

Title: 13/14 PSI - Cosmology Review - Lecture 8

Date: Feb 07, 2014 11:30 AM

URL: <http://pirsa.org/14020014>

Abstract:



Galaxy Cluster Abell 2218

HST • WFPC2

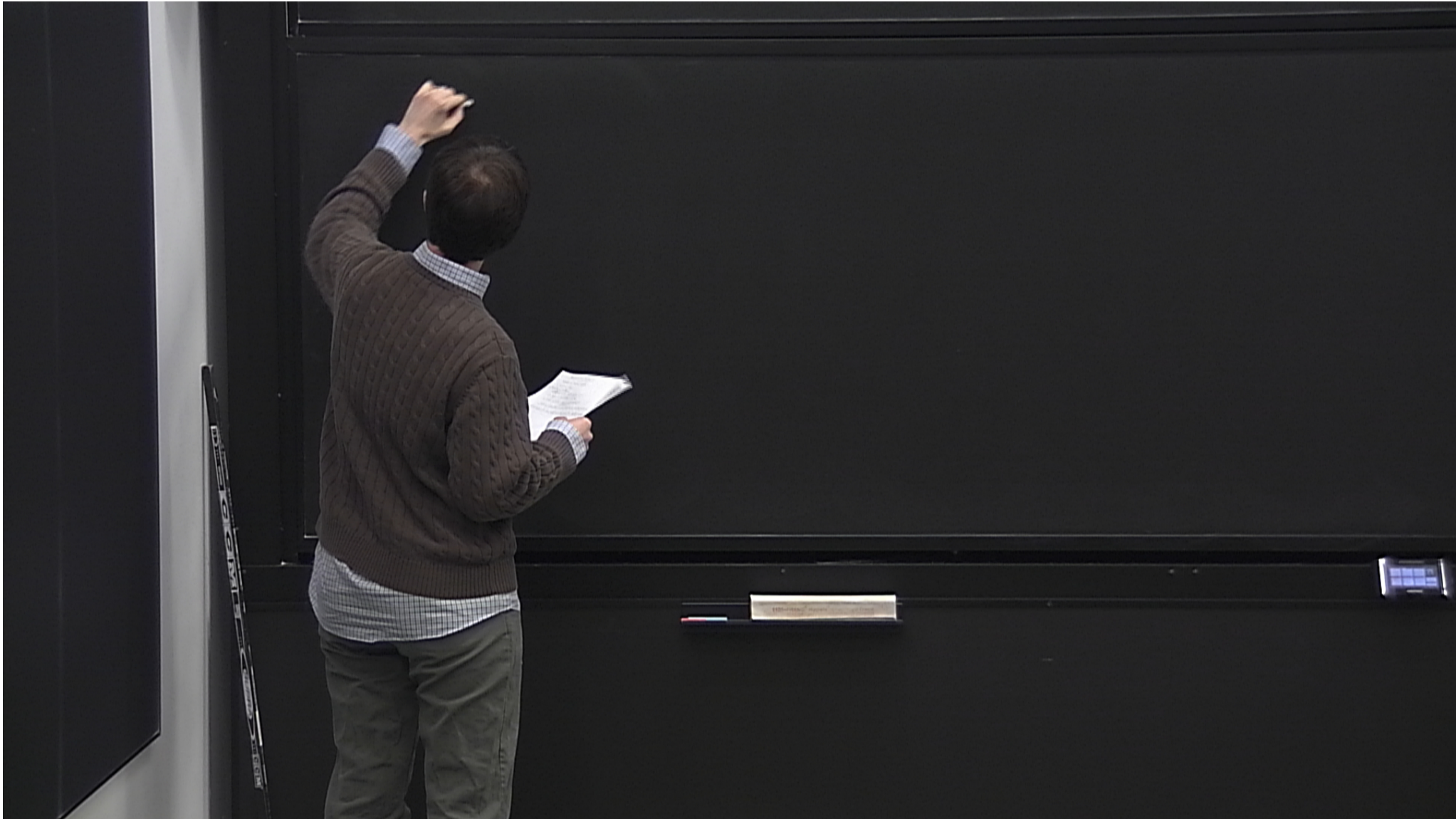
NASA, A. Fruchter and the ERO Team (STScI, ST-ECF) • STScI-PRC00-08

