Title: A non-minimal perspective on the misalignment mechanism

Speakers: Gonzalo Alonso-Ã•lvarez

Series: Particle Physics

Date: October 01, 2019 - 1:00 PM

URL: http://pirsa.org/19100060

Abstract: Non minimal couplings of scalar fields to gravity are a generic feature of Lagrangian formulations of gravity. Although challenging to probe at low energies and small curvature, such couplings can play a crucial role in cosmological setups. We focus on their impact in the production of scalar dark matter and its interplay with inflationary physics. We show how the standard non-thermal production mechanism of scalar dark matter, the misalignment mechanism, is modified, and explore how alternative scenarios like production from inflationary fluctuations become viable. We study potentially observable features of these scenarios, such as the enhancement of dark matter substructure at small scales and the generation of an isocurvature component in the fluctuations of the CMB.

05.09836

↳ Non-thermal production of DM

→ Axions / ALPs – misalignment

↳ Gravitational interactions

$$S = \int d^4x \sqrt{-g} \left(\frac{1}{2} M_p^2 R + \mathcal{L}_\phi \right) \rightarrow G_{\mu\nu} = \frac{1}{M_p^2} T_{\mu\nu}$$

→ Axions / ALPs – misalignment

↳ Gravitational interactions

$$S = \int d^4x \sqrt{-g} \left(\frac{1}{2} M_p^2 R + \mathcal{L}_\phi \right) \rightarrow G_{\mu\nu} = \frac{1}{M_p^2} T_{\mu\nu}$$

BUT:

– EFT of gravity: R^2, $R_{\mu\nu} R^{\mu\nu}$, $\phi^2 R$, $R \partial_\mu \phi \partial_\nu \phi$, ...

A non-minimal perspective on the misalignment mechanism

Gonzalo Alonso-Álvarez 1807.09785
w/ T. Hugle & J. Jaeckel 1905.09836

OUTLINE

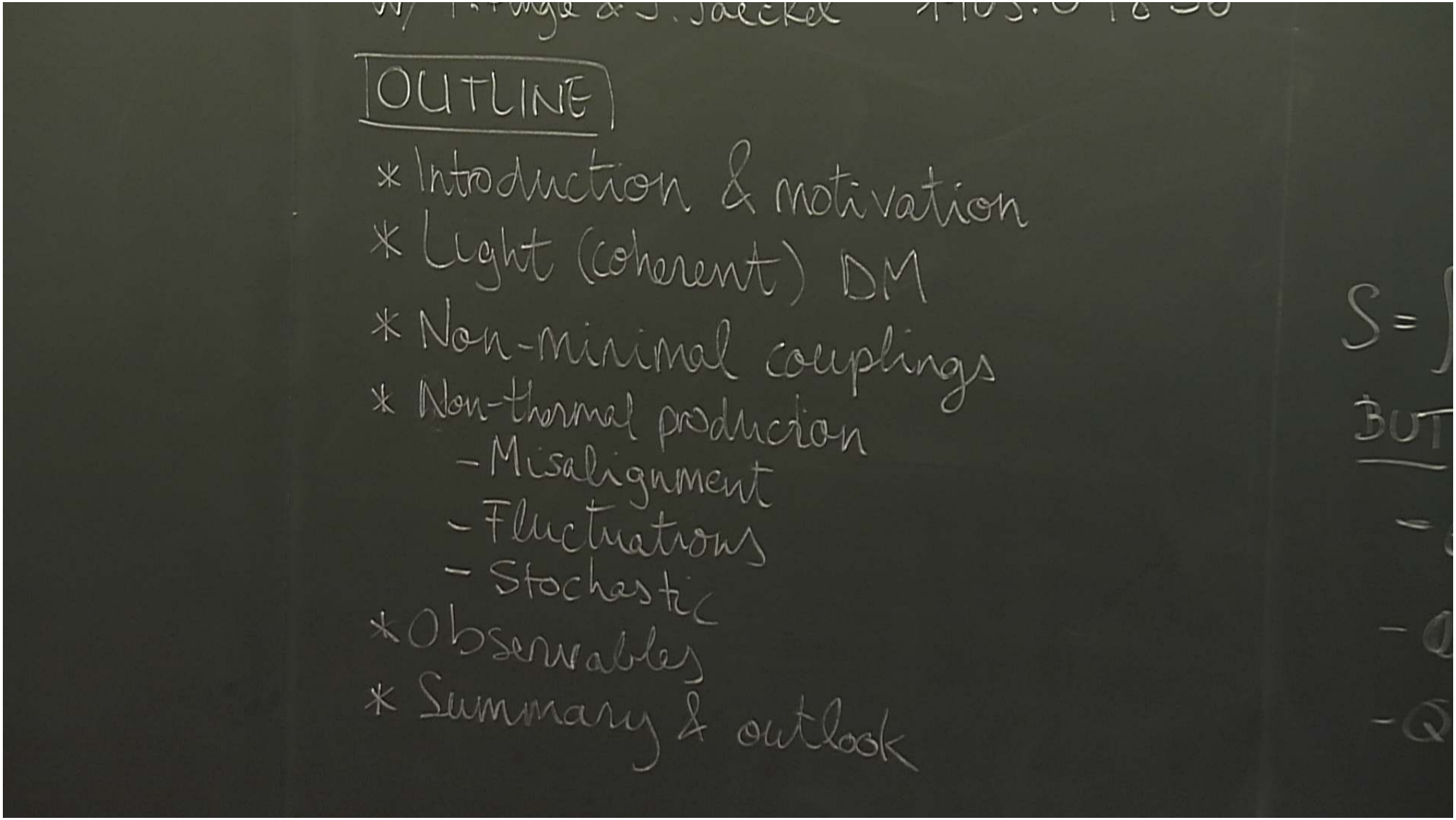
* Introduction & motivation
* Light (ultra-)

↳ Gravitational interactions

$$S = \int d^4x \sqrt{-g} \left(\frac{1}{2} M_p^2 R + \mathcal{L}_\phi \right) \rightarrow G_{\mu\nu} = \frac{1}{M_p^2} T_{\mu\nu}$$

BUT:

- EFT of gravity: R^2, $R_{\mu\nu} R^{\mu\nu}$, $\phi^2 R$, $R^{\mu\nu} \partial_\mu \phi \partial_\nu \phi$, ...
- Quantisation in classical curved background
- QG: Asymptotic safety, ...


OUTLINE
* Introduction & motivation
* Light (coherent) DM
* Non-minimal couplings
* Non-thermal production
- Misalignment
- Fluctuations
- Stochastic
* Observables
* Summary & outlook

A non-minimal perspective on the misalignment mechanism

Gonzalo Alonso-Álvarez 1807.09785
w/ T. Hugle & J. Jaeckel 1905.09836

OUTLINE

* Introduction & motivation
* Light (coherent) DM
* Non-minimal couplings
* Non-thermal

TIVATION

lence for DM → gravitational

weakly interacting

Non-thermal production of DM

→ Axions / ALPs – misalignment

Gravitational interactions

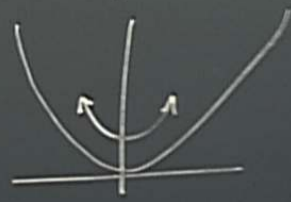
$\sqrt{g}\left(\frac{1}{2}M_p^2 R + \mathcal{L}_\phi\right) \to G_{\mu\nu} = \frac{1}{M_p^2} T_{\mu\nu}$

T of gravity: R^2, $R_{\mu\nu}R^{\mu\nu}$, $\phi^2 R$, $R^{\mu\nu}\partial_\mu\phi\partial_\nu\phi$

* LIGHT DM

Very light bosons → high occupation #

→ Classical fields



Classical EOM:

