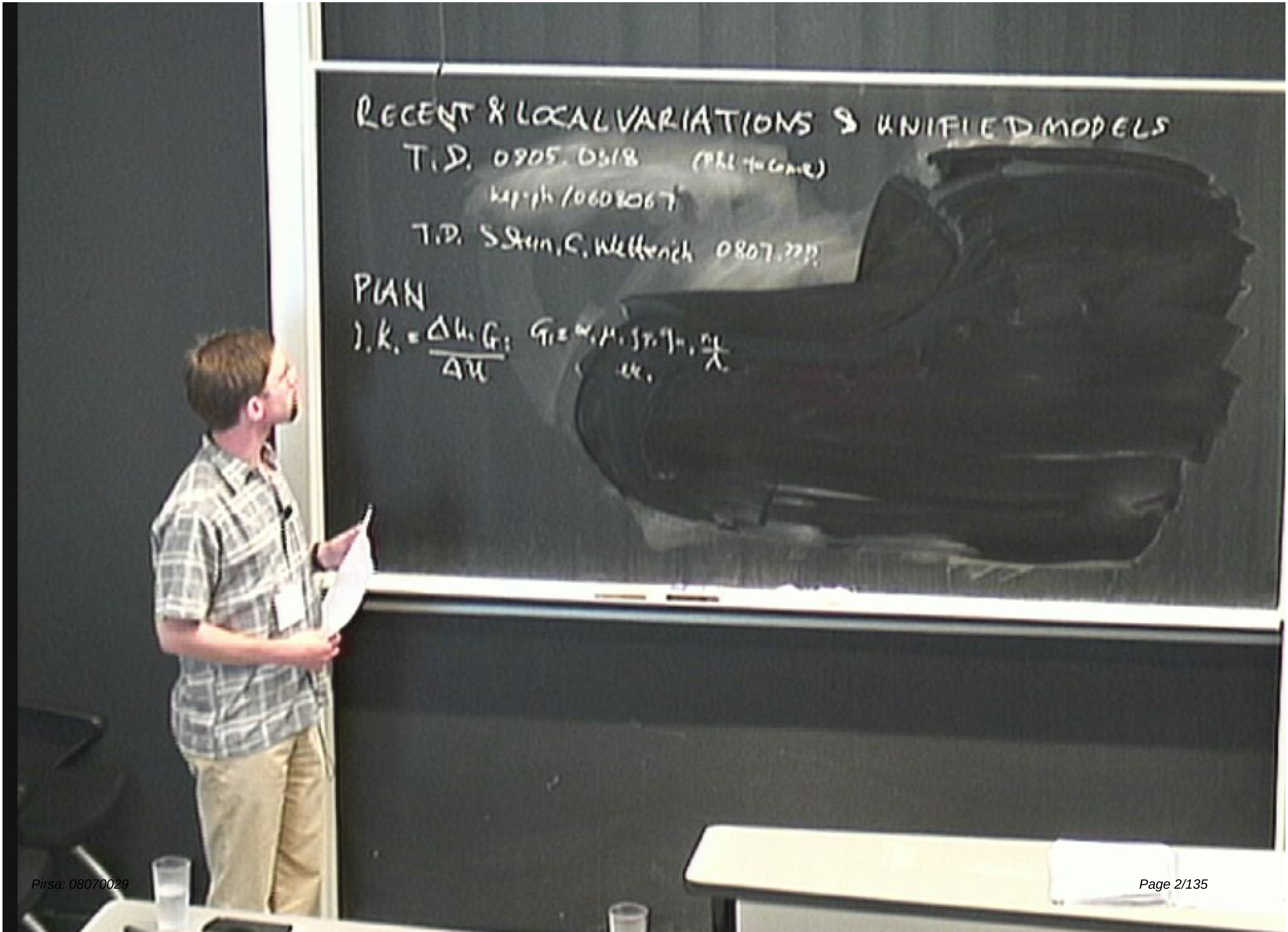
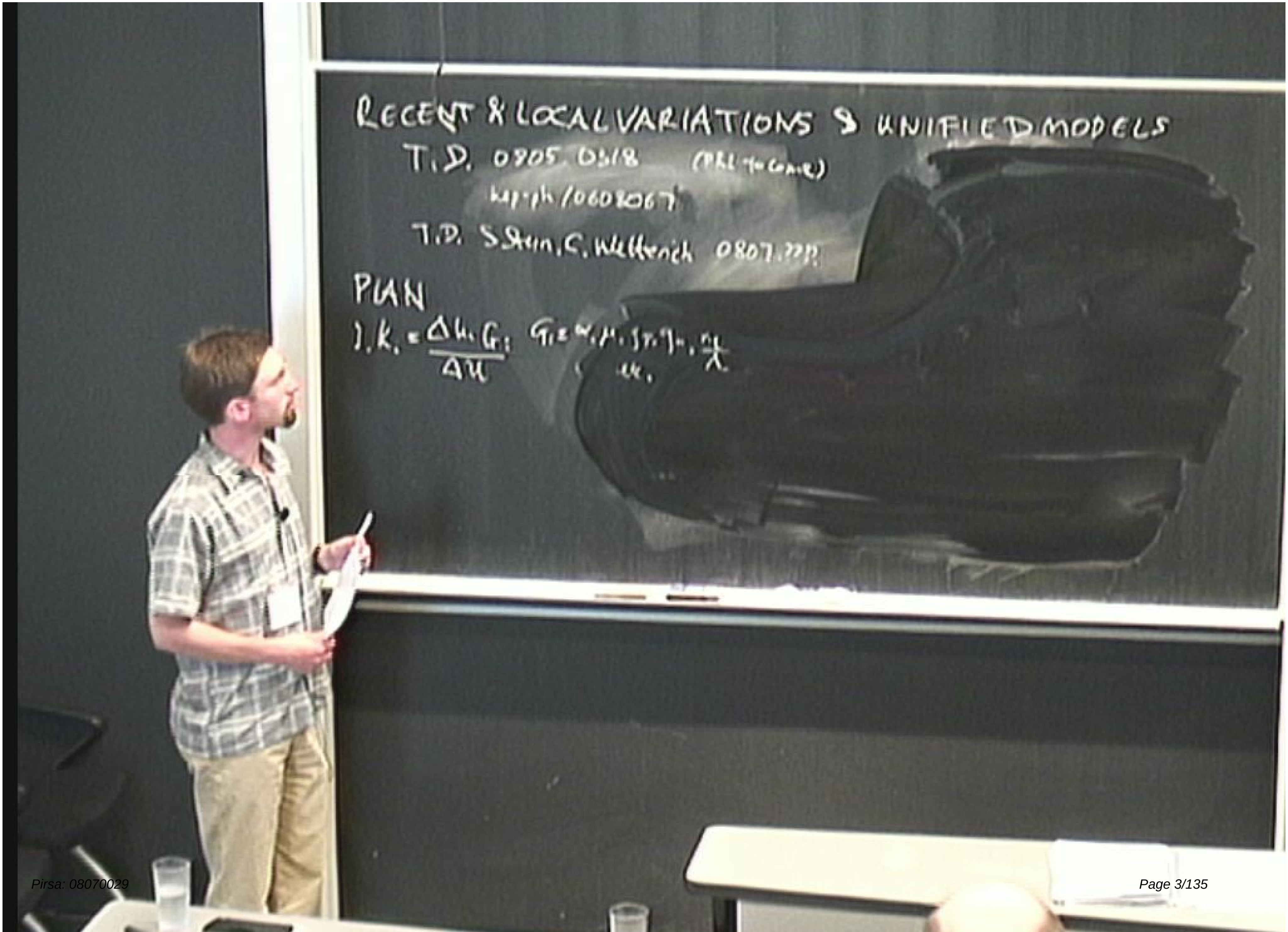
Title: Recent and Local Variations and Unified Models

Date: Jul 17, 2008 03:50 PM

URL: http://pirsa.org/08070029

Abstract: Precision tests of Local Position Invariance (LPI) involve many different methods in atomic, nuclear and gravitational physics, astrophysics and cosmology, and many different epochs and environments. We present some methods for comparing or combining different methods, either in a model-independent way or within simple scalar field models of variation. We focus on which methods are most sensitive to cosmologically recent time variation, and also on tests of spatial variation within the Solar System.


RECENT & LOCAL VARIATIONS & UNIFIED MODELS
T.D. 0805.0318 (PRL to come)
T.D. S.Stein, C.Wetterich 0807.
PLAN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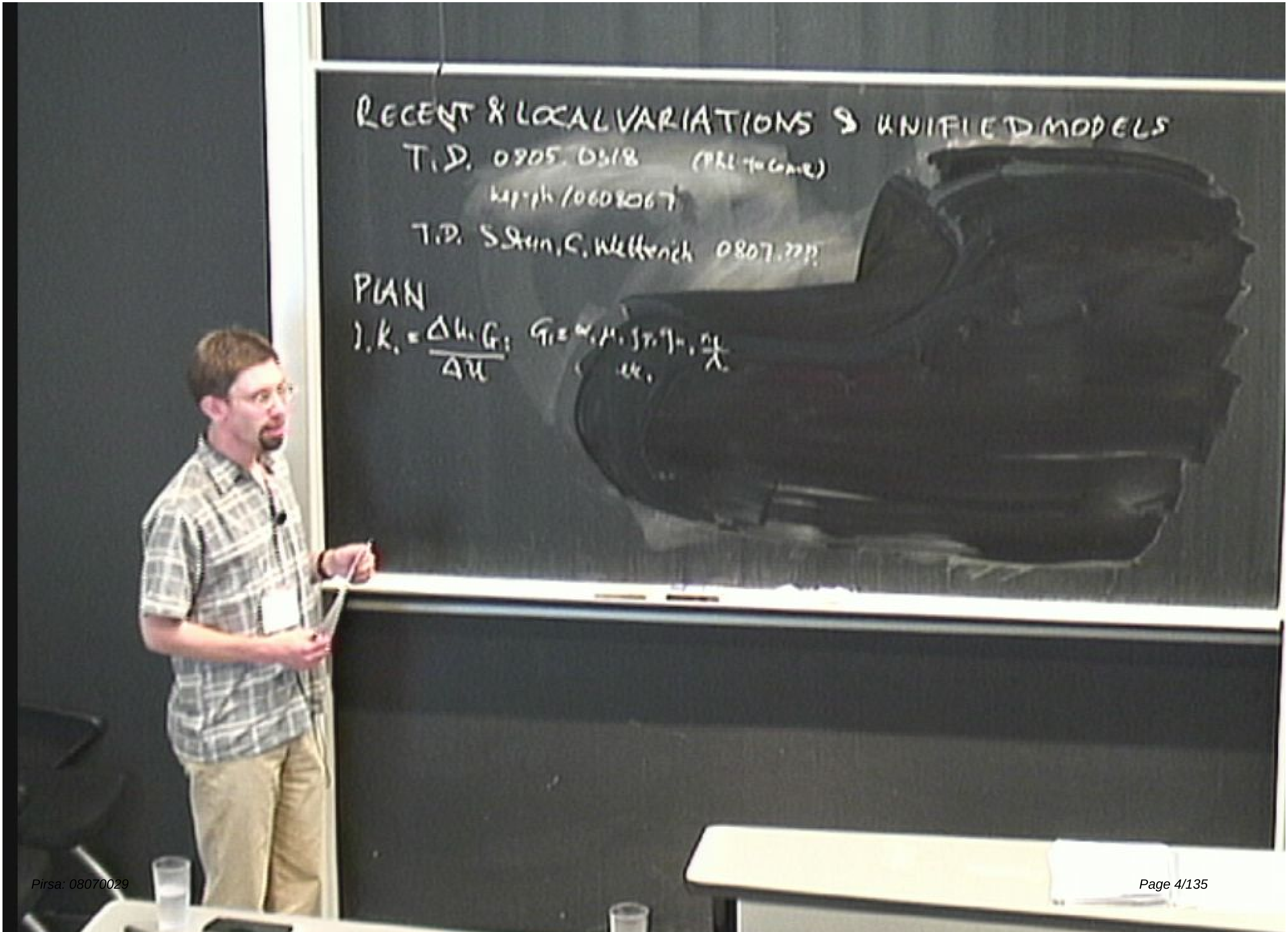
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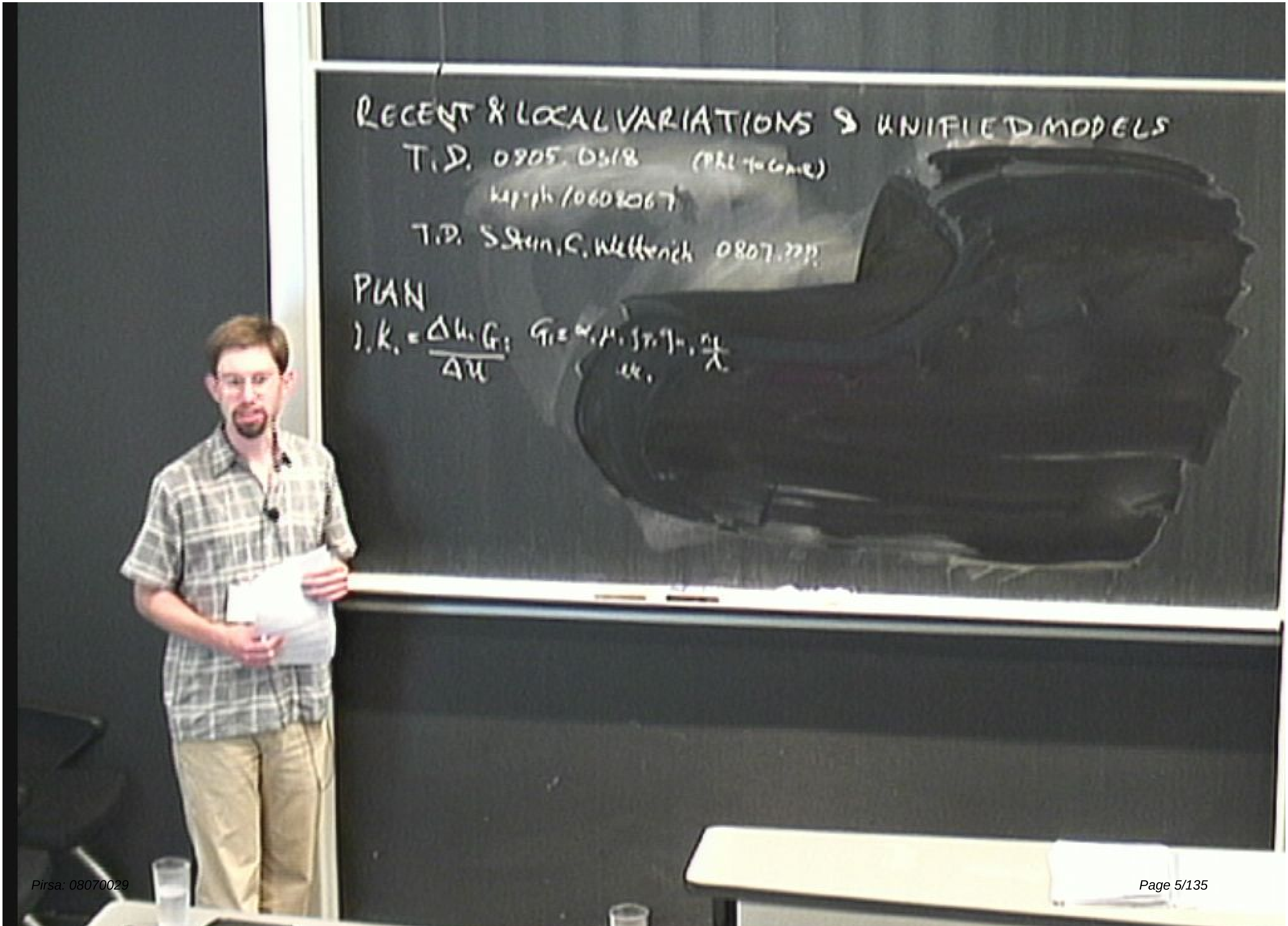
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PLAN

1. $k_i \equiv \frac{\Delta \ln G_i}{\Delta u}$; $G_i \equiv \alpha, \mu, g_p, g_n, \frac{m_q}{\Lambda}$ etc.

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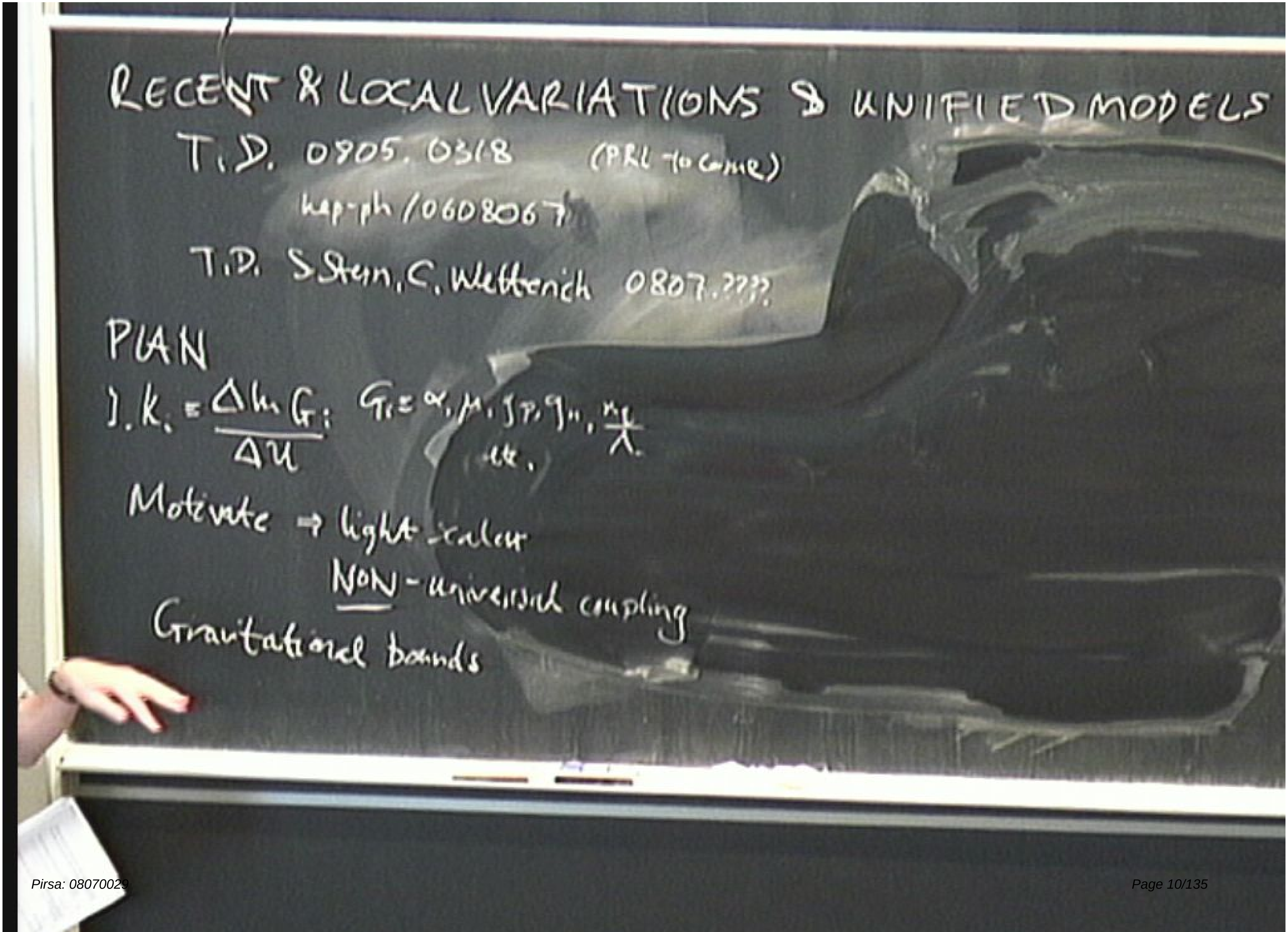
Motivate ⇒ light scalar

NON-universal coupling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1. k_i = Δ ln G_i / Δu ; G_i = α, μ, g_p, g_n, m_e/λ
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RECENT & LOCAL VARIATIONS & UNIFIED MODELS

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Gravitational bounds $\longrightarrow |k_i| < 10^{-6} \dots 10^{-4}$

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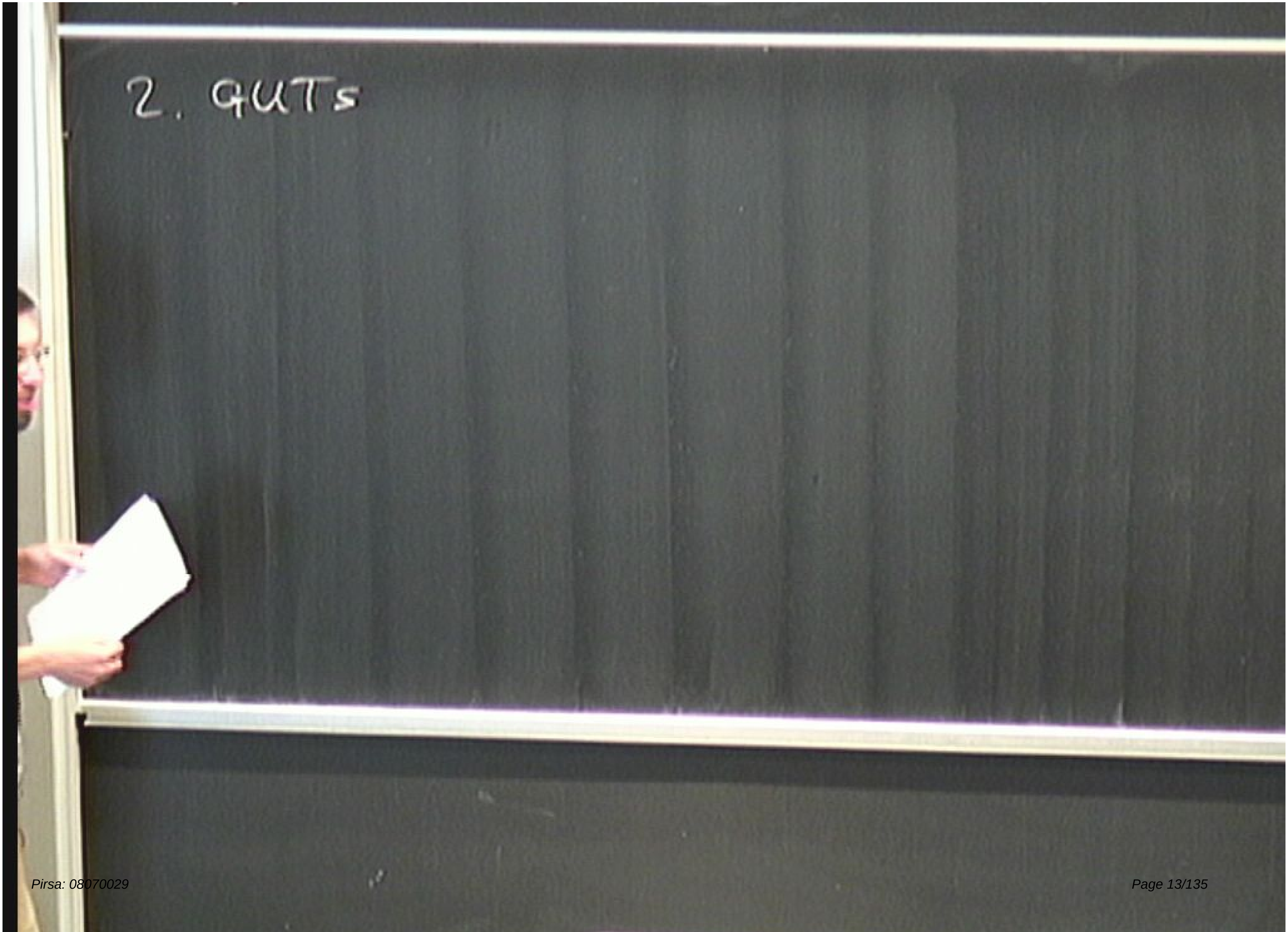
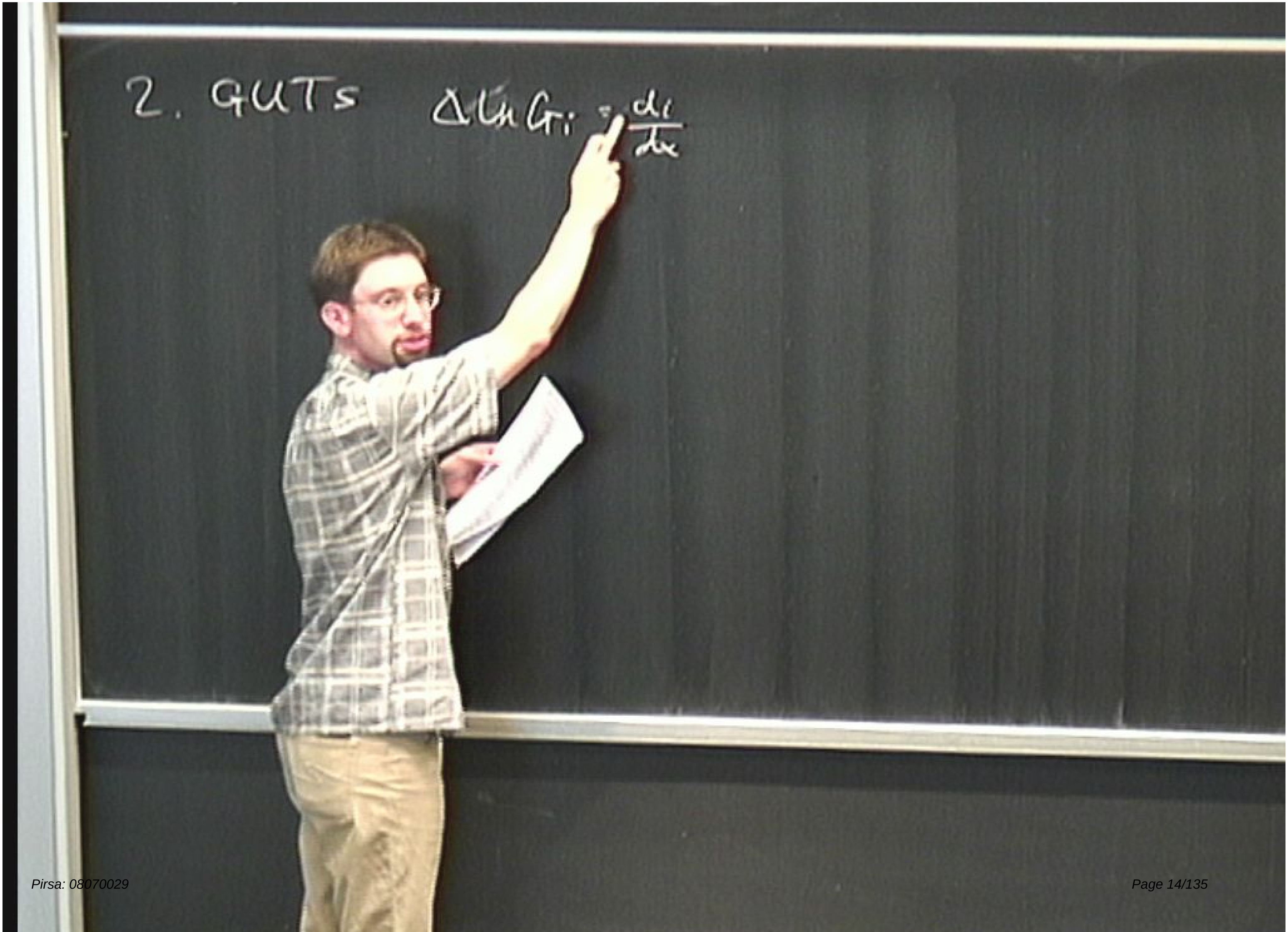

2. GUTs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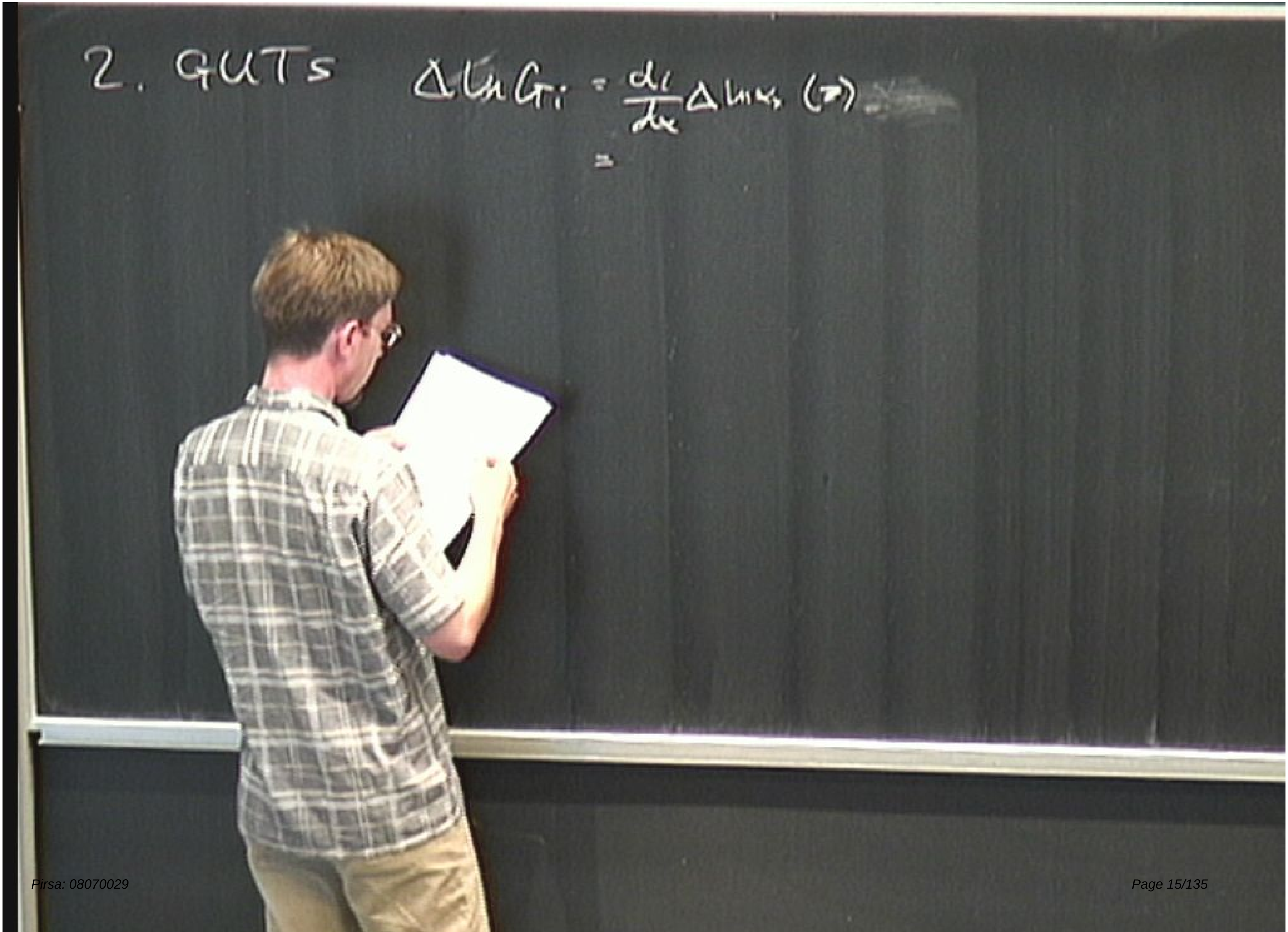
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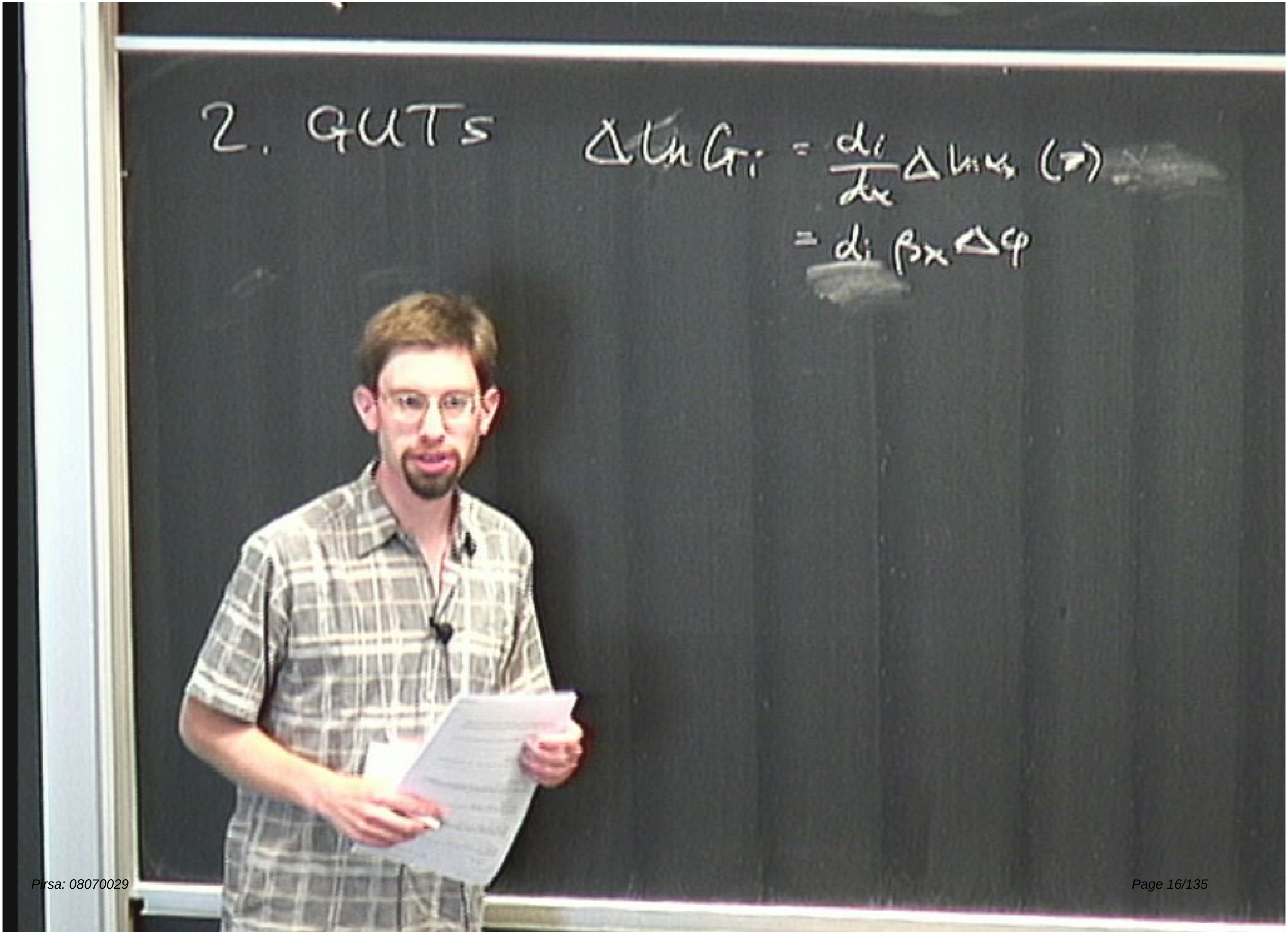
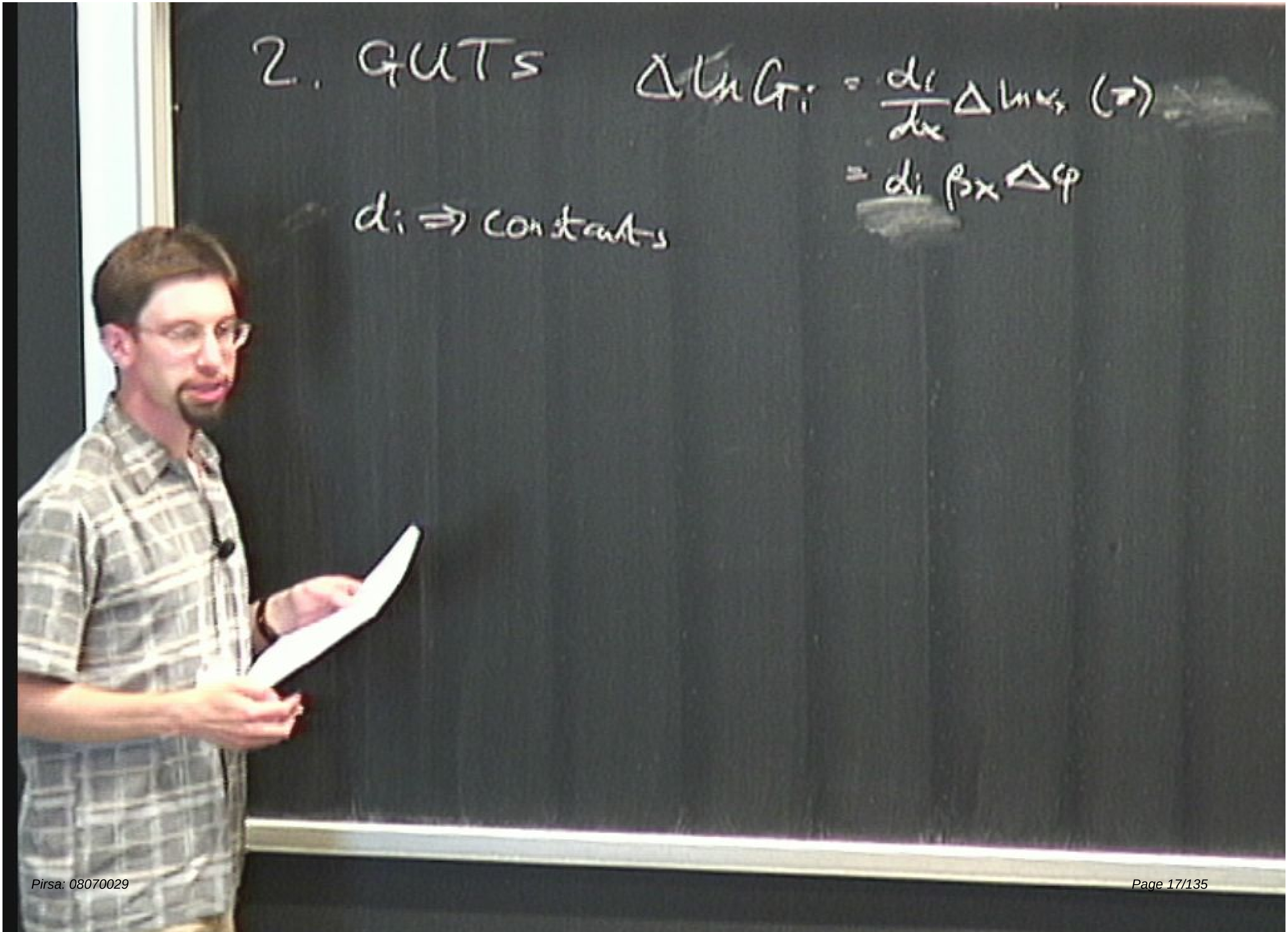

2. GUTs
Δ ln G_i = d_i/d_x Δ ln κ_x
= d_i β_x Δφ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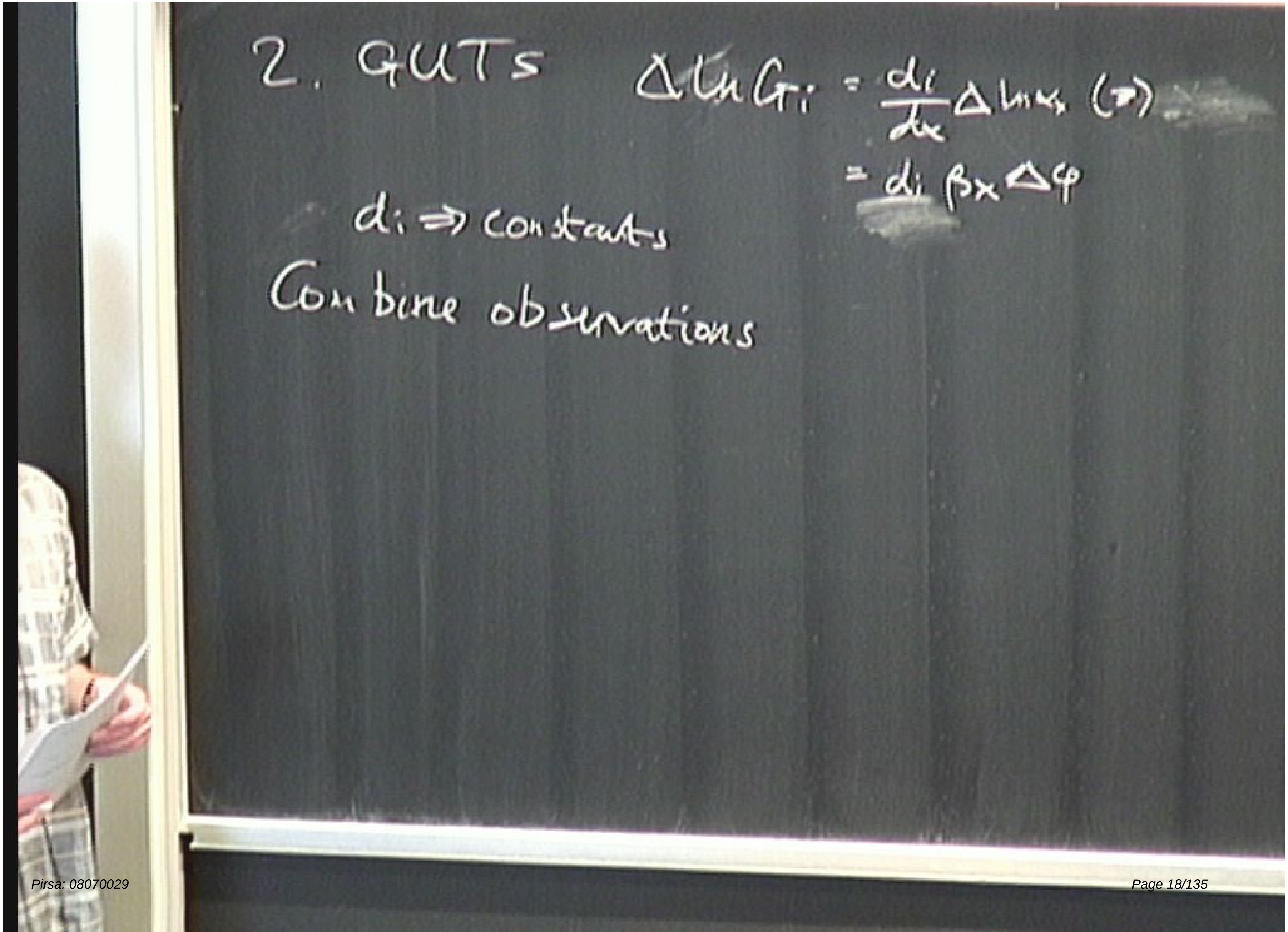
$\Delta \ln G_i = \frac{d_i}{d_x} \Delta \ln \alpha_x$ (?)
$= d_i \beta_x \Delta \varphi$
$d_i \Rightarrow$ constants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Combine observations

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$$\frac{\Delta \ln \mu}{\Delta \ln \alpha}$$

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Combine observations

$$\frac{\Delta \ln \mu}{\Delta \ln \alpha}$$

$$\frac{g'}{g}$$

Who can detect variation first?

