

Title: Review on Proposed Models for Dark Energy 2

Date: May 11, 2010 10:00 AM

URL: <http://pirsa.org/10050012>

Abstract:

C.C Problem:

C.C. Problem:

$$\Omega_{\Lambda} \sim 0.7 \rightarrow \rho_{\Lambda} \sim 10^{-47} \text{ (GeV)}^4$$

$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim 1$$

CC Problem:

$$\Omega_{\Lambda} \sim 0.7 \rightarrow \rho_{\Lambda} \sim 10^{-47} \text{ (GeV)}^4$$

$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim 1$$

$$\rho \sim$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cl. off}})^4$$

CC Problem:

$$\Omega_{\Lambda} \sim 0.7 \rightarrow \rho_{\Lambda} \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_{\Lambda} \sim (\Lambda_{\text{cut off}})^4$$

$$\Delta \rho_{\Lambda} \sim (100 \text{ GeV})^4$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cutoff}})^4$$

$$\Delta \rho_{\text{f.w.}} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cut off}})^4$$

$$\Delta \rho_{\text{EW}} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Lambda + \Delta \rho_{\text{EW}} \sim \Lambda_{\text{eff}} 10^{-47} \text{ units}$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cut off}})^4$$

$$\Delta \rho_{\text{eff}} \sim (300 \text{ GeV})^4 \sim 10^9 (\text{GeV})^4$$

$$\Lambda_{\text{eff}} \Delta \rho_{\text{eff}} \sim \Lambda_{\text{eff}} 10^{-47} (\text{GeV})^4$$



$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cutoff}})^4$$

$$\Delta \rho_{\text{EW}} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho = \Lambda_{\text{cutoff}}^4 + \Delta \rho_{\text{EW}} \sim \Lambda_{\text{eff}}^4 10^{-57} \text{ units}$$



$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cut off}})^4$$



$$\Delta \rho_{\text{EW}} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{\text{cut}} = \Lambda_{\text{eff}} + \Delta \rho_{\text{EW}} \sim \Lambda_{\text{eff}} 10^{-47} (\text{GeV})^4$$

$$S_L \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} \text{ (GeV)}^4$$

$$\rho_m \sim 0.3$$

$$\rho_{tot} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{cut-off})^4$$



$$\Delta \rho_{(EW)} \sim (300 \text{ GeV})^4 \sim 10^9 \text{ (GeV)}^4$$

$$\Delta \rho_{(EW)} \sim \Lambda_{cut-off}^4$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cut off}})^4$$

$$\Delta \rho_{\text{EW}} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{\text{cut}} = \Lambda_{\text{cut}} + \Delta \rho_{\text{EW}} \sim \Lambda_{\text{cut}} 10^{-47} (\text{GeV})^4$$

$$z_\Lambda \gg 1$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cut off}})^4$$

$$\Delta \rho_{\text{EW}} \sim (300_{\text{GeV}})^4$$

$$\Delta \rho_{\text{GUT}} \sim \Lambda_{\text{GUT}}^4 + \Delta \rho_{\text{EW}} \sim$$

$$\Omega_\Lambda \gg 1$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cut off}})^4$$

$$\Delta \rho_{\text{Fey}} \sim (300 \text{ GeV})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{\text{GUT}} + \Lambda + \Delta \rho_{\text{EW}} \sim \Lambda_{\text{eff}} 10^{-47} (\text{GeV})^4$$

$$z_\Lambda \gg 1$$

$$\rho_m(z) > \rho_\Lambda$$

$$\rho_m(1, z)^2$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cut off}})^4$$

$$\Delta \rho_{\text{EW}} \sim (300 \text{ GeV})^4 \sim$$

$$+ \Delta \rho_{\text{GUT}} + \Lambda_{\text{eff}} + \Delta \rho_{\text{EW}} \sim \Lambda_{\text{eff}}$$

$$z_\Lambda \gg 1$$

$$\sim 1$$

$$\rho_m(z) > \rho_\Lambda$$

$$\rho_m(1, z)^2 = \rho_\Lambda$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cut off}})^4$$

$$\Delta \rho_{\text{(EW)}} \sim (300 \text{ GeV})^4 \sim$$

$$\Delta \rho_{\text{GUT}} + \Lambda + \Delta \rho_{\text{(EW)}} \sim \Lambda_{\text{eff}}$$

$$z_\Lambda \gg 1$$

$$\rho_m(z) > \rho_\Lambda$$

$$\rho_m(1, z_\Lambda)^2 = \rho_\Lambda$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cutoff}})^4$$

$$\Delta \rho_{\text{Fey}} \sim (300 \text{ GeV})^4 \sim 10^9 (\text{GeV})^4$$

$$\rho_\Lambda + \Delta \rho_{\text{Fey}} \sim \Lambda_{\text{eff}} 10^{-57} (\text{GeV})^4$$



$$z_\Lambda \gg 1$$

$$\rho_m(z) > \rho_\Lambda$$

$$\rho_m(1, z_\Lambda) = \rho_\Lambda$$

$$\rho_\Lambda < 10^{-63} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{cut off}})^4$$

$$\Delta \rho_{\text{EW}} \sim (300 \text{ GeV})^4$$

$$\Delta \rho_{\text{SUS}}$$

$$\Delta \rho_{\text{GUT}} + \Lambda + \Delta \rho_{\text{EW}} \sim$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} \text{ (GeV)}^4$$

$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim$$

$$\Delta \rho_\Lambda$$

$$\Delta \rho_{eff}$$

$$\sim 10^9 \text{ (GeV)}^4$$

$$\Lambda_{eff} \sim 10^{-47} \text{ (GeV)}^4$$



$$z_\Lambda \gg 1$$

$$\sim 1$$

$$\rho_{M(z)} > \rho_\Lambda$$

$$\rho_{M(1,z)} = \rho_\Lambda$$

$$\rho_\Lambda < 10^{-43} \text{ (GeV)}^4$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} \text{ (GeV)}^4$$

$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{eff})^4$$

$$\Delta \rho_{eff} \sim$$

$$\Delta \rho_{eff} = \Lambda_{eff}^4$$



$$10^9 \text{ (GeV)}^4$$

$$10^{-47} \text{ (GeV)}^4$$

$$z_\Lambda \gg 1$$

$$\sim 1$$

$$\rho_M(z) > \rho_\Lambda$$

$$\rho_M(1, z)^2 = \rho_\Lambda$$

$$\rho_\Lambda < 10^{-43} \text{ (GeV)}^4$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} \text{ (GeV)}^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{tot} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{eff})^4 \quad 10^{15}$$



$$\Delta \rho_{(EW)} \sim (300 \text{ GeV})^4 \sim 10^9 \text{ (GeV)}^4$$

ω_{eff}

$$\Delta \rho_{eff} = \Lambda_{eff} \Delta \rho_{(EW)} \sim \Lambda_{eff} 10^{-47} \text{ (GeV)}^4$$

$$z_\Lambda \gg 1$$

$$\sim 1$$

$$\rho_M(z) > \rho_\Lambda$$

$$\rho_M(1, z)^2 = \rho_\Lambda$$

$$\rho_\Lambda < 10^{-43} \text{ (GeV)}^4$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} \text{ (GeV)}^4$$

$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{eff})^4 \quad 10^{15}$$

$$\Delta \rho_{EW} \sim (300 \text{ GeV})^4 \sim 10^{16}$$

$$\Delta \rho_{GUT} \sim \Lambda_{eff} \cdot \Delta \rho_{EW} \sim \Lambda_{eff} 10^{57}$$

$$z_\Lambda \gg 1$$

$$\sim 1$$

$$\rho_M(z) > \rho_\Lambda$$

$$\rho_M(1, z_\Lambda^2) = \rho_\Lambda$$

$$\rho_\Lambda < 10^{-63} \text{ (GeV)}^4$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_m \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{eff}})^4 \quad 10^{15}$$



$$\Delta \rho_{\text{EW}} \sim (300 \text{ GeV})^4 \sim 10^9 (\text{GeV})^4$$

$$\rho_\Lambda + \Delta \rho_{\text{EW}} \sim \Lambda_{\text{eff}} 10^{-47} (\text{GeV})^4$$

$$z_\Lambda \gg 1$$

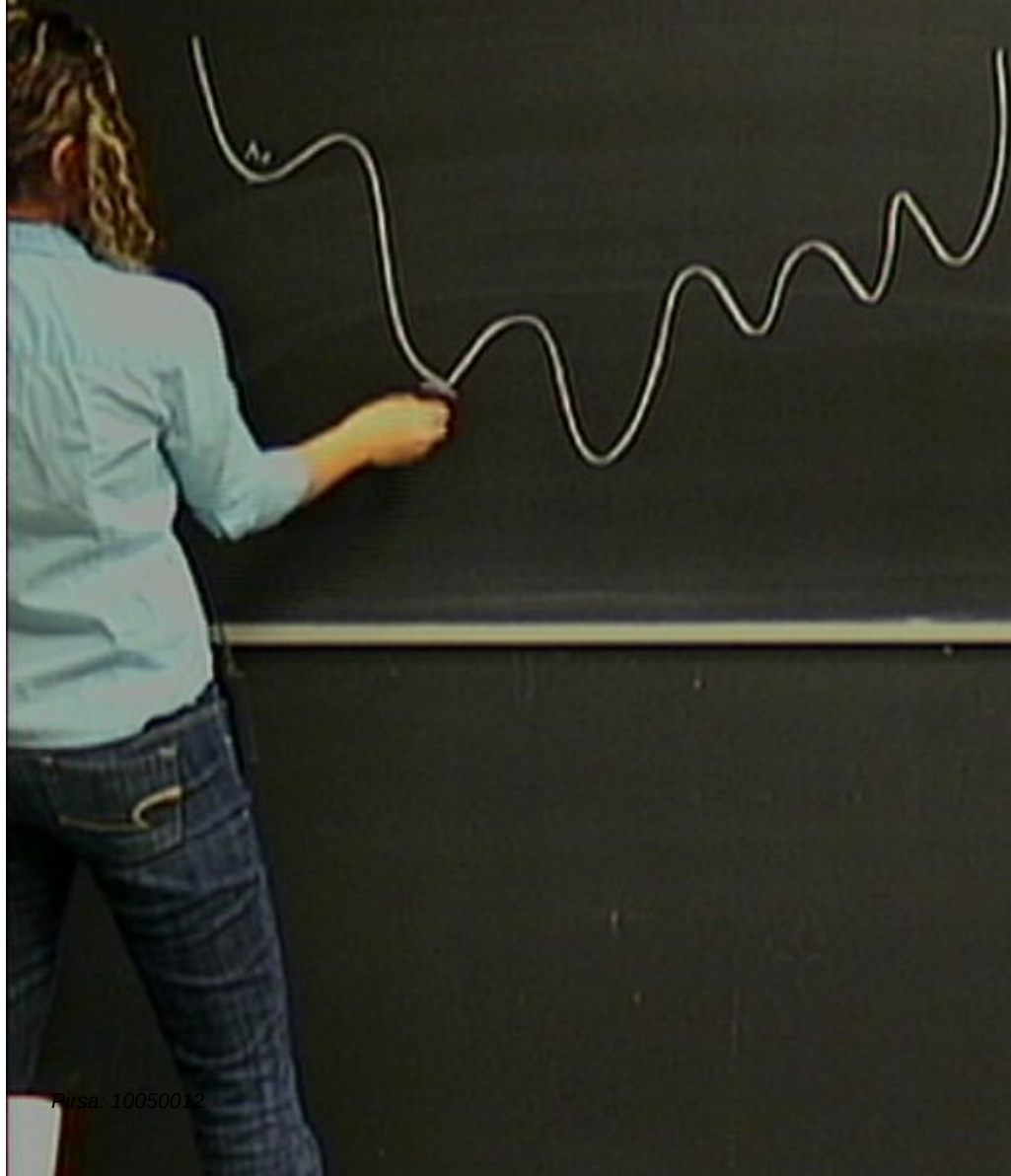
$$\sim 1$$

$$\rho_{M(z)} > \rho_\Lambda$$

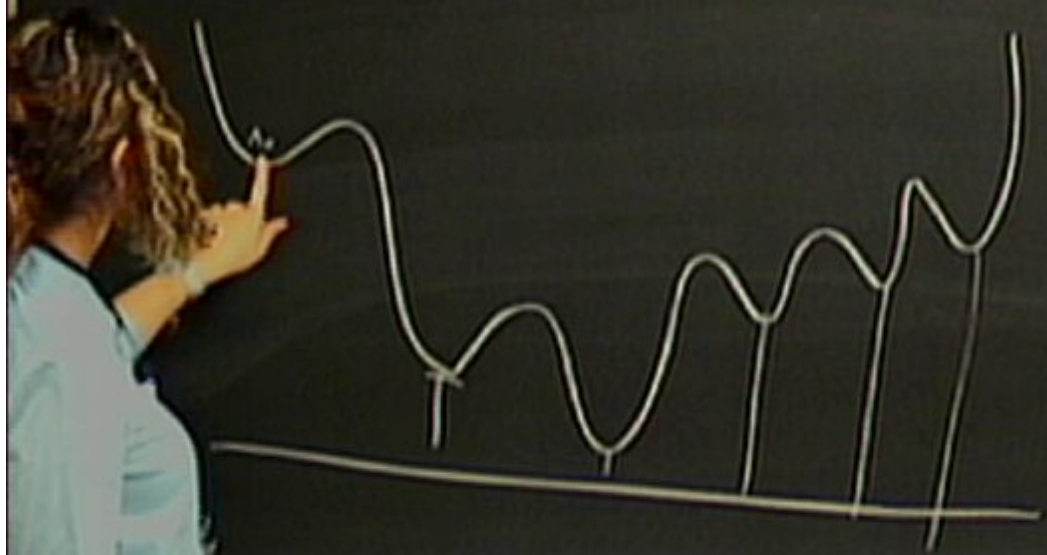
$$\rho_{M(z)} = \rho_\Lambda$$

$$\rho_\Lambda < 10^{-43} (\text{GeV})^4$$

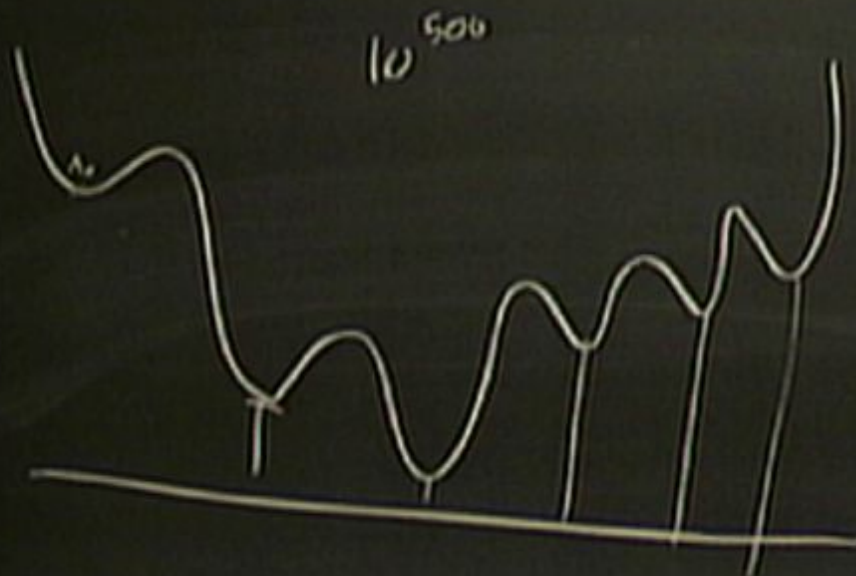
$$\Gamma(\Delta) + \Gamma(\Delta) \sim \Lambda_{eff} 10^{-57} \text{ (GeV)}$$



$$\Gamma_{\text{cut}} + \Gamma_{\text{cut}} + \Delta \Gamma_{\text{cut}} \sim \Lambda_{\text{eff}} 10^{-57} \text{ (GeV)}$$



$$\Gamma(\Delta) + \Gamma(\Delta) \sim \Lambda_{eff} 10^{-57} \text{ (GeV)}$$



$$\Omega_m \sim 0.3$$

$$\Omega_{tot} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{eff})^4 \quad 10^{15}$$

$$\Delta \rho_{(EW)} \sim (300 \text{ GeV})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{GUT} = \Lambda_{eff} + \Delta \rho_{(EW)} \sim 10^{57} (\text{GeV})^4$$



$$\rho_M(z) > \rho_\Lambda$$

$$\rho_M(1, z) = \rho_\Lambda$$

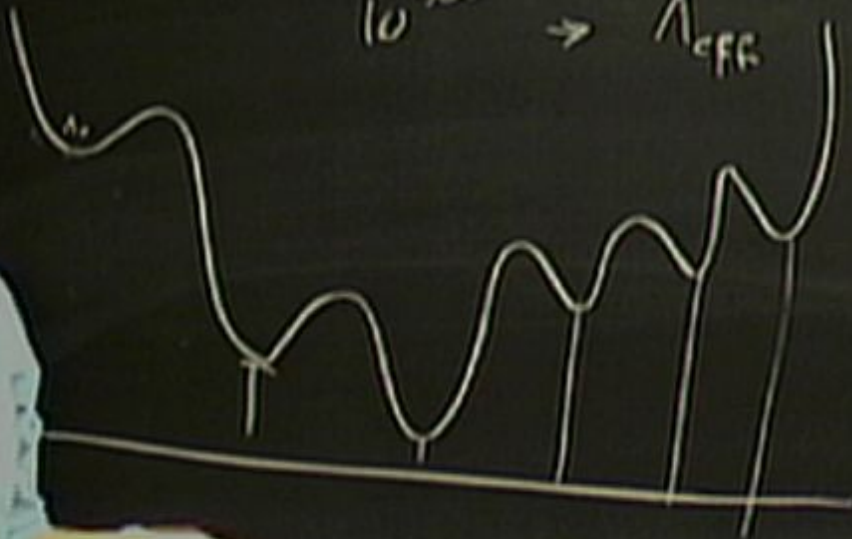
$$-10^{-63} < \rho_\Lambda < 10^{-63} (\text{GeV})^4$$

$$\Delta \rho_{\text{EW}} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{\text{GUT}} = \Lambda_{\text{GUT}} + \Delta \rho_{\text{EW}} \sim \Lambda_{\text{eff}} 10^{57} \text{ units}$$

$$10^{-63} < \rho_{\Lambda} < 10^{-53} (\text{GeV})^4$$

$$10^{500} \rightarrow \Lambda_{\text{eff}}$$



$$\Delta \rho_{(W)} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{\text{GUT}} = \Lambda_{\text{GUT}}^4 \sim \Lambda_{\text{eff}}^4 10^{57} (\text{GeV})^4$$

$$10^{-63} < \beta_A < 10^{-53} (\text{GeV})^4$$



$$\Delta \rho_{EW} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{\text{GUT}} = \Lambda_{\text{GUT}} + \Delta \rho_{EW} \sim \Lambda_{\text{eff}} 10^{57} \text{ units}$$

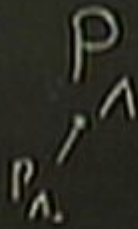
$$10^{-63} < \rho_{\Lambda} < 10^{-53} (\text{GeV})^4$$



$$\Delta \rho_{EW} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{\text{GUT}} = \Lambda_{\text{GUT}} \Delta \rho_{\text{GUT}} \sim \Lambda_{\text{eff}} 10^{57} \text{ units}$$

$$10^{-63} < \rho_{\Lambda} < 10^{-53} (\text{GeV})^4$$



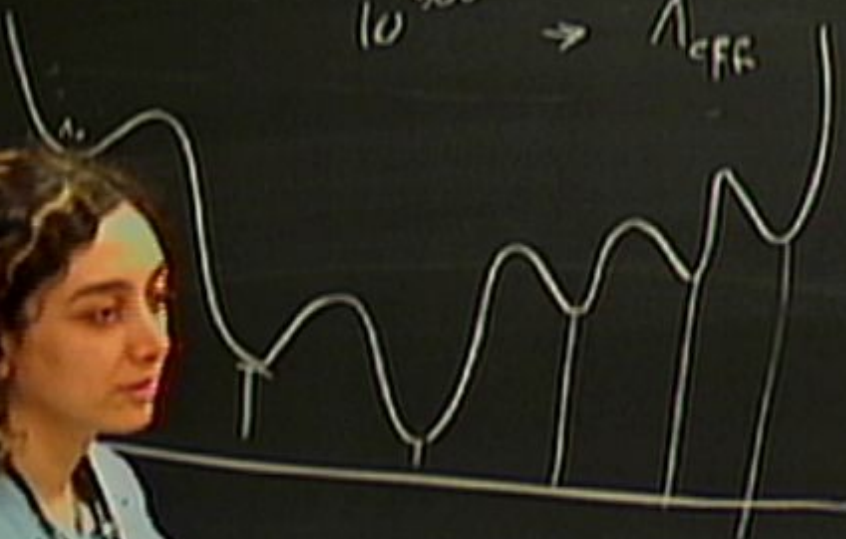
$$\Delta \rho_{EW} \sim (300_{GeV})^4 \sim 10^9 (GeV)^4$$

$$\Delta \rho_{GUT} = \Lambda_{eff} \Delta \rho_{GUT} \sim \Lambda_{eff} 10^{57} GeV^4$$

$$10^{-63} < \rho_\Lambda < 10^{-53} (GeV)^4$$

$$10^{500} \rightarrow \Lambda_{eff}$$

$$P_{\Lambda_{eff}} \rightarrow P_{\Lambda_{eff}}$$



CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} \text{ (GeV)}^4$$

$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{EW})^4$$

$$\Delta \rho_{(EW)} \sim (\Lambda_{EW})^4$$

$$\Delta \rho_{GUT} \sim \Lambda_{GUT}^4$$



$$z_\Lambda \gg 1$$

$$z_\Lambda \sim 1$$

$$\rho_M(z) > \rho_\Lambda$$

$$\rho_M(1, z_\Lambda)^3 = \rho_\Lambda$$

$$10^{-63} < \rho_\Lambda < 10^{-43} \text{ (GeV)}^4$$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_M \sim 0.3$$

$$\Omega_{\text{tot}} \sim 1$$

$$\Delta \rho_\Lambda \sim (\Lambda_{\text{eff}})^4 \quad 10^{15}$$

$$\Delta \rho_{\text{EW}} \sim (300 \text{ GeV})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{\text{GUT}} : \Lambda_i + \Delta \rho_{\text{EW}} \sim \Lambda_{\text{eff}} 10^{-47} (\text{GeV})^4$$



$$z_\Lambda \gg 1$$

$$\sim 1$$

$$\rho_M(z) > \rho_\Lambda$$

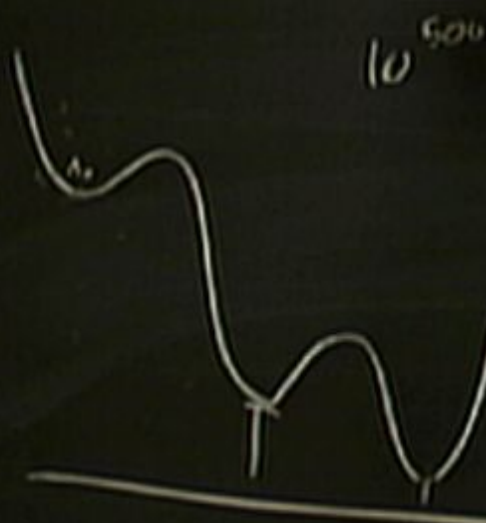
$$\rho_M(1, z_\Lambda) = \rho_\Lambda$$

$$-10^{-63} < \rho_\Lambda < 10^{-43} (\text{GeV})^4$$

$$\Delta \rho_{EW} \sim (300_{\text{GeV}})^4 \sim 10^9 (\text{GeV})^4$$

$$\Delta \rho_{\text{GUT}} = \Lambda_{\text{GUT}} + \Delta \rho_{EW} \sim \Lambda_{\text{eff}} 10^{57} \text{ units}$$

$$10^{-63} < \rho_{\Lambda} < 10^{-53} (\text{GeV})^4$$

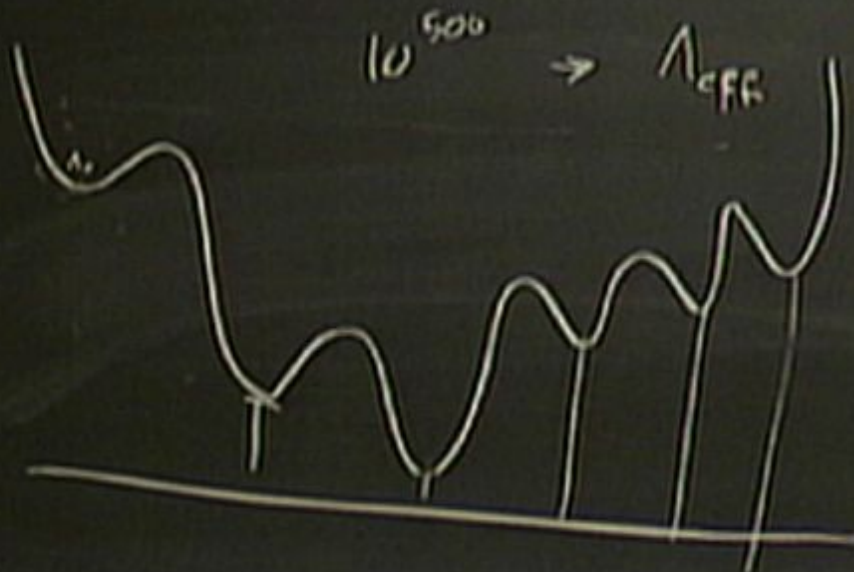


$$\rho_{\Lambda_0} \rightarrow \rho_{\Lambda}$$

$$\rho_{\Lambda} = \text{const}$$

$\Delta \rho_{EW} \sim (300_{GeV})^4 \sim 10^9 (GeV)^4$
 $\Delta \rho_{GUT} = \Lambda_* + \Delta \rho_{EW} \sim \Lambda_{eff} 10^{57} units$

