

Title: Inflationary Cosmology - Lecture 2

Date: Jun 30, 2009 10:00 AM

URL: <http://pirsa.org/09060085>

Abstract:

Slow-roll inflation

v

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Slow-roll inflation

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Slow-roll inflation

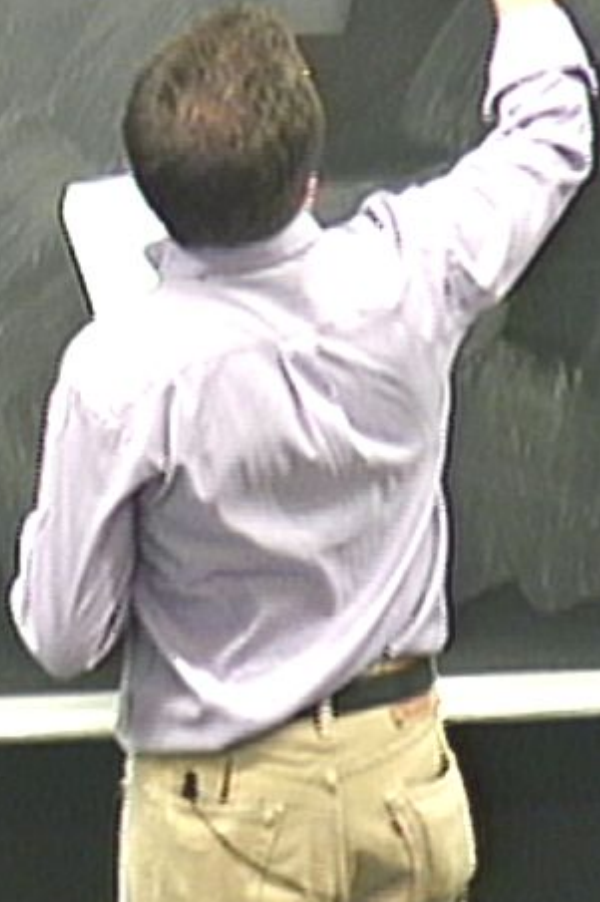
v



dS

$\sim dS$

$$S = \int d^d x \sqrt{-g} \left[\frac{M_{Pl}^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - \right]$$



$$S = \int d^d x \sqrt{-g} \left[\frac{M_{\text{Pl}}^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right]$$

$$S = \int d^d x \sqrt{-g} \left[\frac{M_{Pl}^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right]$$

$$T_{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta S}{\delta g^{\mu\nu}} = \partial_\mu \phi \partial_\nu \phi + g_{\mu\nu} \left[-\frac{1}{2} g^{\alpha\beta} \partial_\alpha \phi \partial_\beta \phi - V(\phi) \right]$$

$$\rho = \frac{1}{2} \dot{\phi}^2 + V(\phi) \quad \phi(t)$$

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

$$T_{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta S}{\delta g^{\mu\nu}} = \partial_\mu \phi \partial_\nu \phi + g_{\mu\nu} \left[-\frac{1}{2} g^{\alpha\beta} \partial_\alpha \phi \partial_\beta \phi - V(\phi) \right]$$

$$\begin{cases} \mathcal{P} = \frac{1}{2} \dot{\phi}^2 + V(\phi) \\ \mathcal{P} = \frac{1}{2} \dot{\phi}^2 - V(\phi) \end{cases} \quad \phi(t)$$

$$S = \int d^4x \sqrt{-g} \left[\frac{M_{Pl}^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right]$$

$$T_{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta S}{\delta g^{\mu\nu}} = \partial_\mu \phi \partial_\nu \phi + g_{\mu\nu} \left[-\frac{1}{2} g^{\alpha\beta} \partial_\alpha \phi \partial_\beta \phi - V(\phi) \right]$$

$$\left\{ \begin{array}{l} \rho = \frac{1}{2} \dot{\phi}^2 + V(\phi) \\ p = \frac{1}{2} \dot{\phi}^2 - V(\phi) \end{array} \right.$$

$\phi(t)$

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

Slow-roll

$$(T_{\mu\nu} = -g_{\mu\nu} T) \quad t \geq 0$$

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

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

Hubble fraction

$$(T_{\mu\nu} - \frac{1}{2}g_{\mu\nu} T) / t^t \geq 0$$

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

$$\dot{\rho} + 3H(\rho + p) = 0$$

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

$$\rho \propto a^{-6}$$

$$\dot{\phi} \propto a^{-3}$$

Hubble fraction

$$V = \frac{1}{2} m^2 \phi^2$$

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

$$\ddot{\phi} + \frac{\sqrt{3/2}}{M_{Pl}} \left(\dot{\phi}^2 + m^2 \phi^2 \right)^{1/2} \dot{\phi} + \epsilon^2 \phi = 0$$

$$V = \frac{1}{2} m^2 \phi^2$$

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

$$\ddot{\phi} + \frac{\sqrt{3/2}}{M_{Pl}} \left(\dot{\phi}^2 + m^2 \phi^2 \right)^{1/2} \dot{\phi} + \epsilon^2 \phi = 0$$

$$\ddot{\phi} = \frac{d\dot{\phi}}{d\phi} \dot{\phi}$$

$$\frac{d\dot{\phi}}{d\phi} = -\frac{1}{\dot{\phi}} \left[\frac{\sqrt{3/2}}{M_{Pl}} \dot{\phi} \left(\dot{\phi}^2 + m^2 \phi^2 \right)^{1/2} + \epsilon m^2 \phi \right]$$

$$V = \frac{1}{2} m^2 \phi^2$$

$$H^2 = \frac{1}{3M_{pl}^2} \left(\frac{\dot{\phi}^2}{2} + \frac{\epsilon^2 \phi^2}{2} \right)$$

$$\boxed{\phi \gg H_{pl}}$$

$$\ddot{\phi} + \frac{\sqrt{3/2}}{H_{pl}} \left(\dot{\phi}^2 + m^2 \phi^2 \right)^{1/2} \dot{\phi} + \epsilon^2 \phi = 0$$

$$\ddot{\phi} = \frac{d\dot{\phi}}{d\phi} \dot{\phi}$$

$$\frac{d\dot{\phi}}{d\phi} = -\frac{1}{\dot{\phi}} \left[\frac{\sqrt{3/2}}{H_{pl}} \dot{\phi} \left(\dot{\phi}^2 + \epsilon^2 \phi^2 \right)^{1/2} + m^2 \phi \right]$$

$$\dot{\phi}^2 \gg m^2 \phi^2$$

$$\frac{d\dot{\phi}}{d\phi} = -\frac{\sqrt{3/2}}{M_{\text{Pl}}} |\dot{\phi}|$$

• $\dot{\phi}^2 \gg m^2 \phi^2$

Kinetic domination

$$\frac{d|\dot{\phi}|}{d\phi} = -\frac{\sqrt{3/2}}{M_{Pl}} |\dot{\phi}|$$

• $m^2 \phi^2 \gg \dot{\phi}^2$

• $\dot{\phi}^2 \gg m^2 \phi^2$ Kinetic domination

$$\frac{d\dot{\phi}}{d\phi} = -\frac{\sqrt{3/2}}{M_{Pl}} |\dot{\phi}|$$

• $m^2 \phi^2 \gg \dot{\phi}^2$

$$\frac{d\dot{\phi}}{d\phi} \approx 0$$

$$\frac{d\dot{\phi}}{d\phi} \approx \frac{\sqrt{3/2}}{M_{Pl}} \phi \Rightarrow \dot{\phi} = \sqrt{\frac{2}{3}} m M_{Pl}$$

