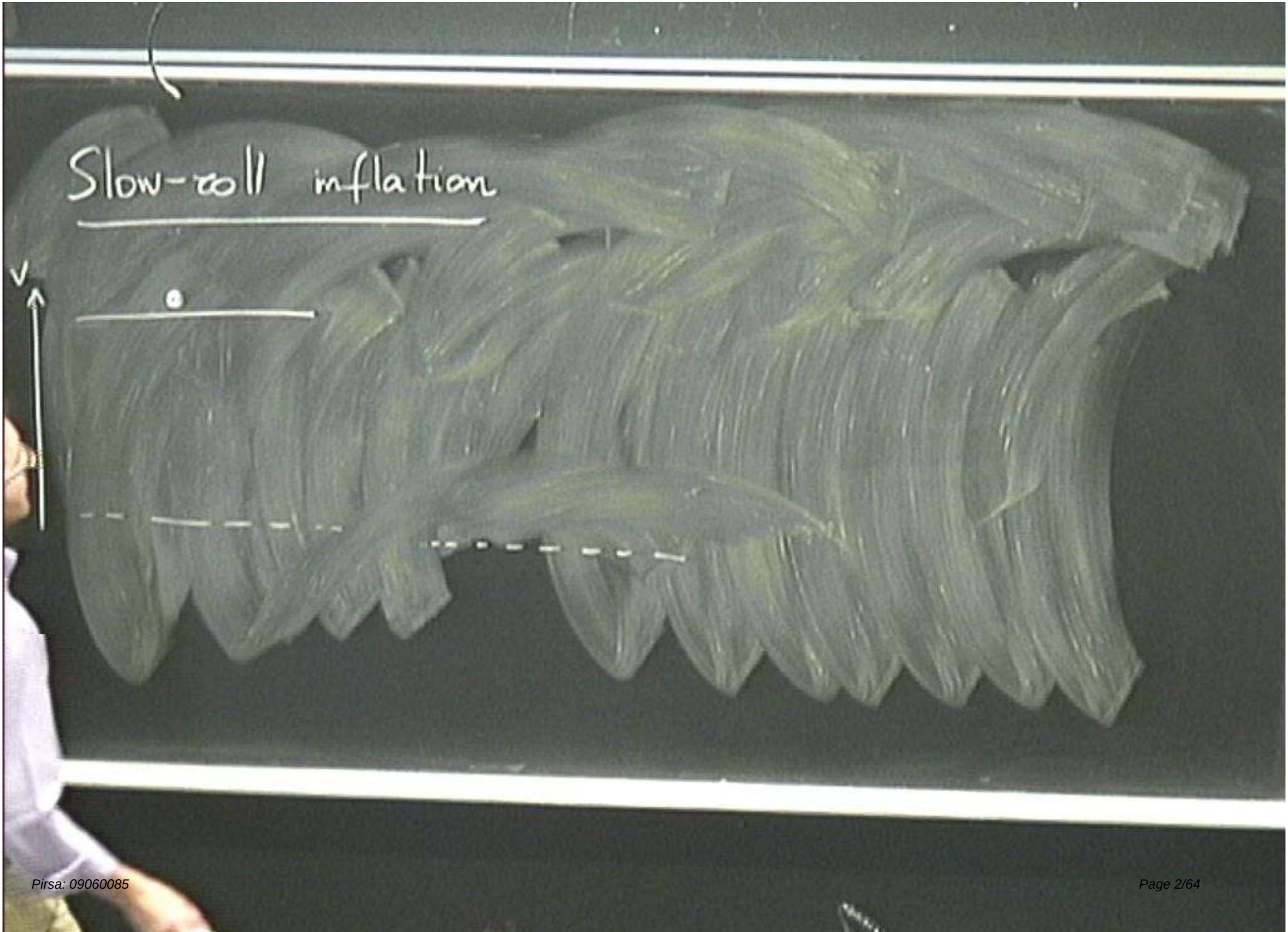
Title: Inflationary Cosmology - Lecture 2

Date: Jun 30, 2009 10:00 AM

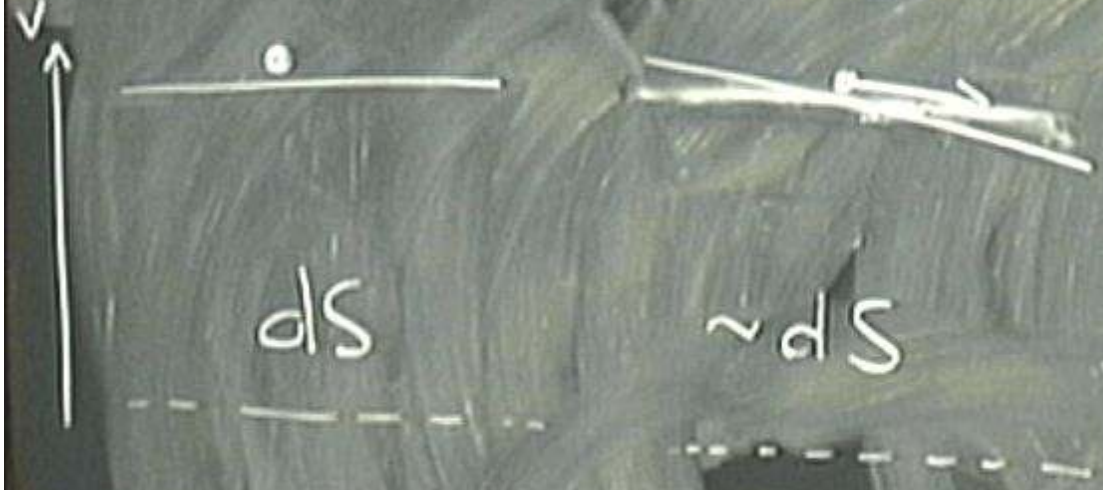
URL: http://pirsa.org/09060085

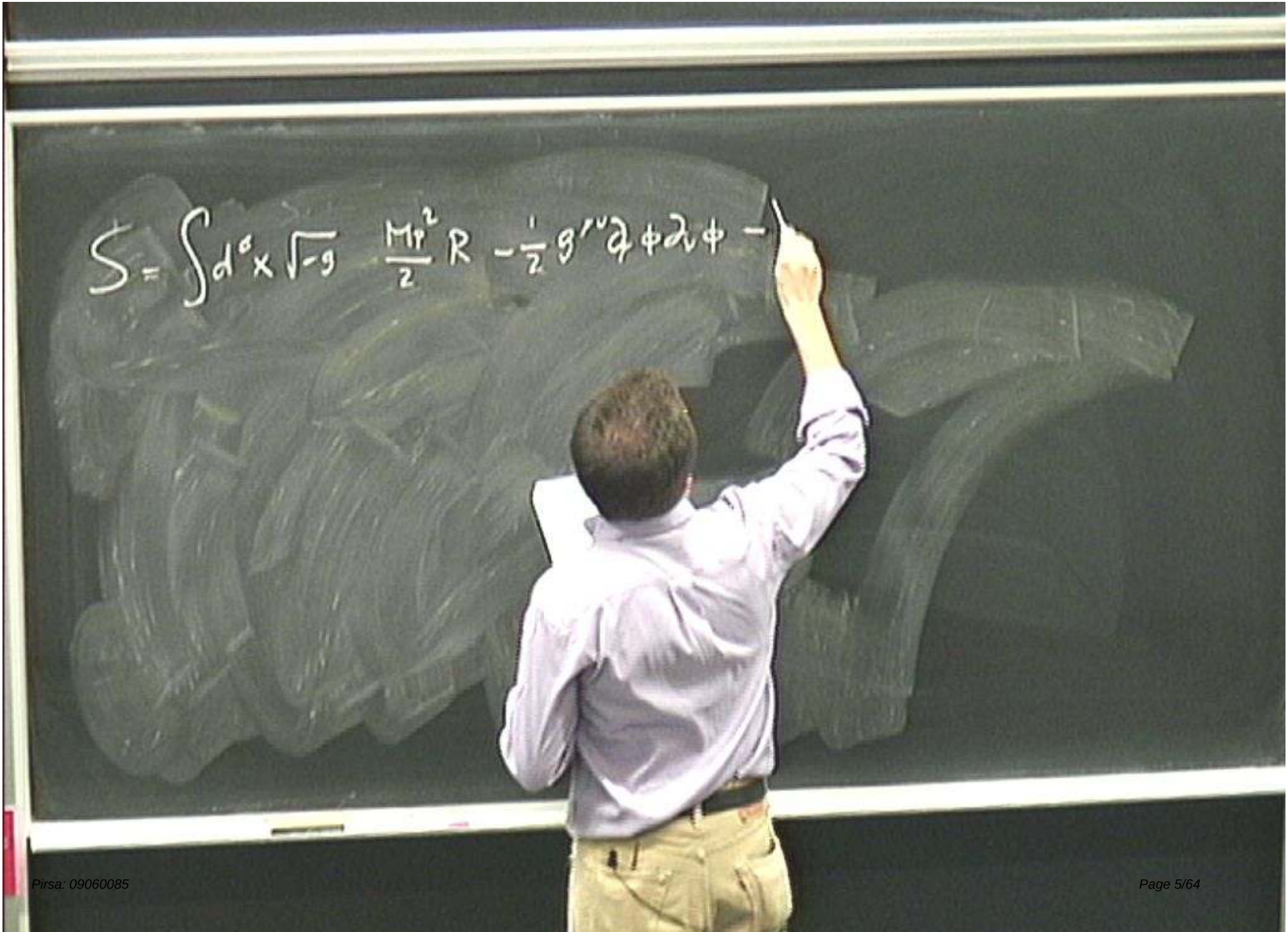
Abstract:

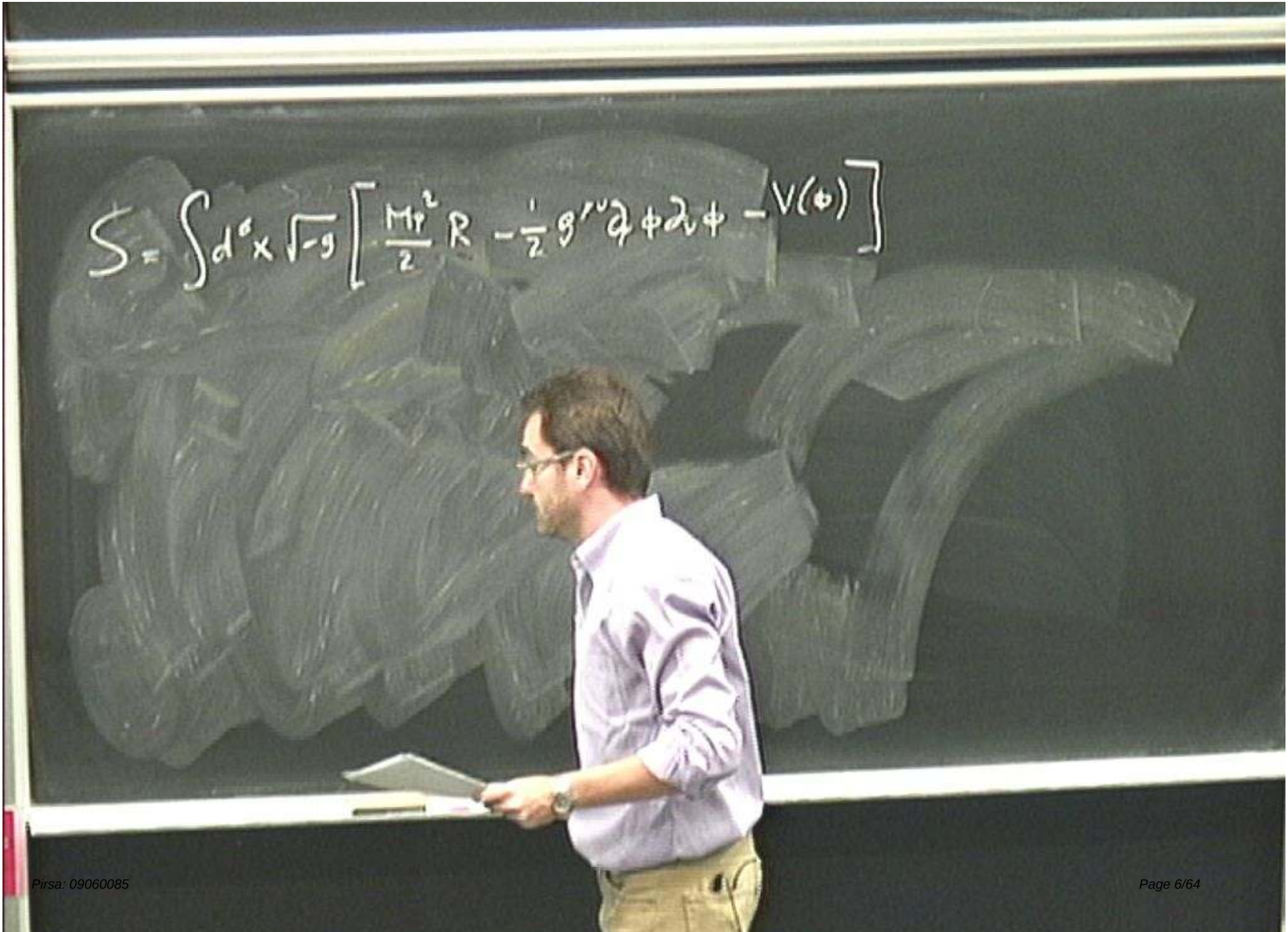

Slow-roll inflation
V

Slow-roll inflation

Slow-roll inflation




$S = \int d^4x \sqrt{-g} \left[\frac{M_P^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - \right.$


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

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

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

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

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

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

$$\begin{cases} \rho = \frac{1}{2} \dot{\phi}^2 + V(\phi) \\ p = \frac{1}{2} \dot{\phi}^2 - V(\phi) \end{cases}$$

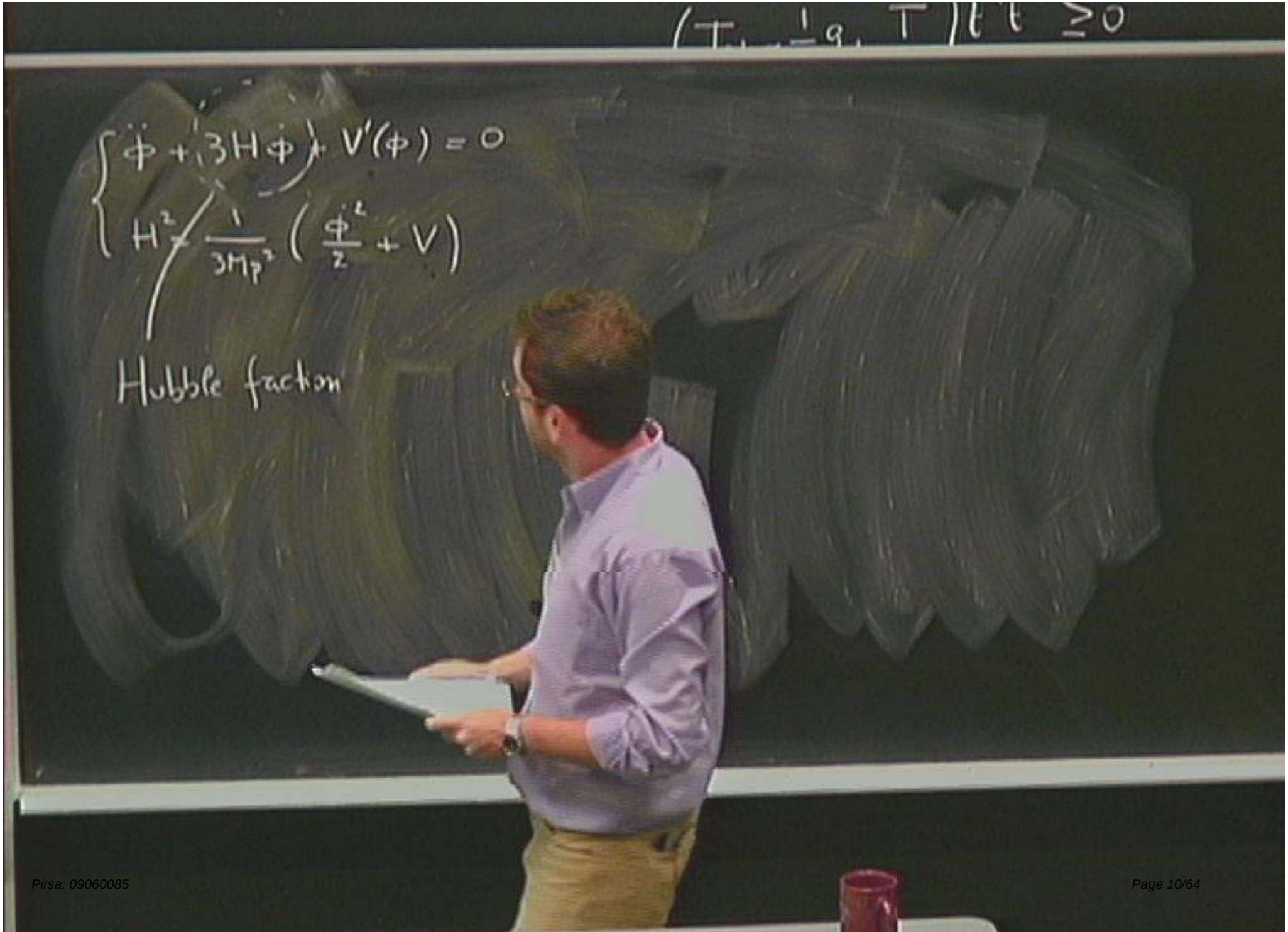
$\phi(t)$

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

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

$$\begin{cases} \rho = \frac{1}{2}\dot{\phi}^2 + V(\phi) \\ p = \frac{1}{2}\dot{\phi}^2 - V(\phi) \end{cases} \qquad \phi(t)$$

$$\frac{\dot{\phi}^2}{2} \ll V \quad : \text{slow-roll}$$


$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$
$H^2 = \frac{1}{3M_P^2}\left(\frac{\dot{\phi}^2}{2} + V\right)$
Hubble fraction