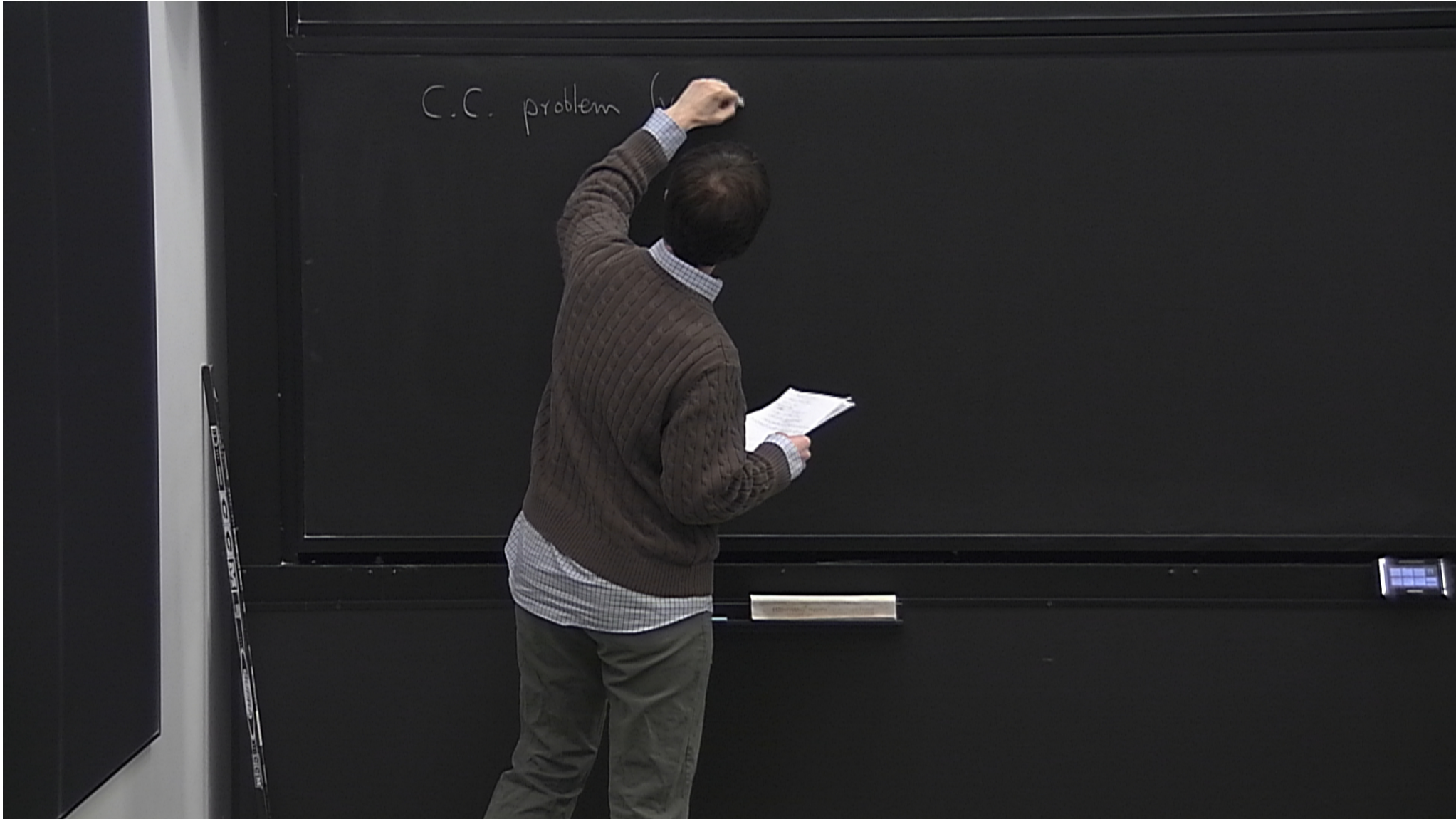


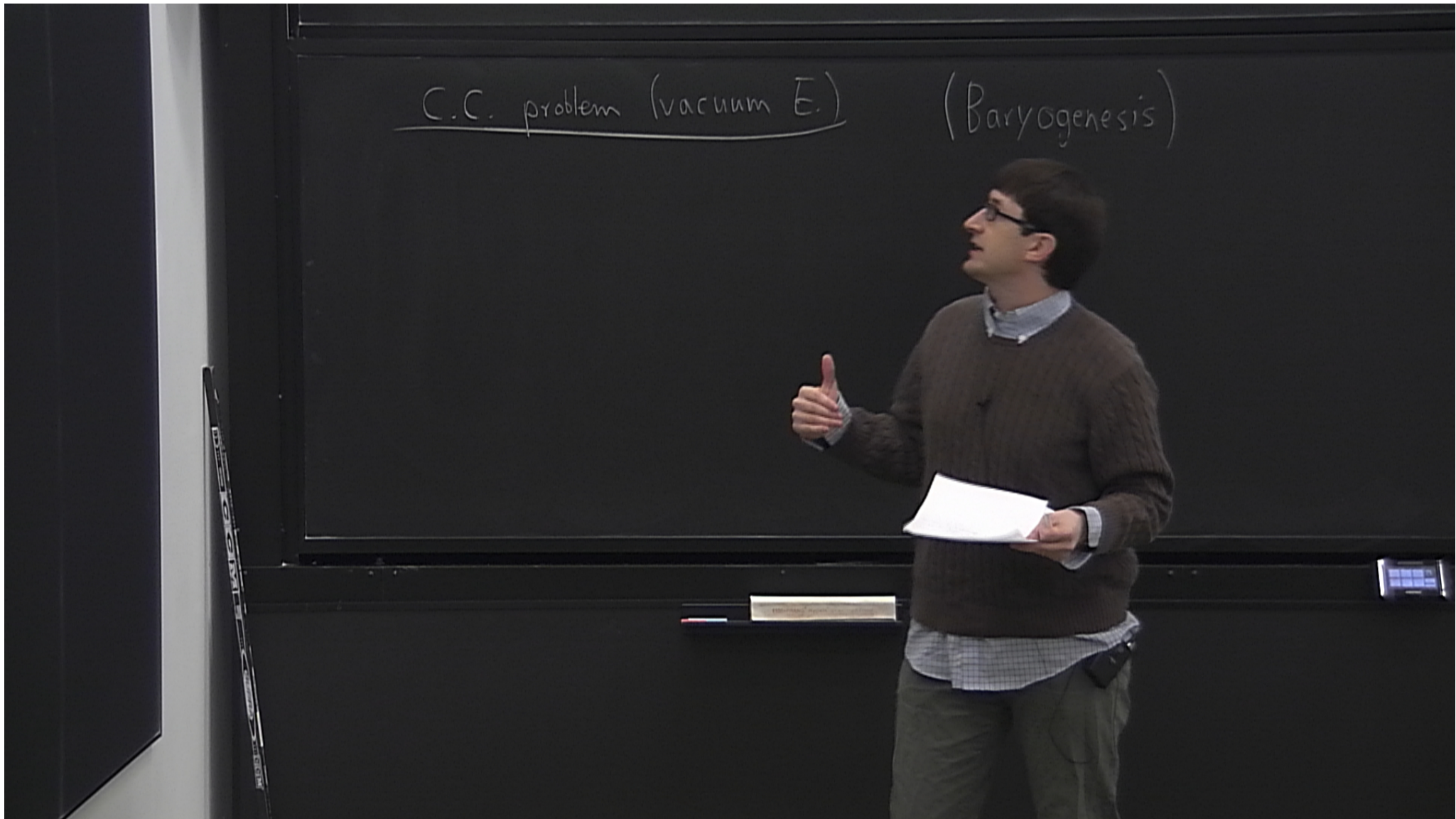
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C.C. problem (vacuum E.)

(Baryogenesis)

$$S = \int d^4x \sqrt{-g} \left[\frac{R - 2\Lambda}{16\pi G} \right]$$

C.C. problem (vacuum E.)

(Baryogenesis)

$$S = \int d^4x \sqrt{g} \left[\frac{R - 2\Lambda}{16\pi G_N} + L_{\text{matter}} \right]$$

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G_N T_{\mu\nu}$$

C.C. problem (vacuum E.) (Baryogenesis)

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$$\cancel{G_{\mu\nu} + \Lambda g_{\mu\nu}} = 8\pi G_N T_{\mu\nu} - \Lambda g_{\mu\nu} = 8\pi G_N T'_{\mu\nu}$$

C.C. problem (vacuum E.)

(Baryogenesis)

$$S = \int d^4x \sqrt{g} \left[\frac{R - 2\Lambda}{16\pi G_N} + \text{matter} - \frac{1}{2}(\partial_\mu \phi)^2 - V(\phi) \right]$$

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi$$

$$g_{\mu\nu} = 8\pi G_N T'_{\mu\nu}$$

C.C. problem (vacuum E.) (Baryogenesis)

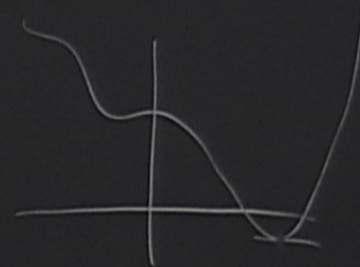
$$S = \int d^4x \sqrt{g} \left[\frac{R - 2\Lambda}{16\pi G_N} + \cancel{\mathcal{L}_{\text{matter}}} - \frac{1}{2}(\partial_\mu \phi)^2 - V \right]$$

$$\cancel{G_{\mu\nu} + \Lambda g_{\mu\nu}} = 8\pi G_N T_{\mu\nu} - \Lambda g_{\mu\nu} = 8\pi G_N T'_{\mu\nu}$$

C.C. problem (vacuum E.) (Baryogenesis)

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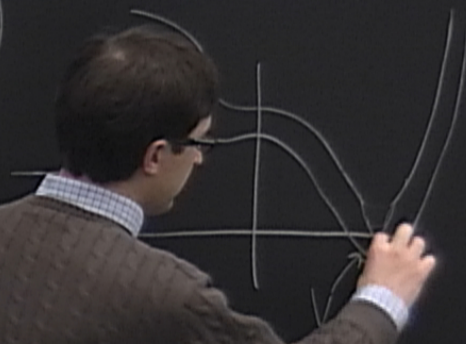
$$\cancel{G_{\mu\nu} + \Lambda g_{\mu\nu}} = 8\pi G_N T_{\mu\nu} - \Lambda g_{\mu\nu} = 8\pi G_N T_{\mu\nu}$$



C.C. problem (vacuum E.) (Baryogenesis)

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$$\cancel{G_{\mu\nu} + \Lambda g_{\mu\nu}} = 8\pi G_N T_{\mu\nu} - \Lambda g_{\mu\nu} = 8\pi G_N T'_{\mu\nu}$$



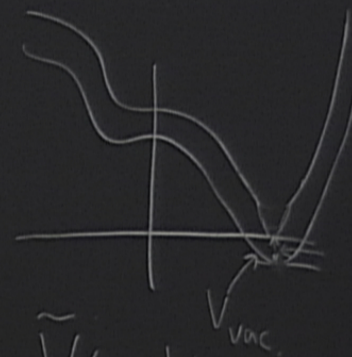
C.C. problem (vacuum E.)

(Baryogenesis)

$$S = \int d^4x \sqrt{g} \left[\frac{R-2\Lambda}{16\pi G} - \cancel{\mathcal{L}_{\text{matter}}} - \frac{1}{2}(\partial_\mu \phi)^2 - V(\phi) \right]$$

$$G_{\mu\nu} + \Lambda g_{\mu\nu}$$

$$-\Lambda g_{\mu\nu} = 8\pi G_{\mu\nu} T'_{\mu\nu}$$



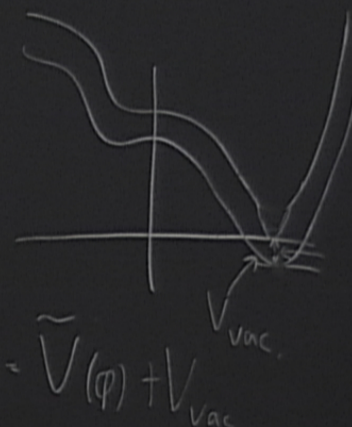
$$V(\phi) = \tilde{V}(\phi) + V_{\text{vac}}$$

C.C. problem (vacuum E.)

(Baryogenesis)

$$= \int d^4x \sqrt{g} \left[\frac{R - 2\Lambda}{16\pi G_N} + \cancel{\mathcal{L}_{\text{matter}}} - \frac{1}{2}(\partial_\mu \phi)^2 - V(\phi) \right]$$

$$\cancel{G_{\mu\nu}} + \cancel{\Lambda g_{\mu\nu}} = 8\pi G_N T_{\mu\nu} - \Lambda g_{\mu\nu} = 8\pi G_N T'_{\mu\nu}$$

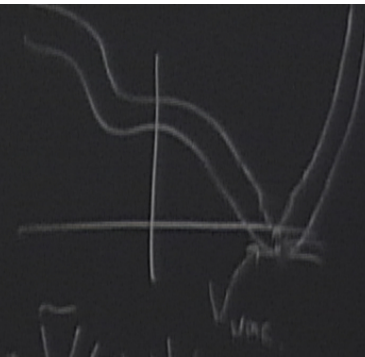


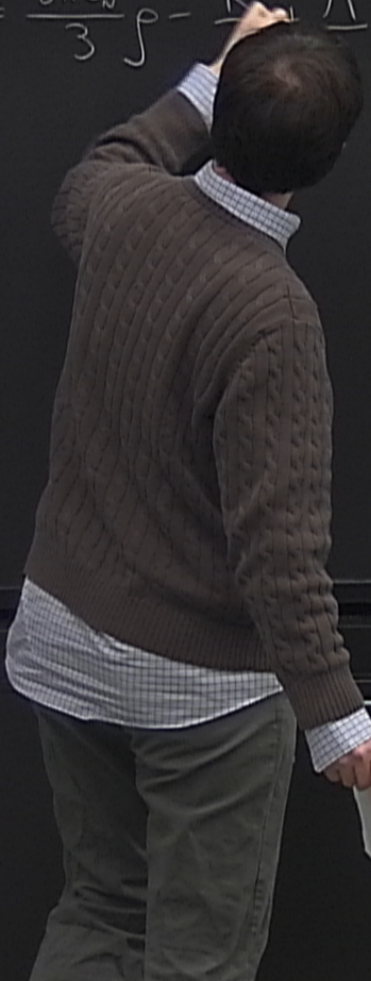
(Baryogenesis)

$$S = \int d^4x \sqrt{g} \left[\frac{R - 2\Lambda}{16\pi G_N} + \cancel{L_{matter}} - \frac{1}{2}(\partial_\mu \phi)^2 - V(\phi) \right]$$

$$G_{\mu\nu} + \cancel{\Lambda g_{\mu\nu}} = 8\pi G_N T_{\mu\nu} \quad \cancel{g_{\mu\nu}} = 8\pi G_N T'_{\mu\nu}$$

