambda^\gamma A_{\alpha\beta\gamma}(x,\theta)$$

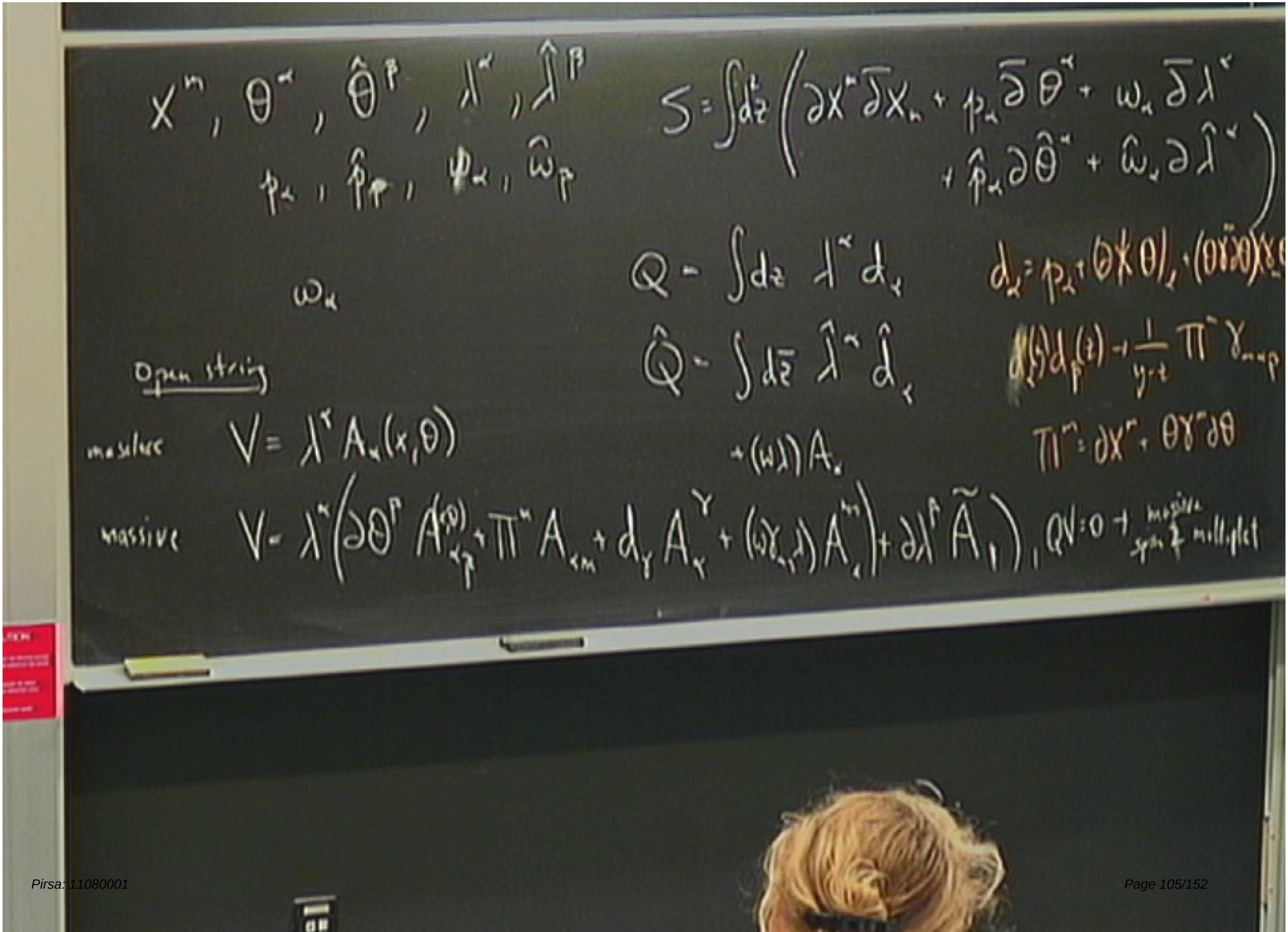
$$QV = 0$$

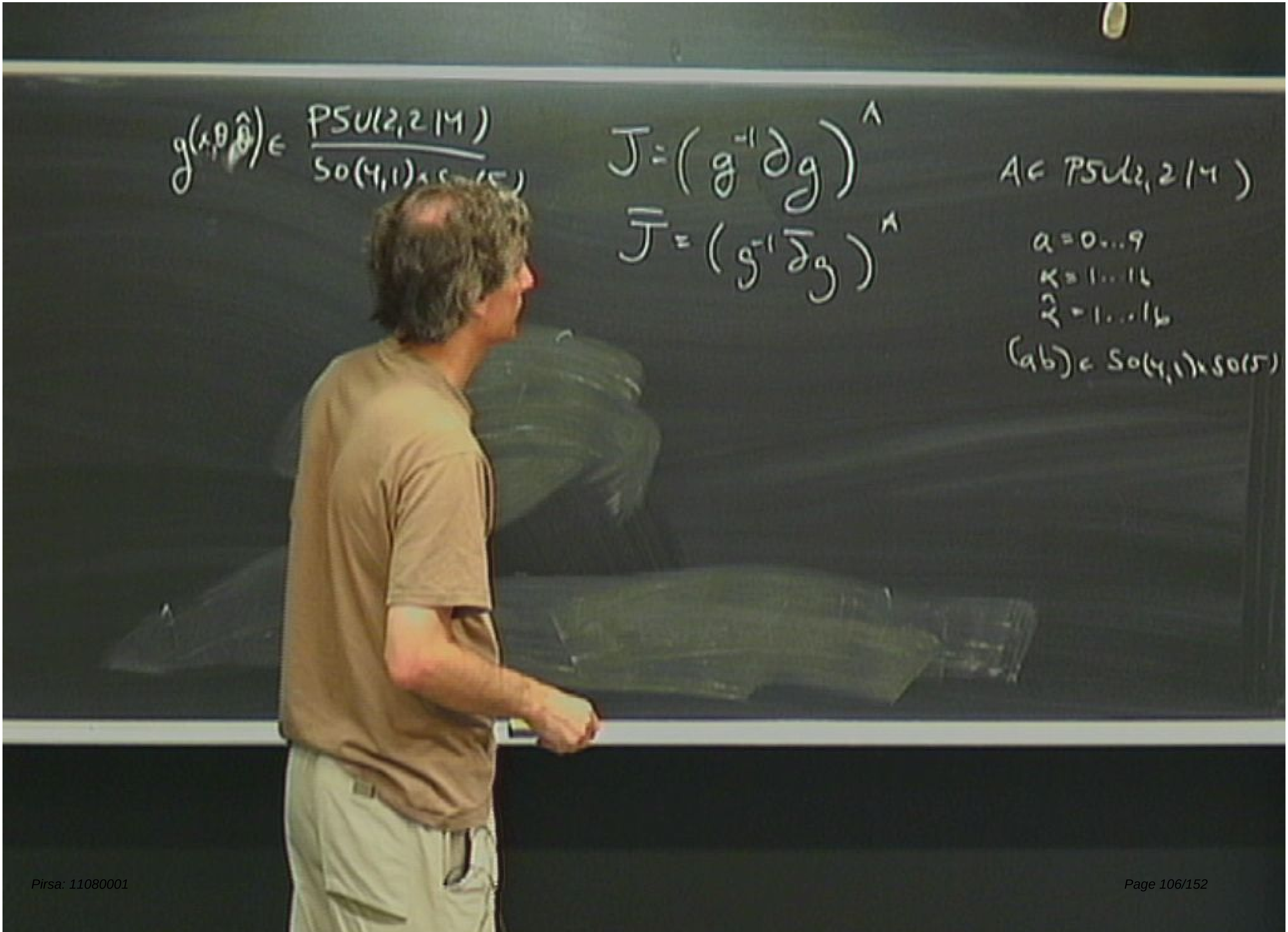
$$\Rightarrow A_{\alpha\beta\gamma} = (\gamma\theta)_\alpha (\gamma\theta)_\beta (\gamma\theta)_\gamma\, b_{mnp} + \ldots$$

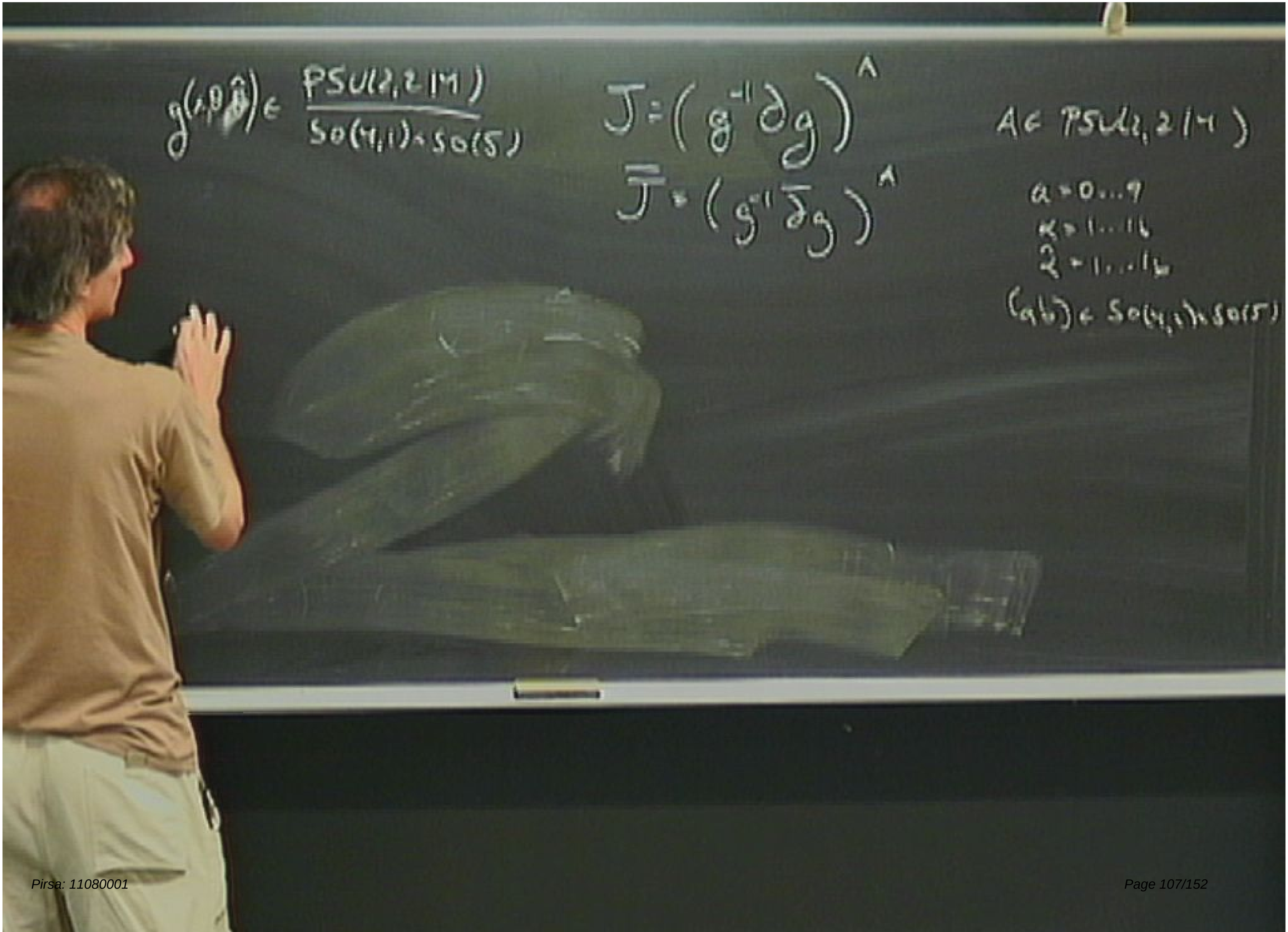

m = 0, ... 10
α = 1, ... 32
∫dτ (P_m Ẋ^m + p_α Θ̇^α + w_α λ̇^α)
{D_α, D_β} = γ^m_αβ P_m
λγ^m λ = 0
QV = 0
+ ...


Open string
massless
massive
massive spin 2 multiplet


Open string
massless
massive


$X^m, \theta^\alpha, \hat{\theta}^\beta, \lambda^\alpha, \hat{\lambda}^\beta$
$p_\alpha, \hat{p}_\beta, w_\alpha, \hat{w}_\beta$
$S = \int d^2z \left(\partial X^m \bar{\partial} X_m + p_\alpha \bar{\partial} \theta^\alpha + w_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_\alpha \partial \hat{\theta}^\alpha + \hat{w}_\alpha \partial \hat{\lambda}^\alpha \right)$
w_α
$Q = \int dz \, \lambda^\alpha d_\alpha$
$\hat{Q} = \int d\bar{z} \, \hat{\lambda}^\alpha \hat{d}_\alpha$
$d_\alpha = p_\alpha + (\theta \gamma^m \theta)_\alpha + (\theta \gamma^m \partial \theta)(\gamma_m \theta)_\alpha$
$d_\alpha(y) d_\beta(z) \to \frac{1}{y-z} \Pi^m \gamma_{m\alpha\beta}$
$\Pi^m = \partial X^m + \theta \gamma^m \partial \theta$
Open string
massless $V = \lambda^\alpha A_\alpha(x, \theta)$
$+ (w\lambda) A_\alpha$
massive $V = \lambda^\alpha \left(\partial \theta^\beta A^{(\theta)}_{\alpha\beta} + \Pi^m A_{\alpha m} + d_\gamma A^\gamma_\alpha + (w \gamma_{m\alpha} \lambda) A^{mn}_\alpha \right) + \partial \lambda^\beta \tilde{A}_\beta$, $QV = 0 \to$ massive spin 2 multiplet


g(x,θ,θ̂) ∈ PSU(2,2|4) / SO(4,1)×
J = (g^-1 ∂g)^A
J̄ = (g^-1 ∂̄g)^A
A ∈ PSU(2,2|4)
a = 0...9
α = 1..16
α̂ = 1...16
(ab) ∈ SO(4,1)×SO(5)


g(x,θ,θ̂) ∈ PSU(2,2|4) / SO(4,1)×SO(5)
J = (g⁻¹∂g)^A
J̄ = (g⁻¹∂̄g)^A
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a = 0...9
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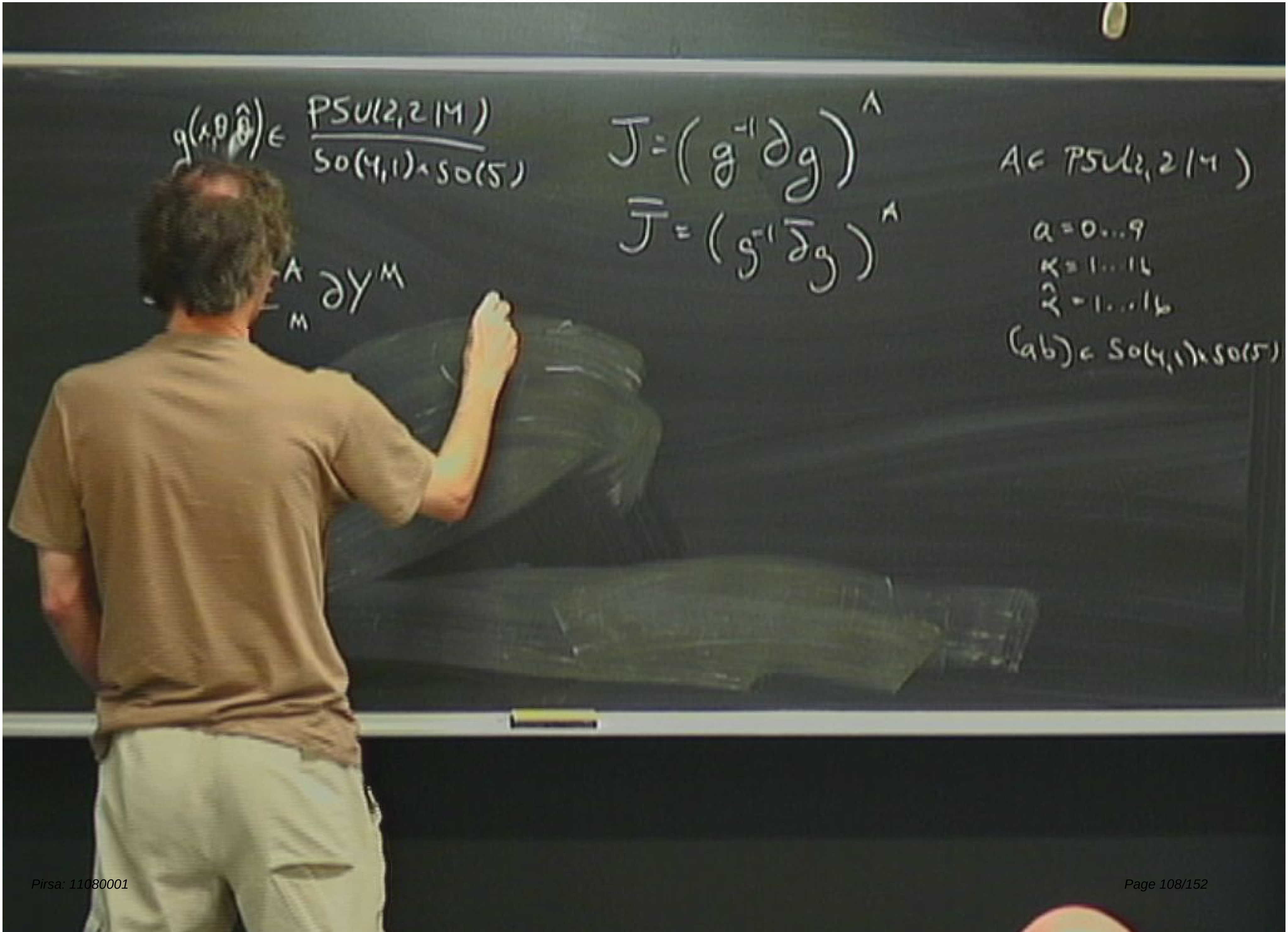

g(x,θ,θ̂) ∈ PSU(2,2|4) / SO(4,1)×SO(5)
J = (g⁻¹∂g)^A
J̄ = (g⁻¹∂̄g)^A
A ∈ PSU(2,2|4)
a = 0...9
α = 1...16
α̂ = 1...16
(ab) ∈ SO(4,1)×SO(5)
∂y^M