• $\dot{\phi}^2 \gg m^2 \phi^2$ Kinetic domination

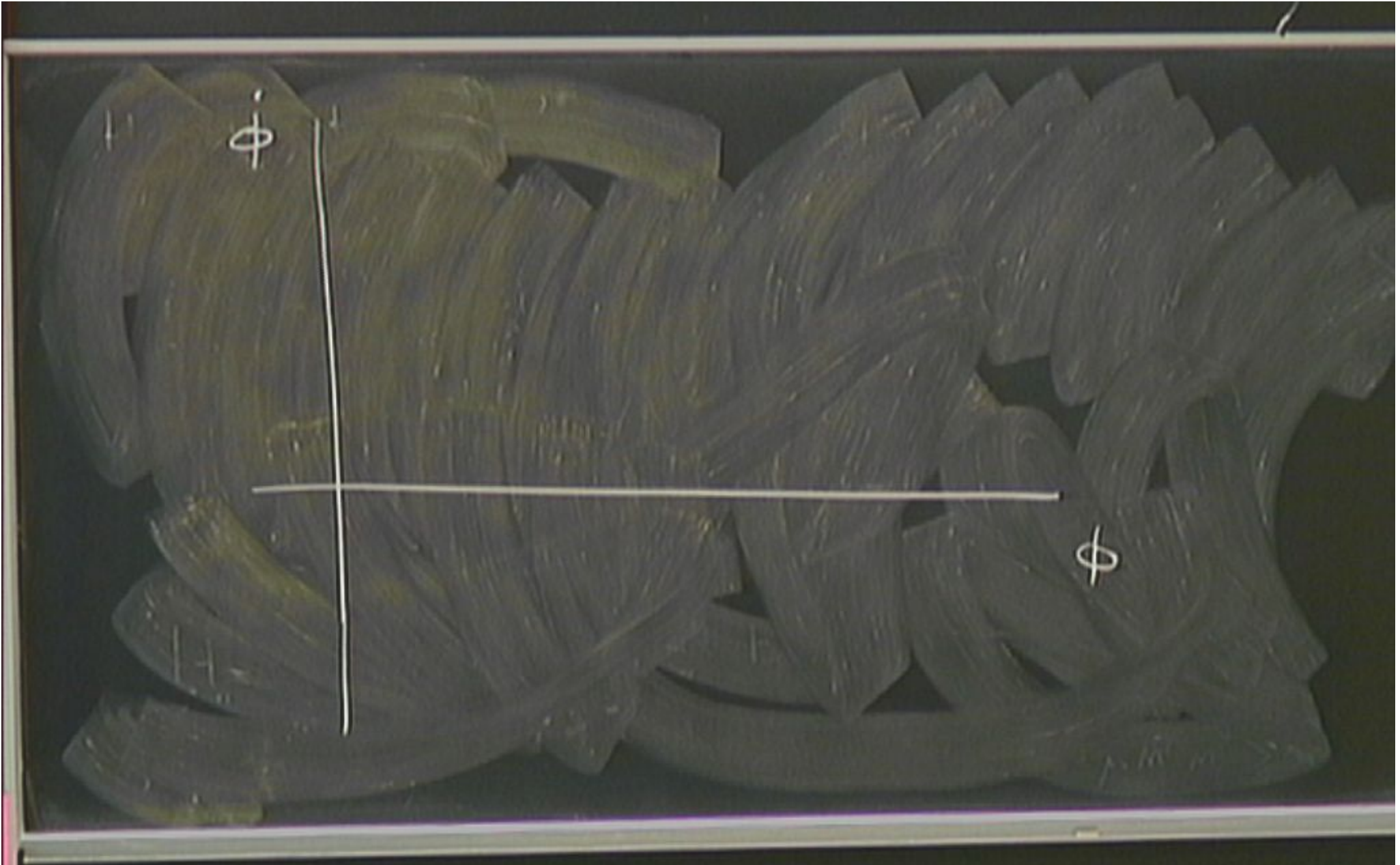
$$\frac{d\dot{\phi}}{d\phi} = -\frac{\sqrt{3/2}}{H_P} |\dot{\phi}|$$