Scalar: $\ddot{\phi} + 3H\dot{\phi} + m_\phi^2\phi = 0$

Vector: $\ddot{X}_i + 3H\dot{X}_i + m_X^2 X_i = 0$

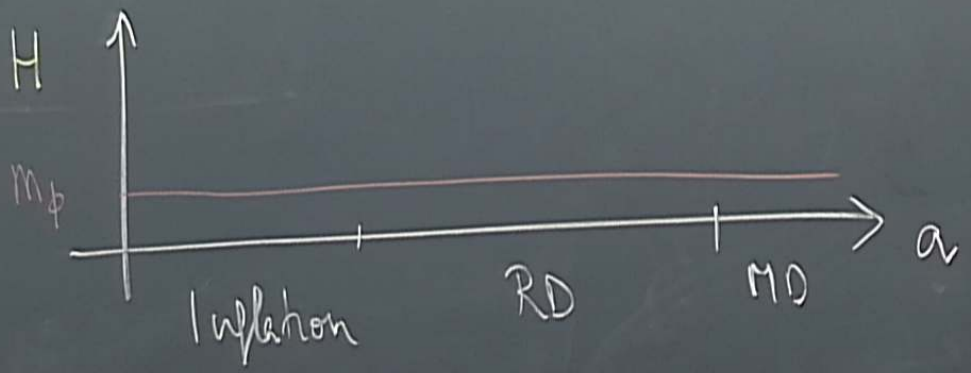
$X_i = \frac{X_i}{a}$

$\Rightarrow \rho_\phi, \rho_X \propto a^{-3}$ → Very CDM

pation #

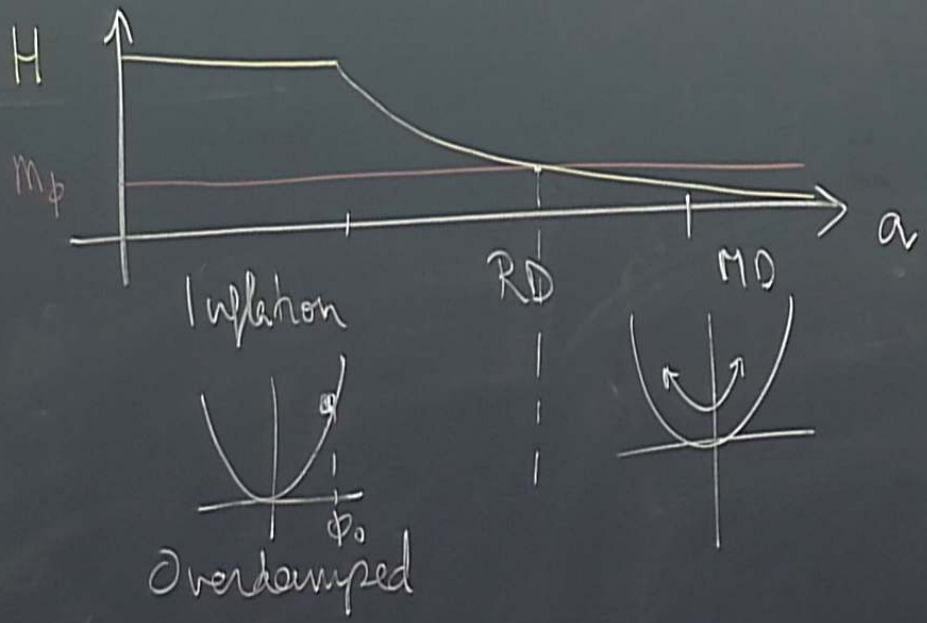
$\chi_i = \frac{X_i}{a}$

Misalignment mechanism



Misalignment mechanism

Fluctuations

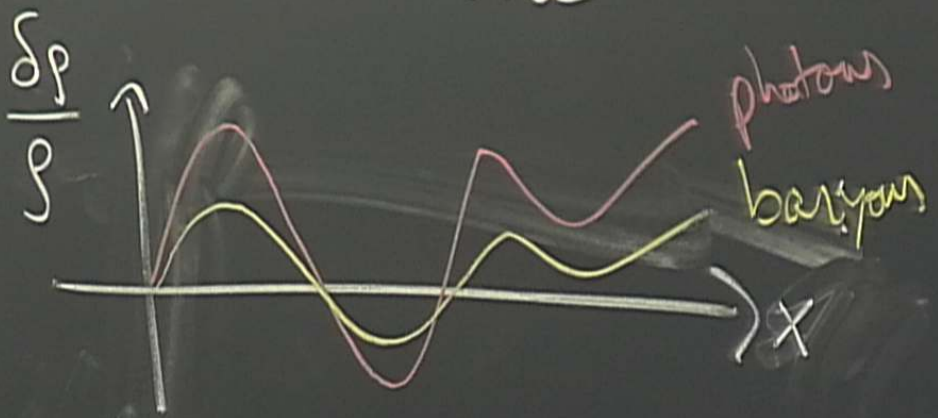


Overdamped

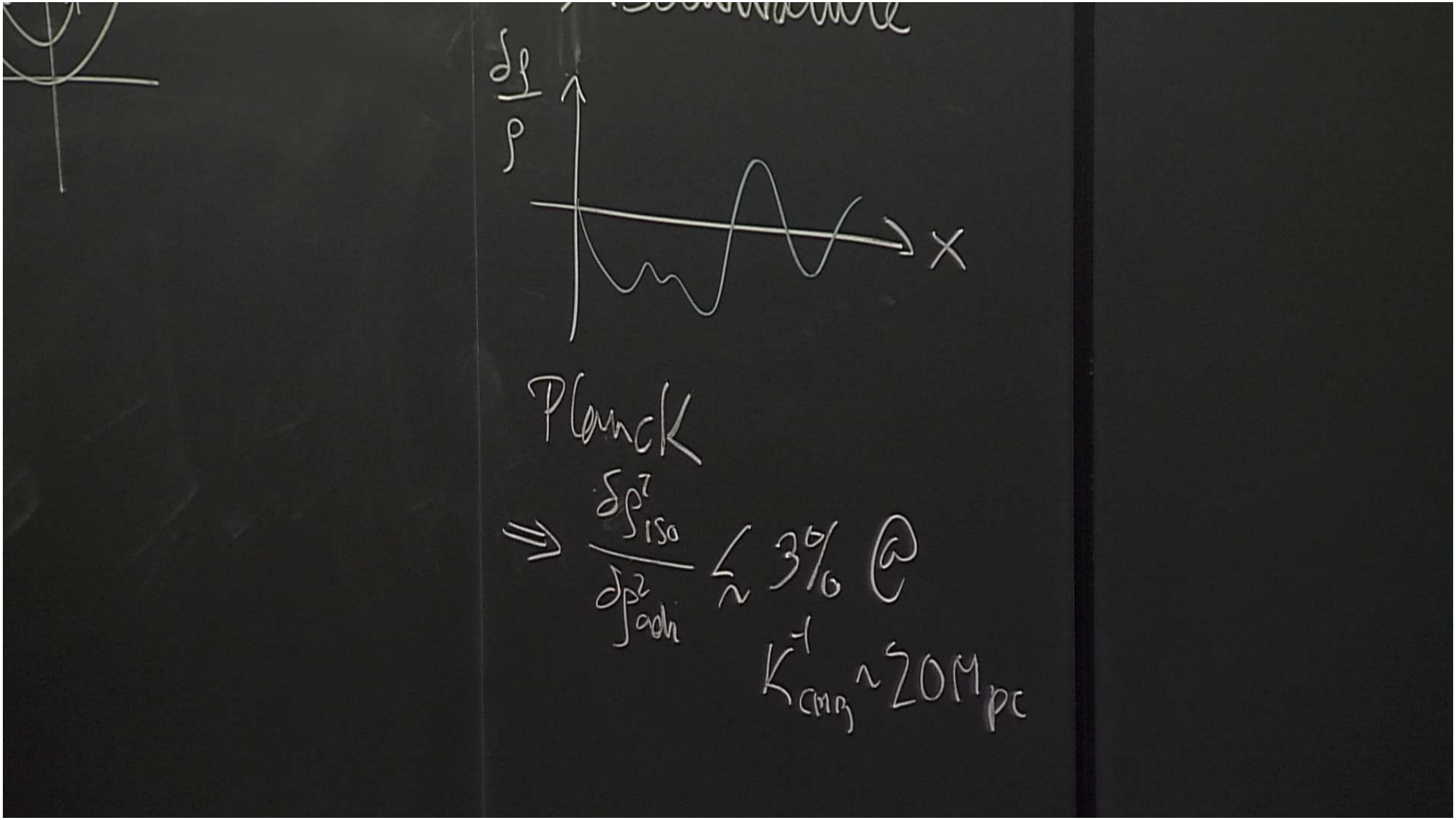
$$\frac{\Omega_\phi}{\Omega_{CDM}} \sim \left(\frac{\phi_0}{10^{11}\,GeV}\right)^2 \sqrt{\frac{m}{1eV}}$$

Fluctuations

→ Adiabatic



→ Isocurvature


$\frac{\delta\rho}{\rho}$
x
Planck
$\Rightarrow \frac{\delta\rho^2_{iso}}{\delta\rho^2_{adi}} \lesssim 3\%$ @
$k^{-1}_{cmb} \sim 20 Mpc$

nt mechanism

1807.09785
1905.09836

vation
M
lings

* NON-MINIMAL COUPLINGS

$$S_\phi = \int d^4x \sqrt{-g} \left[\frac{1}{2}(M_{Pl}^2 - \xi\phi^2)R - \frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{2}m_\phi^2\phi^2 \right]$$

$$S_\chi = \int d^4x \sqrt{-g} \left[\frac{1}{2}(M_P^2 + \frac{K}{6}\chi_\mu\chi^\mu)R - \frac{1}{4}\chi_{\mu\nu}\chi^{\mu\nu} - \frac{1}{2}m_\chi^2\chi_\mu\chi^\mu \right]$$

→ GI?

$$(D_\mu\Phi)^2 + V(\phi, R)$$

$\phi^2 R$

Vev $\langle\phi\rangle \propto R$

* LIG

Very light

⟹ Clas

Classic

Scalar:

Vector:

⟹ fo

1807.09785
1905.09836

$$S_X = \int d^4x \sqrt{-g} \left[\frac{1}{2}\left(M_P^2 + \frac{K}{6} X_\mu X^\mu\right) R - \frac{1}{4} X_{\mu\nu} X^{\mu\nu} - \frac{1}{2} m_X^2 X_\mu X^\mu \right]$$

→ GI?

$$(D_\mu \Phi)^2 + V(\phi, R)$$

ϕ R

Vev $\langle\phi\rangle \propto R$

$\phi \to \langle\phi\rangle + \tilde{\phi}$

$R(T_{\mu\nu})$

Very light

→ Clas

Classica

Scalar:

Vector:

⇒ f_{ϕ}, f

vation

M

lings

→ GI? → Ghost instability?