$$g(x,\theta,\hat{\theta}) \in \frac{PSU(2,2|4)}{SO(4,1)\times SO(5)}$$

$$J = \left(g^{-1}\partial g\right)^{A}$$

$$\bar{J} = \left(g^{-1}\bar{\partial} g\right)^{A}$$

$A \in PSU(2,2|4)$

$a = 0 \ldots 9$

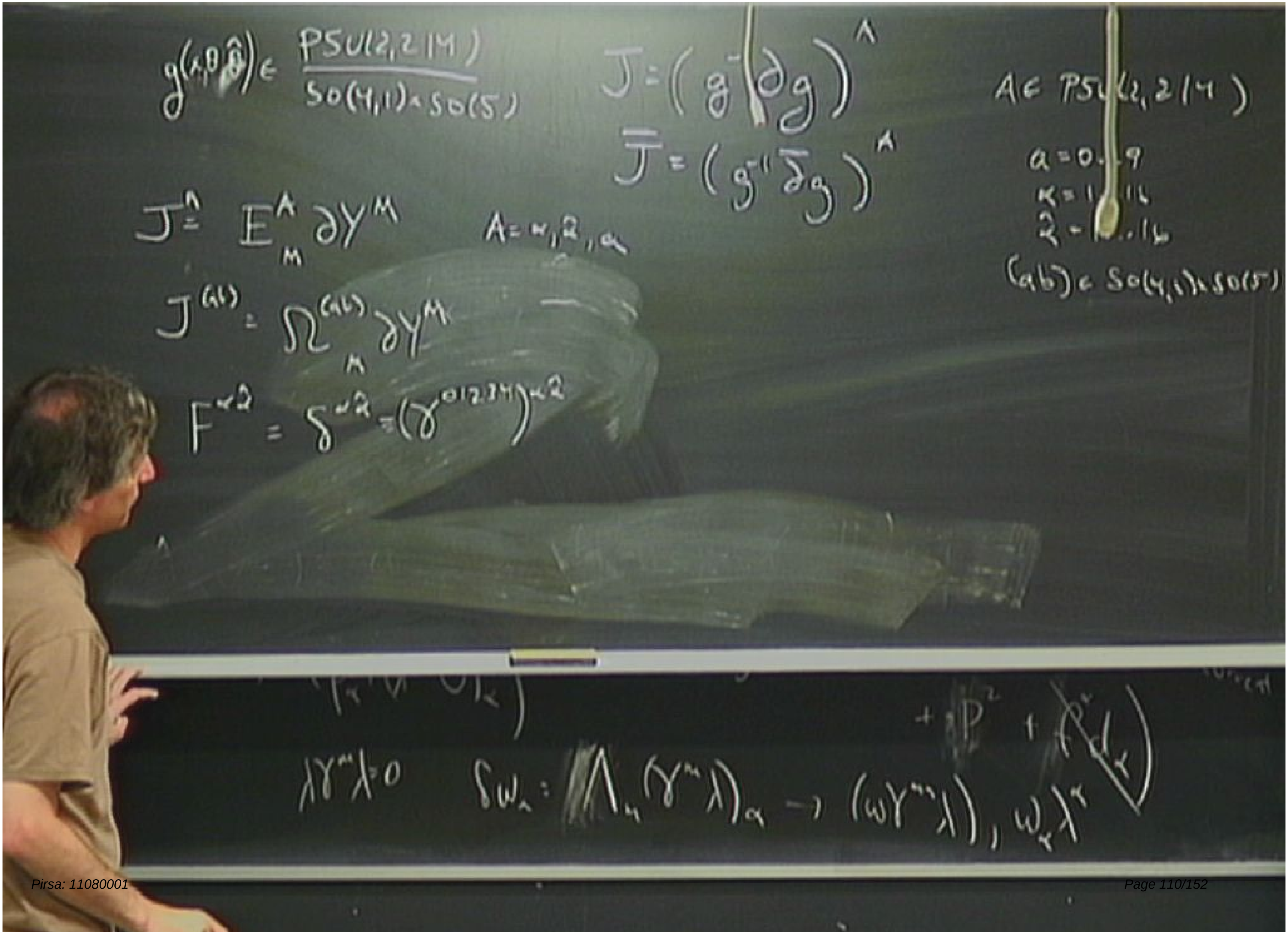
$\alpha = 1 \ldots 16$

$\hat{\alpha} = 1 \ldots 16$

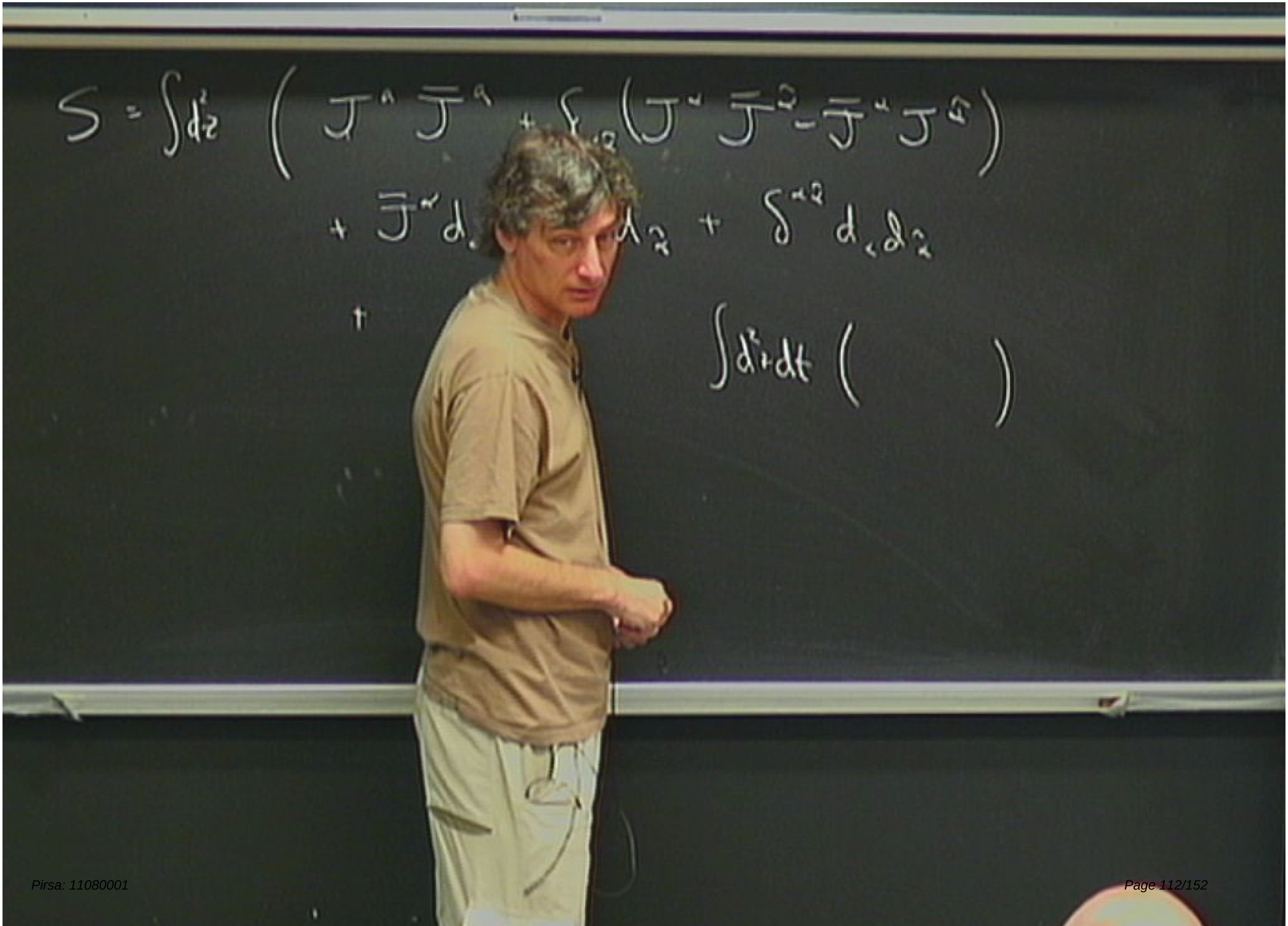
$(ab) \in SO(4,1)\times SO(5)$

$$J^{A} = E^{A}_{M}\,\partial Y^{M} \qquad A = \alpha, \hat{\alpha}, a$$

$$J^{(ab)} = \Omega^{(ab)}_{M}\,\partial Y^{M}$$


g(x,θ,θ̂) ∈ PSU(2,2|4) / SO(4,1)×SO(5)
J = (g⁻¹∂g)^A
J̄ = (g⁻¹∂̄g)^A
A ∈ PSU(2,2|4)
J^A = E^A_M ∂Y^M
A = m, α̂, α
J^(ab) = Ω^(ab)_M ∂Y^M
F^{αα̂} = δ^{αα̂} = (γ^{01234})^{αα̂}
(ab) ∈ SO(4,1)×SO(5)
λγ^m λ = 0
δw_α = Λ_m (γ^m λ)_α → (wγ^{mn}λ), w_α λ^α

$$S = \int d^2z \left(J^a \bar{J}^a + f_{\alpha\hat{\alpha}}\left(J^\alpha \bar{J}^{\hat{\alpha}} - \bar{J}^\alpha J^{\hat{\alpha}}\right) + \bar{J}^\alpha d_\alpha + J^{\hat{\alpha}} \bar{d}_{\hat{\alpha}} + \delta^{\alpha\hat{\alpha}} d_\alpha d_{\hat{\alpha}} \right)$$


S = ∫d²z (J^a J̄^a + ε_{a2}(J^a J̄^2 − J̄^a J^2))
+ J̄^a d_a
d_2 + δ^{a2} d_a d_2
+
∫d²z dt ( )

$$S = \int d^2z \left(J^a \bar{J}^a + f_{\alpha\hat{\alpha}} \left(J^\alpha \bar{J}^{\hat{\alpha}} - \bar{J}^\alpha J^{\hat{\alpha}} \right) + \bar{J}^\alpha d_\alpha + J^{\hat{\alpha}} \bar{d}_{\hat{\alpha}} + \delta^{\alpha\hat{\alpha}} d_\alpha d_{\hat{\alpha}} \right.$$

$$+ \qquad \int d^2z\, dt \, (\qquad)$$

$$S = \int d^2z \left(J^a \bar{J}^a + f_{\alpha\hat{\beta}} \left(J^\alpha \bar{J}^{\hat{\beta}} - \bar{J}^\alpha J^{\hat{\beta}} \right) \right.$$

$$\left. + \bar{J}^\alpha d_\alpha + J^{\hat{\alpha}} \hat{d}_{\hat{\alpha}} + \delta^{\alpha\hat{\beta}} d_\alpha \hat{d}_{\hat{\beta}} \right)$$

$$S = \int d^2z \left(J^a \bar{J}^a + f_{a\hat{a}} \left(J^a \bar{J}^{\hat{a}} - \bar{J}^a J^{\hat{a}} \right) \right.$$

$$+ \bar{J}^a d_a + J^{\hat{a}} \hat{d}_{\hat{a}} + \delta^{a\hat{a}} d_a \hat{d}_{\hat{a}}$$

$$\left. + \hat{d}_a (w\gamma\lambda) \quad + \quad + (w\gamma\lambda)(\hat{w}\gamma\hat{\lambda}) \right)$$

$$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$$

$$= \frac{\partial \mathcal{L}}{\partial(\theta^\alpha)}$$

$$(x, \theta, \theta)\, d_\alpha d_{\hat{\alpha}}$$

$$+ \Omega_M{}^{ab}\, \partial Y^M (\hat{w}\gamma_{ab}\hat{\lambda}) + \hat{\Omega}_M{}^{ab} (w\gamma_{ab}\lambda) \bar{\partial} Y^M$$

$$+ C^{\alpha ab} d_\alpha (\hat{w}\gamma_{ab}\hat{\lambda}) + \hat{C}^{\hat{\alpha} ab} (w\gamma_{ab}\lambda) \hat{d}_{\hat{\alpha}} + R^{abcd} (w\gamma_{ab}\lambda)(\hat{w}\gamma_{cd}\hat{\lambda})$$

$$+ w\bar{\partial}\lambda + \hat{w}\partial\hat{\lambda} \qquad + \alpha' \int d^2z\, \varphi(x, \theta, \bar{\theta})\, R$$

$$N^{mn} = \psi^m \psi^n$$

$$\int dz \left(A_m \partial X^m + F_{mn} \psi^m \psi^n \right)$$

$$N^{mn} N^{mn} \to \frac{1}{(y-z)^2}$$

$$N_1 + N_2$$

$$k_1 = +4$$

$$k_2 = -3$$

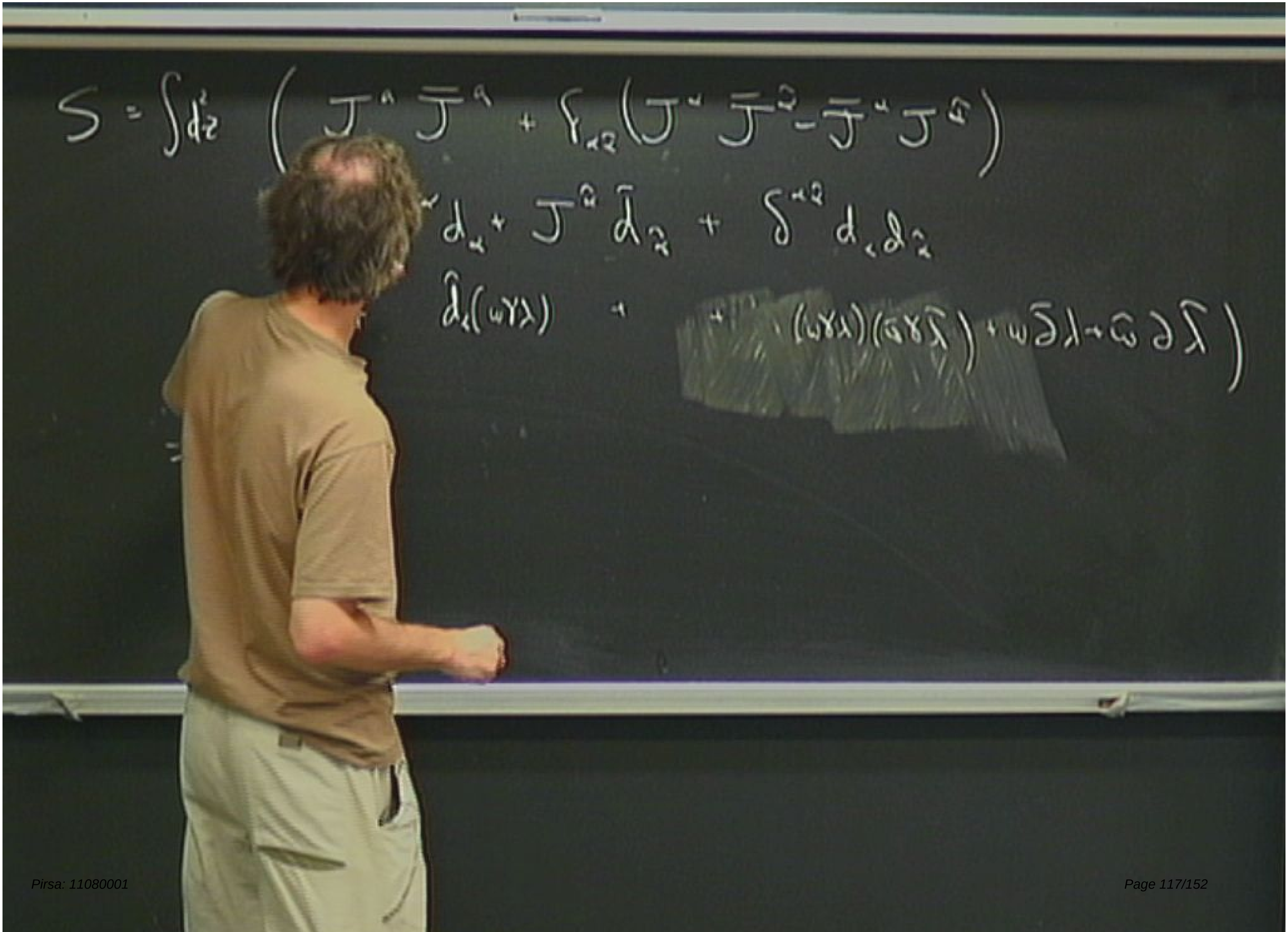
$$\int dz\, d\bar{z} \left((g_{mn} + b_{mn}) \partial X^m \bar{\partial} X^n \right.$$

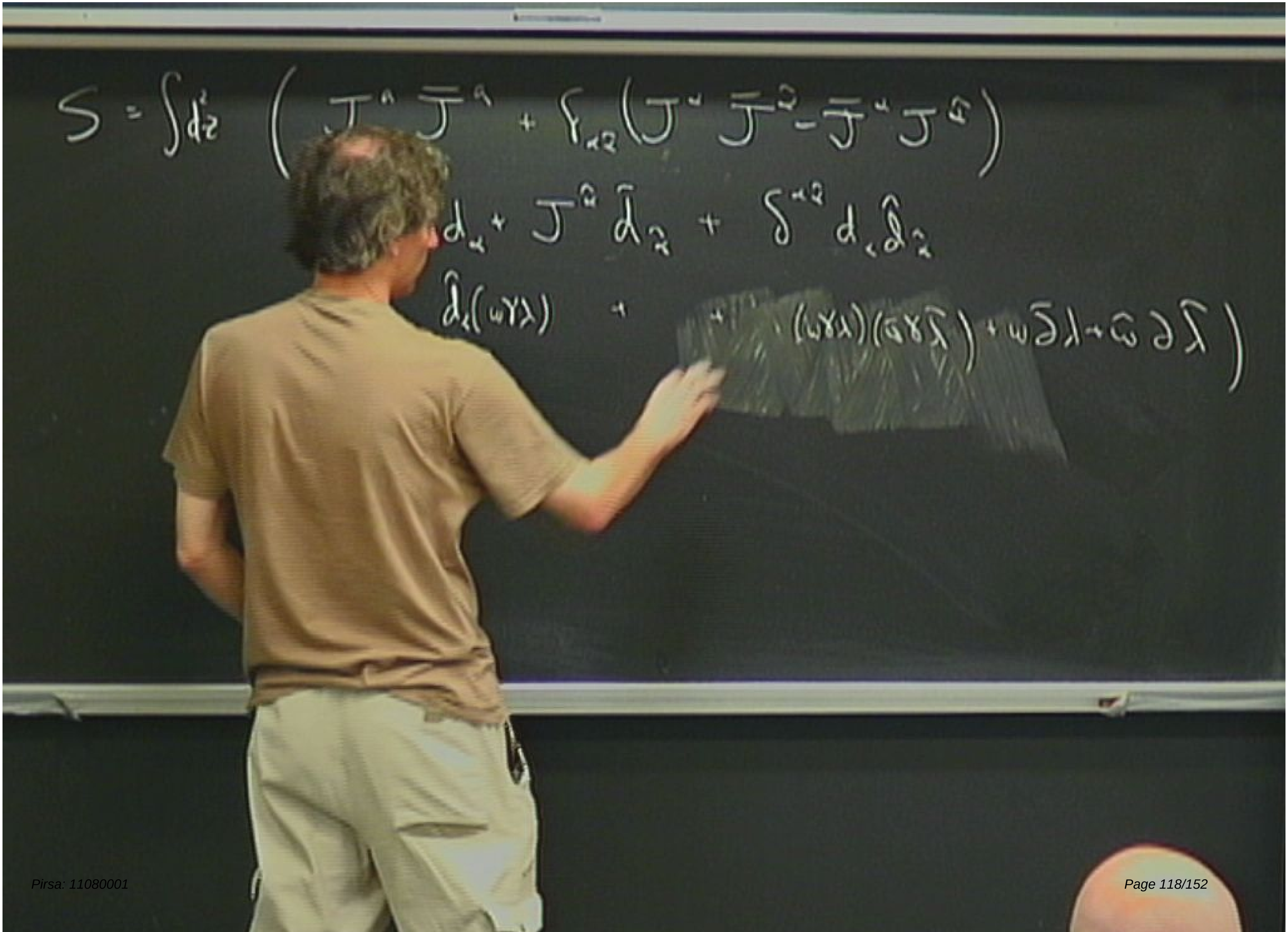
$$+ w_m{}^{ab} \partial X^m \bar{\psi}_a \bar{\psi}_b + \hat{w}_m{}^{ab} \psi_a \psi_b \bar{\partial} X^m$$

