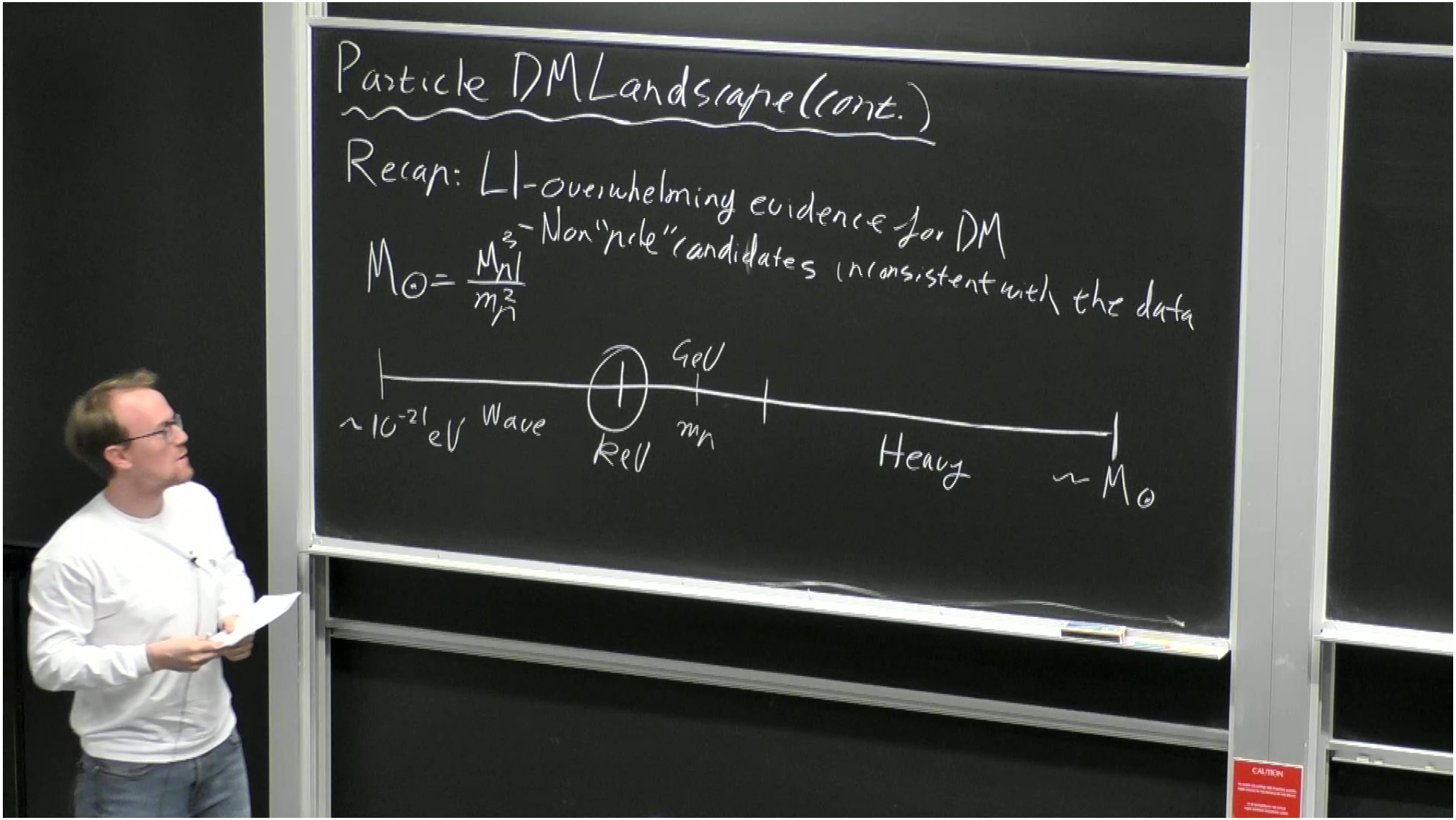
Title: Dark Sector Theory

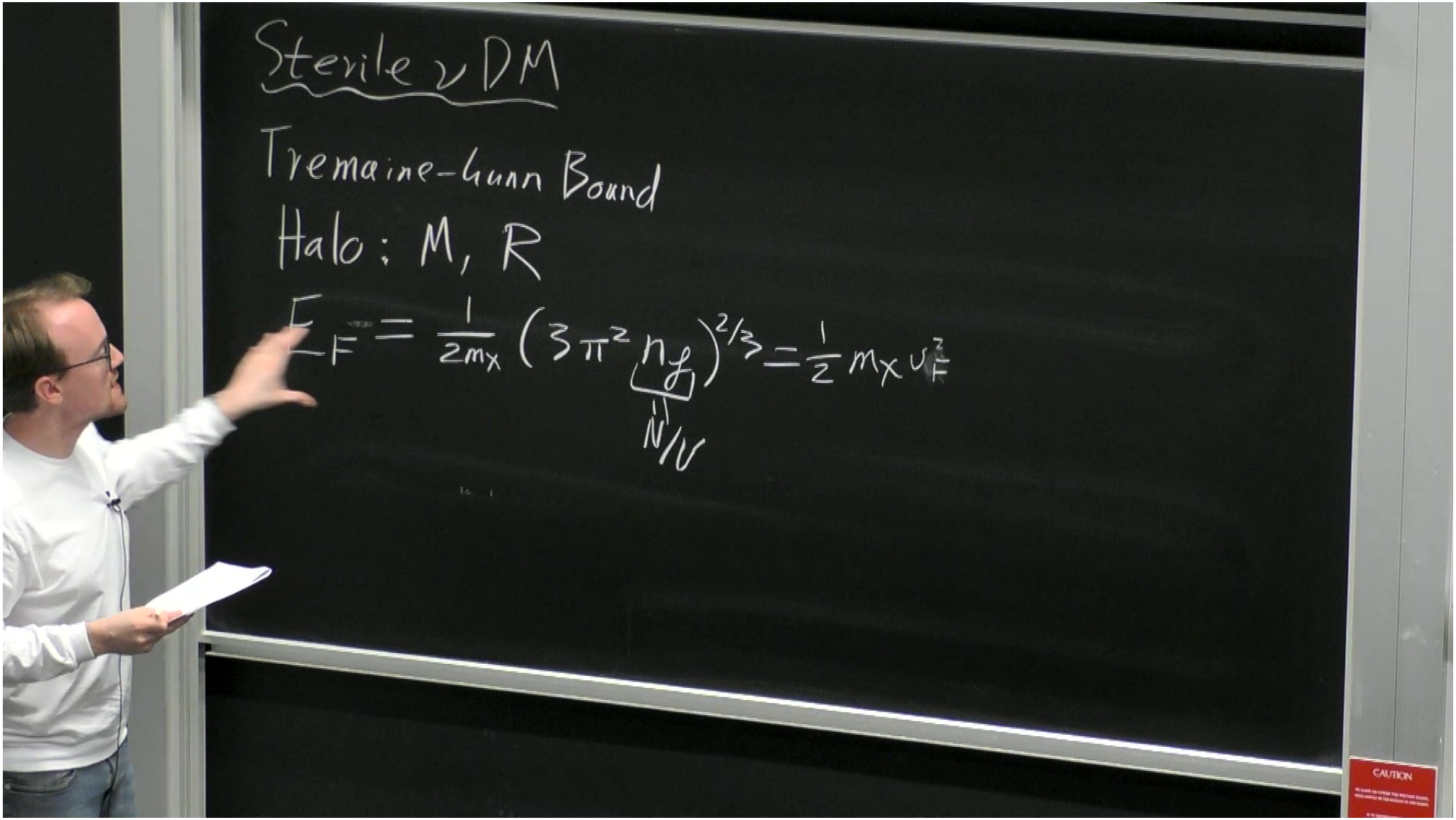
Speakers:

