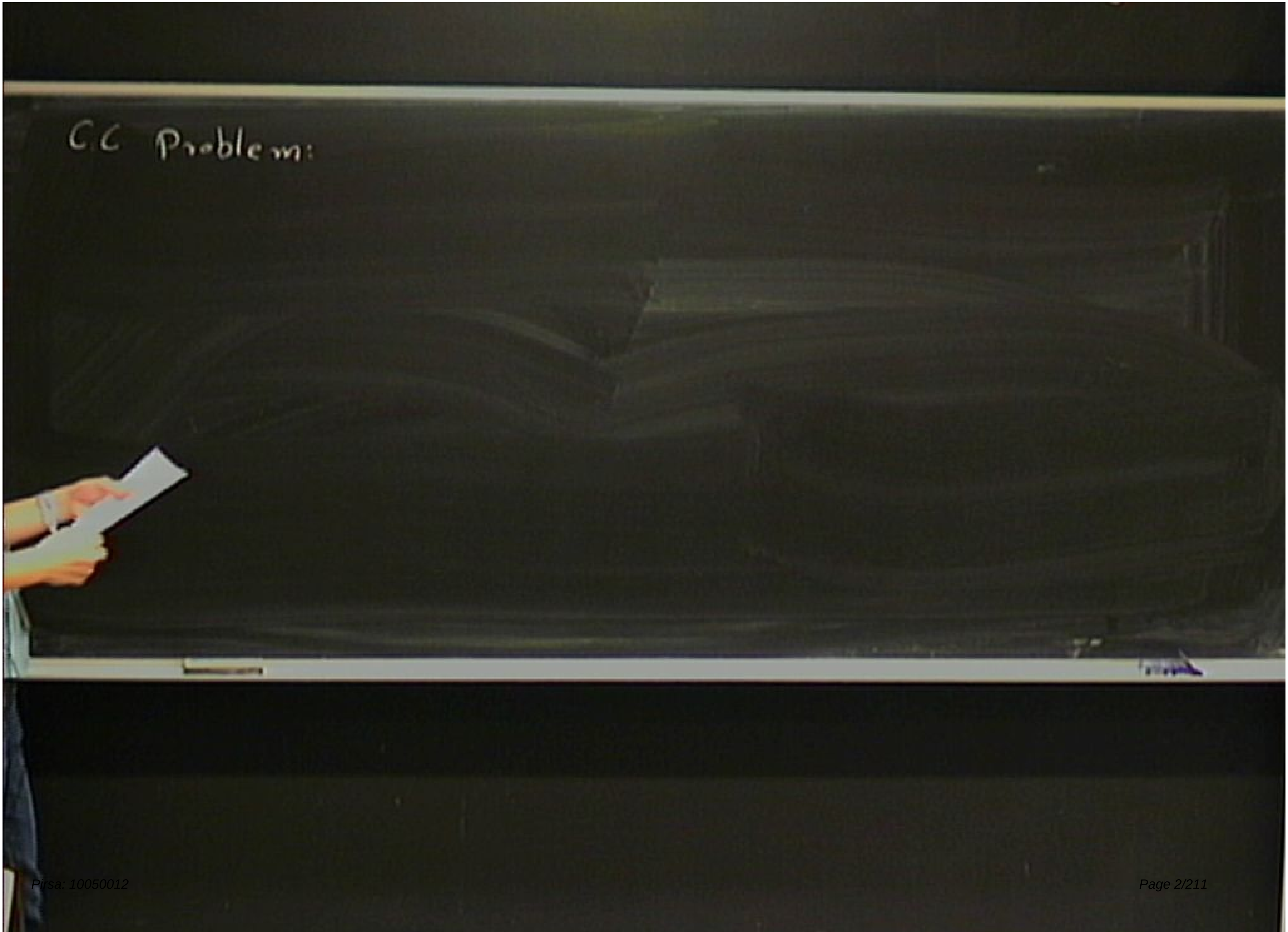
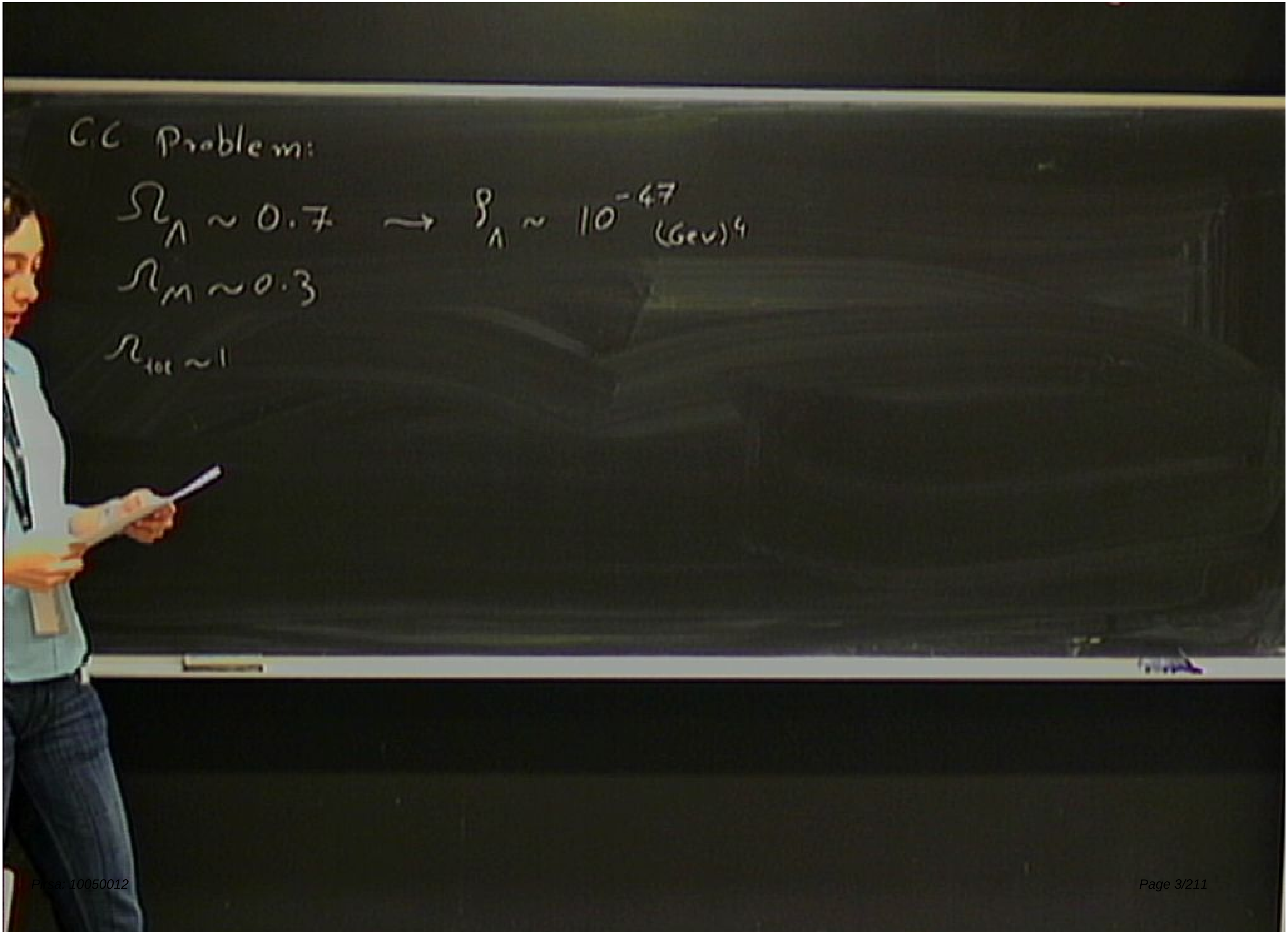
Title: Review on Proposed Models for Dark Energy 2

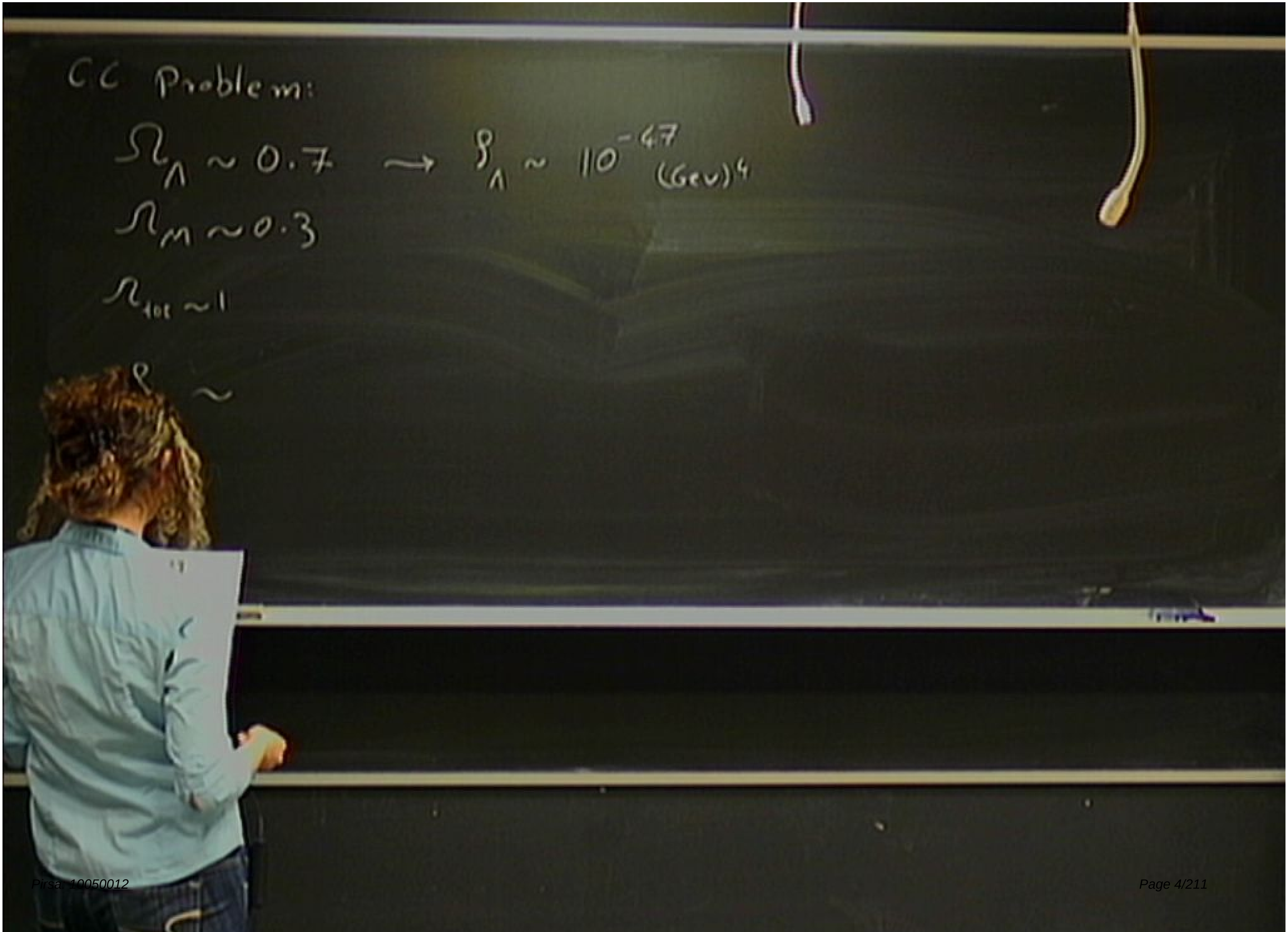
Date: May 11, 2010 10:00 AM

URL: http://pirsa.org/10050012

Abstract:


CC Problem:


CC Problem:
$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47}\,(\text{GeV})^4$
$\Omega_m \sim 0.3$
$\Omega_{tot} \sim 1$


CC Problem:
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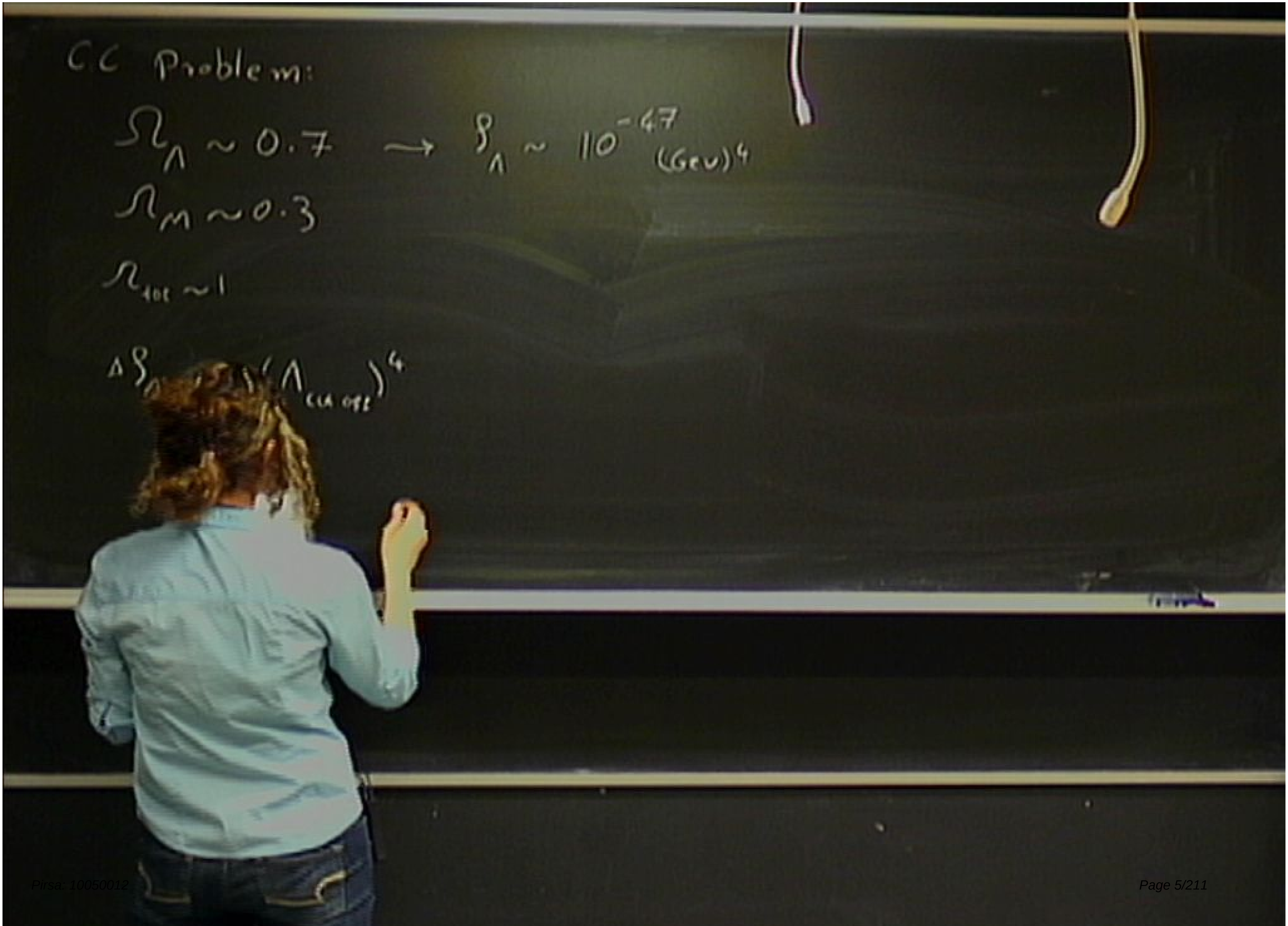
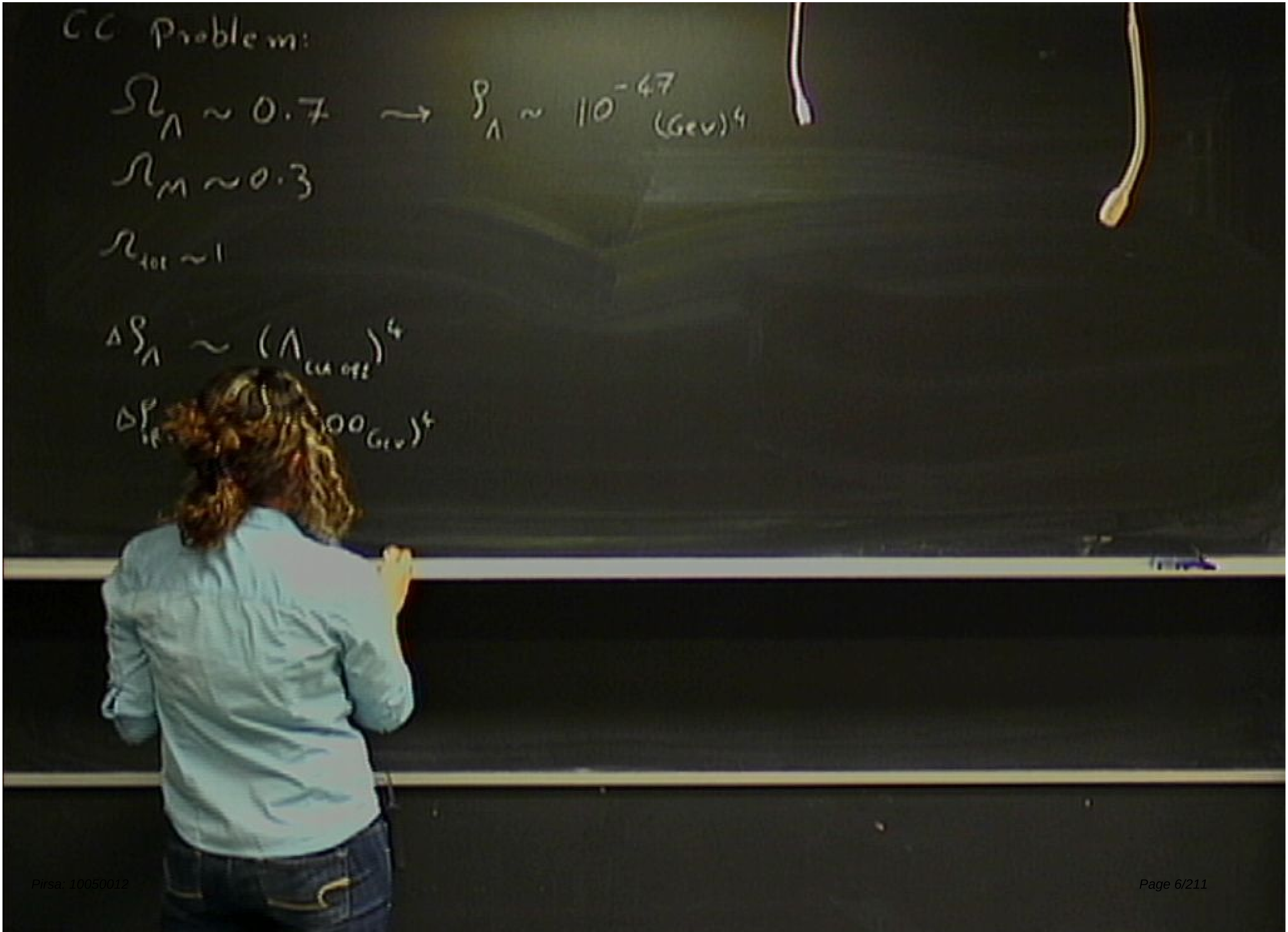
$\Omega_m \sim 0.3$
$\Omega_{tot} \sim 1$
$\rho \sim$


CC Problem:
$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47} (\mathrm{GeV})^4$
$\Omega_M \sim 0.3$
$\Omega_{tot} \sim 1$
$\Delta\rho_\Lambda$ $(\Lambda_{cutoff})^4$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$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$
$\Omega_M \sim 0.3$
$\Omega_{tot} \sim 1$
$\Delta\rho_\Lambda \sim (\Lambda_{cutoff})^4$

CC Problem:

$$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47} (\text{GeV})^4$$

$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim 1$$

$$\Delta\rho_\Lambda \sim (\Lambda_{cut\,off})^4$$

$$\Delta\rho_{(EW)} \sim (300\,\text{GeV})^4 \sim 10^9 (\text{GeV})^4$$

$$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47}\,(\mathrm{GeV})^4$$

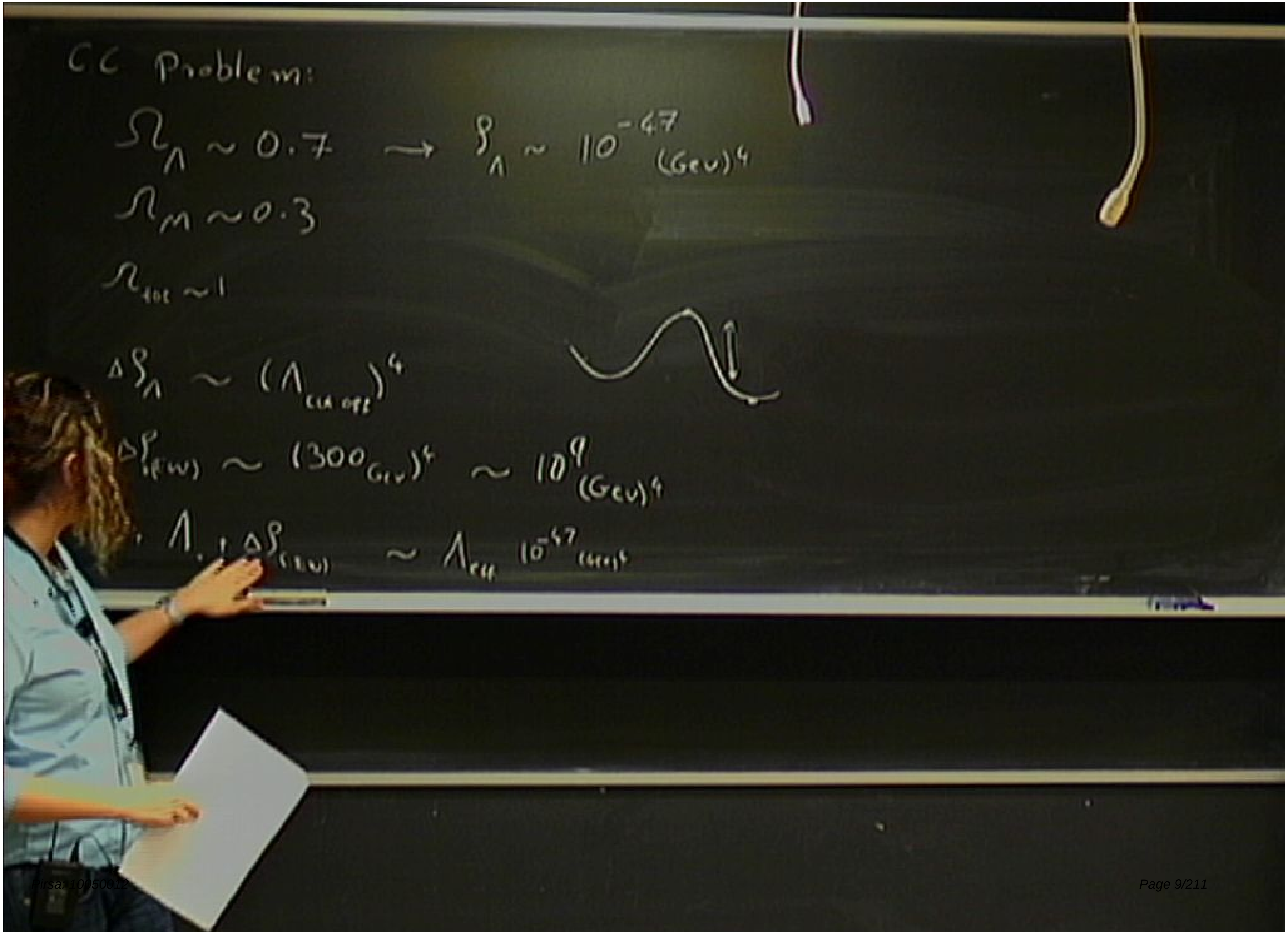
$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim 1$$

$$\Delta\rho_\Lambda \sim (\Lambda_{cut\,off})^4$$

$$\Delta\rho_{(EW)} \sim (300_{\mathrm{GeV}})^4 \sim 10^9\,(\mathrm{GeV})^4$$

$$\Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff}\ 10^{-47}\,(\mathrm{GeV})^4$$


CC Problem:
$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47} (\mathrm{GeV})^4$
$\Omega_M \sim 0.3$
$\Omega_{tot} \sim 1$
$\Delta\rho_\Lambda \sim (\Lambda_{cutoff})^4$
$\Delta\rho_{(EW)} \sim (300\,\mathrm{GeV})^4 \sim 10^9 (\mathrm{GeV})^4$
$\Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff}\ 10^{-47} (\mathrm{GeV})^4$

$$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47}\,(\mathrm{GeV})^4$$

$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim 1$$

$$\Delta\rho_\Lambda \sim (\Lambda_{cutoff})^4$$

$$\Delta\rho_{(EW)} \sim (300\,\mathrm{GeV})^4 \sim 10^{9}\,(\mathrm{GeV})^4$$

$$\Delta\rho + \Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff}\ 10^{-47}\,(\mathrm{GeV})^4$$

$$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47}\,(\mathrm{GeV})^4$$

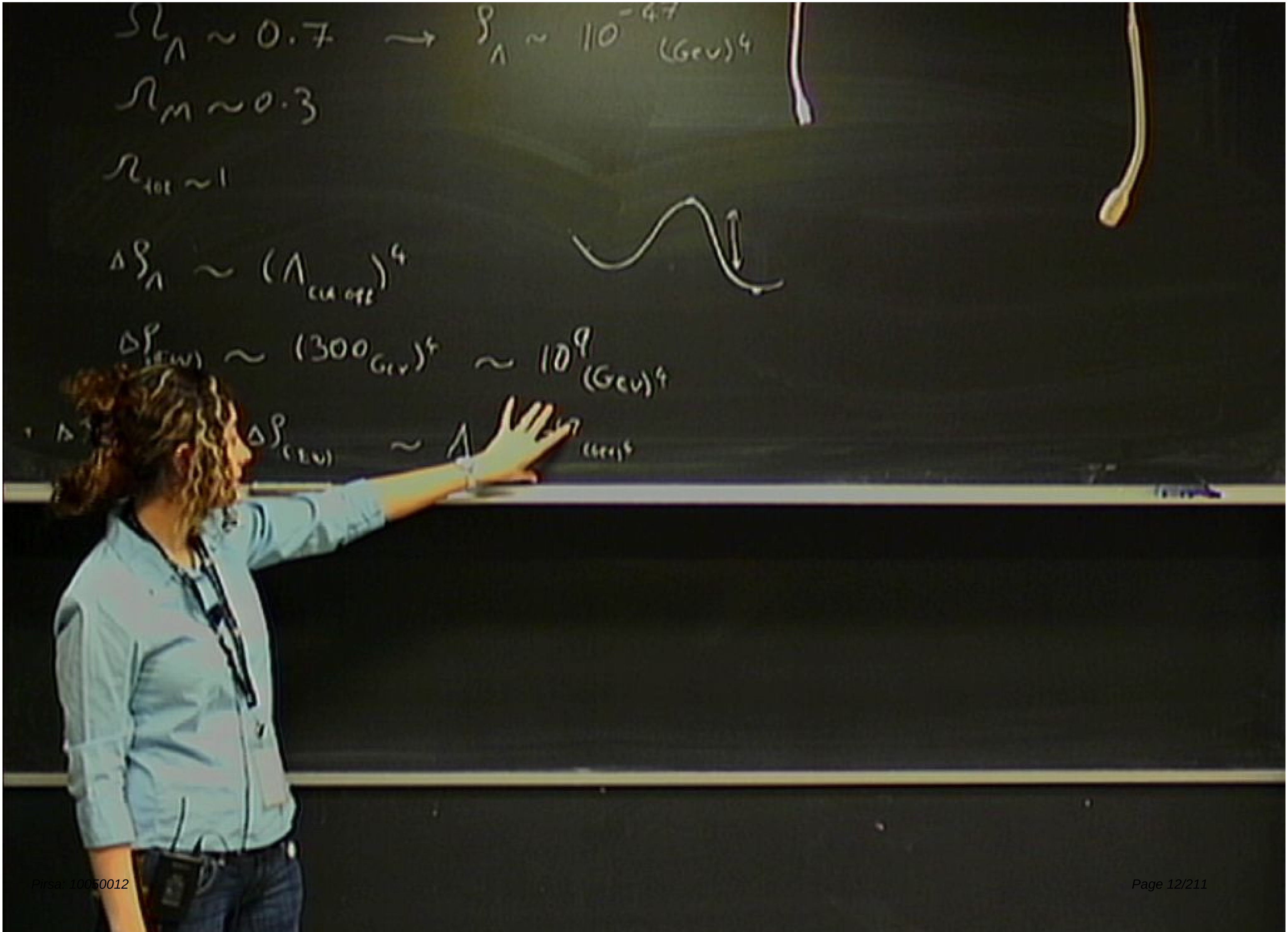
$$\Omega_M \sim 0.3$$

$$\Omega_{tot} \sim 1$$

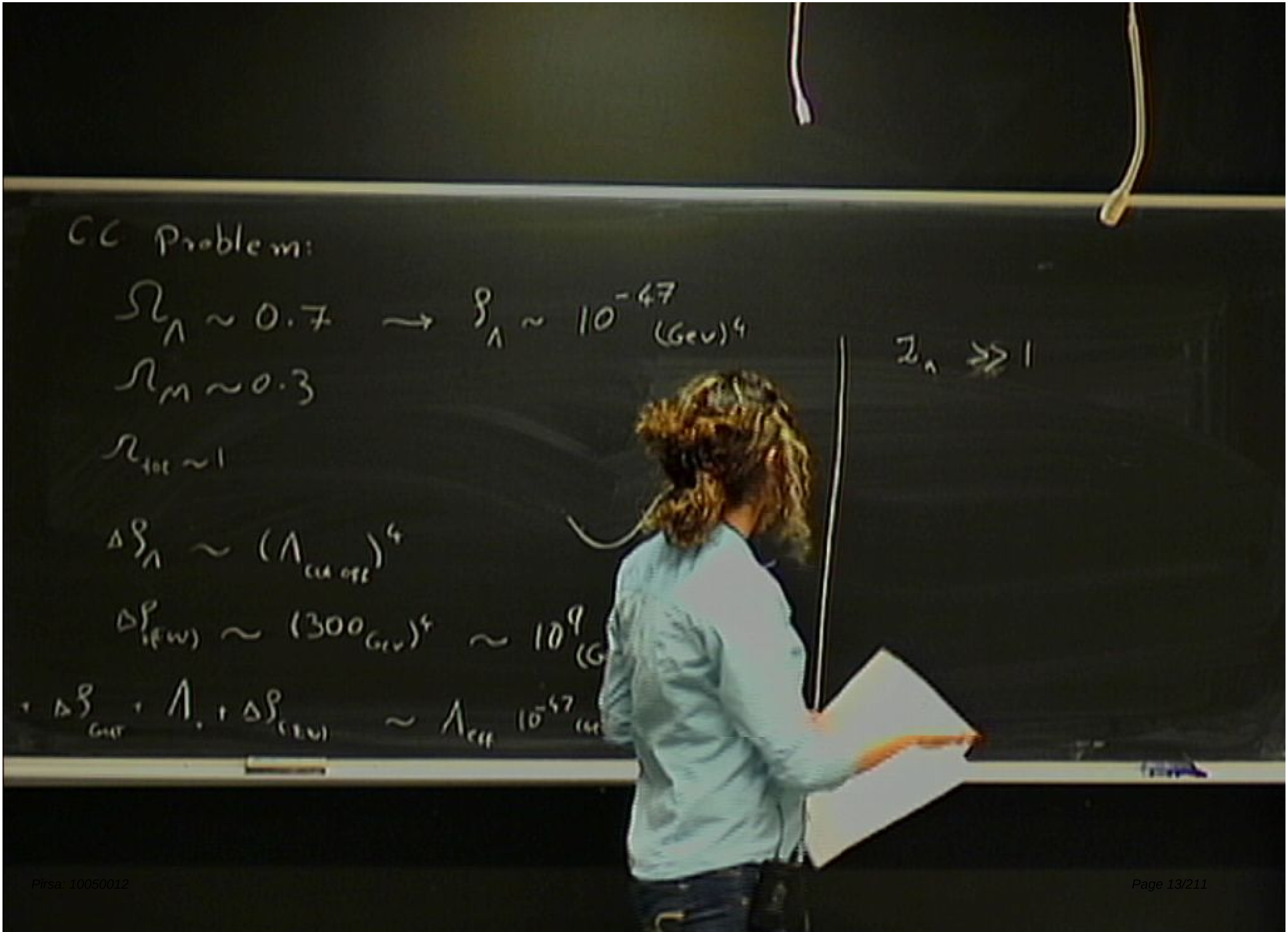
$$\Delta\rho_\Lambda \sim (\Lambda_{\mathrm{cut\,off}})^4$$

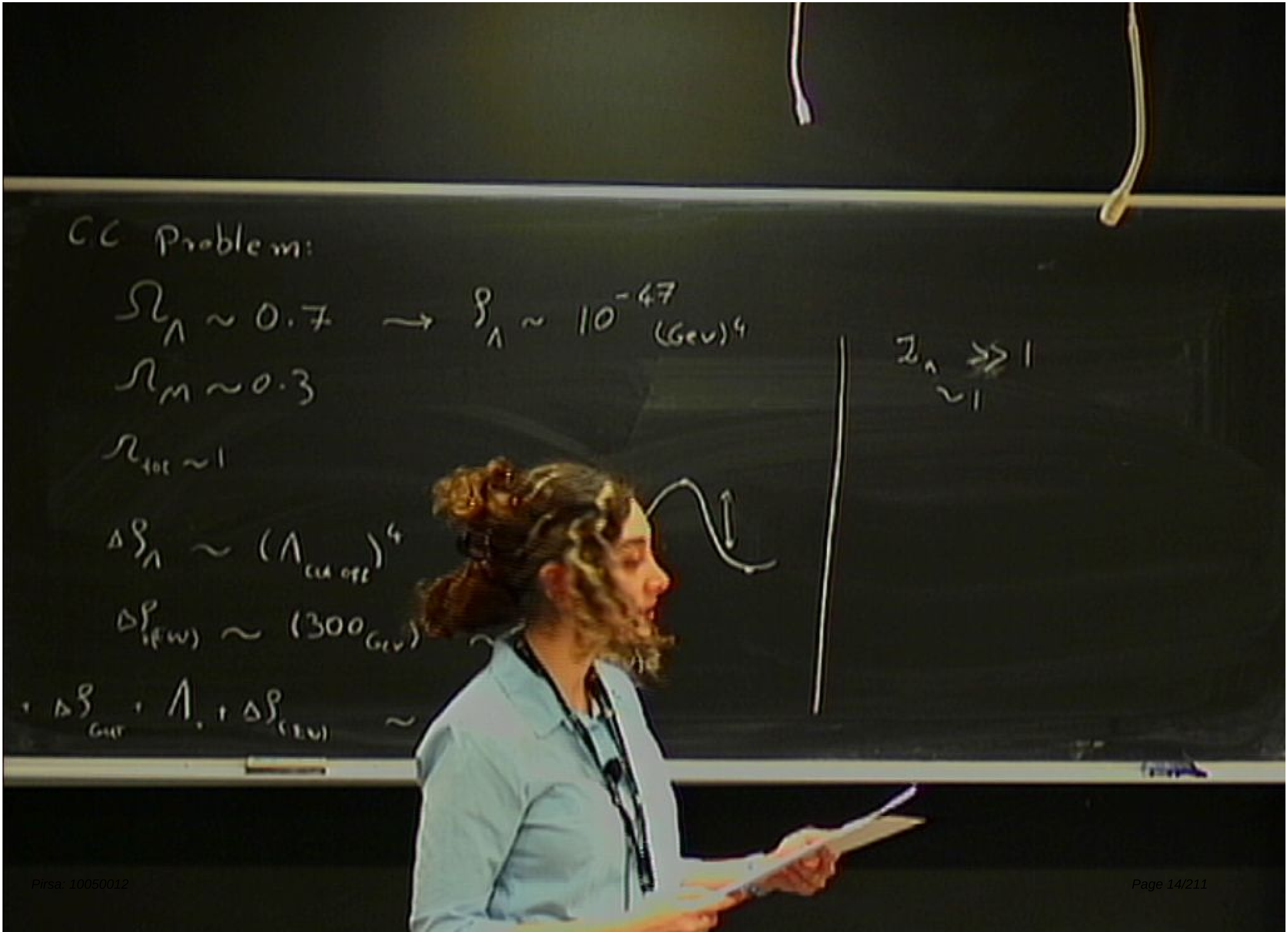
$$\Delta\rho_{(EW)} \sim (300\,\mathrm{GeV})^4 \sim 10^9\,(\mathrm{GeV})^4$$

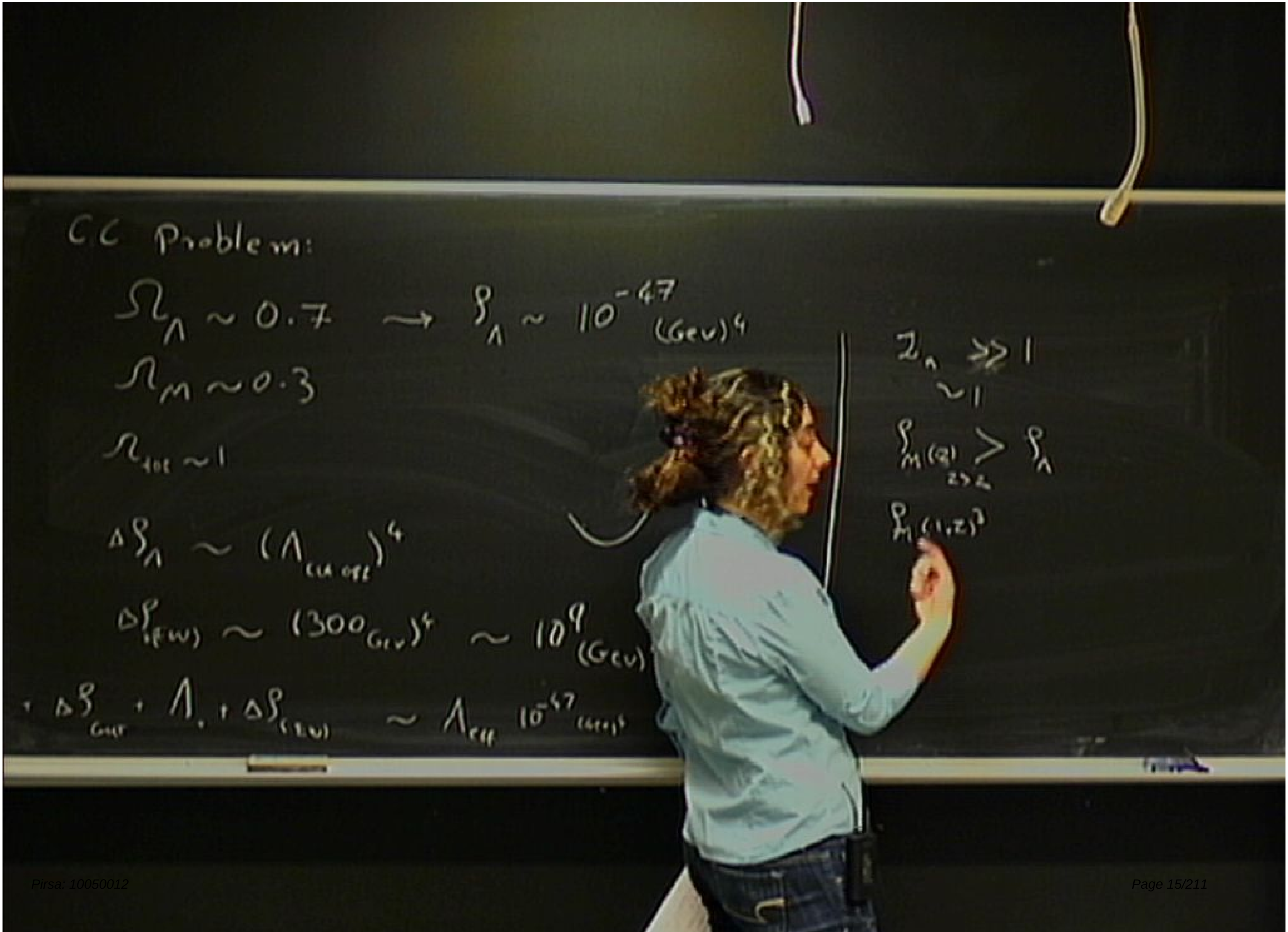
$$\Delta\rho_{GUT} + \Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff}\; 10^{-47}\,(\mathrm{GeV})^4$$

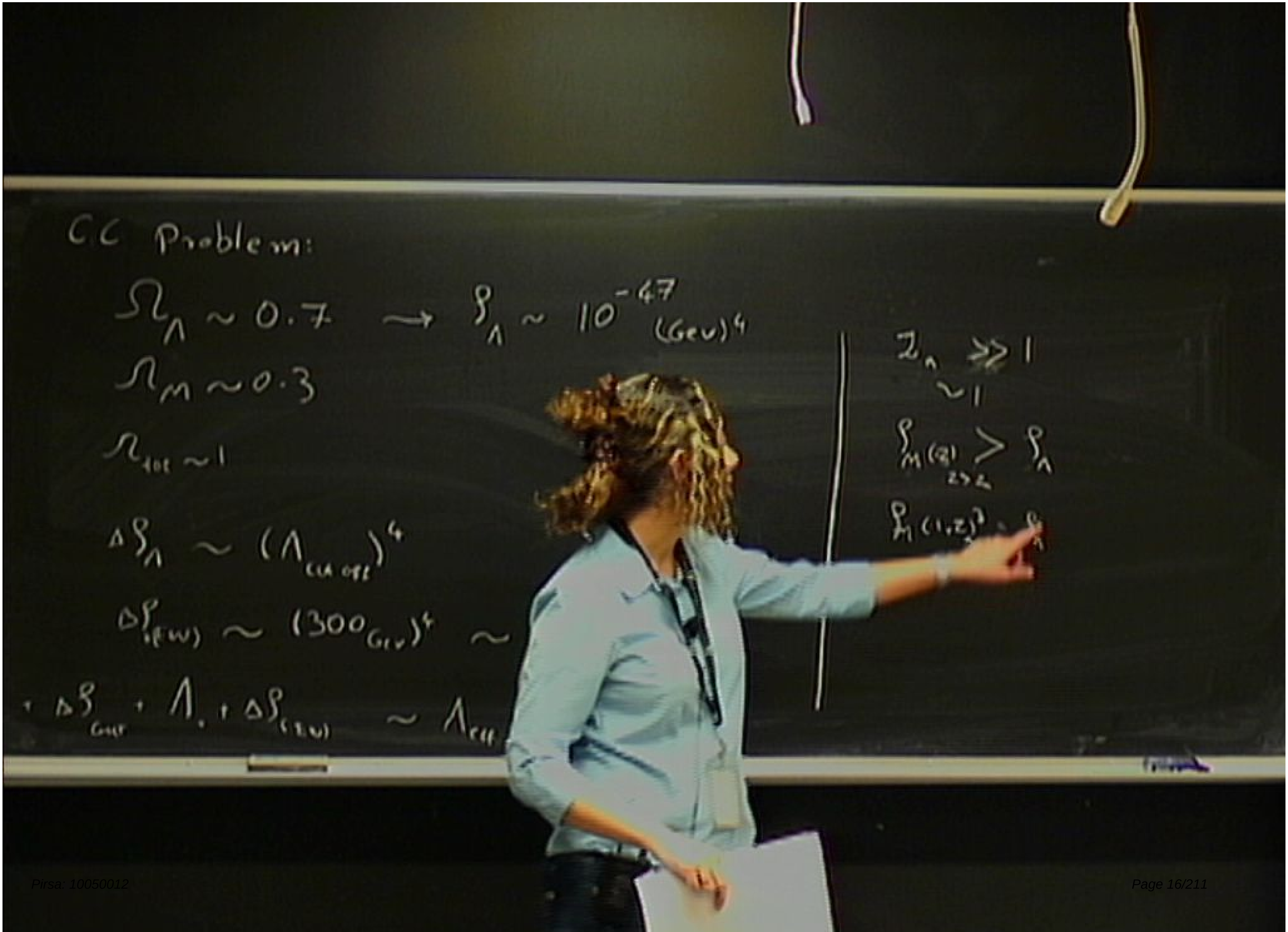


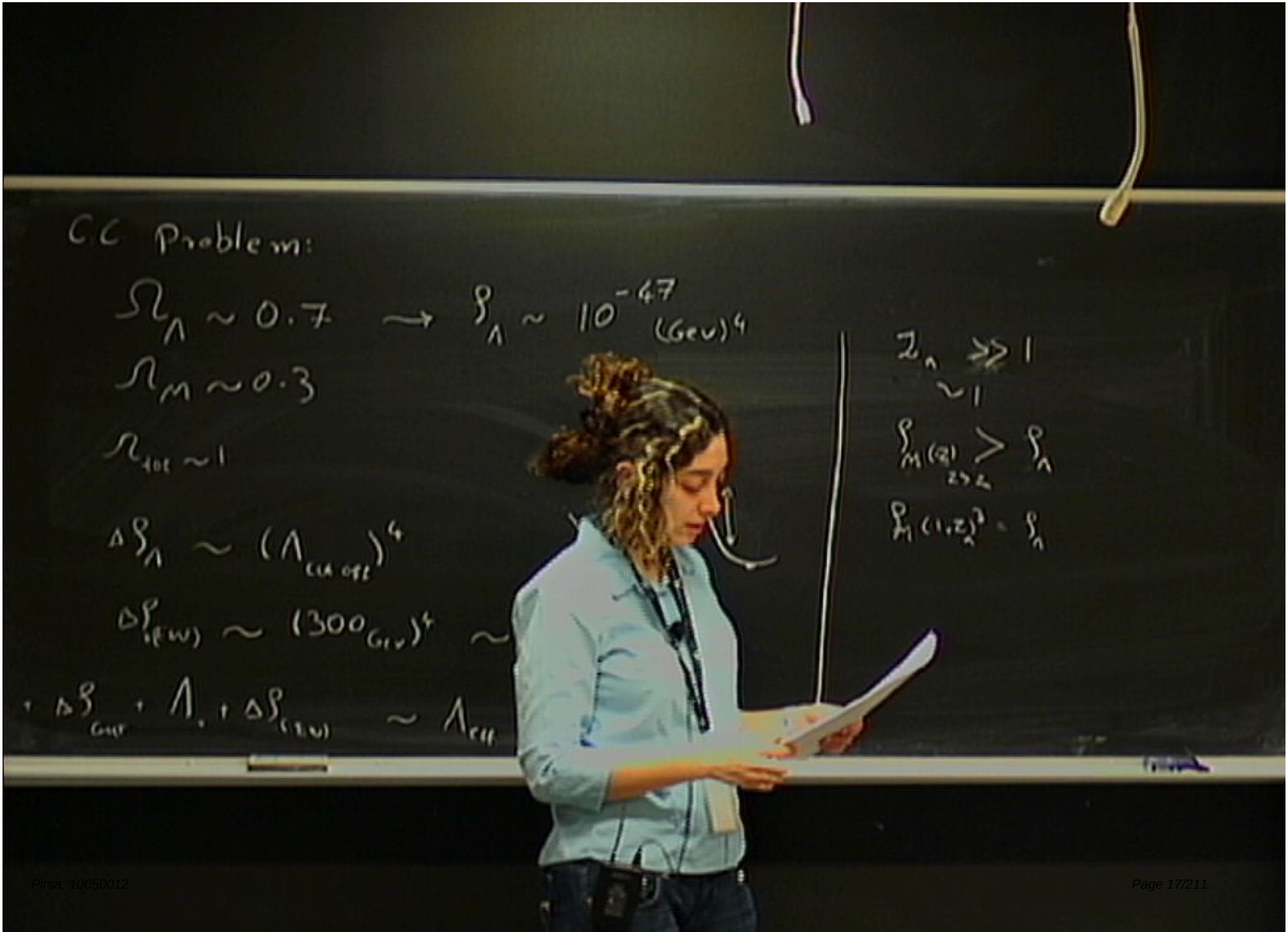
$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47} (GeV)^4$
$\Omega_M \sim 0.3$
$\Omega_{tot} \sim 1$
$\Delta\rho_\Lambda \sim (\Lambda_{cutoff})^4$
$\Delta\rho_{(EW)} \sim (300\,GeV)^4 \sim 10^9 (GeV)^4$

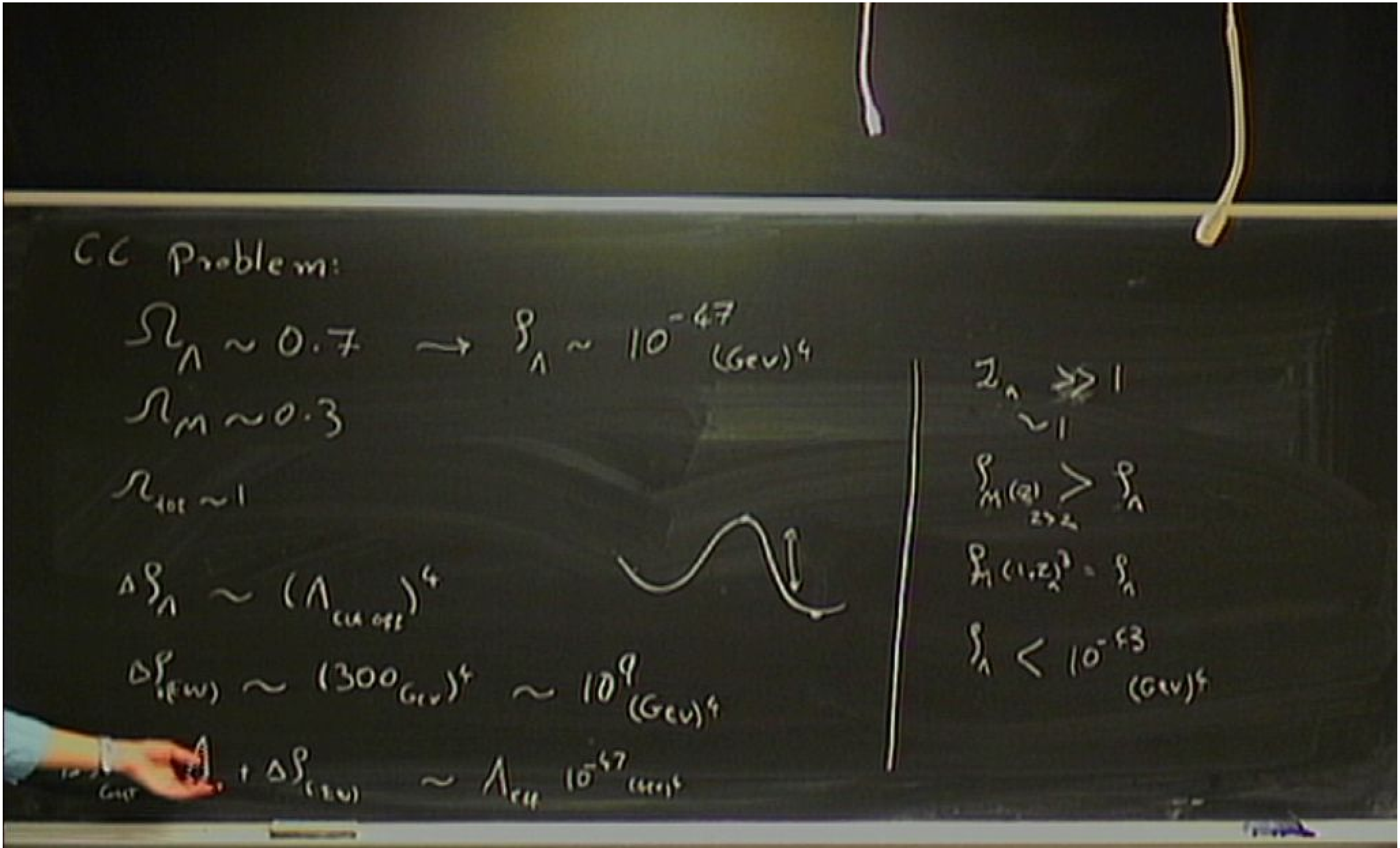

CC Problem:
$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47} (GeV)^4$
$\mathcal{I}_\Lambda \gg 1$
$\Omega_M \sim 0.3$
$\Omega_{tot} \sim 1$
$\Delta\rho_\Lambda \sim (\Lambda_{cut\ off})^4$
$\Delta\rho_{(EW)} \sim (300_{GeV})^4 \sim 10^9$
$+ \Delta\rho_{GUT} + \Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff}\ 10^{-47}$

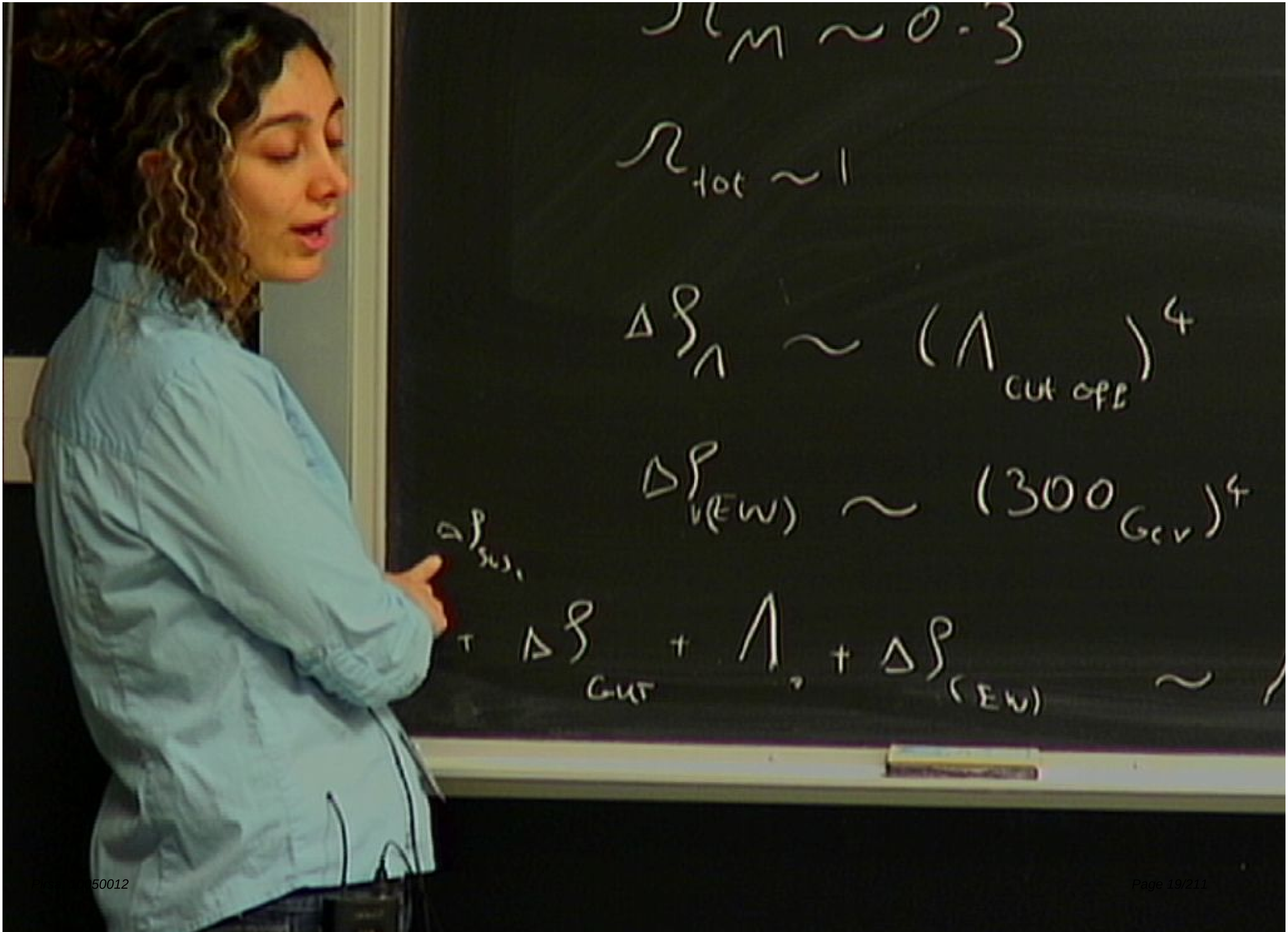

CC Problem:
Ω_Λ ~ 0.7 → ρ_Λ ~ 10^-47 (GeV)^4
Ω_M ~ 0.3
Ω_tot ~ 1
Δρ_Λ ~ (Λ_cut off)^4
Δρ_(EW) ~ (300 GeV)^4 ~
+ Δρ_GUT + Λ_0 + Δρ_(EW) ~
Ω_Λ >> 1
~1


CC Problem:
$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47} (GeV)^4$
$\Omega_M \sim 0.3$
$\Omega_{tot} \sim 1$
$\Delta\rho_\Lambda \sim (\Lambda_{cut\,off})^4$
$\Delta\rho_{(EW)} \sim (300\,GeV)^4 \sim 10^9 (GeV)$
$\Omega_\Lambda \gg 1$
~ 1
$\rho_{M(z)} > \rho_\Lambda$
$\rho_M (1+z)^3$

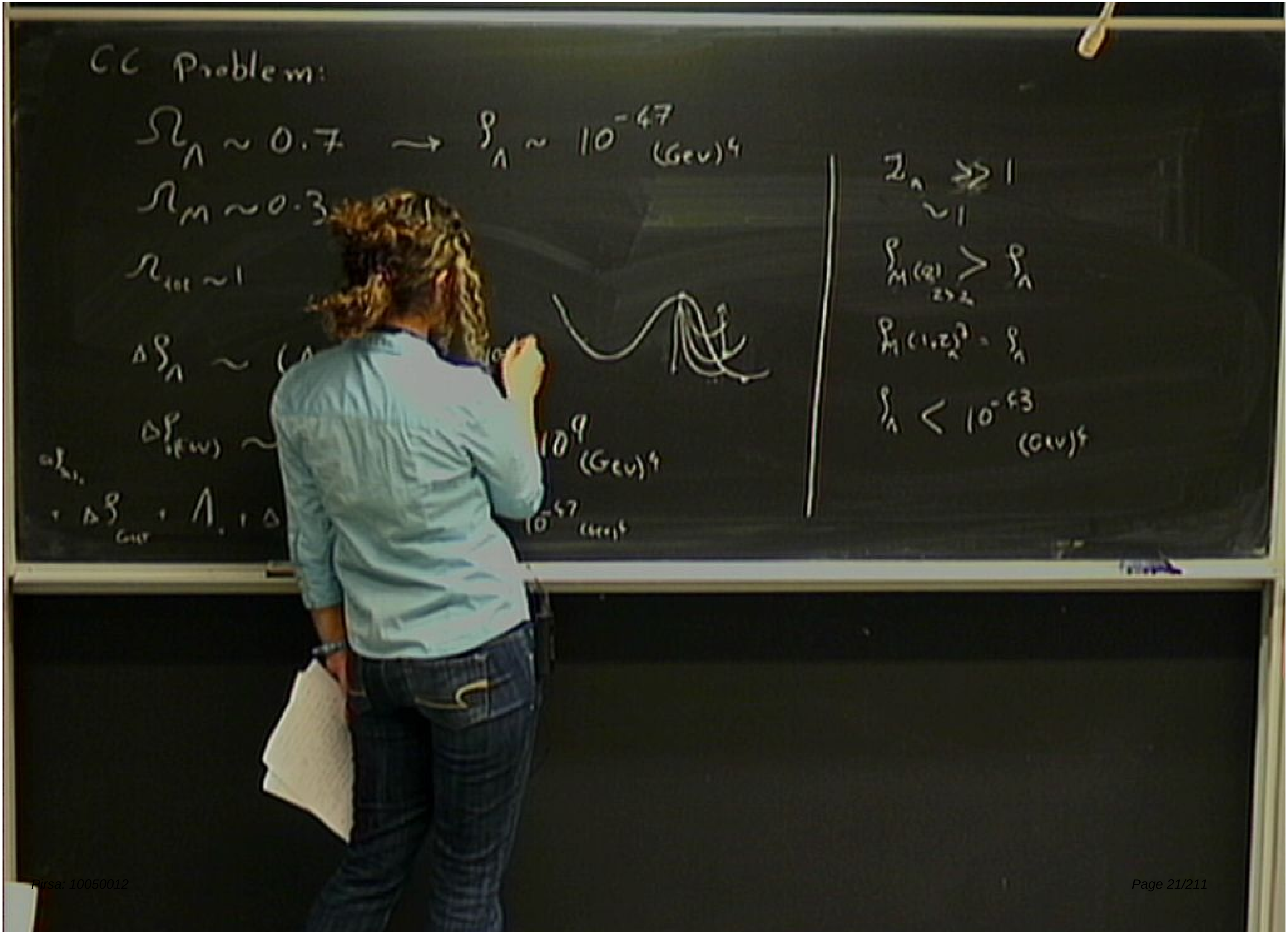

CC Problem:
Ω_Λ ~ 0.7 → ρ_Λ ~ 10^-47 (GeV)^4
Ω_M ~ 0.3
Ω_tot ~ 1
Δρ_Λ ~ (Λ_cut off)^4
Δρ_(EW) ~ (300 GeV)^4 ~
+ Δρ_GUT + Λ_0 + Δρ_(EW) ~ Λ_eff
Ω_Λ >> 1
~1
ρ_M(z) > ρ_Λ
z > z
ρ_M (1+z)^3 ~ ρ_Λ


CC Problem:
Ω_Λ ~ 0.7 → ρ_Λ ~ 10^-47 (GeV)^4
Ω_M ~ 0.3
Ω_tot ~ 1
Δρ_Λ ~ (Λ_cut off)^4
Δρ_(EW) ~ (300 GeV)^4 ~
+ Δρ_GUT + Λ_0 + Δρ_(EW) ~ Λ_eff
z_Λ >> 1
~1
ρ_M(z) > ρ_Λ
z > z_Λ
ρ_M (1+z_Λ)^3 = ρ_Λ


CC Problem:
Ω_Λ ~ 0.7 → ρ_Λ ~ 10^-47 (GeV)^4
Ω_M ~ 0.3
Ω_tot ~ 1
Δρ_Λ ~ (Λ_cut off)^4
Δρ(EW) ~ (300 GeV)^4 ~ 10^9 (GeV)^4
Λ + Δρ(EW) ~ Λ_eff 10^-47 (GeV)^4
Ω_Λ >> 1
~ 1
ρ_M(z) > ρ_Λ
ρ_M (1+z)^3 = ρ_Λ
ρ_Λ < 10^-43 (GeV)^4


Ω_M ~ 0.3
Ω_tot ~ 1
Δρ_Λ ~ (Λ_cut off)^4
Δρ_v(EW) ~ (300 GeV)^4
Δρ_susy
+ Δρ_cut + Λ_0 + Δρ_(EW) ~


CC Problem:
Ω_Λ ~ 0.7 → ρ_Λ ~ 10^-47 (GeV)^4
Ω_M ~ 0.3
~ 10^9 (GeV)^4
Λ_eff 10^-47 (GeV)^4
Ω_Λ >> 1
~ 1
ρ_M(z) > ρ_Λ
ρ_Λ < 10^-53 (GeV)^4


CC Problem:
Ω_Λ ~ 0.7 → ρ_Λ ~ 10^-47 (GeV)^4
Ω_M ~ 0.3
Ω_tot ~ 1
Δρ_Λ ~
Δρ_(EW) ~ 10^9 (GeV)^4
10^-47 (GeV)^4
z_Λ >> 1
~ 1
ρ_M(z) > ρ_Λ
z > z_Λ
ρ_M (1+z_Λ)^3 = ρ_Λ
ρ_Λ < 10^-43 (GeV)^4

CC Problem:

$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47}\,(GeV)^4$

$\Omega_M \sim 0.3$

$\Omega_{tot} \sim 1$

$\Delta\rho_\Lambda \sim (\Lambda_{cut\,off})^4 \quad 10^{15}$

$\Delta\rho_{(EW)} \sim (300_{GeV})^4 \sim 10^{9}\,(GeV)^4$

$\Delta\rho_{m.i.}$

$+\Delta\rho_{GUT} + \Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff} \quad 10^{-47}\,(GeV)^4$

$z_\Lambda \gg 1$

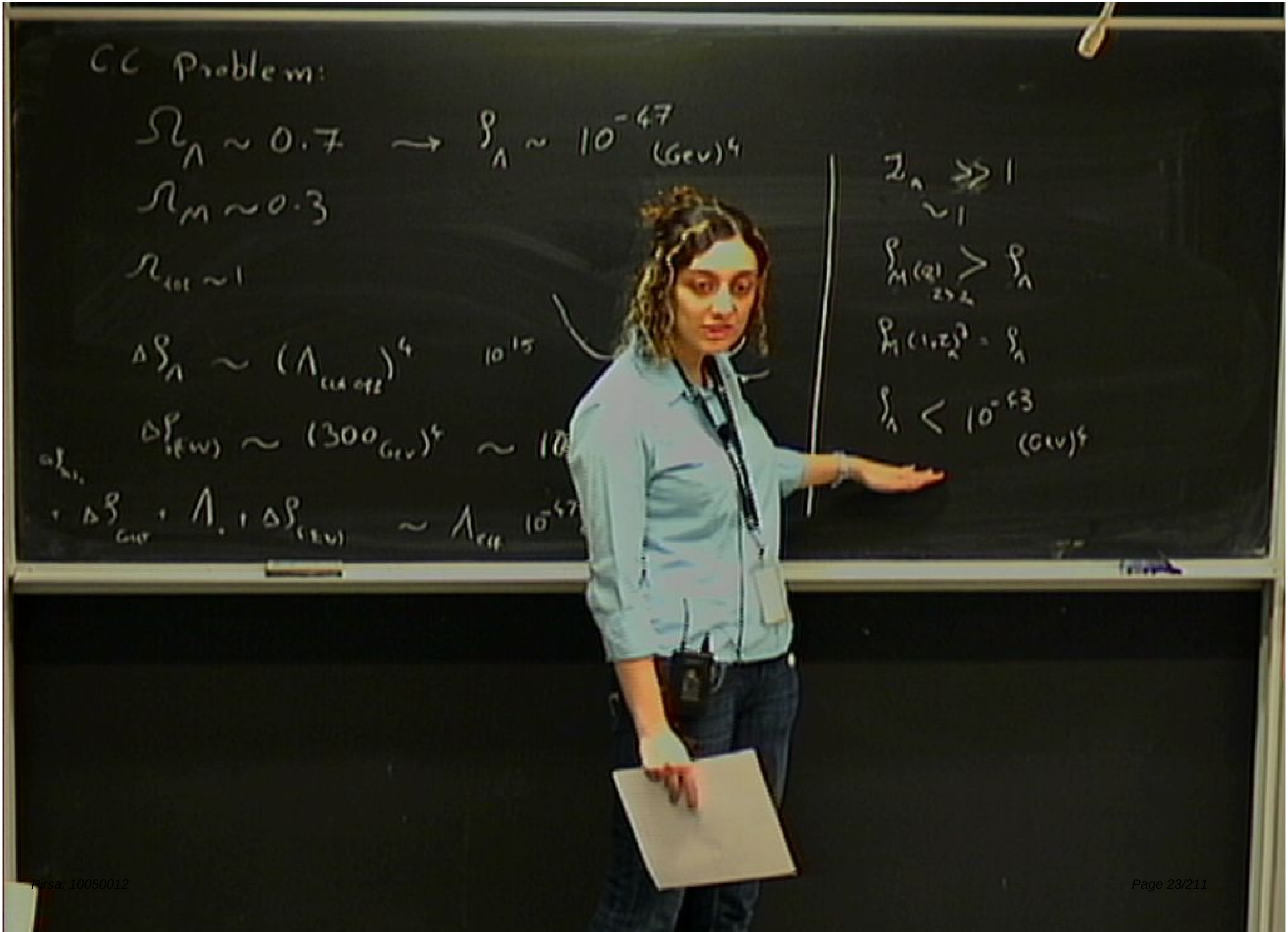
~ 1

$\rho_{M}(z) > \rho_\Lambda$

$z > z_\Lambda$

$\rho_M (1+z_\Lambda)^3 = \rho_\Lambda$

$\rho_\Lambda < 10^{-43}\,(GeV)^4$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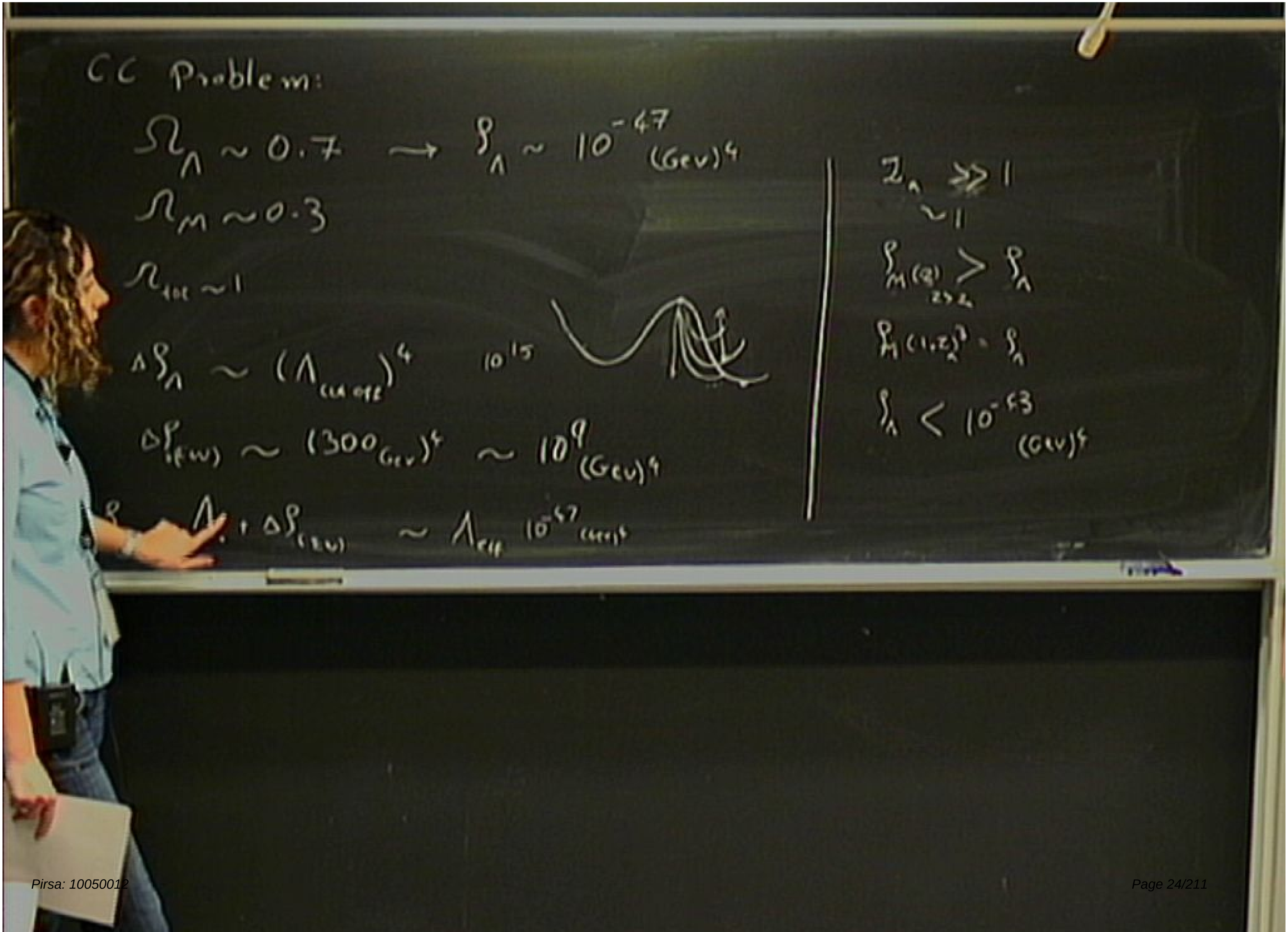
$\Omega_\Lambda \sim 0.7 \longrightarrow \rho_\Lambda \sim 10^{-47} (\mathrm{GeV})^4$
$\Omega_M \sim 0.3$
$\Omega_{tot} \sim 1$
$\Delta\rho_\Lambda \sim (\Lambda_{cut\,off})^4$
10^{15}
$\Delta\rho_{(EW)} \sim (300_{GeV})^4$
$\rho_\Lambda < 10^{-53} (\mathrm{GeV})^4$


CC Problem:
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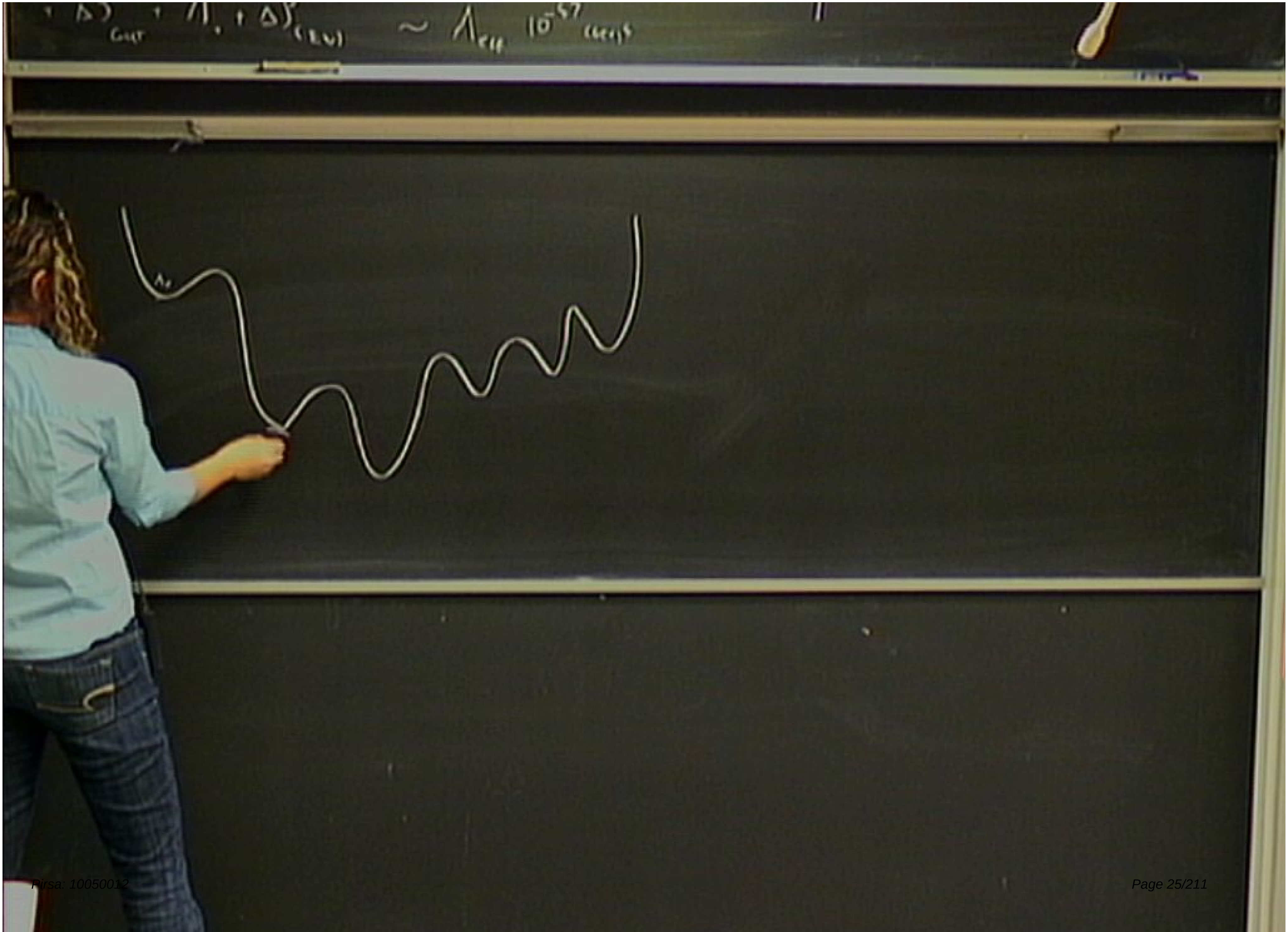
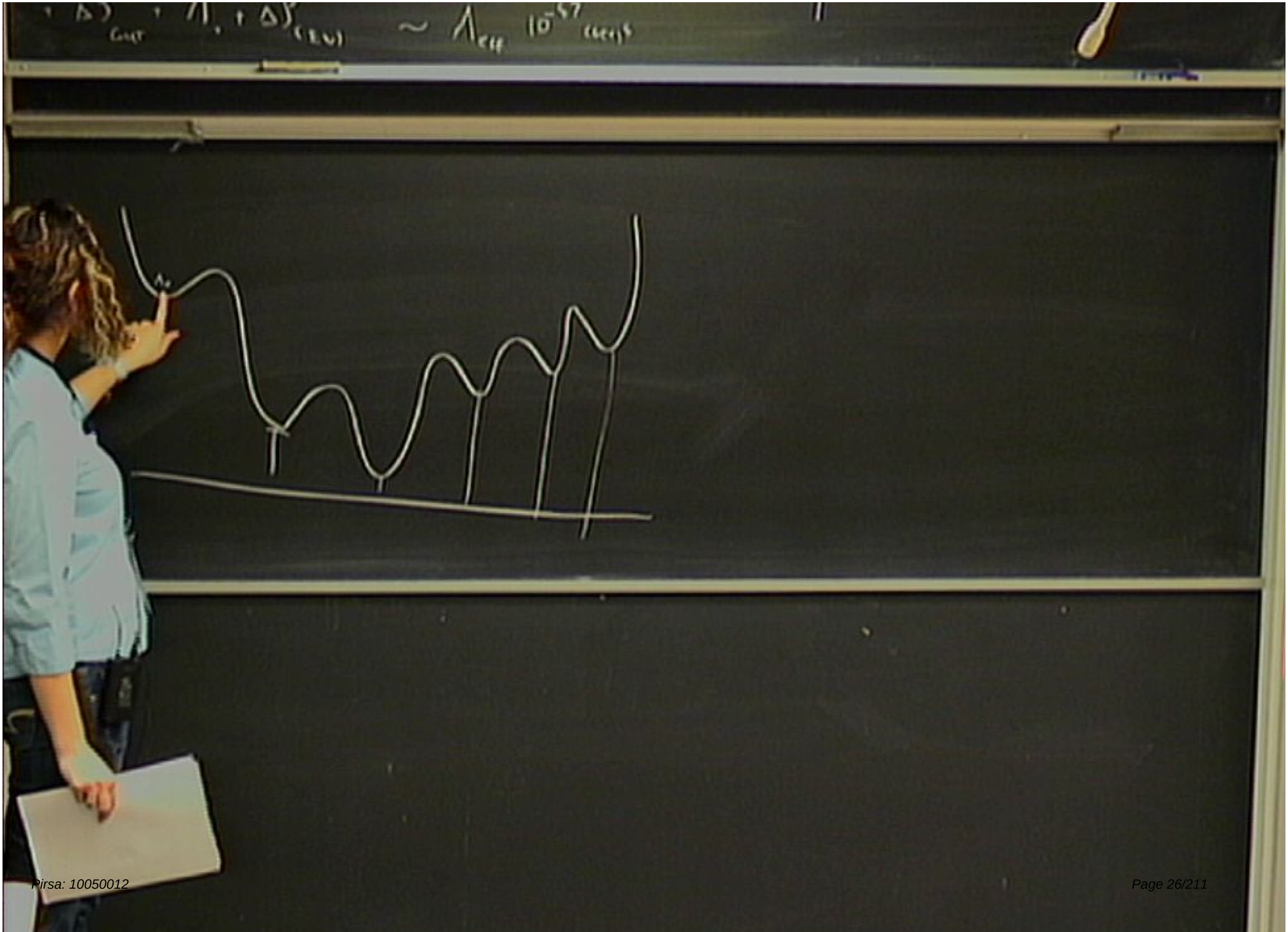
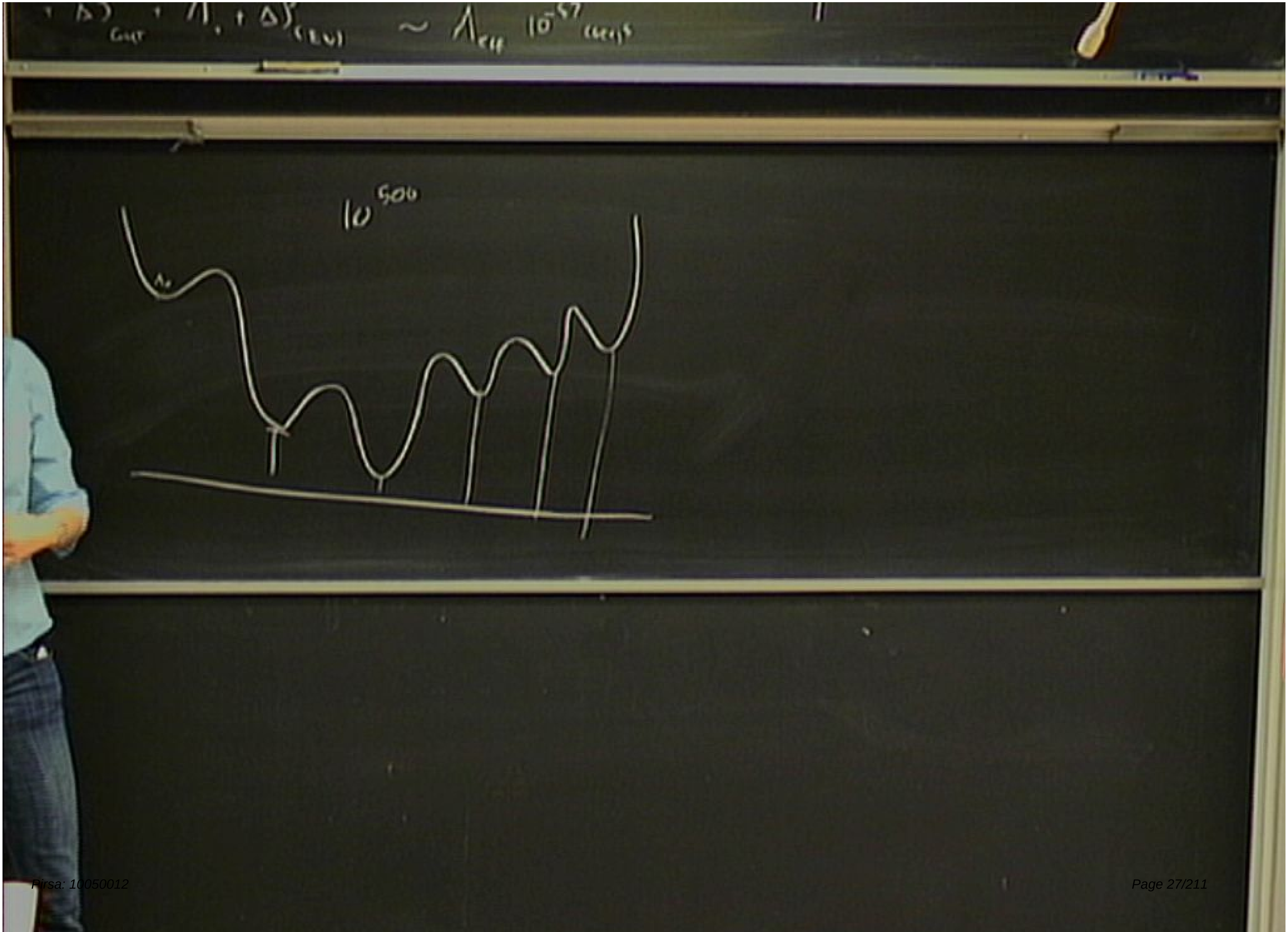
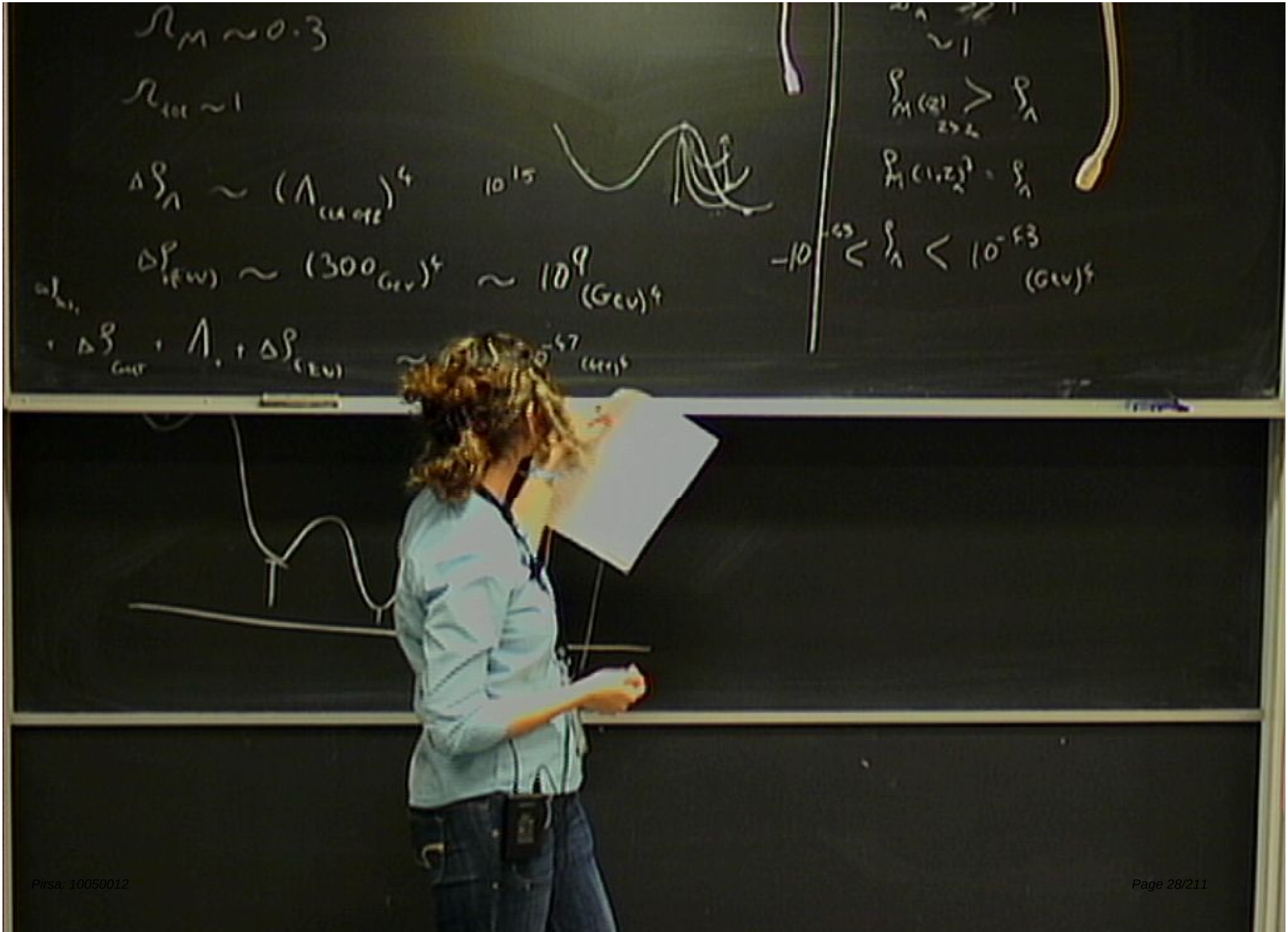
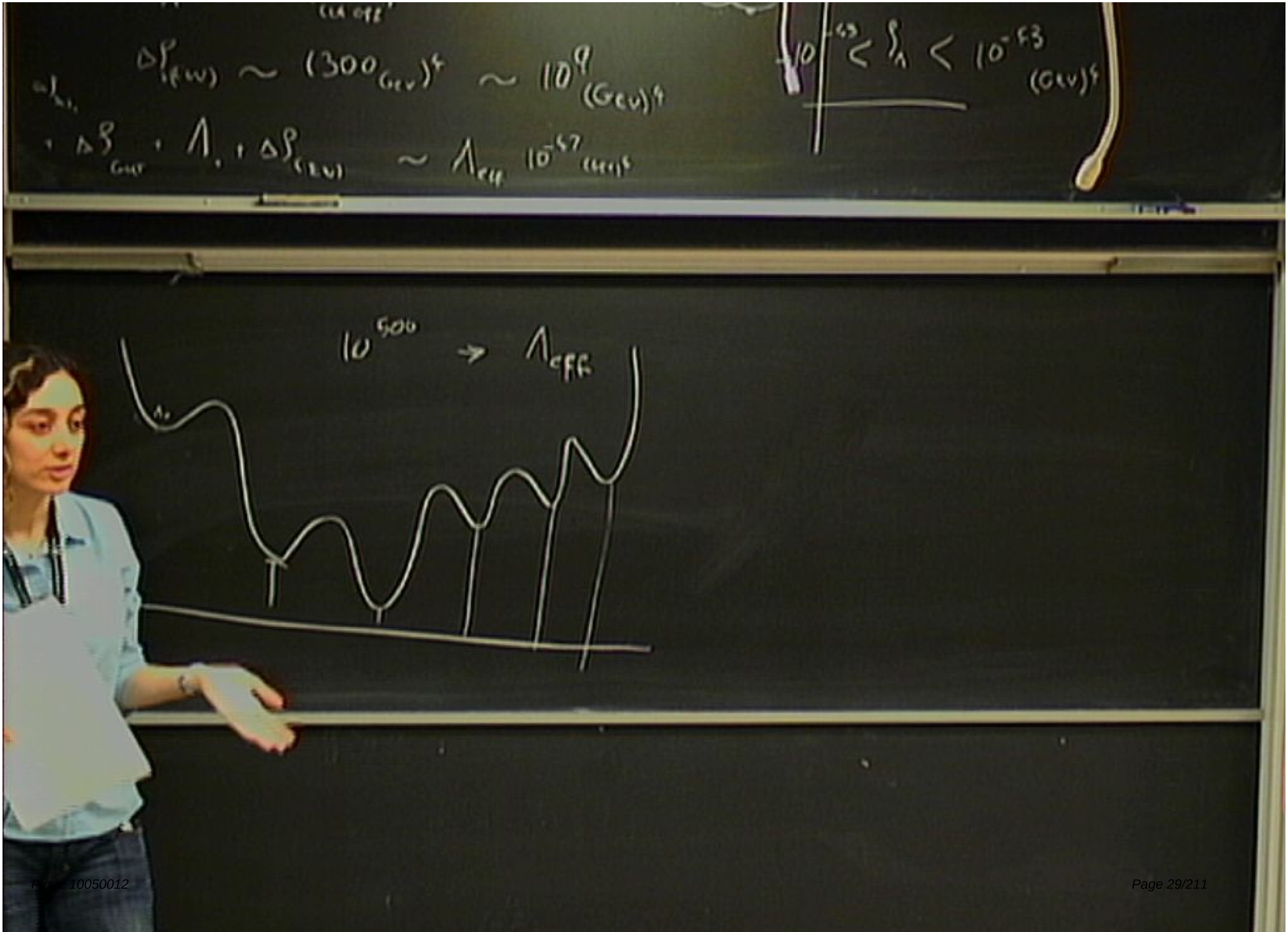
Ω_M ~ 0.3
Ω_tot ~ 1
Δρ_Λ ~ (Λ_cutoff)^4
10^15
Δρ_(EW) ~ (300 GeV)^4 ~ 10^9 (GeV)^4
10^-47 (GeV)^4
Ω_Λ >> 1
~1
ρ_M(z) > ρ_Λ
ρ_M (1+z)^3 = ρ_Λ
ρ_Λ < 10^-43 (GeV)^4

