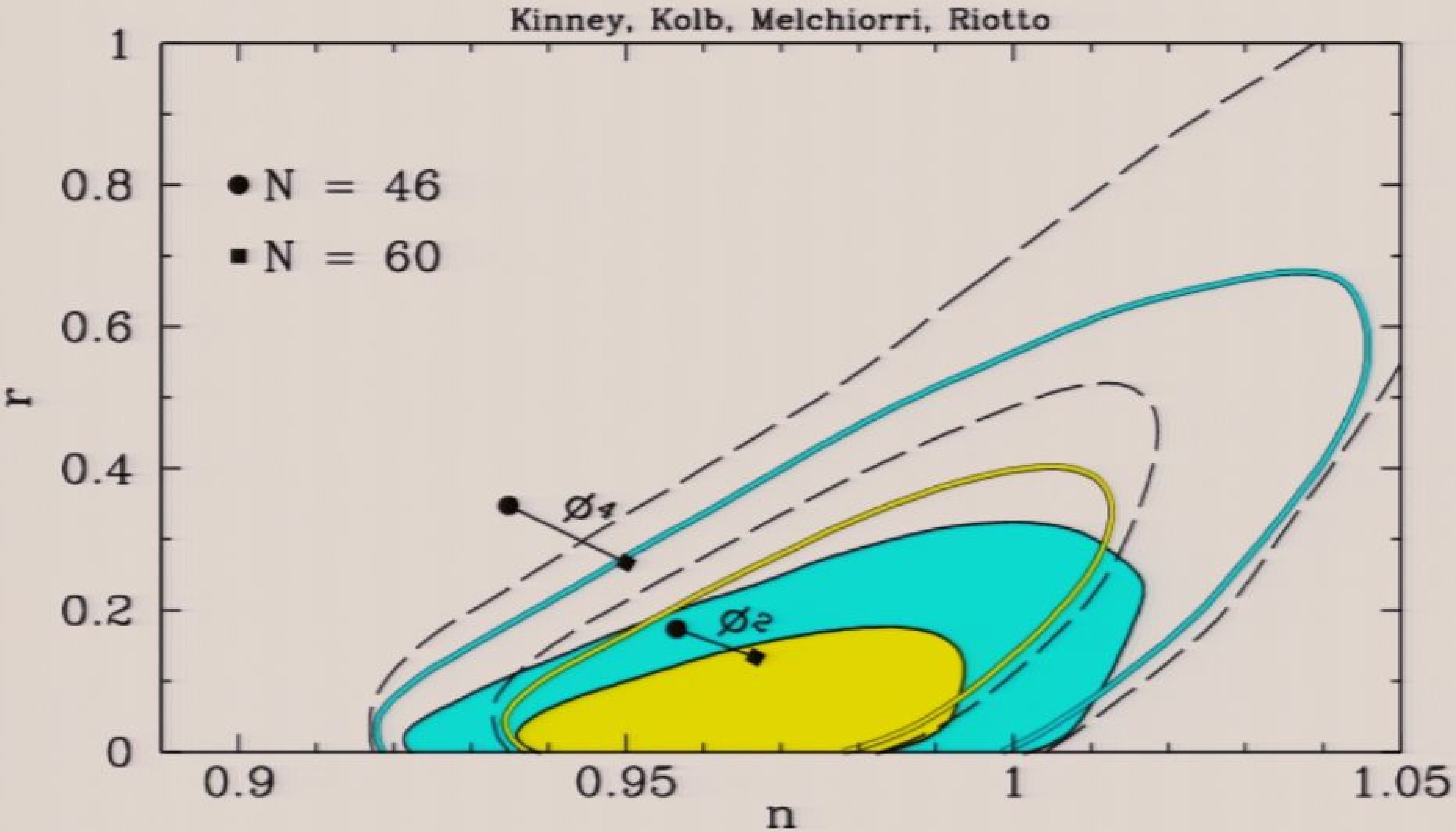
Title: Inflation: What Now?

Date: Nov 11, 2006 11:00 AM

URL: http://pirsa.org/06110047

Abstract:

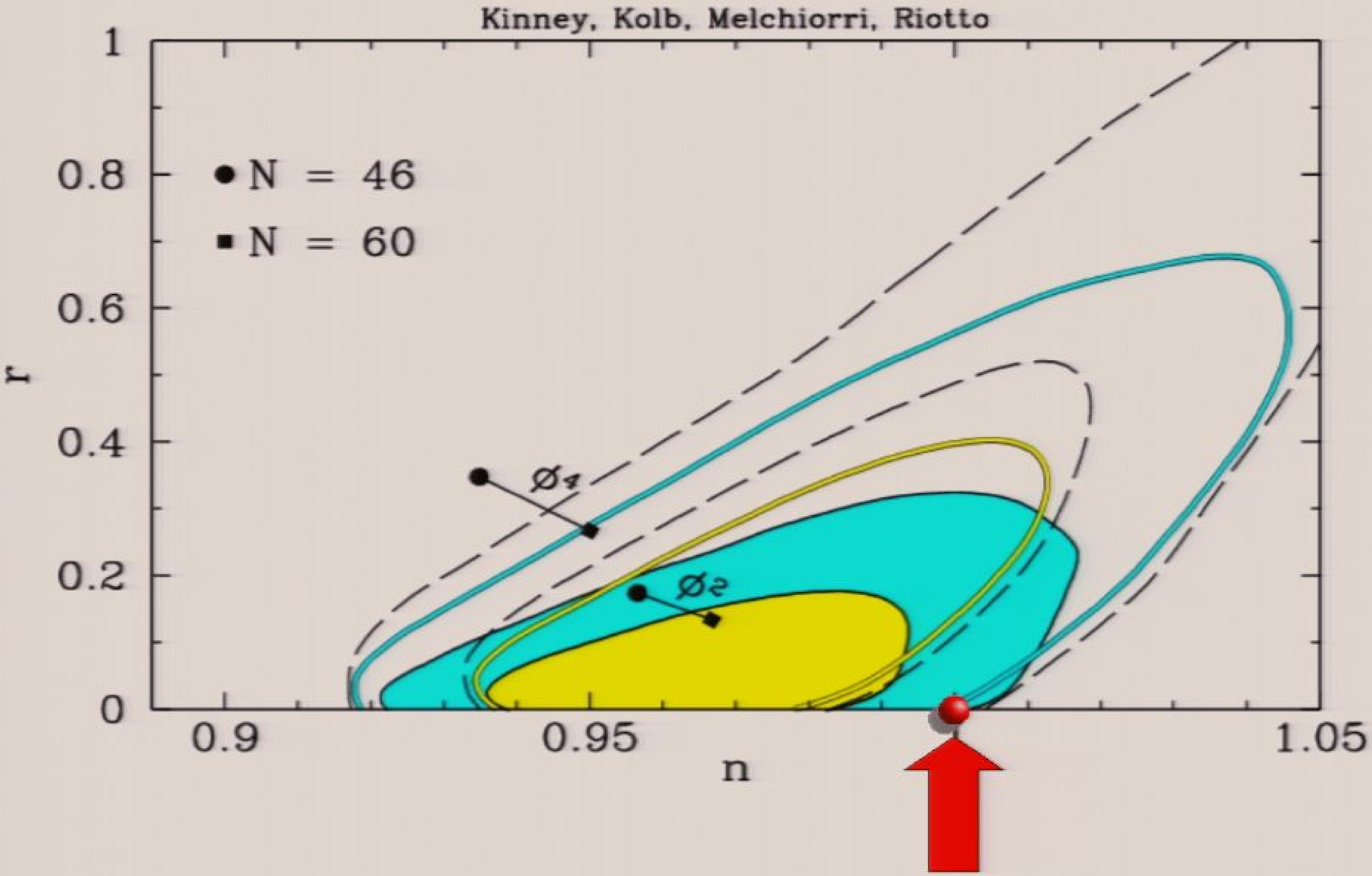
WMAP3a (+SDSS) limits on the (n,r) plane



r = tensor/scalar ratio

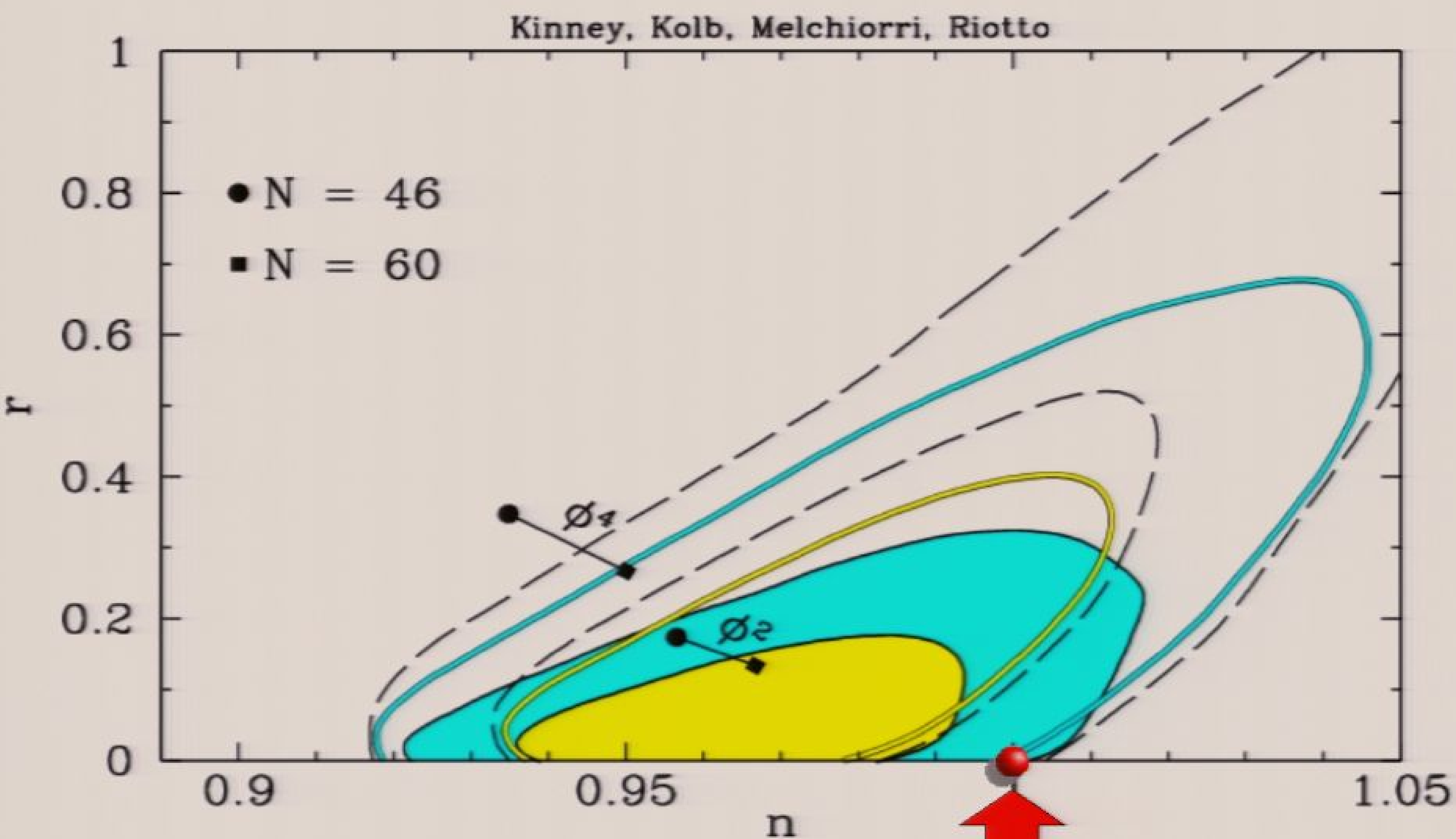
n = scalar spectral index

WMAP3a (+SDSS) limits on the (n,r) plane



Scale-invariant limit is
consistent with *all data sets!*

WMAP3a (+SDSS) limits on the (n,r) plane



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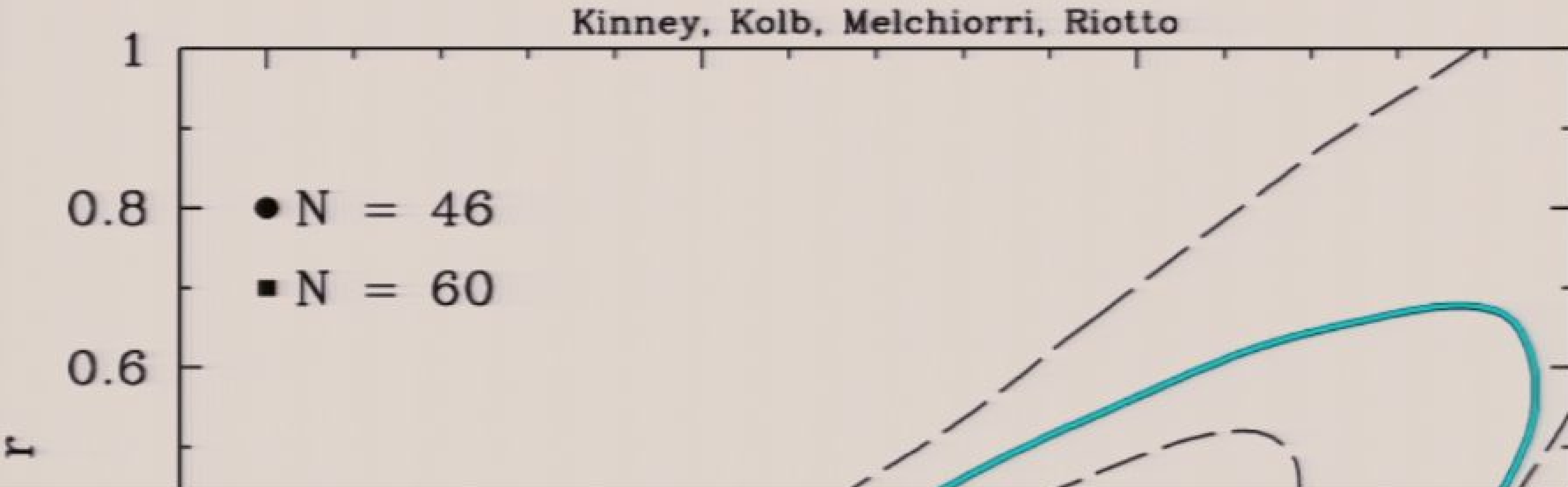
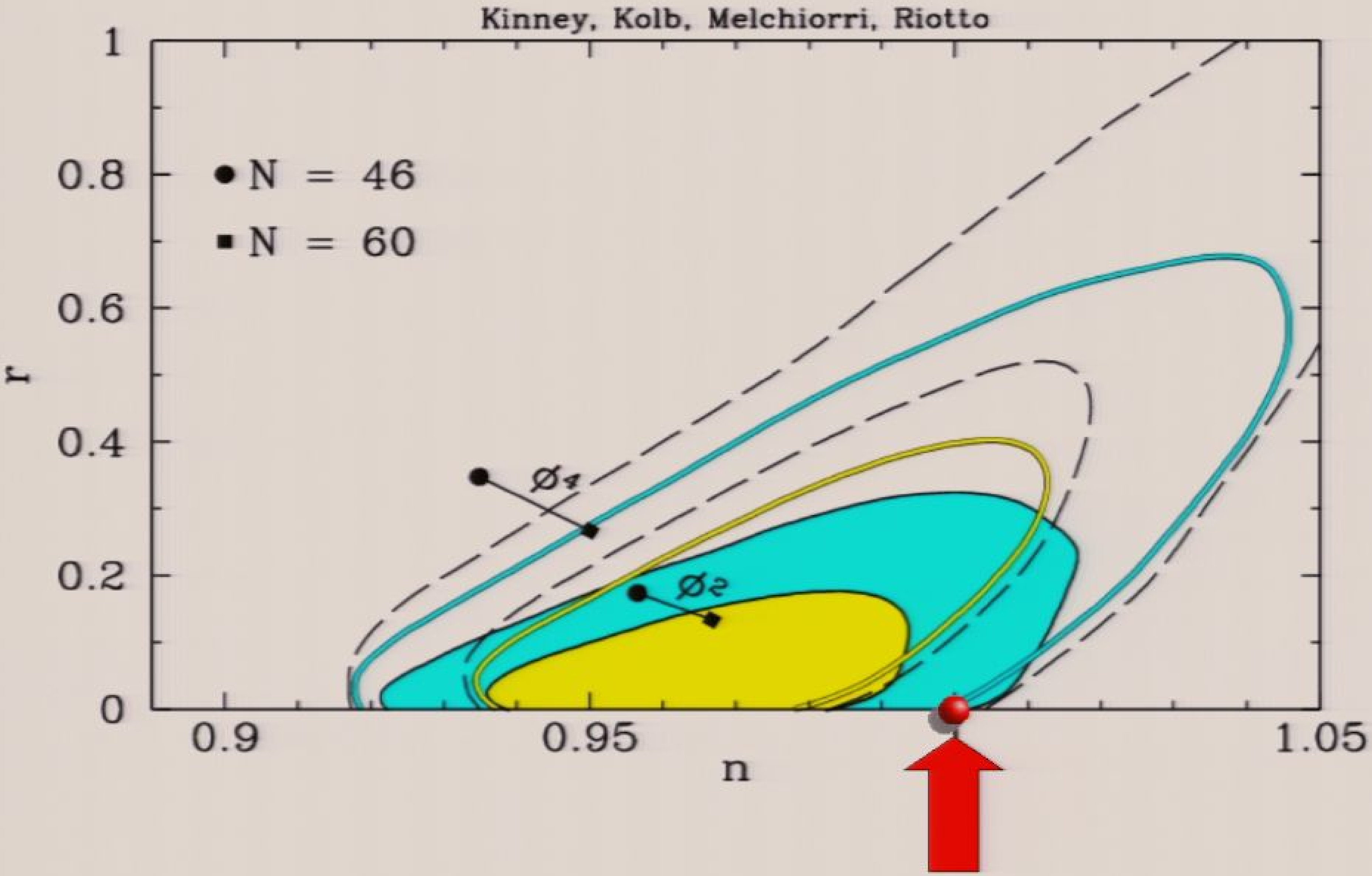


