Title: Explorations in Particle Theory - Lecture 6

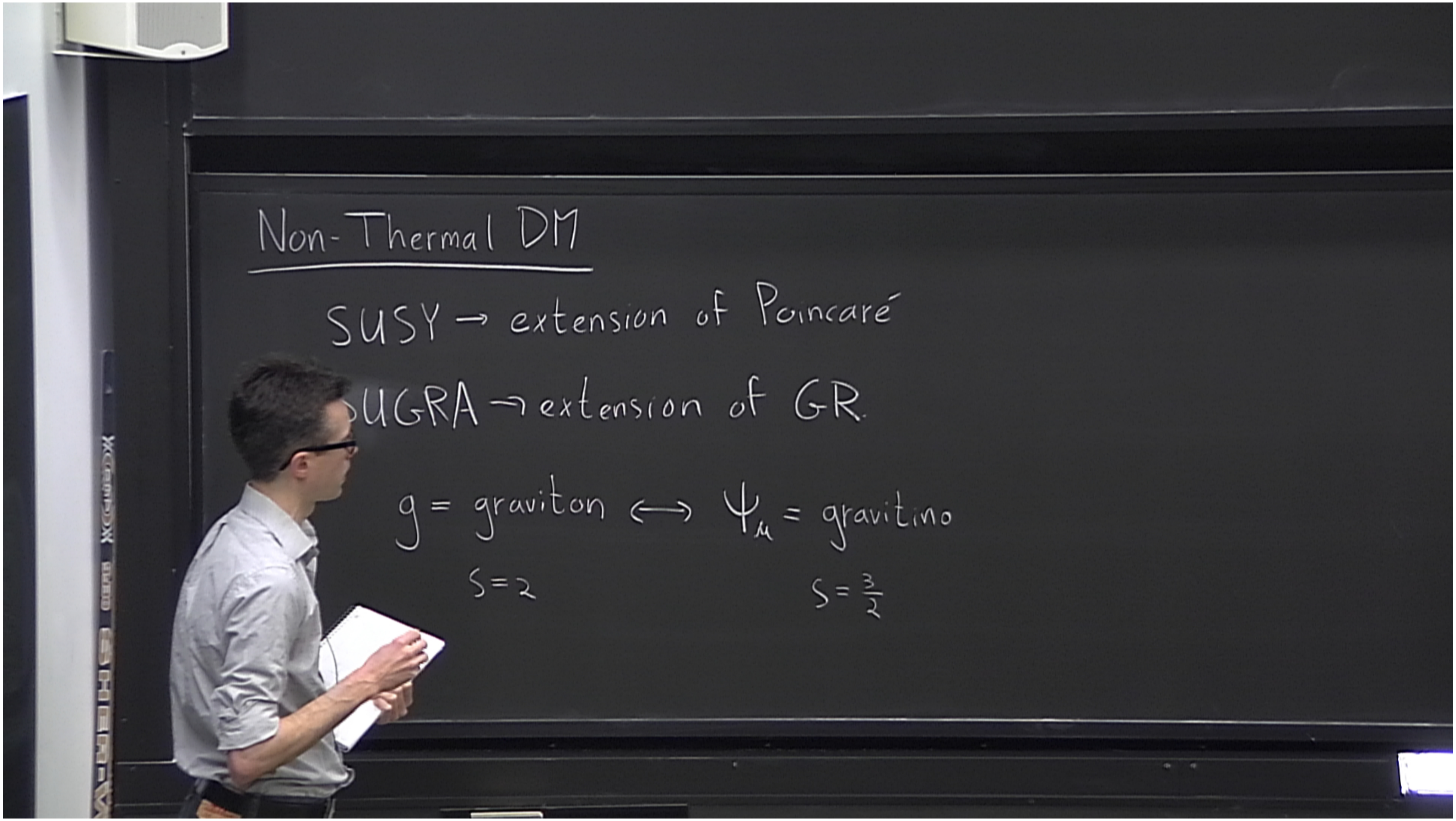
Date: Apr 10, 2012 09:00 AM

URL: http://pirsa.org/12040008

Abstract:

Non-Thermal DM

SUSY $\rightarrow$ extension of Poincaré


Non-Thermal DM
SUSY → extension of Poincaré
UGRA → extension of GR
g = graviton ⟷ ψ_μ = gravitino
s = 2
s = $\frac{3}{2}$