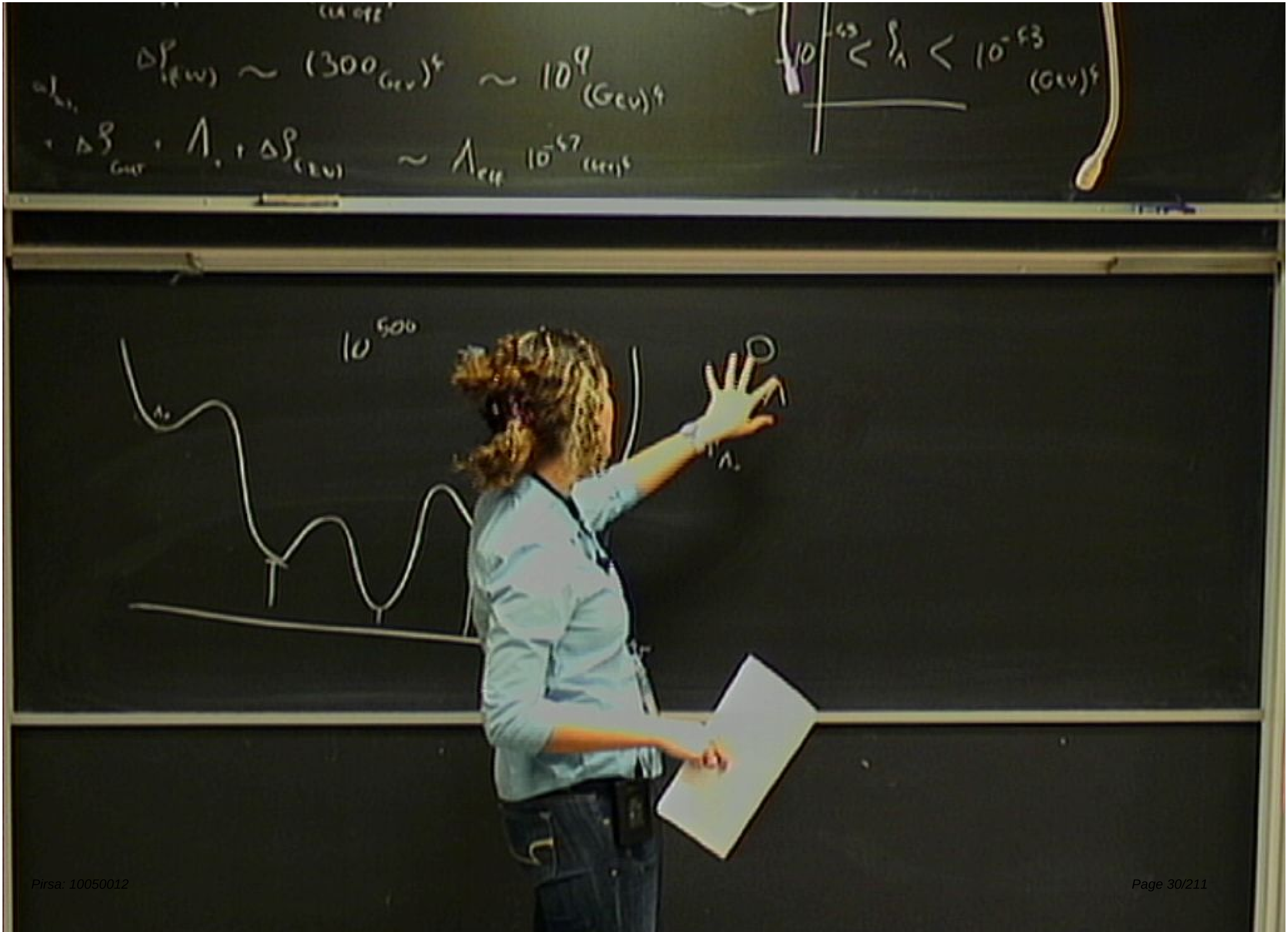




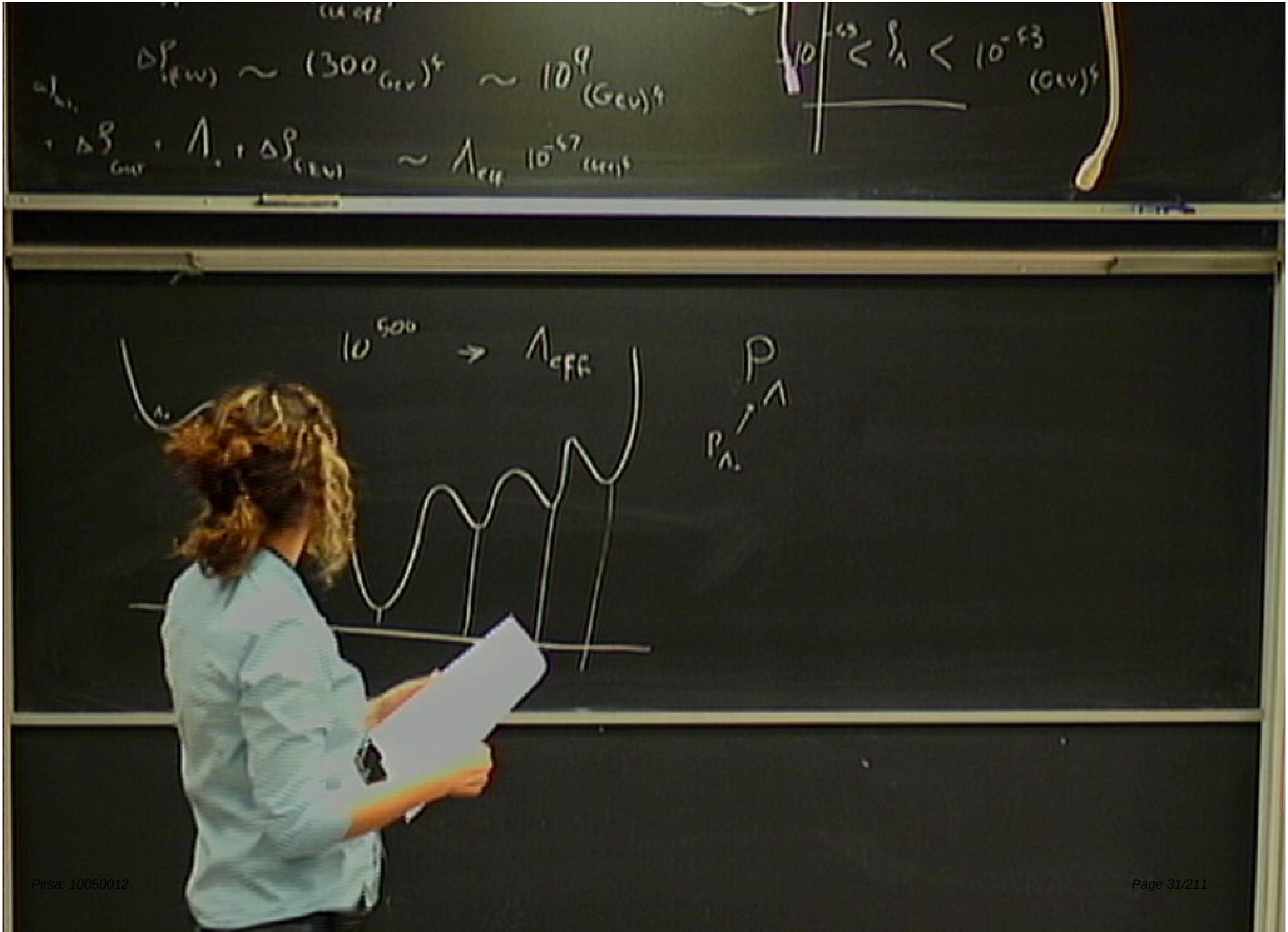

10^500

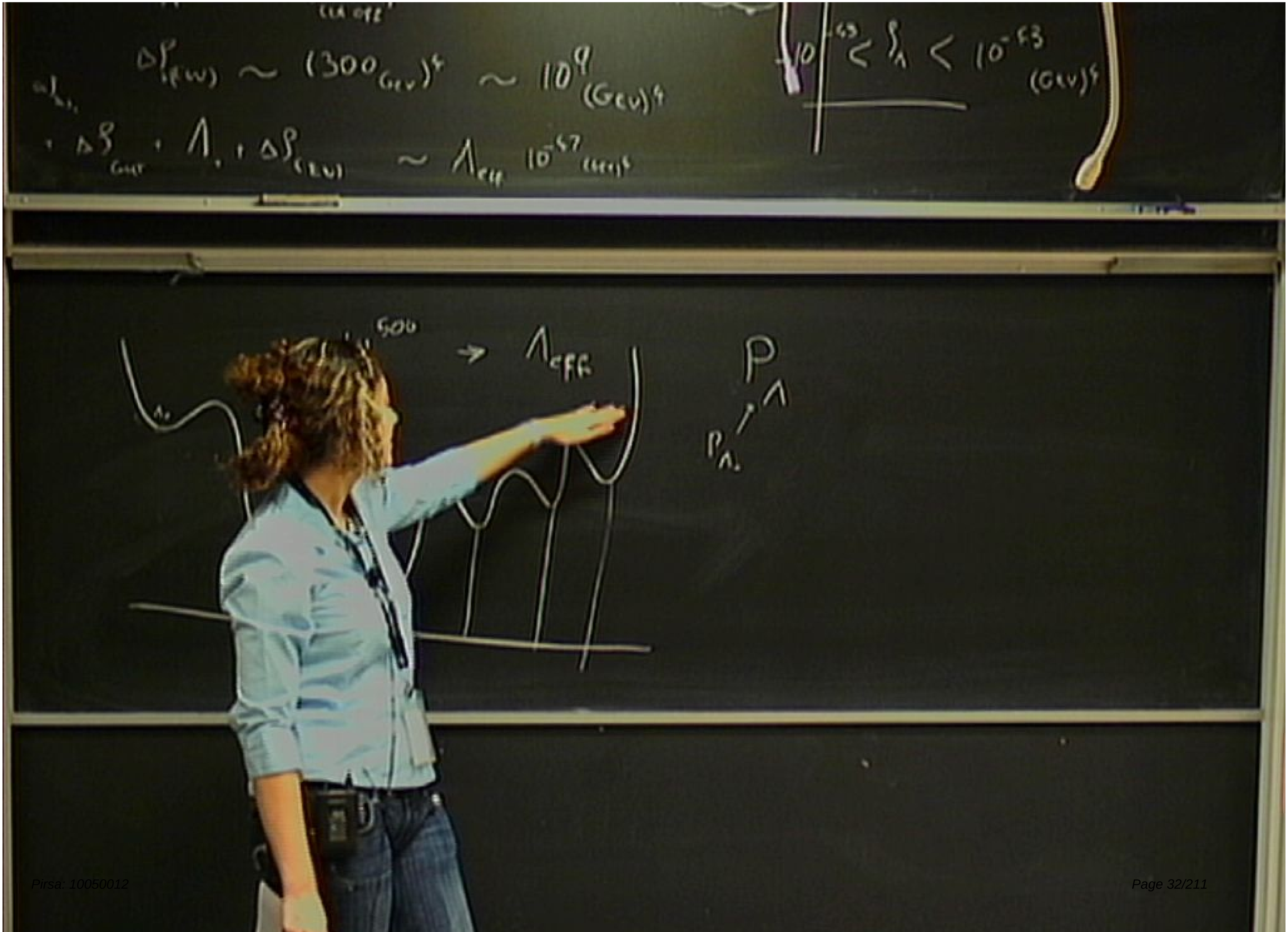

Ω_M ~ 0.3
Ω_tot ~ 1
Δρ_Λ ~ (Λ_cutoff)^4
10^15
Δρ_(EW) ~ (300 GeV)^4 ~ 10^9 (GeV)^4
-10^-53 < ρ_Λ < 10^-53 (GeV)^4
ρ_M(z) > ρ_Λ


ΔρEW ~ (300 GeV)^4 ~ 10^9 (GeV)^4
+ Δρ GUT + Λ0 + Δρ EW ~ Λeff 10^-47 (GeV)^4
10^500 → Λeff

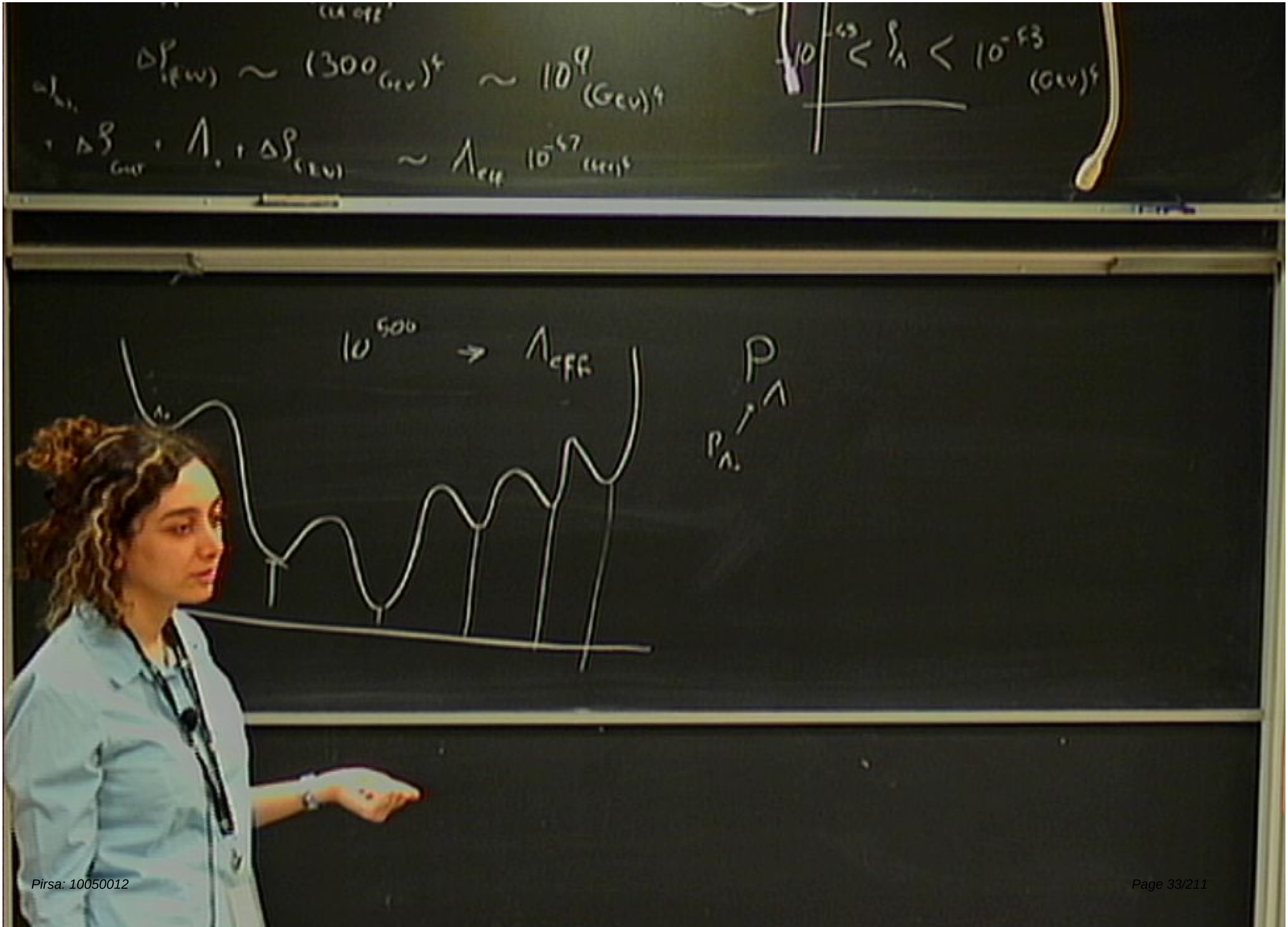


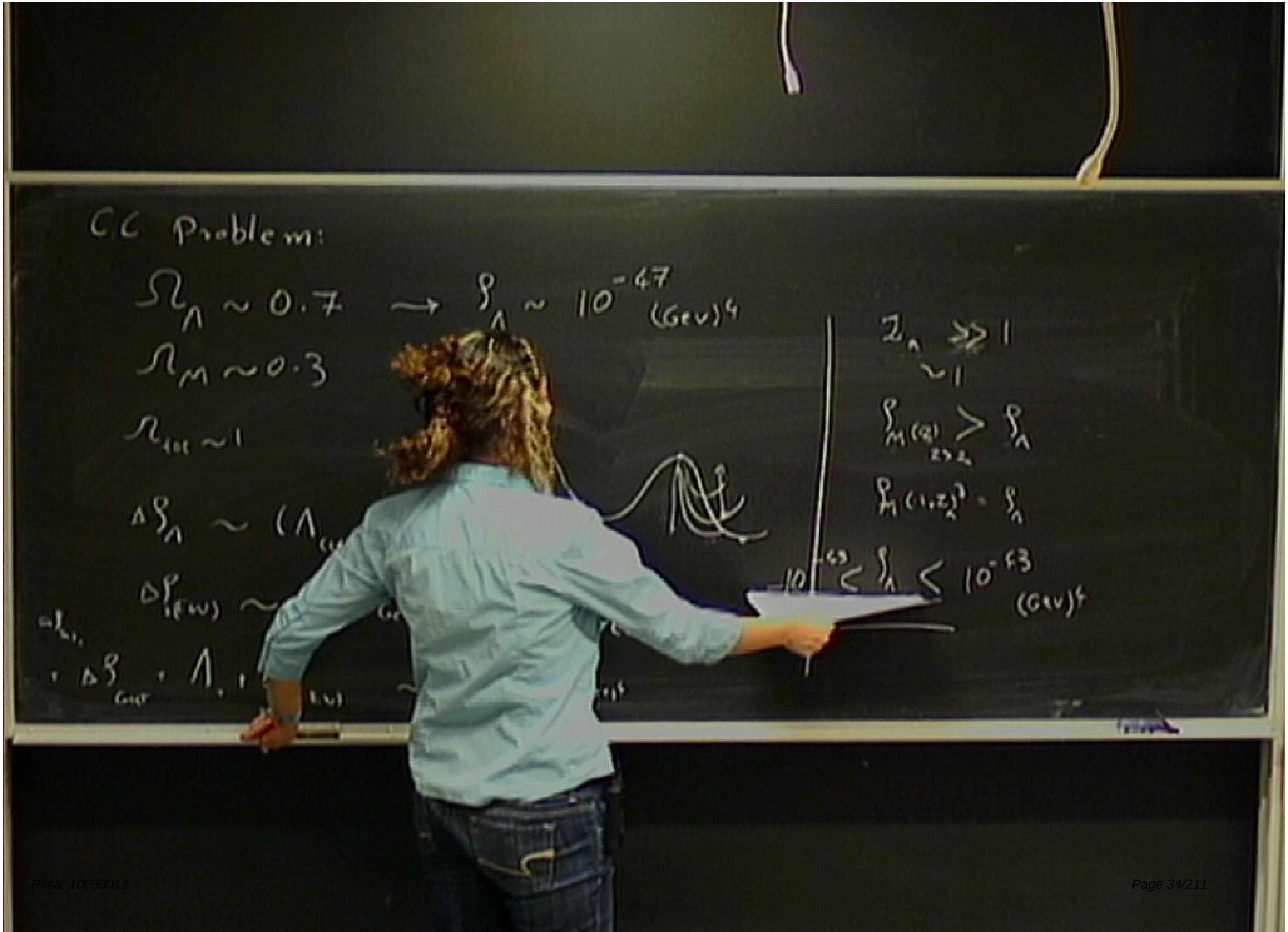
$\Delta\rho_{(EW)} \sim (300_{GeV})^4 \sim 10^9 (GeV)^4$
$\Delta\rho_{Cont} + \Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff}\ 10^{-47} (GeV)^4$
$10^{-53} < \rho_\Lambda < 10^{-53} (GeV)^4$
10^{500}


Δρ(EW) ~ (300 GeV)^4 ~ 10^9 (GeV)^4
< ρ_Λ < 10^-53 (GeV)^4
10^500 → Λ_eff
P_Λ



Δρ(EW) ~ (300 GeV)^4 ~ 10^9 (GeV)^4
10^-63 < ρΛ < 10^-53 (GeV)^4
Λeff 10^-57 (GeV)^4
10^500 → Λeff
P_Λ


$\Delta\rho_{(EW)} \sim (300_{GeV})^4 \sim 10^9_{(GeV)^4}$
$10^{-63} < \rho_\Lambda < 10^{-53}_{(GeV)^4}$
$+ \Delta\rho_{GUT} + \Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff}\ 10^{-47}_{(GeV)^4}$
$10^{500} \rightarrow \Lambda_{eff}$
P_Λ
P_{Λ_0}


CC Problem:
Ω_Λ ~ 0.7 → ρ_Λ ~ 10^-47 (GeV)^4
Ω_M ~ 0.3
Ω_tot ~ 1
(GeV)^4

CC Problem:

$\Omega_\Lambda \sim 0.7 \rightarrow \rho_\Lambda \sim 10^{-47}\,(GeV)^4$

$\Omega_M \sim 0.3$

$\Omega_{tot} \sim 1$

$\Delta\rho_\Lambda \sim (\Lambda_{cutoff})^4 \quad 10^{15}$

$\Delta\rho_{(EW)} \sim (300\,GeV)^4 \sim 10^{9}\,(GeV)^4$

$\Delta\rho_{GUT} + \Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff}\ 10^{-47}\,(GeV)^4$

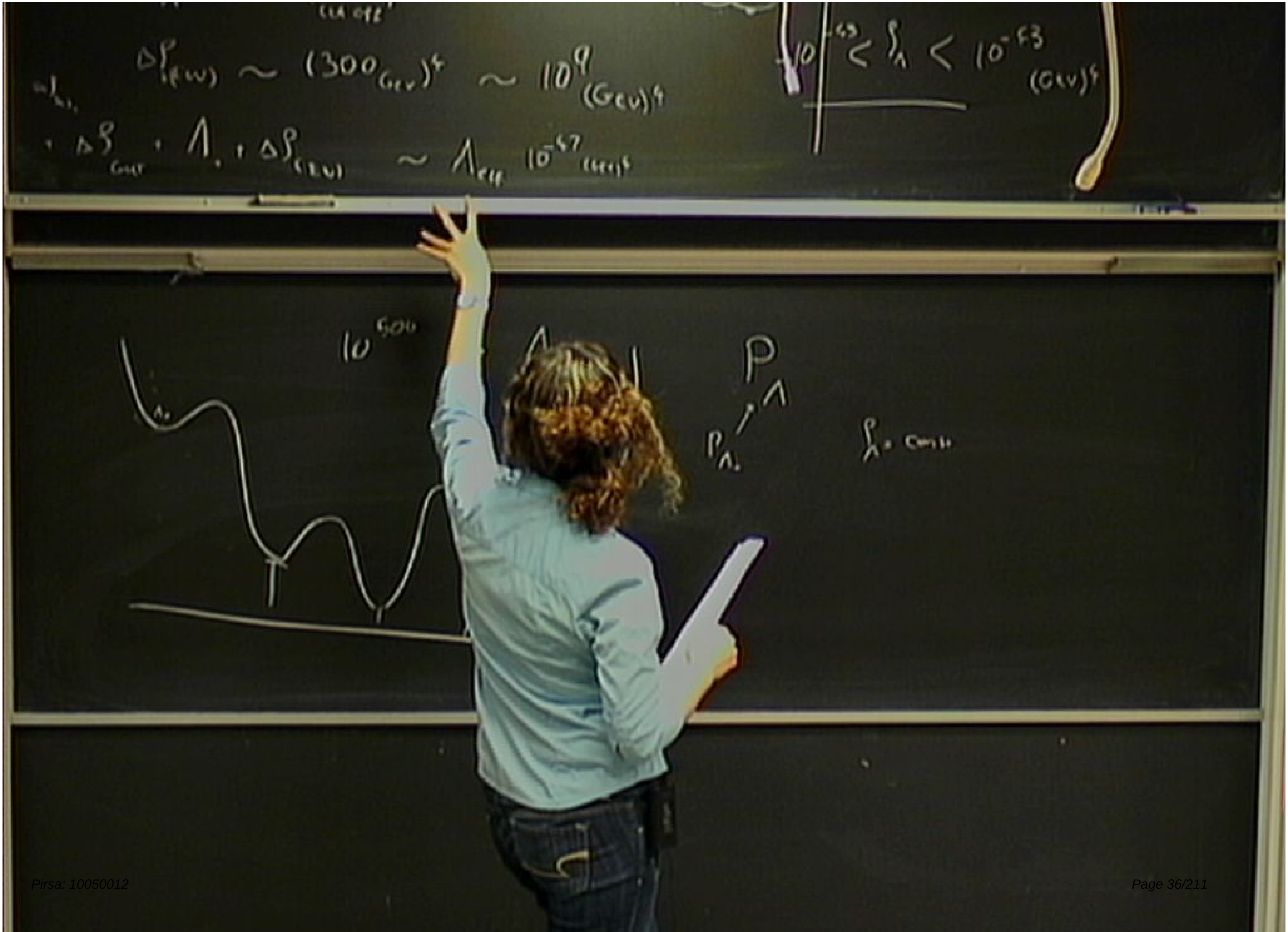
$z_\Lambda \gg 1$

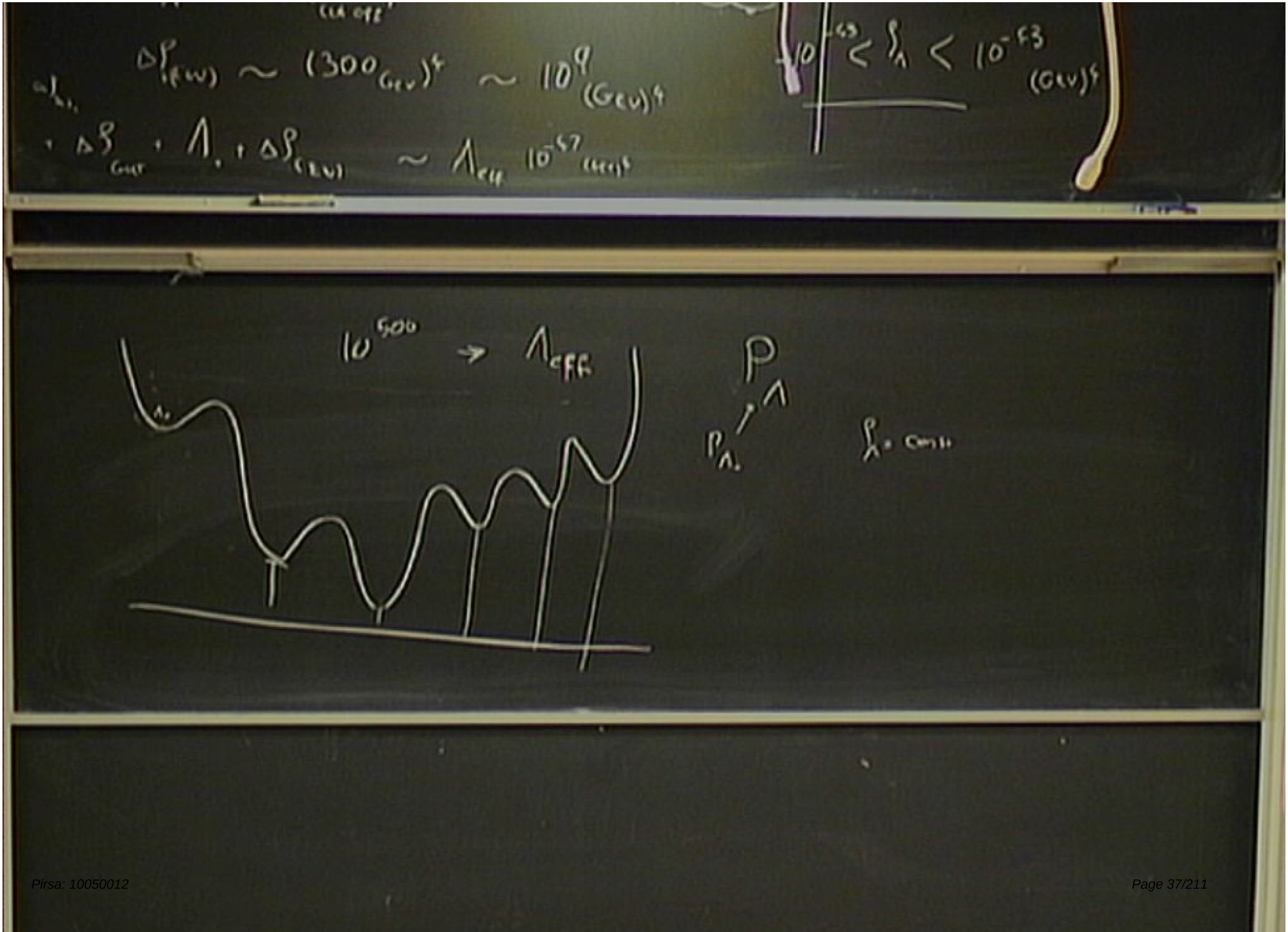
~ 1

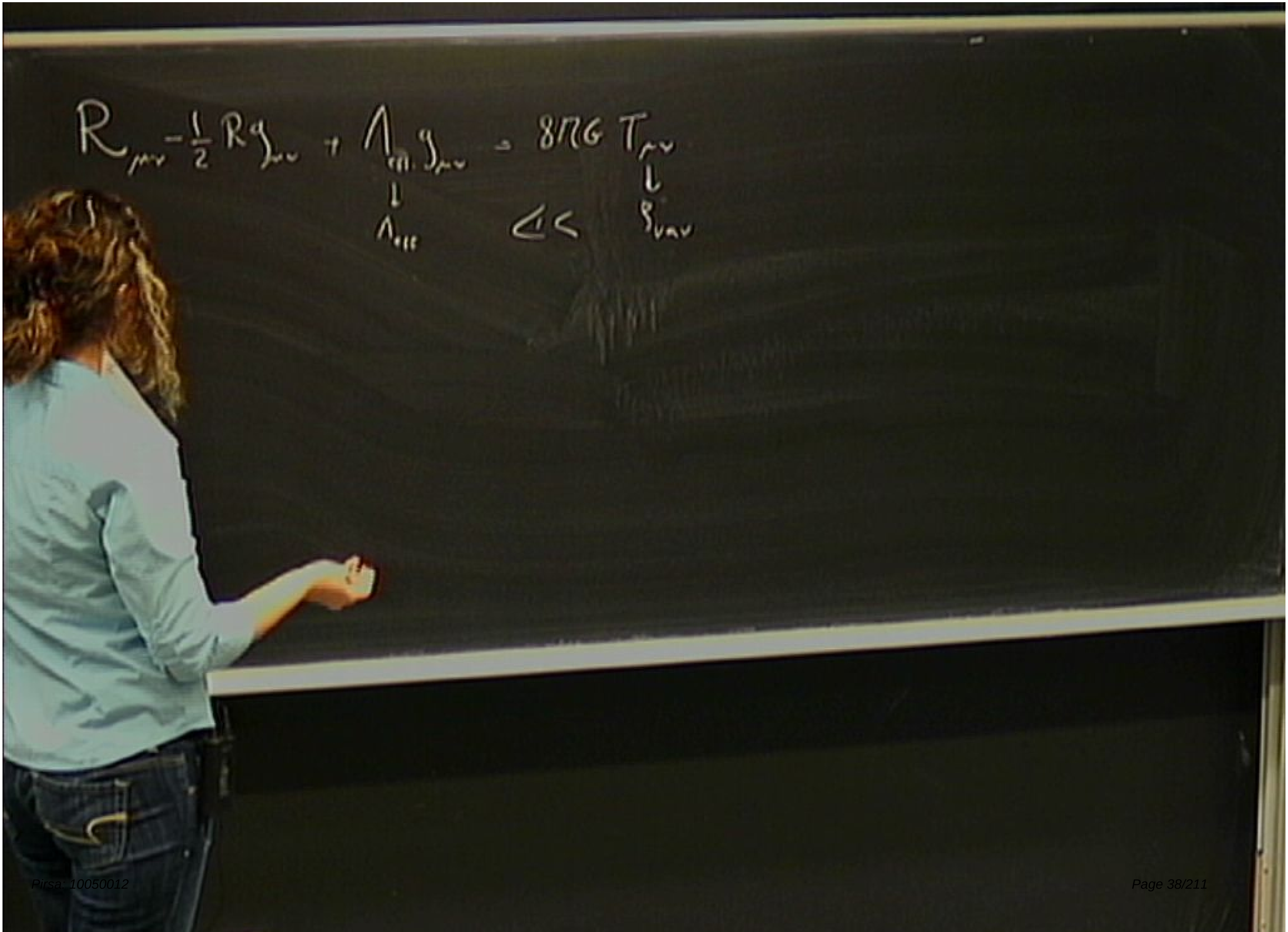
$\rho_{M(z)} > \rho_\Lambda \quad z > z_\Lambda$

$\rho_M (1+z_\Lambda)^3 = \rho_\Lambda$

$-10^{-43} < \rho_\Lambda < 10^{-43}\,(GeV)^4$


Δρ(EW) ~ (300 GeV)^4 ~ 10^9 (GeV)^4
< ρΛ < 10^-53 (GeV)^4
Λ0 + Δρ(EW) ~ Λeff 10^-47 (GeV)^4
10^500
P
ρΛ = const


$\Delta\rho_{(EW)} \sim (300_{GeV})^4 \sim 10^9 (GeV)^4$
$+ \Delta\rho_{GUT} + \Lambda_0 + \Delta\rho_{(EW)} \sim \Lambda_{eff}\ 10^{-47} (GeV)^4$
$-10^{-63} < \rho_\Lambda < 10^{-63}$ $(GeV)^4$
$10^{500} \to \Lambda_{eff}$
P_Λ
P_{Λ_0}
$\rho_\Lambda =$ const


$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$
$\Lambda_{eff} \ll \rho_{vac}$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{th}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$$

$$\Lambda_{eff} \ll \rho_{vac}$$

$$\int \sqrt{g}\, R\, d^4x + \int \sqrt{g}\, L_M\, d^4x$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$$

$$\Lambda_{eff} \ll \rho_{vac}$$

$$\int \sqrt{g}\, R\, d^4x + \int \sqrt{g}\, L_M\, d^4x$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{th} g_{\mu\nu} = 8\pi G \, T_{\mu\nu}$$

$$\Lambda_{th} \downarrow \Lambda_{eff} \qquad \ll \qquad T_{\mu\nu} \downarrow \rho_{vac}$$

$$\int \sqrt{g} \, R \, d^4x + \int \sqrt{g} \, L_M^{4} \, d^4x$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{\text{th}}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$$

$$\Lambda_{\text{eff}} \ll \rho_{vac}$$

$$S = \int \sqrt{g}\, R\, d^4x + \int \sqrt{g}\, L_M\, d^4x$$

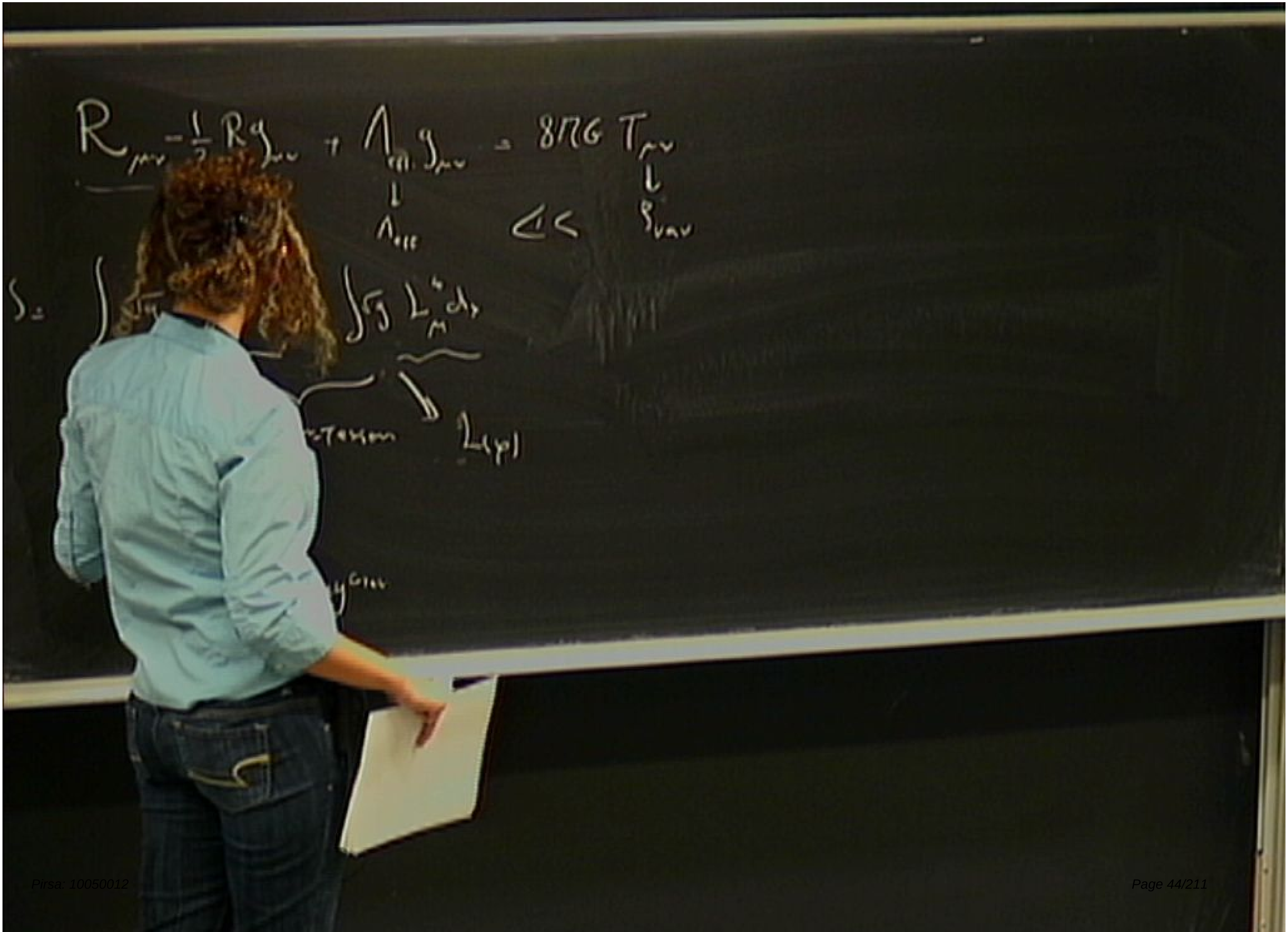
$$f(R)$$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{(B)} g_{\mu\nu} = 8\pi G \, T_{\mu\nu}$$

$$\Lambda_{eff} \ll \rho_{vac}$$

$$S = \int \sqrt{g}\, R^{(4)} d^4x + \int \sqrt{g}\, L_M^{(4)} d^4x$$

$F(R)$ Scalar-Tensor $L(\varphi)$


$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$
Λ_{eff}
$<<$
ρ_{vac}
$\int \sqrt{g}\, L_M^4\, d^4x$
$L(\phi)$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{th}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$$

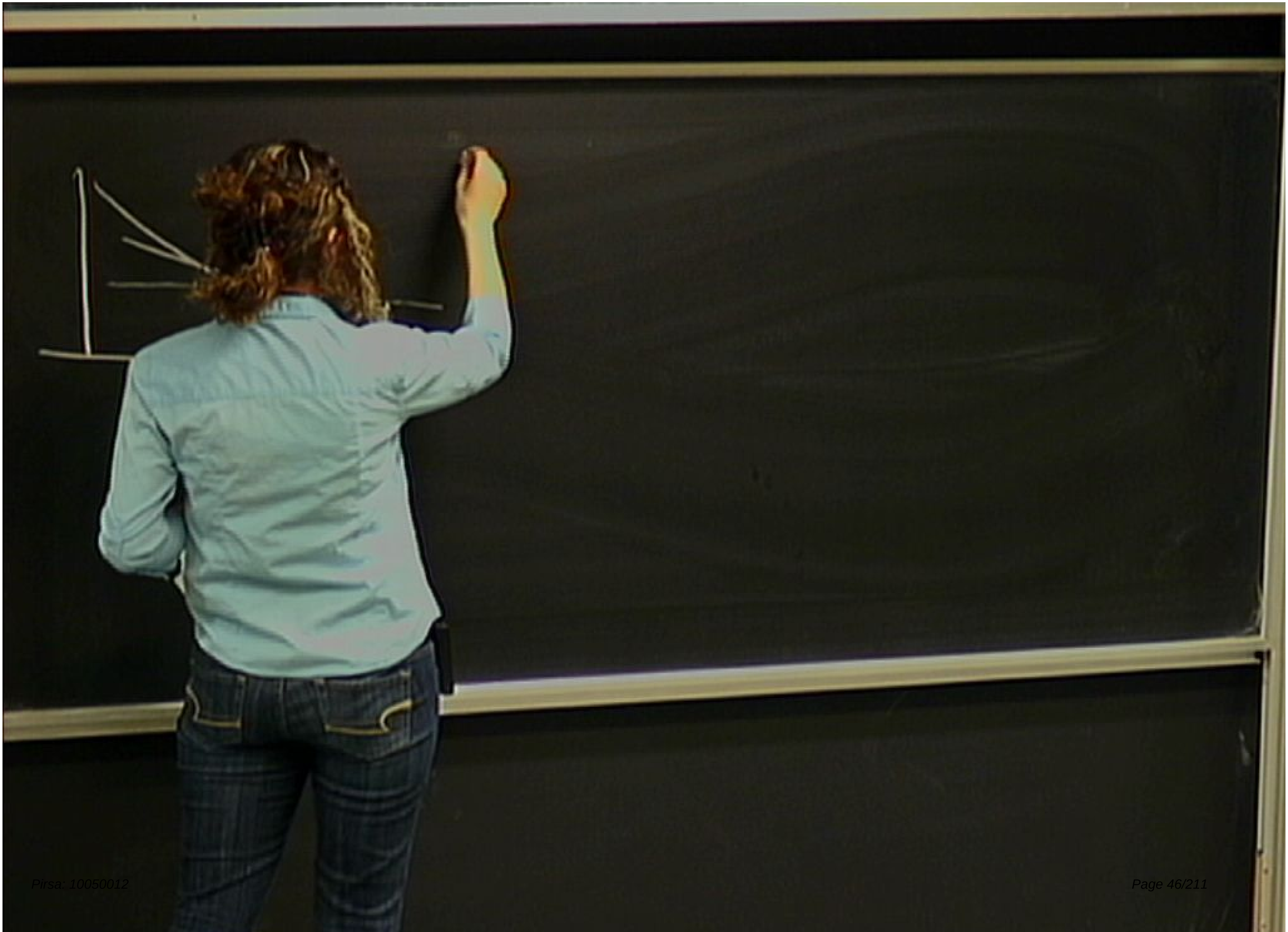
$$\Lambda_{th} \downarrow \Lambda_{eff} \quad \ll \quad T_{\mu\nu} \downarrow \rho_{vac}$$

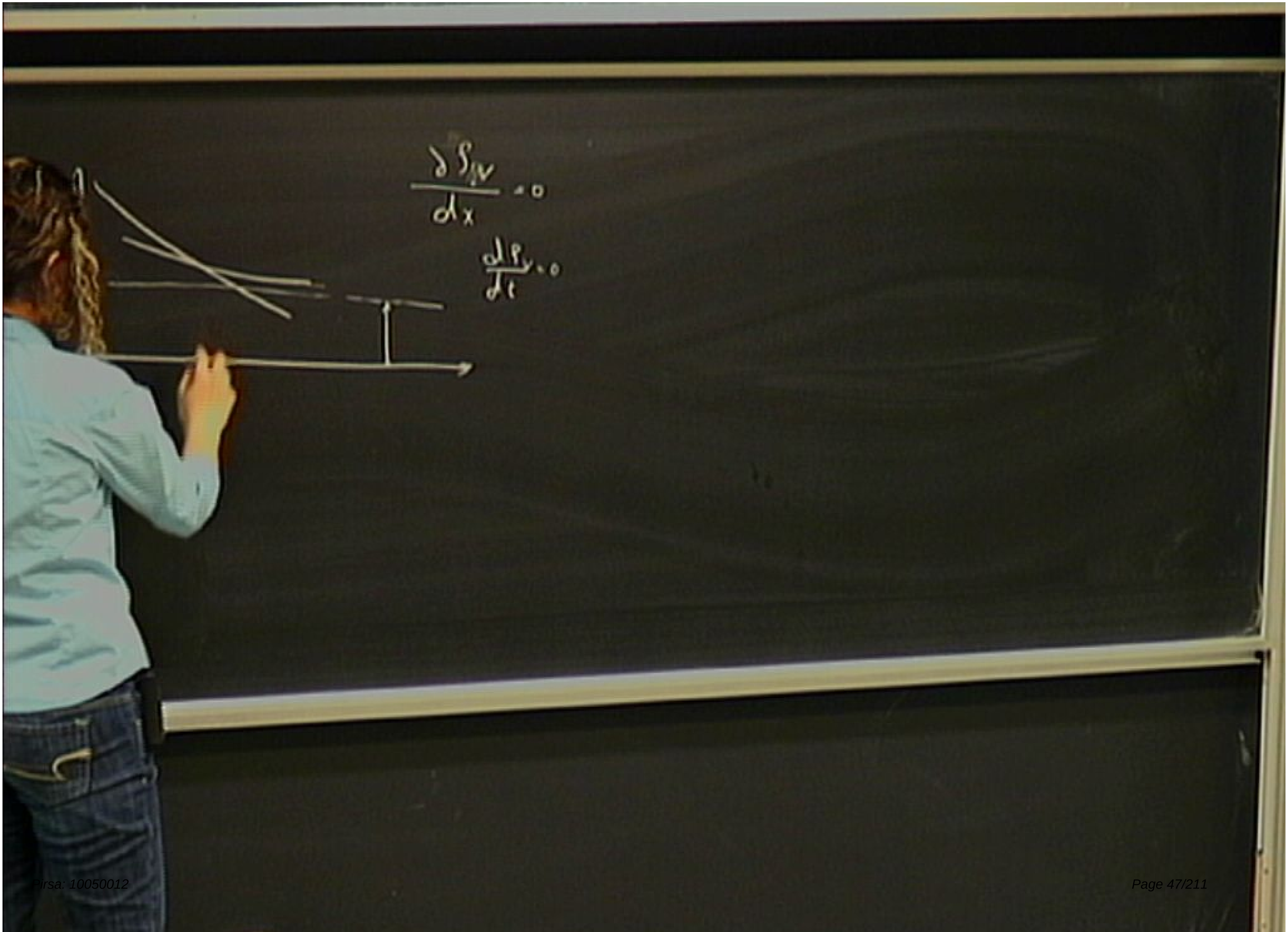
$$S = \int \sqrt{g}\, R^{(4)} d^4x + \int \sqrt{g}\, L_M^{(4)} d^4x$$

$F(R)$ Scalar-Tensor $L(\varphi)$

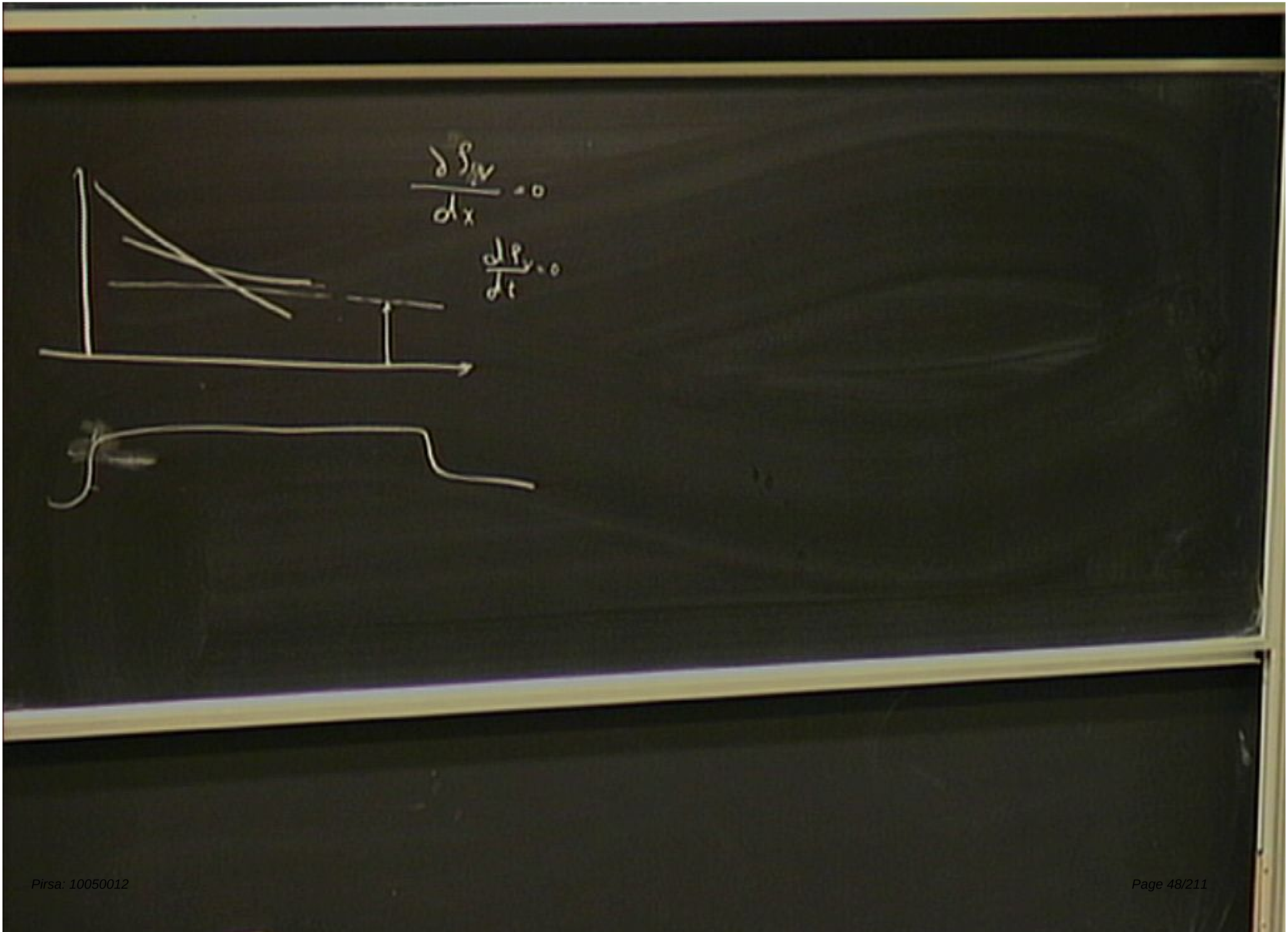
$R^{(D),(6)}$ → DGP

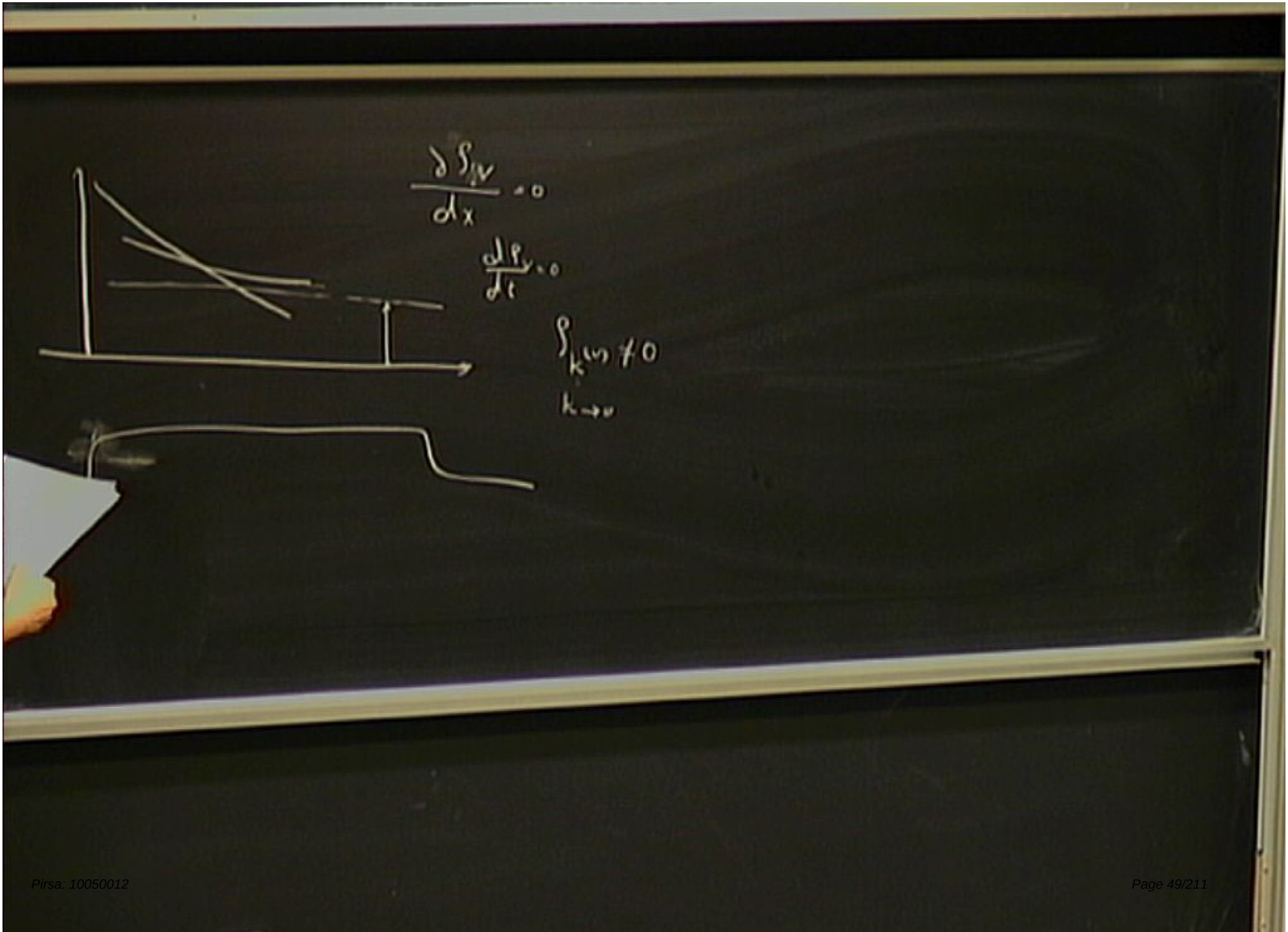
→ cascading grav.

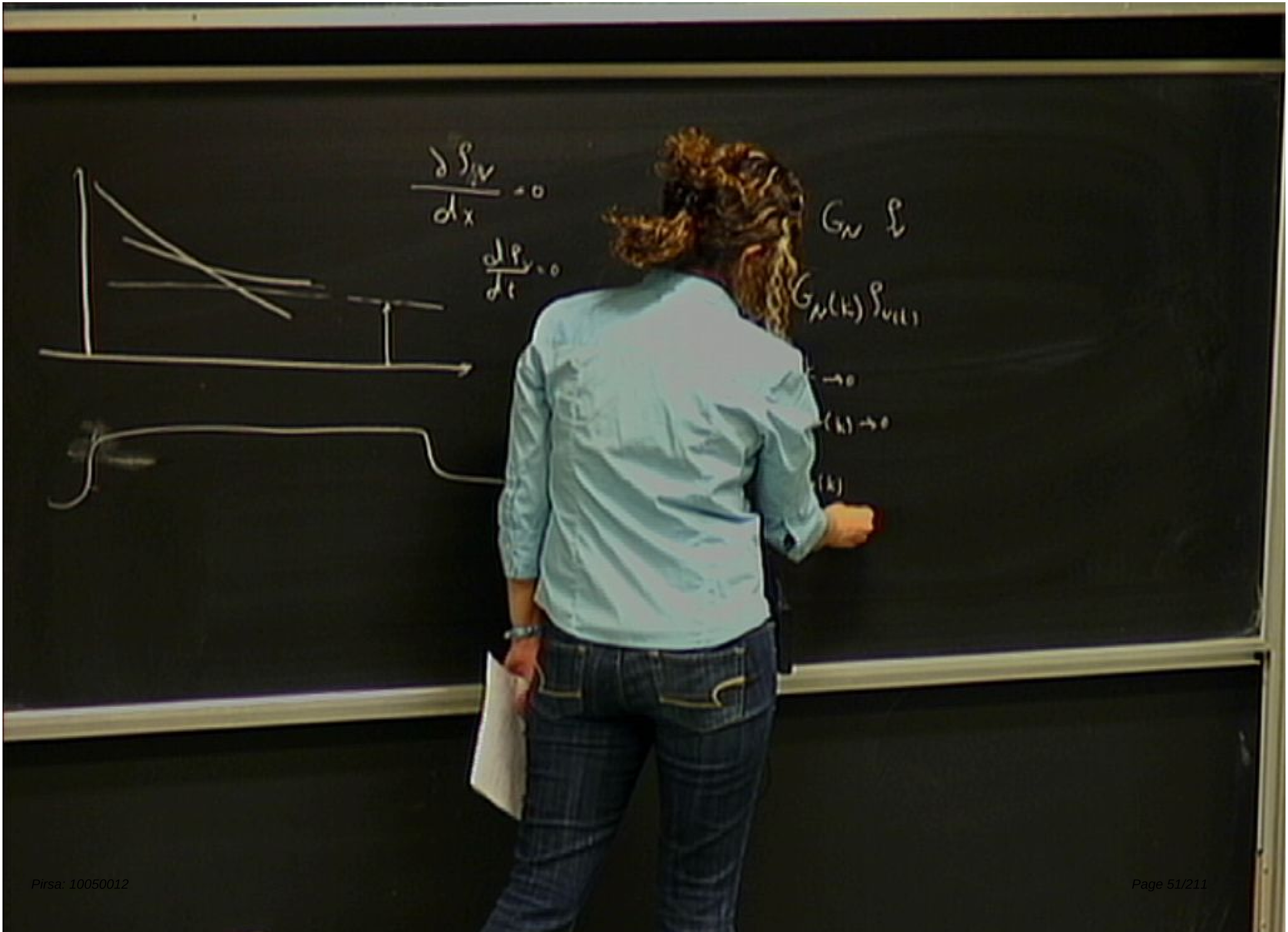




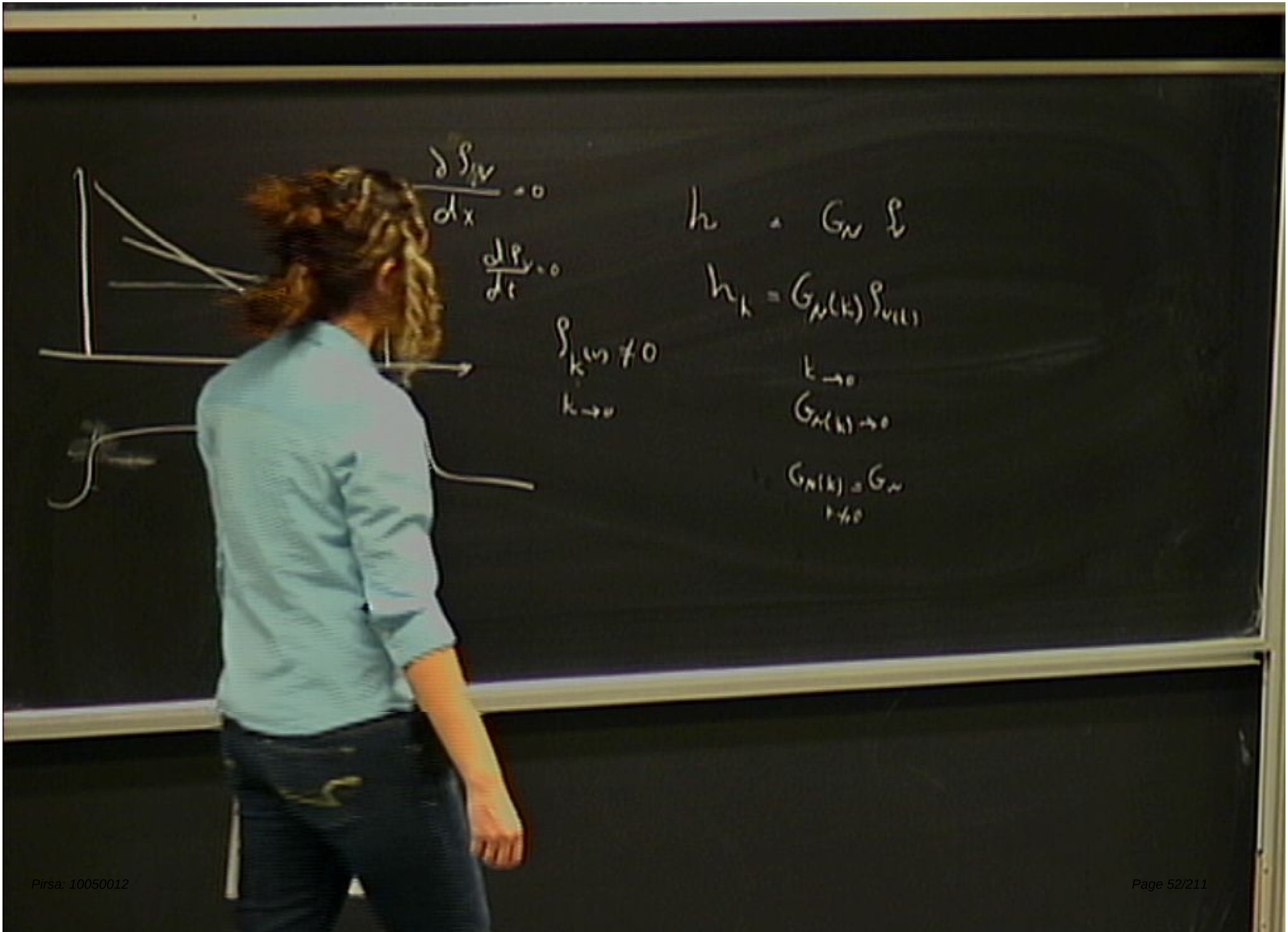
$\frac{d \rho_{\mu\nu}}{dx} = 0$
$\frac{d \rho_{\nu}}{dt} = 0$

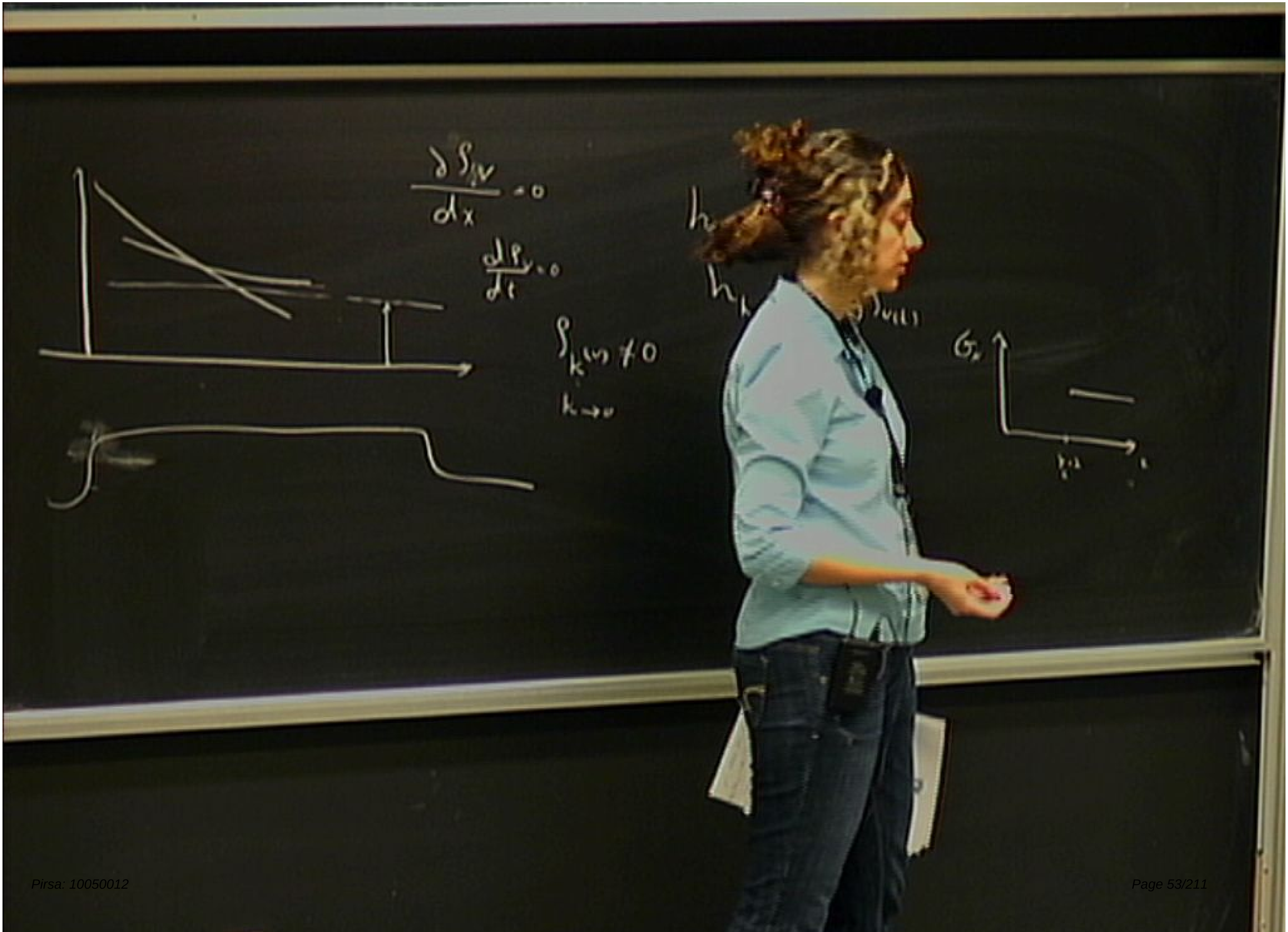

$\frac{\partial \rho_{\mu\nu}}{\partial x} = 0$
$\frac{d \rho_{\nu}}{d t} = 0$

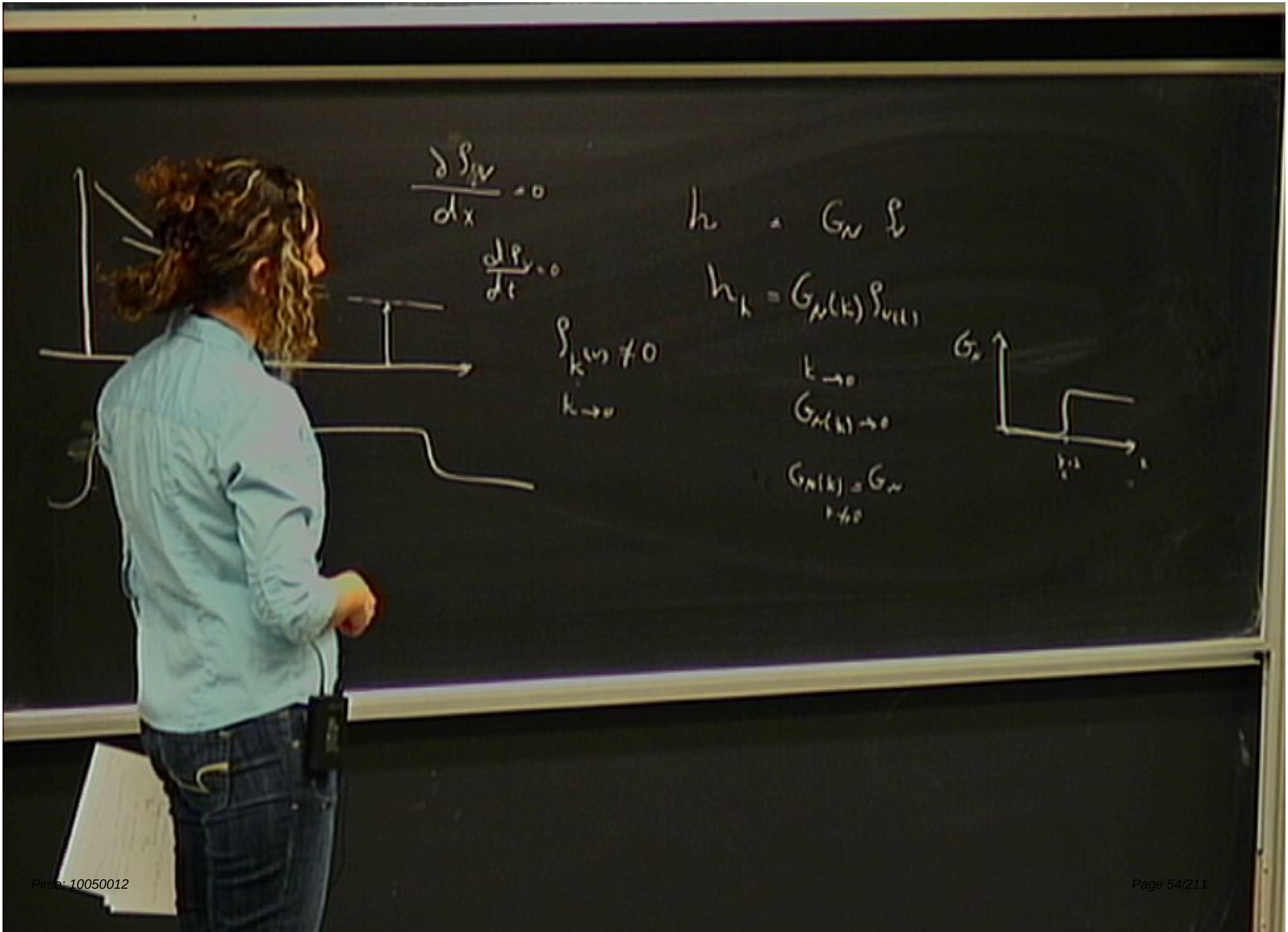

$\frac{\partial \rho_N}{\partial x} = 0$
$\frac{d\rho_N}{dt} = 0$
$\rho_k(\omega) \neq 0$
$k \to 0$



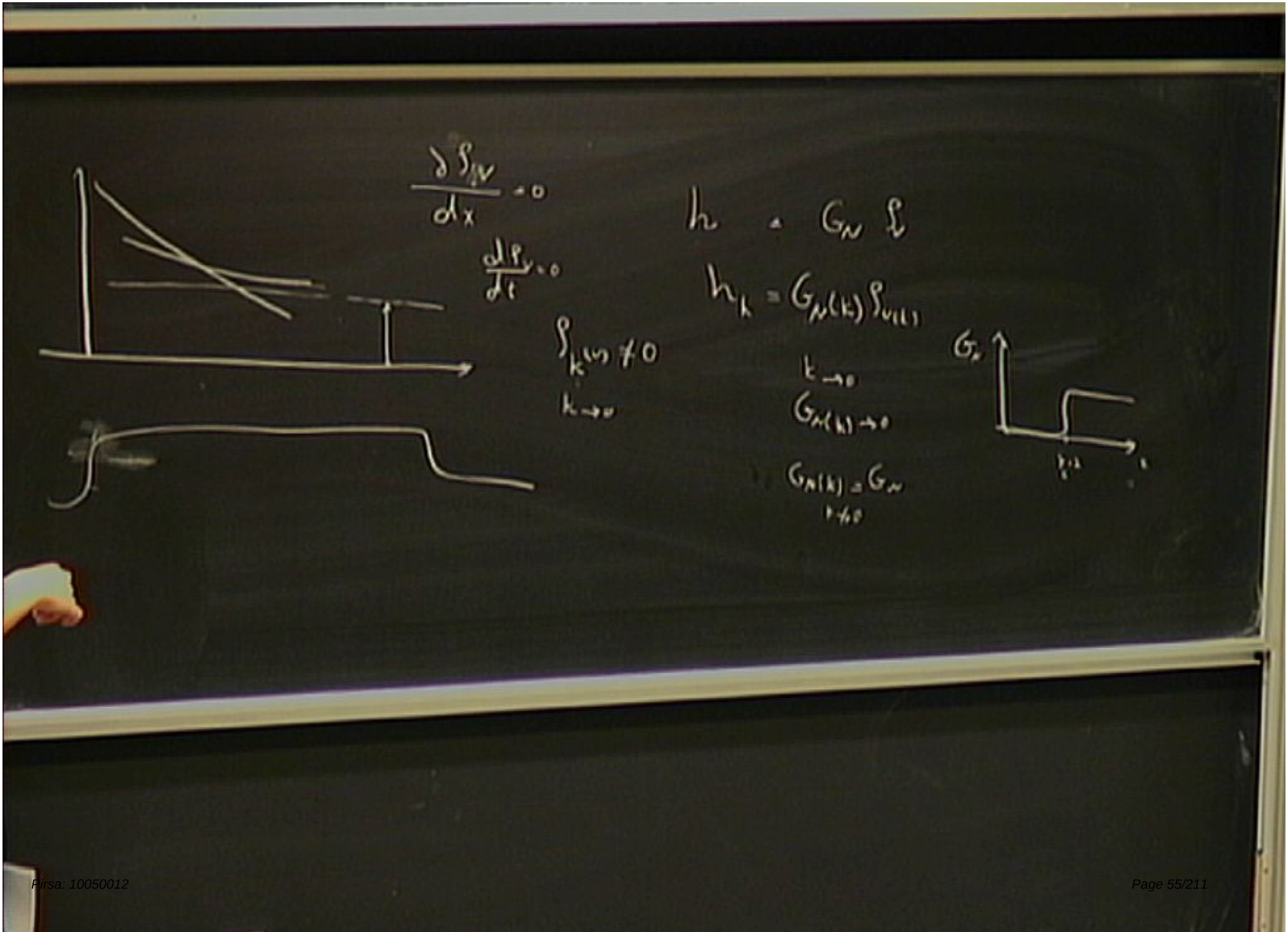
$\frac{\partial \rho_N}{\partial x} = 0$
$\frac{d\rho_N}{dt} = 0$
G_N ρ
$G_N(k)\,\rho_{N(k)}$


$\frac{\partial \rho_\nu}{\partial x} = 0$
$\frac{d\rho_\nu}{dt} = 0$
$\rho_{k(x)} \neq 0$
$k \to 0$
$h = G_N \rho$
$h_k = G_{N(k)} \rho_{\nu(k)}$
$k \to 0$
$G_{N(k)} \to 0$
$G_{N(k)} = G_N$
$k \neq 0$

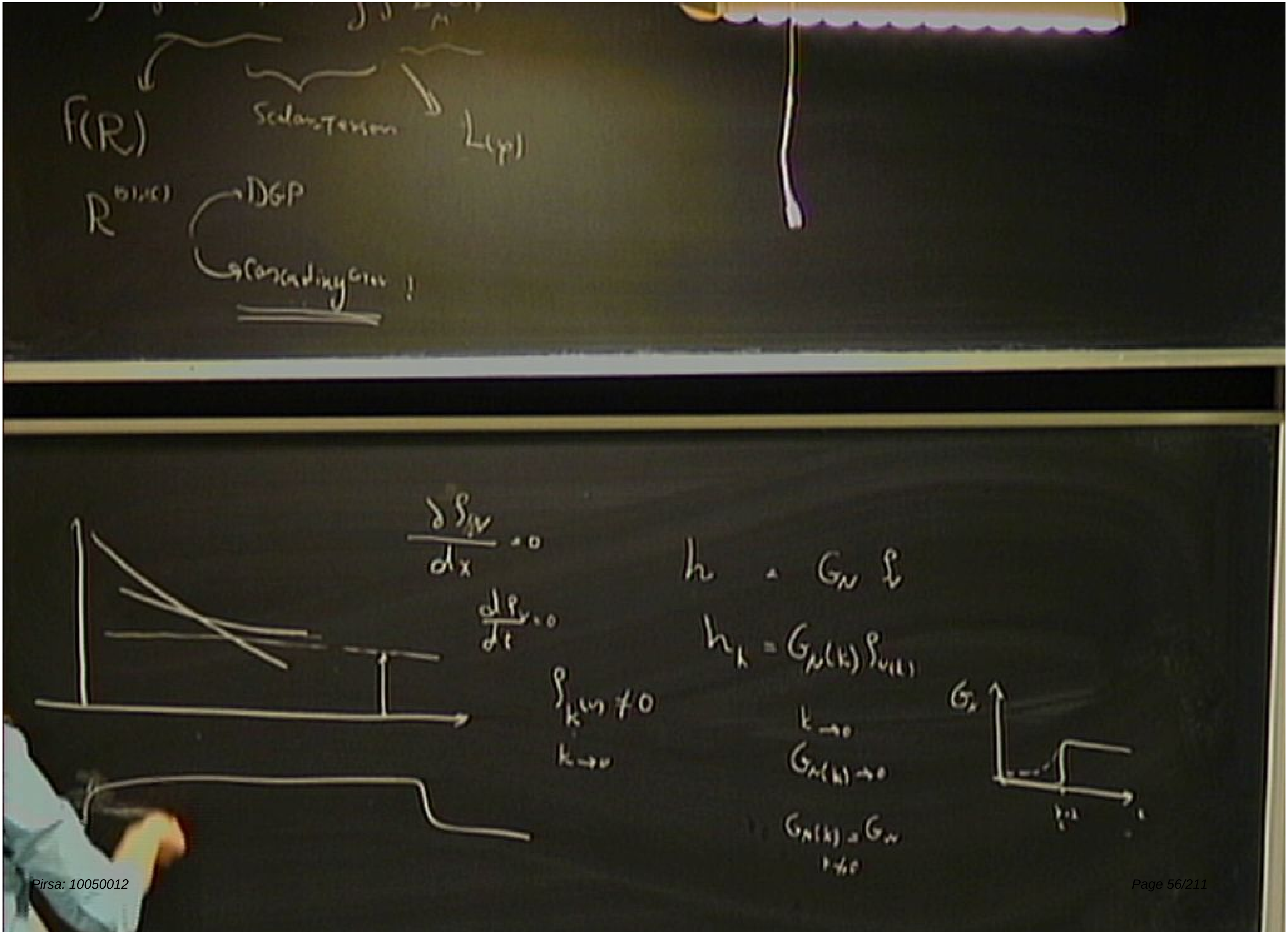

$\frac{\partial \rho_N}{\partial x} = 0$
$\frac{d\rho_N}{dt} = 0$
$\rho_k(t) \neq 0$
$k \to 0$



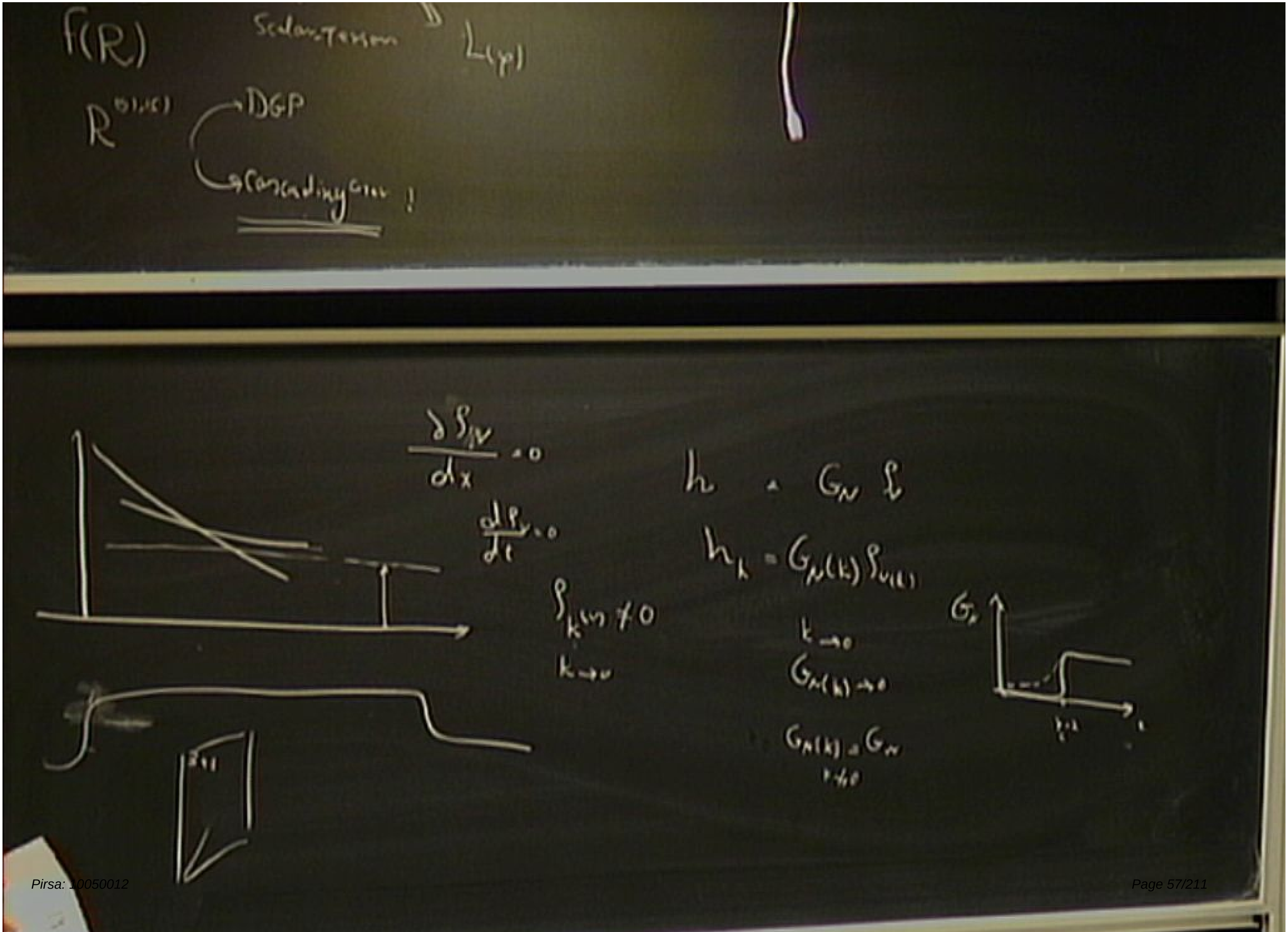
$\frac{\partial \rho_{N}}{dx} = 0$
$\frac{d\rho_{N}}{dt} = 0$
$\rho_{k(x)} \neq 0$
$k \to 0$
$h = G_N \rho$
$h_k = G_{N(k)} \rho_{v(k)}$
$k \to 0$
$G_{N(k)} \to 0$
$G_{N(k)} = G_N$
G_N



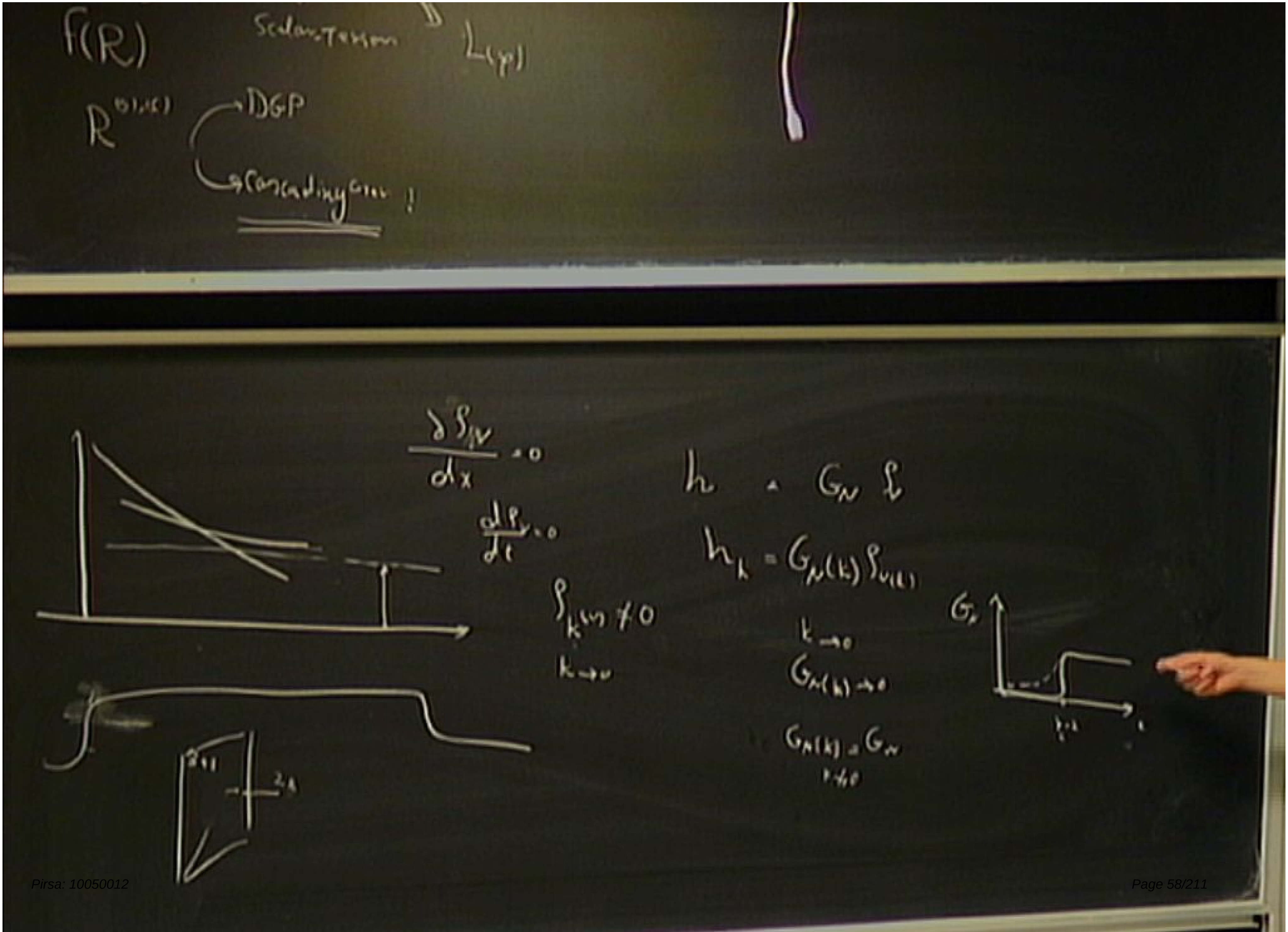
dρ_N / dx = 0
dρ_N / dt = 0
ρ_k(t) ≠ 0
k → 0
h = G_N ρ
h_k = G_N(k) ρ_N(k)
k → 0
G_N(k) → 0
G_N(k) = G_N
k ≠ 0
G_N



f(R)
Scalar-Tensor
L(φ)
DGP
Cascading Grav !
h = G_N ρ
h_k = G_N(k) ρ_v(k)
ρ_k ≠ 0
k → 0
G_N(k) → 0
G_N(k) = G_N



f(R)
DGP
h = G_N ρ
k→0
G_N(k) = G_N



f(R)
Scalar-Tensor
DGP
Cascading grav !
h = G_N ρ

$f(R)$

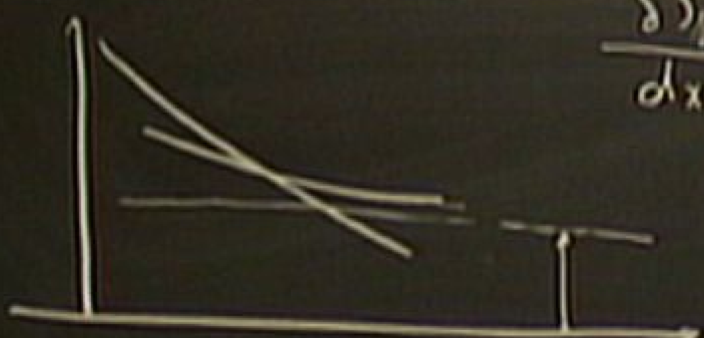
Scalar-Tensor

$L(p)$

$R^{(5)}$

DGP

Cascading grav !



