Title: Sequestering the Standard Model Vacuum Energy

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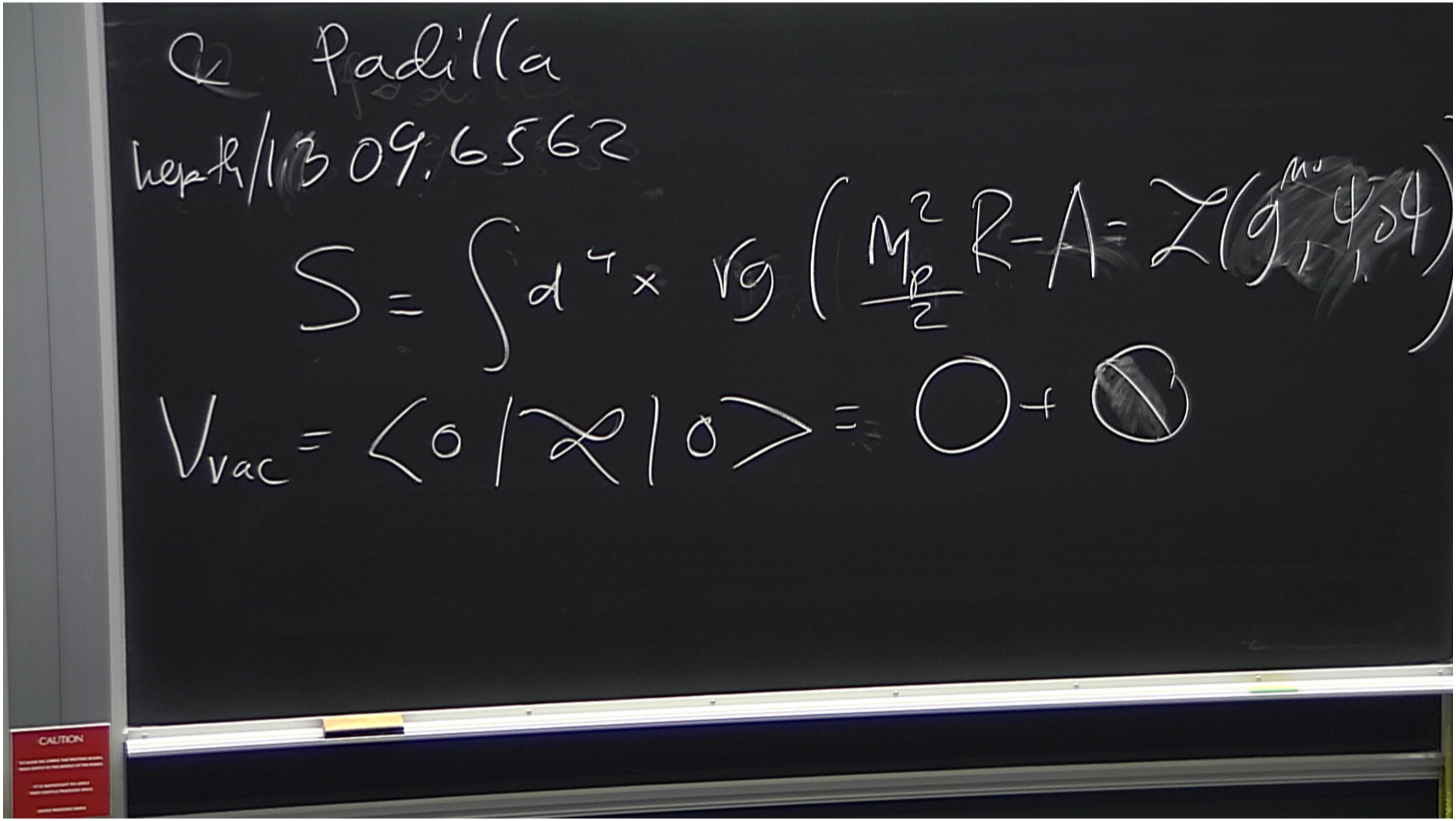
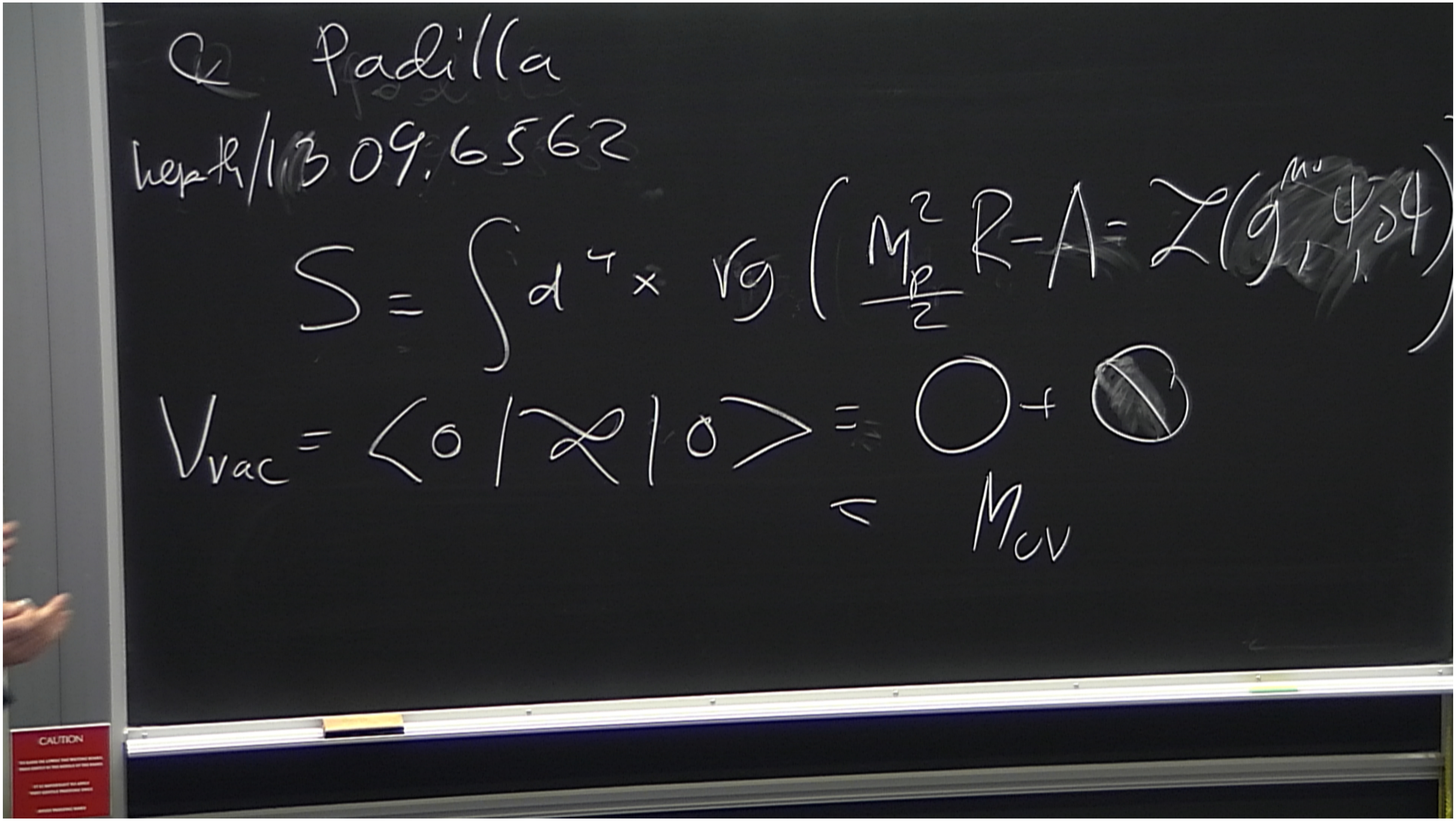
Abstract: We propose a very simple reformulation of General Relativity, which completely sequesters from gravity {\it all} of the vacuum energy from a matter sector, including all loop corrections and renders all contributions from phase transitions automatically small. The idea is to make the dimensional parameters in the matter sector functionals of the 4-volume element of the universe. For them to be nonzero, the universe should be finite in spacetime. If this matter is the Standard Model of particle physics, our mechanism prevents any of its vacuum energy, classical or quantum, from sourcing the curvature of the universe. The mechanism is consistent with the large hierarchy between the Planck scale, electroweak scale and curvature scale, and early universe cosmology, including inflation. Consequences of our proposal are that the vacuum curvature of an old and large universe is not zero, but very small, that wDEâ‰ƒâˆ’1 is a transient, and that the universe will collapse in the future.


