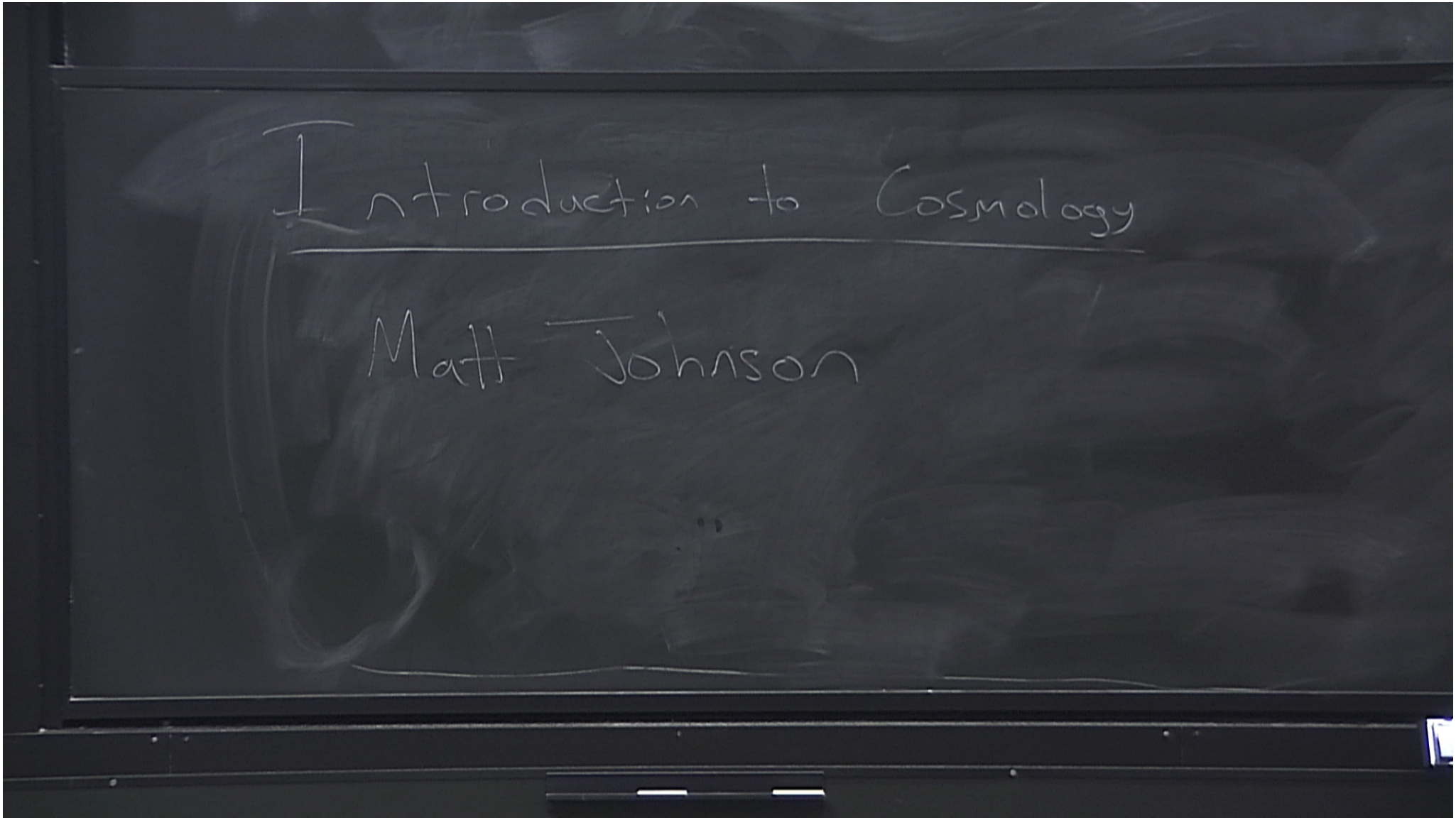
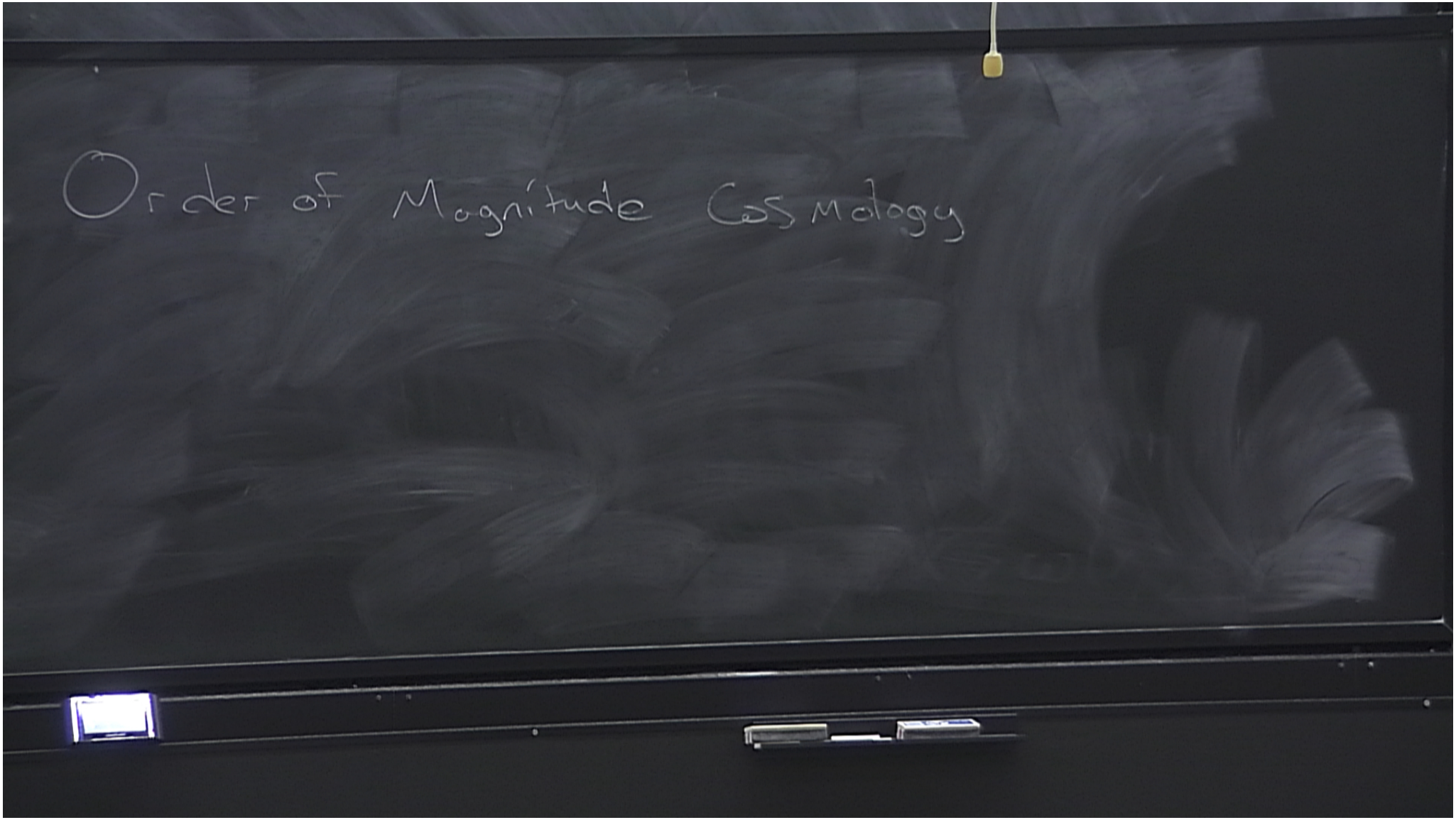
Title: Introduction to Cosmology - Matt Johnson

Date: Aug 25, 2015 10:30 AM

URL: http://pirsa.org/15080110

Abstract:


Introduction to Cosmology
Matt Johnson


Order of Magnitude Cosmology

Units + Scales



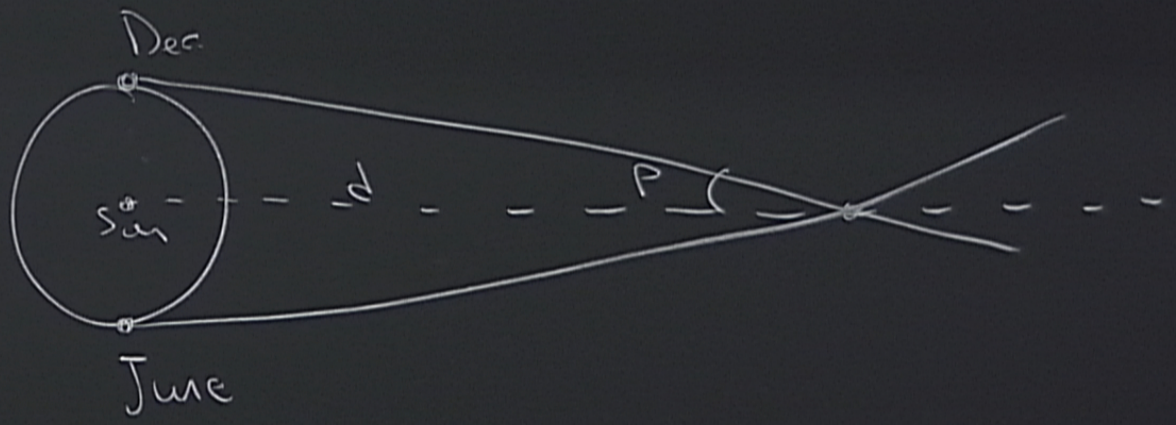
1 meter

Meter is very inconvenient for cosmology, QM, Particle Physics...