$\frac{\partial \rho_N}{dx} = 0$

$\frac{d\rho_N}{dt} = 0$

$\rho_{k(x)} \neq 0$

$k \to \infty$

$h = G_N \rho$

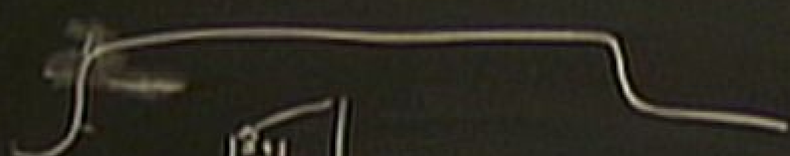
$h_k = G_{N(k)} \rho_{N(k)}$

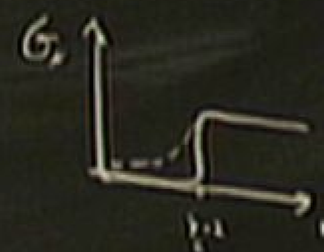
$k \to 0$

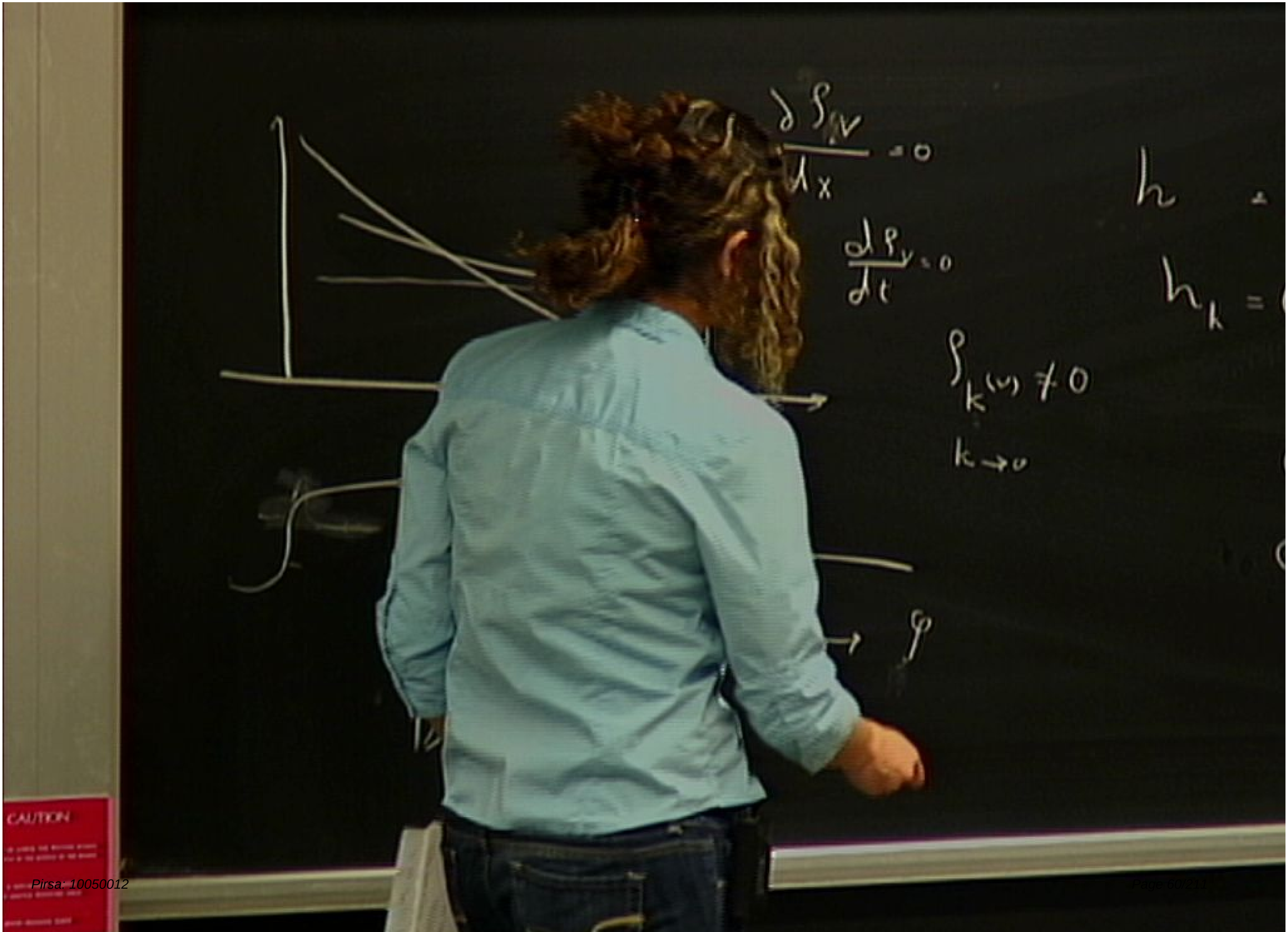
$G_{N(k)} \to 0$

$G_{N(k)} = G_N$

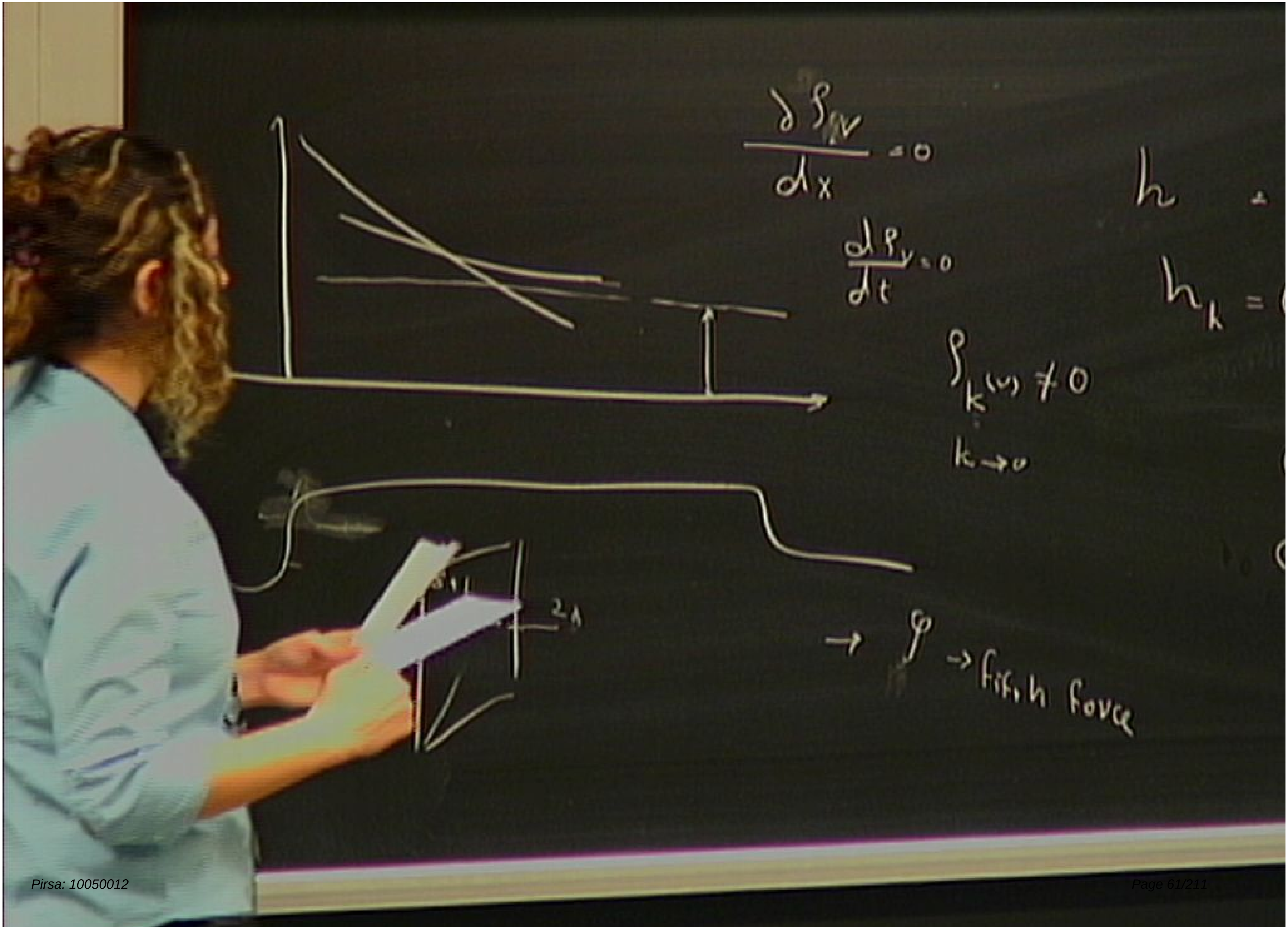
$k \neq 0$

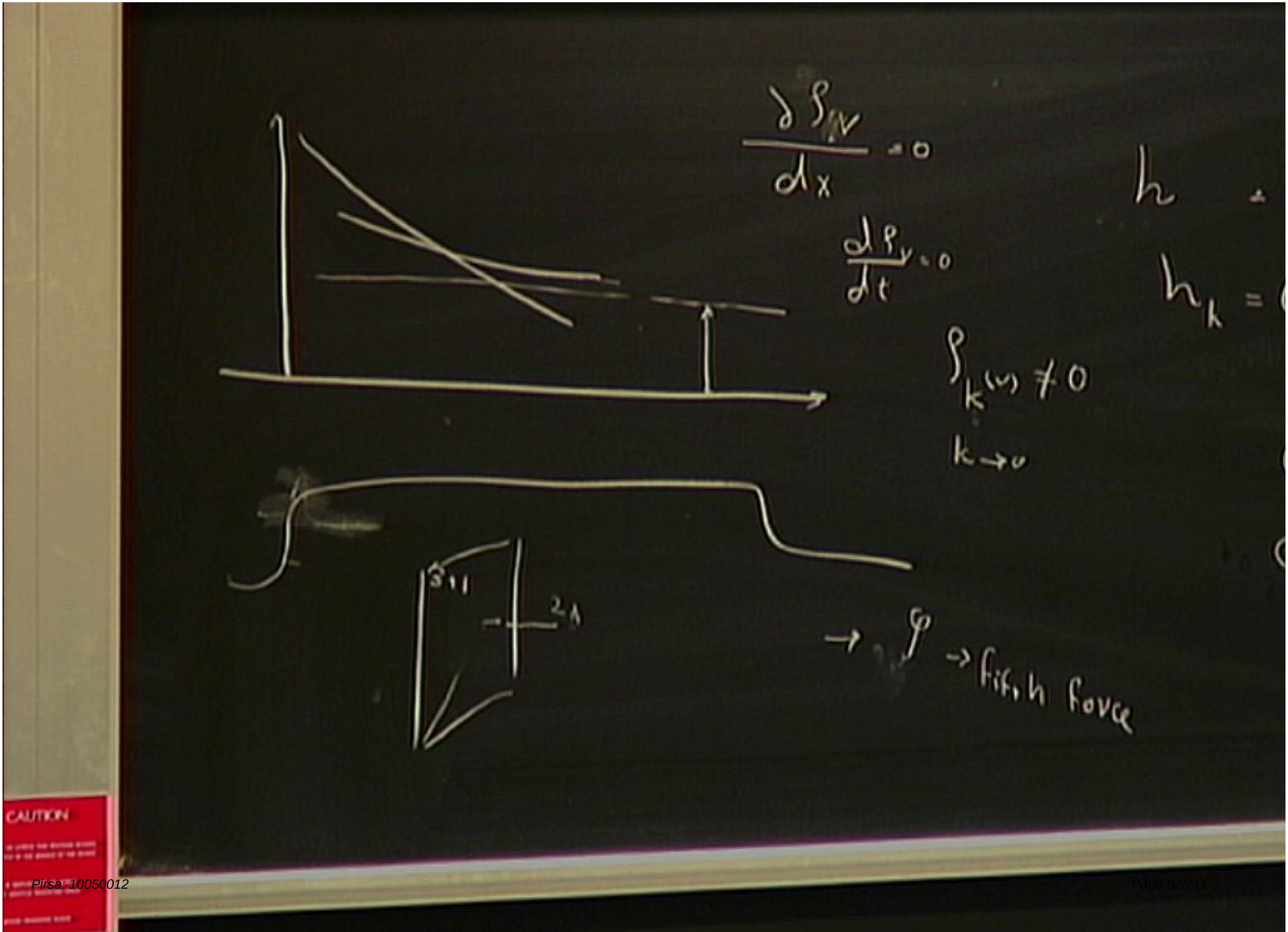




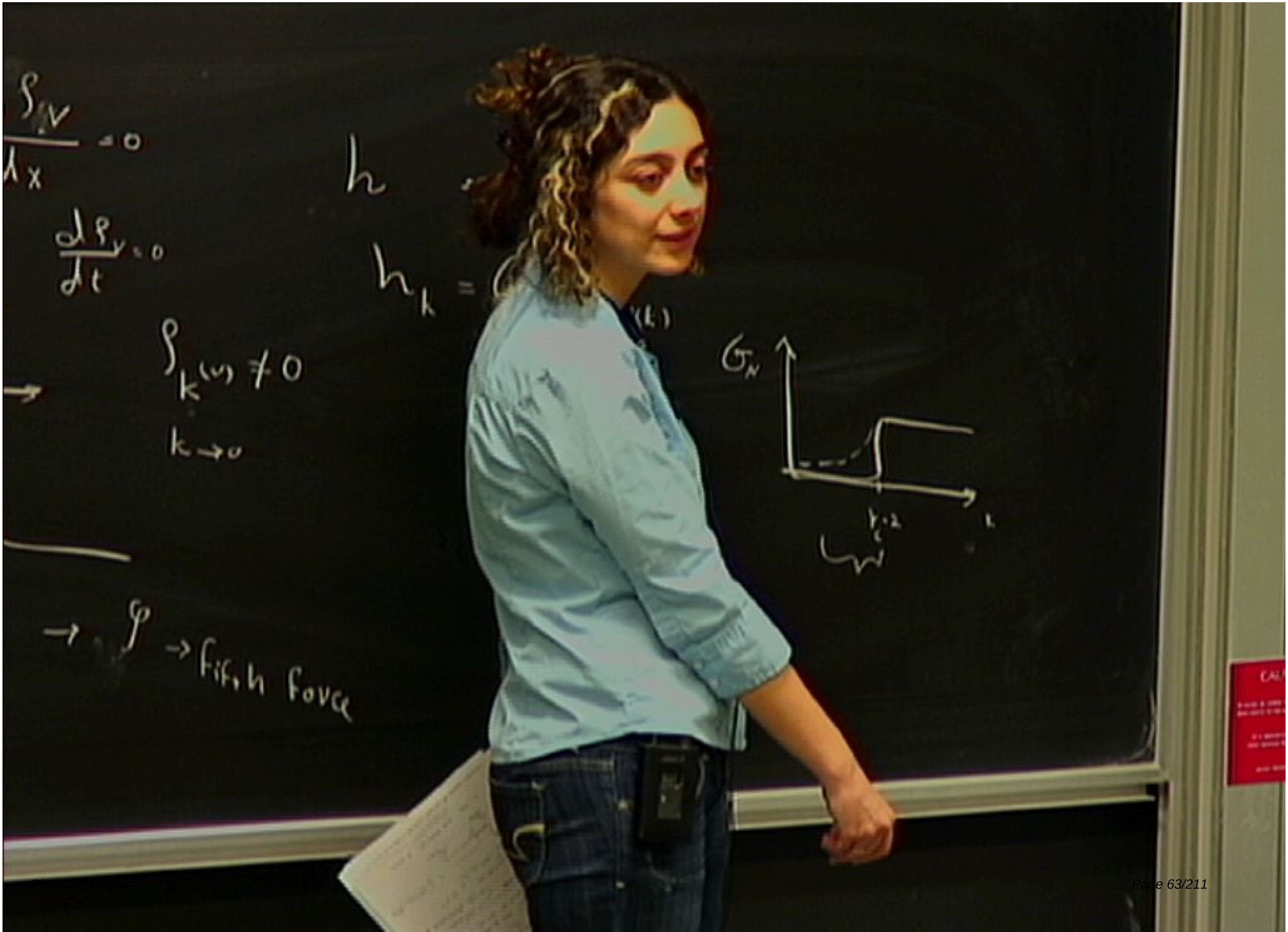


CAUTION
= 0
h
h_k =
k → 0

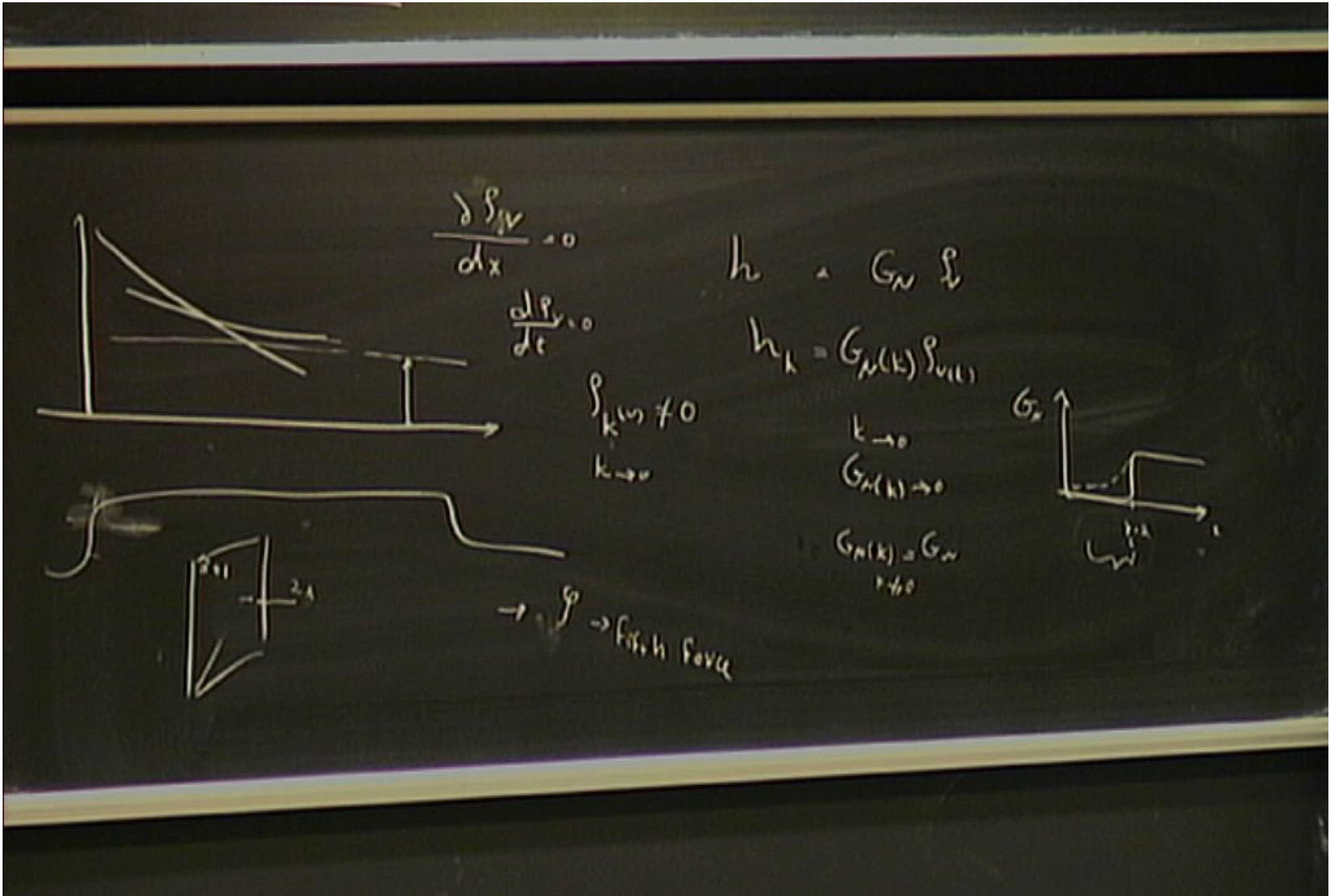

$\frac{d\rho_\nu}{dt} = 0$
$\rho_{k(\nu)} \neq 0$
$k \to 0$
force

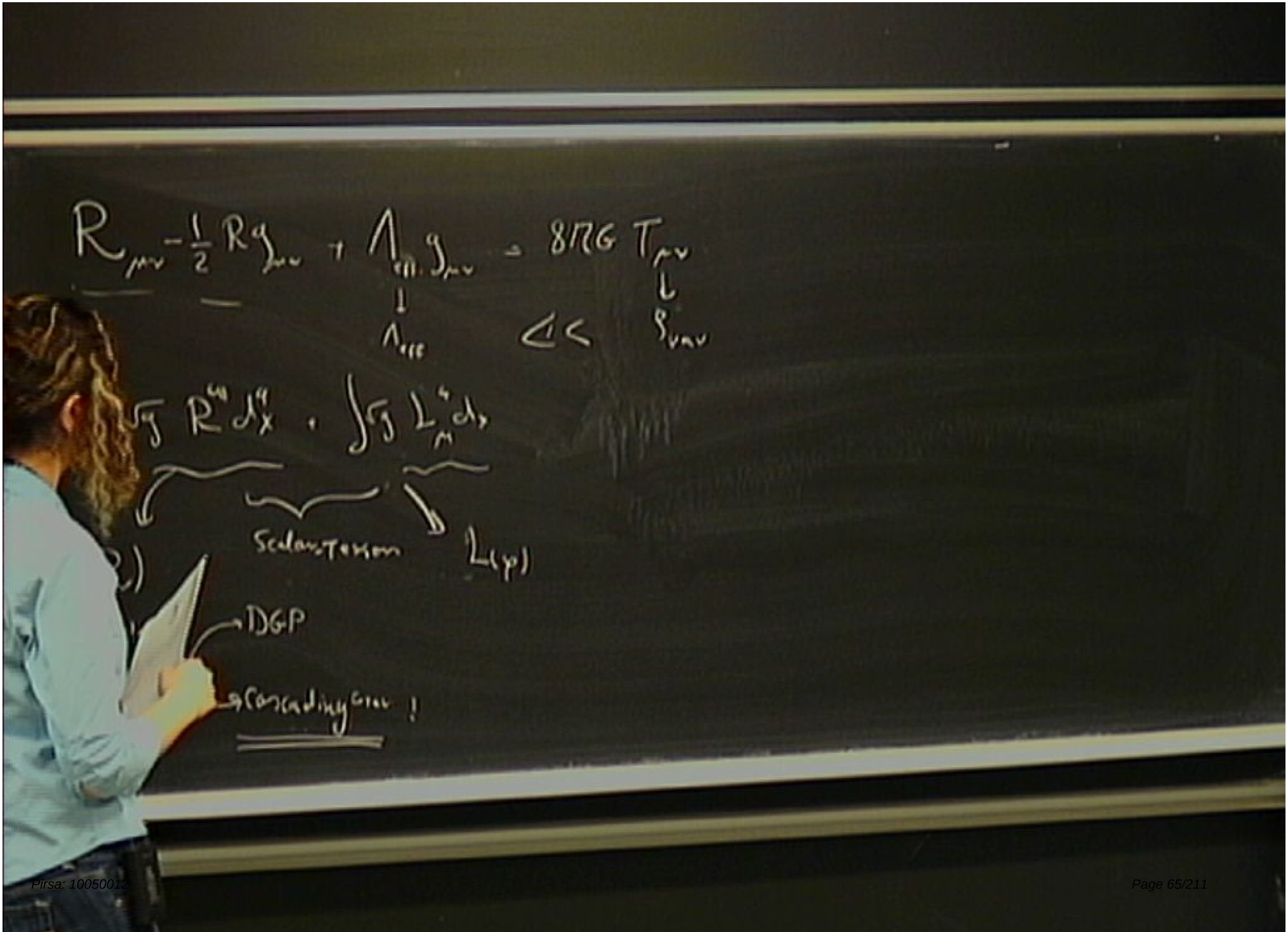


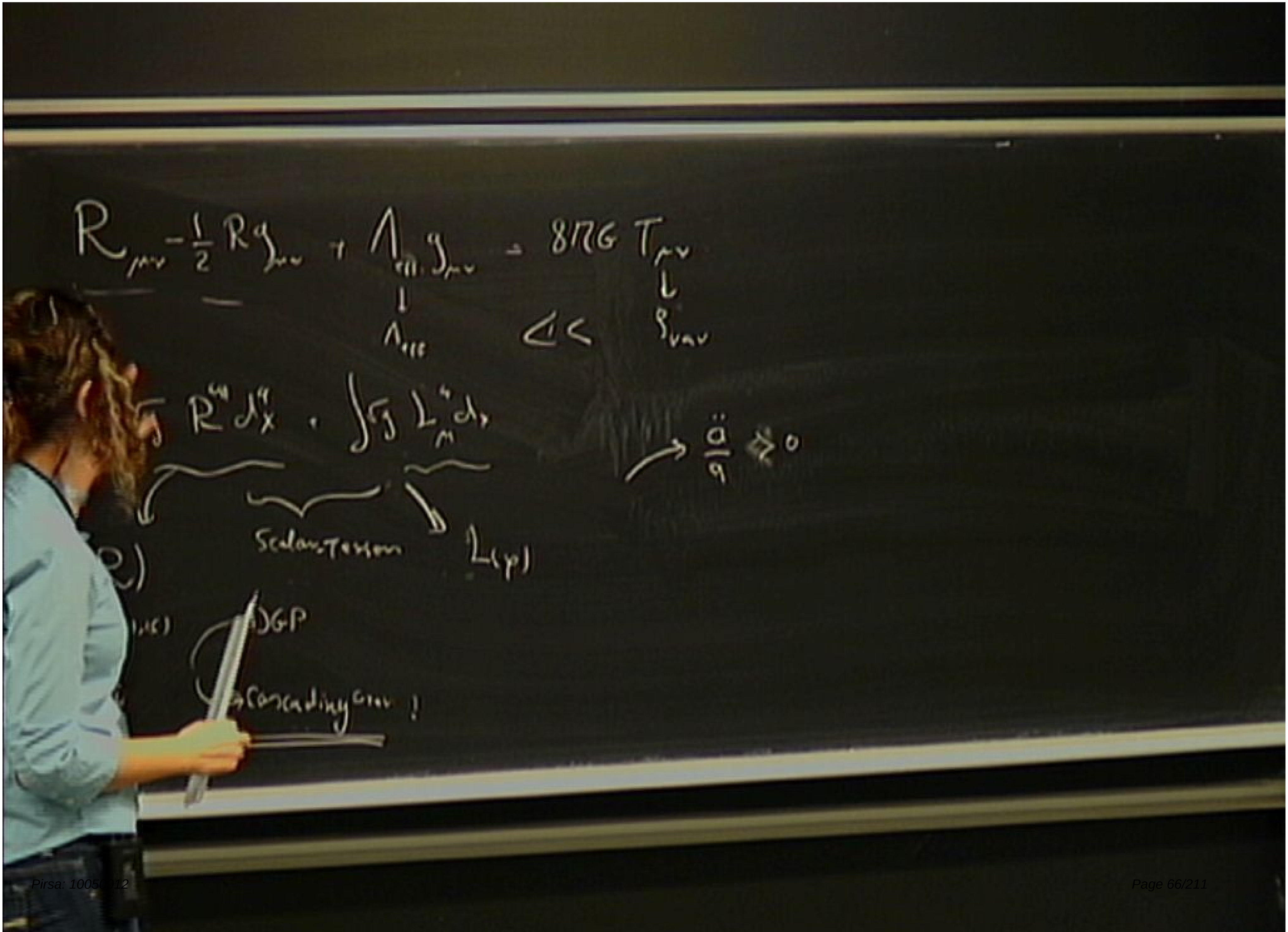
$\frac{\partial \rho_N}{dx} = 0$
$\frac{d\rho_\nu}{dt} = 0$
$\rho_{k(\nu)} \neq 0$
$k \to 0$
$\to \varphi \to$ fifth force
h
$h_k =$
CAUTION

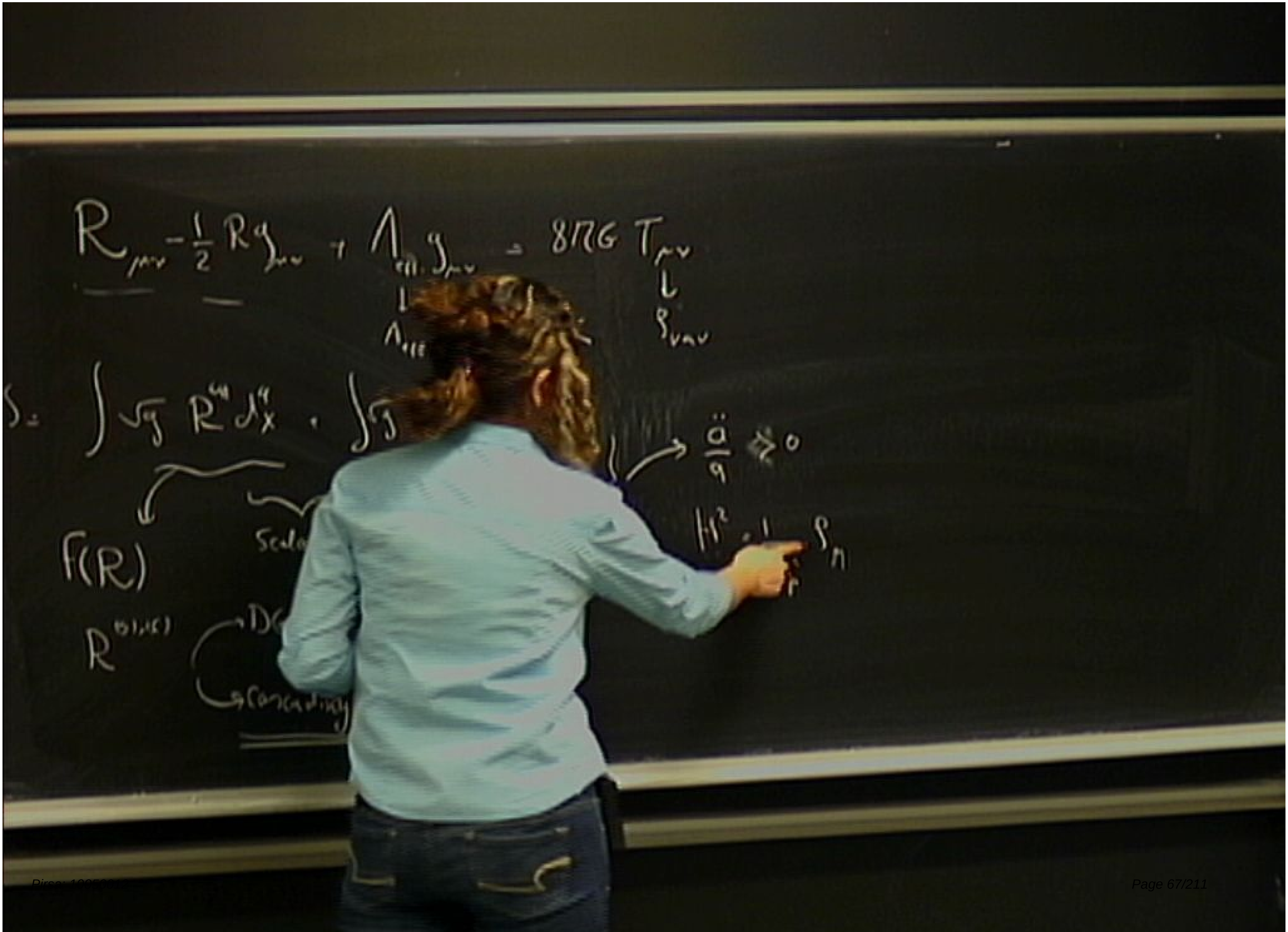


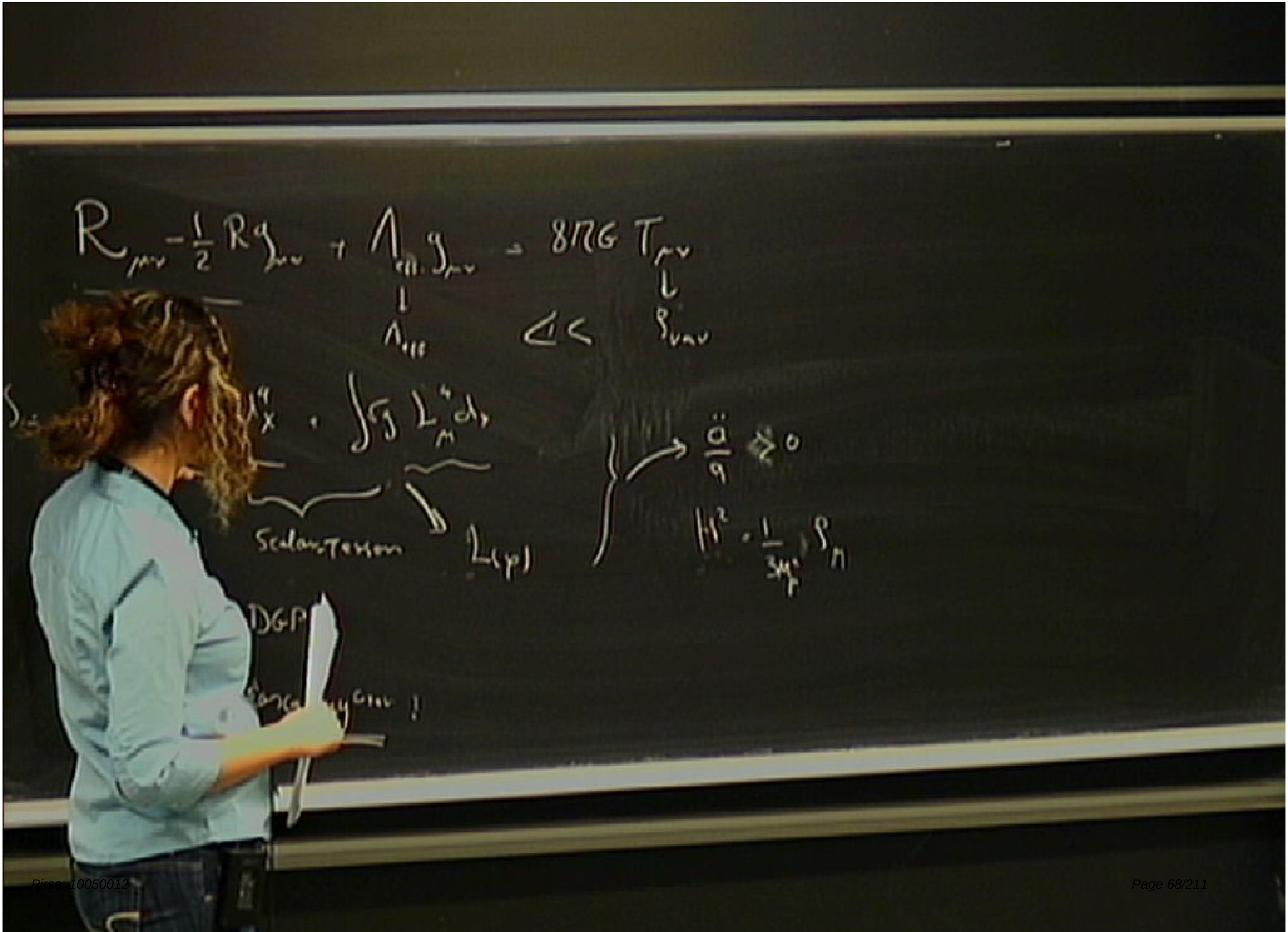
fifth force

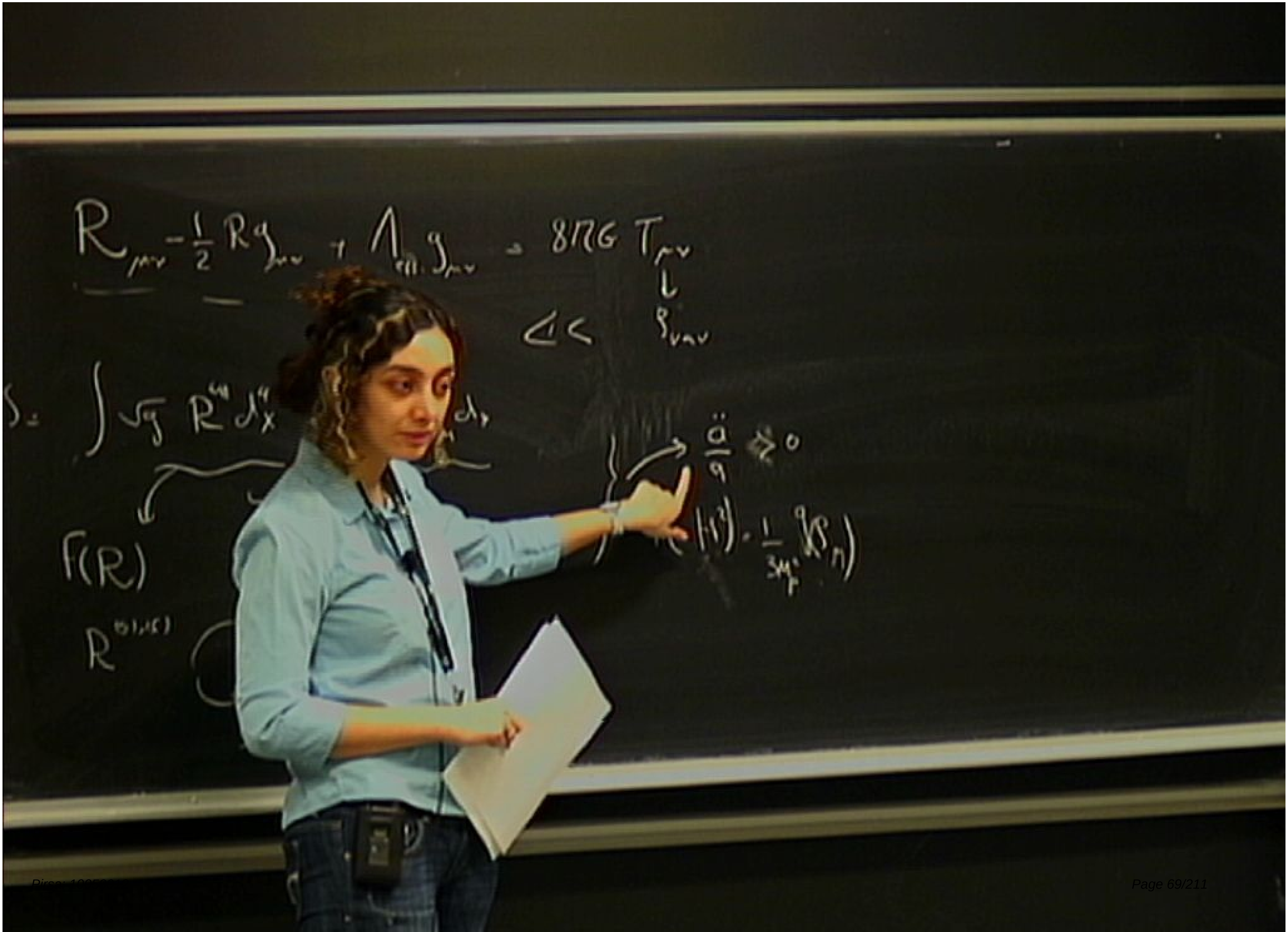

∂ρ_N / dx = 0
dρ_v / dt = 0
ρ_k(v) ≠ 0
k → 0
h = G_N ρ
h_k = G_N(k) ρ_v(k)
k → 0
G_N(k) → 0
G_N(k) = G_N
k ≠ 0
G_N
fifth force


$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{th} g_{\mu\nu} = 8\pi G T_{\mu\nu}$
Λ_{eff}
$\ll$
ρ_{vac}
$\sqrt{g}\, R^{4} d^{4}x + \int \sqrt{g}\, L_{m}^{4} d^{4}x$
Scalar-Tensor
$L(\varphi)$
DGP
Cascading Grav !

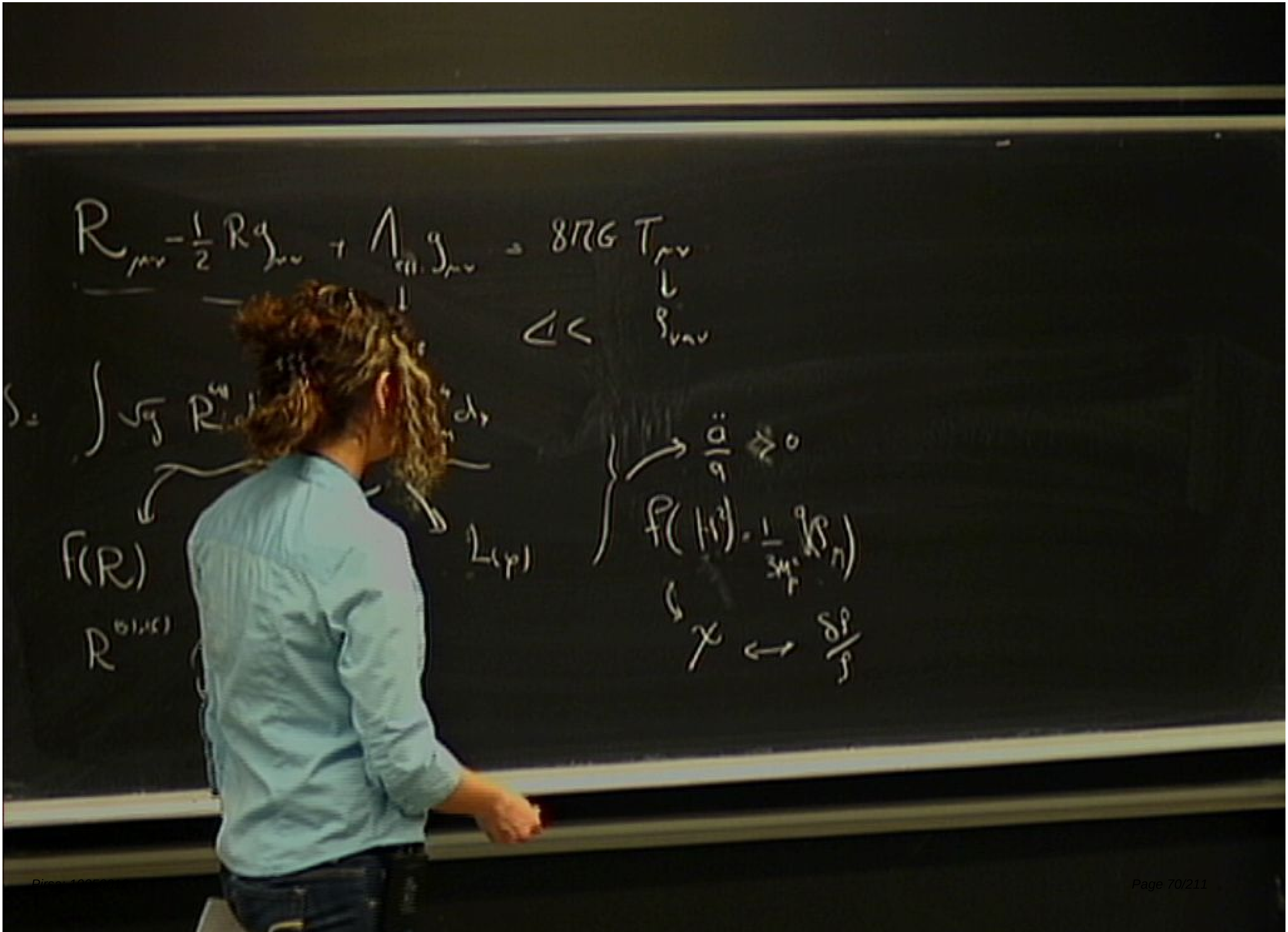

$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$
Λ_{eff}
$\ll$
ρ_{vac}
$R^4 d^4x + \int \sqrt{g}\, L_m^4\, d^4x$
$\frac{\ddot{a}}{a} > 0$
Scalar-Tensor
$L(\varphi)$
DGP
Cascading Grav !

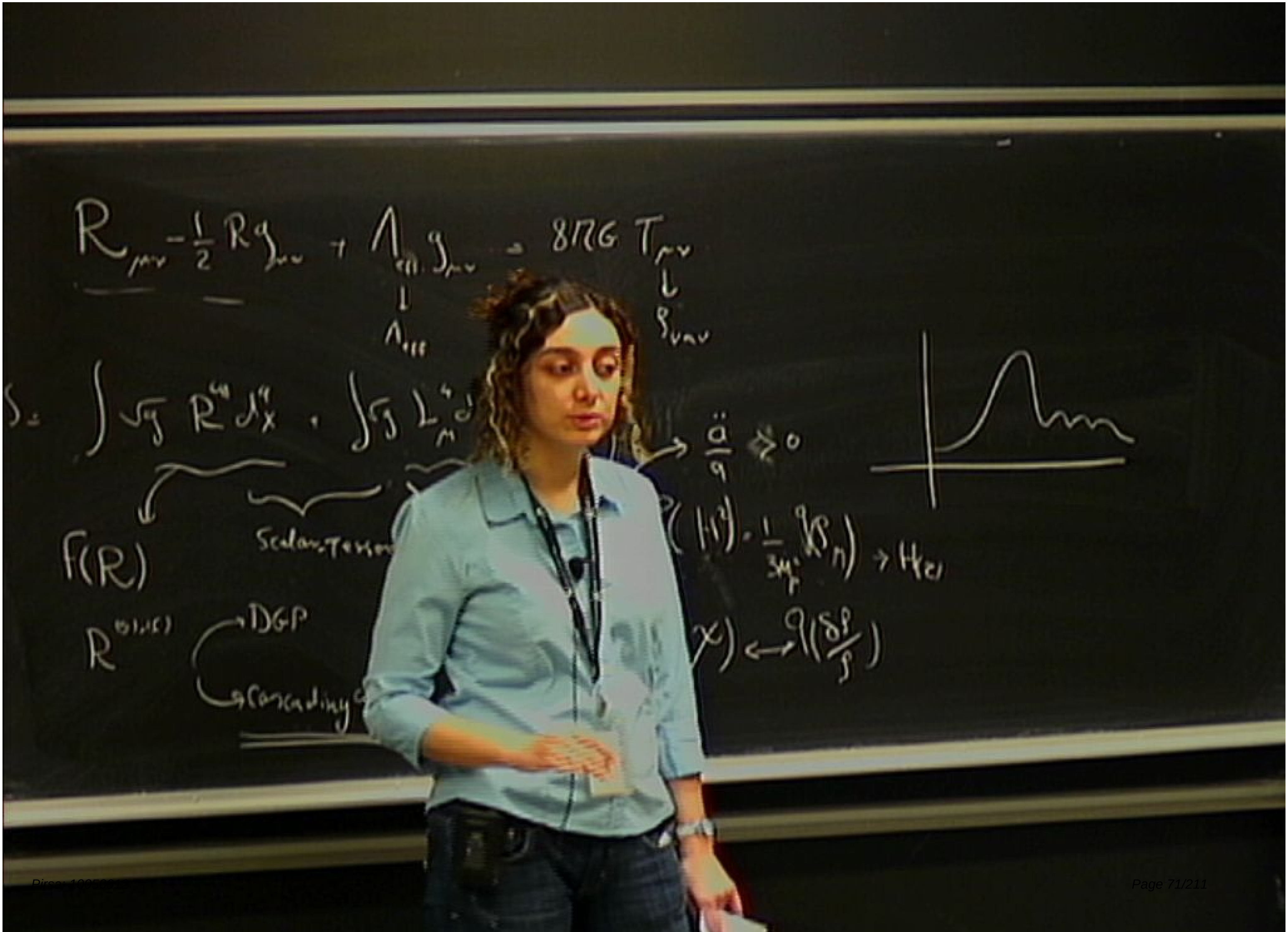

$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff} g_{\mu\nu} = 8\pi G T_{\mu\nu}$
ρ_{vac}
$S = \int \sqrt{g} R^{4} d^4x + \int \sqrt{g}$
$\frac{\ddot{a}}{a}$
$f(R)$
Scalar
$R^{(5),(6)}$
Cascading


$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$
Λ_{eff}
$<<$
ρ_{vac}
Scalar-Tensor
$L(\varphi)$
DGP



$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff} g_{\mu\nu} = 8\pi G T_{\mu\nu}$
f(R)


$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$
$\ll \quad \rho_{vac}$
$S = \int \sqrt{g}\, R \ldots$
$f(R)$
$\mathcal{L}(\varphi)$
$\frac{\ddot{a}}{a} > 0$
$\chi \leftrightarrow \frac{\delta\rho}{\rho}$


f(R)
DGP
Cascading
Scalar-Tensor

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$$

$$\Lambda_{eff} \ll \rho_{vac}$$

$$S = \int \sqrt{g}\, R^4 d^4x + \int \sqrt{g}\, L_m^4 d^4x$$

$f(R)$ Scalar-Tensor $L(\phi)$

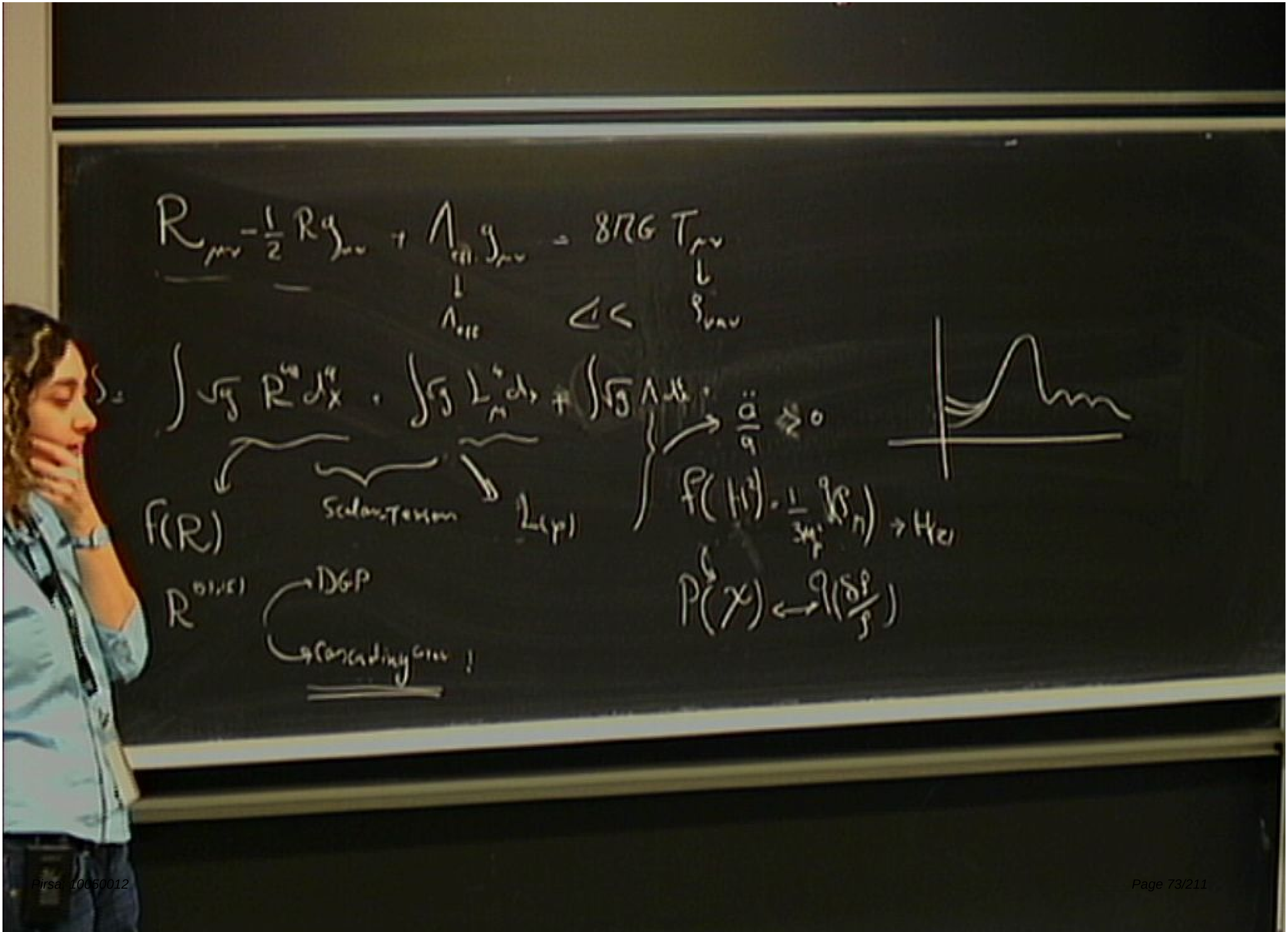
$R^{(5),(6)}$ → DGP

Cascading Grav!

$$\frac{\ddot{a}}{a} > 0$$

$$f\left(H(z)^2 = \frac{1}{3M_p^2} \sum \rho_n\right) \to H(z)$$

$$P(\chi) \longleftrightarrow \rho\left(\frac{\delta\rho}{\rho}\right)$$


R_{μν} - 1/2 R g_{μν} + Λ_{eff} g_{μν} = 8πG T_{μν}
f(R)
Scalar-Tensor
DGP

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{eff}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$$

$$\Lambda_{eff} \ll \rho_{vac}$$

$$S = \int \sqrt{g}\, R^{(4)} d^4x + \int \sqrt{g}\, L_m^{(4)} d^4x + \int \sqrt{g}\, \Lambda\, d^4x \to \frac{\ddot{a}}{a} \gtrless 0$$

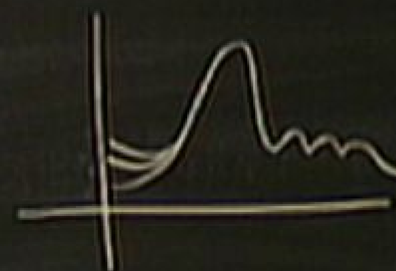
$f(R)$ — Scalar-Tensor — $L(\varphi)$

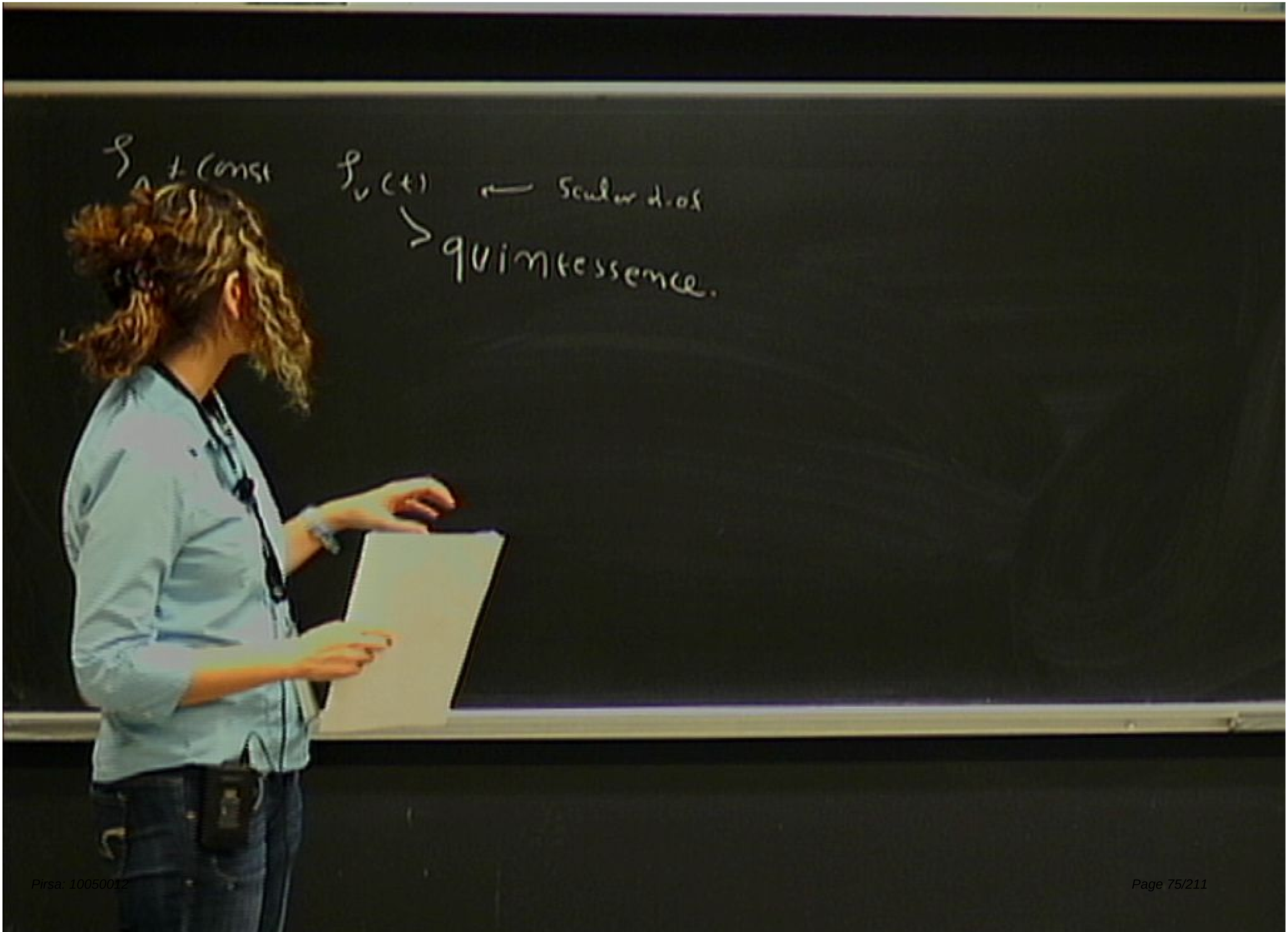
$$f(H(t)) = \frac{1}{3M_p^2} \sum \rho_n \to H(z)$$

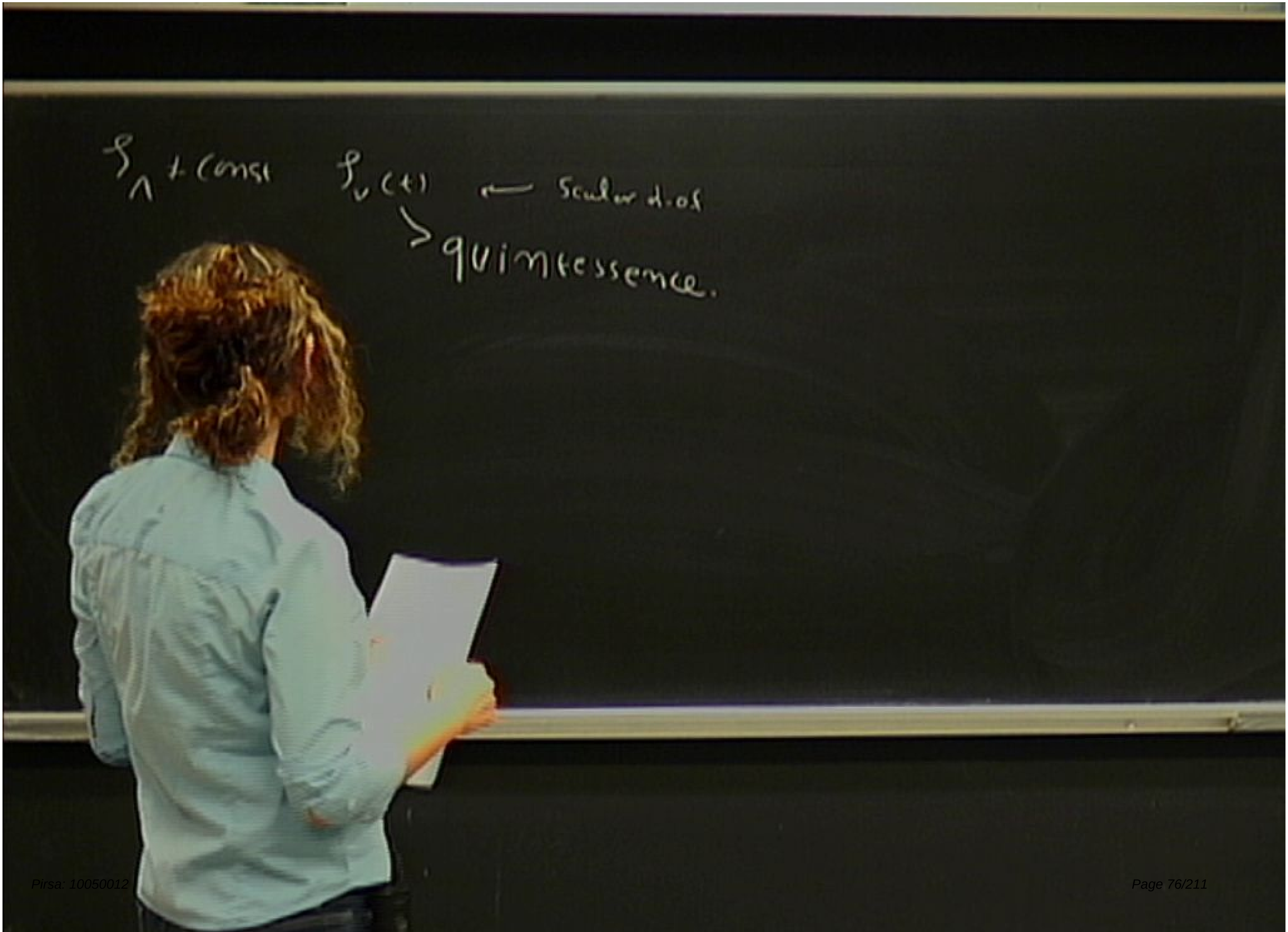
$$P(\chi) \longleftrightarrow q\left(\frac{\delta\rho}{\rho}\right)$$

$R^{(D>4)}$ → DGP

↳ Cascading Grav. !

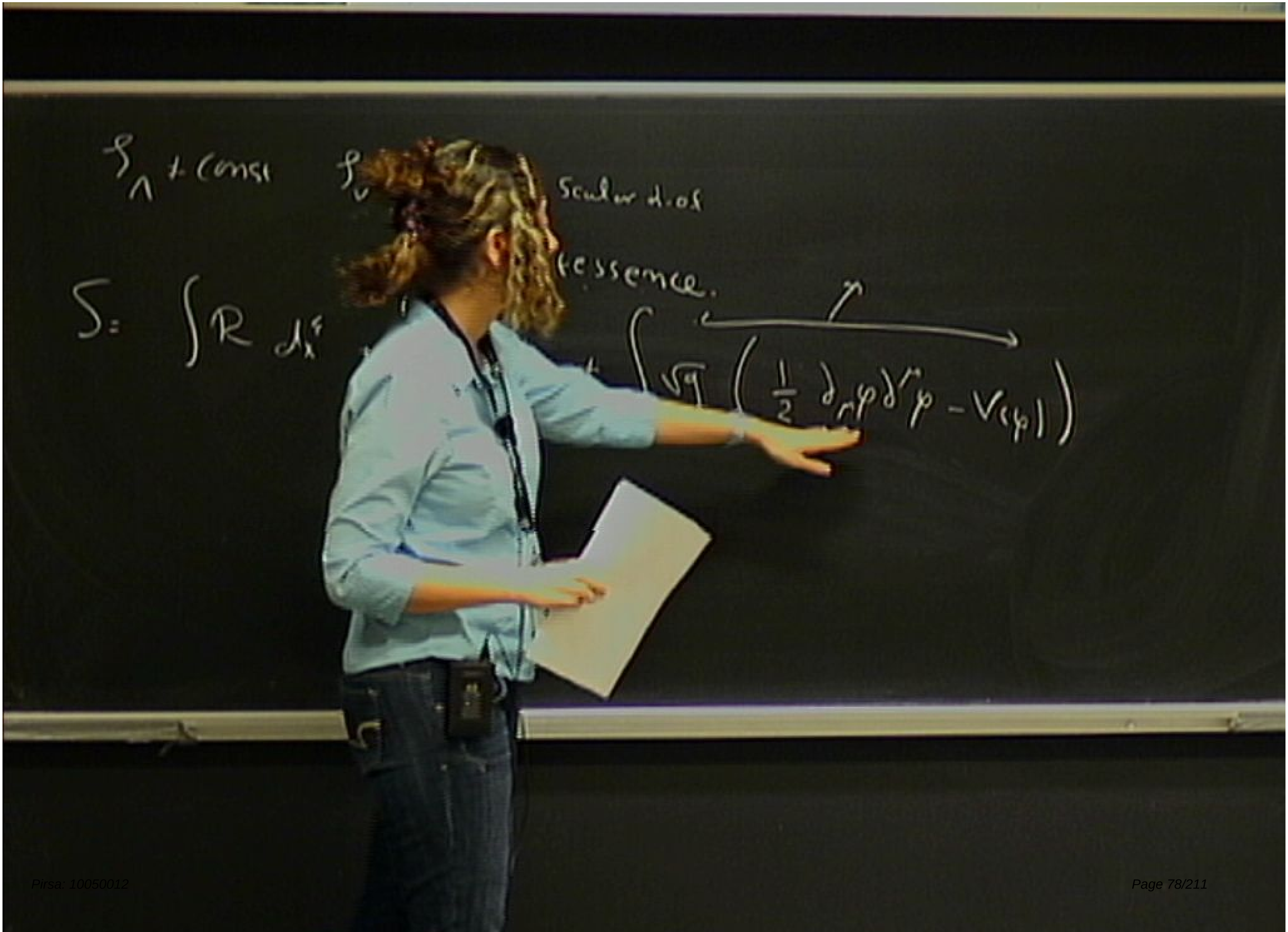



$\rho_\Lambda \neq$ const
$\rho_v(t)$ ← scalar d.o.f
> quintessence.

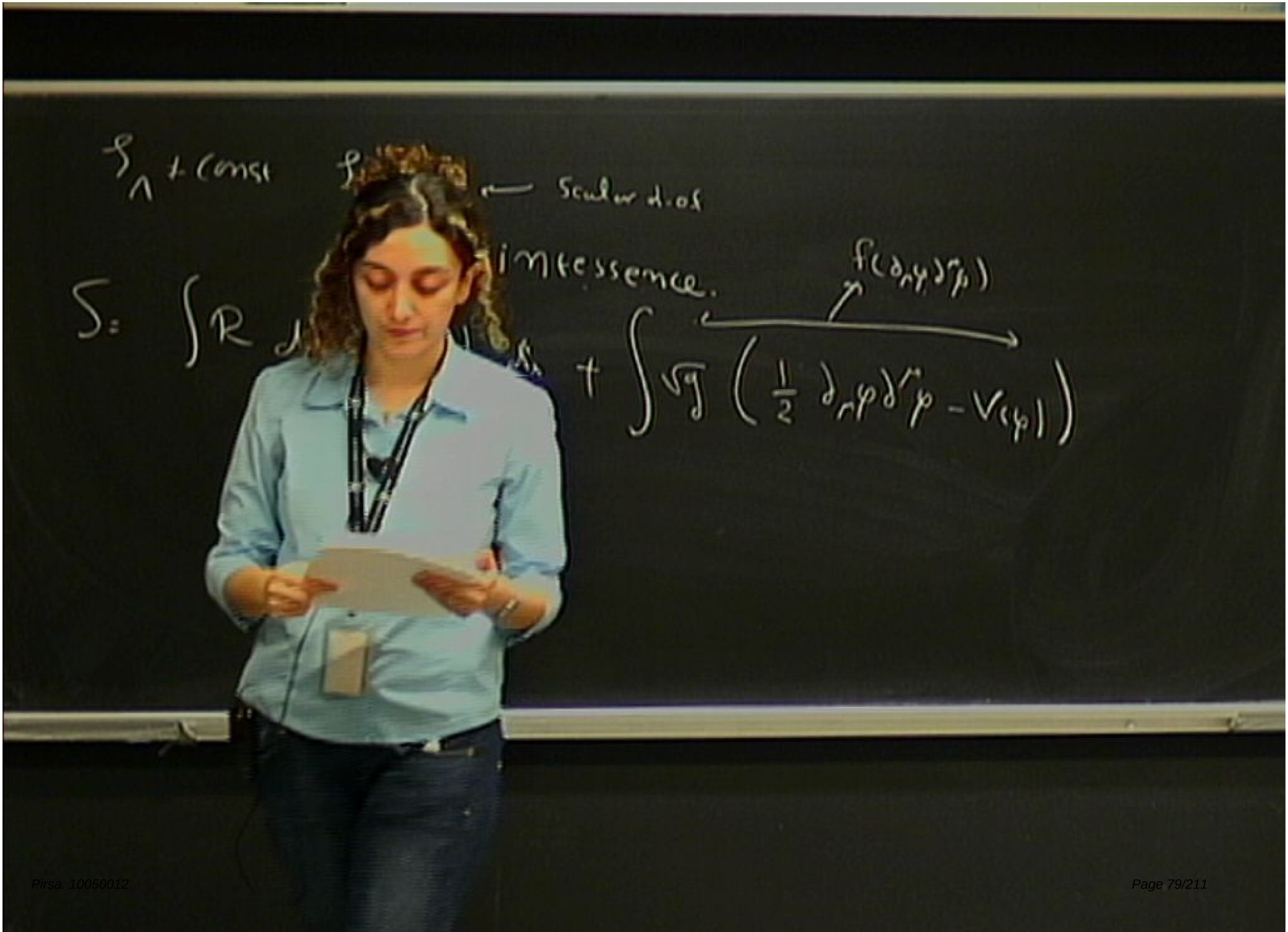

$\rho_\Lambda \neq$ const
$\rho_v(t)$ ← scalar d.o.f
quintessence.

$\rho_\Lambda \neq \text{const}$ $\quad \rho_v(t) \leftarrow$ scalar d.o.f

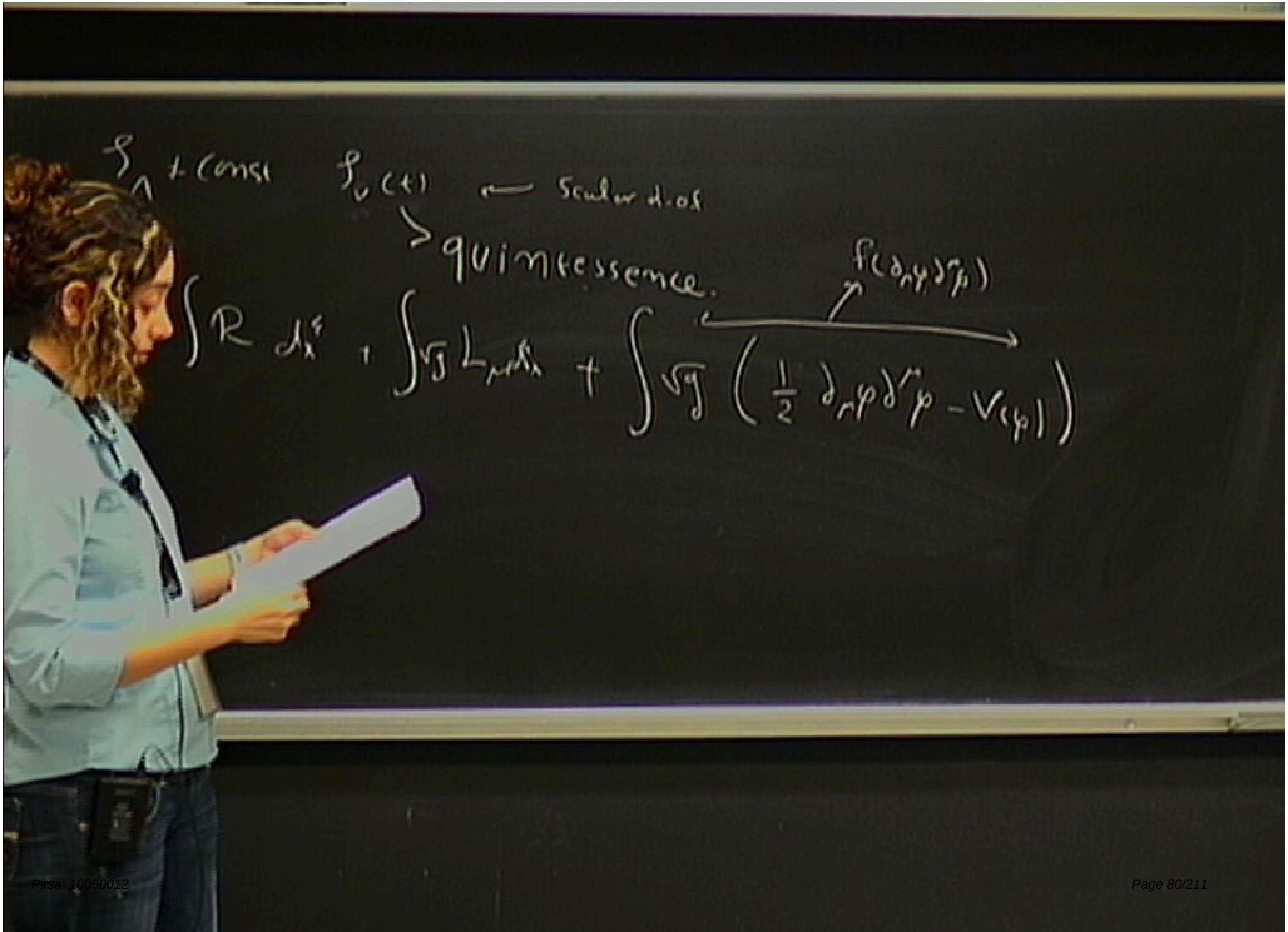
$>$ quintessence.

