Title: Non thermal DM/Misalignment

Speakers: Giovanni Villadoro

Collection: School on Table-Top Experiments for Fundamental Physics

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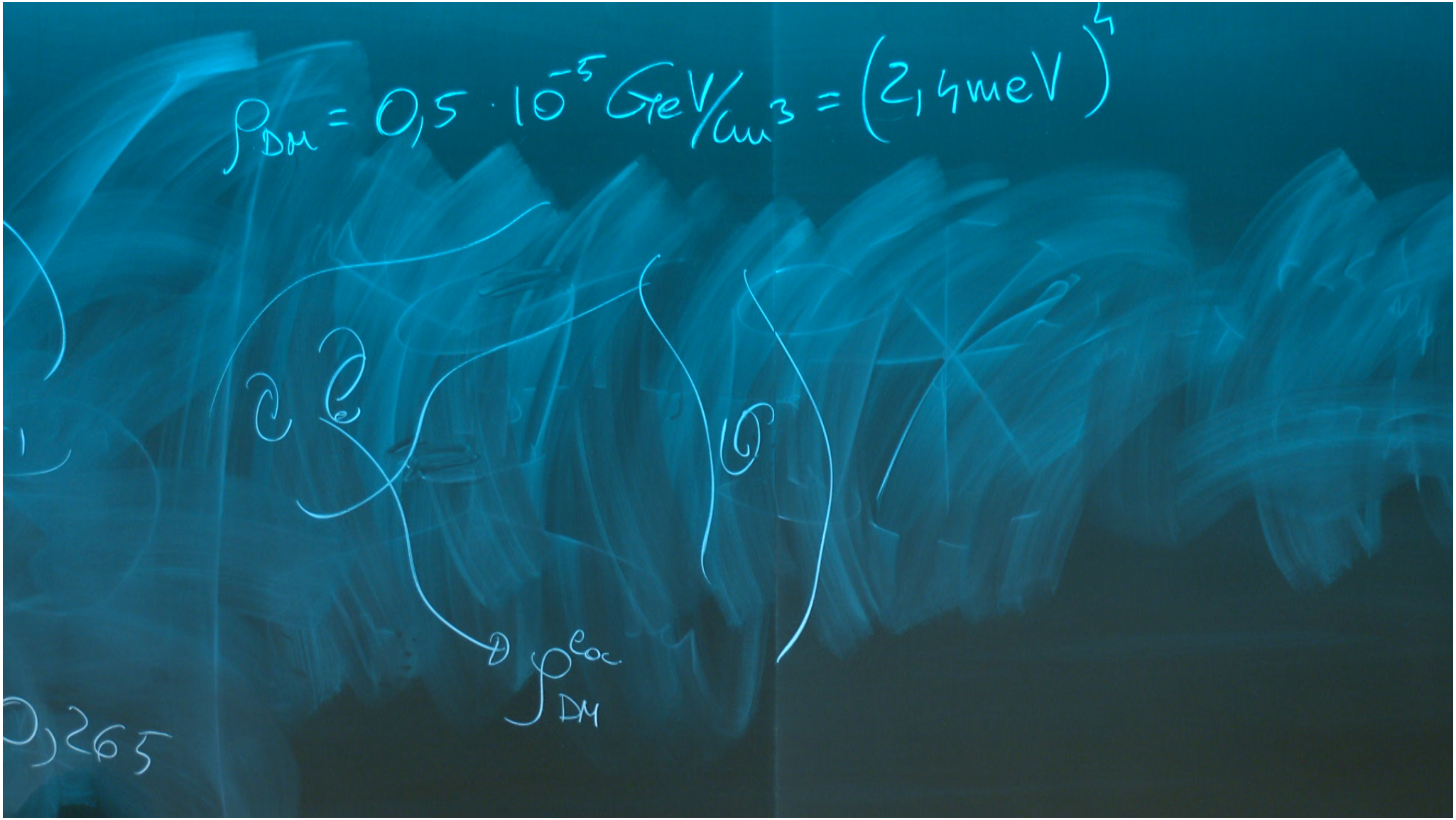
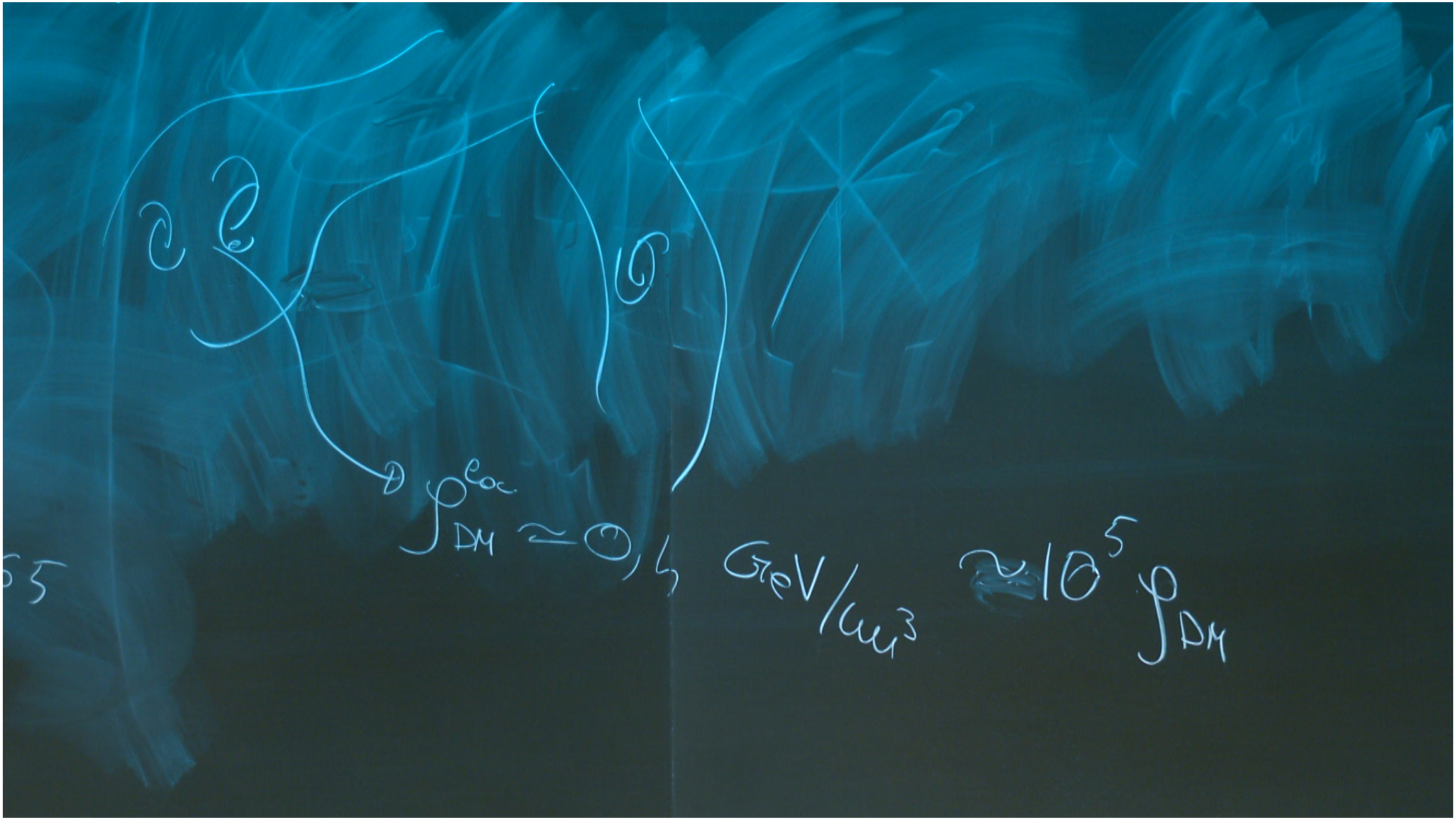
URL: https://pirsa.org/22090007


$\rho_{DM} = 0{,}5 \cdot 10^{-5}\ GeV/cm^3 = (2{,}4\,meV)^4$
$\rho_{DM}^{loc.}$


$\rho_{DM}^{loc} \simeq 0.4\ \mathrm{GeV/cm^3} \simeq 10^5\ \rho_{DM}$

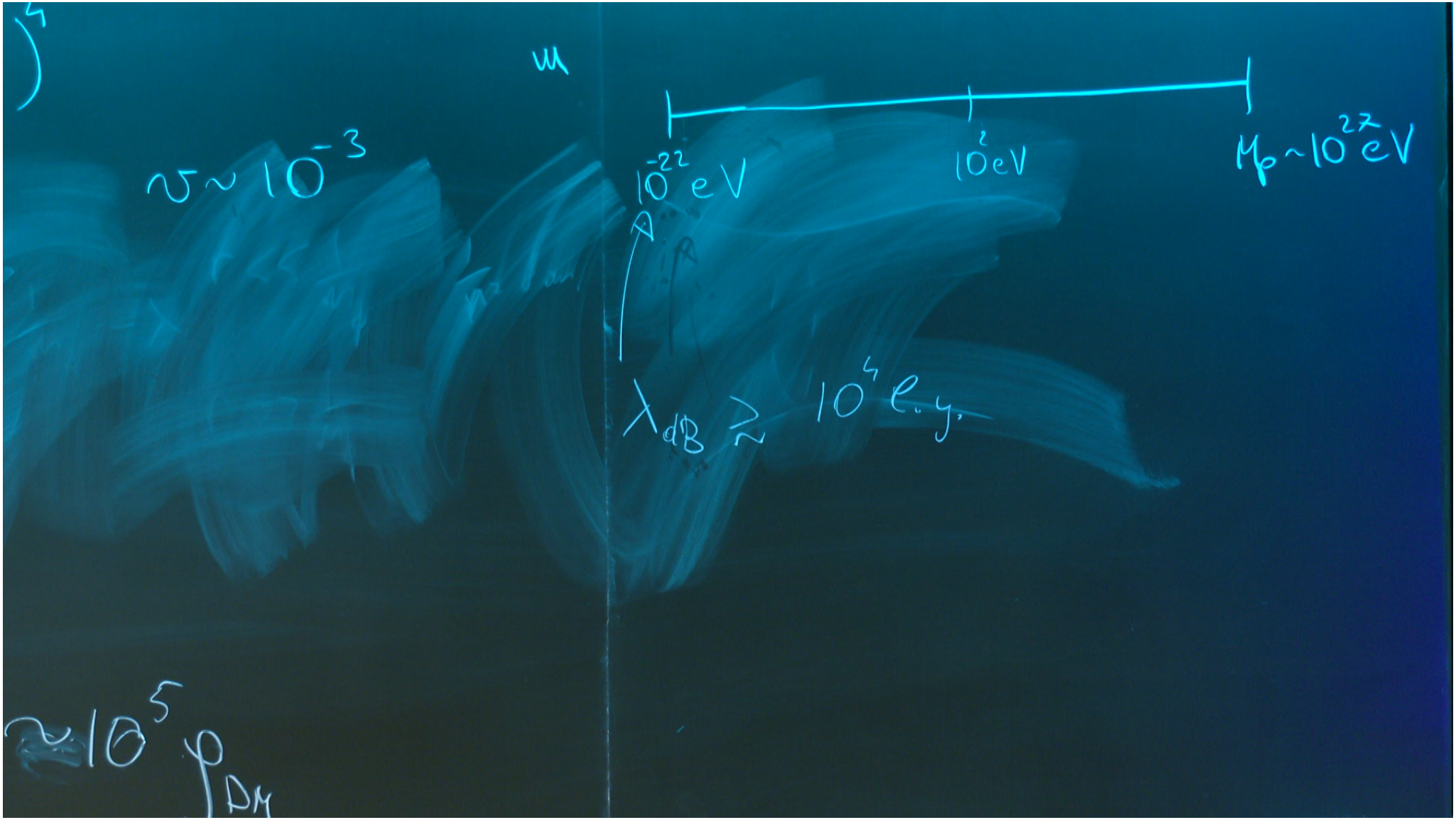
(MISALIGNMENT)