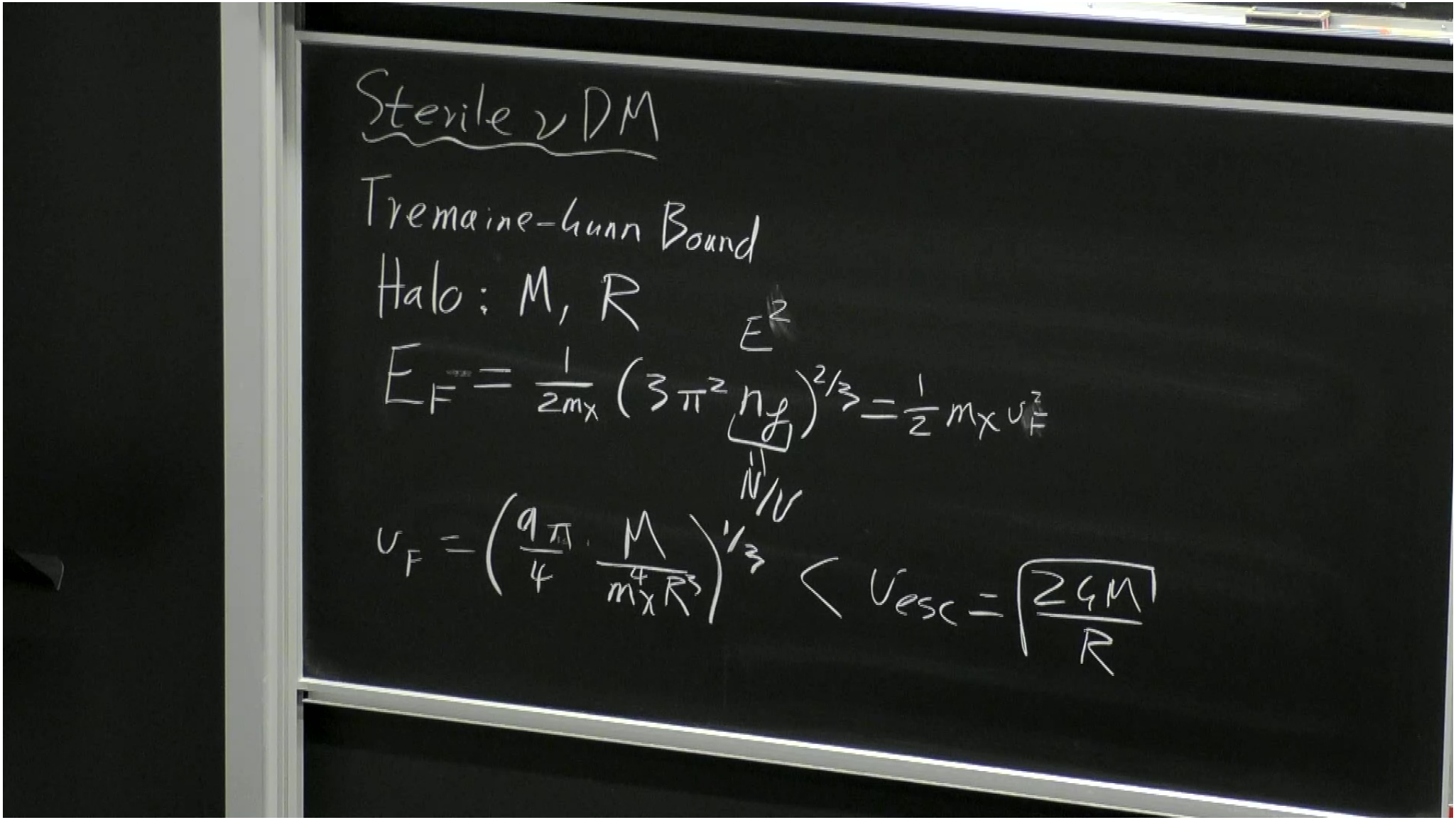
Collection: TRISEP 2023

Date: June 23, 2023 - 11:00 AM

URL: https://pirsa.org/23060069


Particle DM Landscape (cont.)
Recap: LI-overwhelming evidence for DM
- Non "particle" candidates inconsistent with the data
$M_\odot = \frac{M_{Pl}^2}{m_\chi^2}$
GeV
$\sim 10^{-21}$ eV
Wave
keV
mp
Heavy
$\sim M_\odot$
CAUTION


Sterile ν DM
Tremaine-Gunn Bound
Halo: M, R
$E_F = \frac{1}{2m_x}(3\pi^2 n_\chi)^{2/3} = \frac{1}{2} m_x v_F^2$
N/V
CAUTION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$E_F = \frac{1}{2m_x}(3\pi^2 n_\chi)^{2/3} = \frac{1}{2} m_x v_F^2$
E^2
N/V
$v_F = \left(\frac{9\pi}{4}\frac{M}{m_x^4 R^3}\right)^{1/3} < v_{esc} = \sqrt{\frac{2GM}{R}}$

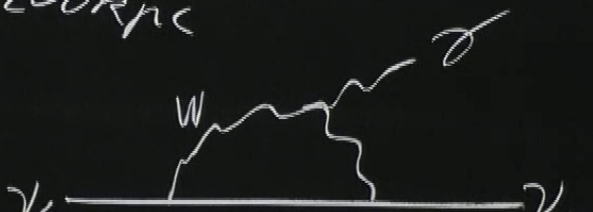
$$m_X > \left[\left(\frac{9\pi}{4}\right)^2 \frac{1}{8 G^3 M R^3} \right]^{1/8}$$

