

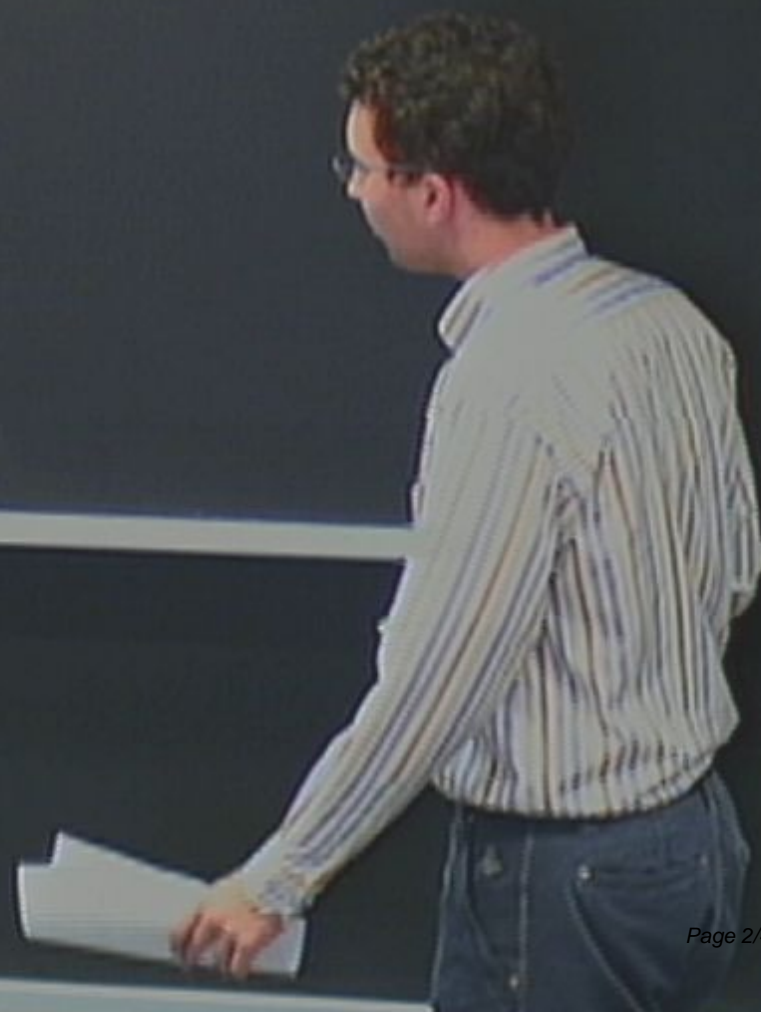
Title: Undergrad Research Project Talk

Date: Aug 20, 2009 03:00 PM

URL: <http://pirsa.org/09080033>

Abstract:

Renormalization of a clock field coupled to
low energy gravity



Renormalization of a clock field coupled to
low energy gravity

$$\frac{1}{\omega^2 - |\vec{k}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{k}|^2 - |\vec{k}|^2 \alpha}$$

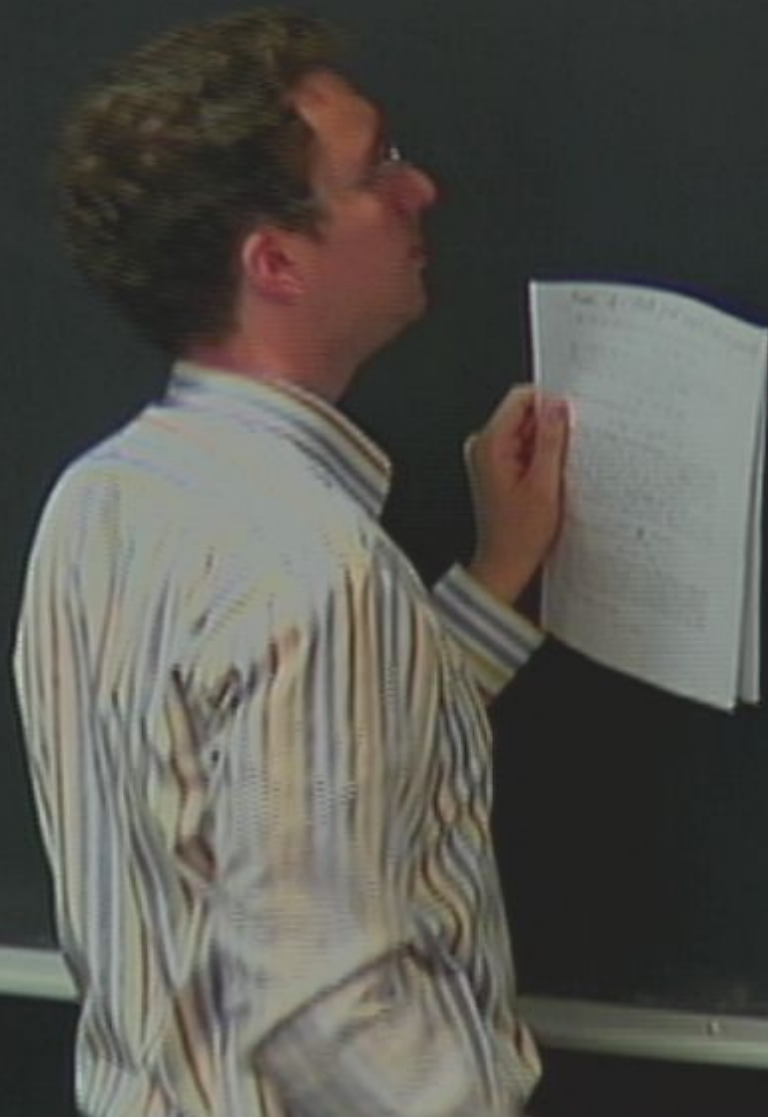
Renormalization of a clock field coupled to
low energy gravity

$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}|^2 \alpha^2}$$

Renormalization of a clock field coupled to
low energy gravity

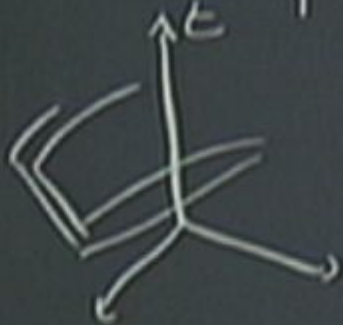
$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}|^2 \alpha}$$

Horava 0901.3775



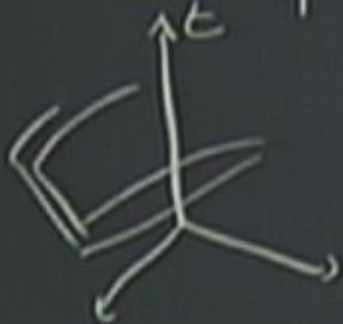
Renormalization of a clock field coupled to low energy gravity