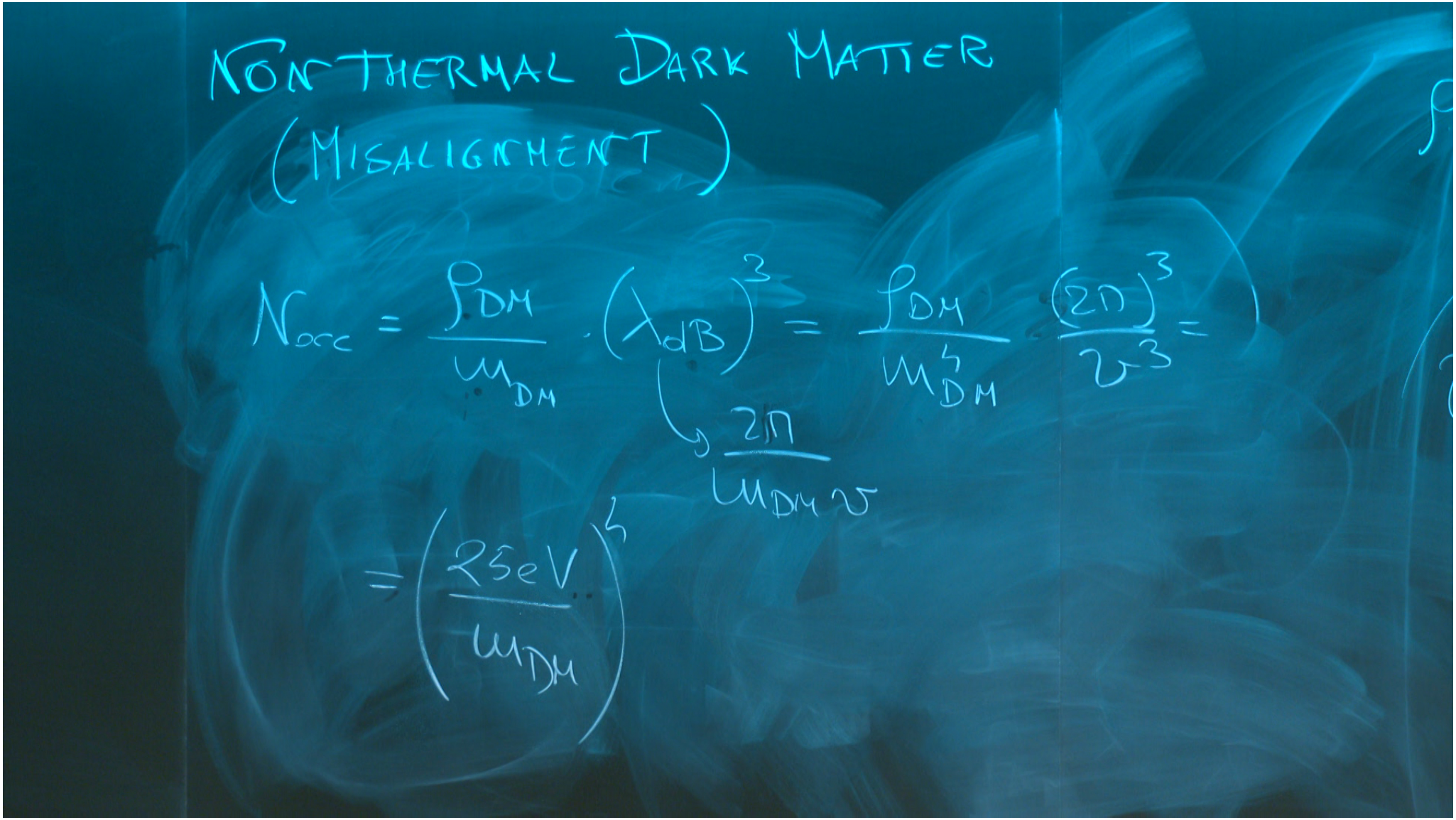
NATURAL UNITS $(\hbar = c = 1)$

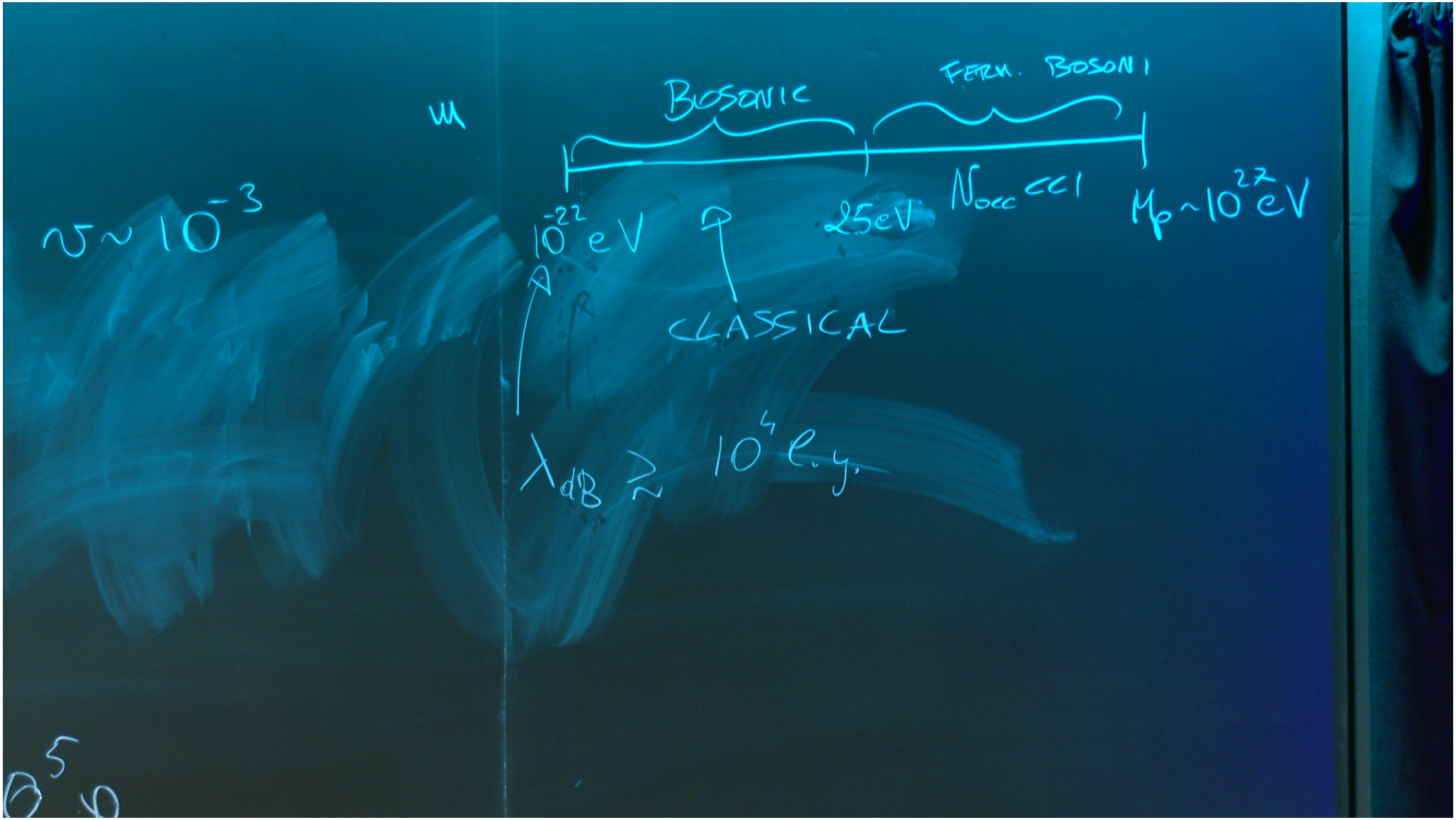
$(\Pi = 2 = 1)$

DARK MATTER

$$\Omega_{DM} \equiv \frac{\rho_{DM}}{\rho_{TOT}} \simeq 0,265$$


$v \sim 10^{-3}$
10^{-22} eV
10^{2} eV
$M_p \sim 10^{22}$ eV
$\lambda_{dB} \gtrsim 10^{4}$ e.y.
$\simeq 10^{5}\, \rho_{DM}$


NON THERMAL DARK MATTER
(MISALIGNMENT)
$N_{occ} = \frac{\rho_{DM}}{m_{DM}} \cdot (\lambda_{dB})^3 = \frac{\rho_{DM}}{m_{DM}^4} \frac{(2\pi)^3}{v^3} =$
$\lambda_{dB} \to \frac{2\pi}{m_{DM} v}$
$= \left(\frac{25eV}{m_{DM}} \right)^4$

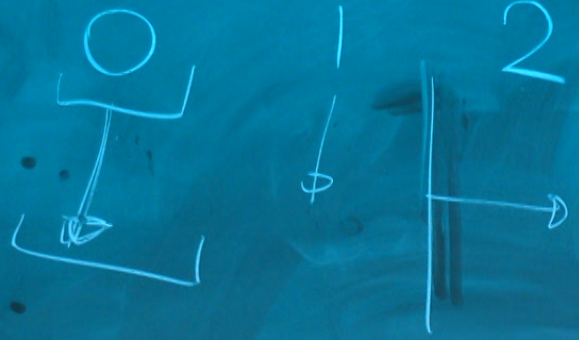

BOSONIC
FERM. BOSONI
10^{-22} eV
25eV
$N_{occ} \ll 1$
$M_p \sim 10^{27}$ eV
CLASSICAL
$\lambda_{dB} \gtrsim 10^4$ l.y.

NON THERMAL DARK MATTER

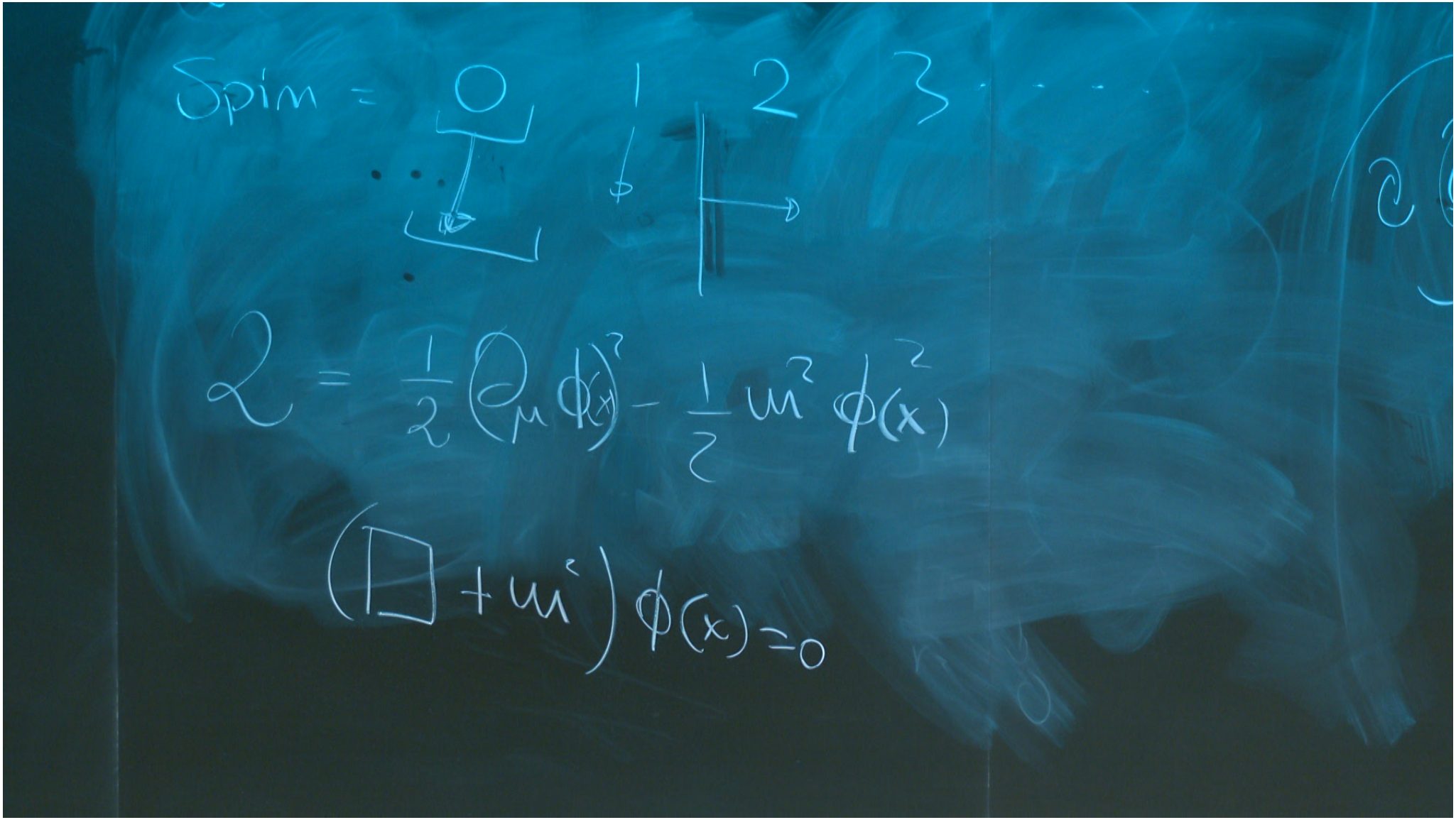
(MISALIGNMENT)