@ Padilla
hep-th/1309.6562
$S = \int d^4x \sqrt{g} \left(\frac{M_p^2}{2} R - \Lambda - \mathcal{L}(g^{\mu\nu}, \psi, \partial\psi) \right)$
$V_{vac} = \langle 0 | \mathcal{L} | 0 \rangle =$
CAUTION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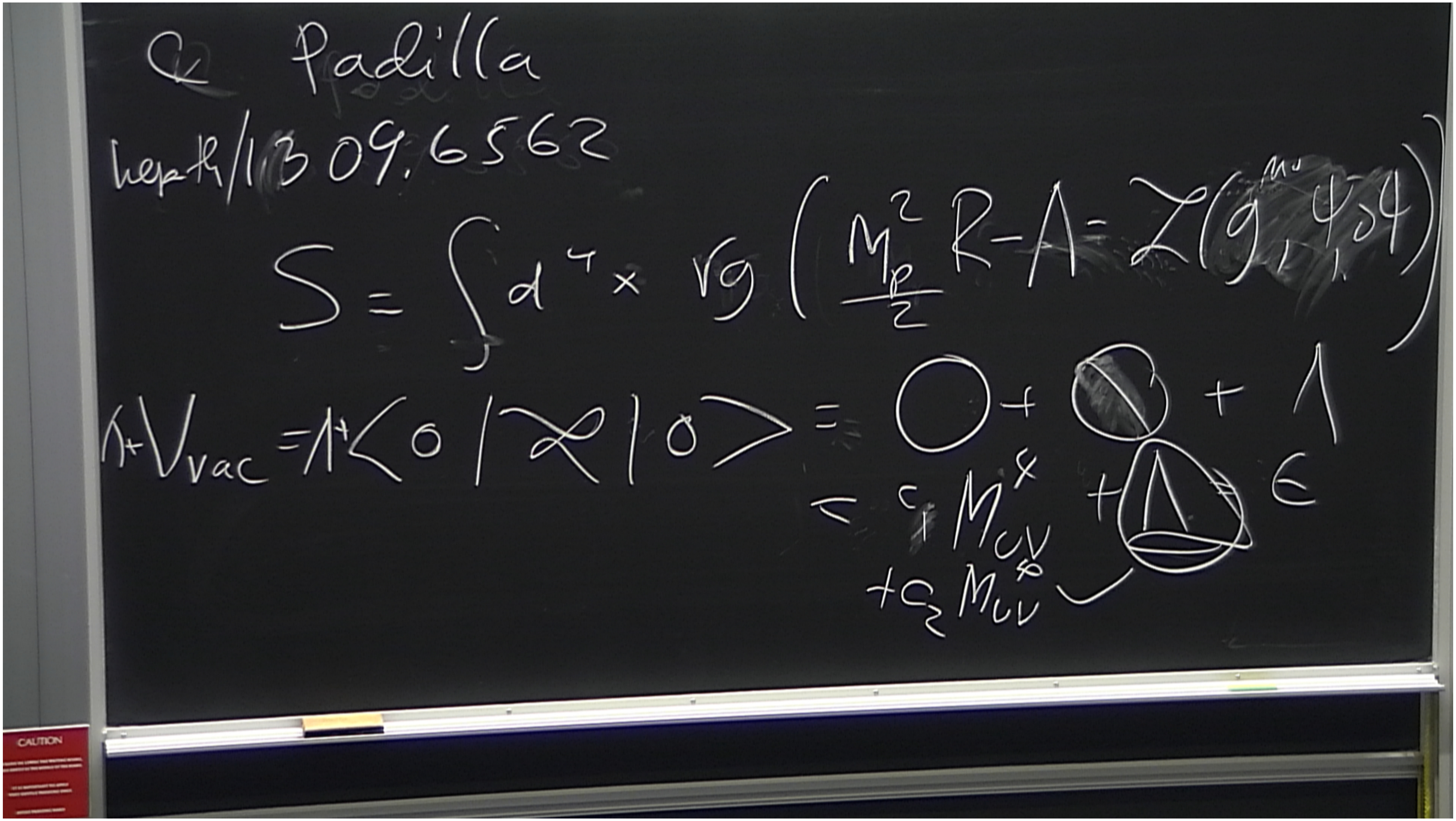
hep-th/1309.6562
S = ∫d⁴x √g (M_p²/2 R − Λ − L(g^{μν}, ψ, ∂ψ))
V_vac = ⟨0|L|0⟩ = ○ + ○
= M_cv
CAUTION



