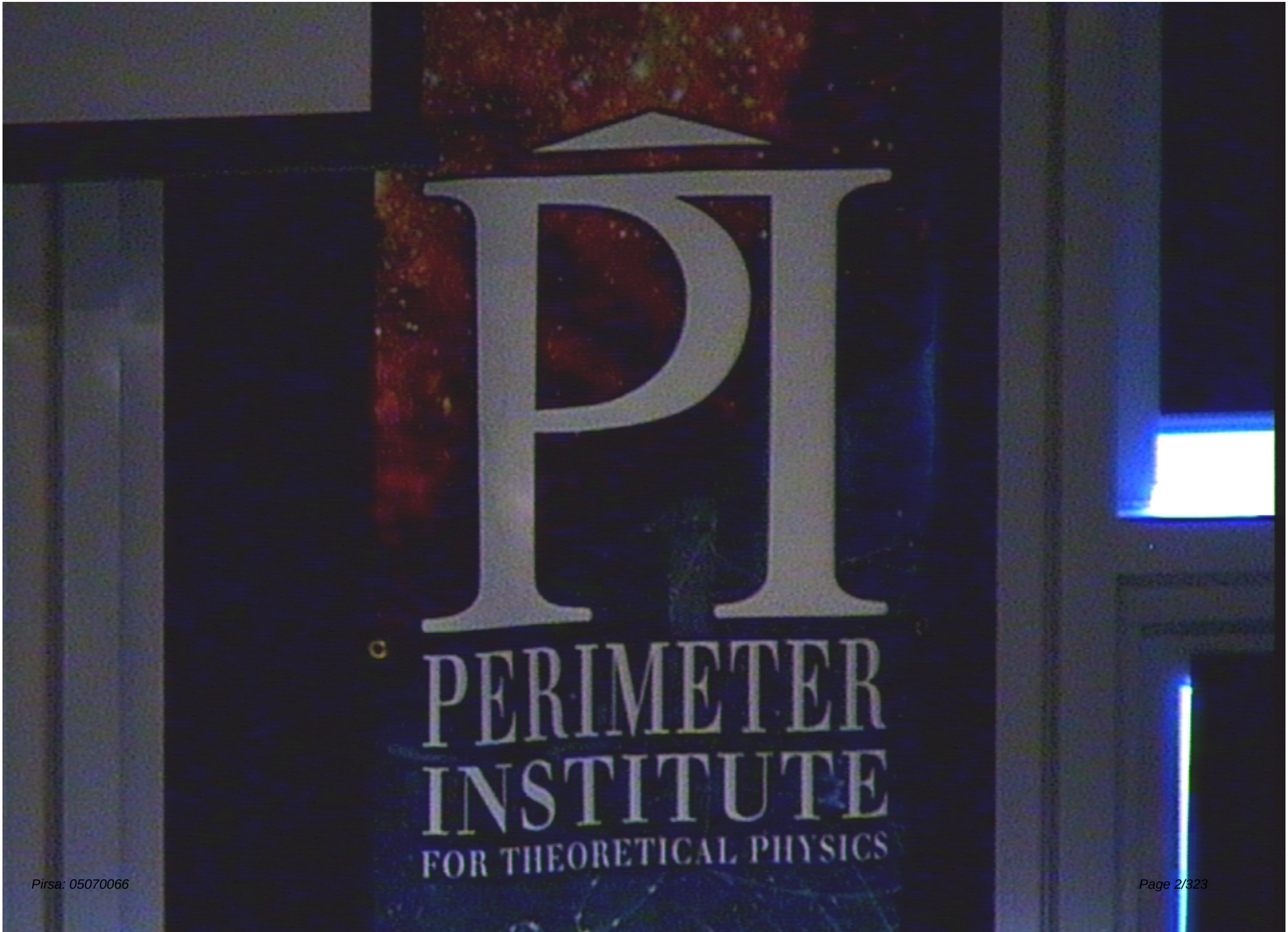
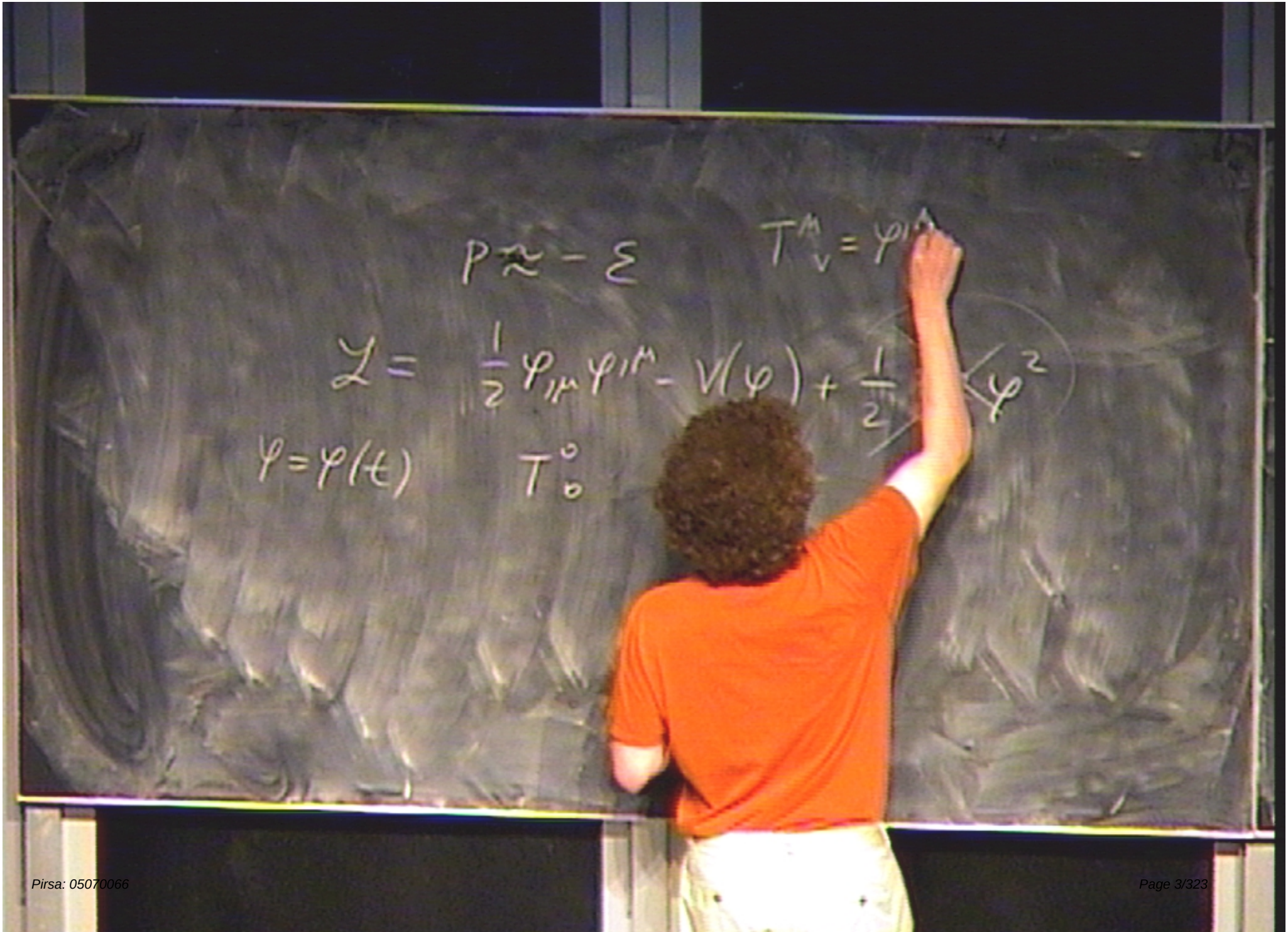
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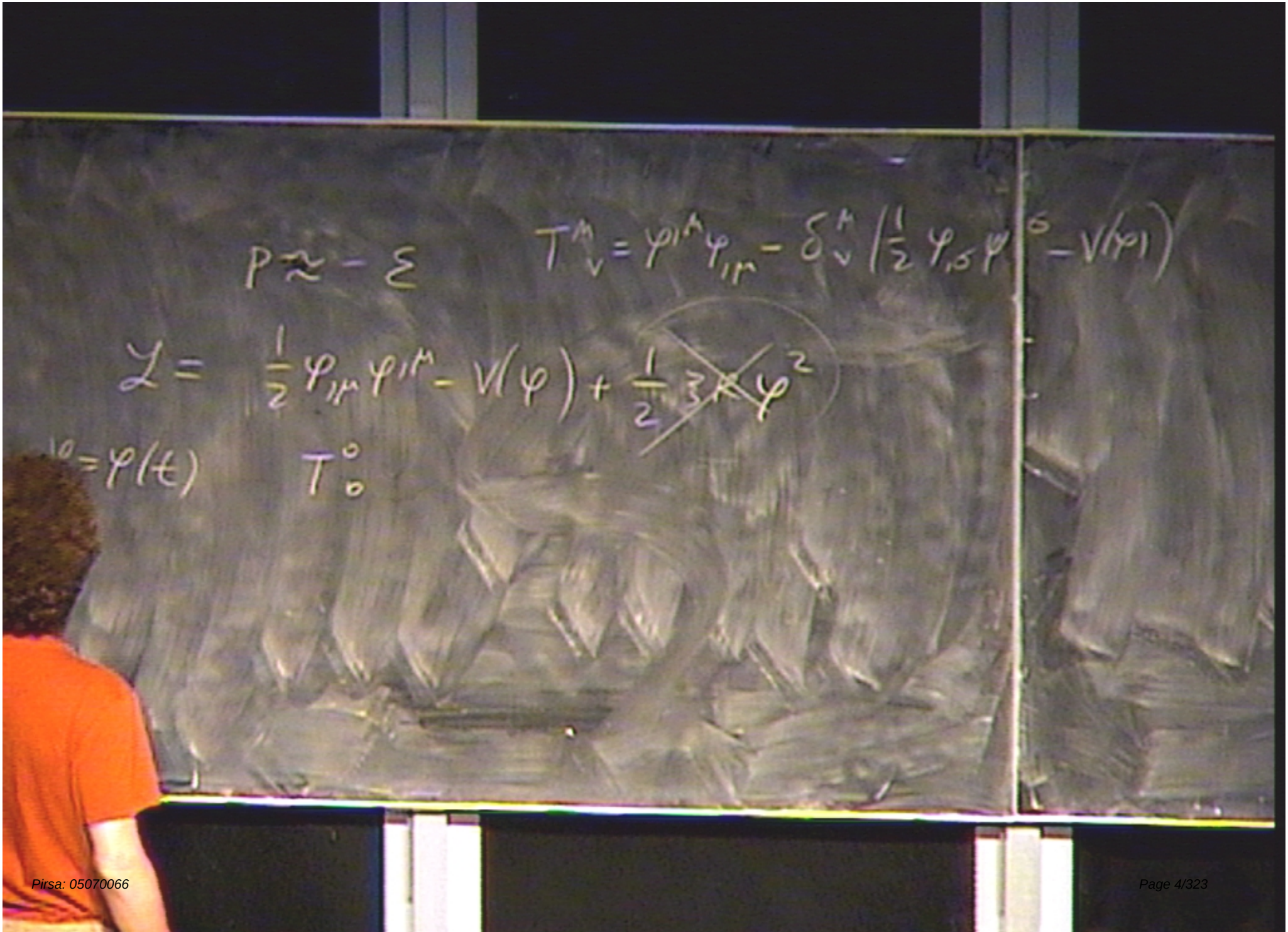
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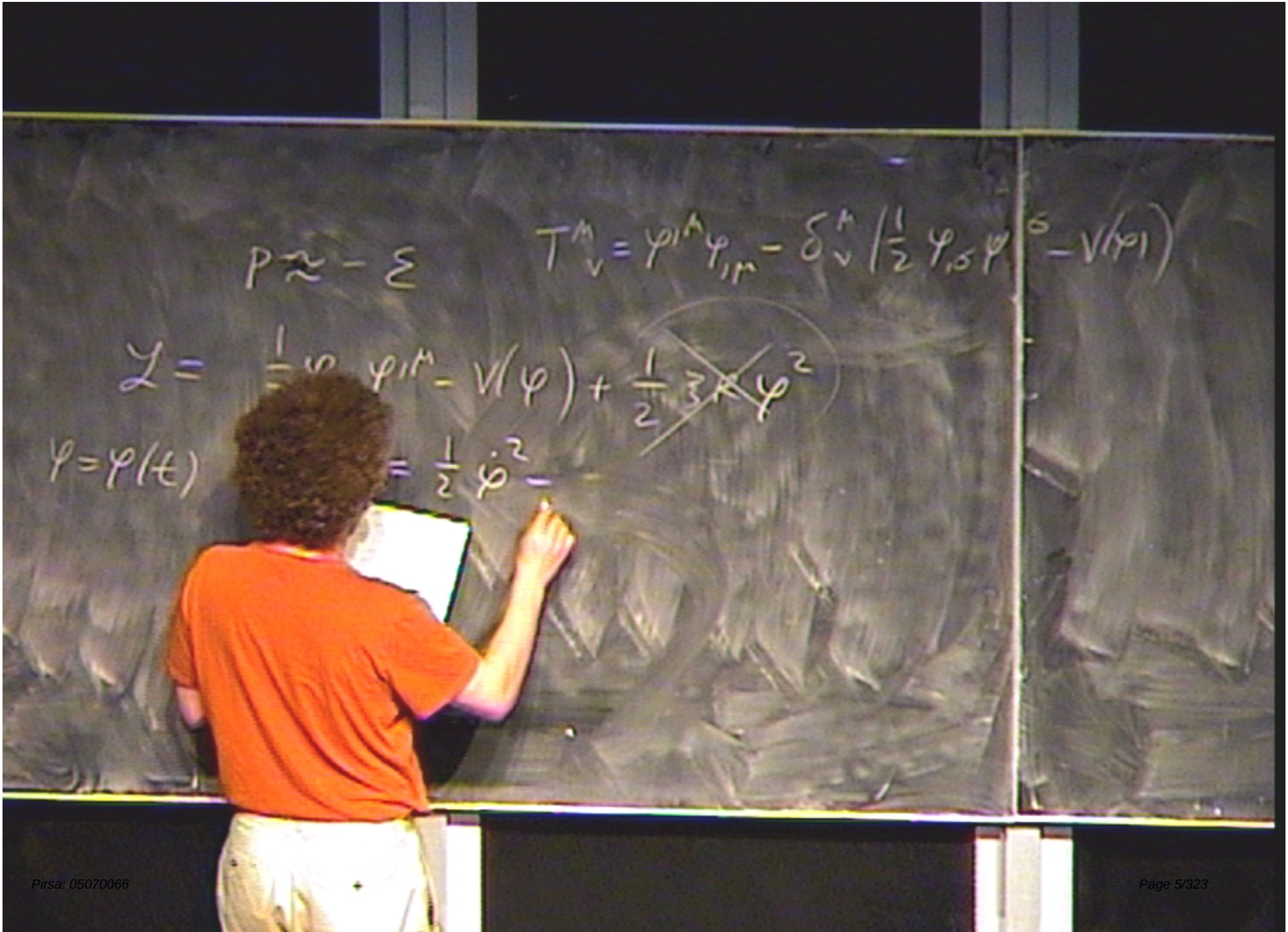
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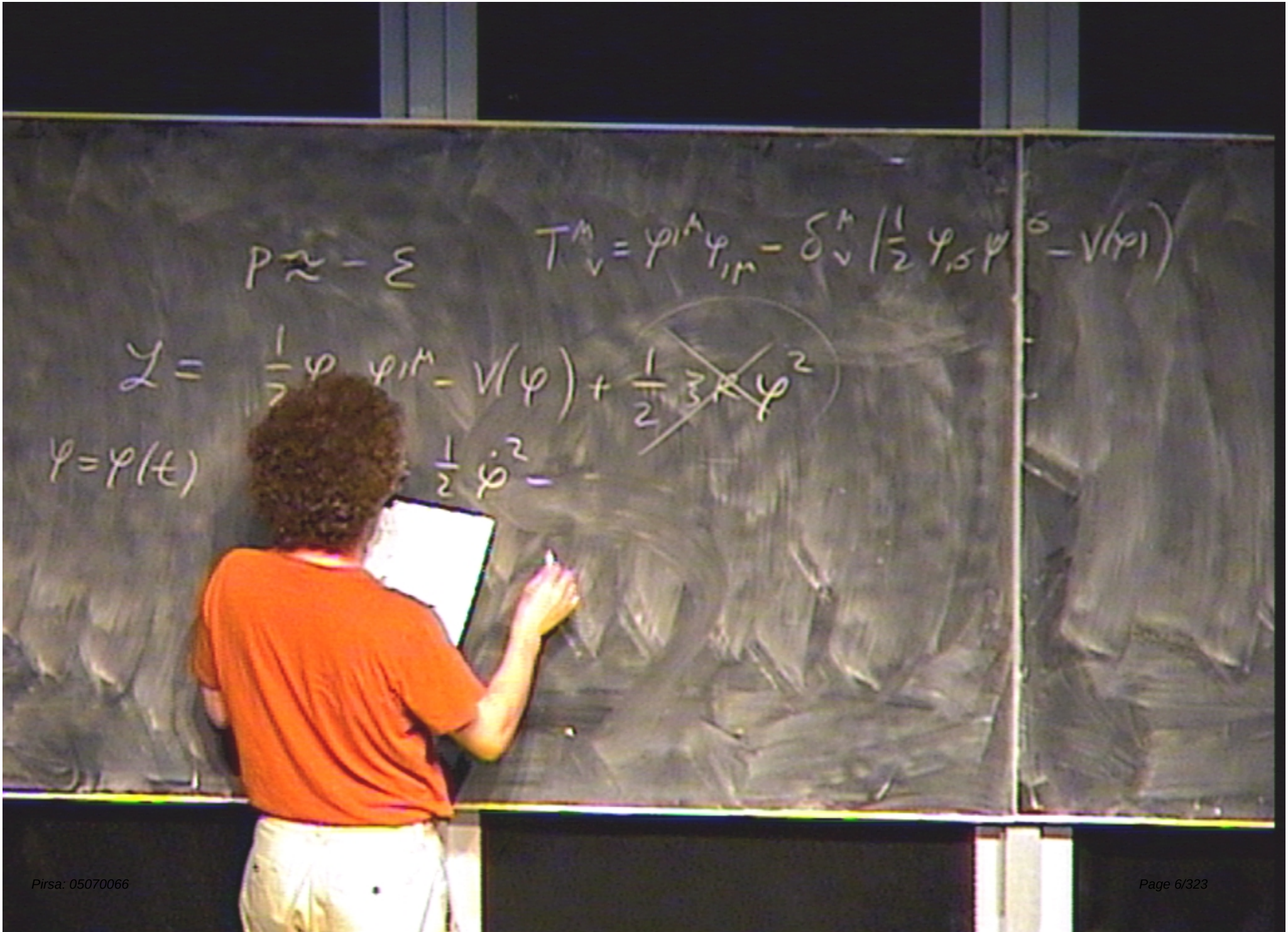
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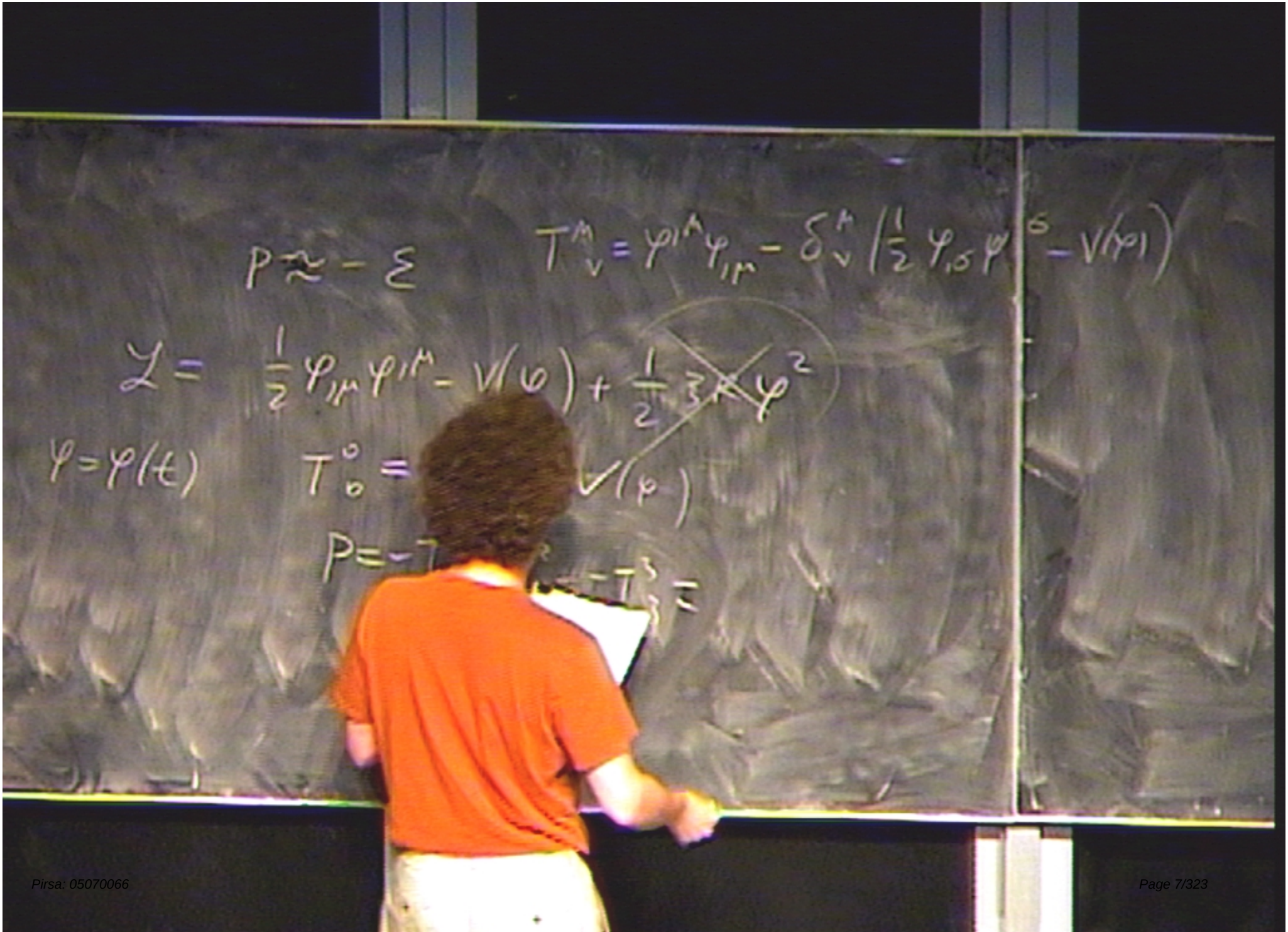

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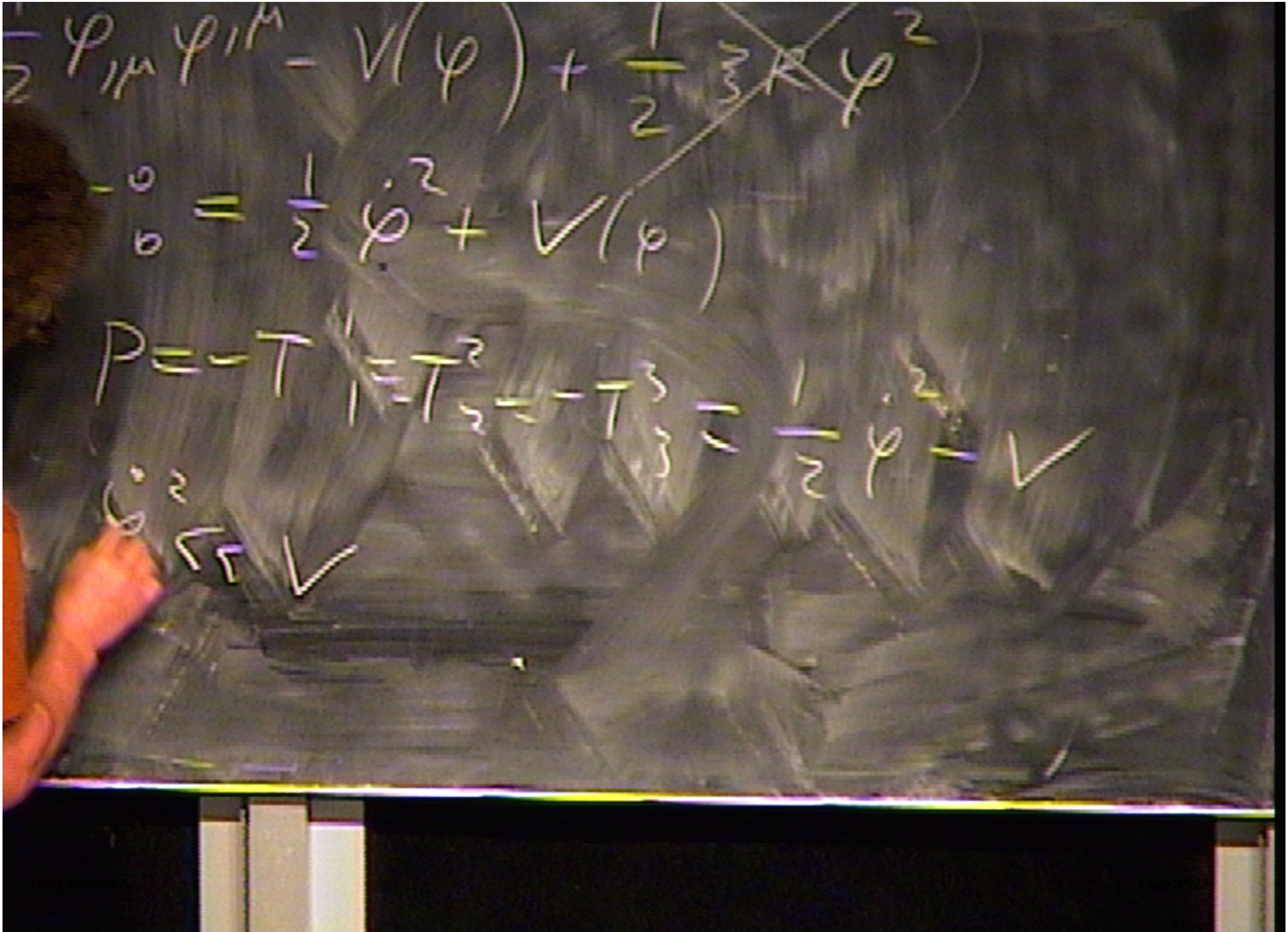

$p \approx -\varepsilon$
$T^{\mu}_{\nu} = \varphi,^{\mu}$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V(\varphi) + \frac{1}{2}$
φ^2
$\varphi = \varphi(t)$
T^{0}_{0}

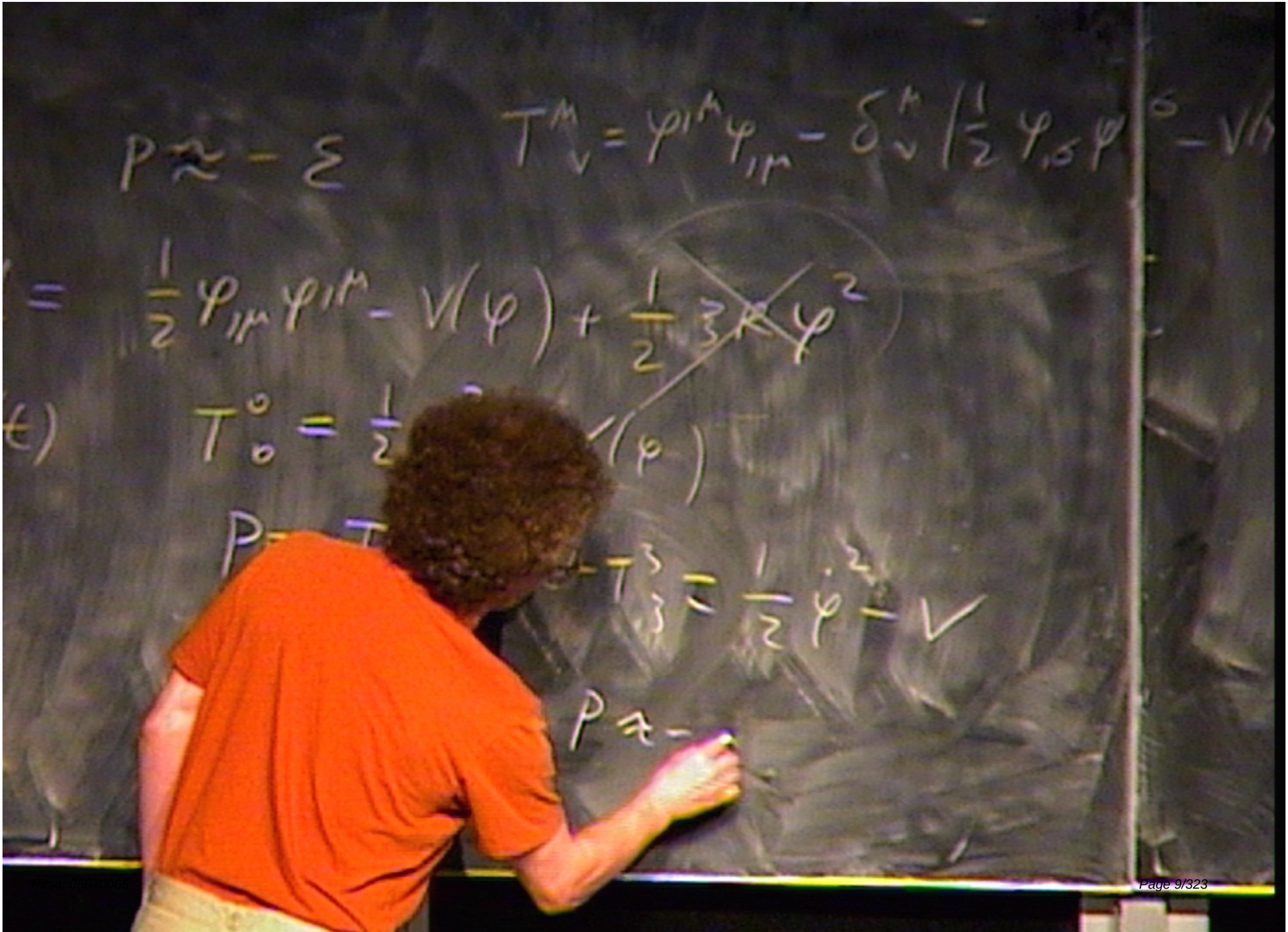

$P \approx -\mathcal{E}$
$T^{\mu}_{\nu} = \varphi^{,\mu}\varphi_{,\mu} - \delta^{\mu}_{\nu}\left(\frac{1}{2}\varphi_{,\sigma}\varphi^{,\sigma} - V(\varphi)\right)$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V(\varphi) + \frac{1}{2}\cancel{3\kappa}\varphi^2$
$\varphi^0 = \varphi(t)$
T^0_0

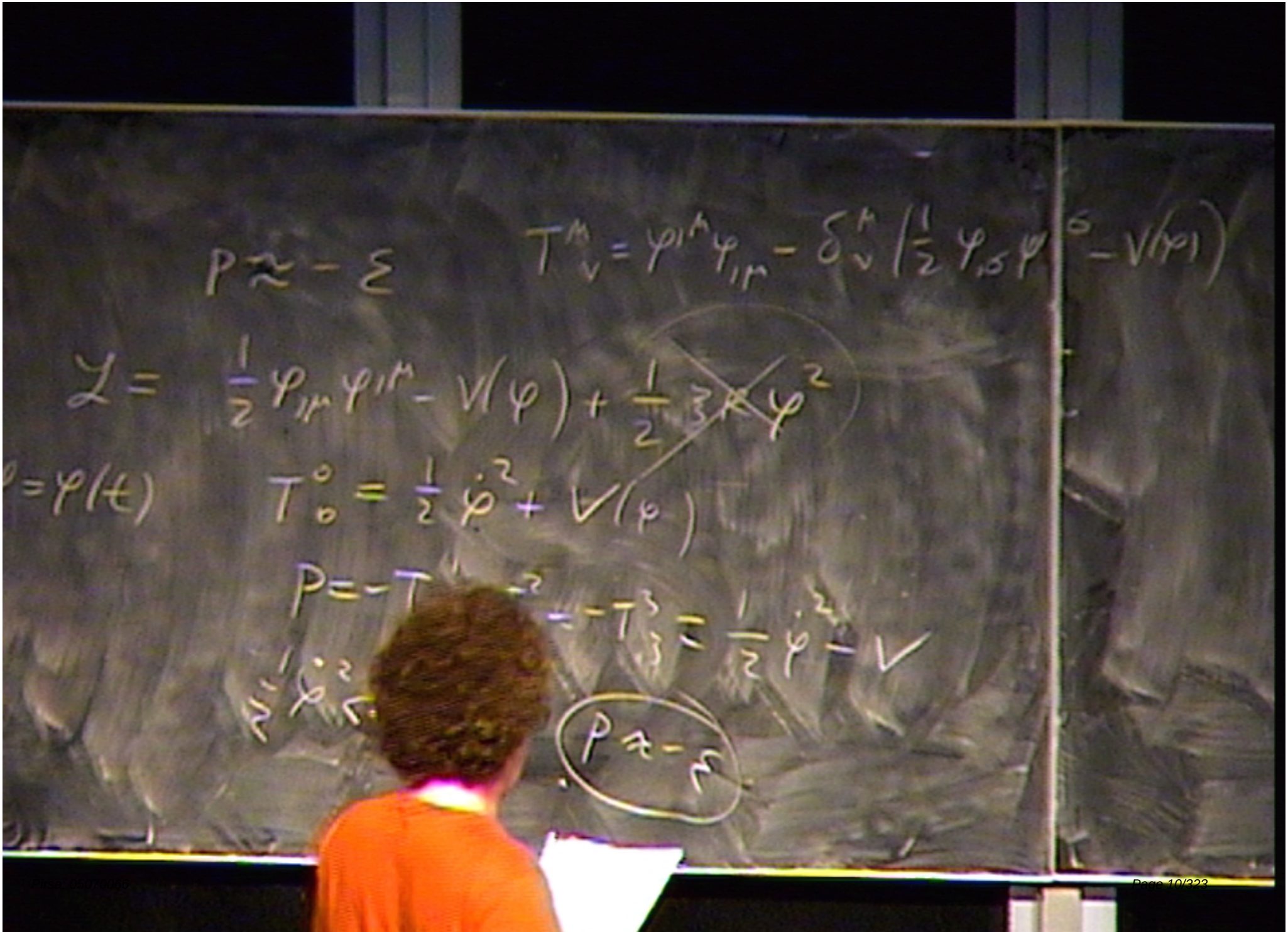

$p \approx -\varepsilon$
$T^{\mu}_{\ \nu} = \varphi^{,\mu}\varphi_{,\mu} - \delta^{\mu}_{\nu}\left(\frac{1}{2}\varphi_{,\sigma}\varphi^{,\sigma} - V(\varphi)\right)$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V(\varphi) + \frac{1}{2}\cancel{3\kappa}\varphi^2$
$\varphi = \varphi(t)$
$= \frac{1}{2}\dot{\phi}^2 -$


$p \approx -\varepsilon$
$T^{\mu}_{\nu} = \varphi^{,\mu}\varphi_{,\mu} - \delta^{\mu}_{\nu}\left(\frac{1}{2}\varphi_{,\sigma}\varphi^{,\sigma} - V(\varphi)\right)$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V(\varphi) + \frac{1}{2}3H\varphi^2$
$\varphi = \varphi(t)$
$\frac{1}{2}\dot{\varphi}^2 -$


$p \approx -\varepsilon$
$T^{\mu}_{\nu} = \varphi^{,\mu}\varphi_{,\mu} - \delta^{\mu}_{\nu}\left(\frac{1}{2}\varphi_{,\sigma}\varphi^{,\sigma} - V(\varphi)\right)$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V(\varphi) + \frac{1}{2}3H\dot{\varphi}^2$
$\varphi = \varphi(t)$
$T^{0}_{0} =$
$V(\varphi)$
$p = -T$


$\frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V(\varphi) + \frac{1}{2}\xi R\varphi^2$
$-\frac{\rho}{\rho_0} = \frac{1}{2}\dot{\varphi}^2 + V(\varphi)$
$p = -T^1{}_1 = -T^2{}_2 = -T^3{}_3 = \frac{1}{2}\dot{\varphi}^2 - V$
$\dot{\varphi}^2 \ll V$


$p \approx -\varepsilon$
$T^{\mu}_{\nu} = \varphi_{,}{}^{\mu}\varphi_{,\mu} - \delta^{\mu}_{\nu}\left[\frac{1}{2}\varphi_{,\sigma}\varphi^{,\sigma} - V(\varphi)\right]$
$= \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V(\varphi) + \frac{1}{2}3H^2\varphi^2$
$\epsilon)\quad T^{0}_{0} = \frac{1}{2}$
(φ)
$P = T$
$T^{3}_{3} = \frac{1}{2}\dot{\varphi}^2 - V$
$p \approx -$


$p \approx -\varepsilon$
$T^{\mu}_{\nu} = \varphi^{,\mu}\varphi_{,\mu} - \delta^{\mu}_{\nu}\left(\frac{1}{2}\varphi_{,\sigma}\varphi^{,\sigma} - V(\varphi)\right)$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V(\varphi) + \frac{1}{2}\beta R\varphi^2$
$\varphi = \varphi(t)$
$T^{0}_{0} = \frac{1}{2}\dot{\varphi}^2 + V(\varphi)$
$p = -T^{1}_{1} = -T^{2}_{2} = -T^{3}_{3} = \frac{1}{2}\dot{\varphi}^2 - V$
$\approx \frac{1}{2}\dot{\varphi}^2 - \frac{1}{2}\dot{\varphi}^2$
$p \approx -\varepsilon$

$p \approx -\varepsilon$

$T^{\mu}_{\nu} = \varphi^{,\mu}\varphi_{,\mu} - \delta^{\mu}_{\nu}\left(\frac{1}{2}\varphi_{,\sigma}\varphi^{,\sigma} - V(\varphi)\right)$

$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V(\varphi) + \frac{1}{2}\cancel{3R}\varphi^2$

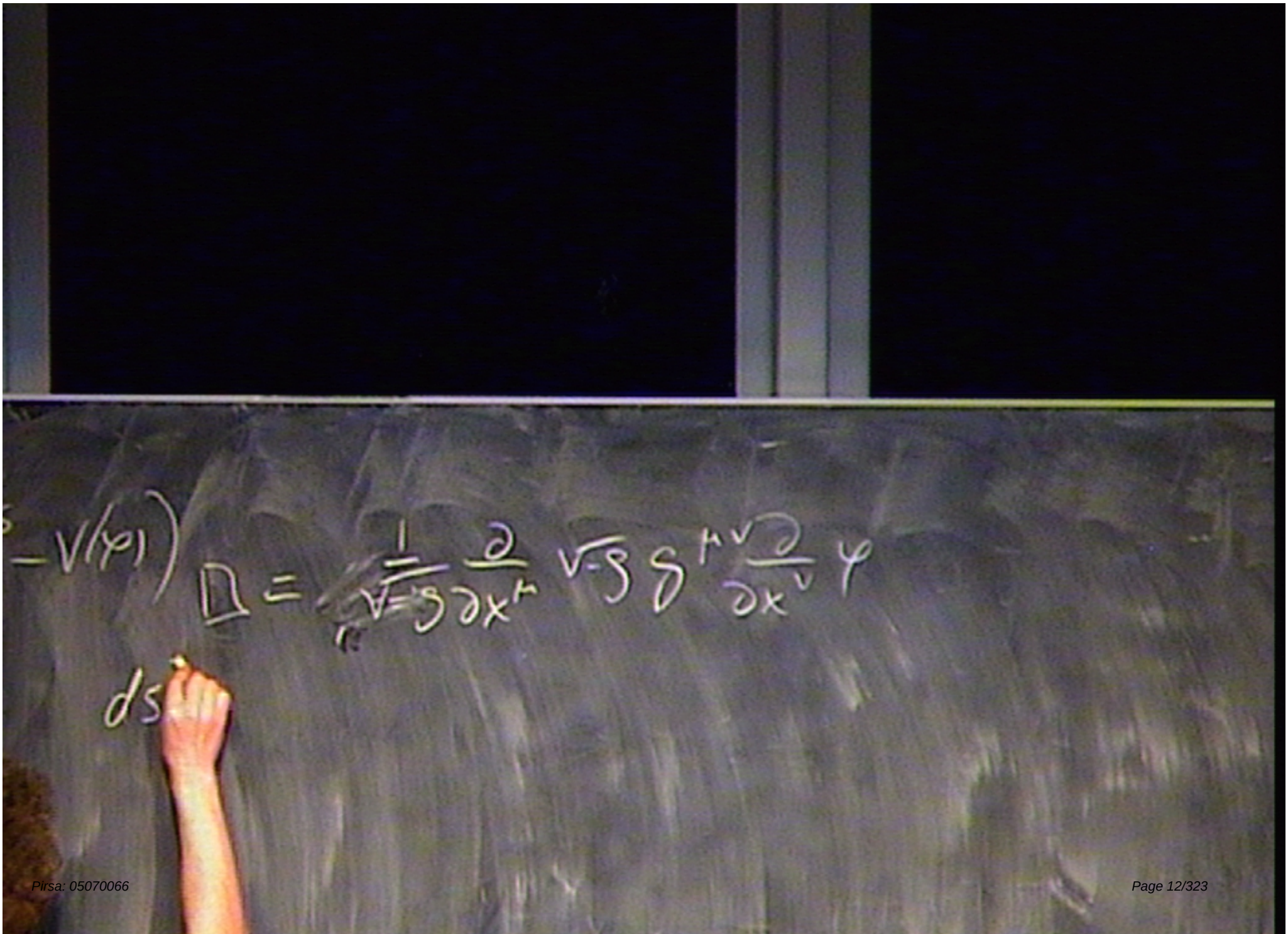
$\varphi = \varphi(t)$

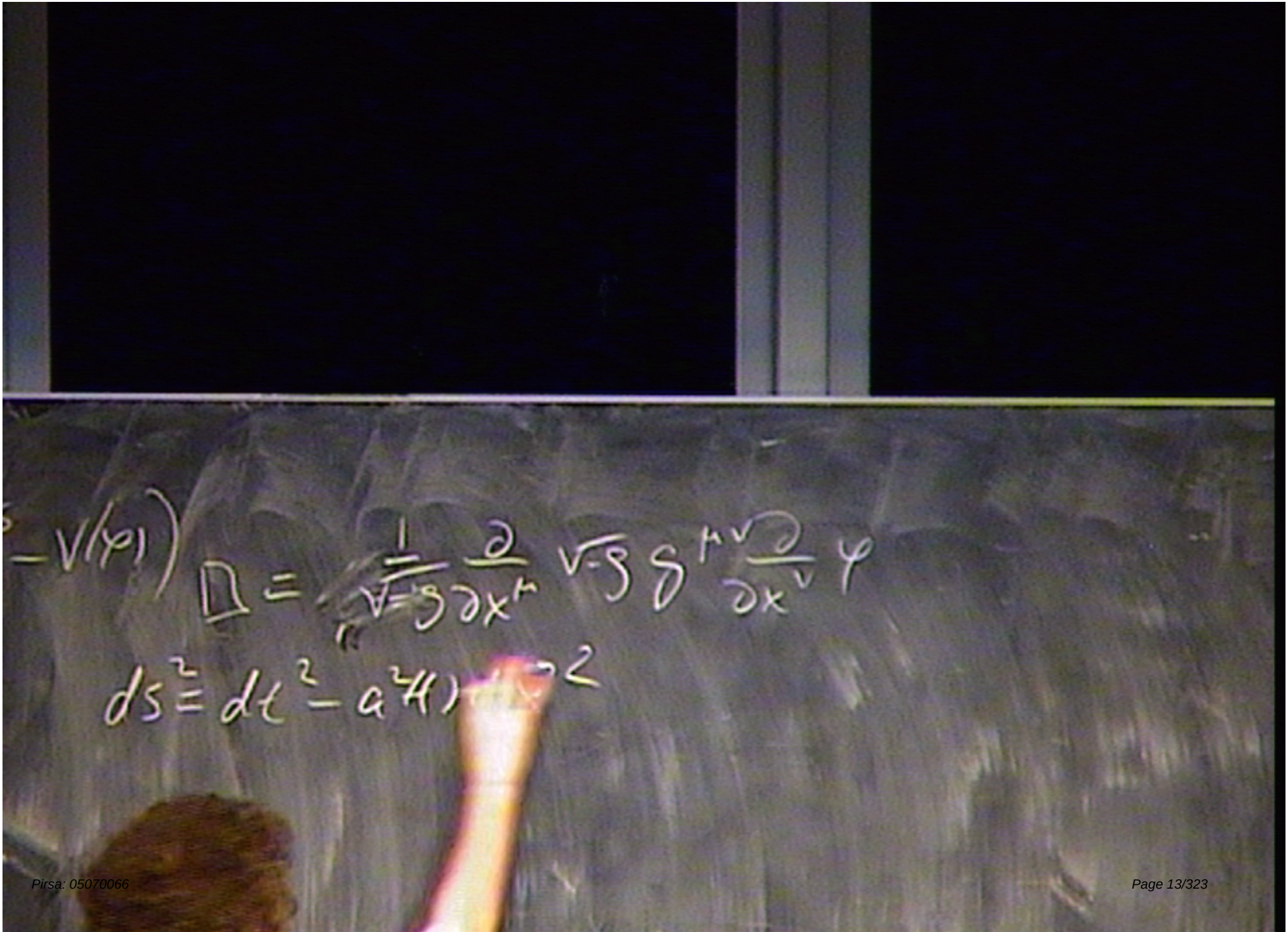
$T^{0}_{0} = \frac{1}{2}\dot{\varphi}^2 + V(\varphi)$

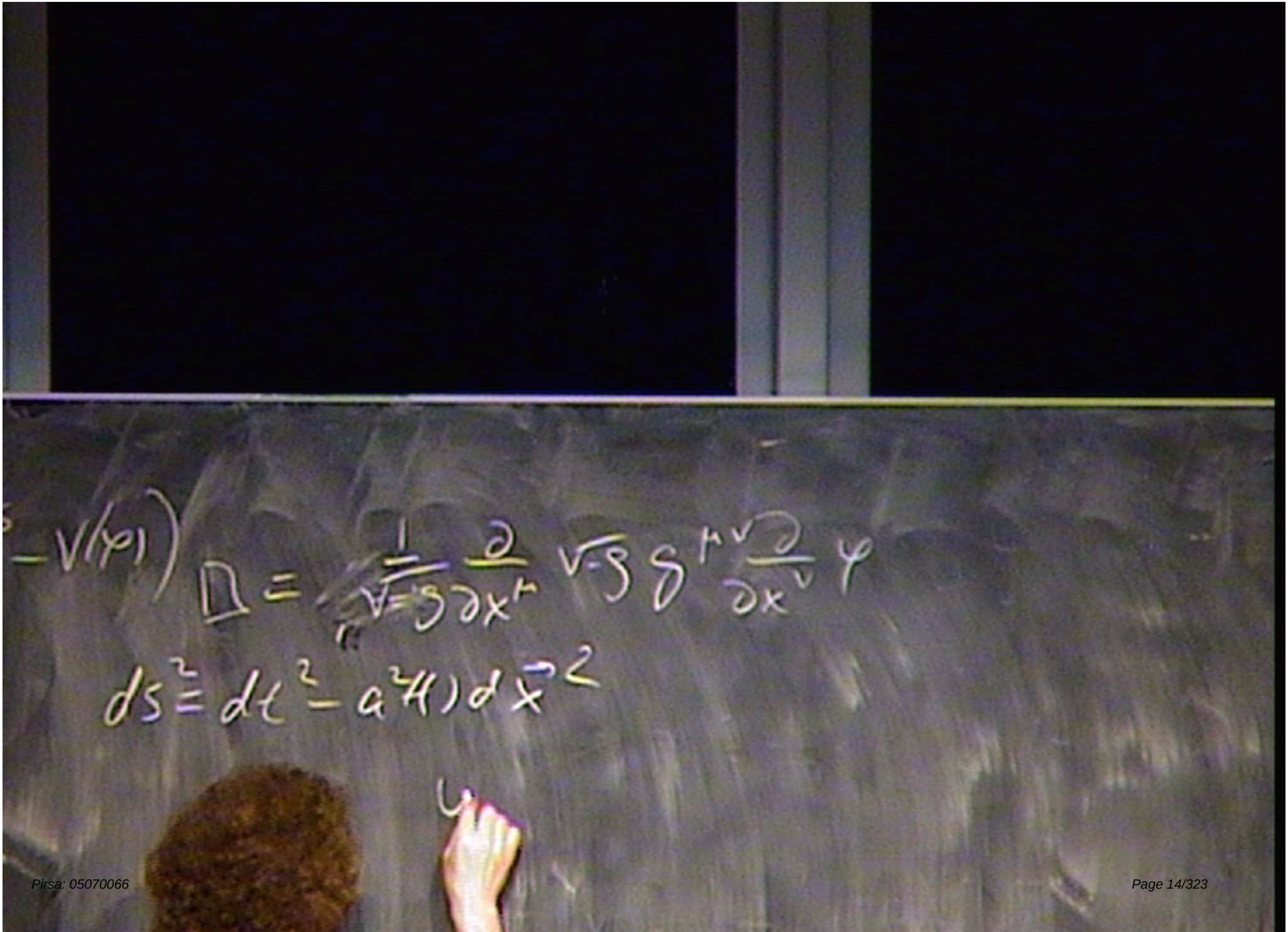
$p = -T^{1}_{1} = -T^{2}_{2} = -T^{3}_{3} = \frac{1}{2}\dot{\varphi}^2 - V$

$\approx \frac{1}{2}\dot{\varphi}^2 \ll V$

$p \approx -\varepsilon$


$-V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
ds^2


$-V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
$ds^2 = dt^2 - a^2(t)$

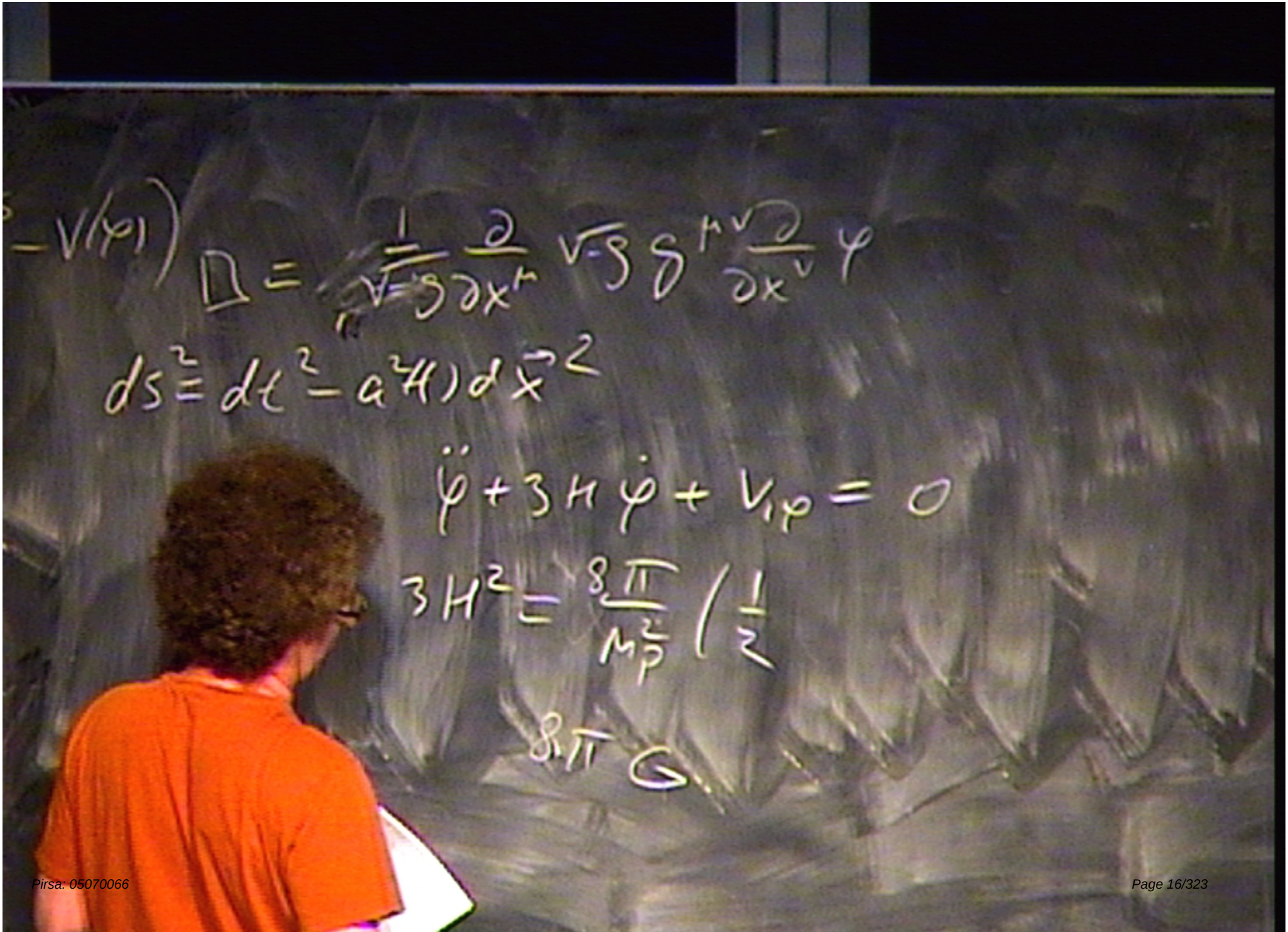

$-V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
$ds^2 = dt^2 - a^2(t) d\vec{x}^2$

$-V(\varphi)$

$$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$$

$$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$$

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


$-V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} = 0$
$3H^2 = \frac{8\pi}{M_p^2} \left(\frac{1}{2} \right.$
$8\pi G$

$-V(\varphi)$

$$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$$

$$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$$

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

$$3H^2 = \frac{8\pi}{M_p^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$$

$8\pi G$

$$G \sim \frac{1}{M_p^2}$$

$$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$$

$$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi}$$

$$3H^2 = \frac{8\pi}{M_P^2}\left(\frac{1}{2}\right.$$

$$\dot{H} = -\frac{4\pi}{M_P^2}\dot{\varphi}^2$$

$$8\pi G$$

$$G \sim \frac{1}{M_P^2}$$

$-V(\varphi)$

$$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$$

$$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$$

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

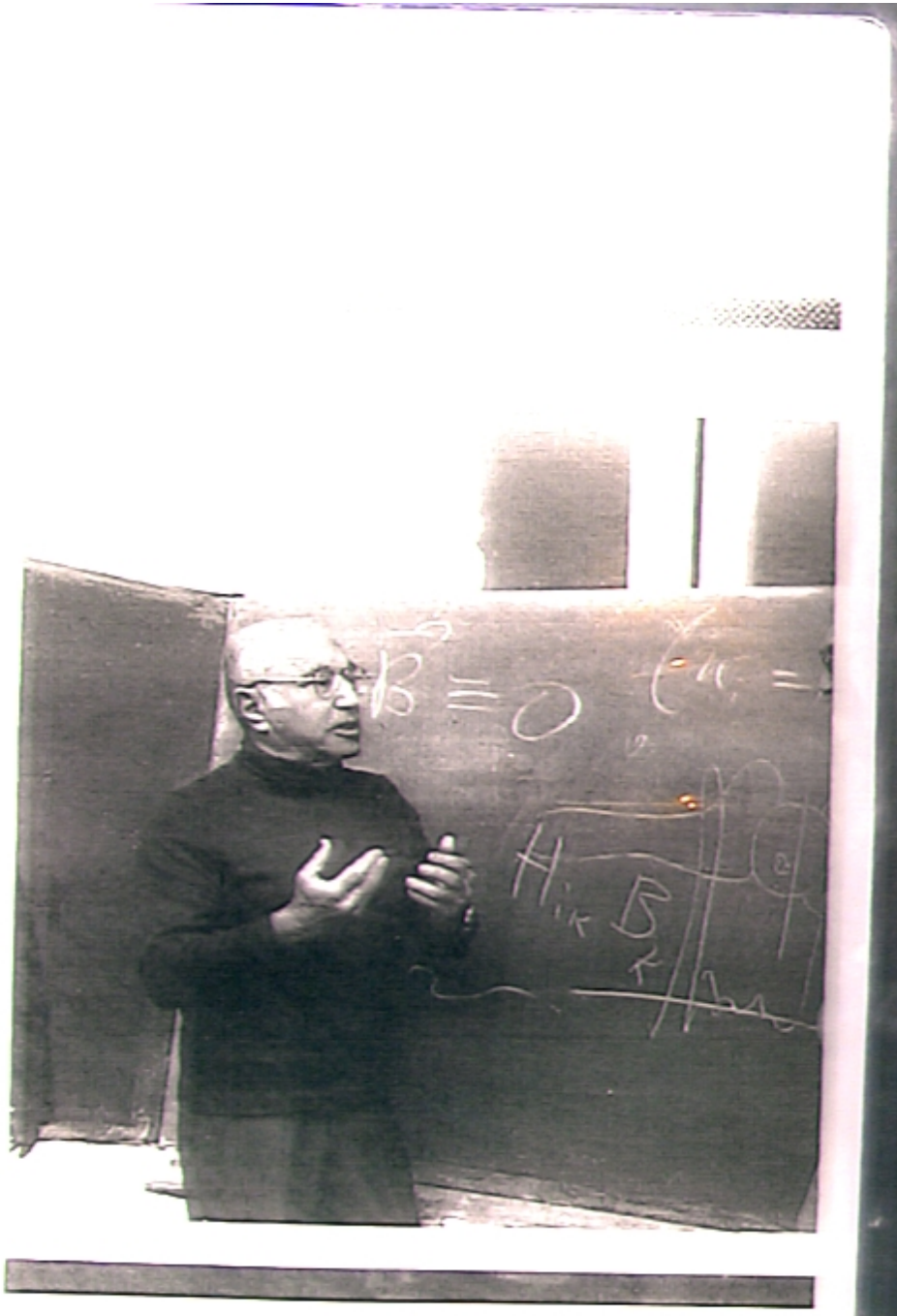
$$3H^2 = \frac{8\pi}{M_P^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$$

$$\dot{H} = -\frac{4\pi}{M_P^2}\dot{\varphi}^2$$

$8\pi G$

$H = \frac{\dot{a}}{a}$

$G \sim \frac{1}{M_P^2}$



$-V(\varphi)$

$$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$$

$$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$$

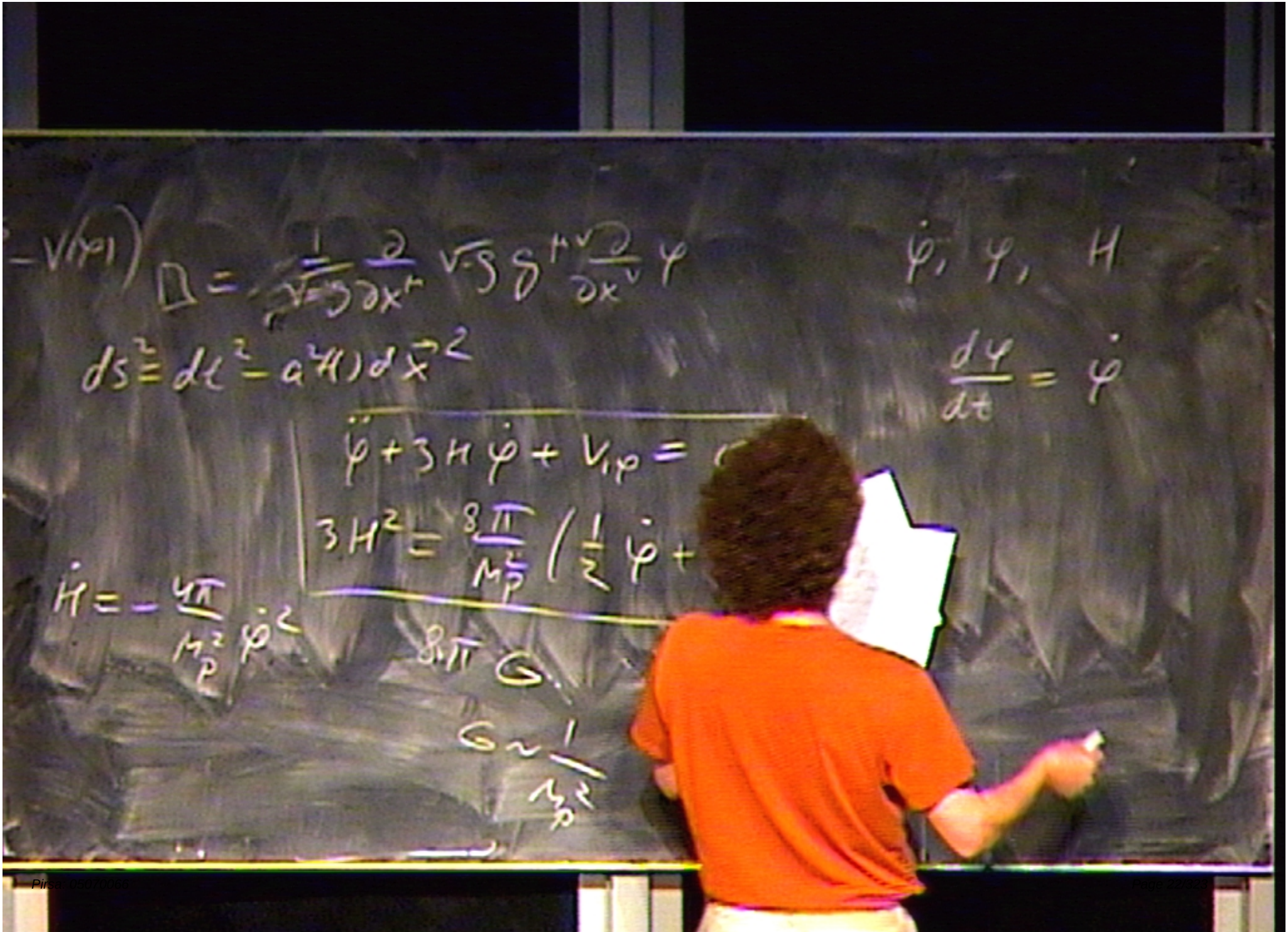
$$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} = 0$$

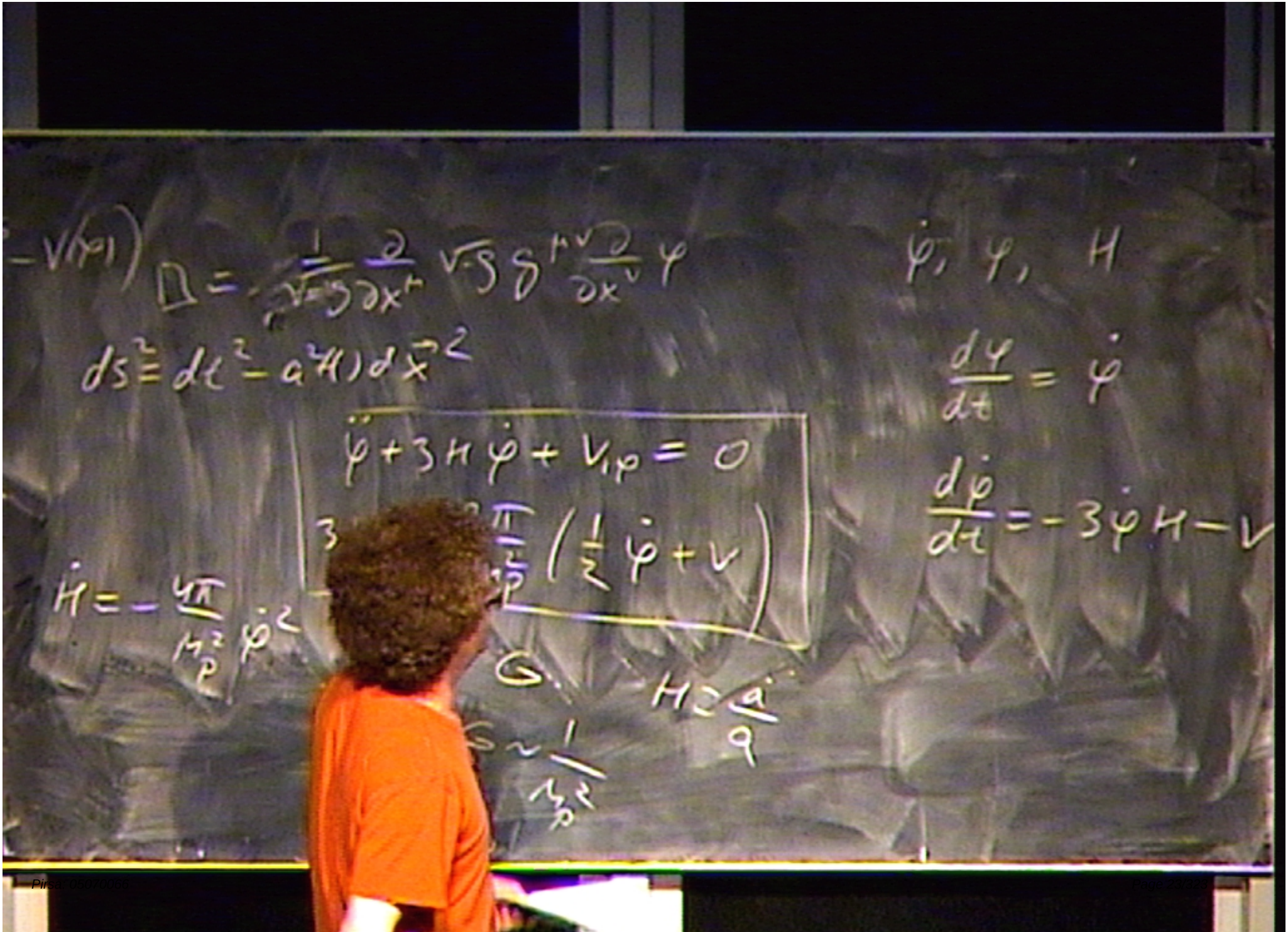
$$3H^2 = \frac{8\pi}{M_P^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$$

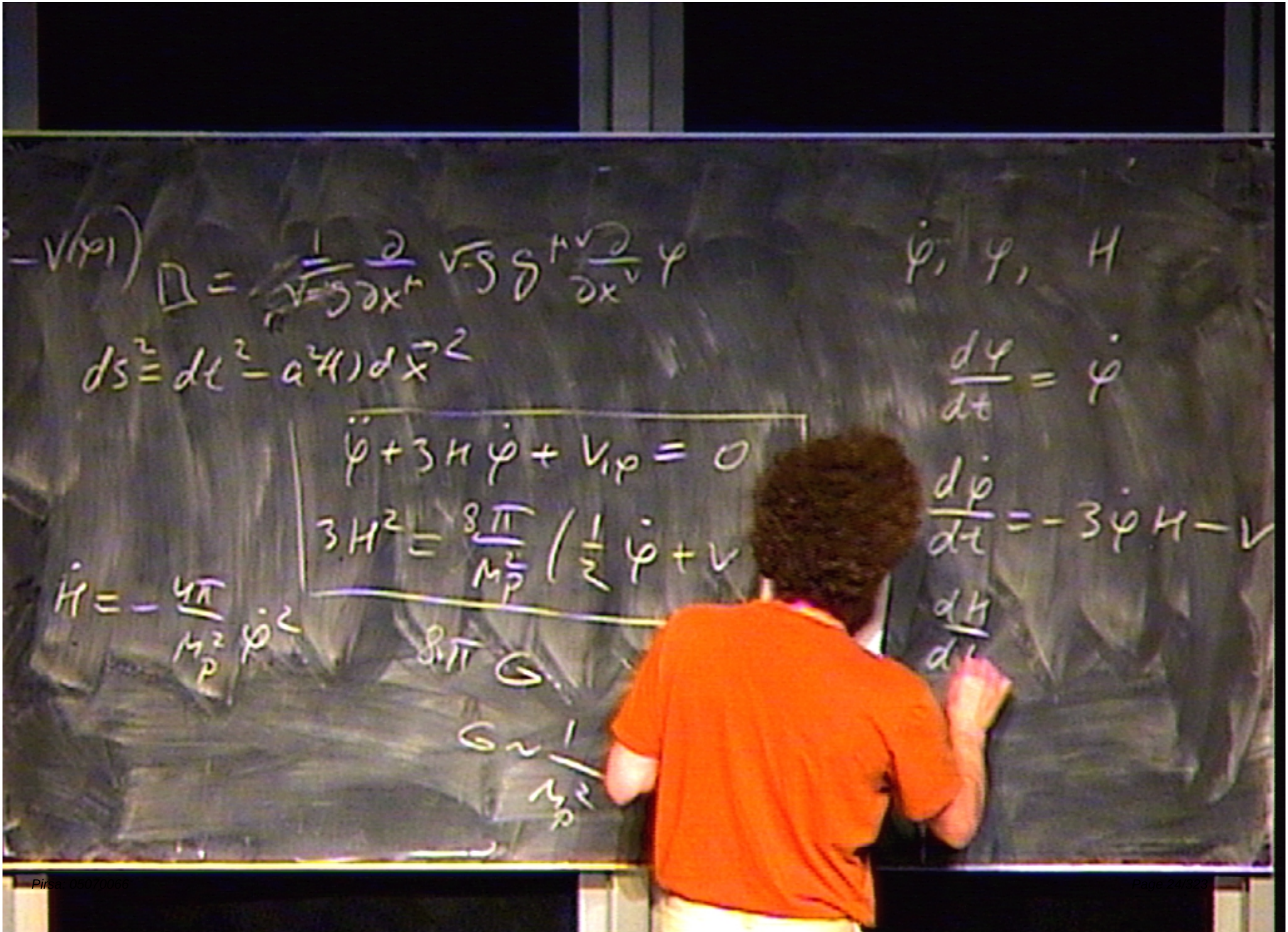
$$\dot{H} = -\frac{4\pi}{M_P^2}$$

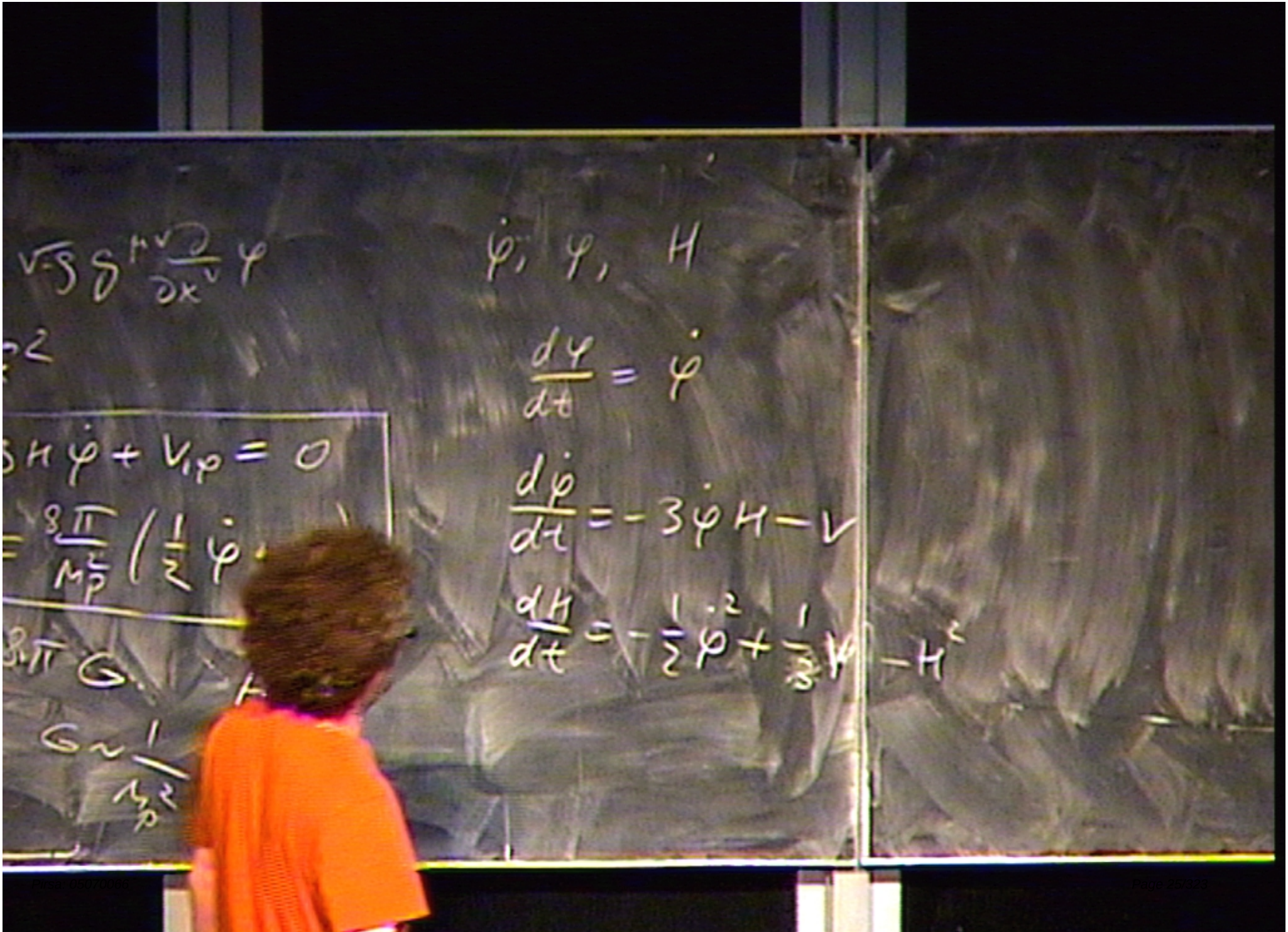
$8\pi G$ $\quad H = \frac{\dot{a}}{a}$

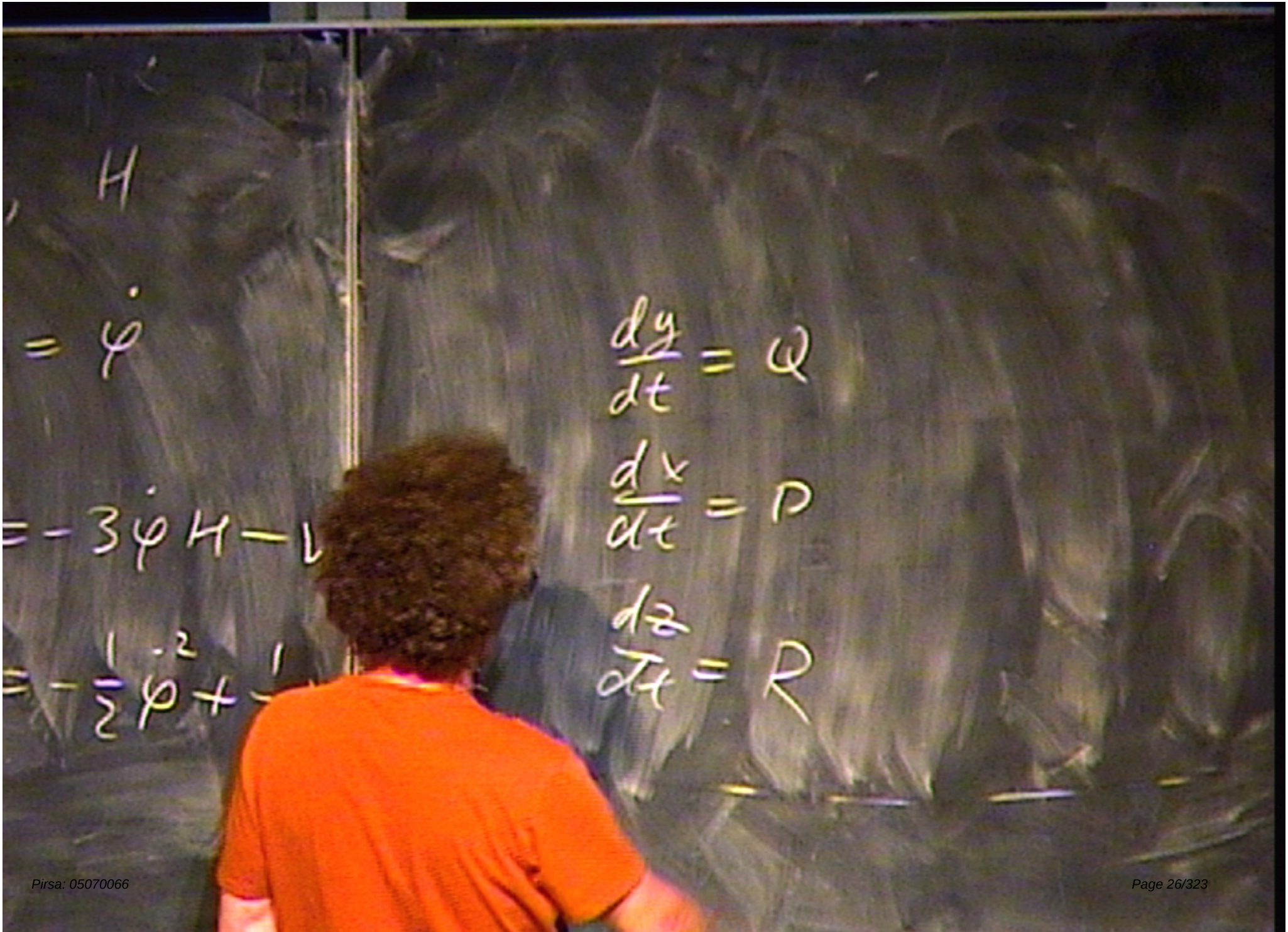
$$G \sim \frac{1}{M_P^2}$$

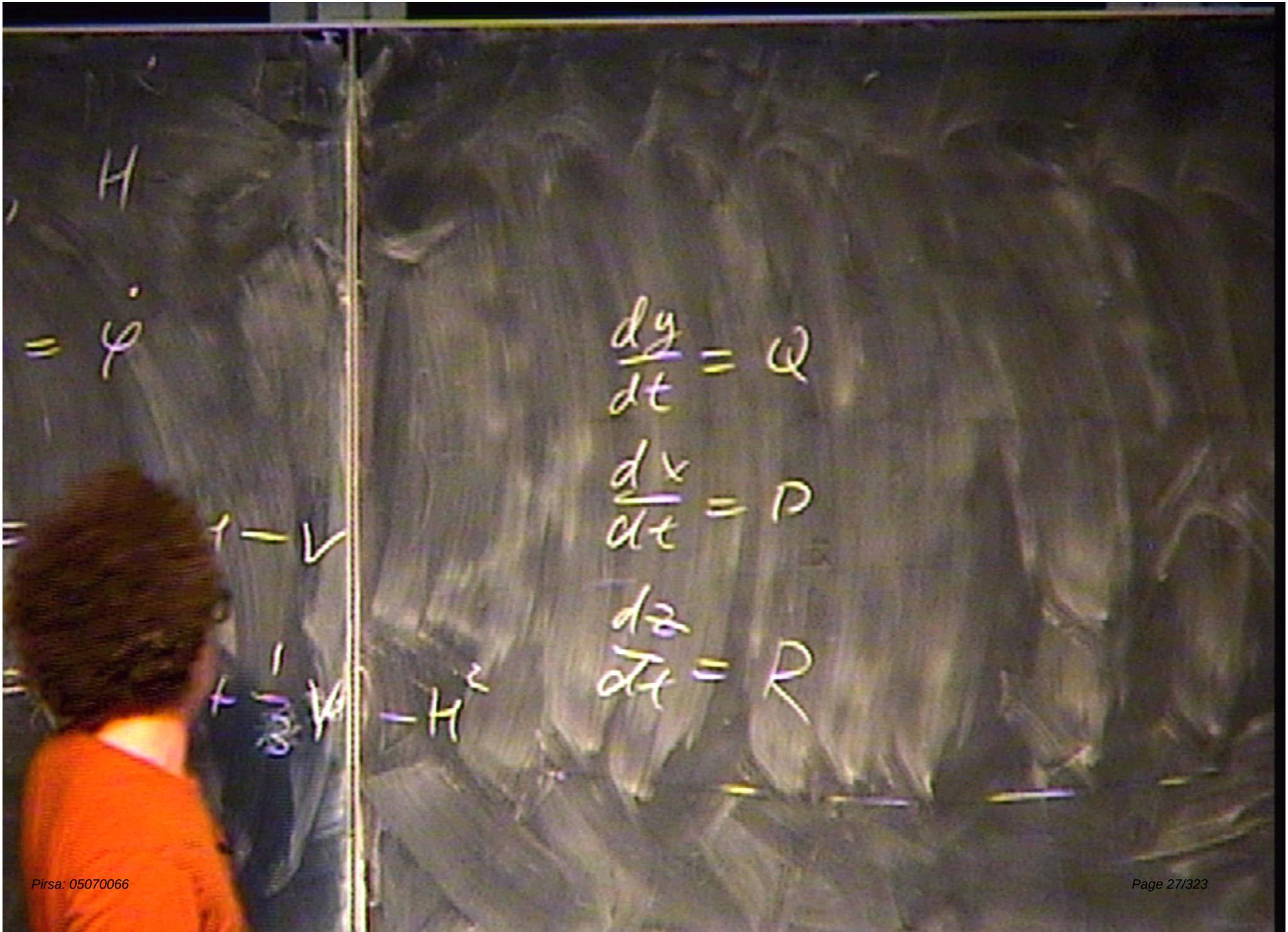

$-V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
$\dot{\varphi}, \varphi, H$
$ds^2 = dt^2 - a^2(t) d\vec{x}^2$
$\frac{d\varphi}{dt} = \dot{\varphi}$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} =$
$3H^2 = \frac{8\pi}{M_P^2} \left(\frac{1}{2} \dot{\varphi} + \right.$
$\dot{H} = -\frac{4\pi}{M_P^2} \dot{\varphi}^2$
$8\pi G$
$G \sim \frac{1}{M_P^2}$


$\dot\varphi,\ \varphi,\ H$
$\frac{d\varphi}{dt} = \dot\varphi$
$\frac{d\dot\varphi}{dt} = -3\dot\varphi H - V$
$\ddot\varphi + 3H\dot\varphi + V_{,\varphi} = 0$
$H = -\frac{4\pi}{M_P^2}\dot\varphi^2$
$H = \frac{\dot a}{a}$


$-V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
$\dot{\varphi}, \varphi, H$
$ds^2 = dt^2 - a^2(t) d\vec{x}^2$
$\frac{d\varphi}{dt} = \dot{\varphi}$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} = 0$
$3H^2 = \frac{8\pi}{M_P^2} \left(\frac{1}{2}\dot{\varphi} + V \right.$
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H - V$
$\dot{H} = -\frac{4\pi}{M_P^2}\dot{\varphi}^2$
$\frac{dH}{dt}$
$8\pi G$
$G \sim \frac{1}{M_P^2}$


$\sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
φ; χ, H
$\frac{d\chi}{dt} = \dot{\varphi}$
$3H\dot{\varphi} + V_{,\varphi} = 0$
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H - V$
$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{3}V - H^2$
$8\pi G$
$G \sim \frac{1}{M_p^2}$


H
$= \dot{\varphi}$
$= -3\dot{\varphi}H - V$
$= -\frac{1}{2}\dot{\varphi}^2 + V$
$\frac{dy}{dt} = Q$
$\frac{dv}{dt} = P$
$\frac{dz}{dt} = R$


H
$= \dot{\varphi}$
$= \quad 1 - V$
$= \quad + \frac{1}{3} V - H^2$
$\frac{dy}{dt} = Q$
$\frac{dv}{dt} = P$
$\frac{dz}{dt} = R$

H

$= \dot{\varphi}$

$= -3\dot{\varphi}H - V$

$= -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{3}V - H^2$

$\frac{dy}{dt} = Q$

$\frac{dx}{dt} = P$

$\frac{dz}{dt} = R$

H

$= \dot{\varphi}$

$= -3\dot{\varphi}H - V$

$= -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{3}V - H^2$

$\frac{dy}{dt} = Q$

$\frac{dx}{dt} = P$

$\frac{dz}{dt} = R$

(t, y, z)

$\mu^\nu \frac{\partial}{\partial x^\nu} \varphi$

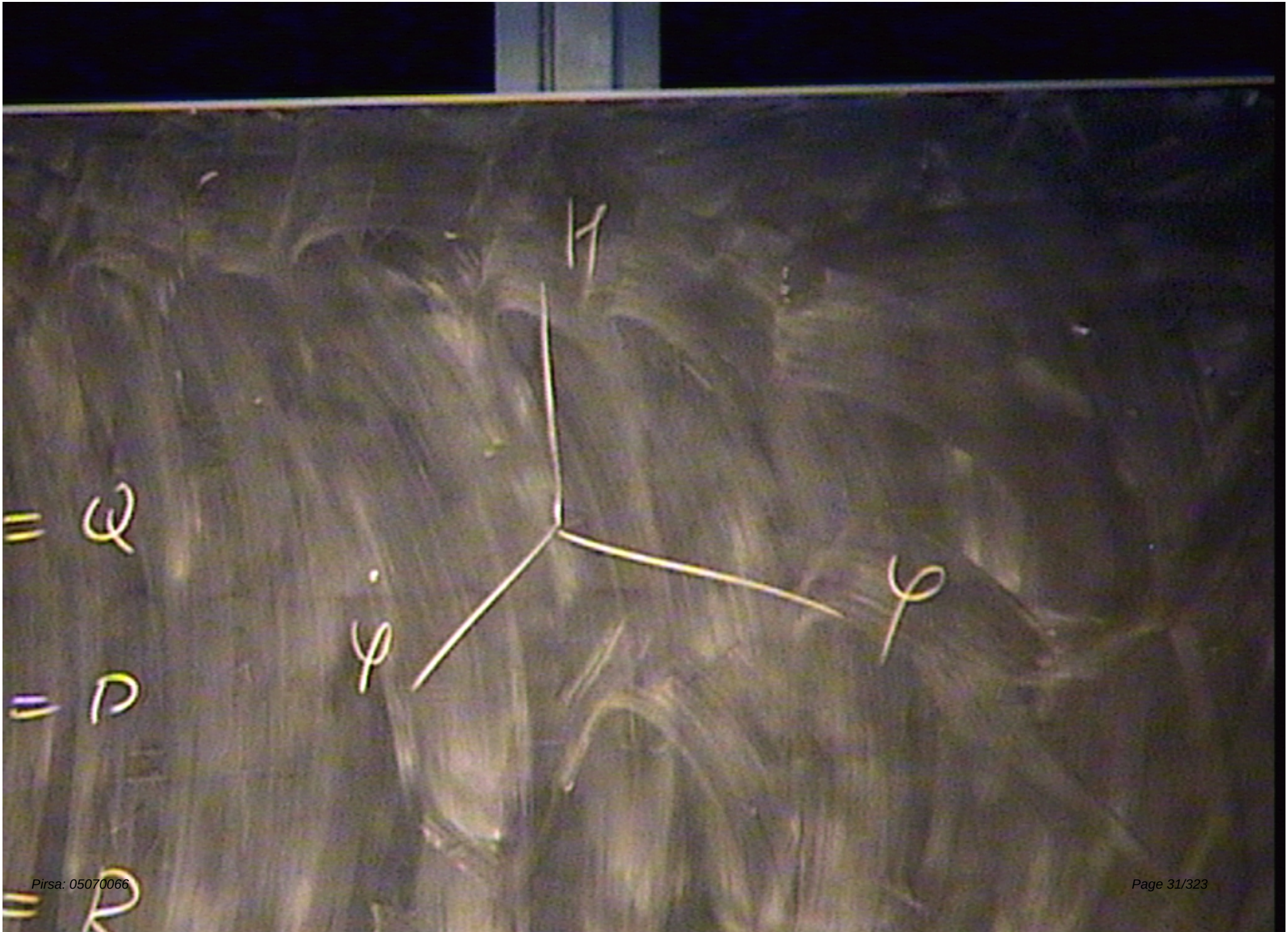
$\dot{\varphi}, \varphi, H$

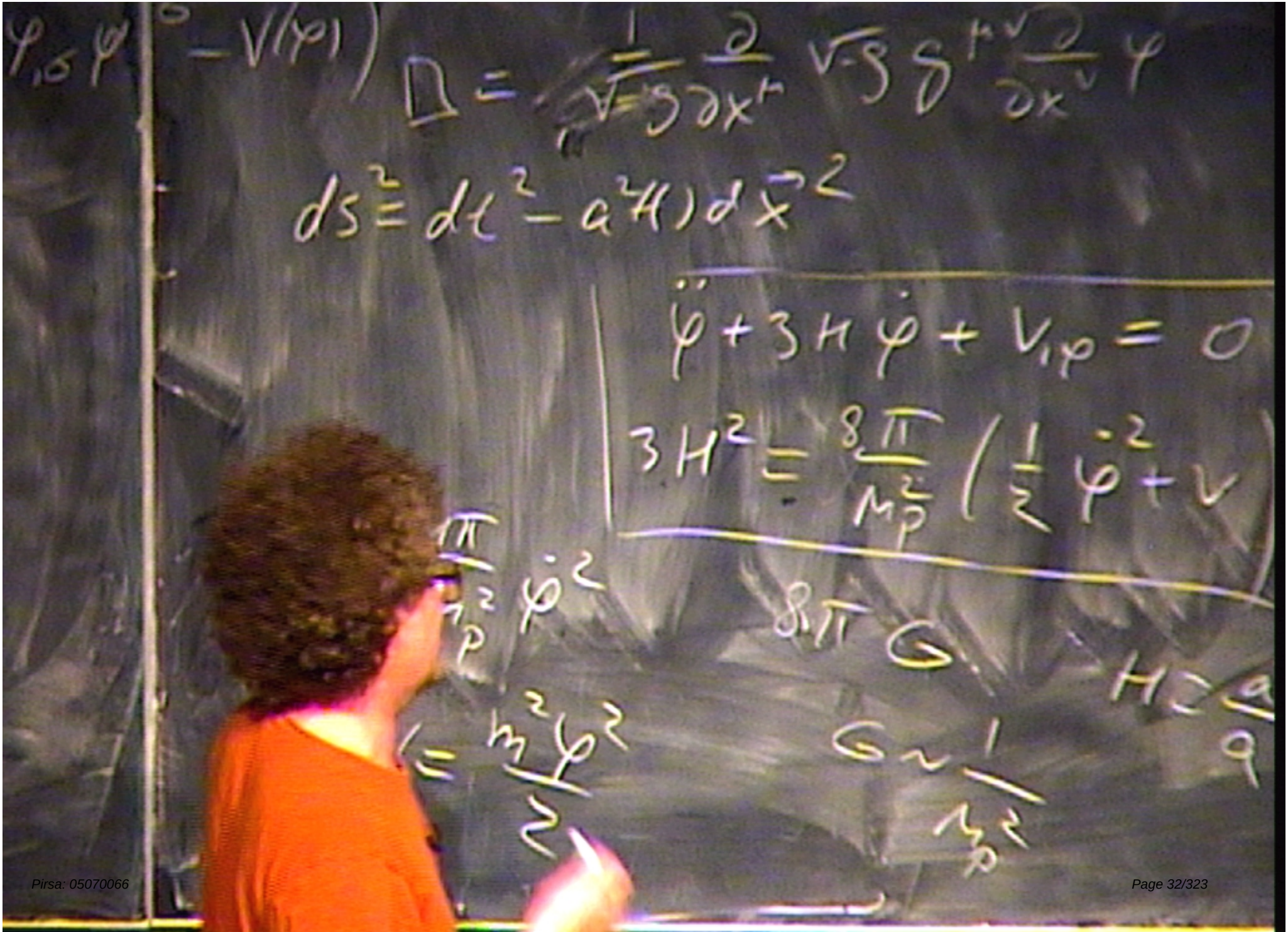
$\frac{d\varphi}{dt} = \dot{\varphi}$

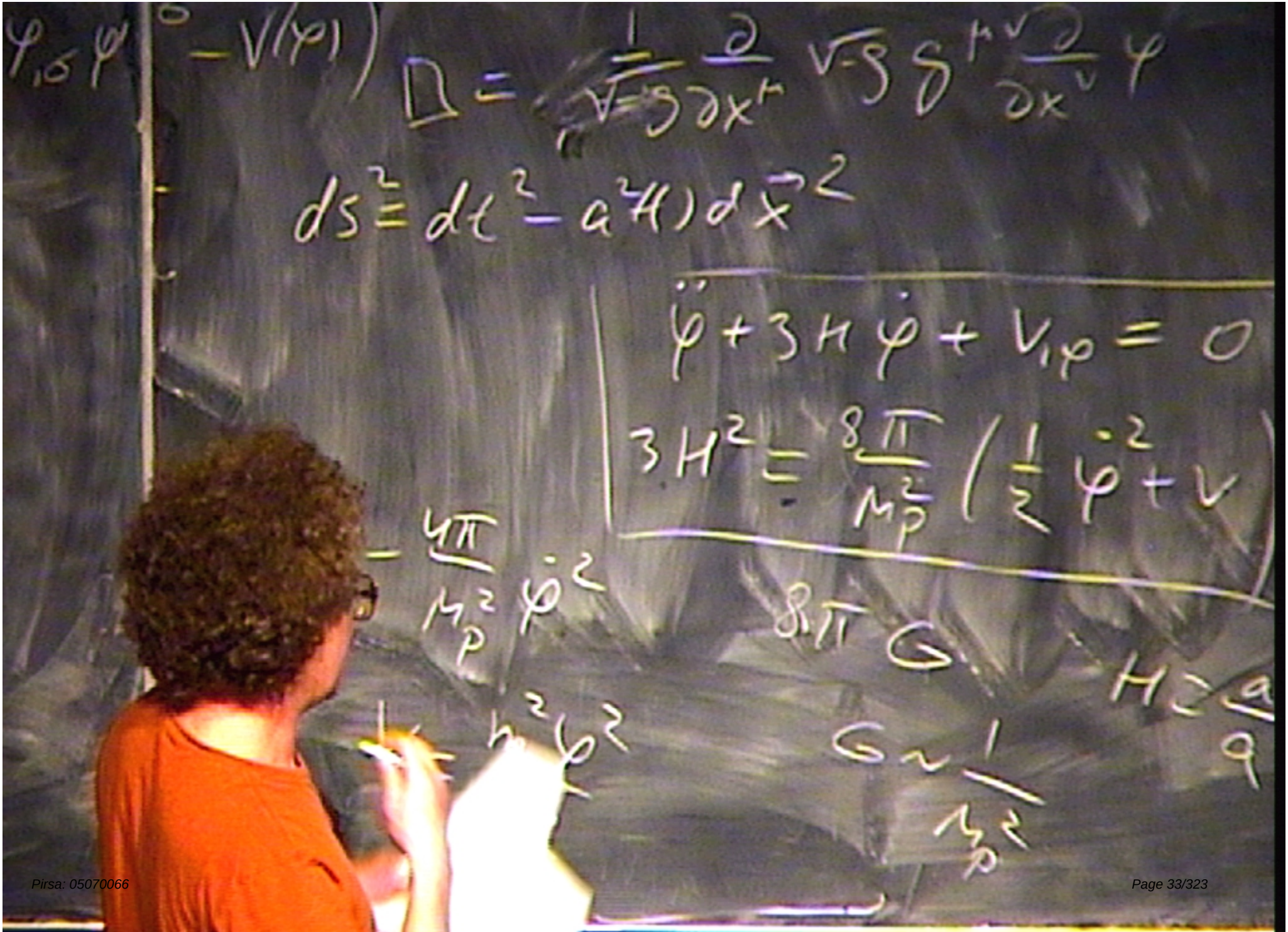
$+ V_{,\varphi} = 0$

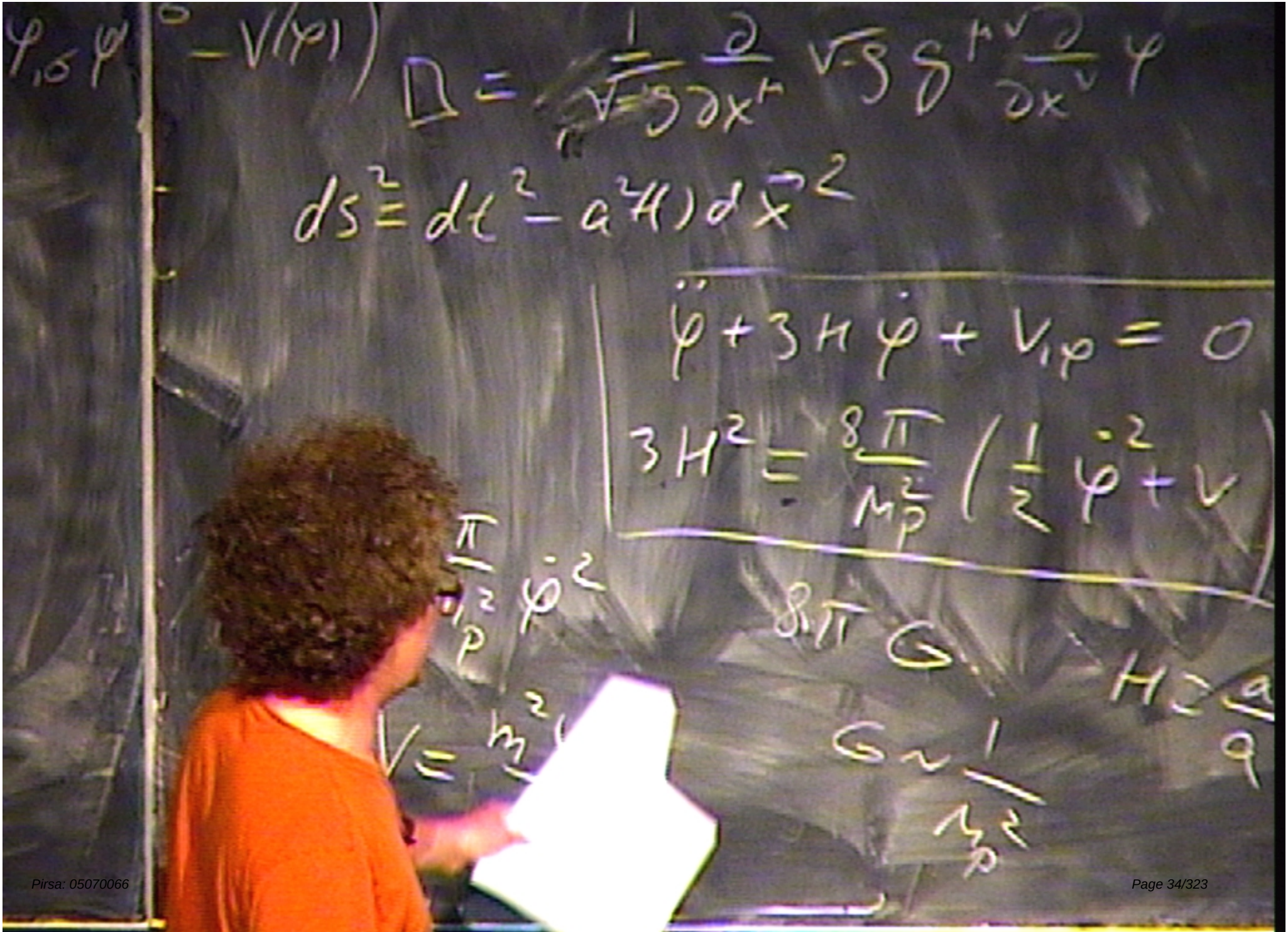
$\left(\frac{1}{2}\dot{\varphi} + V\right)$

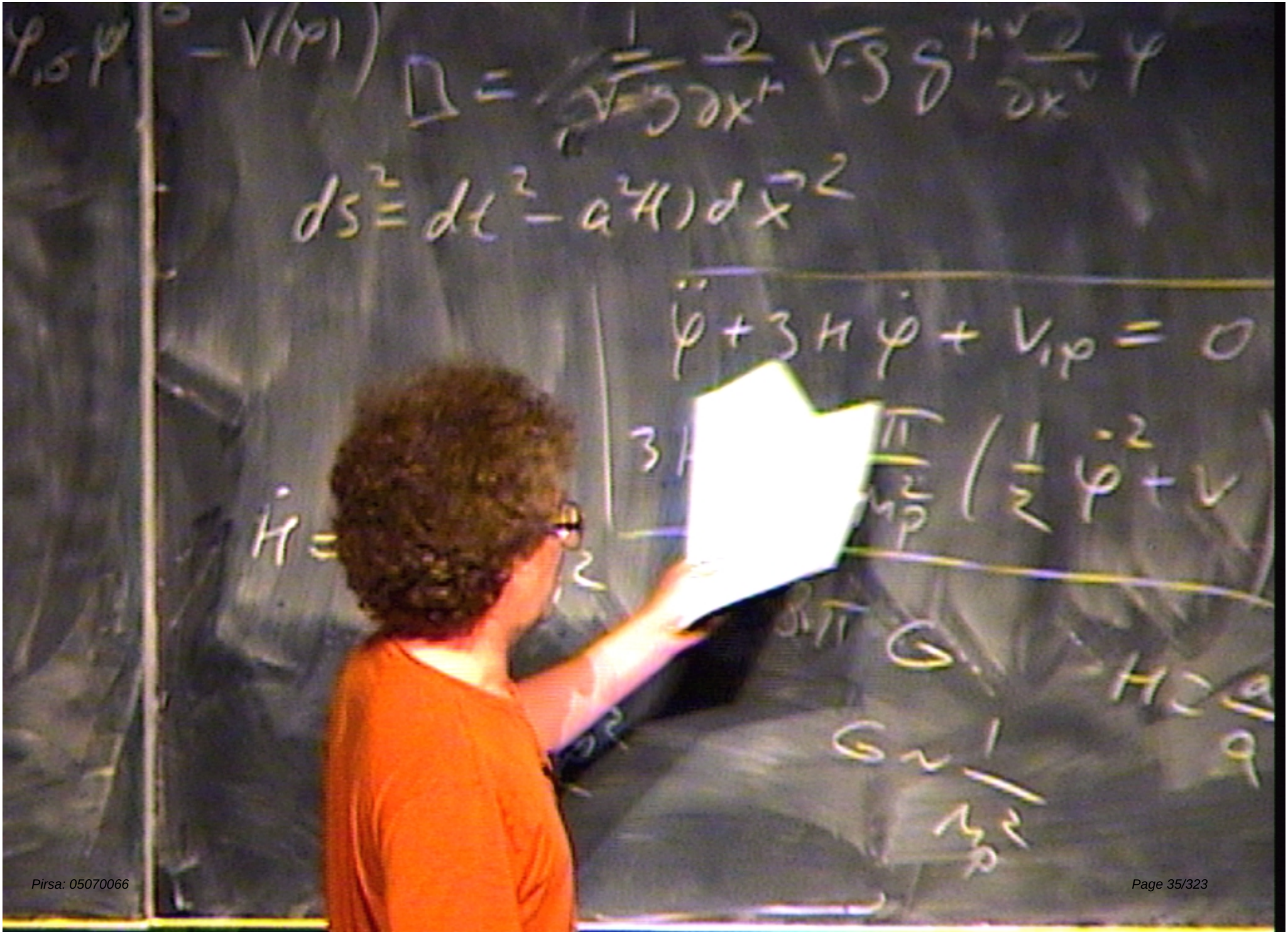
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H - V$

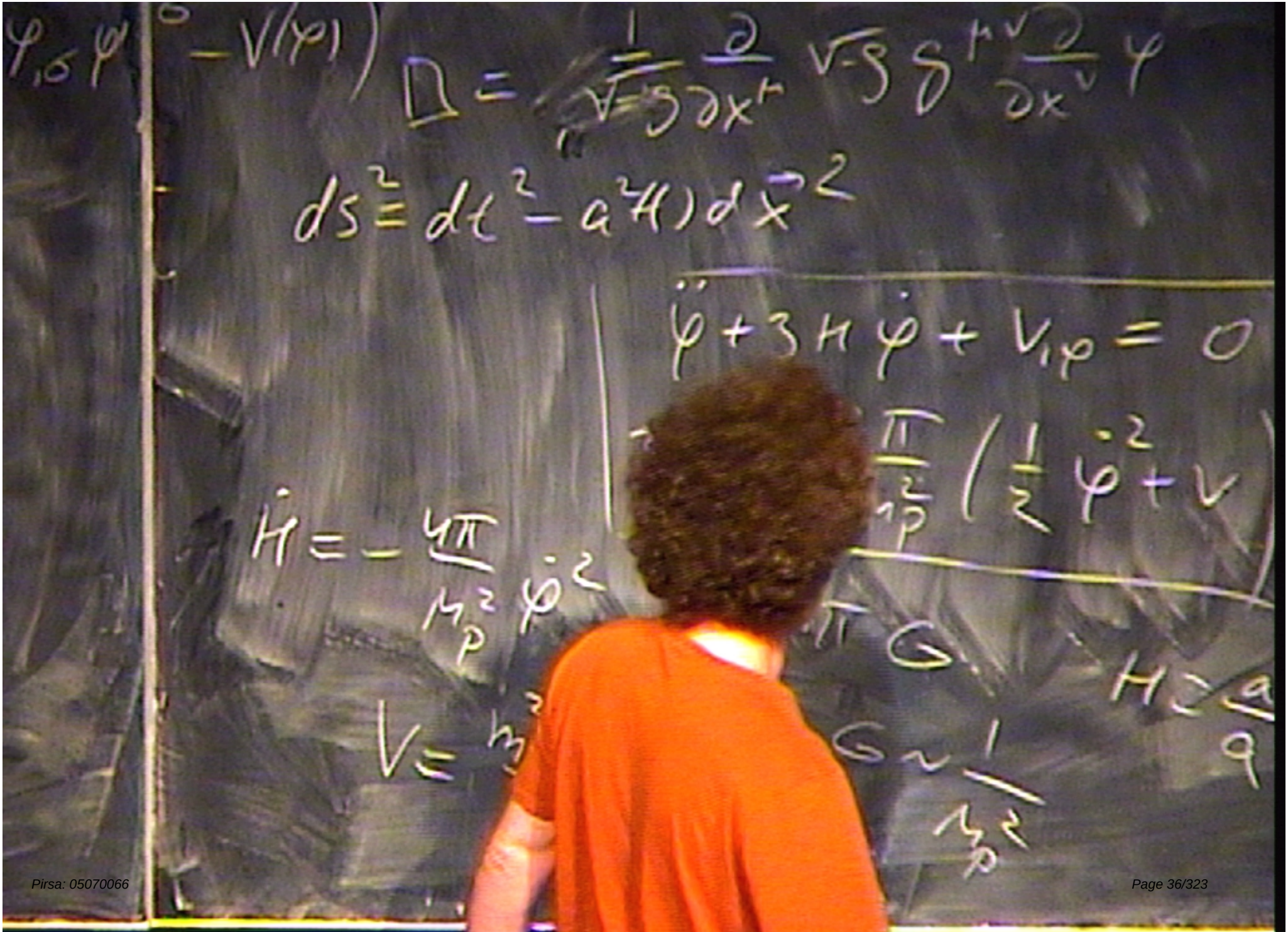

H
φ
φ
= Q
= P
= R


$\varphi, \varphi^2 - V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} = 0$
$3H^2 = \frac{8\pi}{M_p^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$
$\frac{\pi}{2} \dot{\varphi}^2$
$8\pi G$
$H = \frac{\dot{a}}{a}$
$= \frac{m^2 \varphi^2}{2}$
$G \sim \frac{1}{m_p^2}$


$\varphi_{,0}\varphi^{,0} - V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}}\frac{\partial}{\partial x^\mu}\sqrt{-g}\,g^{\mu\nu}\frac{\partial}{\partial x^\nu}\varphi$
$ds^2 = dt^2 - a^2(t)\,d\vec{x}^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} = 0$
$3H^2 = \frac{8\pi}{M_p^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$
$-\frac{4\pi}{M_p^2}\dot{\varphi}^2$
$8\pi G$
$H = \frac{a}{a}$
$G \sim \frac{1}{M_p^2}$


$\varphi, \dot{\varphi}$
$-V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} = 0$
$3H^2 = \frac{8\pi}{M_p^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$
$\frac{\pi}{p^2}\dot{\varphi}^2$
$8\pi G$
$H = \frac{a}{a}$
$V = m^2$
$G \sim \frac{1}{m_p^2}$


$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} = 0$
$ds^2 = dt^2 - a^2(t)\,d\vec{x}^2$
$H^2 = \frac{8\pi}{3M_p^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$
$G \sim \frac{1}{M_p^2}$


$\varphi_{,0}\varphi^{,0} - V(\varphi)$
$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$
$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} = 0$
$\frac{\pi}{m_p^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$
$H = -\frac{4\pi}{m_p^2}\dot{\varphi}^2$
πG
$H = \frac{a}{9}$
$V = m^2$
$G \sim \frac{1}{m_p^2}$

$-V(\varphi)$

$$\Box = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g}\, g^{\mu\nu} \frac{\partial}{\partial x^\nu} \varphi$$

$$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$$

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

$$3H^2 = \frac{8\pi}{M_P^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$$

$$\dot{H} = -\frac{4\pi}{M_P^2}\dot{\varphi}^2$$

$$V = \frac{m^2\varphi^2}{2}$$

$$G = \frac{1}{M_P^2}$$

$$H = \frac{\dot{a}}{a}$$

$(\dot{\varphi},\ \varphi,\ H)$

$$\frac{d\varphi}{dt} = \dot{\varphi}$$

$$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H - V_{,\varphi}$$

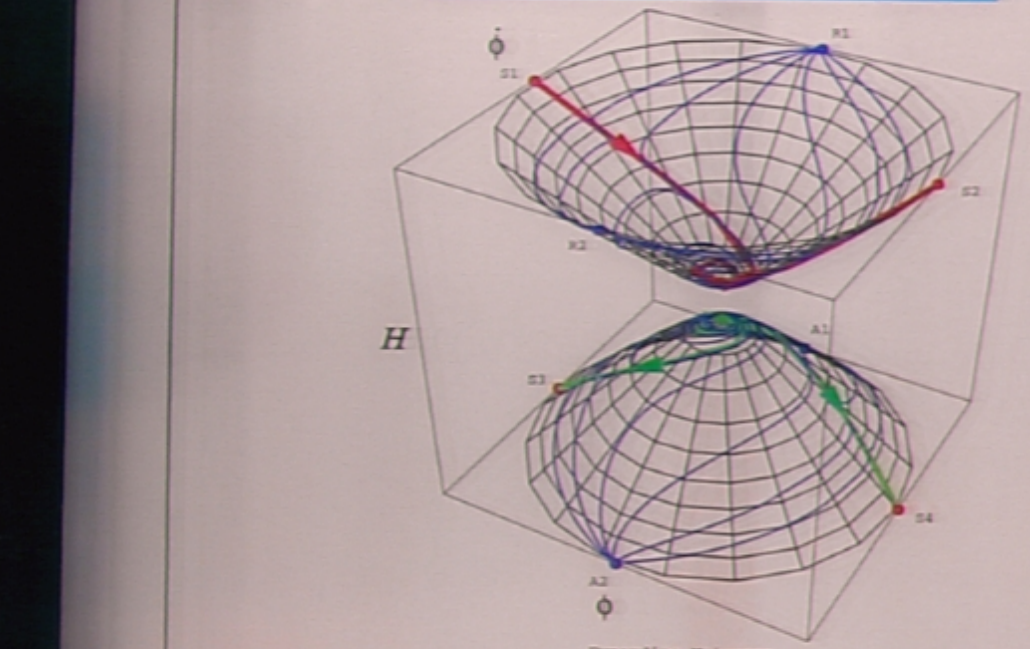
$$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{3}V - H^2$$

$$3H^2 - \frac{8\pi}{M_P^2}\dot{\varphi}^2 - 8\pi m^2\varphi^2 = 0$$

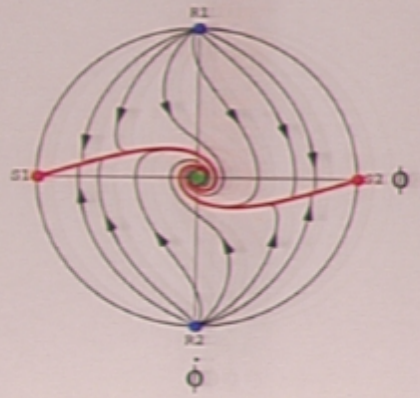
$\frac{d\varphi}{dt}$ $\frac{d\dot{\varphi}}{dt}$ $\frac{dH}{dt}$

$(t, \varphi, \dot{\varphi})$

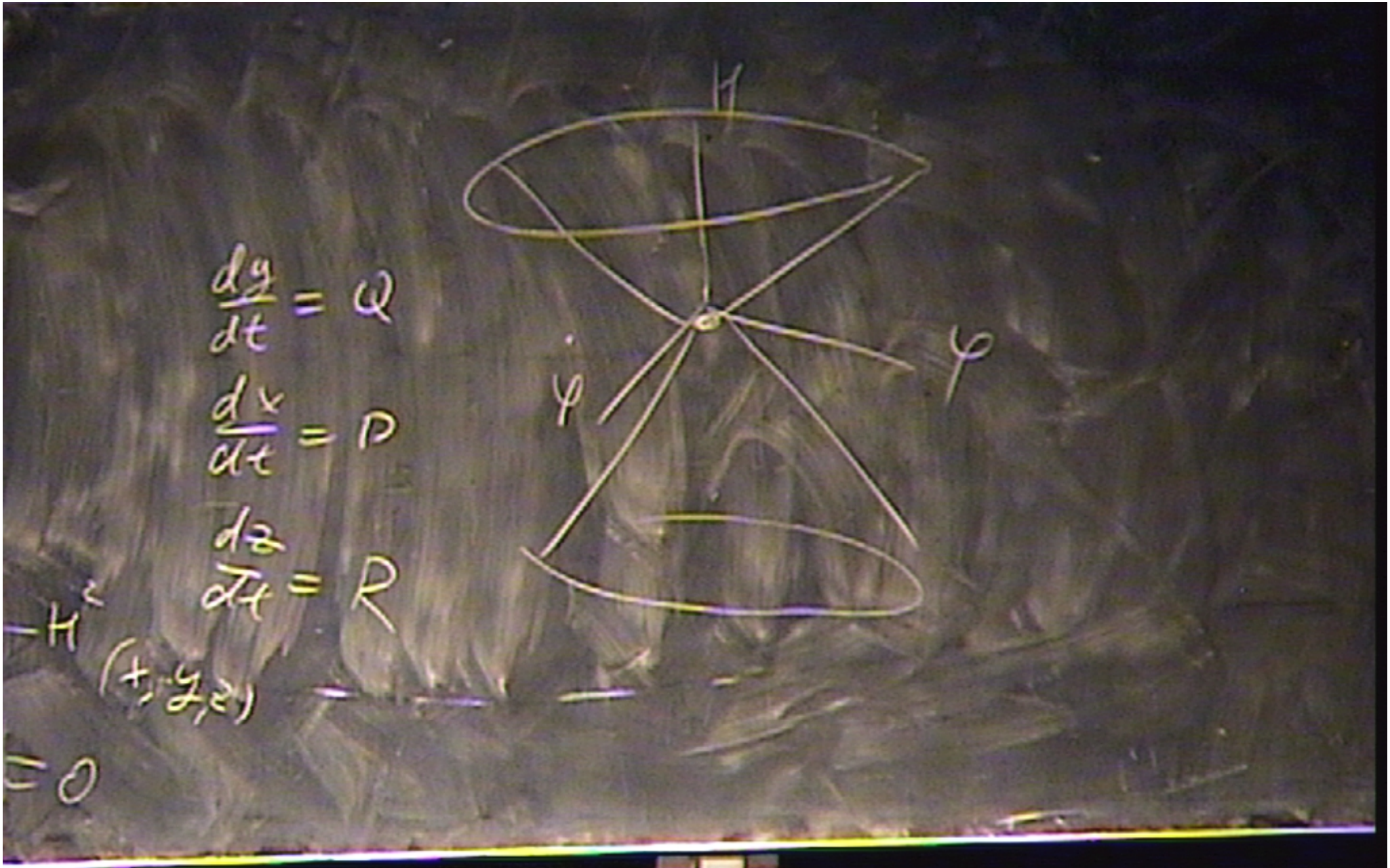
$$V(\phi) = \tfrac{1}{2}m^2\phi^2 + \Lambda, \quad \Lambda > 0$$

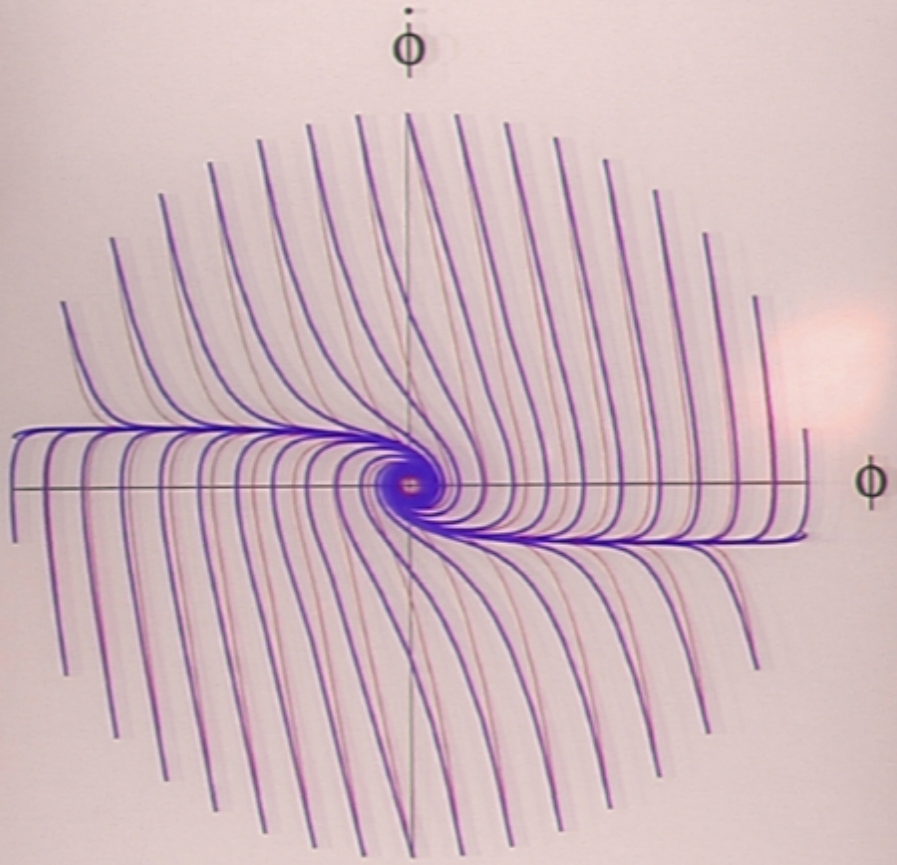


Expanding Universe



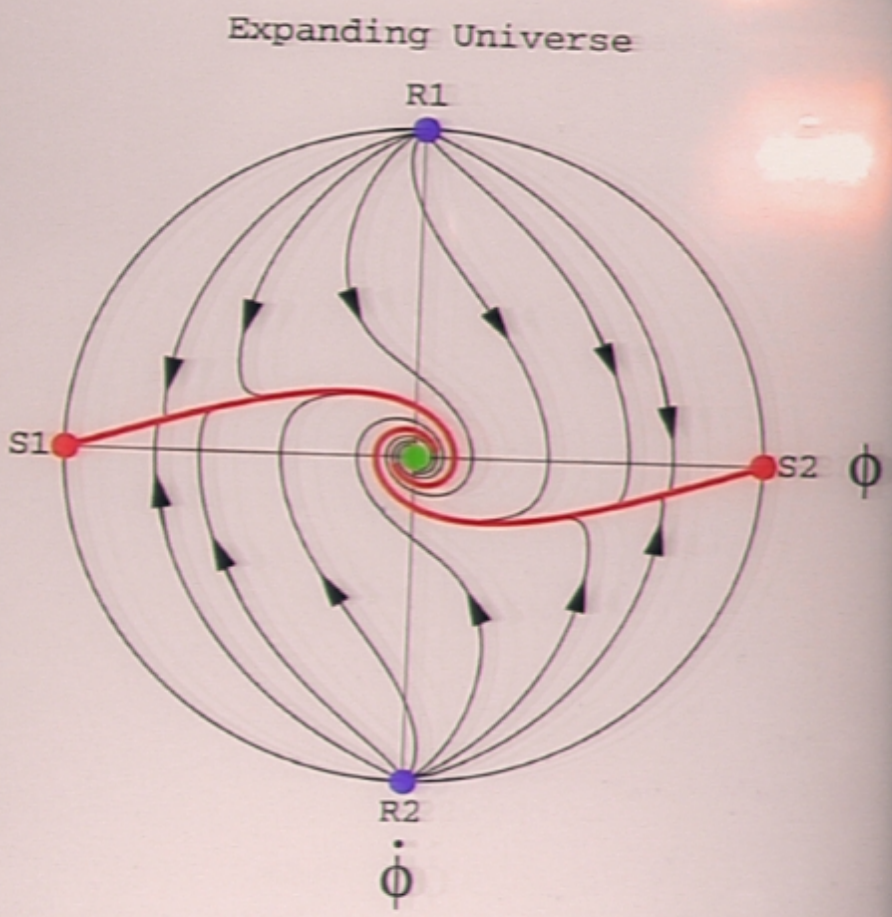
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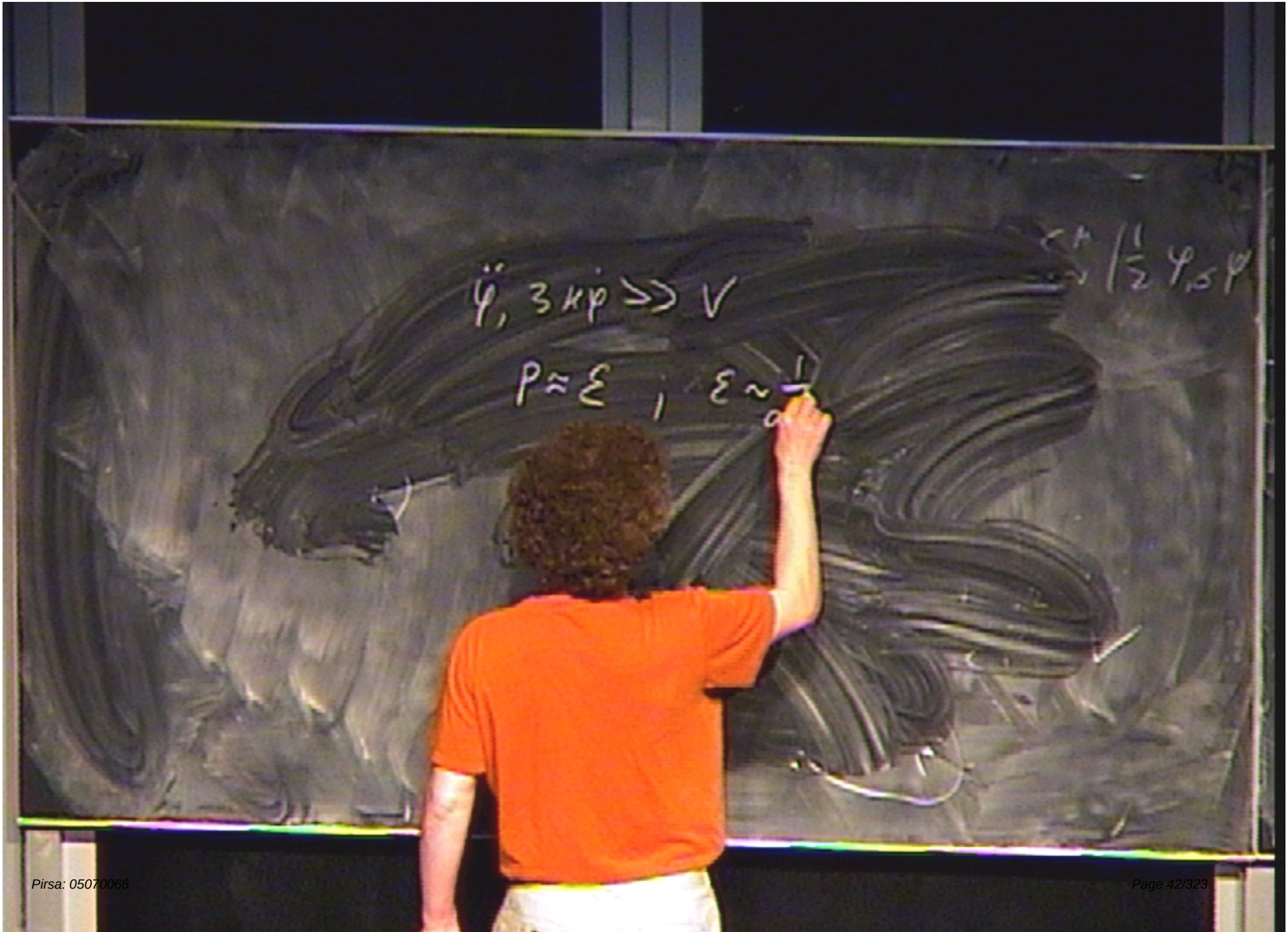

H
φ
φ
$\frac{dy}{dt} = Q$
$\frac{dx}{dt} = P$
$\frac{dz}{dt} = R$
H^2
(x, y, z)
$= 0$

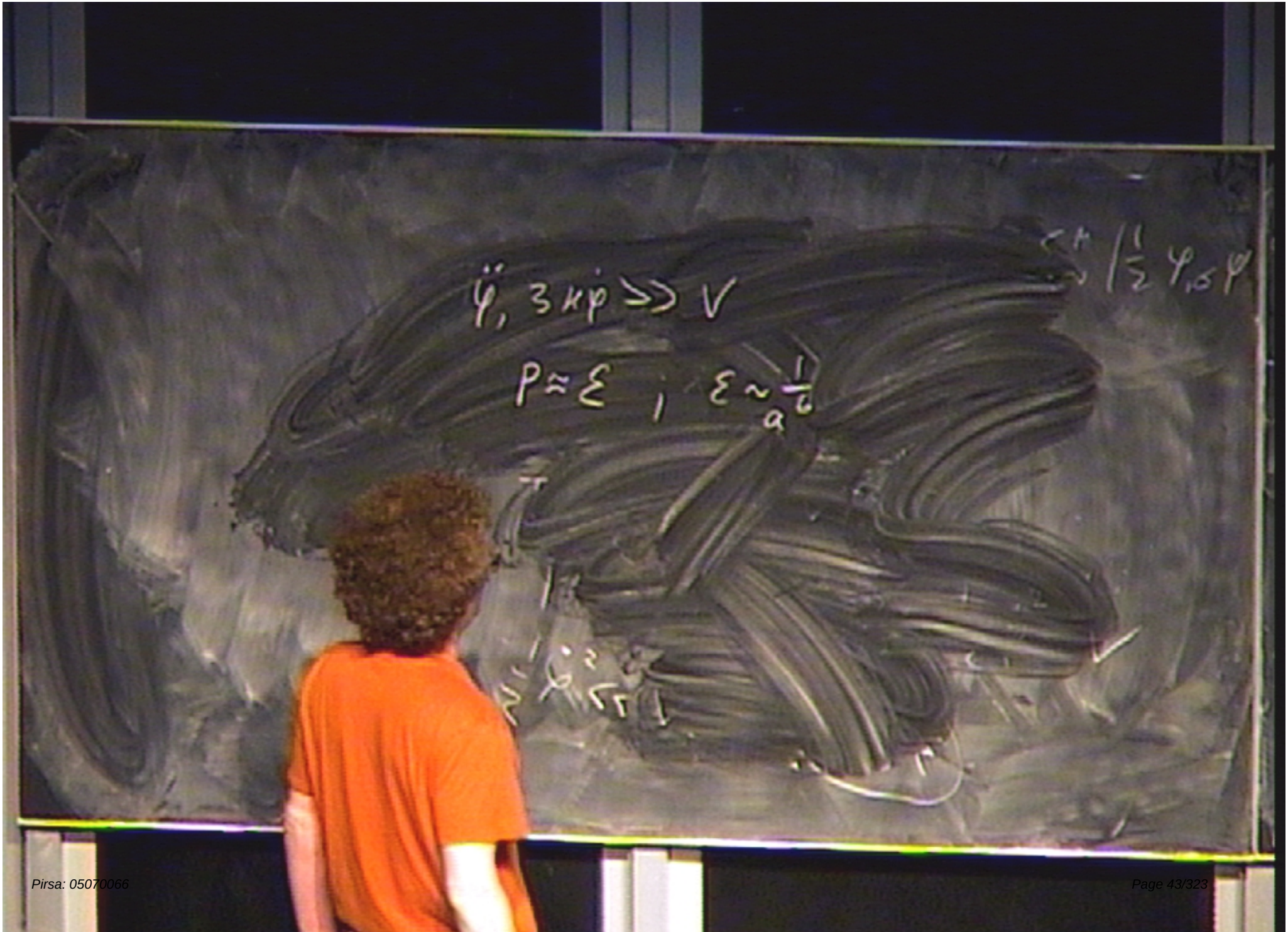


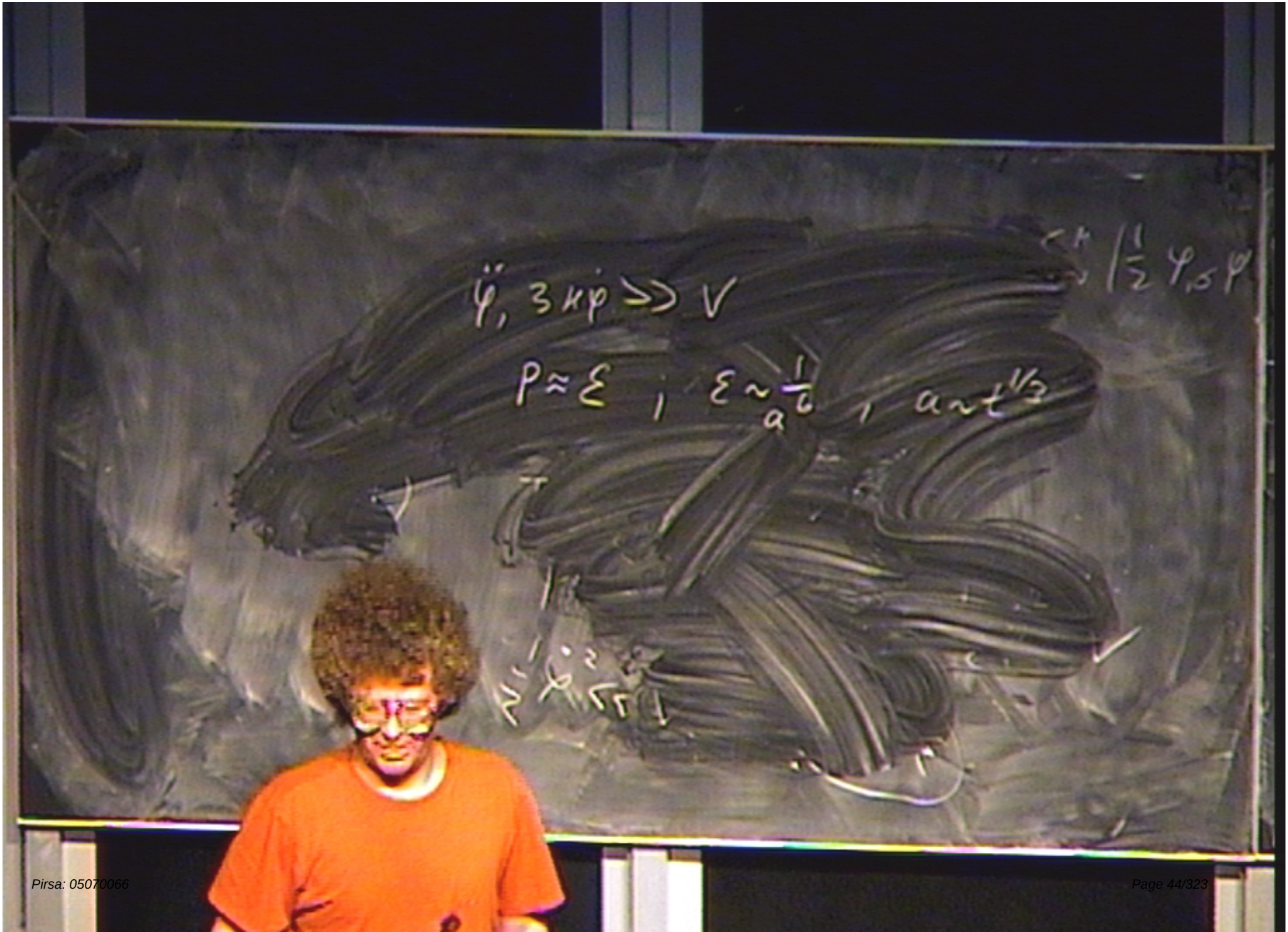
$$\ddot{\phi} + 3\frac{\dot{a}}{a}\dot{\phi} + m^2\phi = 0$$

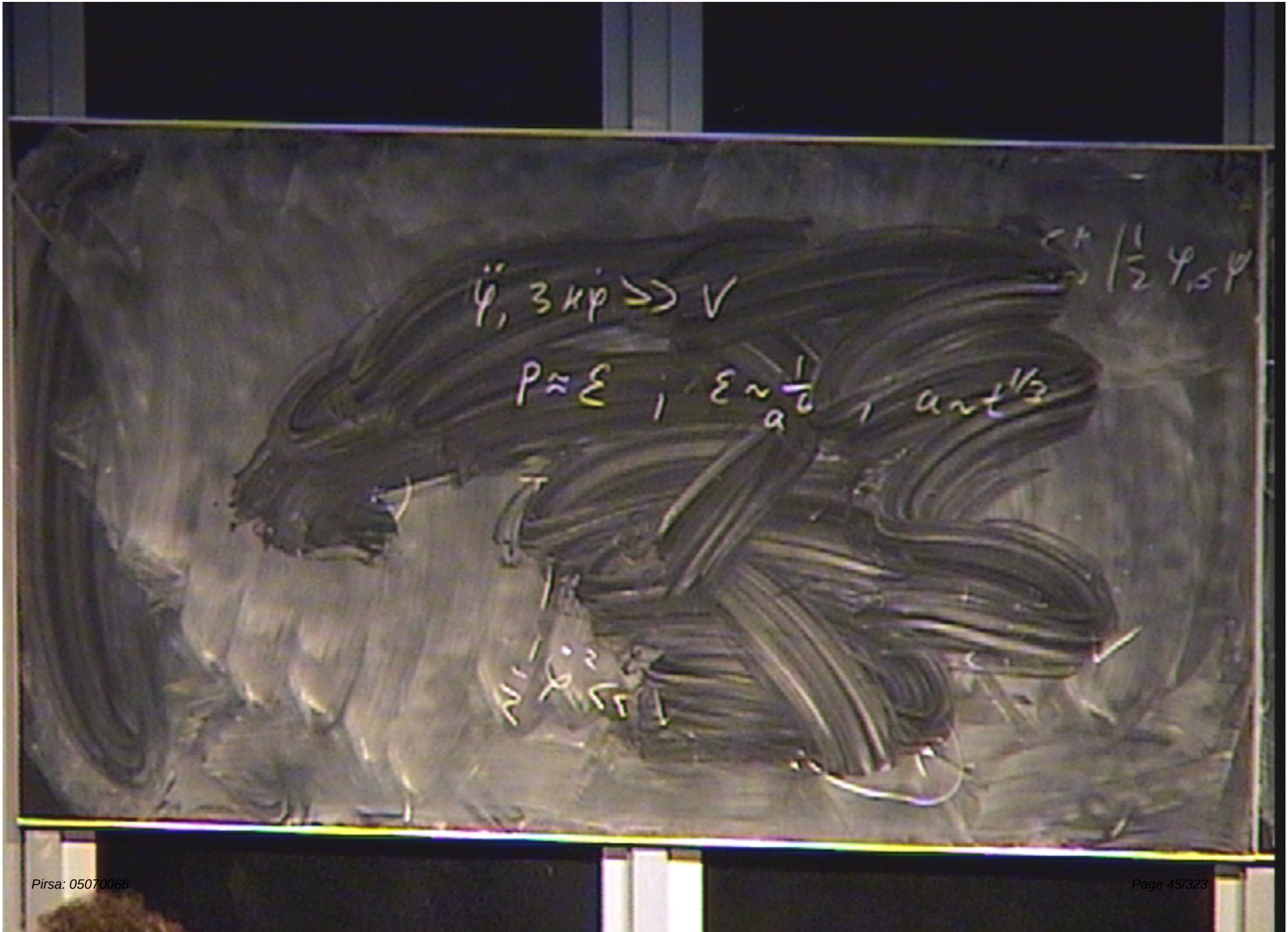
$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi}{3m_p^2}\left(\frac{1}{2}\dot{\phi}^2 + m^2\frac{\phi^2}{2}\right)$$

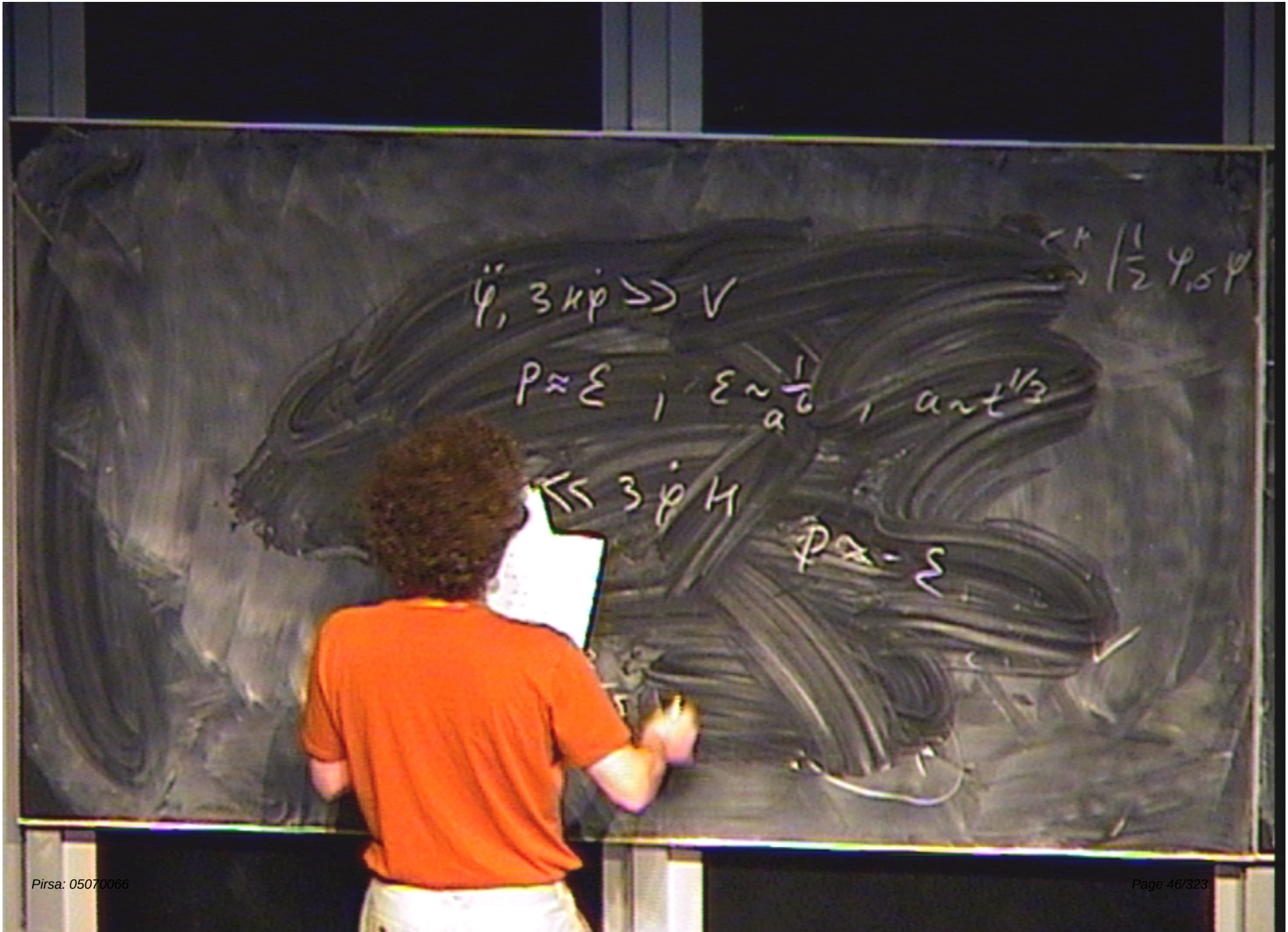

Expanding Universe
R1
S1
S2
ϕ
R2
$\dot{\phi}$

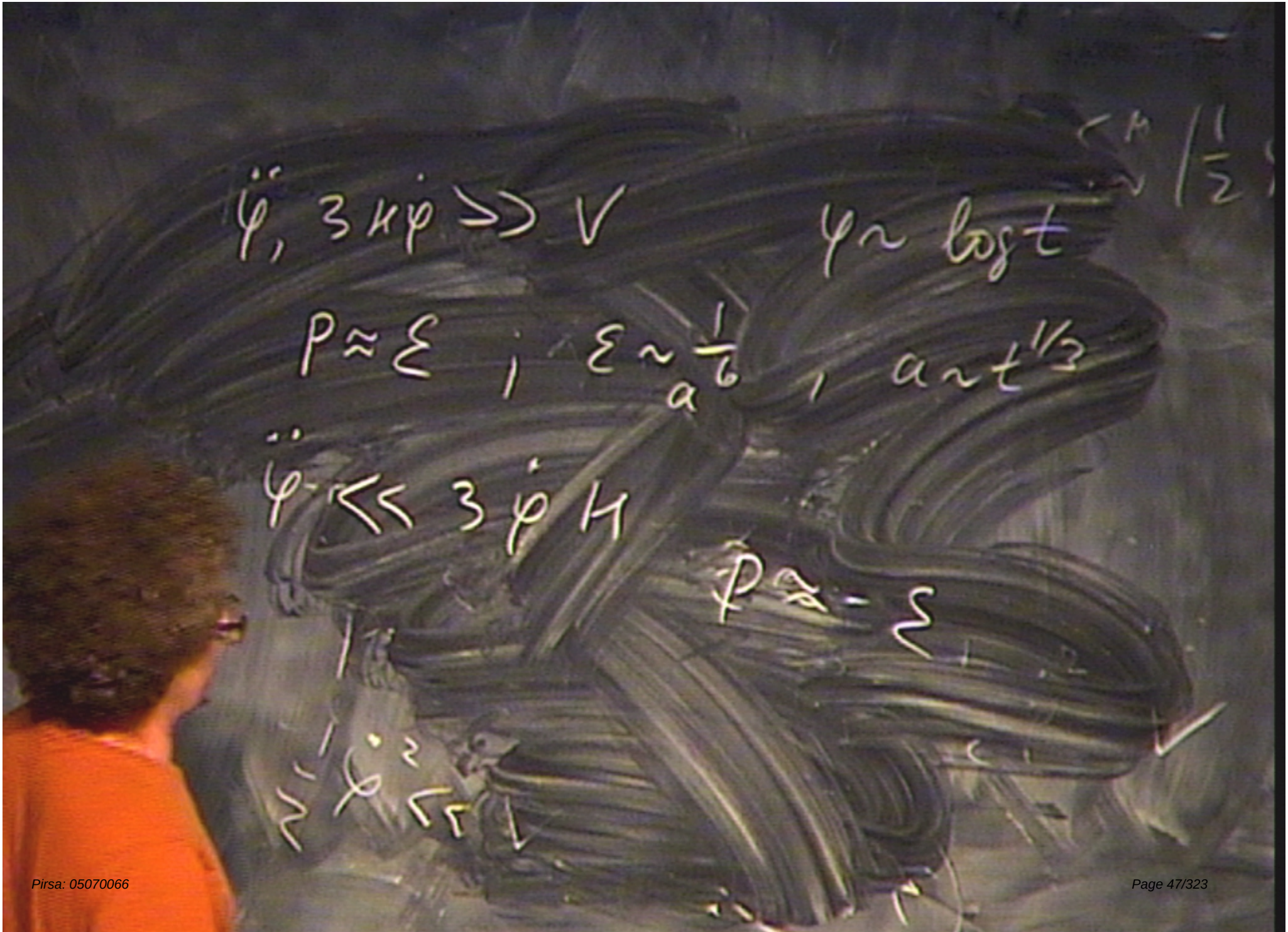

$\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$P \approx \mathcal{E}$; $\mathcal{E} \sim \frac{1}{a^4}$
$\frac{1}{2}\dot{\varphi}^2 - V$