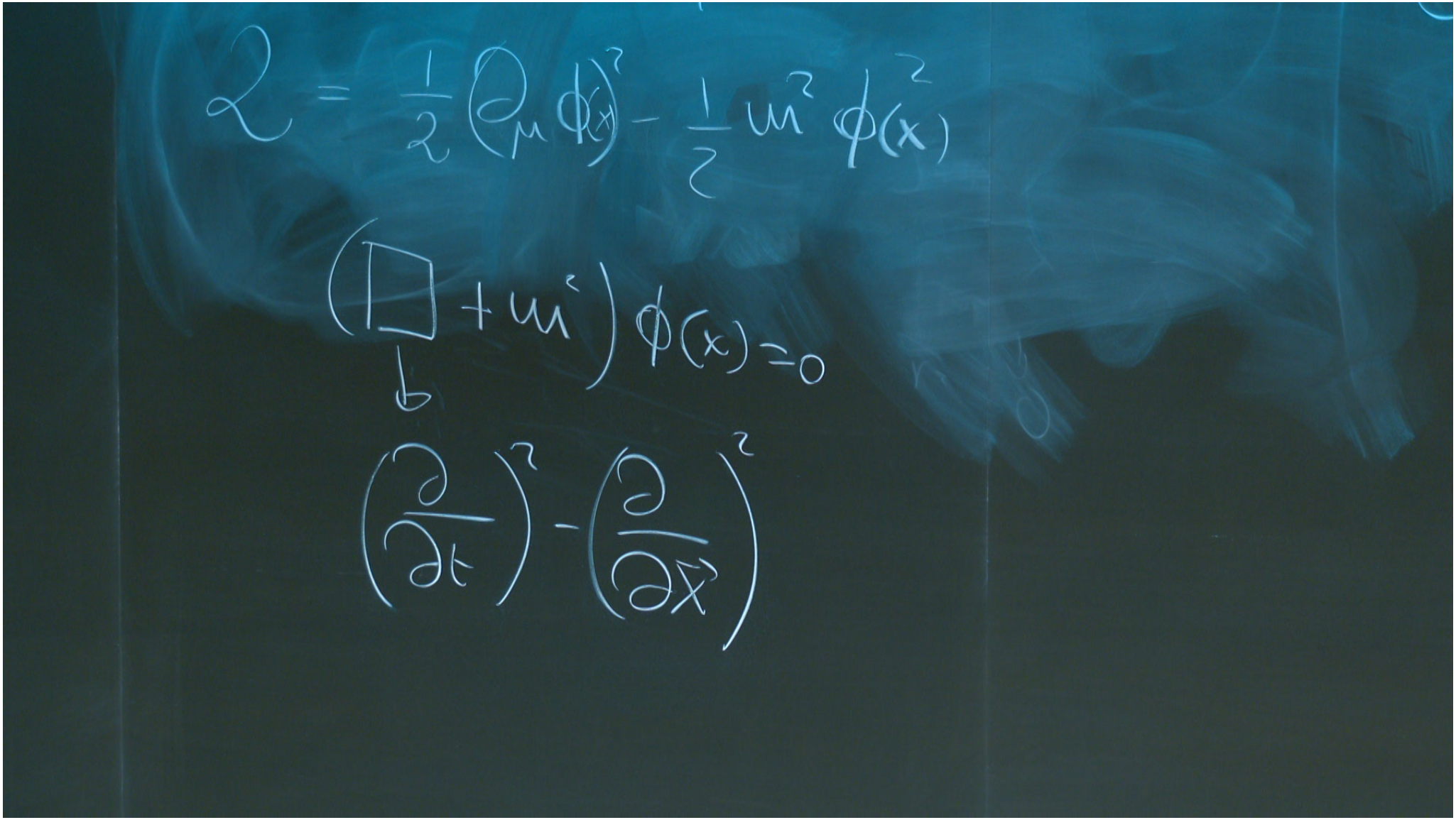
ρ_{DM}

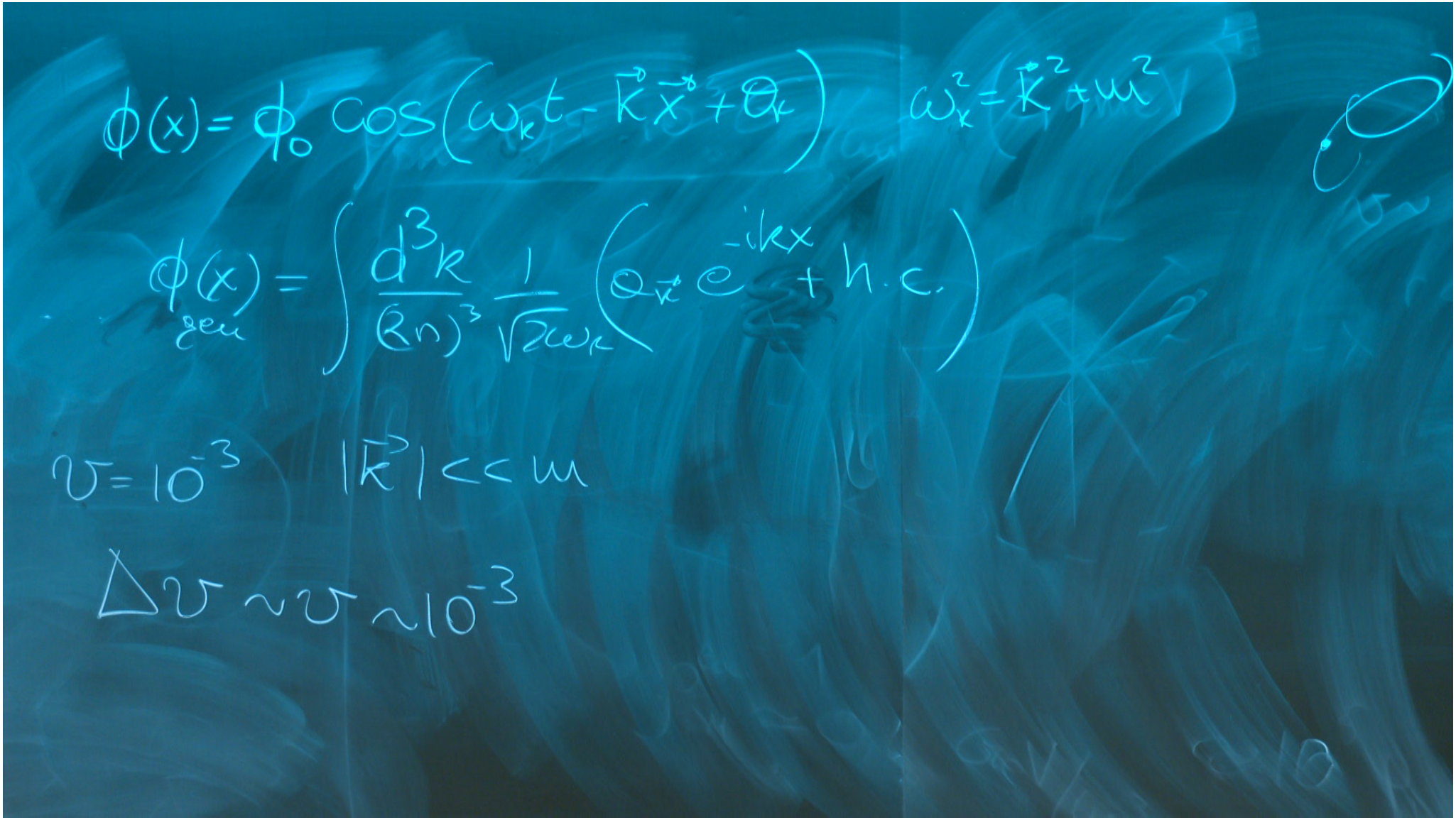
Spin = 0 1 2 3 . . . .



$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi(x))^2 - \frac{1}{2} m^2 \phi(x)^2$$

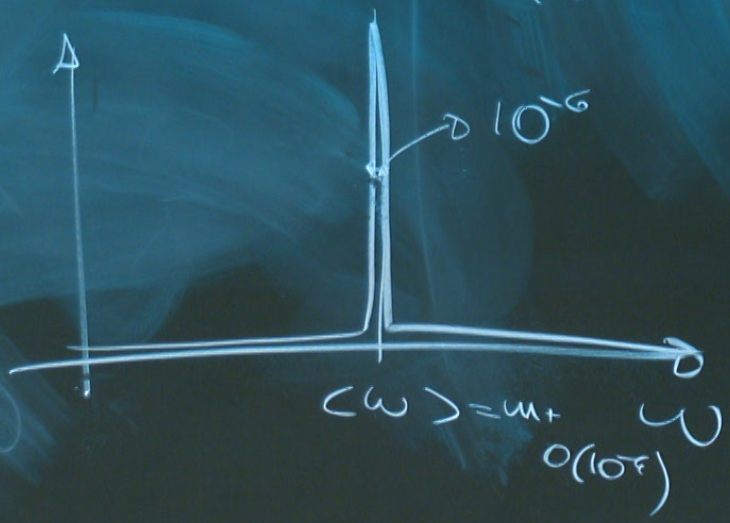

Spin = 0 1 2 3
$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi(x))^2 - \frac{1}{2}m^2\phi(x)^2$
$(\Box + m^2)\phi(x) = 0$