WMAP3a (+SDSS) limits on the (n,r) plane



Scale-invariant limit is consistent with *all data sets!*

PAPER: gr-qc/0503017

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TWO QUESTIONS:

(1) WHAT HAPPENS WHEN $\dot{\phi} \to 0$?

$$P_R \sim \frac{H^2}{\dot{\phi}}$$

PAPER: gr-qc/0503017

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(1) WHAT HAPPENS WHEN $\dot{\phi} \to 0$?

$$P_R \approx \frac{H^2}{\dot{\Phi}}$$

Seto, et. al astro-ph/9911119

Inoue et al hep-ph/0104083

(2) P_R

PAPER: gr-qc/0503017

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(2) P_R in non-slow roll models?

MODEL

$$V = V_0 = \text{const.}$$

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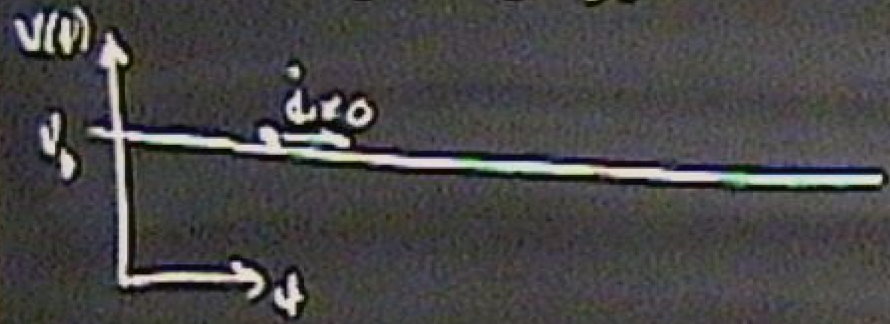
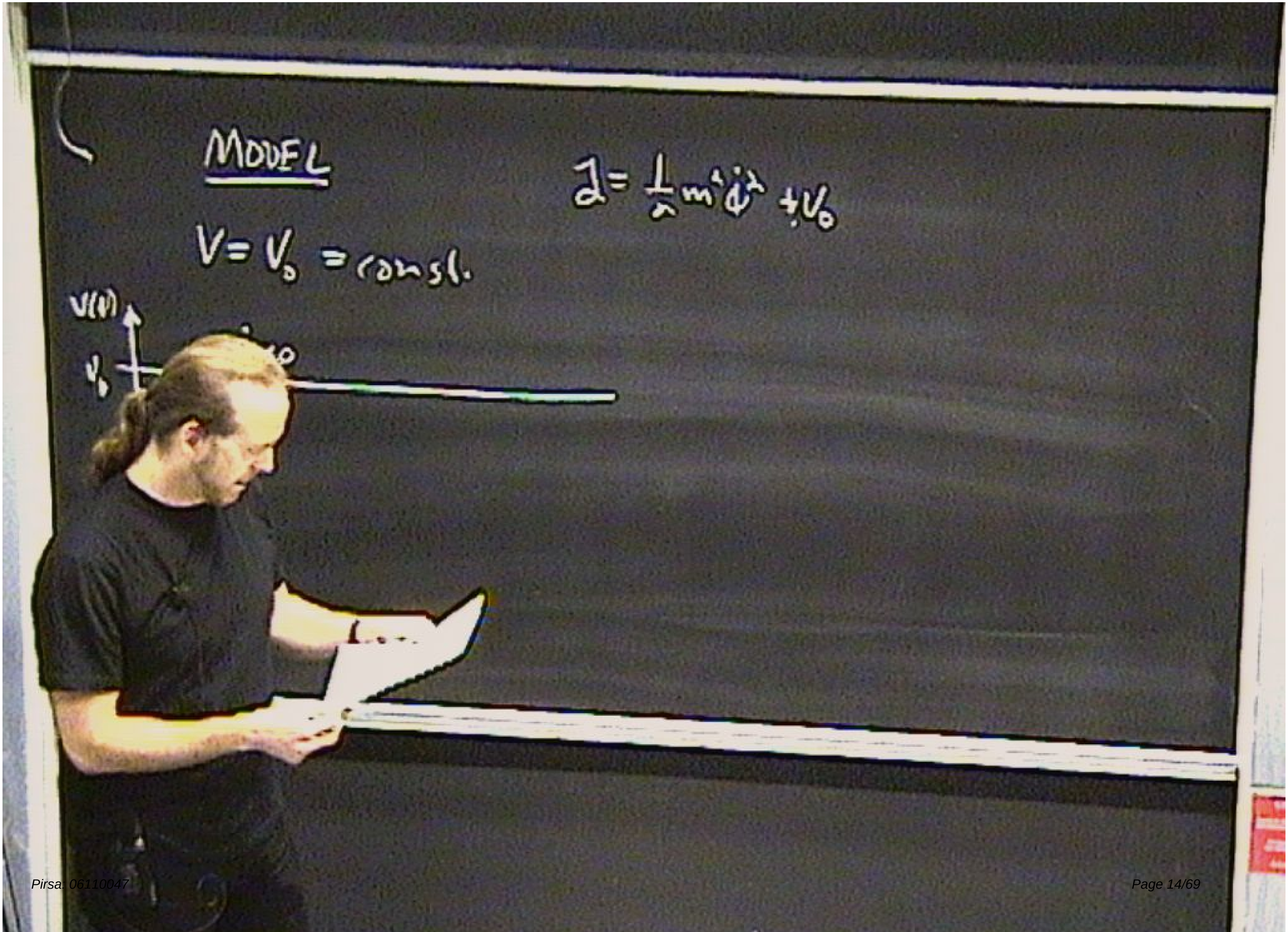
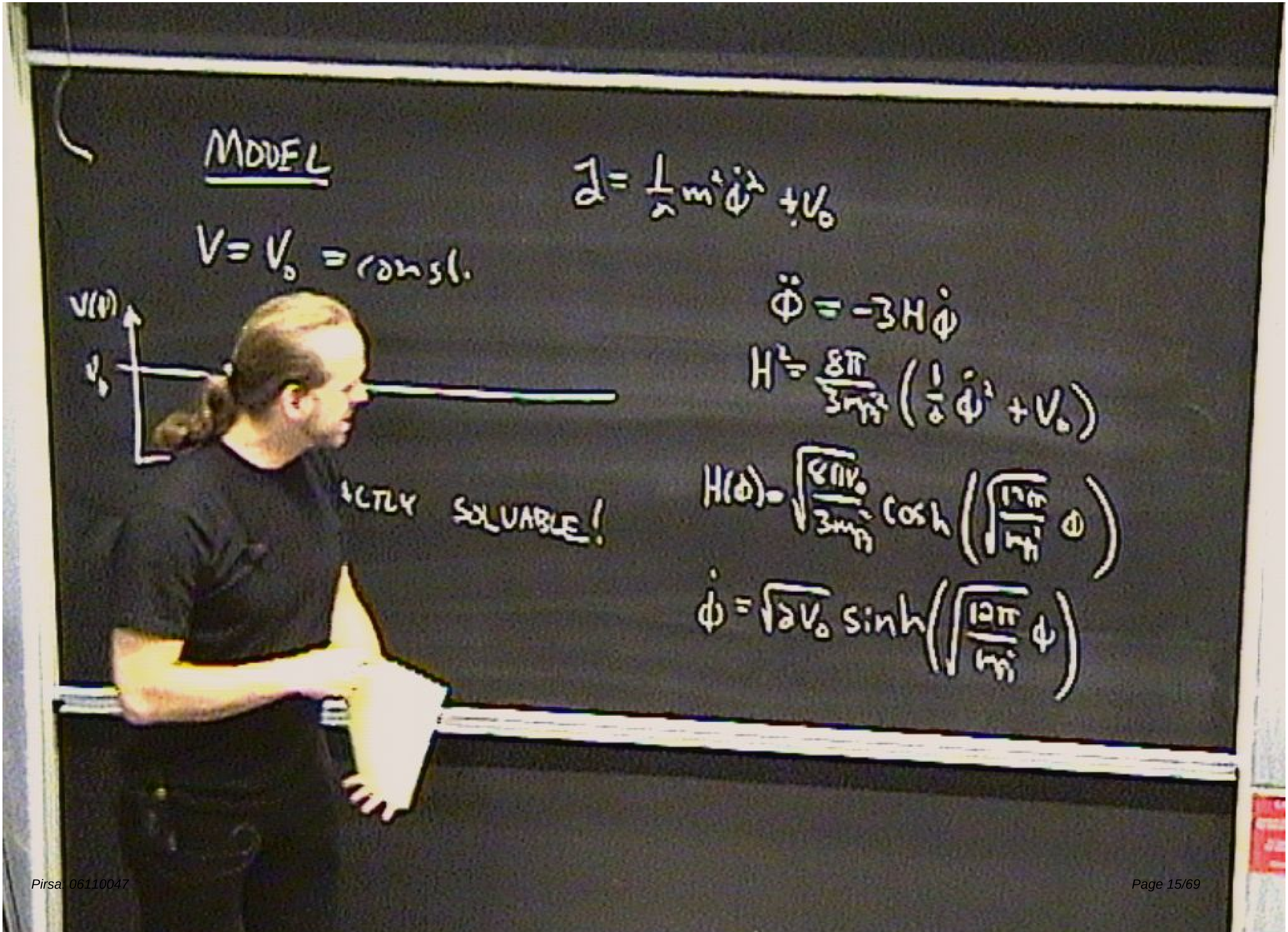
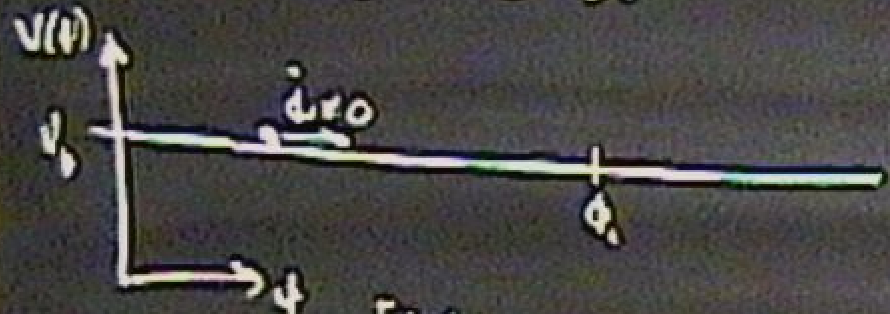



MODEL
V = V₀ = const.
ℒ = ½ m² φ̇² + V₀
V(φ)
V₀


MODEL
$\mathcal{L} = \frac{1}{2} m^2 \dot{\phi}^2 + V_0$
$V = V_0 = \text{const.}$
$V(\phi)$
V_0
ACTLY SOLUABLE!
$\ddot{\phi} = -3H\dot{\phi}$
$H^2 = \frac{8\pi}{3m_{Pl}^2}\left(\frac{1}{2}\dot{\phi}^2 + V_0\right)$
$H(\phi) = \sqrt{\frac{8\pi V_0}{3m_{Pl}^2}} \cosh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right)$
$\dot{\phi} = \sqrt{2V_0}\,\sinh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right)$

MODEL

$$V = V_0 = \text{const.}$$



EXACTLY SOLUABLE!

$$\mathcal{L} = \frac{1}{2} m^2 \dot{\phi}^2 + V_0$$

$$\ddot{\phi} = -3H\dot{\phi}$$

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$$\boxed{H(\phi) = \sqrt{\frac{8\pi V_0}{3m_{Pl}^2}} \cosh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right)}$$

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PAPER: [illegible] th/0503017

TWO QUESTIONS:

(1) WHAT HAPPENS WHEN $\dot{\phi} \to 0$?

$$P_R \sim \frac{H^2}{\dot{\phi}} \longrightarrow \infty$$

Seto, et. al astro-ph/9911119

Inoue et. al hep-ph/0104083

(2) P_R in non-slow roll models?

MODEL

$$\mathcal{L} = \frac{1}{2} m^2 \dot{\phi}^2 + V_0$$

$V = V_0$ [illegible]

(2) P_R in non-slow roll models?