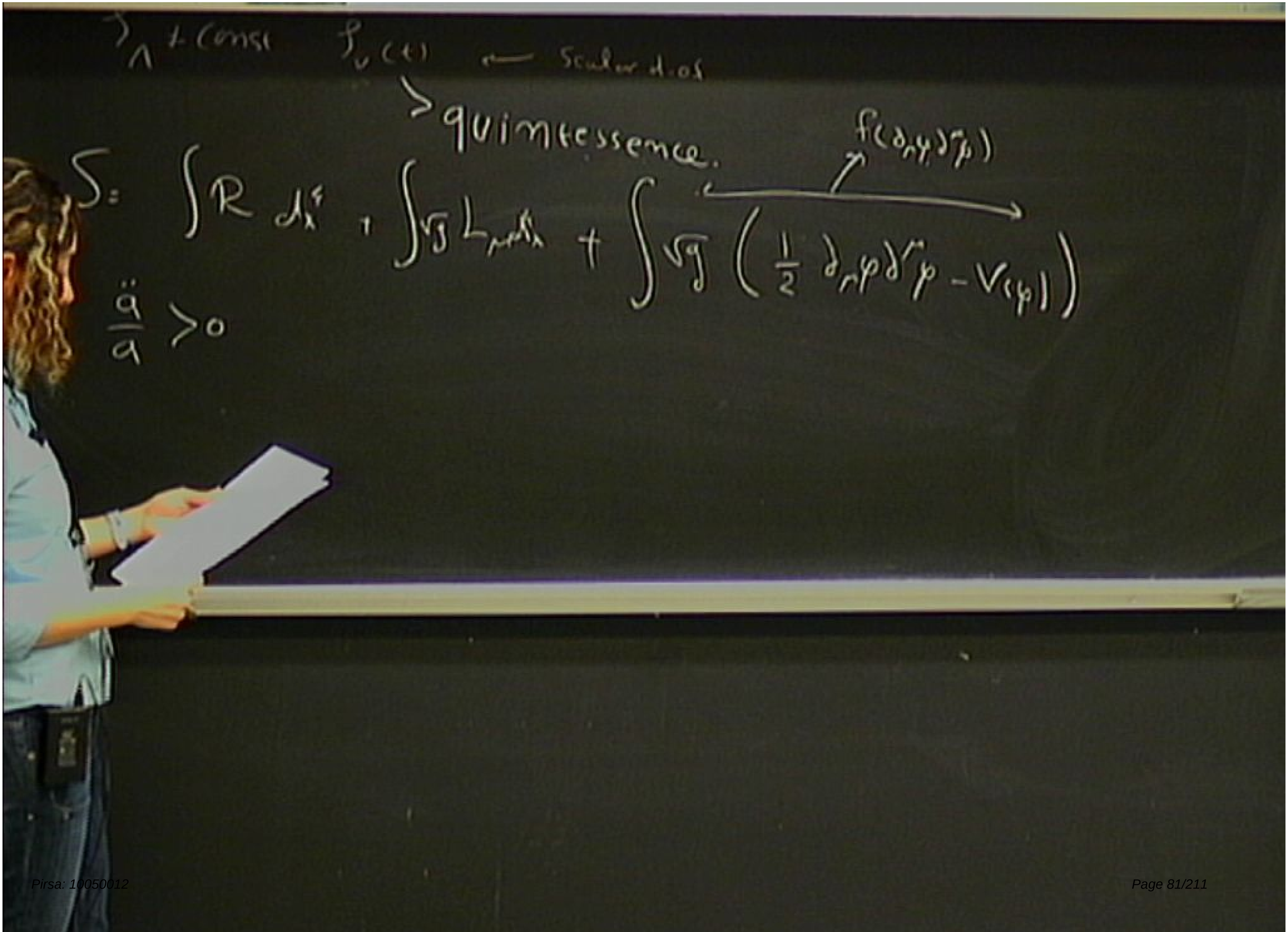


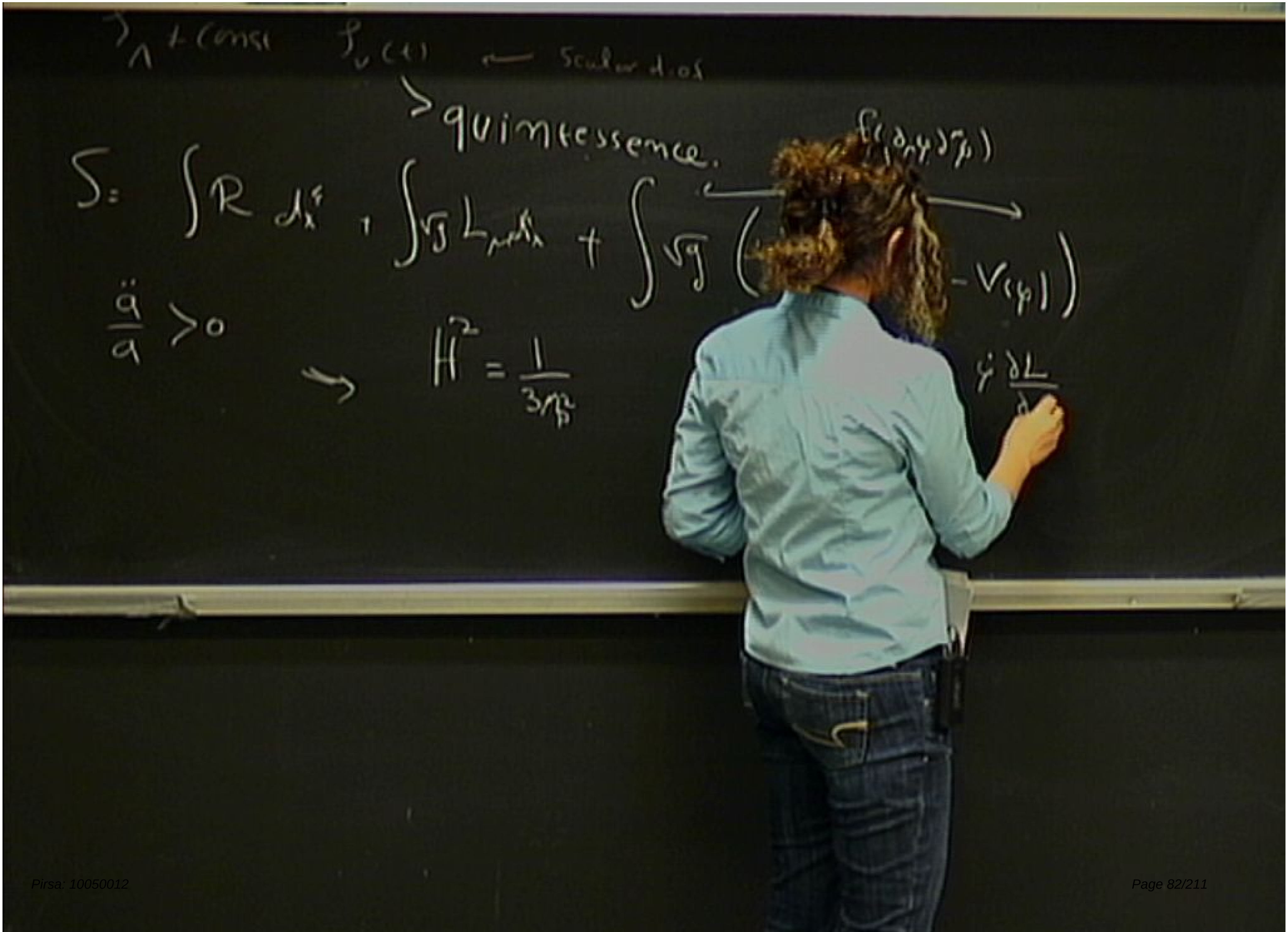
$\rho_\Lambda \neq const$ ρ_v
Scalar d.o.f
tessence.
$S = \int R \, d^4x$
$\int \sqrt{g} \left(\frac{1}{2} \partial_\mu \varphi \partial^\mu \varphi - V(\varphi) \right)$

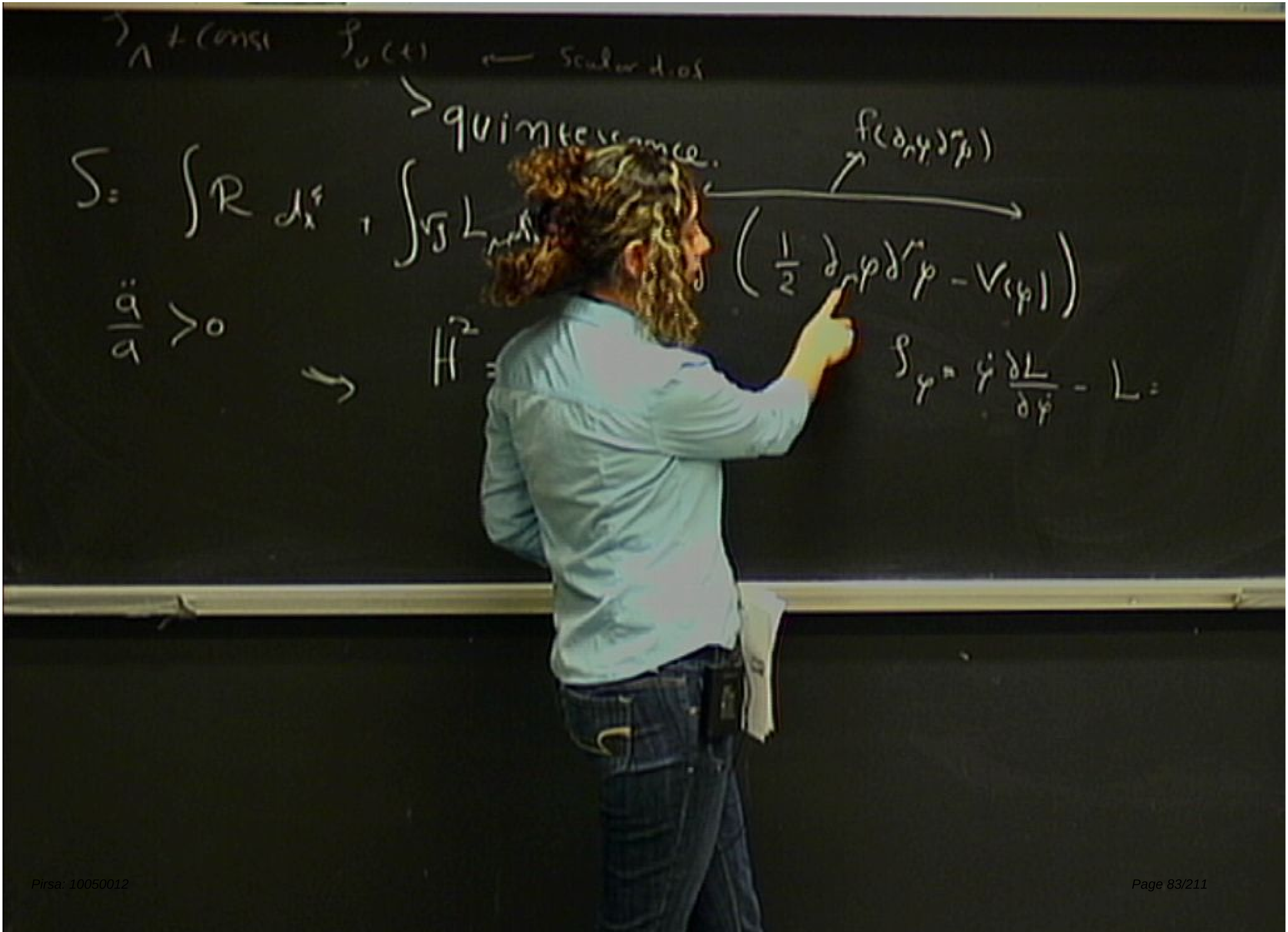


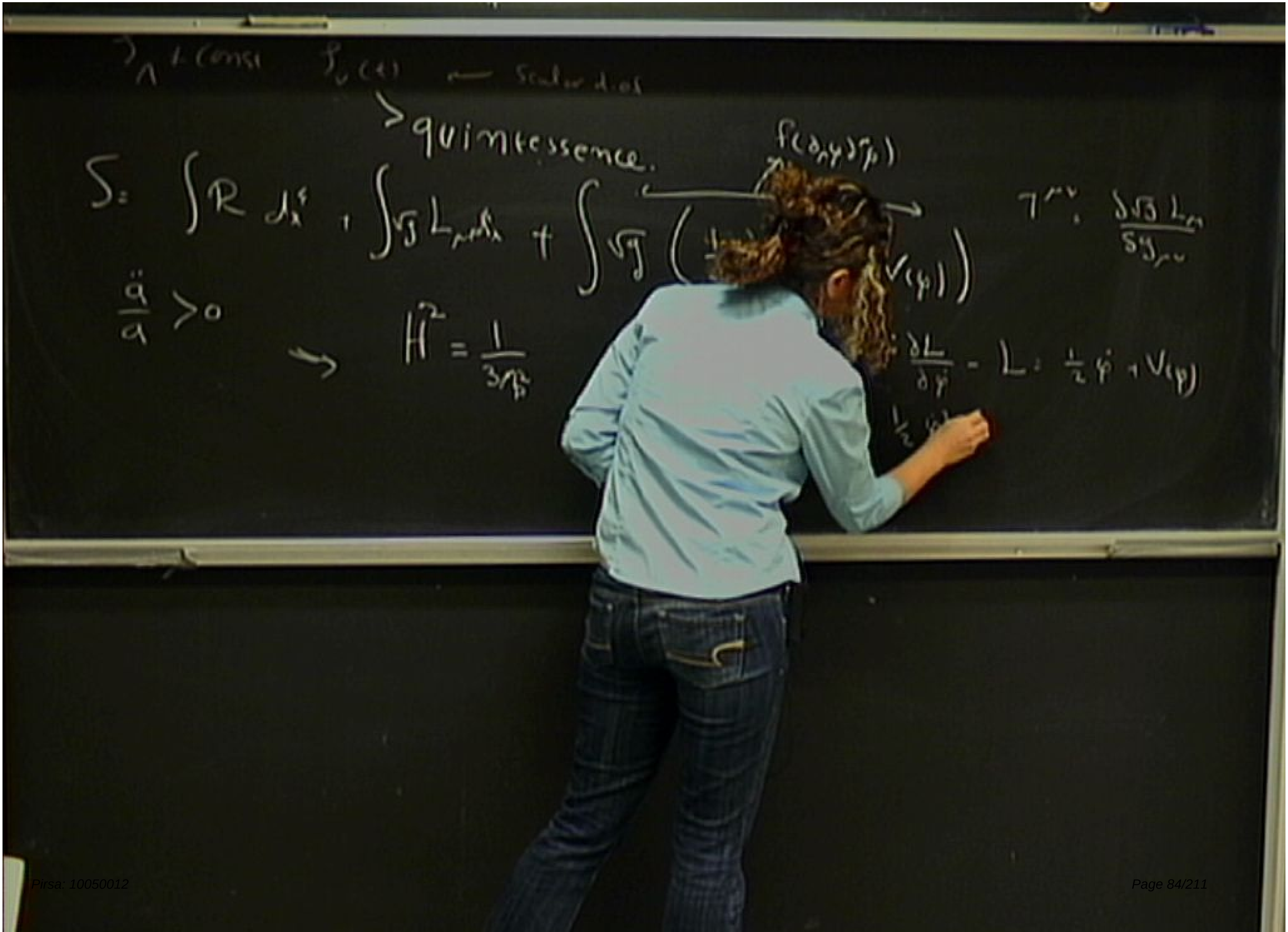
ρ_Λ + const
← Scalar d.o.f
intessence.
$f(\partial_\mu\varphi\partial^\mu\varphi)$
$S = \int R$
$+ \int \sqrt{g}\left(\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi - V(\varphi)\right)$

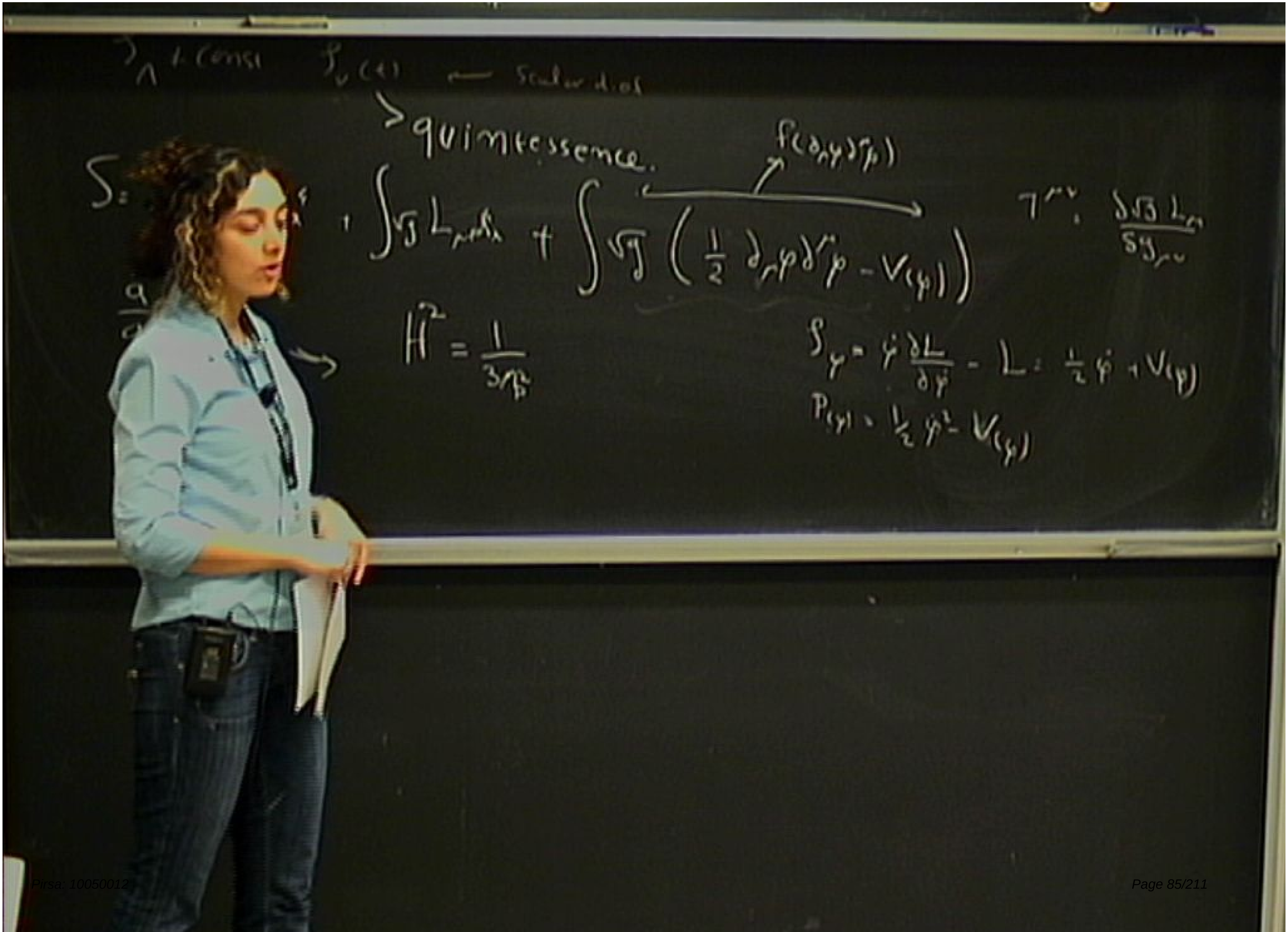

$\rho_\Lambda \neq$ const $\rho_v(t)$ ← scalar d.o.f
quintessence.
$f(\partial_\mu\varphi\partial^\mu\varphi)$
$\int R\, d^4x + \int\sqrt{g}\, L_{matter} + \int\sqrt{g}\left(\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi - V(\varphi)\right)$


$\rho_\Lambda \neq \text{const}$ $\rho_v(t)$ ← Scalar d.o.f
quintessence.
$f(\partial_\mu\varphi\partial^\mu\varphi)$
$S = \int R\, d^4x + \int\sqrt{g}\, L_{matter} + \int\sqrt{g}\left(\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi - V(\varphi)\right)$
$\frac{\ddot{a}}{a} > 0$

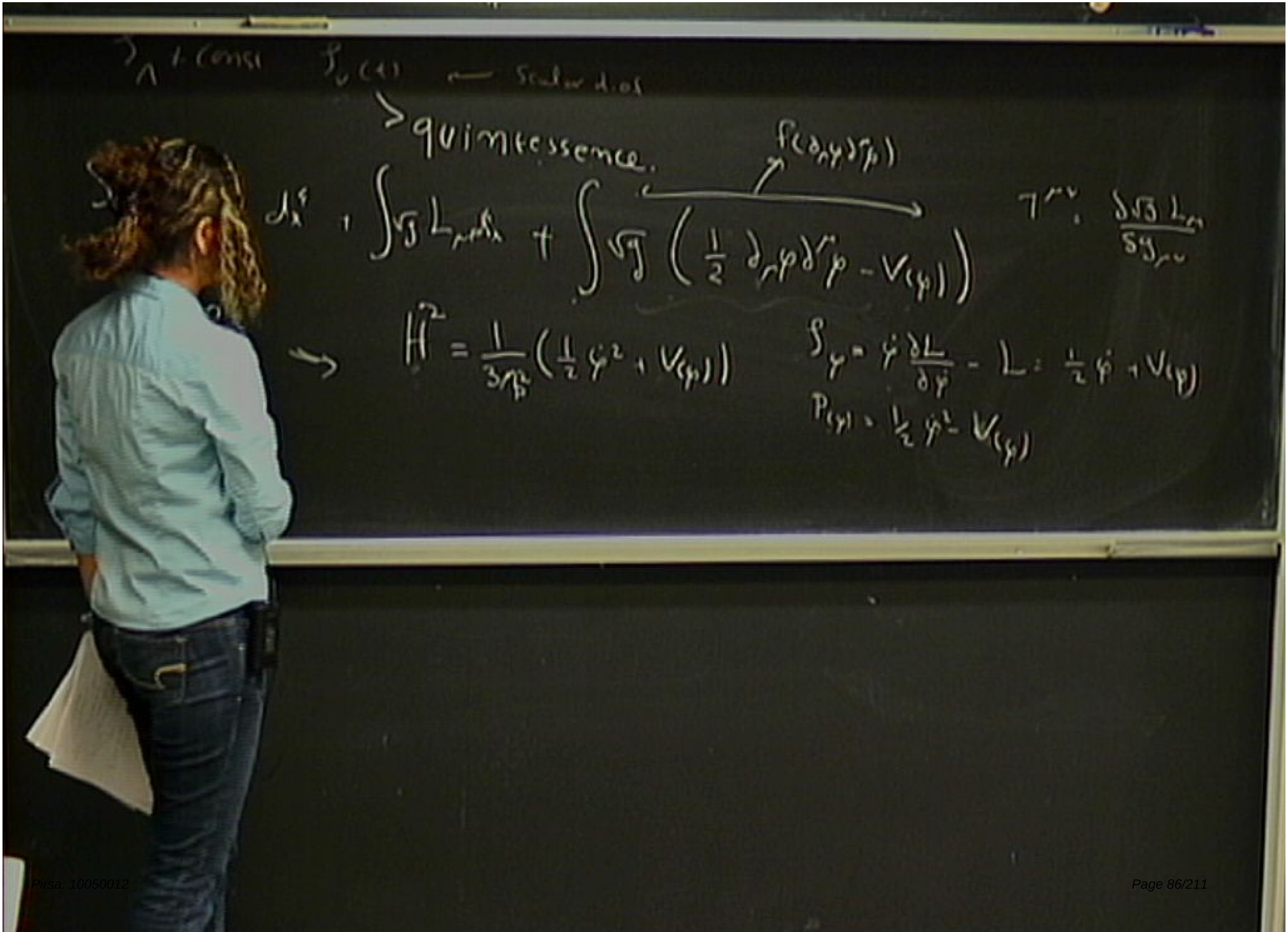

Scalar d.o.f
quintessence.
$\frac{\ddot{a}}{a} > 0$
$H^2 = \frac{1}{3M_p^2}$

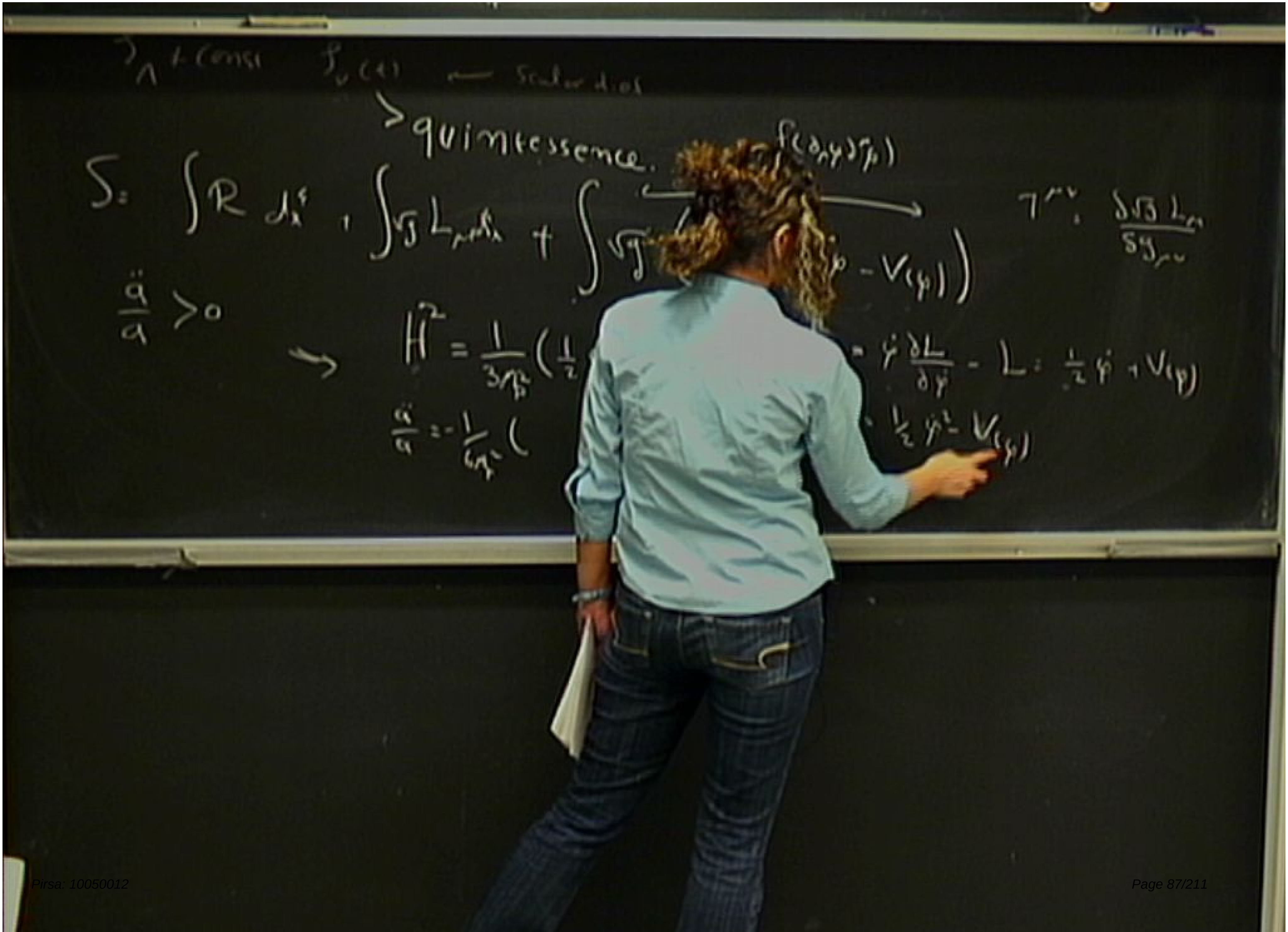

quintessence.
Scalar d.o.f


quintessence.
S = ∫R d⁴x + ∫√g L_matter + ∫√g (
V(φ))
f(∂_μφ∂^μφ)
T^μν = δ√g L_m / δg_μν
ä/a > 0
H² = 1/3M_p²
∂L/∂φ̇ − L = ½ φ̇ + V(φ)
scalar d.o.f



quintessence.
T^μν = δ√g L_m / δg_μν
H² = 1/3M_p²


Λ : const   ρ_Λ(t) ← scalar d.o.f
quintessence
f(∂_μφ ∂^μφ)
d^4x + ∫√g L_matter + ∫√g (1/2 ∂_μφ ∂^μφ − V(φ))
T^μν = δ√g L_m / δg_μν
H^2 = 1/(3M_p^2) (1/2 φ̇^2 + V(φ))
ρ_φ = φ̇ ∂L/∂φ̇ − L = 1/2 φ̇ + V(φ)
P(φ) = 1/2 φ̇^2 − V(φ)


quintessence.

ρ_Λ = const $\rho_v(t)$ ⟵ Scalar d.o.f.

> quintessence.

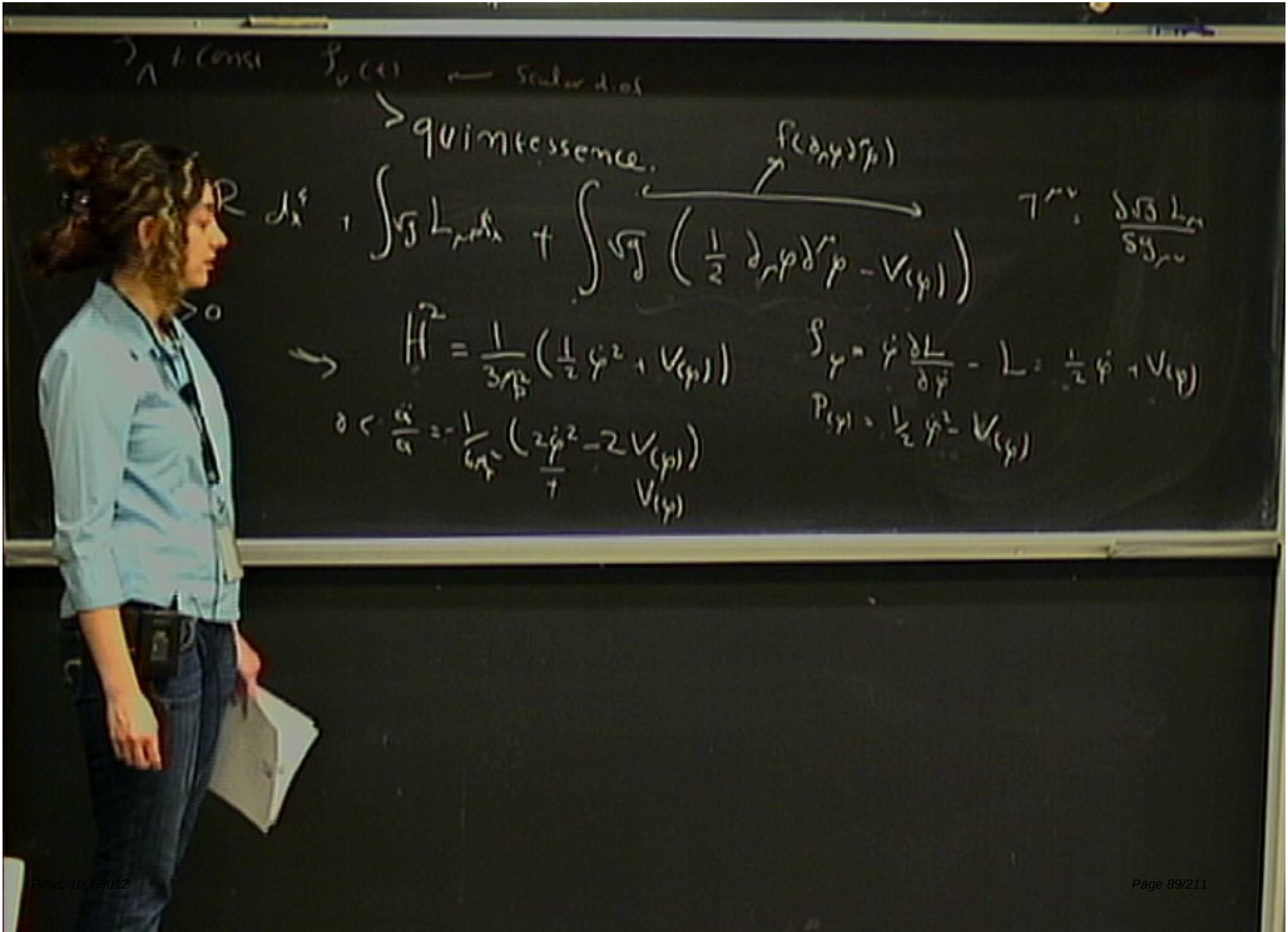
$$\int R\, d^4x + \int \sqrt{g}\, L_{matter} + \int \sqrt{g} \left(\tfrac{1}{2} \partial_\mu \varphi \partial^\mu \varphi - V(\varphi) \right) \qquad \partial_\mu \varphi \partial^\mu \varphi \to f(\partial_\mu \varphi \partial^\mu \varphi)$$

$$T^{\mu\nu} = \frac{\delta \sqrt{g} L_m}{\delta g_{\mu\nu}}$$

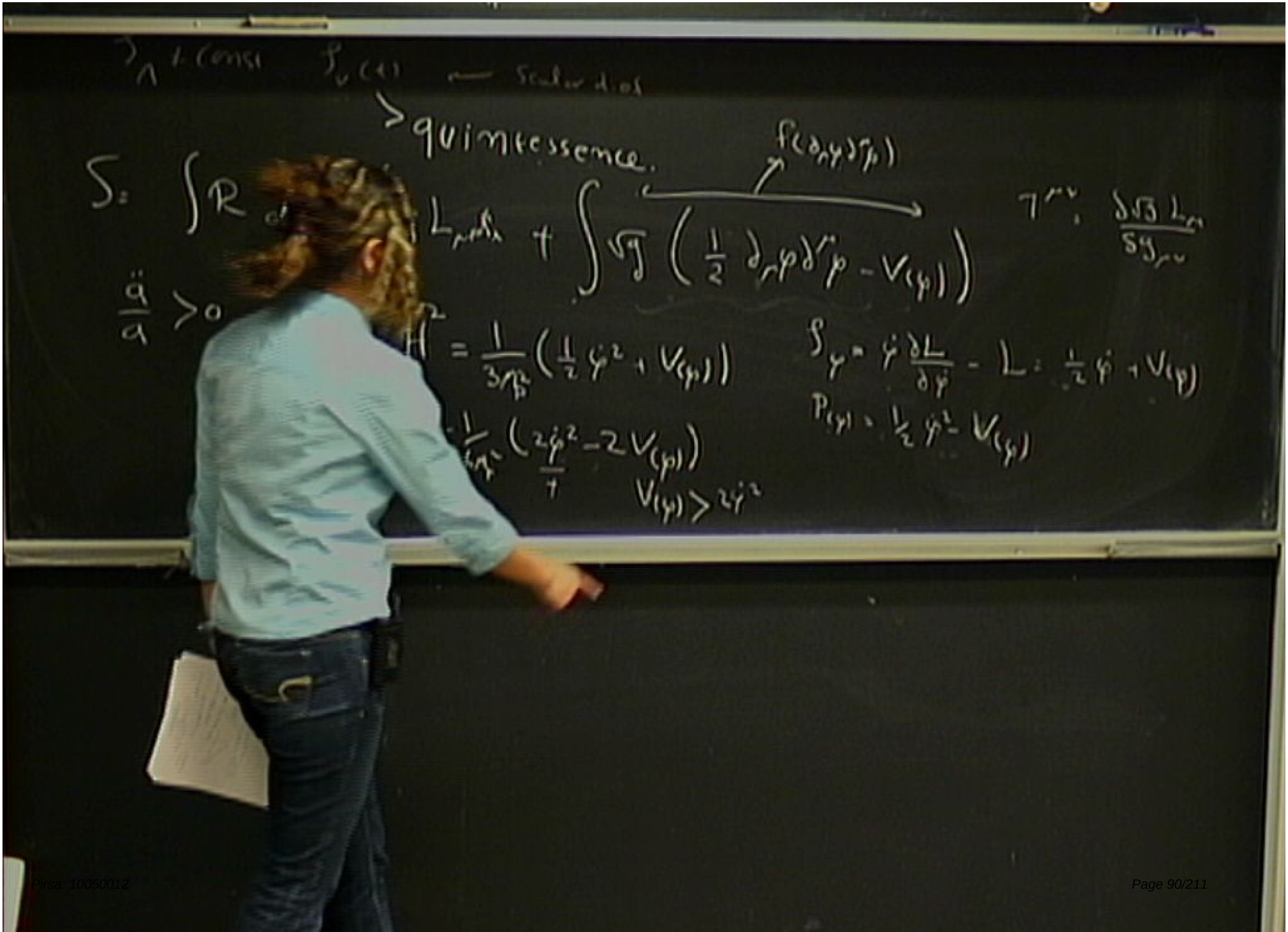
$\frac{\ddot a}{a} > 0$

$$\rightsquigarrow \quad H^2 = \frac{1}{3 M_p^2} \left(\tfrac{1}{2} \dot\varphi^2 + V(\varphi) \right) \qquad \rho_\varphi = \dot\varphi \frac{\partial L}{\partial \dot\varphi} - L = \tfrac{1}{2} \dot\varphi^2 + V(\varphi)$$

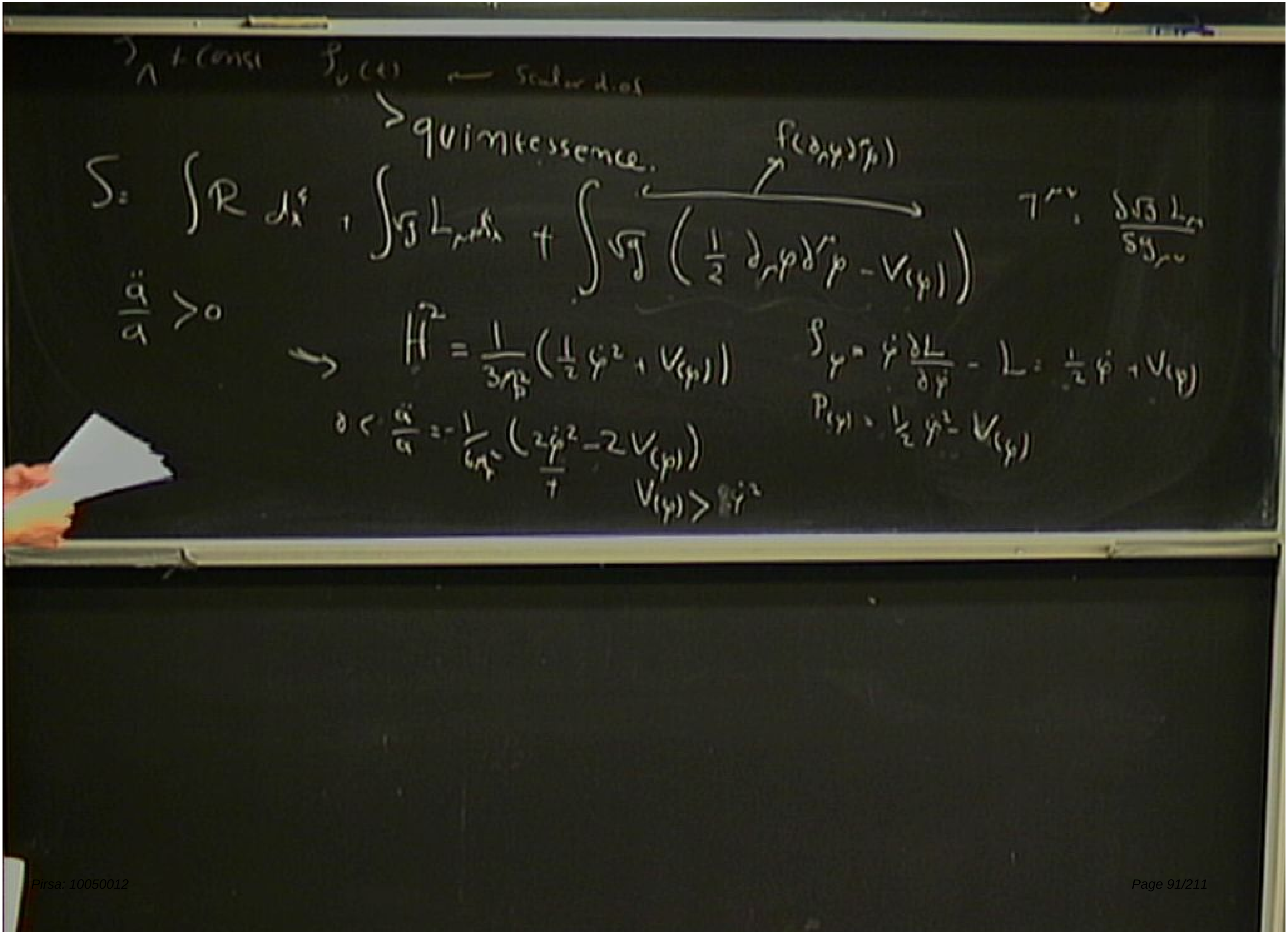
$$\frac{\ddot a}{a} = -\frac{1}{6 M_p^2} \left(2\dot\varphi^2 - 2V(\varphi) \right) \qquad P(\varphi) = \tfrac{1}{2} \dot\varphi^2 - V(\varphi)$$

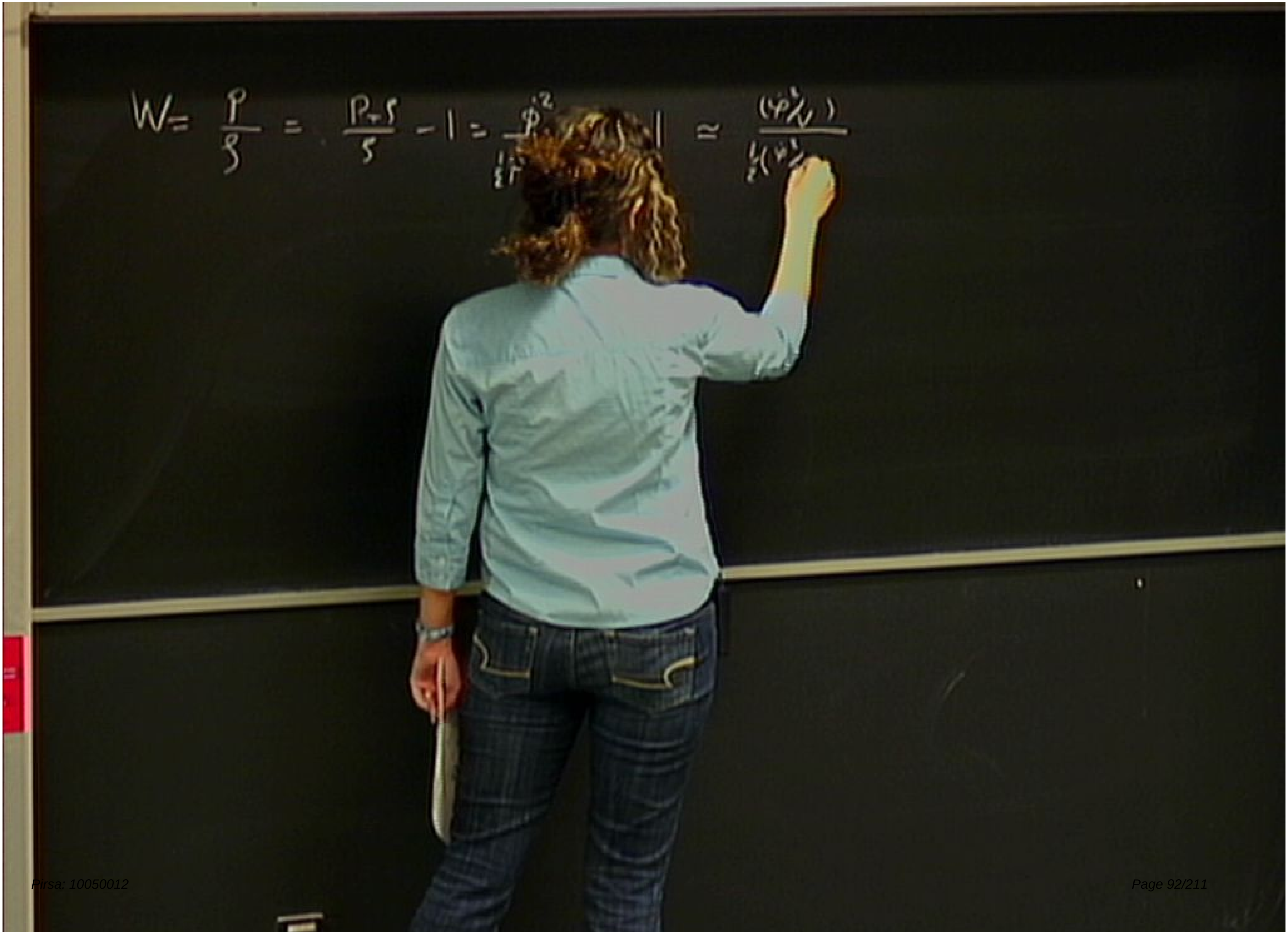


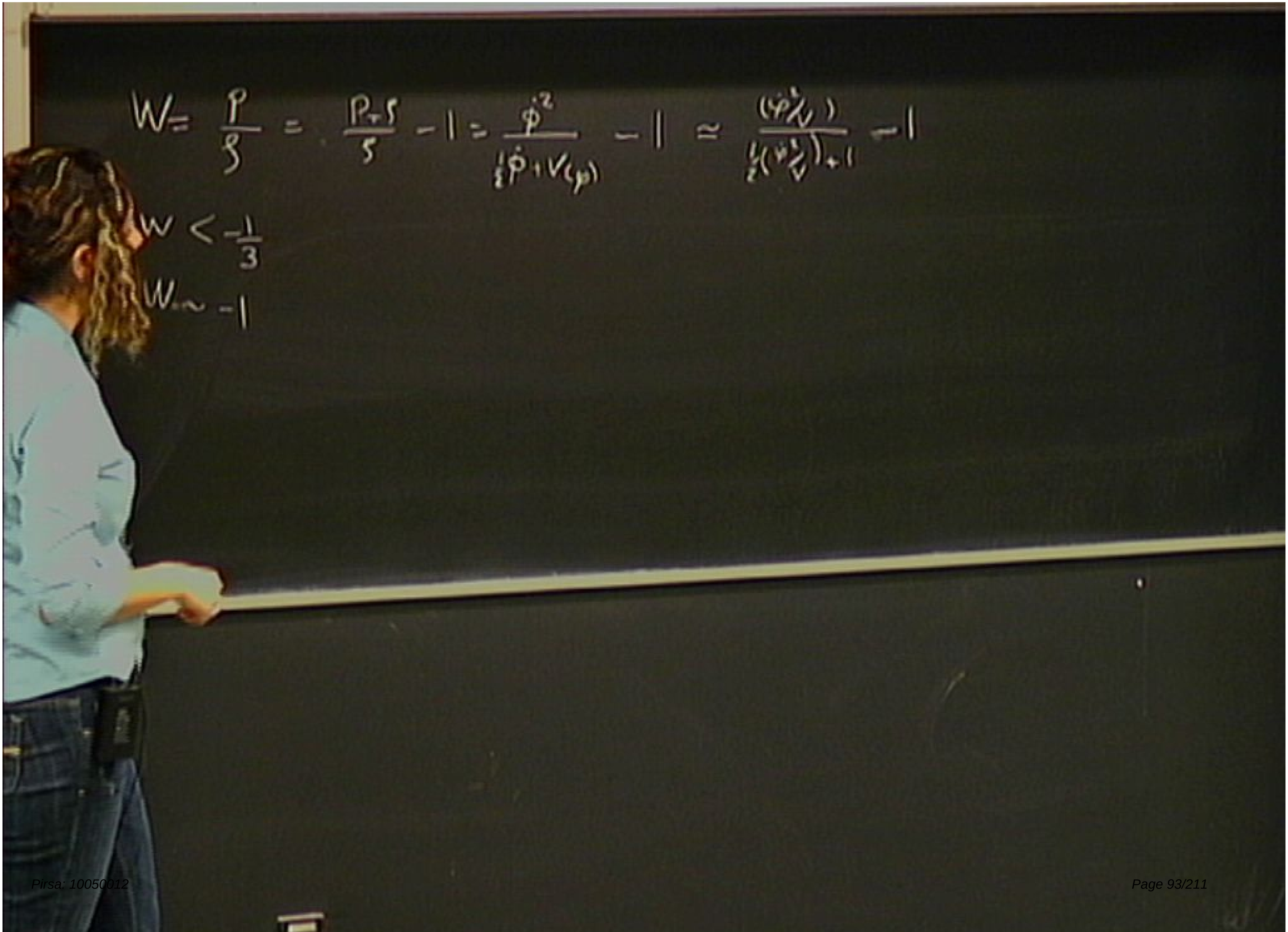
quintessence.
$\int \sqrt{g}\left(\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi - V(\varphi)\right)$
$H^2 = \frac{1}{3M_p^2}\left(\frac{1}{2}\dot\varphi^2 + V(\varphi)\right)$
$P_{(\varphi)} = \frac{1}{2}\dot\varphi^2 - V(\varphi)$

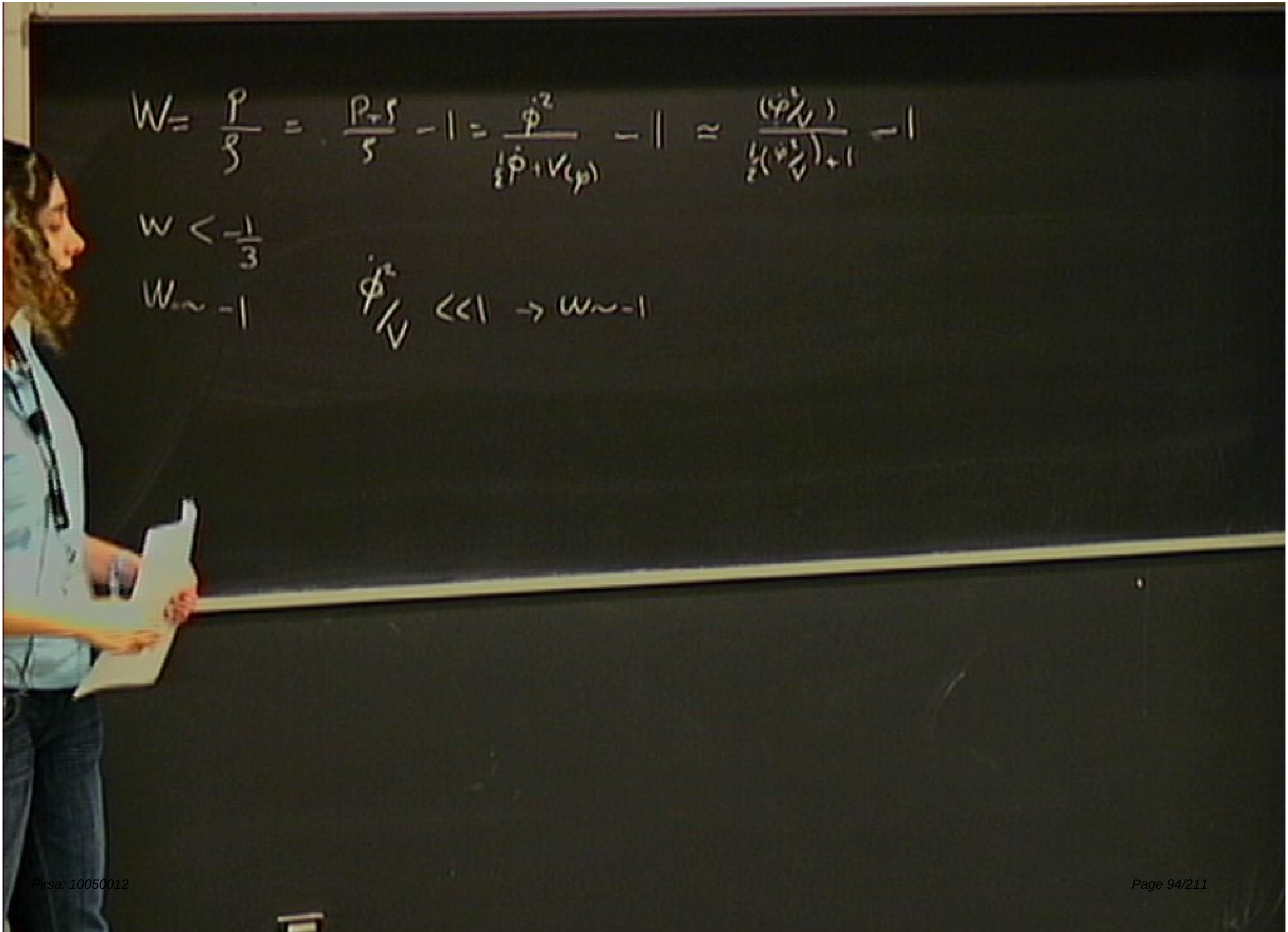


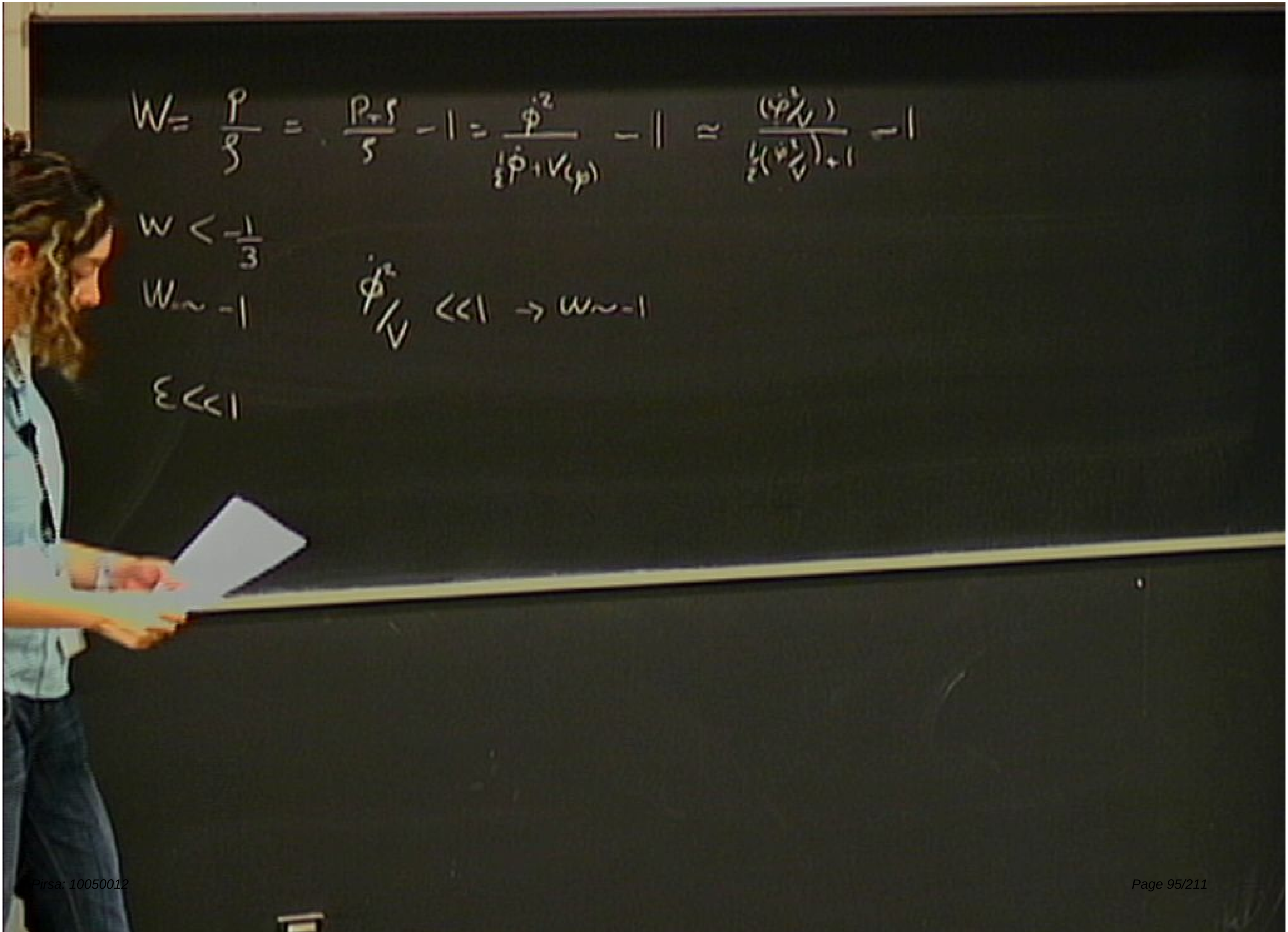
quintessence.
$S = \int R$
$L_{matter} + \int \sqrt{g} \left(\frac{1}{2} \partial_\mu \varphi \partial^\mu \varphi - V(\varphi) \right)$
$f(\partial_\mu \varphi \partial^\mu \varphi)$
$T^{\mu\nu} = \frac{\delta \sqrt{g} L_m}{\delta g_{\mu\nu}}$
$\frac{\ddot{a}}{a} > 0$
$H^2 = \frac{1}{3 M_p^2} \left(\frac{1}{2} \dot{\varphi}^2 + V(\varphi) \right)$
$\rho_\varphi = \dot{\varphi} \frac{\partial L}{\partial \dot{\varphi}} - L = \frac{1}{2} \dot{\varphi} + V(\varphi)$
$P(\varphi) = \frac{1}{2} \dot{\varphi}^2 - V(\varphi)$
$V(\varphi) > 2\dot{\varphi}^2$

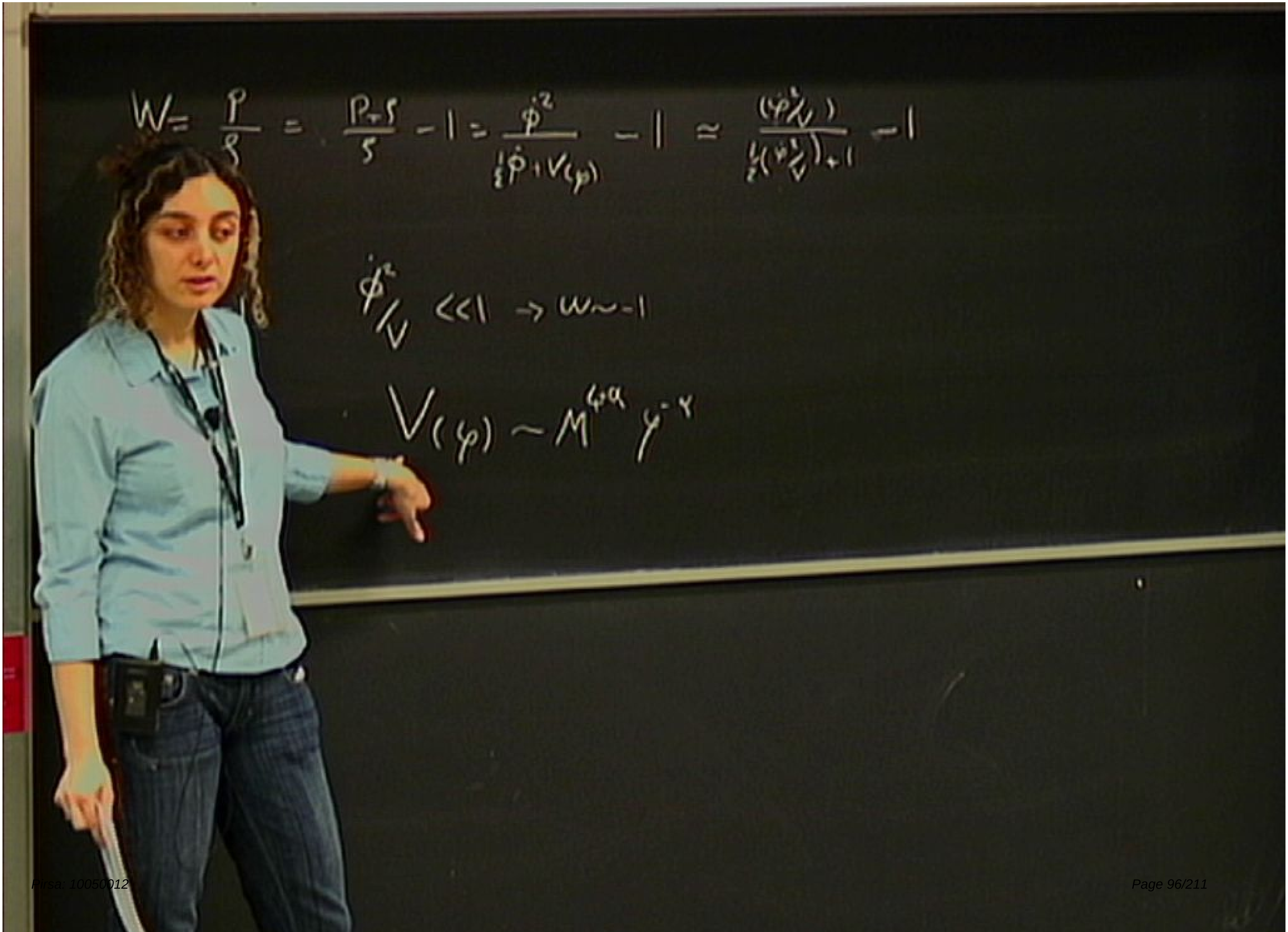

$\rho_\Lambda \neq \text{const} \quad \rho_v(t) \leftarrow$ scalar d.o.f
quintessence
$f(\partial_\mu\varphi \partial^\mu\varphi)$
$S = \int R\, d^4x + \int \sqrt{g}\, L_{matter} + \int \sqrt{g} \left(\frac{1}{2} \partial_\mu \varphi \partial^\mu \varphi - V(\varphi) \right)$
$T^{\mu\nu} = \frac{\delta \sqrt{g}\, L_m}{\delta g_{\mu\nu}}$
$\frac{\ddot{a}}{a} > 0$
$H^2 = \frac{1}{3M_p^2} \left(\frac{1}{2} \dot{\varphi}^2 + V(\varphi) \right)$
$\rho_\varphi = \dot{\varphi} \frac{\partial L}{\partial \dot{\varphi}} - L = \frac{1}{2} \dot{\varphi} + V(\varphi)$
$0 < \frac{\ddot{a}}{a} = -\frac{1}{6M_p^2} \left(2\dot{\varphi}^2 - 2V(\varphi) \right)$
$P(\varphi) = \frac{1}{2} \dot{\varphi}^2 - V(\varphi)$
$V(\varphi) > \dot{\varphi}^2$

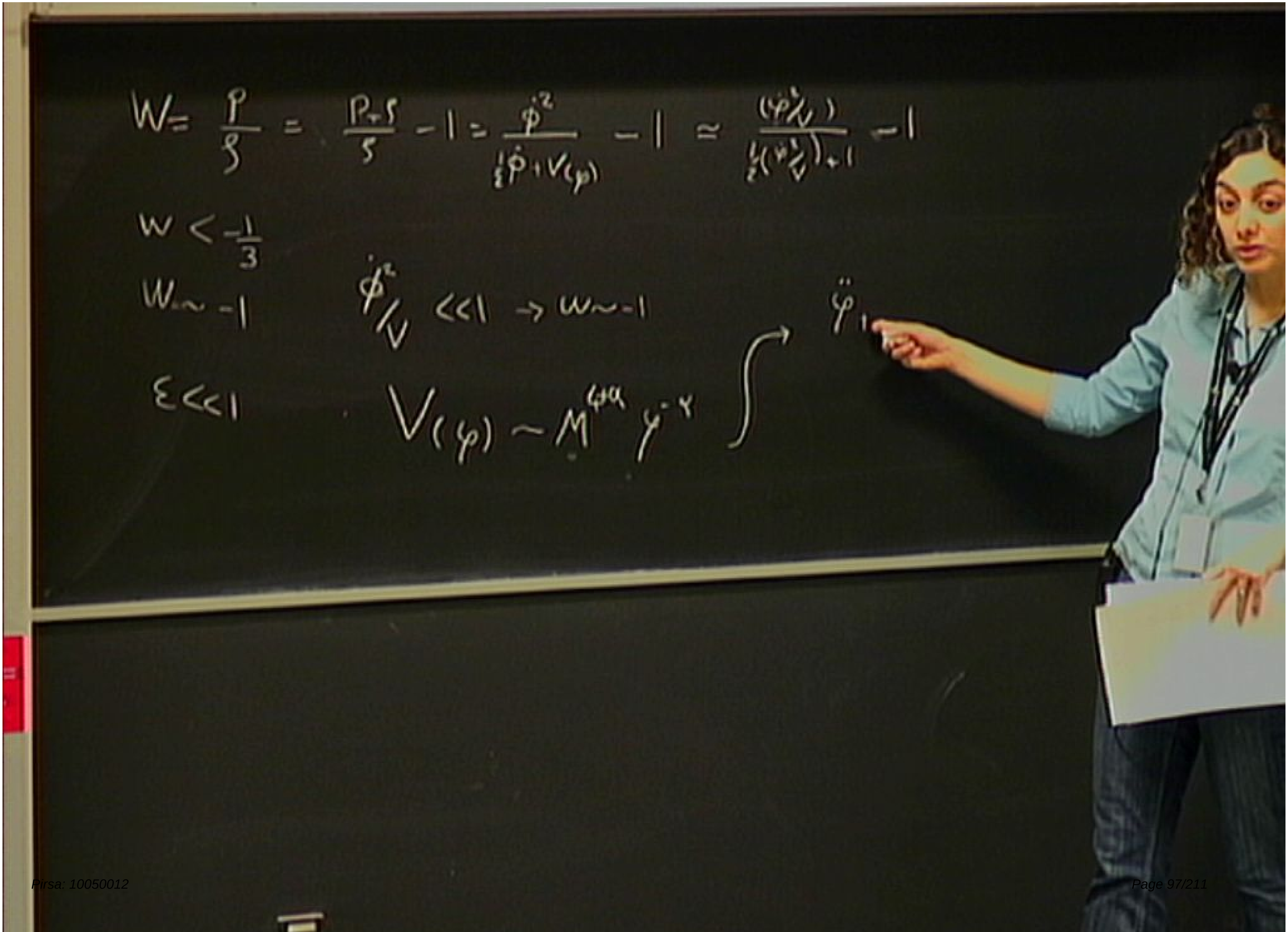

$W = \frac{P}{\rho} = \frac{P+\rho}{\rho} - 1 =$

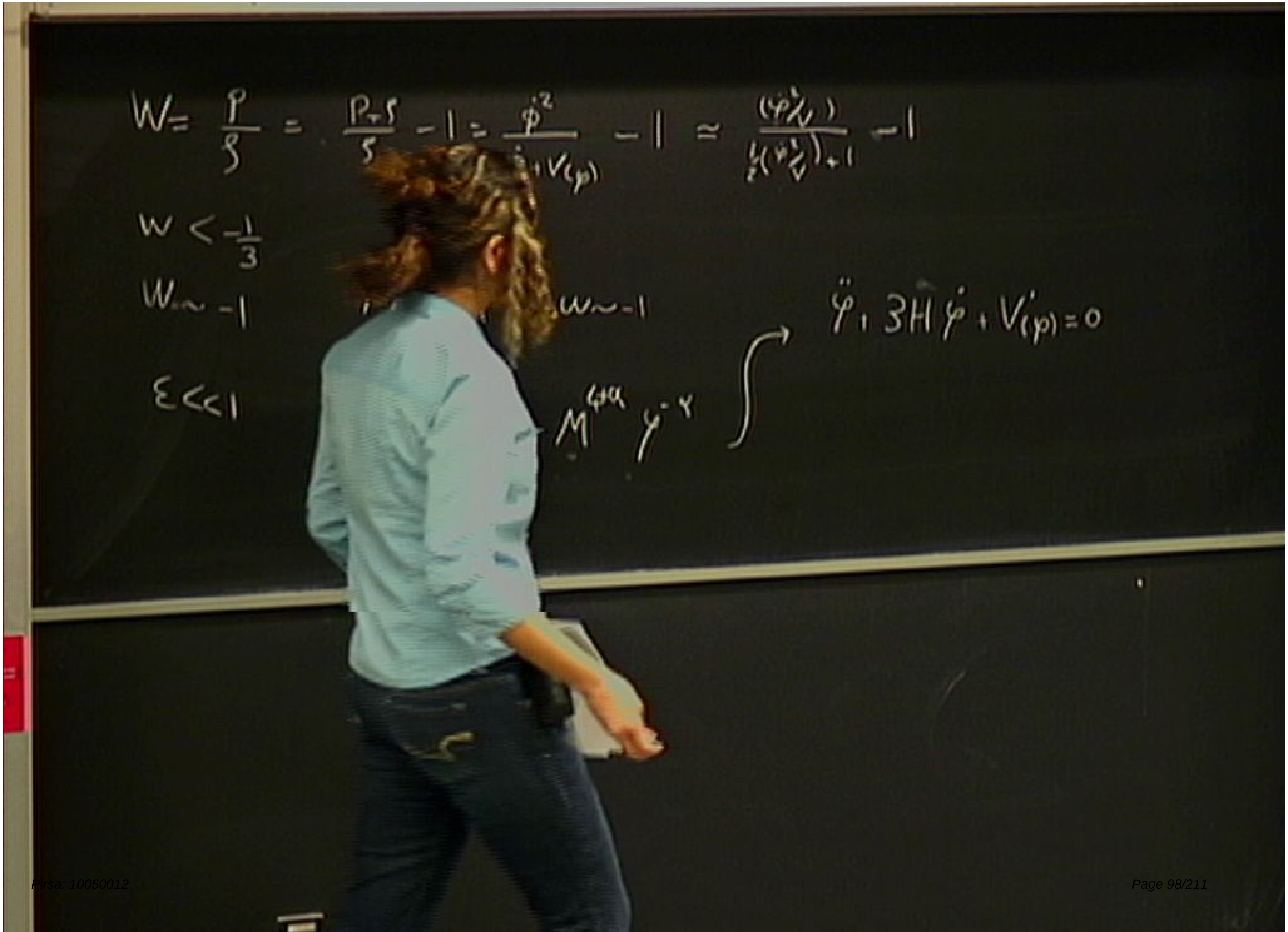

$W = \frac{P}{\rho} = \frac{P+\rho}{\rho} - 1 = \frac{\dot\phi^2}{\frac{1}{2}\dot\phi^2 + V(\phi)} - 1 \simeq \frac{(\dot\phi^2/V)}{\frac{1}{2}(\dot\phi^2/V)+1} - 1$
$w < -\frac{1}{3}$
$W \sim -1$

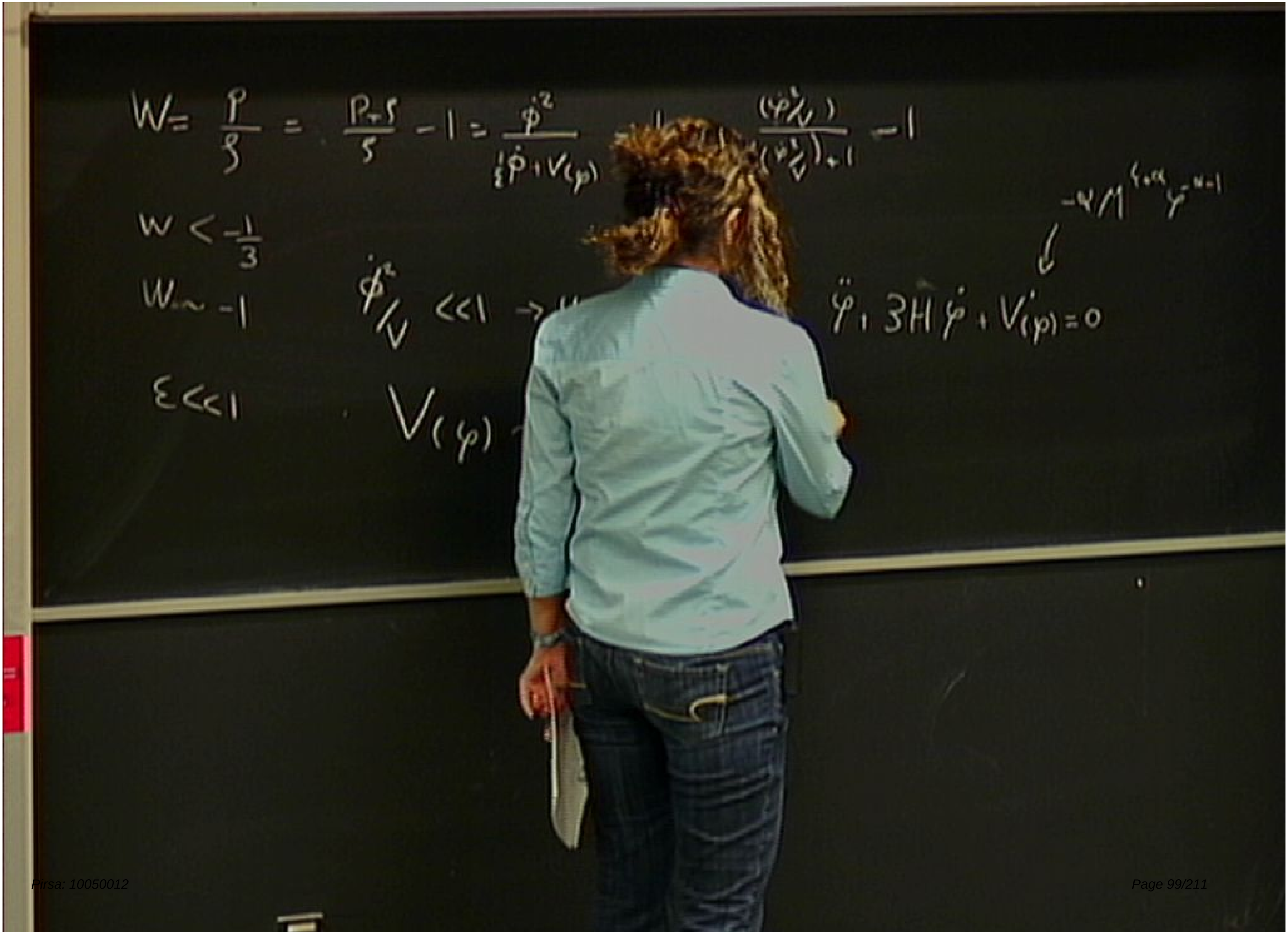

$W = \frac{p}{\rho} = \frac{p+\rho}{\rho} - 1 = \frac{\dot\phi^2}{\frac{1}{2}\dot\phi^2 + V(\phi)} - 1 \simeq \frac{(\dot\phi^2/V)}{\frac{1}{2}(\dot\phi^2/V)+1} - 1$
$w < -\frac{1}{3}$
$W \sim -1$
$\dot\phi^2/V \ll 1 \rightarrow w \sim -1$


$W = \frac{P}{\rho} = \frac{P+\rho}{\rho} - 1 = \frac{\dot\phi^2}{\frac{1}{2}\dot\phi^2 + V(\phi)} - 1 \simeq \frac{(\dot\phi^2/V)}{\frac{1}{2}(\dot\phi^2/V)+1} - 1$
$w < -\frac{1}{3}$
$W \sim -1$
$\dot\phi^2/V \ll 1 \rightarrow w \sim -1$
$\varepsilon \ll 1$


$W = \frac{P}{\rho} = \frac{P+\rho}{\rho} - 1 = \frac{\dot\phi^2}{\frac{1}{2}\dot\phi^2 + V(\varphi)} - 1 \simeq \frac{(\dot\phi^2/V)}{\frac{1}{2}(\dot\phi^2/V)+1} - 1$
$\dot\phi^2/V \ll 1 \rightarrow w \sim -1$
$V(\varphi) \sim M^{4+\alpha}\varphi^{-\alpha}$


$W = \frac{P}{\rho} = \frac{P+\rho}{\rho} - 1 = \frac{\dot\phi^2}{\frac{1}{2}\dot\phi^2 + V(\phi)} - 1 \simeq \frac{(\dot\phi^2/V)}{\frac{1}{2}(\dot\phi^2/V)+1} - 1$
$w < -\frac{1}{3}$
$W \sim -1$
$\dot\phi^2/V \ll 1 \to w \sim -1$
$\ddot\varphi$
$\varepsilon \ll 1$
$V(\varphi) \sim M^{4+\alpha}\varphi^{-\alpha}$


w < -1/3
W ~ -1
w ~ -1
ε << 1
φ̈ + 3H φ̇ + V'(φ) = 0


$W = \frac{P}{\rho} = \frac{P+\rho}{\rho} - 1 = \frac{\dot\phi^2}{\frac{1}{2}\dot\phi^2 + V(\varphi)}$
$\frac{(\dot\varphi^2/V)}{(\dot\varphi^2/V)+1} - 1$
$w < -\frac{1}{3}$
$W \sim -1$
$\dot\phi^2/V \ll 1$
$-\alpha M^{4+\alpha}\varphi^{-\alpha-1}$
$\ddot\varphi + 3H\dot\varphi + V'(\varphi) = 0$
$\varepsilon \ll 1$
$V(\varphi)$

$$W = \frac{p}{\rho} = \frac{p+\rho}{\rho} - 1 = \frac{\dot\phi^2}{\frac{1}{2}\dot\phi^2 + V(\varphi)} - 1 \simeq \frac{(\dot\varphi^2/V)}{\frac{1}{2}(\dot\varphi^2/V) + 1} - 1$$

$w < -\frac{1}{3}$

$W \sim -1$ $\qquad \dot\phi^2/V \ll 1 \to w \sim -1$

$\varepsilon \ll 1$ $\qquad V(\varphi) \sim M^{4+\alpha} \varphi^{-\alpha}$

$-\alpha M^{4+\alpha} \varphi^{-\alpha-1}$

$\ddot\varphi + 3H\dot\varphi + V'(\varphi) = 0$

$\ddot\varphi + 3H\dot\varphi - \alpha M^{4+\alpha} \varphi^{-\alpha-1} = 0$

$\varphi = At^{\gamma}$

$$W = \frac{P}{\rho} = \frac{P+\rho}{\rho} - 1 = \frac{\dot\varphi^2}{\frac{1}{2}\dot\varphi^2 + V(\varphi)} - 1 \simeq \frac{(\dot\varphi^2/V)}{\frac{1}{2}(\dot\varphi^2/V)+1} - 1$$

$w < -\frac{1}{3}$

$W \sim -1 \qquad \dot\varphi^2/V \ll 1 \to w \sim -1$

$\varepsilon \ll 1 \qquad V(\varphi) \sim M^{4+\alpha}\varphi^{-\alpha}$

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

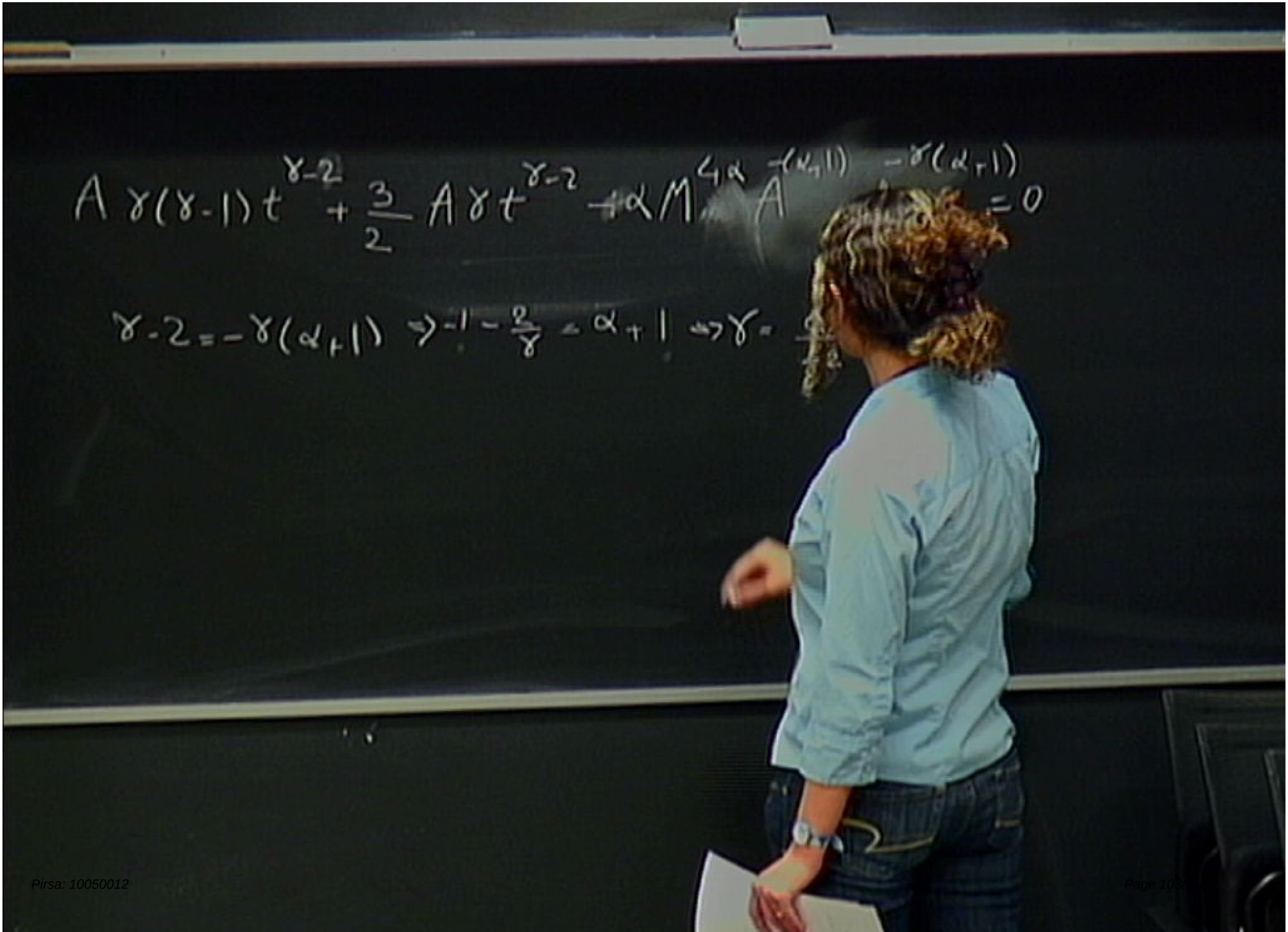
$-\alpha M^{4+\alpha}\varphi^{-\alpha-1}$

$\ddot\varphi + 3H\dot\varphi + V'(\varphi) = 0$

$\ddot\varphi + 3H\dot\varphi - \alpha M^{4+\alpha}\varphi^{-\alpha-1} = 0$

$\varphi = At^{\gamma}$

$$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} - 4\alpha M^{4\alpha} A\, t^{(-\alpha-1)\gamma} = 0$$



$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} + \alpha M^{4\alpha} A^{-(\alpha+1)} \quad {}^{-\gamma(\alpha+1)} = 0$
$\gamma - 2 = -\gamma(\alpha+1) \Rightarrow -1 - \frac{2}{\gamma} = \alpha + 1 \Rightarrow \gamma =$

$$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} + \alpha M^{4\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 - \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{-2}\right)^{-1} = \frac{-2}{\alpha+2}$$

$$A = \alpha(2+\alpha)^2 M^4$$

$$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} + \alpha M^{4+\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1-\frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{-2}\right)^{-1} = \frac{-2}{\alpha+2}$$

$$A = \alpha(2+\alpha)^2 M^{4+\alpha}$$

$$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} + \alpha M^{4+\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma - 2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha + 1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2}\right)^{-1} = {+2}/{\alpha+2}$$

$$A = \alpha(2+\alpha)^2 M^{4+\alpha}$$

$$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} + \alpha M^{4+\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