MW : $M = 10^{12} M_\odot$ / $R \simeq 200\,\mathrm{kpc}$

$m_X > 5\,\mathrm{eV}$

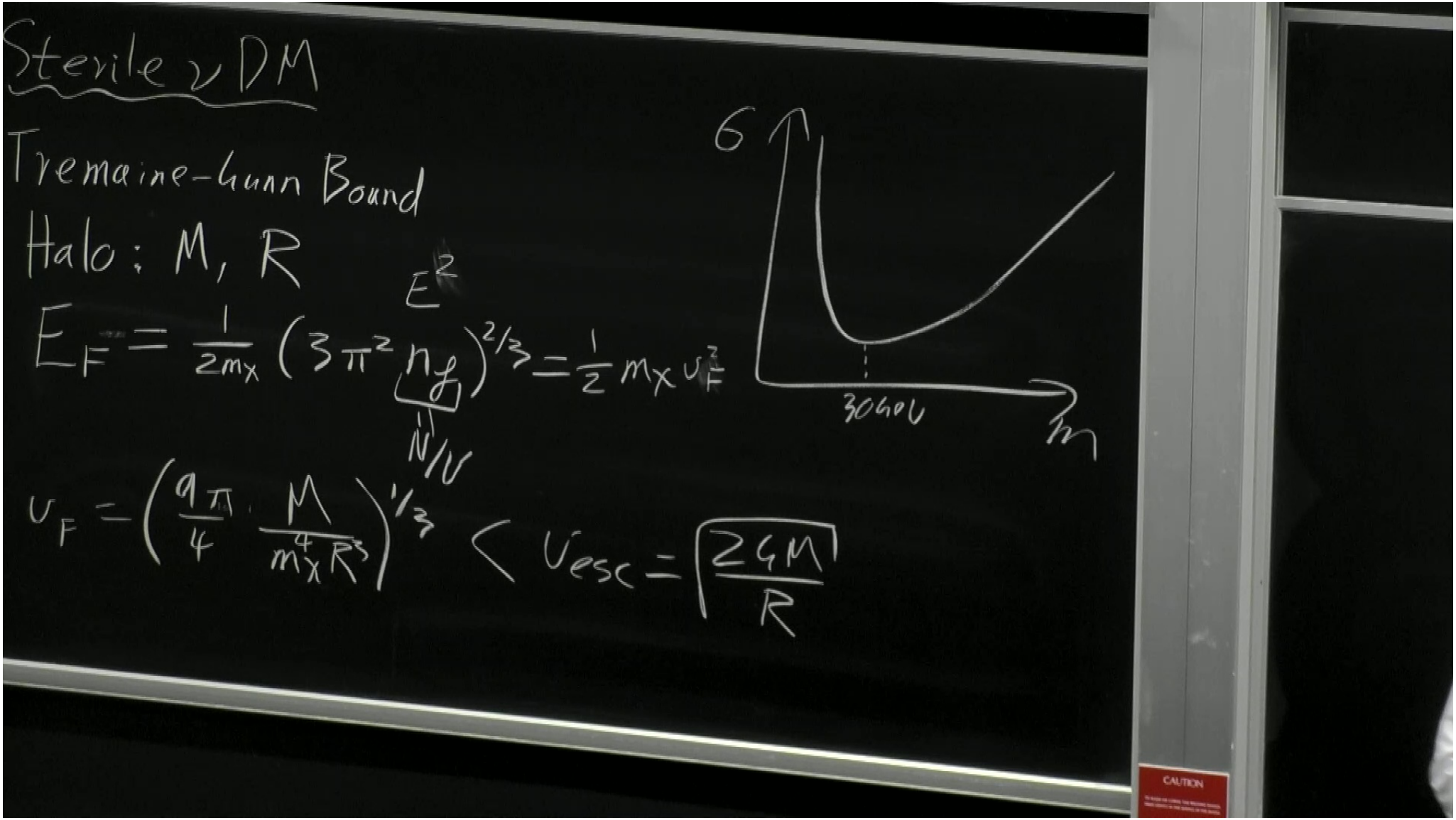
$\Rightarrow$ Detailed analysis

$m_X >$ a few keV



$E_\gamma \sim$ keV

$\sim$ X-ray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Tremaine-Gunn Bound
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$E_F = \frac{1}{2m_x}(3\pi^2 n_f)^{2/3} = \frac{1}{2} m_x v_F^2$
E^2
n_f
N/V
$v_F = \left(\frac{9\pi}{4} \frac{M}{m_x^4 R^3}\right)^{1/3} < v_{esc} = \sqrt{\frac{2GM}{R}}$
G
30 GeV
m
CAUTION

Sterile ν DM

Tremaine-Gunn Bound

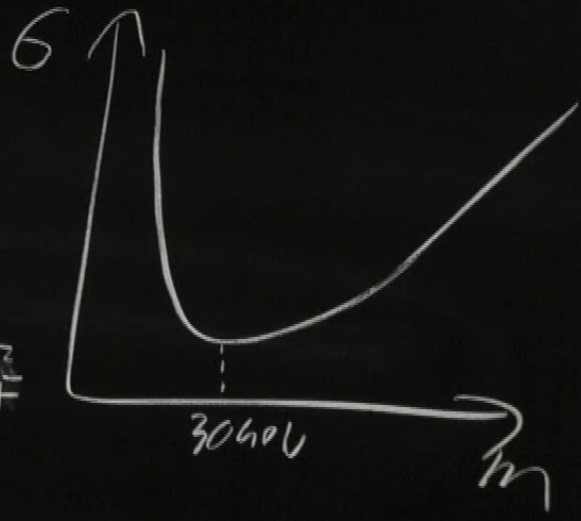
Halo: M, R

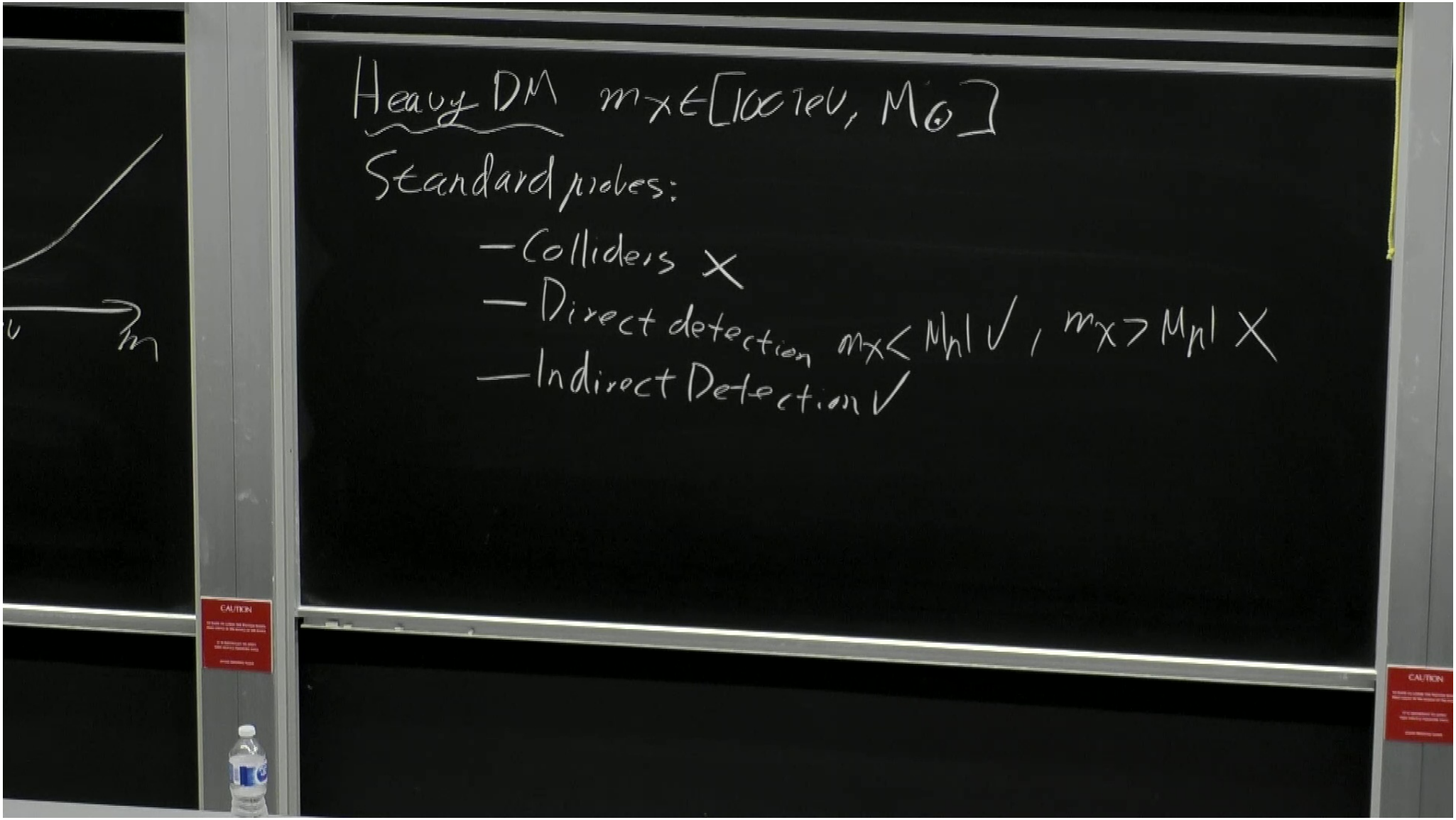
$$E_F = \frac{1}{2m_\chi}\left(3\pi^2 n_\chi\right)^{2/3} = \frac{1}{2} m_\chi v_F^2$$