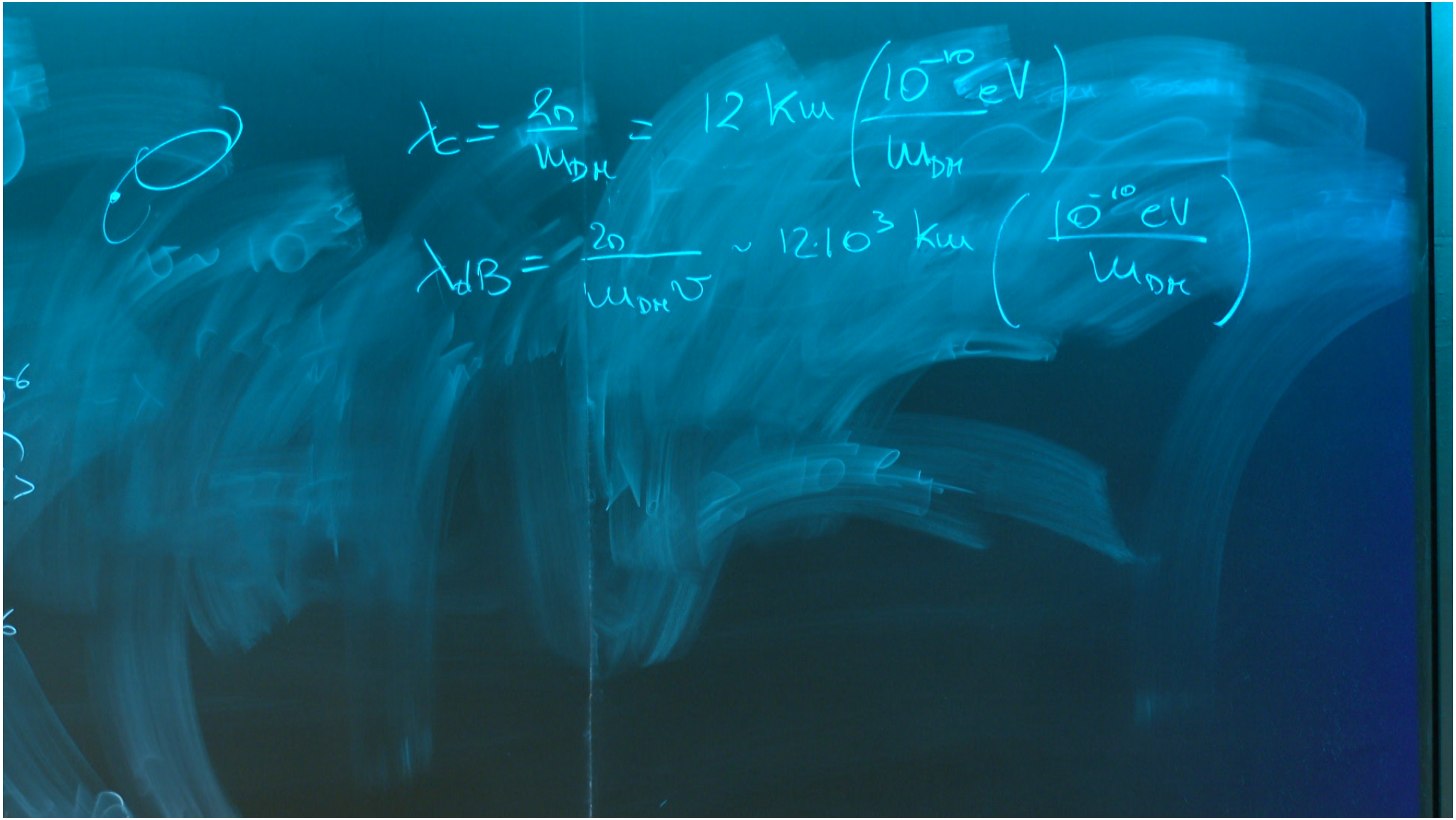

$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi(x))^2 - \frac{1}{2} m^2 \phi(x)^2$
$(\Box + m^2)\phi(x) = 0$
$\left(\frac{\partial}{\partial t}\right)^2 - \left(\frac{\partial}{\partial x}\right)^2$

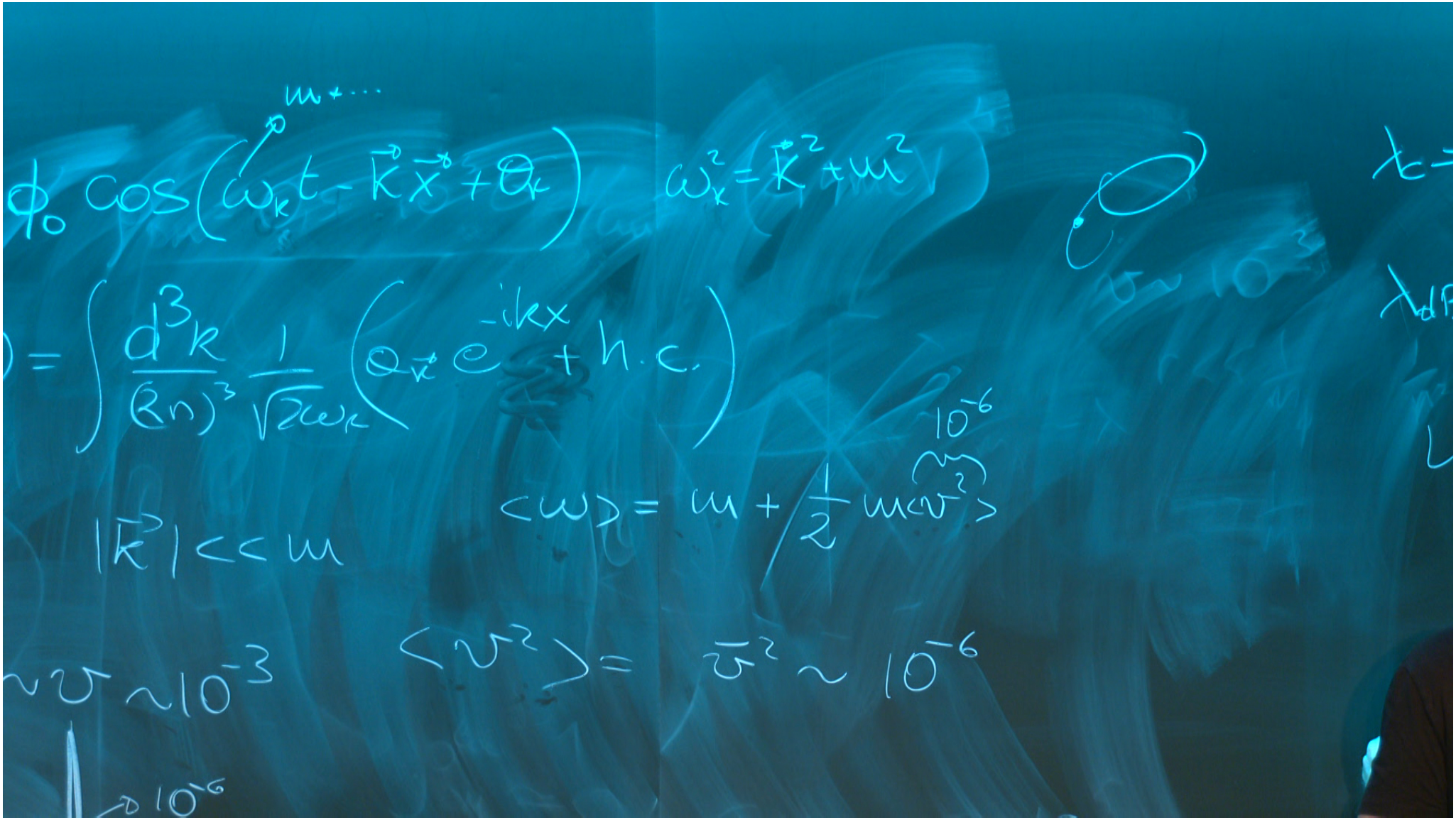

$\phi(x) = \phi_0 \cos(\omega_k t - \vec{k}\vec{x} + \theta_k)$
$\omega_k^2 = \vec{k}^2 + m^2$
$\phi(x) = \int \frac{d^3k}{(2\pi)^3} \frac{1}{\sqrt{2\omega_k}} \left(a_k^* e^{-ikx} + h.c. \right)$
$v = 10^{-3}$
$|\vec{k}| << m$
$\Delta v \sim v \sim 10^{-3}$

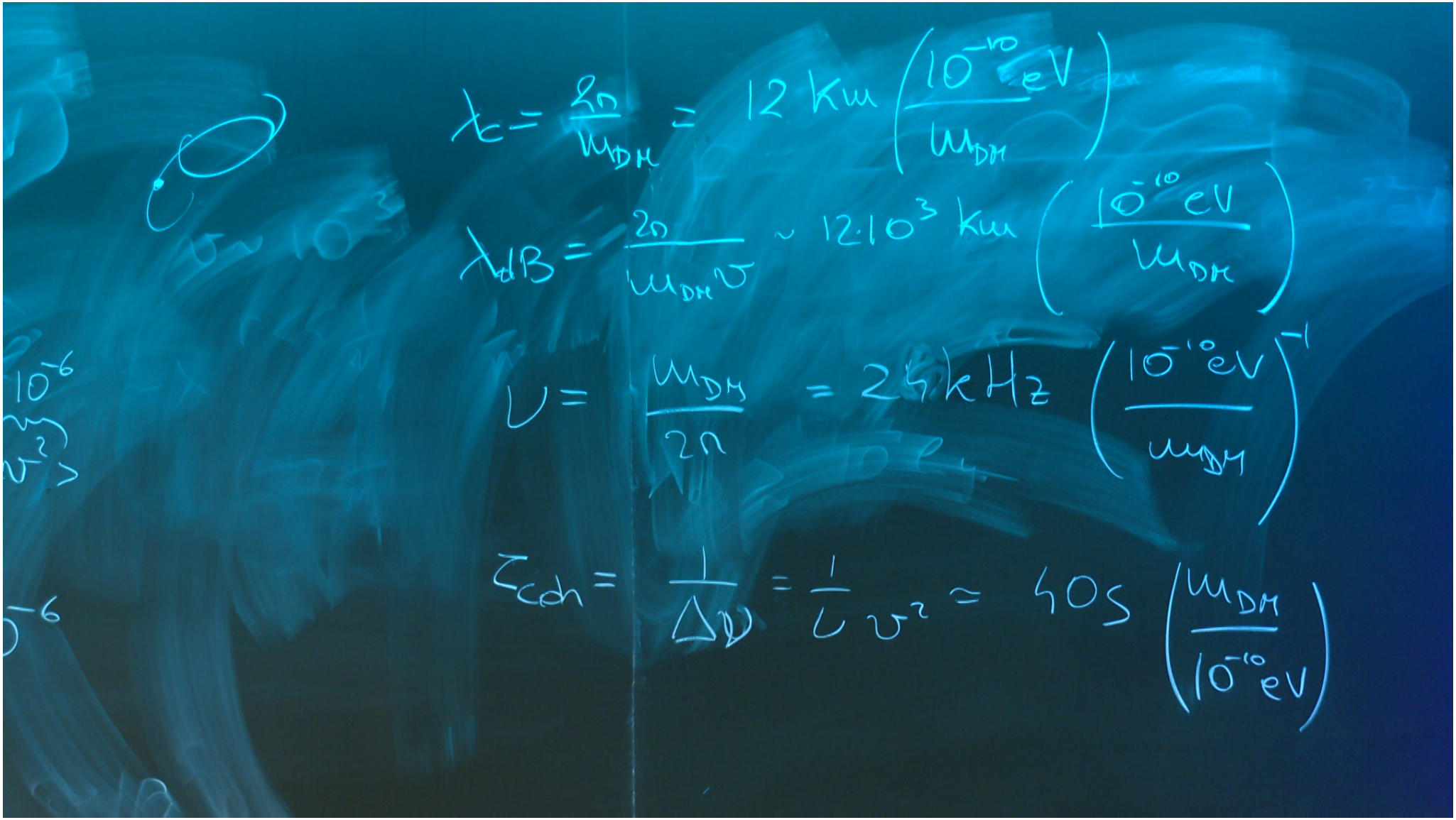
$v = 10^{-3}$ $|\vec{k}| << m$ $\langle \omega \rangle = m + \frac{1}{2} m \langle v^2 \rangle$

$\Delta v \sim v \sim 10^{-3}$ $\langle v^2 \rangle = \bar{v}^2 \sim 10^{-6}$




$\lambda_c = \frac{2\pi}{m_{DM}} = 12\ \mathrm{km}\left(\frac{10^{-10}\ \mathrm{eV}}{m_{DM}}\right)$
$\lambda_{dB} = \frac{2\pi}{m_{DM} v} \sim 12 \cdot 10^3\ \mathrm{km}\left(\frac{10^{-10}\ \mathrm{eV}}{m_{DM}}\right)$