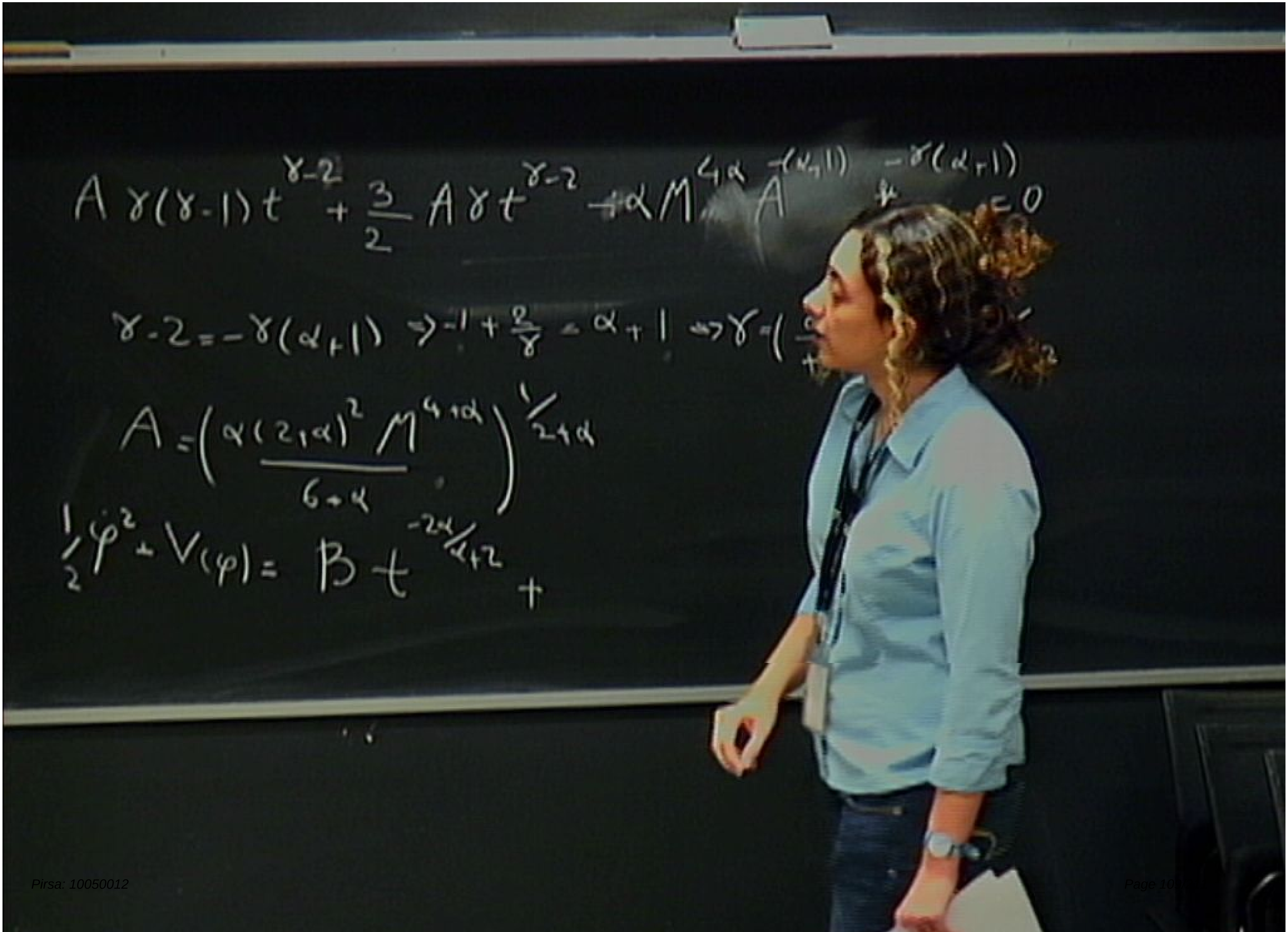
$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1+\frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2}\right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{\frac{1}{2+\alpha}}$$

$$A\gamma(\gamma-1)t^{\gamma-2}+\frac{3}{2}A\gamma t^{\gamma-2}+\alpha M^{4\alpha}A^{-(\alpha+1)}t^{-\gamma(\alpha+1)}=0$$

$$\gamma-2=-\gamma(\alpha+1)\Rightarrow -1+\frac{2}{\gamma}=\alpha+1\Rightarrow\gamma=\left(\frac{\alpha+2}{+2}\right)^{-1}=+2/\alpha+2$$

$$A=\left(\frac{\alpha(2+\alpha)^2M^{4+\alpha}}{6+\alpha}\right)^{1/2+\alpha}$$


$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} + \alpha M^{4+\alpha} A^{-(\alpha+1)} \quad t^{-\gamma(\alpha+1)} = 0$
$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1+\frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = ($
$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{1/(2+\alpha)}$
$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B t^{-2\alpha/(\alpha+2)} +$

$$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} - \alpha M^{4+\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2}\right)^{-1} = {+2}/{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{1/2+\alpha}$$

$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B\, t^{-2\alpha/\alpha+2} +$$

$$W = \frac{p}{\rho} = \frac{p+\rho}{\rho} - 1 = \frac{\dot\varphi^2}{\frac{1}{2}\dot\varphi^2 + V(\varphi)} - 1 \simeq \frac{(\dot\varphi^2/V)}{\frac{1}{2}(\dot\varphi^2/V) + 1} - 1$$

$$w < -\frac{1}{3}$$

$$W \sim -1$$

$$\dot\varphi^2/V \ll 1 \to w \sim -1$$

$$\varepsilon \ll 1$$

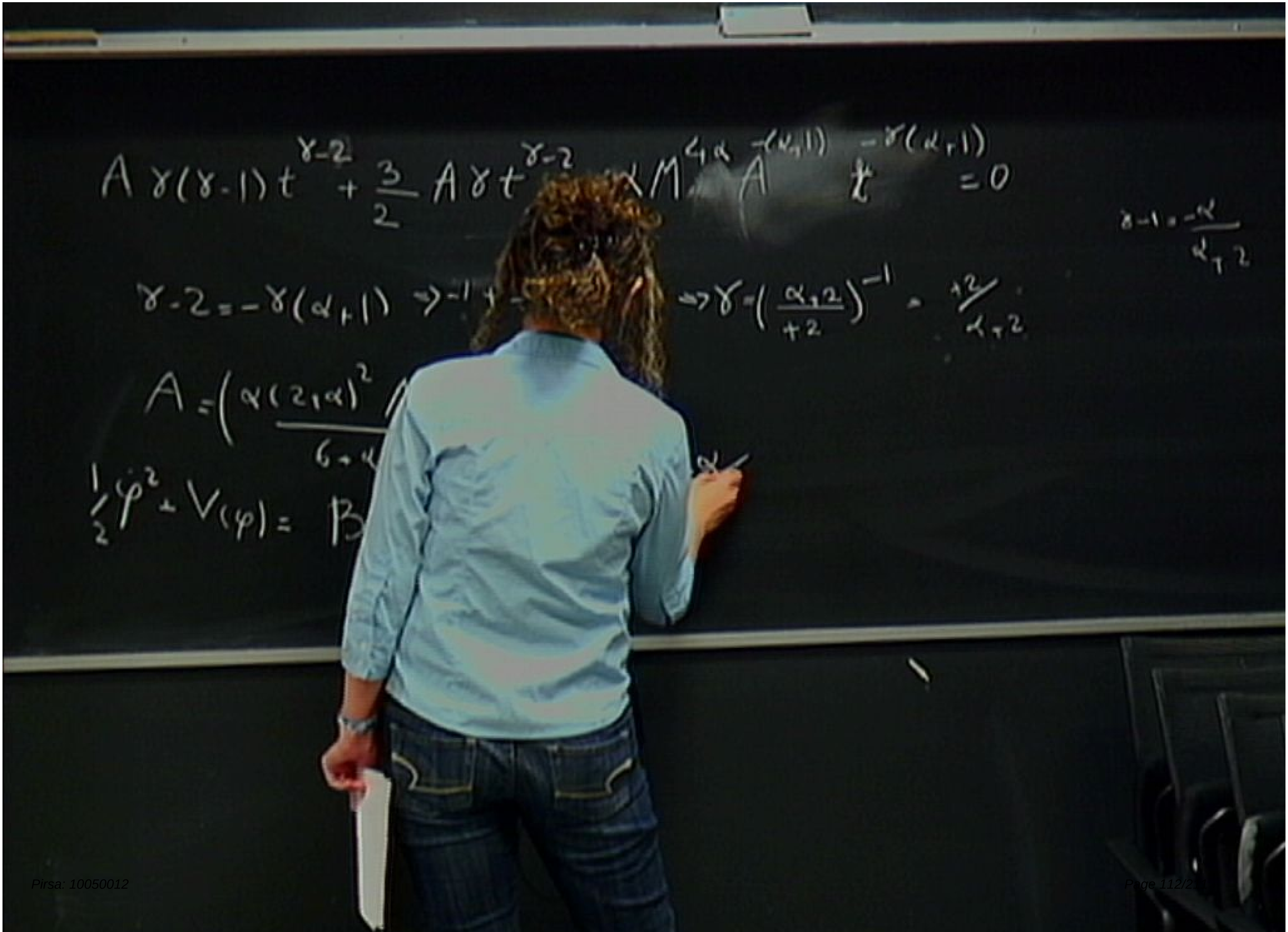
$$V(\varphi) \sim M^{4+\alpha} \varphi^{-\alpha}$$

$$\frac{\dot a}{a} \qquad -\alpha M^{4+\alpha} \varphi^{-\alpha-1}$$

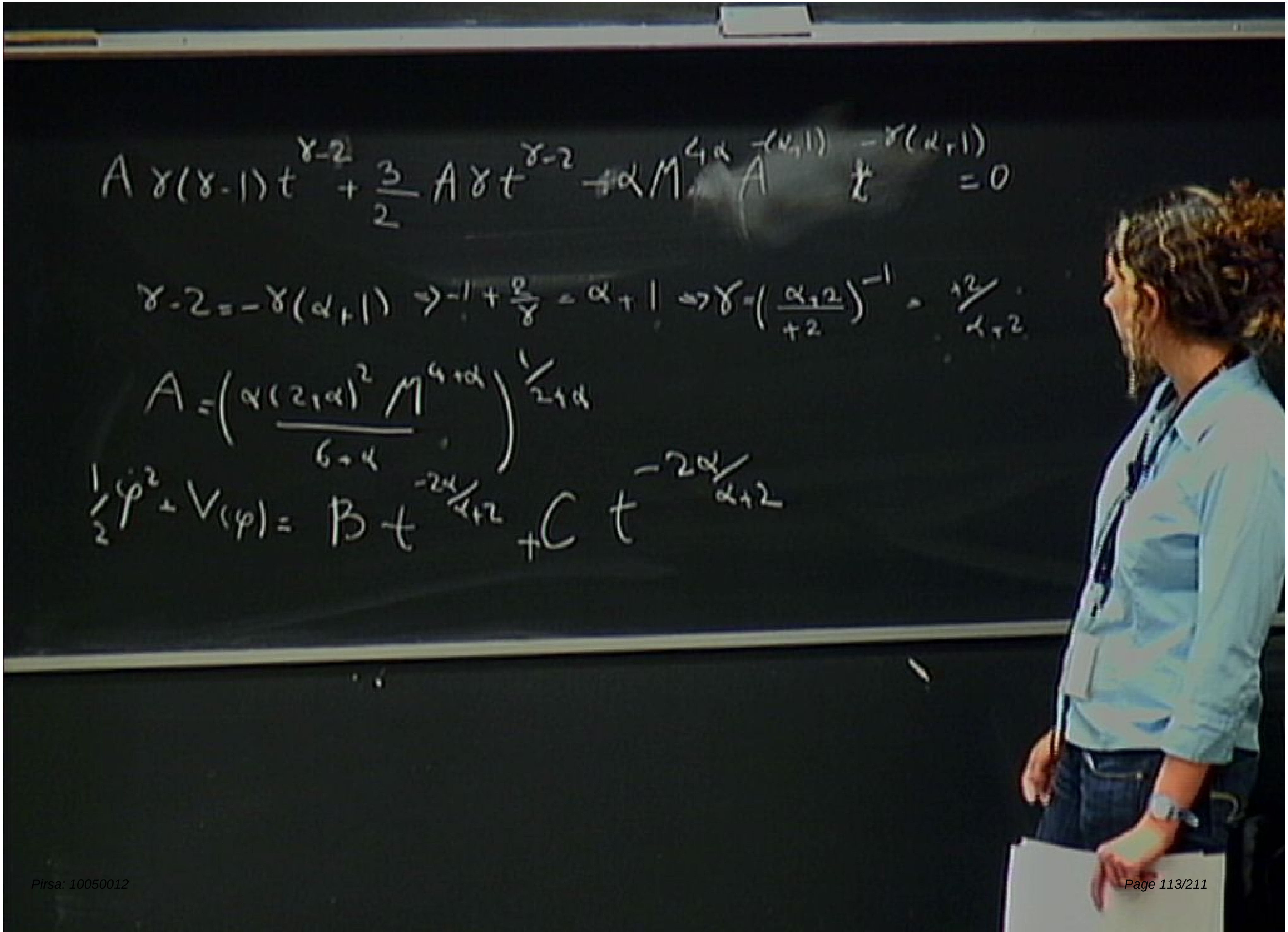
$$\ddot\varphi + 3H\dot\varphi + V'(\varphi) = 0$$

$$\ddot\varphi + 3H\dot\varphi - \alpha M^{4+\alpha} \varphi^{-\alpha-1} = 0$$

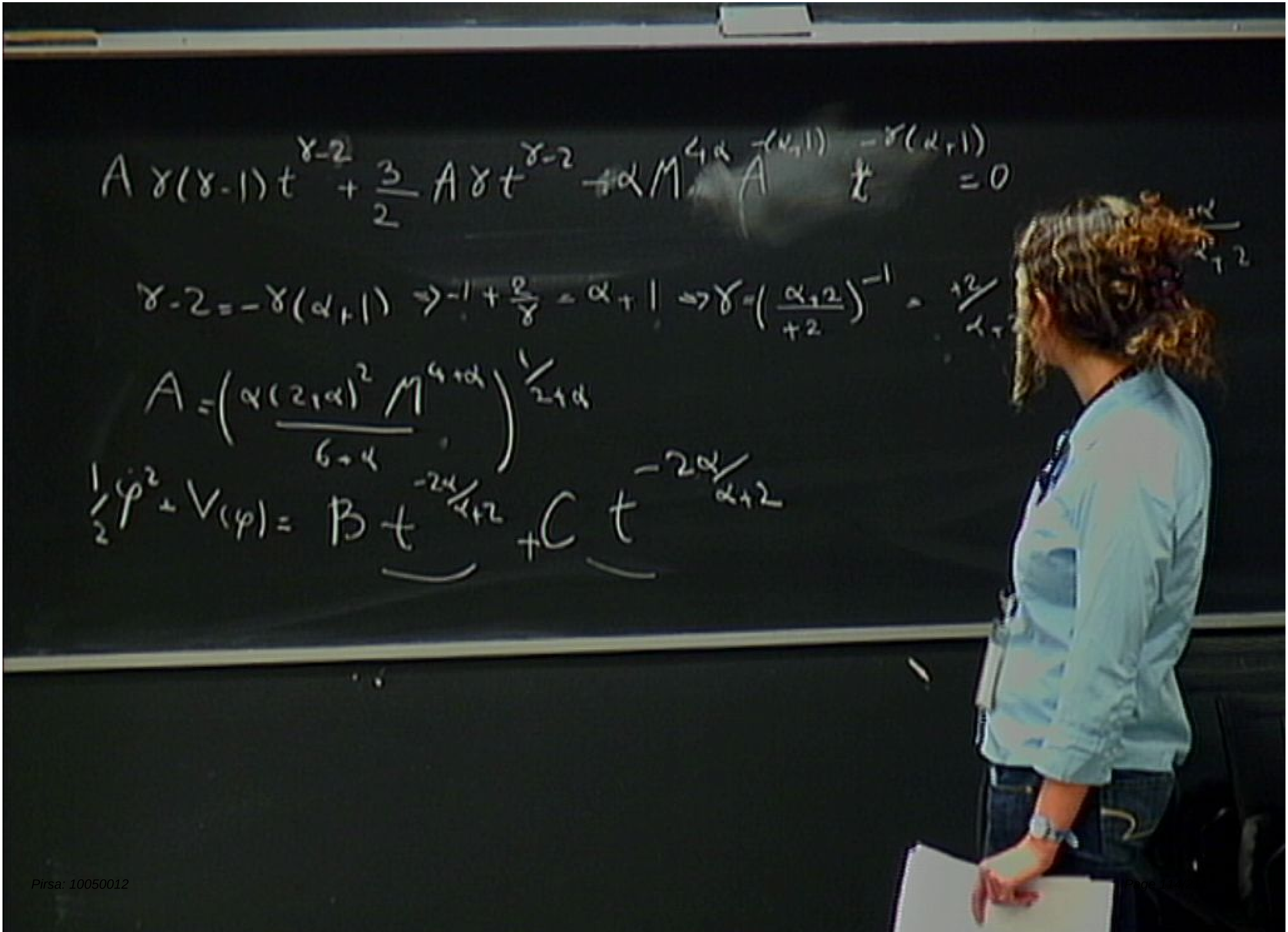
$$\varphi = A t^{\gamma} \qquad \dot\varphi^2 \propto t^{(\gamma-1)2}$$



A γ(γ-1) t^{γ-2} + 3/2 A γ t^{γ-2}
αM^{4α} A^{-(α+1)} t^{-γ(α+1)} = 0
γ-1 = -α/(α+2)
γ-2 = -γ(α+1)
⇒ γ = ((α+2)/+2)^{-1} = +2/(α+2)
A = (α(2+α)^2
1/2 φ̇^2 + V(φ) = B



$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} - \alpha M^{4+\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$
$\gamma-2=-\gamma(\alpha+1) \Rightarrow -1+\frac{2}{\gamma}=\alpha+1 \Rightarrow \gamma=\left(\frac{\alpha+2}{+2}\right)^{-1} = {+2}/{\alpha+2}$
$A=\left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{1/2+\alpha}$
$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B t^{-2\alpha/\alpha+2} + C t^{-2\alpha/\alpha+2}$


$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} + \alpha M^{4+\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$
$\gamma-2 = -\gamma(\alpha+1) \Rightarrow -1+\frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2}\right)^{-1} = {+2}/{\alpha+2}$
$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{1/(2+\alpha)}$
$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B\,t^{-2\alpha/(\alpha+2)} + C\,t^{-2\alpha/(\alpha+2)}$

$$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} - \alpha M^{4+\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$$

$$\gamma - 1 = \frac{-\alpha}{\alpha+2}$$

$$\gamma - 2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha+1 \Rightarrow \gamma = \left(\frac{\alpha+2}{+2}\right)^{-1} = \frac{+2}{\alpha+2}$$

$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{1/(2+\alpha)}$$

$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$

$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$$

R → DGP

→ Condensing Grav !

$\to H(z)$

$$P(X) \longleftrightarrow q\left(\frac{\delta\rho}{\rho}\right)$$

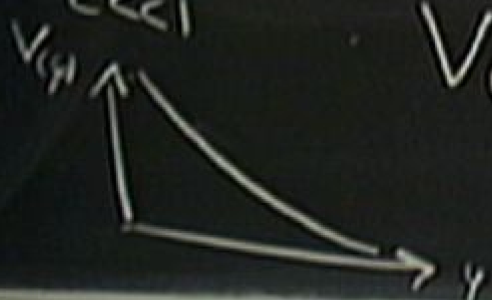
$$W = \frac{p}{\rho} = \frac{p+\rho}{\rho} - 1 = \frac{\dot\varphi^2}{\frac{1}{2}\dot\varphi^2 + V(\varphi)} - 1 \simeq \frac{(\dot\varphi^2/V)}{\frac{1}{2}(\dot\varphi^2/V)+1} - 1$$

$w < -\frac{1}{3}$

$W \sim -1$

$\dot\varphi^2/V \ll 1 \to w \sim -1$

$\varepsilon \ll 1$



$$V(\varphi) \sim M^{4+\alpha}\varphi^{-\alpha}$$

$\frac{\dot a}{a}$ $\qquad -\alpha M^{4+\alpha}\varphi^{-\alpha-1}$

$$\ddot\varphi + 3H\dot\varphi + V'(\varphi) = 0$$

$$\ddot\varphi + 3H\dot\varphi - \alpha M^{4+\alpha}\varphi^{-\alpha-1} = 0$$

$\varphi = A t^{\gamma}$ $\qquad \dot\varphi^2 \propto t^{(\gamma-1)2}$

$R^{\dots}$ DGP

Cond String Gas !

$P(\chi) \leftrightarrow q\left(\frac{\delta\rho}{\rho}\right)$

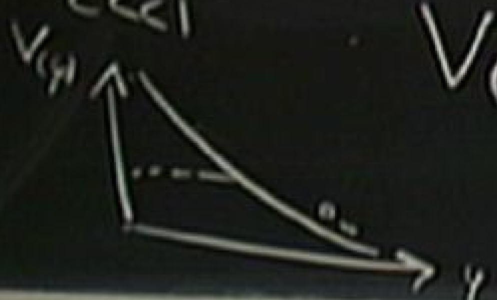
$$W = \frac{p}{\rho} = \frac{p+\rho}{\rho} - 1 = \frac{\dot\varphi^2}{\frac{1}{2}\dot\varphi^2 + V(\varphi)} - 1 \simeq \frac{(\dot\varphi^2/V)}{\frac{1}{2}(\dot\varphi^2/V)+1} - 1$$

$w < -\frac{1}{3}$

$w \sim -1$

$$\dot\varphi^2/V \ll 1 \rightarrow w \sim -1$$

$\varepsilon \ll 1$

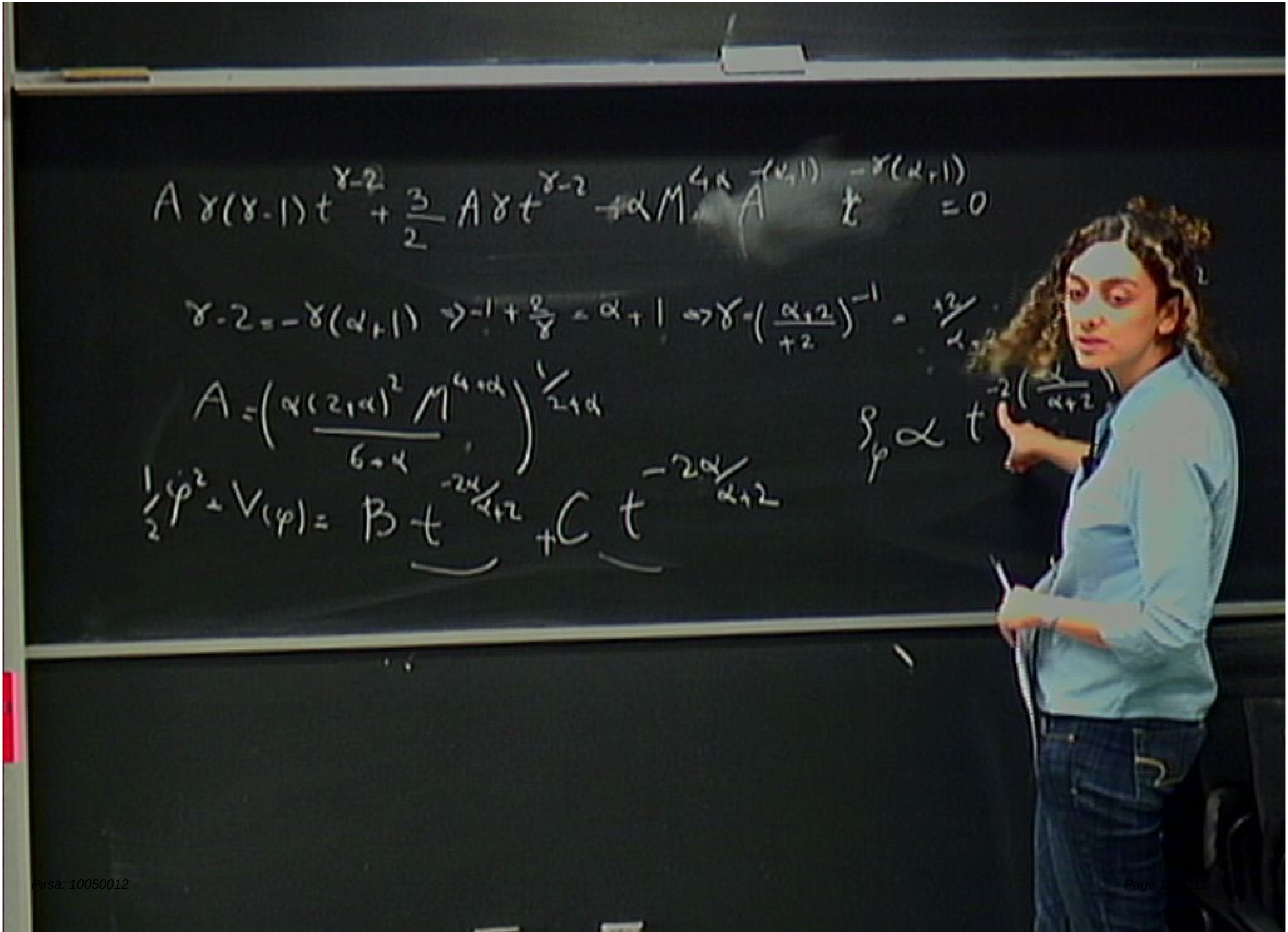


$$V(\varphi) \sim M^{4+\alpha}\varphi^{-\alpha}$$

$$\ddot\varphi + 3\overset{\dot a/a}{H}\dot\varphi + \overset{-\alpha M^{4+\alpha}\varphi^{-\alpha-1}}{V'(\varphi)} = 0$$

$$\ddot\varphi + 3H\dot\varphi - \alpha M^{4+\alpha}\varphi^{-\alpha-1} = 0$$

$$\varphi = A t^{\gamma} \qquad \dot\varphi^2 \propto t^{(\gamma-1)2}$$

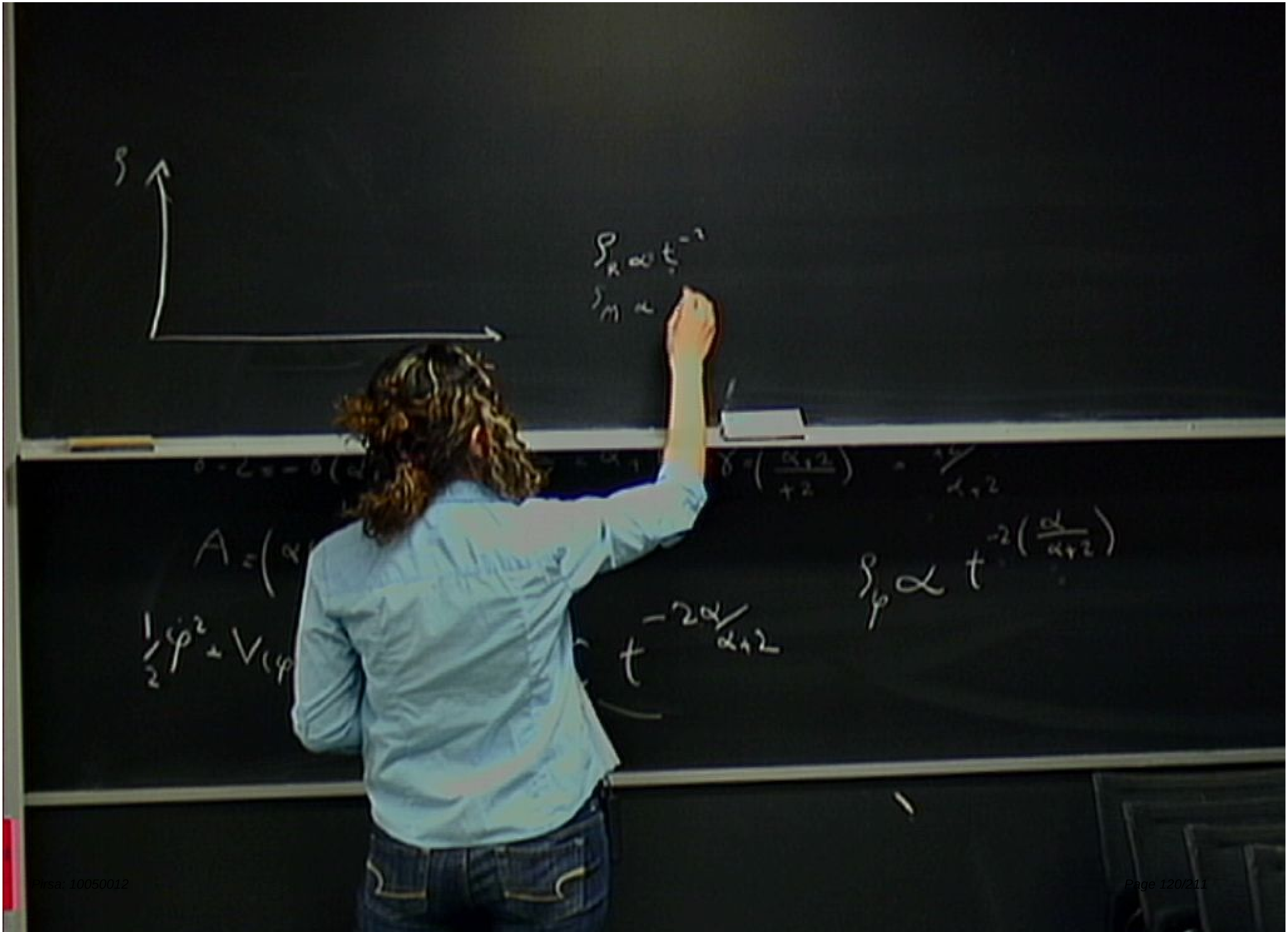

$A\gamma(\gamma-1)t^{\gamma-2} + \frac{3}{2}A\gamma t^{\gamma-2} + \alpha M^{4+\alpha} A^{-(\alpha+1)} t^{-\gamma(\alpha+1)} = 0$
$\gamma - 2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha + 1 \Rightarrow \gamma = \left(\frac{\alpha+2}{2}\right)^{-1} = \frac{2}{\alpha+2}$
$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{1/(2+\alpha)}$
$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$

$$\ldots -2 = -\delta(\alpha+1) \Rightarrow -1 + \frac{2}{\delta} = \alpha + 1 \Rightarrow \delta = \left(\frac{\alpha+2}{+2}\right) = \frac{+2}{\alpha+2}$$

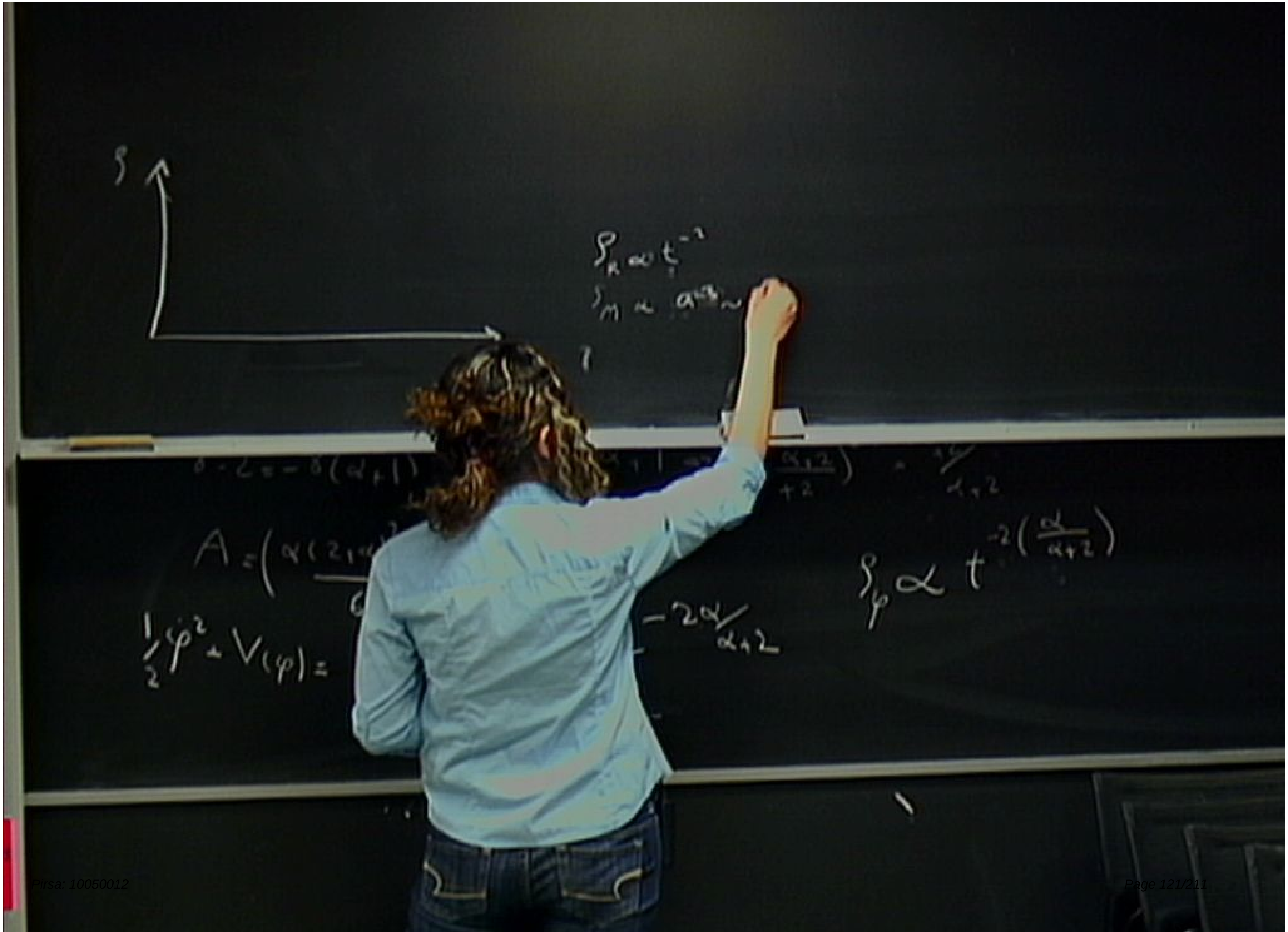
$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{1/(2+\alpha)}$$

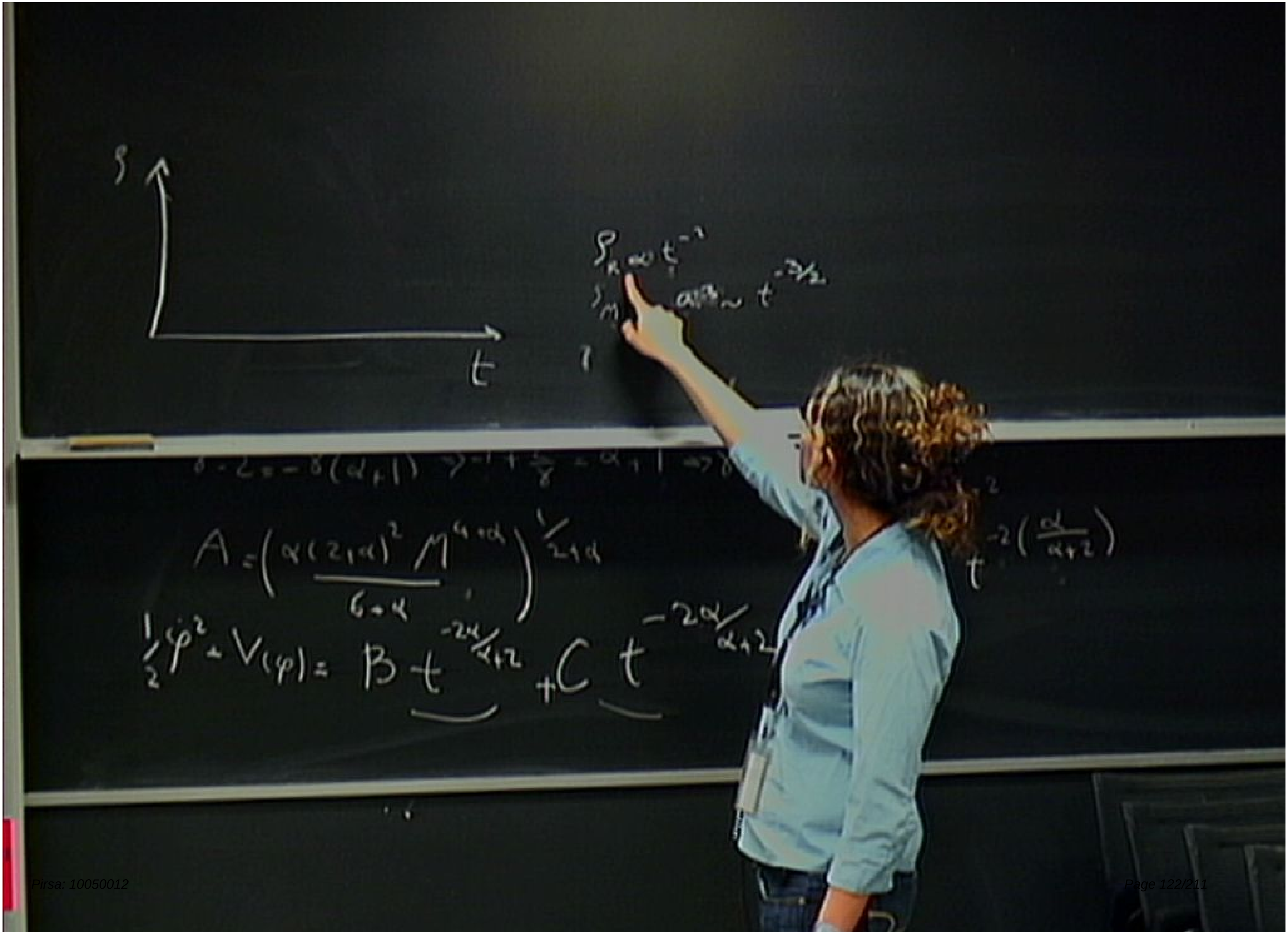
$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$

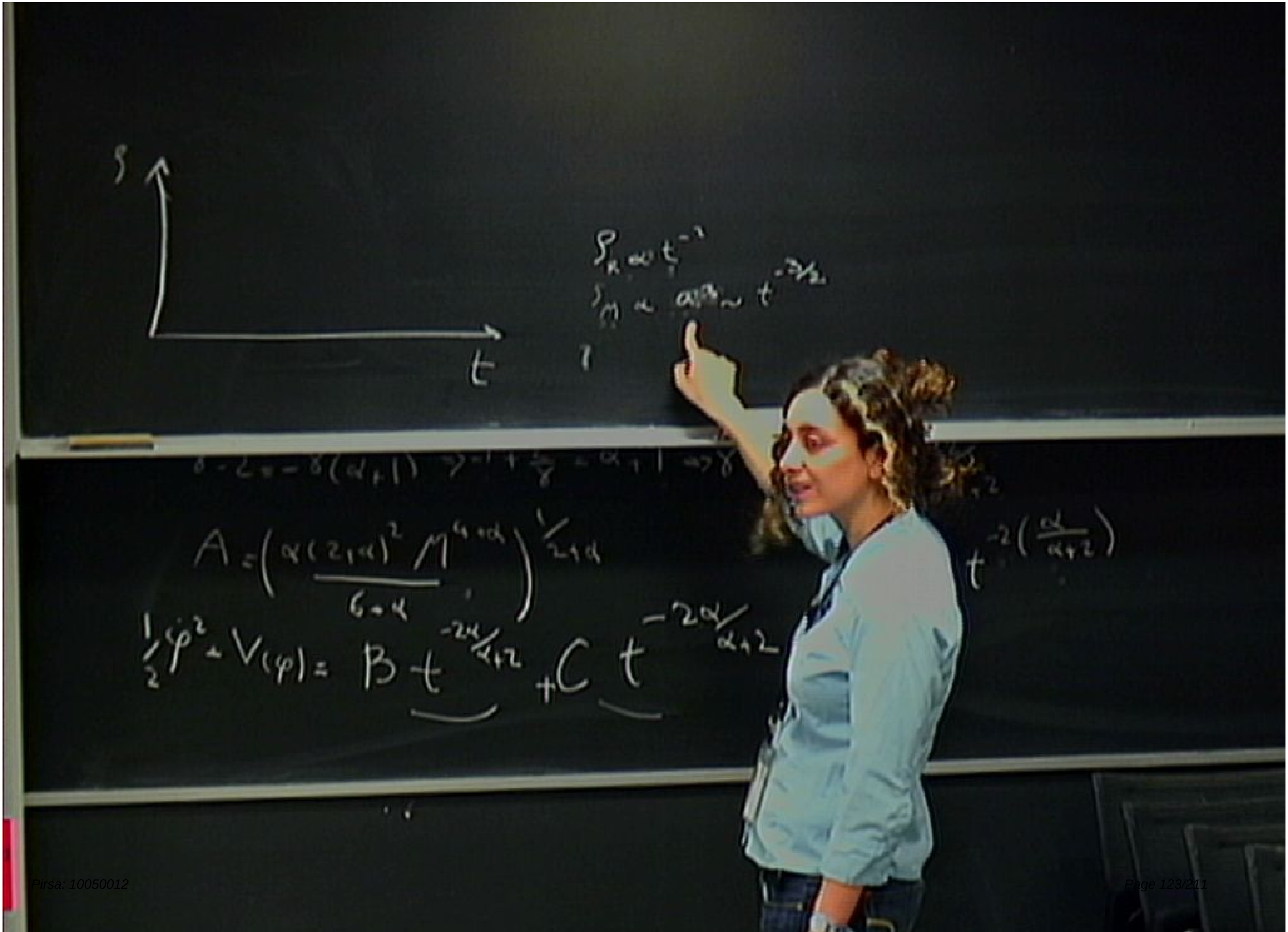
$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$$

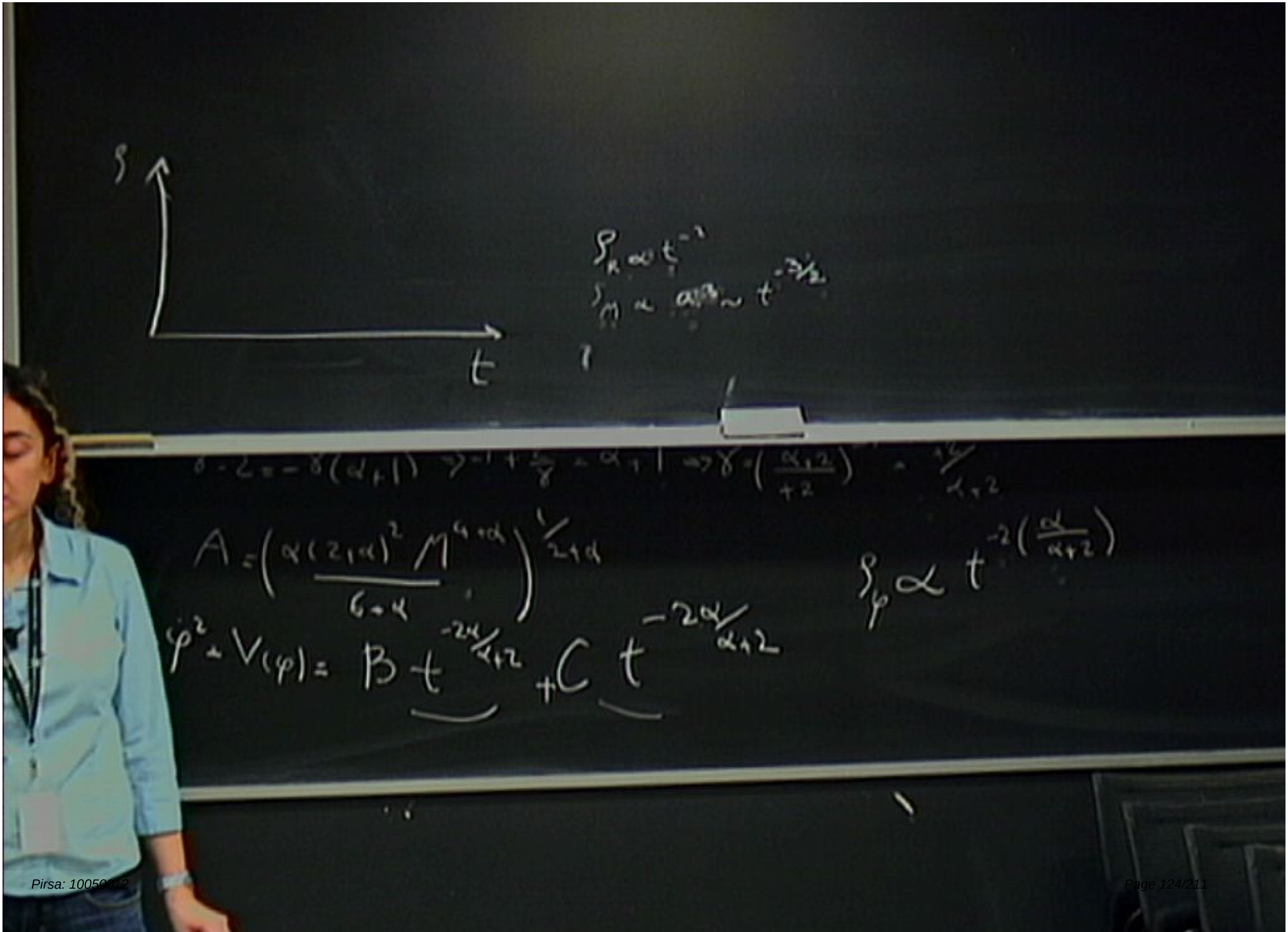


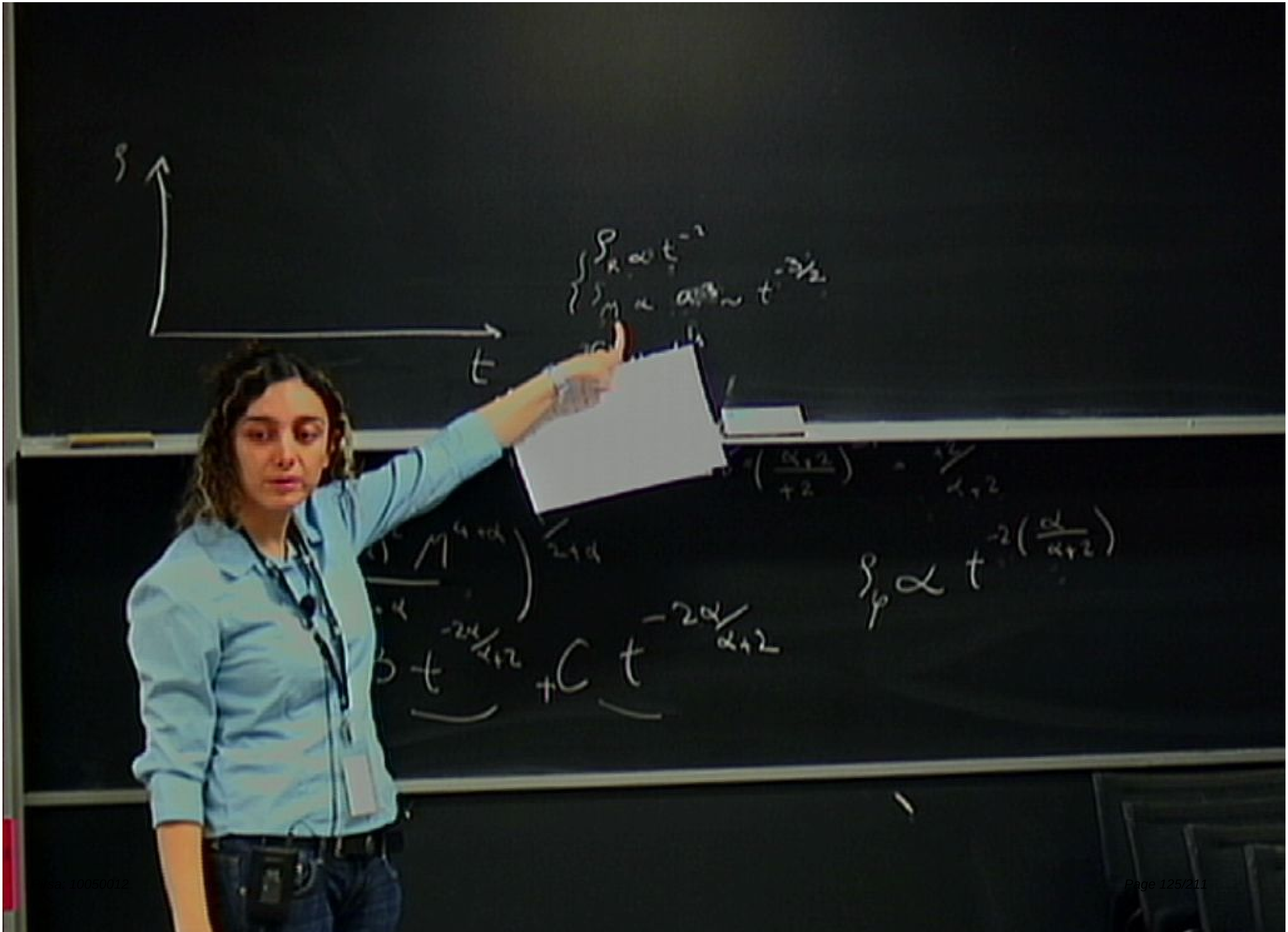
$\rho_R \propto t^{-2}$
$\rho_m \propto$
$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$
$t^{-2\alpha/\alpha+2}$


ρ_φ ∝ t^{-2(α/(α+2))}
½φ̇² + V(φ) =

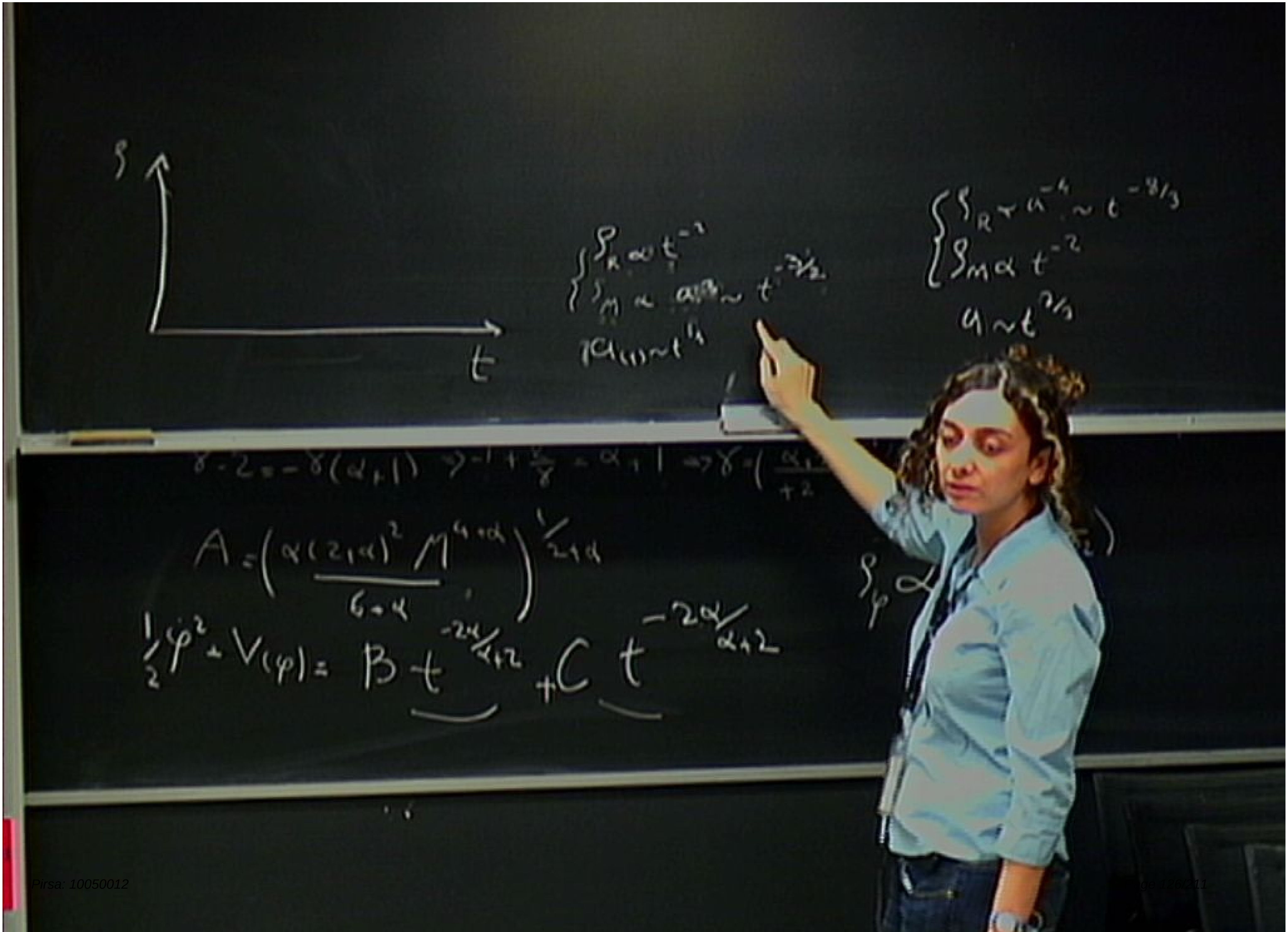

ρ
t
ρ_R ∝ t^-2
ρ_M ∝ t^-3/2
A = (α(2+α)² M^(4+α) / 6+α)^(1/(2+α))
½ φ̇² + V(φ) = B t^(-2α/(α+2)) + C t^(-2α/(α+2))

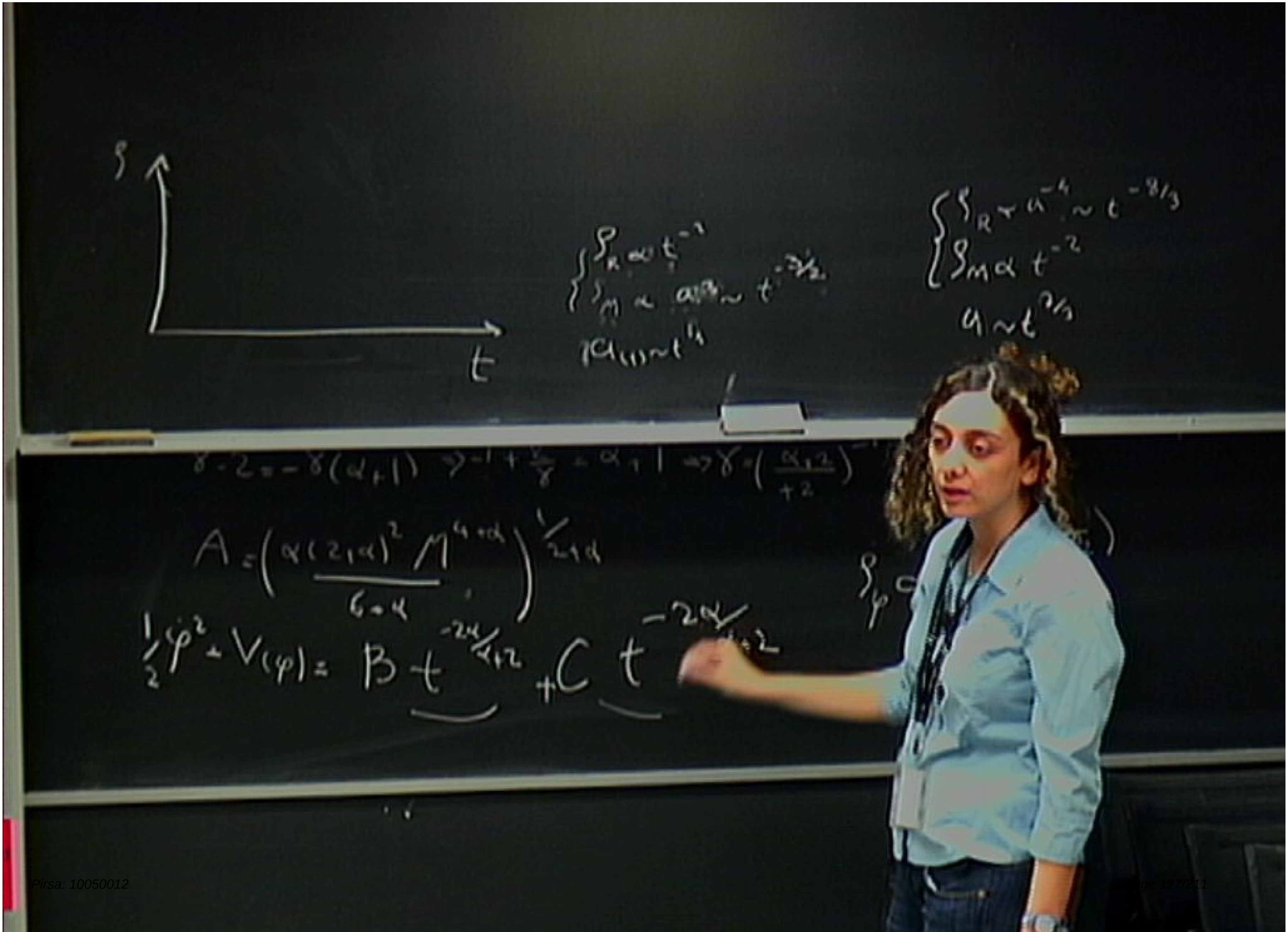

t
A = (α(2+α)^2 M^(4+α) / (6+α))^(1/(2+α))
1/2 φ̇^2 + V(φ) = B t^(-2α/(α+2)) + C t^(-2α/(α+2))
t^(-2(α/(α+2)))


ρ
t
$\rho_R \propto t^{-2}$
$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{1/(2+\alpha)}$
$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$
$\dot{\varphi}^2 + V(\varphi) = B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$



ρ
t
$\rho_R \propto t^{-2}$
$\rho_\phi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$
$+ C\, t^{-2\alpha/\alpha+2}$


ρ
t
ρ_R ∝ t^-2
ρ_M ∝ ~ t^-3/2
a(t) ~ t^1/2
ρ_R ∝ a^-4 ~ t^-8/3
ρ_M ∝ t^-2
a ~ t^2/3
A = (α(2+α)^2 M^4+α / 6+α)^1/2+α
1/2 φ̇^2 + V(φ) = B t^-2α/α+2 + C t^-2α/α+2



$\rho_R \propto a^{-4} \sim t^{-8/3}$
$\rho_M \propto t^{-2}$
$a \sim t^{2/3}$
$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{1/(2+\alpha)}$
$\frac{1}{2}\dot\varphi^2 + V(\varphi) = B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$

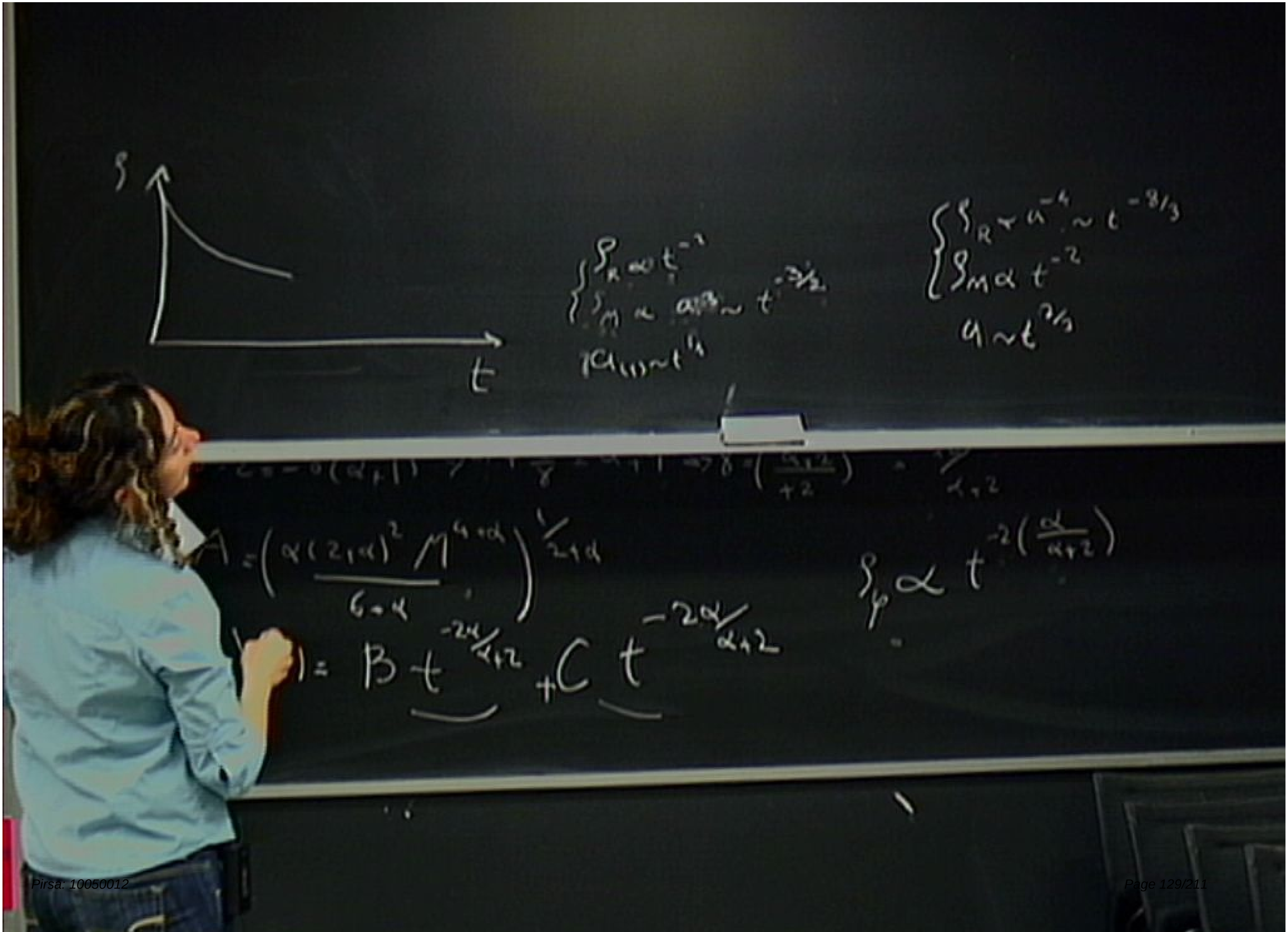
$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_M \propto a^{-3} \sim t^{-3/2} \end{cases} \qquad a(t) \sim t^{1/2}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \end{cases} \qquad a \sim t^{2/3}$$

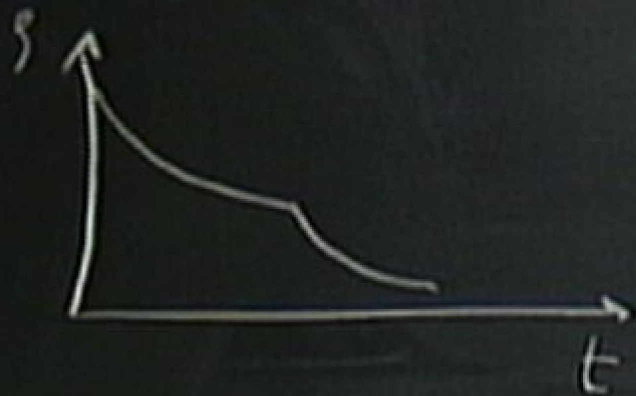
$$= \left(\frac{\alpha (2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{1/(2+\alpha)}$$

$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$

$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$$



ρ
t
$\rho_R \propto t^{-2}$
$\rho_M \propto a^{-3} \sim t^{-3/2}$
$a(t) \sim t^{1/2}$
$\rho_R \propto a^{-4} \sim t^{-8/3}$
$\rho_M \propto t^{-2}$
$a \sim t^{2/3}$
$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{1/(2+\alpha)}$
$\rho_\phi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$
$= B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$



$$\begin{cases} \rho_R \propto t^{-1} \\ \rho_m \propto a^{-3} \sim t^{-3/2} \end{cases}$$

$$a(t) \sim t^{1/2}$$

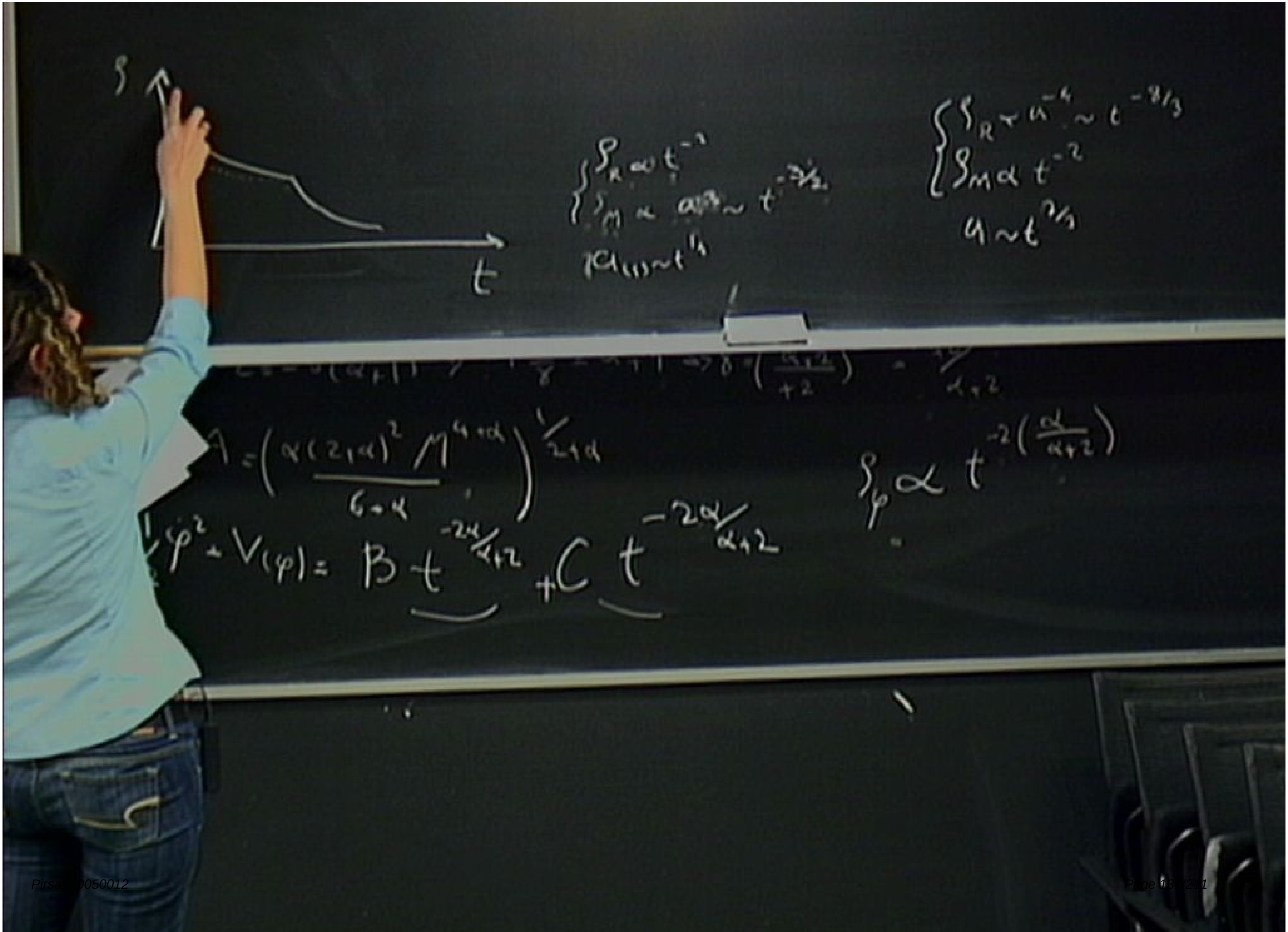
$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \end{cases}$$

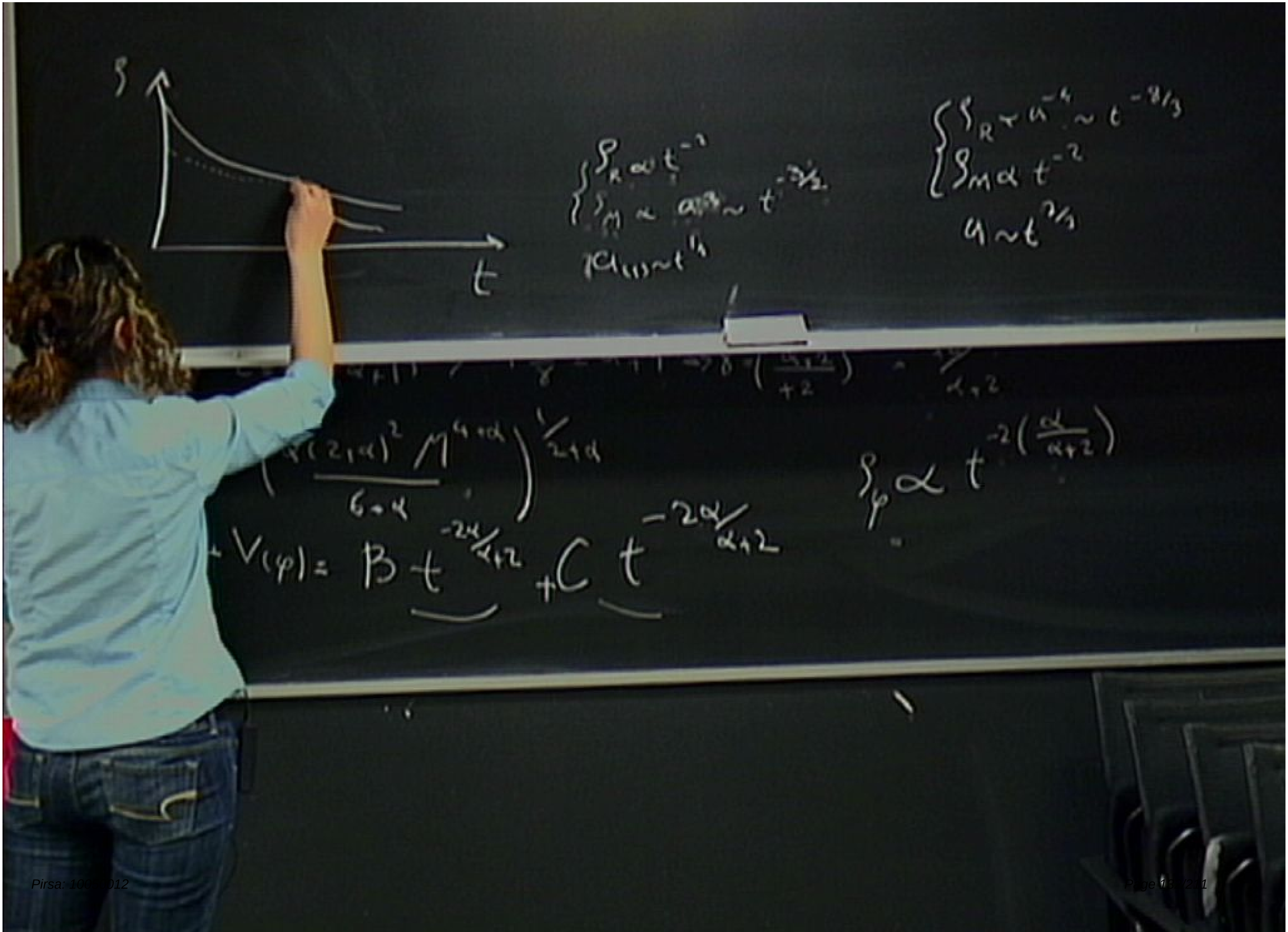
$$a \sim t^{2/3}$$

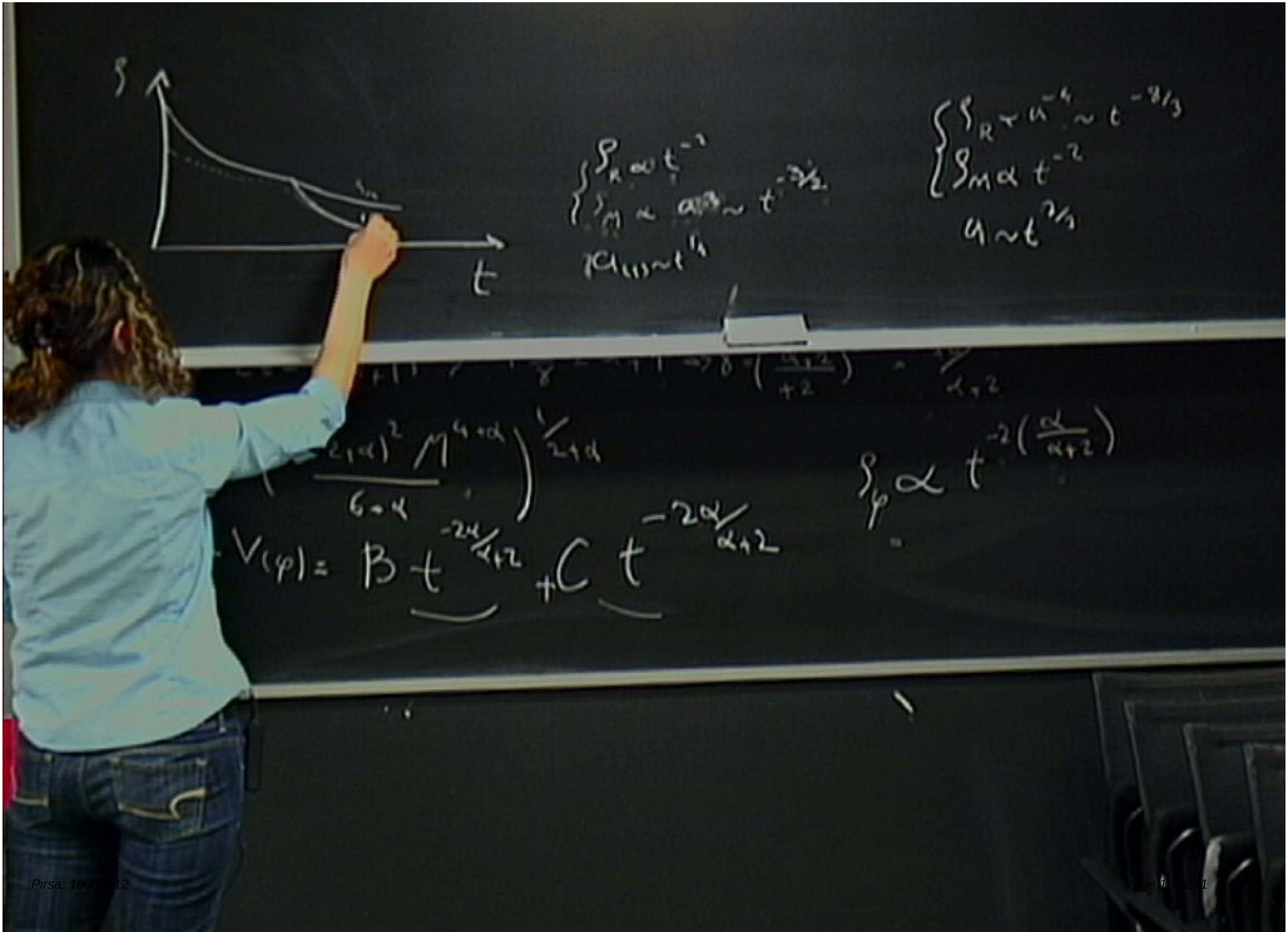
$$A = \left(\frac{\alpha (2+\alpha)^2 M^{4+\alpha}}{6+\alpha} \right)^{1/(2+\alpha)}$$

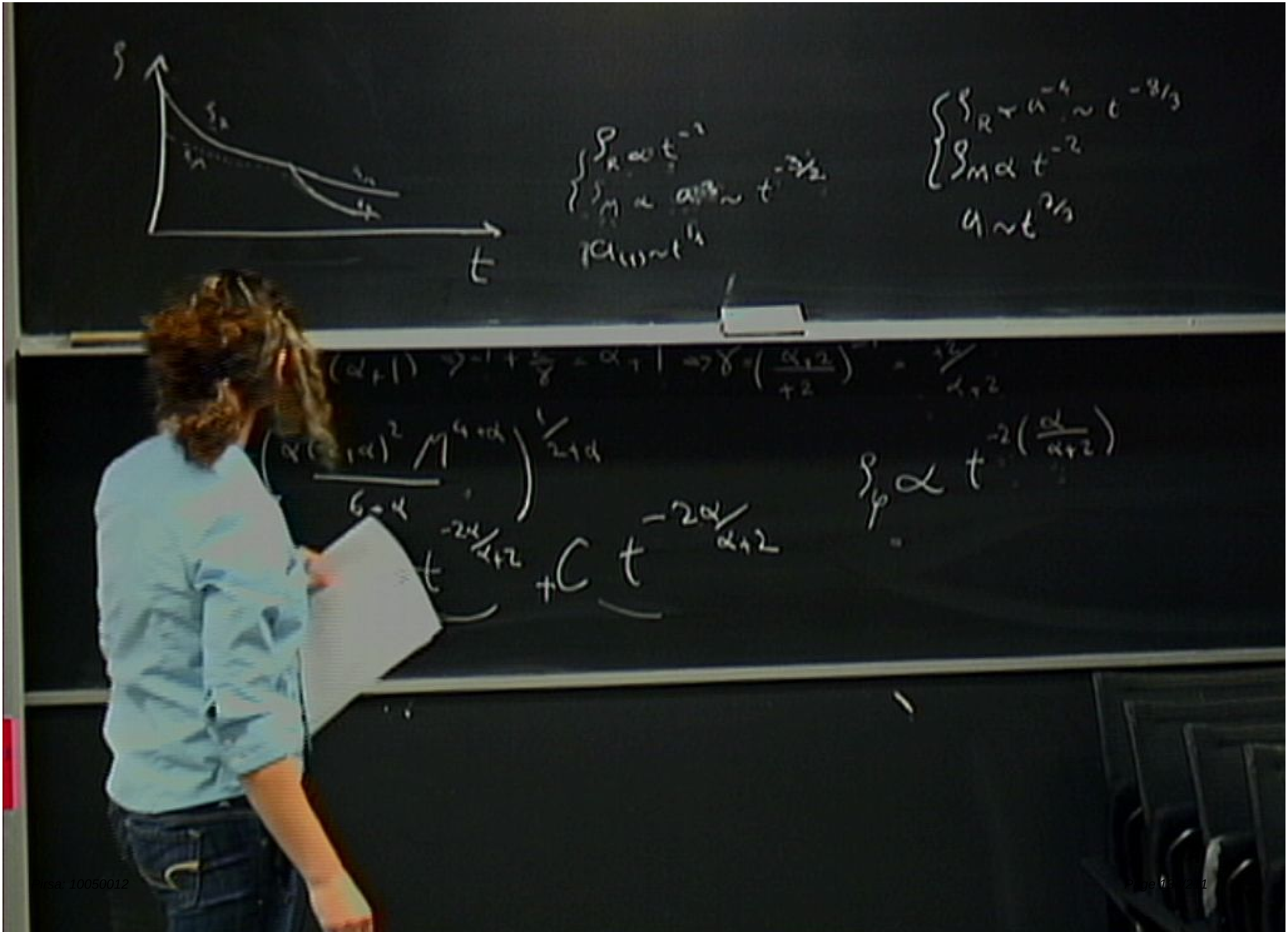
$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$

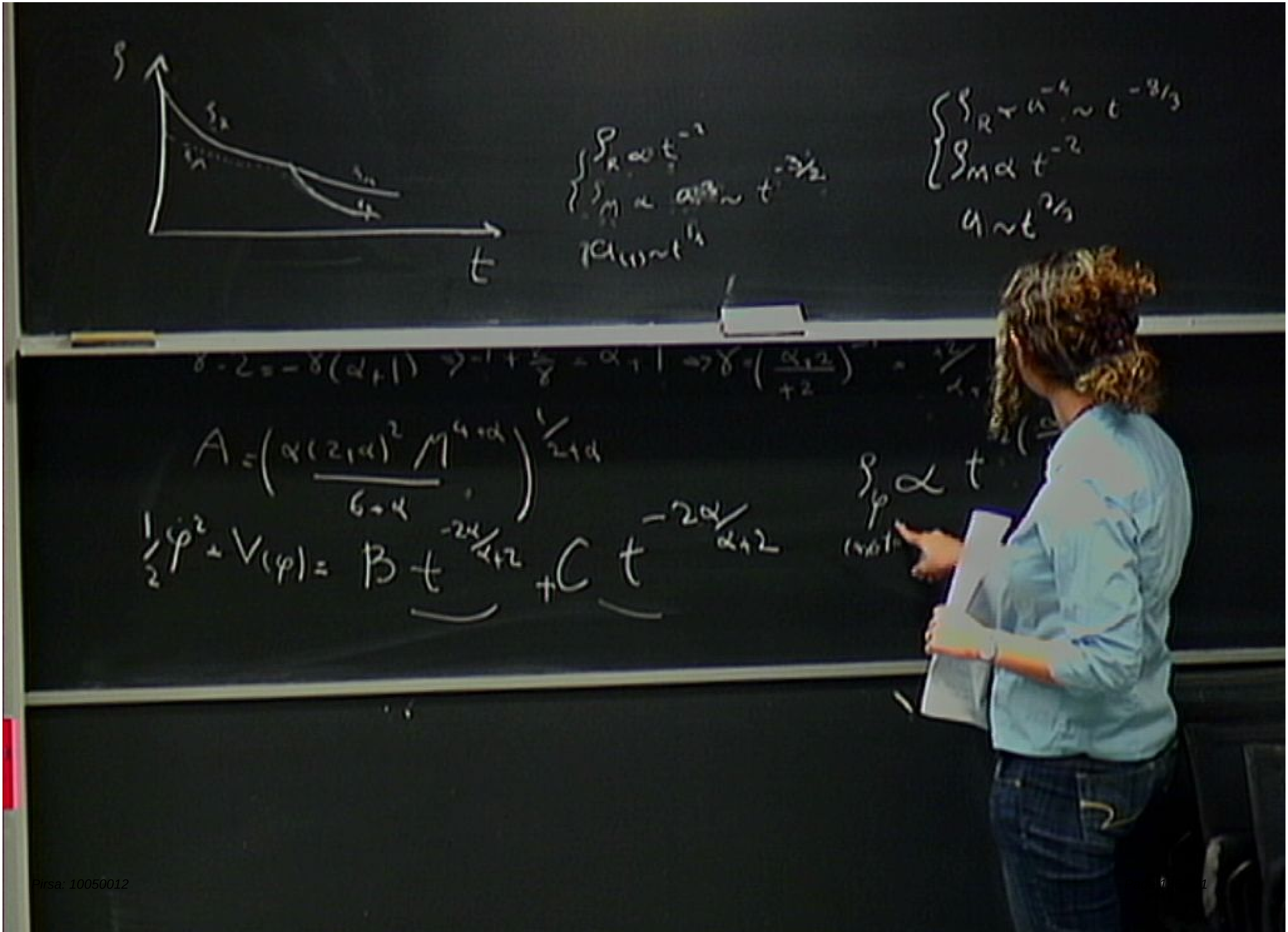
$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$$