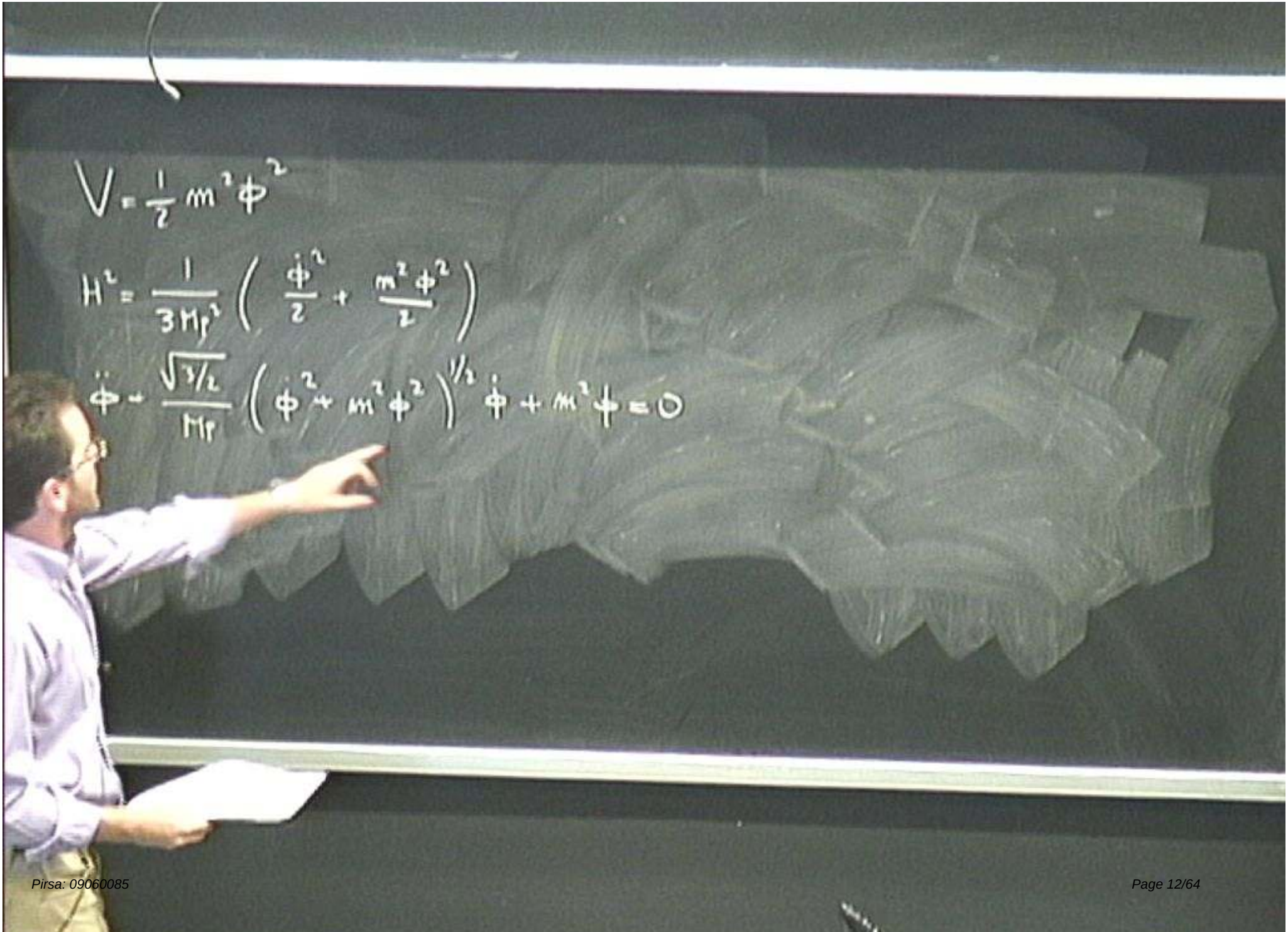
$$\begin{cases} \ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0 \\ H^2 = \frac{1}{3M_p^2}\left(\frac{\dot{\phi}^2}{2} + V\right) \end{cases}$$

Hubble faction

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

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

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


$V = \frac{1}{2} m^2 \phi^2$
$H^2 = \frac{1}{3M_p^2}\left(\frac{\dot{\phi}^2}{2} + \frac{m^2\phi^2}{2}\right)$
$\ddot{\phi} + \frac{\sqrt{3/2}}{M_p}\left(\dot{\phi}^2 + m^2\phi^2\right)^{1/2}\dot{\phi} + m^2\phi = 0$

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

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

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

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

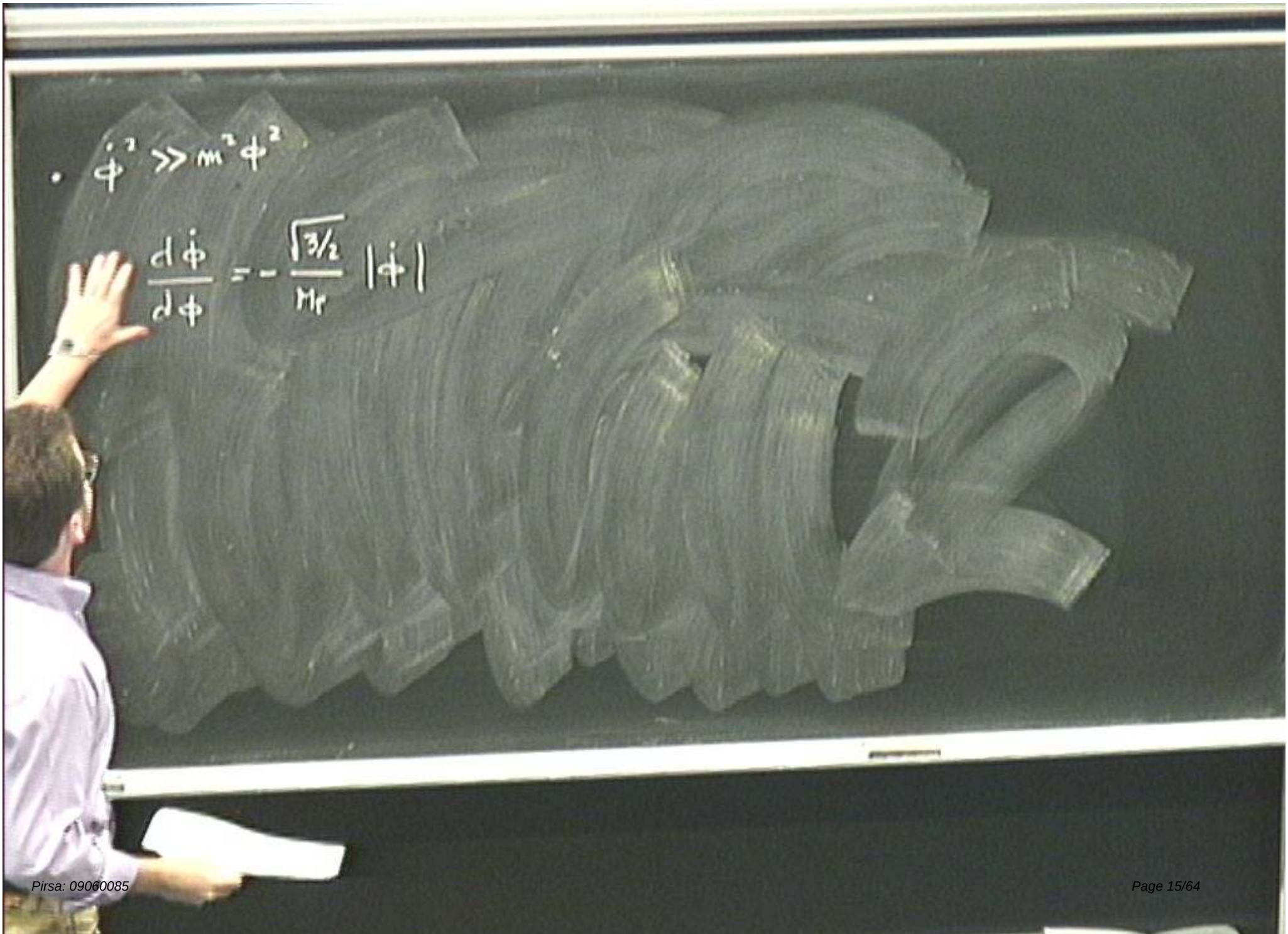
$$V = \frac{1}{2} m^2 \phi^2$$

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

$$\boxed{\phi \gg M_p}$$

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

$$\ddot\phi = \frac{d\dot\phi}{d\phi}\dot\phi \qquad \frac{d\dot\phi}{d\phi} = -\frac{1}{\dot\phi}\left[\sqrt{3/2}\,\frac{\dot\phi}{M_p}\left(\dot\phi^2 + m^2\phi^2\right)^{1/2} + m^2\phi\right]$$


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

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

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

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

- $\dot\phi^2 \gg m^2\phi^2$ Kinetic domination

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

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

$$\frac{d\dot\phi}{d\phi} \sim 0 \qquad \frac{d\dot\phi}{d\phi} < \frac{\sqrt{3/2}}{M_P}\dot\phi\, m\phi + m^2\phi \Rightarrow \dot\phi = -\sqrt{\frac{2}{3}}\, m M_P$$

- $\dot\phi^2 \gg m^2\phi^2$ Kinetic domination

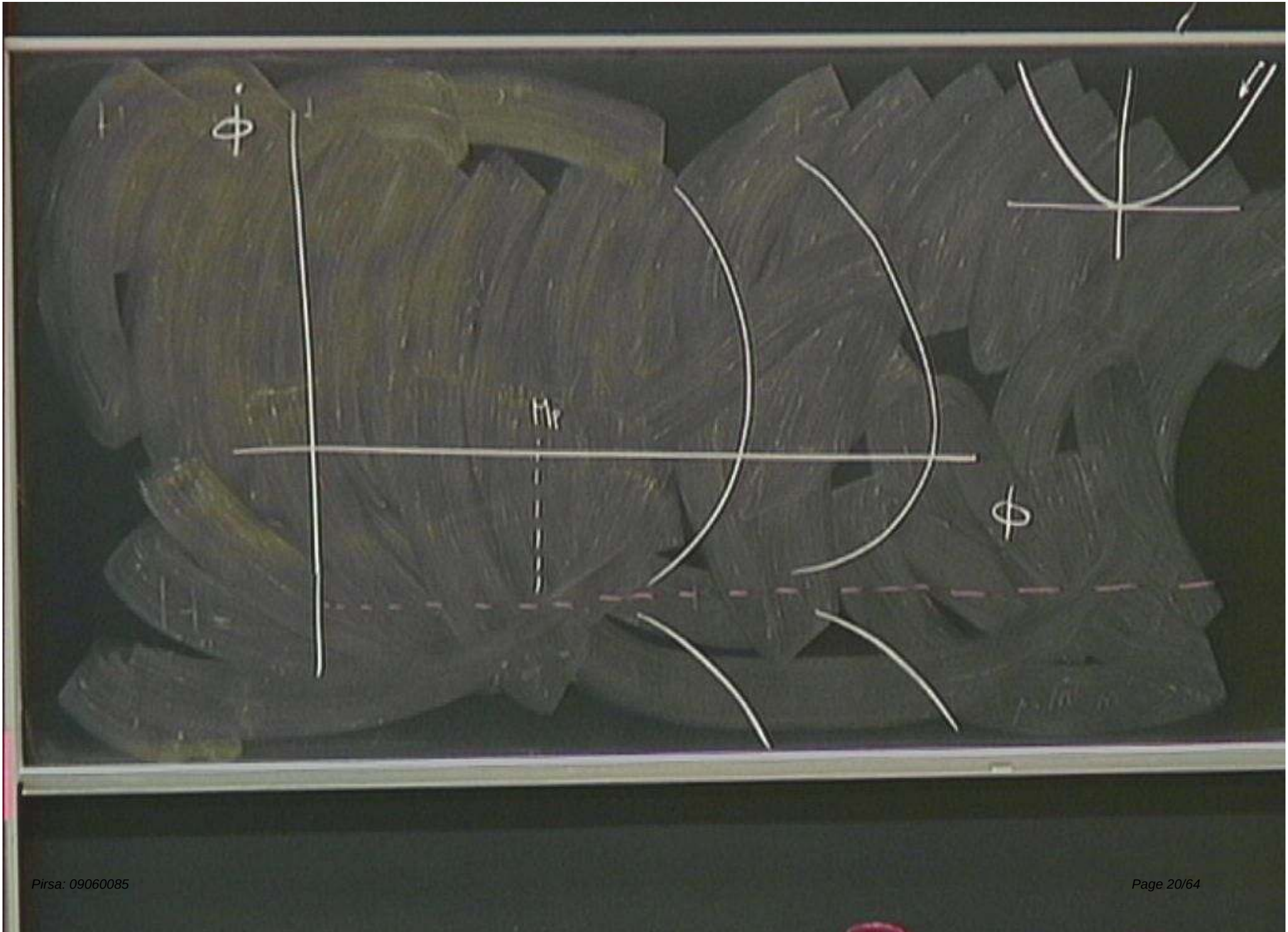
$$\frac{d\dot\phi}{d\phi} = -\frac{\sqrt{3/2}}{M_P}|\dot\phi|$$

