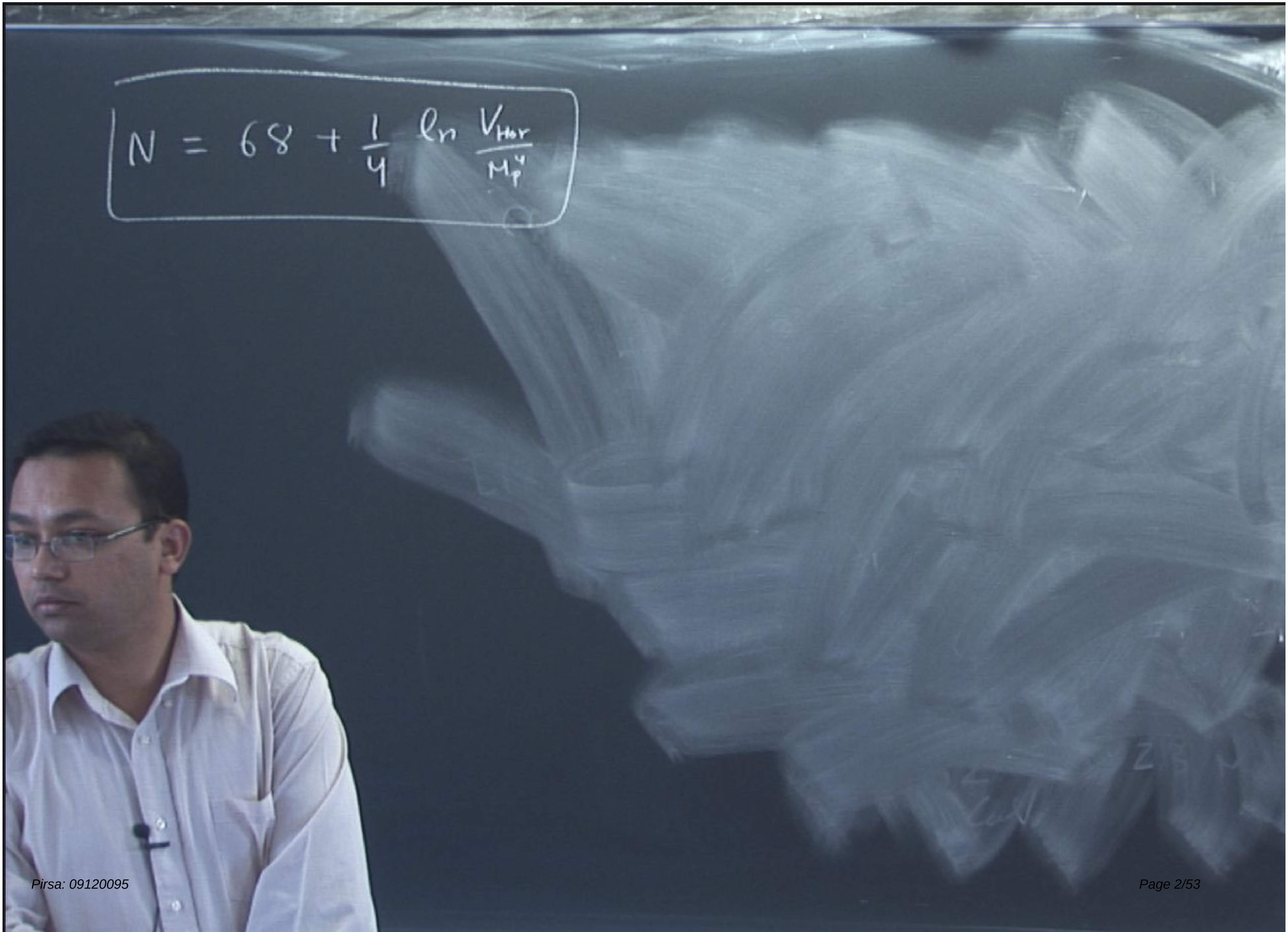
Title: Cosmology - Review (PHYS 621) - Lecture 13

Date: Dec 16, 2009 10:00 AM

URL: http://pirsa.org/09120095

Abstract:


$N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}$

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{\rm Hor}}{M_p^4}}$$

$$\frac{a_{eq} H_{eq}}{a_0 H_0} \simeq 219\, \Omega_{m(0)} h$$

$$\Omega$$

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}}$$

$$\frac{a_{eq} H_{eq}}{a_0 H_0} \simeq 219 \, \Omega_{m(0)} h$$

*. $$\Omega_{r(0)} = 4.15 \times 10^{-5} \, h^{-2}$$

$$1 + z_{eq} = 2.41 \, \Omega_{m(0)} h^2 \times 10^4$$

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}}$$

$$\frac{a_{eq} H_{eq}}{a_0 H_0} \simeq 219\, \Omega_{m(0)}\, h$$

*. $$\Omega_{r(0)} = 4.15 \times 10^{-5}\, h^{-2}$$

$$z_{eq} = 2.41\, \Omega_{m(0)} h^2 \times 10^4$$

$\frac{[illegible]}{H_0}$; $$H_{eq}^2 = \frac{8\pi}{3 m_p^2} \left(\rho_{m(z_{eq})} + \rho_{r(z_{eq})} \right)$$

$$\rho_{m(z_{eq})} = \rho_{r(z_{eq})}$$

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}}$$

$$\frac{a_{eq} H_{eq}}{a_0 H_0} \simeq 219\, \Omega_{m(0)} h$$

x. $\Omega_{r(0)} = 4.15 \times 10^{-5}\, h^{-2}$

$$1 + z_{eq} = 2.41\, \Omega_{m(0)} h^2 \times 10^4$$

$\frac{H_{eq}}{H_0}$; $\quad H_{eq}^2 = \frac{8\pi}{3m_p^2}\left(\rho_{m(z_{eq})} + \rho_{r(z_{eq})}\right) = \frac{4\pi}{3m_p^2} \rho_m(z_{eq}) = \frac{4\pi}{3m_p^2} \rho_{m,0}(1+z_{eq})^3$

$$\rho_{m(z_{eq})} = \rho_{r(z_{eq})}$$

$$\frac{\ldots q}{\ldots_0} = \sqrt{2\Omega_{m(0)}}\,(1+z_{eq})^{3/2}$$

$$\frac{\ldots H_{eq}}{a_0 H_0} = \sqrt{2\Omega_{m(0)}}\,(1+z_{eq})^{1/2}$$

$$\ldots(z_{eq}) = \frac{4\pi}{3m_p^2}\,\rho_{m(0)}(1+z_{eq})^3 = \frac{4\pi}{3m_p^2}\,\frac{3m_p^2}{8\pi}\,\Omega_{m(0)}\,H_0^2(1+z_{eq})^3$$

$$\frac{H_{eq}}{H_0} = \sqrt{2\Omega_{m(0)}}\,(1+z_{eq})^{3/2}$$

$$\boxed{\frac{a_{eq}H_{eq}}{a_0 H_0} = \sqrt{2\Omega_{m(0)}}\,(1+z_{eq})^{1/2}}$$

$$= \frac{4\pi}{3m_p^2}\rho_m(z_{eq}) = \frac{4\pi}{3m_p^2}\rho_{m(0)}(1+z_{eq})^3 = \frac{4\pi}{3m_p^2}\;\frac{3m_p^2}{8\pi}\,\Omega_{m(0)}\,H_0^2(1+$$

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_P^4}} \to \epsilon \quad \to 63 + \frac{1}{4} \ln \epsilon$$

$$\boxed{\frac{a_{eq} H_{eq}}{a_0 H_0} = \sqrt{2\Omega_{m(0)}} \; (1}$$

$$\boxed{N = 68 + \frac{1}{4}\ln\frac{V_{Hor}}{M_p^4}}$$

$\to \epsilon$

$\to 63 + \frac{1}{4}\ln\epsilon$

d Inflation (Guth 1981)

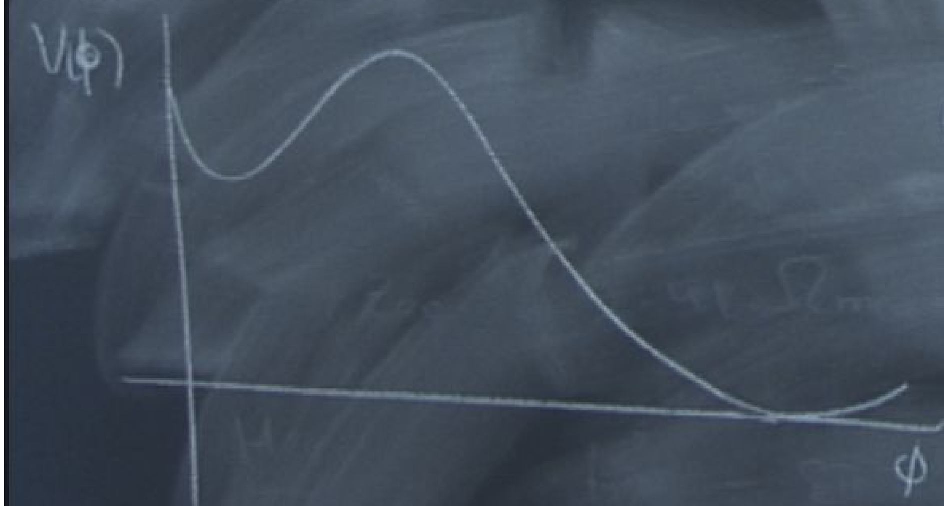
$$\boxed{\frac{a_{eq}H_{eq}}{a_0 H_0} = \sqrt{2\Omega_{m(0)}}} \quad (1$$

$$\boxed{N = 68 + \frac{1}{4}\ln\frac{V_{Hor}}{M_P^4}}$$

$\to \epsilon$

$\to 63 + \frac{1}{4}\ln\epsilon$

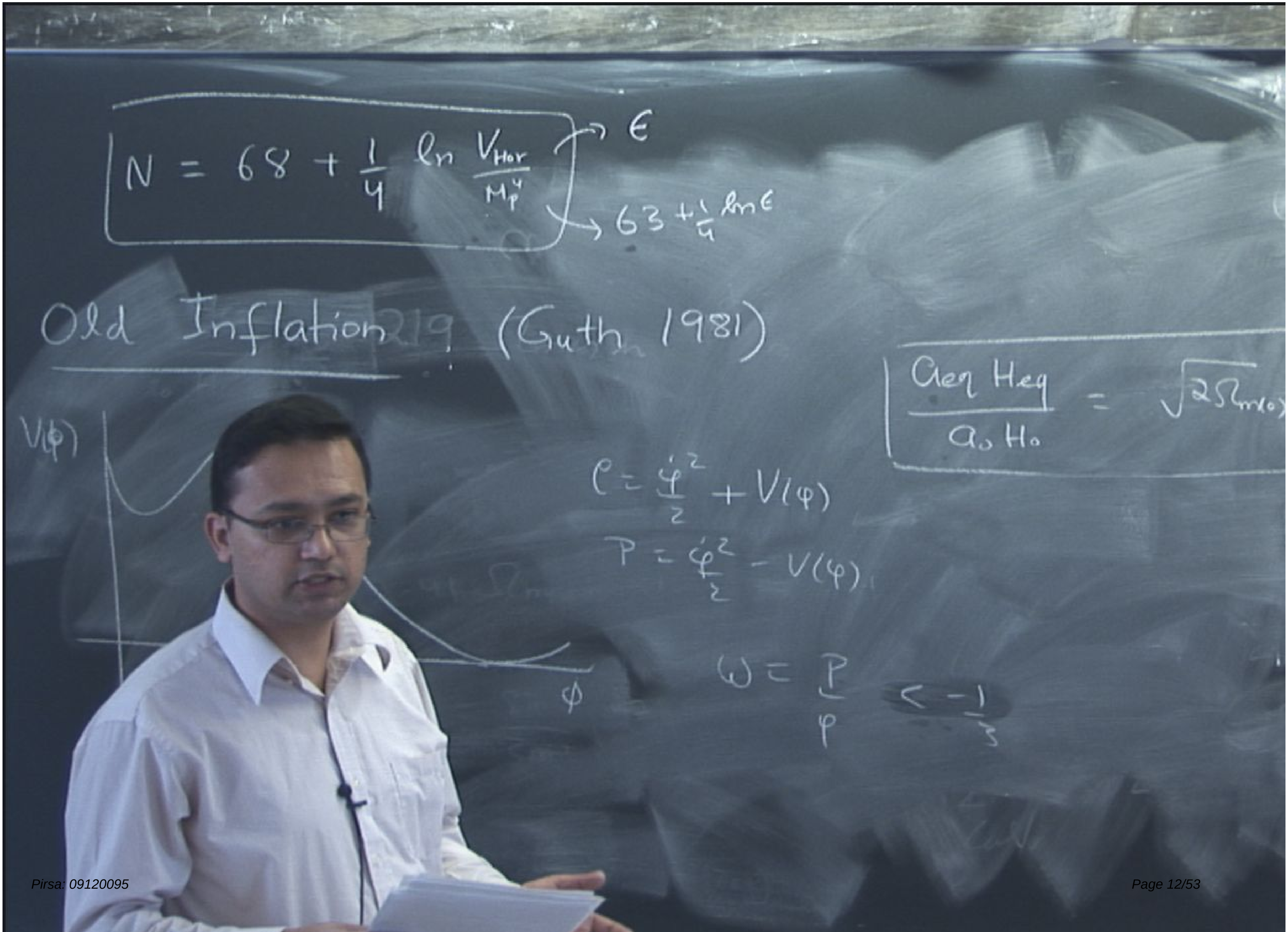
Old Inflation (Guth 1981)