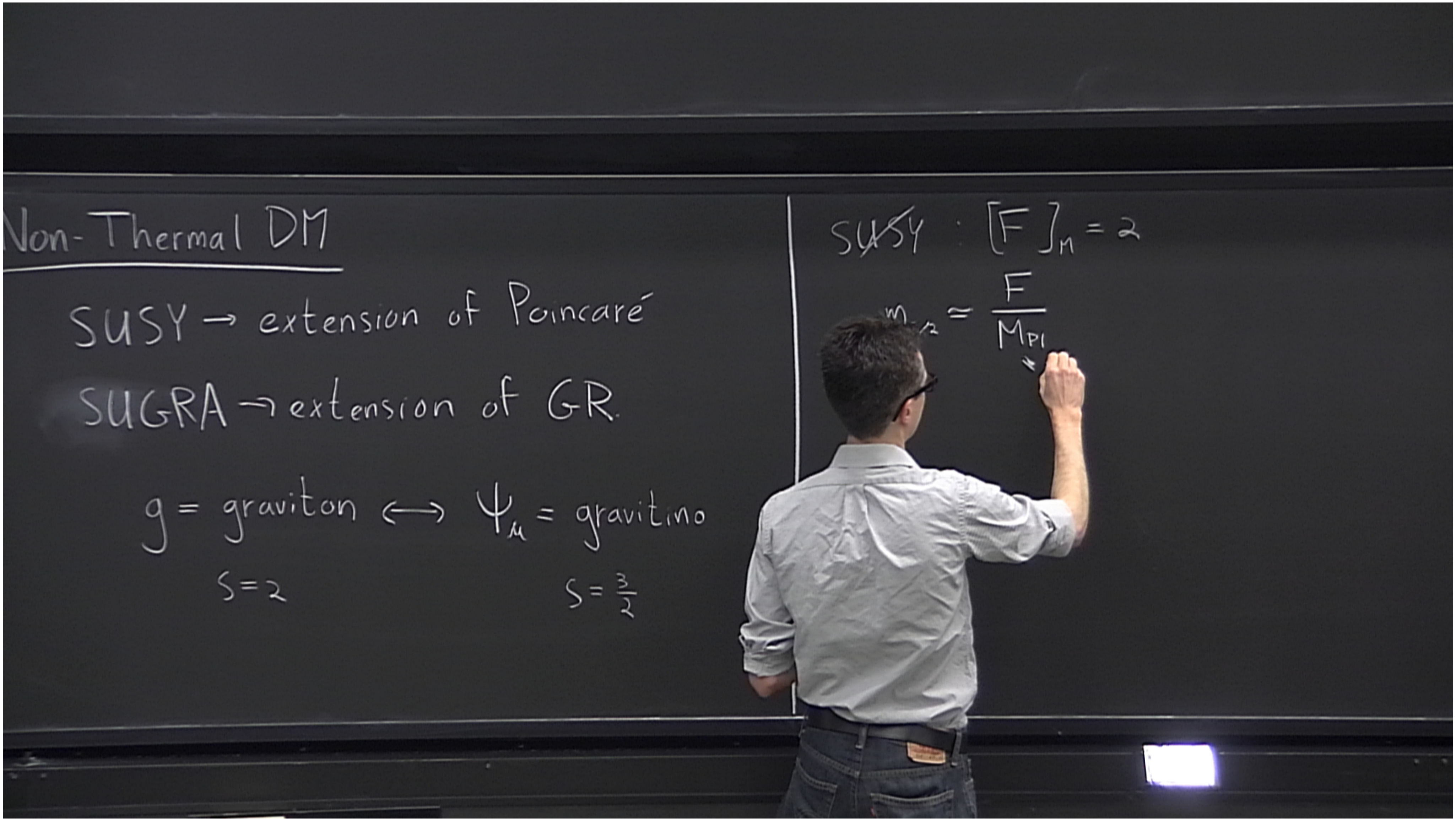
Non-Thermal DM

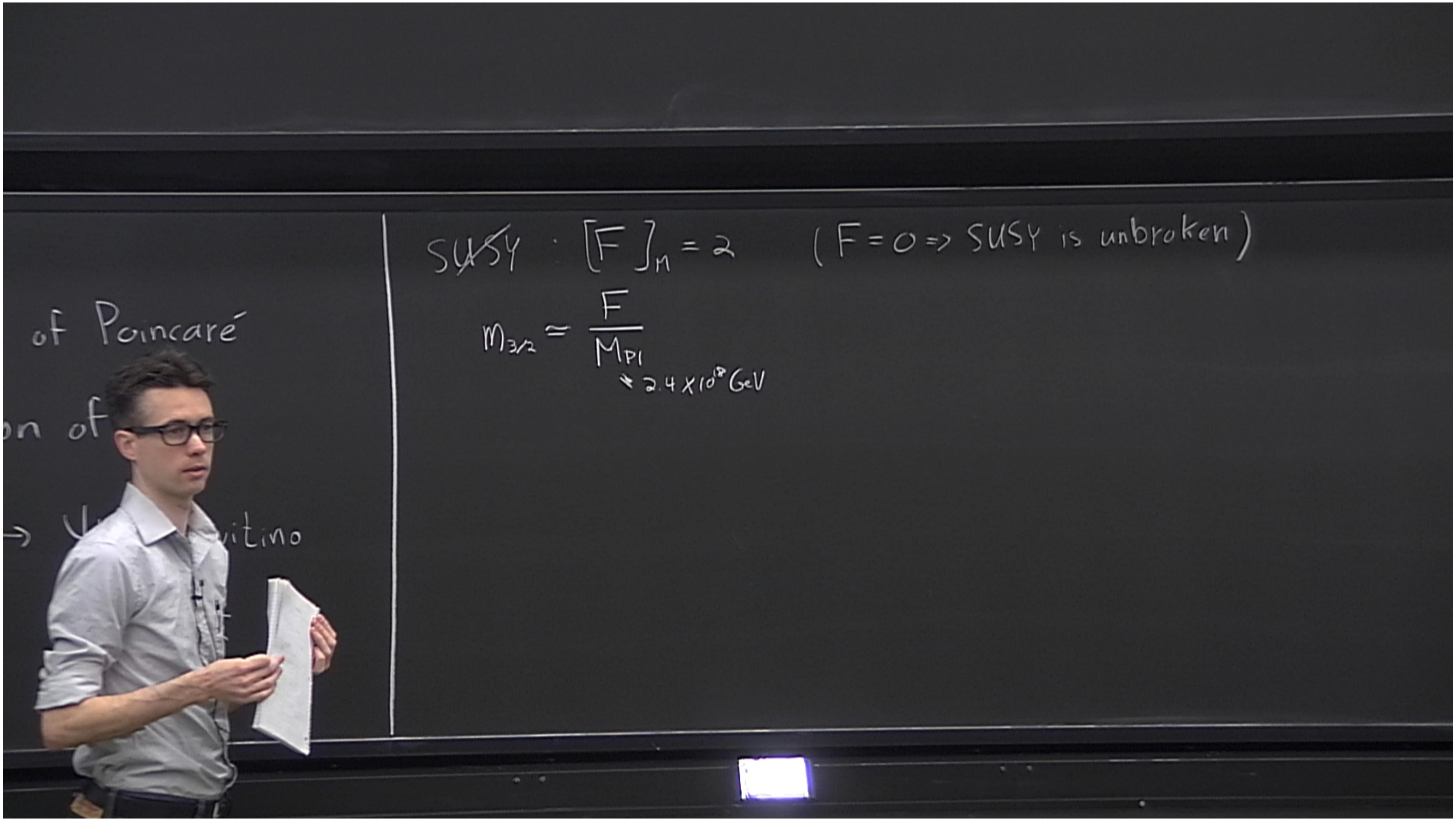
SUSY → extension of Poincaré

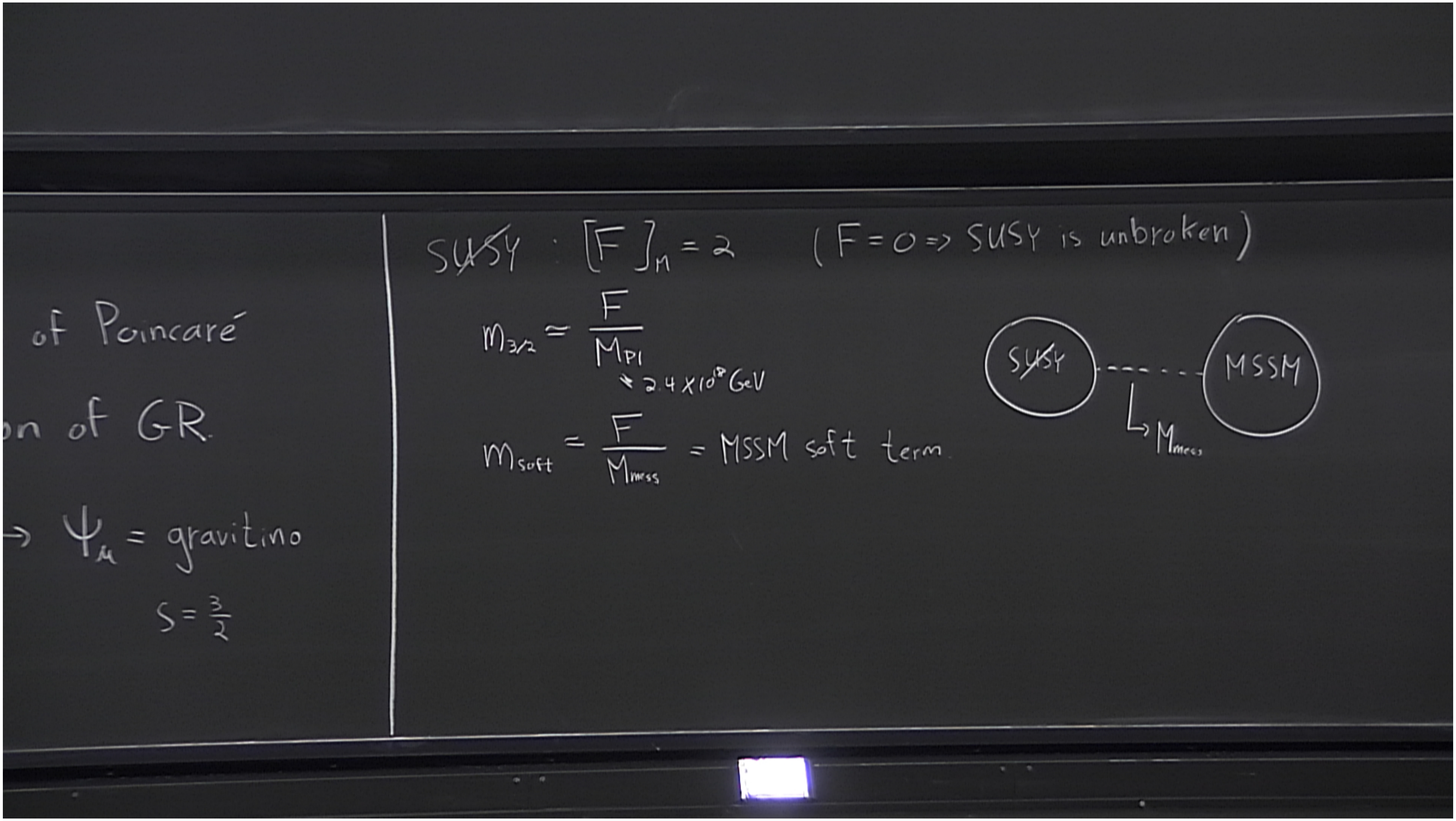
SUGRA → extension of GR

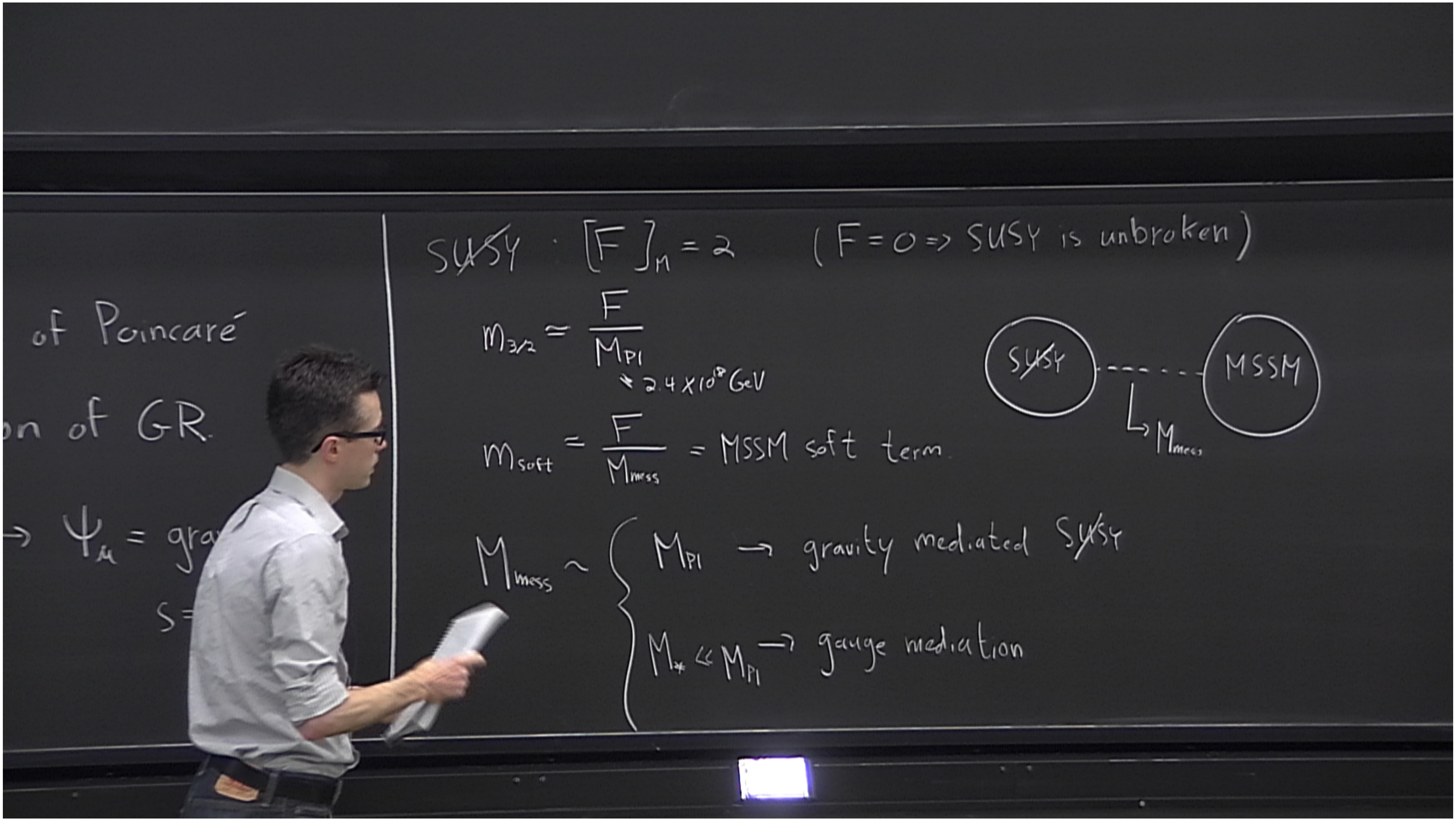
g = graviton $\longleftrightarrow$ ψ_μ = gravitino

$s = 2$ $\qquad\qquad$ $s = \frac{3}{2}$


Non-Thermal DM
SUSY → extension of Poincaré
SUGRA → extension of GR.
g = graviton ⟷ Ψμ = gravitino
s = 2
s = 3/2
SUSY : [F]M = 2
F
MPl