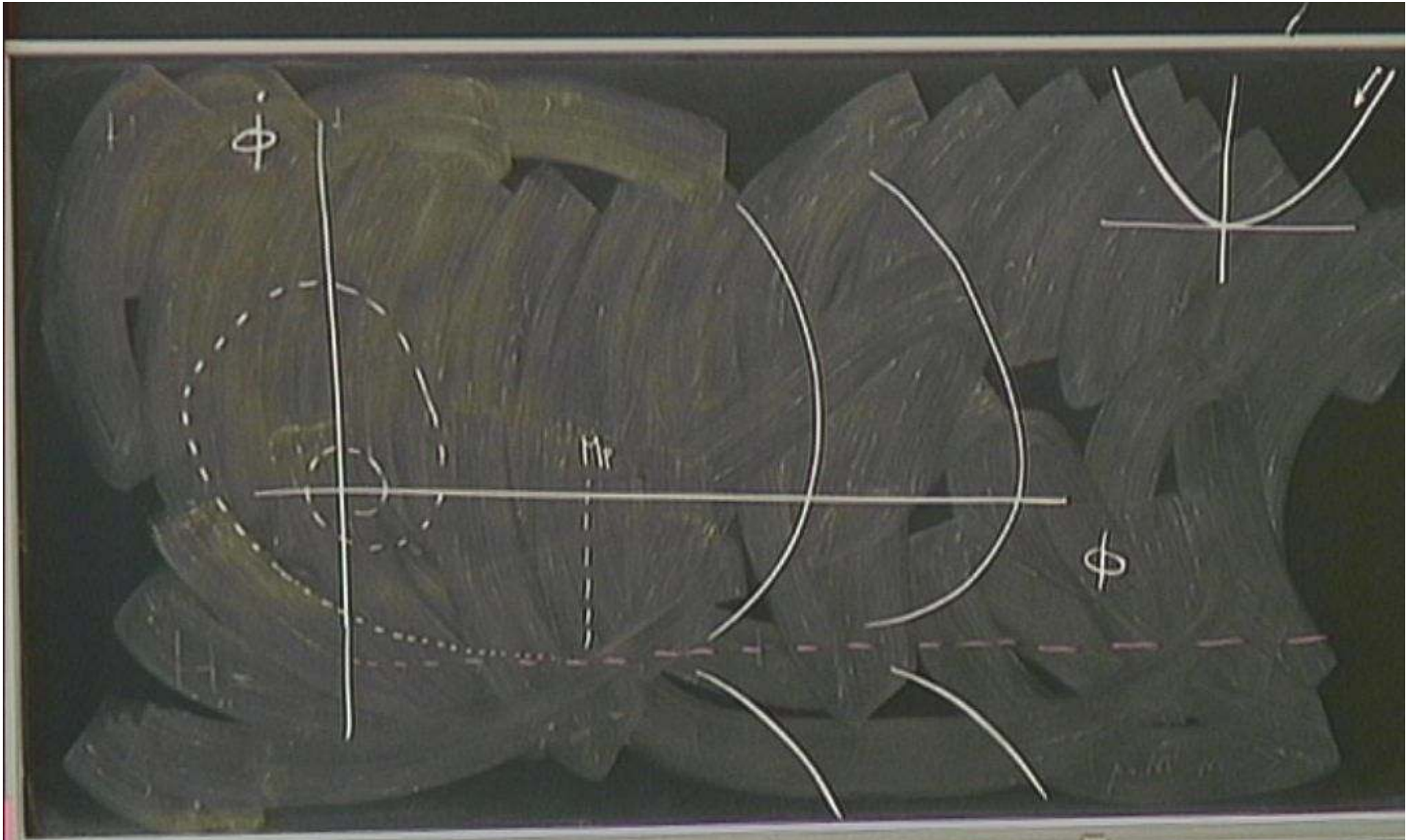
- $m^2\phi^2 \gg \dot\phi^2$

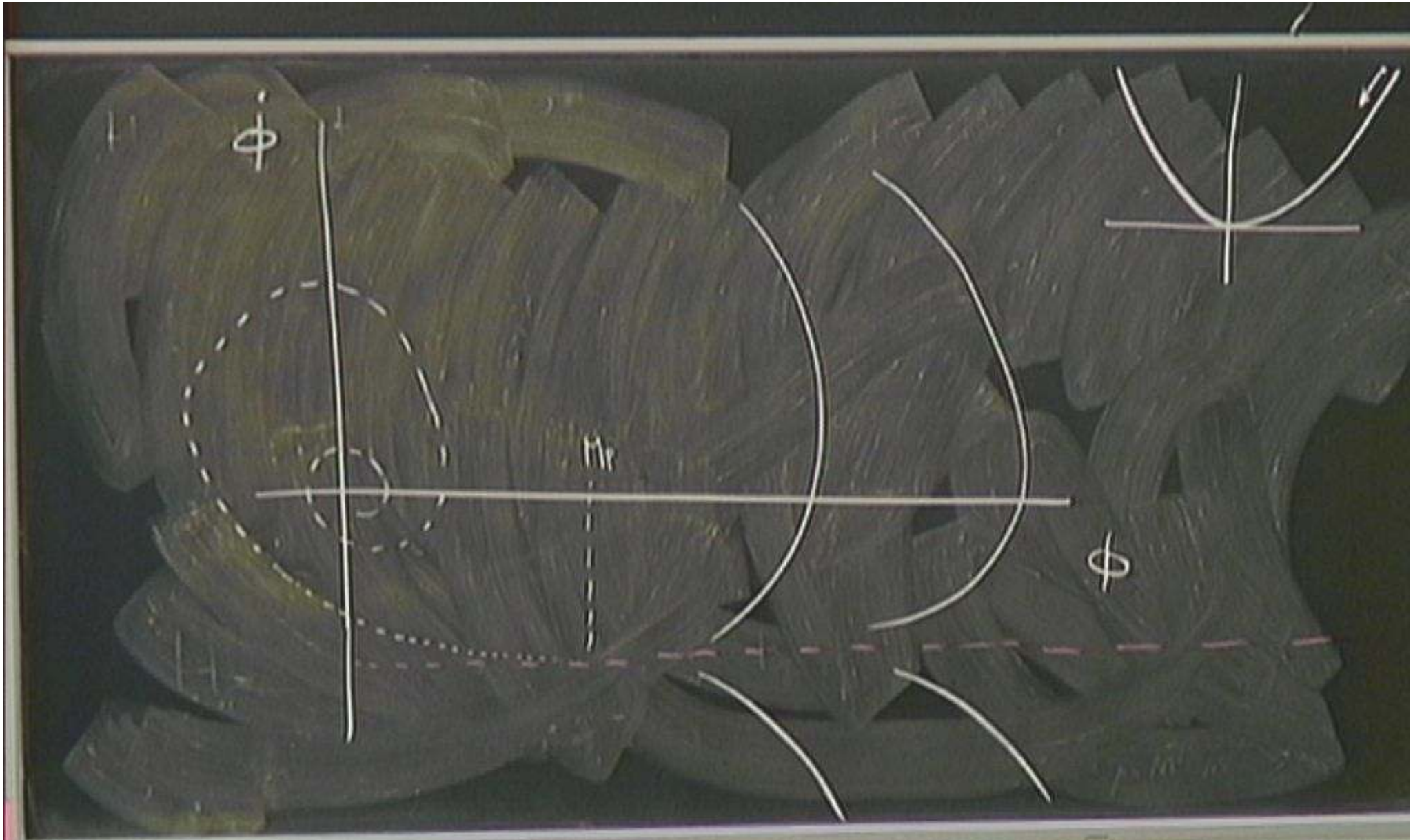
$$\frac{d\dot\phi}{d\phi} \approx 0 \qquad \frac{d\dot\phi}{d\phi} < \frac{\sqrt{3/2}}{M_P}\dot\phi\, m\phi + m^2\phi \Rightarrow \dot\phi \sim -\sqrt{\frac{2}{3}}\, m M_P$$

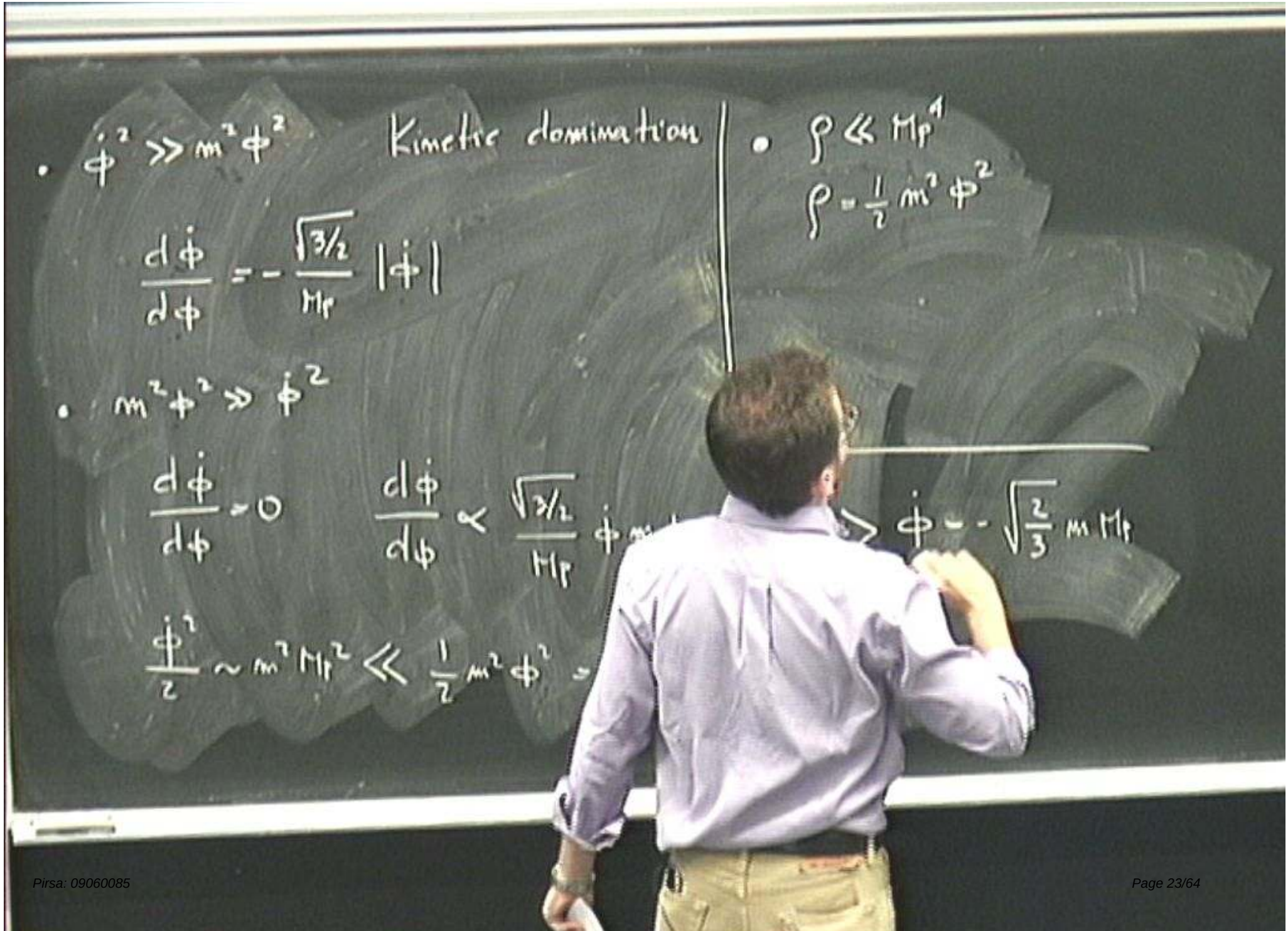
$$\frac{\dot\phi^2}{2} \sim m^2 M_P^2 \ll \frac{1}{2}m^2\phi^2 \sim V$$

ϕ
ϕ


ϕ
H_r
ϕ


ϕ
M_r
ϕ


Φ
Mr
Φ


• $\dot\phi^2 \gg m^2\phi^2$ Kinetic domination
$\frac{d\dot\phi}{d\phi} = -\frac{\sqrt{3/2}}{M_P}|\dot\phi|$
• $m^2\phi^2 \gg \dot\phi^2$
$\frac{d\dot\phi}{d\phi} = 0$
$\frac{d\dot\phi}{d\phi} \propto \frac{\sqrt{3/2}}{M_P}\dot\phi$
$\frac{\dot\phi^2}{2} \sim m^2 M_P^2 \ll \frac{1}{2}m^2\phi^2$
• $\rho \ll M_P^4$
$\rho = \frac{1}{2}m^2\phi^2$
$\dot\phi = -\sqrt{\frac{2}{3}}\, m M_P$

- $\dot\phi^2 \gg m^2\phi^2$ Kinetic domination

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

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

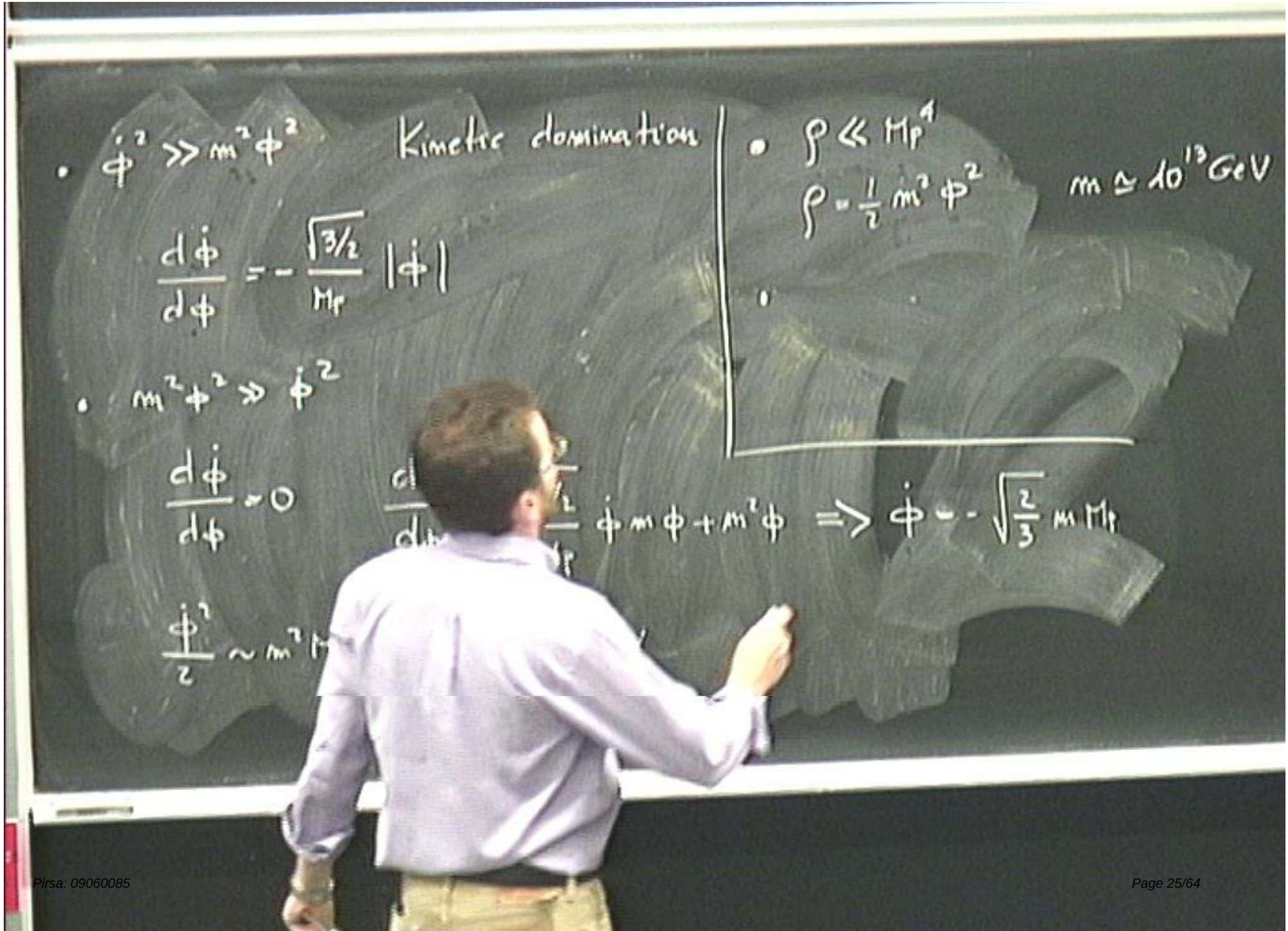
$$\frac{d\dot\phi}{d\phi} = 0$$

- $\rho \ll M_P^4$

$\rho = \frac{1}{2}m^2\phi^2$ $\quad m \simeq 10^{13}\,GeV$

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

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


$\dot\phi^2 \gg m^2\phi^2$ Kinetic domination
$\frac{d\dot\phi}{d\phi} = -\frac{\sqrt{3/2}}{M_P}|\dot\phi|$
$m^2\phi^2 \gg \dot\phi^2$
$\frac{d\dot\phi}{d\phi} \simeq 0$
$\frac{\dot\phi^2}{2} \sim m^2$
$\rho \ll M_P^4$
$\rho = \frac{1}{2}m^2\phi^2$
$m \simeq 10^{13}$ GeV
$\Rightarrow \dot\phi \sim -\sqrt{\frac{2}{3}}\, m M_P$

