

Title: Cosmology and Black Holes in Massive Gravity

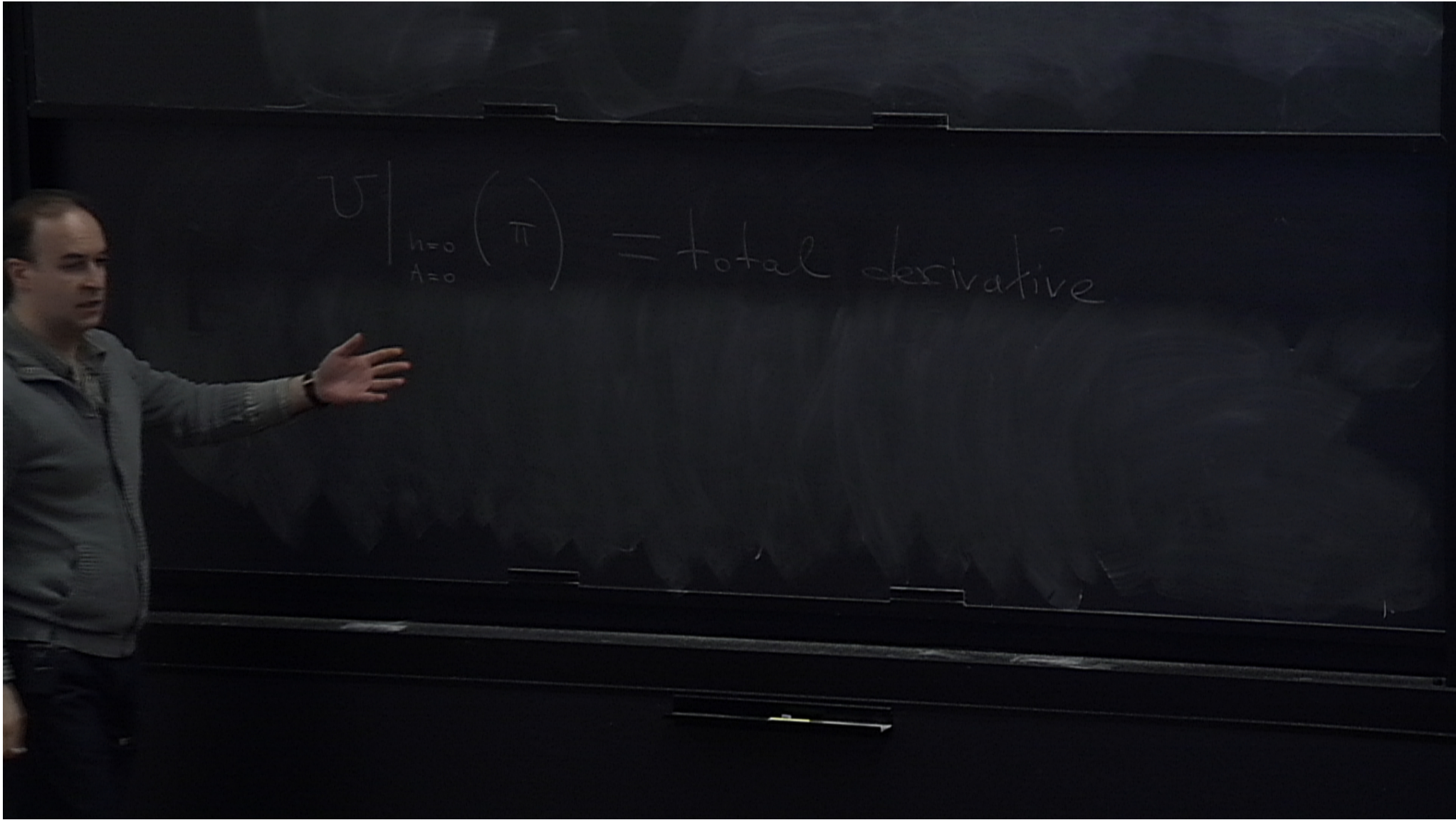
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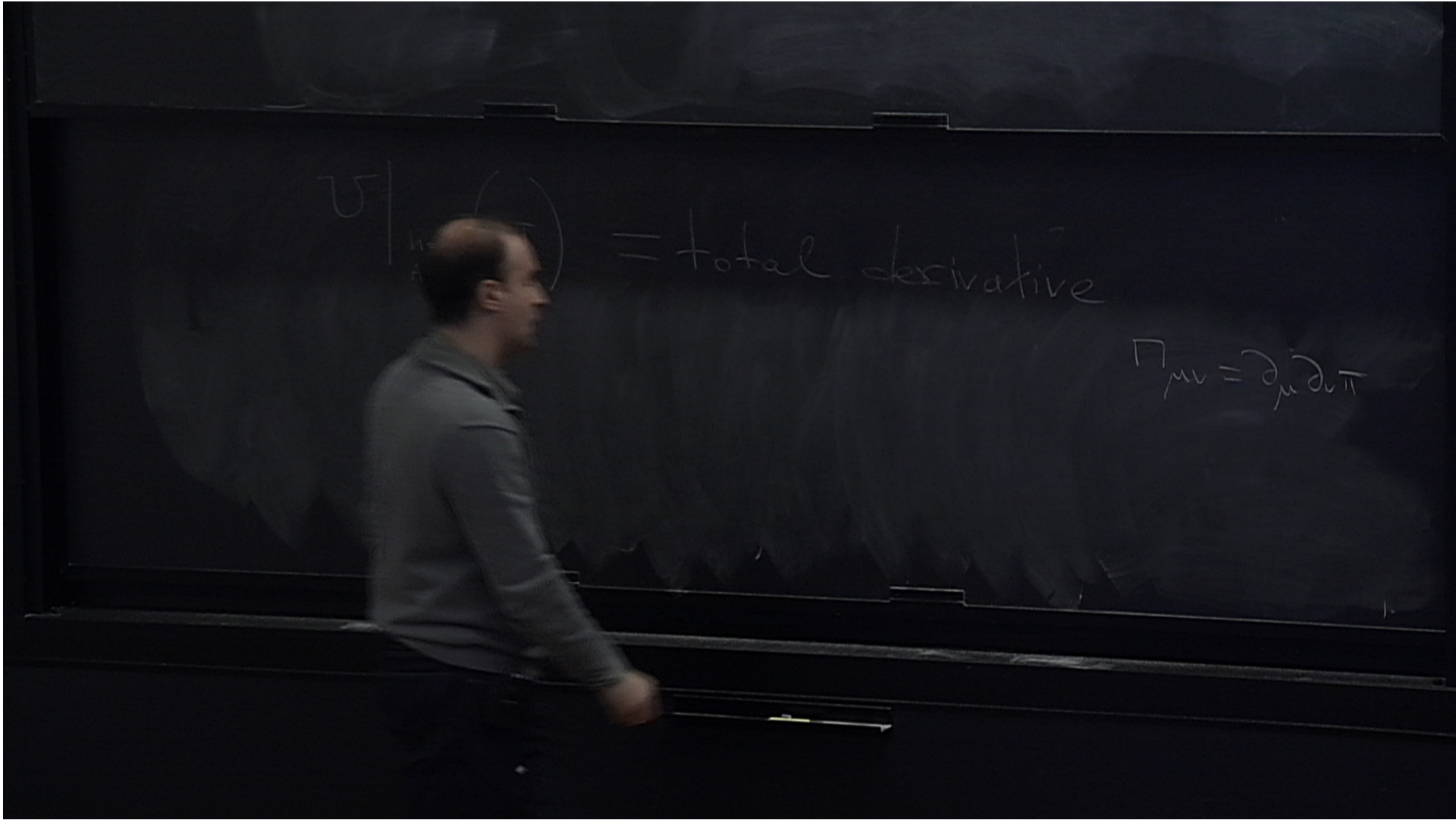
URL: <http://pirsa.org/12010168>

Abstract: For a long time it was believed that a classical nonlinear theory of a single massive spin-2 state does not exist.









$\mathcal{U} \Big|_{\substack{h=0 \\ A=0}} (\pi) = \text{total derivative}$

$$\mathcal{L}_2 = (\Box \pi)^2 - (\partial \partial \pi)^2 \sim \epsilon_{\mu\dots} \epsilon_{\nu\dots} \Pi_{\mu\nu}$$

$$\Pi_{\mu\nu} = \partial_\mu \partial_\nu \pi$$

$\mathcal{L} \Big|_{\substack{h=0 \\ A=0}} (\pi) = \text{total derivative}$

$$\mathcal{L}_2 = (\Box \pi)^2 - (\partial \partial \pi)^2 \sim \sum_{\mu\alpha} \dots \sum_{\nu\beta} \dots \Pi_{\mu\nu} \Pi_{\alpha\beta} \quad \Pi_{\mu\nu} = \partial_\mu \partial_\nu \pi$$