$(\partial_\mu \Phi)^2 + V(\phi, R)$ vev $\langle\phi\rangle \propto R$

$\phi^2 R$ $\quad \phi \to \langle\phi\rangle + \tilde{\phi}$

$\tilde{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}$ $\quad R(T_{\mu\nu})$

$\Omega^2 \sim \left(1 - \frac{\xi \phi^2}{M_p^2}\right)$

$\frac{\xi \phi}{M_p} \ll 1$

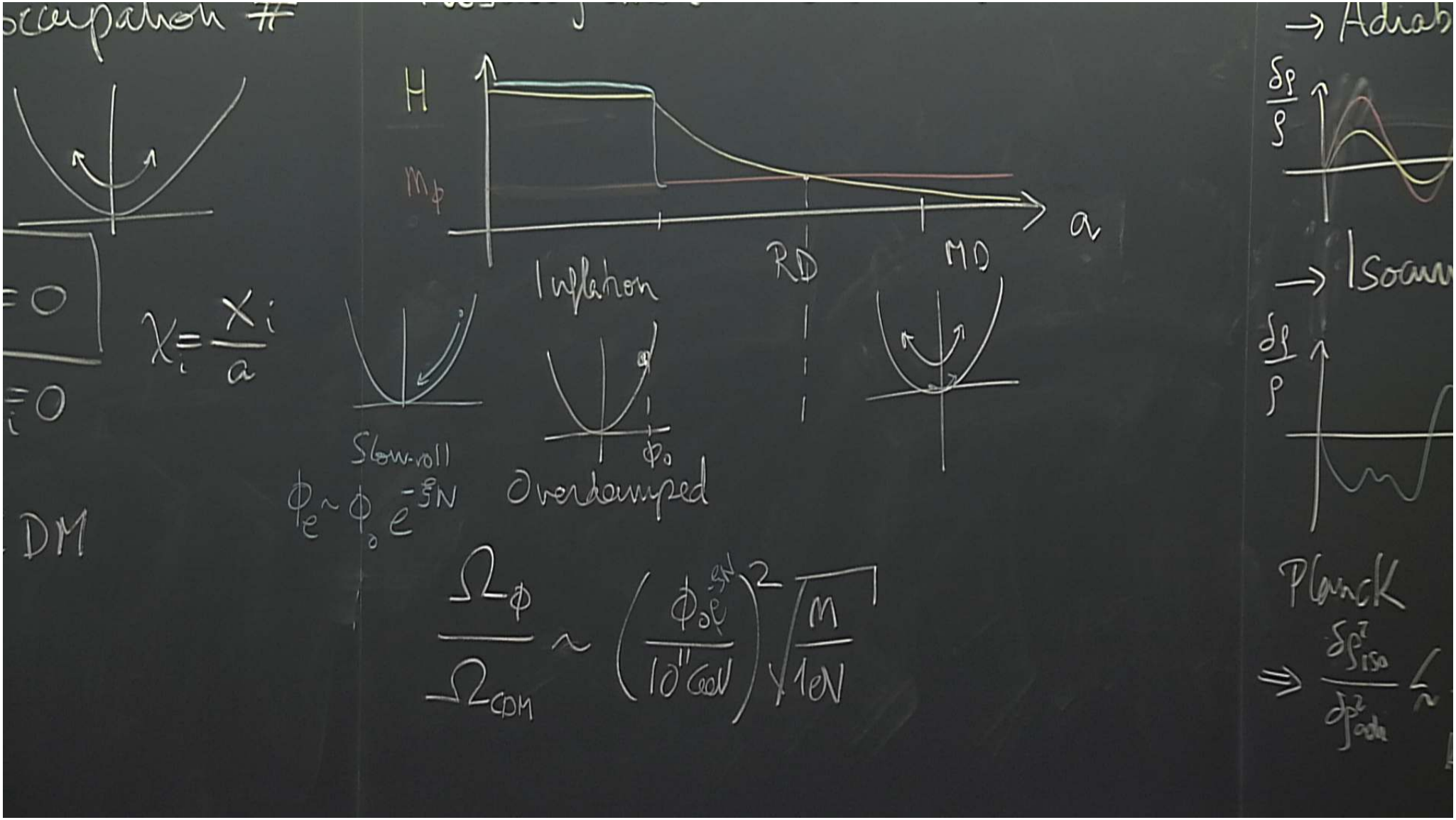
$\Rightarrow m_{\phi,\text{eff}}^2 = m_\phi^2 + \xi R$

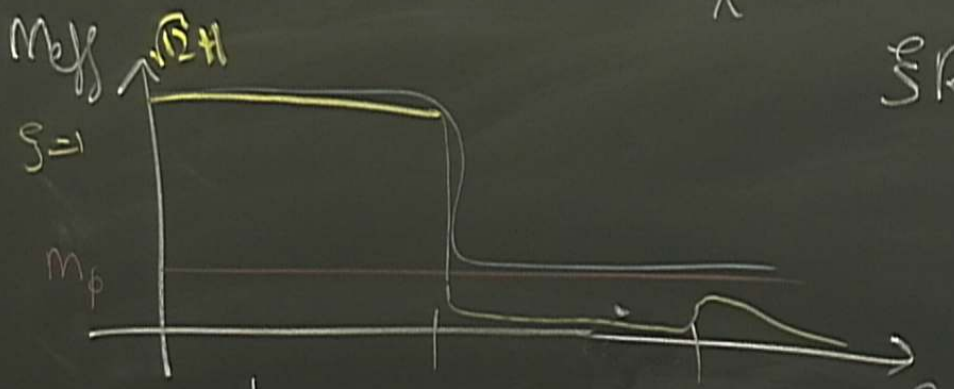
Classic

Scalar:

Vector:

$\Rightarrow p_{\phi,}$


H
m_ϕ
a
RD
MD
Inflation
Slow-roll
Overdamped
$\phi_e \sim \phi_0 e^{-\xi N}$
$\chi_i = \frac{X_i}{a}$
$\frac{\Omega_\phi}{\Omega_{CDM}} \sim \left(\frac{\phi_0 e^{-\xi N}}{10^{11}\,GeV}\right)^2 \times \frac{m}{1eV}$
$\frac{\delta\rho}{\rho}$
Planck
$\Rightarrow \frac{\delta\rho^2_{iso}}{\delta\rho^2_{adia}}$