- $\dot\phi^2 \gg m^2\phi^2$ Kinetic domination

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

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

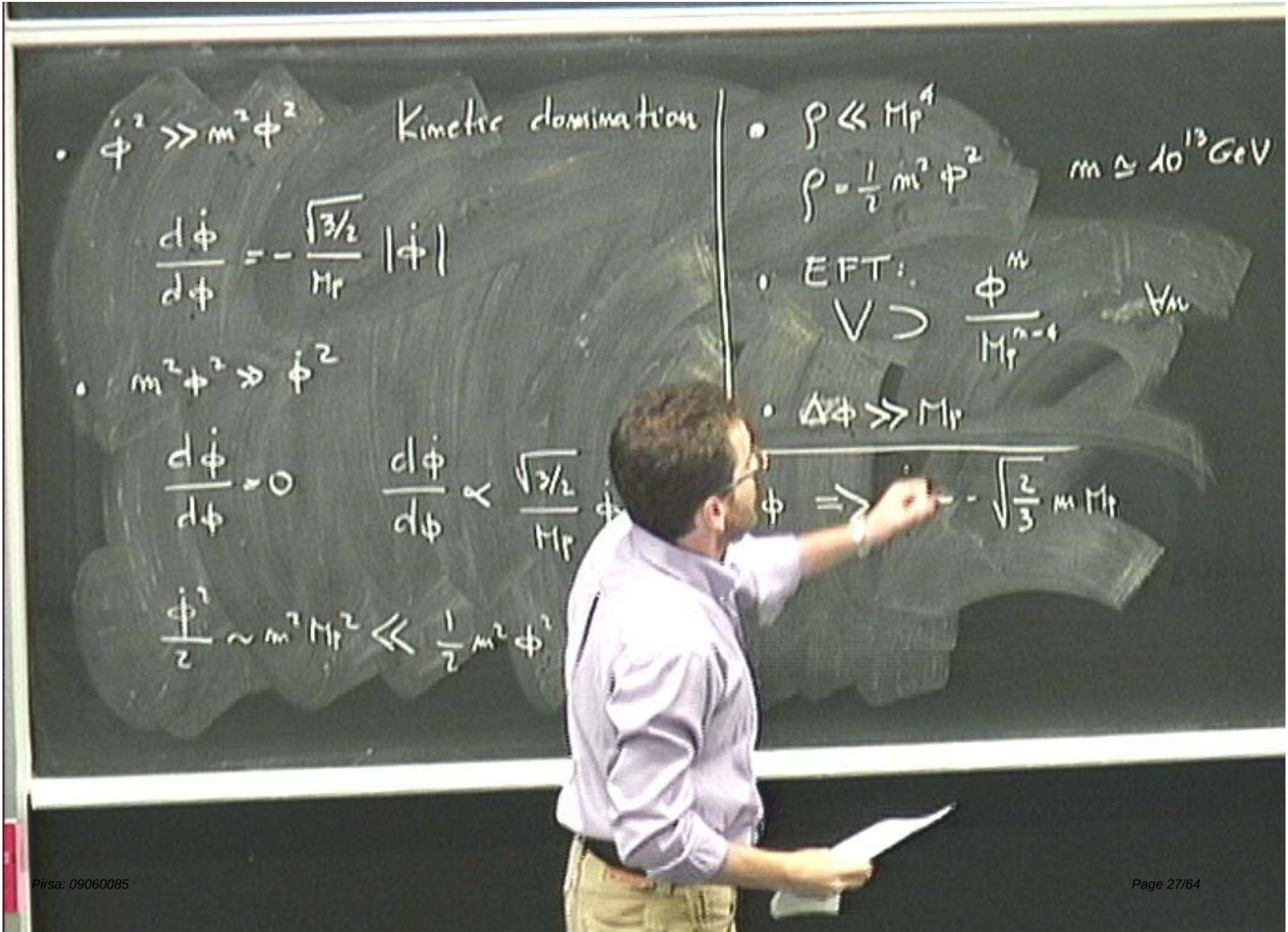
$$\frac{d\dot\phi}{d\phi} \simeq 0 \qquad \frac{d\dot\phi}{d\phi} \propto \frac{\sqrt{3/2}}{M_P}\dot\phi\, m\phi + m^2\phi \Rightarrow \dot\phi = -\sqrt{\frac{2}{3}}\, m M_P$$

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

- $\rho \ll M_P^4$

$\rho = \frac{1}{2}m^2\phi^2$ $\quad m \simeq 10^{13}\,GeV$

- EFT: $V \supset \dfrac{\phi^n}{M_P^{n-4}}$


• $\dot\phi^2 \gg m^2\phi^2$ Kinetic domination
$\frac{d\dot\phi}{d\phi} = -\frac{\sqrt{3/2}}{M_P}|\dot\phi|$
• $m^2\phi^2 \gg \dot\phi^2$
$\frac{d\dot\phi}{d\phi} \simeq 0$
$\frac{d\dot\phi}{d\phi} \propto \frac{\sqrt{3/2}}{M_P}\dot\phi$
$\frac{\dot\phi^2}{2} \sim m^2 M_P^2 \ll \frac{1}{2}m^2\phi^2$
• $\rho \ll M_P^4$
$\rho = \frac{1}{2}m^2\phi^2$
$m \simeq 10^{13}$ GeV
• EFT: $V \supset \frac{\phi^n}{M_P^{n-4}}$ $\forall n$
• $\Delta\phi \gg M_P$
$\phi \Rightarrow -\sqrt{\frac{2}{3}}\, m M_P$

- $\dot\phi^2 \gg m^2\phi^2$ Kinetic domination

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

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

$$\frac{d\dot\phi}{d\phi} \sim 0 \qquad \frac{d\dot\phi}{d\phi} < \frac{\sqrt{3/2}}{M_P}\dot\phi\, m\phi + m^2\phi \Rightarrow \dot\phi \sim -\sqrt{\frac{2}{3}}\, m M_P$$

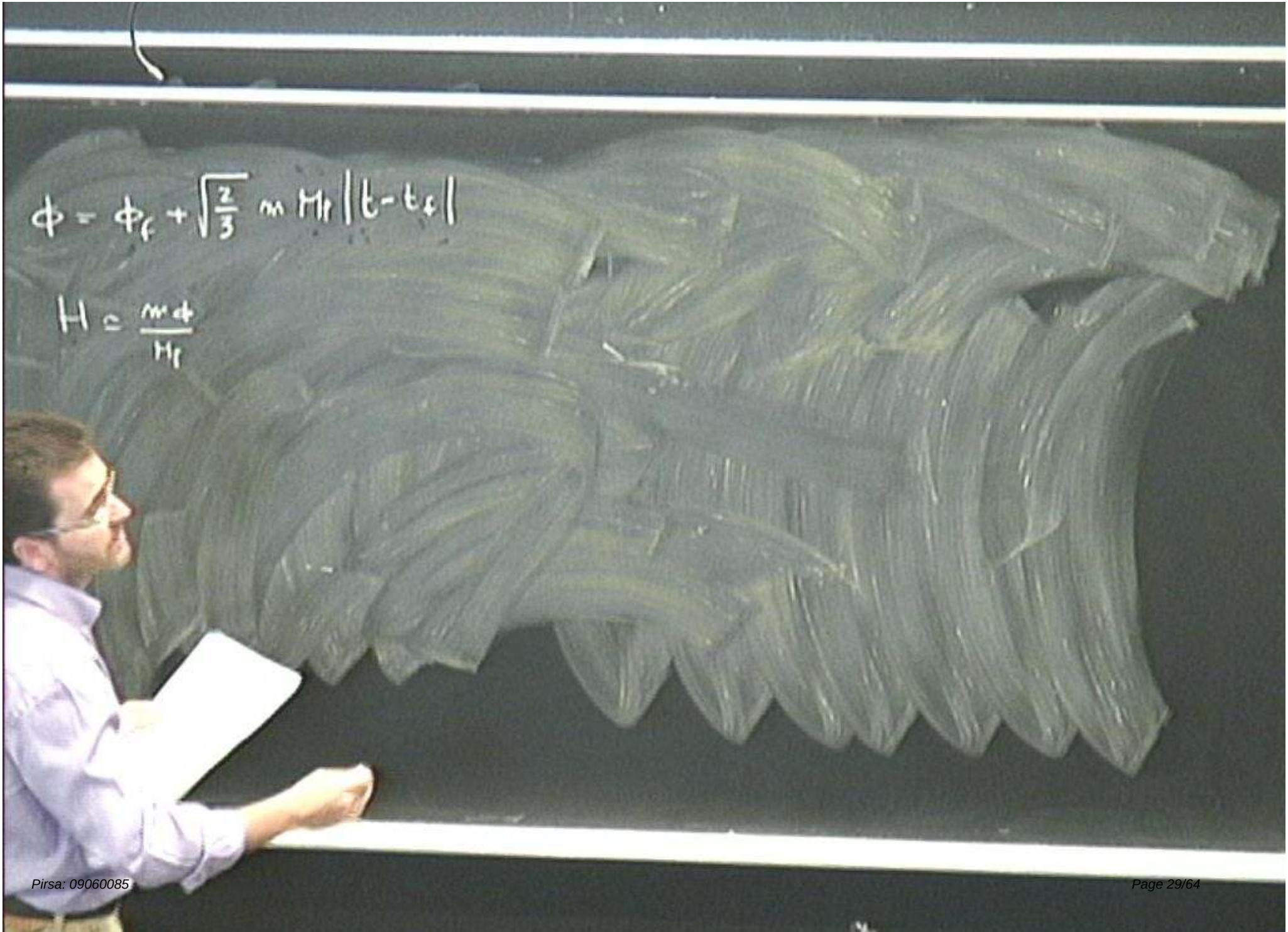
$$\frac{\dot\phi^2}{2} \sim m^2 M_P^2 \ll \frac{1}{2}m^2\phi^2 \sim V$$

- $\rho \ll M_P^4$

$\rho = \frac{1}{2}m^2\phi^2$ $\quad m \simeq 10^{13}\,\text{GeV}$

- EFT: $V \supset \dfrac{\phi^n}{M_P^{n-4}}$ $\forall n$

- $\Delta\phi \gg M_P \longleftrightarrow$ Observable GWs


$\phi = \phi_i + \sqrt{\frac{2}{3}}\, m M_{Pl} |t - t_i|$
$H \simeq \frac{m\phi}{M_{Pl}}$

$$\phi = \phi_i + \sqrt{\frac{2}{3}}\, m M_P |t - t_i|$$

$a(t)$?

$$H \simeq \frac{m\phi}{M_P}$$

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

$$\phi = \phi_i + \sqrt{\frac{2}{3}}\, m M_P |t - t_i|$$

$a(t)$?

$$H \simeq \frac{m\phi}{M_P}$$

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

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

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

$a(t)$?

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

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

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

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

$a(t)$?

$$H \simeq \frac{m\phi}{M_P}$$

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

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

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

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

$a(t)$?

$$H \simeq \frac{m\phi}{M_P}$$

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

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

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

$\sim dS$

$$\phi = \phi_i + \sqrt{\frac{2}{3}}\, m M_P |t - t_i|$$

$a(t)$?

$$H \simeq \frac{m\phi}{M_P}$$

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

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

$$a(t) = e^{\frac{m^2}{6}|t - t_i|^2}; \quad N$$

$\sim dS$

$$\phi = \phi_\Lambda + \sqrt{\frac{2}{3}}\, m M_p |t - t_f|$$

$a(t)$?

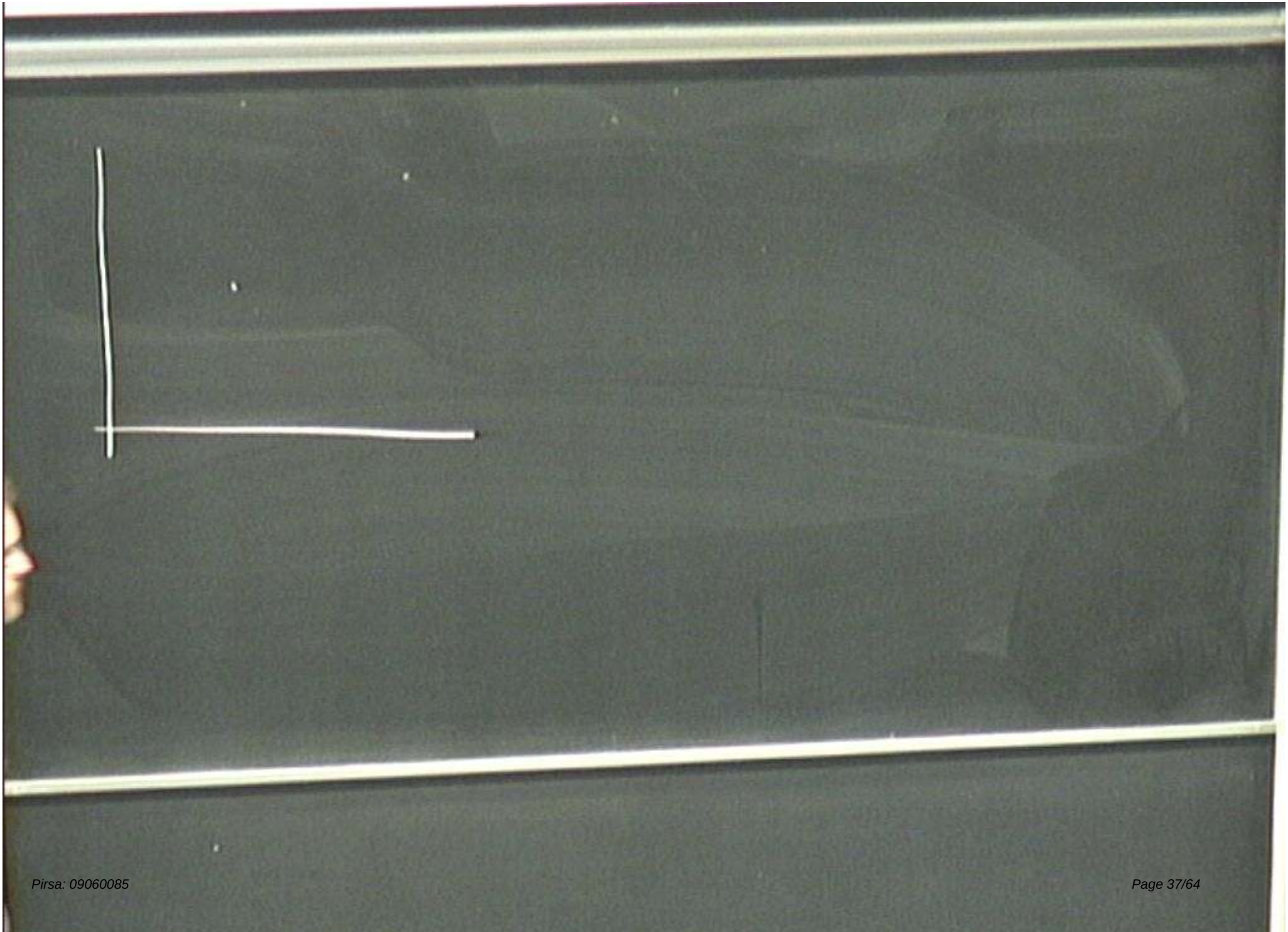
$$H = \frac{m\phi}{M_p}$$

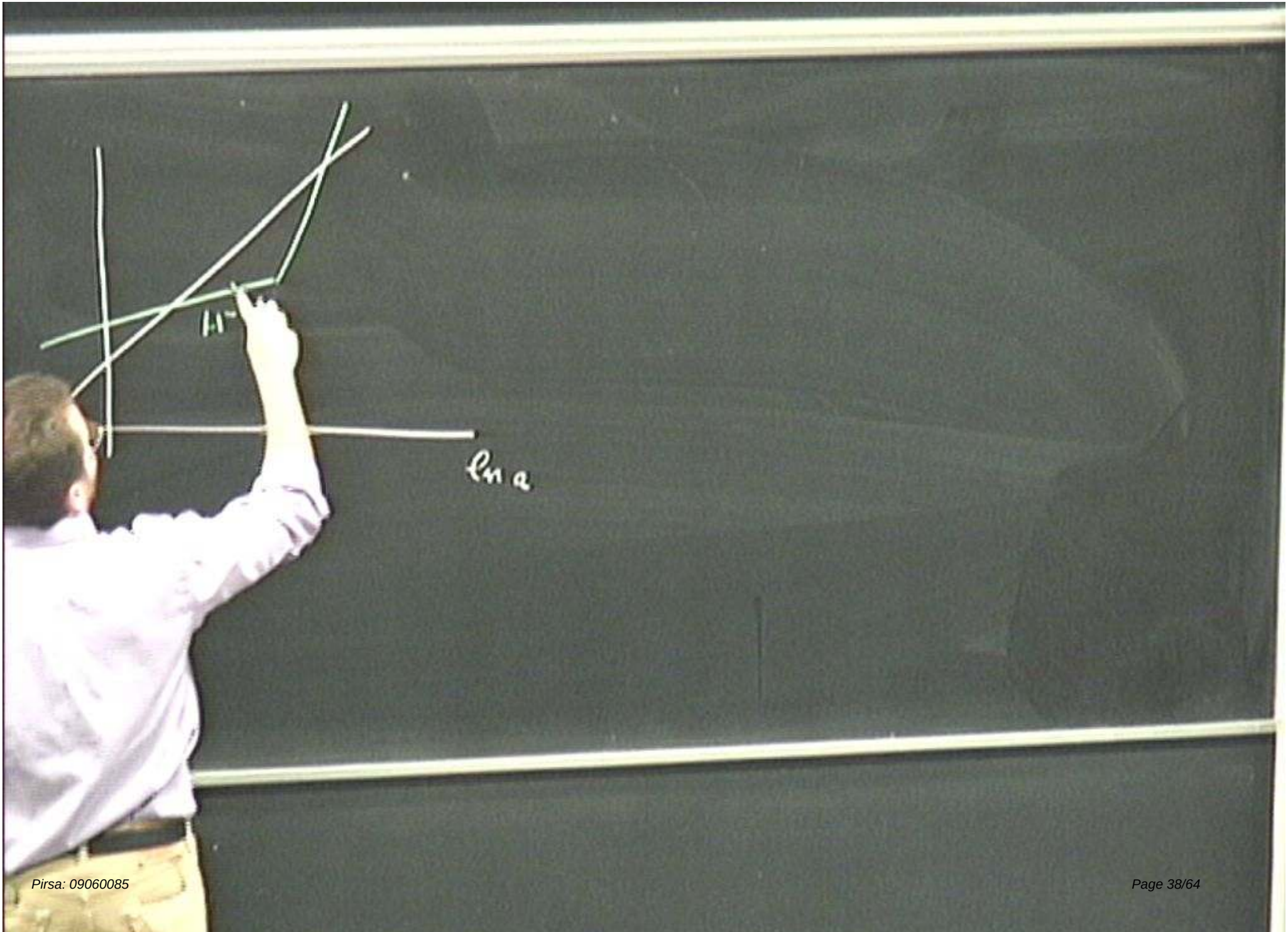
$$\left(\frac{\dot a}{a}\right)^2 = \frac{1}{3M_p^2}\,\frac{2}{3}\,\frac{1}{2}\, m^4 M_p^2 |t - t_f|^2$$