$10^{-63} < \rho_\Lambda < 10^{-53} (GeV)^4$



$\rho_{\Lambda_*} \rightarrow \rho$

$\rho_{\Lambda} = const$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{\text{eff}}}_{\Lambda_{\text{eff}}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{S_{\mu\nu}}$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{\text{eff}}}_{\Lambda_{\text{eff}}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{S_{\mu\nu}}$$

$$\int \sqrt{g} R d^4x + \int \sqrt{g} L_m d^4x$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{\text{eff}}}_{\Lambda_{\text{eff}}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{S_{\mu\nu}}$$

$$\int \sqrt{g} R d^4x + \int \sqrt{g} L_m d^4x$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{\text{eff}}}_{\Lambda_{\text{eff}}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{S_{\mu\nu}}$$

$$\int \sqrt{g} R d^4x + \int \sqrt{g} \underbrace{L_M}_{L_M} d^4x$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{\text{eff}}}_{\Lambda_{\text{eff}}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{S_{\mu\nu}}$$

$$S = \underbrace{\int \sqrt{g} R d^4x}_{F(R)} + \underbrace{\int \sqrt{g} L_M d^4x}$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{\text{eff}}}_{\Lambda_{\text{eff}}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{S_{\mu\nu}}$$

$$S = \underbrace{\int \sqrt{g} R^{\text{eff}} d^4x}_{F(R)} + \underbrace{\int \sqrt{g} L_M^{\text{eff}} d^4x}_{\text{Scalar-Tension}} \underbrace{L(y)}_{L(y)}$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{\text{eff}}}_{\Lambda_{\text{eff}}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{S_{\mu\nu}}$$

$$S = \int d^4x \sqrt{-g} \underbrace{L_M}_{\text{Matter}} + \underbrace{\int d^4x \sqrt{-g} L_g}_{\text{Gravity}}$$

$\swarrow$ $L(\varphi)$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{\text{eff}}}_{\Lambda_{\text{eff}}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{S_{\mu\nu}}$$

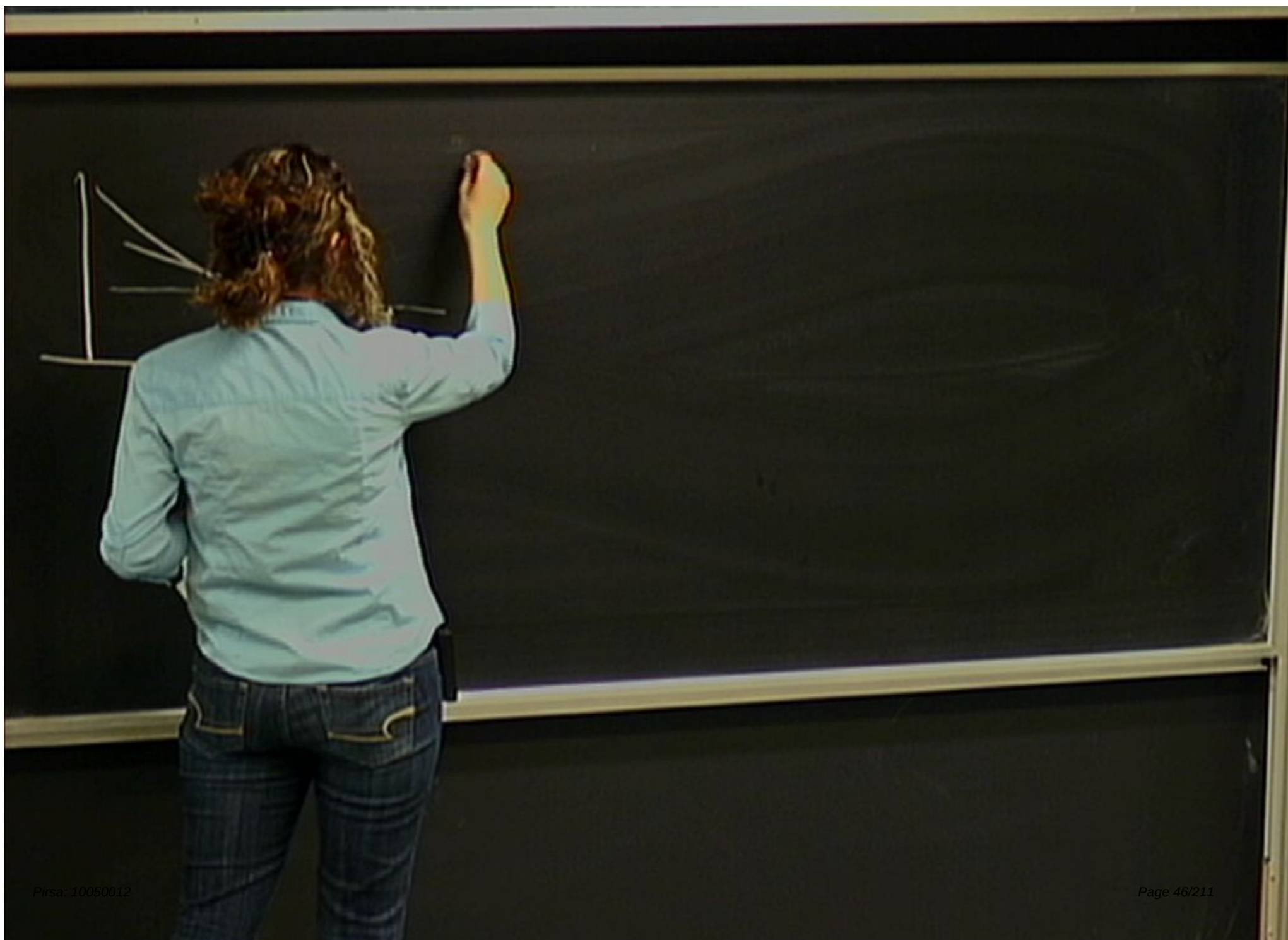
$$S = \int \sqrt{g} R^4 d^4x + \int \sqrt{g} L_M^4 d^4x$$

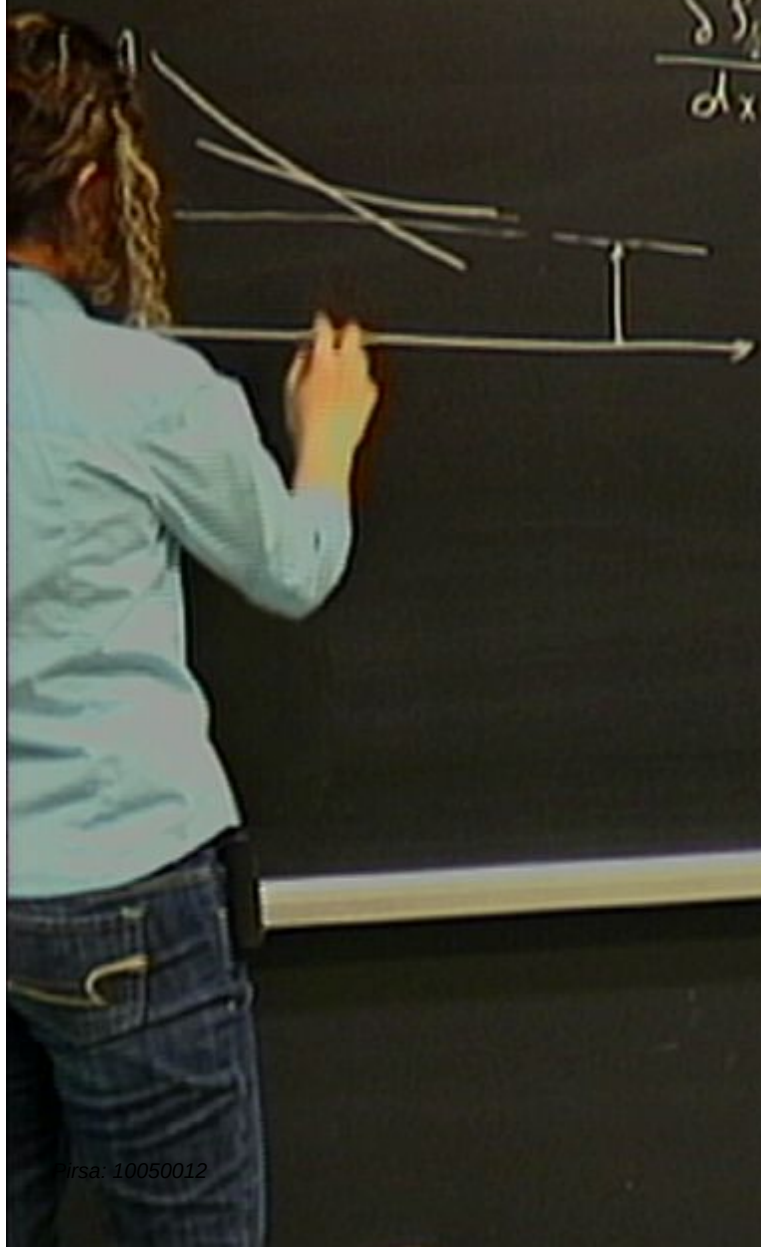
$\underbrace{\hspace{10em}}_{\text{Scalar-Tension}} \quad \underbrace{\hspace{10em}}_{L(y)}$

$F(R)$

R^{DGP}

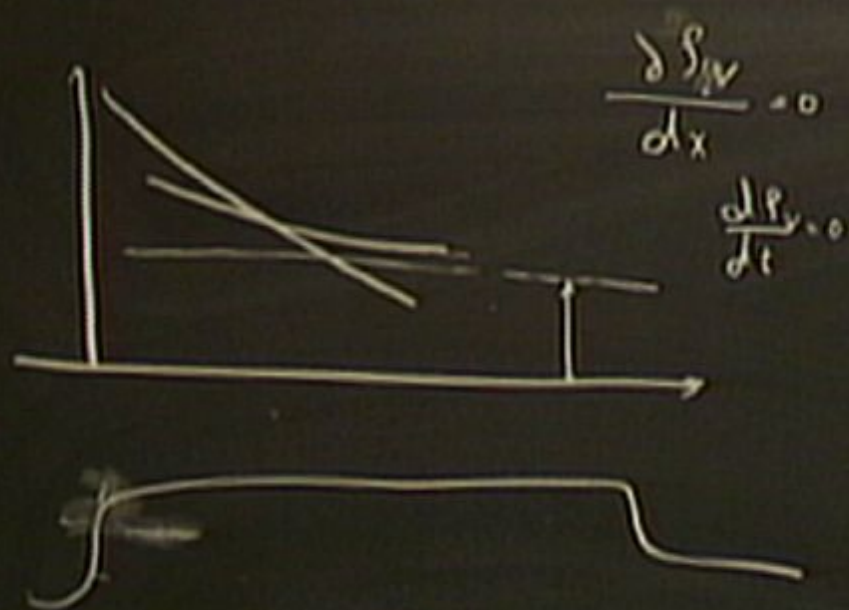
DGP
 Conforming





$$\frac{\delta S_{IV}}{\delta x} = 0$$

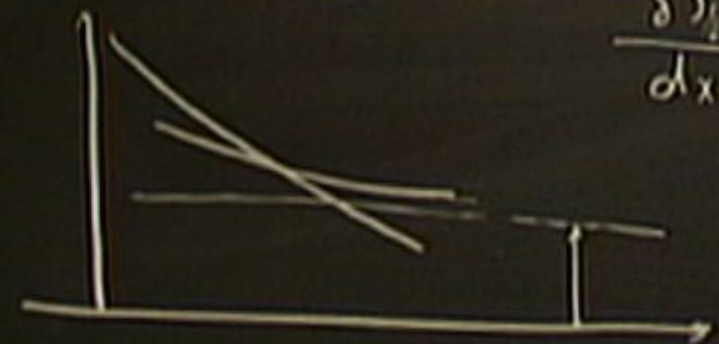
$$\frac{\delta P_{IV}}{\delta t} = 0$$



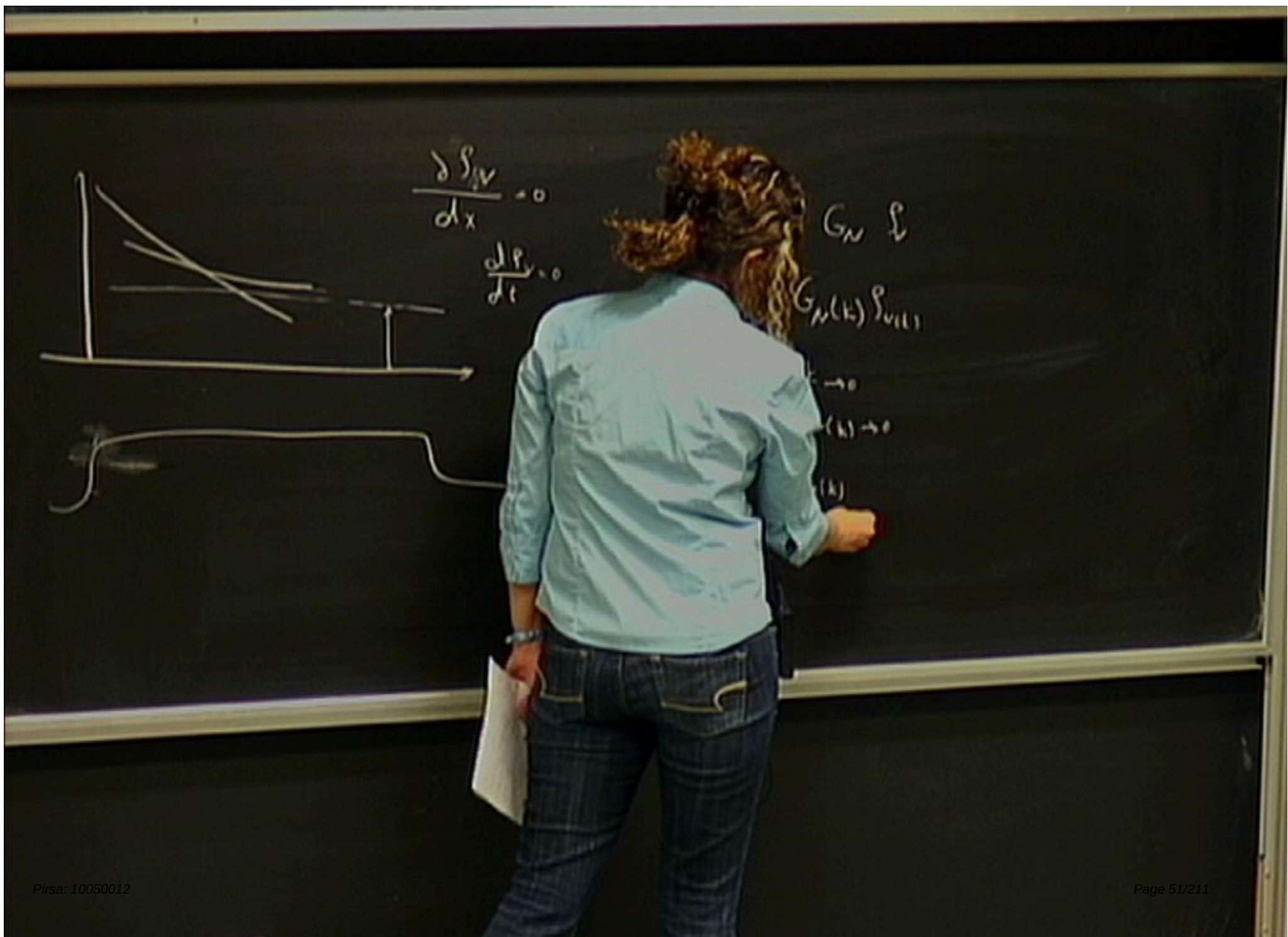
$$\frac{\delta S_{IV}}{\delta x} = 0$$

$$\frac{dP_{y,0}}{dt} = 0$$

$$\lim_{k \rightarrow 0} \rho_k \neq 0$$







$$\frac{\partial S_{IV}}{\partial x} = 0$$

$$\frac{\partial P_y}{\partial t} = 0$$

$$G_N \downarrow$$

$$G_N(t) P_{VII}$$

$$\rightarrow 0$$

$$(k) \rightarrow 0$$

$$(k)$$

$$\frac{\partial S_{IV}}{\partial x} = 0$$

$$\frac{dP_{IV}}{dt} = 0$$

$$\lim_{k \rightarrow 0} \rho_k \neq 0$$

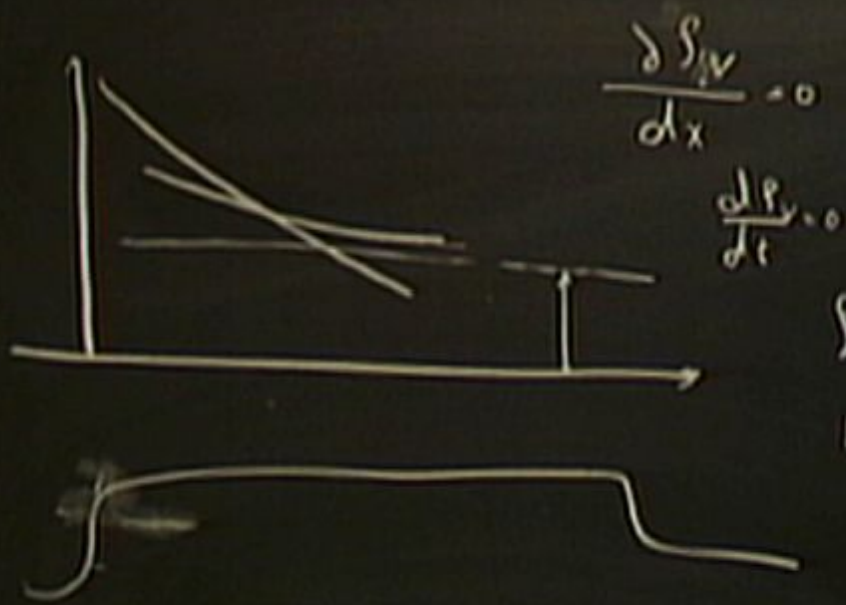
$$h = G_N \rho$$

$$h_k = G_N(k) \rho_{IV}(k)$$

$$\lim_{k \rightarrow 0} G_N(k) \rightarrow 0$$

$$G_N(k) = G_N$$





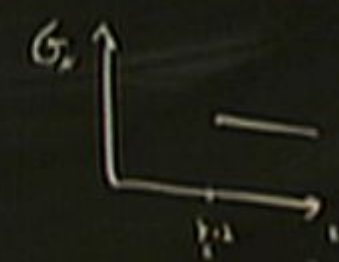
$$\frac{\partial S_{IV}}{\partial x} = 0$$

$$\frac{dP_{IV}}{dt} = 0$$

$$S_{k \infty} \neq 0$$

$$k \rightarrow 0$$

h_0
 h_k
 h_{null}



$$\frac{\partial S_{IV}}{\partial x} = 0$$

$$\frac{dP_{IV}}{dt} = 0$$

$$S_{k \rightarrow 0} \neq 0$$

$$h = G_N \downarrow$$

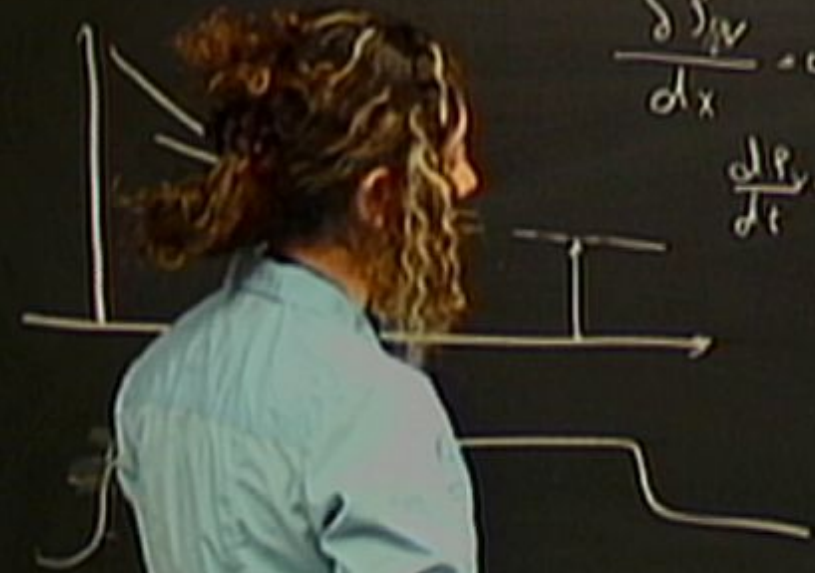
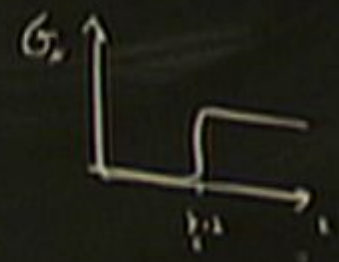
$$h_k = G_N(k) S_{IV}(k)$$

$$k \rightarrow 0$$

$$G_N(k) \rightarrow 0$$

$$G_N(k) = G_N$$

$$k \neq 0$$



$$\frac{\partial S_{IV}}{\partial x} = 0$$

$$\frac{dP_{IV}}{dt} = 0$$

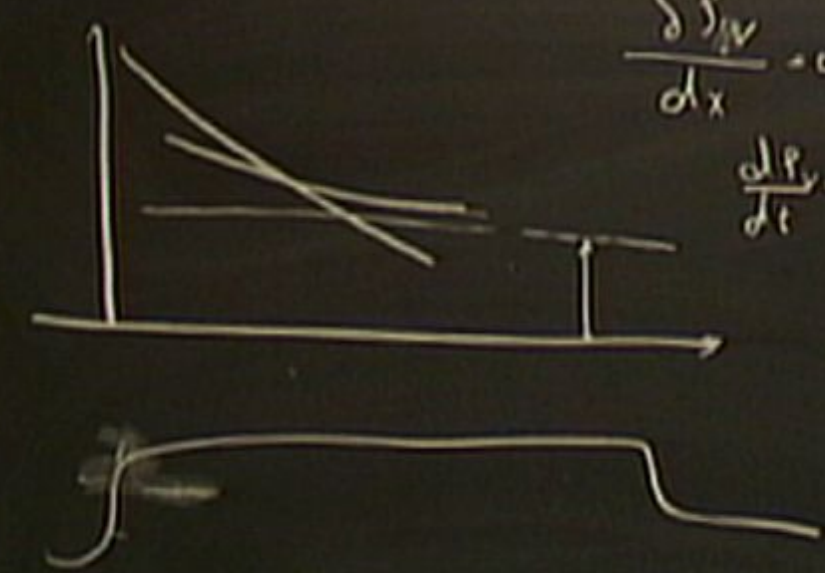
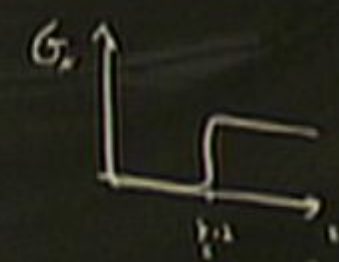
$$\lim_{k \rightarrow \infty} P_k \neq 0$$

$$h = G_N \downarrow$$

$$h_k = G_N(k) P_{IV}(k)$$

$$\begin{aligned} k \rightarrow \infty \\ G_N(k) \rightarrow 0 \end{aligned}$$

$$G_N(k) = G_N \quad k \neq \infty$$



$f(R)$

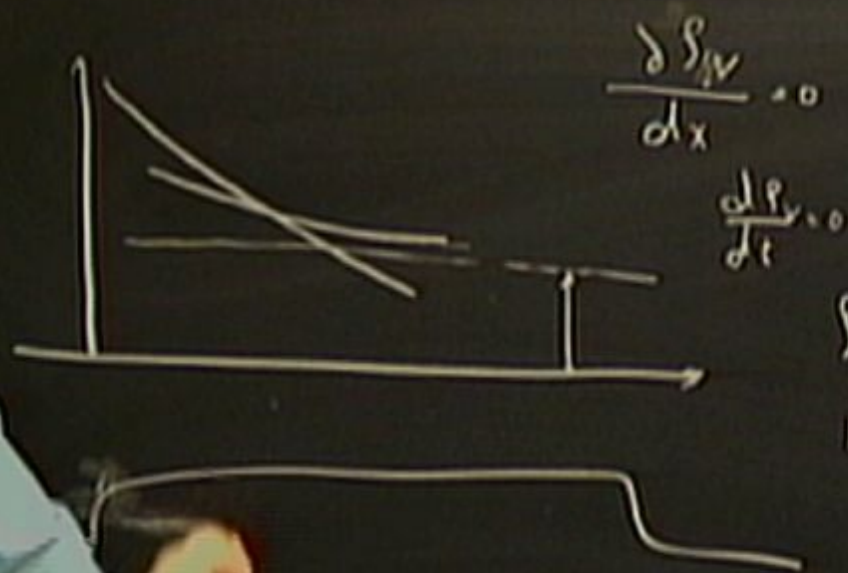
Scalar-Tensor

$L(p)$

$R^{(1)}(x)$

DGP

Concordance !



$$\frac{\delta S_N}{\delta x} = 0$$

$$\frac{dP_N}{dt} = 0$$

$$P_{k \rightarrow \infty} \neq 0$$

$$h = G_N \rho$$

$$h_k = G_N(k) \rho_{\text{tot}}$$

$$k \rightarrow 0$$

$$G_N(k) \rightarrow 0$$

$$G_N(k) = G_N$$

$$k \neq 0$$



$f(R)$

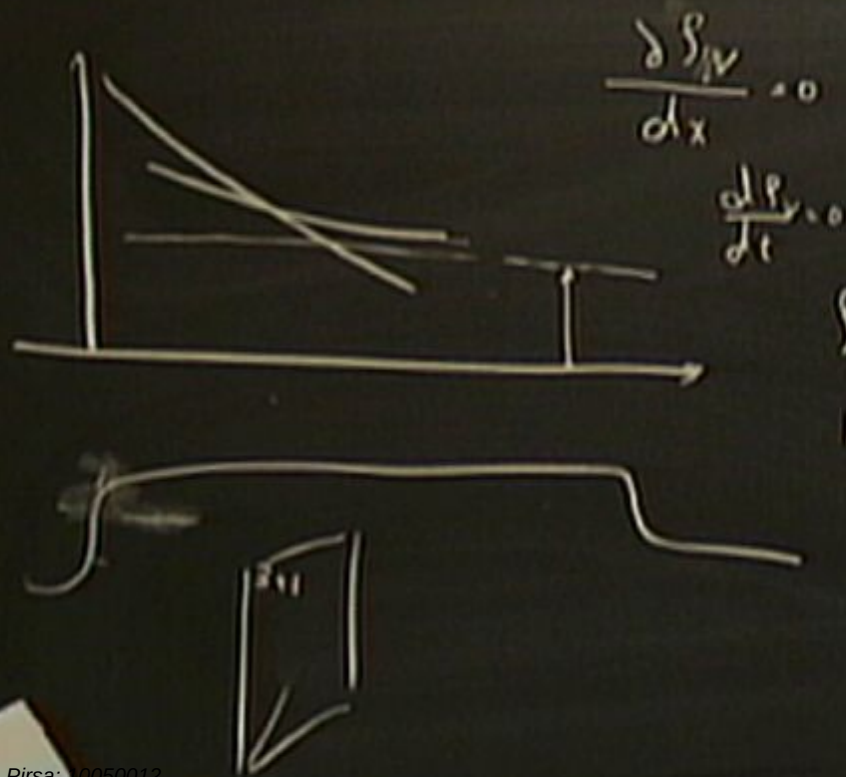
Scalar Tension

$L(p)$

$R^{(1), (2)}$

DGP

Ascending Curv!