SUSY : [F]M = 2 (F = 0 => SUSY is unbroken)
m3/2 ≃ F / MPl
≈ 2.4 x 10^18 GeV
of Poincaré
on of
itino


of Poincaré
on of GR
→ Ψ_μ = gravitino
$s = \frac{3}{2}$
$\cancel{SUSY}$: $[F]_M = 2$ ($F = 0 \Rightarrow$ SUSY is unbroken)
$m_{3/2} \simeq \frac{F}{M_{Pl}}$
2.4×10^{18} GeV
$m_{soft} = \frac{F}{M_{mess}}$ = MSSM soft term
$\cancel{SUSY}$
MSSM
M_{mess}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$M_* \ll M_{Pl} \rightarrow$ gauge mediation
of Poincaré
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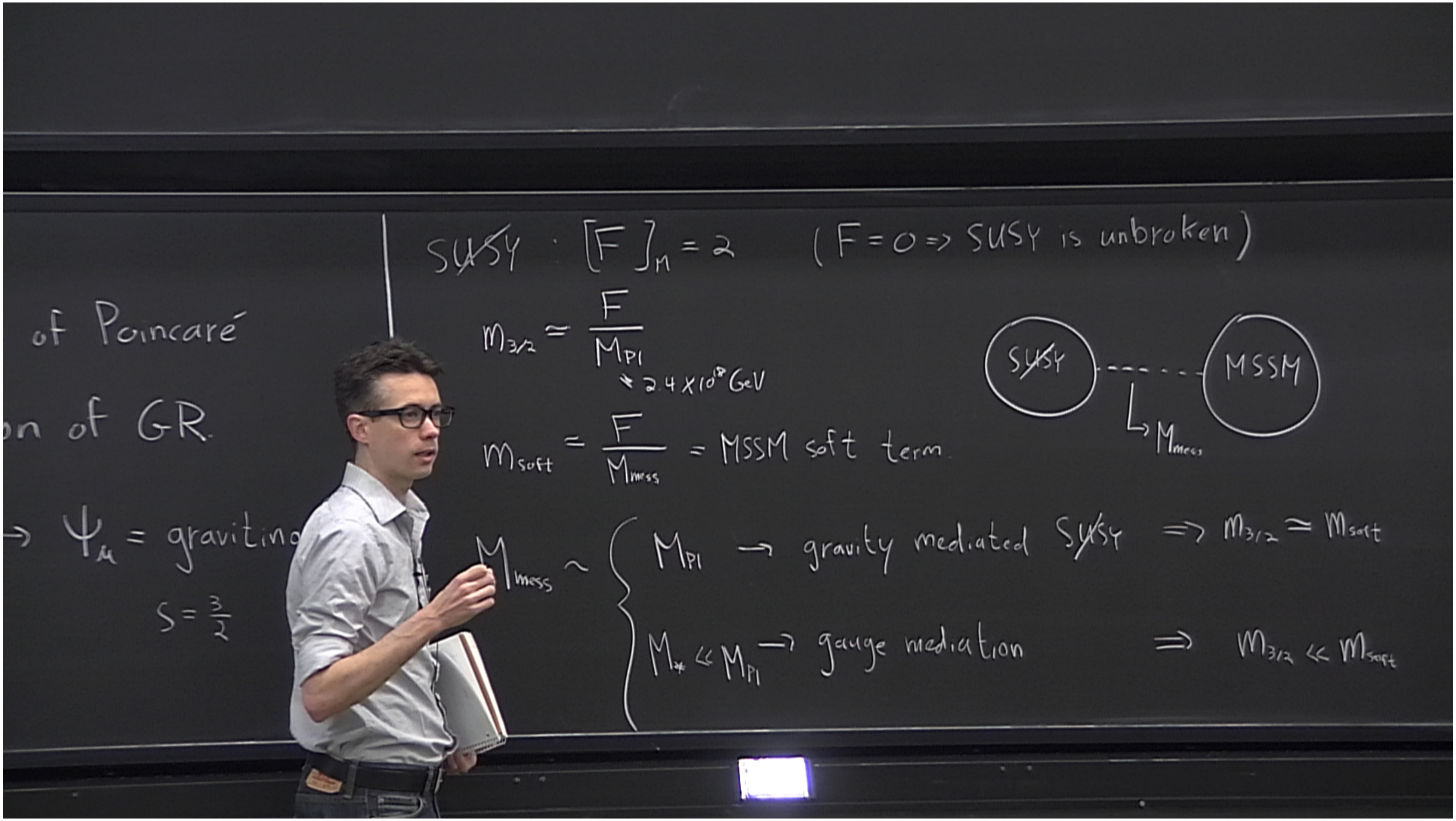
$\rightarrow \Psi_\mu =$ gra



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$\rightarrow \Psi_\mu$ = gravitino
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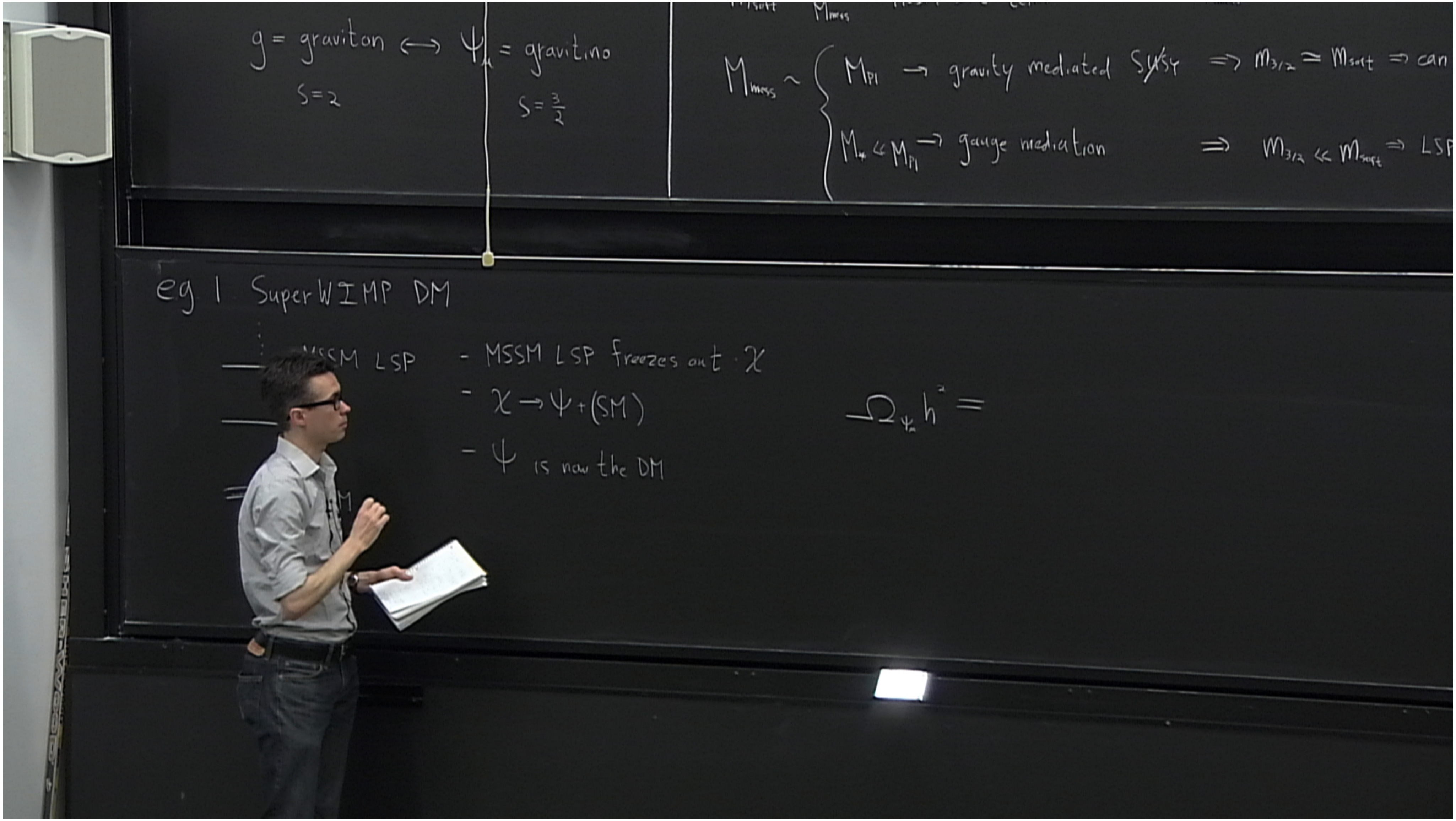
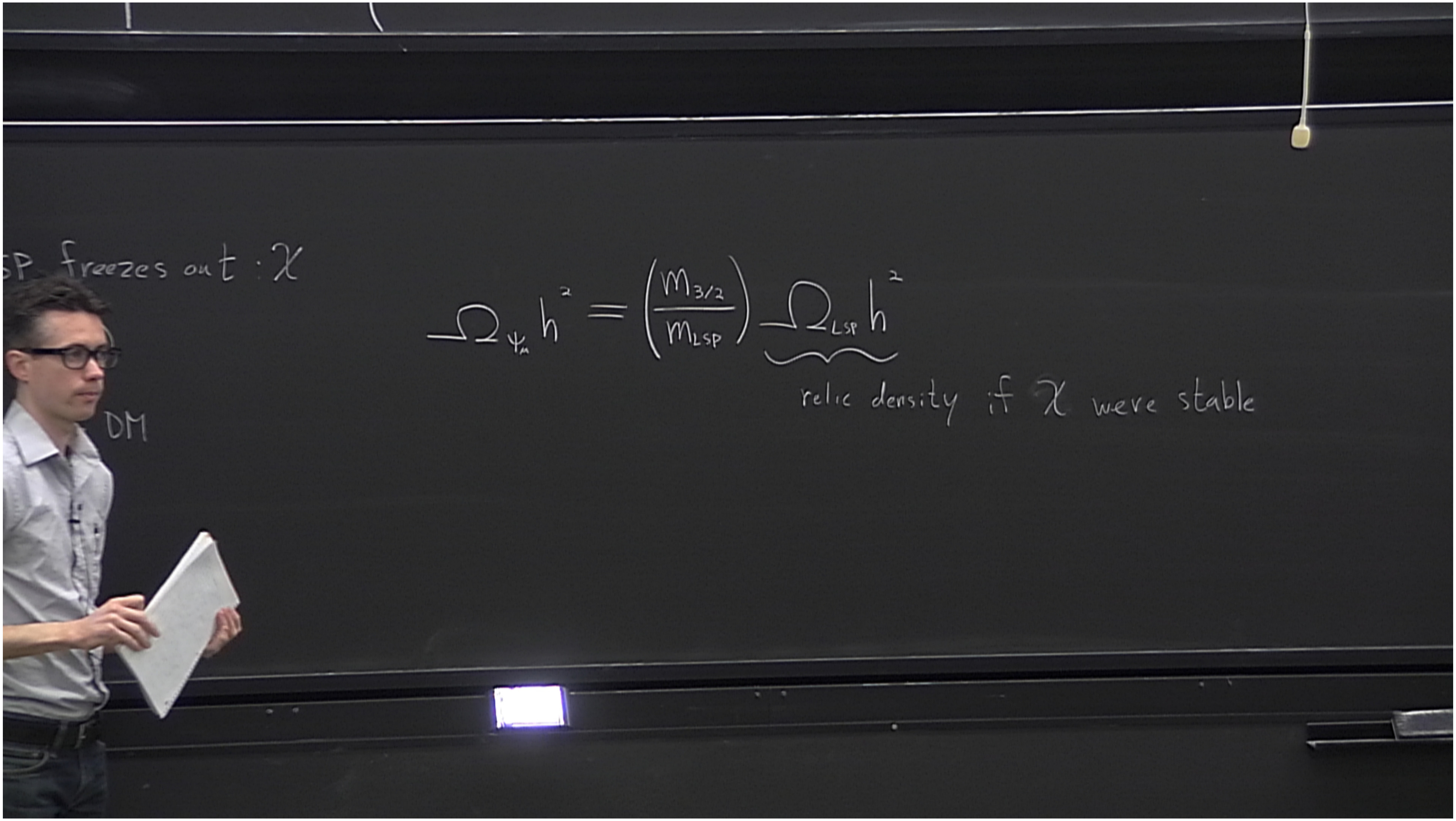