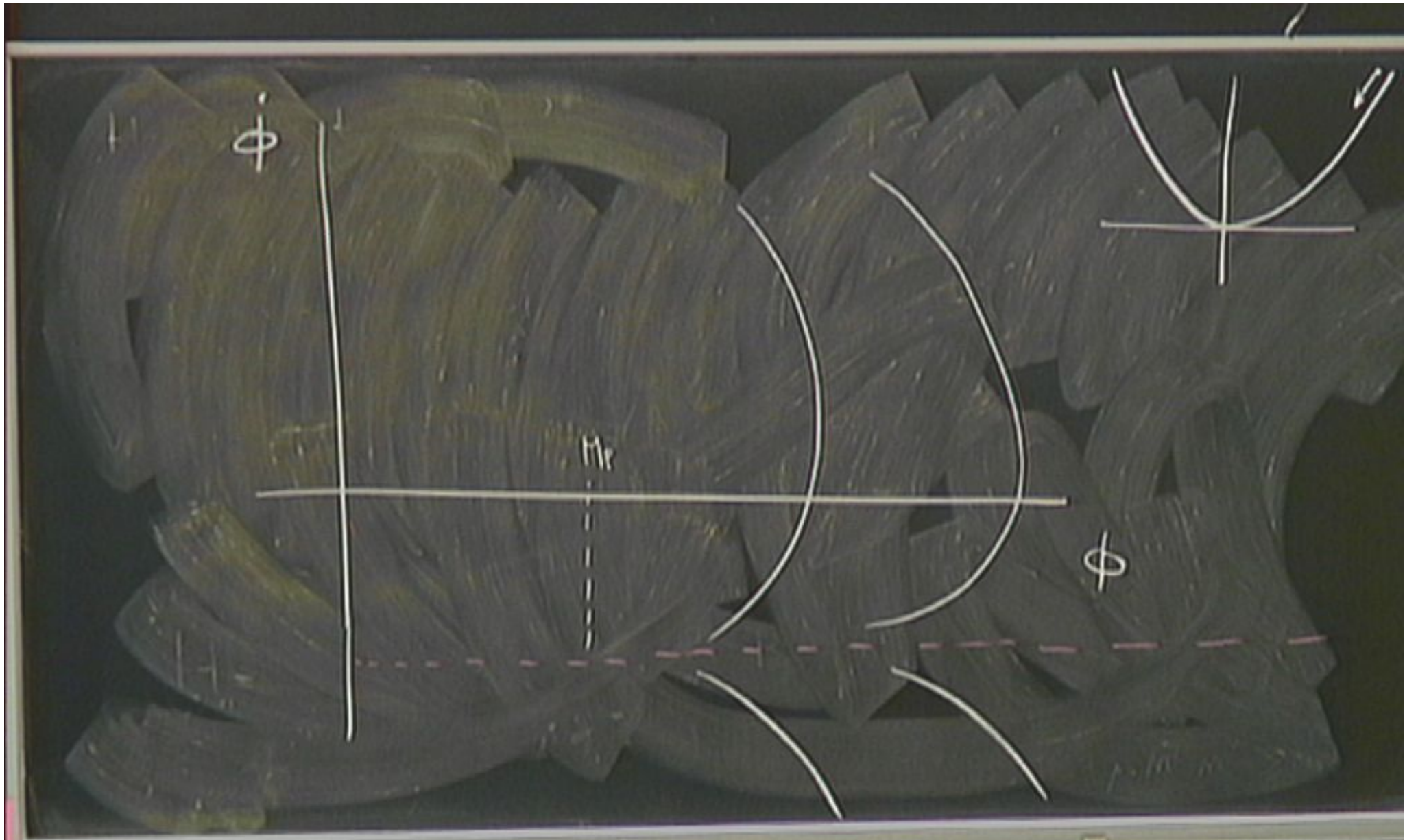
• $m^2 \phi^2 \gg \dot{\phi}^2$

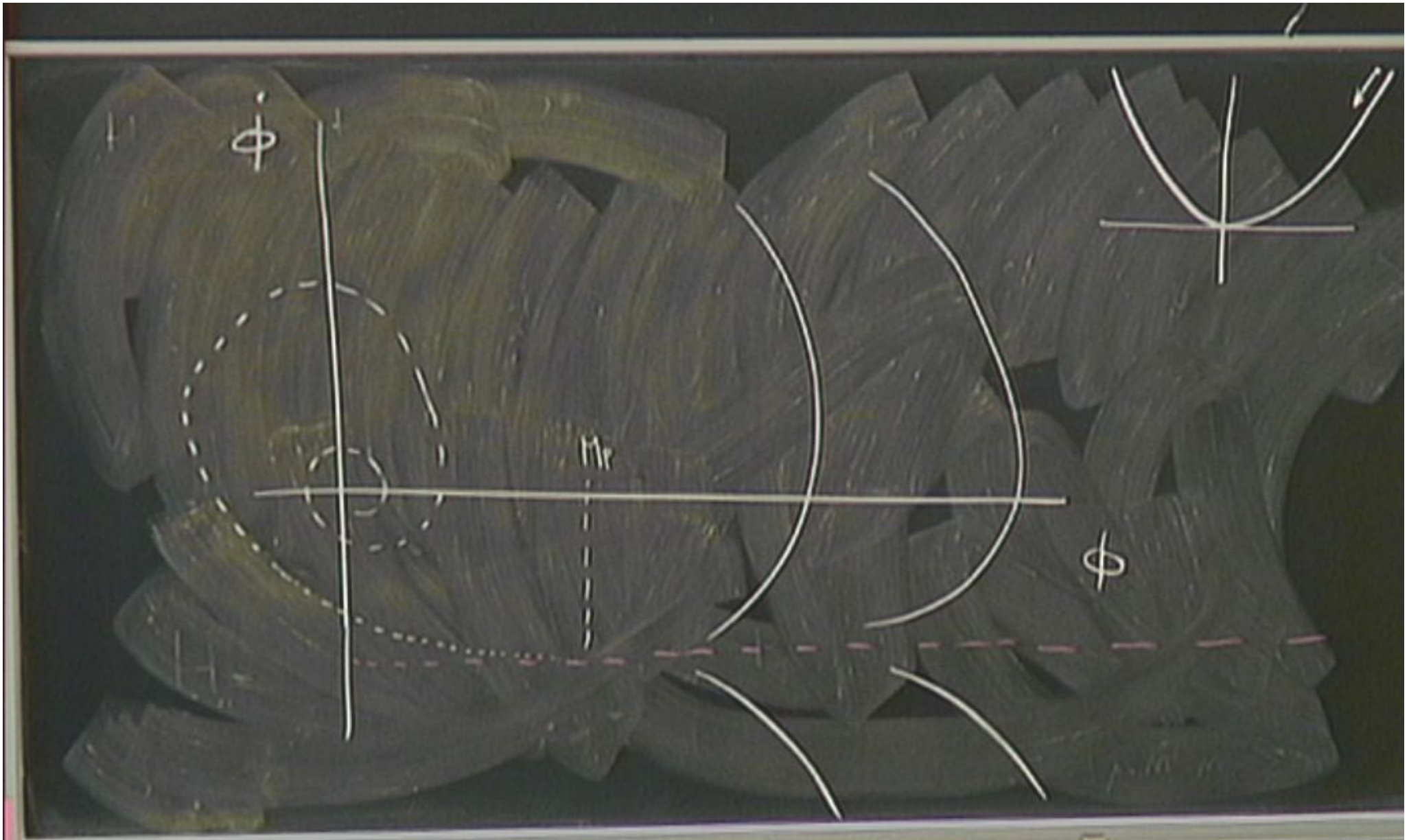
$$\frac{d\dot{\phi}}{d\phi} \approx 0$$

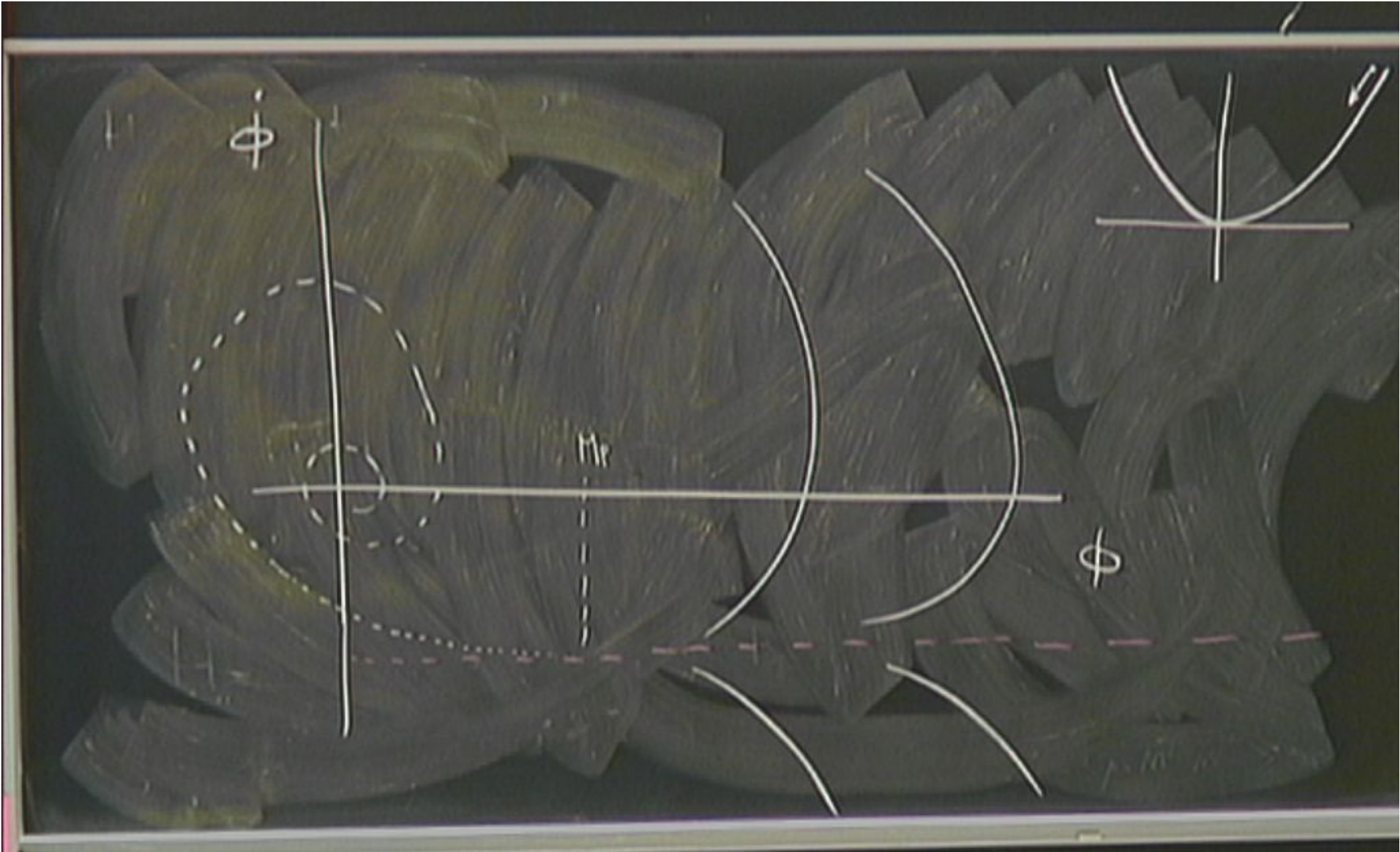
$$\frac{d\dot{\phi}}{d\phi} \approx \frac{\sqrt{3/2}}{H_P} \phi \Rightarrow \phi = \frac{\sqrt{2}}{3} m H_P$$

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









$$\bullet \dot{\phi}^2 \gg m^2 \phi^2$$

Kinetic domination

$$\bullet \rho \ll M_{\text{Pl}}^4$$

$$\rho = \frac{1}{2} m^2 \phi^2$$

$$\frac{d\dot{\phi}}{d\phi} = -\frac{\sqrt{3/2}}{M_{\text{Pl}}} |\dot{\phi}|$$

$$\bullet m^2 \phi^2 \gg \dot{\phi}^2$$

$$\frac{d\dot{\phi}}{d\phi} \approx 0$$

$$\frac{d\dot{\phi}}{d\phi} \ll \frac{\sqrt{3/2}}{M_{\text{Pl}}} \dot{\phi} m$$

$$\dot{\phi} \approx \sqrt{\frac{2}{3}} m M_{\text{Pl}}$$

$$\frac{\dot{\phi}^2}{2} \sim m^2 M_{\text{Pl}}^2 \ll \frac{1}{2} m^2 \phi^2$$

- $\dot{\phi}^2 \gg m^2 \phi^2$

Kinetic domination

$$\frac{d\dot{\phi}}{d\phi} = -\frac{\sqrt{3/2}}{M_P} |\dot{\phi}|$$

- $m^2 \phi^2 \gg \dot{\phi}^2$

$$\frac{d\dot{\phi}}{d\phi} \rightarrow 0$$

$$\frac{d\dot{\phi}}{d\phi} \propto \frac{\sqrt{3/2}}{M_P} \dot{\phi} m \phi + m^2 \phi \Rightarrow \dot{\phi} = -\sqrt{\frac{2}{3}} m M_P$$

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

- $\rho \ll M_P^4$

$$\rho = \frac{1}{2} m^2 \phi^2$$

$$m \simeq 10^{13} \text{ GeV}$$

- $\dot{\phi}^2 \gg m^2 \phi^2$

Kinetic domination

$$\frac{d\dot{\phi}}{d\phi} = -\frac{\sqrt{3/2}}{M_P} |\dot{\phi}|$$

- $m^2 \phi^2 \gg \dot{\phi}^2$

$$\frac{d\dot{\phi}}{d\phi} \approx 0$$

$$\frac{\dot{\phi}^2}{2} \sim m^2 \phi^2$$

- $\rho \ll M_P^4$

$$\rho = \frac{1}{2} m^2 \phi^2$$

$$m \simeq 10^{13} \text{ GeV}$$

$$\frac{d}{dt} \left(\frac{1}{2} \dot{\phi}^2 + m^2 \phi^2 \right) = 0 \Rightarrow \dot{\phi} = -\sqrt{\frac{2}{3}} m M_P$$

$$\bullet \dot{\phi}^2 \gg m^2 \phi^2$$

Kinetic domination

$$\frac{d\dot{\phi}}{d\phi} = -\frac{\sqrt{3/2}}{M_P} |\dot{\phi}|$$

$$\bullet m^2 \phi^2 \gg \dot{\phi}^2$$

$$\frac{d\dot{\phi}}{d\phi} \rightarrow 0$$

$$\frac{d\dot{\phi}}{d\phi} \propto \frac{\sqrt{3/2}}{M_P} \dot{\phi} m \phi + m^2 \phi \Rightarrow \dot{\phi} = -\sqrt{\frac{2}{3}} m M_P$$

$$\frac{\dot{\phi}^2}{2} \sim m^2 M_P^2 \ll \frac{1}{2} m^2 \phi^2 = V$$

$$\bullet \rho \ll M_P^4$$

$$\rho = \frac{1}{2} m^2 \phi^2$$

$$m \simeq 10^{13} \text{ GeV}$$

EFT:

$$V \supset \frac{\phi^3}{M_P^{3-4}}$$

$$\dot{\phi}^2 \gg m^2 \phi^2$$

Kinetic domination

$$\frac{d\dot{\phi}}{d\phi} = -\frac{\sqrt{3/2}}{M_P} |\dot{\phi}|$$

$$m^2 \phi^2 \gg \phi^2$$

$$\frac{d\dot{\phi}}{d\phi} \approx 0$$

$$\frac{d\dot{\phi}}{d\phi} \approx \frac{\sqrt{3/2}}{M_P} \dot{\phi}$$

$$\frac{\dot{\phi}^2}{2} \sim m^2 M_P^2 \ll \frac{1}{2} m^2 \phi^2$$

$$\rho \ll M_P^4$$

$$\rho = \frac{1}{2} m^2 \phi^2$$

$$m \simeq 10^{13} \text{ GeV}$$

EFT:

$$V \supset$$

$$\frac{\phi^2}{M_P^{2-4}}$$

V_M

$$\Delta\phi \gg M_P$$

$$\phi \gg \frac{\sqrt{2}}{3} M_P$$

• $\dot{\phi}^2 \gg m^2 \phi^2$

Kinetic domination

$$\frac{d\dot{\phi}}{d\phi} = -\frac{\sqrt{3/2}}{M_P} |\dot{\phi}|$$

• $m^2 \phi^2 \gg \dot{\phi}^2$

$$\frac{d\dot{\phi}}{d\phi} \rightarrow 0$$

$$\frac{d\dot{\phi}}{d\phi} \propto \frac{\sqrt{3/2}}{M_P} \dot{\phi} m \phi + m^2 \phi \Rightarrow \dot{\phi} \sim \sqrt{\frac{2}{3}} m M_P$$