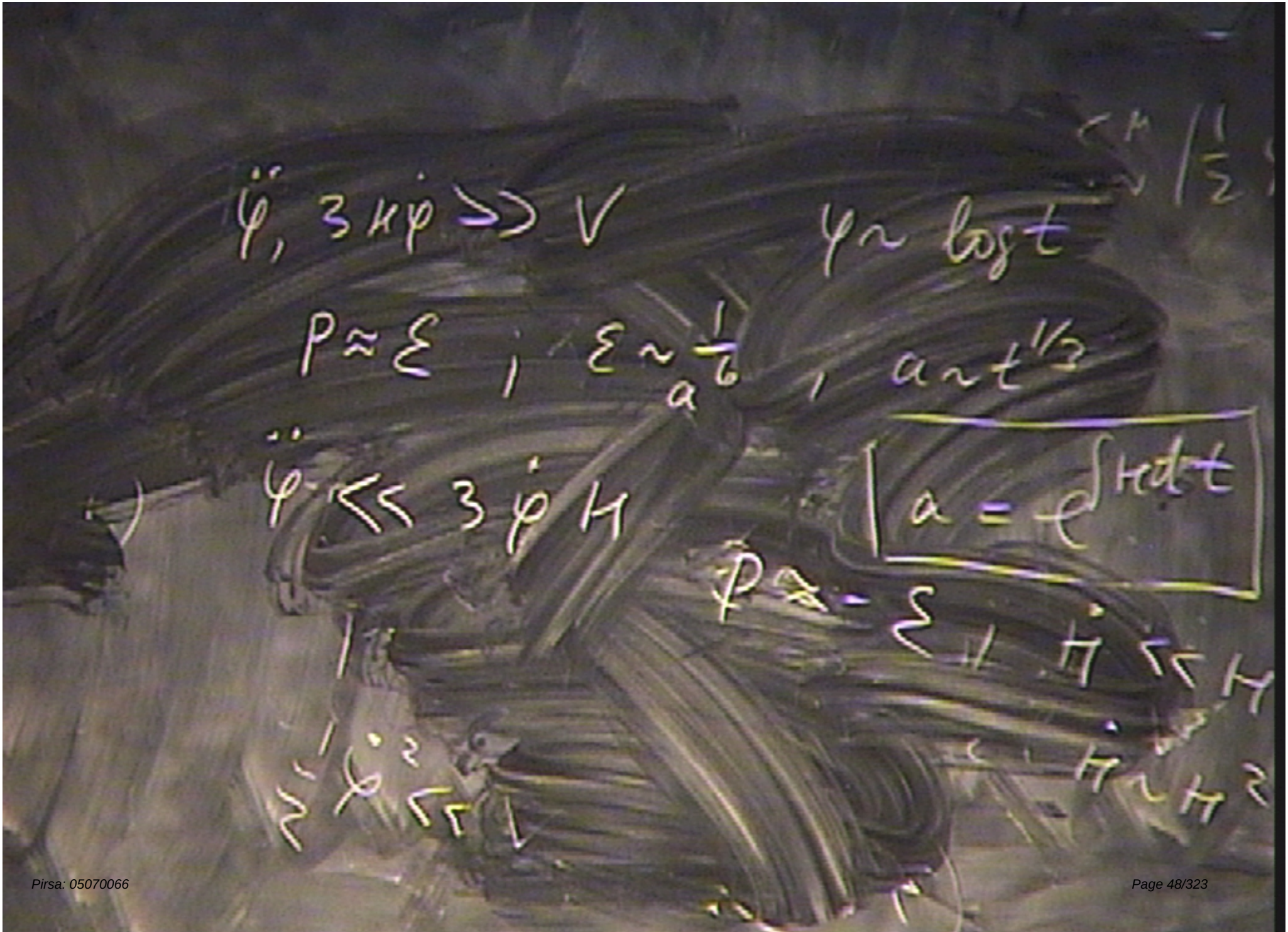

$\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$P \approx \varepsilon \; , \; \varepsilon \sim \frac{1}{a^6}$

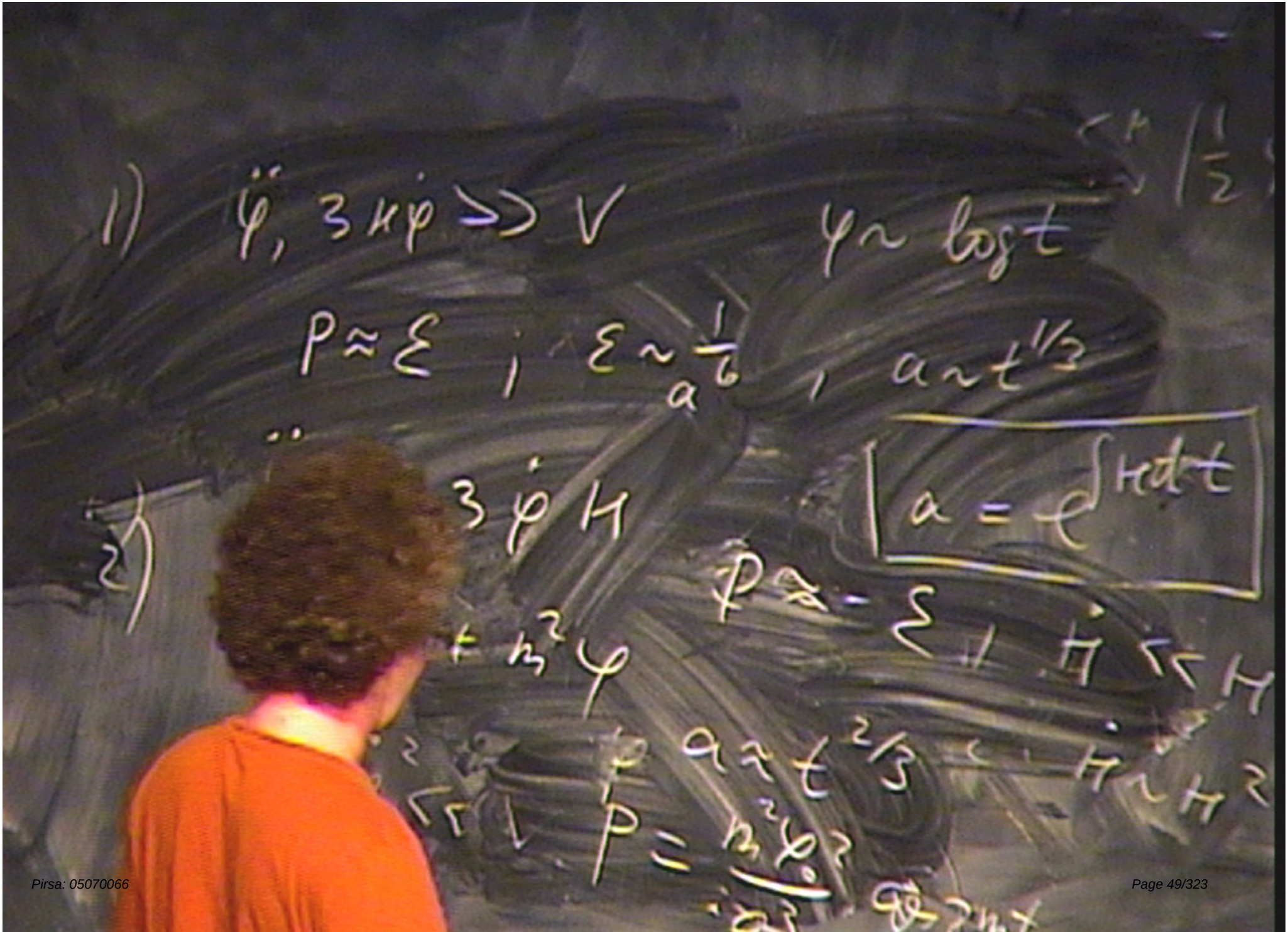

$\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$p \approx \varepsilon \; , \; \varepsilon \sim \frac{1}{a^6} \; , \; a \sim t^{1/3}$


$\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$P \approx \mathcal{E}$, $\mathcal{E} \sim \frac{1}{a^6}$, $a \sim t^{1/3}$


$\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$p \approx \varepsilon$, $\varepsilon \sim \frac{1}{a^6}$, $a \sim t^{1/3}$
$\ll 3\dot{\varphi} H$
$p \approx -\varepsilon$


$\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$\varphi \sim \log t$
$p \approx \varepsilon$; $\varepsilon \sim \frac{1}{a^6}$, $a \sim t^{1/3}$
$\ddot{\varphi} \ll 3\dot{\varphi} H$
$\bar{p} \approx -\varepsilon$
$\frac{1}{2}\dot{\varphi}^2$


$\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$\varphi \sim \log t$
$P \approx \mathcal{E}$, $\mathcal{E} \sim \frac{1}{a^6}$, $a \sim t^{1/3}$
$\ddot{\varphi} \ll 3\dot{\varphi} H$
$a = e^{\int H dt}$
$P \approx -\mathcal{E}$, $\dot{H} \ll H^2$
$\sim \frac{1}{2}\dot{\varphi}^2 \ll V$
$\sim H^2$


1) $\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$\varphi \sim \log t$
$p \approx \varepsilon$; $\varepsilon \sim \frac{1}{a^6}$, $a \sim t^{1/3}$
2) $\ddot{\varphi} + 3\dot{\varphi}H + m^2\varphi$
$a = e^{\int H dt}$
$\dot{p} \approx -\varepsilon$, $\dot{H} < < H$
$a \approx t^{2/3}$, $\dot{H} \sim H^2$
$p = \frac{m^2\varphi^2}{2}$

1) $\ddot{\varphi}, 3H\dot{\varphi} \gg V$ $\quad \varphi \sim \log t$

$p \approx \varepsilon$, $\varepsilon \sim \frac{1}{a^6}$, $a \sim t^{1/3}$

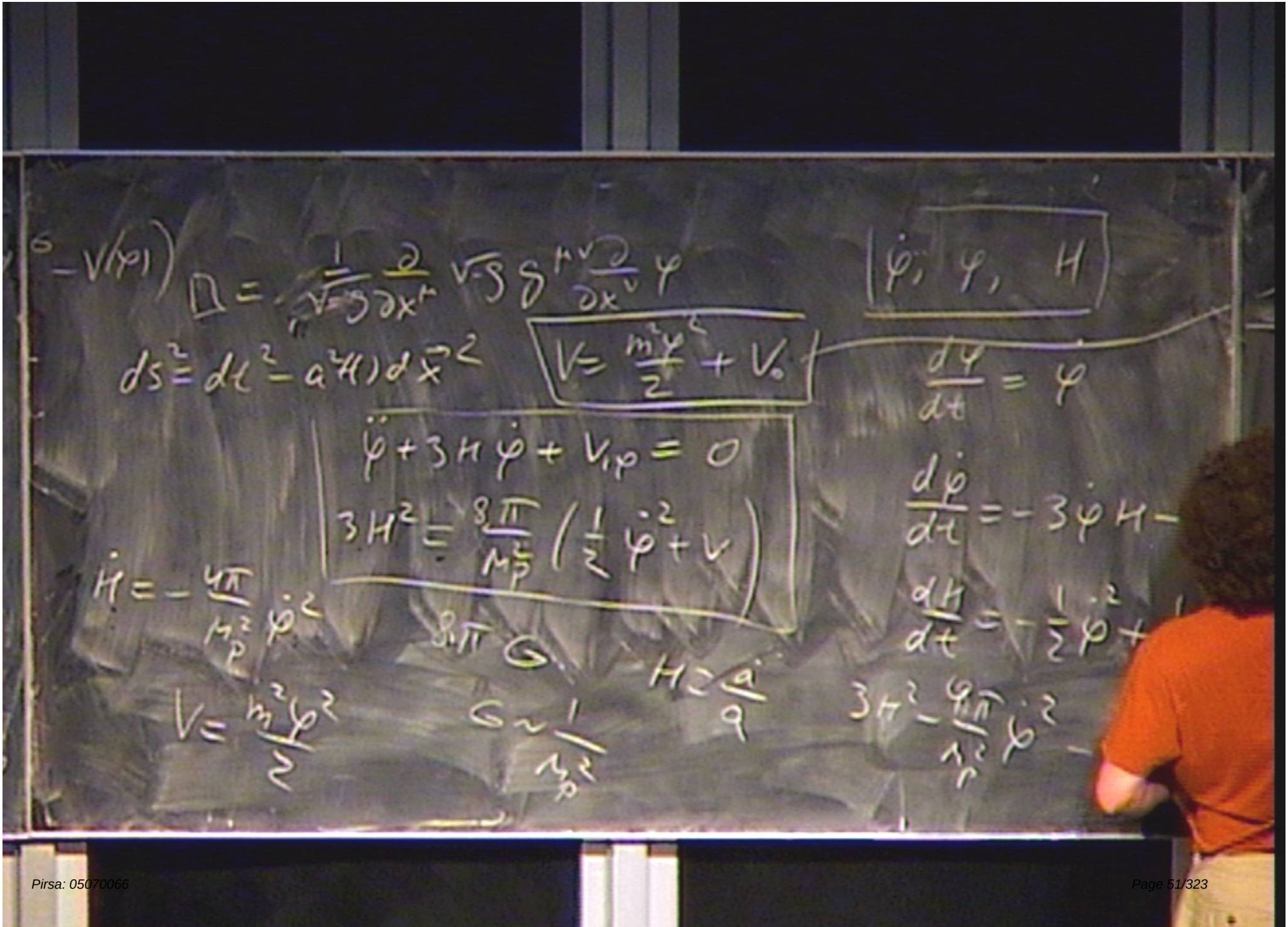
2) $\ddot{\varphi} \ll 3\dot{\varphi} H$ $\quad \boxed{a = e^{\int H dt}}$

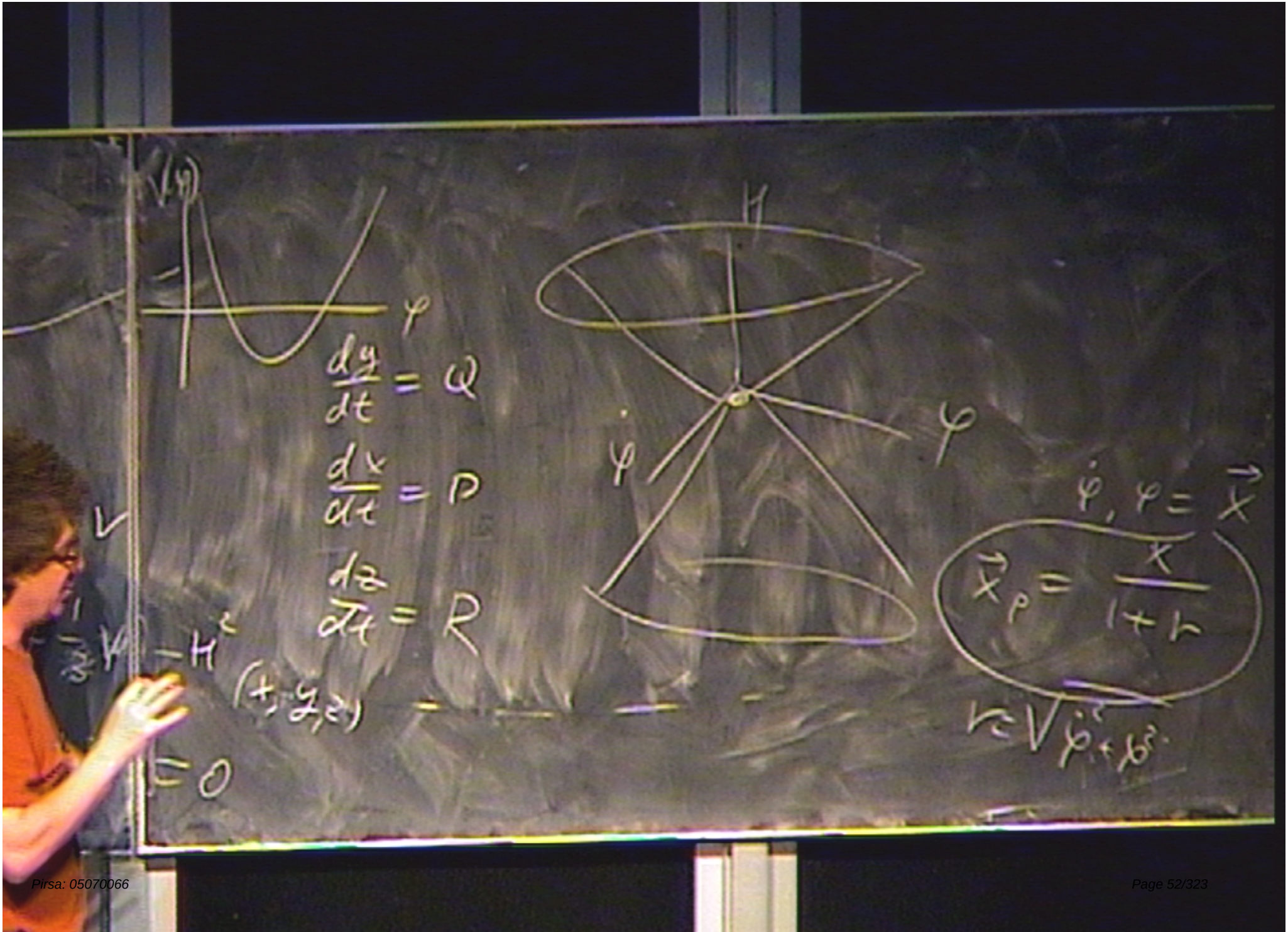
$\ddot{\varphi} \neq m^2 \varphi$ $\quad p \approx -\varepsilon$, $\dot{H} \ll H^2$

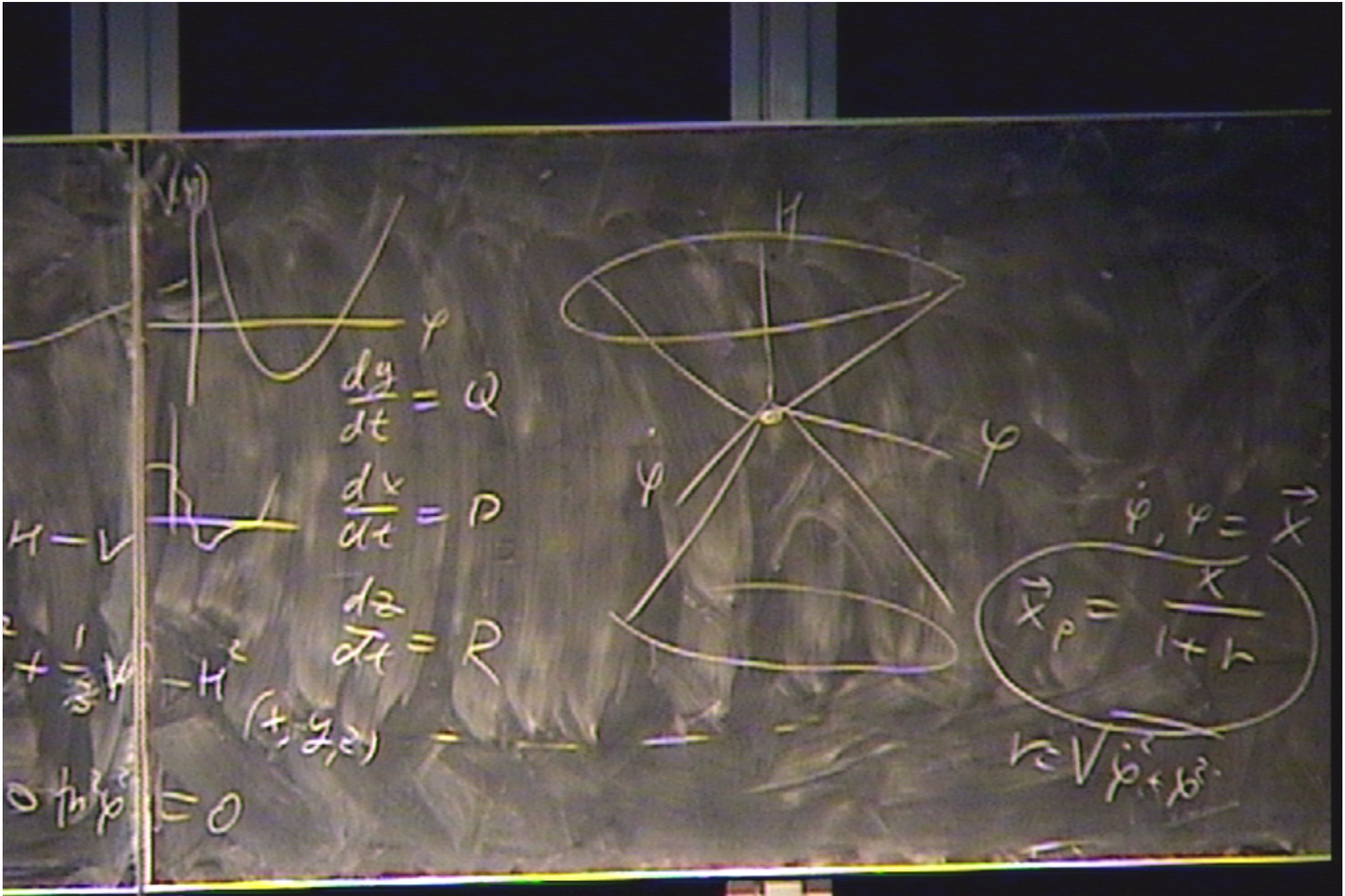
$\dot{\varphi}^2 \ll 1$ $\quad a \approx t^{2/3}$ $\quad \dot{H} \sim H^2$

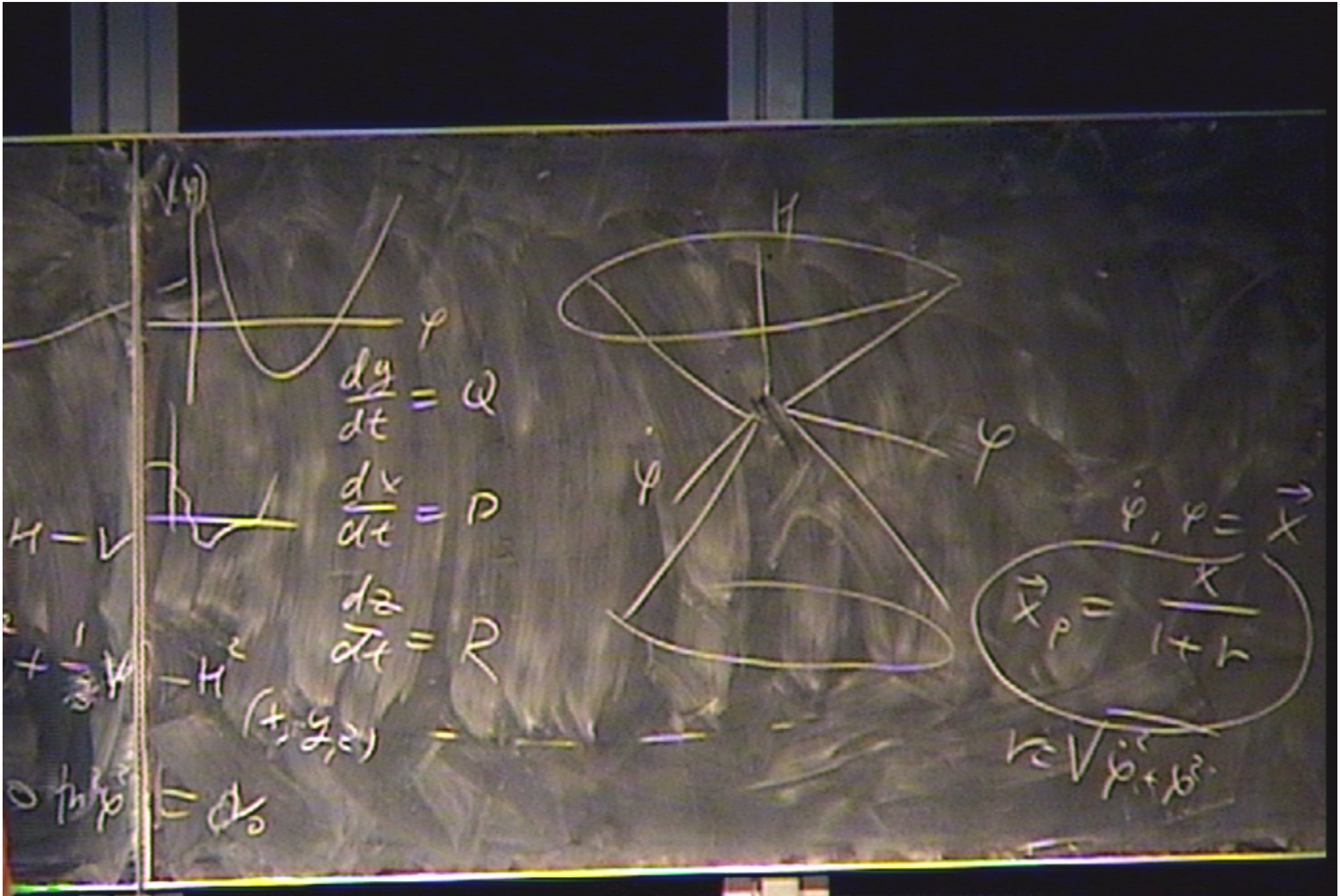
$p = -\frac{m^2 \varphi^2}{\dot{\varphi}^2}$ $\quad \varphi \sim mt$, $\langle p \rangle = 0$

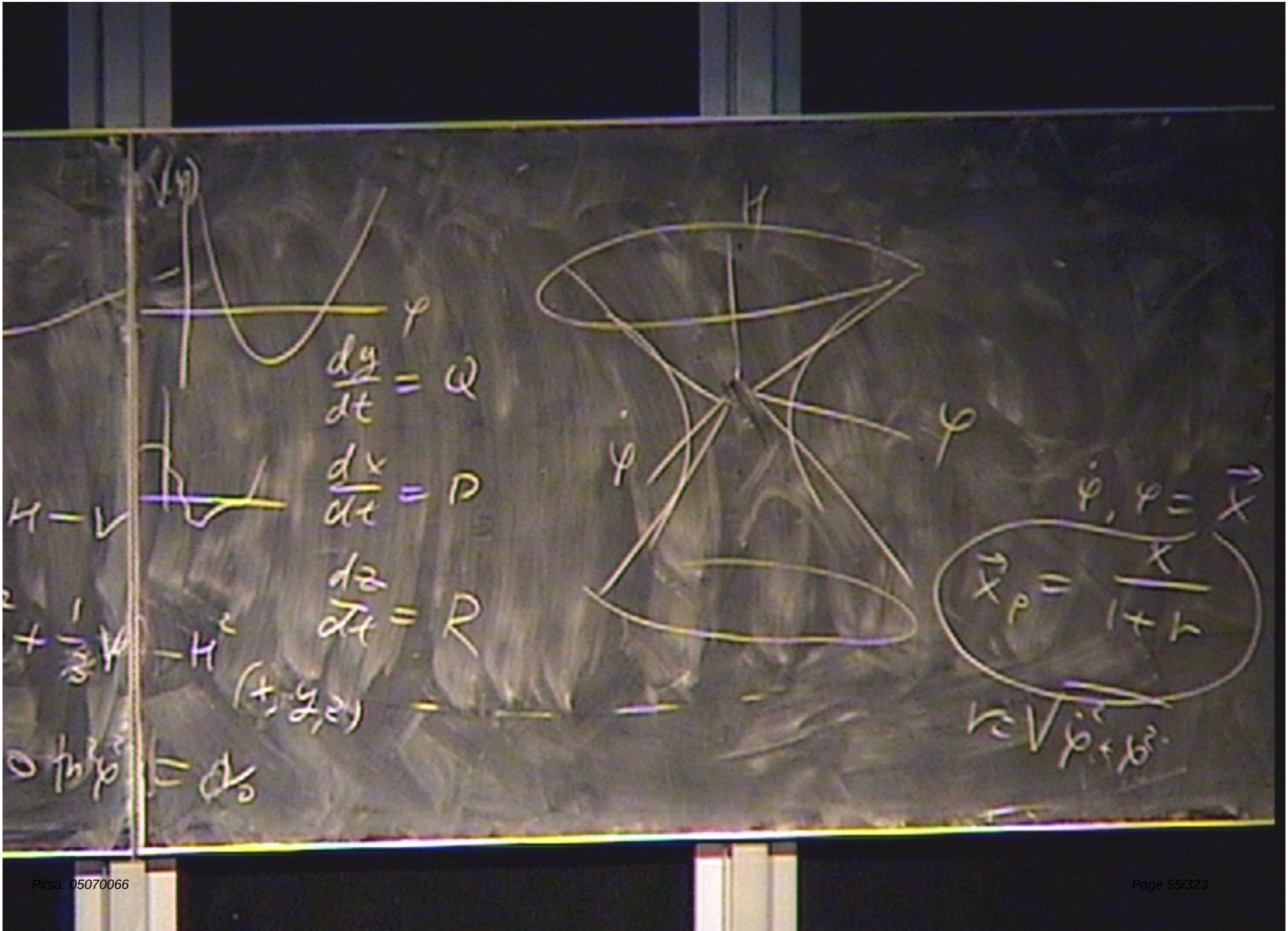
$\langle \rho \rangle = \frac{1}{2} \dot{\varphi}^2 + V$


$\dot{\varphi}$; φ, H
$\frac{d\varphi}{dt} = \dot{\varphi}$
$V = \frac{m^2\varphi^2}{2} + V_0$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} = 0$
$3H^2 = \frac{8\pi}{M_P^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H -$
$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 +$
$\dot{H} = -\frac{4\pi}{M_P^2}\dot{\varphi}^2$
$8\pi G$
$H = \frac{\dot{a}}{a}$
$V = \frac{m^2\varphi^2}{2}$
$G \sim \frac{1}{M_P^2}$
$3H^2 = \frac{8\pi}{M_P^2}\dot{\varphi}^2 -$
$ds^2 = dt^2 - a^2(t)d\vec{x}^2$
$\Box = \frac{1}{\sqrt{-g}}\frac{\partial}{\partial x^\mu}\sqrt{-g}\,g^{\mu\nu}\frac{\partial}{\partial x^\nu}\varphi$
$-V(\varphi)$

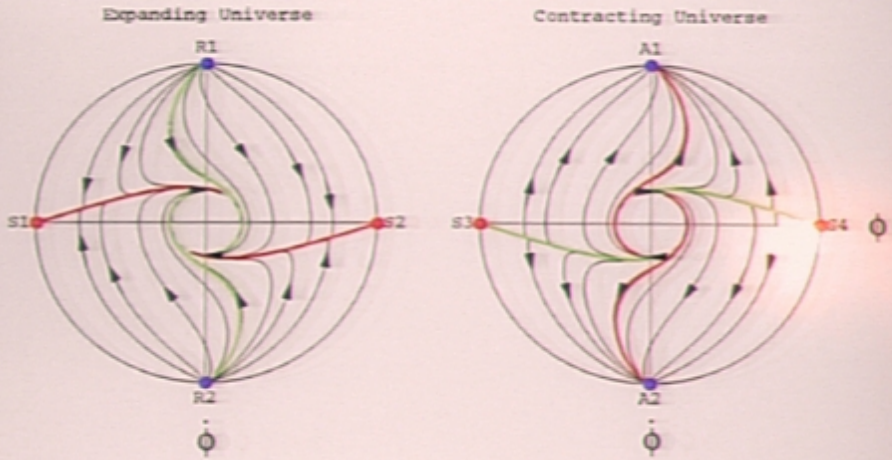

V(φ)
φ
dy/dt = Q
dx/dt = P
dz/dt = R
H
φ
φ
φ̇, φ = ẋ
ẋ_ρ = ẋ / (1 + h)
r = √(ρ² + h²)
(t, x, z)
= 0

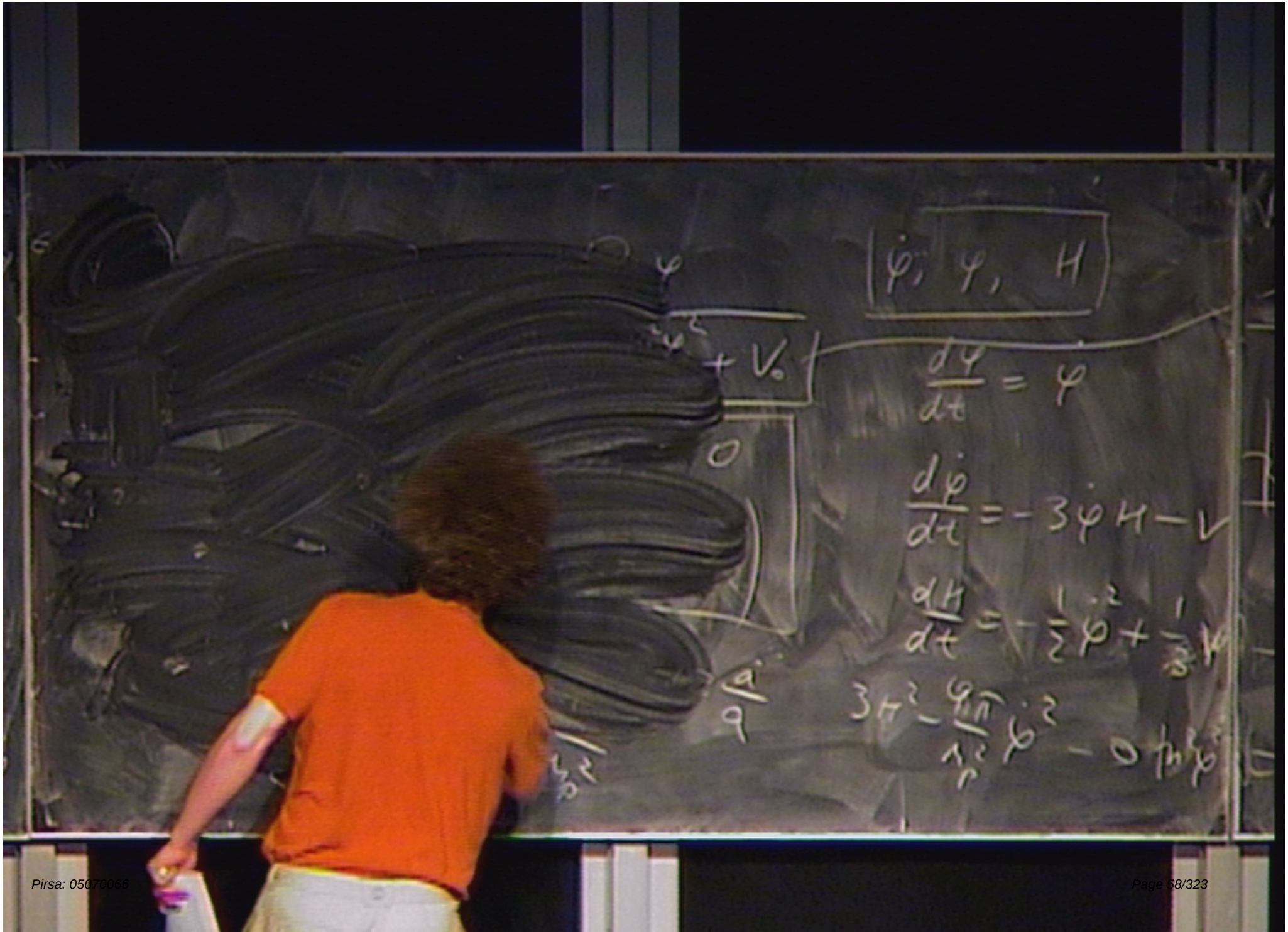

H
φ
$\frac{dy}{dt} = Q$
$\frac{dx}{dt} = P$
$\frac{dz}{dt} = R$
H
φ
φ
$\dot{\varphi}, \varphi = \vec{x}$
$\vec{x}_\rho = \frac{\vec{x}}{1+\rho}$
$\rho = \sqrt{\dot{\varphi}^2 + \varphi^2}$
$H - V$
$+ \frac{1}{3} H$
$- H^2$
(x, y, z)
$= 0$

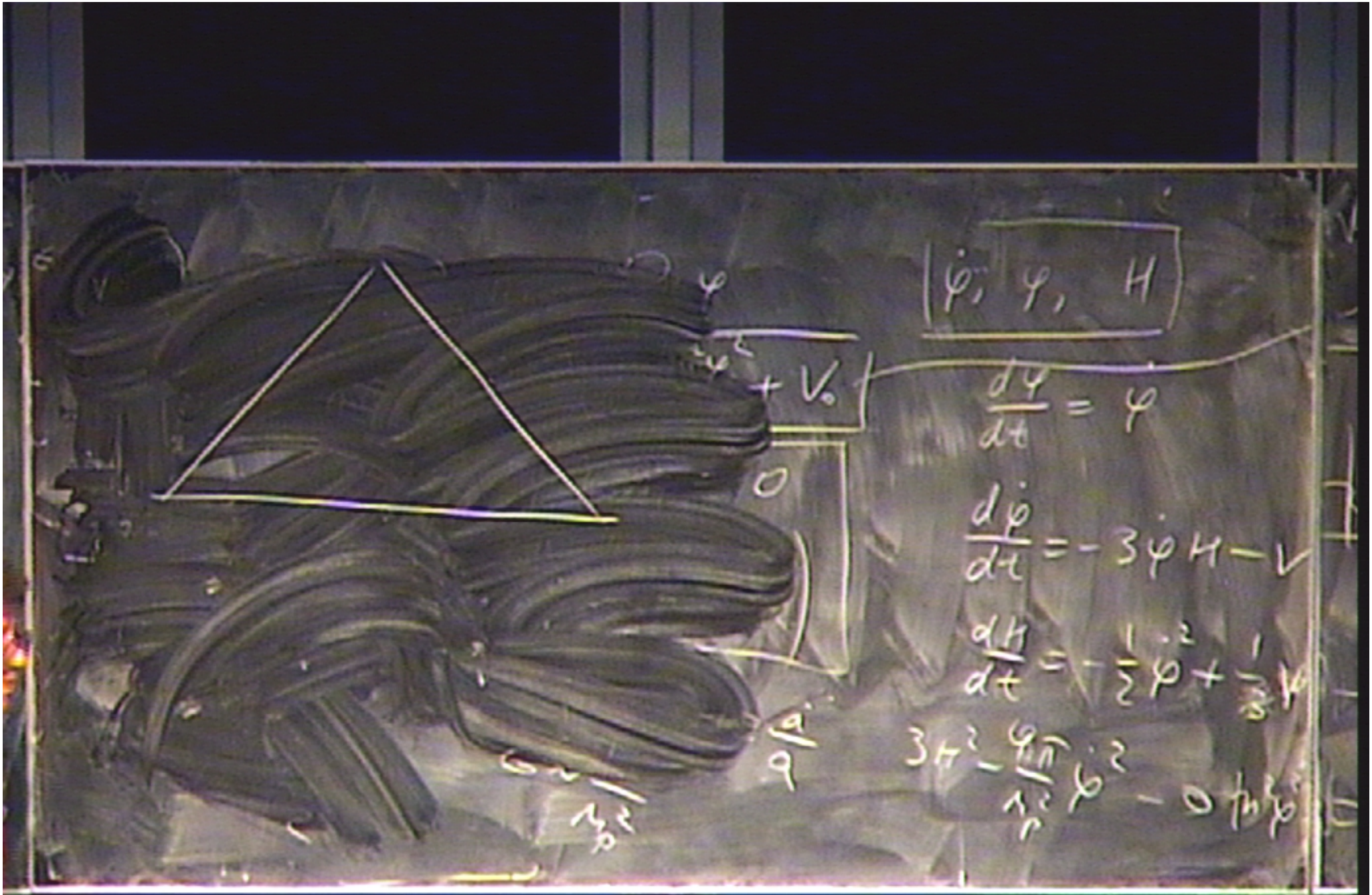

H
φ
$\frac{dy}{dt} = Q$
$\frac{dx}{dt} = P$
$\frac{dz}{dt} = R$
H
φ
φ
$\dot{\varphi}, \varphi = \vec{x}$
$\vec{x}_\rho = \frac{\vec{x}}{1+h}$
$r = \sqrt{\dot{\varphi}^2 + h^2}$
$H - V$
$+ \frac{1}{3} H^2 - H^2$
(t, z, z) = ___ ___ ___
$\dot{\varphi} h^2 = d_0$

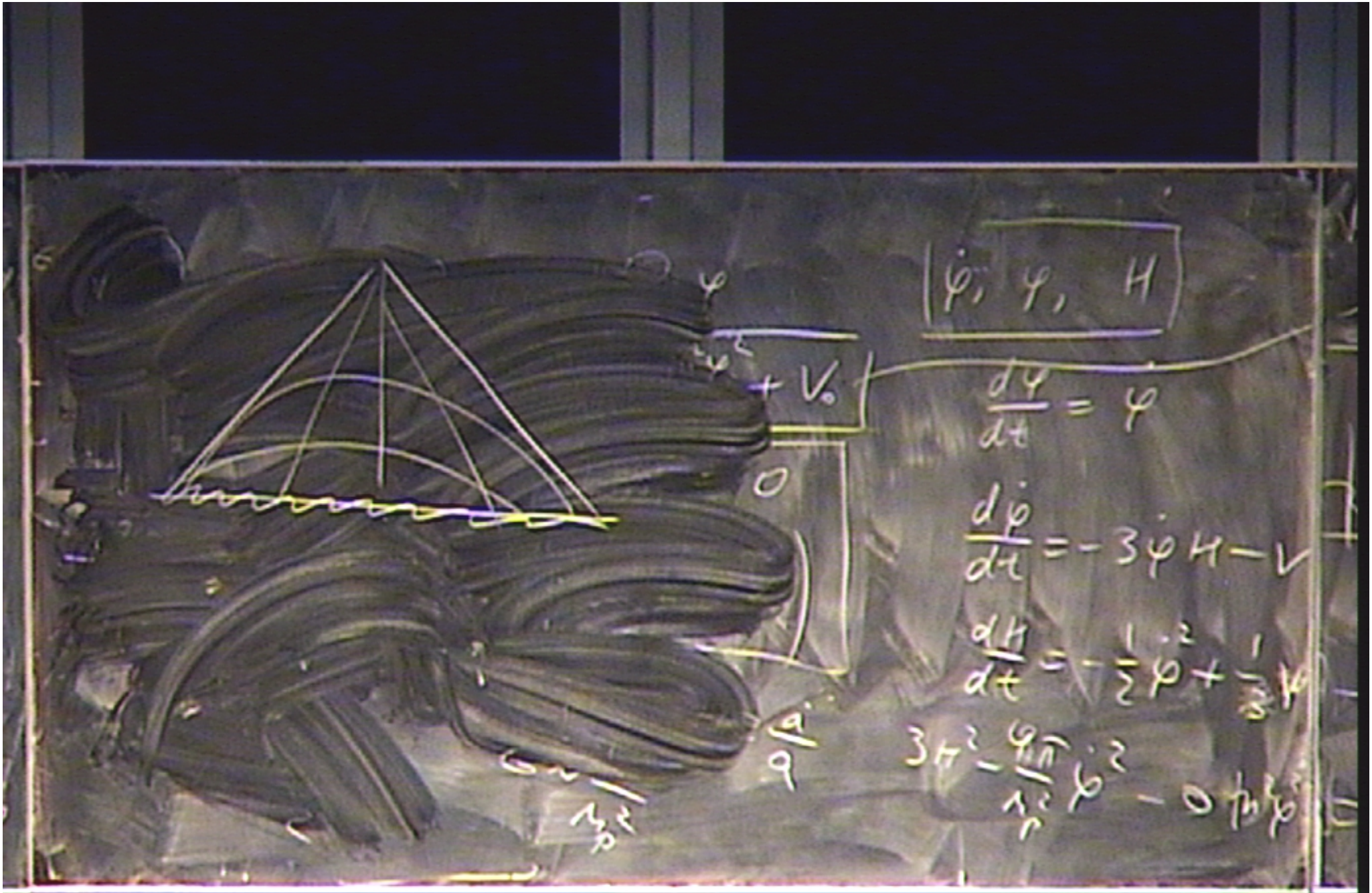

V(φ)
φ
dy/dt = Q
dx/dt = P
dz/dt = R
H
φ
φ
φ̇, φ = x⃗
x⃗_ρ = x / (1+r)
r = √(ρ²+b²)

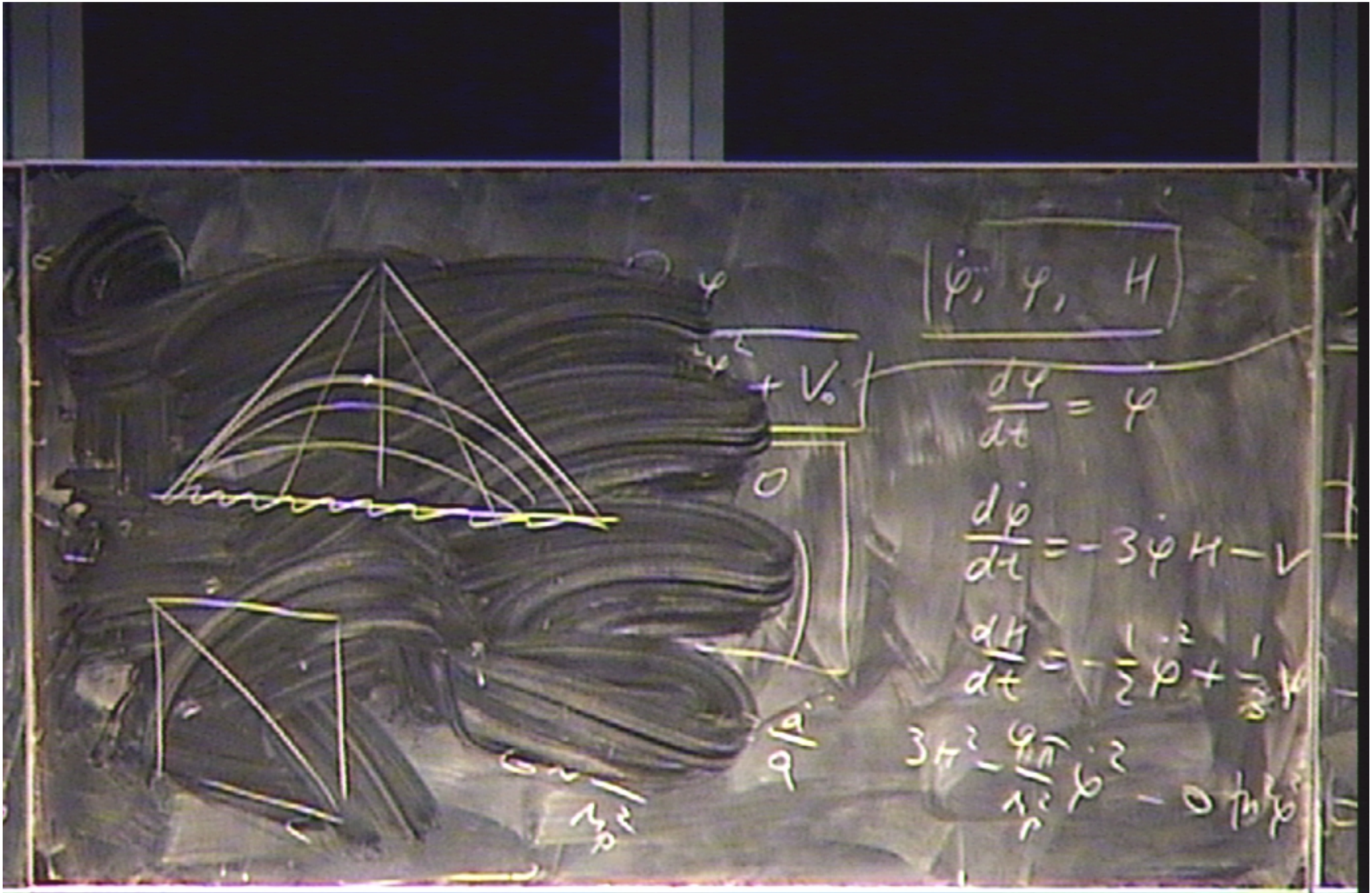
R1
S1
S2
R2
R1
S3
S4
R2
$\dot{\phi}$
H
$\dot{\phi}$

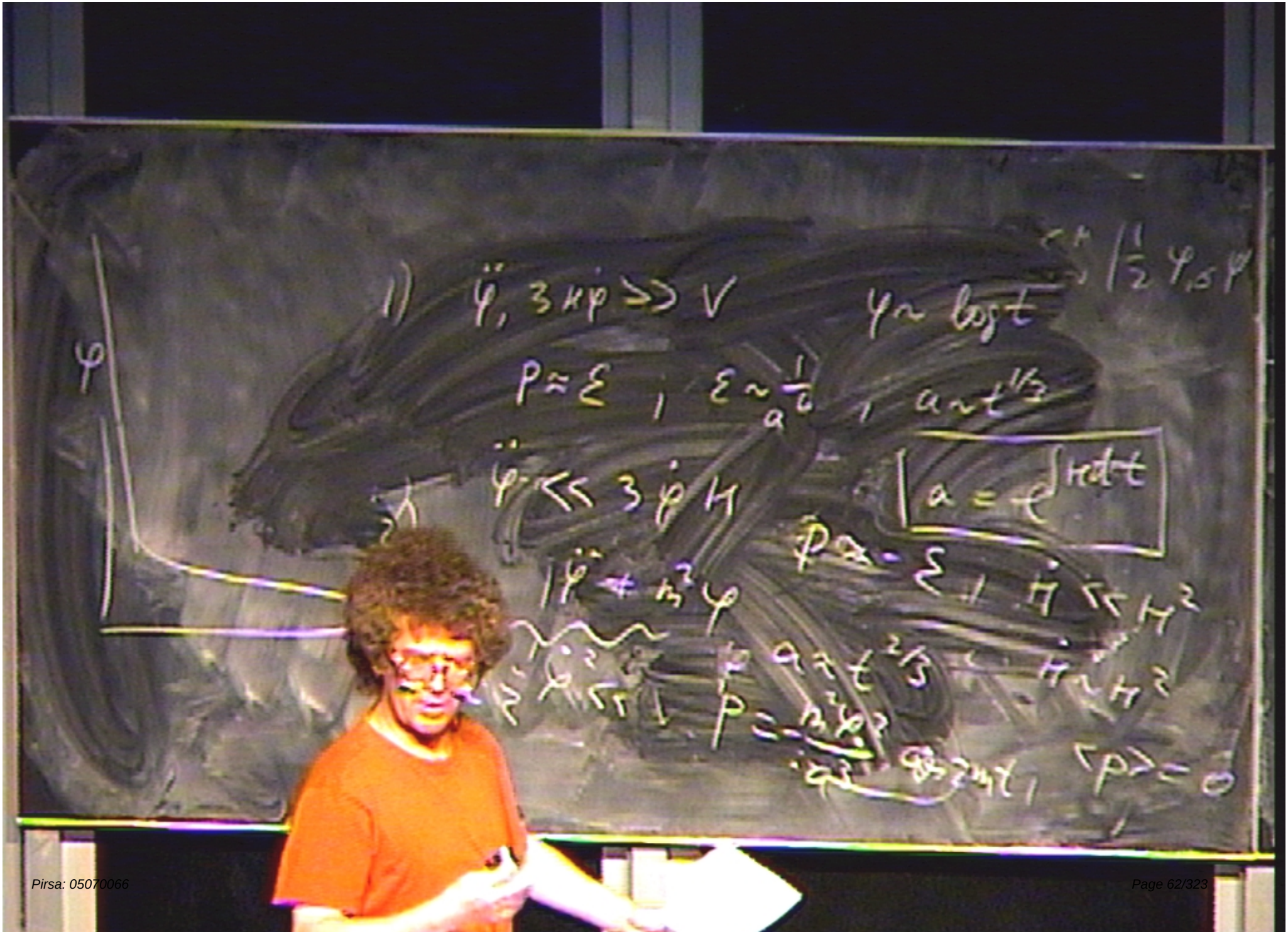

Expanding Universe
R1
S1
S2
R2
$\dot{\phi}$
Contracting Universe
A1
S3
S4
ϕ
A2
$\dot{\phi}$

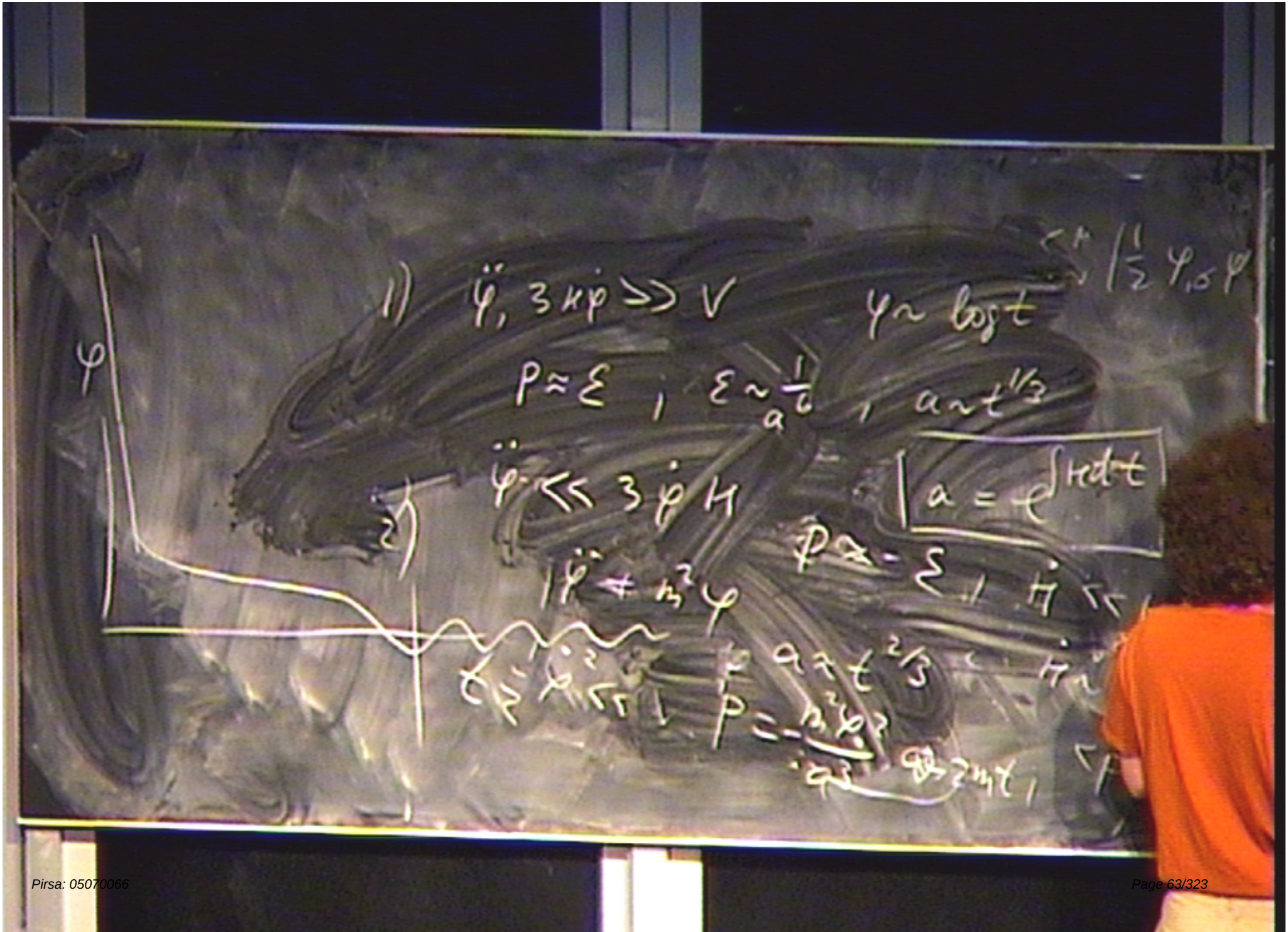

φ, φ, H
+ V₀
0
$\frac{d\varphi}{dt} = \dot{\varphi}$
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H - V$
$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{3}H$
$3H^2 - \frac{\varphi^2}{2}\dot{\varphi}^2 - 0$

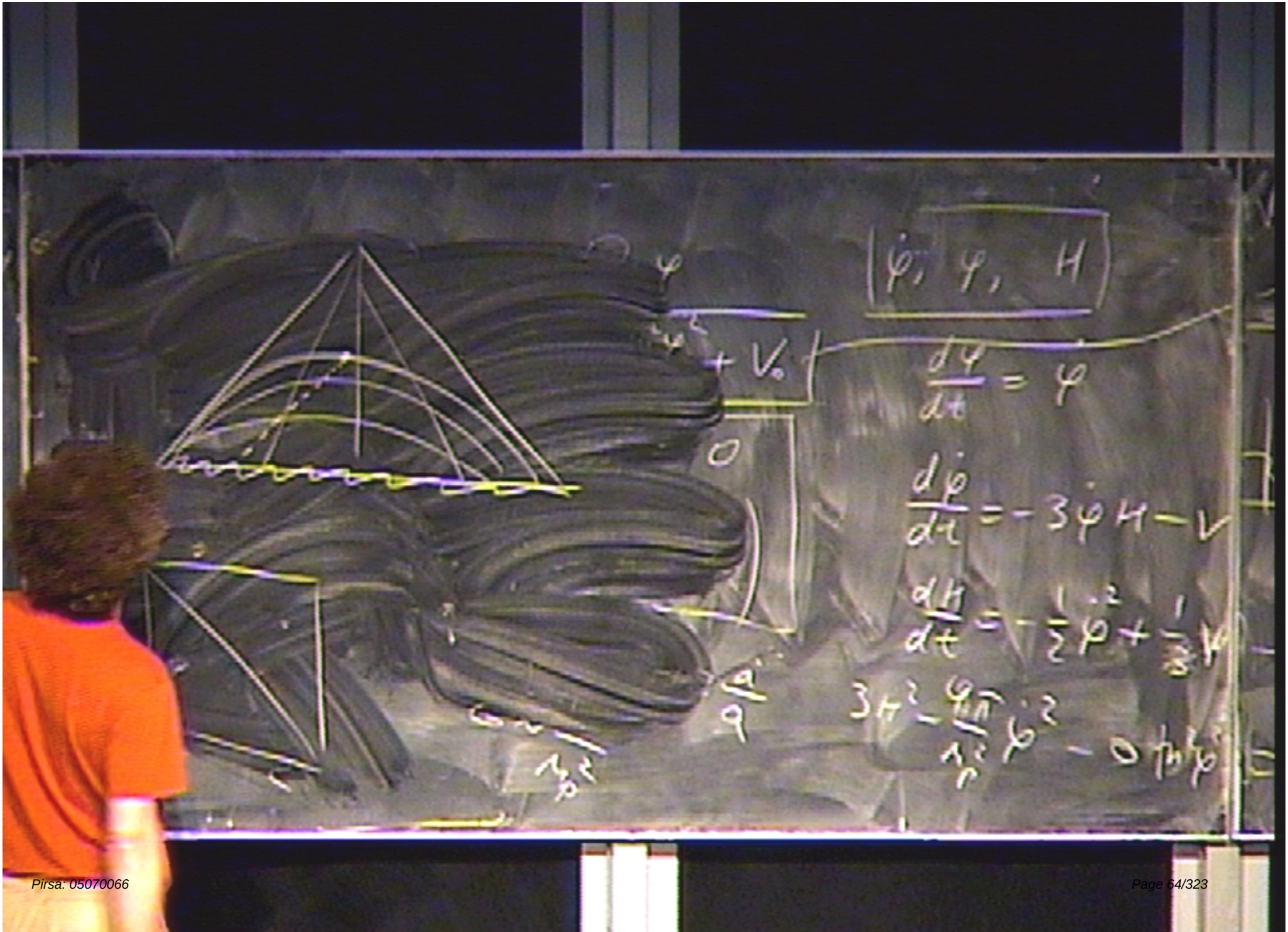

φ
+ V₀
0
φ̇; φ, H
dφ/dt = φ̇
dφ̇/dt = −3φ̇H − V
dH/dt = −½φ̇² + ⅓H
3H² = φ̇²

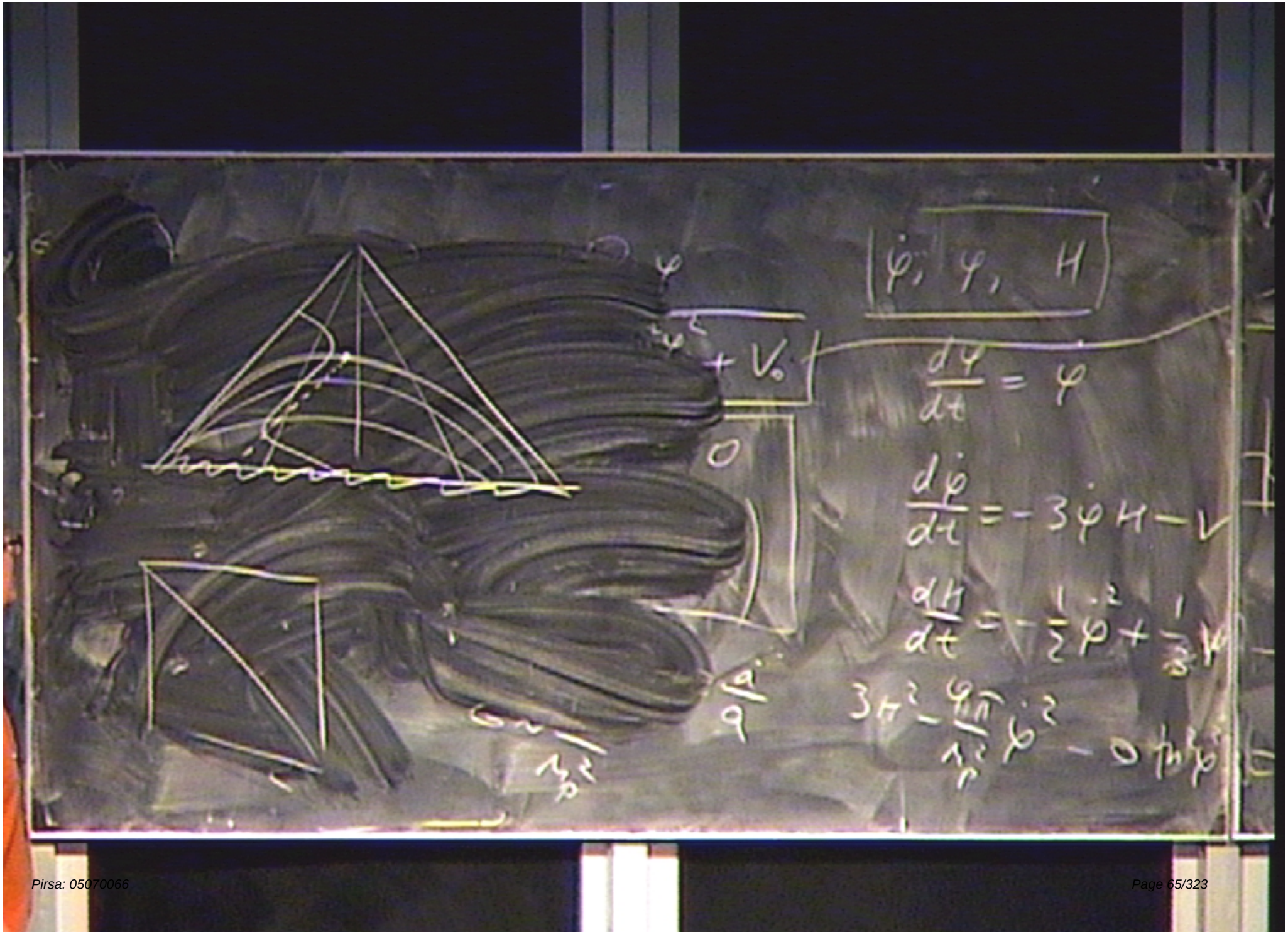

φ
+ V₀
0
φ; φ̇, H
dφ/dt = φ̇
dφ̇/dt = −3φ̇H − V
dH/dt = −½φ̇² + ⅓H
3H² = φ̇²/M_p² − 0 + ρ

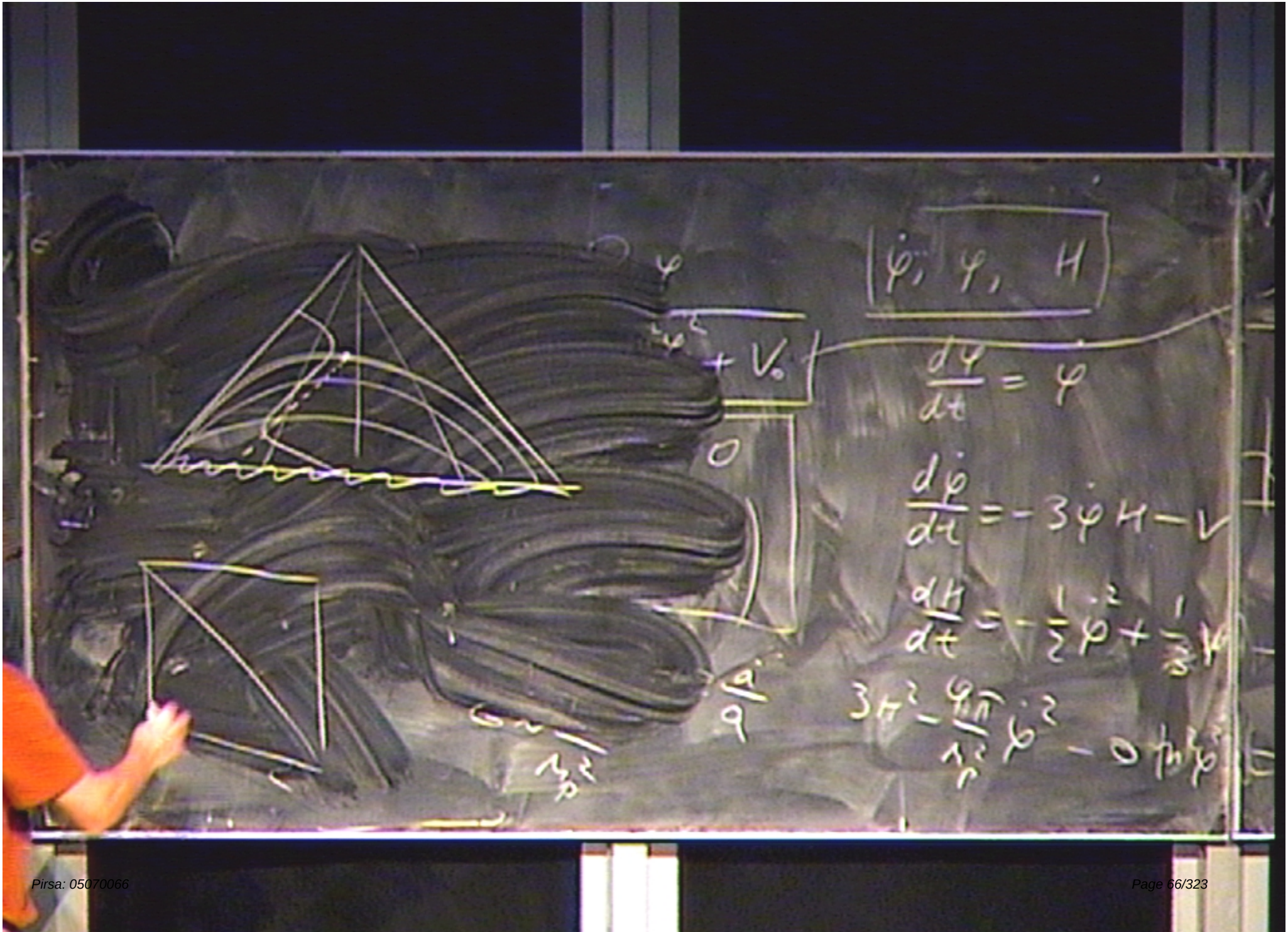

φ
+ V₀
0
φ; φ, H
dφ/dt = φ̇
dφ̇/dt = −3φ̇H − V
dH/dt = −½φ̇² + ⅓H
3H² = φ̇²/2 + V(φ)

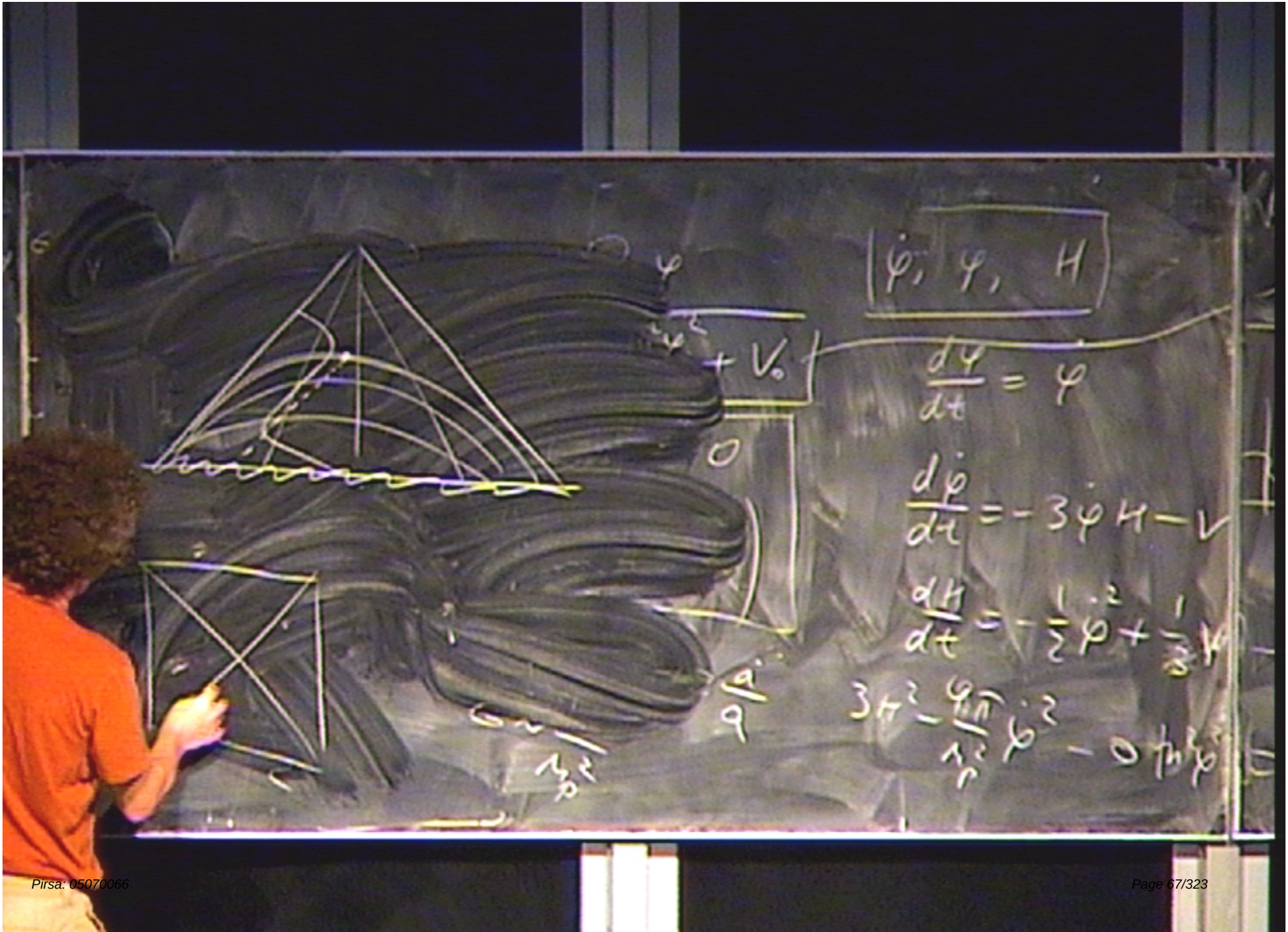

1) $\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$\varphi \sim \log t$
$P \approx \varepsilon$, $\varepsilon \sim \frac{1}{a}$, $a \sim t^{1/3}$
$\ddot{\varphi} \ll 3\dot{\varphi} H$
$a = e^{\int H dt}$
$\ddot{\varphi} + m^2\varphi$
$P \approx -\varepsilon$, $\dot{H} \ll H^2$
$a \sim t^{2/3}$, $\dot{H} \sim H^2$
$P = \frac{m^2\varphi^2}{\rho^2}$
$\langle p \rangle = 0$

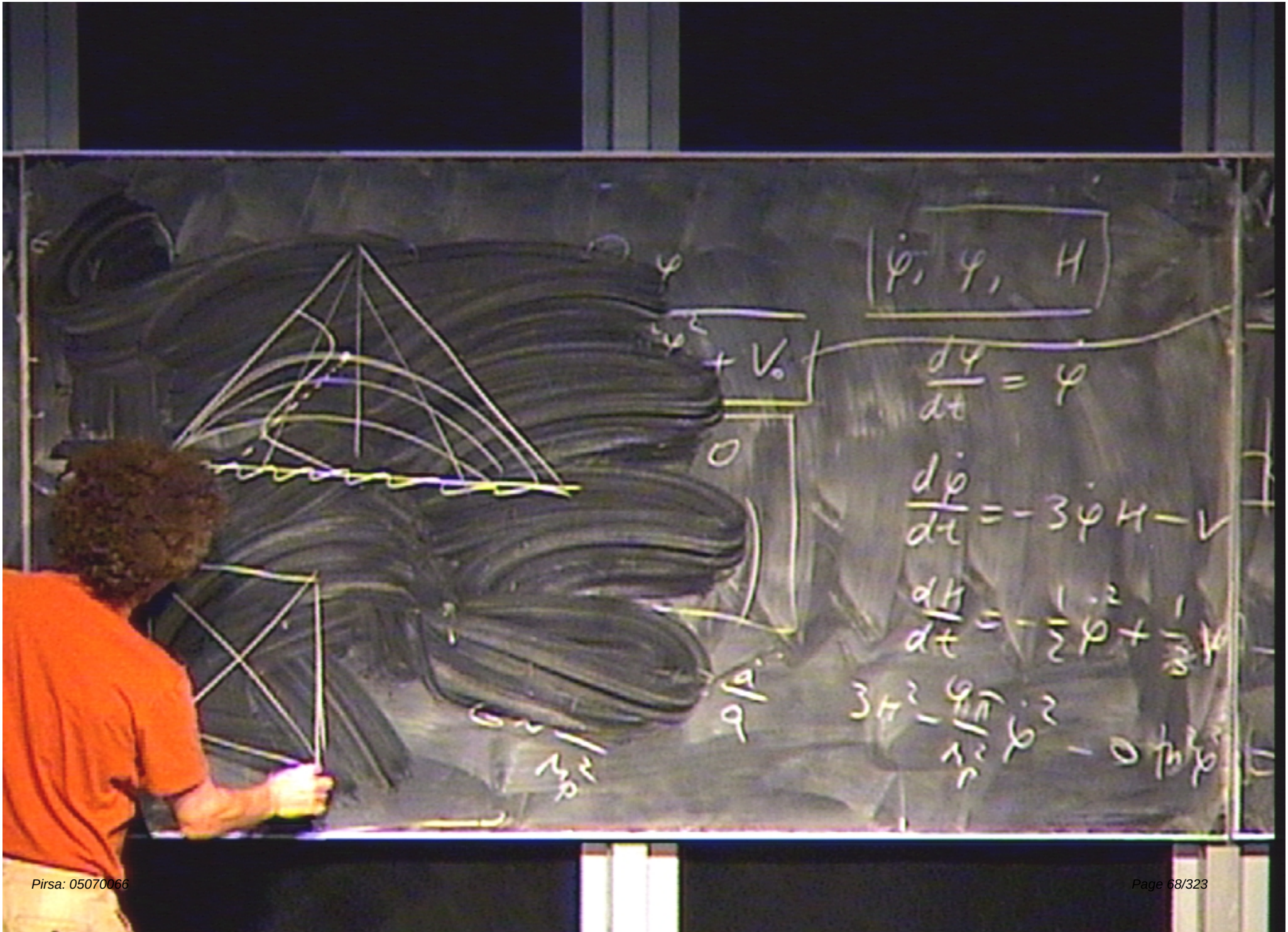

φ
1) $\ddot{\varphi}, 3H\dot{\varphi} \gg V$
$\varphi \sim \log t$
$P \approx \varepsilon$, $\varepsilon \sim \frac{1}{a}$, $a \sim t^{1/3}$
$\frac{1}{2}\dot{\varphi}^2 - V(\varphi)$
2) $\ddot{\varphi} \ll 3\dot{\varphi}H$
$a = e^{\int H dt}$
$\ddot{\varphi} + m^2\varphi$
$P \approx -\varepsilon$, $\dot{H} \ll$
$a \sim t^{2/3}$
$\dot{H} \sim$
$\varepsilon \sim \dot{\varphi}^2 \ll 1$, $P = \frac{m^2\dot{\varphi}^2}{\varepsilon^2}$
$\varepsilon \gg m\varphi$,

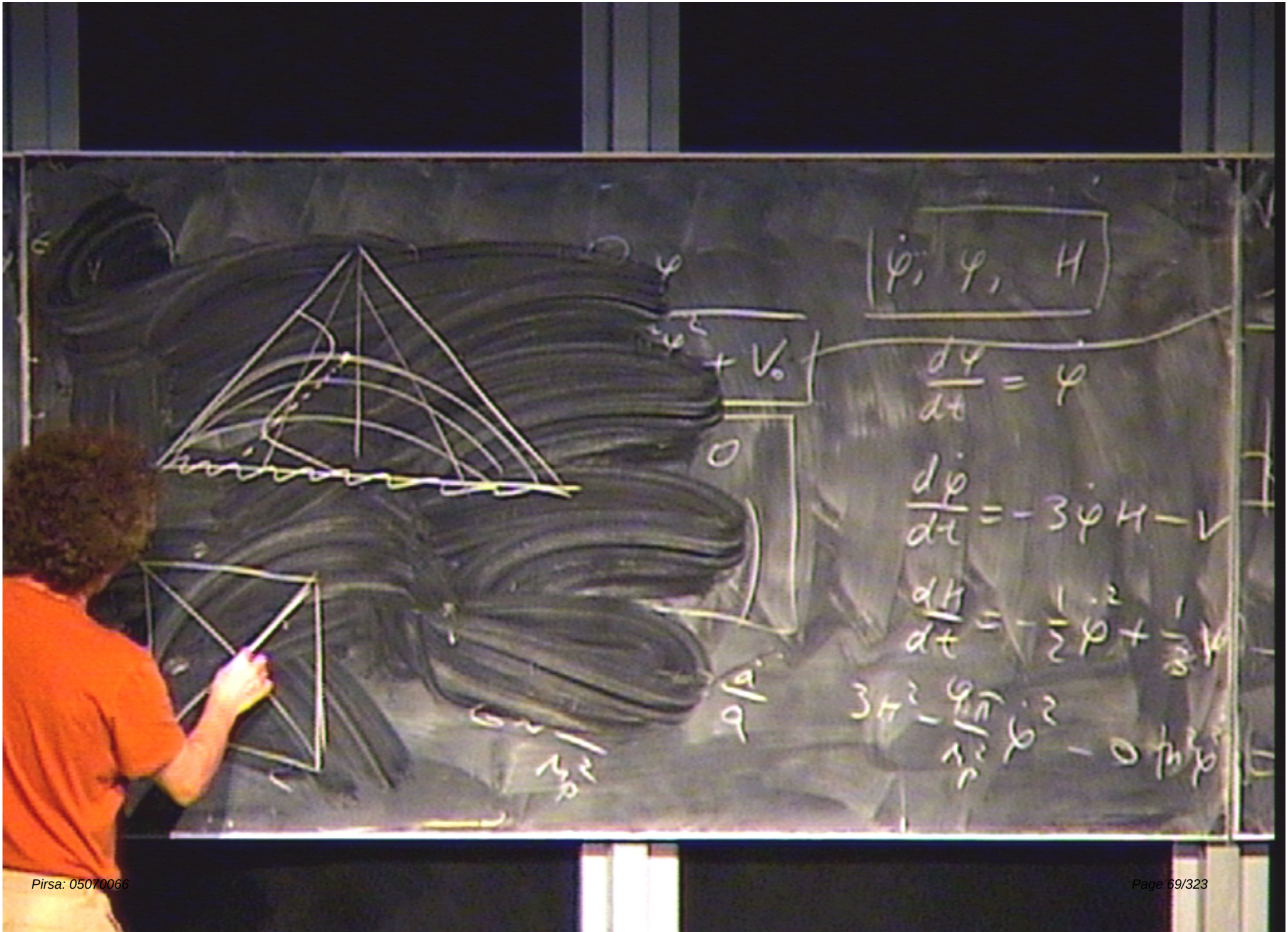

φ
+ V₀
0
φ, φ̇, H
dφ/dt = φ̇
dφ̇/dt = -3φ̇H - V'
dH/dt = -½φ̇² + ⅓H
3H² = φ̇²/m_p² + V/m_p²

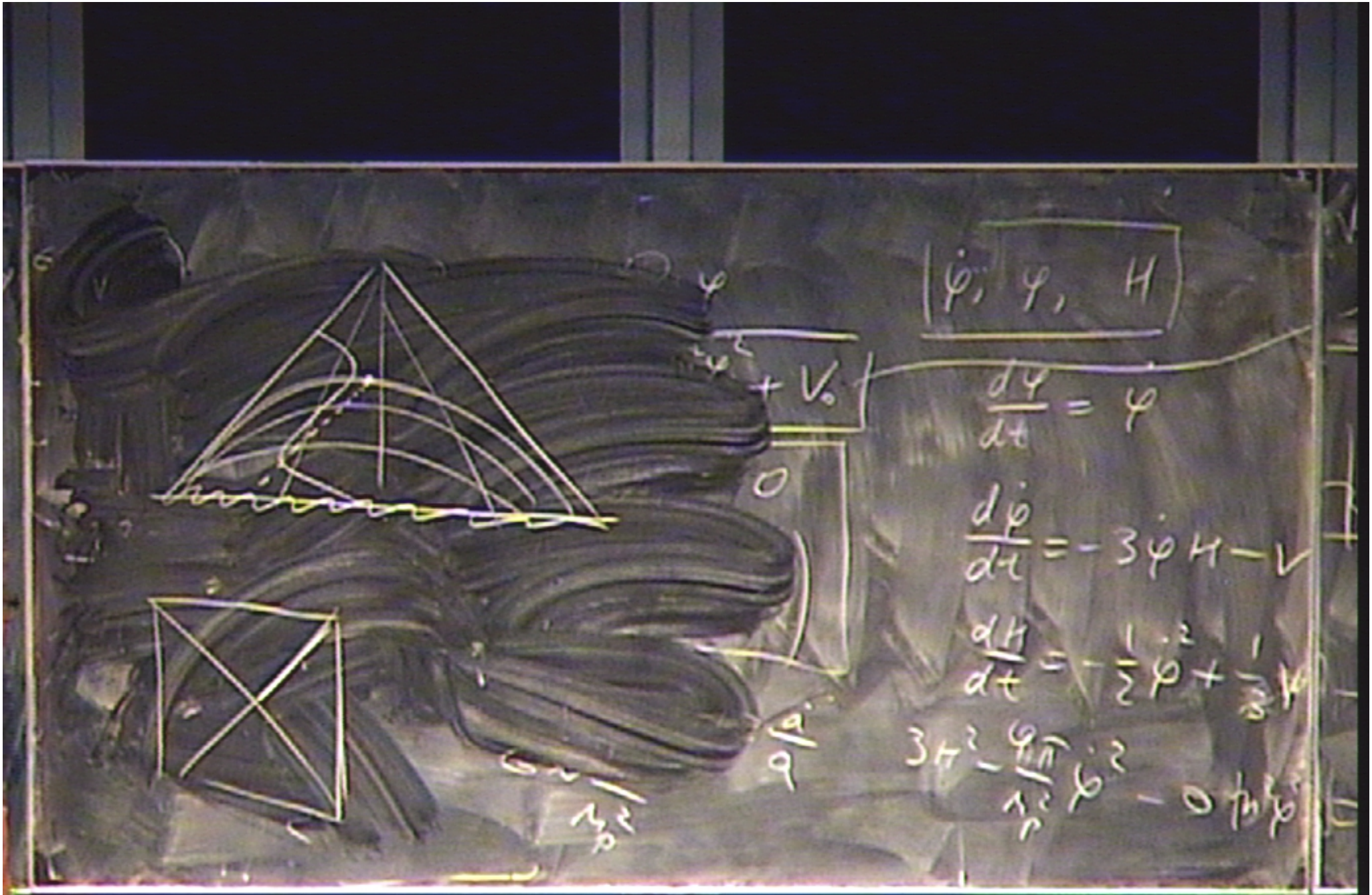

φ
+ V₀
0
φ̇; φ, H
dφ/dt = φ̇
dφ̇/dt = −3φ̇H − V
dH/dt = −½φ̇² + ⅓H
3H² − φ̇²

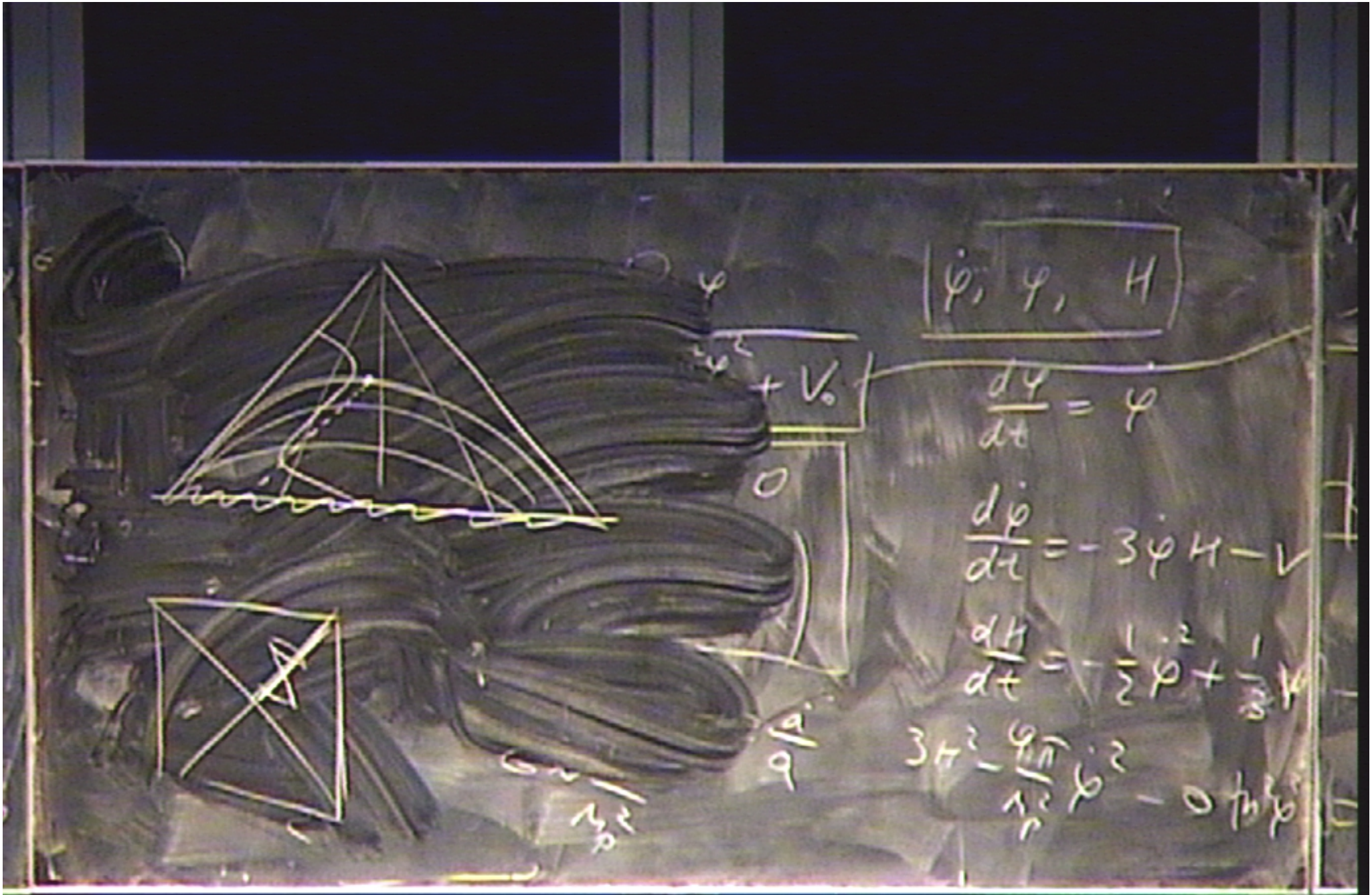

φ
+ V₀
0
φ; φ̇, H
dφ/dt = φ̇
dφ̇/dt = −3φ̇H − V
dH/dt = −½φ̇² + ⅓H
3H² = φ̇²/2 + V(φ)

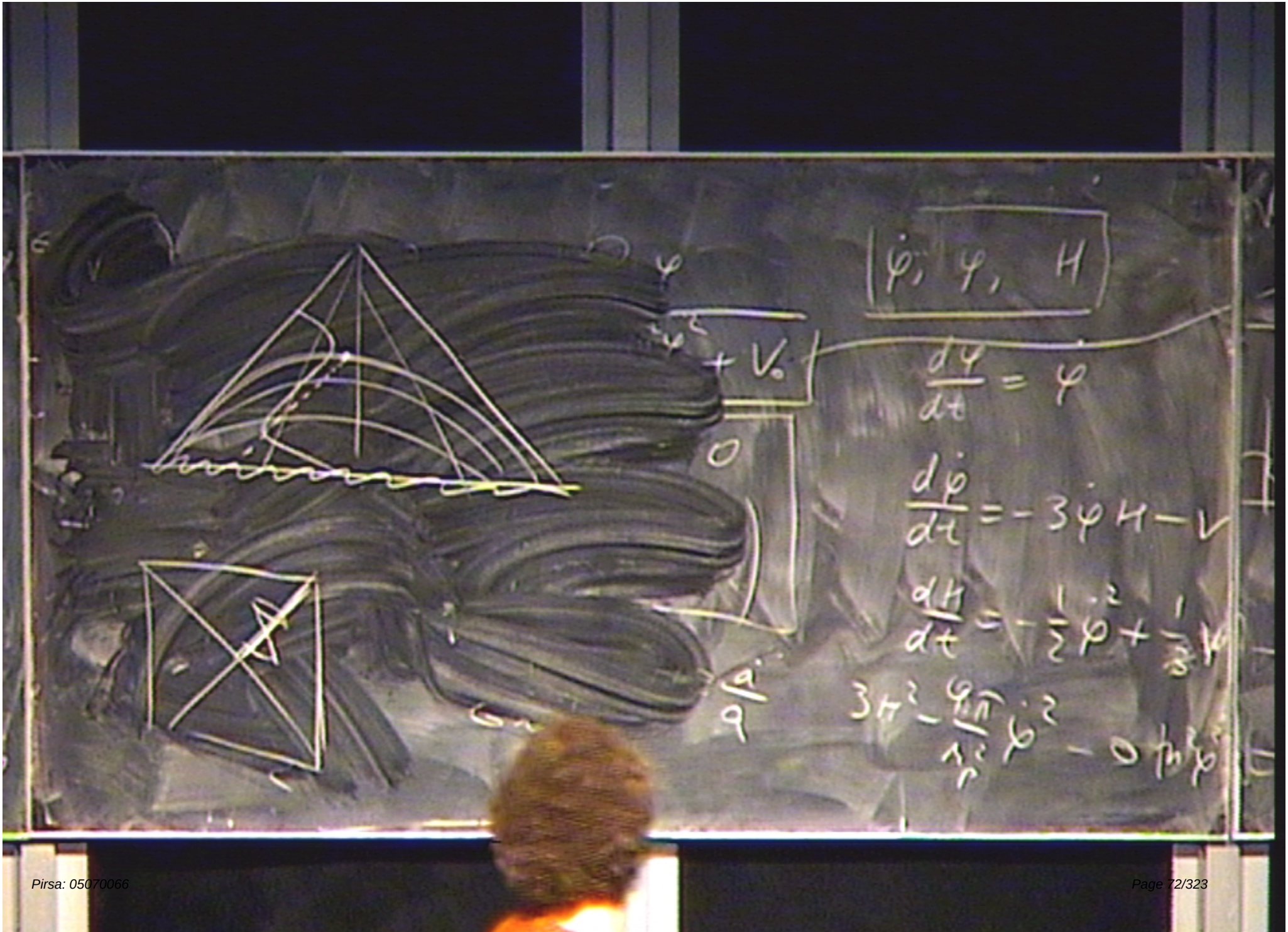

φ, φ̇, H
+ V₀
0
dφ/dt = φ̇
dφ̇/dt = -3φ̇H - V'
dH/dt = -½φ̇² + ⅓H
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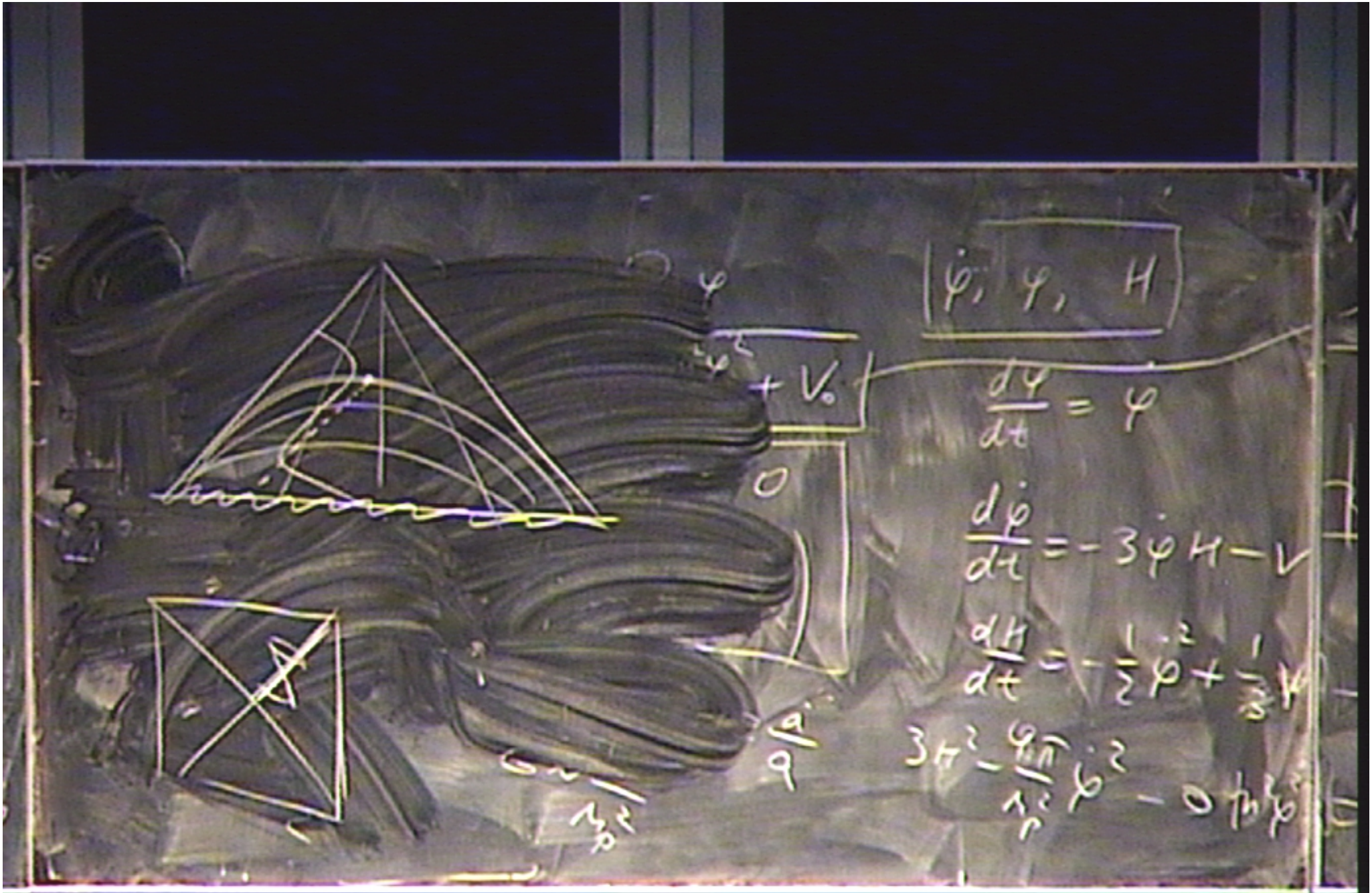

φ, φ̇, H
+ V₀
0
dφ/dt = φ̇
dφ̇/dt = −3φ̇H − V′
dH/dt = −½φ̇² + ⅓H
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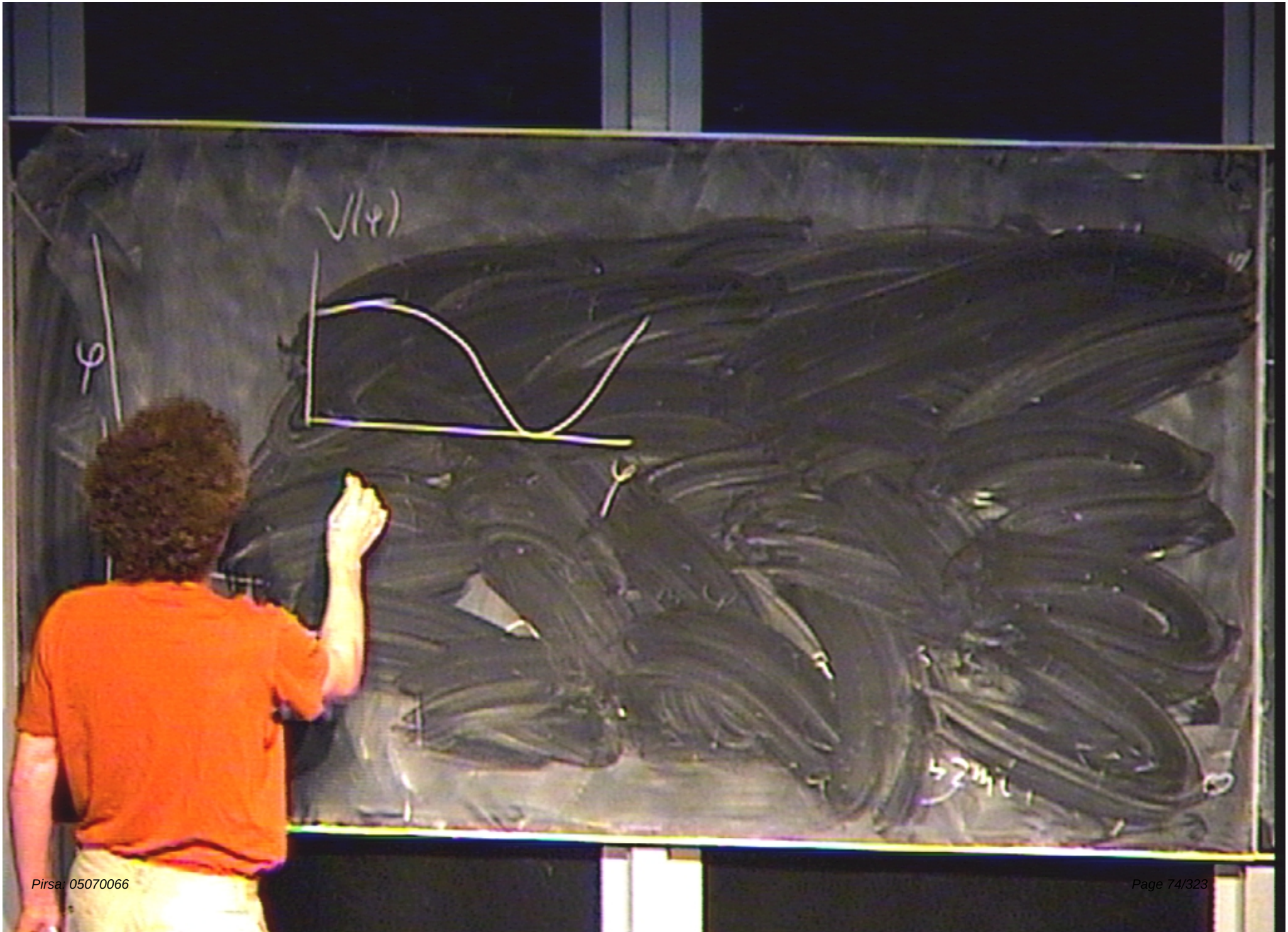

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3H² = φ̇²/2 + V(φ)


φ
+ V₀
0
φ; φ, H
dφ/dt = φ̇
dφ̇/dt = −3φ̇H − V′
dH/dt = −½φ̇² + ⅓H
3H² − φ̇²/2 − 0 m²φ²

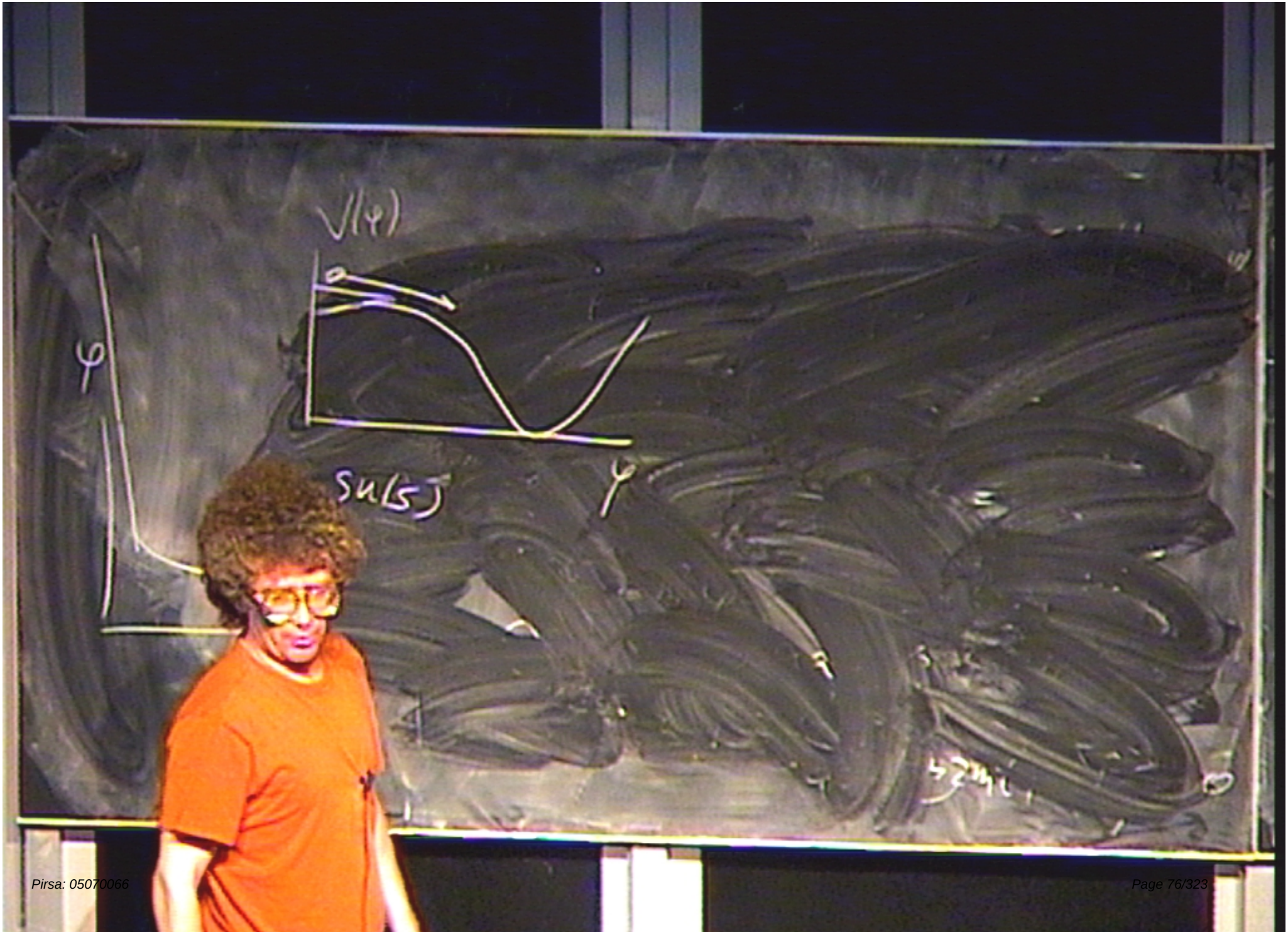

φ
+ V₀
0
φ; φ, H
dφ/dt = φ̇
dφ̇/dt = -3φ̇H - V'
dH/dt = -1/2 φ̇² + 1/3 H
3H² = φ̇²/2 + V(φ)

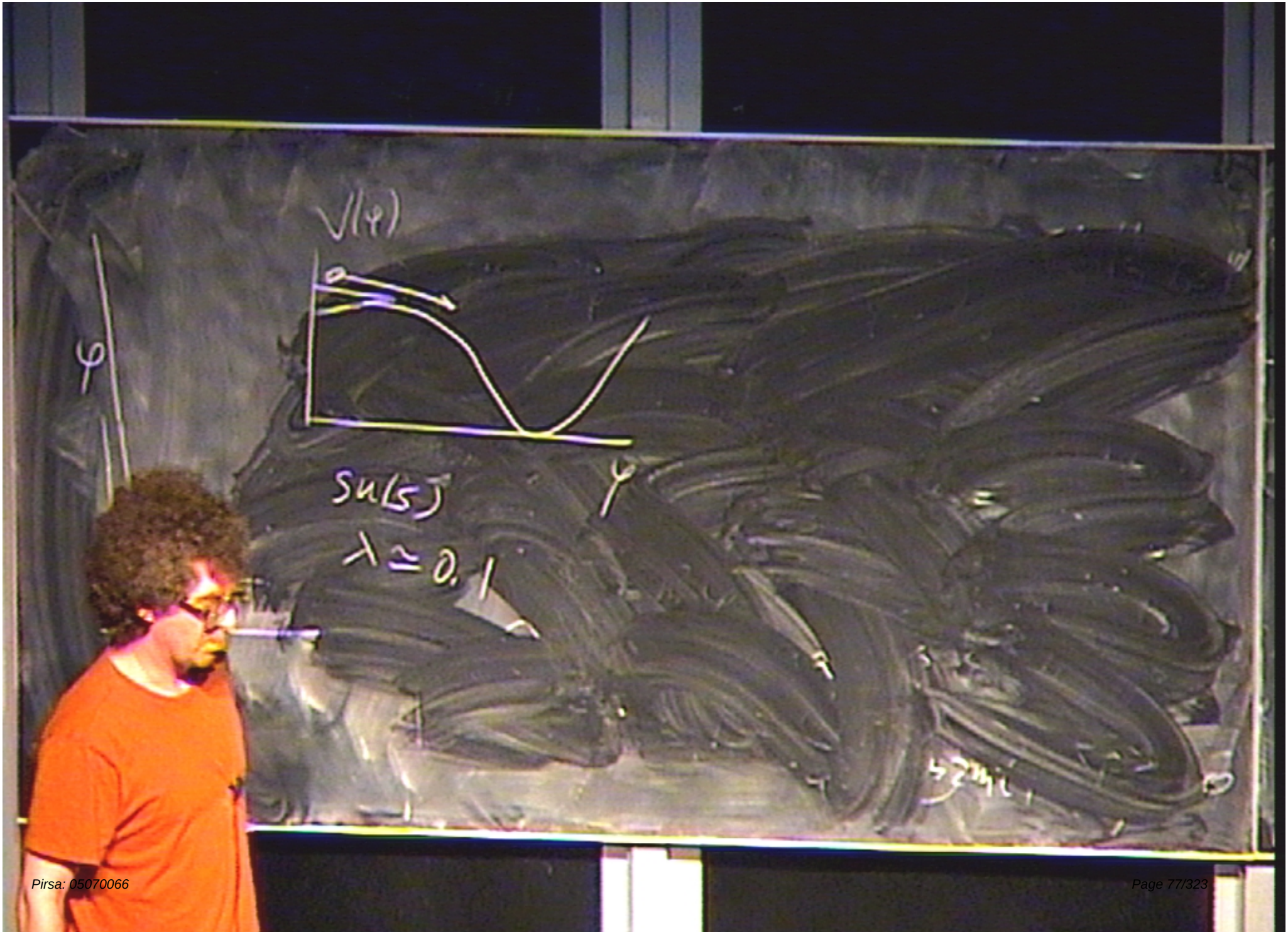

φ
+ V₀
0
φ; φ̇, H
dφ/dt = φ̇
dφ̇/dt = −3φ̇H − V′
dH/dt = −½φ̇² + ⅓H
3H² = (φ̇²/2) + V(φ)
ȧ/a

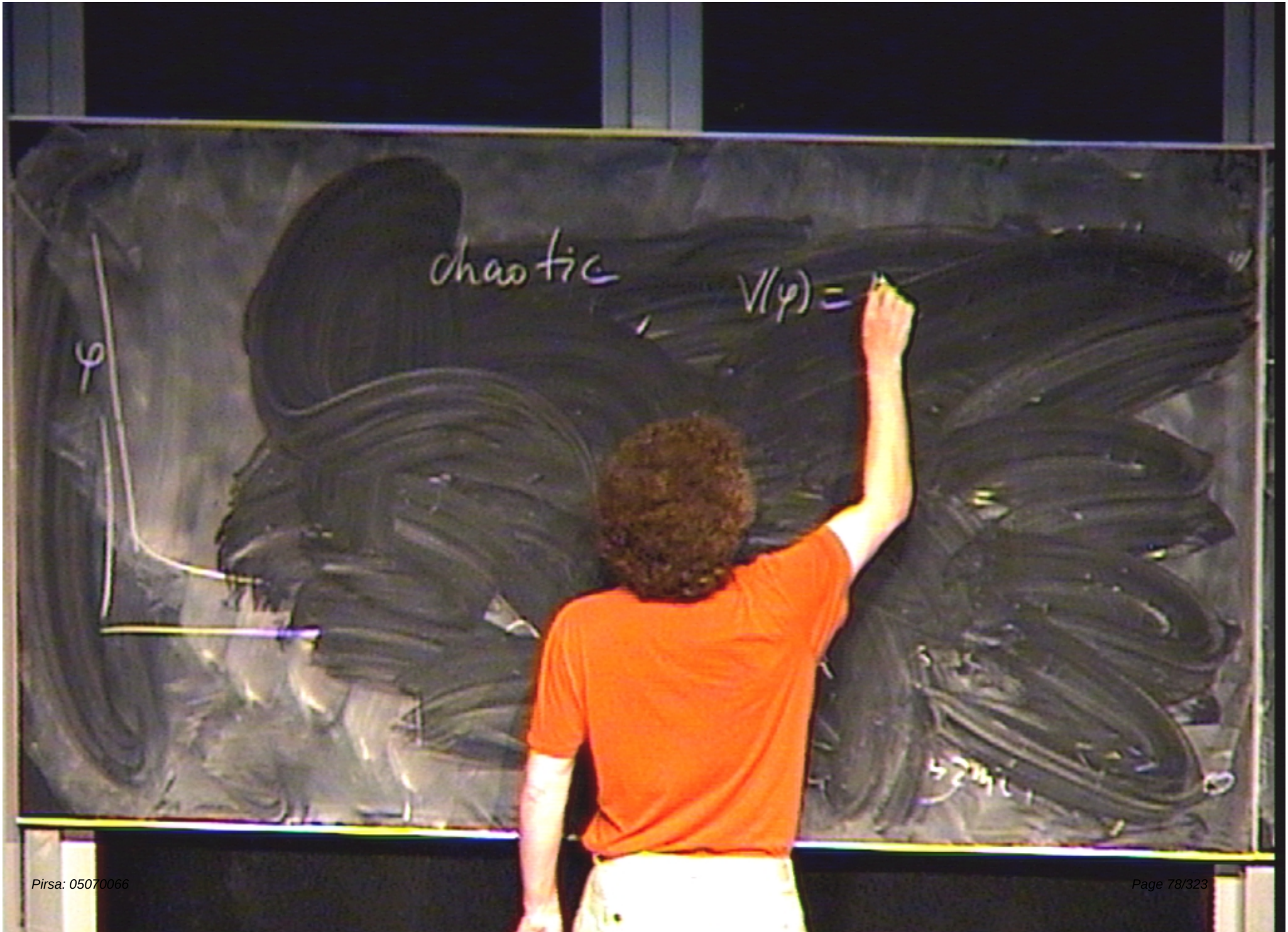

φ
+ V₀
0
φ̇; φ, H
dφ/dt = φ̇
dφ̇/dt = −3φ̇H − V
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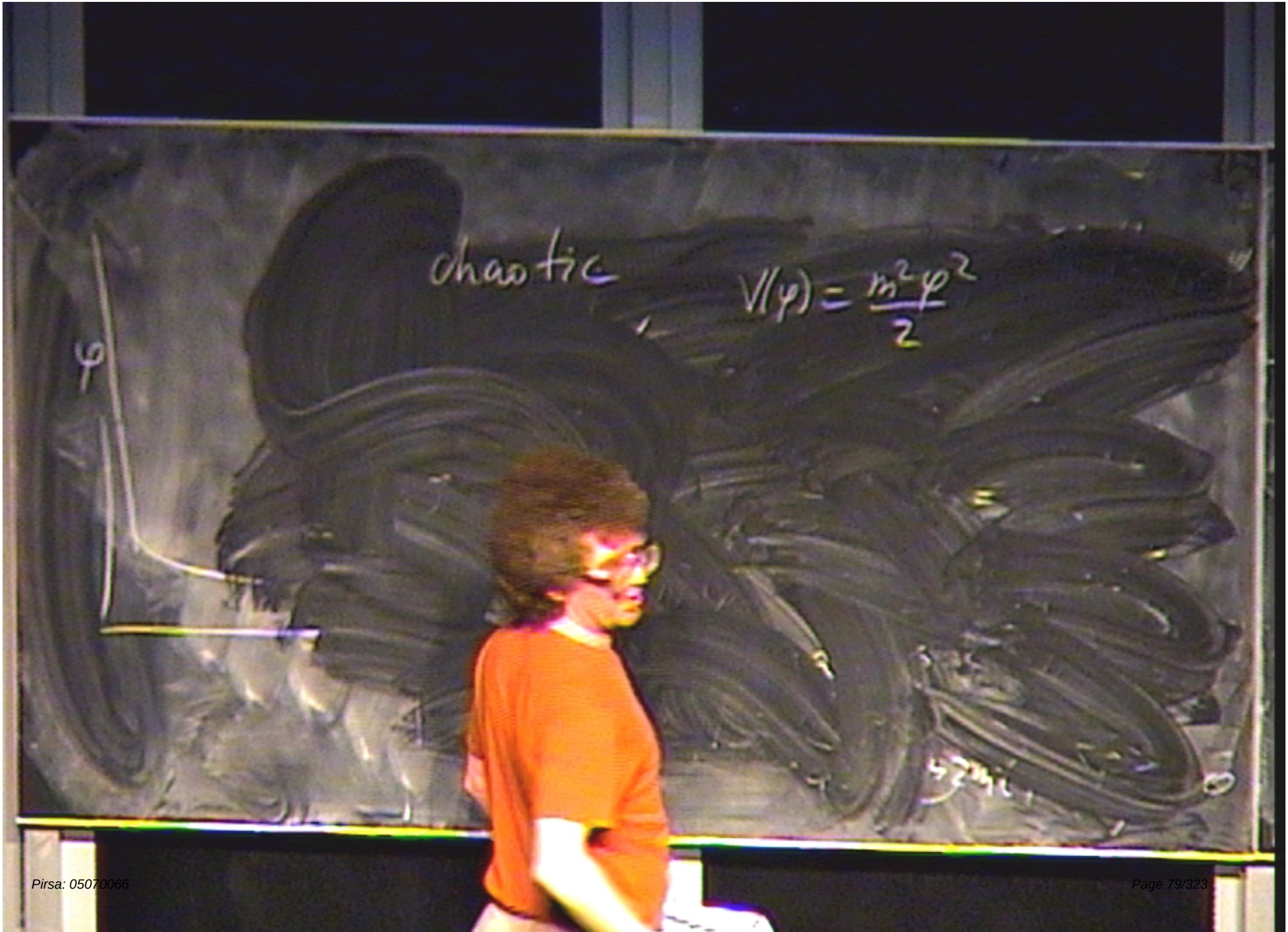

V(φ)
φ
φ

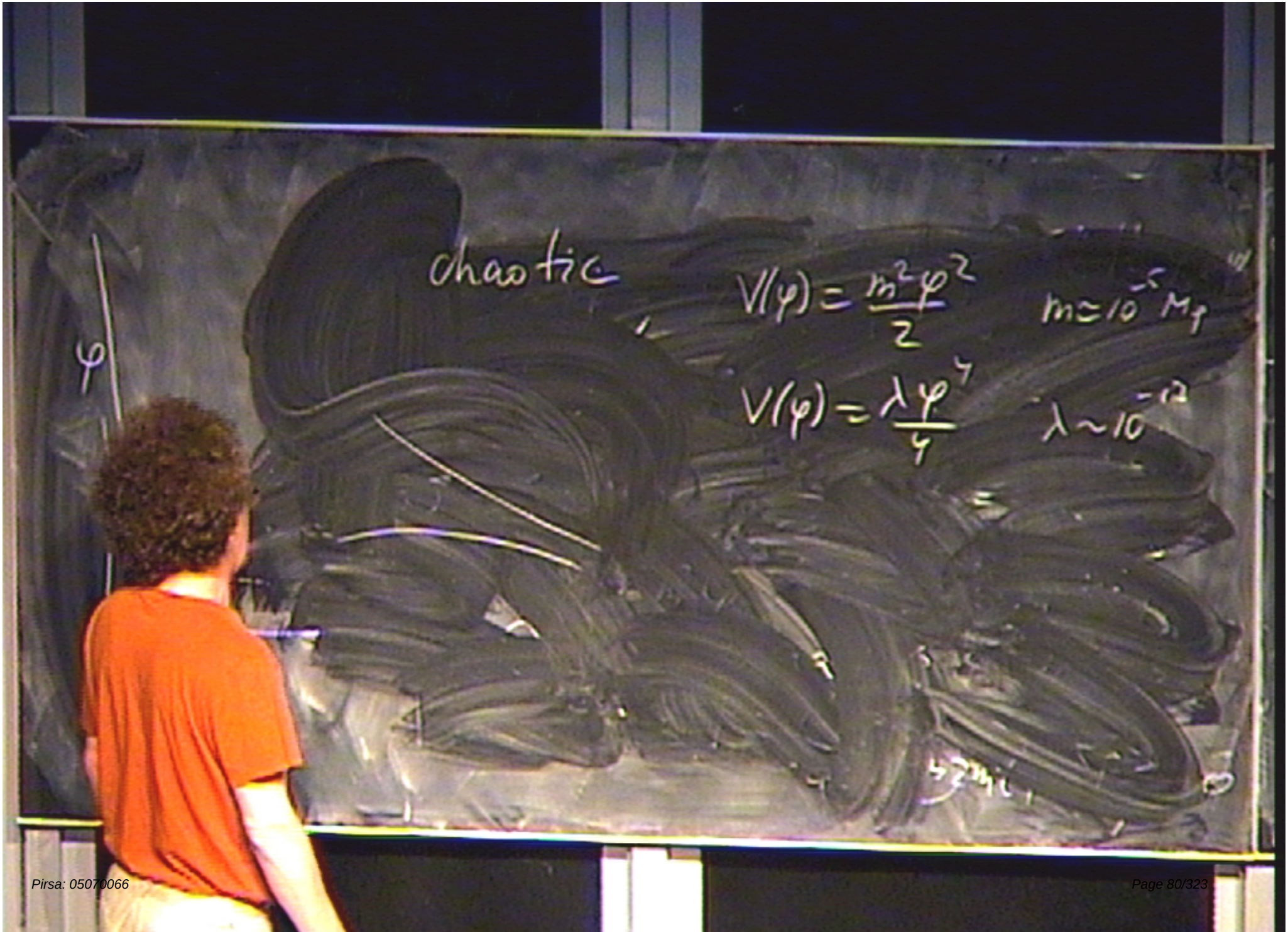

V(φ)
φ
Su(5)
φ

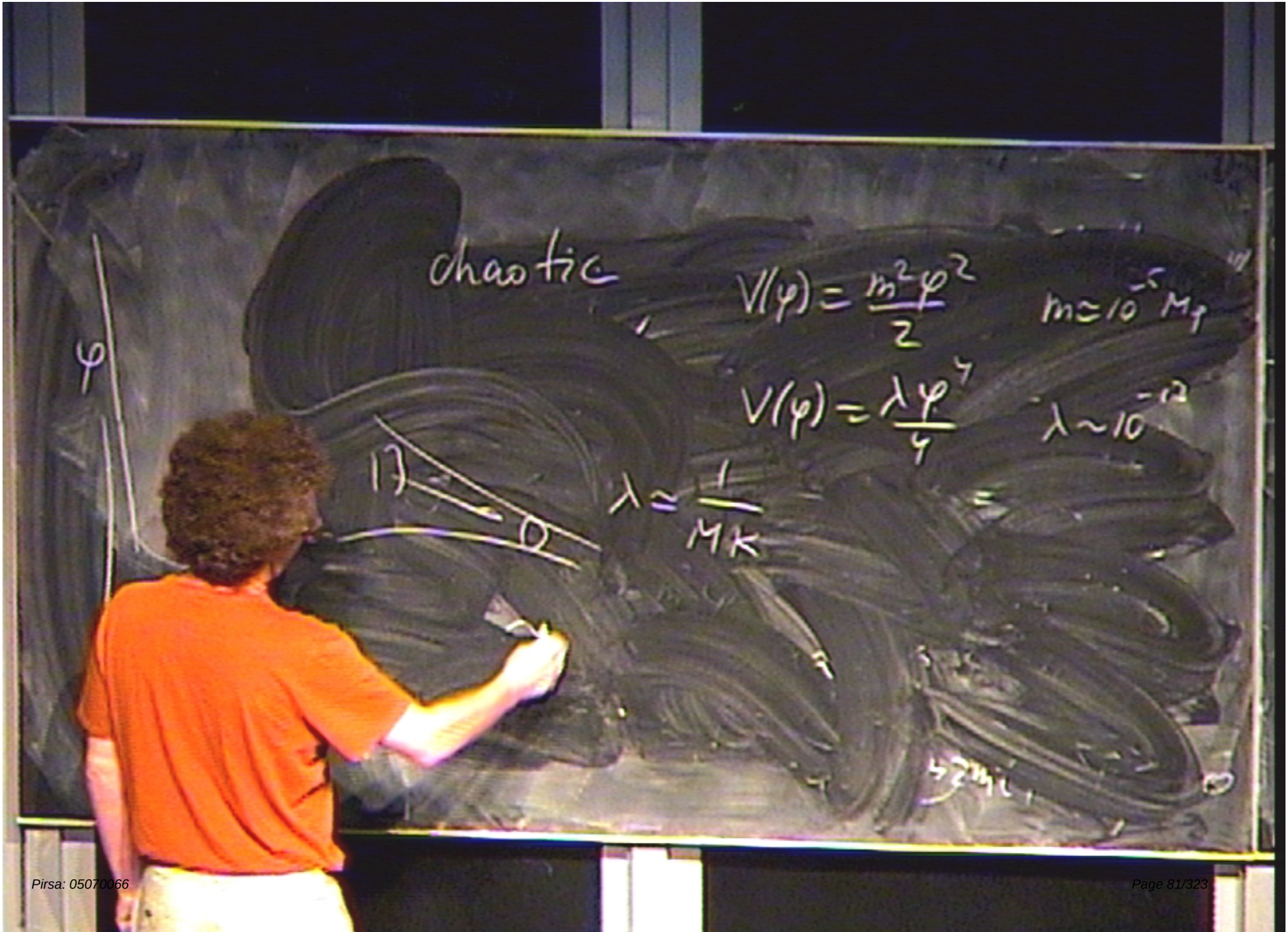

V(φ)
φ
φ

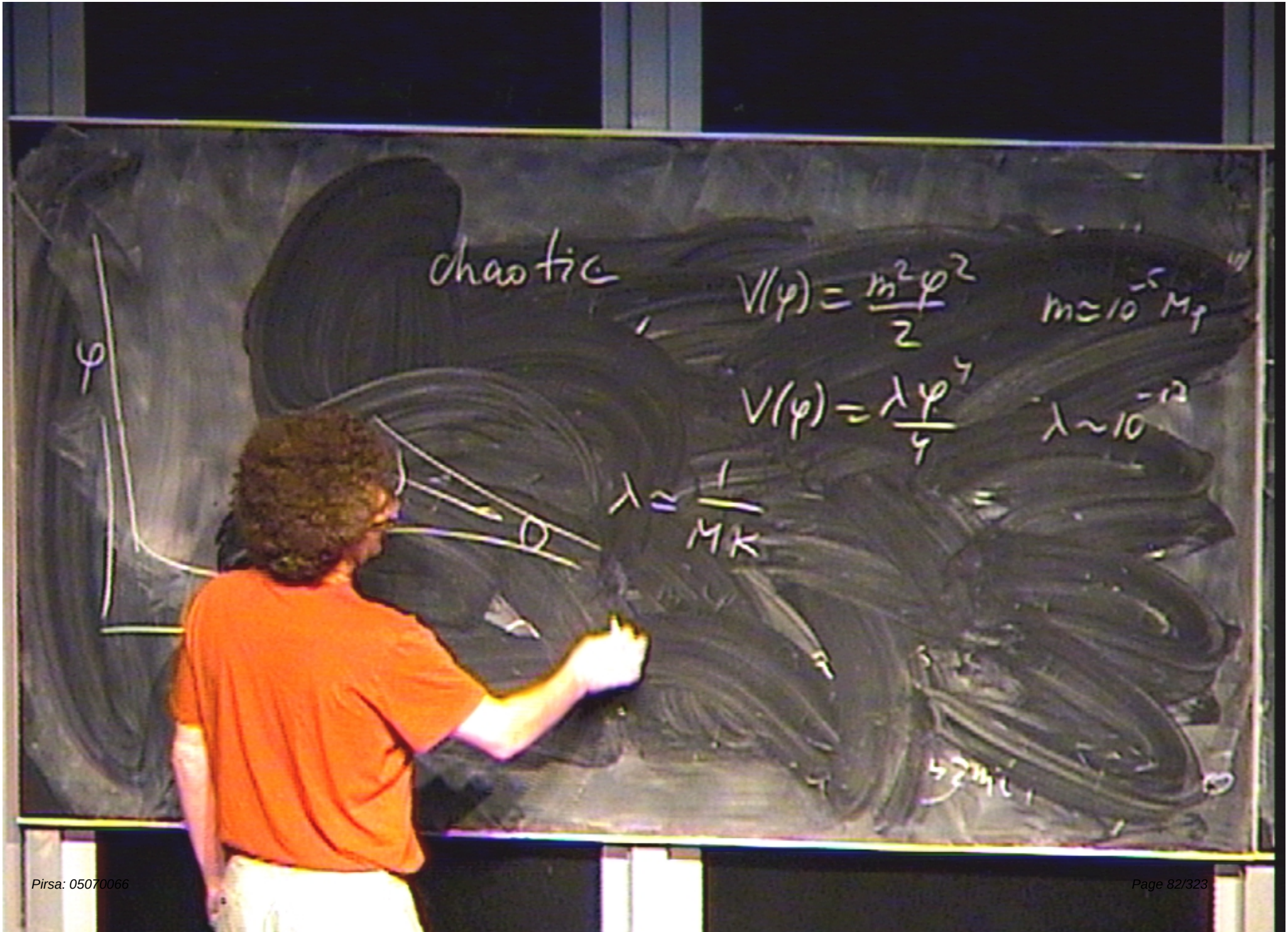

V(φ)
φ
SU(5)
λ ≃ 0.1

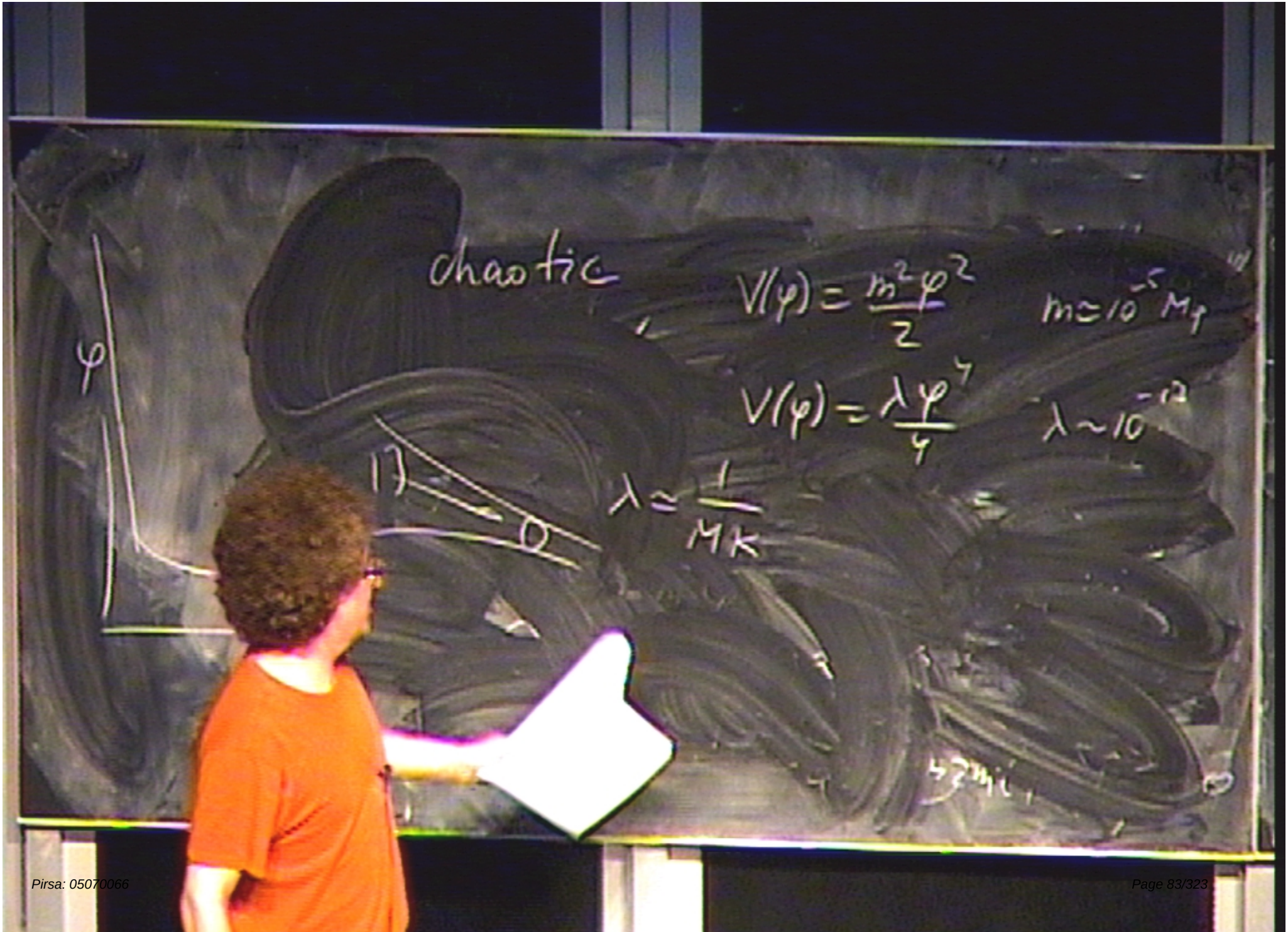

chaotic
V(φ) =
φ

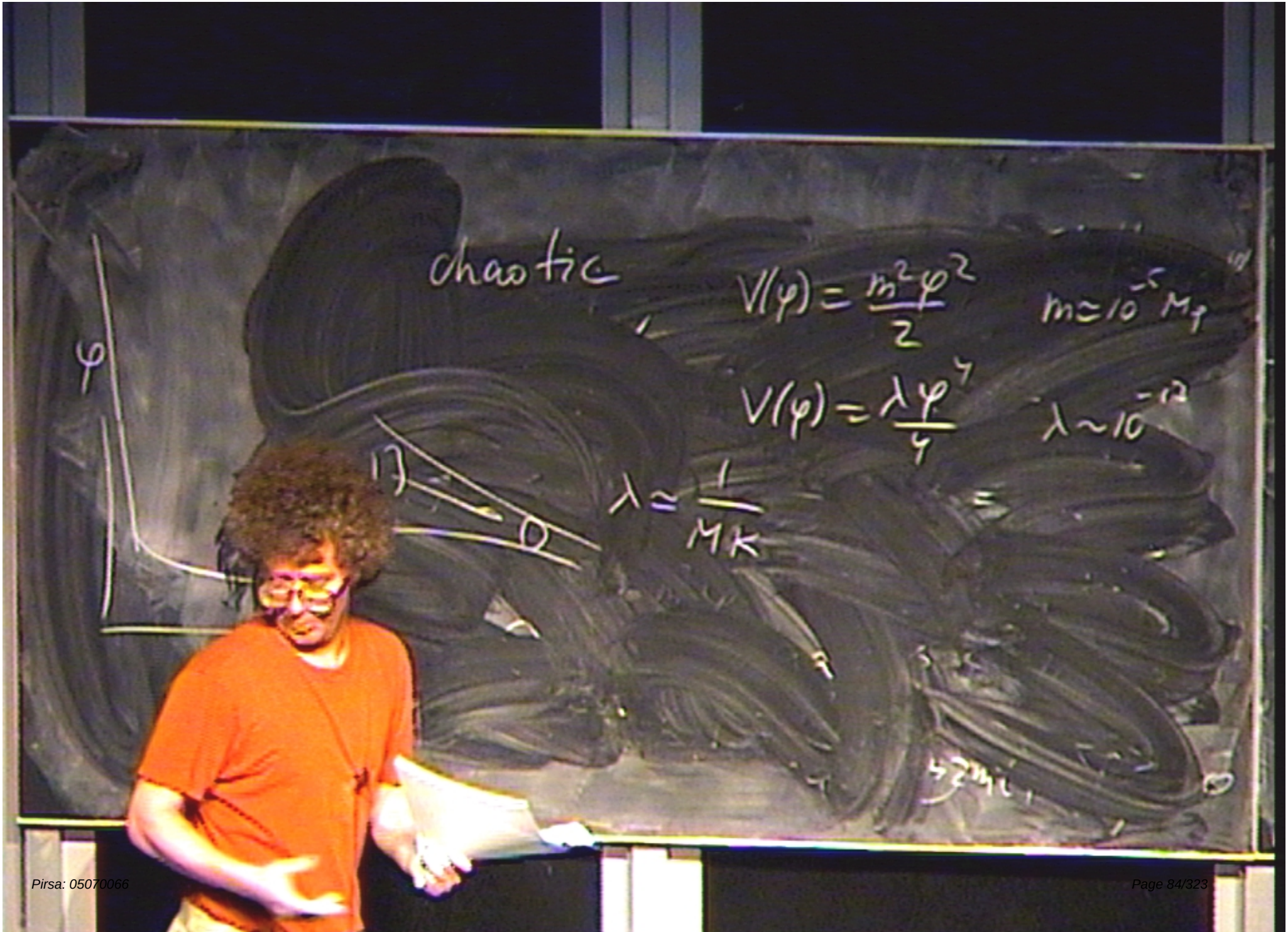

chaotic
$V(\varphi) = \frac{m^2 \varphi^2}{2}$
φ

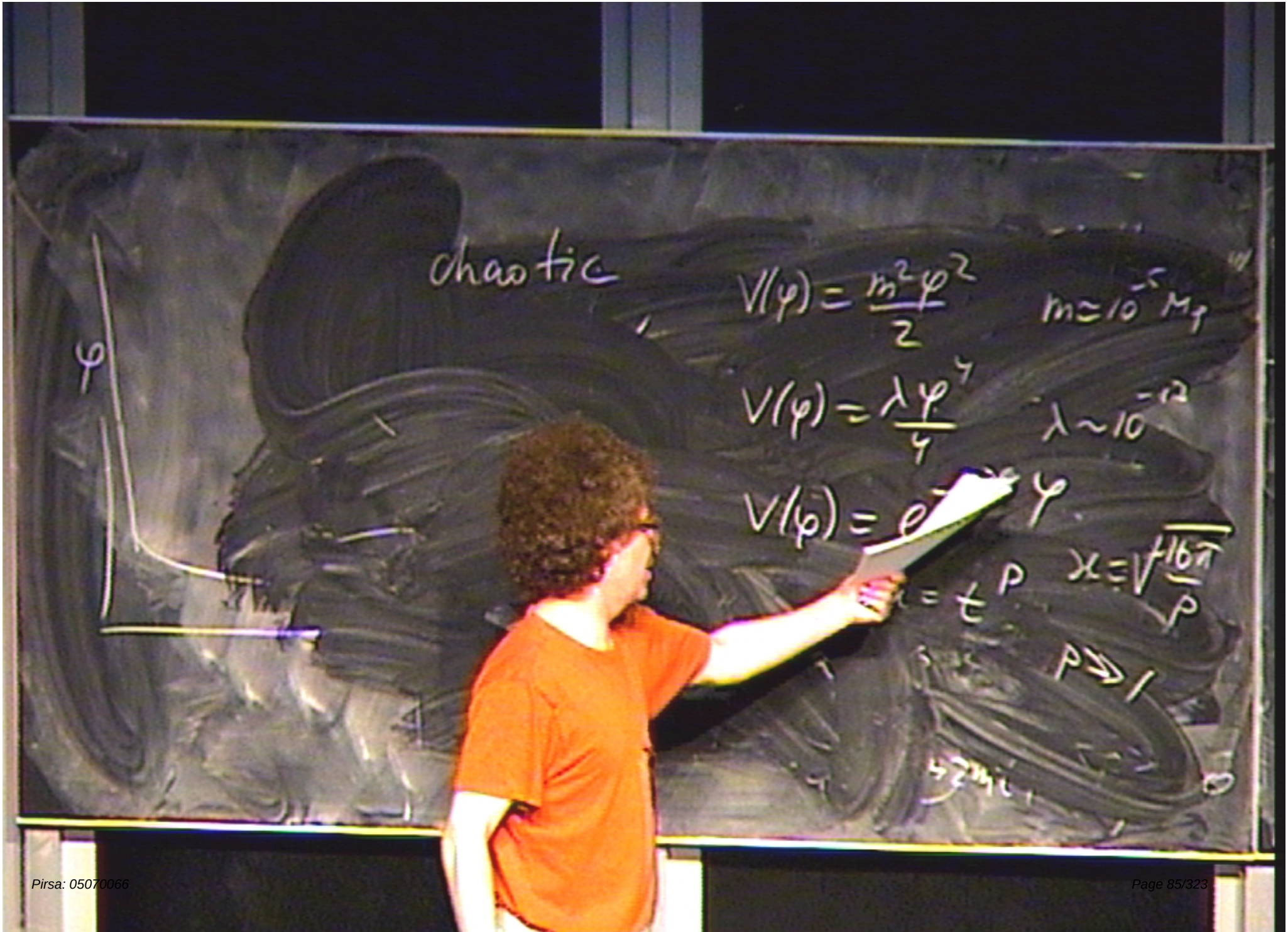

chaotic
$V(\varphi) = \frac{m^2\varphi^2}{2}$
$m \simeq 10^{-5} M_P$
$V(\varphi) = \frac{\lambda\varphi^4}{4}$
$\lambda \sim 10^{-12}$
φ