$$h = G_N \rho$$

$$h_k = G_N(k) \rho_{0(k)}$$

$$k \rightarrow 0 \\ G_N(k) \rightarrow 0$$

$$G_N(k) = G_N \\ \neq 0$$



$f(R)$

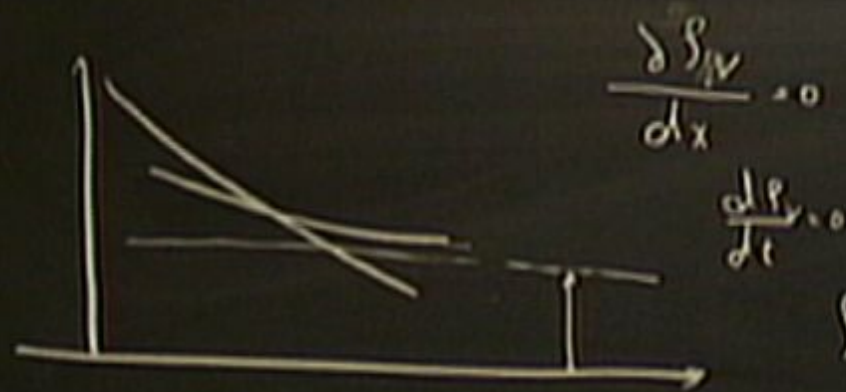
Scalar Tension

$L(p)$

$R^{(1), (2)}$

DGP

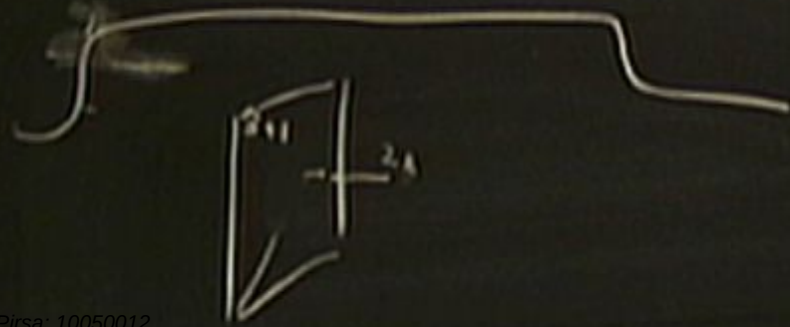
Concavity



$$\frac{\delta \mathcal{L}}{\delta x} = 0$$

$$\frac{d \mathcal{L}}{d t} = 0$$

$$\rho_{k, \infty} \neq 0$$



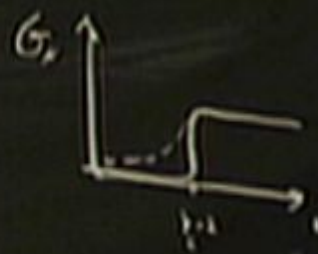
$$h = G_N \rho$$

$$h_k = G_N(k) \rho_{v(k)}$$

$$k \rightarrow 0$$

$$G_N(k) \rightarrow 0$$

$$G_N(k) = G_N$$



$f(R)$

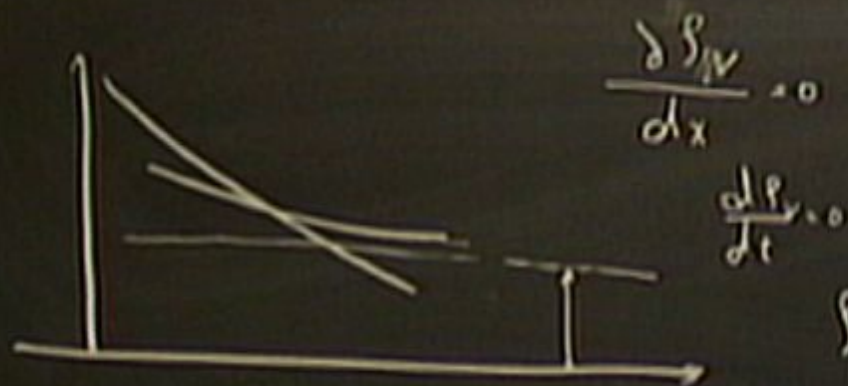
Scalar-Tension

$L(p)$

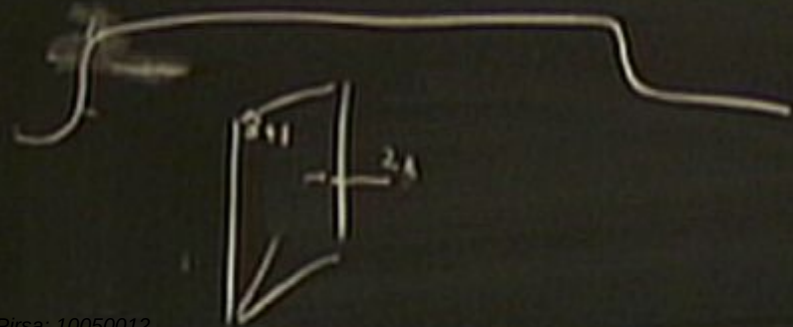
$R^{(1,1)}$

DGP

Ascending Gen !



$P_{k \rightarrow \infty} \neq 0$



$$h = G_N \rho$$

$$h_k = G_N(k) \rho_{0(k)}$$

$$k \rightarrow 0 \\ G_N(k) \rightarrow 0$$

$$G_N(k) = G_N \\ \neq 0$$





$$\frac{\partial \mathcal{P}_V}{\partial \lambda_x} = 0$$

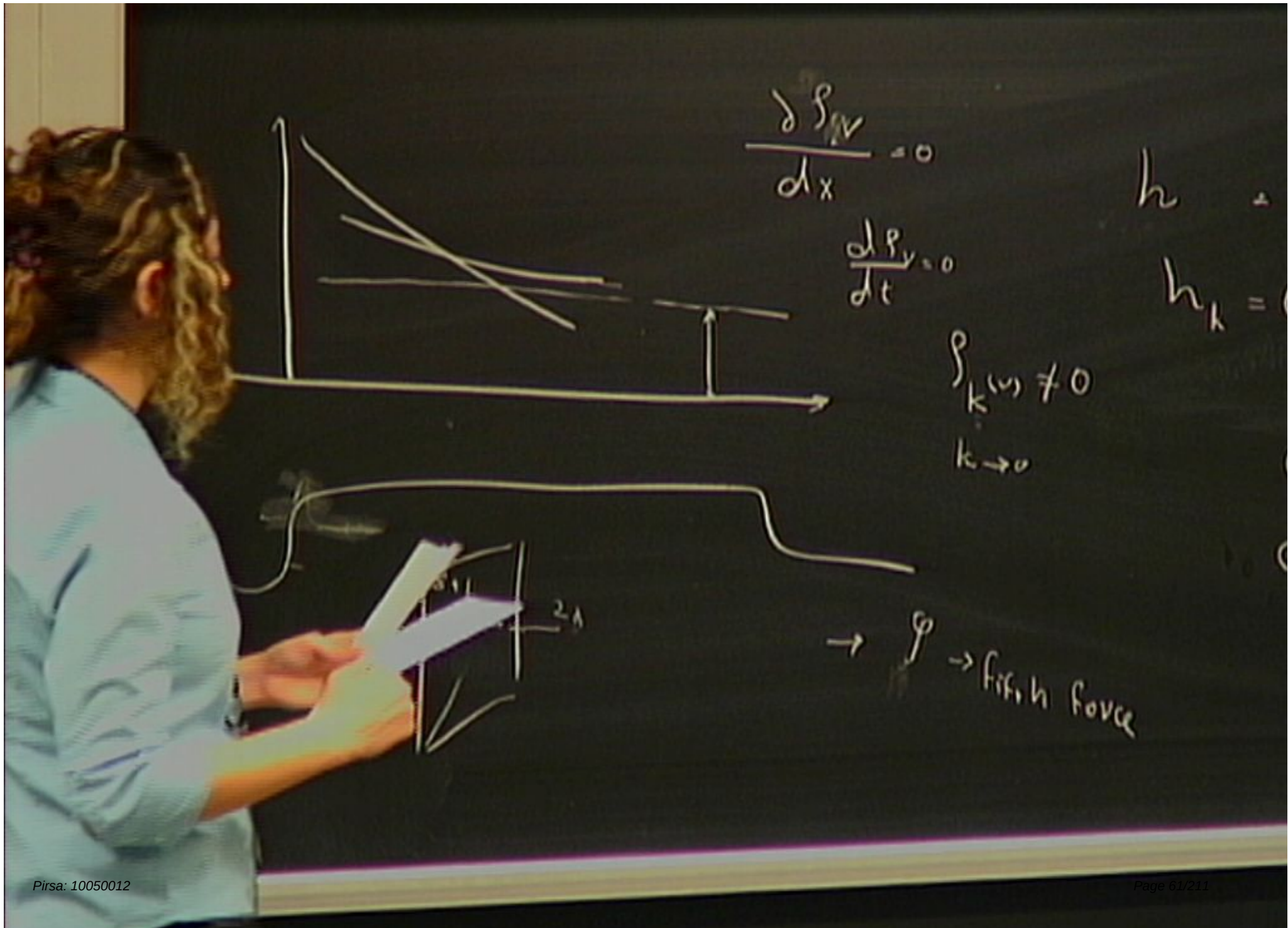
$$\frac{\partial \mathcal{P}_y}{\partial t} = 0$$

$$\mathcal{P}_{k(\omega)} \neq 0$$

$$k \rightarrow 0$$

$$h =$$

$$h_k =$$



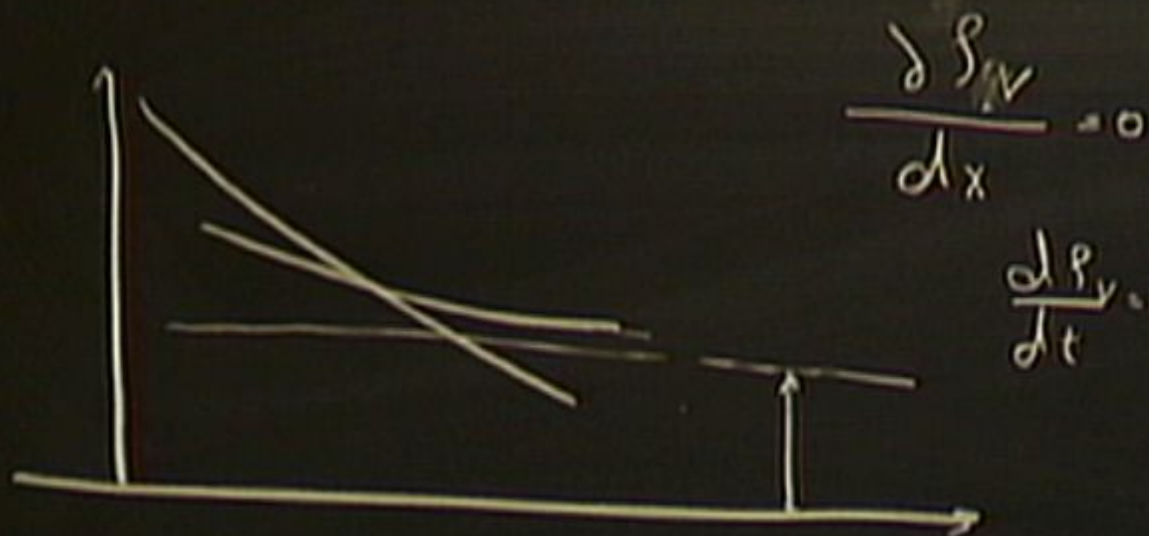
$$\frac{\partial \mathcal{P}_N}{\partial x} = 0$$

$$\frac{d\mathcal{P}_y}{dt} = 0$$

$$h_k =$$

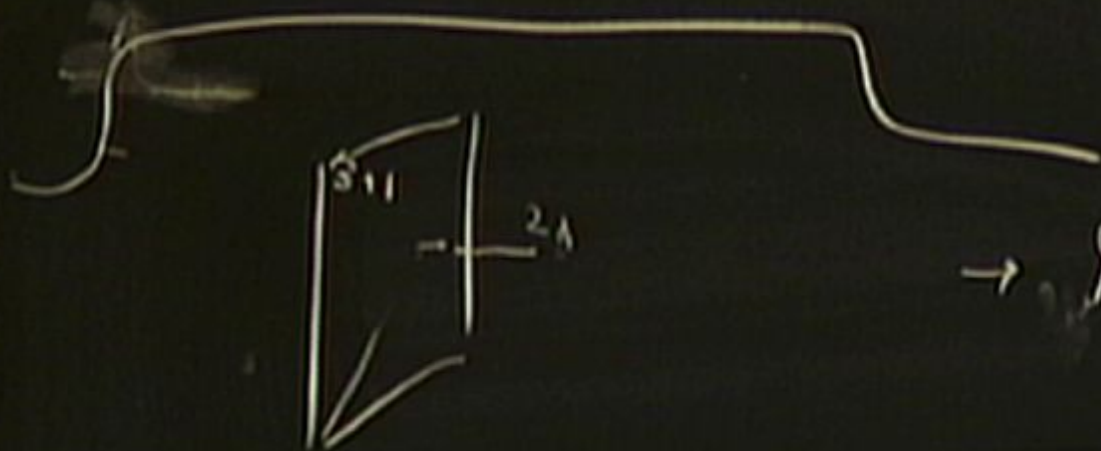
$$\mathcal{P}_{k(\omega)} \neq 0$$
$$k \rightarrow 0$$

$\rightarrow \mathcal{P} \rightarrow \text{fifth force}$



$$h =$$

$$h_k =$$



$\rightarrow \mathcal{P} \rightarrow$ fifth force

CAUTION

DO NOT USE THE BOARD FOR ANY OTHER PURPOSES

$$\frac{\partial p_v}{\partial x} = 0$$

$$\frac{dp_v}{dt} = 0$$

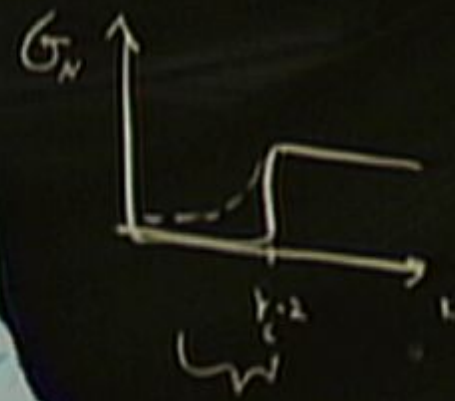
$$\rho_{k(\omega)} \neq 0$$

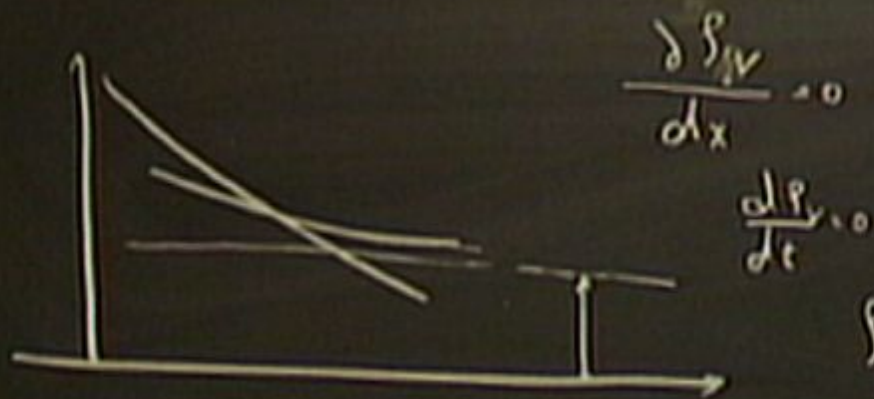
$$k \rightarrow 0$$

$\rightarrow \rho \rightarrow \text{fit, h force}$

h

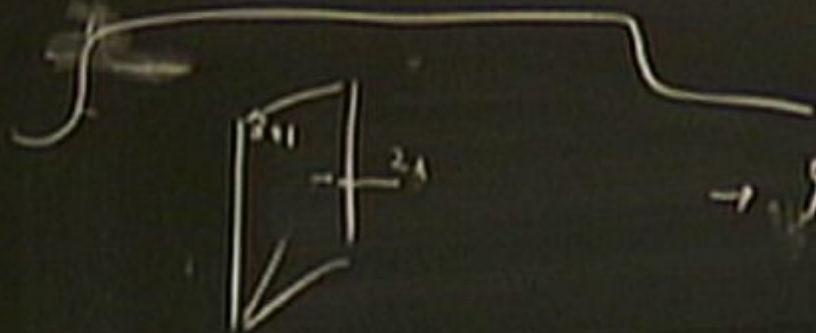
$$h_k = \dots (k)$$





$$p_{k(t)} \neq 0$$

$$k \rightarrow 0$$



$\rightarrow$ Fick force

$$h = G_N p$$

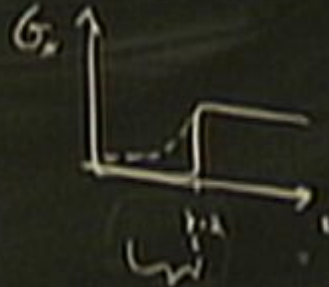
$$h_k = G_N(k) p_{iv}(k)$$

$$k \rightarrow 0$$

$$G_N(k) \rightarrow 0$$

$$G_N(k) = G_N$$

$$k \neq 0$$



$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff} g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$\Lambda_{eff} \ll \rho_{vac}$

$$\int \sqrt{g} R^4 d^4x + \int \sqrt{g} L_m^4 d^4x$$

Scalar-Tension $L(p)$

→ DGP

→ accelerating Univ. !

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff} g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$\Lambda_{eff} \quad \leftarrow \quad \Lambda_{eff} \quad \leftarrow \quad \rho_{vac}$

$$R^{\mu\nu} \partial_\mu \partial_\nu \cdot \int d^4x \sqrt{g} \mathcal{L}_m$$

$$\rightarrow \frac{\delta}{\delta \phi} \approx 0$$

Scalar-Tensor

$\mathcal{L}(\varphi)$

GP

→ Cascading Grav !

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{eff}}_{\Lambda_{eff}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{S_{\mu\nu}}$$

$$S = \int d^4x \cdot \int d^4p \underbrace{L_M^4}_{\text{Scalar-Tensor}} \underbrace{L(p)}_{L(p)} \quad \left\{ \begin{array}{l} \frac{\delta S}{\delta \phi} = 0 \\ \frac{\delta S}{\delta p} = \frac{1}{4\pi} S_M \end{array} \right.$$

DGP

Scalar-Tensor!

$$S = \int \sqrt{g} R^{\mu\nu} A_\mu A_\nu$$

$$f(R)$$

$$\frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \right) = \frac{1}{2}$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$\downarrow$ $\downarrow$
 $\mathcal{L}$ $\mathcal{L}$ $\mathcal{L}$ $\mathcal{L}$

$$S = \int \sqrt{-g} R d^4x$$

$$F(R)$$

$$R^{(n)}(x)$$

$$\mathcal{L}(p)$$

$$\left\{ \begin{array}{l} \frac{\partial}{\partial t} \approx 0 \\ f(\vec{r}) = \frac{1}{\sqrt{2\pi}} e^{-\frac{r^2}{2\sigma^2}} \end{array} \right.$$

$\chi \leftrightarrow \frac{\delta p}{p}$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff} g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$\downarrow$ $\downarrow$
 Λ_{eff} $g_{\mu\nu}$

$$S = \int \sqrt{g} R^4 d^4x + \int \sqrt{g} L_m^4 d^4x$$

$f(R)$

Scalar-Tensor

$R^{(5,1,1)}$

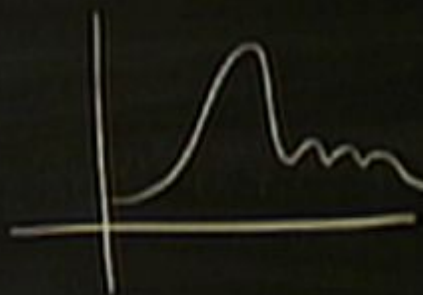
DGP

→ Confining

$$\frac{\partial}{\partial \phi} \approx 0$$

$$\left(\frac{1}{H^2} \right) \cdot \left(\frac{1}{M_{Pl}^2} \right) \rightarrow H_{eff}$$

$$x) \leftrightarrow q\left(\frac{\delta p}{p}\right)$$



$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff} g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$\Lambda_{eff} \quad \triangleleft \quad \Lambda$

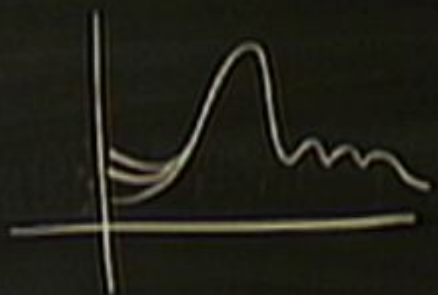
$$S = \int \sqrt{g} R^4 d^4x + \int \sqrt{g} L_m^4 d^4x$$

$F(R)$ $\underbrace{\hspace{2cm}}_{\text{Scalar-Tensor}} \rightarrow L(\varphi)$

$R^{(5D)}$

$\rightarrow$ DGP
 $\rightarrow$ concordance Ω_m !

$\frac{\partial}{\partial \varphi} \rightarrow 0$
 $F(H) = \frac{1}{3H^2} \dot{H} \rightarrow H_{eff}$
 $P(\chi) \leftrightarrow q(\frac{\delta \rho}{\rho})$

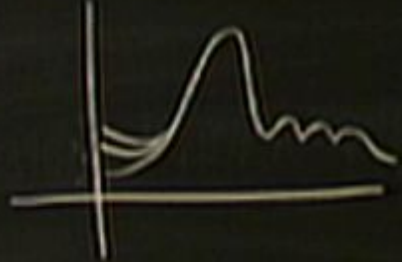


$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \underbrace{\Lambda_{eff}}_{\Lambda_{eff}} g_{\mu\nu} = 8\pi G \underbrace{T_{\mu\nu}}_{T_{\mu\nu}}$$

$$S = \underbrace{\int \sqrt{g} R^4 dx^4}_{f(R)} + \underbrace{\int \sqrt{g} L_m^4 dx^4}_{\text{Scalar-Tension}} + \underbrace{\int \sqrt{g} \Lambda dx^4}_{L(p)} \rightarrow \frac{\partial S}{\partial g} \approx 0$$

$f(R)$
 $R^{(5)/4}$ → DGP
 → concordance !

$f(H^2) = \frac{1}{3H^2} \rho_m \rightarrow H_{eff}$
 $P(\chi) \leftrightarrow P(\delta \rho / \rho)$



$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{\text{eff}} g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$\Lambda_{\text{eff}} \quad \leftarrow \quad \Lambda_{\text{eff}}$

$$S = \int \sqrt{g} R^4 dx + \int \sqrt{g} L_m^4 dx + \int \sqrt{g} \Lambda dx$$

$f(R)$

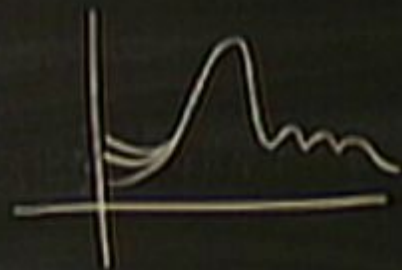
Scalar-Tensor

$L(p)$

$$f(H) = \frac{1}{3H^2} \dot{H} \rightarrow H_{\text{eff}}$$

$R^{(DGP)}$ $\rightarrow$ DGP $\rightarrow$ concordance

$$P(\chi) \leftarrow q\left(\frac{\delta p}{f}\right)$$



$\rho_A \neq \text{const}$ $\rho_V(t) \leftarrow$ scalar d.o.f
> quintessence.

$\rho_\Lambda + \text{const}$ $\rho_\nu(t) \leftarrow$ scalar d.o.f
 $\rightarrow$ quintessence.