$\phi_0 \cos\left(\omega_k t - \vec{k}\vec{x} + \theta_k\right)$
$m + \cdots$
$\omega_k^2 = \vec{k}^2 + m^2$
$= \int \frac{d^3k}{(2\pi)^3} \frac{1}{\sqrt{2\omega_k}} \left(a_k^* e^{-ikx} + h.c. \right)$
$|\vec{k}| \ll m$
$\langle \omega \rangle = m + \frac{1}{2} m \langle v^2 \rangle$
10^{-6}
$\sim v \sim 10^{-3}$
$\langle v^2 \rangle = \bar{v}^2 \sim 10^{-6}$
$\sim 10^{-6}$


$\lambda_c = \frac{2\pi}{m_{DM}} = 12\,\mathrm{km}\left(\frac{10^{-10}\,\mathrm{eV}}{m_{DM}}\right)$
$\lambda_{dB} = \frac{2\pi}{m_{DM} v} \sim 12\cdot 10^3\,\mathrm{km}\left(\frac{10^{-10}\,\mathrm{eV}}{m_{DM}}\right)$
$\nu = \frac{m_{DM}}{2\pi} = 24\,\mathrm{kHz}\left(\frac{10^{-10}\,\mathrm{eV}}{m_{DM}}\right)$
$\tau_{coh} = \frac{1}{\Delta\nu} = \frac{1}{\nu v^2} \simeq 40\,\mathrm{s}\left(\frac{m_{DM}}{10^{-10}\,\mathrm{eV}}\right)$

NON THERMAL DARK MATTER

(MISALIGNMENT)

$$\phi(x) = \phi_0 \cos($$

$$\phi(x_0) = \sum_n \phi_0 e^{i(\omega t - \vec{k}_n \vec{x}_0 + \theta_n)} \qquad \phi(x) = \int \frac{d^3k}{(2\pi)^3}$$

$$\propto \sqrt{\Gamma_{occ}}\, e^{i m t + i 10^{-6} t}$$

$$v = 10^{-3} \qquad |\vec{k}| <$$

$$\Delta v \sim v \sim 10$$

10^{-6}

$$\phi(x) = \phi_0 \cos\left(\omega_k t - \vec{k}\vec{x} + \theta_k\right) \qquad \omega_k^2 = \vec{k}^2 + m^2$$

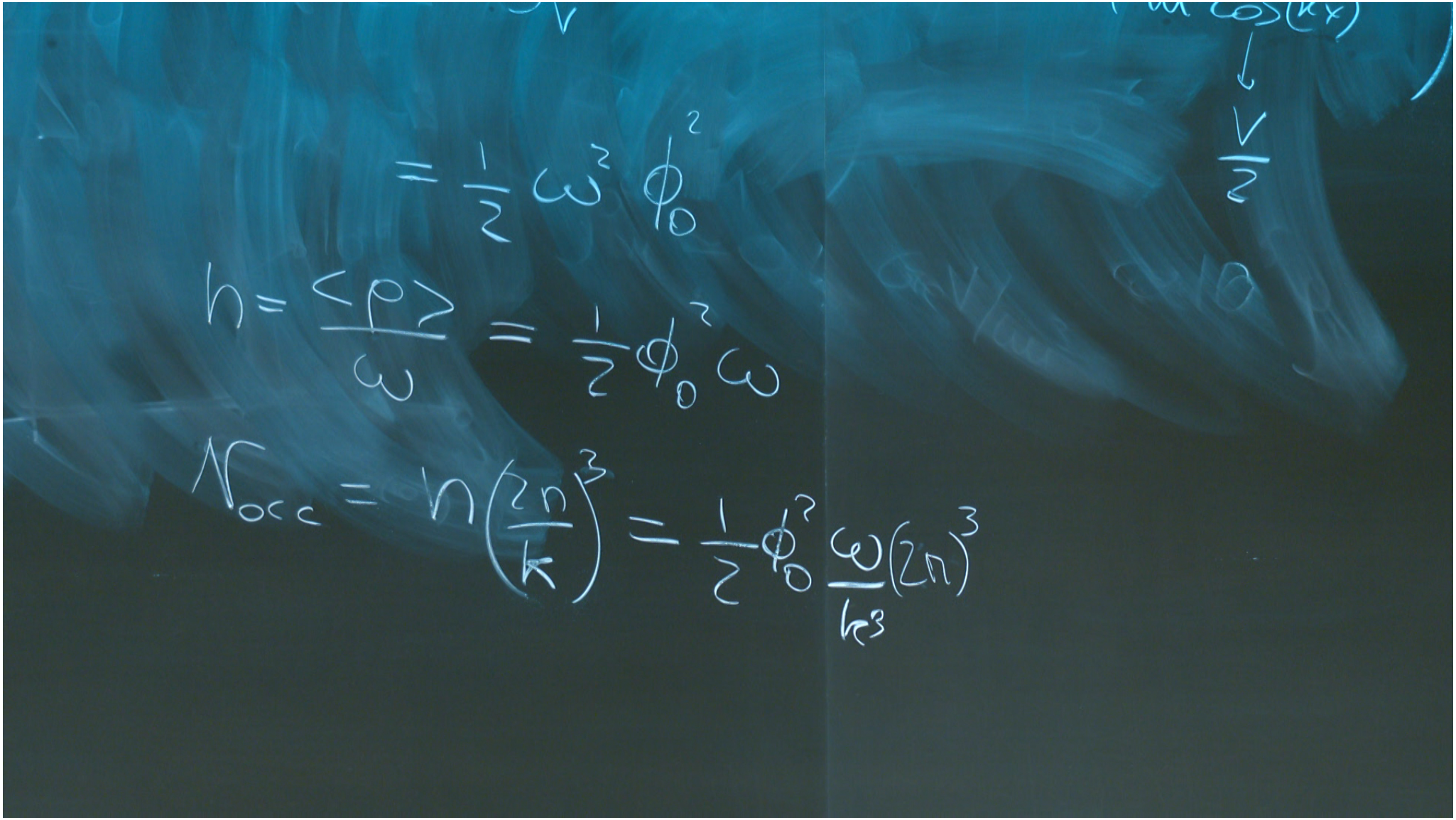
$$\rho(x) = \mathcal{H}(x) = \frac{1}{2}\dot{\phi}^2(x) + \frac{1}{2}\left(\vec{\nabla}\phi\right)^2 + \frac{1}{2}m^2\phi(x)^2$$

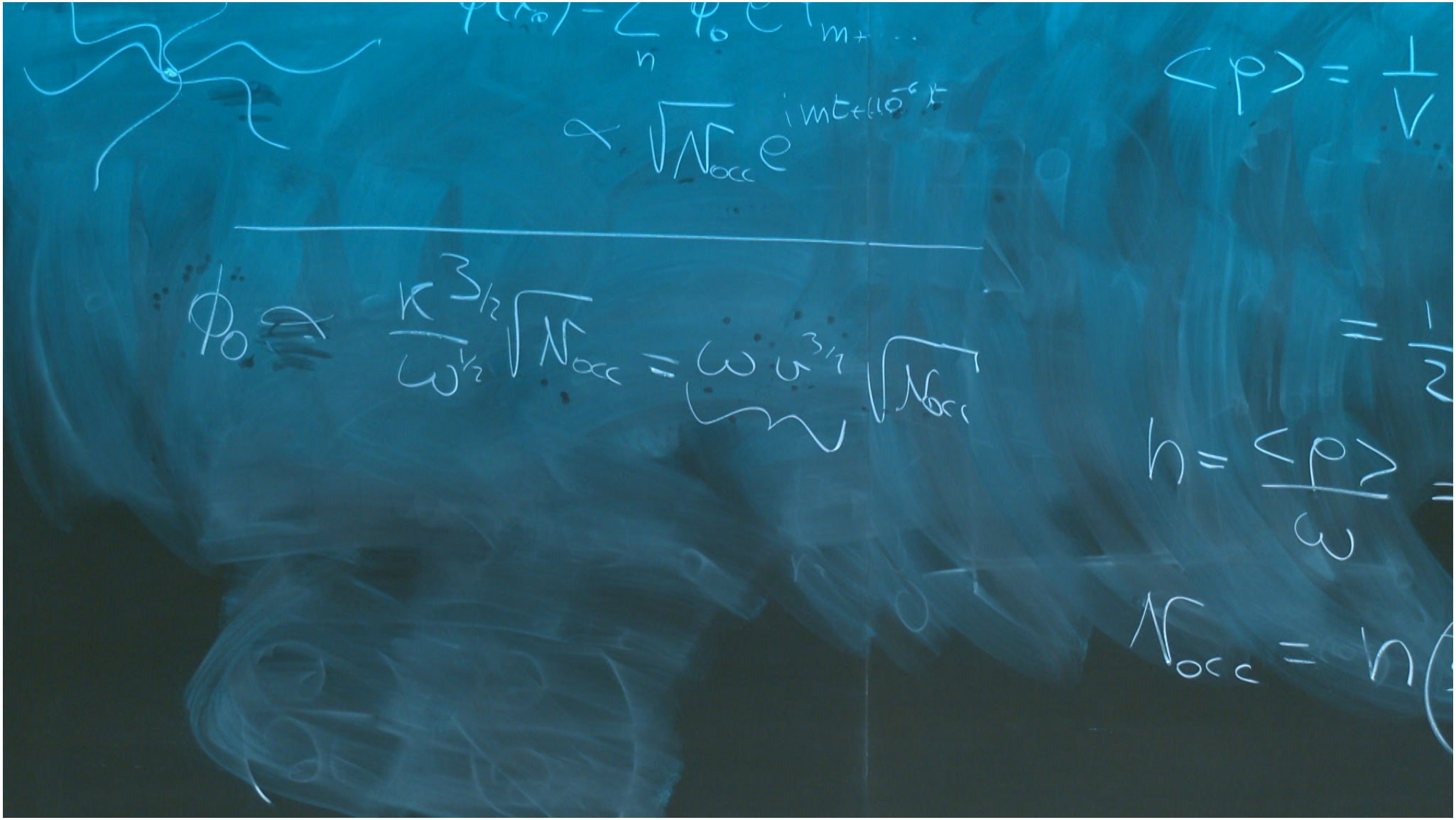
$$\langle\rho\rangle = \frac{1}{V}\int_V d^3x\,\rho(x) = \frac{1}{V}\int d^3x\,\frac{1}{2}\left(\omega^2\sin^2(kx) + \vec{k}^2\right.$$