$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}|^4}$$



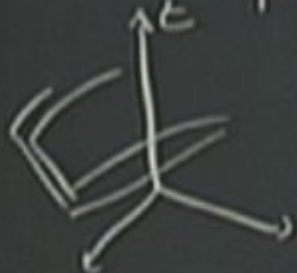
Renormalization of a clock field coupled to low energy gravity

$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}|^2 \alpha} \approx \frac{1}{p_\mu p^\mu - \alpha (h_{\mu\nu} p^\mu p^\nu)^2}$$



Renormalization of a clock field coupled to low energy gravity

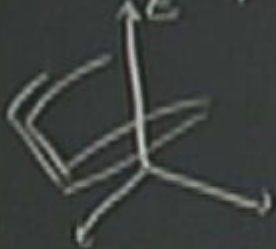
$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}|^2} \approx \frac{1}{p_\mu p^\mu - \alpha (h_{\mu\nu} p^\mu p^\nu)^2}$$



$$h_{\mu\nu} = \eta_{\mu\nu} + \frac{m}{\mu} \eta_{\mu\nu}$$

Renormalization of a clock field coupled to low energy gravity

$$\frac{1}{\omega^2 - k^2} \rightarrow \frac{1}{\omega^2 - k^2 - \frac{1}{2} \alpha (k^\mu k^\nu) \epsilon} \approx \frac{1}{k^\mu k^\nu - \alpha (h_{\mu\nu} k^\mu k^\nu) \epsilon} \quad g_{\mu\nu} \eta^{\mu\nu} = 1$$



$$h_{\mu\nu} = g_{\mu\nu} + \frac{1}{M^2} T_{\mu\nu}$$

Renormalization of a clock field coupled to low energy gravity

$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}|^2} \approx \frac{1}{\pi^\mu \pi^\mu - \alpha (h_{\mu\nu} \pi^\mu \pi^\nu)^2} \quad g_{\mu\nu} = \eta_{\mu\nu} - 1$$



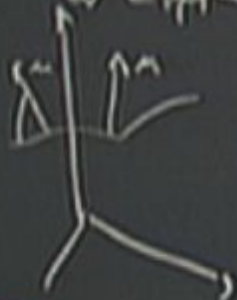
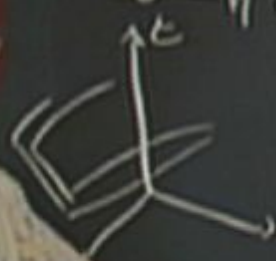
$$h_{\mu\nu} = g_{\mu\nu} + \eta_{\mu\nu}$$

Renormalization of a clock field coupled to low energy gravity

$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}|^2 \alpha} \approx \frac{1}{\pi_{\mu\nu} \pi^{\mu\nu} - \alpha (h_{\mu\nu} \pi^{\mu} \pi^{\nu})} c$$

$$g_{\mu\nu} = \eta_{\mu\nu} - 1$$

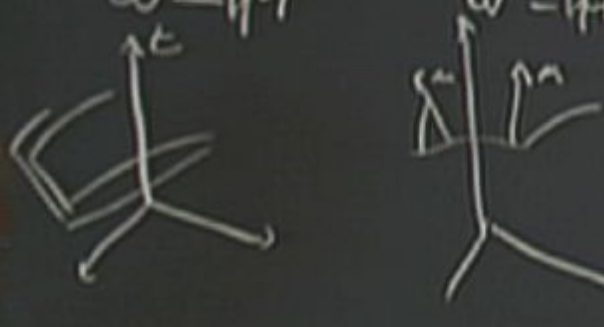
$$h_{\mu\nu} = g_{\mu\nu} + \eta_{\mu\nu}$$



$$M_{\mu\nu} = -N \partial_{\mu} \chi$$

$$\mathcal{F}_c = \{x_i, \chi(x) = c\}$$

Renormalization of a clock field coupled to low energy gravity

$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}|^2 \alpha} \approx \frac{1}{\pi^\mu \pi^\mu - \alpha (h_{\mu\nu} \pi^\mu \pi^\nu)} \quad \partial_{\mu\nu} \eta^{\mu\nu} = -1$$


$$h_{\mu\nu} = \eta_{\mu\nu} + \pi_{\mu\nu}$$

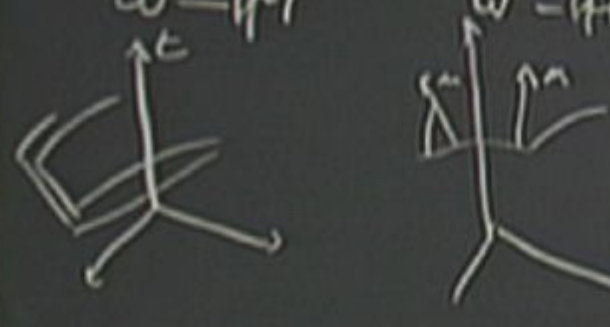
$$K_{\mu\nu} = \frac{1}{2} \mathcal{L}_m g_{\mu\nu} = D_\mu \partial_\nu \chi + D_\nu \partial_\mu \chi$$

$$M_{\mu\nu} = -N \partial_\mu \chi$$

$$\Sigma_c = \{x_i, \chi(x) = t\}$$

Renormalization of a clock field coupled to low energy gravity

$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}|^2} \approx \frac{1}{\pi_{\mu\nu} \pi^{\mu\nu} - \alpha (h_{\mu\nu} \pi^{\mu\nu})^2} \quad g_{\mu\nu} = \eta_{\mu\nu} - 1$$



$$M_{\mu\nu} = -N \partial_{\mu} \chi$$

$$\mathcal{H}_c = \left\{ x_i, \chi(x) = t \right\}$$

$$h_{\mu\nu} = g_{\mu\nu} + \eta_{\mu\nu}$$

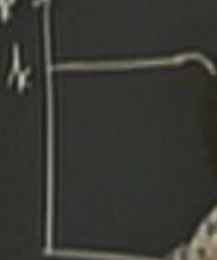
$$K_{\mu\nu} = \frac{1}{2} \partial_{\mu} g_{\nu\rho} = D_{\mu} \partial_{\nu} \chi + D_{\nu} \partial_{\mu} \chi$$

$$Z[\mathcal{T}] = \int \mathcal{D}\phi e^{-S + \int \mathcal{J}\phi - \int \phi^2 R_h(\tau)}$$

Horava 0901

Germani 090

$R_h(\tau)$



$$k \rightarrow 0 = \Gamma$$

$$\Gamma_{k \rightarrow \infty} = S_{\text{bare}}$$

$$Z[\mathcal{T}] = \int \mathcal{D}\phi e^{-S + \int \mathcal{J}\phi - \int \phi^2 R_k(\tau)}$$