Photo: 10050012

$\rho_{\Lambda} \neq \text{const}$

ρ_v

Scalar d.o.f

essence.

$$S = \int R d^4x$$

$$+ \int \sqrt{-g} \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right)$$

$\phi_A \neq \text{const}$ $\phi_B \neq \text{const}$ $\leftarrow$ Scalar d.o.f

in essence.

$$S = \int R \sqrt{g} + \int \sqrt{g} \left(\frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right)$$

$f(\partial_\mu \phi \partial^\mu \phi)$

$\rho_\Lambda \neq \text{const}$ $\rho_\nu(t) \leftarrow \text{scalar d.o.f}$

$\rightarrow$ quintessence.

$$\int R \, d^4x + \int \sqrt{g} \, L_{\text{m}} \, d^4x + \int \sqrt{g} \, \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right) d^4x$$

$\xrightarrow{\quad f(\partial_\mu \phi \partial^\mu \phi) \quad}$

$\Lambda \neq \text{const}$ $\phi_v(t)$ ← scalar d.o.f

> quintessence.

$$S = \int R d^4x + \int \sqrt{g} L_{\text{matt}} + \int \sqrt{g} \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right)$$

$f(\partial_\mu \phi \partial^\mu \phi)$

$$\frac{d}{dt} \dot{\phi} > 0$$

$\Lambda + \text{const } f_v(t) \leftarrow \text{scalar d.o.f}$

$\rightarrow$ quintessence.

$$S = \int R d^4x + \int \sqrt{g} L_{\text{mat}} + \int \sqrt{g} \left(\frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right)$$

$$\frac{\ddot{a}}{a} > 0$$

$\rightarrow$

$$H^2 = \frac{1}{3m_p^2}$$

$$\phi \frac{\delta L}{\delta \phi}$$

$\gamma_\Lambda \neq \text{const}$ $\rho_\nu(t)$ ← scalar d.o.f

> quintessence

$$S = \int R d^4x + \int \sqrt{-g} L_{\text{matt}}$$

$f(\partial_\mu \varphi, \partial_\nu \varphi)$

$$\left(\frac{1}{2} \partial_\mu \varphi \partial^\mu \varphi - V(\varphi) \right)$$

$$\frac{d^2 \varphi}{dt^2} > 0$$

→

$$H^2 =$$

$$\mathcal{L}_\varphi = \dot{\varphi} \frac{\partial L}{\partial \dot{\varphi}} - L =$$

$\rightarrow \Lambda$ const $f_\nu(t)$ — scalar d.o.f

$\rightarrow$ quintessence.

$$S = \int R d^4x + \int \sqrt{g} L_{\text{matter}} + \int \sqrt{g} \left(\frac{1}{2} \dot{\varphi}^2 - V(\varphi) \right)$$

$f(\partial_\mu \varphi, \partial_\nu \varphi)$

$V(\varphi)$

$$T^{\mu\nu} = \frac{\delta \sqrt{g} L_{\text{matter}}}{\delta g_{\mu\nu}}$$

$$\frac{d^2 \varphi}{dt^2} > 0$$

$\rightarrow$

$$H^2 = \frac{1}{3\rho_{\text{pl}}}$$

$$\frac{\delta L}{\delta \dot{\varphi}} = \dot{\varphi} = \frac{1}{2} \dot{\varphi}^2 + V(\varphi)$$

$$\frac{1}{2} \dot{\varphi}^2$$

γ_μ L (const) $\phi_\mu(t)$ — scalar d.o.f

> quintessence.

$$S = \int \sqrt{-g} L_{\text{matter}} + \int \sqrt{-g} \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right)$$

$\gamma^{\mu\nu} \frac{\delta \sqrt{-g} L_{\text{matter}}}{\delta g_{\mu\nu}}$

$$H^2 = \frac{1}{3\rho_{\text{pl}}}$$

$$\begin{aligned} \mathcal{L}_\phi &= \dot{\phi} \frac{\partial \mathcal{L}}{\partial \dot{\phi}} - \mathcal{L} = \frac{1}{2} \dot{\phi}^2 - V(\phi) \\ P(\phi) &= \frac{1}{2} \dot{\phi}^2 - V(\phi) \end{aligned}$$

γ_Λ 1. const $\gamma_\phi(t)$ — scalar d.o.f

> quintessence.

$$d\lambda^2 = \int \sqrt{g} L_{\text{matter}} + \int \sqrt{g} \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right) \quad \xrightarrow{f(\partial_\mu \phi \partial^\mu \phi)} \quad T^{\mu\nu} = \frac{\delta \sqrt{g} L_{\text{matter}}}{\delta g_{\mu\nu}}$$

$$\rightarrow H^2 = \frac{1}{3M_{\text{Pl}}^2} \left(\frac{1}{2} \dot{\phi}^2 + V(\phi) \right) \quad \begin{aligned} \mathcal{L} &= \dot{\phi} \frac{\partial \mathcal{L}}{\partial \dot{\phi}} - \mathcal{L} = \frac{1}{2} \dot{\phi}^2 + V(\phi) \\ P(\phi) &= \frac{1}{2} \dot{\phi}^2 - V(\phi) \end{aligned}$$

Λ const $f_\nu(t)$ — scalar d.o.f

> quintessence.

$$S = \int R d^4x + \int \sqrt{-g} L_{\text{matter}} + \int \sqrt{-g} \left(\frac{1}{2} \dot{\phi}^2 - V(\phi) \right)$$

$f(\phi, \gamma, \dot{\gamma})$

$$T^{\mu\nu} = \frac{\delta \sqrt{-g} L_{\text{matter}}}{\delta g_{\mu\nu}}$$

$$\frac{d^2 a}{dt^2} > 0$$

$$\begin{aligned} \rightarrow H^2 &= \frac{1}{3M_{\text{Pl}}^2} \left(\frac{1}{2} \dot{\phi}^2 - V(\phi) \right) = \dot{\phi} \frac{\partial L}{\partial \dot{\phi}} - L = \frac{1}{2} \dot{\phi}^2 - V(\phi) \\ \frac{d^2 a}{dt^2} &= -\frac{1}{6M_{\text{Pl}}^2} \left(\frac{1}{2} \dot{\phi}^2 - V(\phi) \right) \end{aligned}$$

$\gamma \wedge$ 1. consi $\phi_v(t)$ — scalar d.o.f

> quintessence.

$$\int R d^4x + \int \sqrt{g} L_{\text{matter}} + \int \sqrt{g} \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right)$$

$f(\partial_\mu \phi \partial^\mu \phi)$

$$T^{\mu\nu} = \frac{\delta \sqrt{g} L_{\text{matter}}}{\delta g_{\mu\nu}}$$

> 0

$$\rightarrow H^2 = \frac{1}{3M_{\text{Pl}}^2} \left(\frac{1}{2} \dot{\phi}^2 + V(\phi) \right)$$

$$\mathcal{L} = \dot{\phi} \frac{\partial \mathcal{L}}{\partial \dot{\phi}} - \mathcal{L} = \frac{1}{2} \dot{\phi}^2 + V(\phi)$$

$$\frac{\ddot{\phi}}{H} = -\frac{1}{6M_{\text{Pl}}^2} (2\dot{\phi}^2 - 2V(\phi))$$

$$P(\phi) = \frac{1}{2} \dot{\phi}^2 - V(\phi)$$

1. Consider $\phi_v(t)$ — scalar d.o.f

> quintessence.

$$R \, d\lambda^2 + \int \sqrt{g} L_{\text{rad}} d\lambda + \int \sqrt{g} \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right) \quad \xrightarrow{f(\partial_\mu \phi \partial^\mu \phi)} \quad T^{\mu\nu} = \frac{\delta \sqrt{g} L_{\text{rad}}}{\delta g_{\mu\nu}}$$

$$\rightarrow H^2 = \frac{1}{3M_{\text{Pl}}^2} \left(\frac{1}{2} \dot{\phi}^2 + V(\phi) \right)$$

$$0 < \frac{\ddot{\phi}}{\dot{\phi}} = -\frac{1}{6M_{\text{Pl}}^2} \left(\frac{2\dot{\phi}^2}{\dot{\phi}} - 2 \frac{V(\phi)}{\dot{\phi}} \right)$$

$$\mathcal{L}_{\phi} = \dot{\phi} \frac{\partial \mathcal{L}}{\partial \dot{\phi}} - \mathcal{L} = \frac{1}{2} \dot{\phi}^2 + V(\phi)$$

$$P(\phi) = \frac{1}{2} \dot{\phi}^2 - V(\phi)$$

γ_A 1. const $f_v(t)$ — scalar d.o.f

> quintessence.

$$S = \int R \, d^4x + \int \sqrt{g} \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right) \quad \xrightarrow{f(\partial_\mu \phi \partial^\mu \phi)} \quad T^{\mu\nu} = \frac{\delta \mathcal{L}}{\delta g_{\mu\nu}}$$

$$\frac{a}{a'} > 0$$

$$H^2 = \frac{1}{3M_{\text{Pl}}^2} \left(\frac{1}{2} \dot{\phi}^2 + V(\phi) \right)$$

$$\mathcal{L} = \dot{\phi} \frac{\partial \mathcal{L}}{\partial \dot{\phi}} - \mathcal{L} = \frac{1}{2} \dot{\phi}^2 + V(\phi)$$

$$-\frac{1}{6M_{\text{Pl}}^2} \left(\frac{2\dot{\phi}^2}{7} - 2V(\phi) \right)$$

$$P(\phi) = \frac{1}{2} \dot{\phi}^2 - V(\phi)$$

$$V(\phi) > 2\dot{\phi}^2$$

γ_Λ + const $f_\nu(t)$ — scalar d.o.f

> quintessence.

$$S = \int R d\lambda^4 + \int \sqrt{g} L_{\text{matter}} + \int \sqrt{g} \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right)$$

$f(\partial_\mu \phi \partial^\mu \phi)$

$$T^{\mu\nu} = \frac{\delta \sqrt{g} L_{\text{matter}}}{\delta g_{\mu\nu}}$$

$$\frac{a}{a} > 0$$

$$\rightarrow H^2 = \frac{1}{3M_{\text{Pl}}^2} \left(\frac{1}{2} \dot{\phi}^2 + V(\phi) \right)$$

$$\mathcal{L} = \dot{\phi} \frac{\partial \mathcal{L}}{\partial \dot{\phi}} - \mathcal{L} = \frac{1}{2} \dot{\phi}^2 + V(\phi)$$

$$0 < \frac{\ddot{a}}{a} = -\frac{1}{6M_{\text{Pl}}^2} \left(\frac{2\dot{\phi}^2}{3} - 2V(\phi) \right)$$

$$V(\phi) > \frac{2}{3} \dot{\phi}^2$$

$$P(\phi) = \frac{1}{2} \dot{\phi}^2 - V(\phi)$$

$$W = \frac{P}{S} = \frac{P+S}{S} - 1 = \frac{\dot{\phi}^2}{\frac{1}{2} \dot{\phi}^2} - 1 \approx \frac{(\dot{\phi}^2)}{\frac{1}{2}(\dot{\phi}^2)}$$

$$W = \frac{p}{\dot{\phi}} = \frac{p_T \dot{\phi}}{\dot{\phi}} - 1 = \frac{\dot{\phi}^2}{\dot{\phi} + V(\phi)} - 1 \approx \frac{(\dot{\phi}^2/V)}{(\dot{\phi}^2/V) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$W = \frac{p}{\rho} = \frac{p + \rho}{\rho} - 1 = \frac{\dot{\phi}^2}{\frac{1}{2}\dot{\phi} + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)}{\frac{1}{2}(\dot{\phi}/V) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$W = \frac{p}{\rho} = \frac{p + \rho}{\rho} - 1 = \frac{\dot{\phi}^2}{\frac{1}{2}\dot{\phi} + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)}{\frac{1}{2}(\dot{\phi}/V) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$\epsilon \ll 1$$

$$W = \frac{P}{S} = \frac{P+S}{S} - 1 = \frac{\dot{\phi}^2}{\frac{1}{2}\dot{\phi} + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)}{\frac{1}{2}(\dot{\phi}/V) + 1} - 1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow w \sim -1$$

$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$



$$W = \frac{P}{\rho} = \frac{P + \rho}{\rho} - 1 = \frac{\dot{\phi}^2}{\frac{1}{2}\dot{\phi}^2 + V(\phi)} - 1 \approx \frac{(\dot{\phi}/\dot{\phi}_V)^2}{\frac{1}{2}(\dot{\phi}/\dot{\phi}_V)^2 + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\epsilon \ll 1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\ddot{\phi}_1$$

$$W = \frac{p}{\rho} = \frac{p + \rho}{\rho} - 1 = \frac{\dot{\phi}^2}{2 + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)^2}{\frac{1}{2}(\dot{\phi}/V)^2 + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\epsilon \ll 1$$

$$W \sim -1$$

$$M_{\text{Pl}}^{4\alpha} \gamma^{-\alpha}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$W = \frac{p}{\rho} = \frac{p + \rho}{\rho} - 1 = \frac{\dot{\phi}^2}{2\dot{\phi} + V(\phi)} - 1 = \frac{(\dot{\phi}/V)^2}{(\dot{\phi}/V) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\epsilon \ll 1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow$$

$$V(\phi)$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$-4/11 \quad \zeta + \alpha \quad \gamma^{-4-1}$$

$$W = \frac{P}{\rho} = \frac{P + \dot{\phi}^2}{\dot{\phi}^2 + V(\phi)} - 1 = \frac{\dot{\phi}^2}{\dot{\phi}^2 + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)^2}{\frac{1}{2}(\dot{\phi}/V)^2 + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\epsilon \ll 1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\phi = A t^Y$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - \alpha M^{4+\alpha} \phi^{-\alpha-1} = 0$$

$$-\alpha M^{4+\alpha} \phi^{-\alpha-1}$$

$$W = \frac{P}{\rho} = \frac{P + \dot{\phi}^2}{\dot{\phi}^2 + V(\phi)} - 1 = \frac{\dot{\phi}^2}{\dot{\phi}^2 + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)^2}{\frac{1}{2}(\dot{\phi}/V)^2 + 1} - 1$$

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$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 2M^{4+\alpha}\phi^{-\alpha-1} = 0$$

$$\phi = At^\gamma$$

$-2M^{4+\alpha}\phi^{-\alpha-1}$

$$A \gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} - \alpha M A^{\frac{4}{\alpha}} (-\alpha-1) \gamma = 0$$

$$A \gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} + \alpha M_{\text{in}} A^{\gamma(\alpha+1)} - \gamma(\alpha+1) = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 - \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \frac{2}{\alpha+2}$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} + \alpha M_{\text{pl}}^{4\alpha} A^{-\alpha+1} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma = -\gamma(\alpha+1) \Rightarrow -1 - \frac{2}{\gamma} = \alpha + 1 \Rightarrow \gamma = \left(\frac{\alpha+2}{-2} \right)^{-1} = \frac{-2}{\alpha+2}$$

$$A = \alpha(2, \alpha)^2 M^4$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} + \alpha M^{4+\alpha} A \frac{-(\alpha+1)}{t^{\gamma(\alpha+1)}} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 - \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{-2} \right)^{-1} = \frac{-2}{\alpha+2}$$

$$A = \alpha(2+\alpha)^2 M^{4+\alpha}$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} + \alpha M^{4\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2} \right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \alpha(2+\alpha)^2 M^{4+\alpha}$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} + \alpha M^{4\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2} \right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} + \alpha M^{4+\alpha} A t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2} \right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} + \alpha M^{4\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{2}{\alpha+2} \right)^{-1}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} +$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} + \alpha M^{4\alpha} A^{\alpha+1} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2} \right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} +$$

$$W = \frac{P}{\rho} = \frac{P_{\text{eff}}}{\rho} - 1 = \frac{\dot{\phi}^2}{\frac{1}{2}\dot{\phi} + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)}{\frac{1}{2}(\dot{\phi}/V) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\epsilon \ll 1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - \alpha M^{4+\alpha} \phi^{-\alpha-1} = 0$$

$$\phi = A t^{\gamma} \quad \dot{\phi}^2 \propto t^{(\gamma-1)2}$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} = M_{\gamma} A^{\gamma} t^{\gamma} = 0$$

$$\gamma-1 = -\frac{2}{\gamma+2}$$

$$\gamma-2 = -\gamma(\gamma+1) \Rightarrow -1 + \dots \Rightarrow \gamma = \left(\frac{\alpha+2}{+2} \right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2, \alpha)^2}{6+4} \right)$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} - \alpha M^{4+\alpha} A^{(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2} \right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} - \alpha M^{4+\alpha} A^{(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2} \right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} - \alpha M^{4\alpha} A^{(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-1 = -\frac{2\alpha}{\alpha+2}$$

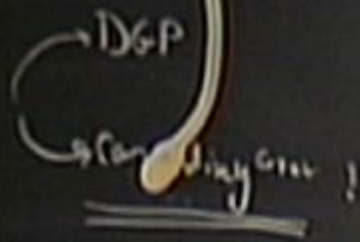
$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2} \right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2, \alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\rho \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$R^{(0,1)}(E)$



$$P(X) \leftrightarrow Q\left(\frac{\delta P}{\delta}\right)$$

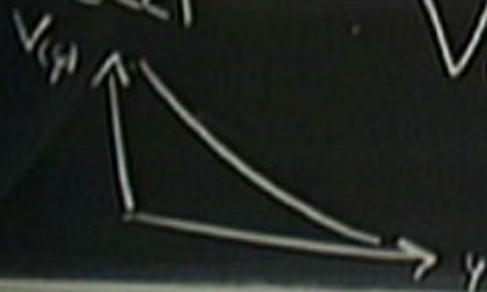
$$W = \frac{P}{\dot{\phi}} = \frac{P - \dot{\phi}}{\dot{\phi}} - 1 = \frac{\dot{\phi}^2}{2\dot{\phi} + V(\phi)} - 1 \approx \frac{(\dot{\phi}^2/V)}{2(\dot{\phi}^2/V) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$\epsilon \ll 1$$



$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - \alpha M^{4+\alpha} \phi^{-\alpha-1} = 0$$

$$\phi = A t^Y \quad \dot{\phi}^2 \propto t^{(Y-1)2}$$

$R^{(1,2)}$ $\rightarrow$ sing. cur. !

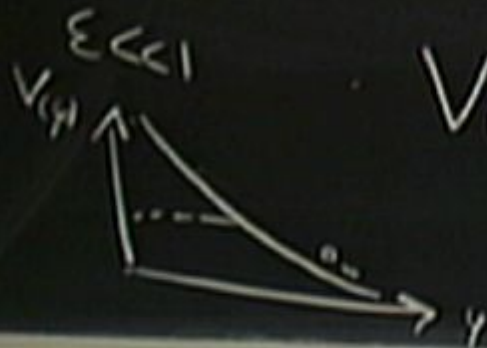
$$P(X) \leftrightarrow Q\left(\frac{\delta P}{\delta}\right)$$

$$W = \frac{P}{S} = \frac{P-S}{S} - 1 = \frac{\dot{\phi}^2}{2\dot{\phi} + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)}{2(\dot{\phi}/V) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$



$$V(\phi) \sim M^{4\alpha} \phi^{-\alpha}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4\alpha} \phi^{-\alpha-1} = 0$$

$$\phi = A t^\gamma \quad \dot{\phi}^2 \propto t^{(4\alpha-1)2}$$

$-4M^{4\alpha} \phi^{-\alpha-1}$

$$A \gamma(\gamma-1) t^{\gamma-2} + \frac{3}{2} A \gamma t^{\gamma-2} - \alpha M^{4+\alpha} A t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2} \right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\varphi \propto t^{-\frac{2}{\alpha+2}}$$

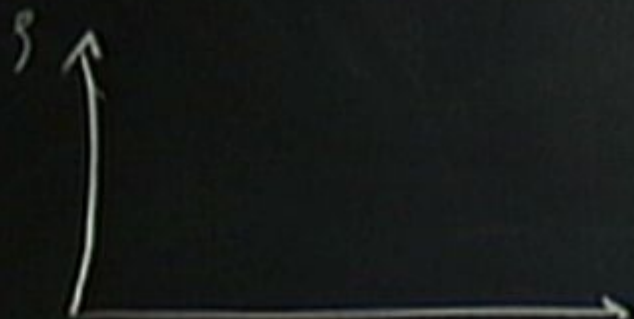


$$-2 = -\delta(\alpha+1) \Rightarrow -1 + \frac{1}{\delta} = \alpha+1 \Rightarrow \delta = \left(\frac{\alpha+2}{+2} \right) = \frac{\alpha+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B \underbrace{t^{-\frac{2\alpha}{\alpha+2}}} + C \underbrace{t^{-\frac{2\alpha}{\alpha+2}}}$$

$$\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\rho_R \propto t^{-2}$$

$$\rho_M \propto$$

$$0 - 2 = -2(\alpha)$$

$$\gamma = \left(\frac{\alpha + 2}{\alpha + 2} \right) = \frac{\alpha}{\alpha + 2}$$

$$A = (\alpha)$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi)$$

$$t^{-2\alpha/(\alpha+2)}$$

$$\rho_p \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\rho_R \propto t^{-2}$$

$$\rho_M \propto a^3 \sim$$

$$\delta - \mathcal{L} = -\delta(\alpha + 1)$$

$$A = \left(\alpha(2, \alpha) \right)$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) =$$

$$-2\alpha / (\alpha + 2)$$

$$\rho_\varphi \propto t^{-2 \left(\frac{\alpha}{\alpha + 2} \right)}$$



$$\rho_R \sim t^{-1}$$

$$\rho_M \sim t^{-3/2}$$

$$\delta - 2 = -\delta(\alpha + 1) \Rightarrow -1 + \frac{1}{\delta} = \alpha + 1 \Rightarrow \delta$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+4} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\rho_R \propto t^{-1}$$

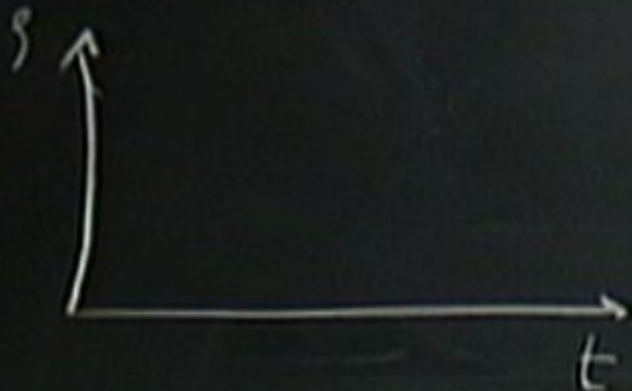
$$\rho_M \propto \omega^3 \sim t^{-3/2}$$

$$\delta - 2 = -\delta(\alpha + 1) \Rightarrow -1 + \frac{2}{\delta} = \alpha + 1 \Rightarrow \delta$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+4} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\rho_R \propto t^{-1}$$

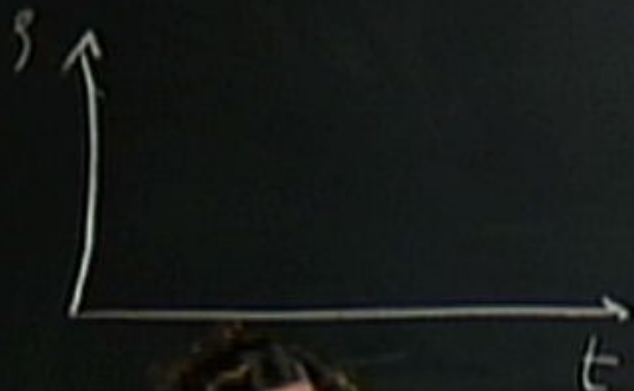
$$\rho_M \propto \rho_R \sim t^{-3/2}$$

$$\delta - 2 = -\delta(\alpha + 1) \Rightarrow -1 + \frac{1}{\delta} = \alpha + 1 \Rightarrow \delta = \left(\frac{\alpha + 2}{+2} \right) = \frac{\alpha}{\alpha + 2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+4} \right)^{\frac{1}{2+\alpha}}$$

$$\dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_M \propto \rho_R \sim t^{-3/2} \end{cases}$$

$$= \left(\frac{\alpha+2}{+2} \right) = \frac{\alpha}{\alpha+2}$$

$$\rho_p \propto t^{-2 \left(\frac{\alpha}{\alpha+2} \right)}$$

$$\left(\frac{1}{2} \right)^{4+\alpha} \frac{1}{2+\alpha} + C t^{-2\alpha/\alpha+2}$$



$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_M \propto a^3 \propto t^{-3/2} \\ \rho_{\text{dark}} \propto t^{-1} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\delta - 2 = -\delta(\alpha + 1) \Rightarrow -1 + \frac{2}{\delta} = \alpha + 1 \Rightarrow \delta = \left(\frac{\alpha + 2}{2} \right)$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B t^{\frac{-2\alpha}{\alpha+2}} + C t^{\frac{-2\alpha}{\alpha+2}}$$

$$\rho_p \propto$$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_M \propto a^3 \propto t^{-3/2} \\ \rho_{\text{dark}} \propto t^{-1/3} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\delta - 2 = -\delta(\alpha + 1) \Rightarrow -1 + \frac{2}{\delta} = \alpha + 1 \Rightarrow \delta = \left(\frac{\alpha + 2}{+2} \right)^{-1}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{\frac{-2\alpha}{\alpha+2}} + C t^{\frac{-2\alpha}{\alpha+2}}$$

$$\rho_{\varphi} =$$



$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_M \propto a^3 \sim t^{-3/2} \\ \kappa \sim t^{1/2} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ u \sim t^{2/3} \end{cases}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{\frac{-2\alpha}{\alpha+2}} + C t^{\frac{-2\alpha}{\alpha+2}}$$

$$= \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_M \propto a^3 \sim t^{-3/2} \\ \rho_{\text{kin}} \sim t^{-1/2} \end{cases}$$

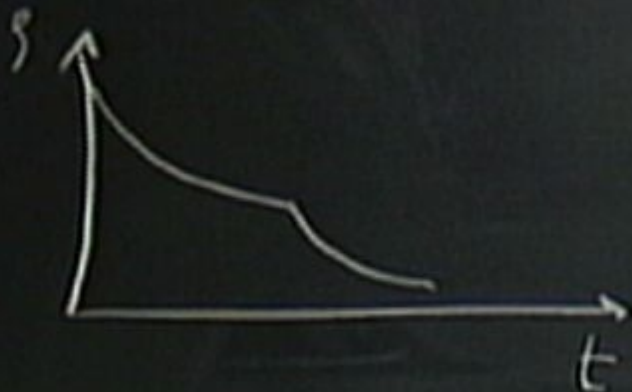
$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$-2 = -\alpha(\alpha+1) \Rightarrow \alpha+1 = 2 \Rightarrow \alpha = 1 \Rightarrow \delta = \left(\frac{1+\alpha}{\alpha+2} \right) = \frac{2}{3}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$1 = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_p \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_M \propto a^3 \propto t^{-3/2} \\ \rho_{\text{dark}} \propto t^{-1/2} \end{cases}$$

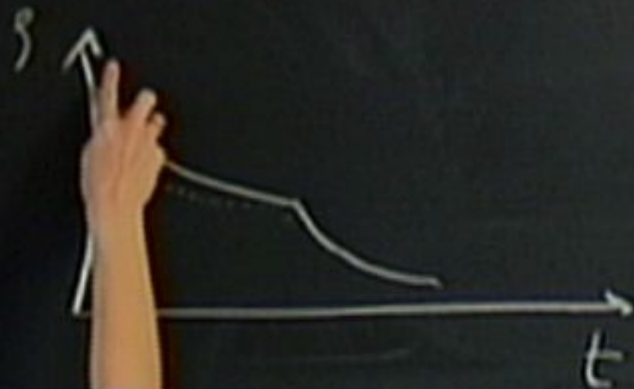
$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$0 = \mathcal{L} = -6(\alpha+1) \Rightarrow -1 + \frac{1}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{\alpha+1} \right) = \frac{1}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_M \propto a^3 \sim t^{-3/2} \end{cases}$$

cluster

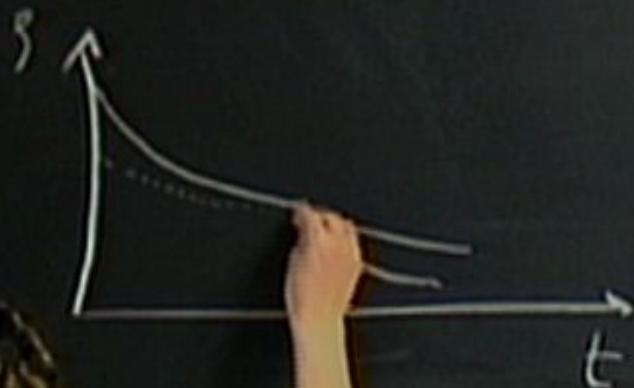
$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-2/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$L = -\frac{1}{2}(\dot{\phi}^2 + \dot{\chi}^2) - V(\phi, \chi) \Rightarrow \delta = \left(\frac{15+2}{4+2} \right) = \frac{13}{6}$$

$$\Gamma = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+4} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2}\dot{\phi}^2 + V(\phi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_\phi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



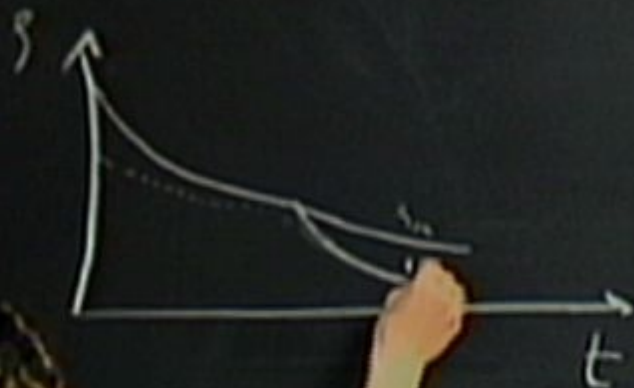
$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_M \propto a^3 \sim t^{-3/2} \end{cases}$$