$z < 0.8$

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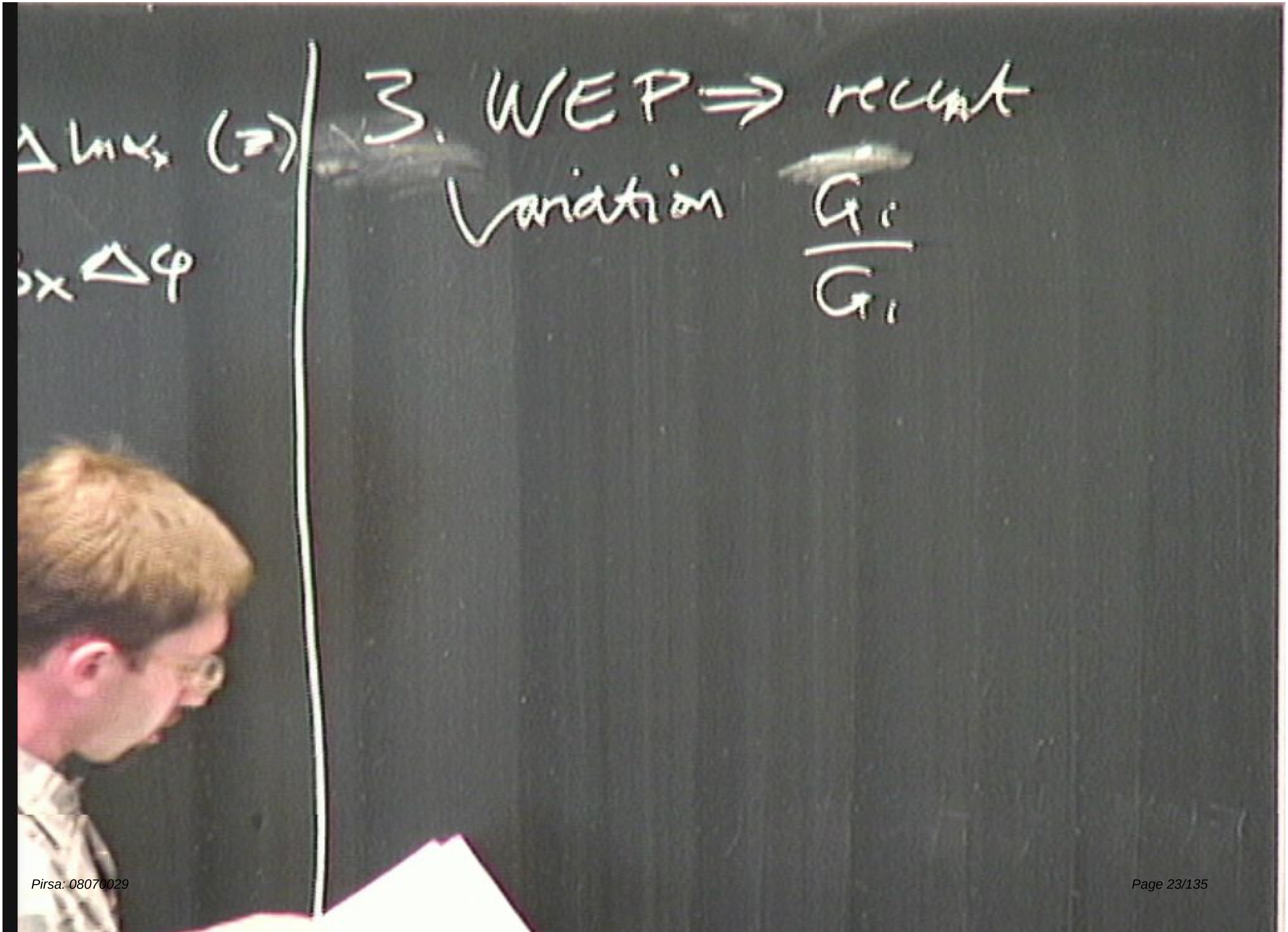
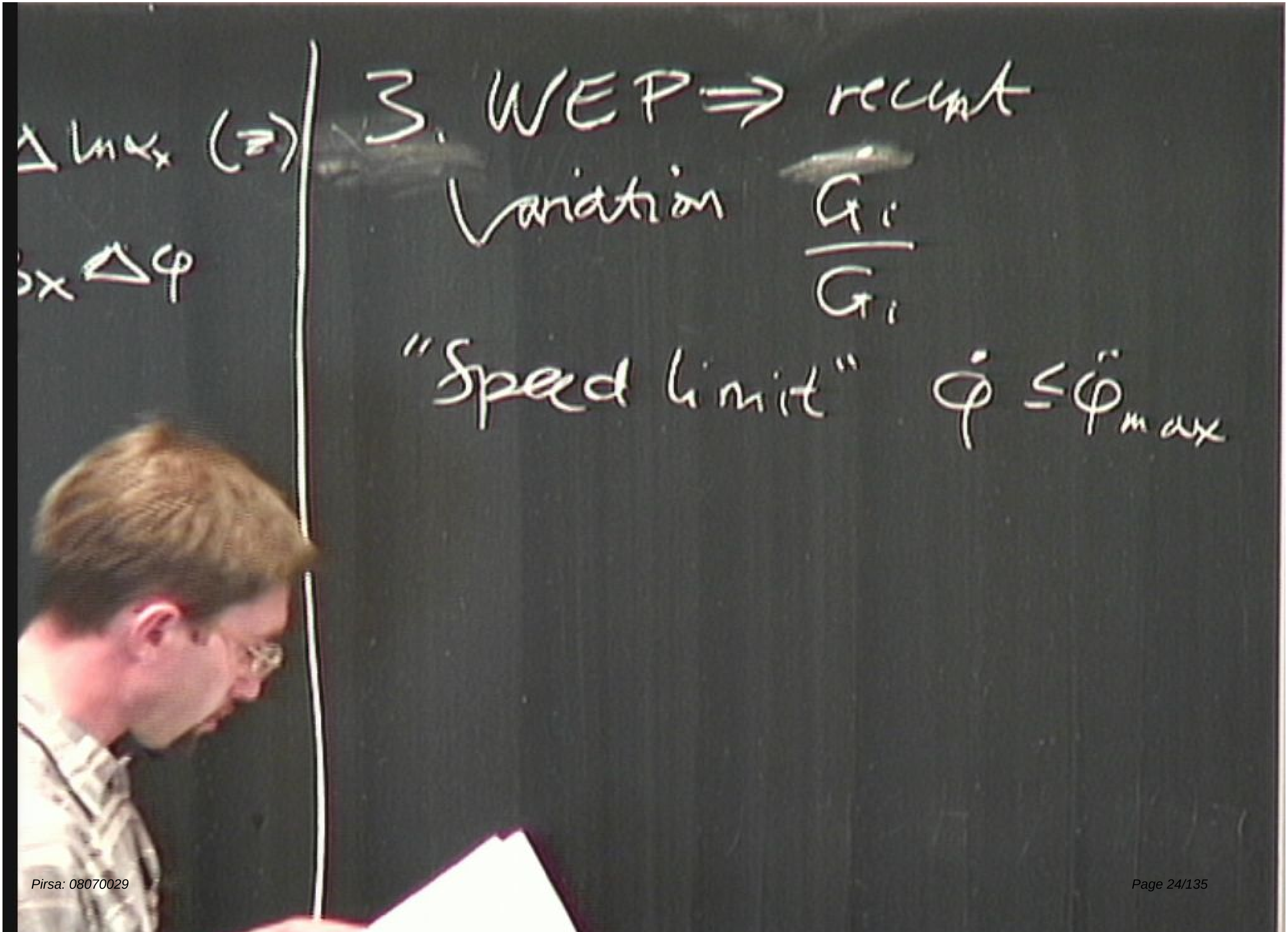
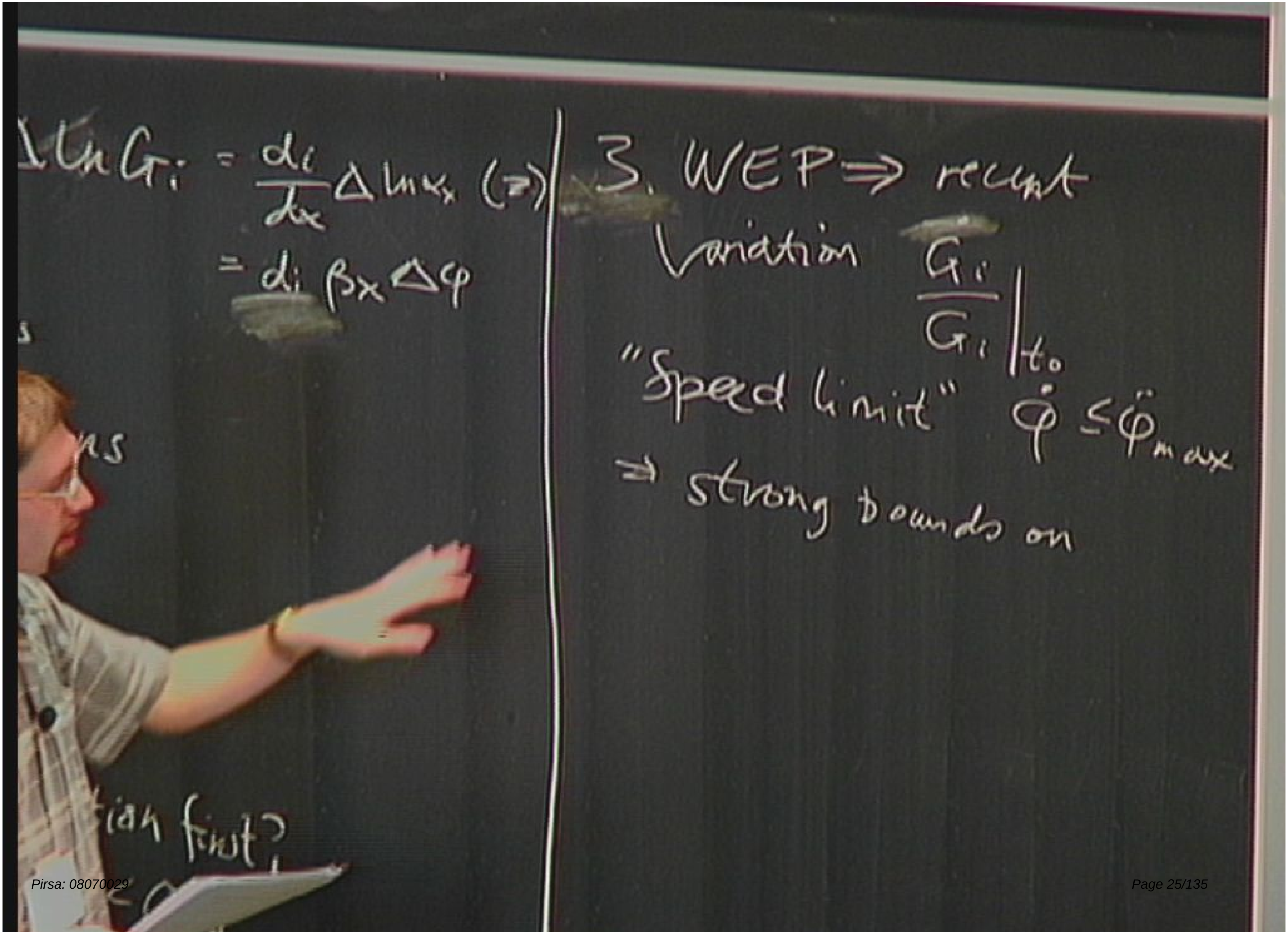

3. WEP ⇒ recent
Variation $\frac{G_i}{G_i}$


Δ ln α_x (z)
βx Δφ
3. WEP ⇒ recent
Variation Gi / Gi
"Speed limit" φ̇ ≤ φ̇max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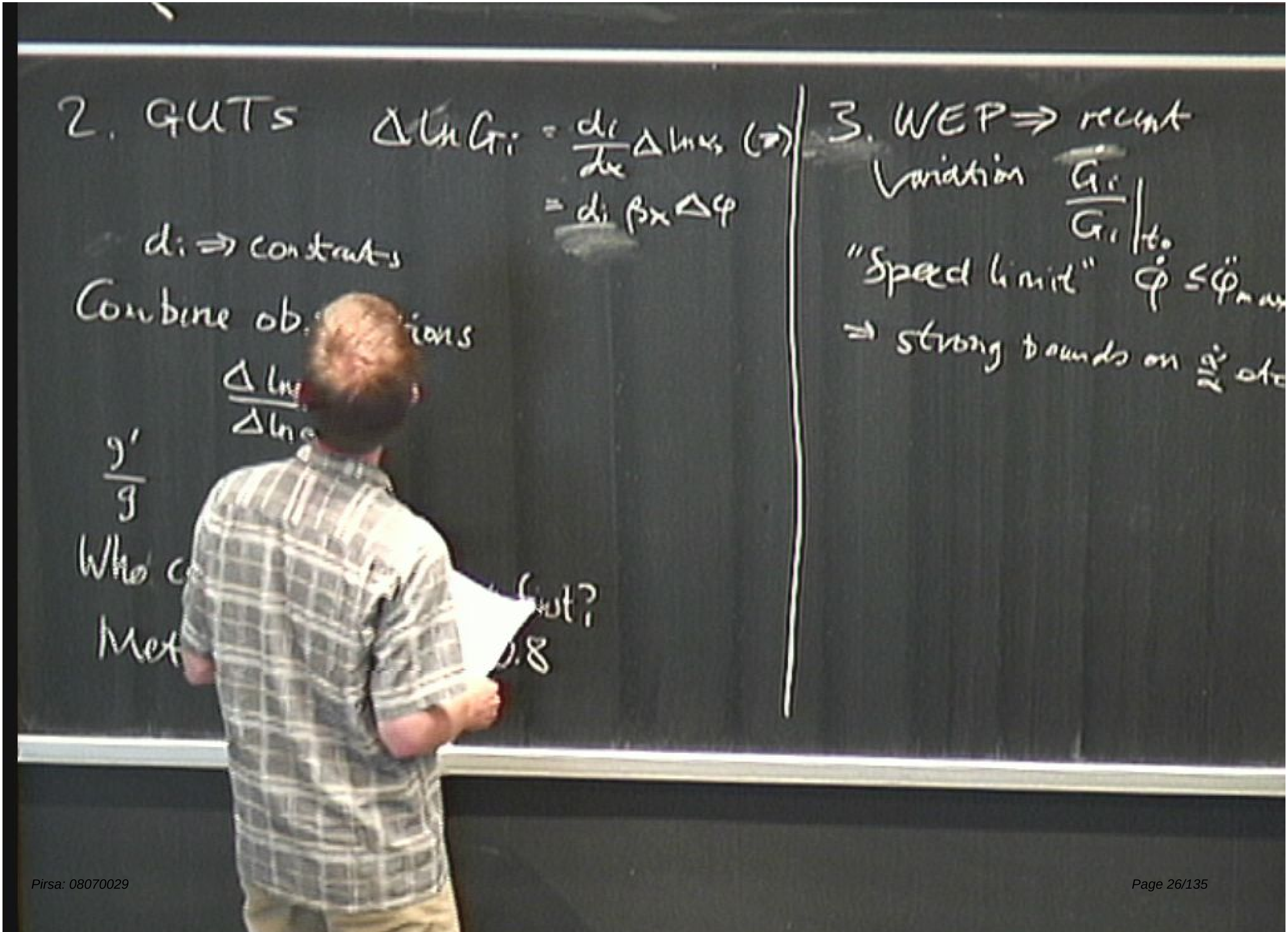
Variation $\frac{\dot{G}_i}{G_i}\Big|_{t_0}$
"Speed limit" $\dot{\varphi} \leq \dot{\varphi}_{max}$
$\Rightarrow$ strong bounds on



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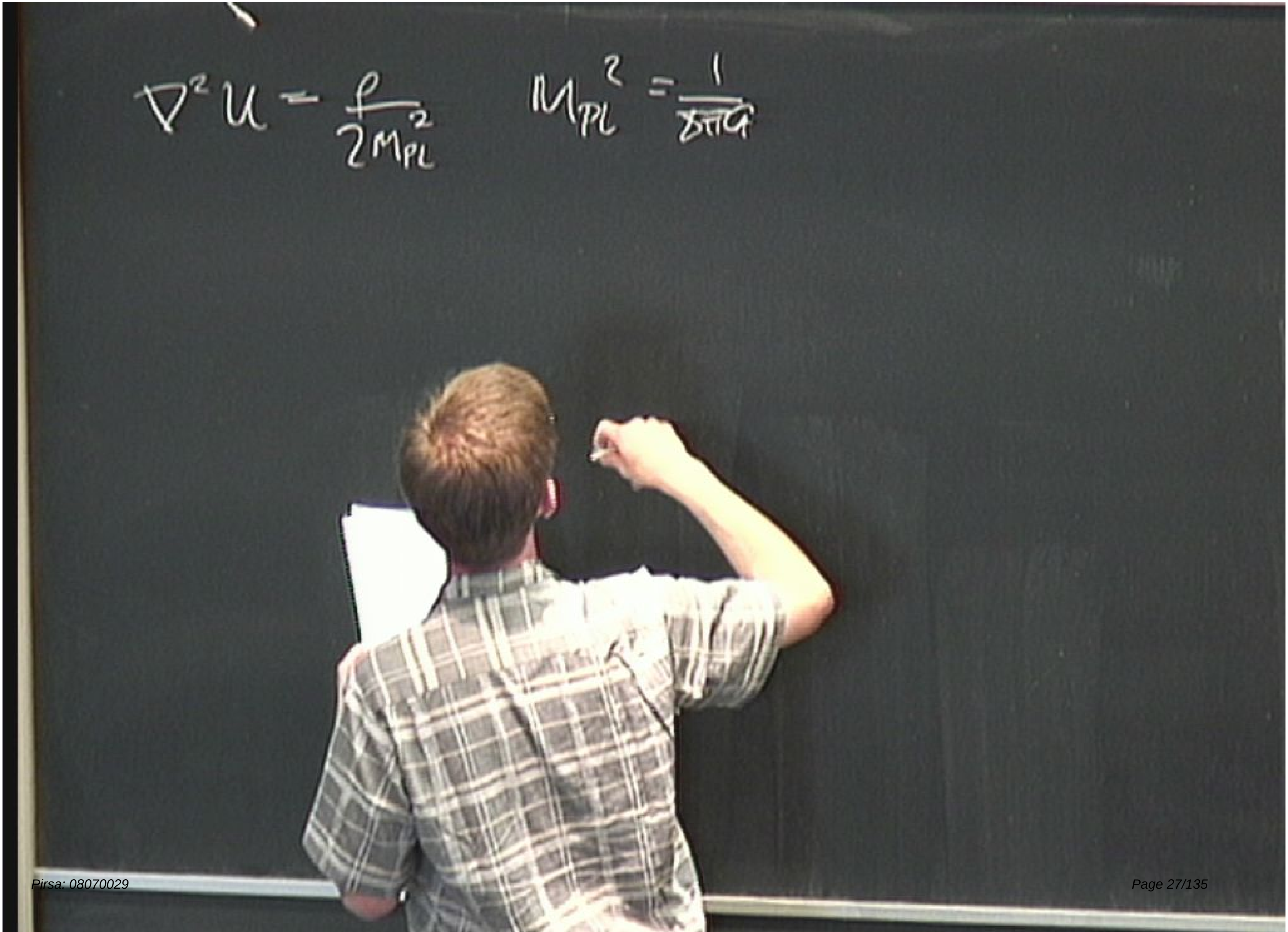
$\nabla^2 U = \frac{\rho}{2M_{PL}^2}$
$M_{PL}^2 = \frac{1}{8\pi G}$

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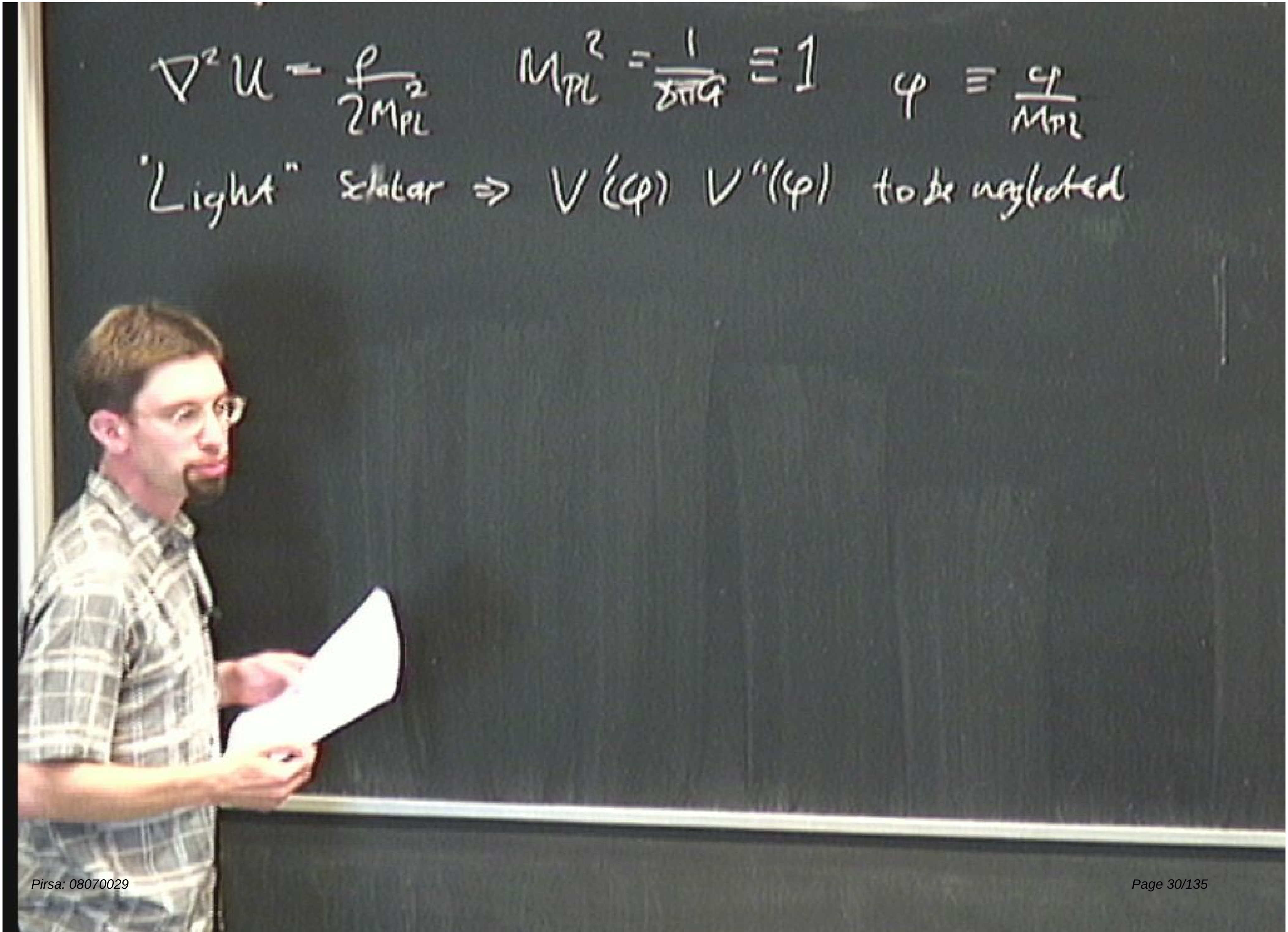
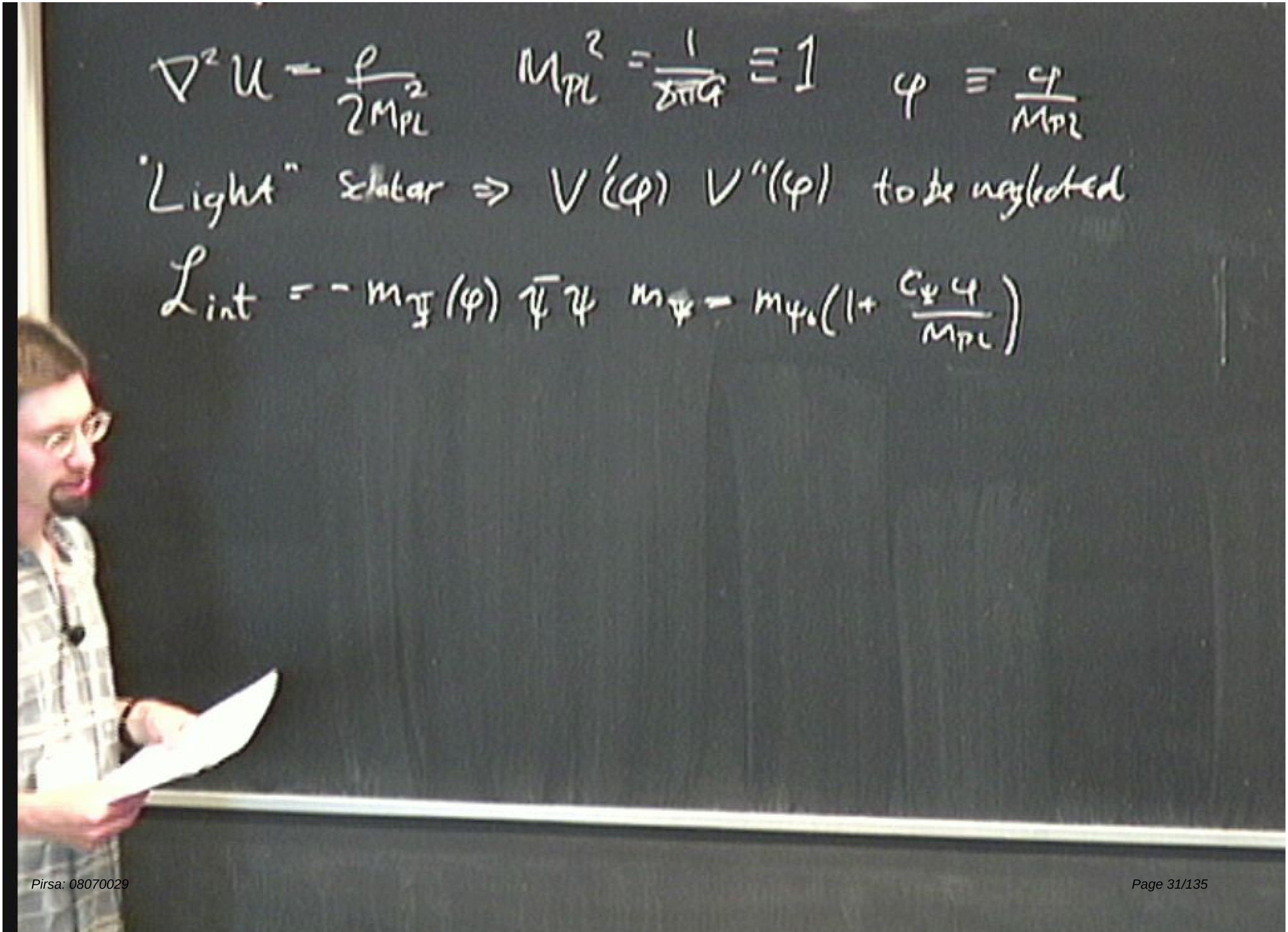

$\nabla^2 U = \frac{\rho}{2M_{Pl}^2}$ $M_{Pl}^2 = \frac{1}{8\pi G} \equiv 1$ $\varphi \equiv \frac{\varphi}{M_{Pl}}$
"Light" scalar $\Rightarrow$ $V'(\varphi)$ $V''(\varphi)$ to be neglected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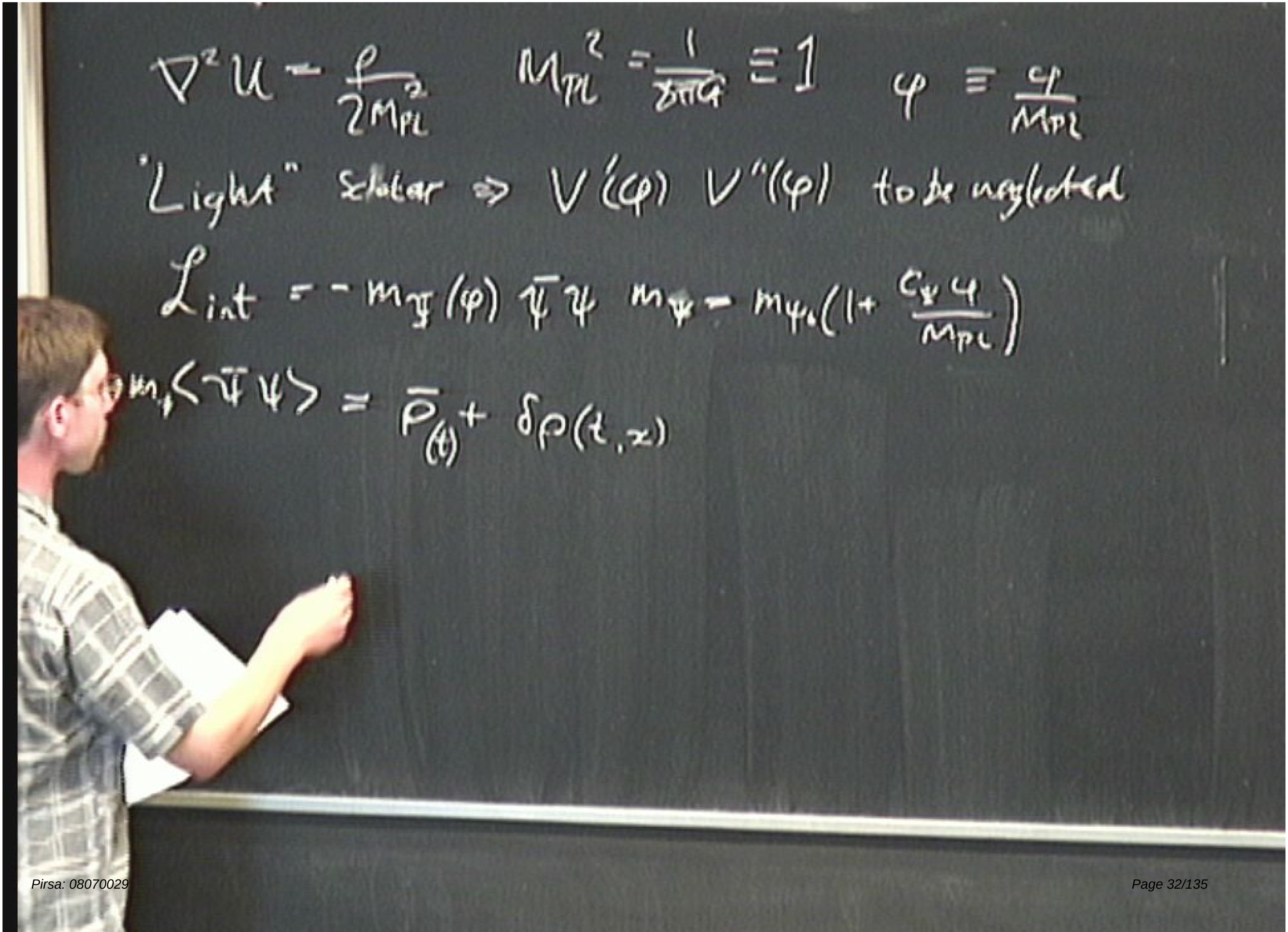
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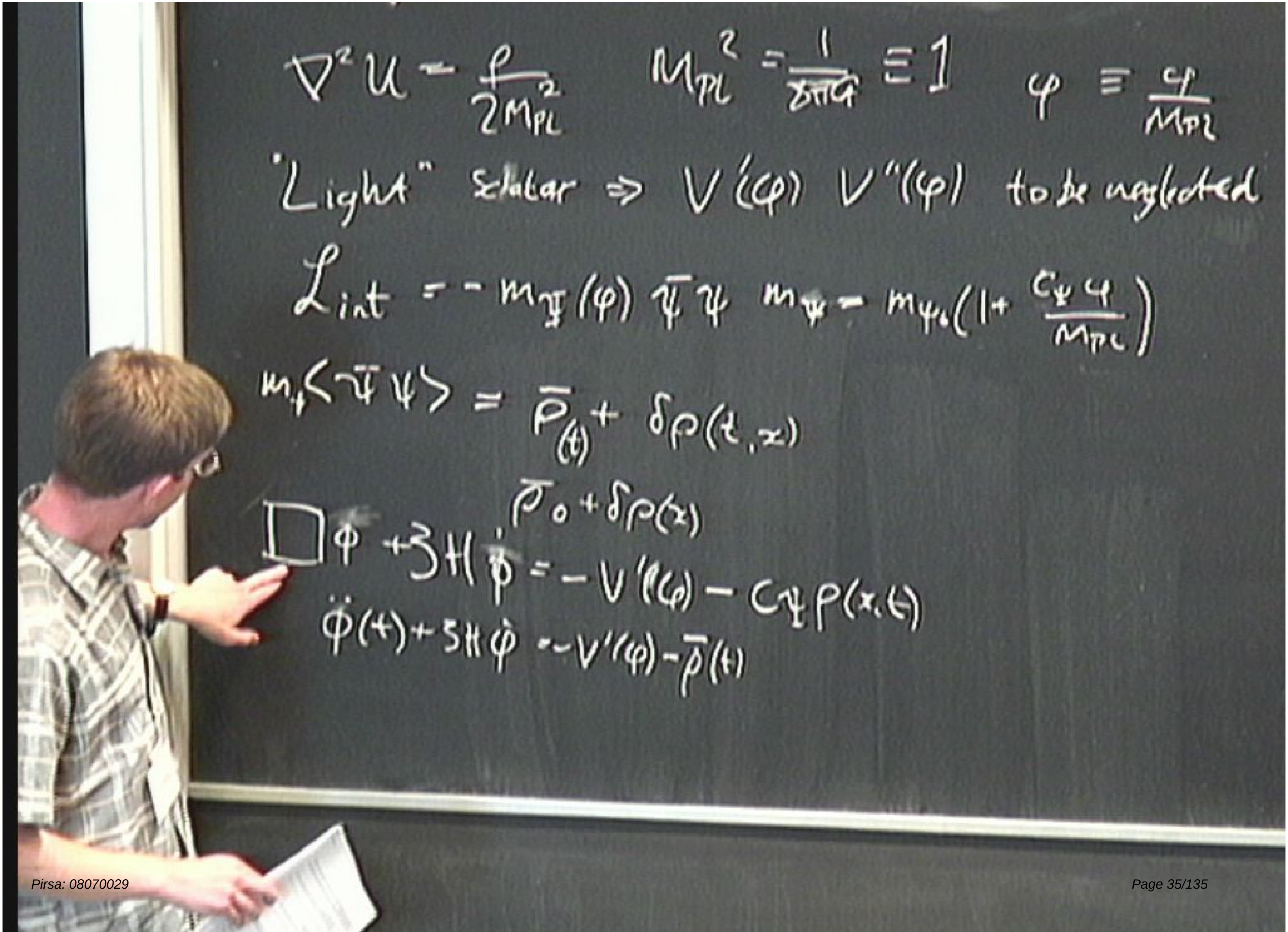
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$$m_\psi \langle \bar{\Psi}\psi \rangle = \bar{\rho}_{(t)} + \delta\rho(t, x)$$

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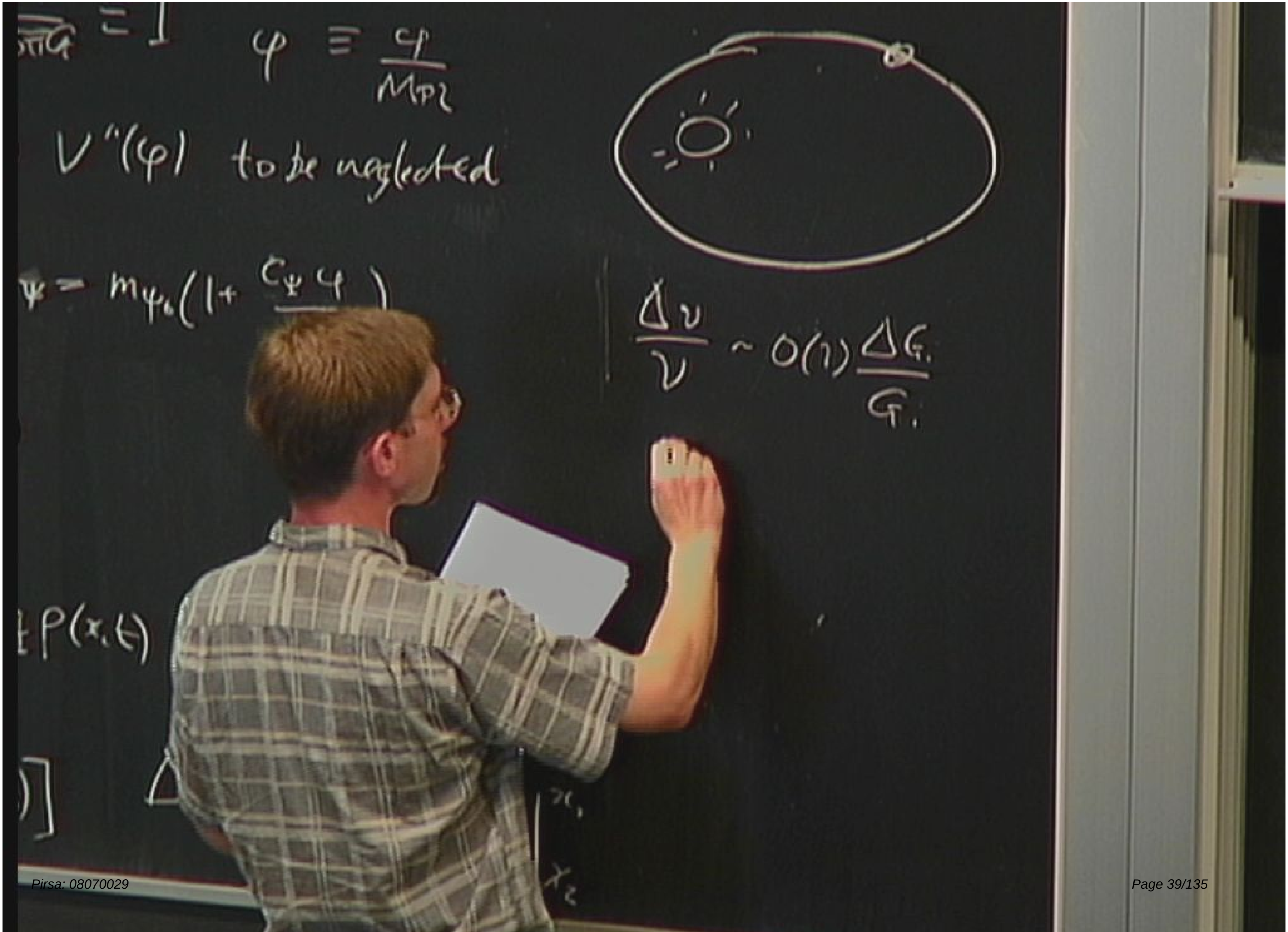
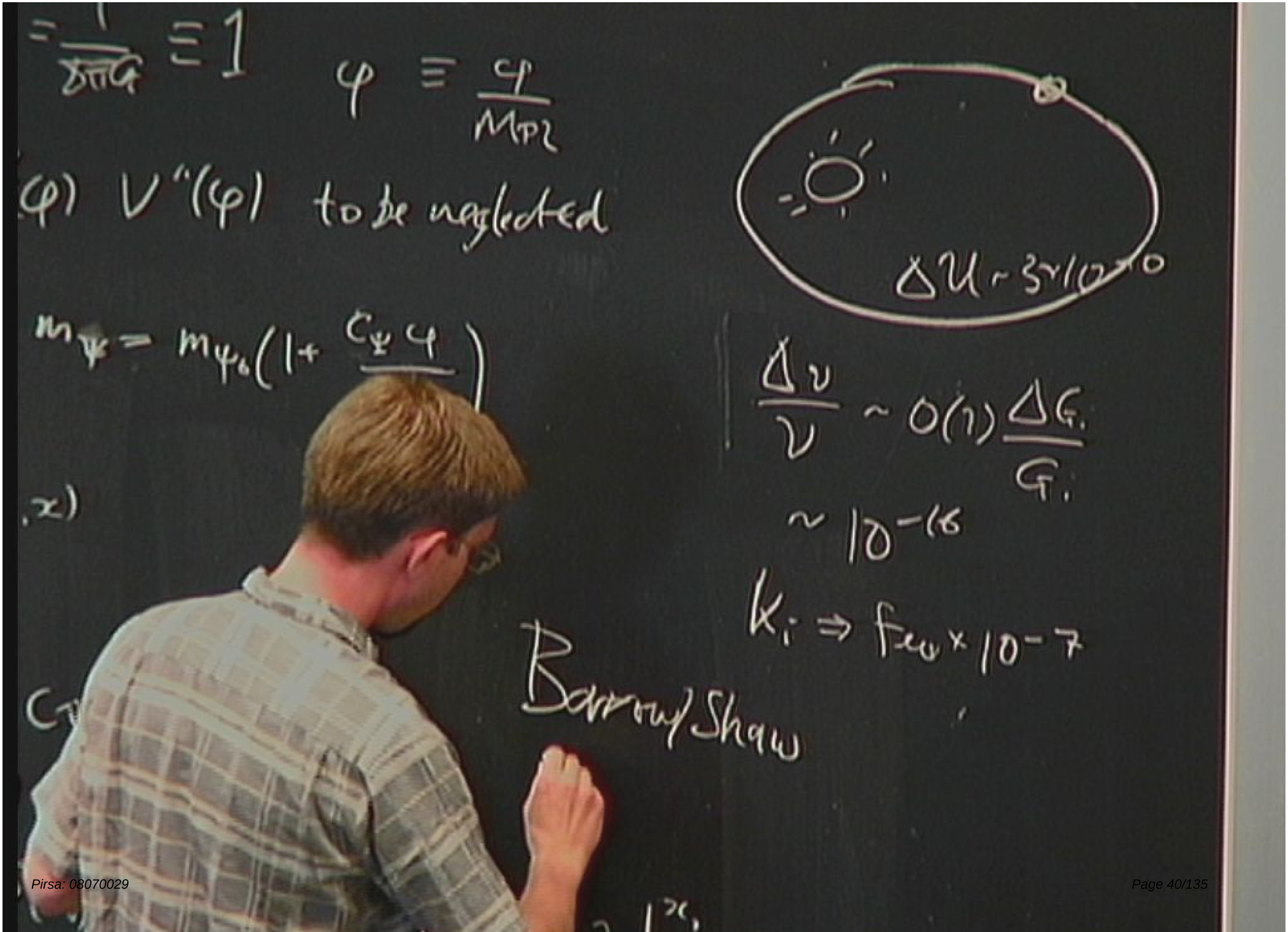
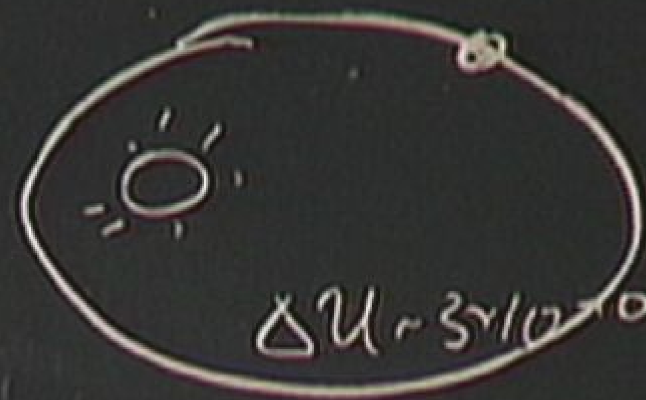