x^4

ξR

$R=3(1-3w)H^2$

$H_{eq}\sim 10^{-28}$ eV

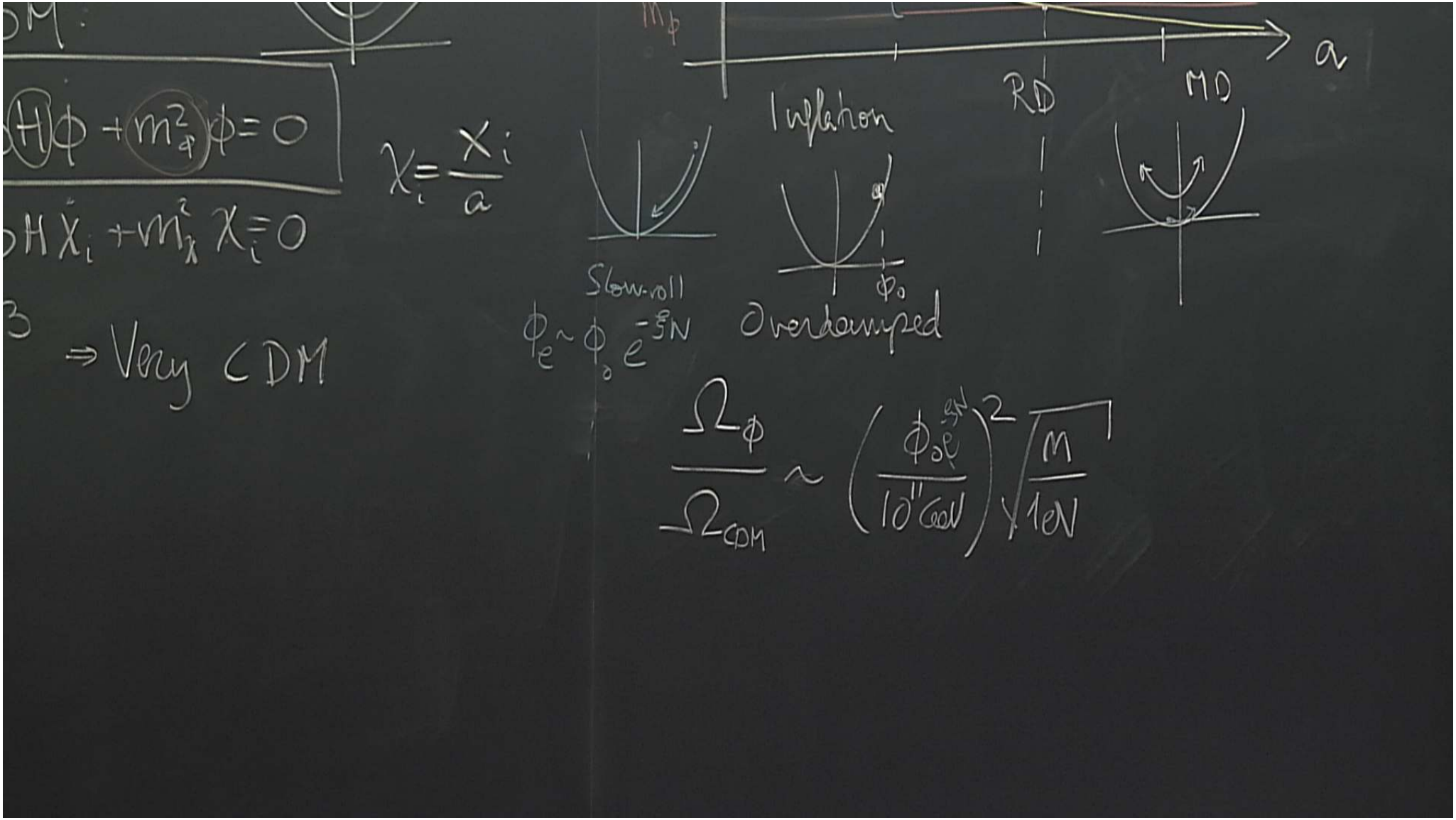
$m_{eff}^2=m_\phi^2+\xi R$

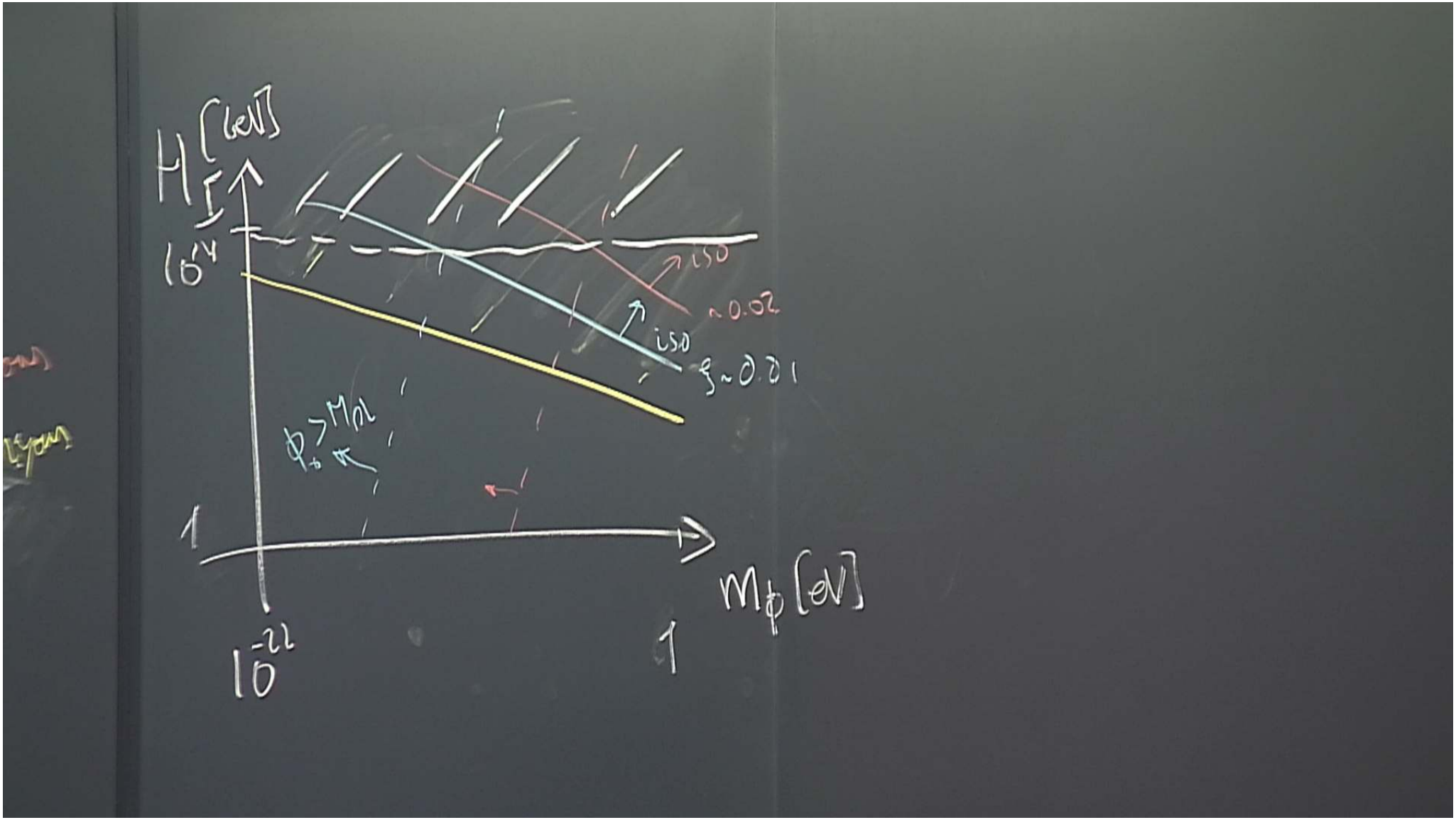
Classic

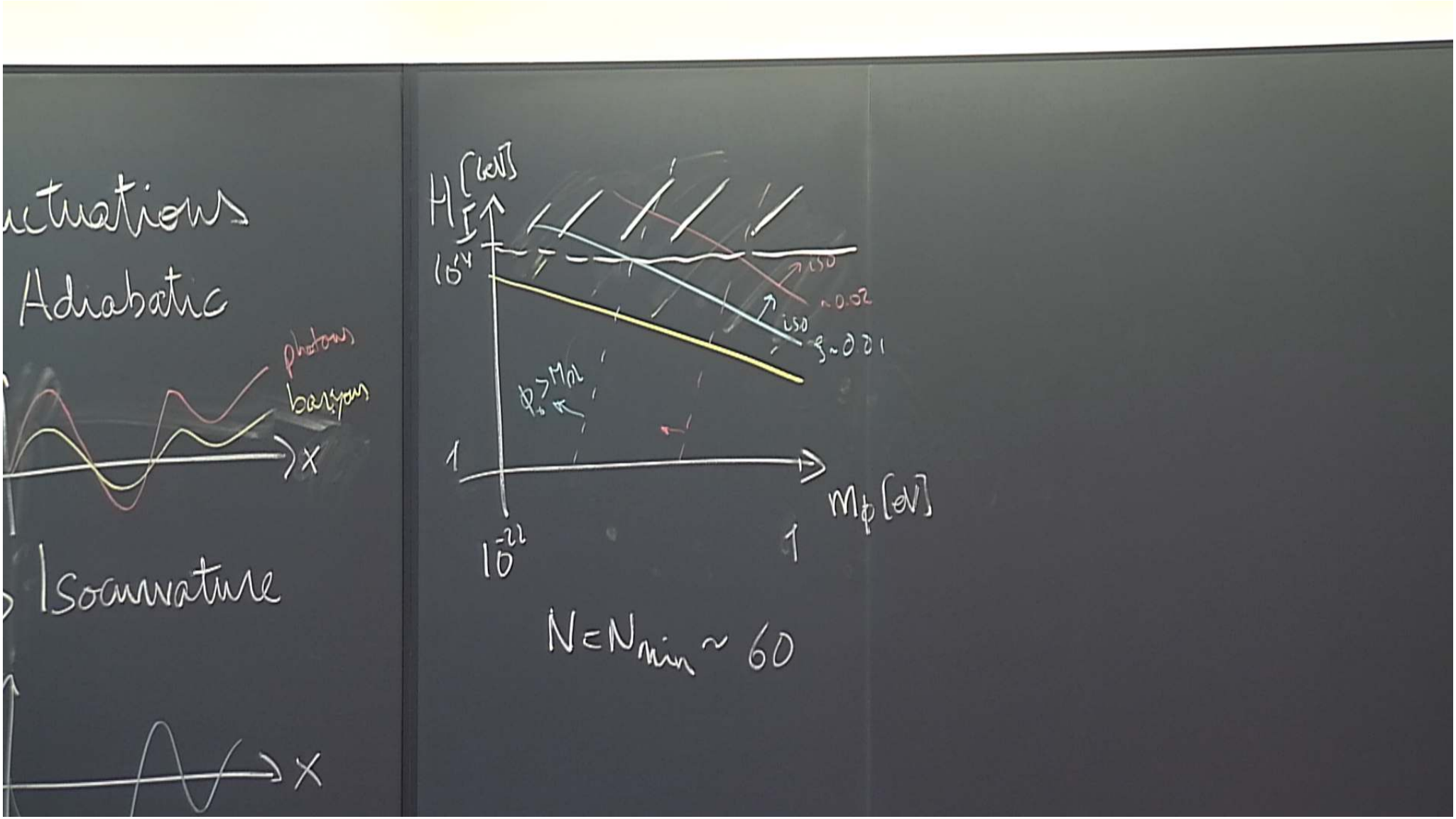
Scalar:

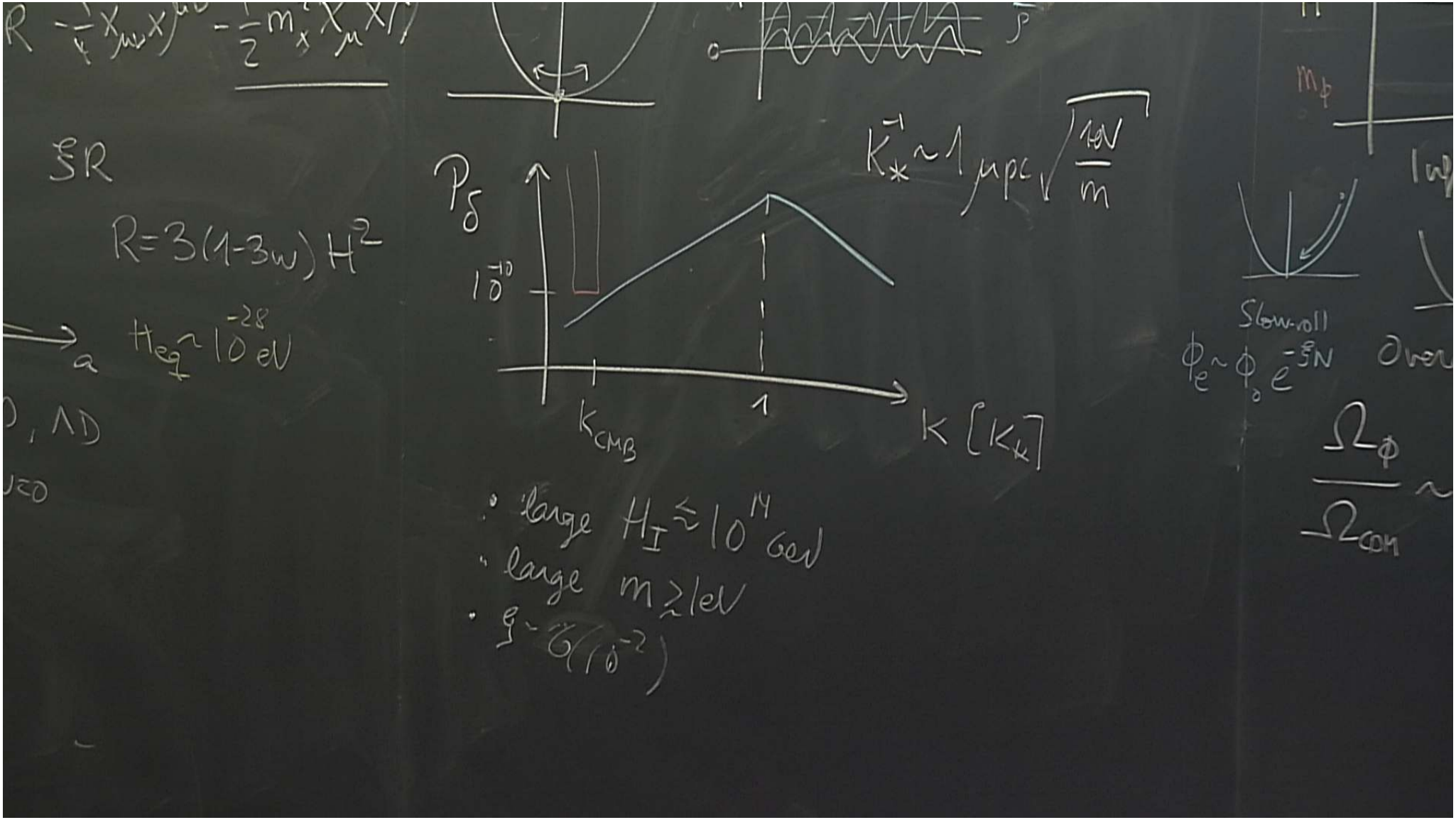
Vector:

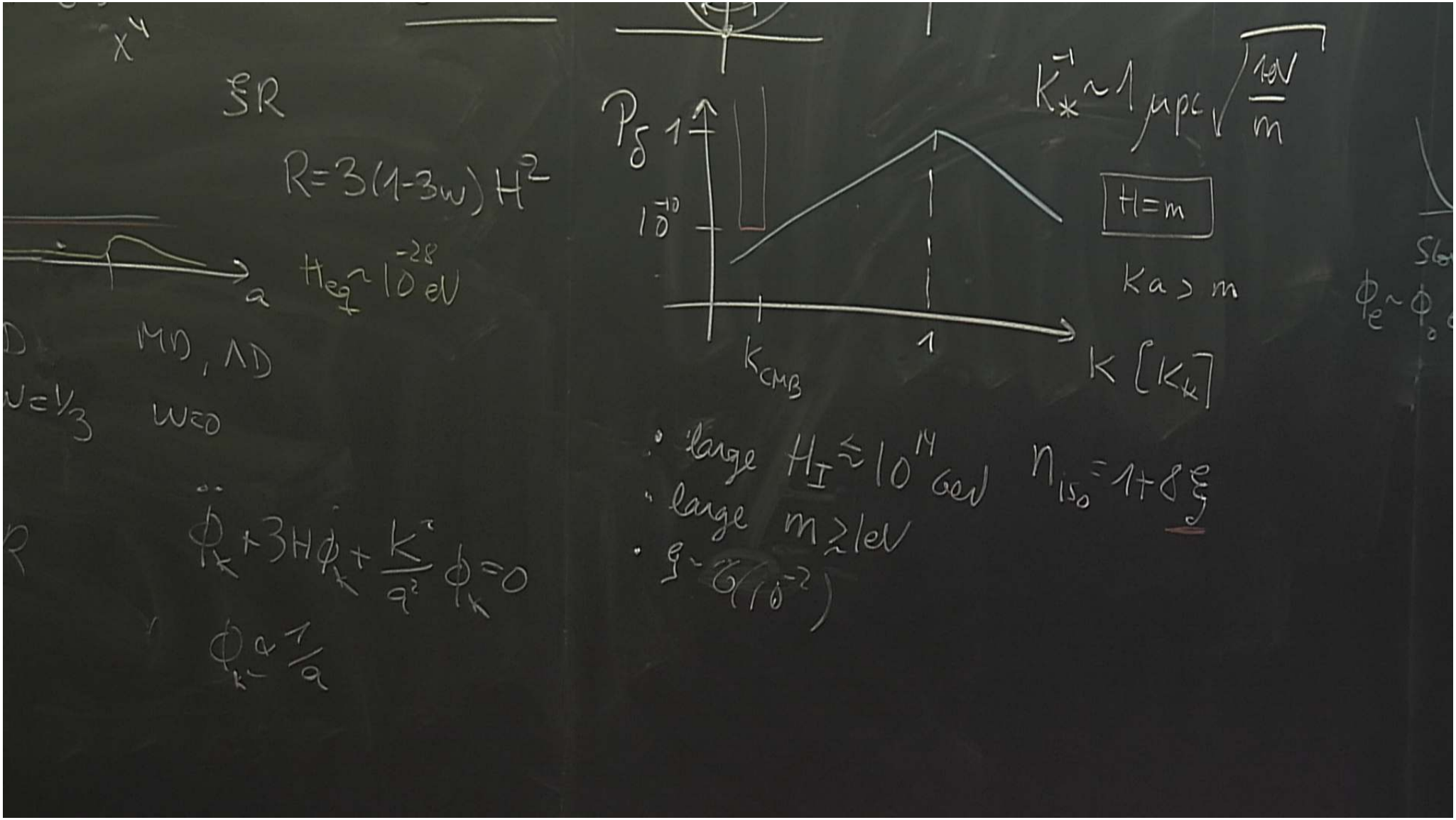
$\Rightarrow \rho_\phi, \rho_$

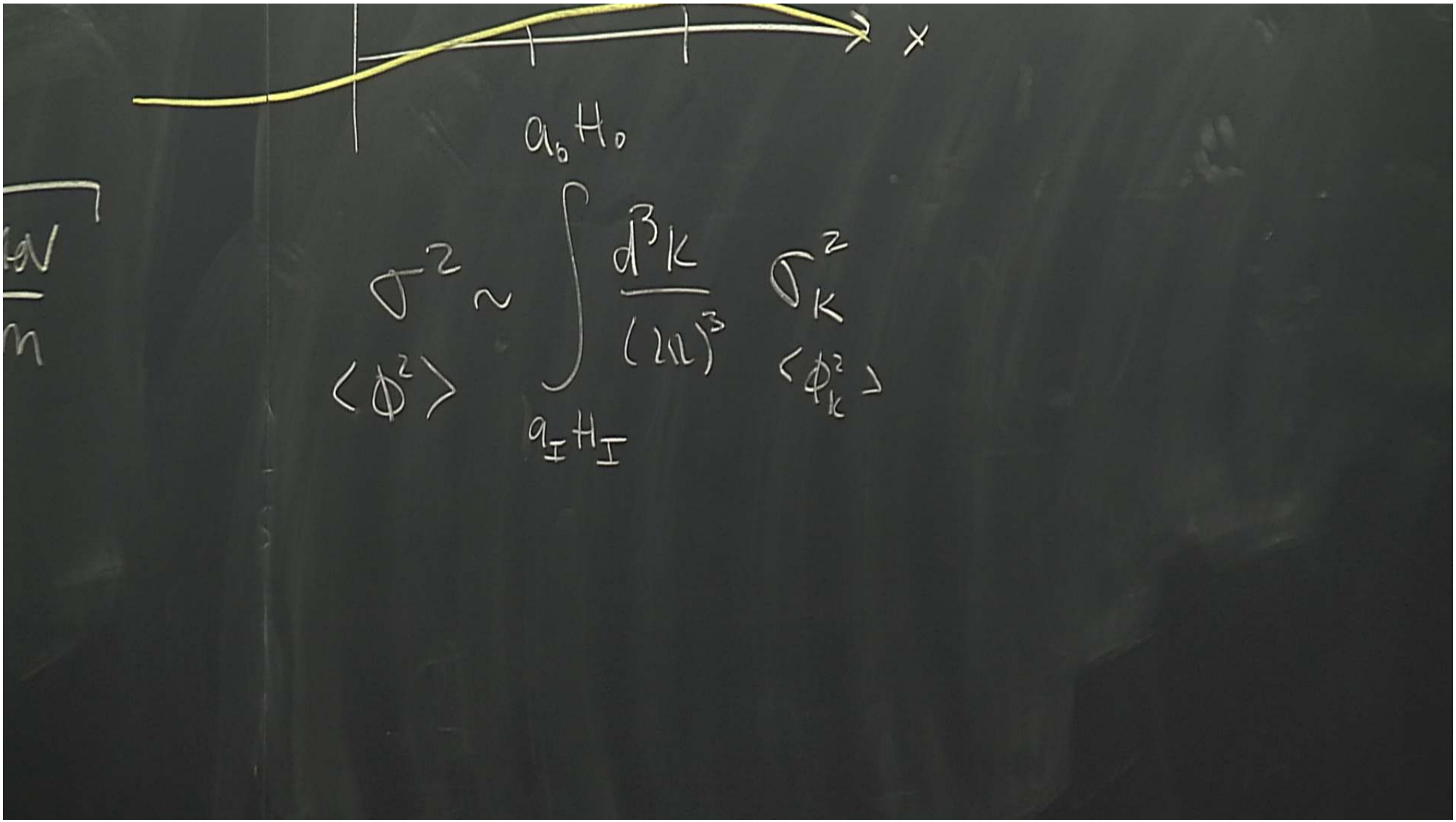

m_ϕ
a
RD
MD
Inflaton
Slow-roll
Overdamped
ϕ_0
$\ddot{\phi} + 3H\dot{\phi} + m_\phi^2 \phi = 0$
$\chi_i = \frac{X_i}{a}$
$\ddot{X}_i + 3H\dot{X}_i + m_{X_i}^2 X_i = 0$
$\Rightarrow$ Very CDM
$\phi_e \sim \phi_0 e^{-\frac{3}{2}N}$
$\frac{\Omega_\phi}{\Omega_{CDM}} \sim \left(\frac{\phi_0 e^{-\frac{3}{2}N}}{10^{11}\,GeV}\right)^2 \sqrt{\frac{m}{1\,eV}}$

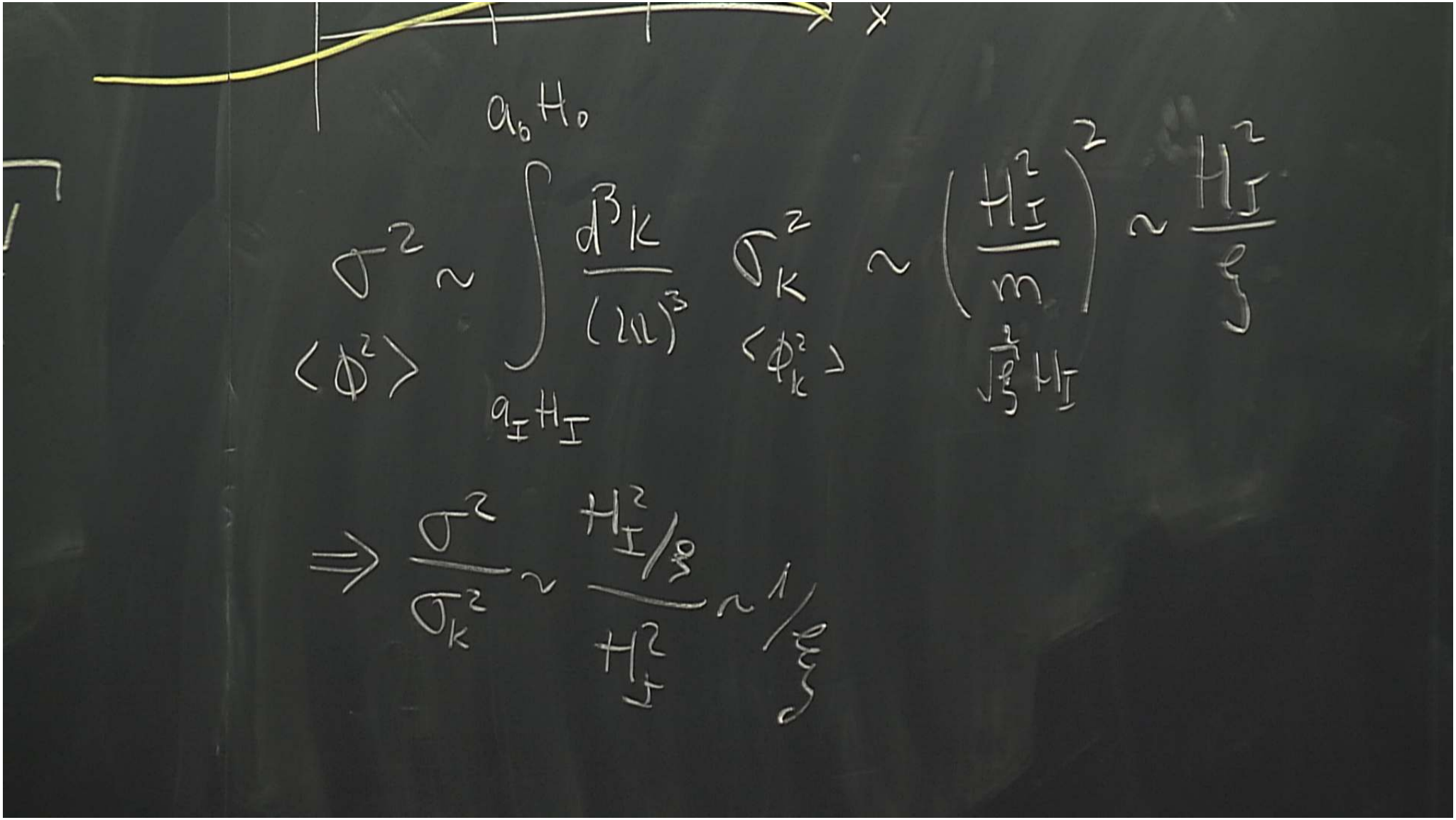

H [eV]
10^{4}
iso
~ 0.02
iso
$\xi \sim 0.21$
$\phi_0 > M_{Pl}$
1
10^{-22}
1
m_ϕ [eV]

