Title: PSI 2018/2019 - Cosmology Review - Lecture 6

Date: Jan 14, 2019 09:00 AM

URL: http://pirsa.org/19010007

Abstract:

Structure formation

1) How massive is large structure?

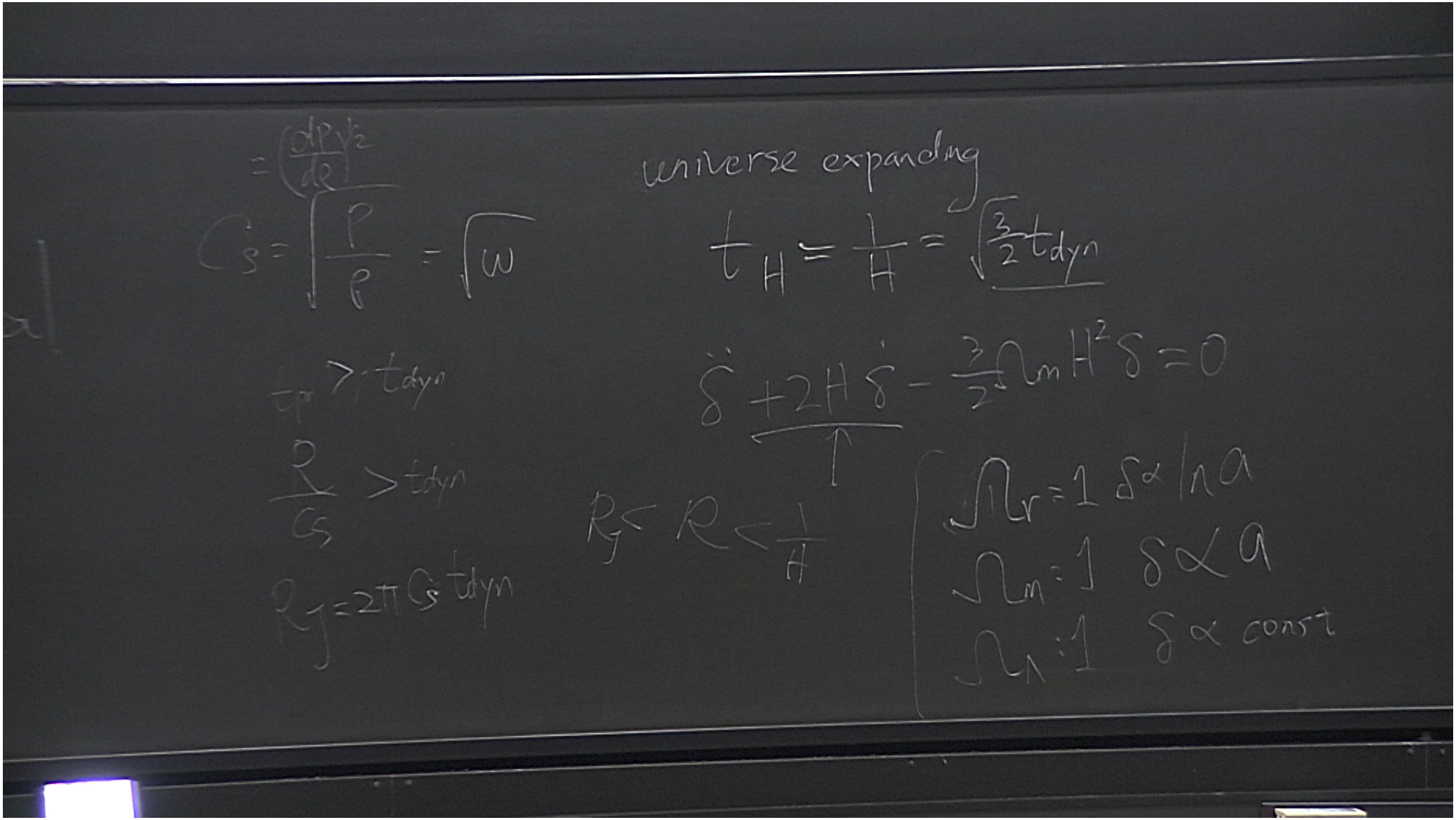
2) Power spectrum

Recap.

Friday + tutorial

$$t_{dyn} = \sqrt{\frac{1}{4\pi G \bar{\rho}}}$$

$$t_{pre} = \frac{R}{c_s}$$


$= \left(\frac{dP}{d\rho}\right)^{1/2}$
$c_s = \sqrt{\frac{P}{\rho}} = \sqrt{w}$
universe expanding
$t_H = \frac{1}{H} = \sqrt{\frac{3}{2}} t_{dyn}$
$\tau_{pr} > t_{dyn}$
$\frac{R}{c_s} > t_{dyn}$
$R_J = 2\pi c_s t_{dyn}$
$\ddot{\delta} + 2H\dot{\delta} - \frac{3}{2}\Omega_m H^2 \delta = 0$
$R_J < R < \frac{1}{H}$
$\Omega_r = 1 \quad \delta \propto \ln a$
$\Omega_m = 1 \quad \delta \propto a$
$\Omega_\Lambda = 1 \quad \delta \propto \text{const}$

$M_J = \frac{4\pi R_J^3}{3} \rho_{bary}$

baryonic matter + radiation. Just before

$\rho_\gamma > \rho_{bary}$

$R_J = 2\pi \sqrt{\frac{1}{3}} \sqrt{\frac{2}{3}} \frac{1}{H}$ (3)