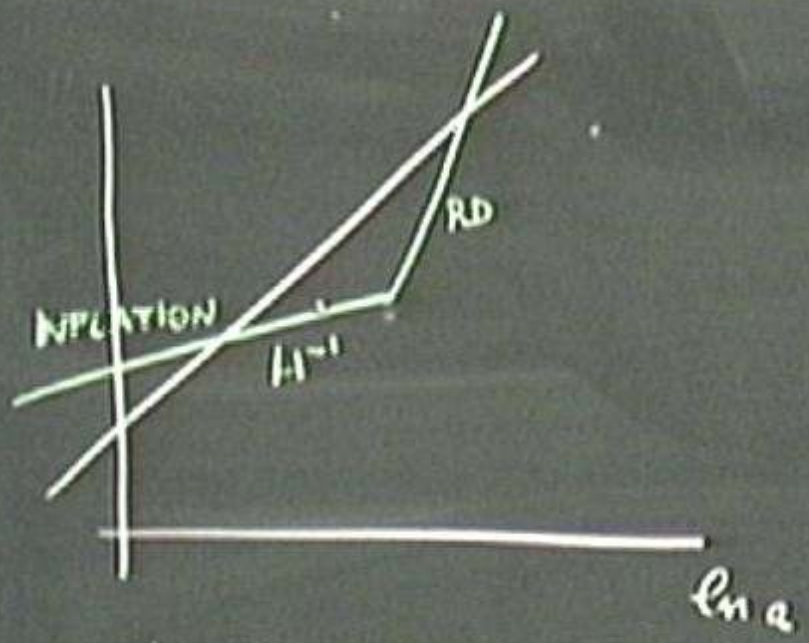
$$\frac{\dot H}{H^2} = \frac{1}{m^2 |t - t_f|^2} \simeq \frac{1}{N}$$