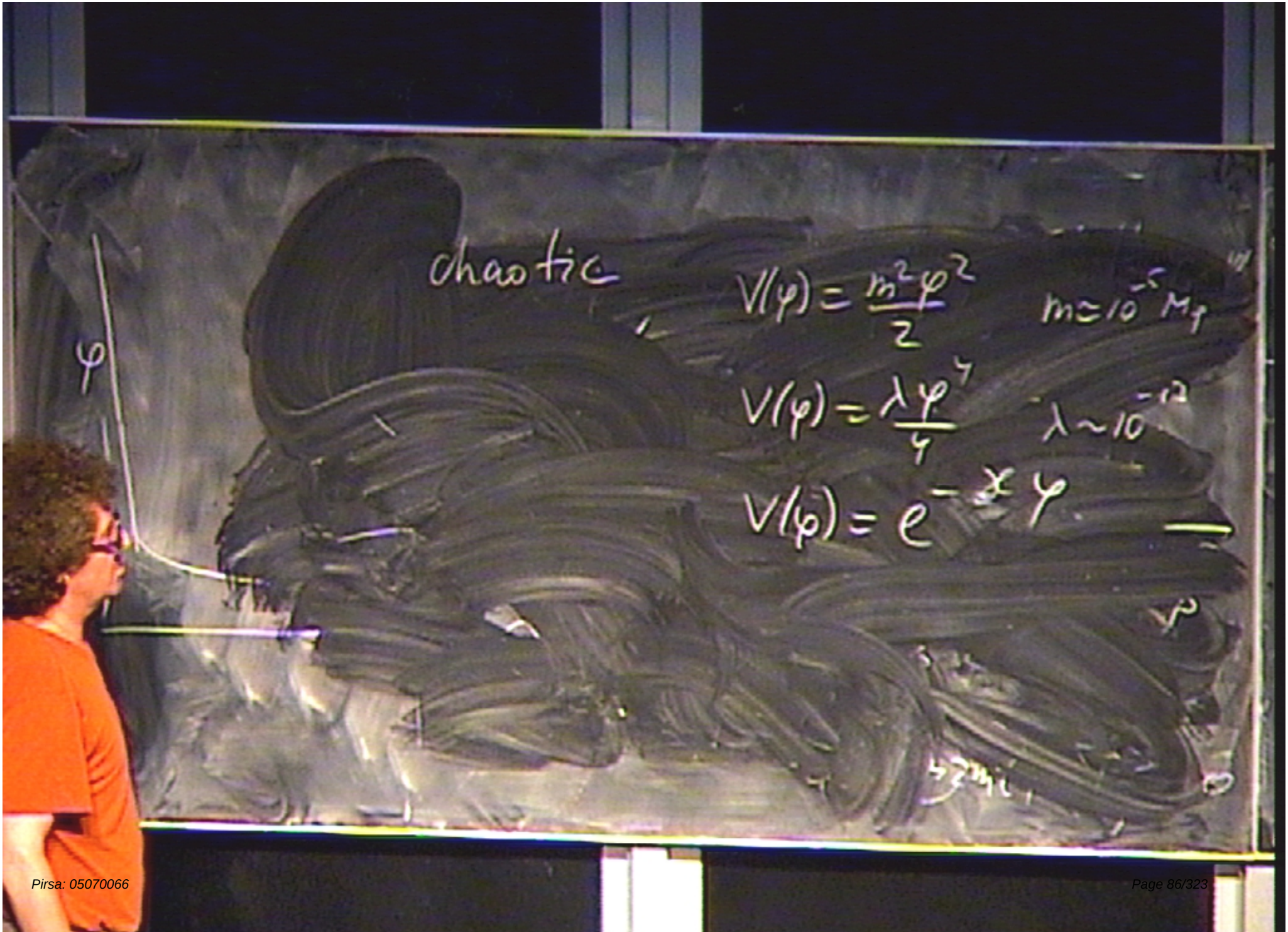

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φ
$\lambda \simeq \frac{1}{MK}$

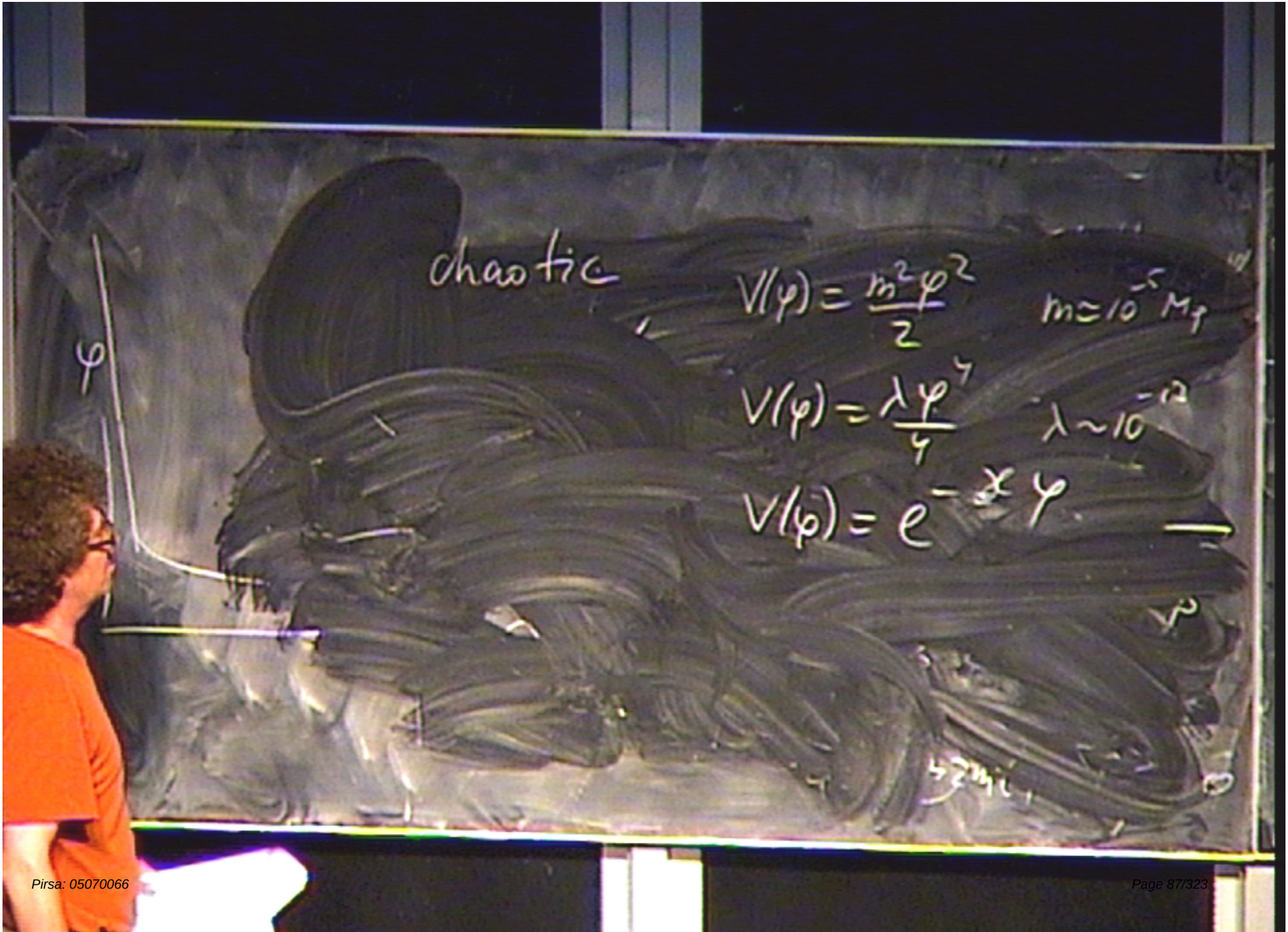

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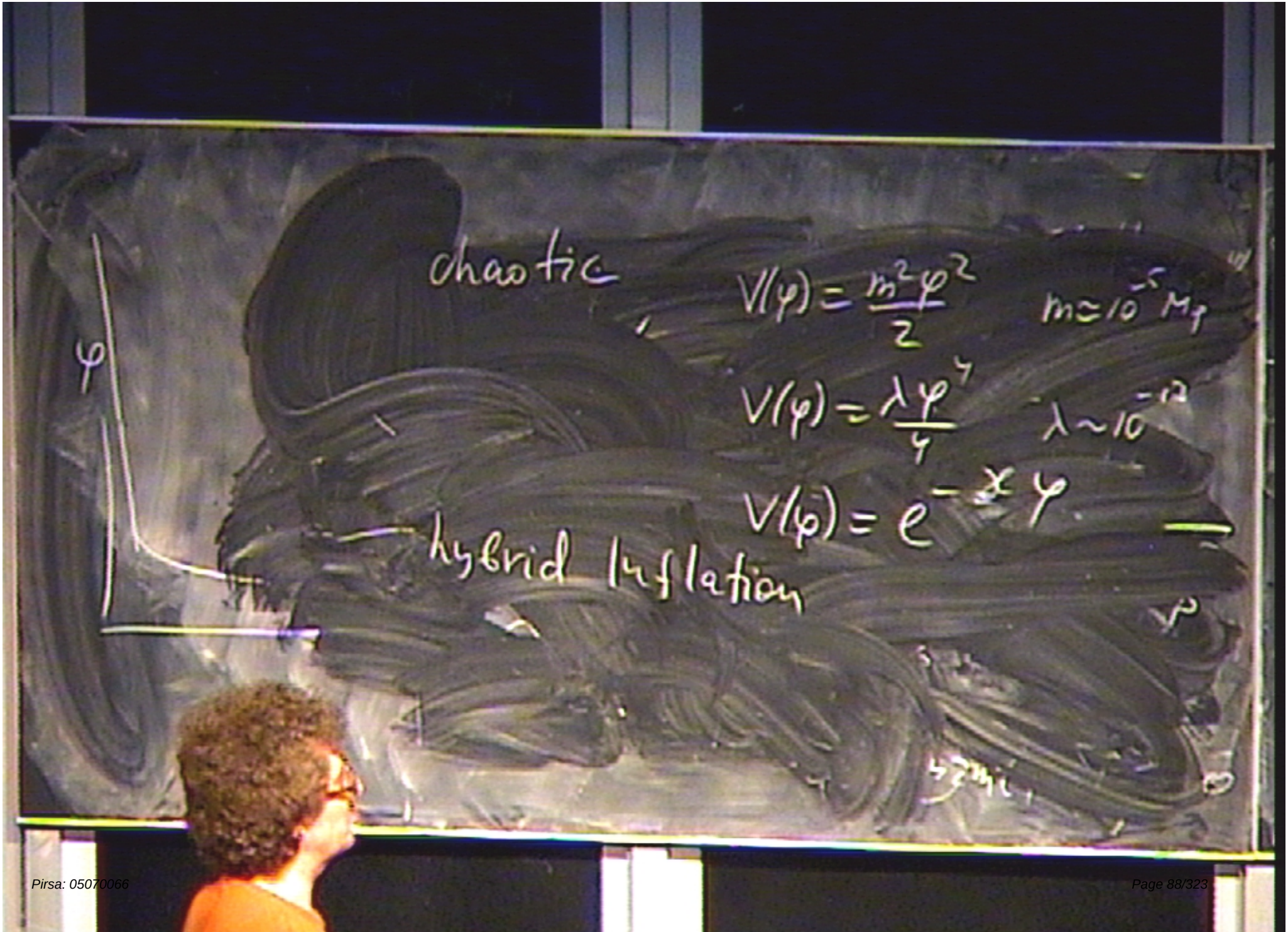

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$\lambda \sim 10^{-12}$
φ
$\lambda \simeq \frac{1}{MK}$
0

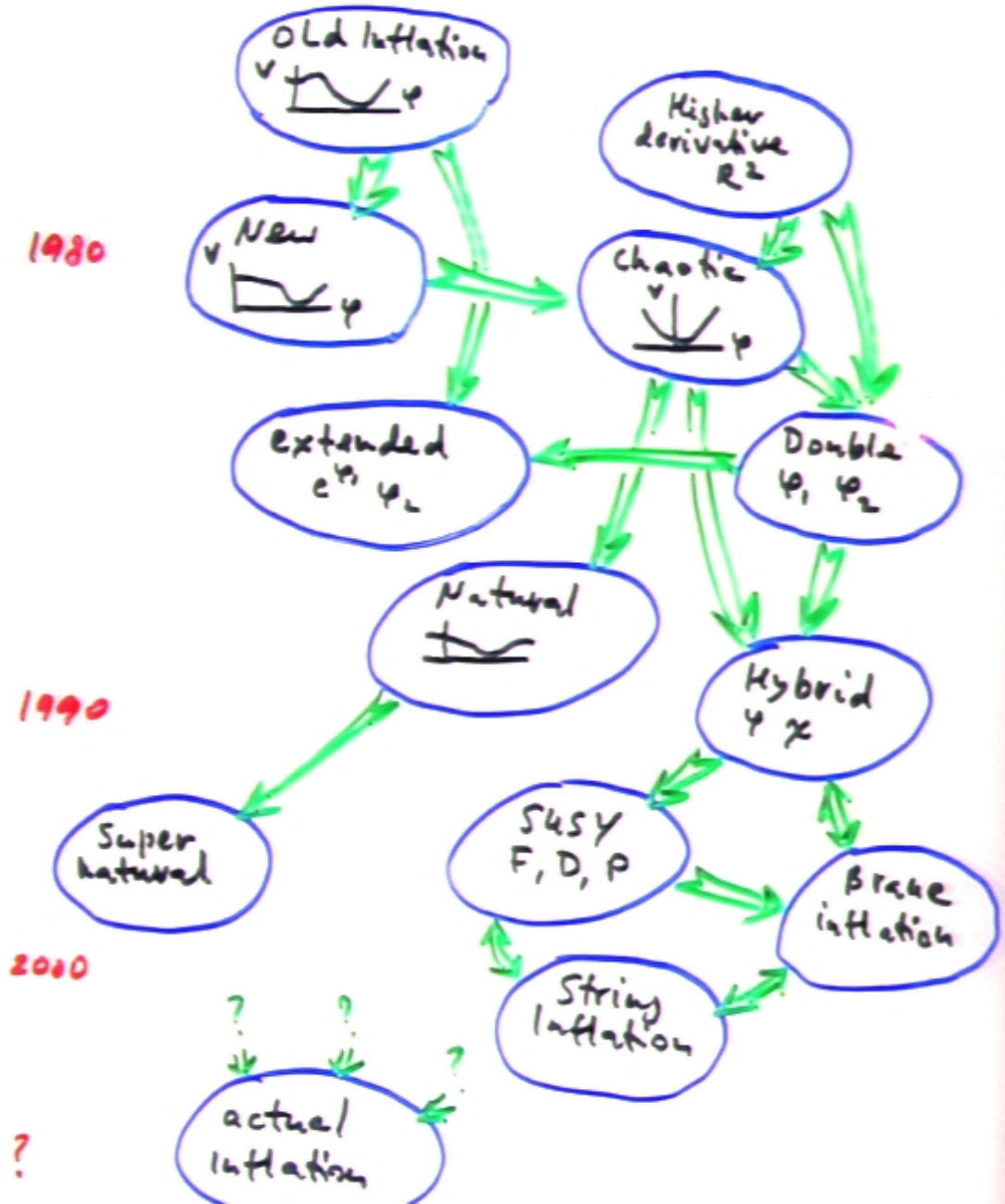

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φ
η
0
$\lambda \simeq \frac{1}{MK}$

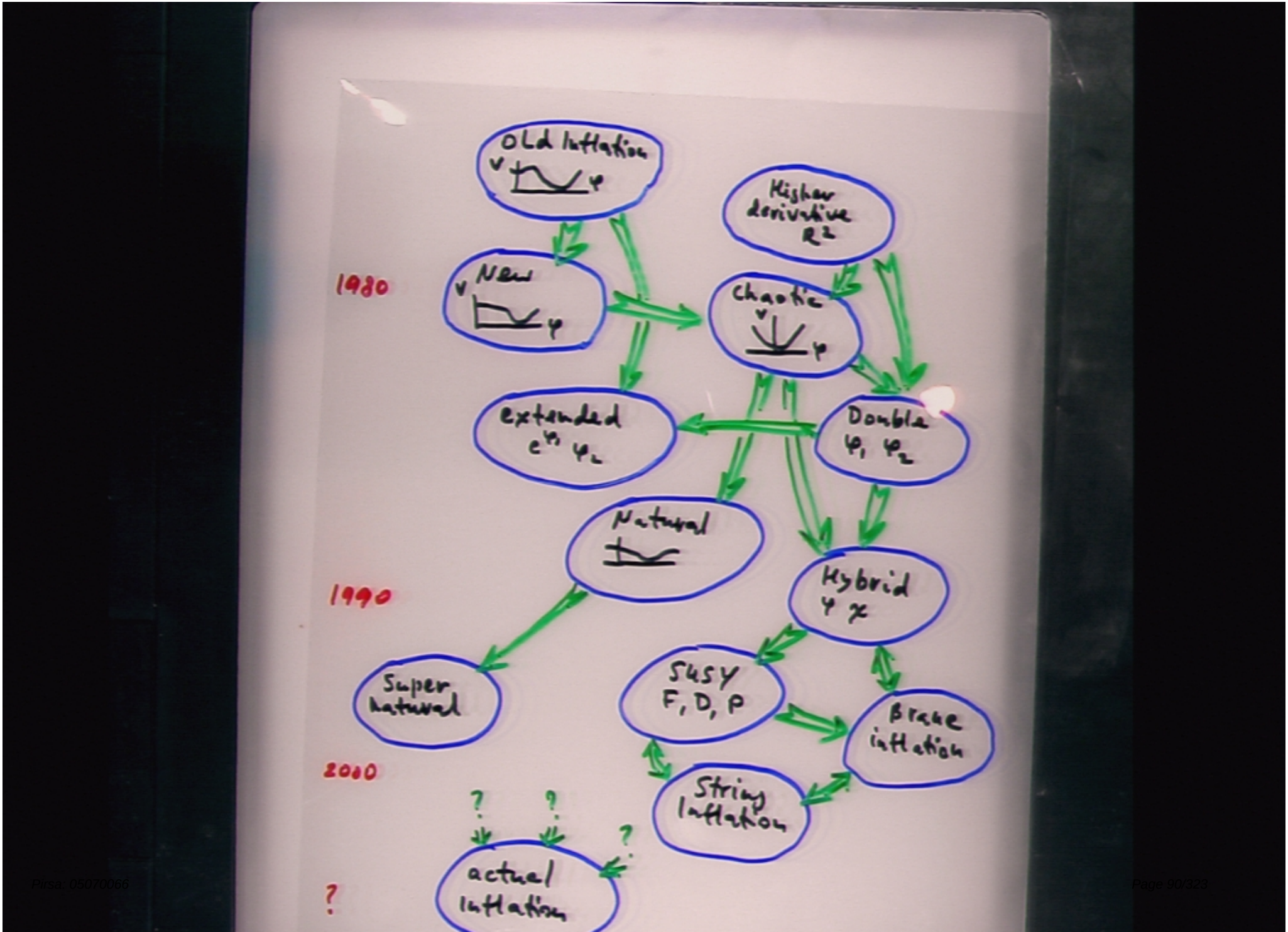

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$\lambda \sim 10^{-12}$
$V(\varphi) = e^{-\varphi}$
φ
$t = t_P$
$\chi = \sqrt{\frac{16\pi}{p}}$
$p \gg 1$

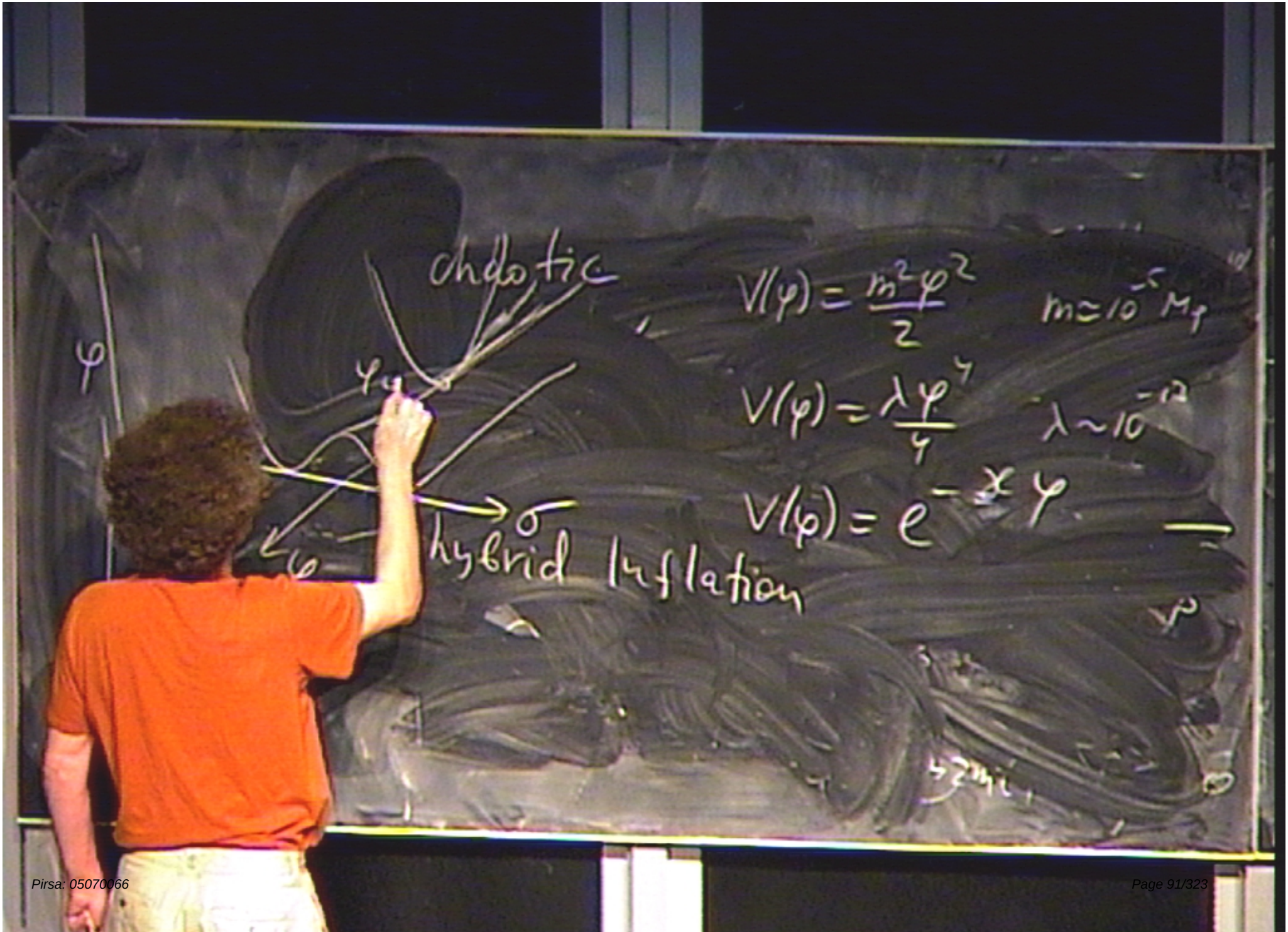

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$\lambda \sim 10^{-12}$
$V(\varphi) = e^{-\alpha\varphi}$
φ

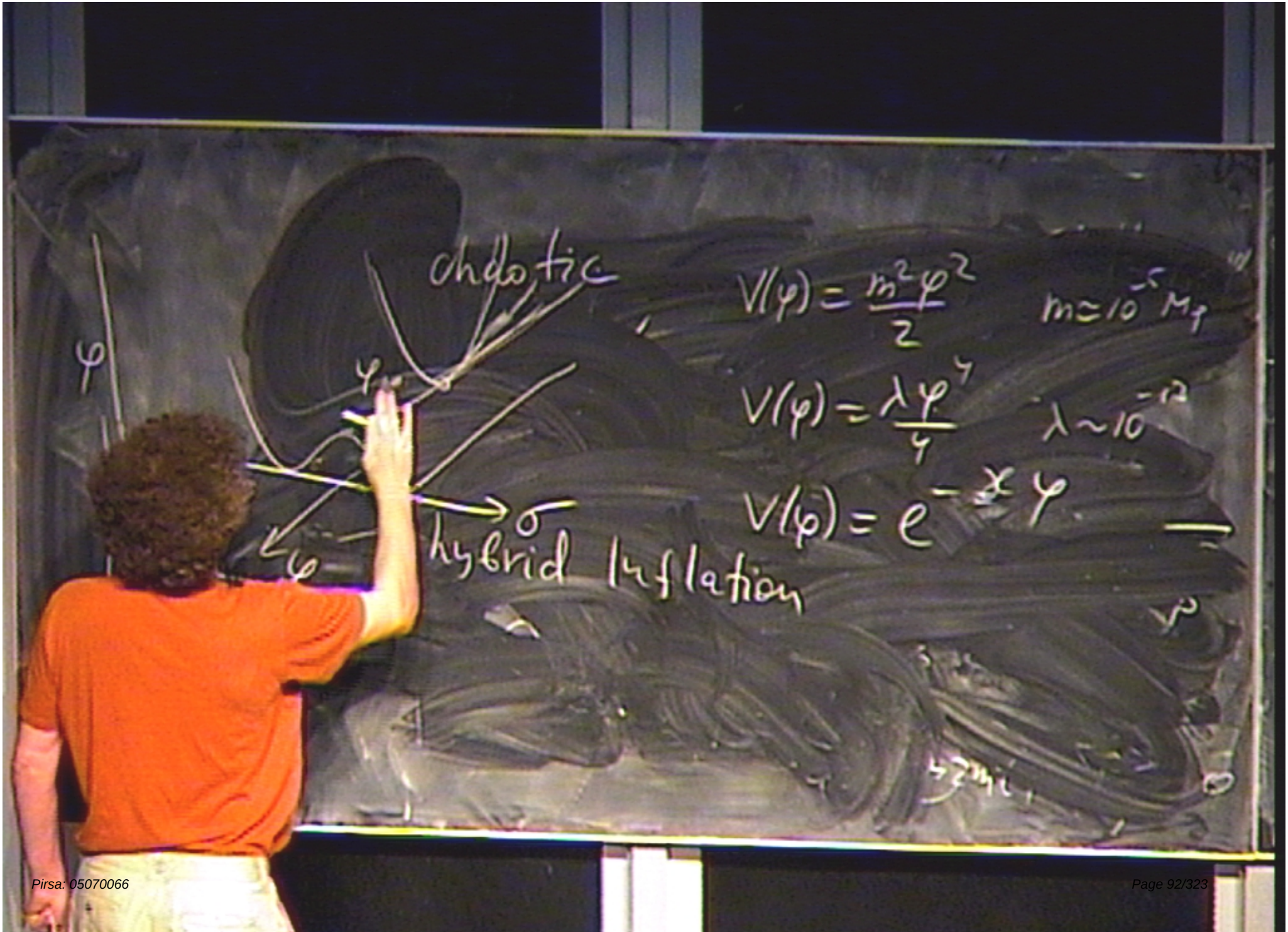

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$V(\varphi) = e^{-\alpha\varphi}$
φ
V

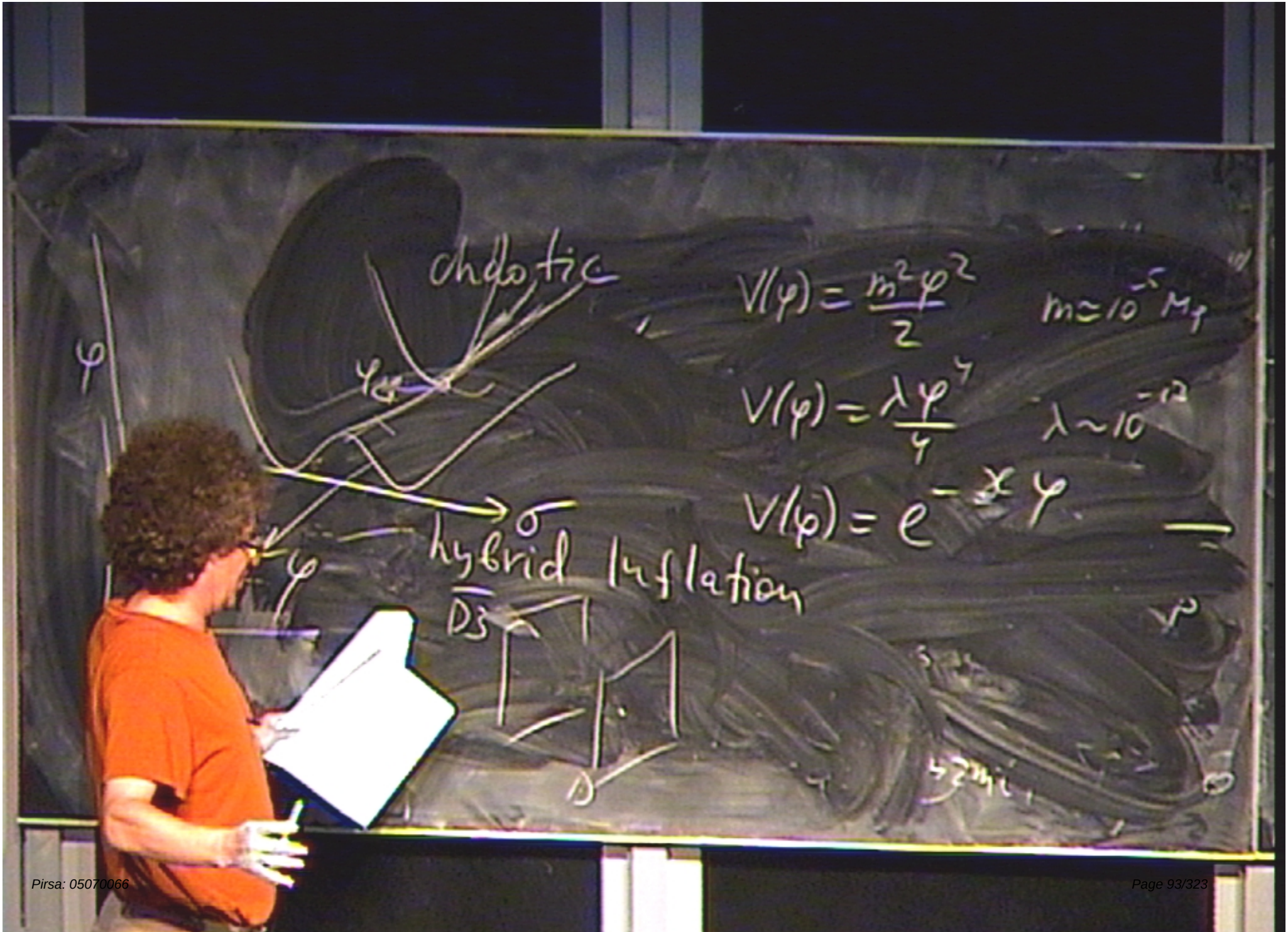

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$\lambda \sim 10^{-12}$
$V(\varphi) = e^{-\alpha\varphi}$
hybrid inflation
φ
V

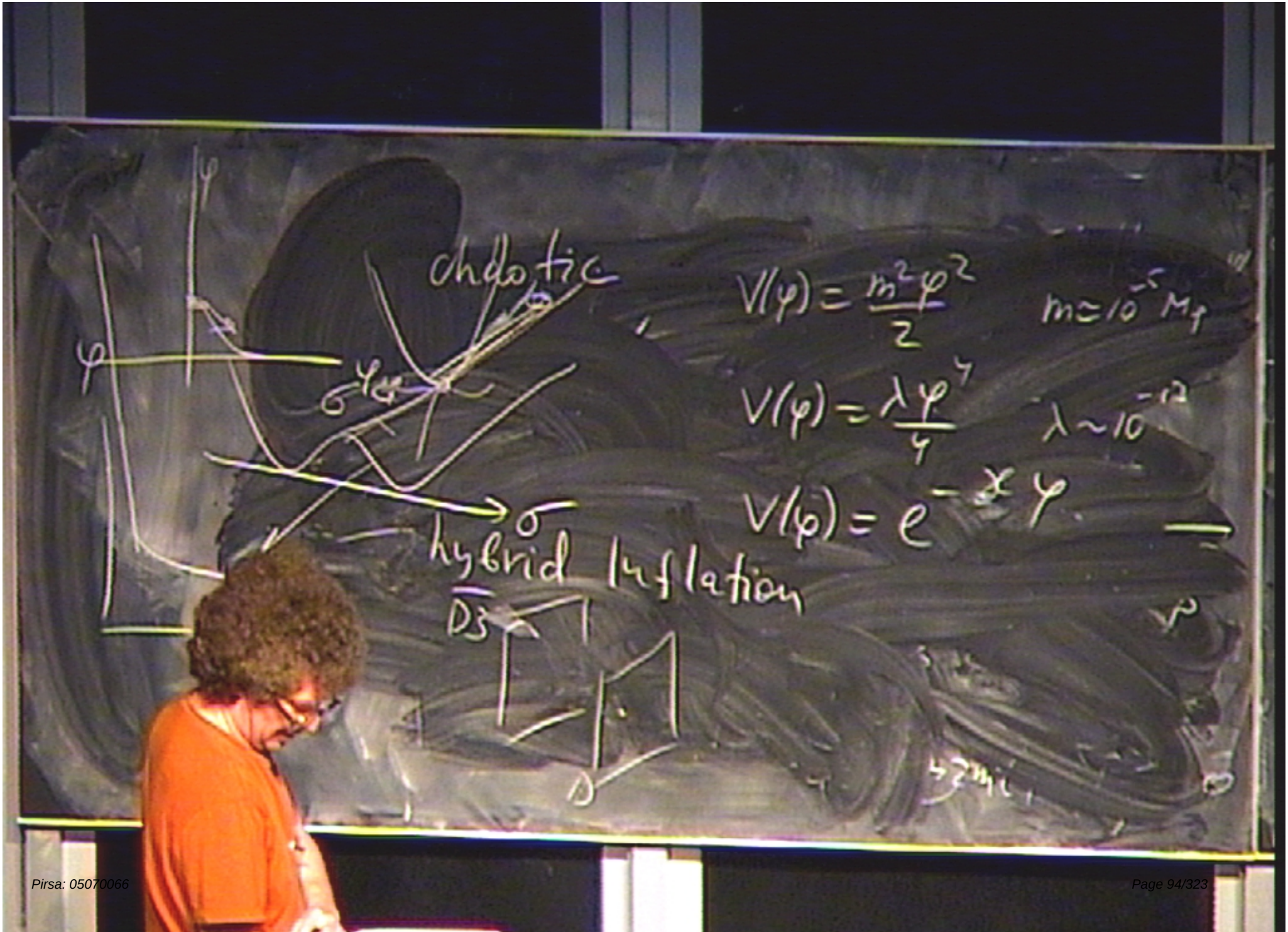

1980
1990
2000
?
Old Inflation
V
φ
Higher derivative R²
New
V
φ
Chaotic
V
φ
extended
Double φ₁ φ₂
Natural
Hybrid
φ χ
Super natural
SUSY F, D, P
Brane inflation
String Inflation
? ? ?
actual Inflation

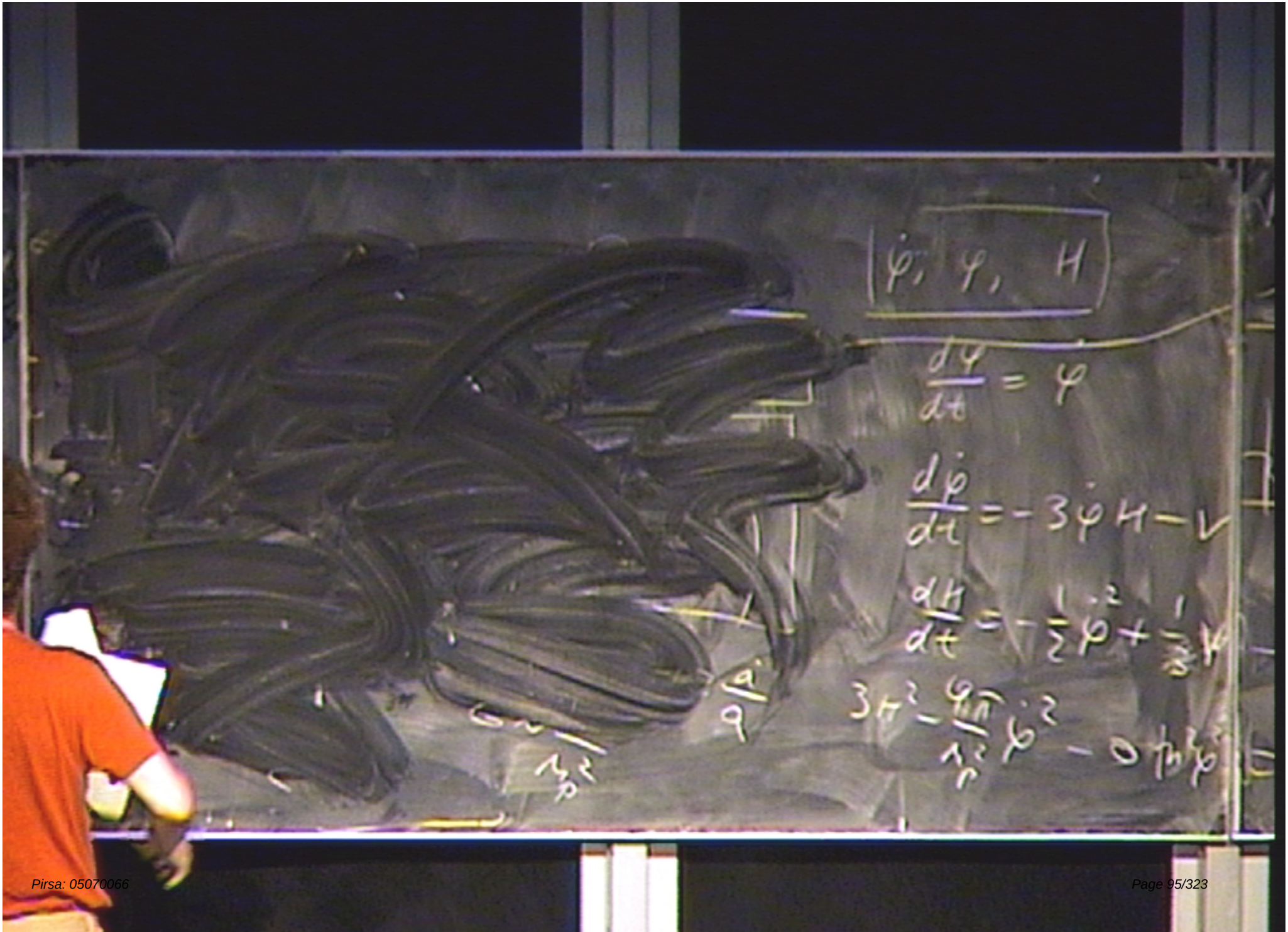

Old Inflation
V
φ
Higher derivative R²
1980
New
V
φ
Chaotic
V
φ
extended
$e^{\kappa\varphi_1}\varphi_2$
Double
φ_1 φ_2
Natural
1990
Hybrid
φ χ
Super Natural
SUSY
F, D, P
Brane Inflation
2000
String Inflation
? ? ?
actual Inflation
?

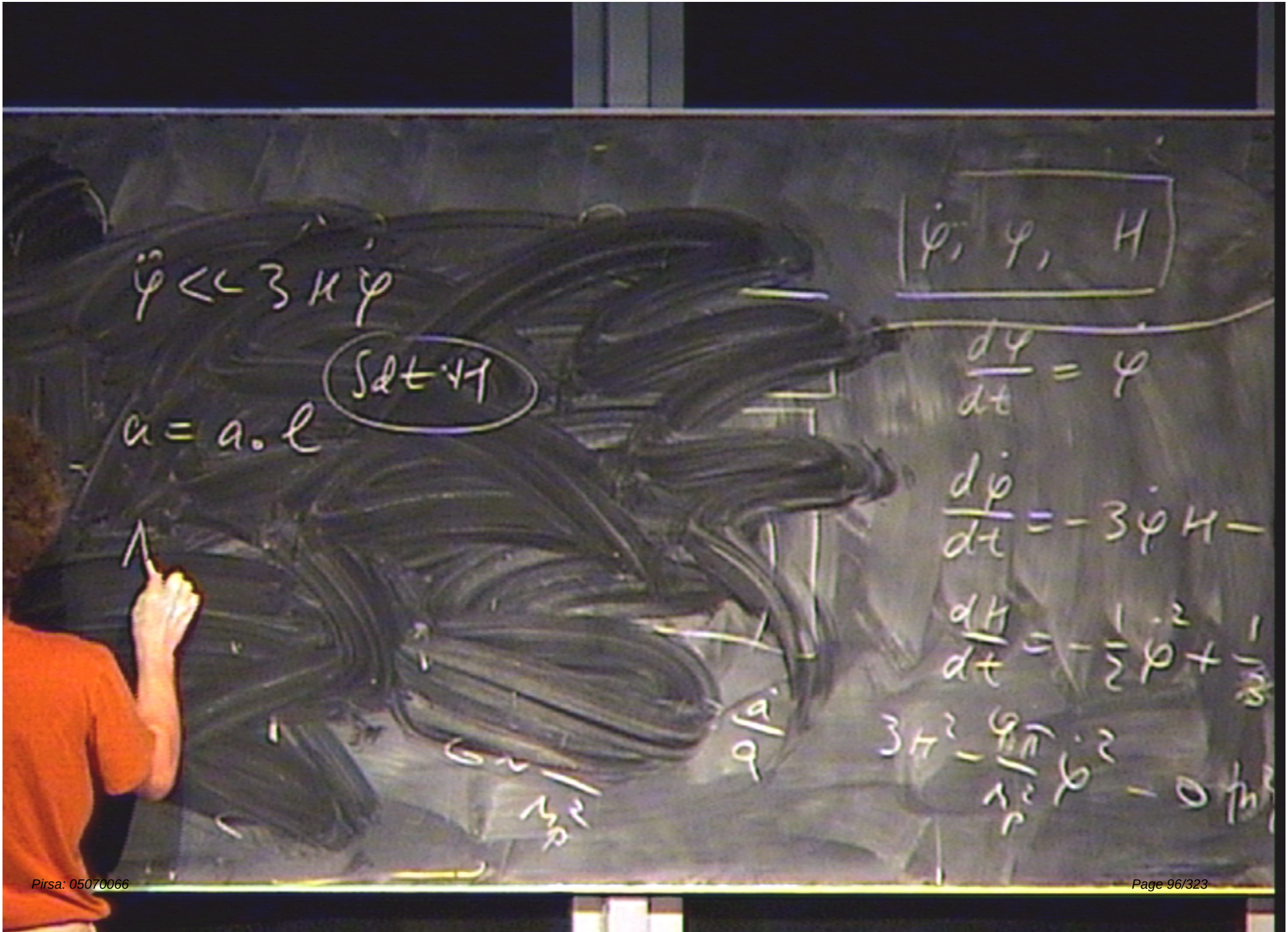

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$V(\varphi) = e^{-\alpha\varphi}$
φ
σ
hybrid inflation

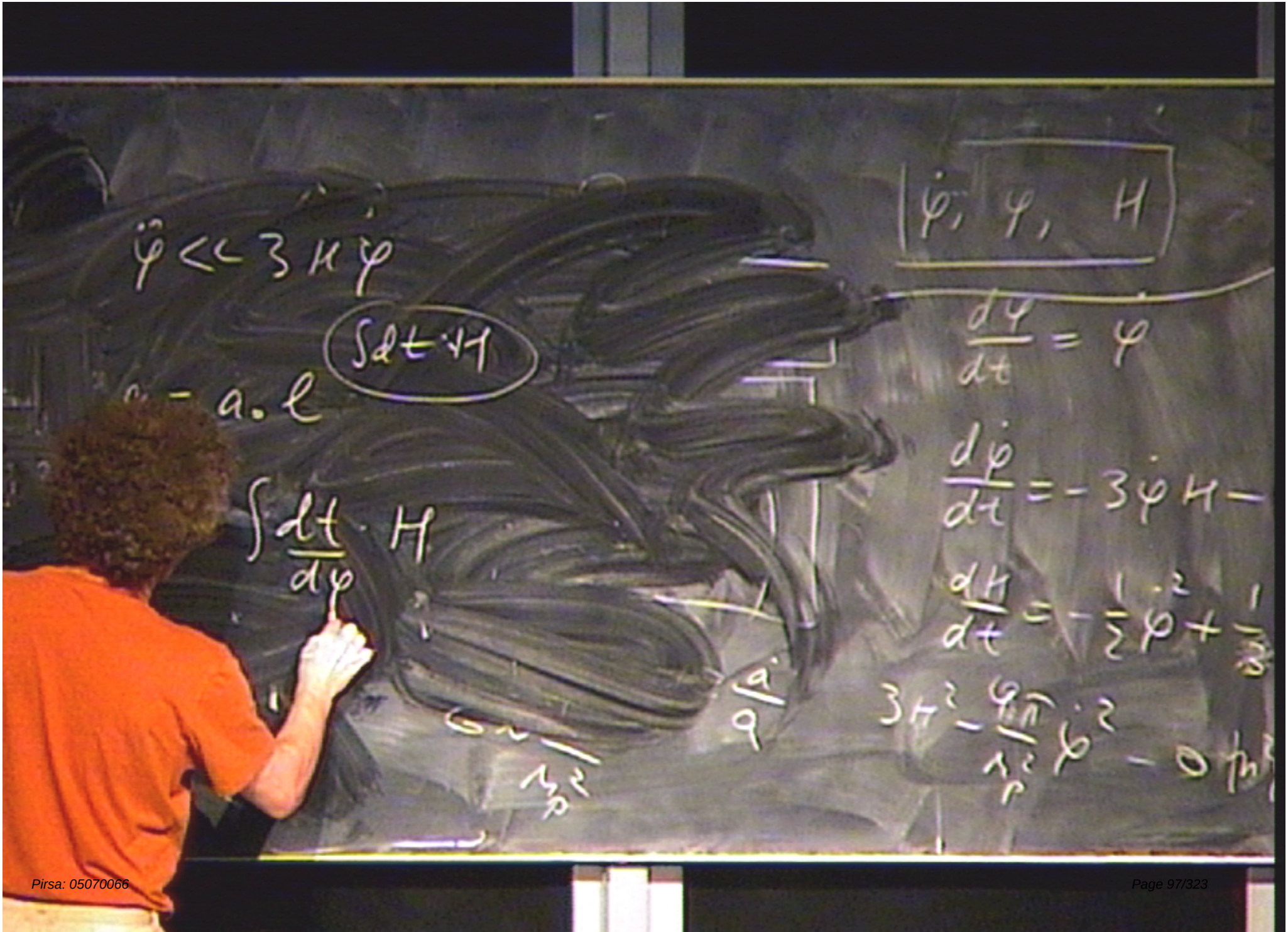

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σ
hybrid inflation

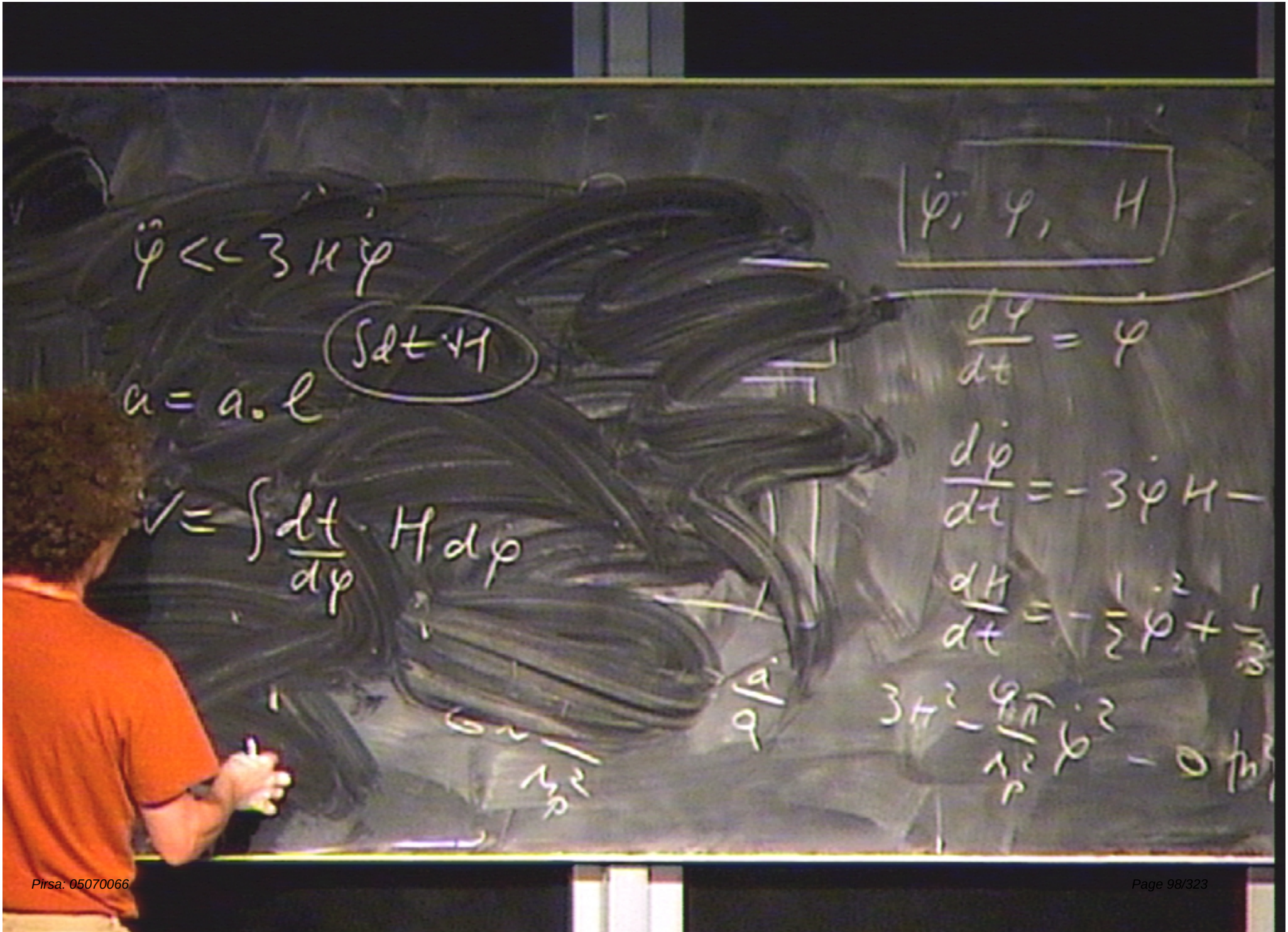

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φ
σ
hybrid inflation

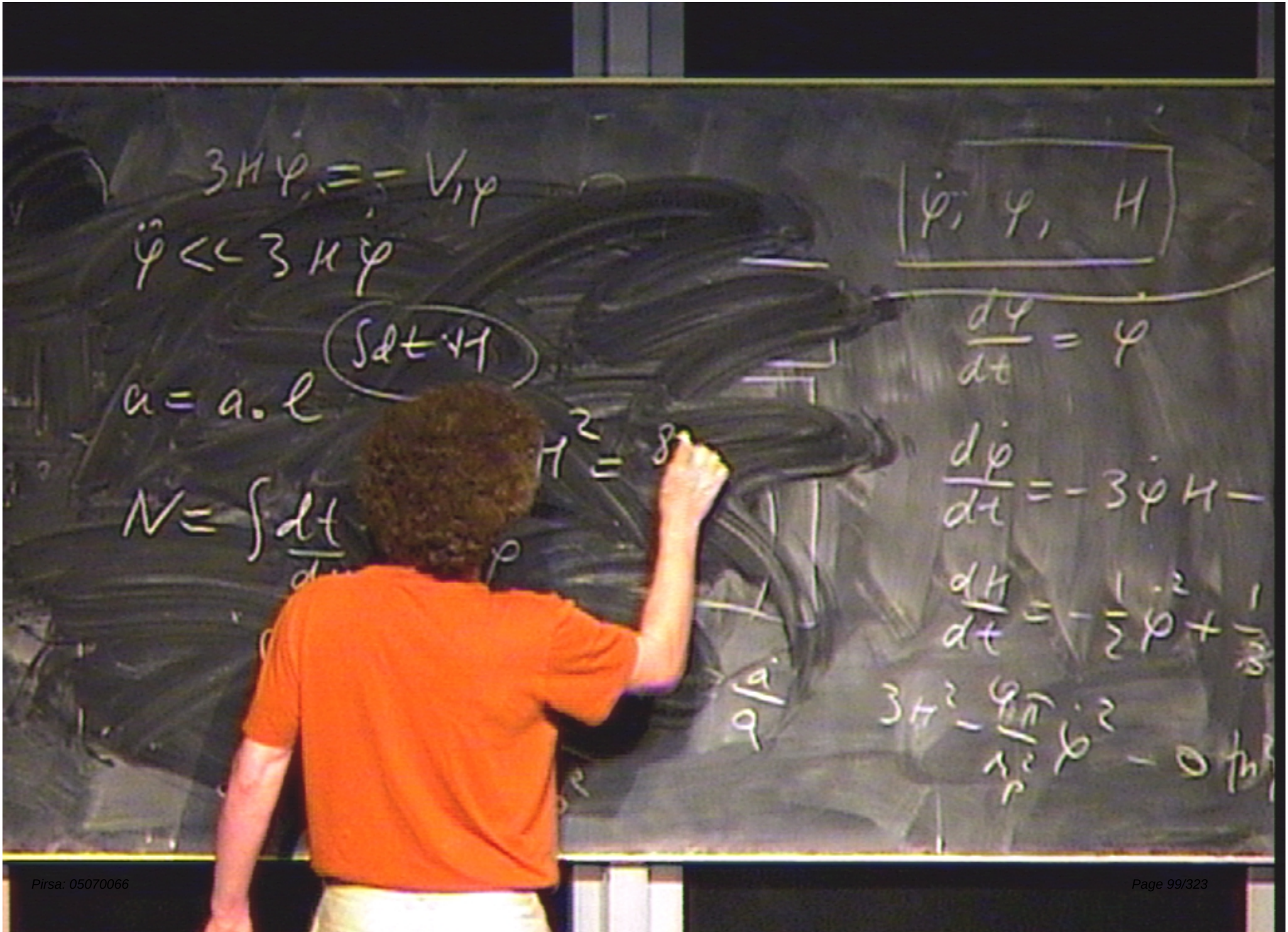

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$\lambda \sim 10^{-12}$
$V(\varphi) = e^{-\alpha\varphi}$
hybrid inflation
σ
φ


$\varphi;\ \dot{\varphi},\ H$
$\frac{d\varphi}{dt} = \dot{\varphi}$
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H - V$
$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{3}H$
$3H^2 = \frac{\varphi_{in}}{M_p^2}\dot{\varphi}^2 - 0 + m^2\varphi^2$


$\ddot{\varphi} << 3H\dot{\varphi}$
$dt \cdot H$
$a = a_0 e$
$\dot{\varphi}, \varphi, H$
$\frac{d\varphi}{dt} = \dot{\varphi}$
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H -$
$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{2}$
$\frac{\dot{a}}{a}$
$3H^2 - \frac{\varphi^2}{M_p^2}\dot{\varphi}^2 - 0$


$\ddot{\varphi} \ll 3H\dot{\varphi}$
$\int dt \cdot H$
$\dot{\varphi}, \varphi, H$
$\frac{d\varphi}{dt} = \dot{\varphi}$
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H -$
$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{2}$
$3H^2 - \frac{1}{2}\dot{\varphi}^2 - 0$


$\ddot{\varphi} \ll 3H\dot{\varphi}$
$\int dt \cdot H$
$a = a_0 e$
$V = \int \frac{dt}{d\varphi} \cdot H \, d\varphi$
$\dot{\varphi}, \varphi, H$
$\frac{d\varphi}{dt} = \dot{\varphi}$
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H -$
$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{2}$
$\frac{\dot{a}}{a}$
$3H^2 - \frac{\varphi^2}{M_p^2}\dot{\varphi}^2 - \rho$


$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$\int dt \cdot H$
$a = a_0 e$
$N = \int \frac{dt}{}$
$H^2 = 8$
$\dot{\varphi}, \varphi, H$
$\frac{d\varphi}{dt} = \dot{\varphi}$
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H -$
$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{}$
$3H^2 - \frac{}{}\dot{\varphi}^2 - 0$

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

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

$\int dt \cdot H$

$a = a_0 e$

$N = \int \frac{dt}{d\varphi} \cdot H\, d\varphi$

$3H^2 = \frac{8\pi}{m_p^2} V$

$\int d\varphi \cdot \frac{H^2}{V_{,\varphi}} \frac{m_p^2}{8\pi}$

$\frac{\dot{a}}{a}$

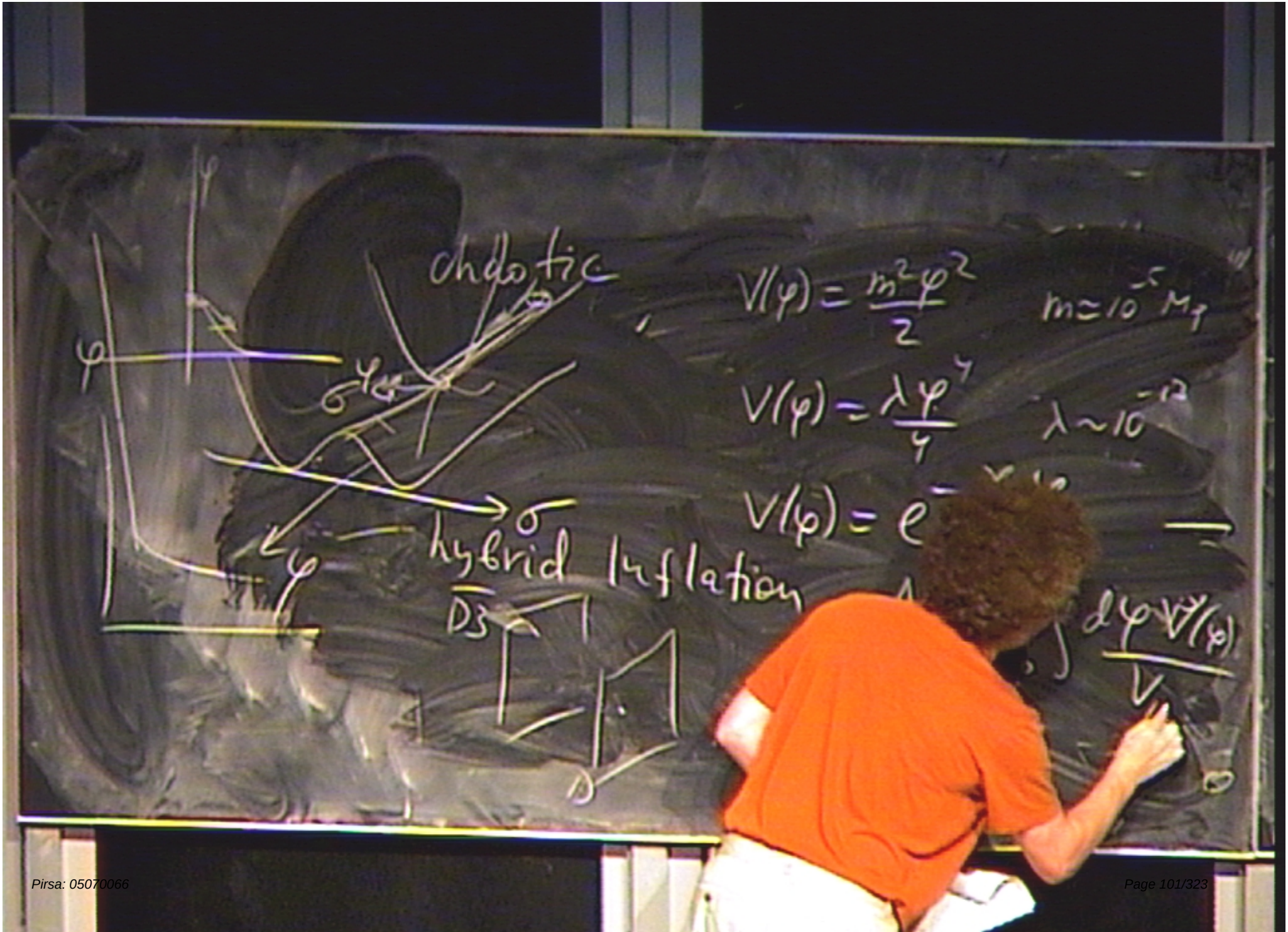
φ; $\dot{\varphi}$, H

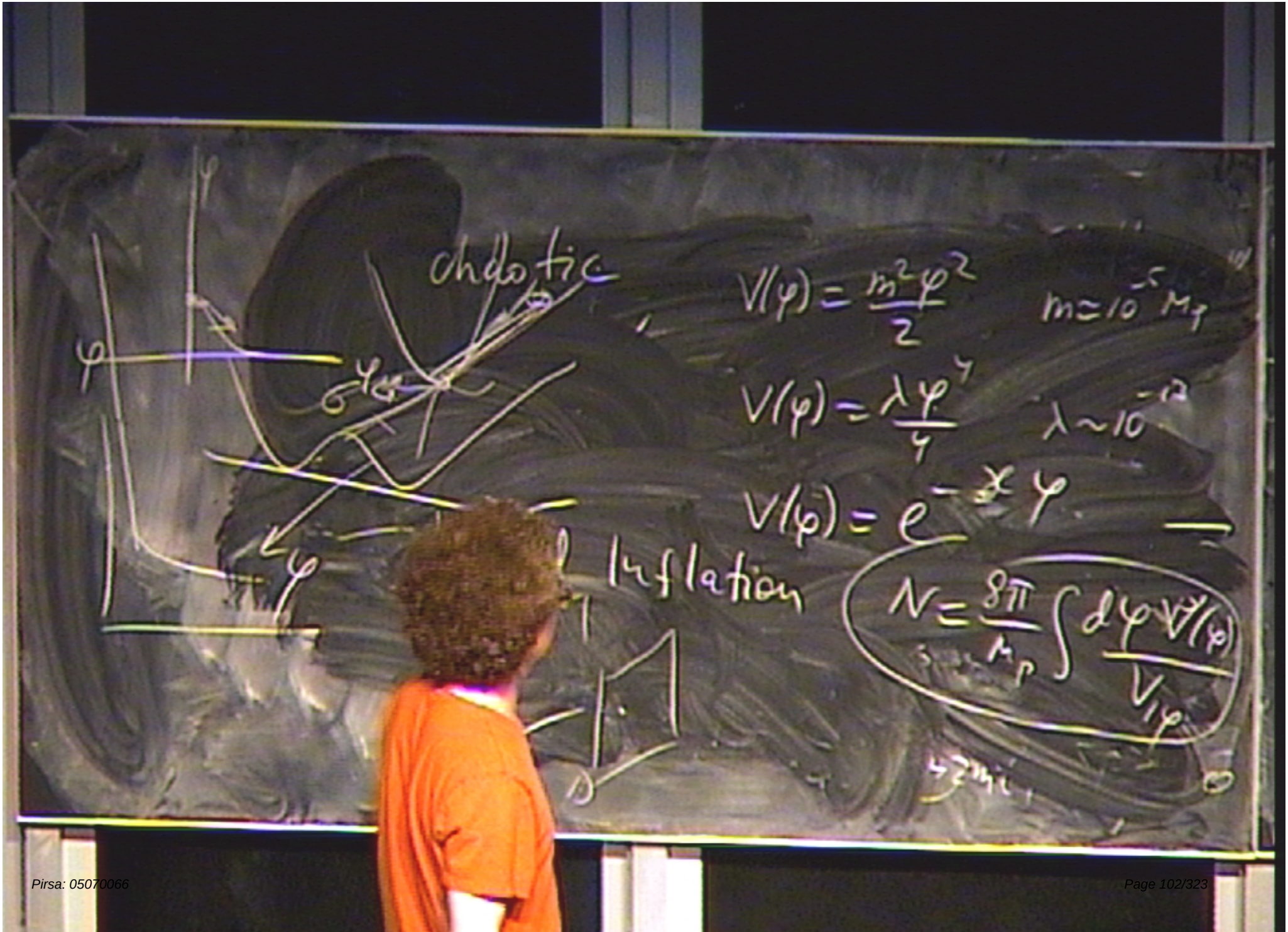
$\frac{d\varphi}{dt} = \dot{\varphi}$

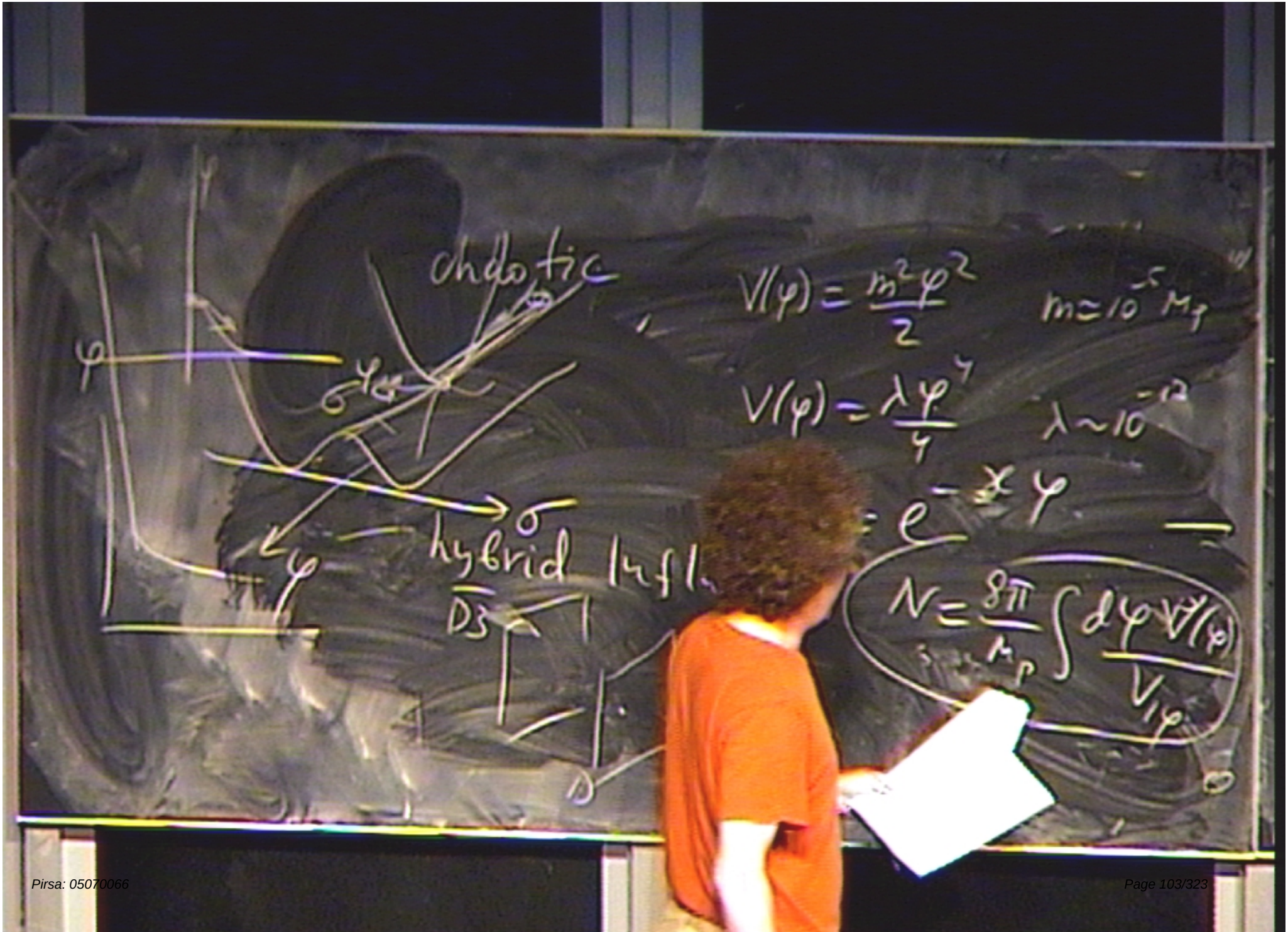
$\frac{d\dot{\varphi}}{dt} = -3\dot{\varphi}H -$

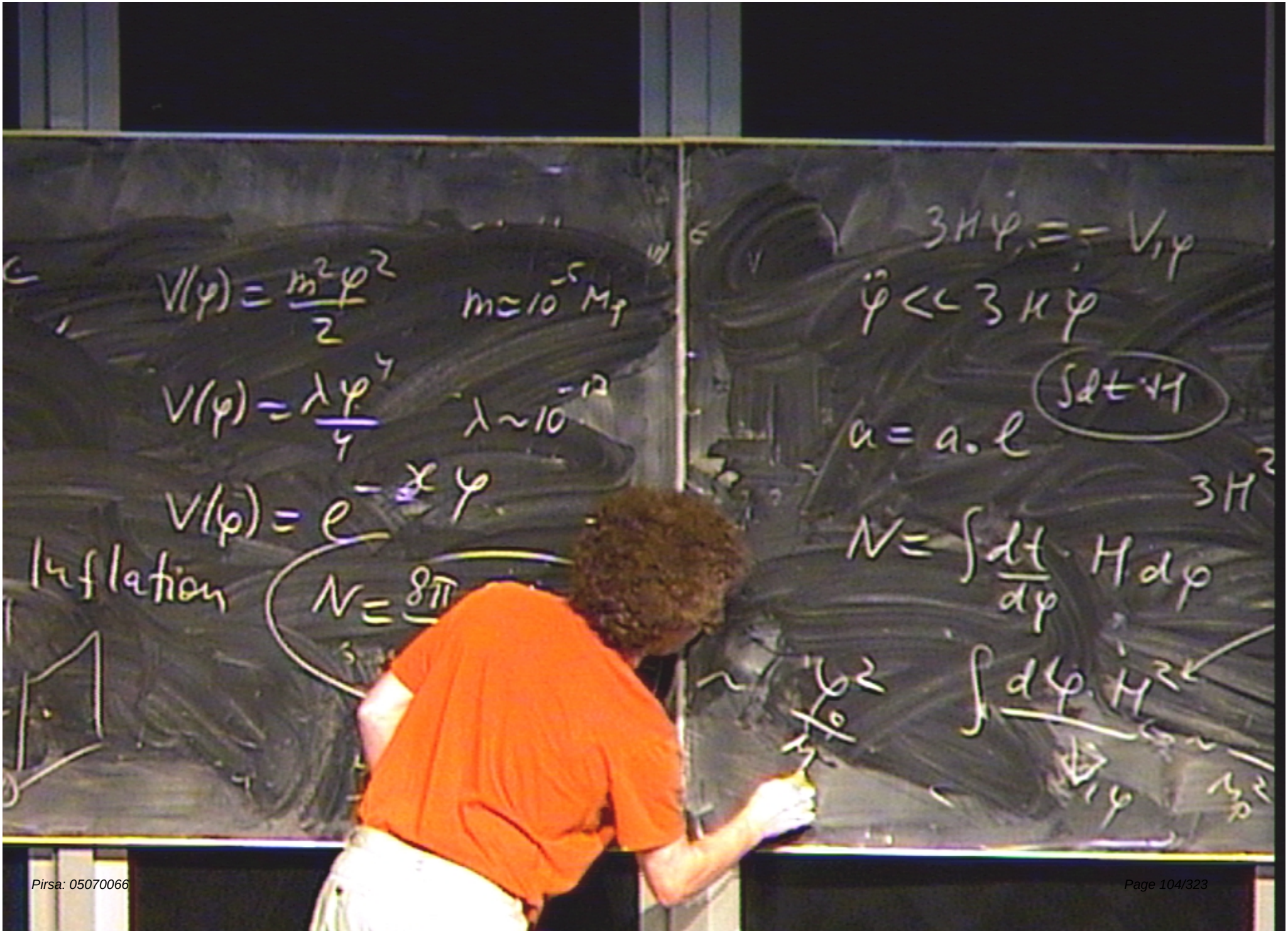
$\frac{dH}{dt} = -\frac{1}{2}\dot{\varphi}^2 + \frac{1}{3}$

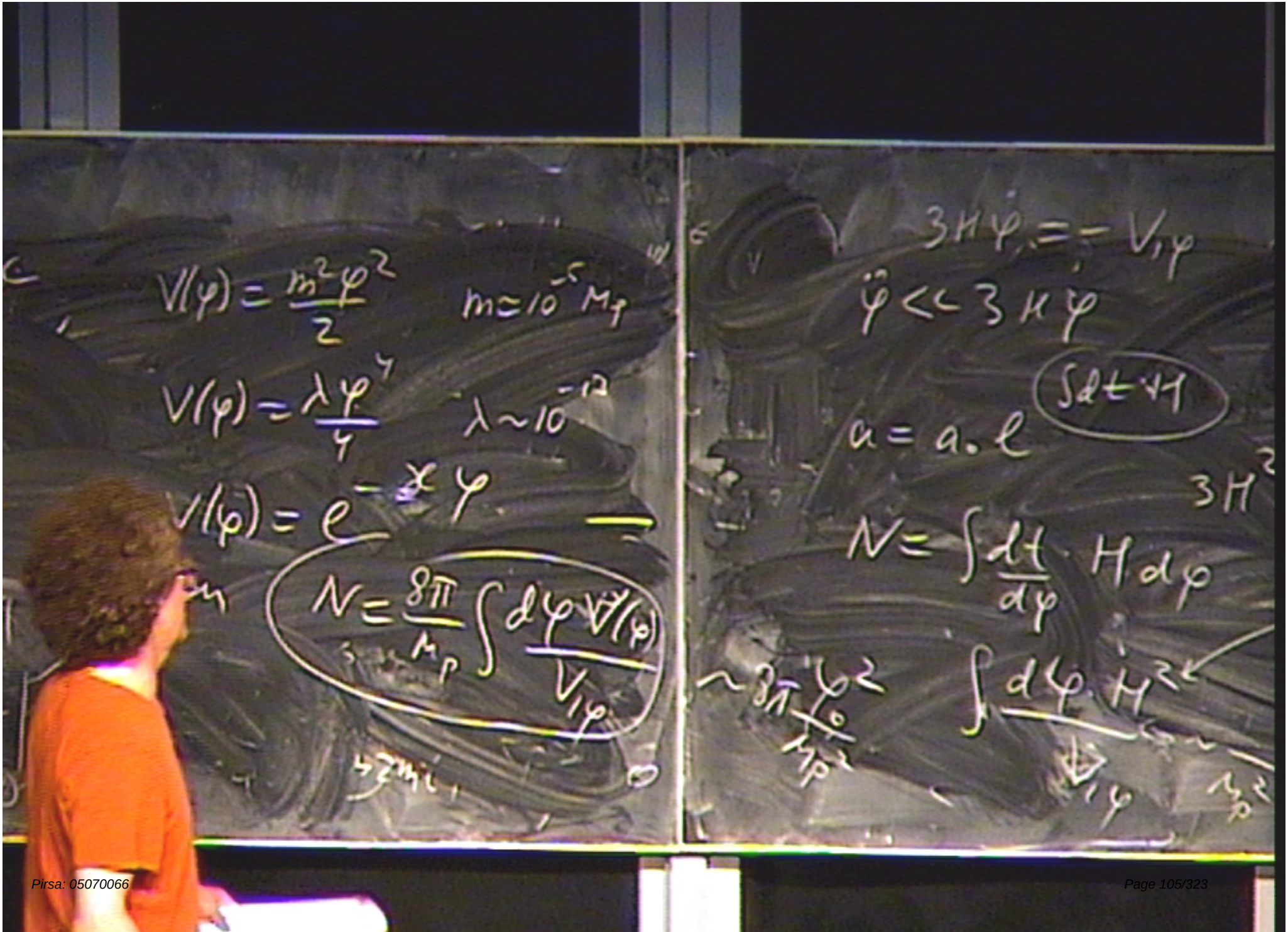
$3H^2 - \frac{4\pi}{m_p^2}\dot{\varphi}^2 - 0$

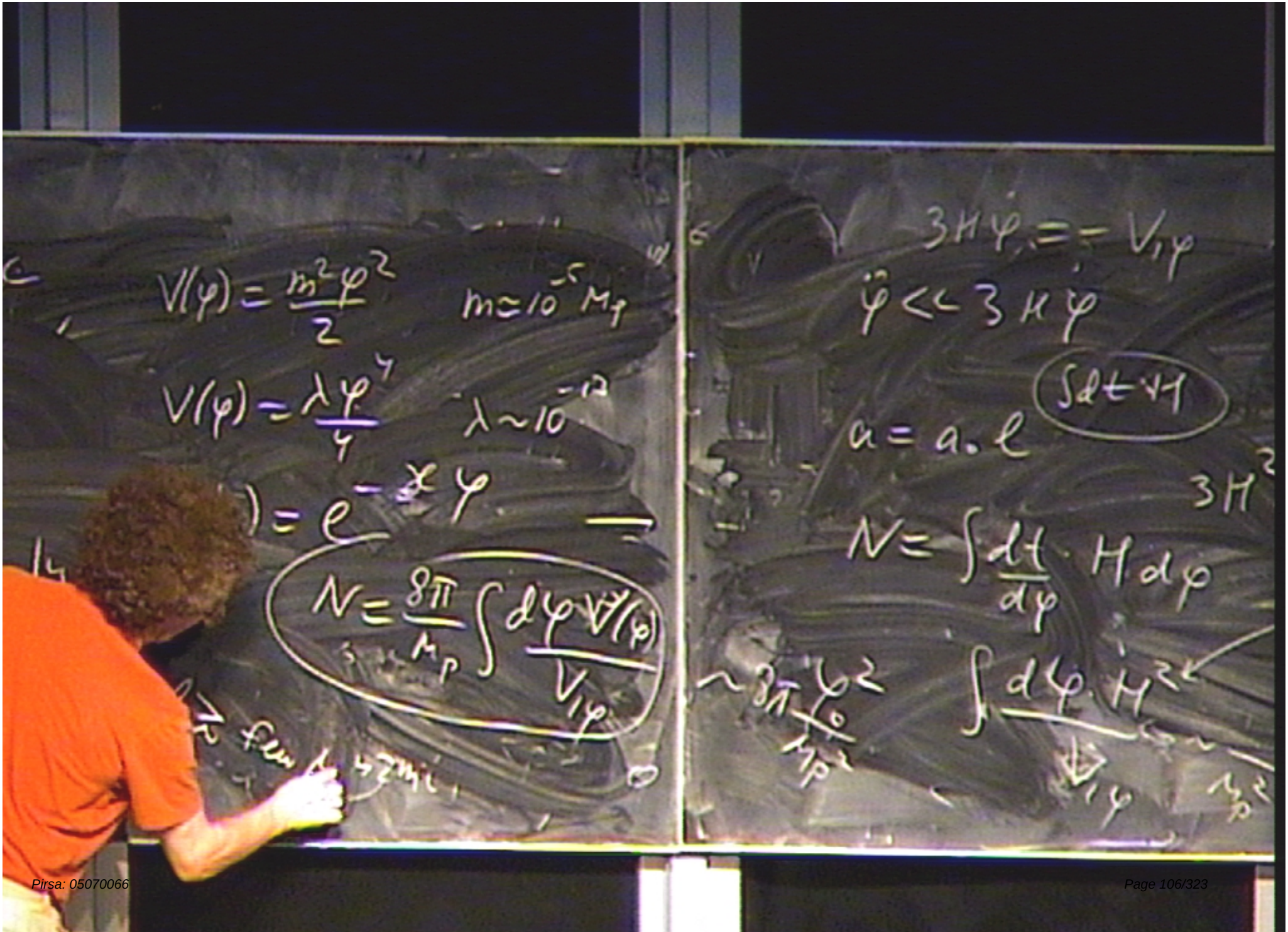

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$\lambda \sim 10^{-12}$
$V(\varphi) = e^{-}$
hybrid inflation
D3
$\int \frac{d\varphi V(\varphi)}{V}$

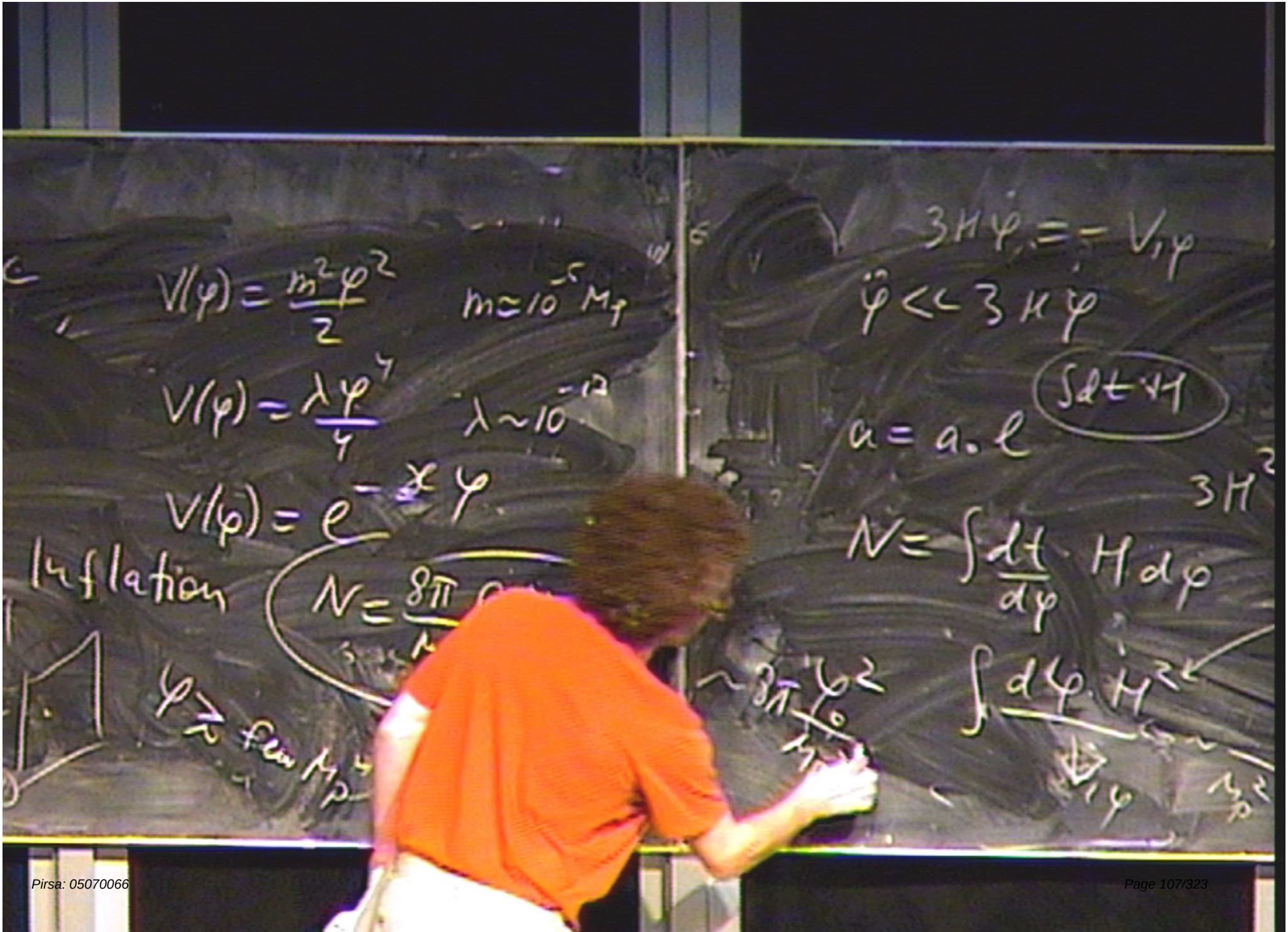

chaotic
$V(\varphi) = \frac{m^2\varphi^2}{2}$
$m \simeq 10^{-5} M_p$
$V(\varphi) = \frac{\lambda\varphi^4}{4}$
$\lambda \sim 10^{-12}$
$V(\varphi) = e^{-\alpha\varphi}$
inflation
$N = \frac{8\pi}{M_p} \int d\varphi \frac{V(\varphi)}{V'(\varphi)}$


chaotic
$V(\varphi) = \frac{m^2\varphi^2}{2}$
$m \simeq 10^{-5} M_p$
$V(\varphi) = \frac{\lambda\varphi^4}{4}$
$\lambda \sim 10^{-12}$
$= e^{-\alpha\varphi}$
hybrid
$N = \frac{8\pi}{M_p^2} \int d\varphi \frac{V(\varphi)}{V'(\varphi)}$


$V(\varphi) = \frac{m^2\varphi^2}{2}$
$m \simeq 10^{-5} M_P$
$V(\varphi) = \frac{\lambda\varphi^4}{4}$
$\lambda \sim 10^{-12}$
$V(\varphi) = e^{-\alpha\varphi}$
Inflation
$N = \frac{8\pi}{5}$
$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{\int dt \cdot H}$
$3H^2$
$N = \int \frac{dt}{d\varphi} \cdot H\, d\varphi$
$\sim \frac{\varphi^2}{4}$
$\int d\varphi \cdot H^2$
$V_{,\varphi}$
M_P^2


$V(\varphi) = \frac{m^2\varphi^2}{2}$
$m \simeq 10^{-5} M_P$
$V(\varphi) = \frac{\lambda\varphi^4}{4}$
$\lambda \sim 10^{-12}$
$V(\varphi) = e^{-\alpha\varphi}$
$N = \frac{8\pi}{M_P^3} \int d\varphi \frac{V(\varphi)}{V_{,\varphi}}$
$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{\int dt\, H}$
$3H^2$
$N = \int \frac{dt}{d\varphi} H\, d\varphi$
$\sim 3\pi \frac{\varphi^2}{M_P^2}$
$\int \frac{d\varphi \cdot H^2}{V_{,\varphi}}$
$\sim M_P^2$


$V(\varphi) = \frac{m^2\varphi^2}{2}$
$m \simeq 10^{-5} M_P$
$V(\varphi) = \frac{\lambda\varphi^4}{4}$
$\lambda \sim 10^{-12}$
$= e^{-\alpha\varphi}$
$N = \frac{8\pi}{M_P} \int d\varphi \frac{V(\varphi)}{V_{,\varphi}}$
$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{\int dt\, H}$
$3H^2$
$N = \int \frac{dt}{d\varphi} H d\varphi$
$\sim 3\pi \frac{\varphi^2}{M_P^2}$
$\int \frac{d\varphi \cdot H^2}{V_{,\varphi}}$
M_P^2


$V(\varphi) = \frac{m^2\varphi^2}{2}$
$m \simeq 10^{-5} M_P$
$V(\varphi) = \frac{\lambda\varphi^4}{4}$
$\lambda \sim 10^{-12}$
$V(\varphi) = e^{-\alpha\varphi}$
Inflation
$N = \frac{8\pi}{3}$
$\varphi \gtrsim$ few M_P
$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{Ht}$
$H = \frac{\dot{a}}{a}$
$3H^2$
$N = \int \frac{dt}{d\varphi} H d\varphi$
$\sim 3\pi \frac{\varphi^2}{M_P^2}$
$\int \frac{d\varphi \cdot H^2}{\dot{\varphi}} \sim \frac{\varphi^2}{M_P^2}$

$V(\varphi) = \frac{m^2 \varphi^2}{2}$ $\quad m \simeq 10^{-5} M_P$

$V(\varphi) = \frac{\lambda \varphi^4}{4}$ $\quad \lambda \sim 10^{-12}$

$V(\varphi) = e^{-\alpha \varphi}$

Inflation

$N = \frac{8\pi}{M_P} \int \frac{d\varphi \, V(\varphi)}{V_{,\varphi}}$

$\varphi \gtrsim$ few M_P

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

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

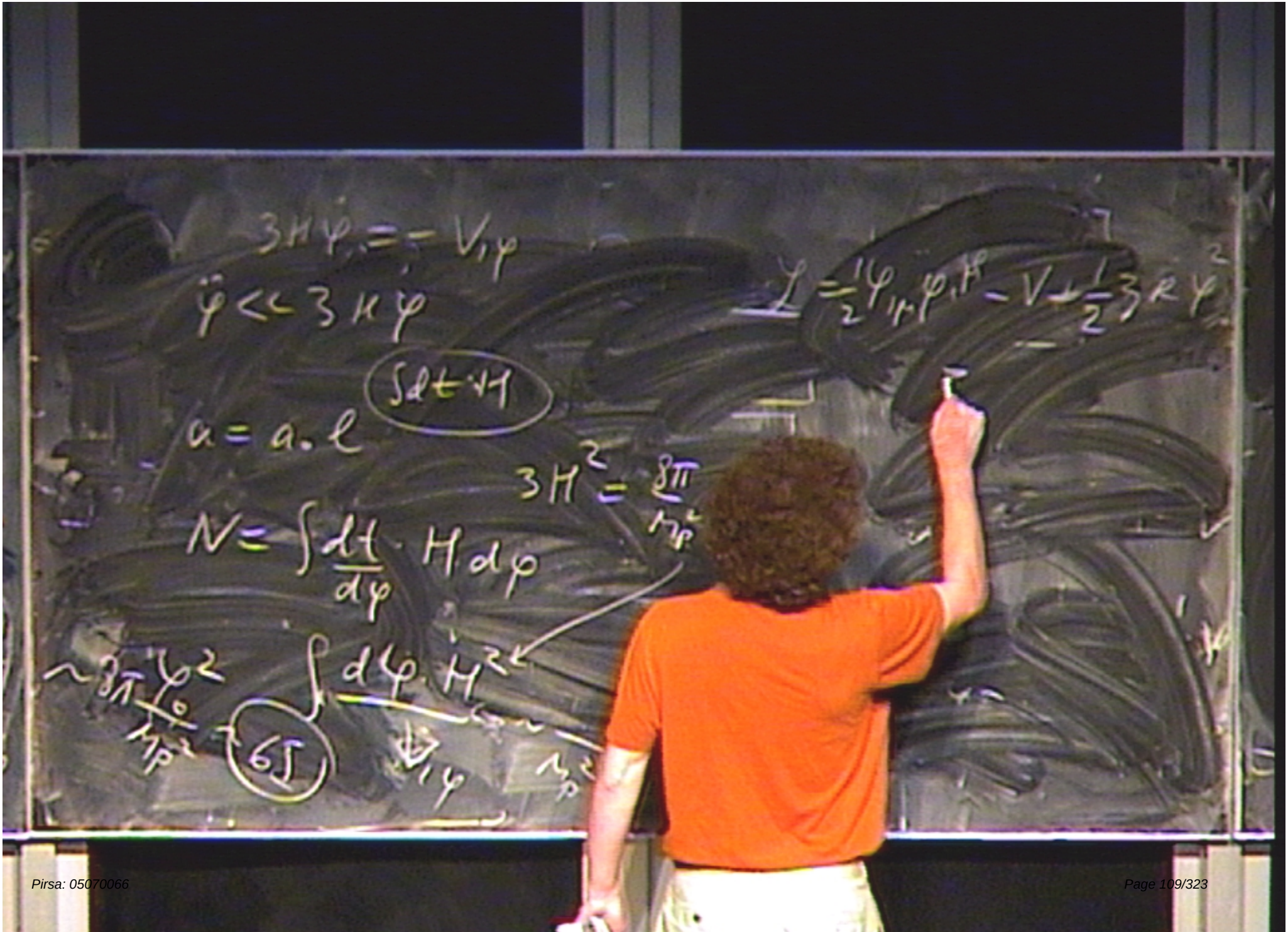
$a = a_0 e^{\int dt \, H}$

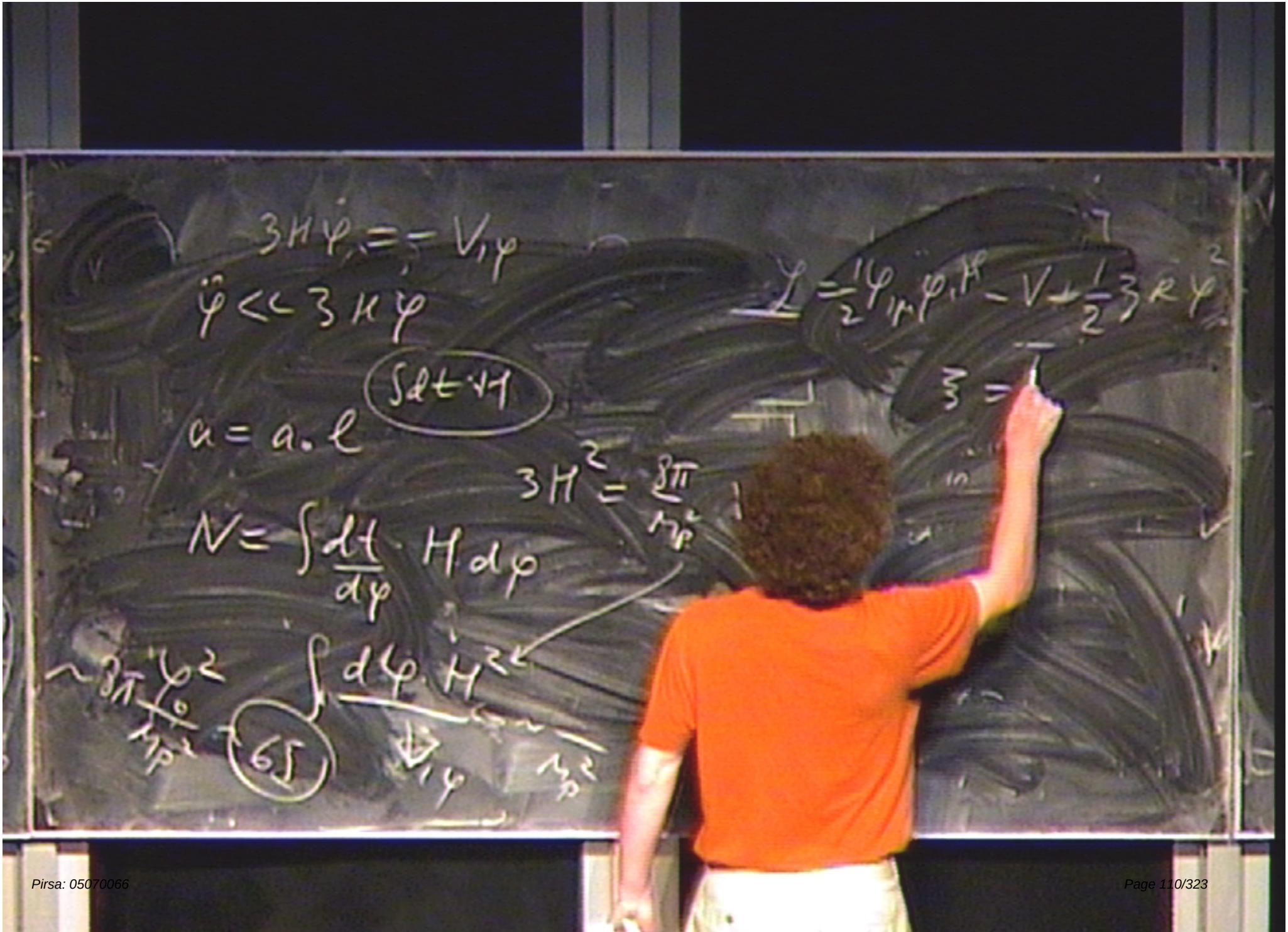
$3H^2$

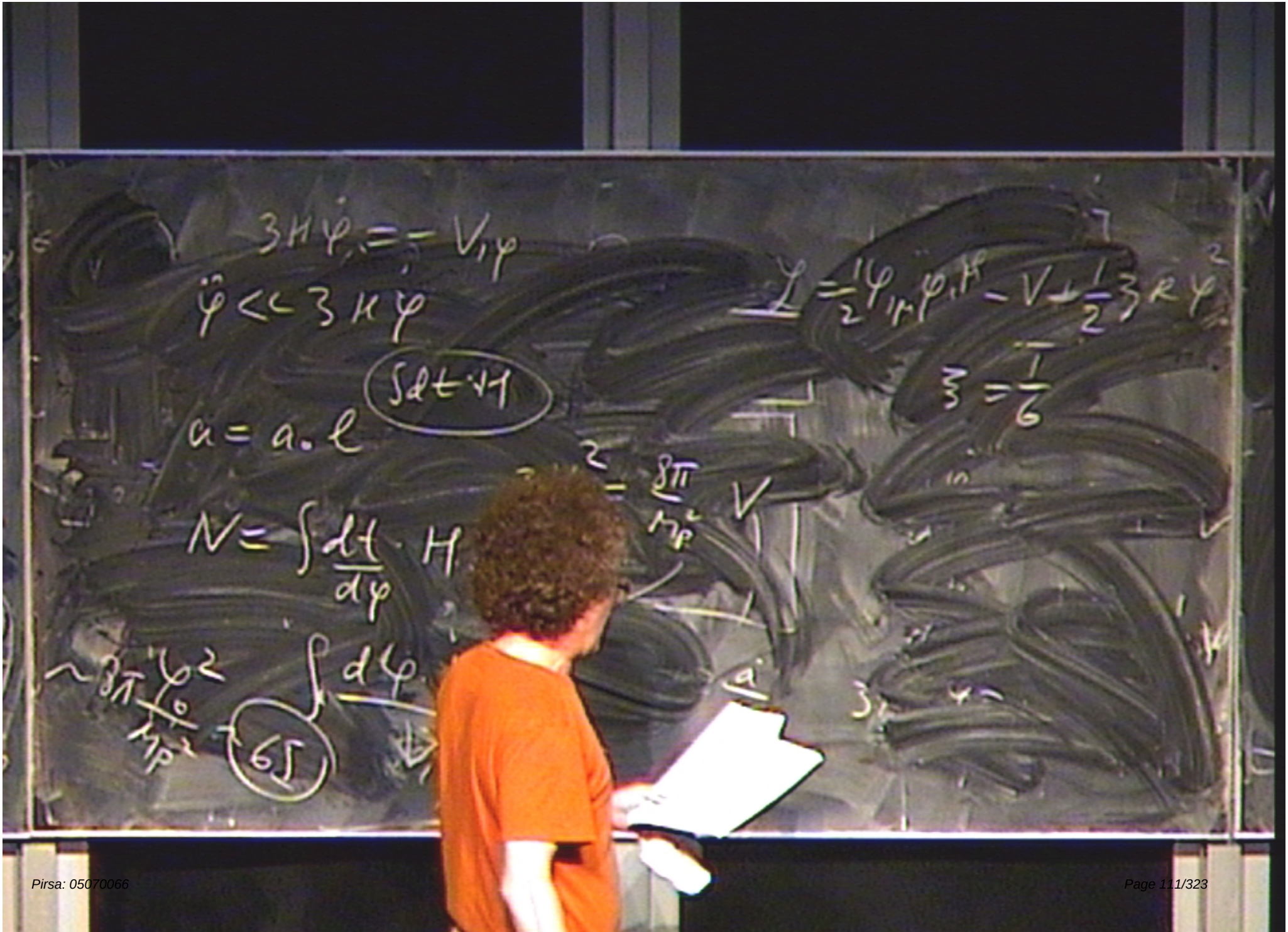
$N = \int \frac{dt}{d\varphi} H \, d\varphi$

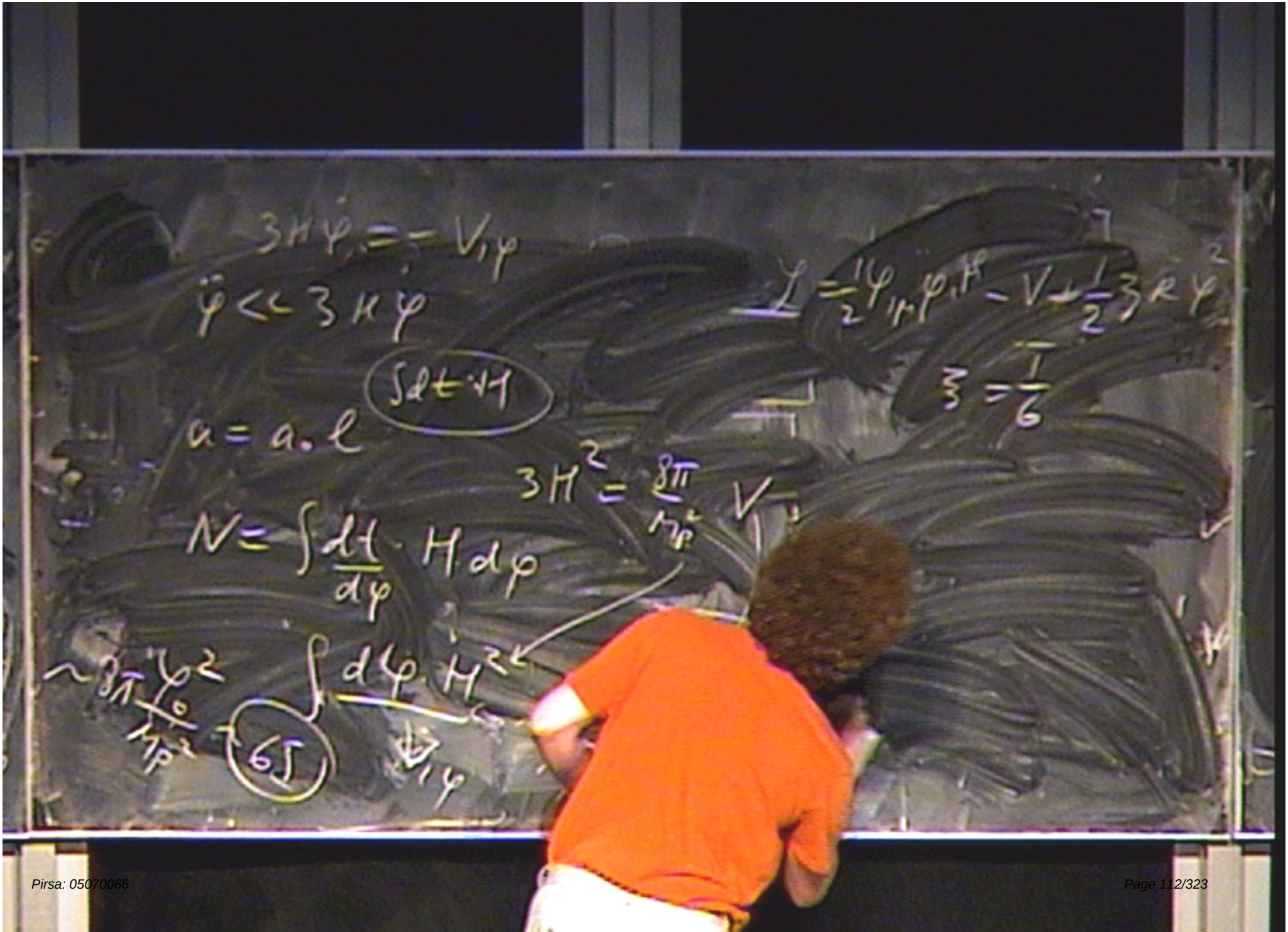
$\sim 3\pi \frac{\varphi^2}{M_P^2}$ (6)

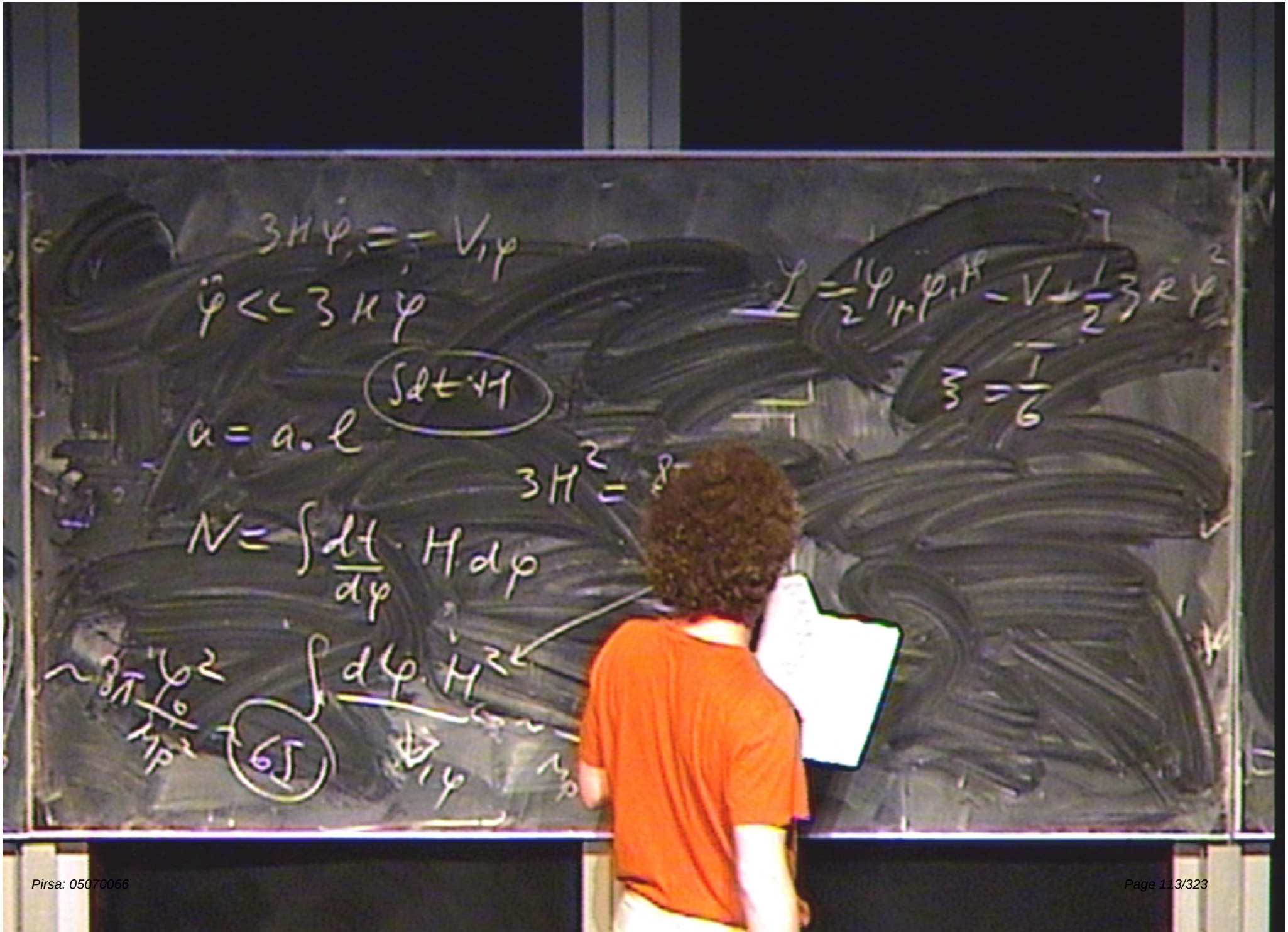
$\int \frac{d\varphi \cdot H^2}{V_{,\varphi}} \sim M_P^2$

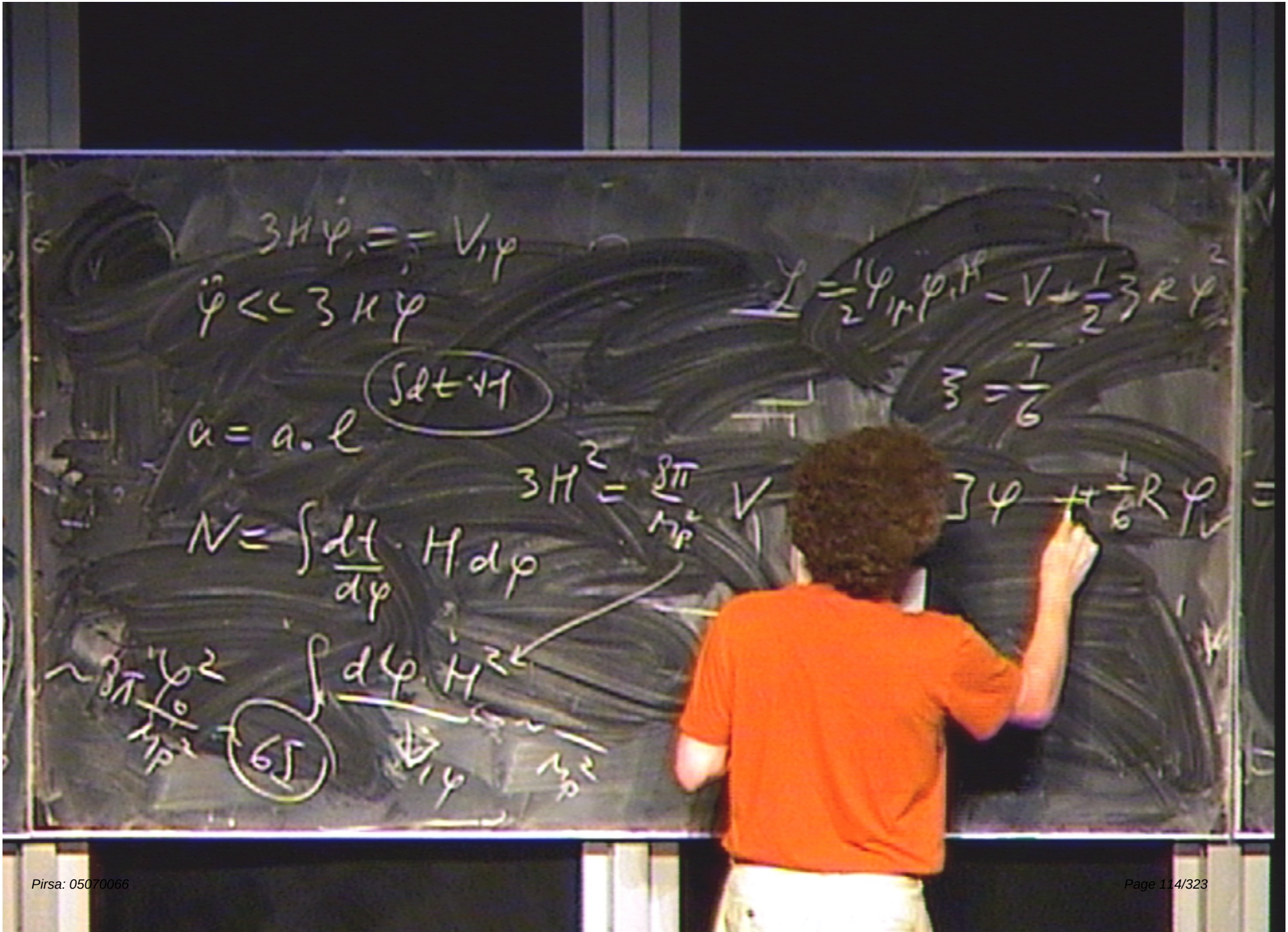

$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{\int dt\, H}$
$N = \int \frac{dt}{d\varphi} H\, d\varphi$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V + \frac{1}{2}\xi R\varphi^2$
$3H^2 = \frac{8\pi}{m_p^2}$
$\int d\varphi \frac{H^2}{V_{,\varphi}} \sim \frac{\varphi^2}{m_p^2}$
65

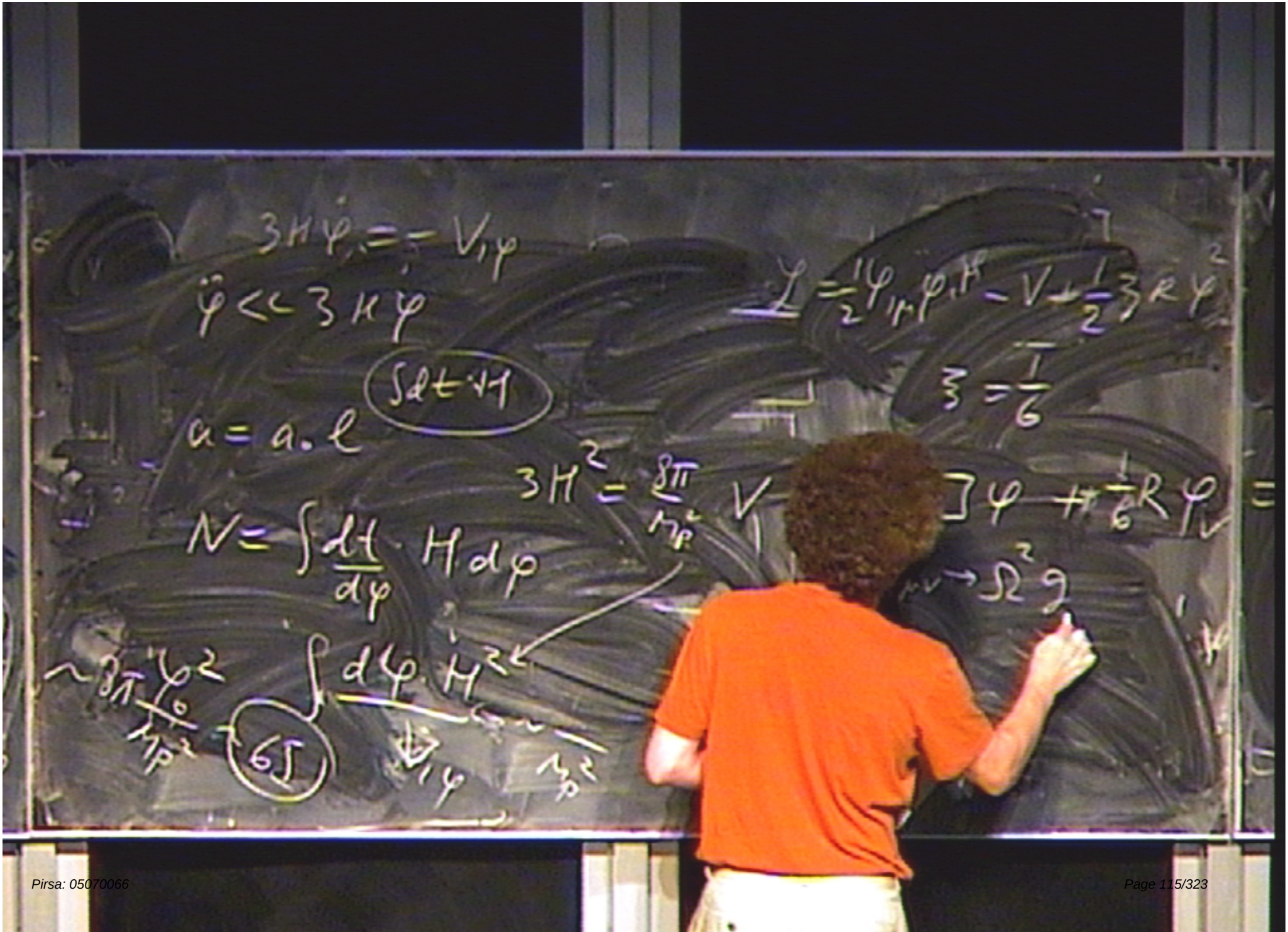

$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
Slow-roll
$a = a_0 e^{Ht}$
$N = \int \frac{dt}{d\varphi} H\, d\varphi$
$3H^2 = \frac{8\pi}{m_p^2}$
$\int d\varphi \frac{H^2}{V_{,\varphi}} \frac{m_p^2}{8\pi}$
65

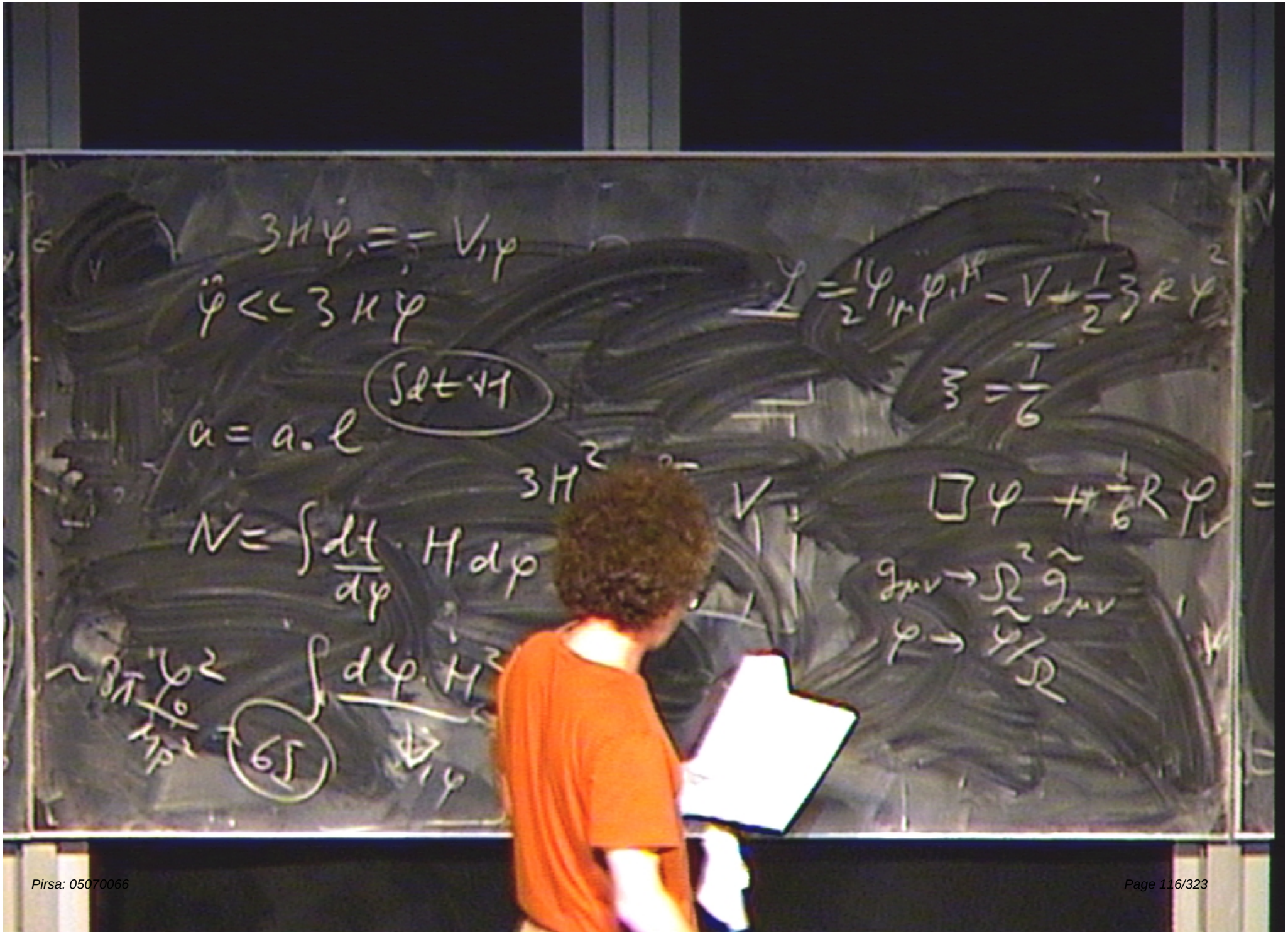

$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{Hdt}$
$N = \int \frac{dt}{d\varphi} H$
$\sim 3\pi \frac{\varphi_0^2}{m_p^2}$
$\int \frac{d\varphi}{}$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V + \frac{1}{2}\xi R\varphi^2$
$\xi = \frac{1}{6}$
$= \frac{8\pi}{m_p^2} V$

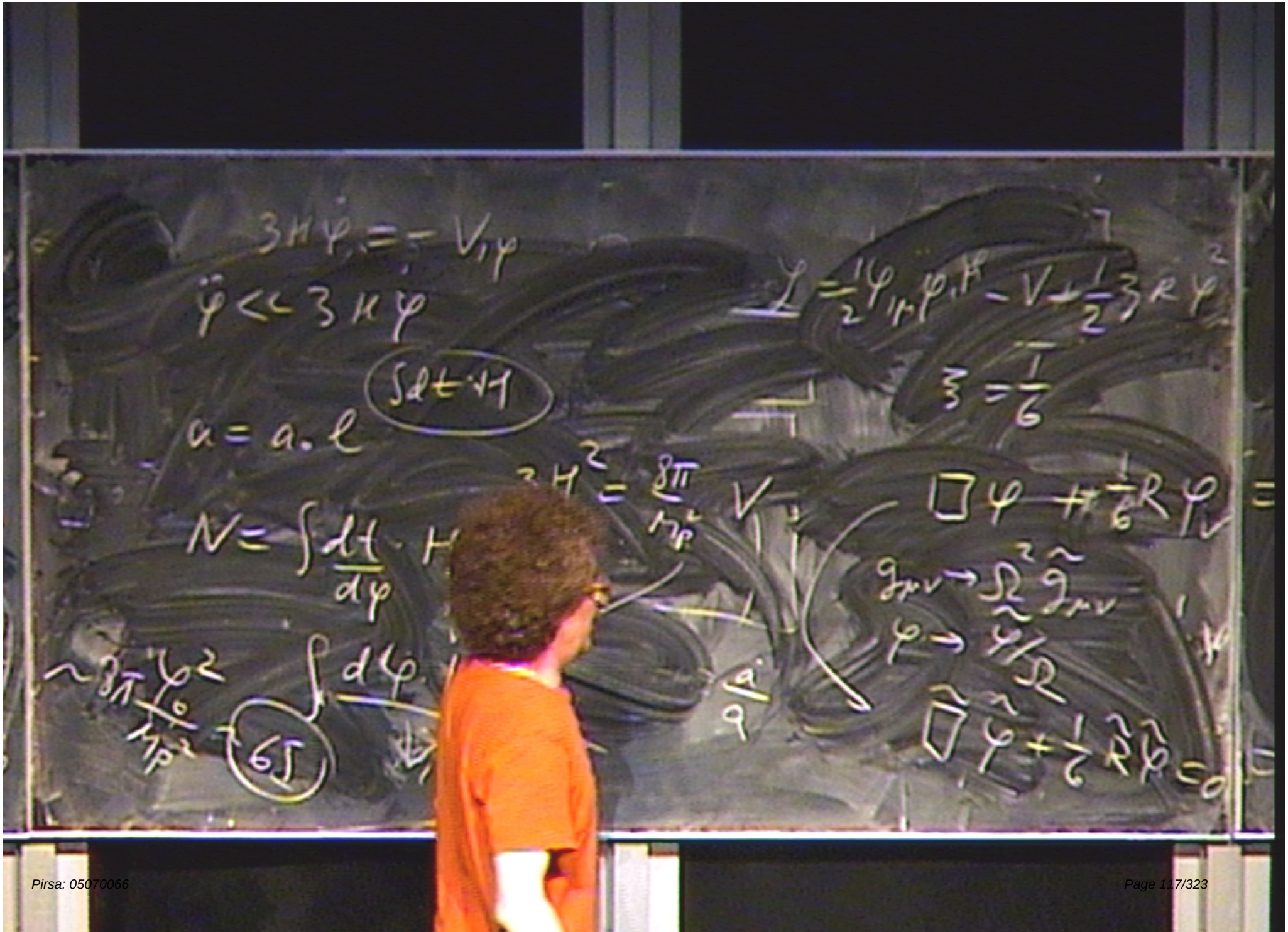

$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{\int dt\, H}$
$N = \int \frac{dt}{d\varphi} H\, d\varphi$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V + \frac{1}{2}\xi R\varphi^2$
$\xi = \frac{1}{6}$
$3H^2 = \frac{8\pi}{m_p^2} V$
$\sim 8\pi \frac{\varphi_0^2}{m_p^2}$
$\int d\varphi \frac{H^2}{V_{,\varphi}}$
60

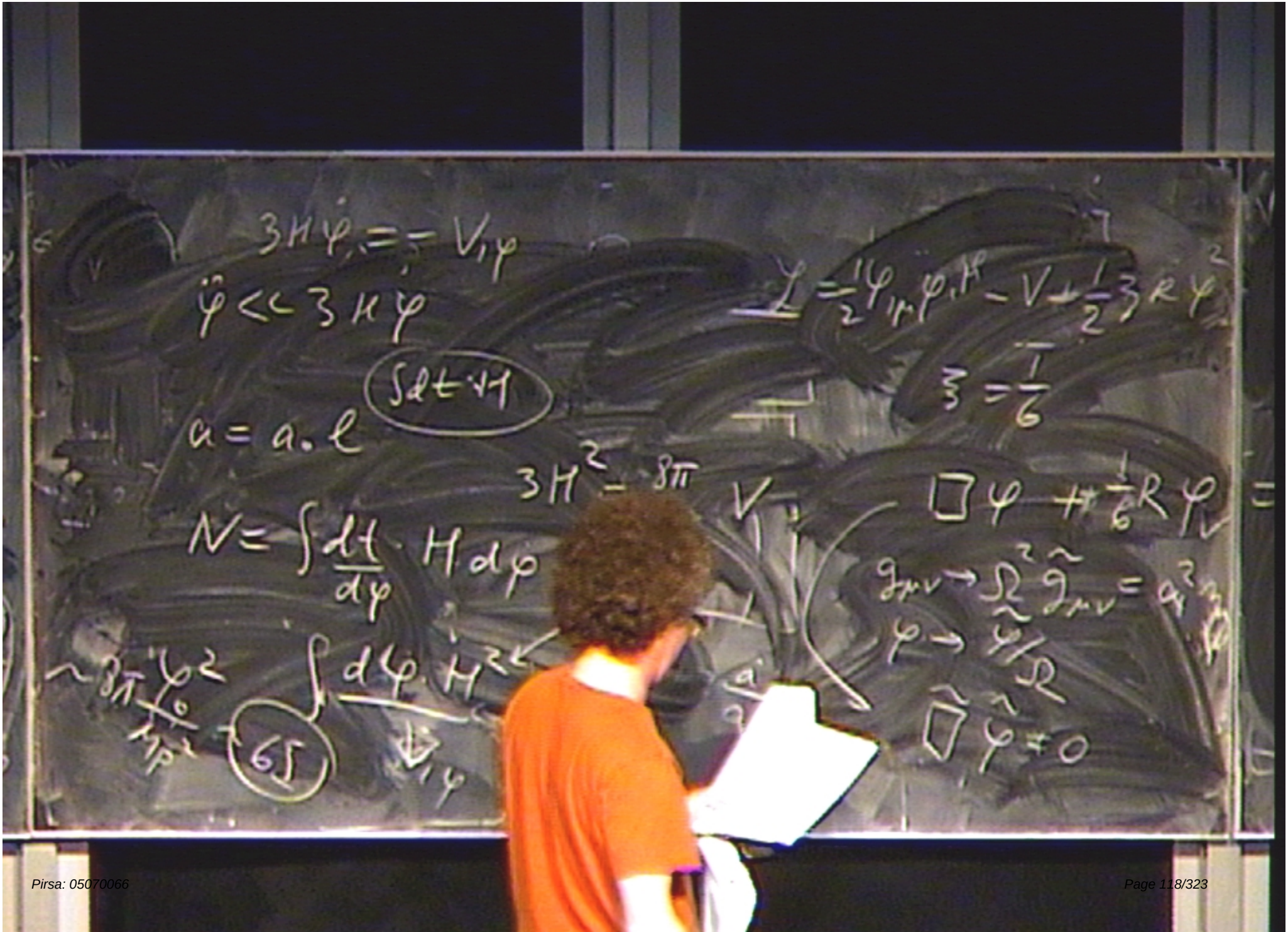

$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{\int dt\, H}$
$N = \int \frac{dt}{d\varphi} H\, d\varphi$
$\int d\varphi \frac{H^2}{V_{,\varphi}}$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V + \frac{1}{2}\xi R\varphi^2$
$\xi = \frac{1}{6}$
$3H^2 =$
$\sim 3\pi \frac{\varphi_0^2}{m_p^2}$
60

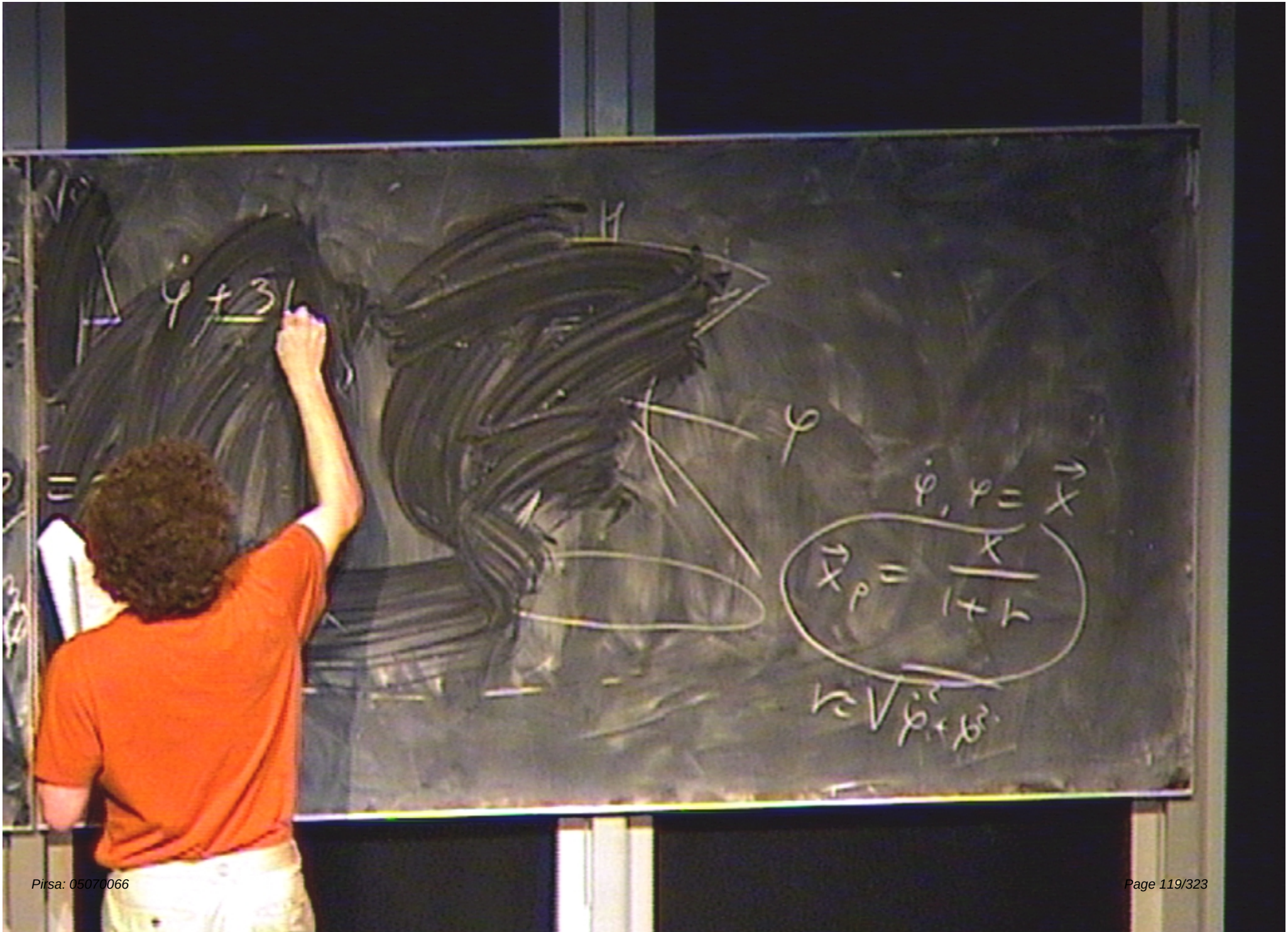

$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{\int dt\, H}$
$N = \int \frac{dt}{d\varphi} \cdot H\, d\varphi$
$\sim 3\pi \frac{\varphi_0^2}{m_p^2}$
$\int d\varphi \frac{H^2}{V_{,\varphi}} \sim m_p^2$
$3H^2 = \frac{8\pi}{m_p^2} V$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V + \frac{1}{2}\xi R\varphi^2$
$\xi = \frac{1}{6}$
$\Box\varphi + \frac{1}{6}R\varphi =$

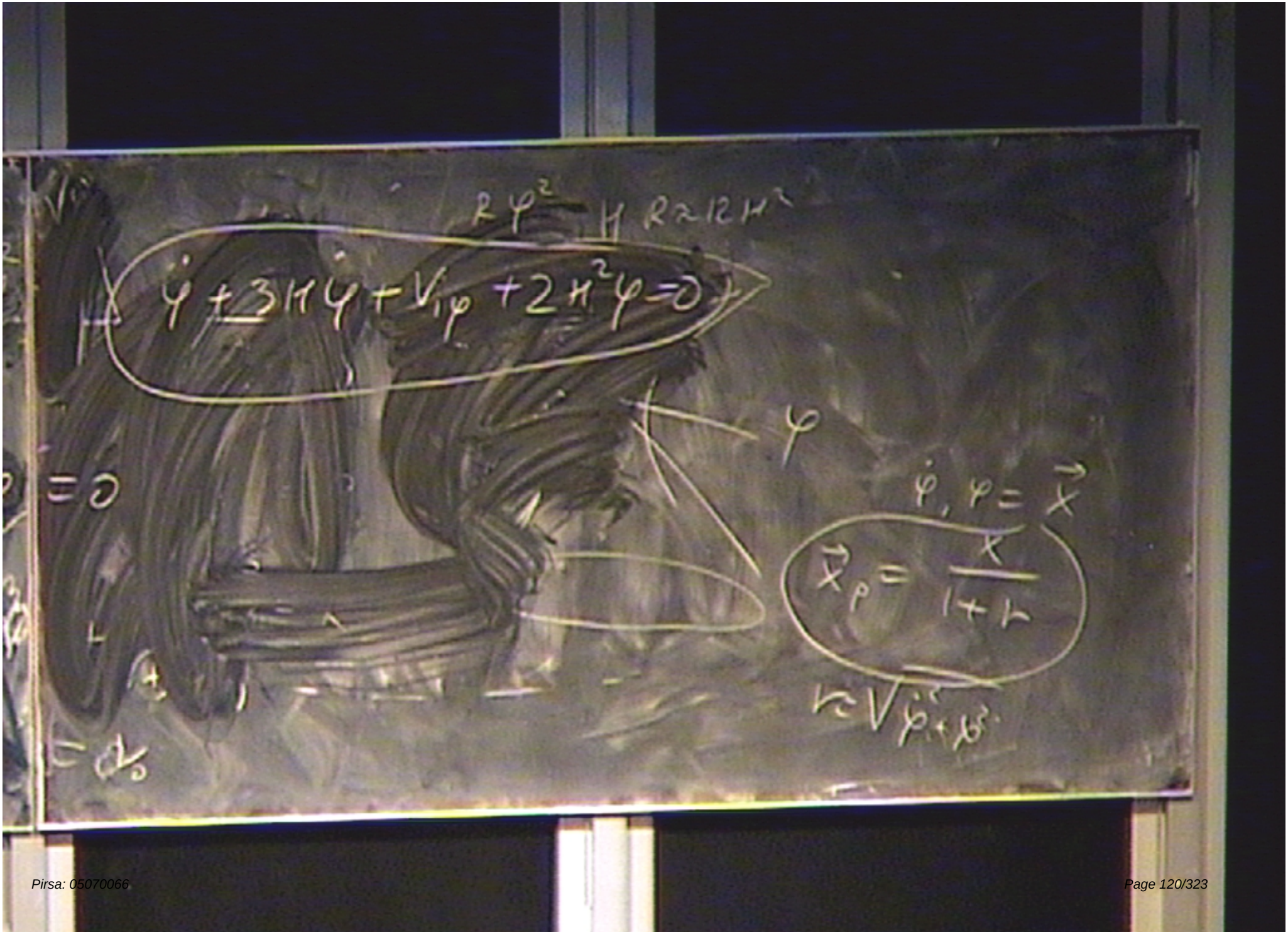

3Hφ̇ = −V,φ
φ̈ << 3Hφ̇
Salt-N
a = a₀ e^{Ht}
N = ∫ (dt/dφ) H dφ
3H² = (8π/m_p²) V
∫ dφ H²/V,φ
(6.5)
~ 8π φ₀²/m_p²
ℒ = ½ φ,μ φ,^μ − V + ½ ξ R φ²
ξ = 1/6
□φ + ⅙ R φ =
g_μν → Ω² g

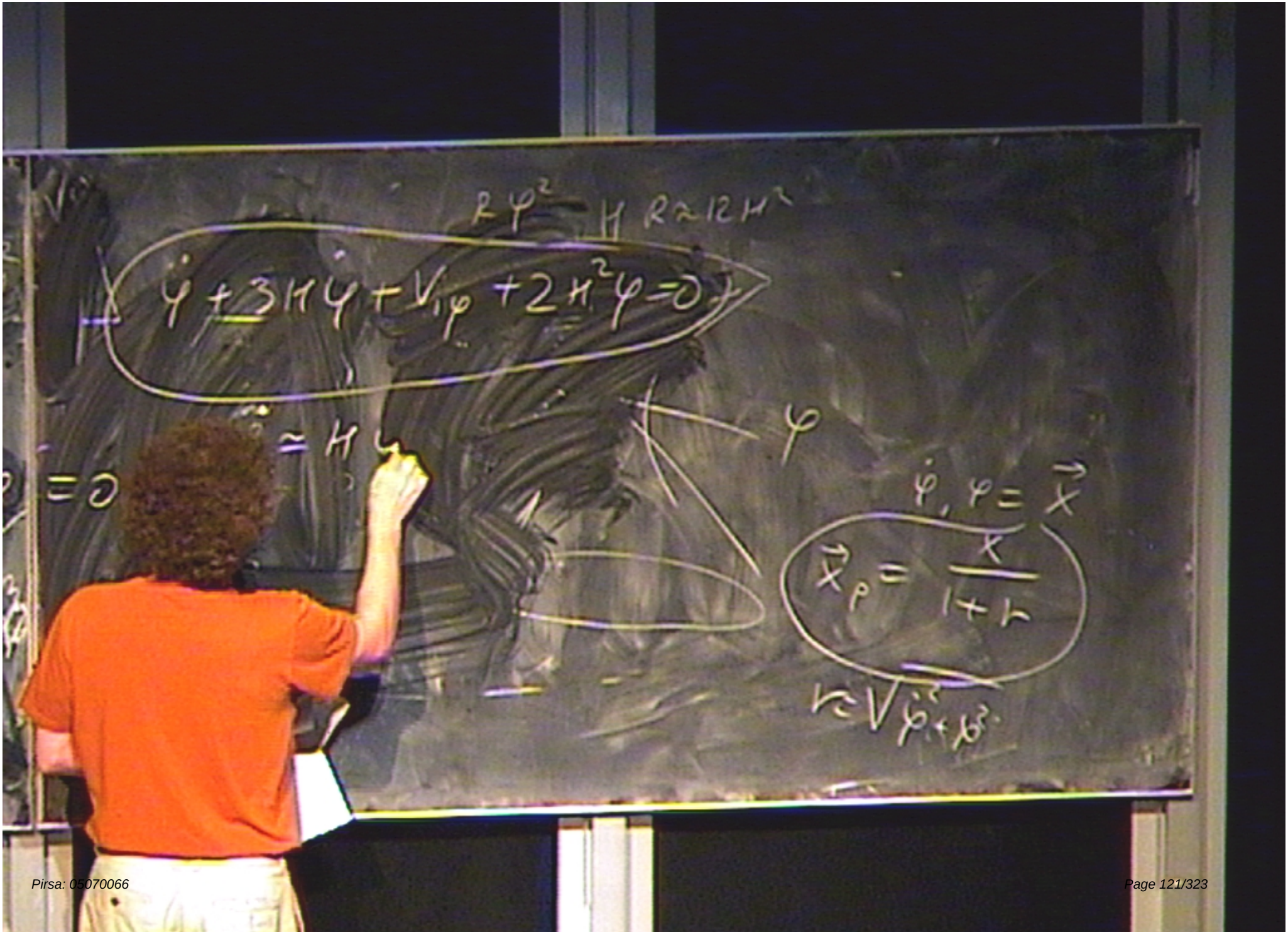

$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{Ht}$
$N = \int \frac{dt}{d\varphi} H d\varphi$
$\sim 3\pi \frac{\varphi_0^2}{M_P^2}$
$\int \frac{d\varphi \, H^2}{V_{,\varphi}}$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V + \frac{1}{2}\xi R \varphi^2$
$\xi = \frac{1}{6}$
$3H^2 = V$
$\Box\varphi + \frac{1}{6}R\varphi =$
$g_{\mu\nu} \to \Omega^2 \tilde{g}_{\mu\nu}$
$\varphi \to \tilde{\varphi}/\Omega$

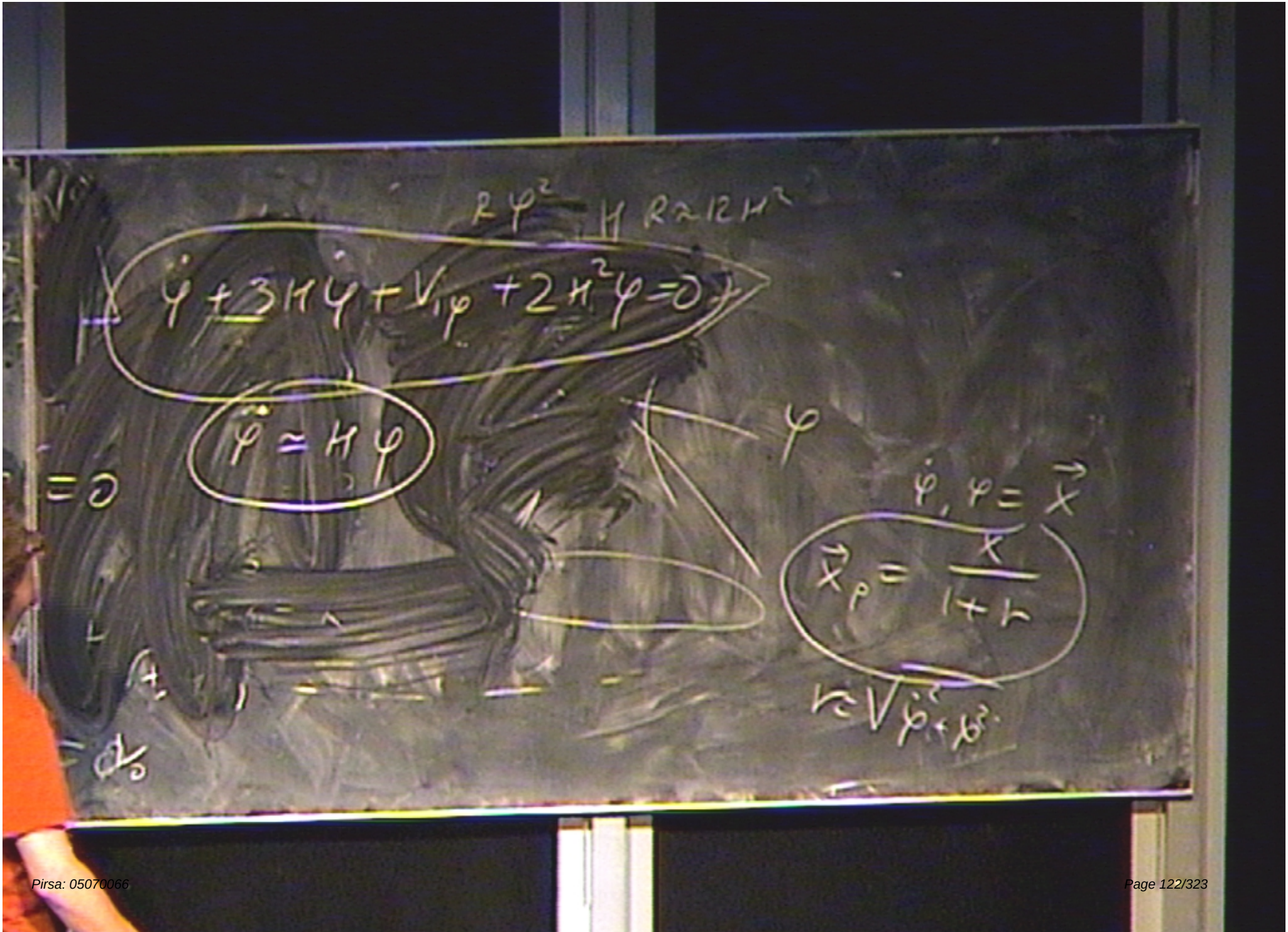

$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{\int dt\, H}$
$N = \int \frac{dt}{d\varphi} \cdot H$
$\sim 8\pi \frac{\varphi_0^2}{m_p^2}$
$\int d\varphi$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V + \frac{1}{2}\xi R\varphi^2$
$\xi = \frac{1}{6}$
$H^2 = \frac{8\pi}{m_p^2} V$
$\Box\varphi + \frac{1}{6}R\varphi =$
$g_{\mu\nu} \to \Omega^2 \tilde{g}_{\mu\nu}$
$\varphi \to \tilde{\varphi}/\Omega$
$\tilde{\Box}\tilde{\varphi} + \frac{1}{6}\tilde{R}\tilde{\varphi} = 0$
$\frac{a'}{a}$