$\mathcal{L} \Big|_{\substack{h=0 \\ A=0}} (\pi) = \text{total derivative}$

$$\mathcal{L}_2 = (\Box \pi)^2 - (\partial_\mu \partial_\nu \pi)^2 \sim \epsilon_{\mu\alpha\dots} \epsilon_{\nu\beta\dots} \Pi_{\mu\nu} \Pi_{\alpha\beta} \quad \Pi_{\mu\nu} = \partial_\mu \partial_\nu \pi$$

$$\mathcal{U} \Big|_{\substack{h=0 \\ A=0}} (\pi) = \text{total derivative}$$

$$\mathcal{U}_2 = (\square \pi)^2 - (\partial_\mu \partial_\nu \pi)^2 \sim \epsilon_{\mu\alpha} \dots \epsilon_{\nu\beta} \dots \Pi_{\mu\nu} \Pi_{\alpha\beta} \quad \Pi_{\mu\nu} = \partial_\mu \partial_\nu \pi$$

$$\mathcal{U}_3 = (\square \pi)^3 - 3 \square \pi (\partial \partial \pi)^2 + 2 (\square \pi)^3 \sim \epsilon_{\mu\alpha\beta} \epsilon_{\nu\gamma\delta} \Pi_{\mu\nu} \Pi_{\alpha\beta} \Pi_{\gamma\delta}$$

$$\mathcal{U} \Big|_{\substack{h=0 \\ A=0}} (\pi) = \text{total derivative}$$

$$\mathcal{U}_2 = (\partial\pi)^2 - (\partial_\mu\partial_\nu\pi)^2 \sim \epsilon_{\mu\alpha\dots}\epsilon_{\nu\beta\dots} \Pi_{\mu\nu} \Pi_{\alpha\beta} \quad \Pi_{\mu\nu} = \partial_\mu\partial_\nu\pi$$

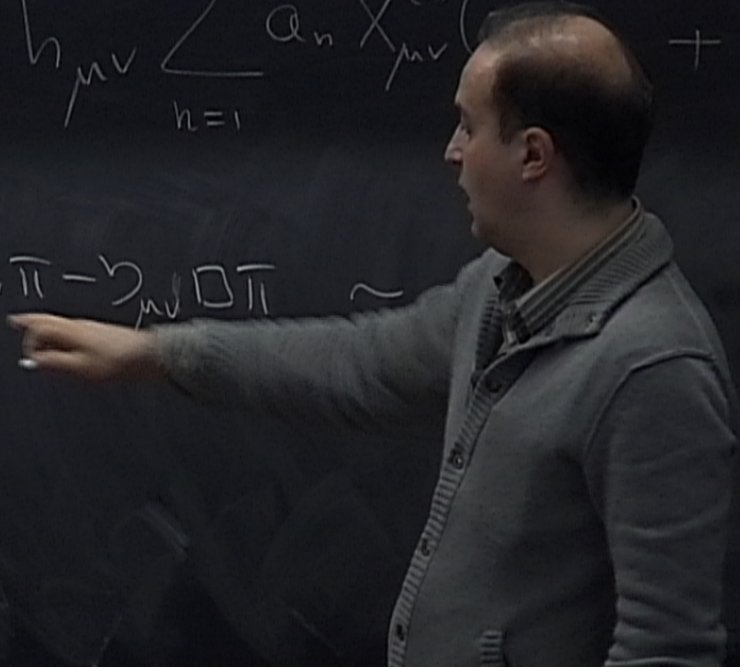
$$\mathcal{U}_3 = (\partial\pi)^3 - 3\partial\pi(\partial\partial\pi)^2 + 2(\partial\partial\pi)^3 \sim \epsilon_{\mu\alpha\beta\dots}\epsilon_{\nu\gamma\delta\dots} \Pi_{\mu\nu} \Pi_{\alpha\beta} \Pi_{\gamma\delta}$$

$$\mathcal{U}_4 = ((\partial\pi)^4 + \dots) \sim \epsilon_{\mu\alpha\beta\gamma\dots}\epsilon_{\nu\delta\epsilon\zeta\dots} \Pi_{\mu\nu} \Pi_{\alpha\beta} \Pi_{\gamma\delta} \Pi_{\epsilon\zeta}$$

$$\mathcal{L}_{\text{dec}} = -\frac{1}{2}(\dot{h} \hat{E} \dot{h}) + h_{\mu\nu} \sum_{n=1}^3 a_n X_{\mu\nu}^{(n)}(\pi) + h_{\mu\nu} T^{\mu\nu}$$

$$\mathcal{L}_{\text{dec}} = -\frac{1}{2}(\dot{h}\hat{E}h) + h_{\mu\nu} \sum_{n=1}^3 a_n X_{\mu\nu}^{(n)} + h_{\mu\nu} T^{\mu\nu}$$

$$X_{\mu\nu}^{(1)} = \partial_\mu \partial_\nu \pi - \eta_{\mu\nu} \square \pi \sim$$



$$\mathcal{L}_{\text{dec}} = -\frac{1}{2}(\dot{h}\hat{E}h) + h_{\mu\nu} \sum_{n=1}^3 a_n X_{\mu\nu}^{(n)} + h_{\mu\nu} T^{\mu\nu}$$

$$X_{\mu\nu}^{(1)} = \partial_\mu \partial_\nu \pi - \eta_{\mu\nu} \square \pi \sim$$

$$\mathcal{L} = -\frac{1}{2}(\dot{h} \hat{E} h) + h_{\mu\nu} \sum_{n=1}^3 a_n X_{\mu\nu}^{(n)}(\pi) + h_{\mu\nu} T^{\mu\nu}$$

$$\mathcal{L}^{(1)} = \partial_\mu \partial_\nu \pi - \eta_{\mu\nu} \square \pi \sim \epsilon_{\mu\alpha\nu} \epsilon_{\rho\beta\gamma} \Pi_{\alpha\rho}$$

$$\mathcal{L} = -\frac{1}{2}(\dot{h}\hat{E}h) + h_{\mu\nu} \sum_{n=1}^3 a_n X_{\mu\nu}^{(n)}(\pi) + h_{\mu\nu} T^{\mu\nu}$$

$$X_{\mu\nu}^{(1)} = \partial_\mu \partial_\nu \pi - \eta_{\mu\nu} \square \pi \sim \epsilon_{\mu\alpha\beta} \epsilon_{\nu\rho\delta} \Pi_{\alpha\rho} \Pi_{\beta\delta}$$

$$" \quad " \quad " \sim \epsilon_{\mu\alpha\rho} \epsilon_{\nu\rho\delta} \Pi_{\alpha\beta} \Pi_{\beta\delta}$$

$$\mathcal{L}_{\text{dec}} = -\frac{1}{2}(\dot{h}\hat{E}h) + h_{\mu\nu} \sum_{n=1}^3 a_n X_{\mu\nu}^{(n)}(\pi) + h_{\mu\nu} T^{\mu\nu}$$

$$X_{\mu\nu}^{(1)} = \partial_\mu \partial_\nu \pi - \eta_{\mu\nu} \square \pi \sim \epsilon_{\mu\alpha\nu} \epsilon_{\nu\rho\sigma} \Pi_{\alpha\rho}$$

$$X_{\mu\nu}^{(2)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho} \epsilon_{\nu\rho\sigma} \Pi_{\alpha\sigma} \Pi_{\rho\delta}$$

$$X_{\mu\nu}^{(3)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho} \epsilon_{\nu\rho\sigma} \Pi_{\alpha\lambda} \Pi_{\rho\delta} \Pi_{\lambda\epsilon}$$

$$\mathcal{L}_{\text{dec}} = \frac{1}{2} (\hat{E}h)^2 + h_{\mu\nu} \sum_{n=1}^3 a_n X_{\mu\nu}^{(n)}(\pi) + h_{\mu\nu} T^{\mu\nu}$$

$$a_1 = 1$$

$$\begin{aligned} \eta^{\alpha\beta} \partial_\nu \pi - \gamma_{\mu\nu} \square \pi &\sim \epsilon_{\mu\alpha\nu} \epsilon_{\nu\rho\sigma} \Pi_{\alpha\rho} \\ \text{"} &\sim \epsilon_{\mu\alpha\rho} \epsilon_{\nu\rho\sigma} \Pi_{\alpha\sigma} \Pi_{\rho\delta} \\ \text{"} &\sim \epsilon_{\mu\alpha\rho} \epsilon_{\nu\rho\sigma} \Pi_{\alpha\sigma} \Pi_{\rho\delta} \Pi_{\lambda\epsilon} \end{aligned}$$

$$\mathcal{L}_{dec} = -\frac{1}{2}(hEb) + h_{\mu\nu} \sum_{k=1}^{\infty} a_k \chi_{\mu\nu}^{(k)} + h_{\mu\nu} T^{\mu\nu}$$

$$\chi_{\mu\nu}^{(1)} = \partial_{\mu} \partial_{\nu} \pi - \eta_{\mu\nu} \square \pi \sim \epsilon_{\mu\alpha\kappa} \epsilon_{\nu\rho\lambda} \Pi_{\alpha\rho} \Pi_{\lambda\kappa}$$

$$\chi_{\mu\nu}^{(2)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho\lambda} \epsilon_{\nu\rho\sigma\kappa} \Pi_{\alpha\lambda} \Pi_{\rho\sigma} \Pi_{\kappa\tau}$$

$$\chi_{\mu\nu}^{(3)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho\lambda} \epsilon_{\nu\rho\sigma\kappa} \Pi_{\alpha\lambda} \Pi_{\rho\sigma} \Pi_{\kappa\tau}$$

$$a_1 = 1$$

$$a_2 = 6c_3 - 1$$

$$a_3 = c_3 + 8d_5$$

$$\mathcal{L}_{\text{dec}} = -\frac{1}{2}(h\hat{E}h) + h_{\mu\nu} \sum_{n=1} a_n X_{\mu\nu}^{(n)}(\pi) +$$

$$h_{\mu\nu} T^{\mu\nu}$$

$$\pi \rightarrow \pi + c_3 X_{\mu\nu} + c$$

$$X_{\mu\nu}^{(1)} = \partial_\mu \partial_\nu \pi - \eta_{\mu\nu} \square \pi \sim \epsilon_{\mu\alpha\beta} \epsilon_{\nu\rho\sigma} \Pi_{\alpha\beta}$$