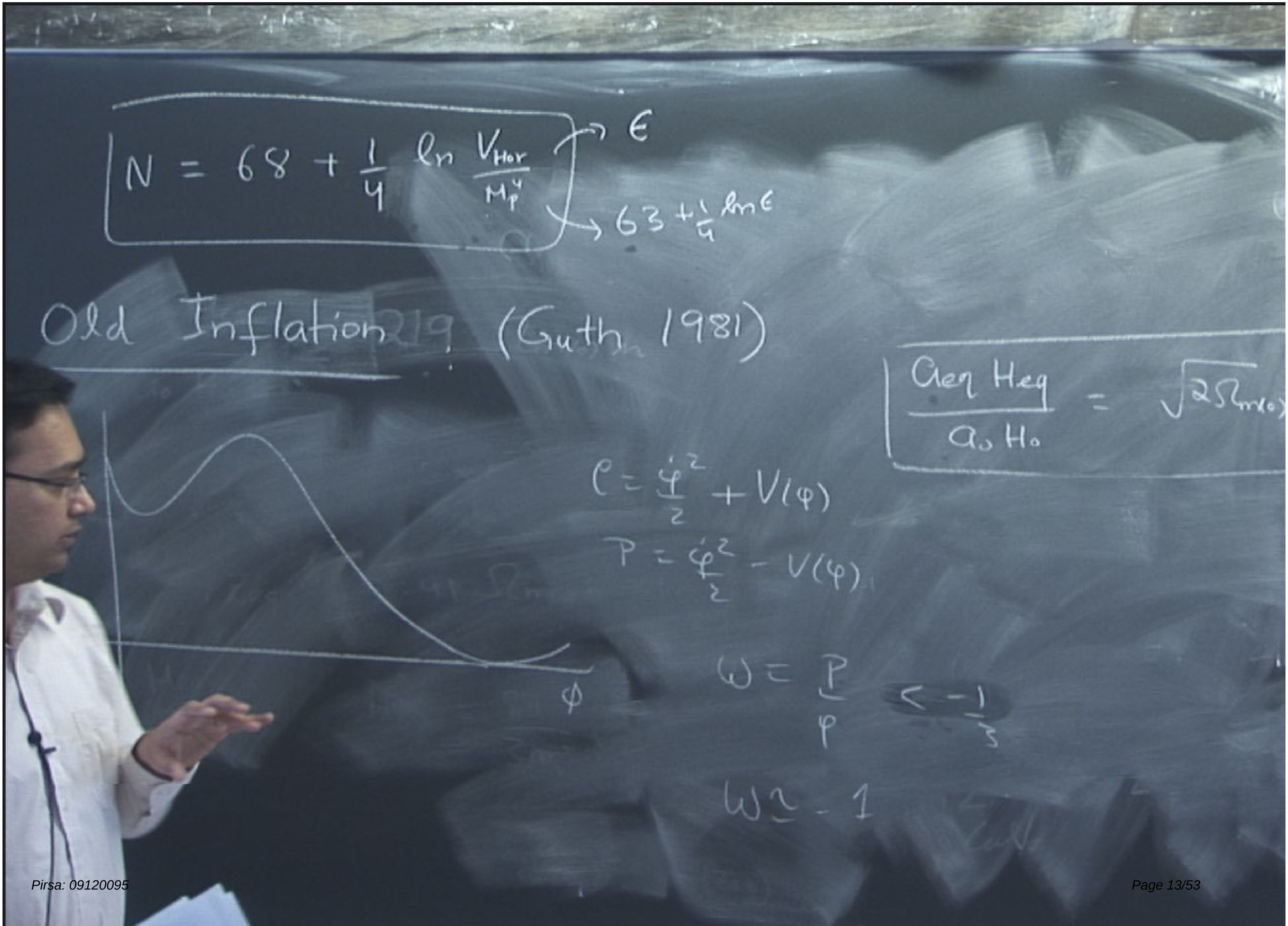


$$\rho = \frac{\dot\varphi^2}{2} + V(\varphi)$$

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

$$\boxed{\frac{a_{eq} H_{eq}}{a_0 H_0} = \sqrt{2\Omega_{m(0)}}}$$


$N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}$
ϵ
$63 + \frac{1}{4} \ln \epsilon$
Old Inflation (Guth 1981)
$\frac{a_{eq} H_{eq}}{a_0 H_0} = \sqrt{2\Omega_{m(0)}}$
$V(\phi)$
ϕ
$\rho = \frac{\dot{\varphi}^2}{2} + V(\varphi)$
$P = \frac{\dot{\varphi}^2}{2} - V(\varphi)$
$\omega = \frac{P}{\rho} < -\frac{1}{3}$



N = 68 + 1/4 ln V_Hor / M_p^4
→ ε
→ 63 + 1/4 ln ε
Old Inflation (Guth 1981)
a_eq H_eq / a_0 H_0 = √(2Ω_m(0))
ρ = φ̇²/2 + V(φ)
P = φ̇²/2 − V(φ)
ω = P/ρ < −1/3
ω ≃ −1
φ

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_P^4}}$$

$\rightarrow \epsilon$

$\rightarrow 63 + \frac{1}{4} \ln \epsilon$

Old Inflation (Guth 1981)

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

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

$$\omega = \frac{P}{\rho} < -\frac{1}{3}$$

$$\omega \simeq -1$$

$$\boxed{\frac{a_{eq} H_{eq}}{a_0 H_0} = \sqrt{2\Omega_{m(0)}}}$$

$$\boxed{N = 68 + \frac{1}{4}\ln\frac{V_{Hor}}{M_p^4}} \to \epsilon \qquad \to 63 + \frac{1}{4}\ln\epsilon$$

Old Inflation (Guth 1981)

$$\boxed{\frac{a_{eq} H_{eq}}{a_0 H_0} = \sqrt{2\Omega_{m(0)}}}$$

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

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

$$w = \frac{P}{\rho} < -\frac{1}{3}$$

$$w \simeq -1$$

$$\boxed{N = 68 + \frac{1}{4}\ln\frac{V_{Hor}}{M_p^4}} \rightarrow \epsilon$$

$$\rightarrow 63 + \frac{1}{4}\ln\epsilon$$

Old Inflation (Guth 1981)

$$\boxed{\frac{a_{eq} H_{eq}}{a_0 H_0} = \sqrt{2\Omega_{m(0)}}}$$

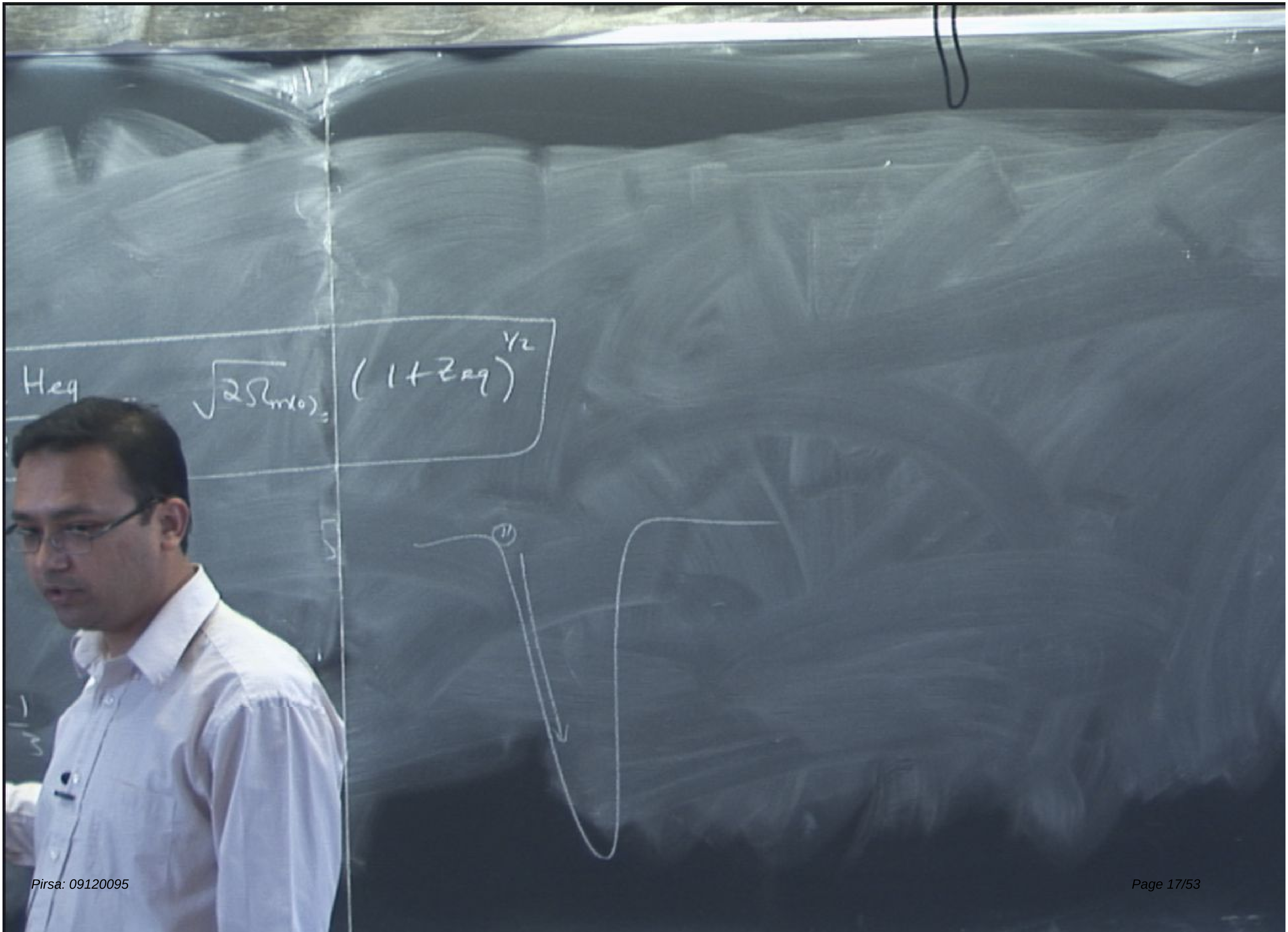
$$\rho = \frac{\dot\varphi^2}{2} + V(\varphi)$$