φ ≡ φ/M_Pl
V''(φ) to be neglected
m_ψ = m_ψ0(1+ c_ψ φ
Δν/ν ~ O(1) ΔG/G
ρ(x,t)



$\equiv 1$
$\varphi \equiv \frac{\varphi}{M_{Pl}}$
$V''(\varphi)$ to be neglected
$m_\psi = m_{\psi_0}(1 + \frac{C_\psi \varphi}{})$
$\Delta U \sim 3\times10^{-10}$
$\frac{\Delta \nu}{\nu} \sim O(1) \frac{\Delta G_i}{G_i}$
$\sim 10^{-16}$
$k_i \Rightarrow$ few $\times 10^{-7}$
Barrow/Shaw

$M_{Pl} \quad \frac{\quad}{8\pi G} \equiv 1] \qquad \varphi \equiv \frac{\varphi}{M_{Pl}}$



$V'(\varphi) \quad V''(\varphi)$ to be neglected

$\psi \quad m_\psi = m_{\psi_0}\left(1 + \frac{c_\psi \varphi}{M_{Pl}}\right)$

$\frac{\Delta \nu}{\nu} \sim O(1) \frac{\Delta G_{\cdot}}{G_{\cdot}}$

(t, x)

$\sim 10^{-16}$

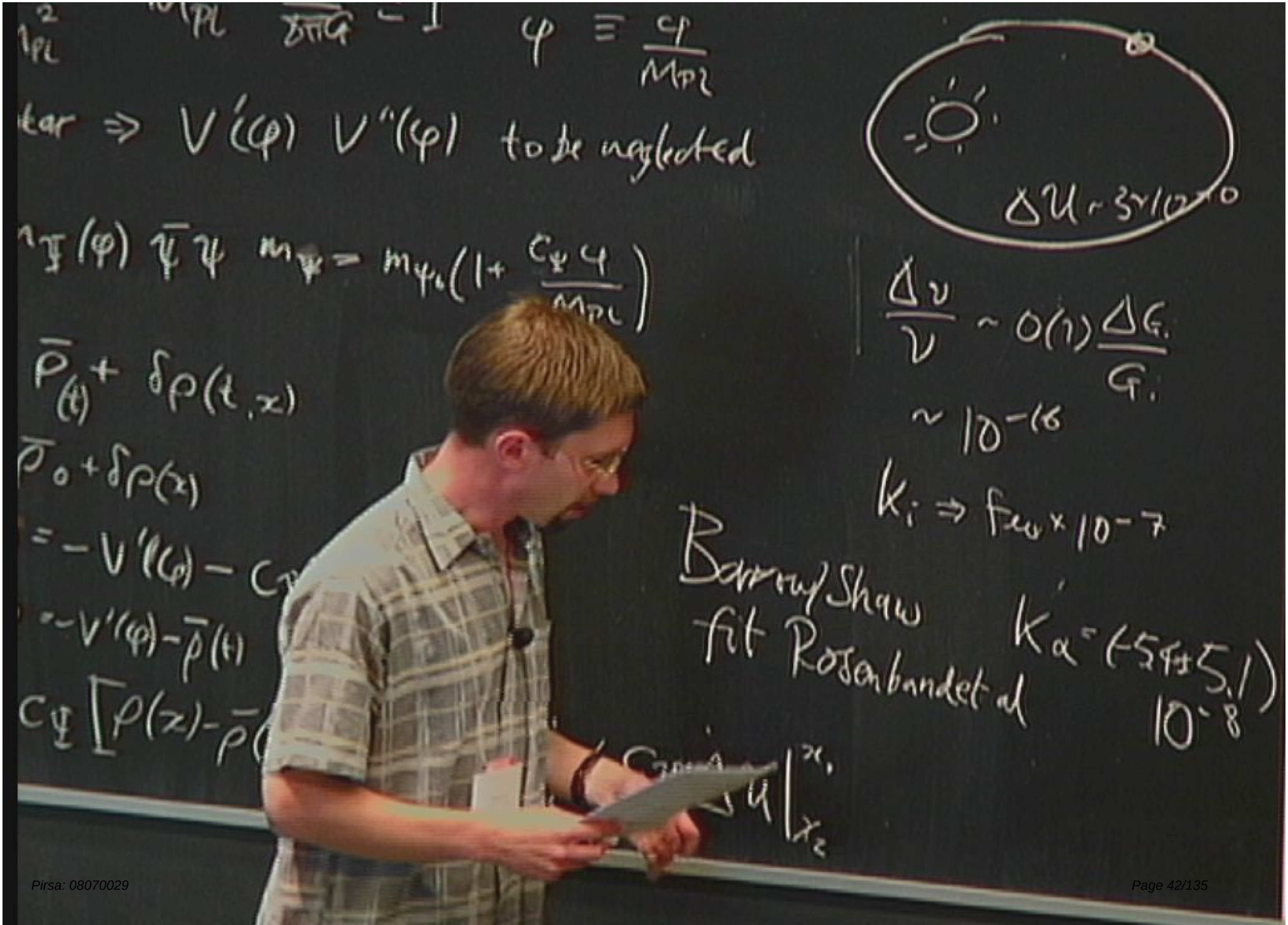
$k_i \Rightarrow f_{e\omega} \times 10^{-7}$

Barrow/Shaw

fit Rosenband et al

$c_\psi \rho(x, t)$

$(t_0)] \qquad \Delta\varphi\Big|_{x_2}^{x_1} \propto c_\psi \Delta U\Big|_{x_2}^{x_1}$


to be neglected
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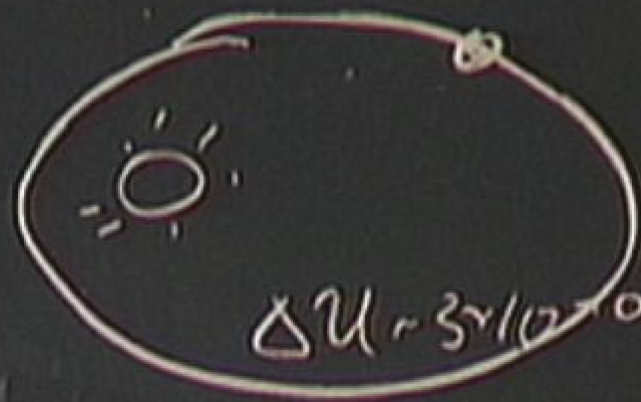
$= \frac{1}{8\pi G} \equiv 1]$ $\quad \varphi \equiv \frac{\varphi}{M_{Pl}}$



$(\varphi) \quad V''(\varphi)$ to be neglected

$m_\Psi = m_{\Psi_0}\left(1 + \frac{C_\Psi \varphi}{M_{Pl}}\right)$

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(x)

$\sim 10^{-16}$

$k_i \Rightarrow$ few $\times 10^{-7}$

Barrow/Shaw

$C_\Psi \rho(x,t)$

fit Rosenband et al $\quad k_\alpha = (-5.4 \pm 5.1)\; 10^{-8}$

$(t_0)] \quad \Delta\varphi \Big|_{x_2}^{x_1} \propto C_\Psi \Delta U \Big|_{x_2}^{x_1}$ $\Big|\; k_\mu$ few $\times 10^{-6}$

k_e

M_{Pl}

$(\varphi)\ V''(\varphi)$ to be neglected

$\Delta \mathcal{U} \sim 3 \times 10^{-10}$

$m_\Psi = m_{\Psi_0}\left(1 + \frac{c_\Psi \varphi}{M_{Pl}}\right)$

$\frac{\Delta \nu}{\nu} \sim O(1) \frac{\Delta G_i}{G_i}$

$\sim 10^{-16}$

$x)$

$k_i \Rightarrow$ few $\times 10^{-7}$

Barrow/Shaw

$c_\Psi \rho(x,t)$

fit Rosenband et al

$k_\alpha = (-5.4 \pm 5.1)$

10^{-8}

$(t_0)]$

$\Delta\varphi \Big|_{x_2}^{x_1} \propto c_\Psi \Delta \mathcal{U} \Big|_{x_2}^{x_1}$

k_μ few $\times 10^{-6}$

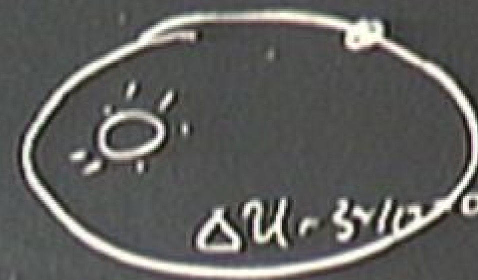
k_q

m_e

$$\rho(r_0)\,] \qquad \Delta\varphi\,\big|_{x_c} \propto C$$

$$k_q \Rightarrow \frac{m_q}{\Lambda_{QCD}} \qquad m_q = \frac{m_u + m_d}{2}$$

$\nabla^2 U = \frac{\rho}{2 M_{Pl}^2}$ $\quad M_{Pl}^2 = \frac{1}{8\pi G} \equiv 1$ $\quad \varphi \equiv \frac{\varphi}{M_{Pl}}$



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$\nabla^2\varphi = c_\Psi\left[\rho(x) - \bar{\rho}(t_0)\right]$ $\quad \Delta\varphi\Big|_{x_2}^{x_1} \propto c_\Psi\,\Delta U\Big|_{x_2}^{x_1}$

$\frac{\Delta\nu}{\nu} \sim O(1)\,\frac{\Delta G_i}{G_i}$

$\sim 10^{-16}$

$k_i \Rightarrow$ few $\times 10^{-7}$

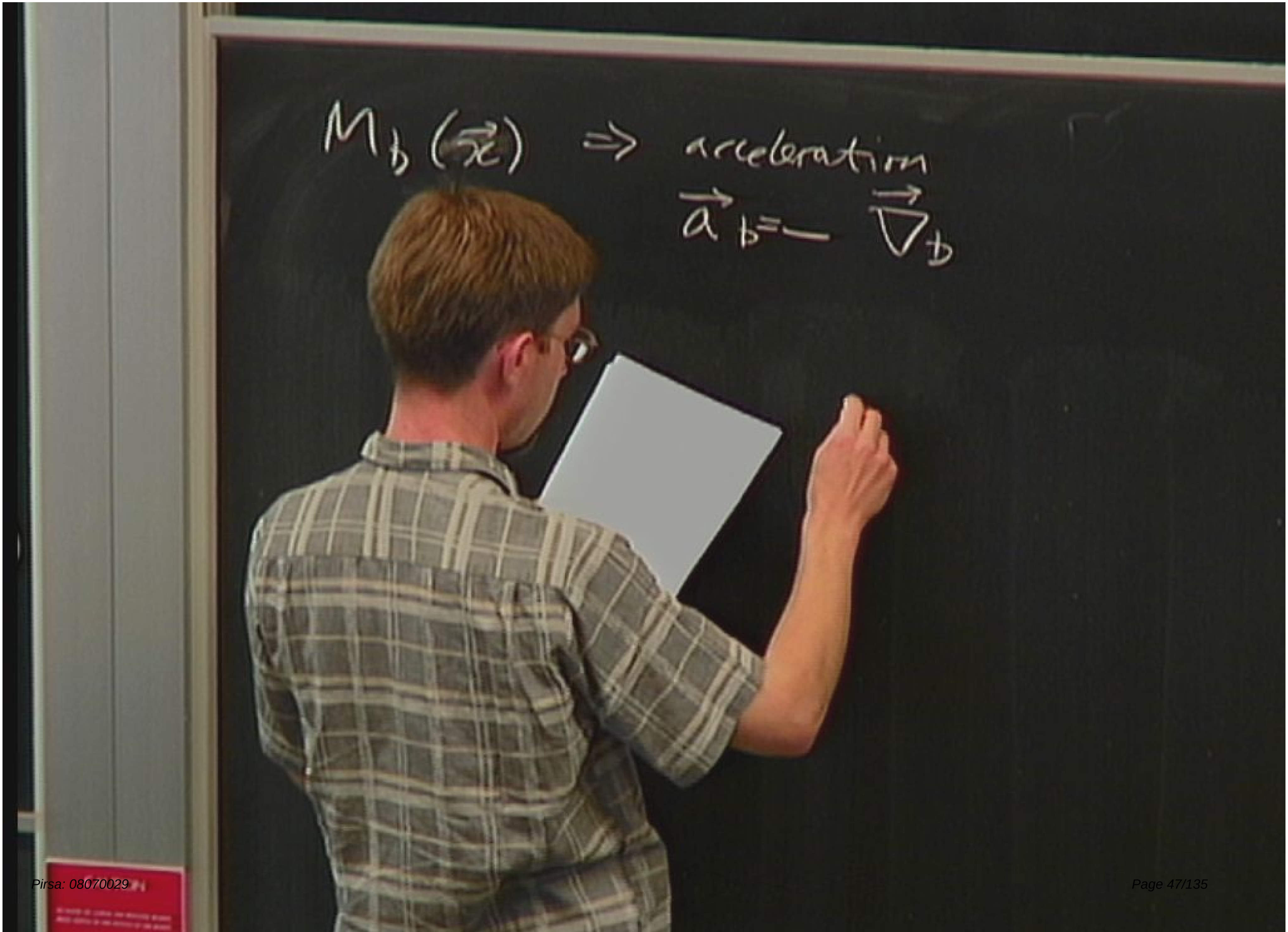
Barrow/Shaw $\quad k_\alpha = (-5.4 \pm 5.1)$

fit Rosenband et al $\quad 10^{-8}$

k_μ few $\times 10^{-6}$

k_q 10^{-5}

$k_q \to \frac{m_q}{\Lambda_{QCD}}$ $\quad m_q = \frac{m_u + m_d}{2}$


$M_b(\vec{x}) \Rightarrow$ acceleration
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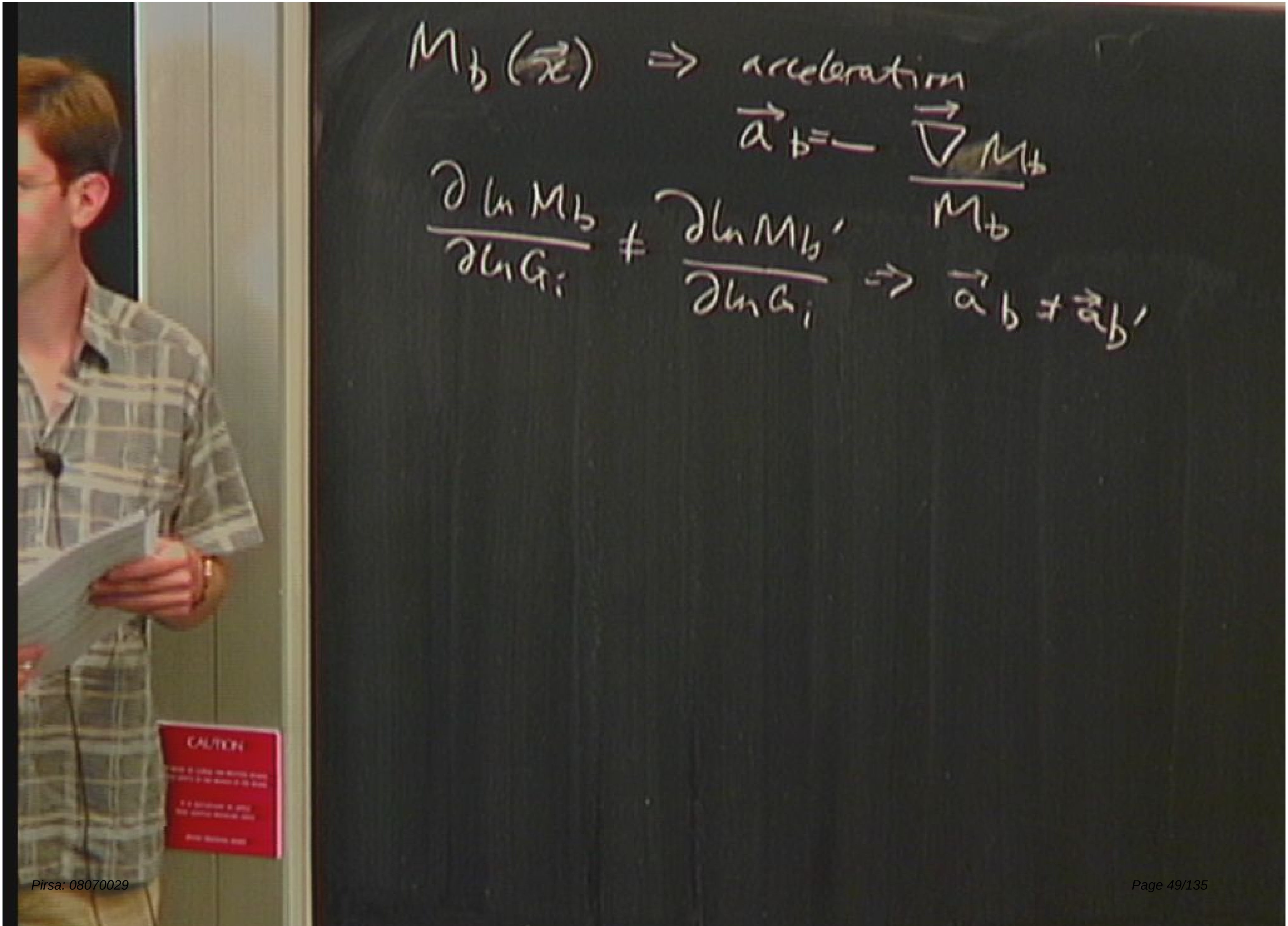
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CAUTION

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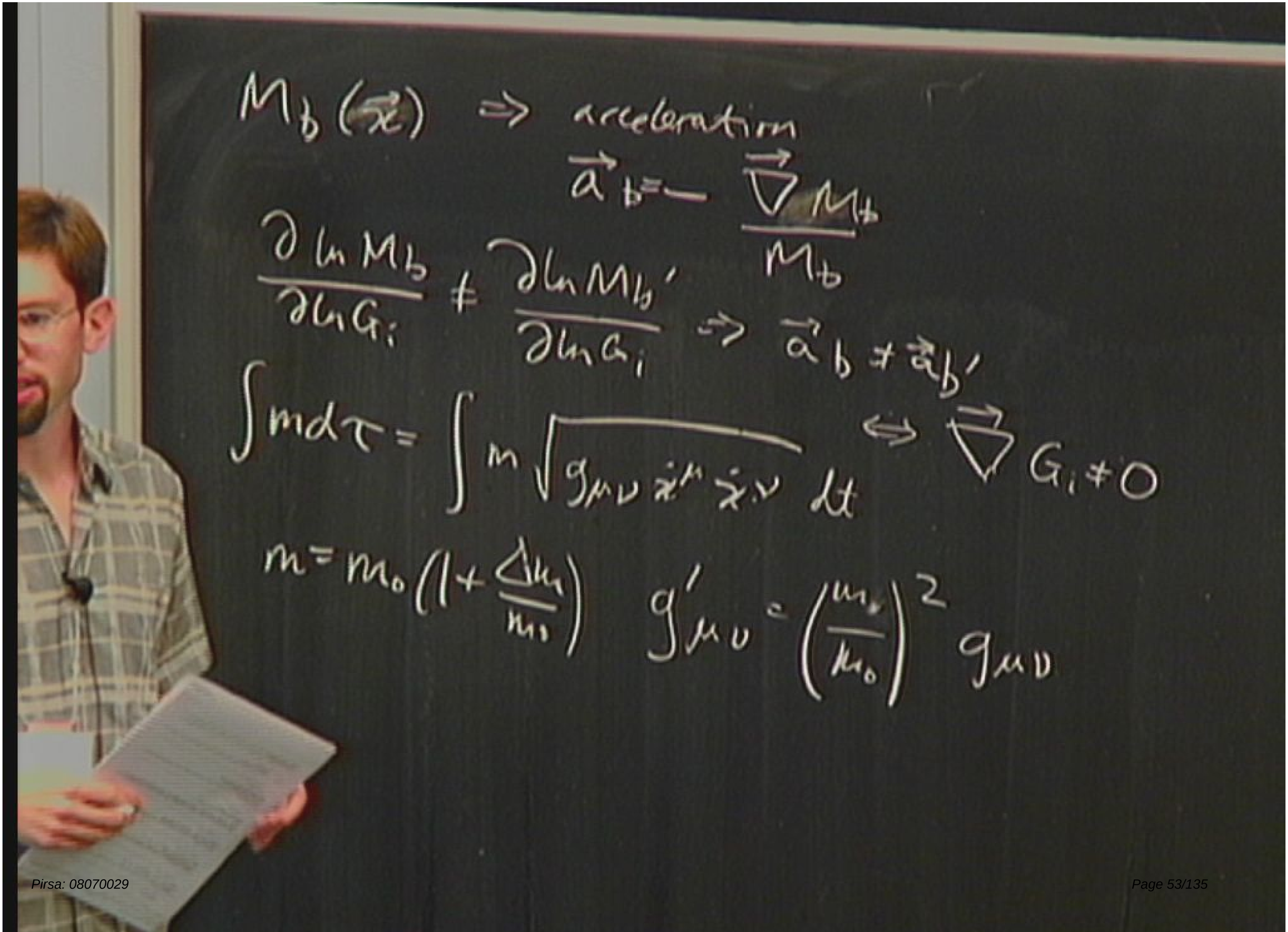
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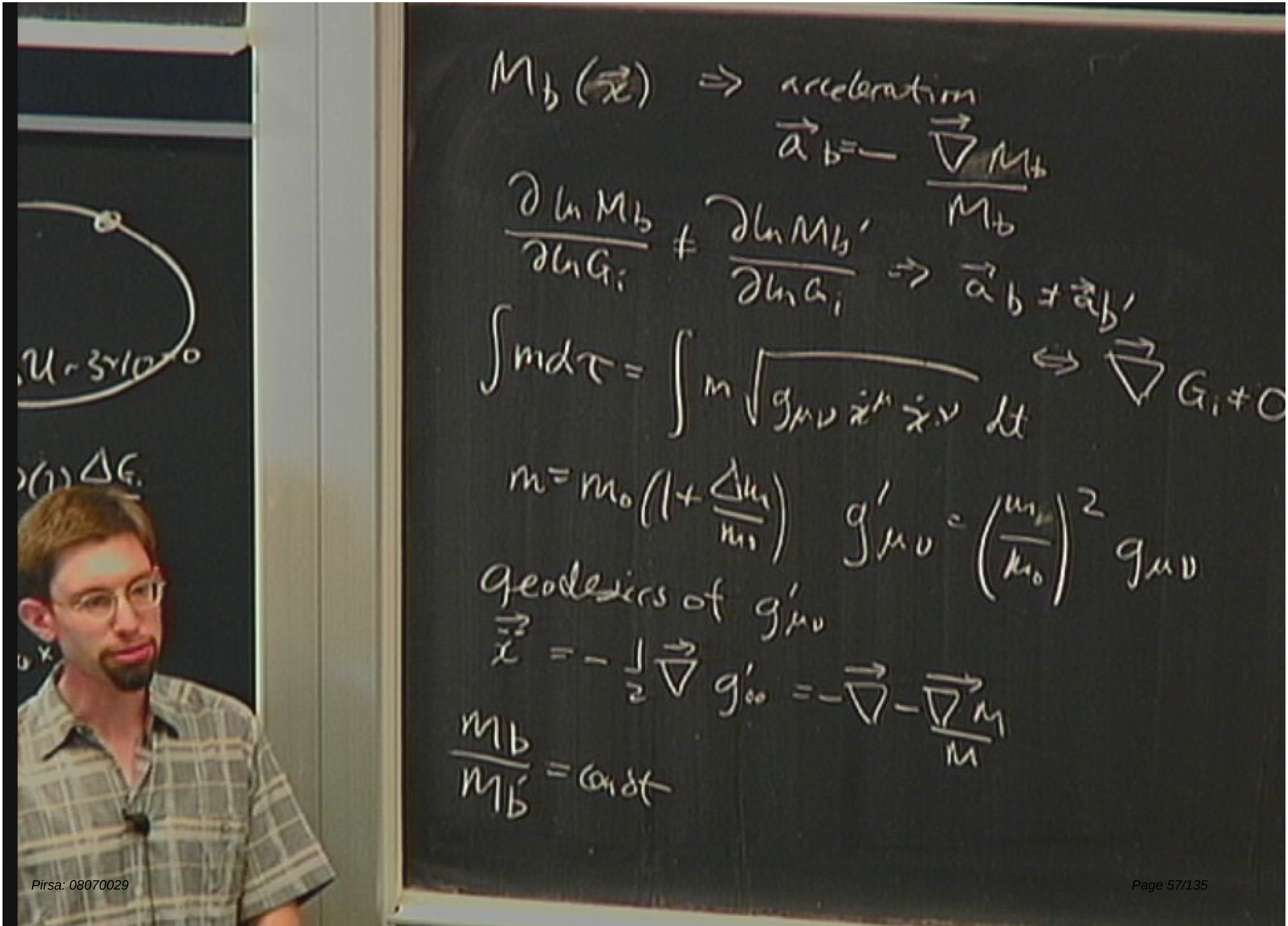

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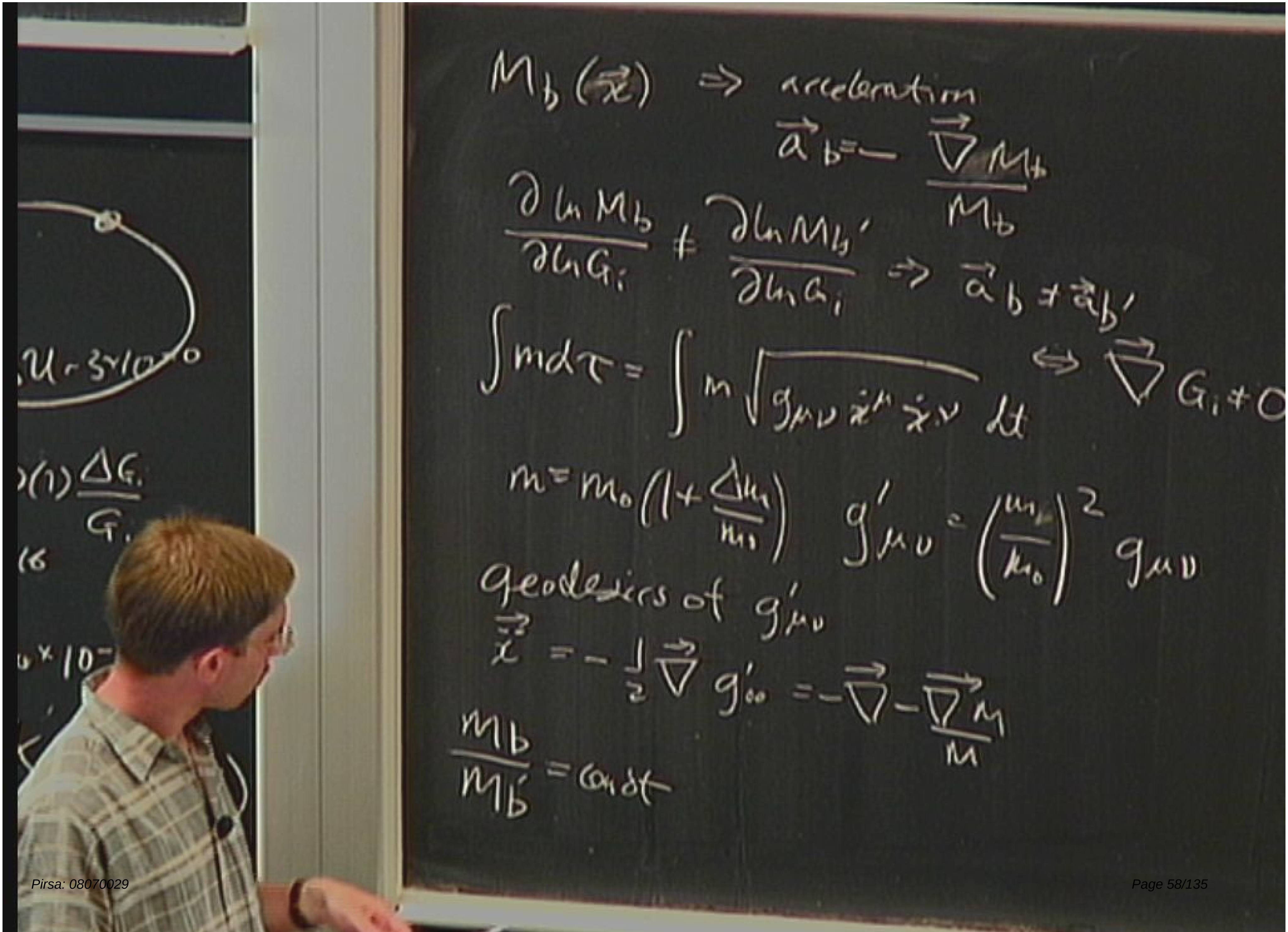
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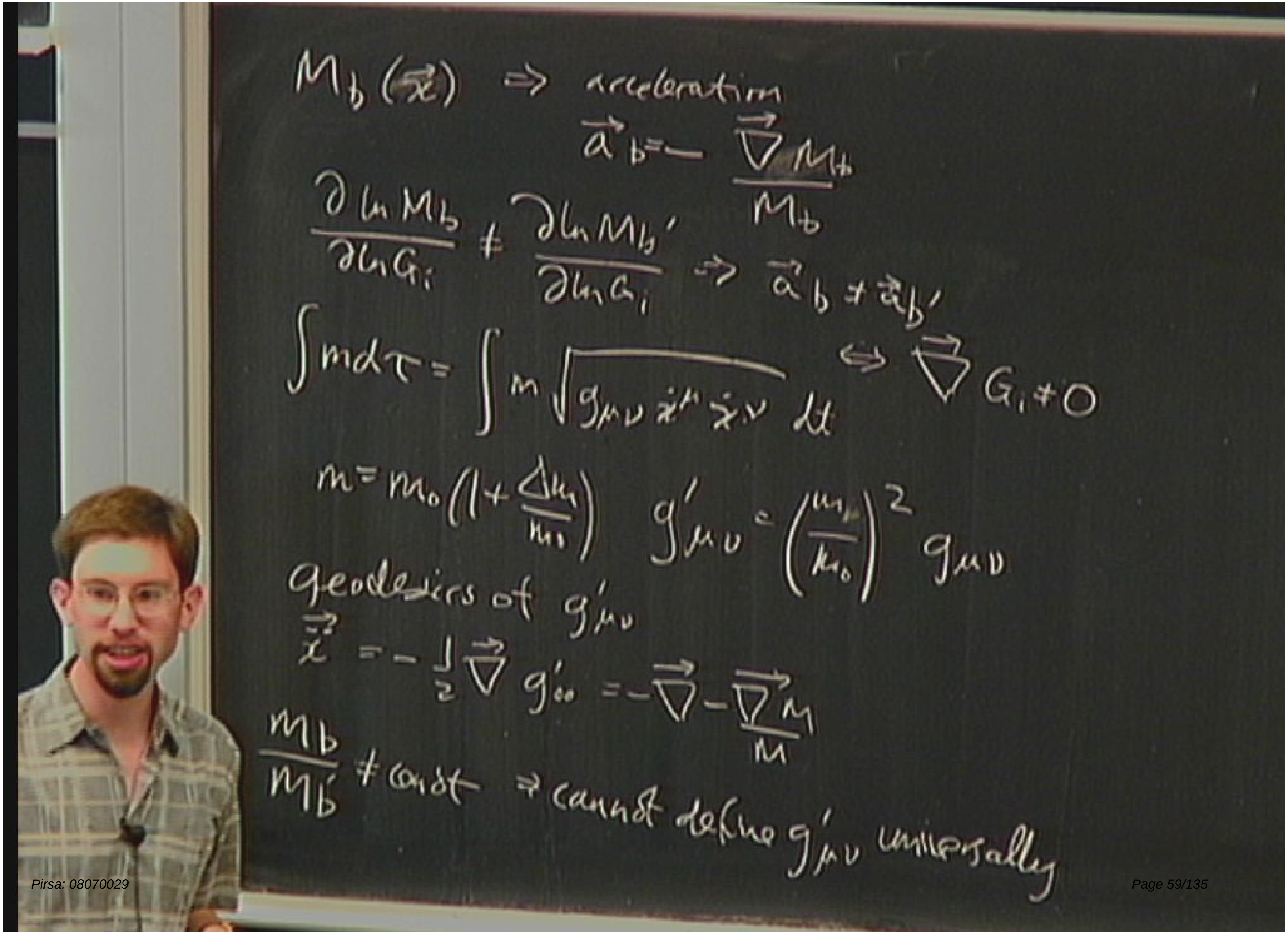
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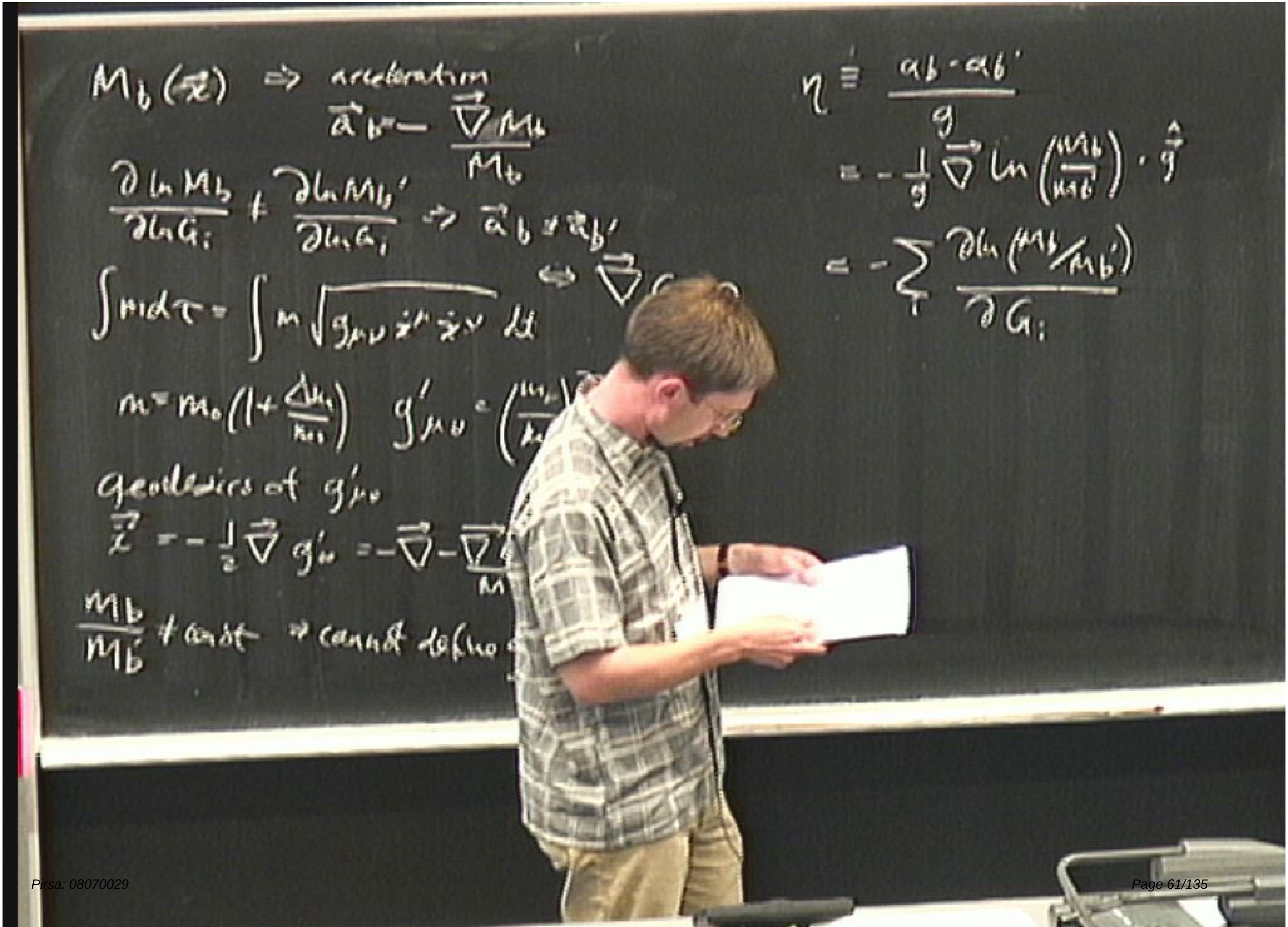
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$$\vec{\nabla}$$