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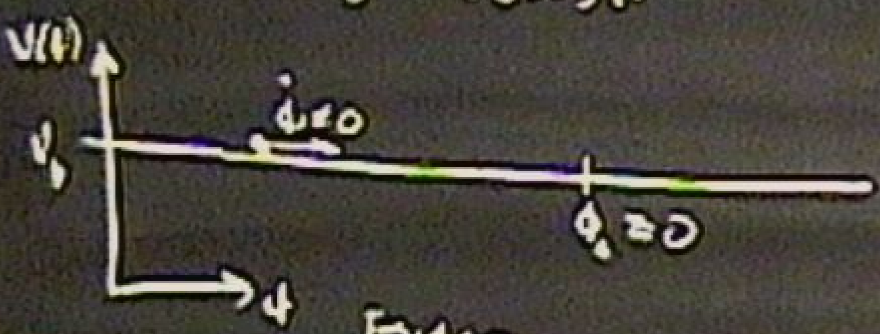
$$\mathcal{L} = \frac{1}{2} m^2 \dot{\phi}^2 + V_0$$

$$V = V_0 = \text{const.}$$



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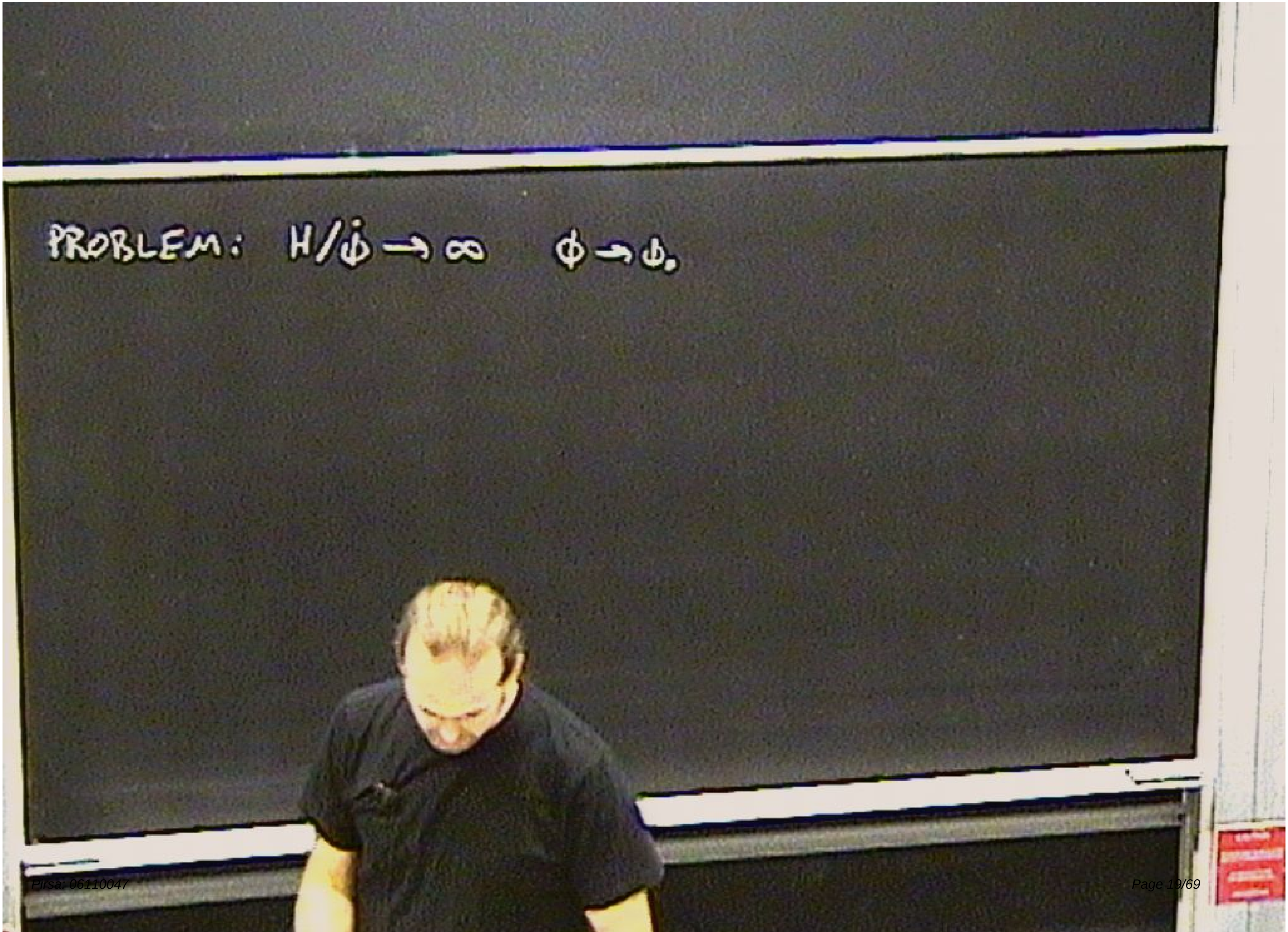
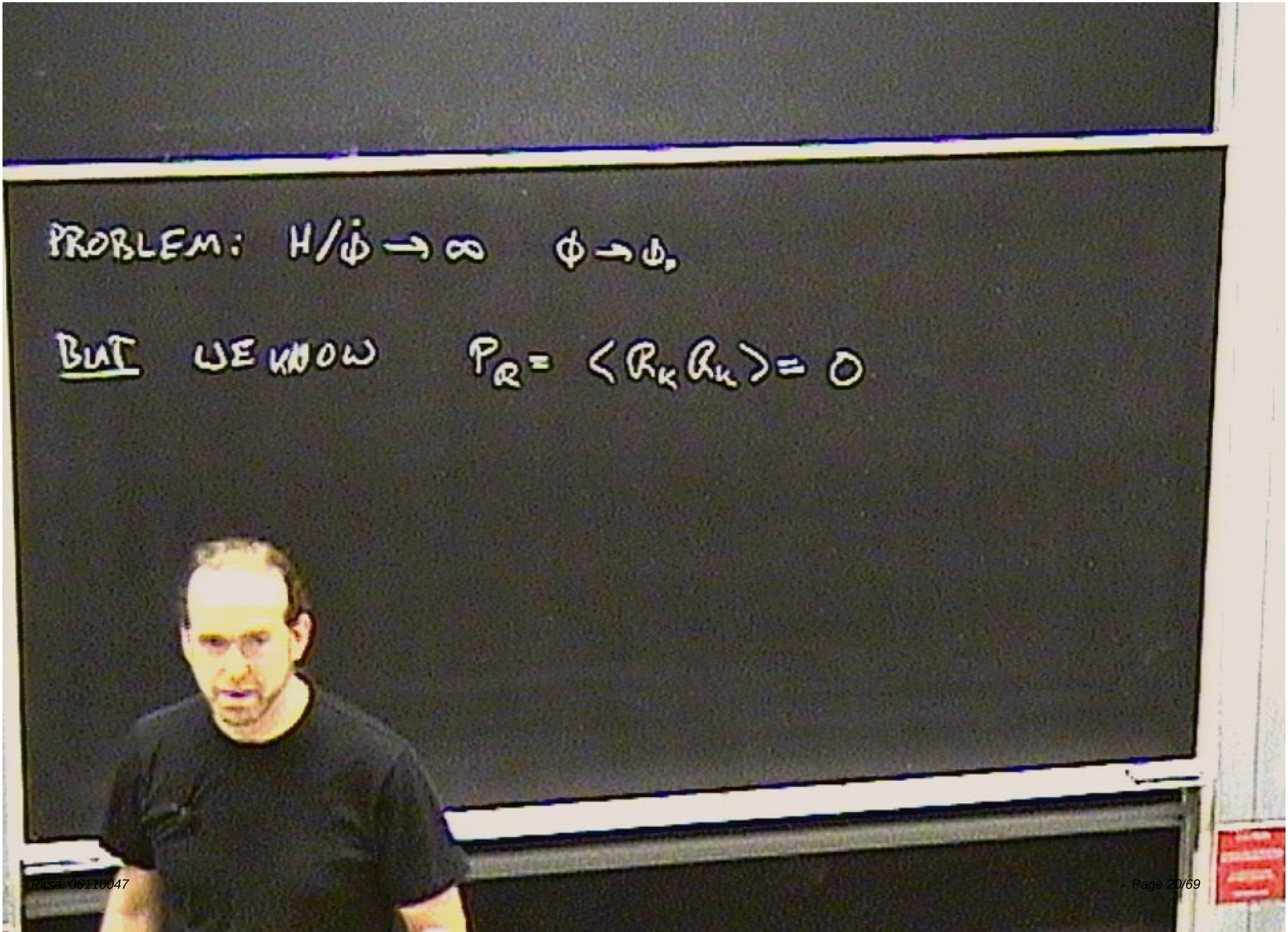
$$\ddot{\phi} = -3H\dot{\phi}$$

$$H^2 = \frac{8\pi}{3m_{Pl}^2}\left(\frac{1}{2}\dot{\phi}^2 + V_0\right)$$

$$\boxed{\begin{aligned} H(\phi) &= \sqrt{\frac{8\pi V_0}{3m_{Pl}^2}}\cosh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right) \\ \dot{\phi} &= \sqrt{2V_0}\,\sinh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right) \end{aligned}}$$


PROBLEM: $H/\dot{\phi} \to \infty$ $\phi \to \phi_0$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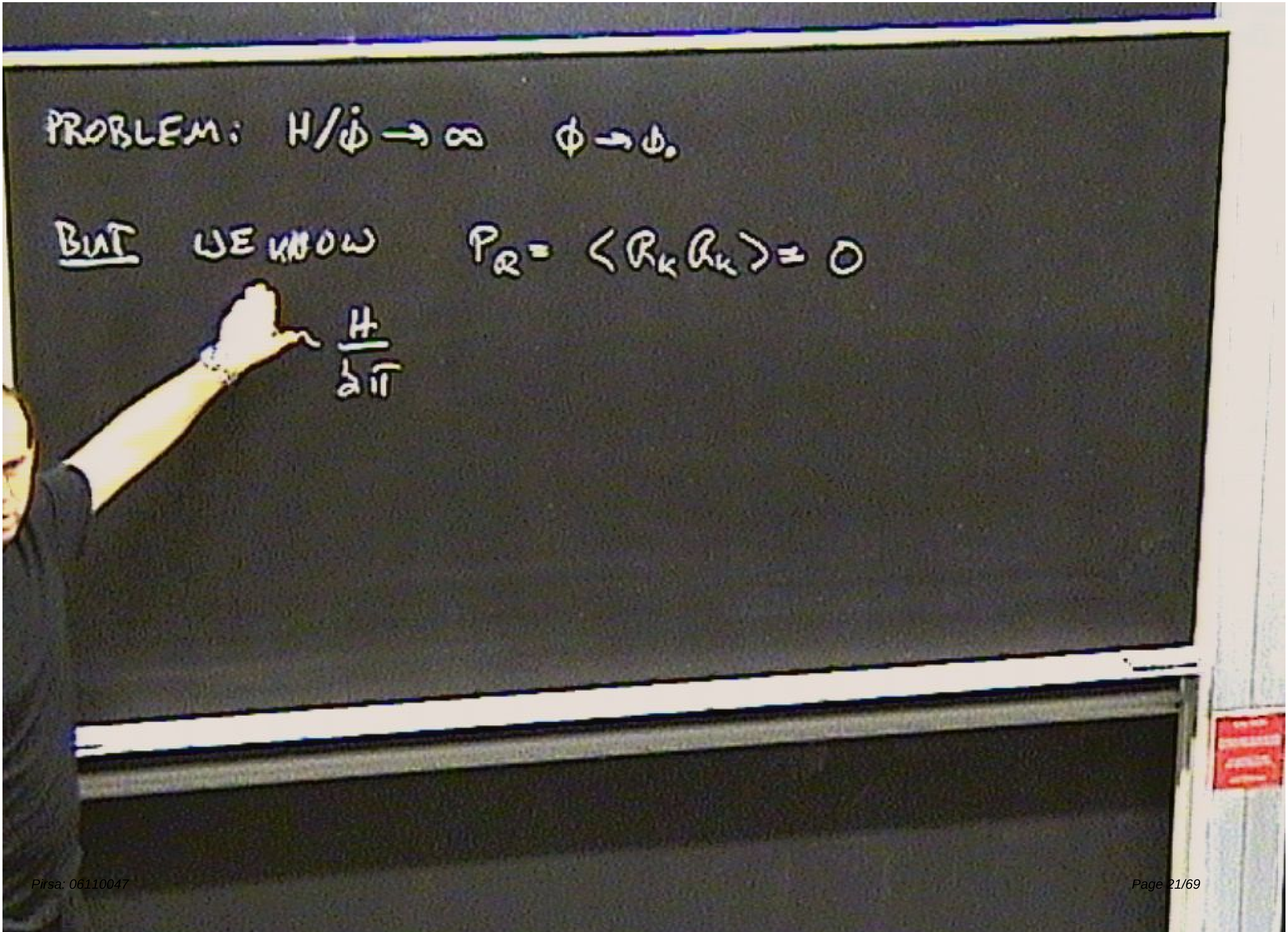
BUT WE KNOW $P_R = \langle R_k R_k \rangle = 0$


PROBLEM: H/φ̇ → ∞ φ → φ₀
BUT WE KNOW P_R = ⟨R_k R_k⟩ = 0
H/2π

PROBLEM: $H/\dot{\phi} \to \infty$ $\quad \phi \to \phi_0$

BUT WE KNOW $\quad P_{R} = \langle R_k R_k \rangle = 0$

$$\delta\phi \sim \frac{H}{2\pi}$$

MODEL

$$\mathcal{L} = \frac{1}{2} m^2 \dot{\phi}^2 + V_0$$

$$V = V_0 = \text{const.}$$

$$\ddot{\Phi} = -3H\dot{\phi}$$

$$H^2 = \frac{8\pi}{3m_{Pl}^2}\left(\frac{1}{2}\dot{\phi}^2 + V_0\right)$$

EXACTLY SOLVABLE!

$$\boxed{\begin{aligned} H(\phi) &= \sqrt{\frac{8\pi V_0}{3m_{Pl}^2}}\cosh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right) \\ \dot{\phi} &= \sqrt{2V_0}\,\sinh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right) \end{aligned}}$$

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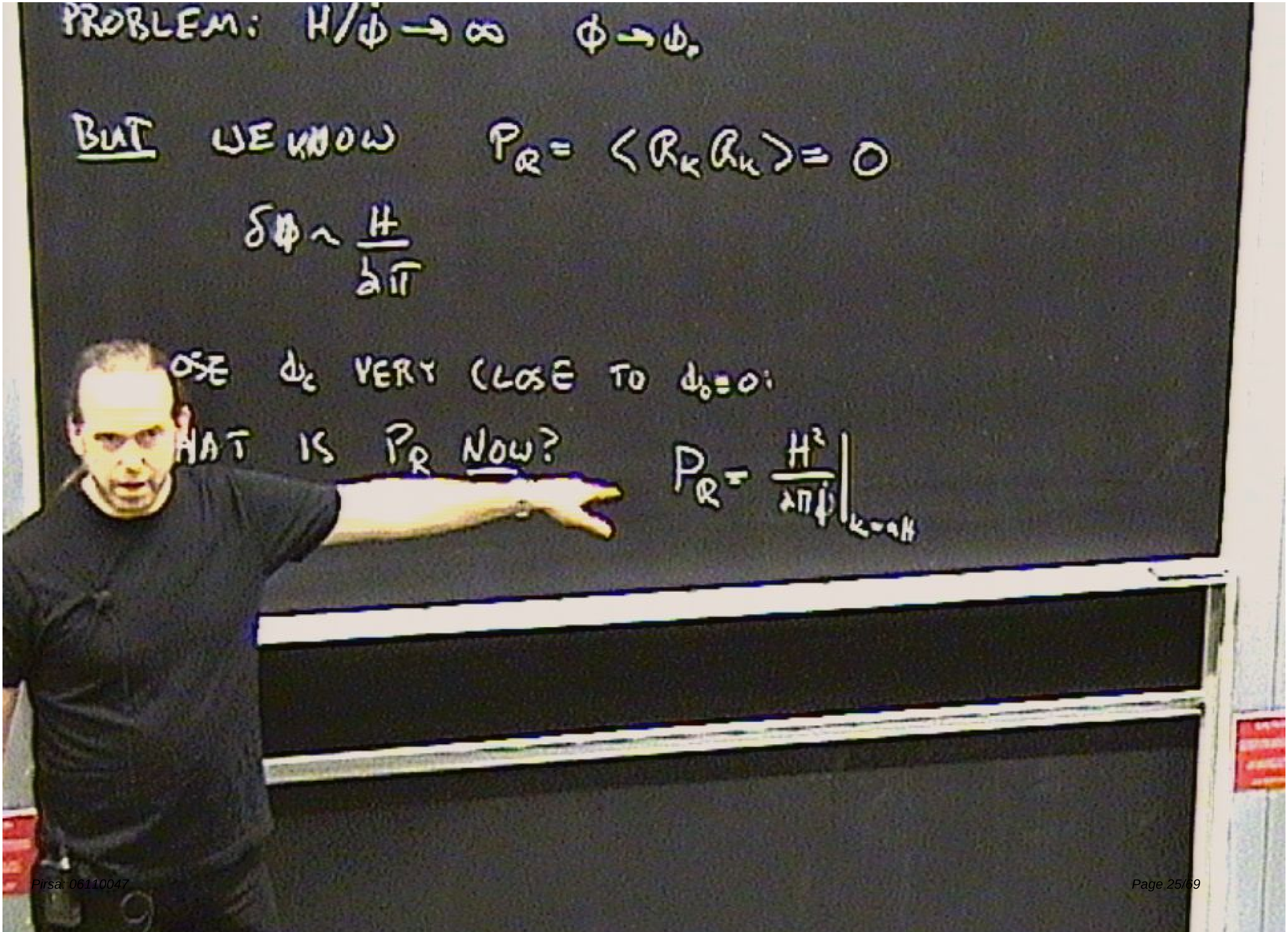
BUT WE KNOW $\quad P_R = \langle R_k R_k \rangle = 0$

$$\delta\phi \sim \frac{H}{2\pi}$$

CHOOSE ϕ_c VERY CLOSE TO $\phi_0 = 0$:

WHAT IS P_R NOW?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OSE ϕ_c VERY CLOSE TO $\phi_0 = 0$:
HAT IS P_R NOW?
$P_R = \frac{H^2}{2\pi\dot{\phi}}\Big|_{k=aH}$