$$r_{obs} = 5,000,000,000,000,000,000,000,000,000 \text{ m}$$

$$= 5 \times 10^{26} \text{ m}$$

- Better Units: Astronomical Scales

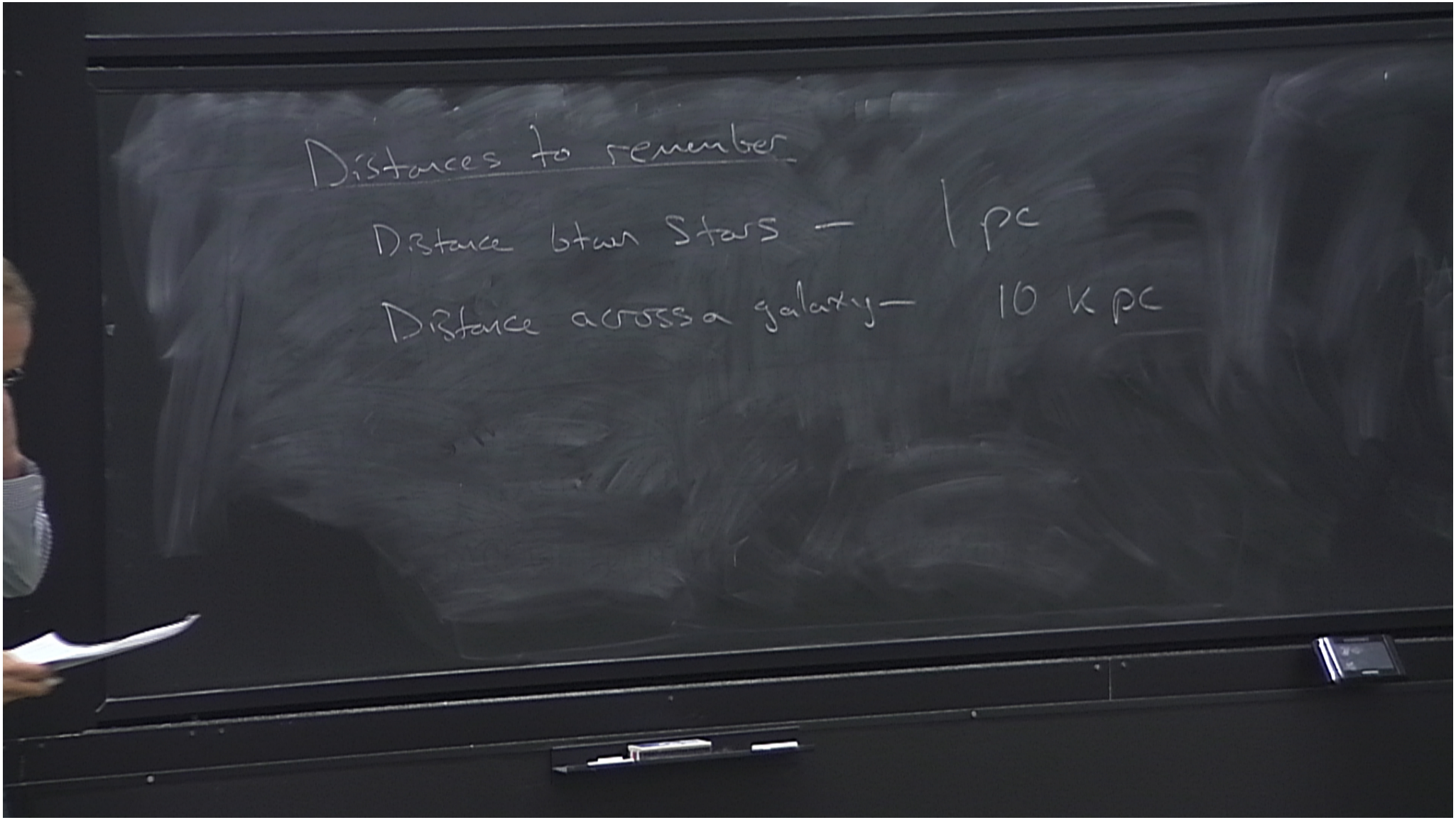


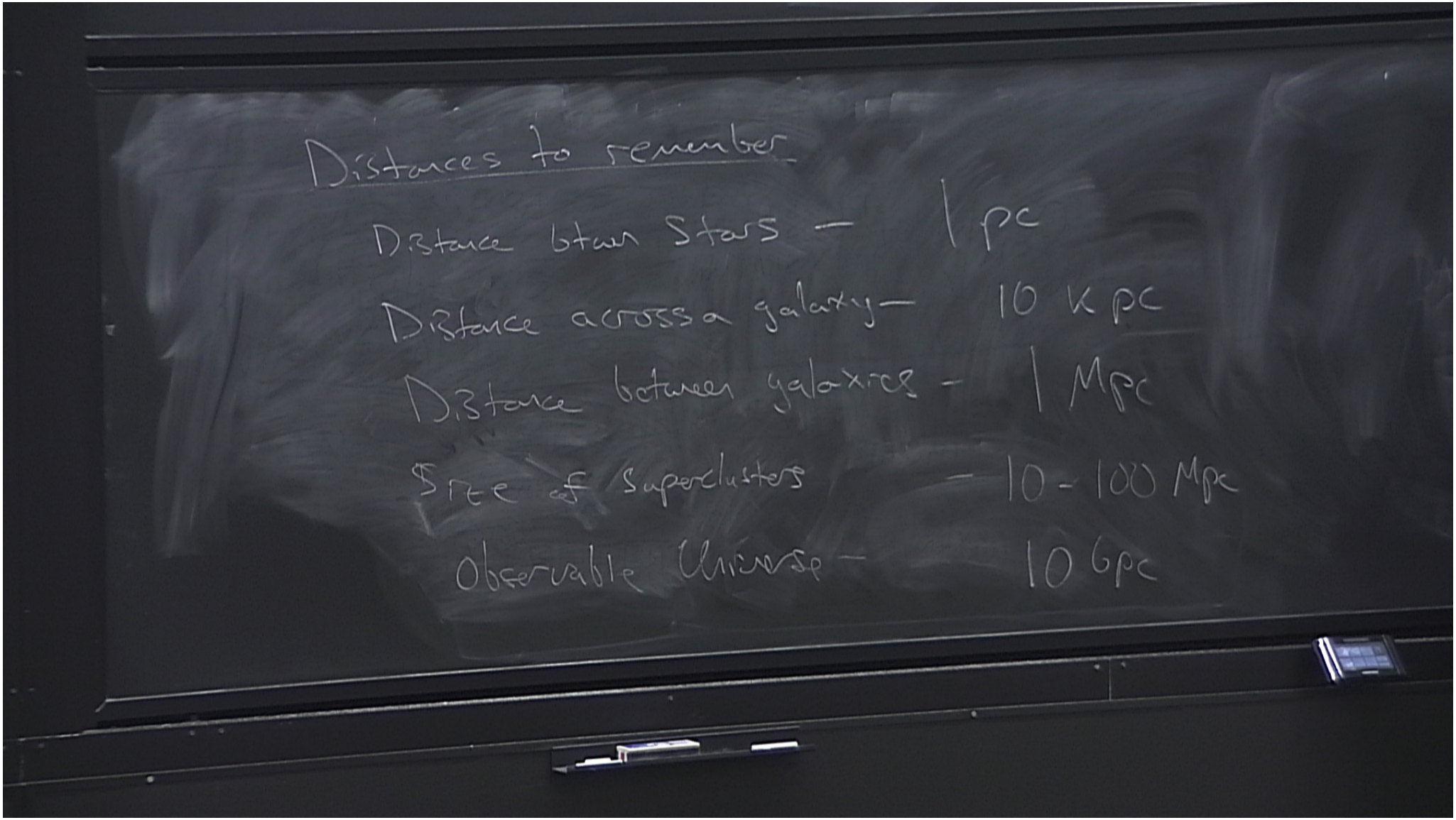
Scales

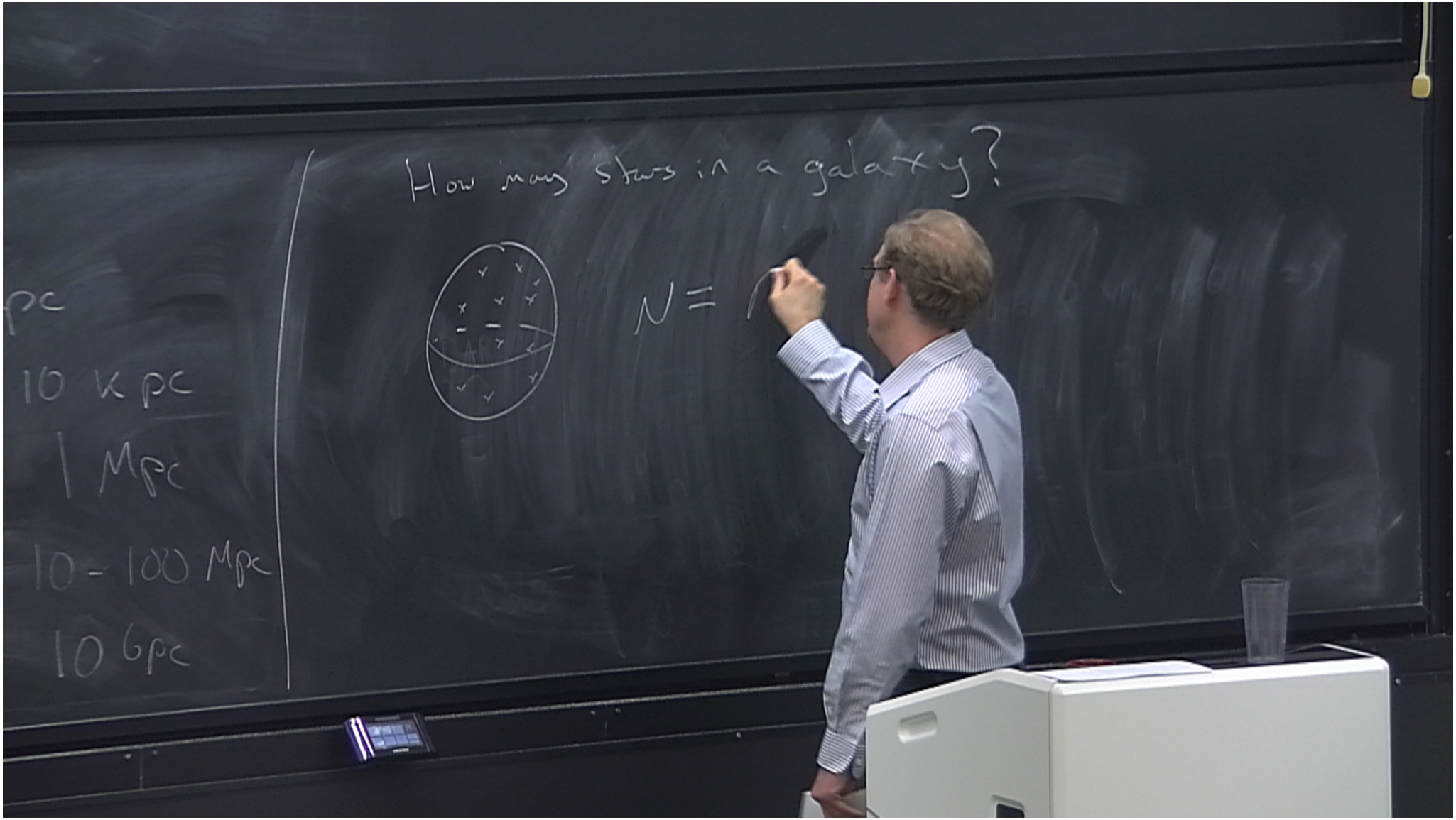
1 parsec = distance of an object subtending 1 arc sec of parallax