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

• $\rho \ll M_P^4$

$$\rho = \frac{1}{2} m^2 \phi^2$$

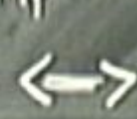
$m \approx 10^{13} \text{ GeV}$

• EFT:

$$V \supset \frac{\phi^4}{M_P^{4-n}}$$

V_{eff}

• $\Delta\phi \gg M_P$



Observable
GWs

$$\phi = \phi_f + \sqrt{\frac{2}{3}} m H_f |t - t_f|$$

$$H = \frac{m \phi}{H_f}$$

$$\phi = \phi_f + \sqrt{\frac{2}{3}} m H_f |t - t_f|$$

$a(t) ?$

$$H = \frac{m \dot{\phi}}{H_f}$$

$$\left(\frac{\dot{\phi}}{H_f}\right)^2 = \frac{1}{3}$$

$$\phi = \phi_f + \sqrt{\frac{2}{3}} m M_P |t - t_f|$$

$a(t) ?$

$$H = \frac{\dot{\phi}}{M_P}$$

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{1}{3M_P^2} \frac{2}{3} \frac{1}{2} m^4 M_P^2 |t - t_f|^2$$

$$a(t) = e^{\frac{m^2}{6} |t - t_f|^2}$$

$$\phi = \phi_f + \sqrt{\frac{2}{3}} m M_P |t - t_f|$$

$a(t) ?$

$$H = \frac{\dot{\phi}}{M_P}$$

$$\left(\frac{\dot{\phi}}{a}\right)^2 = \frac{1}{3M_P^2} \frac{2}{3} \frac{1}{2} m^4 M_P^2 |t - t_f|^2$$

$$a(t) = e^{\frac{m^2}{6} |t - t_f|^2}$$

$$\phi = \phi_f + \sqrt{\frac{2}{3}} m M_P |t - t_f|$$

$a(t) ?$

$$H = \frac{\dot{\phi}}{M_P}$$

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{1}{3M_P^2} \frac{2}{3} \frac{1}{2} m^4 M_P^2 |t - t_f|^2$$

$$\frac{\dot{H}}{H^2} \rightarrow \frac{1}{m^2 |t - t_f|^2} \rightarrow \frac{1}{N^2}$$

$$a(t) = e^{\frac{m^2}{2} |t - t_f|^2} \cdot N$$

$$\phi = \phi_f + \sqrt{\frac{2}{3}} m M_P |t - t_f|$$

$a(t) ?$

$$H = \frac{\dot{\phi}}{M_P}$$

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{1}{3M_P^2} \frac{2}{3} \frac{1}{2} m^4 M_P^2 |t - t_f|^2$$

$$a(t) = e^{\frac{m^2}{6} |t - t_f|^2} \cdot N$$

$$\frac{\dot{H}}{H^2} \sim \frac{1}{m^2 |t - t_f|^2} \sim \frac{1}{N}$$

$$\sim dS$$

$$\phi = \phi_f + \sqrt{\frac{2}{3}} m M_P |t - t_f|$$

$a(t) ?$

$$H = \frac{\dot{\phi}}{M_P}$$

$$\left(\frac{\dot{\phi}}{M_P}\right)^2 = \frac{1}{3M_P^2} \frac{2}{3} \frac{1}{2} m^4 M_P^2 |t - t_f|^2$$

$$\frac{\dot{\phi}}{M_P^2} \rightarrow \frac{1}{m^2 |t - t_f|^2} \approx \frac{1}{N^2}$$

$$a(t) = e^{\frac{m^2}{6} |t - t_f|^2} \sim N$$

$\sim dS$

$$\phi = \phi_N + \sqrt{\frac{2}{3}} m M_P |t - t_f|$$

$a(t) ?$

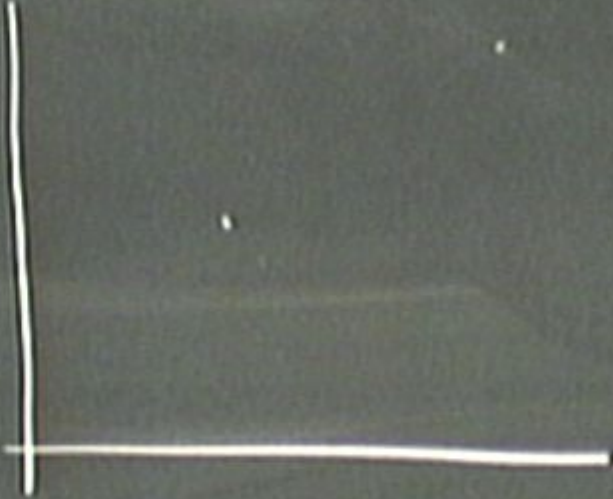
$$H = \frac{\dot{\phi}}{M_P}$$

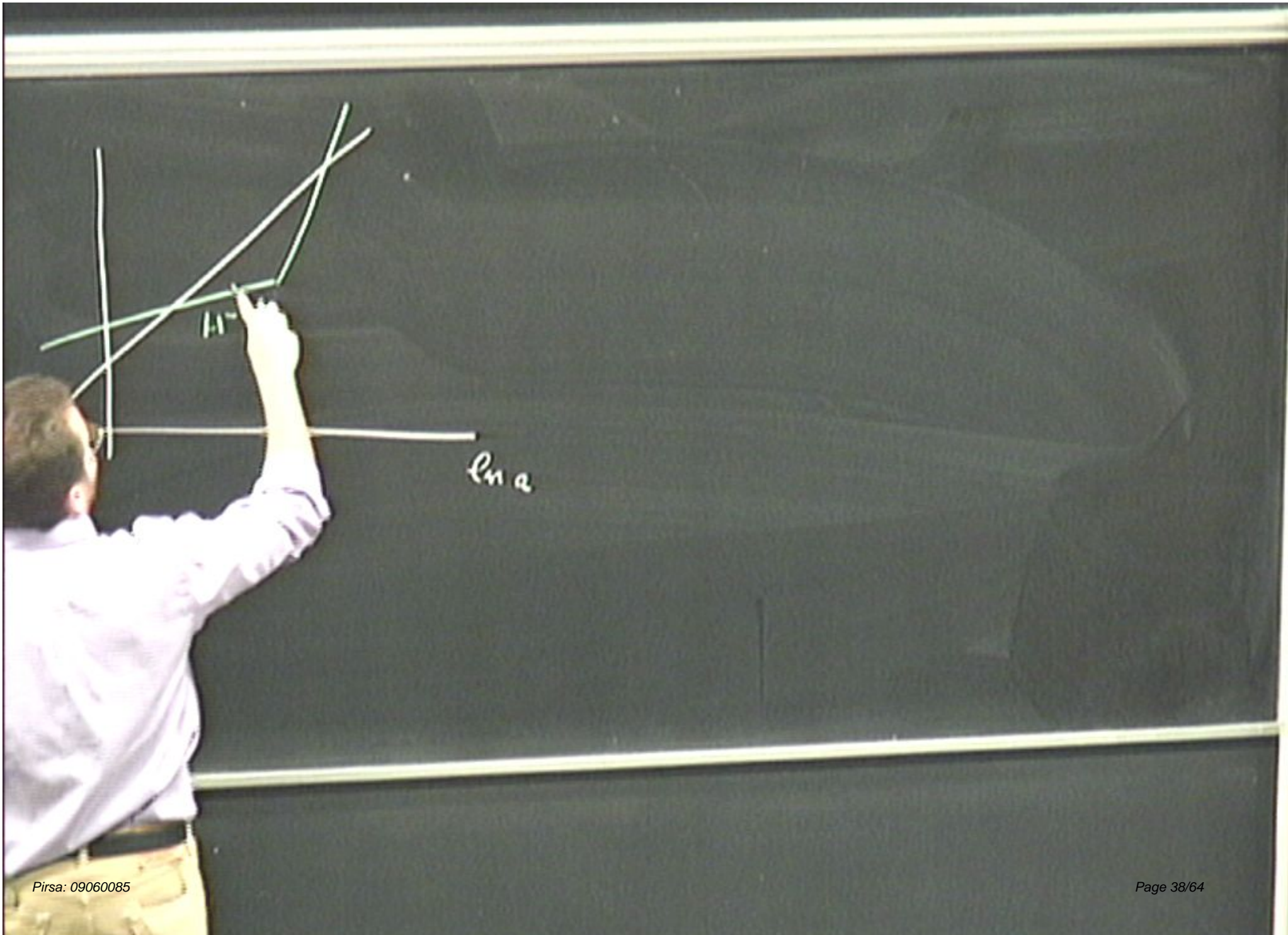
$$\left(\frac{\dot{Q}}{a}\right)^2 = \frac{1}{3M_P^2} \frac{2}{3} \frac{1}{2} m^4 M_P^2 |t - t_f|^2$$