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

$$\omega = \frac{P}{\rho} < -\frac{1}{3}$$

$$\omega \simeq -1$$

$$a \propto e^{\sqrt{\Lambda}\, t}$$

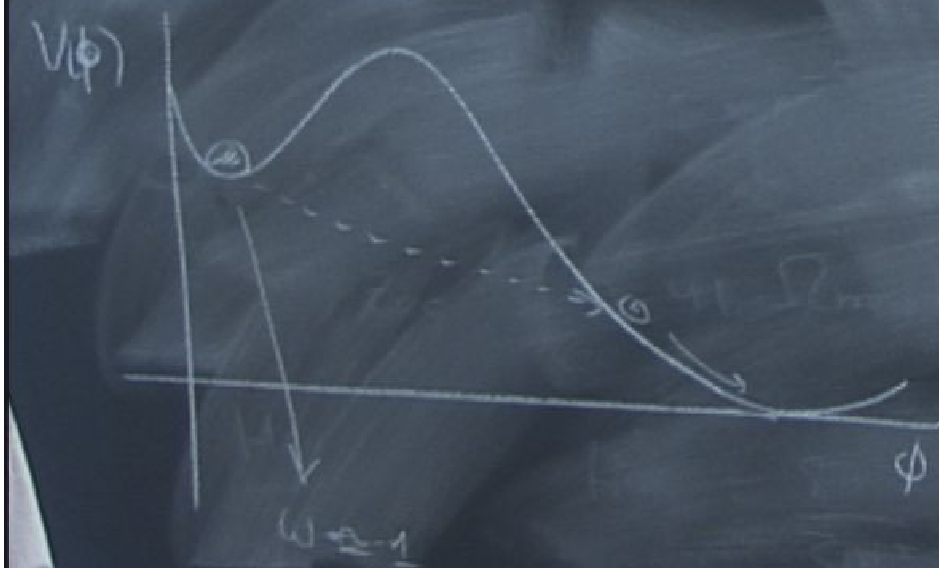

Heq
(1+Zeq)^1/2

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_P^4}} \to \epsilon$$

$$\to 63 + \frac{1}{4} \ln \epsilon$$

Old Inflation (Guth 1981)

$$\boxed{\frac{a_{eq} H_{eq}}{a_0 H_0} = \sqrt{2 \Omega_{m(0)}}}$$



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

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$$\omega \simeq -1$$

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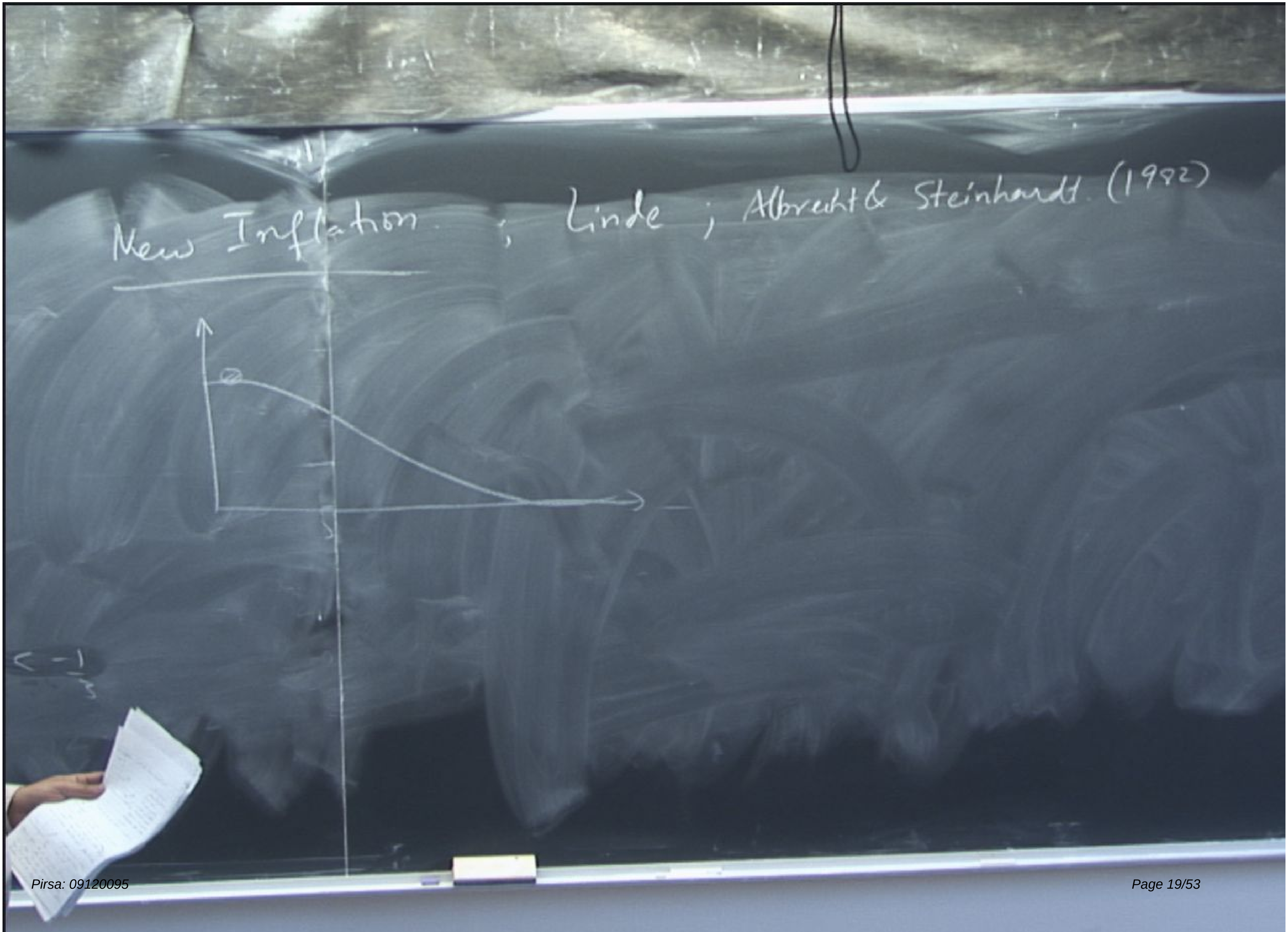
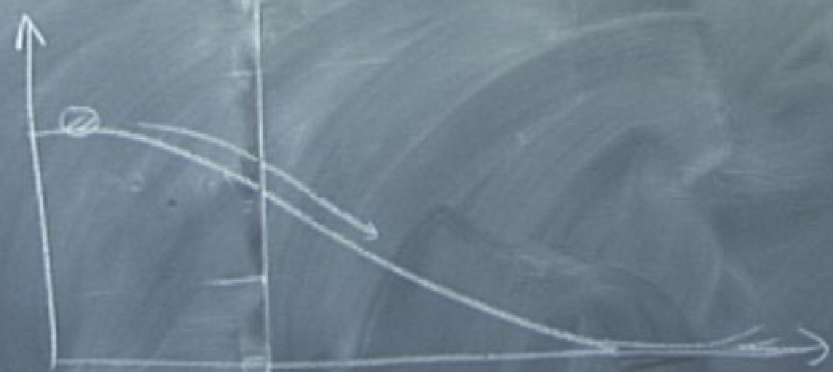
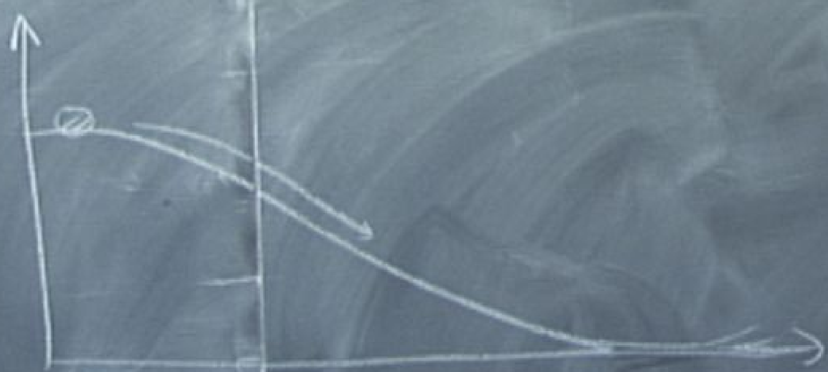

New Inflation ; Linde ; Albrecht & Steinhardt (1982)

New Inflation ; Linde ; Albrecht & Steinhardt (1982)



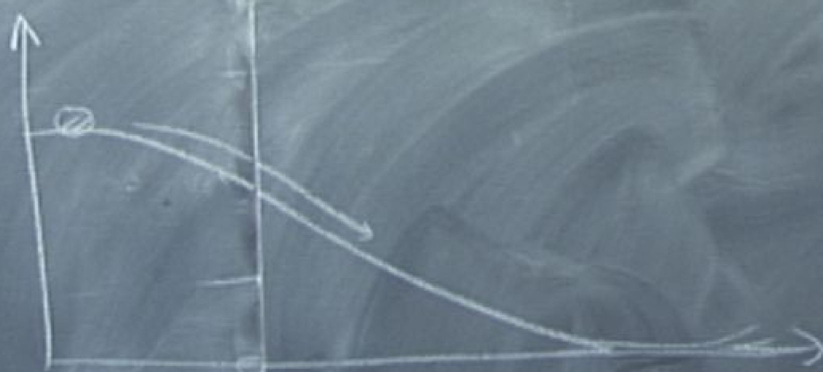
⊛ Chaotic Inflation

New Inflation ; Linde ; Albrecht & Steinhardt (1982)



⊛ Chaotic Inflation

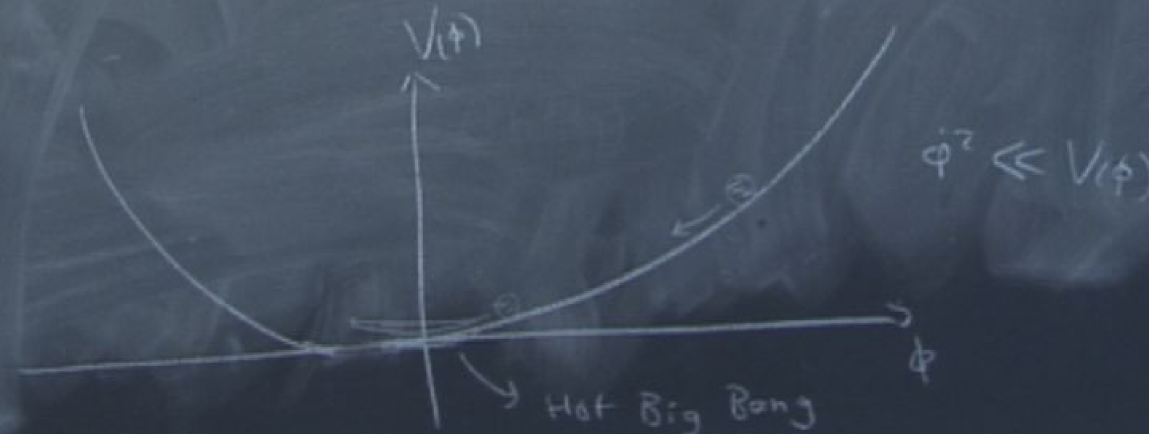
New Inflation ; Linde ; Albrecht & Steinhardt (1982)