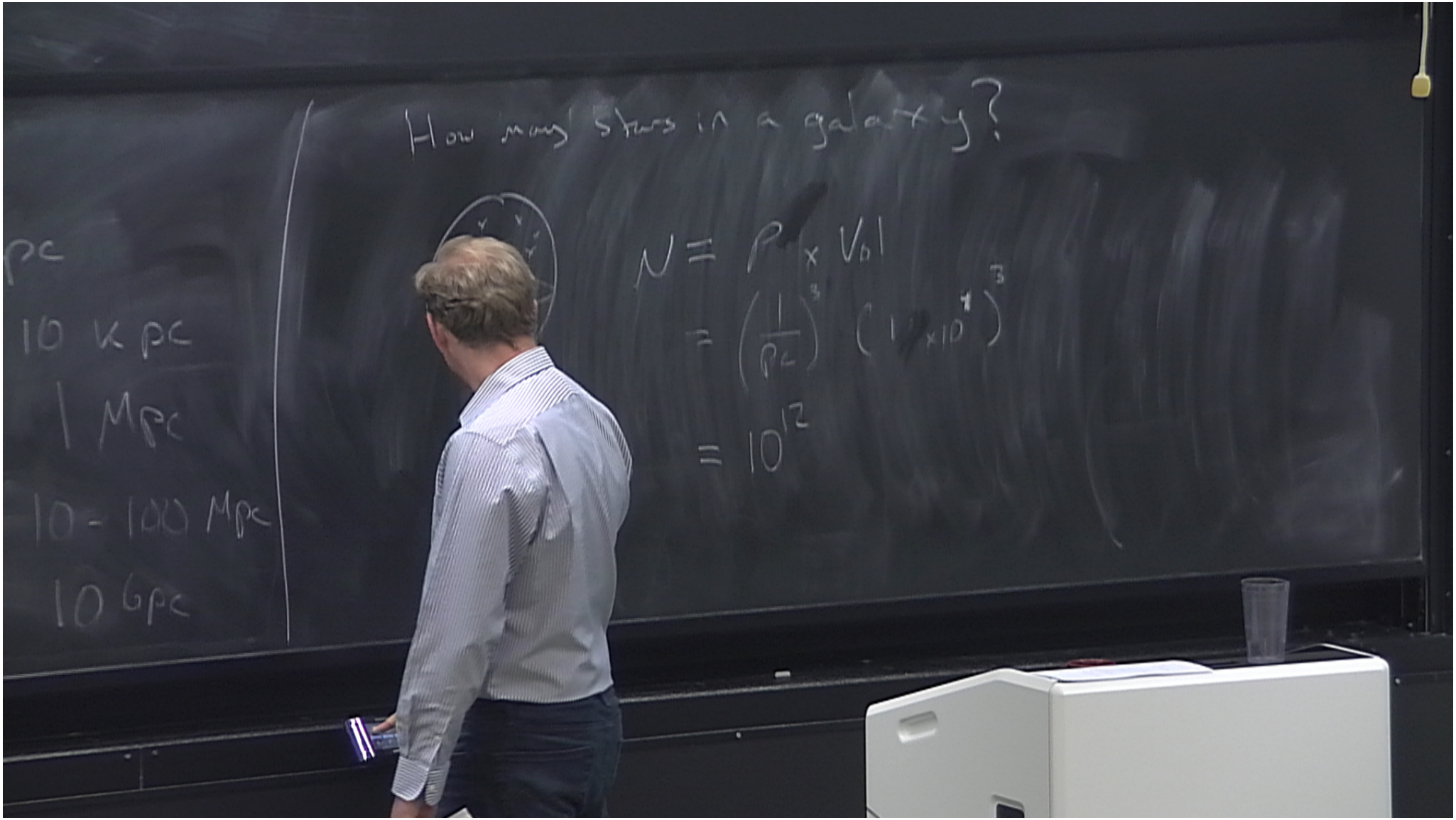
= distance to closest stars

= 3 light years

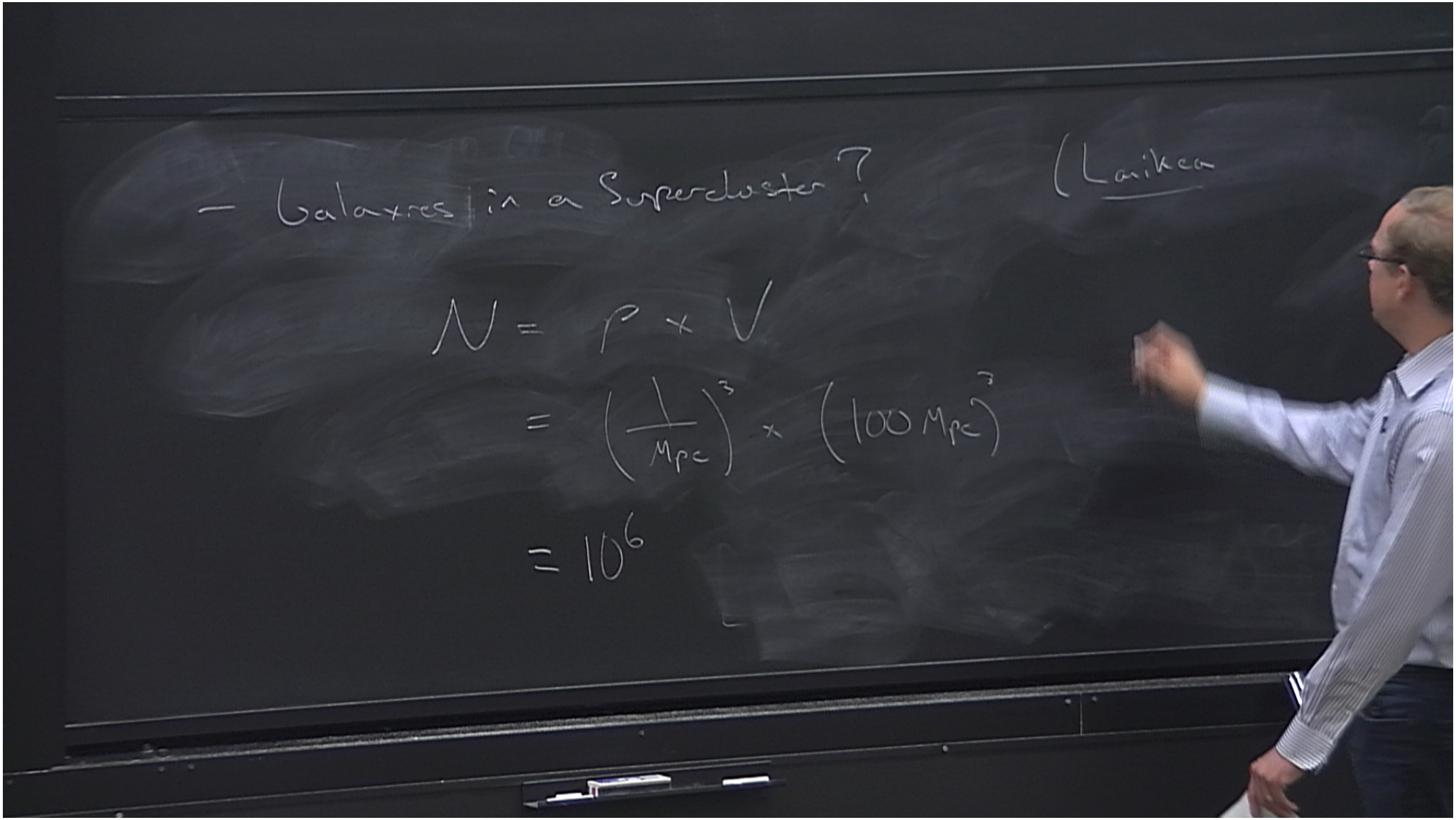

Distances to remember
Distance btwn stars — 1 pc
Distance across a galaxy — 10 K pc