g = graviton ⟷ ψ_μ = gravitino
S = 2
S = 3/2
M_mess ~ M_Pl → gravity mediated SUSY ⇒ m_3/2 ≃ m_soft ⇒ can
M_* ≪ M_Pl → gauge mediation ⇒ m_3/2 ≪ m_soft ⇒ LSP
eg 1 SuperWIMP DM
MSSM LSP
- MSSM LSP freezes out χ
- χ → ψ + (SM)
- ψ is now the DM
Ω_ψ h² =


SP freezes out : χ
DM
$\Omega_{\psi_\mu} h^2 = \left(\frac{m_{3/2}}{m_{LSP}}\right) \underbrace{\Omega_{LSP} h^2}_{\text{relic density if } \chi \text{ were stable}}$

SP freezes out : χ

+ (SM)

w the DM

$$\Omega_{\psi_m} h^2 = \left(\frac{m_{3/2}}{m_{LSP}}\right) \underbrace{\Omega_{LSP}\, h^2}_{\text{relic density if } \chi \text{ were stable}}$$

decay happens late $\Rightarrow$ can mess up Nucleosynthesis

g = graviton $\longleftrightarrow$ Ψ_μ = gravitino

$s=2$ $\qquad$ $s=\frac{3}{2}$

$$M_{mess} \sim \begin{cases} M_{Pl} \to \text{gravity mediated SUSY} \Rightarrow m_{3/2} \simeq m_{soft} \Rightarrow \text{can} \\ M_* \ll M_{Pl} \to \text{gauge mediation} \Rightarrow m_{3/2} \ll m_{soft} \Rightarrow \text{LSP} \end{cases}$$

eg 1 SuperWIMP DM

MSSM LSP

Ψ_μ

SM

- MSSM LSP freezes out χ
- $\chi \to \Psi + (SM)$ $\to$ decay happens late $\Rightarrow$ can mess up Nucleosynthesis
- Ψ is now the DM

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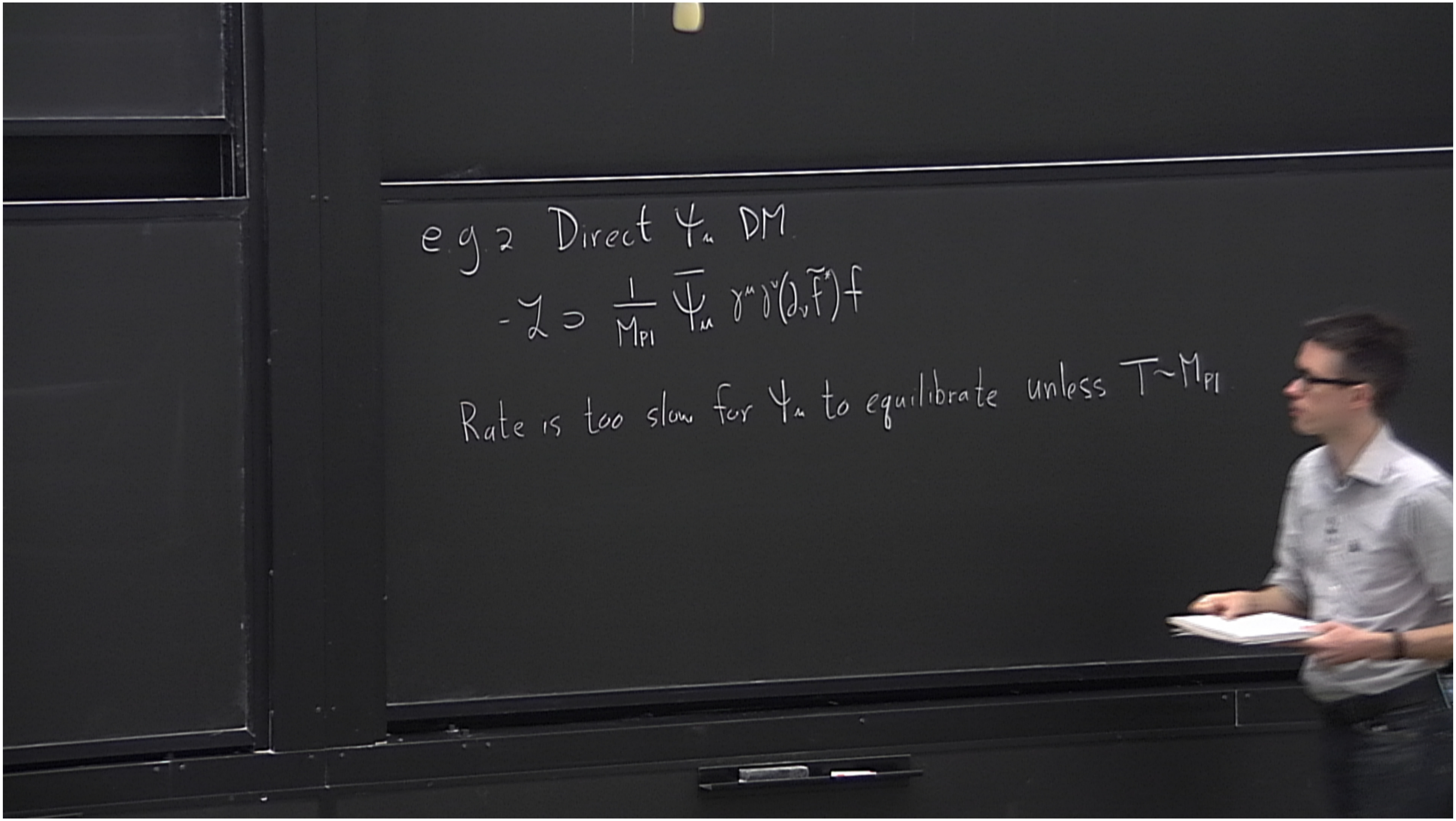
e.g. 2 Direct Ψ_μ DM
$-\mathcal{L} \supset \frac{1}{M_{Pl}} \overline{\Psi}_\mu \gamma^\mu \gamma^\nu (\partial_\nu \tilde{f}^*) f$
Rate is too slow for Ψ_μ to equilibrate unless $T \sim M_{Pl}$

e.g 2 Direct ψ_μ DM

$$-\mathcal{L} \supset \frac{1}{M_{Pl}} \bar{\Psi}_\mu \gamma^\mu \gamma^\nu (\partial_\nu \tilde{f}^*) f$$

Massive vector $\quad -\eta_{\mu\nu} + p_\mu p_\nu / m_W^2$

enhancement

Rate is too slow for ψ_μ to equilibrate unless $T \sim M_{Pl}$.