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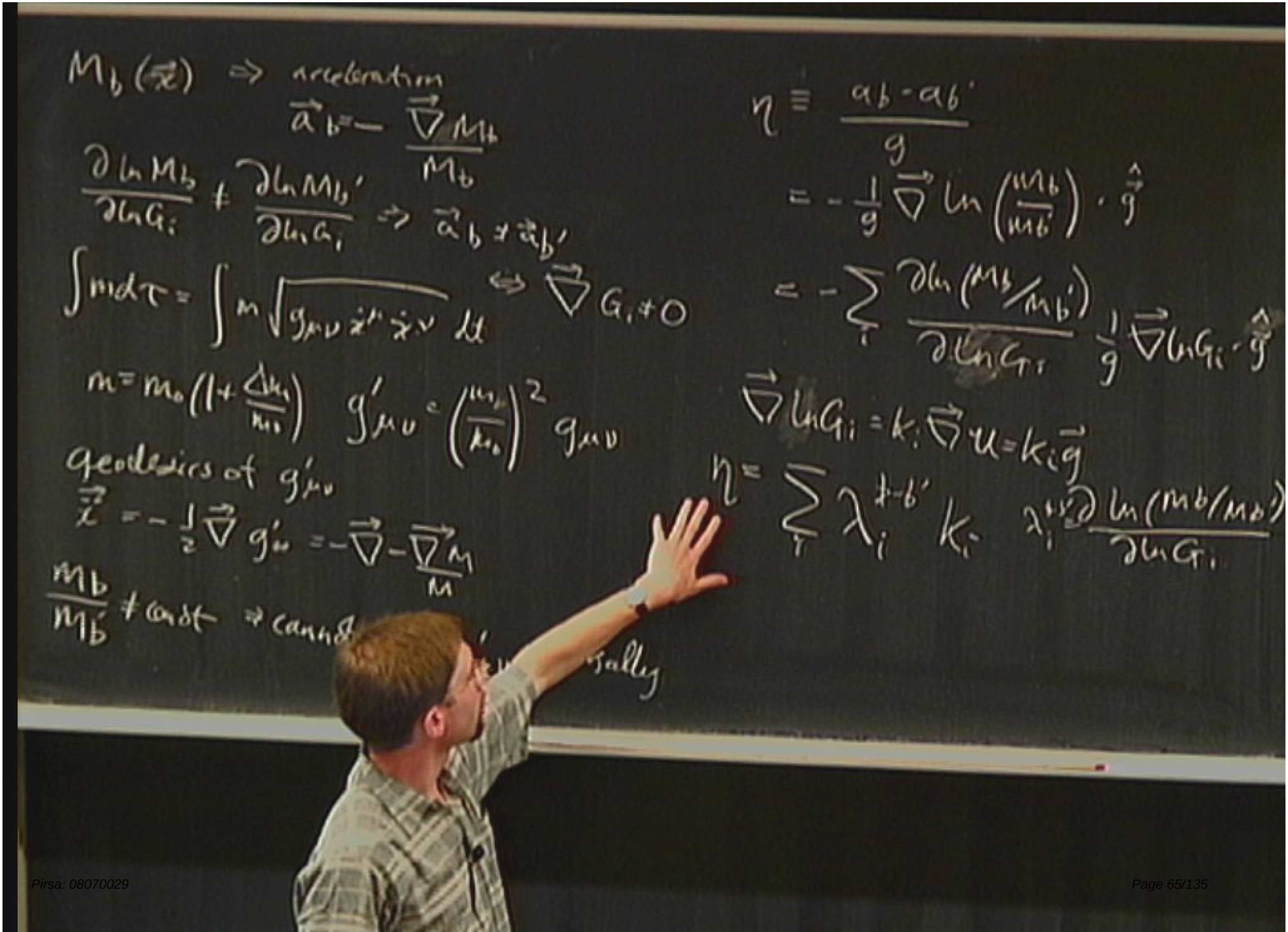

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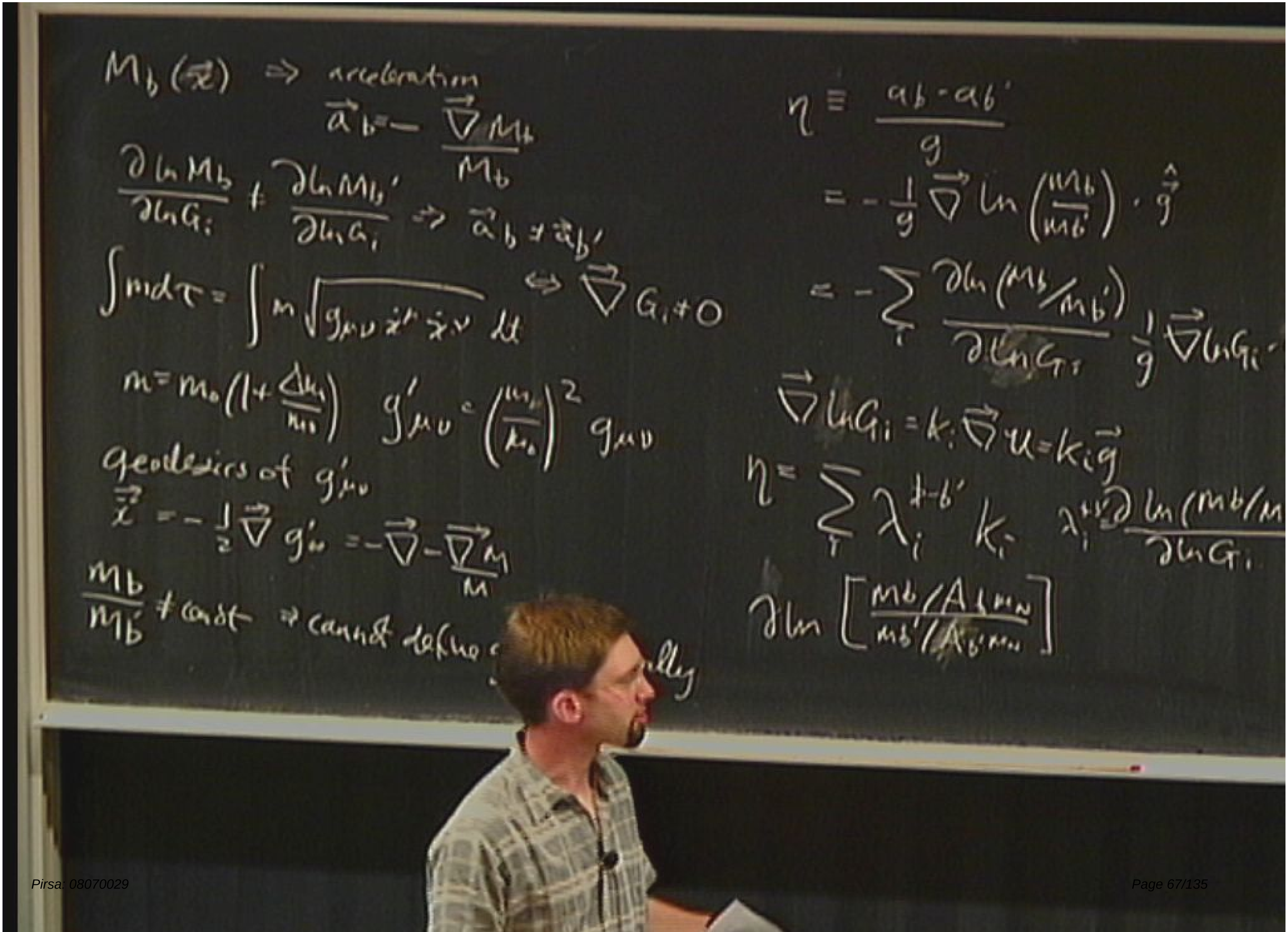
M_b (x) ⇒ acceleration
a_b = − ∇M_b / M_b
∂ ln M_b / ∂ ln G_i ≠ ∂ ln M_b' / ∂ ln G_i ⇒ a_b ≠ a_b'
∫ m dτ = ∫ m √(g_μν ẋ^μ ẋ^ν) dt ⇔ ∇G_i ≠ 0
m = m_0 (1 + Δm/m_0)   g'_μν = (m/m_0)^2 g_μν
geodesics of g'_μν
ẍ = − 1/2 ∇ g'_00 = − ∇ − ∇m / m
m_b / m_b' ≠ const ⇒ cannot define
η ≡ (a_b − a_b') / g
= − 1/g ∇ ln (m_b / m_b') · ĝ
= − Σ_i ∂ ln (m_b / m_b') / ∂ ln G_i · 1/g ∇ ln G_i
∇ ln G_i = k_i ∇U = k_i g
η = Σ_i λ_i^{b−b'} k_i
∂ ln [(m_b / A_b m_N) / (m_b' / A_b' m_N)]

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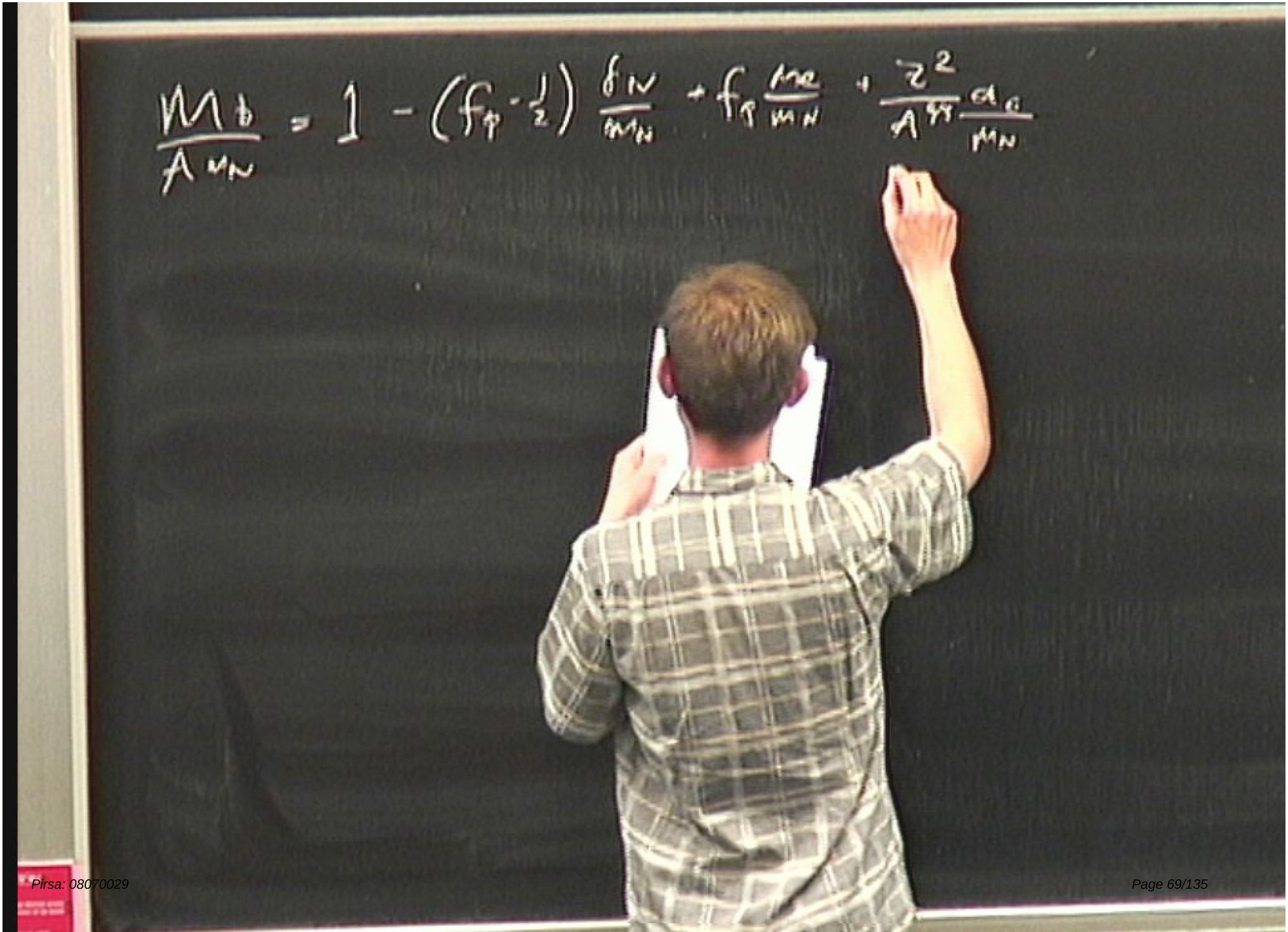
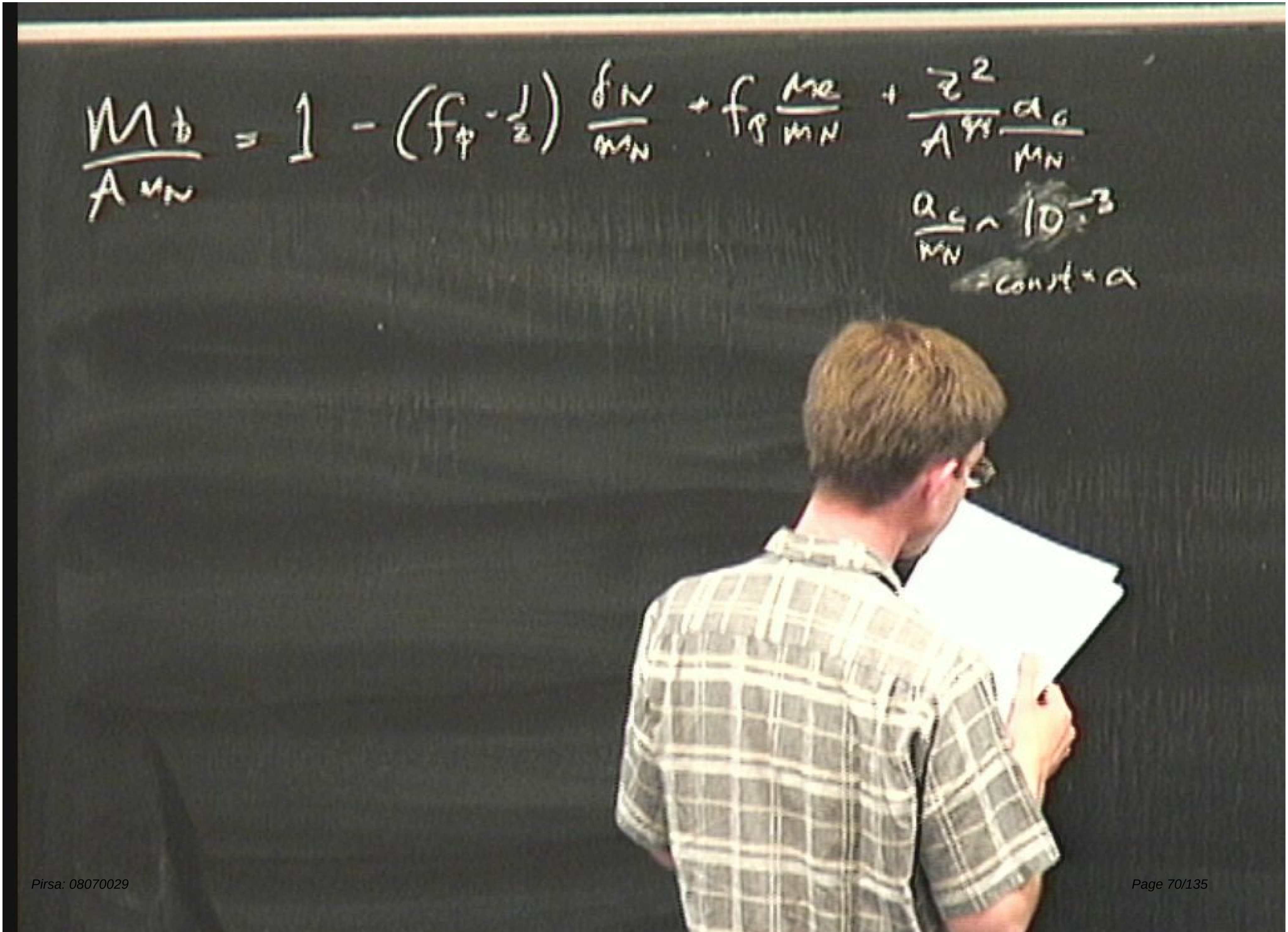
$$\partial \ln \left[\frac{M_b / A_b m_N}{M_b' / A_{b'} m_N}\right] \qquad m_N = \frac{m_p + m_n}{2}$$

M_b


$\frac{M_b}{A\, m_N} = 1 - \left(f_p - \frac{1}{2}\right)\frac{\delta_N}{m_N} + f_p \frac{m_e}{m_N} + \frac{Z^2}{A^{4/3}}\frac{a_c}{m_N}$



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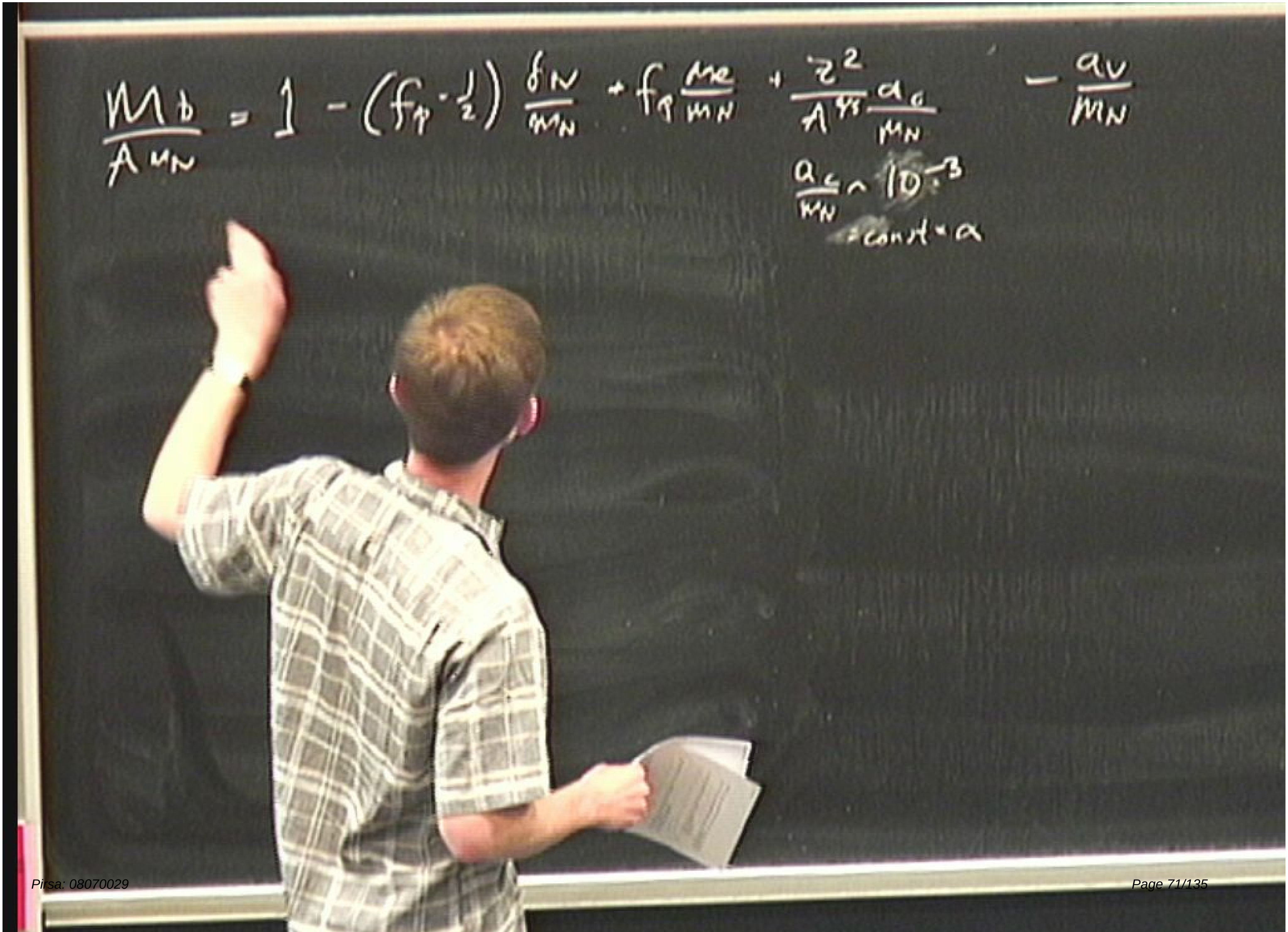
$\frac{a_c}{m_N} \sim 10^{-3}$
$= \text{const} \times \alpha$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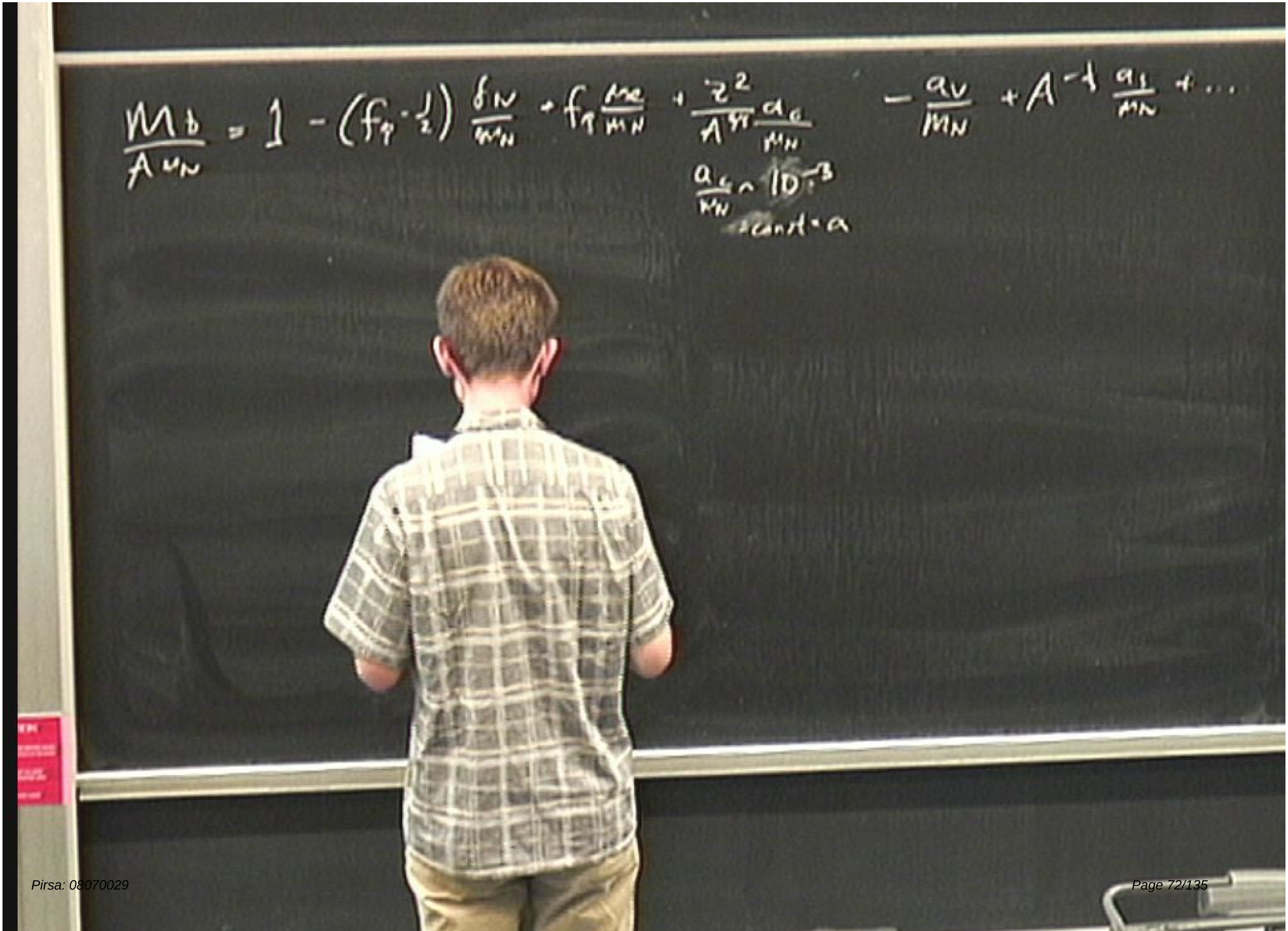
$\frac{M_b}{A m_N} = 1 - (f_q - \frac{1}{2}) \frac{\delta_N}{m_N} + f_q \frac{m_e}{m_N} + \frac{Z^2}{A^{4/3}} \frac{a_c}{m_N} - \frac{a_V}{m_N} + A^{-1/3} \frac{a_s}{m_N} + \dots$
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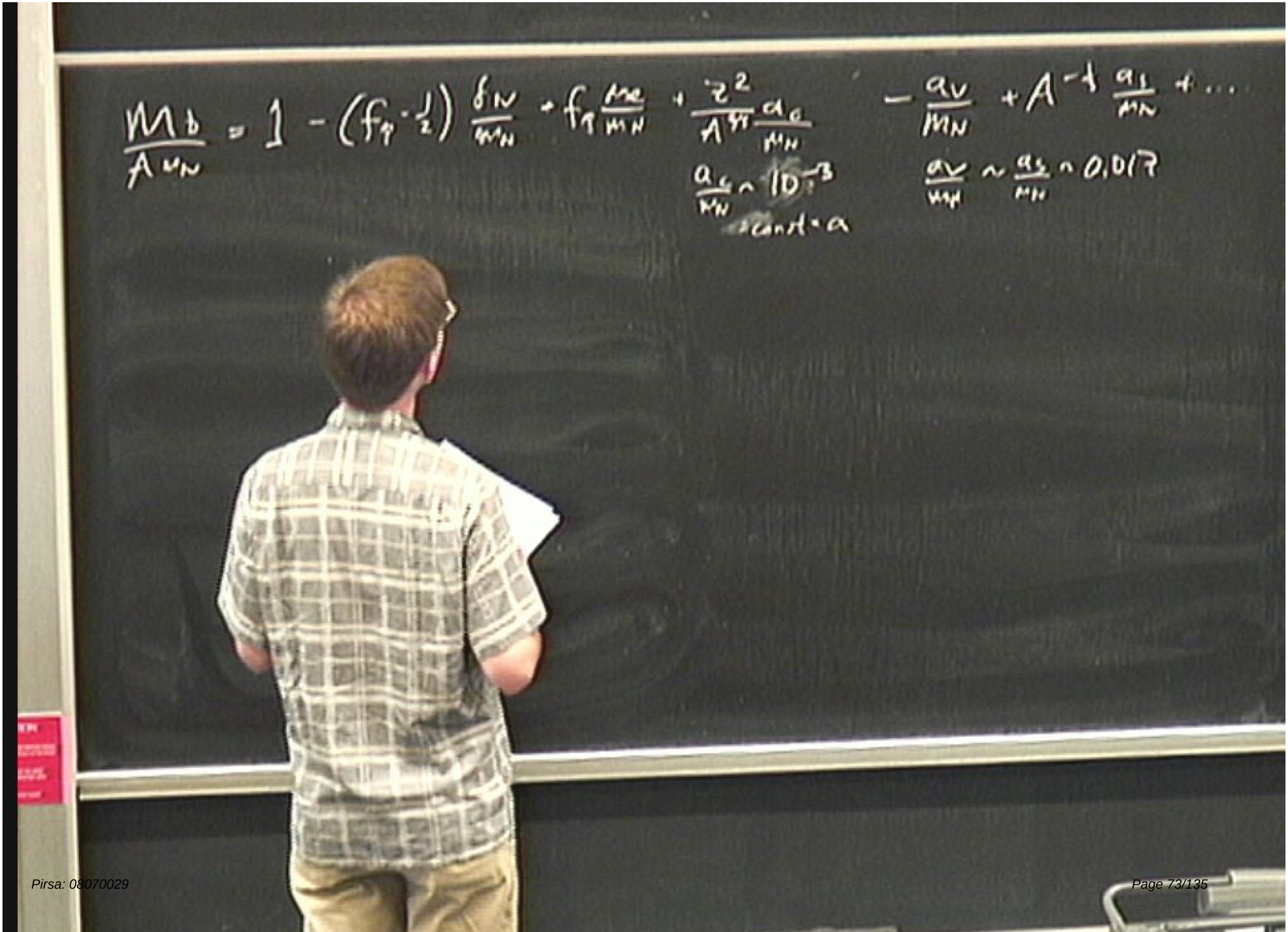
$\cdot$ const $\cdot\, \alpha$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$\frac{a_c}{m_N} \sim 10^{-3}$
const $\cdot\ \alpha$
$\frac{a_V}{m_N} \sim \frac{a_s}{m_N} \sim 0.017$

$$\frac{M_b}{A\, m_N} = 1 - \left(f_p - \tfrac{1}{2}\right)\frac{\delta_N}{m_N} + f_p \frac{m_e}{m_N} + \frac{Z^2}{A^{4/3}}\frac{a_c}{m_N} \quad - \frac{a_V}{m_N} + A^{-1/3}\frac{a_S}{m_N} + \ldots$$

$$\frac{\delta_N}{m_N} = \frac{m_n - m_p}{m_N} \sim 1.3 \cdot 10^{-3} \qquad \frac{a_c}{m_N} \sim 10^{-3} \qquad \frac{a_V}{m_N} \sim \frac{a_S}{m_N} \sim 0.017$$

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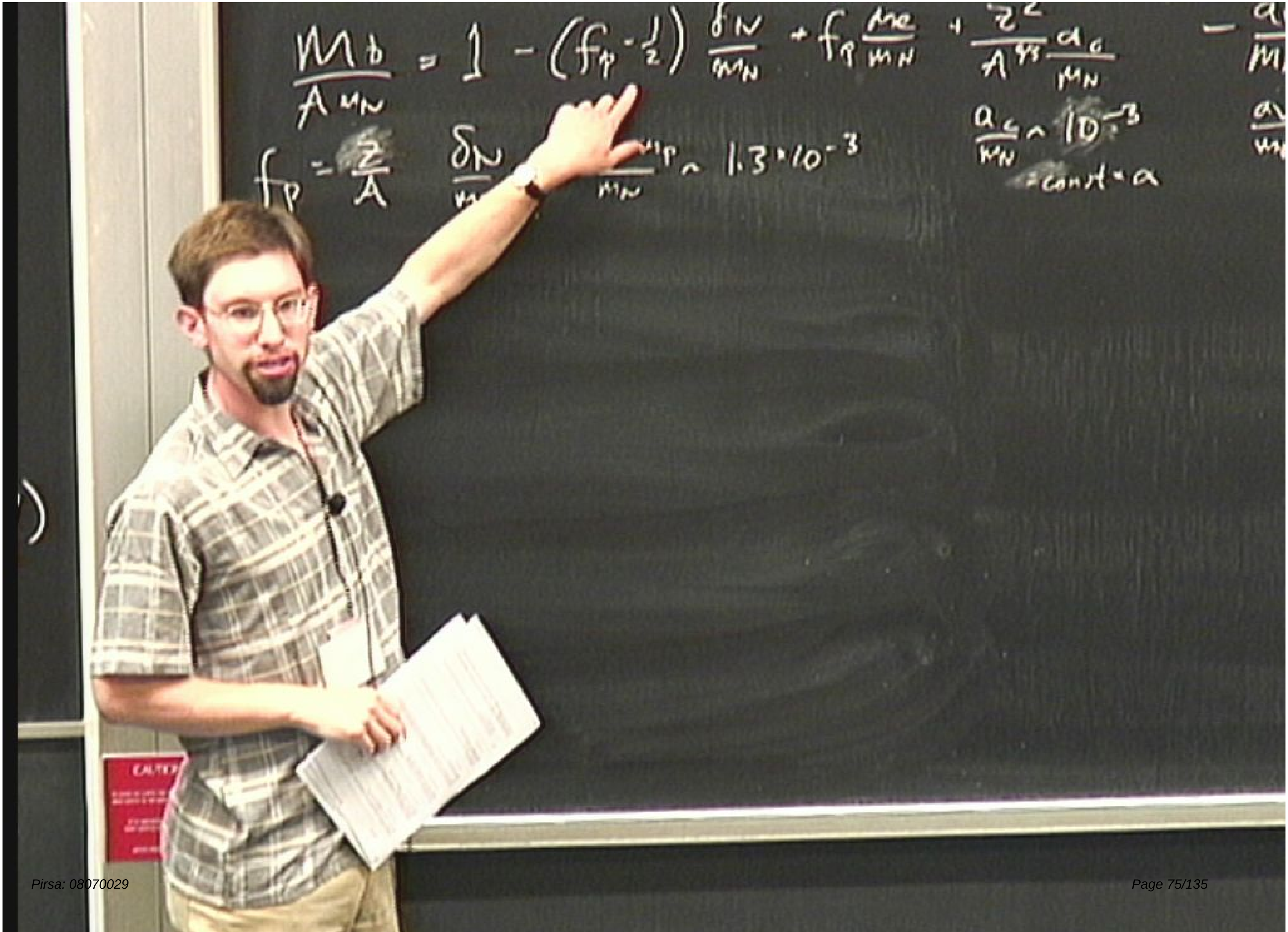
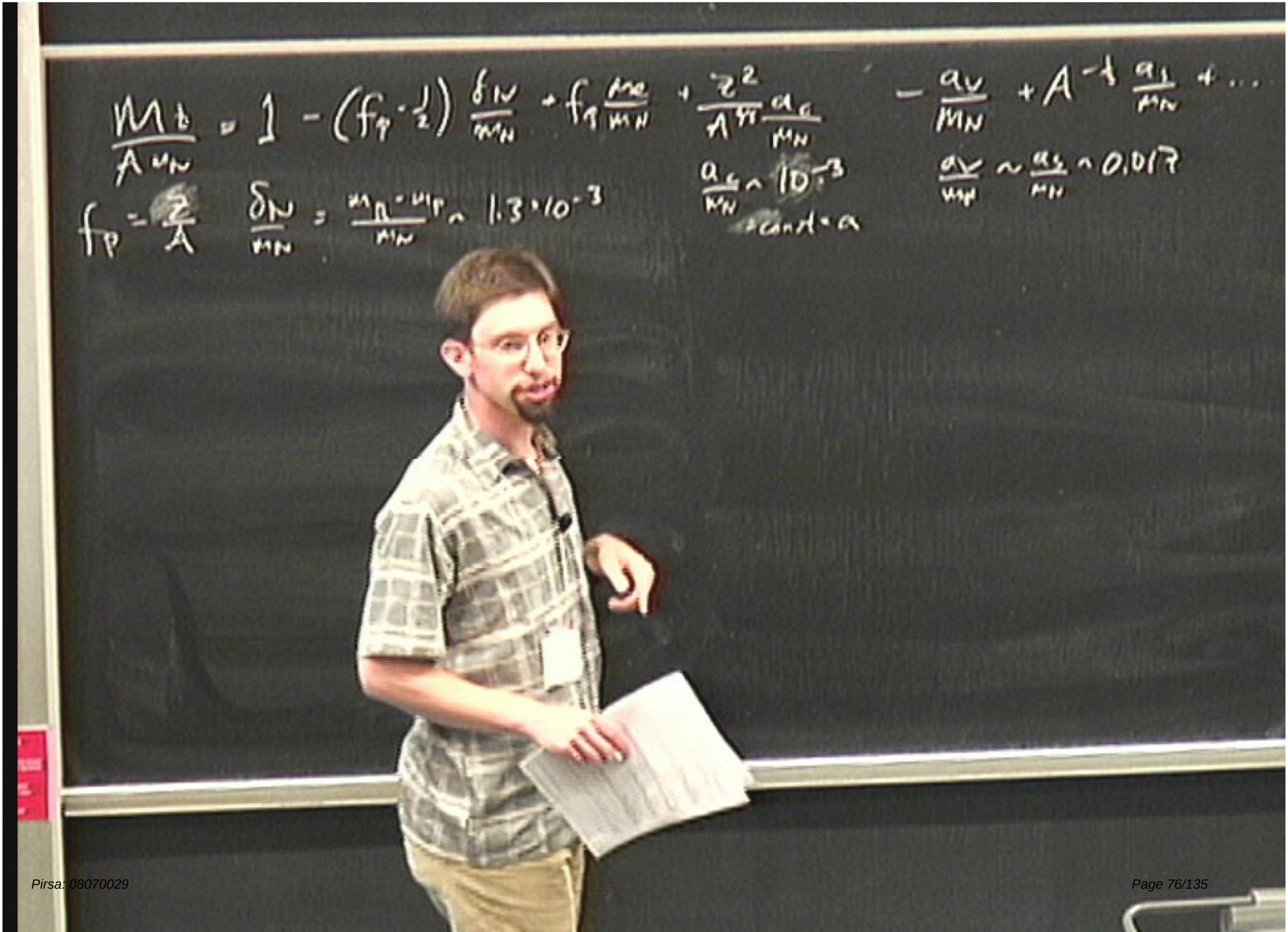
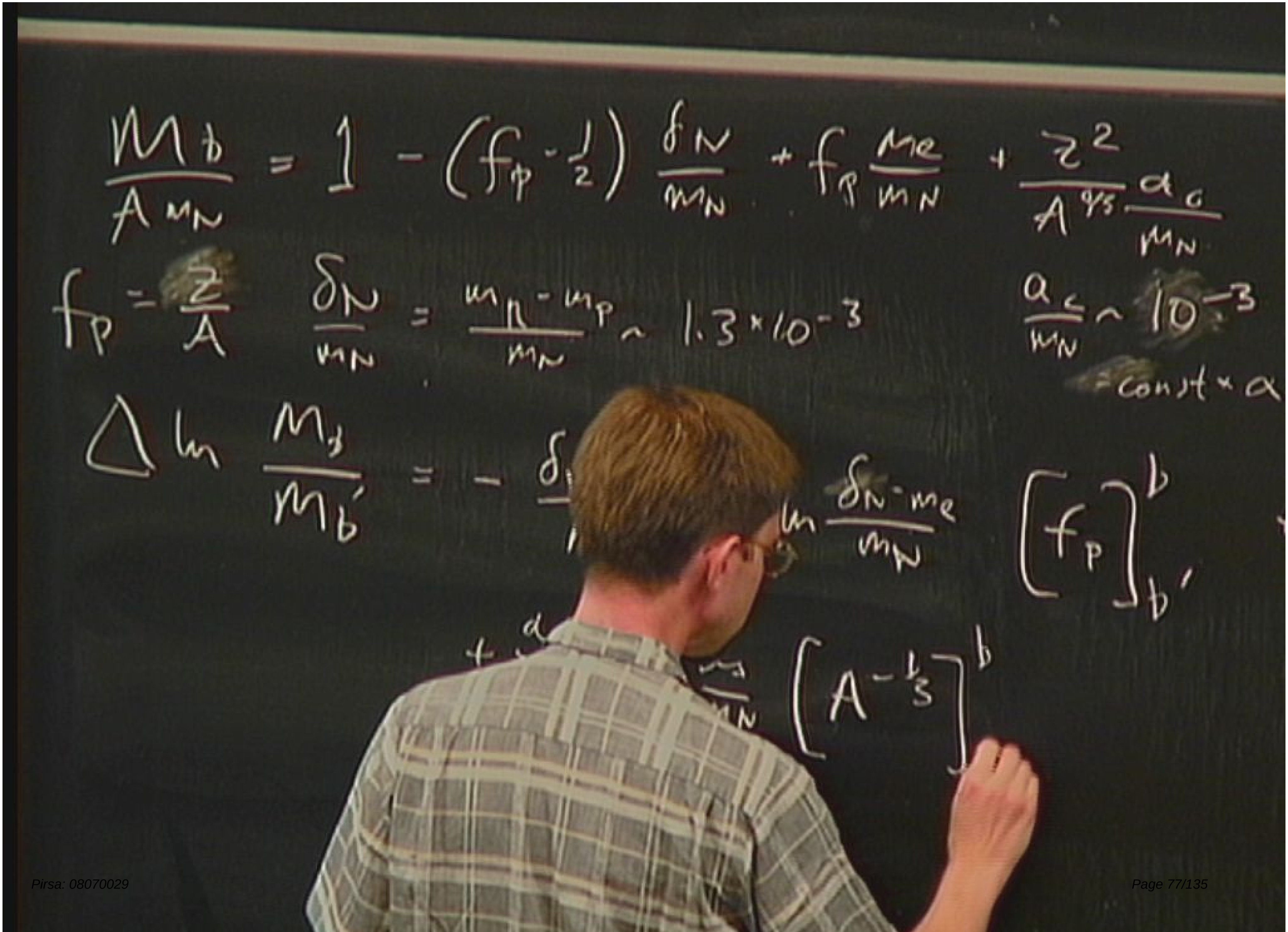
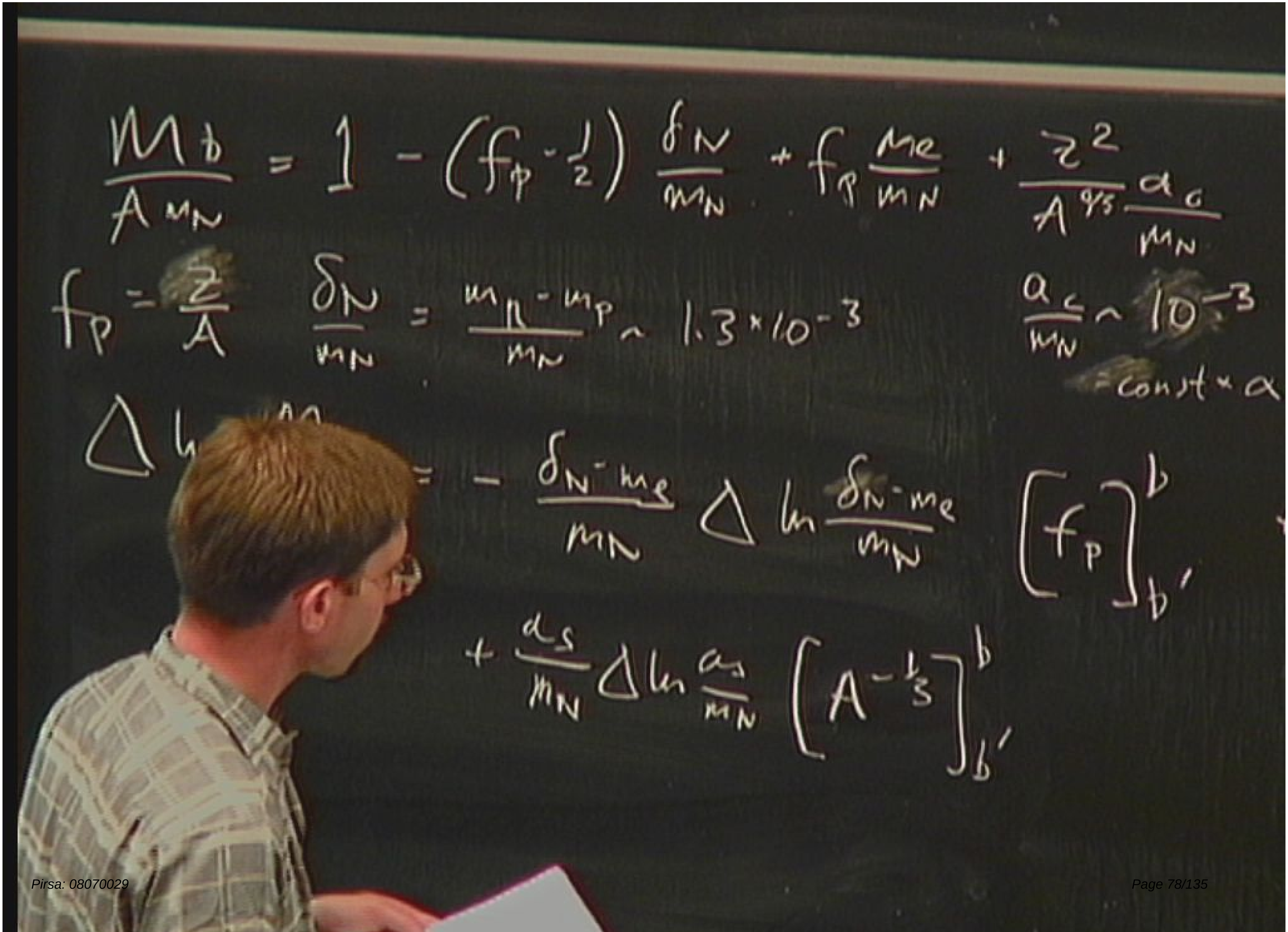