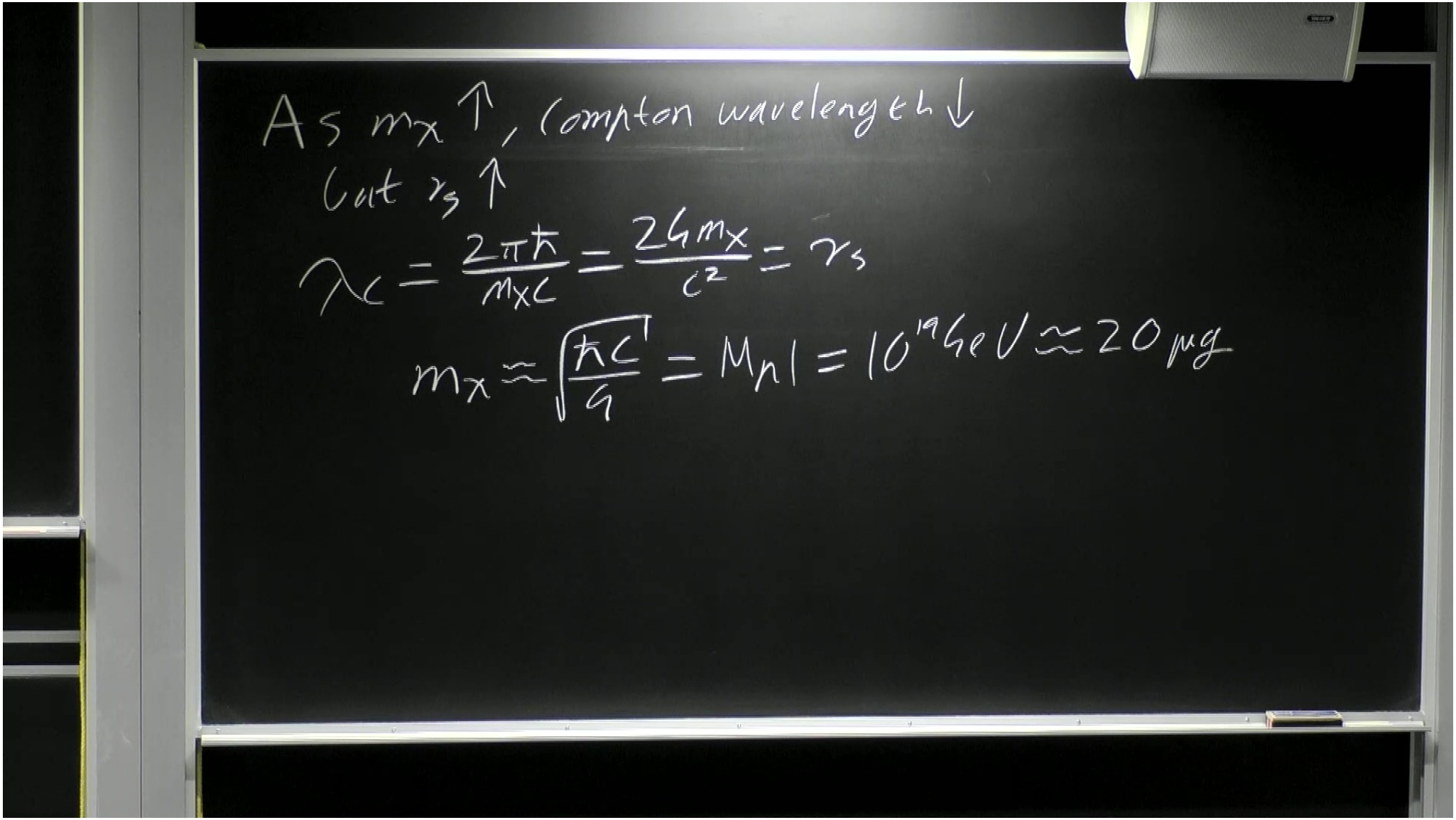
E^2

$n_\chi = N/V$

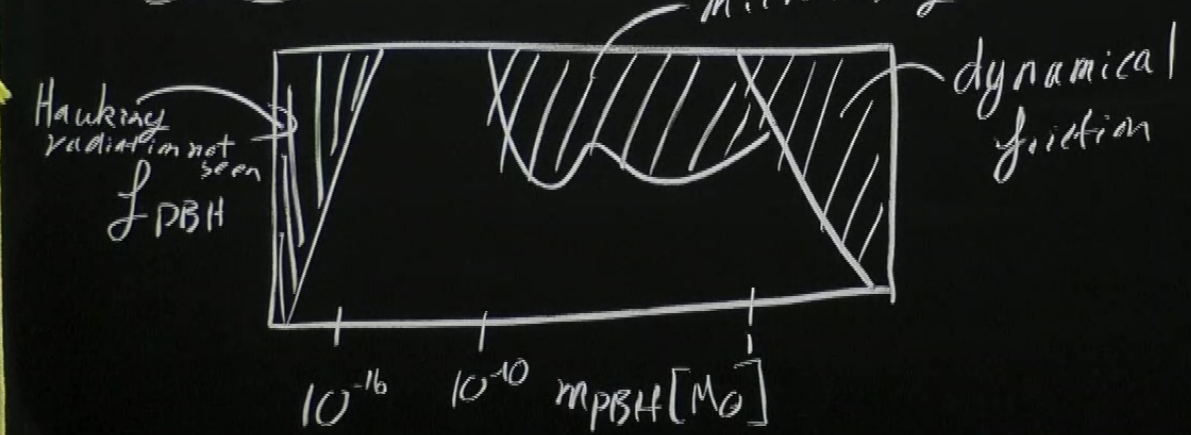
$$v_F = \left(\frac{9\pi}{4}\cdot\frac{M}{m_\chi^4 R^3}\right)^{1/3} < v_{esc} = \sqrt{\frac{2GM}{R}}$$