Horava 0901

Germani 090

$R_k(\tau)$



$$\Gamma_{k=0} = \Gamma$$

$$\Gamma_{k \rightarrow \infty} = S_{\text{bare}}$$

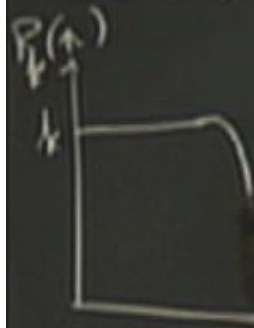
$$k) \frac{\partial \Gamma_k}{\partial k} = \frac{1}{2} \Gamma_k \left[\frac{k \frac{\partial R_k}{\partial k}}{\Gamma_k^{(2)} + R_k} \right]$$

$$Z[\mathcal{T}] = \int \mathcal{D}\phi e^{-S + \int \mathcal{J}\phi - \int \phi^2 R_h(\uparrow)}$$

Horava 09013775

Germani 0906.1201

$$\Gamma_{k=0} = \Gamma \quad \Gamma_{k \rightarrow \infty} = S_{\text{bare}}$$



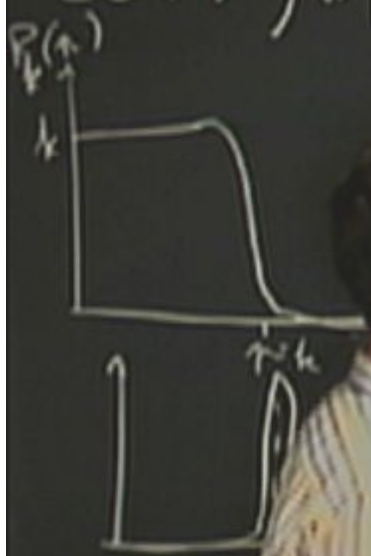
$$k) \frac{\partial}{\partial k} \Gamma_k = \frac{1}{2} \text{Tr} \left[\frac{k \frac{\partial}{\partial k} R_{1k}}{\Gamma_{1k}^{(1/2)} + R_{1k}} \right]$$

$$Z\{T\} = \int \mathcal{D}\phi e^{-S + \int \mathcal{J}\phi - \int \phi^2 R_k(\tau)}$$

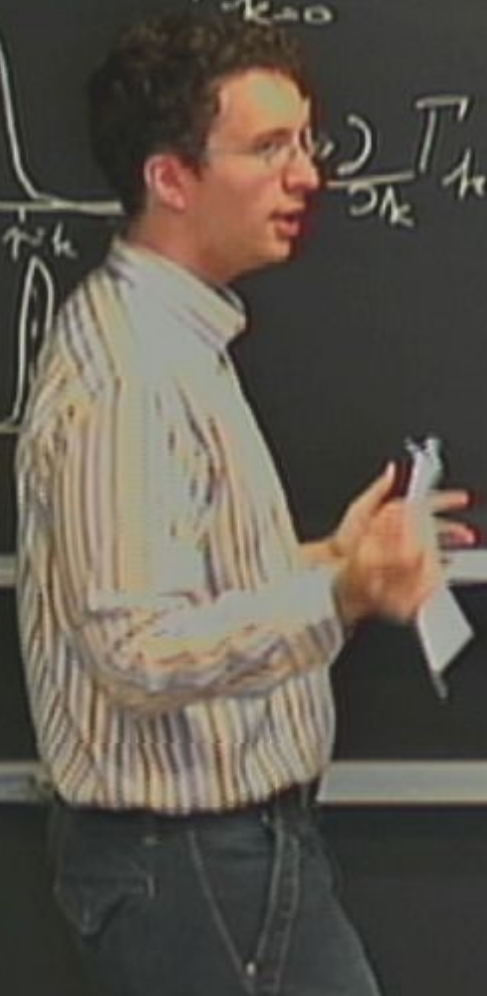
Horava 0901.3775

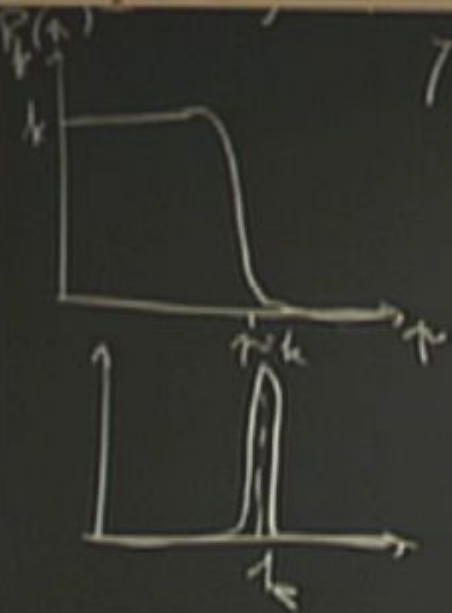
Germani 0906.1201

$$\Gamma_{k \rightarrow 0} = \Gamma \quad \Gamma_{k \rightarrow \infty} = S_{\text{bare}}$$



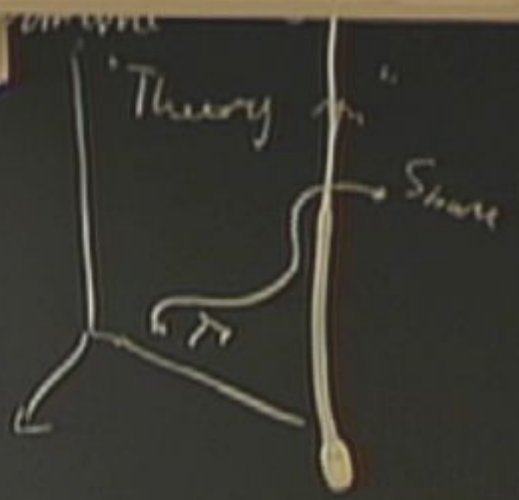
$$\frac{\partial}{\partial k} \Gamma_k = \frac{1}{2} \text{Tr} \left[\frac{1 + \frac{2}{5k} R_{1a}}{\Gamma_{1a}^{(2)} + R_k} \right]$$