1.3 × 10^-3
10^-3
const × α

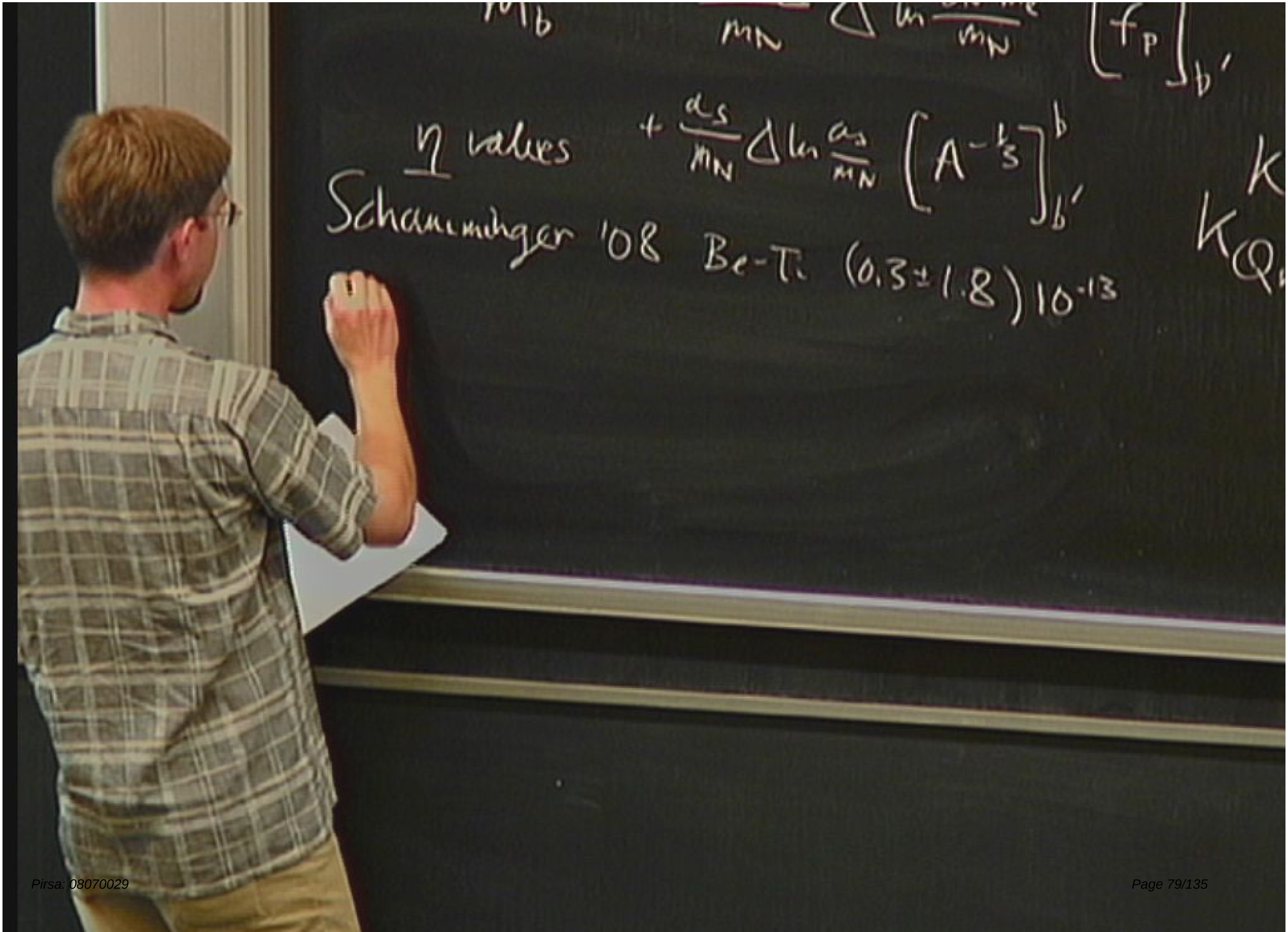

Mb/(A mN) = 1 − (fp − 1/2) δN/mN + fp me/mN + Z²/A^4/3 ac/mN − av/mN + A^-1/3 as/mN + ...
fp = Z/A
δN/mN = (mn − mp)/mN ~ 1.3×10^-3
ac/mN ~ 10^-3
av/mN ~ as/mN ~ 0.017

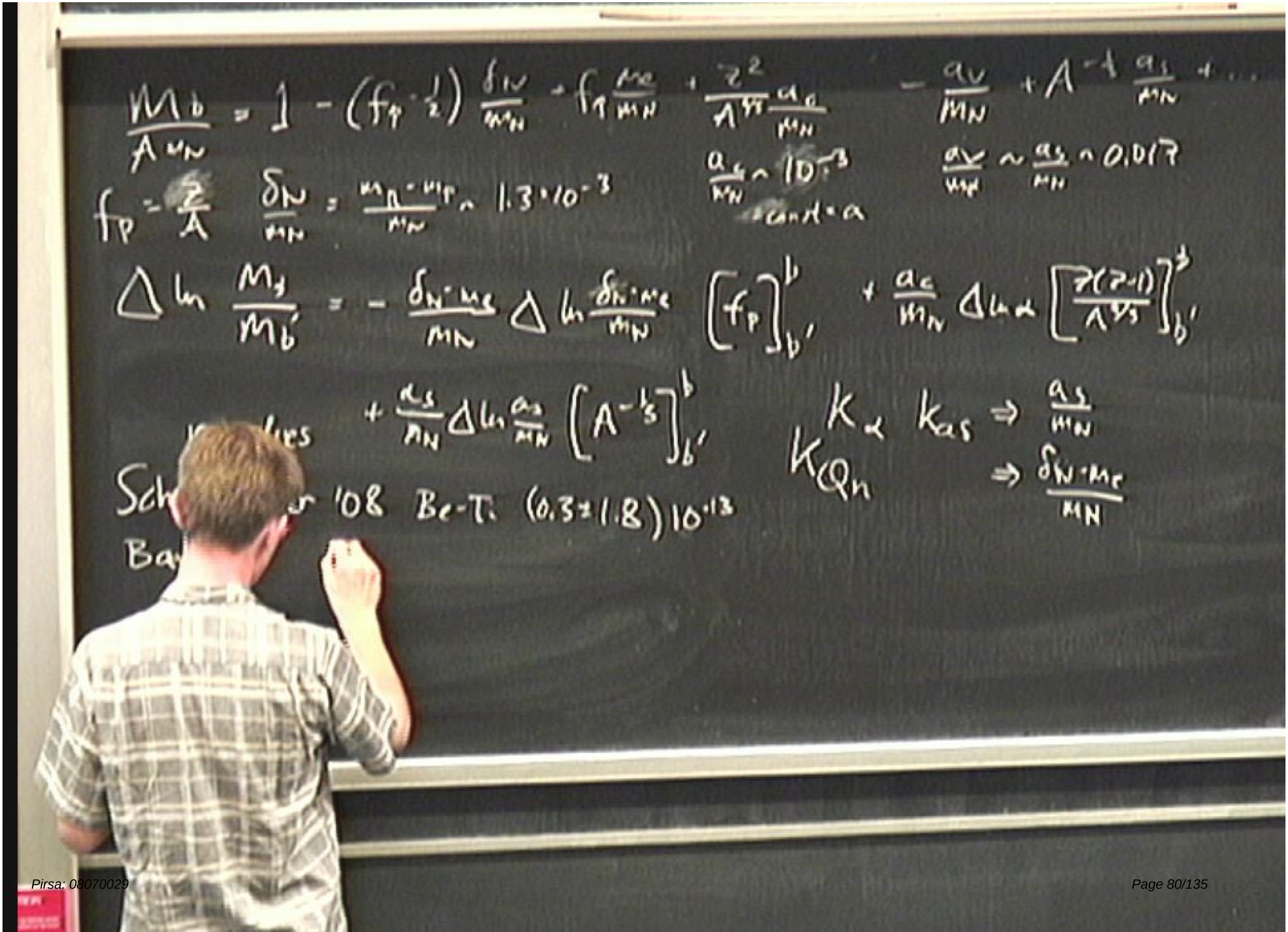


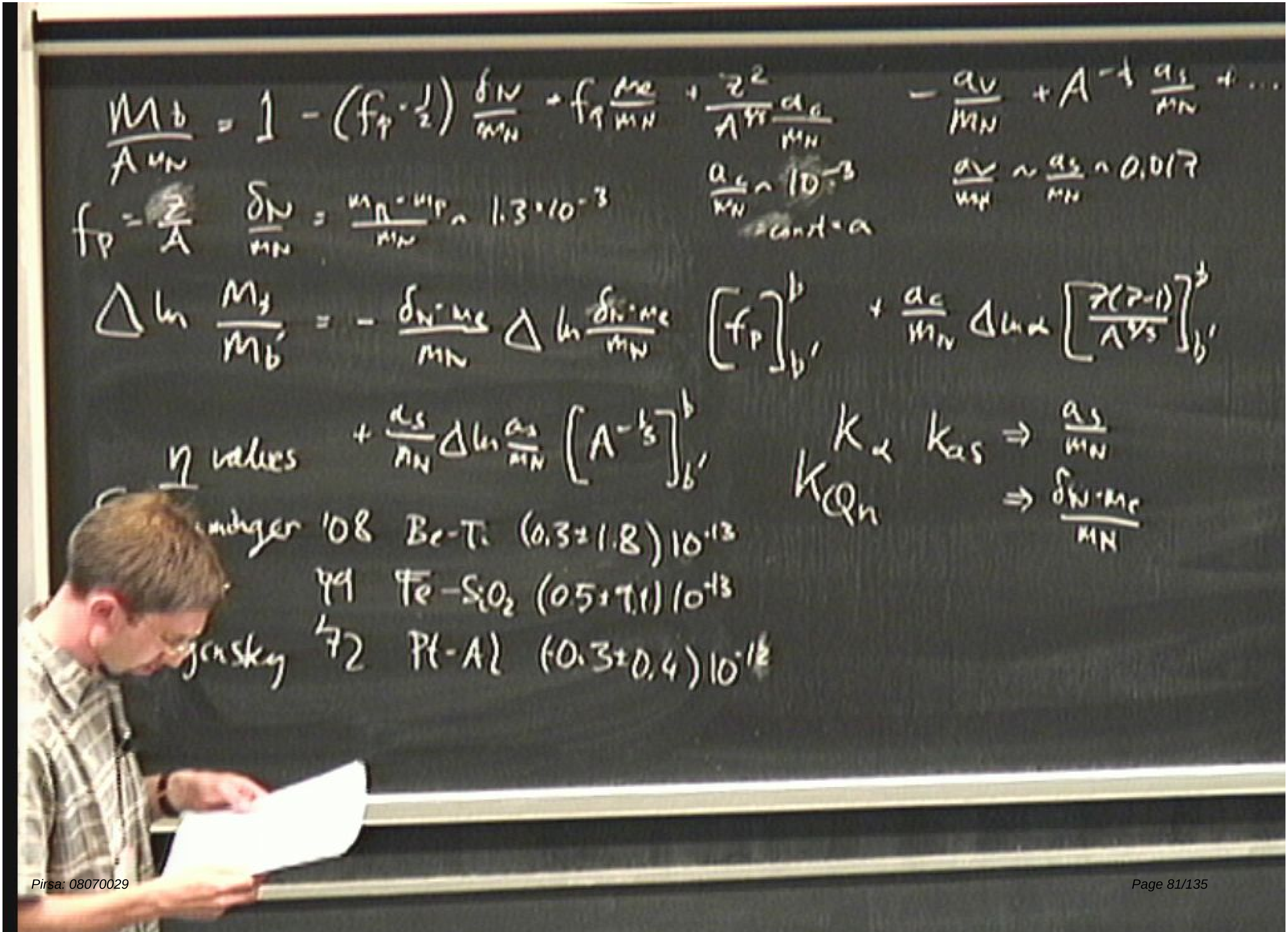
$\frac{M_b}{A m_N} = 1 - (f_p - \frac{1}{2}) \frac{\delta_N}{m_N} + f_p \frac{m_e}{m_N} + \frac{Z^2}{A^{4/3}} \frac{a_c}{m_N}$
$f_p = \frac{Z}{A}$
$\frac{\delta_N}{m_N} = \frac{m_n - m_p}{m_N} \sim 1.3 \times 10^{-3}$
$\frac{a_c}{m_N} \sim 10^{-3}$
$= \text{const} \times \alpha$
$\Delta \ln \frac{M_b}{M_{b'}} = -$
$\ln \frac{\delta_N - m_e}{m_N}$
$[f_p]_{b'}^{b}$
$[A^{-1/3}]^{b}$

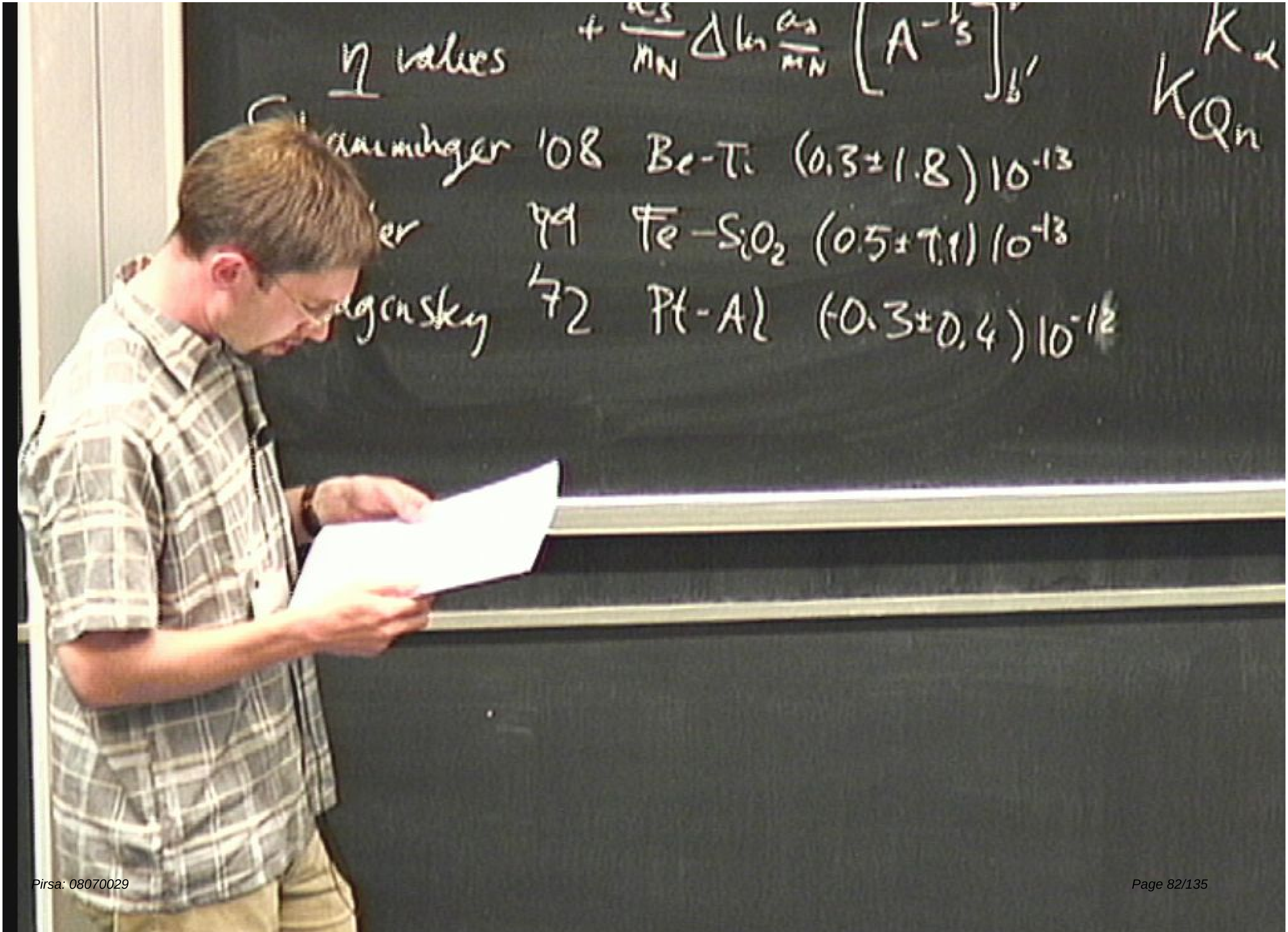


$\frac{M_b}{A m_N} = 1 - (f_p - \frac{1}{2}) \frac{\delta_N}{m_N} + f_p \frac{m_e}{m_N} + \frac{Z^2}{A^{4/3}} \frac{a_c}{m_N}$
$f_p = \frac{Z}{A}$
$\frac{\delta_N}{m_N} = \frac{m_n - m_p}{m_N} \sim 1.3 \times 10^{-3}$
$\frac{a_c}{m_N} \sim 10^{-3}$
$= \text{const} \times \alpha$
$\Delta \ln$
$= - \frac{\delta_N - m_e}{m_N} \Delta \ln \frac{\delta_N - m_e}{m_N} \left[f_p \right]_{b'}^{b}$
$+ \frac{a_s}{m_N} \Delta \ln \frac{a_s}{m_N} \left[A^{-1/3} \right]_{b'}^{b}$


η values
Schamminger '08 Be-Ti (0.3±1.8) 10^-13


$\frac{M_b}{A m_N} = 1 - (f_p - \frac{1}{2}) \frac{\delta_N}{m_N} + f_p \frac{m_e}{m_N} + \frac{Z^2}{A^{4/3}} \frac{a_c}{m_N} - \frac{a_v}{m_N} + A^{-1/3} \frac{a_s}{m_N} + \ldots$
$f_p = \frac{Z}{A}$
$\frac{\delta_N}{m_N} = \frac{m_n - m_p}{m_N} \sim 1.3 \times 10^{-3}$
$\frac{a_c}{m_N} \sim 10^{-3}$
$\frac{a_v}{m_N} \sim \frac{a_s}{m_N} \sim 0.017$
$\Delta \ln \frac{M_b}{M_{b'}} = - \frac{\delta_N + m_e}{m_N} \Delta \ln \frac{\delta_N + m_e}{m_N} [f_p]^b_{b'} + \frac{a_c}{m_N} \Delta \ln \alpha \left[\frac{Z(Z-1)}{A^{4/3}}\right]^b_{b'}$
$+ \frac{a_s}{m_N} \Delta \ln \frac{a_s}{m_N} [A^{-1/3}]^b_{b'}$
$K_\alpha \quad K_{a_s} \Rightarrow \frac{a_s}{m_N}$
$K_{Q_n} \Rightarrow \frac{\delta_N + m_e}{m_N}$
'08 Be-Ti $(0.3 \pm 1.8) 10^{-13}$


$\frac{M_b}{A m_N} = 1 - (f_p - \frac{1}{2}) \frac{\delta_N}{m_N} + f_p \frac{m_e}{m_N} + \frac{Z^2}{A^{4/3}} \frac{a_c}{m_N} - \frac{a_v}{m_N} + A^{-1/3} \frac{a_s}{m_N} + \dots$
$f_p = \frac{Z}{A}$
$\frac{\delta_N}{m_N} = \frac{m_n - m_p}{m_N} \sim 1.3 \cdot 10^{-3}$
$\frac{a_c}{m_N} \sim 10^{-3}$
const $\cdot\, \alpha$
$\frac{a_v}{m_N} \sim \frac{a_s}{m_N} \sim 0.017$
$\Delta \ln \frac{M_b}{M_{b'}} = - \frac{\delta_N + m_e}{m_N} \Delta \ln \frac{\delta_N + m_e}{m_N} \left[f_p \right]_{b'}^{b} + \frac{a_c}{m_N} \Delta \ln \alpha \left[\frac{Z(Z-1)}{A^{4/3}} \right]_{b'}^{b}$
$+ \frac{a_s}{m_N} \Delta \ln \frac{a_s}{m_N} \left[A^{-1/3} \right]_{b'}^{b}$
$K_\alpha \quad K_{a_s} \Rightarrow \frac{a_s}{m_N}$
$K_{CQn} \Rightarrow \frac{\delta_N + m_e}{m_N}$
η values
'08 Be-Ti $(0.3 \pm 1.8) 10^{-13}$
'94 Fe-SiO$_2$ $(0.5 \pm 7.1) 10^{-13}$
'72 Pt-Al $(-0.3 \pm 0.4) 10^{-12}$


η values
'08 Be-Ti (0.3±1.8) 10^-13
Fe-SiO2
'72 Pt-Al (-0.3±0.4) 10^-12
KQn

$$\frac{M_b}{A\, m_N} = 1 - \left(f_p - \tfrac{1}{2}\right)\frac{\delta_N}{m_N} + f_p\frac{m_e}{m_N} + \frac{Z^2}{A^{4/3}}\frac{a_c}{m_N} - \frac{a_v}{m_N} + A^{-1/3}\frac{a_s}{m_N} + \cdots$$

$$f_p = \frac{Z}{A} \qquad \frac{\delta_N}{m_N} = \frac{m_n - m_p}{m_N} \sim 1.3\times 10^{-3} \qquad \frac{a_c}{m_N} \sim 10^{-3} \qquad \frac{a_v}{m_N} \sim \frac{a_s}{m_N} \sim 0.017$$

$= \text{const}\cdot\alpha$

$$\Delta \ln \frac{M_b}{M_{b'}} = -\frac{\delta_N - m_e}{m_N}\,\Delta \ln \frac{\delta_N - m_e}{m_N}\left[f_p\right]_{b'}^{b} + \frac{a_c}{m_N}\,\Delta \ln \alpha \left[\frac{Z(Z-1)}{A^{4/3}}\right]_{b'}^{b} + \frac{a_s}{m_N}\,\Delta \ln \frac{a_s}{m_N}\left[A^{-1/3}\right]_{b'}^{b}$$

$k_\alpha \quad k_{as} \Rightarrow \frac{a_s}{m_N}$

$k_{Q_n} \Rightarrow \frac{\delta_N - m_e}{m_N}$

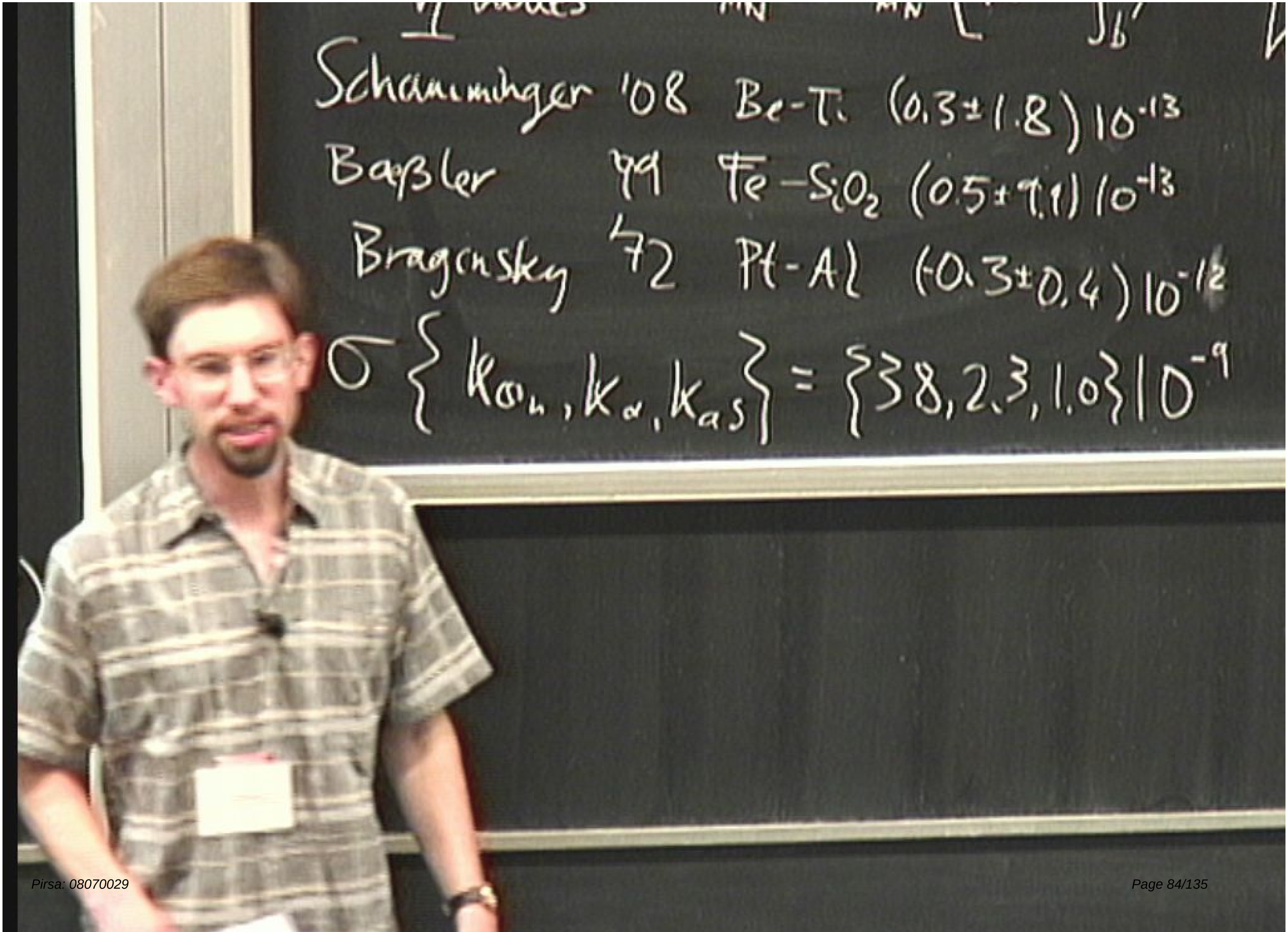
η values

Schlamminger '08 Be-Ti $(0.3 \pm 1.8)\,10^{-13}$

Baeßler '99 Be-SiO_2 $(0.5 \pm 1.1)\,10^{-13}$

Braginsky '72 Pt-Al $(-0.3 \pm 0.4)\,10^{-12}$

$$\sigma\{k_{Q_n}, k_\alpha, k_{as}\} = \{38, 2.3, 1.0\}\,10^{-9}$$

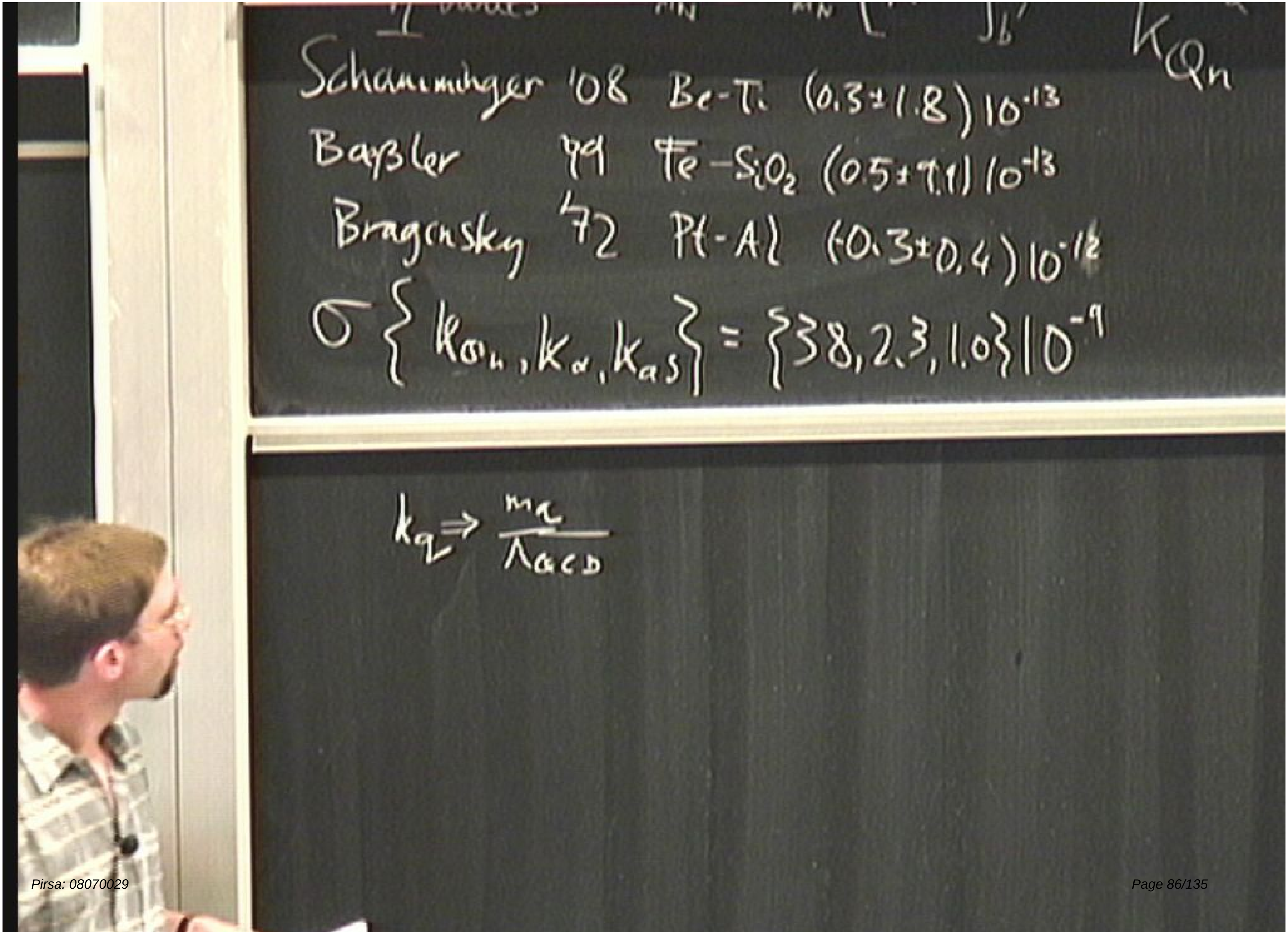

Schlamminger '08 Be-Ti (0.3±1.8) 10^-13
Baeßler '99 Fe-SiO2
Bragensky '72 Pt-Al (-0.3±0.4) 10^-12
σ {k_CMB, k_α, k_aS} = {38, 2.3, 1.0} 10^-9

Schamminger '08 Be-Ti $(0.3 \pm 1.8)\,10^{-13}$

Baeßler '99 Be-Ti $(0.5 \pm 7.1)\,10^{-13}$

Braginsky '72 Pt-Al $(-0.3 \pm 0.4)\,10^{-12}$

$$\sigma\{k_{\sigma n}, k_{\alpha}, k_{aS}\} = \{38, 2.3, 1.0\}\,10^{-9}$$



k_{Qn}
Schamminger '08 Be-Ti $(0.3 \pm 1.8)\,10^{-13}$
Baeßler '99 Fe-SiO_2 $(0.5 \pm 7.1)\,10^{-13}$
Braginsky '72 Pt-Al $(-0.3 \pm 0.4)\,10^{-12}$
$\sigma\{k_{Qn}, k_\alpha, k_{\alpha s}\} = \{38, 2.3, 1.0\}\,10^{-9}$
$k_q \Rightarrow \frac{m_q}{\Lambda_{QCD}}$

k_{Q_n}

Schlamminger '08 Be-Ti $(0.3 \pm 1.8)\,10^{-13}$

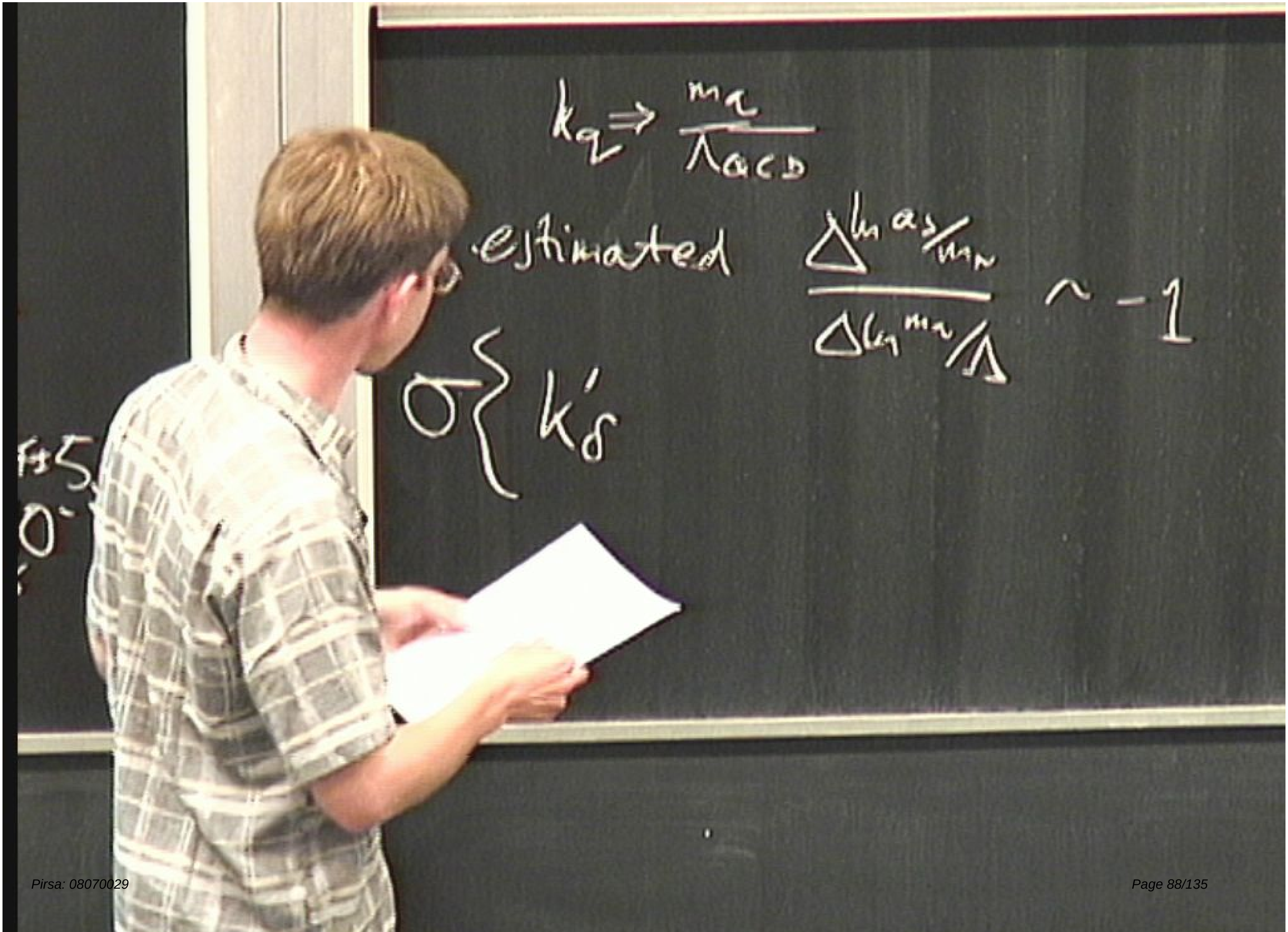
Baßler '99 Be-SiO_2 $(0.5 \pm 1.1)\,10^{-13}$

Braginsky '72 Pt-Al $(-0.3 \pm 0.4)\,10^{-12}$

$$\sigma\left\{k_{Q_n}, k_{\alpha}, k_{\alpha_S}\right\} = \{38, 2.3, 1.0\}\,10^{-9}$$

$$k_q \Rightarrow \frac{m_q}{\Lambda_{QCD}}$$

estimated $\dfrac{\Delta \ln \alpha_S / m_N}{\Delta \ln m_N / \Lambda} \sim -1$


$k_q \Rightarrow \frac{m_q}{\Lambda_{QCD}}$
estimated
~ -1
$\sigma \{ k'_\delta$

K_{Q_n}

Schamminger '08 Be-Ti $(0.3 \pm 1.8)10^{-13}$

Baeßler '99 Fe-SiO_2 $(0.5 \pm 1.1)10^{-13}$

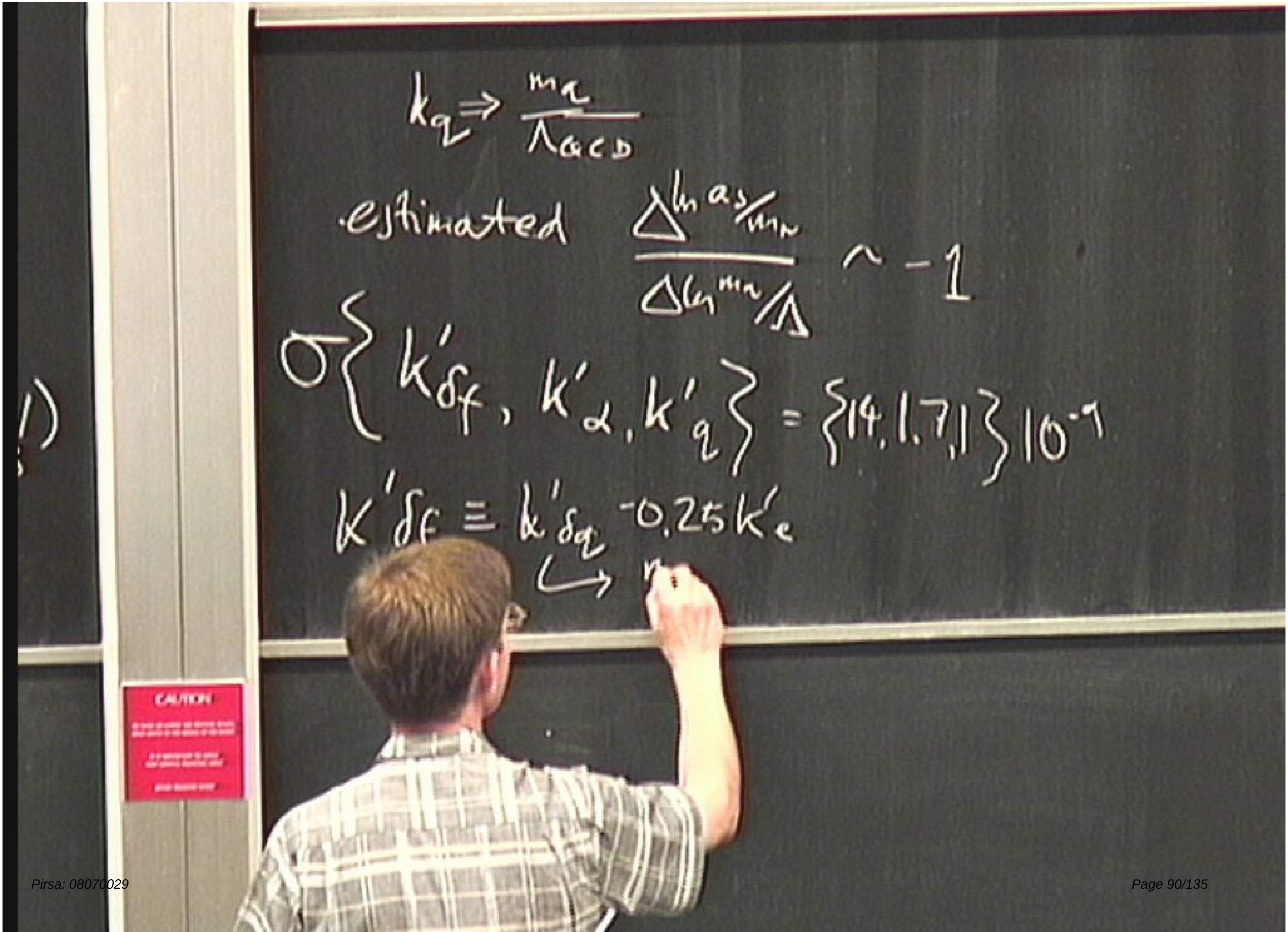
Braginsky '72 Pt-Al $(-0.3 \pm 0.4)10^{-12}$