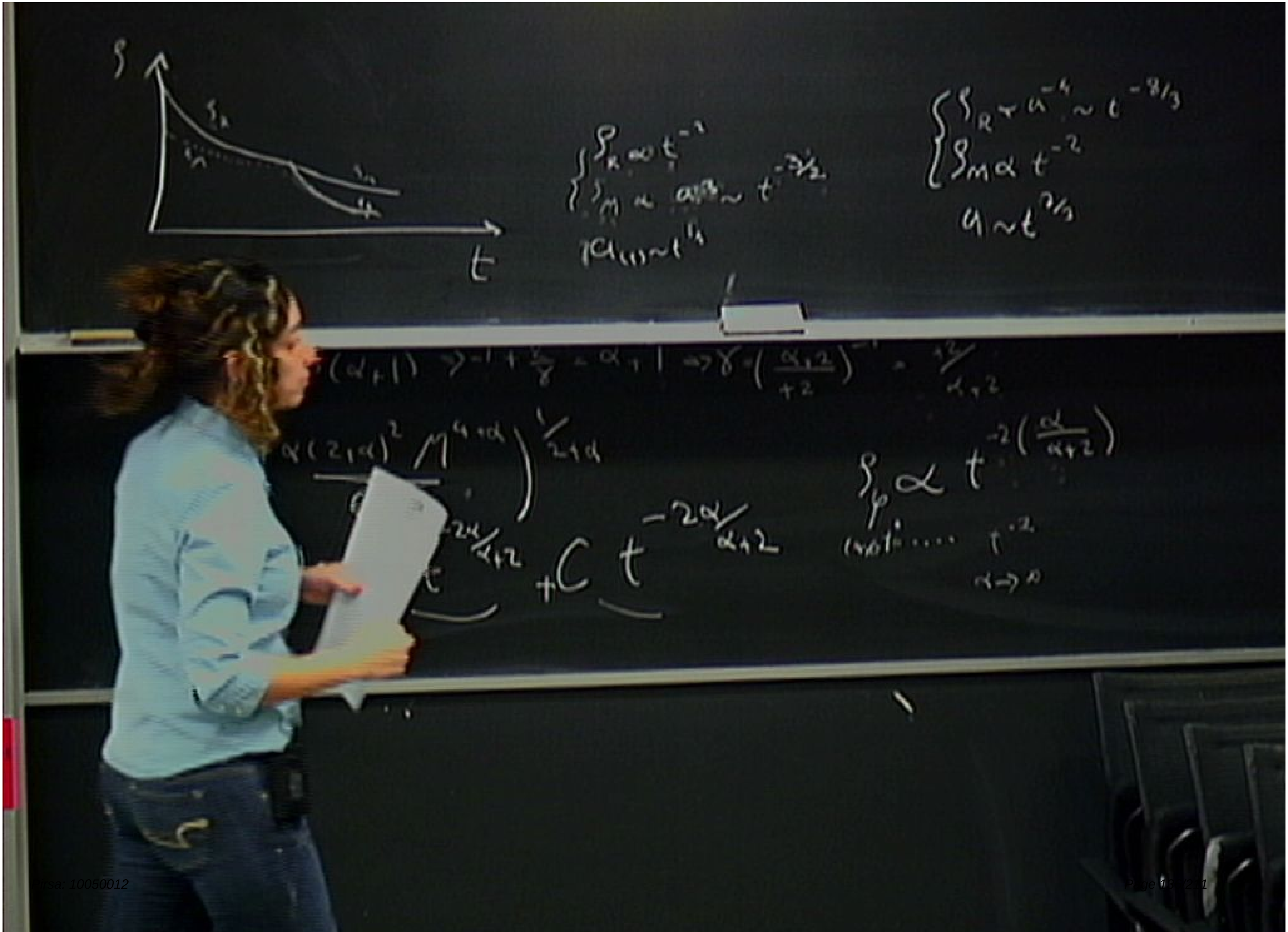

ρ
t
ρ_R ∝ t^-2
ρ_M ∝ a^-3 ~ t^-3/2
a(t) ~ t^1/2
ρ_R ∝ a^-4 ~ t^-8/3
ρ_M ∝ t^-2
a ~ t^2/3
ρ_φ ∝ t^-2(α/(α+2))
+ B t^-2α/(α+2) + C t^-2α/(α+2)

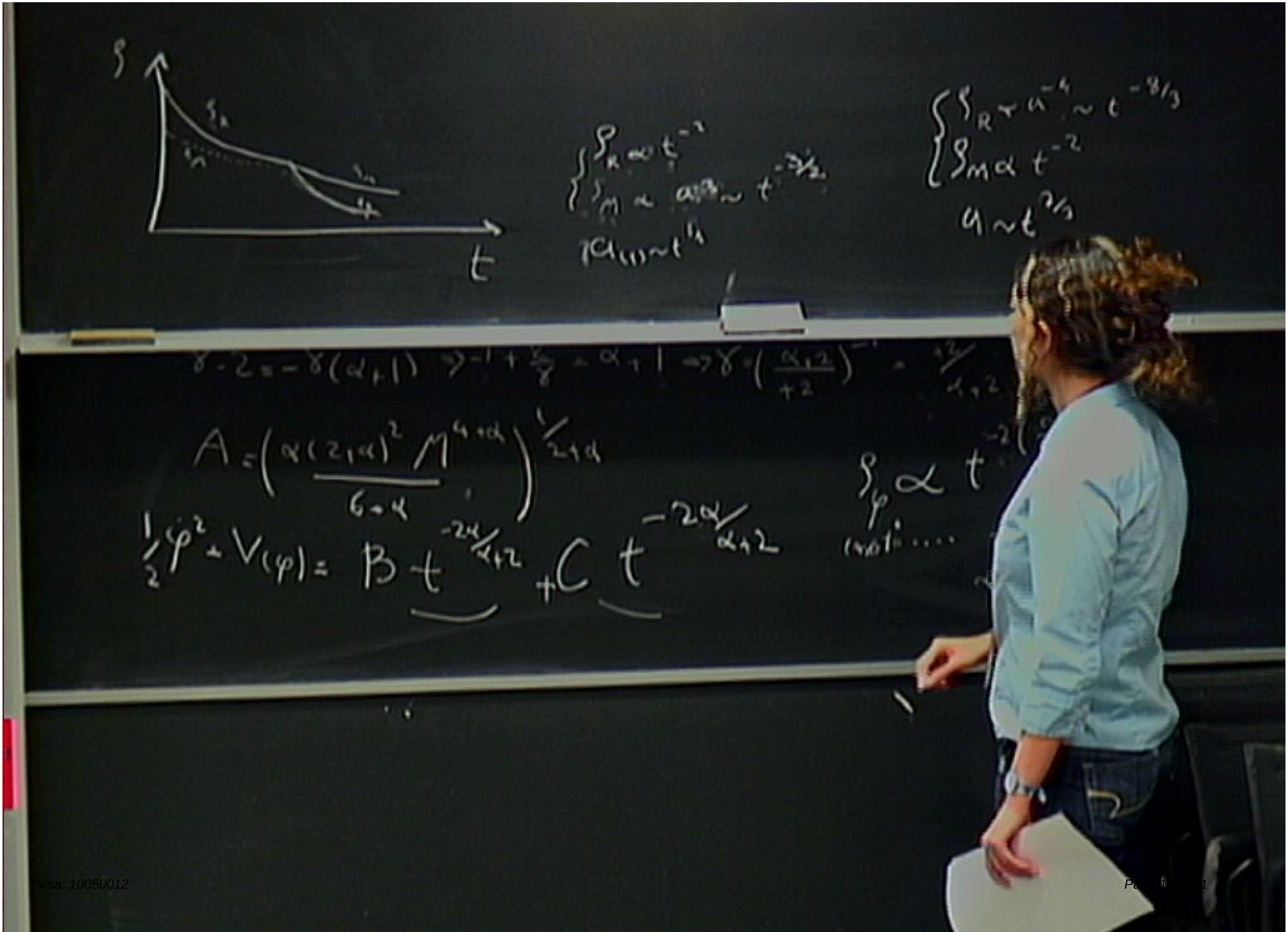

t
a ~ t^{2/3}
V(φ) = B t^{-2α/α+2} + C t^{-2α/α+2}

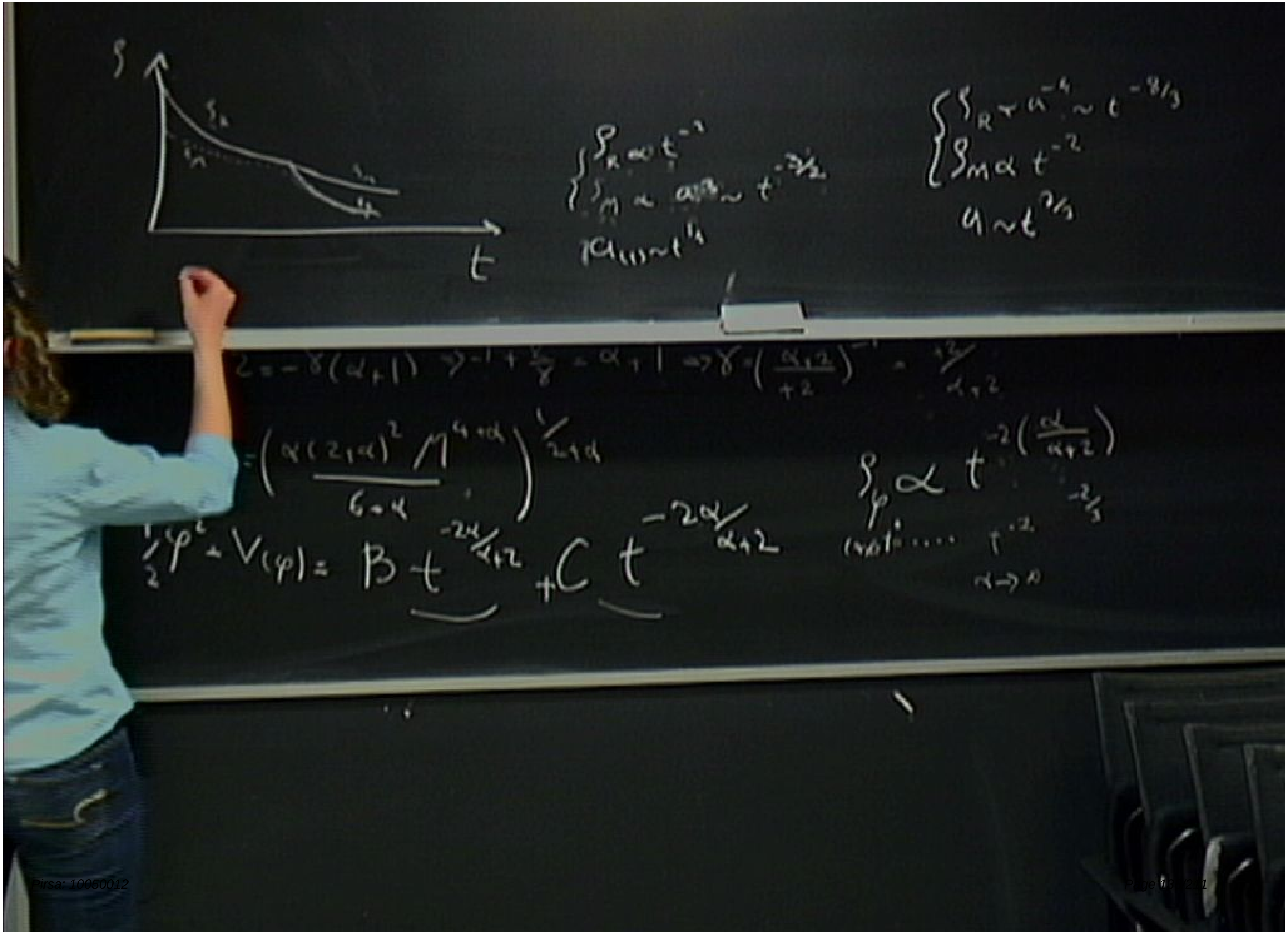

ρ_R ∝ t^-2
ρ_M ∝ a^-3 ~ t^-3/2
a(t) ~ t^1/2
ρ_R ∝ a^-4 ~ t^-8/3
ρ_M ∝ t^-2
a ~ t^2/3
ρ_φ ∝ t^-2(α/α+2)
V(φ) = B t^-2α/α+2 + C t^-2α/α+2

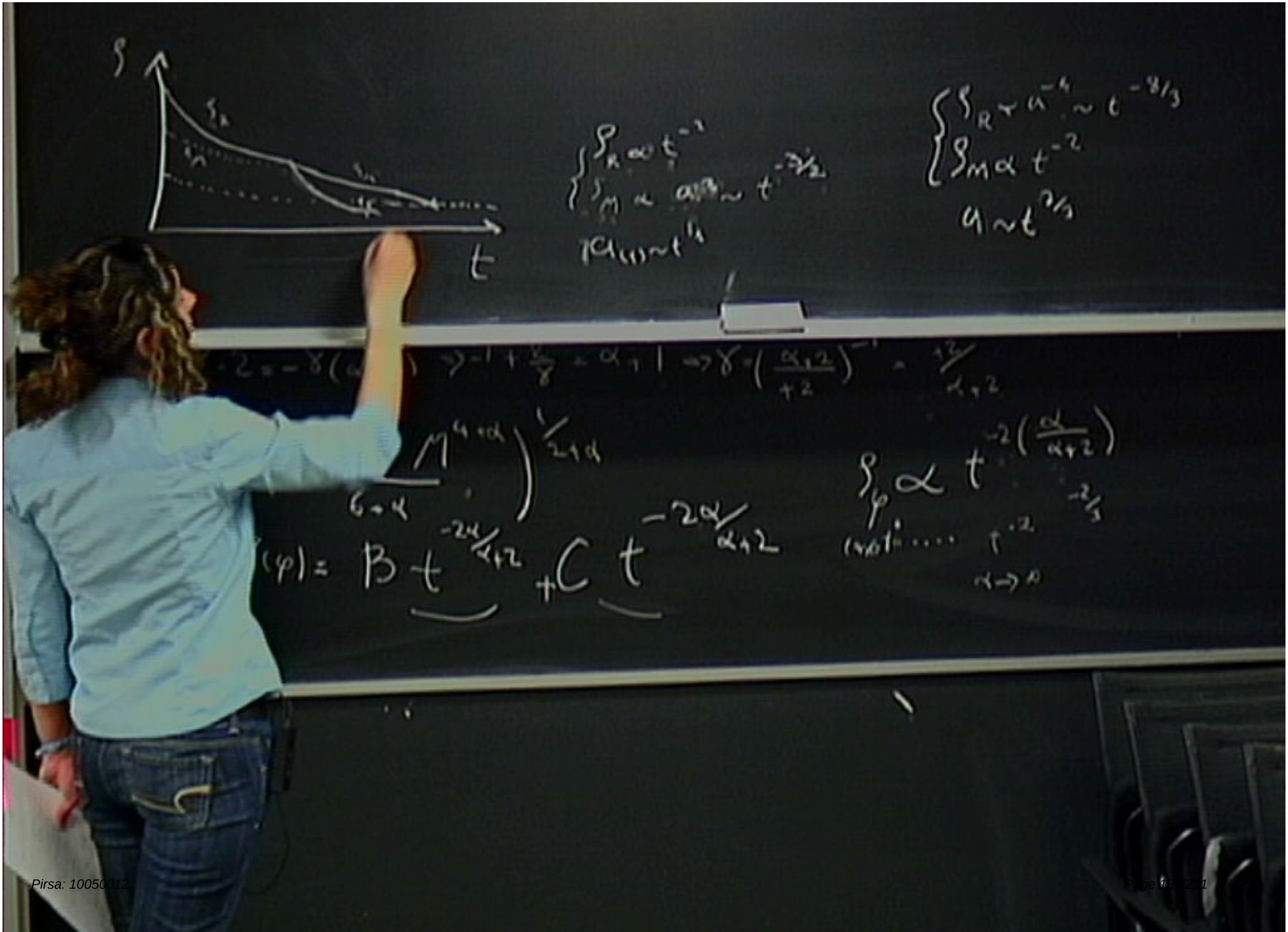



ρ
ρ_R
ρ_M
t
$\rho_R \propto t^{-2}$
$\rho_M \propto a^{-3} \sim t^{-3/2}$
$a(t) \sim t^{1/2}$
$\rho_R \propto a^{-4} \sim t^{-8/3}$
$\rho_M \propto t^{-2}$
$a \sim t^{2/3}$
$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{1/(2+\alpha)}$
$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B\,t^{-2\alpha/(\alpha+2)} + C\,t^{-2\alpha/(\alpha+2)}$
$\rho_\varphi \propto t$

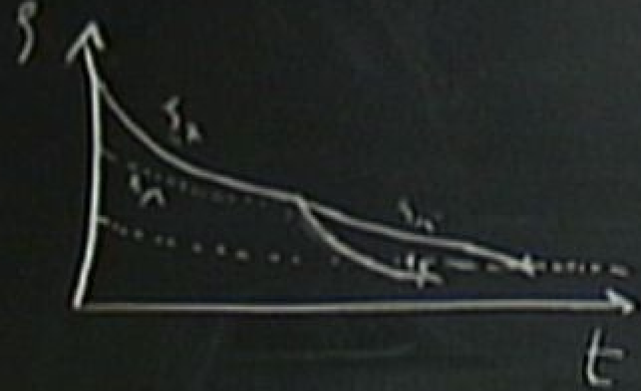



t
ρ_M α t^-2
a ~ t^2/3
A = (α(2+α)^2 M^(4+α) / (6+α))^(1/(2+α))
1/2 φ̇^2 + V(φ) = B t^(-2α/(α+2)) + C t^(-2α/(α+2))


t
a ~ t^{2/3}
ρ_M α t^{-2}
1/2 φ̇² + V(φ) = B t^{-2α/(α+2)} + C t^{-2α/(α+2)}



t
ρR ∝ t^-2
ρM ∝ ~ t^-3/2
a(t) ~ t^1/2
ρR ∝ a^-4 ~ t^-8/3
ρM ∝ t^-2
a ~ t^2/3
ρφ ∝ t^-2(α/α+2)
-2/3
α→0
B t^-2α/α+2 + C t^-2α/α+2



$$\begin{cases}\rho_R \propto t^{-2}\\ \rho_m \propto a^{-3} \sim t^{-3/2}\end{cases}$$
$$a(t) \sim t^{1/2}$$

$$\begin{cases}\rho_R \propto a^{-4} \sim t^{-8/3}\\ \rho_m \propto t^{-2}\end{cases}$$
$$a \sim t^{2/3}$$

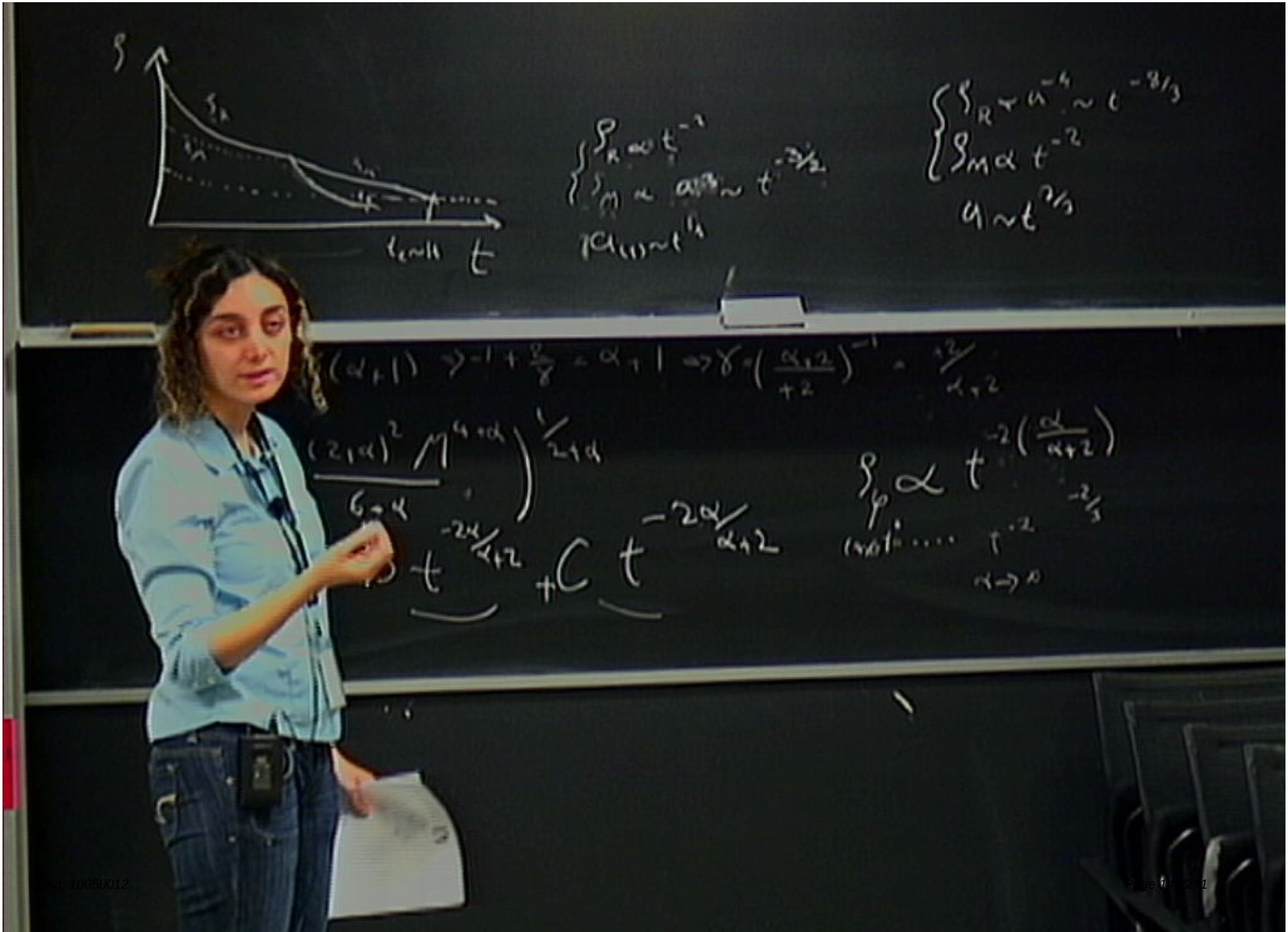
$$\gamma - 2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha + 1 \Rightarrow \gamma = \left(\frac{\alpha+2}{2}\right)^{-1} = \frac{2}{\alpha+2}$$

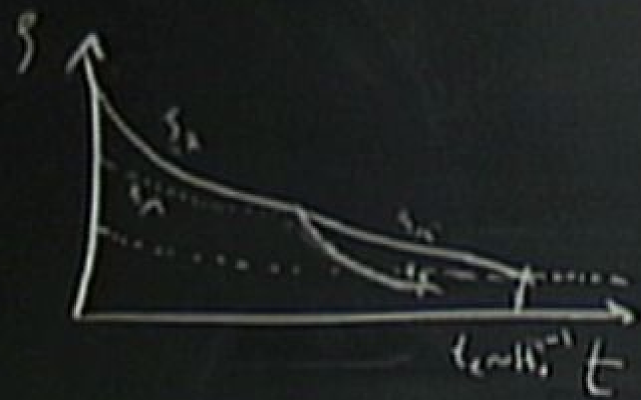
$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{\frac{1}{2+\alpha}}$$

$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$

$$(\alpha\to 0)\ t^{0} \quad \cdots \quad t^{-2} \quad -2/3 \quad \alpha\to\infty$$

$$\frac{1}{2}\dot\varphi^2 + V(\varphi) = B\,\underbrace{t^{-2\alpha/(\alpha+2)}} + C\,\underbrace{t^{-2\alpha/(\alpha+2)}}$$





$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_M \propto a^{-3} \sim t^{-3/2} \end{cases}$$

$$a(t) \sim t^{1/2}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_M \propto t^{-2} \end{cases}$$

$$a \sim t^{2/3}$$

$$\gamma - 2 = -\gamma(\alpha+1) \Rightarrow -1 + \frac{2}{\gamma} = \alpha + 1 \Rightarrow \gamma = \left(\frac{\alpha+2}{2}\right)^{-1} = \frac{2}{\alpha+2}$$

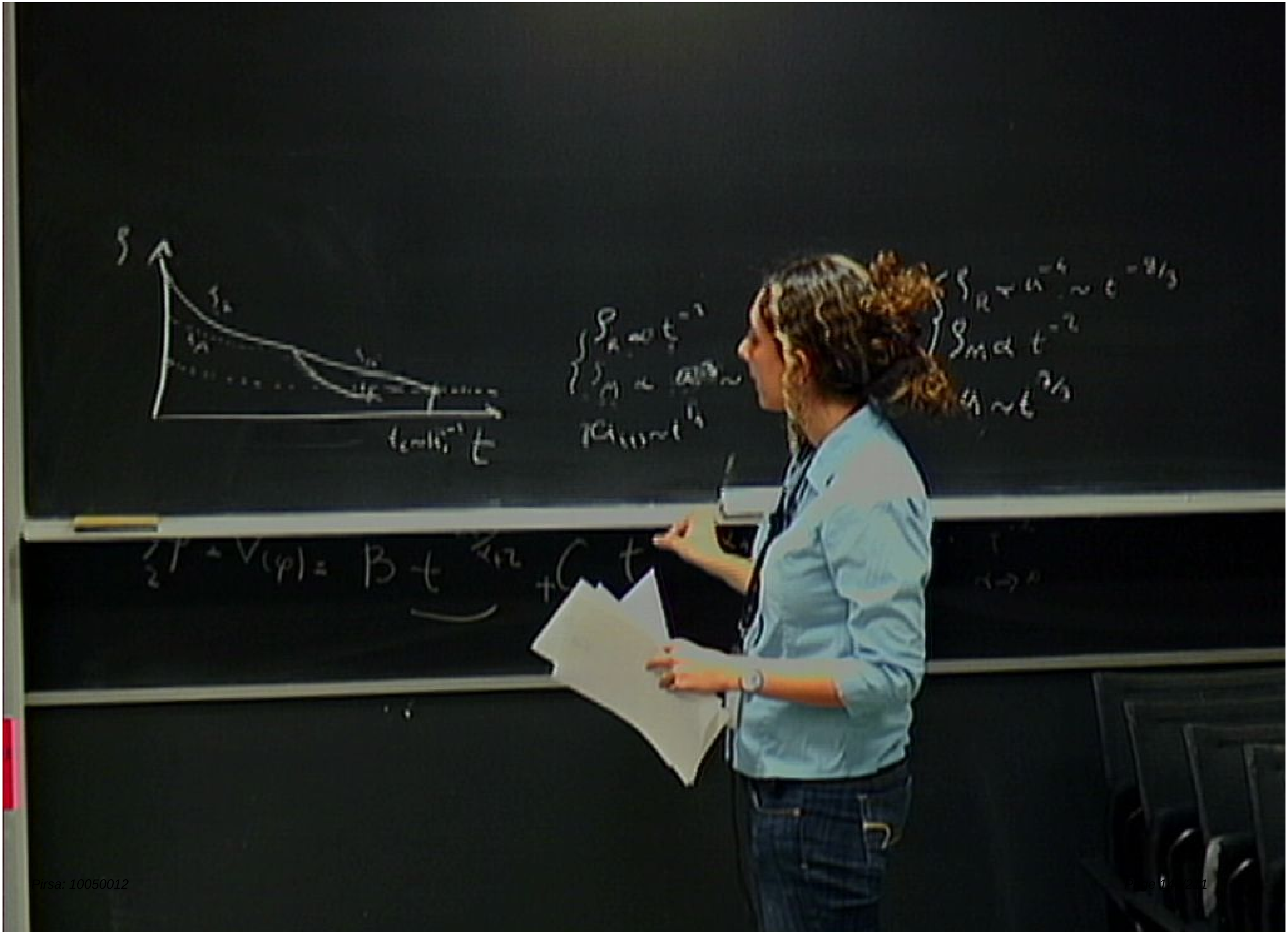
$$A = \left(\frac{\alpha(2+\alpha)^2 M^{4+\alpha}}{6+\alpha}\right)^{1/(2+\alpha)}$$

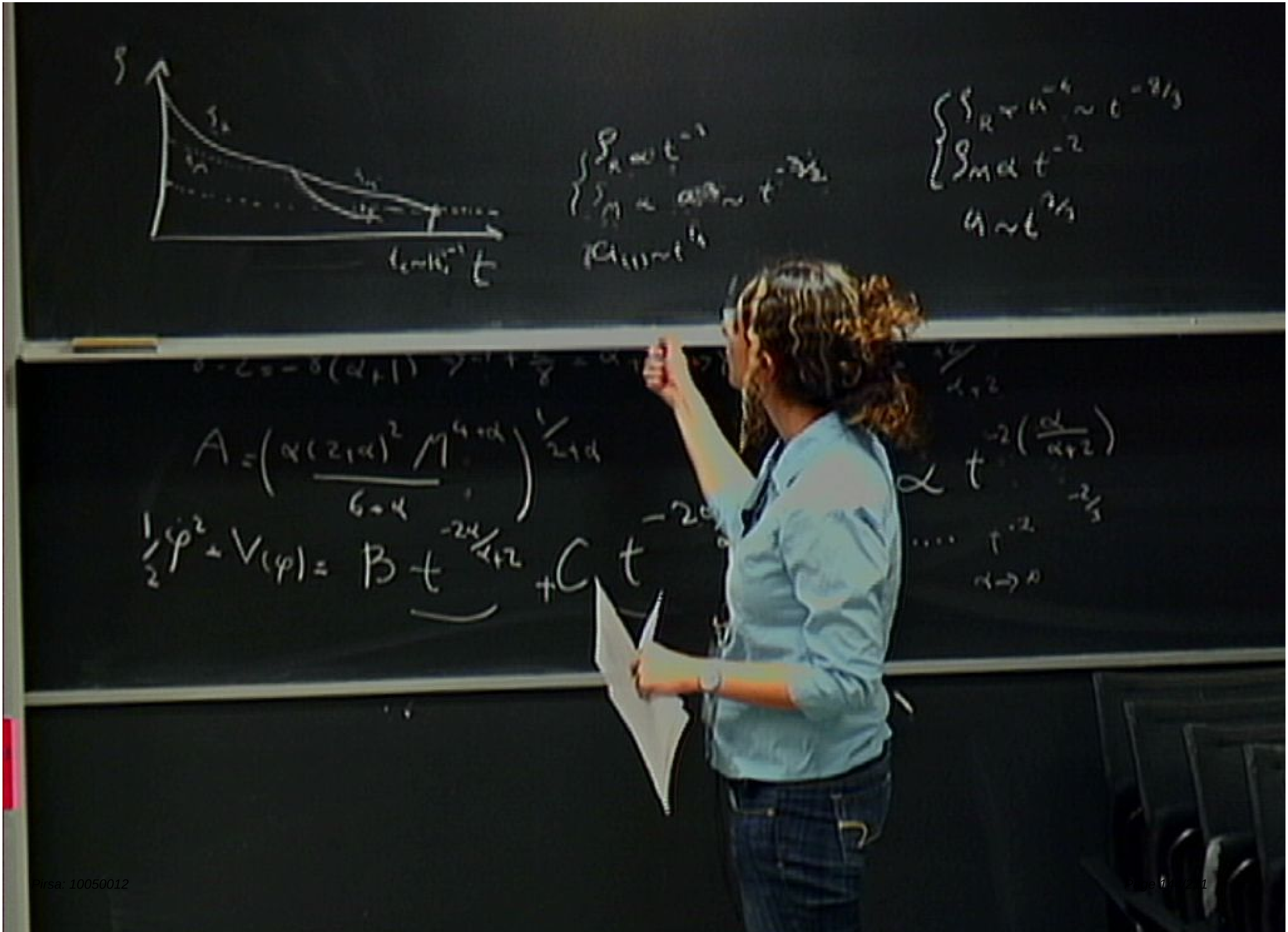
$$\rho_\varphi \propto t^{-2\left(\frac{\alpha}{\alpha+2}\right)}$$

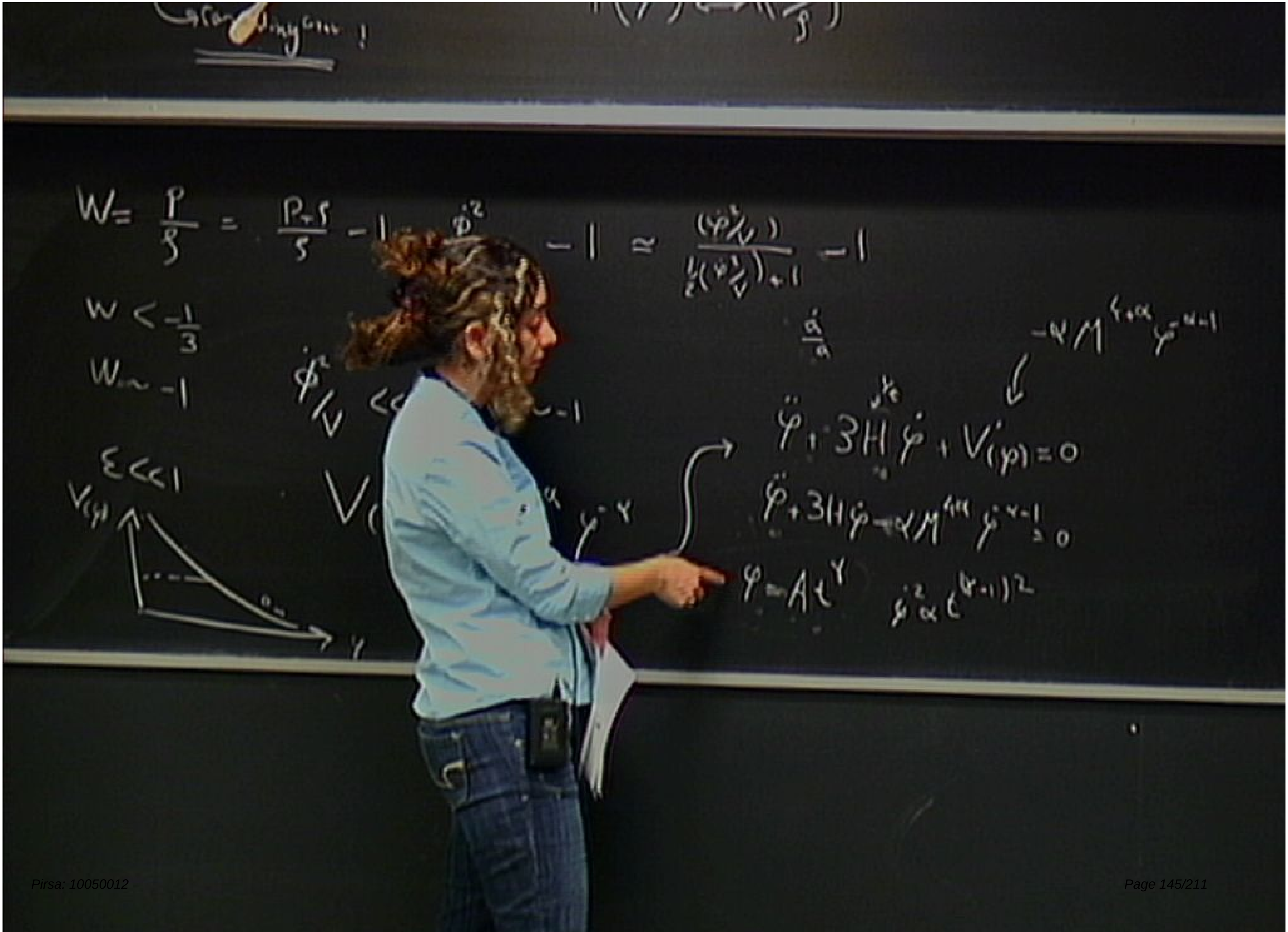
$$\frac{1}{2}\dot{\varphi}^2 + V(\varphi) = B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$$

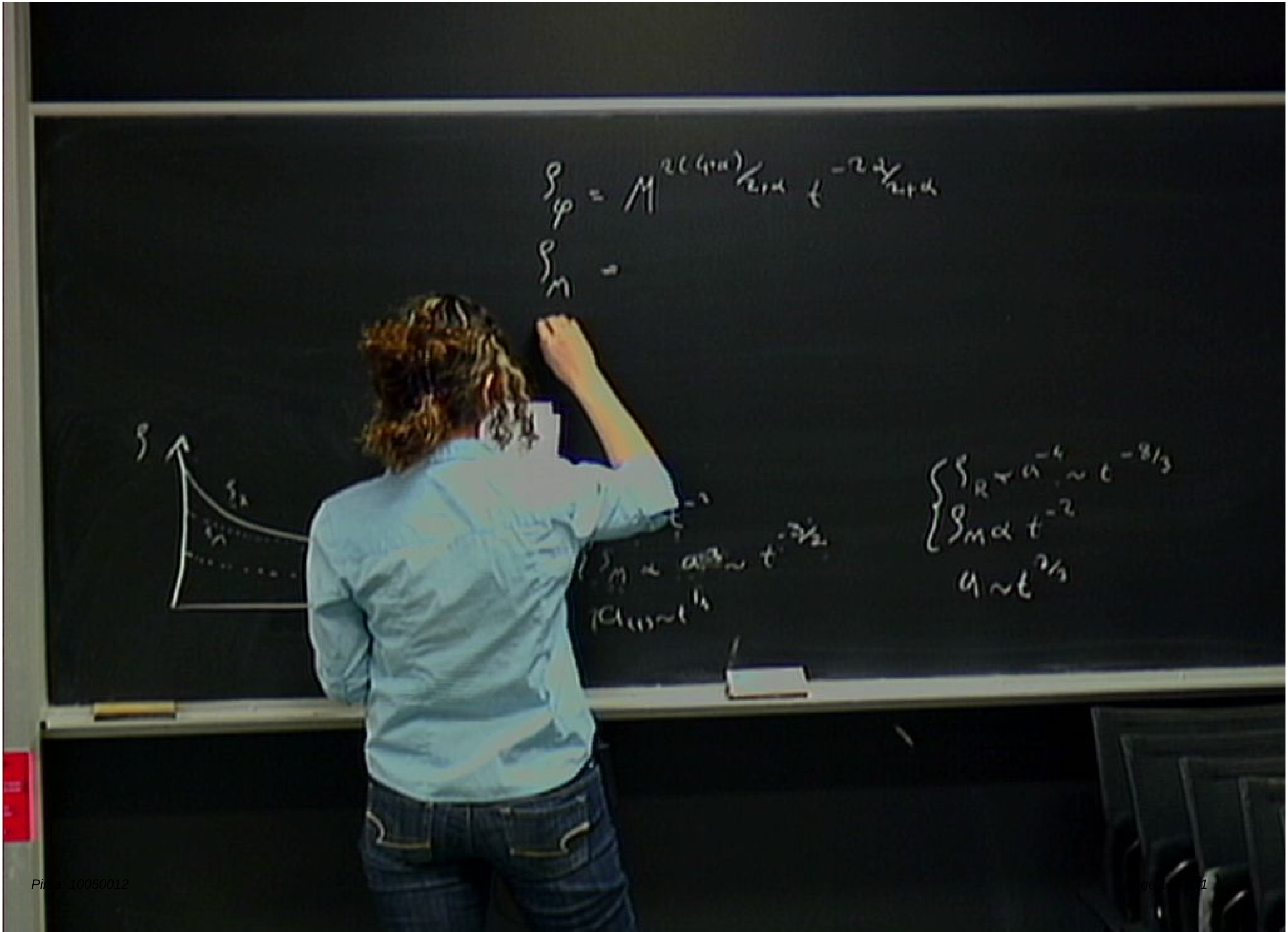
$(\alpha \to 0)$ t^0 ..... t^{-2} $\quad -2/3$

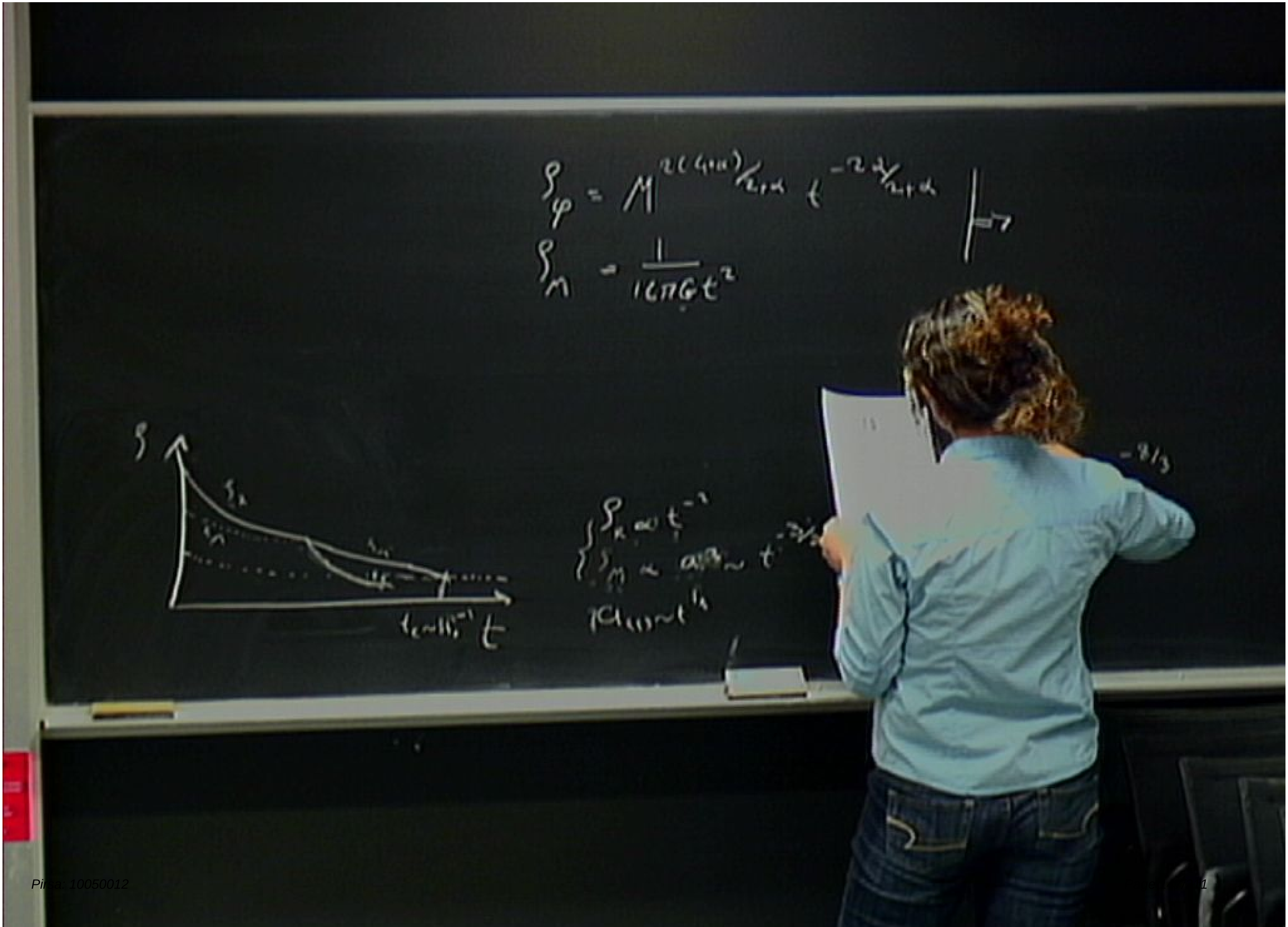
$\alpha \to \infty$

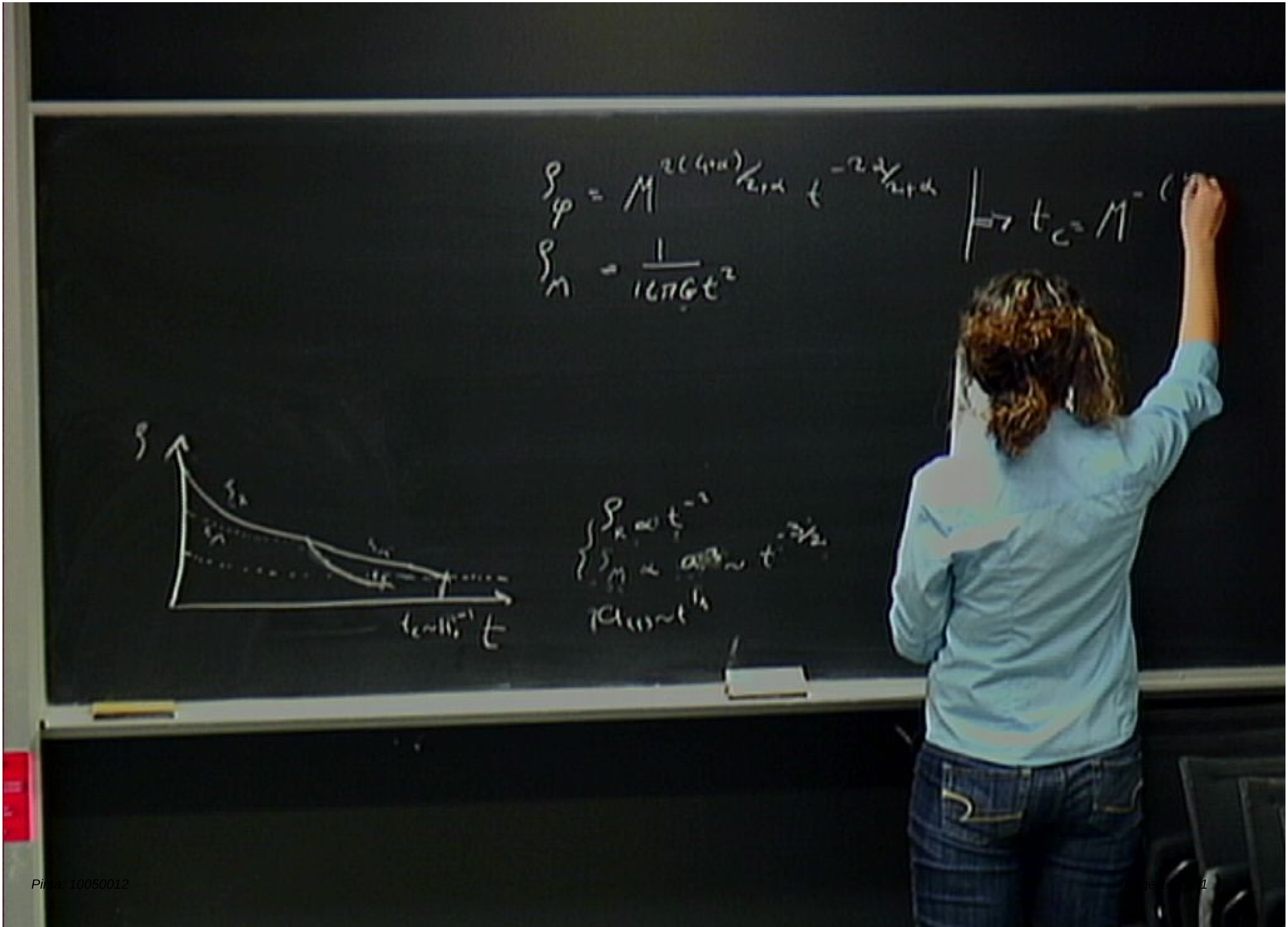


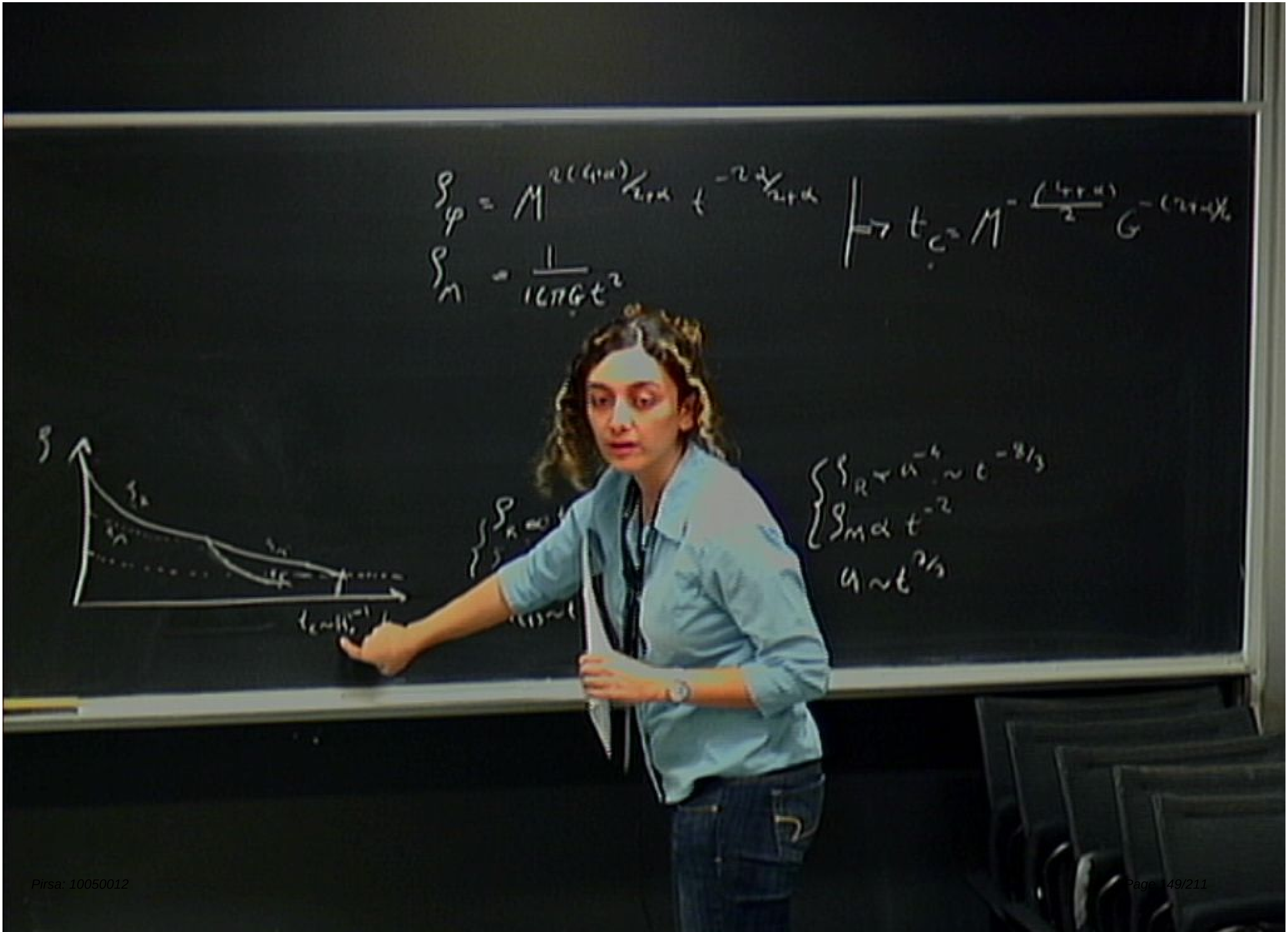


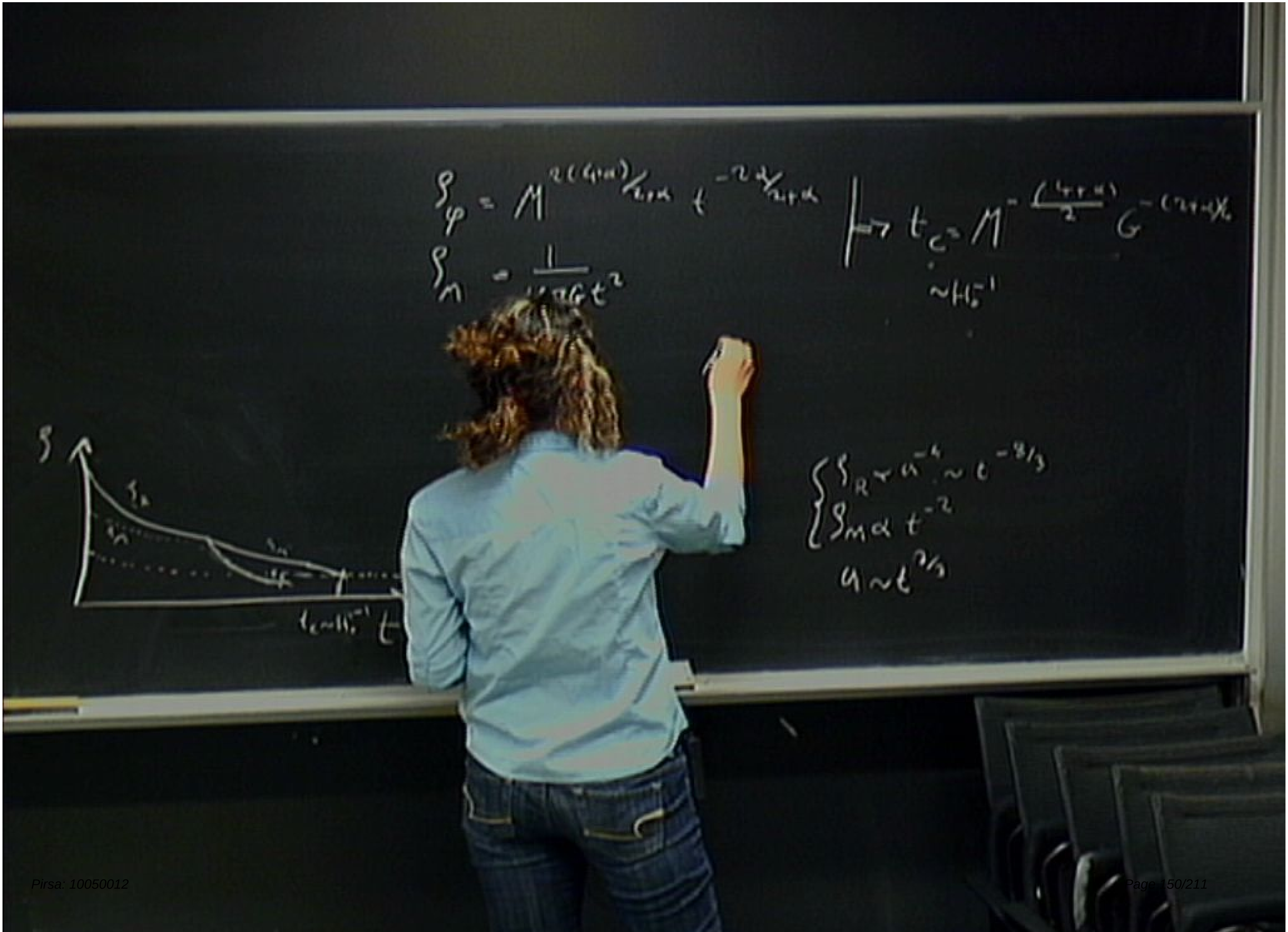

W < -1/3
W ~ -1
ε << 1
φ̈ + 3H φ̇ + V'(φ) = 0
φ = A t^γ

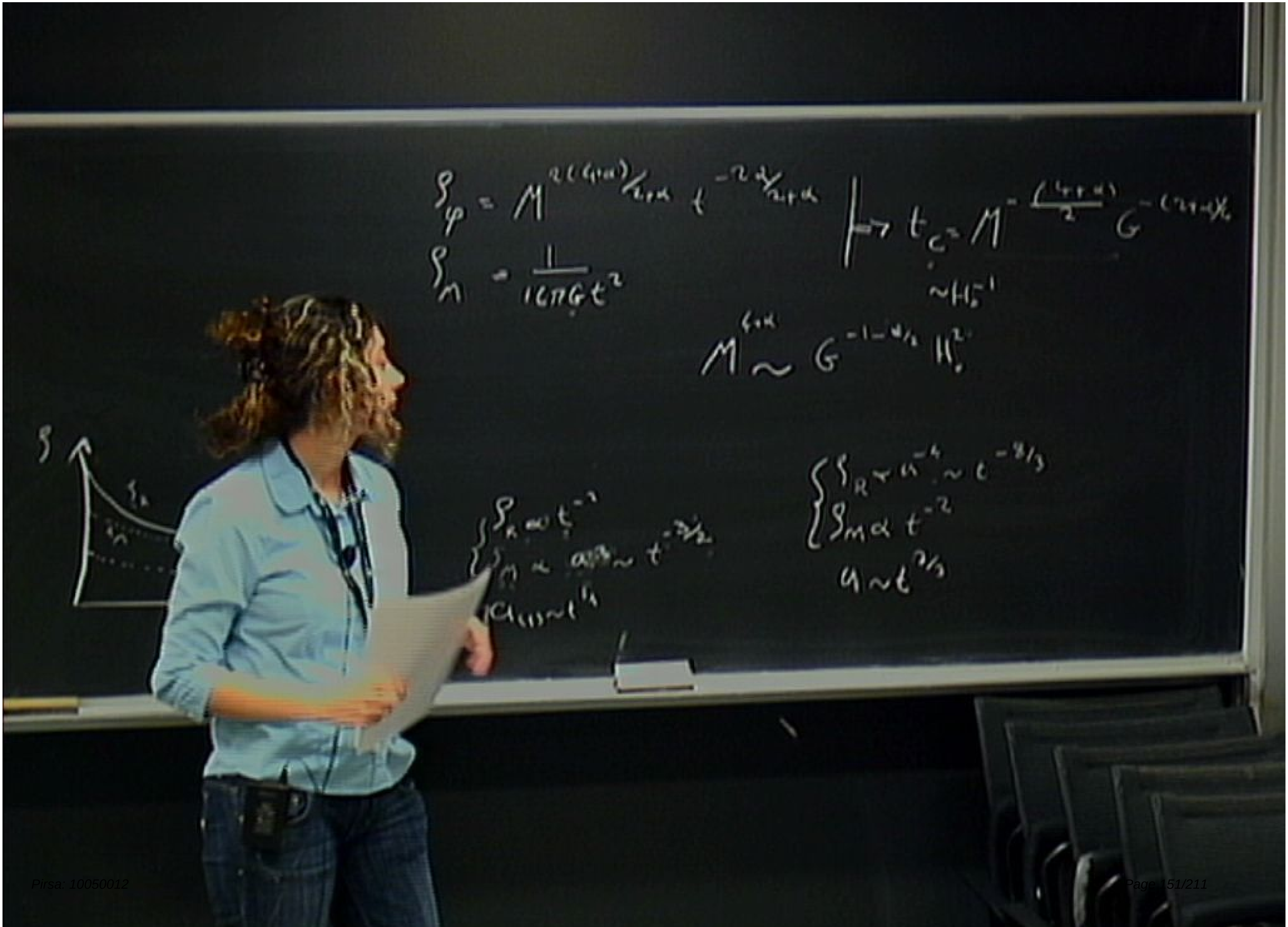

ρ_φ = M^{2(4+α)/2+α} t^{-2·2/2+α}
ρ_m =
ρ_R ∝ a^{-4} ~ t^{-8/3}
ρ_m ∝ t^{-2}
a ~ t^{2/3}
ρ_m ∝ a^{-3} ~ t^{-3/2}
a(t) ~ t^{1/2}

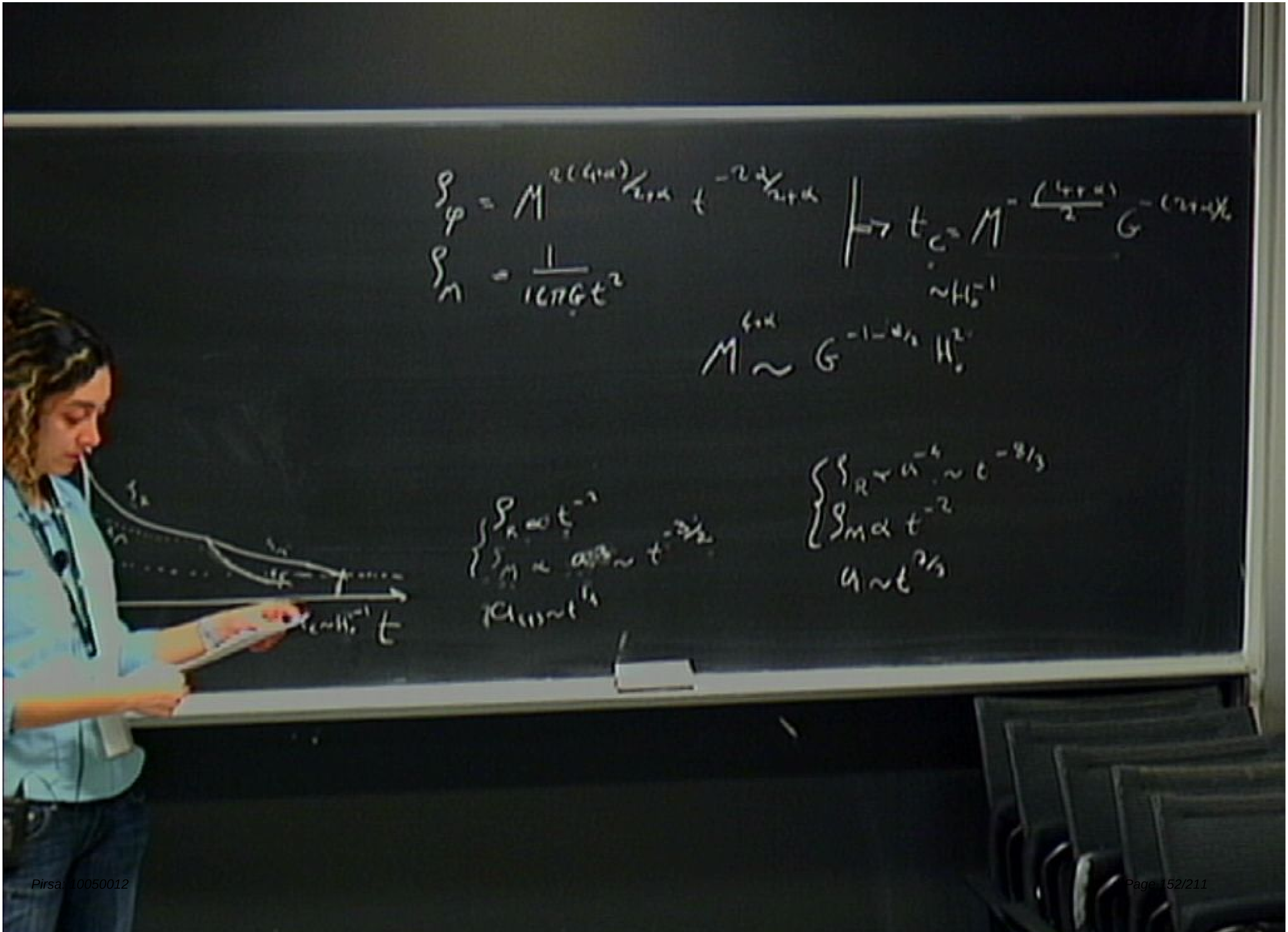

$\rho_\varphi = M^{2(4+\alpha)/2+\alpha}\, t^{-2\alpha/2+\alpha}$
$\rho_m = \frac{1}{16\pi G t^2}$




ρ_m ∝ t^{-2}
a ~ t^{2/3}


ρ_R ∝ a^-4 ∼ t^-8/3
ρ_m ∝ t^-2
a ∼ t^2/3

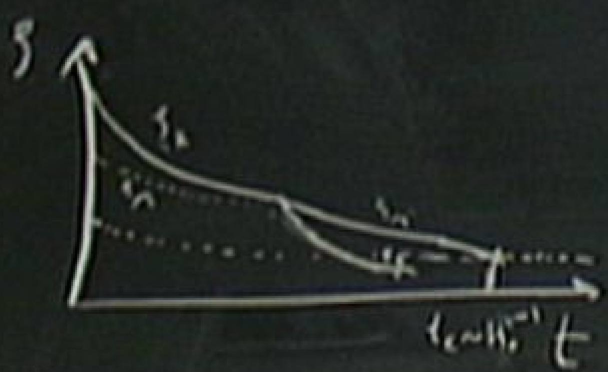

ρ_φ = M^{2(4+α)/(2+α)} t^{-2α/(2+α)}
ρ_m = 1/(16πG t^2)
t_c = M^{-(4+α)/2} G^{-(2+α)/4}
~H_0^{-1}
M^{4+α} ~ G^{-1-α/2} H_0^2
ρ_R ∝ t^{-2}
ρ_m ∝ a^{-3} ~ t^{-3/2}
a(t) ~ t^{1/2}
ρ_R ∝ a^{-4} ~ t^{-8/3}
ρ_m ∝ t^{-2}
a ~ t^{2/3}


ρ_φ = M^{2(4+α)/(2+α)} t^{-2α/(2+α)}
ρ_m = 1/(16πG t^2)
t_c = M^{-(4+α)/2} G^{-(2+α)/4}
~ H_0^{-1}
M^{4+α} ~ G^{-1-α/2} H_0^2
ρ_R ∝ t^{-2}
ρ_m ∝ a^{-3} ~ t^{-3/2}
a(t) ~ t^{1/2}
ρ_R ∝ a^{-4} ~ t^{-8/3}
ρ_m ∝ t^{-2}
a ~ t^{2/3}
t_c ~ H_0^{-1}
t

$$\rho_\varphi = M^{2(4+\alpha)/(2+\alpha)}\, t^{-2\alpha/(2+\alpha)} \quad \Rightarrow \quad t_c = M^{-\frac{(4+\alpha)}{2}}\, G^{-(2+\alpha)/2}$$

$$\rho_m = \frac{1}{16\pi G t^2} \qquad t_c \sim H_0^{-1}$$

$$M^{4+\alpha} \sim G^{-1-\alpha/2}\, H_0^{2}$$



$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_m \propto a^{-3} \sim t^{-3/2} \end{cases}$$

$$a(t) \sim t^{1/2}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \end{cases}$$

$$a \sim t^{2/3}$$

$P(X) \leftrightarrow q(\delta\rho/\rho)$

$$W = \frac{P}{\rho} = \frac{P+\rho}{\rho} - 1 = \frac{\dot\varphi^2}{\frac12\dot\varphi^2 + V(\varphi)} - 1 \simeq \frac{(\dot\varphi^2/V)}{\frac12(\dot\varphi^2/V)+1} - 1$$

$w < -\frac{1}{3}$

$W \sim -1$

$\dot\varphi^2/V \ll 1 \to w \sim -1$

$\epsilon \ll 1$

$$V(\varphi) \sim M^{4+\alpha}\varphi^{-\alpha}$$

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

$-\alpha M^{4+\alpha}\varphi^{-\alpha-1}$

$$\ddot\varphi + 3H\dot\varphi + V'(\varphi) = 0$$

$$\ddot\varphi + 3H\dot\varphi - \alpha M^{4+\alpha}\varphi^{-\alpha-1} = 0$$

$\varphi = At^{\gamma}$ $\quad \dot\varphi^2 \propto t^{(\gamma-1)2}$

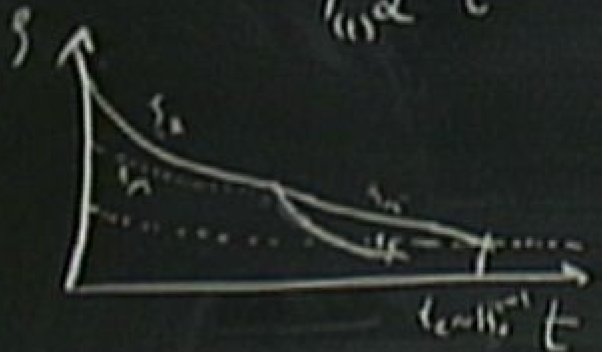
$$\rho_\varphi = M^{2(4+\alpha)/(2+\alpha)}\, t^{-2\alpha/(2+\alpha)} \qquad \Rightarrow t_c = M^{-\frac{(4+\alpha)}{2}}\, G^{-(2+\alpha)/4}$$

$$\rho_m = \frac{1}{16\pi G t^2} \qquad t_c \sim H_0^{-1}$$

$$M^{4+\alpha} \sim G^{-1-\alpha/2} H_0^{2}$$

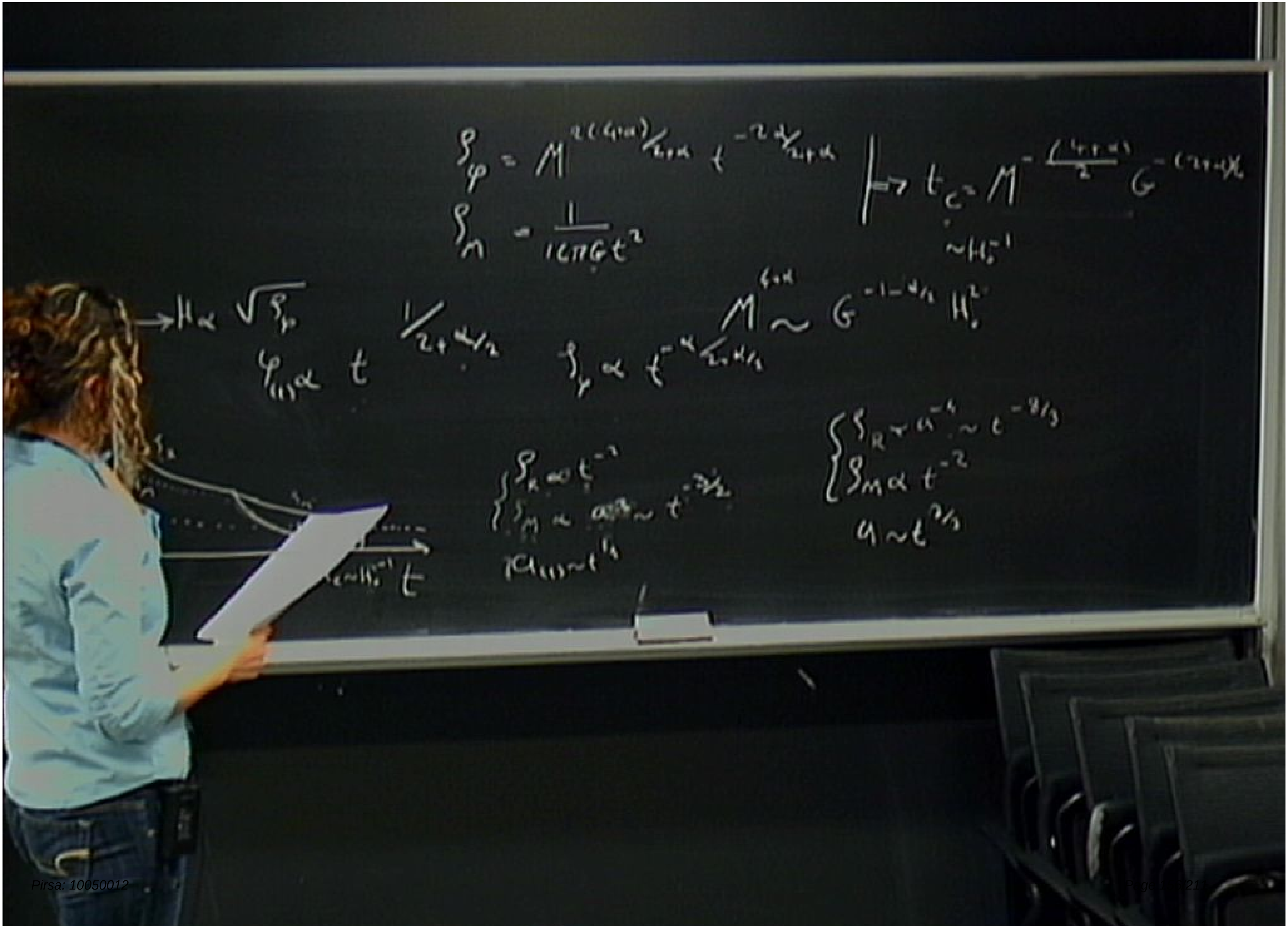
$$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_\varphi}$$

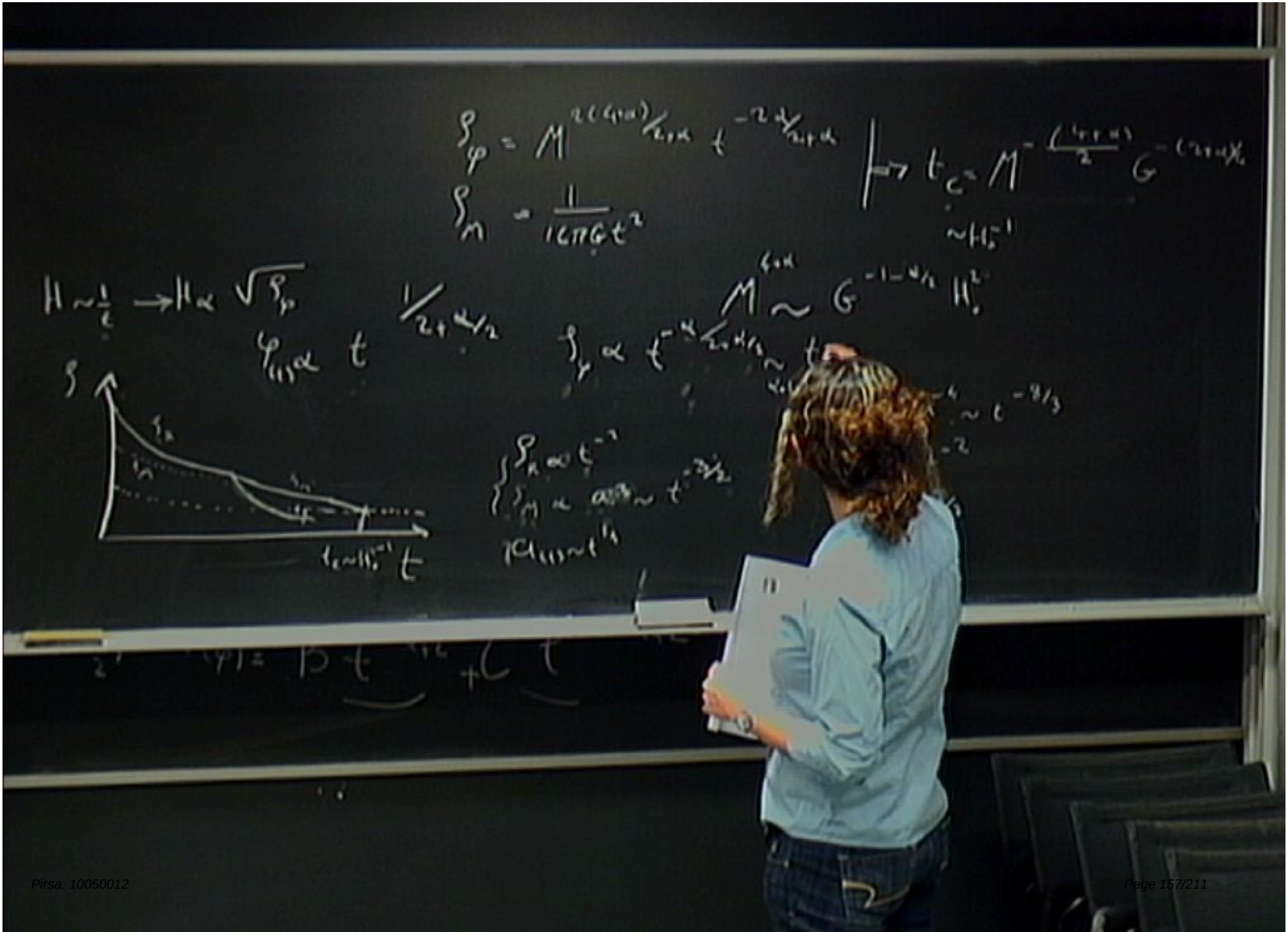
$$\varphi(t) \propto t^{1/(2+\alpha/2)}$$

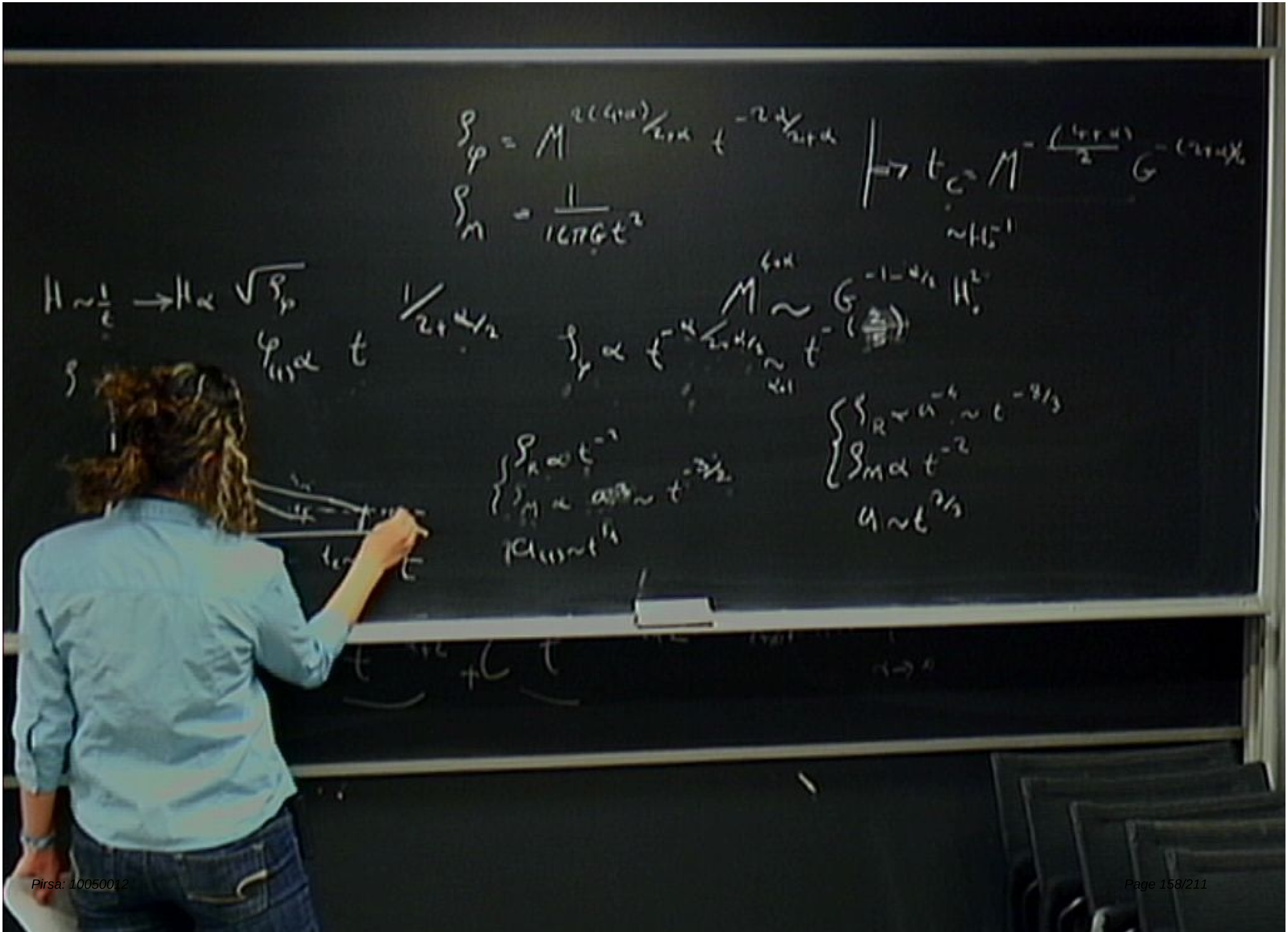


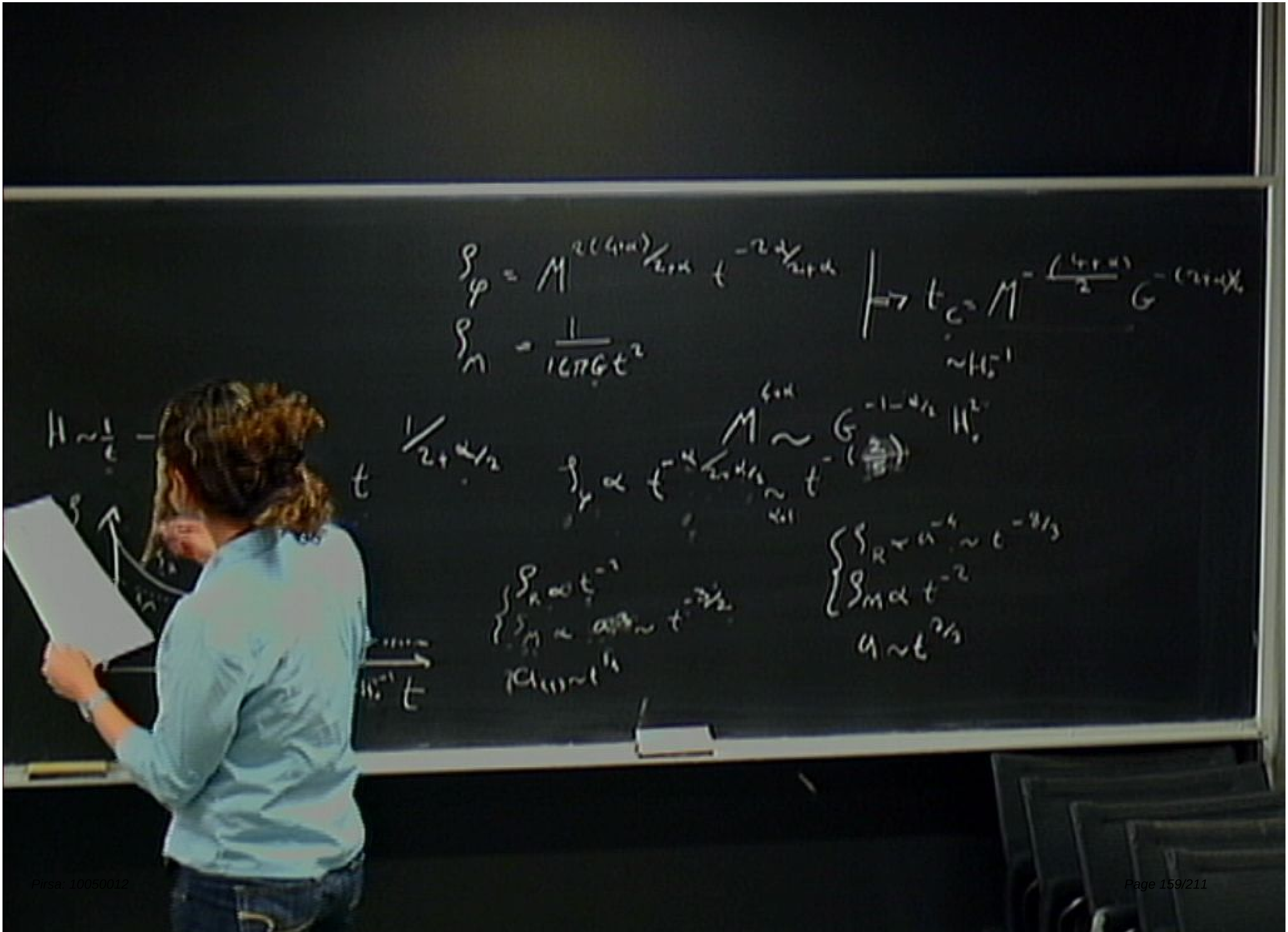
$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_m \propto a^{-3} \sim t^{-3/2} \\ a(t) \sim t^{1/2} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$


ρ_φ = M^(2(4+α)/(2+α)) t^(-2α/(2+α))
ρ_m = 1/(16πG t^2)
t_c = M^(-(4+α)/2) G^(-(2+α)/2)
~H_0^-1
H ∝ √ρ_φ
φ(t) ∝ t^(1/(2+α/2))
ρ_φ ∝ t^(-α/(2+α/2))
M^(4+α) ~ G^(-1-α/2) H_0^2
ρ_R ∝ t^-2
ρ_m ∝ a^-3 ~ t^(-3/2)
a(t) ~ t^(1/2)
ρ_R ∝ a^-4 ~ t^(-8/3)
ρ_m ∝ t^-2
a ~ t^(2/3)
t




$\rho_m = \frac{1}{16\pi G t^2}$
$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_\varphi}$
$\rho_M \propto t^{-2}$
$a \sim t^{2/3}$



$\rho_\varphi = M^{2(4+\alpha)/2+\alpha}\, t^{-2\alpha/2+\alpha}$
$\rho_m = \frac{1}{16\pi G t^2}$
$\mapsto t_c = M^{-\frac{(4+\alpha)}{2}} G^{-(2+\alpha)/2}$
$\sim H_0^{-1}$
$M^{4+\alpha} \sim G^{-1-\alpha/2} H_0^2$
$\rho_\varphi \propto t^{-\alpha/2+\alpha/2} \sim t^{-(\frac{2}{3})}$
$\rho_R \propto t^{-2}$
$\rho_M \propto a^{-3} \sim t^{-3/2}$
$a(t) \sim t^{1/2}$
$\rho_R \propto a^{-4} \sim t^{-8/3}$
$\rho_M \propto t^{-2}$
$a \sim t^{2/3}$
$H \sim \frac{1}{t}$