$M_J \sim 10^{19} M_\odot$

p.n.e.e^- γ

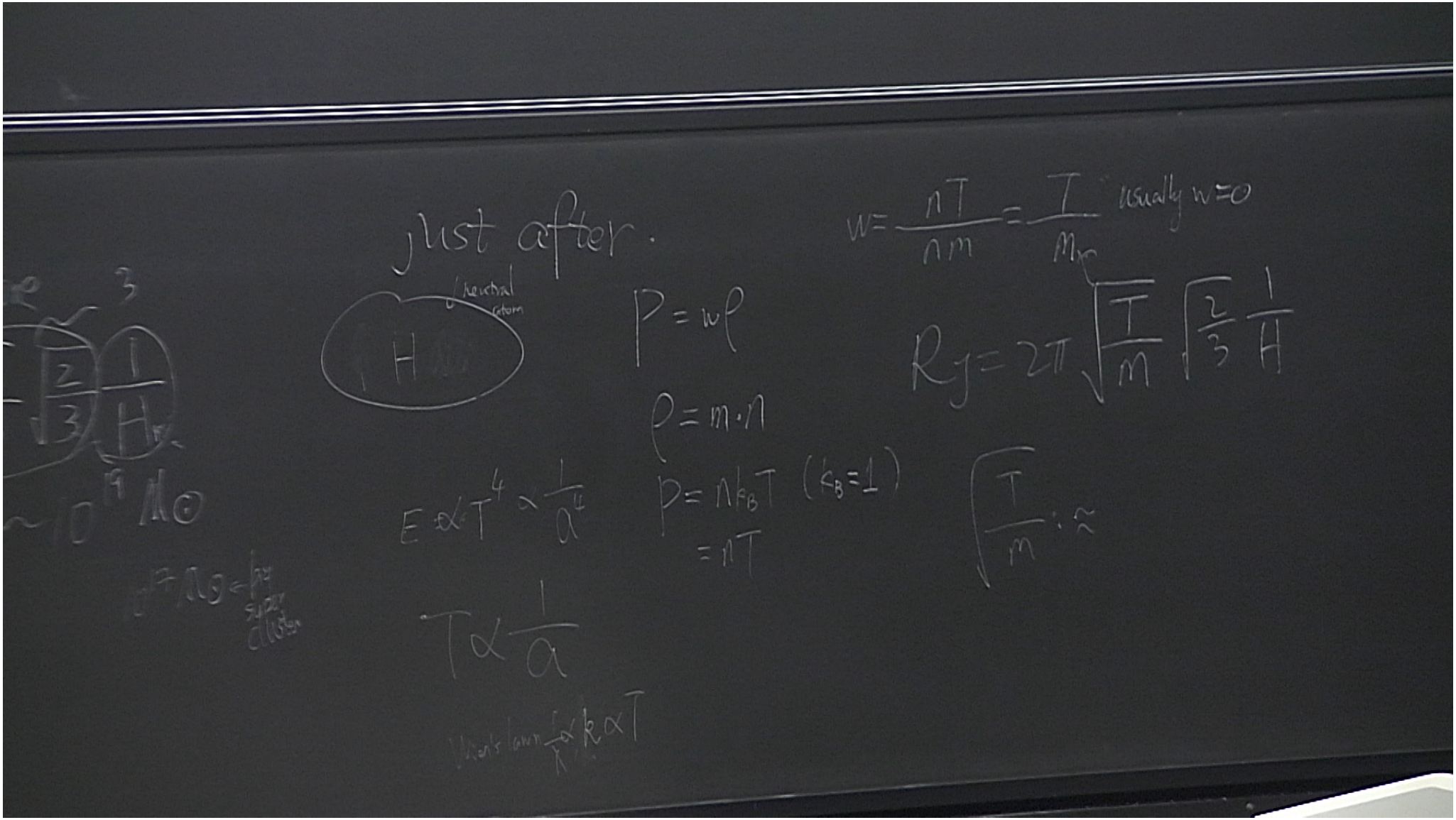
$\rightarrow \rho_{bary,0}$ (Wed tutorial)