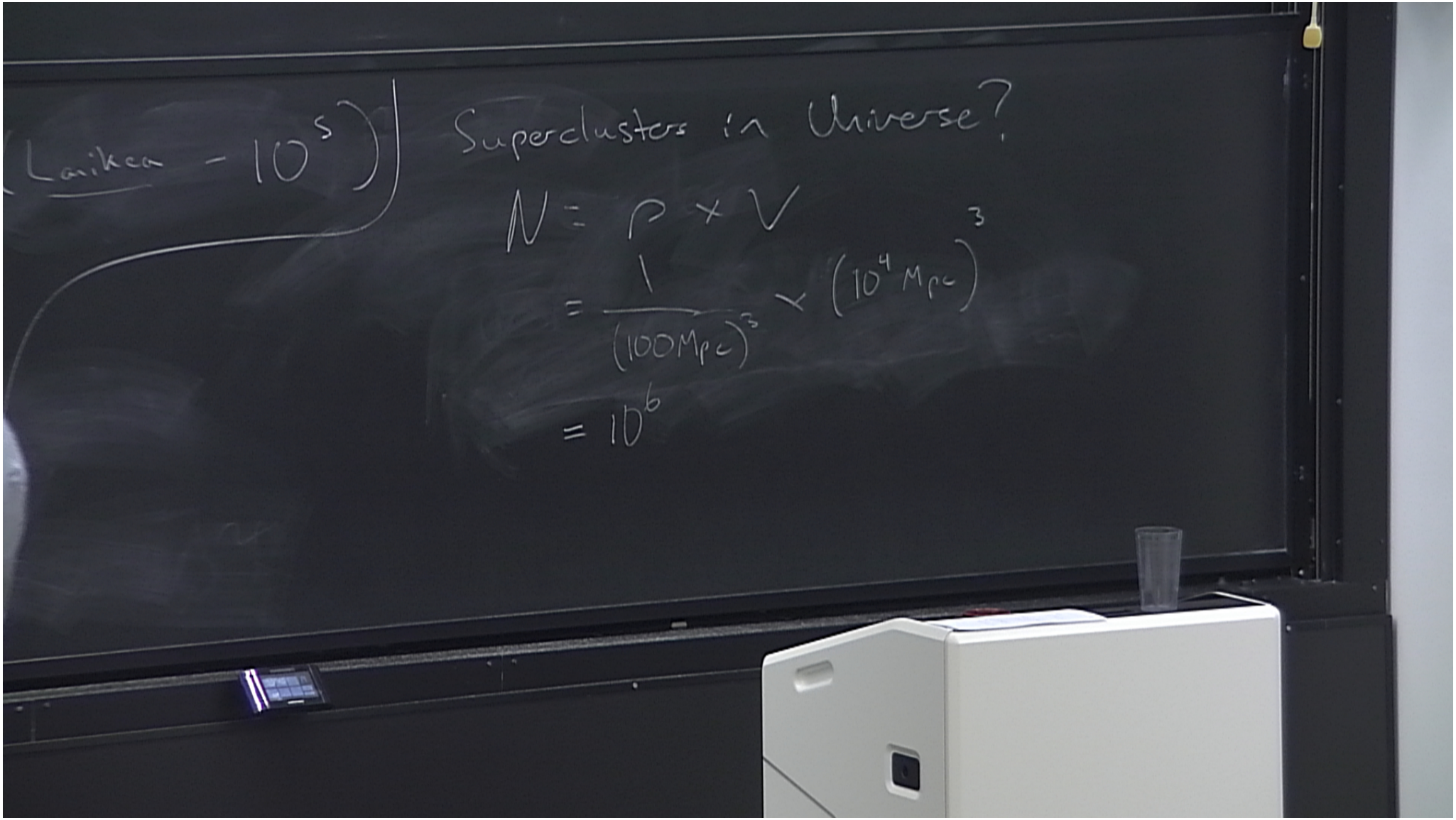

Distances to remember
Distance btwn stars — 1 pc
Distance across a galaxy — 10 K pc
Distance between galaxies — 1 Mpc
Size of superclusters — 10 - 100 Mpc
Observable Universe — 10 Gpc