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

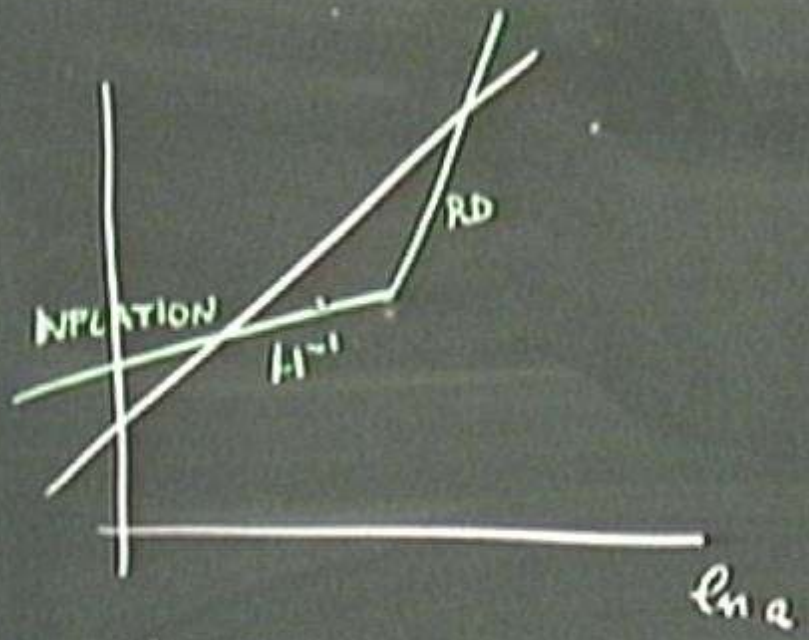
$$\sim dS$$



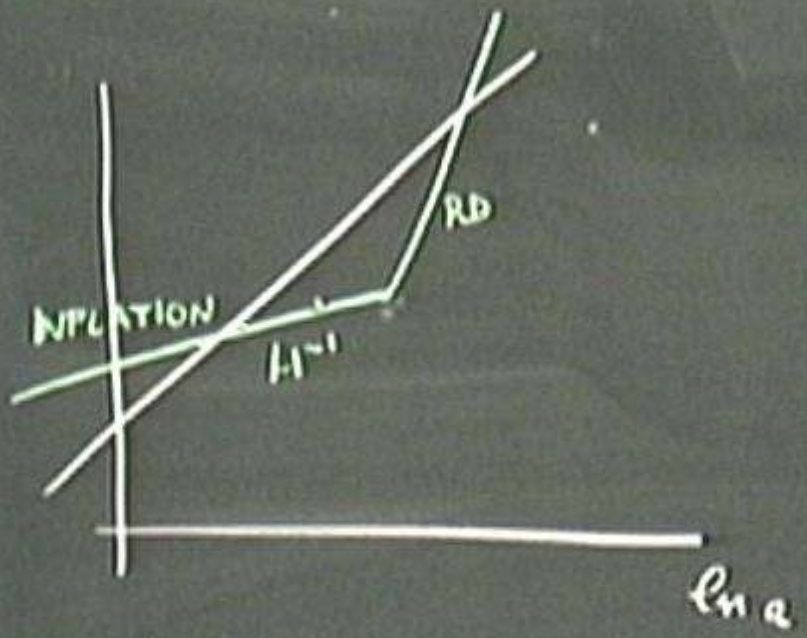

ln a



$$\frac{H^{-1}_{end}\, a_0/a_e}{H_0^{-1}}$$

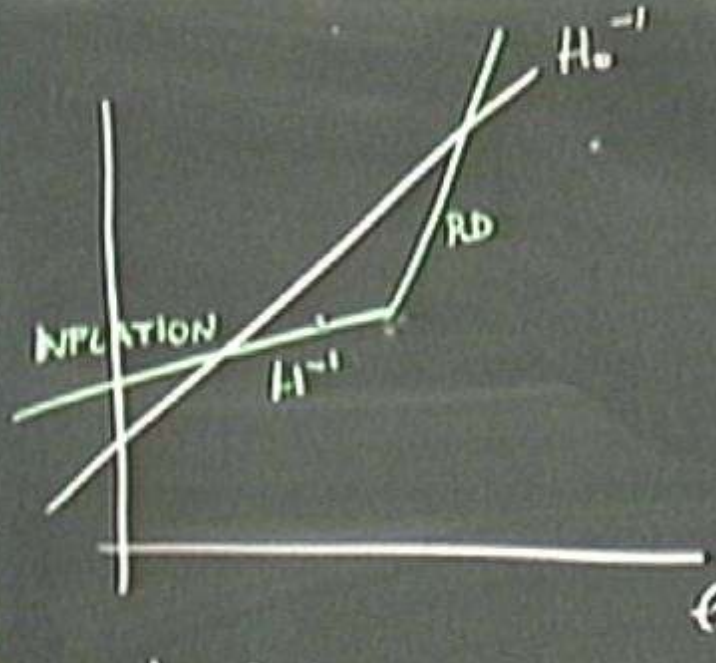


$$\frac{H^{-1}_{end}\ a_0/a_e\ RD}{H_0^{-1}} =$$



$$\frac{H^{-1}_{end}\, a_e/a_e}{H_0^{-1}} \overset{RD}{=} \frac{T_0}{T_e}$$

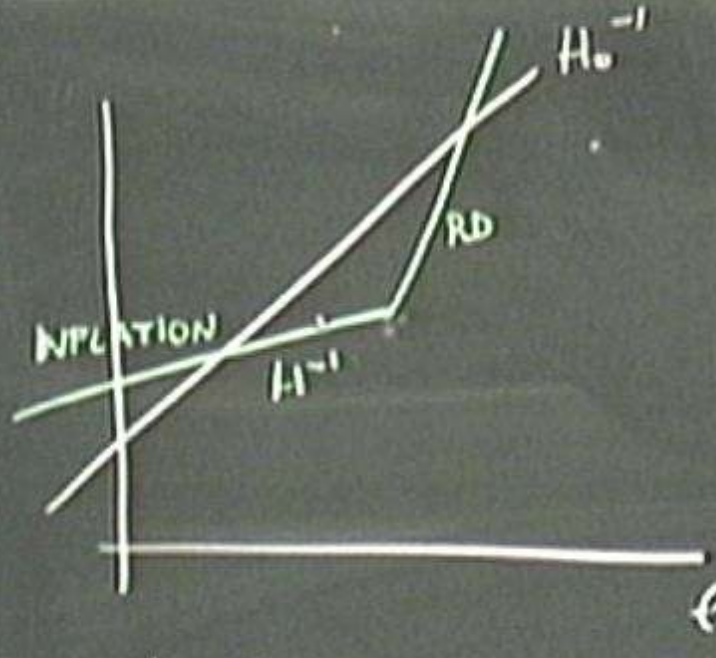
$$T_e \sim 10^{15}\,\mathrm{GeV}$$



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

$$\frac{H^{-1}_{end}\ a_0/a_e\ RD}{H_0^{-1}} = \frac{T_0}{T_e} \simeq 10^{-28}$$

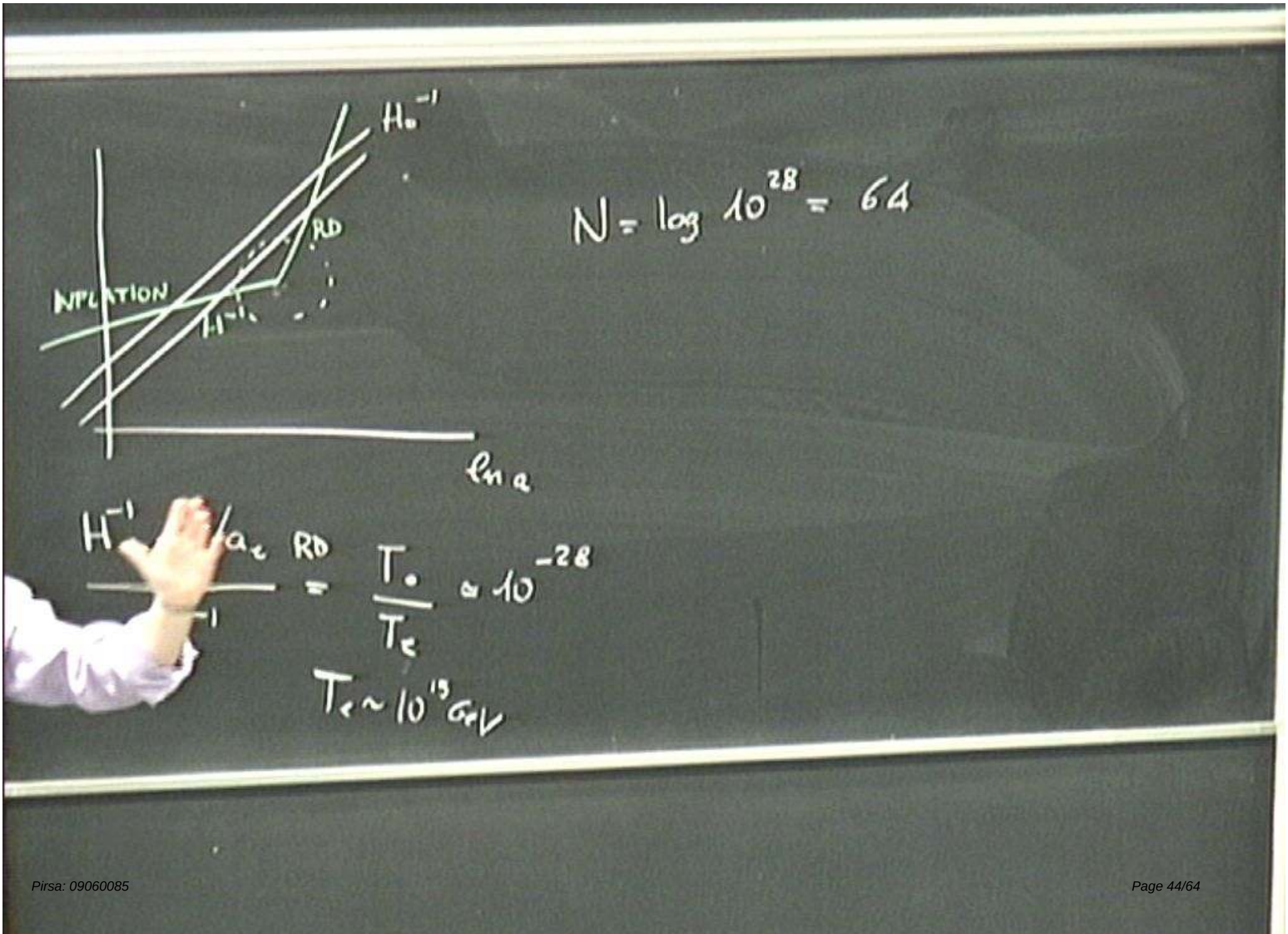
$$T_e \sim 10^{15}\ GeV$$

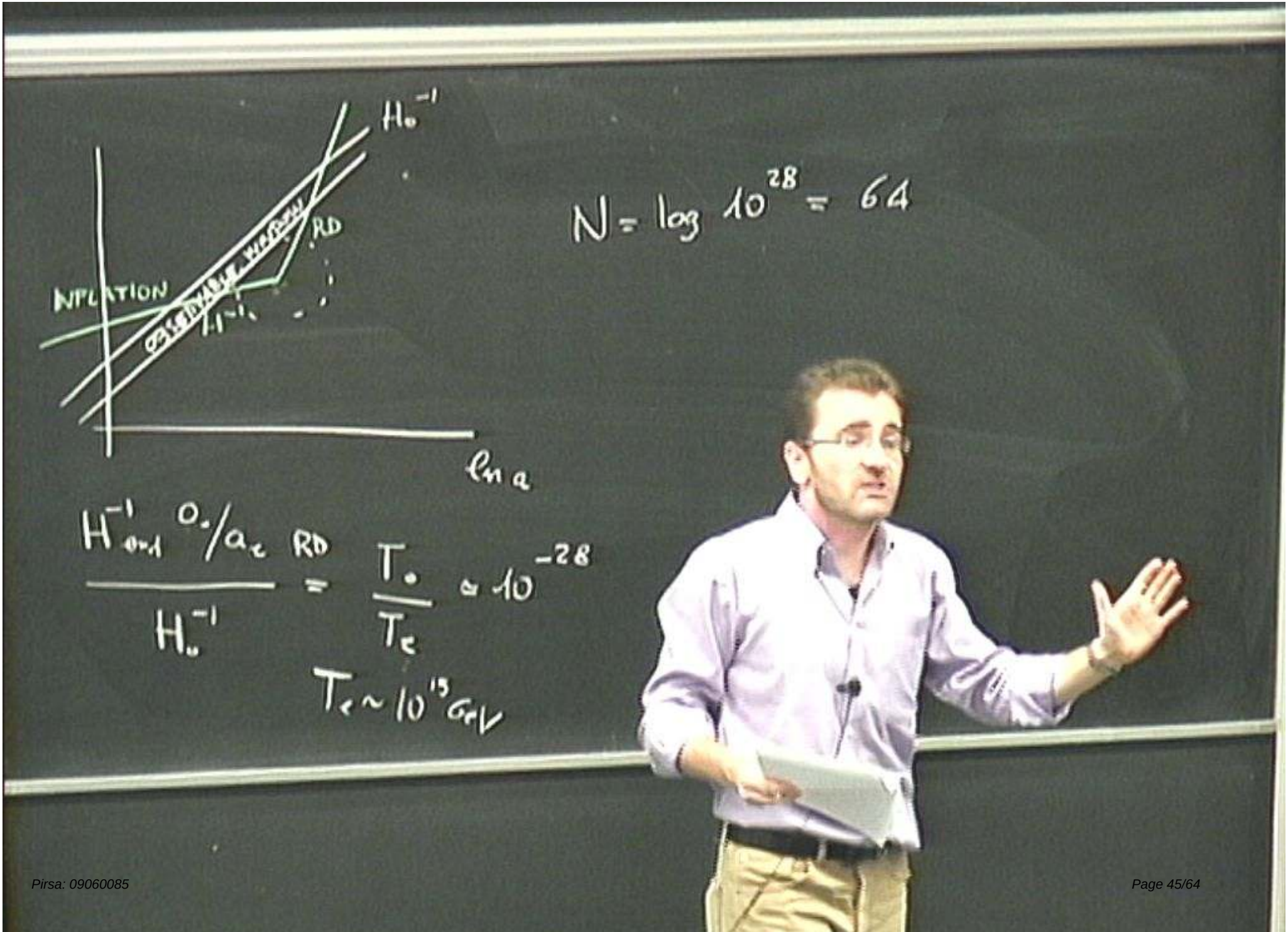


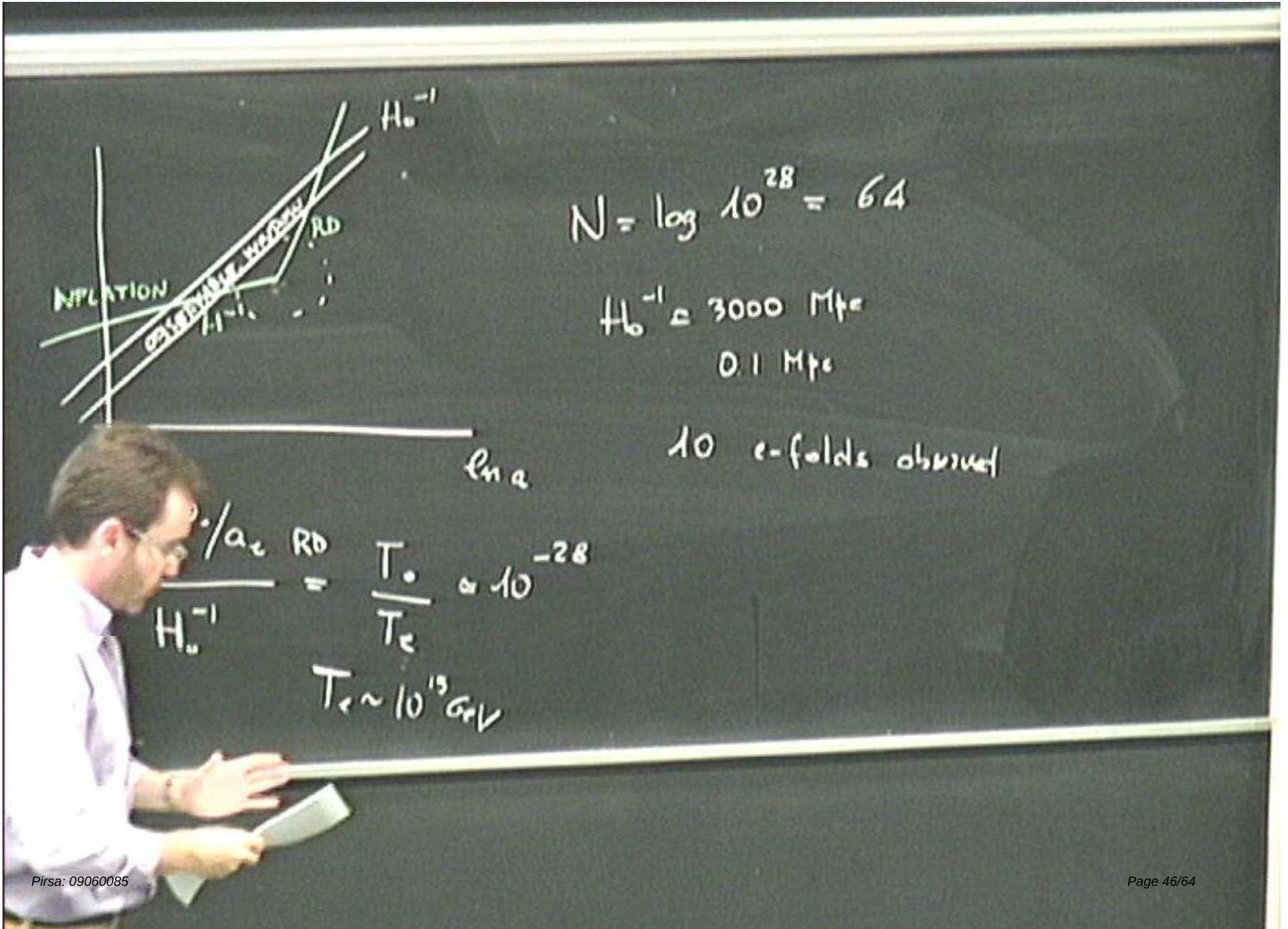
$$N = \log 10^{28} = 64$$

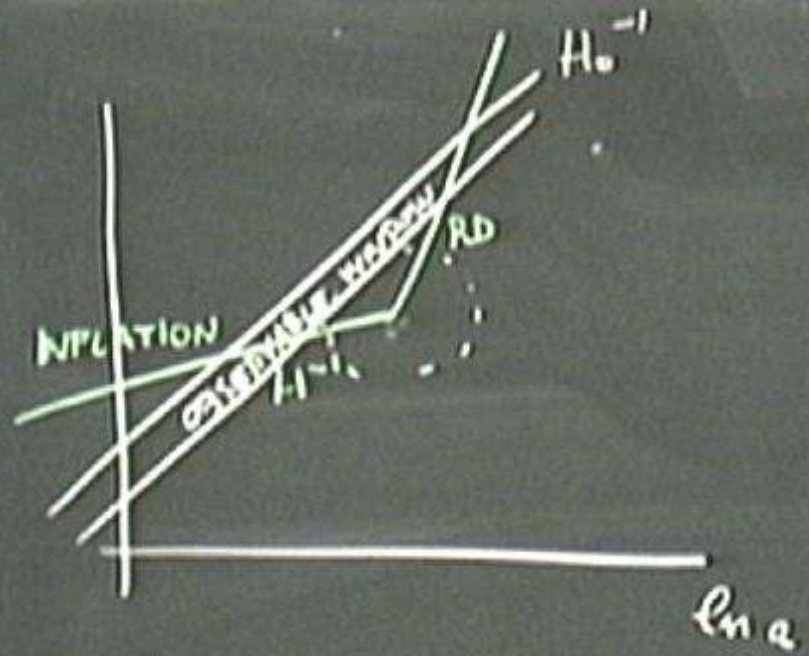
$$\frac{H^{-1}_{end}\ a_0/a_e\ RD}{H_0^{-1}} = \frac{T_0}{T_e} \simeq 10^{-28}$$

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


H_0^{-1}
RD
INFLATION
H^{-1}
$\ln a$
$N = \log 10^{28} = 64$
H^{-1}
a_e
RD
$= \frac{T_0}{T_e} \approx 10^{-28}$
$T_e \sim 10^{15}$ GeV


H_0^{-1}
RD
INFLATION
H^{-1}
$\ln a$
$N = \log 10^{28} = 64$
$\frac{H^{-1}_{end}\, a_0/a_e \; RD}{H_0^{-1}} = \frac{T_0}{T_e} \simeq 10^{-28}$
$T_e \sim 10^{15}$ GeV


H_0^{-1}
RD
INFLATION
H^{-1}
$\ln a$
$N = \log 10^{28} = 64$
$H_0^{-1} \simeq 3000$ Mpc
0.1 Mpc
10 e-folds observed
a_0/a_e RD $= \frac{T_0}{T_e} \simeq 10^{-28}$
H_0^{-1}
$T_e \sim 10^{15}$ GeV



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

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

$$0.1 \text{ Mpc}$$

10 e-folds observed

$$\frac{H^{-1}_{end}\, a_0/a_e \text{ RD}}{H_0^{-1}} = \frac{T_0}{T_e} \simeq 10^{-28}$$

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

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

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

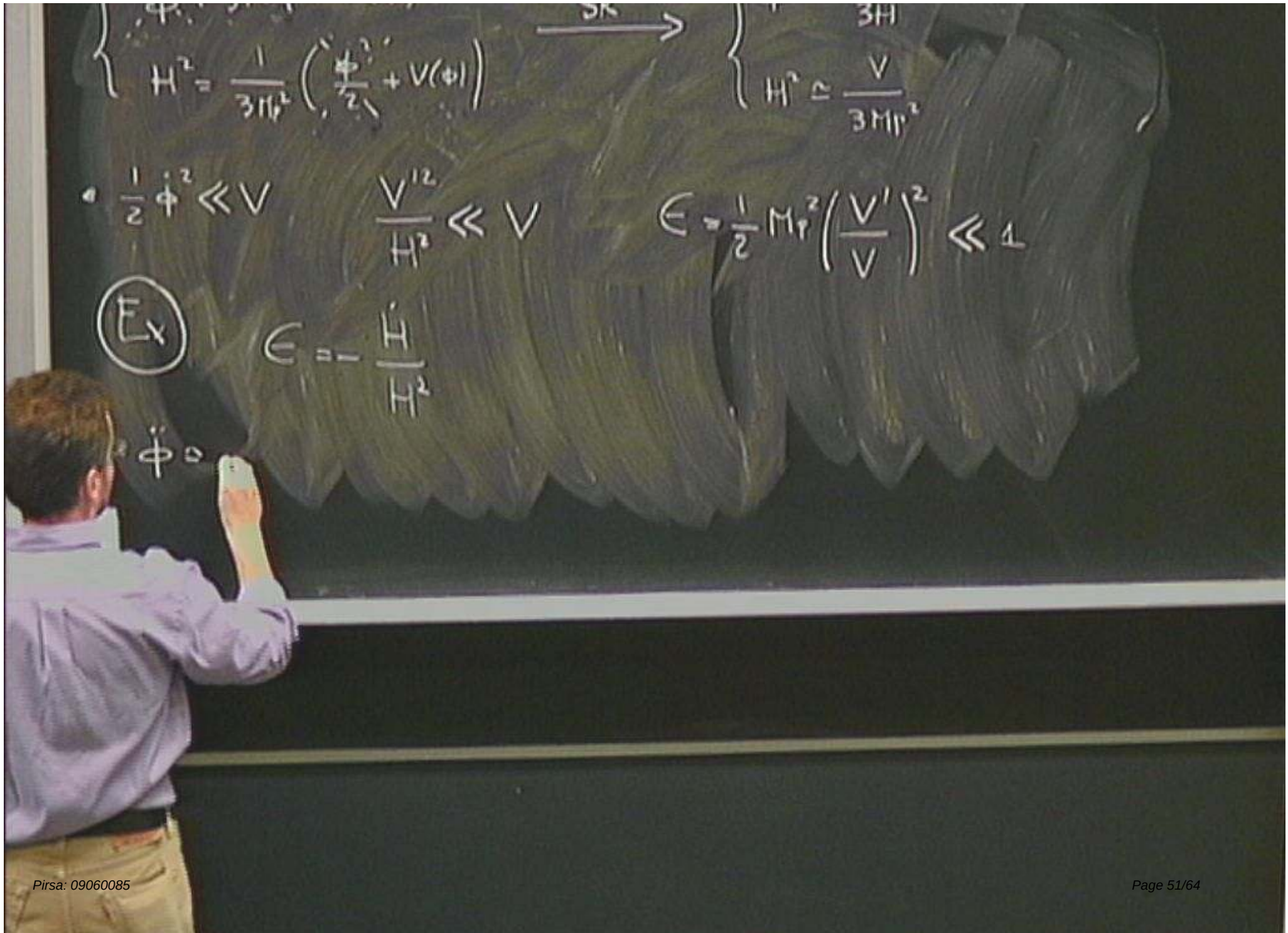
- $\frac{1}{2}\dot{\phi}^2 \ll V \qquad \frac{V'^2}{H^2} \ll V \qquad \epsilon = \frac{1}{2}M_P^2\left(\frac{V'}{V}\right)^2 \ll 1$

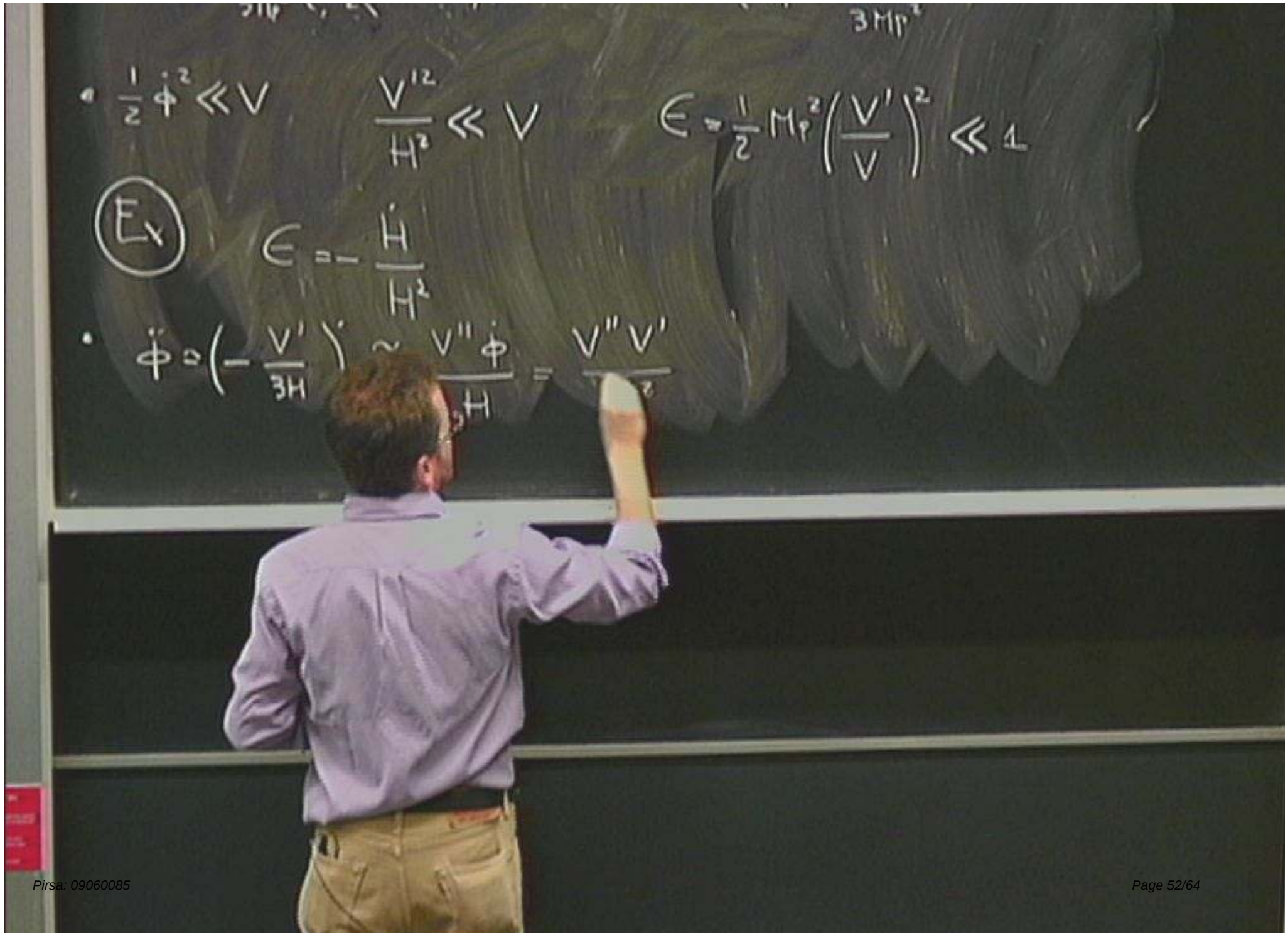
Ex $\quad \epsilon = -\frac{\dot{H}}{H^2}$