$$X_{\mu\nu}^{(2)} = \text{"} \sim \epsilon_{\mu\alpha\beta\gamma} \epsilon_{\nu\rho\sigma\delta} \Pi_{\alpha\beta} \Pi_{\gamma\delta}$$

$$X_{\mu\nu}^{(3)} = \text{"} \sim \epsilon_{\mu\alpha\beta\gamma\delta} \epsilon_{\nu\rho\sigma\tau\epsilon} \Pi_{\alpha\beta} \Pi_{\gamma\delta} \Pi_{\tau\epsilon}$$

$$a_1 = 1$$

$$a_2 = 6c_3 - 1$$

$$a_3 = c_3 + 8d_5$$

$$\mathcal{L}_{\text{dec}} = -\frac{1}{2}(h\hat{E}h) + h_{\mu\nu} \sum_{n=1} a_n X_{\mu\nu}^{(n)}(\pi) + h_{\mu\nu} T^{\mu\nu}$$

$$\pi \rightarrow \pi + c_3 X_{\mu\nu} + c$$

$$X_{\mu\nu}^{(1)} = \partial_\mu \partial_\nu \pi - \eta_{\mu\nu} \square \pi \sim \epsilon_{\mu\alpha\beta} \epsilon_{\nu\rho\gamma} \Pi_{\alpha\beta}$$

$$X_{\mu\nu}^{(2)} = \text{"} \sim \epsilon_{\mu\alpha\beta\gamma} \epsilon_{\nu\rho\delta} \Pi_{\alpha\beta} \Pi_{\gamma\delta}$$

$$X_{\mu\nu}^{(3)} = \text{"} \sim \epsilon_{\mu\alpha\beta\gamma} \epsilon_{\nu\rho\delta\epsilon} \Pi_{\alpha\beta} \Pi_{\gamma\delta} \Pi_{\epsilon\zeta}$$

$$\begin{aligned} a_1 &= 1 \\ a_2 &= 6c_3 - 1 \\ a_3 &= c_3 + 8d_5 \end{aligned}$$

$$\mathcal{L}_{\text{dec}} = -\frac{1}{2}(\dot{h}\hat{E}h) + h_{\mu\nu} \sum_{n=1} a_n X_{\mu\nu}^{(n)}(\pi) + h_{\mu\nu} T^{\mu\nu}$$

$$\pi \rightarrow \pi + c_{\mu\nu} X_{\mu\nu} + c$$

$$m \rightarrow 0 \quad X_{\mu\nu}^{(1)} = \partial_\mu \partial_\nu \pi - \eta_{\mu\nu} \square \pi \sim \epsilon_{\mu\alpha\beta} \epsilon_{\nu\rho\gamma} \Pi_{\alpha\rho\beta}$$

$$X_{\mu\nu}^{(2)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho} \epsilon_{\nu\rho\beta} \Pi_{\alpha\beta\gamma} \Pi_{\rho\delta}$$

$$X_{\mu\nu}^{(3)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho} \epsilon_{\nu\rho\beta} \Pi_{\alpha\gamma} \Pi_{\rho\delta} \Pi_{\gamma\delta}$$

$$a_1 = 1$$

$$a_2 = 6c_3 - 1$$

$$a_3 = c_3 +$$

$$\mathcal{L}_{\text{dec}} = -\frac{1}{2}(\hat{h}\hat{E}h) + h_{\mu\nu} \sum_{n=1} a_n X_{\mu\nu}^{(n)}(\pi) + h_{\mu\nu} T^{\mu\nu}$$

$$\pi \rightarrow \pi + \omega_{\mu} X^{\mu} + c$$

$$M \rightarrow 0 \quad X_{\mu\nu}^{(1)} = \partial_{\mu} \partial_{\nu} \pi - \eta_{\mu\nu} \square \pi \sim \epsilon_{\mu\alpha\beta} \epsilon_{\nu\rho\gamma} \Pi_{\alpha\rho\beta}$$

$$M_p \rightarrow \infty \quad X_{\mu\nu}^{(2)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho\gamma} \epsilon_{\nu\rho\delta\gamma} \Pi_{\alpha\beta\gamma} \Pi_{\rho\delta\gamma}$$

$$X_{\mu\nu}^{(3)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho\gamma} \epsilon_{\nu\rho\delta\gamma} \Pi_{\alpha\beta\gamma} \Pi_{\rho\delta\gamma} \Pi_{\mu\gamma}$$

$$a_1 = 1$$

$$a_2 = 6c_3 - 1$$

$$a_3 = c_3 +$$

$$U \Big|_{\substack{n=0 \\ A=0}} (\pi) = \text{total derivative} \quad \mathcal{L}_5 = \mathcal{L}_4 M_P$$

$$\mathcal{L}_2 = (\Box \pi)^2 - (\partial_\mu \partial_\nu \pi)^2 \sim \epsilon^{\mu\nu\alpha\beta} \Pi_{\alpha\beta}$$

$$\mathcal{L}_3 = (\Box \pi)^3 - 3 \Box \pi (\partial \partial \pi)^2 + 2 (\partial \partial \pi)^3$$

$$\mathcal{L}_4 = ((\Box \pi)^4 + \dots)$$

$$\Gamma_{\mu\nu} = \partial_\mu \partial_\nu \pi$$

$$\epsilon^{\mu\nu\alpha\beta} \Pi_{\alpha\beta}$$

$$\epsilon^{\mu\nu\alpha\beta\gamma} \Pi_{\mu\nu} \Pi_{\alpha\beta} \Pi_{\gamma\delta}$$

$$\epsilon^{\mu\nu\alpha\beta\gamma\delta} \Pi_{\mu\nu} \Pi_{\alpha\beta} \Pi_{\gamma\delta} \Pi_{\epsilon\zeta}$$

$\mathcal{L} \Big|_{\substack{h=0 \\ A=0}} (\pi) = \text{total derivative}$

$\mathcal{L}_2 = (\partial \pi)^2$

$\mathcal{L}_3 =$

$\mathcal{L}_4 =$

$\epsilon_{\mu\alpha\beta\gamma} \epsilon_{\nu\rho\sigma\tau} \Pi_{\mu\nu} \Pi_{\alpha\rho}$

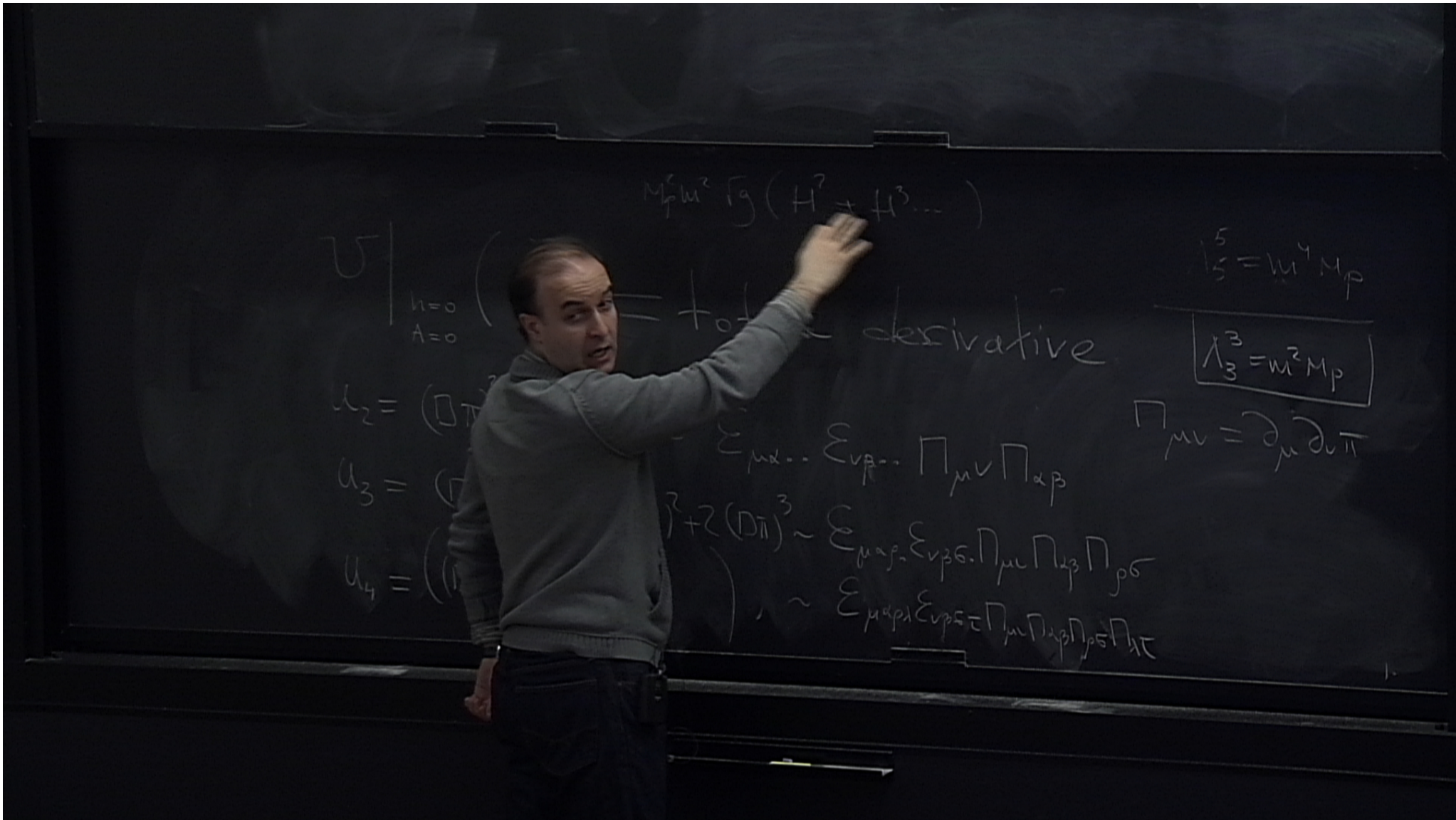
$(\partial \pi)^3 \sim \epsilon_{\mu\alpha\beta\gamma} \epsilon_{\nu\rho\sigma\tau} \Pi_{\mu\alpha} \Pi_{\beta\gamma} \Pi_{\rho\sigma}$