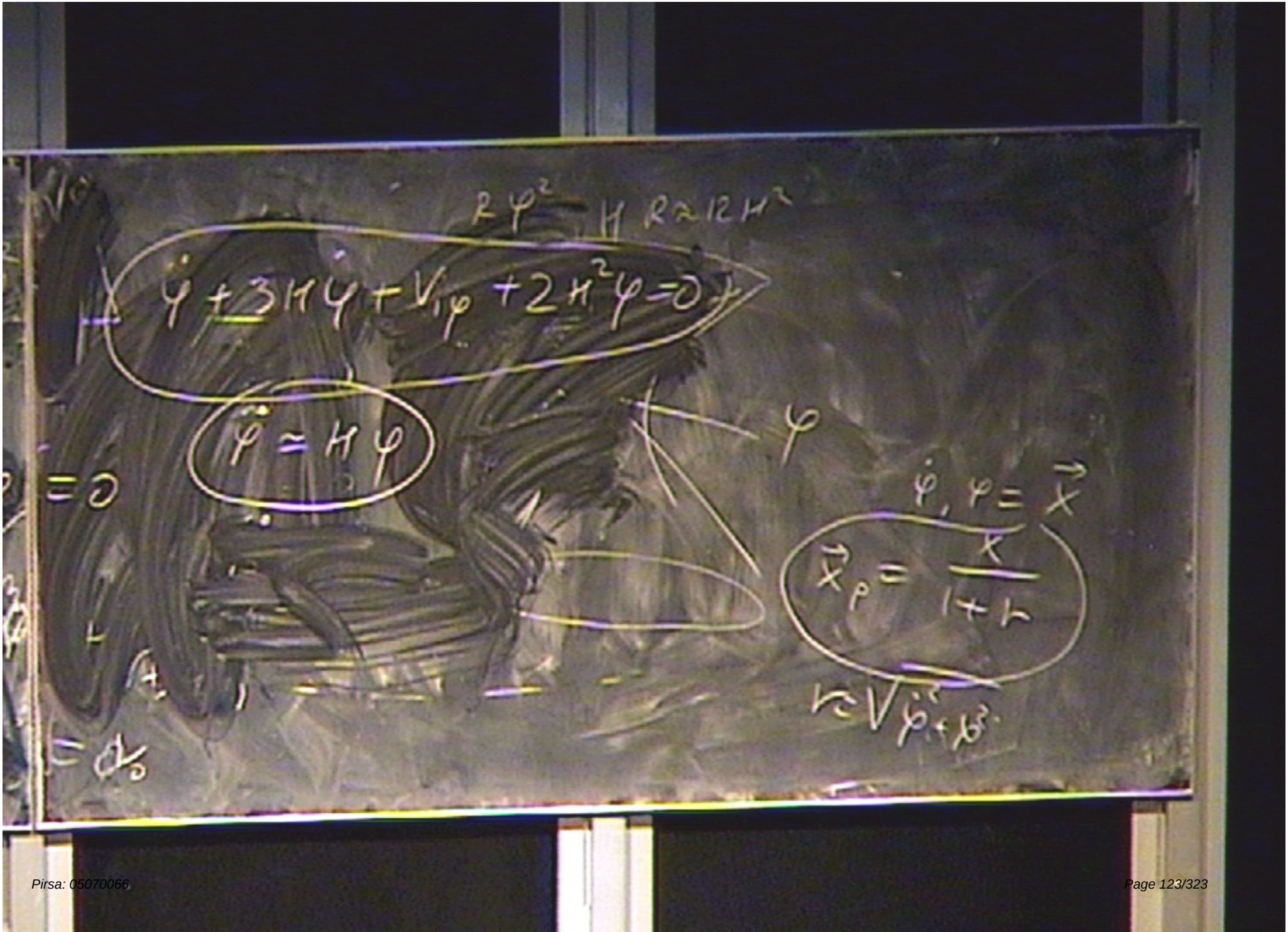

$3H\dot{\varphi} = -V_{,\varphi}$
$\ddot{\varphi} \ll 3H\dot{\varphi}$
$a = a_0 e^{\int dt\, H}$
$N = \int \frac{dt}{d\varphi} H\, d\varphi$
$\sim 3\pi \frac{\varphi^2}{M_P^2}$ (65)
$\int d\varphi \frac{H^2}{V_{,\varphi}}$
$3H^2 = 8\pi V$
$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V + \frac{1}{2}\xi R\varphi^2$
$\xi = \frac{1}{6}$
$\Box\varphi + \frac{1}{6}R\varphi =$
$g_{\mu\nu} \to \Omega^2 \tilde{g}_{\mu\nu} = a^2 \tilde{g}_{\mu\nu}$
$\varphi \to \tilde{\varphi}/\Omega$
$\tilde{\Box}\tilde{\varphi} = 0$

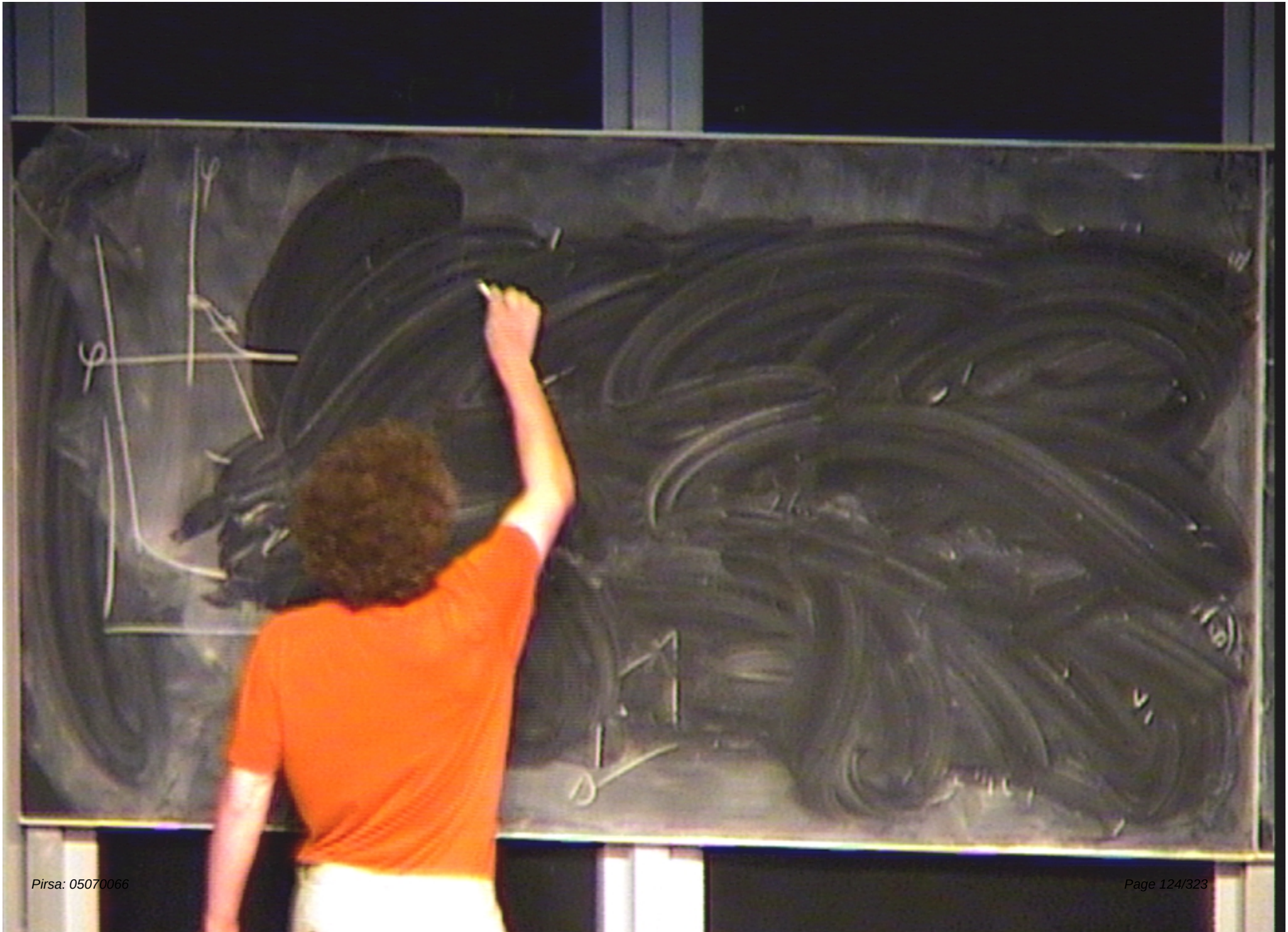

H
φ
φ̇, p = x⃗
x⃗ρ = x / (1+h)
r = √(φ² + ω²)

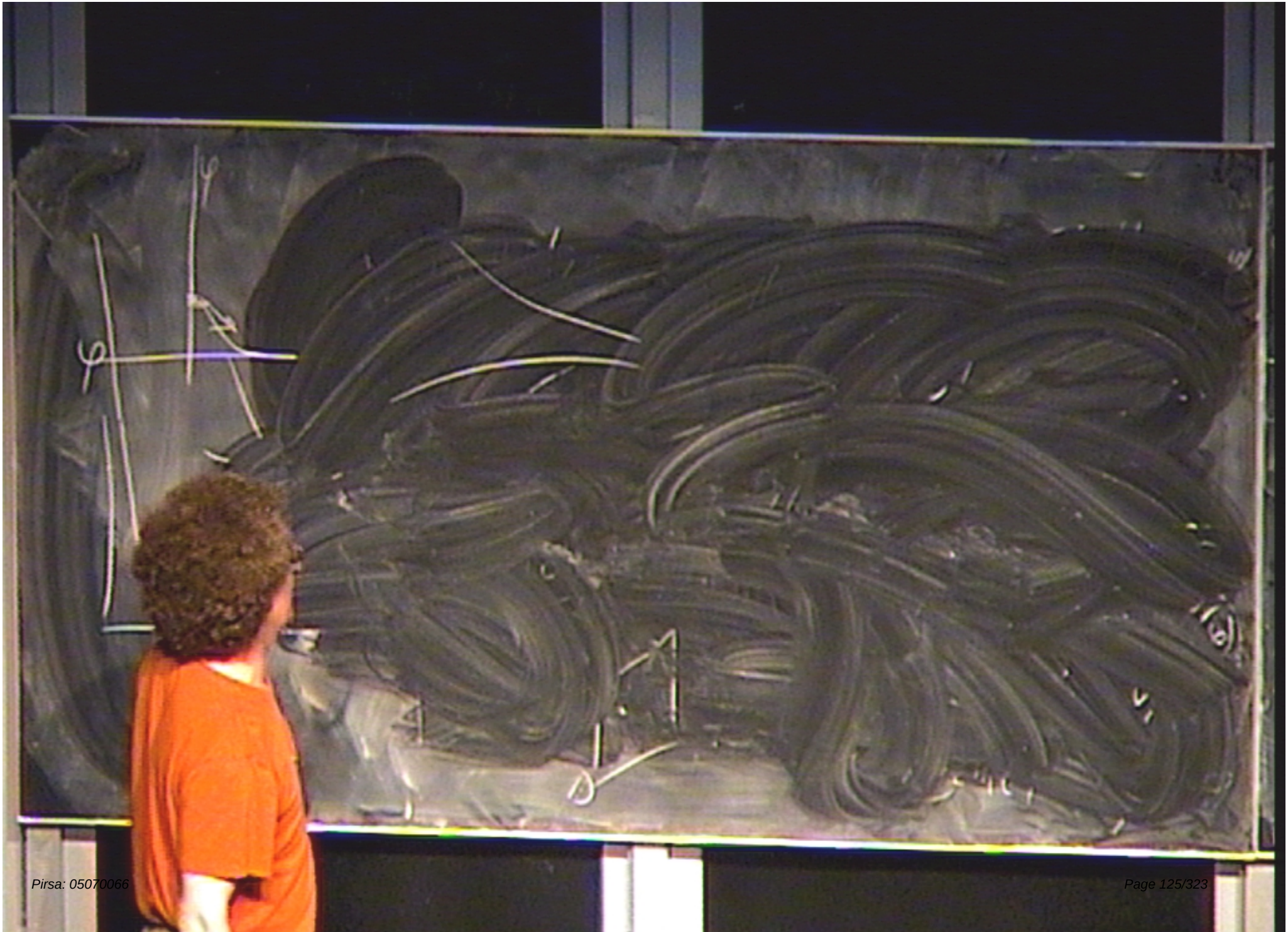

$R\varphi^2$ H $R=12H^2$
$\ddot{\varphi}+3H\dot{\varphi}+V_{,\varphi}+2H^2\varphi=0$
φ
$\dot{\varphi}, \varphi = \vec{x}$
$\vec{x}_p = \frac{\vec{x}}{1+r}$
$=\sqrt{\dot{\varphi}^2+\varphi^2}$

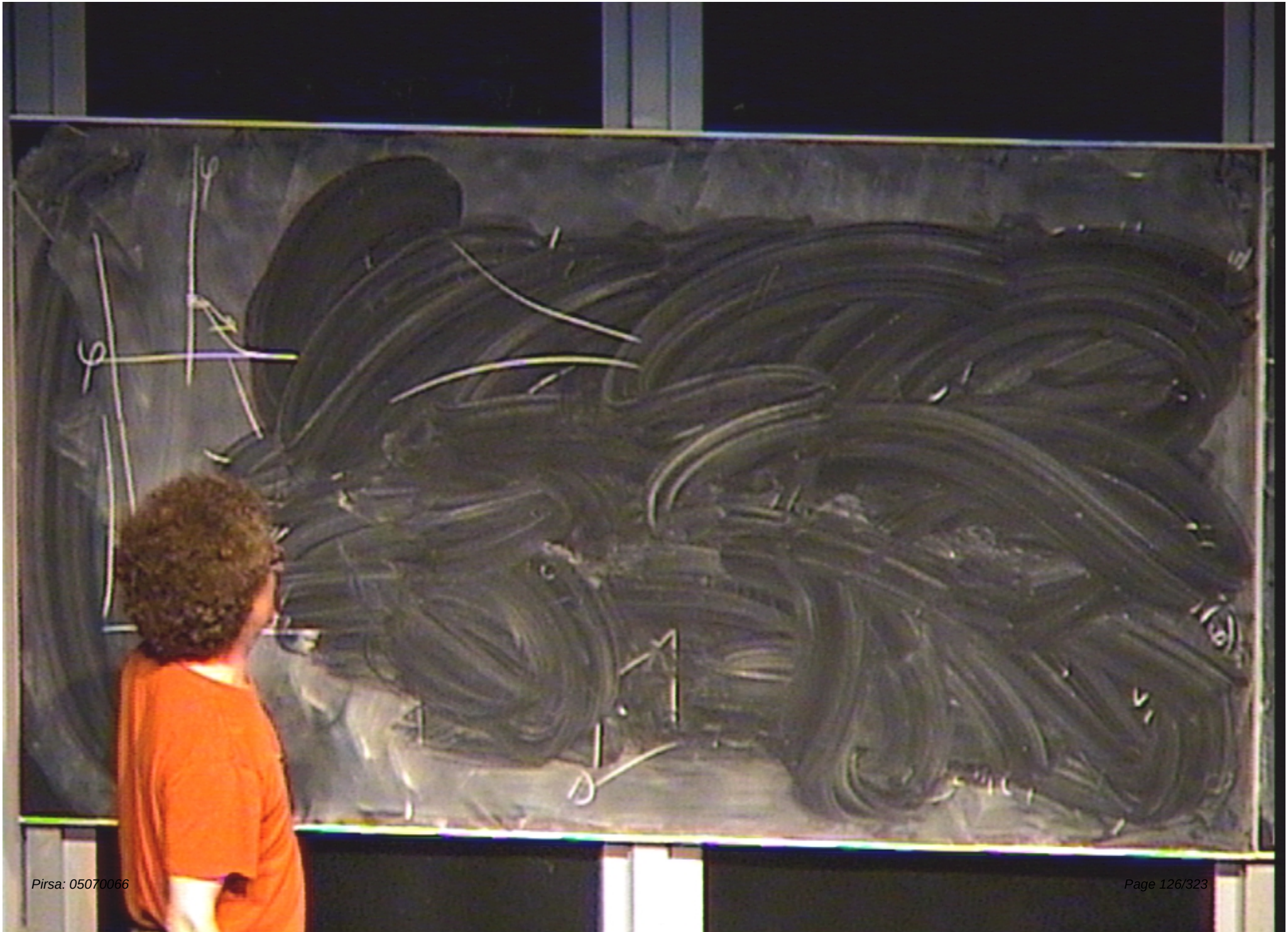

$R\varphi^2$ H $R \simeq 12H^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$= H$
$= 0$
φ
$\dot{\varphi}, \varphi = \vec{x}$
$\vec{x}_\rho = \frac{\vec{x}}{1+h}$
$r = \sqrt{\rho^2 + \beta^2}$

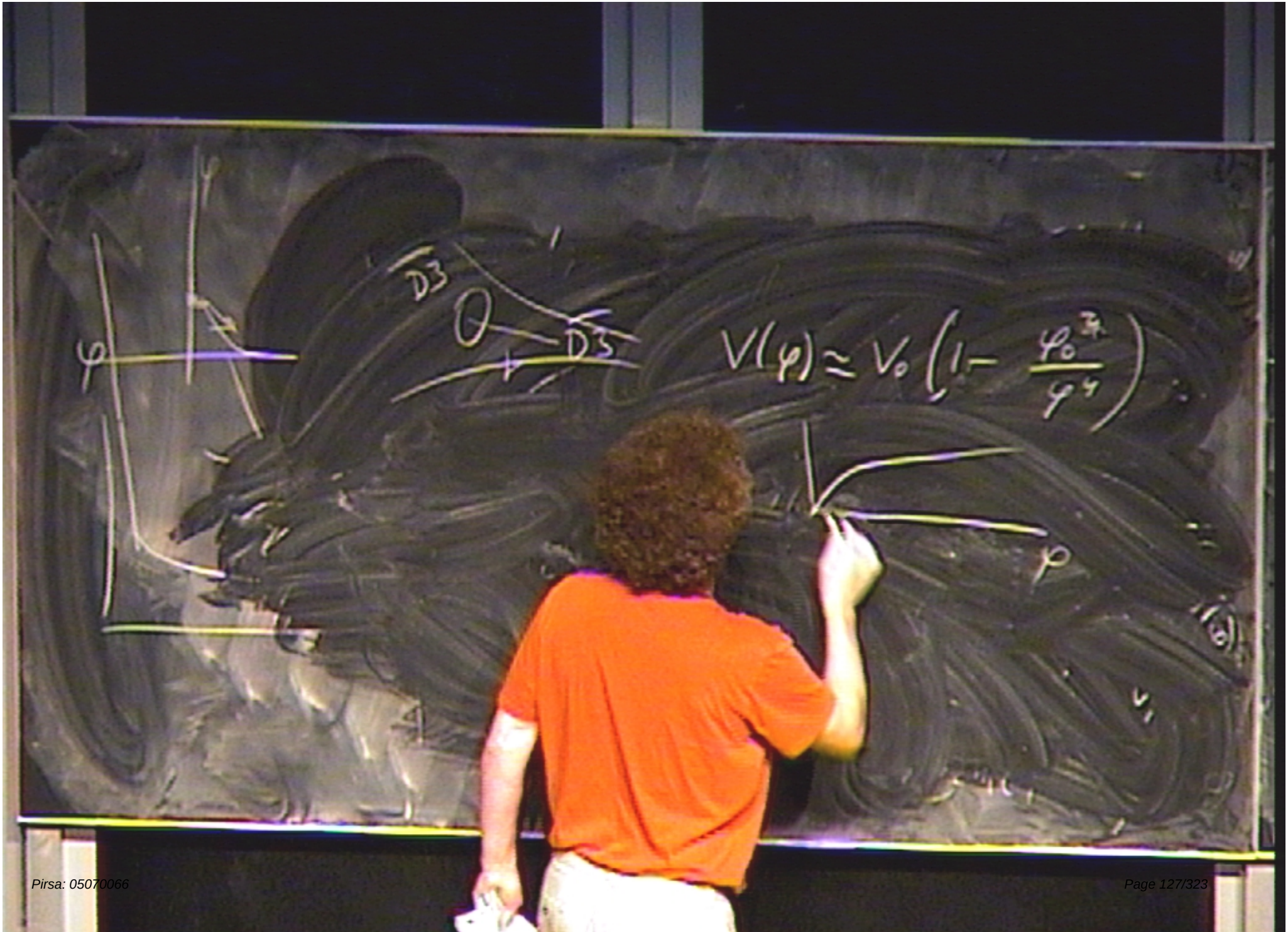

$R\varphi^2$ H $R \simeq 12H^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} \simeq H\dot{\varphi}$
φ
$\dot{\varphi}, \varphi = \vec{x}$
$\vec{x}_\rho = \frac{\vec{x}}{1+h}$
$r = \sqrt{\rho^2 + h^2}$

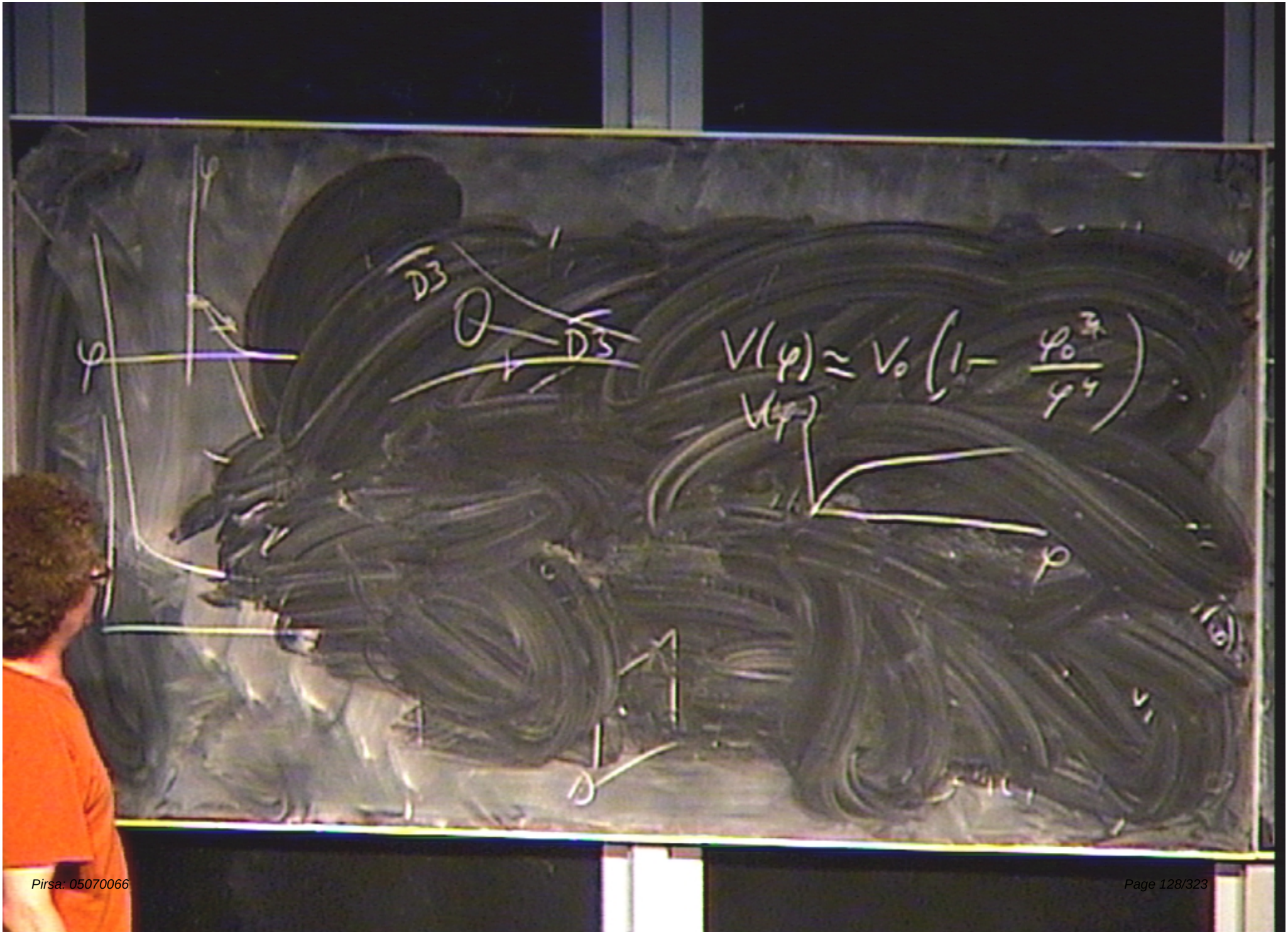

$R\varphi^2$ H $R=12H^2$
$\ddot{\varphi}+3H\dot{\varphi}+V_{,\varphi}+2H^2\varphi=0$
$\ddot{\varphi}=H\dot{\varphi}$
φ
$\dot{\varphi}, \varphi=\vec{x}$
$\vec{x}_\rho=\frac{\vec{x}}{1+h}$
$h=\sqrt{\rho^2+\beta^2}$

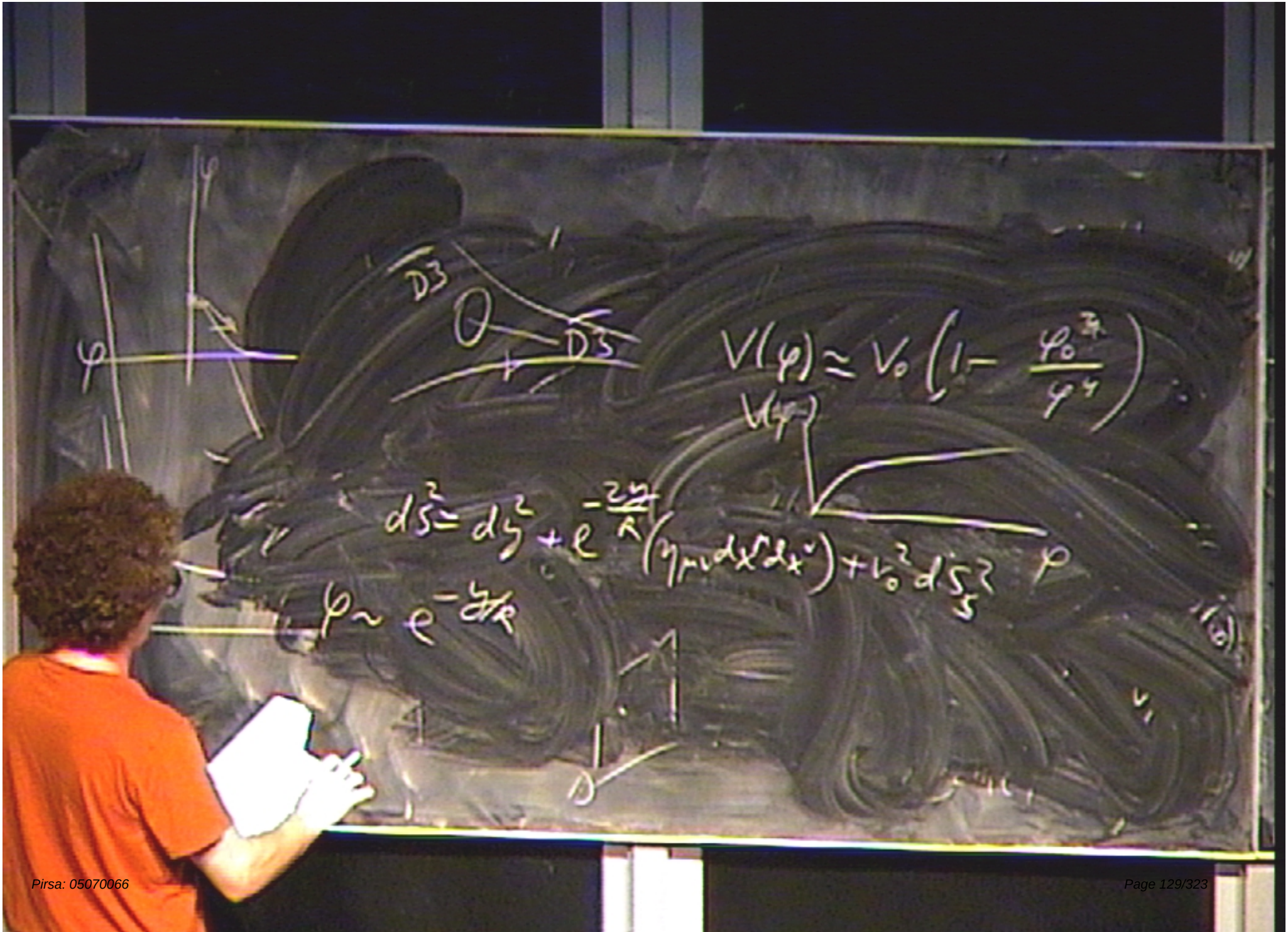


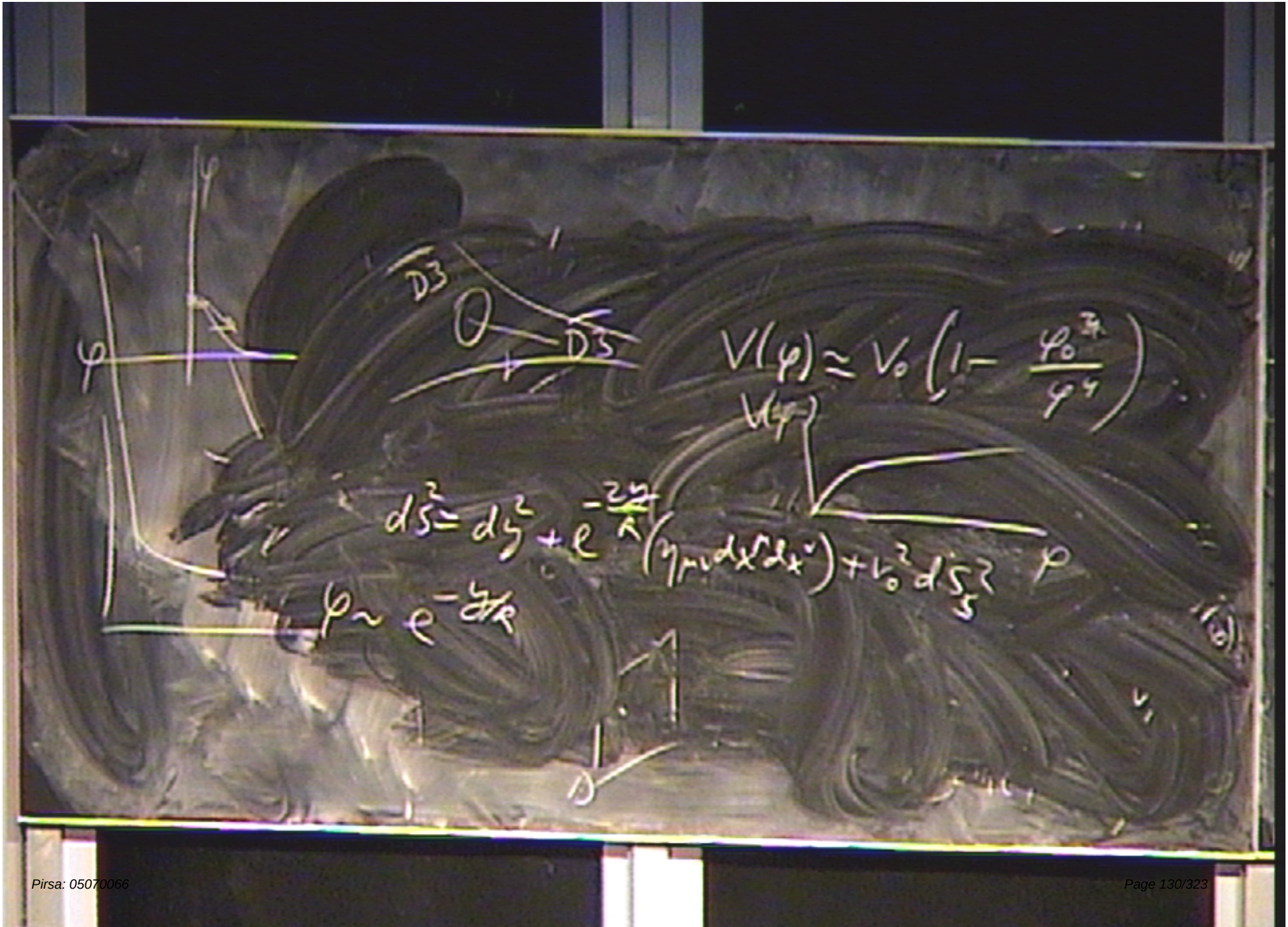


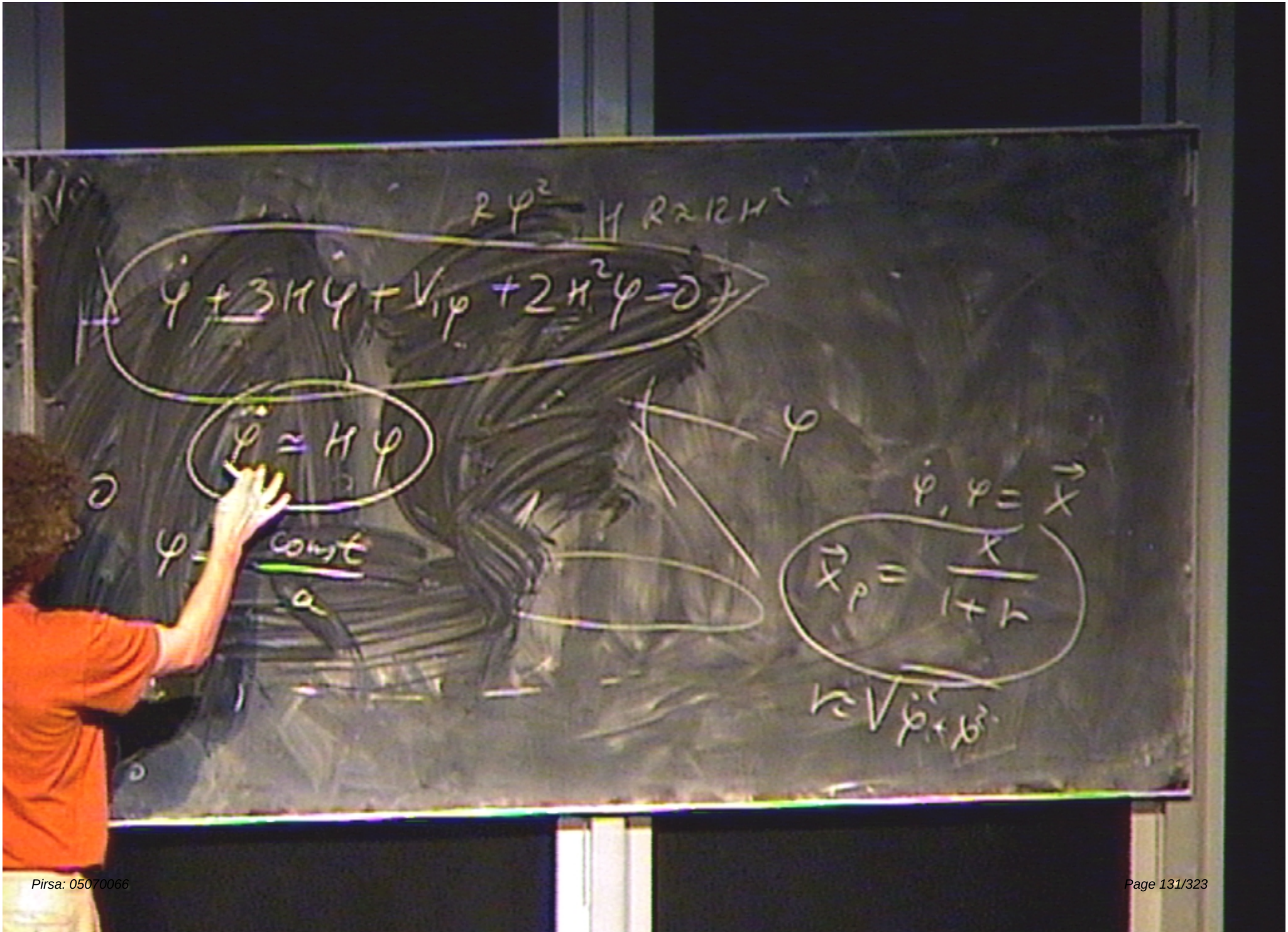


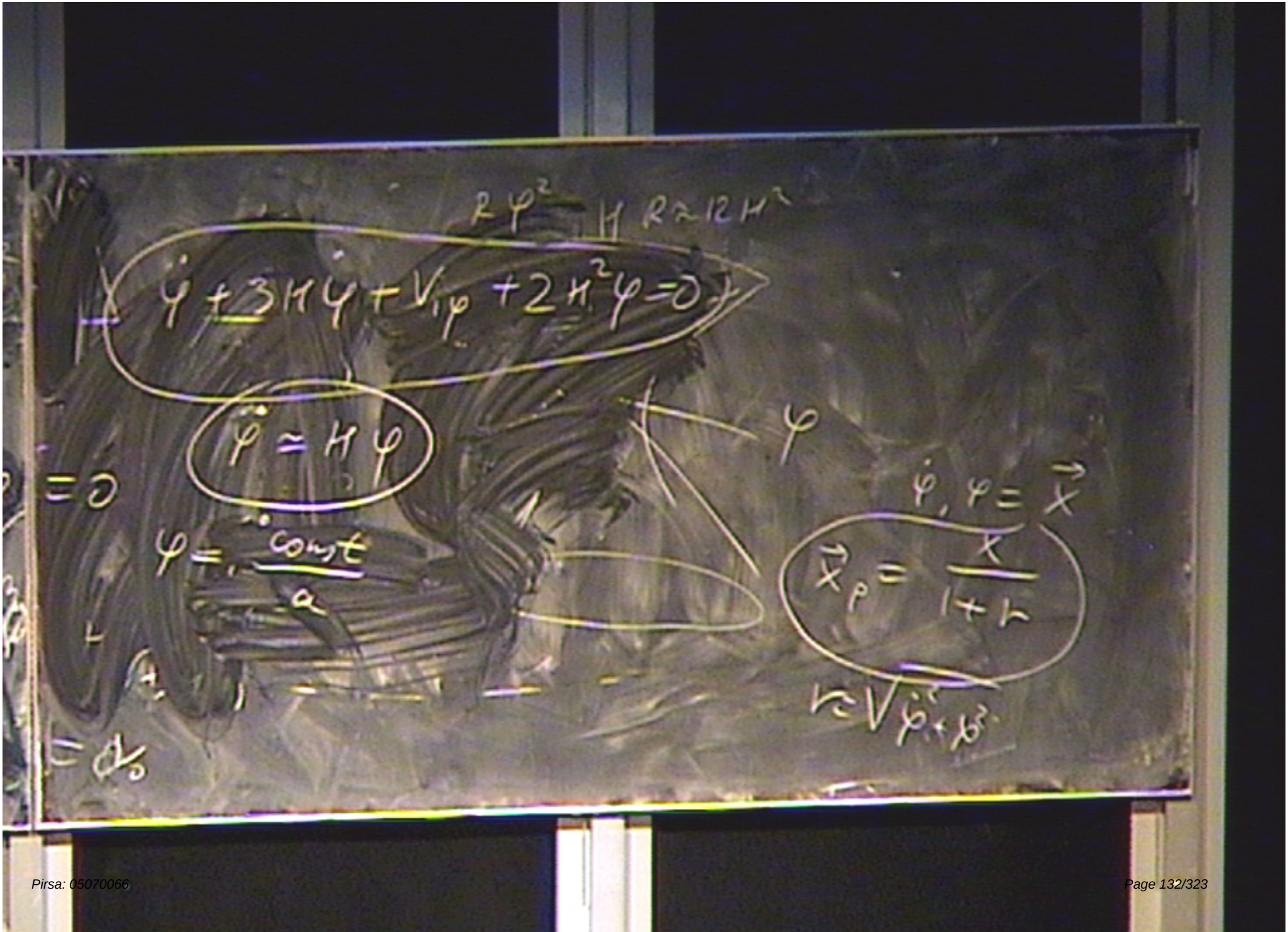

D3
O
D3
$V(\varphi) \approx V_0 \left(1 - \frac{\varphi_0^4}{\varphi^4}\right)$
φ
ρ

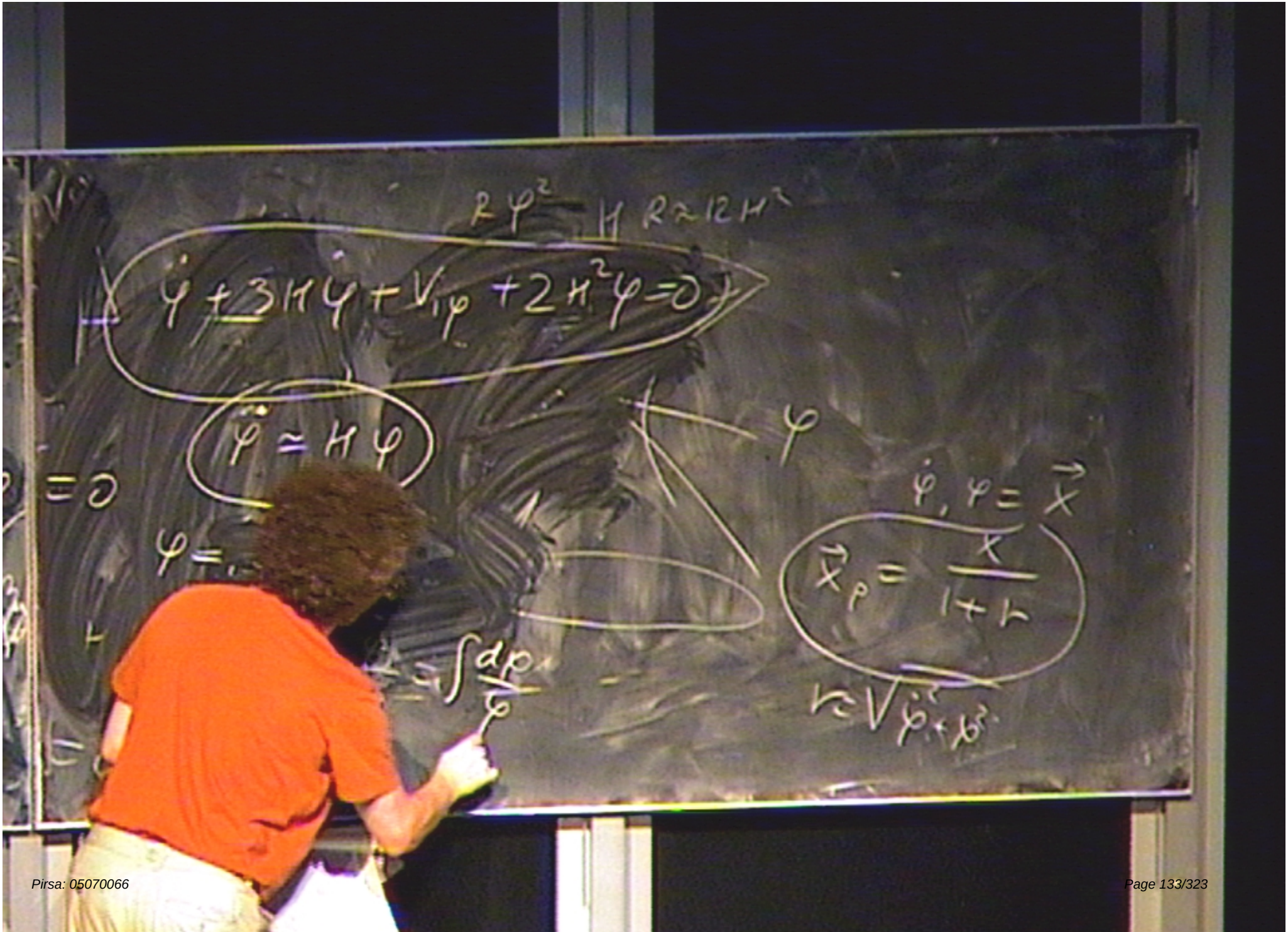

D3
D5
$V(\phi) \approx V_0 \left(1 - \frac{\phi_0^4}{\phi^4}\right)$
$V(\phi)$
ϕ

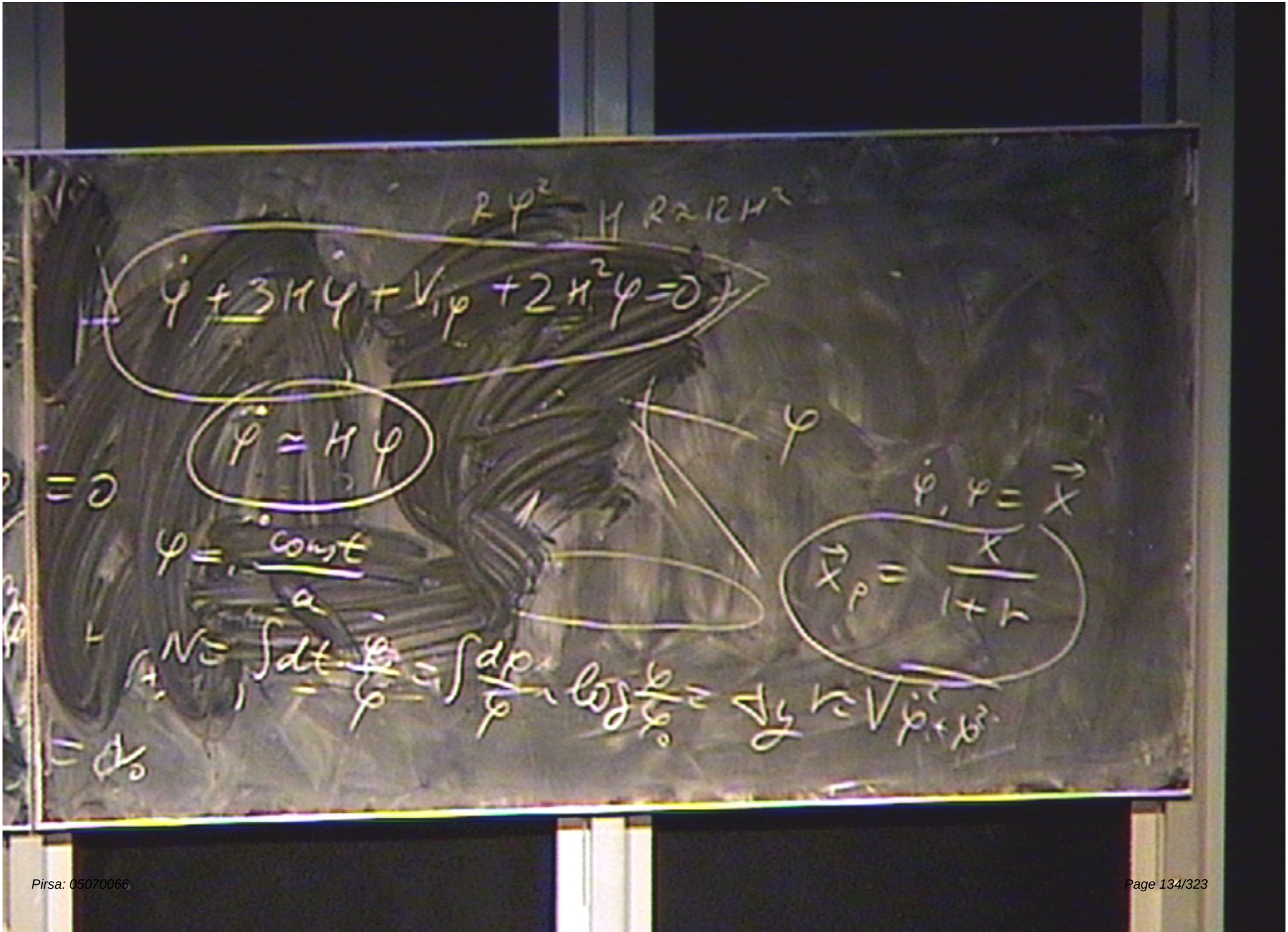

D3
D3
$V(\varphi) \approx V_0 \left(1 - \frac{\varphi_0^4}{\varphi^4}\right)$
$V(\varphi)$
$ds^2 = dy^2 + e^{-\frac{2y}{R}} \left(\eta_{\mu\nu} dx^\mu dx^\nu\right) + R^2 d\Omega_5^2$
$\varphi \sim e^{-\frac{y}{R}}$
ρ

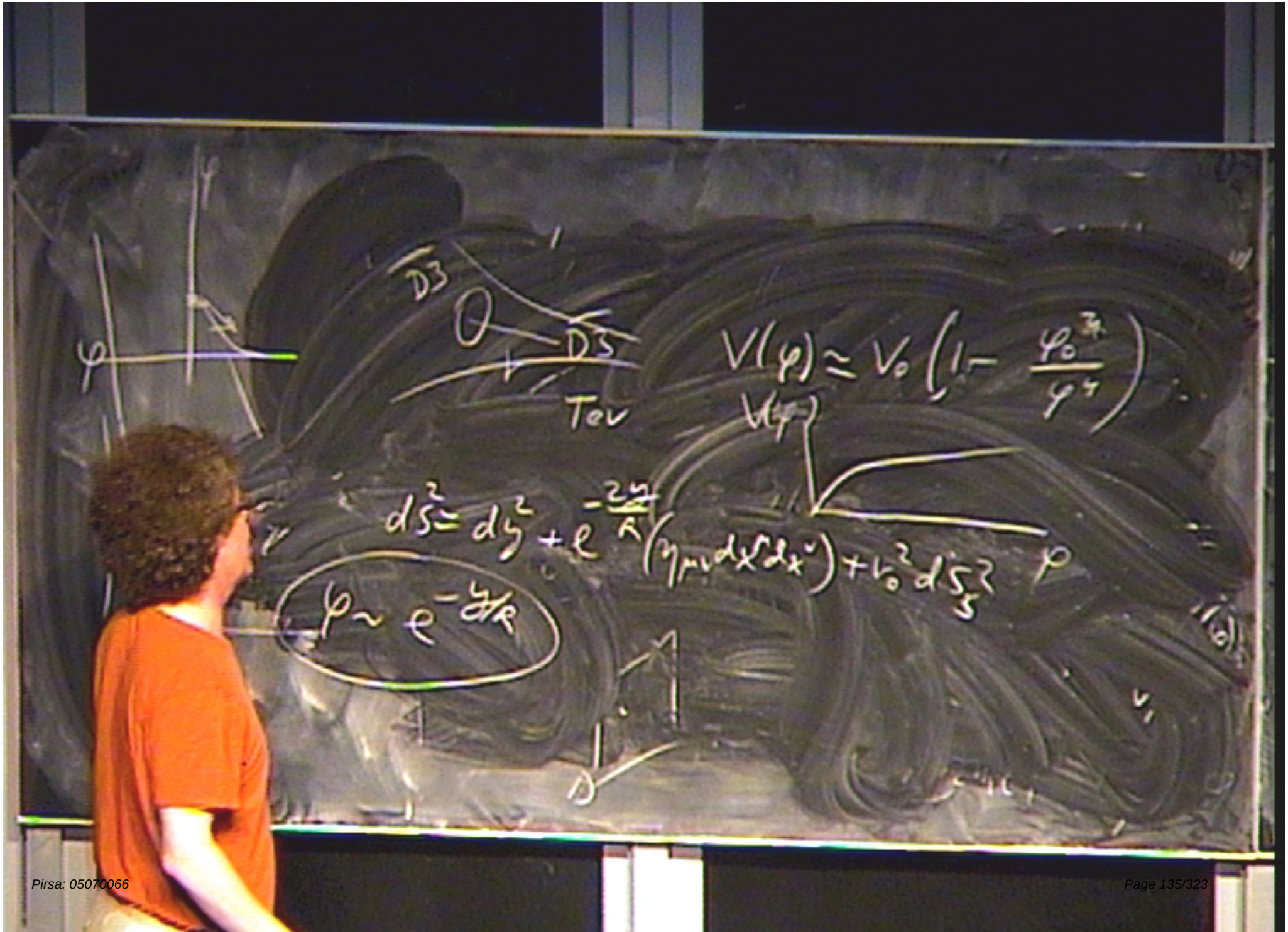

D3
D5
$V(\varphi) \approx V_0 \left(1 - \frac{\varphi_0^4}{\varphi^4}\right)$
$ds^2 = dy^2 + e^{-\frac{2y}{R}} (\eta_{\mu\nu} dx^\mu dx^\nu) + R_0^2 d\Omega_5^2$
$\varphi \sim e^{-\frac{y}{R}}$
$V(\varphi)$
φ
y
ρ

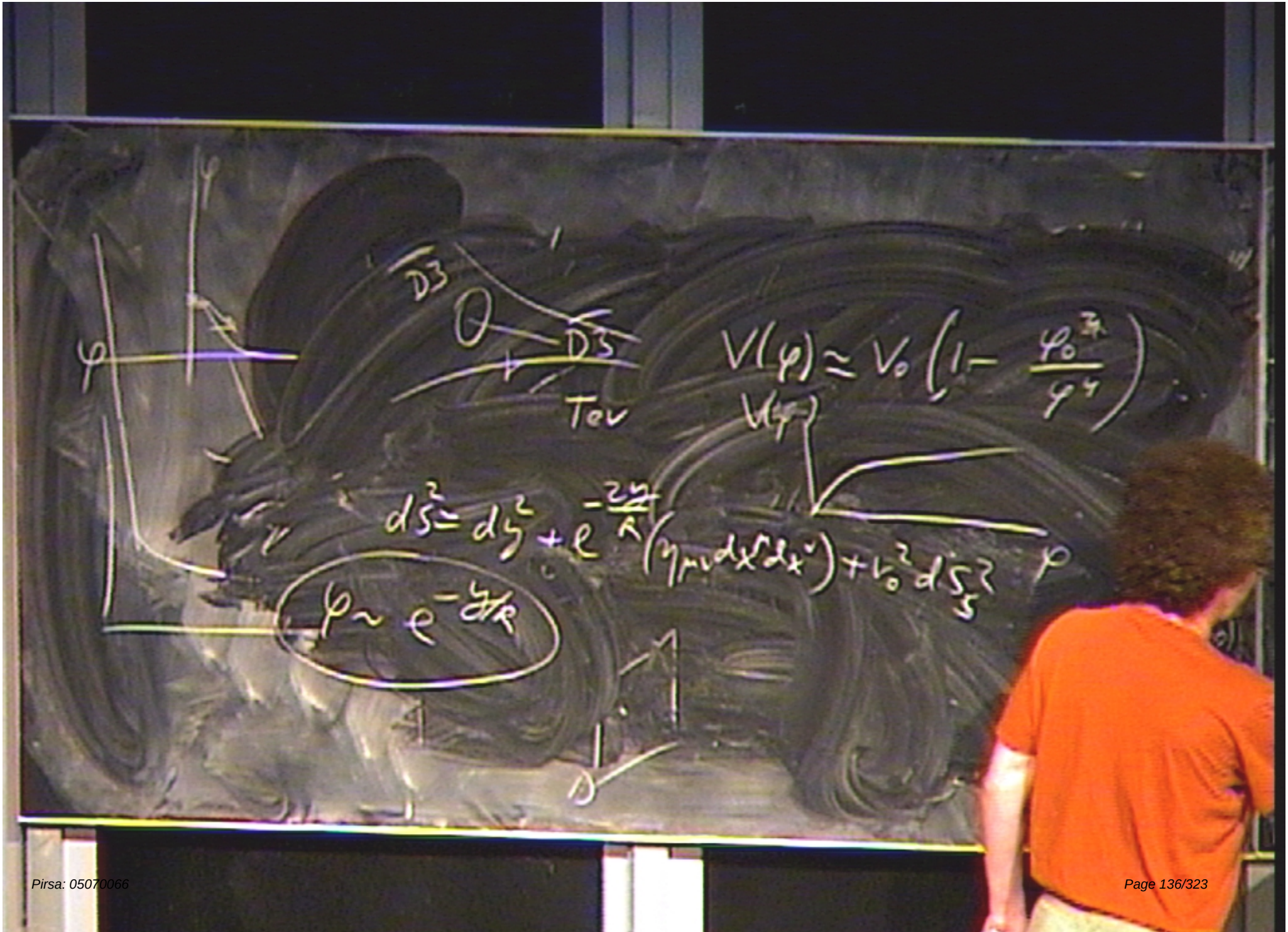

$R\varphi^2$ H $R = 12H^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} \approx H\dot{\varphi}$
φ
$\dot{\varphi}, \varphi = \vec{x}$
$\vec{x}_p = \frac{\vec{x}}{1+h}$
$h = \sqrt{\dot{\varphi}^2 + \ldots}$
$\varphi = \frac{\text{const}}{a}$


$R\varphi^2$ H $R \simeq 12 H^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} \simeq H\dot{\varphi}$
φ
$\dot{\varphi}, \varphi = \vec{x}$
$\vec{x}_p = \frac{\vec{x}}{1+h}$
$h \simeq \sqrt{\varphi^2 + \dot{\varphi}^2}$
$\varphi = \frac{\text{const}}{a}$


$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} \simeq H\dot{\varphi}$
$\dot{\varphi}, \varphi = \vec{x}$
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φ
$\dot{\varphi}, \varphi = \vec{x}$
$\vec{x}_\rho = \frac{\vec{x}}{1+\rho}$
$\varphi = \frac{\text{const}}{a}$
$N = \int dt \frac{\dot{\varphi}}{\varphi} = \int \frac{d\varphi}{\dot{\varphi}} \frac{\dot{\varphi}}{\varphi} = \ln \frac{\varphi}{\varphi_0} = \Delta\chi$
$r = \sqrt{\varphi^2 + \dot{\varphi}^2}$


D3
D5
Tev
$V(\varphi) \approx V_0\left(1 - \frac{\varphi_0^4}{\varphi^4}\right)$
$ds^2 = dy^2 + e^{-\frac{2y}{R}}(\eta_{\mu\nu}dx^\mu dx^\nu) + r_0^2 d\Omega_5^2$
$\varphi \sim e^{-y/R}$


D3
D3
Tev
$V(\varphi) \approx V_0 \left(1 - \frac{\varphi_0^4}{\varphi^4}\right)$
$V(\varphi)$
$ds^2 = dy^2 + e^{-\frac{2y}{R}} (\eta_{\mu\nu} dx^\mu dx^\nu) + r_0^2 d\Omega_5^2$
$\varphi \sim e^{-\frac{y}{R}}$
φ
r
ρ

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

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

Slow-roll

$a = a_0 e^{Ht}$

$N = \int \frac{dt}{d\varphi} H\, d\varphi$

$3H^2 = \frac{8\pi}{m_p^2} V$

$\sim 8\pi \frac{\varphi_0^2}{m_p^2}$ (65)

$\int d\varphi \frac{H^2}{\dot{\varphi}} \sim \frac{a}{9} \frac{m^2}{\dot{\varphi}}$

$\mathcal{L} = \frac{1}{2}\varphi_{,\mu}\varphi^{,\mu} - V + \frac{1}{2}\xi R\varphi^2$

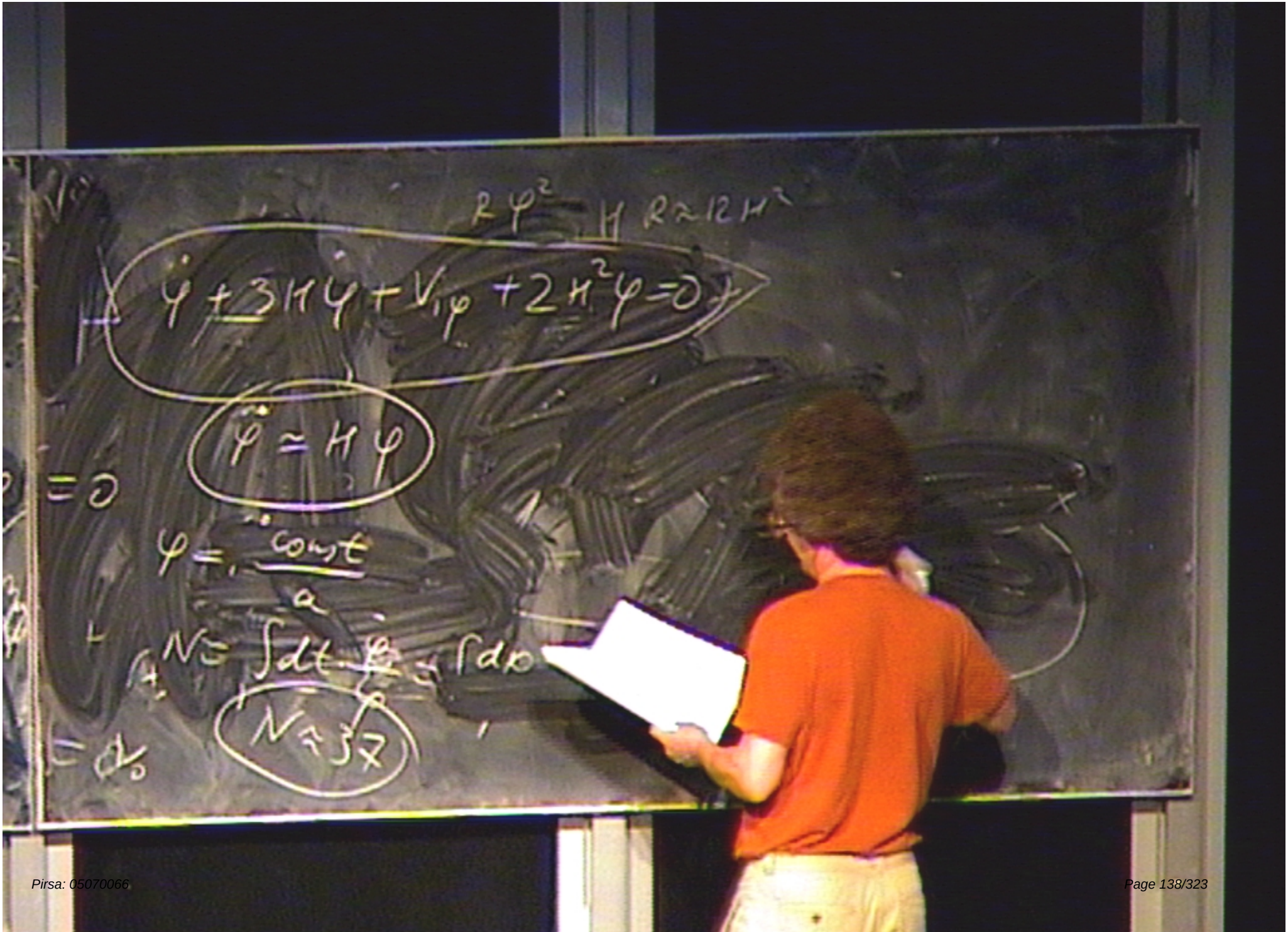
$\xi = \frac{1}{6}$

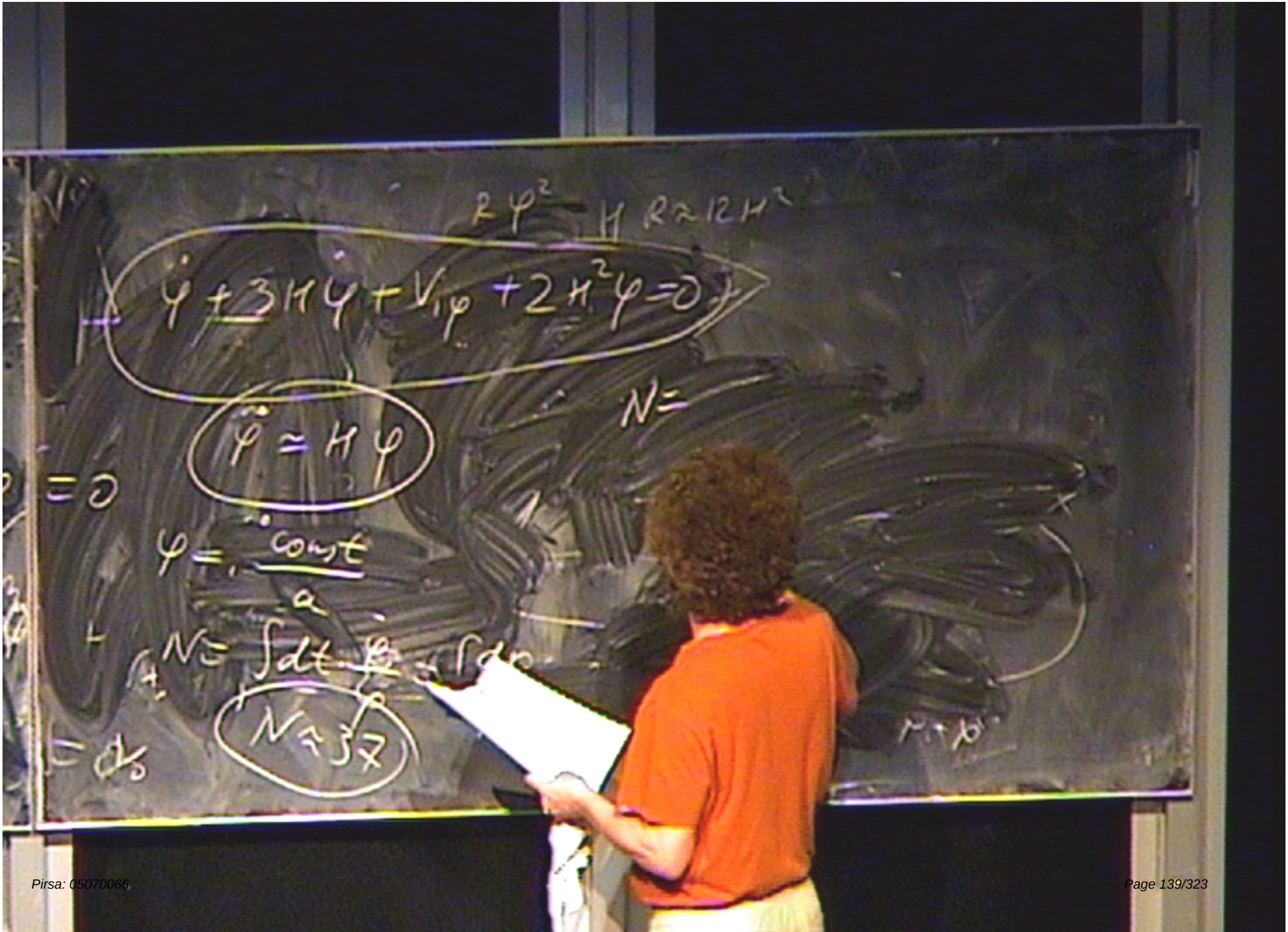
$\Box\varphi + \frac{1}{6}R\varphi =$

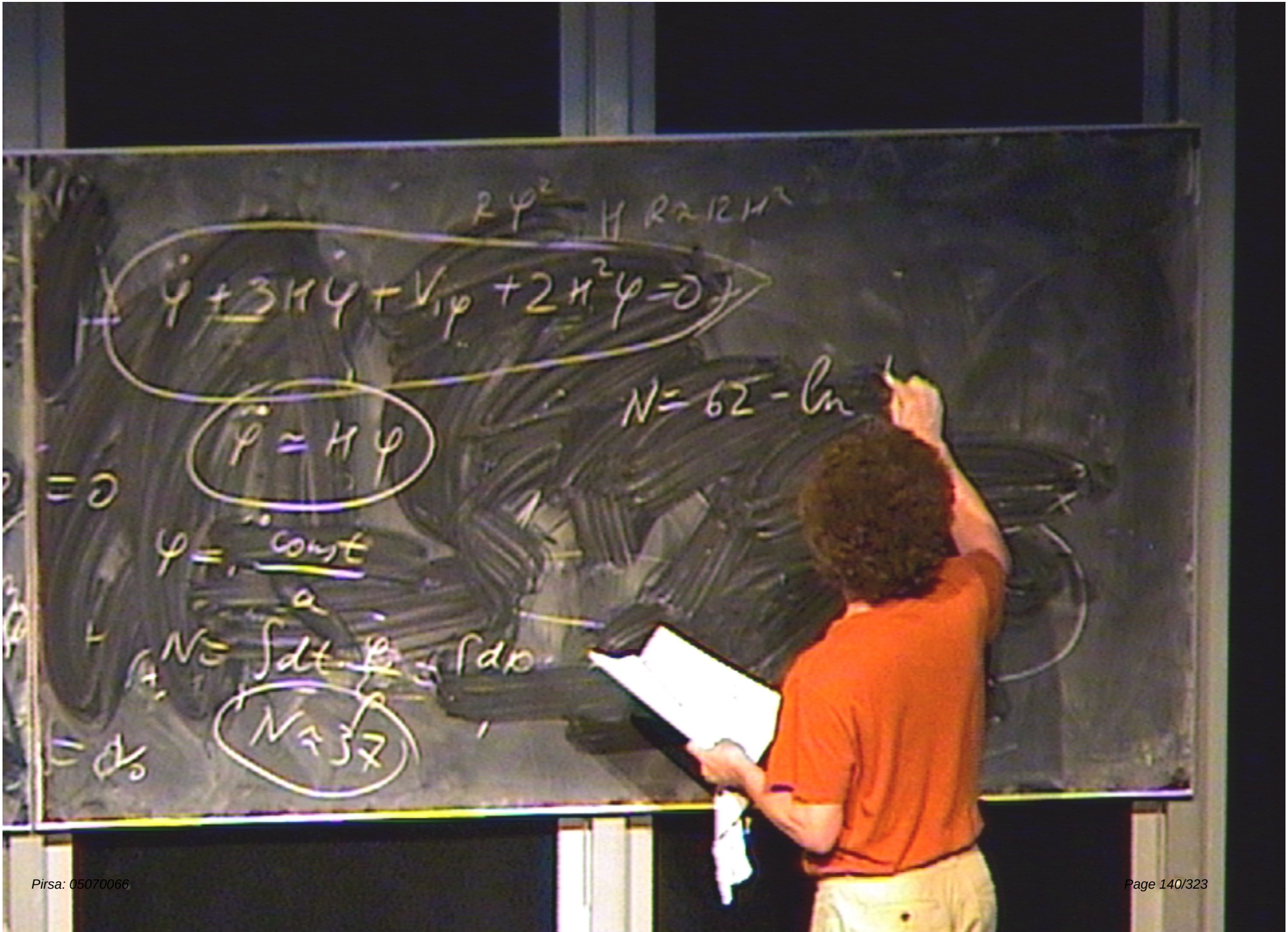
$g_{\mu\nu} \to \Omega^2 \tilde{g}_{\mu\nu} = a^2 \tilde{g}_{\mu\nu}$

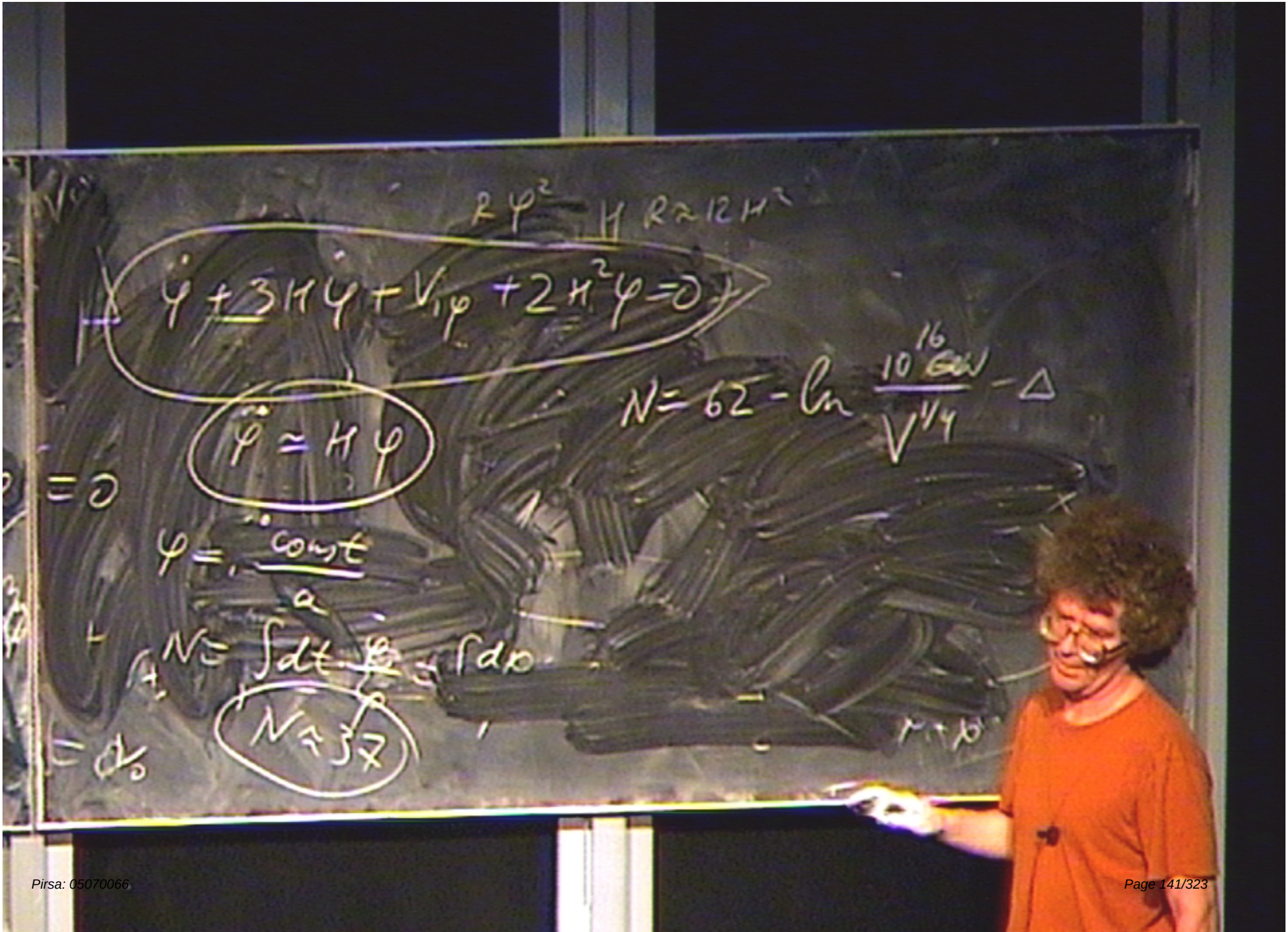
$\varphi \to \tilde{\varphi}/\Omega$

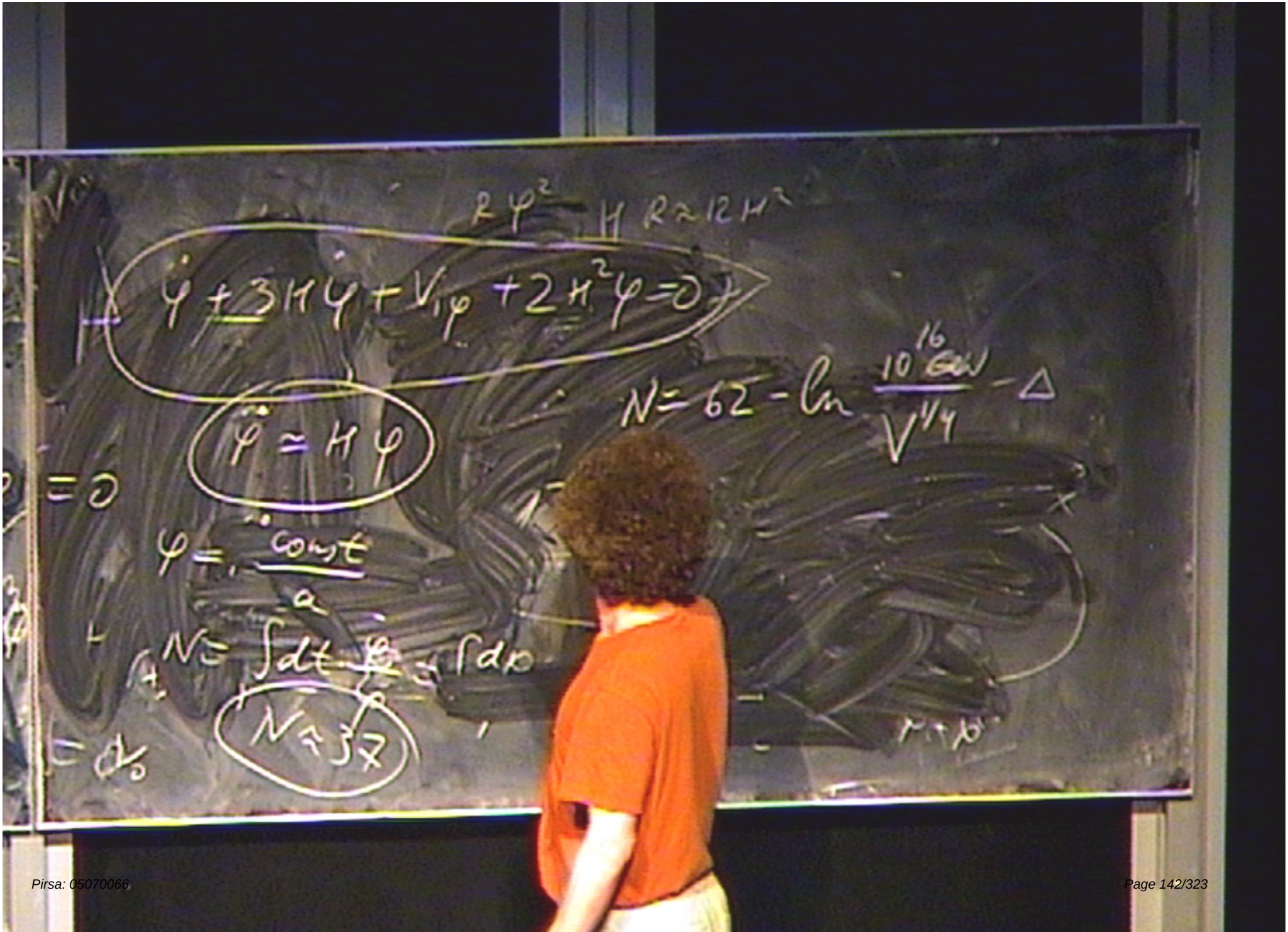
$\tilde{\Box}\tilde{\varphi} = 0$

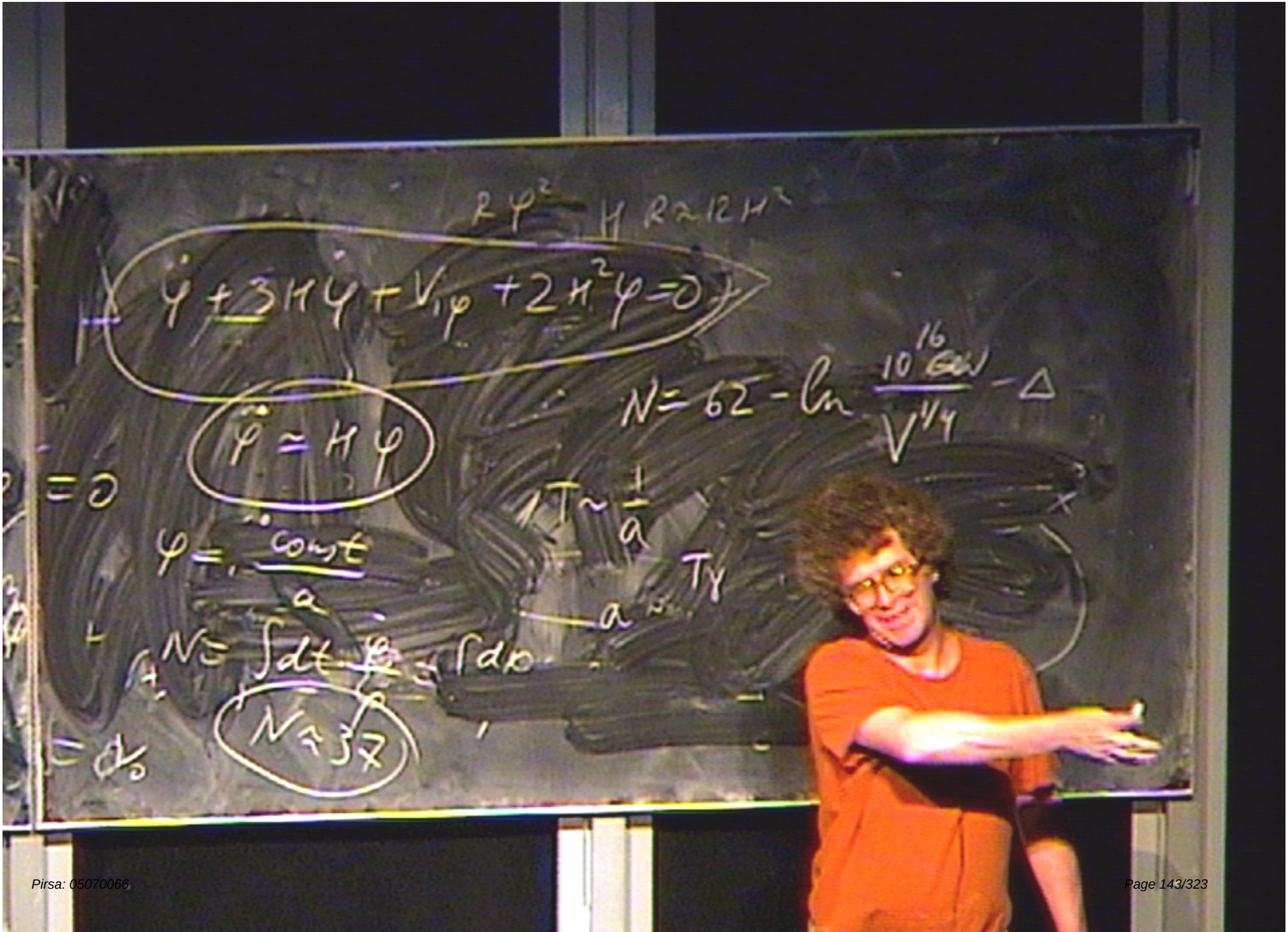

$R\varphi^2$ H $R \simeq 12H^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} \simeq H\dot{\varphi}$
$\dot{\varphi} = \frac{\text{const}}{a}$
$N = \int dt\, H = \int da$
$N \simeq 57$

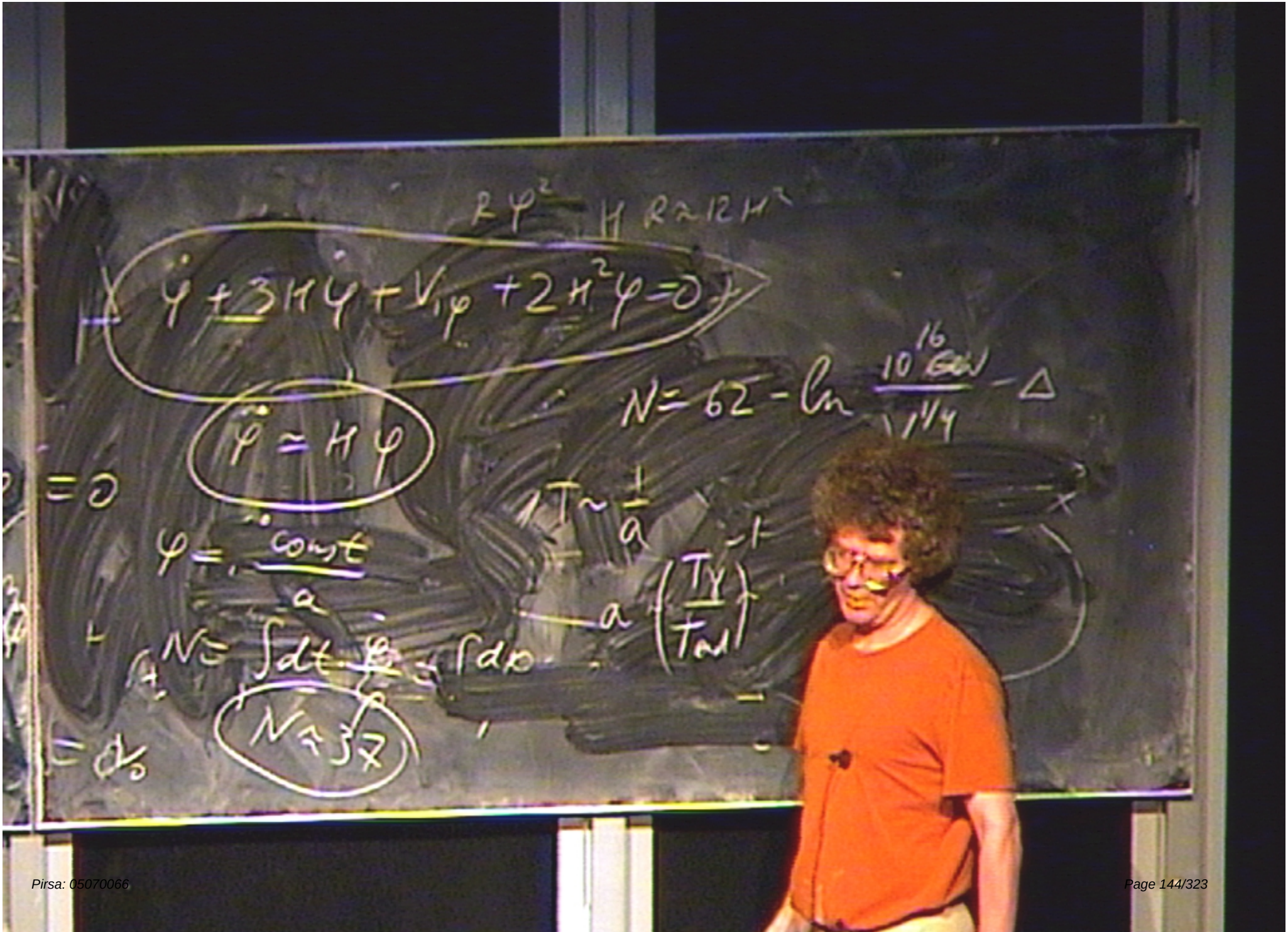

$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} \simeq H\dot{\varphi}$
$\varphi = \frac{\text{const}}{a}$
$N = \int dt\, H \simeq \ln a$
$N \simeq 57$

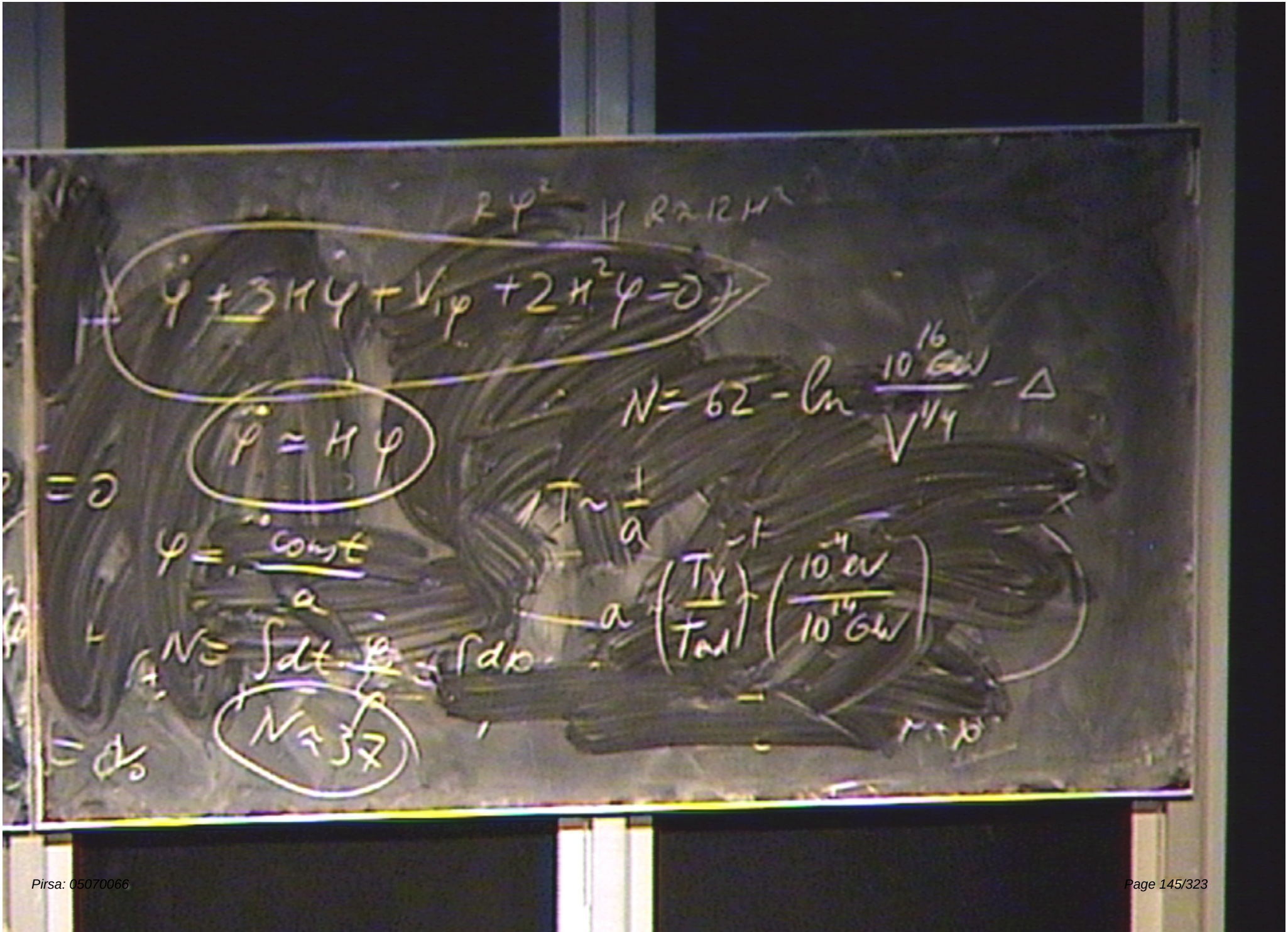

$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} = H\dot{\varphi}$
$N = 62 - \ln$
$\varphi = \frac{\text{const}}{a}$
$N = \int dt\, H = \int da$
$N \simeq 37$

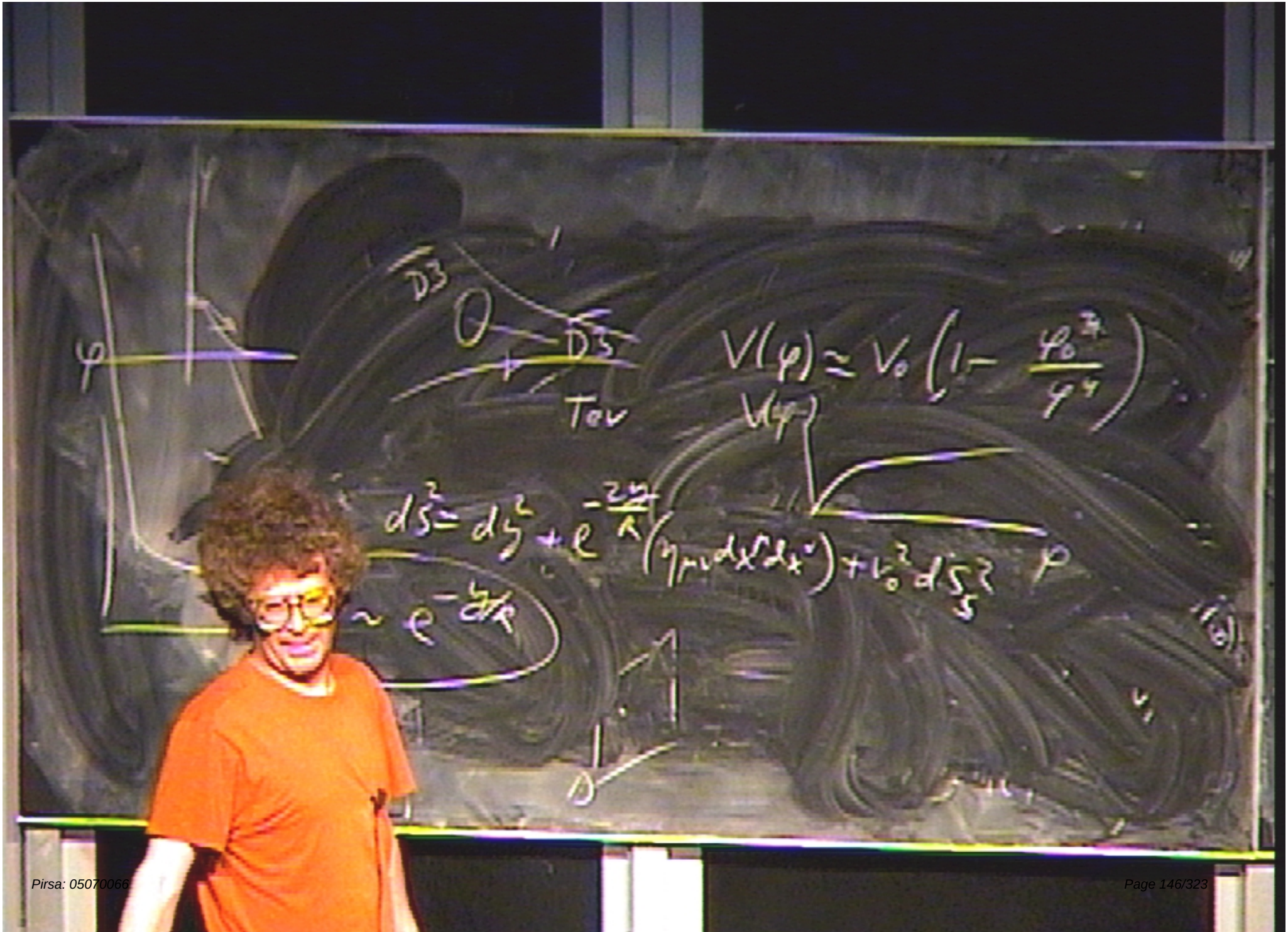

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$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} \simeq H\dot{\varphi}$
$N = 62 - \ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$\dot{\varphi} = \frac{const}{a}$
$N = \int dt\, H = \int da$
$N \simeq 57$

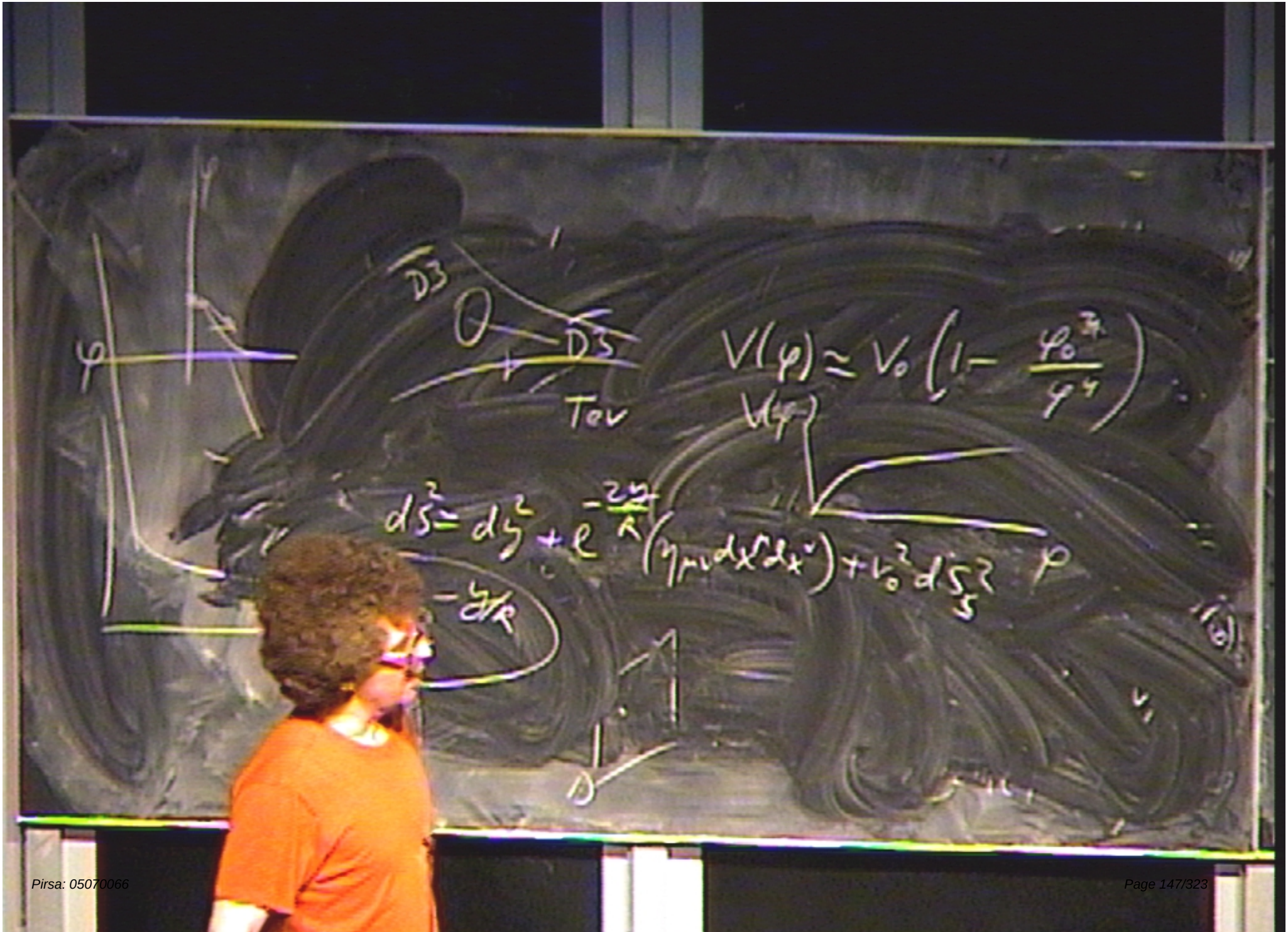

$R\varphi^2$ H $R \approx 12H^2$
$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} \approx H\dot{\varphi}$
$N = 62 - \ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$\dot{\varphi} = \frac{const}{a}$
$N = \int dt\, H = \int da$
$N \approx 37$

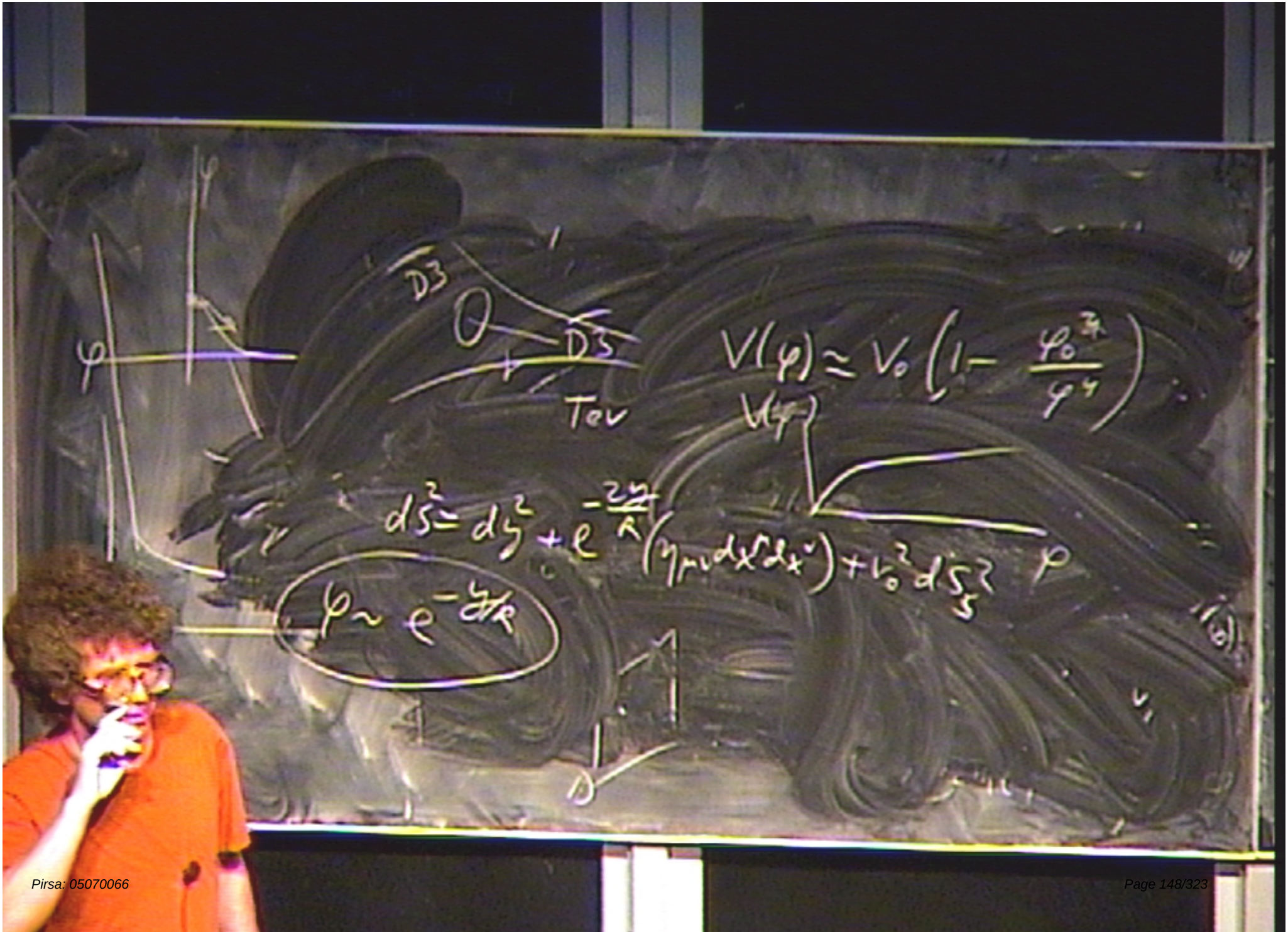

$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} = H\dot{\varphi}$
$\varphi = \frac{\text{const}}{a}$
$N = \int dt\, H = \int da$
$N \approx 37$
$N = 62 - \ln \frac{10^{16}\,\text{GeV}}{V^{1/4}} - \Delta$
$T \sim \frac{1}{a}$
$a \sim T_\gamma$

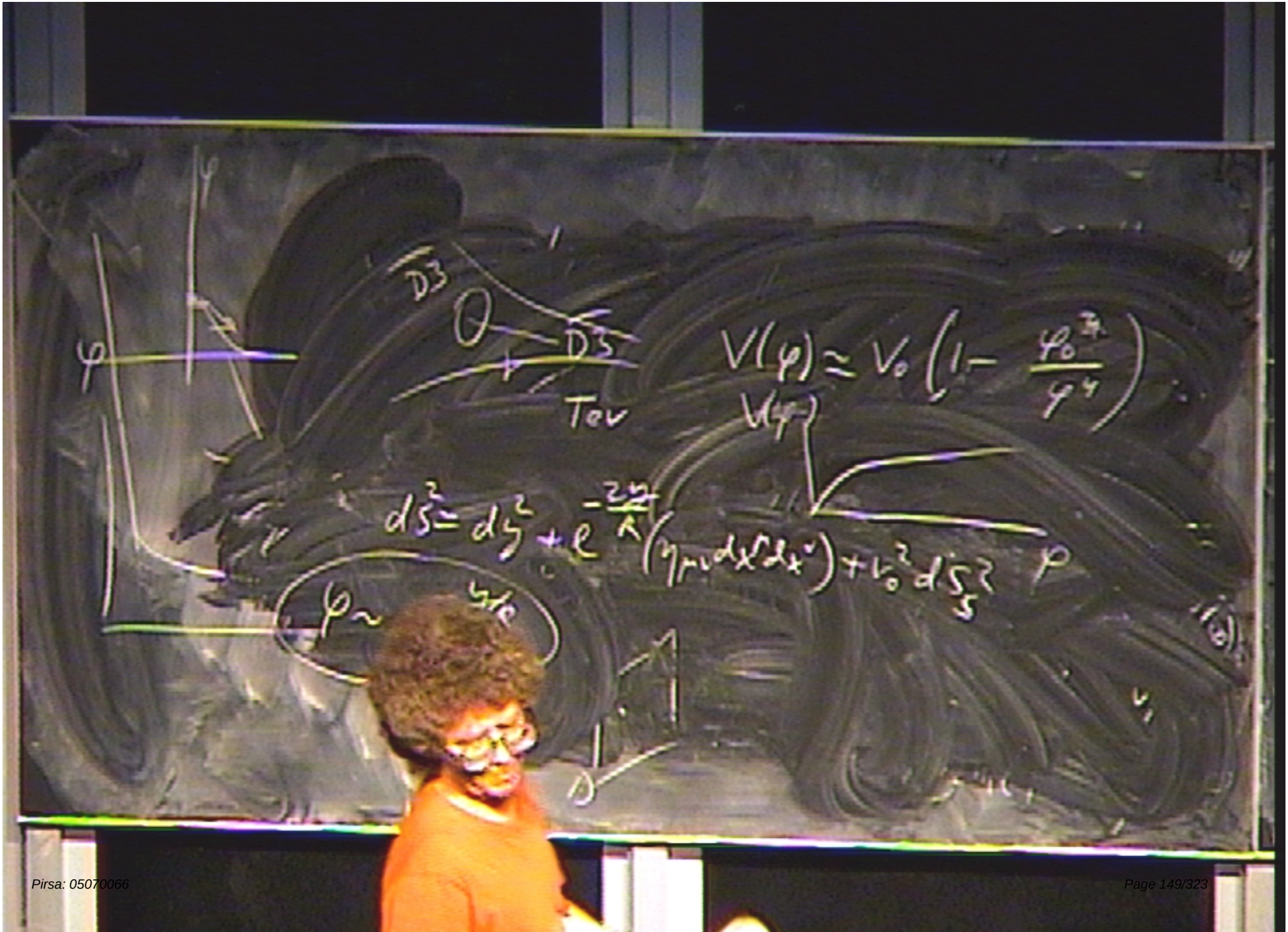

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$\varphi = \frac{\text{const}}{a}$
$N = \int dt\, H = \int da$
$N \simeq 37$
$N = 62 - \ln \frac{10^{16}\,\text{GeV}}{V^{1/4}} - \Delta$
$T \sim \frac{1}{a}$
$a \left(\frac{T_Y}{T_{eq}}\right)^{-1}$

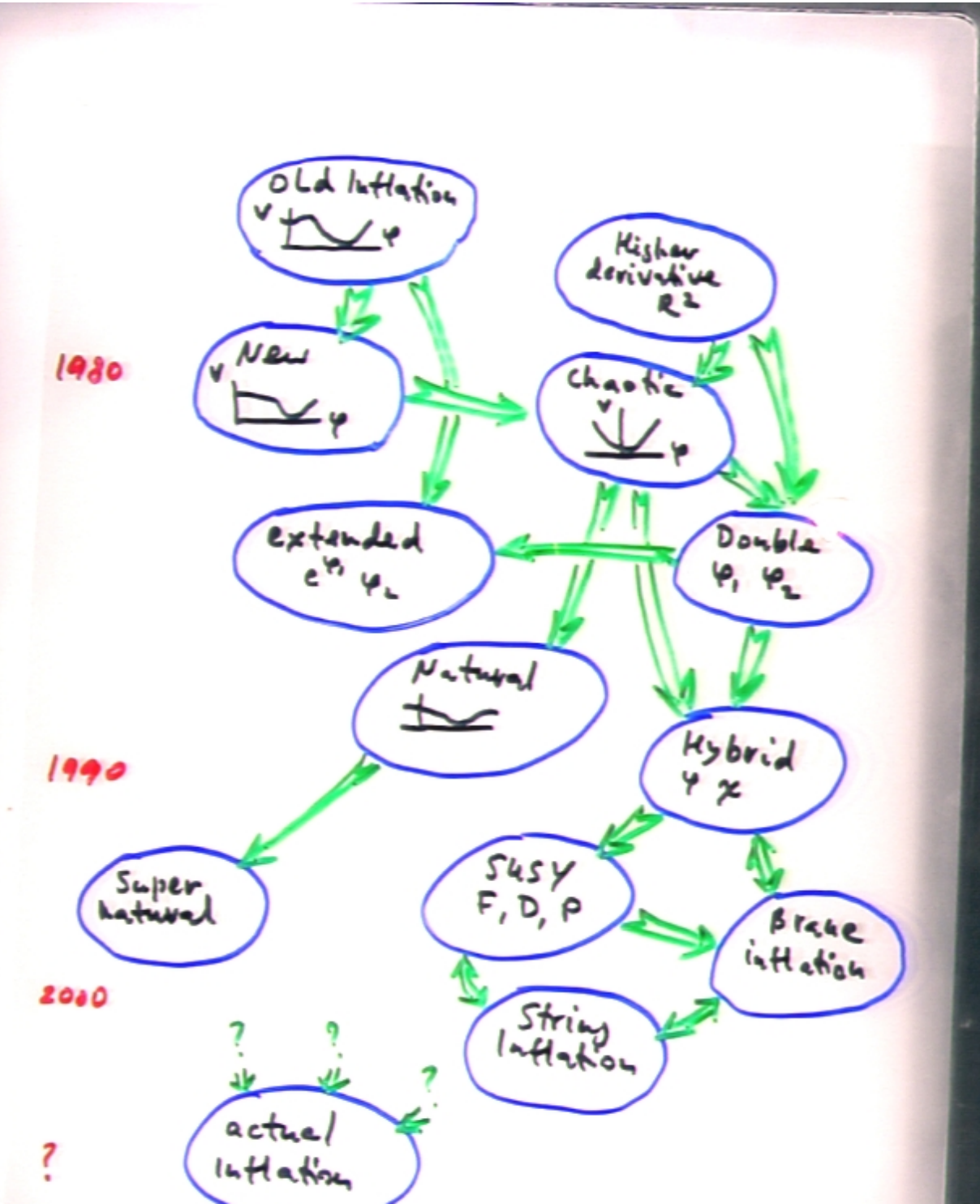

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$\ddot{\varphi} + 3H\dot{\varphi} + V_{,\varphi} + 2H^2\varphi = 0$
$\ddot{\varphi} = H\dot{\varphi}$
$N = 62 - \ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$T \sim \frac{1}{a}$
$\varphi = \frac{\text{const}}{a}$
$a \left(\frac{T_\gamma}{T_{\nu 1}}\right)^{-1} \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$N = \int dt\, H = \int da$
$N \simeq 37$

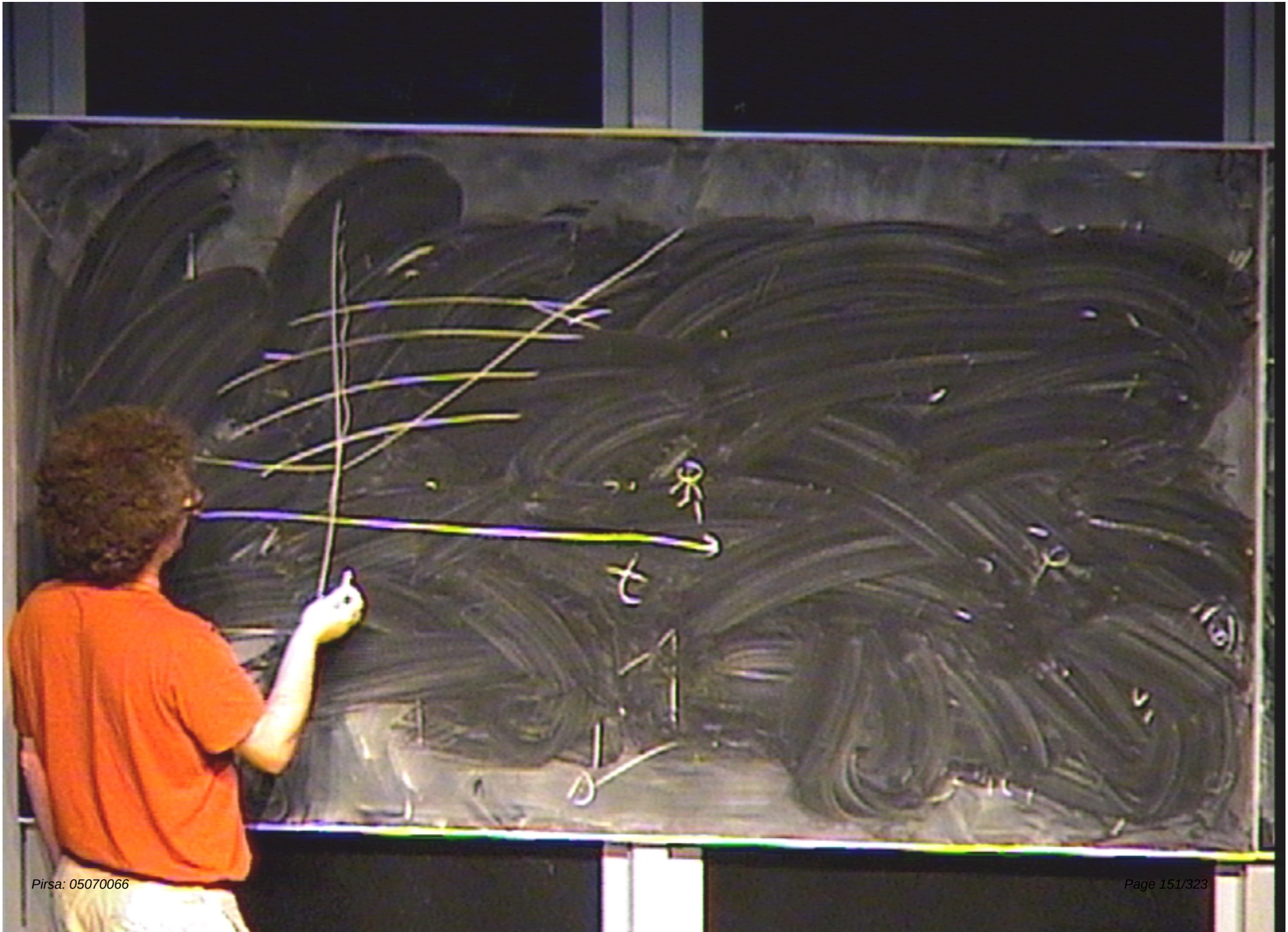

D3
D5
Tev
$V(\varphi) \simeq V_0 \left(1 - \frac{\varphi_0^4}{\varphi^4}\right)$
$ds^2 = dy^2 + e^{-\frac{2y}{R}} (\eta_{\mu\nu} dx^\mu dx^\nu) + r_0^2 d\Omega_5^2$
$\sim e^{-\frac{L}{R}}$


D3
D3
Tev
$V(\varphi) \approx V_0 \left(1 - \frac{\varphi_0^4}{\varphi^4}\right)$
$V(\varphi)$
$ds^2 = dy^2 + e^{-\frac{2y}{R}} (\eta_{\mu\nu} dx^\mu dx^\nu) + r_0^2 d\Omega_5^2$
$-\frac{1}{R}$
ρ

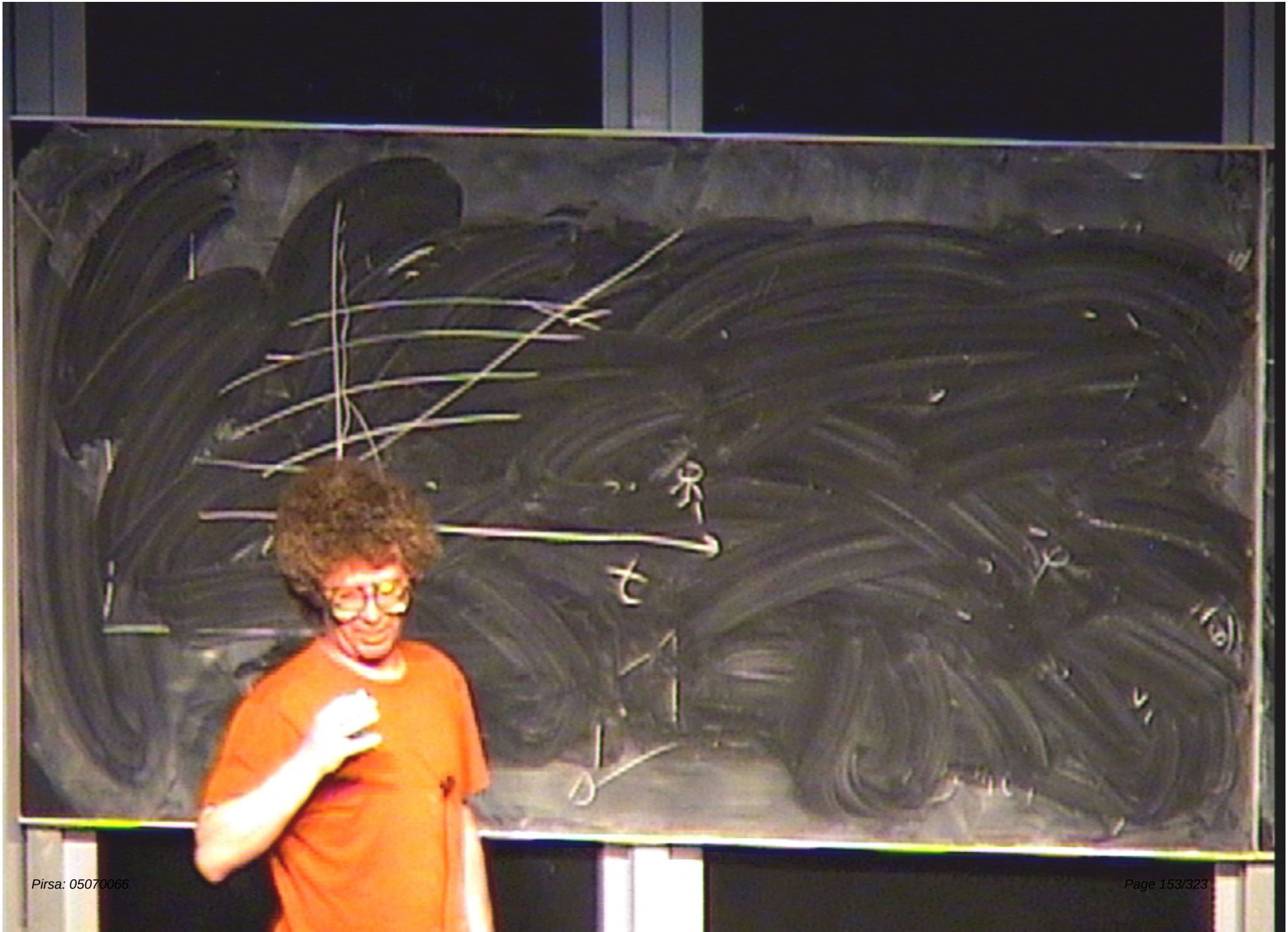

D3
D5
Tev
$V(\varphi) \simeq V_0\left(1 - \frac{\varphi_0^4}{\varphi^4}\right)$
$ds^2 = dy^2 + e^{-\frac{2y}{R}}(\eta_{\mu\nu}dx^\mu dx^\nu) + r_0^2 d\Omega_5^2$
$\varphi \sim e^{-\frac{y}{R}}$
φ
r
ρ

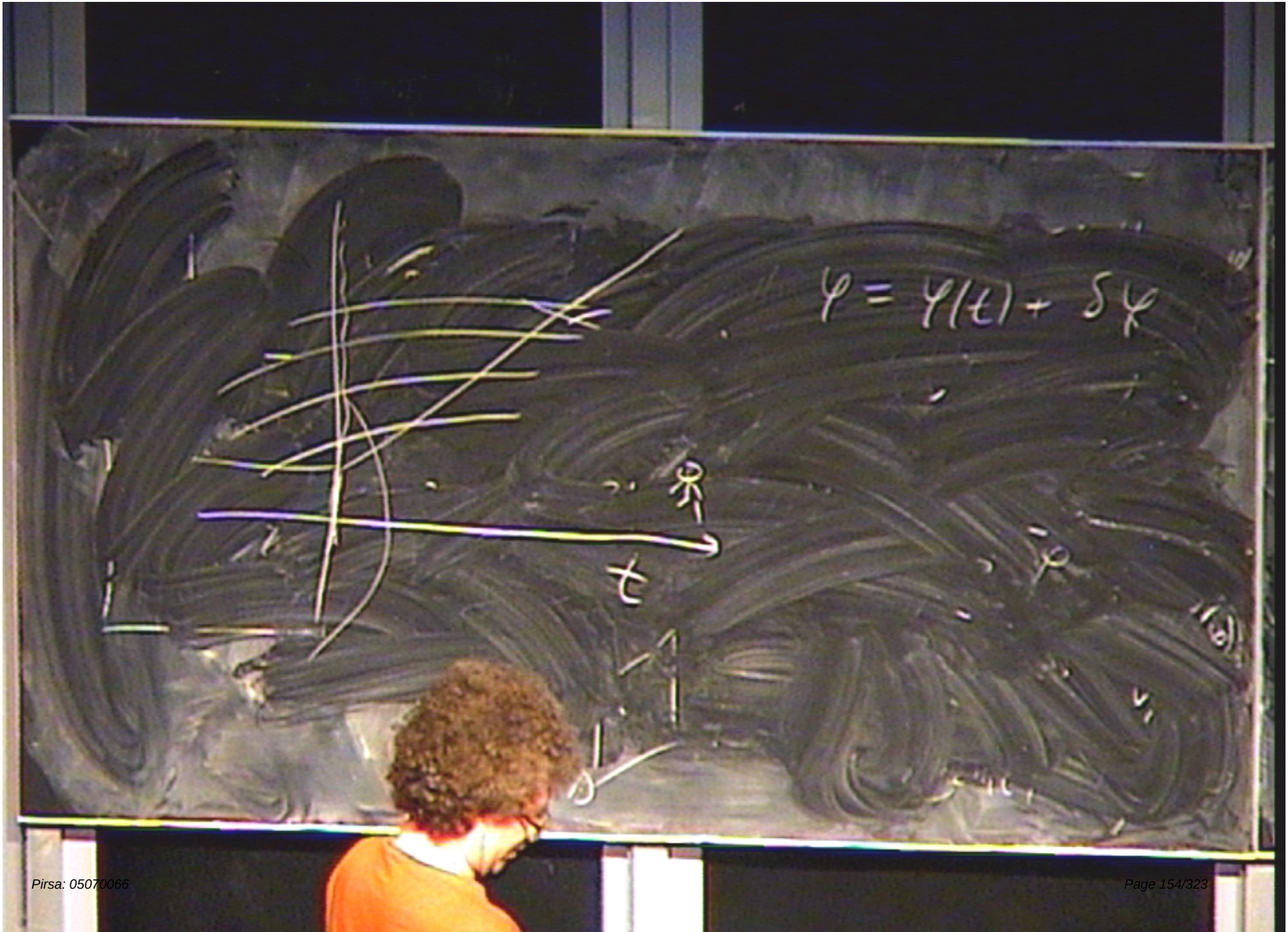

D3
D3
Tev
$V(\varphi) \approx V_0 \left(1 - \frac{\varphi_0^4}{\varphi^4}\right)$
$V(\varphi)$
$ds^2 = dy^2 + e^{-\frac{2y}{R}} (\eta_{\mu\nu} dx^\mu dx^\nu) + r_0^2 d\Omega_5^2$
$\varphi \sim$
$1/\varepsilon$
r_0

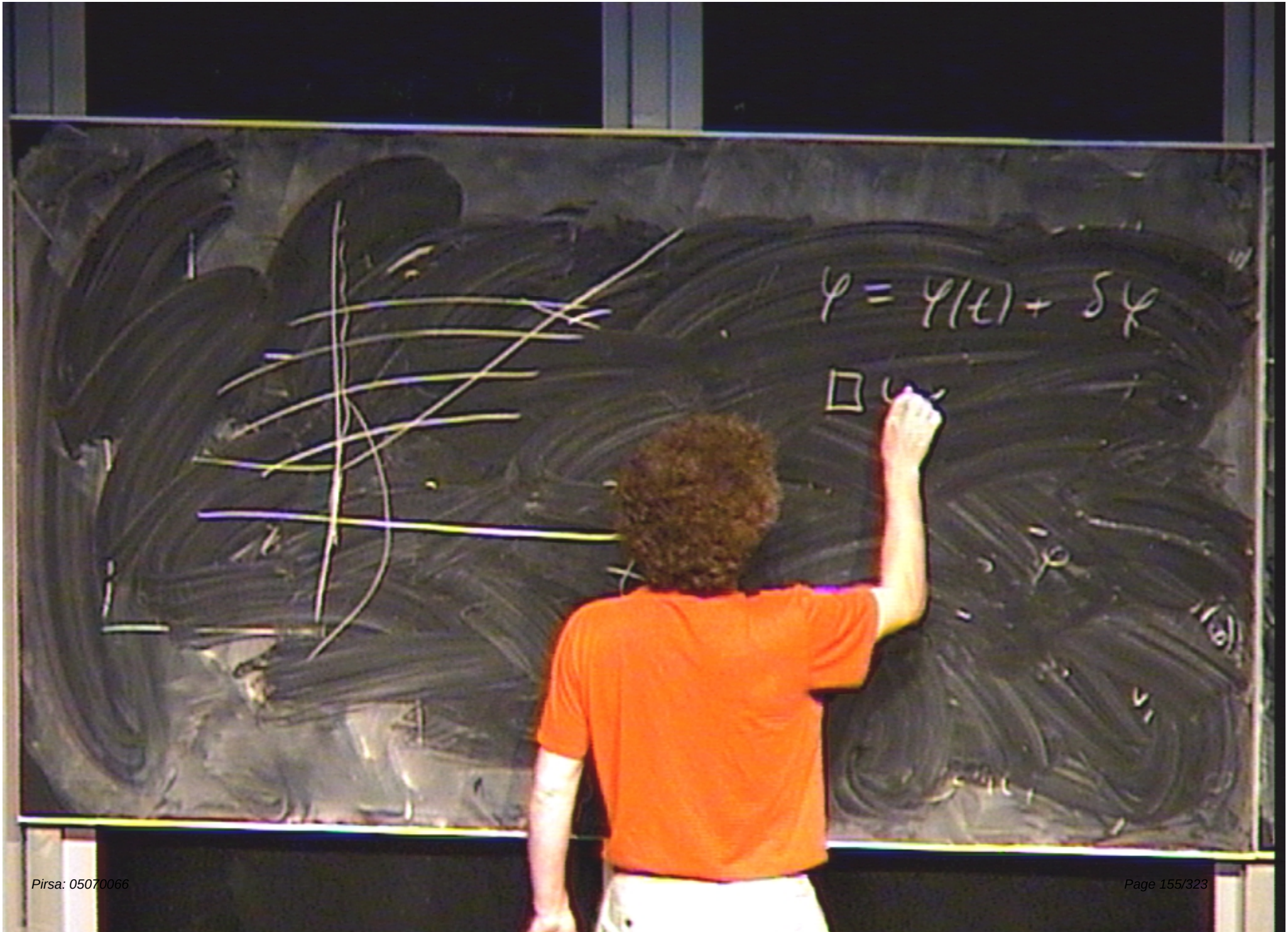

1980
1990
2000
?
Old Inflation
V
φ
New
V
φ
Higher derivative R²
Chaotic
V
φ
extended
Double φ₁ φ₂
Natural
Hybrid
φ χ
Super natural
SUSY F, D, P
Brane inflation
String Inflation
? ? ?
actual Inflation

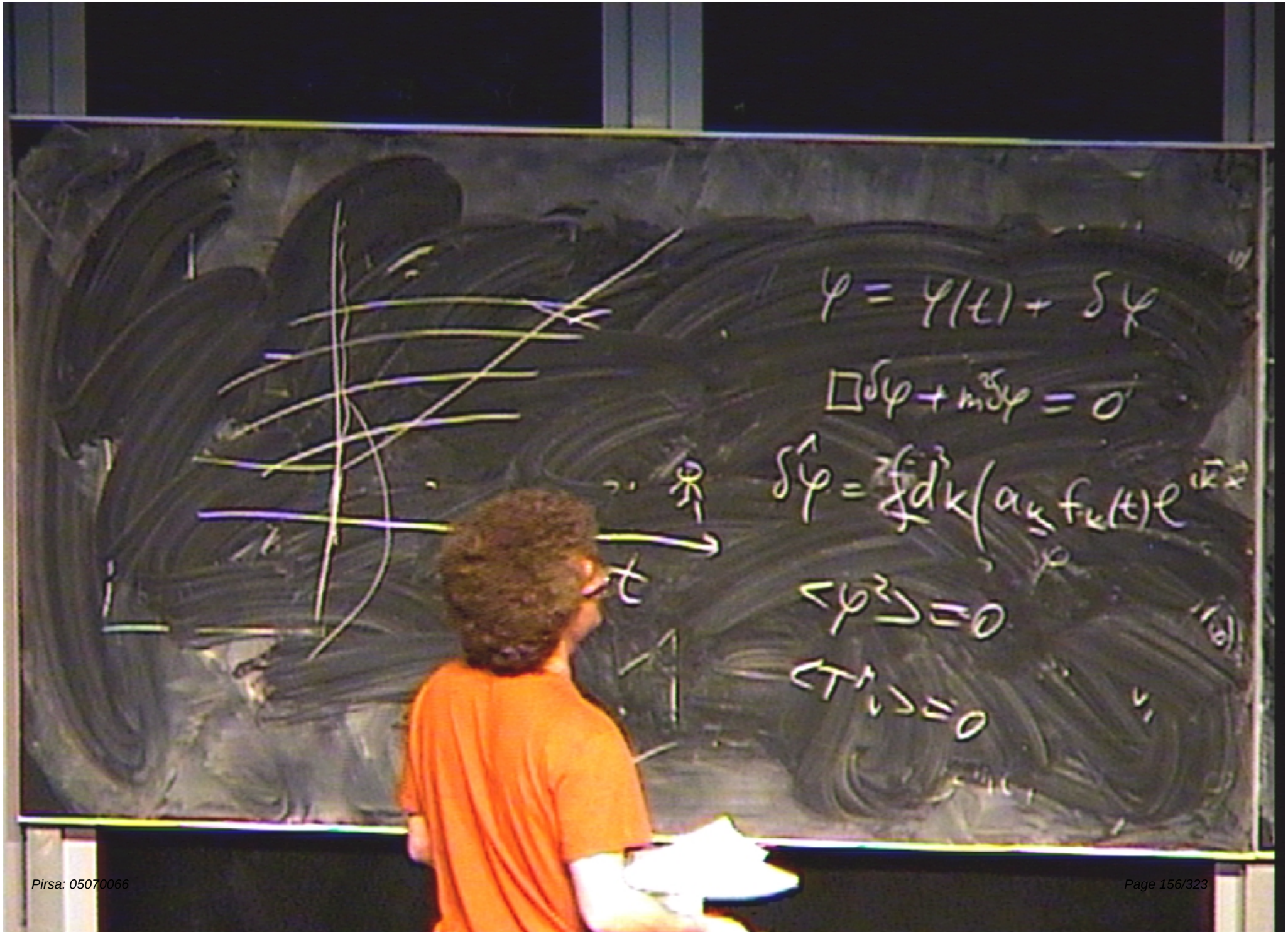


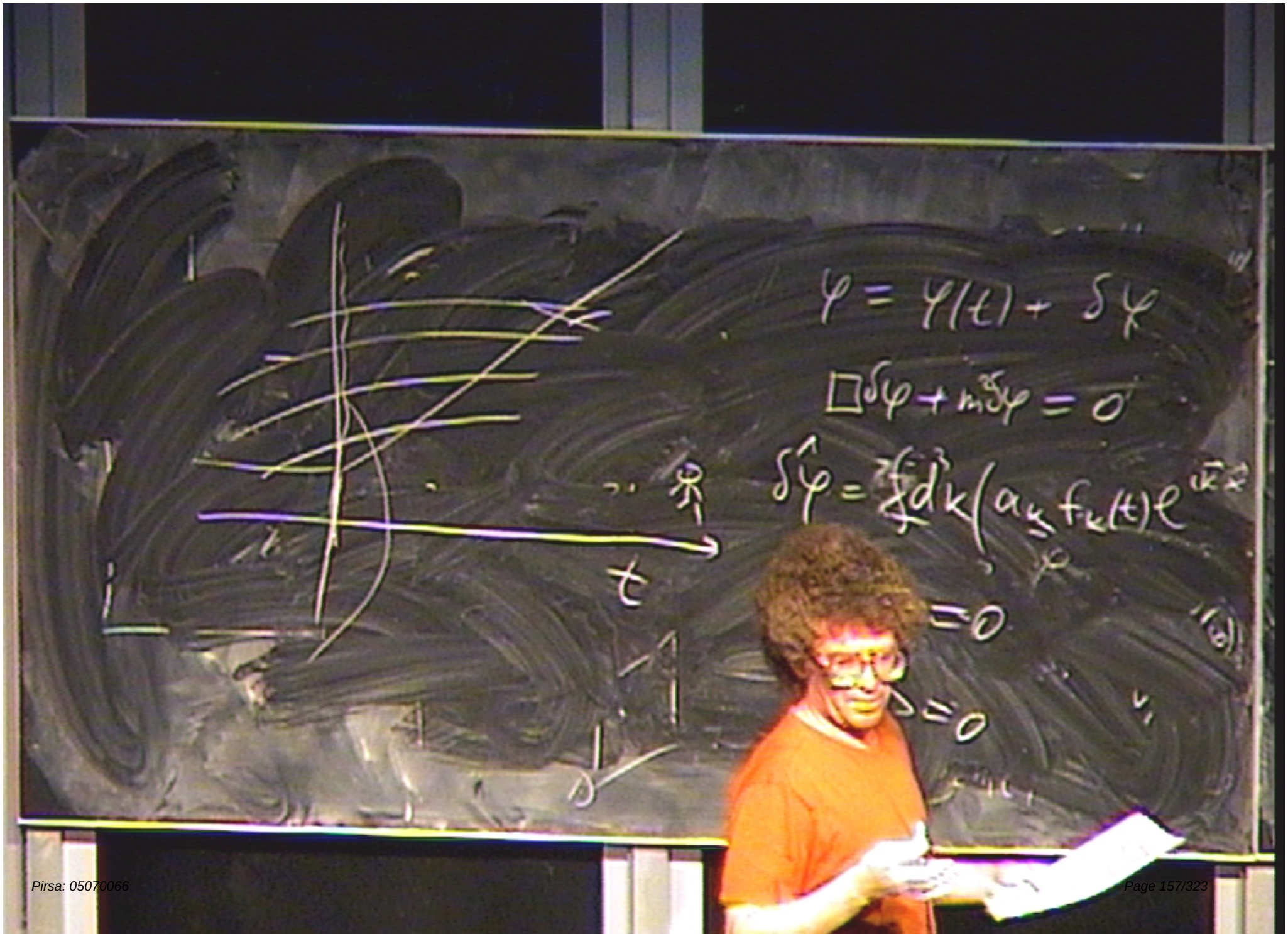


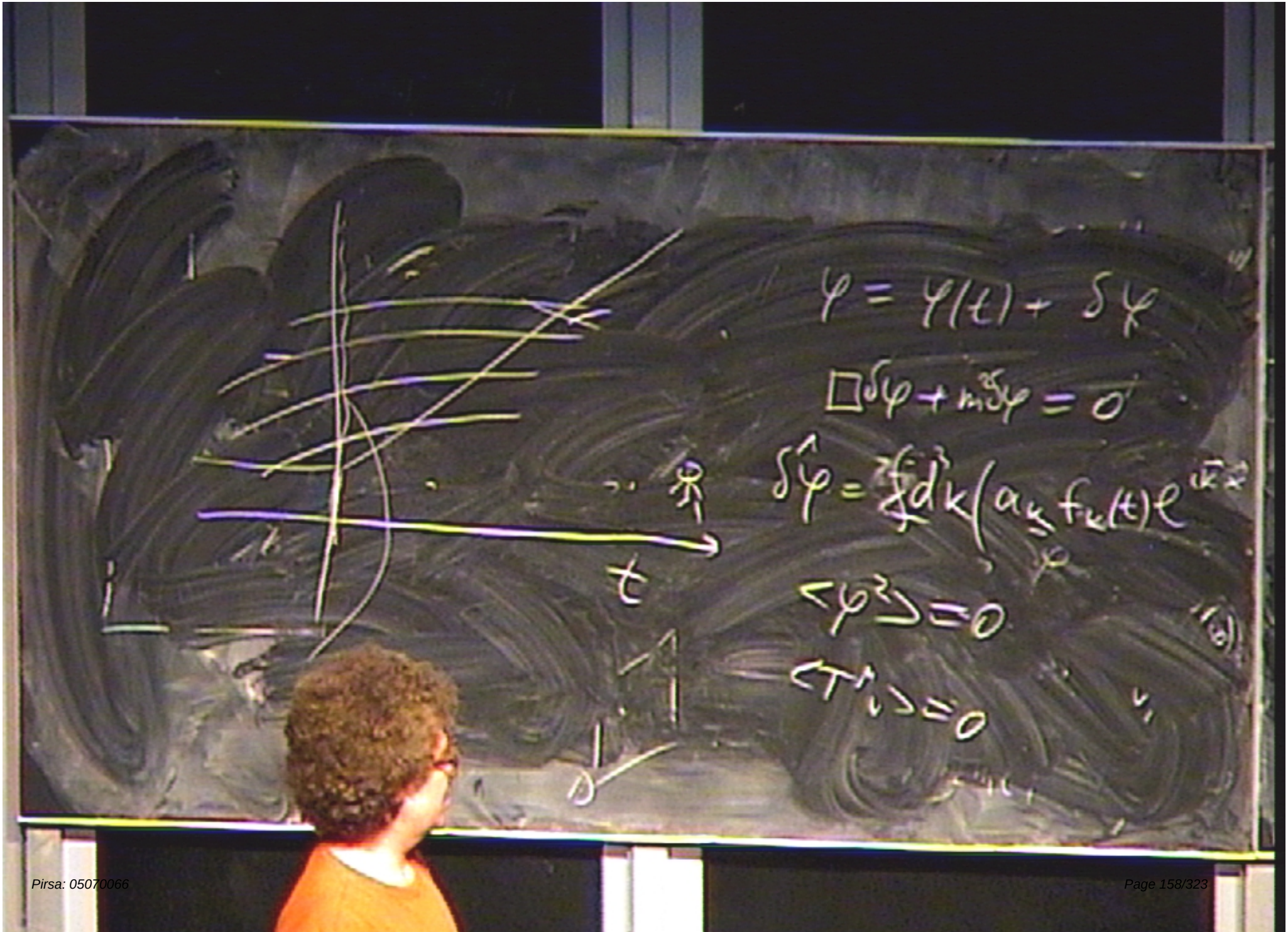


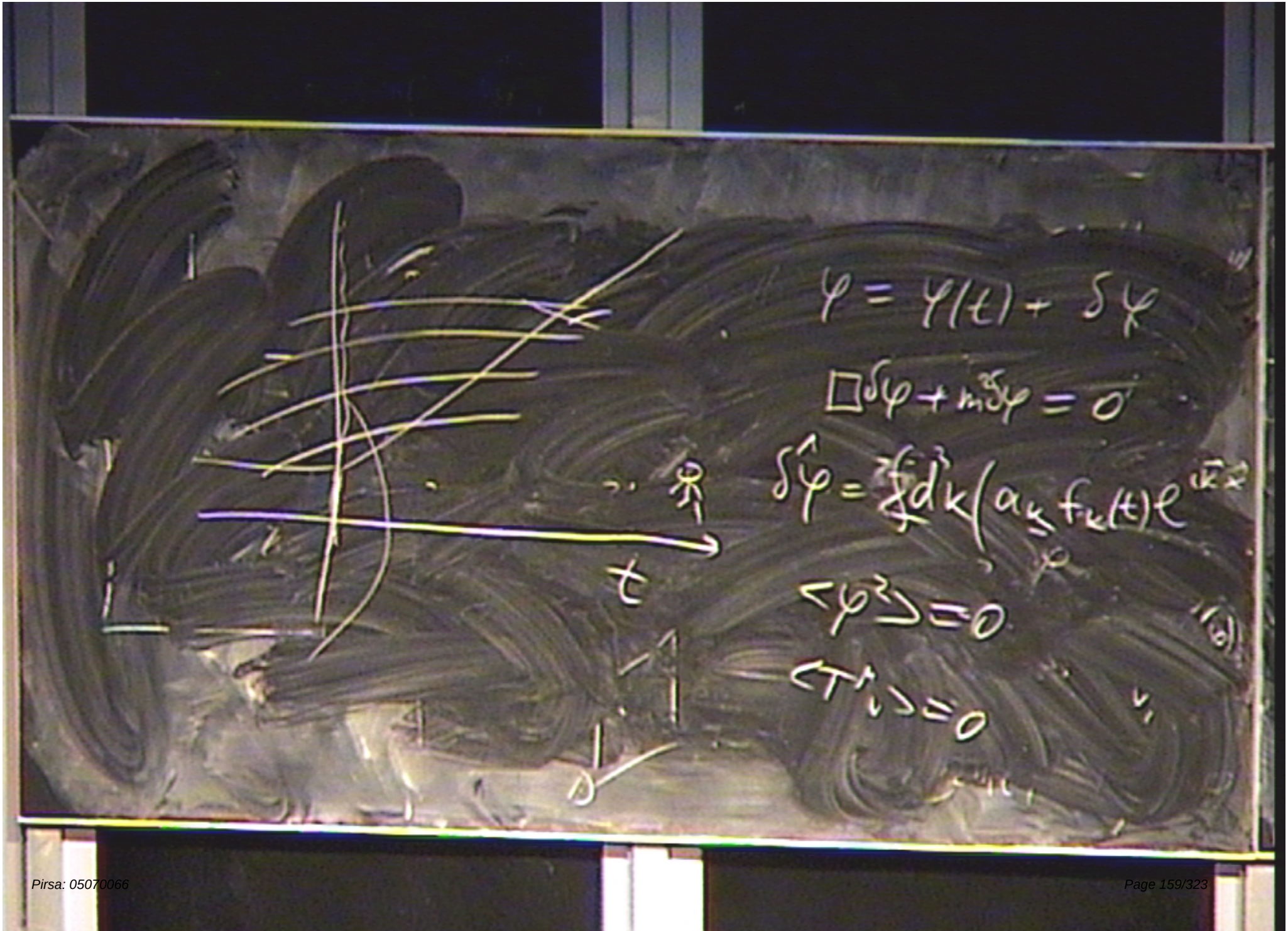

$\varphi = \varphi(t) + \delta\varphi$
t

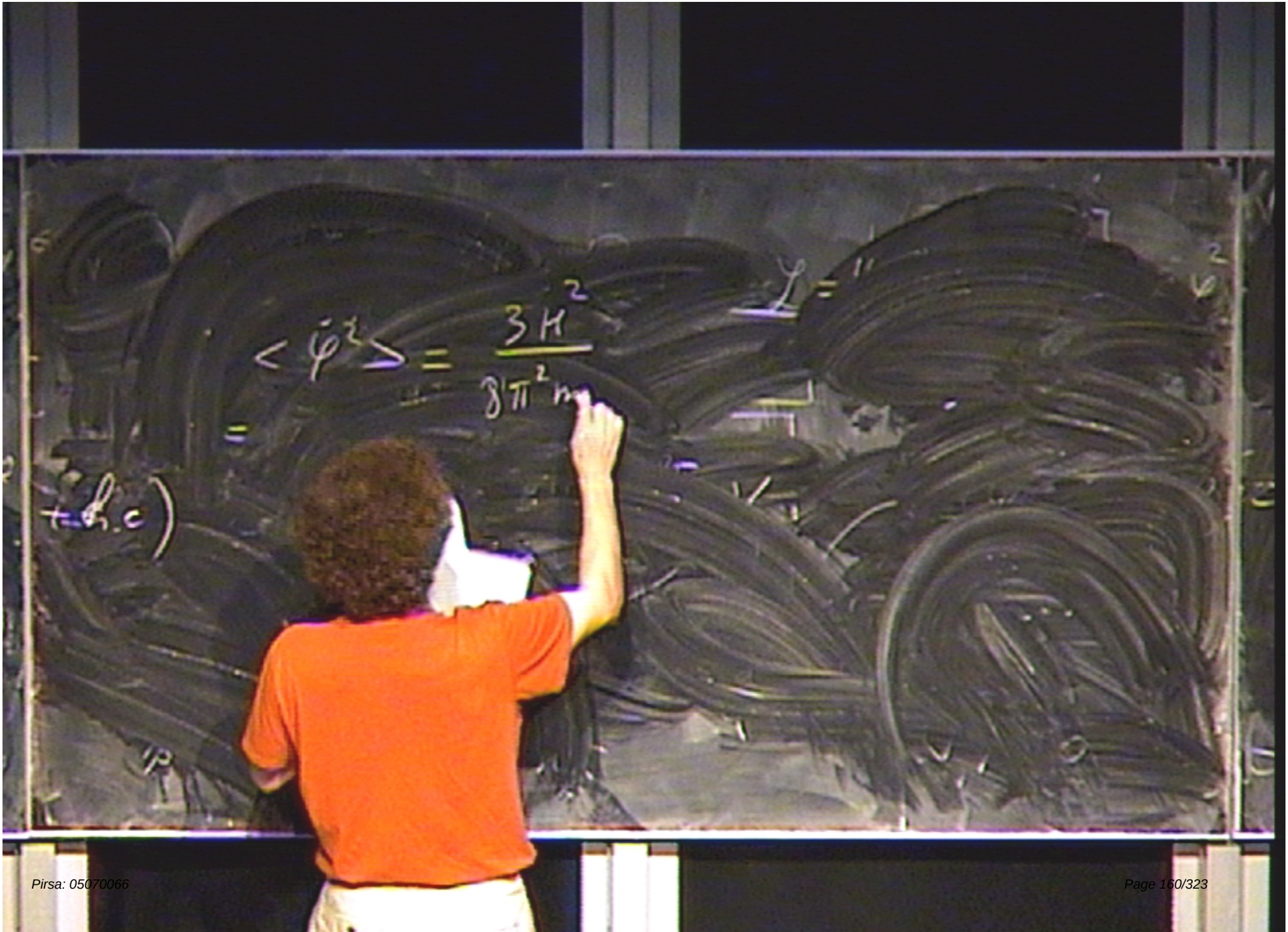

φ = φ(t) + δφ
□φ


$\varphi = \varphi(t) + \delta\varphi$
$\Box\delta\varphi + m^2\delta\varphi = 0$
$\delta\hat{\varphi} = \int d^3k \left(a_{\vec{k}} f_k(t) e^{i\vec{k}\cdot\vec{x}} \right.$
t
$\langle\varphi^2\rangle = 0$
$\langle T^{\mu\nu}\rangle = 0$