Klein's

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-2/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$V(\varphi) = B t^{\frac{-2\alpha}{\alpha+2}} + C t^{\frac{-2\alpha}{\alpha+2}}$$

$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_M \propto a^3 \sim t^{-3/2} \\ \text{Klein's} \end{cases}$$

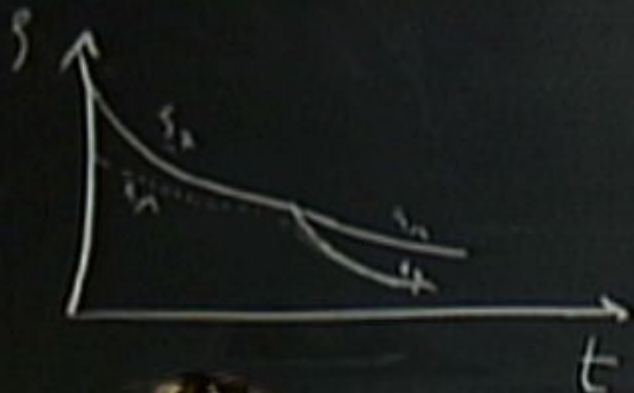
$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-2/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$-1 + 1 + 1 + 1 \rightarrow \delta = \left(\frac{4\alpha + 2}{\alpha + 2} \right) = \frac{4\alpha}{\alpha + 2}$$

$$\frac{2(\alpha+1)^2 M^{4+\alpha}}{6+\alpha} \Big)^{\frac{1}{2+\alpha}}$$

$$V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\begin{cases} \xi_R \propto t^{-1} \\ \xi_m \propto a^{1/3} \sim t^{-3/2} \\ \rho_{\text{kin}} \sim t^{-1/3} \end{cases}$$

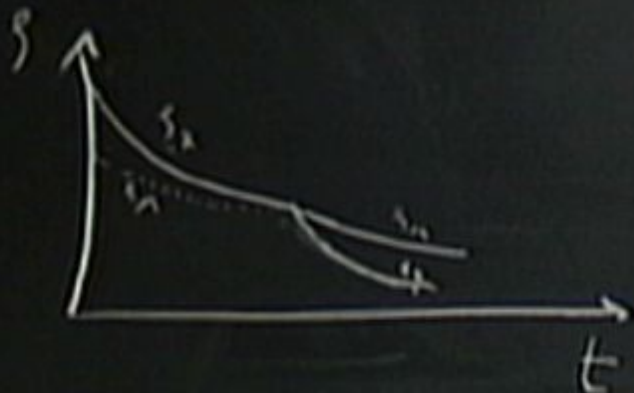
$$\begin{cases} \xi_R \propto a^{-4} \sim t^{-8/3} \\ \xi_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{\alpha+2} \right)^{-1} = \frac{\alpha}{\alpha+2}$$

$$\left(\frac{\alpha(\alpha+1)^2 M^{4+\alpha}}{6-4} \right)^{1/(2+\alpha)}$$

$$t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\xi_p \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$



$$\begin{cases} \rho_R \propto t^{-4} \\ \rho_m \propto a^3 \sim t^{-3/2} \\ \rho_{\text{dark}} \sim t^{-1/3} \end{cases}$$

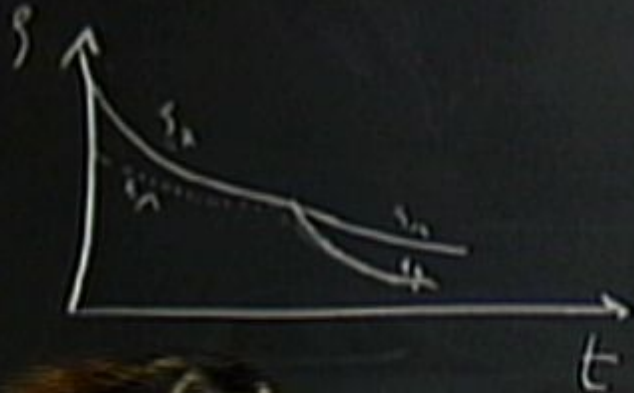
$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\delta - 2 = -\delta(\alpha + 1) \Rightarrow -1 + \frac{2}{\delta} = \alpha + 1 \Rightarrow \delta = \left(\frac{\alpha + 2}{+2} \right)^{-1} = \frac{2}{\alpha + 2}$$

$$A = \left(\frac{\alpha(2, \alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_{\varphi} \propto t^{-1}$$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_M \propto \alpha^3 \sim t^{-3/2} \\ \rho_{\text{kin}} \sim t^{-1/2} \end{cases}$$

$$\begin{cases} \rho_R \propto u^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ u \sim t^{2/3} \end{cases}$$

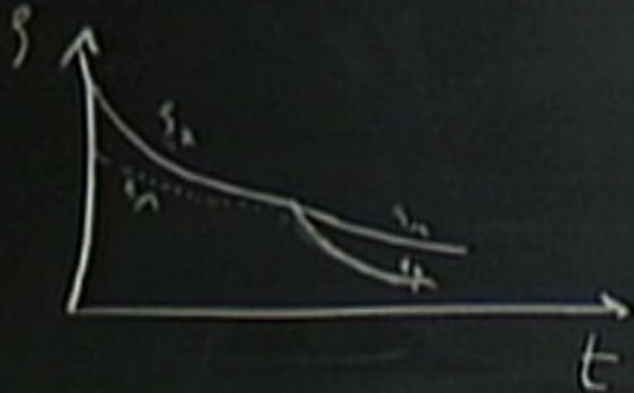
$$(\alpha+1) \rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{\alpha+1} \right)^{-1} = \frac{\alpha+1}{\alpha+2}$$

$$\frac{\alpha(2+\alpha)^2}{\alpha(2+\alpha)^2} \left(\frac{1}{2+\alpha} \right)^{1/2+\alpha}$$

$$t^{-2\alpha/\alpha+2} + C t^{-2\alpha/\alpha+2}$$

$$\rho_p \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$

(not) ... t^{-2}
 $\alpha \rightarrow 0$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_M \propto a^3 \sim t^{-3/2} \\ \rho_{\text{dark}} \sim t^{-1/3} \end{cases}$$

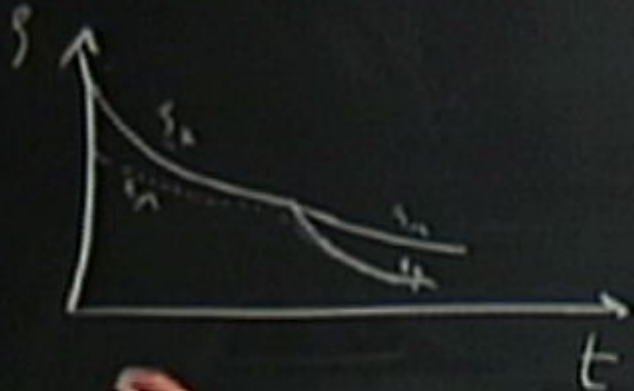
$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\delta - 2 = -\delta(\alpha + 1) \Rightarrow -1 + \frac{2}{\delta} = \alpha + 1 \Rightarrow \delta = \left(\frac{\alpha + 2}{+2} \right)^{-1} = \frac{+2}{\alpha + 2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_\varphi \propto t^{-2}$$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_m \propto a^3 \sim t^{-3/2} \\ \rho_{\text{dark}} \sim t^{-1/3} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ u \sim t^{2/3} \end{cases}$$

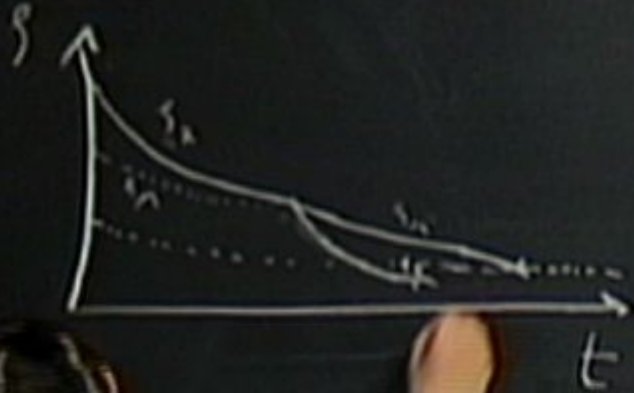
$$2 = -\delta(\alpha+1) \Rightarrow -1 + \frac{\delta}{\delta} = \alpha+1 \Rightarrow \delta = \left(\frac{\alpha+2}{\alpha+2} \right)^{-1} = \frac{\alpha+2}{\alpha+2}$$

$$= \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)} = t^{-\frac{2}{3}}$$

(not) ... t^{-2} $\alpha \rightarrow 0$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_M \propto \alpha^3 \sim t^{-3/2} \\ \rho_{\text{cluster}} \sim t^{-1} \end{cases}$$

$$\begin{cases} \rho_R \propto n^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ n \sim t^{2/3} \end{cases}$$

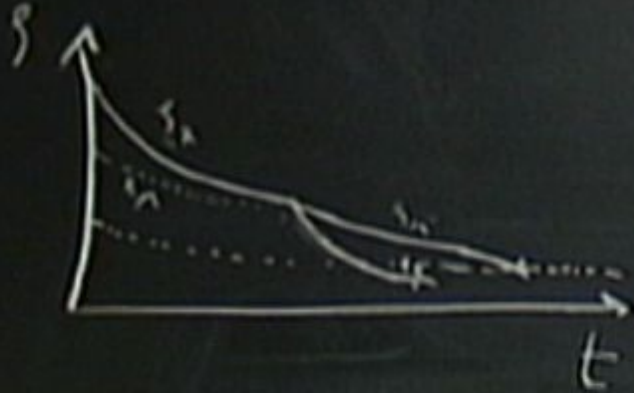
$$-2 = -\gamma(\alpha) \Rightarrow -1 + \frac{\gamma}{\gamma} = \alpha + 1 \Rightarrow \gamma = \left(\frac{\alpha+2}{\alpha+2} \right)^{-1} = \frac{\alpha+2}{\alpha+2}$$

$$M^{4+\alpha} \Big|_{2+\alpha}^{1/2+\alpha}$$

$$\rho(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_p \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)} = t^{-\frac{2}{3}}$$

(for $t \rightarrow \infty$) t^{-2} $\alpha \rightarrow 0$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_M \propto a^3 \sim t^{-3/2} \\ \rho_{\text{dark}} \sim t^{-1/3} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

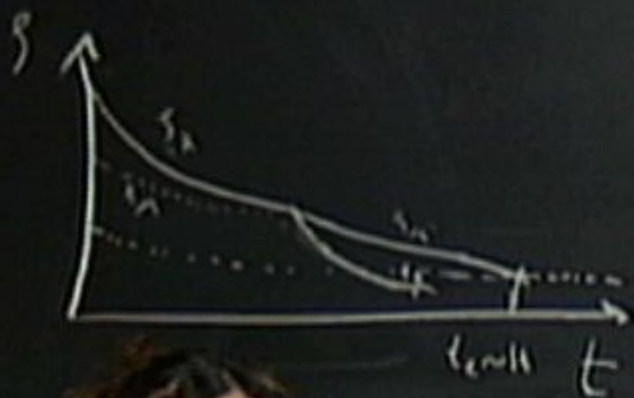
$$\delta - 2 = -\delta(\alpha + 1) \Rightarrow -1 + \frac{2}{\delta} = \alpha + 1 \Rightarrow \delta = \left(\frac{\alpha + 2}{2} \right)^{-1} = \frac{2}{\alpha + 2}$$

$$A = \left(\frac{\alpha(\alpha + 2)^2 M^{4+\alpha}}{6 + 4} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\phi}^2 + V(\phi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_\phi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)} = t^{-\frac{2}{3}}$$

(not) ... t^{-2} $\alpha \rightarrow 0$



$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_M \propto a^3 \sim t^{-3/2} \\ \rho_{coll} \sim t^{-1} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

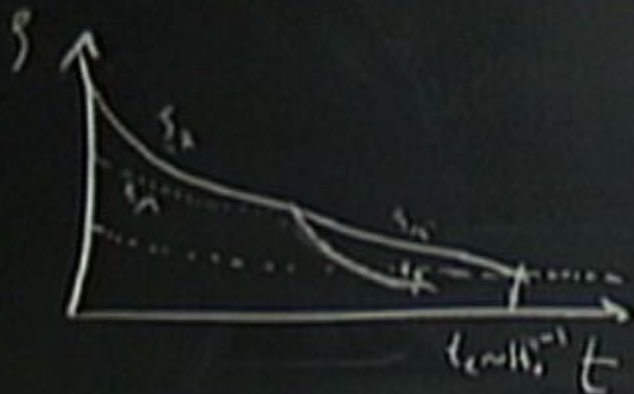
$$(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{\alpha+1} \right)^{-1} = \frac{\alpha+1}{\alpha+2}$$

$$\frac{(2\alpha)^2 M^{4+\alpha}}{2+\alpha}$$

$$t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

$$\rho_p \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)} = t^{-\frac{2}{3}}$$

$\alpha \rightarrow 0$



$$\begin{cases} \rho_R \propto t^{-4} \\ \rho_m \propto a^3 \sim t^{-3/2} \\ \rho_\phi \sim t^{-1} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

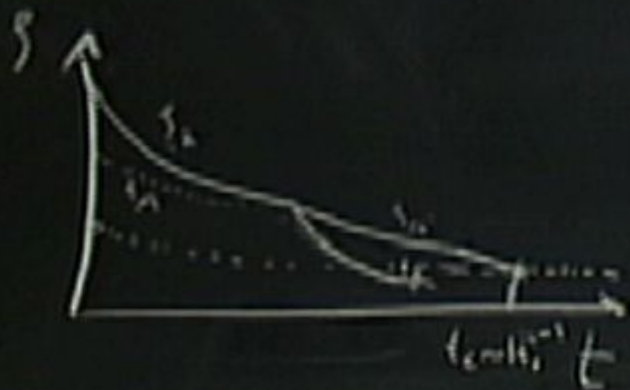
$$\gamma - 2 = -\gamma(\alpha + 1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha + 1 \Rightarrow \gamma = \left(\frac{\alpha + 2}{+2} \right)^{-1} = \frac{+2}{\alpha + 2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-\frac{2\alpha}{\alpha+2}}$$

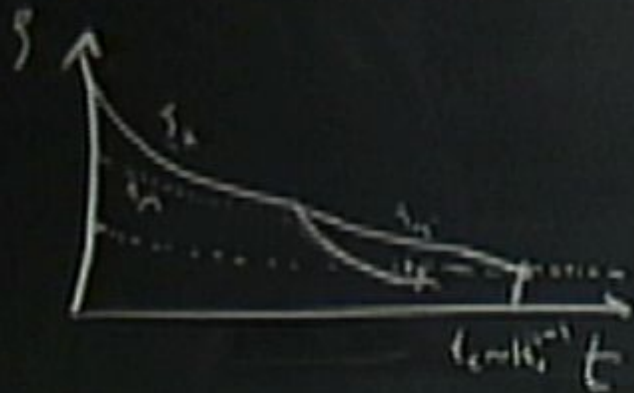
$$\rho_\phi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)} = t^{-\frac{2}{3}}$$

$\alpha \rightarrow 0$



$$\left\{ \begin{array}{l} \rho_R \propto t^{-4} \\ \rho_m \propto t^{-3} \end{array} \right\} \quad \left\{ \begin{array}{l} \rho_R \propto t^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-3} \sim t^{-2/3} \end{array} \right.$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-1/2} + C t^{-1/2}$$



$$\begin{cases} s_R \propto t^{-1} \\ s_M \propto a \propto t^{-2/3} \\ R_{\text{Hubble}} \propto t^{-1/3} \end{cases}$$

$$\begin{cases} s_R \propto t^{-1} \sim t^{-2/3} \\ s_M \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$d - 2 = -d(\alpha + 1) \Rightarrow \frac{1}{\alpha + 1} + \frac{1}{\alpha} = \alpha + 1 \Rightarrow \frac{1}{\alpha + 2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{\frac{1}{2+\alpha}}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{\alpha+2}} + C t^{-2\alpha}$$

$$\propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)} \dots t^{-2} \dots \alpha \rightarrow 0$$

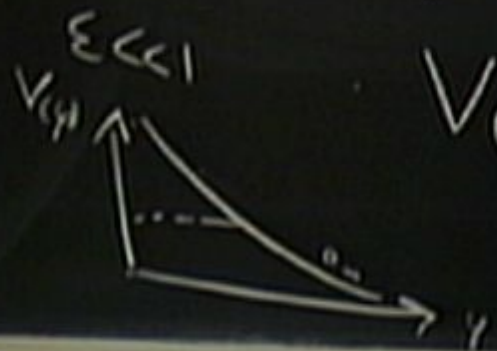
Carroll's equation!

$$W = \frac{P}{\rho} = \frac{P + \rho}{\rho} - 1 = \frac{\dot{\phi}^2}{2(\frac{\dot{\phi}^2}{2}) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1$$



$$-4M^{4+\alpha} \phi^{-\alpha-1}$$

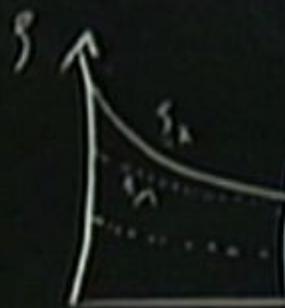
$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4+\alpha} \phi^{-\alpha-1} = 0$$

$$\phi = A t^\gamma \quad \dot{\phi}^2 \propto t^{(\gamma-1)2}$$

$$\rho_{\varphi} = M^{2(4+d)} \frac{1}{2+d} t^{-2\frac{2}{2+d}}$$

$$\rho_m =$$



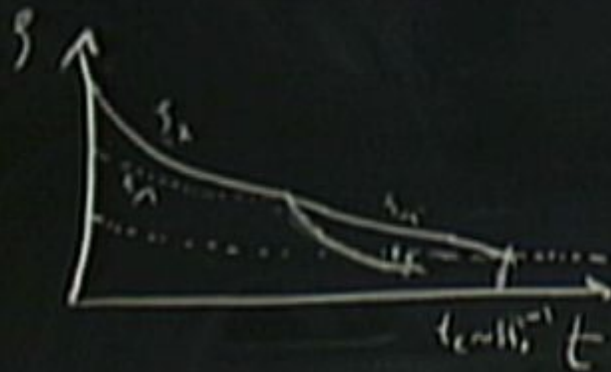
$$\rho_m \propto a^3 \sim t^{-3/2}$$

$$Cl_{100} \sim t^{1/3}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\rho_{\varphi} = M^{2(4+\alpha)} \epsilon_{r,\alpha} t^{-2\frac{\alpha}{2+\alpha}} \quad \Rightarrow$$

$$\rho_M = \frac{1}{16\pi G} t^2$$



$$\begin{cases} \rho_r \propto t^{-2} \\ \rho_M \propto \frac{1}{t^2} \end{cases}$$

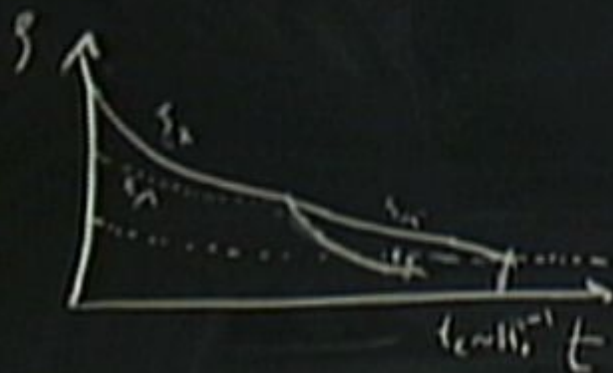
Clusset's

-2/3

$$\rho_{\varphi} = M^{2(4+d)} \kappa_{d,d} t^{-2d/(2+d)}$$

$$\rho_m = \frac{1}{16\pi G} t^2$$

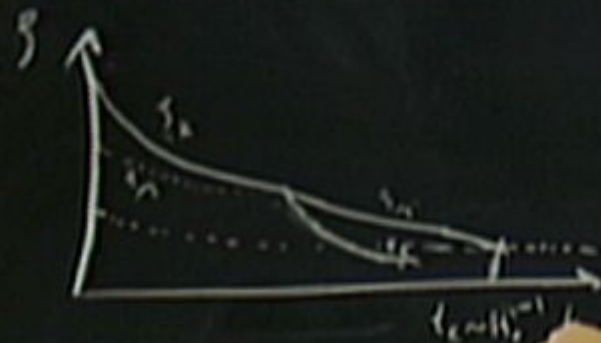
$$\Rightarrow t_c = M^{-1/(4+d)}$$



$$\begin{cases} \rho_{\varphi} \propto t^{-2} \\ \rho_m \propto t^{-2/2} \\ \text{Planck} \end{cases}$$

$$\rho_p = M^{2(1+\alpha)} \epsilon_{rad} t^{-2\alpha} \epsilon_{rad} \quad \rightarrow \quad t_c = M^{-\frac{(1+\alpha)}{2}} G^{-(1+\alpha)/2}$$

$$\rho_m = \frac{1}{16\pi G} t^{-2}$$



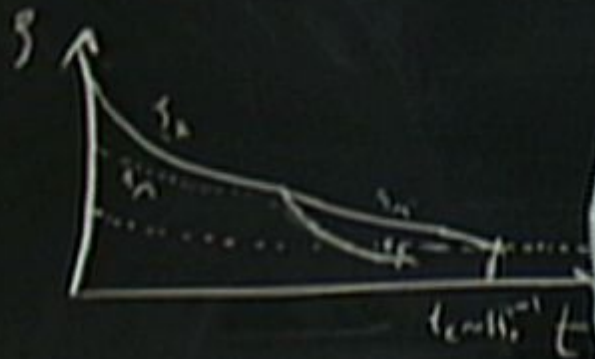
$$\rho_R \propto t^{-4}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-4/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\rho_{\varphi} = M^{2(4+\alpha)} \epsilon_{\text{rad}} t^{-2\alpha} \epsilon_{\text{rad}} \quad \rightarrow \quad t_c = M^{-\frac{(4+\alpha)}{2}} G^{-(2+\alpha)} \epsilon_{\text{rad}}$$

$$\rho_m = \frac{1}{4\pi G} t^{-2}$$

$$\sim H_0^{-1}$$



$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\rho_p = M^{2(4+d)} \epsilon_{\text{rad}} t^{-2\frac{d}{2+d}} \quad \Rightarrow \quad t_c = M^{-\frac{(4+d)}{2}} G^{-(2+d)\frac{1}{2}}$$

$$\rho_m = \frac{1}{16\pi G} t^{-2}$$

$$\sim H_0^{-1}$$

$$M \sim G^{-1-\frac{d}{2}} H_0^2$$

$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_m \propto a^3 \sim t^{-2/3} \\ \epsilon_{\text{rad}} \sim t^{-4} \end{cases}$$

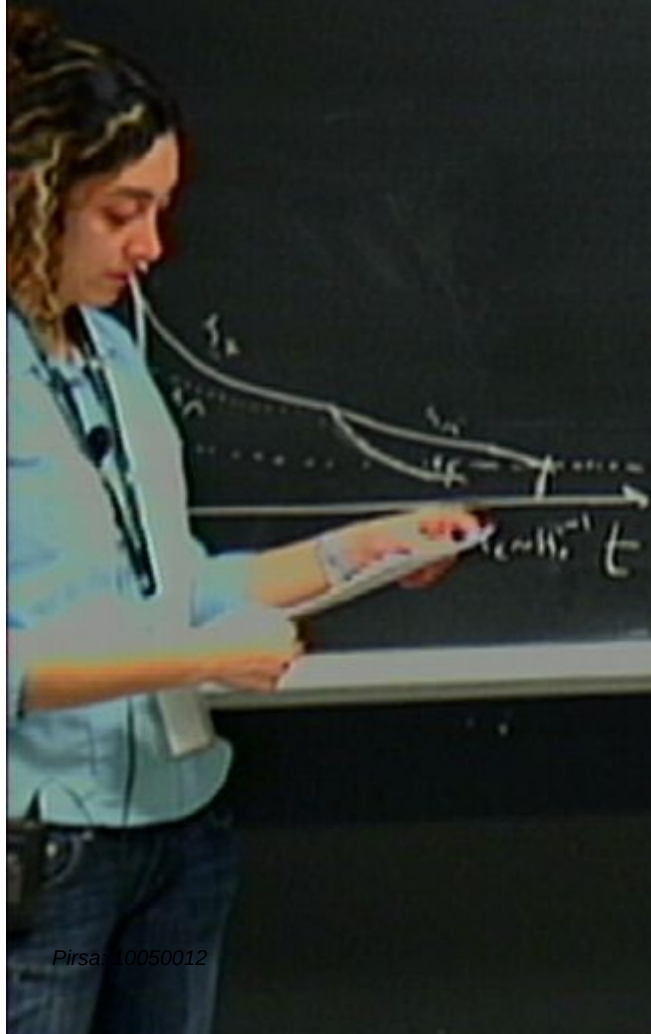
$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$



$$\rho_{\varphi} = M^{2(4+d)} \epsilon_{\text{rad}} t^{-2\frac{d}{2}} \epsilon_{\text{rad}} \quad \rightarrow \quad t_c = M^{-\frac{(4+d)}{2}} G^{-(2+d)/4}$$

$$\rho_m = \frac{1}{16\pi G} t^2 \quad \sim H_0^{-1}$$

$$M \sim G^{-1-4/d} H_0^2$$



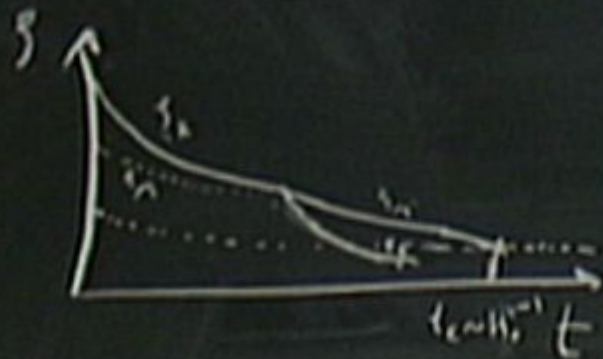
$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_m \propto a^3 \sim t^{-2/3} \\ \rho_{\text{rad}} \sim t^{-4} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\rho_{\varphi} = M^{2(4+d)} \epsilon_{\text{eff}} t^{-2\frac{d}{2+d}} \quad \rightarrow \quad t_c = M^{-\frac{(4+d)}{2}} G^{-(2+d)/4}$$

$$\rho_m = \frac{1}{16\pi G} t^2 \quad \sim H_0^{-1}$$

$$M \sim G^{-1-4/5} H_0^2$$



$$\begin{cases} \rho_r \propto t^{-2} \\ \rho_m \propto a^3 \propto t^{-3/2} \\ \rho_{\text{eff}} \propto t^{-2} \end{cases}$$

$$\begin{cases} \rho_r \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

R $\rightarrow$ $\frac{1}{2} \dot{\phi}^2$
Energy

$$P(\chi) \leftrightarrow Q\left(\frac{\delta P}{\delta \chi}\right)$$

$$W = \frac{P}{\rho} = \frac{P + \rho}{\rho} - 1 = \frac{\dot{\phi}^2}{2(\dot{\phi}^2 + V(\phi))} - 1 \approx \frac{(\dot{\phi}/V)^2}{2(\dot{\phi}^2/V^2) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$\epsilon \ll 1$$