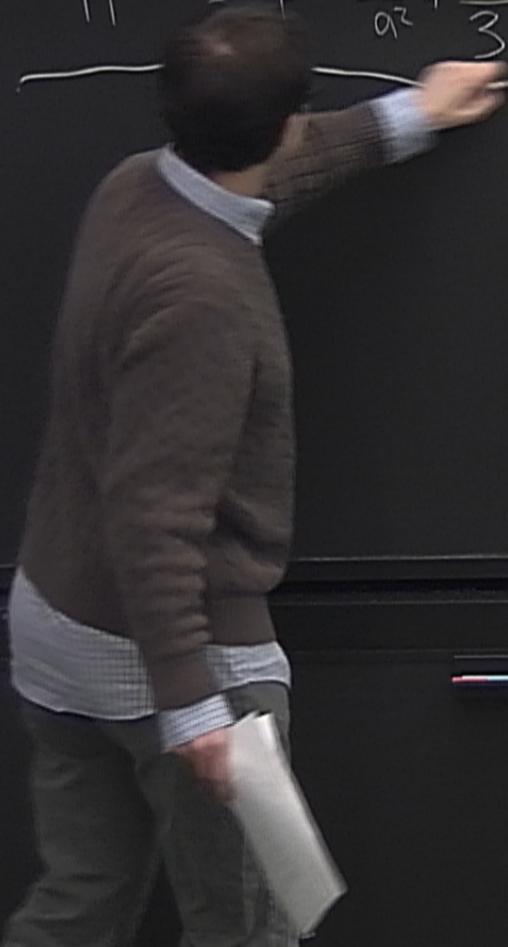
$$V(\phi) = \tilde{V}(\phi) + V_{vac}$$





A man in a brown cable-knit sweater and grey trousers is standing in front of a large blackboard. He is writing the equation $H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \Lambda$ on the board with his right hand. He is holding a piece of paper in his left hand. The blackboard is dark and has a small digital display on the right side.

$$H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \Lambda$$

A man with dark hair, wearing a brown sweater over a light-colored collared shirt and grey trousers, stands in front of a large black chalkboard. He is pointing with his right hand towards the equation written on the board. In his left hand, he holds a white sheet of paper. The chalkboard is mostly black, with the equation and a horizontal line drawn in white chalk. Below the board, a small digital display and some papers are visible on a ledge.
$$H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \frac{\Lambda}{3}$$

$$H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \frac{\Lambda}{3}$$

H_0

$$H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \frac{\Lambda}{3}$$

$$H_0 \rightarrow \rho_{\text{crit}} = \frac{3H_0^2}{8\pi G_N}$$

ρ_m

$$H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \frac{\Lambda}{3}$$

$$H_0 \rightarrow \frac{H_0^2}{8\pi G_N}$$

$$\rho_{dm} = 0.3$$

$$H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \frac{\Lambda}{3}$$

$$H_0 \rightarrow \rho_{\text{crit}} = \frac{3H_0^2}{8\pi G_N}$$

$$\rho_b + \rho_{\text{dm}} = 0.3 \rho_{\text{crit}}$$

$$H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \frac{\Lambda}{3}$$

$$H_0 \rightarrow \frac{3H_0^2}{8\pi G_N} = 0.3 \rho_{\text{crit}}$$

$$H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \frac{\Lambda}{3}$$

$$H_0 \rightarrow \rho_{crit} = \frac{3H_0^2}{8\pi G_N}$$

$$\rho_m = \rho_b + \rho_{dm} = 0.3$$

6 billion yrs.

$\sim 10^{11}$ stars

12 billion

13 billion

$$H^2 = \frac{8\pi G_N}{3} \rho - \frac{K}{a^2} + \frac{\Lambda}{3}$$

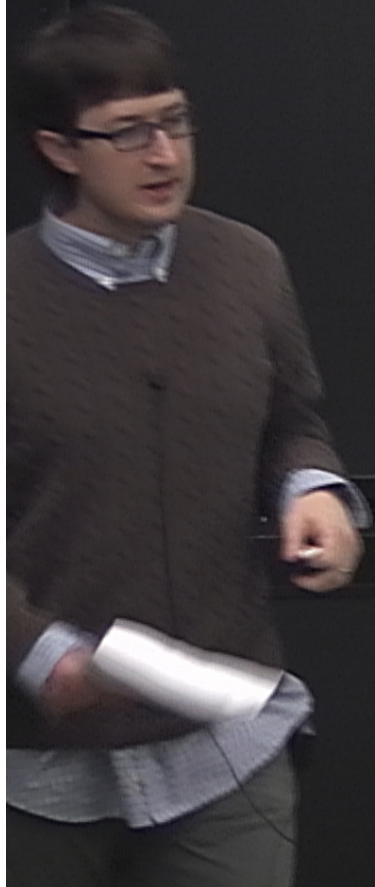
$$\rho_{\text{crit}} = \frac{3H_0^2}{8\pi G_N}$$

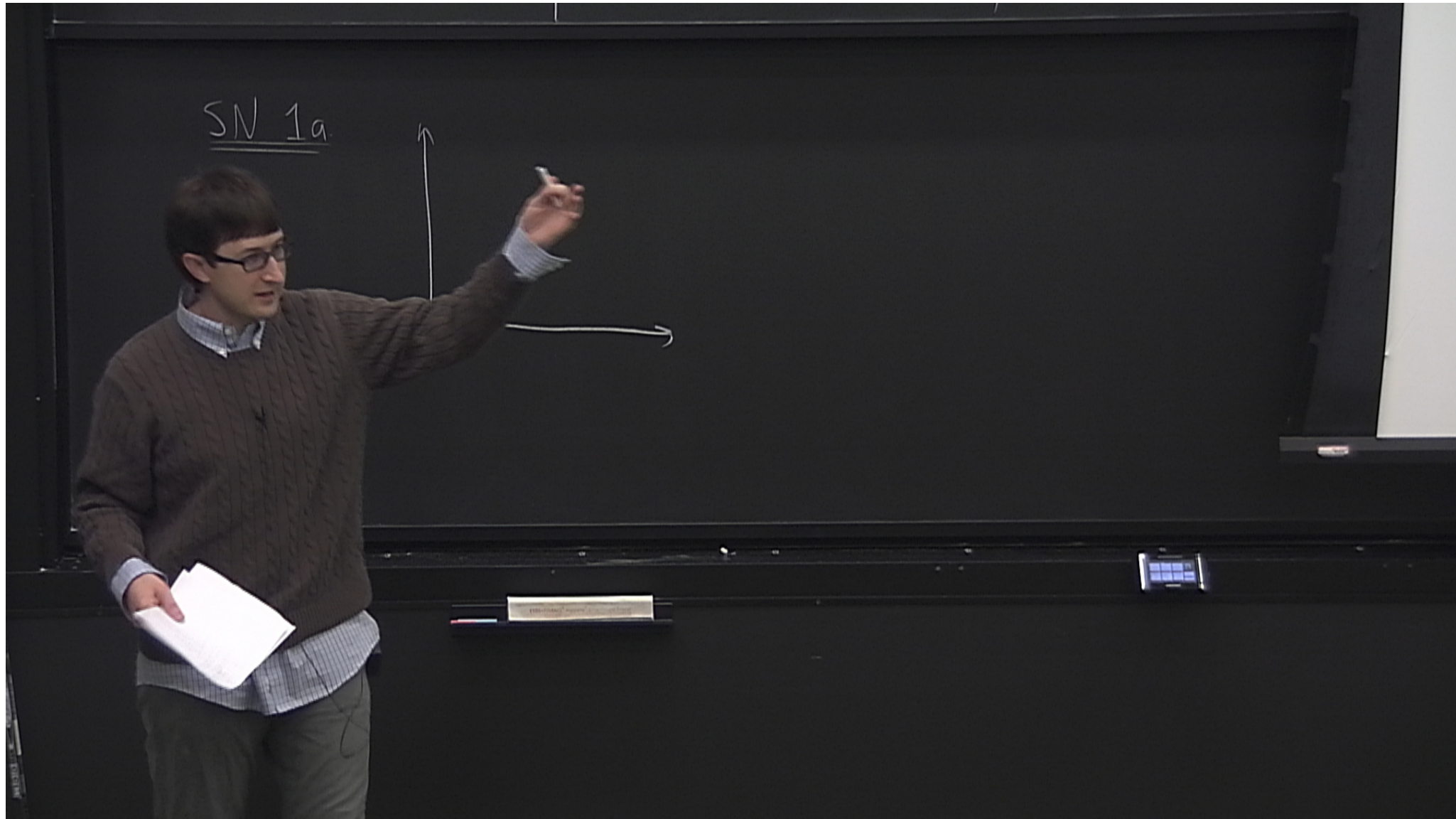
$$\rho_m = 0.3 \rho_{\text{crit}}$$

$t_0 = 8$ billion yrs.