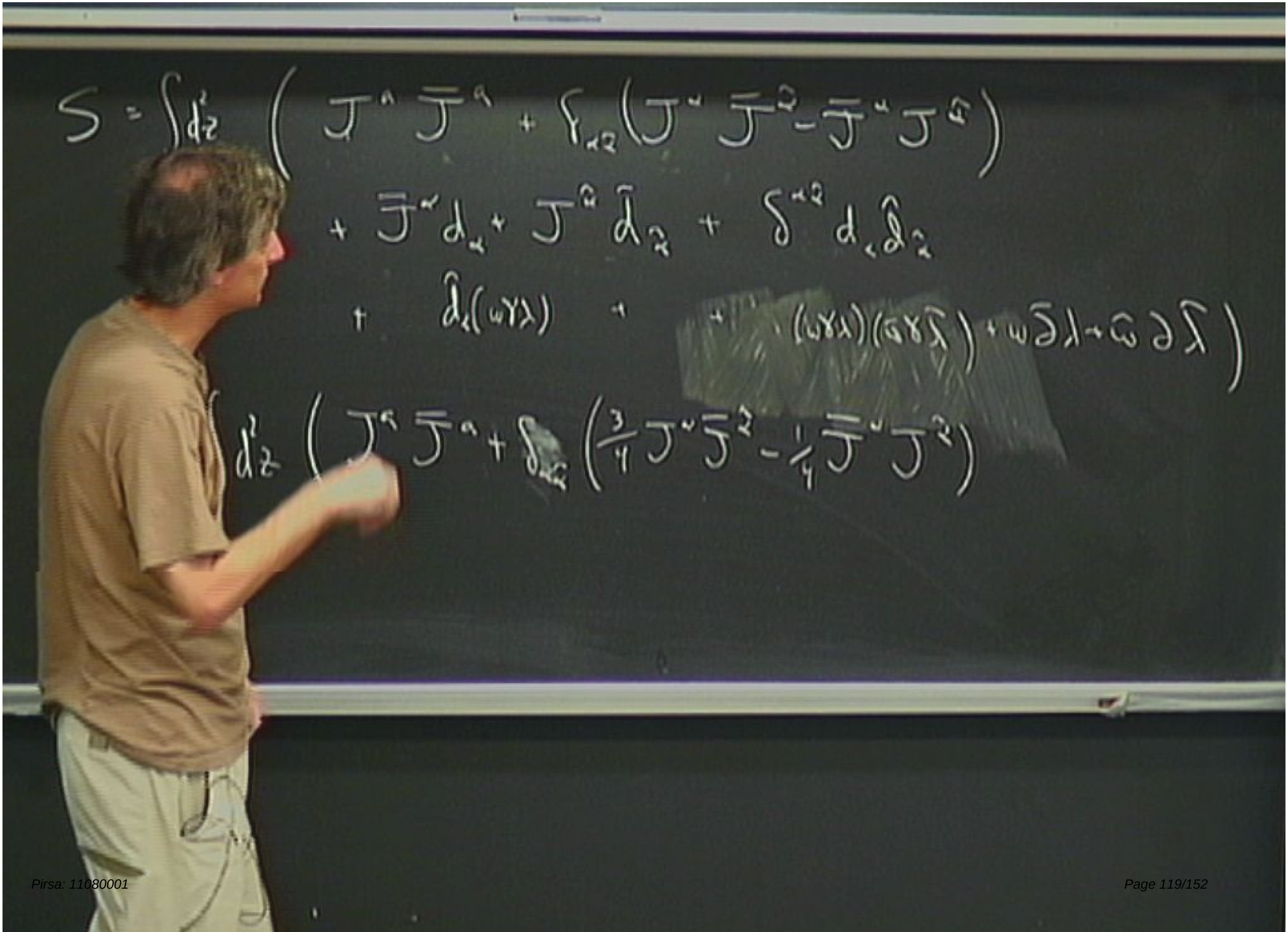
$$\left. + R_{abcd} \psi^a \psi^b \bar{\psi}^c \bar{\psi}^d \right)$$

$$+ \alpha' \int dz\, d\bar{z}\, \varphi\, R$$

$$g_{mn} + b_{mn}\, \partial X^m \bar{\partial} X^n$$


S = ∫d²z (J^a J̄^a + f_αα̂ (J^α J̄^α̂ − J̄^α J^α̂)
J^α̂ d̄_α̂ + δ^αα̂ d_α d_α̂
d̂_α(wγλ)


S = ∫d²z (J^a J̄^a + f_{aâ}(J^a J̄^â − J̄^a J^â))
d_a + J^â d̂_â + δ^{aâ} d_a d̂_â
d̂_â(wγλ) + (wγλ)(ŵγλ̂) + w∂λ + ŵ∂λ̂)


$S = \int d^2z \left(J^a \bar{J}^a + f_{\alpha\hat{\alpha}}\left(J^\alpha \bar{J}^{\hat{\alpha}} - \bar{J}^\alpha J^{\hat{\alpha}}\right) \right.$
$+ \bar{J}^\alpha d_\alpha + J^{\hat{\alpha}} \hat{d}_{\hat{\alpha}} + f^{\alpha\hat{\alpha}} d_\alpha \hat{d}_{\hat{\alpha}}$
$+ \hat{d}_\alpha(w\gamma\lambda) + \quad + (w\gamma\lambda)(\hat{w}\gamma\hat{\lambda}) + w\bar{\partial}\lambda + \hat{w}\partial\hat{\lambda} \left. \right)$
$\int d^2z \left(J^a \bar{J}^a + f_{\alpha\hat{\alpha}}\left(\frac{3}{4} J^\alpha \bar{J}^{\hat{\alpha}} - \frac{1}{4} \bar{J}^\alpha J^{\hat{\alpha}}\right) \right)$

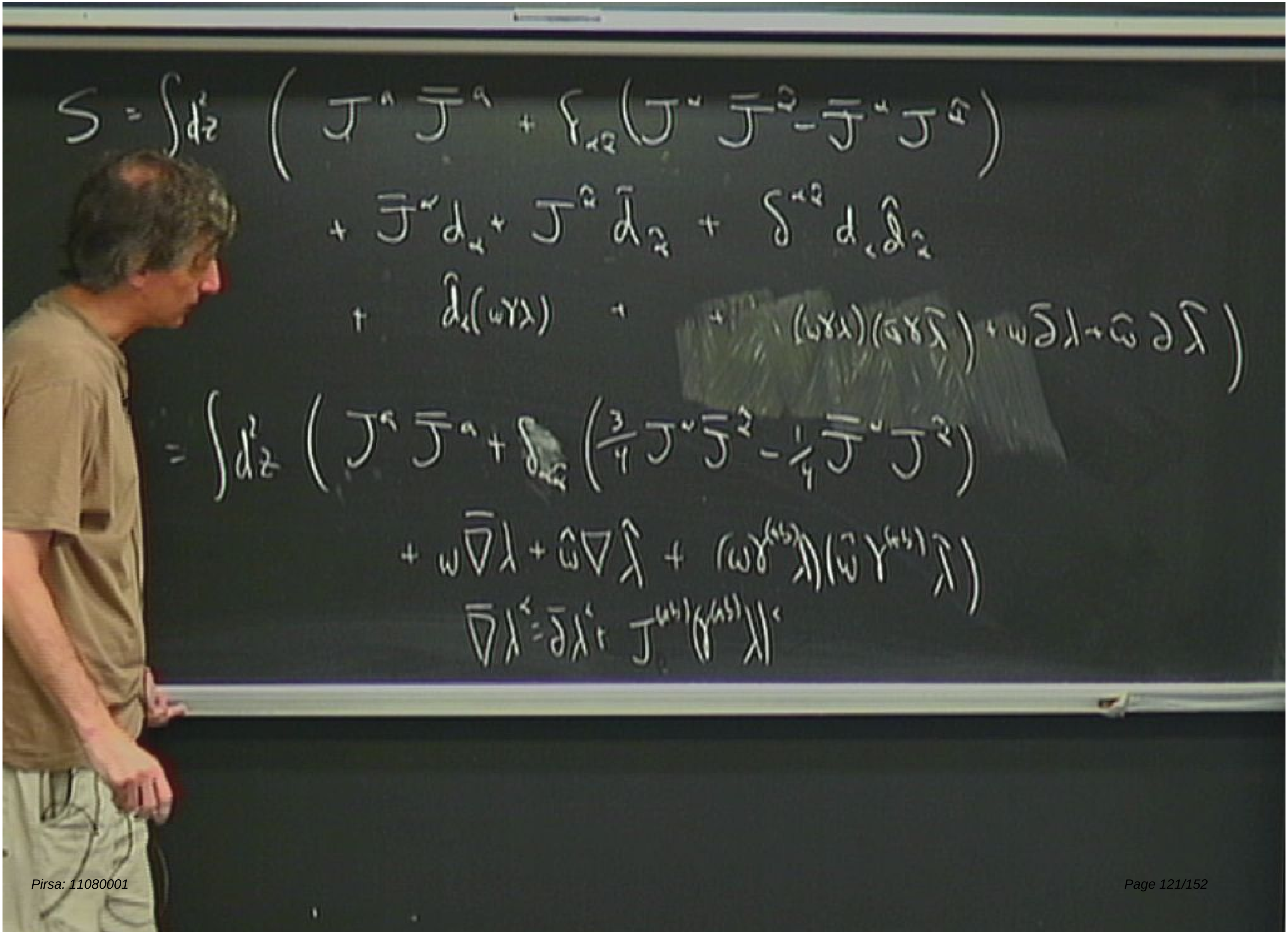
$$S = \int d^2z \Big(J^a \bar{J}^a + f_{\alpha\hat{\beta}}\left(J^\alpha \bar{J}^{\hat{\beta}} - \bar{J}^\alpha J^{\hat{\beta}}\right)$$

$$+ \bar{J}^\alpha d_\alpha + J^{\hat{\beta}} \hat{d}_{\hat{\beta}} + \delta^{\alpha\hat{\beta}} d_\alpha \hat{d}_{\hat{\beta}}$$

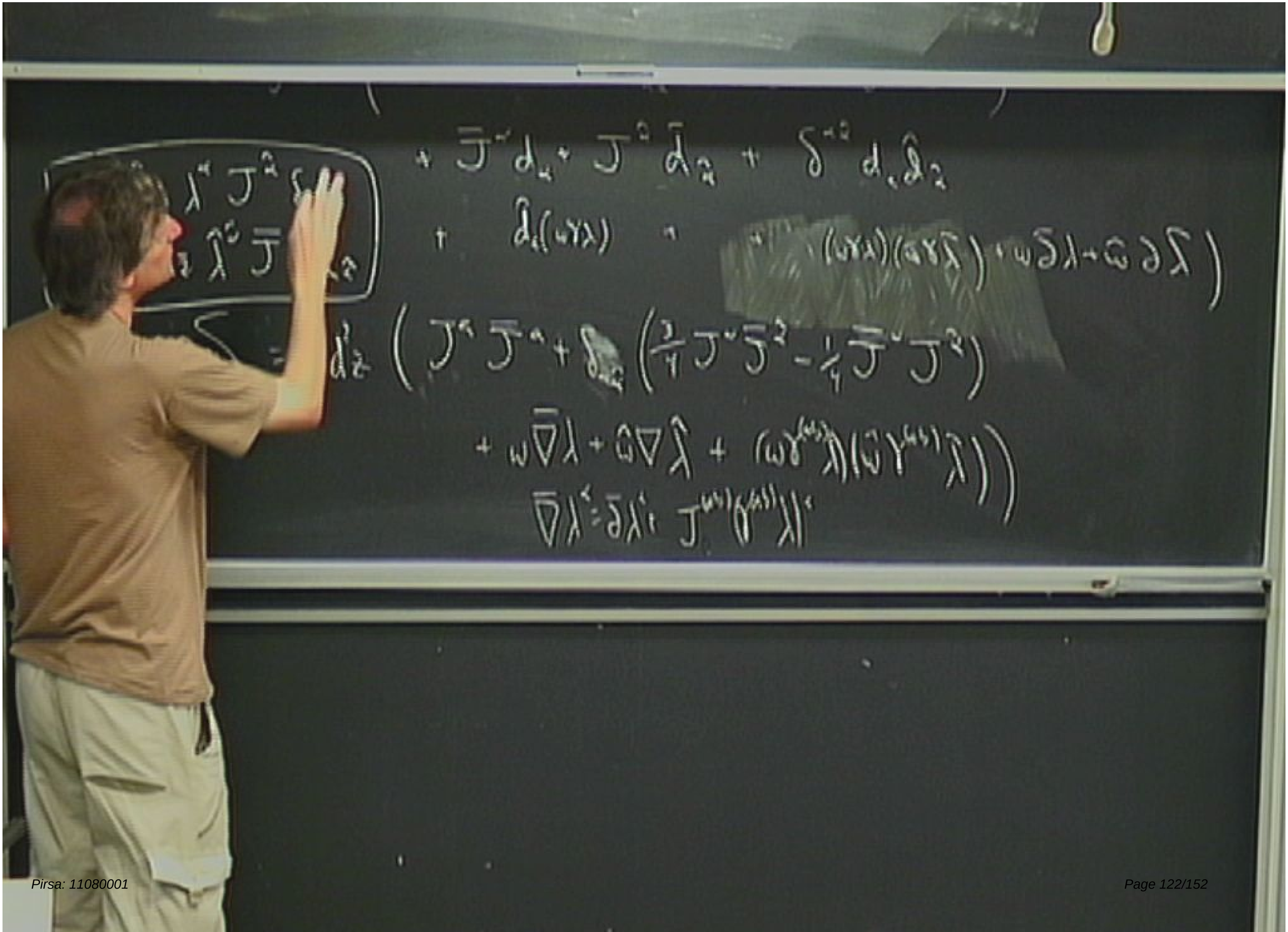
$$+ \hat{d}_\alpha(\omega\gamma\lambda) + + (\omega\gamma\lambda)(\hat{\omega}\gamma\hat{\lambda}) + \omega\bar{\partial}\lambda + \hat{\omega}\partial\hat{\lambda} \Big)$$

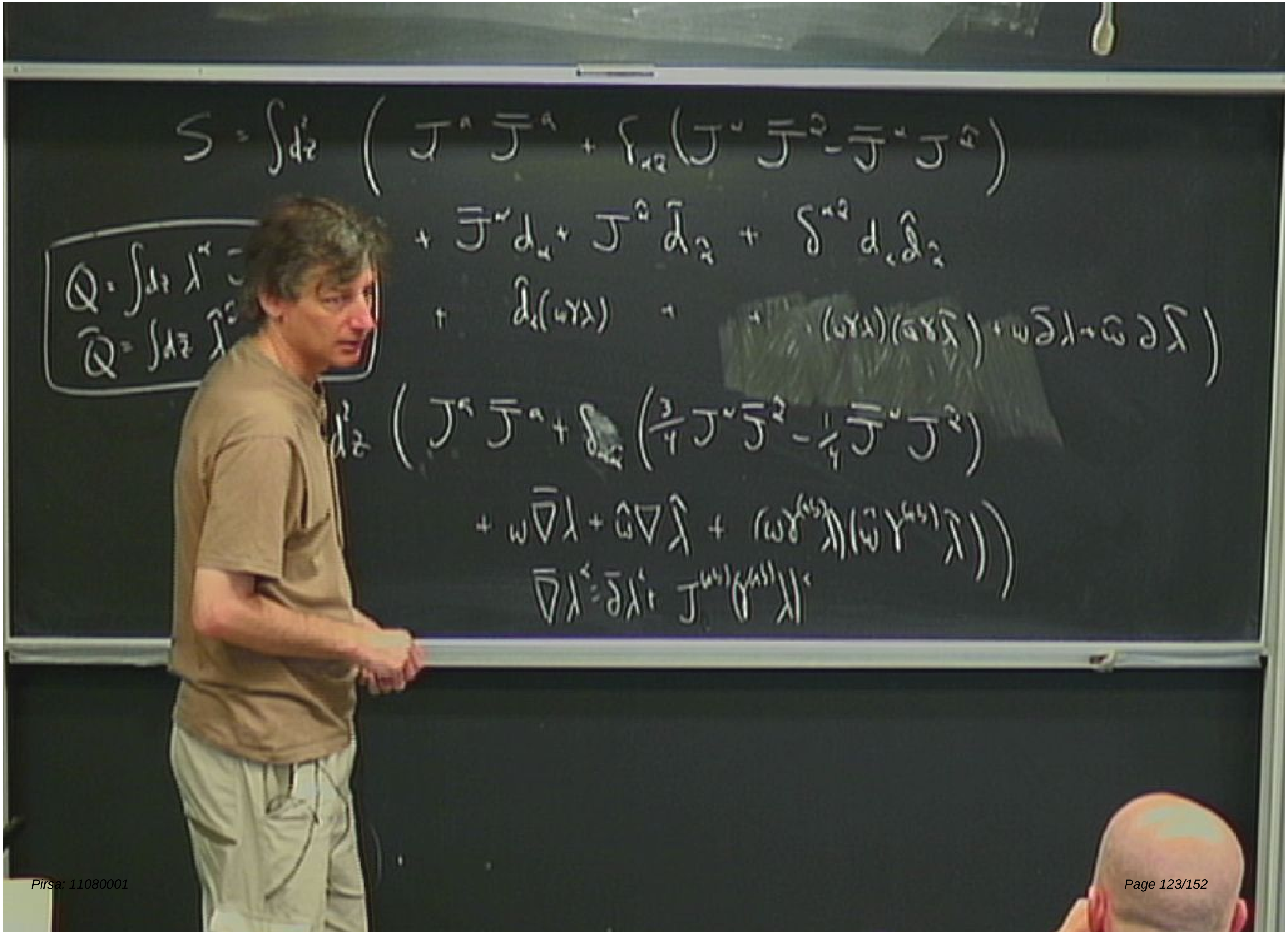
$$= \int d^2z \Big(J^a \bar{J}^a + \delta_{\alpha\hat{\beta}}\left(\tfrac{3}{4} J^\alpha \bar{J}^{\hat{\beta}} - \tfrac{1}{4} \bar{J}^\alpha J^{\hat{\beta}}\right)$$

$$+ \omega\bar{\nabla}\lambda + \hat{\omega}\nabla\hat{\lambda} + (\omega\gamma^{(ab)}\lambda)(\hat{\omega}\gamma^{(ab)}\hat{\lambda}) \Big)$$