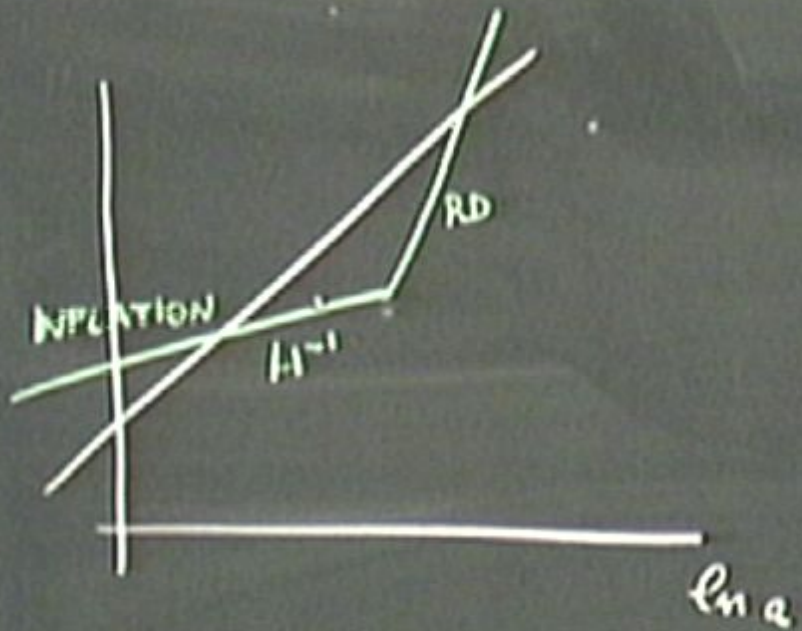
$$\frac{\dot{H}}{H^2} \sim \frac{1}{m^2 |t - t_f|^2} \sim \frac{1}{N^2}$$

$$a(t) = e^{\frac{m^2}{a} |t - t_f|^2} \sim N$$

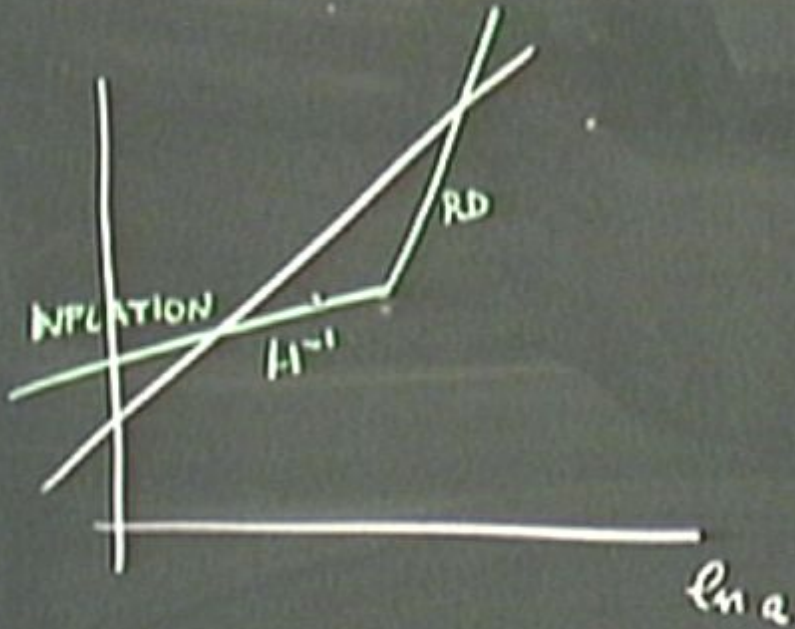
$\sim dS$



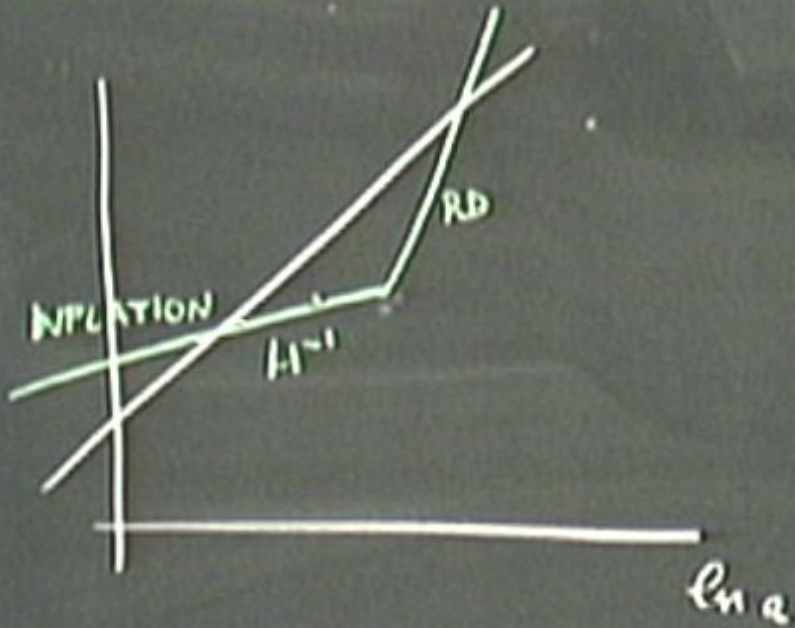




$$\frac{H_{end}^{-1} \cdot 0/a_c}{H_0^{-1}}$$

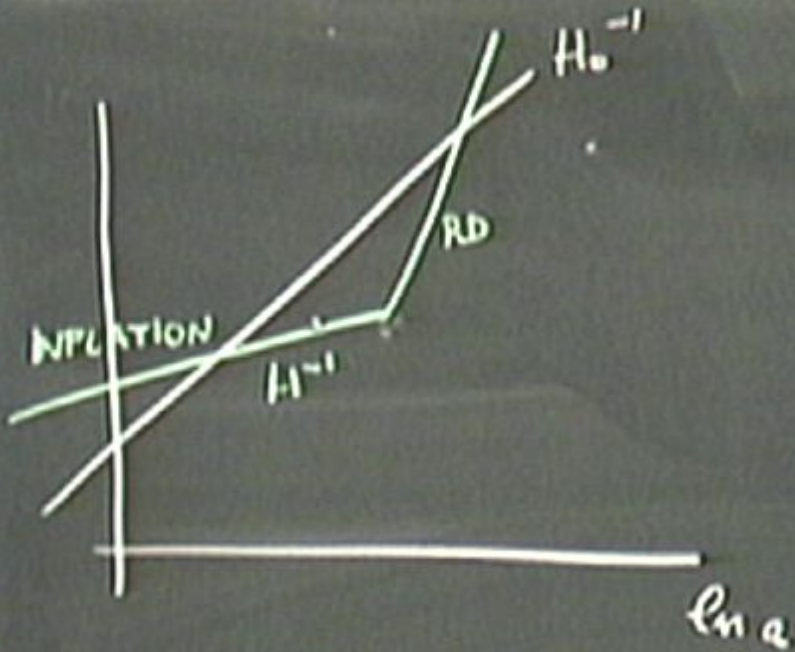


$$\frac{H_{ord}^{-1} \cdot \frac{\partial}{\partial a_2} RD}{H_0^{-1}} = 1$$



$$\frac{H_{\text{end}}^{-1} \cdot 0. / a_c \cdot RD}{H_0^{-1}} = \frac{T_0}{T_c}$$

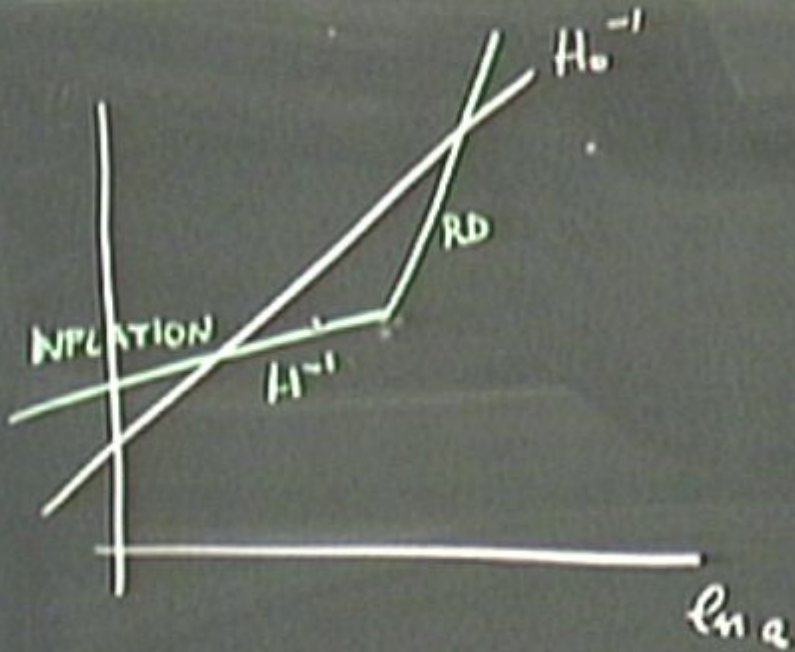
$T_c \sim 10^{15} \text{ GeV}$



$$N = \log 10^{28} = 64$$

$$\frac{H_{\text{end}}^{-1} \cdot 0.1/a_c \cdot R_D}{H_0^{-1}} = \frac{T_0}{T_c} \approx 10^{-28}$$