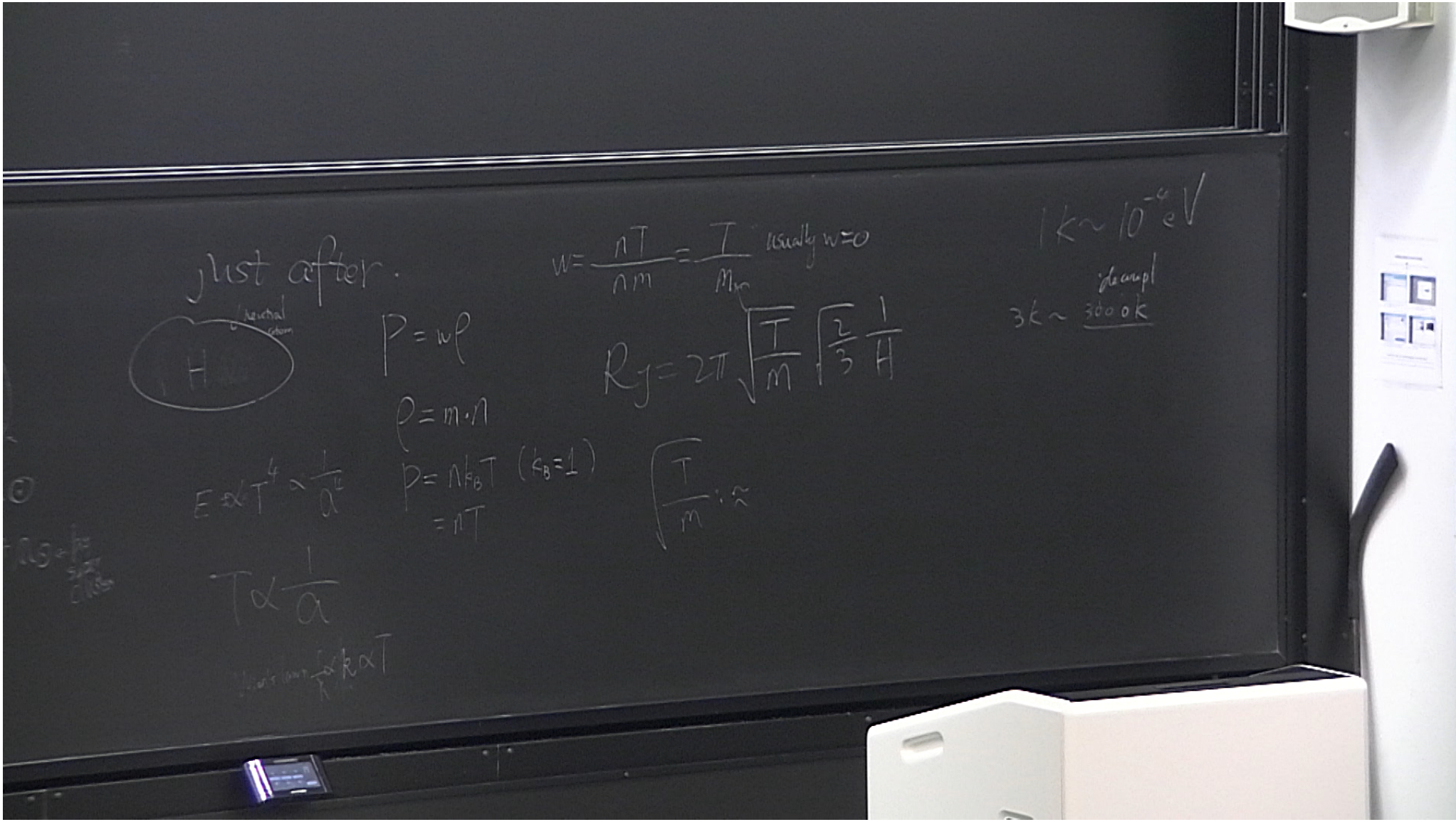
now

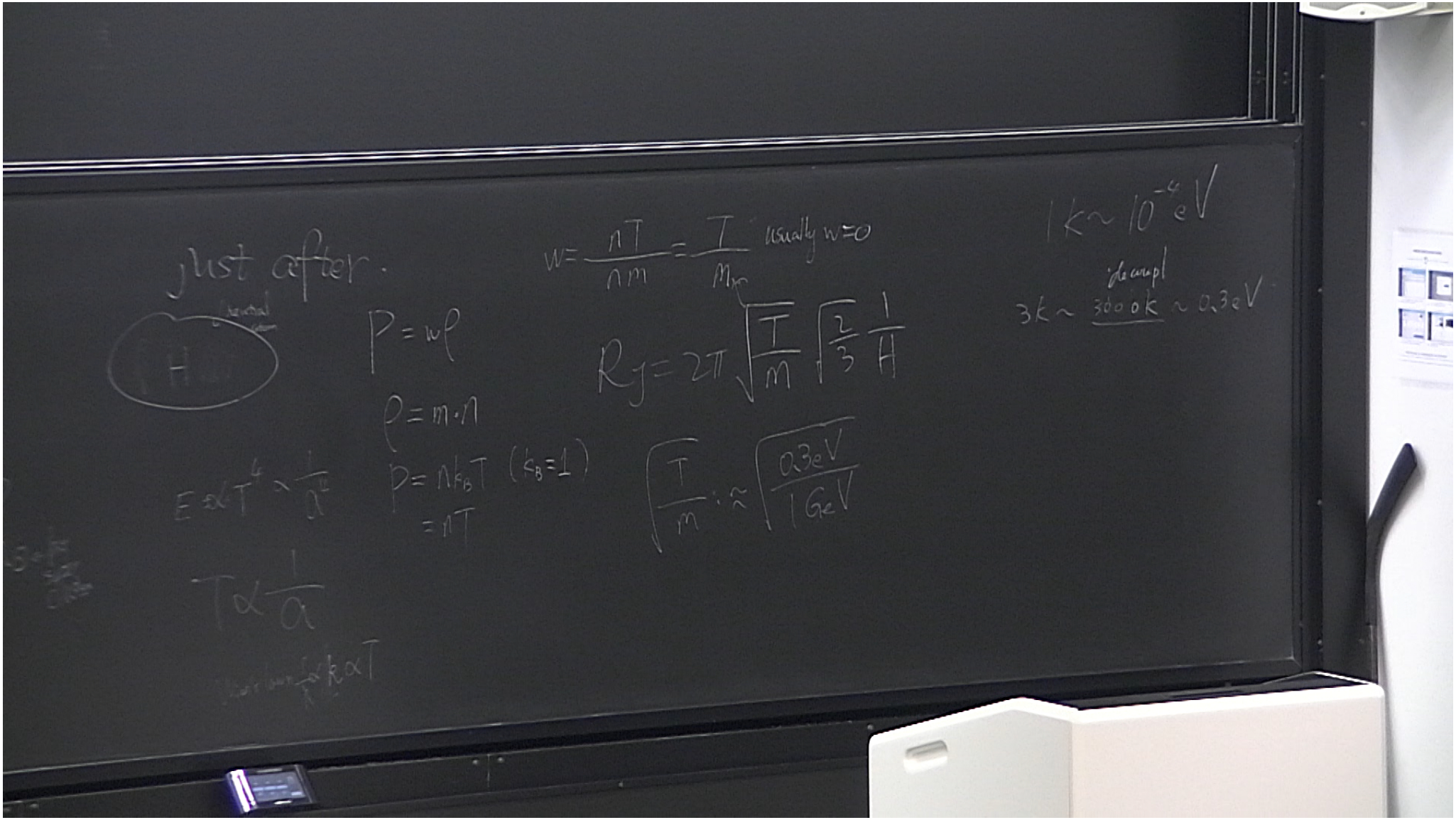
$\rightarrow z \approx 1100$

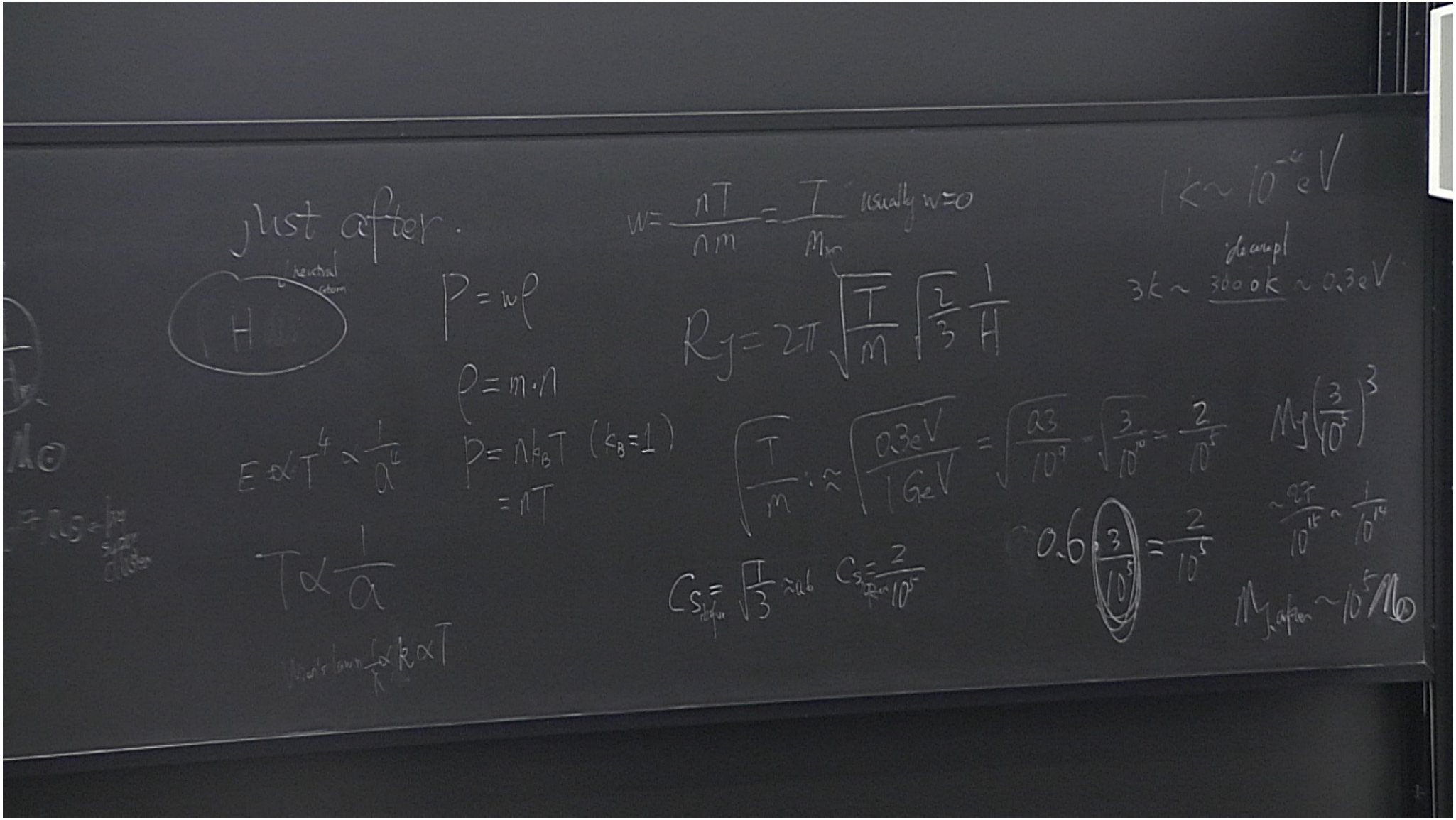
↓ photon decoupling

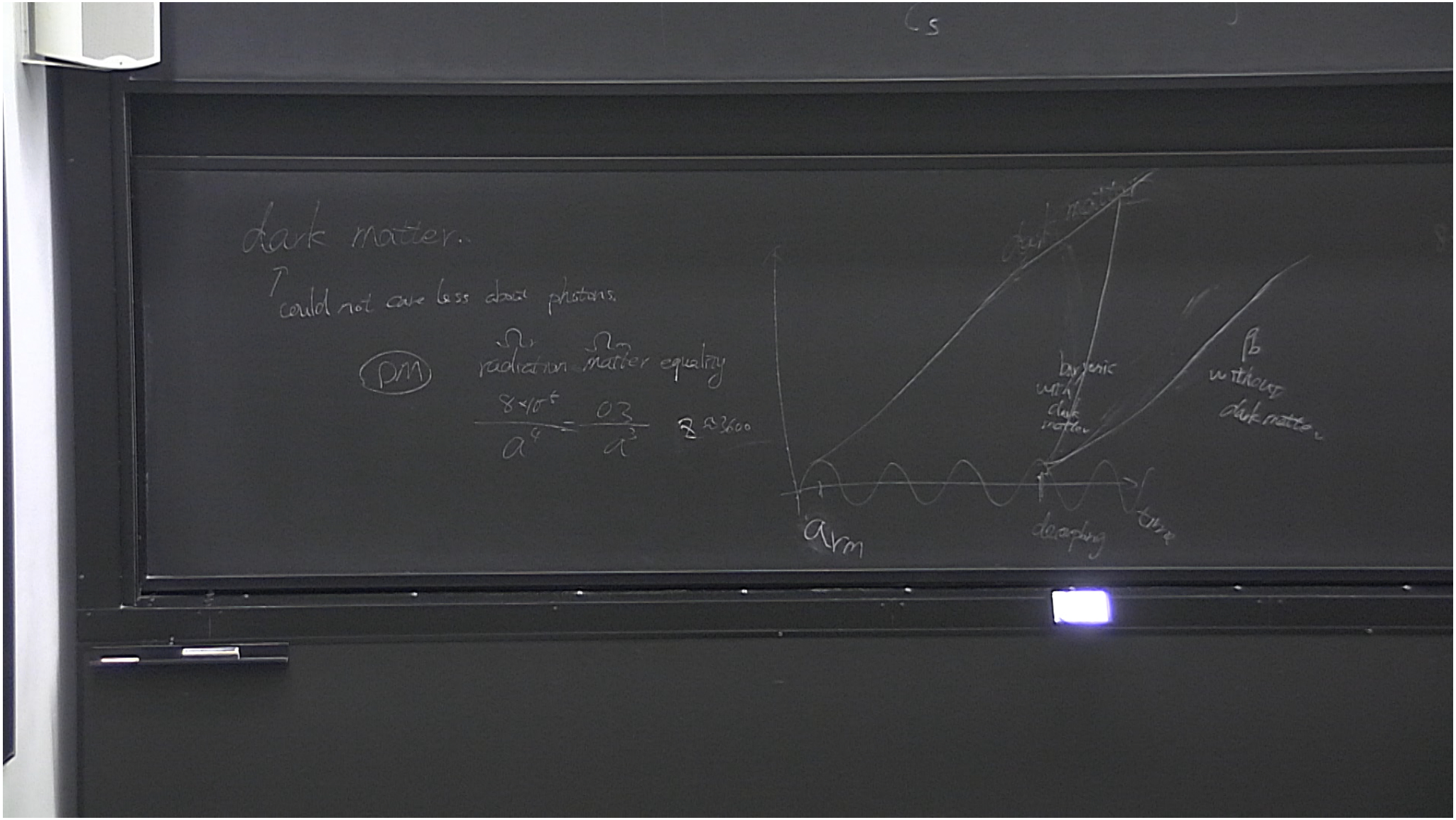
p.n.e.e^- γ

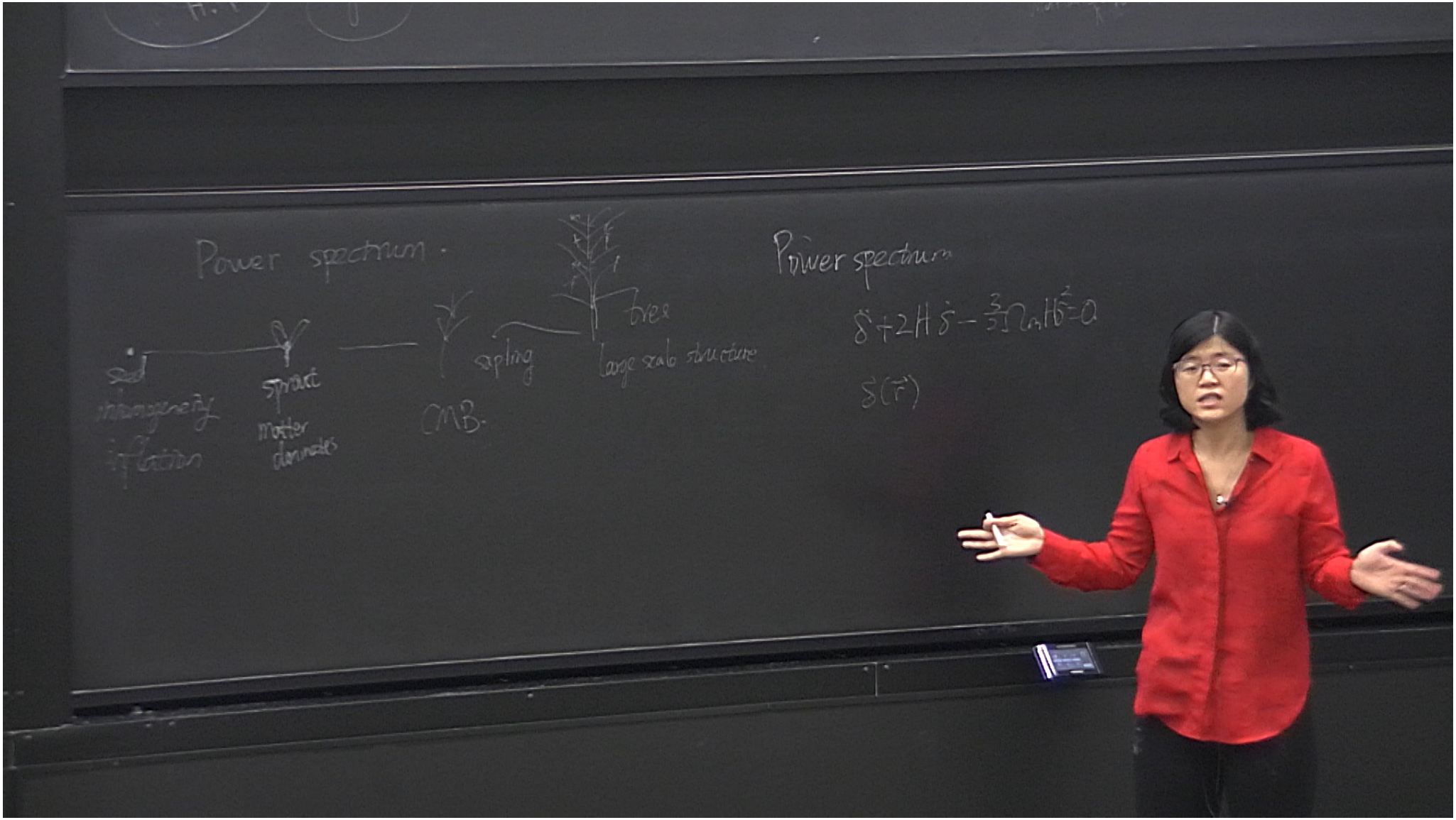

just after.
neutral atom
H
$w = \frac{nT}{nm} = \frac{T}{m}$ usually $w = 0$
$P = w\rho$
$\rho = m \cdot n$
$P = nk_B T \quad (k_B = 1)$
$= nT$
$E \propto T^4 \propto \frac{1}{a^4}$
$T \propto \frac{1}{a}$
$R_J = 2\pi \sqrt{\frac{T}{m}} \sqrt{\frac{2}{3}} \frac{1}{H}$
$\sqrt{\frac{T}{m}} : \approx$


just after.