$S = \int d^2z \left(J^a \bar{J}^a + f_{\alpha\hat{\beta}}\left(J^\alpha \bar{J}^{\hat{\beta}} - \bar{J}^\alpha J^{\hat{\beta}}\right)\right.$
$+ \bar{J}^\alpha d_\alpha + J^{\hat{\alpha}} \bar{\hat{d}}_{\hat{\alpha}} + \delta^{\alpha\hat{\alpha}} d_\alpha \hat{d}_{\hat{\alpha}}$
$+ \hat{d}_\alpha(\omega\gamma\lambda) + \ldots + (\omega\gamma\lambda)(\hat{\omega}\gamma\hat{\lambda}) + \omega\bar{\partial}\lambda + \hat{\omega}\partial\hat{\lambda} \left.\right)$
$= \int d^2z \left(J^a \bar{J}^a + \delta_{\alpha\hat{\alpha}}\left(\frac{3}{4} J^\alpha \bar{J}^{\hat{\alpha}} - \frac{1}{4}\bar{J}^\alpha J^{\hat{\alpha}}\right)\right.$
$+ \omega\bar{\nabla}\lambda + \hat{\omega}\nabla\hat{\lambda} + (\omega\gamma^{(ab)}\lambda)(\hat{\omega}\gamma^{(ab)}\hat{\lambda}) \left.\right)$
$\bar{\nabla}\lambda^\alpha = \bar{\partial}\lambda^\alpha + J^{(ab)}(\gamma^{(ab)}\lambda)^\alpha$





$$S = \int d^2z \left(J^a \bar{J}^a + \delta_{\alpha\hat{\alpha}} \left(J^\alpha \bar{J}^{\hat{\alpha}} - \bar{J}^\alpha J^{\hat{\alpha}} \right) \right.$$

$$+ \bar{J}^\alpha d_\alpha + J^{\hat{\alpha}} \bar{d}_{\hat{\alpha}} + \delta^{\alpha\hat{\alpha}} d_\alpha \hat{d}_{\hat{\alpha}}$$

$$\left. + \Omega \ldots \bar{J} \ldots (\omega \gamma \lambda) + \ldots (\omega\gamma\lambda)(\hat{\omega}\gamma\hat{\lambda}) + \omega \bar{\partial} \lambda + \hat{\omega} \partial \hat{\lambda} \right)$$

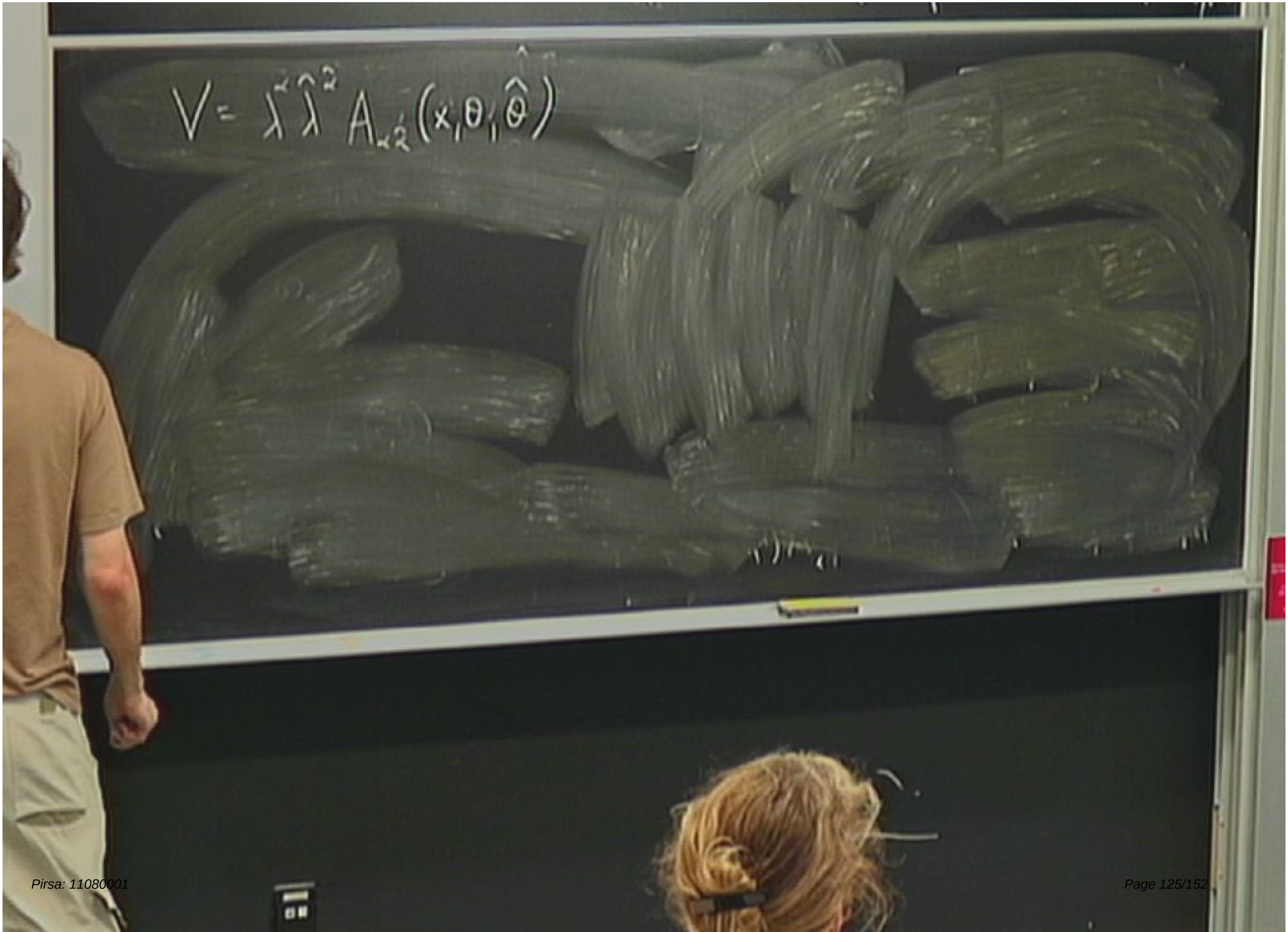
$$Q = \int dz\, \lambda^\alpha J^{\hat{\alpha}} \delta_{\alpha\hat{\alpha}}$$

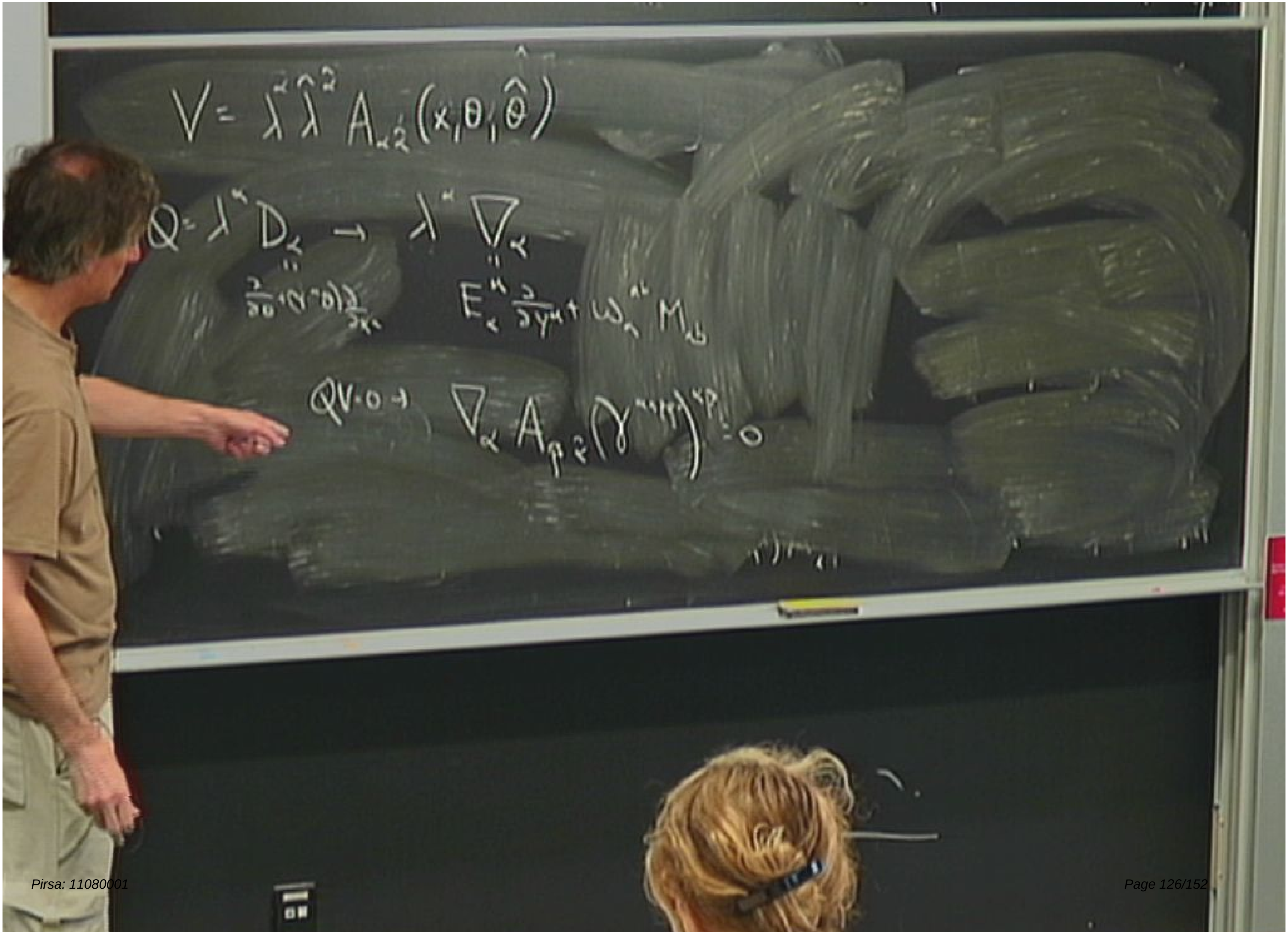
$$\hat{Q} = \int d\bar{z}\, \hat{\lambda}^{\hat{\alpha}} \bar{J}^\alpha \delta_{\alpha\hat{\alpha}}$$

$$S = \int d^2z \left(J^a \bar{J}^a + \delta_{\alpha\hat{\alpha}} \left(\tfrac{3}{4} J^\alpha \bar{J}^{\hat{\alpha}} - \tfrac{1}{4} \bar{J}^\alpha J^{\hat{\alpha}} \right) \right.$$

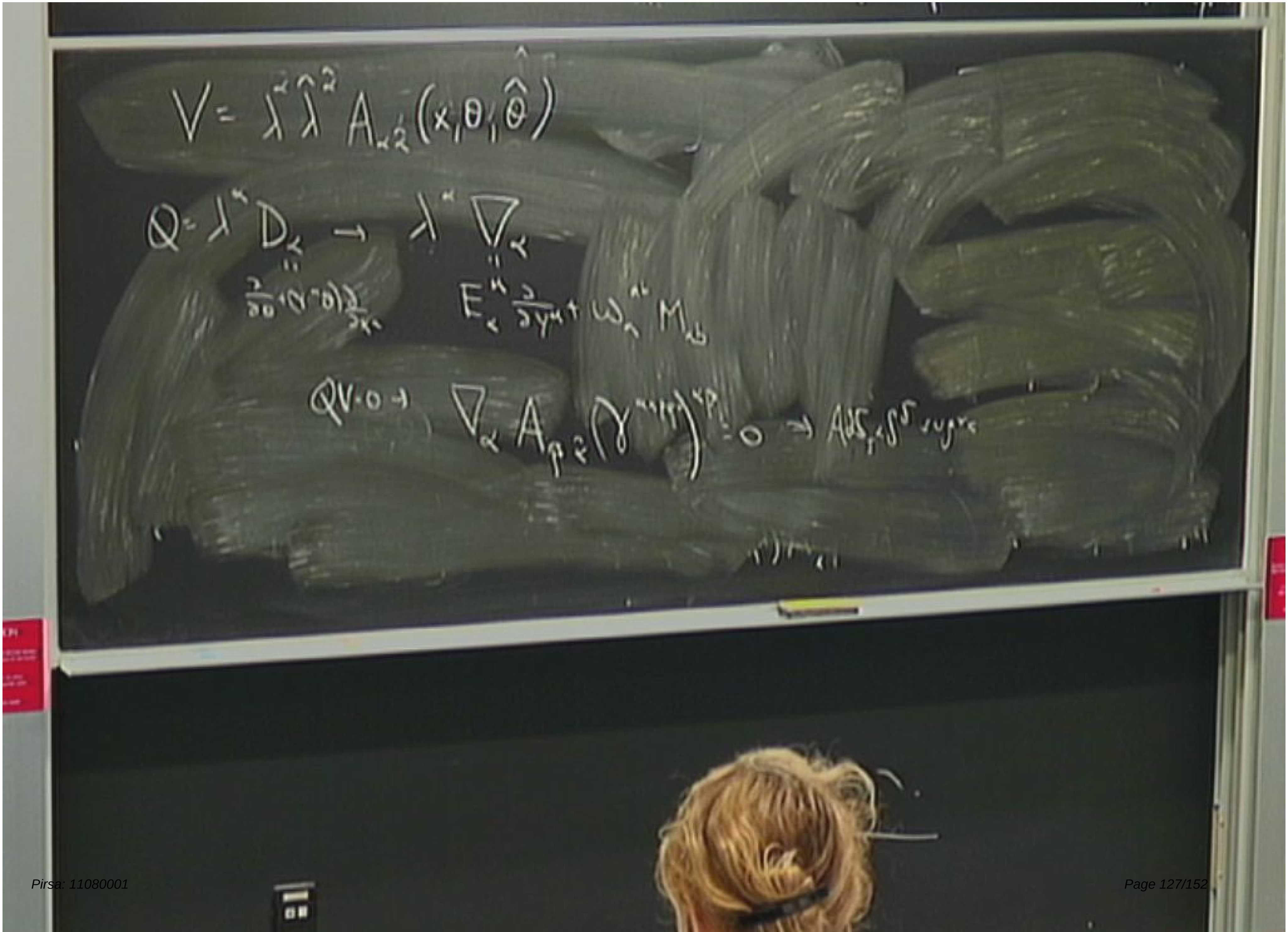
$$\left. + \omega \bar{\nabla} \lambda + \hat{\omega} \nabla \hat{\lambda} + (\omega \gamma^{(ab)} \lambda)(\hat{\omega} \gamma^{(ab)} \hat{\lambda}) \right)$$

$$\bar{\nabla} \lambda^\alpha = \bar{\partial} \lambda^\alpha + \bar{J}^{(ab)} (\gamma^{(ab)} \lambda)^\alpha$$

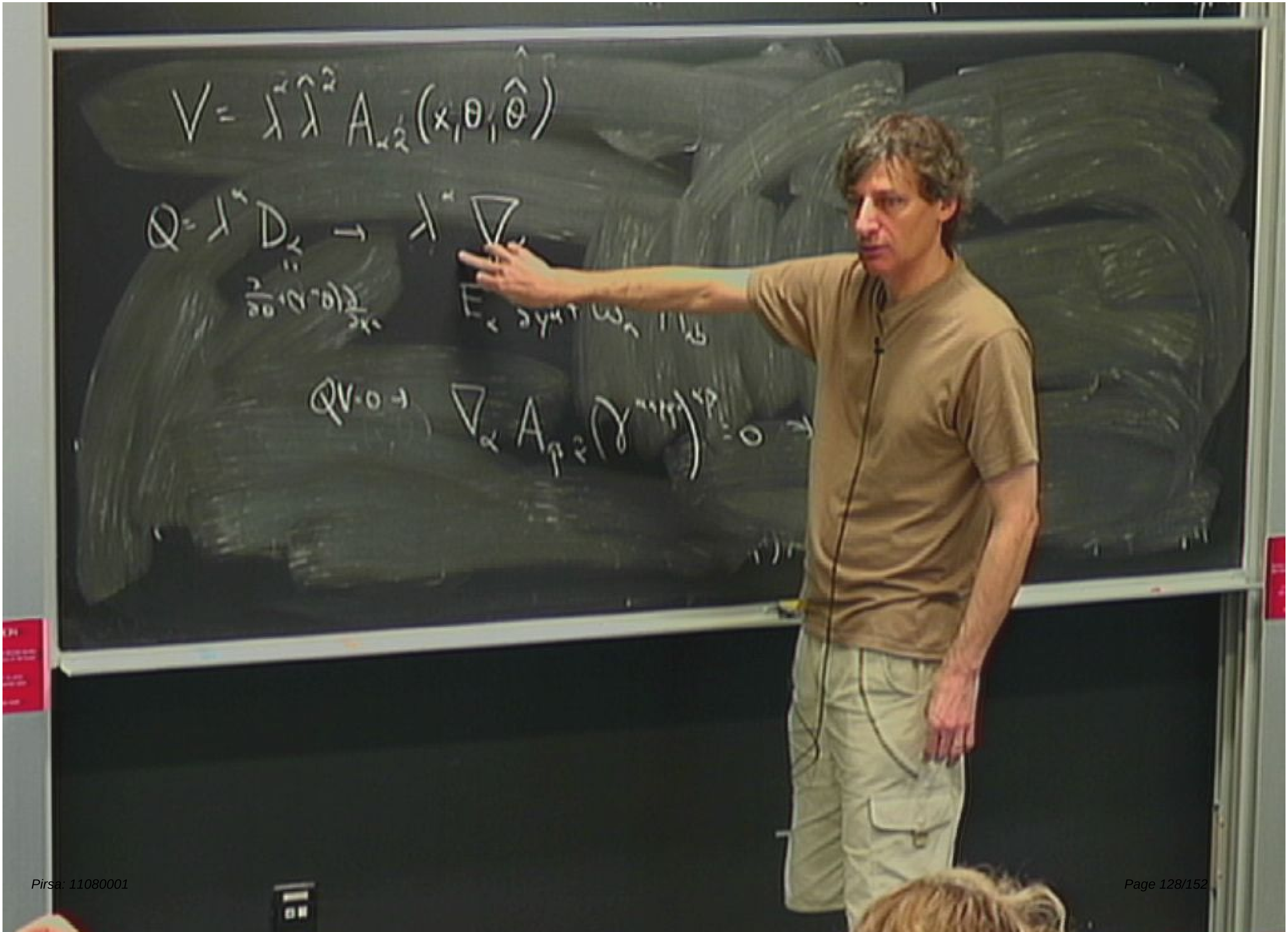

$V = \lambda^{\alpha} \hat{\lambda}^{\hat{\alpha}} A_{\alpha\hat{\alpha}}(x,\theta,\hat{\theta})$