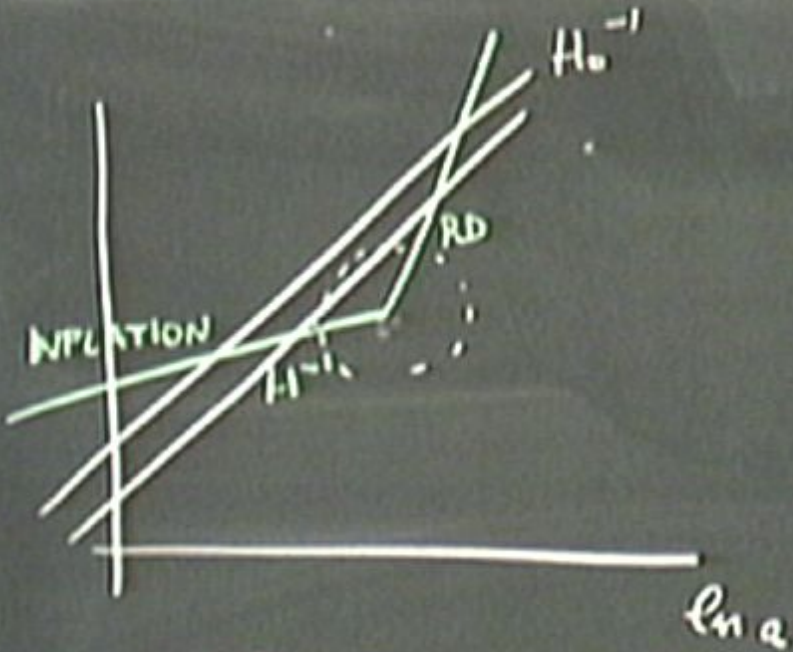
$$T_c \sim 10^{15} \text{ GeV}$$



$$N = \log 10^{28} = 64$$

$$\frac{H_{\text{end}}^{-1} \cdot 0.1/a_c \cdot \text{RD}}{H_0^{-1}} = \frac{T_0}{T_c} \approx 10^{-28}$$

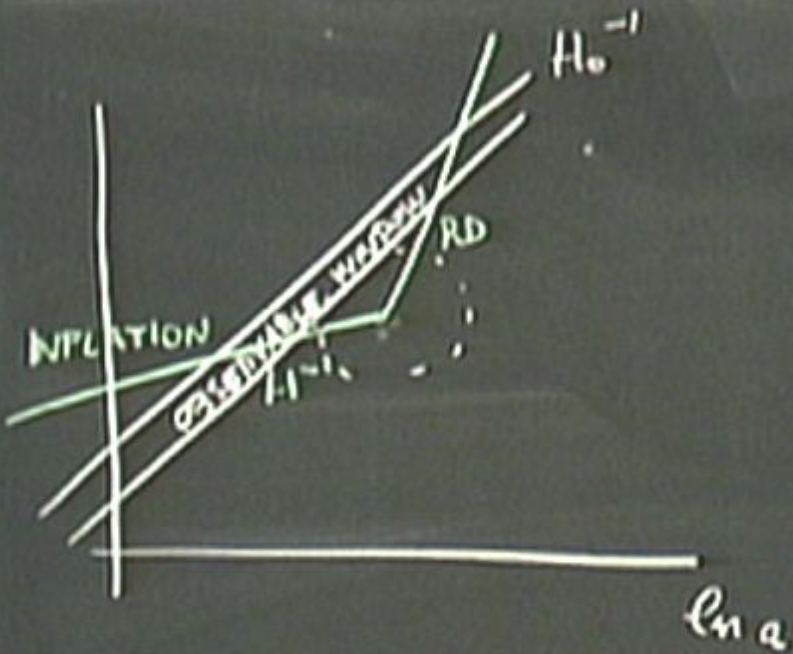
$$T_c \sim 10^{15} \text{ GeV}$$



$$N = \log 10^{28} = 64$$

$$\frac{H^{-1}}{a_e RD} = \frac{T_0}{T_e} \approx 10^{-28}$$

$$T_e \sim 10^{15} \text{ GeV}$$

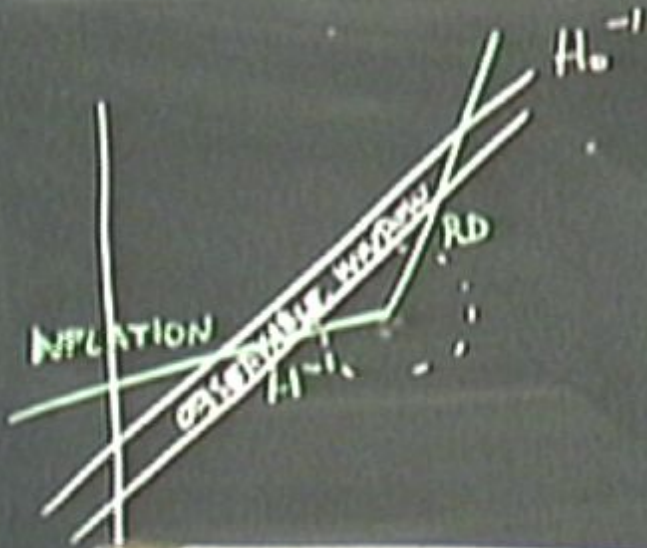


$$N = \log 10^{28} = 64$$

$$\frac{H_{\text{end}}^{-1} \cdot 0.1/a_c \cdot RD}{H_0^{-1}} = \frac{T_0}{T_c} \approx 10^{-28}$$

$$T_c \sim 10^{15} \text{ GeV}$$





$$N = \log 10^{28} = 64$$

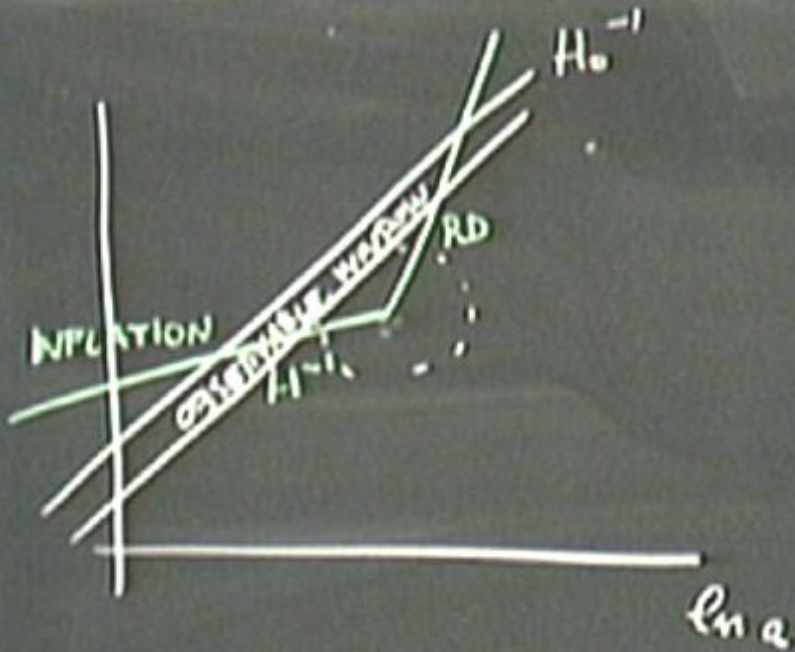
$$H_0^{-1} \approx 3000 \text{ Mpc}$$

$$0.1 \text{ Mpc}$$

10 e-folds observed

$$\frac{c/a_e \text{ RD}}{H_0^{-1}} = \frac{T_0}{T_e} \approx 10^{-28}$$

$$T_e \sim 10^{15} \text{ GeV}$$



$$N = \log 10^{28} = 64$$

$$H_0^{-1} \approx 3000 \text{ Mpc}$$

$$0.1 \text{ Mpc}$$

10 e-folds observed

$$\frac{H_{\text{end}}^{-1} \cdot 0.1 / a_{\text{end}} \cdot RD}{H_0^{-1}} = \frac{T_0}{T_e} \approx 10^{-28}$$

$$T_e \sim 10^{15} \text{ GeV}$$

$$\left\{ \begin{array}{l} \ddot{\phi} + 3H\dot{\phi} + V'(\phi) \\ H^2 = \frac{1}{3M_{Pl}^2} \left(\frac{\dot{\phi}^2}{2} + V(\phi) \right) \end{array} \right. \xrightarrow{SR} \left\{ \begin{array}{l} \dot{\phi} \approx -\frac{V'}{3H} \\ H^2 \approx \frac{V}{3M_{Pl}^2} \end{array} \right.$$