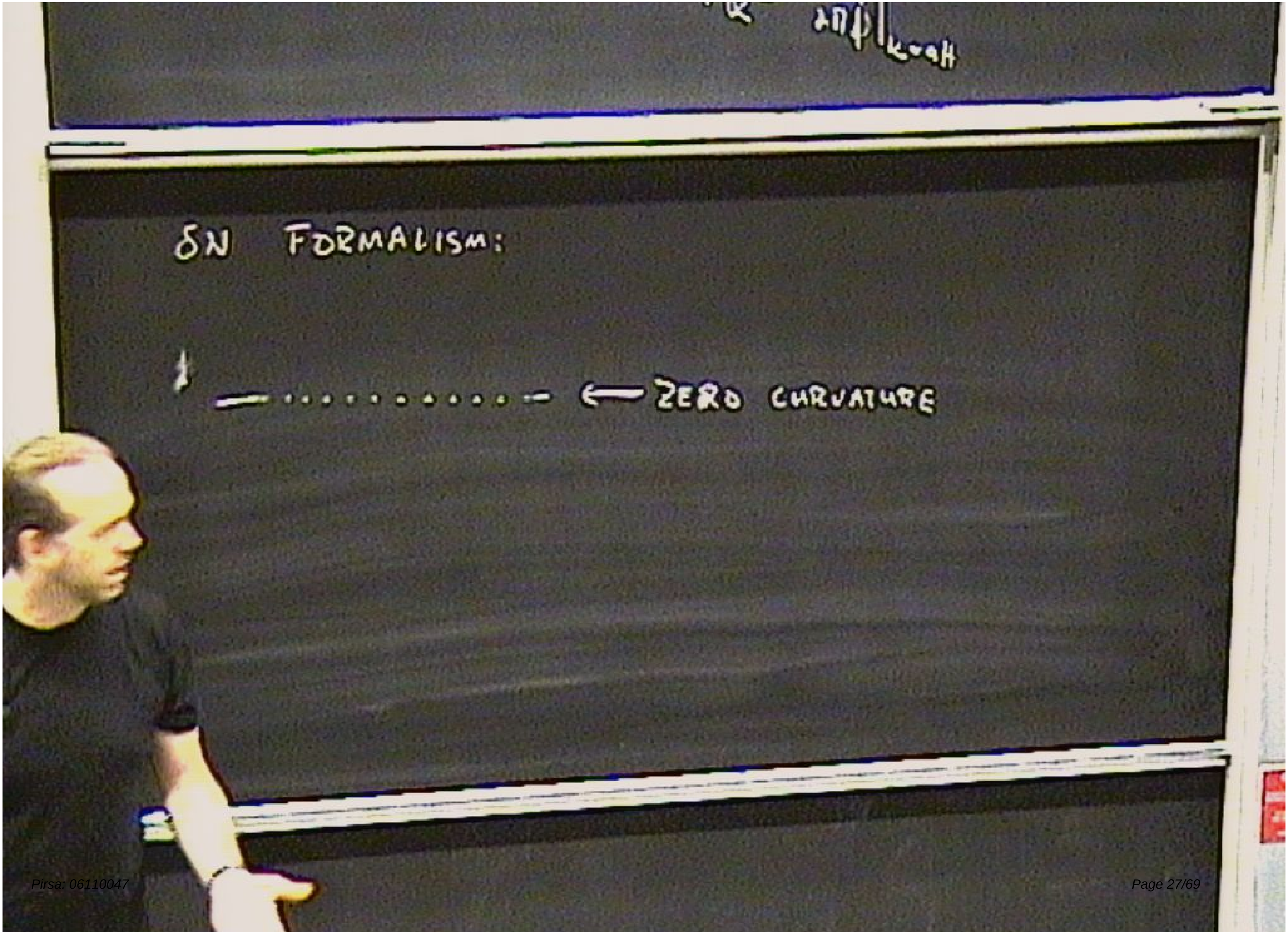
PROBLEM: $H/\dot{\phi} \to \infty \quad \phi \to \phi_0$

BUT WE KNOW $P_R = \langle R_k R_k \rangle = 0$

$$\delta\phi \sim \frac{H}{2\pi}$$

CHOOSE ϕ_c VERY CLOSE TO $\phi_0 = 0$:

WHAT IS P_R NOW? $\quad P_R = \left.\frac{H^2}{2\pi\dot{\phi}}\right|_{k=aH}$


δN FORMALISM:
ZERO CURVATURE

$\ln \phi|_{k=aH}$

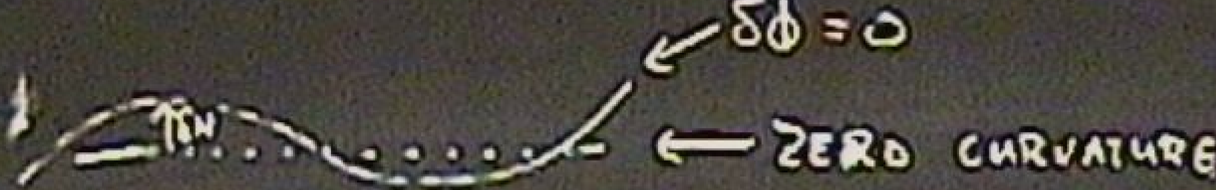
δN FORMALISM:

$\delta\phi = 0$

ZERO CURVATURE

$$\left. \ldots \ln\phi \right|_{k=aH}$$

δN FORMALISM:



$$P_R = \frac{\delta N}{\delta \phi}\,\delta\phi$$

$$\delta\phi \sim \frac{H}{2\pi}$$

CHOOSE ϕ_c VERY CLOSE TO $\phi_0 = 0$:

WHAT IS P_R NOW?

$$P_R = \frac{H^2}{2\pi\dot{\phi}}\bigg|_{k=aH}$$

δN FORMALISM:

$\delta\phi = 0$

⟵ ZERO CURVATURE

$$P_R = \frac{\delta N}{\delta\phi}\delta\phi$$

δN FORMALISM:

$\swarrow \delta\phi = 0$

$\longleftarrow$ ZERO CURVATURE

$$P_R = \frac{\delta N}{\delta \phi}\,\delta\phi$$

GUAGE - INVARIANT VARIABLE

$$u = a\delta\phi - z\mathcal{R} \qquad z \equiv \frac{a\dot{\phi}}{H}$$

δN FORMALISM:

$\leftarrow \delta\phi = 0$

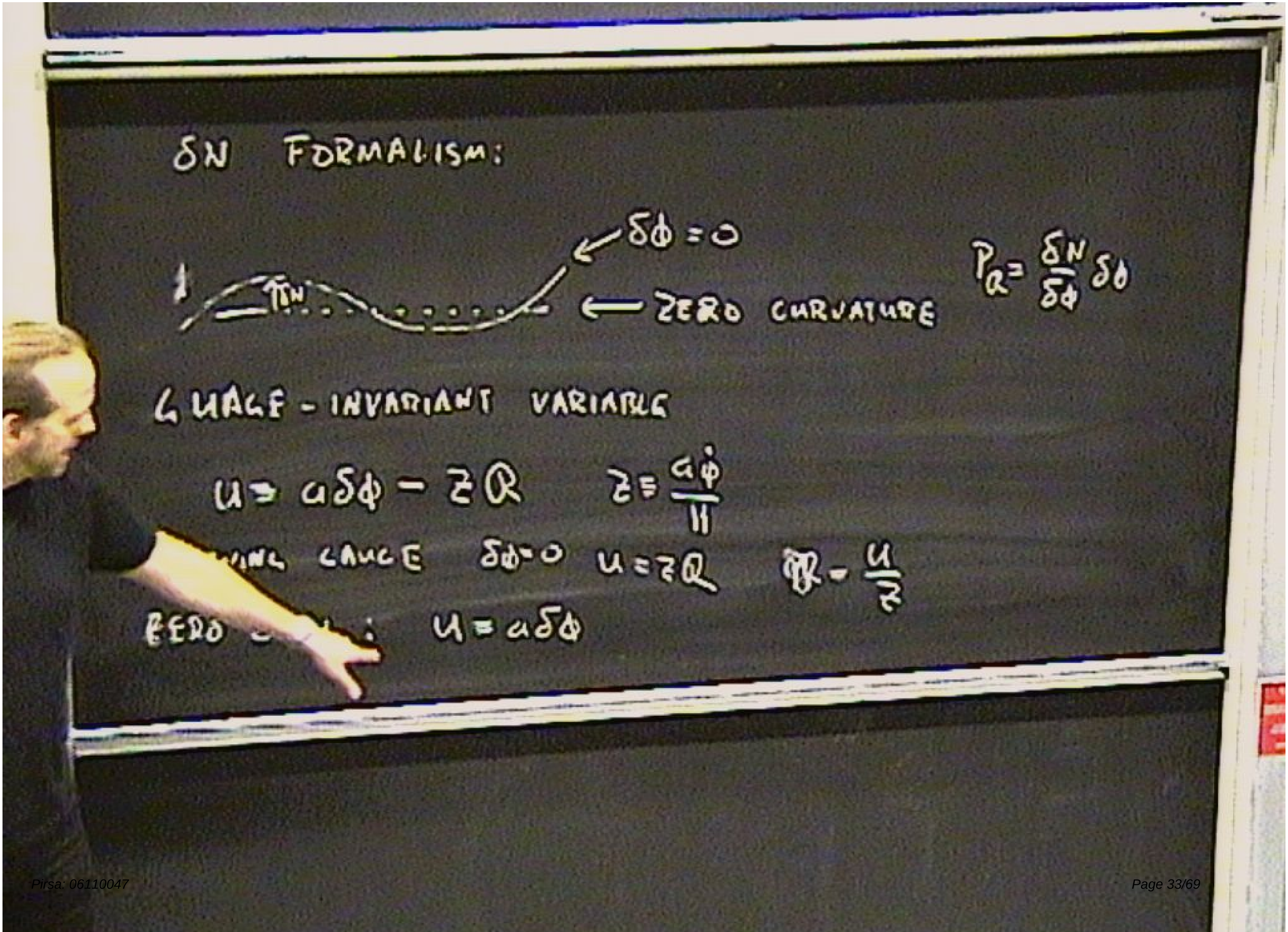
$\leftarrow$ ZERO CURVATURE

$$P_{\mathcal{R}} = \frac{\delta N}{\delta\phi}\,\delta\phi$$

GUAGE - INVARIANT VARIABLE

$$u = a\,\delta\phi - z\,\mathcal{R} \qquad z = \frac{a\dot{\phi}}{H}$$

COMOVING GAUGE $\quad \delta\phi = 0 \quad u = z\mathcal{R} \quad \mathcal{R} = \frac{u}{z}$


δN FORMALISM:
$\delta\phi = 0$
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$P_R = \frac{\delta N}{\delta\phi}\delta\phi$
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GAUGE $\delta\phi = 0$ $u = z\mathcal{R}$ $\mathcal{R} = \frac{u}{z}$
$u = a\delta\phi$

δN FORMALISM:

$\leftarrow \delta\phi = 0$

$\leftarrow$ ZERO CURVATURE

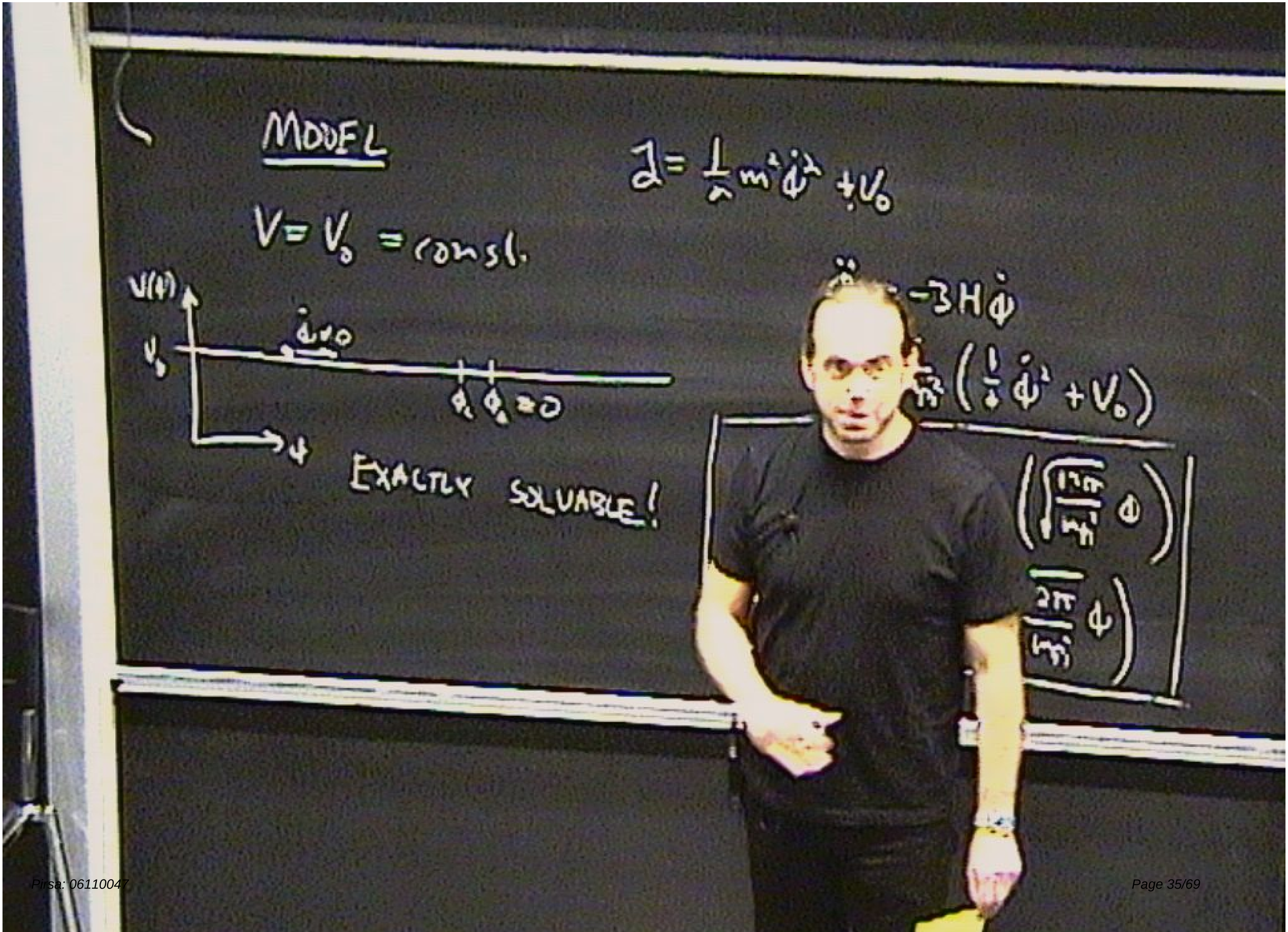
$$P_{R} = \frac{\delta N}{\delta\phi}\delta\phi$$