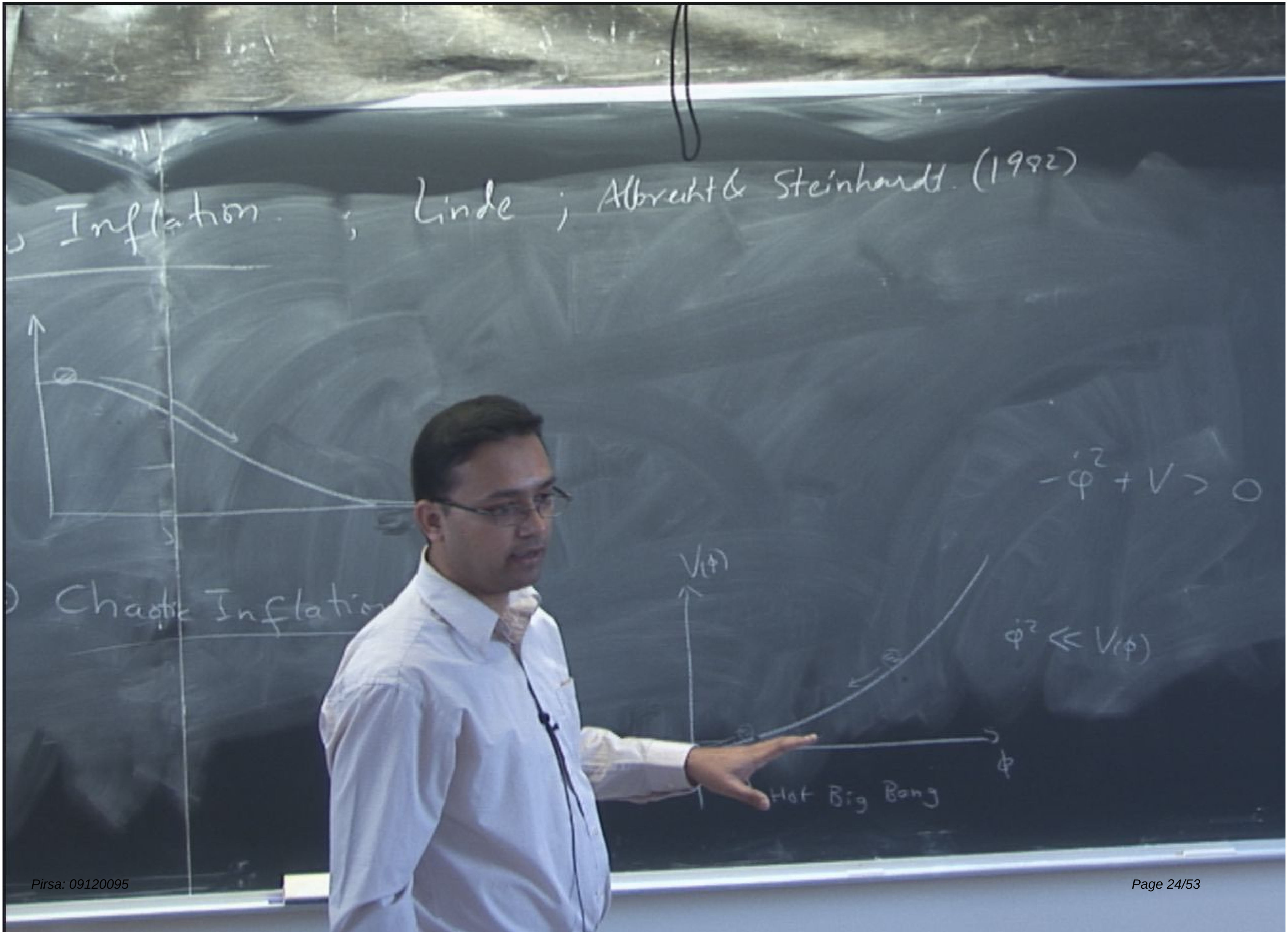


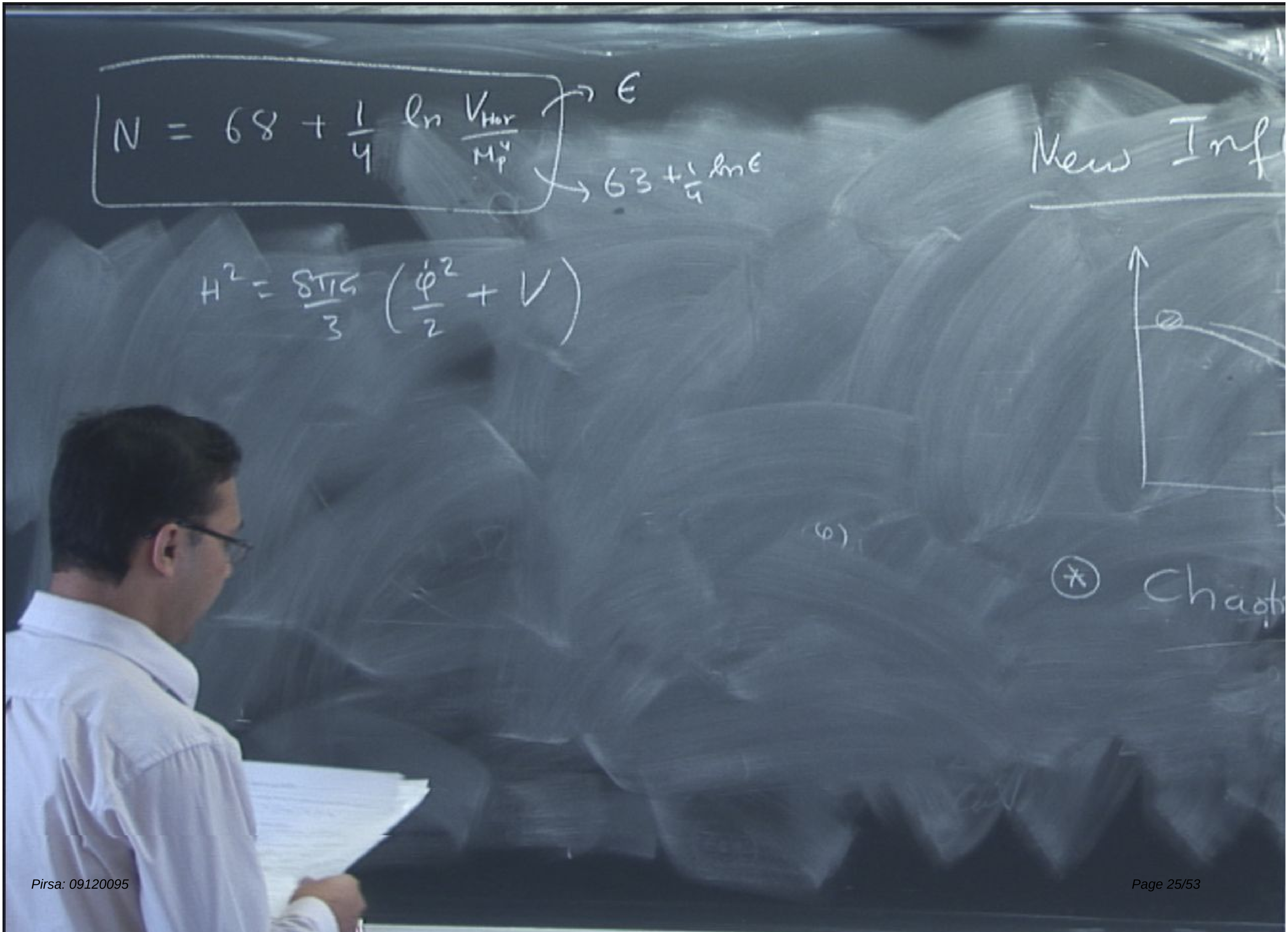
⊛ Chaotic Inflation

New Inflation ; Linde ; Albrecht & Steinhardt (1982)

(*) Chaotic Inflation




Inflation. ; Linde ; Albrecht & Steinhardt (1982)
Chaotic Inflation
$-\dot{\varphi}^2 + V > 0$
$V(\phi)$
$\dot{\varphi}^2 \ll V(\phi)$
ϕ
Hot Big Bang



$N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}$
ϵ
$63 + \frac{1}{4} \ln \epsilon$
$H^2 = \frac{8\pi G}{3} \left(\frac{\dot{\varphi}^2}{2} + V \right)$
New Inf
Chao

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}} \to \epsilon$$

$$\to 63 + \frac{1}{4} \ln \epsilon$$

New Inf

$$\rho = \frac{\dot\varphi^2}{2} + V$$

$$p = \frac{\dot\varphi^2}{2} - V$$

$$H^2 = \frac{8\pi G}{3}\left(\frac{\dot\varphi^2}{2} + V\right)$$

$$\frac{\ddot a}{a} = -\frac{4\pi G}{3}(\rho + 3p) = \frac{8\pi G}{3}(V - \dot\varphi^2)$$

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

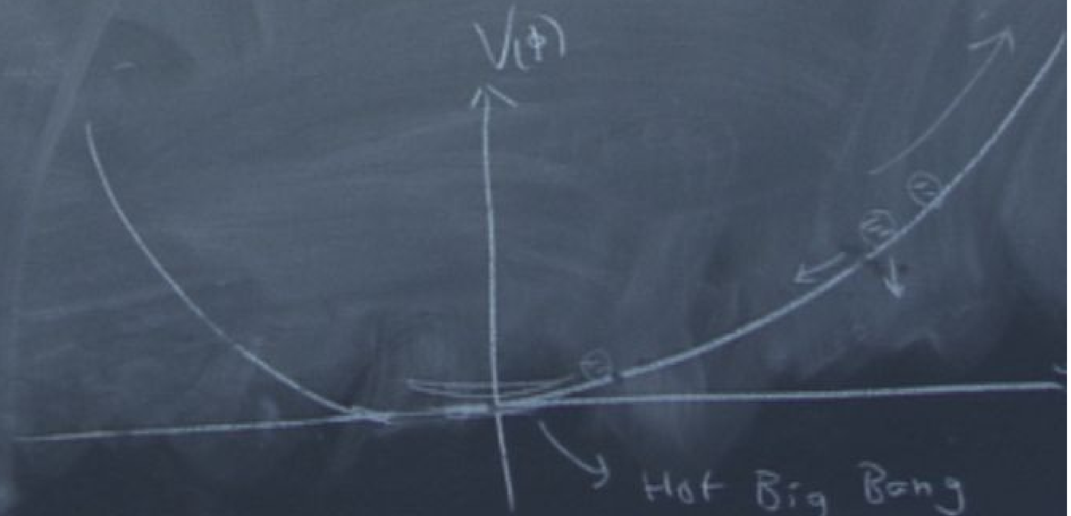
$$\to \boxed{\ddot\varphi + 3H\dot\varphi + V_{,\varphi} = 0}$$