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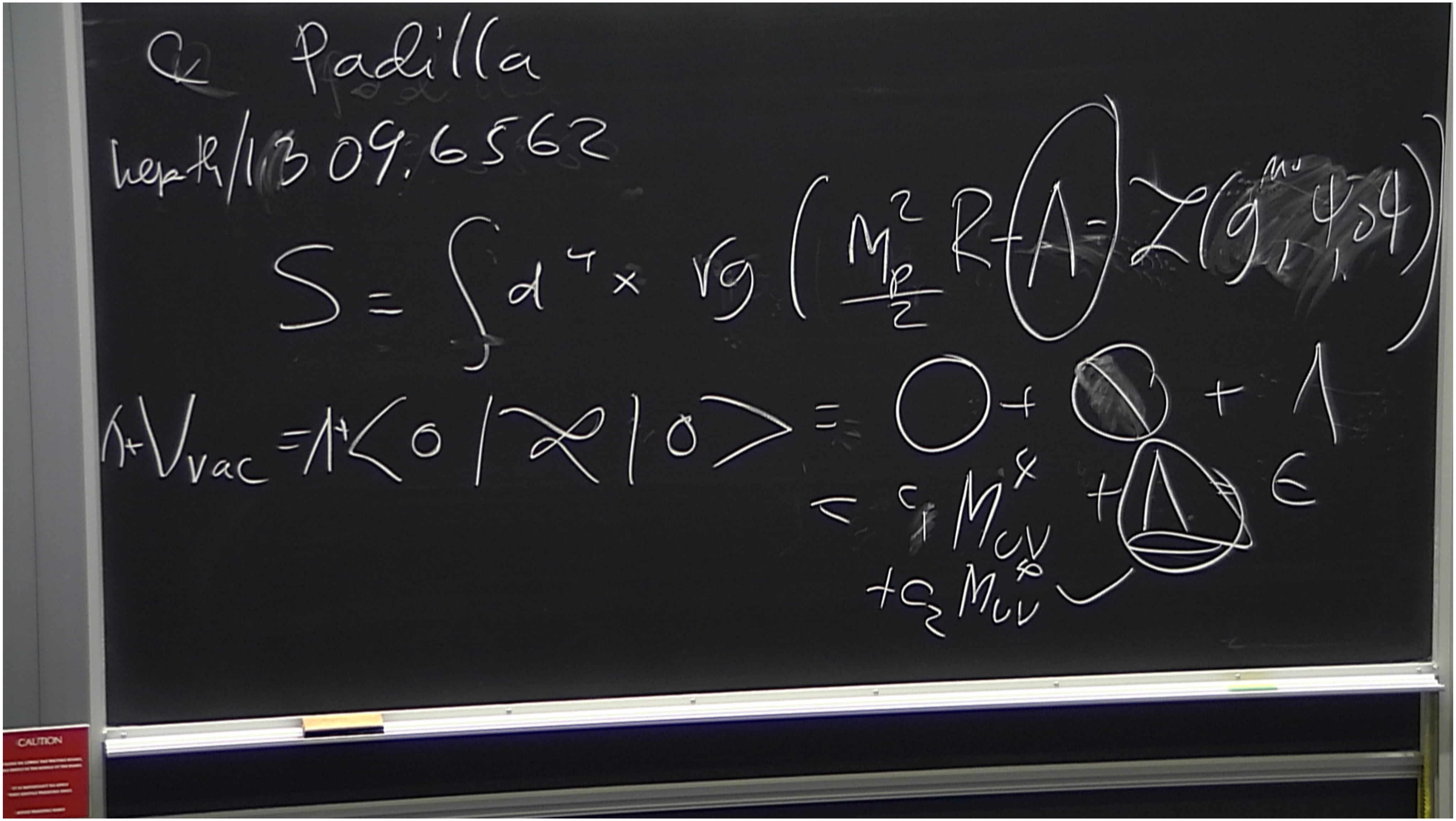
Padilla
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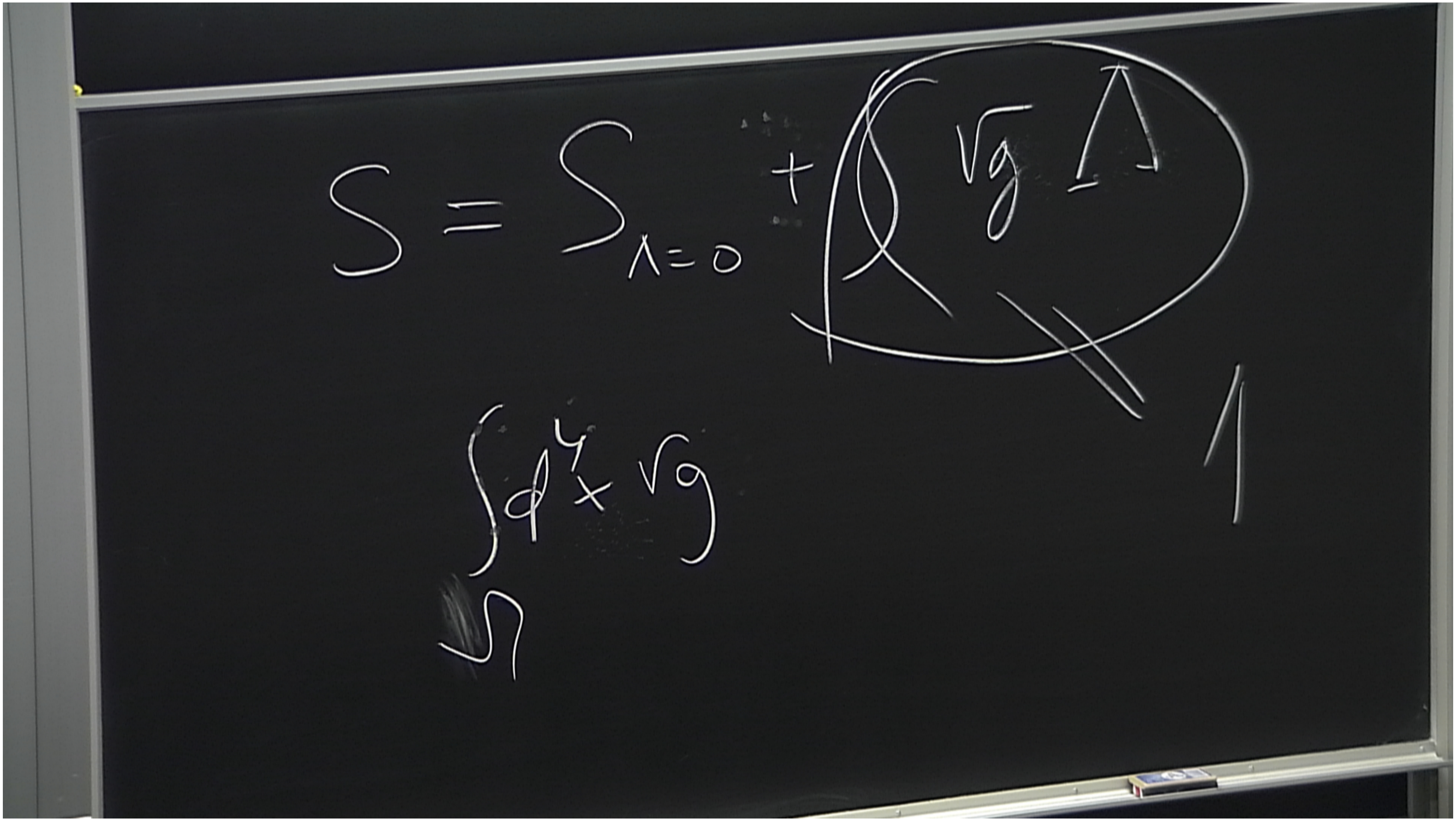
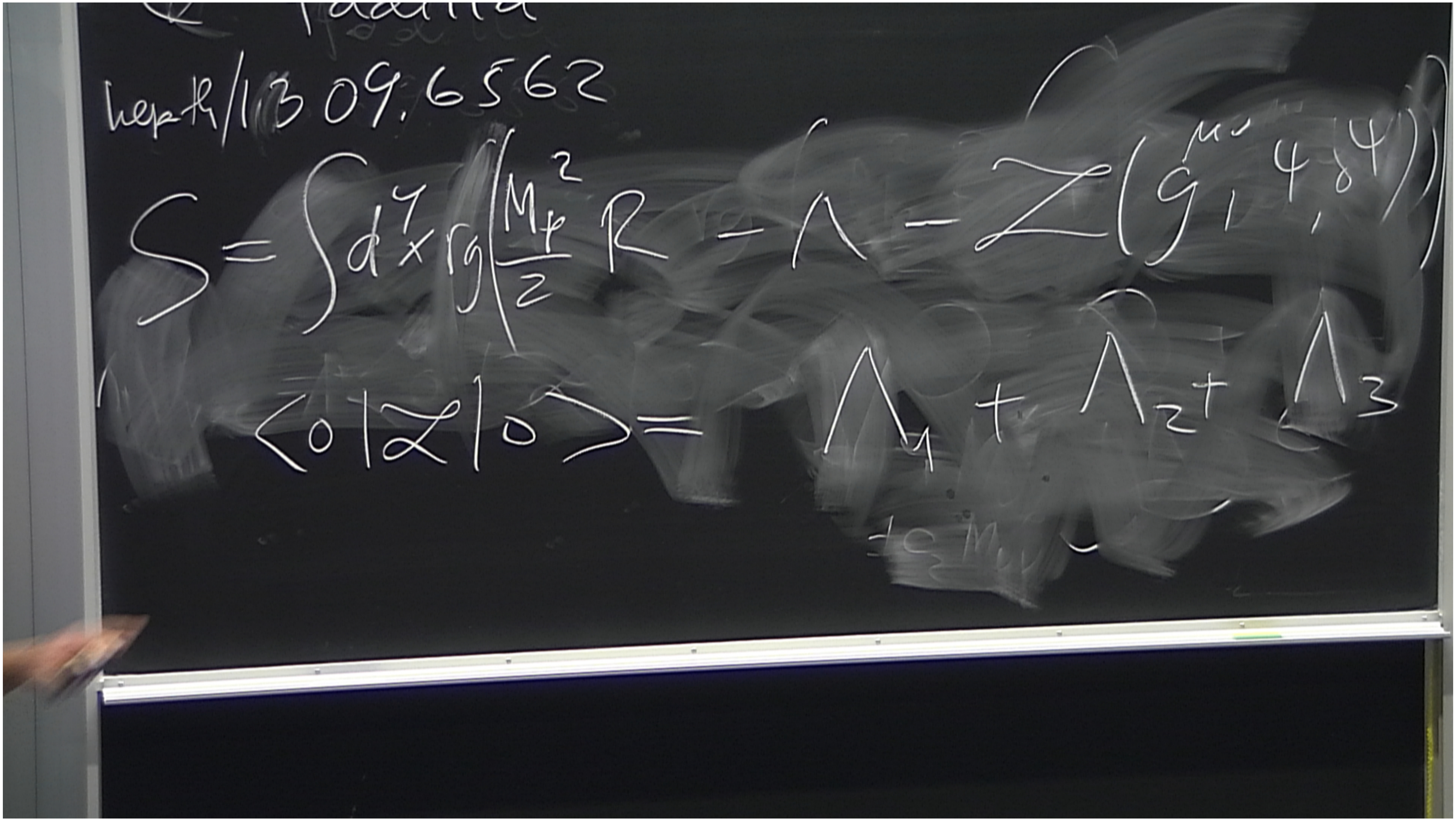
S = ∫ d⁴x √g (M_p²/2 R − Λ − L(g^{μν}, ψ, ∂ψ))
Λ + V_vac = Λ + ⟨0| L |0⟩
= c₁ M_UV⁴ + c₂ M_UV⁴
CAUTION