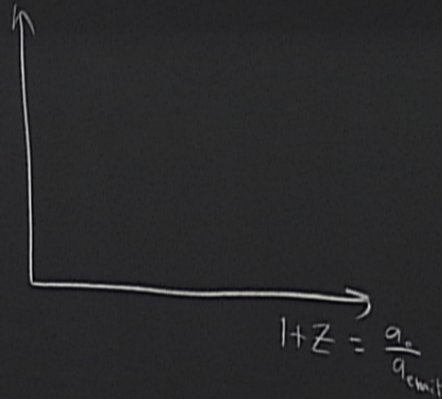
$\circ \quad \circ \ll 10^3$ stars 12 billion
 $\circ \quad \circ$ 13 billion
 $\circ$

SN 1a

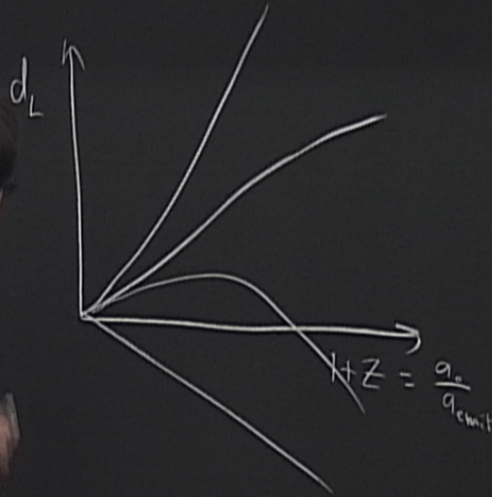


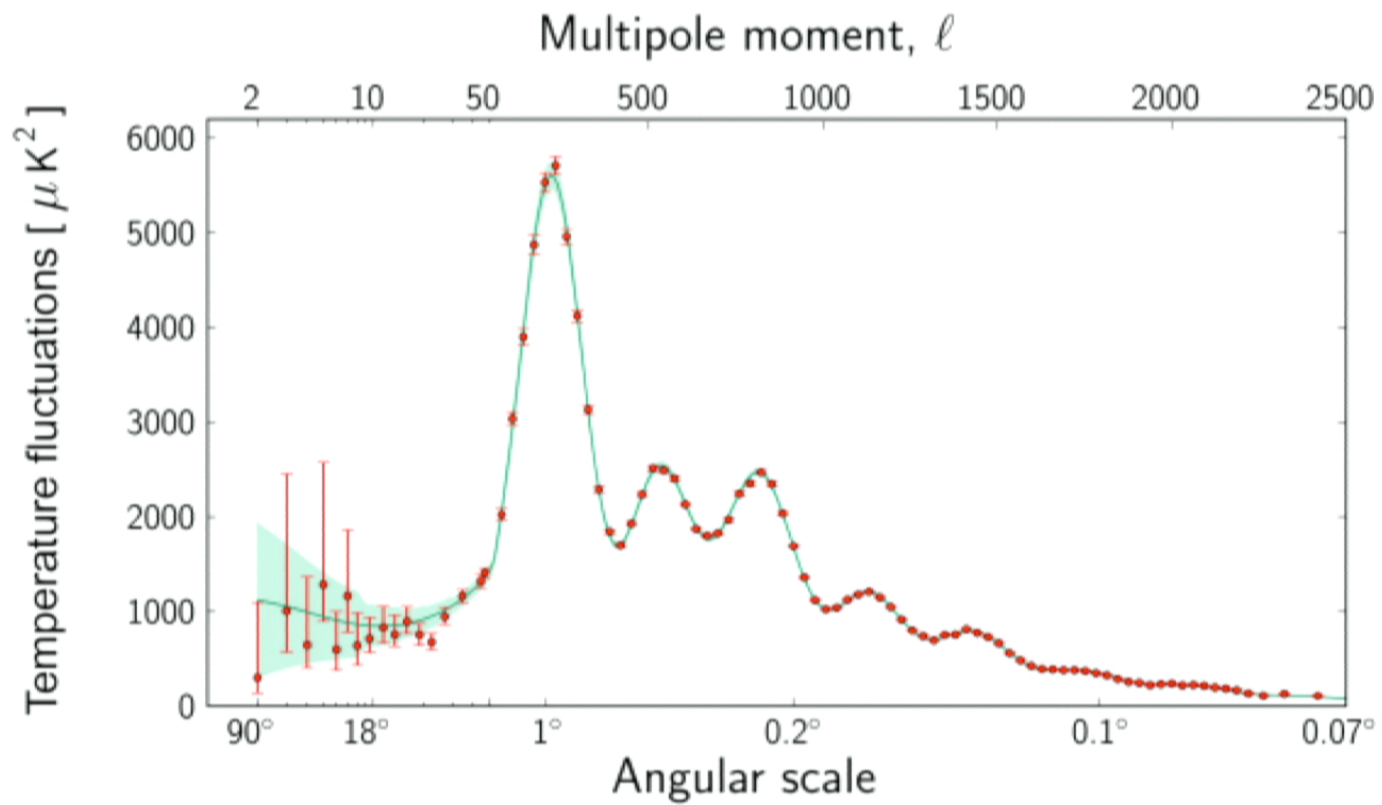


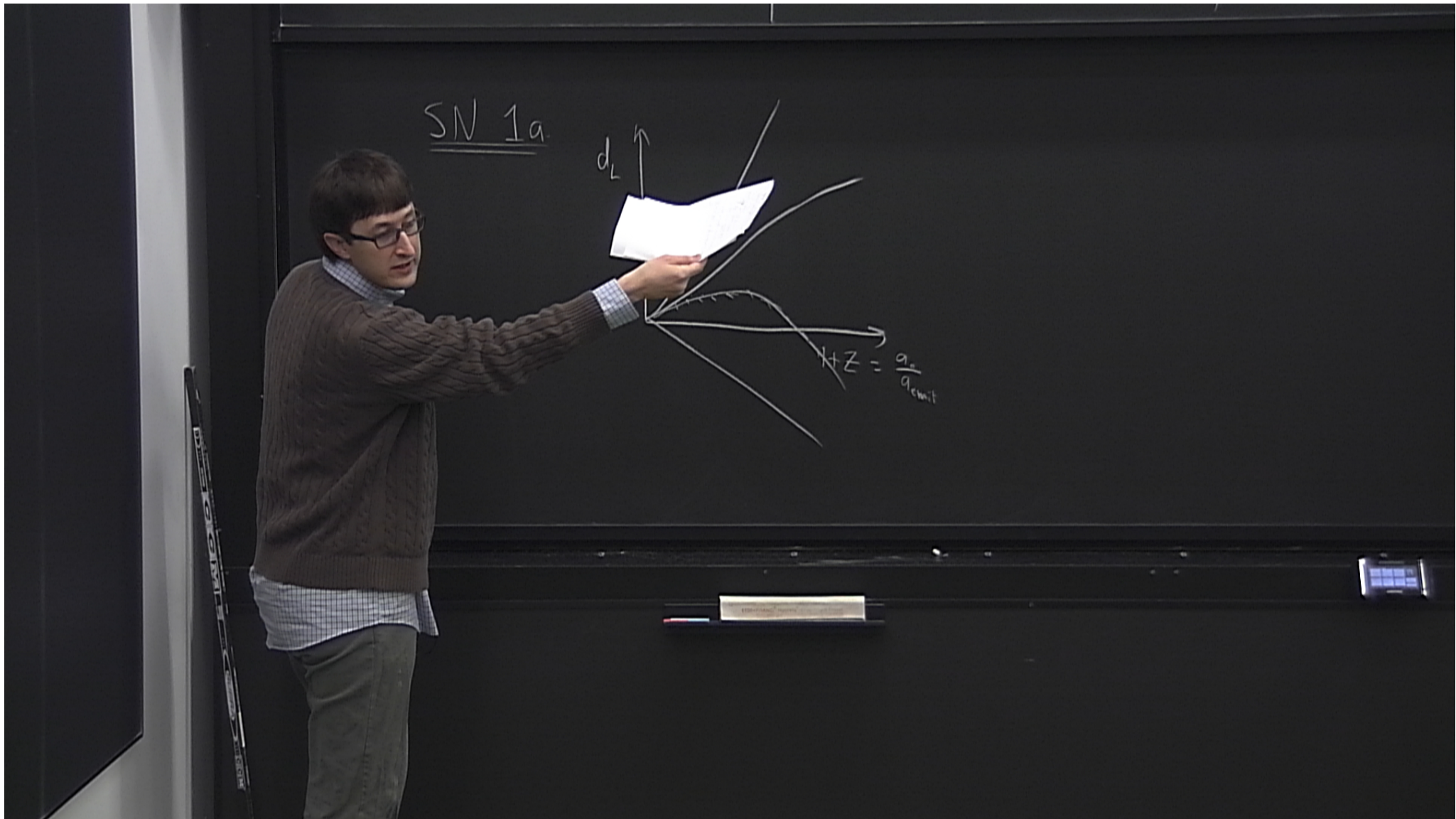
SN 1a


$$1+Z = \frac{q_e}{q_{\text{emit}}}$$

SN 1a







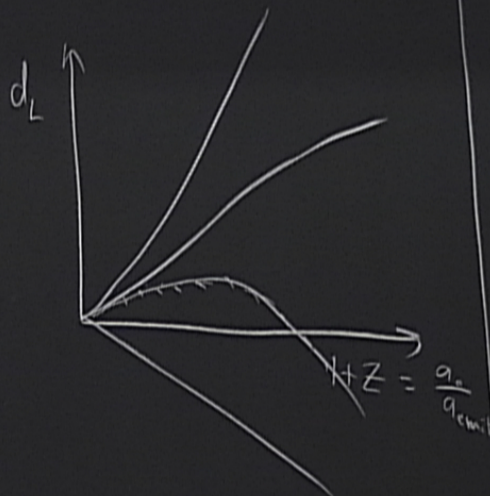
SN 1a

$$K=0$$

p_m, p_h

$$p_m = 0.3$$

$$p_h = 0.7$$



"old"

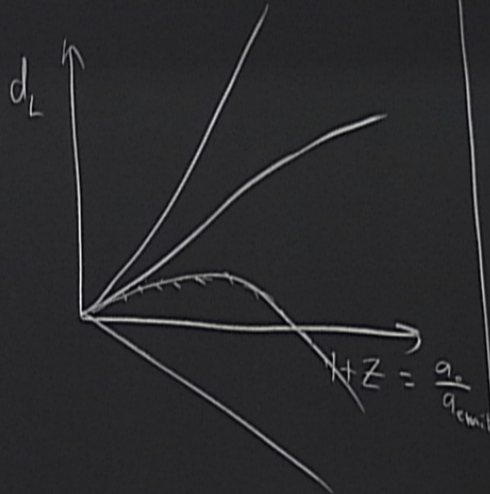
SN 1a

$$K=0$$

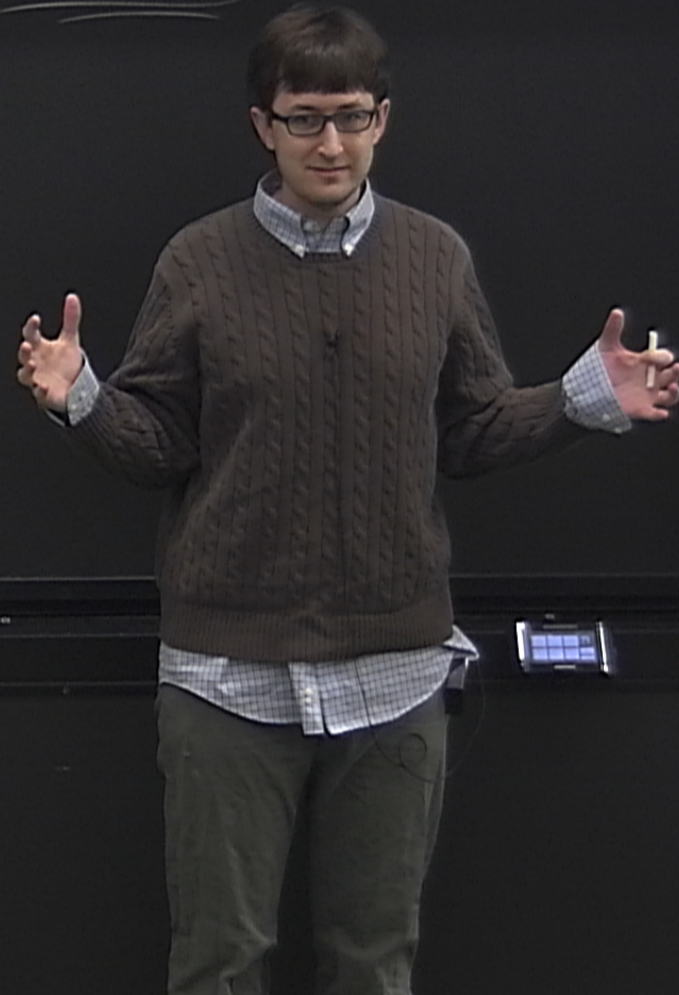