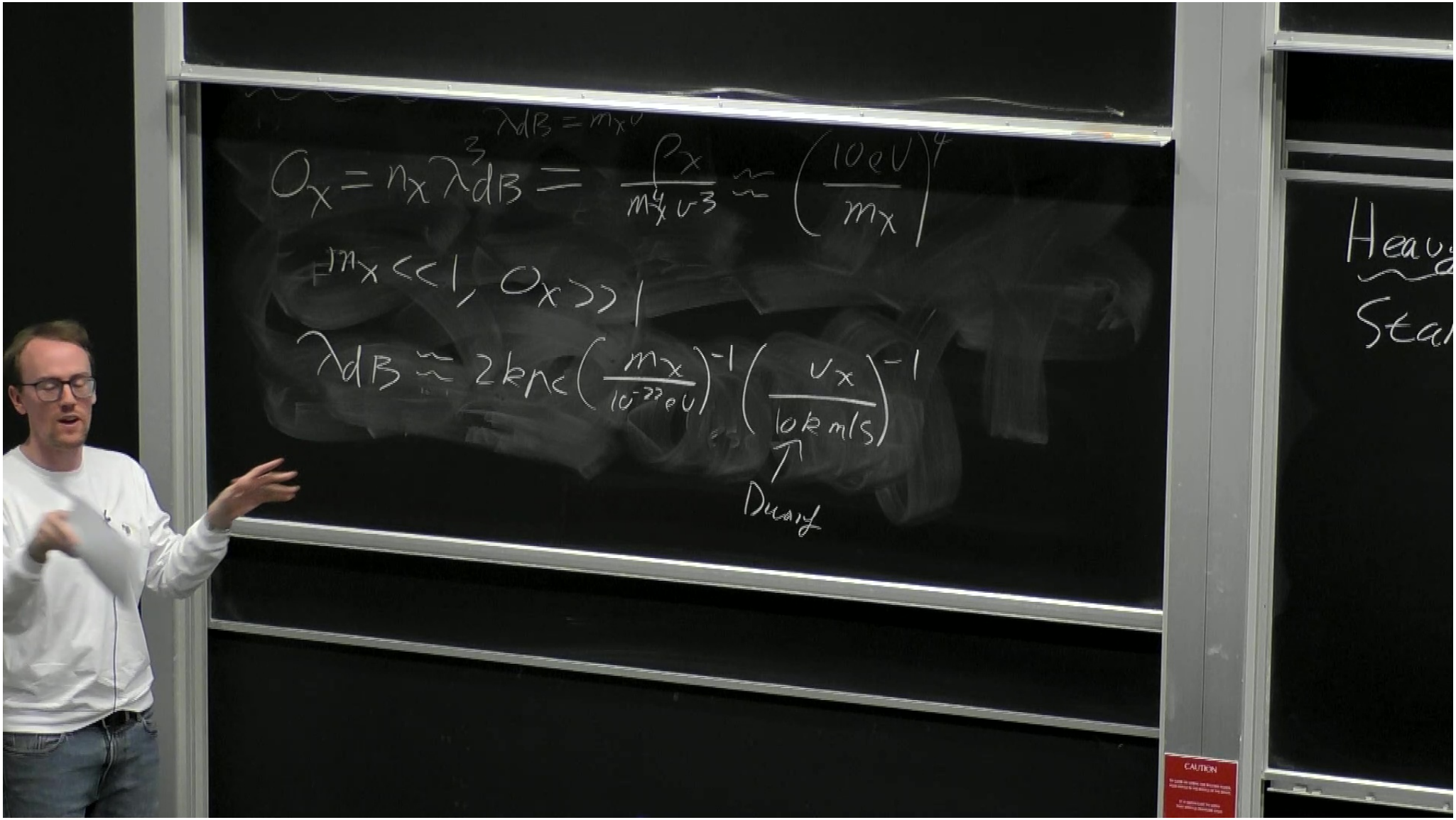


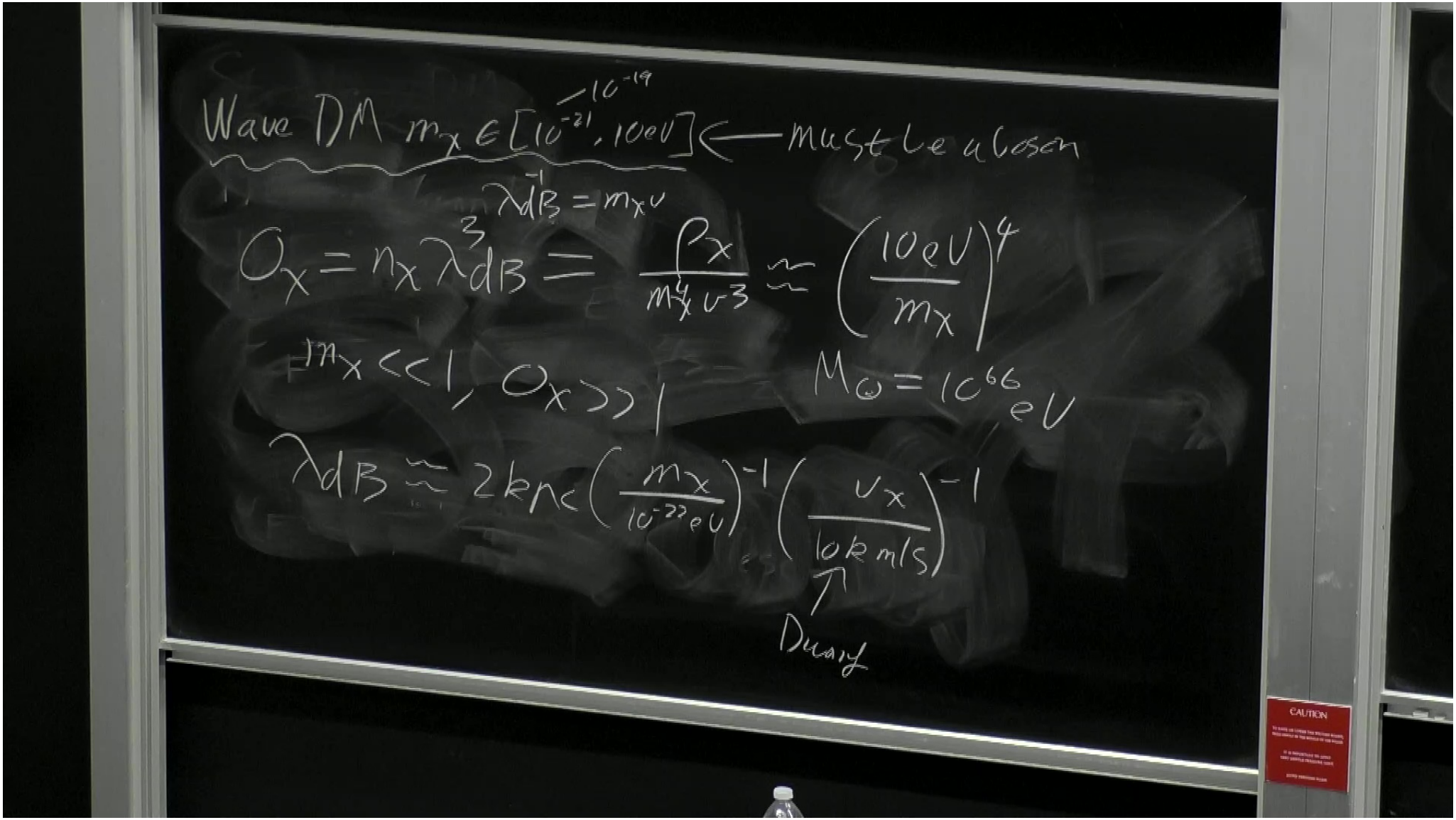

Heavy DM $m_X \in [100\,\text{TeV}, M_0]$
Standard probes:
— Colliders ✗
— Direct detection $m_X < M_{Pl}$ ✓, $m_X > M_{Pl}$ ✗
— Indirect Detection ✓
CAUTION
CAUTION

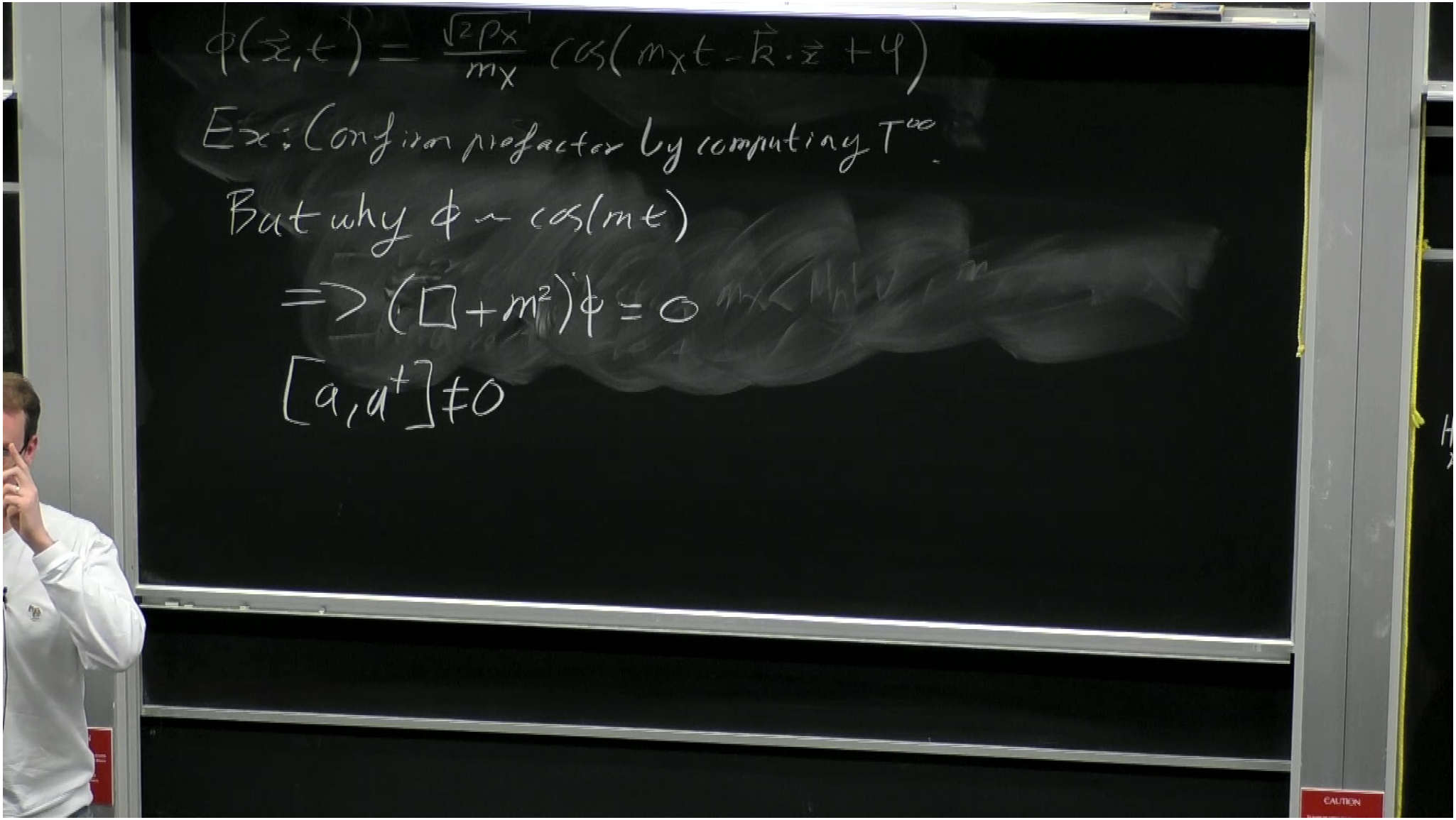

As $m_x \uparrow$, Compton wavelength $\downarrow$
but $r_s \uparrow$
$\lambda_c = \frac{2\pi\hbar}{m_x c} = \frac{2G m_x}{c^2} = r_s$
$m_x \simeq \sqrt{\frac{\hbar c}{G}} = M_{Pl} = 10^{19}\,\mathrm{GeV} \simeq 20\,\mu\mathrm{g}$