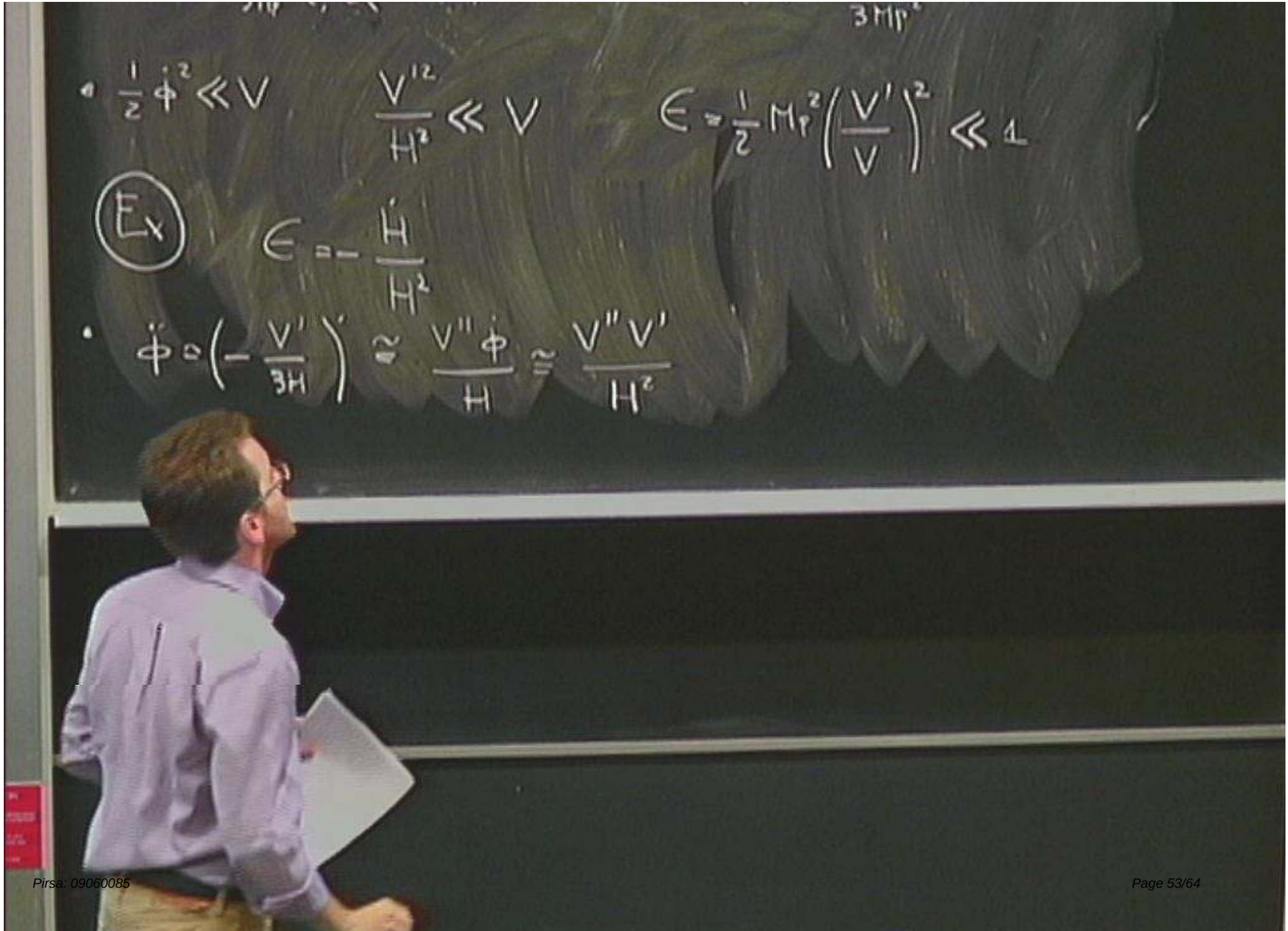
$$\begin{cases} \ddot{\Phi} + 3H\dot{\Phi} + V'(\Phi) \\ H^2 = \frac{1}{3M_P^2}\left(\frac{\dot{\Phi}^2}{2} + V(\Phi)\right) \end{cases} \xrightarrow{SR} \begin{cases} \dot{\Phi} \simeq -\frac{V'}{3H} \\ H^2 \simeq \frac{V}{3M_P^2} \end{cases}$$

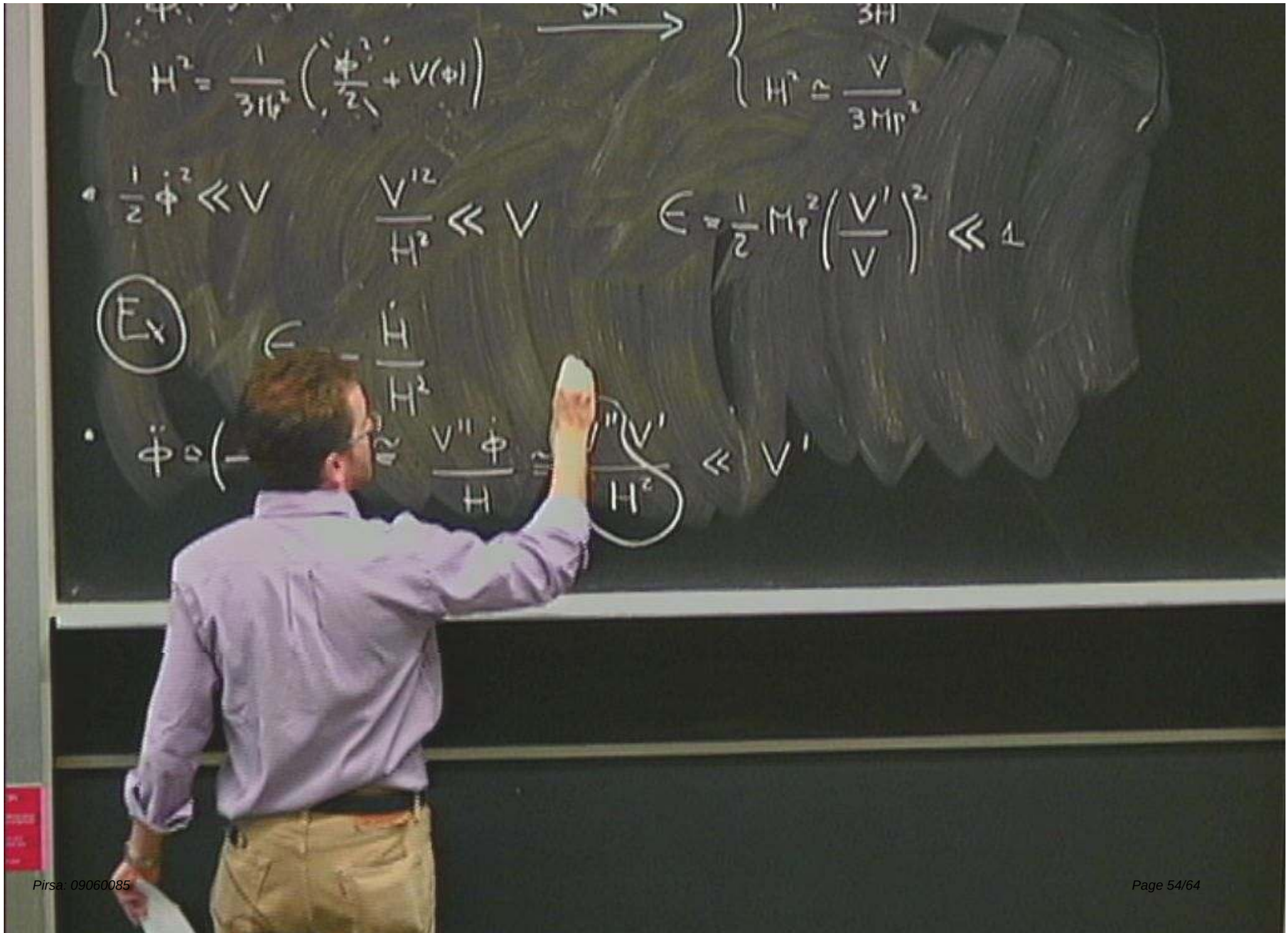
- $\frac{1}{2}\dot{\Phi}^2 \ll V \qquad \frac{V'^2}{H^2} \ll V \qquad \epsilon = \frac{1}{2}M_P^2\left(\frac{V'}{V}\right)^2 \ll 1$

Ex $\epsilon = -\frac{\dot{H}}{H^2}$


$H^2 = \frac{1}{3M_P^2}\left(\frac{\dot\phi^2}{2} + V(\phi)\right)$
SR
$H^2 \simeq \frac{V}{3M_P^2}$
$\frac{1}{2}\dot\phi^2 \ll V$
$\frac{V'^2}{H^2} \ll V$
$\epsilon = \frac{1}{2}M_P^2\left(\frac{V'}{V}\right)^2 \ll 1$
Ex
$\epsilon = -\frac{\dot H}{H^2}$
$\ddot\phi =$


$3M_P^2$
$\frac{1}{2}\dot{\phi}^2 \ll V$
$\frac{V'^2}{H^2} \ll V$
$\epsilon = \frac{1}{2} M_P^2 \left(\frac{V'}{V}\right)^2 \ll 1$
Ex
$\epsilon = -\frac{\dot{H}}{H^2}$
$\ddot{\phi} \simeq \left(-\frac{V'}{3H}\right)' \sim \frac{V''\dot{\phi}}{3H} = \frac{V''V'}{}$


$3M_P^2$
$\frac{1}{2}\dot{\phi}^2 \ll V$
$\frac{V'^2}{H^2} \ll V$
$\epsilon = \frac{1}{2} M_P^2 \left(\frac{V'}{V}\right)^2 \ll 1$
Ex
$\epsilon = -\frac{\dot{H}}{H^2}$
$\ddot{\phi} \simeq \left(-\frac{V'}{3H}\right)' \simeq \frac{V''\dot{\phi}}{H} \simeq \frac{V''V'}{H^2}$

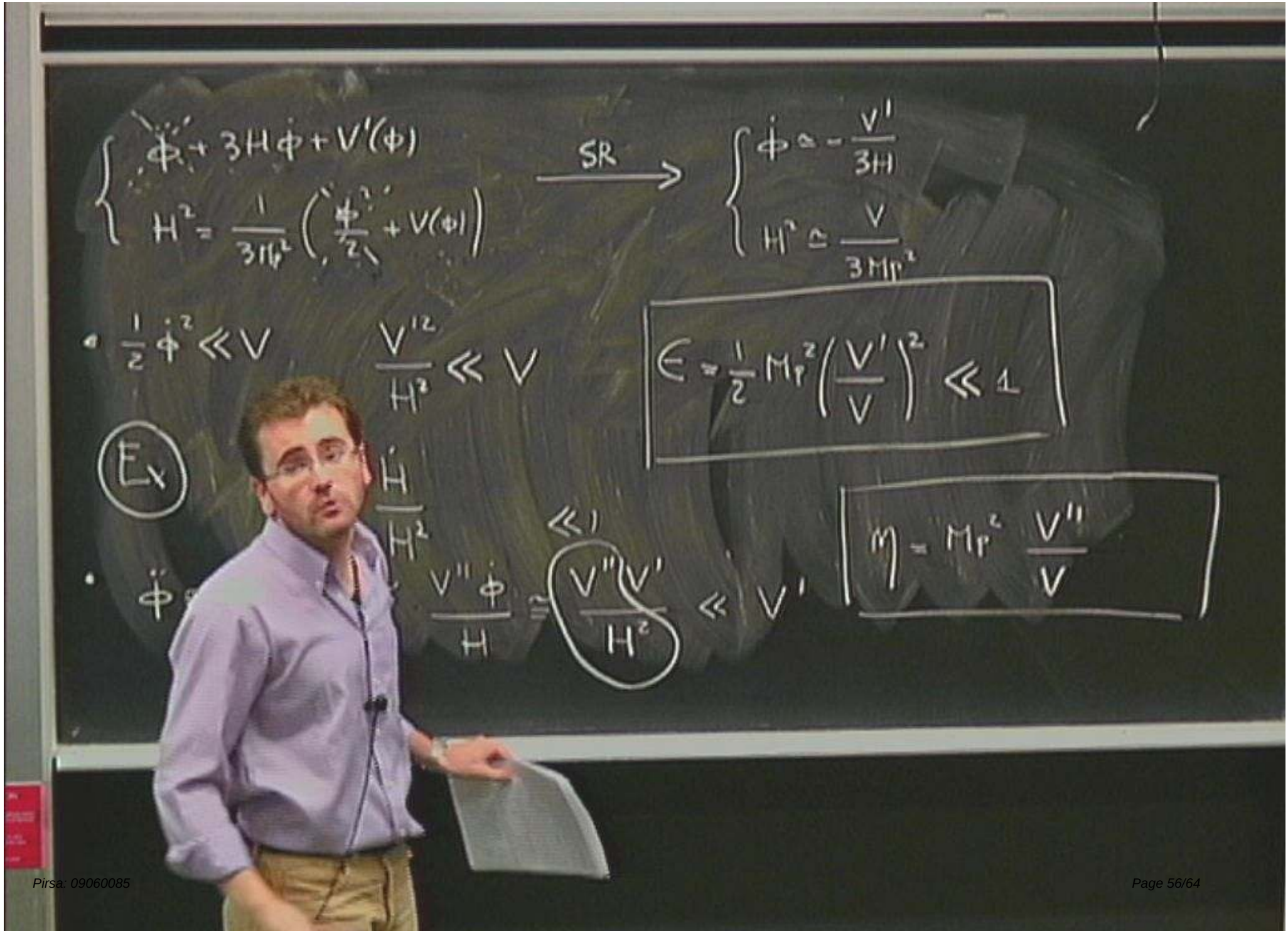

$H^2 = \frac{1}{3M_P^2}\left(\frac{\dot\phi^2}{2} + V(\phi)\right)$
$H^2 \simeq \frac{V}{3M_P^2}$
$\frac{1}{2}\dot\phi^2 \ll V$
$\frac{V''^2}{H^2} \ll V$
$\epsilon = \frac{1}{2}M_P^2\left(\frac{V'}{V}\right)^2 \ll 1$
Ex
$\epsilon = -\frac{\dot H}{H^2}$
$\ddot\phi \simeq \frac{V''\dot\phi}{H} \simeq \frac{V''V'}{H^2} \ll V'$

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

- $\frac{1}{2}\dot\phi^2 \ll V \qquad \frac{V'^2}{H^2} \ll V \qquad \epsilon \equiv \frac{1}{2}M_P^2\left(\frac{V'}{V}\right)^2 \ll 1$

Ex $\quad \epsilon \equiv -\frac{\dot H}{H^2}$

- $\ddot\phi \simeq \left(-\frac{V'}{3H}\right)' \simeq \frac{V''\dot\phi}{H} \simeq \frac{V''V'}{H^2} \ll V'$ $\quad (\ll 1)$


$\ddot{\phi} + 3H\dot{\phi} + V'(\phi)$
$H^2 = \frac{1}{3M_P^2}\left(\frac{\dot{\phi}^2}{2} + V(\phi)\right)$
SR
$\dot{\phi} \simeq -\frac{V'}{3H}$
$H^2 \simeq \frac{V}{3M_P^2}$
$\frac{1}{2}\dot{\phi}^2 \ll V$
$\frac{V'^2}{H^2} \ll V$
$\epsilon = \frac{1}{2}M_P^2\left(\frac{V'}{V}\right)^2 \ll 1$
Ex
$\frac{\dot{H}}{H^2}$
$\ll 1$
$\frac{V''\dot{\phi}}{H} \simeq \frac{V''V'}{H^2} \ll V'$
$\eta = M_P^2\frac{V''}{V}$