neutral atom
H
$w = \frac{nT}{nm} = \frac{I}{M_{tot}}$ usually $w = 0$
$P = w\rho$
$\rho = m \cdot n$
$P = nk_B T \quad (k_B = 1)$
$= nT$
$E \propto T^4 \sim \frac{1}{a^2}$
$T \propto \frac{1}{a}$
$R_J = 2\pi \sqrt{\frac{T}{m}} \sqrt{\frac{2}{3}} \frac{1}{H}$
$\sqrt{\frac{T}{m}} : \approx$
$1k \sim 10^{-4} eV$
decoupl
$3k \sim 3000k$

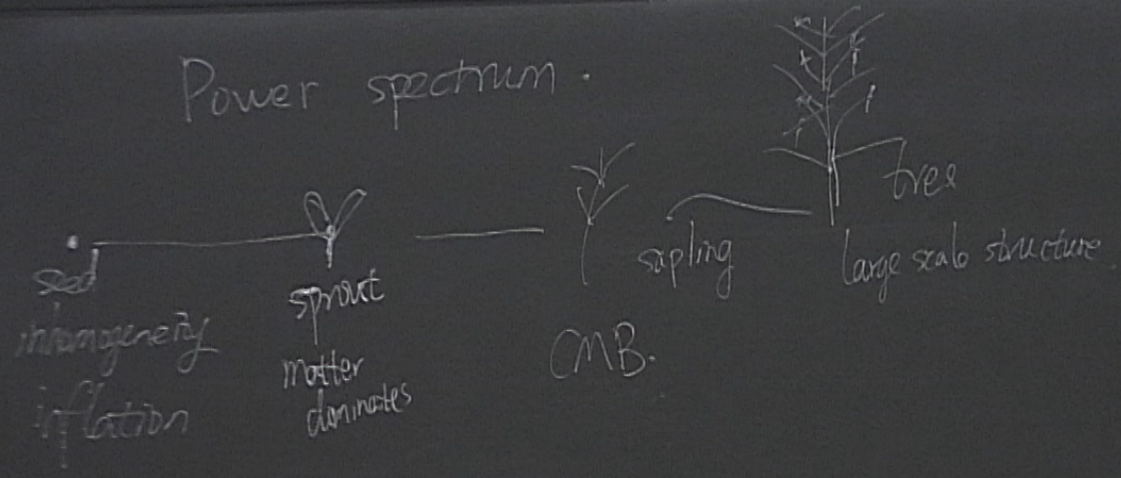

just after.
H
$w = \frac{nT}{nm} = \frac{T}{m}$ usually $w=0$
$P = w\rho$
$\rho = m \cdot n$
$P = nk_B T \quad (k_B = 1)$
$= nT$
$E \propto T^4 \propto \frac{1}{a^4}$
$T \propto \frac{1}{a}$