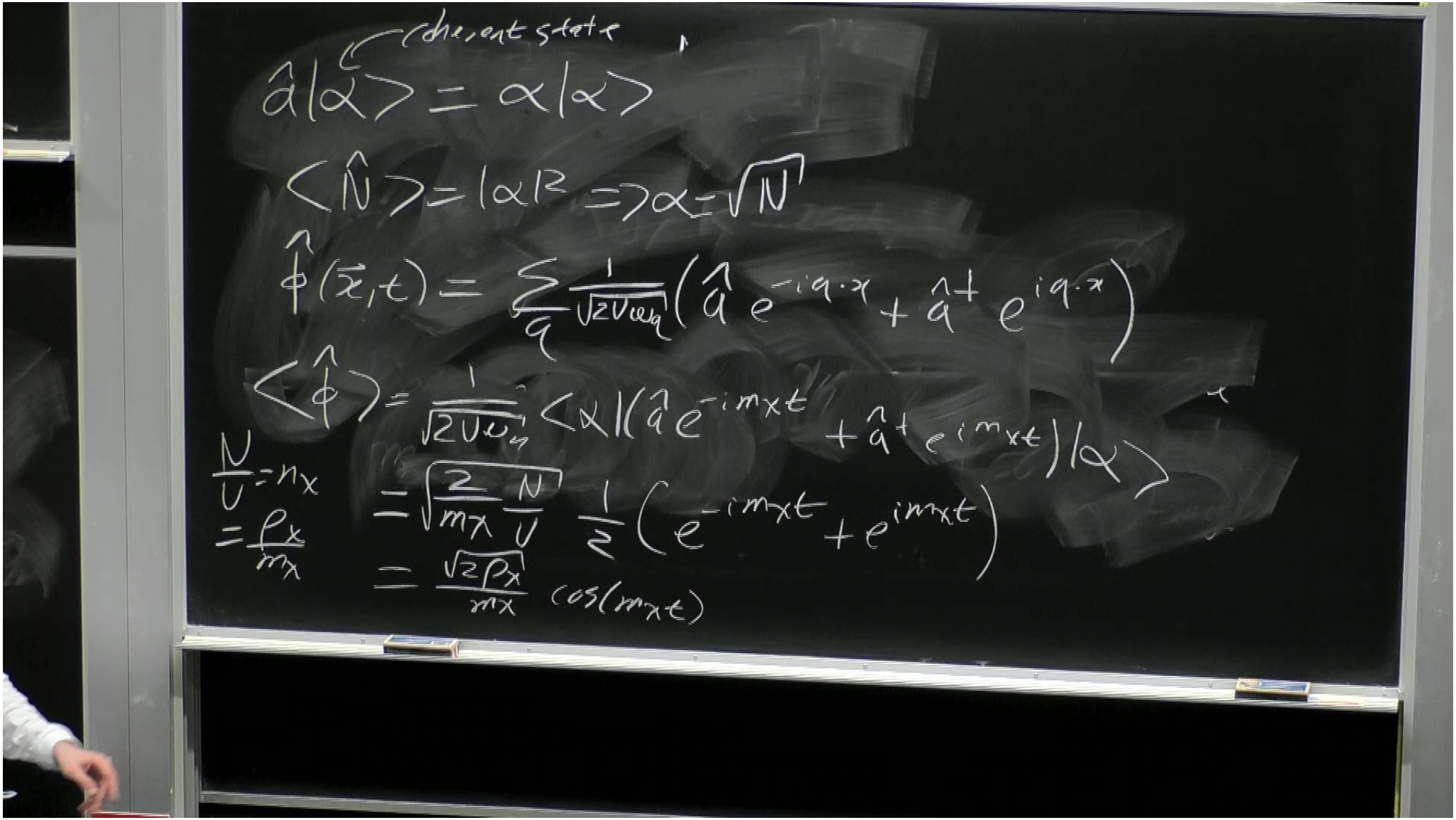
Primordial Black Holes (PBH)