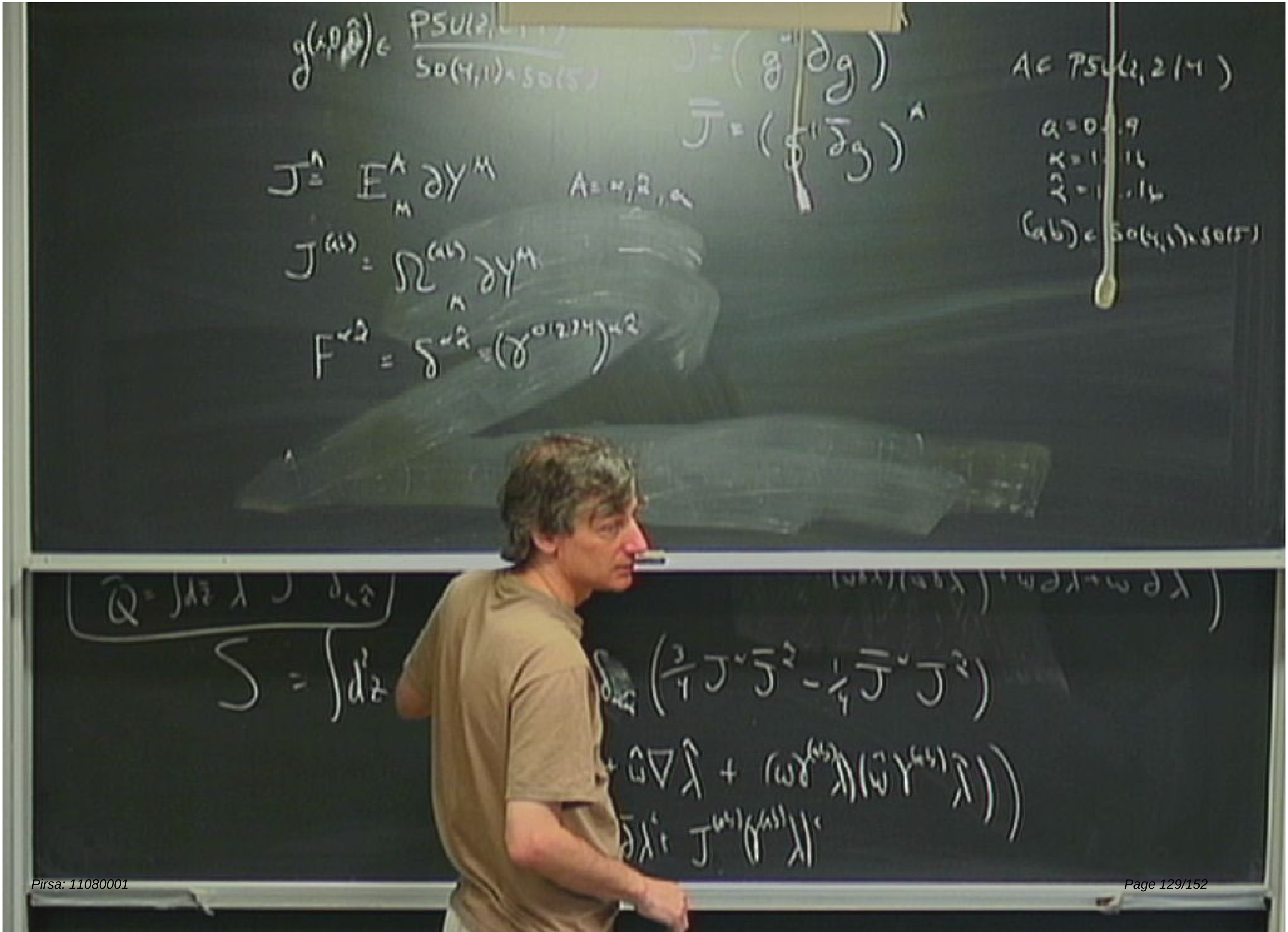


V = λ^α λ̂^α̂ A_{αα̂}(x, θ, θ̂)
Q = λ^α D_α → λ^α ∇_α
QV = 0 → ∇_α A_{βγ̂}(γ^{mnpqr})^{αβ} = 0



$V = \lambda^{\alpha}\hat{\lambda}^{\hat{\alpha}} A_{\alpha\hat{\alpha}}(x, \theta, \hat{\theta})$
$Q = \lambda^{\alpha} D_{\alpha} \rightarrow \lambda^{\alpha} \nabla_{\alpha}$
$D_{\alpha} = \frac{\partial}{\partial\theta^{\alpha}} + (\gamma^{m}\theta)_{\alpha}\frac{\partial}{\partial x^{m}}$
$\nabla_{\alpha} = E_{\alpha}^{M}\frac{\partial}{\partial y^{M}} + \omega_{\alpha}^{ab} M_{ab}$
$QV = 0 \rightarrow \nabla_{\alpha} A_{\beta\hat{\gamma}} (\gamma^{mnpqr})^{\alpha\beta} = 0 \rightarrow AdS_5 \times S^5$ sugra


V = λ^α λ̂^β A_αβ (x, θ, θ̂)
Q = λ^α D_α → λ^α ∇_α
QV = 0 →


A ∈ PSU(2,2|4)
(ab) ∈ SO(4,1)×SO(5)
S = ∫d²z

$$V = \lambda^{\alpha}\hat{\lambda}^{\hat{\alpha}} A_{\alpha\hat{\alpha}}(x,\theta,\hat{\theta})$$

$$Q = \lambda^{\alpha} D_{\alpha} \to \lambda^{\alpha} \nabla_{\alpha}$$

$$D_{\alpha} = \frac{\partial}{\partial\theta} + (\gamma^{m}\theta)\frac{\partial}{\partial x^{m}} \qquad \nabla_{\alpha} = E_{\alpha}^{M}\frac{\partial}{\partial y^{M}} + \omega_{\alpha}^{ab} M_{ab}$$

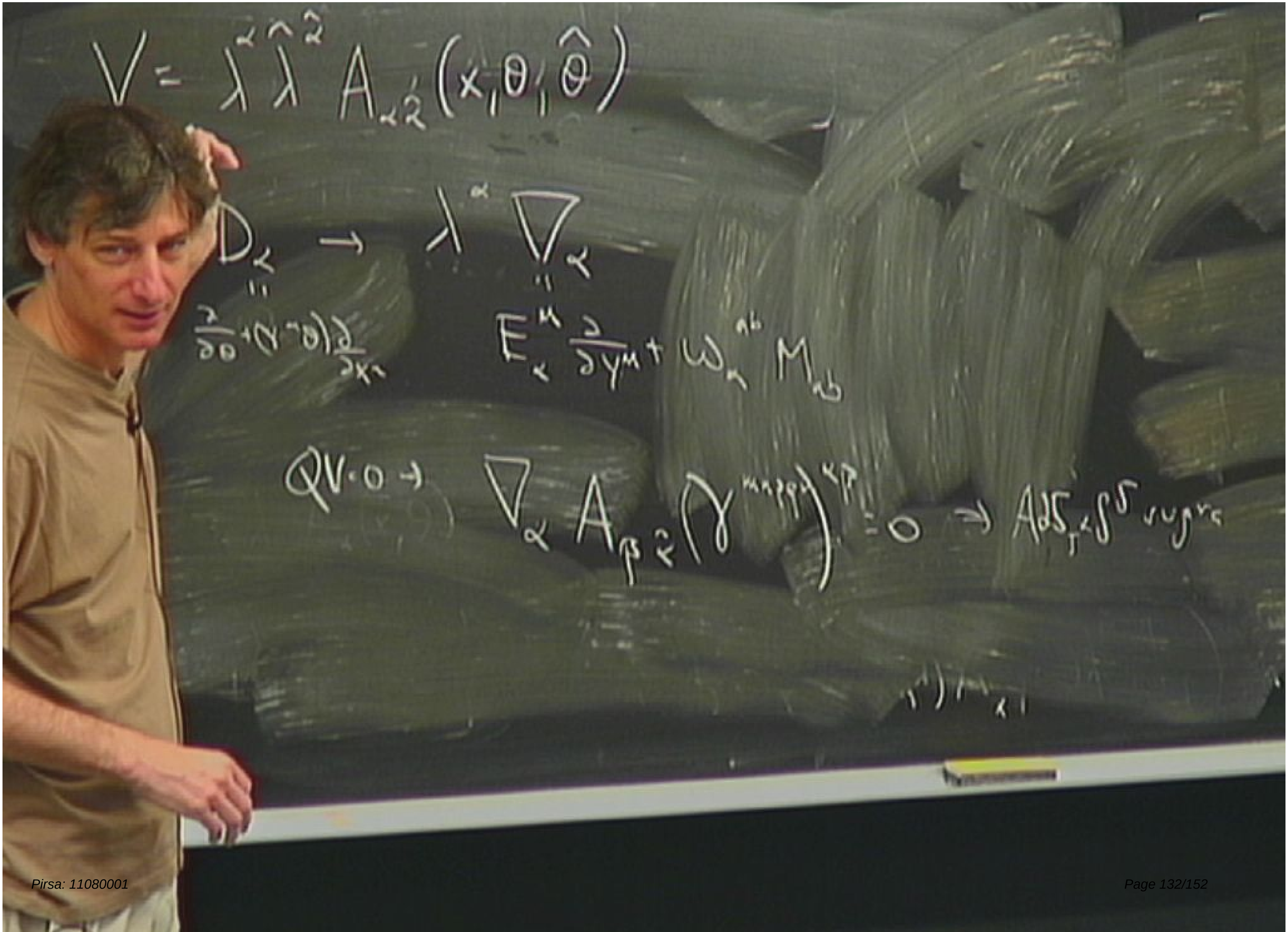
$$QV = 0 \Rightarrow \nabla_{\alpha} A_{\beta\hat{\gamma}} (\gamma^{mnpqr})^{\alpha\beta} = 0 \Rightarrow AdS_{5}\times S^{5} \ldots$$

$$V = \lambda^{\alpha}\hat{\lambda}^{\hat{\alpha}} A_{\alpha\hat{\alpha}}(x, \theta, \hat{\theta})$$

$$Q = \lambda^{\alpha} D_{\alpha} \to \lambda^{\alpha} \nabla_{\alpha}$$

$$D_{\alpha} = \frac{\partial}{\partial\theta^{\alpha}} + (\gamma^{m}\theta)_{\alpha}\frac{\partial}{\partial x^{m}} \qquad \nabla_{\alpha} = E_{\alpha}^{M}\frac{\partial}{\partial y^{M}} + \omega_{\alpha}^{ab} M_{ab}$$

$$QV = 0 \to \nabla_{\alpha} A_{\beta\hat{\alpha}} (\gamma^{mnpqr})^{\alpha\beta} = 0 \to$$ [illegible]


V = λ^α λ̂^α̂ A_αα̂ (x, θ, θ̂)
D_α → λ^α ∇_α
E_α^M ∂/∂y^M + Ω_α^ab M_ab
QV = 0 → ∇_α A_βα̂ (γ^mnpqr)^αβ = 0

$$S = \int d^2z \Big(J^a \bar{J}^a + f_{\alpha\hat{\alpha}}\left(J^\alpha \bar{J}^{\hat{\alpha}} - \bar{J}^\alpha J^{\hat{\alpha}}\right)$$

$$+ \bar{J}^\alpha d_\alpha + J^{\hat{\alpha}} \hat{d}_{\hat{\alpha}} + \delta^{\alpha\hat{\alpha}} d_\alpha \hat{d}_{\hat{\alpha}}$$

$$+ \Omega^{ab}_{n} \bar{\partial} Y^{n}_{a}(\omega \gamma^{a}_{b} \lambda) + \text{[illegible]} + (\omega\gamma\lambda)(\hat{\omega}\gamma\hat{\lambda}) + \omega\bar{\partial}\lambda + \hat{\omega}\partial\hat{\lambda} \Big)$$

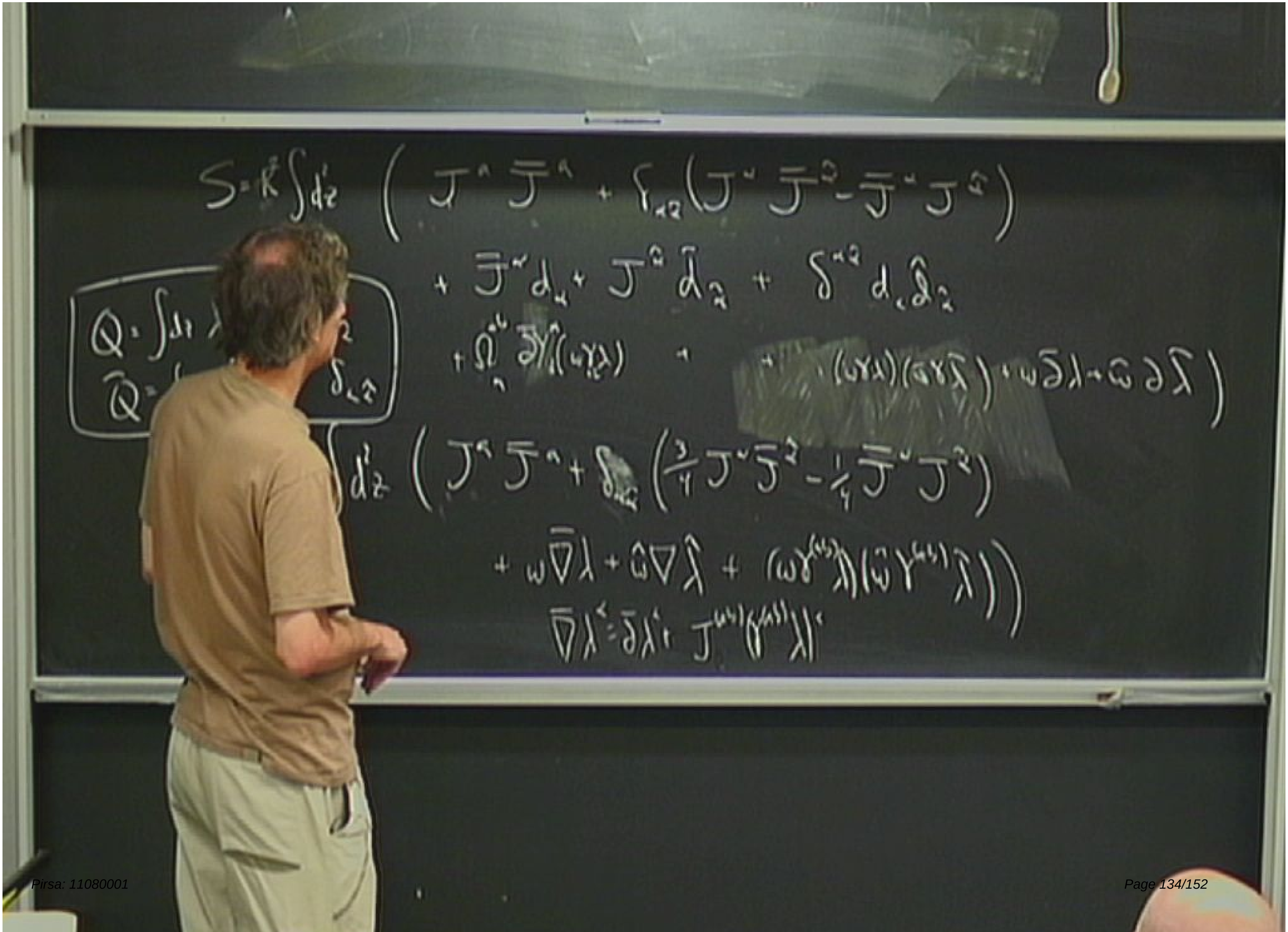
$$Q = \int dz\, \lambda^\alpha J^{\hat{\alpha}} \delta_{\alpha\hat{\alpha}}$$

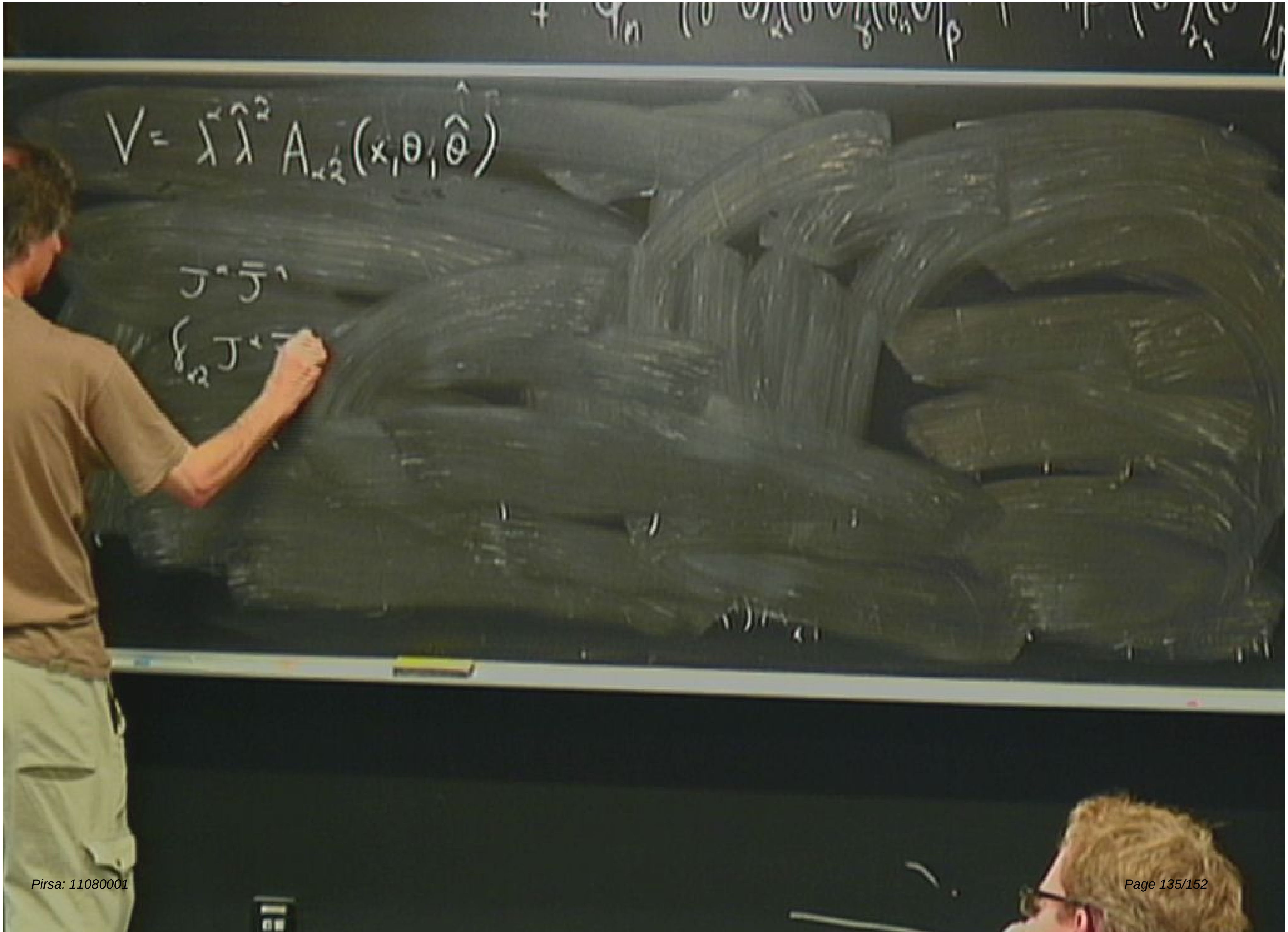
$$\hat{Q} = \int d\bar{z}\, \hat{\lambda}^{\hat{\alpha}} \bar{J}^\alpha \delta_{\alpha\hat{\alpha}}$$