$\sim \epsilon_{\mu\alpha\rho\tau} \epsilon_{\nu\beta\sigma\gamma} \Pi_{\mu\nu} \Pi_{\alpha\beta} \Pi_{\rho\sigma} \Pi_{\gamma\tau}$

$\Lambda_5 = m^4 M_p$

$\Lambda_3 = m^2 M_p$

$\Pi_{\mu\nu} = \partial_\mu \partial_\nu \pi$



$$M_p^2 m^2 f_g (H^2 + H^3 \dots)$$

$$U|_{\substack{h=0 \\ A=0}}$$

derivative

$$\Lambda_5 = m^4 M_p$$

$$\Lambda_3 = m^2 M_p$$

$$\Pi_{\mu\nu} = \partial_\mu \partial_\nu \pi$$

$$u_2 = (D\pi)^2$$

$$u_3 = (D\pi)^3$$

$$u_4 = (D\pi)^4$$

$$\sum_{\mu\alpha} \sum_{\nu\beta} \Pi_{\mu\nu} \Pi_{\alpha\beta}$$

$$+ 2(D\pi)^3 \sim \sum_{\mu\alpha\beta} \sum_{\nu\gamma\delta} \Pi_{\mu\alpha} \Pi_{\nu\beta} \Pi_{\gamma\delta}$$

$$\sim \sum_{\mu\alpha\rho\lambda} \sum_{\nu\beta\sigma\tau} \Pi_{\mu\alpha} \Pi_{\nu\beta} \Pi_{\rho\sigma} \Pi_{\lambda\tau}$$

$$\mathcal{L}_{\text{dec}} = -\frac{1}{2}(h\hat{E}h) + h_{\mu\nu} \sum_{n=1} a_n X_{\mu\nu}^{(n)}(\pi) + h_{\mu\nu} T^{\mu\nu}$$

$$\pi \rightarrow \pi + \omega_\mu X^\mu + c$$

$$X_{\mu\nu}^{(1)} = \partial_\mu \partial_\nu \pi - \eta_{\mu\nu} \square \pi \sim \epsilon_{\mu\alpha\beta} \epsilon_{\nu\rho\gamma} \Pi_{\alpha\rho}$$

$M \rightarrow 0$

$M_p \rightarrow \infty$

$$X_{\mu\nu}^{(2)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho\gamma} \epsilon_{\nu\rho\delta\gamma} \Pi_{\alpha\beta} \Pi_{\rho\delta}$$

$$X_{\mu\nu}^{(3)} = \text{"} \text{"} \sim \epsilon_{\mu\alpha\rho\gamma} \epsilon_{\nu\rho\delta\gamma} \Pi_{\alpha\beta} \Pi_{\rho\delta} \Pi_{\beta\gamma}$$

$$a_1 = 1$$

$$a_2 = \frac{6c_3 - 1}{13}$$

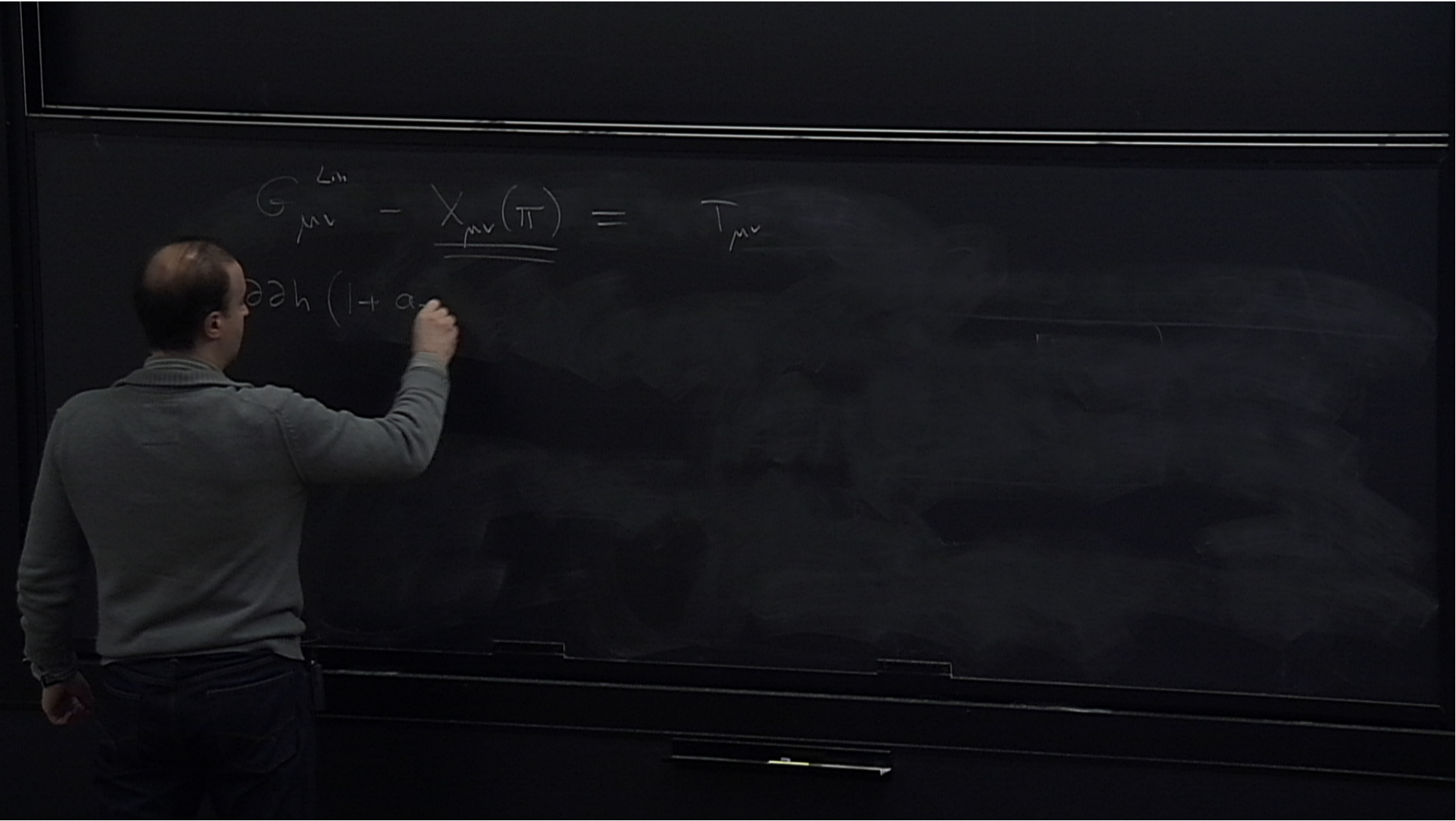
$$a_3 = \frac{c_3 + 1}{13}$$

$$G_{\mu\nu}^{\text{Lin}} - X_{\mu\nu}(\pi)$$

$$G_{\mu\nu}^{\text{Lin}} - X_{\mu\nu}(\pi) = T_{\mu\nu}$$

$$G_{\mu\nu}^{\text{Lin}} - \underline{\underline{X_{\mu\nu}(\pi)}} = T_{\mu\nu}$$





$$\left[\begin{array}{l} G_{\mu\nu}^{\text{Lin}} - \underline{\underline{X_{\mu\nu}(\pi)}} = T_{\mu\nu} \\ \partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^2\pi)^3) = 0 \end{array} \right.$$

$$\left[\begin{aligned} \mathcal{G}_{\mu\nu}^{\mathcal{L}_m} - \underline{\underline{X_{\mu\nu}(\pi)}} &= T_{\mu\nu} \\ \partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^2\pi)^3) &= 0 \\ \pi &= q X_\alpha^2 \end{aligned} \right.$$

$$G_{\mu\nu}^{\text{Lin}} - \underline{X_{\mu\nu}(\pi)} = T_{\mu\nu}$$

$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^2\pi)^3) = 0$$

$$\pi = g_{\text{SO}(2)} X_\alpha^2$$

$$X_{\mu\nu} \Big|_{\pi_{\text{SO}(2)}} = \eta_{\mu\nu} \Lambda_3^3$$

$$G_{\mu\nu}^{Lin} - \frac{X_{\mu\nu}(\pi)}{5\alpha_2} = T_{\mu\nu}$$

$$\partial\partial h (1 + \alpha_2 \pi^2 + \alpha_3 (\partial^2 \pi)^2) = 0$$

$$\pi = \frac{9}{5\alpha_2} X_{\alpha}^2$$

$$X_{\mu\nu} \Big|_{\pi_{5\alpha_2}} = \eta_{\mu\nu} \Lambda_3^3$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$G_{\mu\nu}^{\text{Lin}} - \underline{X_{\mu\nu}(\pi)} = T_{\mu\nu}$$