$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - \alpha M^{4+\alpha} \phi^{-\alpha-1} = 0$$

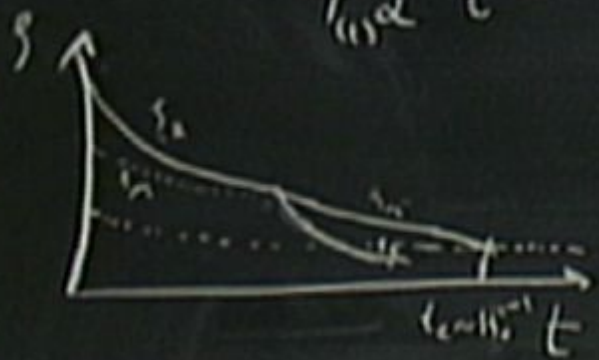
$$\phi = A t^{\frac{2}{\alpha+1}} \quad \dot{\phi}^2 \propto t^{\frac{2(1-\alpha)}{(\alpha+1)^2}}$$

$$\rho_p = M^{2(4+\alpha)} t^{\frac{1}{2+\alpha}} + t^{-2+\frac{\alpha}{2+\alpha}} \quad \Rightarrow \quad t_c = M^{-\frac{(4+\alpha)}{2}} G^{-(2+\alpha)} \sim H_0^{-1}$$

$$\rho_m = \frac{1}{16\pi G} t^2$$

$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p} \quad \rho_p \propto t^{\frac{1}{2+\alpha}}$$

$$M^{\frac{4+\alpha}{2}} \sim G^{-1-\frac{\alpha}{2}} H_0^2$$



$$\begin{cases} \rho_r \propto t^{-2} \\ \rho_m \propto t^2 \\ \rho_p \propto t^{\frac{1}{2+\alpha}} \end{cases}$$

$$\begin{cases} \rho_r \propto a^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\rho_p = M^{2(4+\alpha)} t^{\frac{1}{2+\alpha}} +^{-2\frac{1}{2+\alpha}} t^{\frac{1}{2+\alpha}} \quad \Rightarrow \quad t_c = M^{-\frac{4+\alpha}{2}} G^{-(2+\alpha)} \sim H_0^{-1}$$

$$\rho_m = \frac{1}{16\pi G} t^{-2}$$

$$\rightarrow H \propto \sqrt{\rho_p} \quad \rho_p \propto t^{\frac{1}{2+\alpha}} \quad \rho_p \propto t^{-\frac{4}{2+\alpha}} \quad M^{\frac{4+\alpha}{2}} \sim G^{-1-\alpha} H^2$$

$$\begin{cases} \rho_r \propto t^{-2} \\ \rho_m \propto a^3 \sim t^{-\frac{3}{2}} \\ \rho_{\text{dark}} \sim t^0 \end{cases}$$

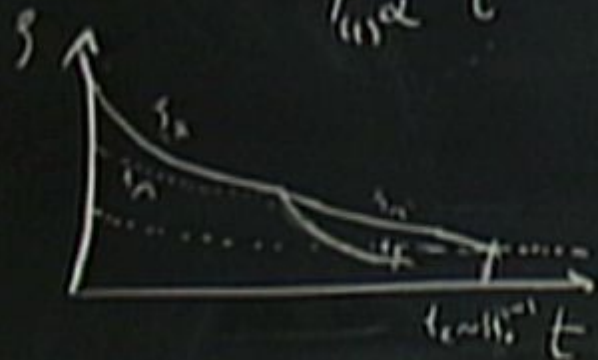
$$\begin{cases} \rho_r \propto a^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\rho_p = M^{2(4+u)} \epsilon_{1,u} t^{-2\frac{4+u}{2+u}} \quad \Rightarrow \quad t_c = M^{-\frac{(4+u)}{2}} G^{-(2+u)/2}$$

$$\rho_m = \frac{1}{16\pi G} t^2 \quad \sim t^{-1}$$

$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p}$$

$$\epsilon_{1,u} \propto t^{\frac{1}{2+u/2}}$$



$$\rho_p \propto t^{-4} \epsilon_{1,u} \sim t^{-4} M^{4+u} \sim G^{-1-u/2} H^2$$

$$\rho_m \propto t^{-2}$$

$$\rho_p \propto t^{-2}$$

$$\rho_m \propto t^{-2}$$

$$\rho_{\text{kin}} \propto t^{-2}$$

$$\rho_{\text{rad}} \propto t^{-4}$$

$$\rho_{\text{dark}} \propto t^{-2}$$

$$\rho_p = M^{2(4+u)} \epsilon_{\text{rad}} t^{-2\frac{4}{2+u}} \quad \Rightarrow \quad t_c = M^{-\frac{(4+u)}{2}} G^{-(2+u)/4}$$

$$\rho_m = \frac{1}{16\pi G} t^2 \quad \sim t_5^{-1}$$

$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p}$$

$$\epsilon_{\text{rad}} \propto t^{\frac{1}{2+u/2}} \quad \rho_p \propto t^{-4} \frac{M^{4+u}}{\epsilon_{\text{rad}}} \sim G^{-1-u/2} H^2$$

$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_m \propto a^3 \sim t^{-3/2} \end{cases}$$

Klausur 14

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\rho_p = M^{2(4+\alpha)} \epsilon_{+4} t^{-2\frac{4+\alpha}{2+\alpha}} \quad \Rightarrow \quad t_c = M^{-\frac{(4+\alpha)}{2}} G^{-(2+\alpha)} \sim H_0^{-1}$$

$$\rho_m = \frac{1}{16\pi G} t^2$$

$H \sim \frac{1}{t}$

$t^{\frac{1}{2} + \frac{4+\alpha}{2}}$

$\rho_p \propto t^{-4} \epsilon_{+4} M^{4+\alpha} \sim G^{-1-\frac{4+\alpha}{2}} H^2$

$\left\{ \begin{array}{l} \rho_R \propto t^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{array} \right.$

$\rho_R \propto t^{-4}$
 $\rho_m \propto t^{-2}$
 $\rho_{\text{curv}} \propto t^2$

$H_0^{-1} t$

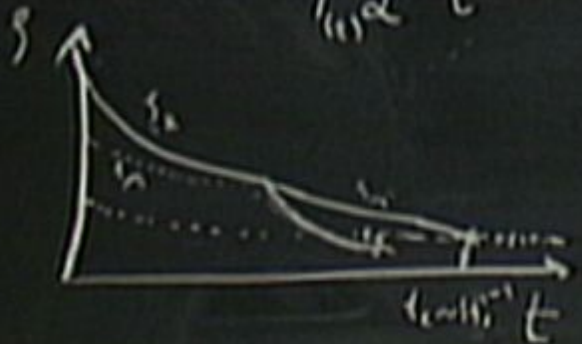
$$h a \propto t^{\frac{2}{2+4/3}}$$

$$\rho_p = M^{2(4/3)} \frac{1}{t^{1/3}} t^{-2 \frac{2}{2+4/3}} \quad \rightarrow \quad t_c = M^{-\frac{(4/3+1)}{2}} G^{-(2+4/3)} \sim t_0^{-1}$$

$$\rho_m = \frac{1}{16\pi G t^2}$$

$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p}$$

$$\varphi_{\text{inf}} \propto t^{\frac{1}{2+4/3}}$$



$$\rho_p \propto t^{-4} \sim t^{-\frac{4}{1+4/3}} \quad M \sim G^{-1-4/3} H^2$$

$$\left\{ \begin{array}{l} \rho_r \propto t^{-4} \\ \rho_m \propto a^{-3} \sim t^{-3/2} \end{array} \right.$$

$$\left\{ \begin{array}{l} \rho_r \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{array} \right.$$

$$h a \propto t^{\frac{2}{2+4\alpha}}$$

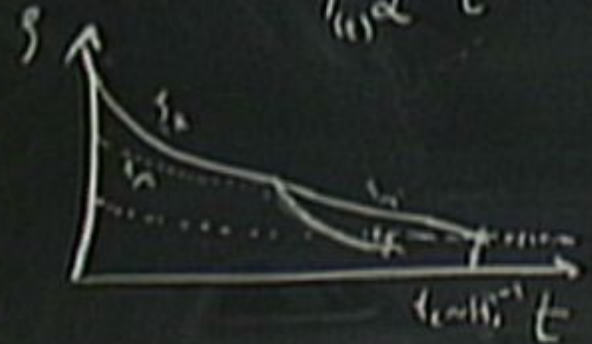
$$h a \propto$$

$$\rho_p = M^{2(4\alpha+1)/6\alpha} t^{-2/(2+4\alpha)} \quad \rightarrow \quad t_c = M^{-\frac{4(4\alpha+1)}{2}} G^{-(2+4\alpha)} \sim H_0^{-1}$$

$$\rho_m = \frac{1}{6\pi G} t^{-2}$$

$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p}$$

$$\varphi_m \propto t^{\frac{1}{2+4\alpha/2}}$$



$$\rho_p \propto t^{-4} \sim t^{-\frac{4}{2+4\alpha/2}} \sim t^{-\left(\frac{2}{1+\alpha}\right)}$$

$$M \sim G^{-1/(2+4\alpha)} H^2$$

$$\begin{cases} \rho_R \propto t^{-4} \\ \rho_m \propto a^{-3} \sim t^{-3/2} \\ \rho_{\text{dark}} \propto t^{-1} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$h a \propto t^{2/3+4/3}$$

$$h a \propto t$$

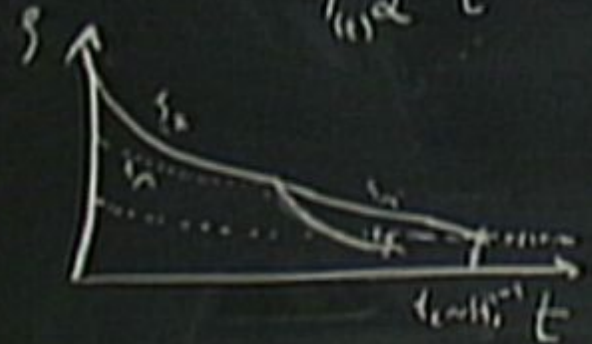
$$\rho_p = M^{2(4+d)/6} t^{-2/3+4/3} \quad \rightarrow \quad t_c = M^{-\frac{4(d+1)}{2}} G^{-(2+d)/6}$$

$$\rho_m = \frac{1}{16\pi G} t^{-2}$$

$$\sim t_0^{-1}$$

$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p}$$

$$\varphi_{inf} \propto t^{1/2+4/2}$$



$$\rho_p \propto t^{-4/3+4/3} \sim t^{-1}$$

$$M \sim G^{-1/2+4/6} H^2$$

$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_m \propto a^3 \sim t^{-3/2} \\ \rho_{crit} \propto t^{-2} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$\ln a \propto t^{\frac{3}{2} + \frac{d}{2}}$$

$$\ln a \propto t$$

$$\rho_p = M^{2(4+d)/6} t^{-2 + \frac{d}{2} + d}$$

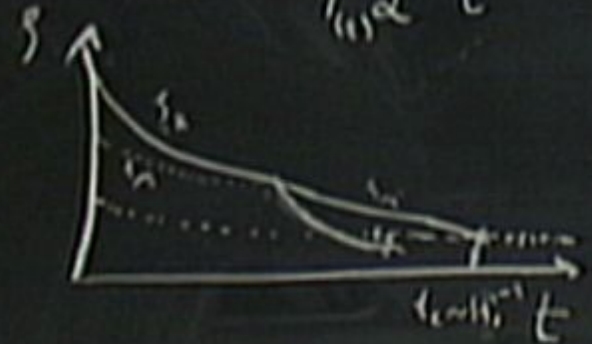
$$\rho_m = \frac{1}{16\pi G} t^{-2}$$

$$\Rightarrow t_c = M^{-\frac{(4+d)}{2}} G^{-(2+d)/6} \sim H_0^{-1}$$

$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p}$$

$$\varphi_{\text{inf}} \propto t^{\frac{1}{2} + \frac{d}{2}}$$

$$\rho_p \propto t^{-4 + \frac{d}{2} + d} \sim t^{-\left(\frac{3}{2} + \frac{d}{2}\right)} \quad M \sim G^{-1 - \frac{d}{2}} H^2$$



$$\begin{cases} \rho_R \propto t^{-3} \\ \rho_m \propto \rho_R \sim t^{-3/2} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$$h a \propto t^{\frac{3}{2} + \frac{d}{2}}$$

$$h a \propto t \quad a \sim e^{t/t_0}$$

$$\rho_p = M^{2(4+d)/2+d} t^{-2 + \frac{d}{2+d}}$$

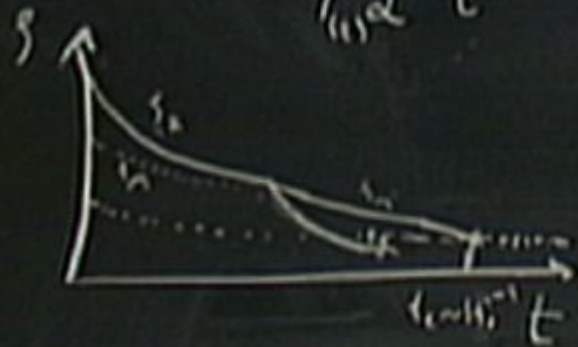
$$\rho_m = \frac{1}{16\pi G t^2}$$

$$\rightarrow t_c = M^{-\frac{(4+d)}{2}} G^{-(2+d)/4}$$

$$\sim H_0^{-1}$$

$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p}$$

$$\varphi_{inf} \propto t^{\frac{1}{2} + \frac{d}{2}}$$



$$\rho_p \propto t^{-4 + \frac{d}{2}} \sim t^{-\left(\frac{2}{1+d}\right)}$$

$$M \sim G^{-1 - \frac{d}{2}} H^2$$

$$\left\{ \begin{array}{l} \rho_R \propto t^{-4} \sim t^{-2/3} \\ \rho_m \propto t^{-2} \end{array} \right.$$

$$a \sim t^{2/3}$$

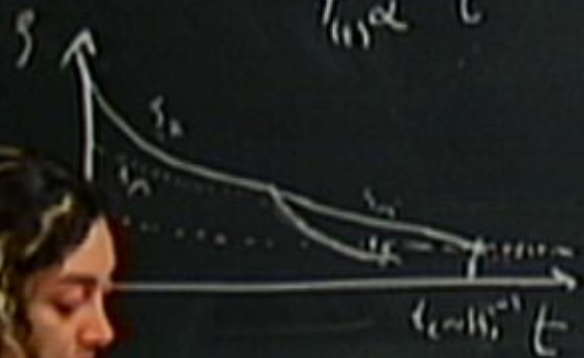
$\ln a \propto t$ and $a \propto e^t$
 $\varphi = M$
 $\Rightarrow t_c = M^{-\frac{1}{2}} G^{-(2+4\epsilon)}$

 $\rho_m = \frac{1}{16\pi G t^2}$
 $\sim H_0^{-1}$

$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p}$
 $\frac{1}{2} + \frac{4}{2}$

 $M \sim G^{-1-4\epsilon} H^2$

 $\varphi_{inf} \propto t$
 $\rho_p \propto t^{-4} \sim t^{-\frac{4}{2+4\epsilon}}$



$\rho_R \propto t^{-3}$
 $\rho_m \propto a^{-3} \sim t^{-3/2}$
 $\rho_{dark} \propto t^{-3}$

$\rho_R \propto a^{-3} \sim t^{-3/2}$
 $\rho_m \propto t^{-2}$
 $a \sim t^{2/3}$

$\varphi(t) = B t^{-\frac{2\epsilon}{2+4\epsilon}} + C t^{-\frac{2\epsilon}{2+4\epsilon}}$
 $\rho \propto t^{-2}$

$$h a \propto t^{\frac{3}{2} + \frac{1}{2}\alpha}$$

$$h a \propto t \quad a \sim e^{t}$$

$$\rho_p = M^{2(4+\alpha)} \frac{1}{t^{2+\alpha}}$$

$$\rho_m = \frac{1}{16\pi G t^2}$$

$$\rightarrow t_c = M^{-\frac{(4+\alpha)}{2}} G^{-(2+\alpha)/2}$$

$$\sim H_0^{-1}$$

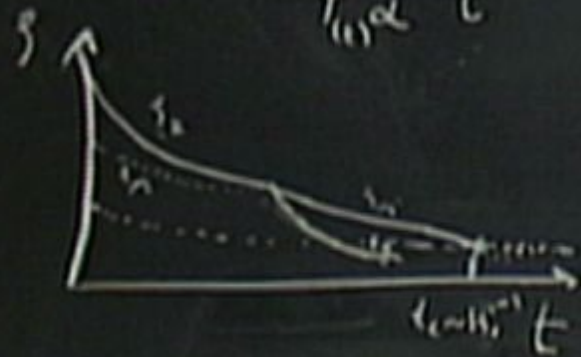
$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_p}$$

$$\rho_m \propto t^{-2}$$

$$\frac{1}{2} + \frac{\alpha}{2}$$

$$\rho_p \propto t^{-4} \frac{M^{4+\alpha}}{t^{2+\alpha}} \sim t^{-2}$$

$$M \sim G^{-1/(4+\alpha)} H^2$$



$$\begin{cases} \rho_R \propto t^{-4} \\ \rho_m \propto t^{-3} \end{cases}$$

$$a \sim t^{2/3}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto a^{-3} \sim t^{-2} \end{cases}$$

$$a \sim t^{2/3}$$

$$\frac{1}{2} \dot{\varphi}^2 + V(\varphi) = B t^{-\frac{2\alpha}{4+\alpha}} + C t^{-\frac{2\alpha}{4+\alpha}}$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff} g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$\Lambda_{eff} \quad \quad \quad \downarrow \quad \quad \quad S_{\mu\nu}$

$$V(\phi) = V_0 + \Delta\phi V'_0$$

$$S = \int \sqrt{g} R^4 d^4x + \int \sqrt{g} L^4 d^4x$$

$F(R)$

Scalar-Tensor

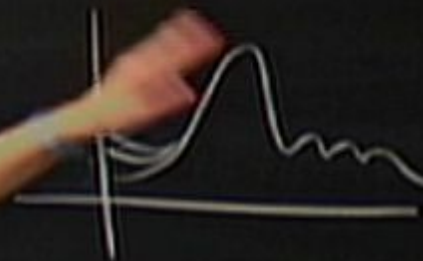
$R^{(1,1)}$

DGP

Concordance Λ CDM

$$H) = \frac{1}{24} \left(\frac{\delta S}{\delta \eta} \right) \rightarrow H_{eff}$$

$$\chi) \leftrightarrow \mathcal{P} \left(\frac{\delta S}{\delta \eta} \right)$$



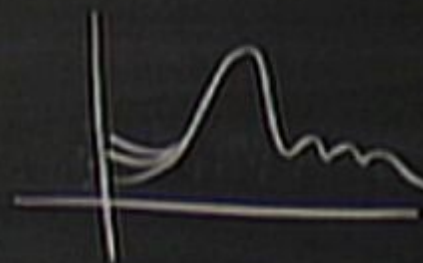
$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff} g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$\Lambda_{eff} \ll \rho_{vac}$

$$V(\phi) = V_0 + \Delta\phi V_0'$$

$$S = \int \sqrt{g} R^4 dx + \int \sqrt{g} L_m dx + \int \sqrt{g} \Lambda dx$$

$\frac{\delta S}{\delta \phi} \approx 0$



$F(R)$

Scalar-Tensor

$L(\phi)$

$F(H^2)$

$\frac{1}{\sqrt{g}} \frac{\delta S}{\delta \eta}$

$\rightarrow H_{eff}$

$R^{(DLP)}$

DGP

concordance

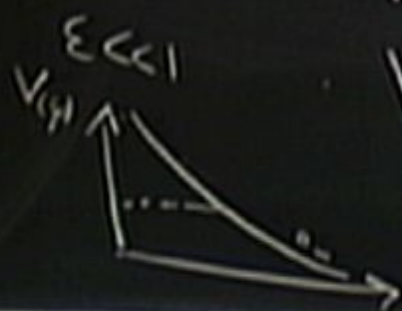
$P(\chi)$

$\leftrightarrow Q(\frac{\delta \rho}{\rho})$

$$W = \frac{p}{\dot{\phi}} = \frac{p - \dot{\phi}}{\dot{\phi}} - 1 = \frac{\dot{\phi}^2}{2(\dot{\phi}^2)} - 1 \approx \frac{(\dot{\phi}^2/V)}{2(\dot{\phi}^2/V) + 1} - 1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$



$\dot{\phi}$
 V
 $W \sim -1$
 4α
 ϕ^{-4}

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4\alpha}\phi^{-4-1} = 0$$

$$\phi = A t^Y \quad \ddot{\phi} \propto t^{(Y-1)2}$$

$$-4M^{4\alpha}\phi^{-4-1}$$

$$W = \frac{P}{\rho} = \frac{P_{\text{eff}}}{\rho} - 1 = \frac{\dot{\phi}^2}{2(\dot{\phi}^2 + V(\phi))} - 1 \approx \frac{(\dot{\phi}/V)^2}{2(\dot{\phi}^2/V^2) + 1} - 1 \rightarrow W(z)$$

$$\dot{\phi}/V \ll 1 \rightarrow w \sim -1$$

$$V(\phi) \sim M^{4+2\alpha} \phi^{-2}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 2M^{4+2\alpha}\phi^{-3} = 0$$

$$\phi = A t^Y \quad \dot{\phi}^2 \propto t^{(Y-1)2}$$

$$W = \frac{P}{S} = \frac{P_{\text{eff}}}{S} - 1 = \frac{\dot{\phi}^2}{2(\dot{\phi}^2 + V(\phi))} - 1 \approx \frac{(\dot{\phi}/V)^2}{2(\dot{\phi}/V)^2 + 1} - 1 \rightarrow W(z)$$

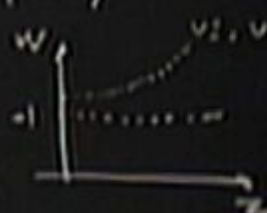
$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4+\alpha}\phi^{-\alpha-1} = 0$$

$$\phi = A t^{\frac{2}{\alpha+1}} \quad \dot{\phi}^2 \propto t^{2(\frac{2}{\alpha+1}-1)} = t^{2\frac{\alpha-1}{\alpha+1}}$$

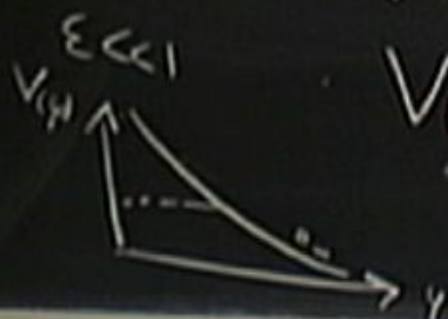


$$W = \frac{P}{\rho} = \frac{P_{\text{eff}}}{\rho} - 1 = \frac{\dot{\phi}^2}{2(\dot{\phi}^2 + V(\phi))} - 1 \approx \frac{(\dot{\phi}/V)^2}{2(\dot{\phi}/V)^2 + 1} - 1 \rightarrow W(z)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

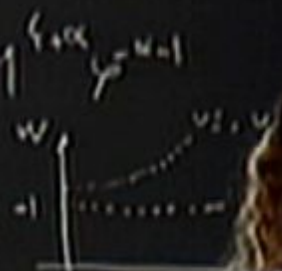


$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4+\alpha} \phi^{-\alpha-1} = 0$$

$$\phi = A t^{\frac{2}{\alpha+1}} \quad \dot{\phi}^2 \propto t^{2(\frac{2}{\alpha+1}-1)}$$



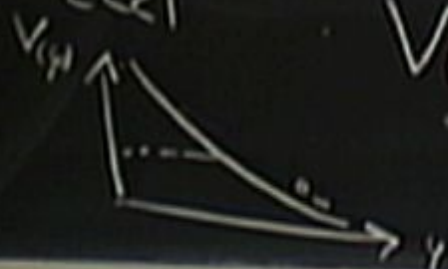
$$W = \frac{P}{S} = \frac{P_{\text{eff}}}{S} - 1 = \frac{\dot{\phi}^2}{2\dot{\phi} + V(\phi)} - 1 \xrightarrow{(\phi)} -1 \rightarrow W(\tau)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

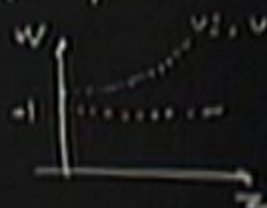
$$\epsilon \ll 1$$



$$V(\phi) \sim M^{4+2\alpha} \phi^{-2}$$

$$3H\dot{\phi} + V'(\phi) = 0$$

$$-4/11 \epsilon \ll 1 \phi^{-4-1}$$



$$\phi \propto (\tau - 1)^2$$

$$\epsilon = 3 - 3^2$$

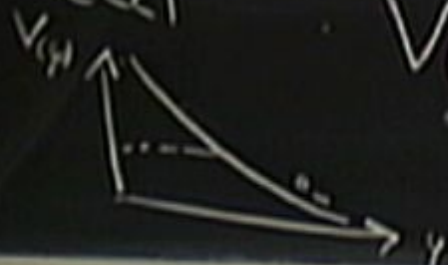
$$W = \frac{P}{S} = \frac{P - \dot{\phi}^2}{S} - 1 = \frac{\dot{\phi}^2}{S + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)}{1 + V/V} - 1 \approx -1$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$\epsilon \ll 1$$

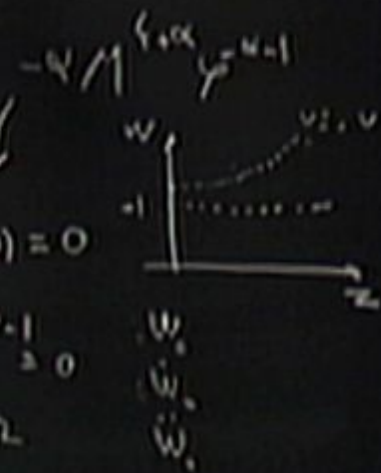


$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$V(\phi) = 0$$

$$-\alpha M^{4+\alpha} \phi^{-\alpha-1} = 0$$

$$\dot{\phi}^2 \propto (\phi^{-1})^2$$

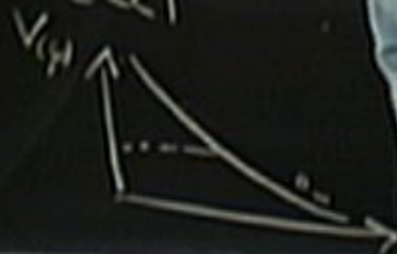


$$W = \frac{P}{S} = \frac{P_0 r}{S} - 1 = \frac{\dot{\phi}^2}{2} - 1 \approx \frac{(\dot{\phi}/\dot{\phi}_0)^2}{2} - 1 \rightarrow W(\tau)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