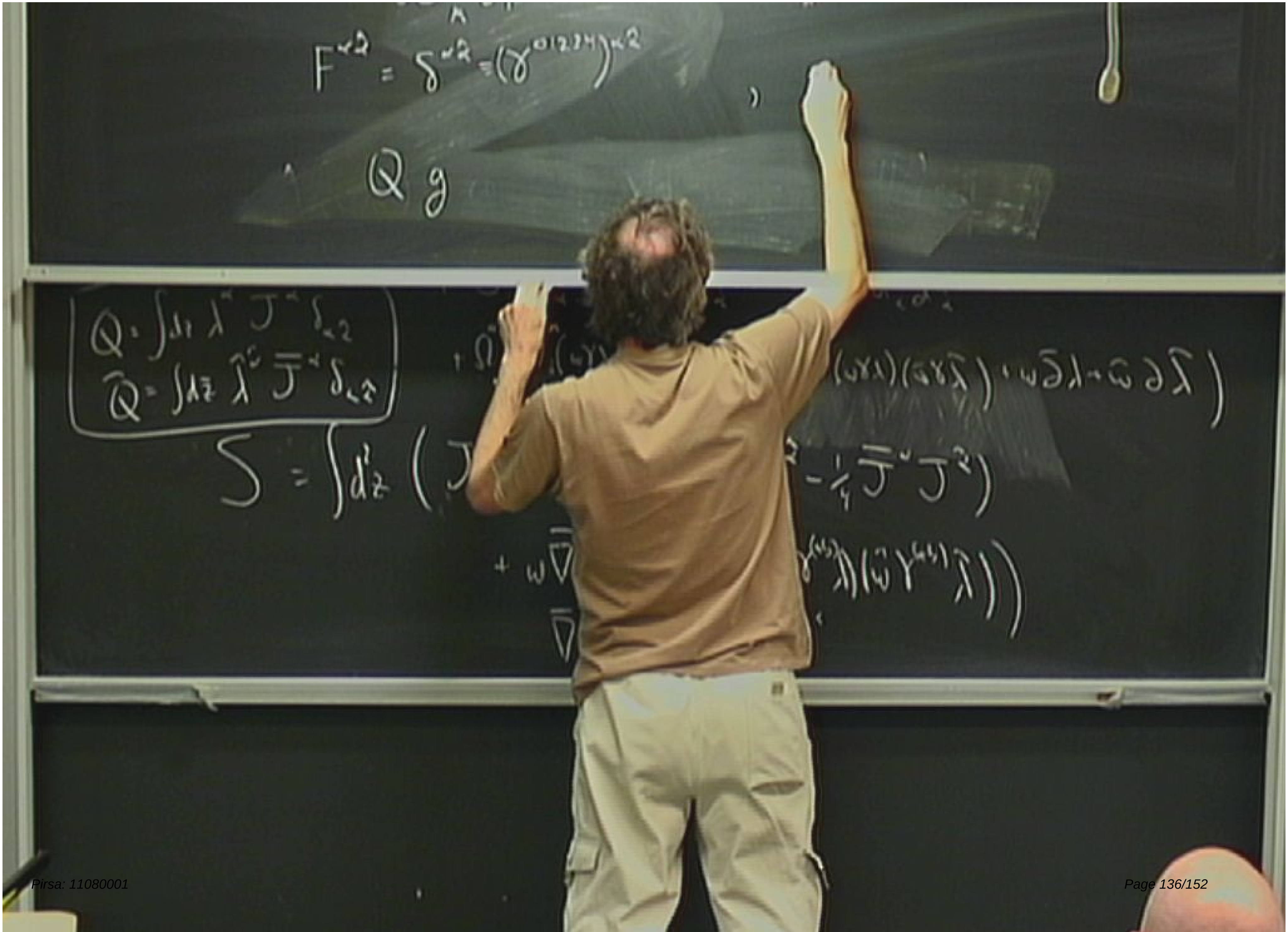
$$S = \int d^2z \Big(J^a \bar{J}^a + \delta_{\alpha\hat{\alpha}}\left(\tfrac{3}{4} J^\alpha \bar{J}^{\hat{\alpha}} - \tfrac{1}{4} \bar{J}^\alpha J^{\hat{\alpha}}\right)$$

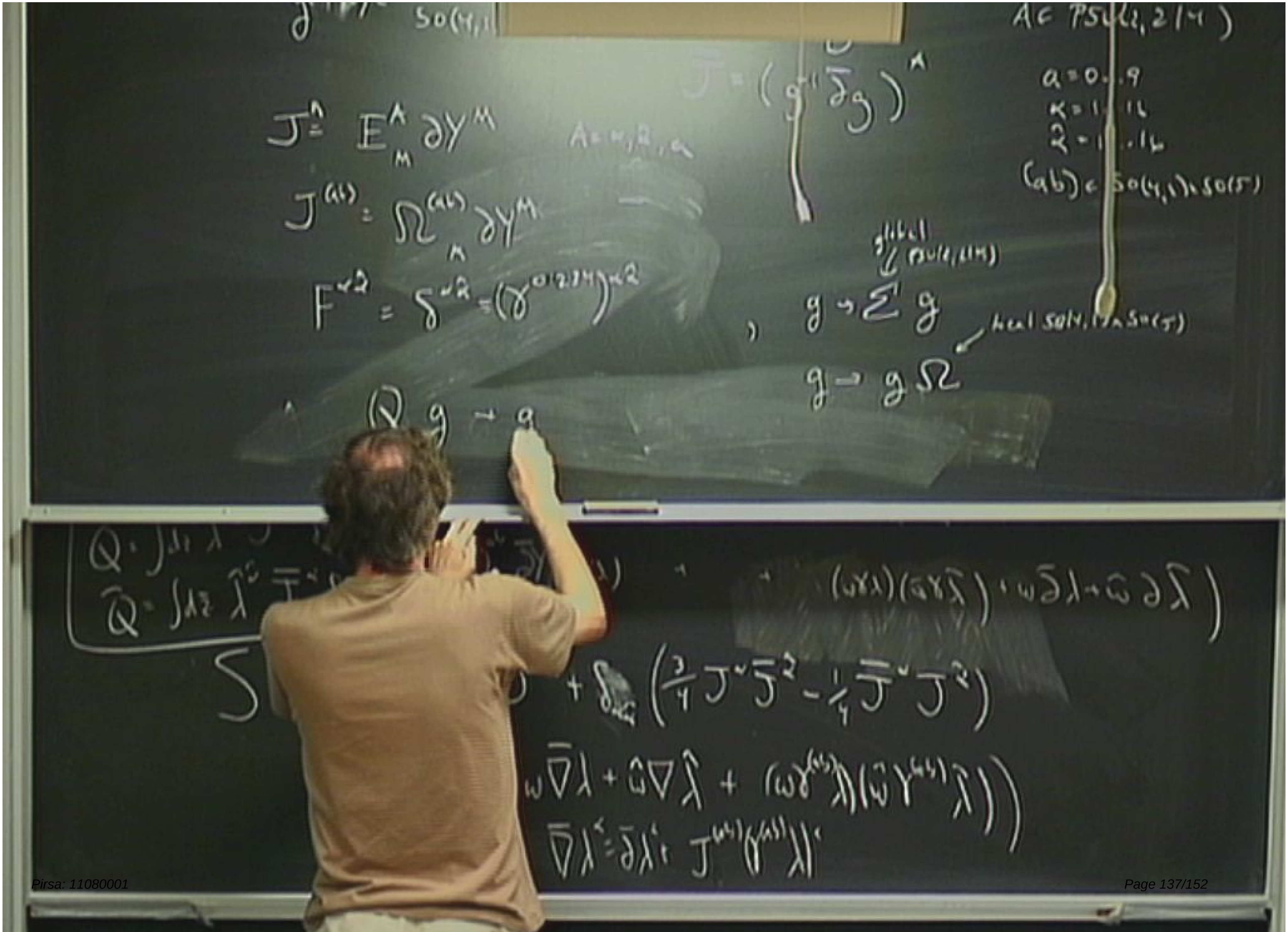
$$+ \omega\bar{\nabla}\lambda + \hat{\omega}\nabla\hat{\lambda} + (\omega\gamma^{(ab)}\lambda)(\hat{\omega}\gamma^{(ab)}\hat{\lambda})\Big)$$

$$\bar{\nabla}\lambda^\alpha = \bar{\partial}\lambda^\alpha + \bar{J}^{(ab)}(\gamma^{(ab)}\lambda)^\alpha$$




V = λ² λ̂² A(x, θ, θ̂)




A ∈ PSU(2,2|4)
a = 0..9
local SO(4,1)×SO(5)
g → g Ω

$$J^{(ab)} = \Omega^{(ab)}_{\wedge}\, \partial Y$$

$(ab) \in SO(4,1)\times SO(5)$

$$F^{\alpha\hat{2}} = \delta^{\alpha\hat{2}} = (\gamma^{01234})^{\alpha\hat{2}}$$

global $\Downarrow$ PSU(2,2|4)

$$g \to \Sigma\, g$$

local $SO(4,1)\times SO(5)$

$$Q\, g = g\,(\lambda^\alpha T_1 + \hat\lambda^{\hat 2} T_2) \qquad g \to g\,\Omega$$

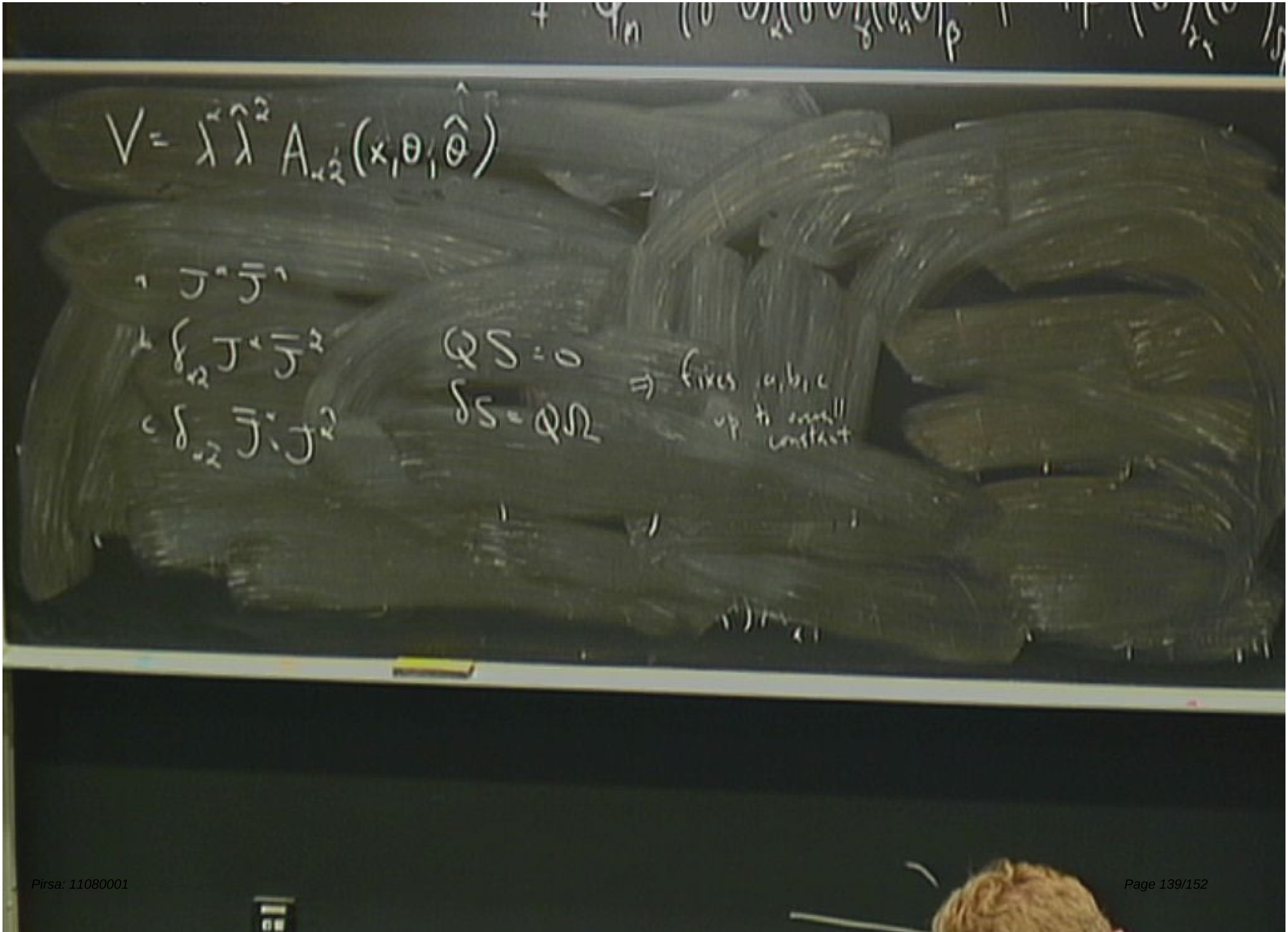
fermionic PSU(2,2|4)

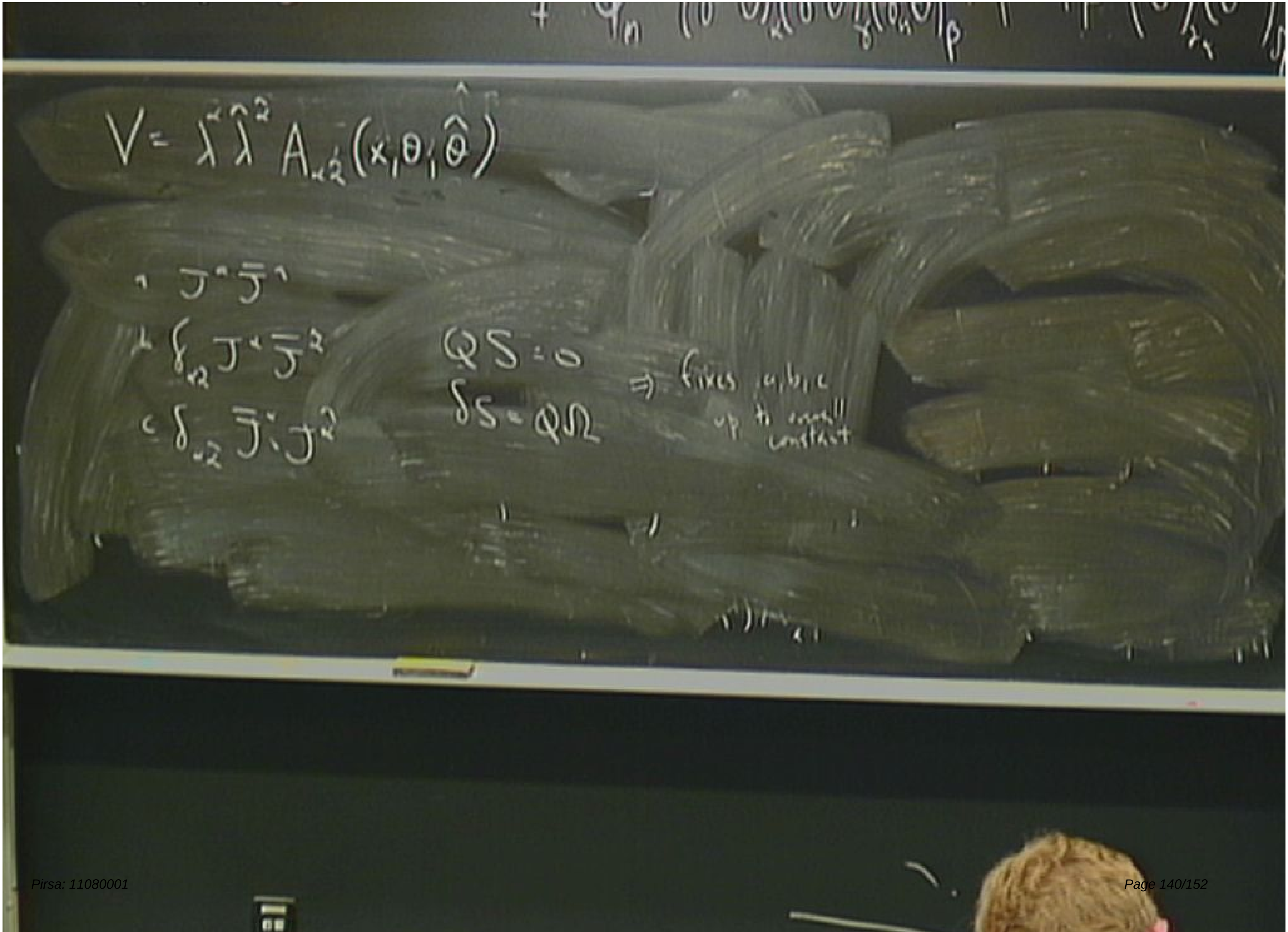
$$S = \frac{R^2}{\alpha'}\int d^2z \left(J^a \bar J^a + \delta_{\alpha\hat 2}\left(J^\alpha \bar J^{\hat 2} - \bar J^\alpha J^{\hat 2}\right) + \bar J^\alpha d_\alpha + J^{\hat 2}\hat d_{\hat 2} + \delta^{\alpha\hat 2} d_\alpha \hat d_{\hat 2} + \Omega^{ab}_{\wedge}\, \bar\partial Y (w \gamma \lambda) + (w\gamma\lambda)(\hat w\gamma\hat\lambda) + w\bar\partial\lambda + \hat w\partial\hat\lambda \right)$$

$$Q = \int dz\, \lambda^\alpha J^{\hat 2}\delta_{\alpha\hat 2}$$
$$\hat Q = \int d\bar z\, \hat\lambda^{\hat 2}\bar J^\alpha \delta_{\alpha\hat 2}$$

$$S = \int d^2z \left(J^a \bar J^a + \delta_{\alpha\hat 2}\left(\tfrac{3}{4} J^\alpha \bar J^{\hat 2} - \tfrac{1}{4}\bar J^\alpha J^{\hat 2}\right) + w\bar\nabla\lambda + \hat w\nabla\hat\lambda + (w\gamma^{(ab)}\lambda)(\hat w\gamma^{(ab)}\hat\lambda)\right)$$

$$\bar\nabla\lambda^\alpha = \bar\partial\lambda^\alpha + \bar J^{(ab)}(\gamma^{(ab)}\lambda)^\alpha$$


V = λ² λ̂² A_{α2}(x, θ, θ̂)
a J^α J̄^α
b δ_{α2} J^α J̄²
c δ_{α2} J̄^α J²
QS = 0
δS = QΩ
⇒ fixes a, b, c
up to overall constant