GAUGE - INVARIANT VARIABLE

$$u = a\delta\phi - zR \qquad z = \frac{a\dot{\phi}}{H}$$

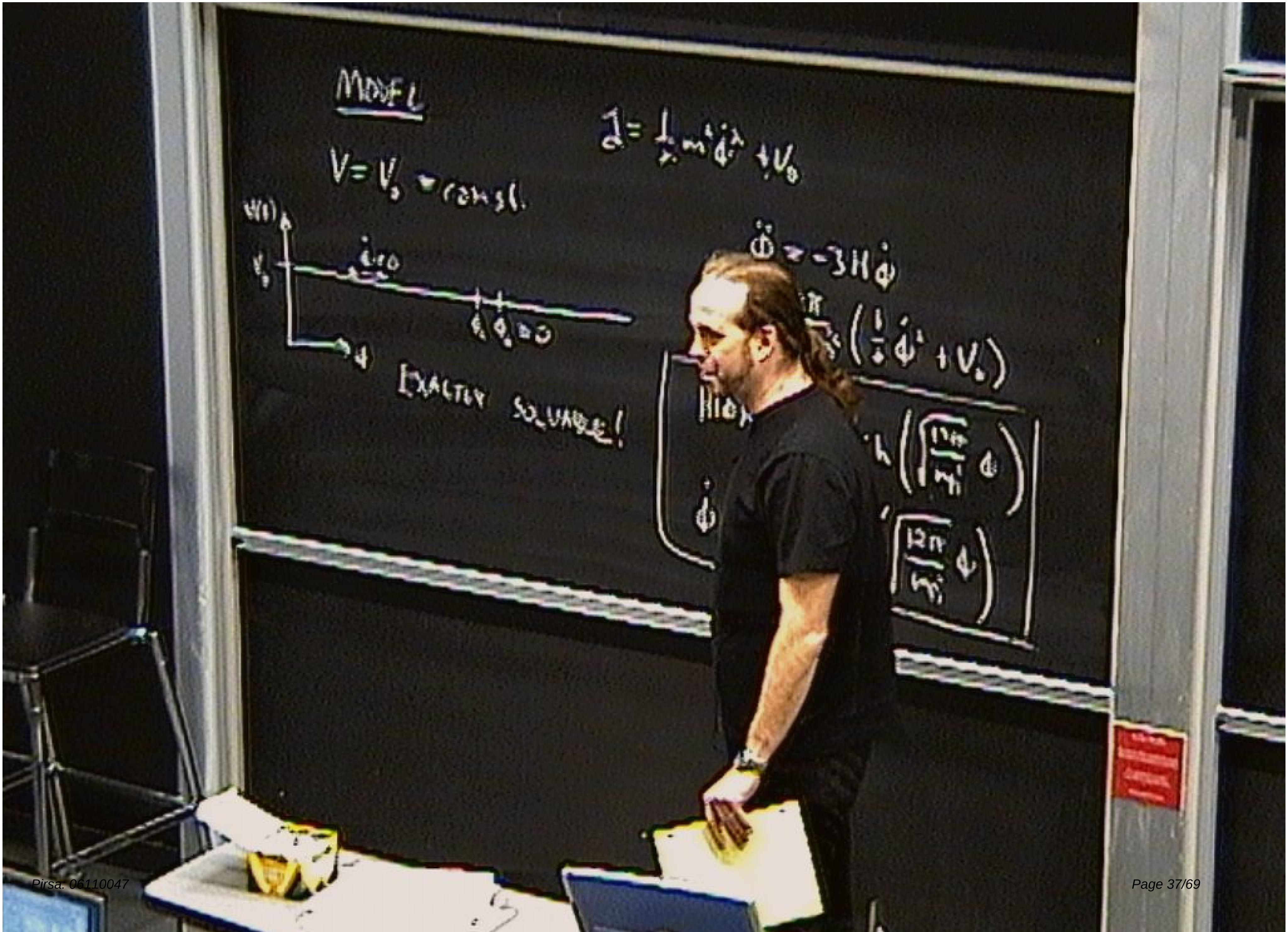
COMOVING GAUGE $\delta\phi = 0$ $u = zR$ $R = \frac{u}{z}$

ZERO CURV. : $u = a\delta\phi$


MODEL
V = V0 = const.
EXACTLY SOLVABLE!

MODE EQUATION

$$u_k'' + \left(k^2 - \frac{z''}{z}\right) u_k = 0$$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MODEL

$$\mathcal{L} = \frac{1}{2} m^2 \dot{\phi}^2 + V_0$$

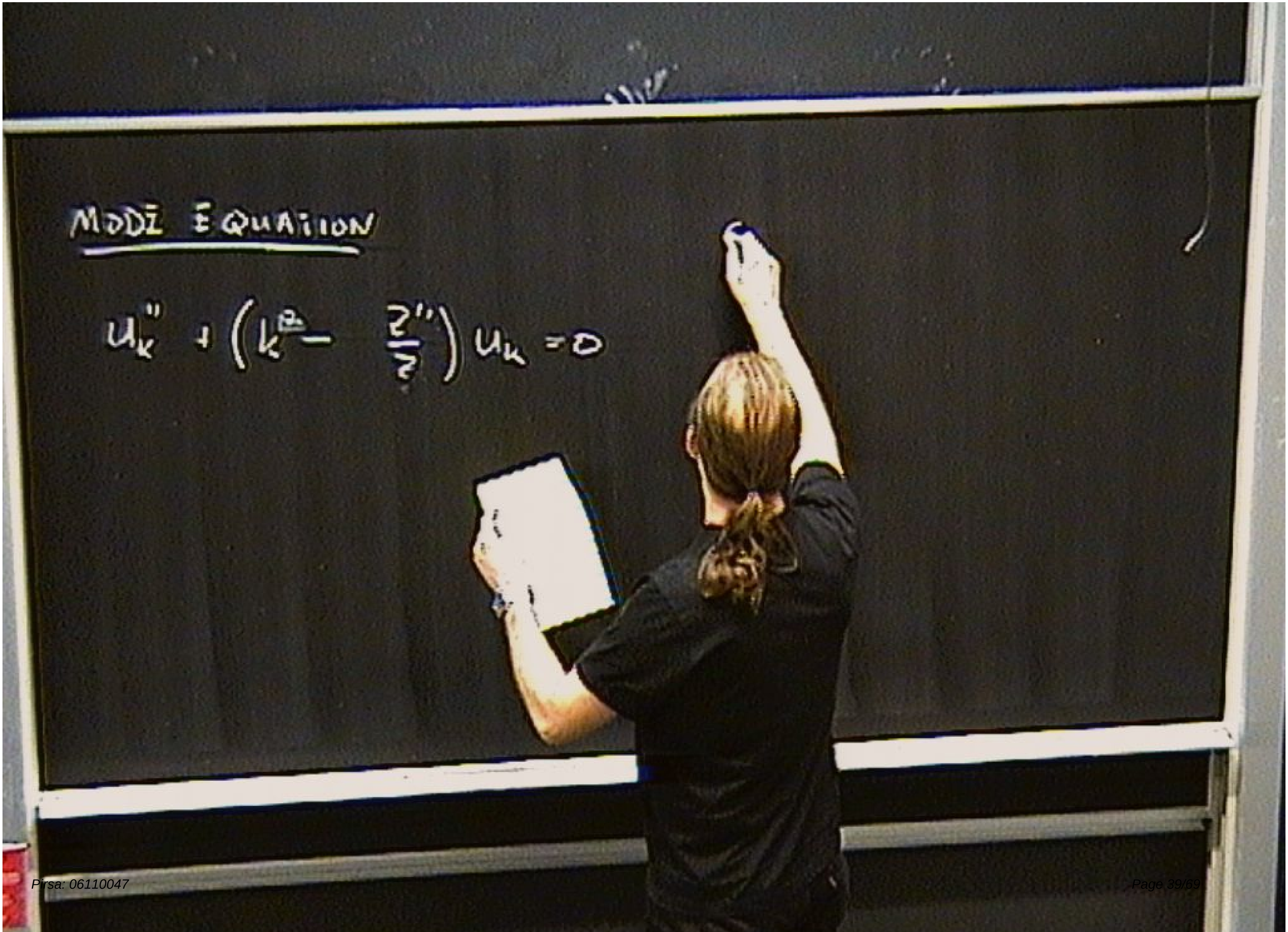
$V = V_0 = \text{const.}$

EXACTLY SOLVABLE!

$$\ddot{\phi} = -3H\dot{\phi}$$

$$H^2 = \frac{8\pi}{3 m_{Pl}^2}\left(\frac{1}{2}\dot{\phi}^2 + V_0\right)$$

$$\boxed{\begin{aligned} H(\phi) &= \sqrt{\frac{8\pi V_0}{3 m_{Pl}^2}}\cosh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right) \\ \dot{\phi} &= \sqrt{2V_0}\,\sinh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right) \end{aligned}}$$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$$\eta(\phi) \approx \frac{H''}{H} = 3$$

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$$\xi^2(\phi) = \cancel{3\epsilon}(\phi)$$

MODE EQUATION

$$u_k'' + \left(k^2 - \frac{z''}{z}\right) u_k = 0$$

$$u_k'' + \left(k^2 - 2a^2H^2\right) u_k = 0$$

$$\epsilon(\phi) = 3\cancel{\tanh^2}\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right) \; 0$$

$$\eta(\phi) \propto \frac{H''}{H} = 3$$

$$\xi^2(\phi) = \cancel{3\epsilon(\phi)} \; 0$$

MODE EQUATION

$$u_k'' + \left(k^2 - \frac{z''}{z}\right) u_k = 0$$

$$u_k'' + \left(k^2 - 2a^2H^2\right) u_k = 0$$

$$u_k = A_k H_{3/2}(-k\tau) + B_k H_{-3/2}(-k\tau)$$

$$\epsilon(\phi) = \cancel{3\tanh^2}\!\!{}^{0}\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right)$$

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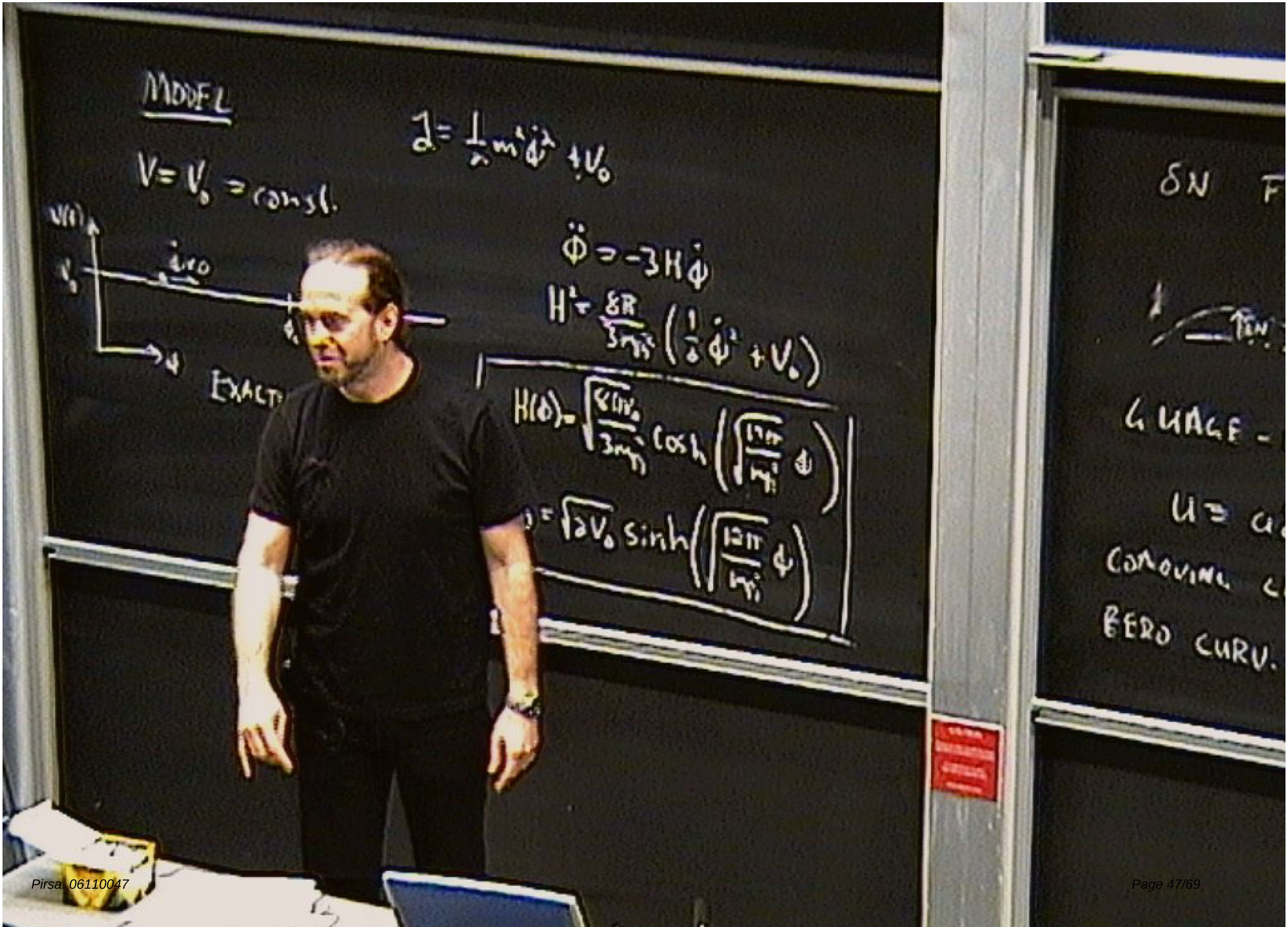
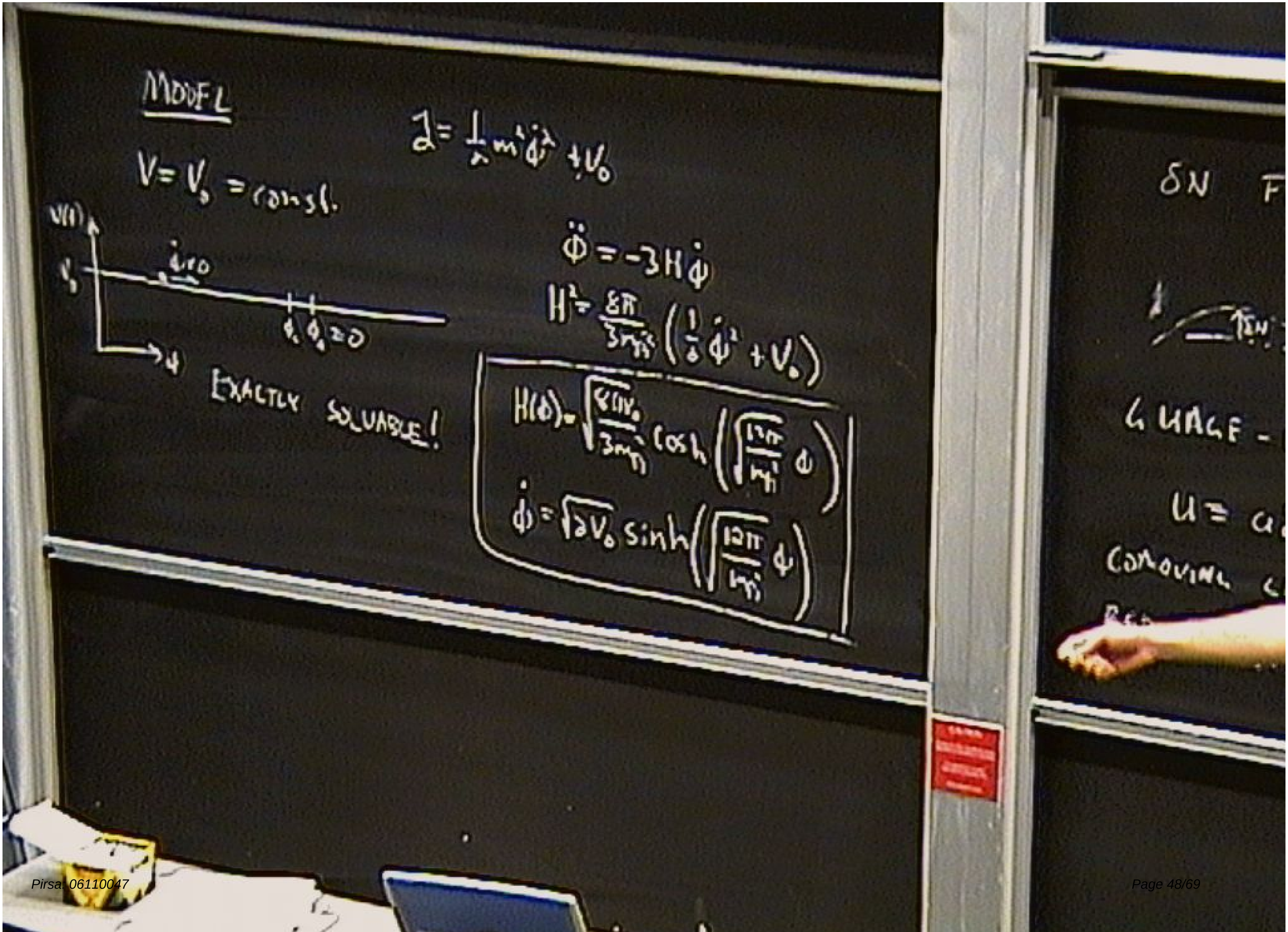
$$P_R = \sqrt{\frac{k^3}{2\pi^2}}\left|\frac{u_k}{z}\right| = \left(\frac{H^2}{2\pi\dot{\phi}}\right)$$

$$\text{B. D.} \Rightarrow u_k = N_k H_{3/2}(-k\tau) \qquad P_R = \left|\frac{k^3}{2\pi^2}\right| \left|\frac{u_k}{z}\right|^2 = \left(\frac{H^2}{2\pi\dot\phi}\right)$$

$$P_R = \left(\frac{H^2}{2\pi\dot\phi}\right)_{k=aH} \Rightarrow n = 1 + 2\eta = \text{[illegible]}$$