$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^2\pi)^3) = 0$$

$$\pi_{\text{SOS}} = g X_\alpha^2$$

$$X_{\mu\nu} \Big|_{\pi_{\text{SOS}}} = \eta_{\mu\nu} \Lambda_3^3$$

$$ds^2 = (1 - H^2 X_\mu^2) (dX^\alpha)^2$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$G_{\mu\nu}^{\text{Lin}} - \underline{X_{\mu\nu}(\pi)} = T_{\mu\nu}$$

$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + \dots) = 0$$

$$\pi_{\text{SOS}} = q$$

$$X_{\mu\nu} / \pi_{\text{SOS}} = \eta_{\mu\nu} \Lambda_3^3$$

$$ds^2 = (1 - \dots)$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_\alpha + \varphi$$

$$\left(\dots \right) h_{\mu\nu} (\partial\partial\varphi - \eta_{\mu\nu} D\varphi)$$

$$G_{\mu\nu}^{\text{Lin}} - \underline{X_{\mu\nu}(\pi)} = T_{\mu\nu}$$

$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^2\pi)^3) = 0$$

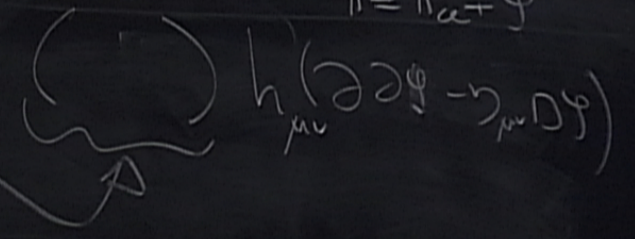
$$\pi = g_{\text{soft}} X_\alpha^2$$

$$X_{\mu\nu} \Big|_{\pi_{\text{soft}}} = \eta_{\mu\nu} \Lambda_3^3$$

$$ds^2 = (1 - H^2 X_\mu^2) (dX^\alpha)^2$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_\alpha + \varphi$$



$$G_{\mu\nu}^{\text{Lin}} - \underline{X_{\mu\nu}(\pi)} = \eta_{\mu\nu} \Lambda_{cc}$$

$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^2\pi)^3) = 0$$

$$\pi = g_{\text{SO}(2)} X_\alpha^2$$

$$X_{\mu\nu} \Big|_{\pi_{\text{SO}(2)}} = \eta_{\mu\nu} \Lambda_3^3$$

$$ds^2 = (1 - H^2 X_\mu^2) (dX^\alpha)^2$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_\alpha + \varphi$$

$$\eta_{\mu\nu} (\partial\partial\varphi - \eta_{\mu\nu} D\varphi)$$

$$G_{\mu\nu}^{\text{Lin}} - \underline{X_{\mu\nu}(\pi)} = \delta_{\mu\nu} \Lambda_{\text{cc}}$$

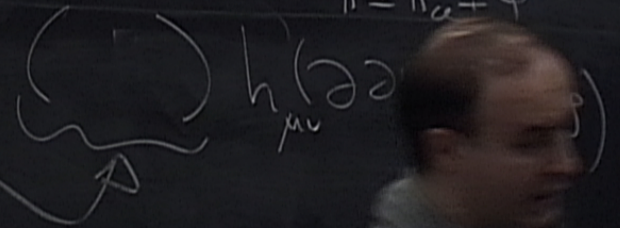
$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^2\pi)^3) = 0$$

$$h_{\mu\nu} = 0$$

$$\pi = \tilde{q} X^2$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_0 + \varphi$$



$$G_{\mu\nu}^{\text{Lin}} - X_{\mu\nu}(\pi) = \delta_{\mu\nu} \Lambda_{cc}$$

$$\partial\partial \left(a_2 (\partial^2 \pi)^2 + a_3 (\partial^2 \pi)^3 \right) = 0$$

$$\pi = \tilde{q} x^2$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_a + \varphi$$

$$\left(\partial\partial\varphi - \eta_{\mu\nu} \partial\varphi \right)$$

$$(\partial\varphi)^2 + \frac{\partial\varphi (\partial\varphi)^2}{\tilde{\Lambda}^3(\Lambda_{cc})}$$

$$G_{\mu\nu}^{LH} - X_{\mu\nu}(\pi) = \partial_{\mu\nu} \Lambda_{cc} + \frac{\text{matt}}{h_{\mu\nu}(SM)}$$

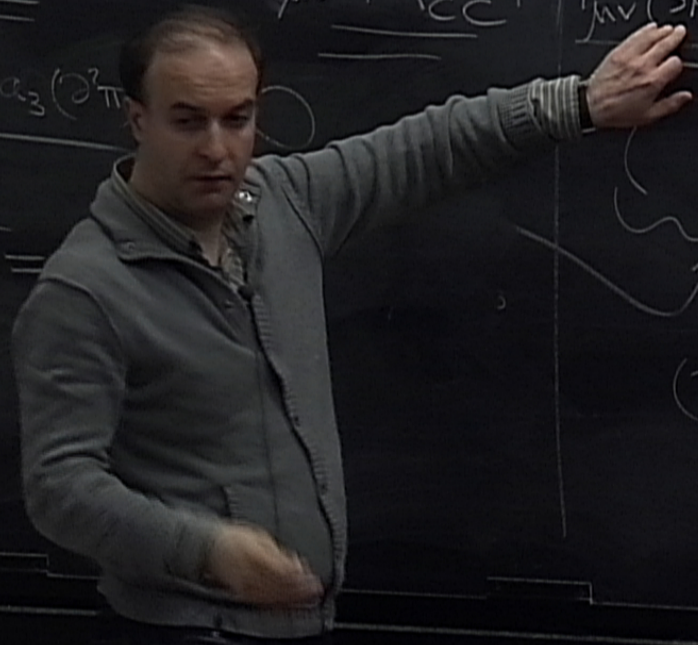
de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^3\pi)^2)$$

$h_{\mu\nu} = 0$ $\pi = \pi_a + \varphi$

$$h_{\mu\nu} (\partial\partial\varphi - \gamma_{\mu\nu}\partial\varphi)$$

$$(\partial\varphi)^2 + \frac{\partial\varphi (\partial\varphi)^2}{\Lambda^3(\Lambda_{cc})}$$

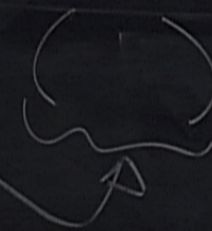


$$G_{\mu\nu}^{\text{Lm}} - X_{\mu\nu}(\pi) = \underbrace{\partial_{\mu\nu} \Lambda_{\text{cc}}}_{\text{circled}} +$$

$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3 \dots) = 0$$

$$h_{\mu\nu} = 0$$

motivated by de Rham, L. Heisenberg
 $\int_{\mu\nu} (SM)$ D. Pirtskhalava GG

$$\pi = \pi_a + \varphi$$


$$h_{\mu\nu} (\partial\partial\varphi - \eta_{\mu\nu} D\varphi)$$

$$(\partial\varphi)^2 + \frac{D\varphi (\partial\varphi)^2}{\Lambda^3(\Lambda_{\text{cc}})}$$



$$G_{\mu\nu}^{\text{Lin}} - X_{\mu\nu}(\pi) = \frac{1}{\Lambda^2} \Lambda^2 (H_0)_{\mu\nu} + \dots$$

$$\partial \partial h (1 + a_2 (\partial^2 \pi)^2 + \dots) = 0$$

$$h_{\mu\nu} = 0$$

$$\langle T_{\mu\nu}^{\text{PP}} \rangle$$

mett
 $L_{\mu\nu}(\text{SM})$

de Rham, L. Heisenberg
 D. Pirtskhalava GG

$$\pi = \pi_a + \varphi$$

$$h_{\mu\nu} (\partial \partial \varphi - \eta_{\mu\nu} \square \varphi)$$

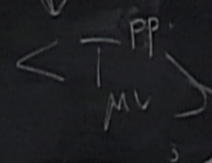
$$(\partial \varphi)^2 + \frac{\square \varphi (\partial \varphi)^2}{\Lambda^3(\Lambda_{\text{cc}})}$$

$$G_{\mu\nu}^{\text{Lin}} - X_{\mu\nu}(\pi) = \frac{1}{\Lambda^2} \Lambda^2 (H_0)_{\mu\nu}$$

