

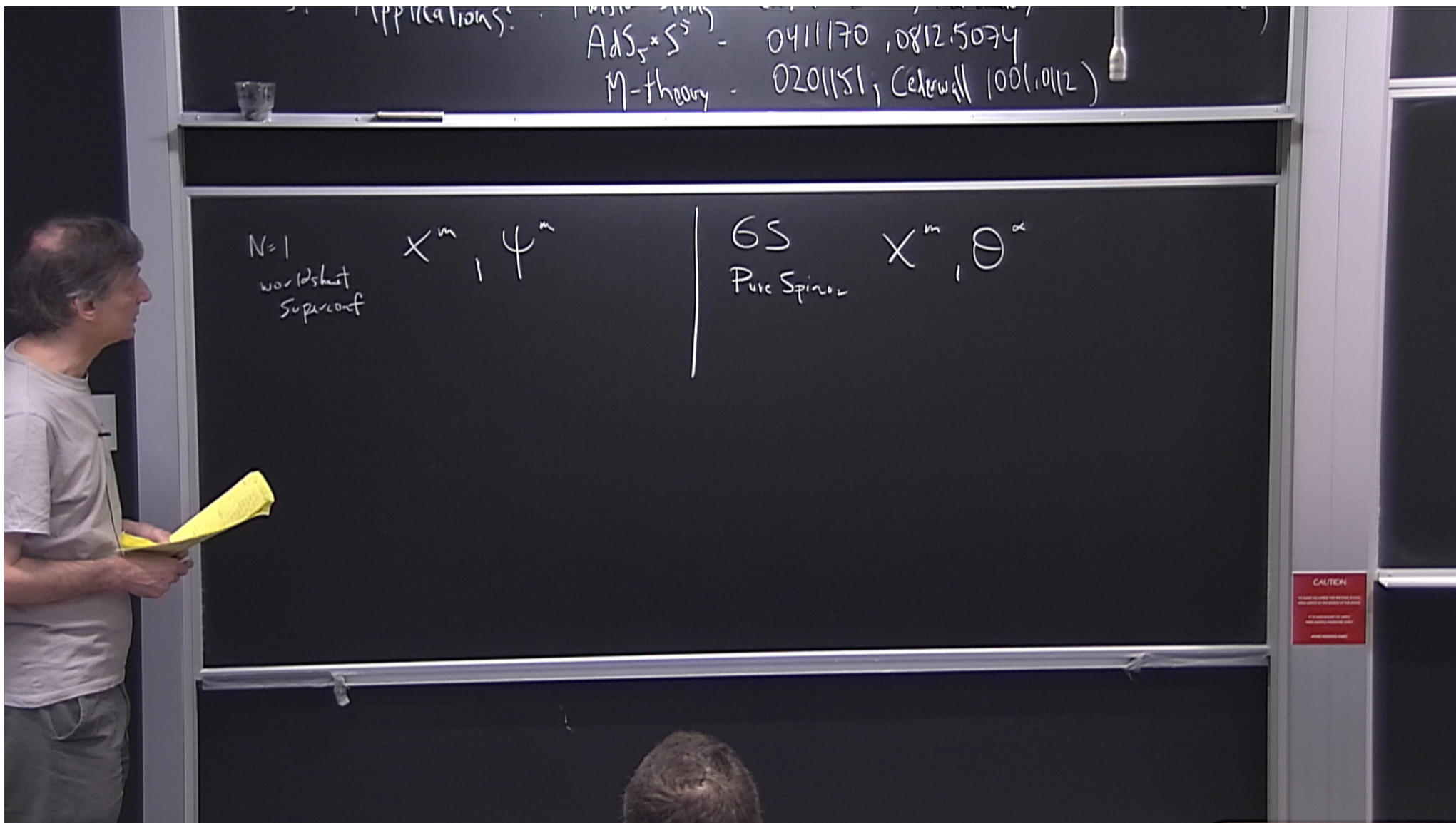
Title: Origin and Applications of the Pure Spinor Formalism

Date: Apr 24, 2015 09:00 AM

URL: <http://pirsa.org/15040175>

Abstract: After reviewing its structure and discussing the twistor-like origin of the pure spinor formalism, I will speculate on possible applications for $\text{AdS}_5 \times \text{S}^5$ and M-theory





3. Superstring

4. B ghost and regulators (0609012 w/ Nekrasov, 0903.3443 w/ Aisake)

5. Applications? : Twistor-string - CHY 1307.2199; Mason+Skinner, 1312.5647; 1311.4156)
AdS₅ × S⁵ - 0411170, 0812.5074
M-theory - 0201151; Cederwall 1001.0112)

X^m, ψ^m

6S

Pure Spinor

X^m, θ^α

5. Applications? Twistor-string - CHY 1307.2199, Mason+Skinner, 1312.5647, 1311.4156)
 $AdS_5 \times S^5$ - 0411170, 0812.5074
 M-theory - 0201151, Cederwall 1001.0112)

$N=1$
 worldsheet
 Superconf
 X^m, ψ^m

R-R backgrounds?

Ramond states?

6S
 Pure Spinor
 X^m, θ^α

$m=0 \dots 9 \quad \alpha=1 \dots 16$

$$(\Gamma^m)_{AB} = \begin{pmatrix} 0 & \gamma^m_{\alpha\beta} \\ \gamma^{m\alpha\beta} & 0 \end{pmatrix}$$

Pure spinor: $S = \int d\tau (P_m \dot{X}^m + \omega_a \dot{\lambda}^a - P_a \dot{\theta}^a)$

$X^m \quad \theta^a \quad \lambda^a$
 $p_m \quad \omega_a$

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

$\Rightarrow \lambda^a \in \frac{SO(10)}{U(5)} \times C^*$

$\omega_a \triangleq \omega_a + (K_L)_a$

$A=1..5$

$\lambda^a = \begin{pmatrix} \lambda^+ \\ \lambda_{AB} \\ \lambda^A \end{pmatrix}$

$\lambda^A = \frac{1}{\lambda^+} \epsilon^{ABDE} \lambda_B \lambda_C \lambda_D \lambda_E$

$Q = \lambda^a d_a = \lambda^a (p_a + \dots)$

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

$$A_m = \gamma_m^{\alpha\beta} D_\alpha A_\beta = a_m + \dots, \quad W^\alpha = \gamma_m^{\alpha\beta} (D_\beta A^m - \partial^m A_\beta) = \chi^\alpha + \dots, \quad F_{mn} = D_m (\gamma^n)^\alpha_\beta W^\beta - (\partial_m a_n)^\alpha - \dots$$

$$QU = \partial V \Rightarrow U = A_\alpha \partial \theta^\alpha + A_m \Pi^m + W^\alpha d_\alpha + F_{mn} N^{mn}$$

$$QB = T \Rightarrow B = \tilde{s} \partial \bar{\lambda}_\alpha + w_\alpha \partial \theta^\alpha + \frac{1}{\lambda \bar{\lambda}} \left(d\bar{\lambda} \bar{\lambda} - \frac{1}{2} (\lambda \gamma^m \partial \theta) (w \gamma_m \bar{\lambda}) \right)$$

$$+ \left(\frac{d\gamma^{mnp} d + N^{mn} \Pi^p}{(\lambda \bar{\lambda})^2} \right) (\bar{\lambda} \gamma_{mnp} r) + \frac{(\bar{\lambda} \gamma^m d) N^{np}}{(\lambda \bar{\lambda})^2} (r \gamma_{np} r) + \frac{(\bar{\lambda} \gamma^{mnp} r)}{(\lambda \bar{\lambda})^4} (r \gamma_{pq} r) N_{mn} N^{pq}$$

$$= \Pi^n \bar{\Gamma}_m + \tilde{s} \partial \bar{\lambda}_\alpha + w_\alpha \partial \theta^\alpha + \frac{1}{\lambda \bar{\lambda}} \left(-\frac{1}{4} \bar{\lambda} \bar{\gamma} \bar{\gamma} r - \frac{1}{2} (w \gamma^m \bar{\lambda}) (\lambda \gamma_m \partial \theta) \right)$$

$$\bar{\Gamma}^n = \frac{1}{(\lambda \bar{\lambda})} \left(\bar{\lambda} \gamma^m d - \frac{1}{4} (\bar{\lambda} \gamma^{mnp} r) N_{np} \right)$$