MODEL
V = V0 = const.
EXACT
δN
GUAGE -
COMOVING
BERO CURV.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$\mathcal{L} = \frac{1}{2} m^2 \dot{\phi}^2 + V_0$
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$H(\phi) = \sqrt{\frac{8\pi V_0}{3m_{Pl}^2}}\cosh\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\phi\right)$
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δN
GAUGE -
COMOVING

$$\text{B.D.} \Rightarrow u_k = N_k H_{3/2}(-k\epsilon)$$

$$P_R = \sqrt{\frac{k^3}{2\pi}}\left|\frac{u_k}{z}\right| = \left(\frac{H^2}{2\pi\dot{\phi}}\right)$$

$$P_R = \left(\frac{H^2}{2\pi\dot{\phi}}\right)_{k=aH} \Rightarrow n = 1 + 2\eta = ⚪$$

$$\frac{u_k''}{u_k} = \frac{z''}{z}$$

$$P_R = \left(\frac{H^2}{2\pi\dot{\phi}}\right)_{\frac{k}{aH}\to 0} \Rightarrow n = 1 + 2\eta = 0$$

$$\frac{u_k''}{u_k} = \frac{z''}{z} \qquad P_Q = \left(\frac{H^2}{2\pi\dot{\phi}}\right)_{\phi=\phi_c} \qquad n - 1 = 0$$

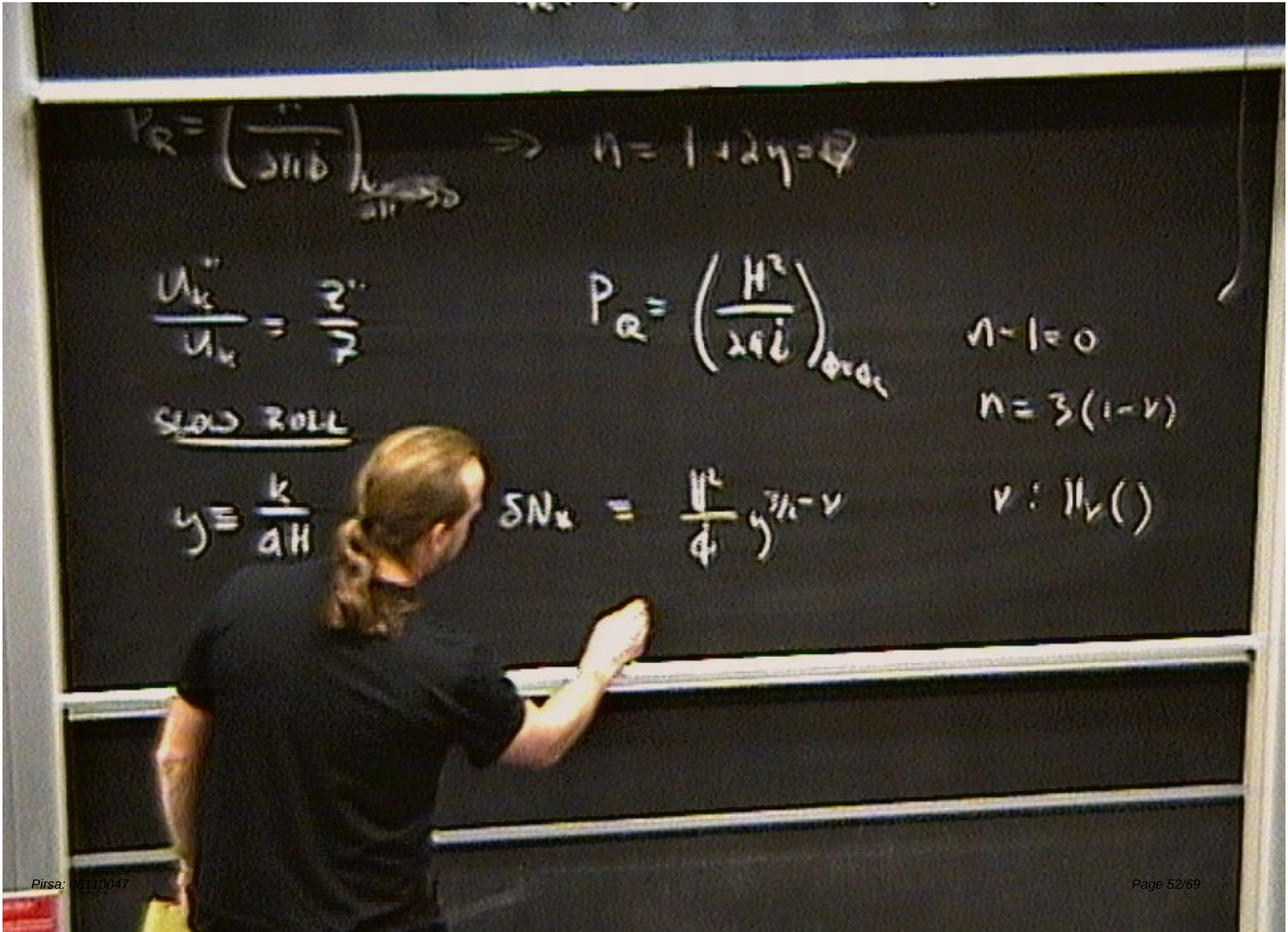
$$P_R = \left(\frac{H^2}{2\pi\dot{\phi}}\right)_{\frac{k}{aH}\to 0} \Rightarrow n = 1 + 2\eta = 0$$

$$\frac{u_k''}{u_k} = \frac{z''}{z}$$

$$P_Q = \left(\frac{H^2}{2\pi\dot{\phi}}\right)_{\phi=\phi_c} \qquad n - 1 = 0$$

SLOW ROLL

$$y \equiv \frac{k}{aH}$$


u_k''/u_k = z''/z
P_R = (H²/2πφ̇)_{a=a_c}
n-1=0
SLOW ROLL
n = 3(1-ν)
y = k/aH
δN_k = H²/φ̇ y^{3/2-ν}
ν : H_ν()

$$P_R = \left(\frac{H}{2\pi\dot{\phi}}\right)_{\frac{k}{aH}\to 0} \Rightarrow n = 1 + 2\eta = 0$$

$$\frac{u_k''}{u_k} = \frac{z''}{z}$$

$$P_Q = \left(\frac{H^2}{2\pi\dot{\iota}}\right)_{\phi=\phi_c}$$

$n - 1 = 0$

$n = 3(1 - \nu)$

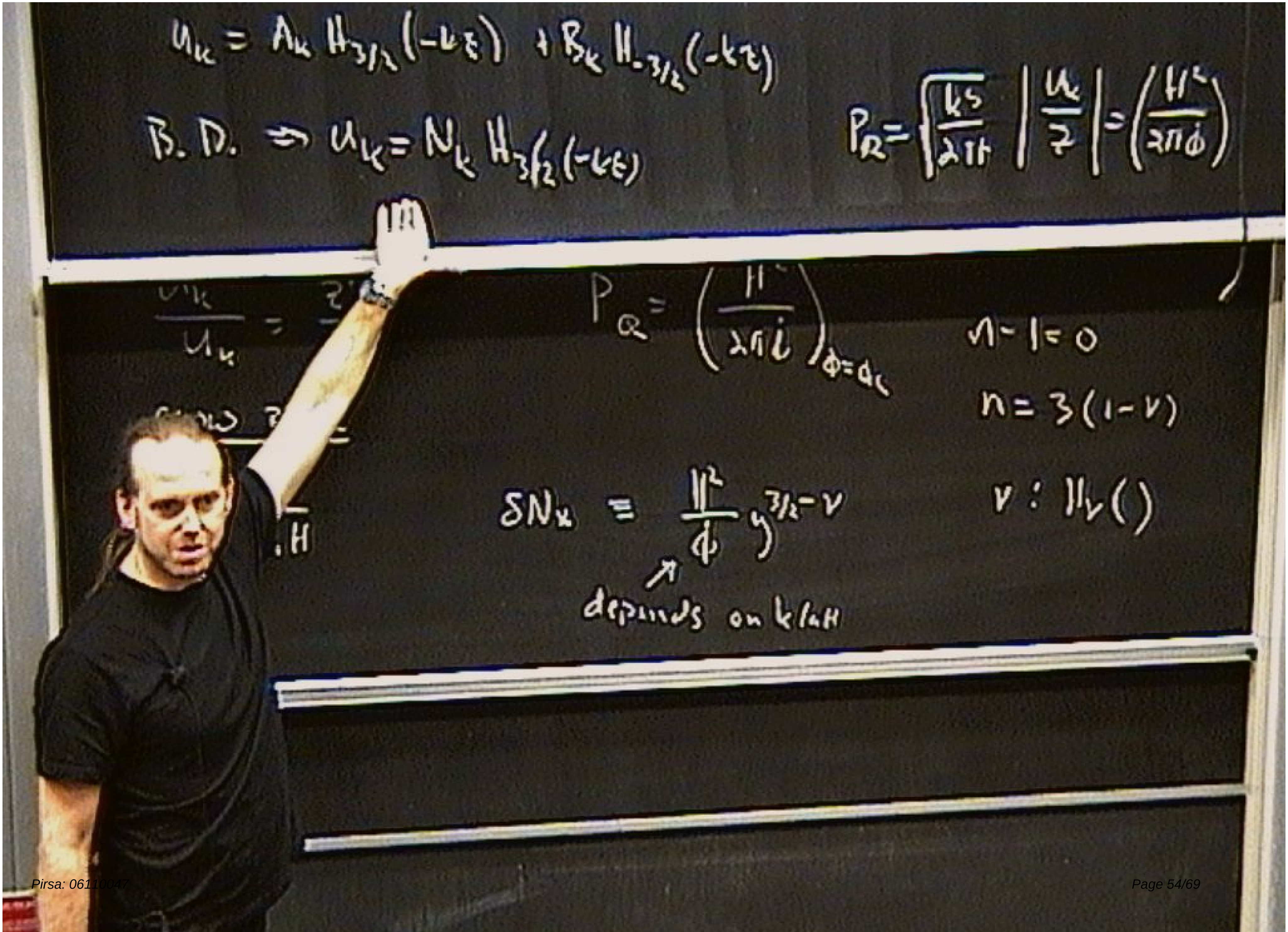
SLOW ROLL

$$y \equiv \frac{k}{aH}$$

$$\delta N_k = \frac{H^2}{\dot{\phi}} y^{3/2-\nu}$$

depends on k/aH

$\nu : H_\nu(\,)$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$B.D. \Rightarrow u_k = N_k H_{3/2}(-k\tau)$
$P_R = \sqrt{\frac{k^3}{2\pi^2}} \left| \frac{u_k}{z} \right| = \left(\frac{H^2}{2\pi\dot\phi} \right)$
$P_Q = \left(\frac{H^2}{2\pi\dot\phi} \right)_{\phi=\phi_c}$
$n-1=0$
$n = 3(1-\nu)$
$\nu : H_\nu(\,)$
$\delta N_k = \frac{H^2}{\dot\phi} y^{3/2-\nu}$
depends on k/aH

$$r_R = \left(\frac{\quad}{2\pi\dot\phi}\right)_{\frac{k}{aH}\to 0} \Rightarrow n = 1 + 2\eta - \dots$$

$$\frac{u_k''}{u_k} = \frac{z''}{z}$$

$$P_R = \left(\frac{H^2}{2\pi\dot\phi}\right)_{\phi=\phi_c}$$

$$n - 1 = 0$$

$$n = 3(1-\nu)$$

SLOW ROLL

$$y \equiv \frac{k}{aH}$$

$$\boxed{\delta N_k = \frac{H^2}{\dot\phi}\, y^{3/2-\nu}}$$

depends on k/aH

$$\nu : H_\nu(\,)$$

SLOW ROLL

$$n = 3(1-\nu)$$

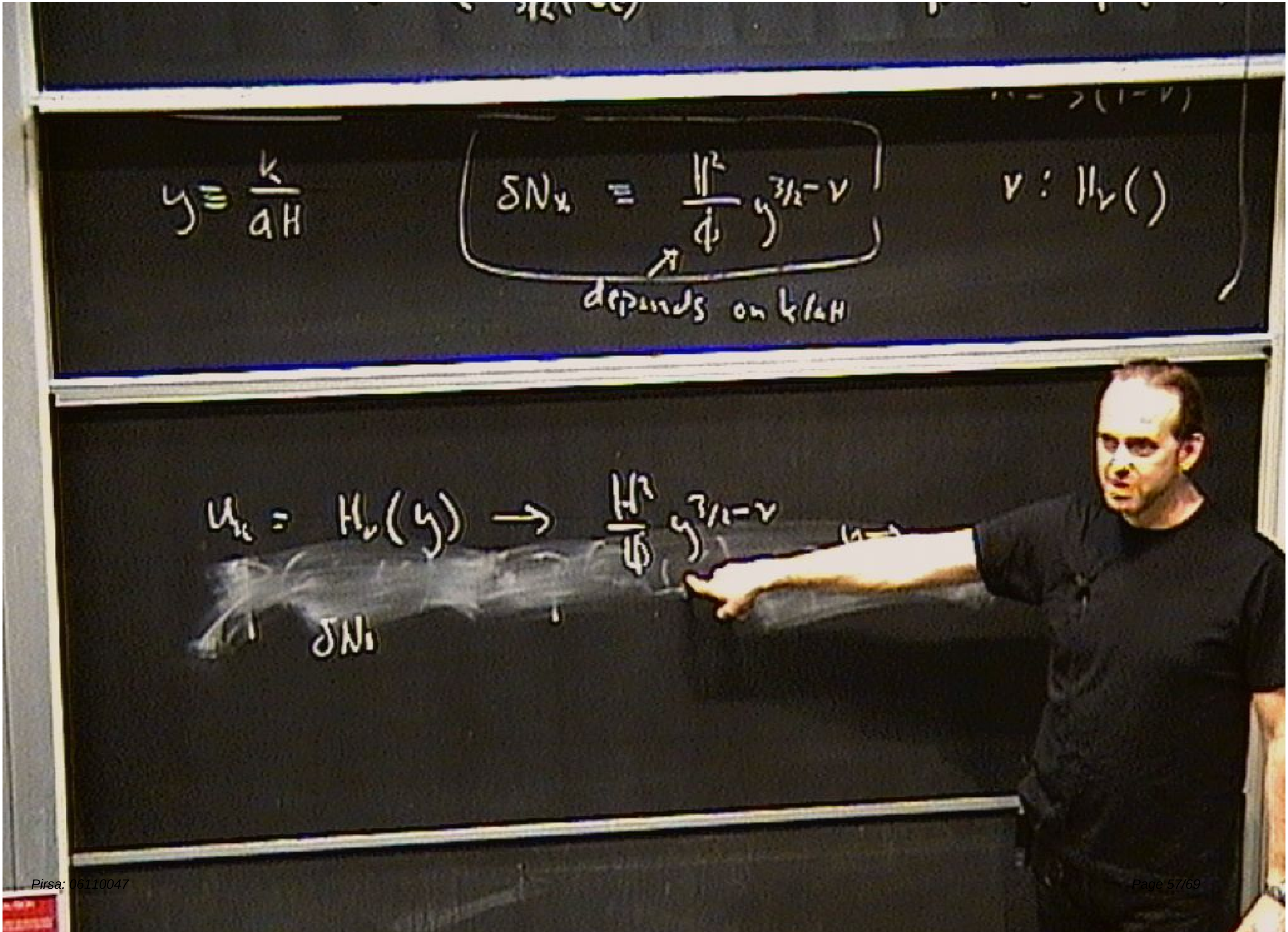
$$y \equiv \frac{k}{aH}$$

$$\boxed{\delta N_k = \frac{H^2}{\dot\phi}\, y^{3/2-\nu}}$$

depends on k/aH

$$\nu : H_\nu(\,)$$

$$u_k = H_\nu(y) \longrightarrow \frac{H^2}{\dot\phi}\, y^{3/2-\nu} \qquad y \to 0$$