↳ ψ_μ never equilibrates

Direct Ψ_μ DM

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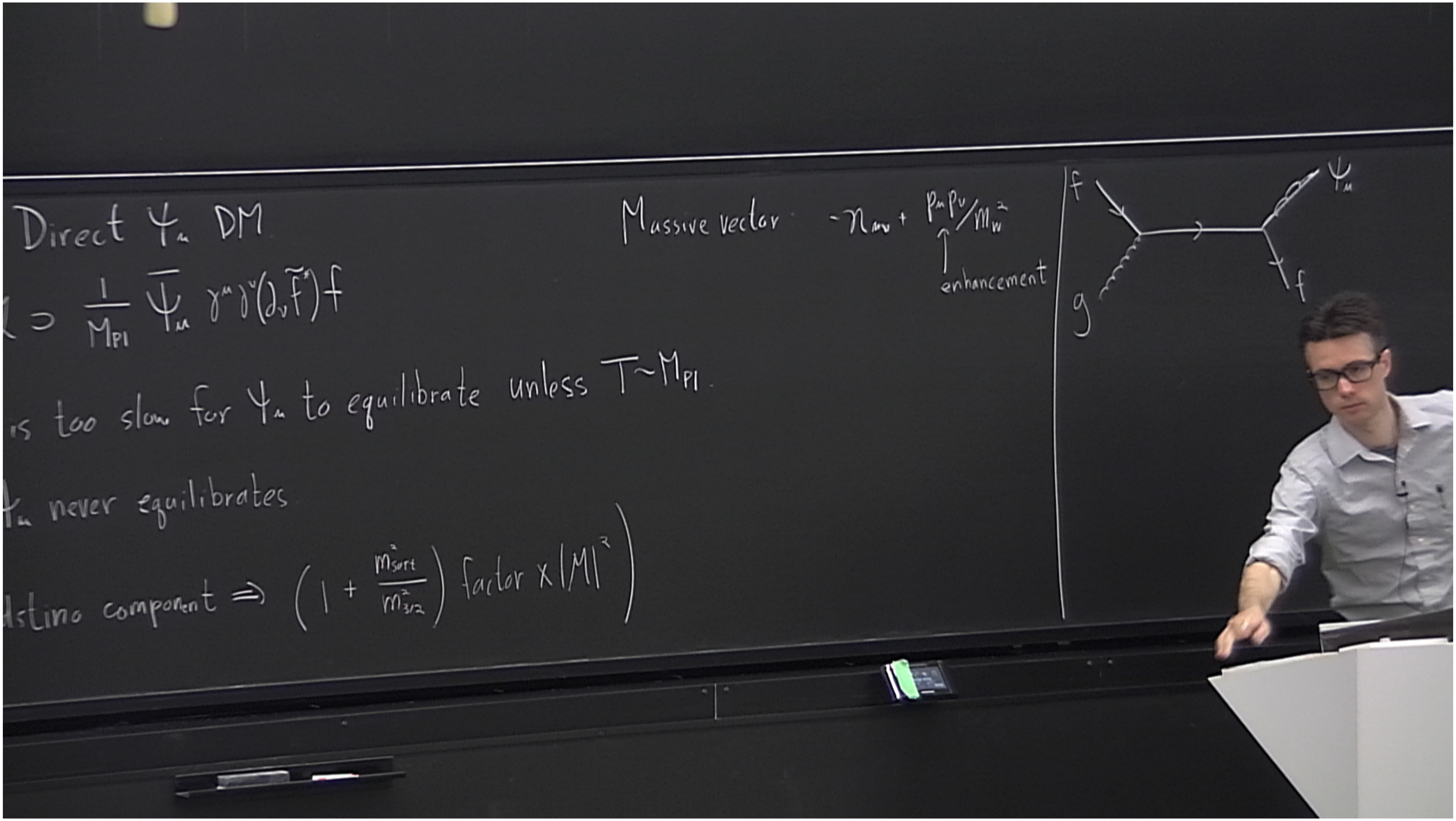
Ψ_μ never equilibrates

dstino component $\Rightarrow$ $\left(1 + \frac{m_{soft}^2}{m_{3/2}^2} \right)$ factor x $|M|^2$)

Massive vector: $-\eta_{\mu\nu} + \underbrace{p_\mu p_\nu / m_W^2}_{\text{enhancement}}$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Massive vector $-\eta_{\mu\nu} + p_\mu p_\nu / m_W^2$
enhancement
f
g
Ψ_μ
f

Massive vector $\quad -\eta_{\mu\nu} + p_\mu p_\nu / m_W^2$

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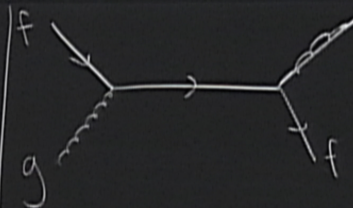
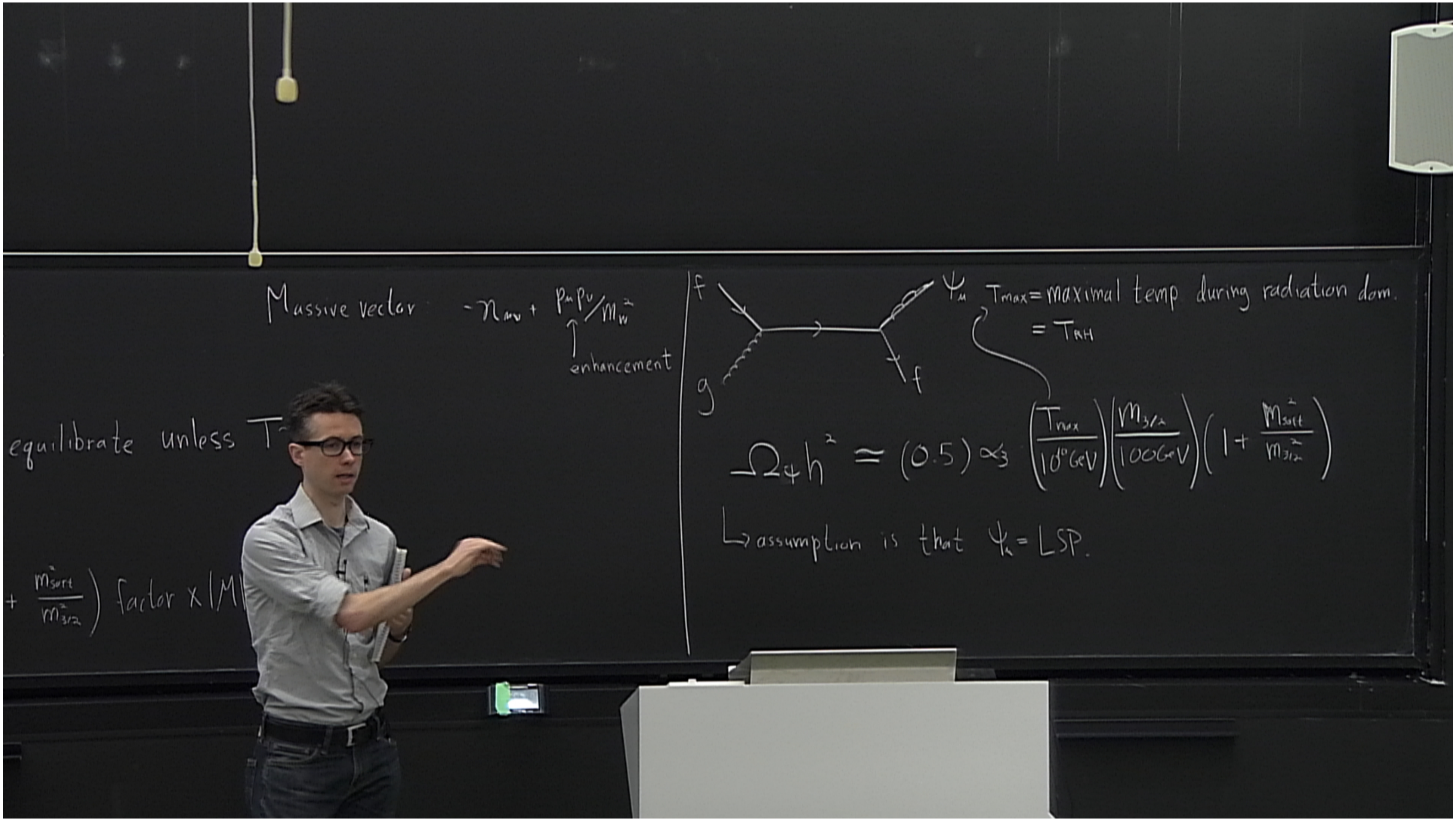


T_{max} = maximal temp during radiation dom.
$= T_{RH}$

$$\Omega_\psi h^2 \simeq (0.5)\,\alpha_3 \left(\frac{T_{max}}{10^{10}\,\mathrm{GeV}}\right)\left(\frac{m_{3/2}}{100\,\mathrm{GeV}}\right)\left(1 + \frac{m_{soft}^2}{m_{3/2}^2}\right)$$


Massive vector
enhancement
equilibrate unless
factor
Tmax = maximal temp during radiation dom.
= TRH
assumption is that

Massive vector $\quad -\eta_{\mu\nu} + p_\mu p_\nu / m_W^2$

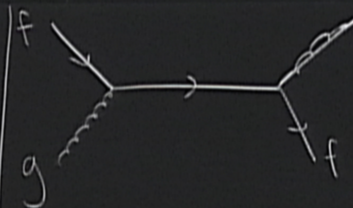
enhancement

equilibrate unless $T \sim M_{Pl}$.

$+ \frac{m_{soft}^2}{m_{3/2}^2}$) factor $\times |M|^2$)