$x^m \theta^a$
 $\gamma_a \omega_a$

$\boxed{\lambda^m \lambda = 0} \rightarrow \lambda^+ \in \frac{SO(10)}{U(5)} \times C^*$
 $\omega_a \approx \omega_a + (\lambda \lambda)_a$

$A=1.5$
 $\lambda^+ = \begin{pmatrix} \lambda^+ \\ \lambda_{AB} \\ \lambda^+ \end{pmatrix}$
 $\lambda^+ = \frac{1}{\lambda^+} e^{ABDE} \lambda^+_{BC} \lambda^+_{DE}$

$Q = \lambda^+ d_a = \lambda^+ (p_a + \frac{1}{2} (\not{p} \not{\theta})_a)$
 $V = \lambda^+ A_a(x, \theta)$
 $D_a = \frac{\partial}{\partial \theta^a} + \frac{1}{2} (\not{\theta}^m \not{\theta}) \frac{\partial}{\partial x^m}$

$\boxed{Q^2 = 0}$
 $QV=0 \Rightarrow \lambda^+ \lambda^+ D_a A_a = 0 \Rightarrow (\cancel{\lambda^m \not{\theta}^m} \lambda^+) (D_{\cancel{m} \not{\theta}^m} A) = 0$
 $V = Q\Omega \Rightarrow \delta A_a = D_a \Omega$
 $\Rightarrow A_a \text{ describes } d=10 \text{ SYM}$

$QV + [V, V] = 0 \Rightarrow \text{SYM}$
 $QV + V \times V = 0 \Rightarrow \text{open superstring}$

CAUTION

$$Q = \gamma^\mu d_\mu = \gamma^\mu \left(p_\mu + \frac{1}{2} (\not{P} \theta)_\mu \right)$$

$$\boxed{Q^2 = 0}$$

$$V = \gamma^\mu A_\mu(x, \theta)$$

$$D_\mu = \frac{\partial}{\partial \theta^\mu} + \frac{1}{2} (\gamma^\mu \theta)^\nu \frac{\partial}{\partial x^\nu}$$

$$QV = 0 \Rightarrow \gamma^\alpha \gamma^\beta D_\beta A_\alpha = 0 \Rightarrow \cancel{(\gamma^{\mu\nu\rho\sigma})} (D_{\mu\nu\rho\sigma} A) = 0$$

Bosonic

$$Q = c \partial X \partial X + \dots$$

$\frac{1}{\alpha'}$

$$\delta V = Q\Omega \Rightarrow \delta A_\alpha = D_\alpha \Omega$$

$\Rightarrow A_\mu$ describes $d=10$ SYM

$$QV + [V, V] = 0 \Rightarrow \text{SYM}$$

$$QV + V \times V = 0 \Rightarrow \text{open superstring}$$

$$Q = \lambda^\alpha d_\alpha = \lambda^\alpha \left(p_\alpha + \frac{1}{2} (\not{p} \theta)_\alpha \right)$$

$$Q^2 = 0$$

No (b, c)

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

$$D_\alpha = \frac{\partial}{\partial \theta^\alpha} + \frac{1}{2} (\gamma^\mu \theta)_\alpha \frac{\partial}{\partial x^\mu}$$

Bosonic

$$Q = c \partial X \partial X + \dots$$

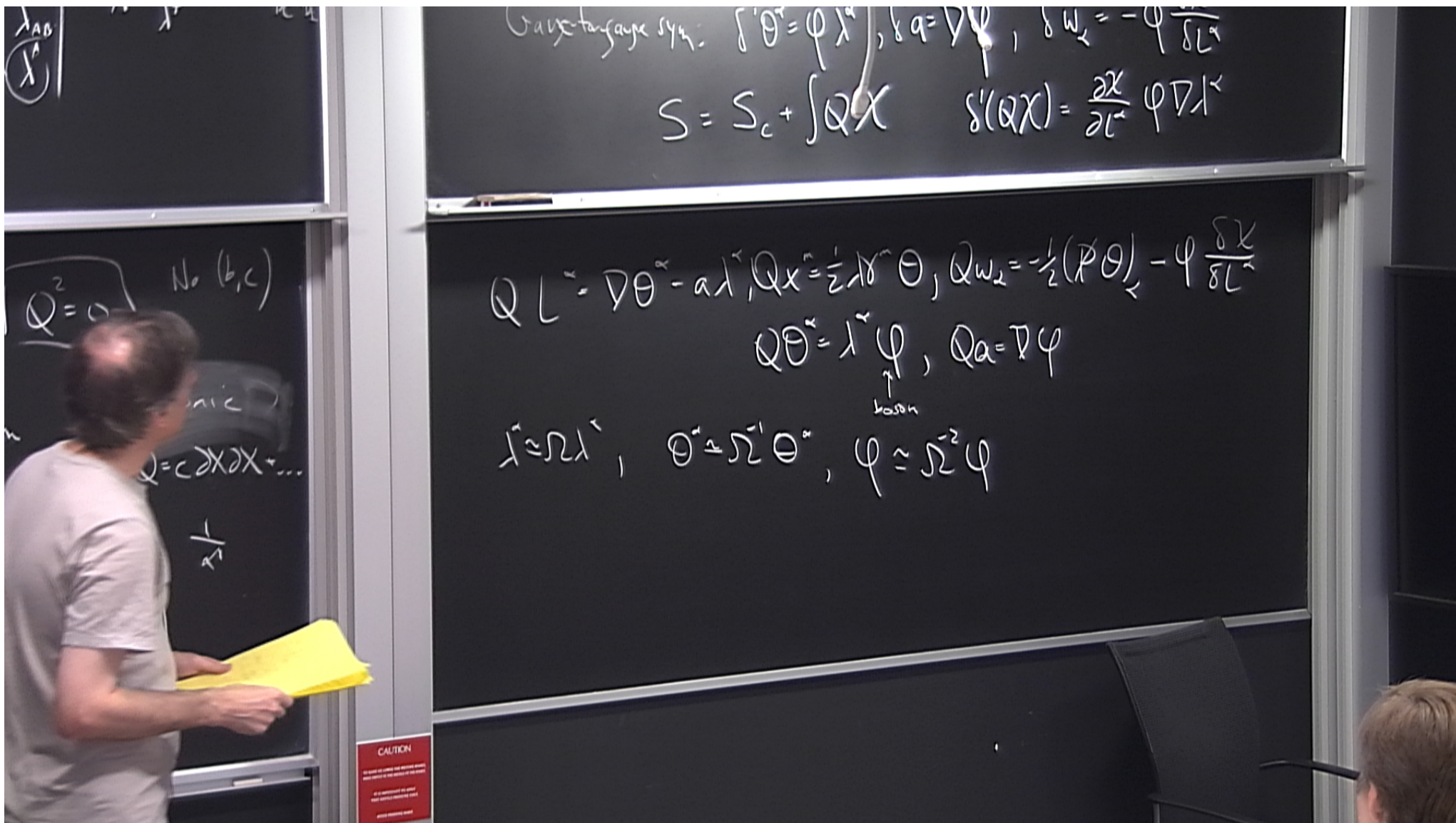
$$QV = 0 \Rightarrow \lambda^\alpha \lambda^\beta D_\beta A_\alpha = 0 \Rightarrow \cancel{(\lambda^\mu \gamma^\nu)} (D_\mu A_\nu) = 0$$

$$\delta V = Q\Omega \Rightarrow \delta A_\alpha = D_\alpha \Omega$$

$\Rightarrow A_\alpha$ describes $d=10$ $\mathcal{N}=1$ Max

$$QV + [V, V] = 0 \Rightarrow \text{SYM}$$

$$QV + V \times V = 0 \Rightarrow \text{open superstring}$$



$$X = p_\alpha \dot{L}^\alpha + \beta \alpha$$

$$Q_\beta = M_\alpha, \quad Q_\beta = N$$

$$QX = -p_\alpha (\nabla \theta^\alpha + \alpha \dot{L}^\alpha) + \beta \nabla \varphi + M_\alpha \dot{L}^\alpha + N \alpha$$

$$S = S_c + \int QX = \int dt \left[P_m \dot{x}^m + N_2 \dot{L}^\alpha - p_\alpha \dot{\theta}^\alpha + \beta \dot{\varphi} + A (\omega \dot{L} + p \theta - 2\beta \varphi) \right]$$

$$(\Gamma^m)_{AB} = \begin{pmatrix} 0 & \gamma^m_{ab} \\ \gamma^{mp} & 0 \end{pmatrix}$$

$$S = S_c = \int QX = \int dt \left(\dot{x}^m + w_\perp \dot{\theta} - p_\perp \dot{\theta} + A(w_\perp + p_\perp \theta - 2\beta\phi) \right)$$