V = λ²λ̂² A₋₂(x, θ, θ̂)
a J^a J̄^a
b δ₋₂ J^a J̄²
c δ₋₂ J̄^a J²
QS = 0
δS = QΩ
⇒ fixes a, b, c
up to overall
constant

$$V = \lambda^2 \hat{\lambda}^2 A_{\alpha 2}(x, \theta, \hat{\theta})$$

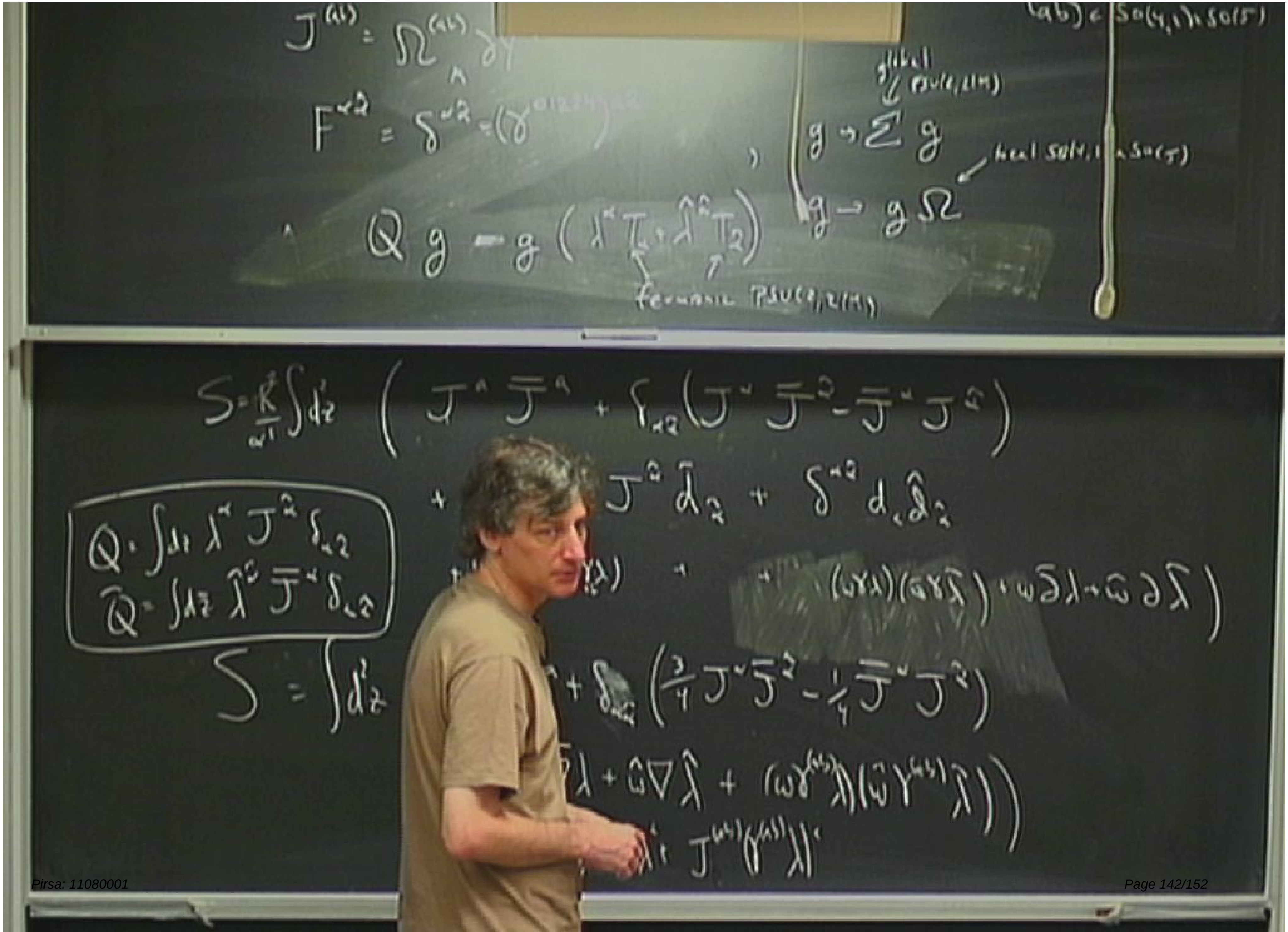
$a \; J^1 \bar{J}^1$

$b \; \delta_{+2} J^1 \bar{J}^2$

$c \; \delta_{-2} \bar{J}^1 J^2$

$QS = 0$

$\delta S = Q\Omega$ $\Rightarrow$ fixes a, b, c up to overall constant


global PSU(2,2|4)
fermionic PSU(2,2|4)

$J^{(ab)} = \Omega^{(ab)}_{\wedge} \partial y$

$(ab) \in SO(4,1)\times SO(5)$

$F^{\alpha\hat\alpha} = \delta^{\alpha\hat\alpha} + (\gamma^{\ldots})$

global $PSU(2,2|4)$

$g \to \Sigma g$

local $SO(4,1)\times SO(5)$

$g \to g\,\Omega$

$Q g = g(\lambda^\alpha T_\alpha + \hat\lambda^{\hat\alpha} T_{\hat\alpha})$

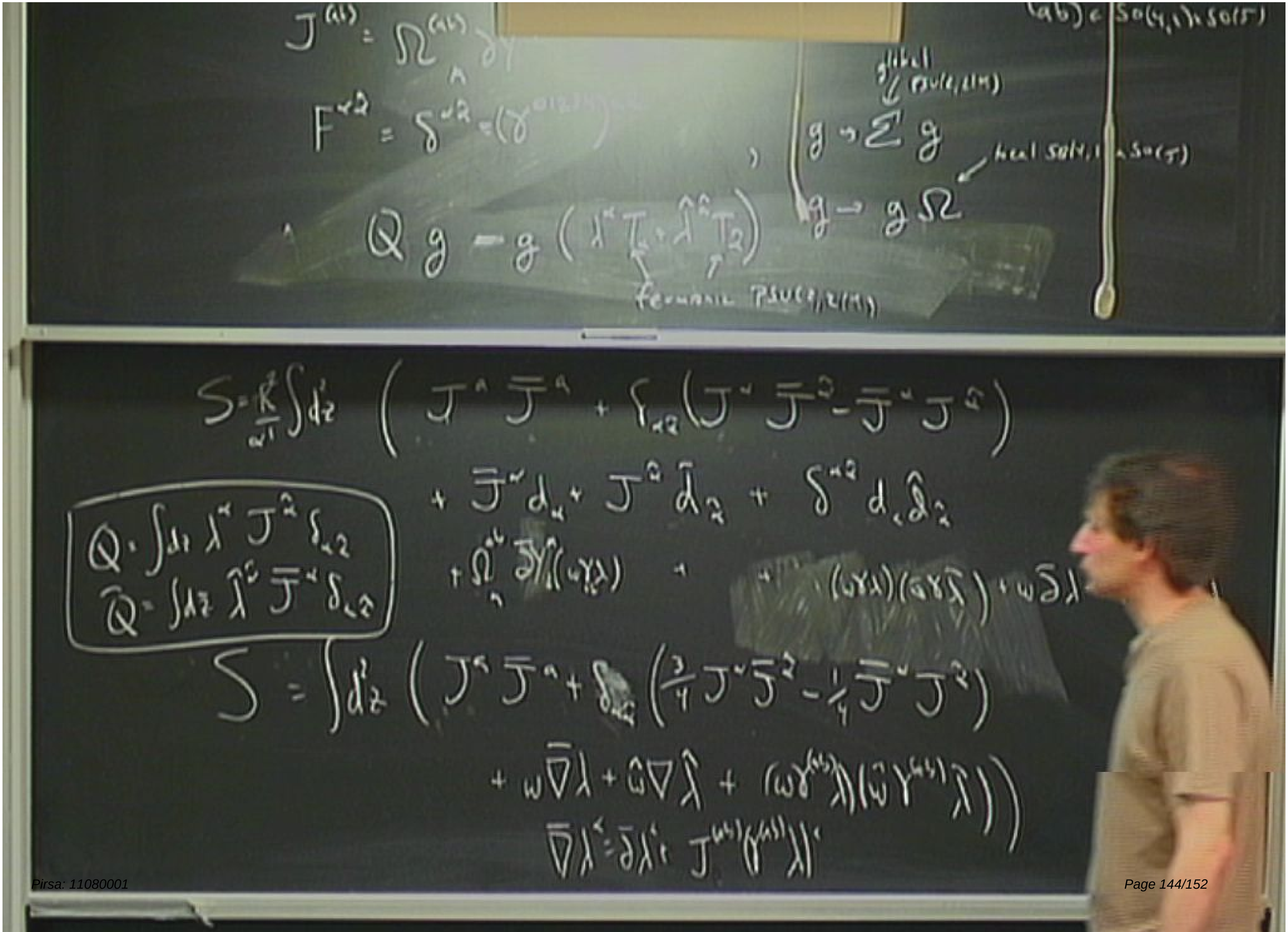
fermionic $PSU(2,2|4)$

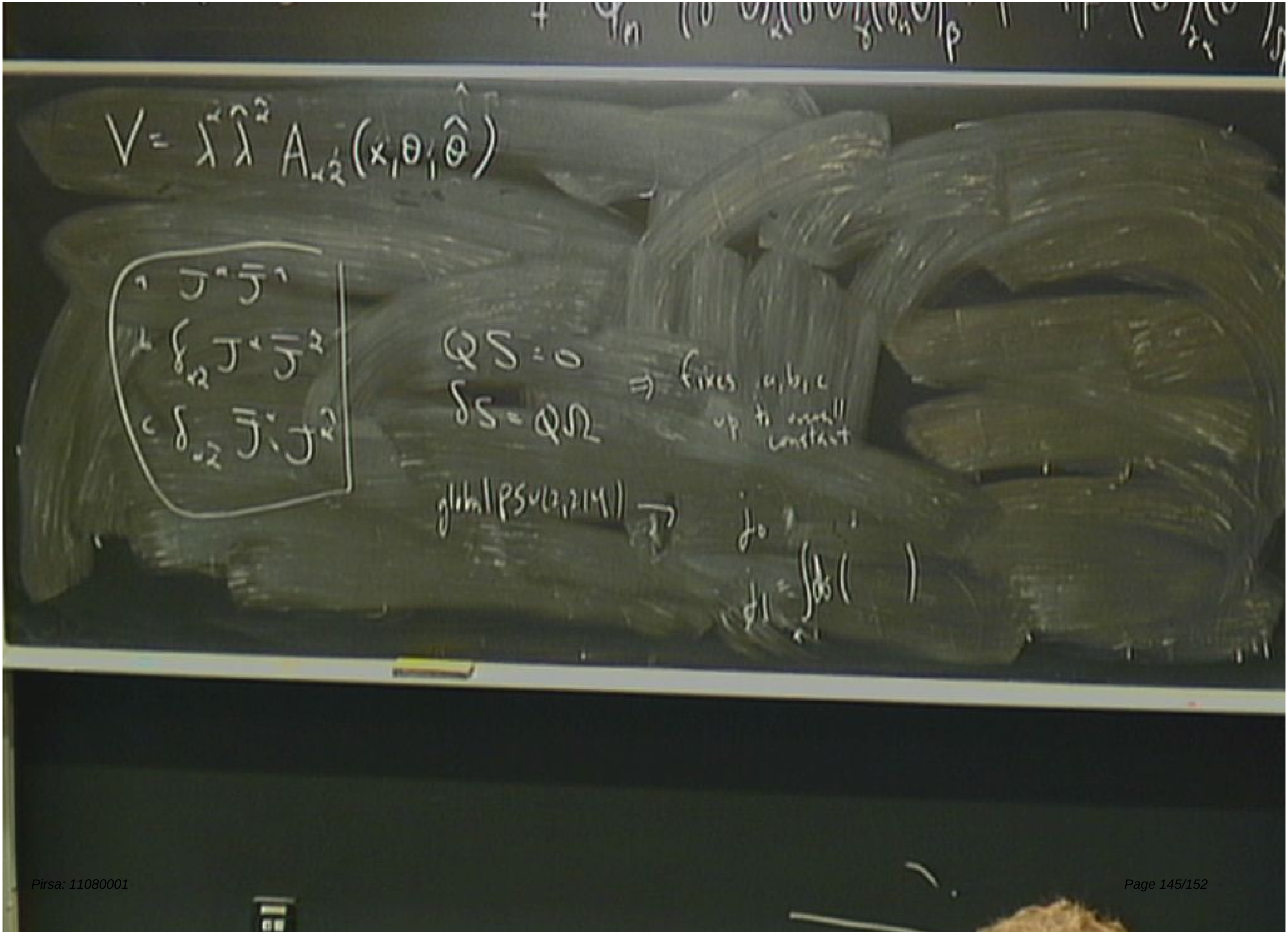
$$S = \frac{R^2}{\alpha'}\int d^2z \Big(J^a \bar J^a + \delta_{\alpha\hat\alpha}(J^\alpha \bar J^{\hat\alpha} - \bar J^\alpha J^{\hat\alpha}) + \bar J^\alpha d_\alpha + J^{\hat\alpha}\hat d_{\hat\alpha} + \delta^{\alpha\hat\alpha} d_\alpha \hat d_{\hat\alpha} + \Omega^{ab}_{\wedge}\bar\partial y\,(w\gamma_{ab}\lambda) + \ldots (w\gamma\lambda)(\hat w\gamma\hat\lambda) + w\bar\partial\lambda + \hat w\partial\hat\lambda \Big)$$

$$Q = \int dz\, \lambda^\alpha J^{\hat\alpha}\delta_{\alpha\hat\alpha}$$
$$\hat Q = \int d\bar z\, \hat\lambda^{\hat\alpha}\bar J^\alpha \delta_{\alpha\hat\alpha}$$

$$S = \int d^2z \Big(J^a \bar J^a + \delta_{\alpha\hat\alpha}\big(\tfrac34 J^\alpha \bar J^{\hat\alpha} - \tfrac14 \bar J^\alpha J^{\hat\alpha}\big) + w\bar\nabla\lambda + \hat w\nabla\hat\lambda + (w\gamma^{(ab)}\lambda)(\hat w\gamma^{(ab)}\hat\lambda)\Big)$$

$$\bar\nabla\lambda^\alpha = \bar\partial\lambda^\alpha + J^{(ab)}(\gamma^{(ab)}\lambda)^\alpha$$


(ab) ∈ SO(4,1) × SO(5)
global PSU(2,2|4)
g → Σ g
local SO(4,1) × SO(5)
g → g Ω
Q g = g (λ^α T_α + λ̂^α̂ T_α̂)
fermionic PSU(2,2|4)
Q = ∫dz λ^α J^α̂ δ_αα̂
Q̂ = ∫dz̄ λ̂^α̂ J̄^α δ_αα̂


V = λ² λ̂² A_{α2}(x, θ, θ̂)
a J^a J̄^a
b δ_{α2} J^a J̄^2
c δ_{α2} J̄^a J^2
QS = 0
δS = QΩ
⇒ fixes a, b, c
up to overall constant
global psu(2,2|4) ⇒
j_0
j_1 = ∮( )

$$V = \lambda^{\alpha}\hat{\lambda}^{\hat{\alpha}} A_{\alpha\hat{\alpha}}(x,\theta,\hat{\theta})$$

$a\; J^{\alpha}\bar{J}^{\hat{\alpha}}$

$b\; \delta_{\alpha 2} J^{\alpha}\bar{J}^{2}$

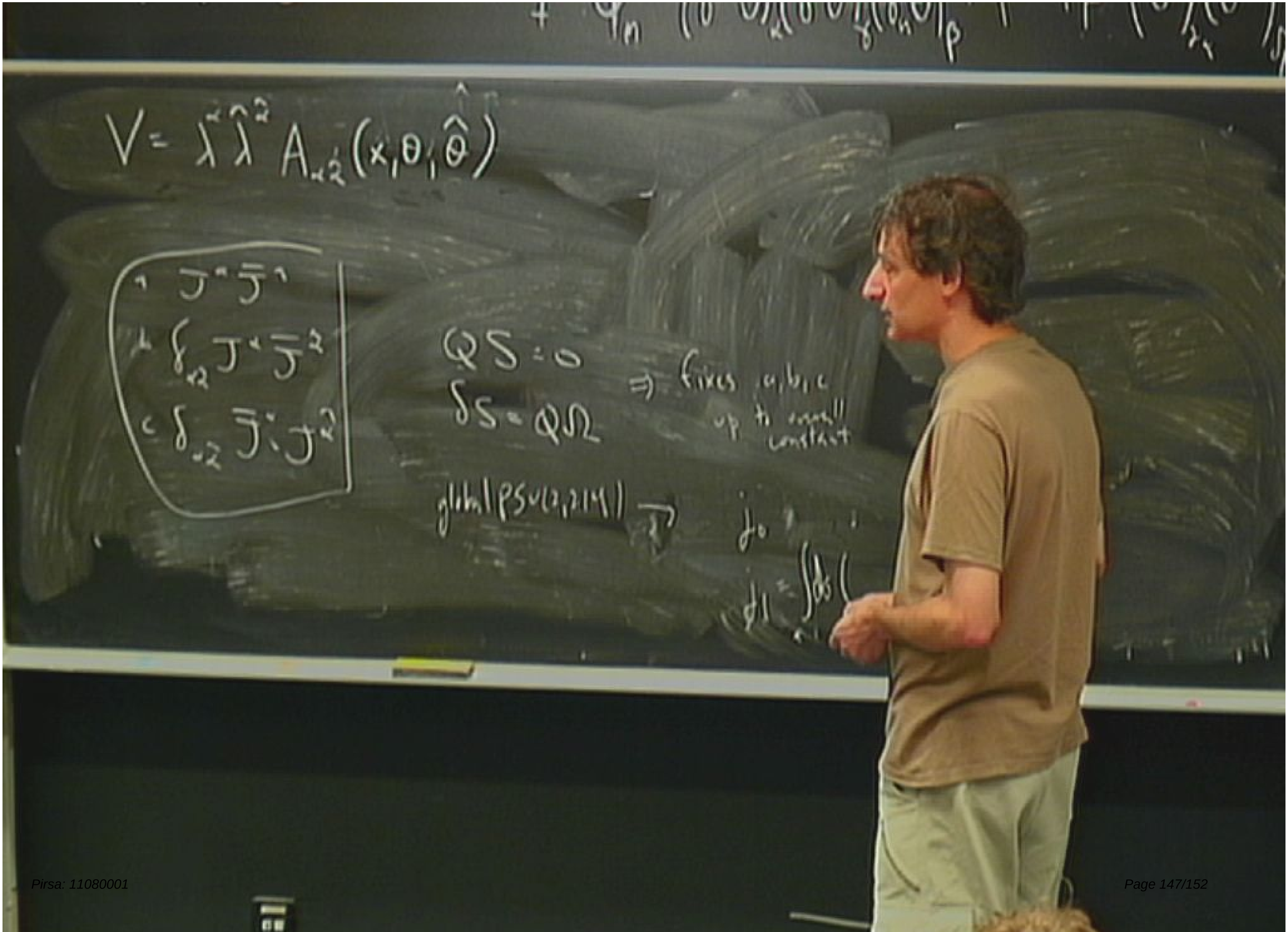
$c\; \delta_{\alpha 2} \bar{J}^{\alpha} J^{2}$