p_m, p_h

$$p_m = 0.3$$

$$p_h = 0.7$$



"old" + "new"



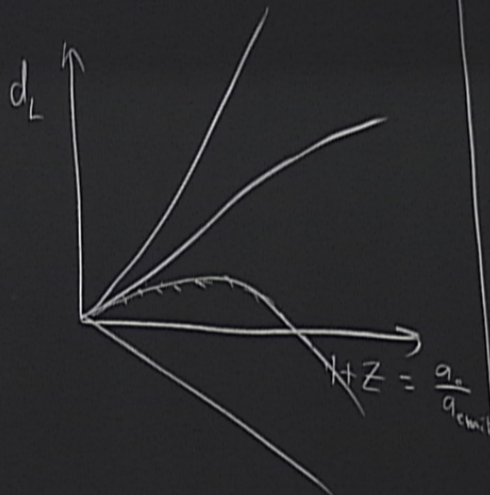
SN 1a

$$K=0$$

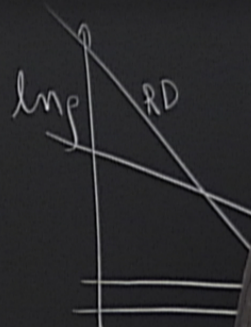
p_m, p_n

$$p_m = 0.3$$

$$p_n = 0.7$$



"old" + "new"



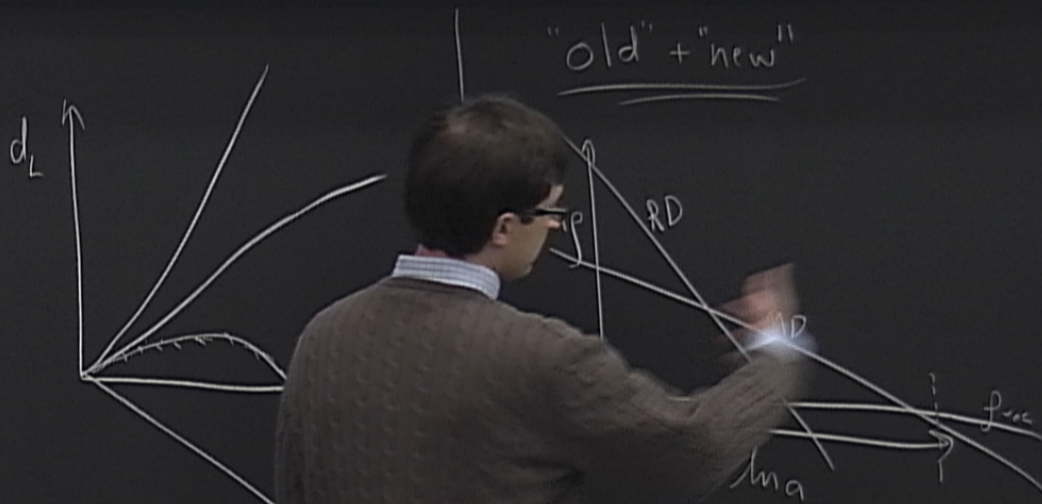
SN 1a

$$K=0$$

p_m, p_n

$$p_m = 0.3$$

$$p_n = 0.7$$



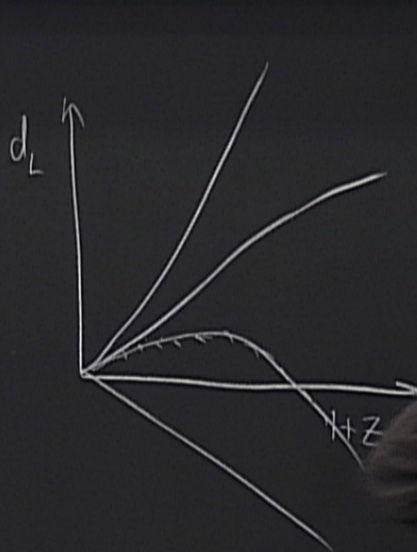
SN 1a

$$K=0$$

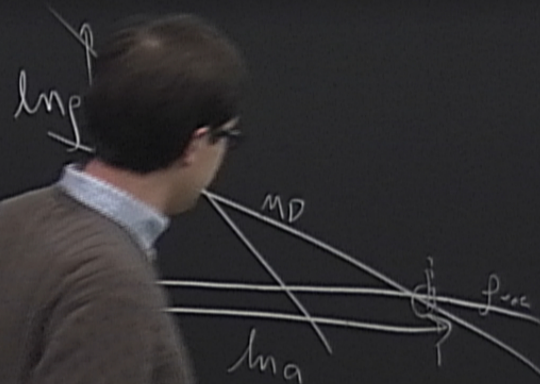
p_m, p_n

$$p_m = 0.3$$

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"old" + "new"