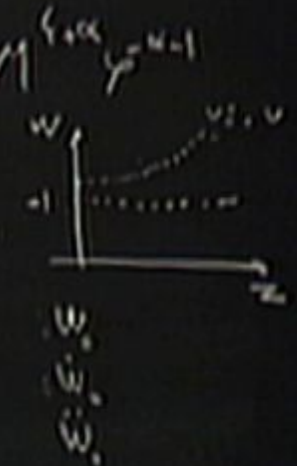
$$\epsilon \ll 1$$



$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4\alpha}\phi^{4\alpha-1} = 0$$

$$\phi = A t^\gamma \quad \phi^2 \propto t^{(4\alpha-1)/2}$$



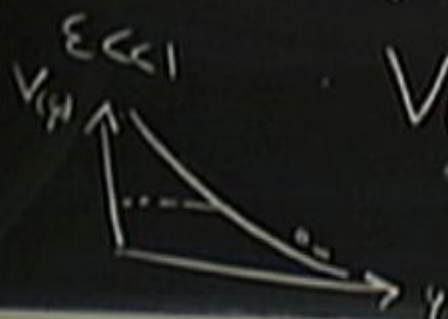
$$W = \frac{P}{\rho} = \frac{P_{\text{eff}}}{\rho} - 1 = \frac{\dot{\phi}^2}{2(\dot{\phi}^2 + V(\phi))} - 1 \approx \frac{(\dot{\phi}/V)^2}{2(1 + (\dot{\phi}/V)^2)} - 1 \rightarrow W(z)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$\dot{\phi} = \frac{1}{3H} \frac{V'}{V} \rightarrow \frac{\dot{\phi}^2}{V} \approx \frac{1}{9H^2} \left(\frac{V'}{V}\right)^2$$



$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - \alpha M^{4+\alpha} \phi^{-\alpha-1} = 0$$

$$\phi = A t^{\frac{1}{1-\alpha}}$$

$$\dot{\phi}^2 \propto t^{\frac{\alpha}{1-\alpha}}$$

$$W = \frac{P}{S} = \frac{P_0}{S} - 1 \approx \frac{(\dot{\phi}/H)^2}{\frac{1}{2}(\dot{\phi}/H)^2 + 1} - 1 \rightarrow W(z)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\epsilon \ll 1$$



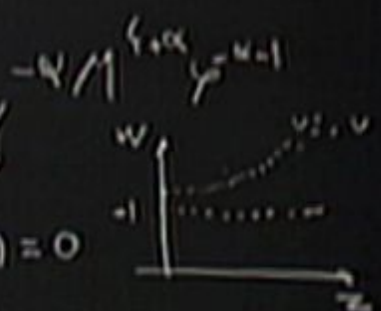
$$\dot{\phi}^2 \ll V$$

$$\frac{1}{2} \dot{\phi}^2 \ll V$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4\alpha} \phi^{-4\alpha-1} = 0$$

$$\phi = A t^Y \quad \dot{\phi}^2 \propto t^{(Y-1)2}$$



$$W = -\frac{1}{3}$$

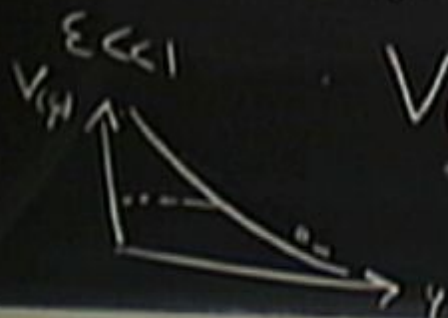
$$W = \frac{P}{S} = \frac{P_{\text{eff}}}{S} - 1 = \frac{\dot{\phi}^2}{\frac{1}{2} \dot{\phi} + V(\phi)} - 1 \xrightarrow{\left(\frac{\dot{\phi}}{V}\right)} \left(\frac{\dot{\phi}}{V}\right) - 1 \rightarrow W(z)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim$$

$$V(\phi) \sim A e^{-\sqrt{2\pi} \phi / f}$$

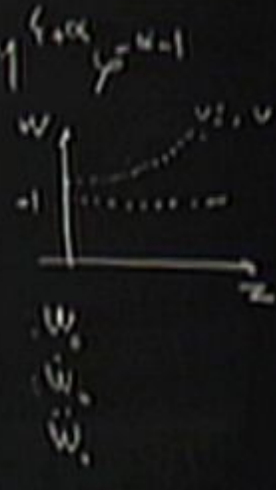


$$\frac{V'}{V} \sim \frac{V'}{V} \quad \frac{V''}{V} \sim \frac{V''}{V} \quad \frac{V'''}{V} \sim \frac{V'''}{V}$$

$$\dot{\phi} + V'(\phi) = 0$$

$$\dot{\phi} = -V'(\phi)$$

$$\dot{\phi}^2 \propto (V')^2$$



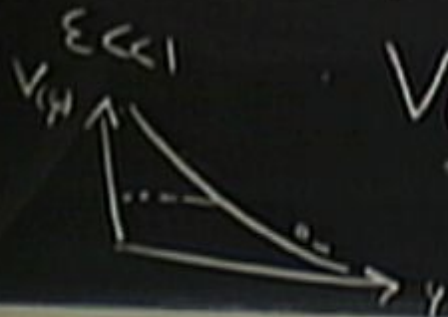
$$W = \frac{P}{\rho} = \frac{P + \rho}{\rho} - 1 = \frac{\dot{\phi}^2}{1 + \frac{\dot{\phi}^2}{\rho}} - 1 \approx \frac{(\frac{\dot{\phi}}{\rho})^2}{1 + \frac{(\frac{\dot{\phi}}{\rho})^2}{\rho}} - 1 \rightarrow W(z)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1$$

$$V(\phi)$$



$$\frac{\dot{\phi}^2}{V} \approx \frac{V'^2}{V} \sim \left(\frac{V'}{V} \right)^2$$

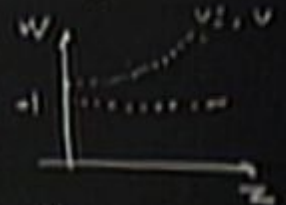
$$3H\dot{\phi} + V'(\phi) = 0$$

$$\dot{\phi} + 3H\dot{\phi} - 4M^{4\alpha} \phi^{4\alpha-1} = 0$$

$$\phi = A e^{\gamma}$$

$$\dot{\phi}^2 \propto (e^{\gamma-1})^2$$

$$-4M^{4\alpha} \phi^{4\alpha-1}$$



$$\frac{\dot{\phi}^2}{V} \ll 1$$

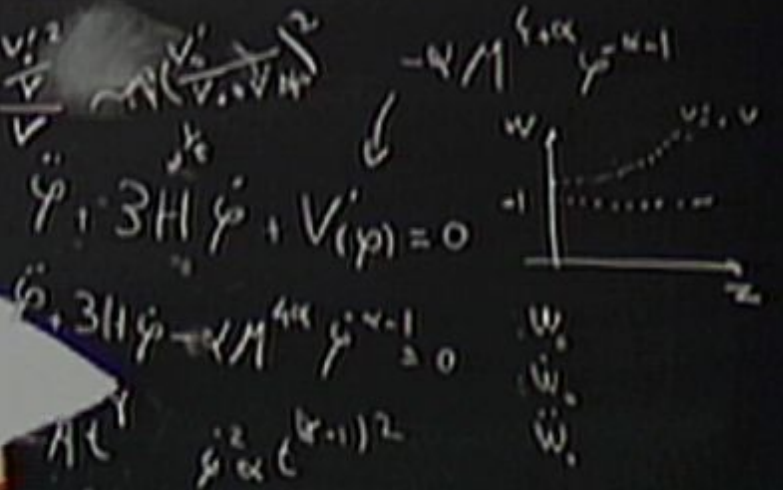
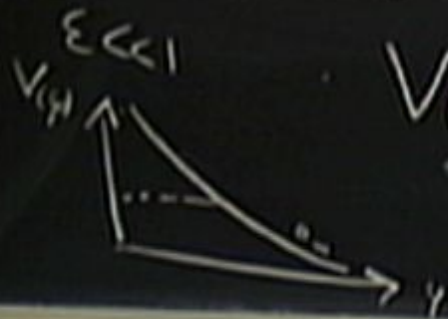
$$W = \frac{P}{\rho} = \frac{P - \rho}{\rho} - 1 \approx \frac{\dot{\phi}^2}{2(\frac{\dot{\phi}^2}{V}) + 1} - 1 \rightarrow W(z)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1$$

$$V(\phi)$$



$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4\alpha} \phi^{4\alpha-1} = 0$$

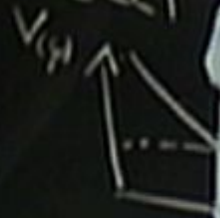
$$\dot{\phi}^2 \propto (\phi^{4\alpha-1})^2$$

$$W = \frac{P}{\rho} = \frac{P - \rho}{\rho} - 1 = \frac{\dot{\phi}^2}{2(\dot{\phi} + V(\phi))} - 1 \rightarrow W(z)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\epsilon \ll 1$$



$$M^{4+2\alpha} \phi^{-2}$$

$$\frac{(\dot{\phi}/V)^2}{2(\dot{\phi}/V) + 1} - 1 \rightarrow W(z)$$

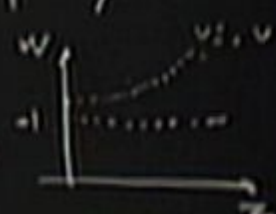
$$\frac{\dot{\phi}}{V} \rightarrow \frac{\dot{\phi}^2}{V^2} \sim \left(\frac{V'}{V} \right)^2$$

$$-4M^{4+2\alpha} \phi^{-2\alpha-1}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4+2\alpha} \phi^{-2\alpha-1} = 0$$

$$\phi = A e^Y \quad \dot{\phi}^2 \propto e^{(2+1)\alpha Y}$$



$$\frac{W}{\epsilon} \sim \frac{1}{\epsilon}$$

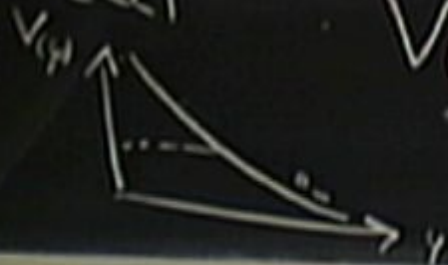
$$W = \frac{P}{\dot{\phi}^2} = \frac{P_{\text{eff}}}{\dot{\phi}^2} - 1 = \frac{\dot{\phi}^2}{2\dot{\phi}^2 + V(\phi)} - 1 \approx \frac{(\dot{\phi}/V)^2}{2} \rightarrow W(\phi)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$

$$\epsilon \ll 1$$



$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

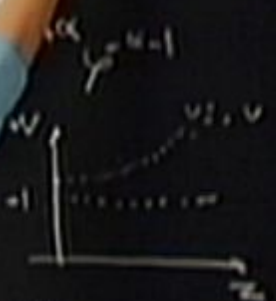
$$W(\phi) \approx \left(\frac{V'}{V} \right)^2$$

$$\rightarrow W(\phi)$$

$$\dot{\phi} = -\frac{V'}{3H} \rightarrow \frac{\dot{\phi}^2}{V} \approx \frac{V'^2}{9H^2 V}$$

$$\left(\frac{V'}{V} \right)^2$$

$$-4$$



$$V(\phi) = 0$$

$$\phi^{-\alpha-1} \geq 0$$

$$1/2$$

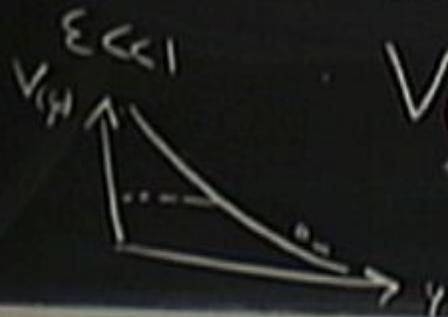
$$\epsilon = \epsilon_0 \epsilon$$

$$W = \frac{P}{S} = \frac{P_{\text{eff}}}{S} - 1 = \frac{\dot{\phi}^2}{\dot{\phi} + V(\phi)} - 1 \approx \frac{(\dot{\phi})^2}{(\dot{\phi})^2} - 1 \rightarrow W(0)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$



$$V(\phi) \sim M^{4+2\alpha}$$

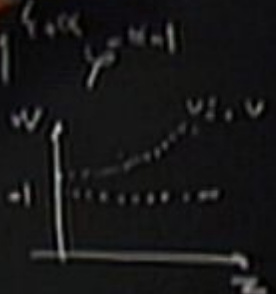
$$W(\phi_0) \approx \frac{1}{2} \left(\frac{V'}{V} \right)^2 - 1$$

$$V(\phi) \sim \frac{1}{2} \phi^2$$

$$\dot{\phi} + V(\phi) = 0$$

$$M^{4+2\alpha} \phi^{2+2\alpha-1} = 0$$

$$\dot{\phi} \propto (\phi-1)^2$$



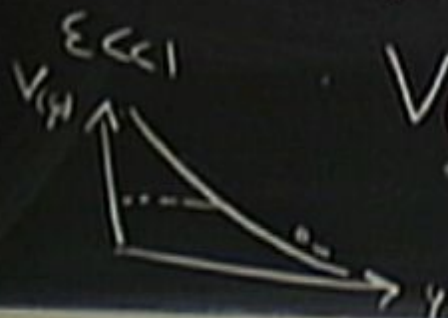
$$\epsilon = \frac{\phi}{M^{2+2\alpha}}$$

$$W = \frac{P}{\rho} = \frac{P_{\text{eff}}}{\rho} - 1 = \frac{\dot{\phi}^2}{2(\dot{\phi} + V(\phi))} - 1 \approx \frac{(\dot{\phi}/V)^2}{2(\dot{\phi}/V) + 1} - 1 \rightarrow W(\phi)$$

$$W < -\frac{1}{3}$$

$$W \sim -1$$

$$\frac{\dot{\phi}^2}{V} \ll 1 \rightarrow W \sim -1$$



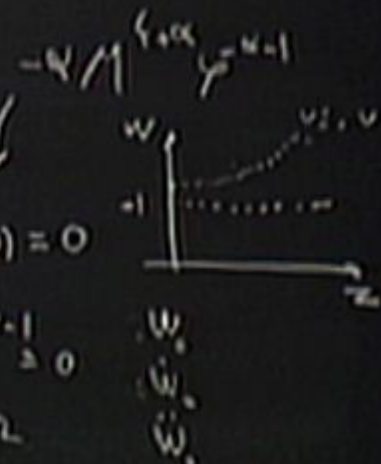
$$V(\phi) \sim M^{4+\alpha} \phi^{-\alpha}$$

$$\dot{\phi} = \frac{V'}{3H} \rightarrow \frac{\dot{\phi}^2}{V} \sim \frac{V'^2}{V} \sim \frac{(V')^2}{V} \sim \frac{(V')^2}{V}$$

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\ddot{\phi} + 3H\dot{\phi} - 4M^{4+\alpha} \phi^{-\alpha-1} = 0$$

$$\phi = A t^Y \quad \dot{\phi}^2 \propto t^{(Y-1)2}$$



$$G_{eff} \sim \Lambda_{eff}^4 \sim 10^{-10} \text{ (GeV)}^4$$

> quintessence.

$$S = \int R d^4x + \int \sqrt{g} \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right)$$

$$f(\partial_\mu \phi \partial^\mu \phi)$$

$$\frac{a}{a''} > 0$$



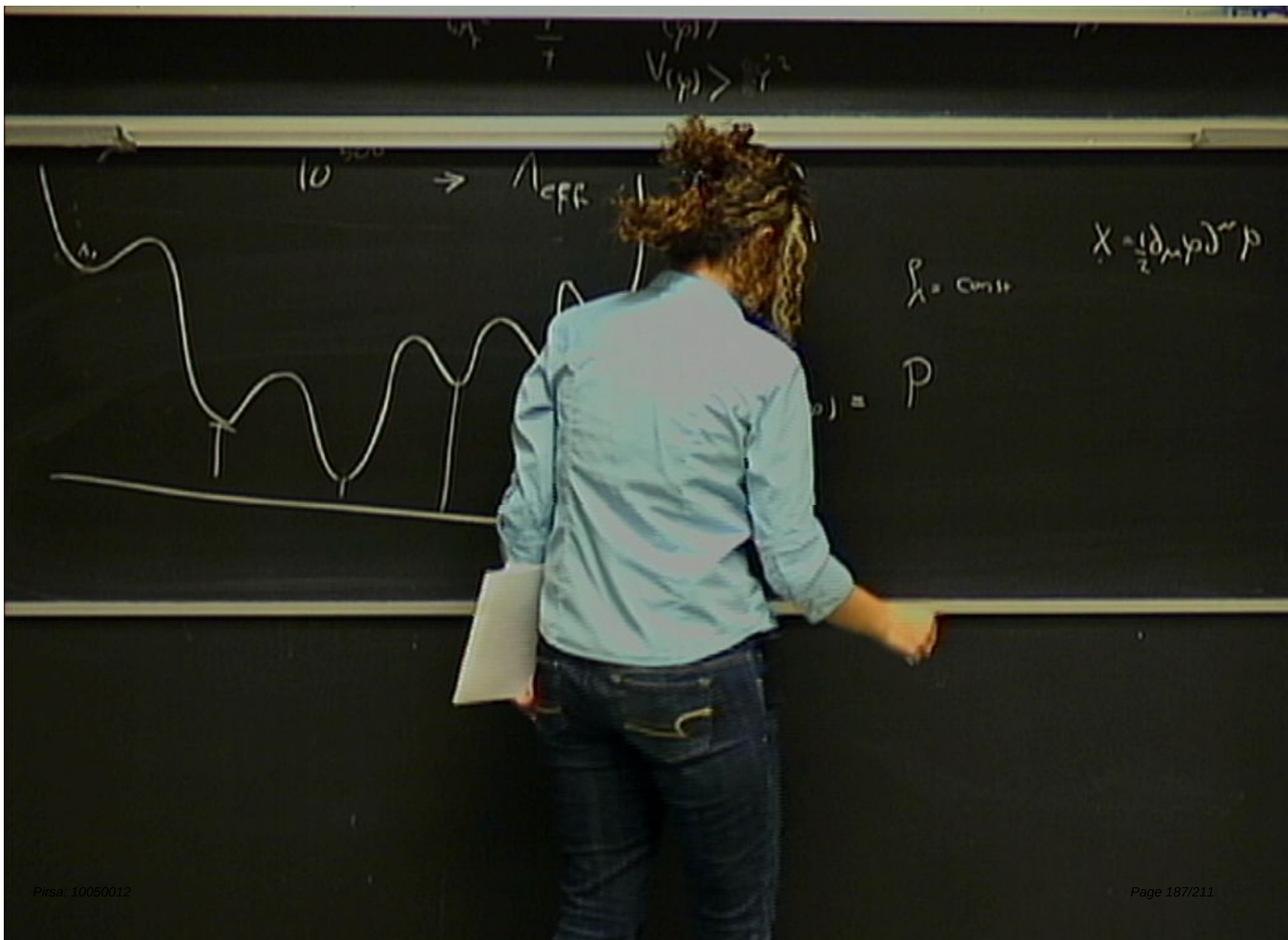
$$\rho = \frac{1}{2} \dot{\phi}^2 + V(\phi)$$

$$\rho < -2V(\phi) \implies V(\phi) > \frac{1}{2} \dot{\phi}^2$$

$$\mathcal{L} = \dot{\phi} \frac{\partial \mathcal{L}}{\partial \dot{\phi}} - \mathcal{L} = \frac{1}{2} \dot{\phi}^2 - V(\phi)$$

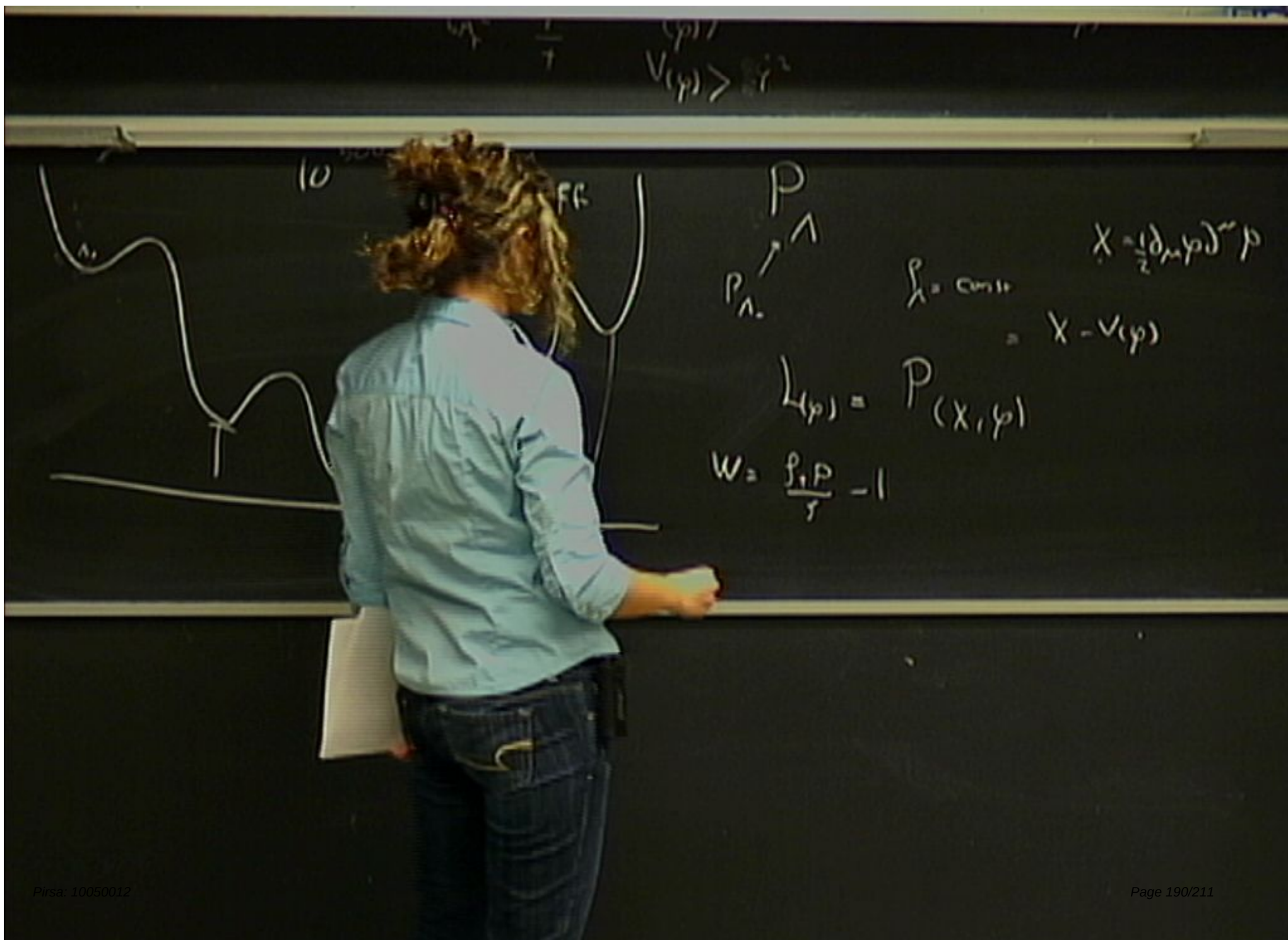
$$P(\phi) = \frac{1}{2} \dot{\phi}^2 - V(\phi)$$













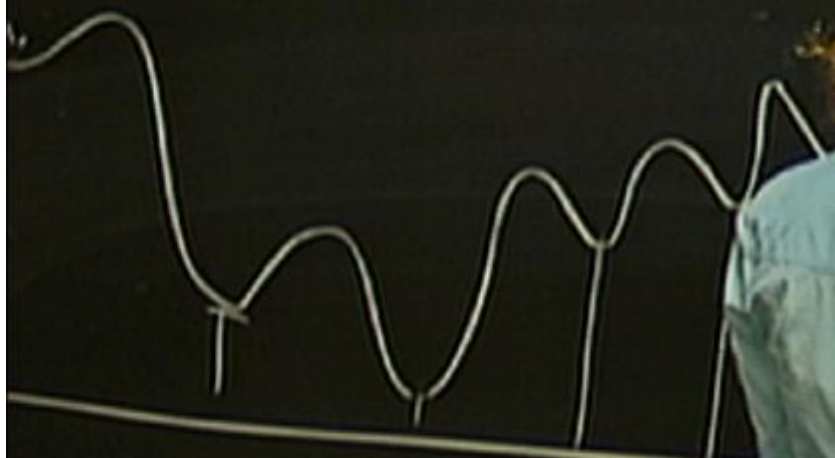






$$V(\varphi) > \frac{1}{2} \dot{\varphi}^2$$

$$10 \rightarrow \Lambda_{\text{eff}} \quad P$$



$$P_{\lambda} = \text{const}$$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\frac{P, P}{T} - 1 =$$