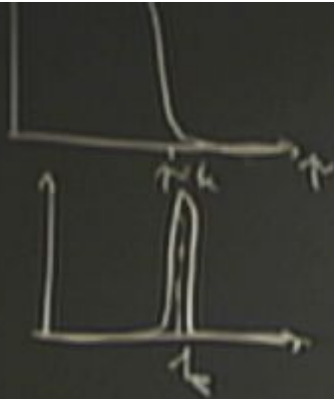


$$T_{k \rightarrow 0} = T_{k \rightarrow \infty}$$

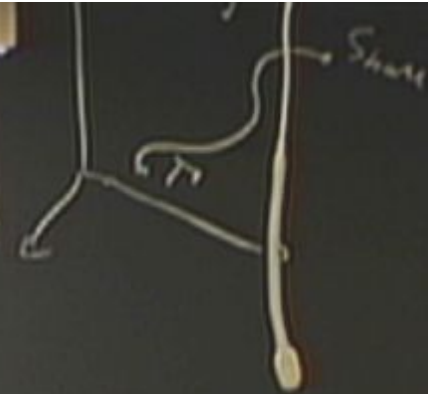
$$1) \frac{\partial T_{1k}}{\partial k} = \frac{1}{2} \text{Tr} \left[\frac{\frac{1}{2} \frac{\partial R_{1k}}{\partial k}}{T_{1k}^{(2)} + R_{1k}} \right]$$



$$T_{\kappa} = \int \phi (-\Delta + \mu \phi^2) \phi + \lambda \phi^4$$



$$1) \frac{\Gamma_{th}}{\omega_k} = \frac{1}{2} \text{Tr} \left[\frac{\frac{1}{2} \omega_k R_{th}}{\Gamma_{th} + \frac{1}{2} \omega_k R_{th}} \right]$$

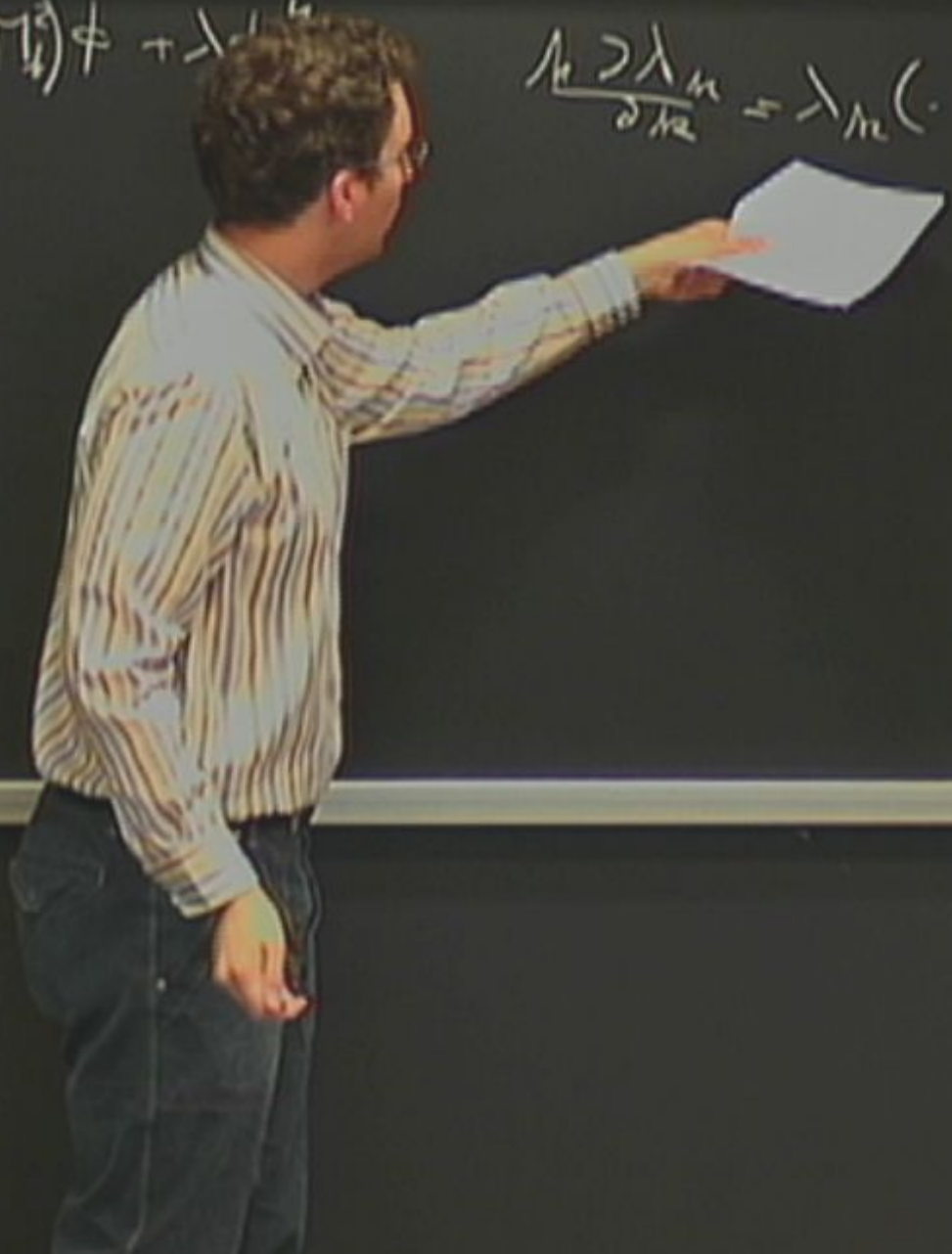


$$\Gamma_{th} = \int \phi (-D + M_{th}) \phi \quad \forall \phi^4$$



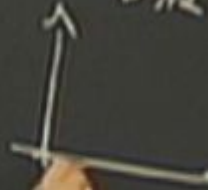
$$P_{\mu} = \int \phi (-D + M_{\mu}) \phi + \lambda \phi^4$$

$$\frac{\partial \lambda_{\mu}}{\partial \lambda} = \lambda_{\mu} (\dots)$$

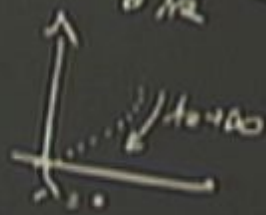


$$T_{\mu} = \int \phi (-D + M_{\mu}^2) \phi + \dots$$

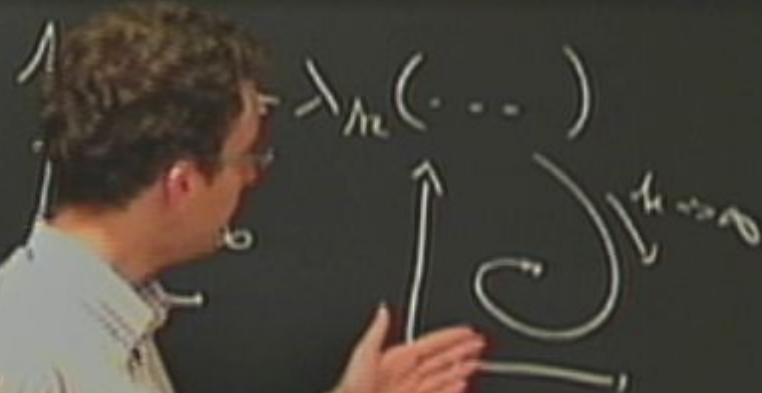
$$\frac{\partial \lambda_{\mu}}{\partial M_{\mu}^2} = \lambda_{\mu} (\dots)$$