Klein-Gordon Eqn

⊛ Chaoti

$\dot{H} = \frac{\ddot{a}}{a} - H^2$; Linde ; Albrecht & Steinhardt (

$\boxed{\dot{H} = -4\pi G \dot{\varphi}^2}$



$$\dot{H} = \frac{\ddot{a}}{a} - H^2$$

$$\boxed{\dot{H} = -4\pi G \dot{\varphi}^2}$$

; Linde ; Albrecht & Steinhardt (

Slow roll

(i) $\dot{\varphi}^2 \ll V(\phi)$

(ii) $\dot{\varphi}$ should not change in one Hubble time

$\frac{8\pi G}{3} V(\phi)$

$\frac{\dot{\varphi}^2}{2} + V$

$= \frac{\dot{\varphi}^2}{2} - V$

$\dot{\varphi}^2)$

; Linde ; Albrecht & Ste

$\dot{H} = \frac{\ddot{a}}{a} - H^2$

$$\boxed{\dot{H} = -4\pi G\, \dot{\varphi}^2}$$

Slow roll

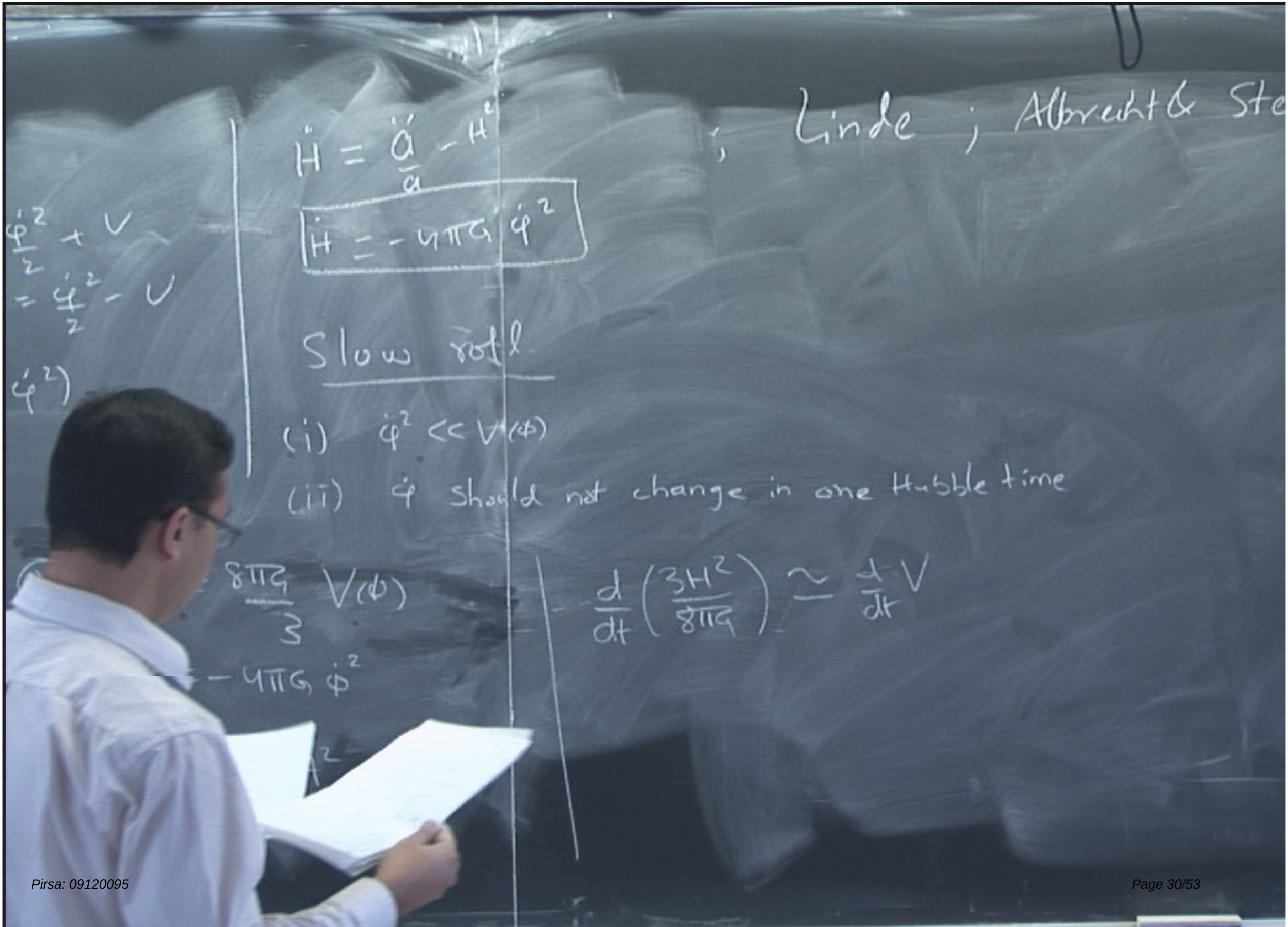
(i) $\dot{\varphi}^2 \ll V(\phi)$

(ii) $\dot{\varphi}$ should not change in one Hubble time

(*) $H^2 \simeq \frac{8\pi G}{3} V(\phi)$

$\dot{H} = -4\pi G\, \dot{\phi}^2$

$|\dot{H}| \ll H^2$


Linde ; Albrecht & Ste
$\dot{H} = \frac{\ddot{a}}{a} - H^2$
$\dot{H} = -4\pi G\,\dot{\varphi}^2$
Slow roll
(i) $\dot{\varphi}^2 << V(\phi)$
(ii) $\dot{\varphi}$ should not change in one Hubble time
$\frac{d}{dt}\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt} V$

$\frac{\dot\varphi^2}{2} + V$

$= \frac{\dot\varphi^2}{2} - V$

$\dot\varphi^2)$

$\dot H = \frac{\ddot a}{a} - H^2$; Linde ; Albrecht & Ste

$$\boxed{\dot H = -4\pi G \dot\varphi^2}$$

Slow roll

(i) $\dot\varphi^2 \ll V(\phi)$

(ii) $\dot\varphi$ should not change in one Hubble time

(*) $H^2 \simeq \frac{8\pi G}{3} V(\phi)$

$\dot H = -4\pi G \dot\phi^2$

$|\dot H| \lll H^2$

$\frac{d}{dt}\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt} V = V_{,\varphi}\dot\varphi$

$\Rightarrow -3H\dot\varphi \simeq V_{,\varphi}$

$\frac{\dot{\varphi}^2}{2} + V$

$= \frac{\dot{\varphi}^2}{2} - V$

$\dot{\varphi}^2)$

$\dot{H} = \frac{\ddot{a}}{a} - H^2$; Linde ; Albrecht & Ste

$$\boxed{\dot{H} = -4\pi G\, \dot{\varphi}^2}$$

Slow roll

(i) $\dot{\varphi}^2 \ll V(\phi)$

(ii) $\dot{\varphi}$ should not change in one Hubble time

$$\textcircled{*}\quad H^2 \simeq \frac{8\pi G}{3} V(\phi)$$

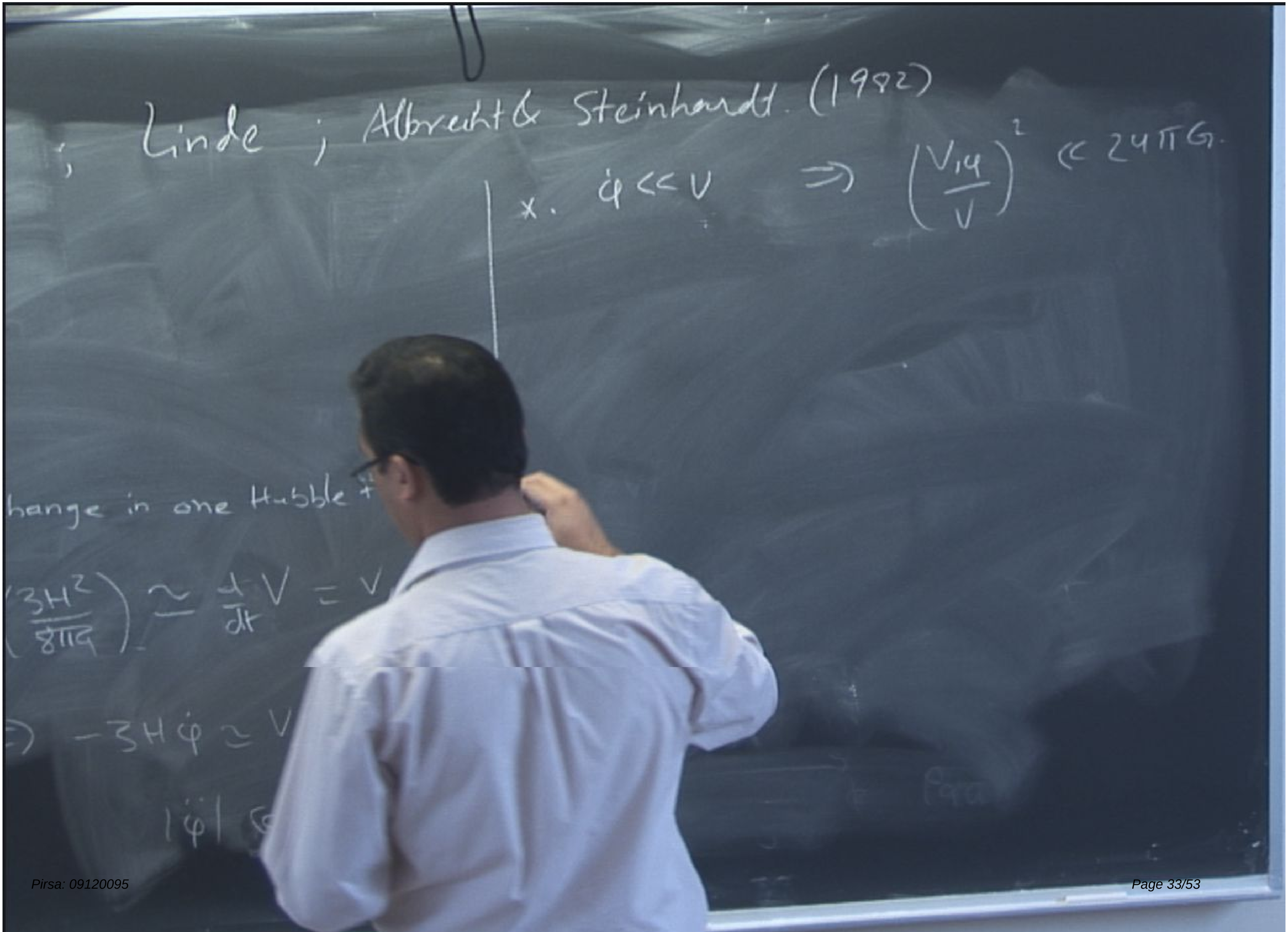
$$\dot{H} = -4\pi G\, \dot{\phi}^2$$

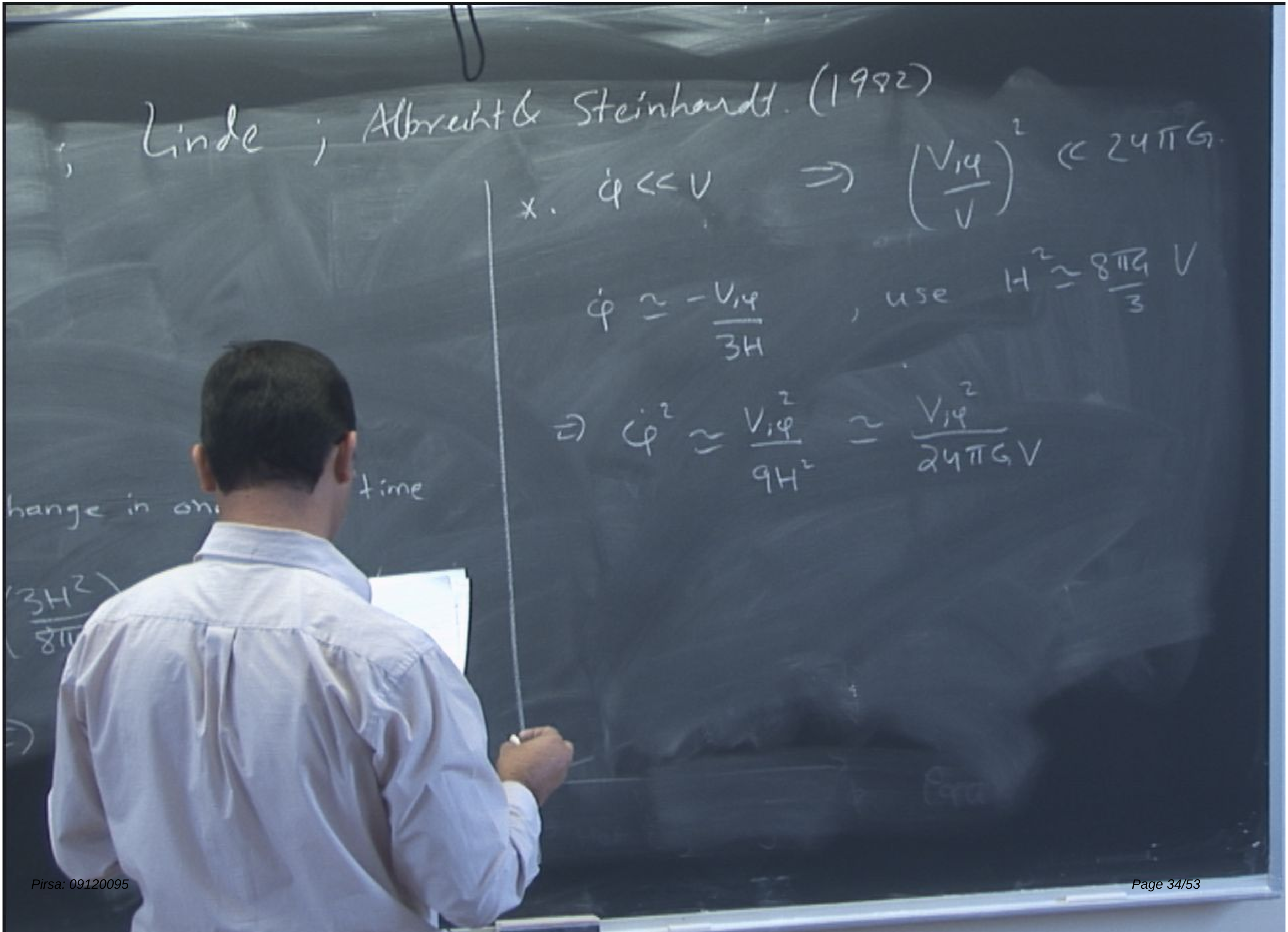
$$|\dot{H}| \ll H^2$$

$$\frac{d}{dt}\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt} V = V_{,\varphi}\, \dot{\varphi}$$