$R_J = 2\pi \sqrt{\frac{T}{m}} \sqrt{\frac{2}{3}} \frac{1}{H}$
$\sqrt{\frac{T}{m}} \approx \sqrt{\frac{0.3eV}{1GeV}}$
$1k \sim 10^{-4} eV$
$3k \sim \underline{3000k} \sim 0.3eV$


just after.
neutral return
H
$w = \frac{nT}{nm} = \frac{T}{m}$ usually $w = 0$
$P = wp$
$p = m \cdot n$
$P = nk_B T \quad (k_B = 1)$
$= nT$
$E \propto T^4 \propto \frac{1}{a^4}$
$T \propto \frac{1}{a}$
$R_J = 2\pi \sqrt{\frac{T}{m}} \sqrt{\frac{2}{3}} \frac{1}{H}$
$\sqrt{\frac{T}{m}} \simeq \sqrt{\frac{0.3eV}{1GeV}} = \sqrt{\frac{0.3}{10^9}} = \sqrt{\frac{3}{10^{10}}} = \frac{2}{10^5}$
$C_s = \sqrt{\frac{1}{3}} \approx 0.6$
$C_s = \frac{2}{10^5}$
$0.6 \frac{3}{10^5} = \frac{2}{10^5}$
$1k \sim 10^{-4} eV$
decoupl
$3k \sim \frac{3000k}{} \sim 0.3eV$
$M_J \left(\frac{3}{10^5}\right)^3$
$\sim \frac{27}{10^{15}} \sim \frac{1}{10^{14}}$
$M_{J,after} \sim 10^5 M_\odot$


dark matter.
"could not care less about photons.
DM
radiation matter equality
baryonic with dark matter
Pb without dark matter
decoupling
time


Power spectrum.
seed
inhomogeneity
inflation
sprout
matter
dominates
CMB.
sapling
tree
large scale structure
Power spectrum
$\ddot{\delta}+2H\dot{\delta}-\frac{3}{2}\Omega_m H^2\delta=0$
$\delta(\vec{r})$

Power spectrum.