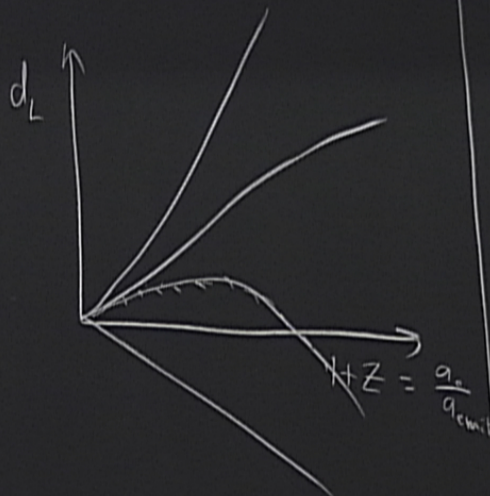
SN 1a

$$K=0$$

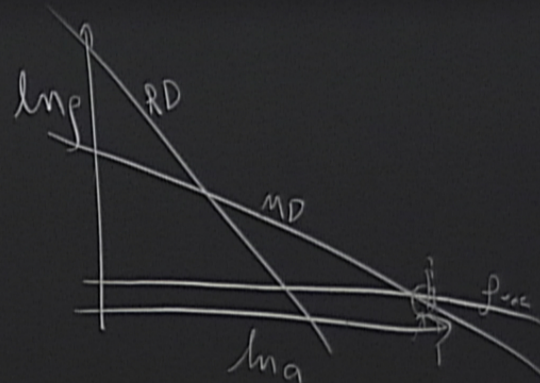
p_m, p_n

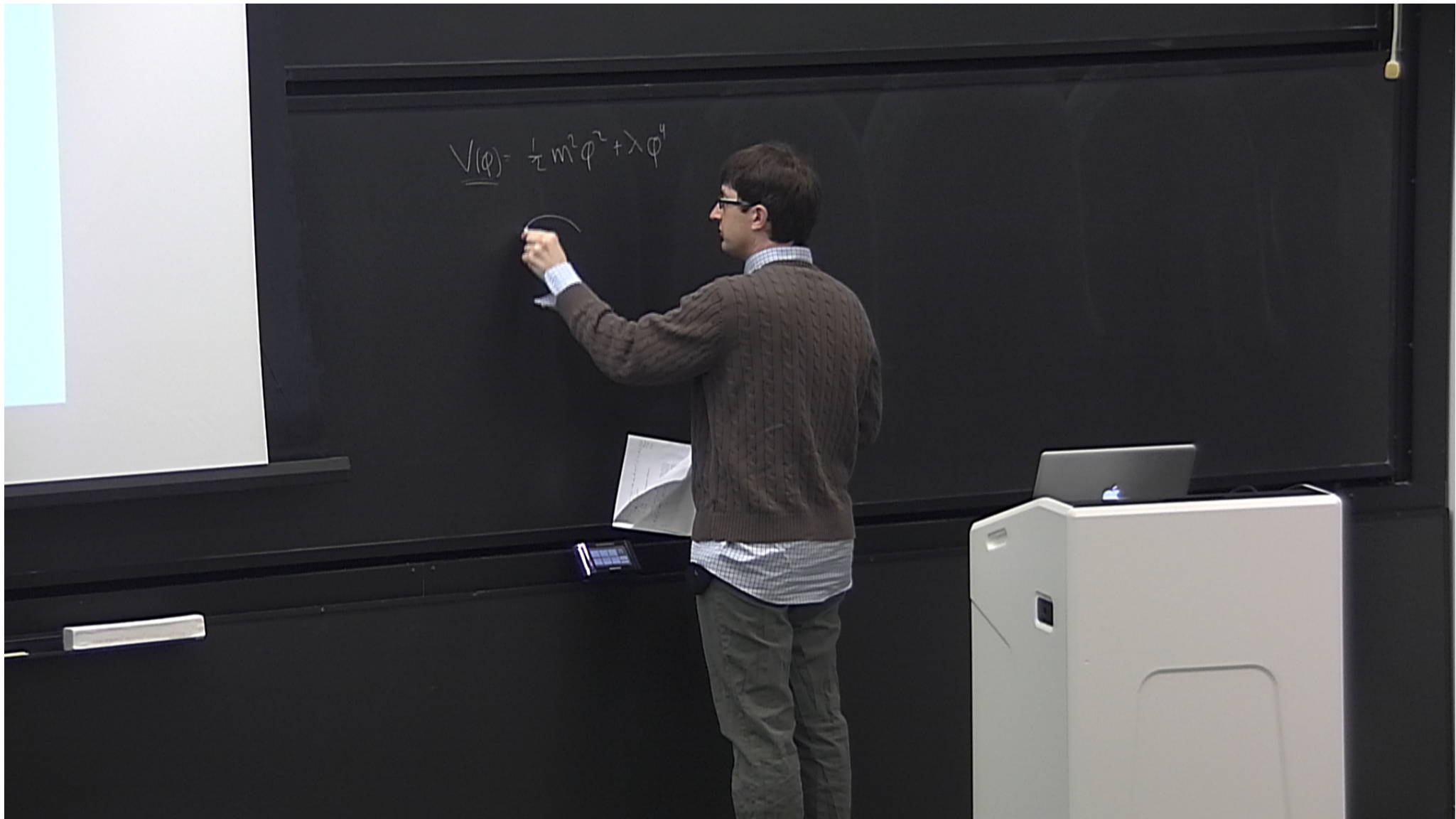
$$p_m = 0.3$$

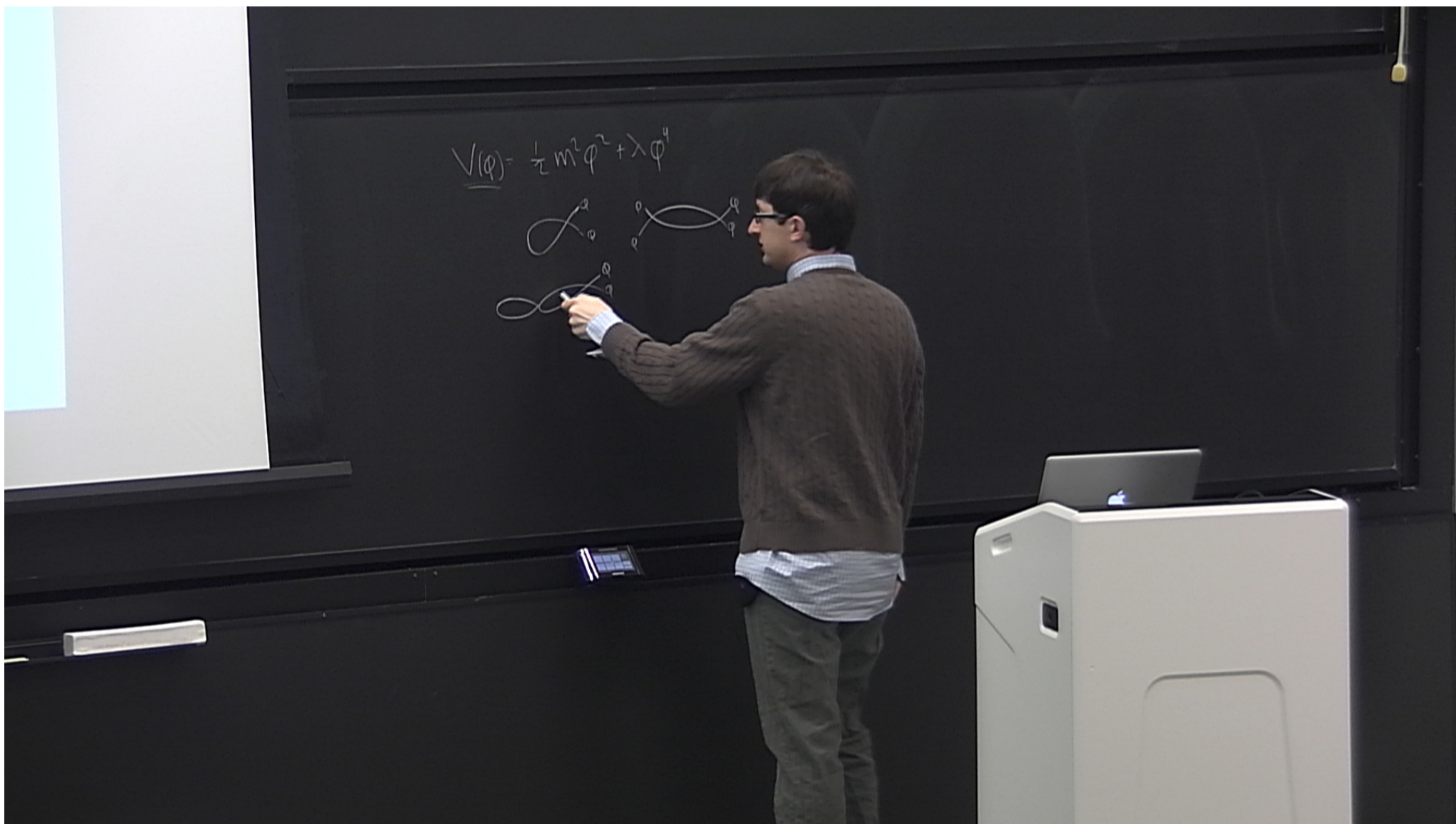
$$p_n = 0.7$$