$\rho_m \, a \propto t^{2/(2+\alpha/2)}$

$\rho_\varphi = M^{2(4+\alpha)/(2+\alpha)} \, t^{-2\alpha/(2+\alpha)}$

$\rho_m = \frac{1}{16\pi G t^2}$

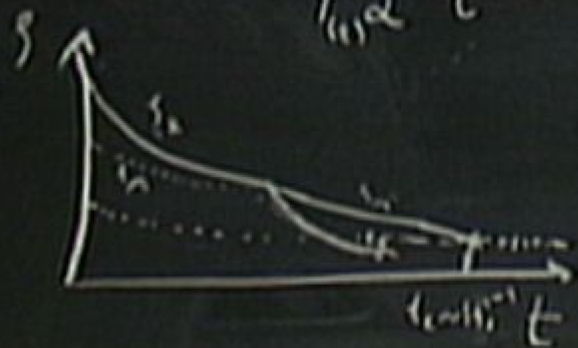
$\Rightarrow t_c = M^{-\frac{(4+\alpha)}{2}} G^{-(2+\alpha)/4} \sim H_0^{-1}$

$H \sim \frac{1}{t} \to H \propto \sqrt{\rho_\varphi}$

$\varphi_{(t)} \propto t^{1/(2+\alpha/2)}$

$M^{4+\alpha} \sim G^{-1-\alpha/2} H_0^2$

$\rho_\varphi \propto t^{-\alpha/(2+\alpha/2)} \underset{\alpha \ll 1}{\sim} t^{-(\frac{2}{?})}$

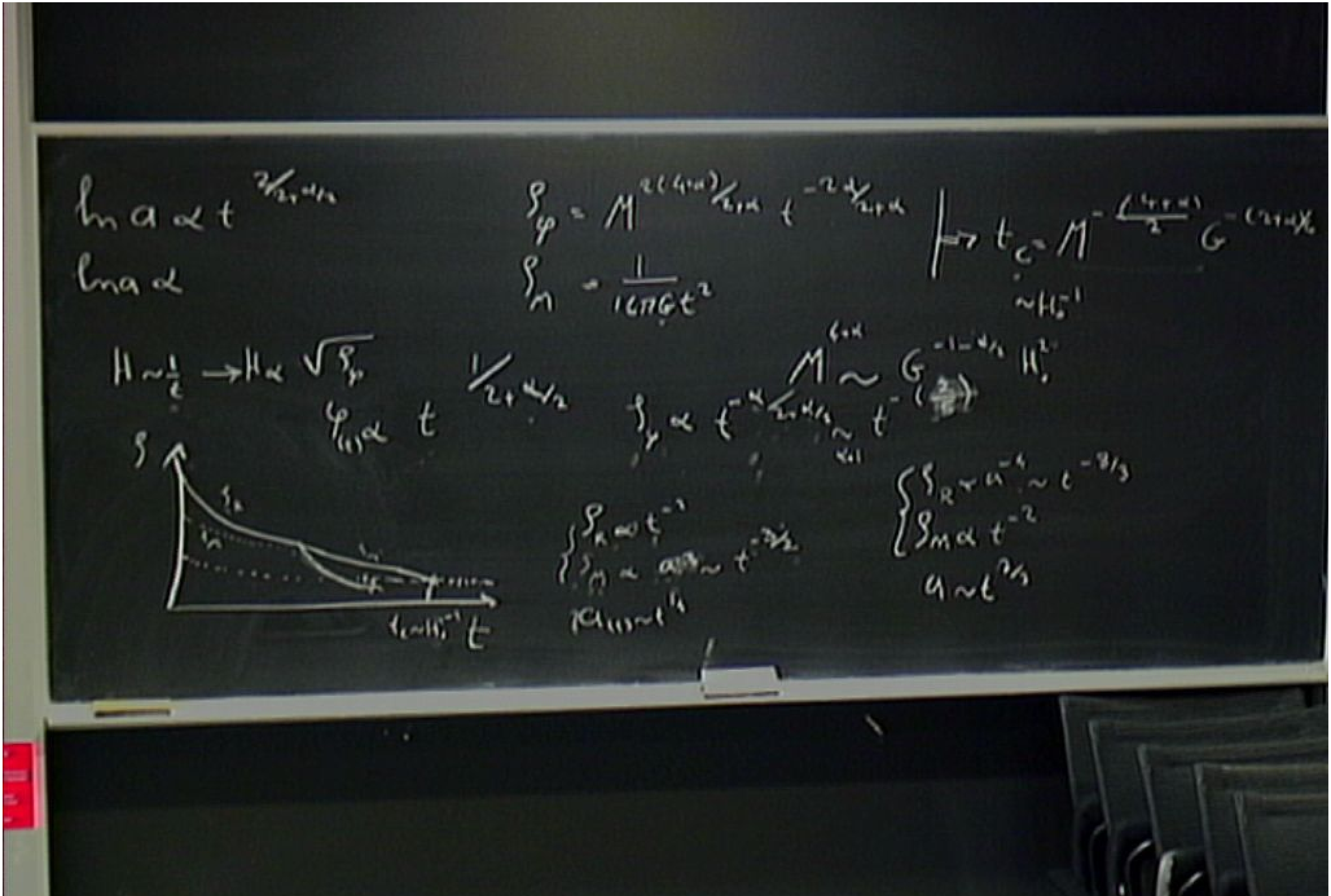


$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_m \propto a^{-3} \sim t^{-3/2} \end{cases}$$

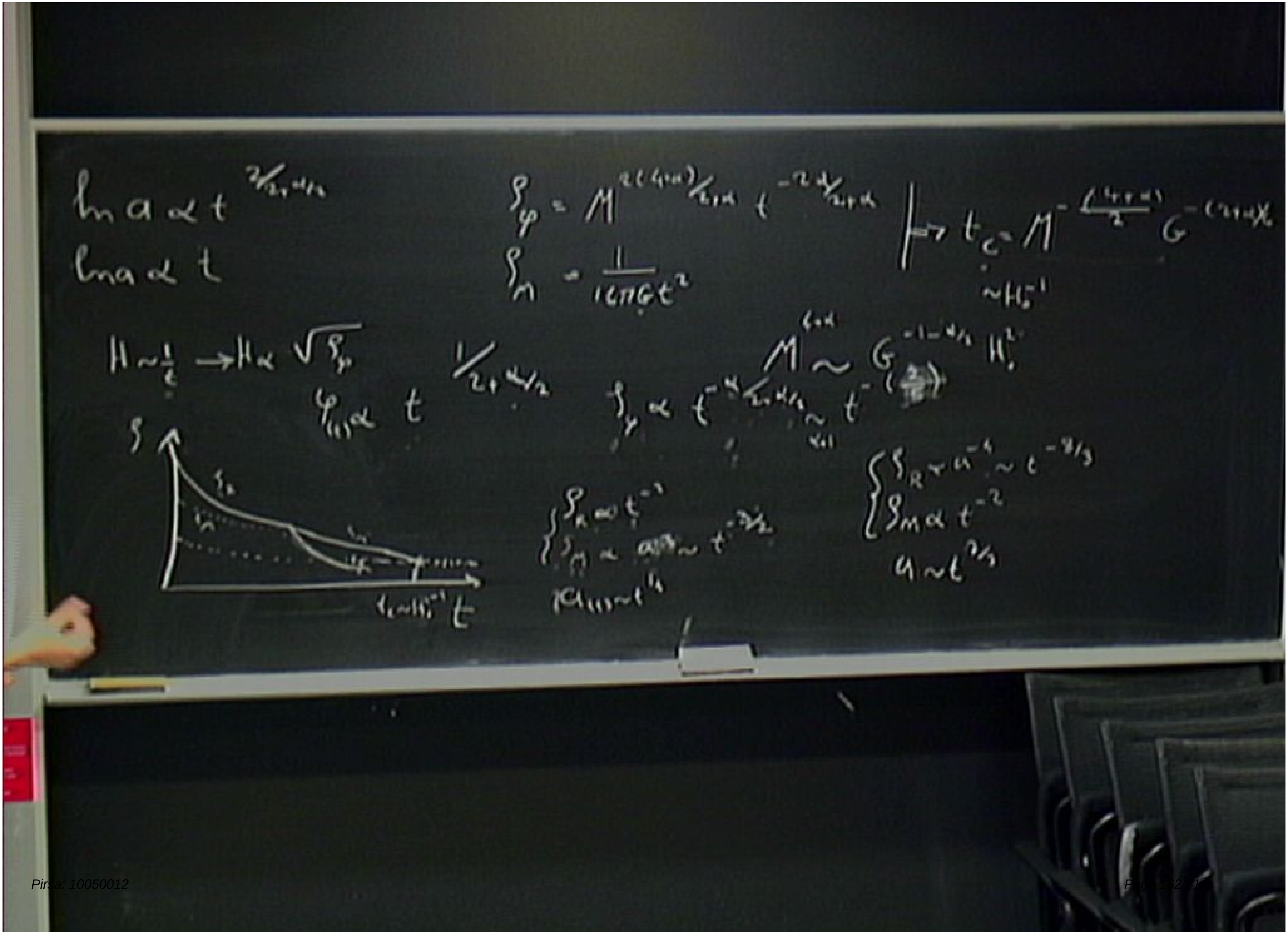
$a_{(t)} \sim t^{1/2}$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \end{cases}$$

$a \sim t^{2/3}$



ln a ∝ t
ρ_φ = M t
ρ_m = 1/16πGt²
t_c = M G
~H₀⁻¹
H ~ 1/t → H ∝ √ρ_φ
φ(t) ∝ t
ρ_φ ∝ t
ρ
ρ_R ∝ t⁻¹
a(t) ~ t
ρ_m ∝ t⁻²
a ~ t^{2/3}
t_c ~ H₀⁻¹
t



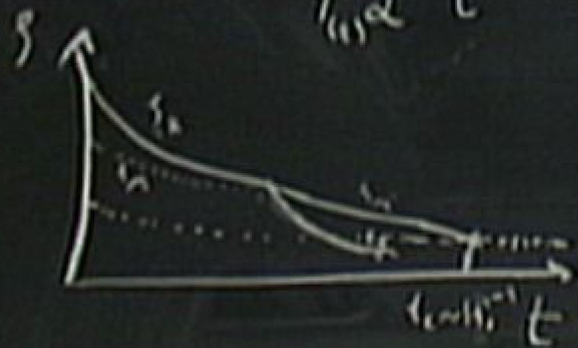
ln a ∝ t
H ~ 1/t → H ∝ √ρ_φ
ρ_m = 1/(16πGt²)
ρ_R ∝ t⁻²
ρ_m ∝ t⁻²
a ~ t^(2/3)

$$\ln a \propto t^{2/(2+\alpha/2)}$$
$$\ln a \propto t$$

$$\rho_\varphi = M^{2(4+\alpha)/(2+\alpha)}\, t^{-2\alpha/(2+\alpha)} \quad \Longrightarrow t_c = M^{-\frac{(4+\alpha)}{2}}\, G^{-(2+\alpha)/4}$$
$$\rho_m = \frac{1}{16\pi G t^2} \qquad \qquad t_c \sim H_0^{-1}$$

$$H \sim \frac{1}{t} \to H \propto \sqrt{\rho_\varphi} \qquad 1/(2+\alpha/2)$$
$$\varphi_{(t)} \propto t$$

$$M^{4+\alpha} \sim G^{-1-\alpha/2}\, H_0^2$$
$$\rho_\varphi \propto t^{-\alpha/(2+\alpha/2)} \underset{\alpha \gg 1}{\sim} t^{-(2)}$$



$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_m \propto a^{-3} \sim t^{-3/2} \\ a_{(t)} \sim t^{1/2} \end{cases}$$

$$\begin{cases} \rho_R \propto a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \\ a \sim t^{2/3} \end{cases}$$

$\ln a \propto t^{2/(2+\alpha/2)}$ $\quad a \sim e^{t^{2/3}}$

$\ln a \propto t$ $\quad a \sim e^{t}$

$\rho_\varphi = M^{2(4+\alpha)/(2+\alpha)}\, t^{-2\alpha/(2+\alpha)}$

$\rho_m = \frac{1}{16\pi G t^2}$

$\mapsto t_c = M^{-\frac{(4+\alpha)}{2}}\, G^{-(2+\alpha)/2}$

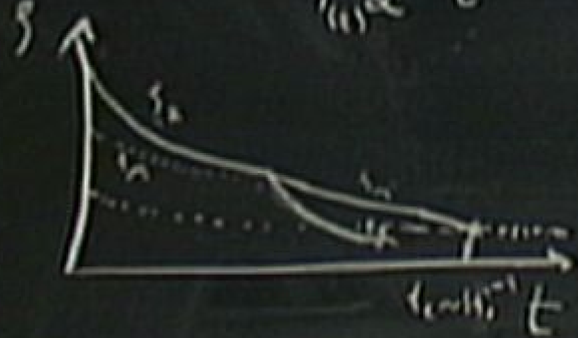
$\sim H_0^{-1}$

$H \sim \frac{1}{t} \to H \propto \sqrt{\rho_\varphi}$

$\varphi_{(t)} \propto t^{1/(2+\alpha/2)}$

$M^{4+\alpha} \sim G^{-1-\alpha/2} H_0^2$

$\rho_\varphi \propto t^{-\alpha/(2+\alpha/2)} \underset{\alpha \ll 1}{\sim} t^{-(\alpha/2)}$



$\rho_R \propto t^{-2}$

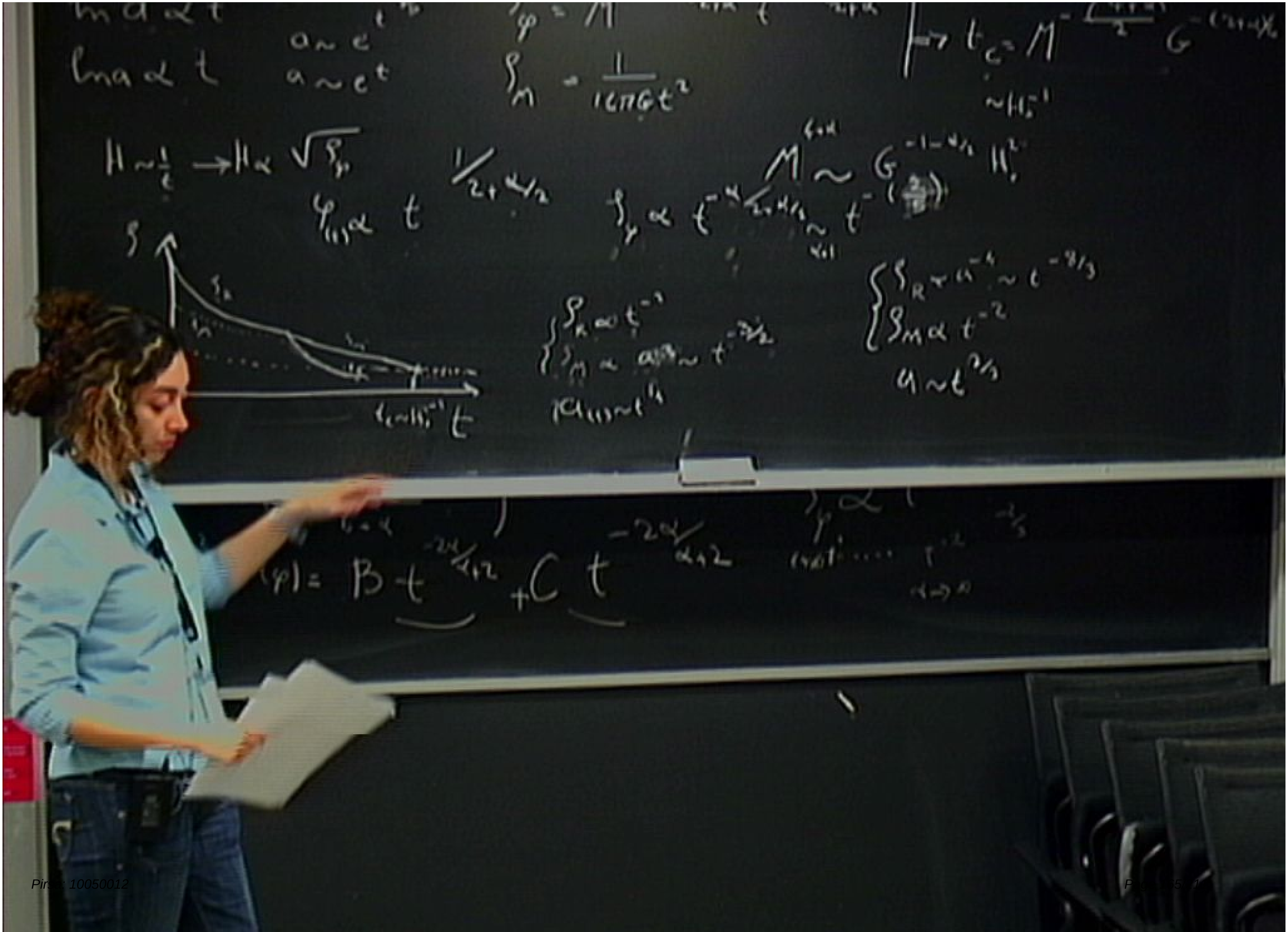
$\rho_m \propto a^{-3} \sim t^{-3/2}$

$a_{(t)} \sim t^{1/2}$

$\rho_R \propto a^{-4} \sim t^{-8/3}$

$\rho_m \propto t^{-2}$

$a \sim t^{2/3}$


ln a ∝ t
a ~ e^t
ρ_M = 1/(16πGt²)
a ~ t^{2/3}

$\ln a \propto t^{2/(2+\alpha/2)}$ $\quad a \sim e^{t^{2/3}}$

$\ln a \propto t$ $\quad a \sim e^{t}$

$\rho_\varphi = M^{2(4+\alpha)/(2+\alpha)}\, t^{-2\alpha/(2+\alpha)}$ $\quad \mapsto t_c = M^{-\frac{(4+\alpha)}{2}}\, G^{-(2+\alpha)/2}$

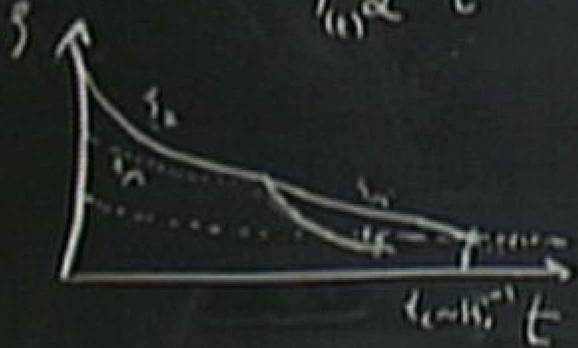
$\rho_m = \dfrac{1}{16\pi G t^2}$ $\quad \sim H_0^{-1}$

$H \sim \frac{1}{t} \rightarrow H \propto \sqrt{\rho_\varphi}$

$\varphi_{(t)} \propto t^{1/(2+\alpha/2)}$

$M^{4+\alpha} \sim G^{-1-\alpha/2} H_0^2$

$\rho_\varphi \propto t^{-\alpha/(2+\alpha/2)} \underset{\alpha \gg 1}{\sim} t^{-(2)}$



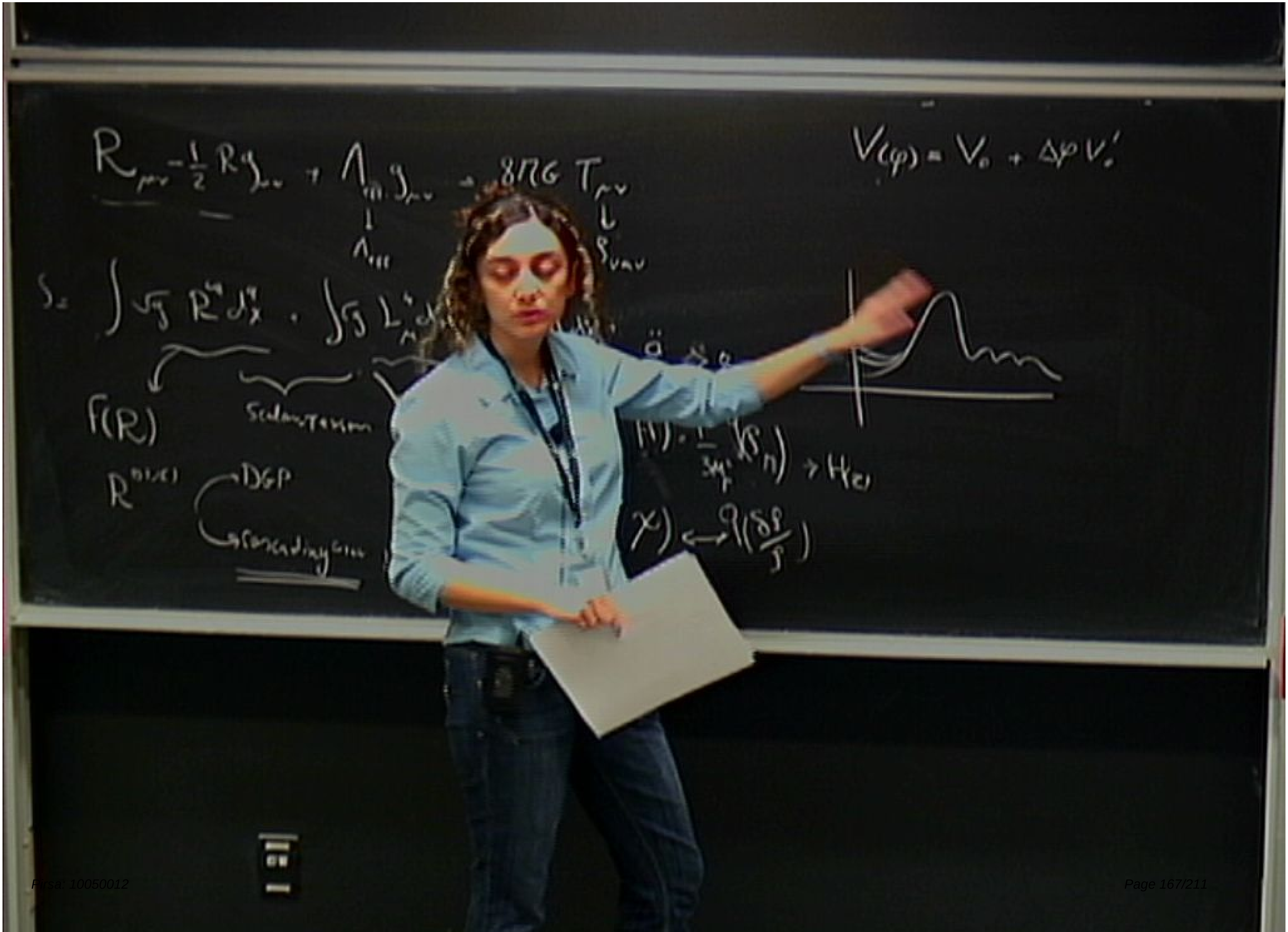
$$\begin{cases} \rho_R \propto t^{-2} \\ \rho_m \propto a^{-3} \sim t^{-3/2} \end{cases}$$

$a_{(t)} \sim t^{1/2}$

$$\begin{cases} \rho_R \sim a^{-4} \sim t^{-8/3} \\ \rho_m \propto t^{-2} \end{cases}$$

$a \sim t^{2/3}$

$\frac{1}{2}\dot\varphi^2 + V(\varphi) = B\, t^{-2\alpha/(\alpha+2)} + C\, t^{-2\alpha/(\alpha+2)}$


f(R)
DGP

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda_{th} g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$$\Lambda_{eff} \lll \rho_{vac}$$

$$V(\varphi) = V_0 + \Delta\varphi V_0'$$

$$S = \underbrace{\int \sqrt{g}\, R^{(4)} d^4x}_{\text{Scalar tensor}} + \int \sqrt{g}\, L_m^{(4)} d^4x + \int \sqrt{g}\, \Lambda\, d^4x$$

$f(R)$ $\quad$ $L(\varphi)$

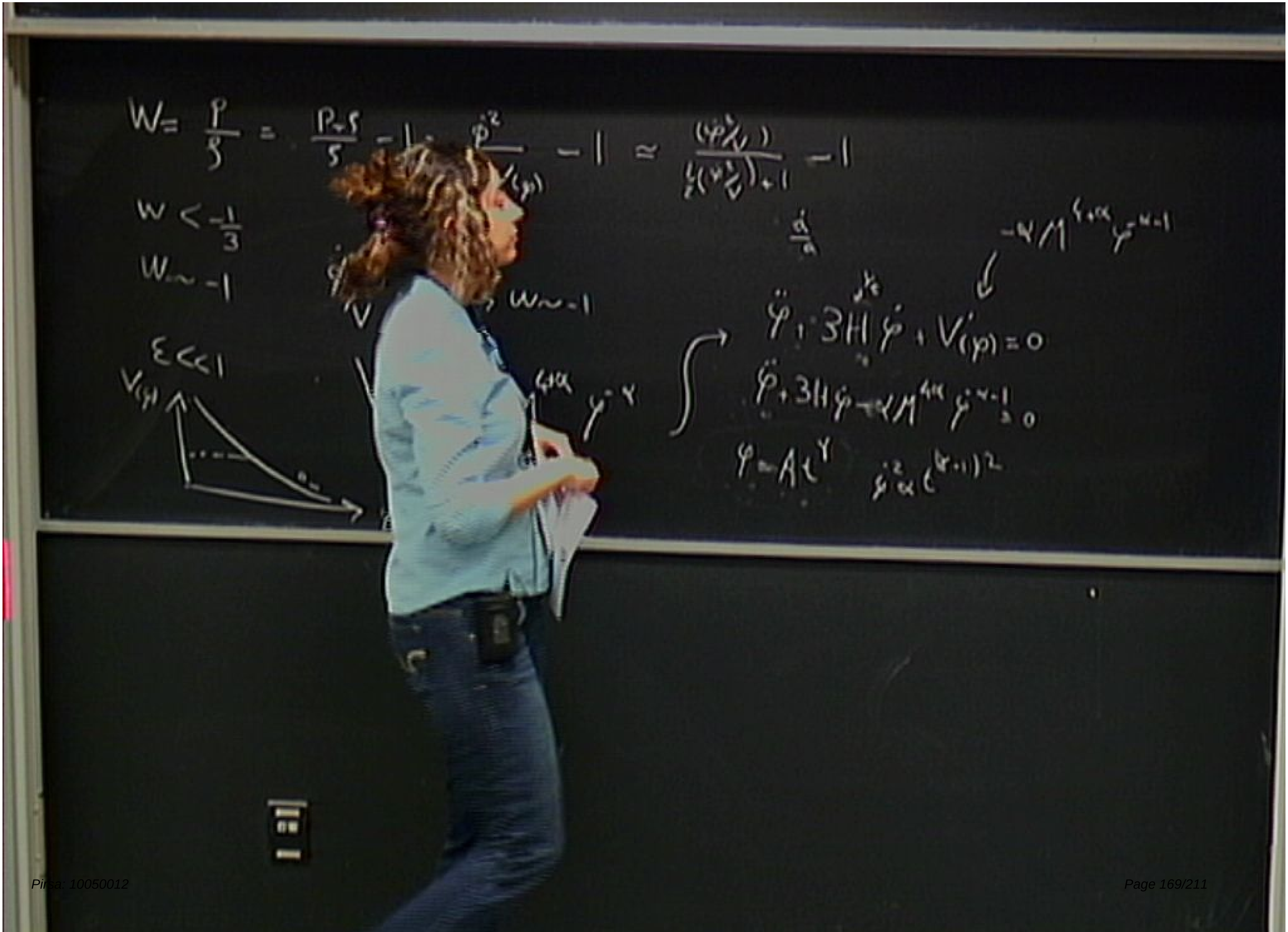
$$\frac{\ddot{a}}{a} \gtrless 0$$

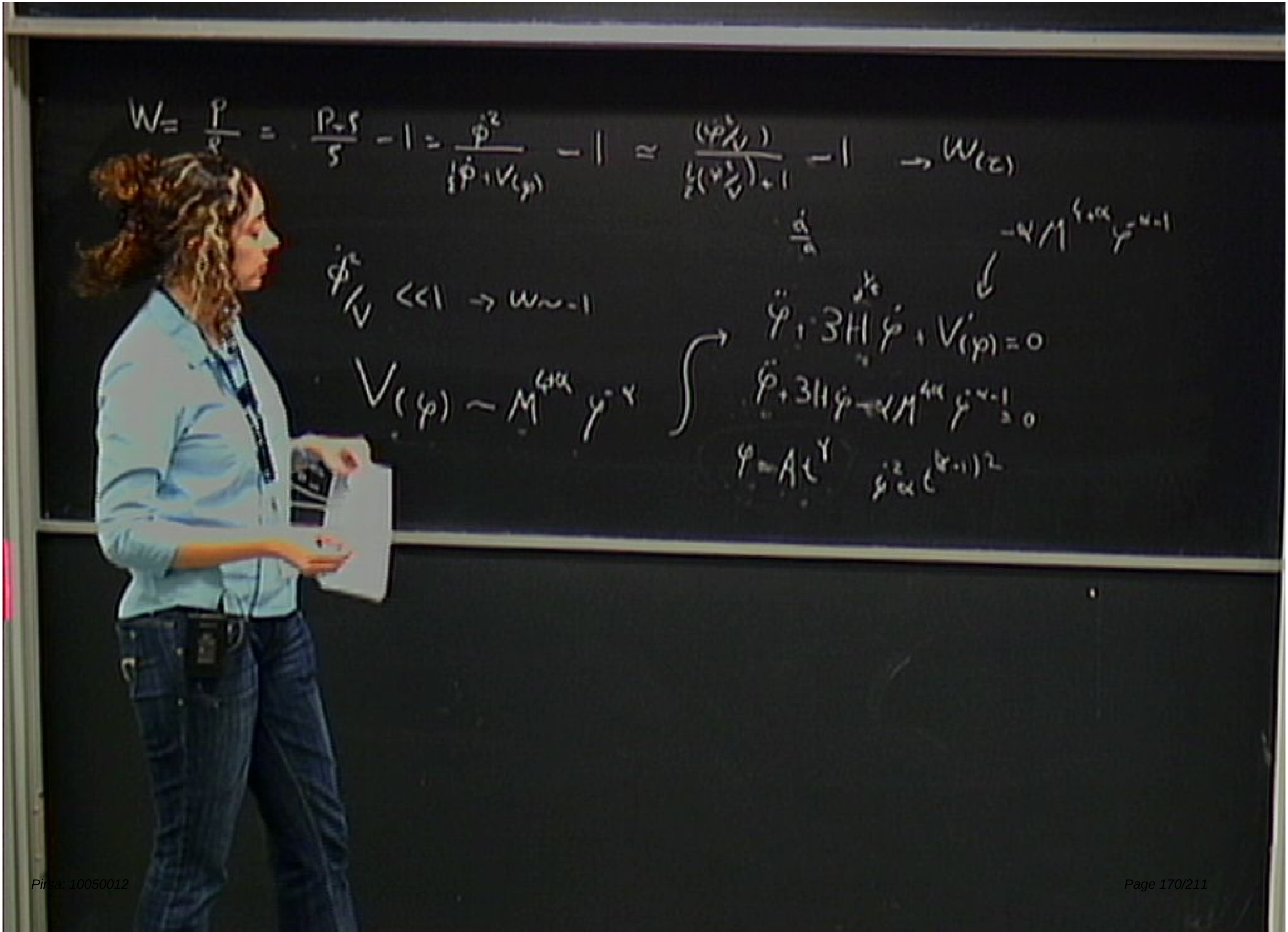
$$P\left(H(t) = \frac{1}{3M_p^2}\rho_m\right) \to H(z)$$

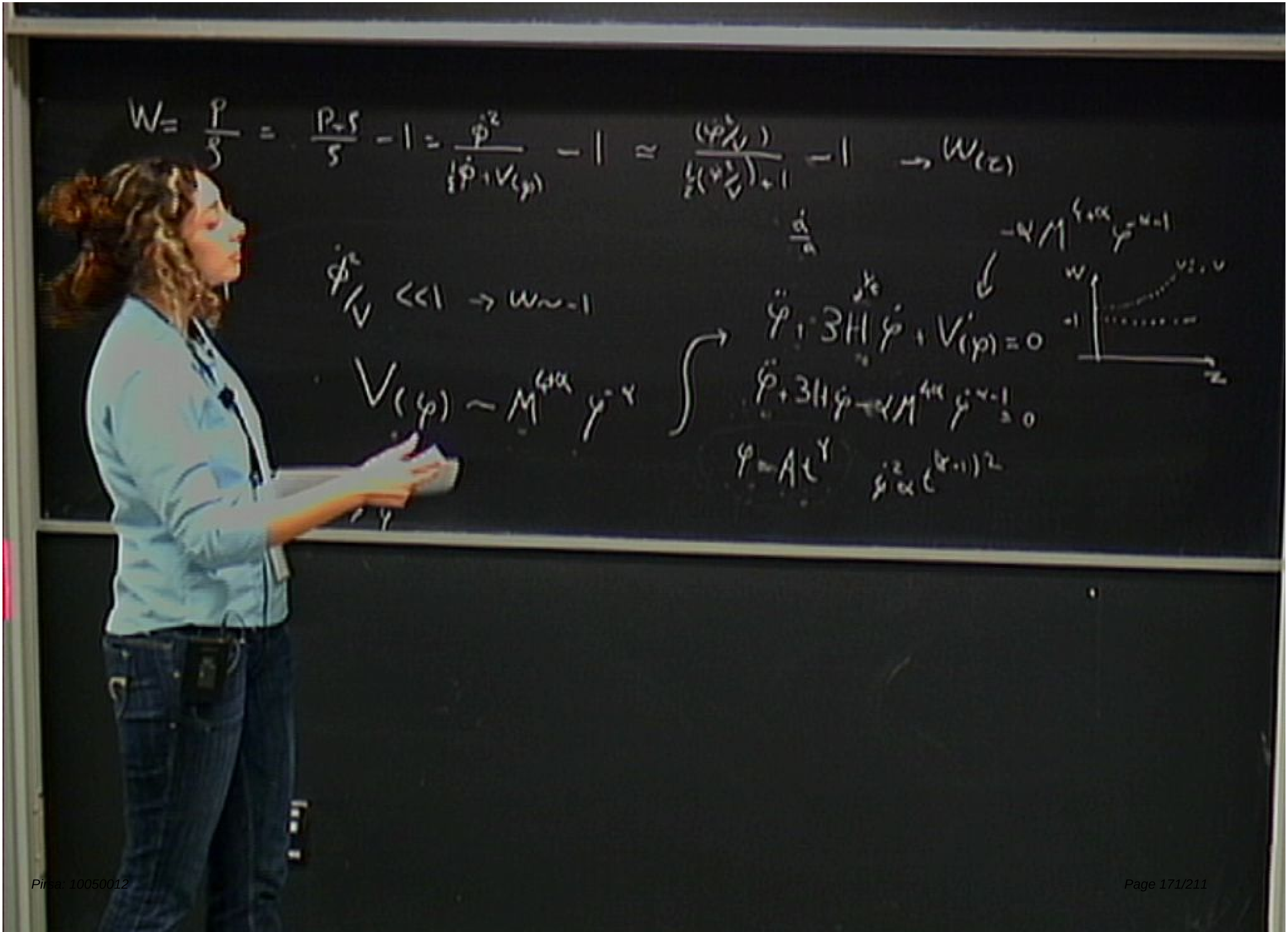
$$P(x) \longleftrightarrow \rho\left(\frac{\delta\rho}{\rho}\right)$$

$R^{(n\times c)}$ → DGP

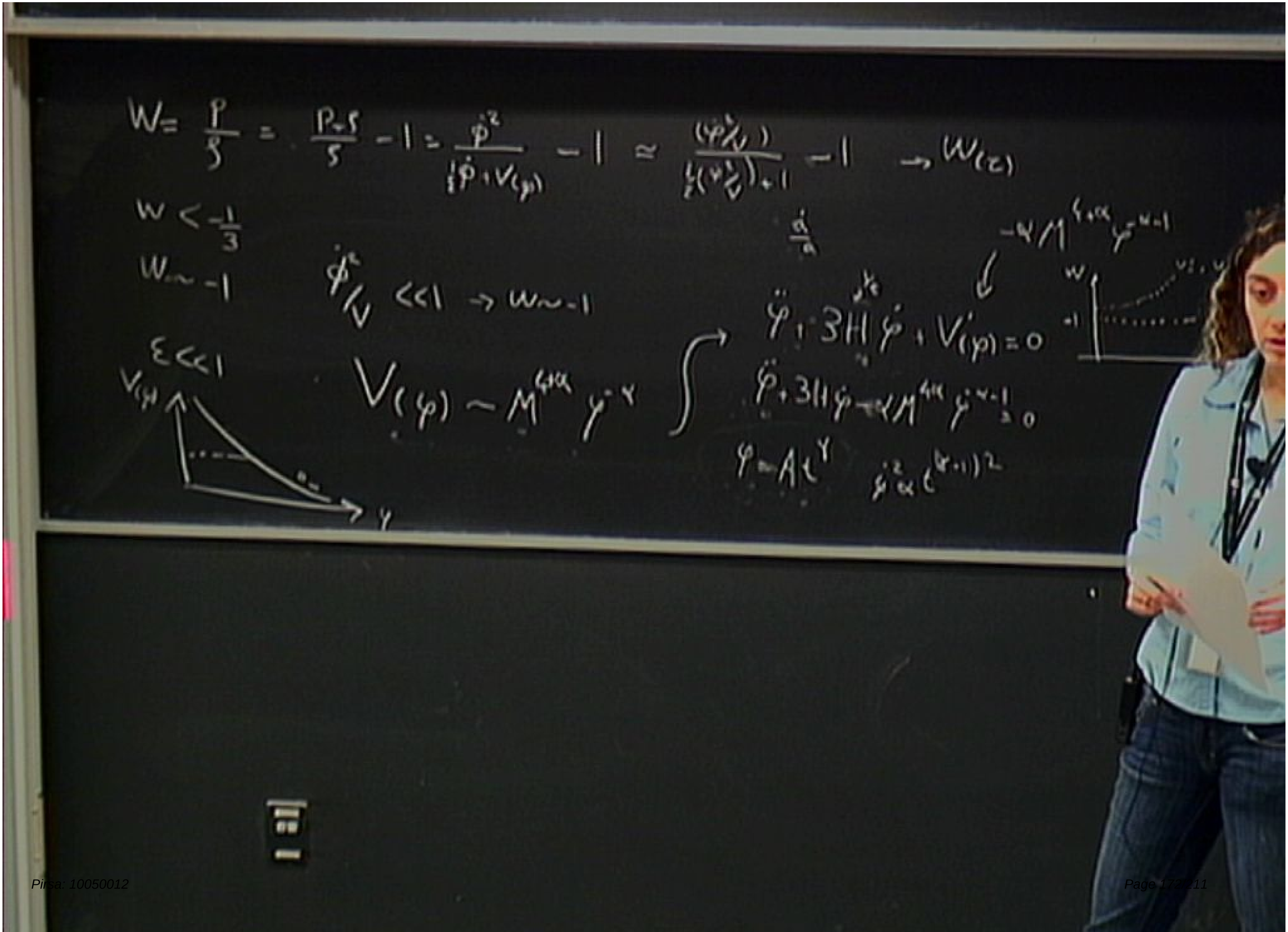
→ Cascading grav !

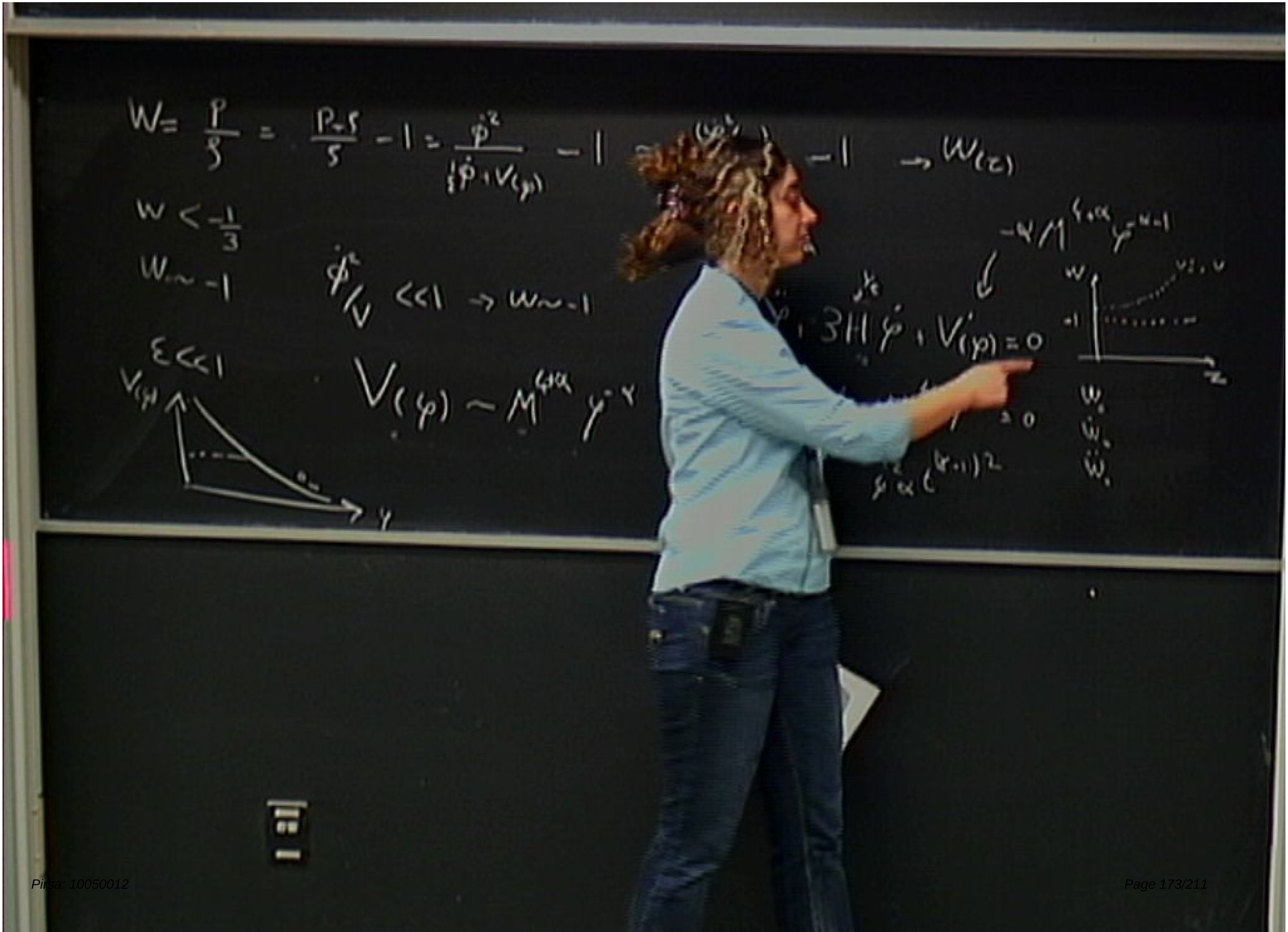

W < -1/3
W ~ -1
ε << 1

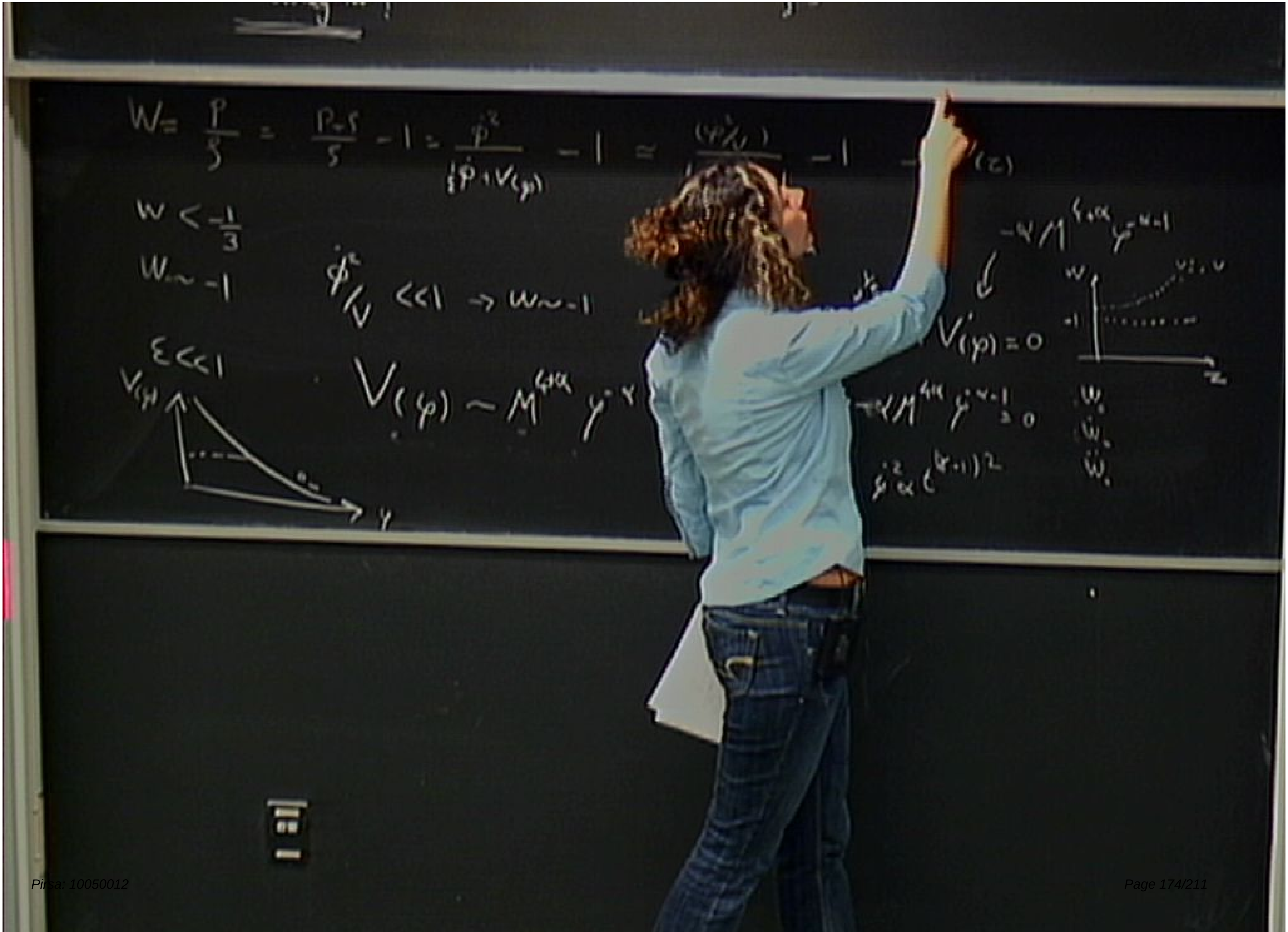

W = P/ρ = (P+ρ)/ρ − 1 = φ̇²/(½φ̇² + V(φ)) − 1 ≃ (φ̇²/V)/(½(φ̇²/V) + 1) − 1 → W(τ)
φ̇²/V << 1 → w ~ −1
V(φ) ~ M^{4+α} φ^{−α}
φ̈ + 3Hφ̇ + V′(φ) = 0
φ = At^γ

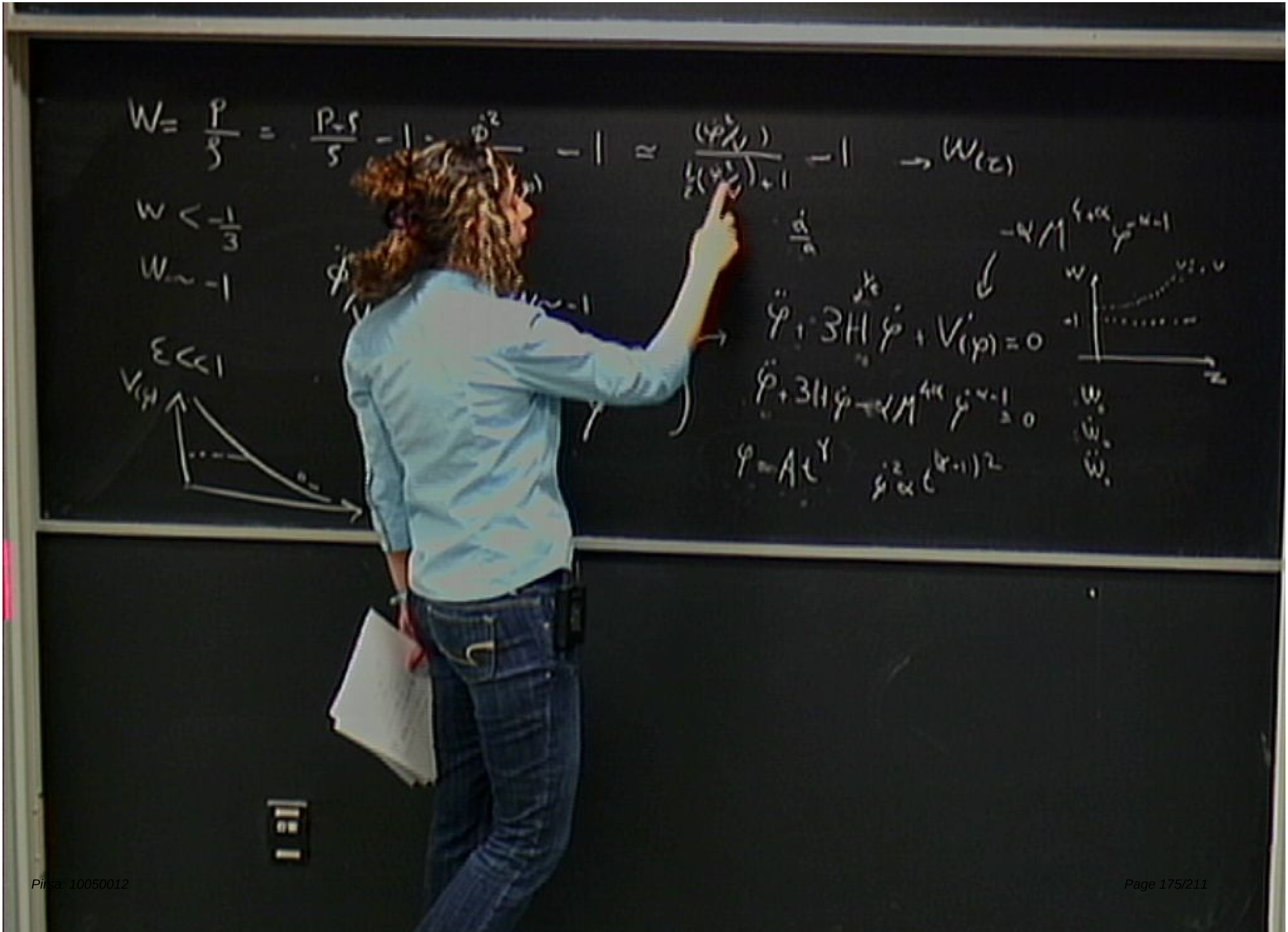


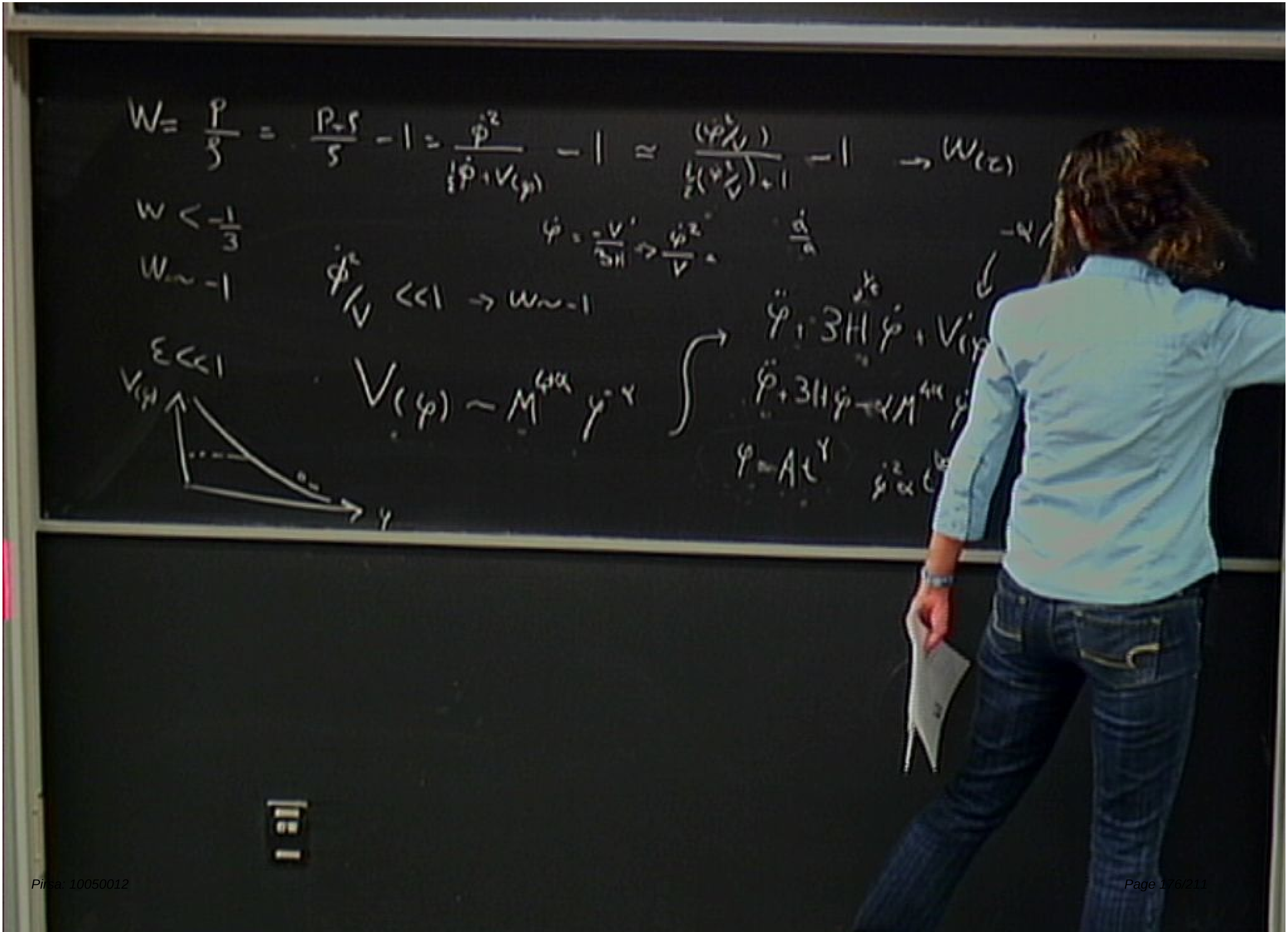
$\dot\varphi^2 / V \ll 1 \to w \sim -1$
$V(\varphi) \sim M^{4+\alpha} \varphi^{-\alpha}$
$\ddot\varphi + 3H\dot\varphi + V'(\varphi) = 0$

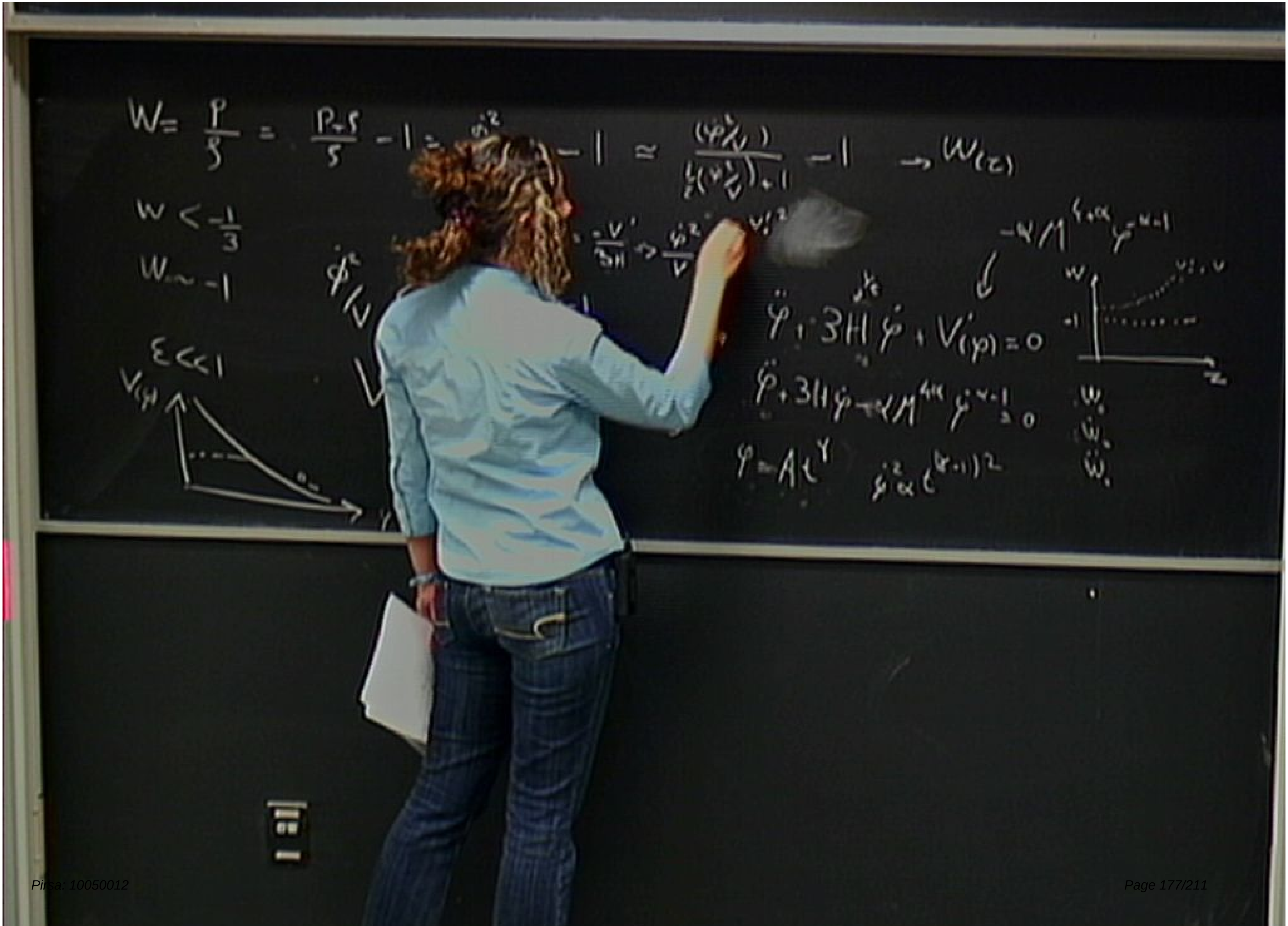

W = P/ρ = (P+ρ)/ρ − 1 = φ̇²/(½φ̇² + V(φ)) − 1 ≃ (φ̇²/V)/(½(φ̇²/V) + 1) − 1 → W(t)
W < −1/3
W ~ −1
φ̇²/V << 1 → w ~ −1
ε << 1
V(φ) ~ M^{4+α} φ^{−α}
φ̈ + 3H φ̇ + V′(φ) = 0
φ = A t^γ

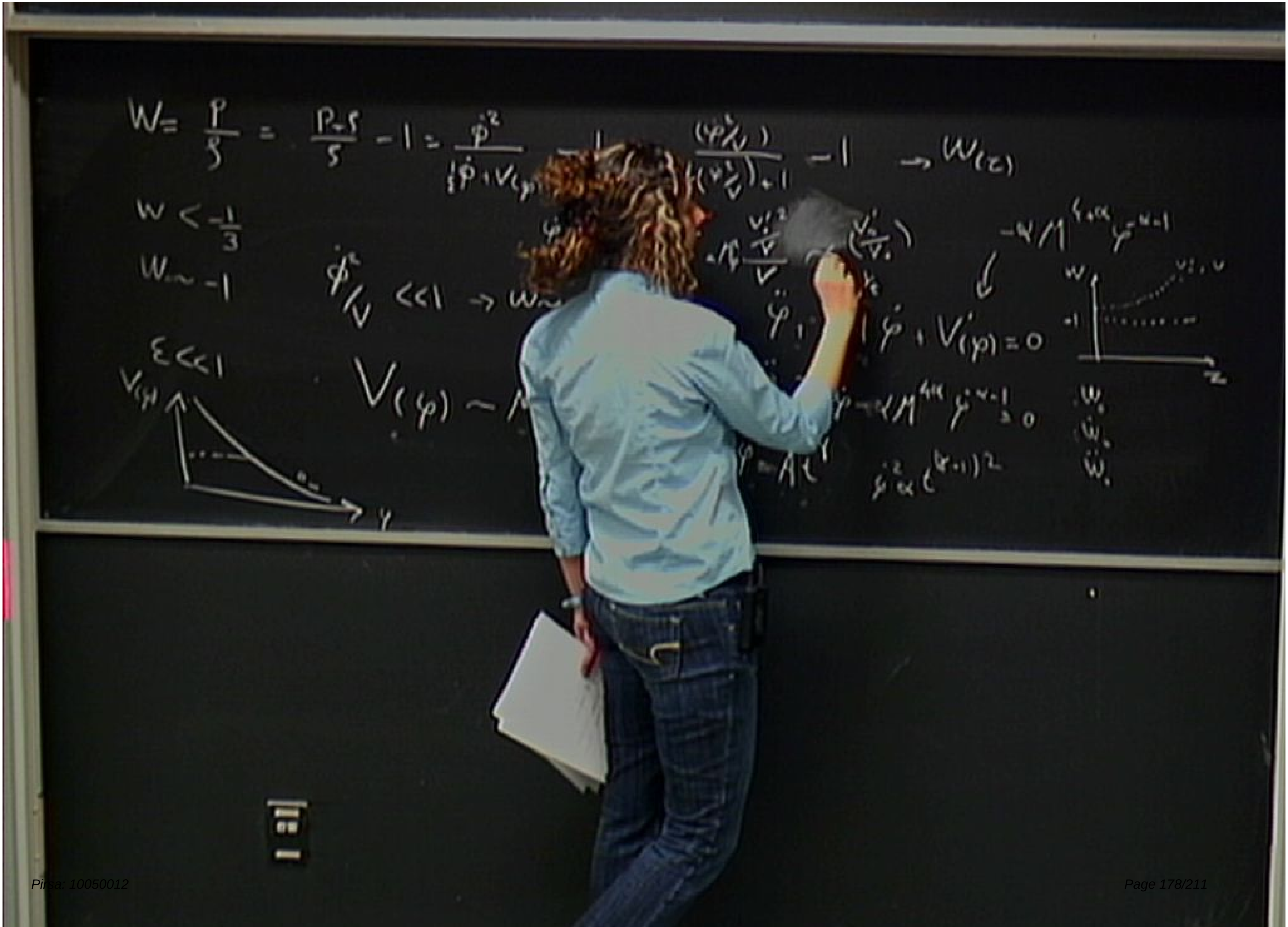

W < -1/3
W ~ -1
ε << 1

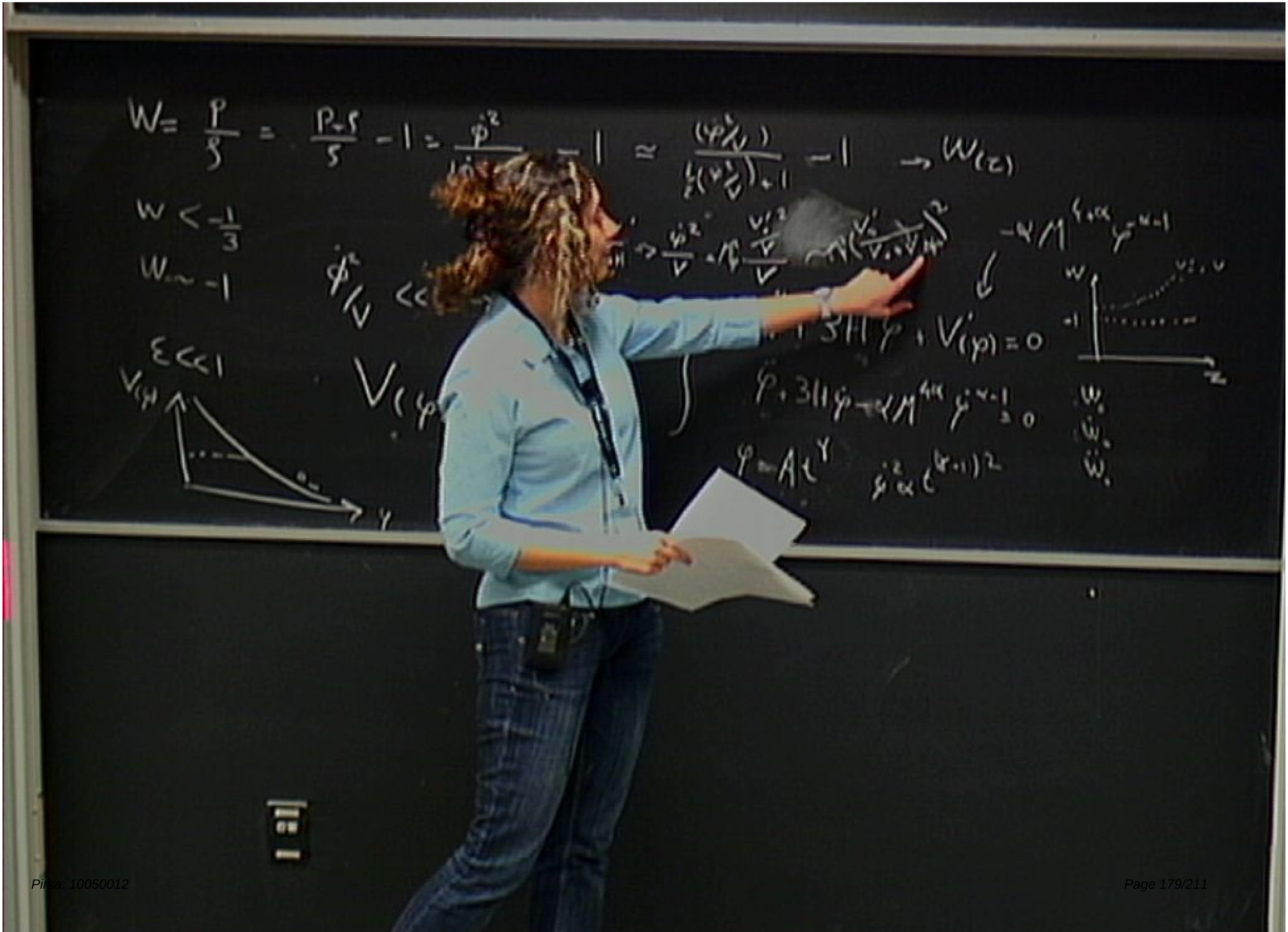

W < -1/3
W ~ -1
ε << 1
<< 1 → W ~ -1
V'(φ) = 0

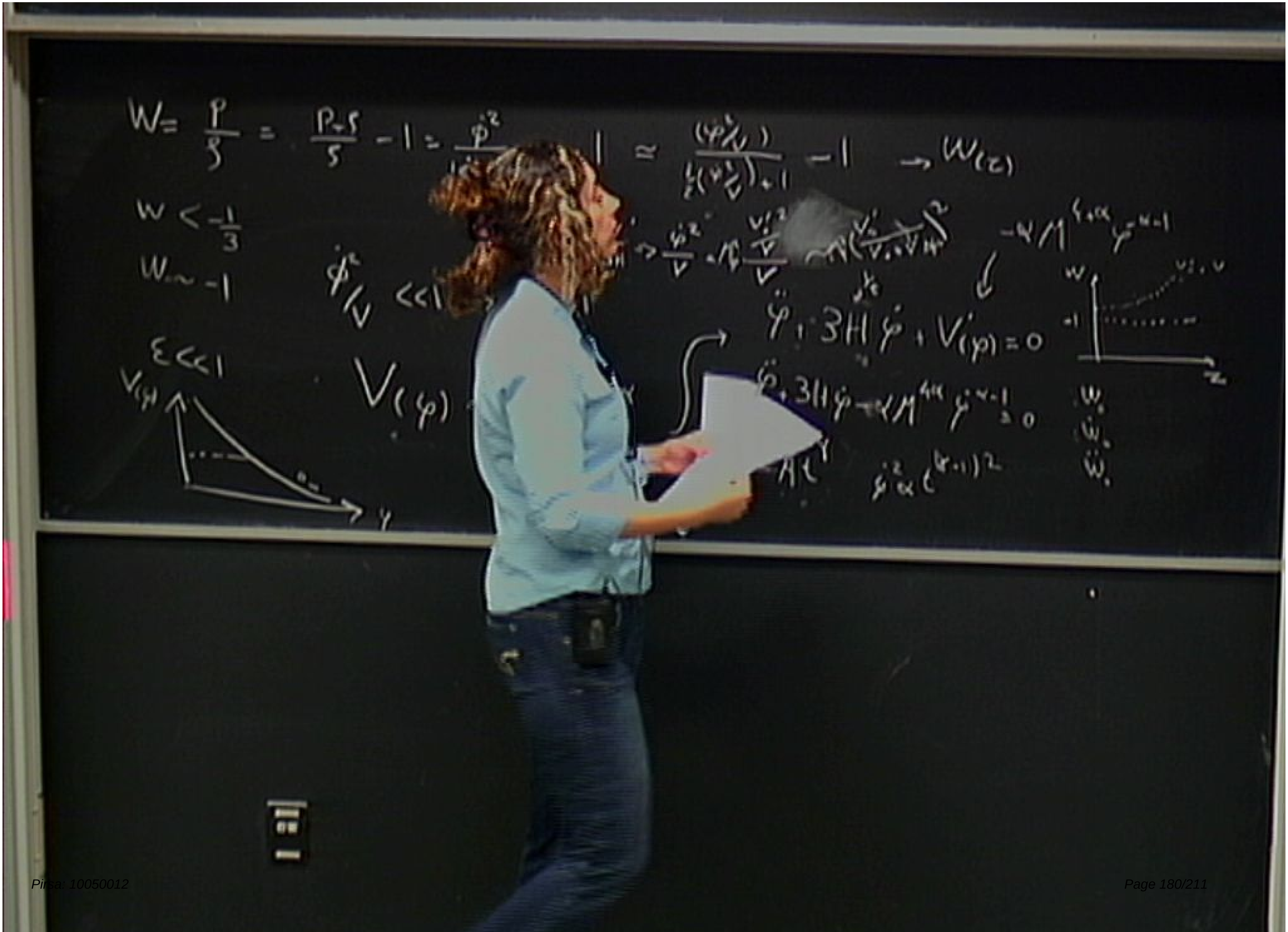

W < -1/3
W ~ -1
ε << 1
φ̈ + 3H φ̇ + V'(φ) = 0
φ = A t^γ

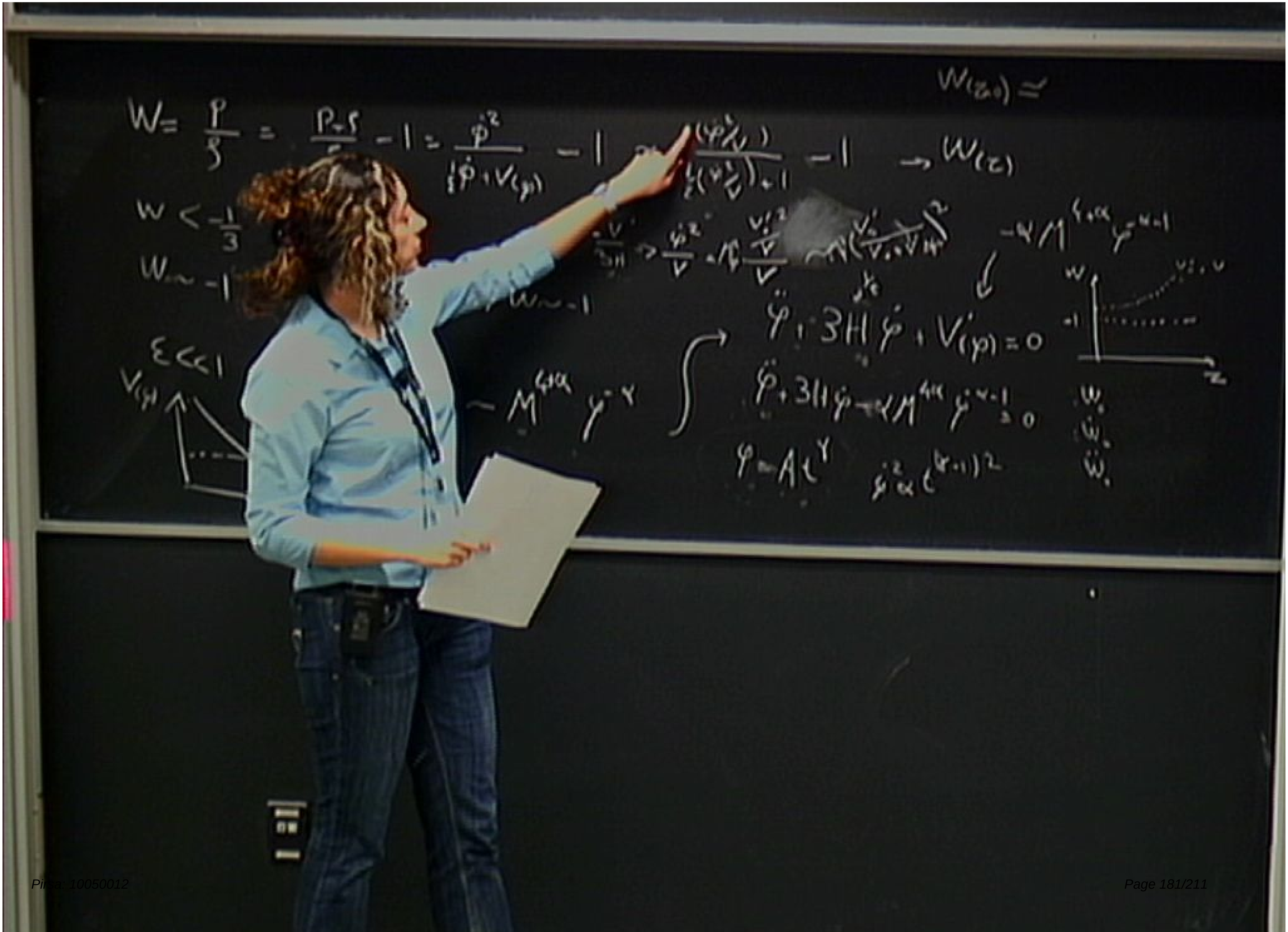

W < -1/3
W ~ -1
ε << 1
V(φ) ~ M^{4+α} φ^{-α}
φ = A t^γ

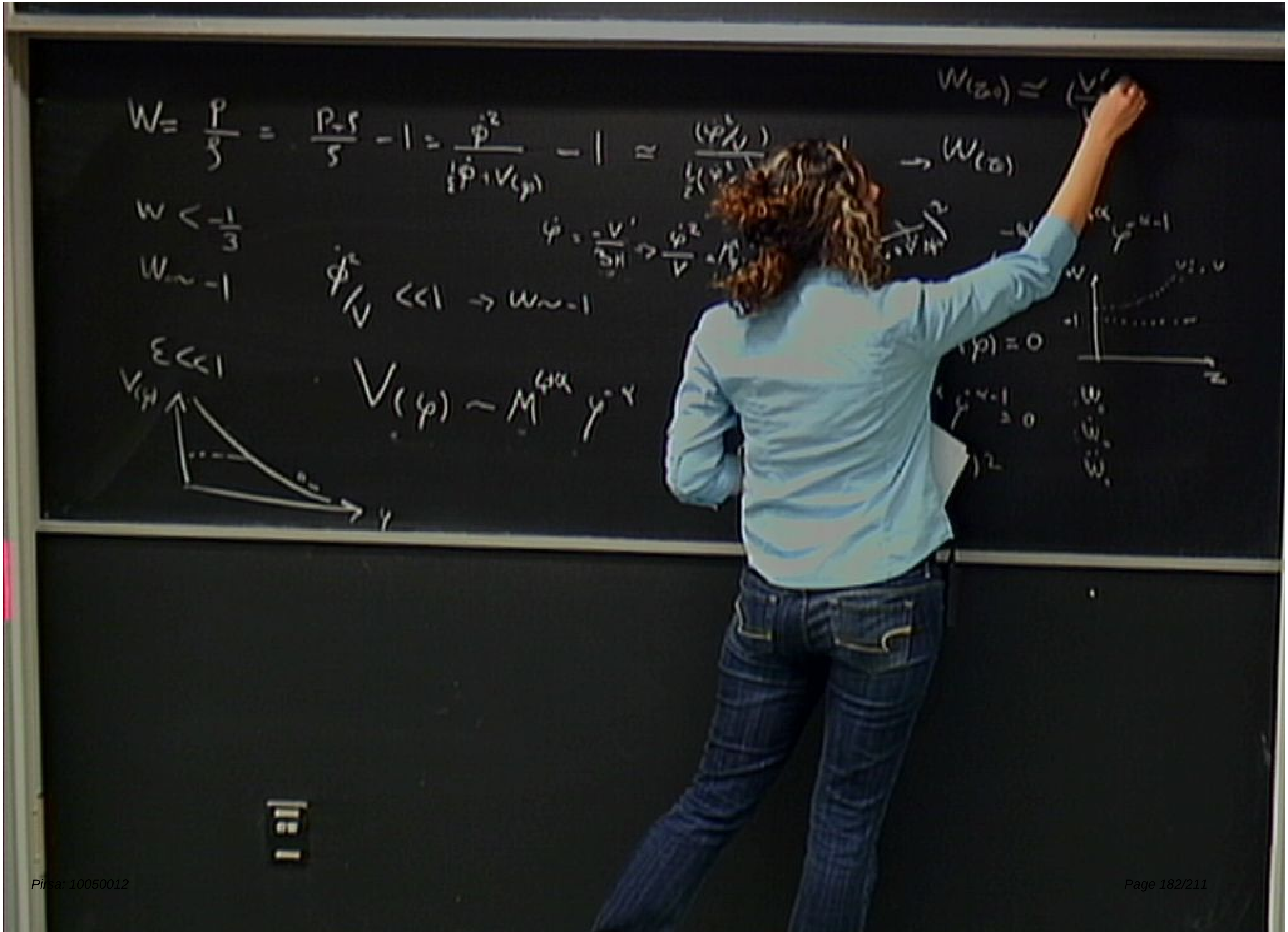

w < -1/3
W ≈ -1
ε << 1

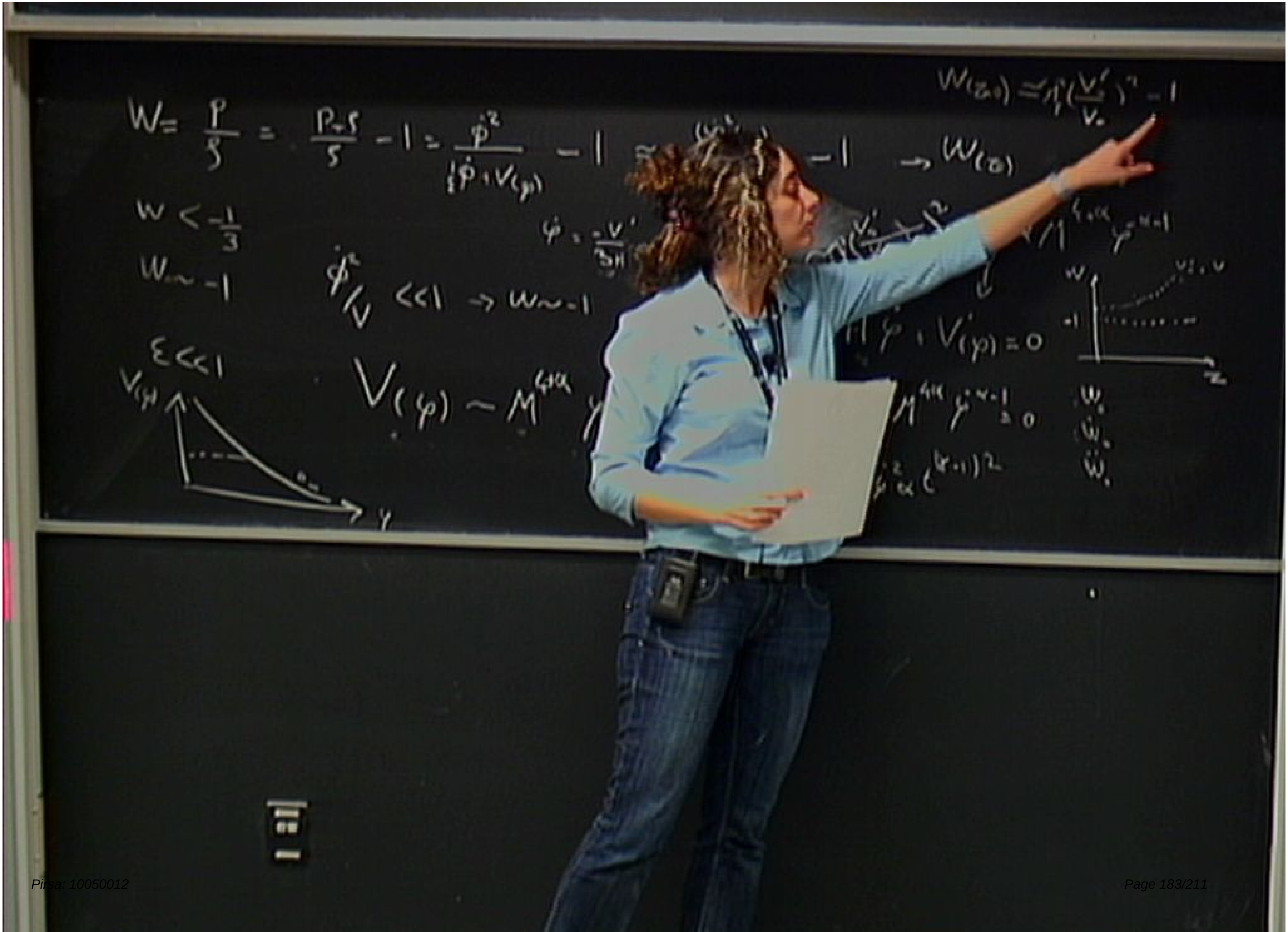

W = P/ρ = (P+ρ)/ρ − 1
→ W(τ)
W < −1/3
W ~ −1
ε << 1
<< 1
V(φ) ~
V(φ)
φ̈ + 3Hφ̇ + V'(φ) = 0








W = P/ρ = (P+ρ)/ρ − 1
w < −1/3
W ~ −1
φ̇²/V << 1 → w ~ −1
ε << 1
V(φ) ~ M^{4+α} φ^{−α}
W(z₀) ≃
W(z)


W < -1/3
W ~ -1
ε << 1
<< 1 → W ~ -1
V(φ) ~ M
W(z=0)
W(0)

$W(z_0) \simeq A_1 \left(\frac{V'}{V_0}\right)^n - 1$

$W = \frac{P}{\rho} = \frac{P+\rho}{\rho} - 1 = \frac{\dot\varphi^2}{\frac{1}{2}\dot\varphi^2 + V(\varphi)} - 1 \simeq \frac{(\dot\varphi^2/V)}{\frac{1}{2}(\dot\varphi^2/V) + 1} - 1 \to W(z)$

$w < -\frac{1}{3}$

$W \sim -1$

$\dot\varphi^2/V \ll 1 \to w \sim -1$

$\dot\varphi = -\frac{V'}{3H} \Rightarrow \frac{\dot\varphi^2}{V} \propto \frac{V'^2}{V}$