$S = S_{\Lambda=0} + \int \sqrt{g}\, \Lambda$
$\int d^4x \sqrt{g}$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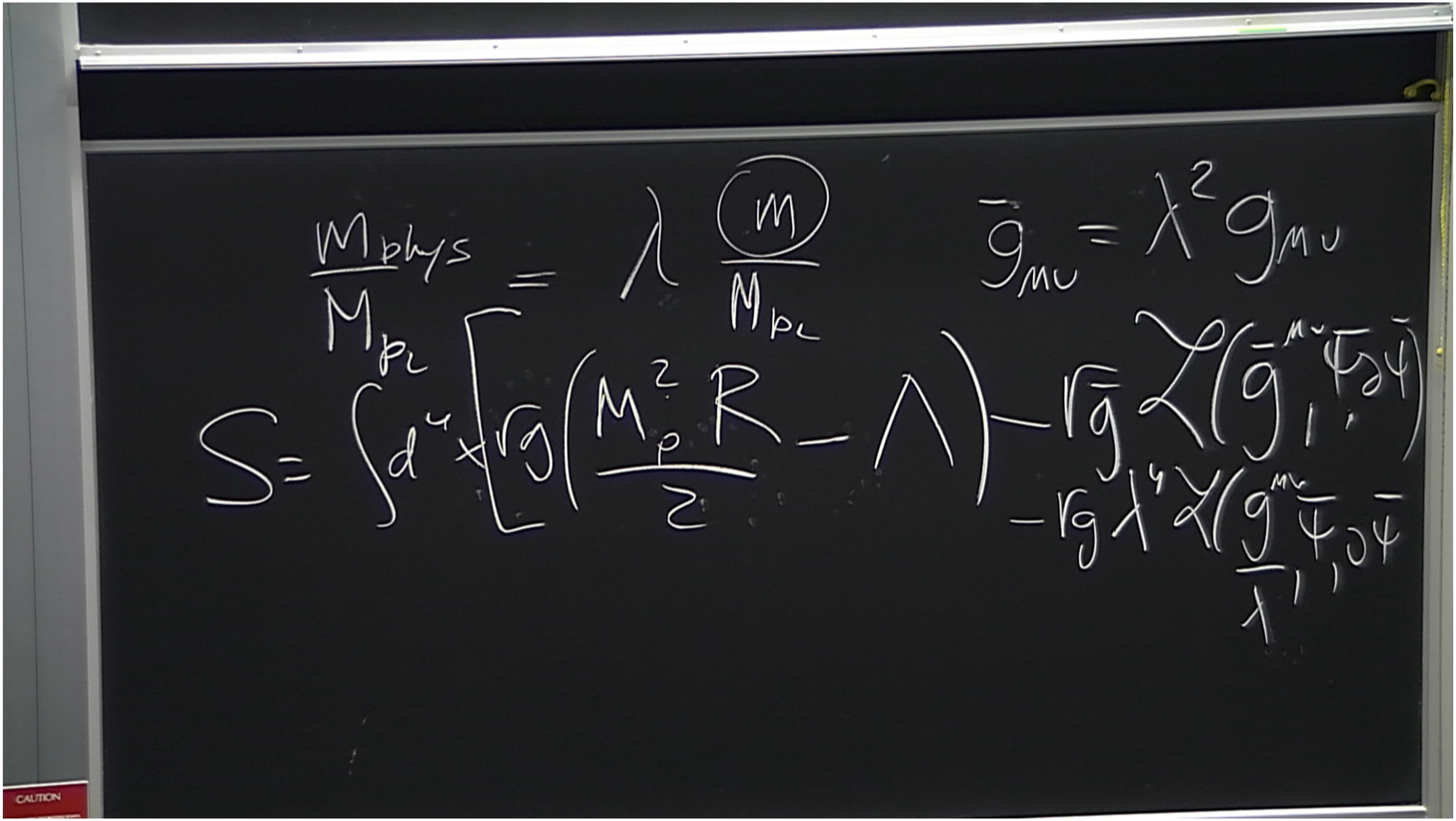
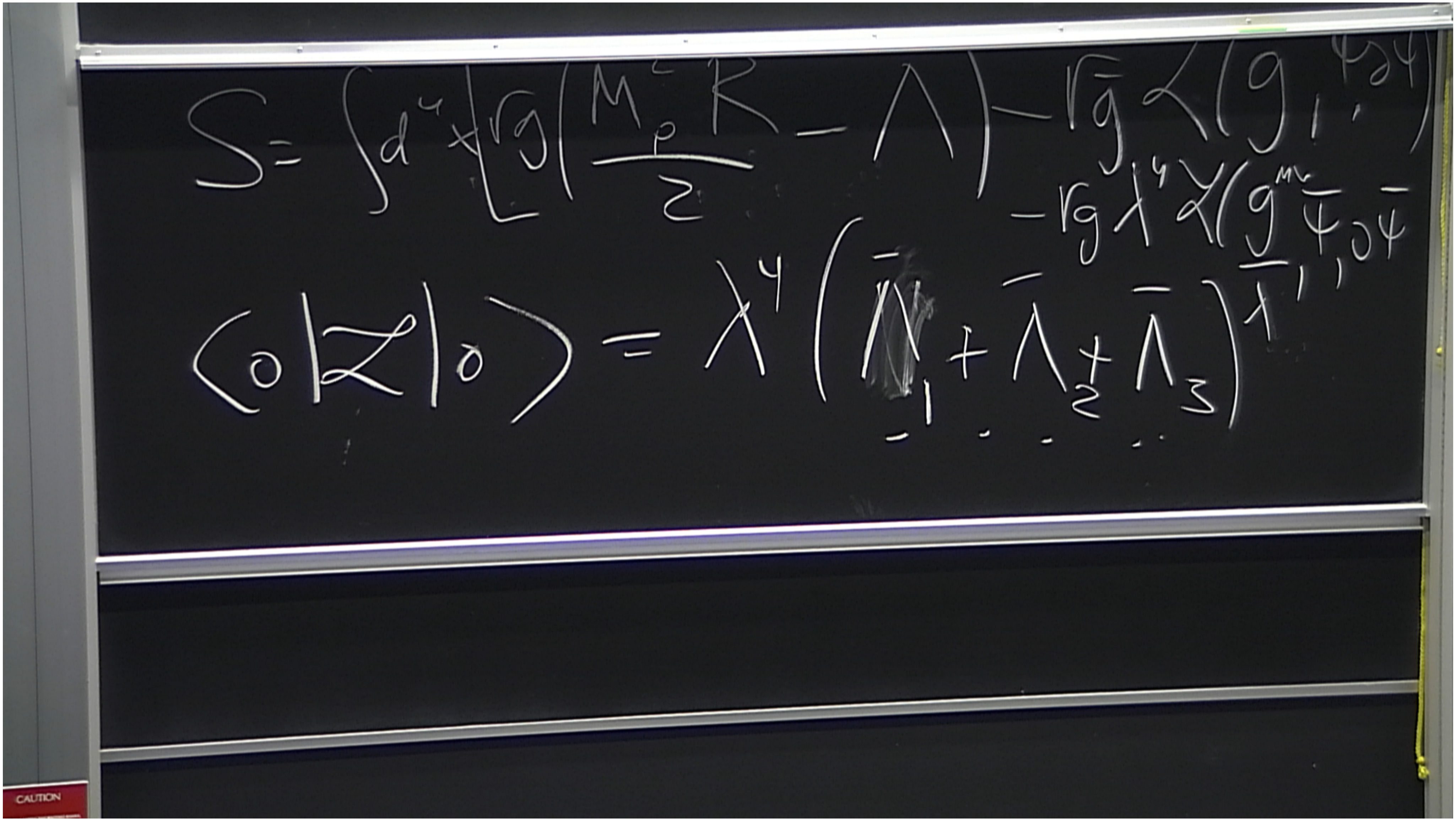
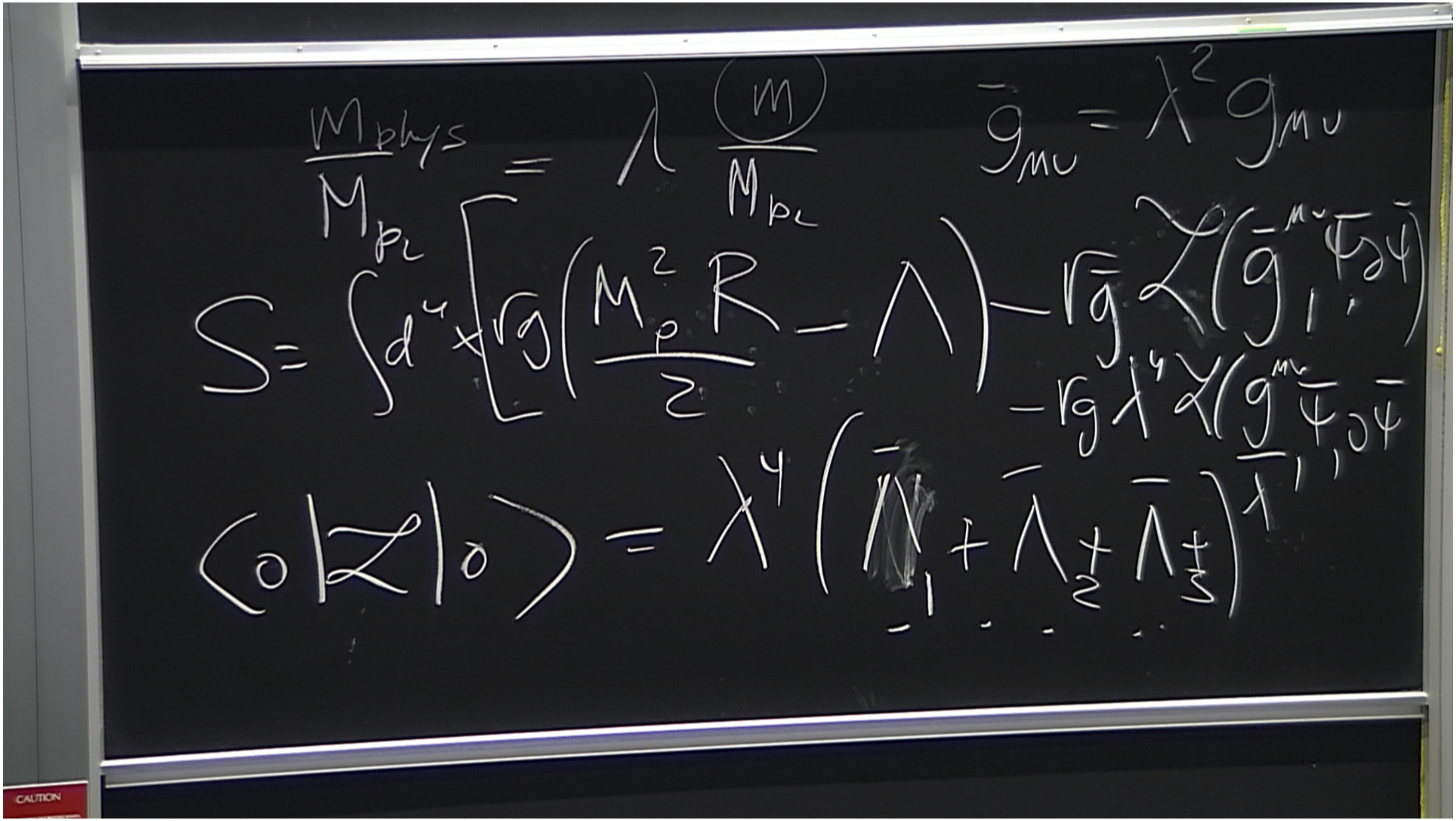
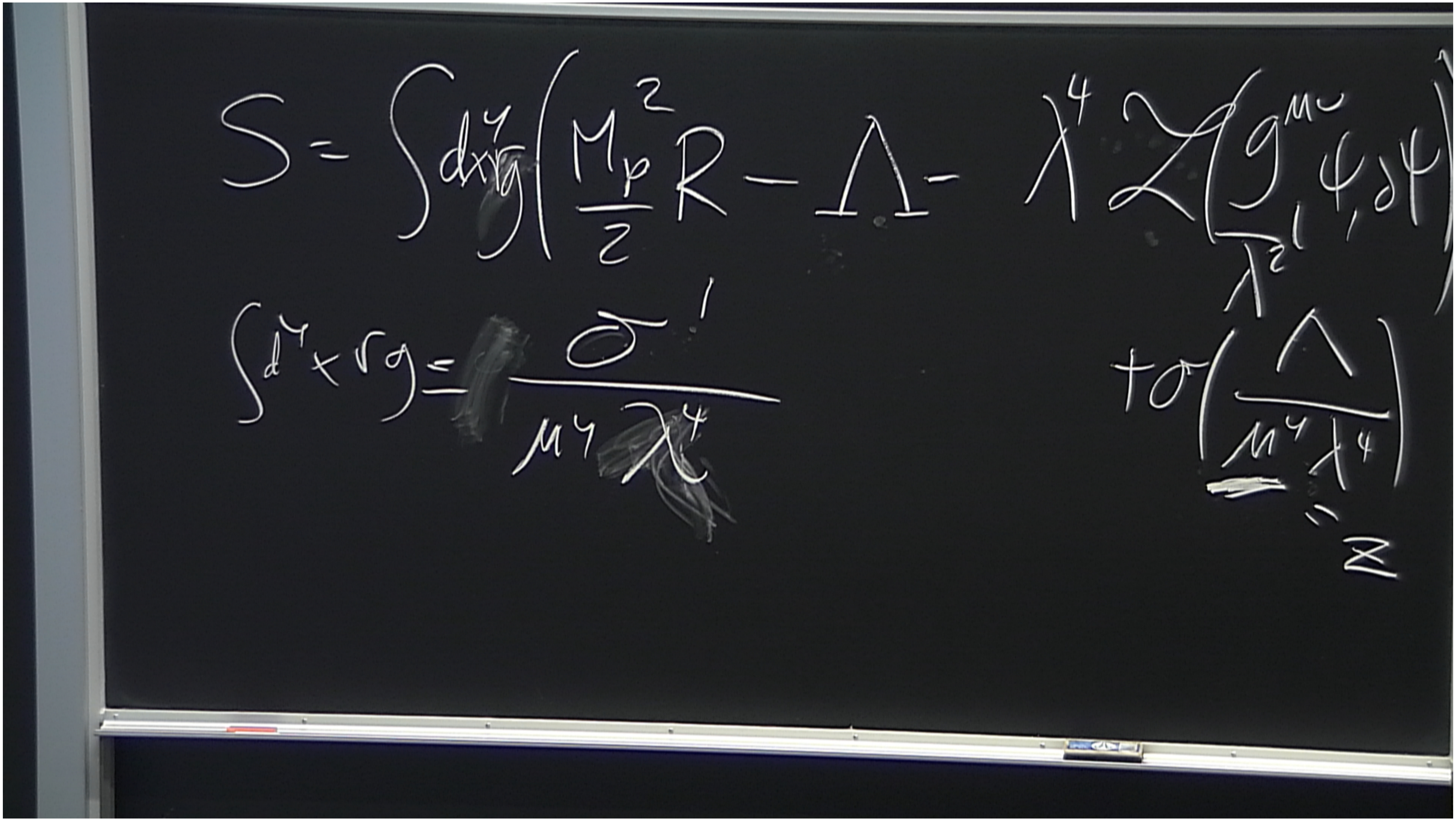
S = ∫d⁷x √g (M_P²/2 R − Λ − ℒ(g^μν, ψ, δψ))
⟨0|ℒ|0⟩ = Λ₁ + Λ₂ + Λ₃