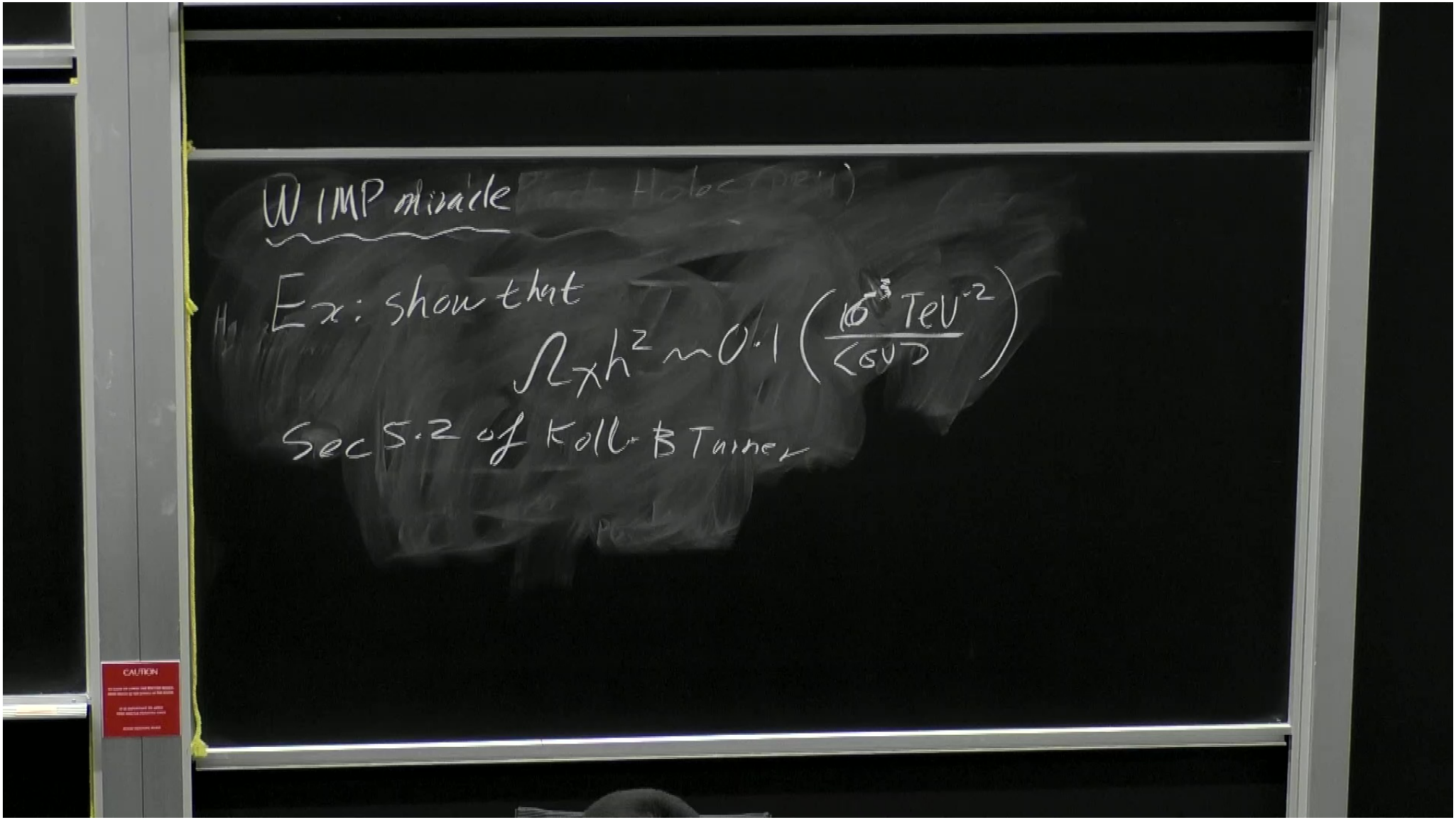


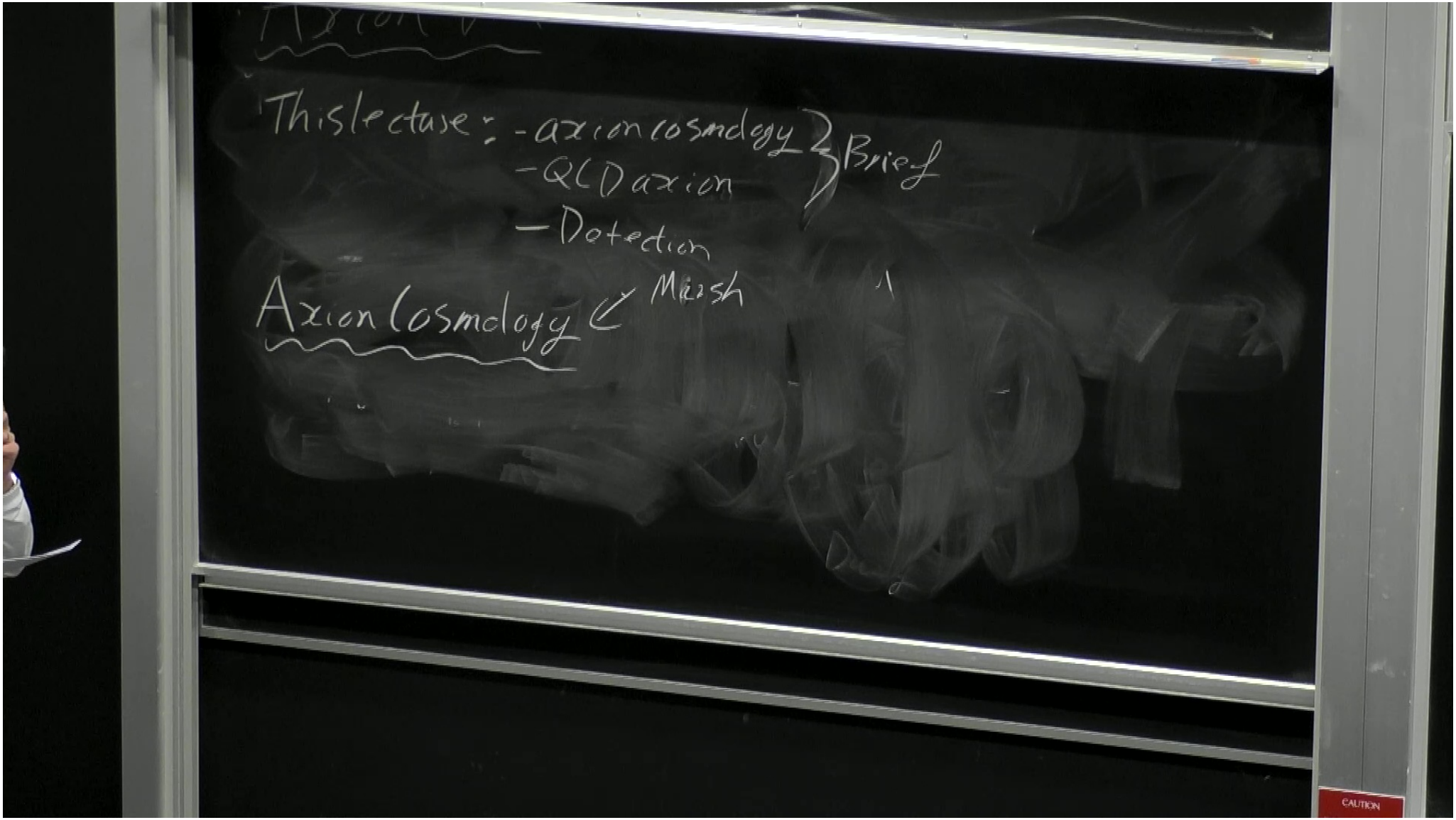

$\lambda_{dB} = m_x v$
$\Omega_x = n_x \lambda_{dB}^3 = \frac{\rho_x}{m_x^4 v^3} \simeq \left(\frac{10\,eV}{m_x}\right)^4$
$m_x \ll 1, \Omega_x \gg 1$
$\lambda_{dB} \simeq 2\hbar c \left(\frac{m_x}{10^{-22}\,eV}\right)^{-1} \left(\frac{v_x}{10\,km/s}\right)^{-1}$
Dwarf
Heavy
Star
CAUTION