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

SR \rightarrow

$$\begin{cases} \dot{\phi} \approx -\frac{V'}{3H} \\ H^2 \approx \frac{V}{3M_{\text{Pl}}^2} \end{cases}$$

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

$$\frac{V^{1/2}}{H^2} \ll V$$

$$\epsilon \equiv \frac{1}{2} M_{\text{Pl}}^2 \left(\frac{V'}{V} \right)^2 \ll 1$$

$$\left(\frac{F}{F_{\text{v}}} \right)$$

$$\epsilon \equiv \frac{F}{F_{\text{v}}}$$

$$\begin{cases} \ddot{\phi} + 3H\dot{\phi} + V'(\phi) \\ H^2 = \frac{1}{3M_{Pl}^2} \left(\frac{\dot{\phi}^2}{2} + V(\phi) \right) \end{cases}$$

SR \rightarrow

$$\begin{cases} \dot{\phi} \approx -\frac{V'}{3H} \\ H^2 \approx \frac{V}{3M_{Pl}^2} \end{cases}$$

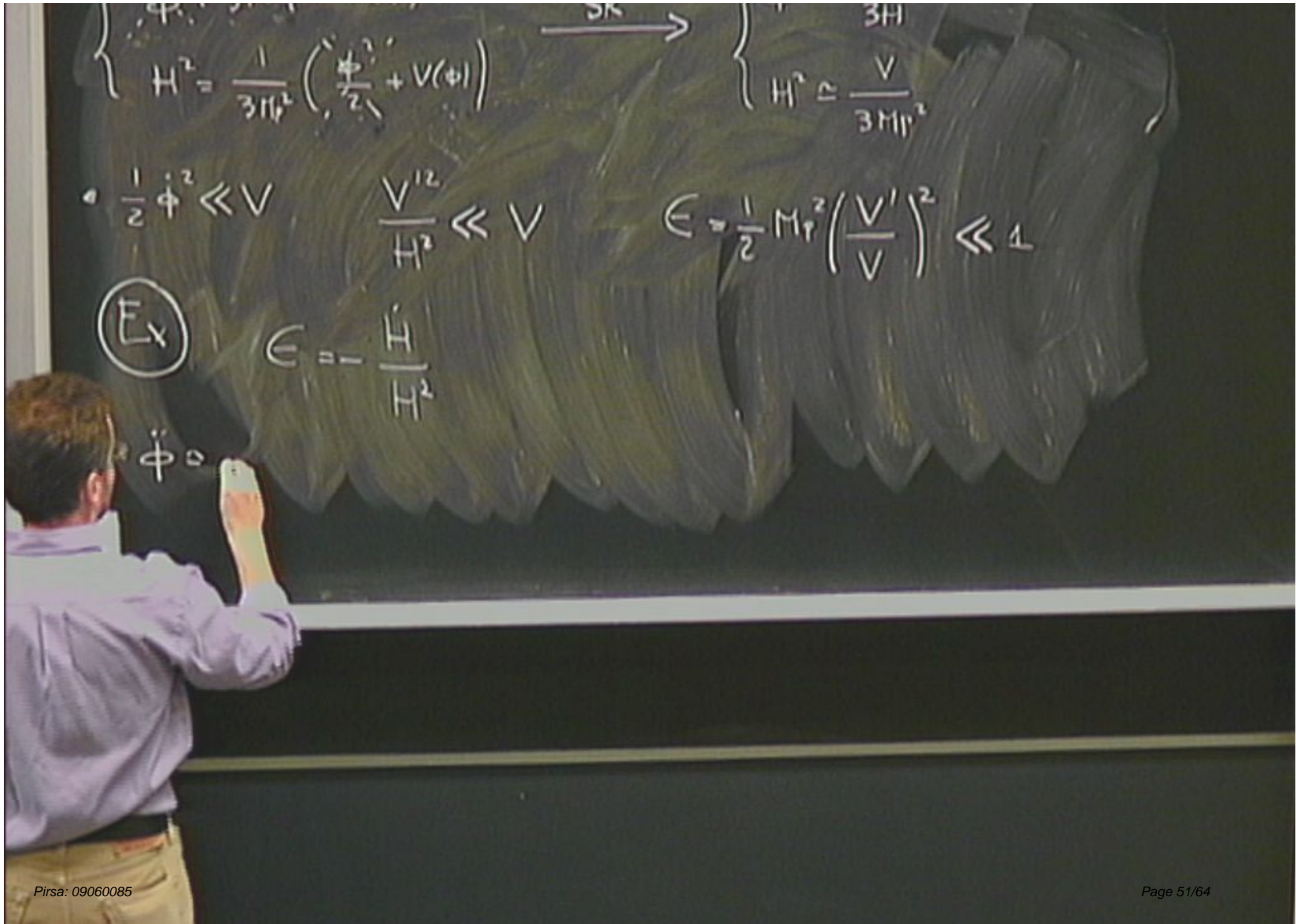
$$\frac{1}{2} \dot{\phi}^2 \ll V$$

$$\frac{V^{1/2}}{H^2} \ll V$$

$$\epsilon = \frac{1}{2} M_{Pl}^2 \left(\frac{V'}{V} \right)^2 \ll 1$$

$$\textcircled{E_V}$$

$$\epsilon = \frac{E_V}{E_P}$$



$$\left\{ \begin{aligned} H^2 &= \frac{1}{3M_{Pl}^2} \left(\frac{\dot{\phi}^2}{2} + V(\phi) \right) \end{aligned} \right. \xrightarrow{SR} \left\{ \begin{aligned} H^2 &\simeq \frac{V}{3M_{Pl}^2} \end{aligned} \right.$$

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

$$\frac{V^{1/2}}{H^2} \ll V$$

$$\Leftrightarrow \frac{1}{2} M_{Pl}^2 \left(\frac{V'}{V} \right)^2 \ll 1$$

$$\textcircled{E_x}$$

$$\Leftrightarrow \frac{V'}{V} \ll 1$$

$$\dot{\phi} \approx 0$$

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

$$\frac{v_{12}}{I_2} \ll v$$

$$\frac{1}{2} M_P^2 \left(\frac{v'}{v} \right)^2 \ll 1$$

$$\textcircled{E_x}$$

$$\frac{v''}{I_2} \ll v$$

$$\ddot{\phi} \approx \left(-\frac{v'}{3H} \right) \approx \frac{v''}{H} \approx \frac{v'' v'}{2}$$