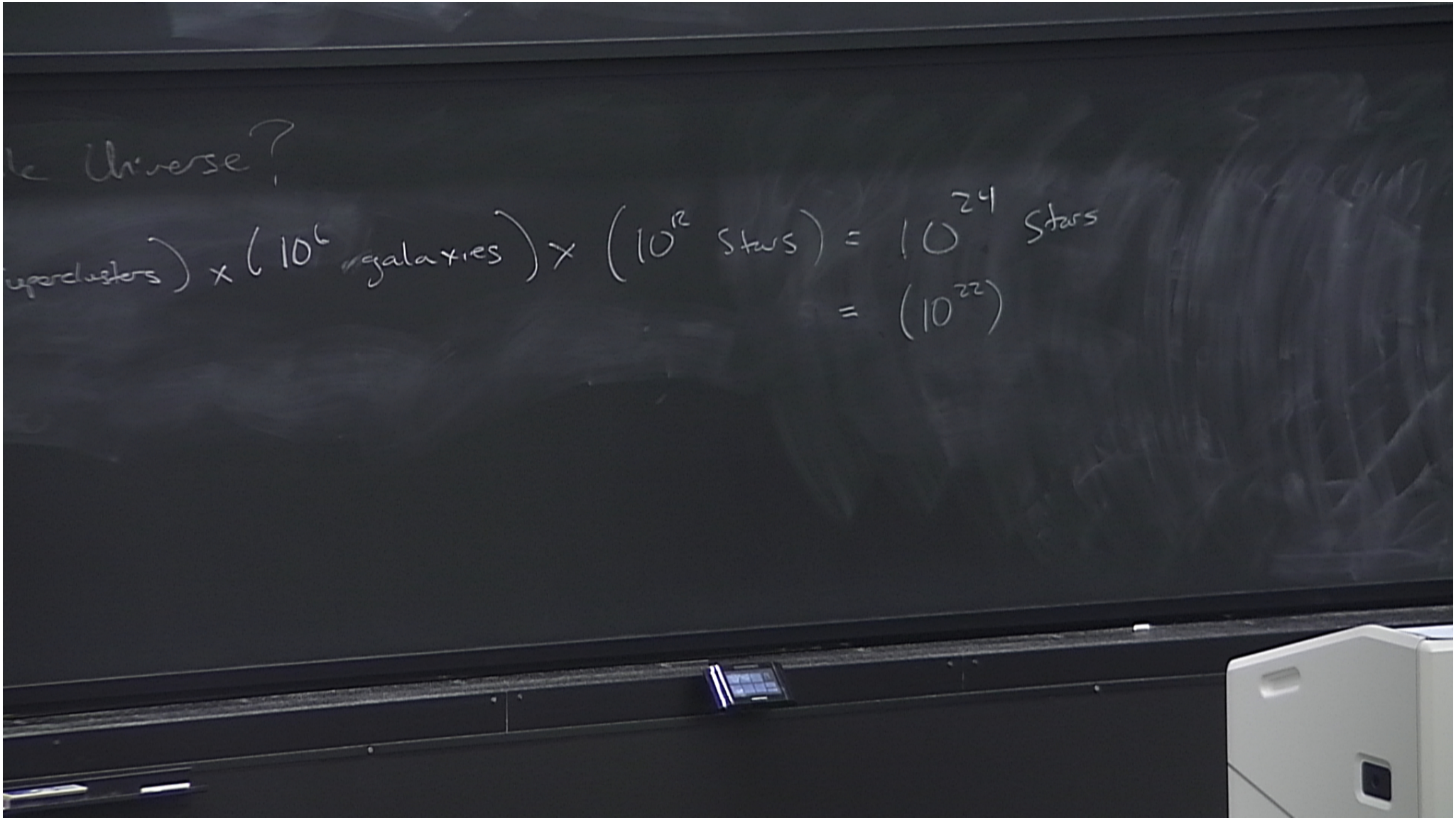

How many stars in a galaxy?
N =
pc
10 kpc
1 Mpc
10 - 100 Mpc
10 Gpc

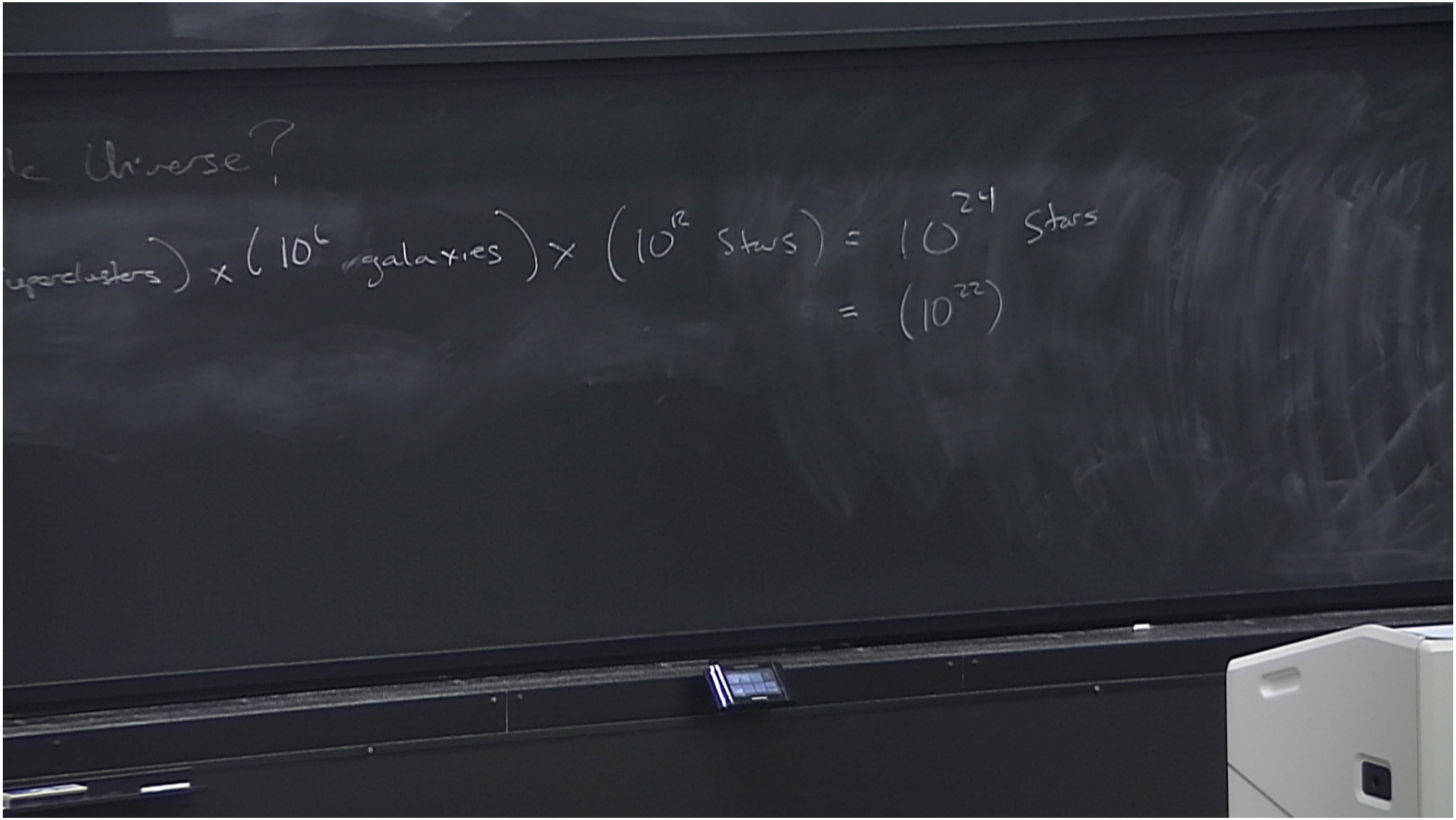

How many stars in a galaxy?
pc
10 kpc
1 Mpc
10 - 100 Mpc
10 Gpc
N = ρ × Vol
= (1/pc)^3 (1 × 10^1)^3
= 10^12

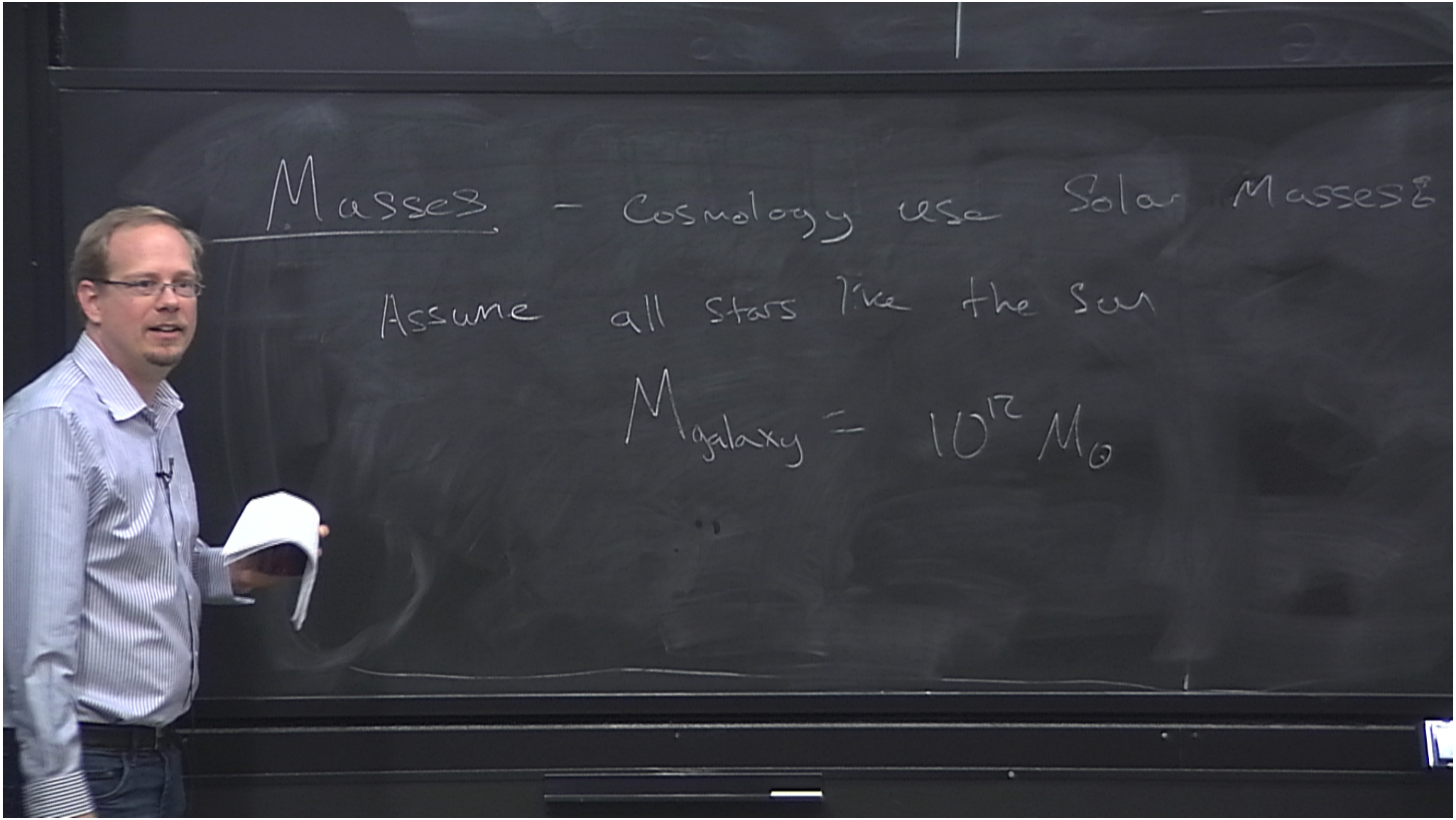

1 Mpc
10 - 100 Mpc
10 Gpc
= 10^12
≃ 10^11
More accurate

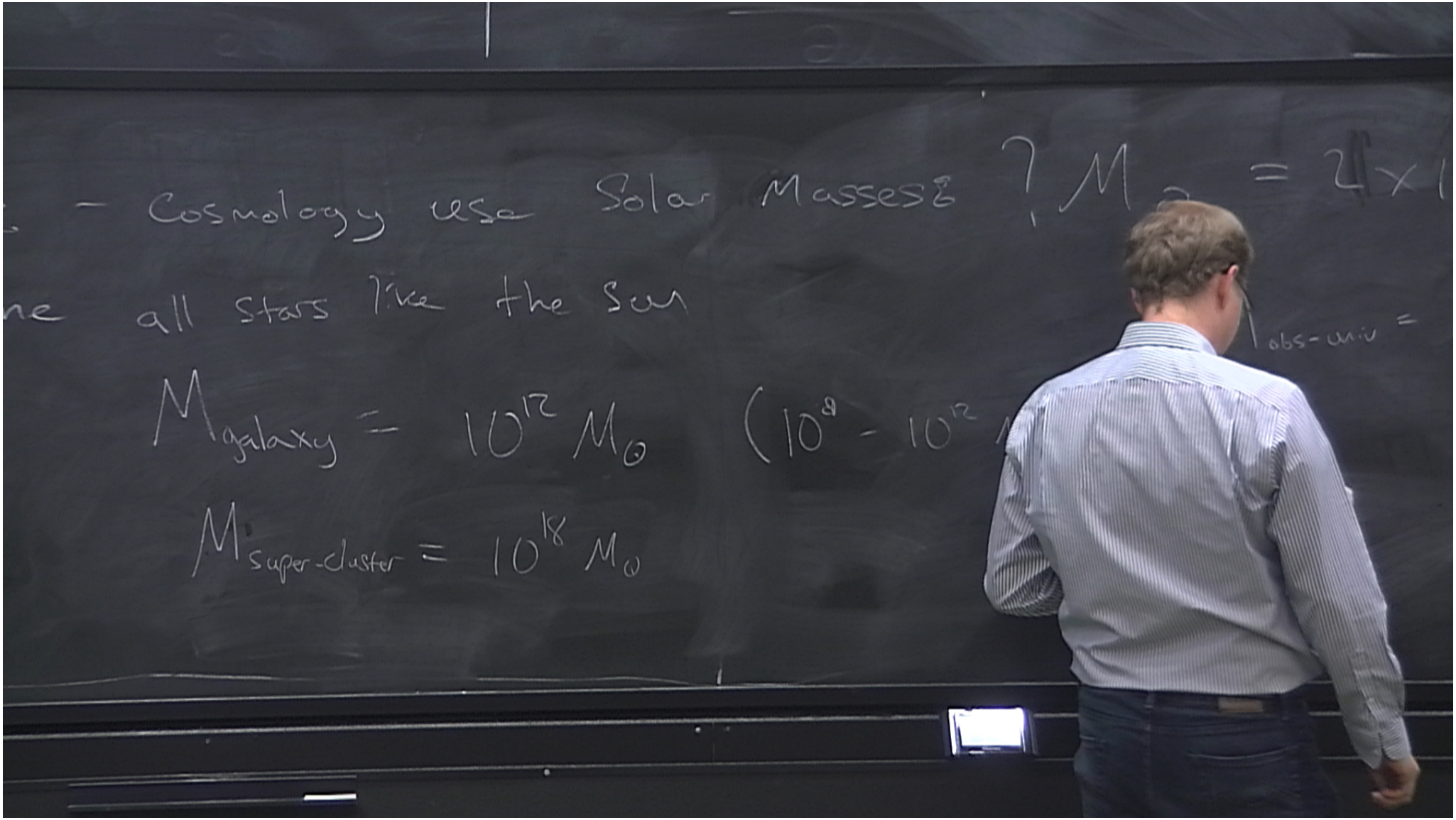

– Galaxies in a Supercluster?
(Laikca
$N = \rho \times V$
$= \left(\frac{1}{\text{Mpc}}\right)^3 \times (100\,\text{Mpc})^3$
$= 10^6$