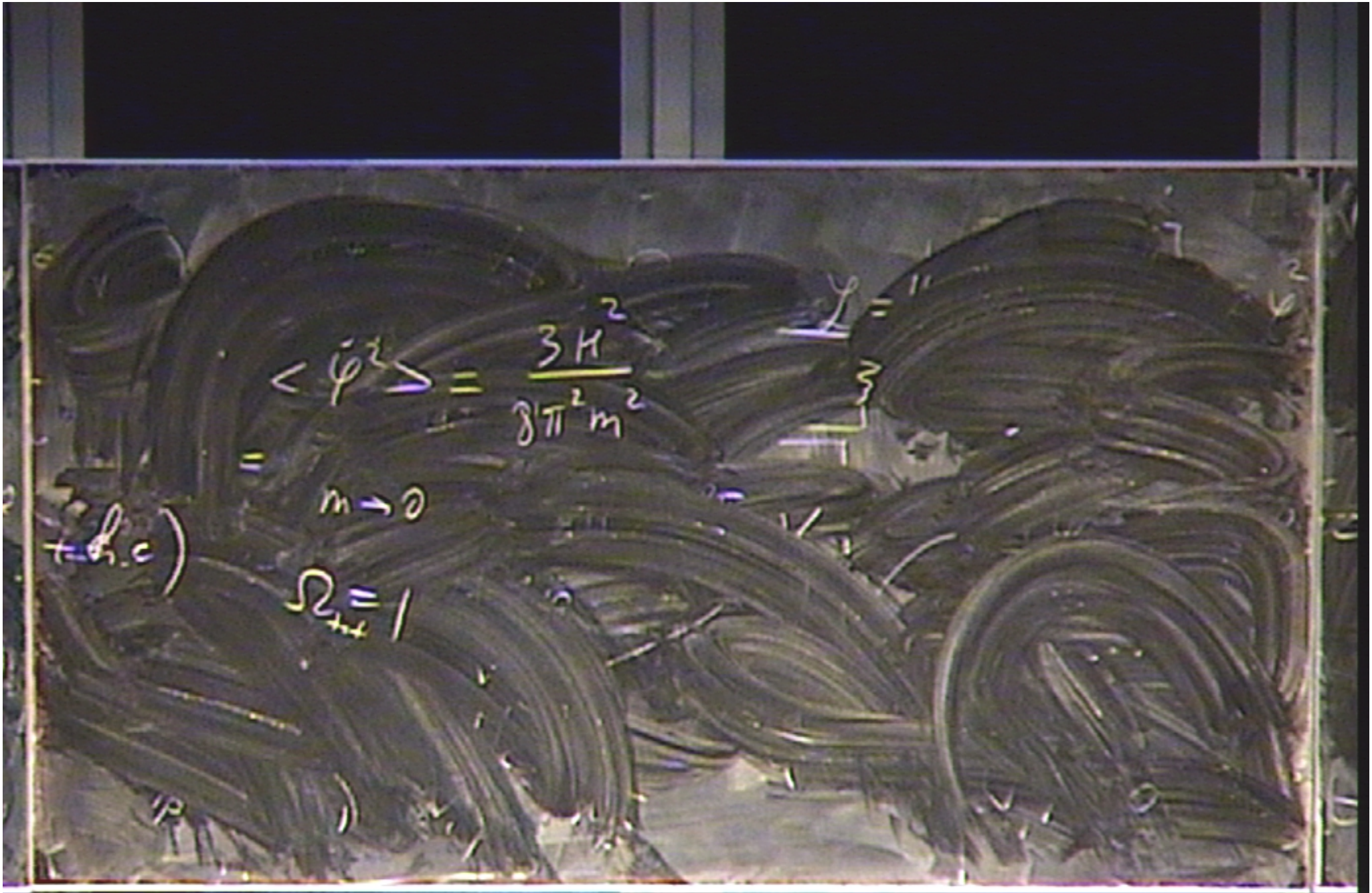

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$\delta\varphi = \int d^3k \left(a_{\vec{k}} f_k(t) e^{i\vec{k}\cdot\vec{x}} \right.$
t
$= 0$
$= 0$

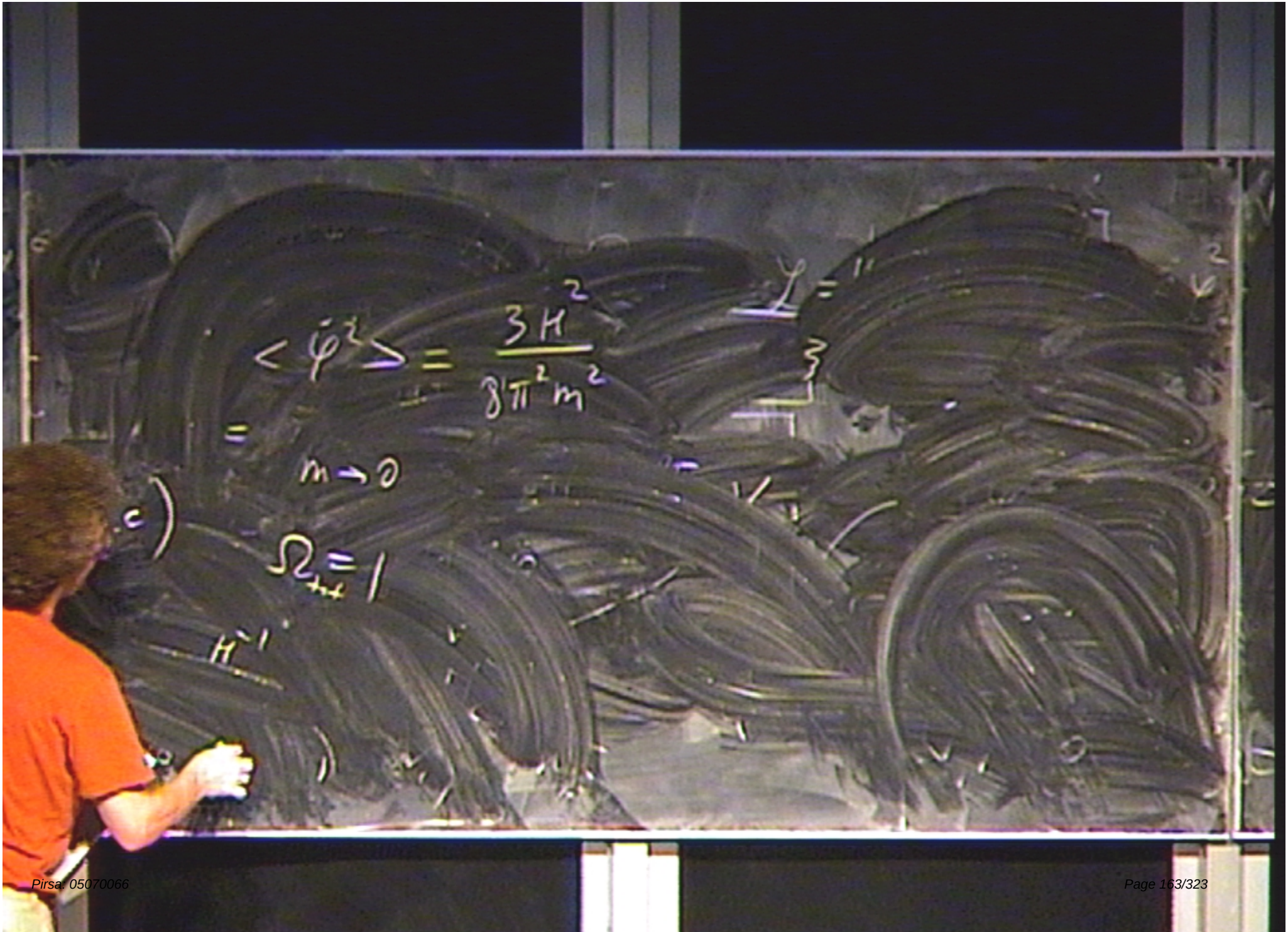

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t
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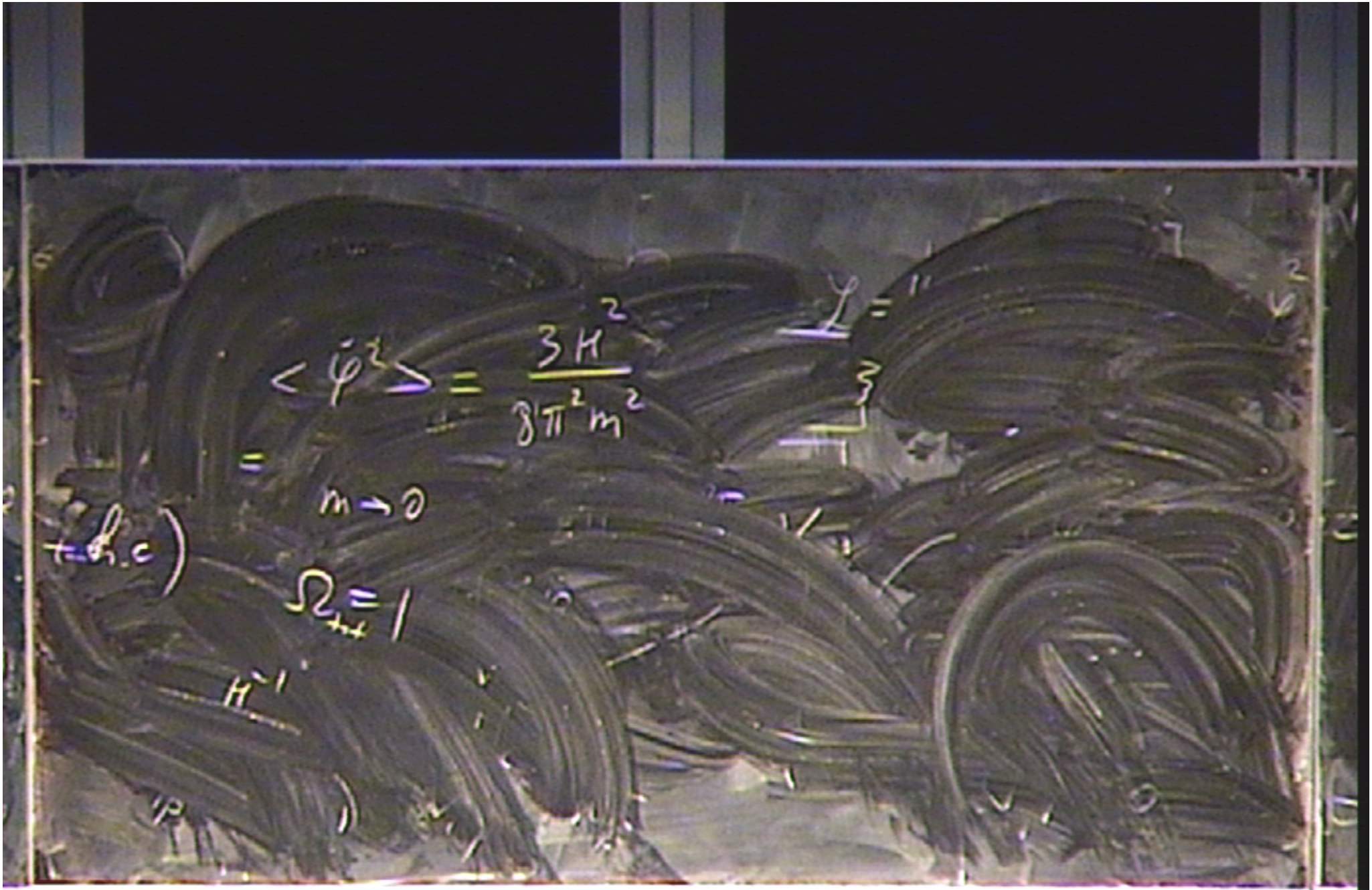

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t
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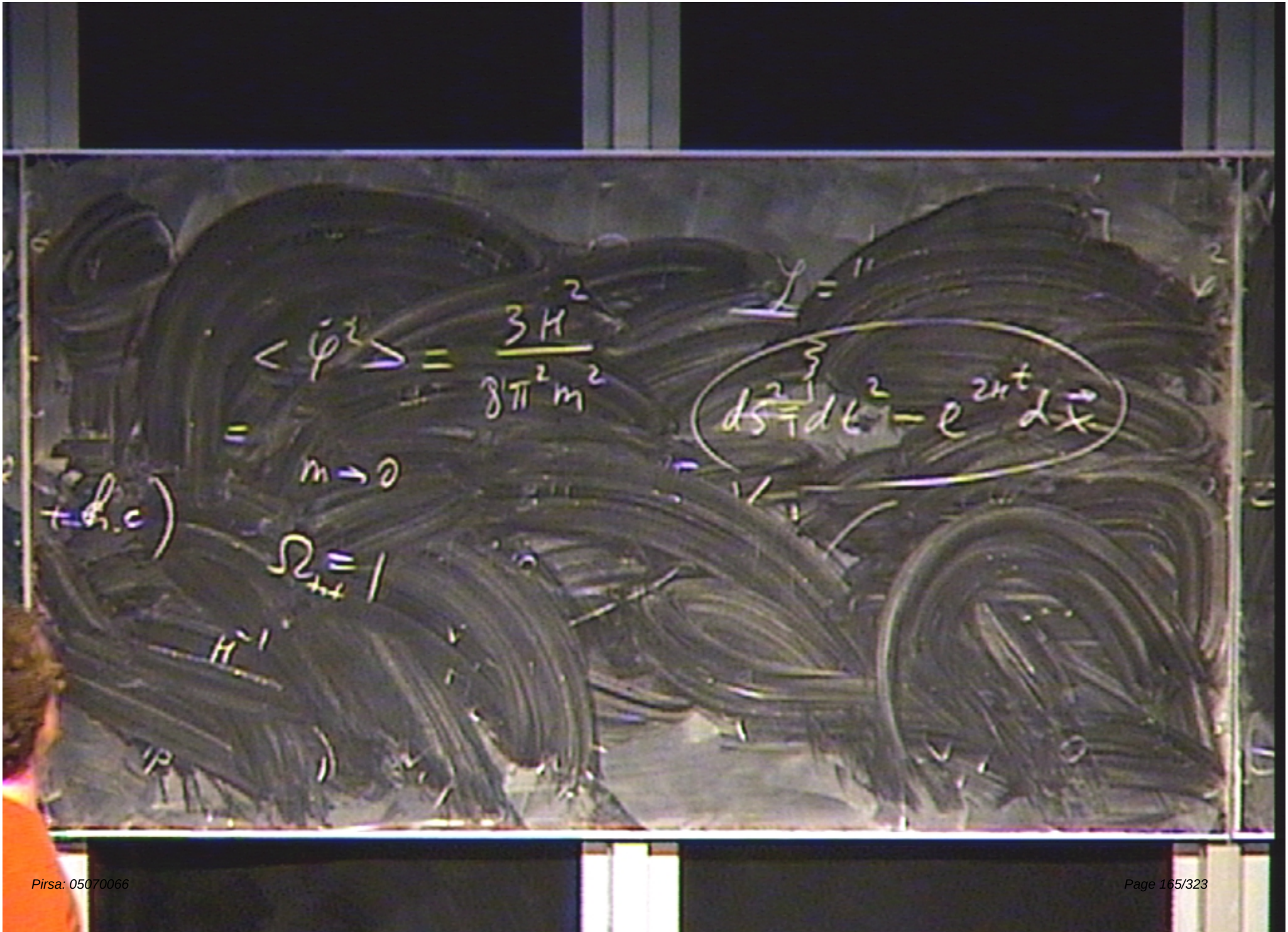

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m}$
+ h.c)


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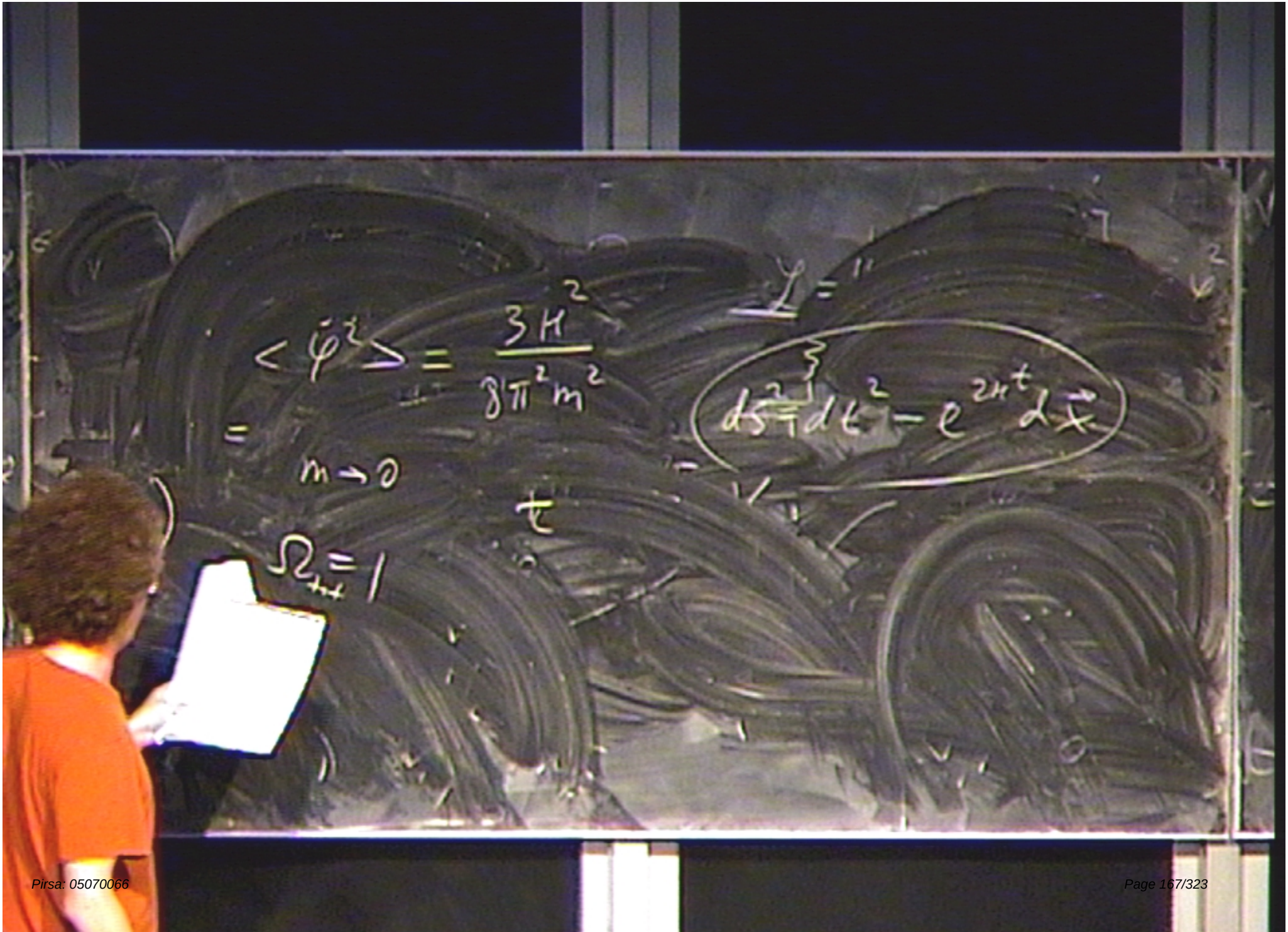

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$

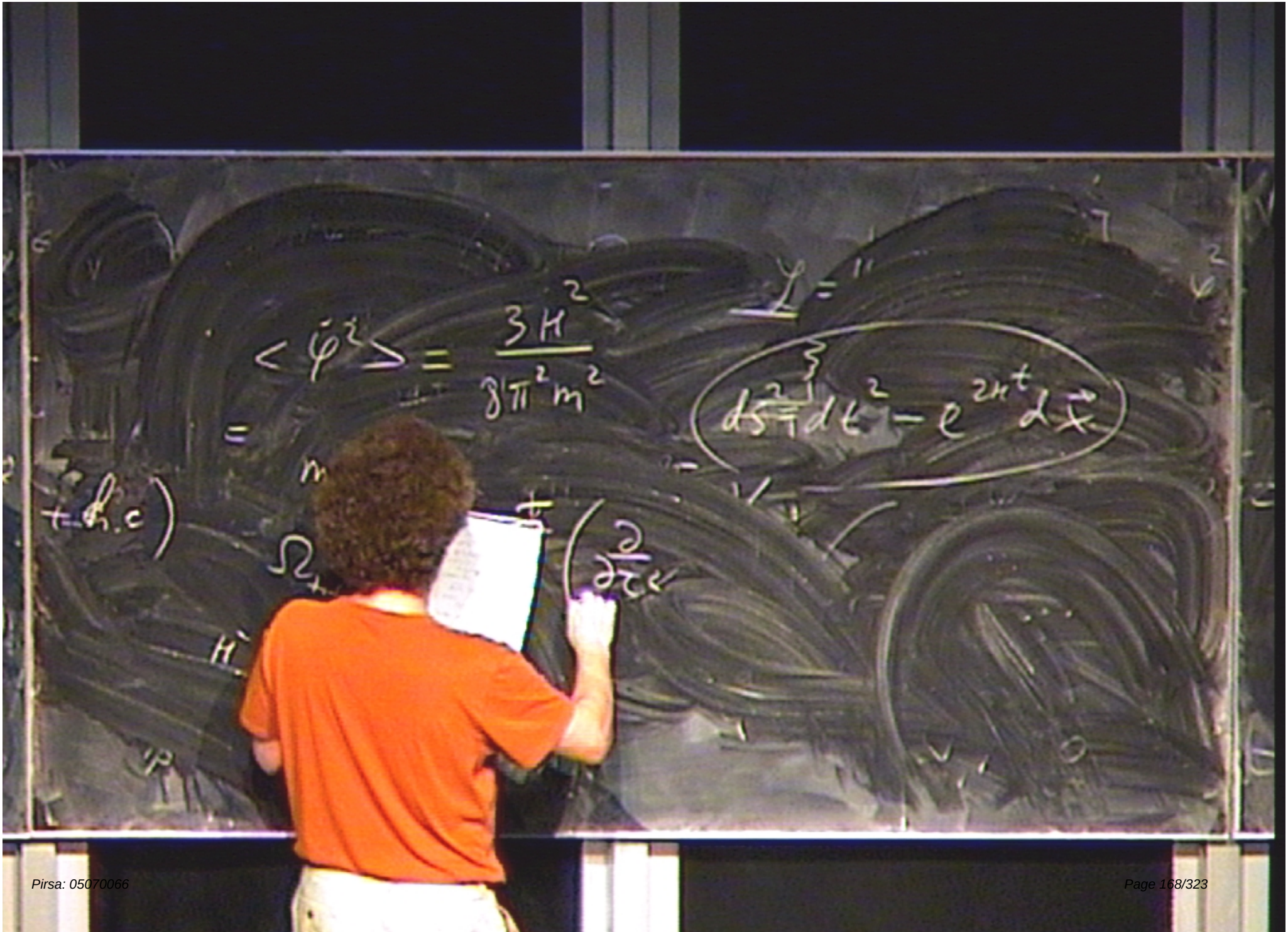

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
c)
$\Omega_{tot} = 1$
H^{-1}

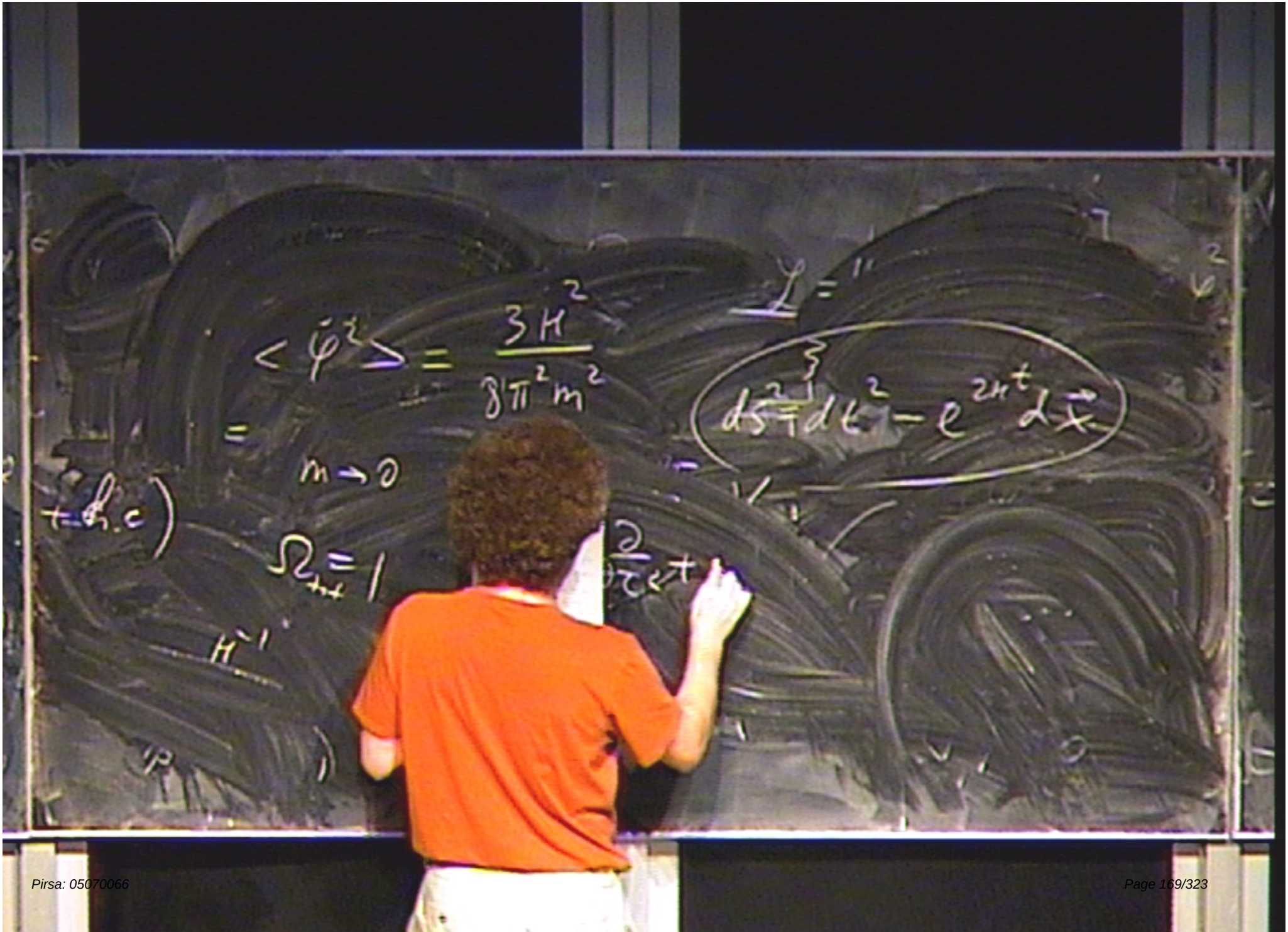

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H^{-1}

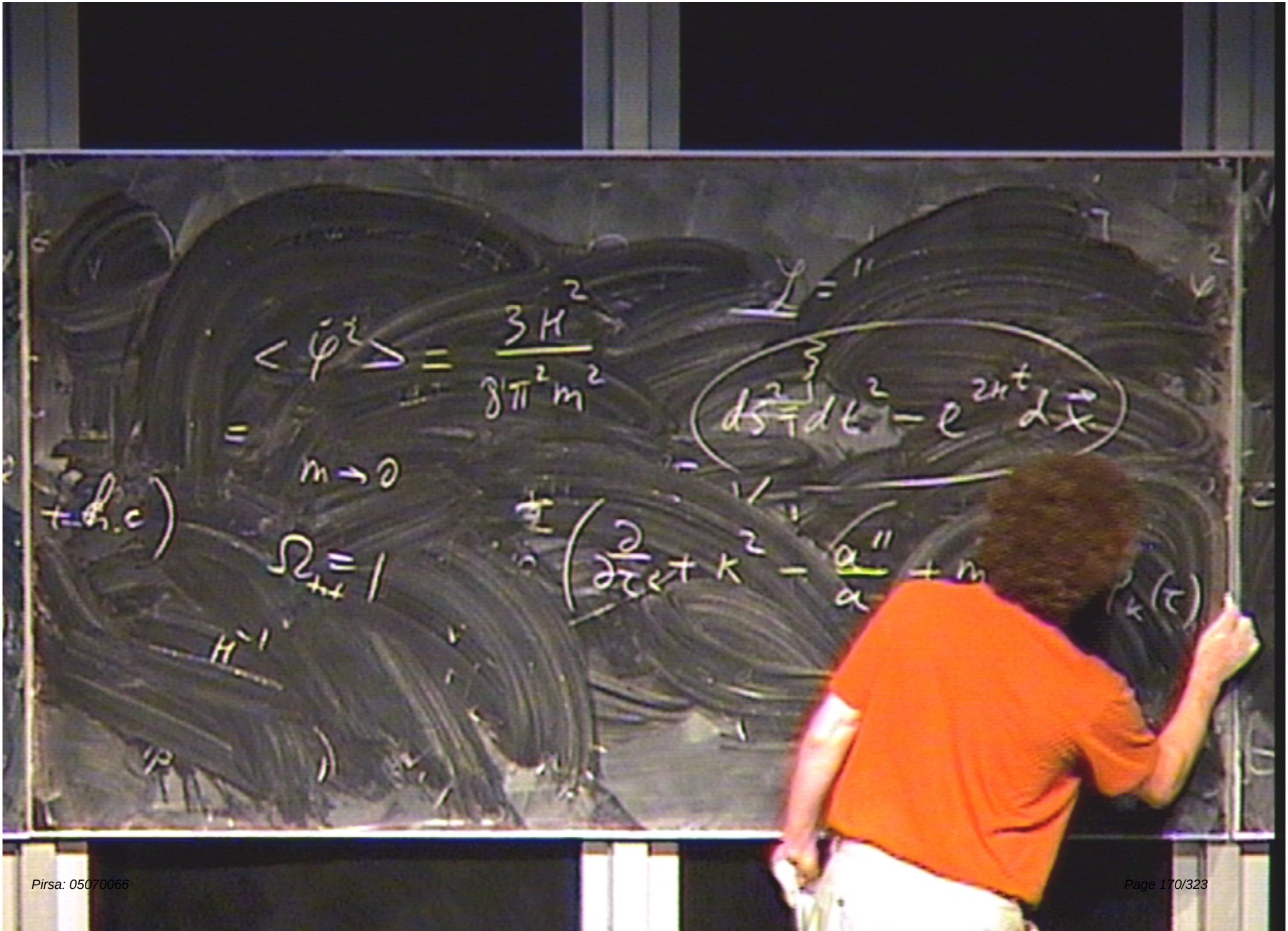

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$\mathcal{L} =$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$

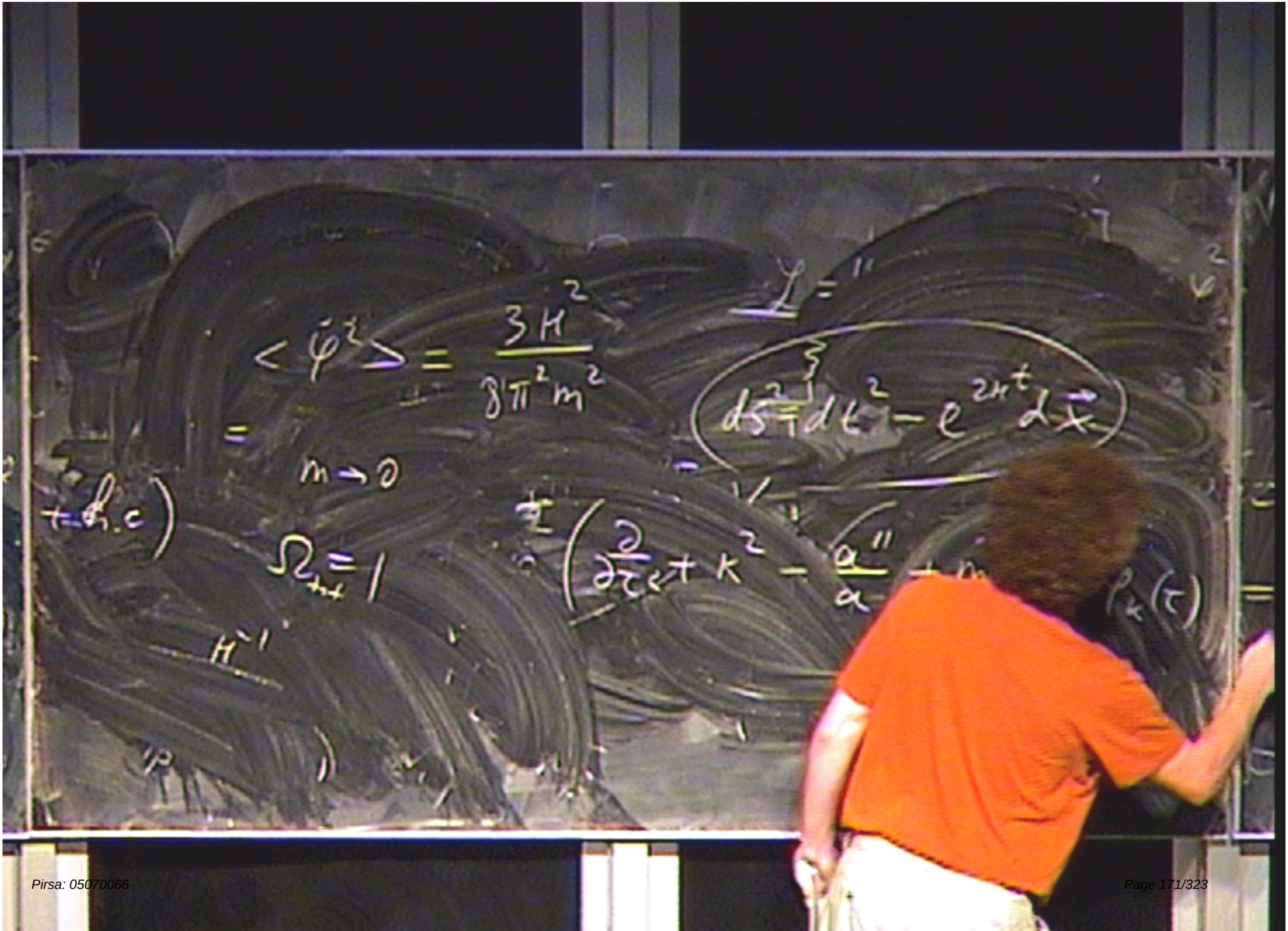

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$m \to 0$
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$ds^2 = dt^2 - e^{2Ht} d\vec{x}$

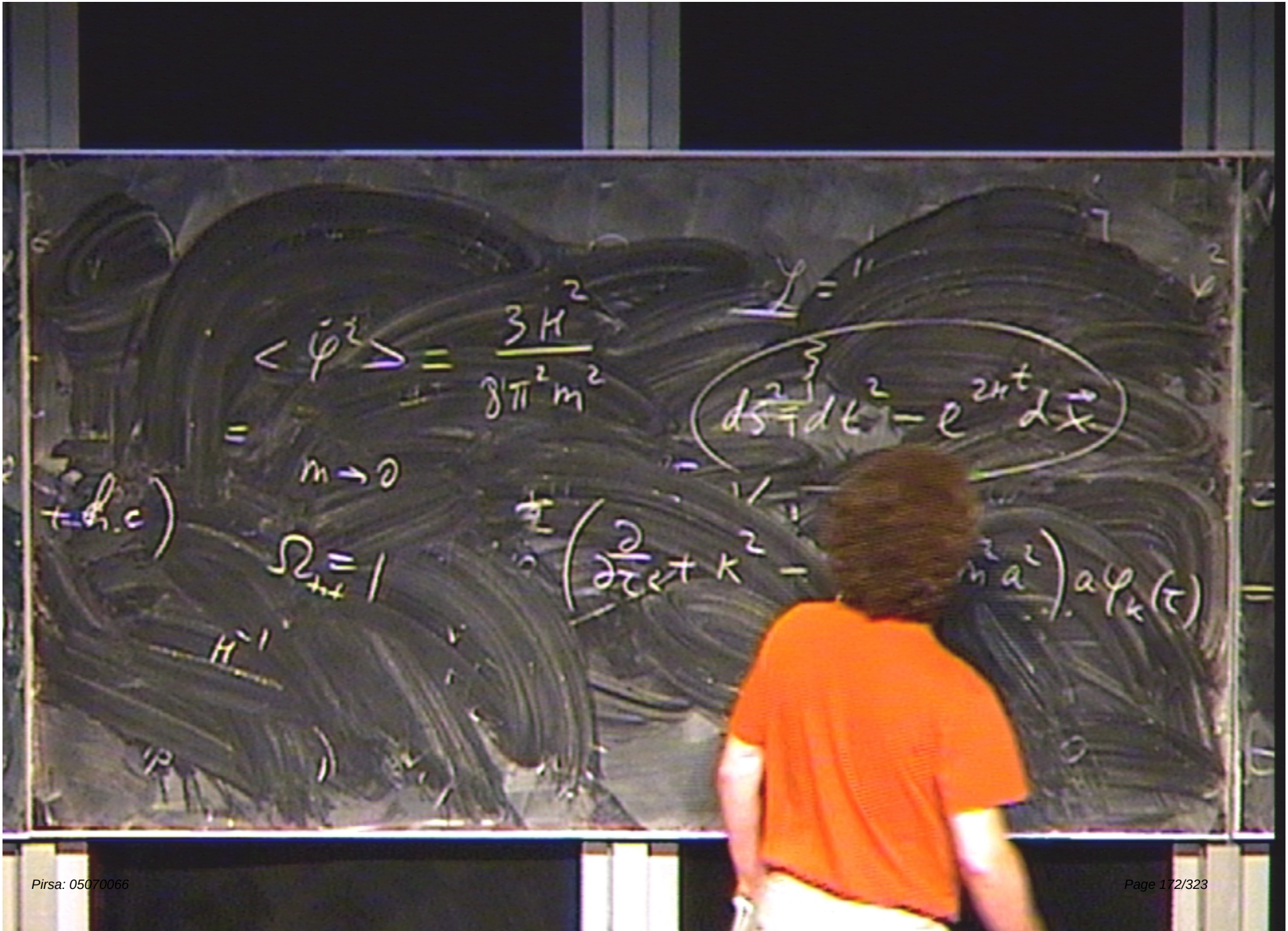

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
t
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$

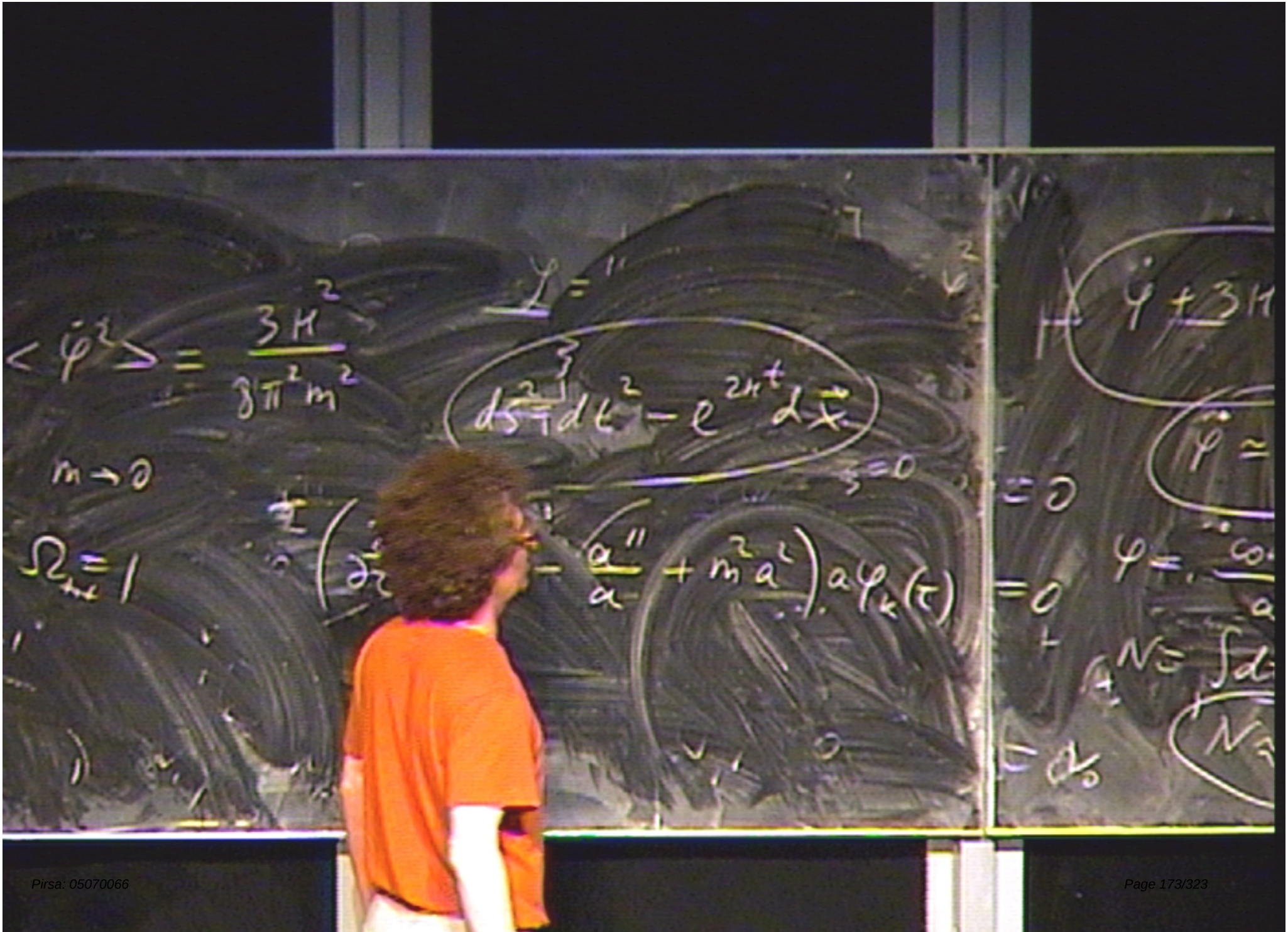

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$

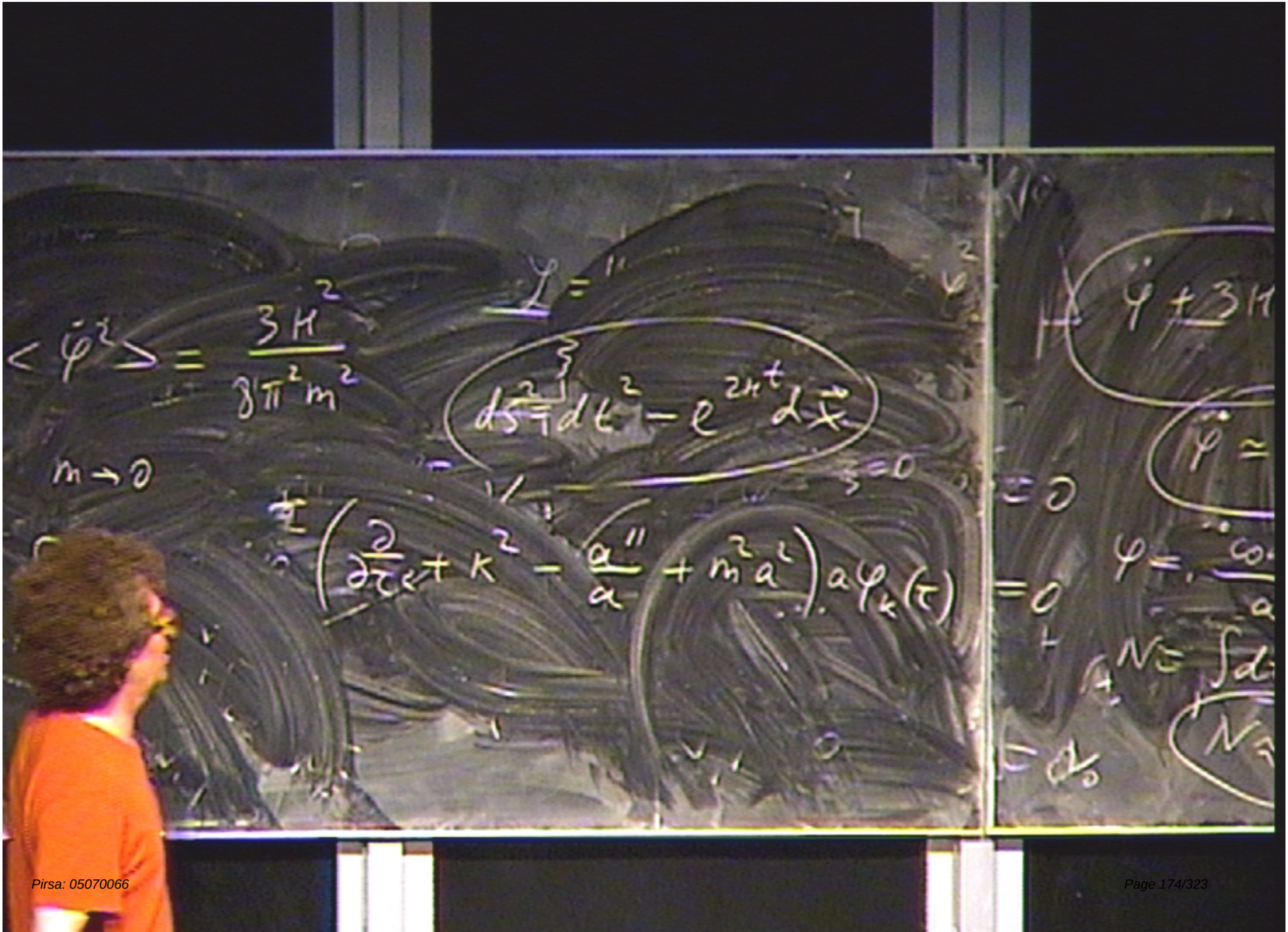

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$

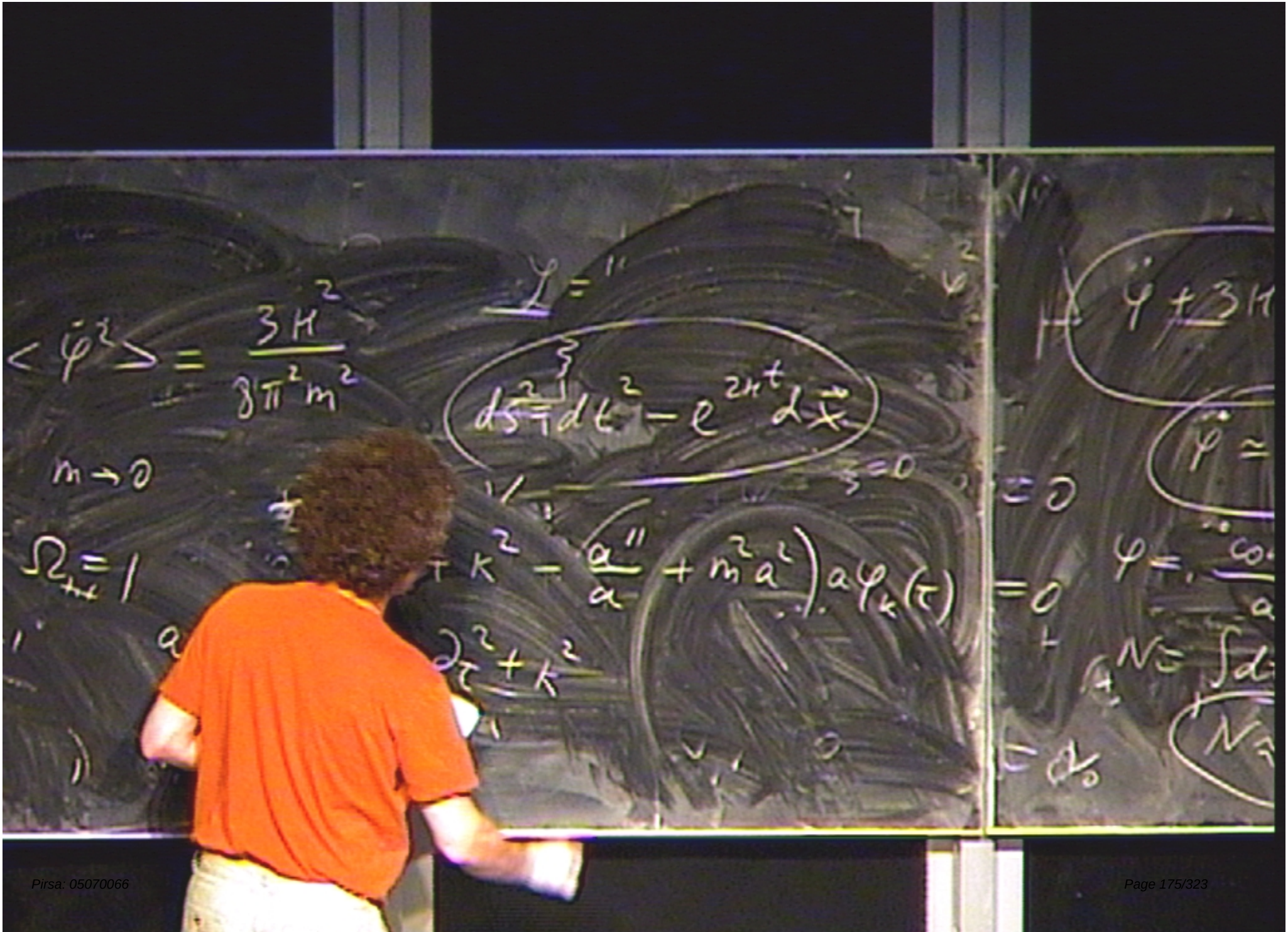

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\left(\frac{\partial^2}{\partial \tau^2} + k^2 - \frac{a''}{a} + m \right)$

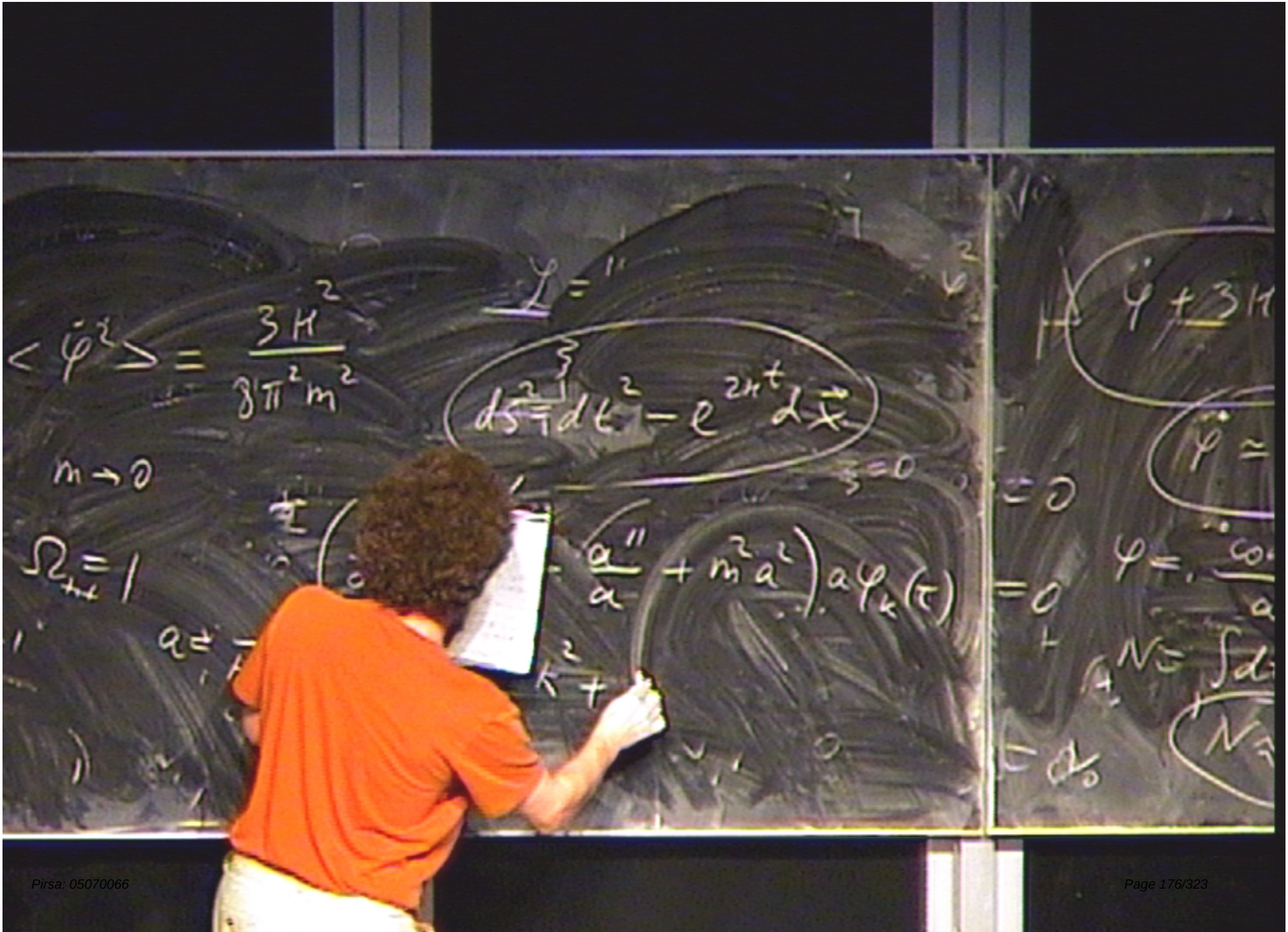

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\left(\frac{\partial^2}{\partial \tau^2} + k^2 - \frac{a''}{a} + m \right)$
$\rho_k(\tau)$

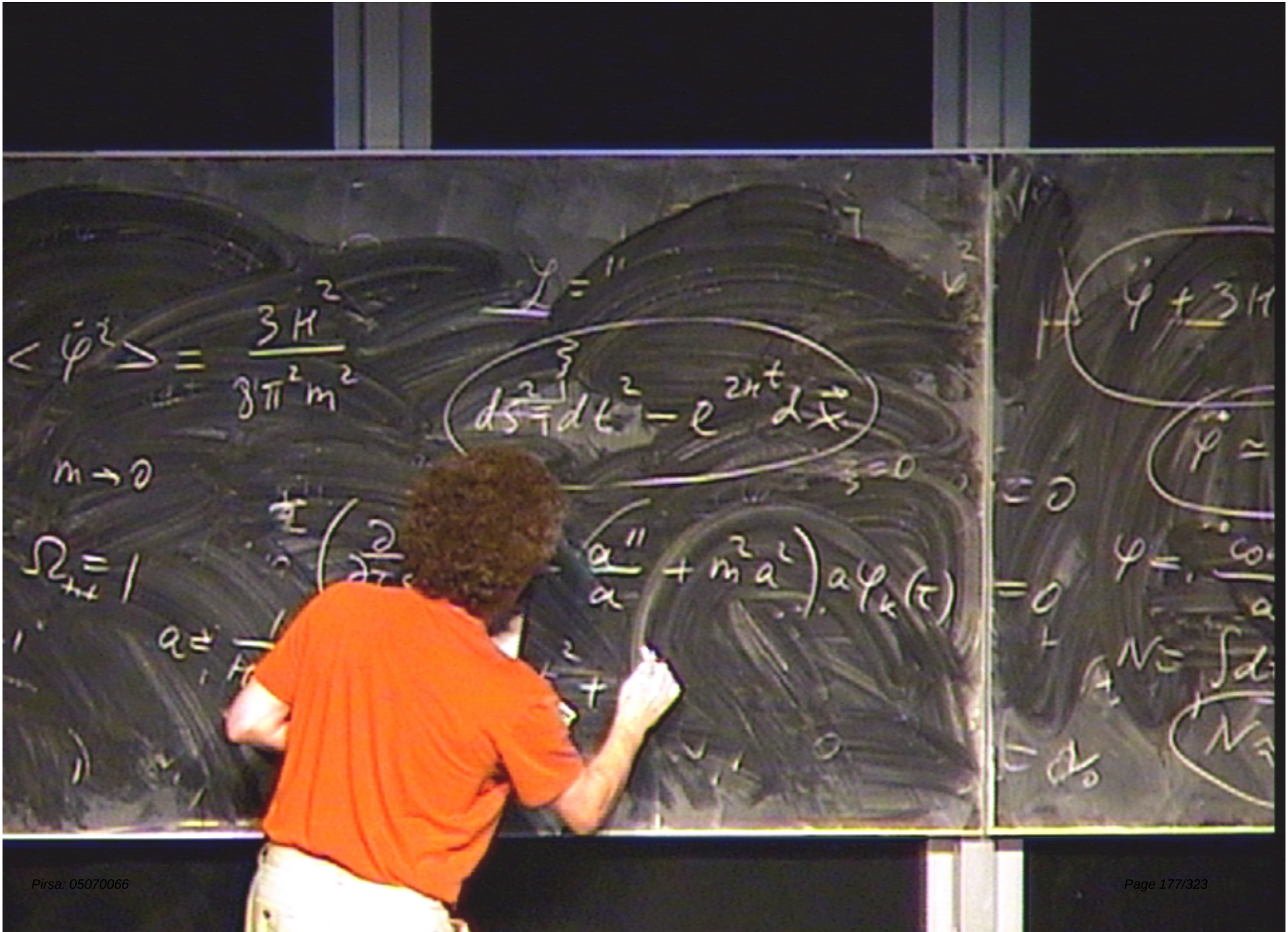

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\left(\frac{\partial^2}{\partial \tau^2} + k^2 - m^2 a^2 \right) a\varphi_k(\tau)$

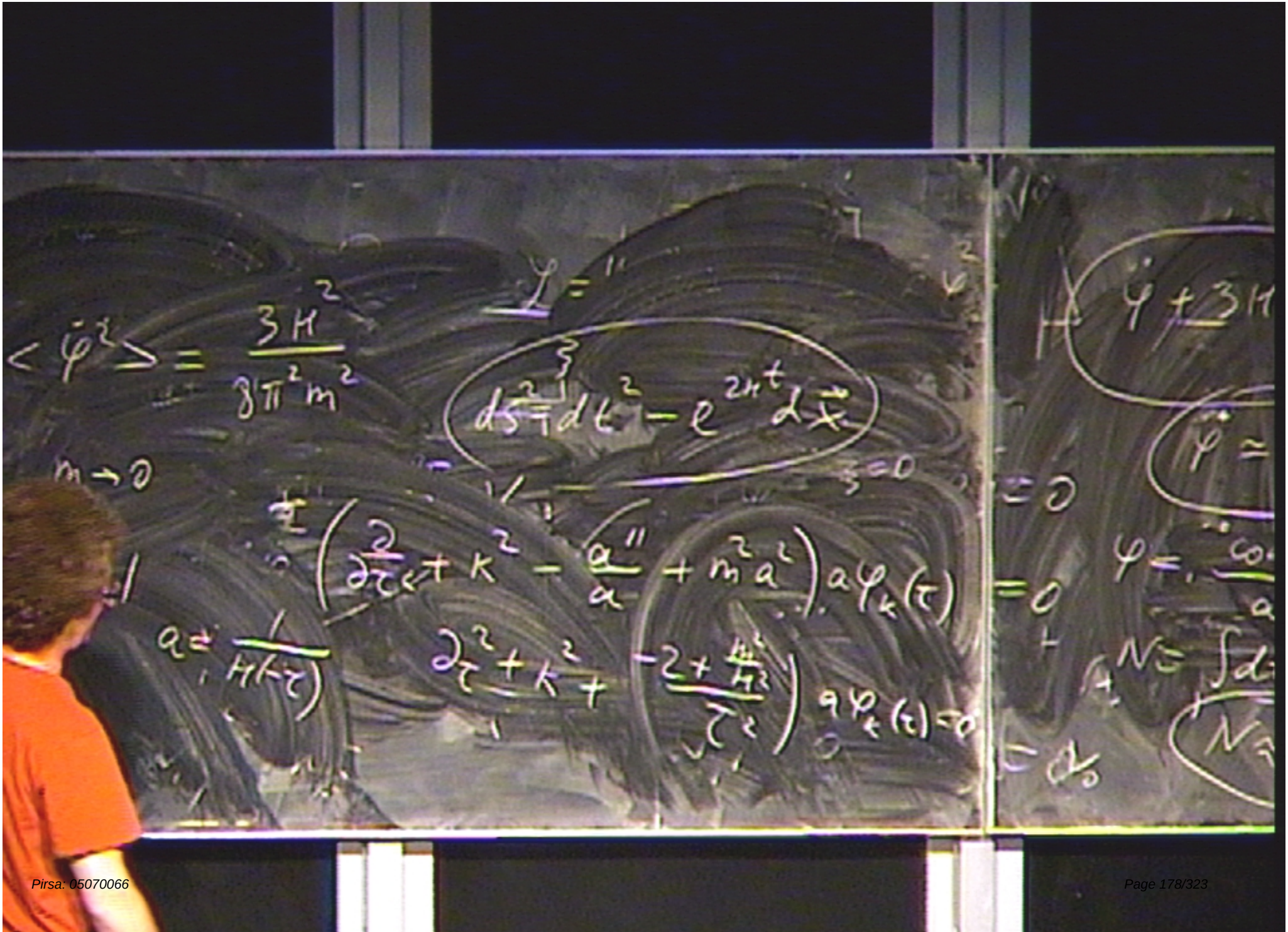

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$m \to 0$
$\Omega = 1$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\varphi = \frac{\dot{\varphi}_0}{a}$
$N = \int dt$
$N =$

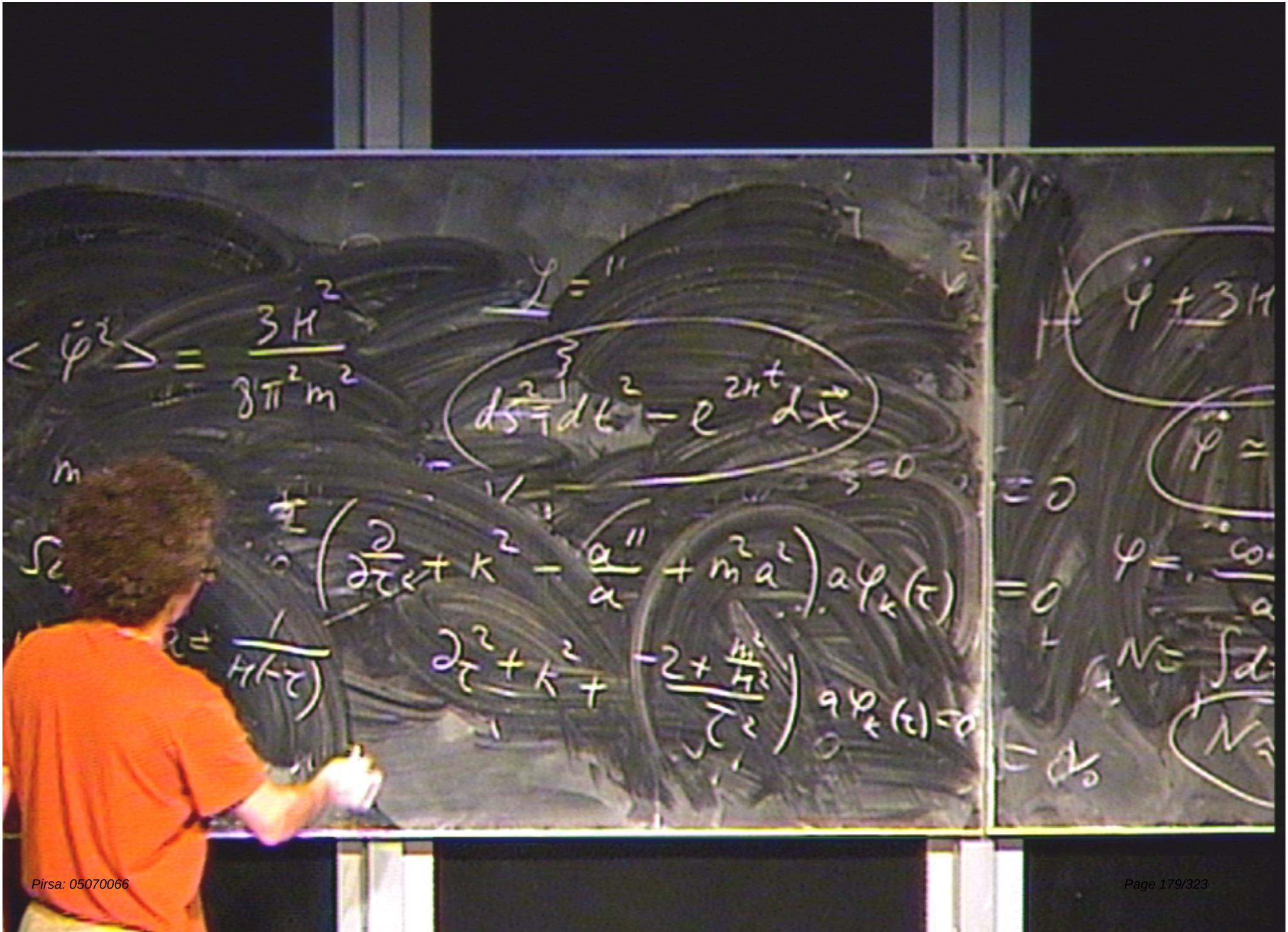

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$m \to 0$
$\left(\frac{\partial^2}{\partial \tau^2} + k^2 - \frac{a''}{a} + m^2 a^2 \right) a\varphi_k(\tau) = 0$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\varphi =$
$N =$

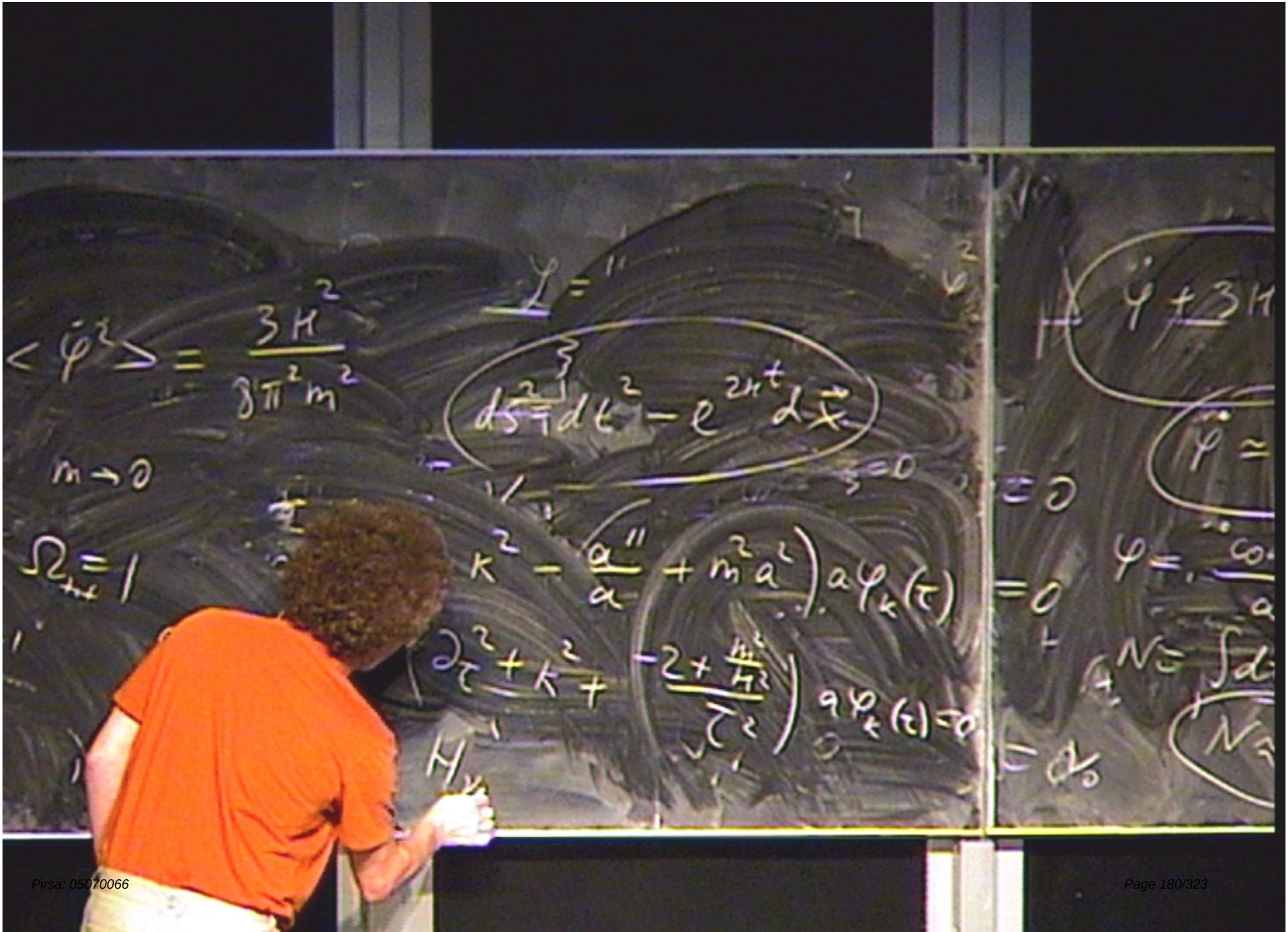

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$m \to 0$
$\Omega_{tot} = 1$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\varphi =$
$N =$

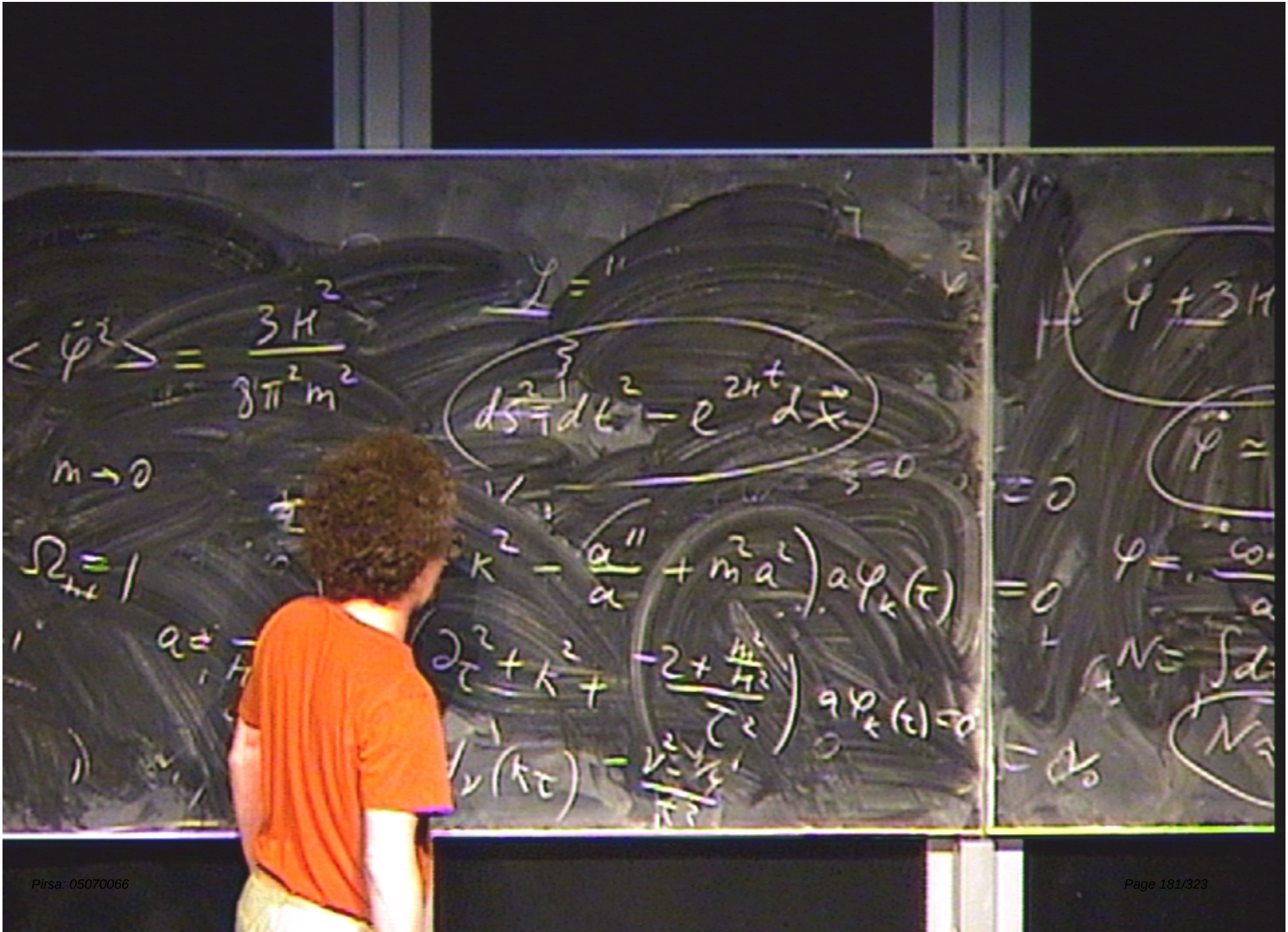

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$m \to 0$
$\Omega_{tot} = 1$
$\left(\frac{a''}{a} + m^2 a^2 \right) a\varphi_k(\tau) = 0$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\varphi = \frac{\dot{\varphi}}{a}$
$N = \int dt$

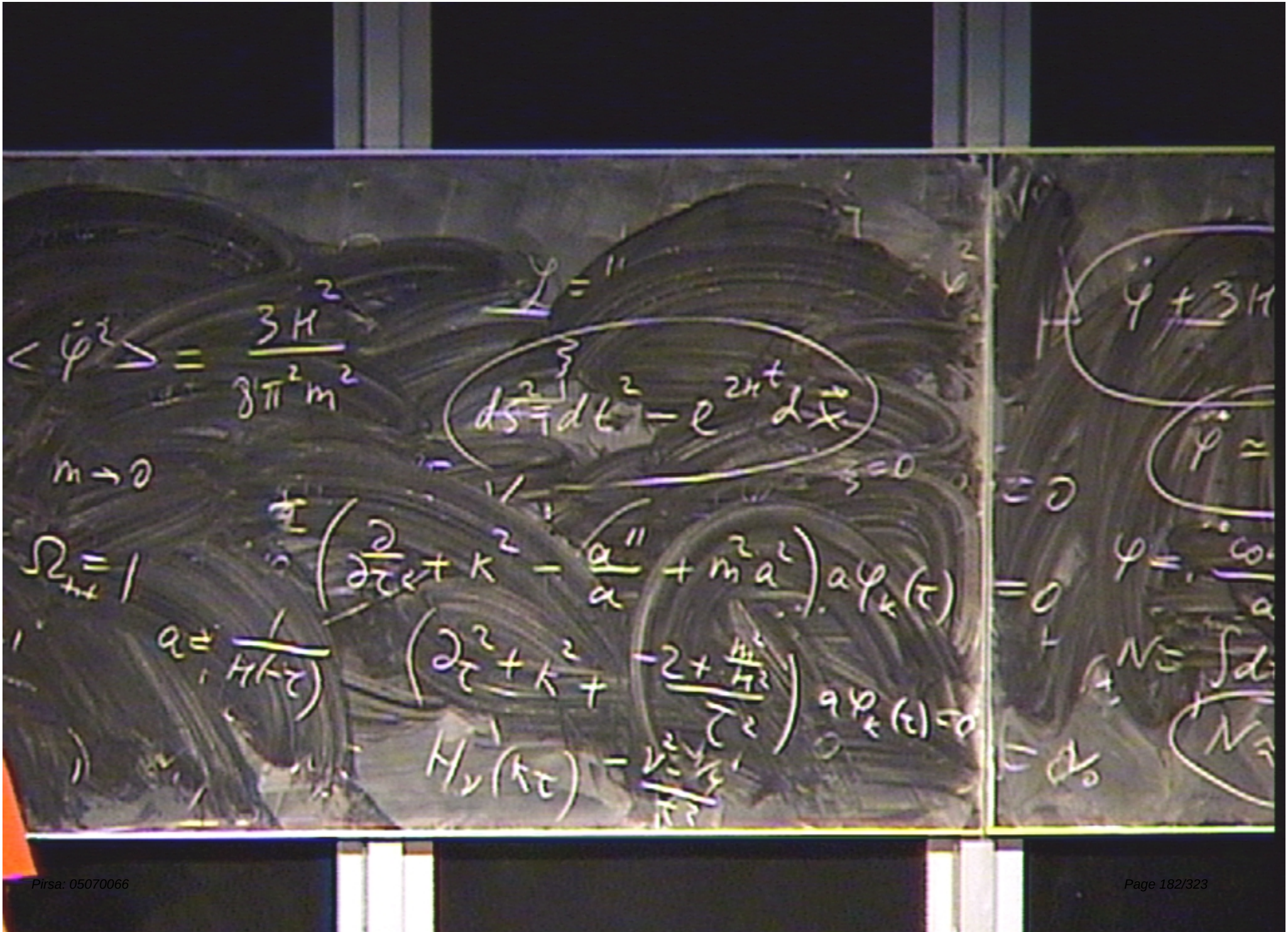

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$m \to 0$
$\Omega_{tot} = 1$
$\left(\frac{\partial}{\partial \tau} \right.$
$\left. - \frac{a''}{a} + m^2 a^2 \right) a \varphi_k(\tau)$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\dot{\varphi} = \frac{\omega}{a}$
$N = \int dt$

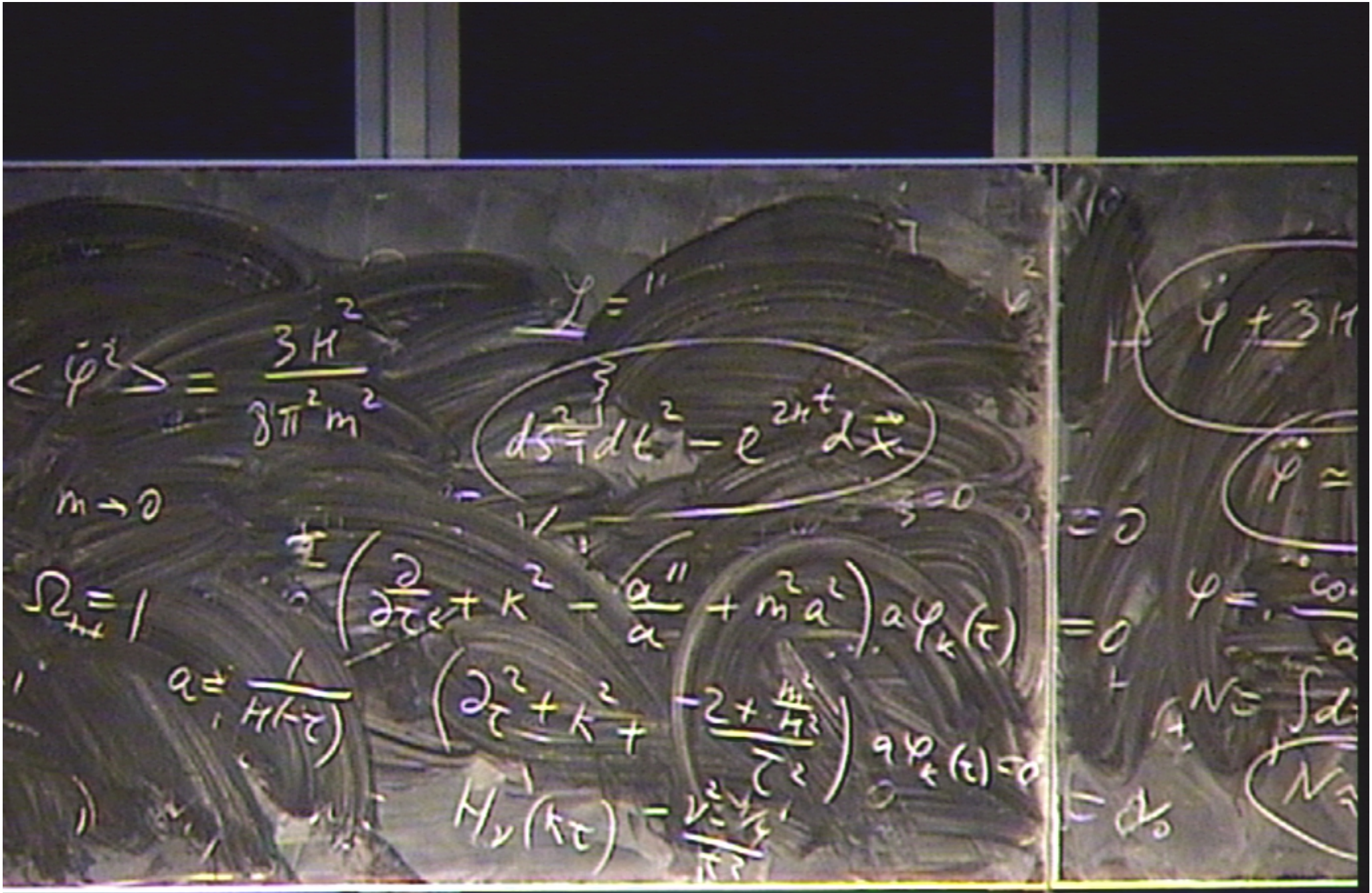

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$\left(\frac{\partial^2}{\partial \tau^2} + k^2 - \frac{a''}{a} + m^2 a^2 \right) a\varphi_k(\tau) = 0$
$a = \frac{1}{H(-\tau)}$
$\partial_\tau^2 + k^2 + \left(\frac{-2 + \frac{m^2}{H^2}}{\tau^2} \right) a\varphi_k(\tau) = 0$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} =$
$\varphi =$
$N =$

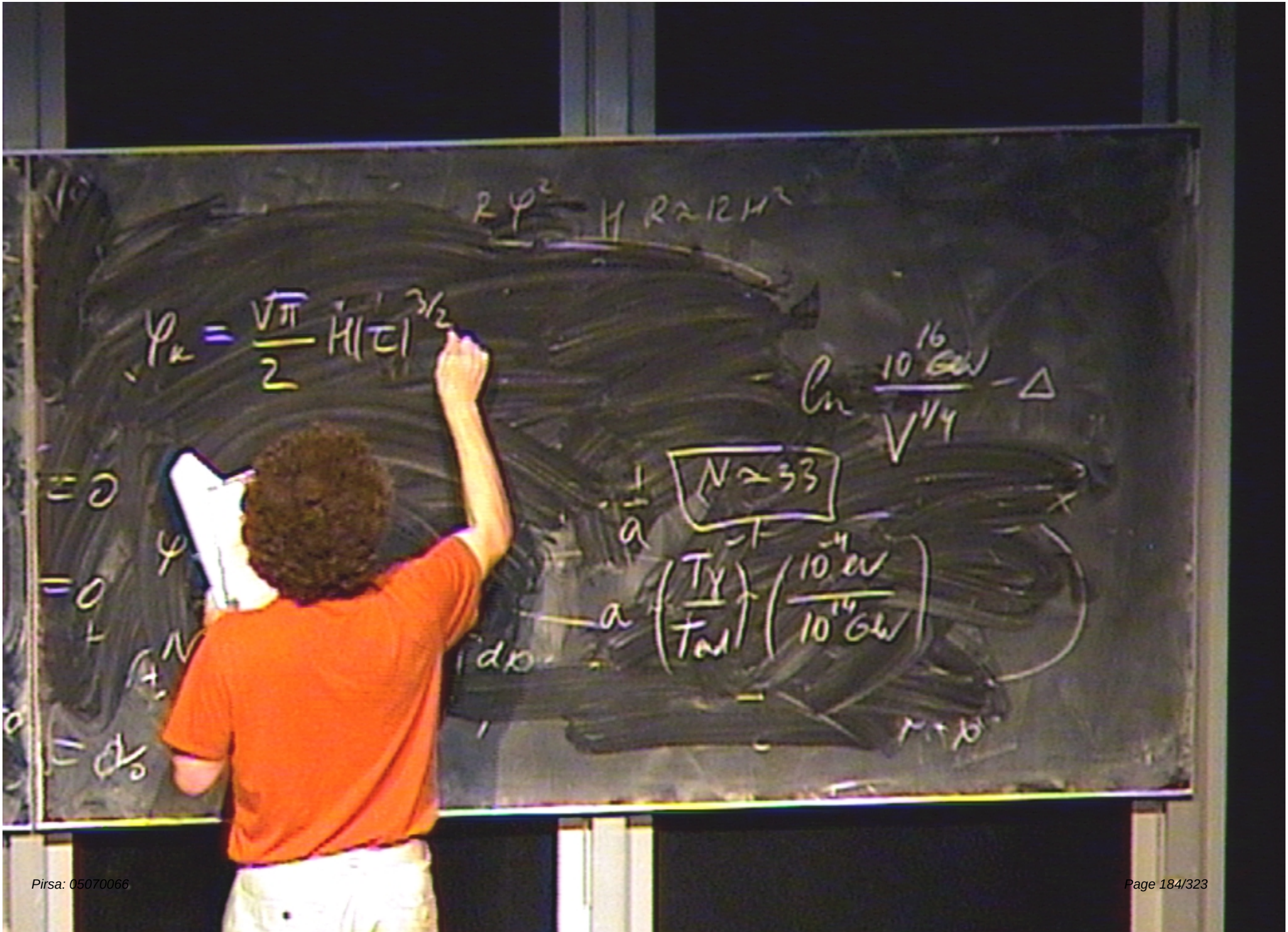

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\left(\frac{\partial^2}{\partial \tau^2} + k^2 - \frac{a''}{a} + m^2 a^2\right) a\varphi_k(\tau) = 0$
$\tau = \frac{1}{H(-\tau)}$
$\partial_\tau^2 + k^2 + \left(\frac{-2 + \frac{m^2}{H^2}}{\tau^2}\right) a\varphi_k(\tau) = 0$

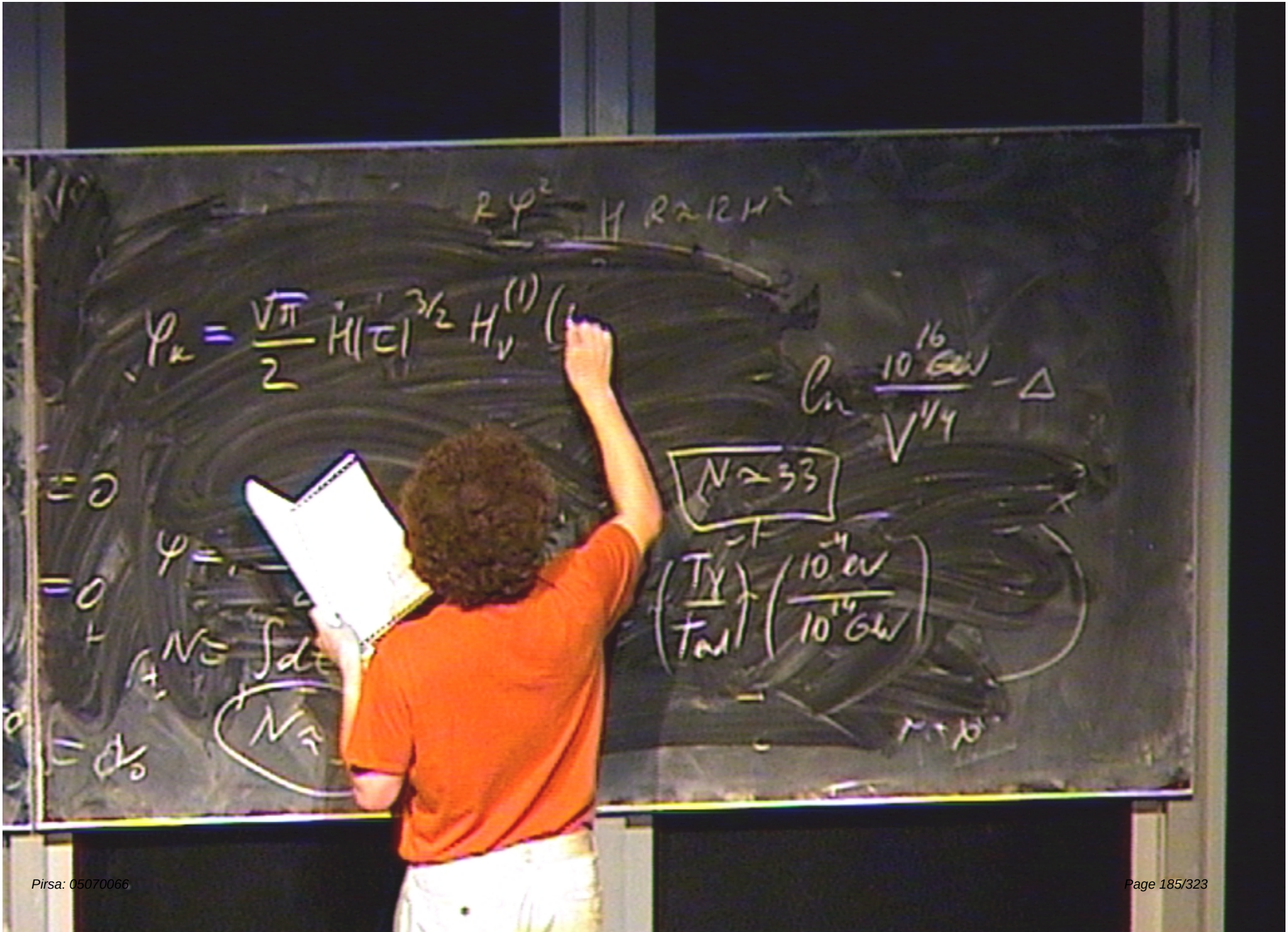

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\left(k^2 - \frac{a''}{a} + m^2 a^2\right) a\varphi_k(\tau) = 0$
$\left(\partial_\tau^2 + k^2 + \frac{-2 + \frac{m^2}{H^2}}{\tau^2}\right) a\varphi_k(\tau) = 0$
H

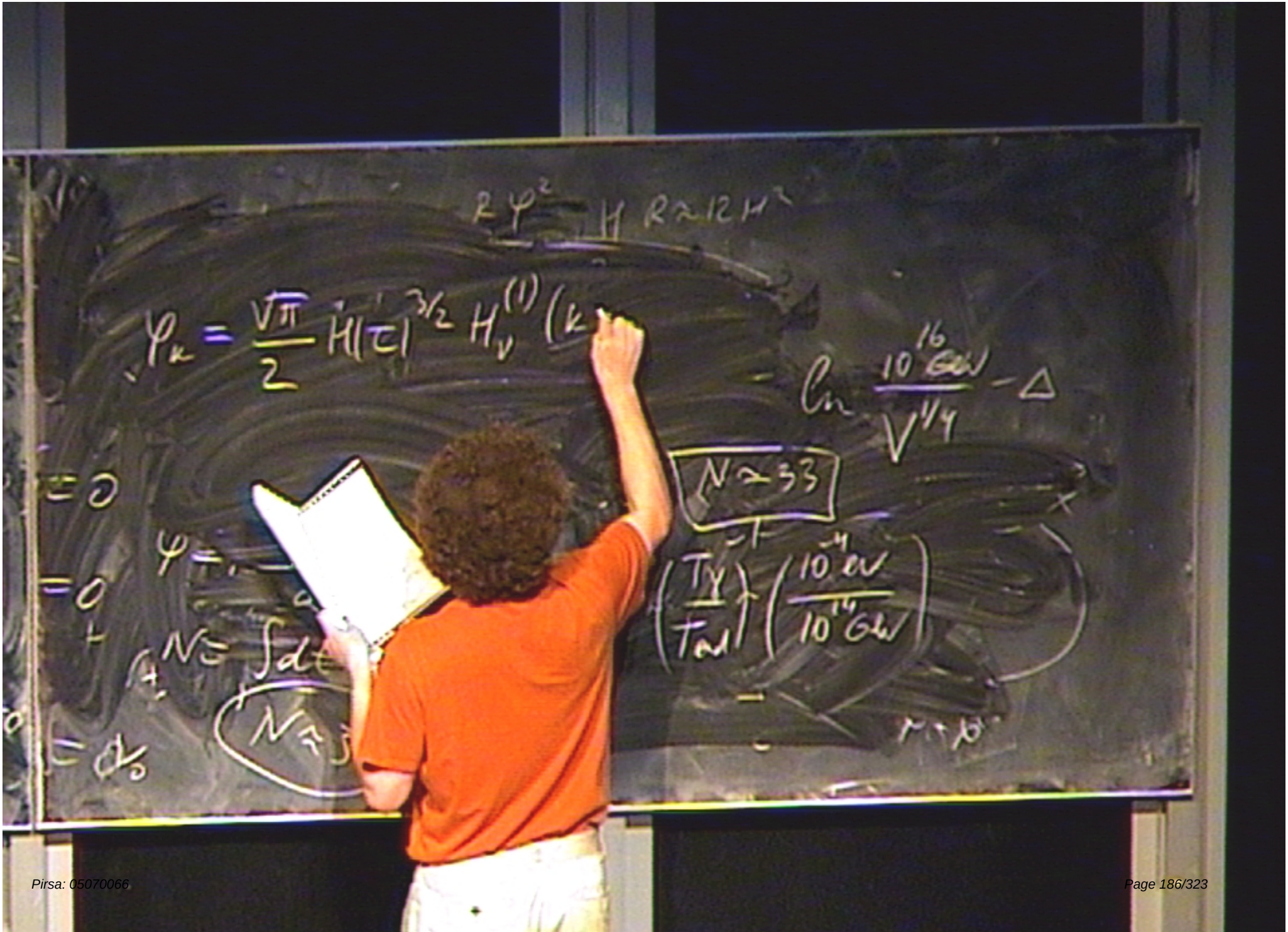

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$m \to 0$
$\Omega_{tot} = 1$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\varphi =$
$N =$

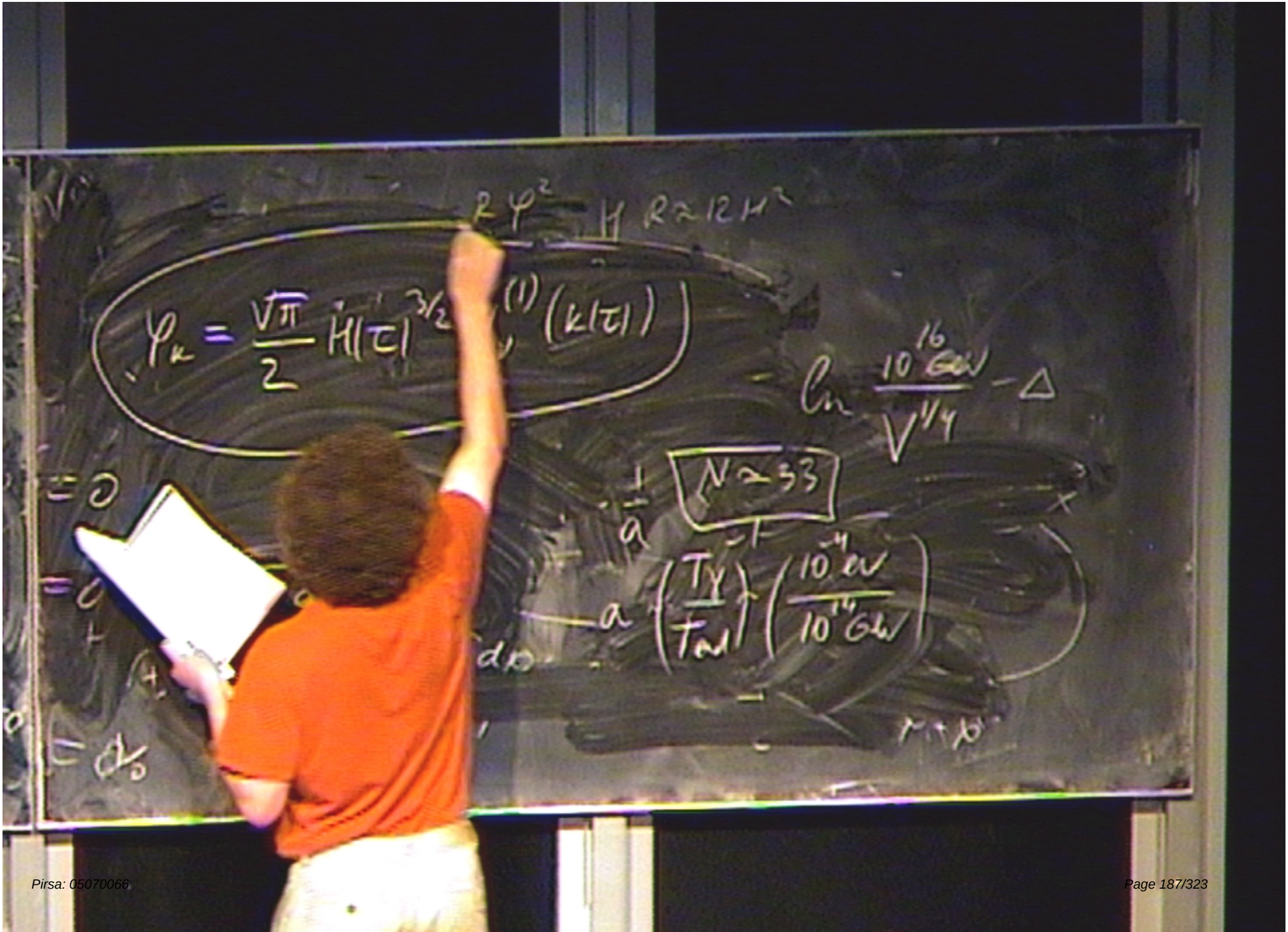

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_m = 1$
$a = \frac{1}{H(-\tau)}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$\left(\frac{\partial}{\partial \tau^2} + k^2 - \frac{a''}{a} + m^2 a^2\right) a\varphi_k(\tau) = 0$
$\left(\partial_\tau^2 + k^2 + \frac{-2 + \frac{m^2}{H^2}}{\tau^2}\right) a\varphi_k(\tau) = 0$
$H_\nu(k\tau)$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\varphi =$
$N =$

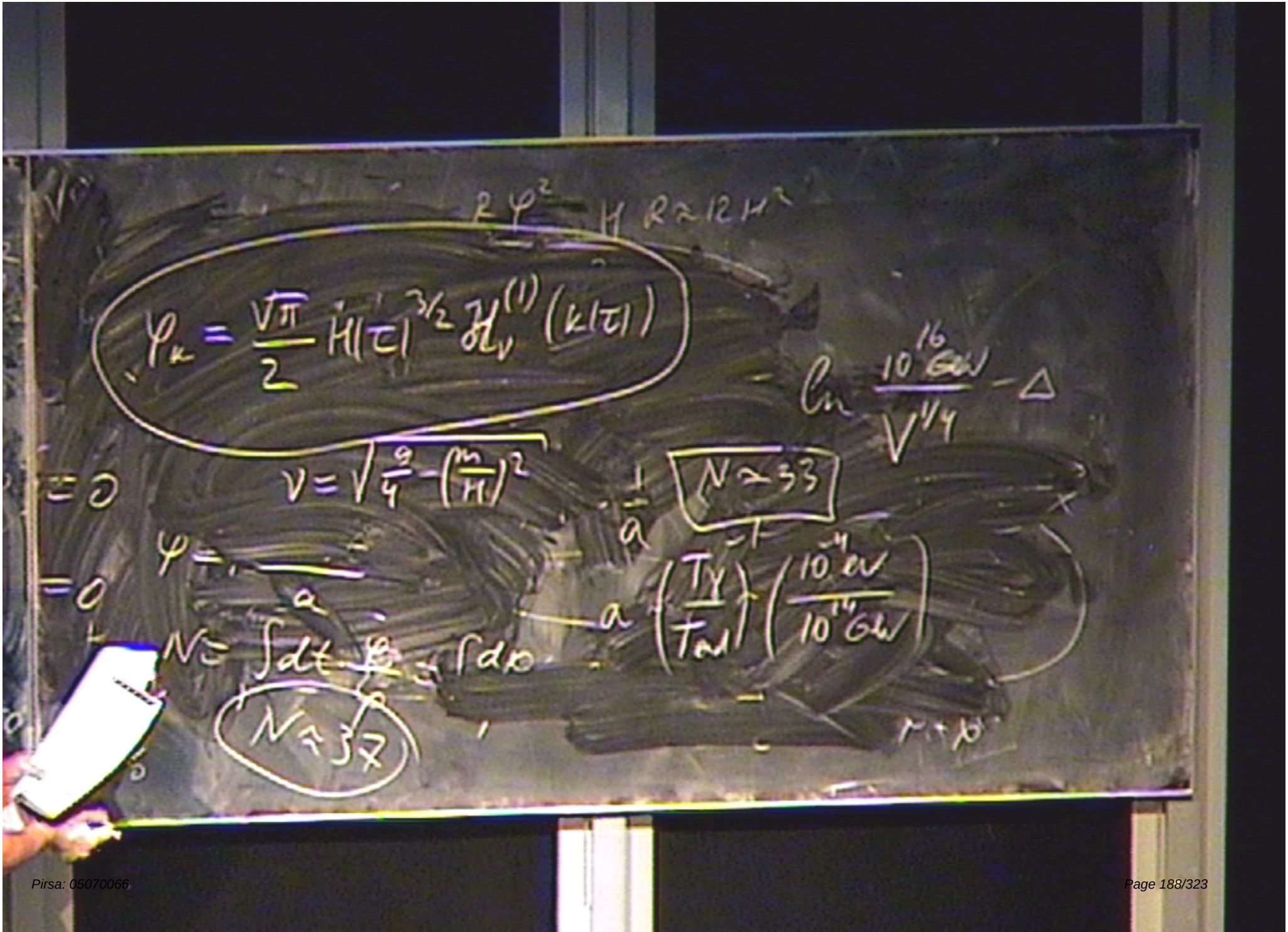

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
$a = \frac{1}{H(-\tau)}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\left(\frac{\partial}{\partial \tau^2} + k^2 - \frac{a''}{a} + m^2 a^2 \right) a\varphi_k(\tau) = 0$
$\left(\partial_\tau^2 + k^2 + \frac{-2 + \frac{H^2}{H^2}}{\tau^2} \right) a\varphi_k(\tau) = 0$
$H_\nu(k\tau)$
$\ddot{\varphi} + 3H$
$\ddot{\varphi} \approx$
$\varphi =$
$N =$

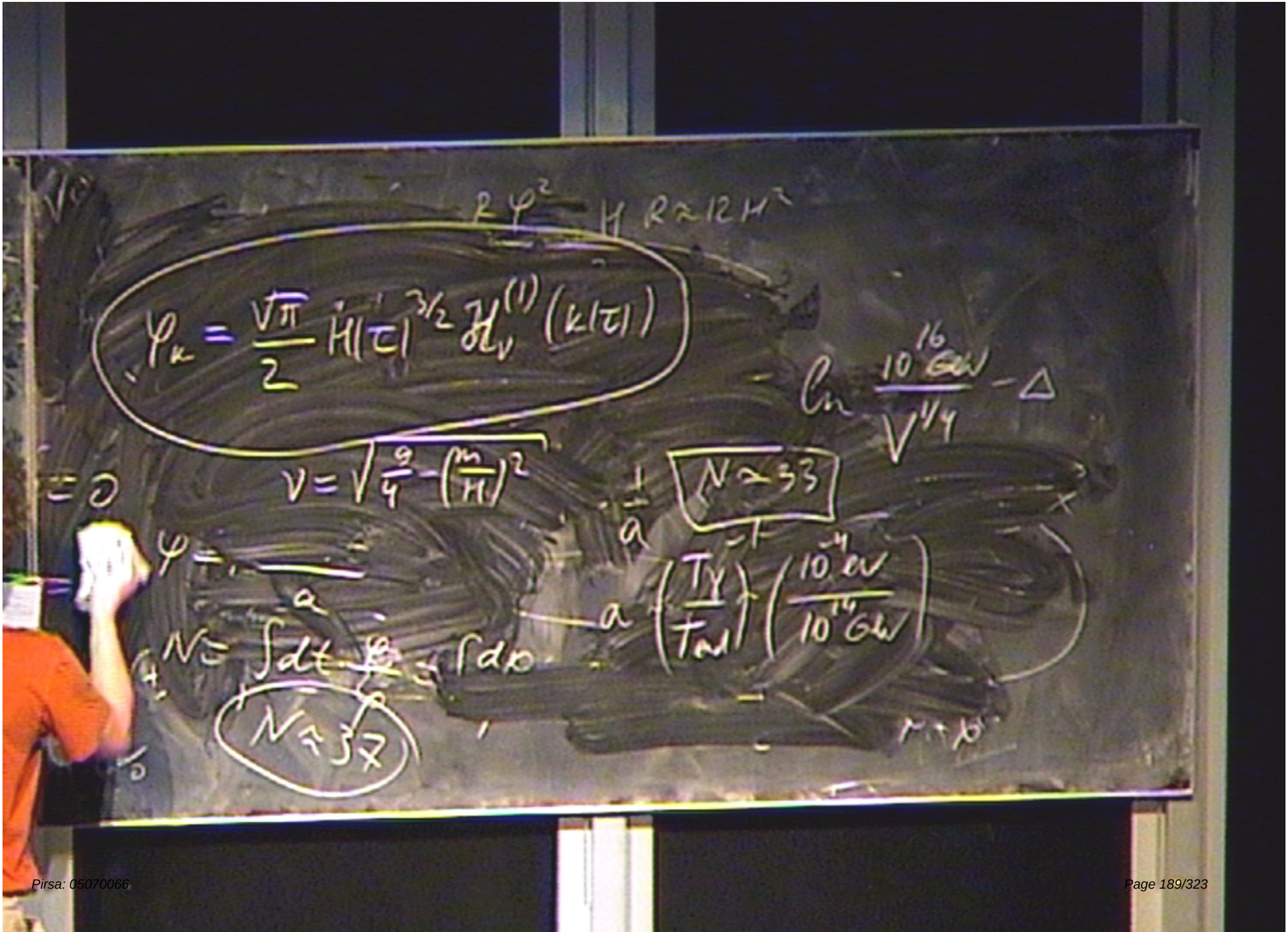

$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H |\tau|^{3/2}$
$\ln \frac{10^{16}\,GeV}{V^{1/4}}$
$N \simeq 33$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_\nu}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

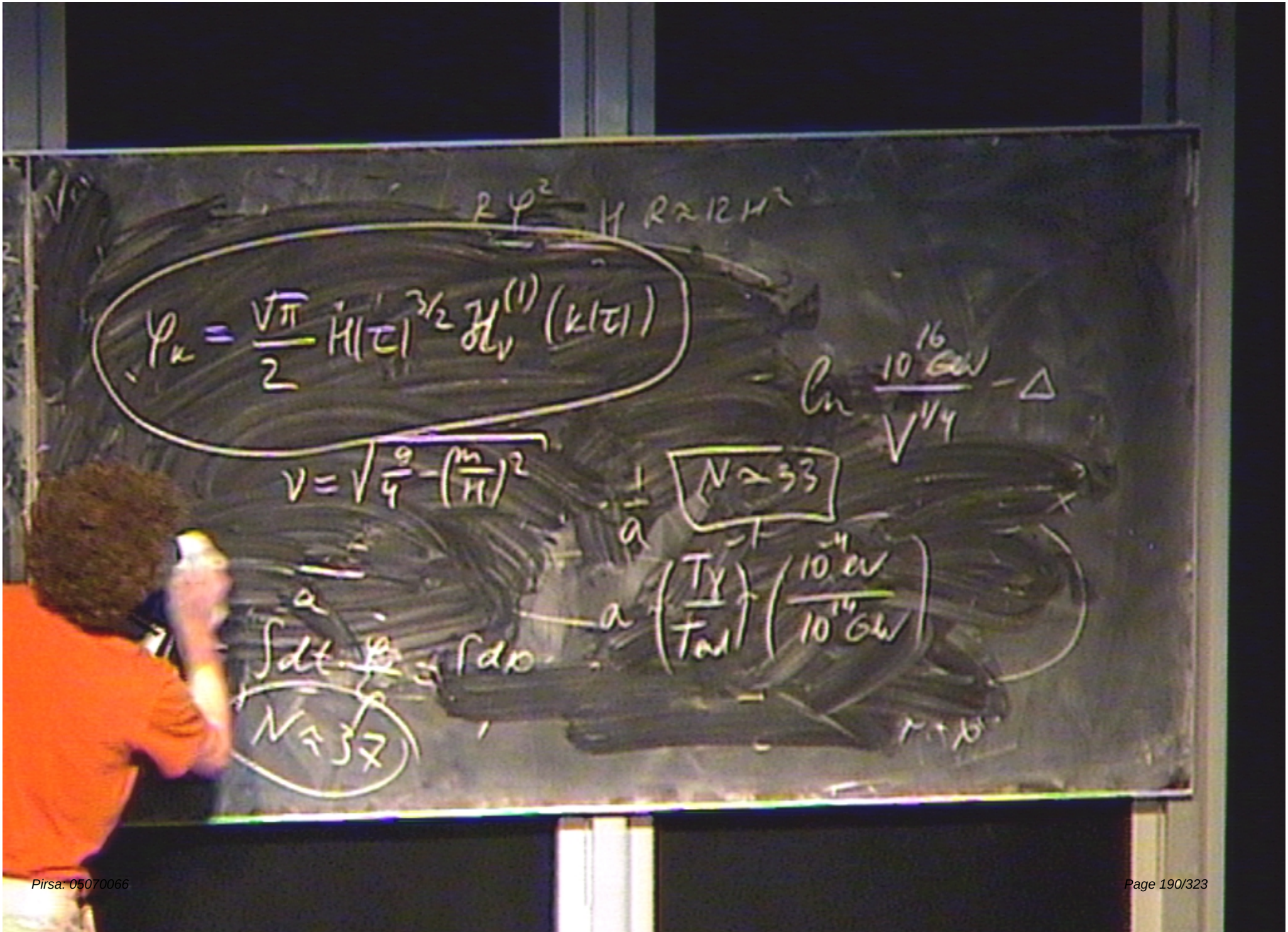

$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}$
$\ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$N \simeq 33$
$\left(\frac{T_\gamma}{T_\nu}\right)^4 \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

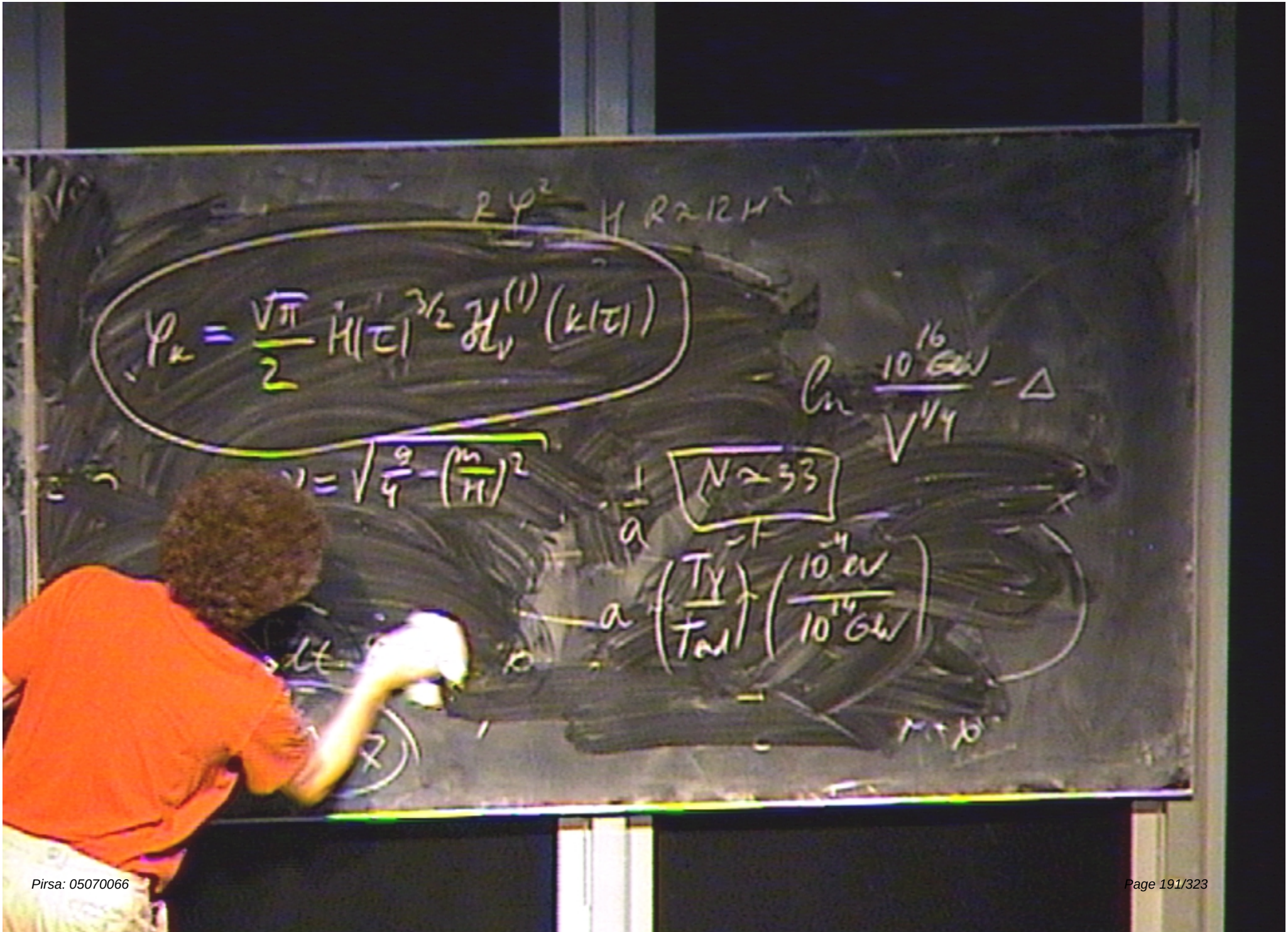

$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k$
$\ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$N \simeq 33$
$\left(\frac{T_\gamma}{T_\nu}\right)^4 \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$N \simeq \int dt$

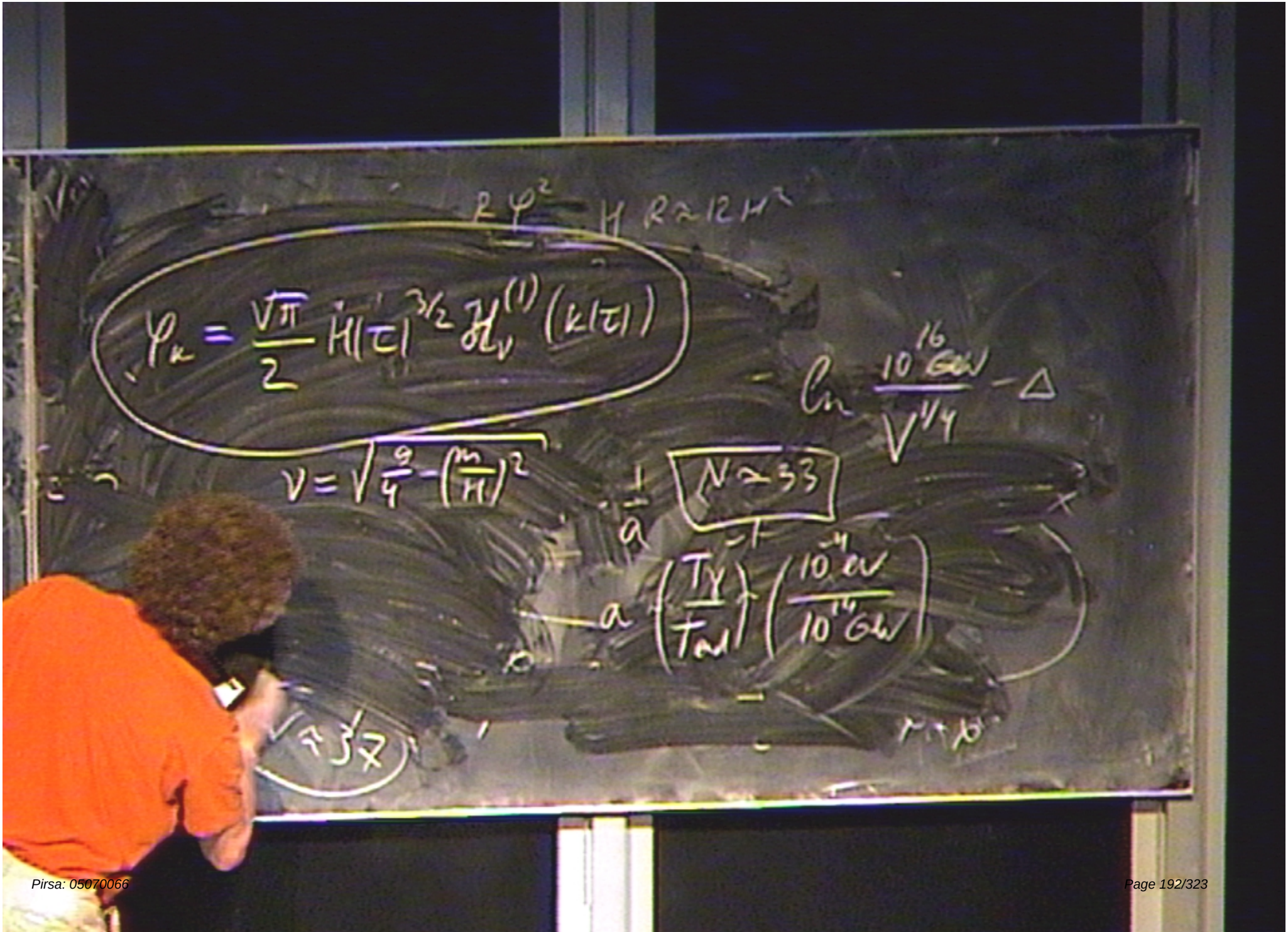

$\frac{1}{2}R\varphi^2$
H
$R \simeq 12H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$N \simeq 53$
$\frac{1}{a}$
$a\left(\frac{T_\gamma}{T_{\gamma 1}}\right)\left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

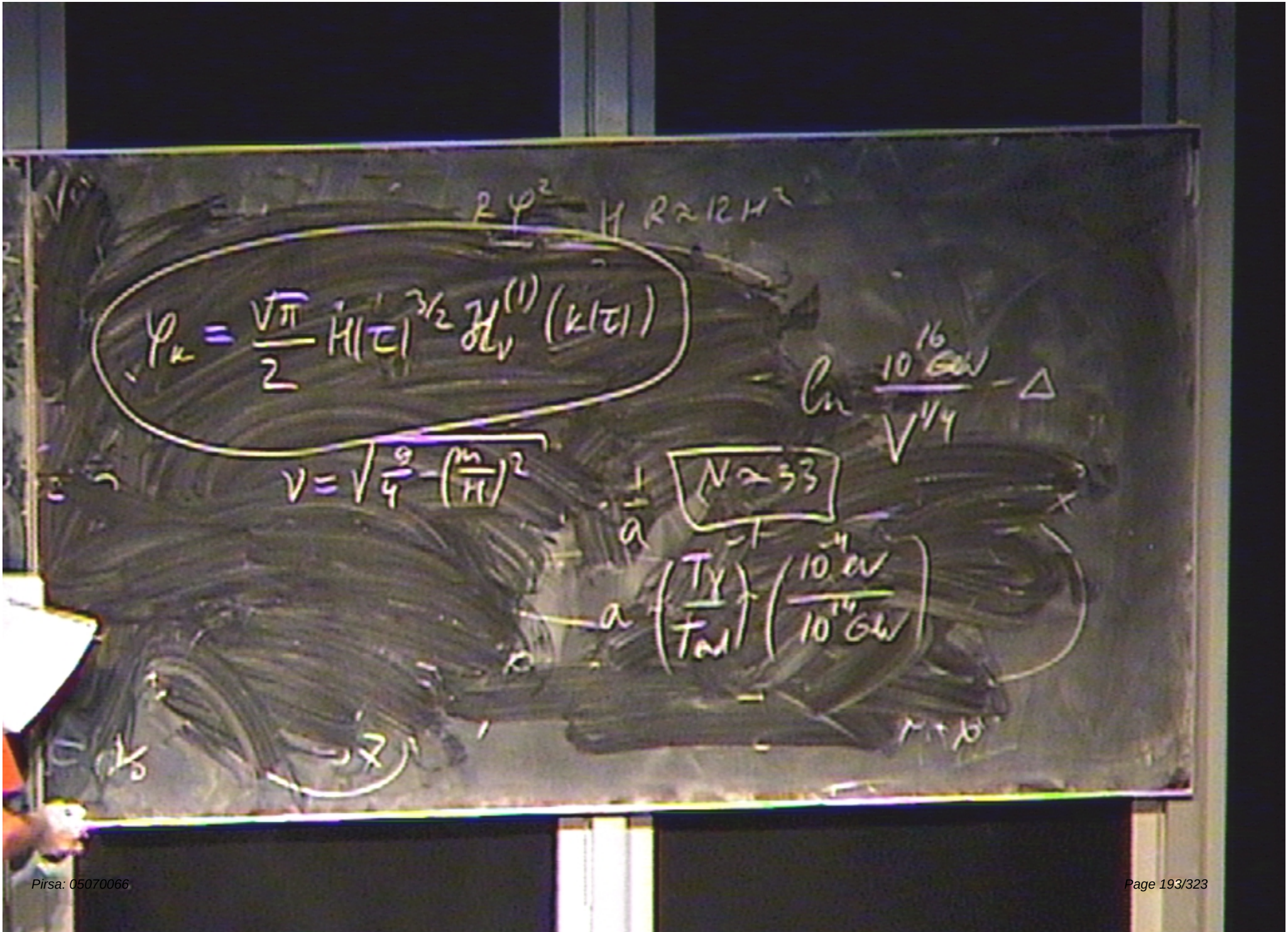

$\frac{1}{2}\dot{\varphi}^2$ H $R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V''^4} - \Delta$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$\frac{1}{a}$
$a\left(\frac{T_\gamma}{T_{\nu 1}}\right)\left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$N = \int dt\, H = \int da$
$N \simeq 37$

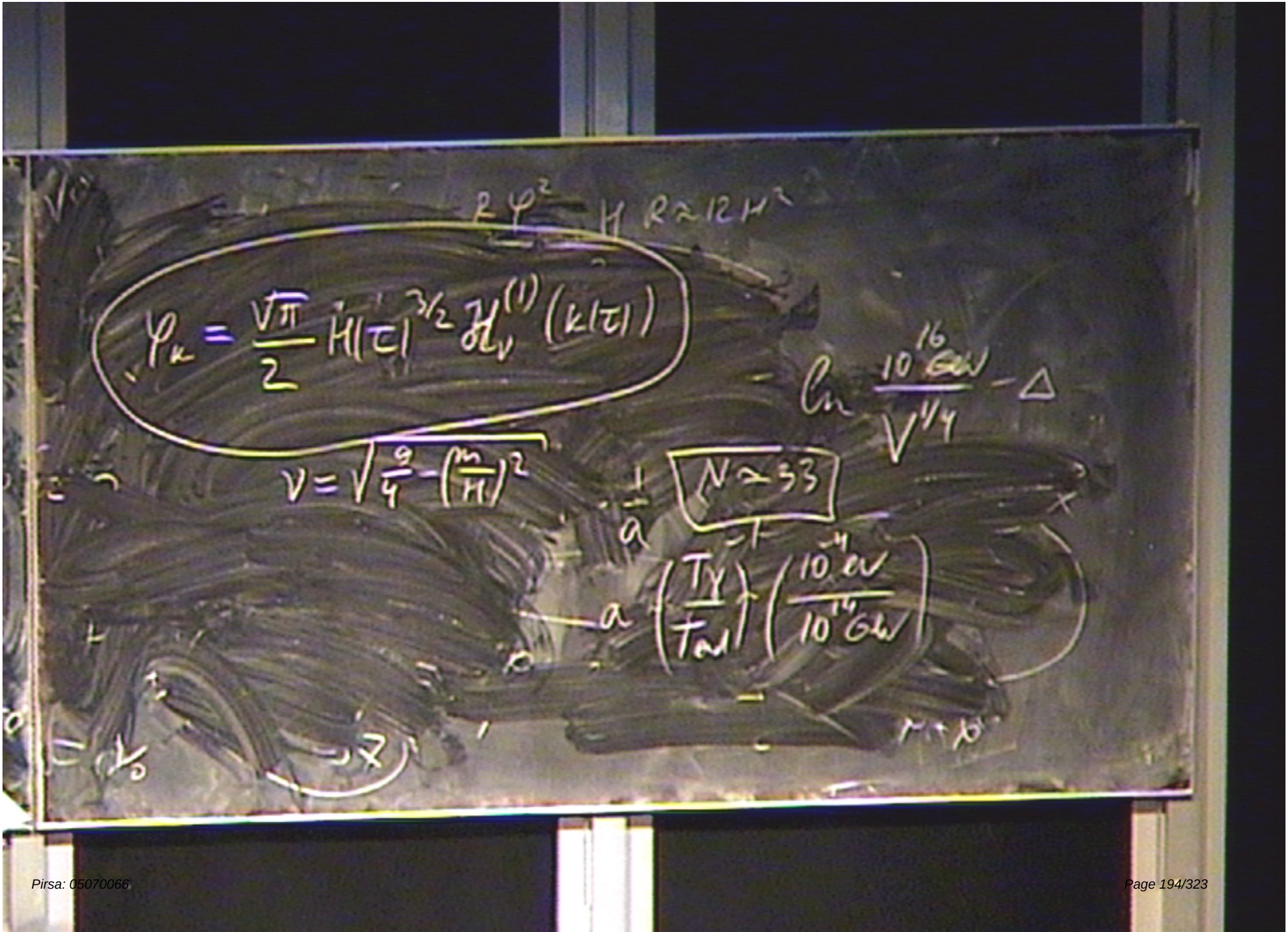

$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$V = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$\frac{1}{a}$
$\varphi \sim \frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$N = \int dt\, H = \int da$
$N \simeq 37$

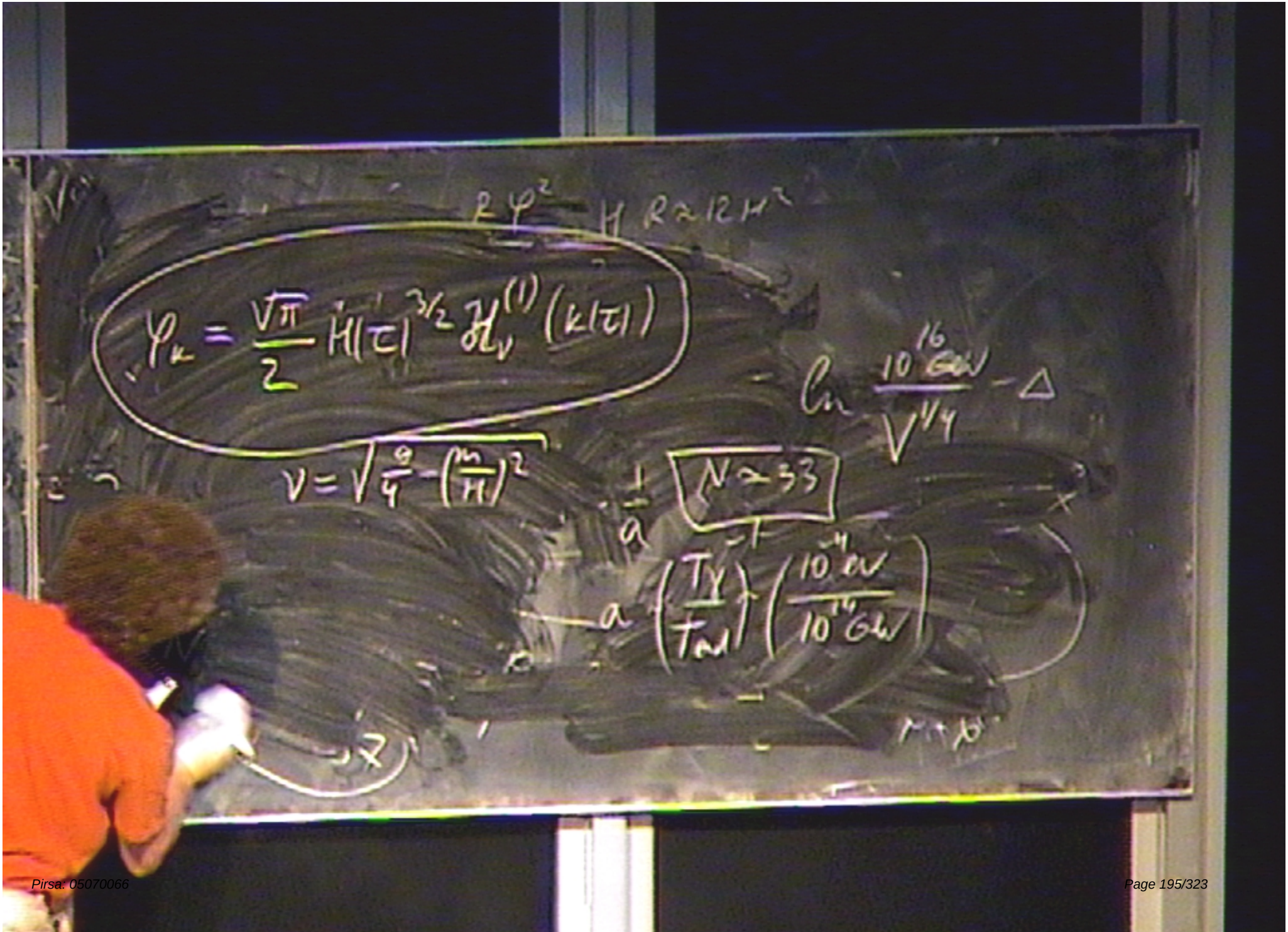

$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} \mathcal{H}_\nu^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$V = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\nu 1}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$\int dt \frac{k}{a} = \int d\eta$
$N \simeq 37$

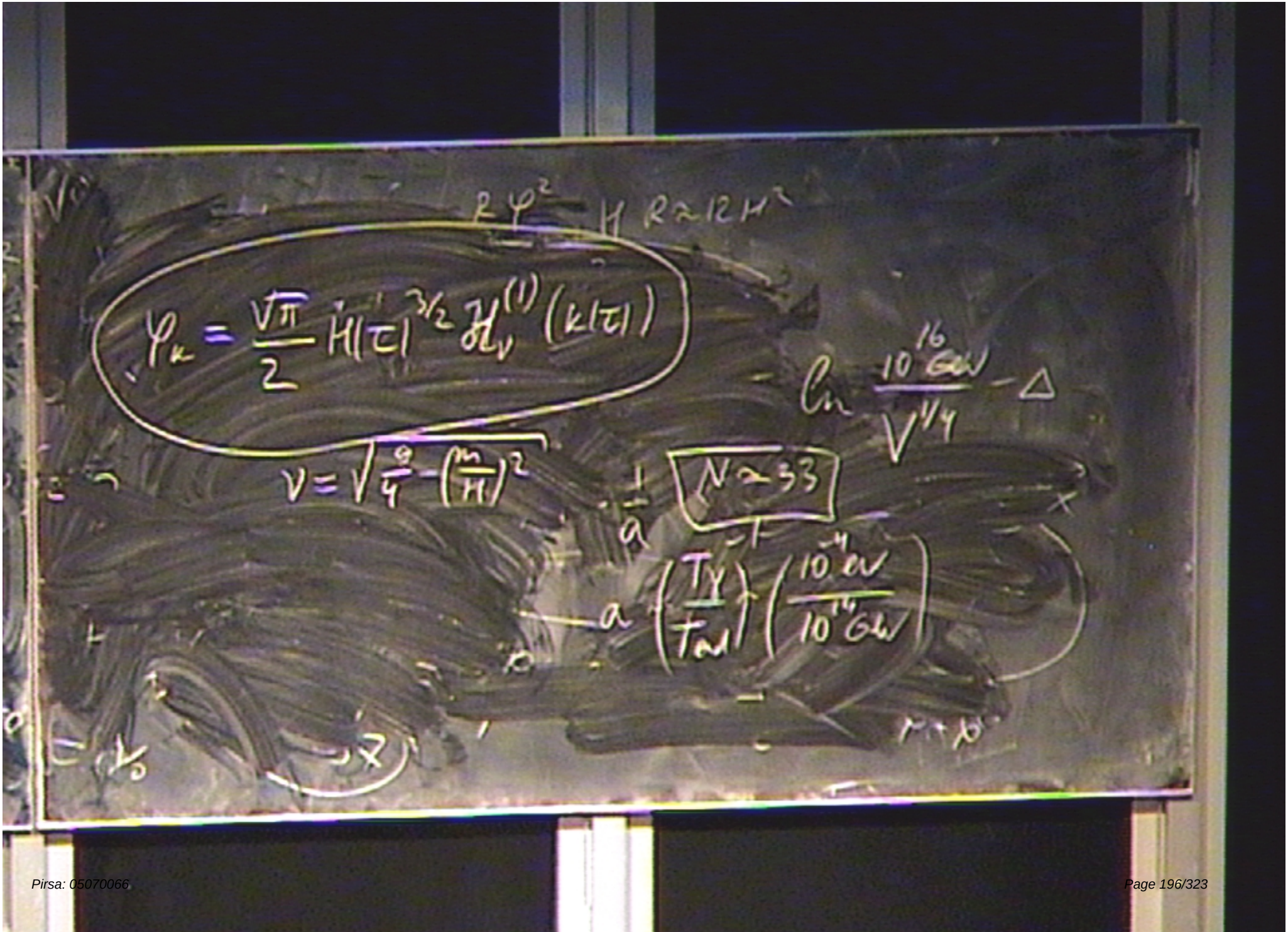

$R\varphi^2$
$R \sim 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k\tau)$
$\ln \frac{10^{16}\,GeV}{V''/4} - \Delta$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \sim 33$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$


$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$\frac{1}{a}$
$N \simeq 33$
$a \left(\frac{T_\gamma}{T_{\nu 1}}\right) \left(\frac{10^{-4}\,eV}{10^{-4}\,GeV}\right)$
$\nu \simeq 3/2$


$R\varphi^2$ H $R \simeq 12H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$\frac{1}{a}$
$N \simeq 53$
$a \left(\frac{T_\gamma}{T_{\nu 1}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$\frac{10^{16}\,GeV}{V^{1/4}}$ Δ


$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$\ln \frac{10^{16}\,\mathrm{GeV}}{V^{1/4}} - \Delta$
$N \simeq 33$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\nu 1}}\right) \left(\frac{10^{-4}\,\mathrm{eV}}{10^{14}\,\mathrm{GeV}}\right)$


$\frac{1}{2}\varphi^2$ $R \simeq 12H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V^{1/4}}$
$V = \sqrt{\frac{\dot\varphi}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$a \left(\frac{T_\gamma}{T_{\nu 1}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$


$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V''^{1/4}} - \Delta$
$V = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

$R\varphi^2$ H $R \simeq 12 H^2$

$$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$$

$$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$$

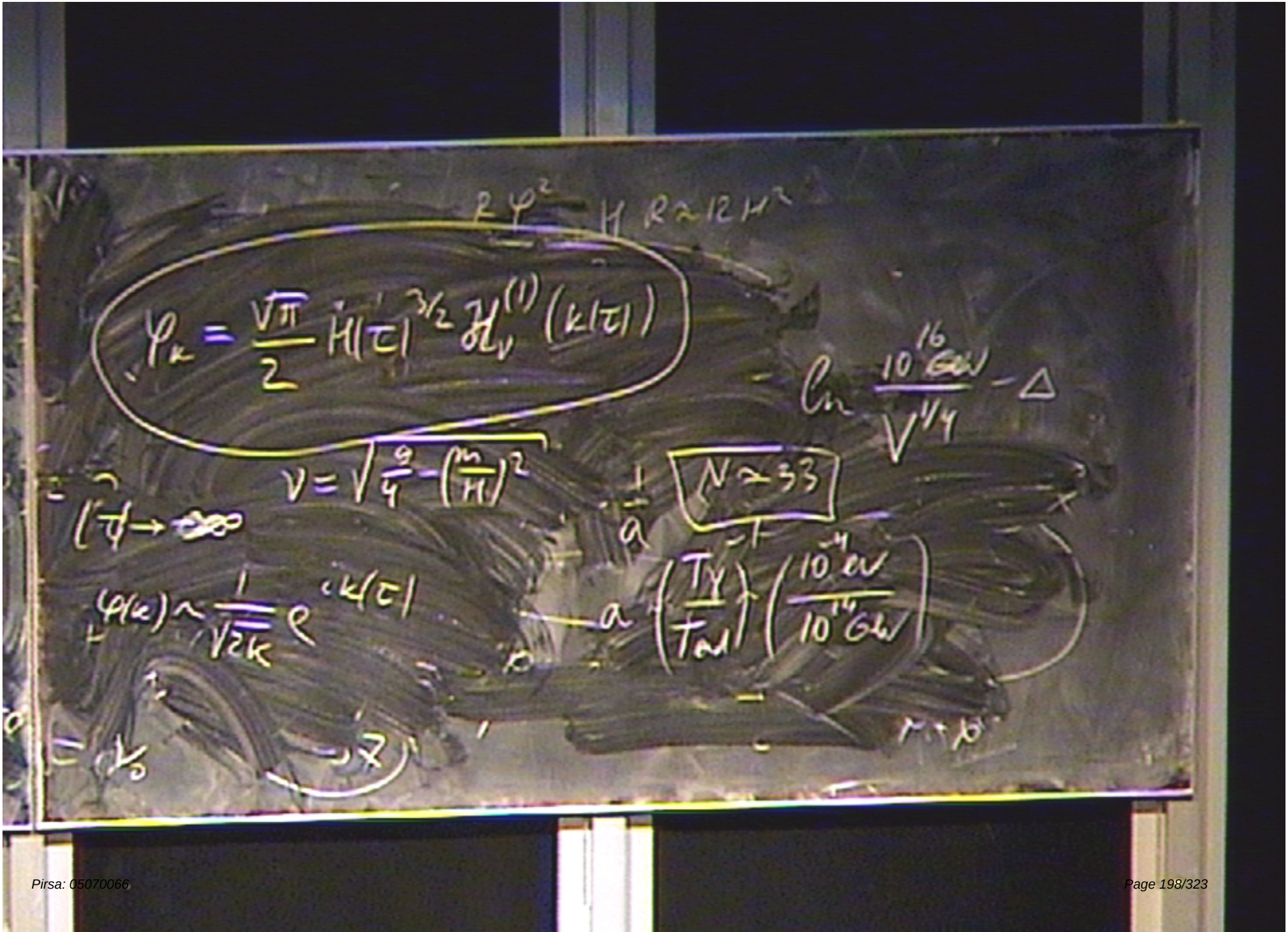
$$\ln \frac{10^{16}\,\mathrm{GeV}}{V^{1/4}} - \Delta$$