$$P_{\mu} = \int \psi (-D + M_{\mu}^{\gamma}) \psi$$

$$\frac{\partial \lambda_{\mu}}{\partial M_{\mu}^{\gamma}} = \lambda_{\mu}(\dots)$$


$$P_{\mu} = \int \phi (-D + M_{\mu}) \phi + \lambda \phi^4$$



$$P_{\mu} = \int \phi (\nabla + iA_{\mu}) \phi + \lambda \phi^4$$

$$\frac{\delta P_{\mu}}{\delta A_{\mu}} = \lambda_{\mu} (\dots)$$

$$T_{\mu} = \int \phi (-\square + M^2) \phi + \lambda \phi^4$$

$$\frac{\partial \lambda_{\mu}}{\partial \mu} = \lambda_{\mu} (\dots)$$

The left diagram shows a coordinate system with a vertical axis and a horizontal axis. A dashed line starts from the origin and moves towards the upper right, with an arrow pointing to it labeled $\mu \rightarrow \infty$.

The right diagram shows a coordinate system with a vertical axis and a horizontal axis. A spiral line starts from the origin and winds outwards, with an arrow pointing to it labeled $\mu \rightarrow \infty$.

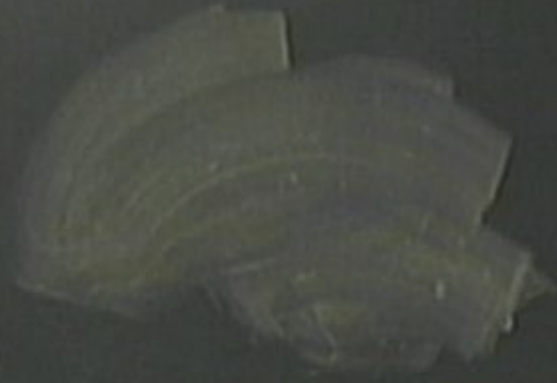
$$-\frac{1}{16\pi G} \int \sqrt{g} (R - 2\Lambda) +$$

$$-\frac{1}{16\pi G} \int d^4x \sqrt{|g|} \left(R - 2\Lambda + a_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} + b_{\mu\nu} D_{\rho} D_{\sigma} R^{\mu\nu\rho\sigma} + c_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} \right) + \text{const.}$$



$$-\frac{1}{16\pi G} \int \sqrt{g} \left(R - 2\Lambda + a_{\mu\nu} \nabla^{\mu} \nabla^{\nu} \phi + b_{\mu\nu} \nabla^{\mu} \nabla^{\nu} \psi + R_{\mu\nu} \nabla^{\mu} \nabla^{\nu} \chi \right) + \text{const.} -$$

$$+ m_{\mu\nu} \nabla^{\mu} \nabla^{\nu} \phi$$



clock field coupled to

$$-\frac{1}{2} \dot{\chi}^2 \approx \frac{1}{2} \left(\dot{\chi}^2 - \alpha (h_{\mu\nu} \dot{x}^\mu \dot{x}^\nu) \right)^2$$

$$g_{\mu\nu} \dot{x}^\mu \dot{x}^\nu = -1$$

$$D_\mu \dot{x}^\nu = D_\nu \dot{x}^\mu$$

$$h_{\mu\nu} = g_{\mu\nu} + \frac{m}{\mu} \frac{m}{\nu}$$

$$m_\mu = -N \partial_\mu \chi$$

$$\mathcal{F}_c = \{ x; \chi(x) = t \}$$

$$K_{\mu\nu} = \frac{1}{2} \partial_\mu g_{\nu\sigma} = D_\mu \partial_\nu \chi + D_\nu \partial_\mu \chi$$

$$-\frac{1}{16\pi G} \int \sqrt{g} (R - 2\Lambda + a_{\mu\nu\rho\sigma} \nabla^\mu \nabla^\nu \nabla^\rho \nabla^\sigma + b_{\mu\nu\rho\sigma} \nabla^\mu \nabla^\nu \nabla^\rho \nabla^\sigma + R_{\mu\nu\rho\sigma} \nabla^\mu \nabla^\nu \nabla^\rho \nabla^\sigma) + \text{const.}$$

$$M_{\mu\nu} = \partial_\mu \chi$$

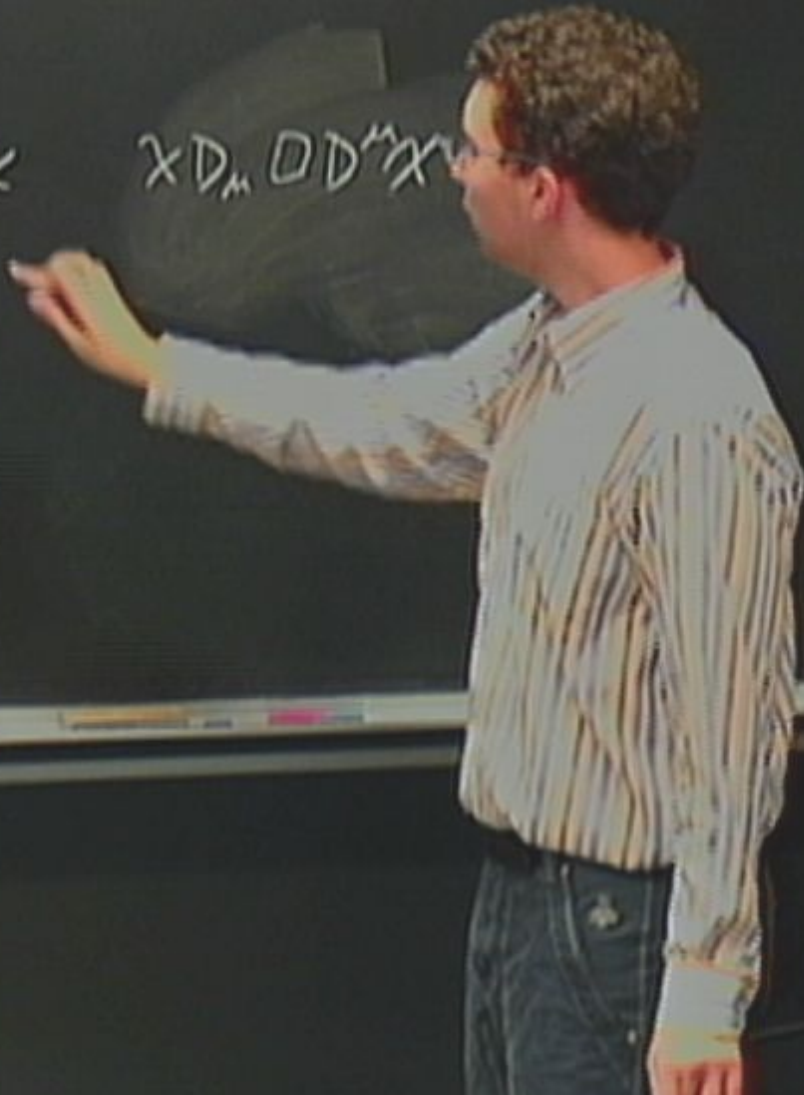


$$-\frac{1}{16\pi G} \int \sqrt{g} (R - 2\Lambda + \alpha_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} + \beta_{\mu\nu\rho\sigma} D_{\mu} D_{\nu} D_{\rho} D_{\sigma}) + \text{matter}$$