Use scale symmetry: $\varphi = 1$ (assuming $\varphi(t) \neq 0 \forall t$)

$\varphi^{5/2} \Theta_{S,g}$ scale inv has ghost $\star = g + S \Rightarrow \lambda^\vee$ has $g_n = +1$

$$S = \int dt \left(P_m \dot{x}^m + w_\perp \dot{\theta} - p_\perp \dot{\theta} \right)$$

$$Q\theta = \lambda^\vee, Qx_m = \frac{1}{2} \lambda^\vee \theta, Qw_\perp = -p_\perp - \frac{1}{2} \phi \theta, \Rightarrow Q = \lambda^\vee d_\alpha$$

$$\text{GS gauge-fixing: } \chi = -\frac{1}{2} \varphi^{-1} L^\vee(\phi\theta)_\perp + p_\perp \Rightarrow Qw_\alpha = 0$$

$$S = \int d\tau \left(\vec{P}_m \dot{X}^m + w_\alpha \dot{\lambda}^\alpha - p_\alpha \dot{\Theta}^\alpha \right)$$

$$Q\Theta^\alpha = \lambda^\alpha, QX_m = \frac{1}{2} \lambda \gamma_m \Theta, Qw_\alpha = -\mathcal{P} - \frac{1}{2} \lambda \gamma_\alpha \Theta \Rightarrow Q = \lambda^\alpha d_\alpha$$

$$\text{GS gauge fixing } \chi = -\frac{1}{2} \Phi^{-1} L^\alpha (\Phi \Theta)_\alpha + \mathcal{P} q \Rightarrow Qw_\alpha = 0$$

$$\text{BRST} \Rightarrow k\text{-symmetries where } \lambda^\alpha = (\not{K})^\alpha$$



$X^m \lambda \hat{\lambda}$ IIB same $\lambda \gamma^m \lambda = 0, \lambda \approx \Omega \lambda$
 $P_m \quad w_2 \quad \hat{w}_2$

$$(P \pm \partial_\sigma X)^2 = 0 \rightarrow (P + \partial_\sigma X)(\gamma_m \lambda) = 0, (P - \partial_\sigma X)(\gamma_m \hat{\lambda}) = 0$$

$$\nabla_\sigma \lambda^\alpha = 0 \quad \hat{\nabla}_\sigma \hat{\lambda} = 0$$

$$S = \int d\tau d\sigma \left(P_m \dot{X}^m + w_2 \nabla \lambda^\alpha + \hat{w}_2 \hat{\nabla} \hat{\lambda}^{\hat{\alpha}} - \frac{1}{2} L \left[(P + \partial_\sigma X) \lambda + \hat{L} (P - \partial_\sigma X) \hat{\lambda} + K \nabla_\sigma \lambda + \hat{K} \hat{\nabla}_\sigma \hat{\lambda} \right] \right)$$

$QV=0 \Rightarrow \lambda \lambda^\alpha \lambda^\beta \Rightarrow (\lambda \gamma^{mnpq} \lambda) (D \gamma_{mnpq} A) = 0$

$\delta V = Q \Omega \Rightarrow \delta$

$\Rightarrow A_2$ describes $d=10$

$V=0 \Rightarrow \text{SYM}$
 $V=0 \Rightarrow \text{open superstring}$

$$S = \int d\tau d\sigma \left(P_m \dot{X}^m + w_\alpha \bar{D} \lambda^\alpha + \bar{w}_\alpha \hat{D} \hat{\lambda}^\alpha - \frac{1}{2} L^\mu (P_\mu / \partial X) \lambda + \hat{L}^\mu (P_\mu / \partial X) \hat{\lambda} \right)$$

λ fixed Top string $\rightarrow$ Varying λ superstring $\rightarrow K D_\sigma \lambda + \hat{K} \hat{D}_\sigma \hat{\lambda}$

$$Q = \lambda d_\sigma = \lambda (P_\sigma + \frac{1}{2} L^\mu (P_\mu / \partial X) \lambda)$$

$$V = \lambda^\alpha A_\alpha(x, \theta) \quad D_\alpha = \frac{\partial}{\partial \theta^\alpha} + \frac{1}{2} (\gamma^\mu \theta)_\alpha \frac{\partial}{\partial x^\mu}$$

$$QV = 0 \Rightarrow \lambda^\alpha \lambda^\beta D_\alpha A_\beta = 0 \Rightarrow (\cancel{\lambda^\alpha \lambda^\beta}) (D_{\alpha\beta} A) = 0$$

$$\{V = Q\Omega \Rightarrow \delta A_\alpha = D_\alpha \Omega$$

$\Rightarrow A_\alpha$ describes $d=10$ SMax

$$QV + [V, V] = 0 \Rightarrow \text{SYM}$$

$$QV + V \times V = 0 \Rightarrow \text{open superstring}$$

Bosonic

$$Q = c \partial X \partial X + \dots$$

$\frac{1}{x^2}$

$$S = \int d^2z \left(-\frac{1}{2} \partial_\mu X^\mu \partial_\nu X^\nu + p_\alpha \partial \theta^\alpha + \text{right-movers} \right)$$

$$T = w \partial \lambda$$

$$J = \lambda w$$

$$N^{mn} = \frac{1}{2} \gamma^{mn} w$$

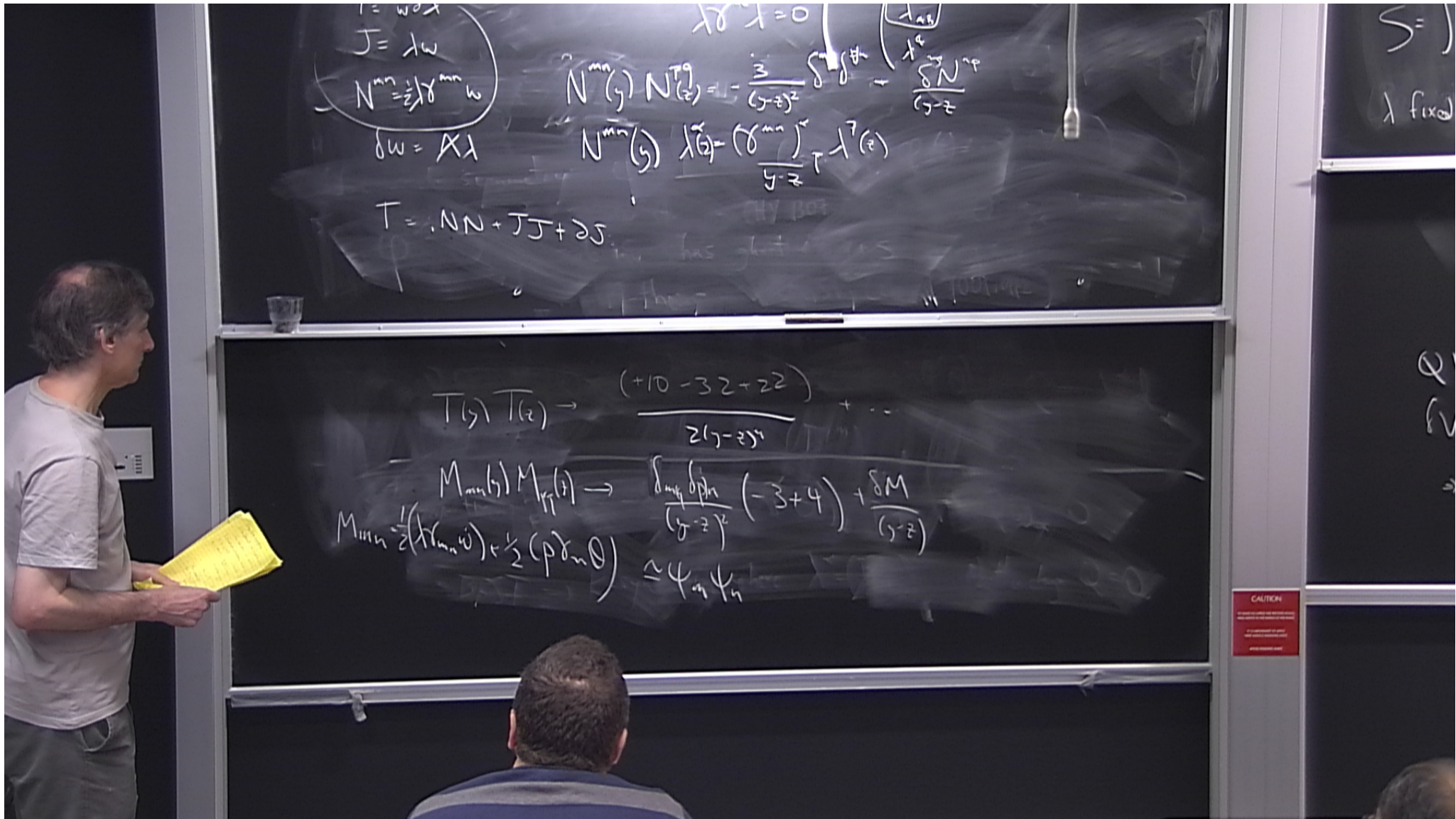
$$\delta w = A \lambda$$

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

$$N^{mn}(y) N^{pq}(z) = -\frac{3}{(y-z)^2} \delta^{mn} \delta^{pq} + \frac{\delta N^{np}}{(y-z)}$$