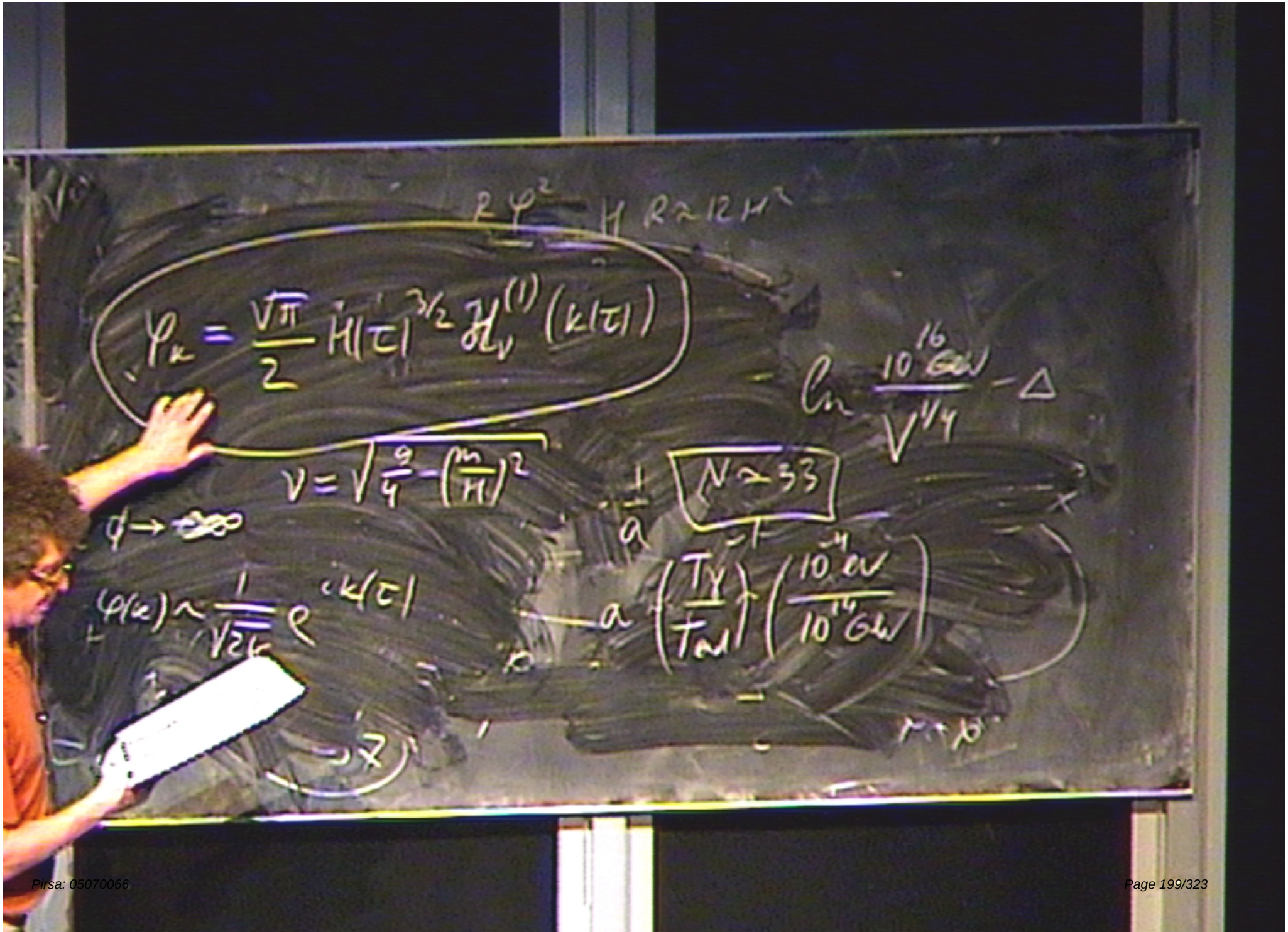
$N \simeq 53$

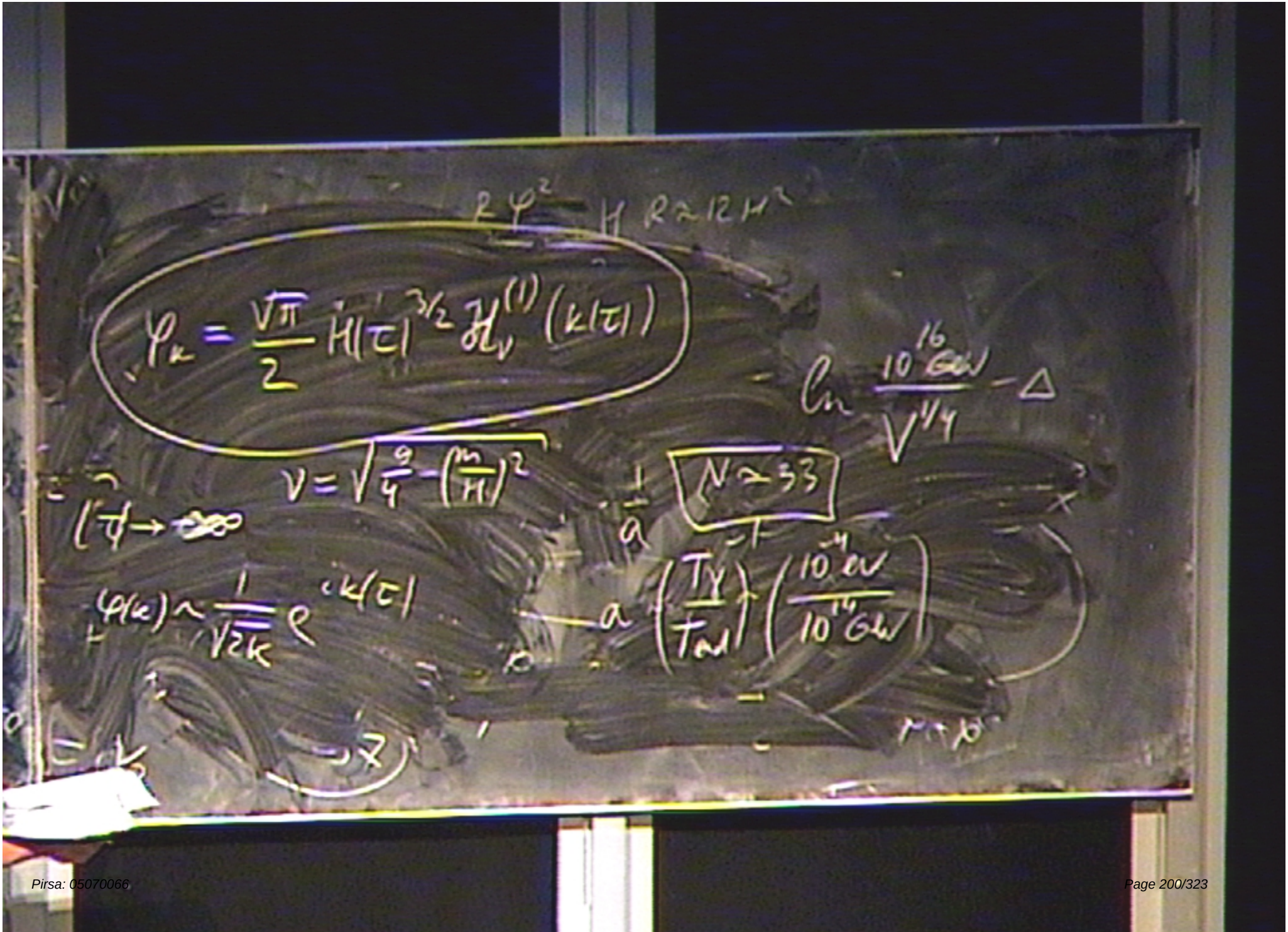
$(\tau \to -\infty)$

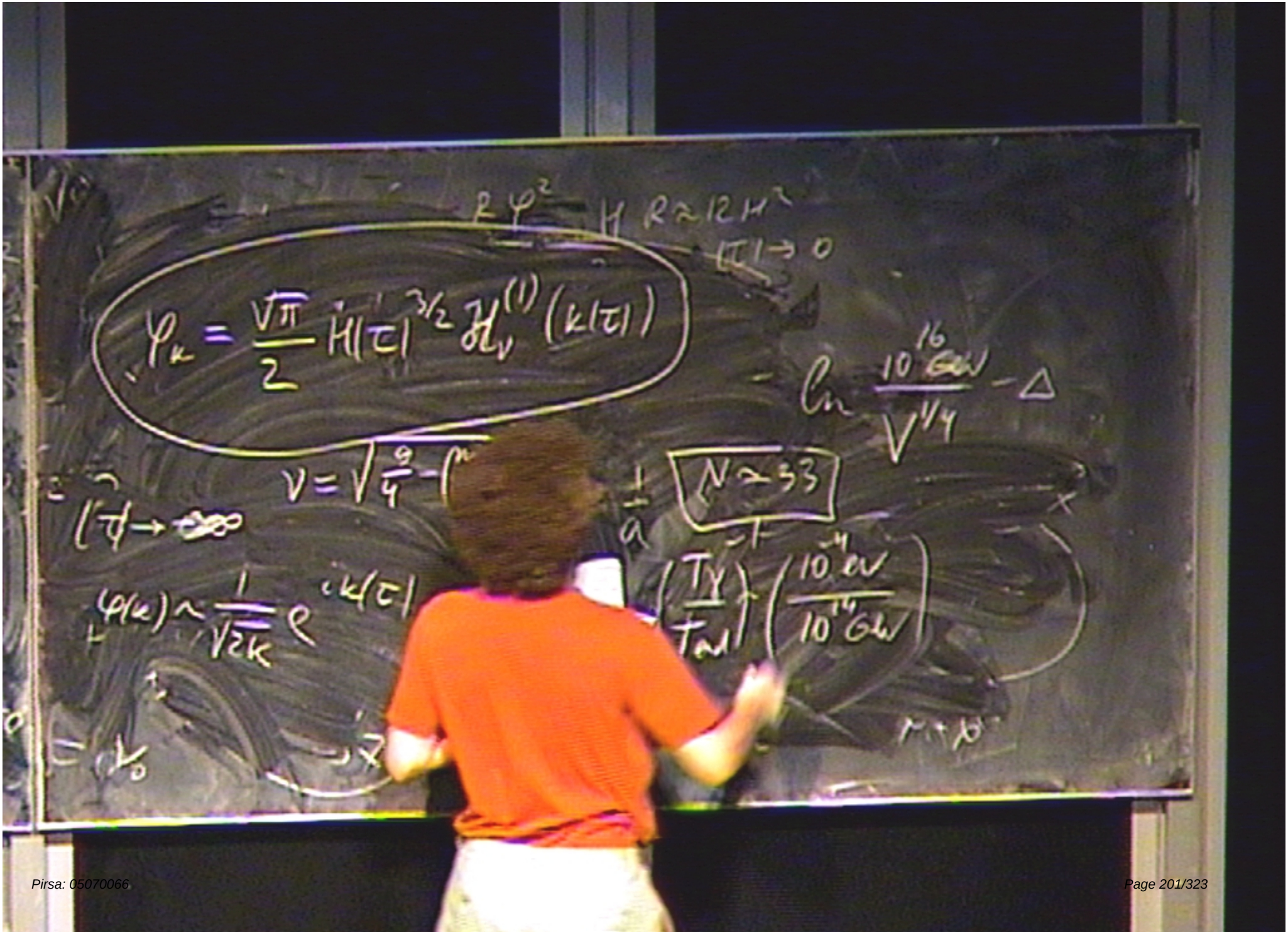
$$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$$

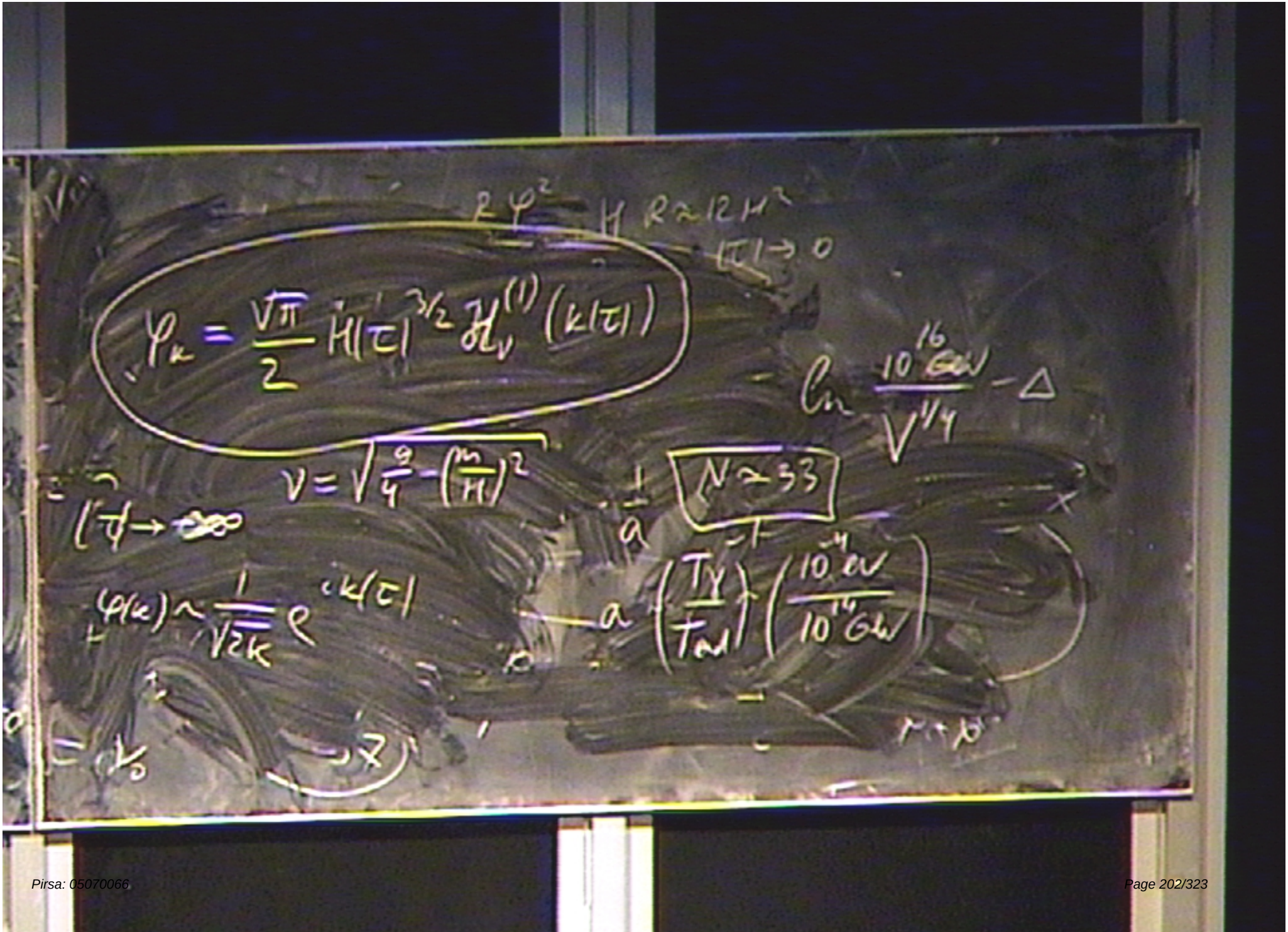
$$\frac{1}{a} \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,\mathrm{eV}}{10^{14}\,\mathrm{GeV}}\right)$$

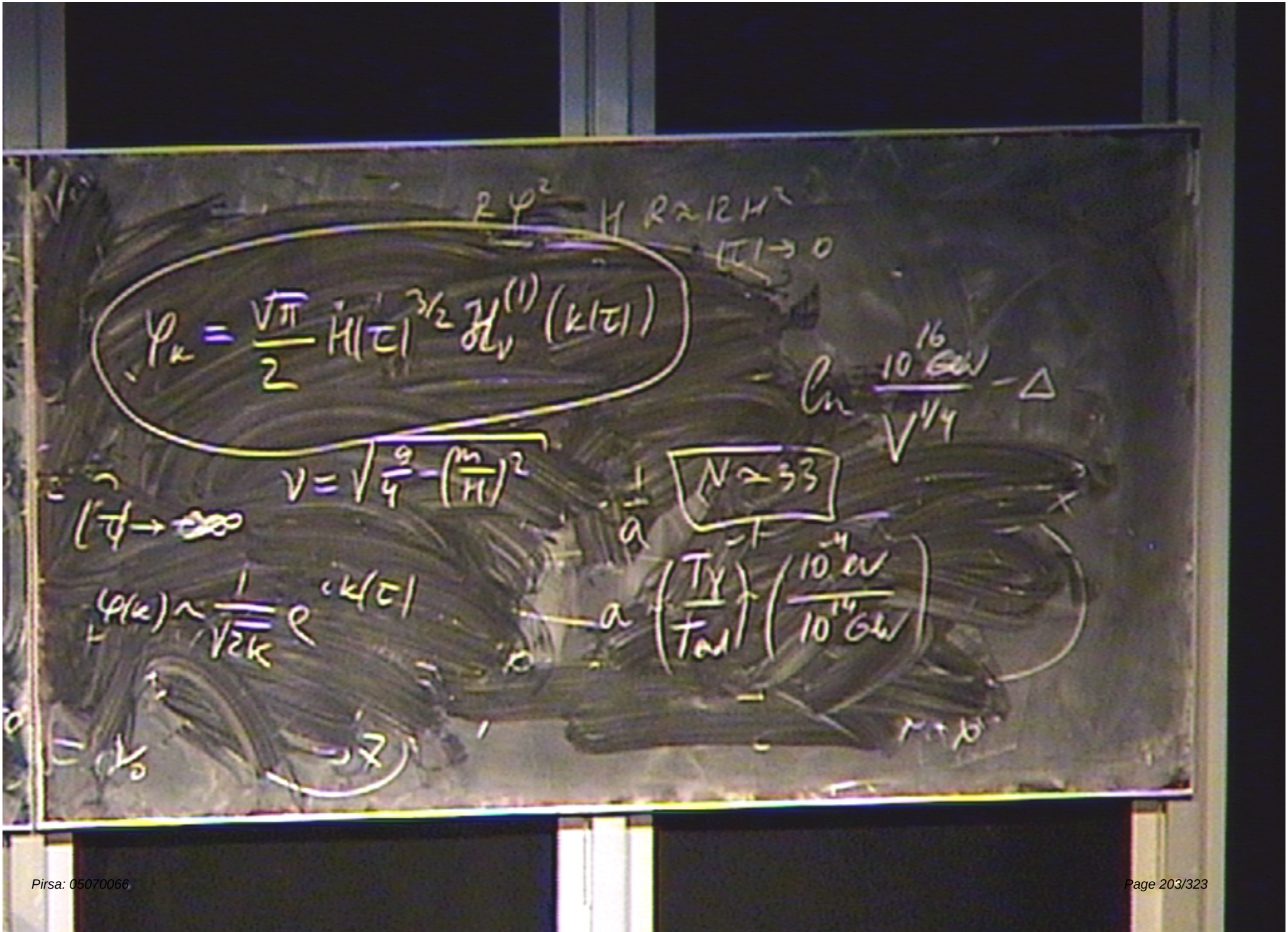

$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$\frac{1}{a}$
$N \simeq 33$
$\tau \to -\infty$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$\tau = \tau_0$
$\tau = 0$

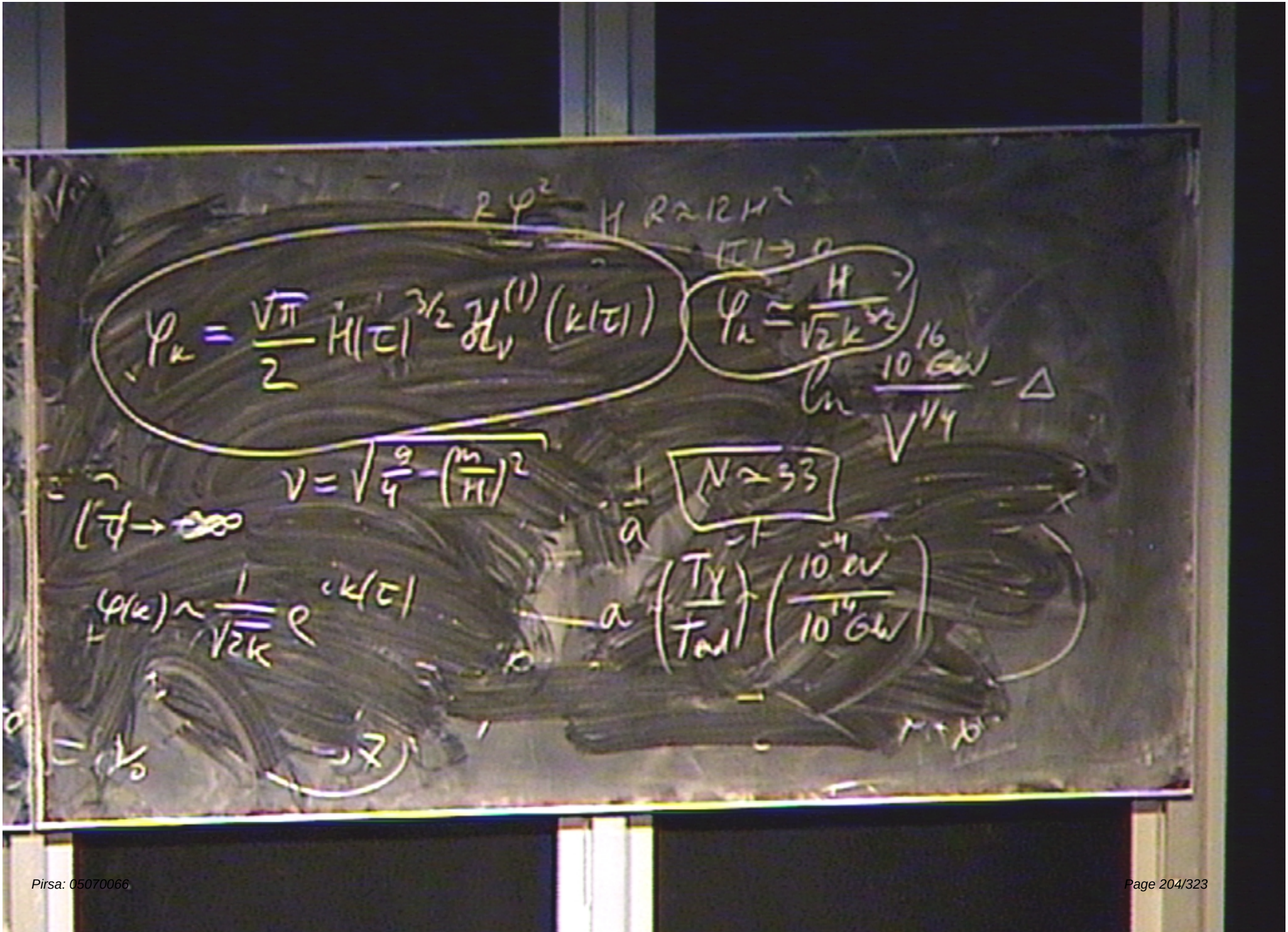

$R\varphi^2$
H
$R \simeq 12 H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V''^{1/4}} - \Delta$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$\varphi \to \infty$
$\frac{1}{a}$
$\varphi(\tau) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

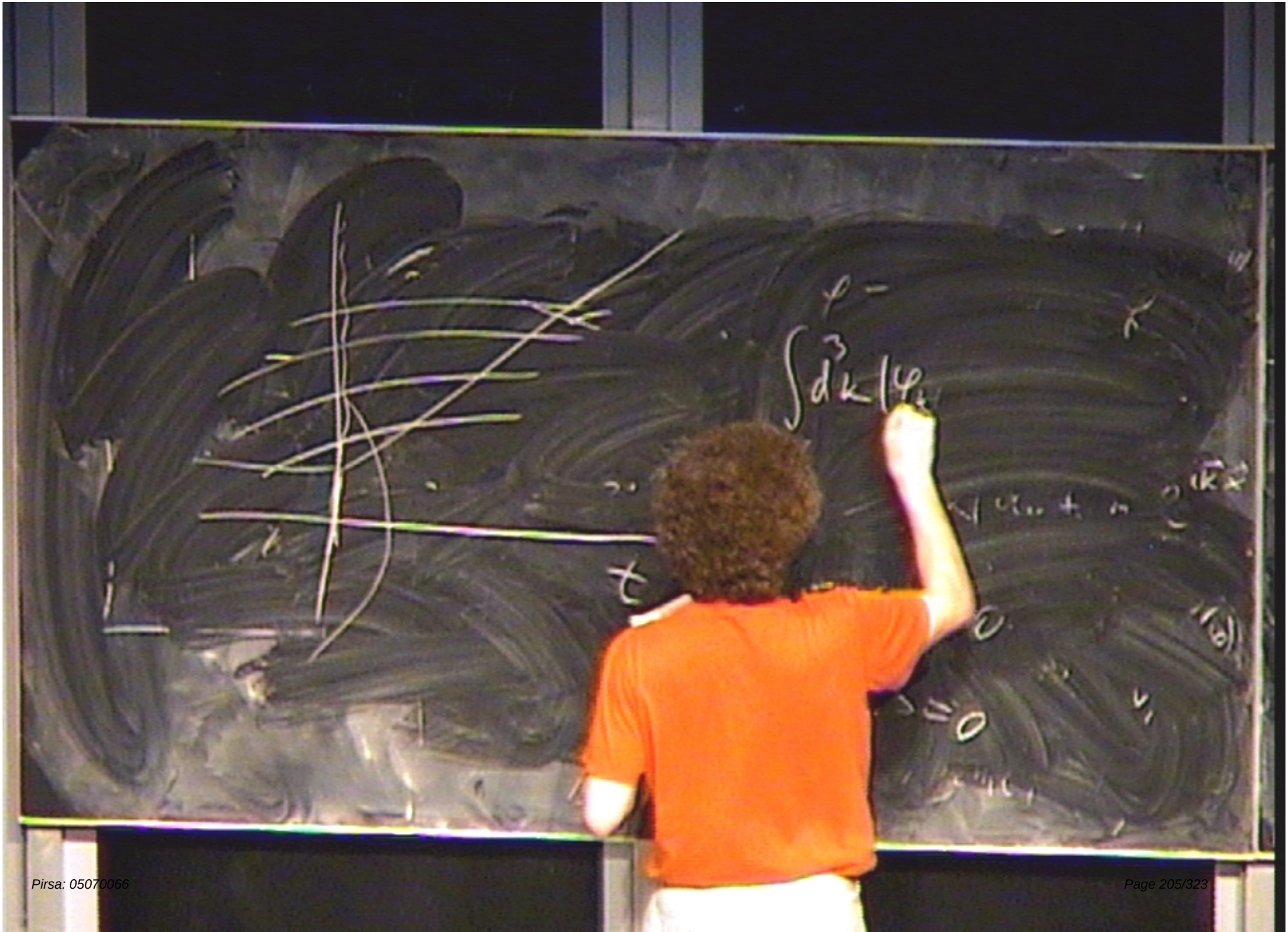

$R\varphi^2$ H $R \simeq 12H^2$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$\frac{1}{a}$ $N \simeq 53$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$a \left(\frac{T_\gamma}{T_{\nu 1}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

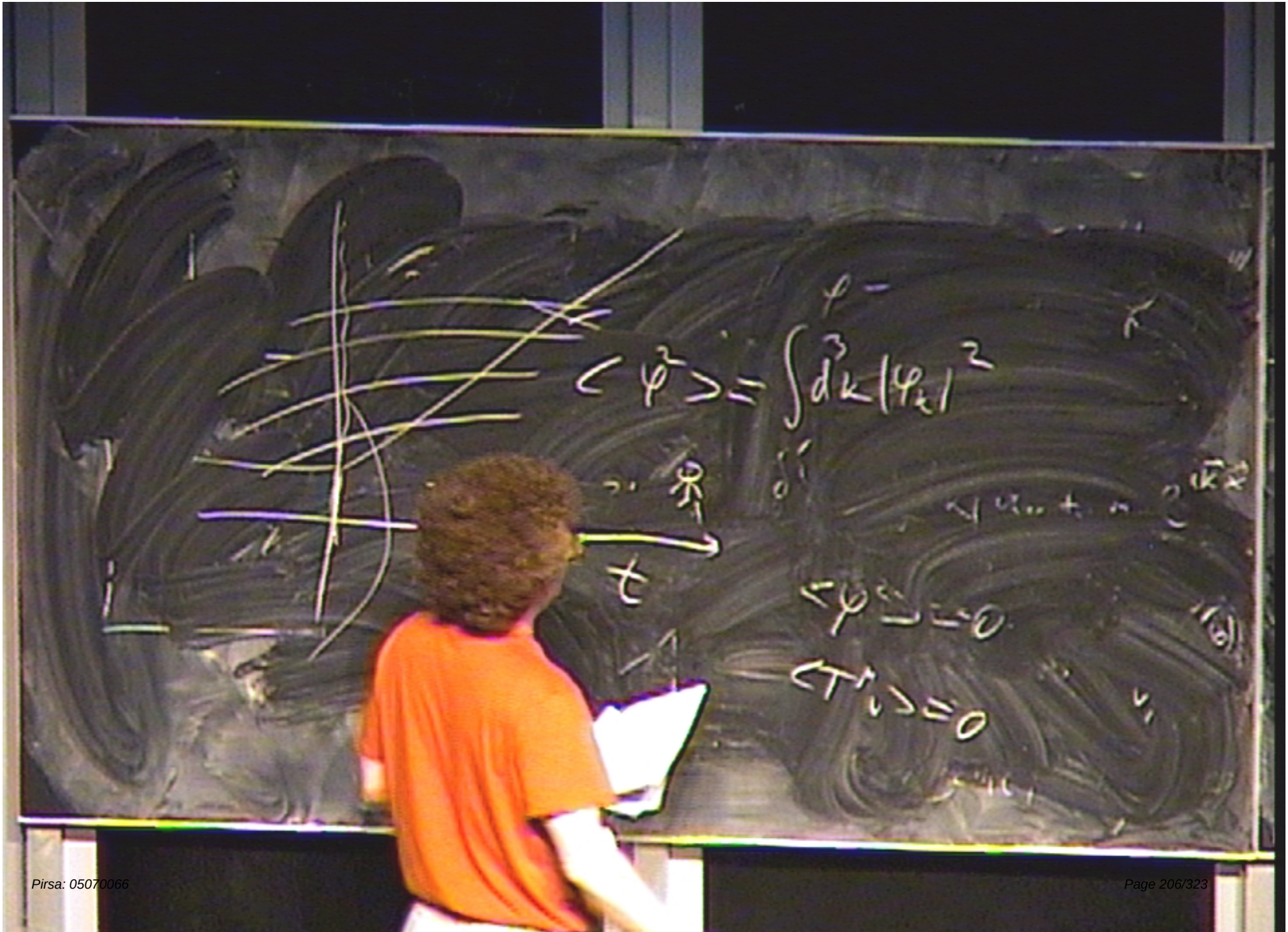

$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$\varphi_k = \frac{\sqrt{\pi}}{2} H |\tau|^{3/2} H_\nu^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$\nu = \sqrt{\frac{9}{4} - f''}$
$N \simeq 33$
$|\tau| \to \infty$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$\left(\frac{T_V}{T_{eq}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$r + \Delta r$

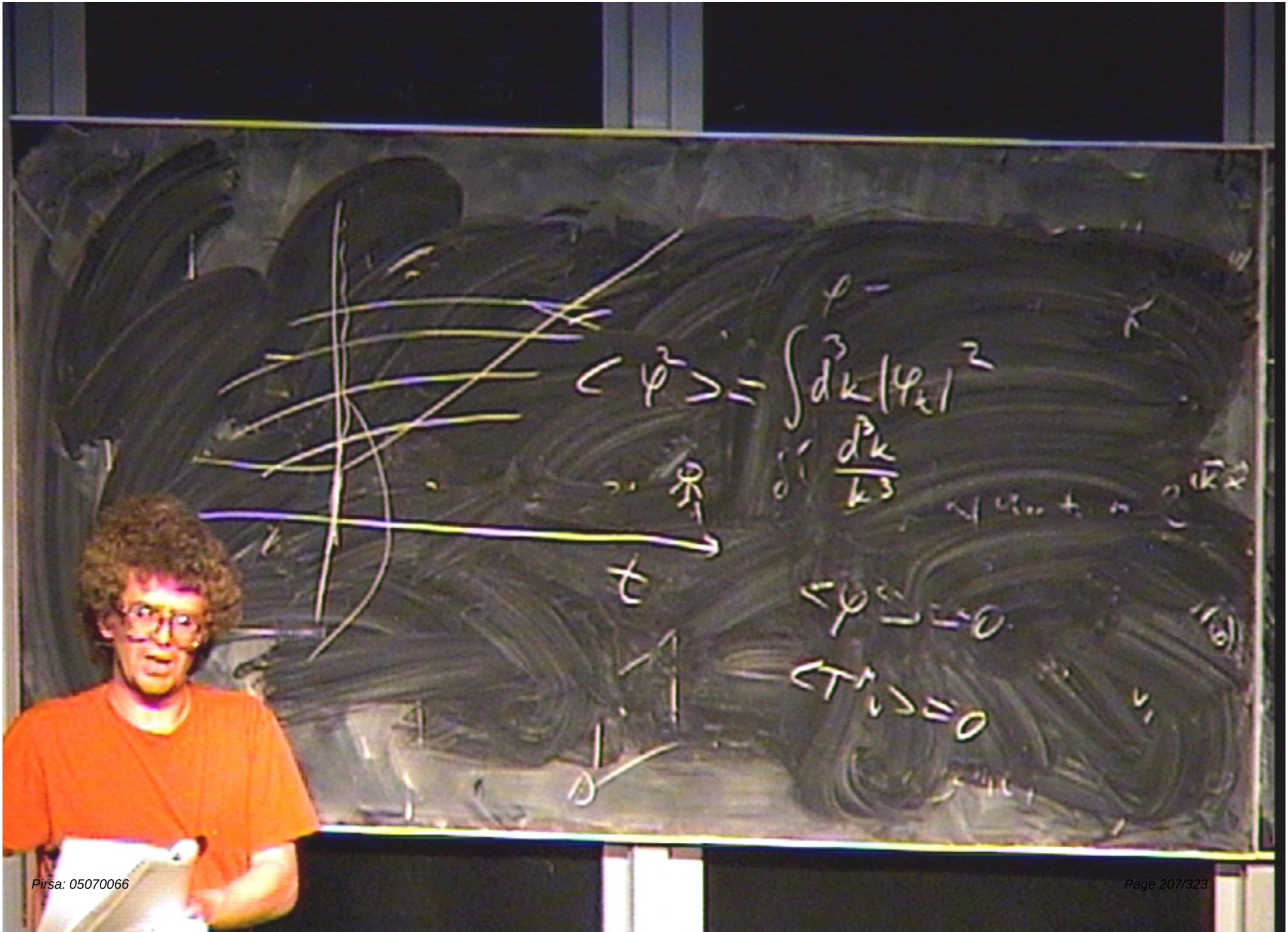

$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$\varphi_k = \frac{\sqrt{\pi}}{2} H |\tau|^{3/2} H_\nu^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V^{1/4}} - \Delta$
$V = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$\frac{1}{a}$
$|\tau| \to \infty$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

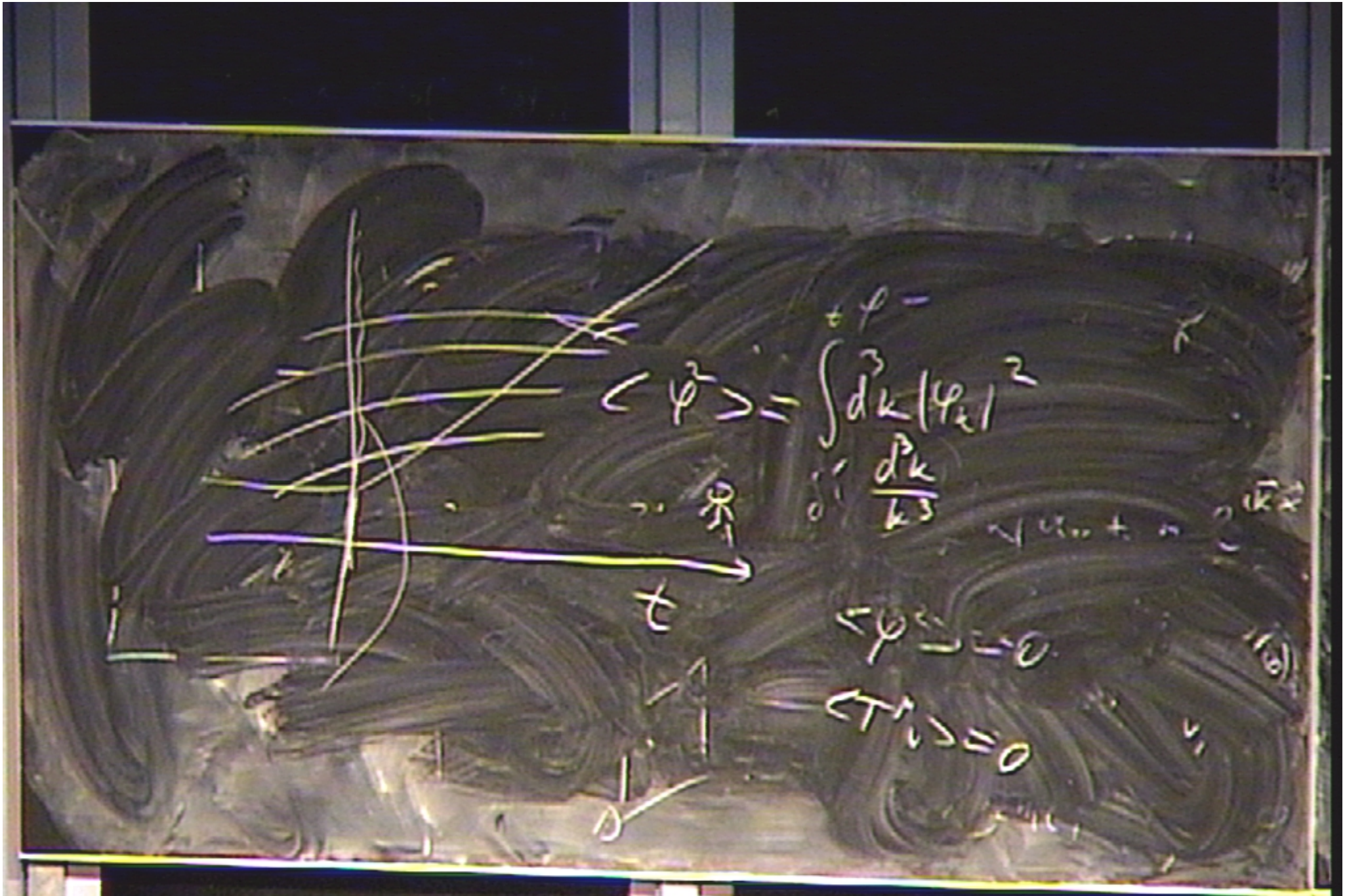

$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\ln \frac{10^{16}\,GeV}{V''^{1/4}} - \Delta$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$

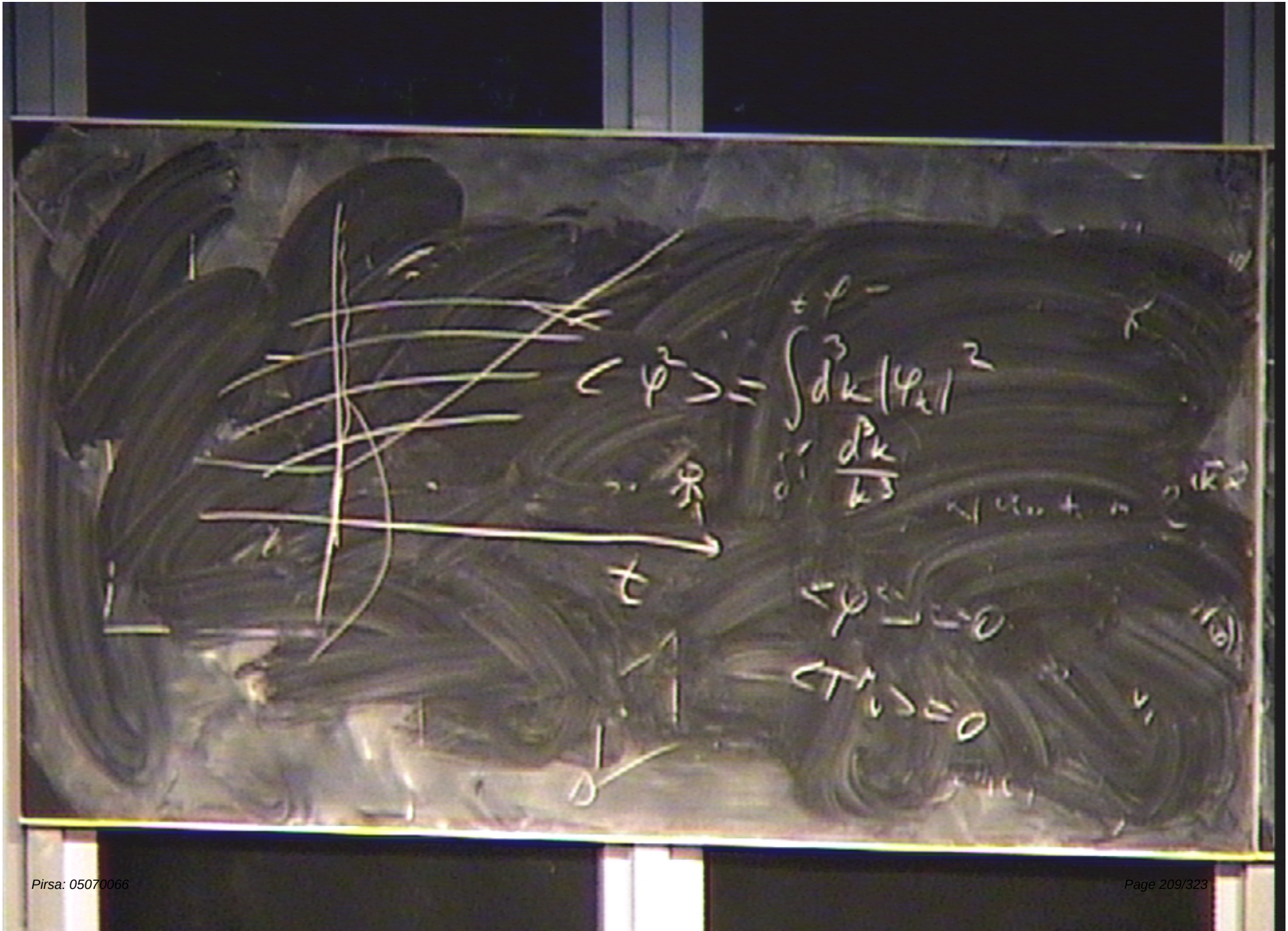

$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2k^3}}$
$\frac{10^{16}\,GeV}{V''/V}$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$\frac{1}{a}$
$|\tau| \to \infty$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$a \left(\frac{T_N}{T_{eq}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
τ_0

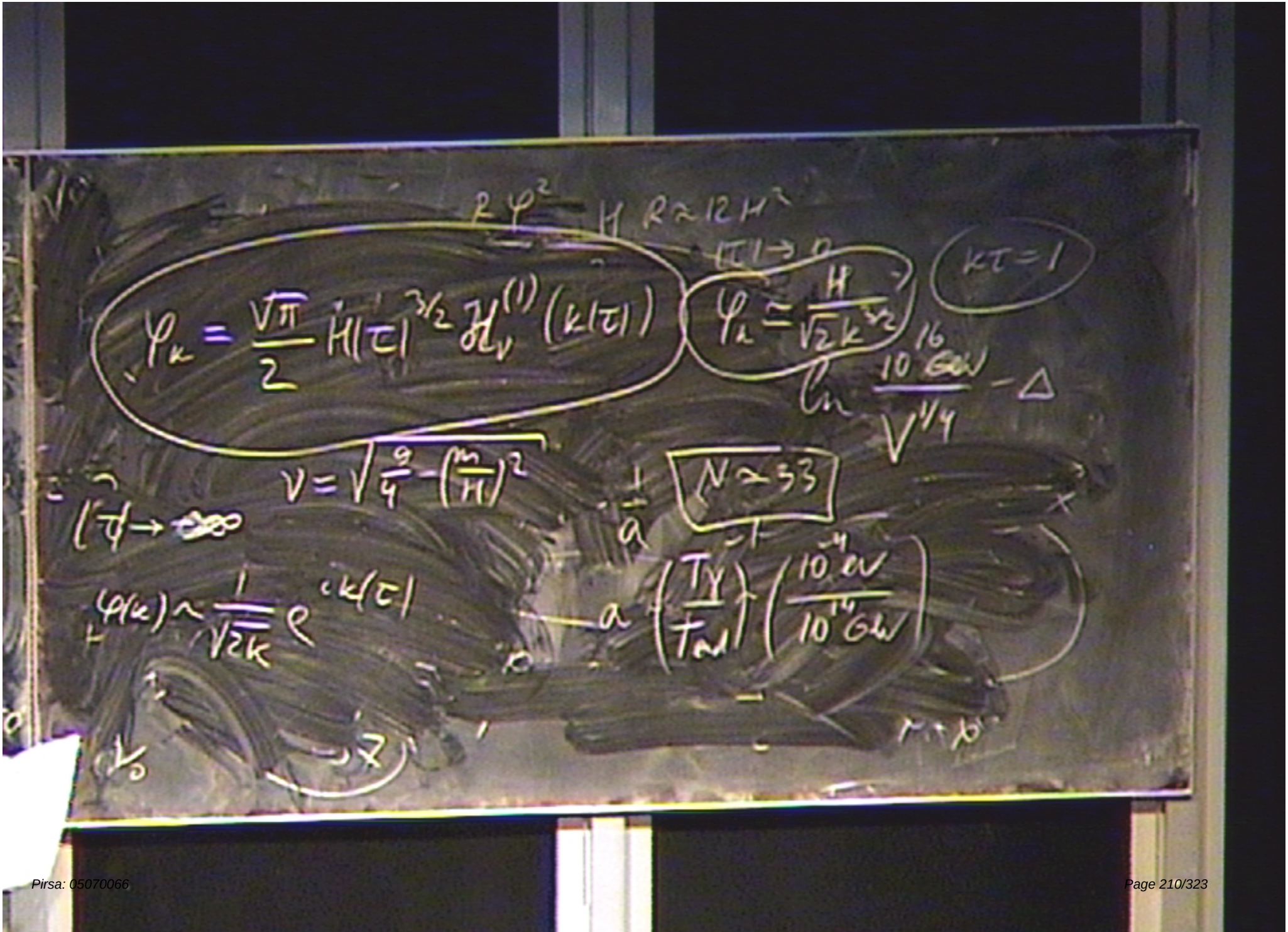


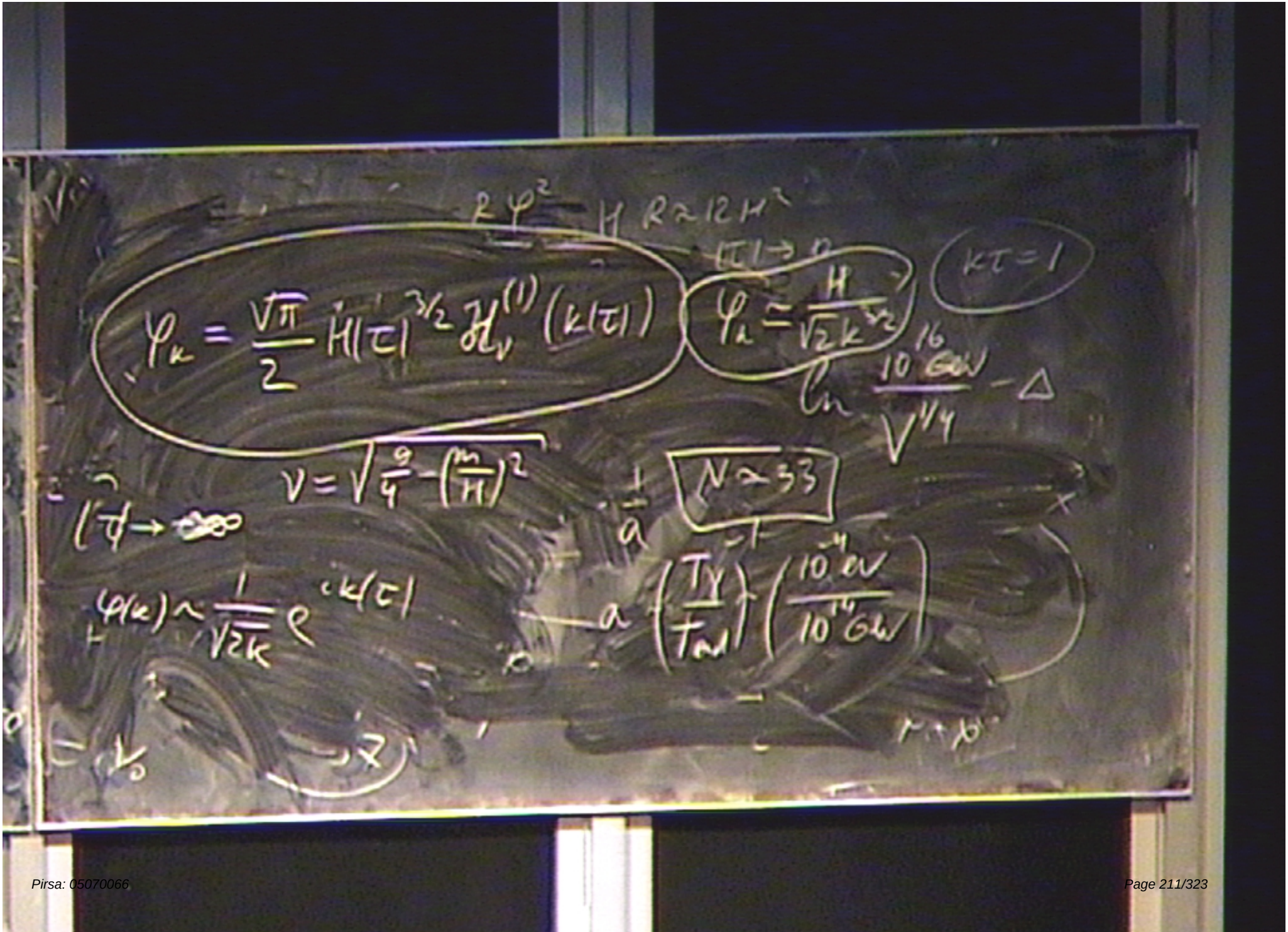

$\langle \varphi^2 \rangle = \int d^3k |\varphi_k|^2$
$\langle \varphi \rangle = 0$
$\langle T^{\mu\nu} \rangle = 0$

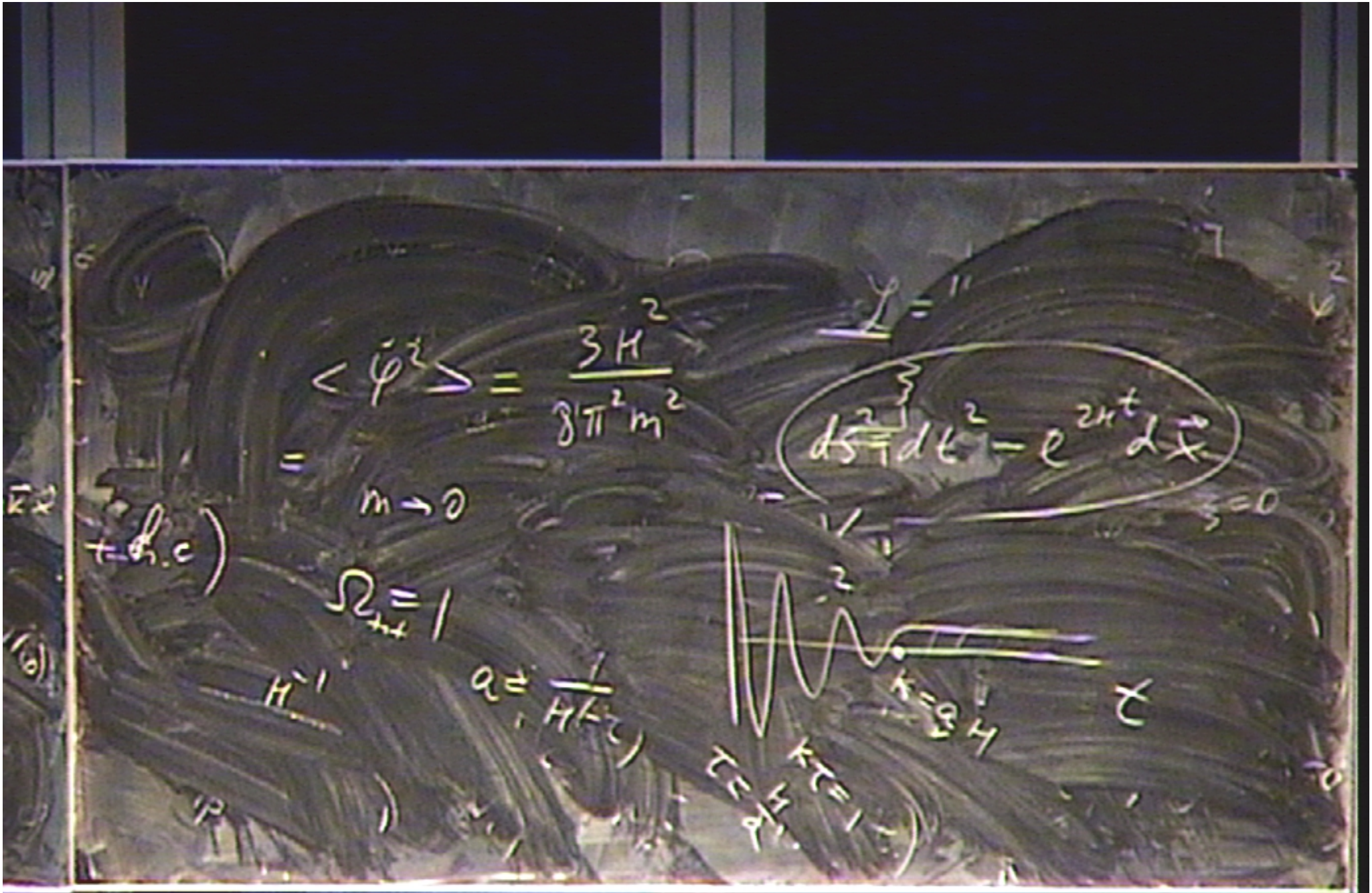

$\langle \varphi^2 \rangle = \int d^3k |\varphi_k|^2$
$\int \frac{d^3k}{k^3}$
t
$\langle \varphi \rangle = 0$
$\langle T^{ij} \rangle = 0$


$\langle \varphi^2 \rangle = \int d^3k \, |\varphi_k|^2$
$\int \frac{d^3k}{k^3}$
t
$\langle \varphi \rangle = 0$
$\langle T^{\mu\nu} \rangle = 0$


$\langle \varphi^2 \rangle = \int d^3k \, |\varphi_k|^2$
$\int \frac{dk}{k^3}$
t
$\langle \varphi \rangle = 0$
$\langle T^{\mu\nu} \rangle = 0$


$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$k\tau = 1$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2} k^{3/2}}$
$\frac{10^{16}\,GeV}{V^{1/4}}$
Δ
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$|\tau| \to \infty$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$


$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$k\tau = 1$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2k^3}}$
$\frac{10^{16}\,GeV}{V^{1/4}}$
Δ
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$|\tau| \to \infty$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$


$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$a = \frac{1}{H(t-t_i)}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$k = aH$
t
$k\tau = 1$
$\tau = \frac{1}{aH}$

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$

$= \quad m \to 0$

$\Omega_{tot} = 1$

H^{-1}

$a = \frac{1}{H(\tau)}$

$\mathcal{L} =$

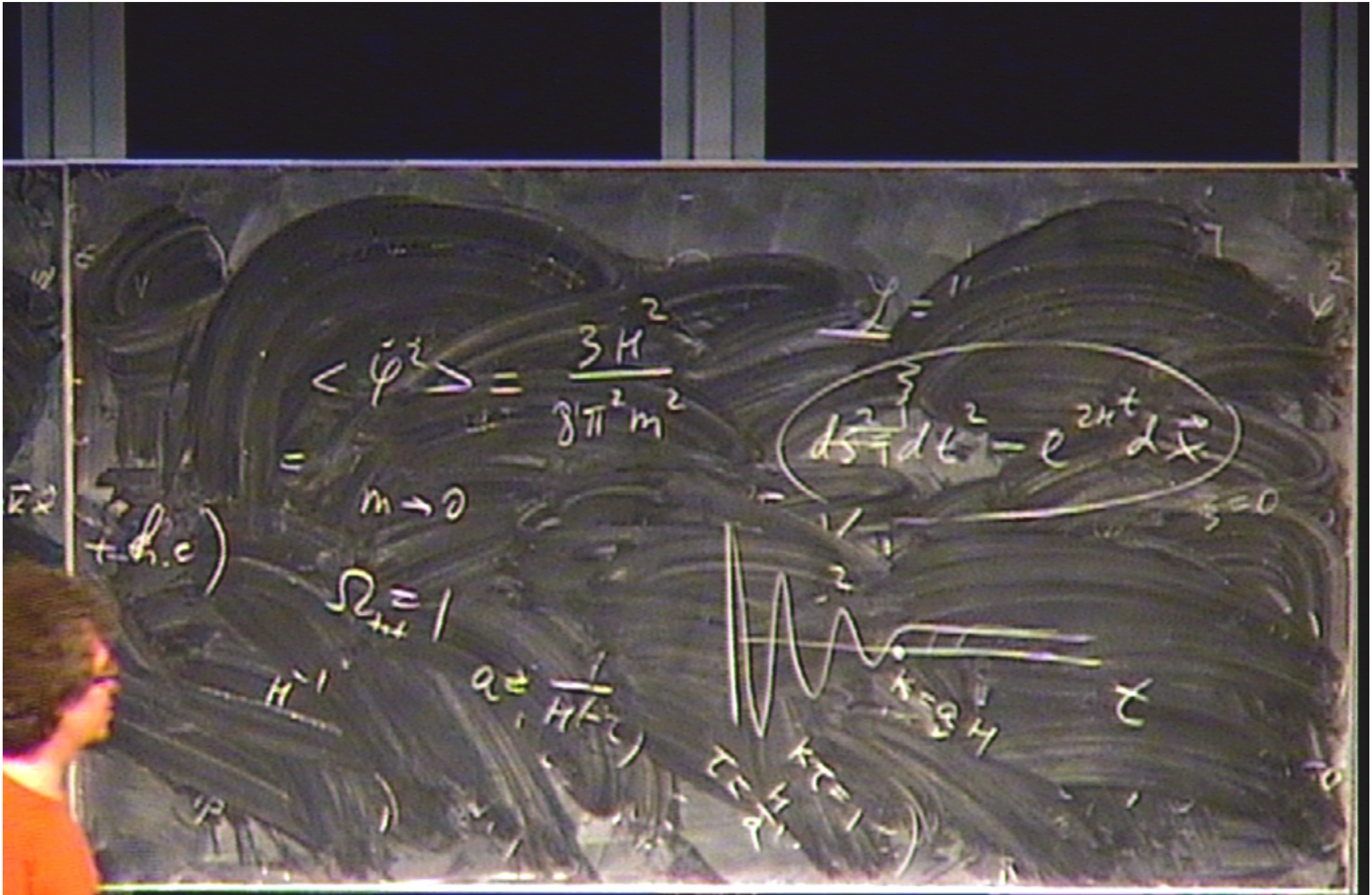
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$

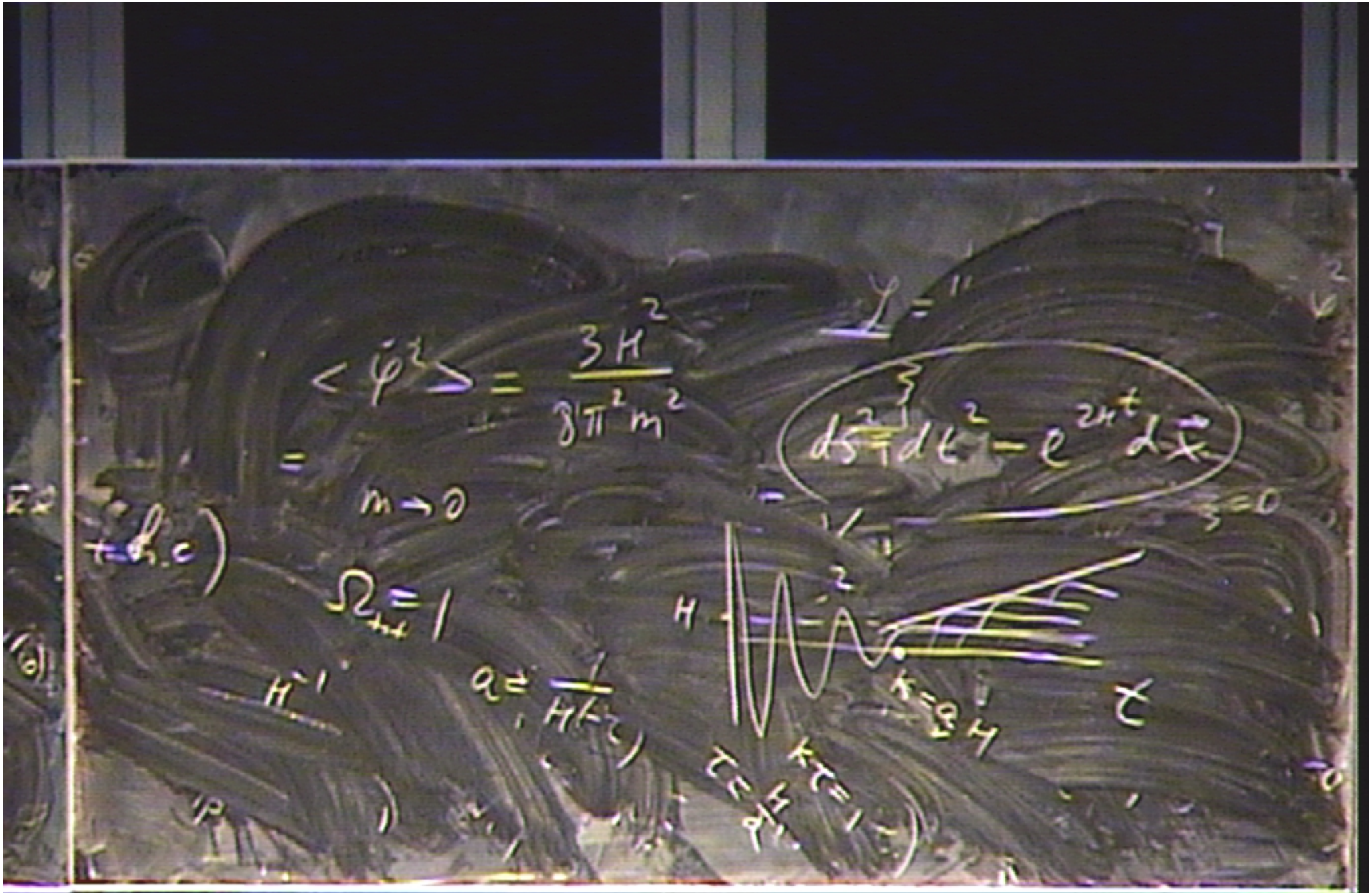
$k\tau = 1$

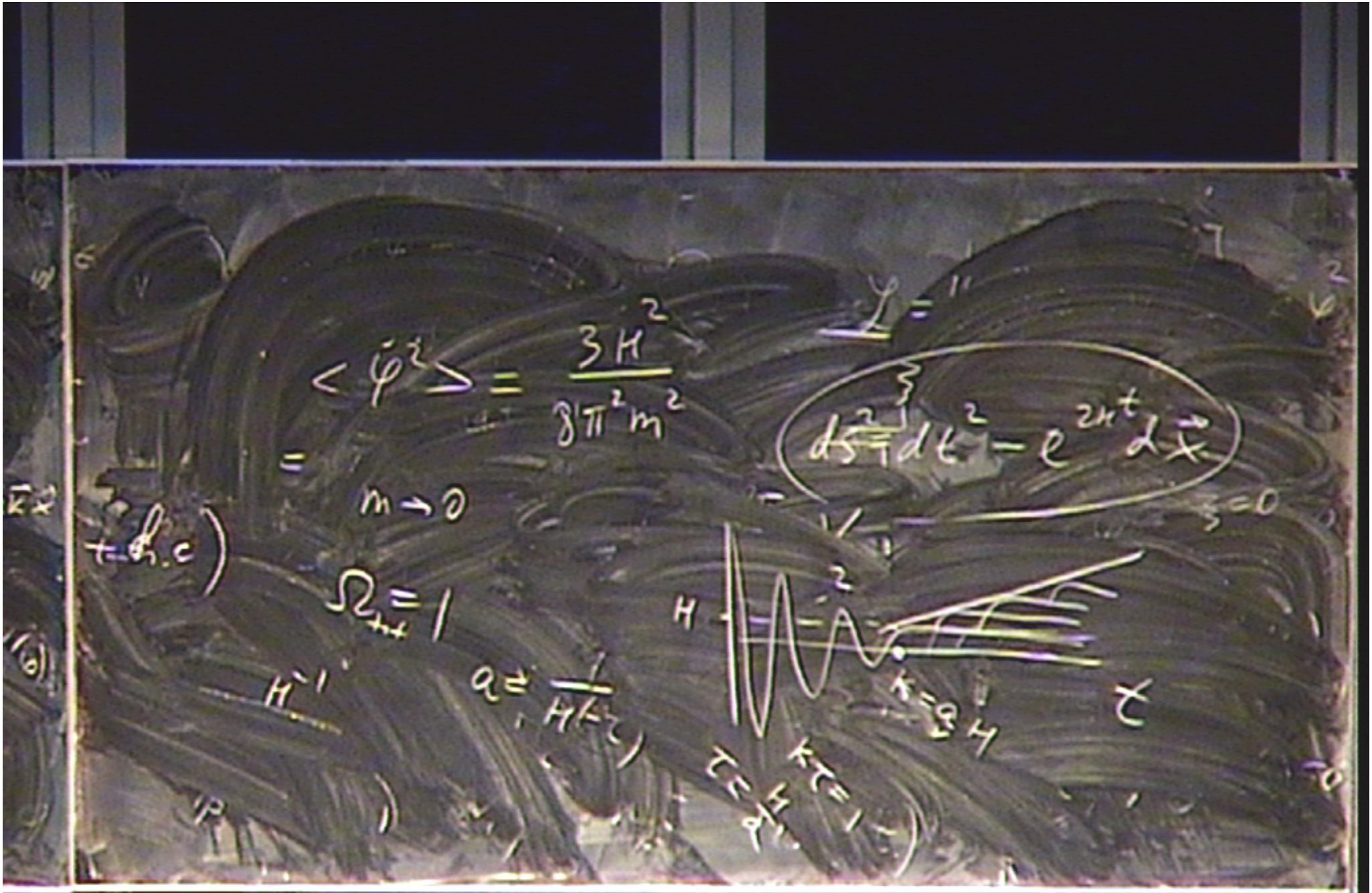
τ

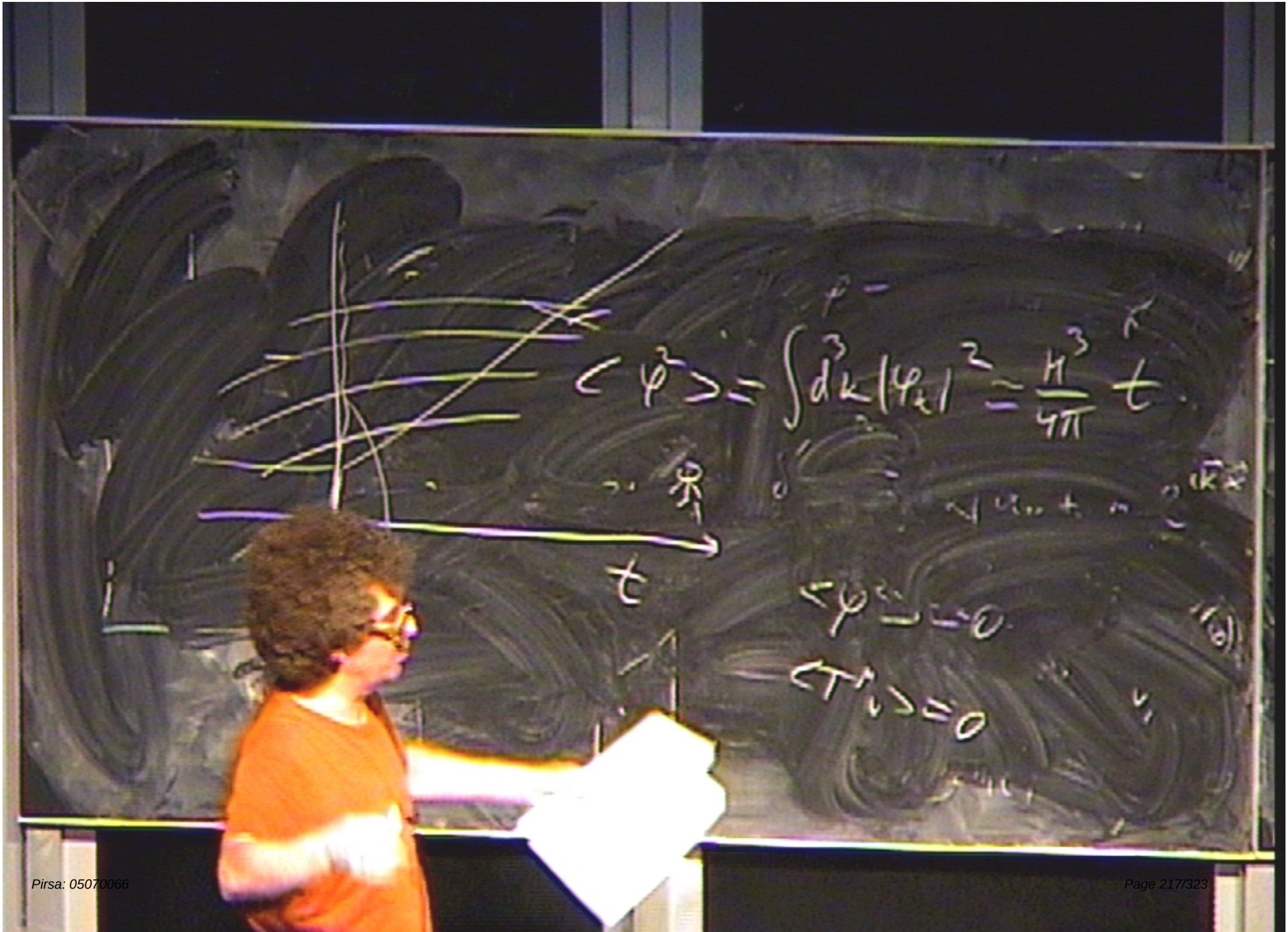
$\pm h.c)$

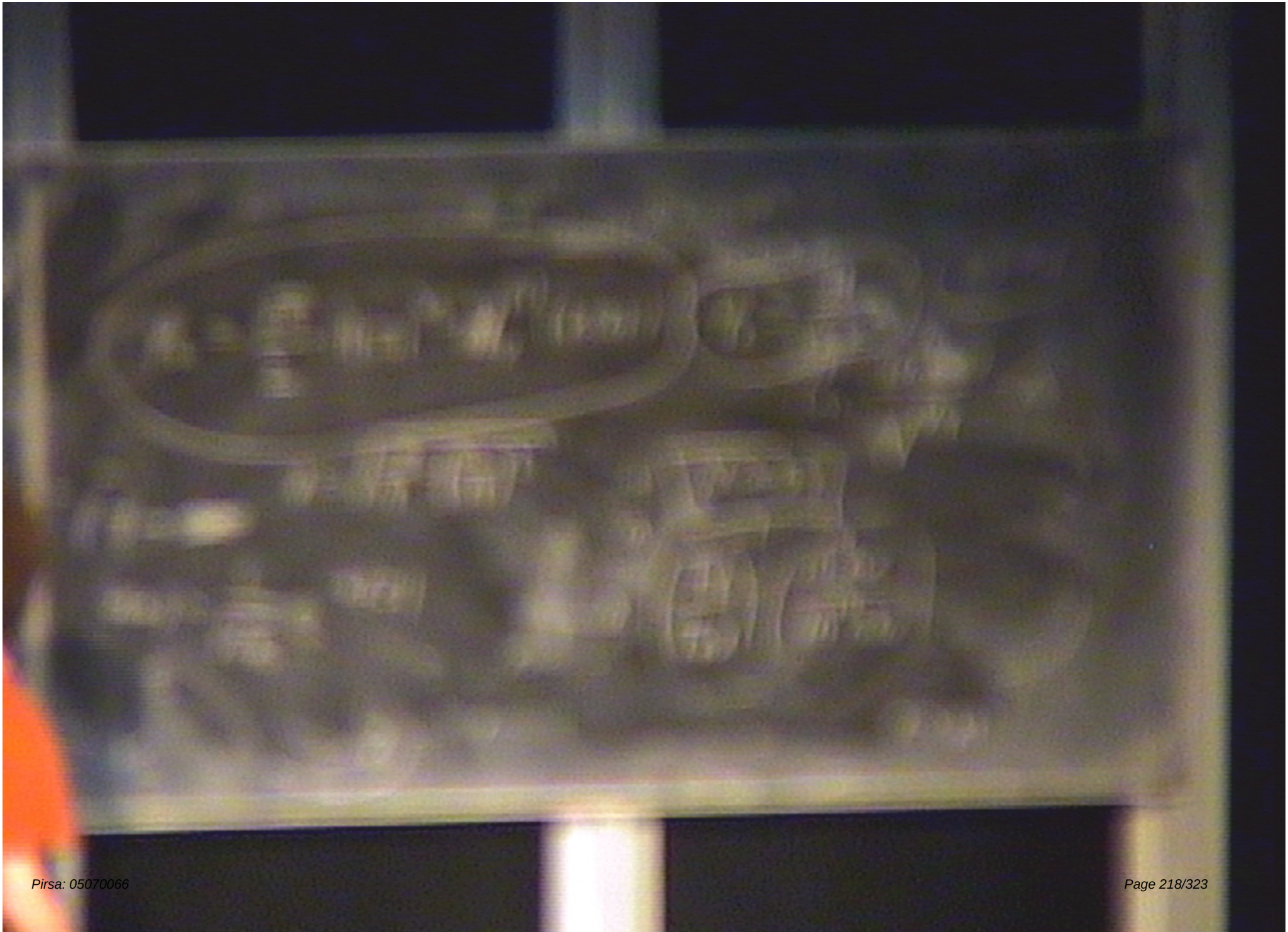
(6)

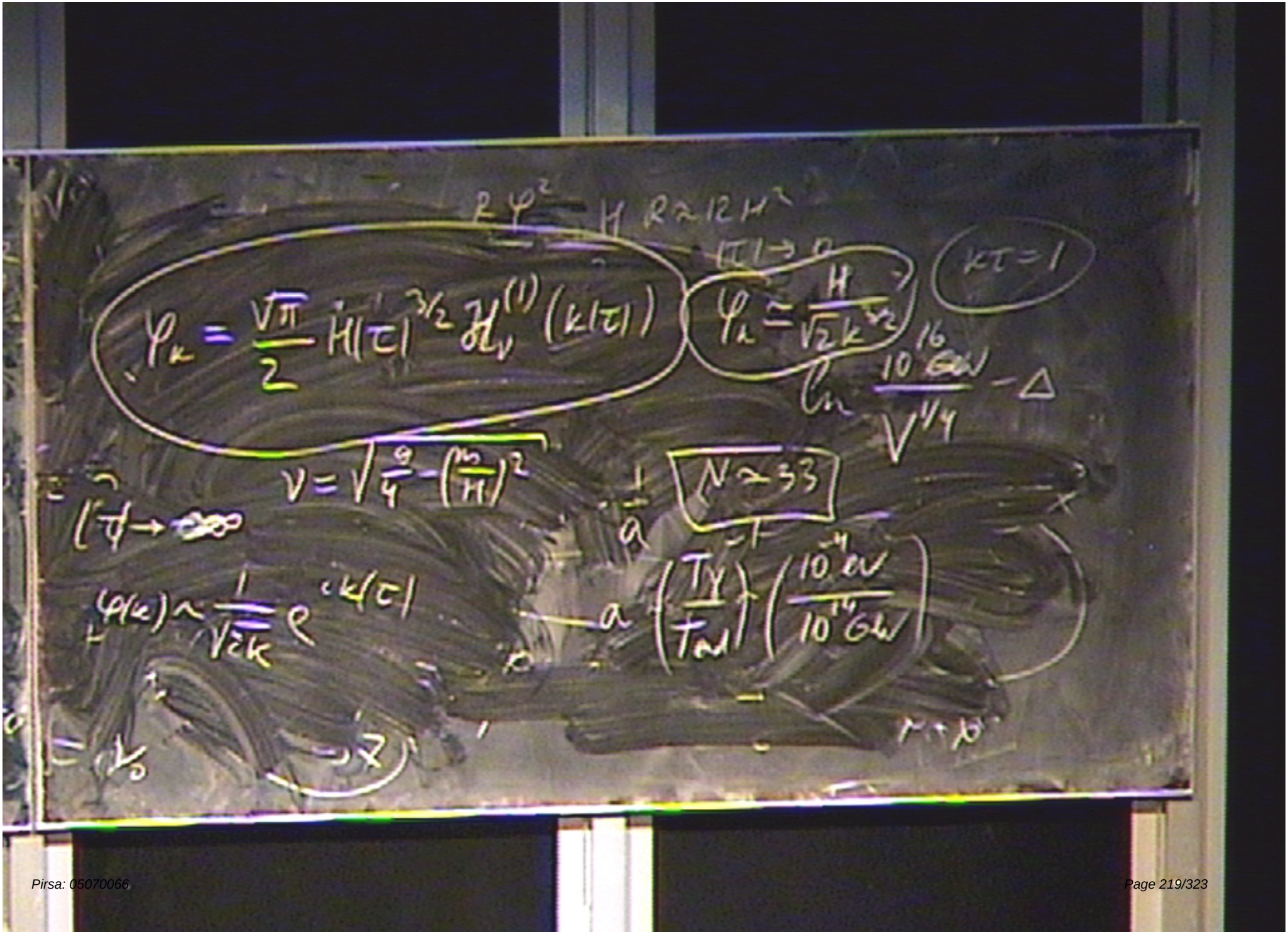

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
H^{-1}
$a = \frac{1}{H(\tau_0 - \tau)}$
τ
τ_0

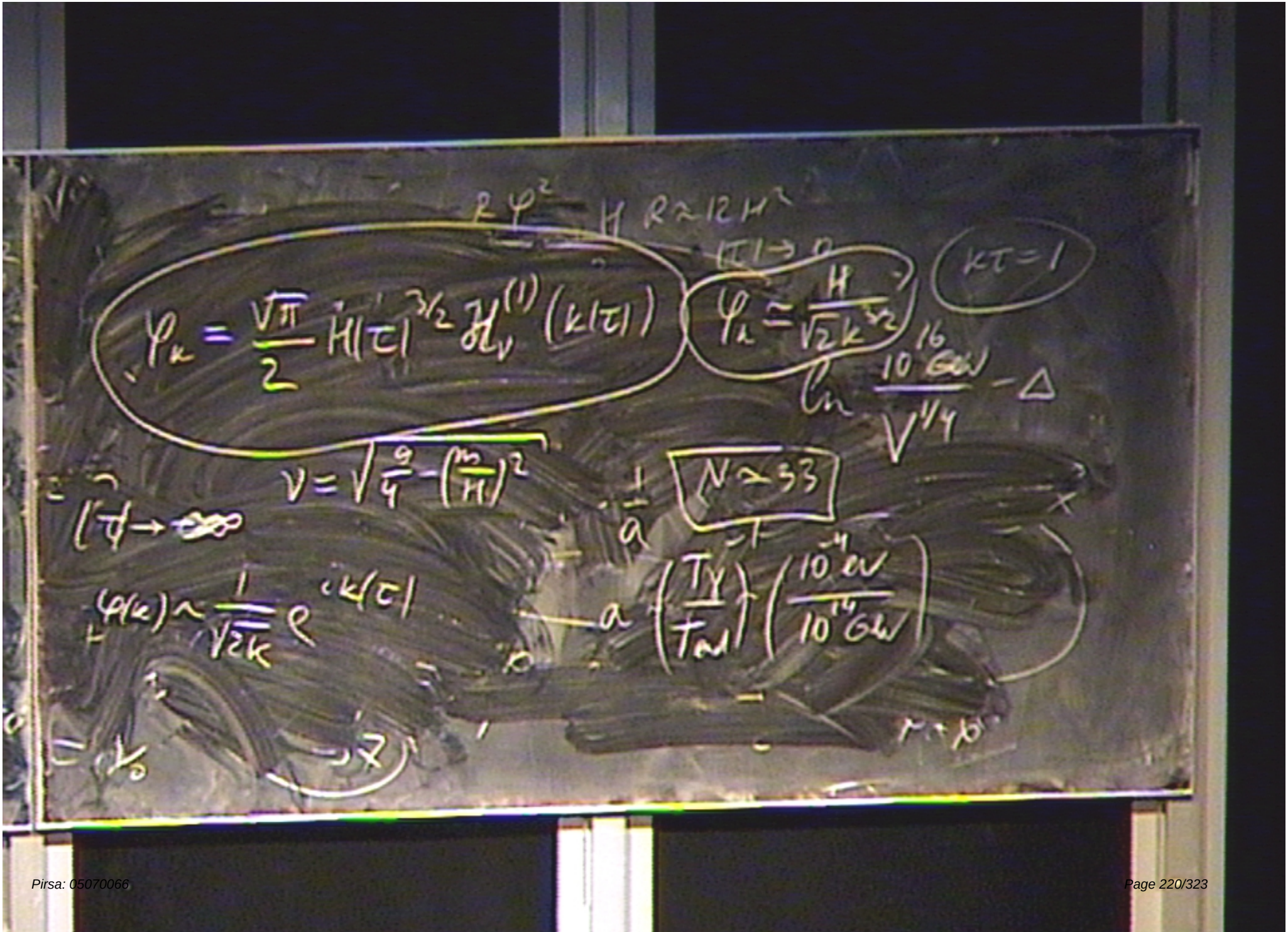

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$q = \frac{1}{H(\tau_0)}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
H
$k = aH$
τ
$k\tau = 1$
$\tau = \frac{H}{k}$

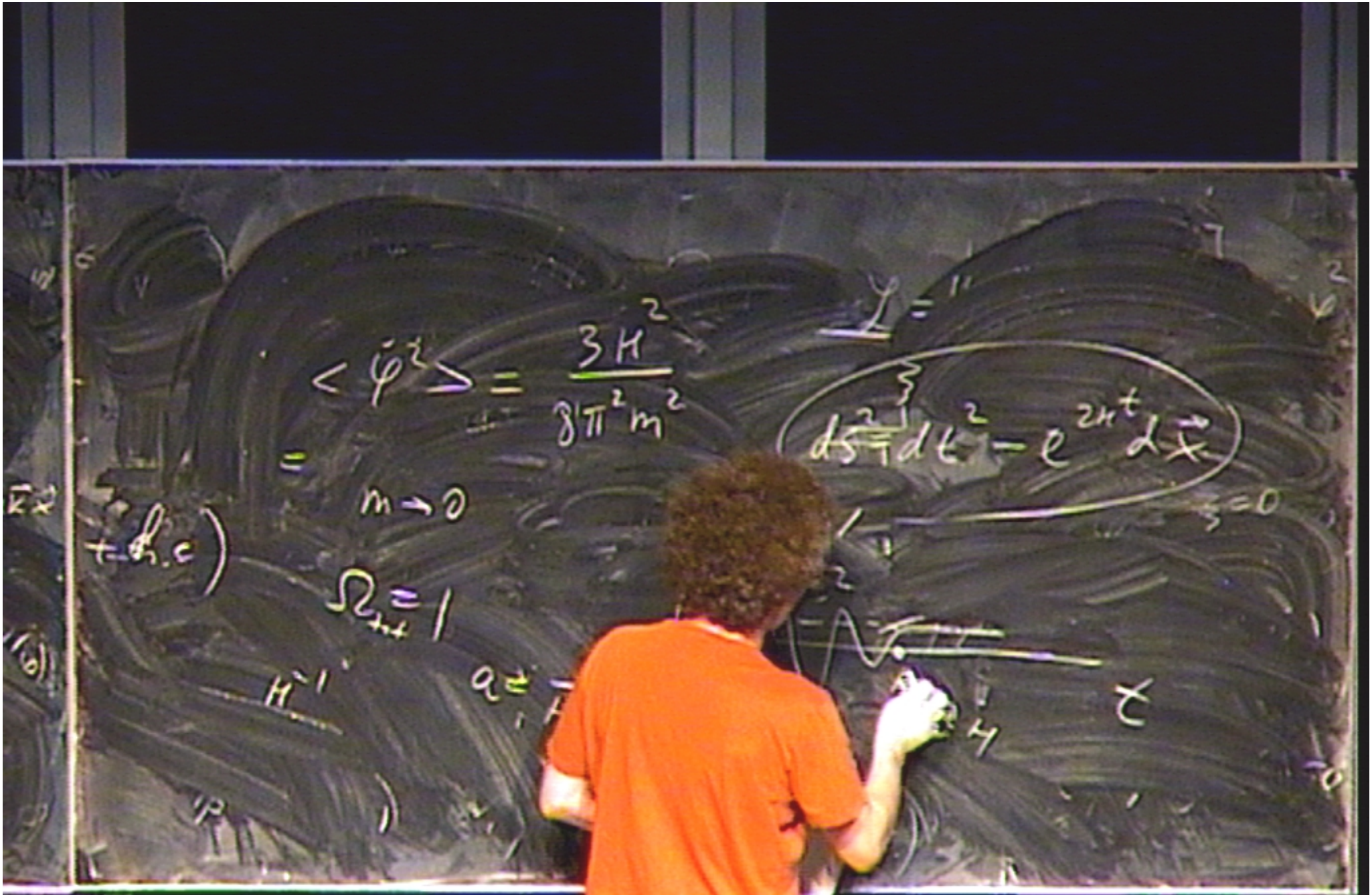

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
H
t

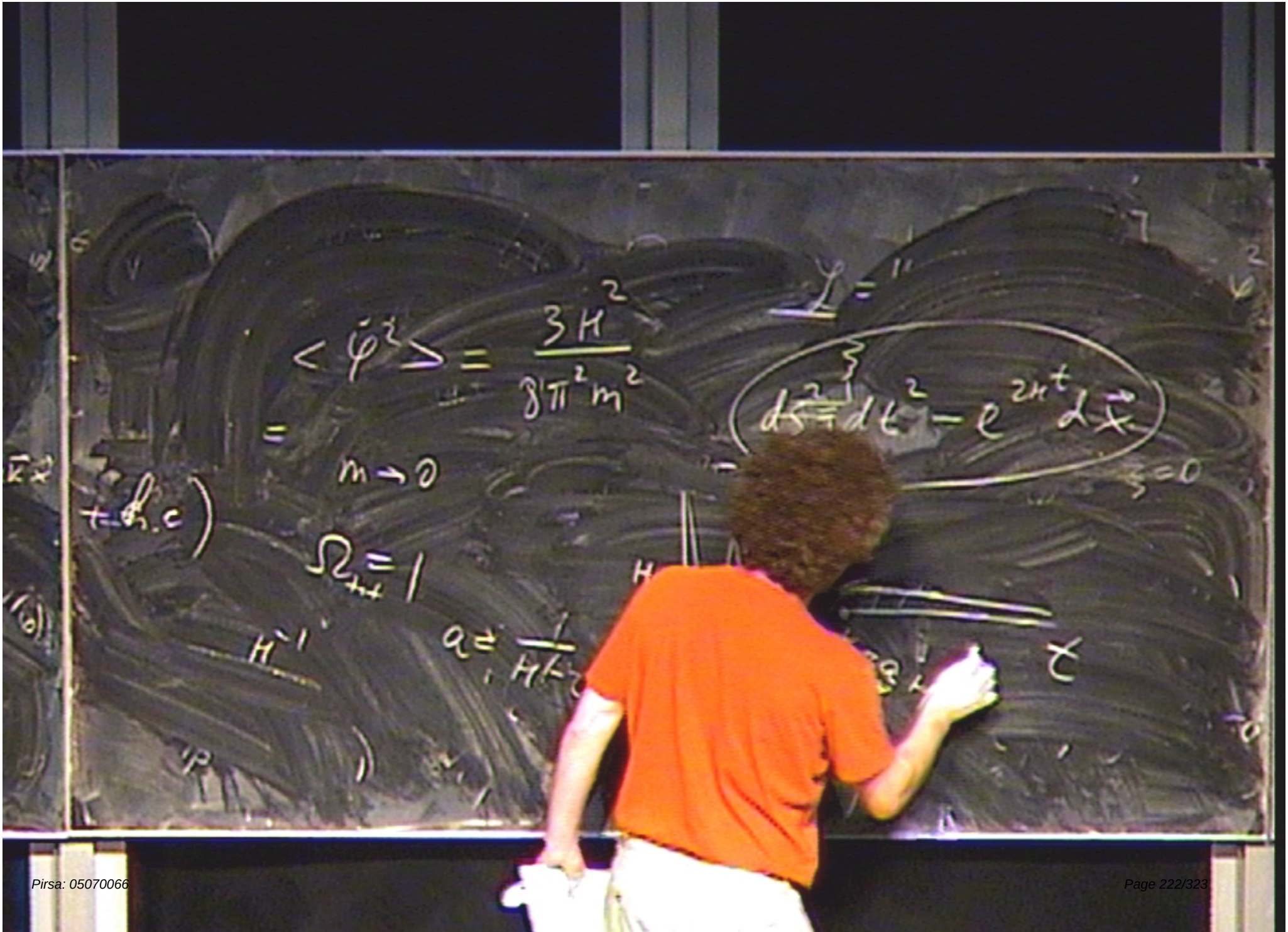

$\langle \varphi^2 \rangle = \int d^3k |\varphi_k|^2 \simeq \frac{H^3}{4\pi} t$
t
$\langle \varphi \rangle = 0$
$\langle T^{\mu\nu} \rangle = 0$

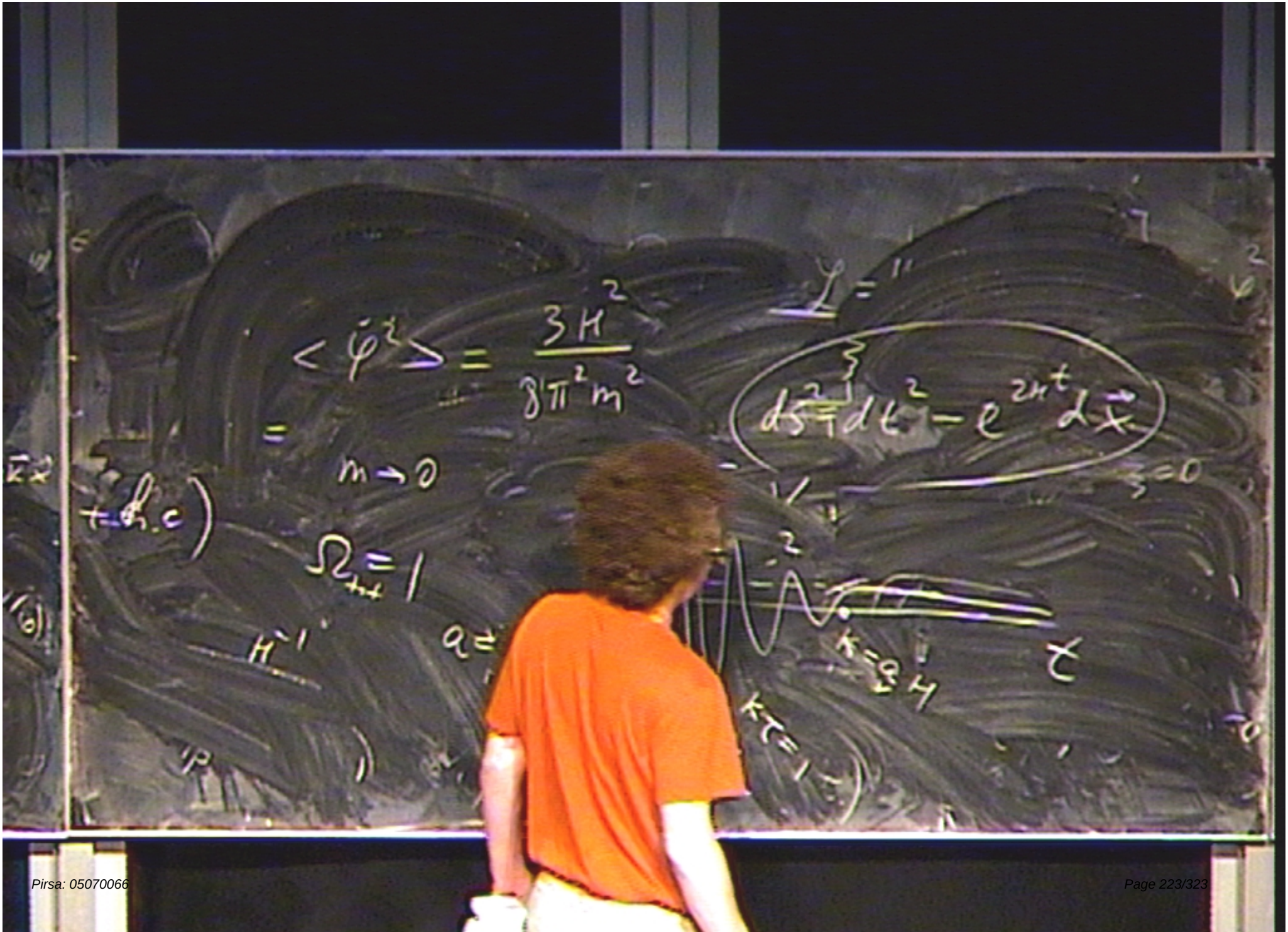


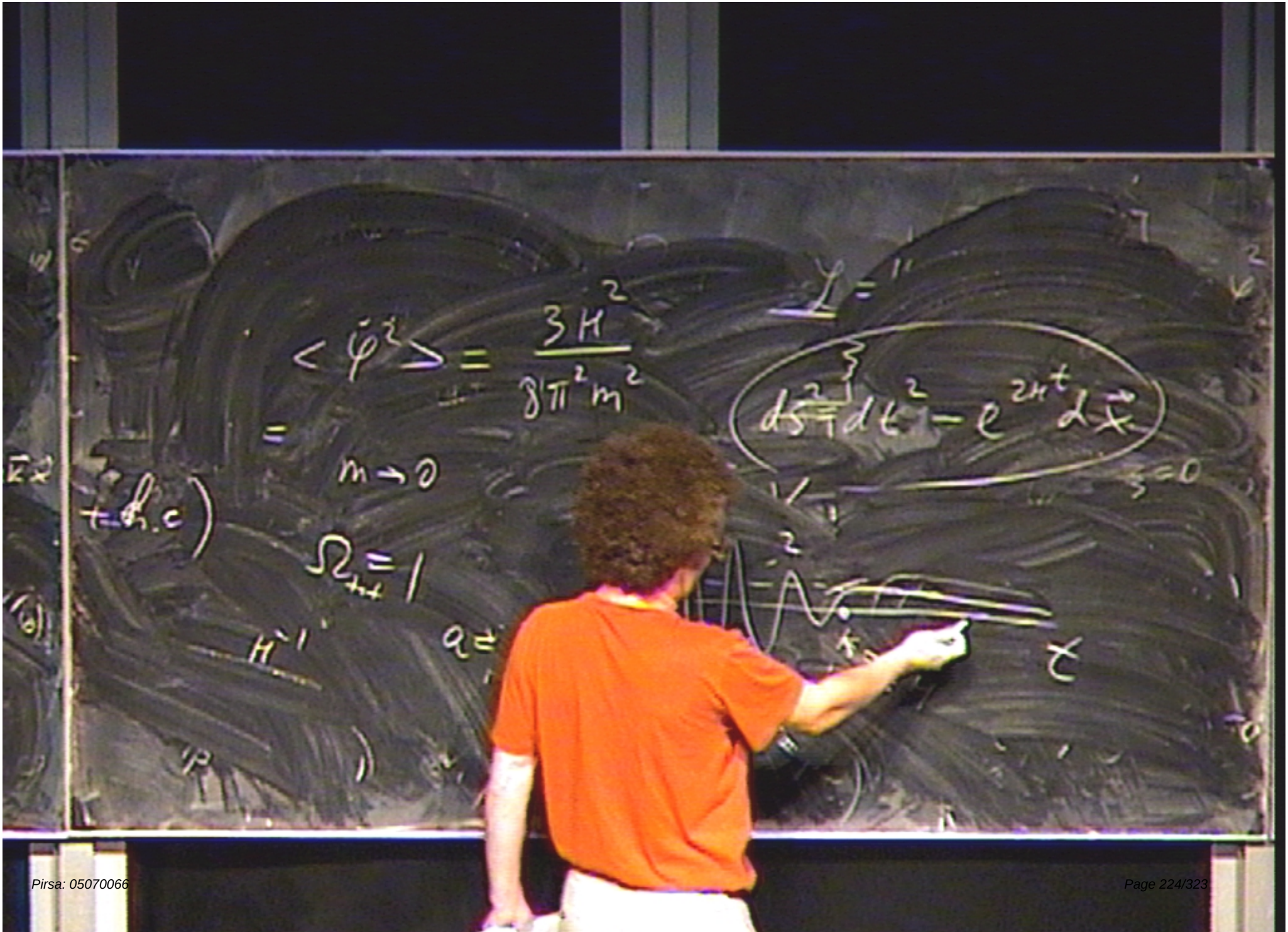

$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$k\tau = 1$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2} k^{3/2}}$
$\frac{10^{16}\,GeV}{V^{1/4}}$
Δ
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$|\vec{x}| \to \infty$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

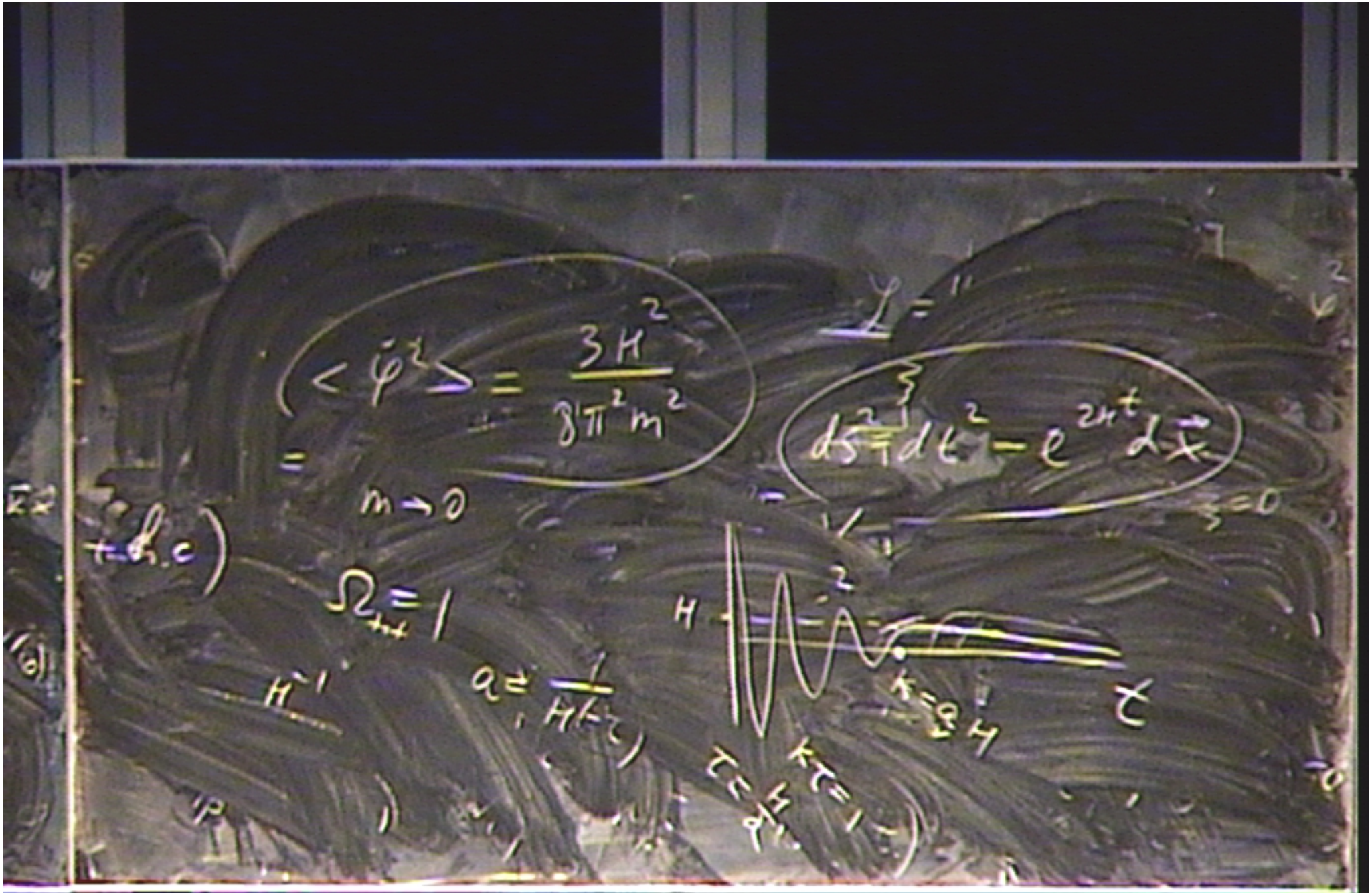

$\frac{1}{2}\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$k\tau = 1$
$\varphi_k = \frac{\sqrt{\pi}}{2} H |\tau|^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2} k^{3/2}}$
$\frac{10^{16}\,GeV}{V^{1/4}}$
Δ
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$|\tau| \to \infty$
$\varphi(k) \sim \frac{1}{\sqrt{2k}} e^{ik|\tau|}$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

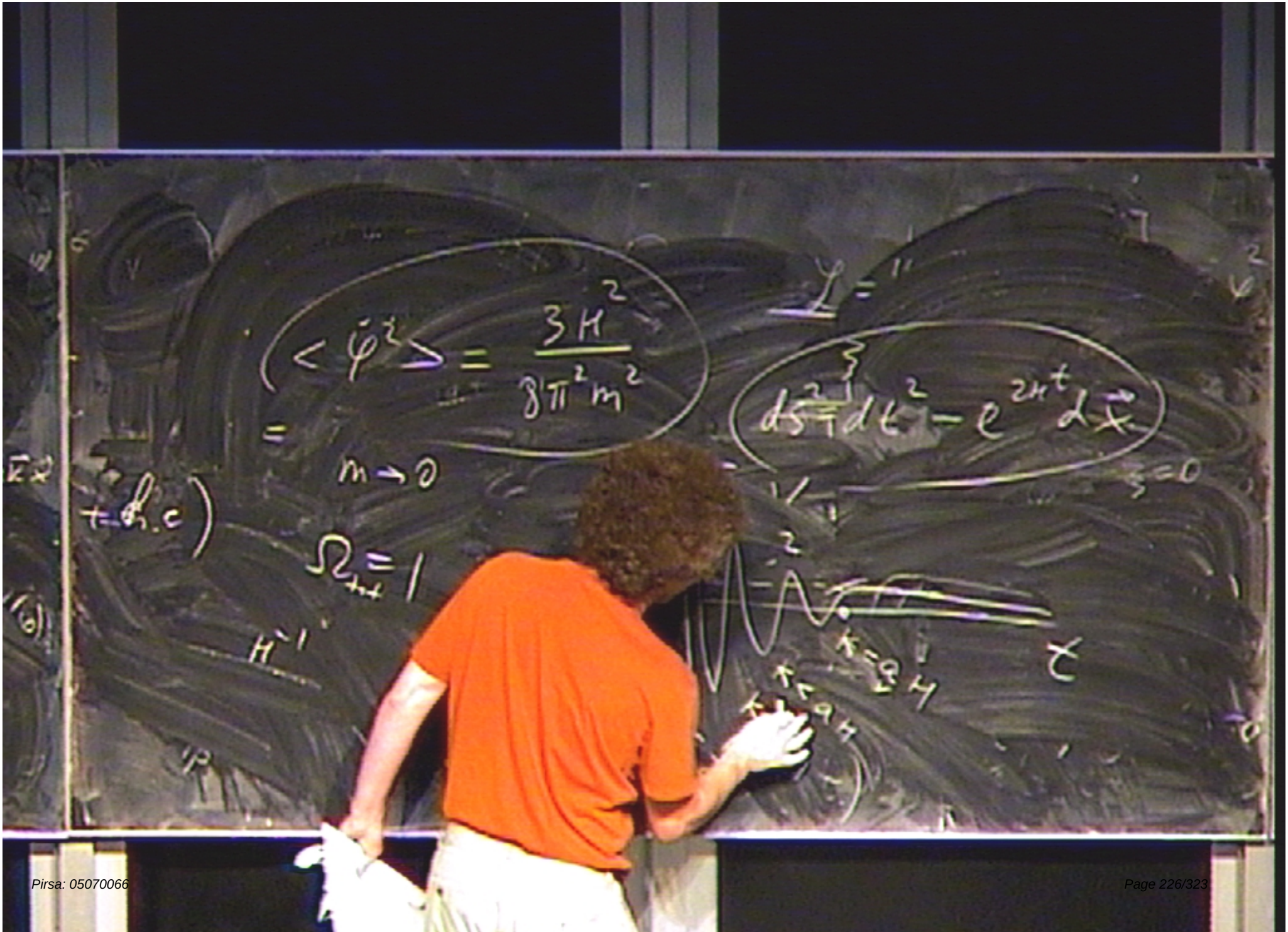

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$t = 0$
t

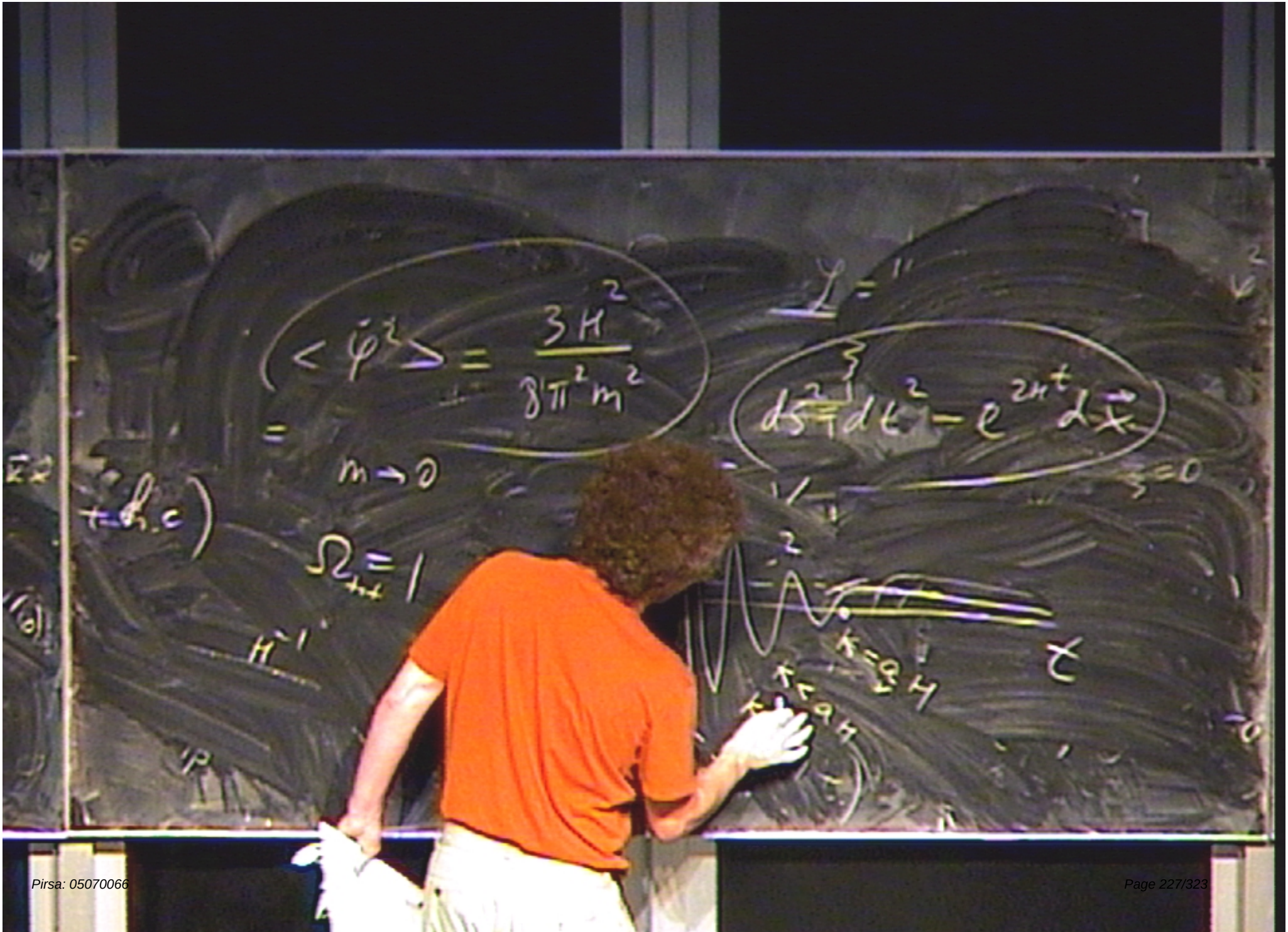

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\mathcal{L} =$
τ

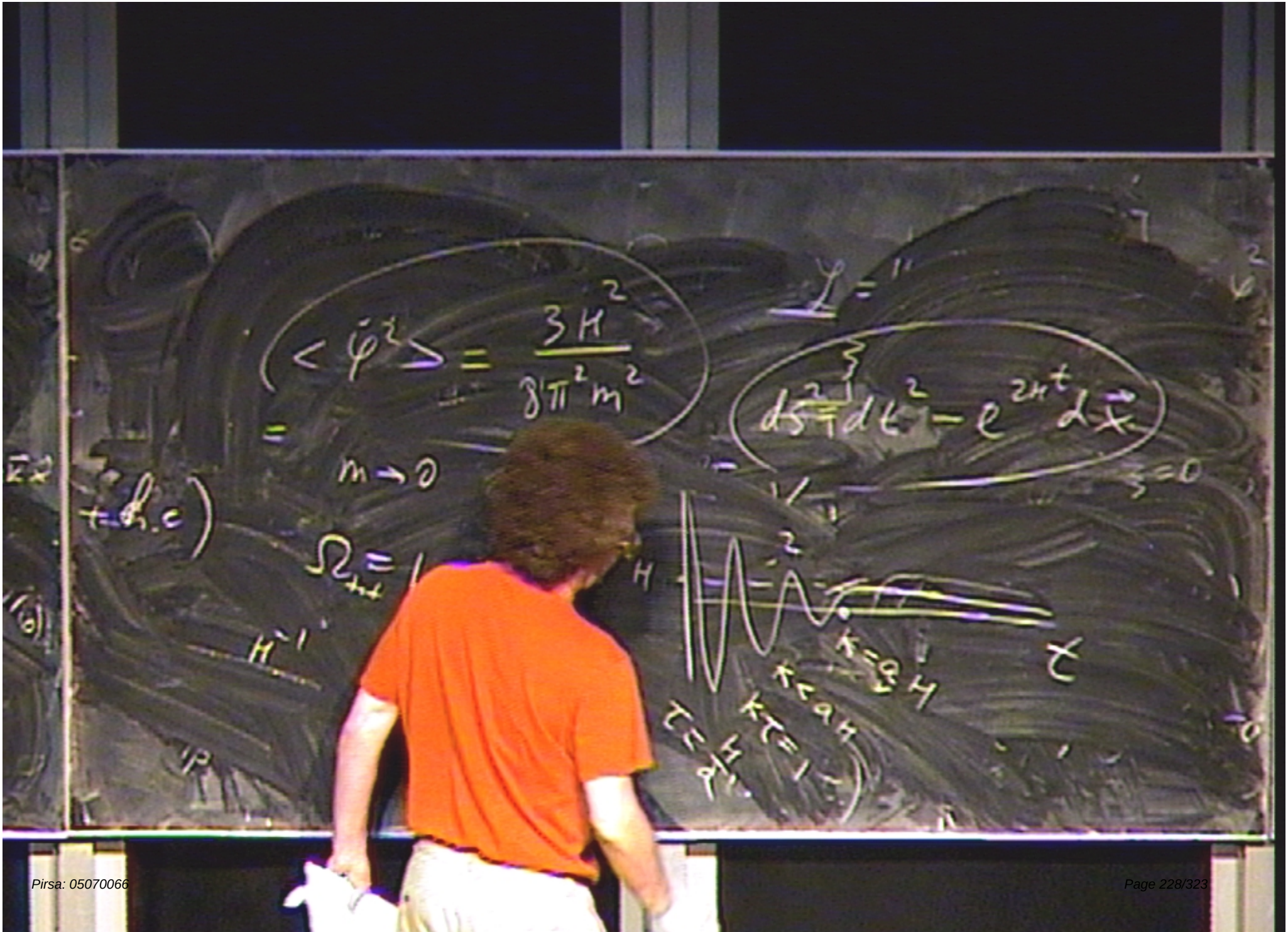

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$= m \to 0$
$\Omega_{tot} = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\ddot{\varphi} + 3H\dot{\varphi} + \frac{\partial V}{\partial \varphi} = 0$
H^{-1}
$k = aH$
$k\tau = 1$
τ

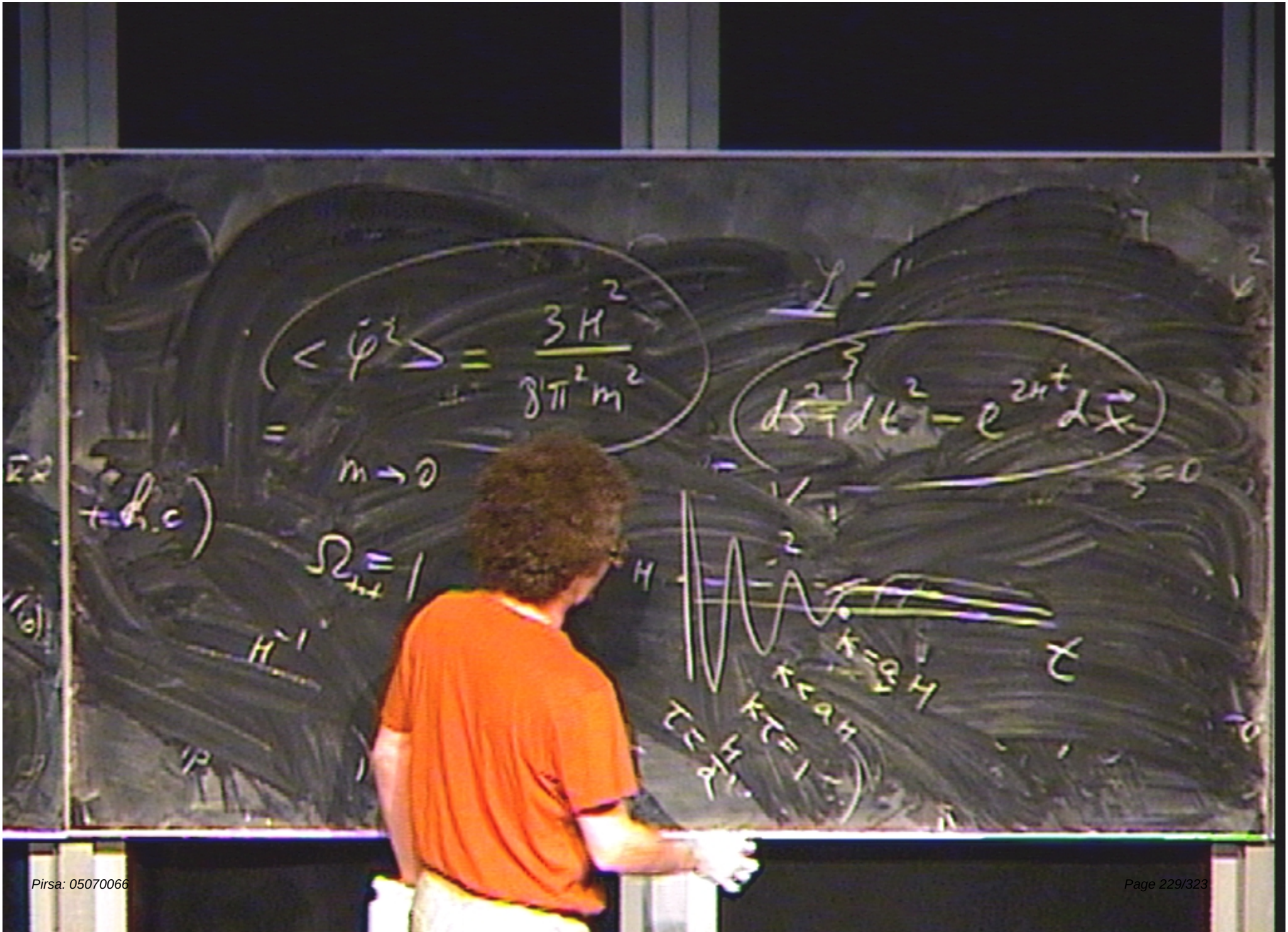

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
t

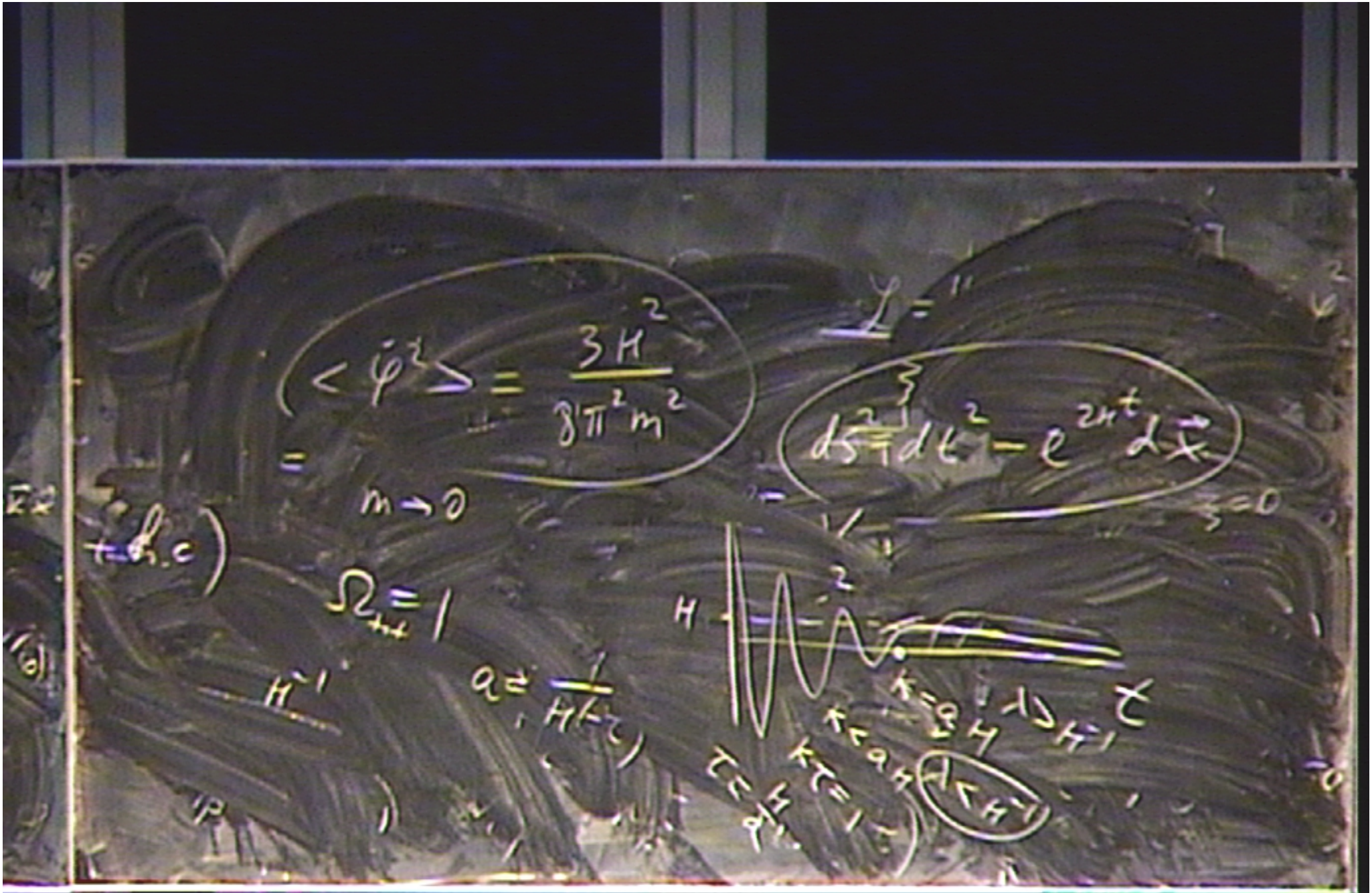

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$a = \frac{1}{H(t-t_i)}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
H
$k = aH$
t
$k\tau = 1$
$\tau = \frac{H}{a^2}$

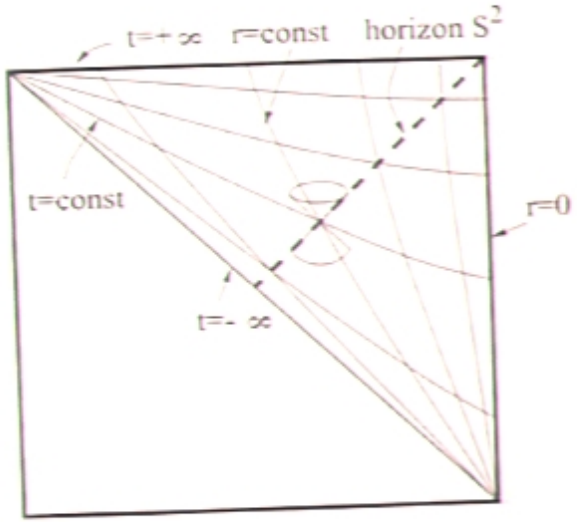

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\mathcal{L} =$
τ

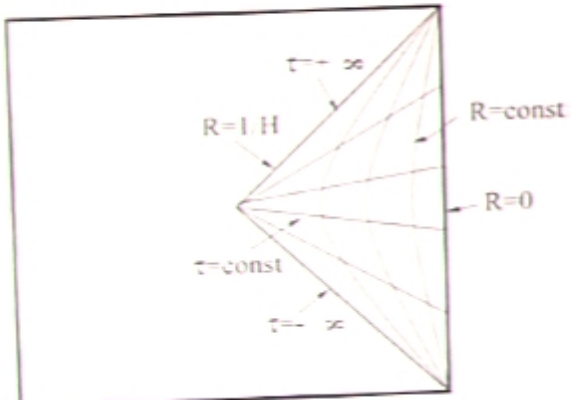

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$

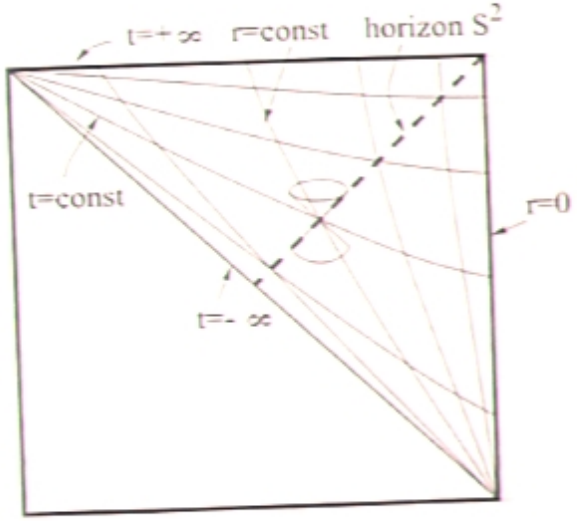

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
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$\mathcal{L} =$
H^{-1}
τ
$k\tau = 1$

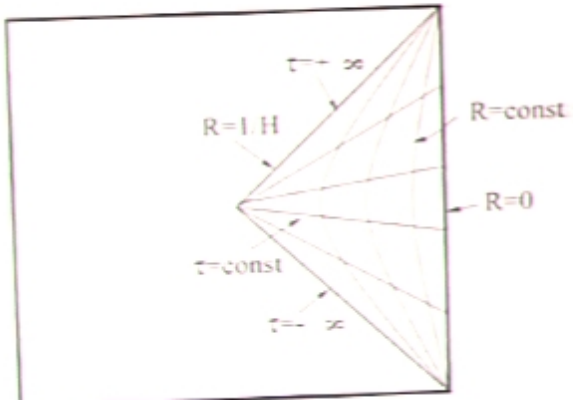

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
H^{-1}
τ

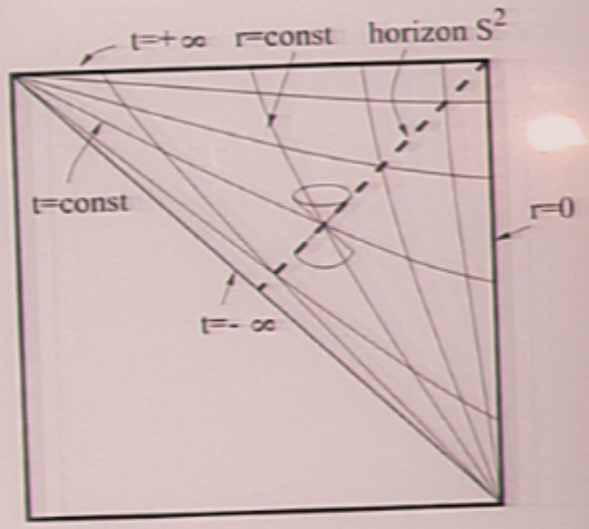

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$m \to 0$
$\Omega_{tot} = 1$
H^{-1}
$q = \frac{1}{H\tau}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
H
$k = aH$
$\lambda > H^{-1}$
τ
$k\tau = qH\tau = 1$
$\lambda < H^{-1}$