$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^2\pi)^3) = 0$$

motth. $\int_{\mu\nu} (SM)$ | de Rham, L. Heisenberg
D. Pirtskhalava GG

$$h_{\mu\nu} = 0, \quad \pi = \tilde{q} X^2$$



$$\pi = \pi_\alpha + \varphi$$

$$h_{\mu\nu} (\partial\partial\varphi - \gamma_{\mu\nu} D\varphi)$$

$$\frac{\varphi (\partial\varphi)^2}{\Lambda^3(\Lambda_{cc})}$$

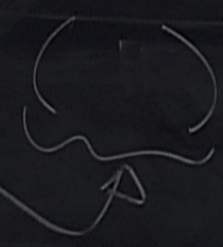
$$G_{\mu\nu}^{Lin} - X_{\mu\nu}(\pi) = \Lambda_{CC}^{(Ho)}$$

$$\partial\partial h (1 + a_2(\partial^2\pi)^2 + a_3(\partial^2\pi)^3) = 0$$

math
 $\int_{\mu\nu}(SM)$ | de Rham, L. Heisenberg
 D. Pirtskhalava GG

$$h_{\mu\nu} = 0, \quad \pi = \tilde{q} X^2$$

PP
 $T_{\mu\nu}$



$$\pi = \pi_a + \varphi$$

$$h_{\mu\nu}(\partial\partial\varphi - \eta_{\mu\nu})$$

$$h_{\mu\nu} T_{\mu\nu}$$

$$\sqrt{g}(g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - m^2 \varphi)$$

$$(\partial\varphi)^2 + \frac{\partial\varphi (\partial\varphi)^2}{\tilde{\Lambda}^3}$$

$$g_{\mu\nu} = \partial_\mu y^a \partial_\nu y^b h_{ab} + \gamma_{\mu\nu}$$

$$h_{\mu\nu} T^{\mu\nu}$$

$$a_1 = 1$$

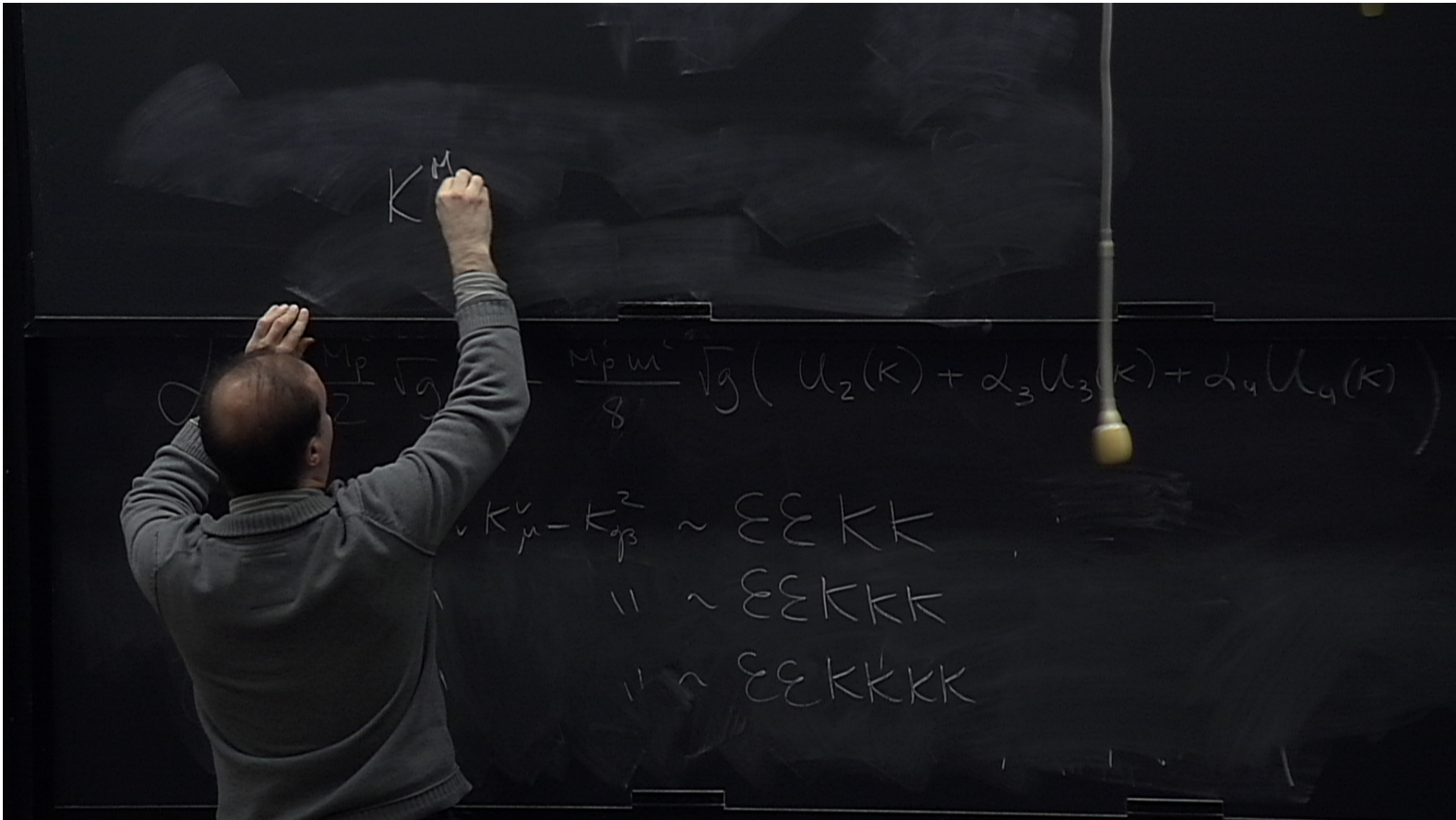
$$a_2 = \frac{6c_3 - 1}{1^3}$$

$$a_3 = \frac{c_3 + 1}{1^3}$$

$$\chi = \frac{M_p^2}{2} \sqrt{g} R - \frac{M_p^2 m^2}{8} \sqrt{g} \left(u_2(K) + \alpha_3 u_3(K) + \alpha_4 u_4(K) \right)$$

$$\mathcal{L} = \frac{M_p^2}{2} \sqrt{g} R - \frac{M_p^2 m^2}{8} \sqrt{g} \left(U_2(K) + \alpha_3 U_3(K) + \alpha_4 U_4(K) \right)$$

$$U_2 = K^\mu_\nu K^\nu_\mu - K_{\mu\nu}^2 \sim \epsilon\epsilon K K$$



$$K^M_{\nu} = \delta^M_{\nu} - \sqrt{g^{M\alpha} \partial_{\alpha} \varphi^a \partial_{\nu} \varphi^b \eta_{ab}}$$

$$\mathcal{L} = \frac{M_P}{2} \sqrt{g} R - \frac{M_P m^2}{8} \sqrt{g} (U_2(K) + \alpha_3 U_3(K) + \alpha_4 U_4(K))$$

$$U_2 = K^M_{\nu} K^{\nu}_{\mu} - K^2_{\mu\nu} \sim \epsilon\epsilon KK$$

$$U_3 = \text{"} \quad \text{"} \sim \epsilon\epsilon KKK$$

$$U_4 = \text{"} \quad \text{"} \sim \epsilon\epsilon KKKK$$

$$K^M_{\nu} = \delta^M_{\nu} - \sqrt{g^{M\alpha}} \partial_{\alpha} \varphi^a \partial_{\nu} \varphi^b \eta_{ab}$$

$$\mathcal{L} = \frac{M_P}{2} \sqrt{g} R - \frac{M_P m^2}{8} \sqrt{g} (u_2(K) + \alpha_3 u_3(K) + \alpha_4 u_4(K))$$

$$u_2 = K^M_{\nu} K^{\nu}_{\mu} - K^2_{\mu\beta} \sim \epsilon\epsilon KK$$

$$u_3 = \text{"} \quad \text{"} \sim \epsilon\epsilon KKK$$

$$u_4 = \text{"} \quad \text{"} \sim \epsilon\epsilon KKKK$$

$$K^M_{\nu} = \delta^M_{\nu} - \sqrt{g^{M\alpha}} \partial_{\alpha} \varphi^a \partial_{\nu} \varphi^b \eta_{a,b}$$

$$\mathcal{L} = \frac{M_P^2}{2} \sqrt{g} R - \frac{M_P^2 m^2}{8} \sqrt{g} (u_2(K) + \alpha_3 u_3(K) + \alpha_4 u_4(K))$$

$$u_2 = K^M_{\nu} K^{\nu}_{\mu} - K^2_{g3} \sim \epsilon \epsilon K K$$

$$u_3 = \text{"} \quad \text{"} \sim \epsilon \epsilon K K K$$

$$u_4 = \text{"} \quad \text{"} \sim \epsilon \epsilon K K K K$$

$$K^M_{\nu} = \delta^M_{\nu} - \sqrt{g^{M\alpha} \partial_{\alpha} \varphi^a \partial_{\nu} \varphi^b \eta_{ab}}$$

$$\mathcal{L} = \frac{M_p^2}{2} \sqrt{g} R - \frac{M_p^2 m^2}{8} \sqrt{g} \left(\mathcal{U}_2(K) + \alpha_3 \mathcal{U}_3(K) + \alpha_4 \mathcal{U}_4(K) \right)$$

$$\mathcal{U}_2 = K^M_{\nu} K^{\nu}_{\mu} - K_{\mu 3}^2 \sim \mathbb{E} \mathbb{E} K K$$

$$\mathcal{U}_3 = \text{"} \quad \text{"} \sim \mathbb{E} \mathbb{E} K K K$$

$$\mathcal{U}_4 = \text{"} \quad \text{"} \sim \mathbb{E} \mathbb{E} K K K K$$

$$\alpha_3 = \alpha_3(c_3, d_5)$$

$$\alpha_4 = \alpha_4(c_3, d_5)$$

$$K^M_{\nu} = \delta^M_{\nu} - \sqrt{g^{M\alpha} \partial_{\alpha} \varphi^a \partial_{\nu} \varphi^b \eta_{ab}}$$

$$\mathcal{L} = \frac{M_P^2}{2} \sqrt{g} R - \frac{M_P^2 m^2}{8} \sqrt{g} \left(\mathcal{U}_2(K) + \alpha_3 \mathcal{U}_3(K) + \alpha_4 \mathcal{U}_4(K) \right)$$