$$N^{mn}(y) \lambda^\alpha(z) = \left(\gamma^{mn} \right)^\alpha_\beta \lambda^\beta(z)$$

$$T = :NN: + JJ + 2J$$



$$\begin{aligned}
 &T = \omega \lambda \\
 &J = \lambda \omega \\
 &N^{mn} = \frac{1}{2} \gamma^{mn} \omega \\
 &\delta \omega = \lambda \lambda \\
 &N^{mn}(y) N^{pq}(z) = \frac{3}{(y-z)^2} \delta^{pq} + \frac{\delta N^{pq}}{(y-z)} \\
 &N^{mn}(y) \lambda(z) = (\gamma^{mn})^r{}_r \lambda^r(z) \\
 &T = :NN: + :JJ: + \partial J
 \end{aligned}$$

$$\begin{aligned}
 &T(y) T(z) \rightarrow \frac{(+10 - 32 + 22)}{2(y-z)^4} + \dots \\
 &M_{mn}(y) M_{pq}(z) \rightarrow \frac{\delta_{mp} \delta_{qn}}{(y-z)^2} (-3 + 4) + \frac{\delta M}{(y-z)} \\
 &M_{mn} = \frac{1}{2} (\lambda \gamma_{mn} \dot{\omega}) + \frac{1}{2} (p \gamma_{mn} \theta) \simeq \psi_m \psi_n
 \end{aligned}$$

$$A_\alpha(x, \theta) = a_m(x) (\gamma^m \theta)_\alpha + \chi^\beta(x) (\gamma^\beta \theta)_\beta (\gamma_m \theta)_\alpha + \mathcal{O}(\theta^3) \quad \partial_m \partial^n a^m = 0, \not\partial \chi = 0$$

$$A_m = \gamma_m^{\alpha\beta} D_\alpha A_\beta = a_m + \dots, \quad W^\alpha = \gamma_m^{\alpha\beta} (D_\beta A^m - \partial^m A_\beta) = \chi^\alpha + \dots, \quad F_{mn} = D_m (\gamma^n)^\alpha_\beta W^\beta - (\partial_m \gamma^n)^\alpha_\beta \chi^\beta + \dots$$

$$QU = \partial V \Rightarrow U = A_\alpha \partial \theta^\alpha + A_m \Pi^m + W^\alpha d_\alpha + F_{mn} N^{mn}$$

$$QB = T \Rightarrow B = \tilde{s} \partial \bar{\lambda}_\alpha + w_\alpha \partial \theta^\alpha + \frac{1}{\lambda \bar{\lambda}} \left(d\bar{\lambda} \bar{\lambda} - \frac{1}{2} (\lambda \gamma^m \partial \theta) (w \gamma_m \bar{\lambda}) \right)$$

$$+ \frac{(d\gamma^{mn} \bar{p} + N^{mn} \Pi^p)}{(\lambda \bar{\lambda})^2} (\bar{\lambda} \gamma_{mnp} r) + \frac{(\bar{\lambda} \gamma^m d) N^{np}}{(\lambda \bar{\lambda})^2} (r \gamma_{mp} \bar{r}) + \frac{(\bar{\lambda} \gamma^{mnp} r)}{(\lambda \bar{\lambda})^4} (r \gamma_{mp} \bar{r}) N_{mn} N^{qr}$$

$$= \Pi^n \bar{\Gamma}_n + \tilde{s} \partial \bar{\lambda}_\alpha + w_\alpha \partial \theta^\alpha + \frac{1}{\lambda \bar{\lambda}} \left(-\frac{1}{4} \bar{\lambda} \bar{p} \bar{\gamma} \bar{r} - \frac{1}{2} (w \gamma^m \bar{\lambda}) (\lambda \gamma_m \partial \theta) \right)$$

$$\bar{\Gamma}^n = \frac{1}{(\lambda \bar{\lambda})} \left(\bar{\lambda} \gamma^m d - \frac{1}{4} (\bar{\lambda} \gamma^{mnp} r) N_{np} \right)$$

$$\boxed{\lambda_p(z) \lambda_p(z) \rightarrow \frac{\gamma_m \Pi_m}{z - \bar{z}}}$$

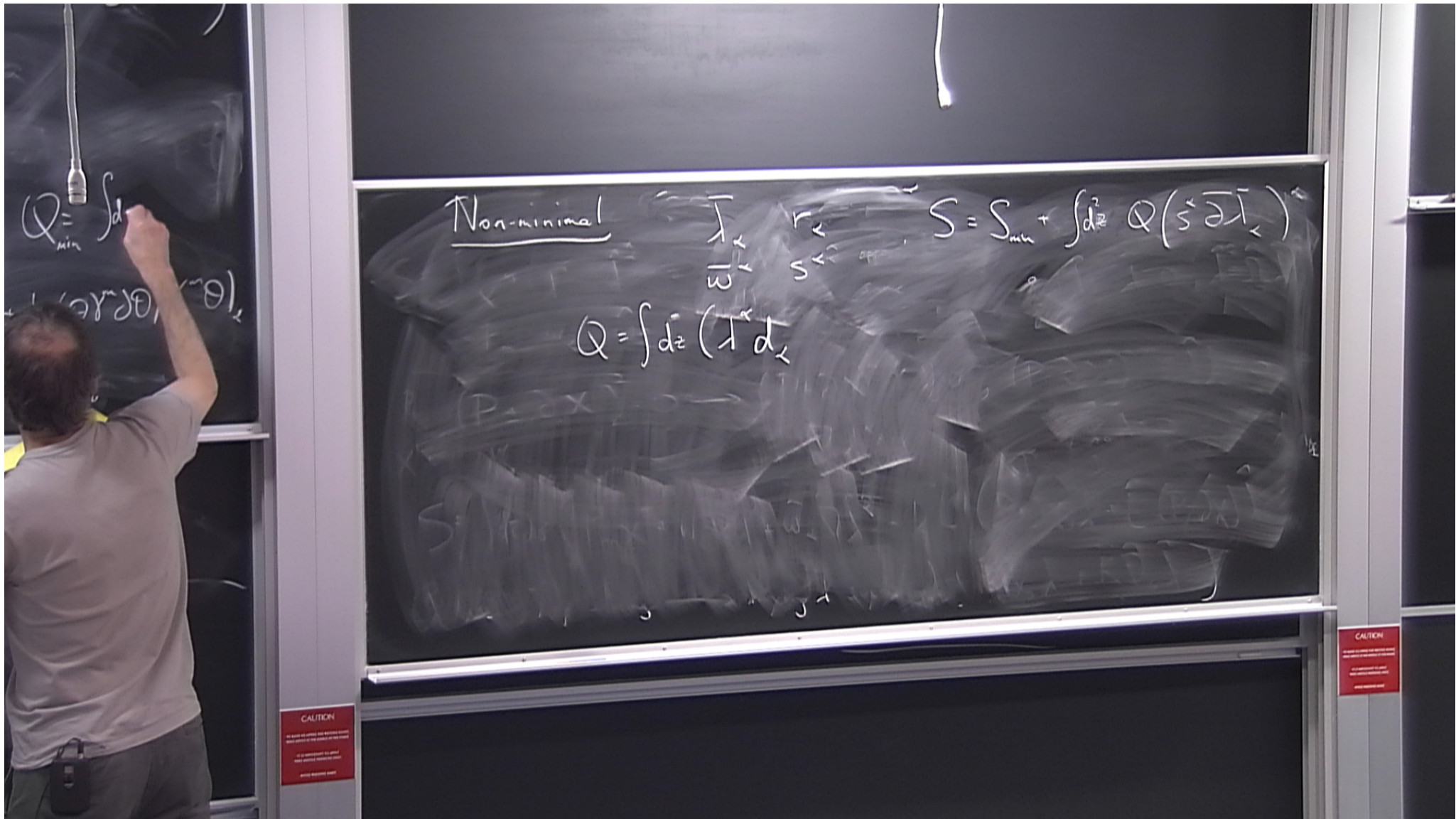
$$p_z = p_z + \frac{1}{2} \partial X^m \partial_m \Theta + \frac{1}{2} (\partial X^m \partial_m \Theta) \gamma^m \Theta$$