$\frac{M_{phys}}{M_{pl}} = \lambda \frac{m}{M_{pl}}$
$\bar{g}_{\mu\nu} = \lambda^2 g_{\mu\nu}$
$S = \int d^4x \left[\sqrt{g} \left(\frac{M_p^2}{2} R - \Lambda \right) - \sqrt{\bar{g}} \mathcal{L}(\bar{g}^{\mu\nu}, \bar{\psi}, \partial\bar{\psi}) \right.$
$- \sqrt{g} \lambda^4 \mathcal{L}(\frac{g^{\mu\nu}}{\lambda}, \bar{\psi}, \partial\bar{\psi})$
CAUTION


$S = \int d^4x \sqrt{g}\left(\frac{M_p^2}{2} R - \Lambda\right) - \sqrt{g}\,\mathcal{L}(g, \psi, \partial\psi)$
$- \sqrt{g}\,\lambda^4 \mathcal{L}(g^{\mu\nu}\lambda^{-2}, \bar\psi, \partial\bar\psi)$
$\langle 0|\mathcal{L}|0\rangle = \lambda^4(\bar\Lambda_1 + \bar\Lambda_2 + \bar\Lambda_3)$
CAUTION


$\frac{M_{phys}}{M_{pl}} = \lambda \frac{m}{M_{pl}}$
$\bar{g}_{\mu\nu} = \lambda^2 g_{\mu\nu}$
$S = \int d^4x \left[\sqrt{g}\left(\frac{M_{pl}^2 R}{2} - \Lambda\right) - \sqrt{\bar{g}}\, \mathcal{L}(\bar{g}^{\mu\nu}, \bar{\psi}, \partial\bar{\psi}) \right.$
$- \sqrt{g}\, \lambda^4 \mathcal{L}(\frac{g^{\mu\nu}}{\lambda}, \bar{\psi}, \partial\bar{\psi})$
$\langle 0 | \mathcal{L} | 0 \rangle = \lambda^4 (\bar{\Lambda}_1 + \bar{\Lambda}_2 + \bar{\Lambda}_3)$
CAUTION