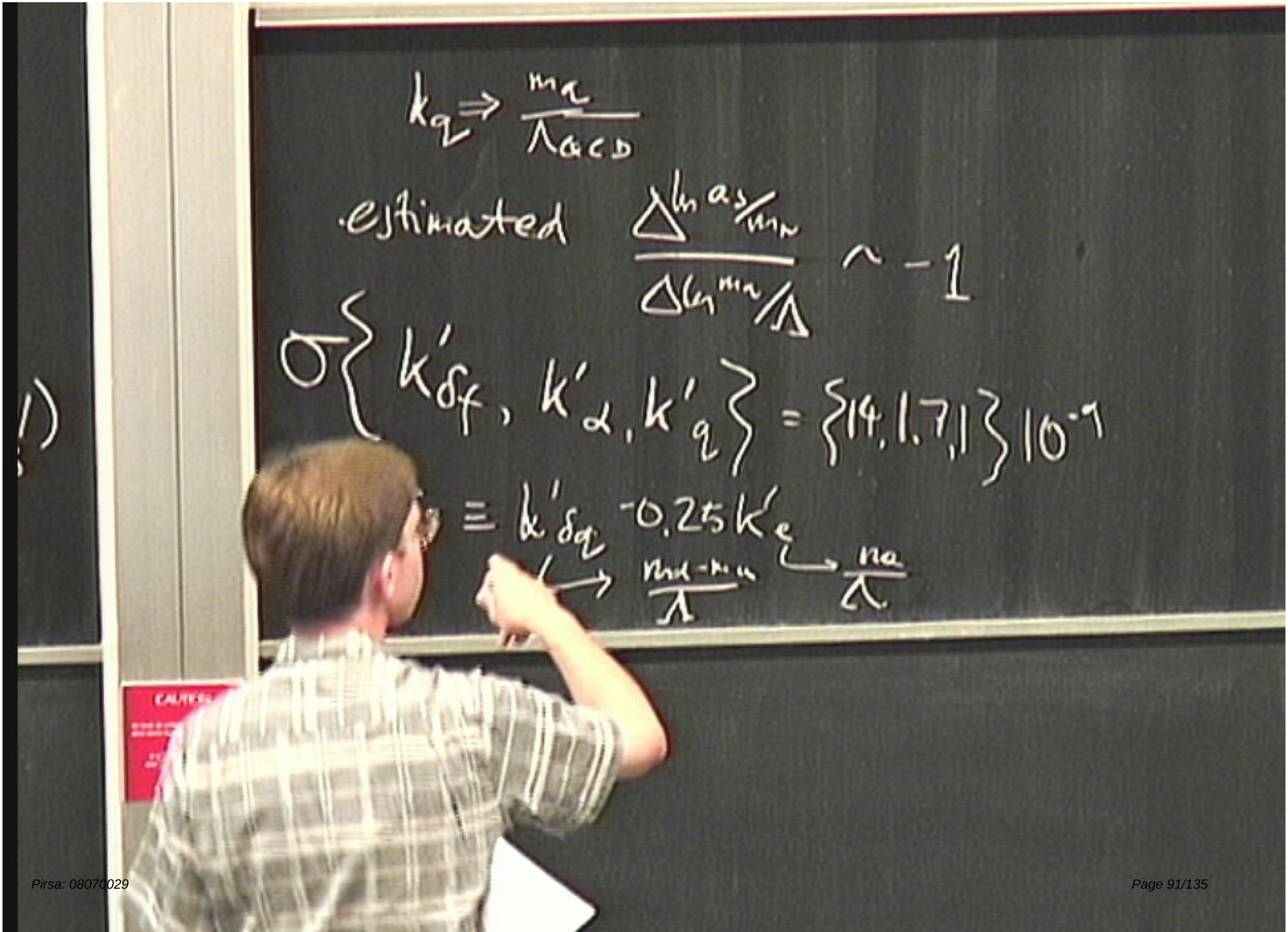
$$\sigma\{k_{\sigma_n}, k_\alpha, k_{as}\} = \{38, 2.3, 1.0\}10^{-9}$$

$$k_q \Rightarrow \frac{m_q}{\Lambda_{QCD}}$$

estimated $\dfrac{\Delta \ln m_s/m_N}{\Delta \ln m_N/\Delta} \sim -1$

$$\sigma\{k'_{\delta f}, k'_\alpha, k'_q\} = \{14, 1.7, 1\}10^{-9}$$


$k_q \Rightarrow \frac{m_q}{\Lambda_{QCD}}$
estimated
~ -1
$\sigma\{k'_{\delta f}, k'_\alpha, k'_q\} = \{14, 1.7, 1\} 10^{-7}$
$k'_{\delta f} \equiv k'_{\delta q} - 0.25 k'_e$
CAUTION


$k_q \Rightarrow \frac{m_q}{\Lambda_{QCD}}$
estimated
$\sigma\{k'_{\delta_f}, k'_\alpha, k'_q\} = \{14, 1, 7, 1\} 10^{-7}$
$\equiv k'_{\delta_q} - 0.25 k'_e$

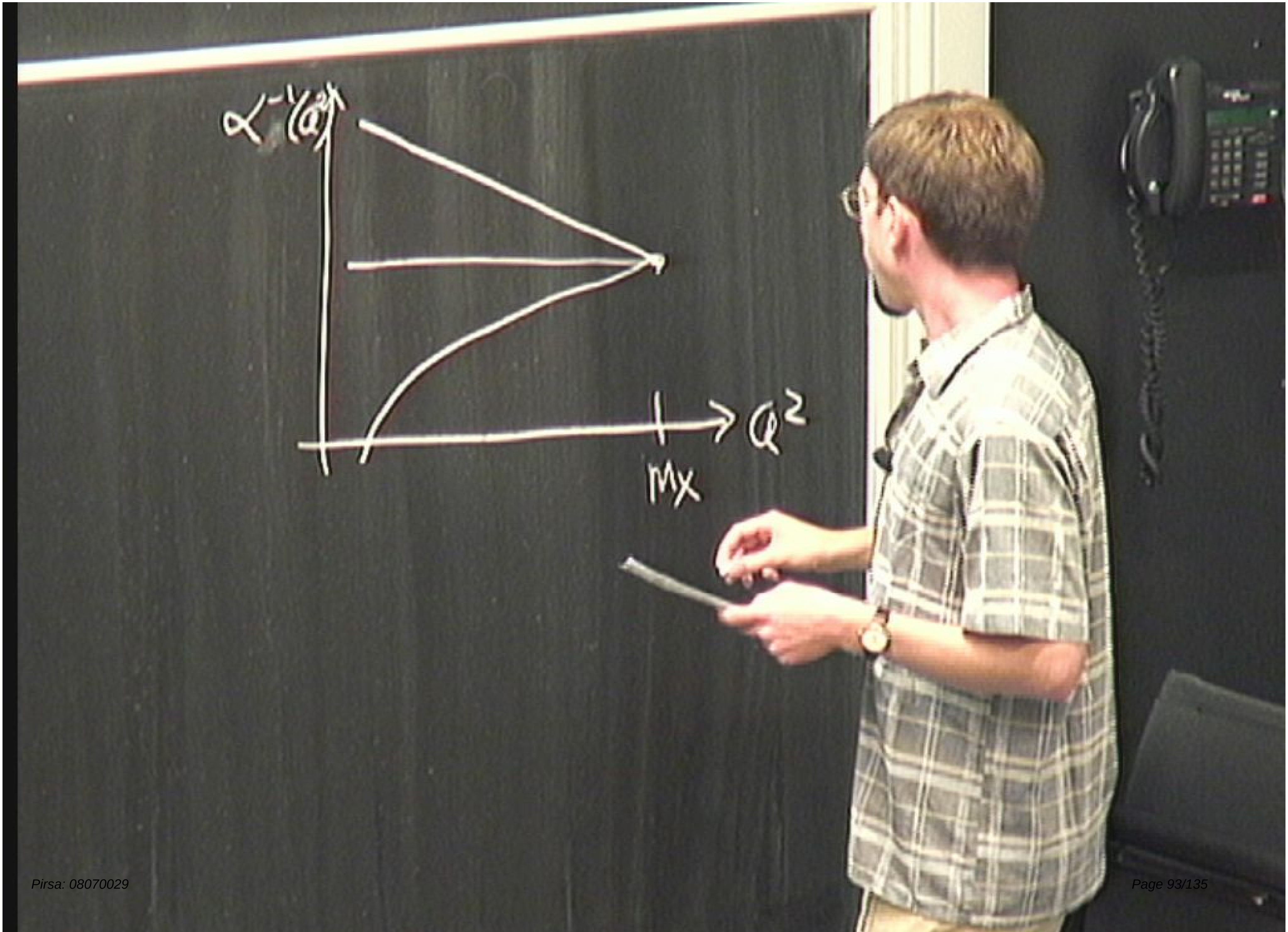
$k_q \Rightarrow \frac{m_q}{\Lambda_{QCD}}$

estimated $\frac{\Delta \ln a_s / m_n}{\Delta \ln m_n / \Lambda} \sim -1$

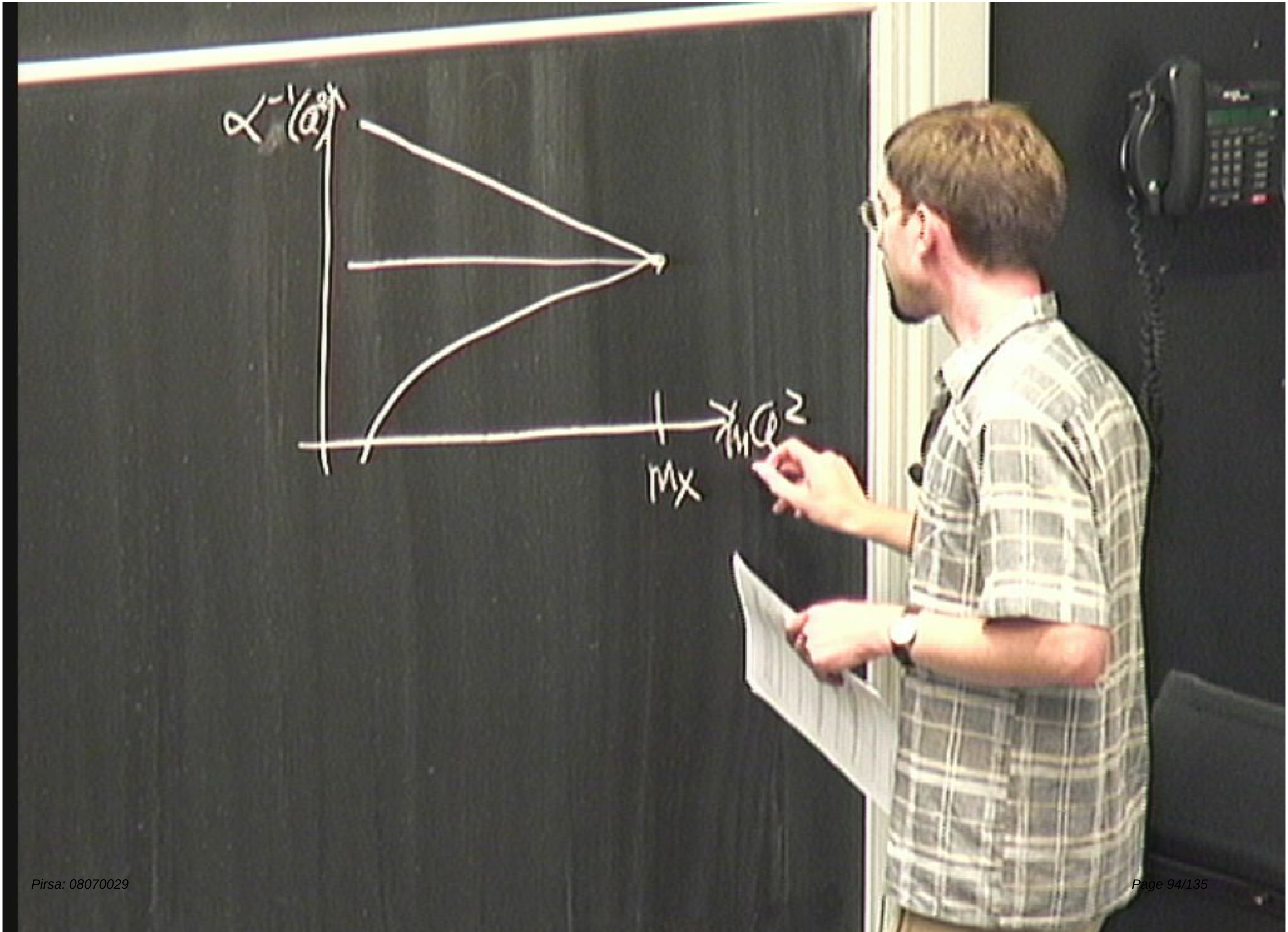
$\sigma\left\{ k'_{\delta f}, k'_{\alpha}, k'_{q} \right\} = \{14, 1, 7, 1\} 10^{-7}$

$k'_{\delta f} \equiv k'_{\delta q} - 0.25 k'_e$

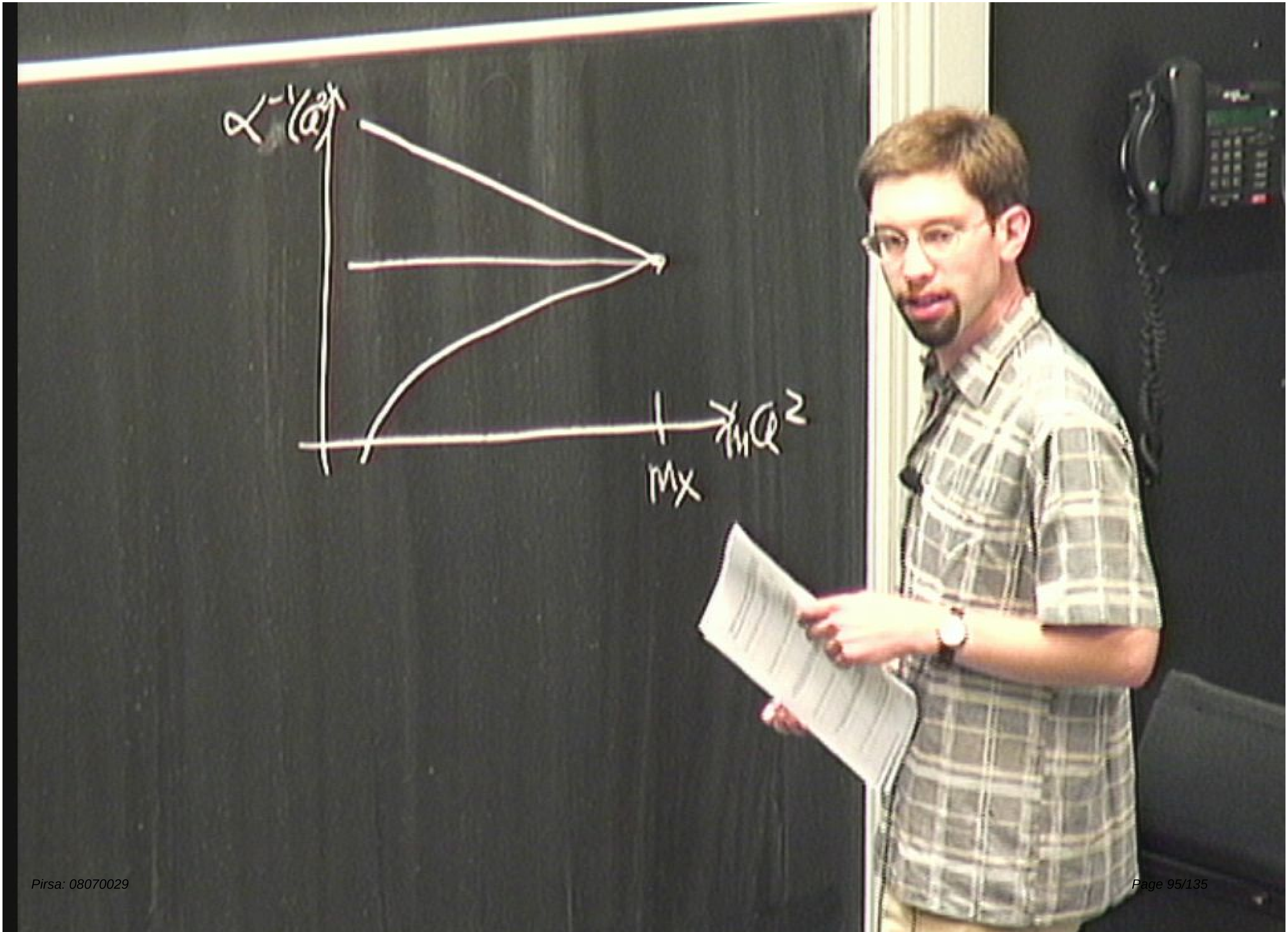
$\hookrightarrow \frac{m_d - m_u}{\Lambda}$ $\hookrightarrow \frac{m_e}{\Lambda}$

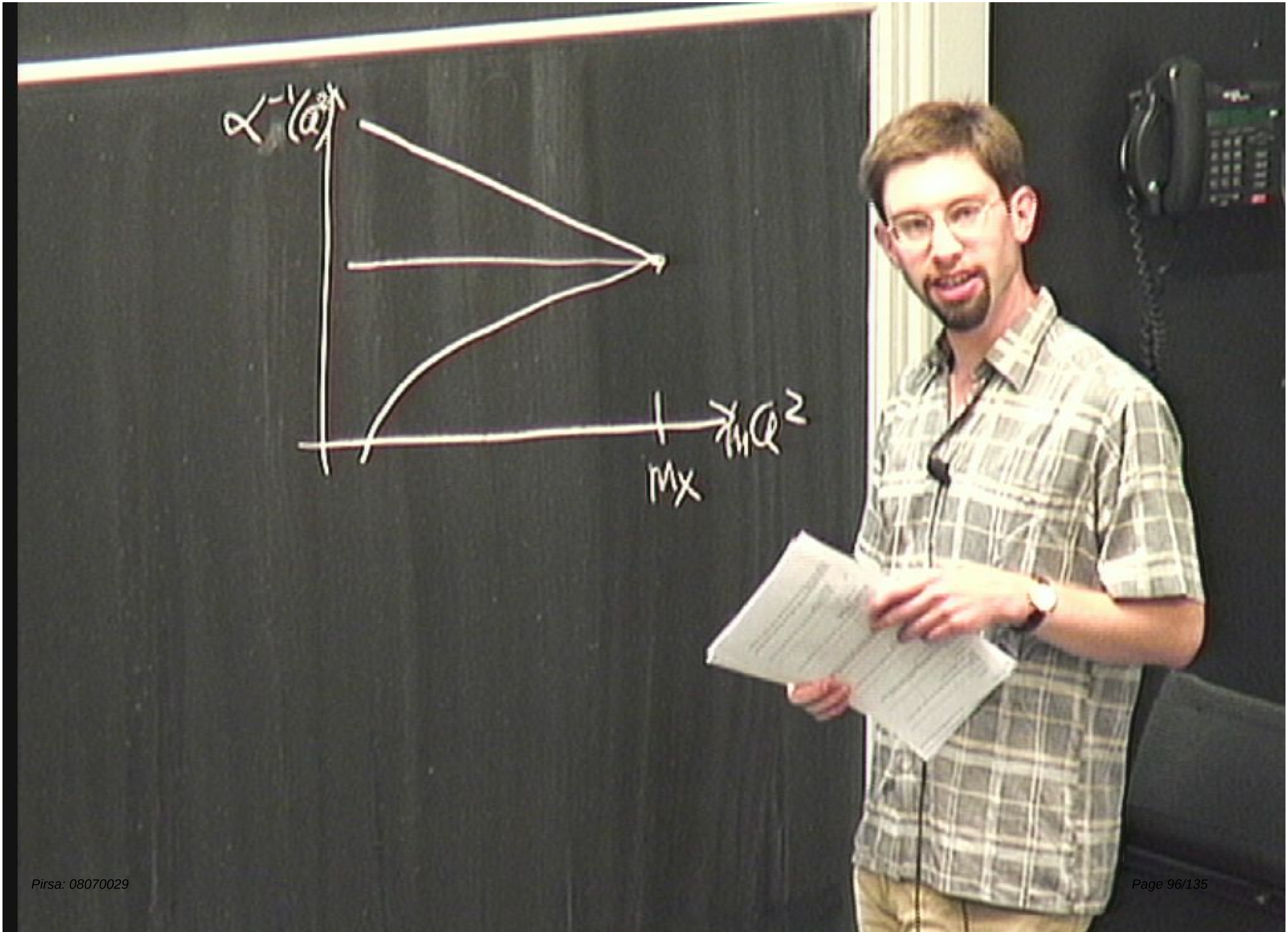


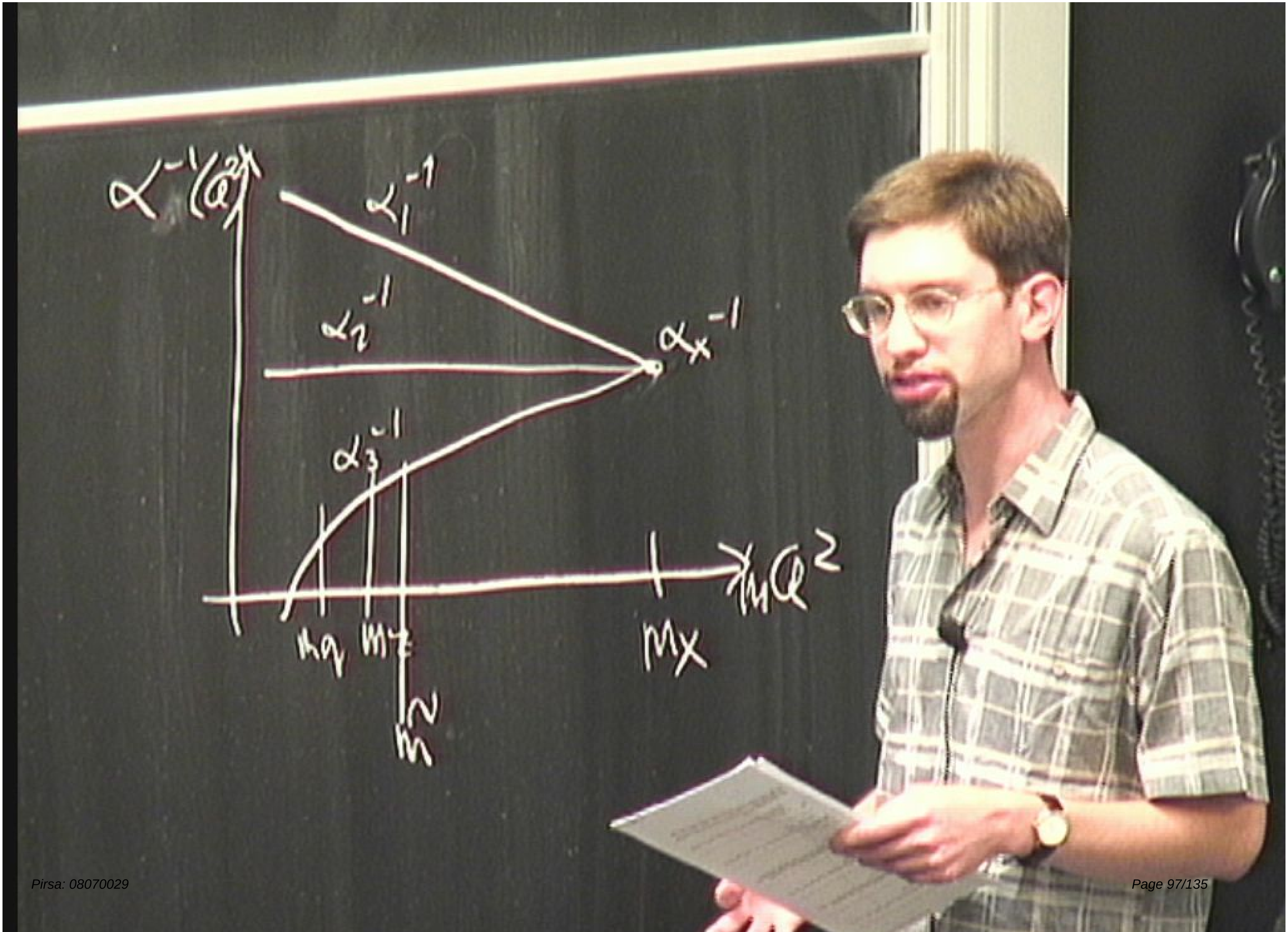
$\alpha^{-1}(Q^2)$
Q^2
m_X

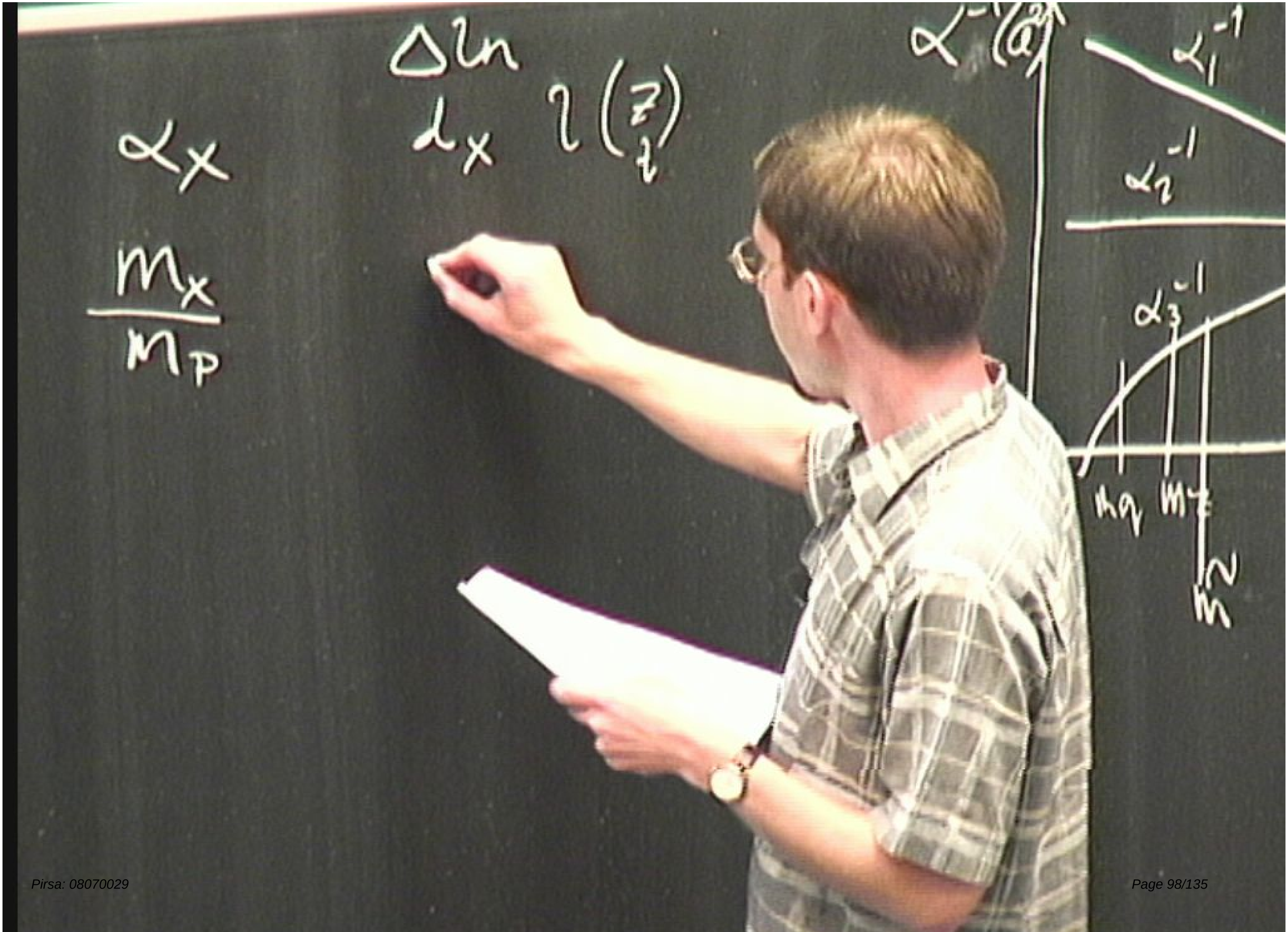


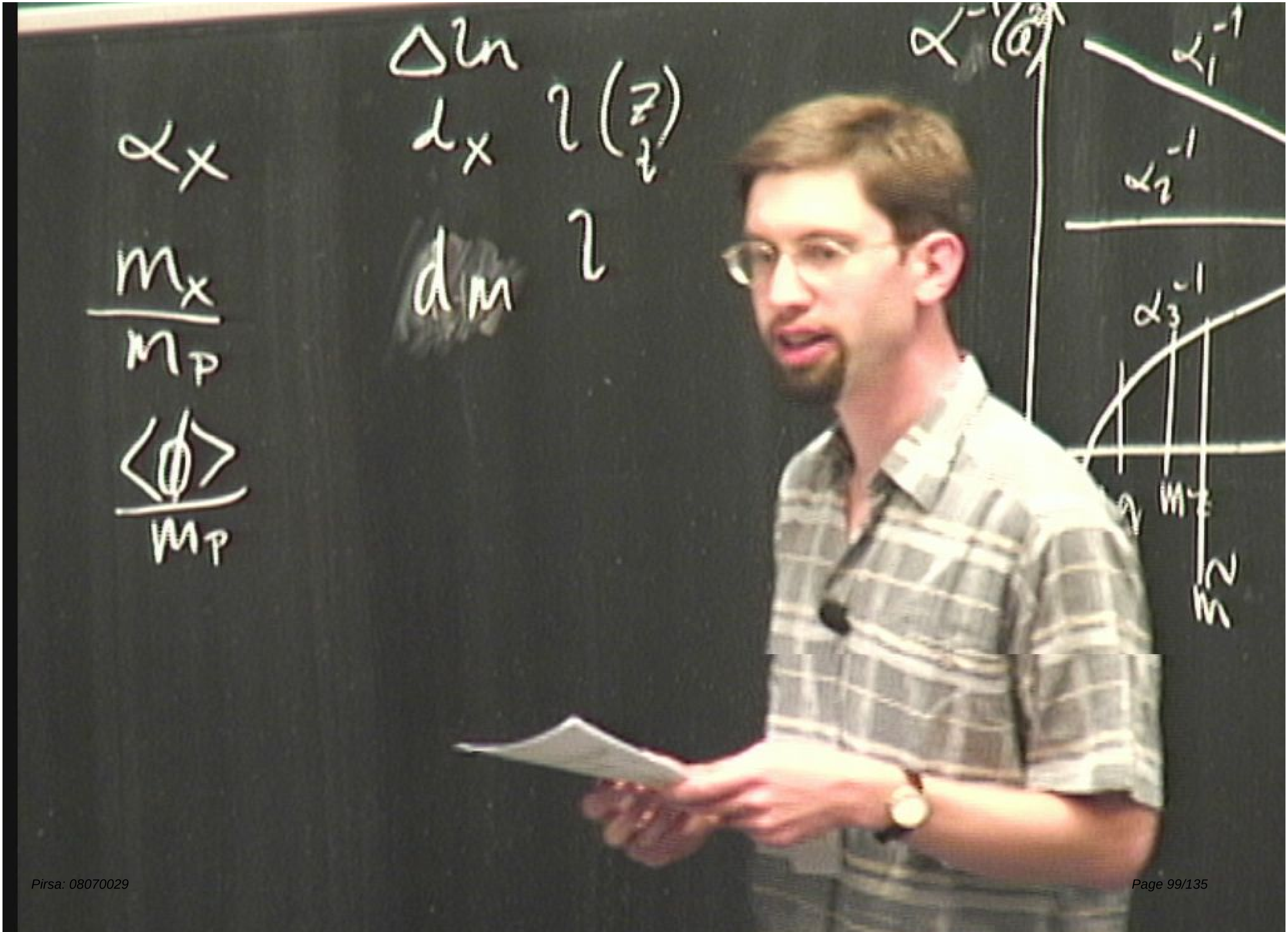
$\alpha^{-1}(Q^2)$
m_X
Q^2


$\alpha^{-1}(Q^2)$
$\ln Q^2$
mx


$\alpha^{-1}(Q^2)$
Q^2
mx


$\alpha^{-1}(Q^2)$
α_1^{-1}
α_2^{-1}
α_X^{-1}
α_3^{-1}
m_q
m_Z
$\tilde{m}$
M_X
$\log Q^2$


Δ ln
α_X
m_X / m_P
α^{-1}(a)
α_1^{-1}
α_2^{-1}
α_3^{-1}
m_q
m_Z
m̃

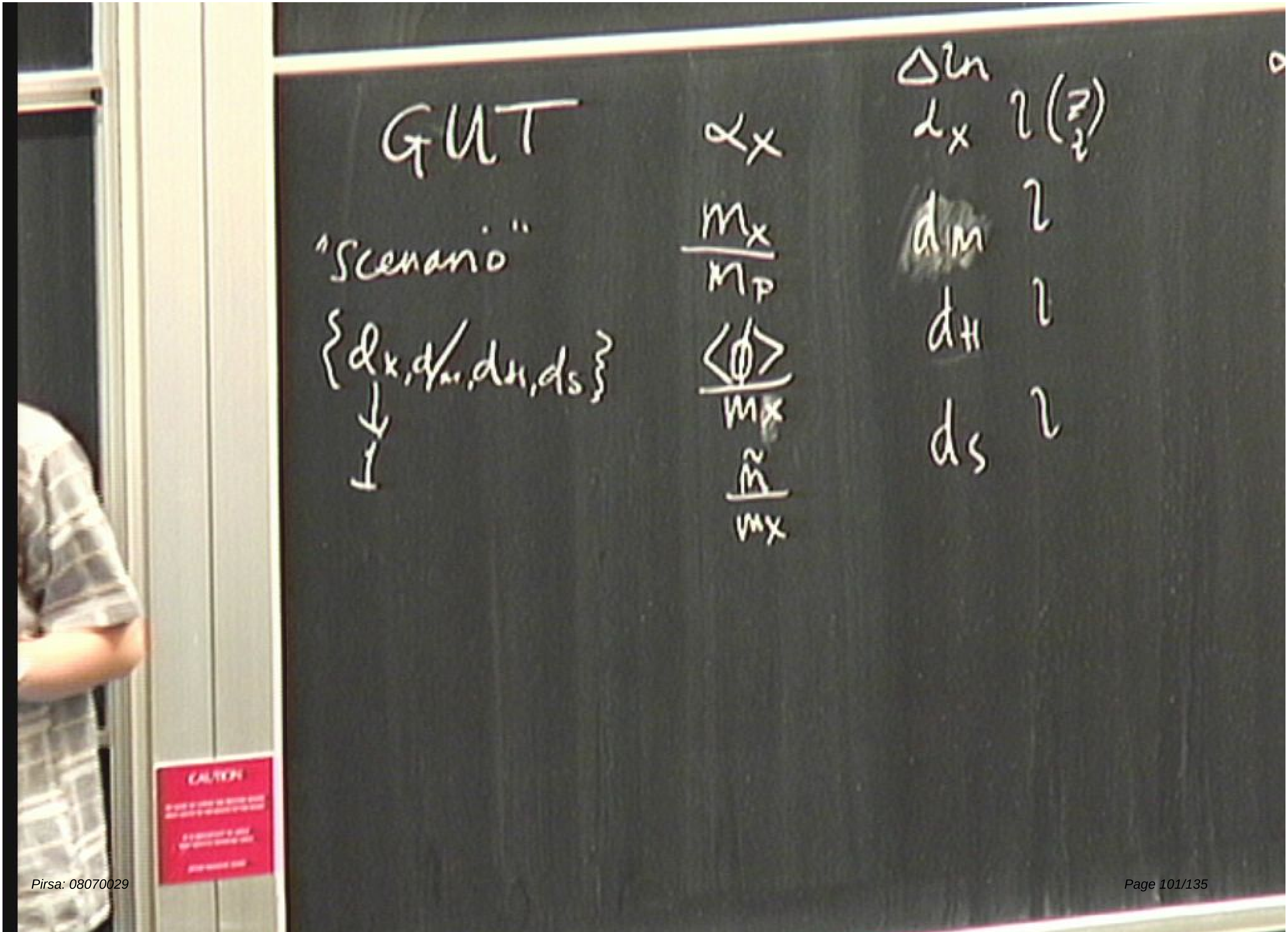

αx
mx / mp
⟨φ⟩ / mp
Δln
dx
dm
α⁻¹
α1⁻¹
α2⁻¹
α3⁻¹

GUT

"Scenario"

$\{d_X, d_m, d_H, d_s\}$

		$\Delta \ln$
α_X	d_X	l (? ?)
$\frac{m_X}{M_P}$	d_m	l
$\frac{\langle\phi\rangle}{m_X}$	d_H	l
$\frac{\tilde{m}}{m_X}$	d_s	l


GUT
"Scenario"
{α_X, α_M, α_H, α_S}
1
α_X
M_X / M_P
⟨φ⟩ / M_X
m̃ / M_X
Δln
α_X 1
α_M 1
α_H 1
α_S 1
CAUTION

GUT α_X d_X ?(?)

"Scenario" $\dfrac{m_X}{M_P}$ d_M ?

$\{\alpha_X, d_M, d_H, d_S\}$ $\dfrac{\langle\phi\rangle}{m_X}$ d_H ?

$\downarrow$ d_S ?