$$\Pi^m = \partial X^m - \frac{1}{2} \partial \Theta \gamma^m \Theta$$

$$V = \lambda^T A_\lambda(x, \theta), \quad QV = \partial V$$

$$\int d^{10}x \int d^4\theta \int d^4\lambda \int d^4\lambda \int d^4\lambda$$

Non-minimal



$$N^{mn} = \frac{1}{2} \dot{\gamma}^{mn}$$

$$\delta w = A \lambda$$

$$N^{mn}(y) \lambda(z) = \frac{(y-z)^2}{y-z} \lambda(z)$$

$$\frac{\delta N^{np}}{(y-z)}$$

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

$$d_\alpha(y) d_\beta(z) \rightarrow \frac{\gamma_{\alpha\beta}^m \pi_m}{y-z}$$

$$d_\alpha = p_\alpha + \frac{1}{2} \partial X^m (\gamma_m)_\alpha + \frac{1}{8} (\partial \gamma^m \partial \theta) (\gamma_m)_\alpha$$

$$\pi^m = \partial X^m - \frac{1}{2} \partial \theta \gamma^m \theta$$

$$V = \int A_\alpha(x, \theta)$$

$$QU = \partial V$$

Non-minimal

$$\text{bosons } \begin{pmatrix} \lambda_\alpha \\ \bar{\omega}^{\dot{\alpha}} \end{pmatrix} \begin{pmatrix} r_\alpha \\ s^{\dot{\alpha}} \end{pmatrix}$$

$$S = S_{\min} + \int d^2z Q(s^\alpha \bar{\partial} \lambda_\alpha) \\ = S_{\min} + \int d^2z (s^\alpha \bar{\partial} r_\alpha + \bar{\omega}^{\dot{\alpha}} \bar{\partial} \lambda_{\dot{\alpha}})$$

$$Q = \int d^2z (\lambda^\alpha d_\alpha + \bar{\omega}^{\dot{\alpha}} r_{\dot{\alpha}})$$

$$\bar{\lambda} \gamma^m \bar{\lambda} = 0$$

$$\bar{\lambda}_\alpha \approx (a^\alpha)^*$$

$$r \gamma^m \bar{\lambda} = 0$$

$$Q L = \dots$$

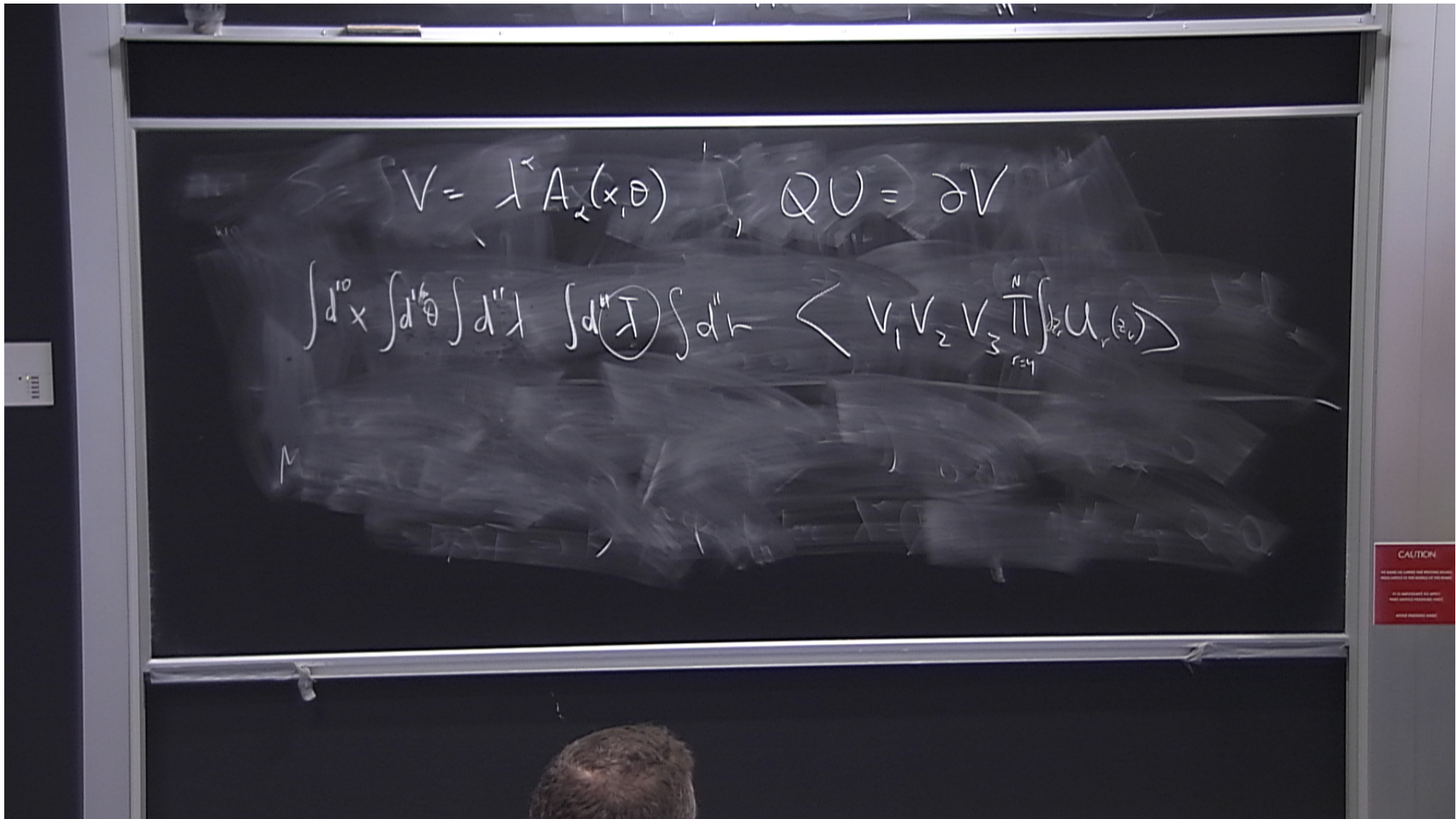
$$\bar{\lambda} \approx \Omega \lambda^*$$

CAUTION

DO NOT USE STANDING FEET OR OTHER OBJECTS TO REACH ABOVE OR BELOW THE BOARD. IF IT IS NECESSARY TO REACH, PLEASE REQUEST ASSISTANCE.