$$\Rightarrow -3H\dot{\varphi} \simeq V_{,\varphi}$$

$$|\ddot{\varphi}| \ll 3H\dot{\varphi}$$


; Linde ; Albrecht & Steinhardt. (1982)
x. $\dot{\varphi} << V$ $\Rightarrow$ $\left(\frac{V_{,\varphi}}{V}\right)^2 << 24\pi G.$
hange in one Hubble t
$\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt} V = V$
$\Rightarrow$ $-3H\dot{\varphi} \simeq V$
$|\dot{\varphi}|$


; Linde ; Albrecht & Steinhardt. (1982)
x. $\dot{\varphi} \ll V \Rightarrow \left(\frac{V_{,\varphi}}{V}\right)^2 \ll 24\pi G.$
$\dot{\varphi} \simeq -\frac{V_{,\varphi}}{3H}$, use $H^2 \simeq \frac{8\pi G}{3} V$
$\Rightarrow \dot{\varphi}^2 \simeq \frac{V_{,\varphi}^2}{9H^2} \simeq \frac{V_{,\varphi}^2}{24\pi G V}$
time

; Linde ; Albrecht & Steinhardt. (1982)

ange in one Hubble time

$$\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt} V = V_{,\varphi}\, \dot{\varphi}$$

$$\Rightarrow -3H\dot{\varphi} \simeq V_{,\varphi}$$

$$|\ddot{\varphi}| \ll 3H\dot{\varphi}$$

x. $\dot{\varphi} \ll V \quad \Rightarrow \quad \left(\frac{V_{,\varphi}}{V}\right)^2 \ll 24\pi G.$

$$\dot{\varphi} \simeq -\frac{V_{,\varphi}}{3H}, \quad \text{use} \quad H^2 \simeq \frac{8\pi G}{3} V$$

$$\Rightarrow \dot{\varphi}^2 \simeq \frac{V_{,\varphi}^2}{9H^2} \simeq \frac{V_{,\varphi}^2}{24\pi G V}$$

$$\left(\frac{V_{,\varphi}}{V}\right)^2 \ll 24\pi G.$$

; Linde ; Albrecht & Steinhardt. (1982)

hange in one Hubble time

$$\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt} V = V_{,\varphi}\, \dot\varphi$$

$$\Rightarrow -3H\dot\varphi \simeq V_{,\varphi}$$

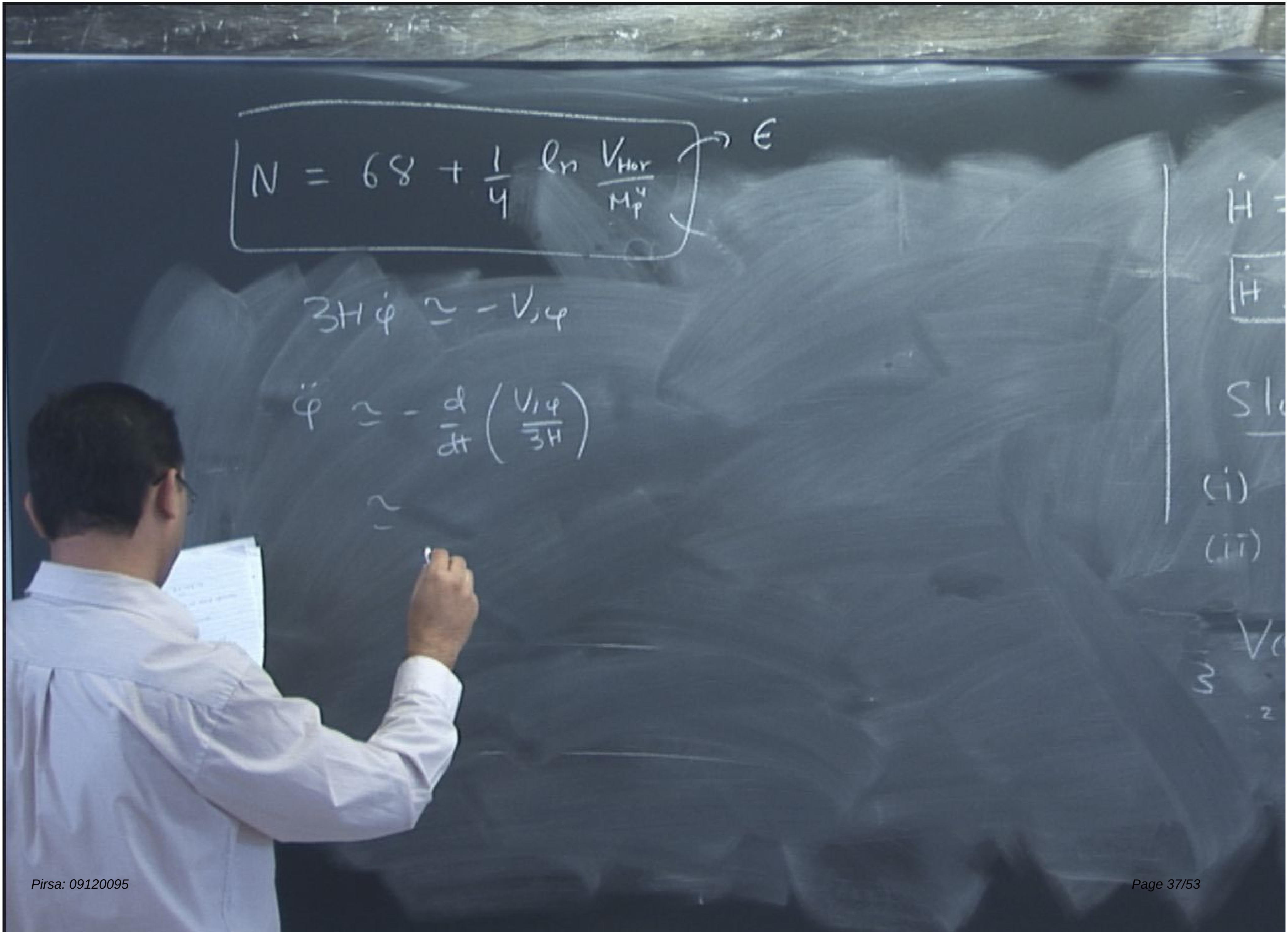
$$|\ddot\varphi| \ll 3H\dot\varphi$$

x. $\dot\varphi \ll V \quad \Rightarrow \quad \left(\frac{V_{,\varphi}}{V}\right)^2 \ll 24\pi G.$

$$\dot\varphi \simeq -\frac{V_{,\varphi}}{3H} \quad , \text{ use } \quad H^2 \simeq \frac{8\pi G}{3} V$$

$$\Rightarrow \dot\varphi^2 \simeq \frac{V_{,\varphi}^2}{9H^2} \simeq \frac{V_{,\varphi}^2}{24\pi G V}$$

$$\left(\frac{V_{,\varphi}}{V}\right)^2 \ll 24\pi G.$$



$N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}$
ϵ
$3H\dot{\varphi} \simeq -V_{,\varphi}$
$\ddot{\varphi} \simeq -\frac{d}{dt}\left(\frac{V_{,\varphi}}{3H}\right)$
$\simeq$
(i)
(ii)

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}} \to \epsilon$$

$$3H\dot{\varphi} \simeq -V_{,\varphi}$$

$$\ddot{\varphi} \simeq -\frac{d}{dt}\left(\frac{V_{,\varphi}}{3H}\right)$$

$$\simeq -\frac{V_{,\varphi\varphi}\,\dot{\varphi}}{3H} + \underbrace{\frac{V_{,\varphi}\,\dot{H}}{3H^2}}_{-\frac{\dot{H}\dot{\varphi}}{H}}$$

$\dot{H} =$

$\boxed{\dot{H}}$

Sl

(i)

(ii)

V(

3

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}} \rightarrow \epsilon$$

$$3H\dot{\varphi} \simeq -V_{,\varphi}$$

$$\ddot{\varphi} \simeq -\frac{d}{dt}\left(\frac{V_{,\varphi}}{3H}\right)$$

$$\simeq -\frac{V_{,\varphi\varphi}\,\dot{\varphi}}{3H} + \underbrace{\frac{V_{,\varphi}}{3H^2}\dot{H}}_{-\frac{\dot{H}\dot{\varphi}}{H}}$$