1 $\dfrac{\tilde{m}}{m_X}$

Den... $\Delta \ln \left\{ \dfrac{\Lambda}{m_X}, \dfrac{m_e}{\Lambda}, \dfrac{m_q}{\Lambda} \right\}$

GUT $\qquad \alpha_X \qquad d_X \quad l(?)$

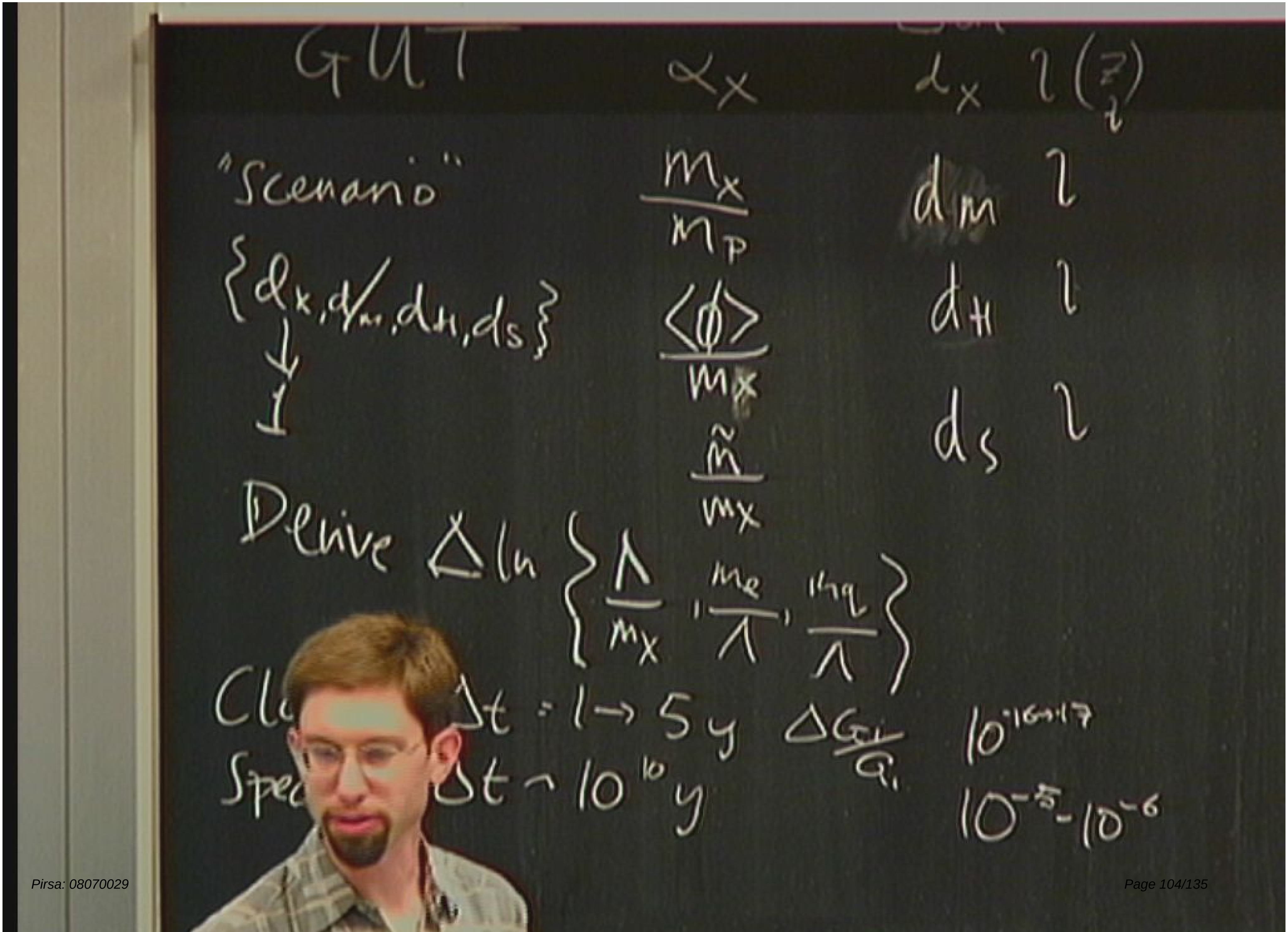
"Scenario" $\qquad \dfrac{m_X}{M_P} \qquad d_M \quad l$

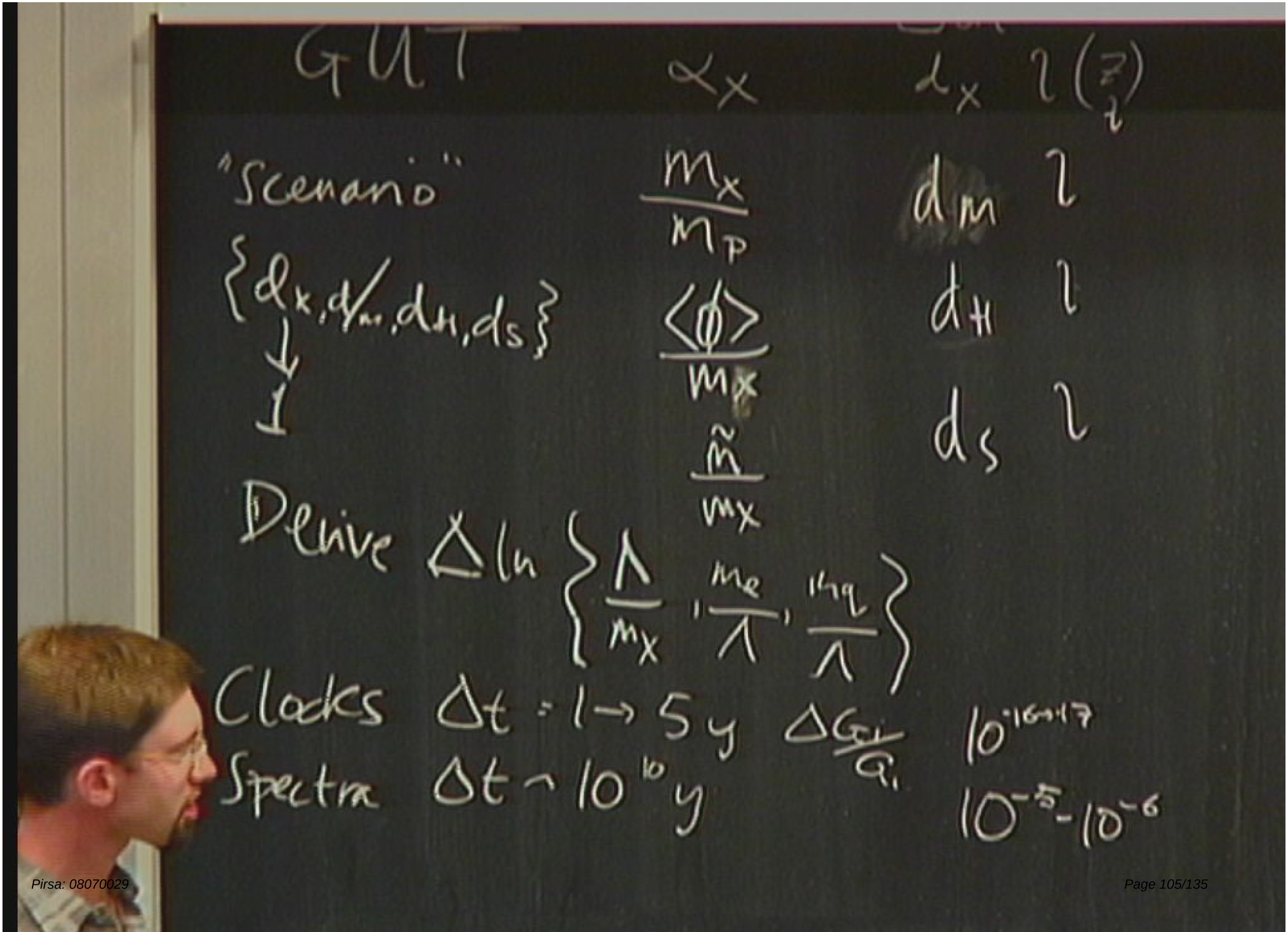
$\{d_X, d_M, d_H, d_S\} \qquad \dfrac{\langle\phi\rangle}{m_X} \qquad d_H \quad l$

$\downarrow \qquad \dfrac{\tilde{m}}{m_X} \qquad d_S \quad l$

$\perp$

Derive $\Delta \ln \left\{ \dfrac{\Lambda}{m_X}, \dfrac{m_e}{\Lambda}, \dfrac{m_q}{\Lambda} \right\}$


GUT
"Scenario"
{dx, dm, dH, ds}
Derive Δ ln {Λ/mx, me/Λ, mq/Λ}
Δt ~ 1 → 5 y
Δt ~ 10^10 y
10^-16→-17
10^-5 - 10^-6


GUT
α_x
d_x 1 (?)
"Scenario"
$\{d_x, d_{m}, d_H, d_s\}$
$\downarrow$
1
$\frac{m_x}{m_p}$ d_m 1
$\frac{\langle\phi\rangle}{m_x}$ d_H 1
$\frac{\tilde{m}}{m_x}$ d_s 1
Derive $\Delta \ln \left\{ \frac{\Lambda}{m_x}, \frac{m_e}{\Lambda}, \frac{m_q}{\Lambda} \right\}$
Clocks $\Delta t \sim 1 \to 5\,y$ $\Delta \frac{G_1}{G_1}$ $10^{-16 \to -17}$
Spectra $\Delta t \sim 10^{10}\,y$ $10^{-5} - 10^{-6}$

GUT $\quad \alpha_X \quad d_X \quad l\,(\frac{Z}{l})$

"Scenario" $\quad \frac{m_X}{m_P} \quad d_m \quad l$

$\{d_X, \cancel{d_m}, d_H, d_S\} \quad \frac{\langle\phi\rangle}{m_X} \quad d_H \quad l$

$\downarrow$

$1 \quad d_S \quad l$

$\frac{\tilde{m}}{m_X}$

Derive $\Delta \ln \left\{ \frac{\Lambda}{m_X}, \frac{m_e}{\Lambda}, \frac{m_q}{\Lambda} \right\}$

Clocks $\Delta t \sim 1 \to 5\,y \quad \Delta \frac{G_{r}}{G_{i}} \quad 10^{-16 \to -17}$

Spectra $\Delta t \sim 10^{10}\,y \quad 10^{-5} - 10^{-6}$

Oklo*

GUT $\quad \alpha_X \quad d_X \; 1\binom{?}{1}$

"Scenario" $\quad \frac{m_X}{m_P} \quad d_m \; 1$

$\{d_X, d/_m, d_H, d_S\}$ $\quad \frac{\langle\phi\rangle}{m_X} \quad d_H \; 1$

$\downarrow$

$1 \quad d_S \; 1$

$\frac{\tilde{m}}{m_X}$

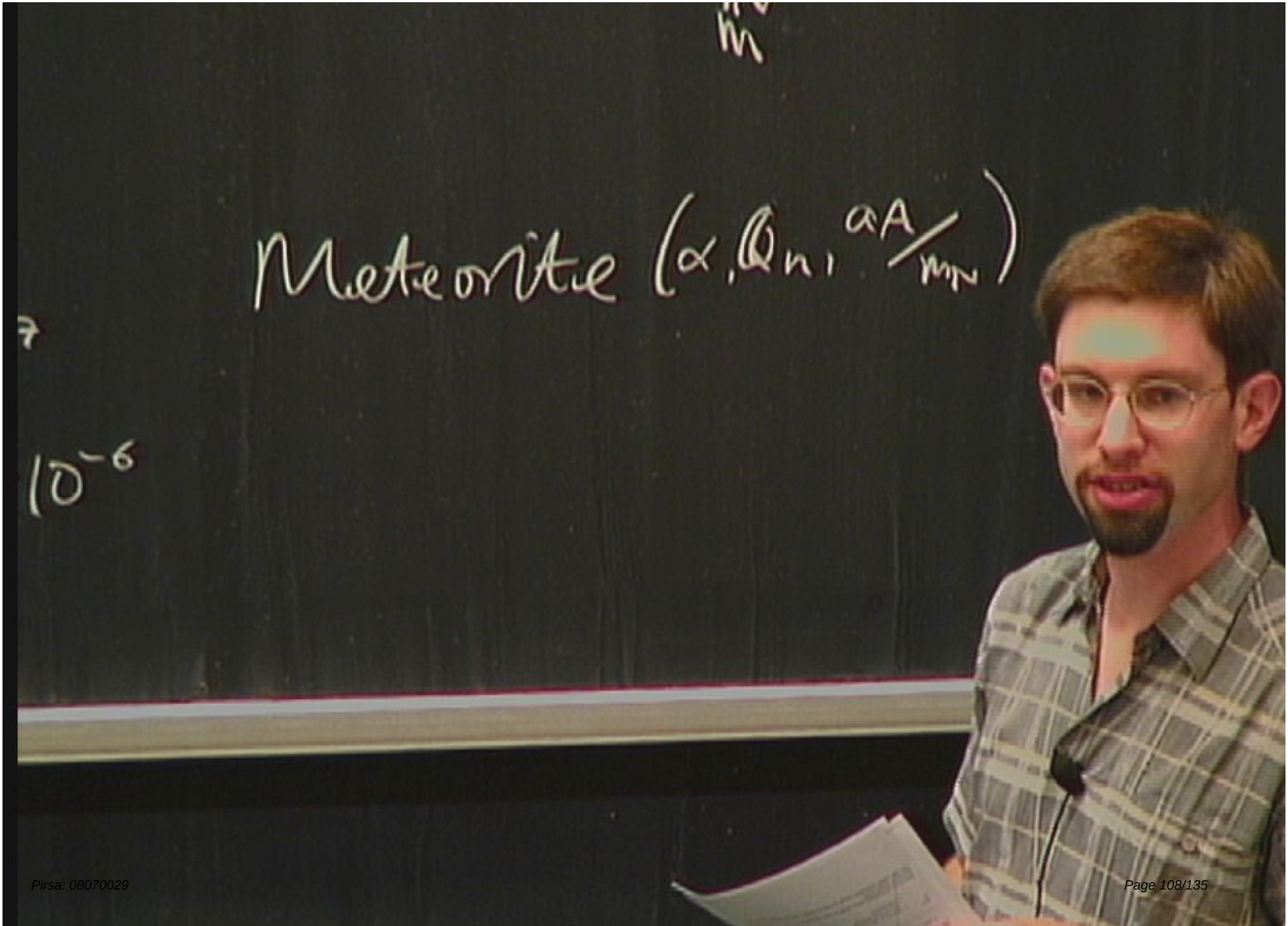
Derive $\Delta \ln \left\{ \frac{\Lambda}{m_X}, \frac{m_e}{\Lambda}, \frac{m_q}{\Lambda} \right\}$

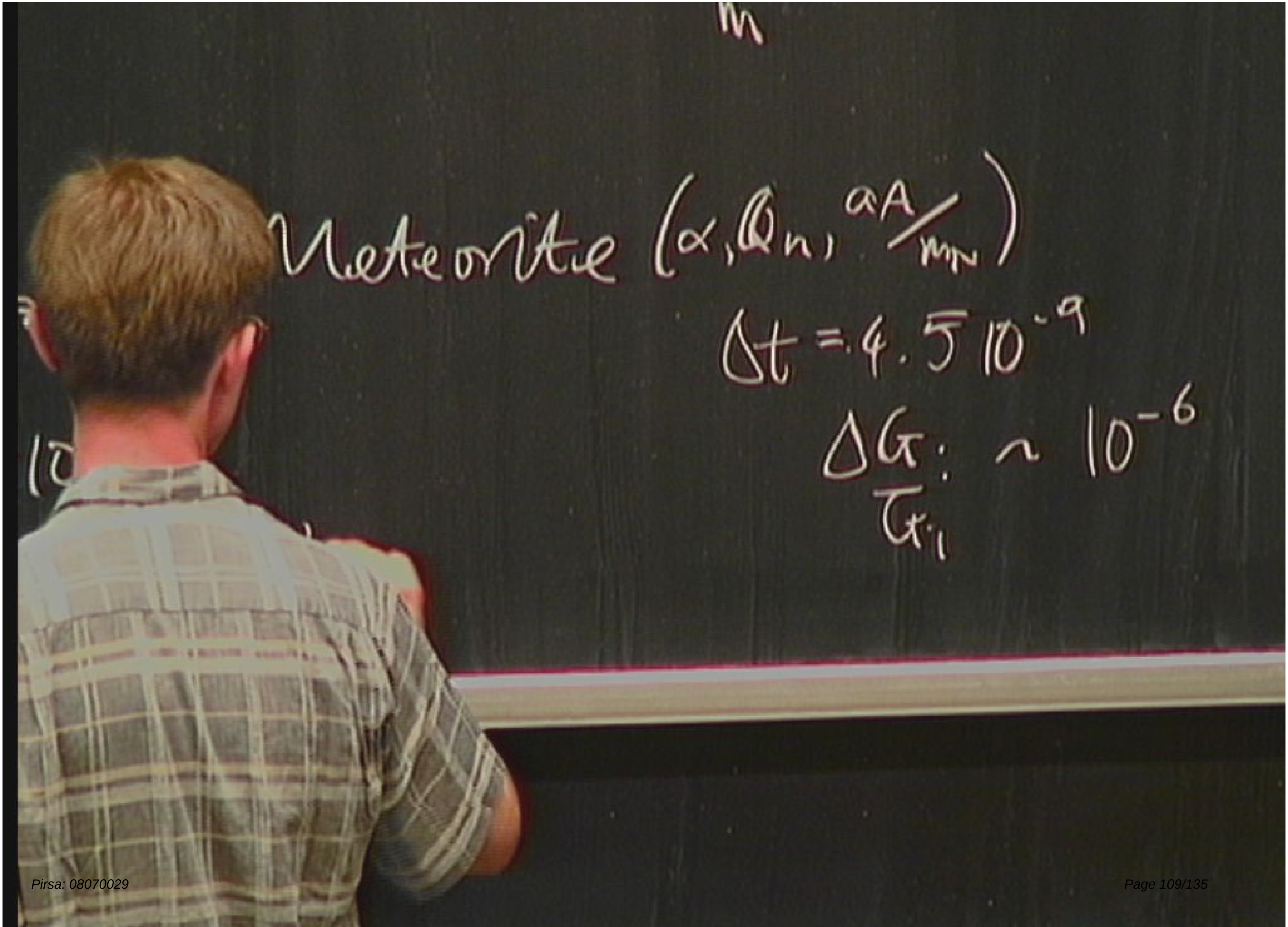
Clocks $\Delta t = 1 \to 5y \quad \Delta G_i / G_i \quad 10^{-16 \to -17}$

Spectra $\Delta t \sim 10^{10} y \quad 10^{-5} - 10^{-6}$

Oklo* $\Delta t \sim 2 \cdot 10^{9} y \quad 10^{-7 \to -8}$

Me


Meteorite (α, Q_n, $\alpha A / m_N$)
10^{-6}


Meteorite (α, Qn, αA/mn)
Δt = 4.5 10^-9
ΔG: ~ 10^-6

Meteorite $(\alpha, Q_n, {}^{aA}/_{m_N})$

$16 \cdot 1 \, 7$

$\Delta t = 4.5 \, 10^{-9}$

$\frac{\Delta G}{G_i} : \sim 10^{-6}$

$-5 - 10^{-6}$

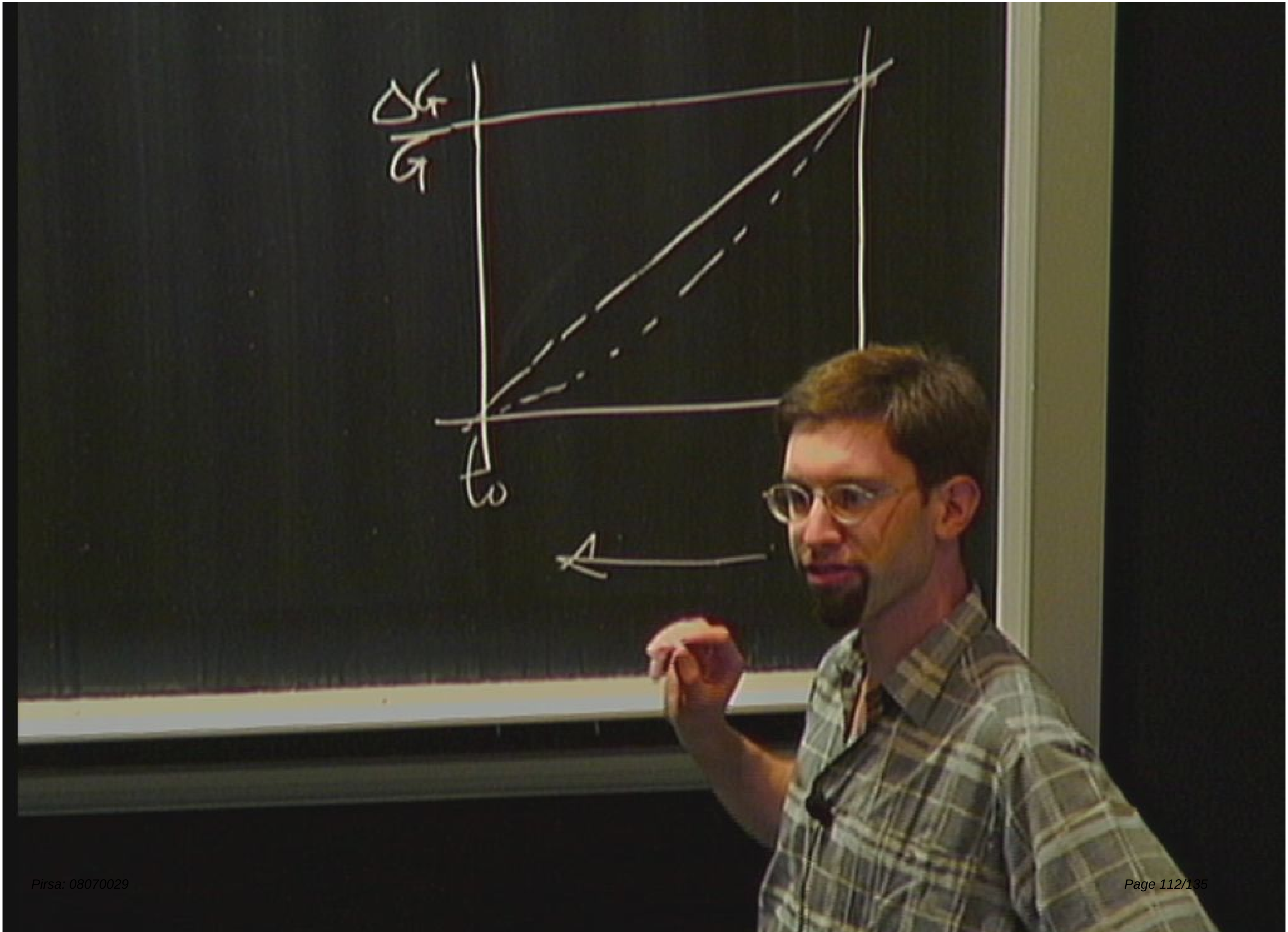
WEP t_0 = now $\dot{\varphi} \le \dot{\varphi}_{max} \simeq 5 \times 10^{-11}$

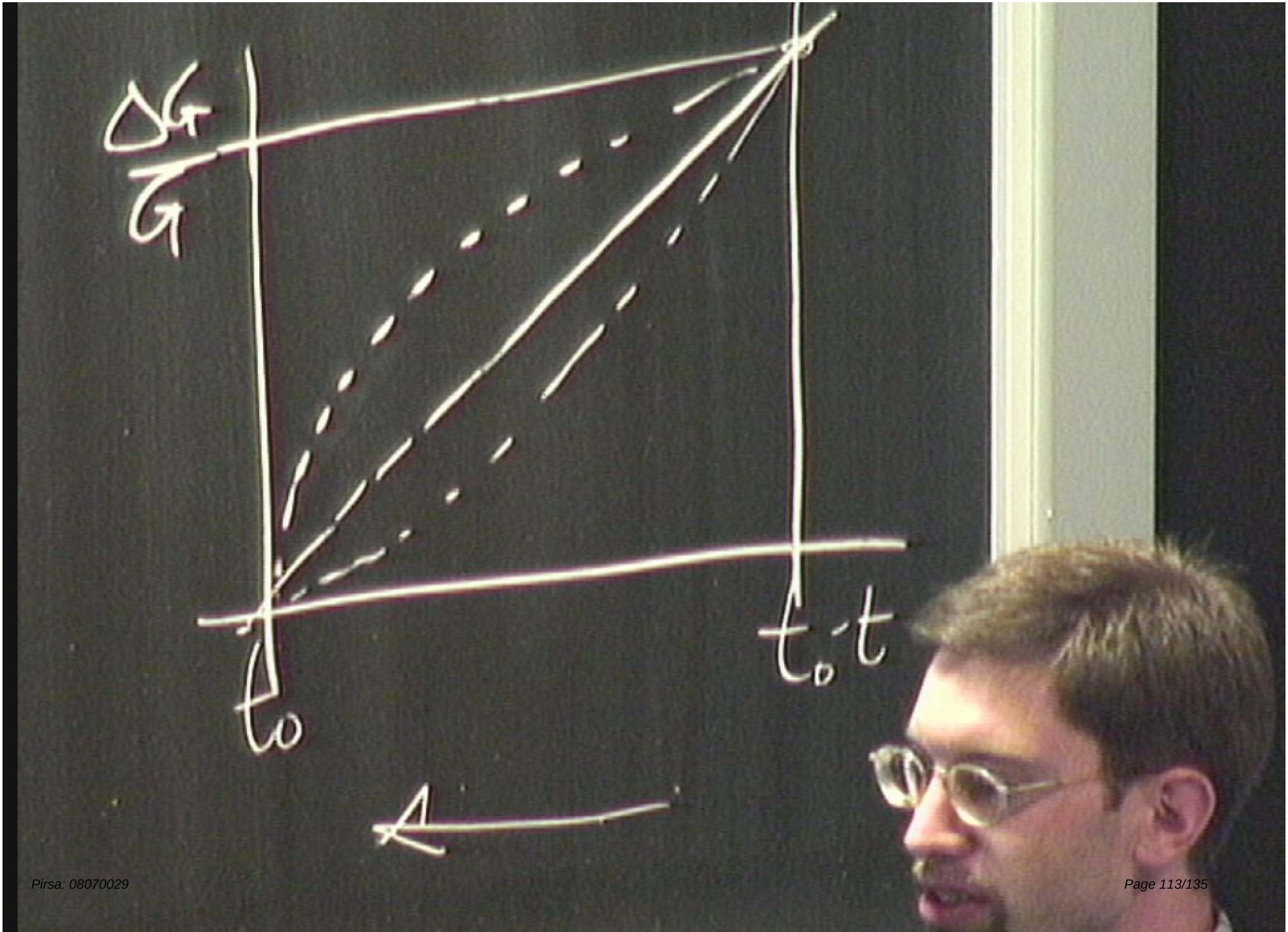
Meteorite $(\alpha, Q_n, {}^{aA}/_{m_N})$

$\Delta t = 4.5\ 10^{-9}$

$\frac{\Delta G}{G_{t_1}} \sim 10^{-6}$

WEP $t_0 = \text{now}$ $\dot{\varphi} \leq \dot{\varphi}_{max} \simeq 5 \times 10^{-11}/y$


ΔG
G
t0

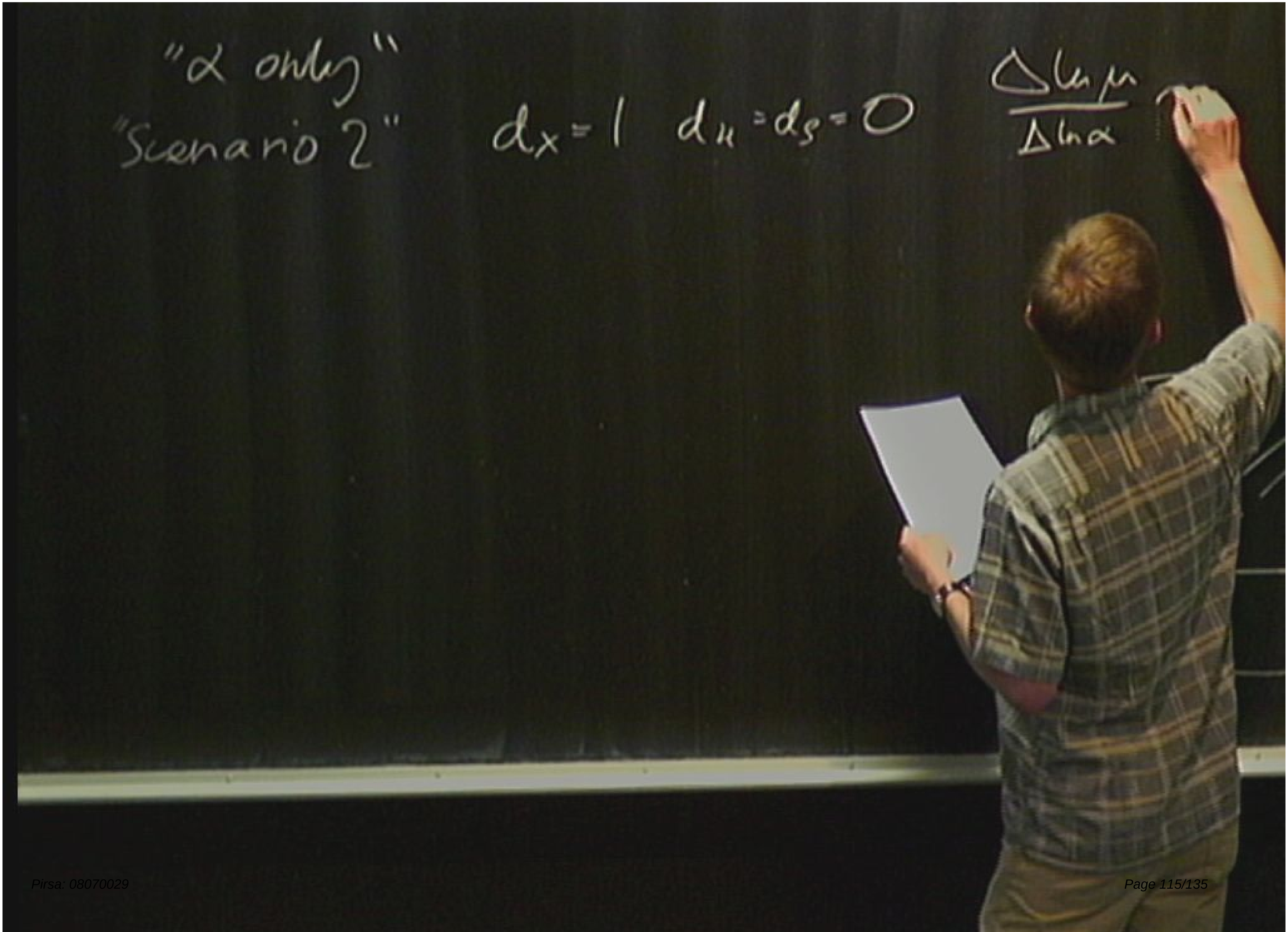


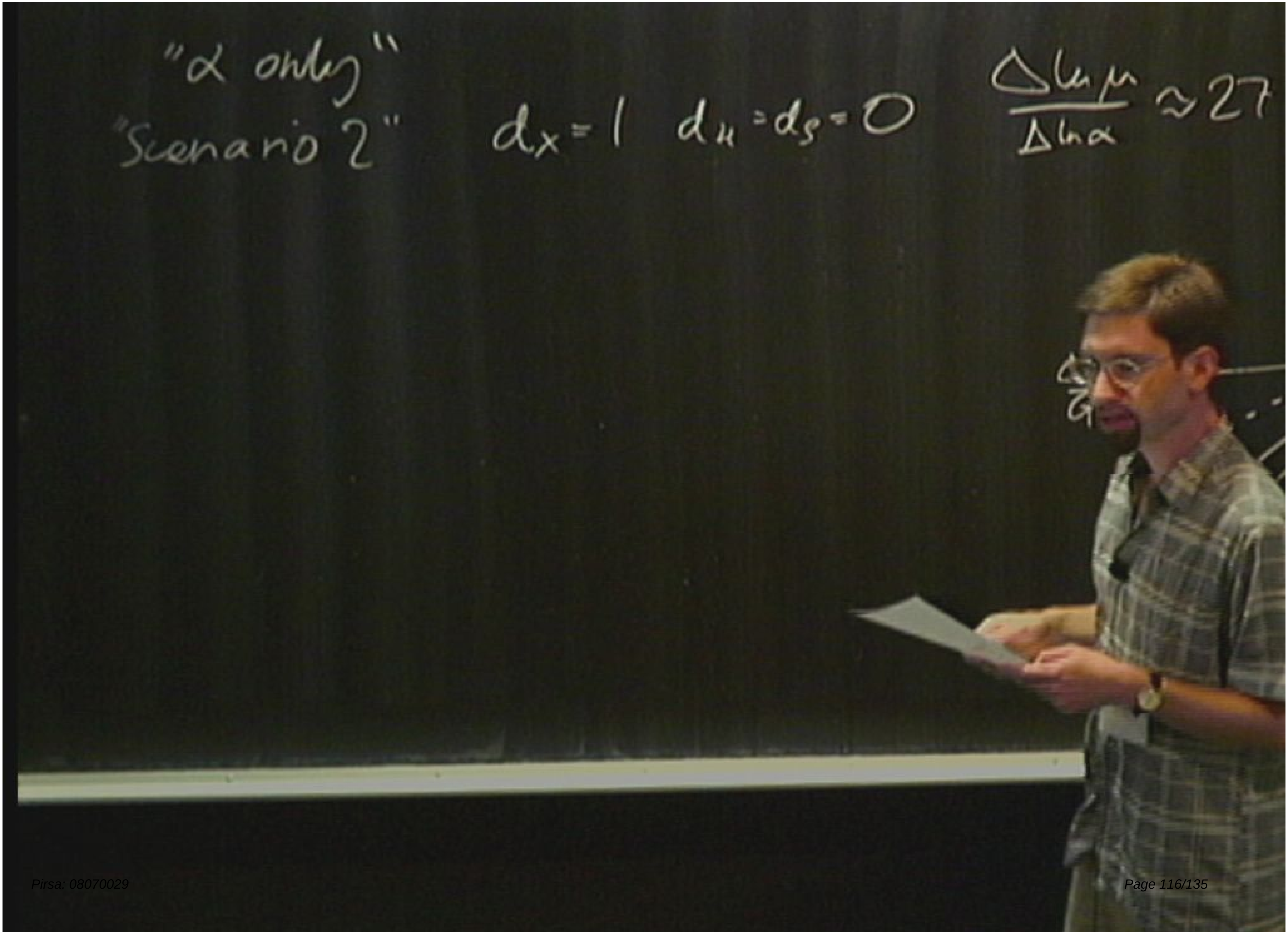
ΔG
G
t₀
t₀-t

Scenario	X	Clocks	WEP	Oklo	Meteorite	Astro
α only	α	0.13 (α)	12	0.033	0.32	0.44 (y)
2	α_X	0.074 (μ)	0.014	0.039	0.015	0.013 (NH_3)
2S	α_X	0.12 (μ)	0.023	0.064	0.026	0.022 (NH_3)
3	$\langle\phi\rangle/M_X$	2.6 (μ)	0.67	18	0.53	0.47 (NH_3)
4	$\langle\phi\rangle/M_X$	6.2 (μ)	0.71	2.6	1.2	1.1 (NH_3)
5, $\tilde{\gamma} = 42$	α_X	0.32 (α)	0.025	0.035	0.069	0.075 (NH_3)
6, $\tilde{\gamma} = 70$	α_X	0.21 (α)	0.016	0.023	0.049	0.054 (NH_3)
6, $\tilde{\gamma} = 25$	α_X	0.25 (μ)	0.022	0.040	0.056	0.044 (NH_3)

Table 4: Competing bounds on recent time variations in unified scenarios. For each scenario we give 1σ uncertainties of bounds on $d(\ln X)/dt$ in units $10^{-15}\mathrm{y}^{-1}$, where X is the appropriate fundamental parameter. The column "Clocks" indicates whether α or μ gives the stronger bound, the column "Astro" indicates which measurements of astrophysical spectra are currently most sensitive.

At present these methods give null results up to redshifts about 0.8, but if a nonzero time variation exists, we can determine for each unified scenario which

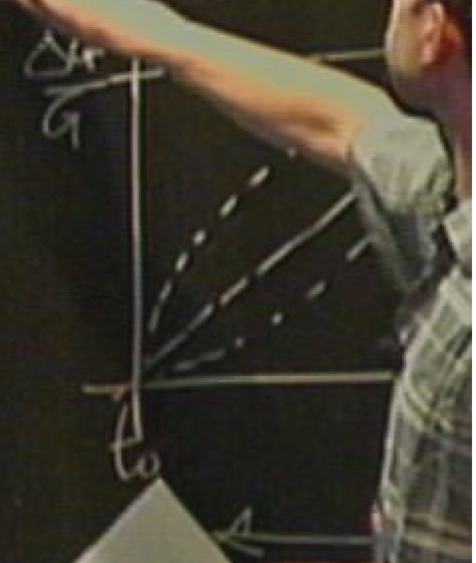

"α only"
"Scenario 2"
$d_x = 1 \quad d_\mu = d_q = 0$
$\frac{\Delta \ln \mu}{\Delta \ln \alpha}$

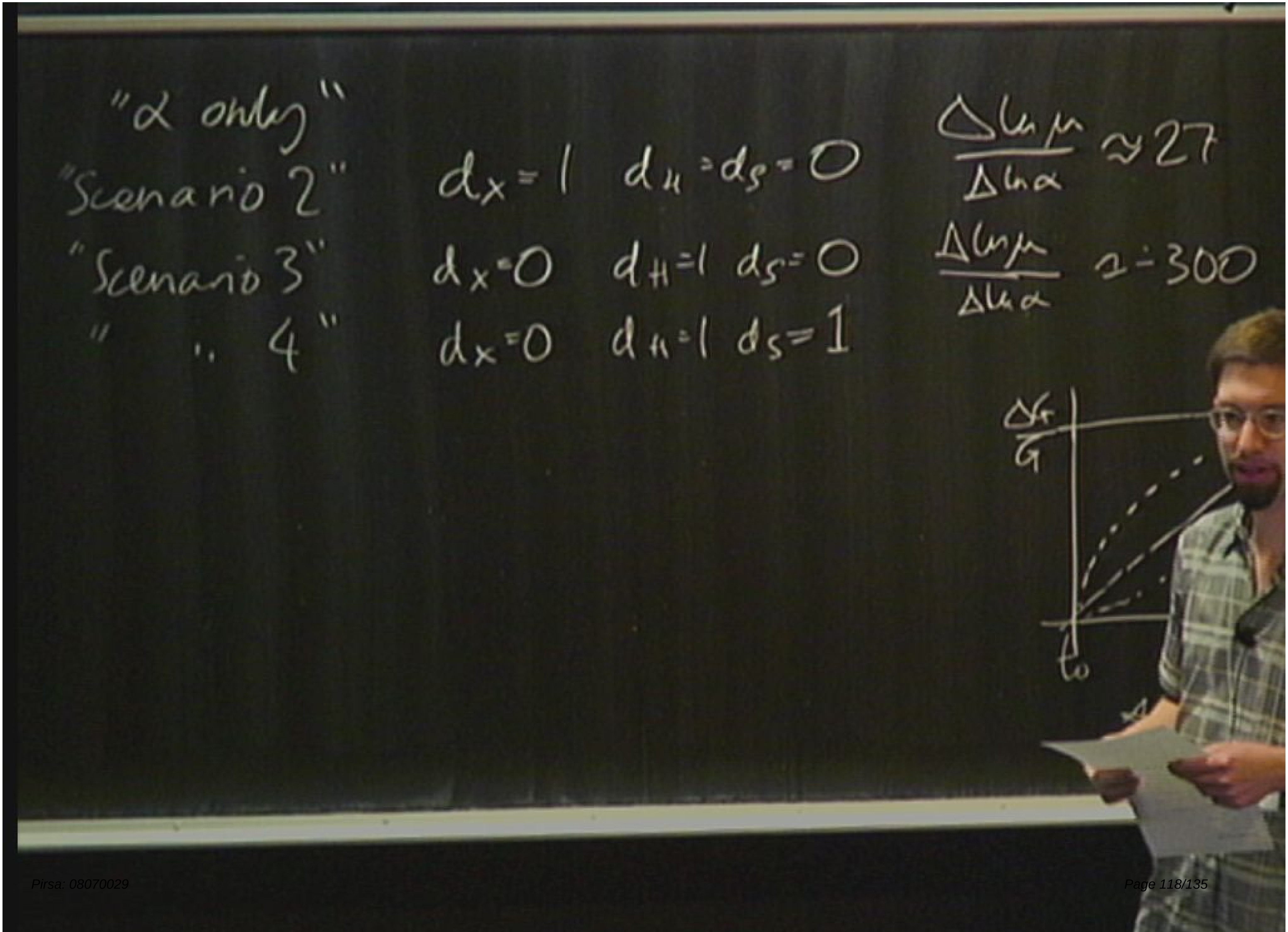

"α only"
"Scenario 2"
$d_X = 1 \quad d_H = d_S = 0$
$\frac{\Delta \ln \mu}{\Delta \ln \alpha} \approx 27$

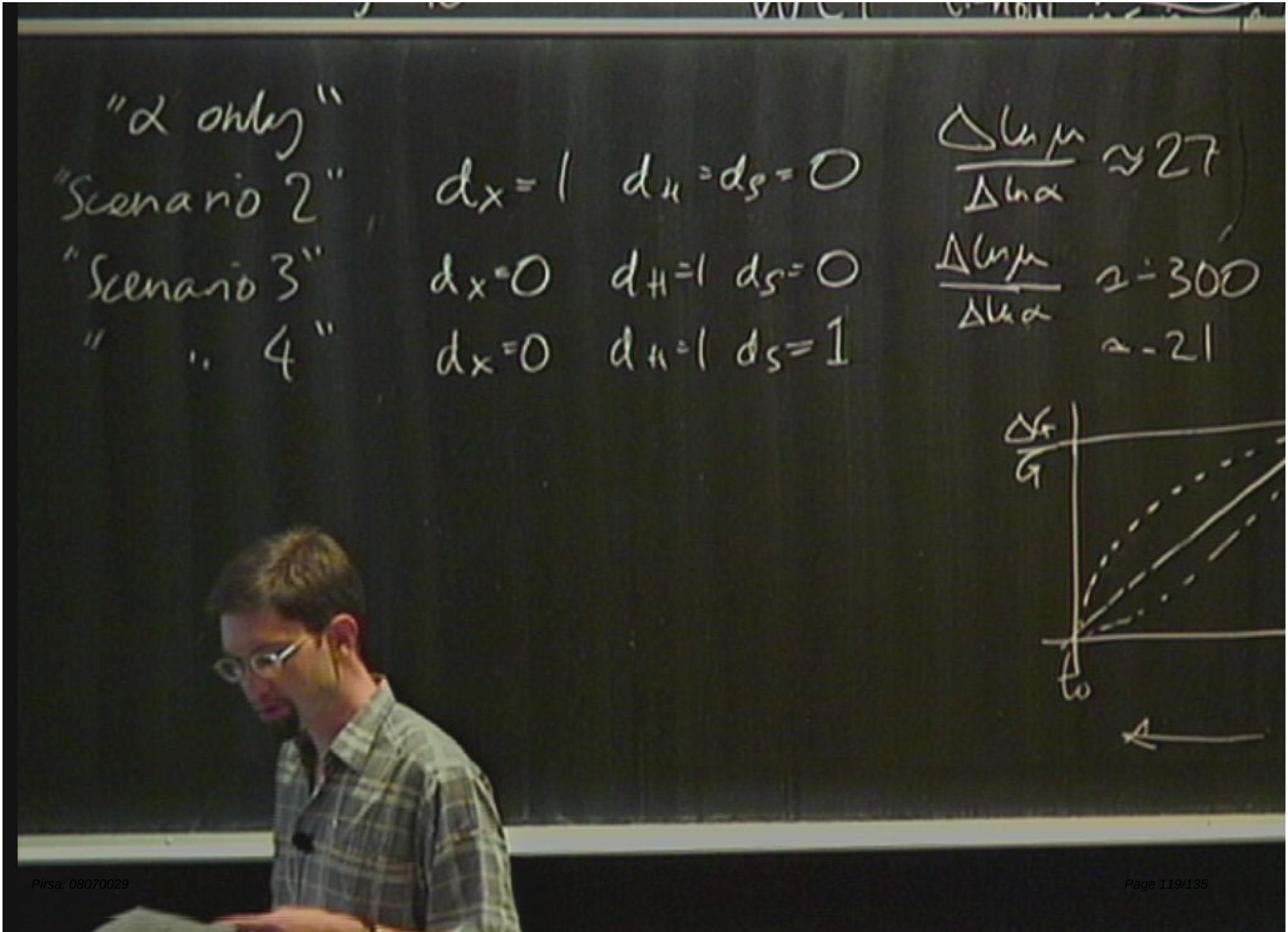
"α only"