$$M_{\mu\nu} = \frac{\delta \mathcal{L}}{\delta g^{\mu\nu}}$$

$$\chi \square^2 \chi$$

$$\chi D_{\mu} \square D^{\mu} \chi$$



$$-\frac{1}{16\pi G_N} \int d^4x \sqrt{|g|} \left(R - 2\Lambda + a_{\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma} + b_{\mu\nu\rho\sigma} D_\mu D_\nu D_\rho D_\sigma + c_{\mu\nu\rho\sigma} R_{\mu\nu\rho\sigma} \right) + \text{matter}$$

$$M_{\mu\nu} = \partial_\mu \chi \partial_\nu \chi$$

$$\chi \square \chi$$

$$\chi D_\mu \square D^\mu \chi$$

$$\chi D^\mu R_{\mu\nu} D^\nu \chi$$

$$-\frac{1}{16\pi G_N} \int d^4x \sqrt{|g|} \left(R - 2\Lambda + a_{\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma} + b_{\mu\nu\rho\sigma} D_\mu D_\nu \tilde{F}^{\rho\sigma} + R_{\mu\nu} \tilde{F}^{\mu\nu} \right) + \text{counter-} \\ + M_{\mu\nu\rho\sigma} \tilde{F}^{\mu\nu} \tilde{F}^{\rho\sigma}$$

$$M_{\mu\nu} = \partial_\mu \chi$$

$$\chi \square$$

$$\chi D_\mu \square D^\mu \chi$$

$$\chi D^\mu R_{\mu\nu} D^\nu \chi$$

$$-\frac{1}{16\pi G} \int \sqrt{g} (R - 2\Lambda + \alpha_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} + \beta_{\mu\nu\rho\sigma} D_{\mu} D_{\nu} D_{\rho} D_{\sigma}) + \text{counter-} \\ + M_{\mu\nu\rho\sigma} D^{\mu} D^{\nu} D^{\rho} D^{\sigma}$$

$$M_{\mu\nu} = \partial_{\mu} \chi \quad \alpha_{\mu\nu\rho\sigma} \chi \square^2 \chi \approx \chi D_{\mu} \square D^{\mu} \chi \quad \chi D^{\mu} R_{\mu\nu} D^{\nu} \chi$$

$$-\frac{1}{16\pi G} \int d^4x \sqrt{|g|} \left(R - 2\Lambda + \alpha R^2 + \beta R_{\mu\nu} R^{\mu\nu} + \gamma R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} + \dots \right) + \text{matter}$$

$$M_{\mu\nu} = \partial_\mu \chi \quad \alpha R^2 \chi \approx \chi \square^2 \chi \approx \chi \square \square \chi \quad \chi \square R_{\mu\nu} \square \chi$$

Renormalization of a clock field coupled to low energy gravity

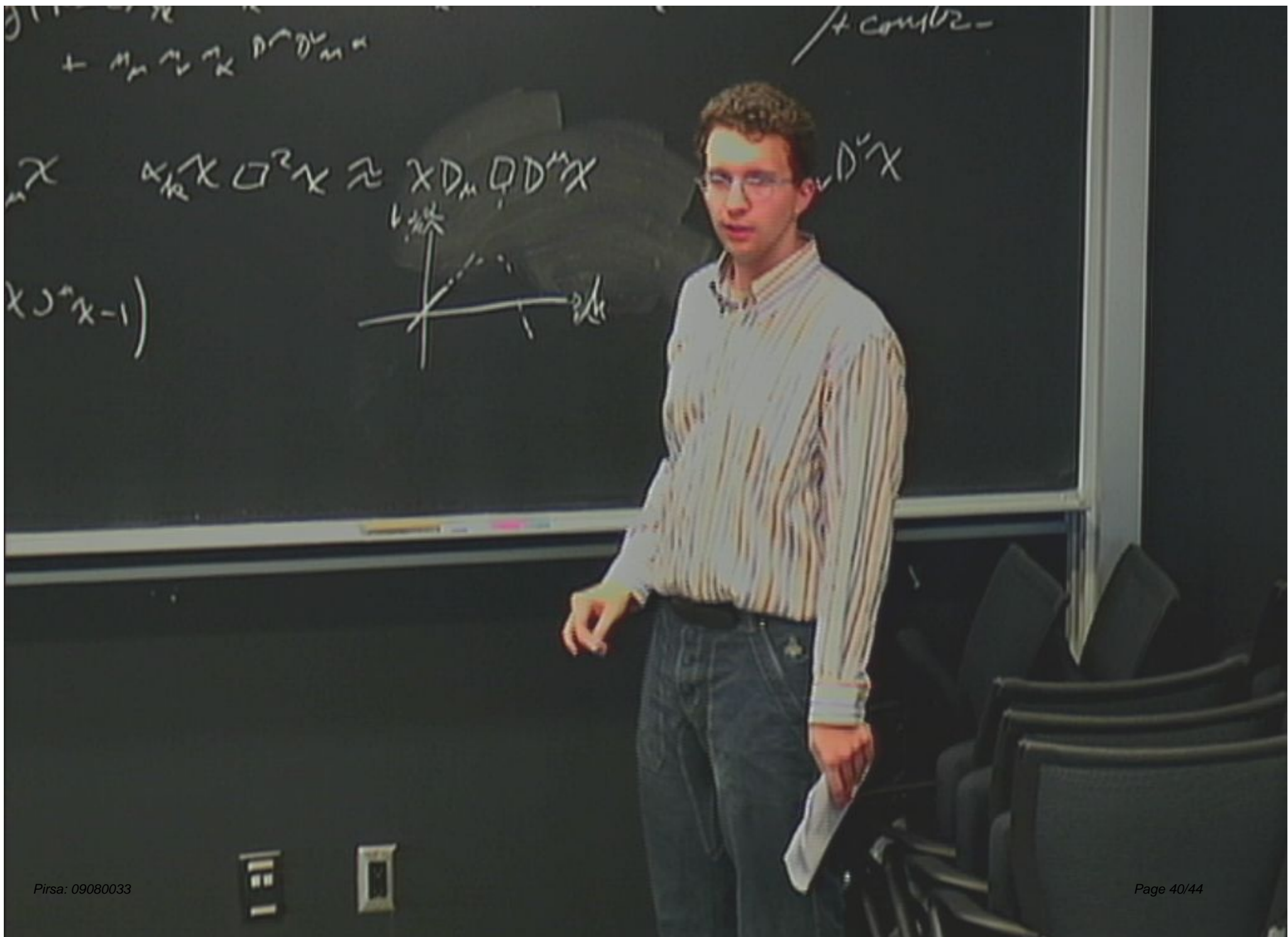
$$\frac{1}{\omega^2 - |\vec{p}|^2} \rightarrow \frac{1}{\omega^2 - |\vec{p}|^2 - |\vec{p}^0|^2} \approx \frac{1}{\pi_\mu \pi^\mu - \alpha (h_{\mu\nu} \pi^\mu \pi^\nu) c}$$