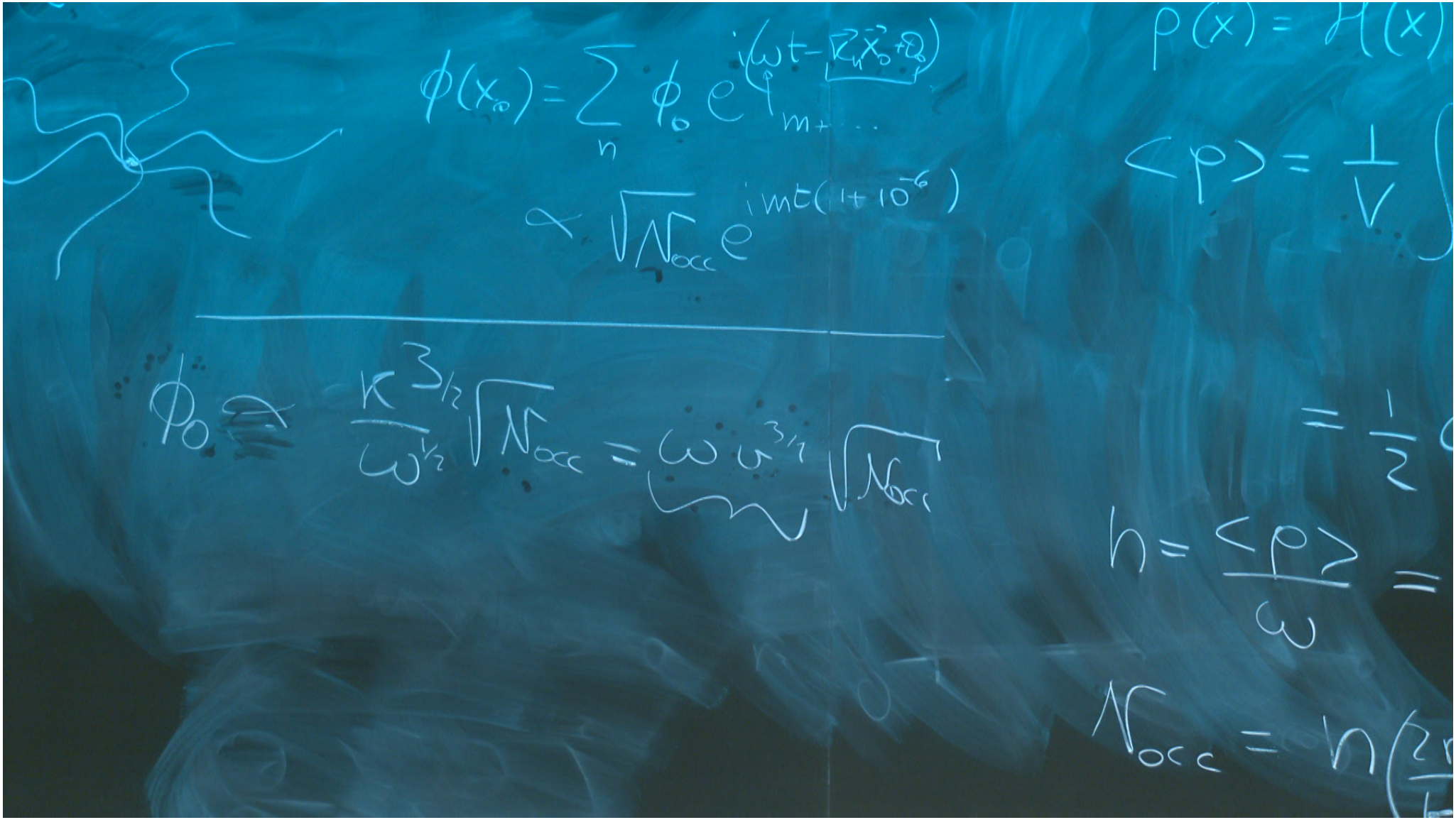
$$\left. + m^2\cos^2(kx)\right)$$

$$\cos^2(kx) \to \frac{V}{2}$$

$$= \frac{1}{2}\omega^2\phi_0^2$$


$= \frac{1}{2}\omega^2\phi_0^2$
$h = \frac{\langle \rho \rangle}{\omega} = \frac{1}{2}\phi_0^2\omega$
$\Gamma_{occ} = n\left(\frac{2\pi}{k}\right)^3 = \frac{1}{2}\phi_0^2\frac{\omega}{k^3}(2\pi)^3$
$\cos(kx)$
$\frac{V}{2}$


$\langle \rho \rangle = \frac{1}{V}$
$\propto \sqrt{\Gamma_{occ}}\, e^{i m t + i \frac{1}{2} \Gamma_{occ} t}$
$\phi_0 \propto \frac{\kappa^{3/2}}{\omega^{1/2}} \sqrt{\Gamma_{occ}} = \omega \omega^{3/2} \sqrt{\Gamma_{occ}}$
$h = \frac{\langle \rho \rangle}{\omega}$
$\Gamma_{occ} = h$


$\phi(x_0) = \sum_n \phi_0 e^{i(\omega t - \vec{k}\vec{x}_0 + \delta_0)}$
$\propto \sqrt{N_{occ}}\, e^{i m c^2 t (1 + 10^{-6})}$
$\rho(x) = \mathcal{N}(x)$
$\langle \rho \rangle = \frac{1}{V}$
$\phi_0 \propto \frac{k^{3/2}}{\omega^{1/2}} \sqrt{N_{occ}} = \omega\, \omega^{3/2} \sqrt{N_{occ}}$
$= \frac{1}{2}$
$h = \frac{\langle \rho \rangle}{\omega} =$
$N_{occ} = n$

$$\lambda_c = \frac{2\pi}{m_{DM}} = 12\ \text{km}\left(\frac{10^{-10}\ \text{eV}}{m_{DM}}\right)$$

$$\lambda_{dB} = \frac{2\pi}{m_{DM} v} \sim 12 \cdot 10^3\ \text{km}\left(\frac{10^{-10}\ \text{eV}}{m_{DM}}\right)$$

$$\nu = \frac{m_{DM}}{2\pi} = 24\ \text{kHz}\left(\frac{10^{-10}\ \text{eV}}{m_{DM}}\right)$$

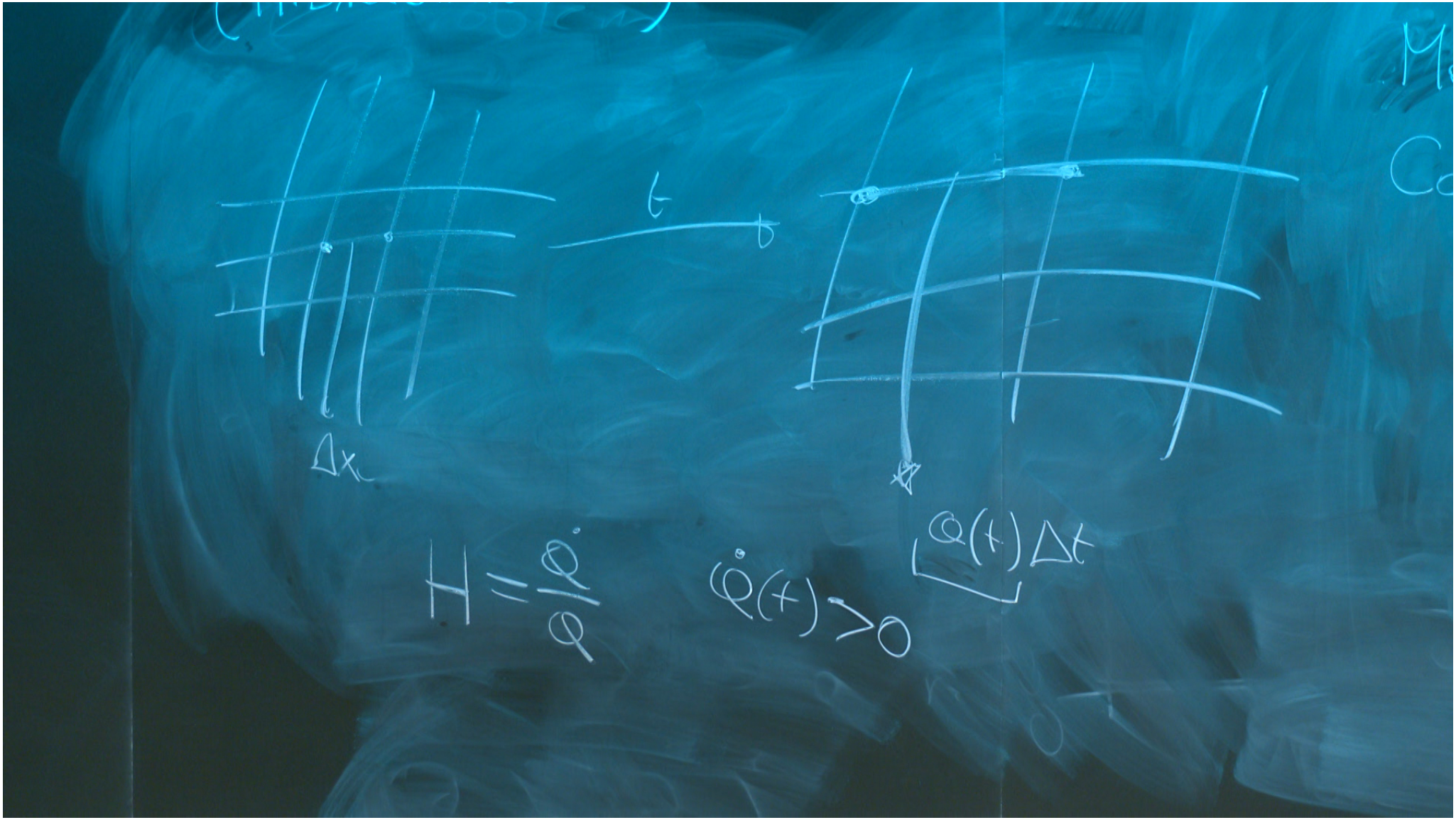
$$\tau_{coh} = \frac{1}{\Delta v} = \frac{1}{v^2} \approx 40\,\text{s}\left(\frac{m_{DM}}{10^{-10}\ \text{eV}}\right)$$