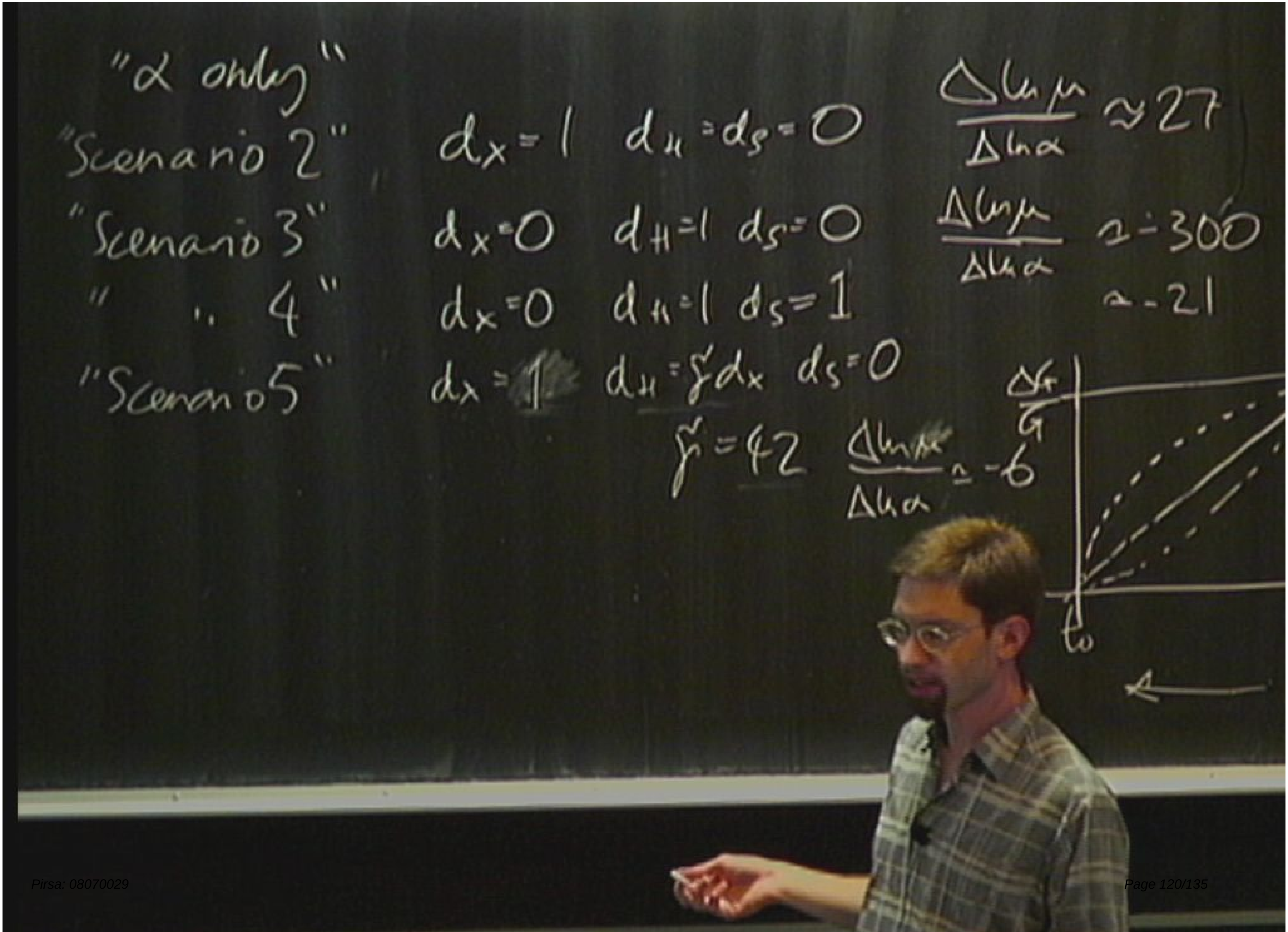
"Scenario 2" $\quad d_x = 1 \quad d_H = d_S = 0 \quad \dfrac{\Delta \ln \mu}{\Delta \ln \alpha} \simeq 27$

"Scenario 3" $\quad d_x = 0 \quad d_H = 1 \quad d_S = 0 \quad \dfrac{\Delta \ln \mu}{\Delta \ln \alpha} \simeq 300$




"α only"
"Scenario 2" $d_x = 1$ $d_H = d_S = 0$ $\frac{\Delta \ln \mu}{\Delta \ln \alpha} \simeq 27$
"Scenario 3" $d_x = 0$ $d_H = 1$ $d_S = 0$ $\frac{\Delta \ln \mu}{\Delta \ln \alpha}$ 1 ÷ 300
" " 4 " $d_x = 0$ $d_H = 1$ $d_S = 1$
$\frac{\Delta G}{G}$
t_0


"α only"
"Scenario 2" $d_X = 1$ $d_H = d_S = 0$ $\frac{\Delta \ln \mu}{\Delta \ln \alpha} \gtrsim 27$
"Scenario 3" $d_X = 0$ $d_H = 1$ $d_S = 0$ $\frac{\Delta \ln \mu}{\Delta \ln \alpha} \simeq -300$
" " 4 " $d_X = 0$ $d_H = 1$ $d_S = 1$ $\simeq -21$
t_0


"α only"
"Scenario 2" $d_X = 1$ $d_H = d_S = 0$ $\frac{\Delta \ln \mu}{\Delta \ln \alpha} \approx 27$
"Scenario 3" $d_X = 0$ $d_H = 1$ $d_S = 0$ $\frac{\Delta \ln \mu}{\Delta \ln \alpha} \simeq -300$
" " 4 " $d_X = 0$ $d_H = 1$ $d_S = 1$ $\simeq -21$
"Scenario 5" $d_X = 1$ $d_H = \tilde{\gamma} d_X$ $d_S = 0$
$\tilde{\gamma} = 42$ $\frac{\Delta \ln \mu}{\Delta \ln \alpha} \simeq -6$
t_0

Adobe Reader - [unifyingApril.pdf]

Scenario	X	Clocks	WEP	Oklo	Meteorite	Astro
α only	α	0.13 (α)	12	0.033	0.32	0.44 (y)
2	α_X	0.074 (μ)	0.014	0.039	0.015	0.013 (NH_3)
2S	α_X	0.12 (μ)	0.023	0.064	0.026	0.022 (NH_3)
3	$\langle\phi\rangle/M_X$	2.6 (μ)	0.67	18	0.53	0.47 (NH_3)
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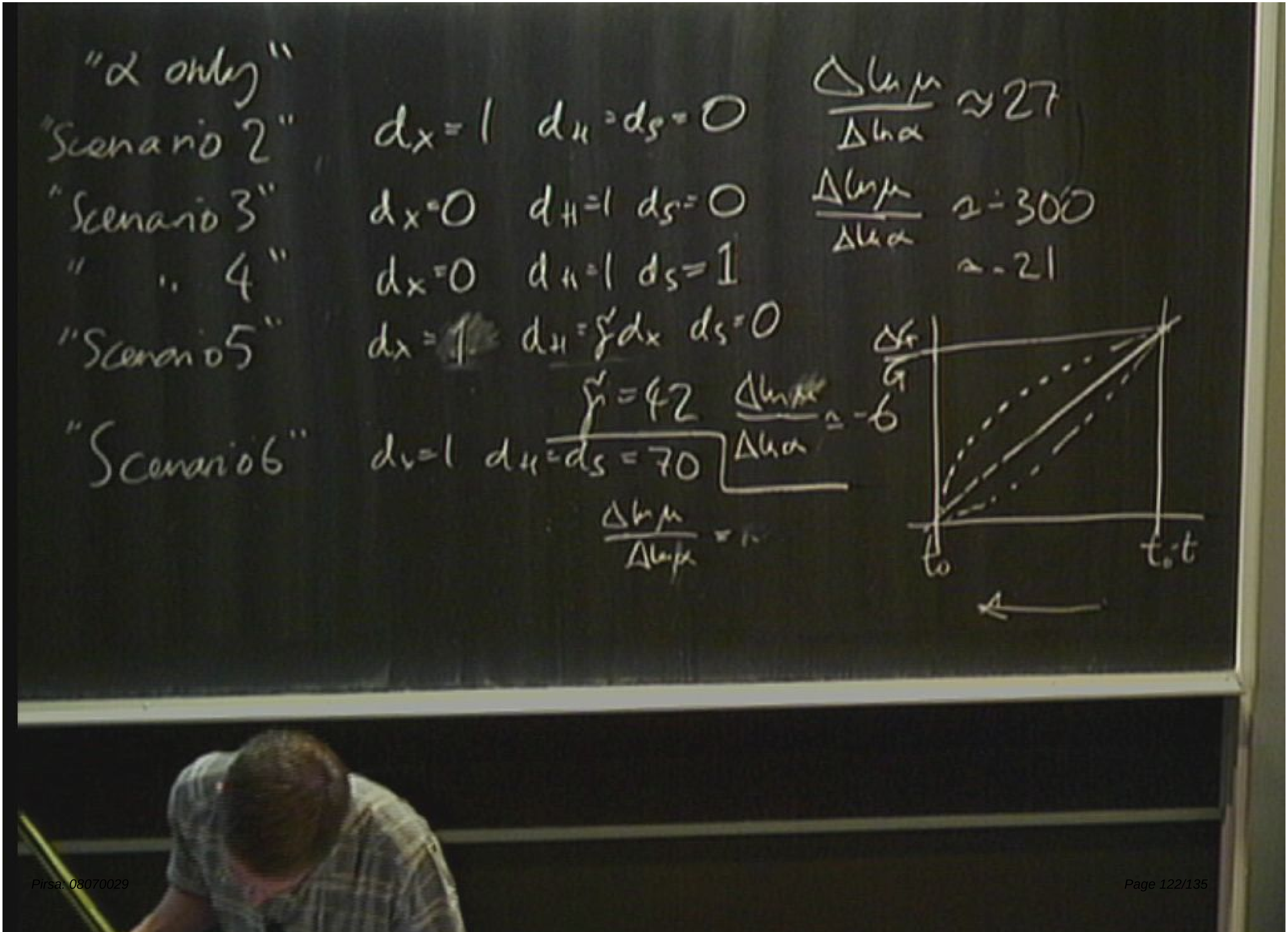
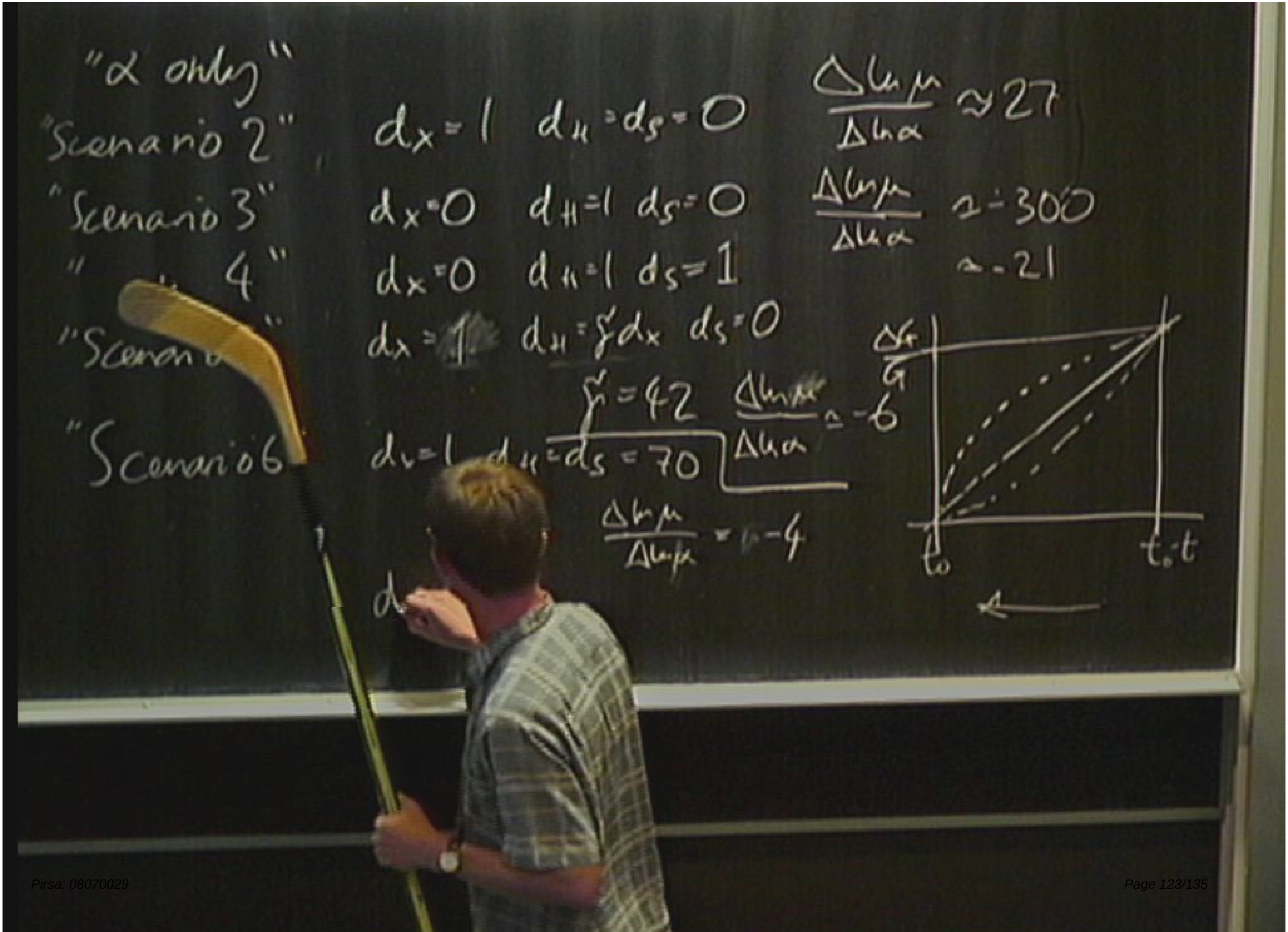
8.26 x 11.69 in

29 of 42


"α only"
"Scenario 2" dx=1 dH=dS=0 Δlnμ/Δlnα ≃ 27
"Scenario 3" dx=0 dH=1 dS=0 Δlnμ/Δlnα ≃ -300
" " 4" dx=0 dH=1 dS=1 ≃ -21
"Scenario 5" dx=1 dH=ζdx dS=0
ζ=42 Δlnμ/Δlnα ≃ -6
"Scenario 6" dx=1 dH=dS=70
Δlnμ/Δlnμ
t0
t0-t


"α only"
"Scenario 2"
$d_X = 1$ $d_H = d_S = 0$
$\frac{\Delta \ln \mu}{\Delta \ln \alpha} \approx 27$
"Scenario 3"
$d_X = 0$ $d_H = 1$ $d_S = 0$
$\frac{\Delta \ln \mu}{\Delta \ln \alpha} \approx -300$
"4"
$d_X = 0$ $d_H = 1$ $d_S = 1$
≈ -21
$d_X = 1$ $d_H = \tilde{\gamma} d_X$ $d_S = 0$
$\tilde{\gamma} = 42$
$\frac{\Delta \ln \mu}{\Delta \ln \alpha} \approx -6$
"Scenario 6"
$d_X = 1$ $d_H = d_S = 70$
$\frac{\Delta \ln \mu}{\Delta \ln \mu} \approx -4$
$\frac{\Delta G}{G}$
t_0
$t_0 - t$

"α only"

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"Scenario 3" $\quad d_x = 0 \quad d_H = 1 \quad d_S = 0 \quad \frac{\Delta \ln \mu}{\Delta \ln \alpha} \approx -300$

" " 4" $\quad d_x = 0 \quad d_H = 1 \quad d_S = 1 \quad \approx -21$

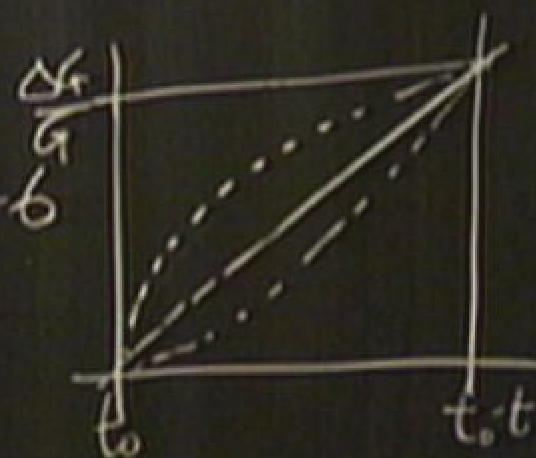
"Scenario 5" $\quad d_x = 1 \quad d_H = \xi d_x \quad d_S = 0$

$\xi = 42 \quad \frac{\Delta \ln \mu}{\Delta \ln \alpha} \approx -6$

"Scenario 6" $\quad d_x = 1 \quad d_H = d_S = 70$

$\frac{\Delta \ln \mu}{\Delta \ln \mu} \approx -4$

$\lambda \quad d_H = d_S = 25 \quad \frac{\Delta \ln \mu}{\Delta \ln \alpha} \approx +8$



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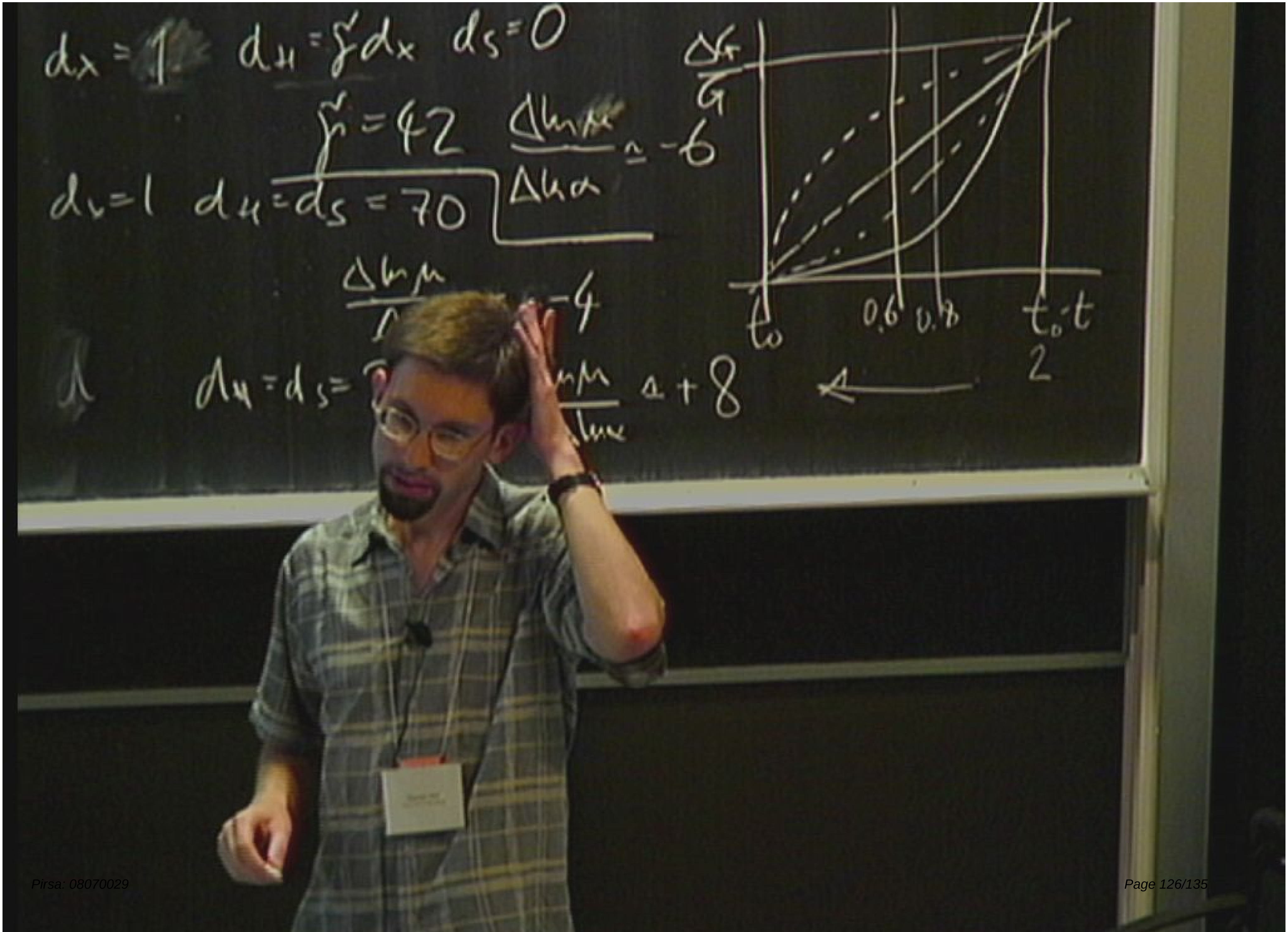
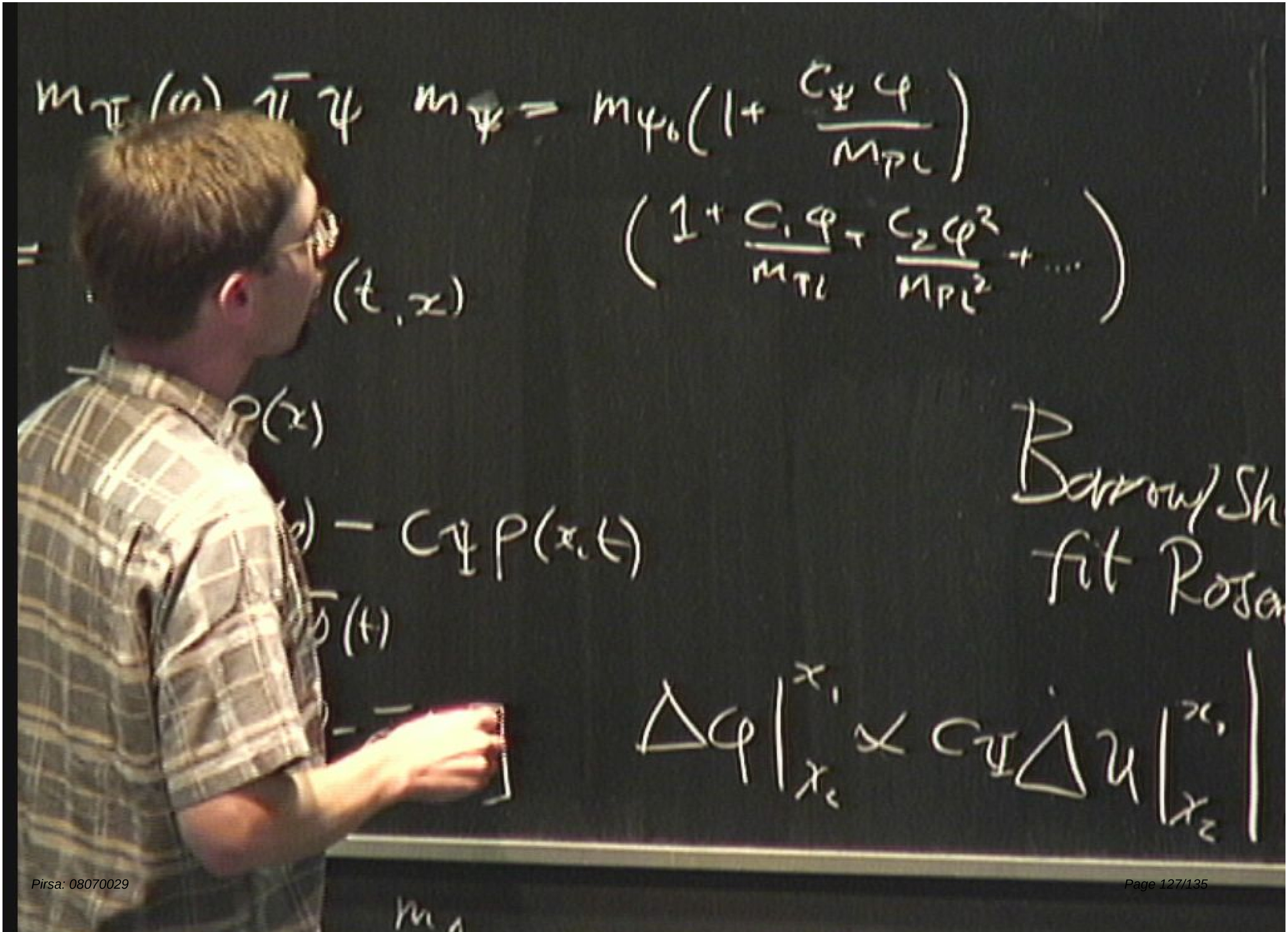
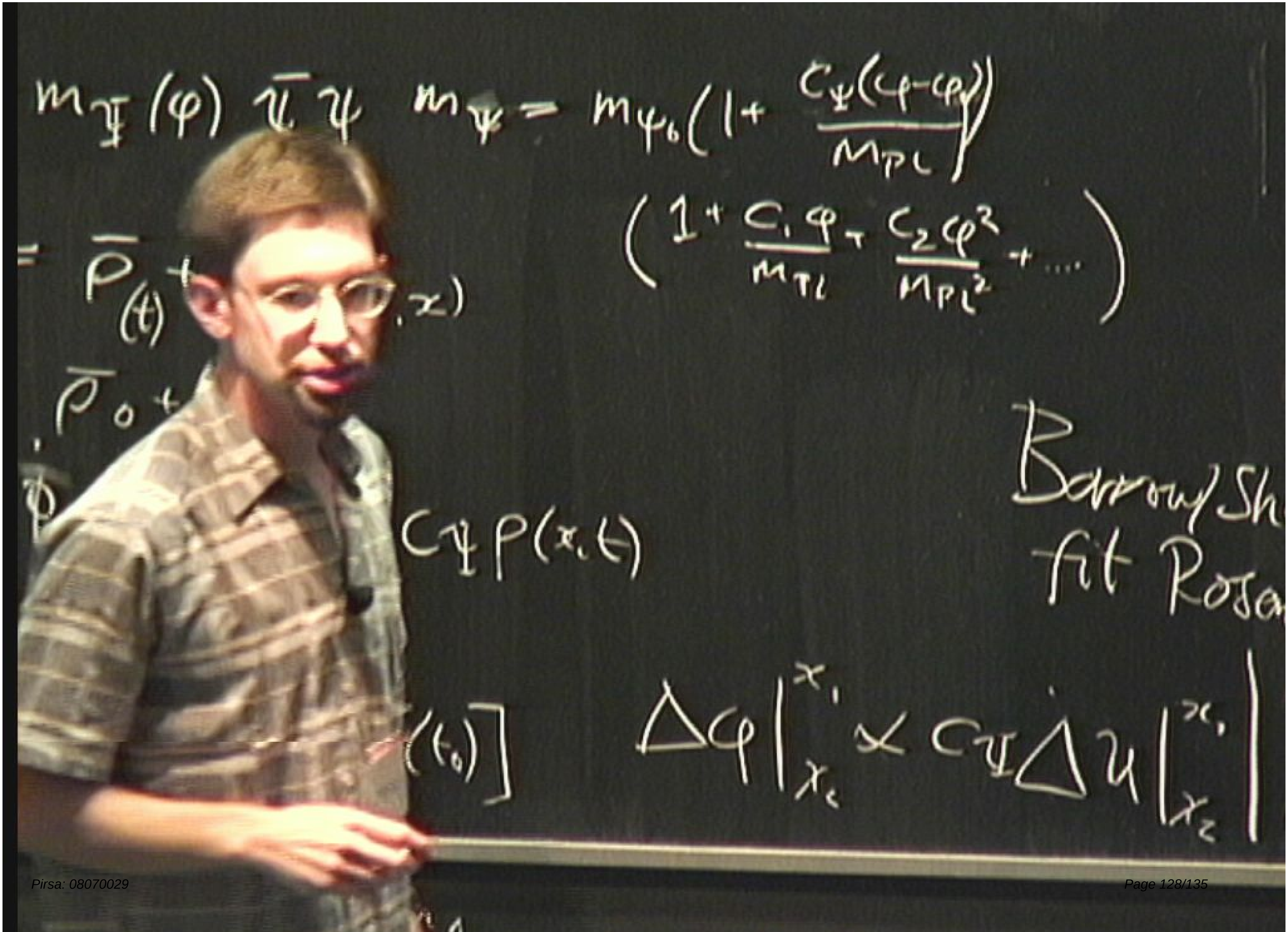
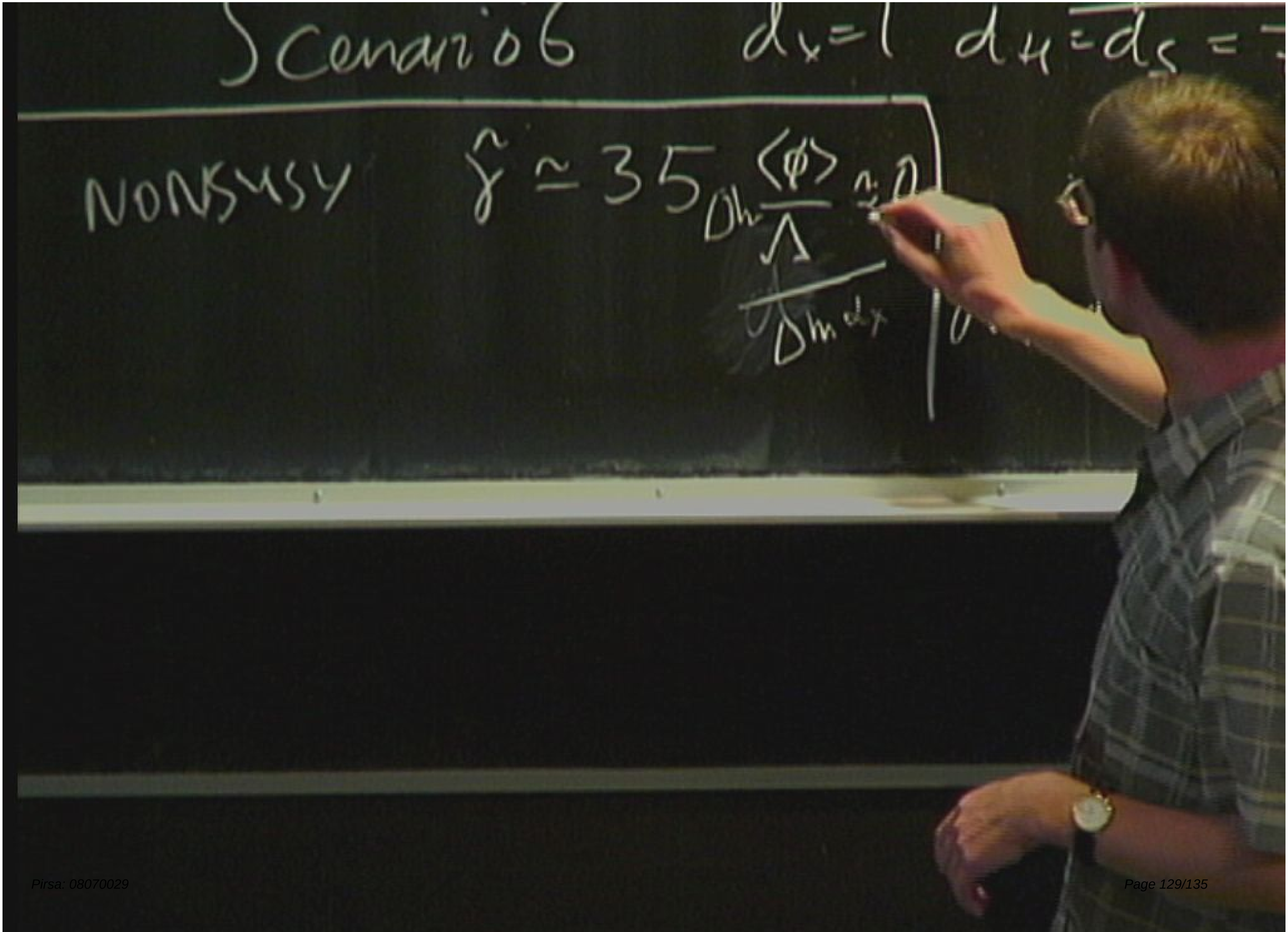
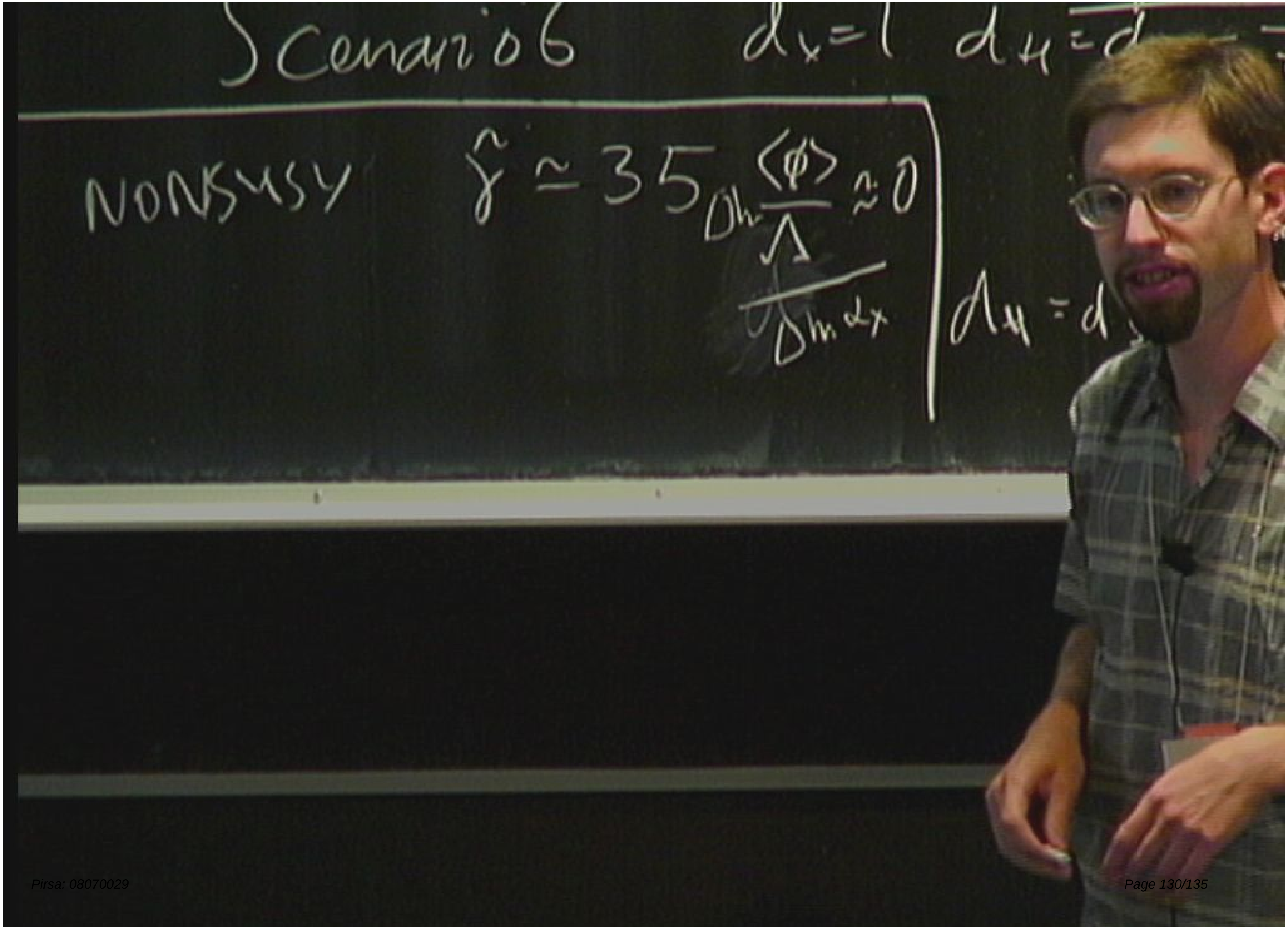


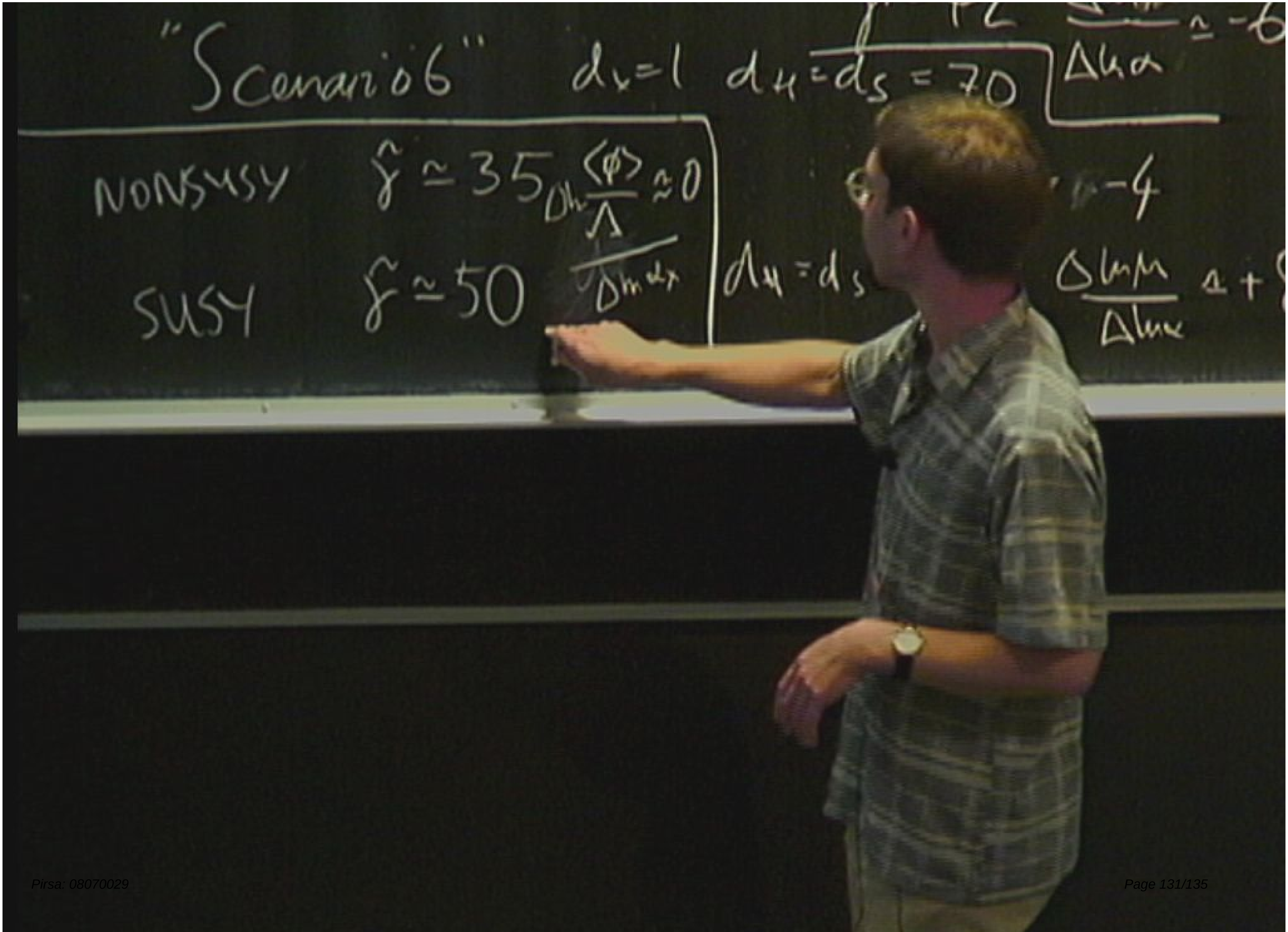
dx = 1 dH = ξ dx ds = 0
ξ = 42
≃ −6
dv = 1 dH = ds = 70
0.6 0.8
t0 t0 − t
2
+ 8


$m_\Psi(\varphi)\bar{\Psi}\psi \quad m_\Psi = m_{\psi_0}\left(1 + \frac{c_\Psi \varphi}{M_{Pl}}\right)$
$\left(1 + \frac{c_1 \varphi}{M_{Pl}} + \frac{c_2 \varphi^2}{M_{Pl}^2} + \dots\right)$
(t, x)
$\rho(x)$
$- c_\Psi \rho(x, t)$
(t)
Barrow/Sh
fit Rosa
$\Delta\varphi\Big|_{x_2}^{x_1} \propto c_\Psi \Delta u\Big|_{x_2}^{x_1}$


$m_\Psi(\varphi)\,\bar{\psi}\,\psi \quad m_\psi = m_{\psi_0}\left(1 + \frac{c_\Psi(\varphi-\varphi_0)}{M_{Pl}}\right)$
$\left(1 + \frac{c_1\varphi}{M_{Pl}} + \frac{c_2\varphi^2}{M_{Pl}^2} + \dots\right)$
$c_\Psi\,\rho(x,t)$
$\Delta\varphi\Big|_{x_2}^{x_1} \propto c_\Psi\,\Delta u\Big|_{x_2}^{x_1}$


Scenario 6
NONSUSY


Scenario 6
NONSUSY
≃ 35
≃ 0


"Scenario 6"
d_x = 1 d_H = d_S = 70
NONSUSY
SUSY
ξ ≃ 35
ξ ≃ 50

Scenarios

NONSUSY $\quad \xi \simeq 35 \quad \Delta m \frac{\langle \phi \rangle}{\Lambda} \simeq 0$

SUSY $\quad \xi \simeq 50 \quad \Delta m\, \alpha_x$

α_x

Scenarios

NONSUSY $\hat{\xi} \simeq 35$ $\quad \Delta m \quad \frac{\langle\phi\rangle}{\Lambda} \simeq 0$

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α_x

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