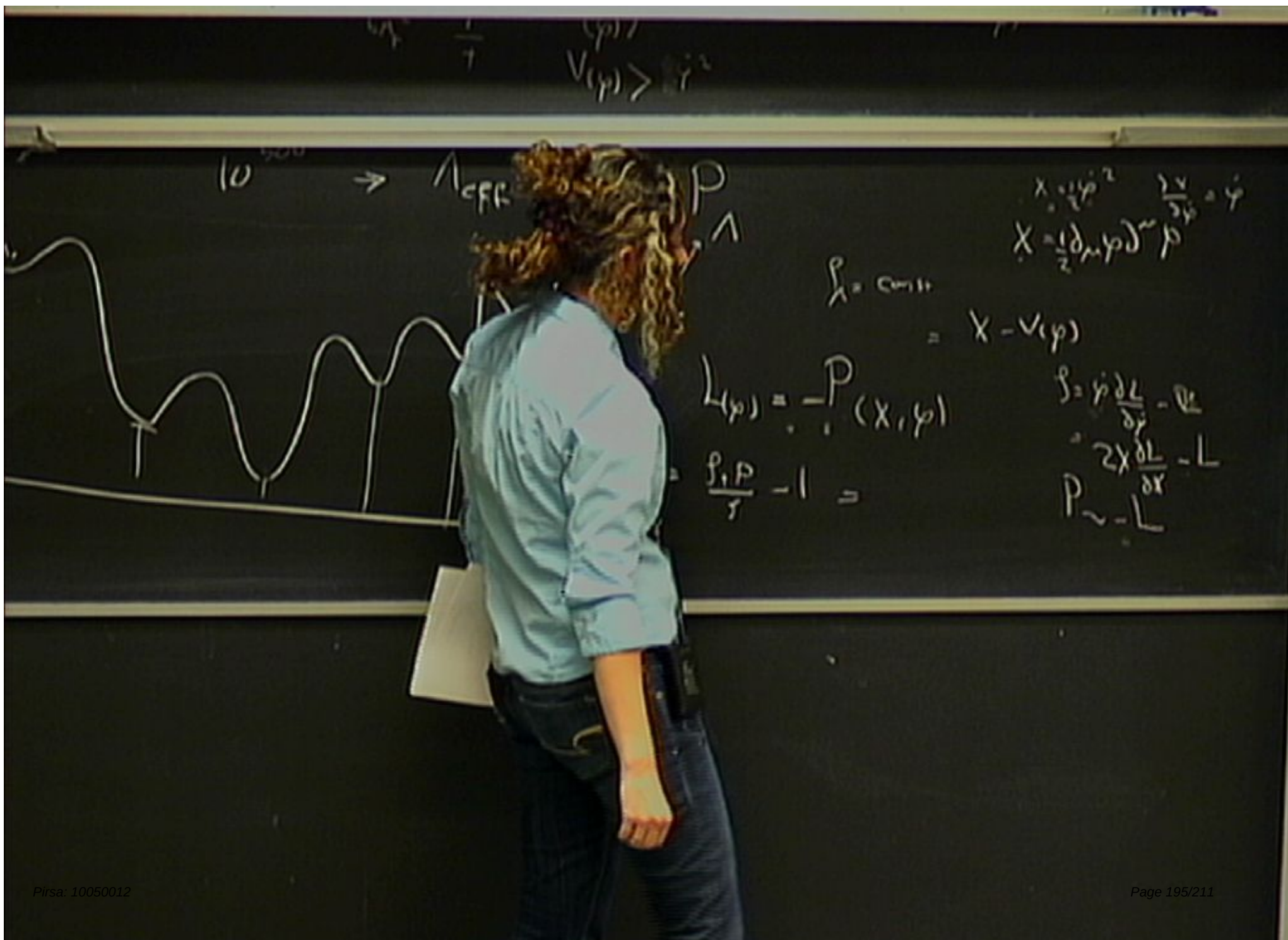
$$X = \frac{1}{2} \dot{\varphi}^2 \quad \frac{\partial V}{\partial \varphi} = \varphi$$

$$X = \frac{1}{2} (\partial_{\mu} \varphi) \partial^{\mu} \varphi$$

$$\mathcal{L} = \dot{\varphi} \frac{\partial L}{\partial \dot{\varphi}} - V_L$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$P \sim -L$$



$$V(y) > \frac{1}{2} \dot{y}^2$$

$$10 \rightarrow \Lambda_{eff} \quad P$$

$$X = \frac{1}{2} \dot{y}^2 \quad \frac{\partial V}{\partial y} = \dot{y}$$

$$X = \frac{1}{2} (\partial_\mu y) \partial^\mu y$$

$$P_\lambda = \text{const}$$

$$= X - V(y)$$

$$L(y) = -P(X, y)$$

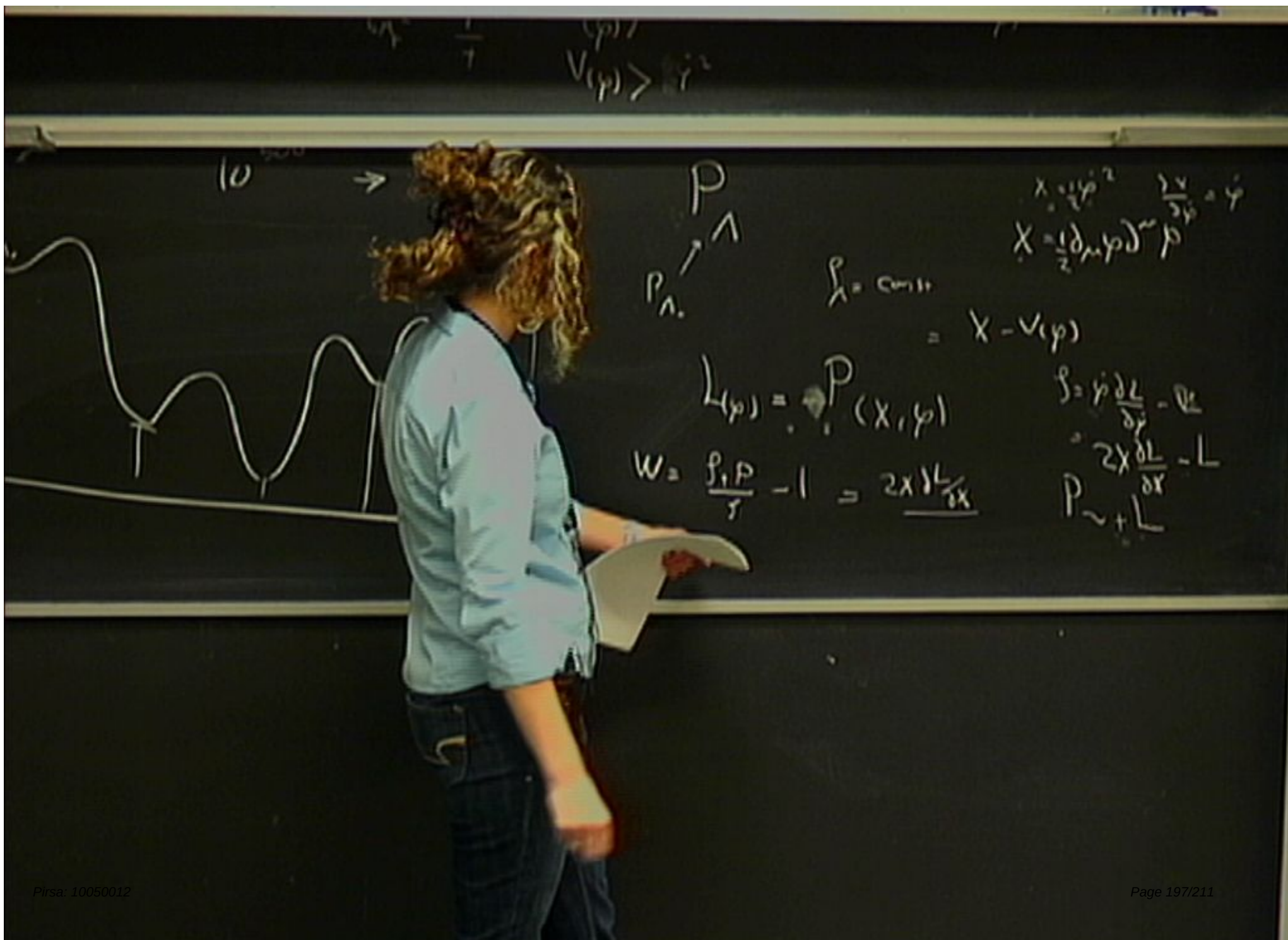
$$= \frac{P_\lambda P}{\gamma} - 1 =$$

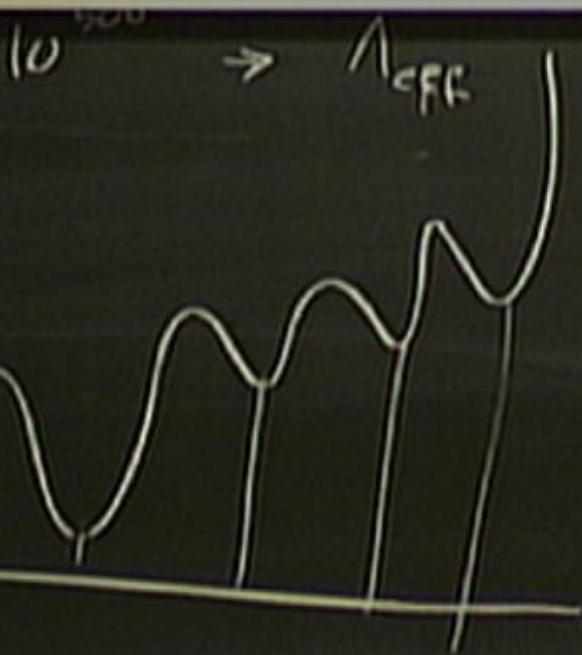
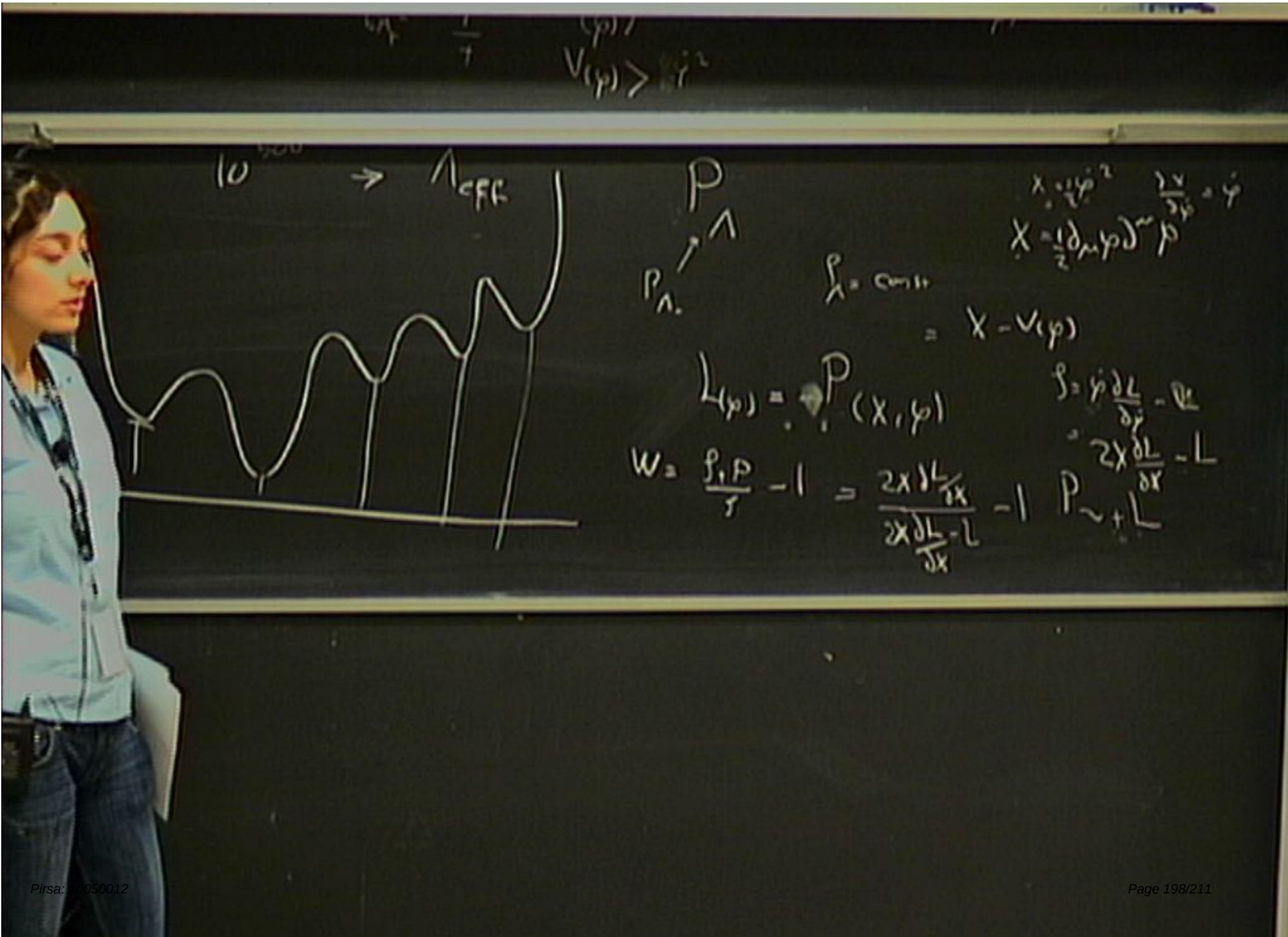
$$\mathcal{L} = y \frac{\partial L}{\partial \dot{y}} - V_L$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$P \sim -L$$







$$P \rightarrow \Lambda$$

$$P_{\Lambda}$$

$$P_{\Lambda} = \text{const}$$

$$= X - V(p)$$

$$L(p) = P(X, p)$$

$$W = \frac{P, P}{f} - 1 = \frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} - 1 \quad P \sim +L$$

$$X = \frac{1}{2} \dot{p}^2 \quad \frac{\partial V}{\partial p} = \dot{p}$$

$$X = \frac{1}{2} (\partial_{\Lambda} p)^2$$

$$f = p \frac{\partial L}{\partial p} - L$$

$$= 2X \frac{\partial L}{\partial X} - L$$



$$V(p) > \dot{\gamma}^2$$

$$P \rightarrow \Lambda$$

$$P_\Lambda = \text{const}$$

$$= X - V(p)$$

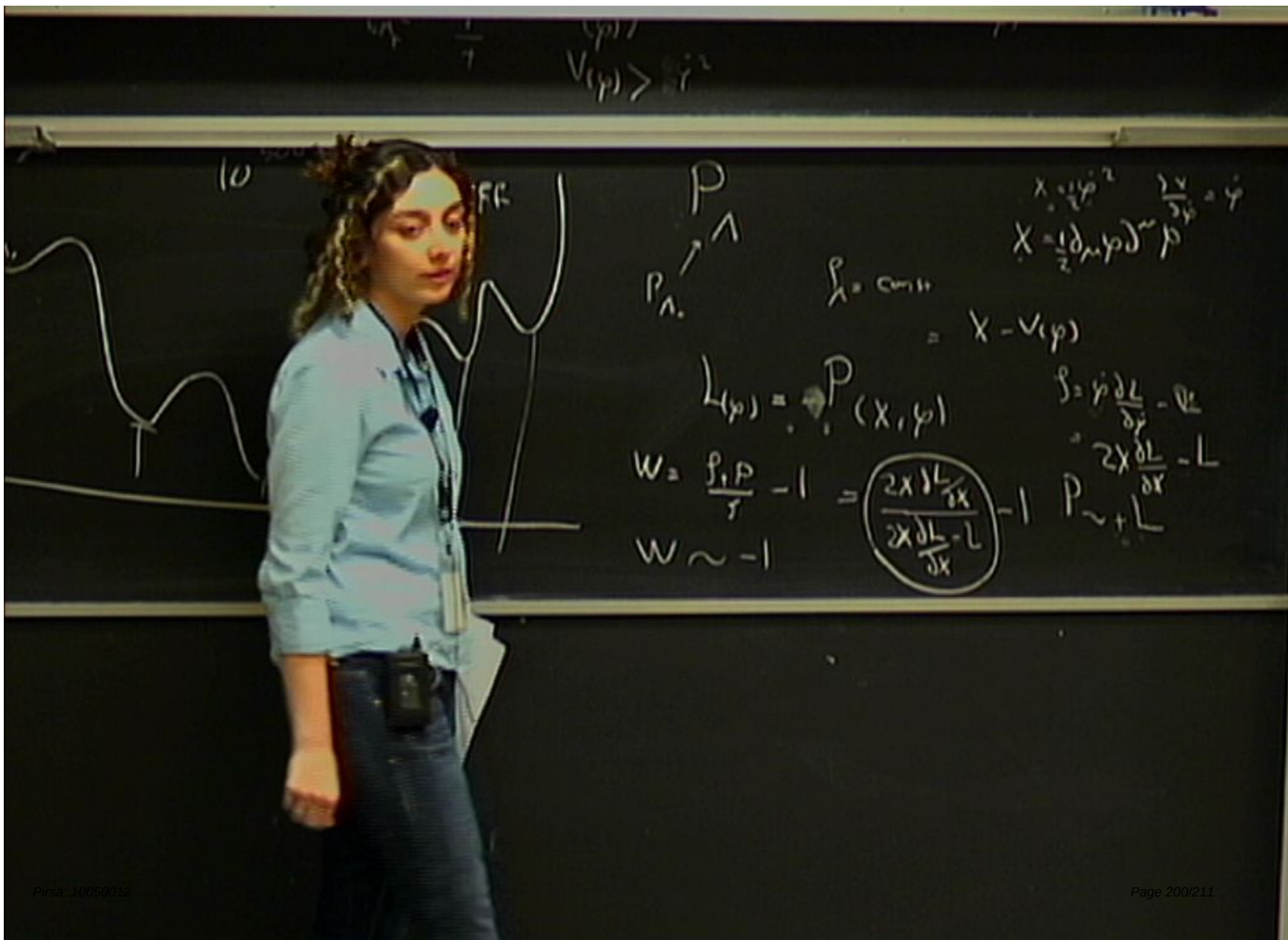
$$X = \frac{1}{2} \dot{\gamma}^2$$

$$L(p) = P(X, p)$$

$$\begin{aligned} \beta &= p \frac{\partial L}{\partial p} - L \\ &= 2X \frac{\partial L}{\partial p} - L \end{aligned}$$

$$W = \frac{\beta, P}{\gamma} - 1 = \frac{2X \frac{\partial L}{\partial p}}{2X \frac{\partial L}{\partial p} - L} - 1 \quad P \sim +L$$

$$W \sim -1$$



$$\delta < \frac{a}{a} = -\frac{1}{6m^2} (2\dot{\varphi}^2 - 2V(\varphi))$$

$$V(\varphi) > \frac{1}{2}\dot{\varphi}^2$$

$$P(\varphi) = \frac{1}{2}\dot{\varphi}^2 - V(\varphi)$$

$$P_{\Lambda}$$

$$\Lambda = \text{const}$$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \varphi \frac{\partial L}{\partial \dot{\varphi}} - V$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$W = \frac{\dot{\varphi} P}{\dot{\varphi}} - 1 = \left(\frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} \right) - 1$$

$$P \sim +L$$

$$W \sim -1$$

$$\delta < \frac{a}{a} = -\frac{1}{6m^2} \left(\frac{2\dot{\varphi}^2}{7} - 2V(\varphi) \right)$$

$$P(\varphi) = \frac{1}{2} \dot{\varphi}^2 - V(\varphi)$$



$\lambda = \text{const}$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \varphi \frac{\partial L}{\partial \varphi} - V_L$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$\left(\frac{2X \partial L}{\partial X} - L \right) - 1$$

$$P \sim +L$$

$$V \sim -1$$

$$\delta < \frac{a}{a} = -\frac{1}{6m^2} (2\dot{\varphi}^2 - 2V(\varphi))$$

$$V(\varphi) > \dot{\varphi}^2$$

$$P(\varphi) = \frac{1}{2} \dot{\varphi}^2 - V(\varphi)$$

$$P_A$$

$$\lambda = \text{const}$$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \varphi \frac{\partial L}{\partial \varphi} - V_L$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$W = \frac{\dot{\varphi} P}{\dot{\varphi}} - 1 = \left(\frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} \right) - 1$$

$$P \sim +L$$

$$W \sim -1$$

$$\frac{\partial L}{\partial \varphi} \approx 1$$

$$\delta < \frac{a}{a} = -\frac{1}{6m^2} (2\dot{\varphi}^2 - 2V(\varphi))$$

$$P(\varphi) = \frac{1}{2} \dot{\varphi}^2 - V(\varphi)$$

$$P_{\Lambda}$$

$$\lambda = \text{const}$$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \varphi \frac{\partial L}{\partial \dot{\varphi}} - V$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$W = \frac{\dot{\varphi} P}{\dot{\varphi}} - 1 = \left(\frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} \right) - 1$$

$$P \sim +L$$

$$W \sim -1$$

$$\frac{\partial L}{\partial \dot{\varphi}} \approx 1$$

$$W \approx 1 \Rightarrow \frac{X}{X-L} < 1$$

$$\delta < \frac{a}{a} = -\frac{1}{6m^2} (2\dot{\varphi}^2 - 2V(\varphi))$$

$$P(\varphi) = \frac{1}{2} \dot{\varphi}^2 - V(\varphi)$$



$$P_A$$

$$\lambda = \text{const}$$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \dot{\varphi} \frac{\partial L}{\partial \dot{\varphi}} - V_L$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$U = \frac{\dot{\varphi} P}{\dot{\varphi}} - 1 = \left(\frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} \right) - 1$$

$$P \sim +L$$

$$\frac{\partial L}{\partial \dot{\varphi}}$$

$$W \sim 1 \Rightarrow \frac{X}{X-L} \ll 1$$

$$\delta < \frac{a}{a} = -\frac{1}{6m^2} \left(\frac{2\dot{\varphi}^2}{7} - 2V(\varphi) \right)$$

$$P(\varphi) = \frac{1}{2} \dot{\varphi}^2 - V(\varphi)$$

$$\lambda = \text{const}$$

$$= X - V(\varphi)$$

$$P(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \varphi \frac{\partial L}{\partial \dot{\varphi}} - V_L$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$\left(\frac{2X \frac{\partial L}{\partial X} - L}{\frac{\partial L}{\partial X}} \right) - 1$$

$$P \sim +L$$

$$\sim -1$$

$$W \sim 1 \Rightarrow \frac{X}{X-L} \ll 1$$

$$\dot{\varphi}^2 \ll 1$$

$$\delta < \frac{a}{a} = -\frac{1}{6m} (2\dot{\varphi}^2 - 2V(\varphi))$$

$$V(\varphi) > \dot{\varphi}^2$$

$$P(\varphi) = \frac{1}{2} \dot{\varphi}^2 - V(\varphi)$$

$$P_A$$

$$\lambda = \text{const}$$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \varphi \frac{\partial L}{\partial \varphi} - V$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$W = \frac{\dot{\varphi} P}{\dot{\varphi}} - 1 = \left(\frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} \right) - 1$$

$$P \sim +L$$

$$\frac{\partial L}{\partial \varphi} \approx 1$$

$$W \approx 1 \Rightarrow \frac{X}{X-L} \ll 1$$

$$\dot{\varphi}^2 \ll 1$$

$$\delta < \frac{a}{a} = -\frac{1}{6m^2} (2\dot{\varphi}^2 - 2V(\varphi))$$

$$V(\varphi) > \dot{\varphi}^2$$

$$P(\varphi) = \frac{1}{2} \dot{\varphi}^2 - V(\varphi)$$

$$P_A$$

$$\lambda = \text{const}$$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \varphi \frac{\partial L}{\partial \varphi} - V_L$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$W = \frac{\dot{\varphi} P}{\dot{\varphi}} - 1 = \left(\frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} \right) - 1$$

$$P \sim +L$$

$$W \sim -1$$

$$\frac{\partial L}{\partial \varphi} \approx 1$$

$$W \approx 1 \Rightarrow \frac{X}{X-L} \ll 1$$

$$\dot{\varphi}^2 \ll 1$$

$$\delta < \frac{g}{2} = -\frac{1}{6m^2} \left(\frac{2\dot{\varphi}^2}{7} - 2V(\varphi) \right)$$

$$V(\varphi) > \frac{7}{2}\dot{\varphi}^2$$

$$P(\varphi) = \frac{1}{2}\dot{\varphi}^2 - V(\varphi)$$

$$P_A$$

$$\lambda = \text{const}$$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \dot{\varphi} \frac{\partial L}{\partial \dot{\varphi}} - V_L$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$W = \frac{\dot{\varphi} P}{\dot{\varphi}} - 1 = \left(\frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} \right) - 1$$

$$P \sim +L$$

$$W \sim -1$$

$$\frac{\partial L}{\partial \dot{\varphi}} \approx 1$$

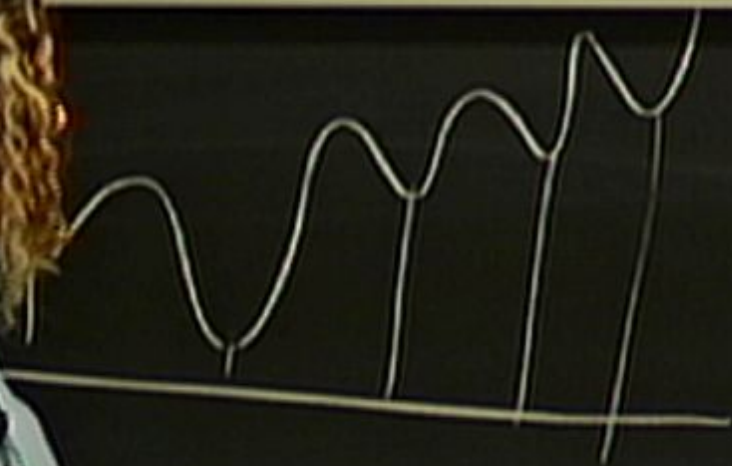
$$W \approx 1 \Rightarrow \frac{X}{X-L} < 1$$

$$\dot{\varphi}^2 \ll 1$$

$$\delta < \frac{a}{a} = -\frac{1}{6m^2} \left(\frac{2\dot{\varphi}^2}{7} - 2V(\varphi) \right)$$

$$V(\varphi) > \frac{2}{7}\dot{\varphi}^2$$

$$P(\varphi) = \frac{1}{2}\dot{\varphi}^2 - V(\varphi)$$



P_A

$\lambda = \text{const}$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \varphi \frac{\partial L}{\partial \varphi} - V$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$W = \frac{\dot{\varphi} P}{\dot{\varphi}} - 1 = \left(\frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} \right) - 1$$

$$P \sim +L$$

$$W \sim -1$$

$$\left. \frac{\partial L}{\partial X} \right|_{X_0} = 0$$

$$\frac{\partial L}{\partial \varphi} \approx 1$$

$$W \approx 1 \Rightarrow \frac{X}{X-L} \ll 1$$

$$\dot{\varphi}^2 \ll 1$$

$$\delta < \frac{a}{a} = -\frac{1}{6m^2} \left(\frac{2\dot{\varphi}^2}{7} - 2V(\varphi) \right)$$

$$V(\varphi) > \frac{2}{7}\dot{\varphi}^2$$

$$P(\varphi) = \frac{1}{2}\dot{\varphi}^2 - V(\varphi)$$

P_A

$\lambda = \text{const}$

$$= X - V(\varphi)$$

$$L(\varphi) = P(X, \varphi)$$

$$\dot{\varphi} = \varphi \frac{\partial L}{\partial \varphi} - V$$

$$= 2X \frac{\partial L}{\partial X} - L$$

$$W = \frac{\dot{\varphi} P}{\dot{\varphi}} - 1 = \left(\frac{2X \frac{\partial L}{\partial X}}{2X \frac{\partial L}{\partial X} - L} \right) - 1$$

$$P \sim +L$$

$$W \sim -1$$

$$\frac{\partial L}{\partial X} \Big|_{X_0} = 0$$

$$\frac{\partial L}{\partial \varphi} = 1$$

$$W \sim 1 \Rightarrow \frac{X}{X-L} \ll 1$$

$$\dot{\varphi}^2 \ll 1$$