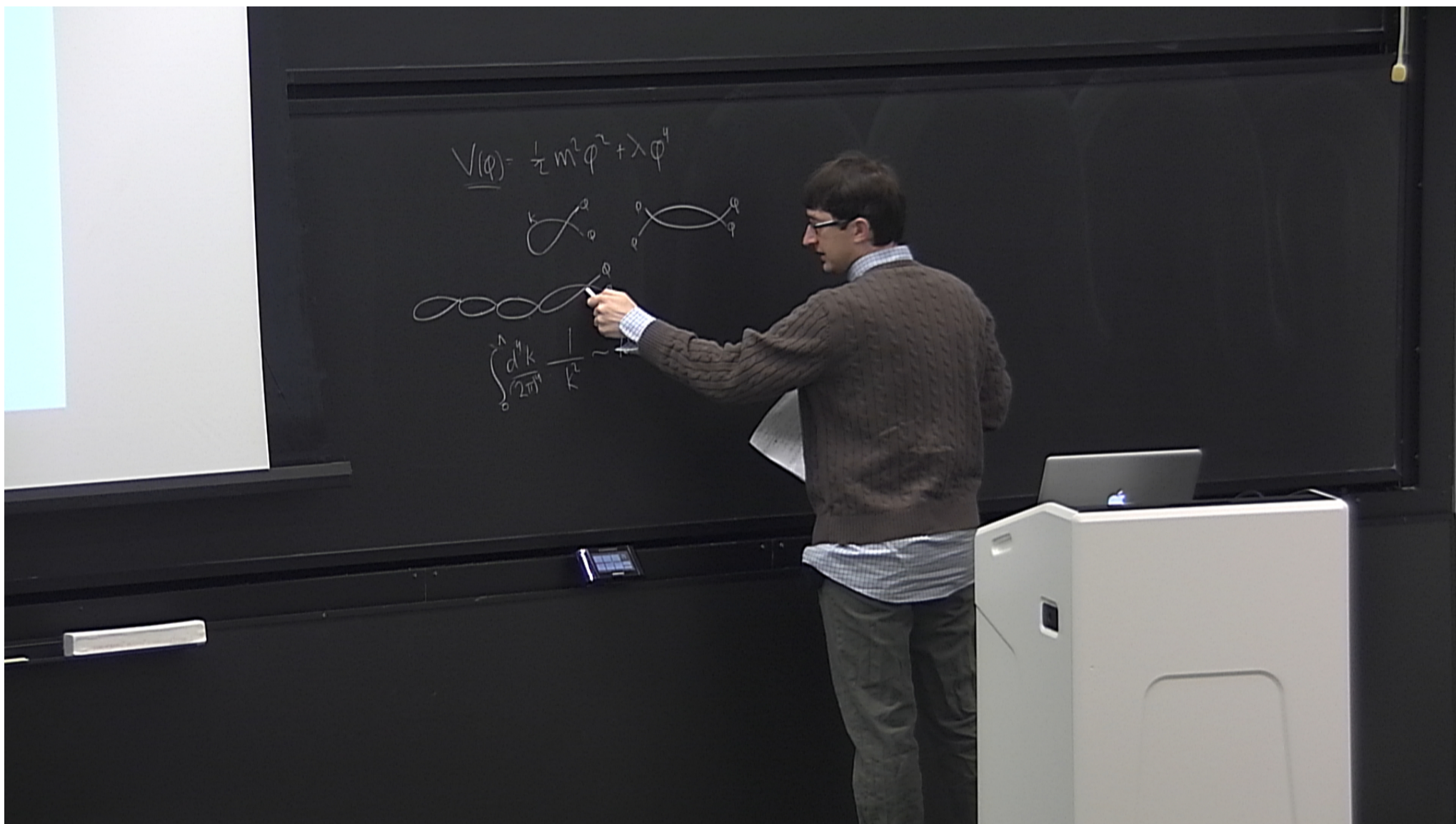


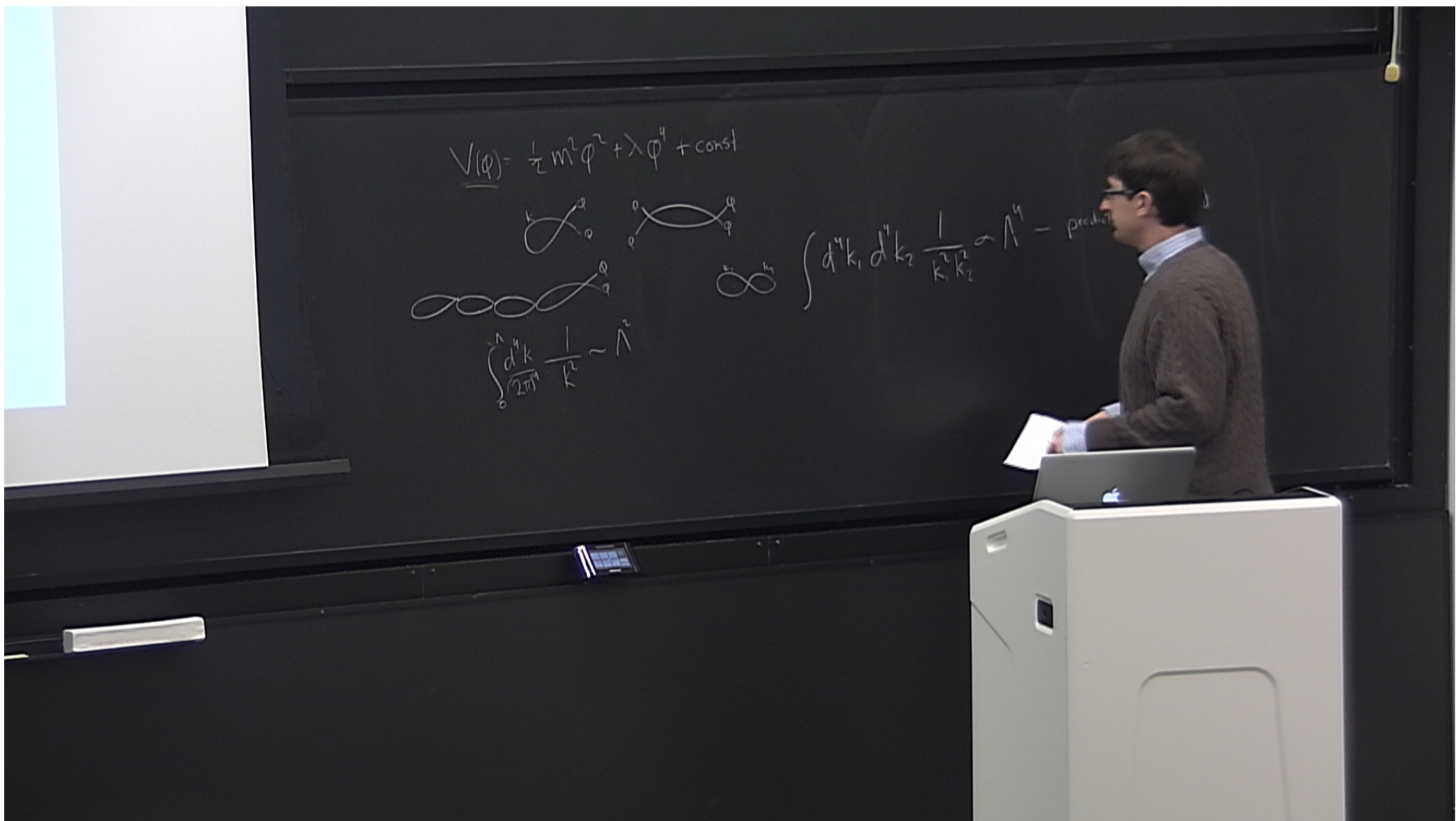
"old" + "new"











$$\underline{V(\phi)} = \frac{1}{2} m^2 \phi^2 + \lambda \phi^4 + \text{const}$$

Feynman diagrams illustrating loop corrections:

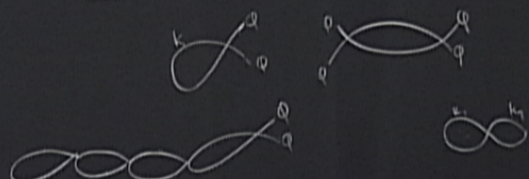
- Self-energy diagram (tadpole): tadpole
- Self-energy diagram (tadpole): tadpole
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- Self-energy diagram (tadpole): tadpole

$$\int d^4 k_1 d^4 k_2 \frac{1}{k_1^2 k_2^2} \sim \Lambda^4 - \text{predict}$$

$$\int \frac{d^4 k}{(2\pi)^4} \frac{1}{k^2} \sim \Lambda^2$$

$$\underline{V(\phi)} = \frac{1}{2} m^2 \phi^2 + \lambda \phi^4 + \text{const}$$

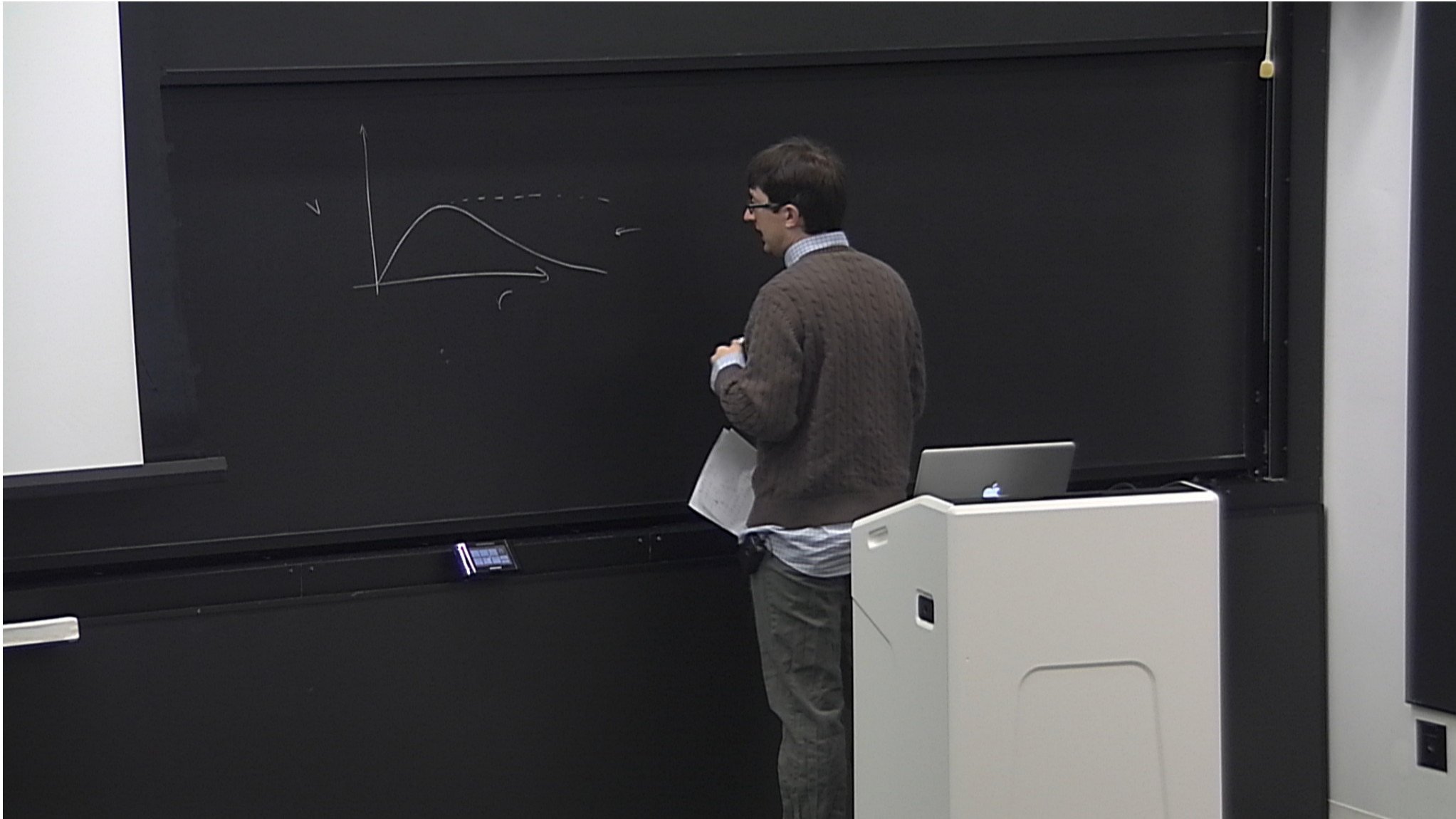
$$\frac{1}{\Lambda} \quad \oplus \left(\frac{1}{\Lambda}\right)^3 \Lambda \tilde{\Lambda}^3 \Lambda^4 \bigg|_R \sqrt{V(x)}$$



Three Feynman diagrams are drawn: a tadpole diagram with a loop, a bubble diagram with two external lines, and a vacuum polarization diagram with two external lines and a loop. Below these is the equation:

$$\int_0^\Lambda \frac{d^4 k}{(2\pi)^4} \frac{1}{k^2} \sim \Lambda^2$$

$$\int d^4 k_1 d^4 k_2 \frac{1}{k_1^2 k_2^2} \sim \Lambda^4 - \text{predicted} \gg \text{observed}$$





$$e^a = e^a_\mu dx^\mu \quad R^a_{\ b\mu\nu} dx^\mu dx^\nu$$

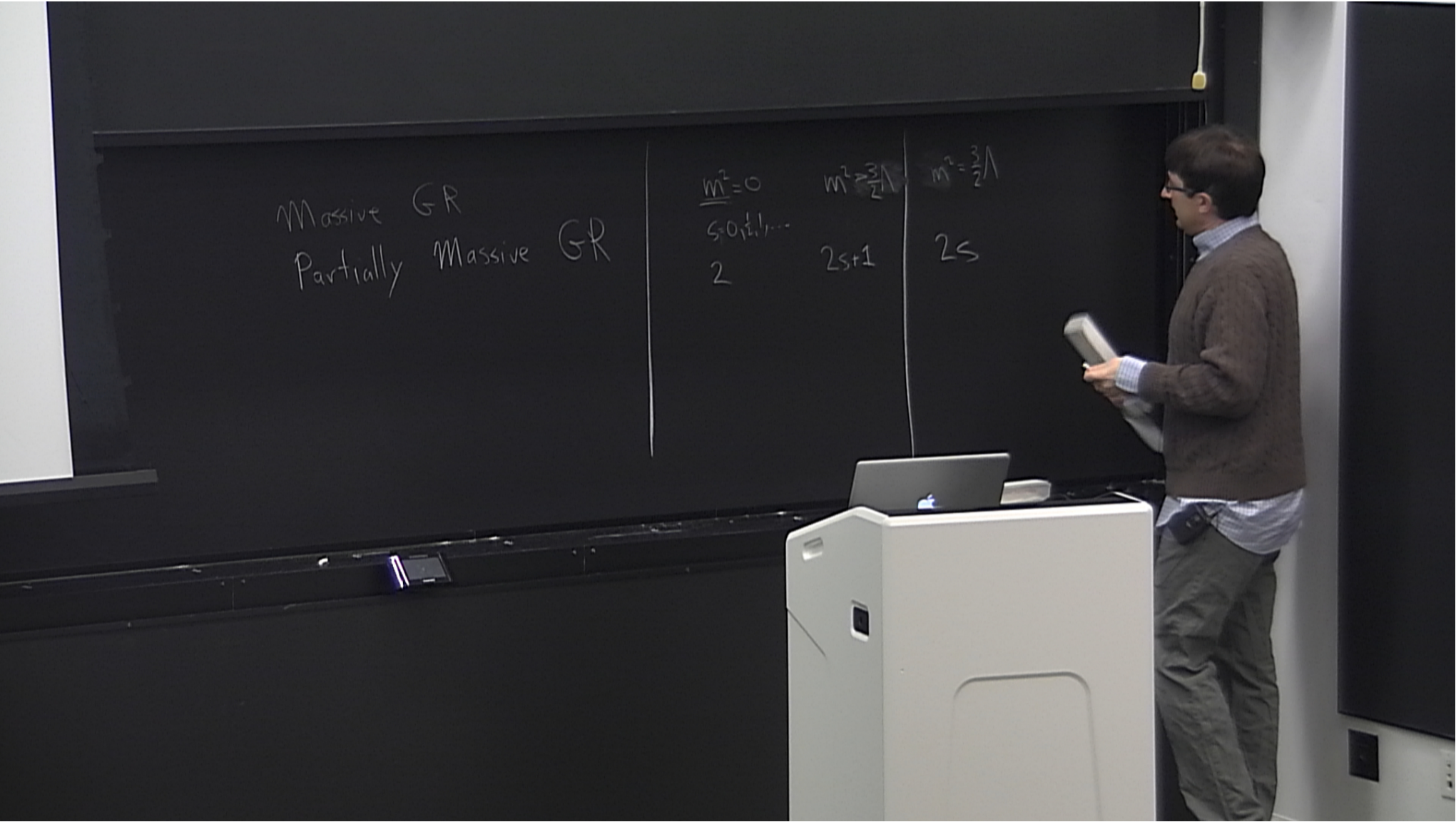
$$\eta_{ab} e^a_\mu e^b_\nu = g_{\mu\nu}$$

$$\int d^4x \sqrt{-g} \frac{R}{16\pi G_N}$$

$$\int R^a_{\ b} e^b_\mu e^c_\nu E^{ab\mu\nu}$$

$$\int e^a_\mu e^b_\nu e^c_\rho e^d_\sigma E^{abcd}$$





Massive GR
Partially Massive GR

$$\underline{m^2=0}$$

$$s=0,1,1,\dots$$

$$2$$

$$m^2=\frac{3}{2}\Lambda$$

$$2s+1$$

$$m^2=\frac{3}{2}\Lambda$$

$$2s$$