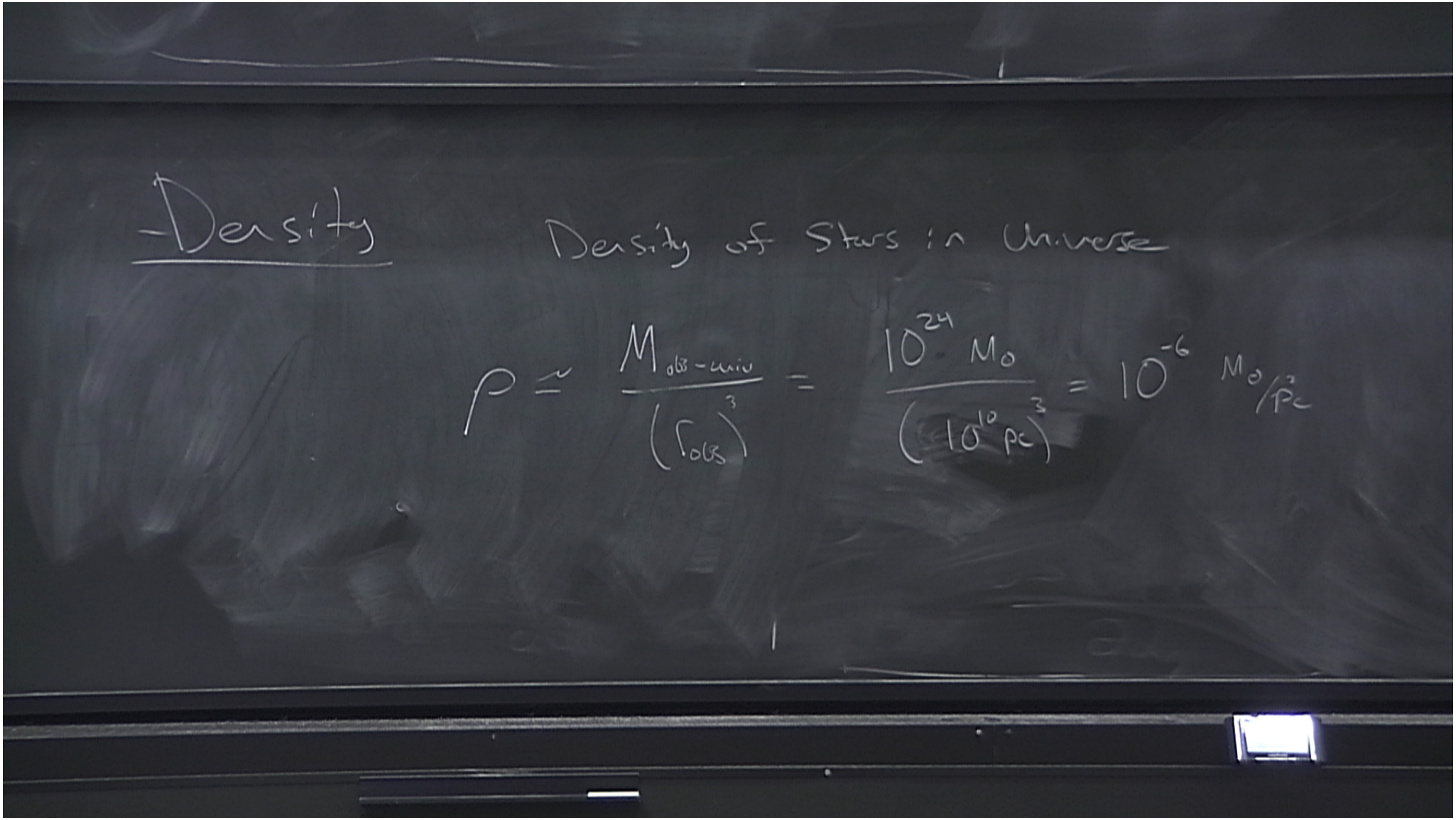

(Laikca - 10^5)
Superclusters in Universe?
$N = \rho \times V$
$= \frac{1}{(100\,\mathrm{Mpc})^3} \times (10^4\,\mathrm{Mpc})^3$
$= 10^6$

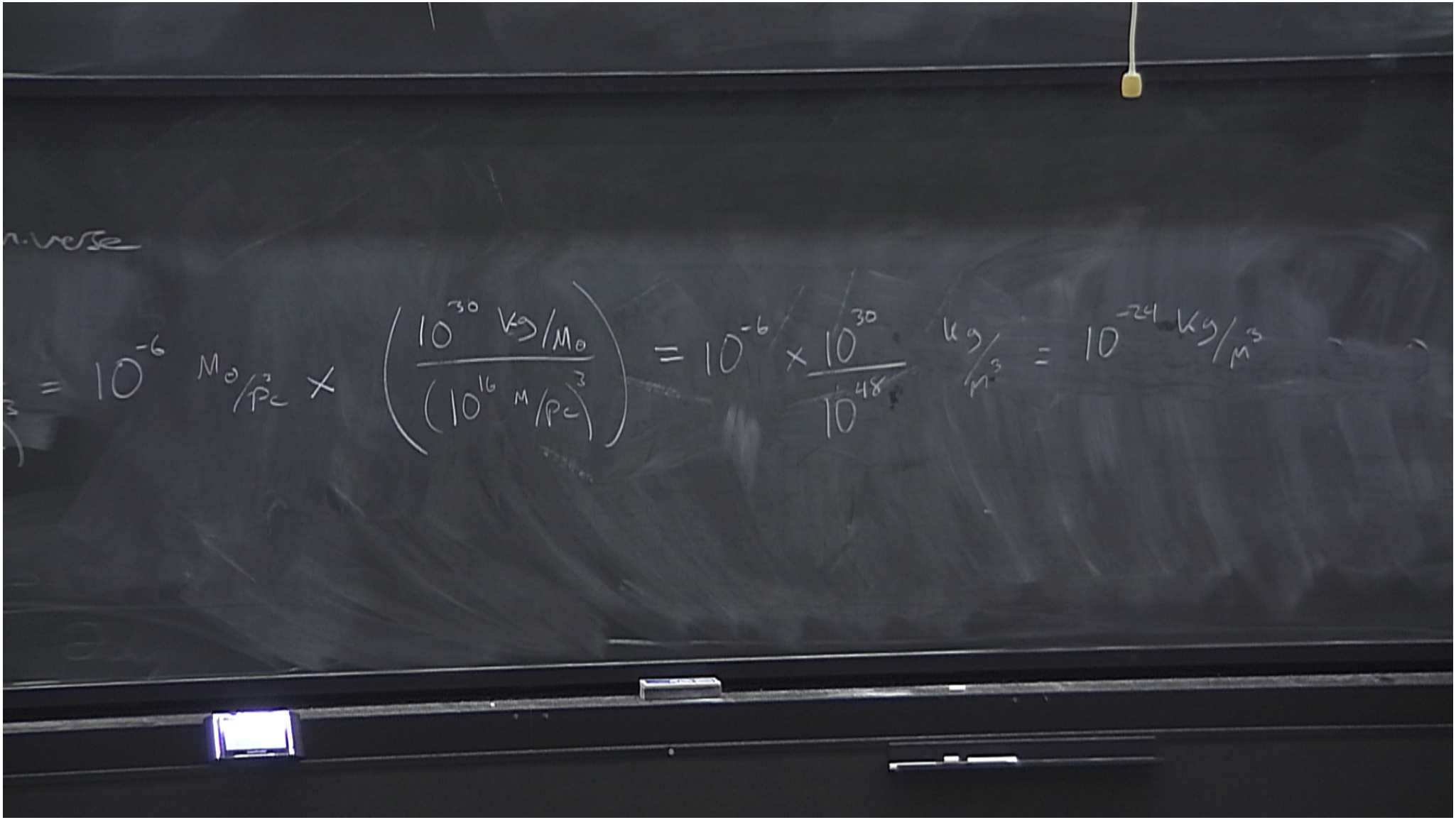

e Universe?
(supercluster) x (10^6 galaxies) x (10^12 stars) = 10^24 stars
= (10^22)