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

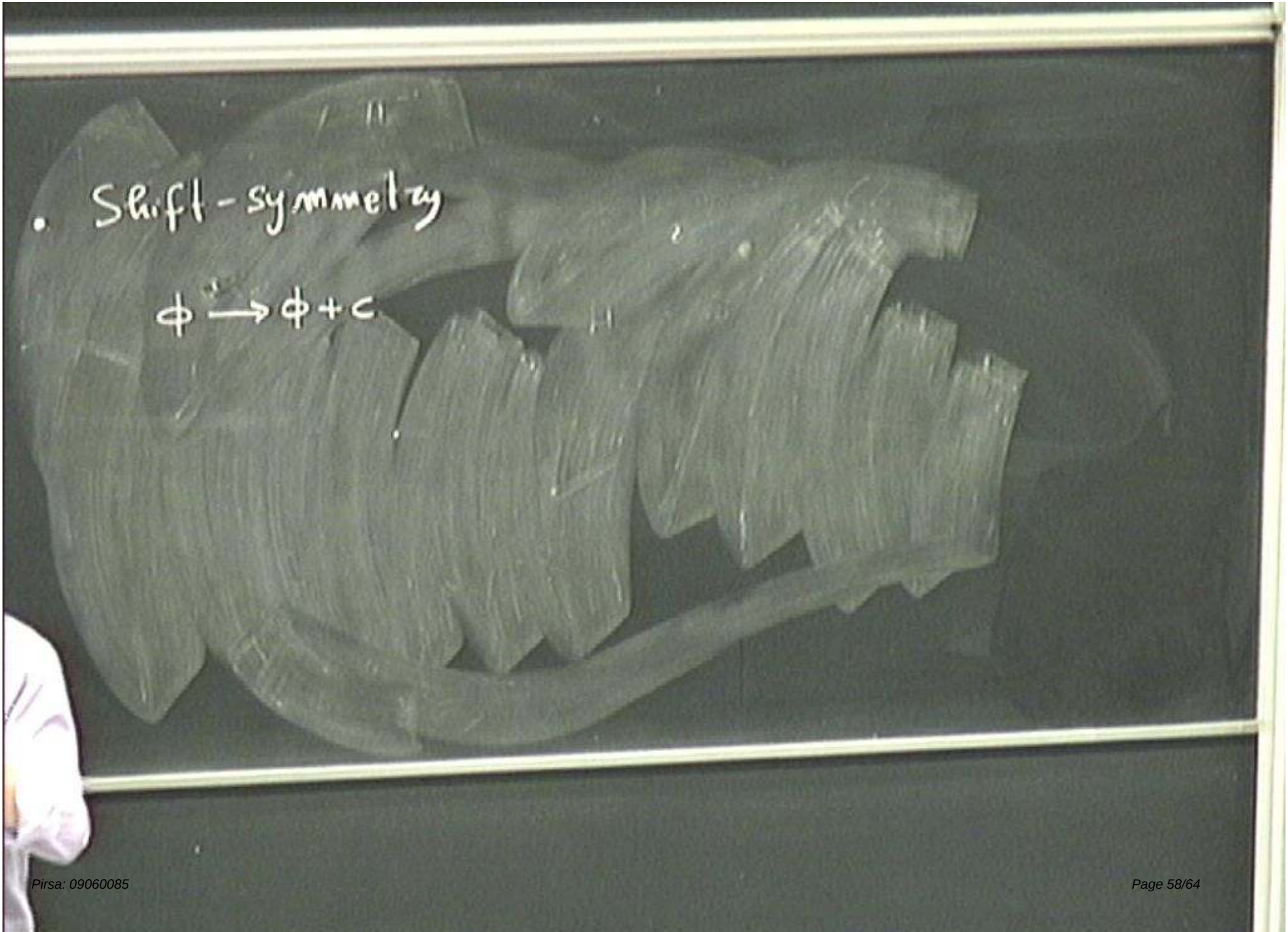
- $\frac{1}{2}\dot{\phi}^2 \ll V \qquad \frac{V'^2}{H^2} \ll V$

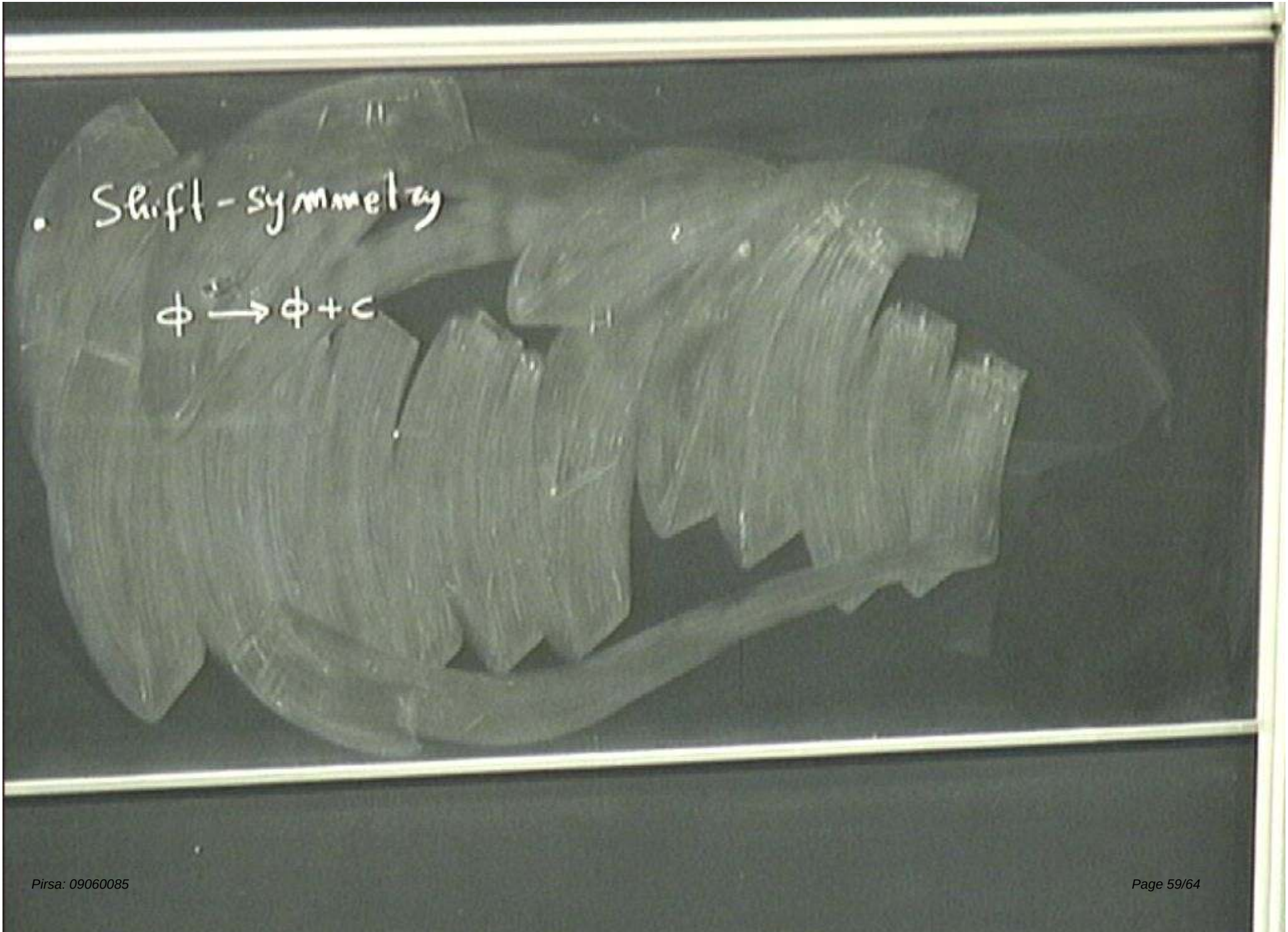
$$\boxed{\epsilon = \frac{1}{2}M_P^2\left(\frac{V'}{V}\right)^2 \ll 1}$$

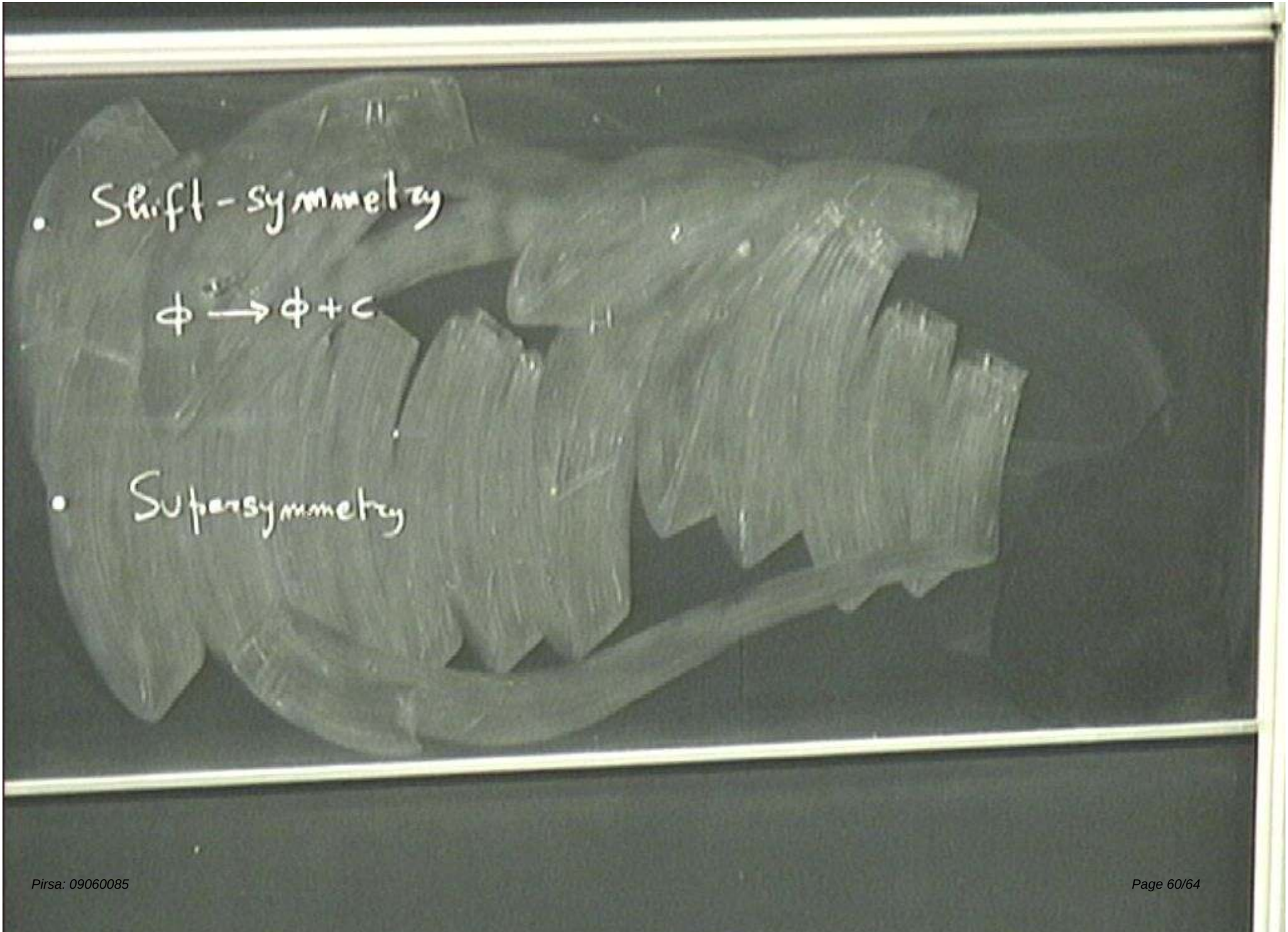
Ex $\quad \epsilon = -\frac{\dot{H}}{H^2}$

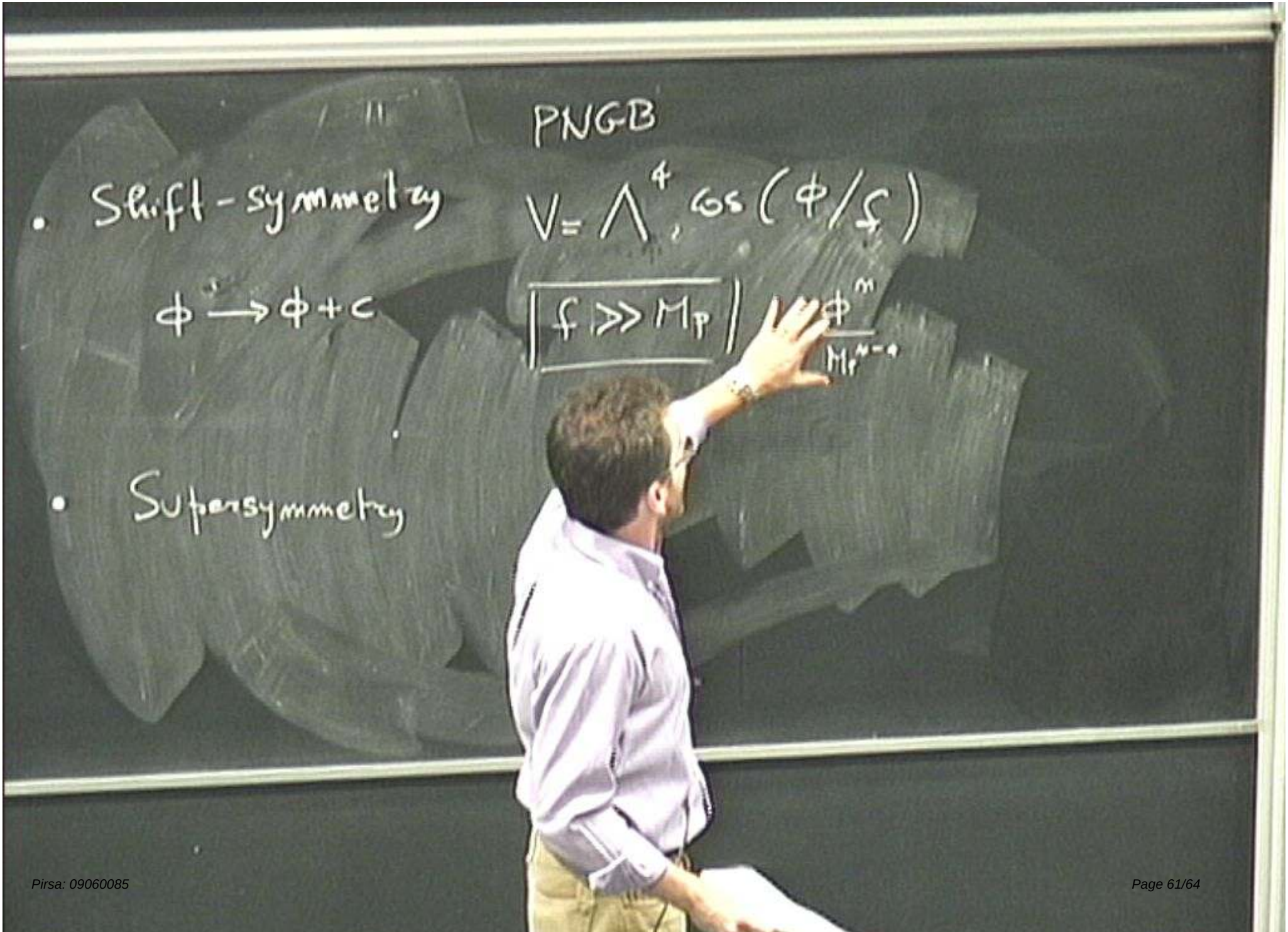
- $\ddot{\phi} \simeq \left(-\frac{V'}{3H}\right)' \simeq \frac{V''\dot{\phi}}{H} \simeq \frac{V''V'}{H^2} \ll V'$ $\quad (\ll 1)$

$$\boxed{\eta = M_P^2\frac{V''}{V}}$$


• Shift - symmetry
$\phi \longrightarrow \phi + c$


• Shift - symmetry
$\phi \longrightarrow \phi + c$


• Shift-symmetry
$\phi \longrightarrow \phi + c$
• Supersymmetry


PNGB
• Shift-symmetry
$V = \Lambda^4 \cos(\phi/f)$
$\phi \to \phi + c$
$f \gg M_P$
$\frac{\phi^n}{M_P^{n-4}}$
• Supersymmetry

PNGB

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

$\phi \longrightarrow \phi + c$ $\quad$ $\boxed{f \gg M_P}$ $\quad$ $\frac{\phi^n}{M_P^{n-4}}$

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

$\swarrow$ GR

Supergravity

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

PNGB

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

$\phi \longrightarrow \phi + c$ $\boxed{f \gg M_P}$ $\frac{\phi^n}{M_P^{n-4}}$, $K = \phi^\dagger \phi$

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

GR

Supergravity

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

PNGB

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

$\phi \longrightarrow \phi + c$ $\quad \boxed{f \gg M_P}$ $\quad \frac{\phi^n}{M_P^{n-4}}$, $K = \phi^\dagger \phi$

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

GR

Supergravity

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