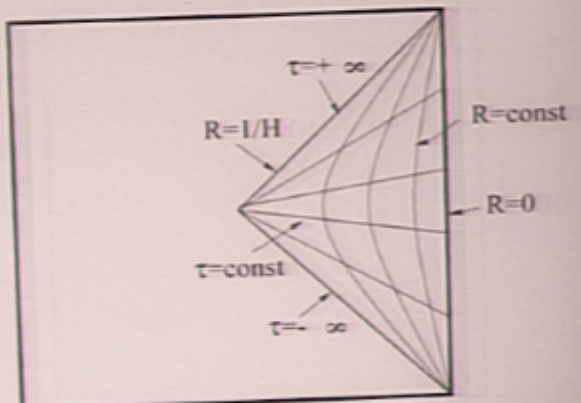

t=+ ∞
r=const
horizon S^2
t=const
r=0
t=- ∞

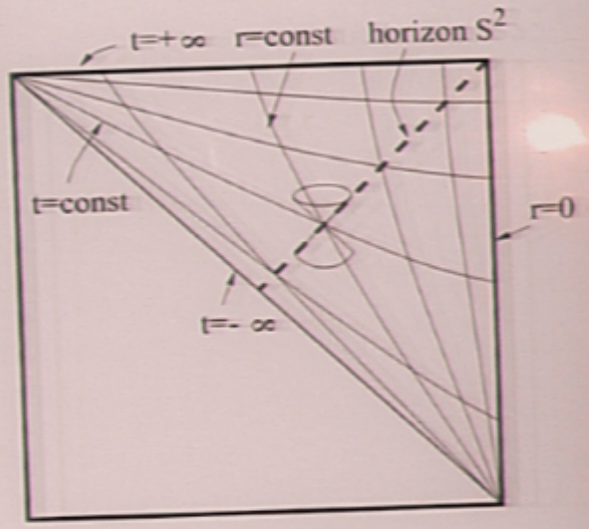

t=+ ∞
R=1/H
R=const
R=0
t=const
t=- ∞

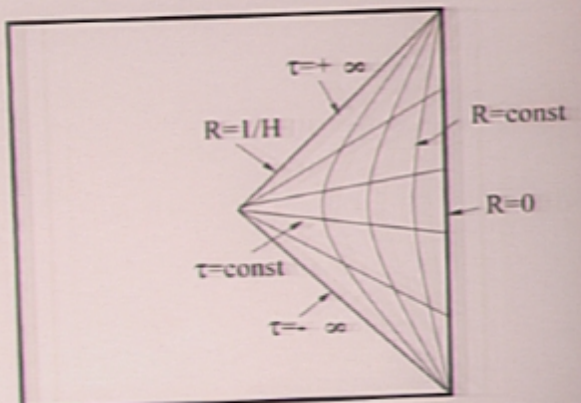

t=+ ∞
r=const
horizon S^2
t=const
r=0
t=- ∞

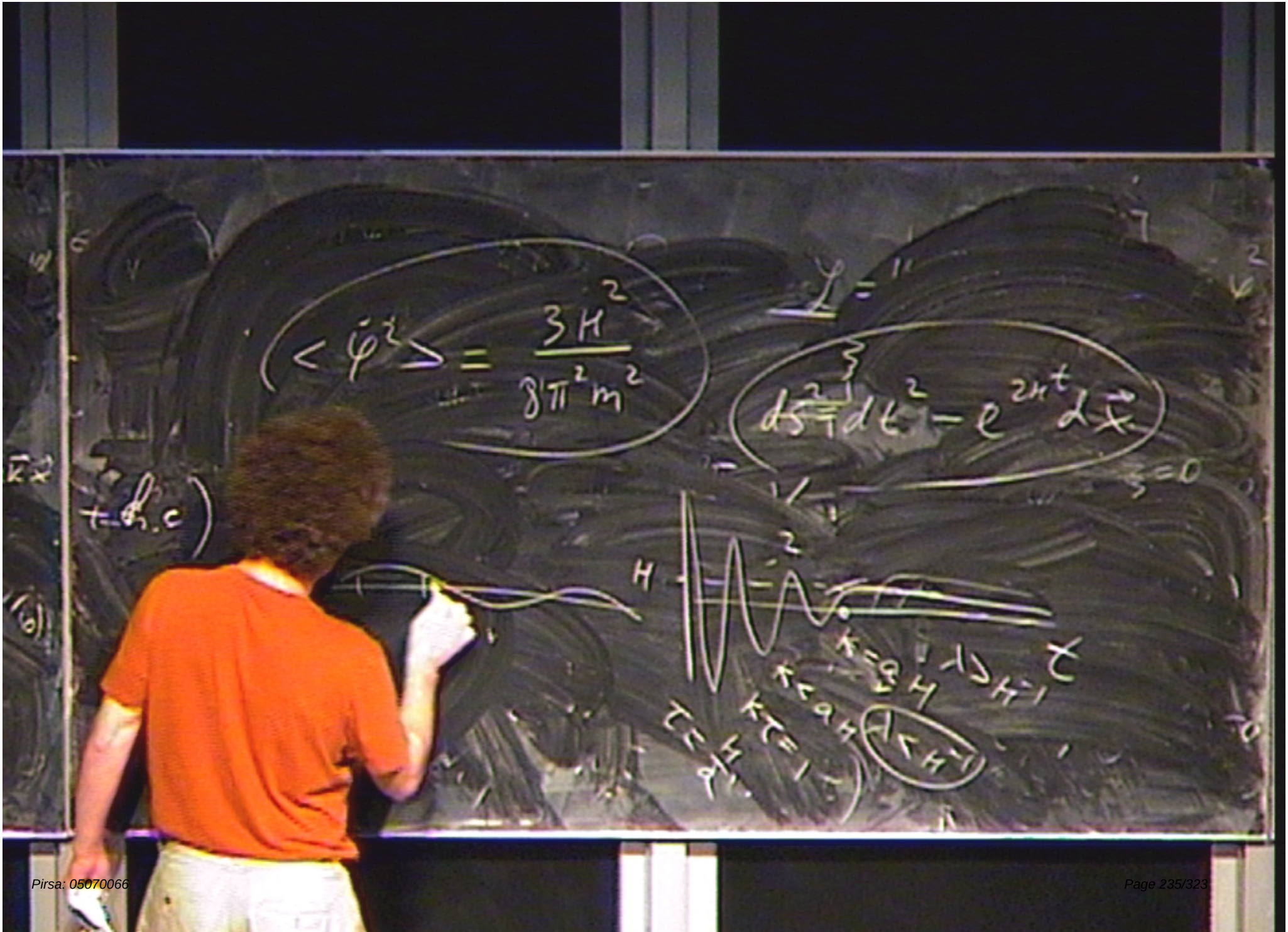

t=+ ∞
R=1/H
R=const
R=0
t=const
t=- ∞

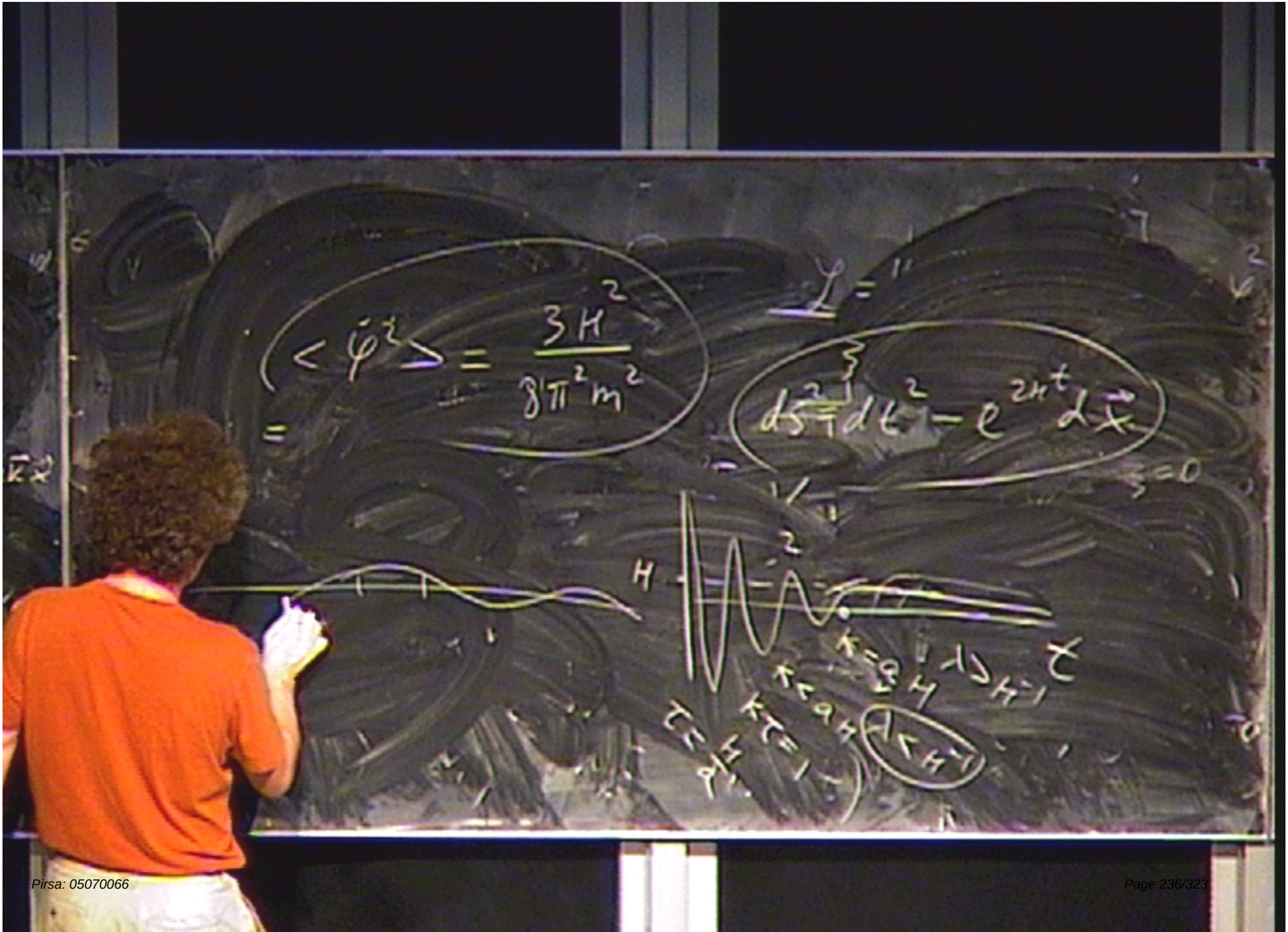

t=+∞
r=const
horizon S^2
t=const
r=0
t=- ∞

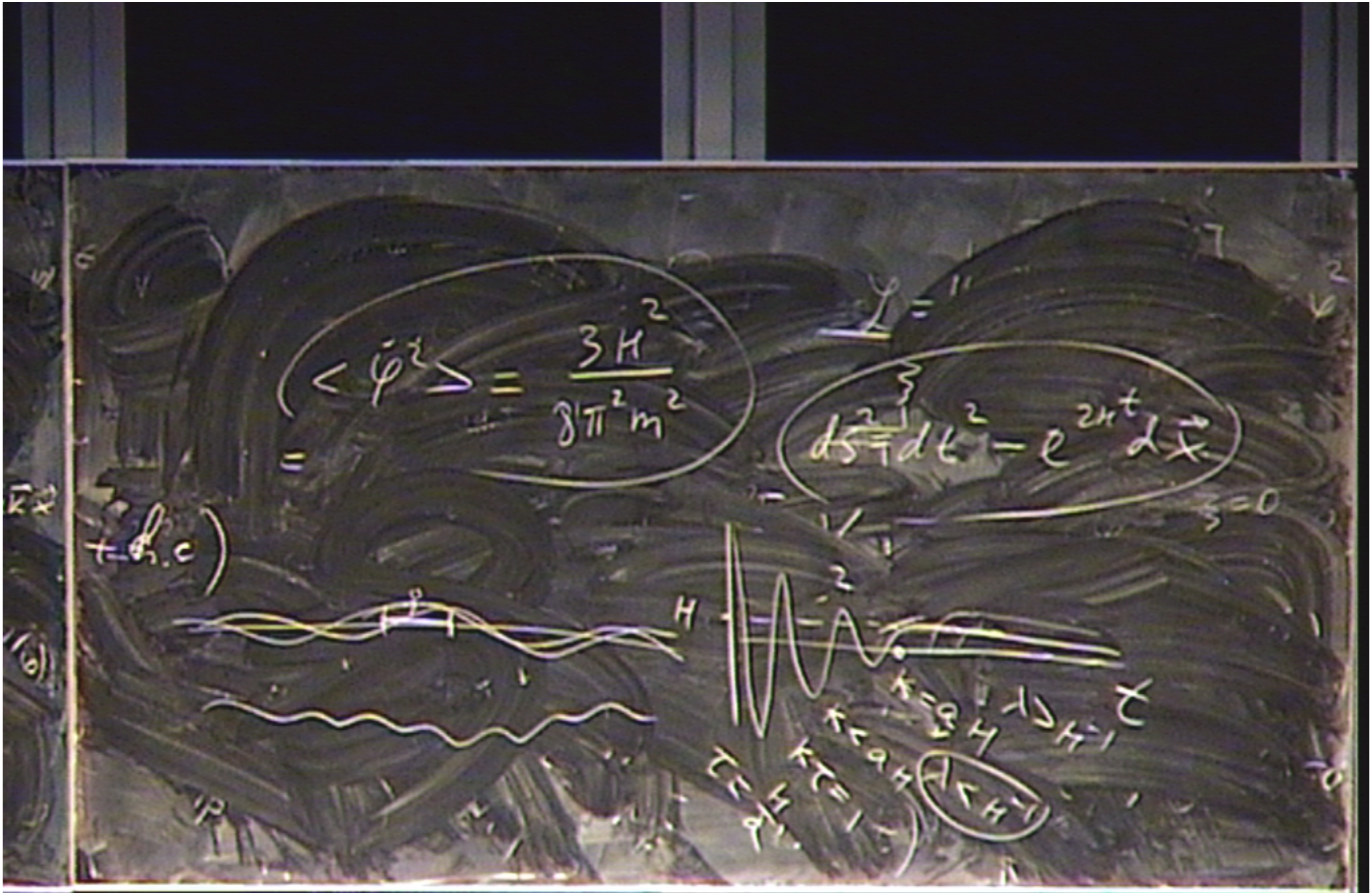

τ=+ ∞
R=1/H
R=const
R=0
τ=const
τ=- ∞

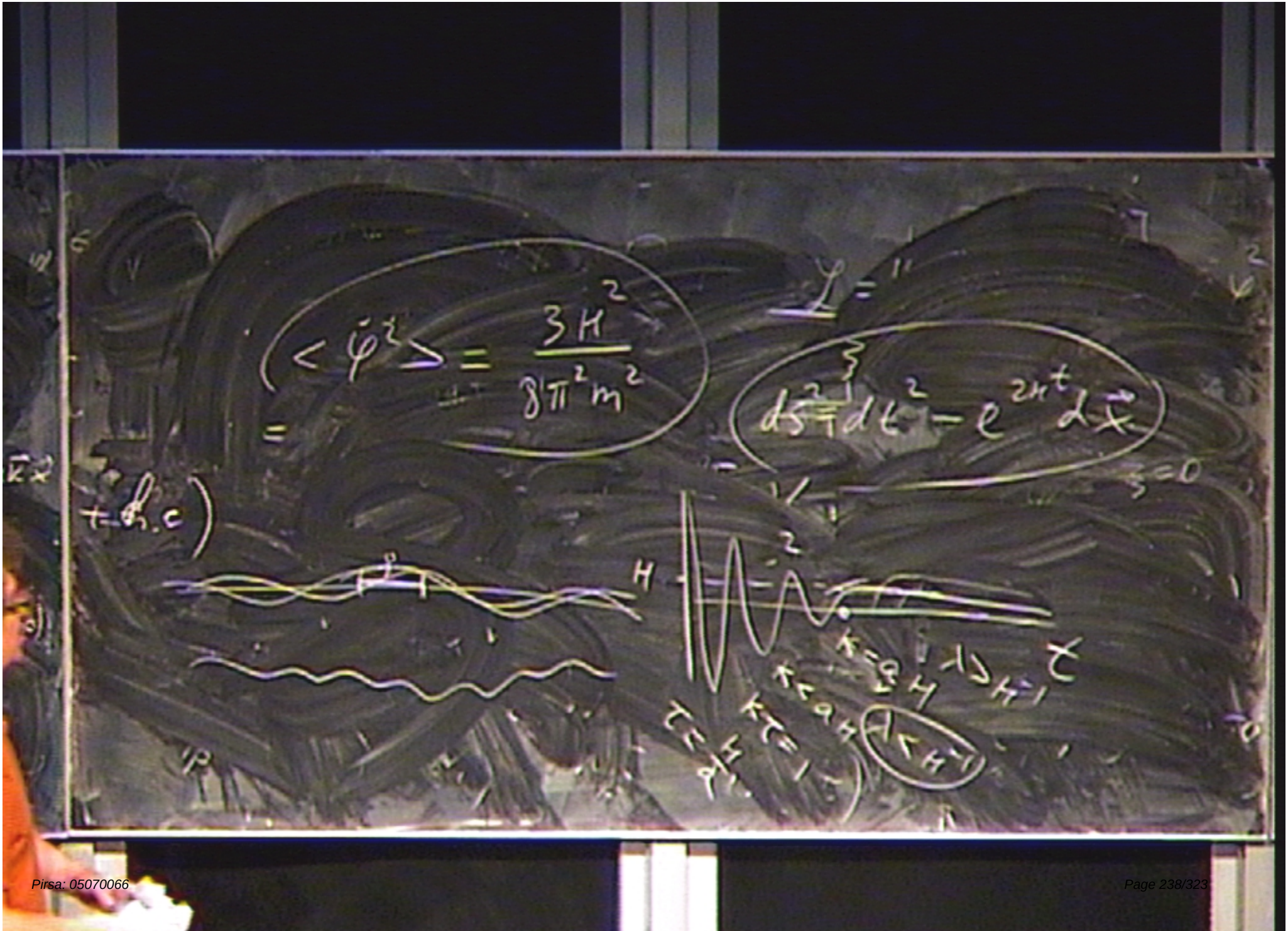

t=+∞
r=const
horizon S^2
t=const
r=0
t=- ∞

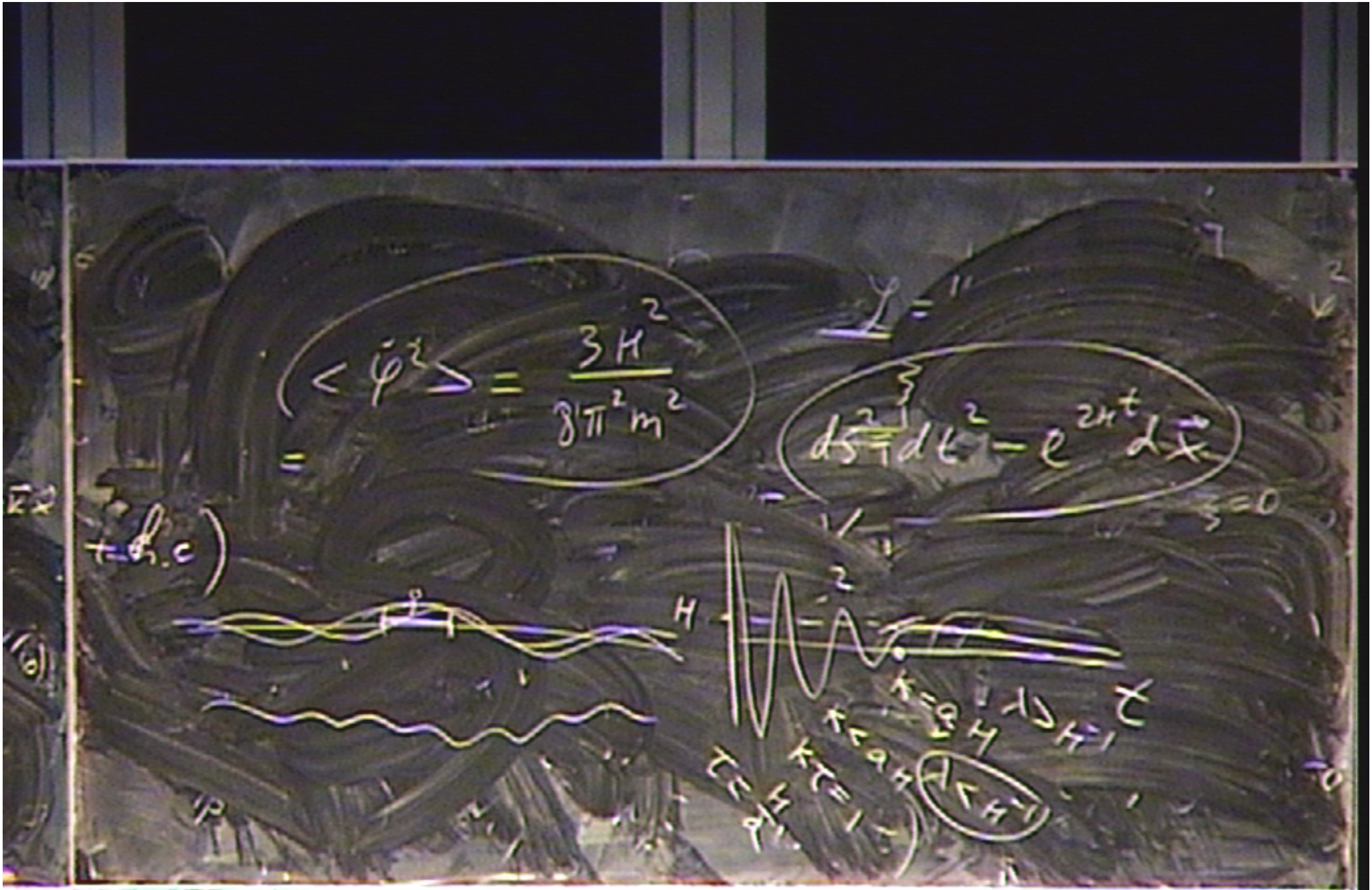

τ=+ ∞
R=1/H
R=const
R=0
τ=const
τ=- ∞

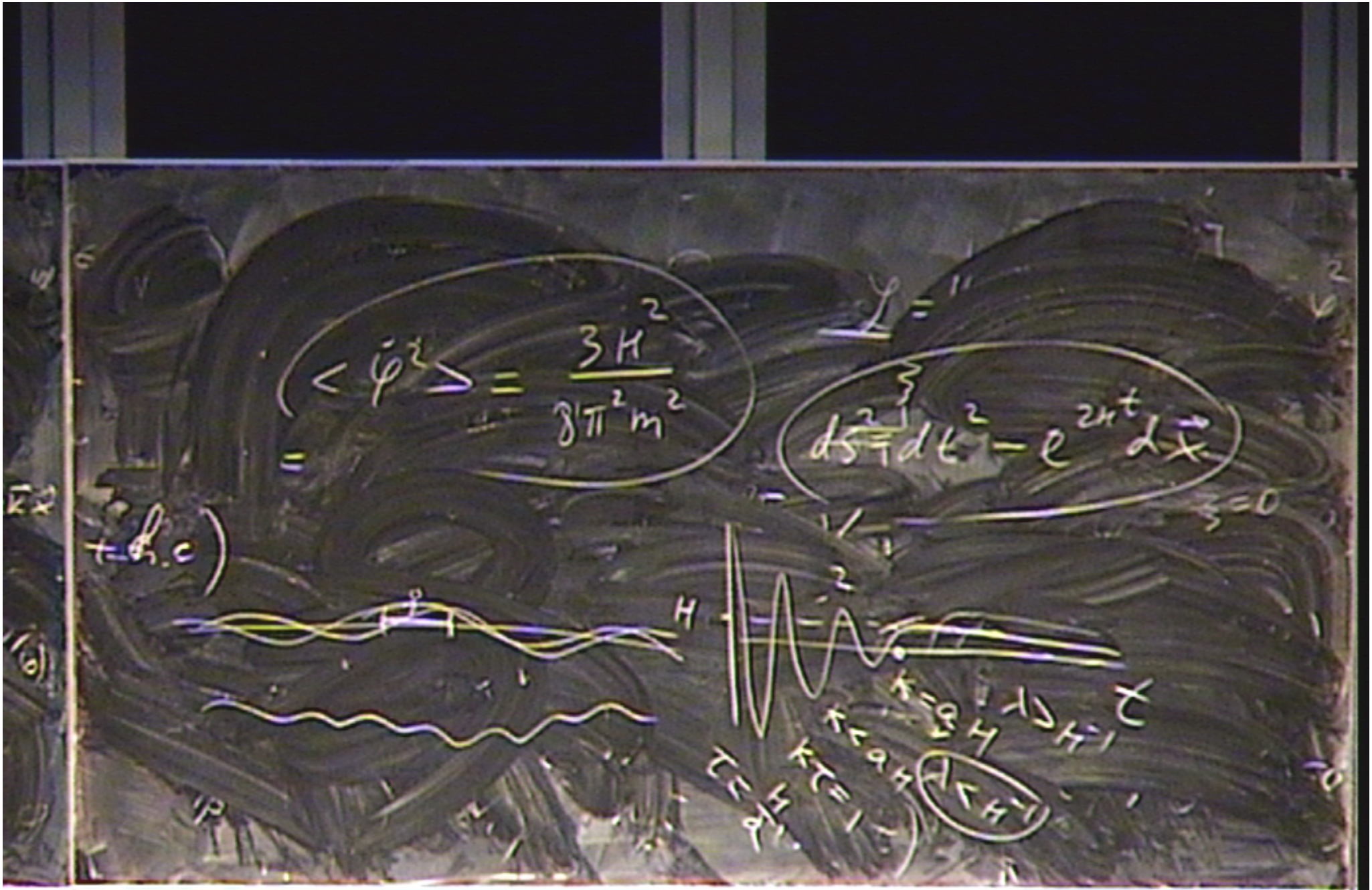

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$+ h.c.$
H
τ

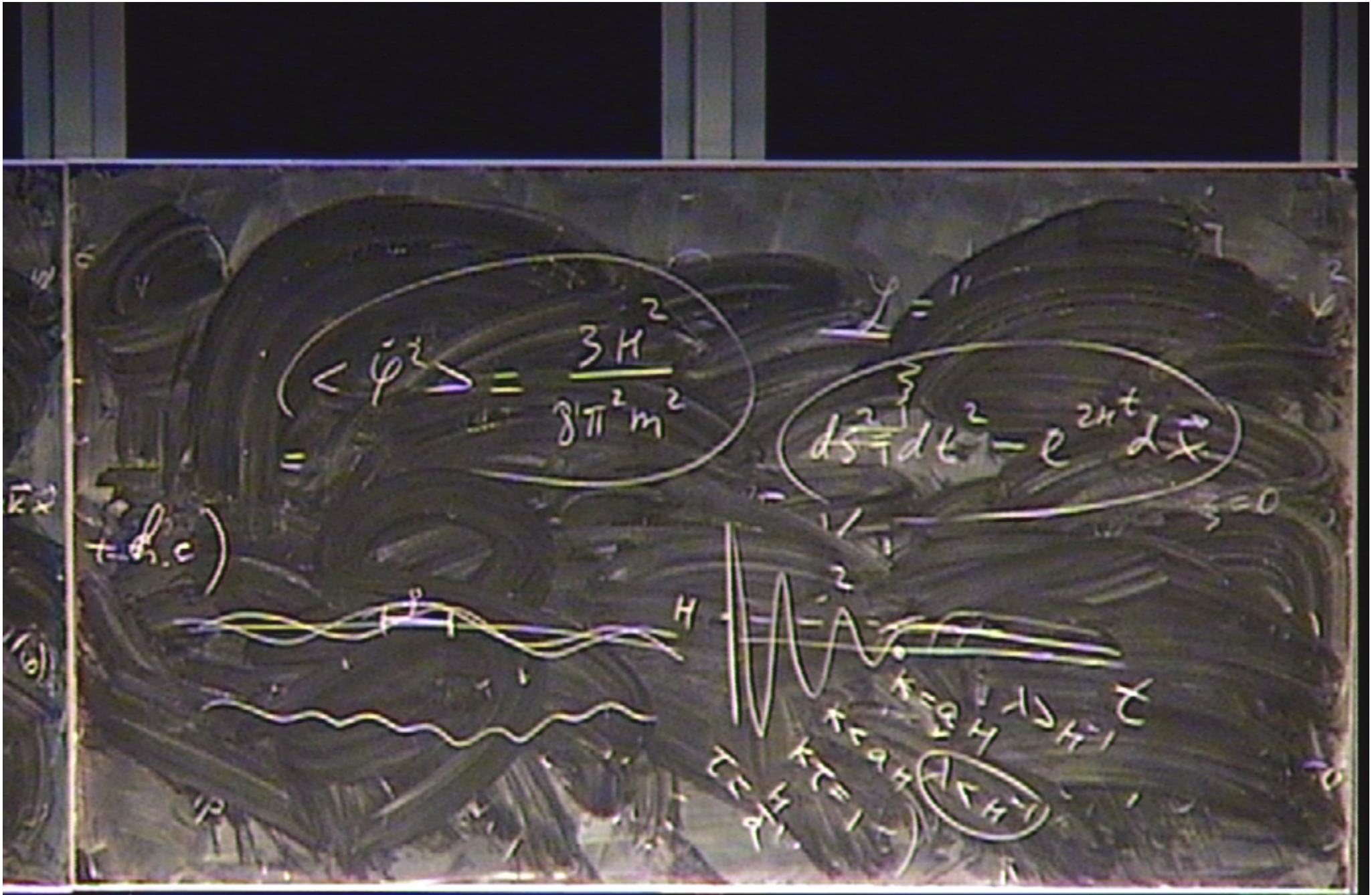

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
H

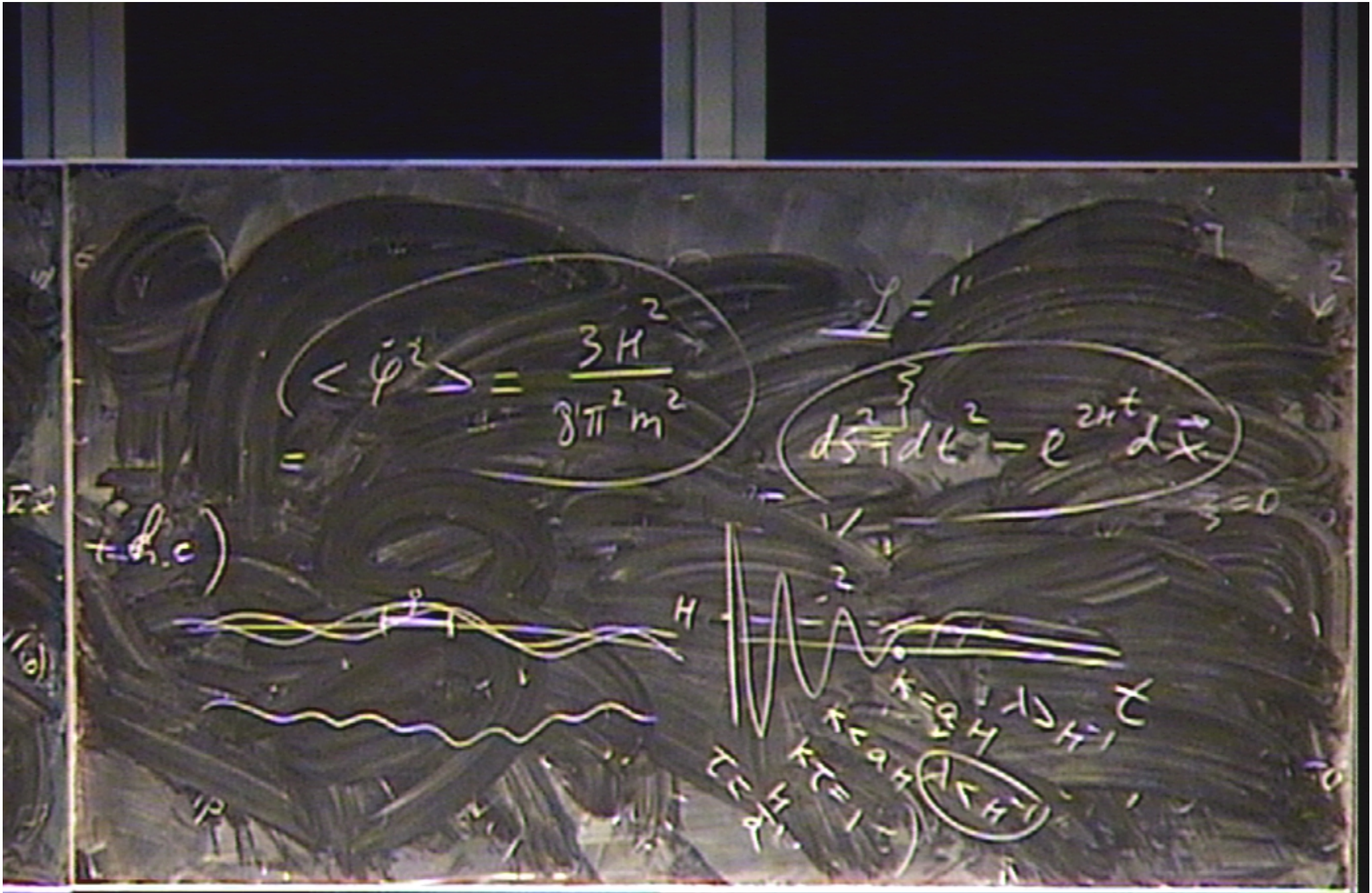

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$+h.c)$
H
$k = aH$
$k\tau = 1$
$\tau = \frac{1}{H}$

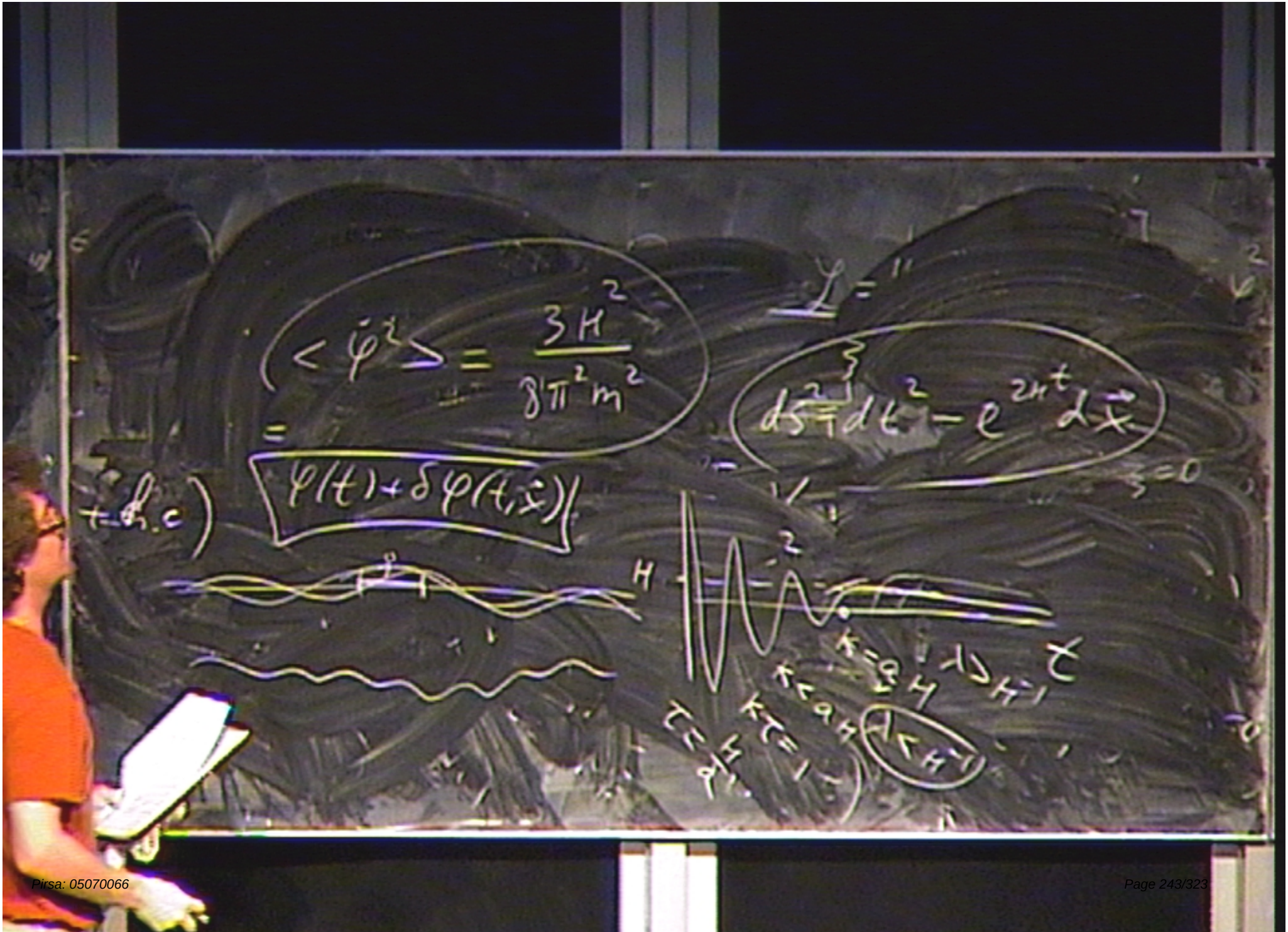

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
+h.c)
H
$k\tau = 1$

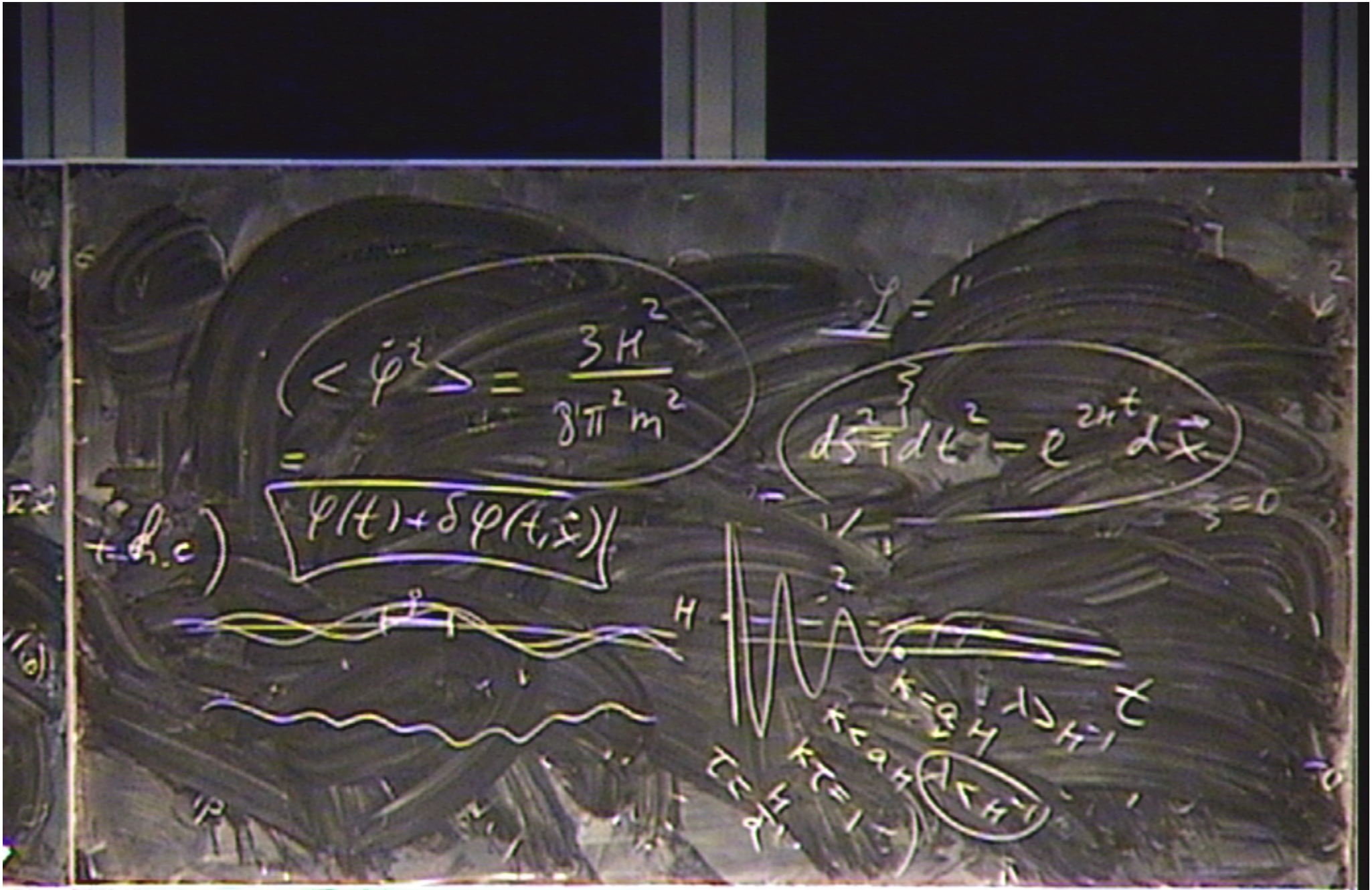

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
H
$k = aH$
$\lambda > H^{-1}$
$k < aH$
τ

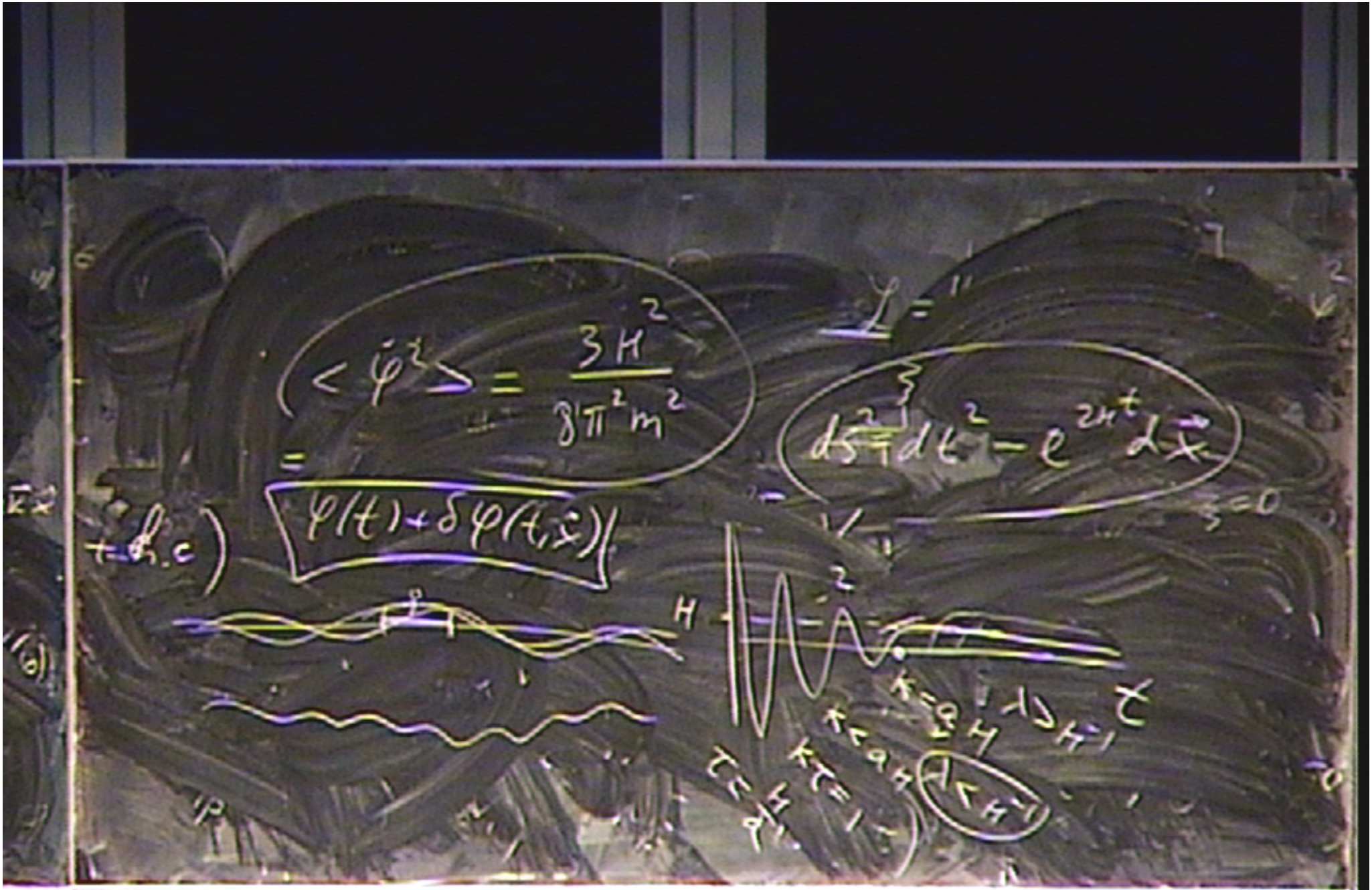

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$\mathcal{L} =$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$+ h.c$
H
$k = aH$
$\lambda > H^{-1}$
τ
$k\tau = 1$
$k\tau < 1$
$k\tau > 1$

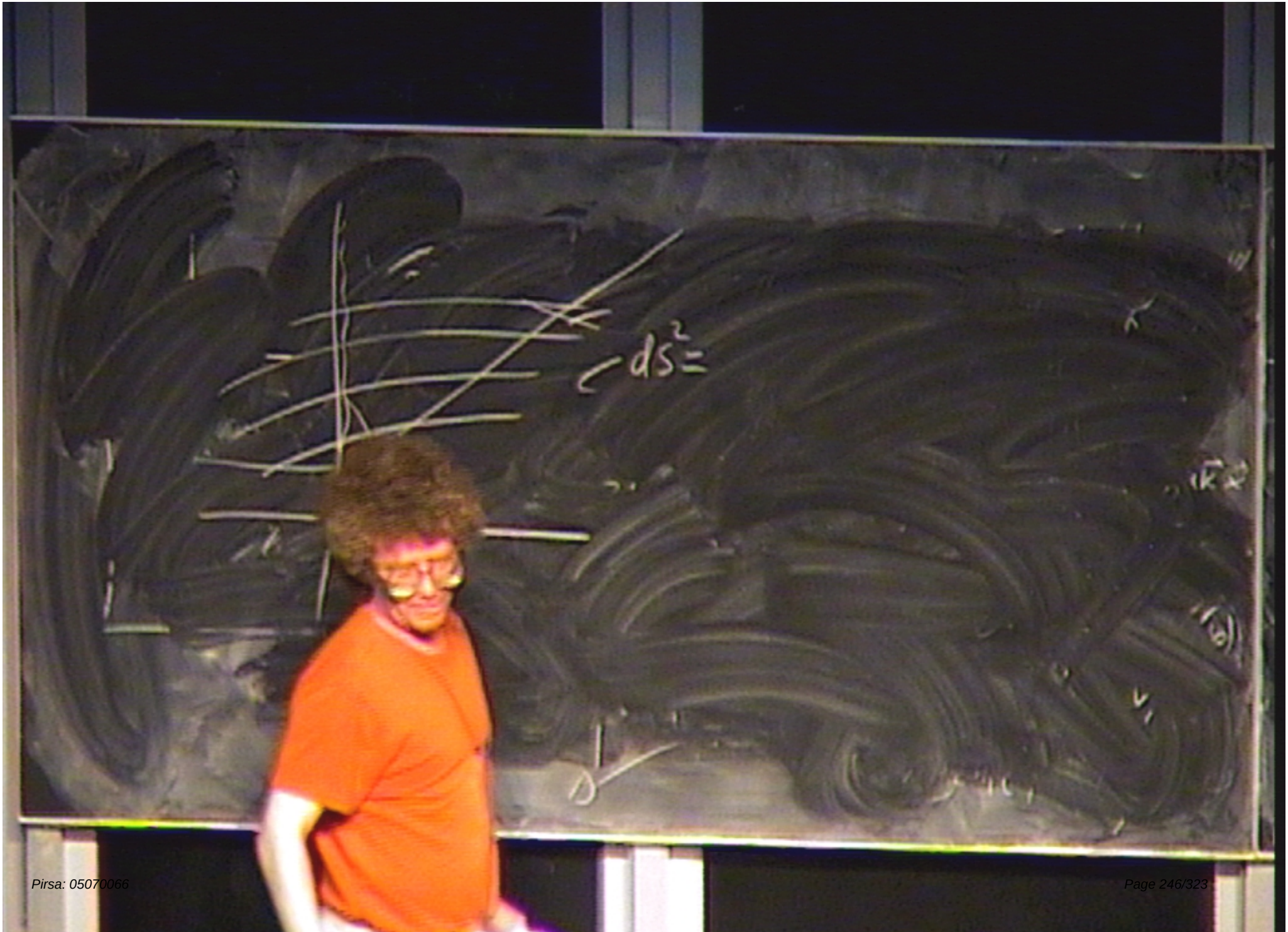

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
+ h.c
H
$k = aH$
$k\tau = 1$
$\tau < H^{-1}$

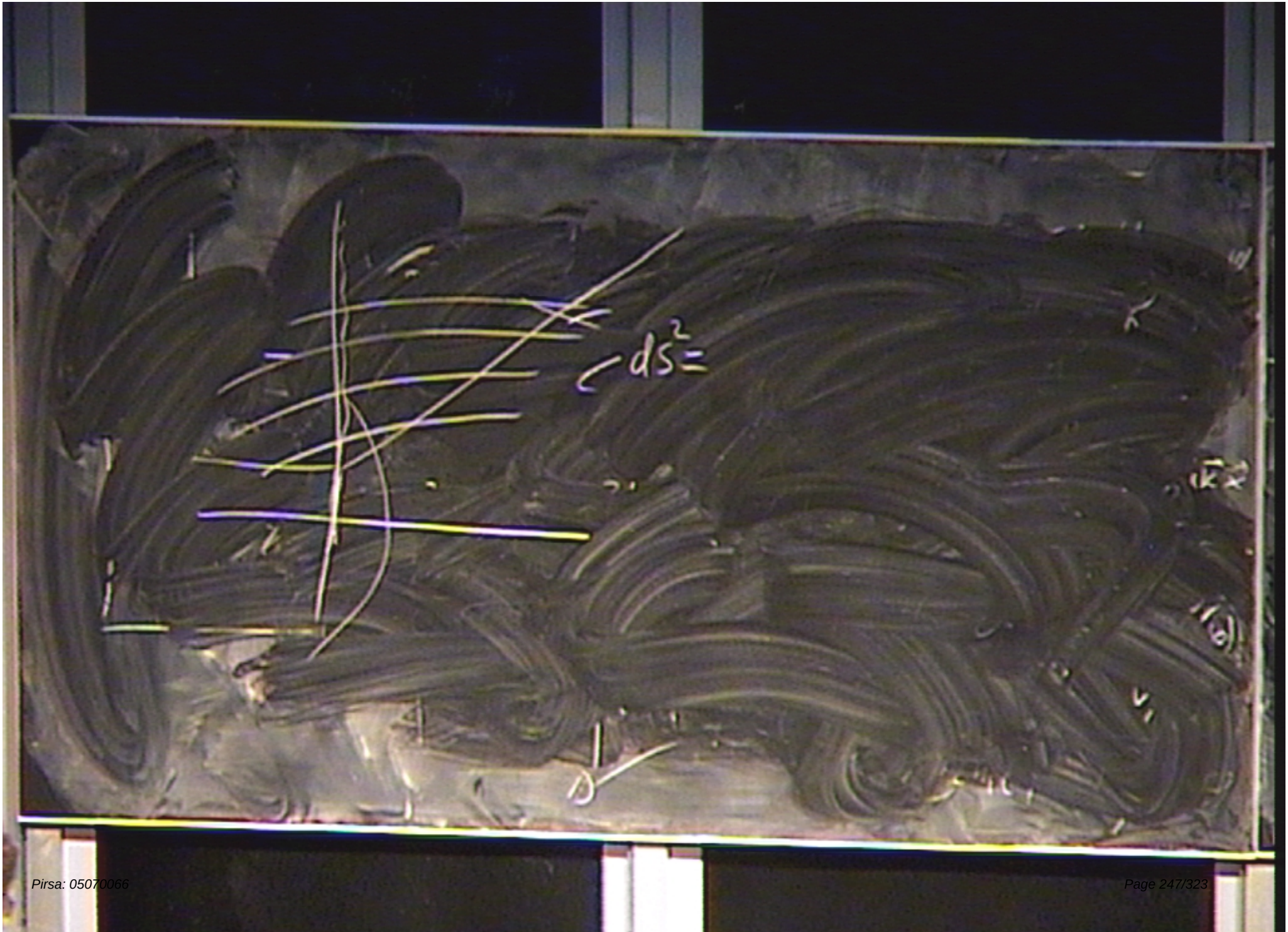

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
H
τ

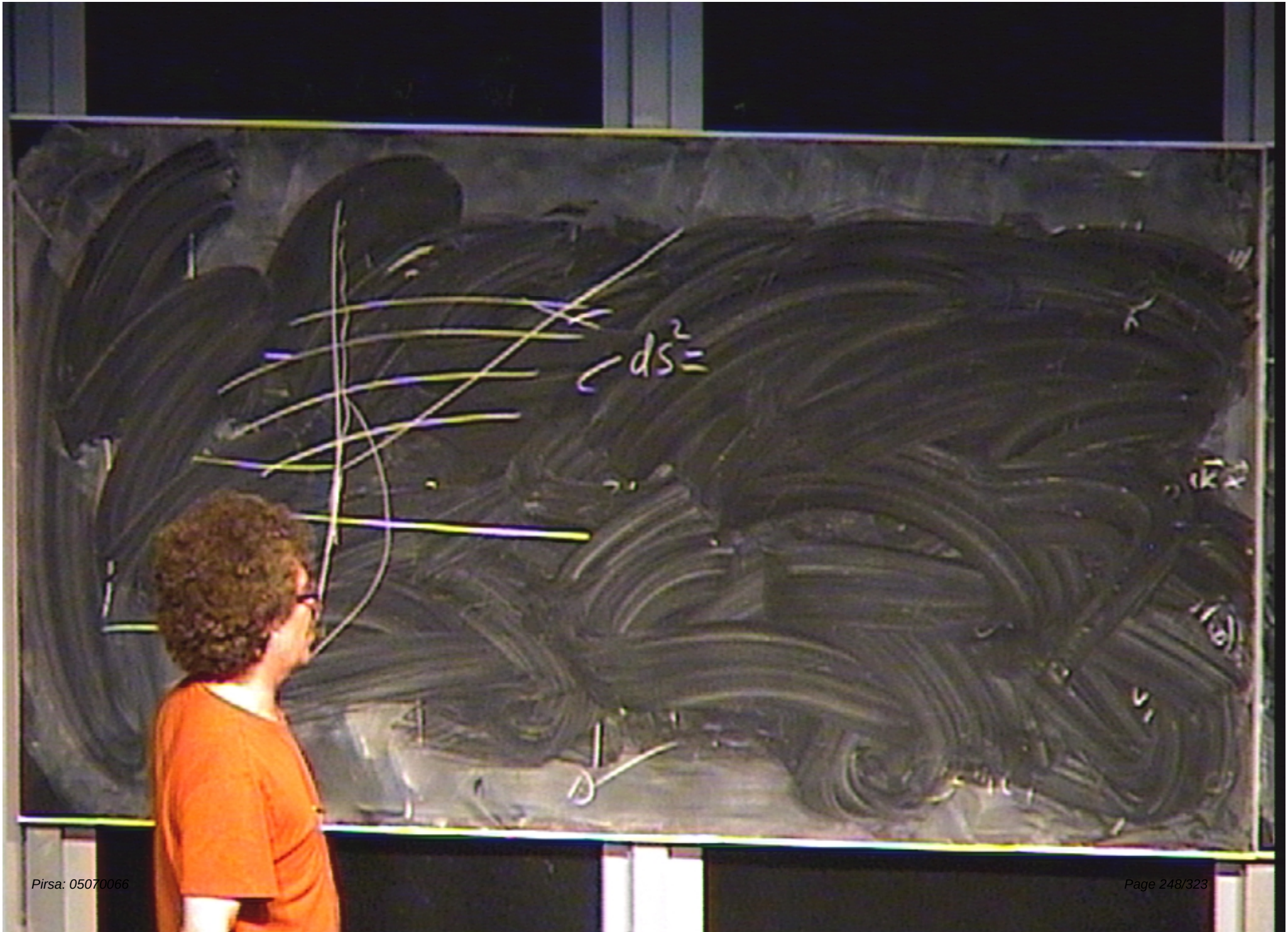

$\langle \delta\varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$\varphi(t) + \delta\varphi(t,\vec{x})$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
H

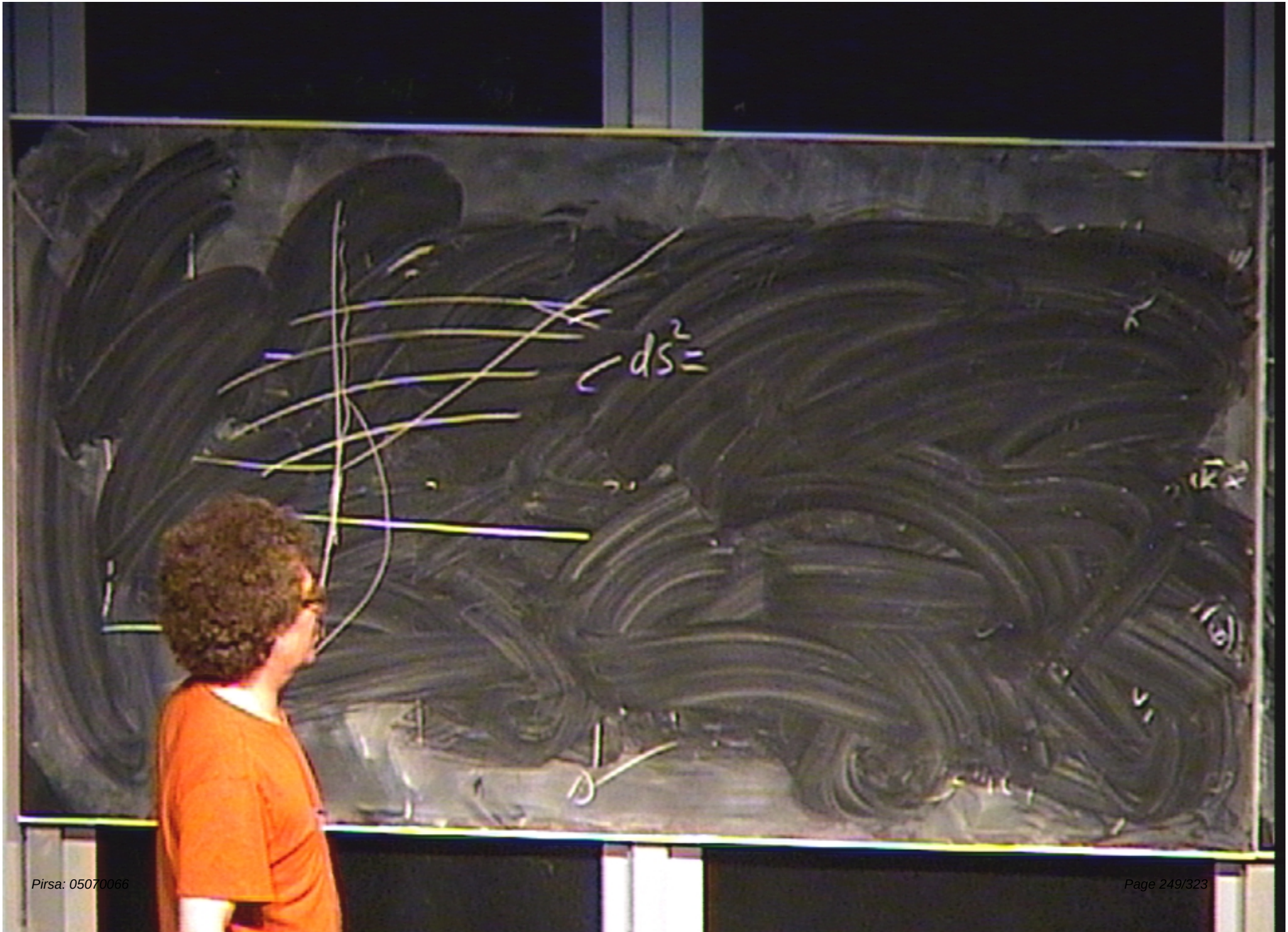

$\langle \delta\varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$= \varphi(t) + \delta\varphi(t,\vec{x})$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\mathcal{L} =$
H
τ

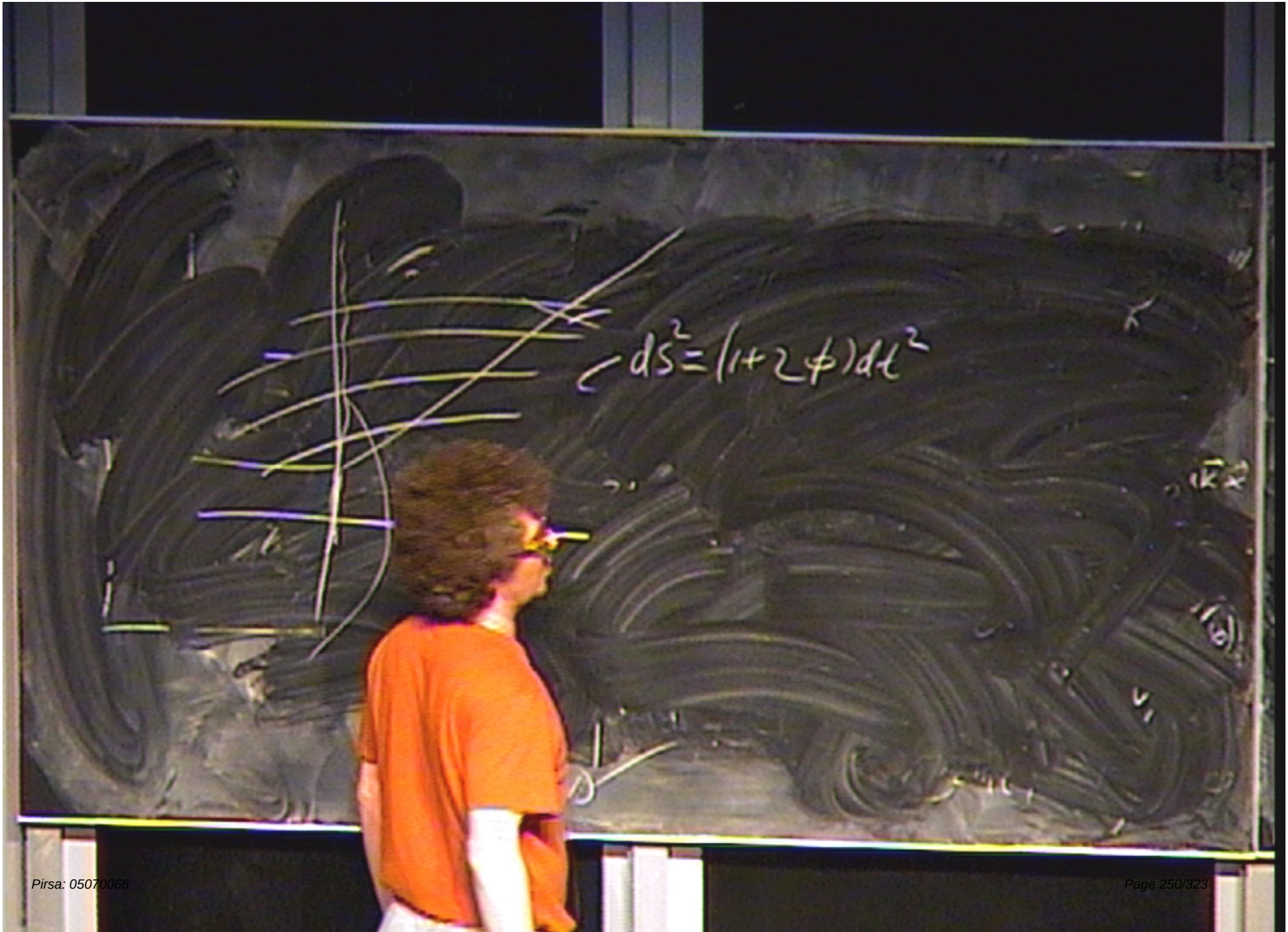

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$\varphi(t) + \delta\varphi(t,\vec{x})$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
H
$k = aH$
$\lambda > H^{-1}$
τ
$k\tau = 1$
$\lambda < H^{-1}$

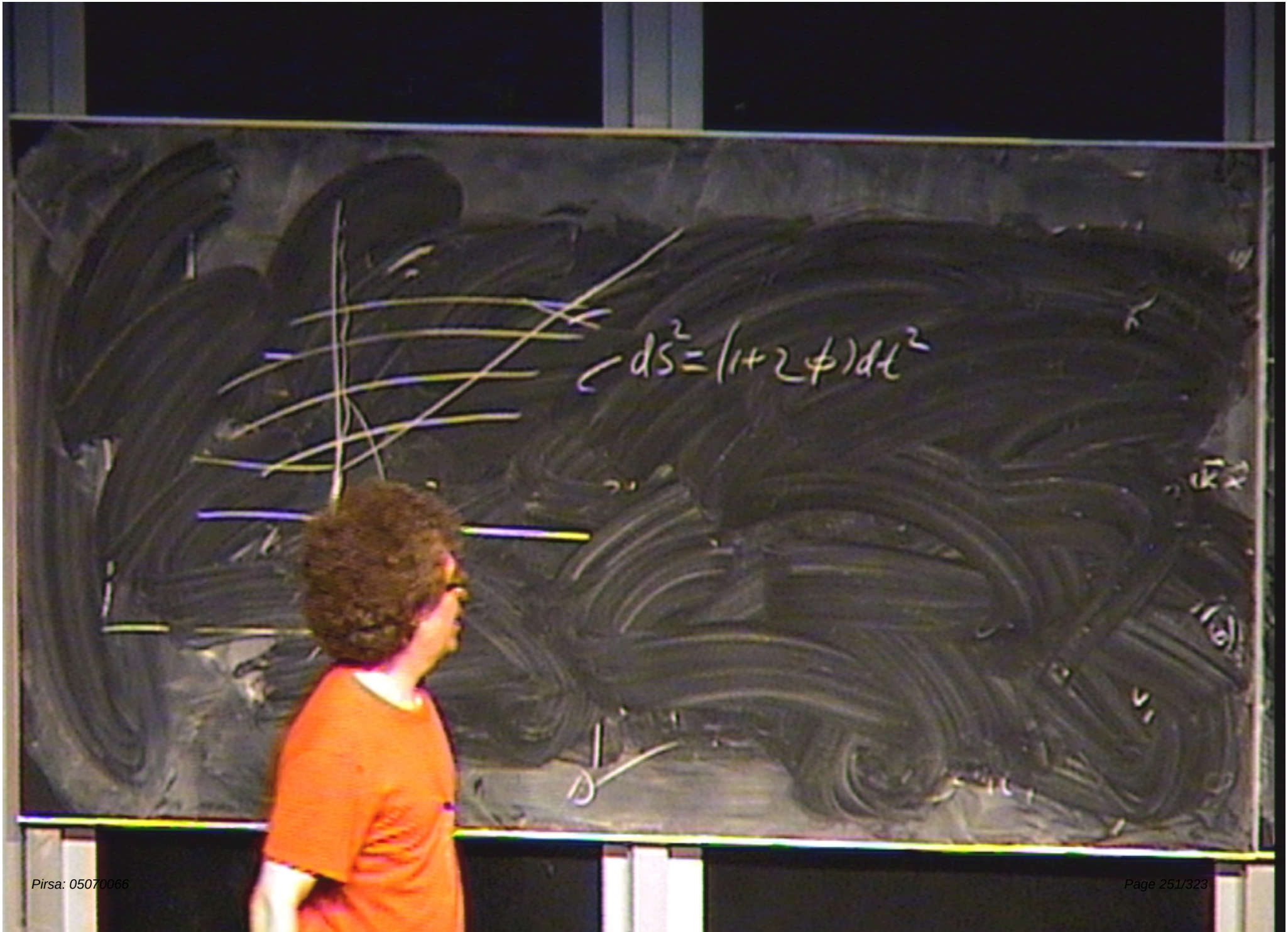

$ds^2 =$

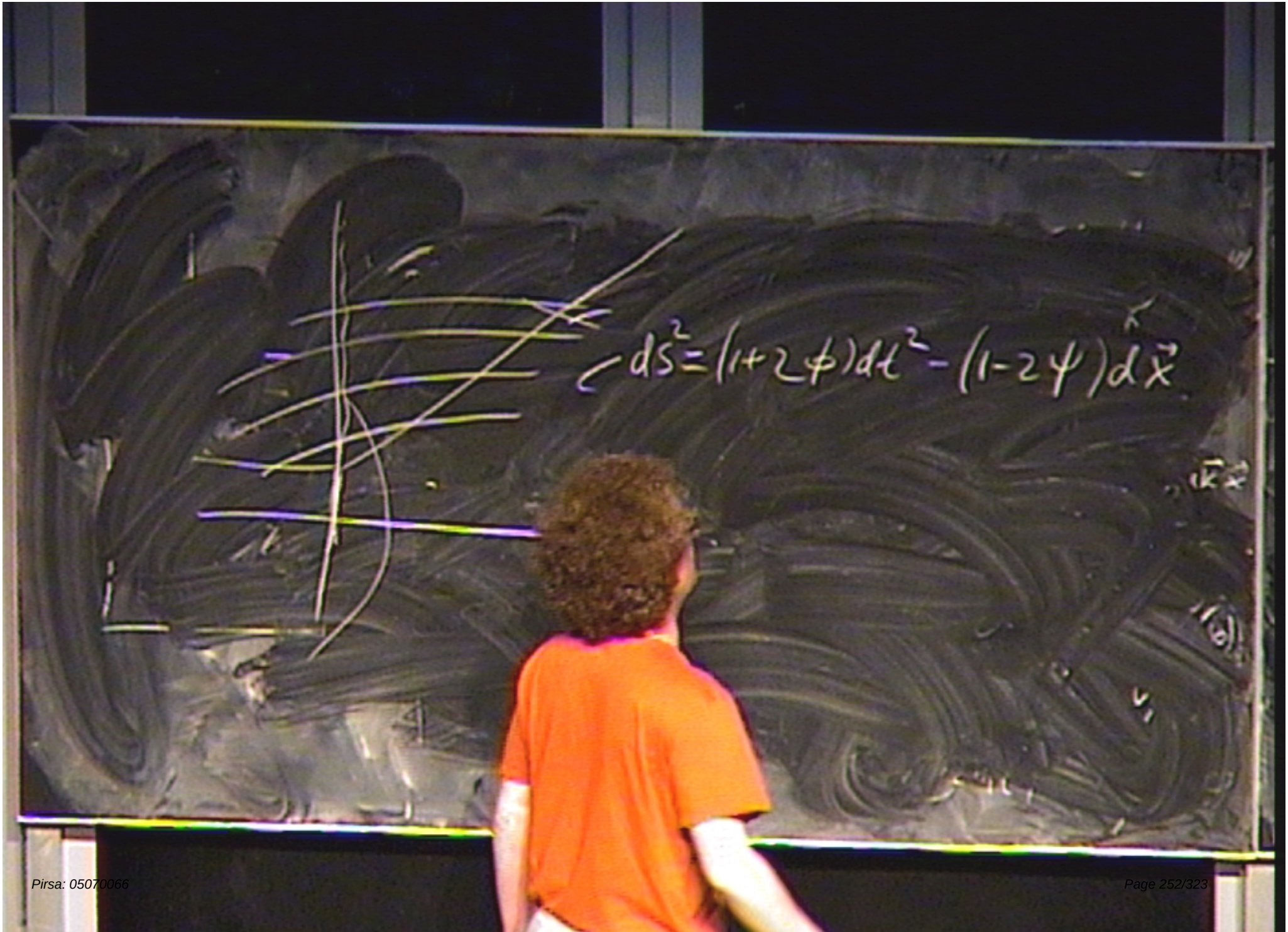

$ds^2 =$

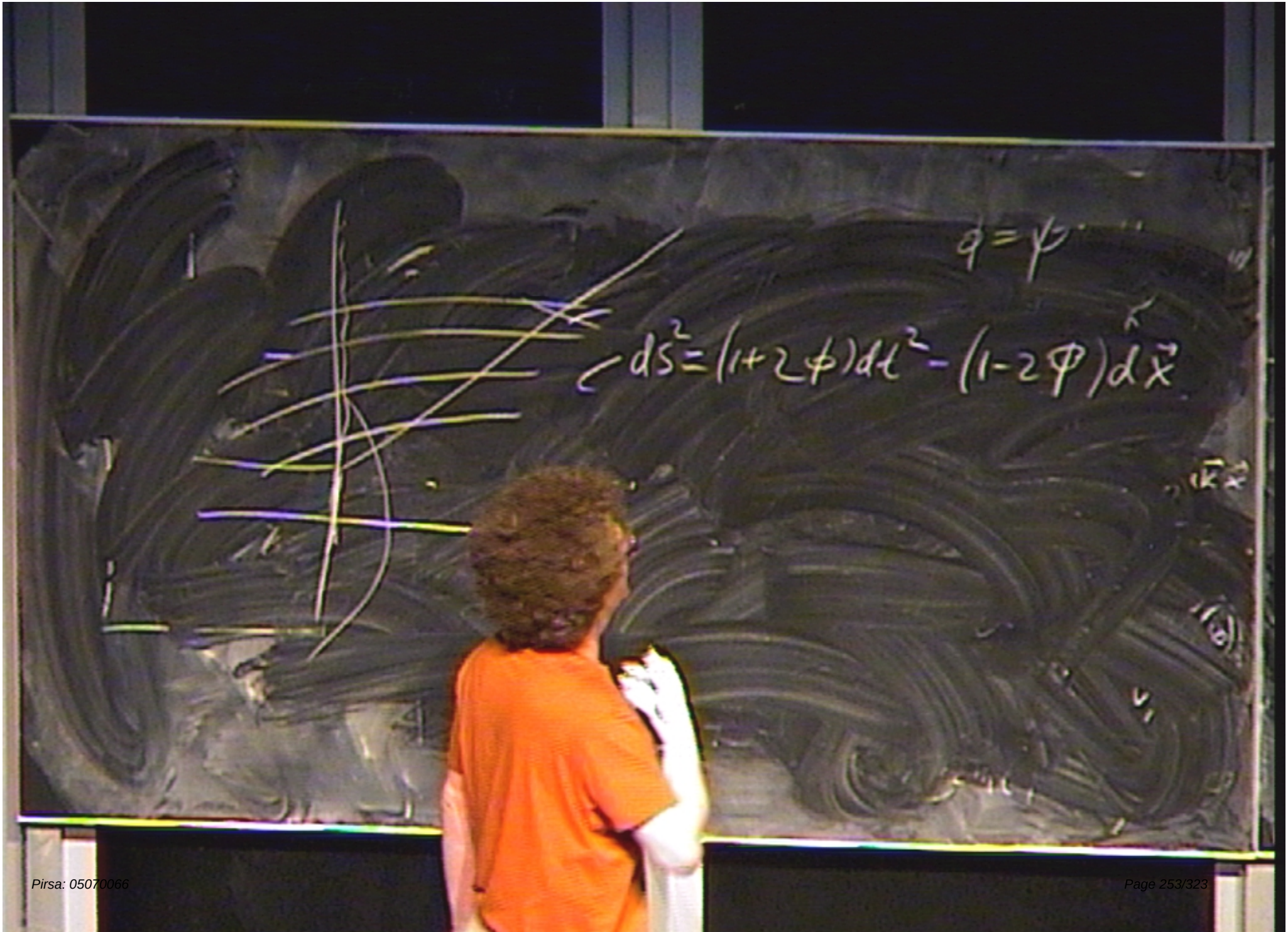

$ds^2 =$

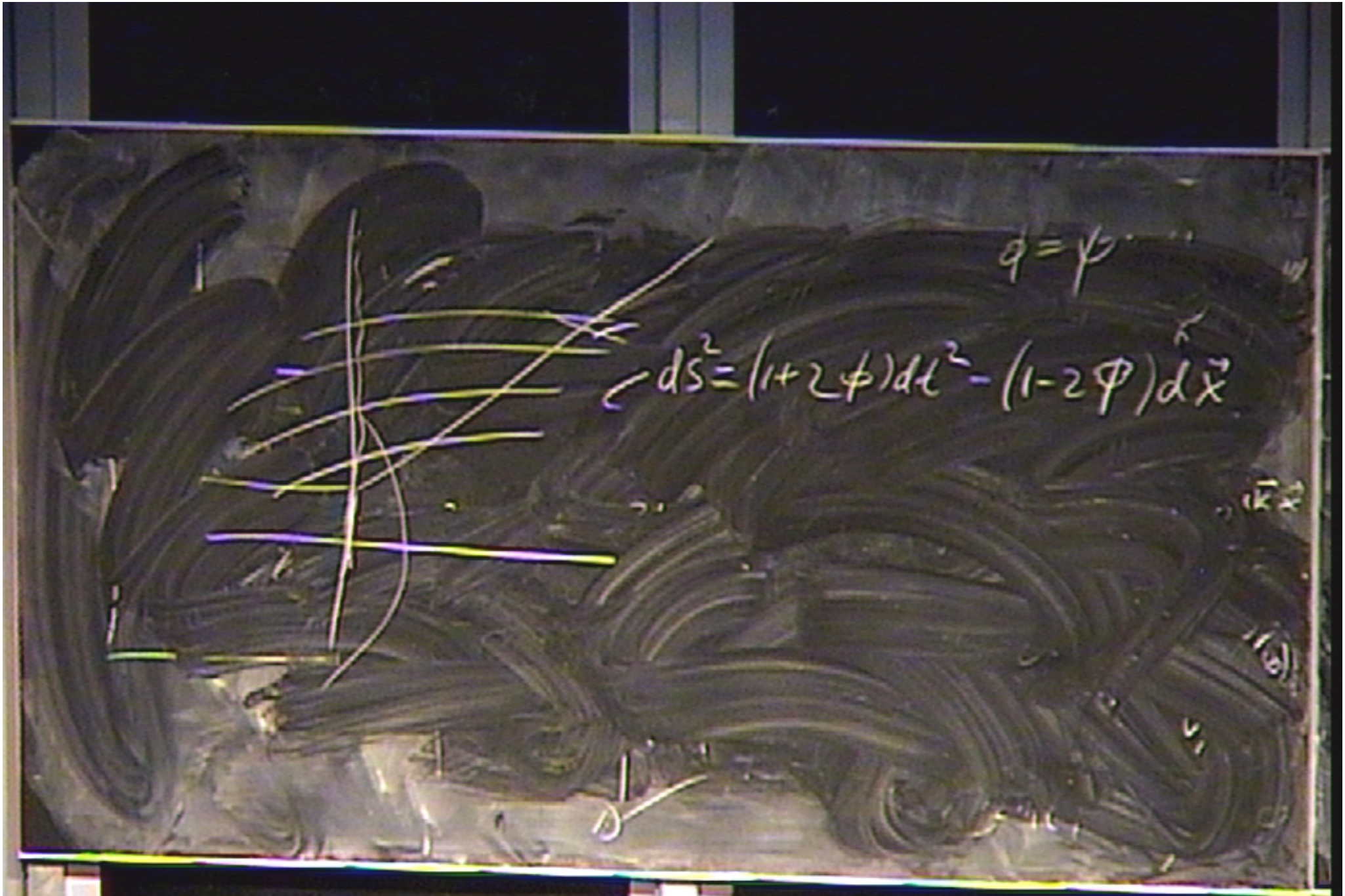

$ds^2 =$

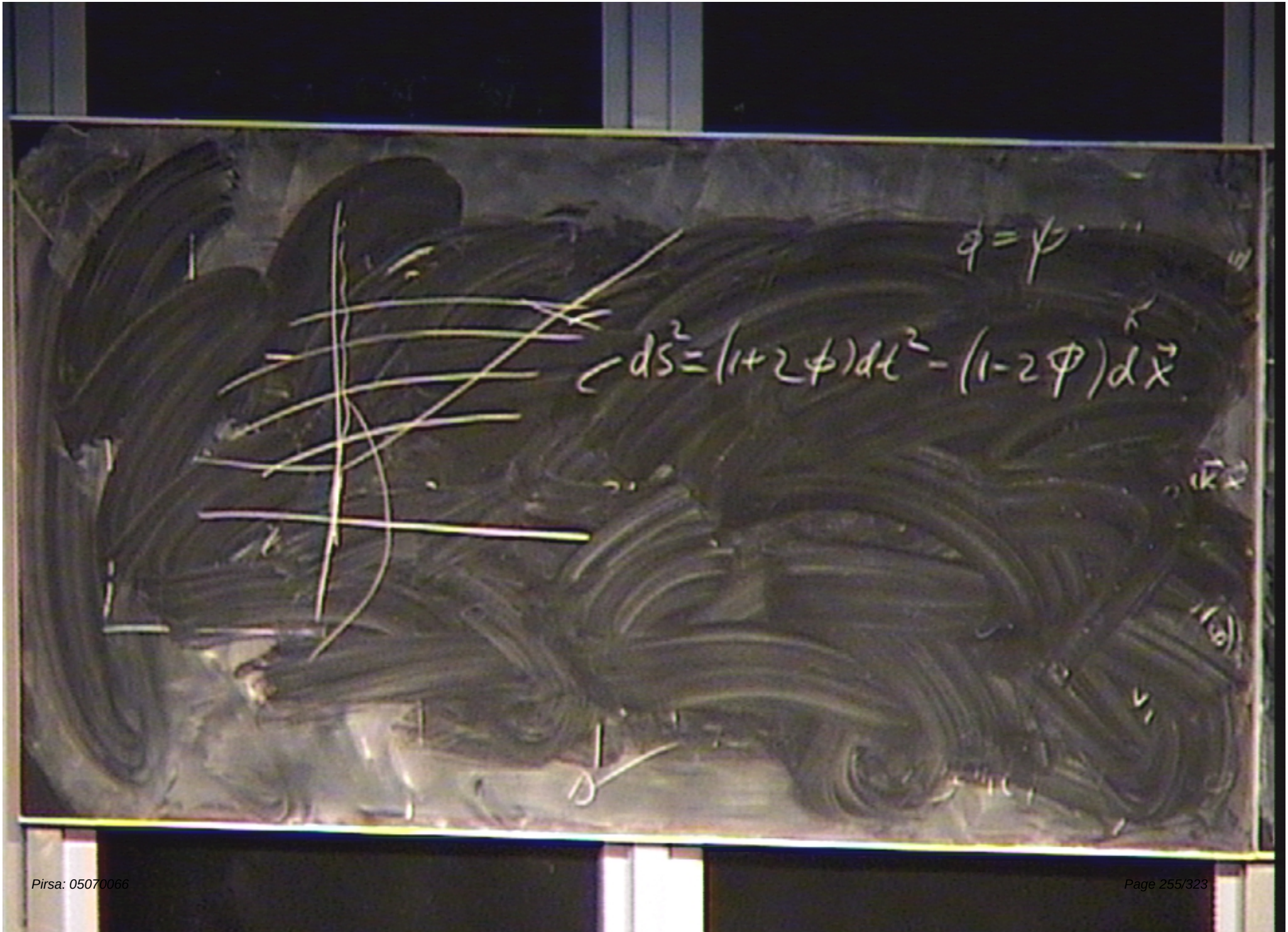

$ds^2 = (1+2\phi)dt^2$

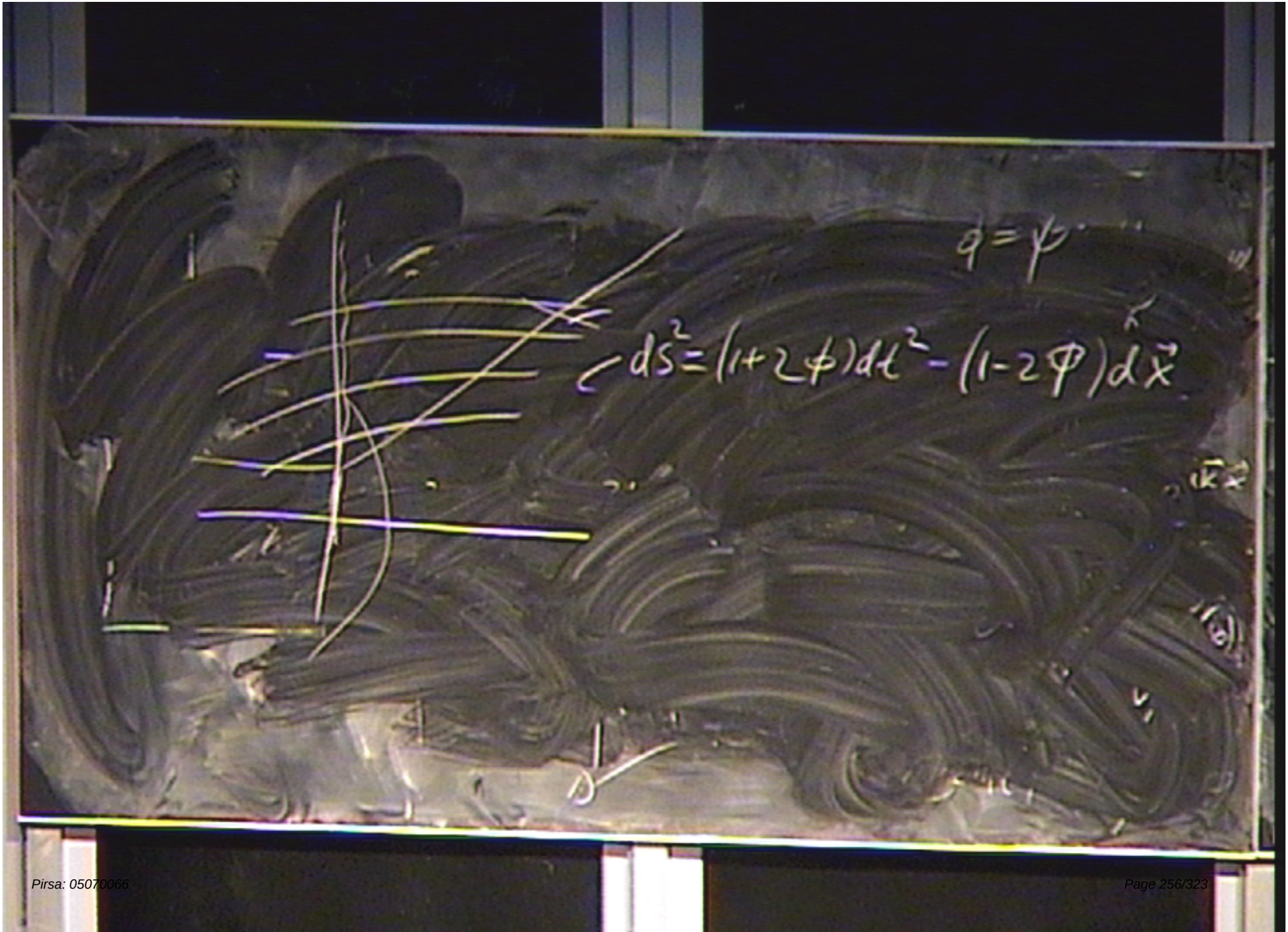

$ds^2 = (1+2\phi)dt^2$

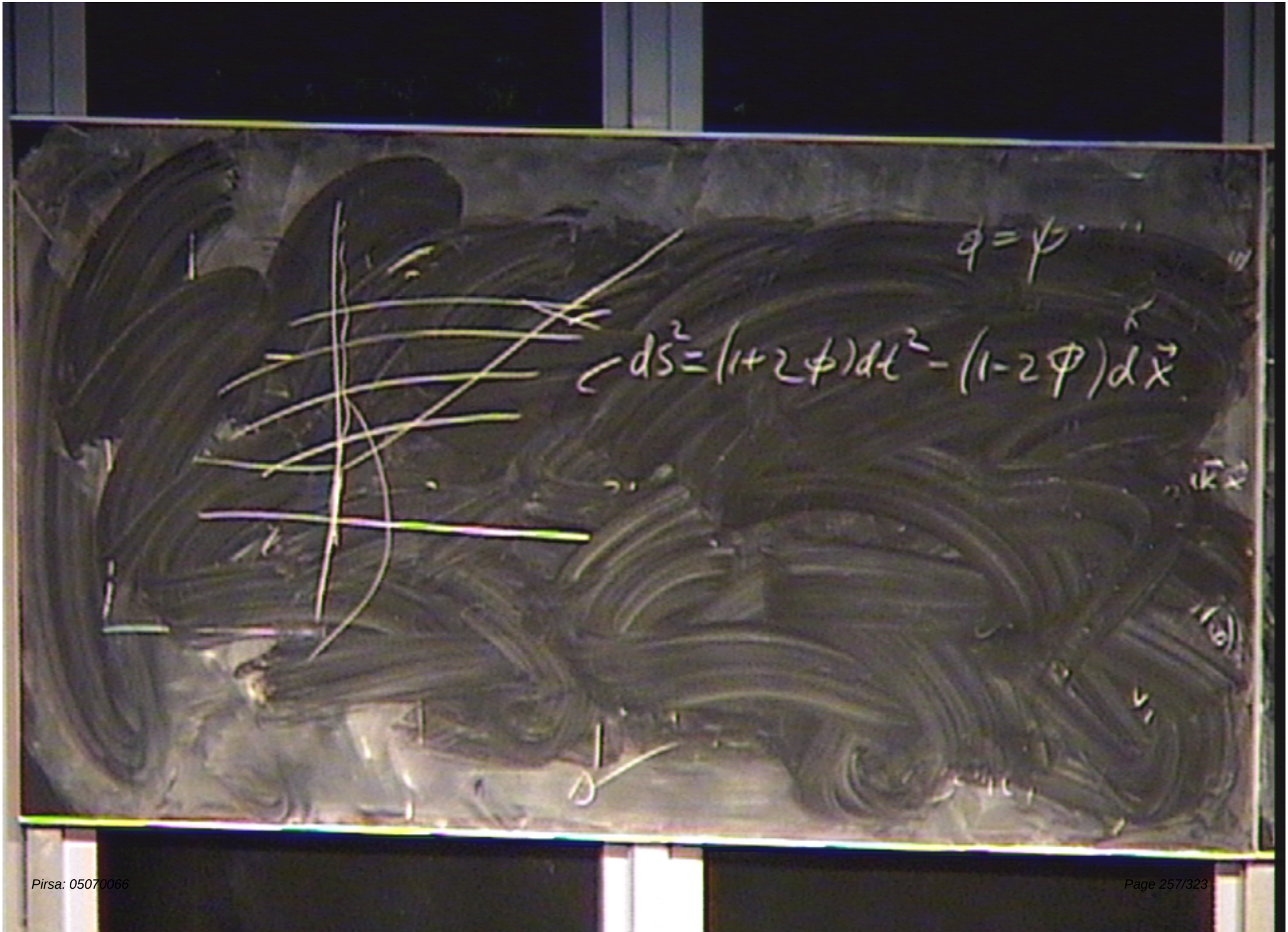

$ds^2 = (1+2\phi)dt^2 - (1-2\psi)d\vec{x}^2$

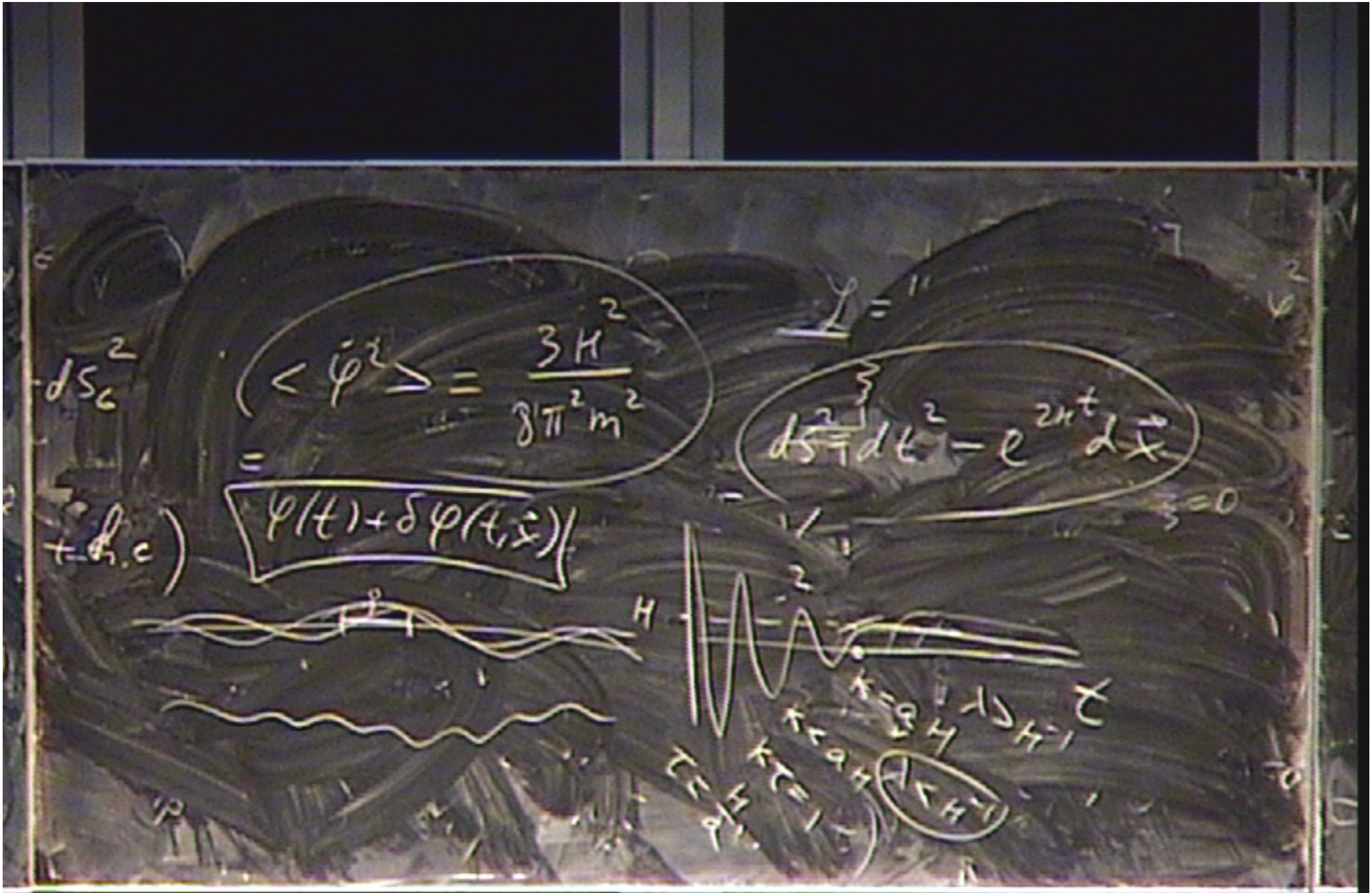

$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2$

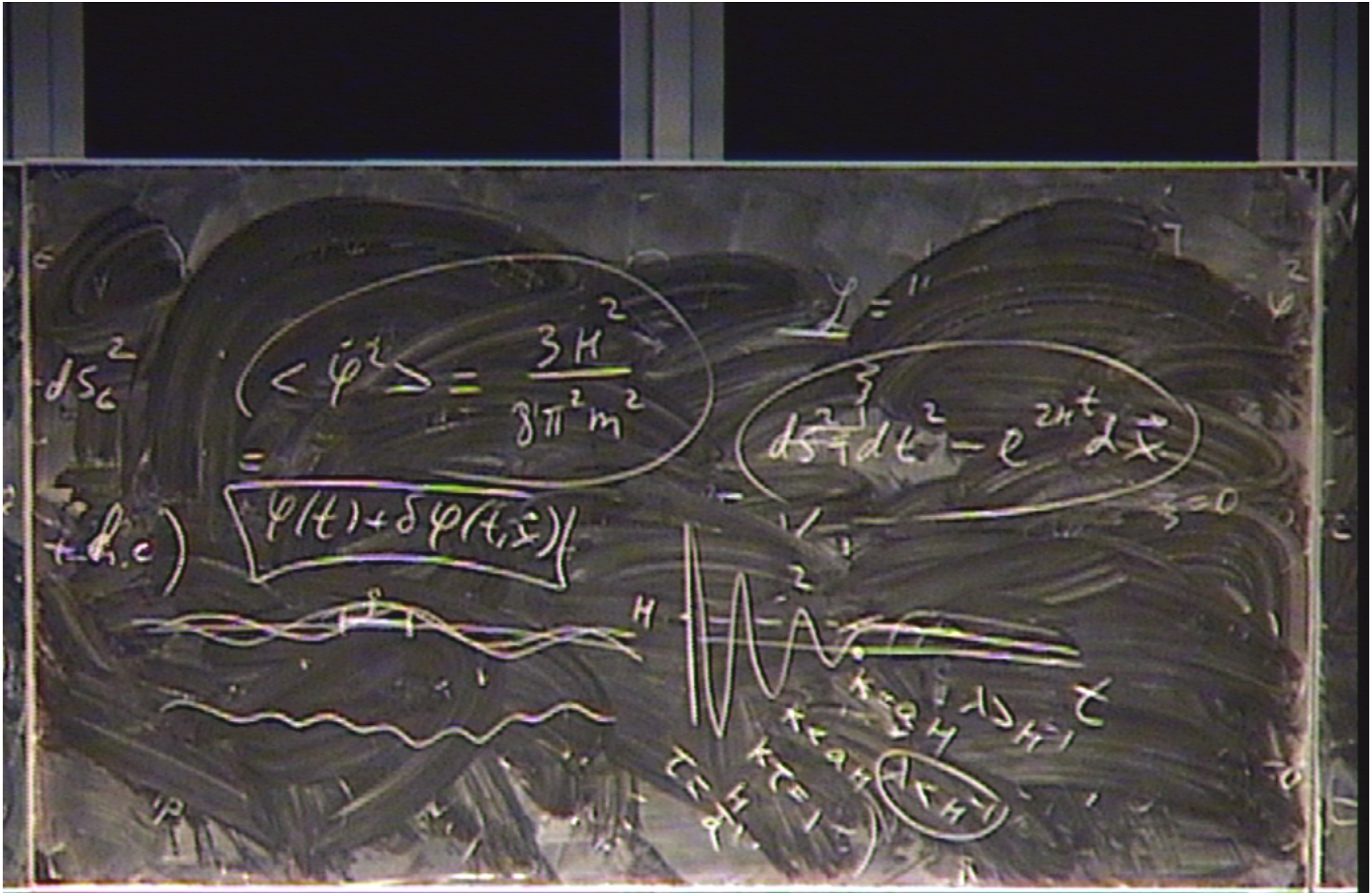

$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2$


$\phi = \psi$
$ds^2 = (1+2\phi)dt^2 - (1-2\phi)d\vec{x}^2$


$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2$


$\phi = \psi$
$ds^2 = (1+2\phi)dt^2 - (1-2\phi)d\vec{x}^2$


$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$\varphi(t) + \delta\varphi(t,\vec{x})$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
H
τ


$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$\varphi(t) + \delta\varphi(t,\vec{x})$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
ds_G^2
$+h.c)$
H
$\lambda > H^{-1}$
$\lambda < H^{-1}$

$q = \varphi$

$ds^2 = (1+2\phi)dt^2 - (1-2\Psi)d\vec{x}^2 + \ldots$

ds_c^2

$+ h_{\mu\nu}$

$\langle \varphi^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$

$= \varphi(t) + \delta\varphi(t,\vec{x})$

H

$q = \varphi$

$ds^2 = (1+2\phi)dt^2 - (1-2\varphi)d\vec{x}^2 +$

ds_c^2

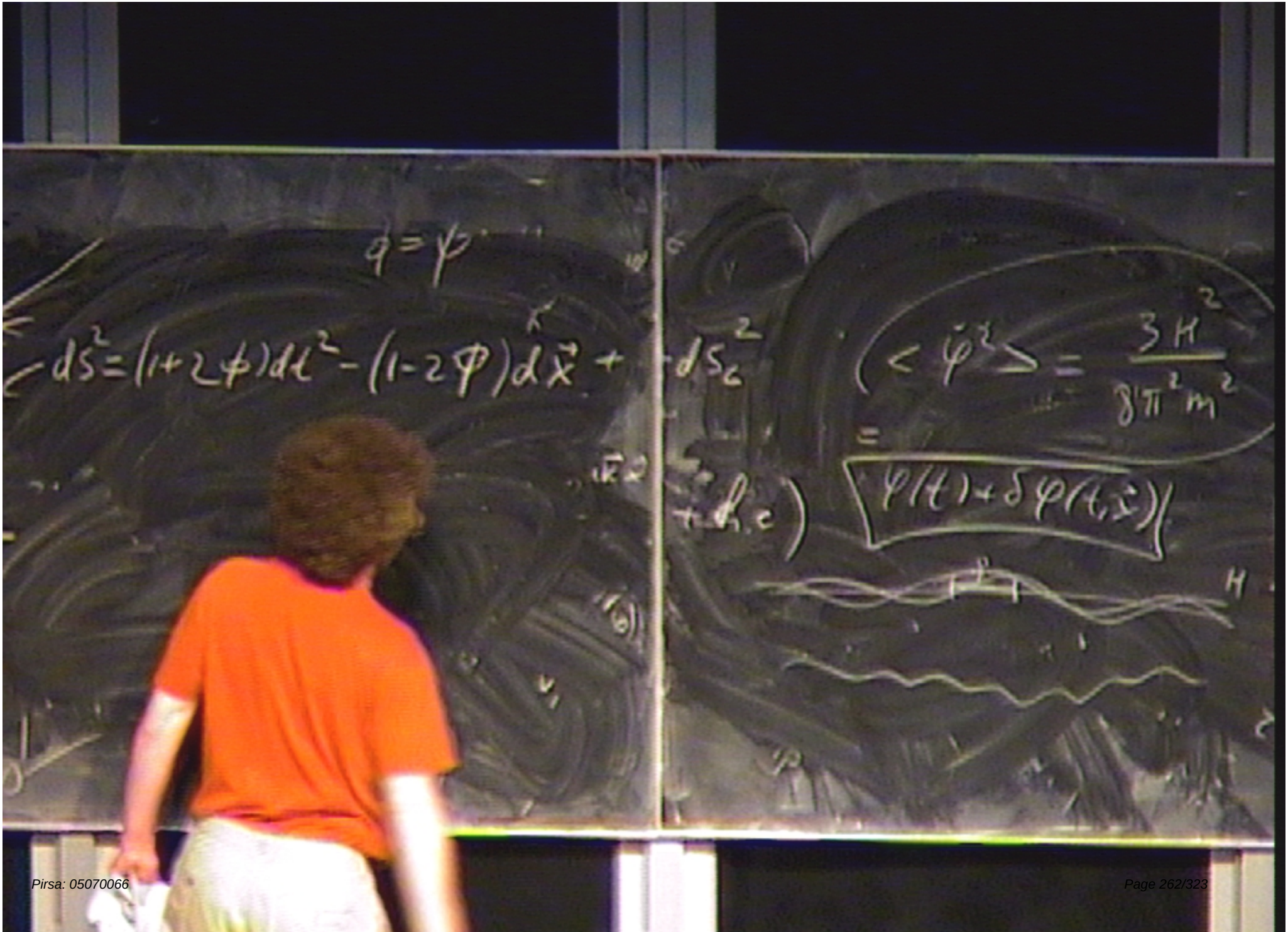
$+ h.c)$

$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$

$=$

$\varphi(t) + \delta\varphi(t,\vec{x})$

H


$ds^2 = (1+2\phi)dt^2 - (1-2\phi)d\vec{x}^2 +$
ds_c^2
$\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}$
$\varphi(t) + \delta\varphi(t,\vec{x})$

$\varphi = \varphi_0 + \dots$

$ds^2 = (1+2\Phi)dt^2 - (1-2\Phi)d\vec{x}^2 + \dots$

$+ h.c.)$

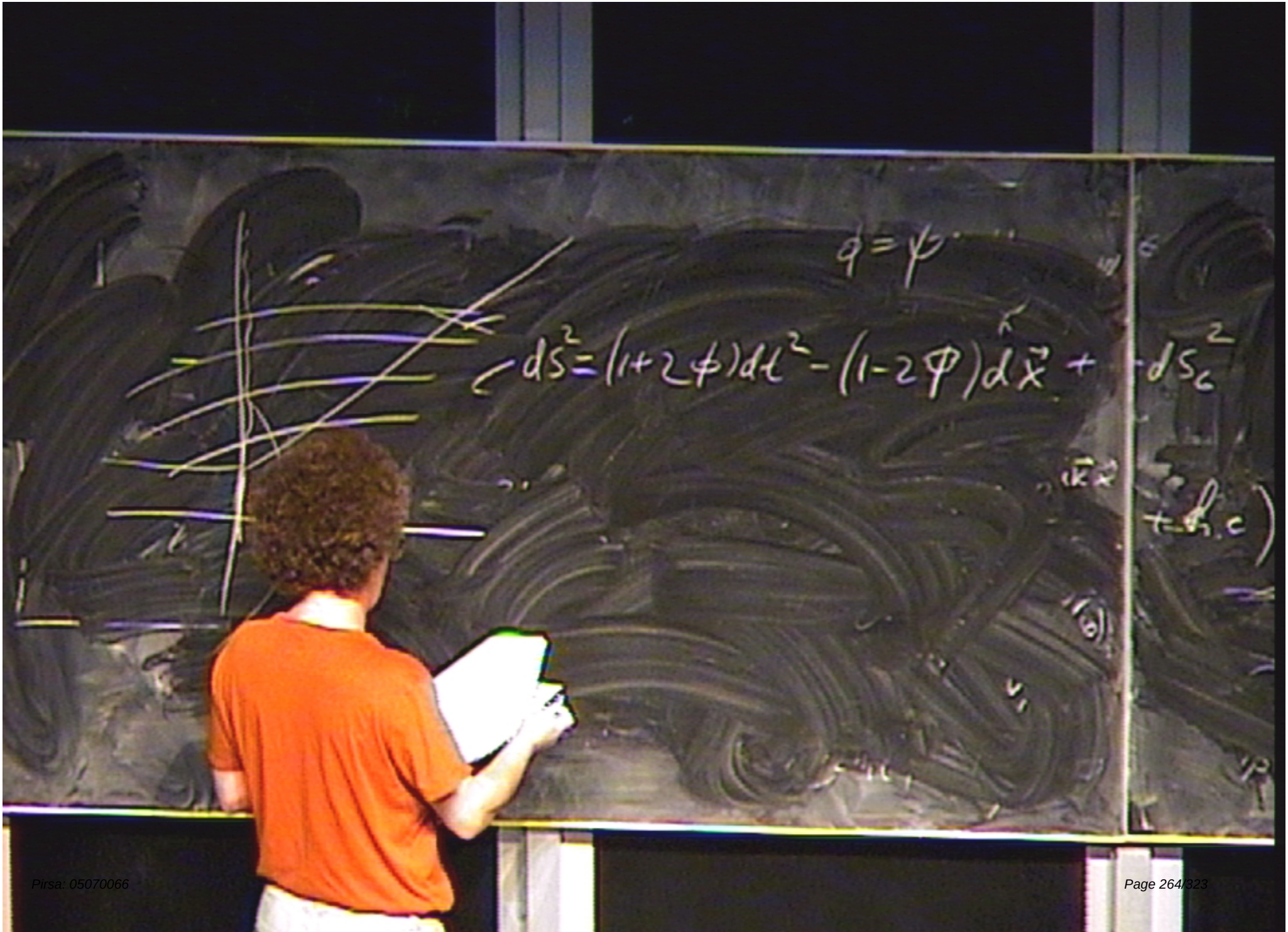
ds_c^2

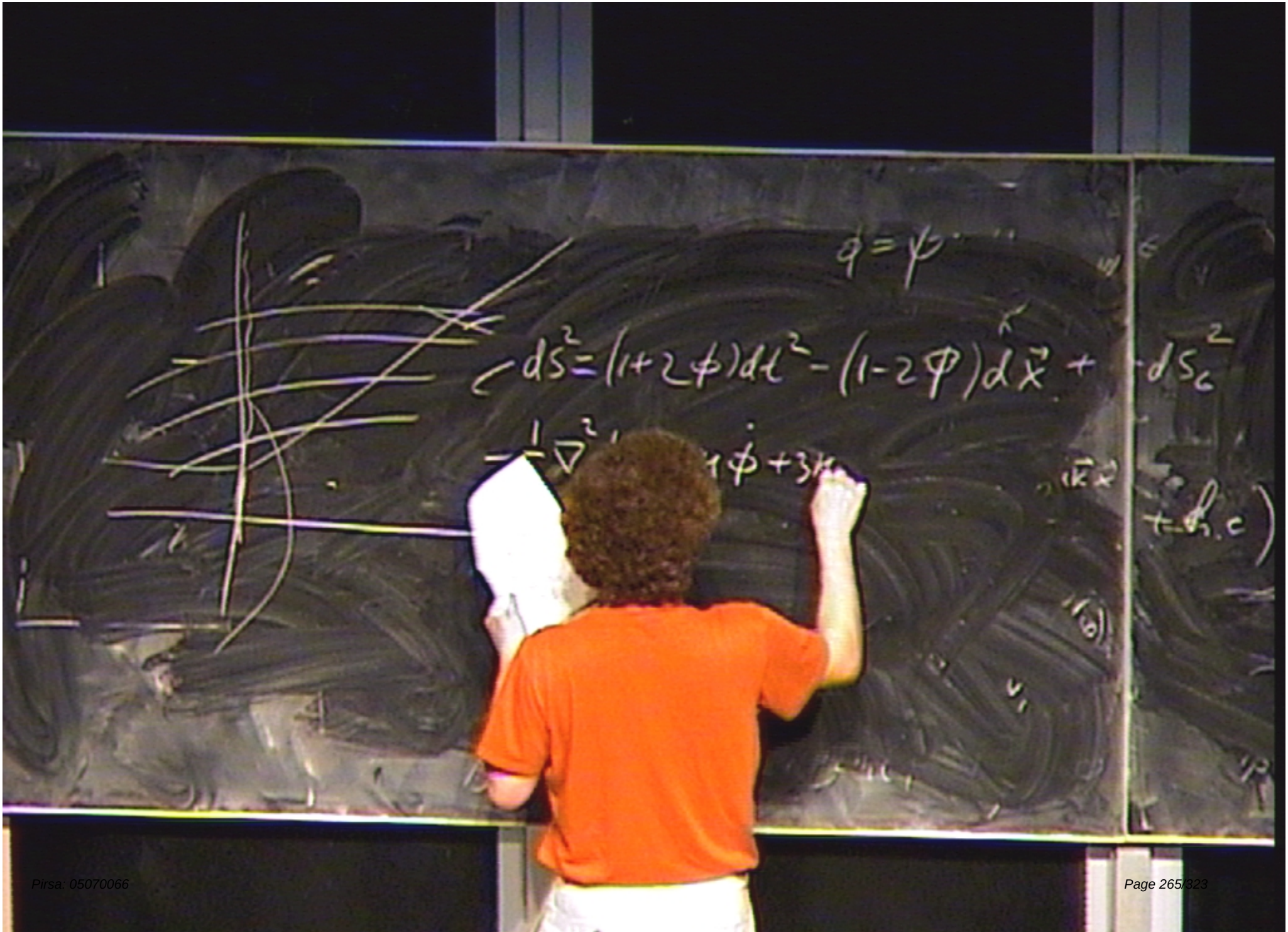
$\left(\langle \dot{\varphi}^2 \rangle = \frac{3H^2}{8\pi^2 m^2}\right.$

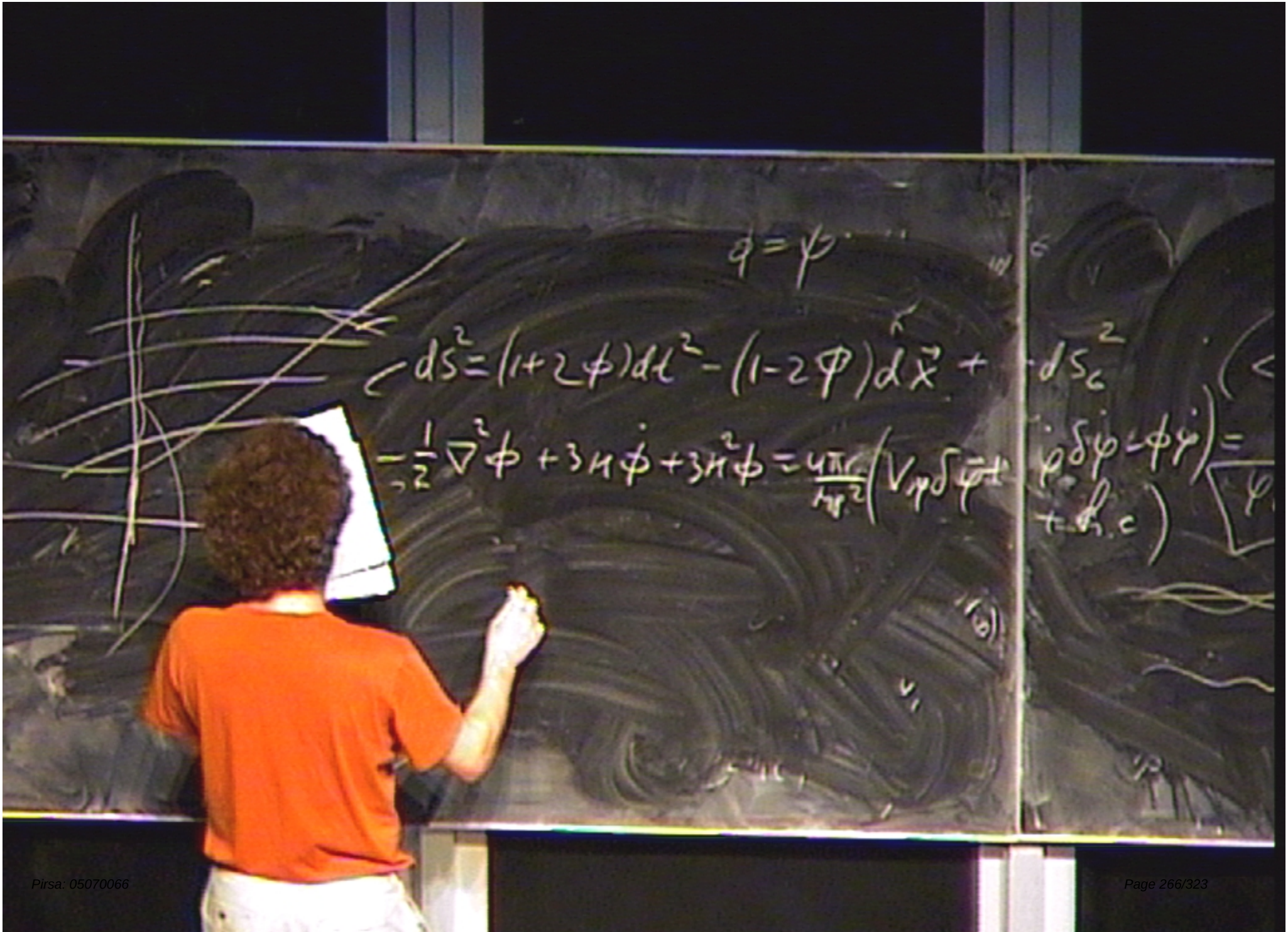
$= \boxed{\varphi(t) + \delta\varphi(t,\vec{x})}$

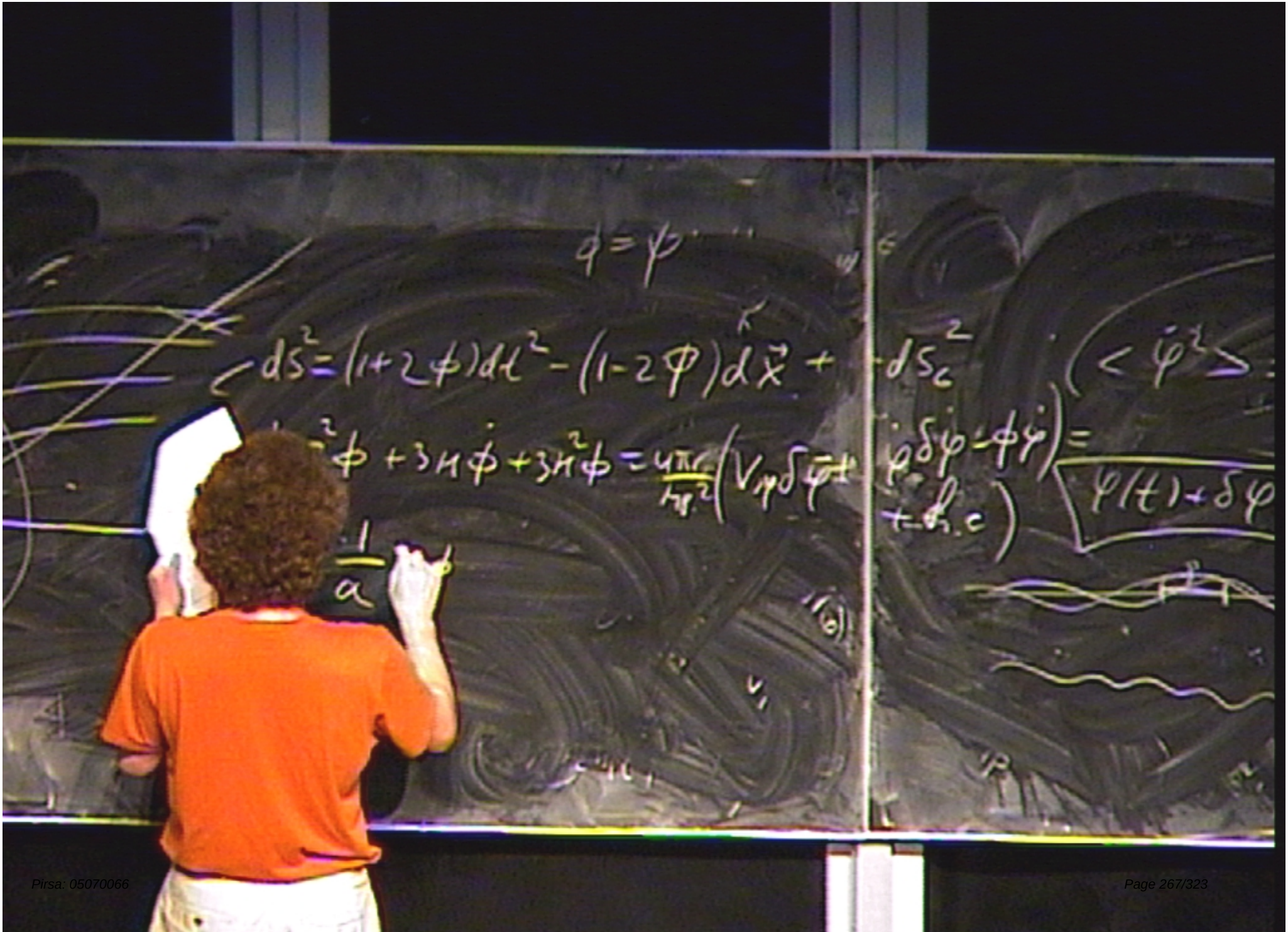
$\left.\right)$

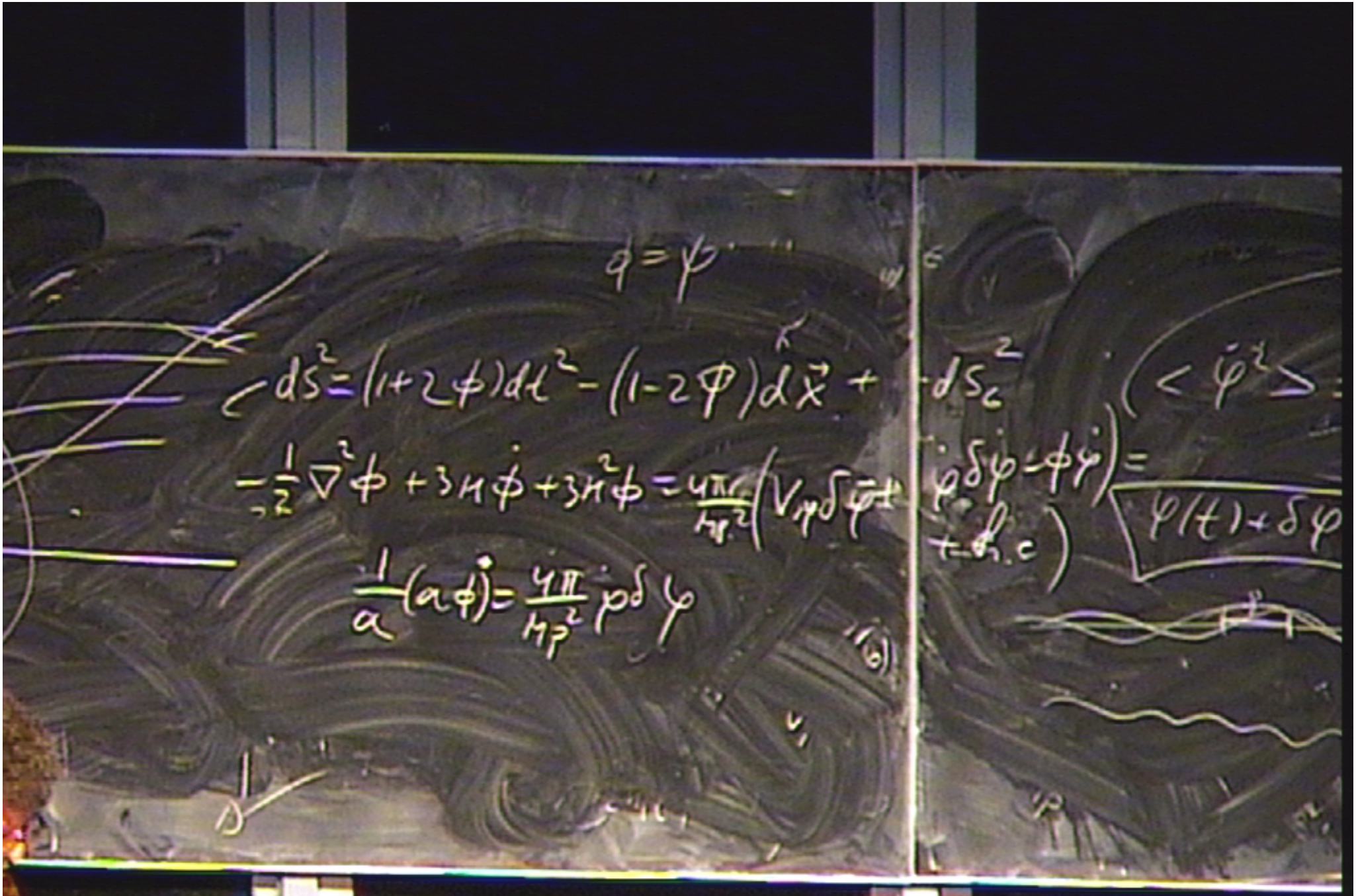
H


$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2 + ds_c^2$


$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2 + ds_c^2$


$q = \psi$
$ds^2 = (1+2\phi)dt^2 - (1-2\Psi)d\vec{x}^2 +$
ds_c^2
$-\frac{1}{2}\nabla^2\phi + 3\mathcal{H}\dot{\phi} + 3\mathcal{H}^2\phi = \frac{4\pi G}{\mathcal{H}^2}\left(V_\eta \delta\dot{\varphi} +\right.$
$\left. + h.c.\right)$


$q = \varphi$
$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2 +$
ds_c^2
$\langle \dot{\varphi}^2 \rangle$
$\varphi(t) + \delta\varphi$
$\frac{1}{a}$


$q = \varphi$
$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2$
$-\frac{1}{2}\nabla^2\phi + 3H\dot{\phi} + 3H^2\phi = \frac{4\pi}{m_P^2}(V_{,\varphi}\delta\varphi +$
$\frac{1}{a}(a\phi)^{\cdot} = \frac{4\pi}{m_P^2}\rho\delta\varphi$
ds_c^2
$\dot{\varphi}\delta\dot{\varphi} - \phi\dot{\varphi}) =$
$+ h.c.)$
$\varphi(t) + \delta\varphi$

$$\varphi = \psi$$

$$ds^2 = (1+2\phi)dt^2 - (1-2\Psi)d\vec{x}^2 + ds_c^2$$

$$-\frac{1}{2}\nabla^2\phi + 3H\dot{\phi} + 3H^2\phi = \frac{4\pi G}{M_P^2}\left(V_{,\varphi}\delta\varphi + \dot{\varphi}\delta\dot{\varphi} - \dot{\varphi}\dot{\phi} + h.c.\right)$$

$$\langle \dot{\varphi}^2 \rangle = \dot{\varphi}(t) + \delta\dot{\varphi}$$

$$\frac{1}{a}(a\dot{\phi}) = \frac{4\pi}{M_P^2}\rho\delta\varphi$$

$$q = \varphi$$

$$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2 + ds_c^2$$

$$-\frac{1}{2}\nabla^2\dot{\phi} + 3H\dot{\phi} + 3H^2\phi = \frac{4\pi G}{M_P^2}\left(V_{,\varphi}\delta\varphi + \dot{\varphi}\delta\dot{\varphi} - \dot{\varphi}\dot{\phi} + \text{h.c.}\right)$$

$$\frac{1}{a}(a\phi)^{\cdot} = \frac{4\pi}{M_P^2}\dot{\varphi}\delta\varphi$$

$$\langle\varphi^2\rangle \;\Rightarrow\; \varphi(t) + \delta\varphi$$

$q = \varphi$

$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2 + \ldots$

$-\frac{1}{2}\nabla^2\phi + 3H\dot{\phi} + 3H^2\phi = \frac{4\pi G}{M_P^2}\left(V_{,\varphi}\delta\varphi + \ldots\right)$

$\frac{1}{a}(a\phi)^{\cdot} = \frac{4\pi}{M_P^2}\rho\delta\varphi$

$u = a\delta\varphi$

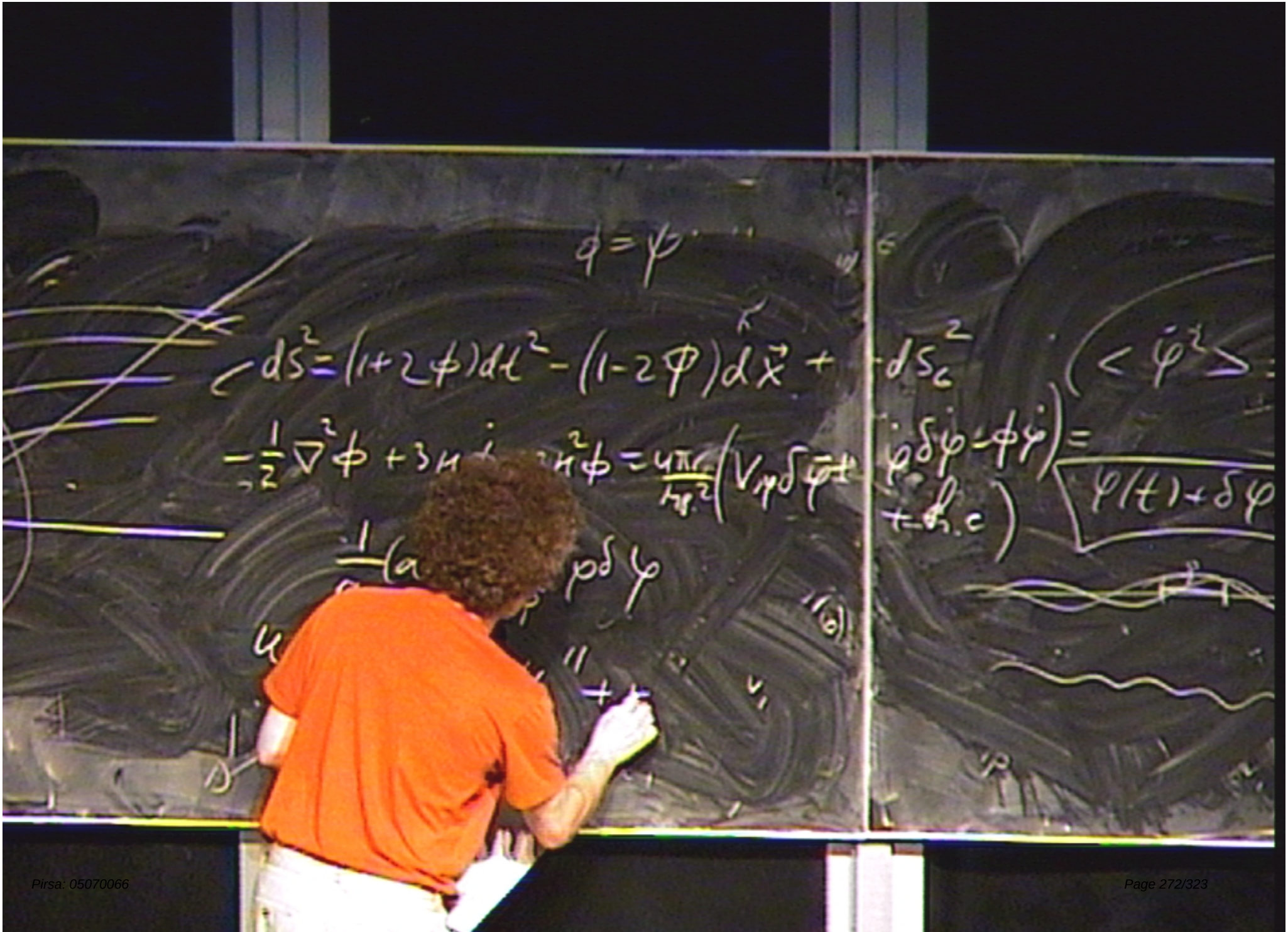
ds_c^2

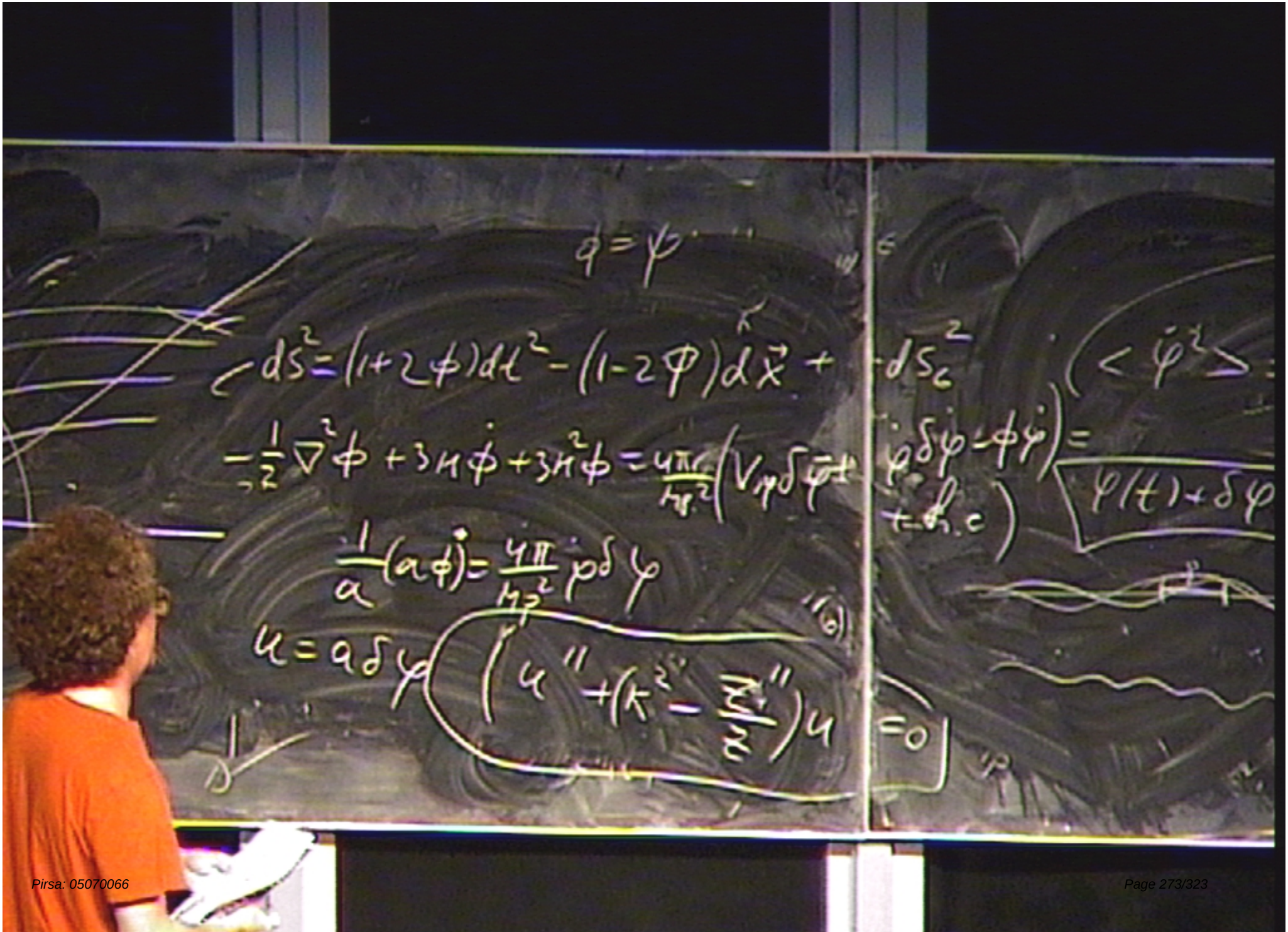
$\left(\dot{\varphi}\delta\dot{\varphi} - \phi\dot{\varphi}\right) =$

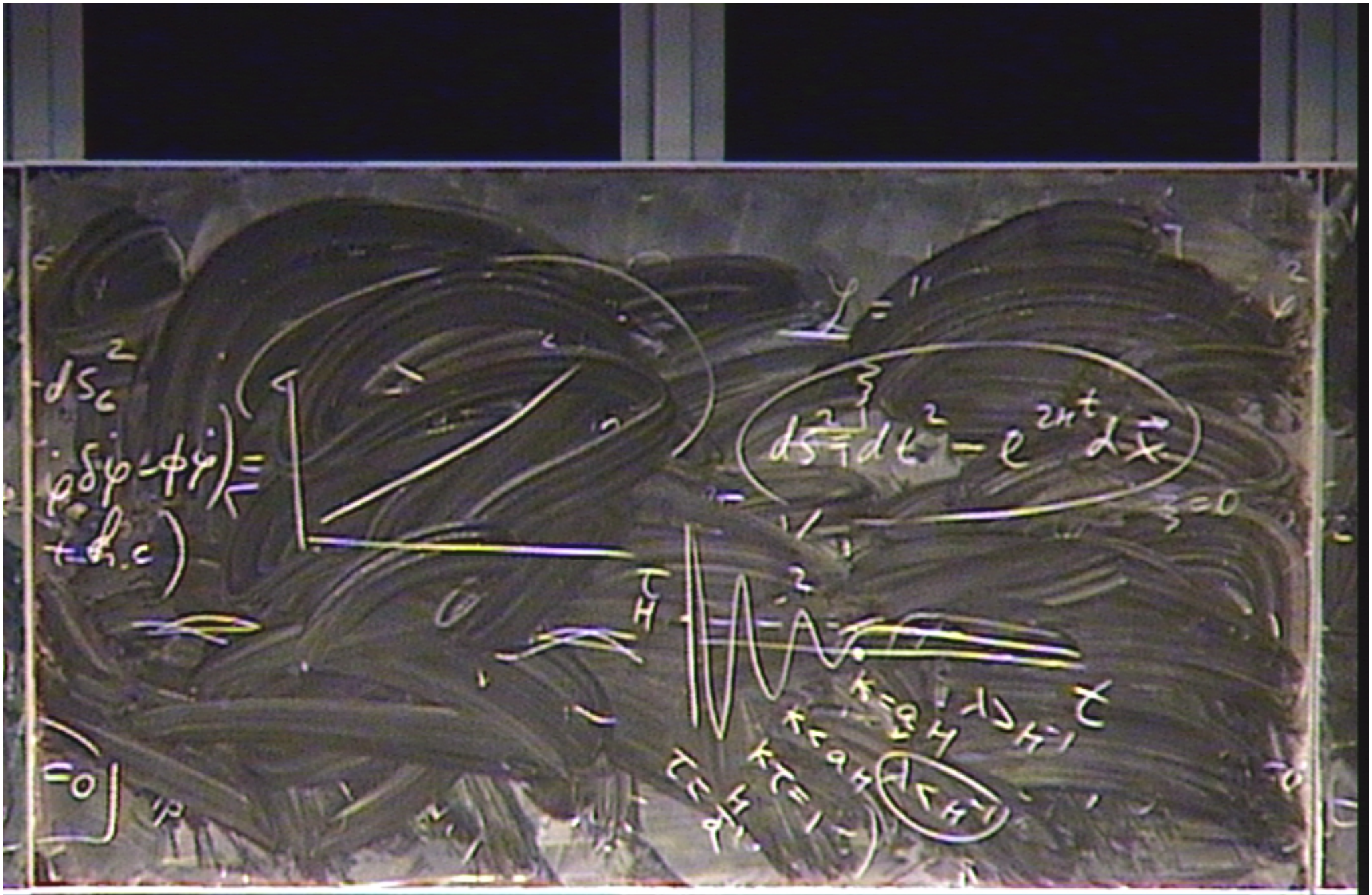
$+ h.c.$

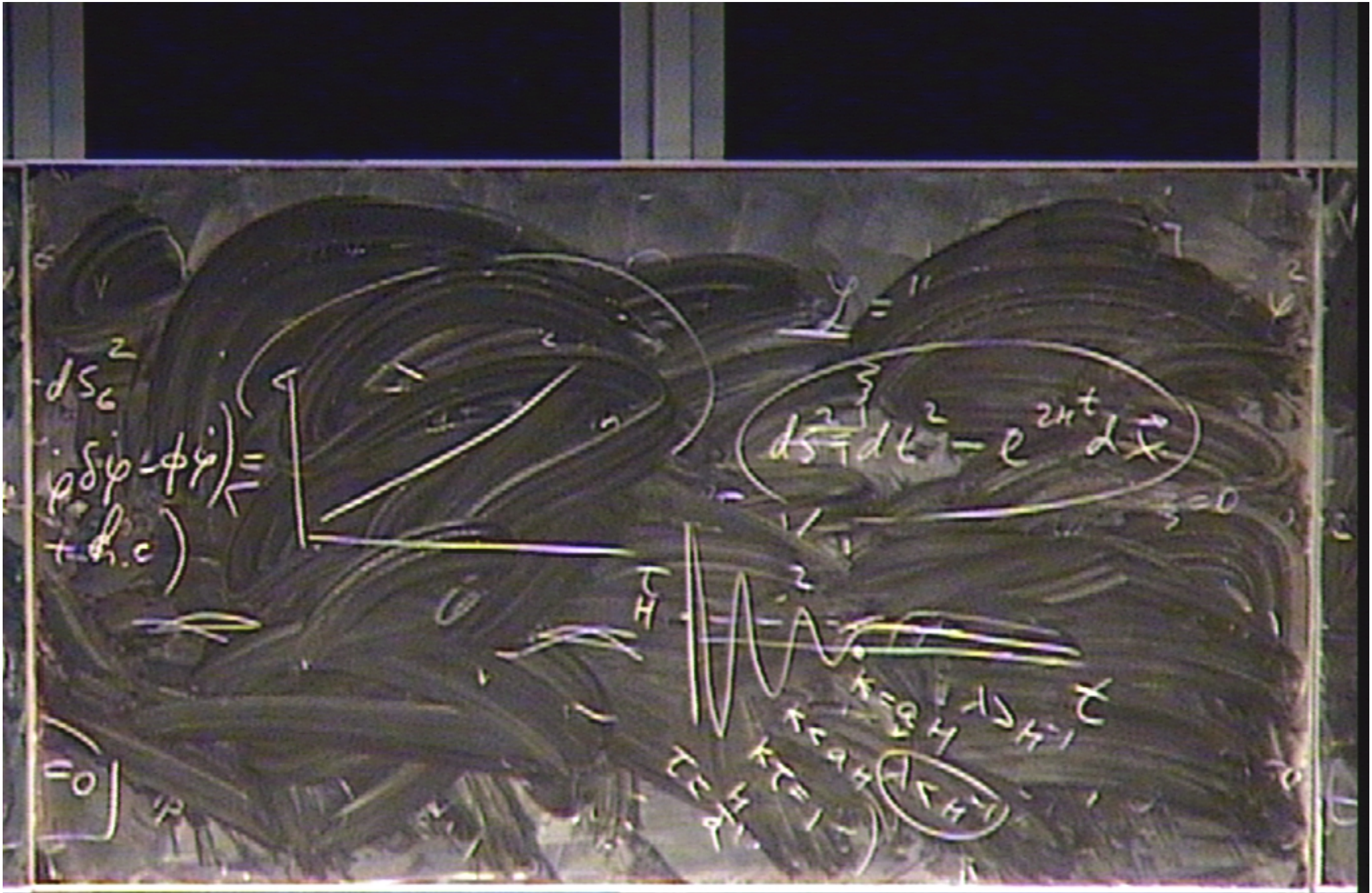
$\langle \dot{\varphi}^2 \rangle$

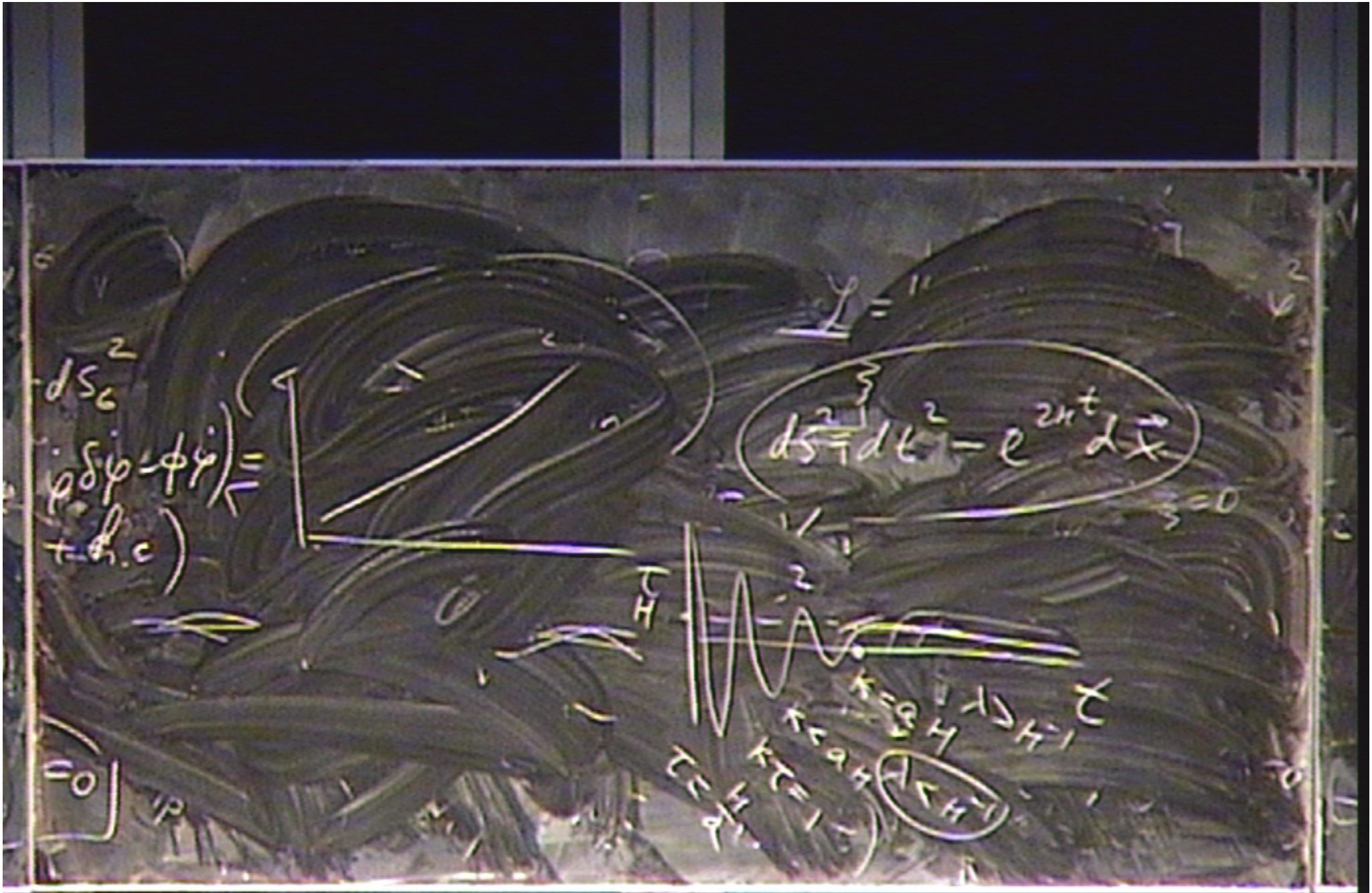
$\varphi(t) + \delta\varphi$

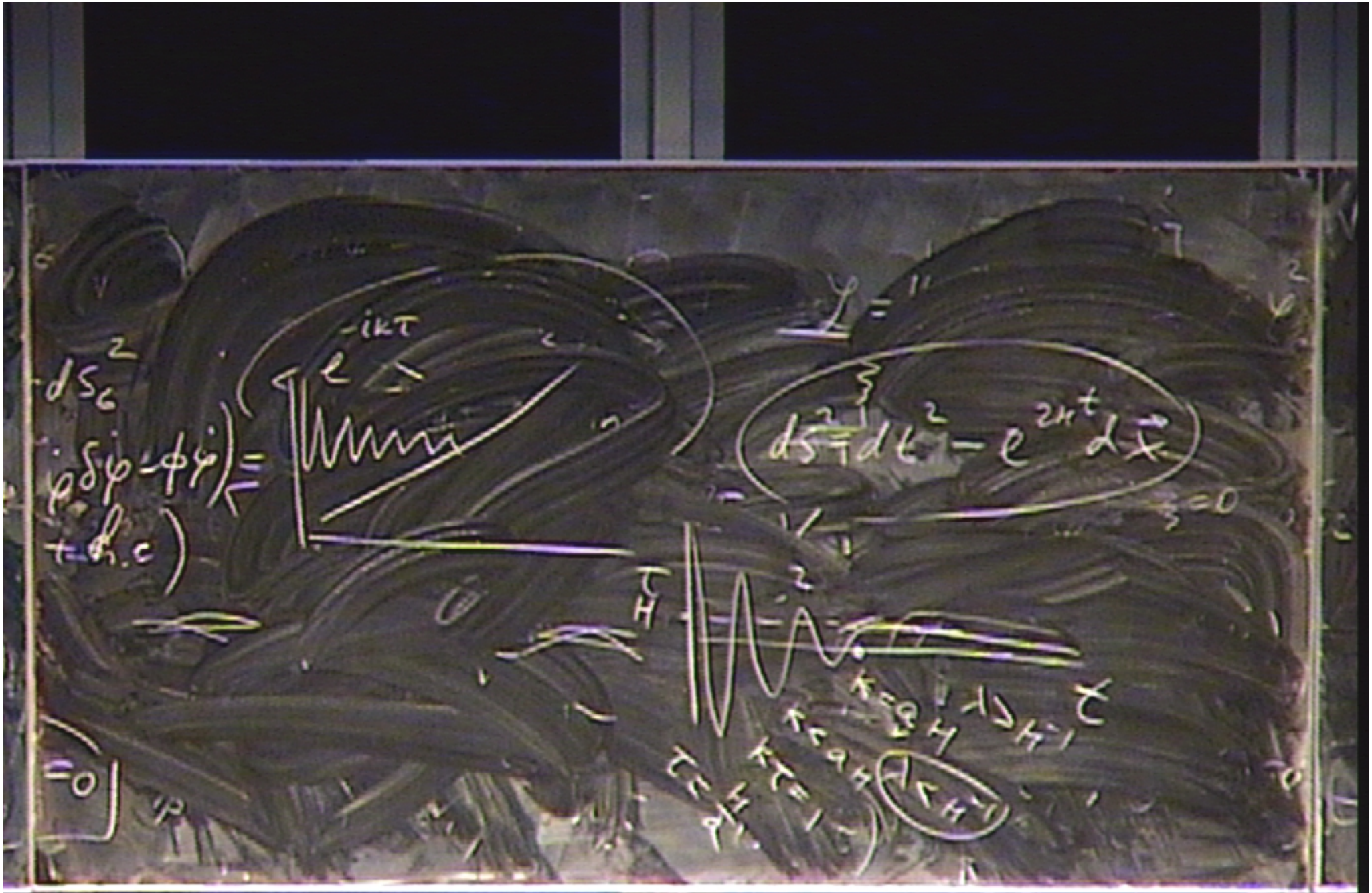

$q = \varphi$
$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2 + ds_c^2$
$\langle \dot{\varphi}^2 \rangle$
$\varphi(t) + \delta\varphi$

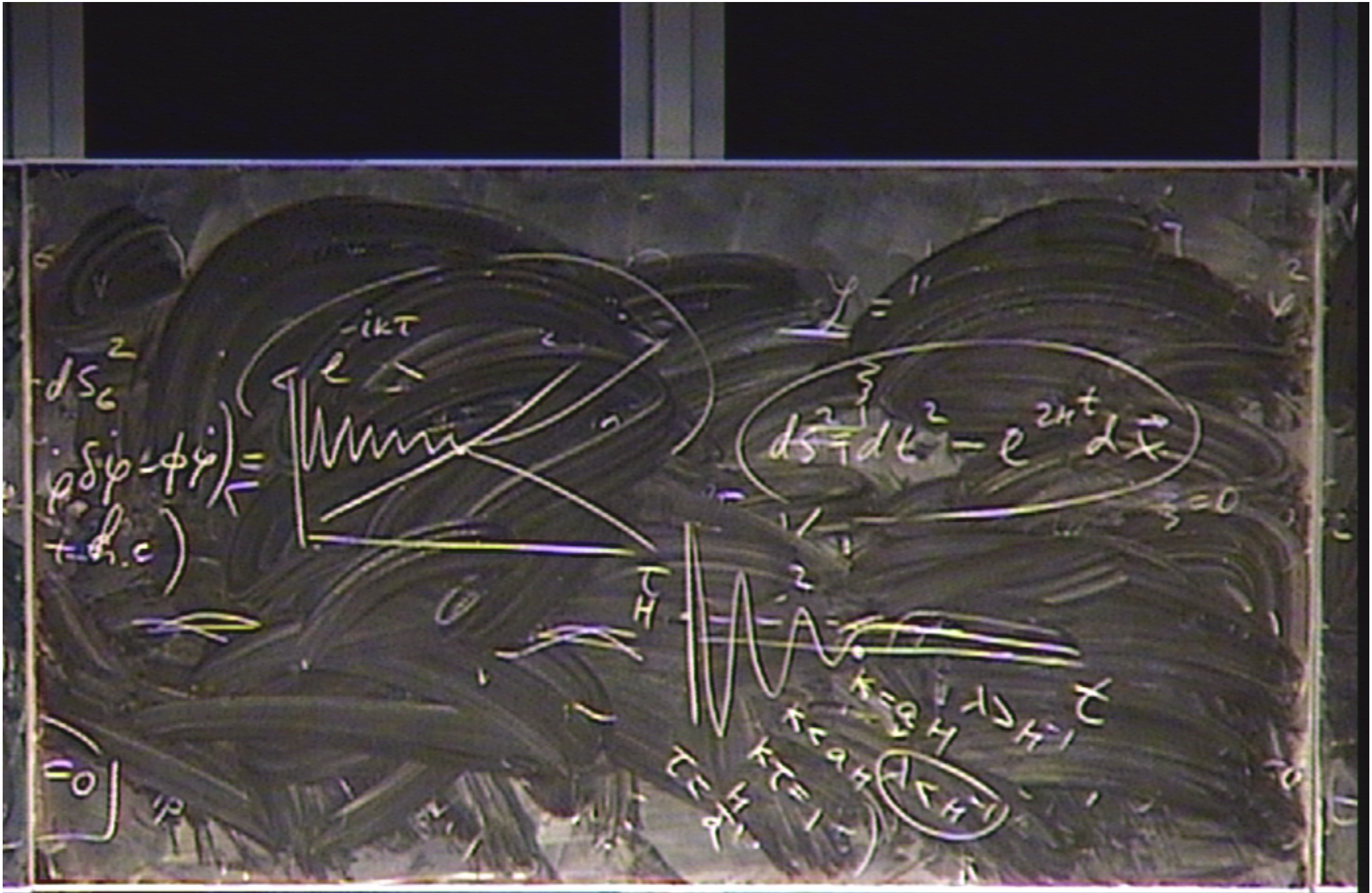

$q = \varphi$
$ds^2 = (1+2\phi)dt^2 - (1-2\Phi)d\vec{x}^2 +$
ds_c^2
$\langle \dot{\varphi}^2 \rangle$
$-\frac{1}{2}\nabla^2\phi + 3H\dot{\phi} + 3H^2\phi = \frac{4\pi G}{M_P^2}(V_{,\varphi}\delta\varphi +$
$\dot{\varphi}\delta\dot{\varphi} - \phi\dot{\varphi}$
$+ h.c)$
$\dot{\varphi}(t) + \delta\dot{\varphi}$
$\frac{1}{a}(a\phi)^{\cdot} = \frac{4\pi}{M_P^2}\rho\delta\varphi$
$u = a\delta\varphi$
$u'' + (k^2 - \frac{z''}{z})u = 0$


ds_c^2
$(\rho\delta\varphi - \phi\dot{\varphi})$
$+ \delta_{ij}c)$
$= 0$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
τ_H
$k = a_H H$
$\lambda > H^{-1}$
$k\tau = 1$
$\tau < H^{-1}$


ds_c^2
$\rho\delta\dot{\varphi} - \phi\dot{\rho}$
$+ h.c$
$= 0$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
H
$k = a_H H$
$k\tau = 1$
$\tau H = 1$

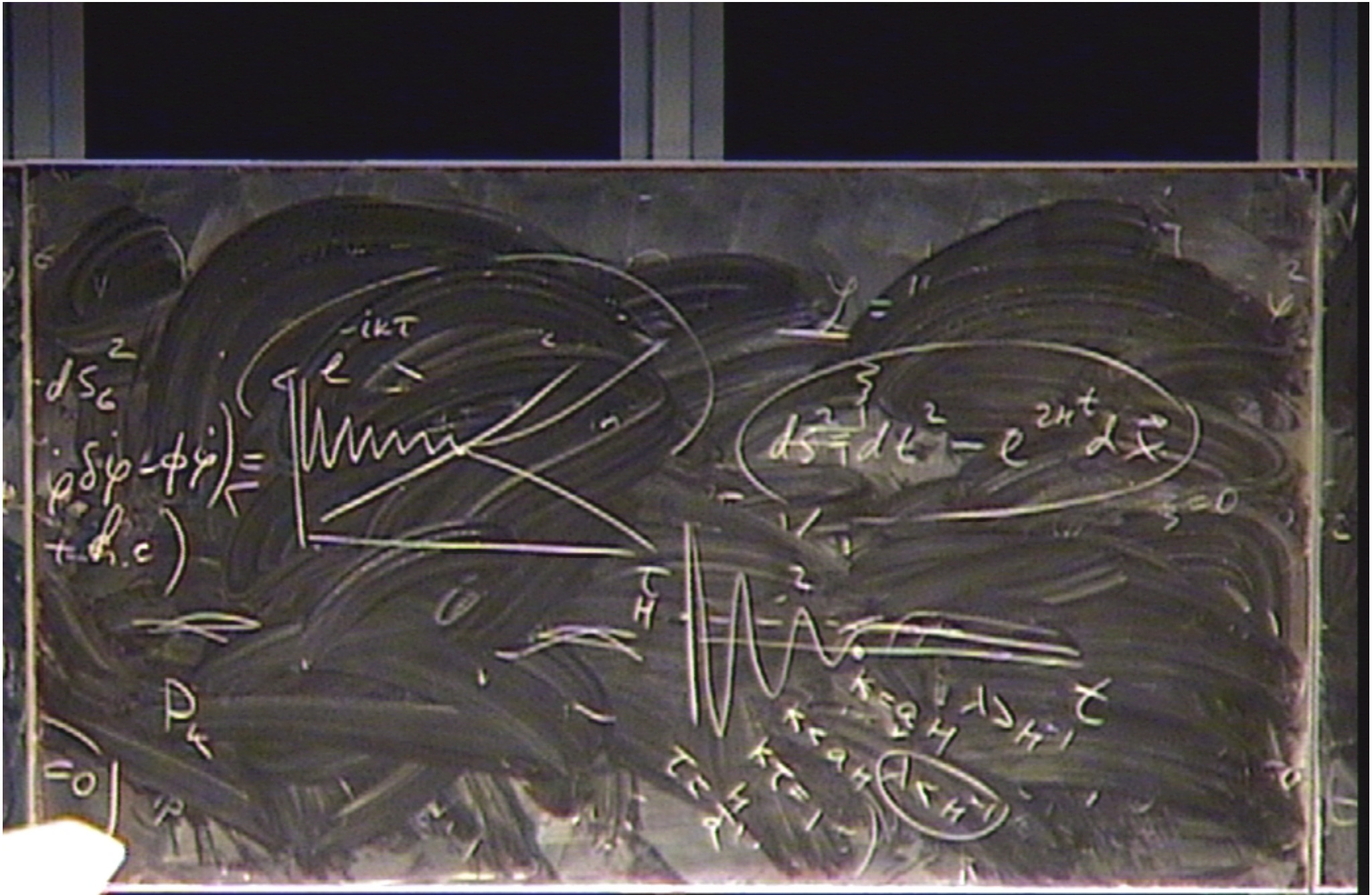

ds_c^2
$\rho\delta\rho - \phi\psi$
$+ d_{1,c}$
$= 0$
$\gamma = 1$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
τ_H
$k\tau = 1$