$y \equiv \frac{k}{aH}$
$\delta N_k = \frac{H^2}{\dot\phi} y^{3/2-\nu}$
depends on k/aH
$\nu : H_\nu()$
$u_k = H_\nu(y) \longrightarrow \frac{H^2}{\dot\phi} y^{3/2-\nu}$
δN_k

$$y \equiv \frac{k}{aH}$$

$$\boxed{\delta N_k = \frac{H^2}{\dot\phi} y^{3/2-\nu}}$$

$\nu : H_\nu(\,)$

depends on k/aH

$$u_k = H_\nu(y) \rightarrow \frac{H^2}{\dot\phi} y^{3/2-\nu} \quad y \rightarrow 0$$

$$\delta N_k(y=1) \sim \left.\frac{H^2}{\dot\phi}\right|_{k=aH}$$

$$y \equiv \frac{k}{aH} \qquad \boxed{\delta N_k = \frac{H^2}{\dot\phi}\, y^{3/2-\nu}} \qquad \nu : H_\nu(\,)$$

depends on k/aH

$$u_k = H_\nu(y) \rightarrow \boxed{\frac{H^2}{\dot\phi}\, y^{3/2-\nu}} \quad y \rightarrow 0$$

$$\delta N_k(y=1) \sim \left.\frac{H^2}{\dot\phi}\right|_{k=aH}$$

$$y \equiv \frac{k}{aH}$$

$$\boxed{\delta N_k = \frac{H^2}{\dot\phi}\, y^{3/2-\nu}}$$

depends on k/aH

$\nu : H_\nu(\ )$

$$u_k = H_\nu(y) \xrightarrow[y \to 0]{} \boxed{\frac{H^2}{\dot\phi}\, y^{3/2-\nu}}$$

$$\frac{d\,\delta N_k}{d\ln k} \sim O(\epsilon^2)$$

$$\delta N_k(y=1) \sim \left.\frac{H^2}{\dot\phi}\right|_{k=aH}$$

$$y \equiv \frac{k}{aH}$$

$$\boxed{\delta N_k = \frac{H^2}{\dot\phi}\, y^{3/2-\nu}}$$

depends on k/aH

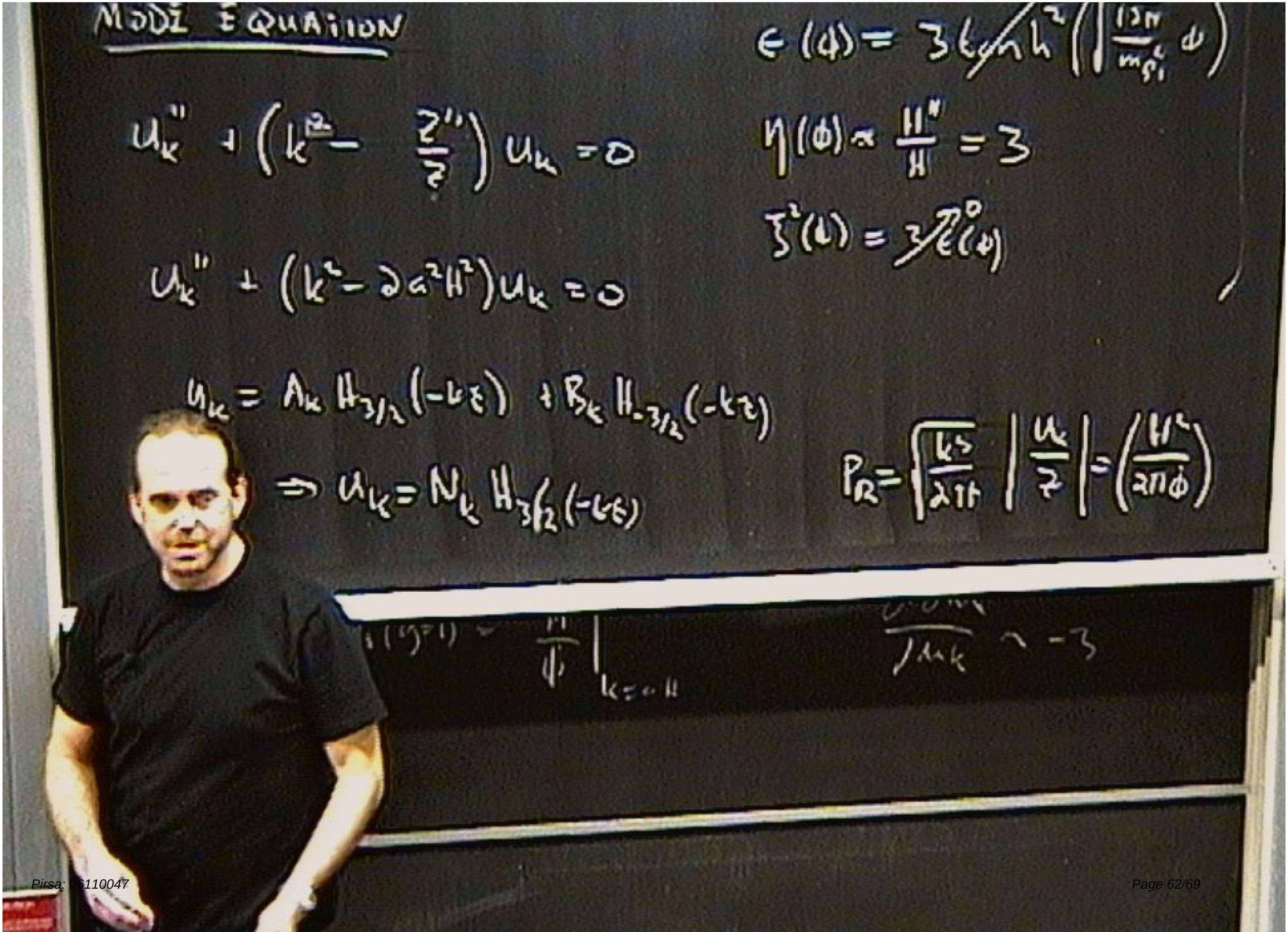
$\nu : H_\nu(\,)$

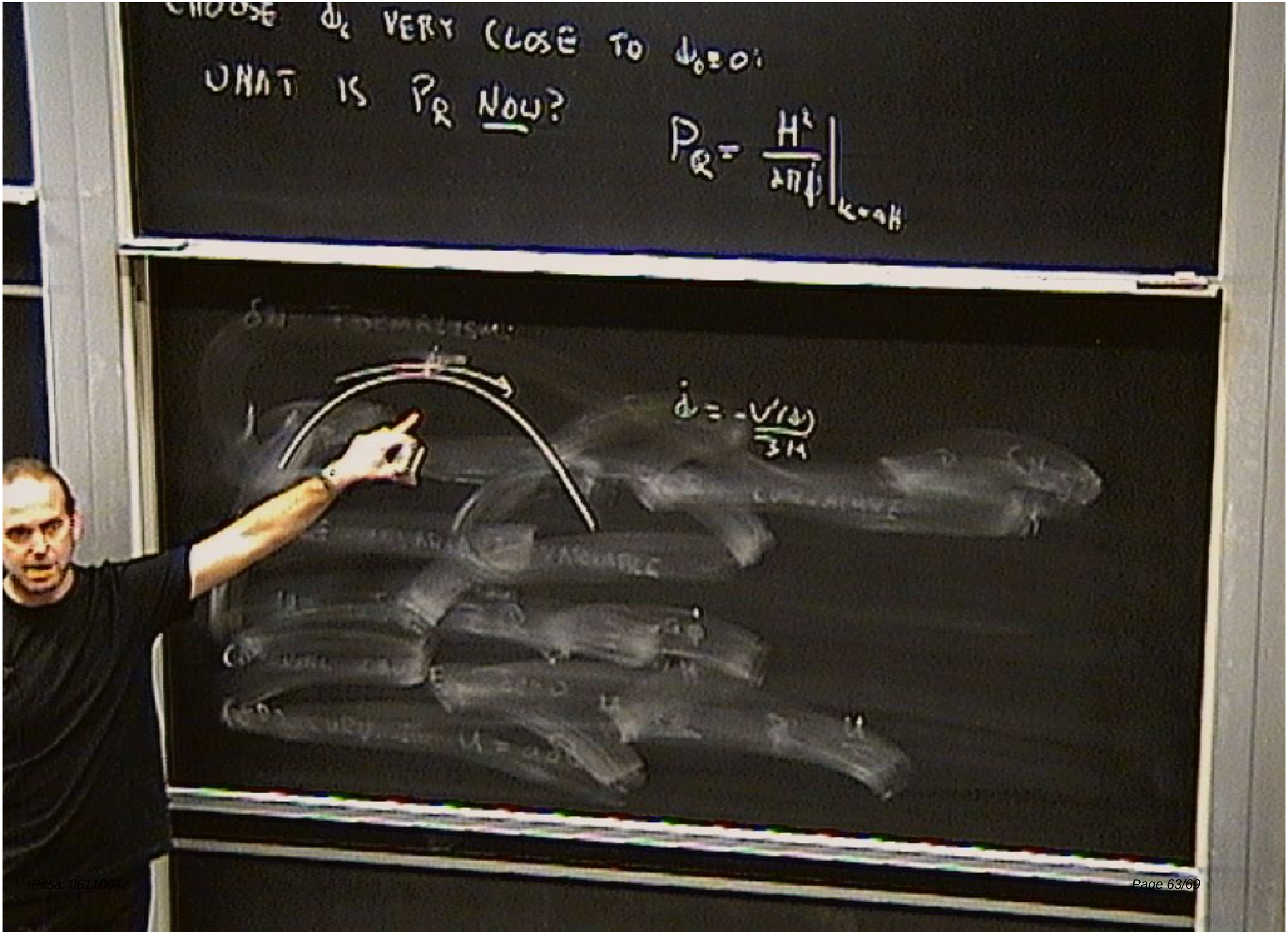
$$u_k = H_\nu(y) \xrightarrow{y\to 0} \boxed{\frac{H^2}{\dot\phi}\, y^{3/2-\nu}}$$

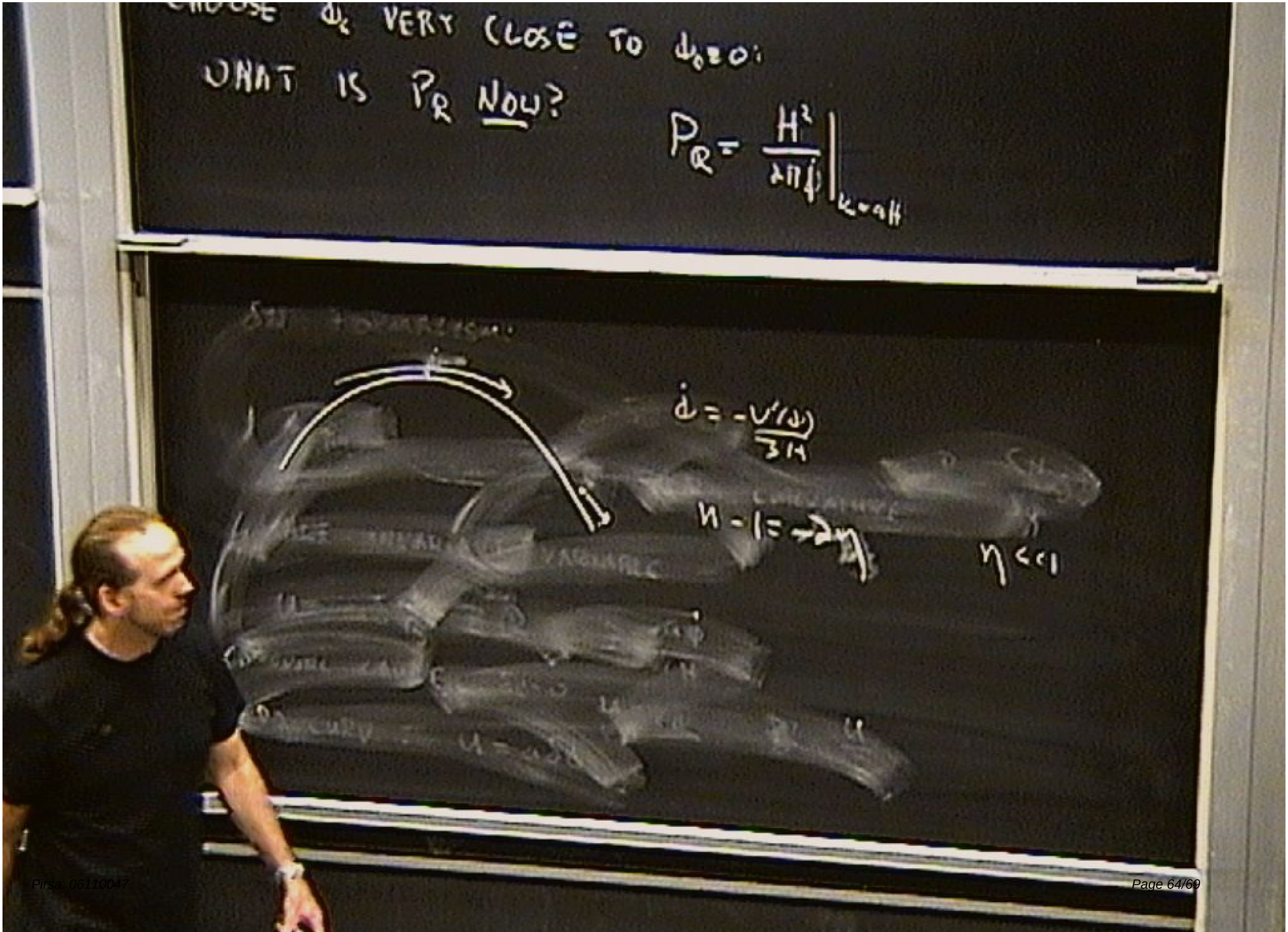
$$\frac{d\,\delta N_k}{d\ln k} \sim O(\epsilon^2)$$

$$\delta N_k(y=1) \sim \left.\frac{H^2}{\dot\phi}\right|_{k=aH}$$

$$\frac{d\,\delta N_k}{d\ln k} \sim -3$$


MODE EQUATION
$u_k'' + \left(k^2 - \frac{z''}{z}\right) u_k = 0$
$u_k'' + (k^2 - 2a^2H^2) u_k = 0$
$u_k = A_k H_{3/2}(-k\tau) + B_k H_{-3/2}(-k\tau)$
$\Rightarrow u_k = N_k H_{3/2}(-k\tau)$
$\epsilon(\phi) = 3\tanh^2\left(\sqrt{\frac{12\pi}{m_{Pl}^2}}\,\phi\right)$
$\eta(\phi) \approx \frac{H''}{H} = 3$
$\xi^2(\phi) = 3\epsilon(\phi)$
$P_R = \sqrt{\frac{k^3}{2\pi}} \left|\frac{u_k}{z}\right| = \left(\frac{H^2}{2\pi\dot\phi}\right)$


CHOOSE ϕ_i VERY CLOSE TO $\phi_0 = 0$:
WHAT IS P_R NOW?
$P_R = \frac{H^2}{2\pi\dot{\phi}}\Big|_{k=aH}$
$\dot{\phi} = -\frac{V'(\phi)}{3H}$



ϕ_i VERY CLOSE TO $\phi_0 = 0$:
WHAT IS P_R NOW?
$P_R = \frac{H^2}{2\pi\dot{\phi}}\Big|_{k=aH}$
$\dot{\phi} = -\frac{V'(\phi)}{3H}$
$n - 1 = -2\eta$
$\eta \ll 1$

CHOOSE ϕ_i VERY CLOSE TO $\phi_0 = 0$:

WHAT IS P_R NOW?