$QS = 0$

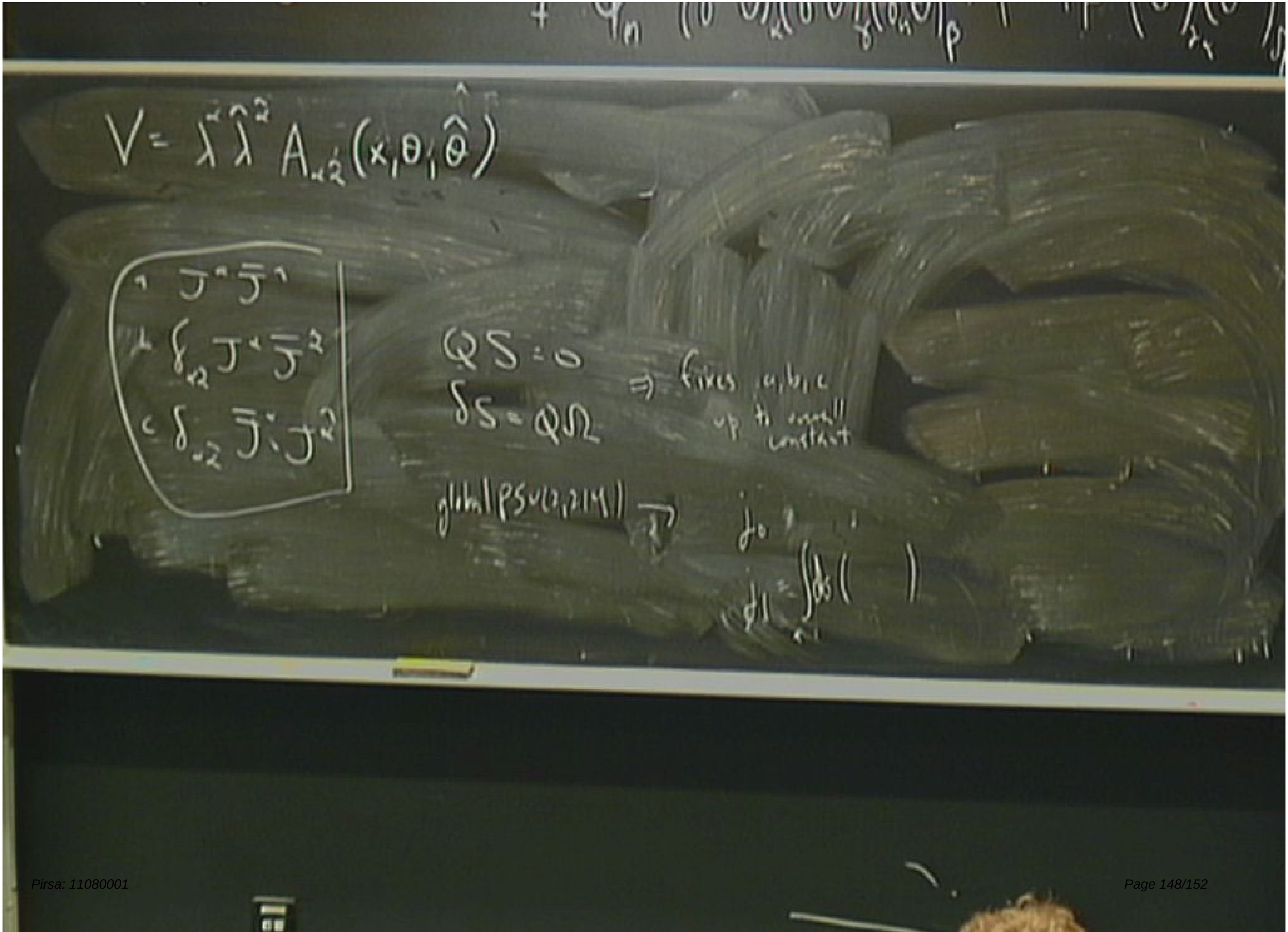
$\delta S = Q\Omega$ ⇒ fixes a, b, c up to overall constant

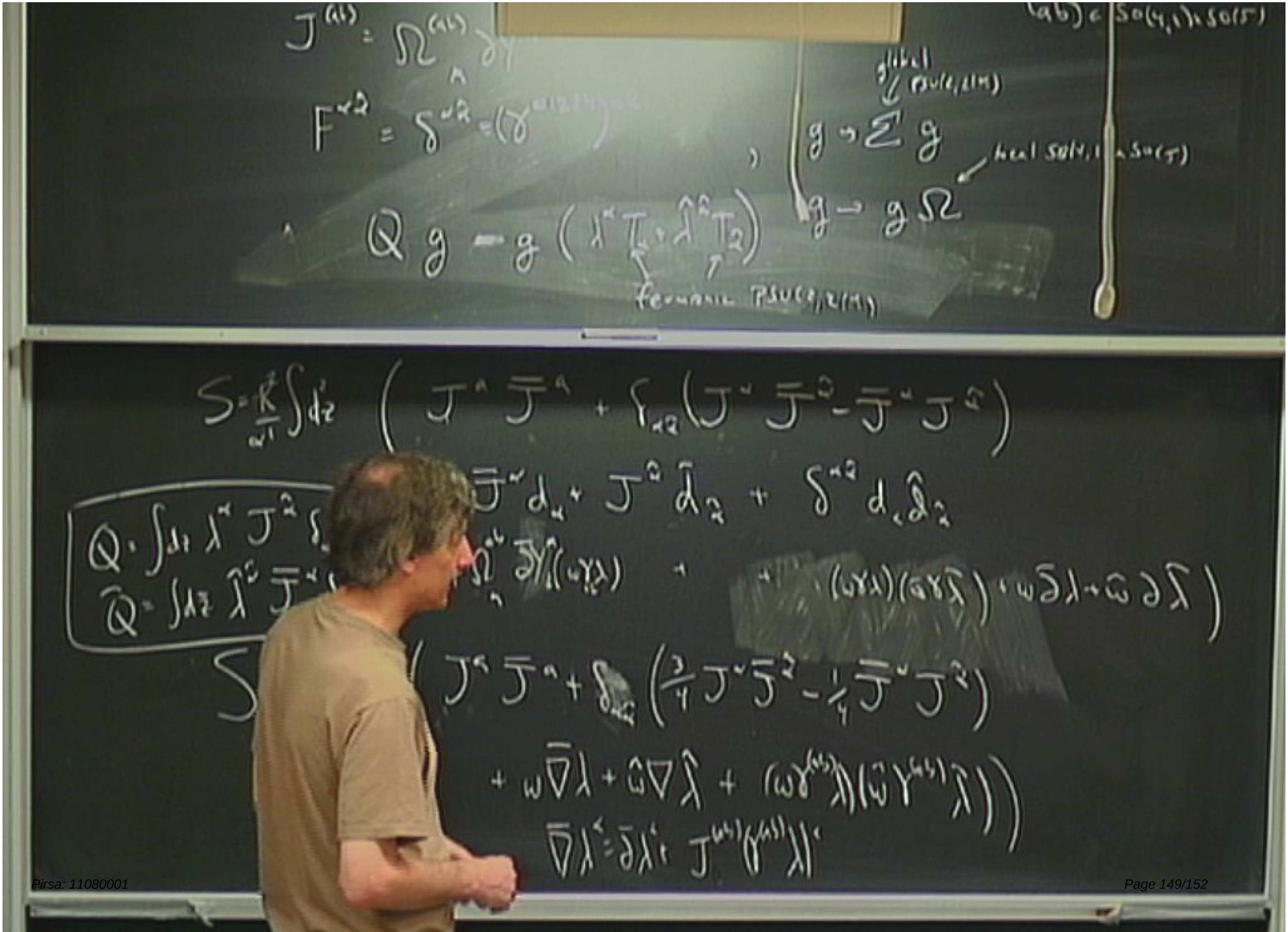
global $PSU(2,2|4)$ ⇒ j_0

$j_1 = \int d\sigma(\quad)$

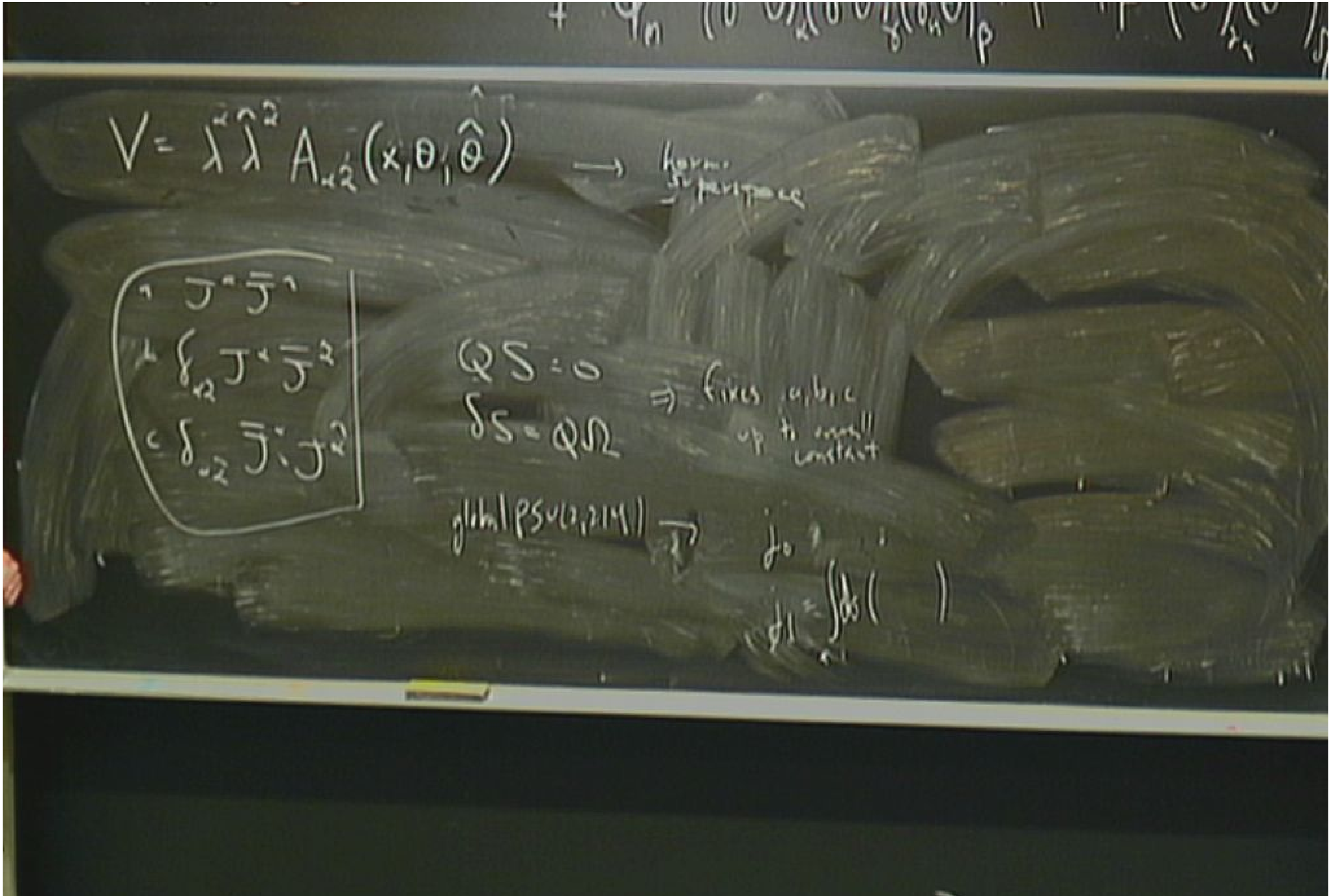


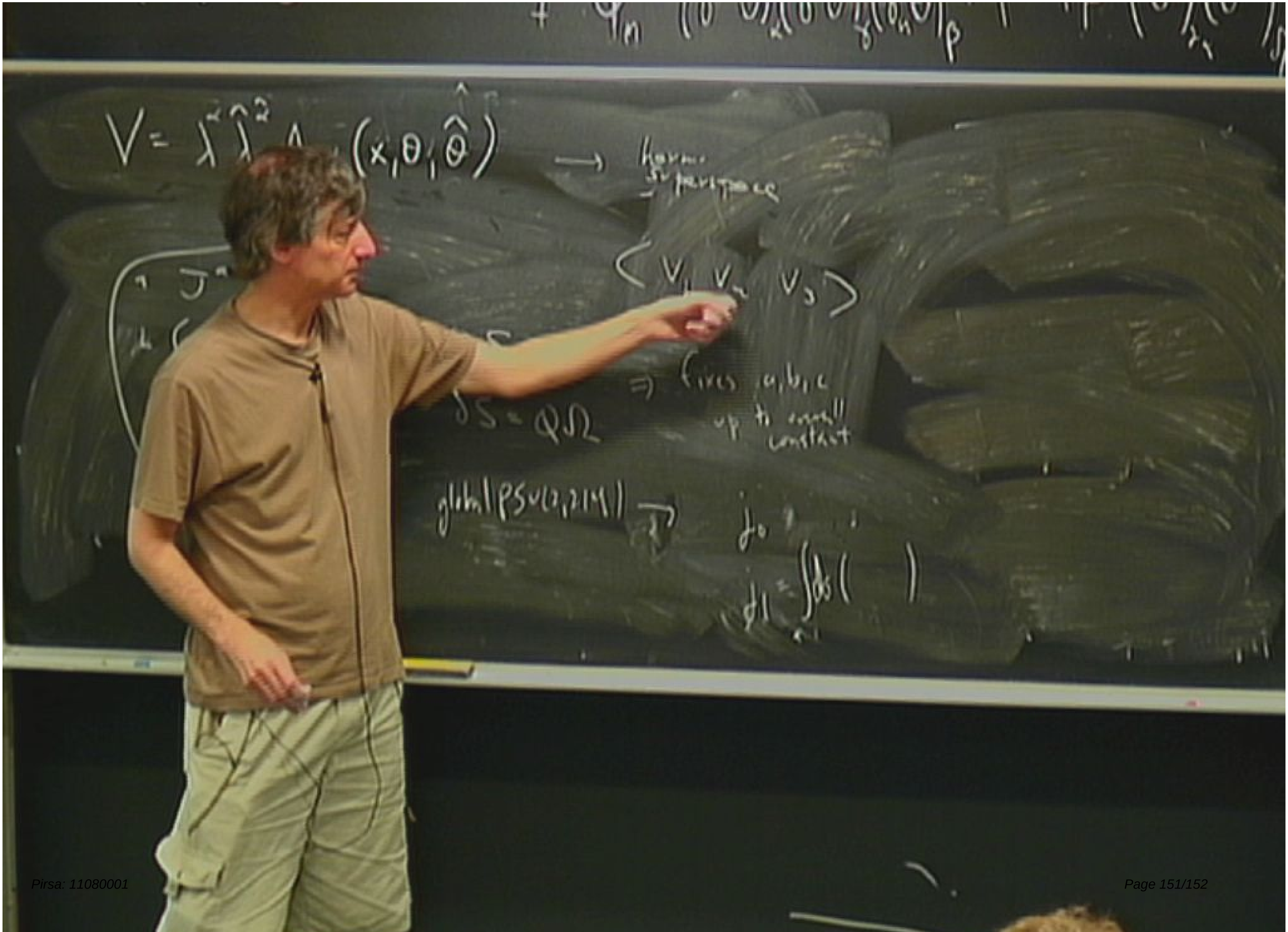
QS = 0
δS = QΩ
⇒ fixes a, b, c
up to overall constant

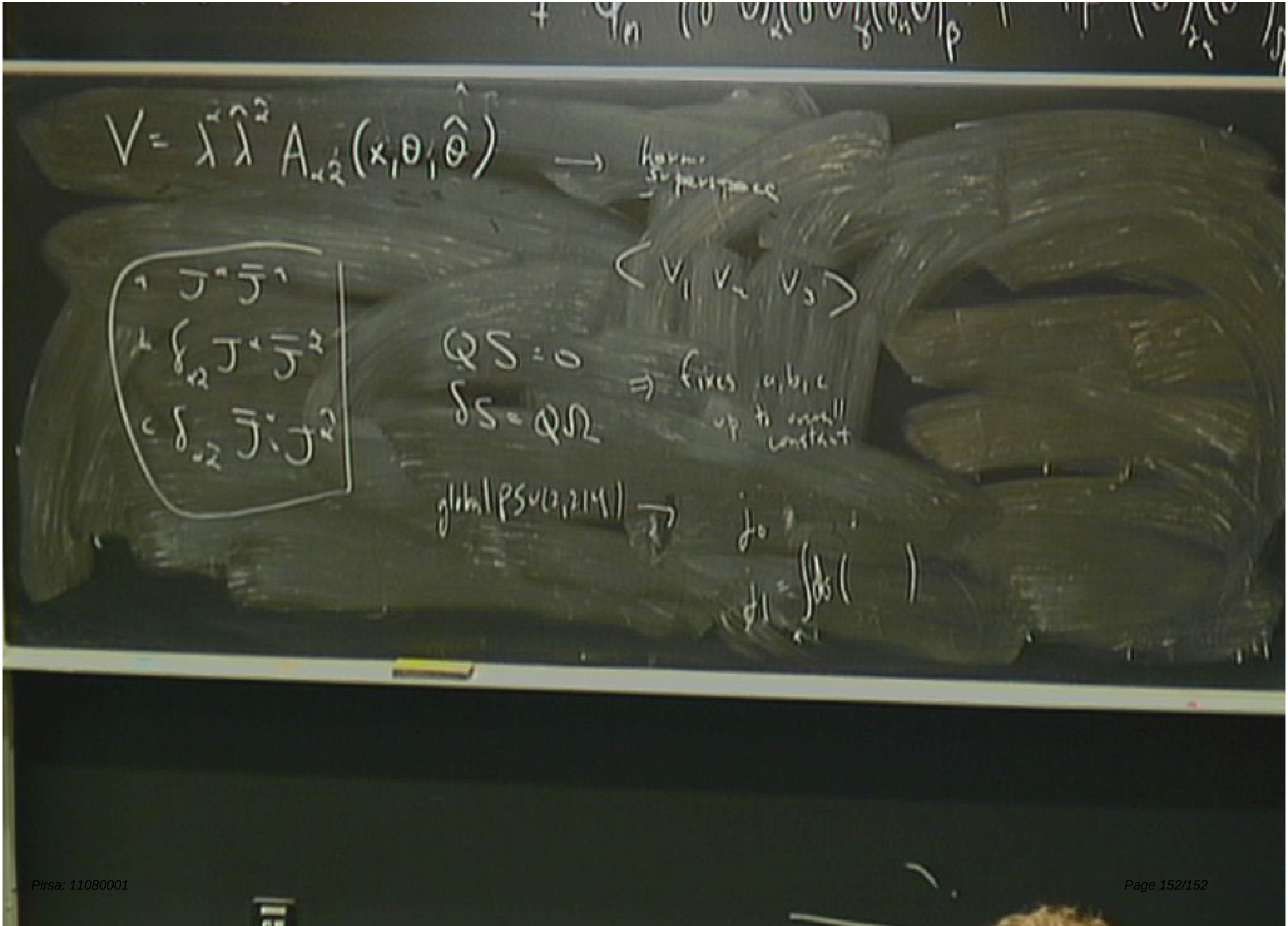

V = λ λ̂ A(x, θ, θ̂)
QS = 0
δS = QΩ
⇒ fixes a, b, c
up to overall constant



(ab) ∈ SO(4,1)×SO(5)
global PSU(2,2|4)
local SO(4,1)×SO(5)
fermionic PSU(2,2|4)


V = λ²λ̂² A(x, θ, θ̂)
harmonic superspace
QS = 0
δS = QΩ
⇒ fixes a, b, c
up to overall constant




V = λ λ̂ A(x, θ, θ̂) → harmonic superspace
⟨V1 V2 V3⟩
QS = 0
δS = QΩ
⇒ fixes a, b, c up to overall constant
global PSU(2,2|4)