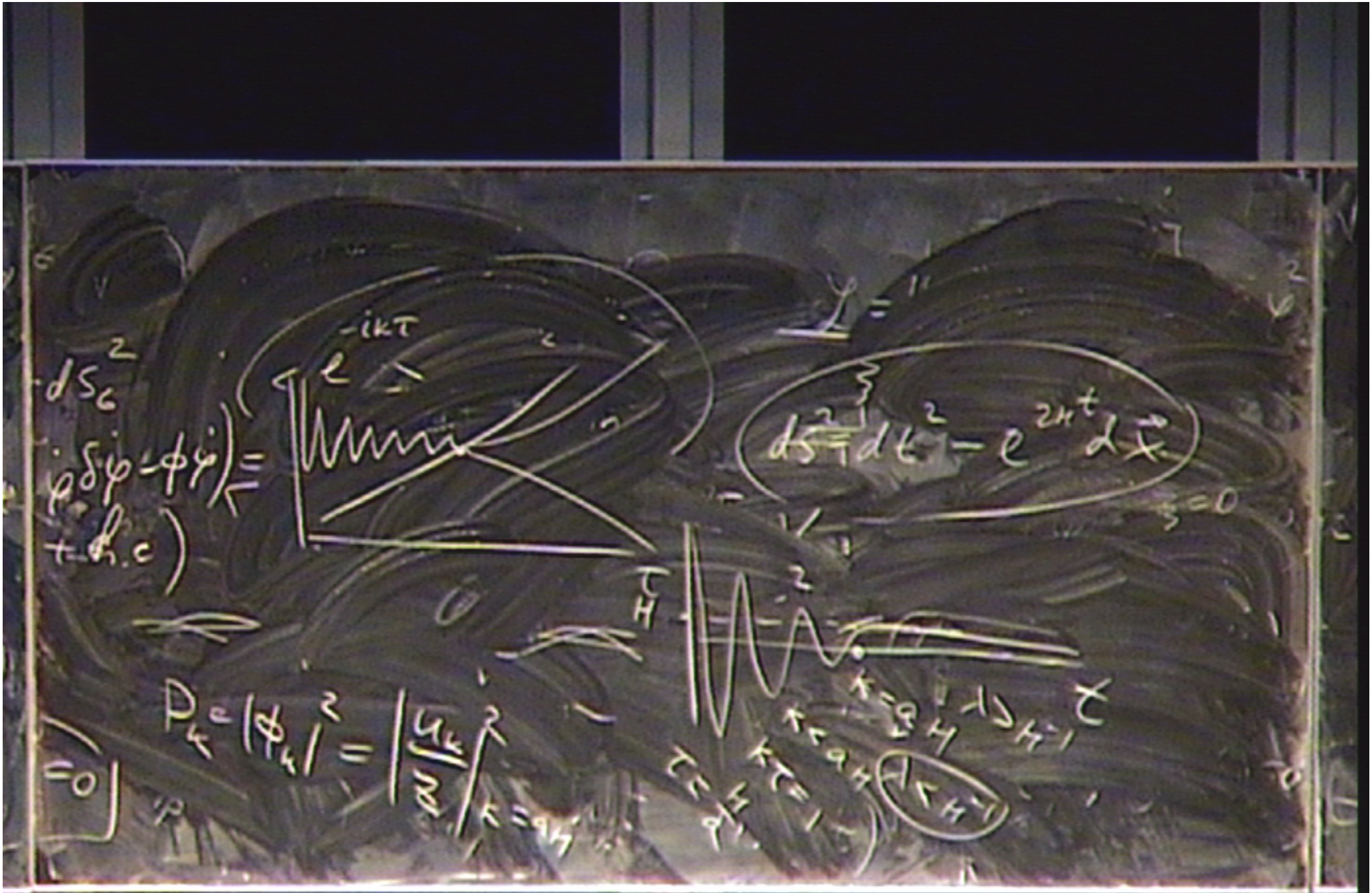

ds_c^2
e^{-ikr}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$\zeta = 0$
r_H
$k = a_H H$
$k\tau = 1$
r_H

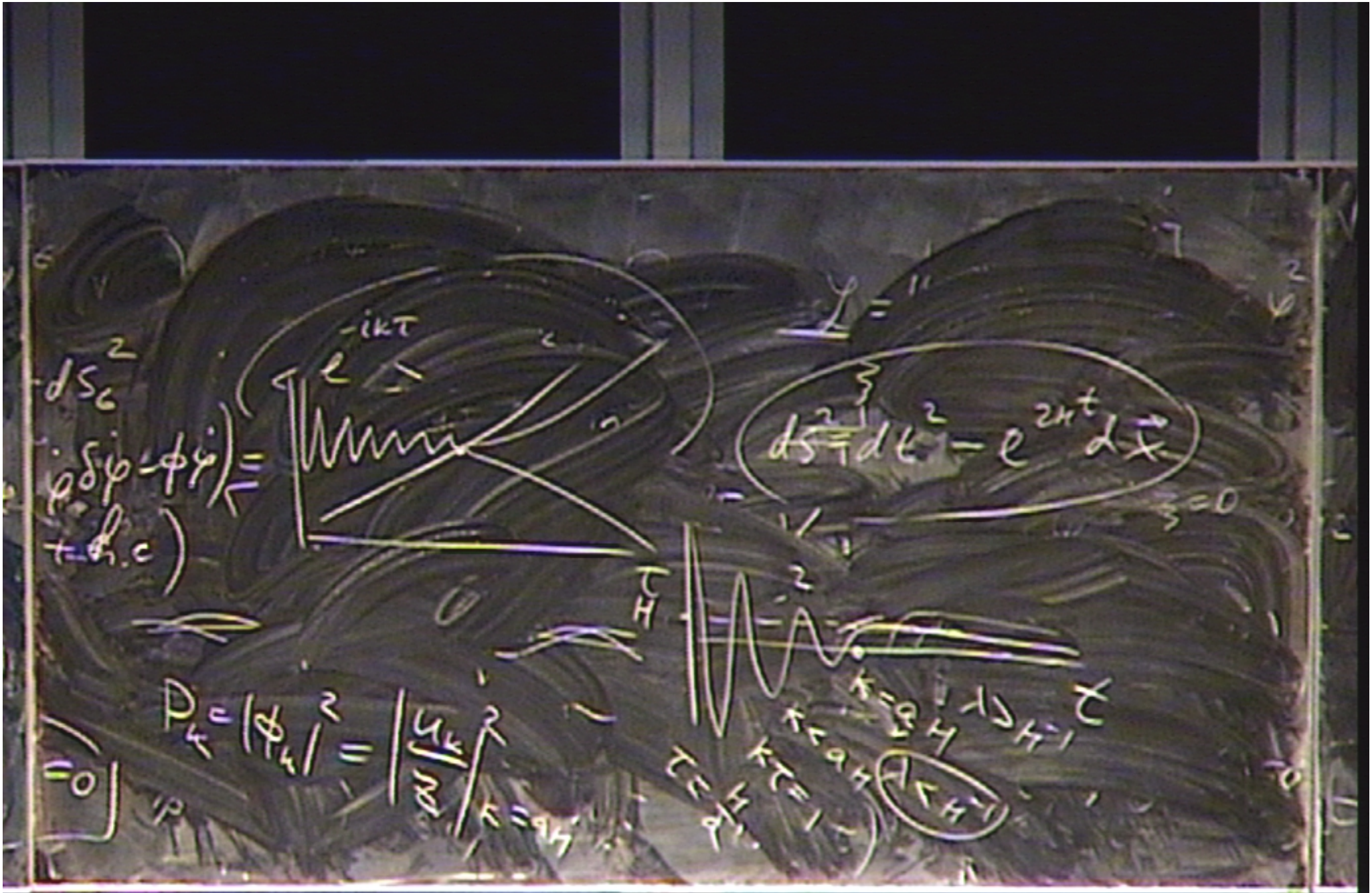

$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
e^{-ikt}
τ_H
$k = a_H H$
$\lambda > H^{-1}$
t


ds_c^2
e^{-ikr}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
r_H
$k = a_H H$
$k\tau = 1$
$\tau < H^{-1}$
$\lambda > H^{-1}$
t

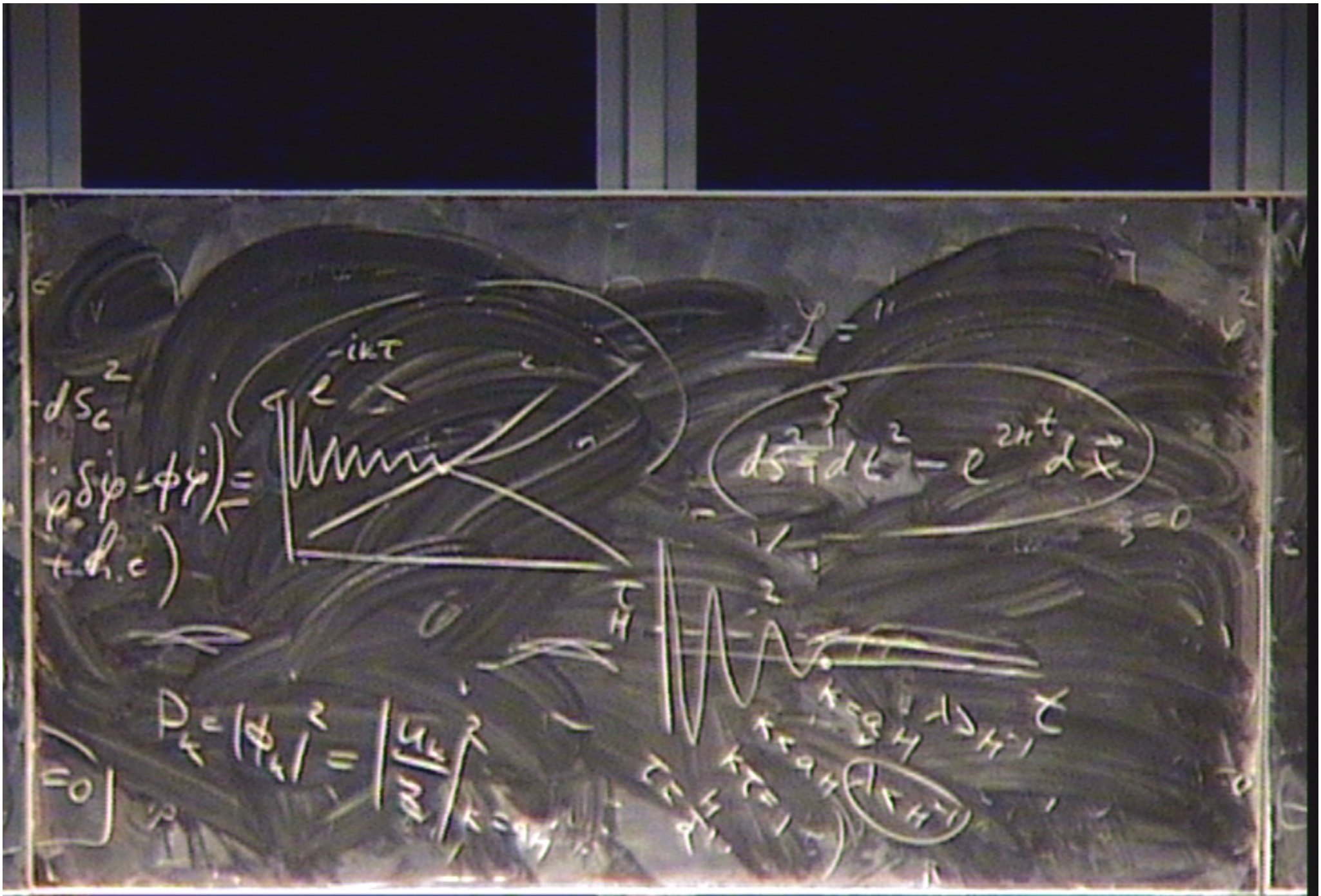

ds_c^2
e^{-ikr}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
r_H
$k = a_H H$
$k\tau = 1$
$r_{H^{-1}}$
τ

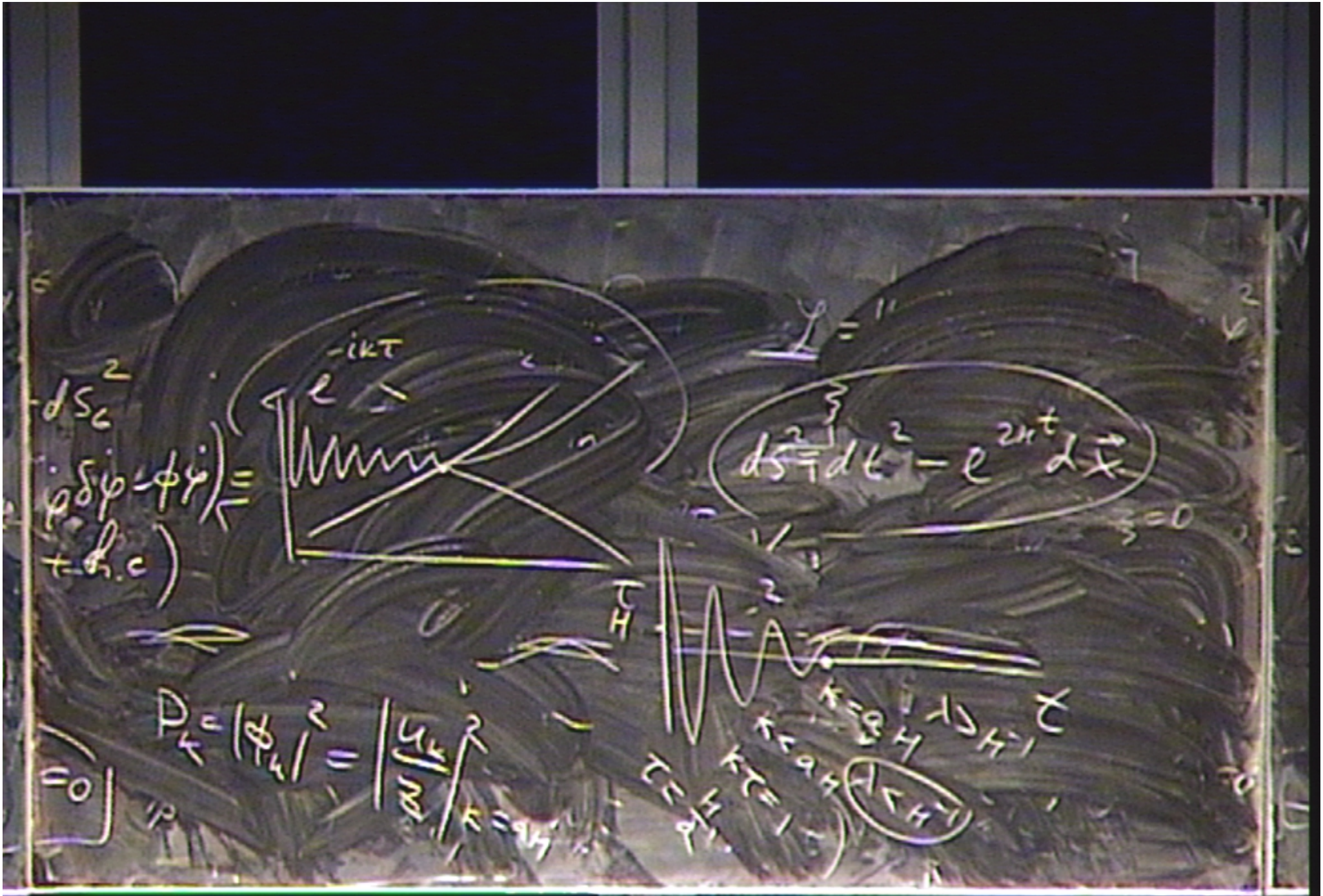

ds_c^2
$e^{-ik\tau}$
$ds^2 = d\tau^2 - e^{2Ht} d\vec{x}$
τ_H
P_k
$k\tau = 1$

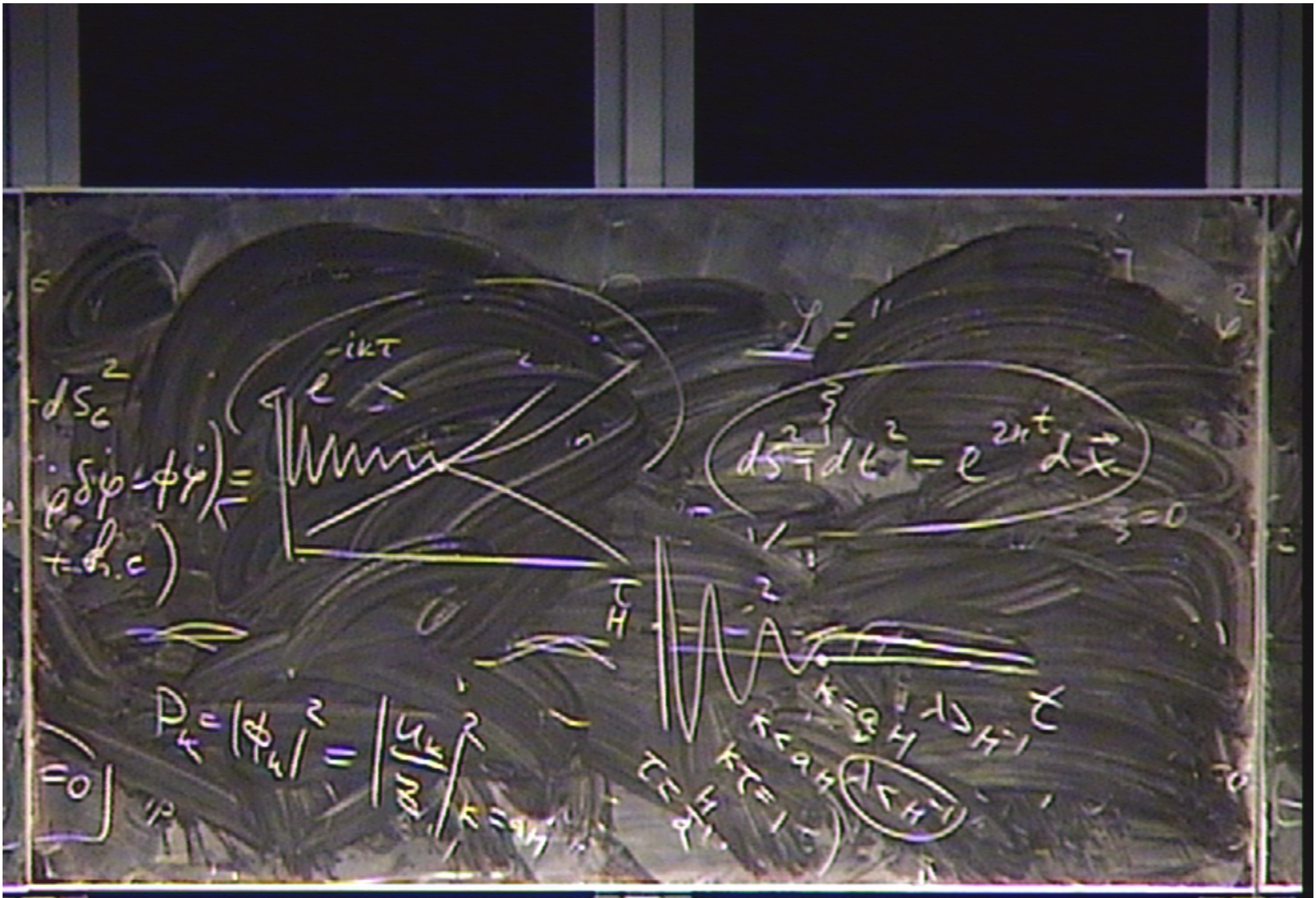

ds_c^2
e^{-ikt}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2_{k=aH}$
$k = aH$
$k\tau = 1$
$\tau = \frac{1}{aH}$
τ_H
τ

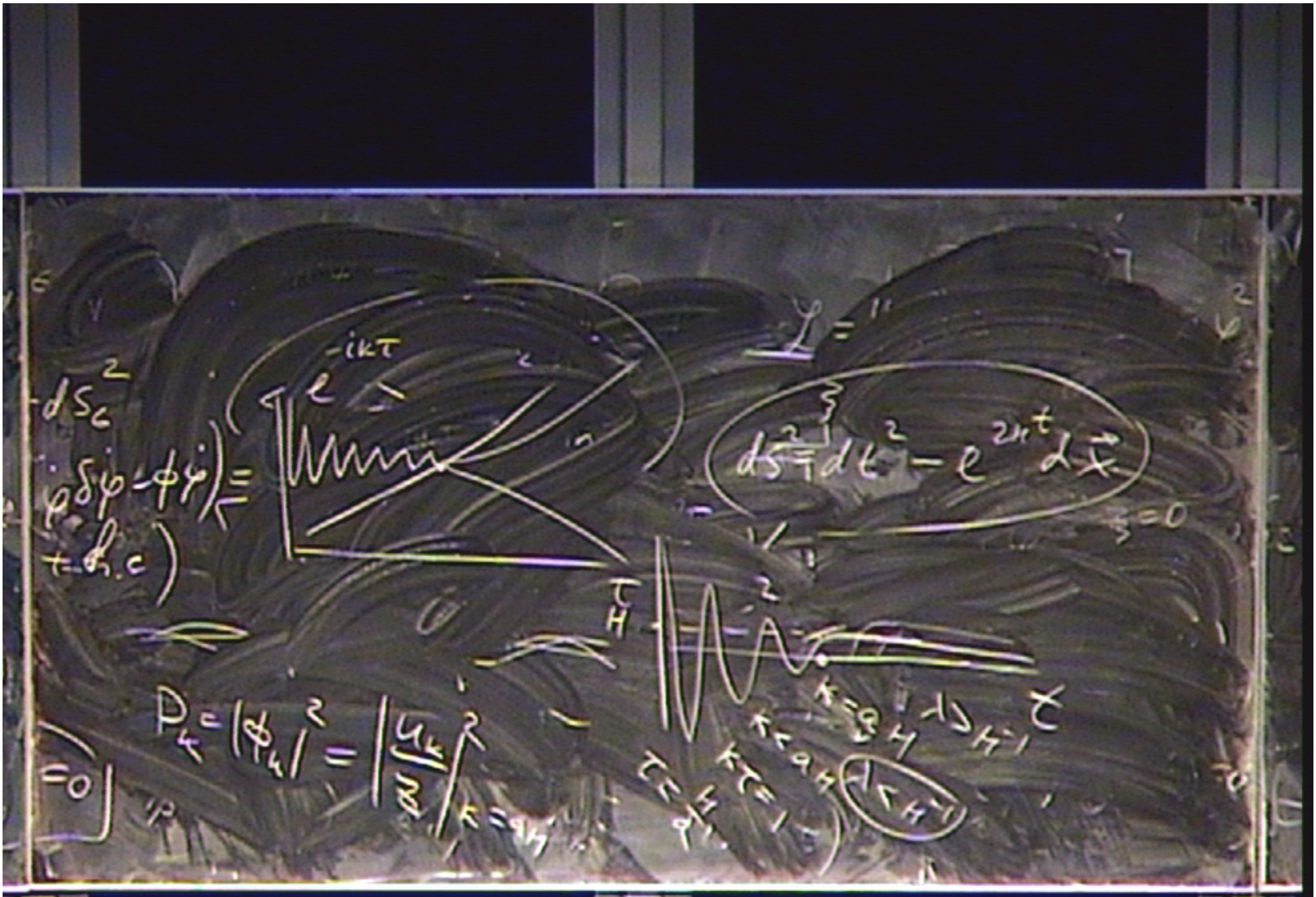

ds_c^2
$e^{-ik\tau}$
$ds^2 = d\tau^2 - e^{2Ht} d\vec{x}$
τ_H
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|_{k=aH}$
$k = aH$
$k\tau = 1$


ds_c^2
$\rho\delta\rho - \phi\psi$
$+ h.c$
e^{-ikT}
$ds^2 = d\tau^2 - e^{2Ht} d\vec{x}$
τ_H
$P_k = |\phi_k|^2 = \left|\frac{\psi_k}{z}\right|_{k=aH}$
$k\tau = 1$
$\tau < \tau_H$
$\lambda > H^{-1}$

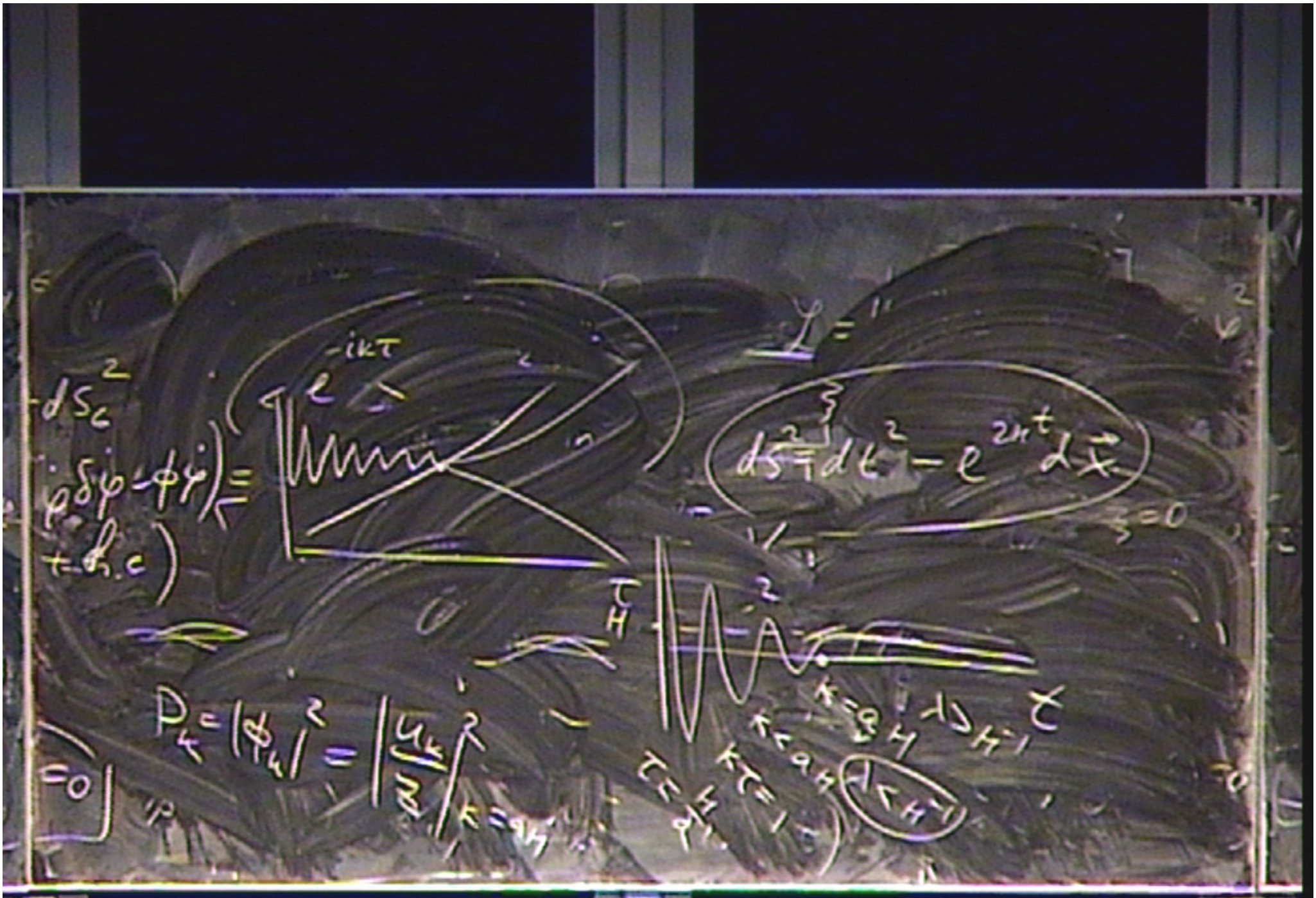

ds_c^2
$(\rho\delta\varphi - \phi\dot{\rho})$
$+h.c)$
e^{-ikT}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2$
$=0$


ds_c^2
e^{-ikr}
$\gamma = 1$
$ds^2 = dt^2 - e^{2ht} d\vec{x}^2$
τ_H
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2_{k=aH}$
$k = aH$
$k\tau = 1$
$\tau = H^{-1}$

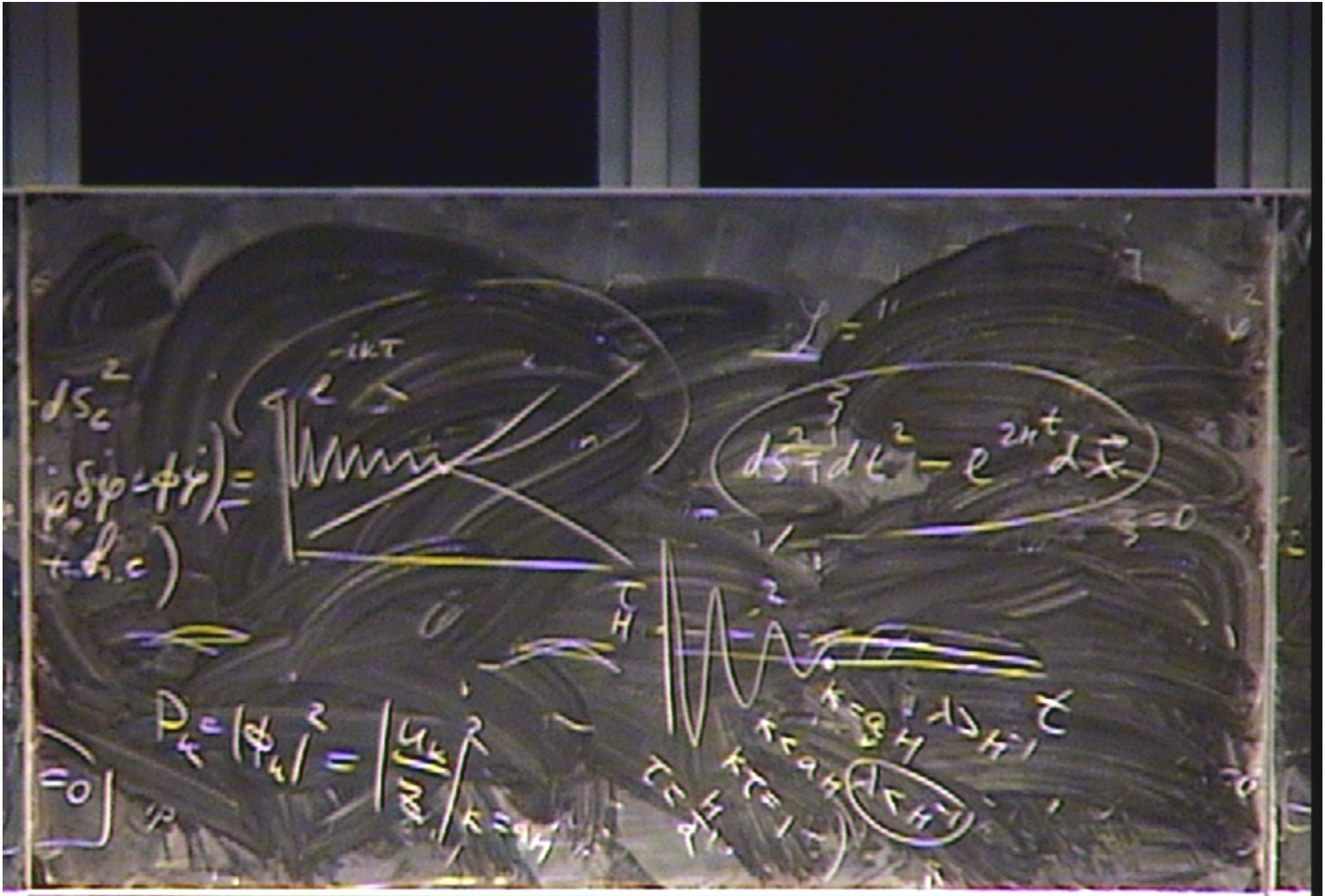

ds_c^2
e^{-ikr}
$d\tilde{s}^2 = dt^2 - e^{2Ht} d\vec{x}$
$\xi = 0$
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2$
$k = aH$
$k\tau = 1$
$\tau = \frac{1}{aH}$
$\lambda > H^{-1}$
τ
τH
$\tau < H^{-1}$
$\gamma = 1$
$\rho\delta\varphi - \phi\dot{\varphi}$
$+ h.c$
$= 0$

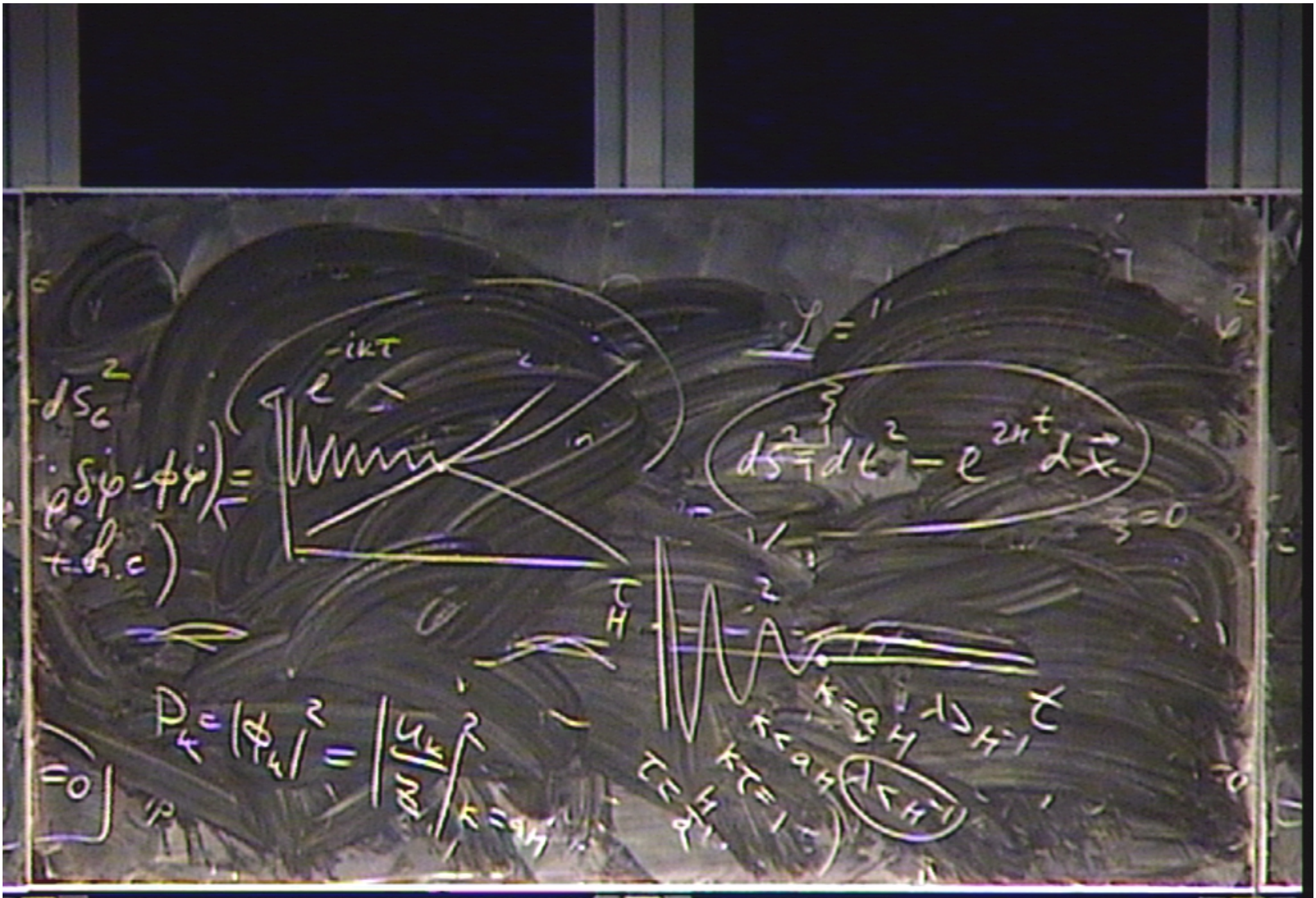

$-ds_c^2$
$e^{-ik\tau}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
τ_H
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2_{k=aH}$
$k\tau = 1$
$k = aH$
$\tau = H^{-1}$


ds_c^2
$e^{-ik\tau}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2_{k=aH}$
$k\tau = 1$
$k = aH$
$\tau = H^{-1}$

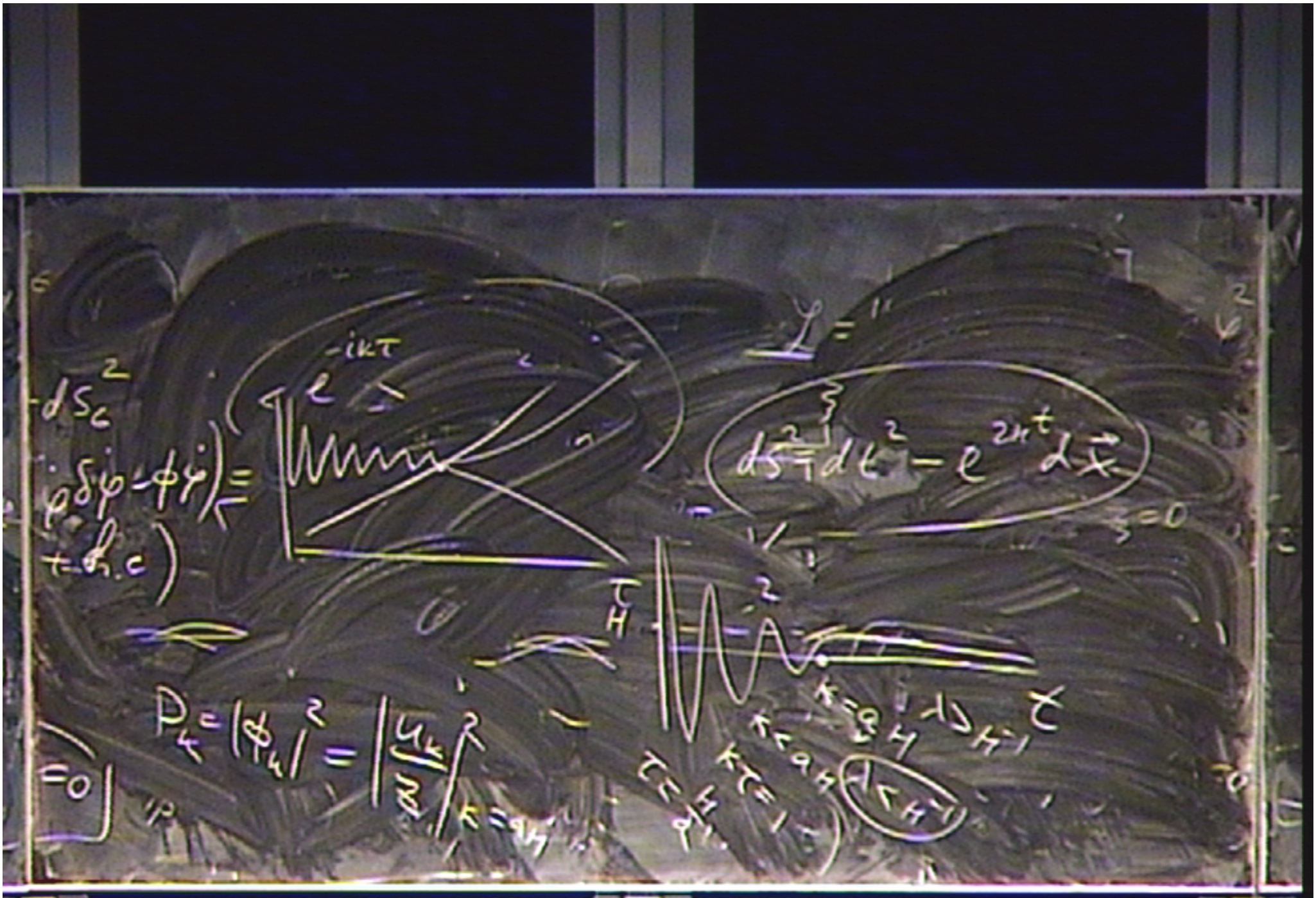

ds_c^2
$e^{-ik\tau}$
$d\tau^2 = dt^2 - e^{2Ht} d\vec{x}$
$P_k = |\phi_k|^2 = \left|\frac{u_k}{z}\right|^2_{k=aH}$
$k\tau = 1$
$k = aH$
$\tau = H^{-1}$


ds_c^2
e^{-ikT}
$d\tau^2 = dt^2 - e^{2Ht} d\vec{x}$
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2_{k=aH}$
$k\tau = 1$
$k = aH$
$\lambda > H^{-1}$
τ

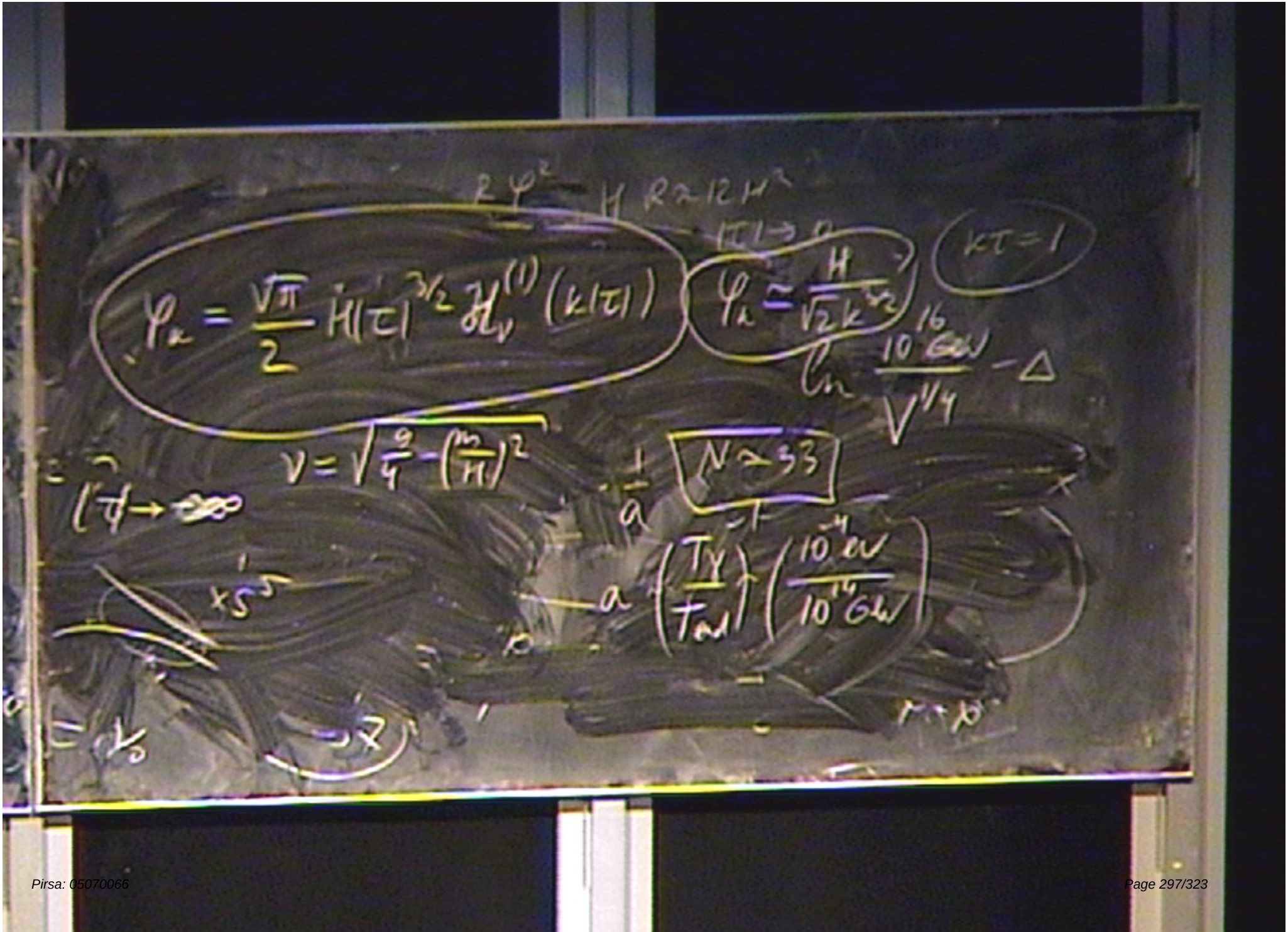

ds_c^2
e^{-ikT}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$P_k = |\Psi_k|^2 = \left|\frac{\psi_k}{z}\right|^2$
$k = q_H$
$k\tau = 1$
$k\tau = q_H$
τ_H
$\lambda > H^{-1}$
τ
$\tau < H^{-1}$
$\tau < q_H^{-1}$
$\delta\varphi - \Phi\psi$
$+ h.c$
$=0$

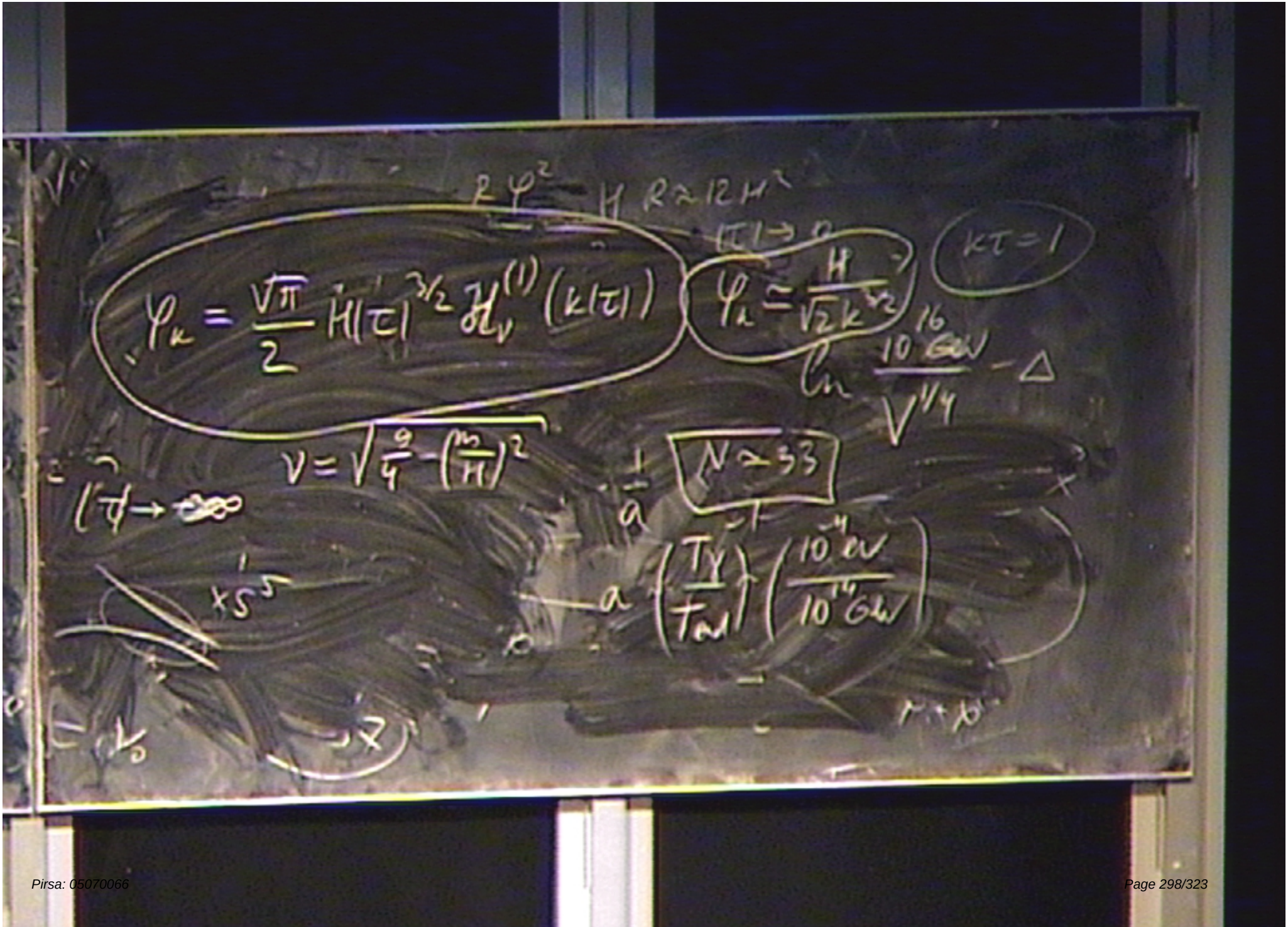

ds_c^2
e^{-ikr}
$\rho\delta\varphi - \phi\psi$
$+h.c$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$P_k = |\alpha_k|^2 = \left|\frac{u_k}{\sqrt{2}}\right|^2$
$k = aH$
$k\tau = 1$
$\tau < H^{-1}$
$\lambda > H^{-1}$
τ
$=0$

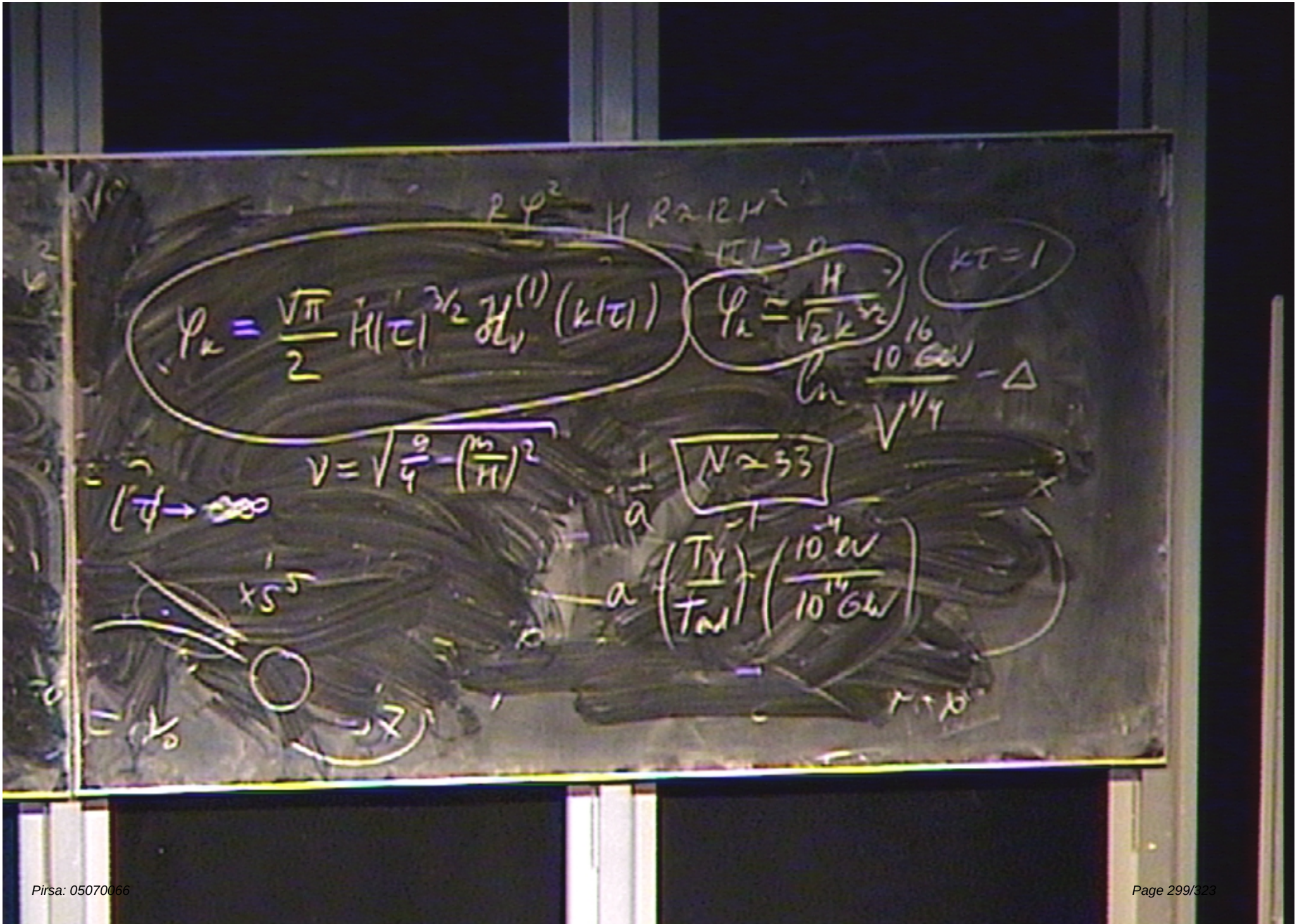

ds_c^2
$\rho\delta\rho - \phi\psi$
$+h.c$
e^{-ikr}
$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2$
$k = aH$
$k\tau = 1$
$\tau = \frac{1}{aH}$
$k\tau = aH(-\tau H^{-1})$
τ
$=0$

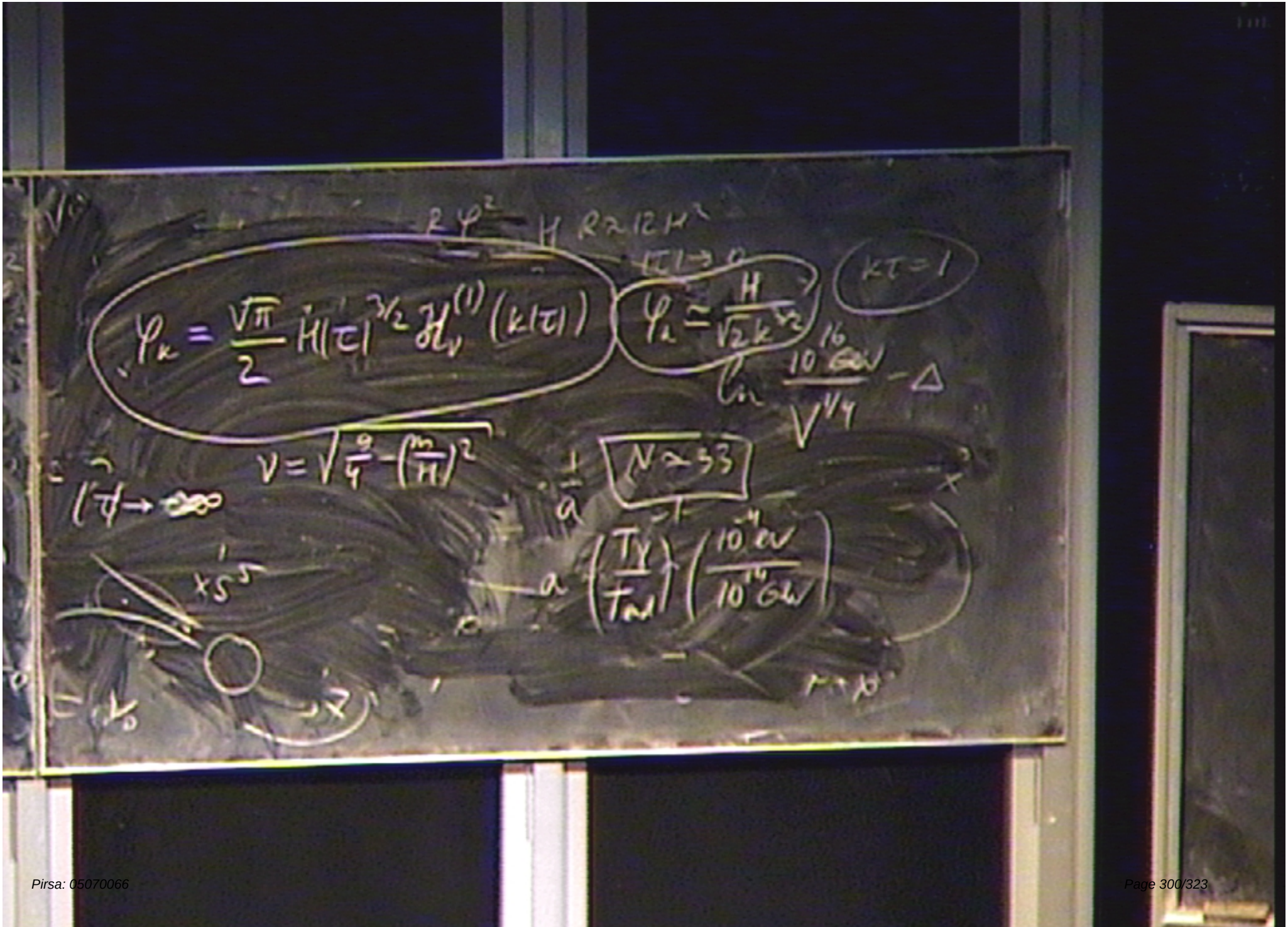

$-ds_c^2$
$\rho\delta\rho - \phi\psi$
$+h.c$
$e^{-ik\tau}$
$\mathcal{L} = 1$
$ds^2 = d\tau^2 - e^{2H\tau} d\vec{x}$
τ_H
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2_{k=aH}$
$k = aH$
$k\tau = 1$
$\tau = \frac{1}{aH}$
$k\tau_H = 1$
τ_H
τ
$=0$

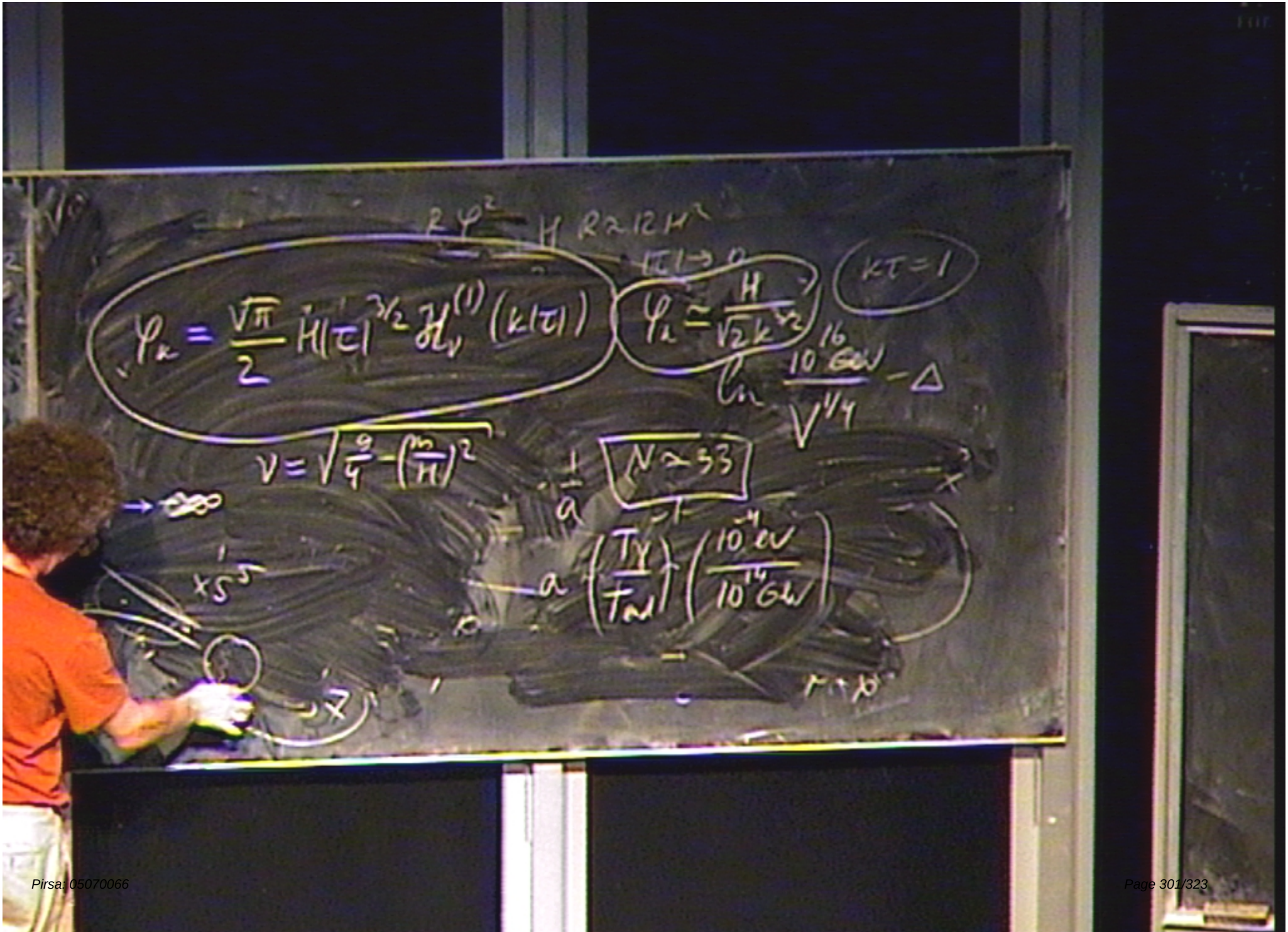

ds_c^2
e^{-ikr}
$d\tau^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$P_k = |\Phi_k|^2 = \left|\frac{u_k}{z}\right|^2_{k=aH}$
$k\tau = 1$
$k = aH$
$\lambda > H^{-1}$
$\tau < H^{-1}$

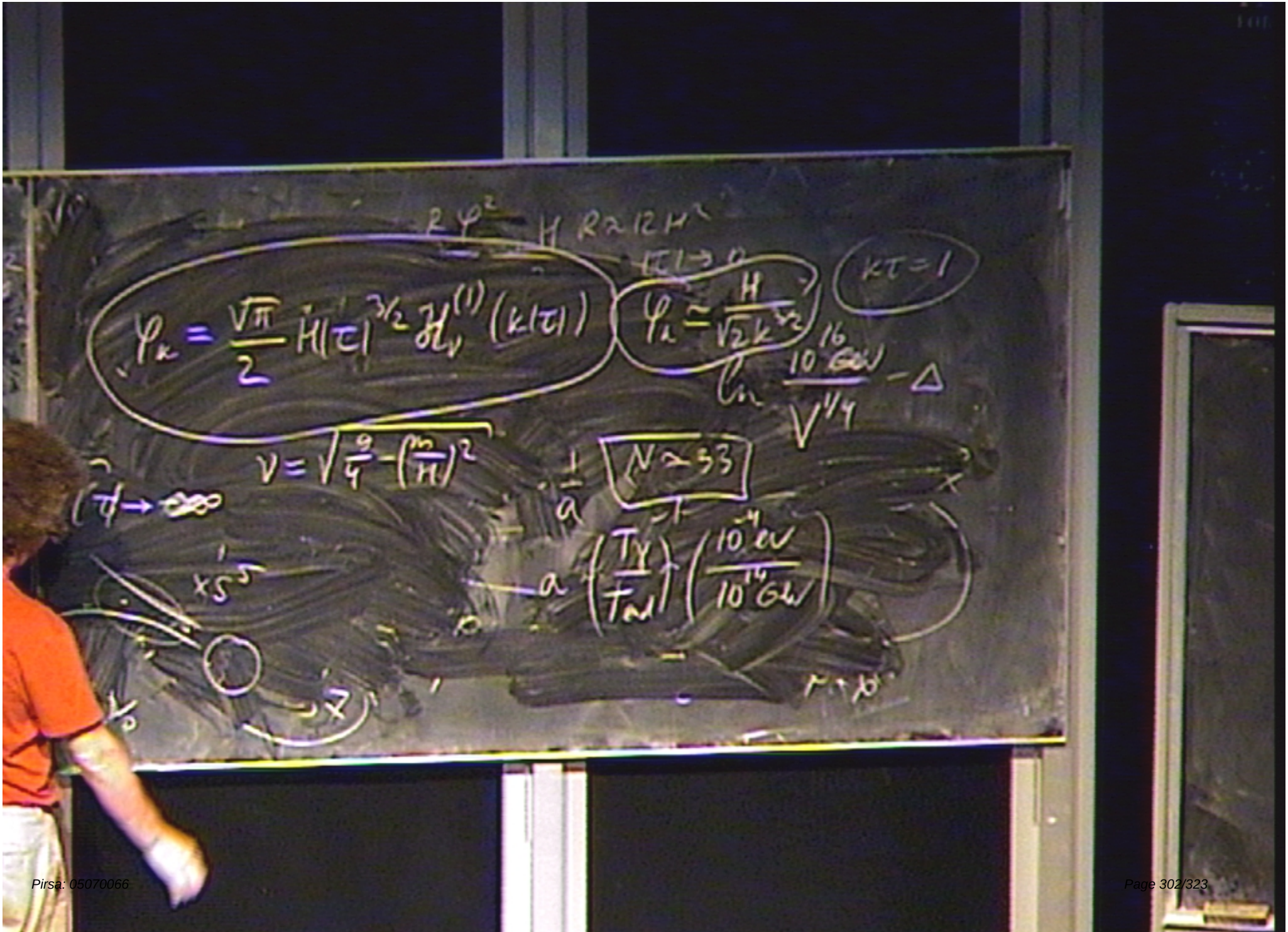

$\frac{1}{2}\dot{\varphi}^2$ — H $R = 12H^2$
$|\tau| \to 0$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(|\tau|)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$
$k\tau = 1$
$\frac{10^{16}\,GeV}{V^{1/4}}$ — Δ
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 33$
$\tau \to -\infty$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$a = a_0$

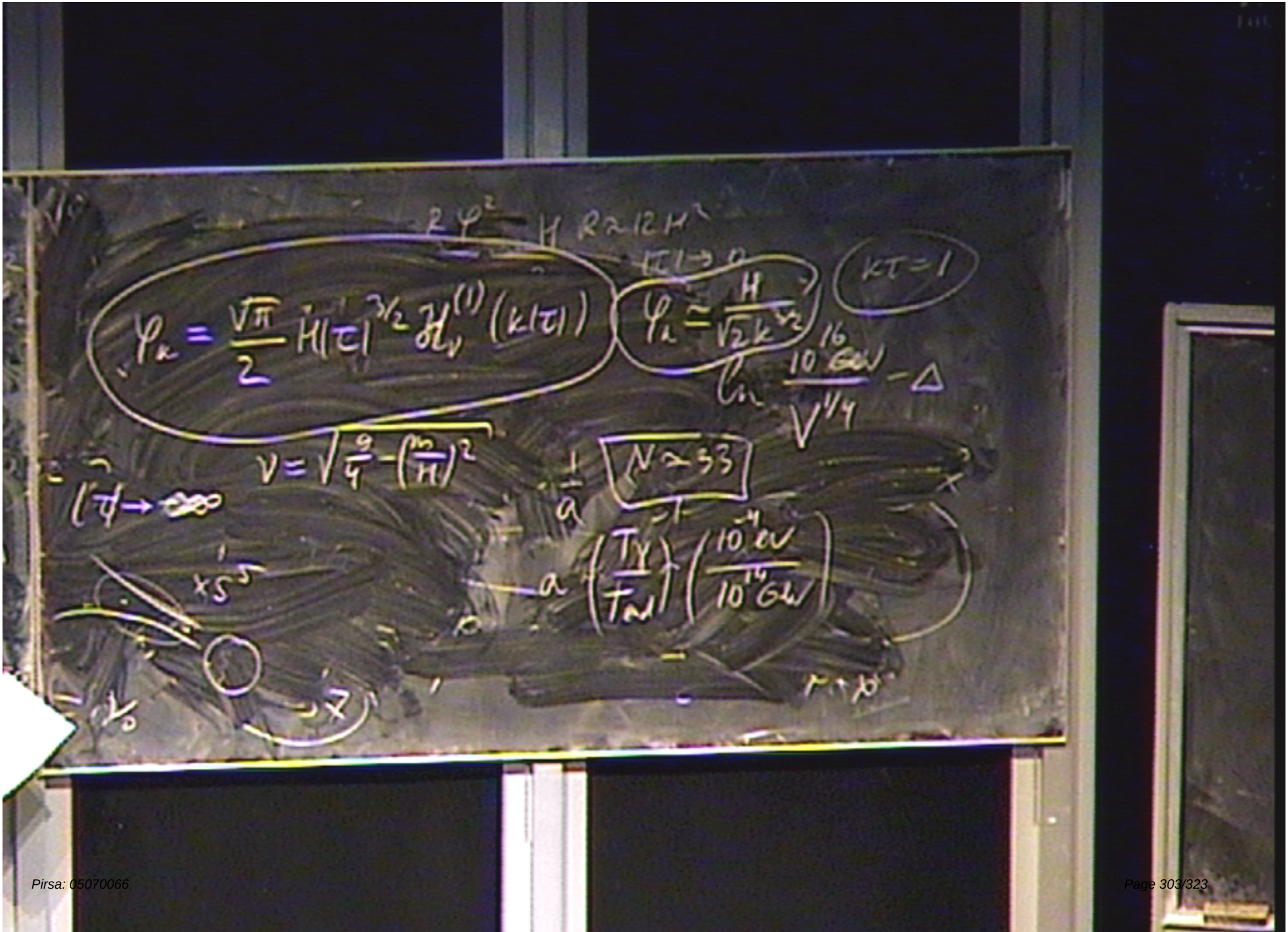

$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$k\tau = 1$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(|\tau|)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2k^3}}$
$\frac{10^{16}\,GeV}{V^{1/4}}$
$V = \sqrt{\frac{\dot\varphi}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

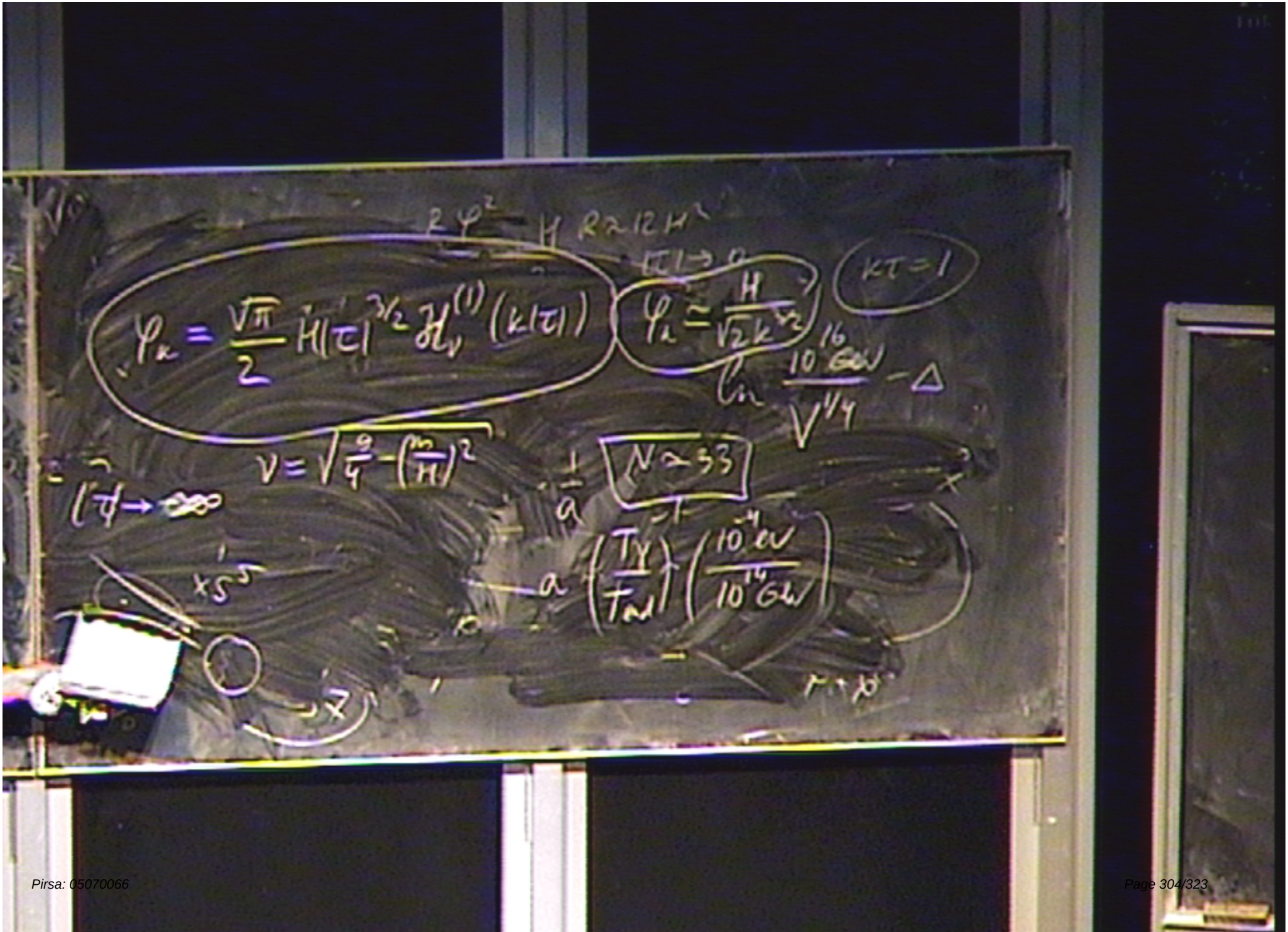

$R\varphi^2$
$R \simeq 12H^2$
$|\tau| \to 0$
$k\tau = 1$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(|\tau|)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$
$\frac{10^{16}\,GeV}{V^{1/4}}$
Δ
$V = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$\times 5$

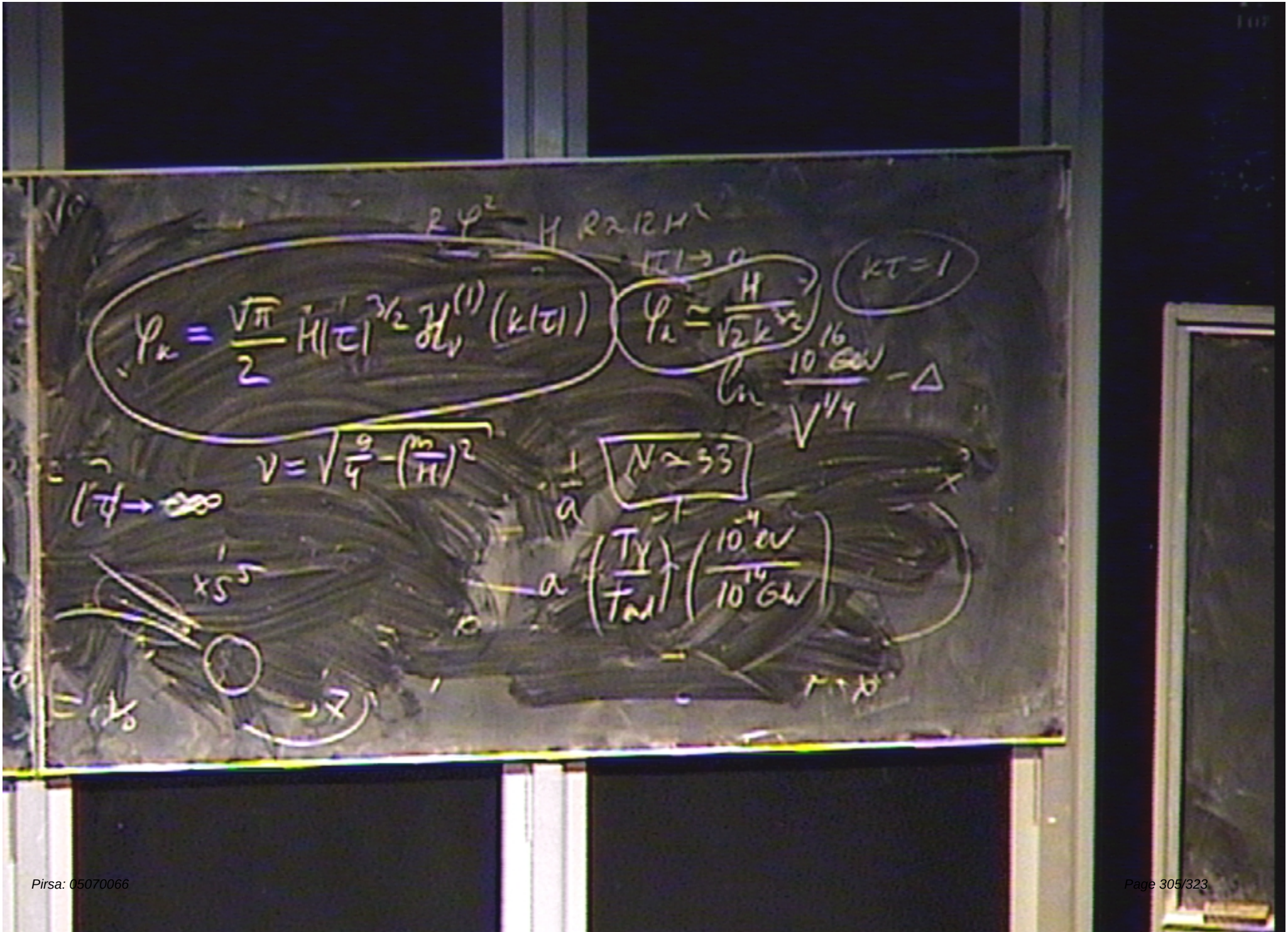

$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$k\tau = 1$
$\varphi_k = \frac{\sqrt{\pi}}{2} H |\tau|^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2k^3}}$
$\frac{10^{16}\,GeV}{V^{1/4}}$
Δ
$V = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$\tau \to \infty$
x^5
x

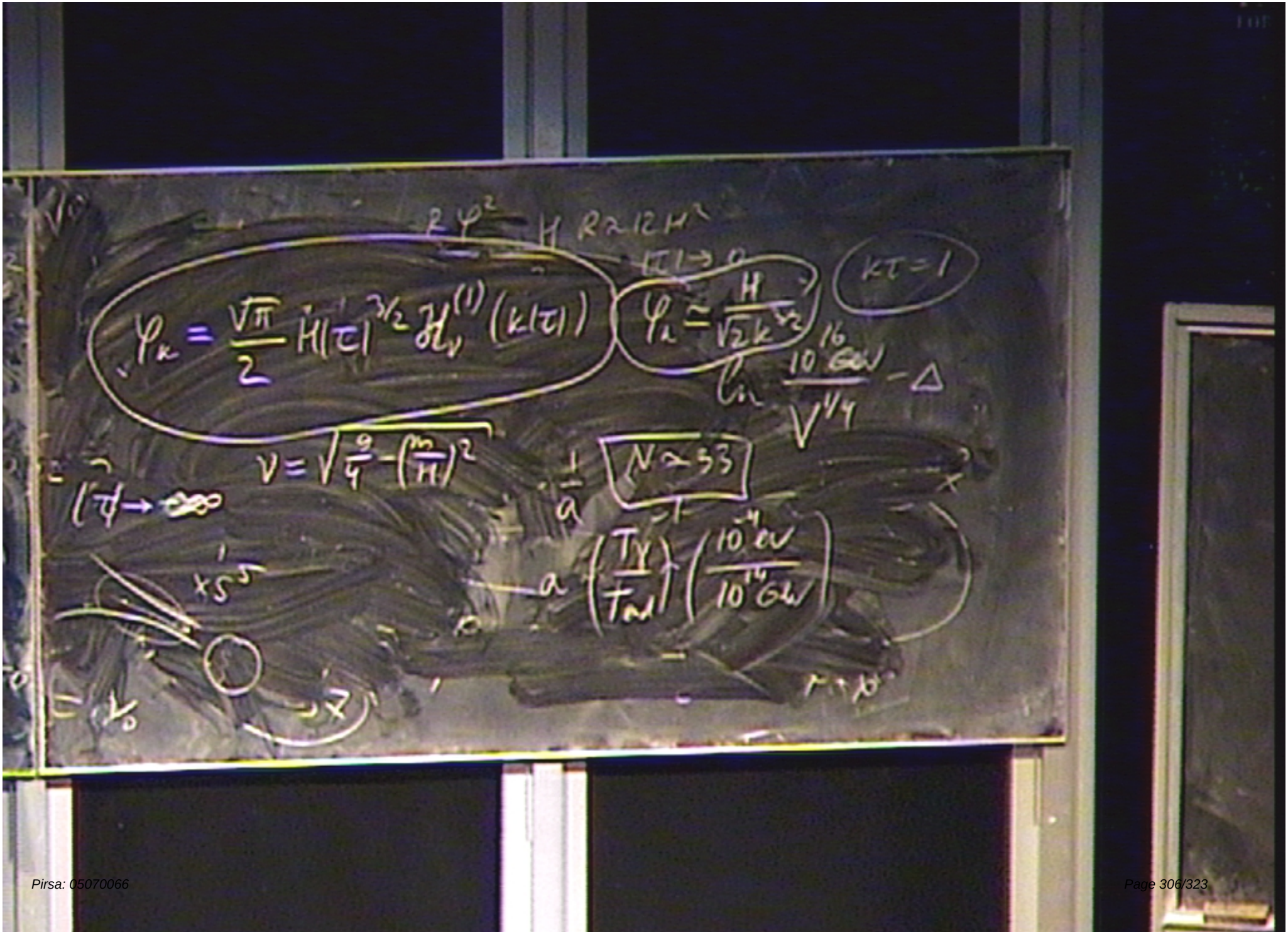

$R\varphi^2$
H
$R \simeq 12 H^2$
$|\tau| \to 0$
$k\tau = 1$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2} k^{3/2}}$
$\frac{10^{16}\,GeV}{V^{1/4}}$
$V = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\nu 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

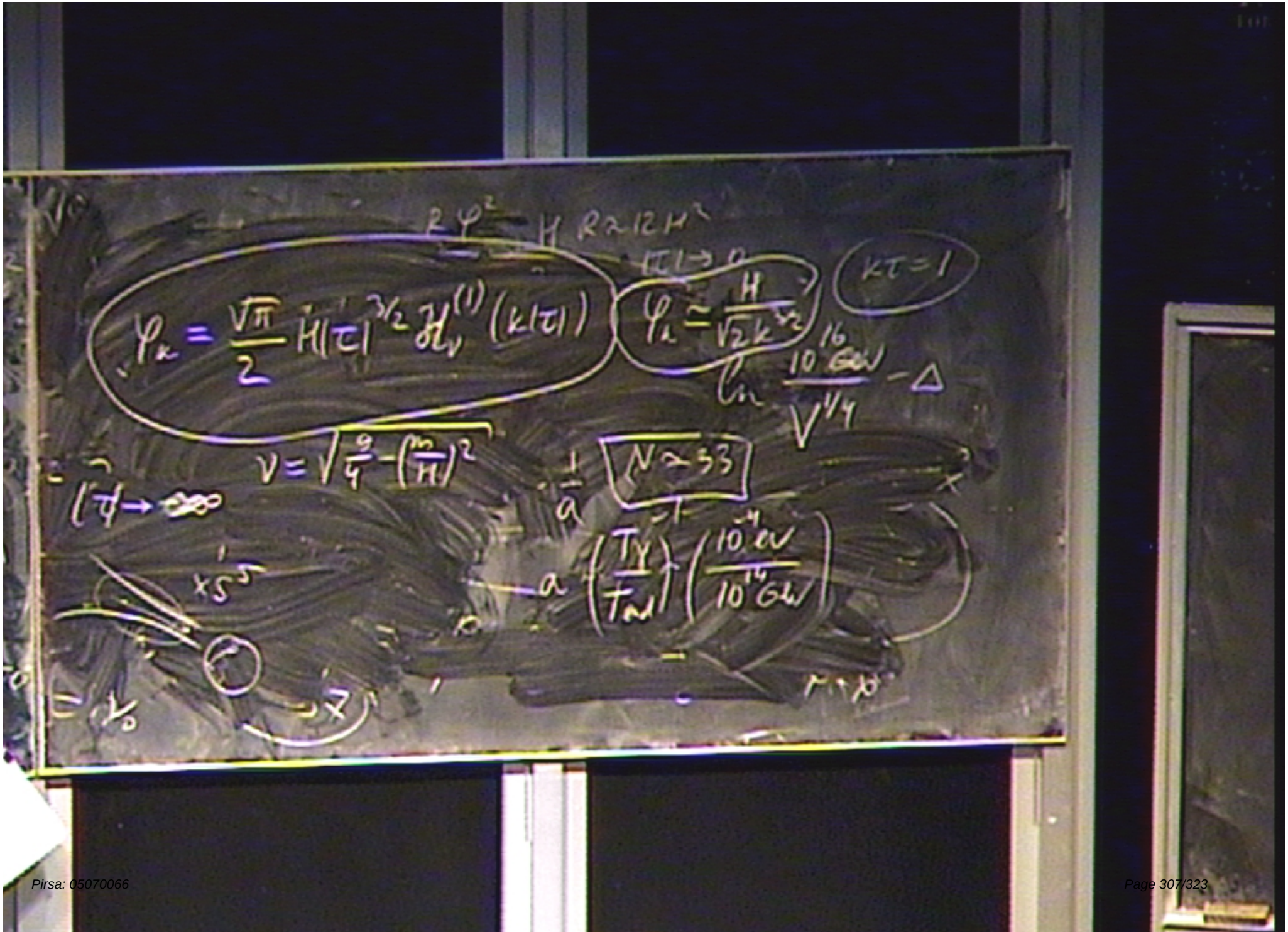

$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$
$k\tau = 1$
$\frac{10^{16}\,GeV}{V^{1/4}}$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$a \left(\frac{T_N}{T_{eq}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

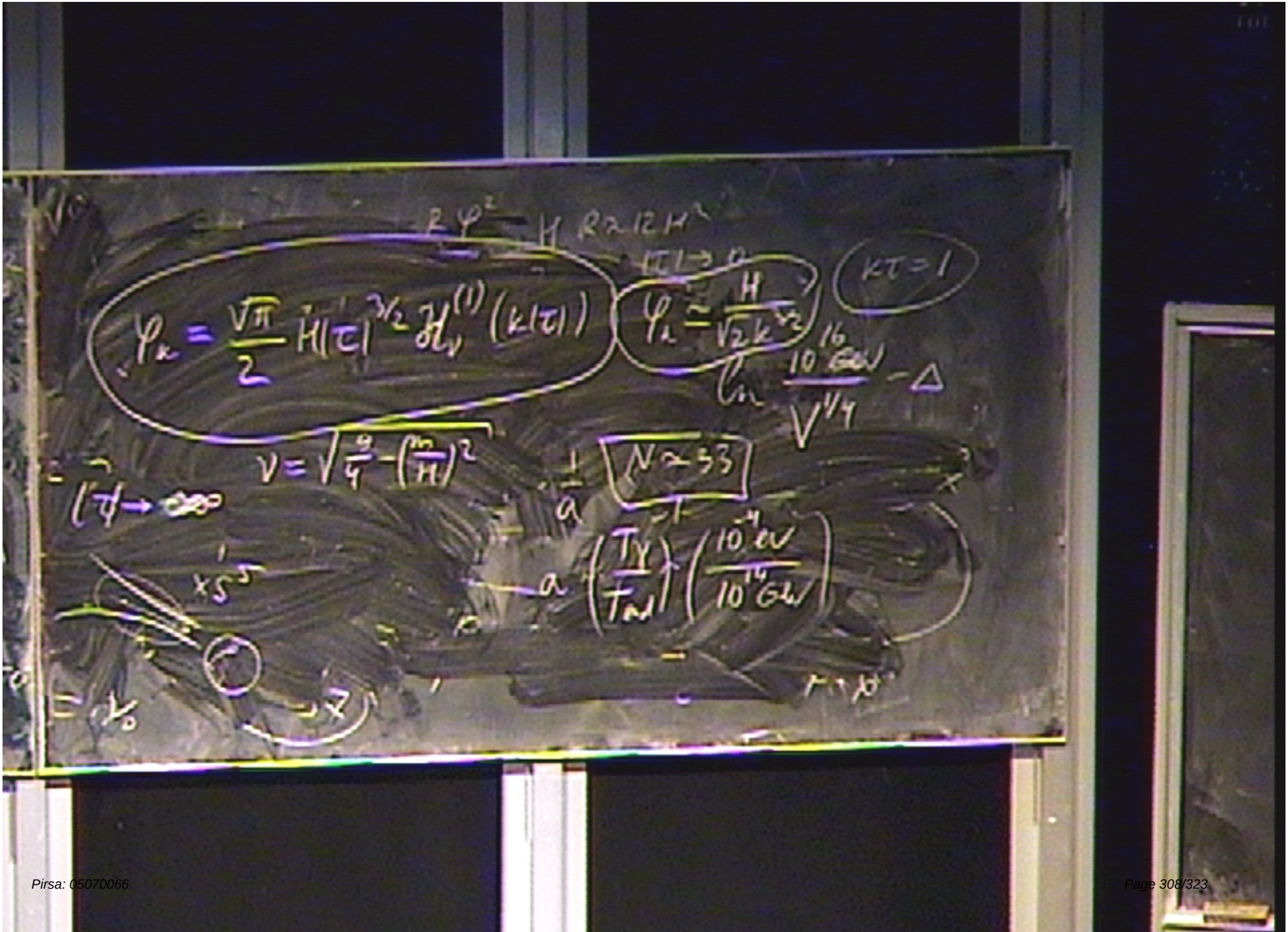

$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k\tau)$
$\varphi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$
$k\tau = 1$
$\frac{10^{16}\,GeV}{V^{1/4}}$
$V = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$\frac{1}{a}$
$a \left(\frac{T_N}{T_{eq}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$


$\varphi_k = \frac{\sqrt{\pi}}{2} H|\tau|^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$
$k\tau = 1$
$R = 12H^2$
$|\tau| \to 0$
$\frac{10^{16}\,GeV}{V^{1/4}}$
Δ
$V = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$\frac{1}{a}$
$a\left(\frac{T_\gamma}{T_{\nu 0}}\right)\left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$|\tau| \to \infty$
$\times 5^5$
$\times 2$

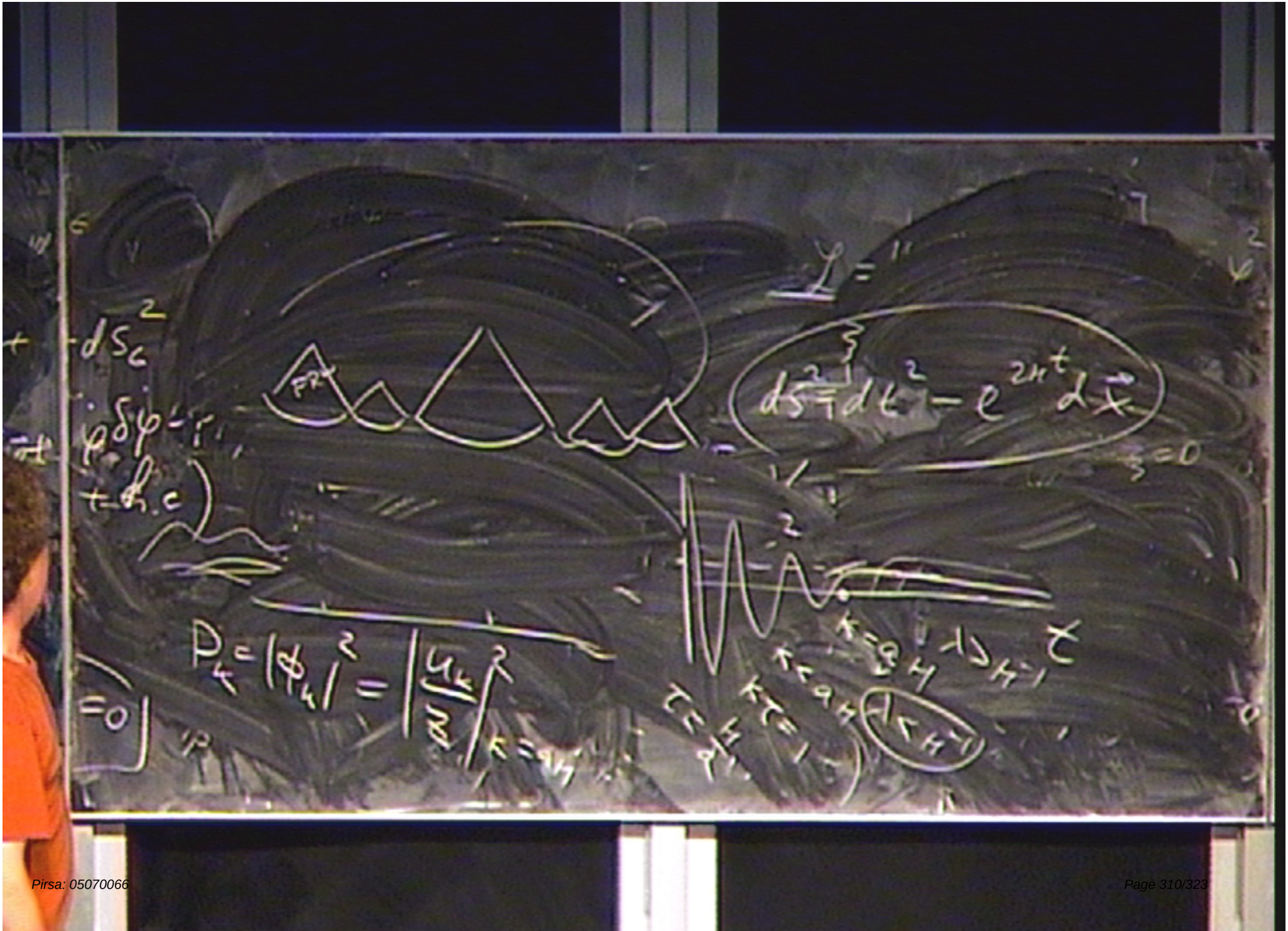

$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$
$k\tau = 1$
$\frac{10^{16}\,GeV}{V^{1/4}}$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$a \left(\frac{T_\gamma}{T_{\nu 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

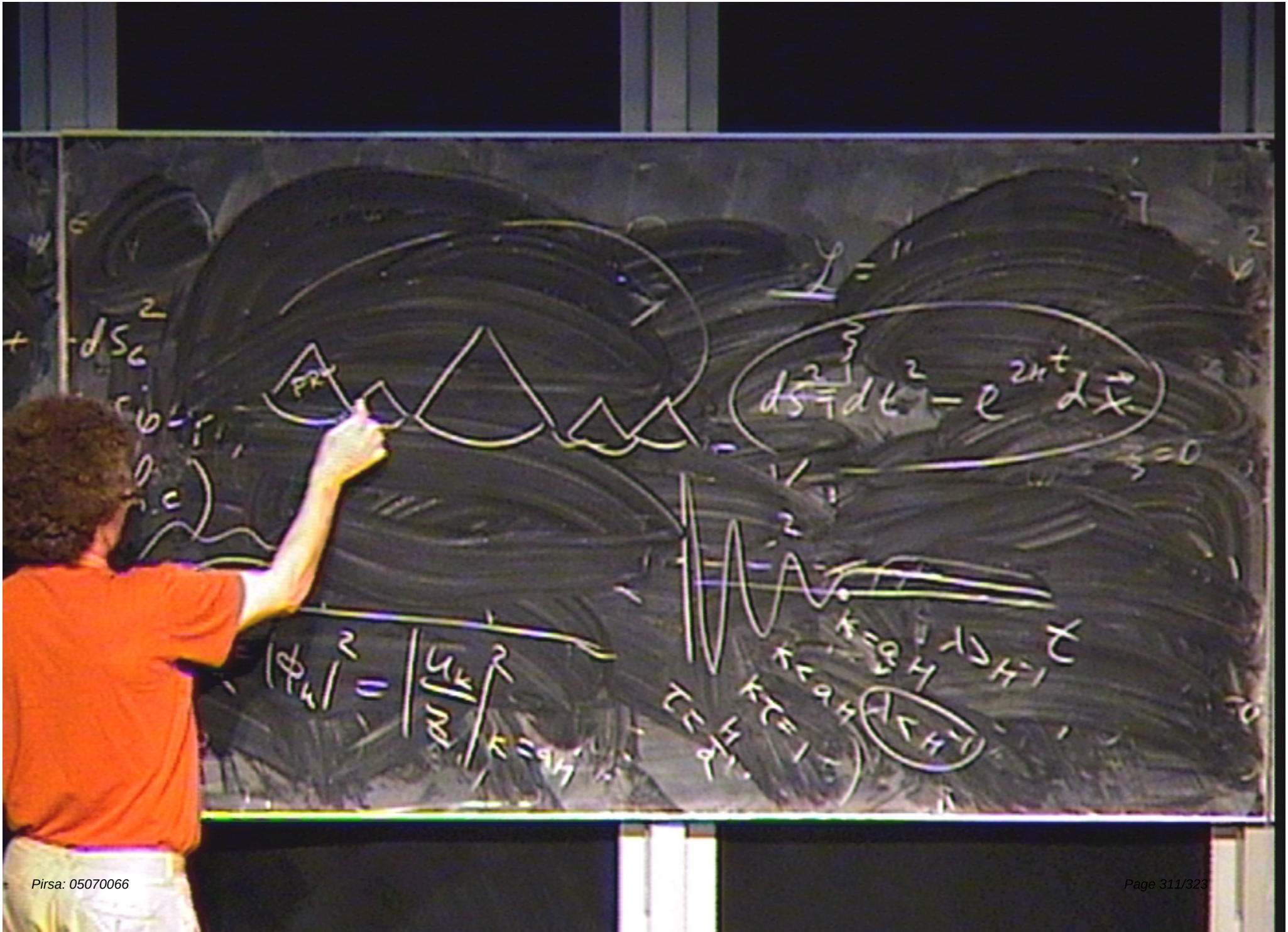

φ^2
$R = 12H^2$
$|\tau| \to 0$
$k\tau = 1$
$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k|\tau|)$
$\varphi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$
$\frac{10^{16}\,GeV}{V^{1/4}}$
Δ
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \simeq 53$
$\frac{1}{a}$
$a \left(\frac{T_\gamma}{T_{\nu 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$
$\tau \to -\infty$
$\times 5^5$

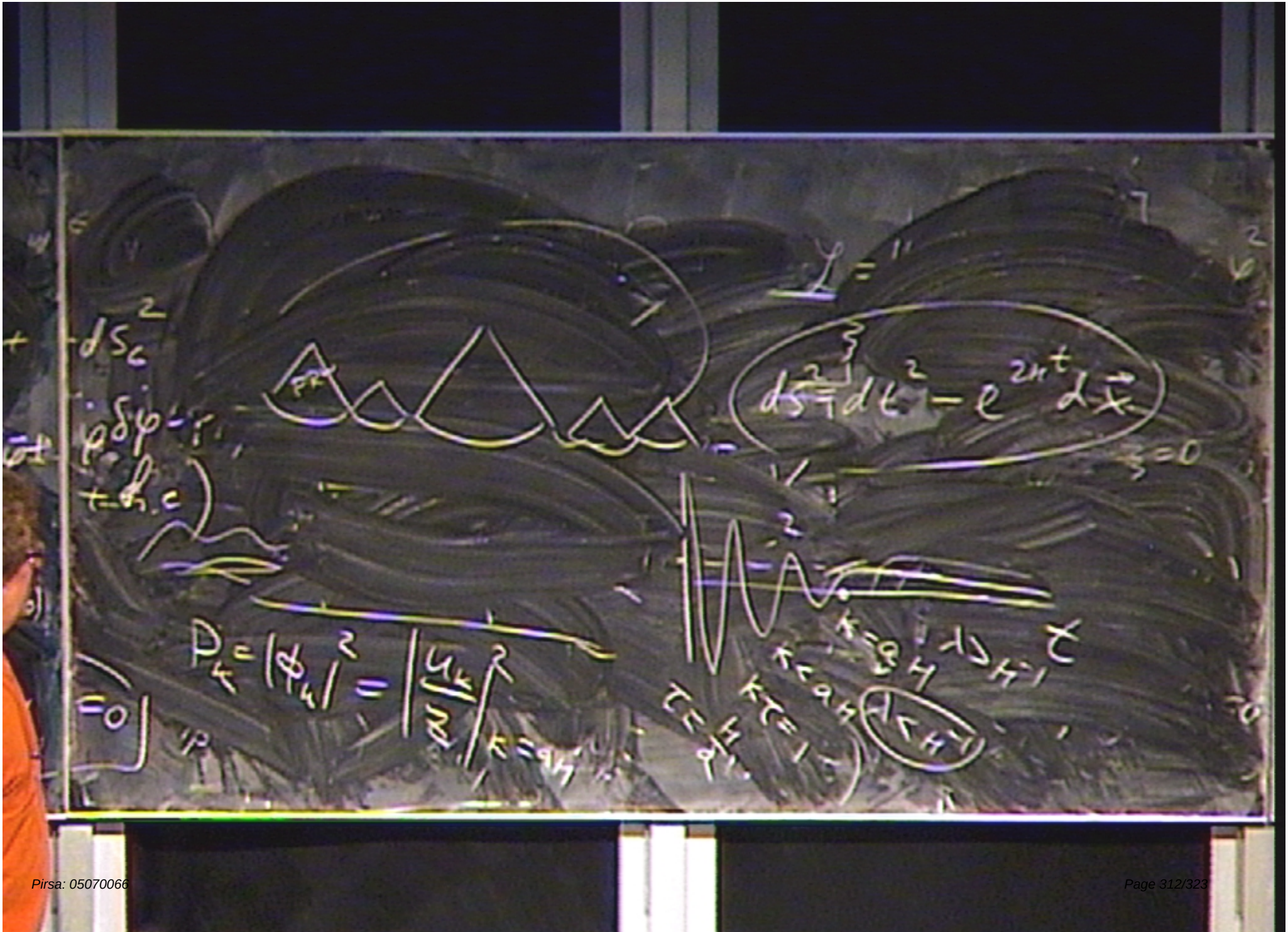

$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k\tau)$
$\varphi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$
$k\tau = 1$
$R\varphi^2$
$R \sim 12H^2$
$\frac{10^{16}\,GeV}{V^{1/4}}$
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$N \sim 53$
$a \left(\frac{T_N}{T_{eq}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

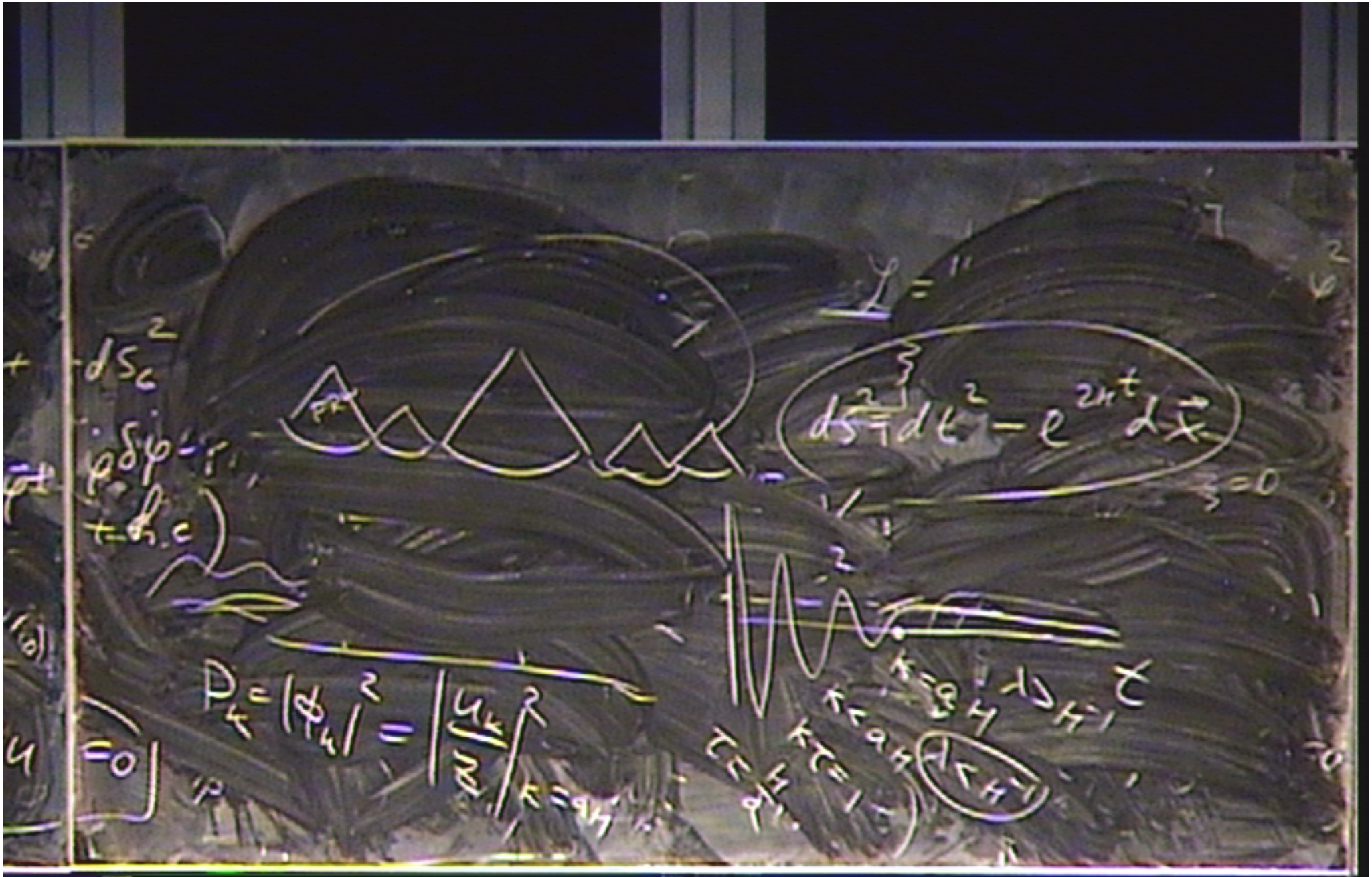

$\varphi_k = \frac{\sqrt{\pi}}{2} H(\tau)^{3/2} H_\nu^{(1)}(k\tau)$
$\varphi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$
$k\tau = 1$
$R\varphi^2$
H
$R \simeq 12H^2$
$\tau \to 0$
$\frac{10^{16}\,GeV}{V^{1/4}}$
Δ
$\nu = \sqrt{\frac{9}{4} - \left(\frac{m}{H}\right)^2}$
$\frac{1}{a}$
$N \simeq 53$
$\tau \to \infty$
$a \left(\frac{T_\gamma}{T_{\gamma 0}}\right) \left(\frac{10^{-4}\,eV}{10^{14}\,GeV}\right)$

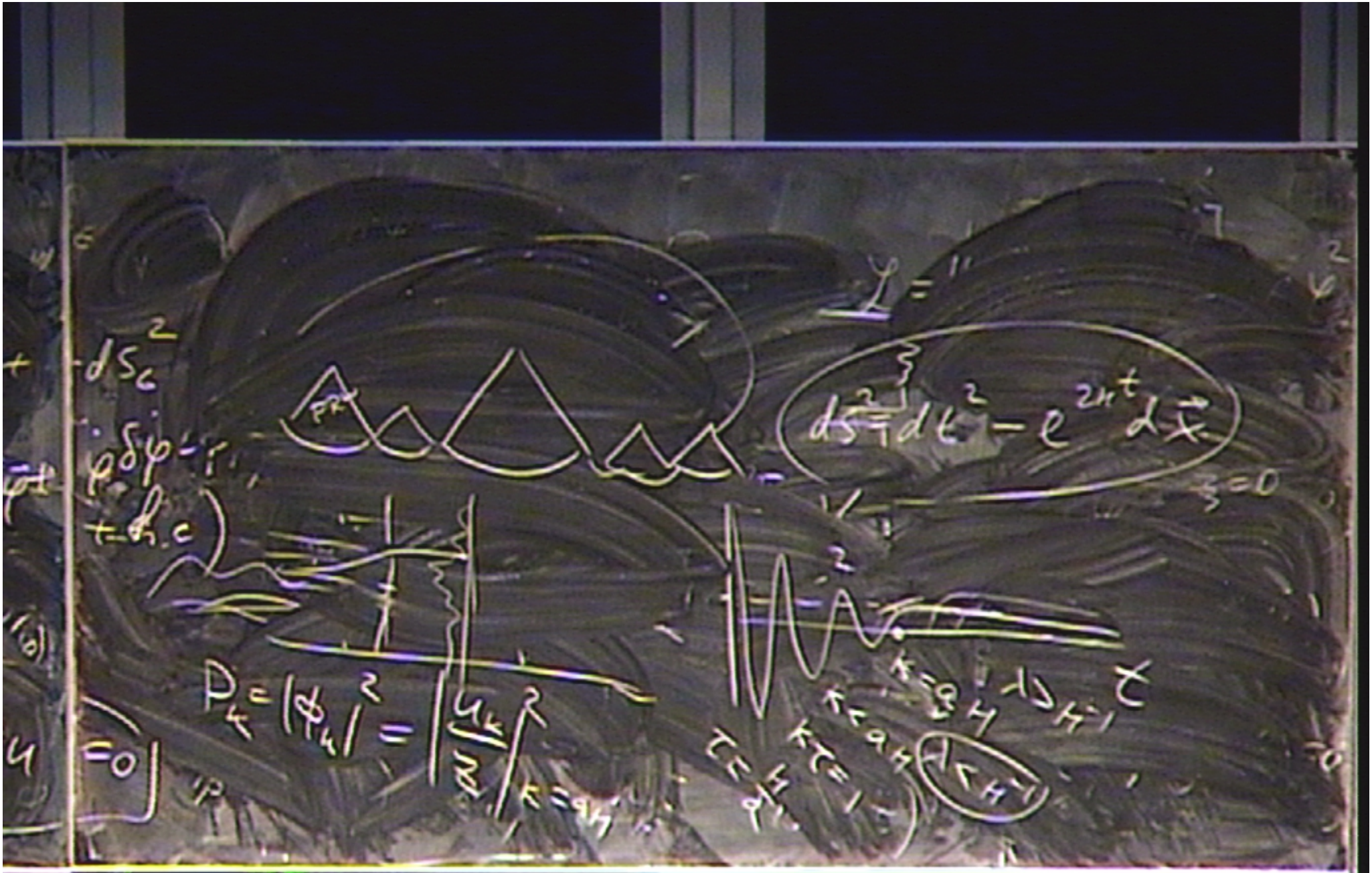

ds_c^2
$\rho\delta\varphi$
$\pm\hbar c$
$ds^2 = dt^2 - e^{2ht} d\vec{x}$
$P_k = |\psi_k|^2 = \left|\frac{\psi_k}{\sqrt{2}}\right|^2$
$k = q_k$
$\tau = \frac{1}{q_k}$

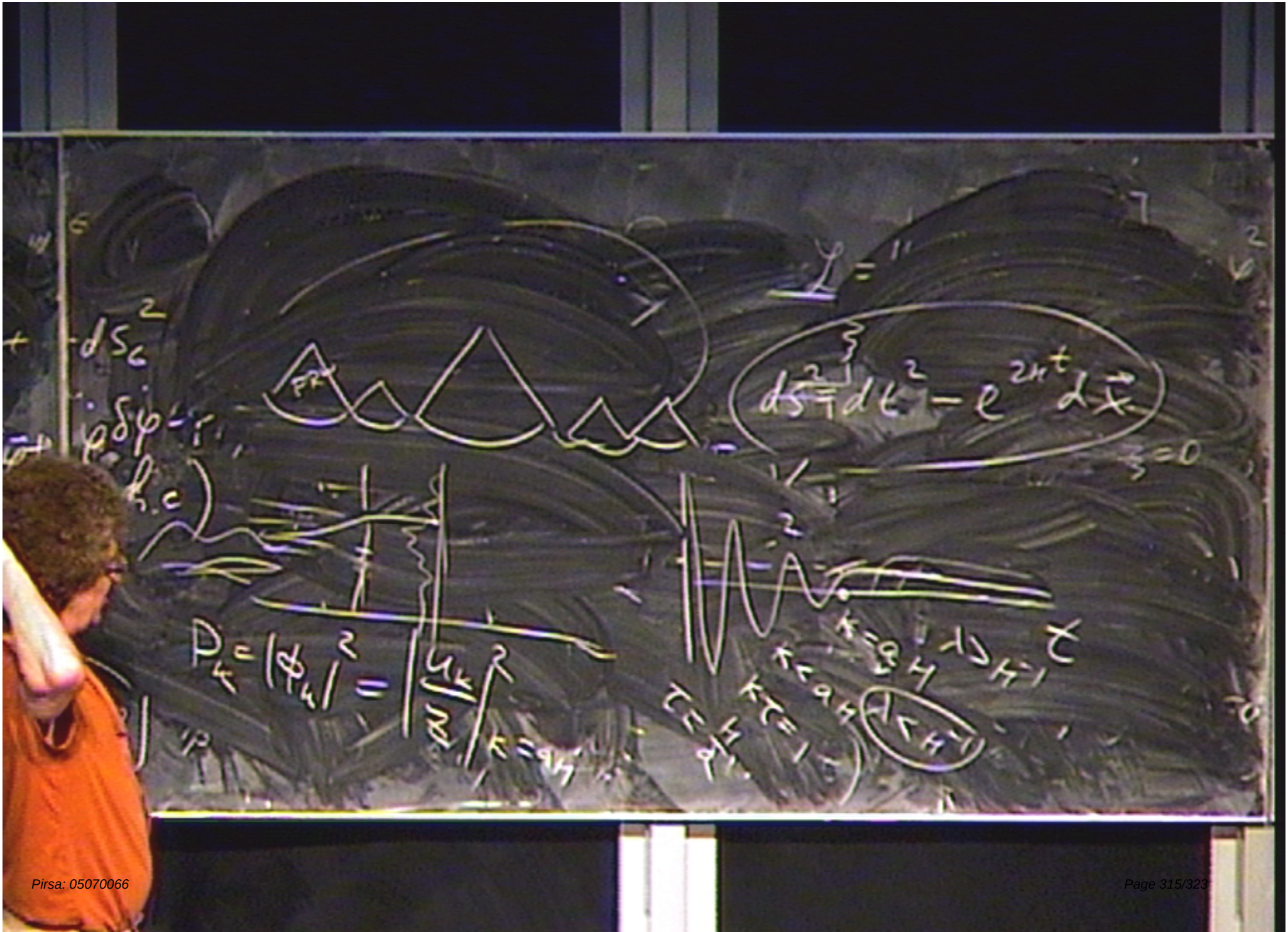

ds_c^2
$\rho\delta\varphi + h.c$
$P_k = |\alpha_k|^2 = \left|\frac{\psi_k}{\sqrt{2k}}\right|^2_{k=aH}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$k = aH$
$k\tau = 1$

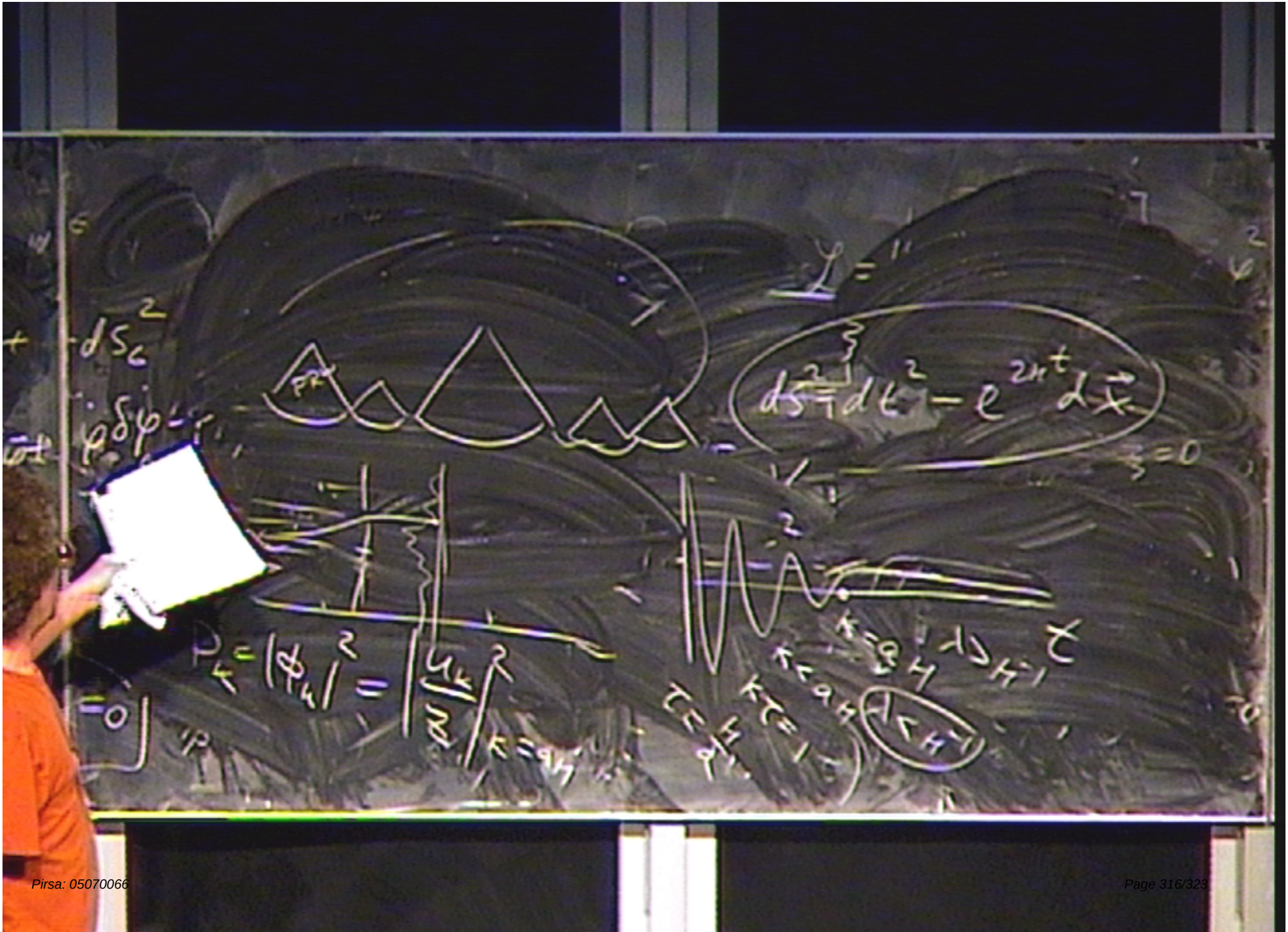

ds_c^2
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$|\Phi_k|^2 = \left|\frac{\mu_k}{\sqrt{2k}}\right|^2_{k=aH}$

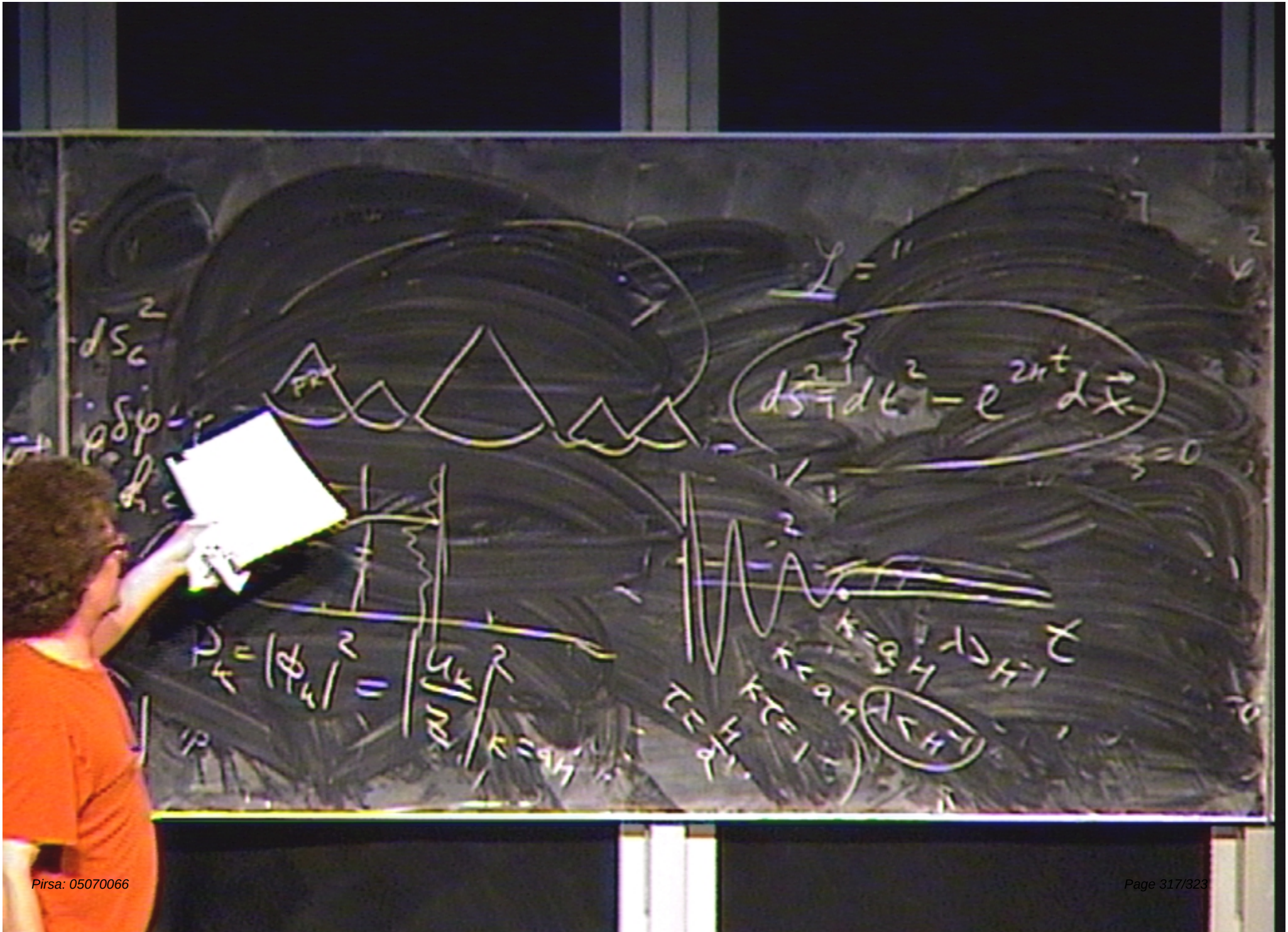

ds_c^2
$\rho\delta\varphi$
$P_k = |\psi_k|^2 = \left|\frac{\psi_k}{\sqrt{2}}\right|^2_{k=q_H}$
$ds^2 = dt^2 - e^{2H_1 t} d\vec{x}$
$k = q_H$
τ


ds_c^2
$\rho\delta\varphi$
$P_k = |\psi_k|^2 = \left|\frac{u_k}{\sqrt{2}}\right|^2_{k=q_k}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$

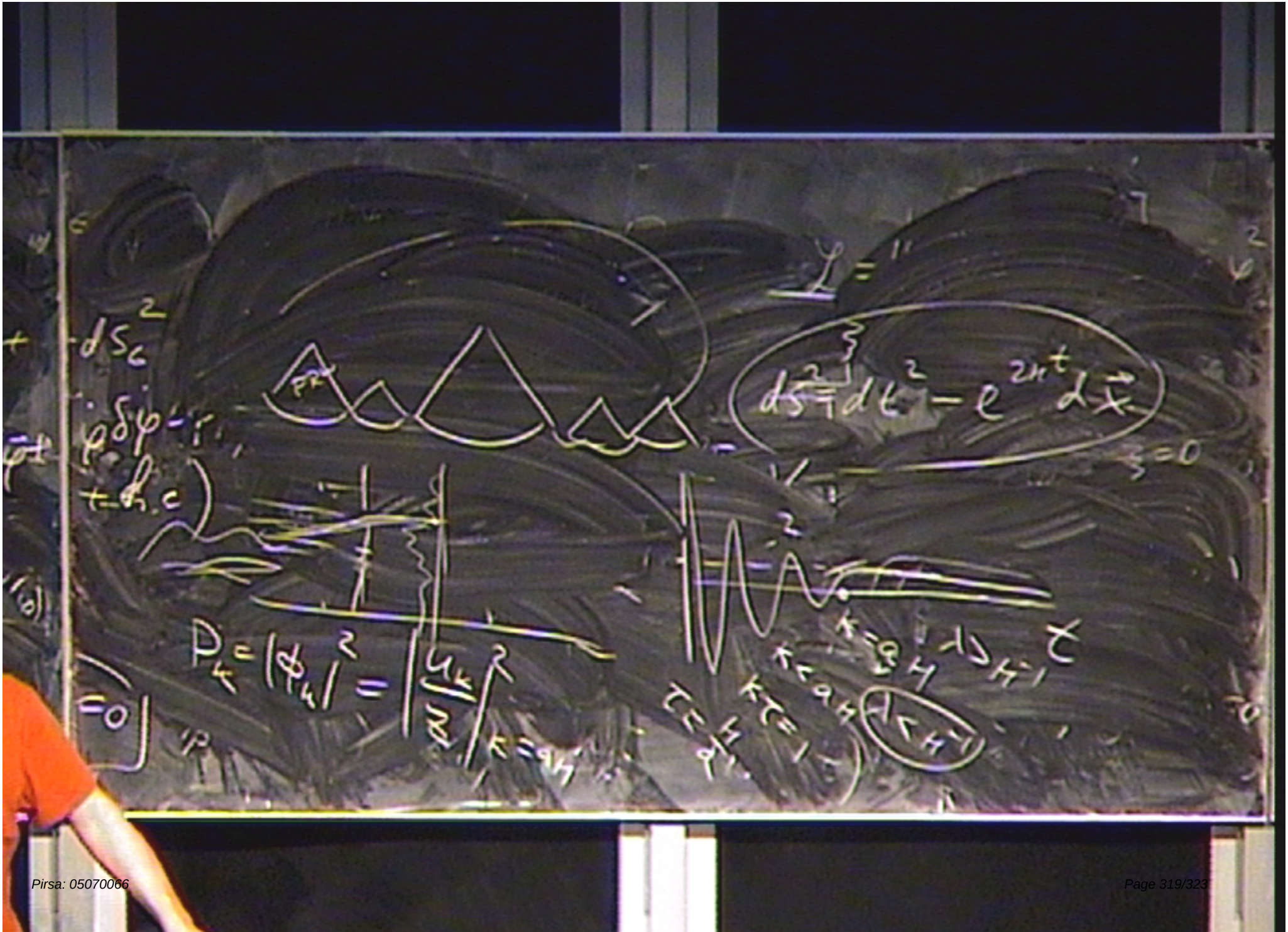

ds_c^2
$\delta\varphi$
$P_k = |\psi_k|^2 = \left|\frac{\psi_k}{\sqrt{2}}\right|^2_{k=q_4}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\zeta = 0$

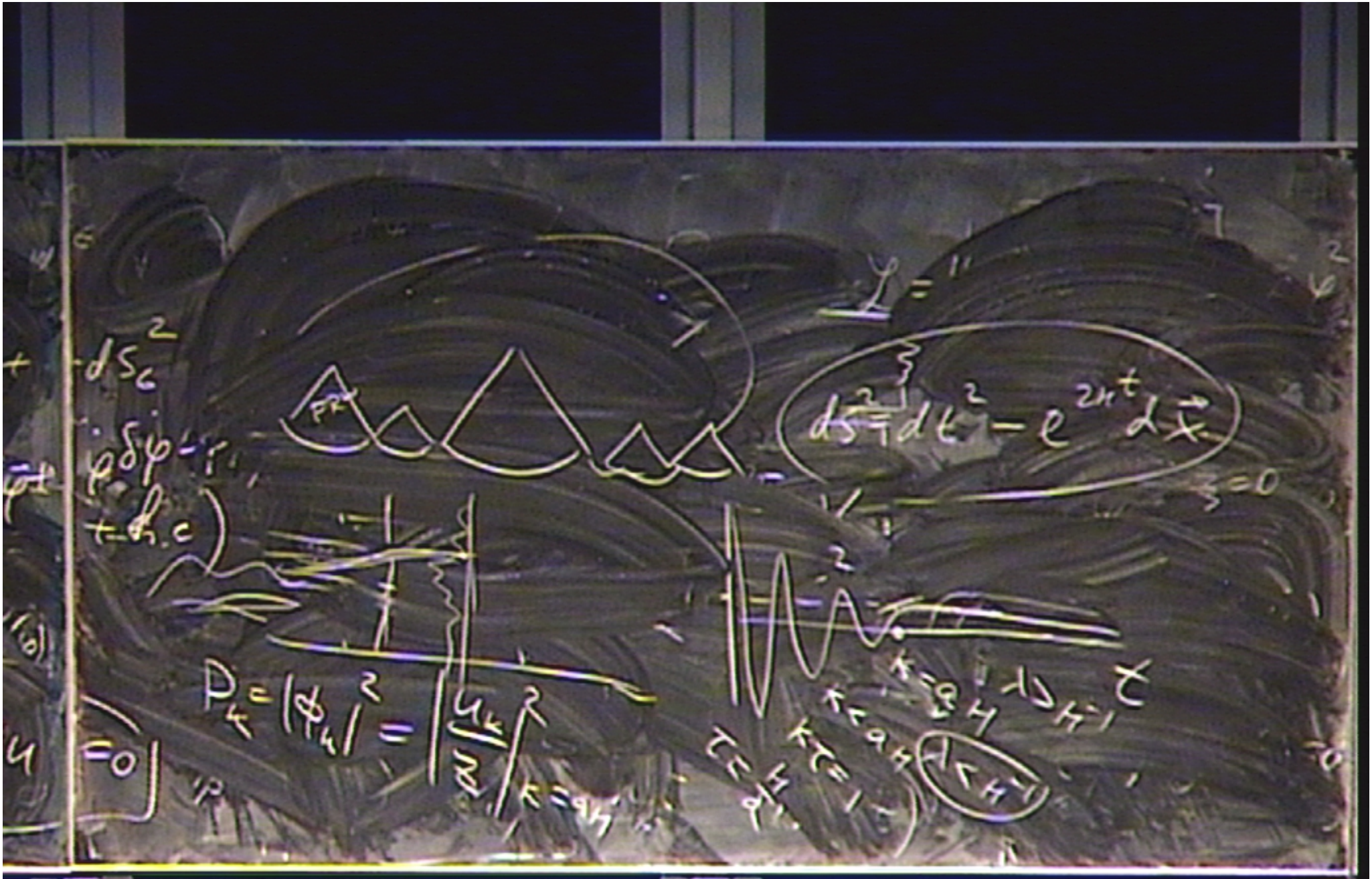

ds_c^2
$\delta\varphi$
$P_k = |\psi_k|^2 = \left|\frac{\psi_k}{\sqrt{2}}\right|^2$
$k = q_4$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$t = 0$
$k = q_4$
$k < q_4$
$k < H$

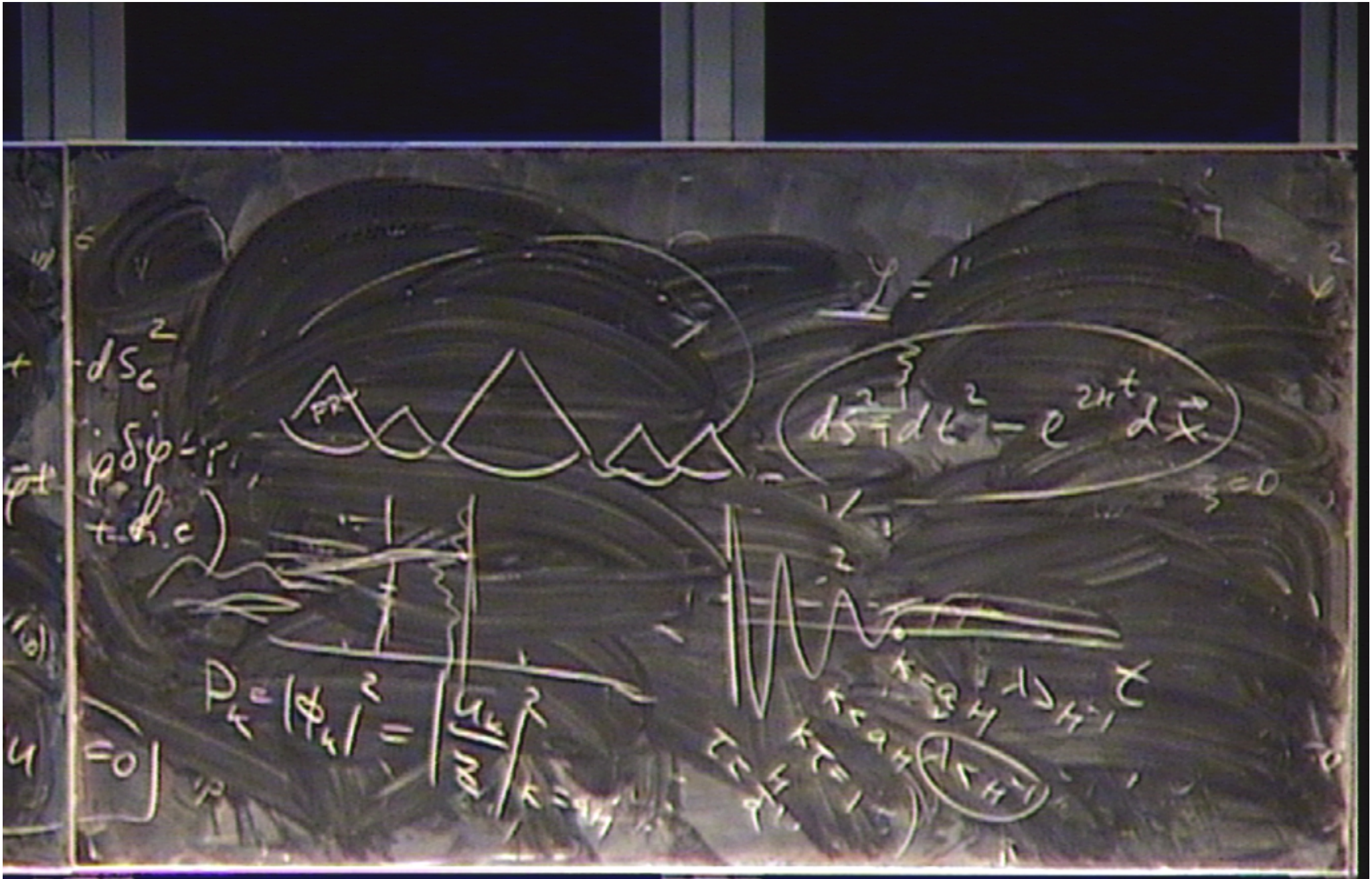

$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$P_k = |\Phi_k|^2 = \left|\frac{\mu_k}{\sqrt{2k}}\right|^2_{k=aH}$

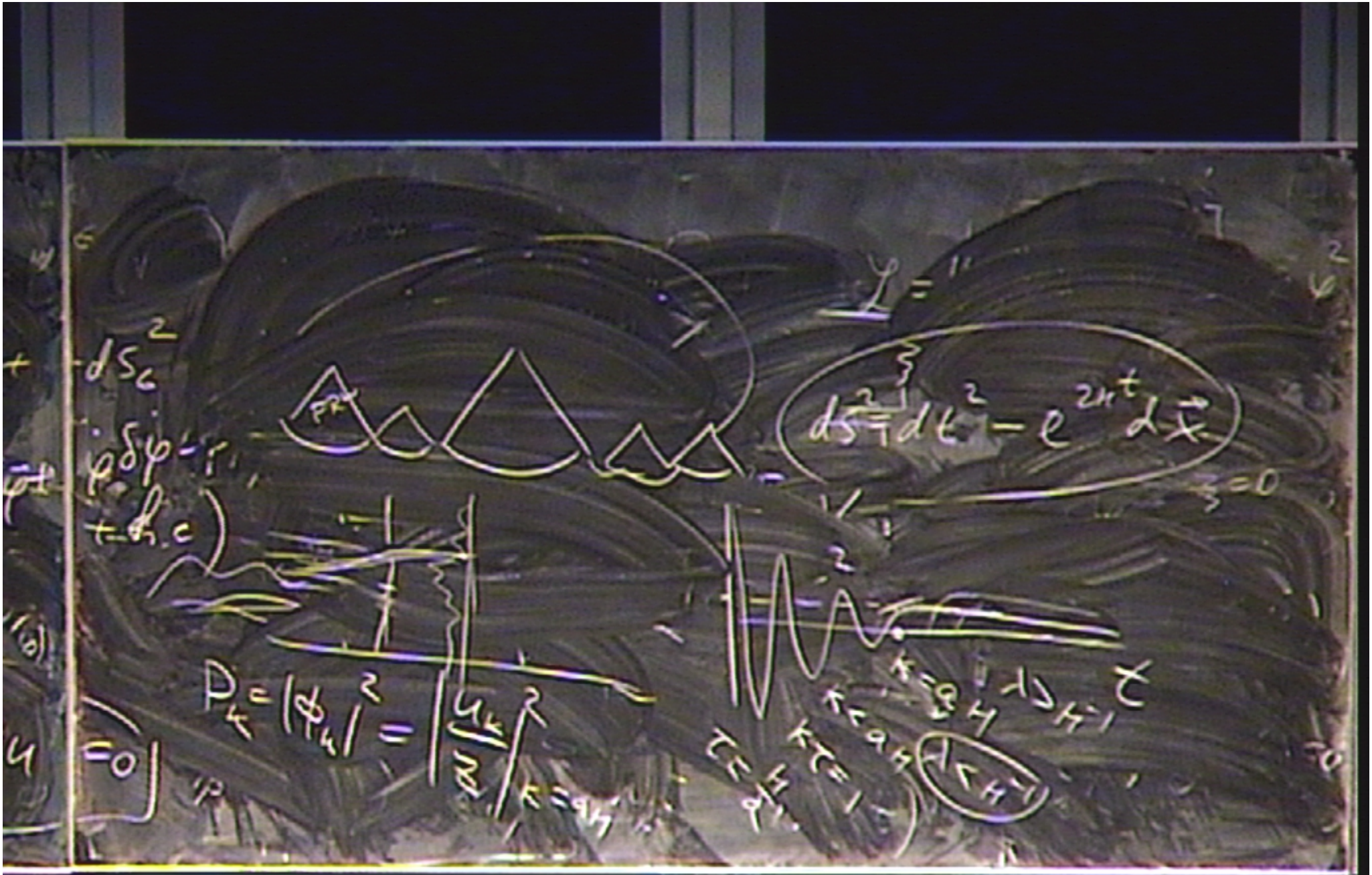

ds_c^2
$\delta\varphi$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$P_k = |\psi_k|^2 = \left|\frac{\psi_k}{\sqrt{2}}\right|^2$
$k = q_H$
$k < q_H$
$k < H$

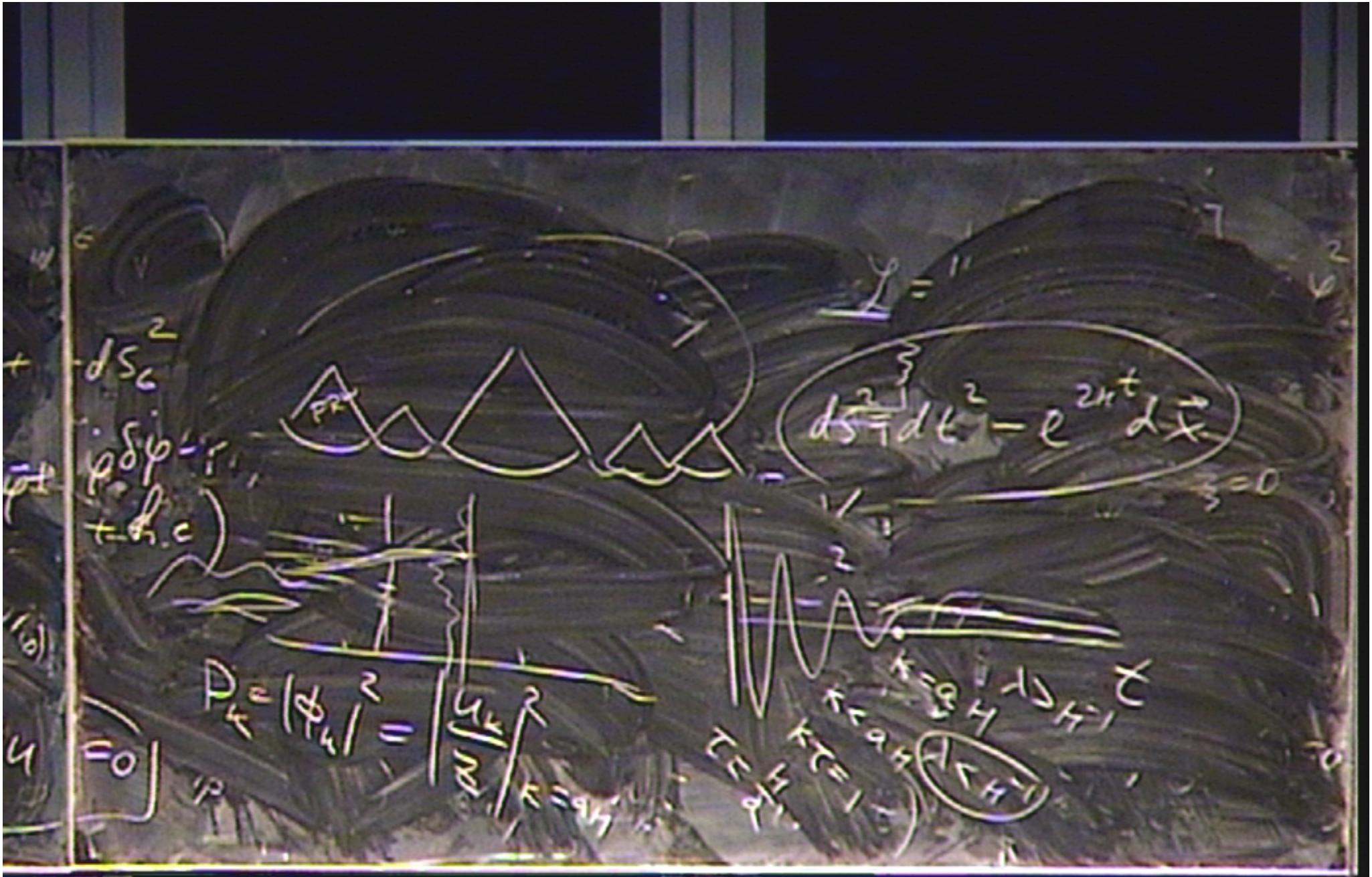

ds_c^2
$\delta\varphi$
$+h.c$
$d\vec{x}$
$P_t = |\psi_t|^2 = \left|\frac{\psi_t}{\sqrt{2}}\right|^2$
$t=0$


$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$P_k = |\phi_k|^2 = \left|\frac{u_k}{a}\right|^2_{k=aH}$
$k = aH$
$k \tau = 1$
$k \ll aH$
$\tau \ll \frac{1}{H}$


$ds^2 = dt^2 - e^{2Ht} d\vec{x}^2$
$\delta\phi$
$P_k = |\phi_k|^2 = \left|\frac{u_k}{\sqrt{2k}}\right|^2$
$k = aH$
$k\tau = 1$
$\tau = \frac{1}{aH}$


ds_c^2
$\delta\varphi$
$+h.c$
$P_k = |\phi_k|^2 = \left|\frac{\psi_k}{\sqrt{N}}\right|^2$
$k=k_4$
$k=0$
$k=k_4 - k_3 - k_2 - k_1$
$k=k_4 - k_3 - k_2$
$k=k_4 - k_3$
$k=k_4$
$k=0$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$t=0$


ds_c^2
$\rho\delta\varphi$
$\pm\hbar c$
$P_k = |\psi_k|^2 = \left|\frac{\psi_k}{N}\right|^2$
$k = q_4$
$k\tau = 1$
$\tau < H^{-1}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$\mathcal{L} =$
τ


ds_c^2
$\rho\delta\varphi$
$\pm\hbar c$
$P_k = |\psi_k|^2 = \left|\frac{\psi_k}{\sqrt{2}}\right|^2_{k=q_H}$
$ds^2 = dt^2 - e^{2Ht} d\vec{x}$
$k = q_H$
$k < q_H$
$k > q_H$
$\tau < H^{-1}$
$\tau \sim \frac{1}{H}$