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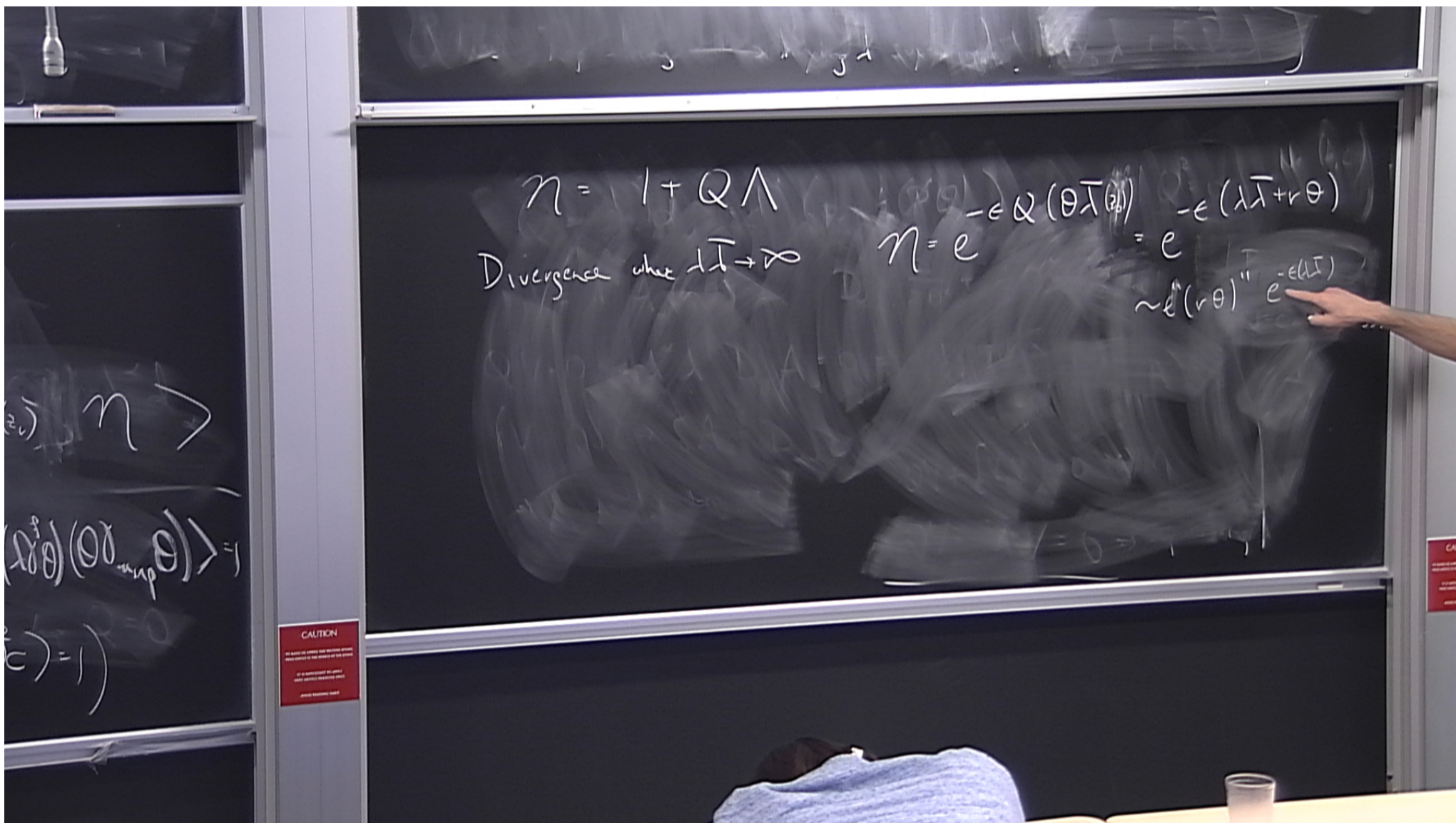


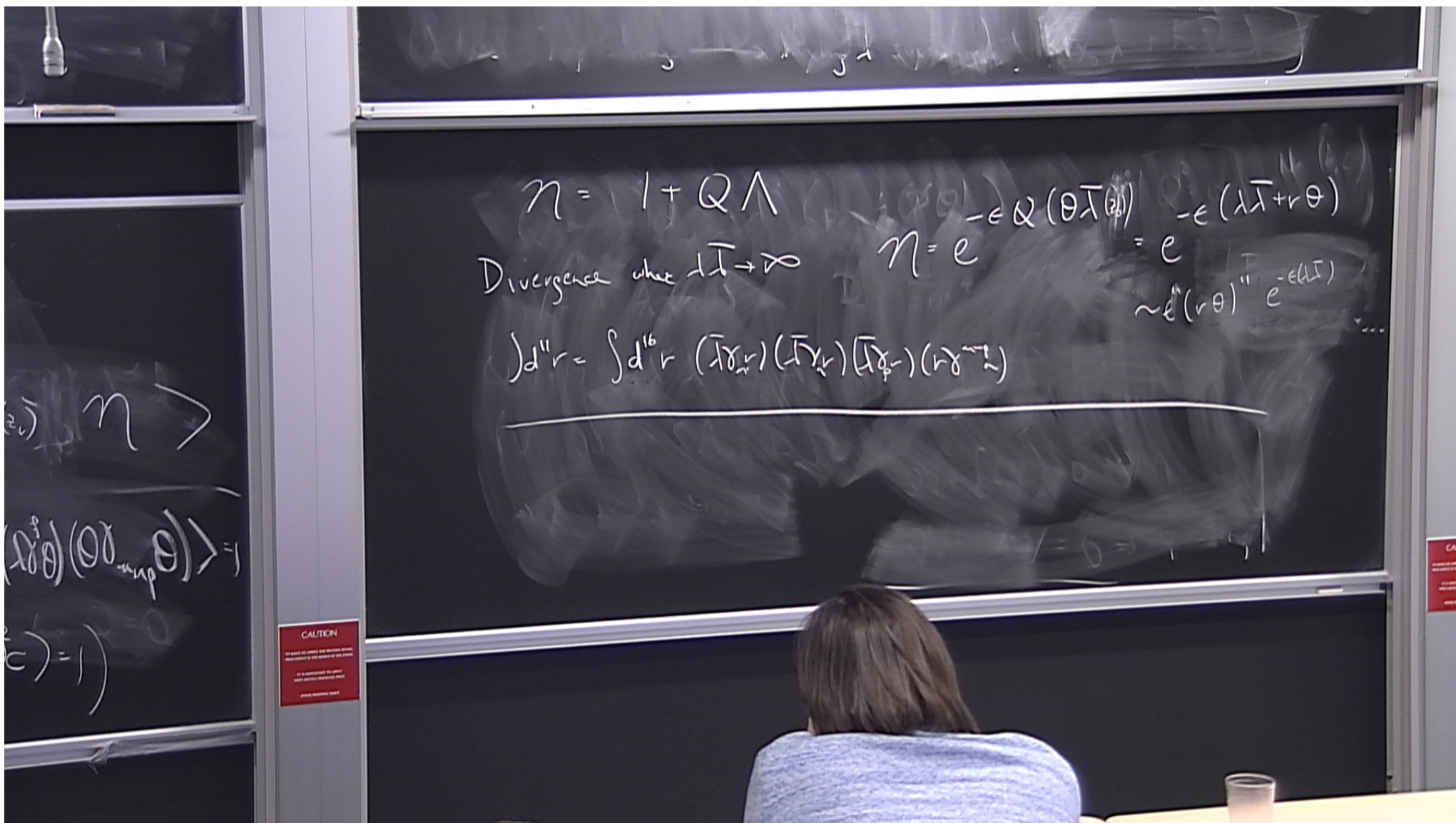
$$S = \int V = \int A_2(x, \theta), \quad QU = \partial V$$