α_3 = QCD coupling
$= g_3^2/4\pi$

↳ evaluated at T_{max}



T_{max} = maximal temp during radiation dom.
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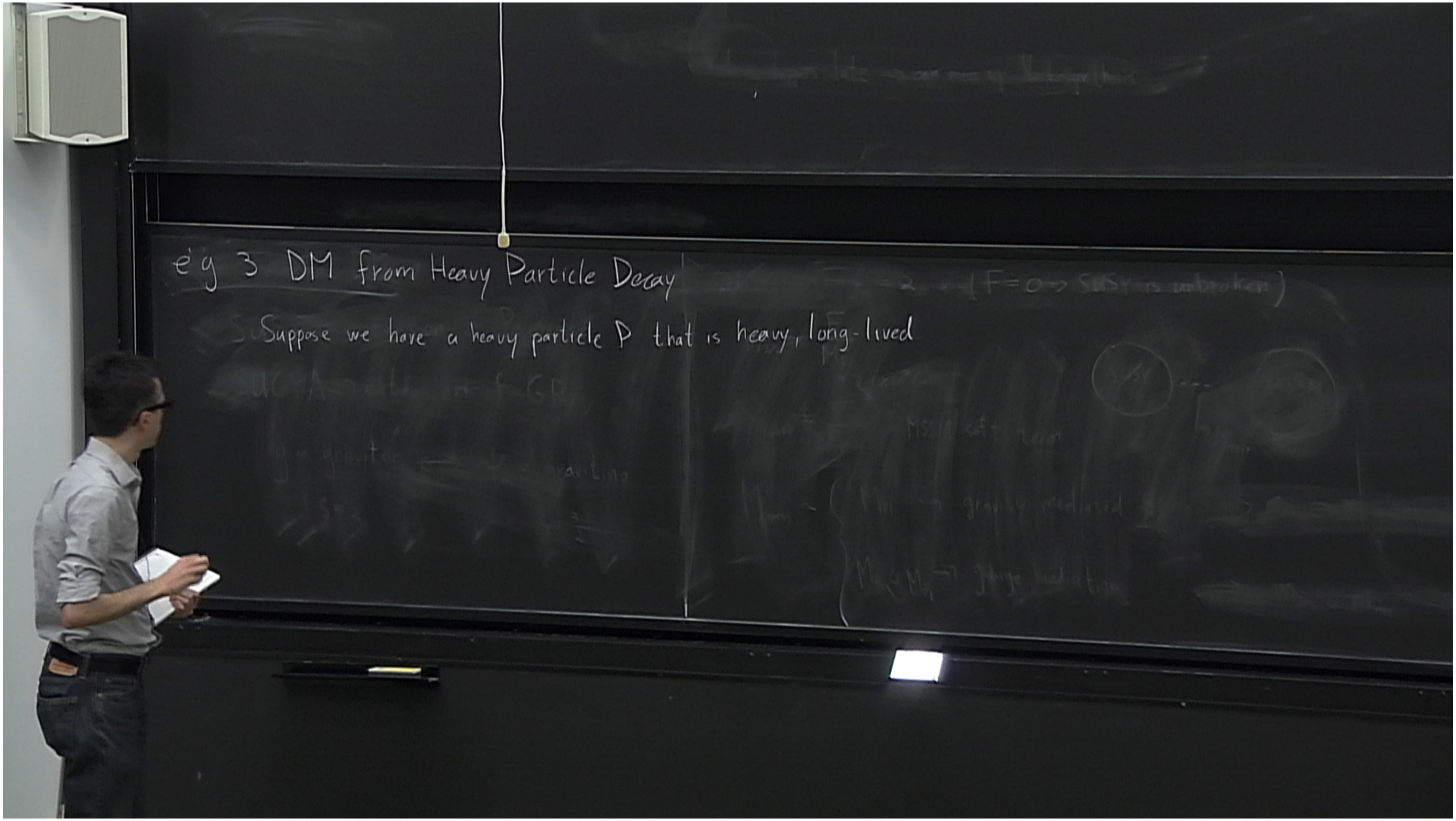
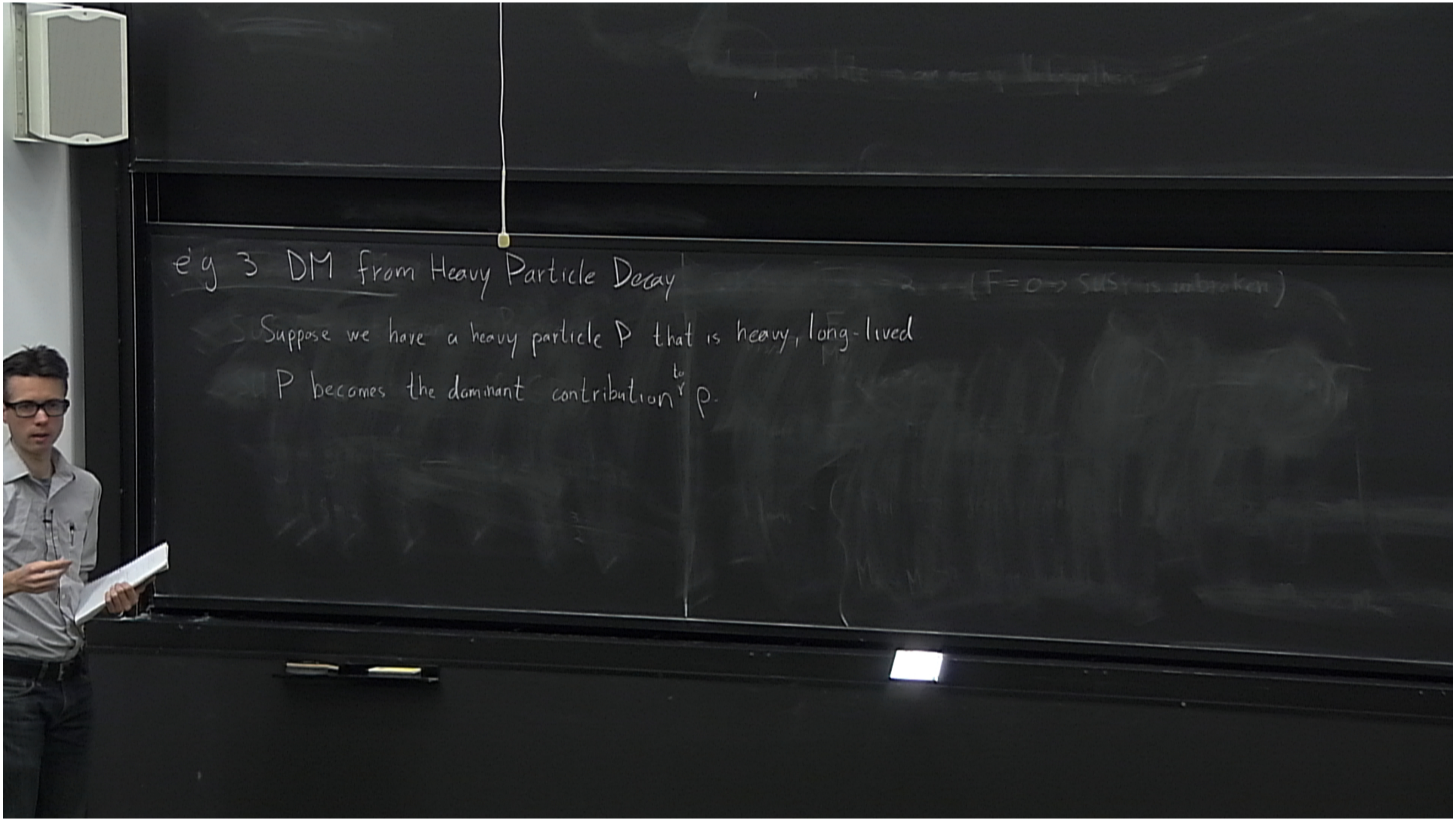
$$\Delta\Omega_\psi h^2 \simeq (0.5)\,\alpha_3 \left(\frac{T_{max}}{10^{10}\,GeV}\right)\left(\frac{m_{3/2}}{100\,GeV}\right)\left(1+\frac{m_{soft}^2}{m_{3/2}^2}\right)$$

↳ assumption is that ψ_μ = LSP.

↳ QCD


e.g. 3 DM from Heavy Particle Decay
Suppose we have a heavy particle P that is heavy, long-lived


e.g 3 DM from Heavy Particle Decay
Suppose we have a heavy particle P that is heavy, long-lived
P becomes the dominant contribution to ρ.

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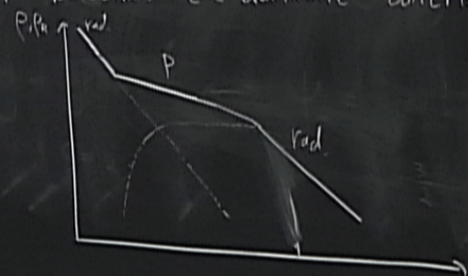

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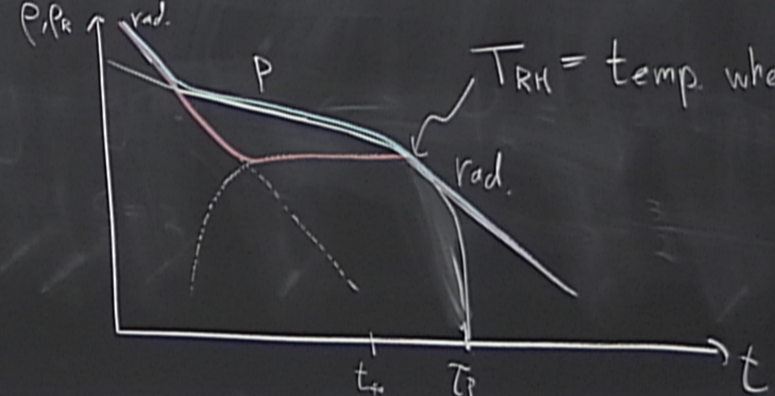
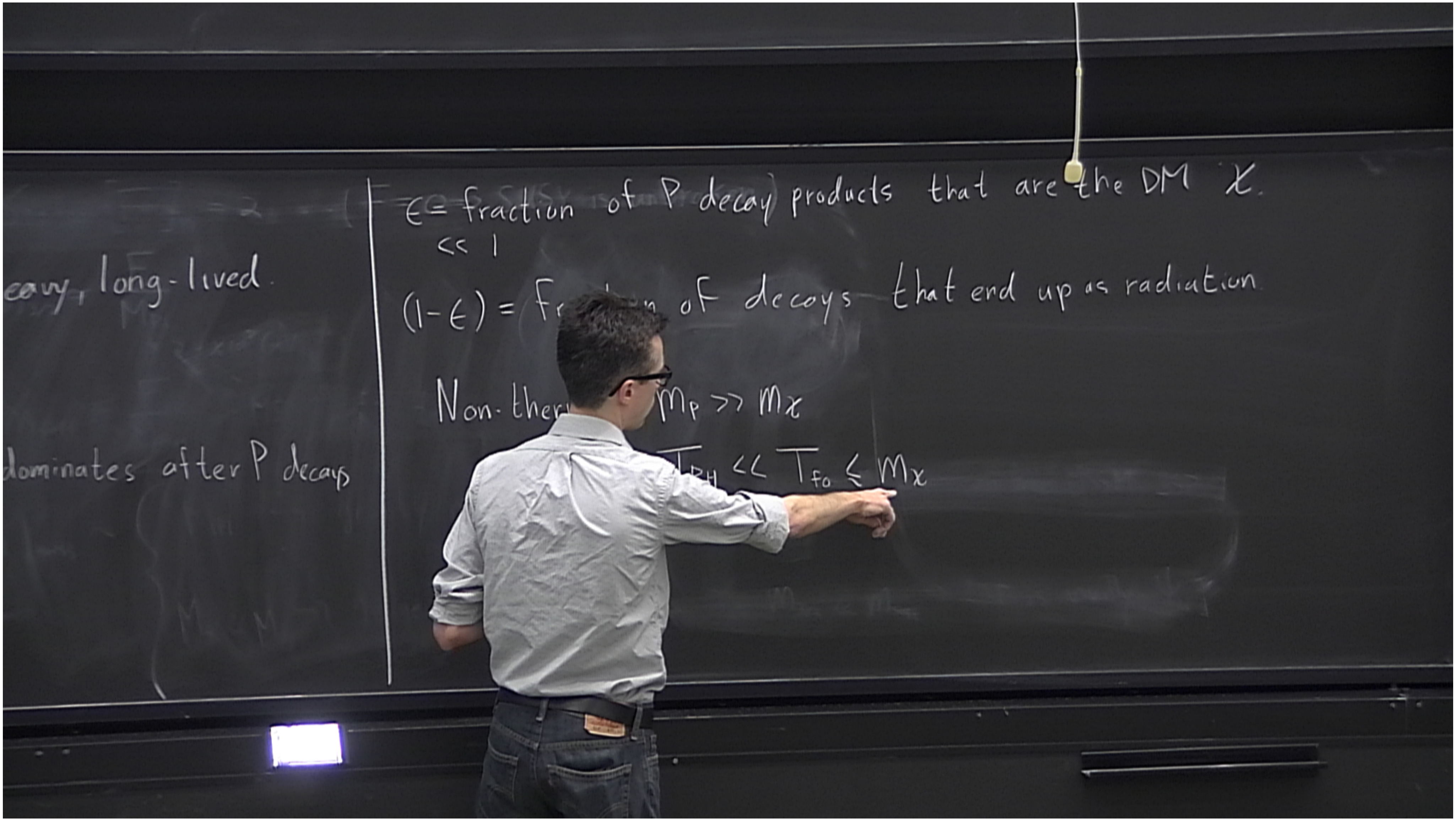