$S = \int d^4x \sqrt{g} \left(\frac{M_p^2}{2} R - \Lambda - \lambda^4 \mathcal{L}\left(\frac{g^{\mu\nu}}{\lambda^2}, \phi, \partial\phi\right) \right)$
$\int d^4x \sqrt{g} = \frac{\sigma'}{\mu^4 \lambda^4}$
$+ \sigma\left(\frac{\Lambda}{\mu^4 \lambda^4}\right)$
$= Z$

$$S = \int d^4x \sqrt{g}\left(\frac{M_p^2}{2} R - \Lambda - \lambda^4 \mathcal{L}\left(\frac{g^{\mu\nu}}{\lambda^2}, \phi, \partial\phi\right)\right) + \sigma\left(\frac{\Lambda}{\mu^4 \lambda^4}\right)$$

$$\int d^4x \sqrt{g} = \frac{\sigma'}{\mu^4 \lambda^4}$$

$$\int d^4x \sqrt{g}\, T^{\mu}{}_{\mu} = \frac{4\Lambda\sigma'}{\lambda^4 \mu^4}$$

$$= Z$$

$$S = \int d^4x \sqrt{g}\left(\frac{M_p^2}{2} R - \Lambda - \lambda^4 \mathcal{L}\left(\frac{g^{\mu\nu}}{\lambda^2}, \psi, \partial\psi\right)\right)$$

$$\int d^4x\sqrt{g} = \frac{\sigma'}{\mu^4\lambda^4} + \sigma\left(\frac{\Lambda}{\mu^4\lambda^4}\right)$$

$$\int d^4x\sqrt{g}\, T^\mu{}_\mu = \frac{4\sigma'}{\lambda^4\mu^4} \Rightarrow \Lambda = \frac{1}{4}\frac{\int d^4x\sqrt{g}\,T^\mu{}_\mu}{\int d^4x\sqrt{g}} = z$$

$$S = \int d^4x\sqrt{g}\left(\frac{M_p^2}{2}R - \Lambda - \lambda^4\mathcal{L}\left(\frac{g^{\mu\nu}}{\lambda^2},\phi,\partial\phi\right)\right)$$

$$\int d^4x\sqrt{g} = \frac{\sigma'}{\mu^4\lambda^4} \qquad + \sigma\left(\frac{\Lambda}{\mu^4\lambda^4}\right)$$

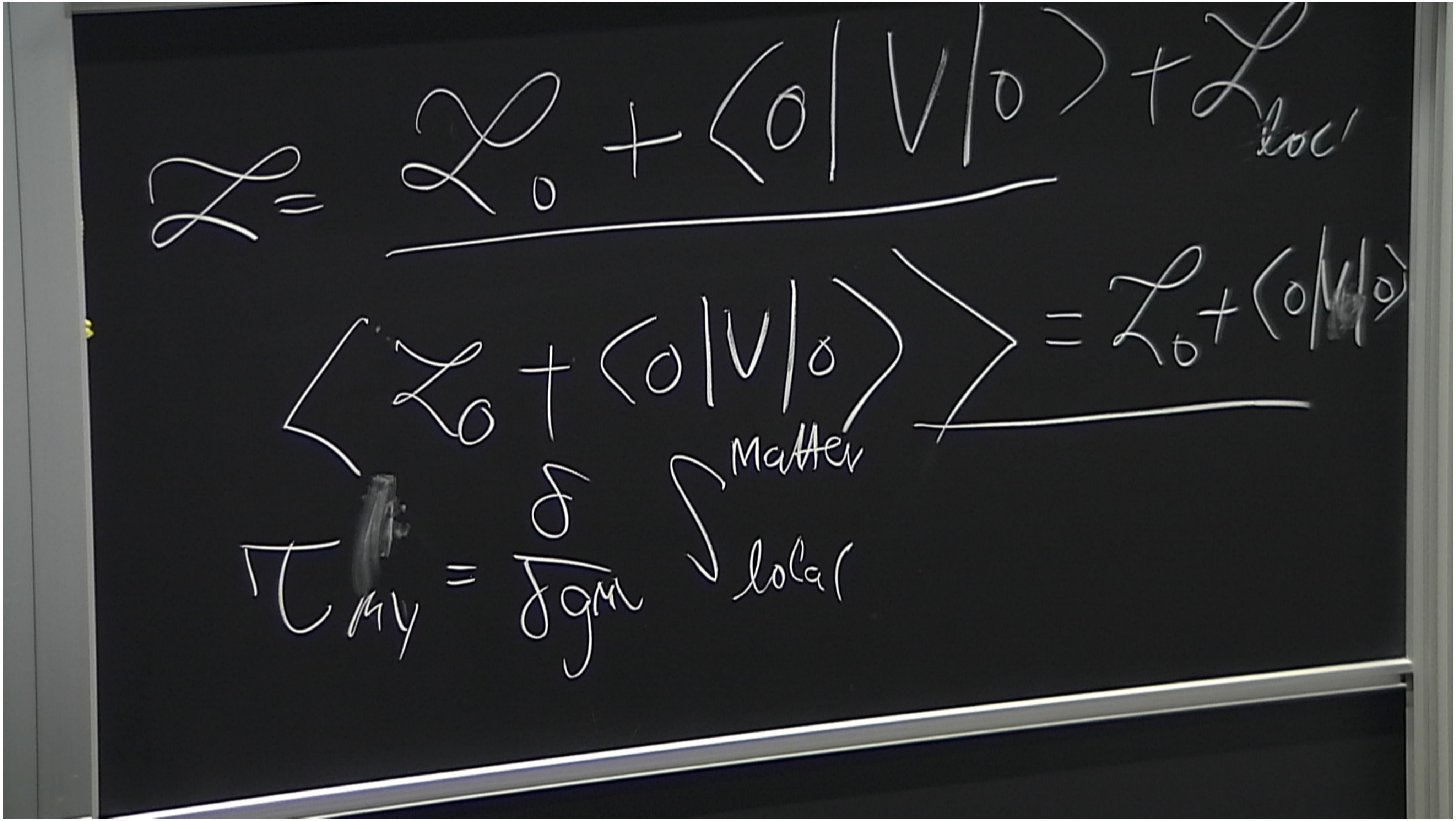
$$\int d^4x\sqrt{g}\,T^\mu{}_\mu = \frac{4\Lambda\sigma'}{\lambda^4\mu^4} \Rightarrow \Lambda = \frac{1}{4}\frac{\int d^4x\sqrt{g}\,T^\mu{}_\mu}{\int d^4x\sqrt{g}} = \frac{1}{4}\langle T^\mu{}_\mu\rangle$$

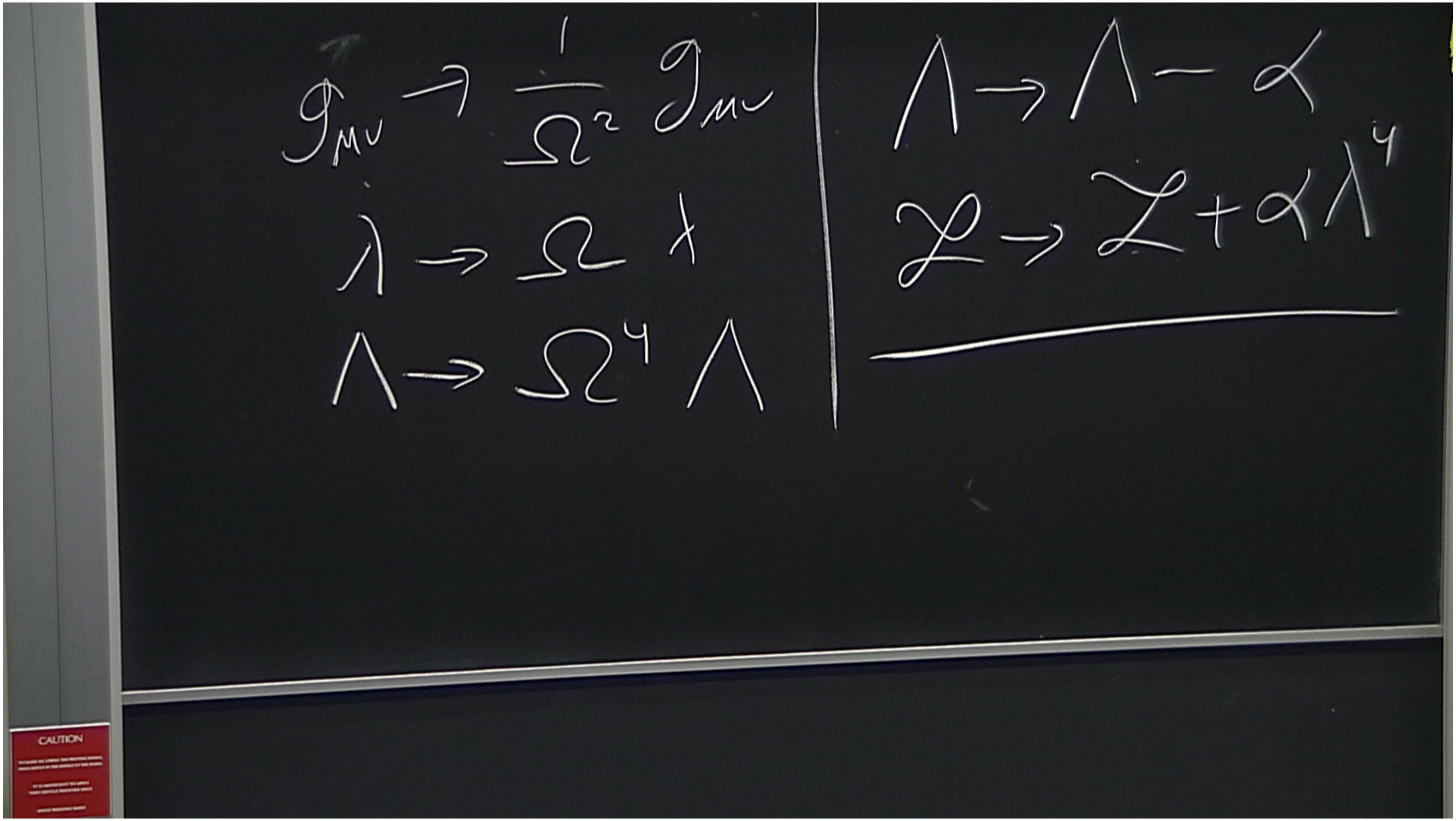
$$\langle 0|\mathcal{L}|0\rangle = \Lambda_1 + \Lambda_2 + \Lambda_3$$