$-\alpha M^{4+\alpha}\varphi^{-\alpha-1}$

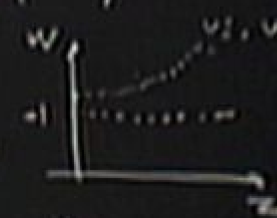
$\varepsilon \ll 1$

$V(\varphi) \sim M^{4+\alpha}\varphi^{-\alpha}$

$\ddot\varphi + 3H\dot\varphi + V'(\varphi) = 0$

$\ddot\varphi + 3H\dot\varphi - \alpha M^{4+\alpha}\varphi^{-\alpha-1} = 0$

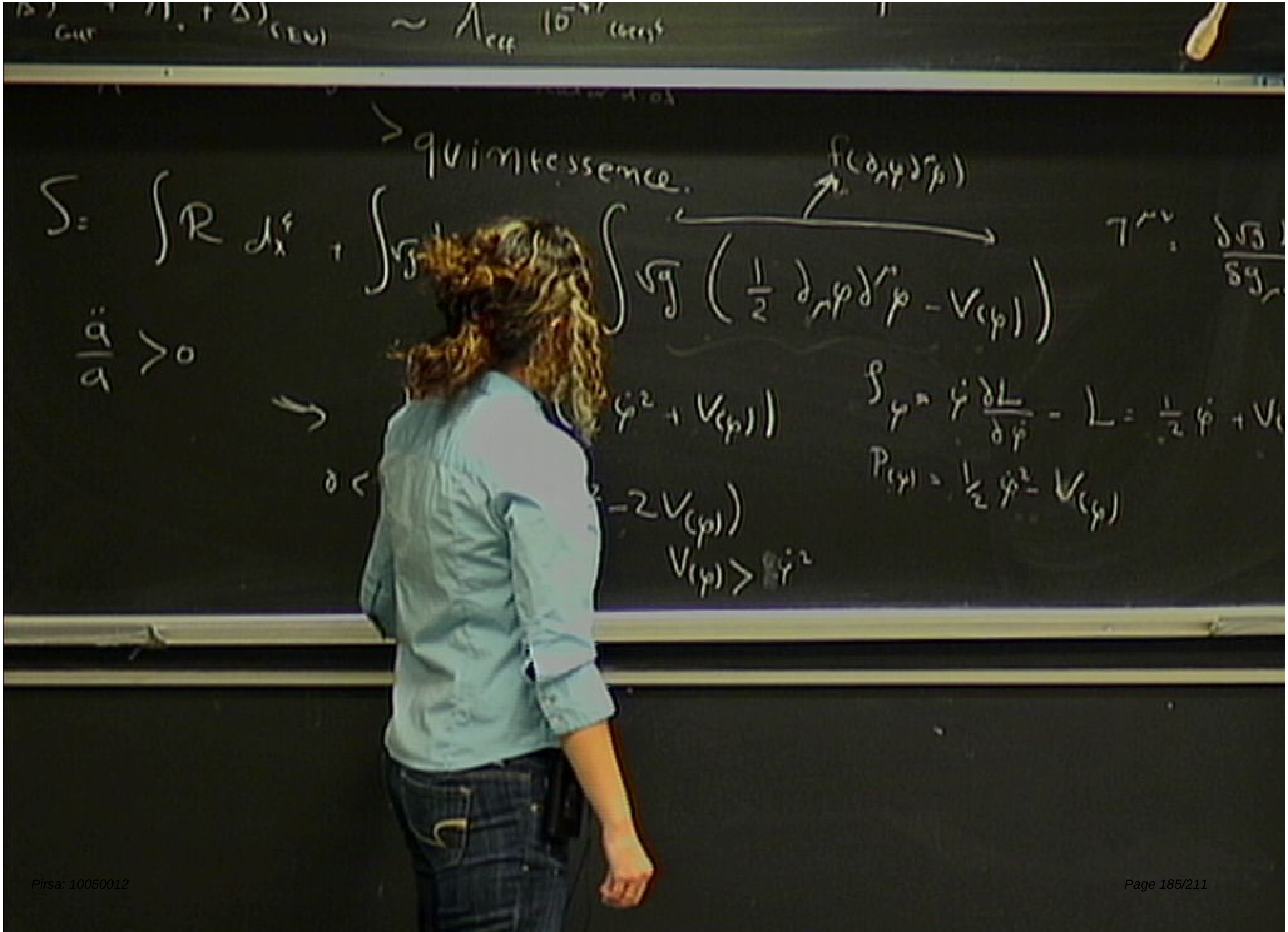
$\varphi = At^{\gamma}$ $\quad \dot\varphi^2 \propto t^{(\gamma-1)2}$



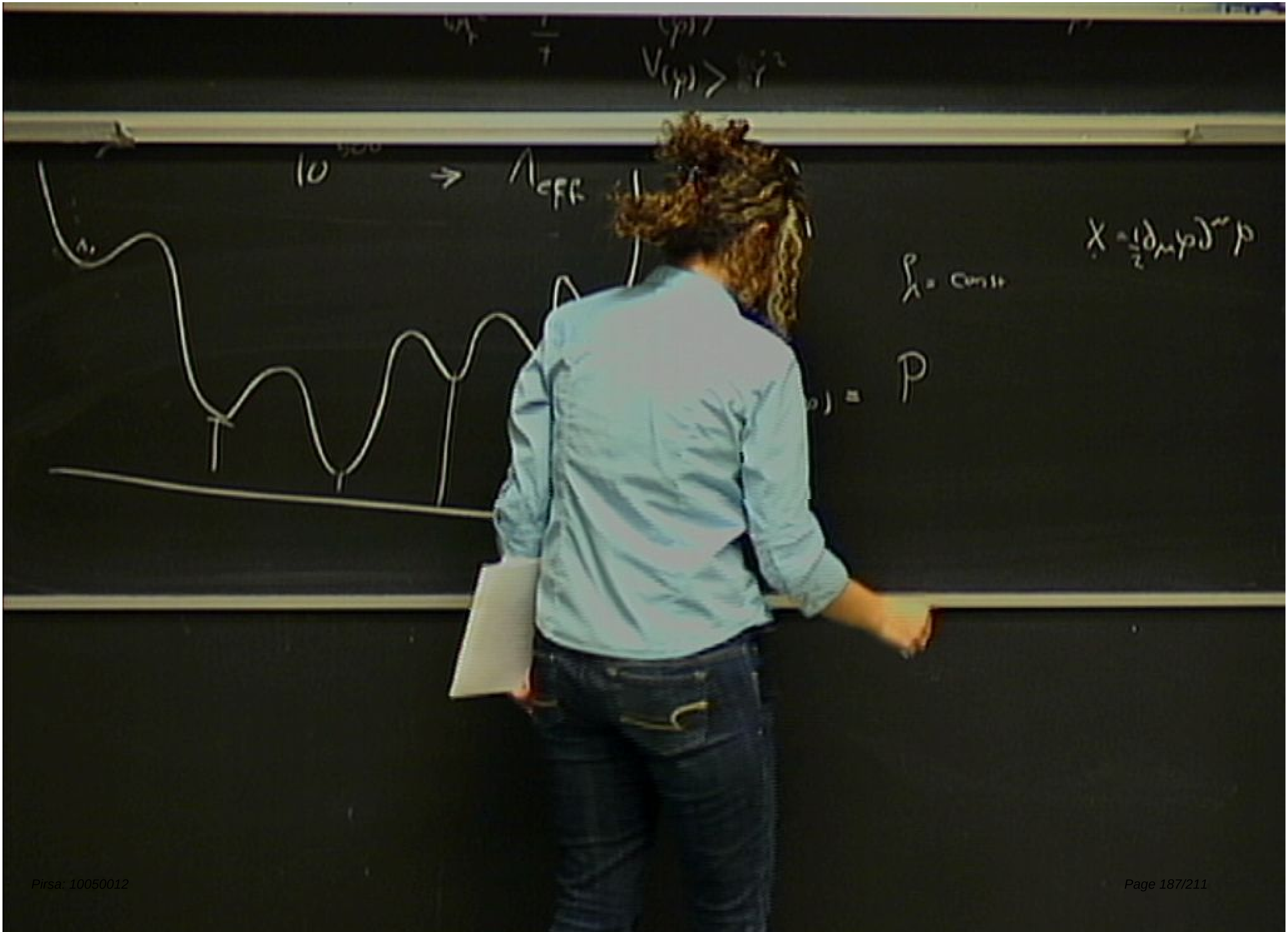
w_0

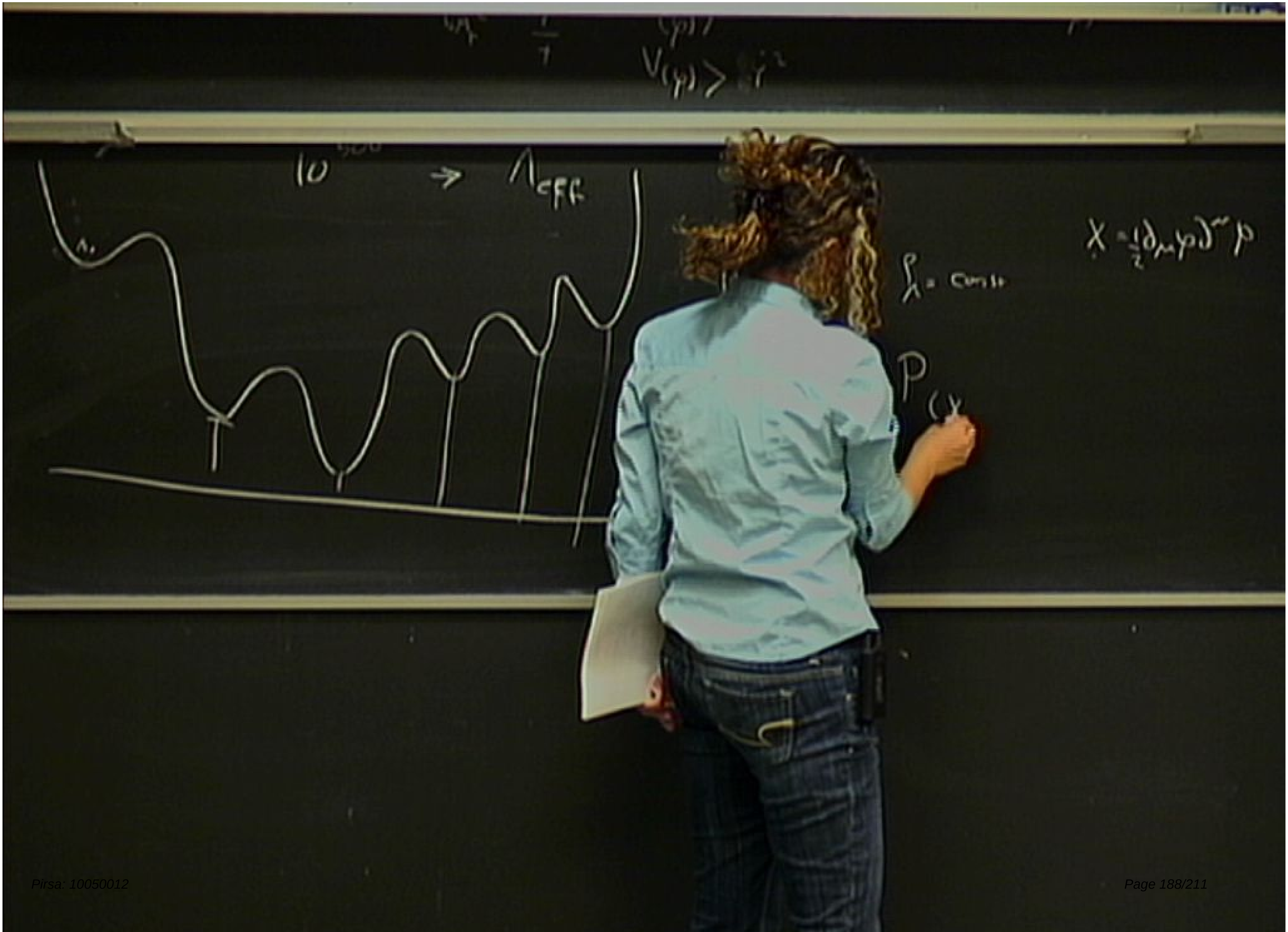
$\dot w_0$

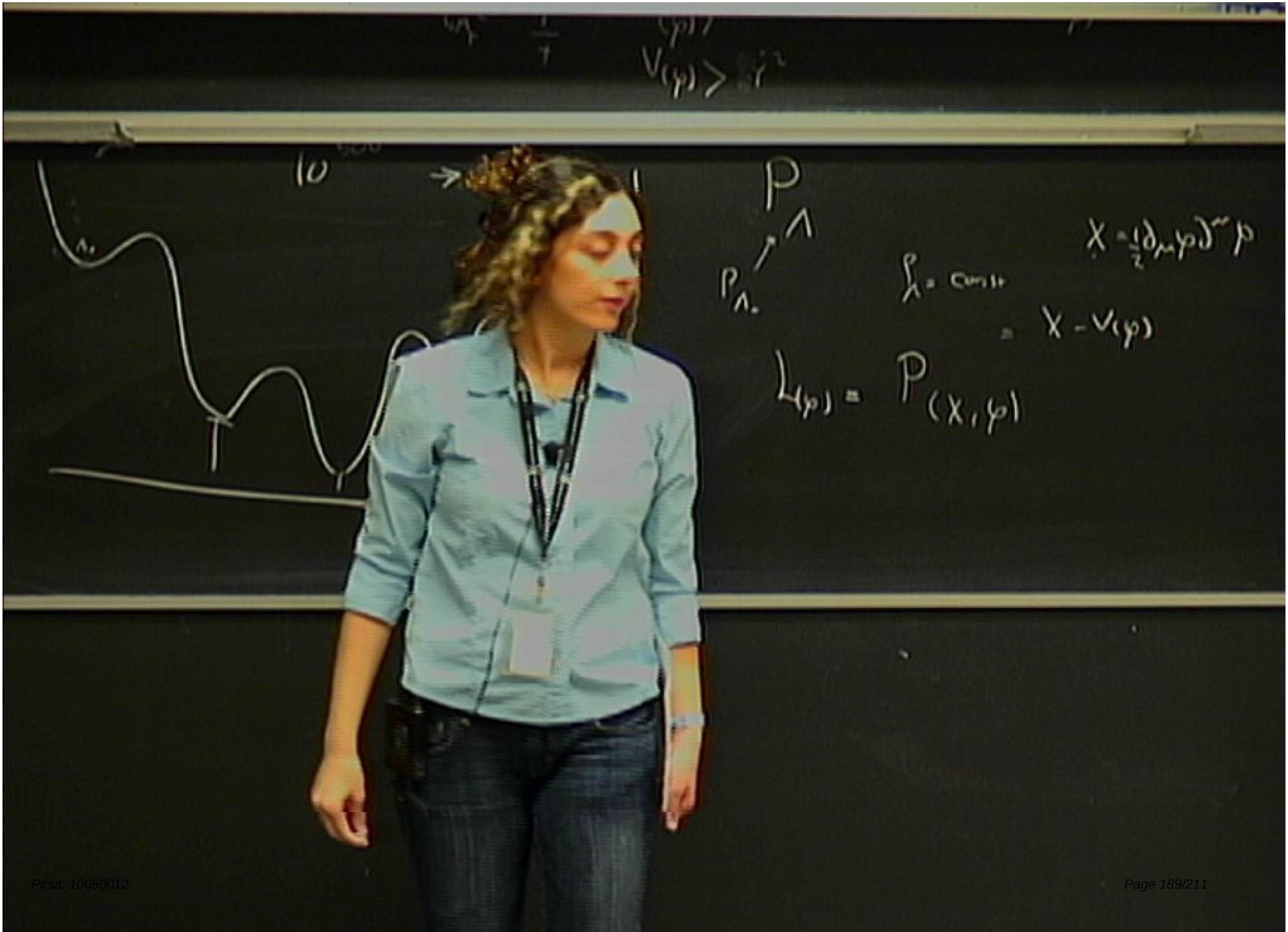
$\ddot w_0$

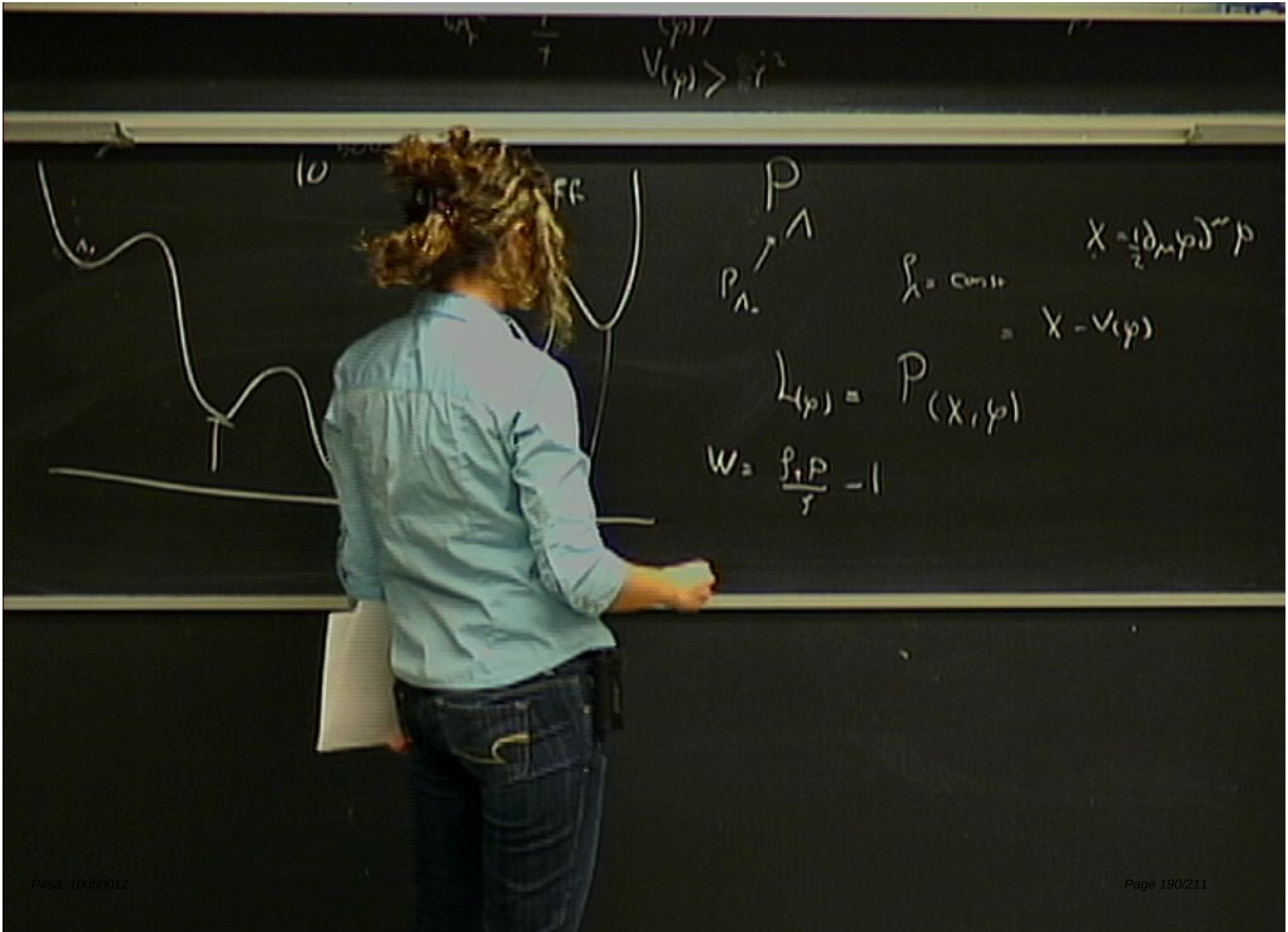

quintessence.
$f(\partial_\mu\varphi\partial^\mu\varphi)$
$S = \int R\, d^4x + \int\sqrt{g} \ldots \int\sqrt{g}\left(\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi - V(\varphi)\right)$
$\frac{\ddot a}{a} > 0$
$\rho_\varphi = \dot\varphi\frac{\partial L}{\partial\dot\varphi} - L = \frac{1}{2}\dot\varphi + V$
$P(\varphi) = \frac{1}{2}\dot\varphi^2 - V(\varphi)$
$V(\varphi) > \dot\varphi^2$


Λeff
const


Λeff
ρλ = const

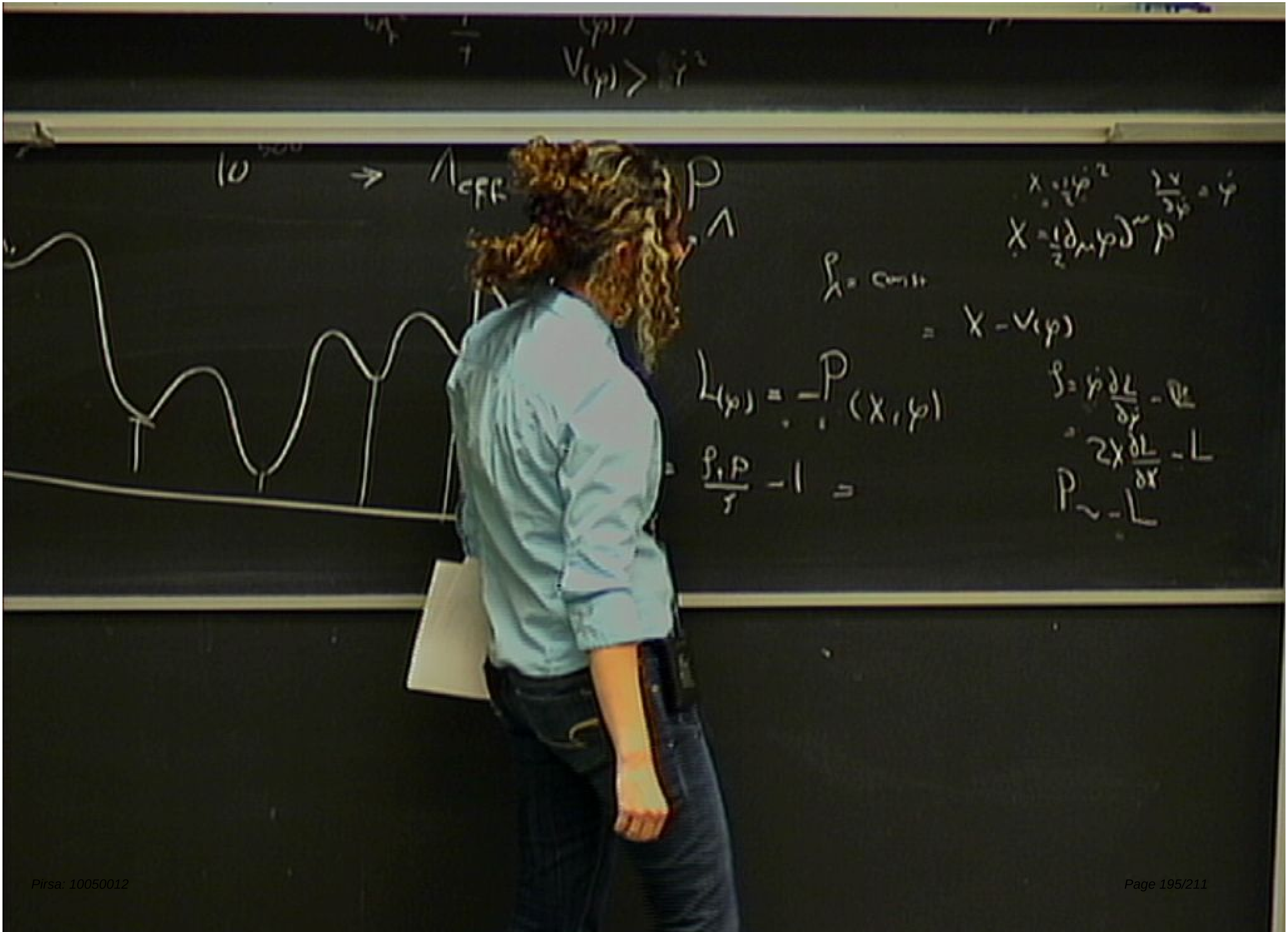

$V(\varphi) > \dot{\varphi}^2$
$10^{500} \rightarrow \Lambda_{eff}$
$\rho_\lambda = \text{const}$
$X = \frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi$


V(φ) >
P
Λ
P Λ₀
ρλ = const
X = ½ ∂μφ ∂^μ φ
= X − V(φ)
L(φ) = P(X, φ)

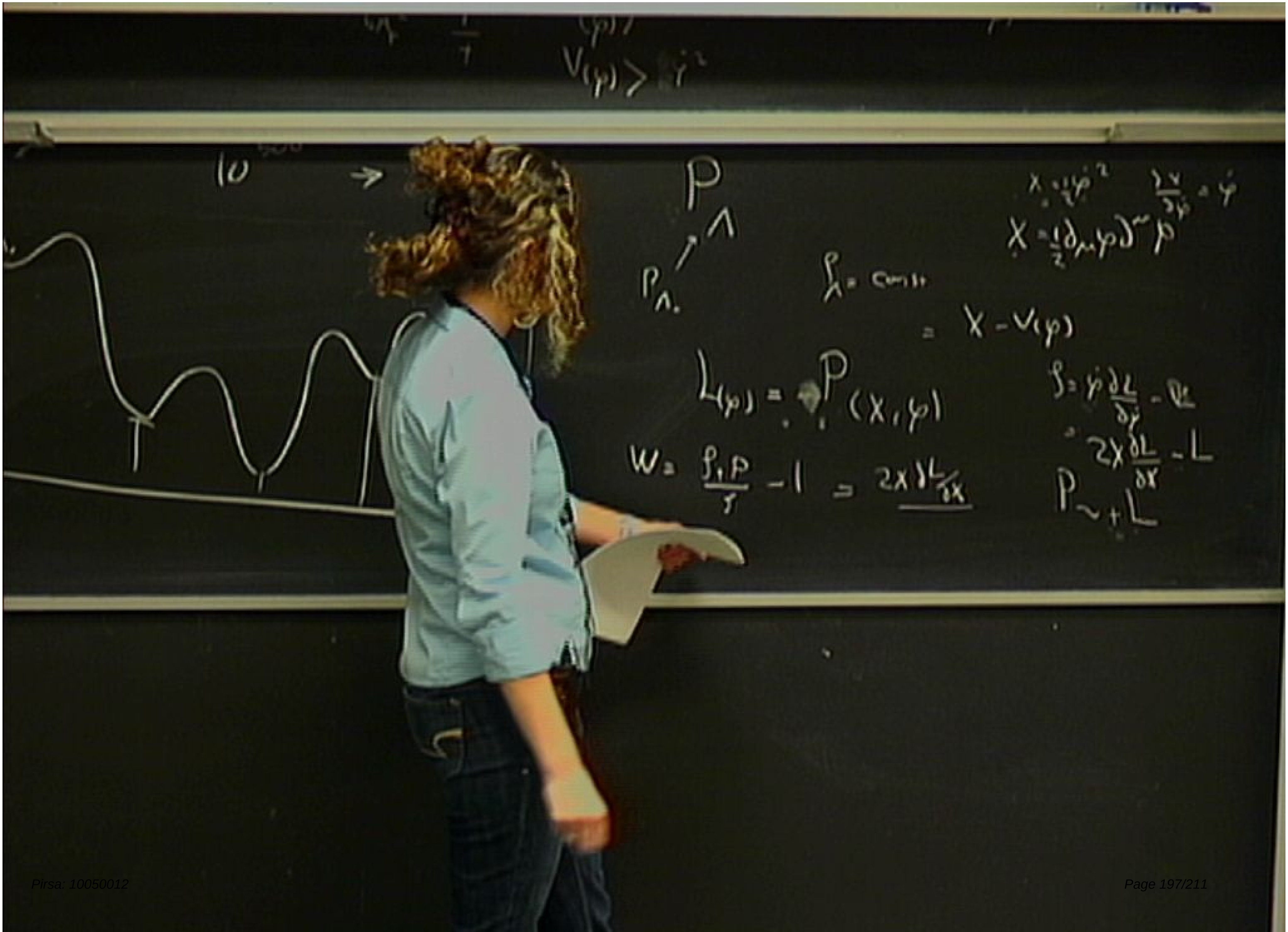

V(φ) >
P
Λ
P_Λ0
ρ_Λ = const
X = ½(∂_μφ)∂^μφ
= X − V(φ)
L(φ) = P(X, φ)
W = (ρ+P)/ρ − 1

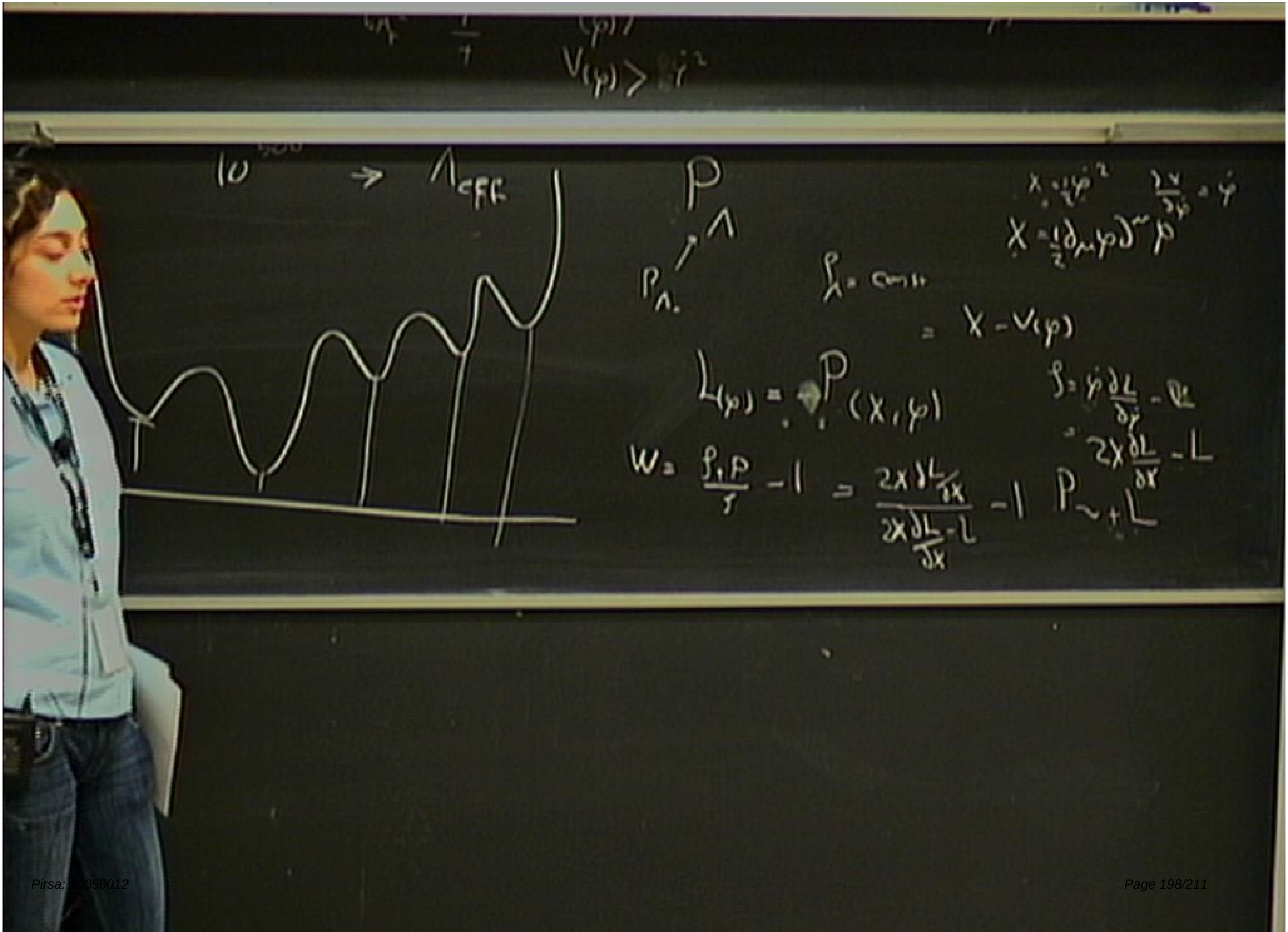

10 → Λeff
X = ½ ∂μφ∂μφ
ρλ = const
= X − V(φ)
P(X, φ)

Λ_eff
ρ_Λ = const
= X - V(φ)
L(φ) = P(X, φ)
P ~ -L

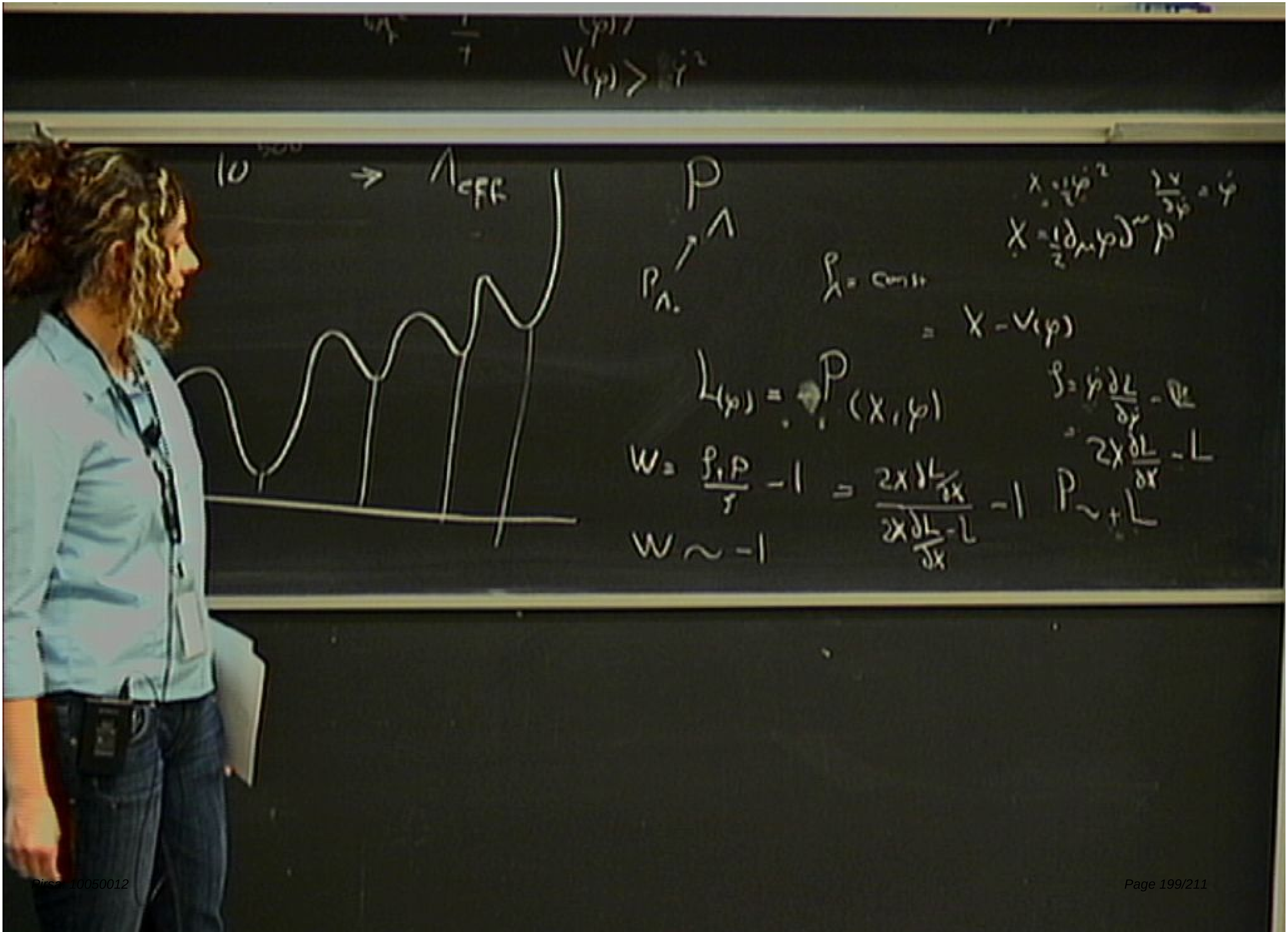

V(φ) > φ̇²
ρ_Λ = const
= X − V(φ)
L(φ) = −P(X, φ)
P ~ −L

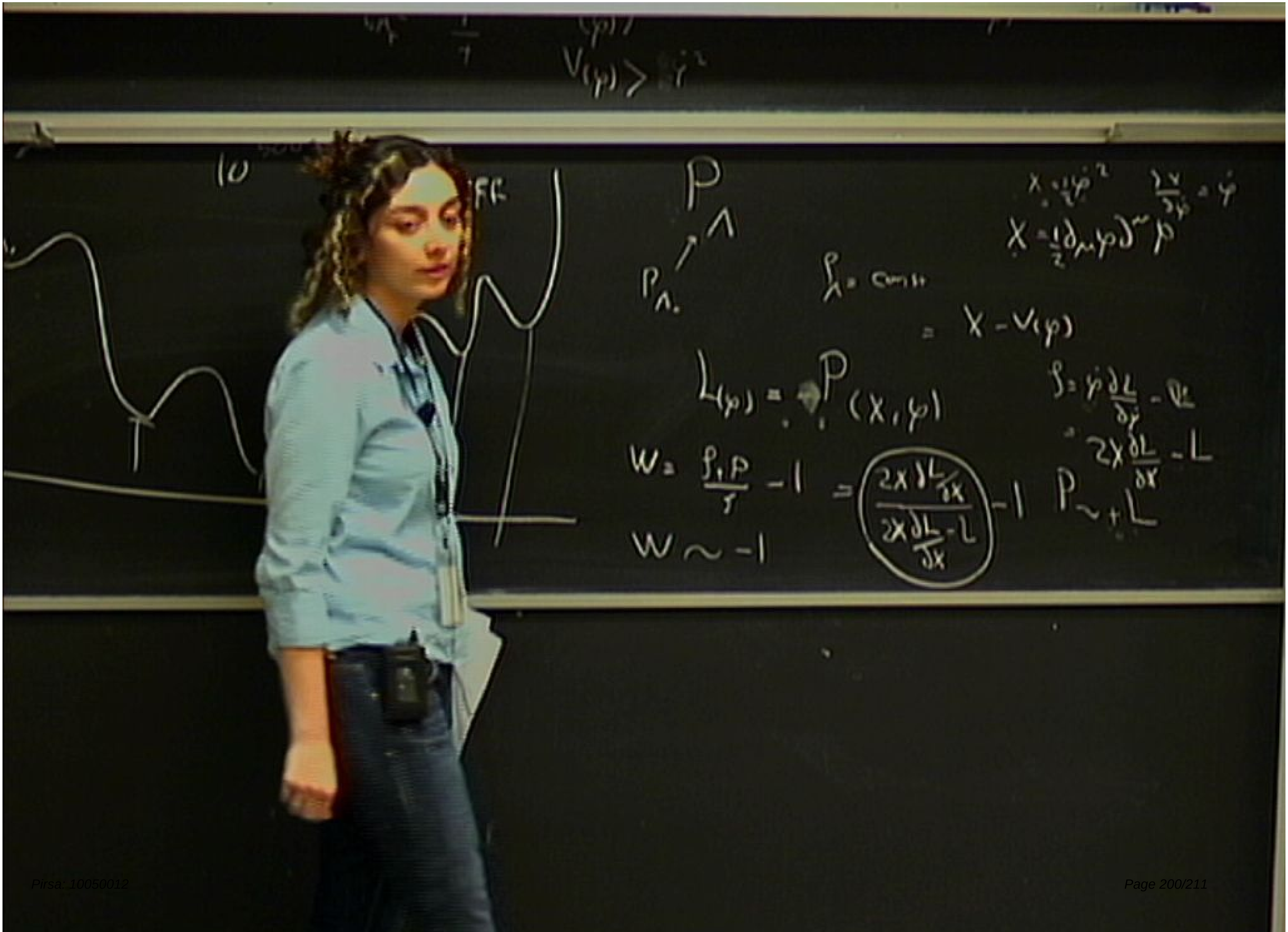
V(φ) > φ²
Λeff
ρΛ = const
= X − V(φ)
P(X, φ)
X = ½ ∂μφ ∂μφ
= 2X ∂L/∂X − L

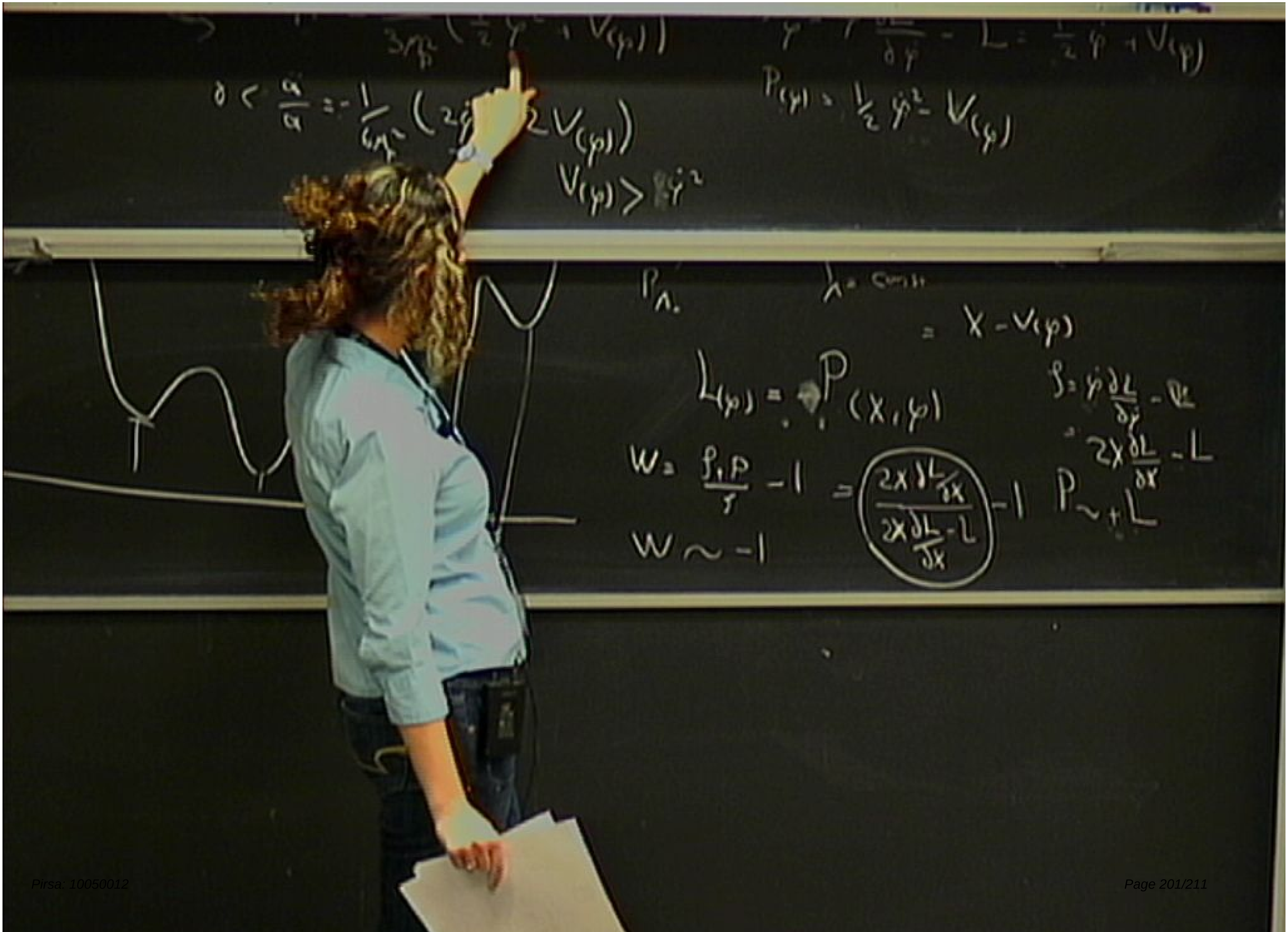


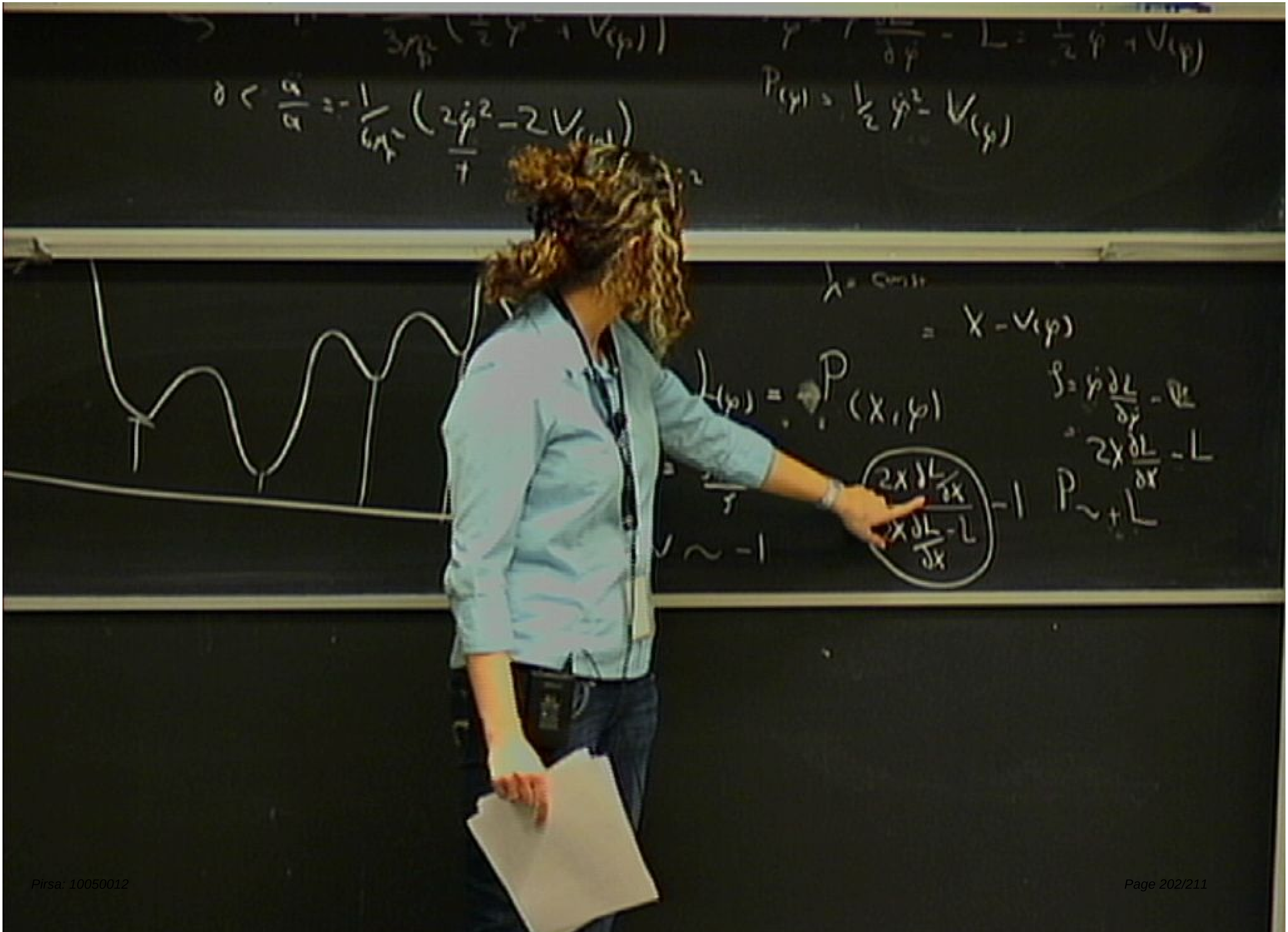


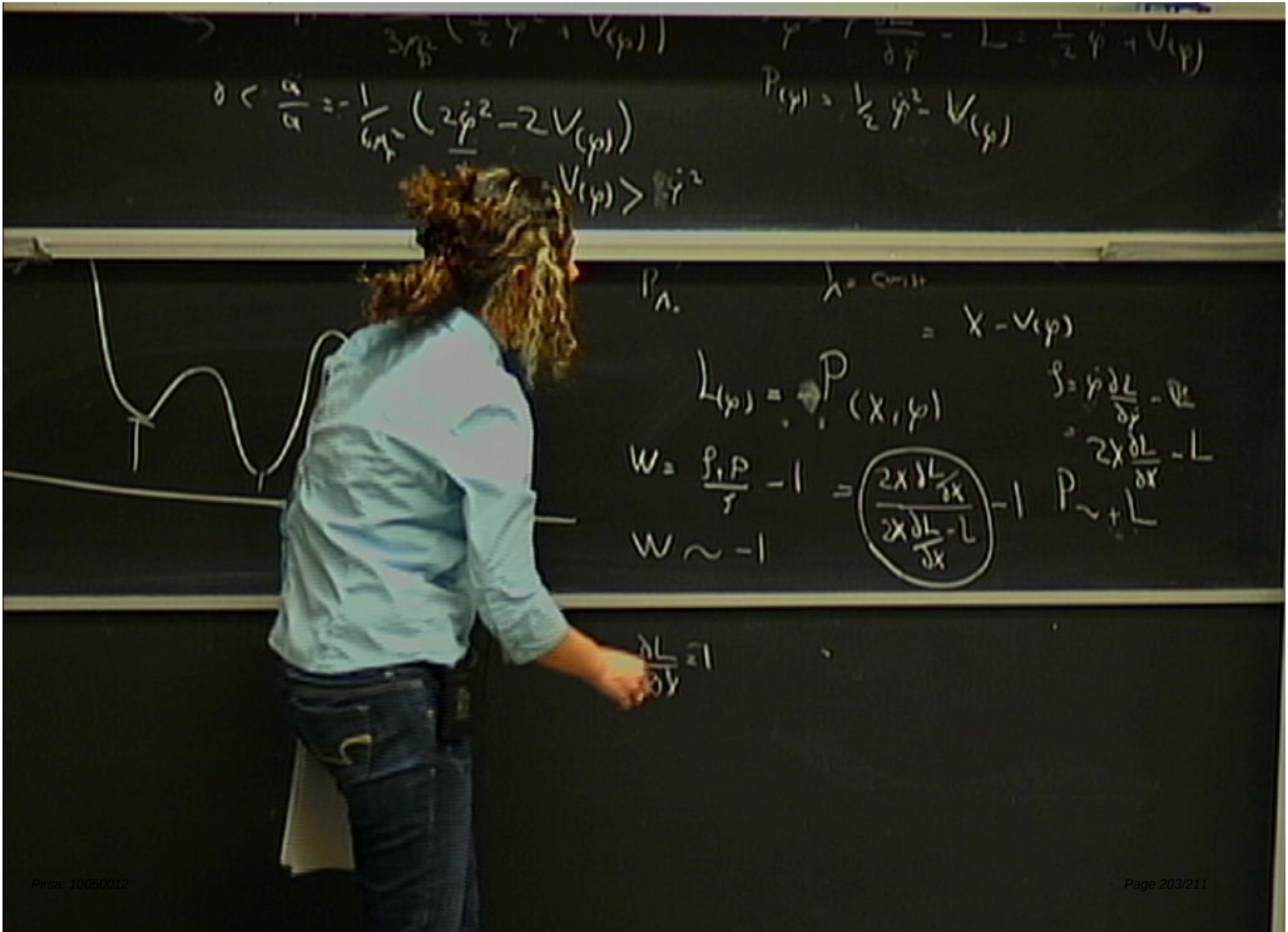
V(φ) > φ̇²
10^500 → Λ_eff
P_Λ
ρ_Λ = const
X = ½(∂_μ φ)²
= X − V(φ)
L(φ) = P(X, φ)
ρ = φ̇ ∂L/∂φ̇ − L
= 2X ∂L/∂X − L
W = (ρ+P)/ρ − 1

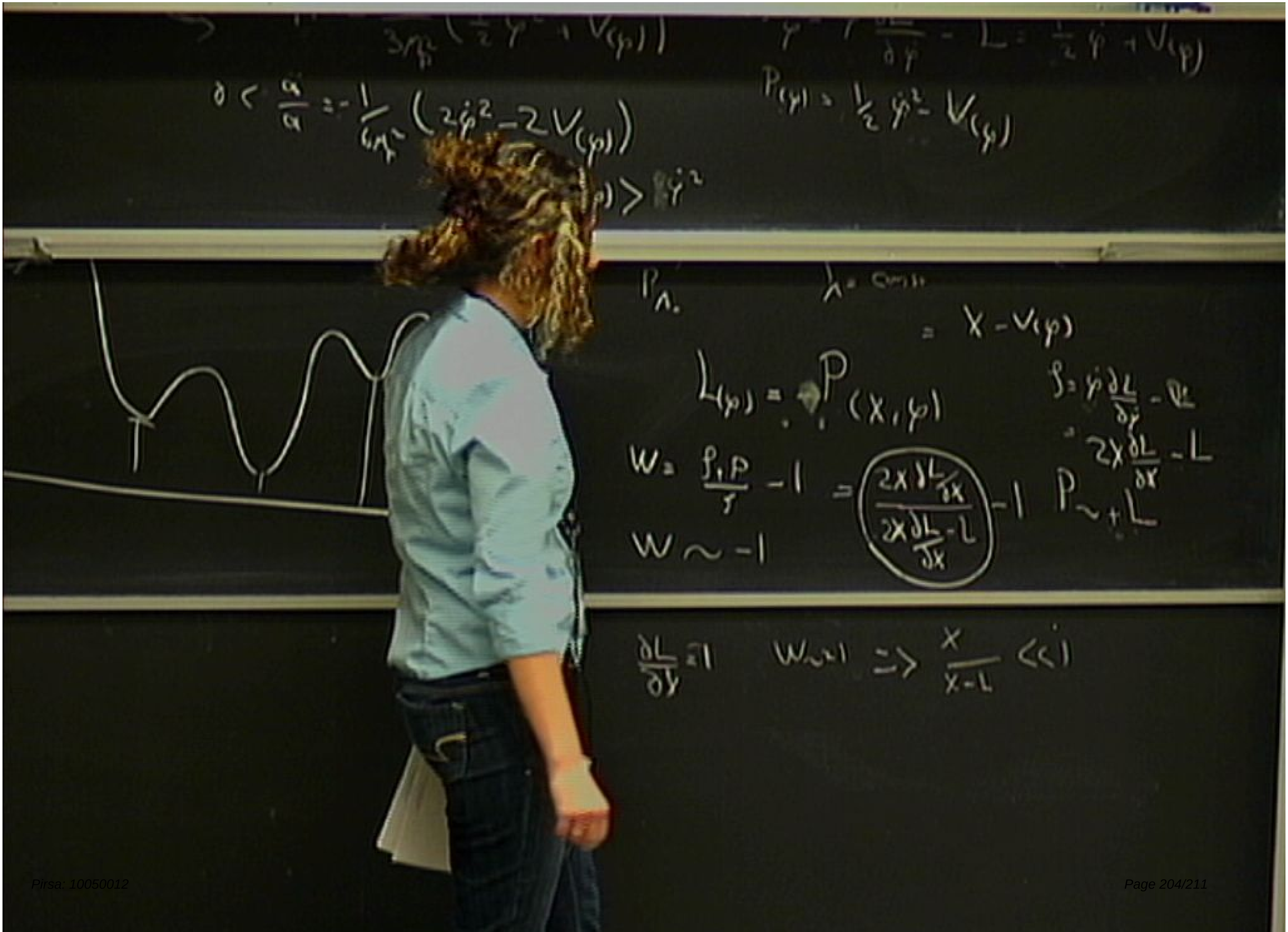

$V(\varphi) > \dot{\varphi}^2$
Λ_{eff}
$\rho_\Lambda = \text{const}$
$= X - V(\varphi)$
$L(\varphi) = P(X, \varphi)$
$W \sim -1$

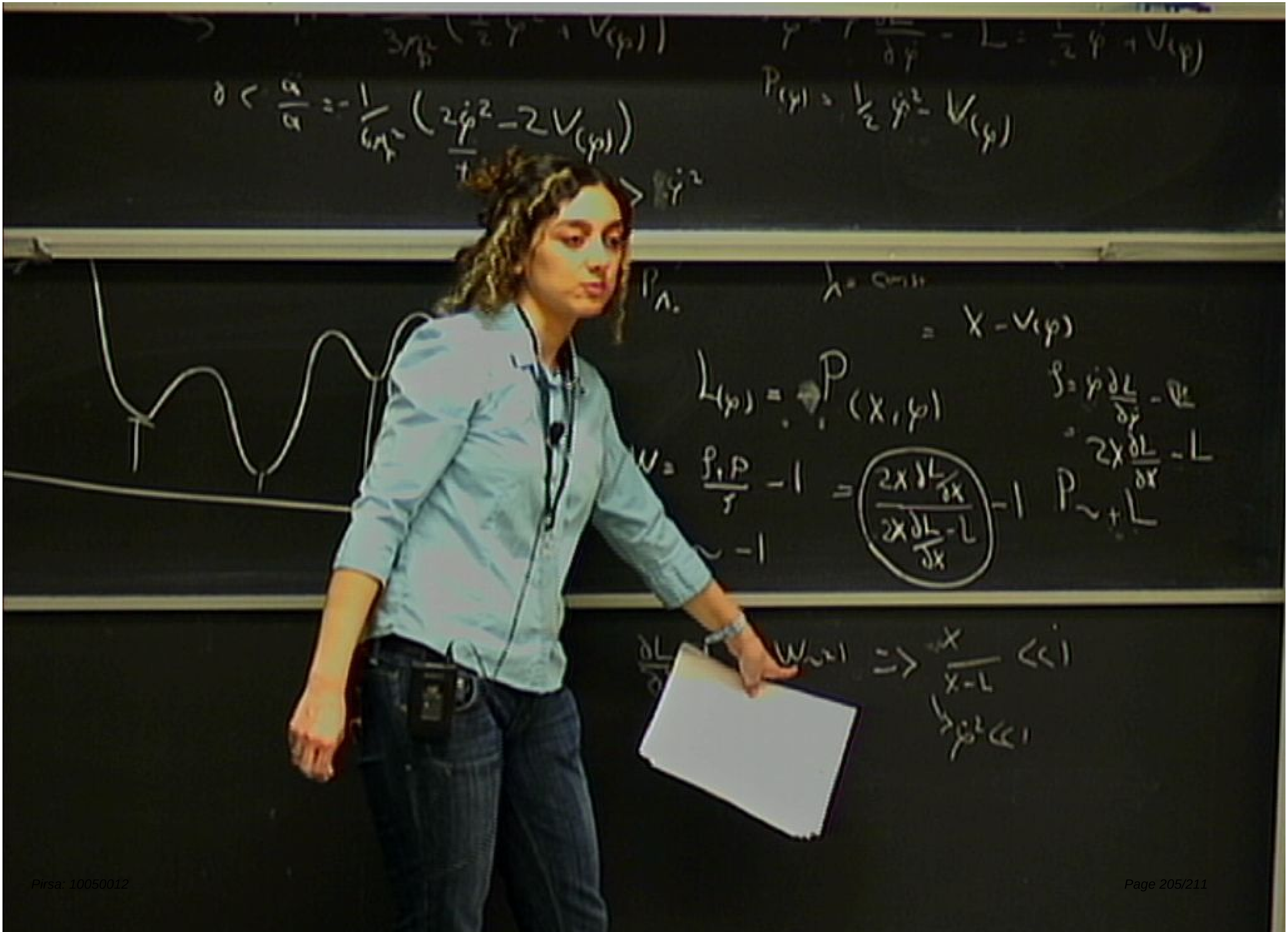

V(φ) > φ̇²
P
Λ
ρ_Λ = const
X = ½ ∂_μφ ∂^μφ
= X − V(φ)
L(φ) = P(X, φ)
ρ = φ̇ ∂L/∂φ̇ − L
= 2X ∂L/∂X − L
W = (ρ+P)/ρ − 1
W ~ −1

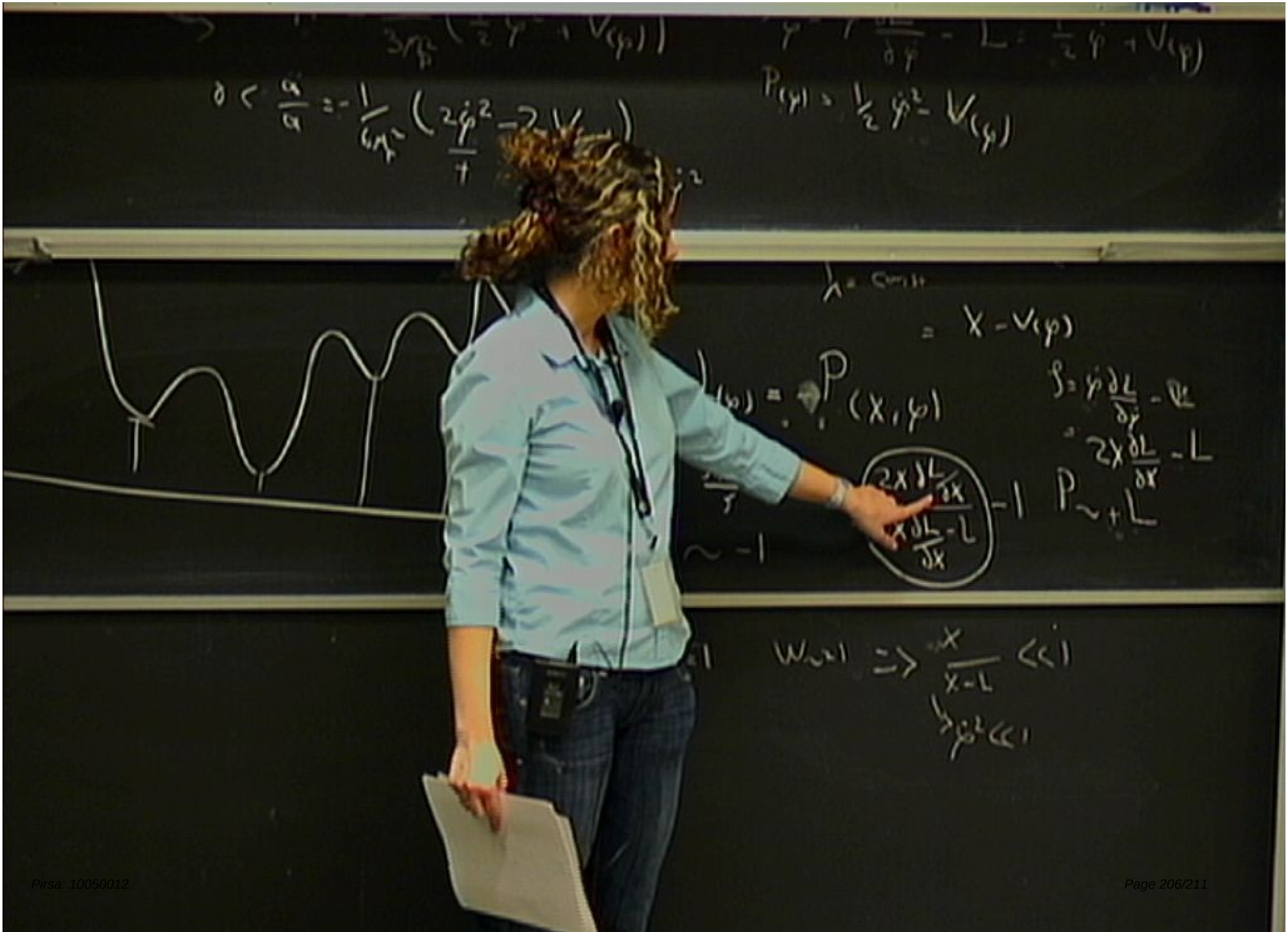

P(φ) = ½ φ̇² − V(φ)
V(φ) > φ̇²
= X − V(φ)
L(φ) = P(X, φ)
W = (ρ+P)/ρ − 1
W ~ −1

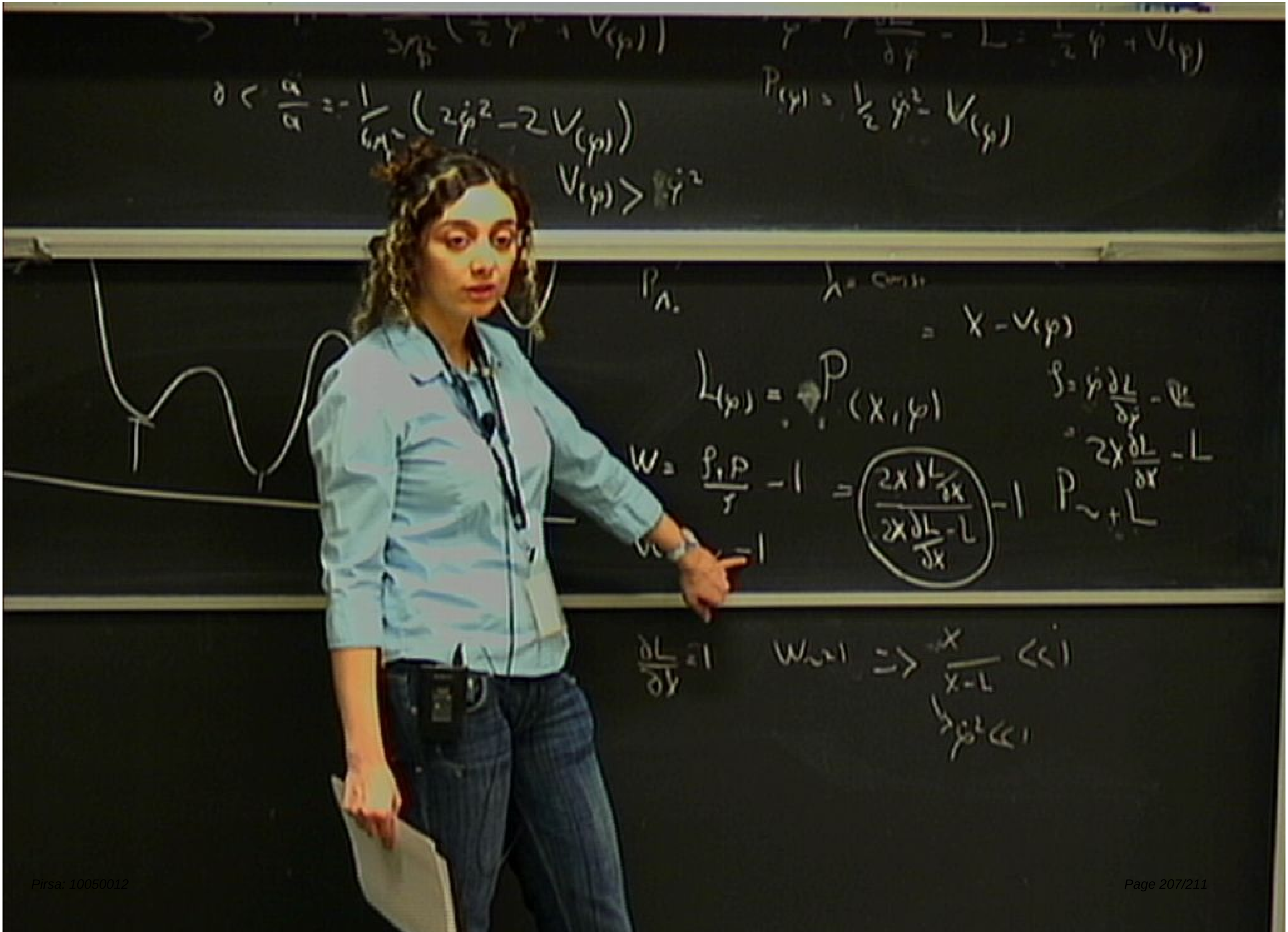



P(φ) = 1/2 φ̇² − V(φ)
V(φ) > φ̇²
= X − V(φ)
L(φ) = P(X, φ)
W ~ −1
∂L/∂X = 1

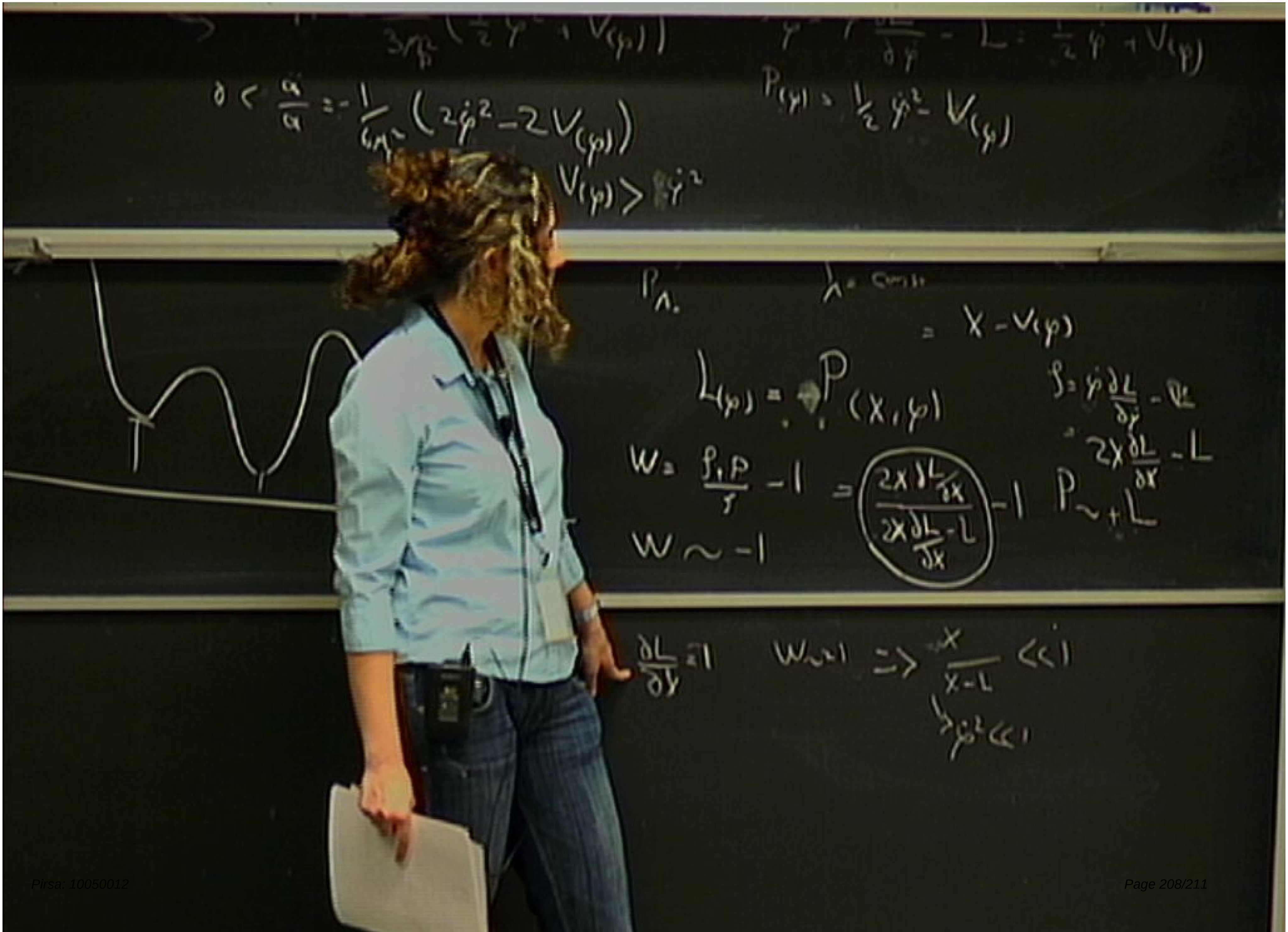

$\frac{1}{3M_p^2}\left(\frac{1}{2}\dot\varphi^2 + V_{(\varphi)}\right)$
$\dot\varphi \frac{\partial L}{\partial \dot\varphi} - L = \frac{1}{2}\dot\varphi^2 + V_{(\varphi)}$
$0 < \frac{\ddot a}{a} = -\frac{1}{6M_p^2}\left(2\dot\varphi^2 - 2V_{(\varphi)}\right)$
$P_{(\varphi)} = \frac{1}{2}\dot\varphi^2 - V_{(\varphi)}$
$V_{(\varphi)} > \dot\varphi^2$
P_{Λ}
$\lambda = \text{const}$
$= X - V(\varphi)$
$L_{(\varphi)} = P_{(X,\varphi)}$
$\rho = \dot\varphi \frac{\partial L}{\partial \dot\varphi} - L$
$= 2X\frac{\partial L}{\partial X} - L$
$W = \frac{\rho + P}{\rho} - 1 = \frac{2X\,\partial L/\partial X}{2X\frac{\partial L}{\partial X} - L} - 1$
$P \sim + L$
$W \sim -1$
$\frac{\partial L}{\partial X} \approx 1$
$W \sim -1 \Rightarrow \frac{X}{X - L} << 1$



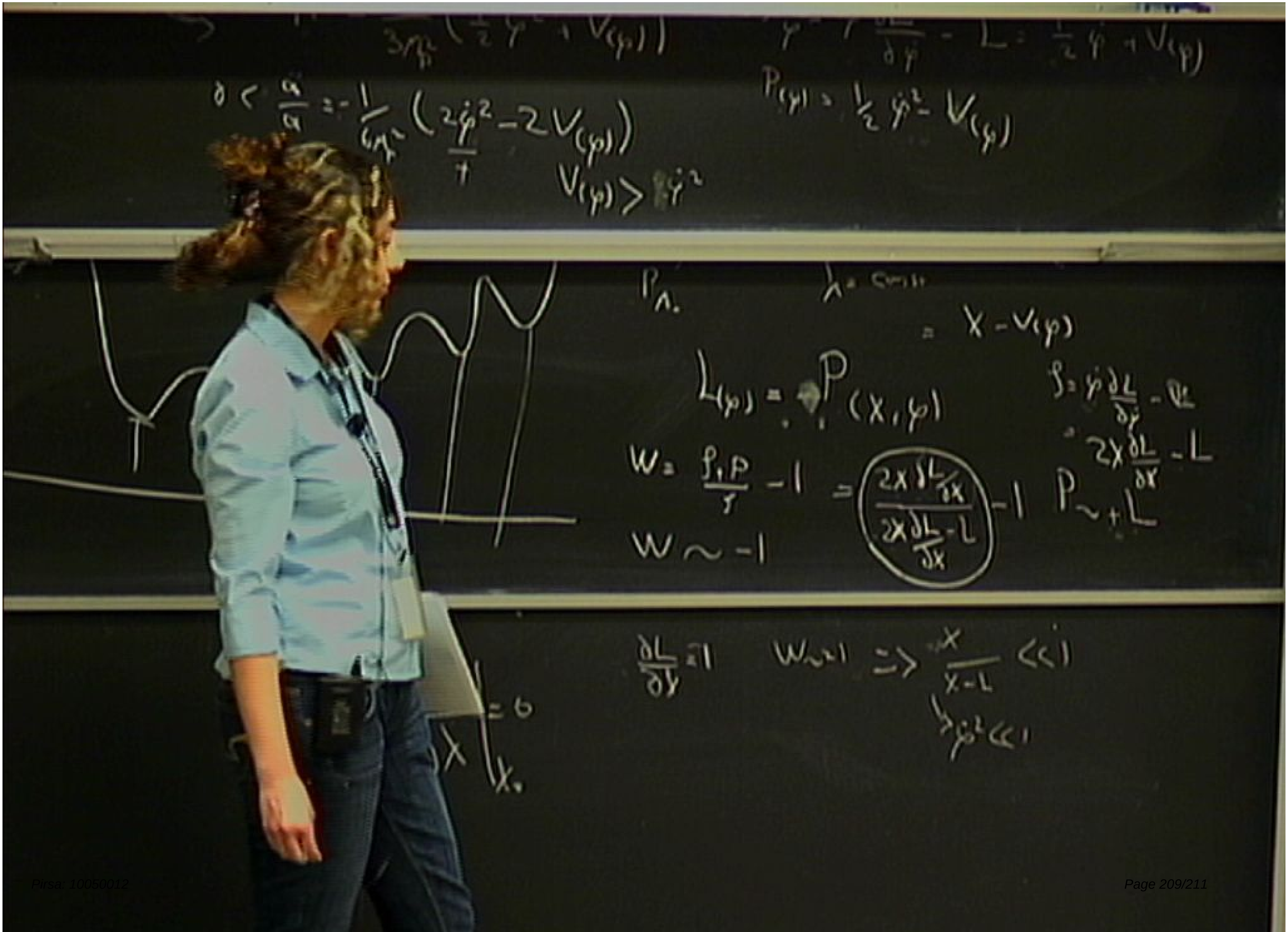


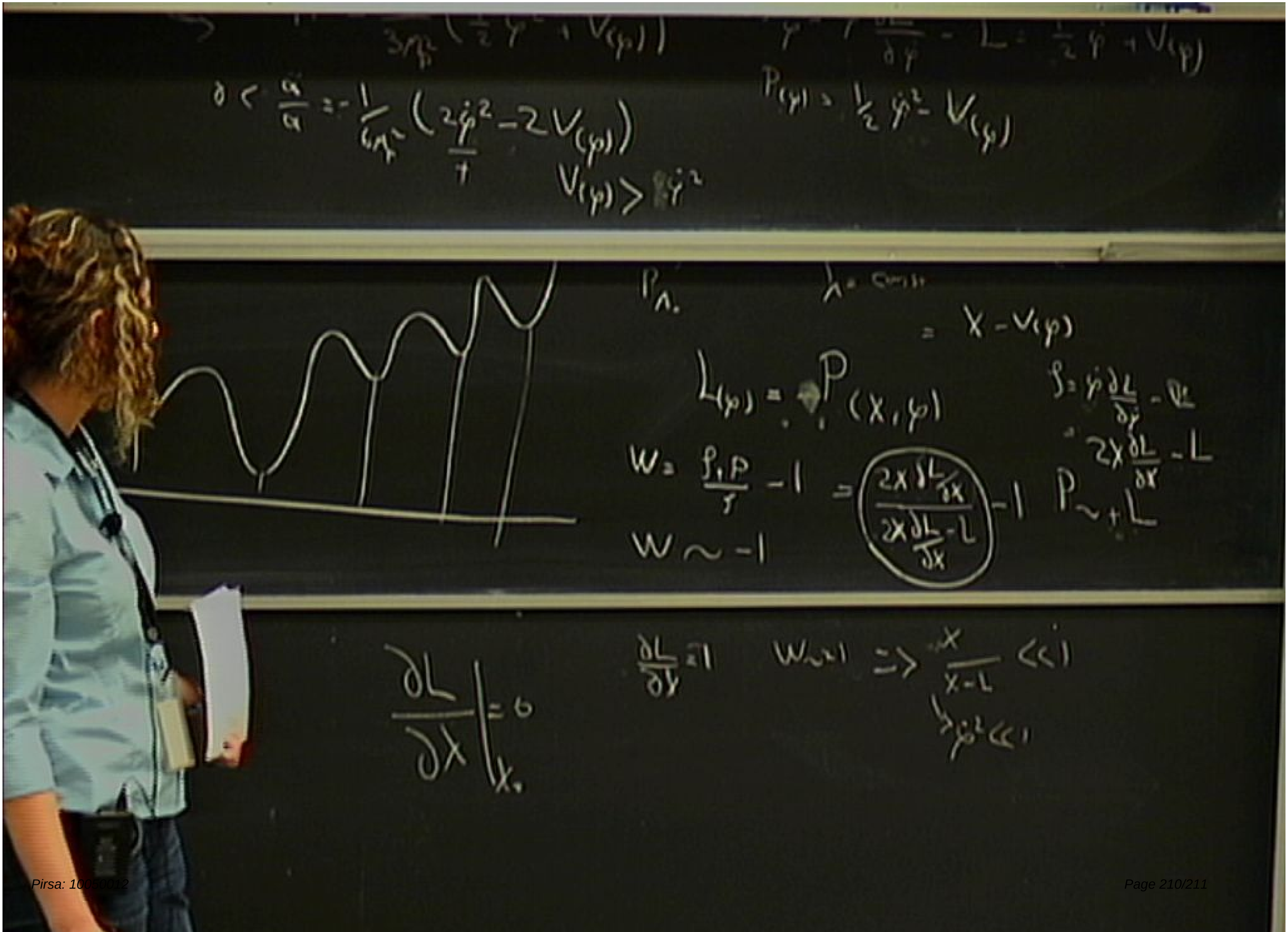


P(φ) = ½ φ̇² − V(φ)
V(φ) > φ̇²
X − V(φ)
L(φ) = P(X, φ)

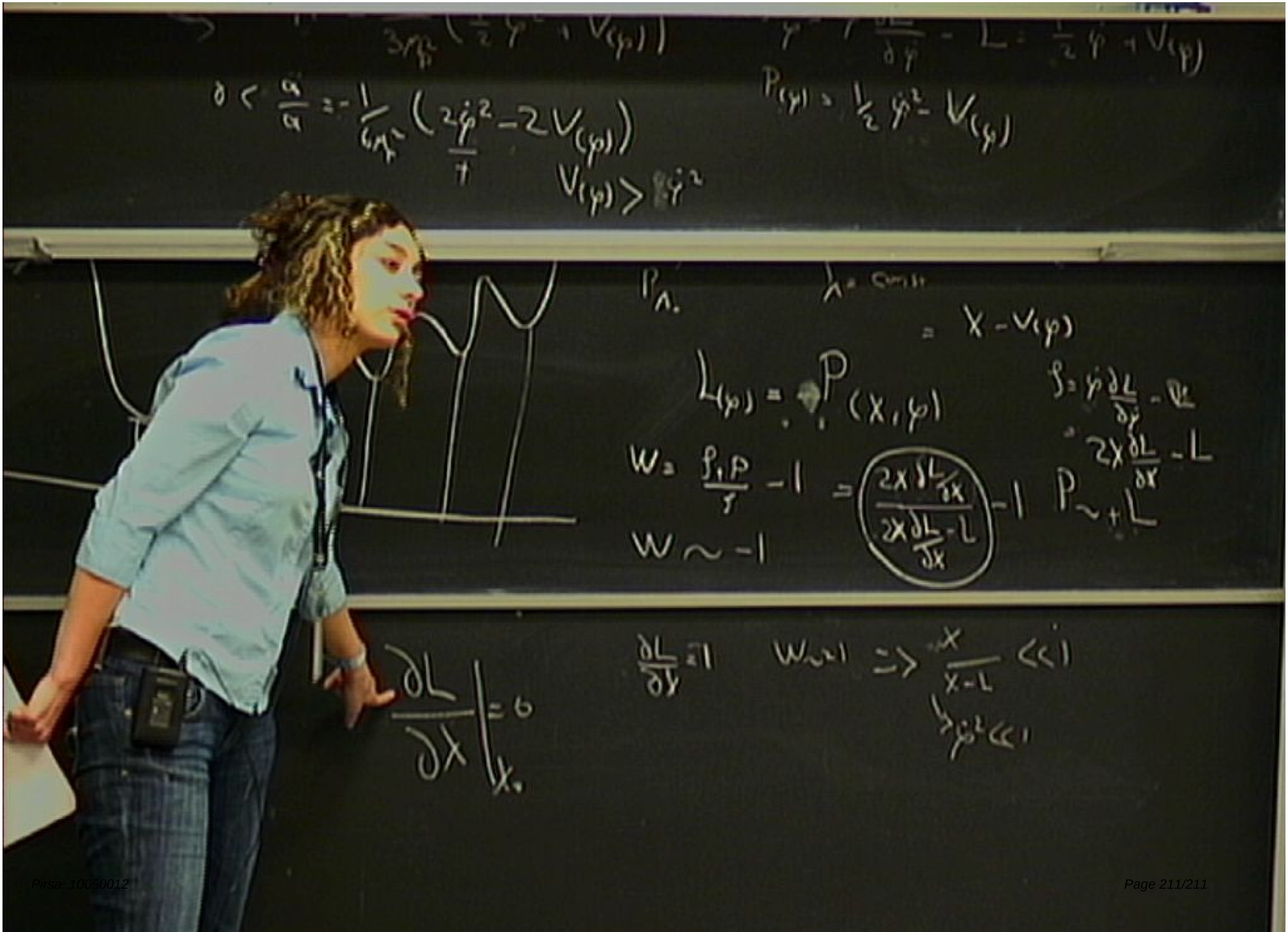


P(φ) = ½ φ̇² − V(φ)
V(φ) > φ̇²
= X − V(φ)
L(φ) = P(X, φ)
W = (ρ + P)/ρ − 1
W ~ −1
∂L/∂X ≈ 1
W ~ −1 ⇒ X/(X − L) << 1





P(φ) = ½ φ̇² − V(φ)
V(φ) > φ̇²
λ = const
= X − V(φ)
L(φ) = P(X, φ)
W ~ −1
∂L/∂X = 1
W ~ −1 => X/(X−L) << 1
φ̇² << 1


P(φ) = ½ φ̇² − V(φ)
V(φ) > φ̇²
= X − V(φ)
L(φ) = P(X, φ)
W ~ −1
∂L/∂X |X₀ = 0
∂L/∂X ≈ 1