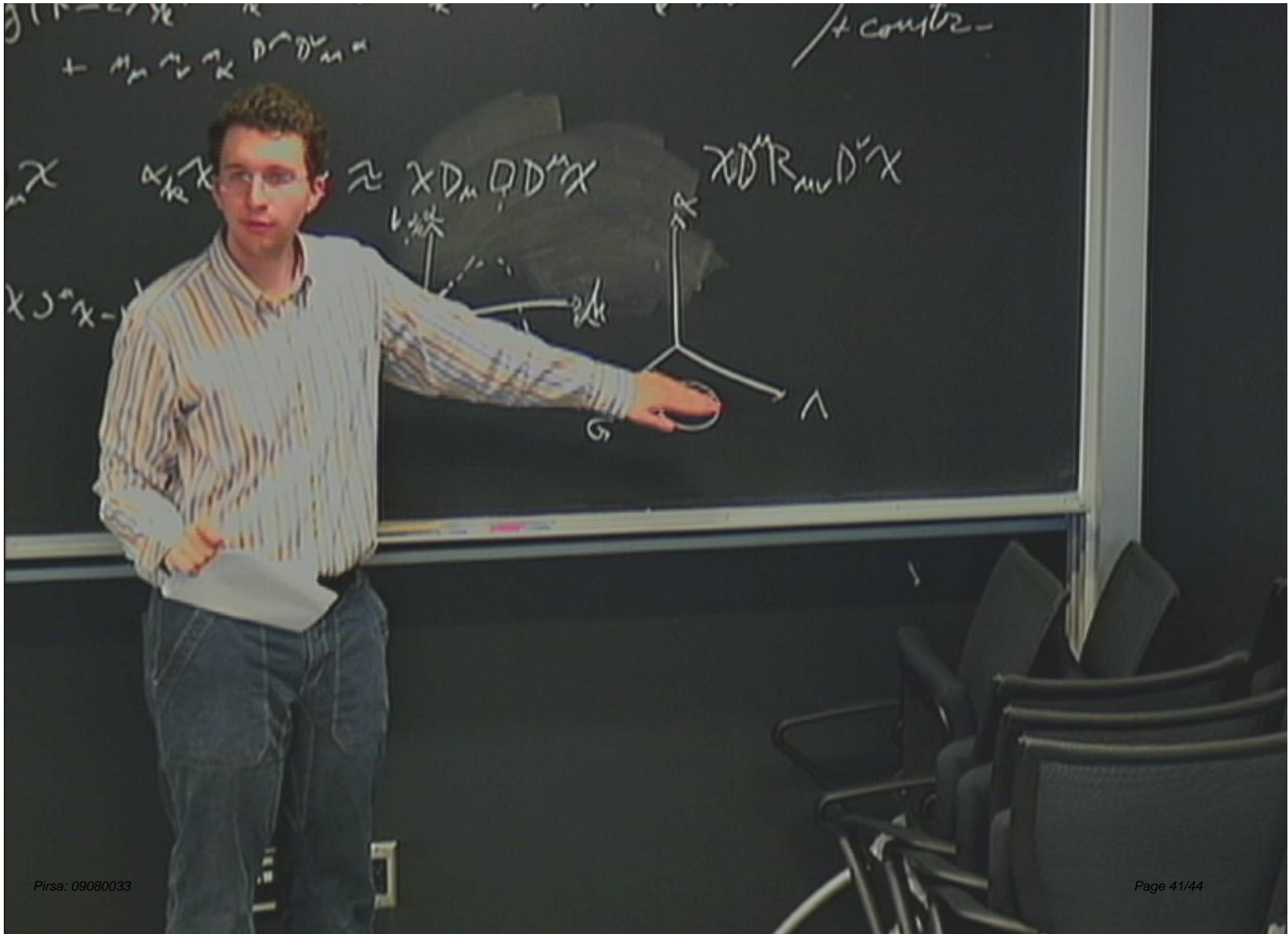
$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