$$P_R = \frac{H^2}{2\pi \dot{\phi}}\Big|_{k=aH}$$

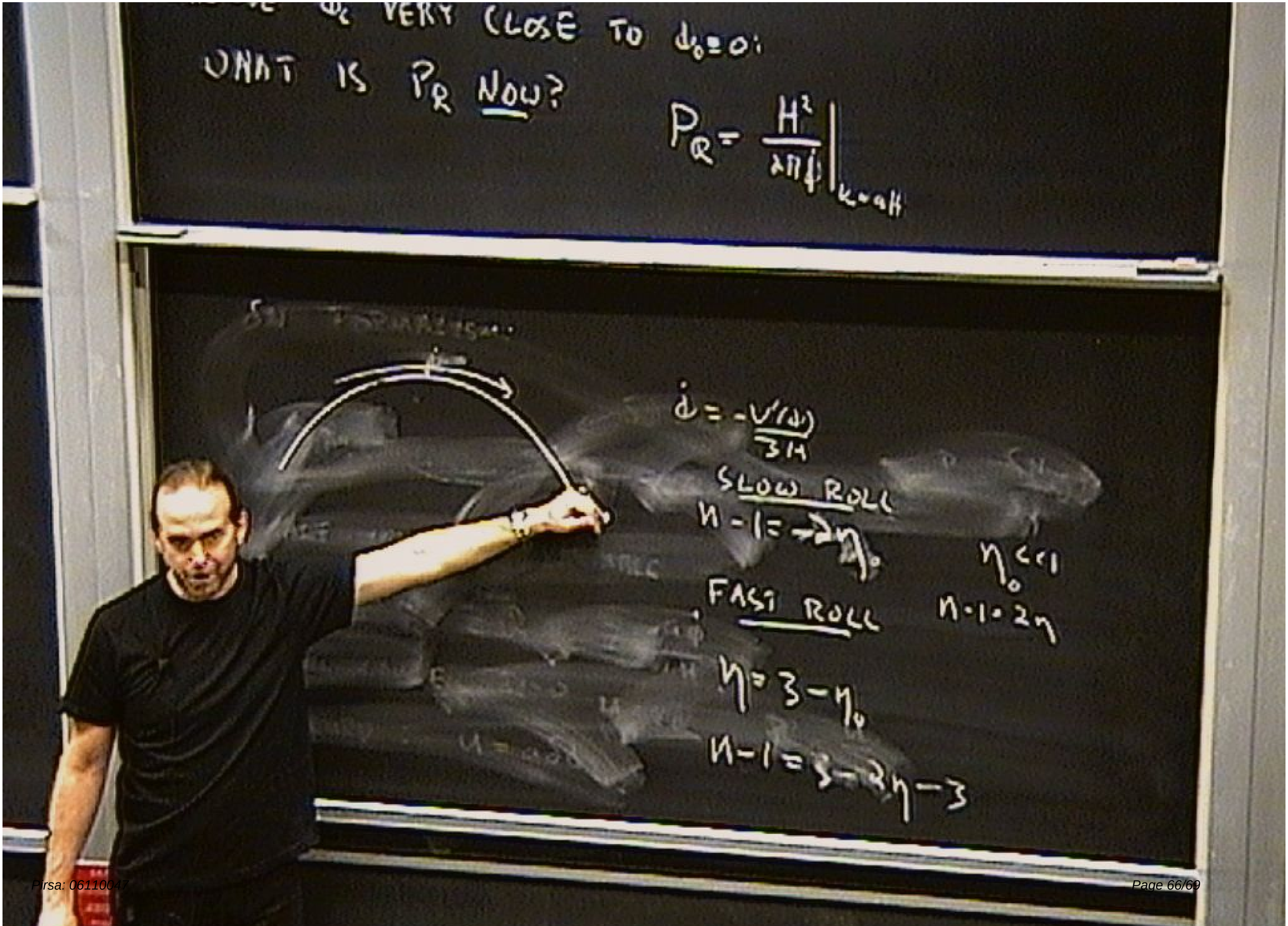
$$\dot{\phi} = -\frac{V'(\phi)}{3H}$$

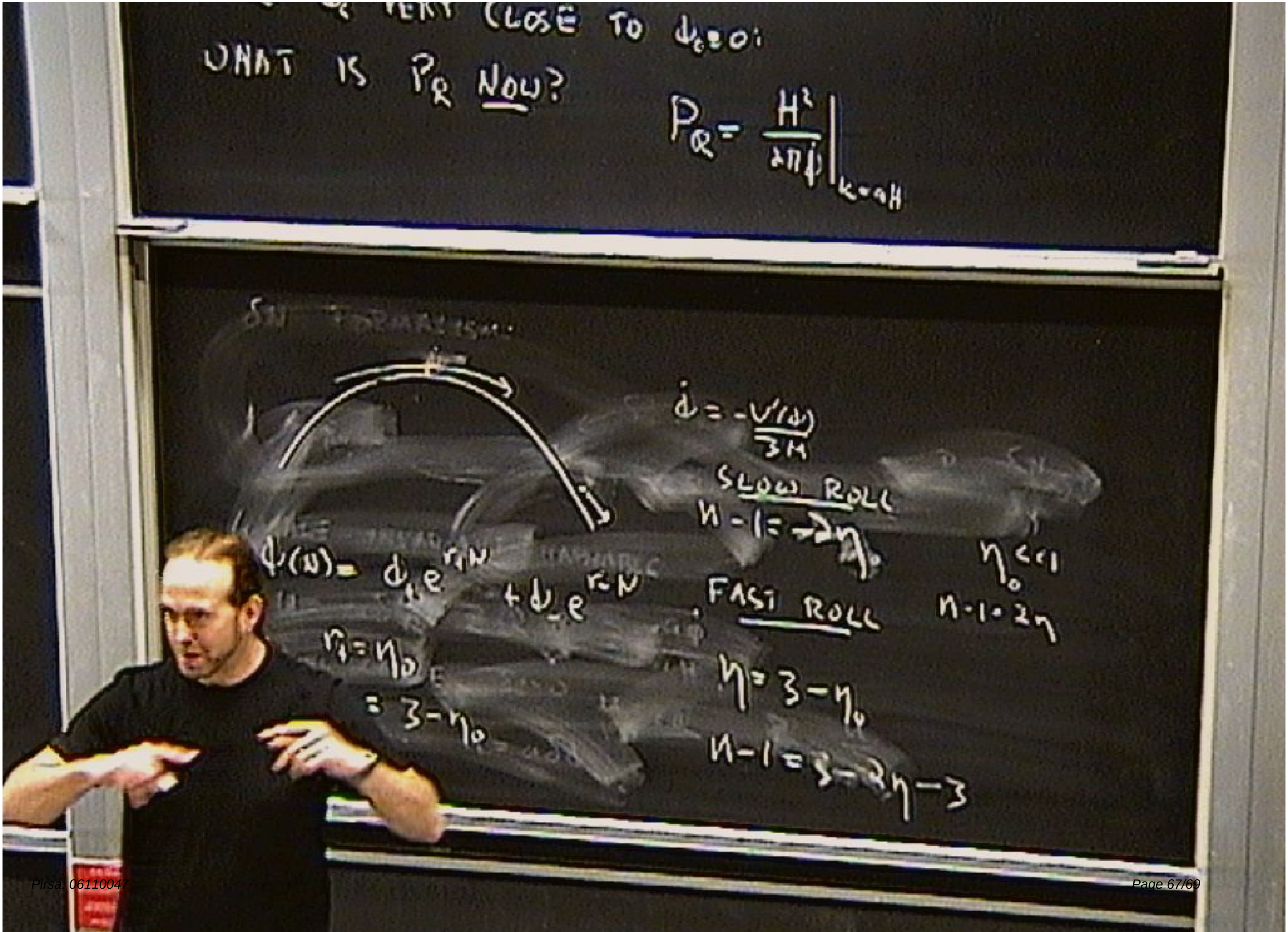
SLOW ROLL

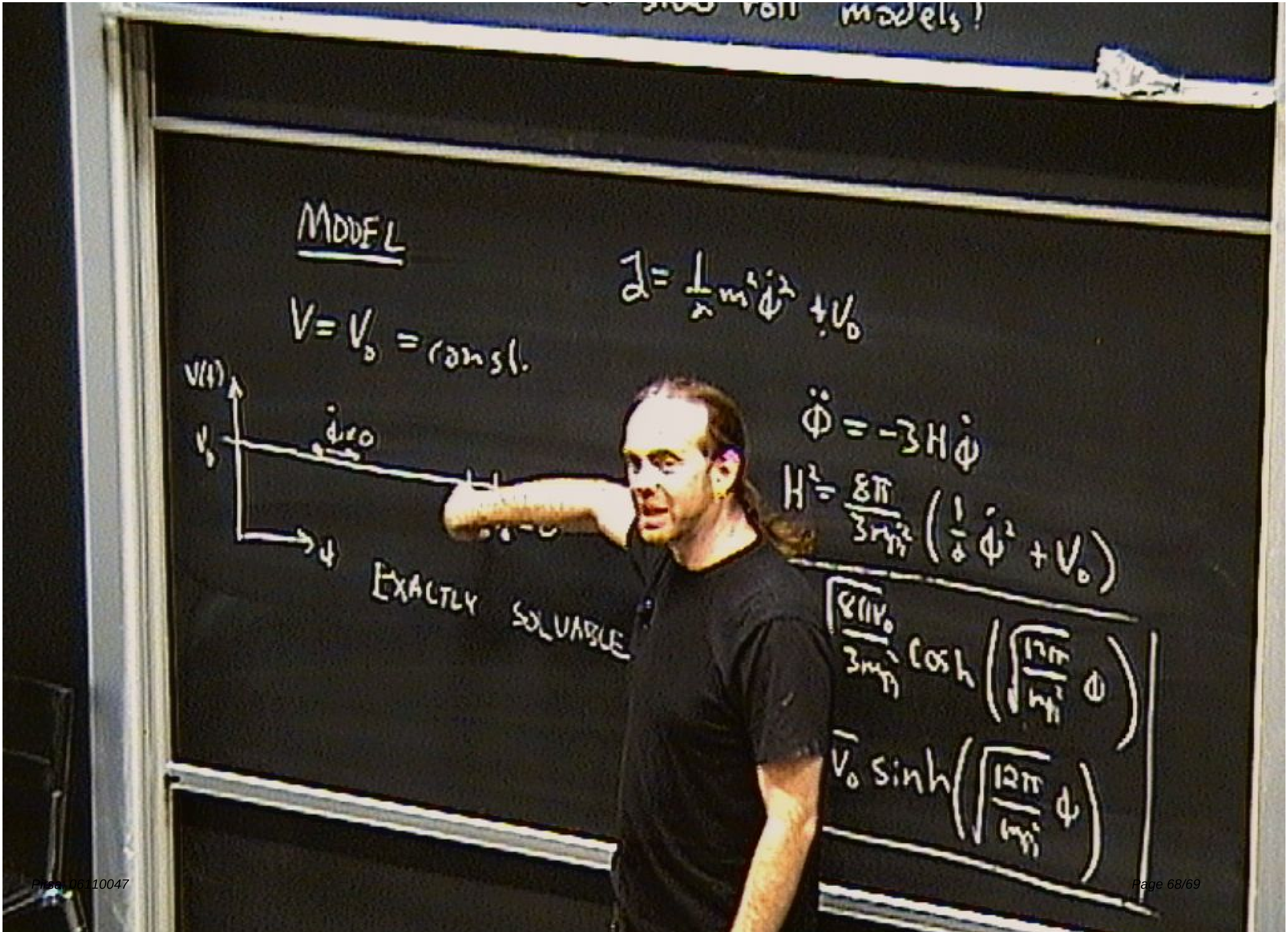
$n - 1 = -2\eta_0$ $\qquad \eta_0 \ll 1$

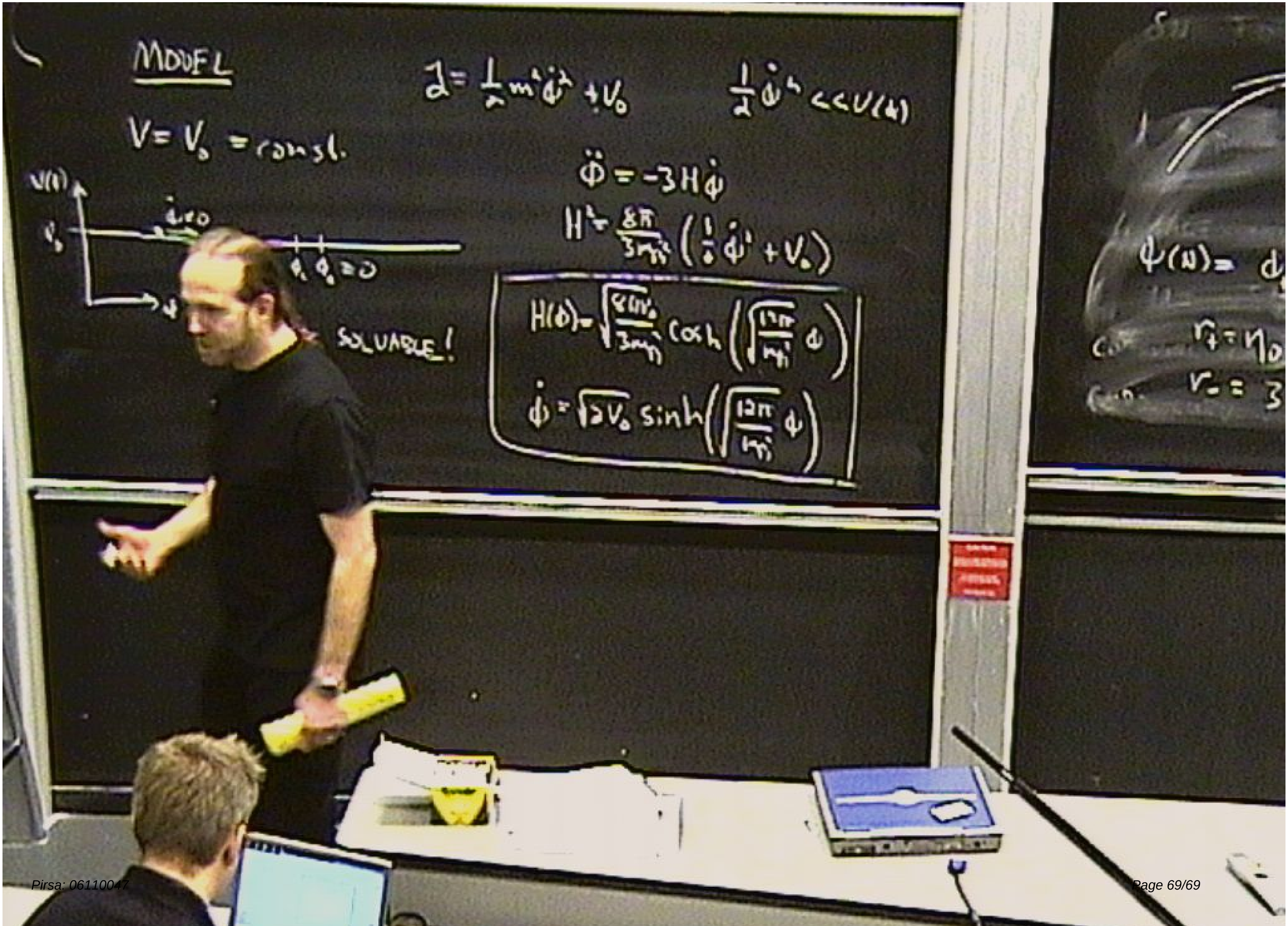
FAST ROLL

$\eta = 3 - \eta_0$


VERY CLOSE TO φ₀=0:
WHAT IS P_R NOW?
P_R = H²/2πφ̇ |_{k=aH}
φ̇ = -V'(φ)/3H
SLOW ROLL
n-1 = -2η₀
η₀ << 1
FAST ROLL
n-1 = 2η
η = 3-η₀
n-1 = 3-2η-3


CLOSE TO
WHAT IS P_R NOW?
SLOW ROLL
FAST ROLL
η = 3 − η_0


MODEL
EXACTLY SOLVABLE


MODEL
V= V0 = const.
SOLVABLE!
Φ̈ = −3Hφ̇
H(φ)= √(8πV0/3mpl²) cosh(√(12π/mpl²) φ)
φ̇ = √(2V0) sinh(√(12π/mpl²) φ)