$$M_p^2 G^\mu_\nu = T^\mu_\nu - \frac{1}{4}\langle T^\mu_\mu\rangle \delta^\mu_\nu$$

$$S = \int d^4x \left[\sqrt{g}\left(\frac{M_p^2 R}{2} - \Lambda\right) + \sqrt{g}\,\mathcal{L}(g, \psi, \partial\psi) - \sqrt{g}\,\lambda^4 \mathcal{L}\left(\frac{\bar{g}^{\mu\nu}}{\lambda}, \bar{\psi}, \partial\bar{\psi}\right)\right]$$

$$\langle 0|\mathcal{L}|0\rangle = \lambda^4\left(\bar{\Lambda}_1 + \bar{\Lambda}_2 + \bar{\Lambda}_3 + \ldots\right)$$


$\mathcal{L} = \frac{\mathcal{L}_0 + \langle 0|V|0\rangle + \mathcal{L}_{local}}{\left\langle \mathcal{L}_0 + \langle 0|V|0\rangle \right\rangle = \mathcal{L}_0 + \langle 0|V|0\rangle}$
$T_{\mu\nu} = \frac{\delta}{\delta g^{\mu\nu}} \int_{local}^{matter}$


$g_{\mu\nu} \to \frac{1}{\Omega^2} g_{\mu\nu}$
$\lambda \to \Omega \lambda$
$\Lambda \to \Omega^4 \Lambda$
$\Lambda \to \Lambda - \alpha$
$\mathcal{L} \to \mathcal{L} + \alpha \lambda^4$
CAUTION