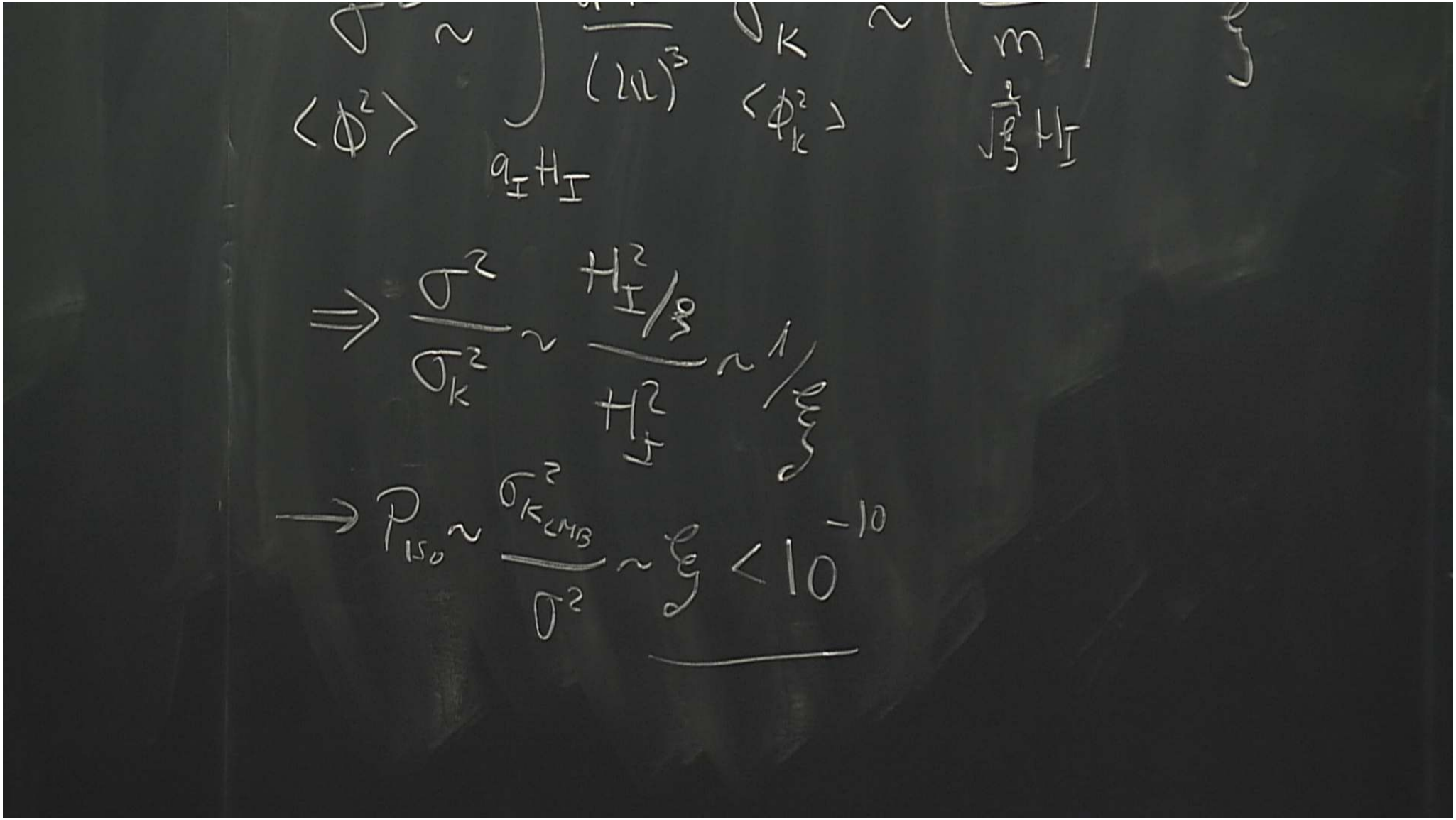

uctuations
Adiabatic
photons
baryons
x
Isocurvature
x
H [eV]
10^4
iso
~0.02
iso
$\xi \sim 0.01$
$\phi > M_{Pl}$
1
10^{-22}
1
m_ϕ [eV]
$N = N_{min} \sim 60$

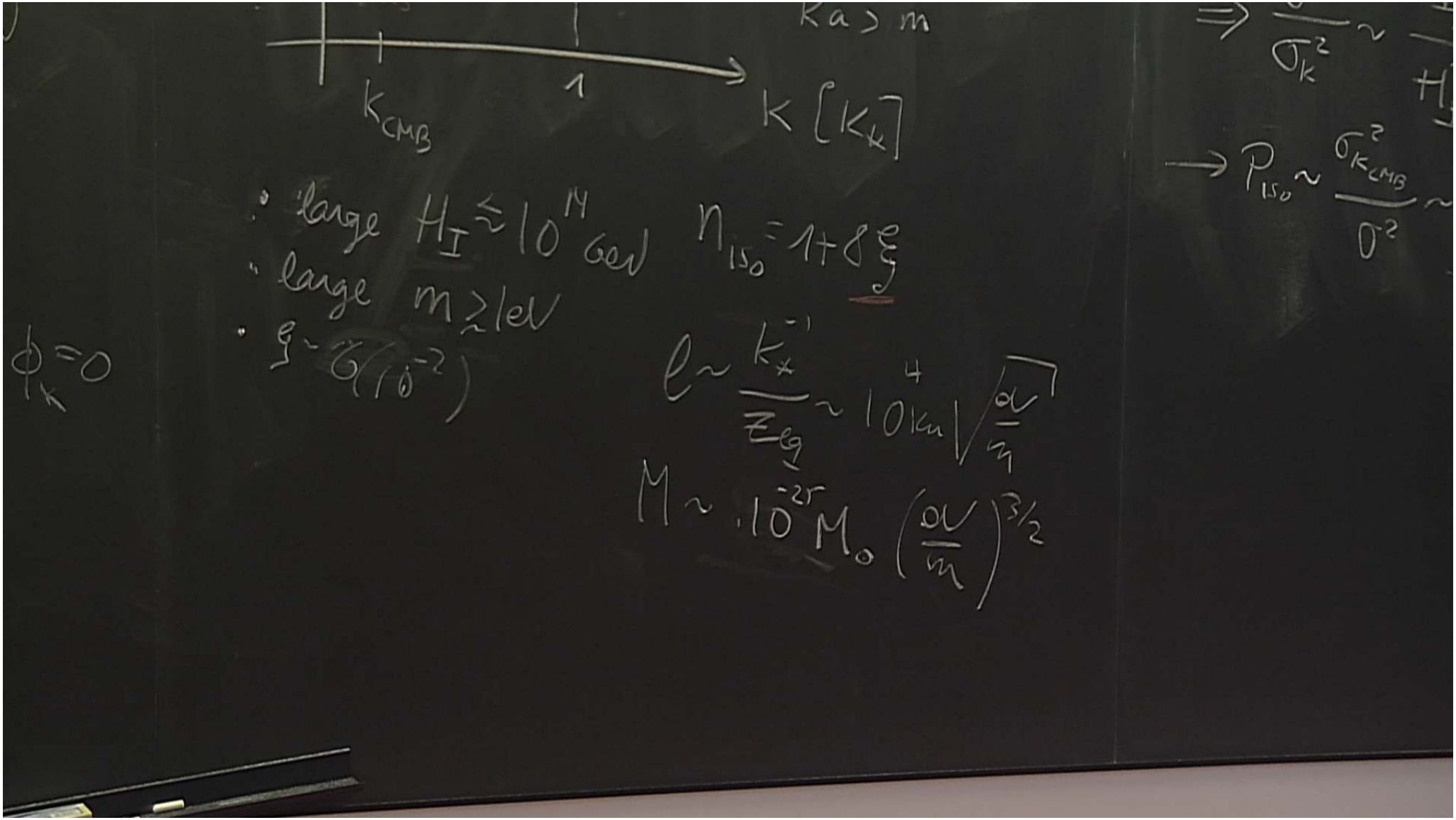

SR
$R = 3(1-3w)H^2$
$H_{eq} \sim 10^{-28}$ eV
P_δ
10^{-10}
k_{CMB}
1
$k\ [k_*]$
$k_*^{-1} \sim 1\ \mu pc \sqrt{\frac{1eV}{m}}$
large $H_I \lesssim 10^{14}$ GeV
large $m \gtrsim 1$ eV
$\xi \sim \mathcal{O}(10^{-2})$
m_ϕ
Slow-roll
$\phi_e \sim \phi_0 e^{-\xi N}$
$\frac{\Omega_\phi}{\Omega_{CDM}} \sim$