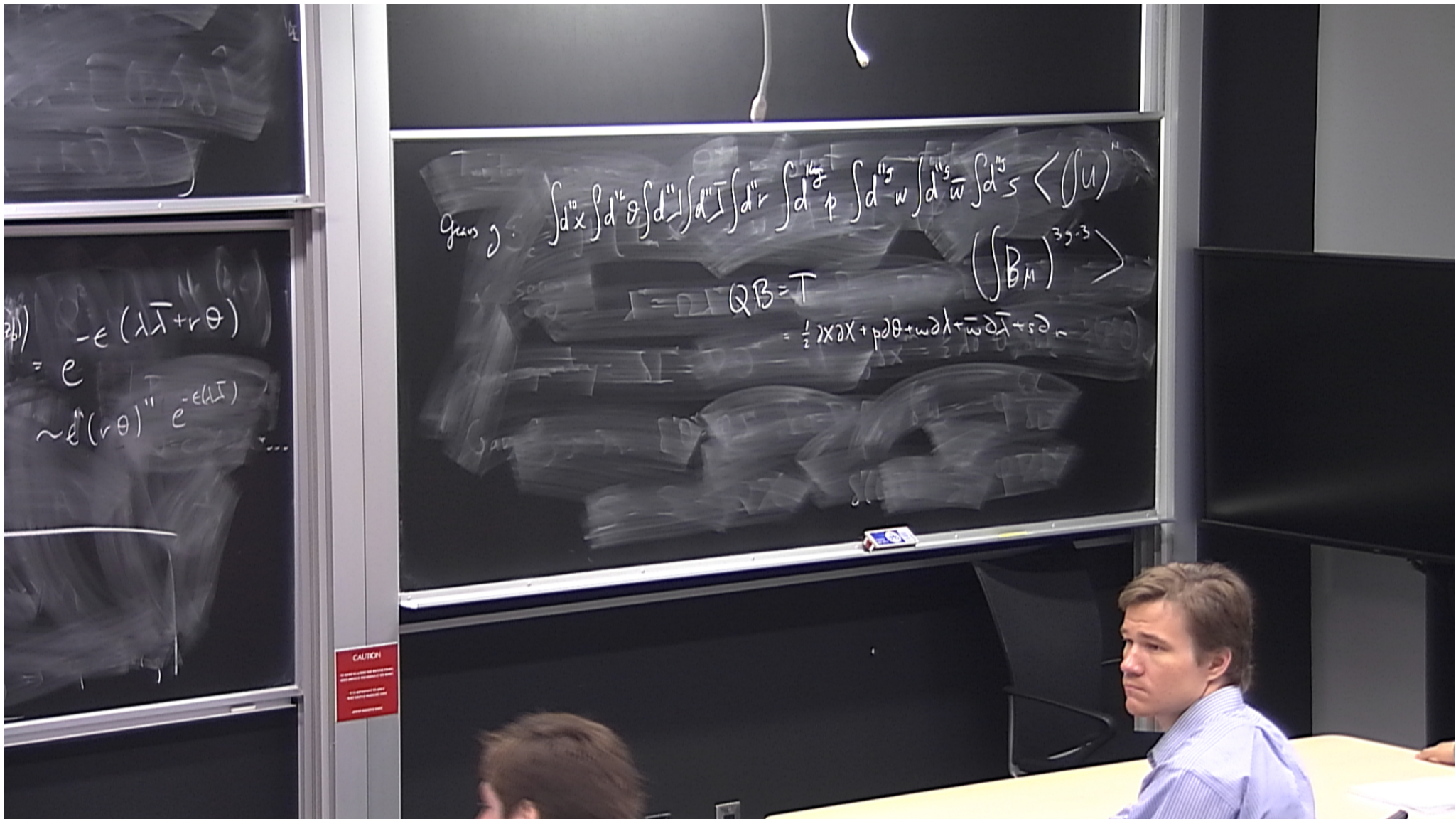
$$S = \int d^{10}x \int d^4\theta \int d^4x \int d^4T \int d^4r \left\langle V_1 V_2 V_3 \prod_{r=1}^N U_r(z_r) \right\rangle$$

$$= \int d^{10}x \left(\frac{\partial}{\partial x^3} \right) \left(\frac{\partial}{\partial \theta} \right)^5 \left(V_1 V_2 V_3 \left(\int U \right)^{N-3} \right) \left\langle (x^{\mu} \partial) (x^{\nu} \partial) (x^{\rho} \partial) (\partial x_{\mu\nu\rho} \theta) \right\rangle = 1$$

$$\left(\left\langle \partial \partial^2 \partial \right\rangle = 1 \right)$$







$$QB = T$$

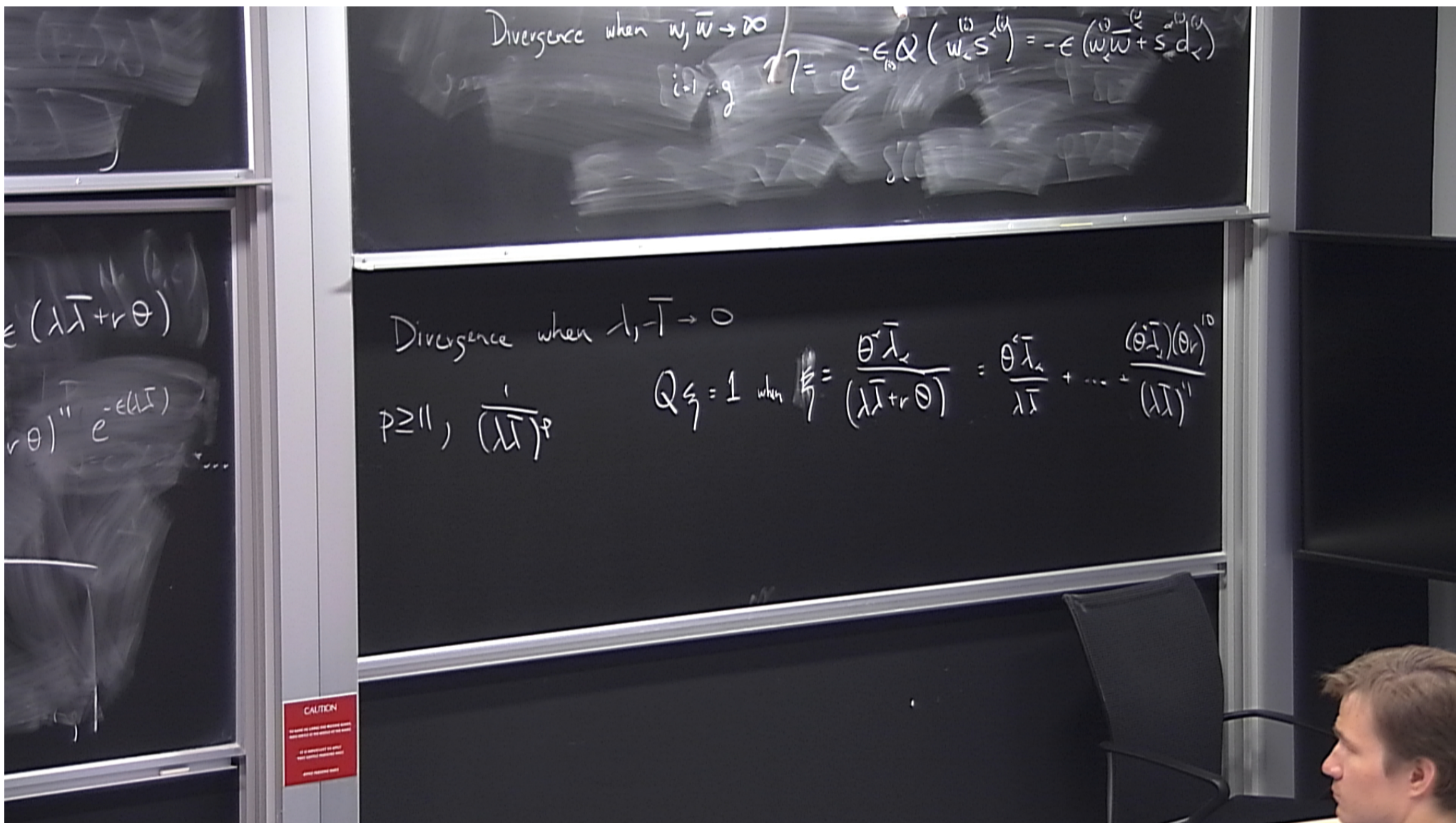
$$(B_M)$$

$$= \frac{1}{2} \lambda \partial \lambda + p \partial \theta + w \partial \lambda + \bar{w} \partial \bar{\lambda} + s \partial \eta$$

Divergence when $w, \bar{w} \rightarrow \infty$

$$i=1 \dots g \quad \eta = e^{-\epsilon \sum_{i=1}^g Q(w_i^{(i)} s_i^{(i)})} = -\epsilon (w_i^{(i)} \bar{w}_i^{(i)} + s_i^{(i)} d_i^{(i)})$$

$$\text{when } d_i - \bar{d}_i \rightarrow 0$$



$$d_z(g) d_{\bar{z}}(z) \rightarrow \frac{1}{y-z}$$

$$d_z = p_z + z \frac{\partial}{\partial z}$$

$$\Pi^m = \partial X^m - \frac{1}{2} \partial \theta \partial^m \theta$$

$$\int df \int d\bar{f} \int dg \int d\bar{g} e^{-i \in \mathbb{Q} (g^* w_2 + \bar{f}_2 s_2 + g^* \bar{f}_2)}$$