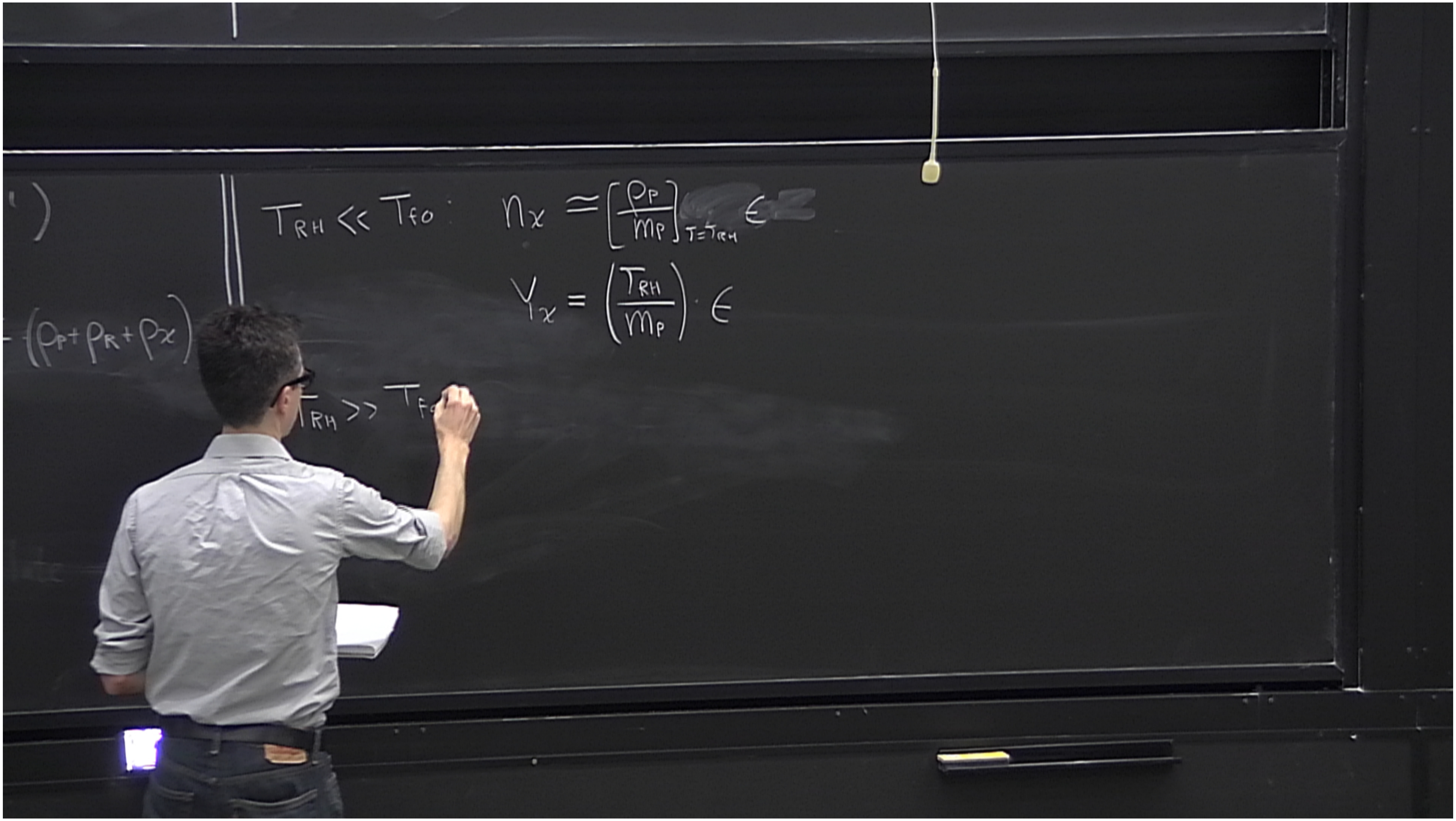
T_{RH} = temp. when radiation dominates afte


ε = fraction of P decay products that are the DM χ.
<< 1
(1-ε) = Fr
of decays that end up as radiation
Non. ther
m_P >> m_χ
T_RH << T_fo ≤ m_χ
long-lived.
dominates after P decays

$$\begin{cases} \dfrac{d\rho_P}{dt} + 3H\rho_P = -\Gamma_P \rho_P \\[2ex] \dfrac{d\rho_R}{dt} + 4H\rho_R = (1-\epsilon)\Gamma_P \rho_P \\[2ex] \dfrac{dn_\chi}{dt} + 3Hn_\chi = \epsilon \Gamma_P \rho_P - \langle \sigma v \rangle \left(n_\chi^2 - n_{\chi_{eq}}^2\right) \end{cases}$$

$$\left(\rho_P = m_P n_P \ , \ \Gamma_P = \tau_P^{-1} \right)$$

$$H^2 = \frac{8\pi G}{3}\left(\rho_P + \rho_R + \rho_\chi\right)$$


$T_{RH} \ll T_{fo}$:
$n_\chi \simeq \left[\frac{\rho_P}{m_P}\right]_{T=T_{RH}} \epsilon$
$Y_\chi = \left(\frac{T_{RH}}{m_P}\right) \cdot \epsilon$
$(\rho_P + \rho_R + \rho_\chi)$
$T_{RH} \gg T_{f}$

$$- \left(\rho_P + \rho_R + \rho_\chi\right)$$

$T_{RH} \ll T_{FO}$: $\quad n_\chi \simeq \left[\frac{\rho_P}{m_P}\right]_{T=T_{RH}} \epsilon \longrightarrow$ non-thermal

$$Y_\chi = \left(\frac{T_{RH}}{m_P}\right) \cdot \epsilon$$

$T_{RH} \gg T_{FO}$: $\quad Y_\chi$ = usual freeze out value $\rightarrow$ thermal

$\hookrightarrow$ DM scattering equilibrates χ density.