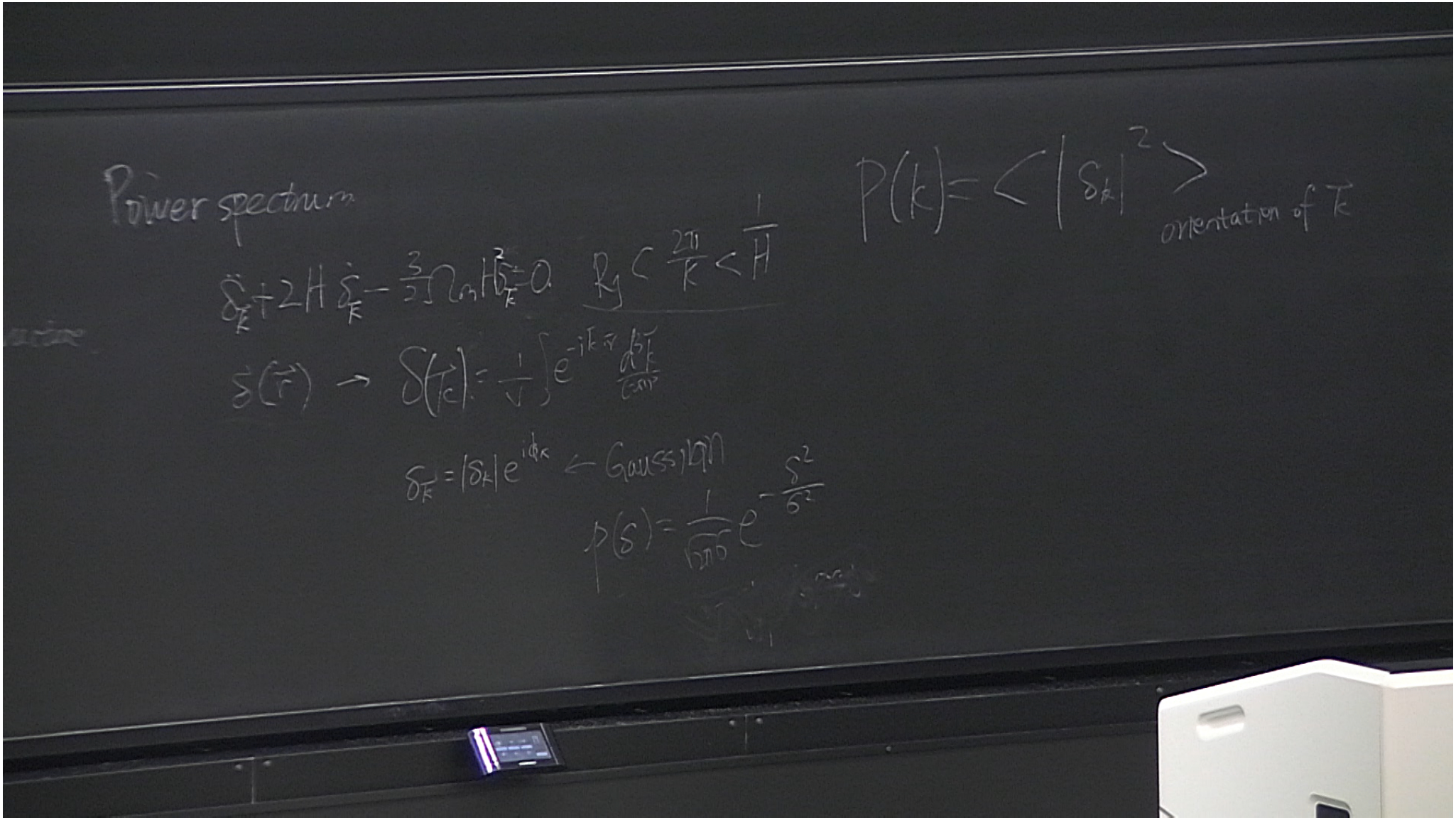


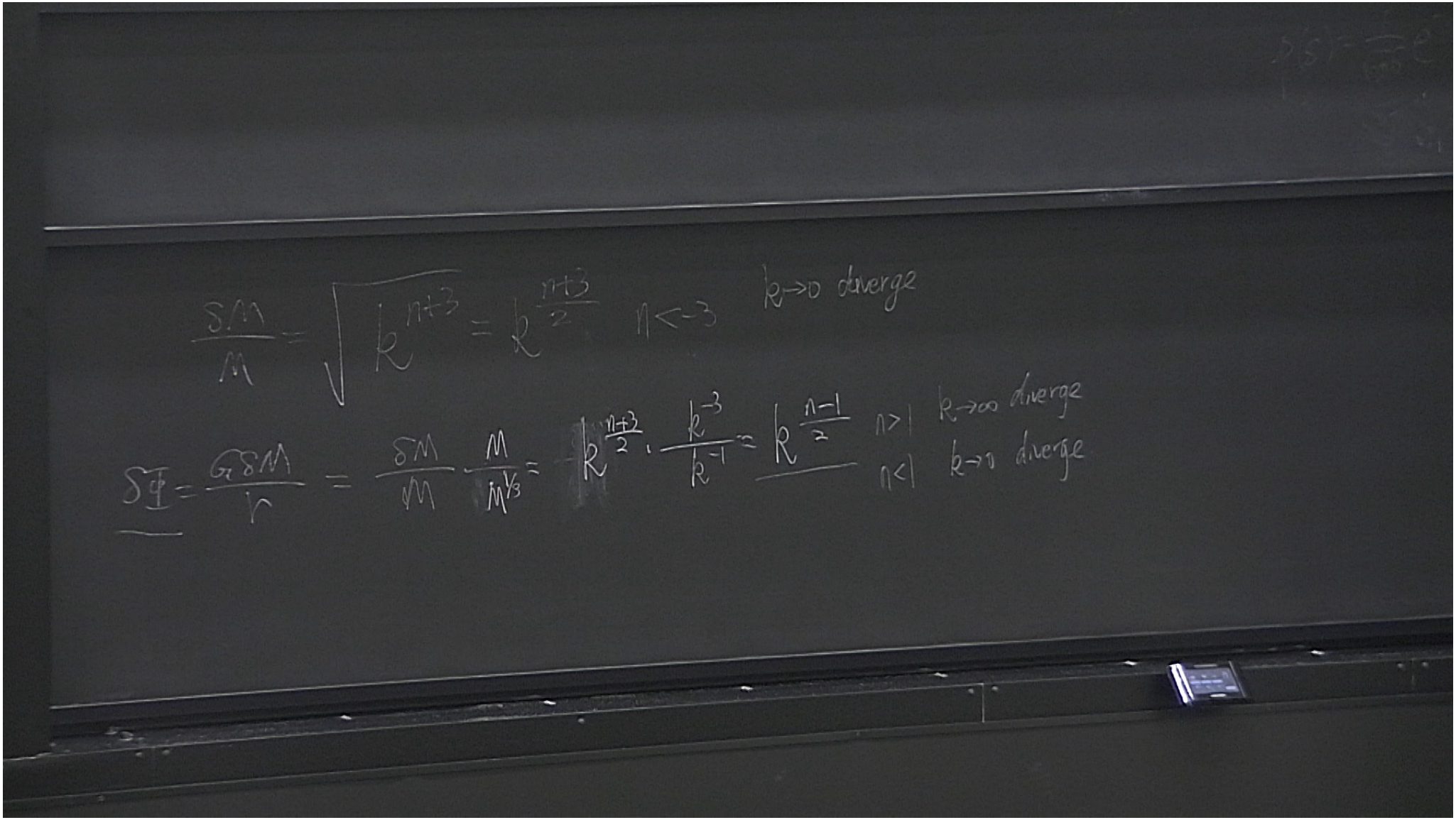
Power spectrum

$$\ddot{\delta}_k + 2H\dot{\delta}_k - \frac{3}{2}\Omega_m H^2 \delta_k = 0$$

$$\delta(\vec{r}) \rightarrow \delta(\vec{r}) = \frac{1}{V}\int e^{-i\vec{k}\cdot\vec{r}}\, d^3k$$

$$\delta_k = |\delta_k| e^{i\phi_k}$$


Power spectrum
$\ddot{\delta}_k + 2H\dot{\delta}_k - \frac{3}{2}\Omega_m H^2 \delta_k = 0$
$R_g < \frac{2\pi}{k} < \frac{1}{H}$
$P(k) = \langle |\delta_k|^2 \rangle$
orientation of $\vec{k}$
$\delta(\vec{r}) \rightarrow \delta(\vec{k}) = \frac{1}{V}\int e^{-i\vec{k}\cdot\vec{r}} d^3\vec{r}$
$\delta_k = |\delta_k| e^{i\phi_k}$ ← Gaussian
$p(\delta) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{\delta^2}{\sigma^2}}$


$\frac{\delta M}{M} = \sqrt{k^{n+3}} = k^{\frac{n+3}{2}}$ $n<-3$ $k\to 0$ diverge
$\delta\Phi = \frac{G\delta M}{r} = \frac{\delta M}{M}\frac{M}{M^{1/3}} = k^{\frac{n+3}{2}}\cdot\frac{k^{-3}}{k^{-1}} = k^{\frac{n-1}{2}}$ $n>1$ $k\to\infty$ diverge
$n<1$ $k\to 0$ diverge

$M_y = \frac{4\pi R_y^3}{3} \rho_{bary}$

baryonic matter + radiation.