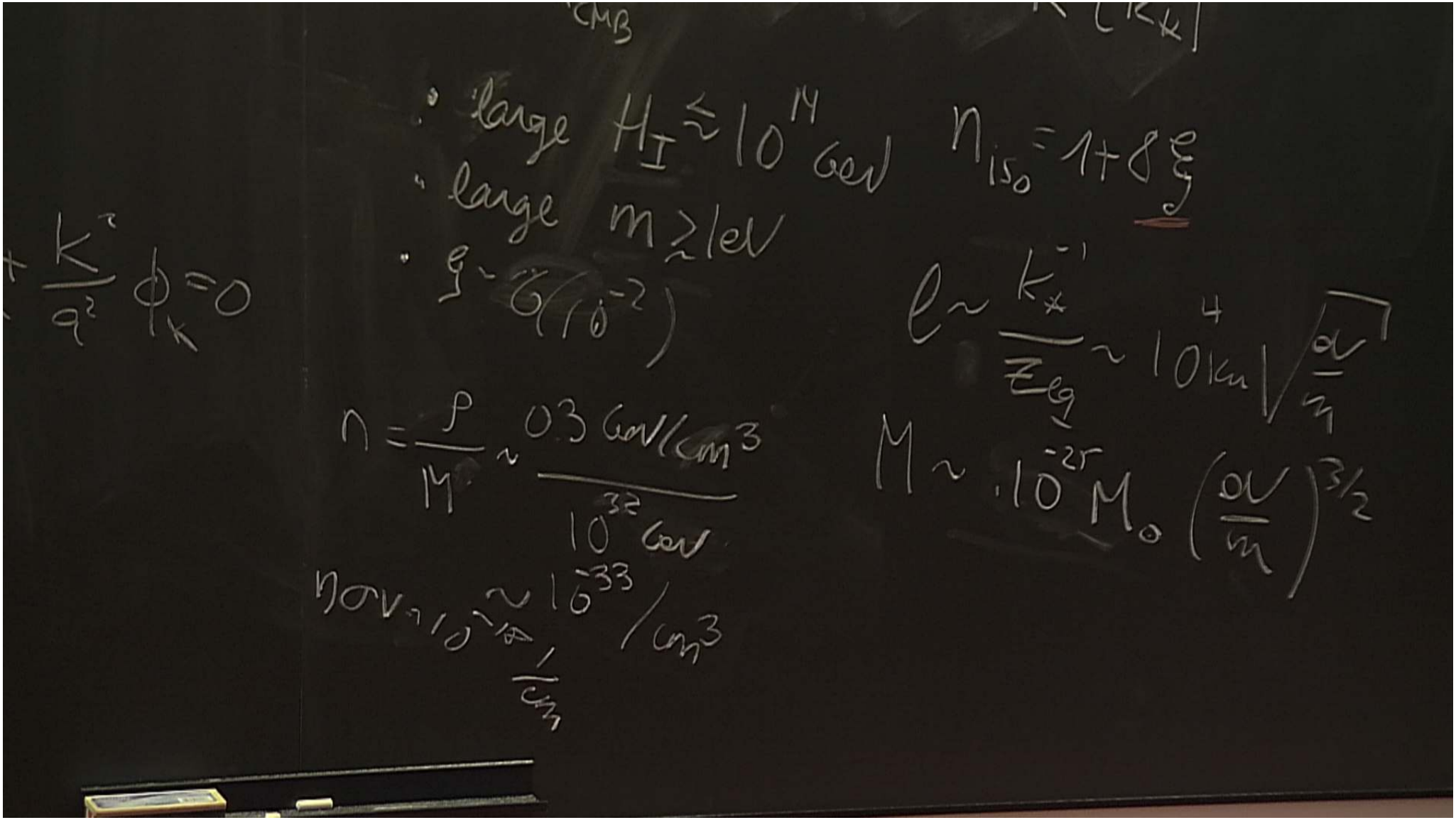

x^4
SR
$R = 3(1-3w)H^2$
$H_{eq} \sim 10^{-28}$ eV
a
MD, ΛD
w=1/3
w=0
$\ddot{\phi}_k + 3H\dot{\phi}_k + \frac{k^2}{a^2}\phi_k = 0$
$\phi_k \propto 1/a$
P_δ
1
10^{-10}
k_{CMB}
1
$k\,[k_*]$
$k_*^{-1} \sim 1\,\mu pc \sqrt{\frac{10\,eV}{m}}$
H=m
ka > m
• large $H_I \lesssim 10^{14}$ GeV
• large $m \gtrsim 1$ eV
• $\xi \sim \mathcal{O}(10^{-2})$
$n_{iso} = 1 + \delta\xi$


x
$a_0 H_0$
$\sigma^2 \sim \int \frac{d^3k}{(2\pi)^3} \sigma_k^2$
$\langle \phi^2 \rangle$
$\langle \phi_k^2 \rangle$
$a_I H_I$


$a_0 H_0$
$a_I H_I$
$\sigma^2 \sim \int \frac{d^3k}{(2\pi)^3} \sigma_k^2 \sim \left(\frac{H_I^2}{m}\right)^2 \sim \frac{H_I^2}{\xi}$
$\langle \phi^2 \rangle$
$\langle \phi_k^2 \rangle$
$\sqrt{\xi} H_I$
$\Rightarrow \frac{\sigma^2}{\sigma_k^2} \sim \frac{H_I^2/\xi}{H_I^2} \sim \frac{1}{\xi}$


$\sigma^2 \sim \int \frac{d^3k}{(2\pi)^3} \sigma_k^2 \sim \left(\frac{m}{\sqrt{\xi}H_I}\right)^2 \xi$
$\langle \phi^2 \rangle$
$q_I H_I$
$\langle \phi_k^2 \rangle$
$\Rightarrow \frac{\sigma^2}{\sigma_k^2} \sim \frac{H_I^2/\xi}{H_I^2} \sim 1/\xi$
$\rightarrow P_{iso} \sim \frac{\sigma_{k_{CMB}}^2}{\sigma^2} \sim \xi < 10^{-10}$


k_{CMB}
1
$k\,[k_*]$
$k a > m$
$\Rightarrow \frac{\sigma_k^2}{\sigma_k^2} \sim$
$\rightarrow P_{iso} \sim \frac{\sigma^2_{k_{CMB}}}{\sigma^2} \sim$
$\phi_k = 0$
large $H_I \lesssim 10^{14}$ GeV
large $m \gtrsim$ keV
$\xi \sim \mathcal{O}(10^{-2})$
$n_{iso} = 1 + \delta\xi$
$\ell \sim \frac{k_*^{-1}}{z_{eq}} \sim 10^4 \text{km} \sqrt{\frac{\text{keV}}{m}}$
$M \sim 10^{-25} M_\odot \left(\frac{\text{keV}}{m}\right)^{3/2}$


CMB
large $H_I \simeq 10^{14}$ GeV
large $m \gtrsim$ keV
$g \sim \mathcal{O}(10^{-2})$
$n_{iso} = 1 + \delta\xi$
$\ell \sim \frac{k_*^{-1}}{z_{eq}} \sim 10^4$ km $\sqrt{\frac{\sigma v}{m}}$
$n = \frac{\rho}{M} \sim \frac{0.3\ \text{GeV/cm}^3}{10^{32}\ \text{GeV}}$
$M \sim 10^{-25} M_\odot \left(\frac{\sigma v}{m}\right)^{3/2}$
$n\sigma v \sim 10^{-33}$ /cm^3
$\sim 10^{-18}$ 1/cm

& motivation

nt) DM

l couplings

oduction

ent

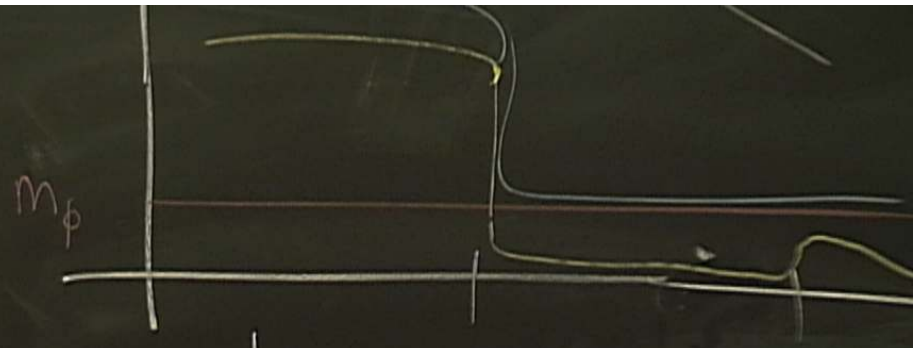
ons

c

outlook

$m \sim \frac{\xi \phi^2}{M_p^2}$

$\sim \xi \frac{\rho}{m^2 M_p^2}$



$m_{eff}^2 = m_\phi^2 + \xi R$