$$\simeq -\frac{V_{,\varphi\varphi}\,\dot{\varphi}}{3H}$$

$$\simeq \frac{V_{,\varphi\varphi}V_{,\varphi}}{9H^2}$$

$\dot{H} =$

$\dot{H}$

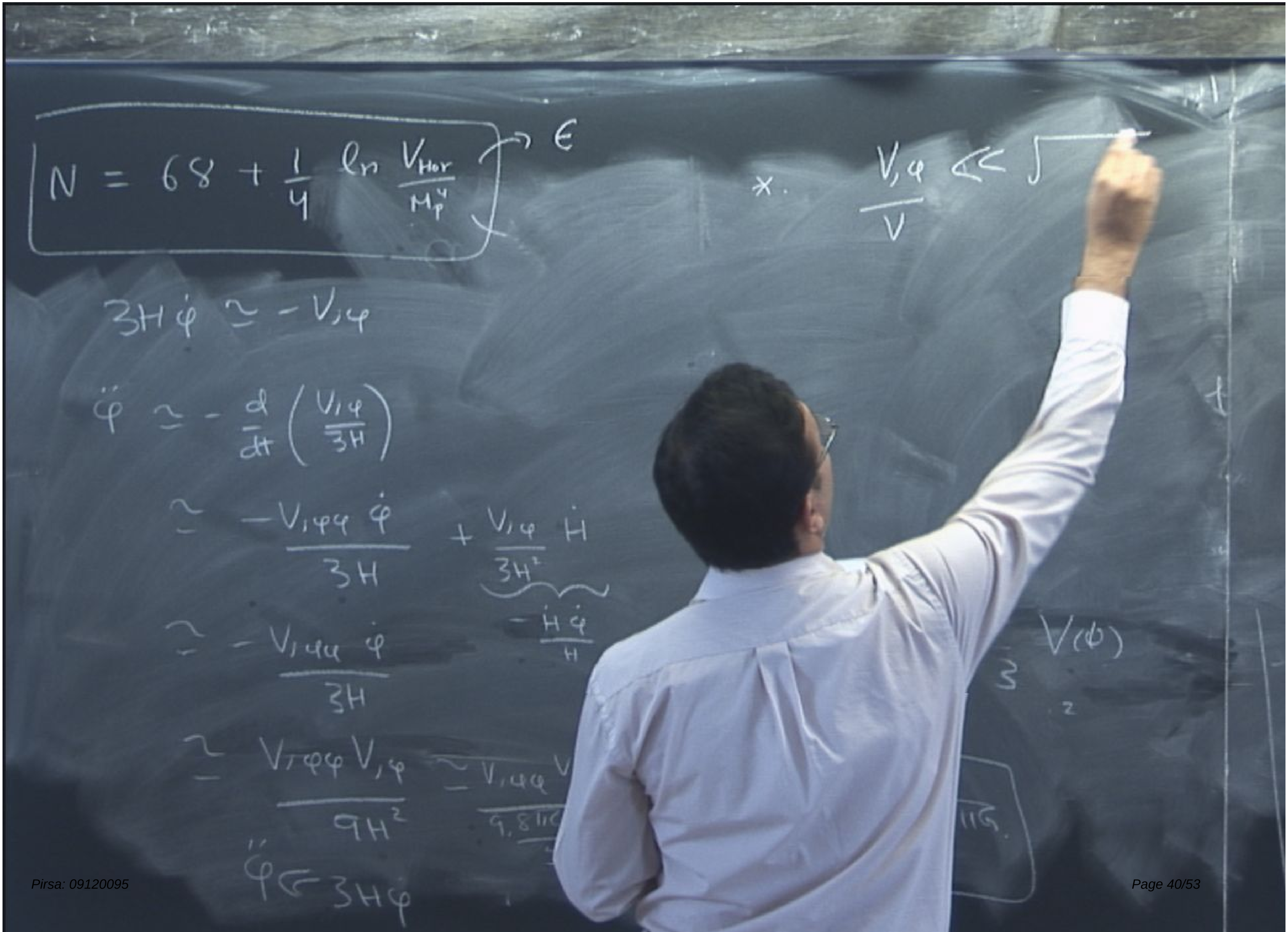
Sl

(i)

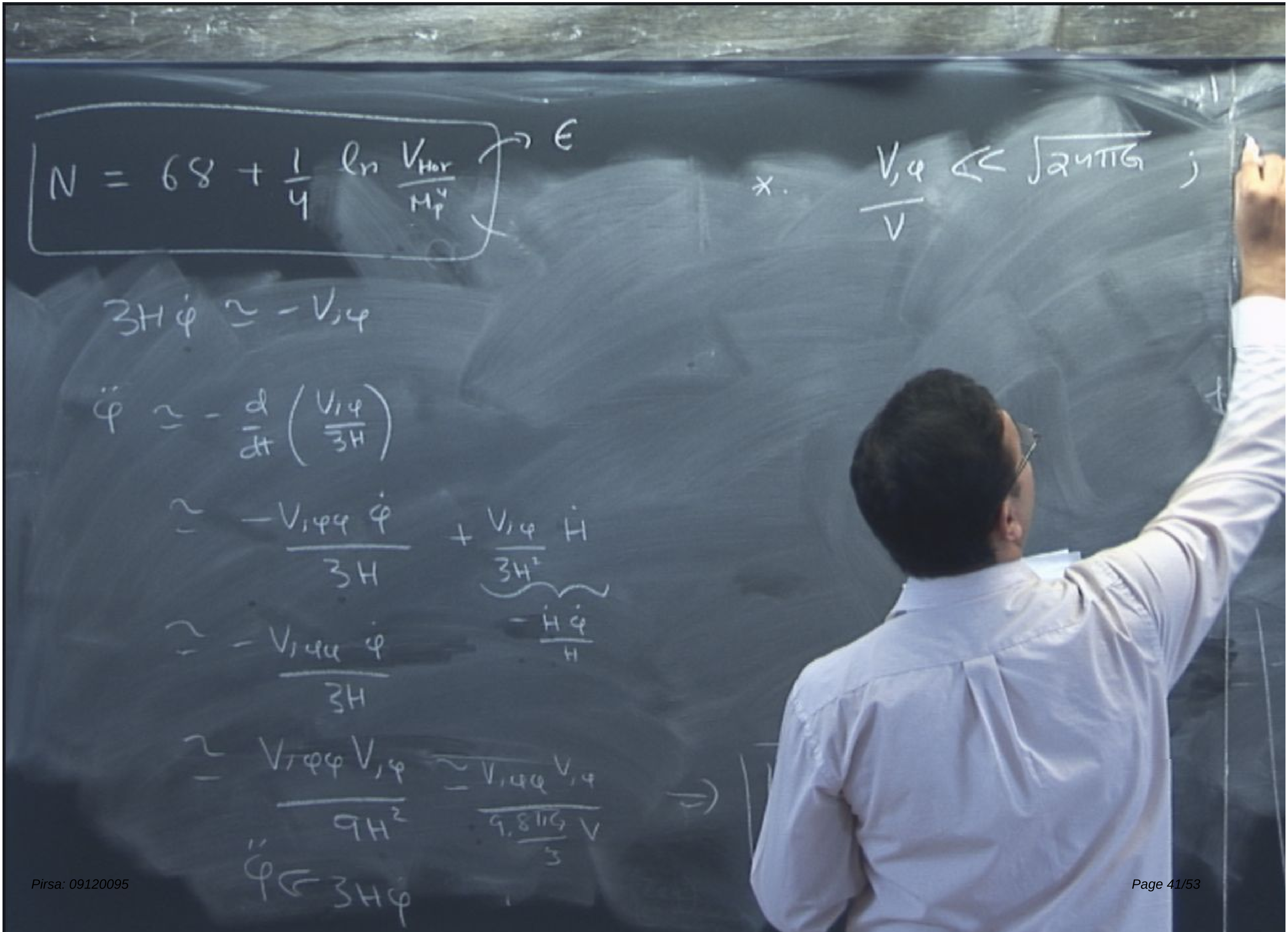
(ii)

V(

3



$N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}$
ϵ
$*.\ \frac{V_{,\varphi}}{V} \ll \sqrt{\ }$
$3H\dot{\varphi} \simeq -V_{,\varphi}$
$\ddot{\varphi} \simeq -\frac{d}{dt}\left(\frac{V_{,\varphi}}{3H}\right)$
$\simeq -\frac{V_{,\varphi\varphi}\dot{\varphi}}{3H} + \frac{V_{,\varphi}}{3H^2}\dot{H}$
$-\frac{\dot{H}\dot{\varphi}}{H}$
$\simeq -\frac{V_{,\varphi\varphi}\dot{\varphi}}{3H}$
$\simeq \frac{V_{,\varphi\varphi}V_{,\varphi}}{9H^2}$
$V(\phi)$
$\ddot{\varphi} \ll 3H\dot{\varphi}$



$\boxed{N = 68 + \frac{1}{4}\ln\frac{V_{Hor}}{M_p^4}} \to \epsilon$
$* \quad \frac{V_{,\varphi}}{V} \ll \sqrt{24\pi G}$;
$3H\dot{\varphi} \simeq -V_{,\varphi}$
$\ddot{\varphi} \simeq -\frac{d}{dt}\left(\frac{V_{,\varphi}}{3H}\right)$
$\simeq -\frac{V_{,\varphi\varphi}\dot{\varphi}}{3H} + \underbrace{\frac{V_{,\varphi}\dot{H}}{3H^2}}_{-\frac{\dot{H}\dot{\varphi}}{H}}$
$\simeq -\frac{V_{,\varphi\varphi}\dot{\varphi}}{3H}$
$\simeq \frac{V_{,\varphi\varphi}V_{,\varphi}}{9H^2} \simeq \frac{V_{,\varphi\varphi}V_{,\varphi}}{9\cdot\frac{8\pi G}{3}V} \Rightarrow$
$\ddot{\varphi} \ll 3H\dot{\varphi}$

$$*.\quad \frac{V_{,\varphi}}{V} \ll \sqrt{24\pi G} \;;\quad \frac{V_{,\varphi\varphi}}{V} \ll 24\pi G$$

Linde ; Albrecht & Ste

$$\epsilon := \frac{1}{16\pi G}\left(\frac{V_{,\varphi}}{V}\right)^2$$

$$\eta :=$$

$$V(\phi)$$

$$\frac{d}{dt}\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt}V = V_{,\varphi}\,\dot\varphi$$

$$\Rightarrow\; -3H\dot\varphi \simeq V_{,\varphi}$$

$$|\ddot\varphi| \ll 3H\dot\varphi$$

$$\boxed{\frac{|V_{,\varphi\varphi}|}{V} \ll 24\pi G}$$

$*.\quad \dot\varphi$

$\dot\varphi$

$\Rightarrow$

$*.\ \frac{V_{,\varphi}}{V} \ll \sqrt{24\pi G}$; $\frac{V_{,\varphi\varphi}}{V} \ll 24\pi G$ Linde ; Albrecht & Ste

$$\epsilon := \frac{1}{16\pi G}\left(\frac{V_{,\varphi}}{V}\right)^2$$

$$\eta := \frac{1}{8\pi G}\left(\frac{V_{,\varphi\varphi}}{V}\right)$$

$$\frac{V(\phi)}{3}$$

$$\boxed{\frac{|V_{,\varphi\varphi}|}{V} \ll 24\pi G}$$

$*.\ \dot{\varphi}$

$\dot{\varphi}$

$\Rightarrow$

$$\frac{d}{dt}\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt}V = V_{,\varphi}\,\dot{\varphi}$$

$$\Rightarrow -3H\dot{\varphi} \simeq V_{,\varphi}$$

$$|\ddot{\varphi}| \ll 3H\dot{\varphi}$$

Linde ; Albrecht & Ste

$*. \quad \frac{V_{,\varphi}}{V} \ll \sqrt{24\pi G} \; ; \quad \frac{V_{,\varphi\varphi}}{V} \ll 24\pi G$

$$\epsilon := \frac{1}{16\pi G}\left(\frac{V_{,\varphi}}{V}\right)^2$$

$$\eta := \frac{1}{8\pi G}\left(\frac{V_{,\varphi\varphi}}{V}\right)$$

$\epsilon \ll 1$

$\eta \ll 1.$

$\frac{V(\phi)}{3}$

$$\boxed{\frac{|V_{,\varphi\varphi}|}{V} \ll 24\pi G.}$$

$$\frac{d}{dt}\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt}V = V_{,\varphi}\,\dot\varphi$$