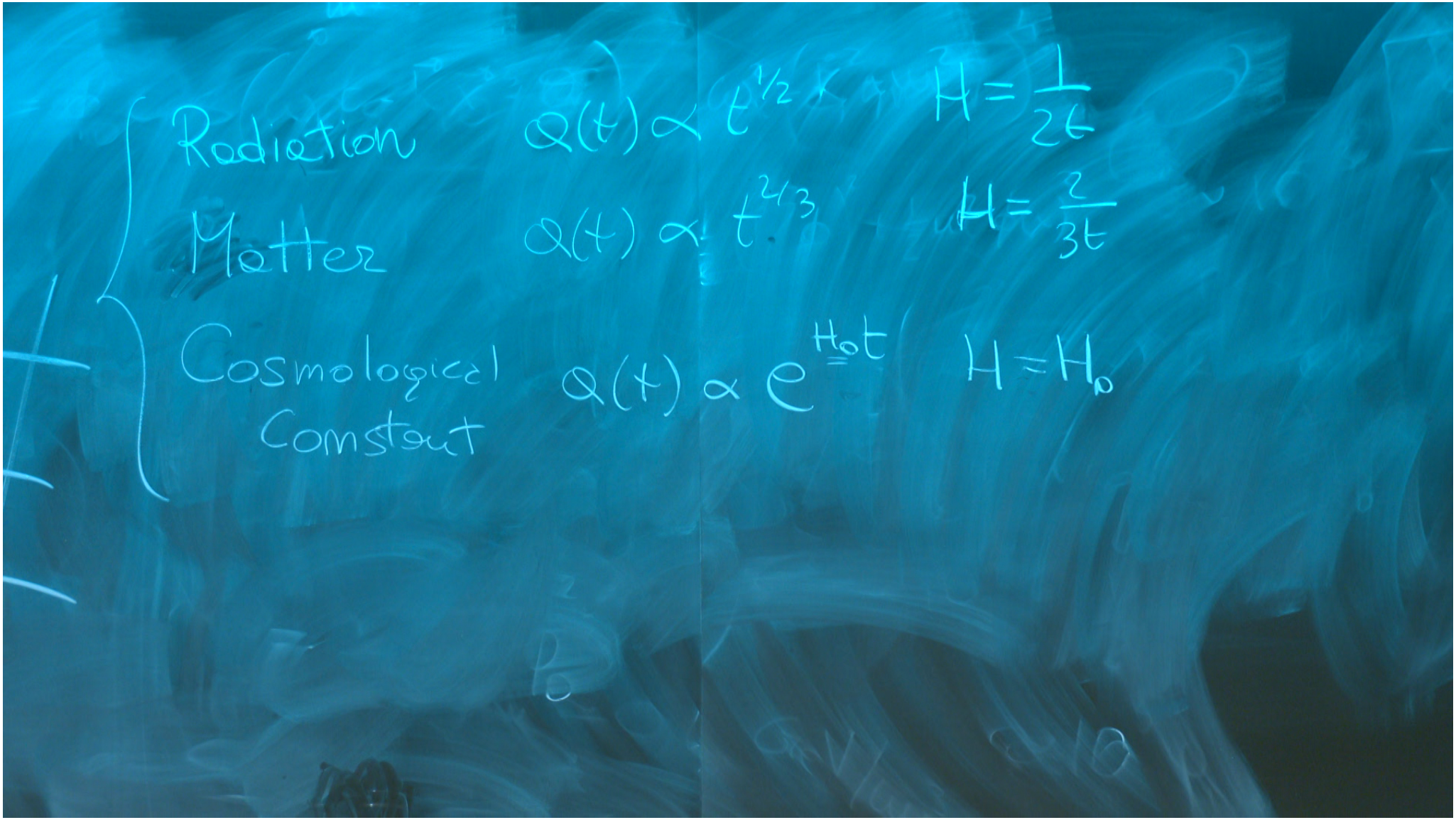
$$\frac{1}{2} m^2 \phi(x)^2$$

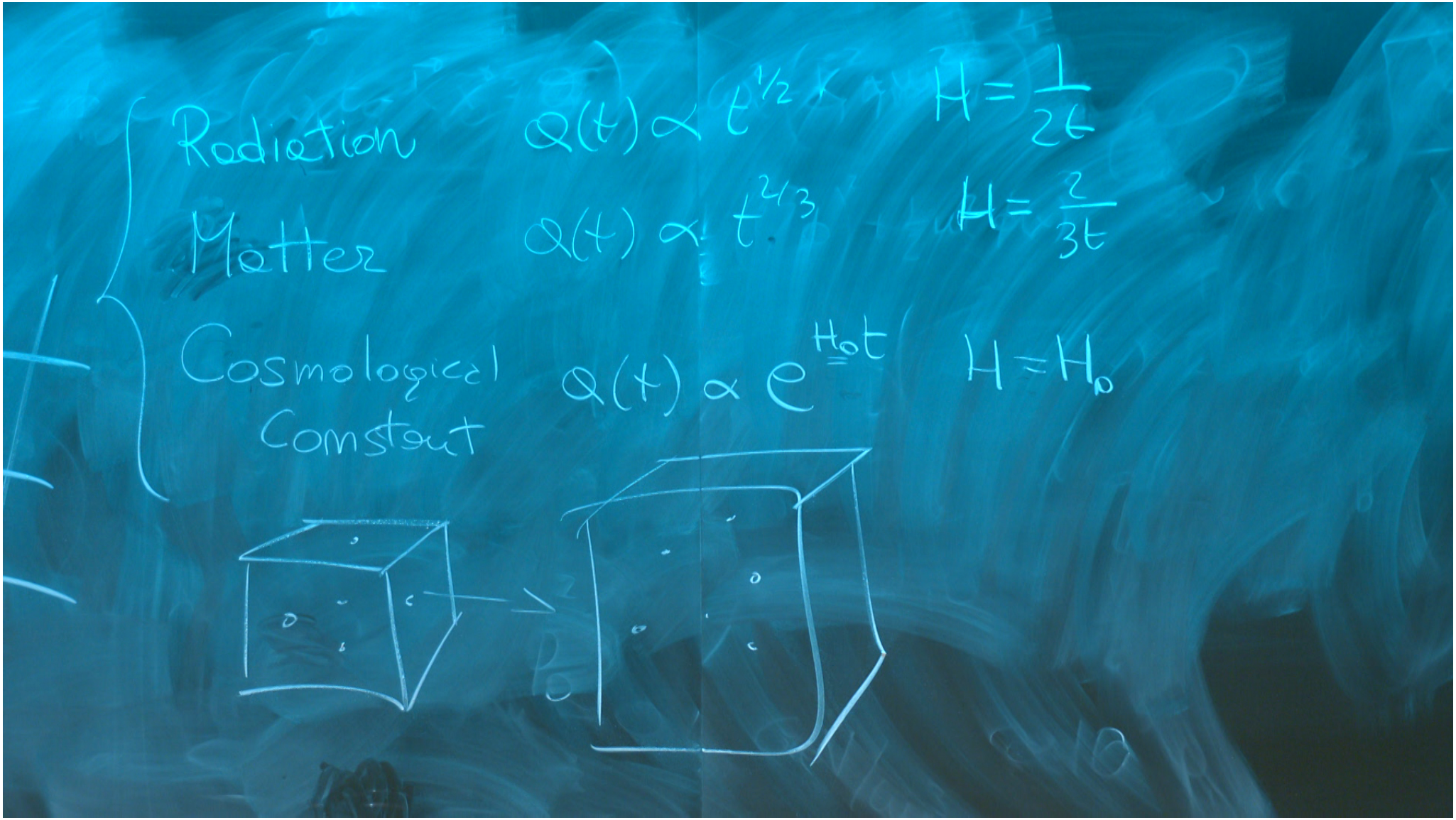
$$\left(\omega^2 \sin^2(kx) + \vec{k}^2 \sin^2(kx) + m^2 \cos^2(kx)\right)\phi_0^2$$

$$\downarrow$$

$$\frac{V}{2}$$


t
Δx
$H = \frac{\dot{\varphi}}{\varphi}$
$\dot{\varphi}(t) > 0$
$\varphi(t)\,\Delta t$


Radiation $a(t) \propto t^{1/2}$ $H = \frac{1}{2t}$
Matter $a(t) \propto t^{2/3}$ $H = \frac{2}{3t}$
Cosmological Constant $a(t) \propto e^{H_0 t}$ $H = H_0$


Radiation
$a(t) \propto t^{1/2}$
$H = \frac{1}{2t}$
Matter
$a(t) \propto t^{2/3}$
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Cosmological Constant
$a(t) \propto e^{H_0 t}$
$H = H_0$

Radiation $a(t) \propto t^{1/2}$ $H = \frac{1}{2t}$

Matter $a(t) \propto t^{2/3}$ $H = \frac{2}{3t}$

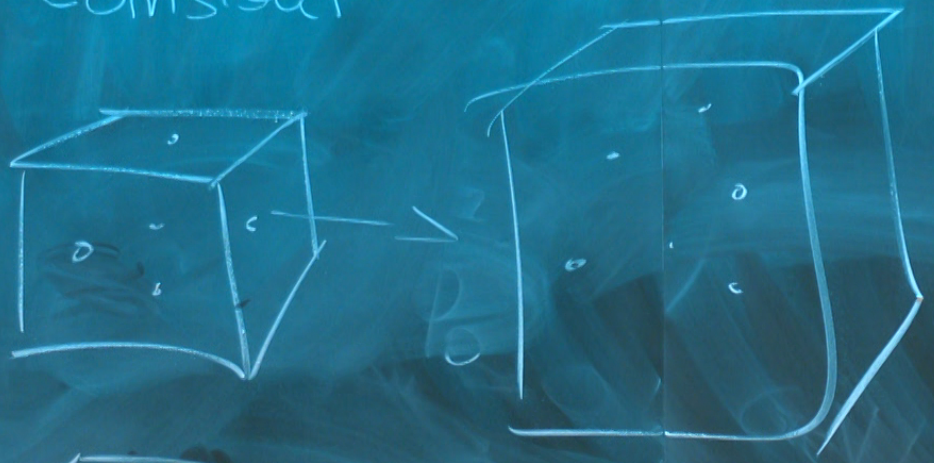
Cosmological Constant $a(t) \propto e^{H_0 t}$ $H = H_0$