$$\mathcal{U}_2 = K^M_{\nu} K^{\nu}_{\mu} - K_{\mu 3}^2 \sim \mathbb{E} \mathbb{E} K K$$

$$\mathcal{U}_3 = \text{"} \quad \text{"} \sim \mathbb{E} \mathbb{E} K K K$$

$$\mathcal{U}_4 = \text{"} \quad \text{"} \sim \mathbb{E} \mathbb{E} K K K K$$

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$$\mathcal{L} = \frac{M_P^2}{2} \sqrt{g} R - \frac{M_P^2 m^2}{8} \sqrt{g} \left(\mathcal{U}_2(K) + \alpha_3 \mathcal{U}_3(K) + \alpha_4 \mathcal{U}_4(K) \right)$$

$$\mathcal{U}_2 = K^M_{\nu} K^{\nu}_{\mu} - K_{\mu 3}^2 \sim \mathbb{E} \mathbb{E} K K$$

$$\mathcal{U}_3 = \text{" " " " } \sim \mathbb{E} \mathbb{E} K K K$$

$$\mathcal{U}_4 = \text{" " " " } \sim \mathbb{E} \mathbb{E} K K K K$$

$$\alpha_3 = \alpha_3(c_3, d_5)$$

$$\alpha_4 = \alpha_4(c_3, d_5)$$

$$G_{\mu\nu} - X_{\mu\nu}(y) = g_{\mu\nu} \Lambda$$

$$\partial\partial h (1 + \alpha_2 (\partial^2 \pi)^2 + \dots) = 0$$

$$h_{\mu\nu} = 0$$

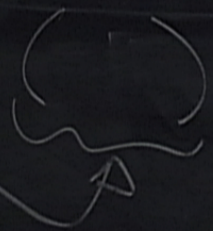
$$h_{\mu\nu}$$

$$\langle T_{\mu\nu}^{PP} \rangle$$

math
 $I_{\mu\nu}(SM)$

de Rham, L. Heisenberg
 D. Pirtskhalava GG

$$\pi = \pi_\alpha + \varphi$$



$$h_{\mu\nu} (\partial\partial\varphi - \eta_{\mu\nu} \square\varphi)$$

$$\partial_\mu \varphi \partial_\nu \varphi - m^2 \varphi$$

$$(\partial\varphi)^2 + \frac{\square\varphi (\partial\varphi)^2}{\Lambda^3 \Lambda_{cc}}$$

$$K^M_{\nu} = \delta^M_{\nu} - \sqrt{g^{\mu\alpha}} \partial_{\alpha} \varphi^a \partial_{\nu} \varphi^b \eta_{ab}$$

$$\mathcal{L} = \frac{M_P^2}{2} \sqrt{g} R - \frac{M_P^2 m^2}{8} \sqrt{g} \left(\mathcal{U}_2(K) + \alpha_3 \mathcal{U}_3(K) + \alpha_4 \mathcal{U}_4(K) \right)$$

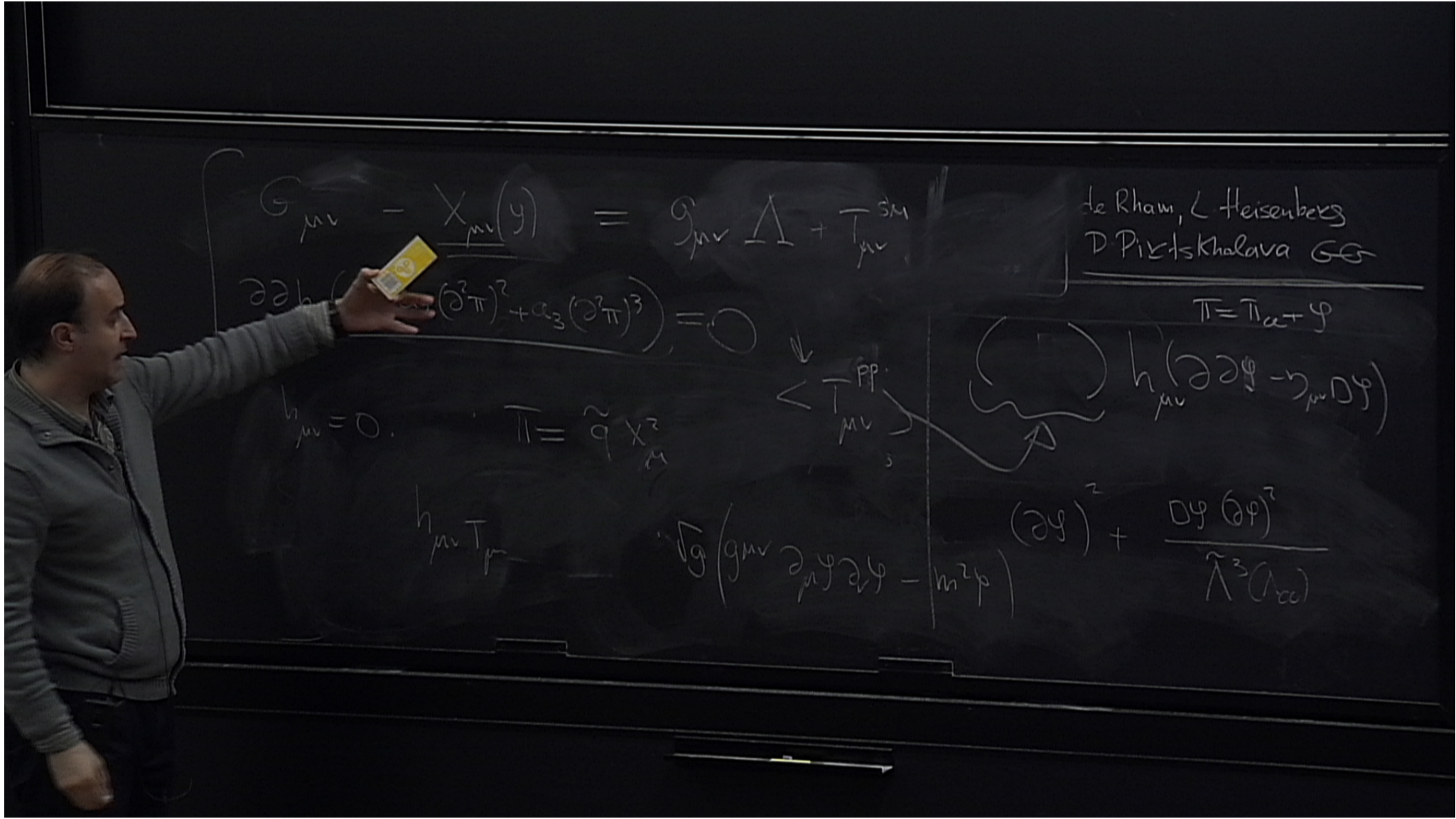
$$\mathcal{U}_2 = K^{\mu}_{\nu} K^{\nu}_{\mu} - K_{\mu 3}^2 \sim \mathbb{E} \mathbb{E} K K$$

$$\mathcal{U}_3 = \text{"} \quad \text{"} \sim \mathbb{E} \mathbb{E} K K K$$

$$\mathcal{U}_4 = \text{"} \quad \text{"} \sim \mathbb{E} \mathbb{E} K K K K$$

$$\alpha_3 = \alpha_3(c_3, d_5)$$

$$\alpha_4 = \alpha_4(c_3, d_5)$$



$$g_{\mu\nu} - X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{5M}{T_{\mu\nu}}$$

$$\partial \partial h_{\mu\nu} (\partial^2 \pi)^2 + a_3 (\partial^2 \pi)^3 = 0$$

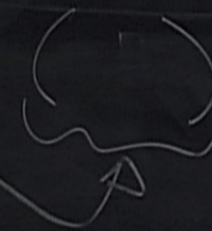
$$h_{\mu\nu} = 0$$

$$\pi = \tilde{q} x^2$$

$$h_{\mu\nu} T_{\mu\nu}$$

$$\sqrt{g} (g_{\mu\nu} \partial_\mu \phi \partial_\nu \phi - m^2 \phi)$$

$$\langle T_{\mu\nu}^{PP} \rangle$$



$$h_{\mu\nu} (\partial \partial \phi - \eta_{\mu\nu} \square \phi)$$

$$(\partial \phi)^2 + \frac{\square \phi (\partial \phi)^2}{\Lambda^3 \Lambda_{cc}}$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_\alpha + \psi$$

$$G_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{8\pi}{\kappa^2} T_{\mu\nu}$$

$$m^2 \nabla^\mu X_{\mu\nu}(y) = 0$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_a + \varphi$$

$$\left(\frac{1}{\kappa^2} T_{\mu\nu}^{PP} \right) \left(\frac{1}{\kappa^2} h_{\mu\nu} (\partial_\alpha \partial_\beta \varphi - \eta_{\mu\nu} \square \varphi) \right)$$

$$(\partial\varphi)^2 + \frac{\square\varphi (\partial\varphi)^2}{\Lambda^3 \Lambda_{cc}}$$

$$h_{\mu\nu} T_{\mu\nu}$$

$$\sqrt{g} (g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - m^2 \varphi^2)$$

$$G_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{8\pi}{T_{\mu\nu}}$$

$$\frac{m^2}{m} \nabla^\mu X_{\mu\nu}(y) = 0$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_a + \psi$$

$$G_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{8\pi}{T_{\mu\nu}}$$

$$\frac{m^2}{m} \nabla^\mu X_{\mu\nu}(y) = 0$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_\alpha + \varphi$$

$$\Lambda_{\text{eff}} = \Lambda \sqrt{\frac{\partial^3 \pi_\alpha}{\Lambda^3}}$$