$$\ldots(\rho_P + \rho_R + \rho_\chi)$$

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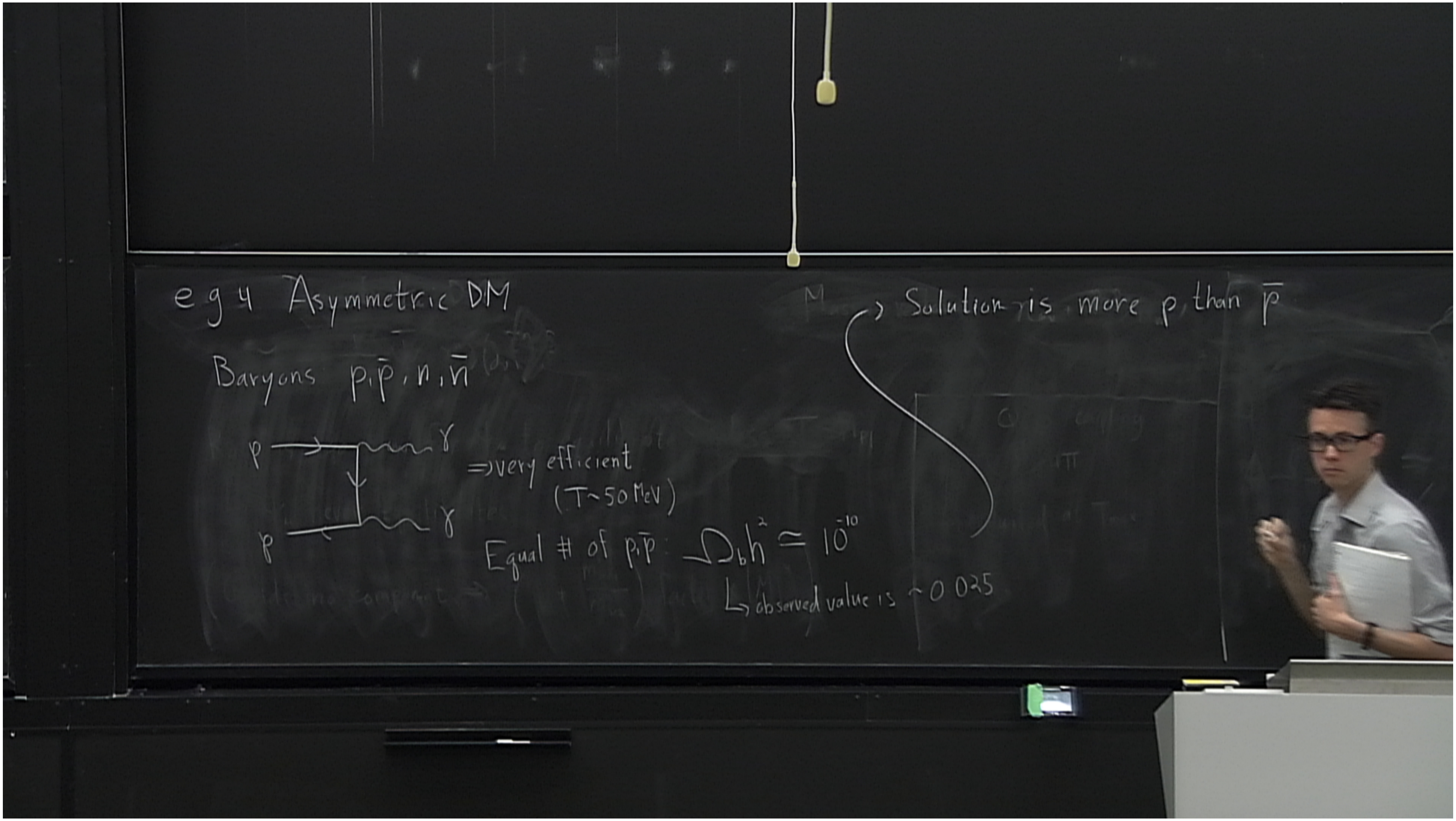
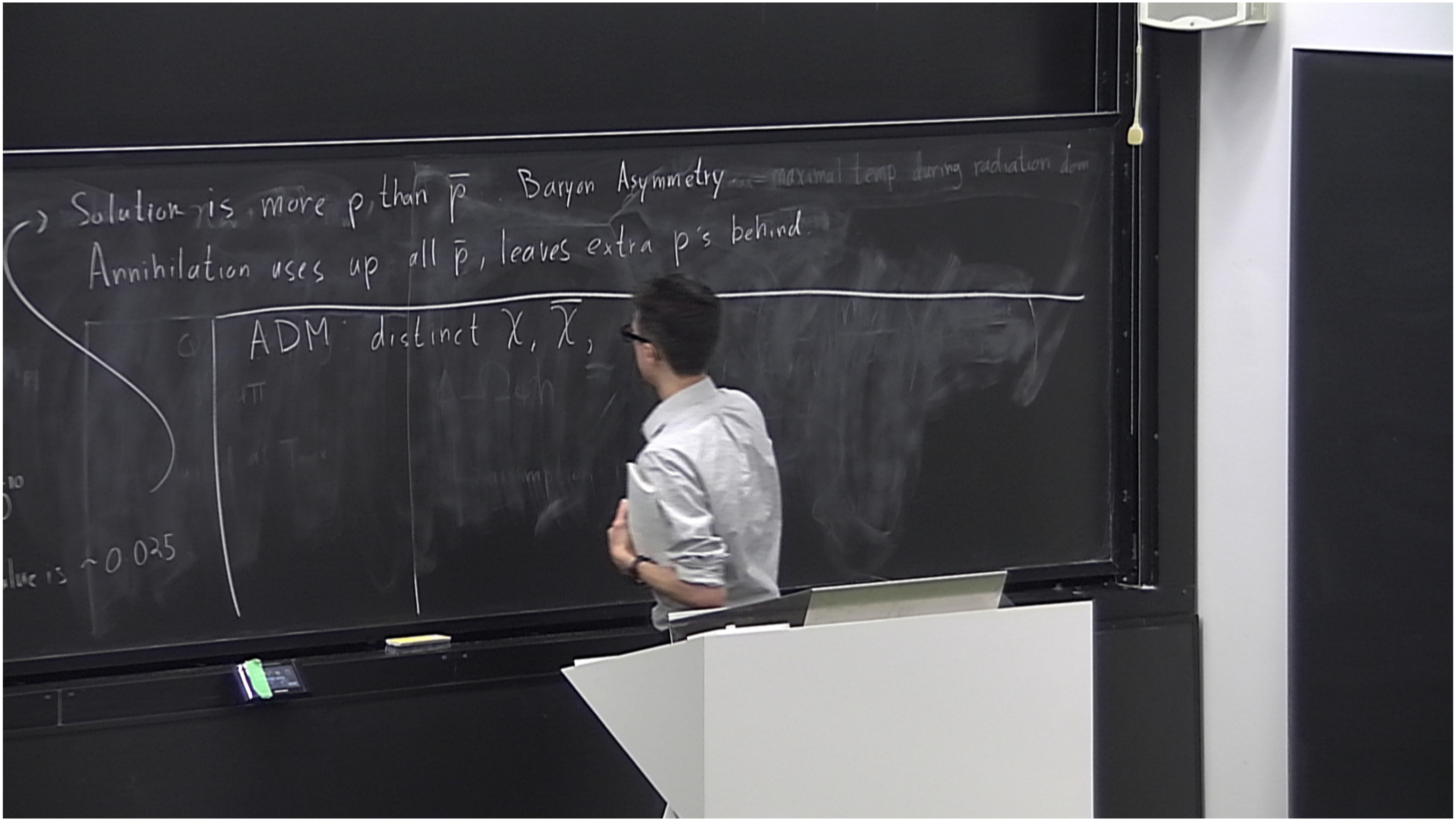
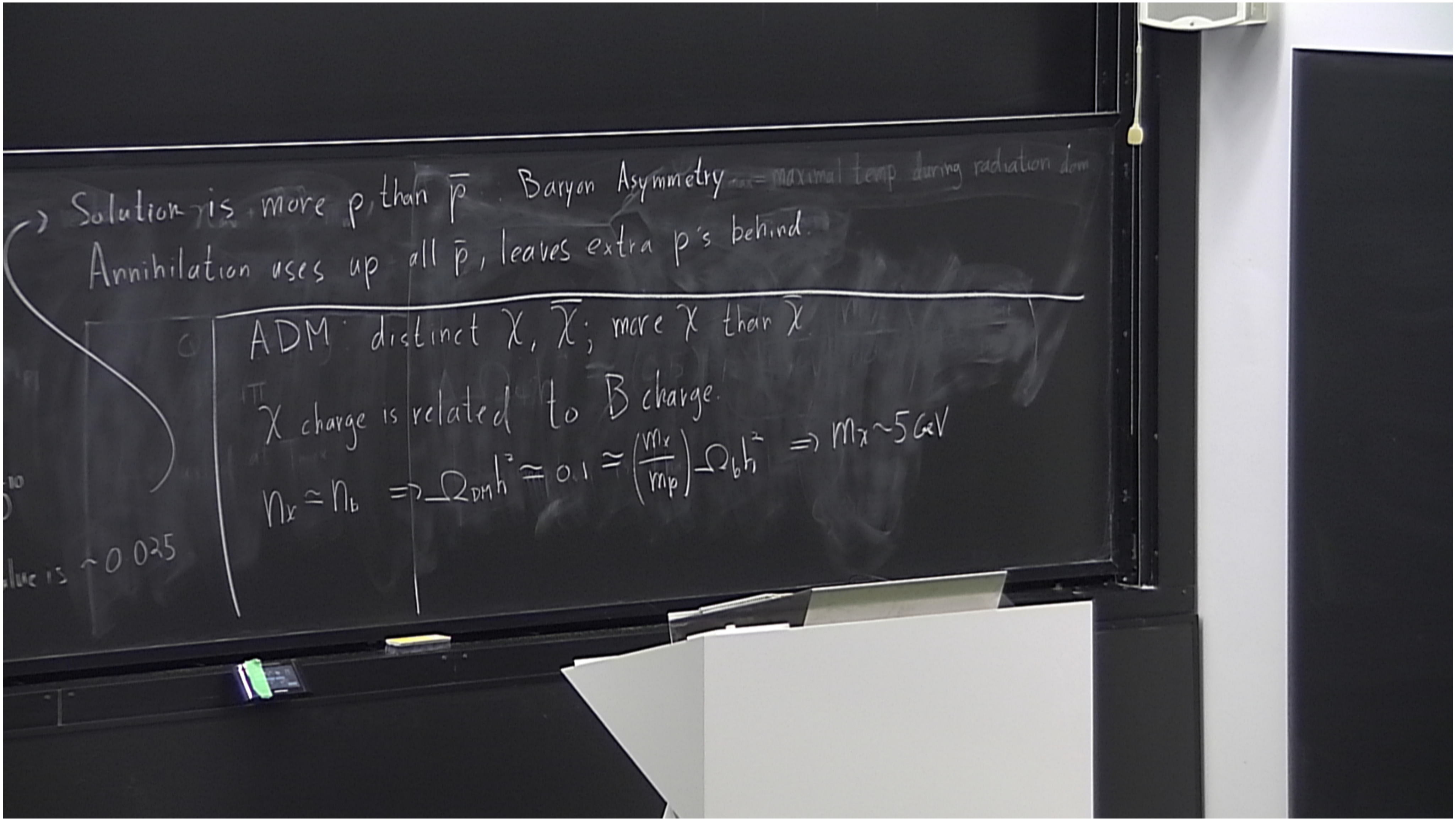

e.g. 4 Asymmetric DM
Baryons $p, \bar{p}, n, \bar{n}$
p
γ
γ
$\Rightarrow$ very efficient
($T \sim 50$ MeV)
Equal # of $p, \bar{p}$: $\Omega_b h^2 \simeq 10^{-10}$
↳ observed value is ~0.025
↳ Solution is more p than $\bar{p}$


Solution is more p than p̄ . Baryon Asymmetry
maximal temp during radiation dom
Annihilation uses up all p̄, leaves extra p's behind.
ADM: distinct χ, χ̄,
lue is ~0.025



Solution is more p than $\bar{p}$: Baryon Asymmetry
maximal temp during radiation dom
Annihilation uses up all $\bar{p}$, leaves extra p's behind.
ADM: distinct χ, $\bar{\chi}$; more χ than $\bar{\chi}$
χ charge is related to B charge.
$n_\chi \simeq n_b \Rightarrow \Omega_{DM} h^2 \simeq 0.1 \simeq \left(\frac{m_\chi}{m_p}\right) \Omega_b h^2 \Rightarrow m_\chi \sim 5\,\mathrm{GeV}$
lue is ~0.025