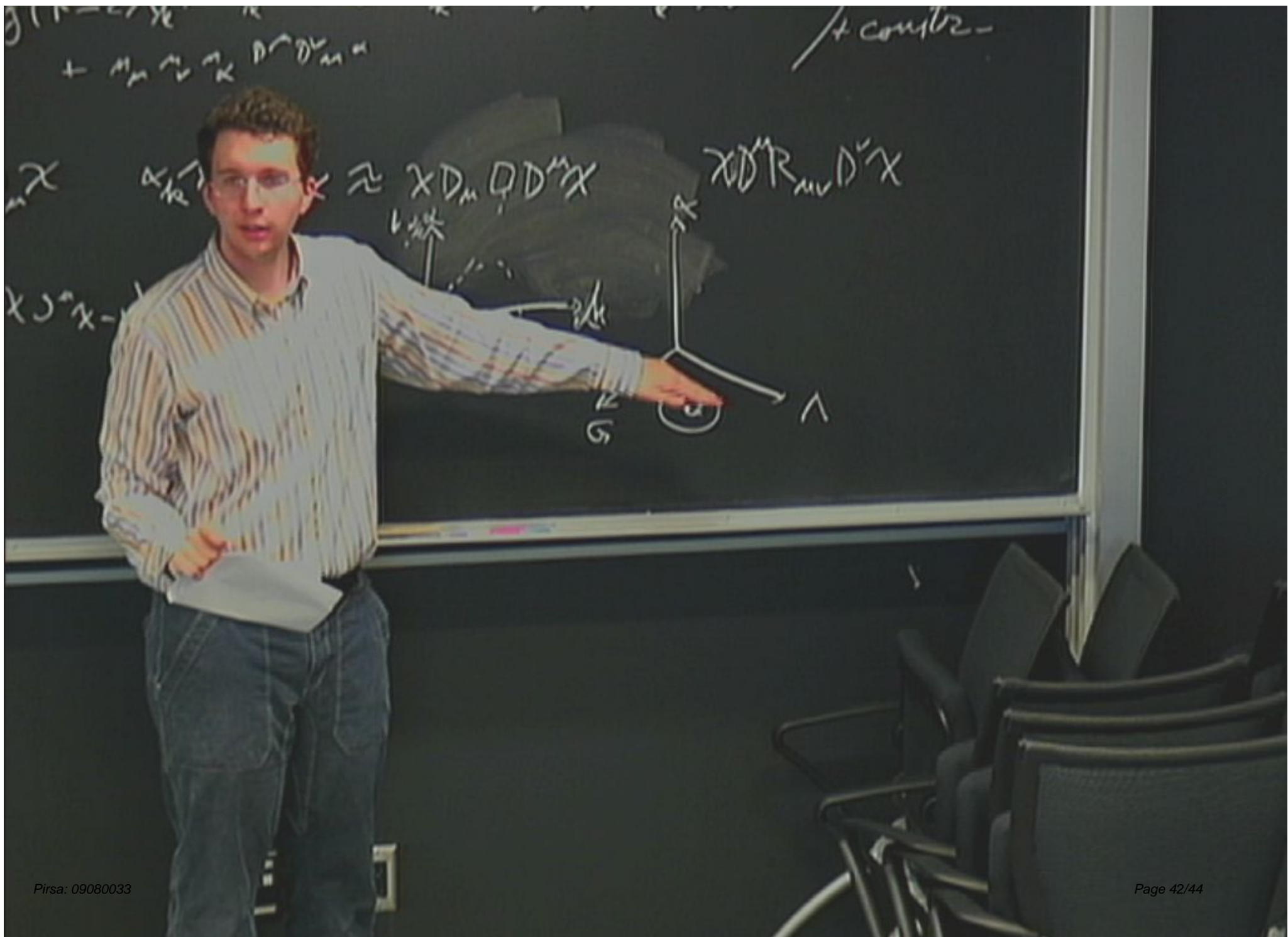
$$K_{\mu\nu} = \frac{1}{2} \frac{\delta S}{\delta g^{\mu\nu}} = D_\mu D_\nu \chi + \dots$$

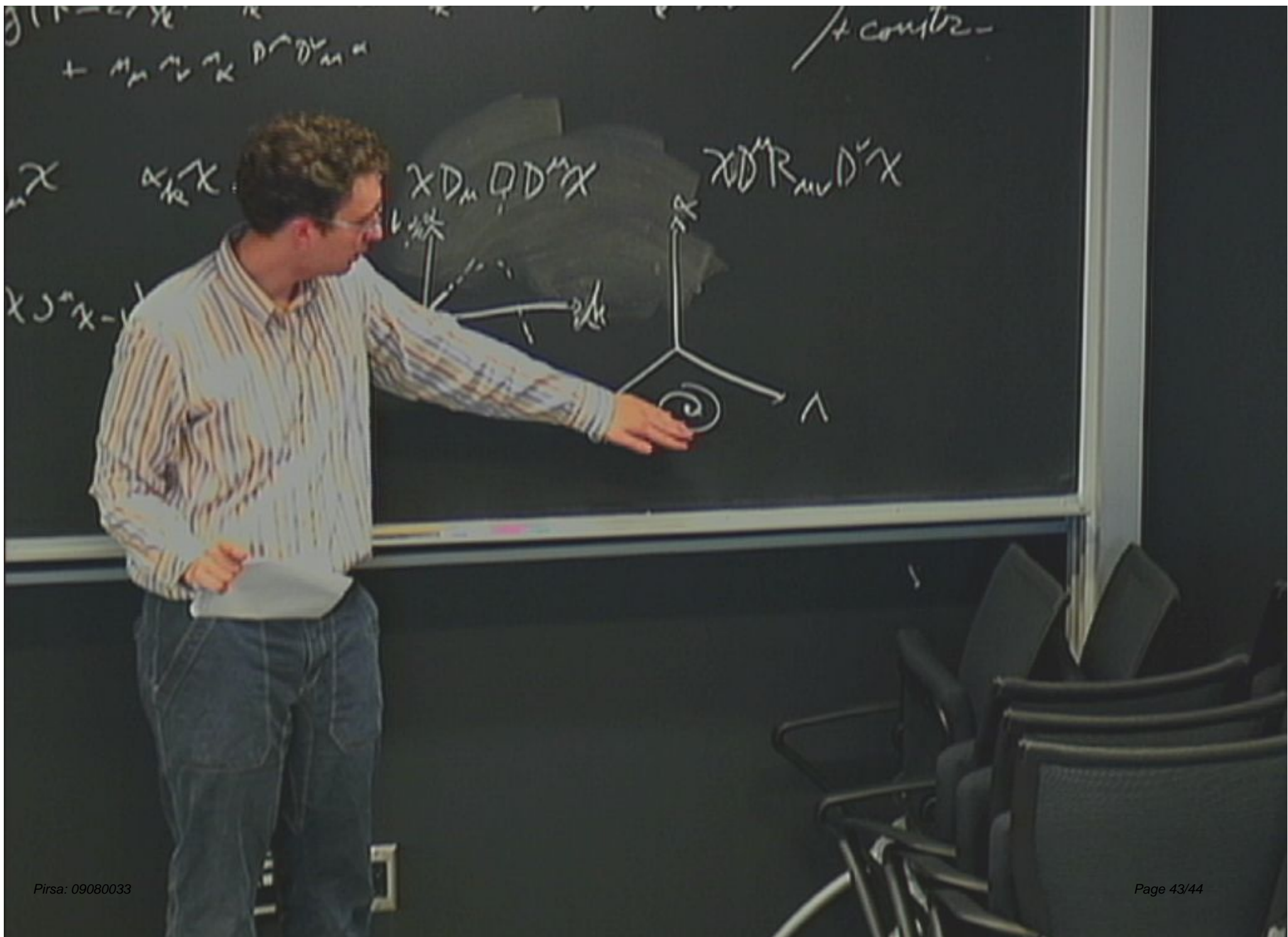
$$M_{\mu\nu} = -N \partial_\mu \chi$$

$$\mathcal{F}_c = \{x_i, \chi(x) = t\}$$









$g(x) = \dots$
 $+ m_1 m_2 \dots m_k D^{\alpha_1} D^{\alpha_2} \dots D^{\alpha_k} x$

$x \quad x D^{\alpha_1} x \approx x D^{\alpha_1} Q D^{\alpha_2} x \quad x D^{\alpha_1} R_{m_1} D^{\alpha_2} x$

$(x D^{\alpha_1} x - 1)$