$n \propto \frac{1}{a^3}$

Cosmological Constant

$a(t) \propto e^{H_0 t}$

$H = H_0$

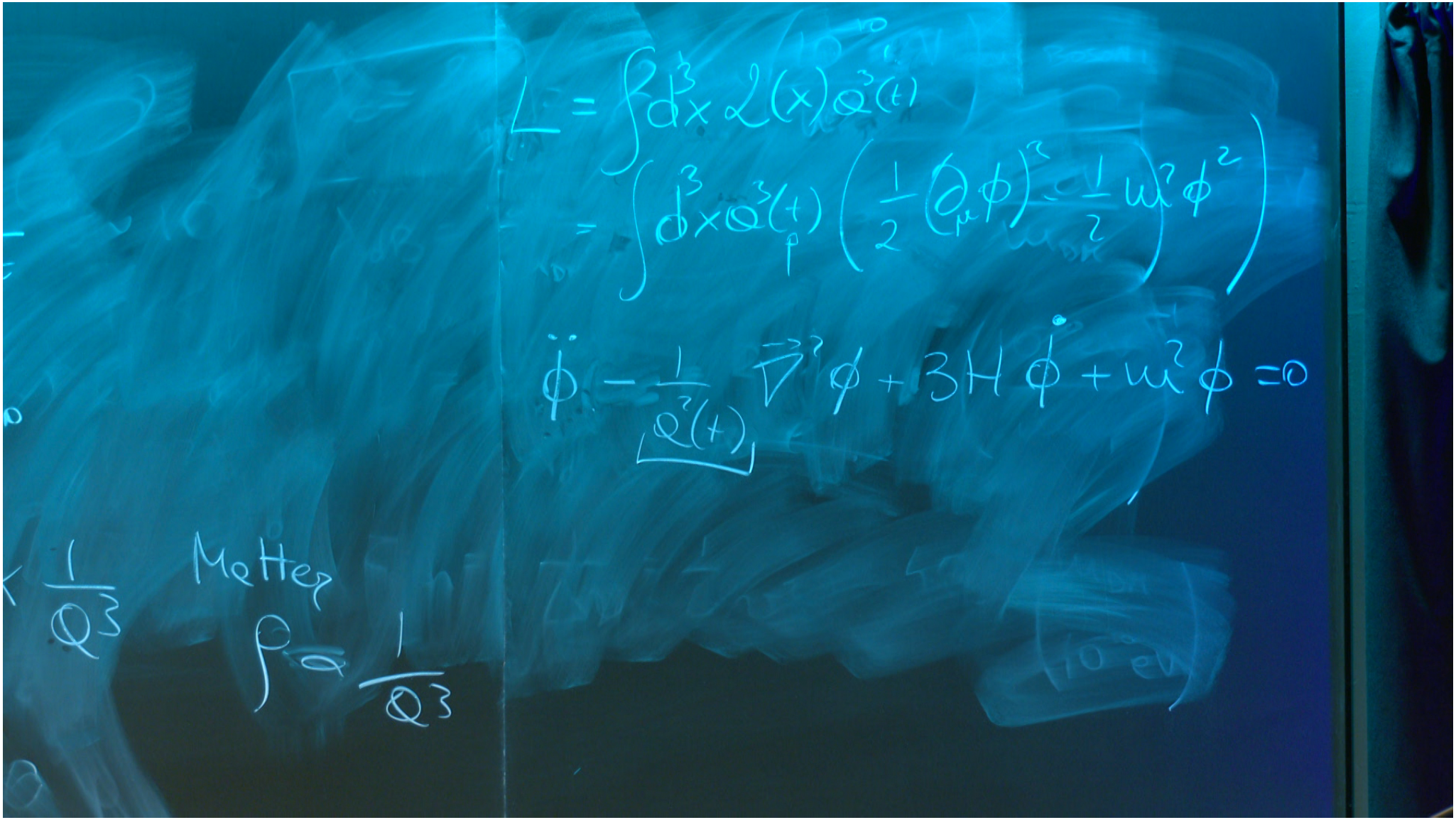


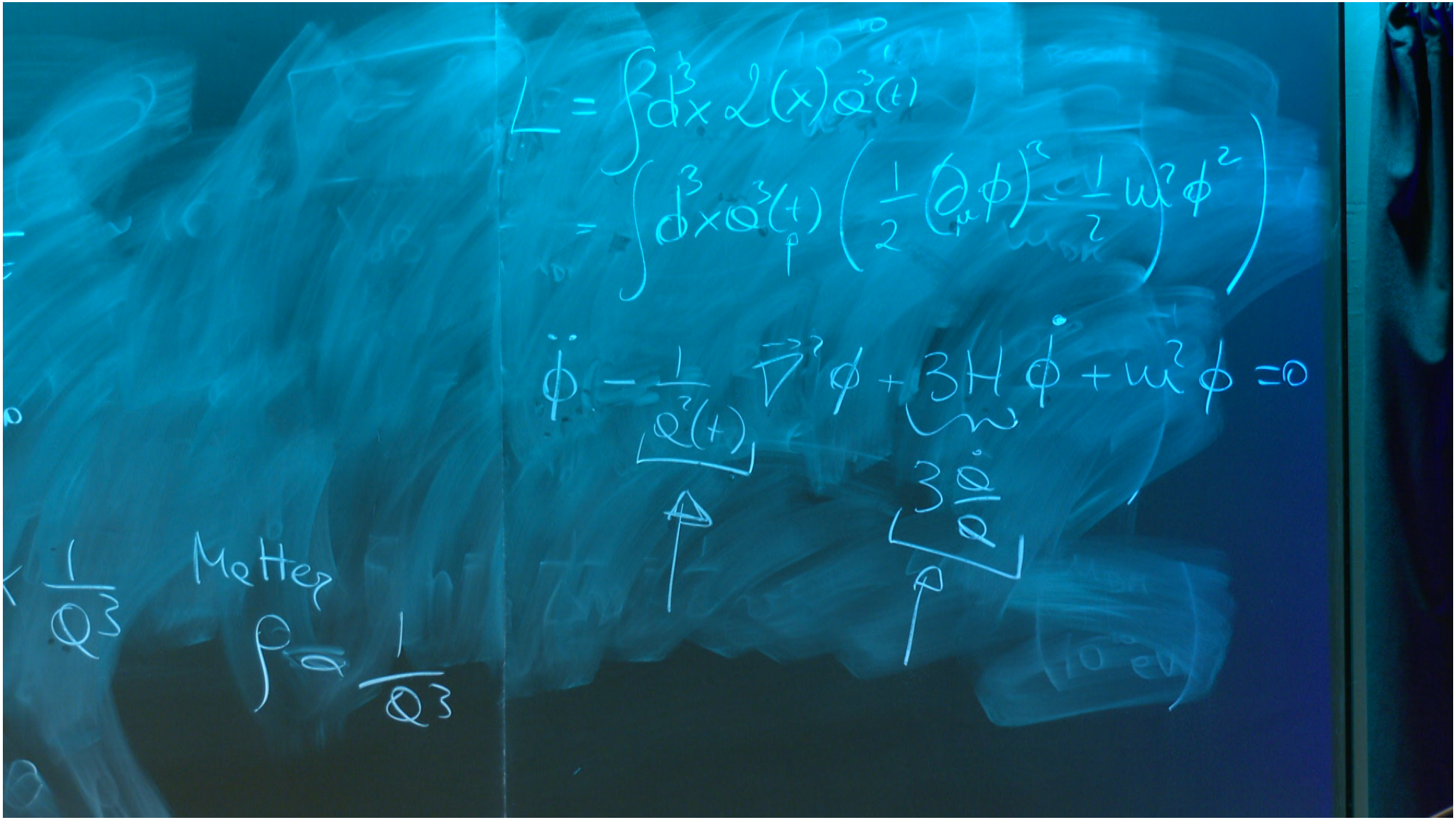
$n \propto \frac{1}{a^3}$

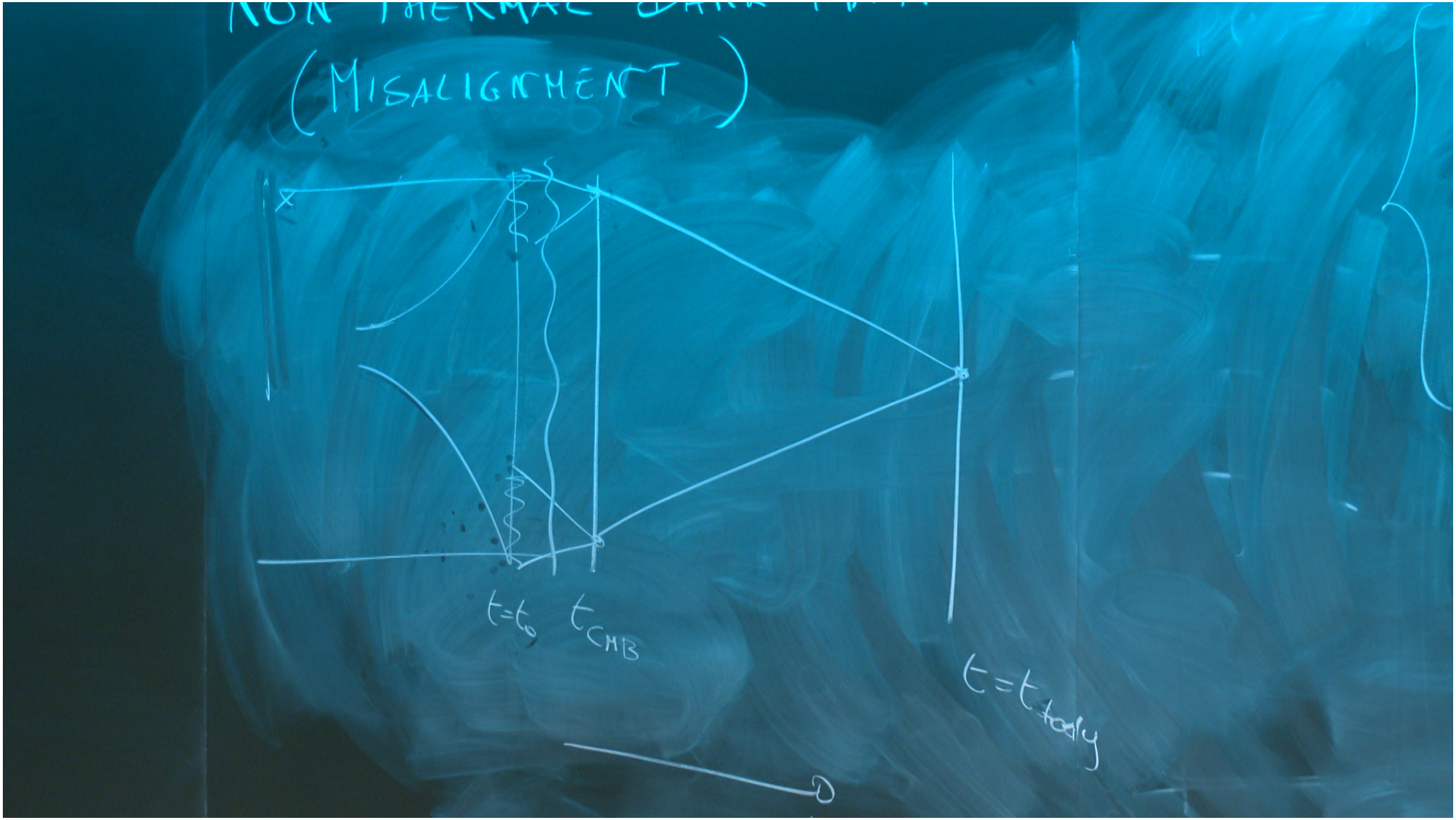
Matter $\rho \propto \frac{1}{a^3}$

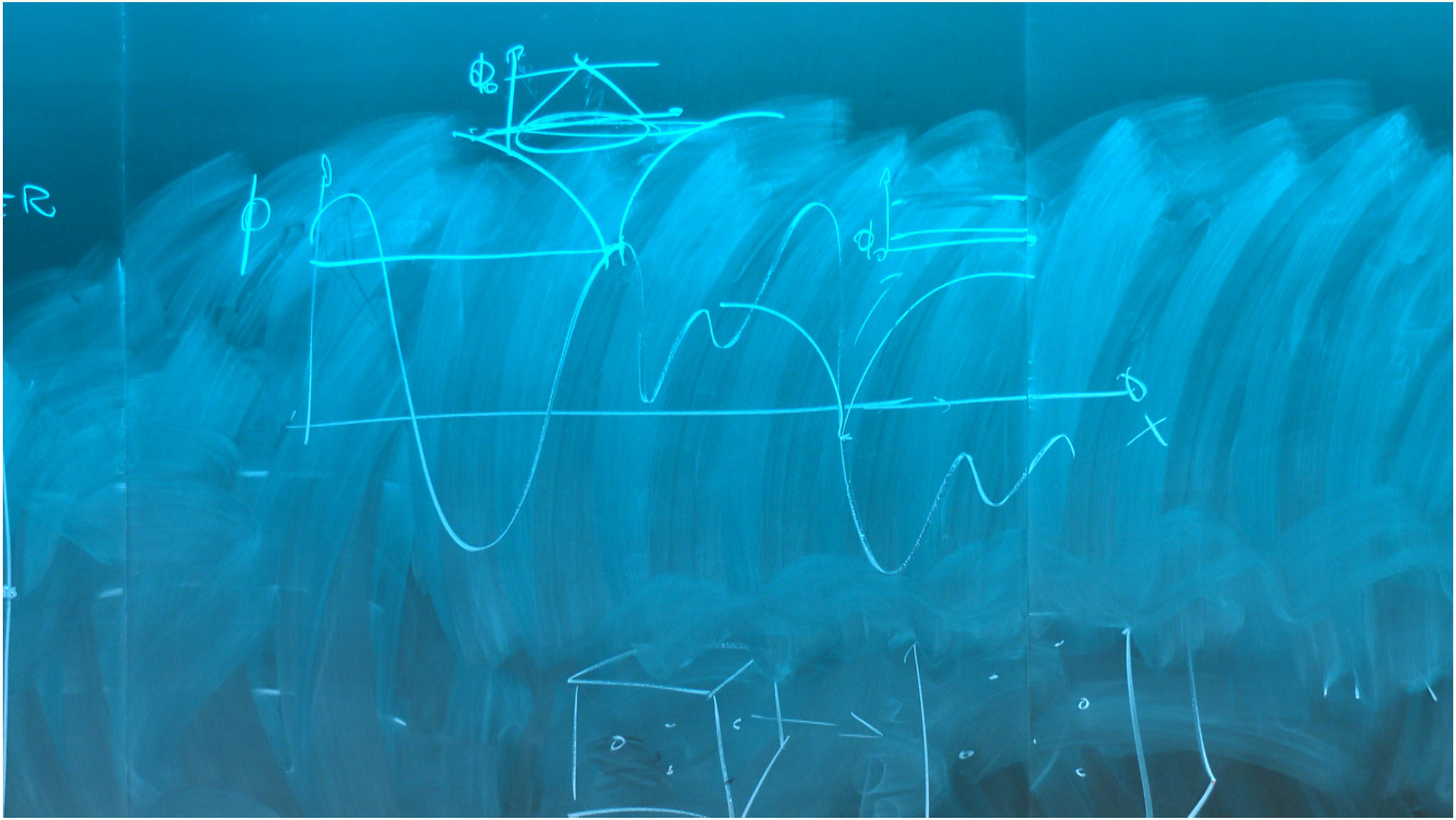
$k \propto \frac{1}{a}$

Radiation $\rho \propto \frac{1}{a^4}$


$L = \int d^3x \, \mathcal{L}(x) a^3(t)$
$= \int d^3x \, a^3(t) \left(\frac{1}{2} (\partial_\mu \phi)^2 - \frac{1}{2} m^2 \phi^2 \right)$
$\ddot{\phi} - \frac{1}{a^2(t)} \vec{\nabla}^2 \phi + 3H \dot{\phi} + m^2 \phi = 0$
$\frac{1}{a^3}$
Matter
$\rho \propto \frac{1}{a^3}$
10 eV


$L = \int d^3x \, \mathcal{L}(x) a^3(t)$
$= \int d^3x \, a^3(t) \left(\frac{1}{2} (\partial_\mu \phi)^2 - \frac{1}{2} m^2 \phi^2 \right)$
$\ddot{\phi} - \frac{1}{a^2(t)} \vec{\nabla}^2 \phi + 3H\dot{\phi} + m^2 \phi = 0$
$3\frac{\dot{a}}{a}$
$\frac{1}{a^3}$
Matter
$\rho \propto \frac{1}{a^3}$
10 eV


(MISALIGNMENT)
$t=t_0$
t_{CMB}
$t=t_{today}$


R
x