$$\left[\begin{array}{l} G_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{SM}{T_{\mu\nu}} \\ m^2 \nabla^\mu X_{\mu\nu}(y) = 0 \end{array} \right.$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_a + \varphi$$

$$\Lambda_{\text{eff}} = \Lambda \sqrt{\frac{3\pi_a}{\Lambda^3}}$$

$$G_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{SM}{T_{\mu\nu}}$$

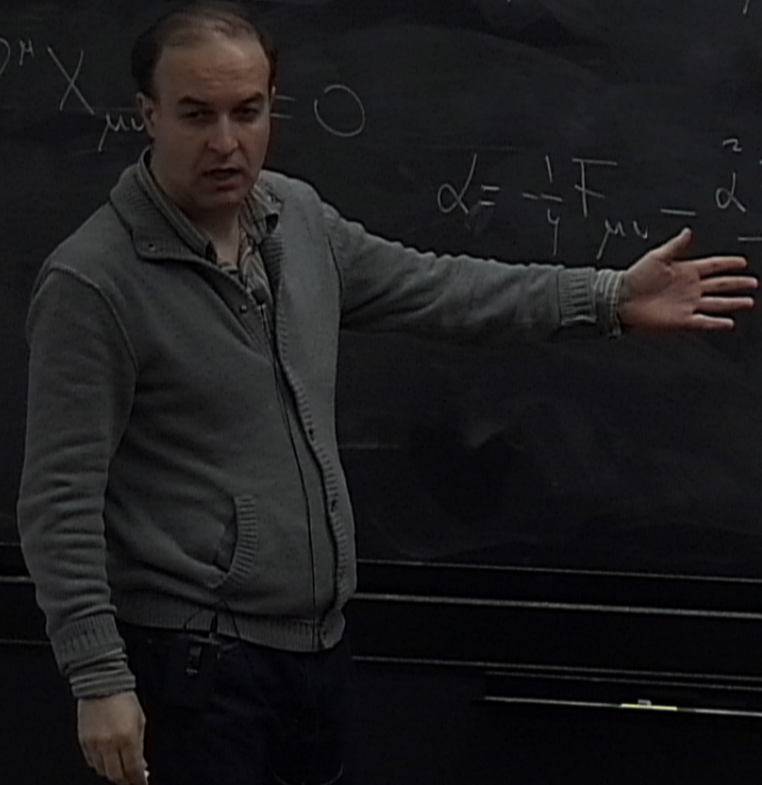
$$m^2 \nabla^\mu X_{\mu\nu} = 0$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_a + \varphi$$

$$\alpha = -\frac{1}{4} F_{\mu\nu}^2 - \frac{d^2 F_{\mu\nu}^4}{M_e^4}$$

$$\Lambda_{\text{eff}} = \Lambda \sqrt{\frac{\partial^3 \pi_{\text{eff}}}{\Lambda^3}}$$



$$G_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{S_M}{T_{\mu\nu}}$$

$$\frac{1}{m^2} \nabla^\mu \nabla_\mu X_{\mu\nu}(y) = 0$$

$$\alpha = -\frac{1}{4} F_{\mu\nu}^2 - \frac{d^2 F_{\mu\nu}^4}{M_e^4}$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_{\alpha + \omega}$$

$$\Lambda_{\text{eff}} = \Lambda$$

$$G_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{S_M}{T_{\mu\nu}}$$

$$m^2 \nabla^\mu X_{\mu\nu}(y) = 0$$

$$\alpha = -\frac{1}{4} F_{\mu\nu}^2 - \frac{m^4}{\Lambda^3} F_{\mu\nu}^4$$

$$Z(g, J) = \int d\psi e^{i S_{SM}(J, g_{\mu\nu})}$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_a + \psi$$

$$\Lambda_{\text{eff}} = \Lambda \sqrt{\frac{\partial^3 \pi_{\text{eff}}}{\Lambda^3}}$$

$$\left[\begin{aligned} \square_{\mu\nu} + m^2 X_{\mu\nu}(y) &= g_{\mu\nu} \Lambda + \frac{sm}{T_{\mu\nu}} \\ \square^{\mu\nu} X_{\mu\nu}(y) &= 0 \end{aligned} \right.$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_{eff} + \varphi$$

$$\alpha = -\frac{1}{4} F_{\mu\nu}^2 - \frac{m^4}{\Lambda^3} F_{\mu\nu}^4$$

$$\Lambda_{eff} = \Lambda \sqrt{\frac{\partial \pi_{eff}}{\partial \Lambda^3}}$$

$$Z(g, J) = \int d\psi_{sm} e^{iS_{sm}(J, g_{\mu\nu})} = \int dA e^{iS_{eff}(J, g)}$$

$$\left[\begin{aligned} \square_{\mu\nu} + m^2 X_{\mu\nu}(y) &= g_{\mu\nu} \Lambda + \frac{sm}{T_{\mu\nu}} \\ m^2 \nabla^\mu X_{\mu\nu}(y) &= 0 \end{aligned} \right. \quad \Lambda^3 = m^2$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\alpha = -\frac{1}{4} F_{\mu\nu}^2 - \frac{m^4}{\Lambda^3} F_{\mu\nu}^4$$

$\pi \pi \alpha + \psi$

$$\sqrt{\frac{3\pi\alpha}{\Lambda^3}}$$

$$Z(g, J) = \int d\psi_{sm} e^{iS_{sm}(J, g_{\mu\nu})}$$



$$\left[\begin{aligned}
 g_{\mu\nu} + m^2 X_{\mu\nu}(y) &= g_{\mu\nu} \Lambda + \frac{S_M}{T_{\mu\nu}} \\
 m^2 \nabla^\mu X_{\mu\nu}(y) &= 0
 \end{aligned} \right.$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\Lambda^3 = m^2$$

$$\pi = \pi_a + \varphi$$

$$\alpha = -\frac{1}{4} F_{\mu\nu}^2 - \frac{d F_{\mu\nu}}{M^4}$$

$$\Lambda_{\text{eff}} = \Lambda \sqrt{\frac{\partial^3 \pi_{\text{eff}}}{\Lambda^3}}$$

$$Z(g, J) = \int d\psi e^{iS}$$

$$iS_{\text{eff}}(J, g)$$

$$g_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{S_M}{T_{\mu\nu}}$$

$$m^2 \nabla^\mu X_{\mu\nu}(y) = 0$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$\Lambda^3 = m^2$

$d = 4$

$d F_{\mu\nu}^4$

M^4

$g_{\mu\nu}$

$$\pi = \pi_a + \varphi$$

$$\Lambda_{\text{eff}} = \Lambda \sqrt{\frac{3\pi_{\text{eff}}}{\Lambda^3}}$$

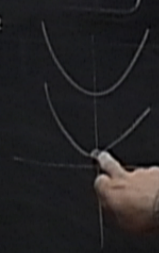
$$Z(g, J) = \int d\psi \exp(i S_M(\psi, g)) = \int dA e^{i S_{\text{eff}}(J, g)}$$

$$g_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{sm}{T_{\mu\nu}}$$

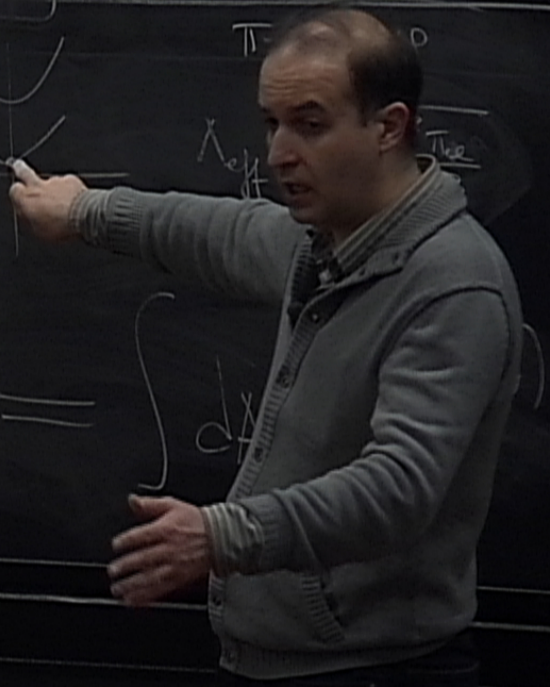
$$m^2 \nabla^\mu X_{\mu\nu}(y) = 0$$

de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\alpha = -\frac{1}{4} F_{\mu\nu}^2 - \frac{m^4}{2} F_{\mu\nu}^4$$



$$Z(g, J) = \int d\psi_{sm} e^{iS_{sm}(J, g_{\mu\nu})} = \int d\psi$$



$$g_{\mu\nu} + m^2 X_{\mu\nu}(y) = g_{\mu\nu} \Lambda + \frac{S_M}{T_{\mu\nu}}$$

$$m^2 \Delta^{\mu\nu} X_{\mu\nu}(y) = 0$$

$$\alpha = -\frac{1}{4} F_{\mu\nu}^2 - \frac{2}{M^4} F_{\mu\nu}^4$$



de Rham, L. Heisenberg
D. Pirtskhalava GG

$$\pi = \pi_a + \varphi$$

$$\Lambda_{\text{eff}} = \Lambda \sqrt{\frac{3\pi_{\text{eff}}}{\Lambda^3}}$$

$$Z(g, J) = \int d\psi e^{iS_M(J, g_{\mu\nu})} = \int dA e^{iS_{\text{eff}}(J, g)}$$