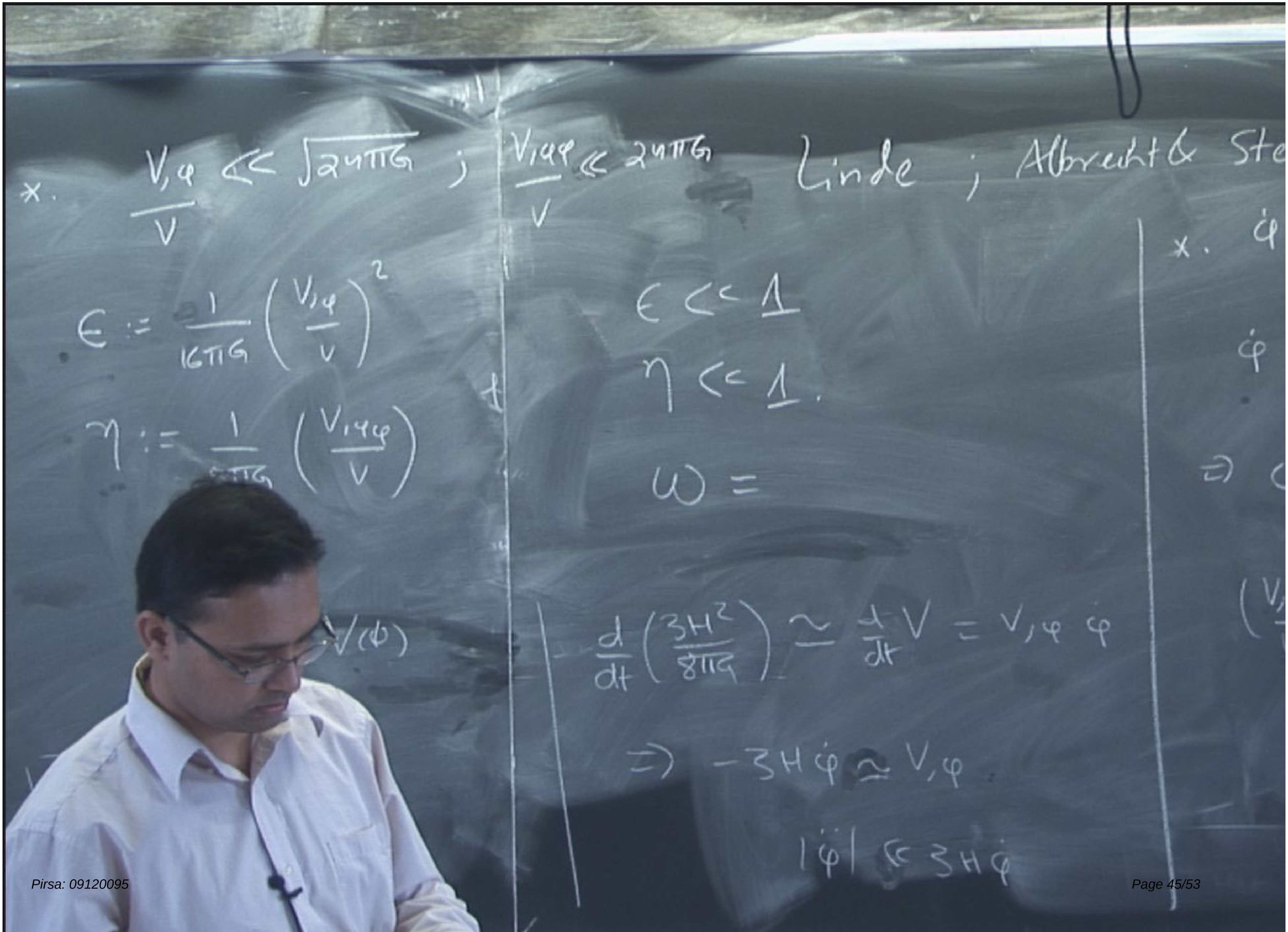
$\Rightarrow \; -3H\dot\varphi \simeq V_{,\varphi}$

$|\ddot\varphi| \ll 3H\dot\varphi$

$*. \quad \dot\varphi$

$\dot\varphi$

$\Rightarrow$


* $\frac{V_{,\varphi}}{V} \ll \sqrt{24\pi G}$; $\frac{V_{,\varphi\varphi}}{V} \ll 24\pi G$
Linde ; Albrecht & Ste
$\epsilon := \frac{1}{16\pi G}\left(\frac{V_{,\varphi}}{V}\right)^2$
$\eta := \frac{1}{8\pi G}\left(\frac{V_{,\varphi\varphi}}{V}\right)$
$\epsilon \ll 1$
$\eta \ll 1$.
$\omega =$
$\frac{d}{dt}\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt}V = V_{,\varphi}\dot{\varphi}$
$\Rightarrow -3H\dot{\varphi} \simeq V_{,\varphi}$
$|\ddot{\varphi}| \ll 3H\dot{\varphi}$

$\ast.\ \frac{V_{,\varphi}}{V} \ll \sqrt{24\pi G}\ ;\ \frac{V_{,\varphi\varphi}}{V} \ll 24\pi G$ Linde ; Albrecht & Ste

$$\epsilon := \frac{1}{16\pi G}\left(\frac{V_{,\varphi}}{V}\right)^2$$

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$\epsilon \ll 1$

$\eta \ll 1.$

$$\boxed{w = -1 + \frac{2}{3}\epsilon}$$

$\frac{V(\phi)}{3}$

$$\frac{d}{dt}\left(\frac{3H^2}{8\pi G}\right) \simeq \frac{d}{dt}V = V_{,\varphi}\dot{\varphi}$$

$$\Rightarrow -3H\dot{\varphi} \simeq V_{,\varphi}$$

$$|\ddot{\varphi}| \ll 3H\dot{\varphi}$$

$$\boxed{\frac{|V_{,\varphi\varphi}|}{V} \ll 24\pi G}$$

$\ast.\ \dot{\varphi}$

$\dot{\varphi}$

$\Rightarrow$

Linde ; Albrecht & Steinhardt (1982)

$$\ll 1$$

$$\ll 1.$$

$$\boxed{w = -1 + \frac{2}{3}\epsilon}$$

$$\epsilon = 1$$

$$\omega = -1/3$$

x. $\dot{\varphi} \ll V \Rightarrow \left(\frac{V_{,\varphi}}{V}\right)^2 \ll 24\pi G.$

$$\dot{\varphi} \simeq -\frac{V_{,\varphi}}{3H} \quad , \text{ use } \quad H^2 \simeq \frac{8\pi G}{3} V$$

$$\Rightarrow \dot{\varphi}^2 \simeq \frac{V_{,\varphi}^2}{9H^2} \simeq \frac{V_{,\varphi}^2}{24\pi G V}$$

$$\left(\frac{V_{,\varphi}}{V}\right)^2 \ll 24\pi G.$$

$$\boxed{N = 68 + \frac{1}{4}\ln\frac{V_{Hor}}{M_p^4}} \to \epsilon$$

$*$. $\frac{V_{,\varphi}}{V} \ll \sqrt{2\ldots}$

(*) In the slow-roll approx

$$P_s = \frac{8V}{3m_p^4}\frac{1}{\epsilon}$$

$$\epsilon := \frac{1}{16\pi G}\left(\frac{V_{,\varphi}}{V}\ldots\right.$$

$$\eta := \frac{1}{8\pi G}\left(\ldots\right.$$

$$\simeq -\frac{V_{,\varphi\varphi}\dot\varphi}{3H}$$

$$\simeq \frac{V_{,\varphi\varphi}V_{,\varphi}}{9H^2} \simeq \frac{V_{,\varphi\varphi}V_{,\varphi}}{9\cdot\frac{8\pi G}{3}V} \Rightarrow \boxed{\frac{|V_{,\varphi\varphi}|}{V} \ll 24\pi G}$$

$$\ddot\varphi \ll 3H\dot\varphi$$

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}} \to \epsilon$$

$\circledast$ In the slow-roll approx

$$P_S = \frac{8V}{3m_p^4} \frac{1}{\epsilon} \simeq 2.6 \times 10^{-9}$$

$$\frac{V}{m_p^4} \simeq 10^{-9} \epsilon$$

$$\simeq -\frac{V_{,\varphi\varphi}\, \dot\varphi}{3H}$$

$$\simeq \frac{V_{,\varphi\varphi} V_{,\varphi}}{9H^2} \simeq \frac{V_{,\varphi\varphi} V_{,\varphi}}{9 \cdot \frac{8\pi G}{3} V} \Rightarrow \boxed{\frac{|V_{,\varphi\varphi}|}{V} \ll 24\pi G}$$

$$\ddot\varphi \ll 3H\dot\varphi$$

$*$. $\frac{V_{,\varphi}}{V} \ll \sqrt{2}$

$$\epsilon := \frac{1}{16\pi G}\left(\frac{V_{,\varphi}}{V}\right.$$

$$\eta := \frac{1}{8\pi G}\left(\frac{V}{}\right.$$

V

3

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}} \to \epsilon$$

$$\ast.\quad \frac{V_{,\varphi}}{V} \ll \sqrt{2}$$

⊛ In the slow-roll approx

$$P_s = \frac{8V}{3m_p^4}\frac{1}{\epsilon} \simeq 2.6 \times 10^{-9}$$

$$\epsilon := \frac{1}{16\pi G}\left(\frac{V_{,\varphi}}{V}\right.$$

$$\eta := \frac{1}{8\pi G}\left(\right.$$

$$\frac{V}{m_p^4} \simeq 10^{-9}\,\epsilon$$

$$N \simeq 63 + \frac{1}{4}\ln\epsilon$$

$$\simeq -\frac{V_{,\varphi\varphi}\,\dot\varphi}{3H}$$

$$\simeq \frac{V_{,\varphi\varphi}V_{,\varphi}}{9H^2} \simeq \frac{V_{,\varphi\varphi}V_{,\varphi}}{9 \cdot \frac{8\pi G}{3} V} \Rightarrow \boxed{\frac{|V_{,\varphi\varphi}|}{V} \ll 24\pi G}$$

$$\ddot\varphi \ll 3H\dot\varphi$$

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}} \to \epsilon$$

$*.\quad \frac{V_{,\varphi}}{V} \lll \sqrt{2}$

⊛ In the slow-roll approx

$$P_s = \frac{8V}{3m_p^4} \frac{1}{\epsilon} \simeq 2.6 \times 10^{-9}$$

$$\frac{V}{m_p^4} \simeq 10^{-9} \epsilon$$

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$$N \simeq 63 + \frac{1}{4} \ln \epsilon$$

$$\simeq - \frac{V_{,\varphi\varphi} \dot{\varphi}}{3H}$$

$$\simeq \frac{V_{,\varphi\varphi} V_{,\varphi}}{9H^2} \simeq \frac{V_{,\varphi\varphi} V_{,\varphi}}{9 \cdot \frac{8\pi G}{3} V} \Rightarrow \boxed{\frac{|V_{,\varphi\varphi}|}{V} \ll 24\pi G}$$

$$\ddot{\varphi} \ll 3H\dot{\varphi}$$

V

3

$$\boxed{N = 68 + \frac{1}{4} \ln \frac{V_{Hor}}{M_p^4}} \to \epsilon$$

* $\frac{V_{,\varphi}}{V} \ll \sqrt{2}$

(*) In the slow-roll approx

$$P_s = \frac{8V}{3m_p^4} \frac{1}{\epsilon} \simeq 2.6 \times 10^{-9}$$

$$\frac{V}{m_p^4} \simeq 10^{-9} \epsilon$$

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$$N \simeq 63 + \frac{1}{4} \ln \epsilon$$

$$\simeq -\frac{V_{,\varphi\varphi} \dot{\varphi}}{3H}$$

$$\simeq \frac{V_{,\varphi\varphi} V_{,\varphi}}{9H^2} \simeq \frac{V_{,\varphi\varphi} V_{,\varphi}}{9 \cdot \frac{8\pi G}{3} V} \Rightarrow \boxed{\frac{|V_{,\varphi\varphi}|}{V} \ll 24\pi G}$$

$$\ddot{\varphi} \ll 3H\dot{\varphi}$$

$\frac{V}{3}$

$\frac{V_{,\varphi\varphi}}{V} \ll 24\pi G$

Linde ; Albrecht & Steinhardt (1982)

$\epsilon \ll 1$

$\eta \ll 1$.

$$\boxed{w = -1 + \frac{2}{3}\epsilon}$$

if $\epsilon = 1$

$w = -1/3$

* $\dot{\varphi} \ll V \Rightarrow \left(\frac{V_{,\varphi}}{V}\right)^2 \ll$

$\dot{\varphi} \simeq -\frac{V_{,\varphi}}{3H}$, use $H^2 \simeq 8$

$\Rightarrow \dot{\varphi}^2 \simeq \frac{V_{,\varphi}^2}{9H^2} \simeq \frac{V_{,\varphi}^2}{24\pi G V}$

$\left(\frac{V_{,\varphi}}{V}\right)^2 \ll 24\pi G$.