3MP

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

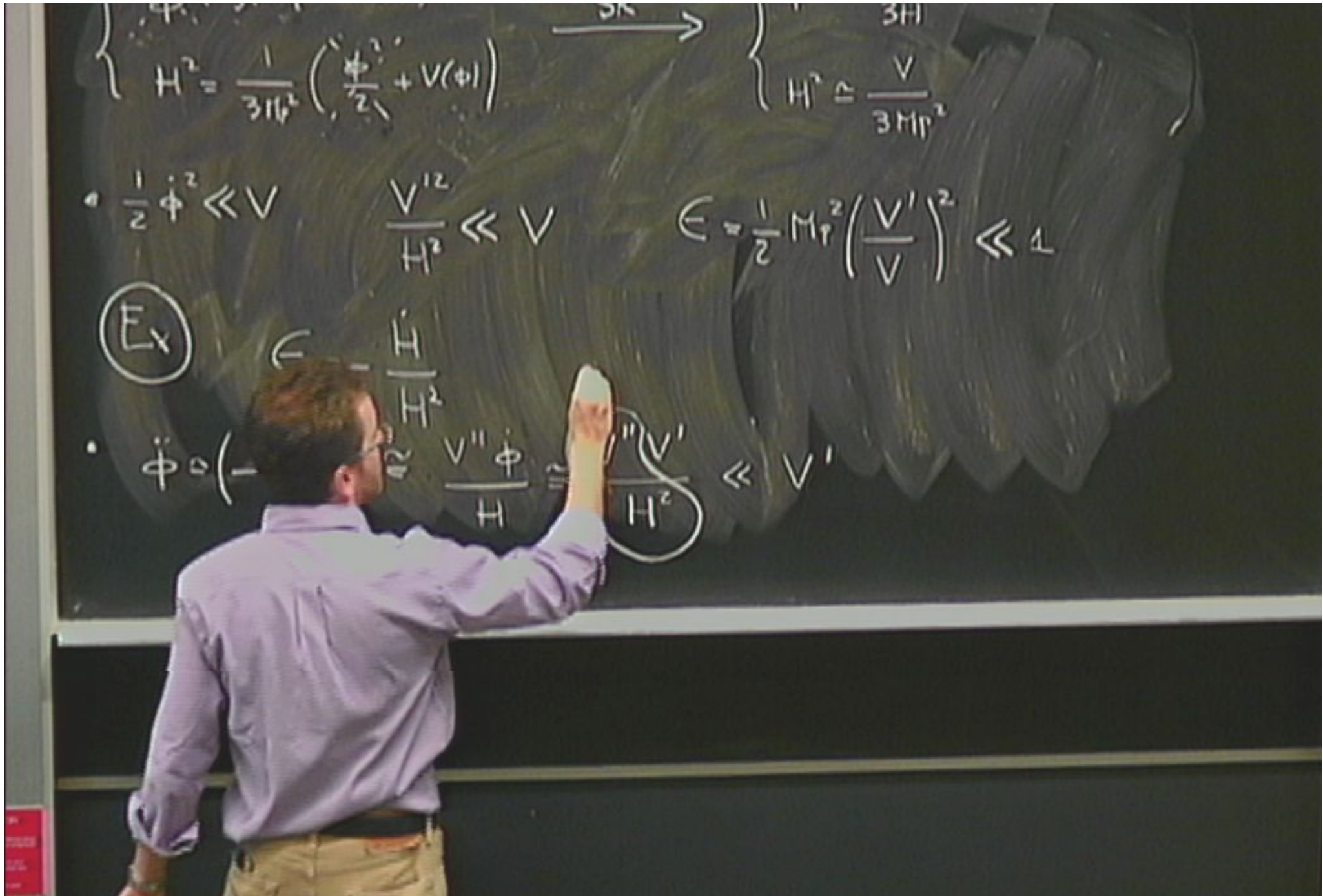
$$\frac{V_{12}}{H^2} \ll V$$

$$\frac{1}{2} M_{pl}^2 \left(\frac{V'}{V} \right)^2 \ll 1$$

$$\left(\frac{F}{F_x} \right)$$

$$\frac{F}{H^2}$$

$$\dot{\phi} \left(-\frac{V'}{3H} \right) \approx \frac{V'' \dot{\phi}}{H} \approx \frac{V'' V'}{H^2}$$



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

$$H^2 \approx \frac{V}{3M_{Pl}^2}$$

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

$$\frac{V^{1/2}}{H^2} \ll V$$

$$\frac{1}{2} M_{Pl}^2 \left(\frac{V'}{V} \right)^2 \ll 1$$

$$\left(\frac{F}{M_{Pl}} \right)^2$$

$$\frac{F}{M_{Pl}}$$

$$\dot{\phi} \ll \dots$$

$$\frac{V}{H^2} \ll \dots$$

$$\frac{V'}{V} \ll \dots$$

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

$$H^2 \approx \frac{V}{3M_{Pl}^2}$$

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

$$\frac{V^{1/2}}{H^2} \ll V$$

$$\Rightarrow \frac{1}{2} M_{Pl}^2 \left(\frac{V'}{V} \right)^2 \ll 1$$

\mathcal{L}_X

$$\Rightarrow \frac{V'}{H^2} \ll 1$$

$$\ddot{\phi} \left(-\frac{V'}{3H} \right) \approx \frac{V'' \dot{\phi}}{H} \Rightarrow \frac{V'' \dot{\phi}}{H^2} \ll V'$$

$$\begin{cases} \ddot{\phi} + 3H\dot{\phi} + V'(\phi) \\ H^2 = \frac{1}{3M_{Pl}^2} \left(\frac{\dot{\phi}^2}{2} + V(\phi) \right) \end{cases} \xrightarrow{SR} \begin{cases} \dot{\phi} \simeq -\frac{V'}{3H} \\ H^2 \simeq \frac{V}{3M_{Pl}^2} \end{cases}$$

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

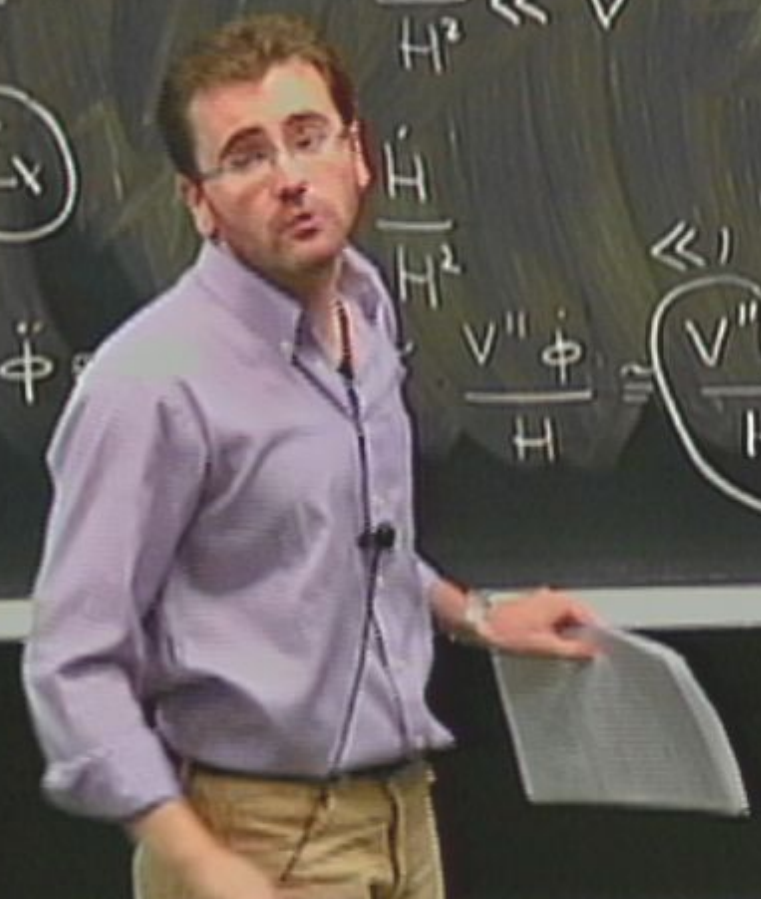
$$\frac{V'^2}{H^2} \ll V$$

$$\epsilon = \frac{1}{2} M_{Pl}^2 \left(\frac{V'}{V} \right)^2 \ll 1$$

$$\eta = M_{Pl}^2 \frac{V''}{V}$$

$$\frac{V'' \dot{\phi}}{H} \simeq \frac{V'' V'}{H^2} \ll V'$$

(E_V)



$$\begin{cases} \ddot{\phi} + 3H\dot{\phi} + V'(\phi) \\ H^2 = \frac{1}{3M_p^2} \left(\frac{\dot{\phi}^2}{2} + V(\phi) \right) \end{cases}$$

SR \rightarrow

$$\begin{cases} \dot{\phi} \simeq -\frac{V'}{3H} \\ H^2 \simeq \frac{V}{3M_p^2} \end{cases}$$

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

$$\frac{V'^2}{H^2} \ll V$$

$$\epsilon = \frac{1}{2} M_p^2 \left(\frac{V'}{V} \right)^2 \ll 1$$

(F_x)

$$\epsilon = \frac{F_x}{F}$$

$$\bullet \dot{\phi} \simeq \left(-\frac{V'}{3H} \right) \Rightarrow \frac{V'' \dot{\phi}}{H} \Rightarrow \frac{V'' V'}{H^2} \ll V'$$

$$\eta = M_p^2 \frac{V''}{V}$$

• Shift-symmetry

$$\phi \rightarrow \phi + c$$

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$$\phi \rightarrow \phi + c$$

• Supersymmetry

• Shift-symmetry

$$\phi \rightarrow \phi + c$$

PNGB

$$V = \Lambda^4 G_4(\phi/f)$$

$$\left[f \gg M_{\text{Pl}} \right] \quad \frac{\phi^3}{M_{\text{Pl}}^{3-d}}$$

• Supersymmetry

• Shift-symmetry

$$\phi \rightarrow \phi + c$$

PNGB

$$V = \Lambda^4 \cos(\phi/f)$$

$$\left[f \gg M_P \right]$$

$$\frac{\phi^3}{M_P^{3-d}}$$

• Supersymmetry

$$V = e^{K/M_P^2} \left[(K^{-1})^i_j L_i L^j - 3 \frac{|W|^2}{M_P^4} \right]$$

GR

Supergravity

$$L_i = W_i + K_i \frac{W}{M_P^2}$$

PNGB

• Shift-symmetry

$$V = \Lambda^4 \cos(\phi/f)$$

$$\phi \rightarrow \phi + c$$

$$\left[f \gg M_P \right]$$

$$\frac{\phi^3}{M_P^{3-d}}$$

$$K = \phi^+ \phi$$

• Supersymmetry

$$V = e^{K/M_P^2} \left[(K^{-1})^i_j L_i L^j - 3 \frac{|W|^2}{M_P^4} \right]$$

↓ GR

Supergravity

$$L_i = W_i + K_i \frac{W}{M_P^2}$$

PNGB

• Shift-symmetry

$$V = \Lambda^4 \cos(\phi/f)$$

$$\phi \rightarrow \phi + c$$

$$\left[f \gg M_P \right]$$

$$\frac{\phi^3}{M_P^{3-d}}$$

$$K = \phi^\dagger \phi$$

• Supersymmetry:

$$V = e^{K/M_P^2} \left[(K^{-1})^i_j L_i L^j - 3 \frac{|W|^2}{M_P^4} \right]$$

↓ GR

Supergravity

$$L_i = W_i + K_i \frac{W}{M_P^2}$$