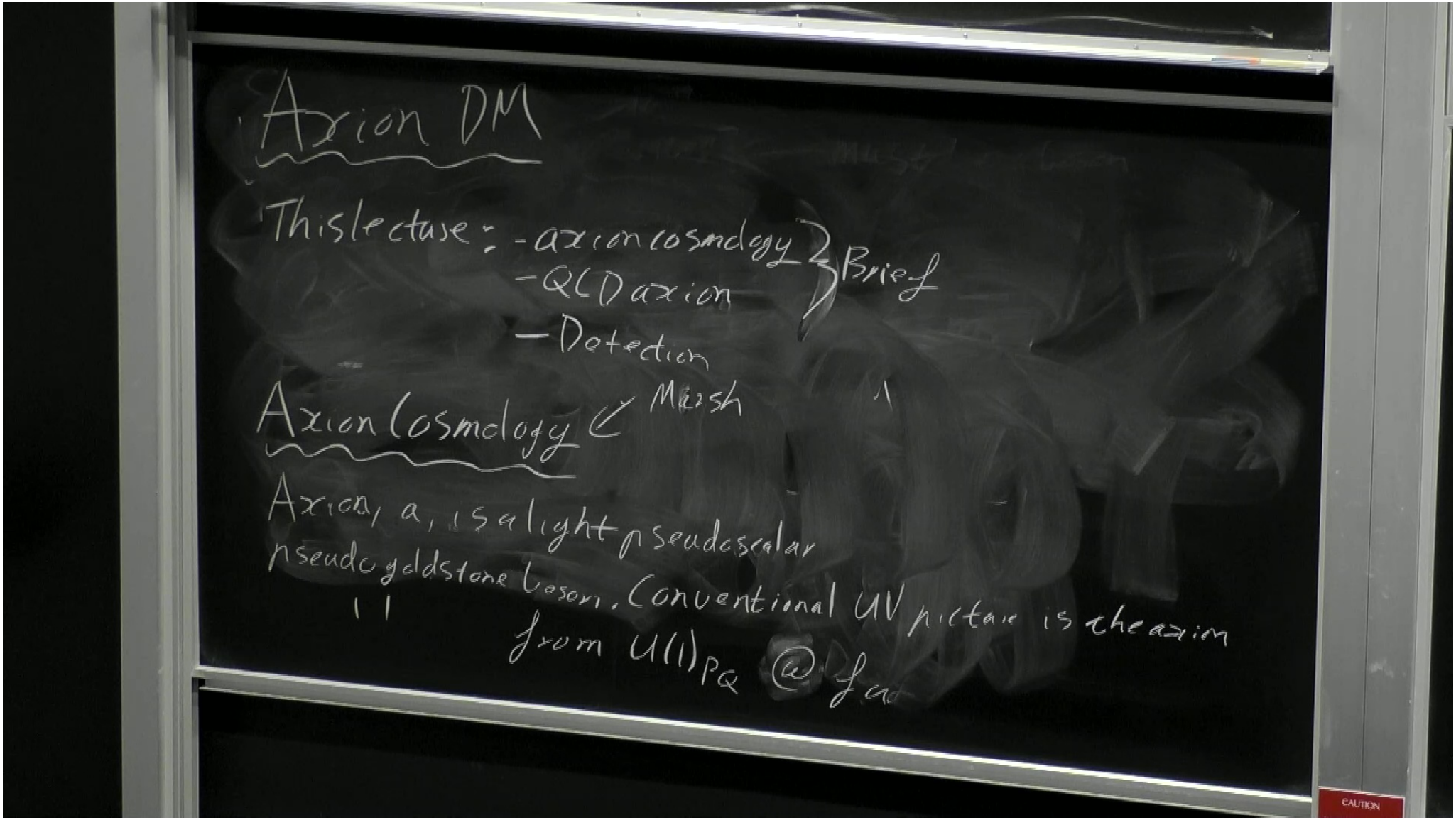

Wave DM $m_x \in [10^{-21}, 10^{-19}\,\text{eV}]$ ← must be chosen
$\lambda_{dB}^{-1} = m_x v$
$O_x = n_x \lambda_{dB}^3 = \frac{\rho_x}{m_x^4 v^3} \simeq \left(\frac{10\,\text{eV}}{m_x}\right)^4$
$m_x \ll 1, \; O_x \gg 1$
$M_\odot = 10^{66}\,\text{eV}$
$\lambda_{dB} \simeq 2\pi c \left(\frac{m_x}{10^{-22}\,\text{eV}}\right)^{-1} \left(\frac{v_x}{10\,\text{km/s}}\right)^{-1}$
Dwarf
CAUTION

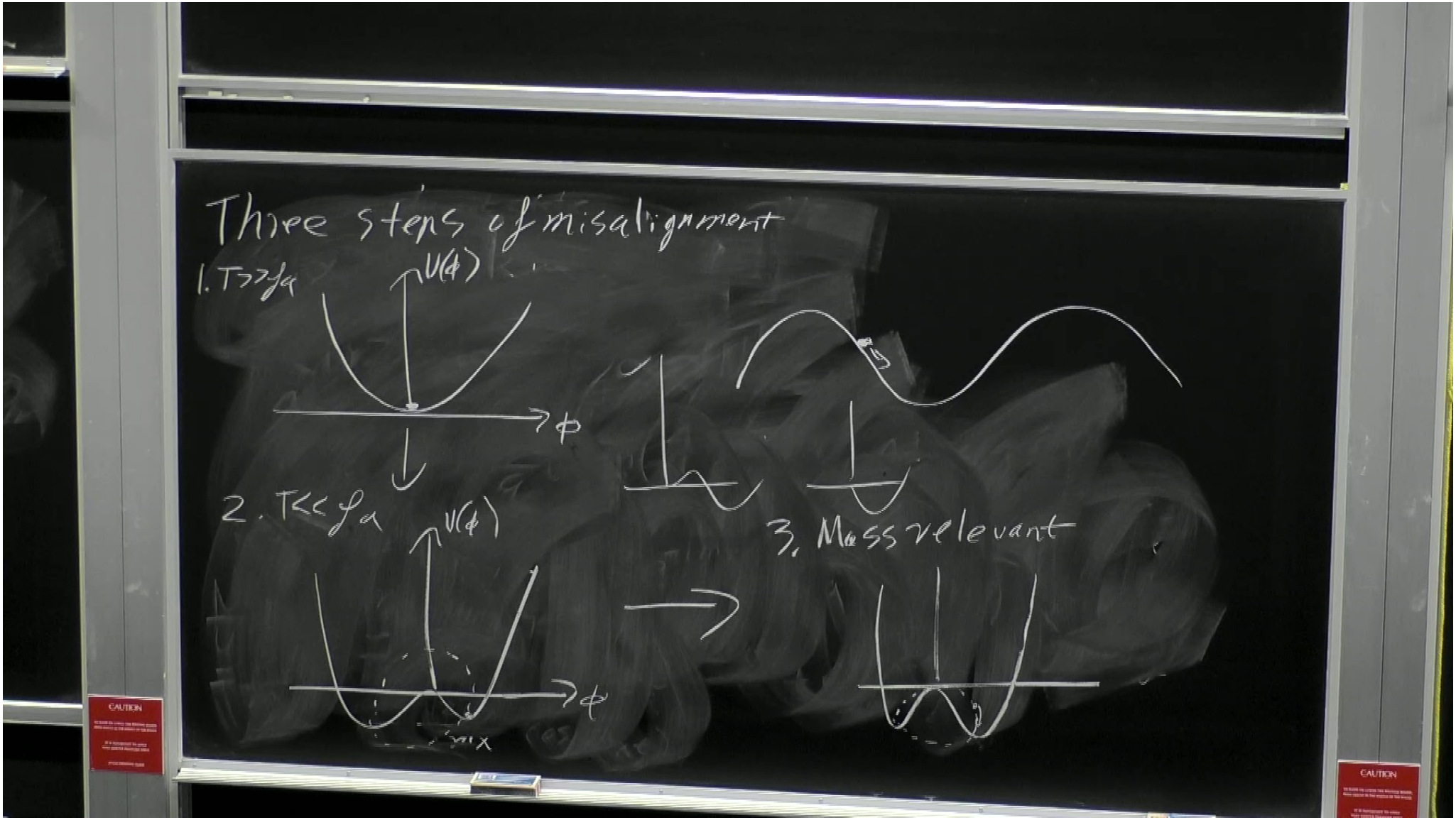

$\phi(\vec{x},t) = \frac{\sqrt{2}\rho_X}{m_X} \cos(m_X t - \vec{k}\cdot\vec{x} + \varphi)$
Ex: Confirm prefactor by computing T^{00}.
But why $\phi \sim \cos(mt)$
$\Rightarrow (\Box + m^2)\phi = 0$
$[a, a^\dagger] \neq 0$


coherent state
$\hat{a}|\alpha\rangle = \alpha|\alpha\rangle$
$\langle \hat{N} \rangle = |\alpha|^2 \Rightarrow \alpha = \sqrt{N}$
$\hat{\phi}(\vec{x},t) = \sum_q \frac{1}{\sqrt{2V\omega_q}} \left(\hat{a}\, e^{-iq\cdot x} + \hat{a}^\dagger e^{iq\cdot x} \right)$
$\langle \hat{\phi} \rangle = \frac{1}{\sqrt{2V\omega_q}} \langle \alpha | \left(\hat{a}\, e^{-im_\chi t} + \hat{a}^\dagger e^{im_\chi t} \right) | \alpha \rangle$
$\frac{N}{V} = n_\chi = \frac{\rho_\chi}{m_\chi}$
$= \sqrt{\frac{2N}{m_\chi V}} \frac{1}{2} \left(e^{-im_\chi t} + e^{im_\chi t} \right)$
$= \frac{\sqrt{2\rho_\chi}}{m_\chi} \cos(m_\chi t)$


WIMP miracle
Ex: show that
$\Omega_\chi h^2 \sim 0.1 \left(\frac{10^{-5}\ \mathrm{TeV}^{-2}}{\langle \sigma v \rangle}\right)$
Sec 5.2 of Kolb & Turner
CAUTION


This lecture: - axion cosmology
- QCD axion
- Detection
Brief
Axion cosmology
Marsh
CAUTION


Axion DM
This lecture: - axion cosmology
- QCD axion
- Detection
Brief
Axion Cosmology
Marsh
Axion, a, is a light pseudoscalar
pseudo goldstone boson. Conventional UV picture is the axion
from U(1)PQ @ fa
CAUTION


Three stens of misalignment
1. T>>fa
V(φ)
φ
2. T<<fa
V(φ)
φ
mix
3. Mass relevant