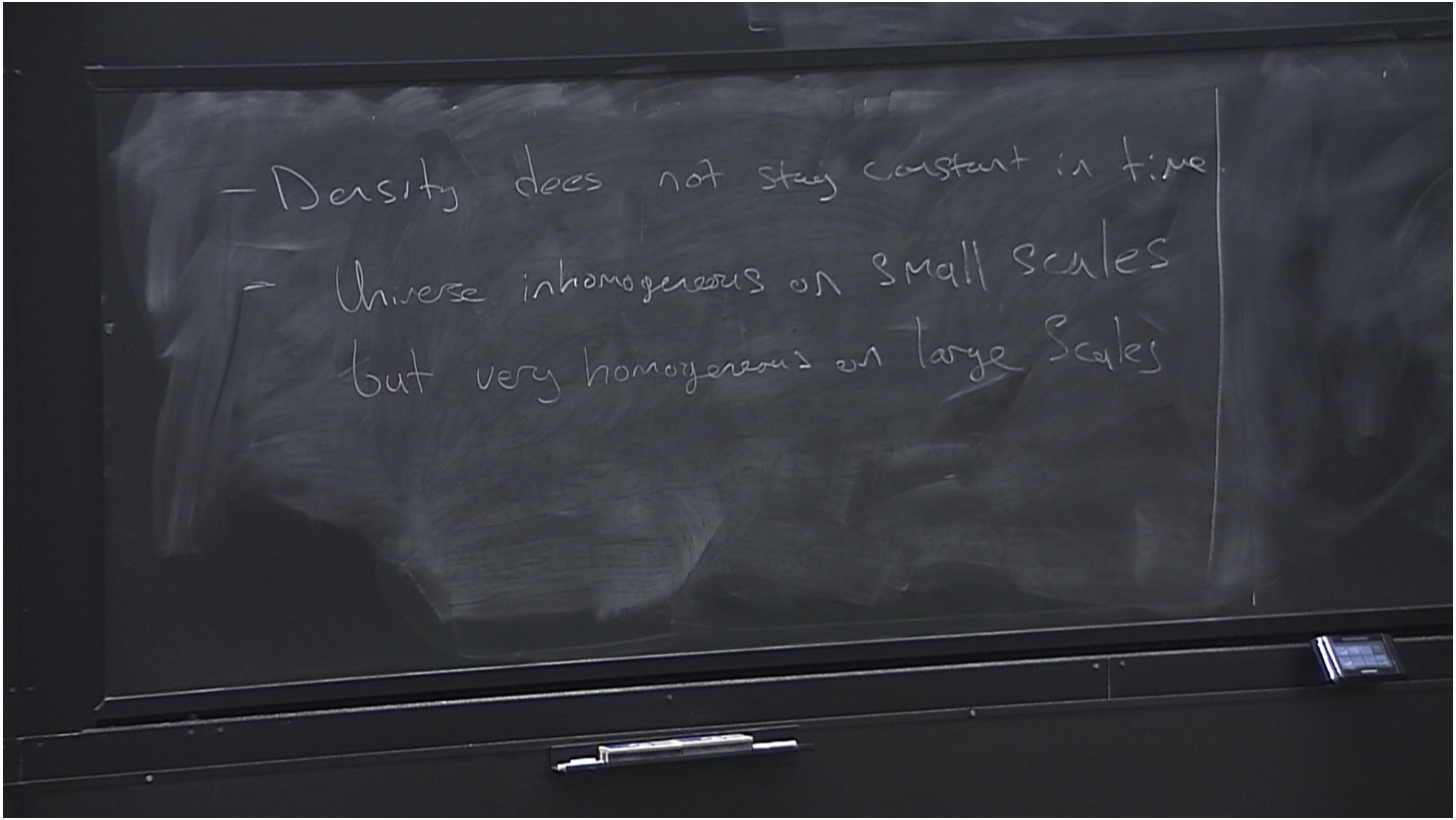

e Universe?
(supercluster) x (10^6 galaxies) x (10^12 stars) = 10^24 stars
= (10^22)

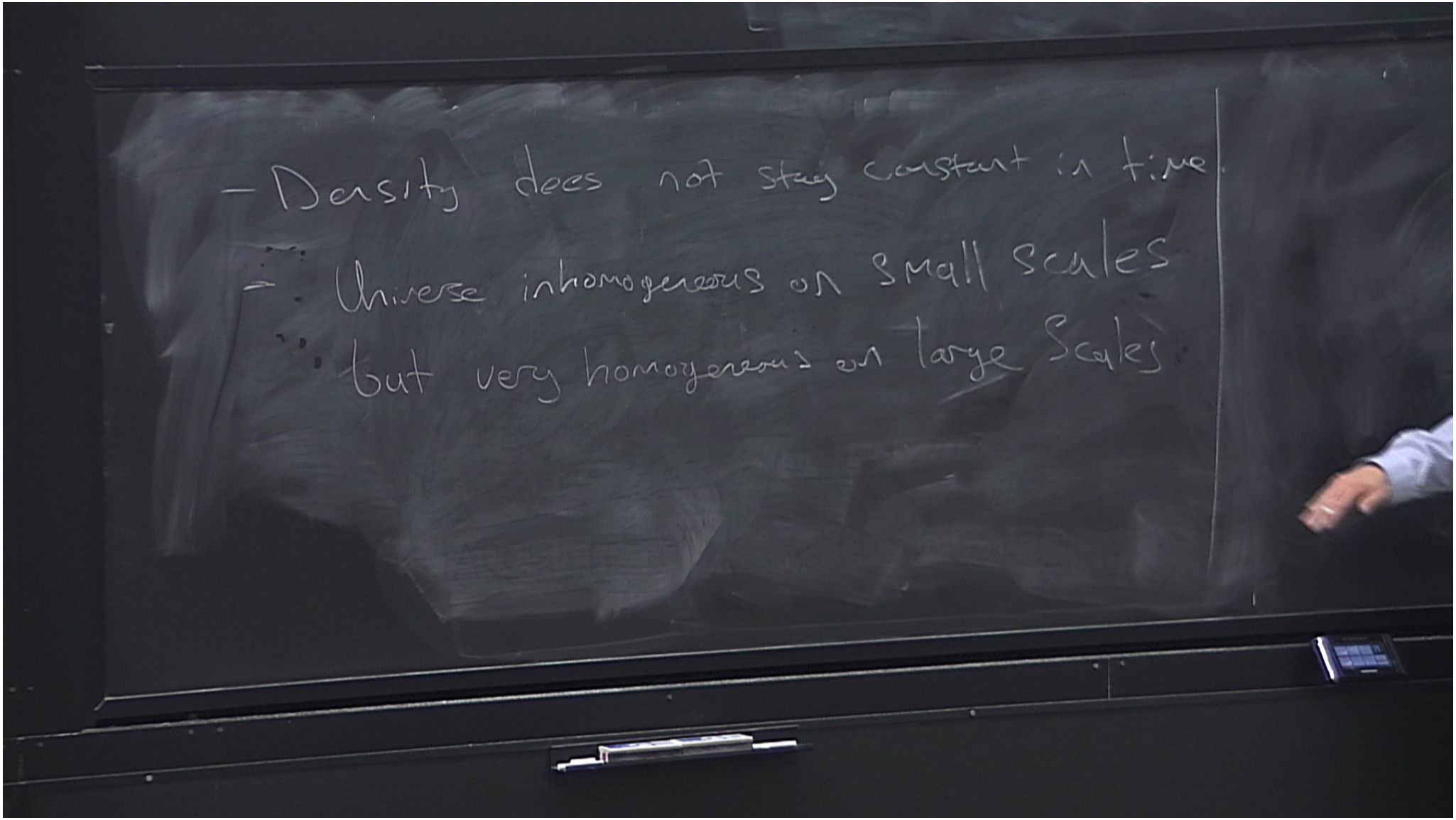

Masses - Cosmology use Solar Masses
Assume all stars like the Sun
$M_{galaxy} = 10^{12} M_\odot$

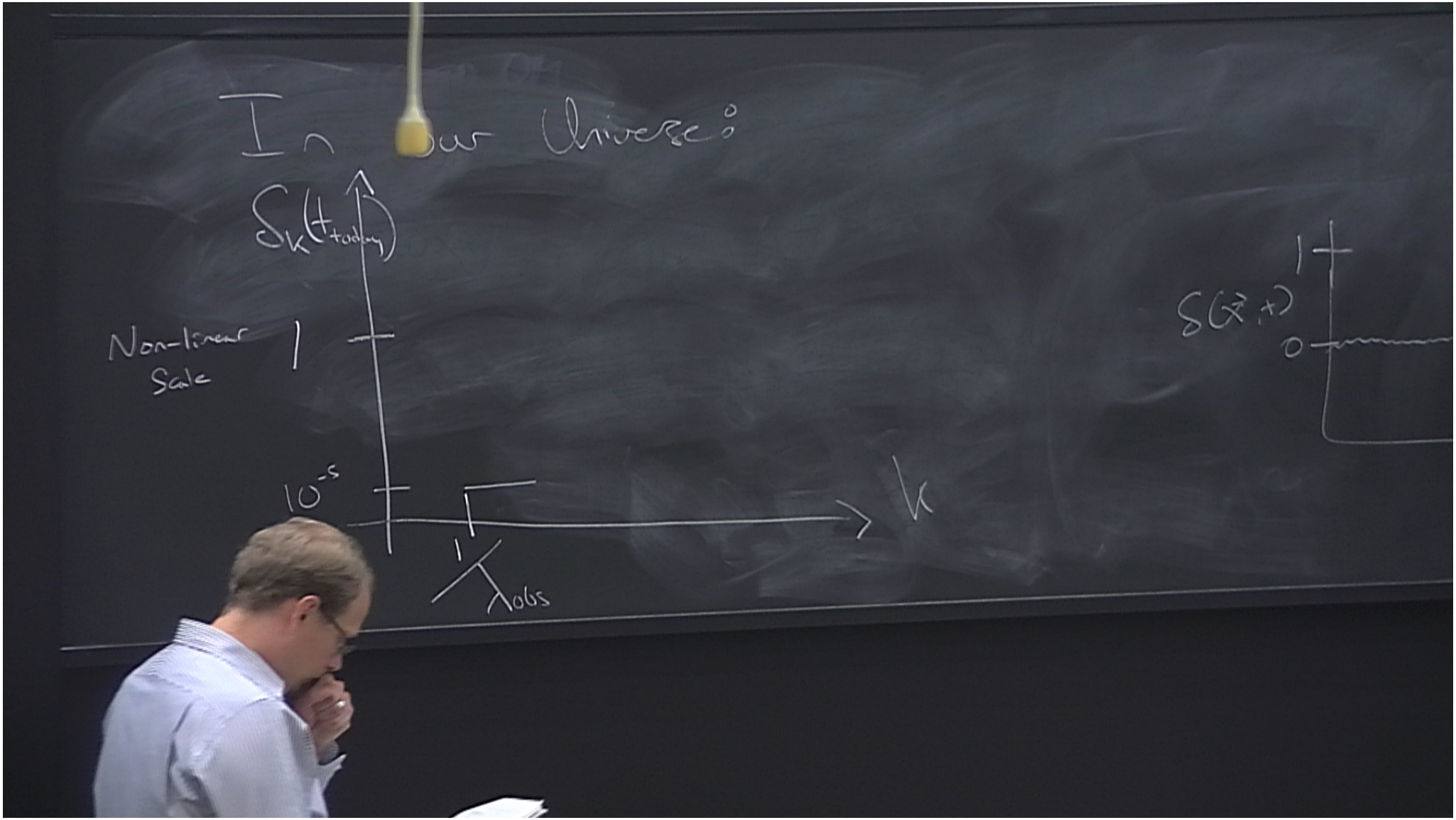

- Cosmology use Solar Masses
all stars like the Sun
$M_{galaxy} = 10^{12} M_\odot$
$M_{super\text{-}cluster} = 10^{18} M_\odot$