just before

$\rho_\gamma > \rho_{bary}$

$R_y = 2\pi \sqrt{\frac{1}{3}} \sqrt{\frac{2}{3}} \frac{1}{H}$

~ 3

$\rightarrow \rho_{bary,0}$

Wed tutorial

$M_y \sim 10^{19} M_\odot$

$10^{17} M_\odot <$ [illegible] supercluster

p.n.e.et. γ

DM

photon decoupling

$z \approx 1100$

atom

H. He

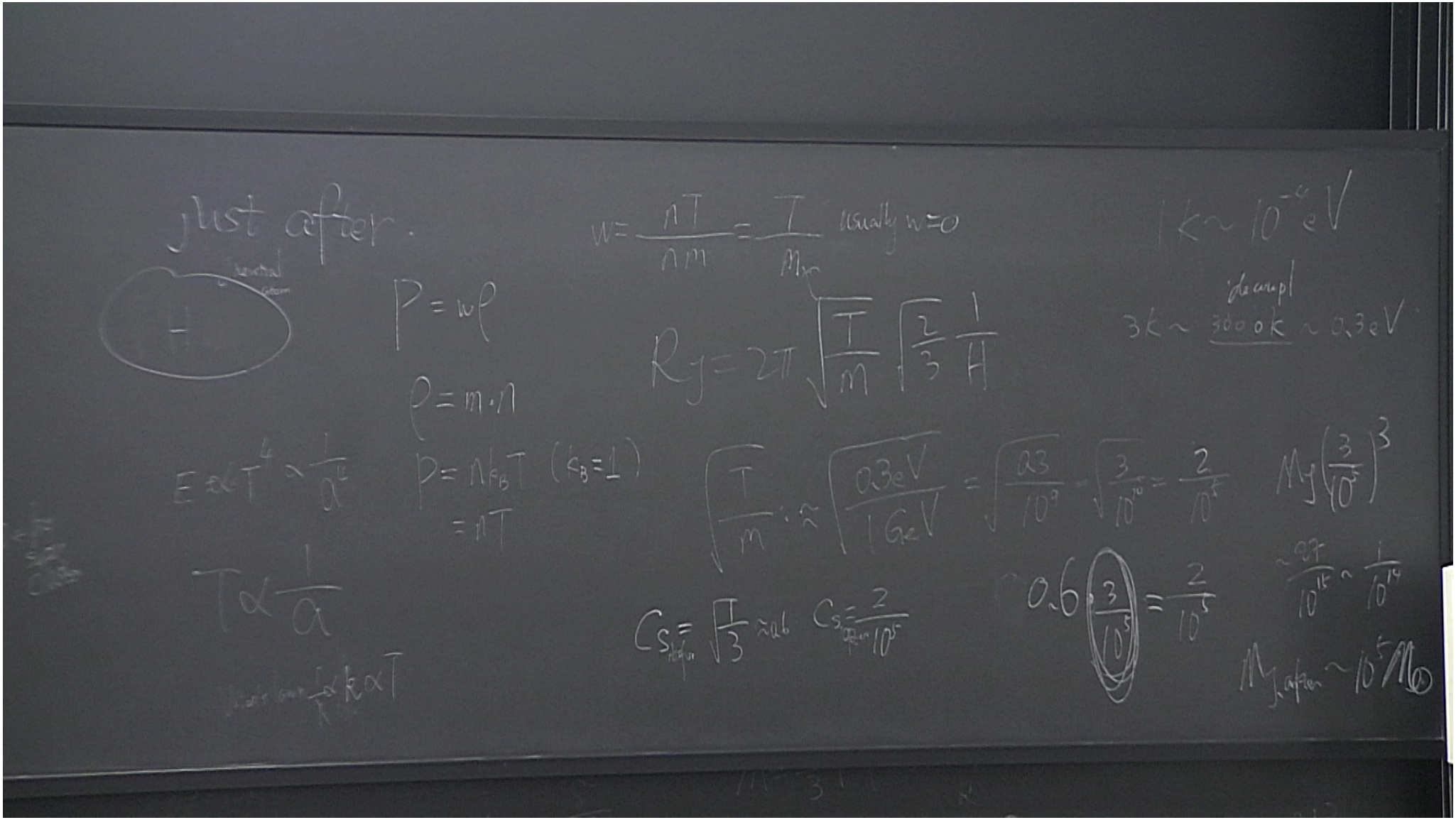
γ

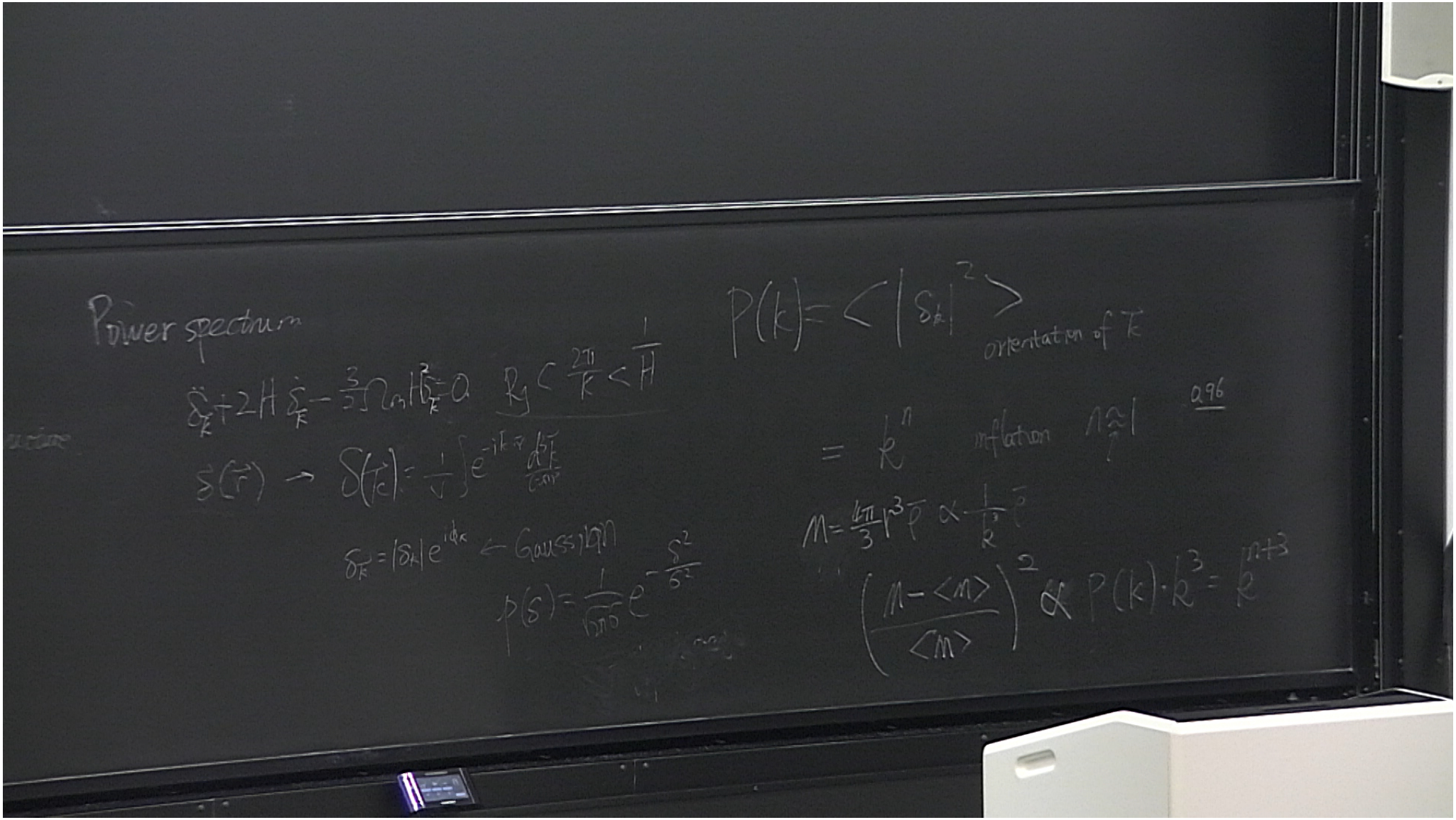
just

H

E ∝ T

T


just after.
$w = \frac{nT}{nm} = \frac{I}{M_{tot}}$ usually $w = 0$
$P = w\rho$
$\rho = m \cdot n$
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$\sqrt{\frac{T}{m}} \approx \sqrt{\frac{0.3\,eV}{1\,GeV}} = \sqrt{\frac{0.3}{10^9}} = \sqrt{\frac{3}{10^{10}}} = \frac{2}{10^5}$
$C_s = \sqrt{\frac{\Gamma}{3}} \approx 0.6$
$0.6 \left(\frac{3}{10^5}\right) = \frac{2}{10^5}$
$1\,K \sim 10^{-4}\,eV$
$3K \sim \underline{3000\,K} \sim 0.3\,eV$
$M_J \left(\frac{3}{10^5}\right)^3$
$\frac{\sim 0.3}{10^{15}} \sim \frac{1}{10^{14}}$
$M_{Jupiter} \sim 10^{-3} M_\odot$


Power spectrum
$\ddot{\delta}_k + 2H\dot{\delta}_k - \frac{3}{2}\Omega_m H^2 \delta_k = 0$
$k_J < \frac{2\pi}{k} < \frac{1}{H}$
$P(k) = \langle |\delta_k|^2 \rangle$
orientation of $\vec{k}$
$\delta(\vec{r}) \rightarrow \delta(\vec{k}) = \frac{1}{V}\int e^{-i\vec{k}\cdot\vec{r}} d^3\vec{r}$
$= k^n$ inflation $n \approx 1$
$\delta_k = |\delta_k| e^{i\phi_k}$ ← Gaussian
$p(\delta) = \frac{1}{\sqrt{2\pi}} e^{-\frac{\delta^2}{\sigma^2}}$
$N = \frac{4\pi}{3} r^3 \bar{\rho} \propto \frac{1}{k^3}\bar{\rho}$
$\left(\frac{N - \langle N \rangle}{\langle N \rangle}\right)^2 \propto P(k)\cdot k^3 = k^{n+3}$