$$g_{\mu\nu} \to \frac{1}{\Omega^2} g_{\mu\nu}$$

$$\lambda \to \Omega \lambda$$

$$\Lambda \to \Omega^4 \Lambda$$

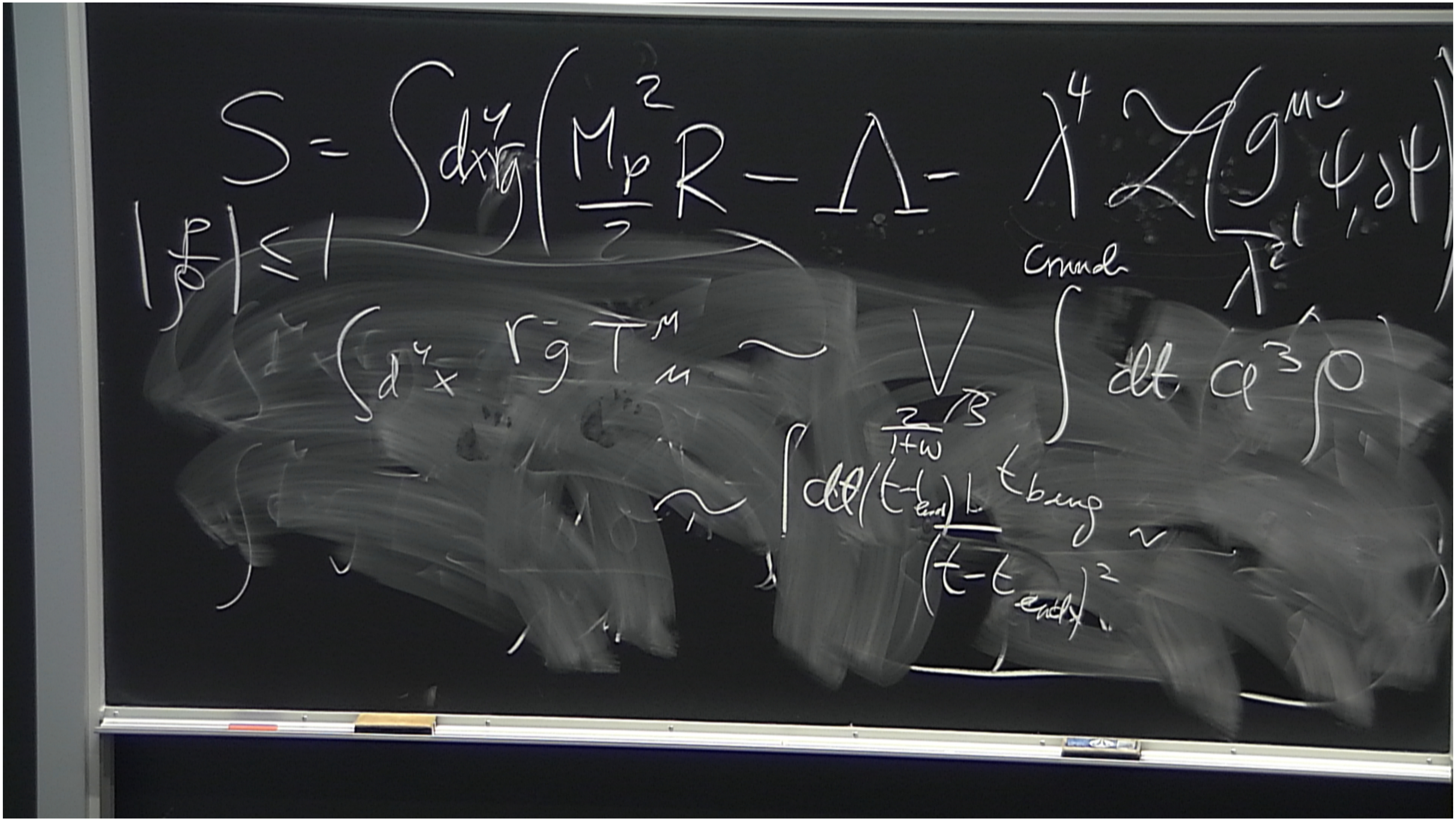
$$\Lambda \to \Lambda - \alpha$$

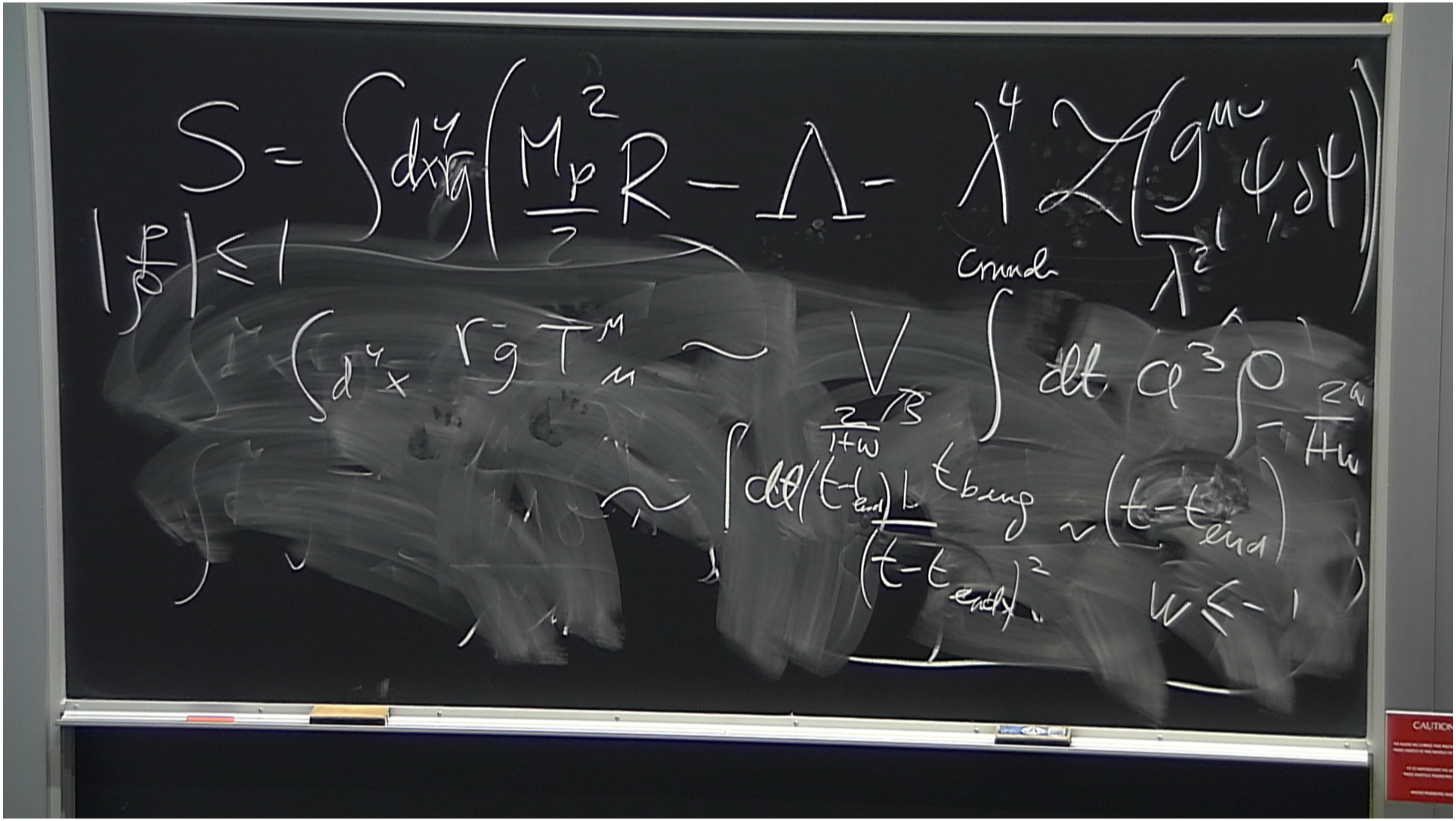
$$\mathcal{L} \to \mathcal{L} + \alpha \lambda^4$$

$$\delta S \to \sigma' \frac{\alpha}{M^4} \propto \alpha \left(\frac{M_{phys}}{M_{Pl}} \right)^4$$

$$S = \int d^4x \sqrt{g}\left(\frac{M_p^2}{2} R - \Lambda - \lambda^4 \mathcal{L}\left(\frac{g^{\mu\nu}}{\lambda^2}, \phi, \partial\phi\right)\right)$$

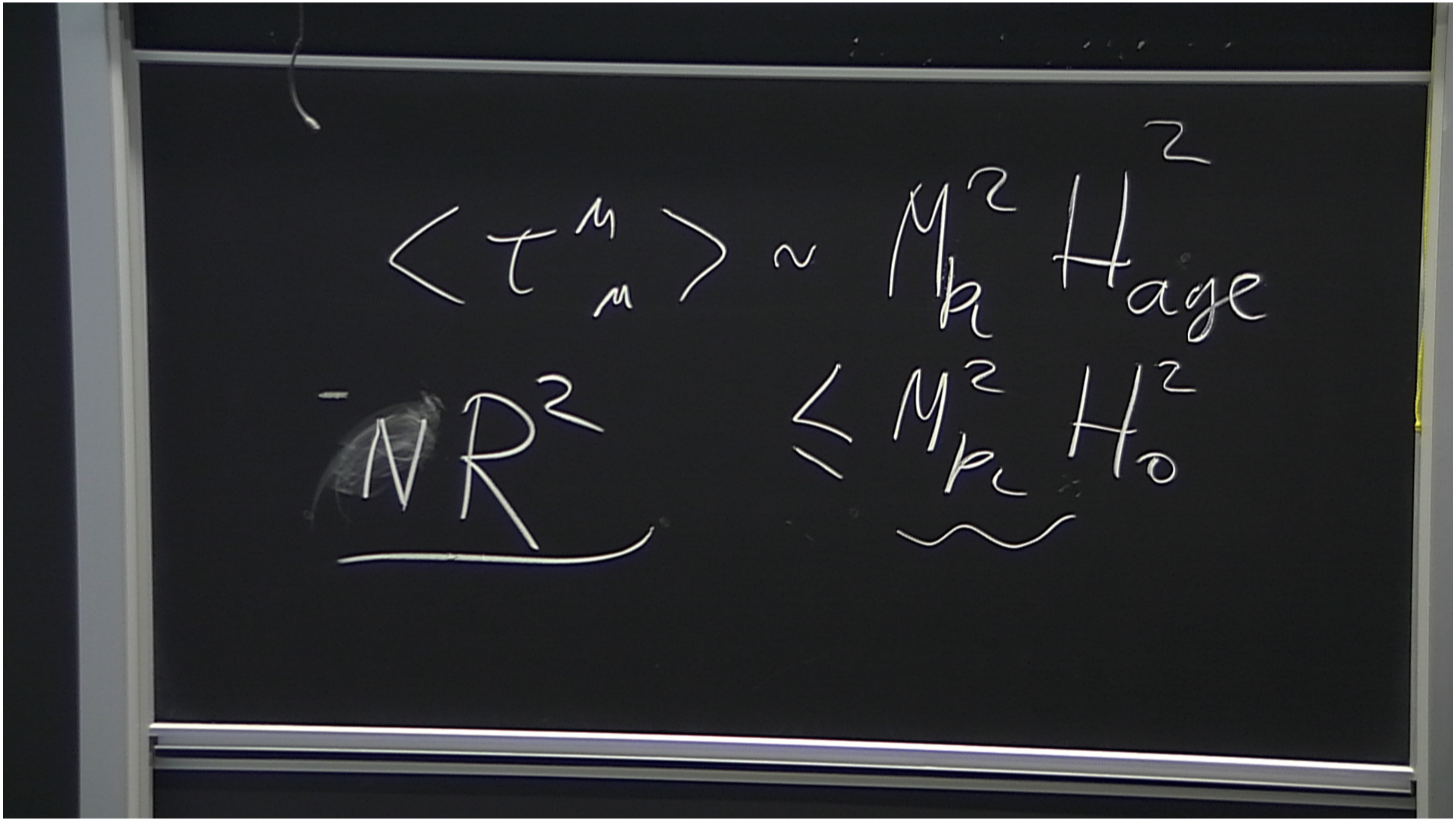
$$\int d^4x \sqrt{g}\, T^{\mu}_{\mu} \sim V_3 \int dt\, a^3 \rho$$


S = ∫d⁴x √g (M_p²/2 R − Λ − λ⁴ ℒ(g^{μν}/λ², φ, ∂φ))
|ṗ/ρ| ≤ 1
∫d⁴x √g T^μ_μ ~ V_3 ∫ dt a³ ρ
crunch
∫dt (t−t_end)^{2/(1+w)} 1/(t−t_end)²
t_bang


$S = \int d^4x \sqrt{g}\left(\frac{M_p^2}{2}R - \Lambda - \lambda^4 \mathcal{L}\left(\frac{g^{\mu\nu}}{\lambda^2}, \psi, \partial\psi\right)\right)$
$\left|\frac{p}{\rho}\right| \le 1$
Crunch
$\int d^4x \sqrt{g}\, T^\mu_\mu \sim V_3 \int dt\, a^3 \rho$
$\frac{2}{1+w}$
$-\frac{2w}{1+w}$
$\sim \int dt\, (t-t_{end}) \frac{1}{(t-t_{end})^2}$
$t_{bang} \sim (t-t_{end})$
$w \le -1$

$$\langle \tau^{\mu}{}_{\mu} \rangle \sim M_{pl}^2 H_{age}^2$$

$$\leq M_{pl}^2 H_0^2$$


$\langle \tau^{\mu}_{\ \mu} \rangle \sim M_{pl}^2 H_{age}^2$
$NR^2 \leq M_{pl}^2 H_0^2$