$$\begin{matrix} f^* & g^* \\ \bar{f}_2 & \bar{g}_2 \end{matrix}$$

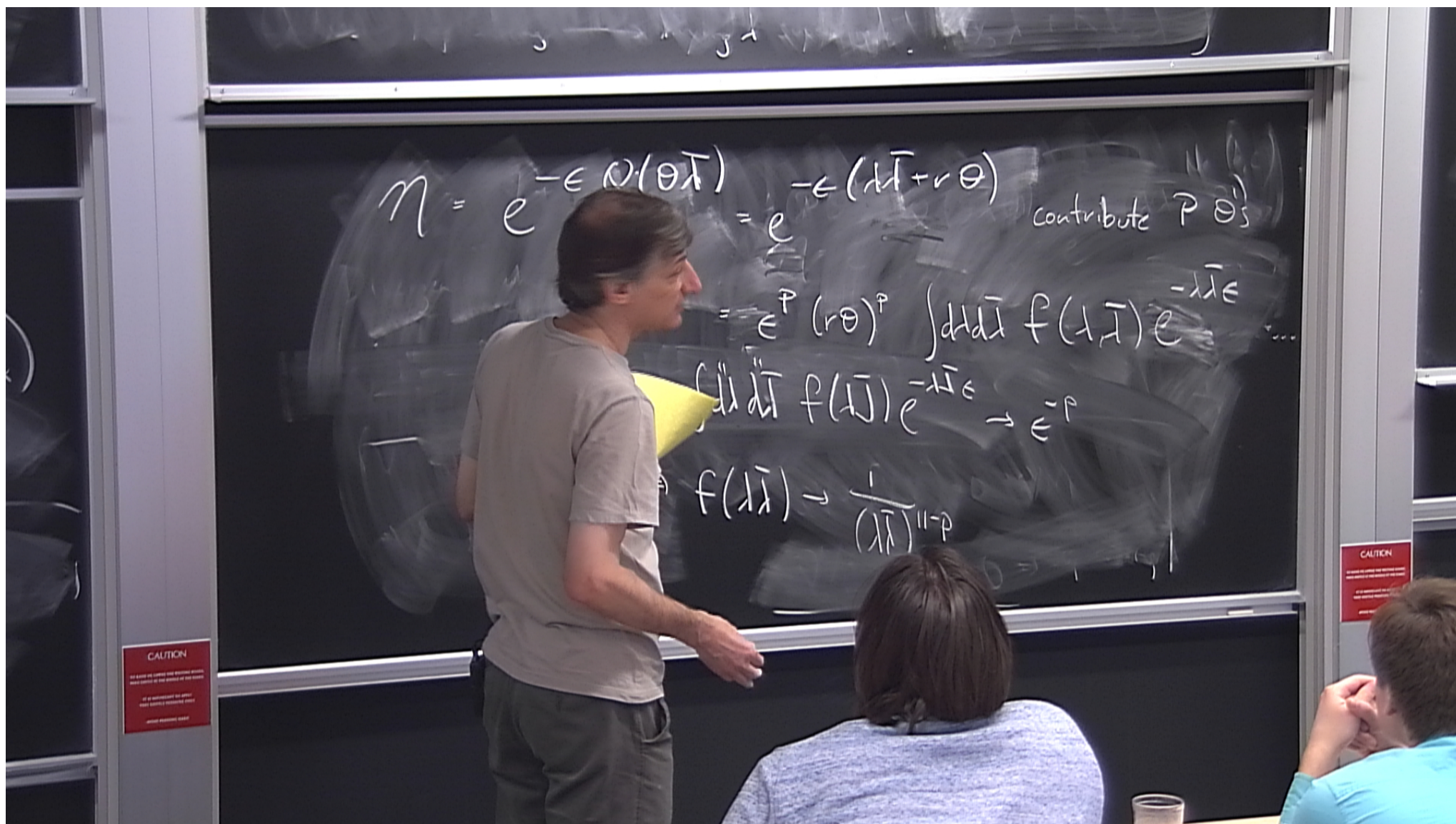
$$e^{-i \in (\bar{f}_2 w_2 + \bar{f}_2 \bar{w}_2 + g^* d_2 + \bar{g}_2 s_2 + f^* \bar{f}_2 - g^* \bar{g}_2)}$$

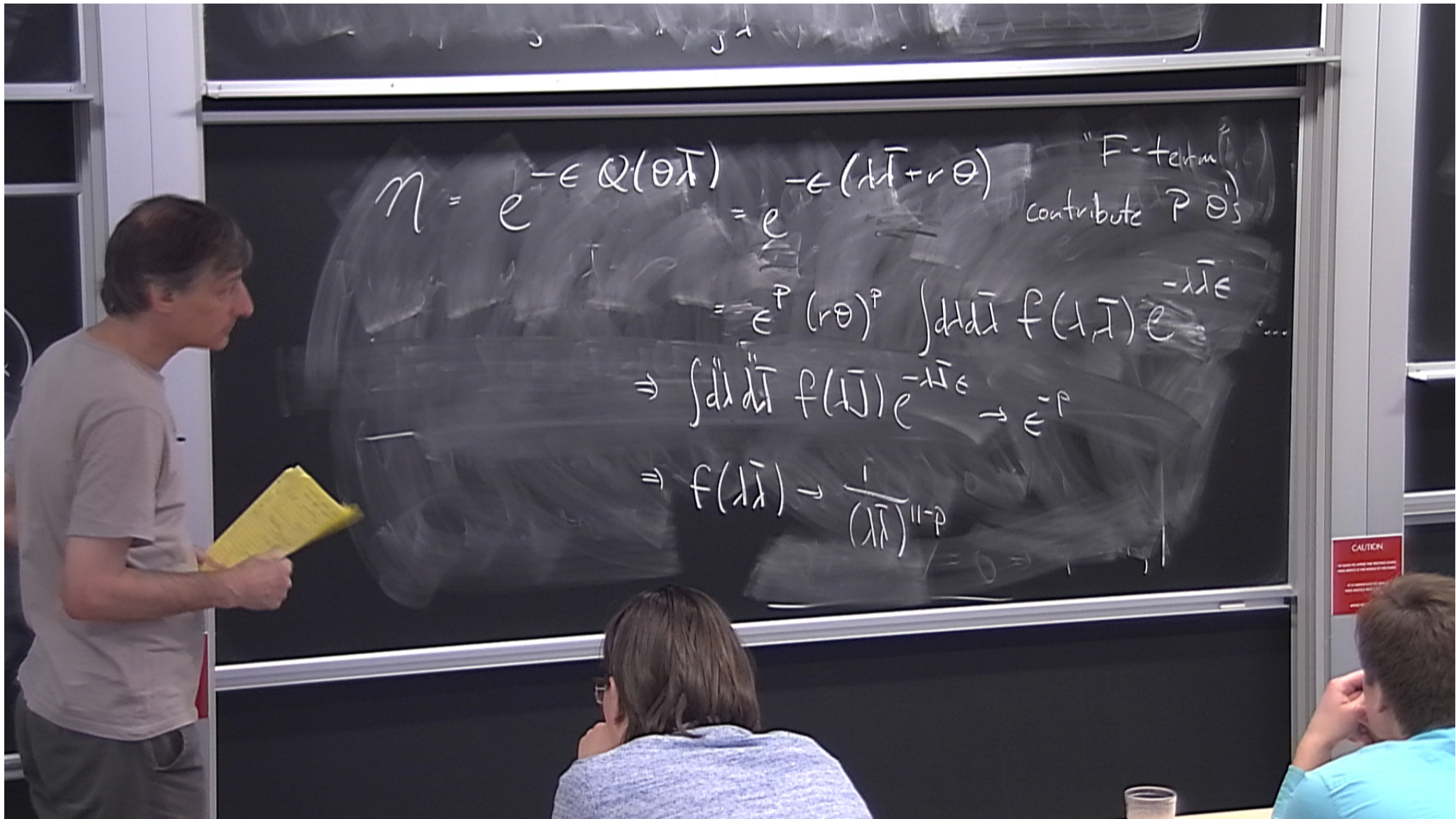
$$\begin{matrix} \mathbb{Q} g^* = f^* \\ \mathbb{Q} \bar{f}_2 = \bar{g}_2 \end{matrix}$$

$$\lambda^* \rightarrow \lambda^*(z) \in f^* G(z, z_0)$$

$$\bar{\lambda}_2 \rightarrow \bar{\lambda}_2(z) \in \bar{f}_2 G(z, \bar{z}_0)$$

CAUTION
DO NOT TOUCH THE BOARD
OR THE SURROUNDING AREA
IF YOU DO, YOU WILL BE
PUNISHED.





$2) \text{AdS}_5 \times S^5 \quad \text{PSU}(2,2|4) \quad \lambda \gamma^{01234} \hat{\lambda} = V_{\text{SYM}}$
 $3) \text{M-theory} \quad \lambda \gamma^m \lambda = 0 \quad m=0, \dots, 10 \quad V = \lambda^\alpha \lambda^\beta \lambda^\gamma C_{\alpha\beta\gamma}(\lambda, \theta)$
 $\langle \lambda^\dagger \theta^\dagger \rangle = 1$