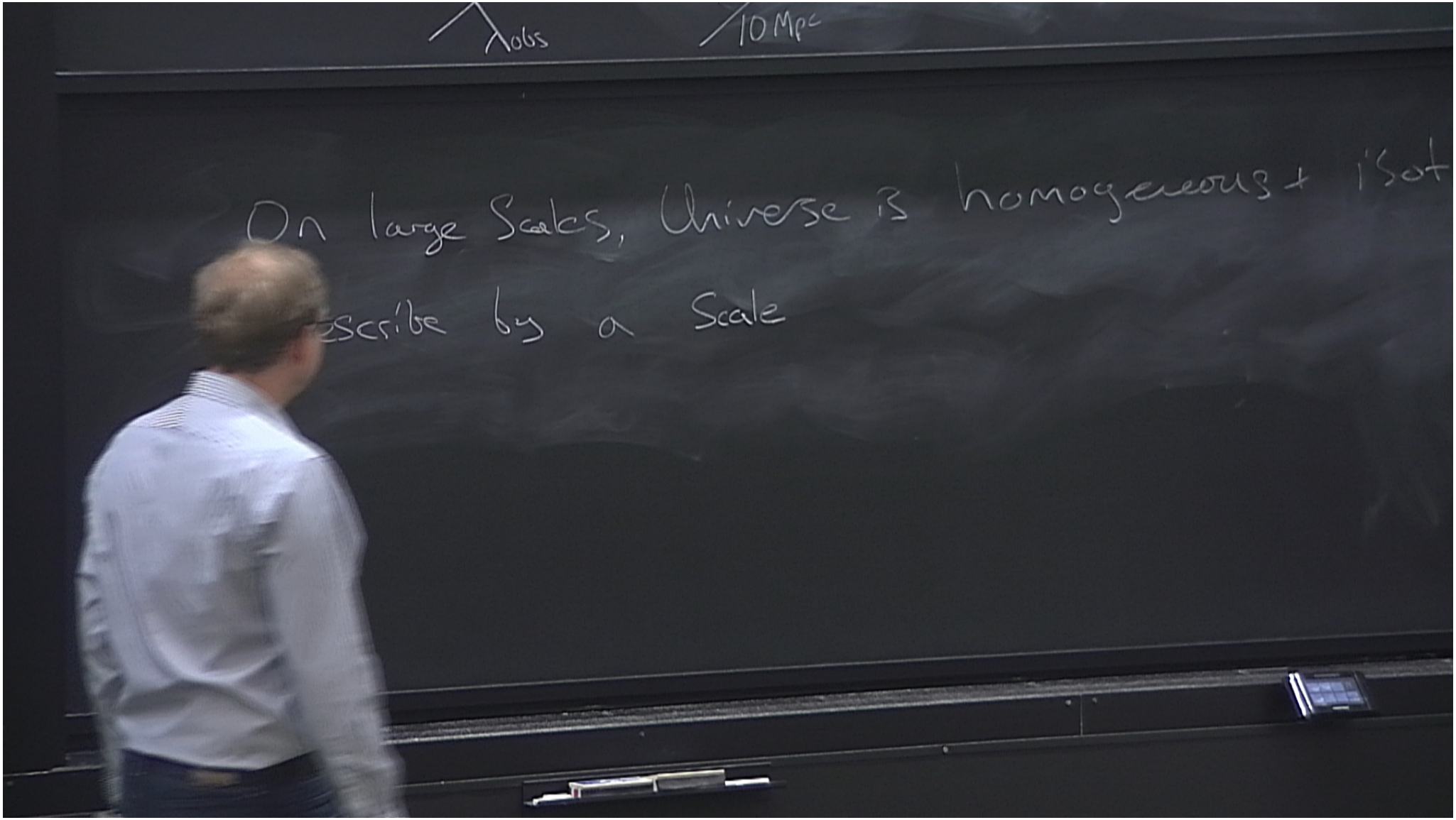

Density
Density of Stars in Universe
$\rho \sim \frac{M_{obs-univ}}{(r_{obs})^3} = \frac{10^{24} M_\odot}{(10^{10} pc)^3} = 10^{-6} M_\odot/pc^3$

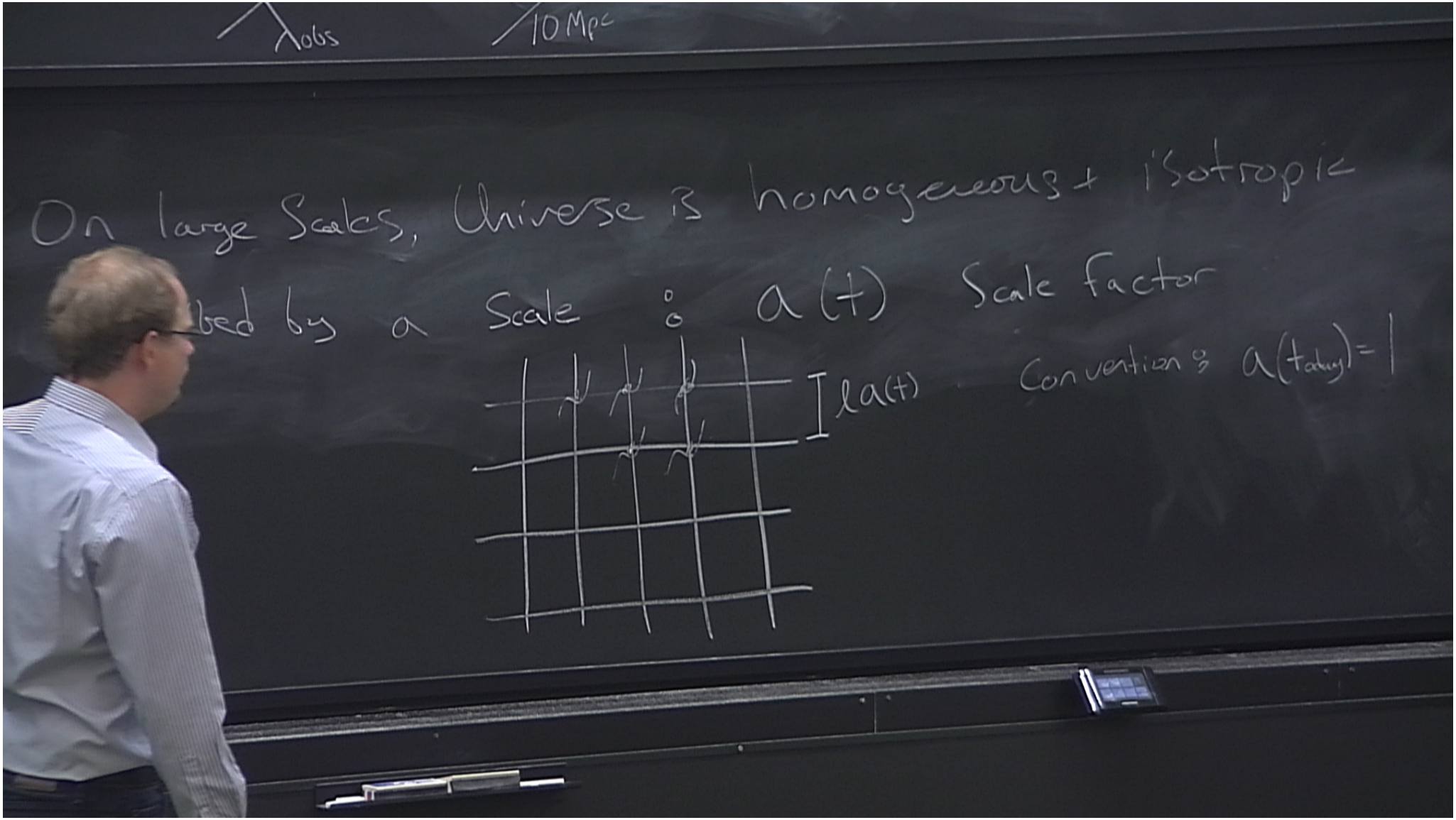

niverse
$= 10^{-6}\ M_\odot/pc^3 \times \left(\frac{10^{30}\ kg/M_\odot}{(10^{16}\ M/pc)^3}\right) = 10^{-6} \times \frac{10^{30}}{10^{48}}\ kg/m^3 = 10^{-24}\ kg/m^3$


- Density does not stay constant in time
- Universe inhomogeneous on small scales
but very homogeneous on large scales


- Density does not stay constant in time
- Universe inhomogeneous on small scales
but very homogeneous on large Scales


In our Universe:
$\delta_k(t_{today})$
Non-linear Scale
1
10^{-5}
k
1
λ_{obs}
$\delta(\vec{x},t)$
1
0

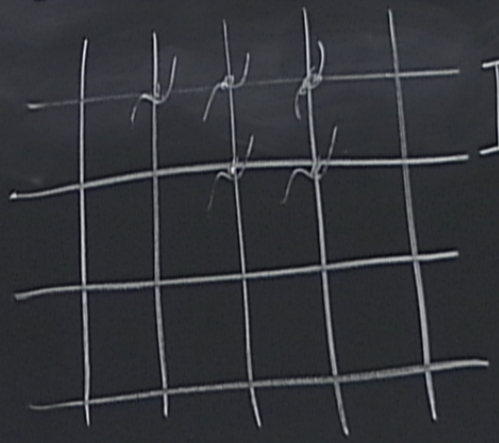

λobs
10 Mpc
On large Scales, Universe is homogeneous + isot
escribe by a Scale


λ_{obs}
10 Mpc
On large Scales, Universe is homogeneous + isotropic
bed by a Scale : a(t) Scale factor
I la(t)
Convention: a(t today) = 1

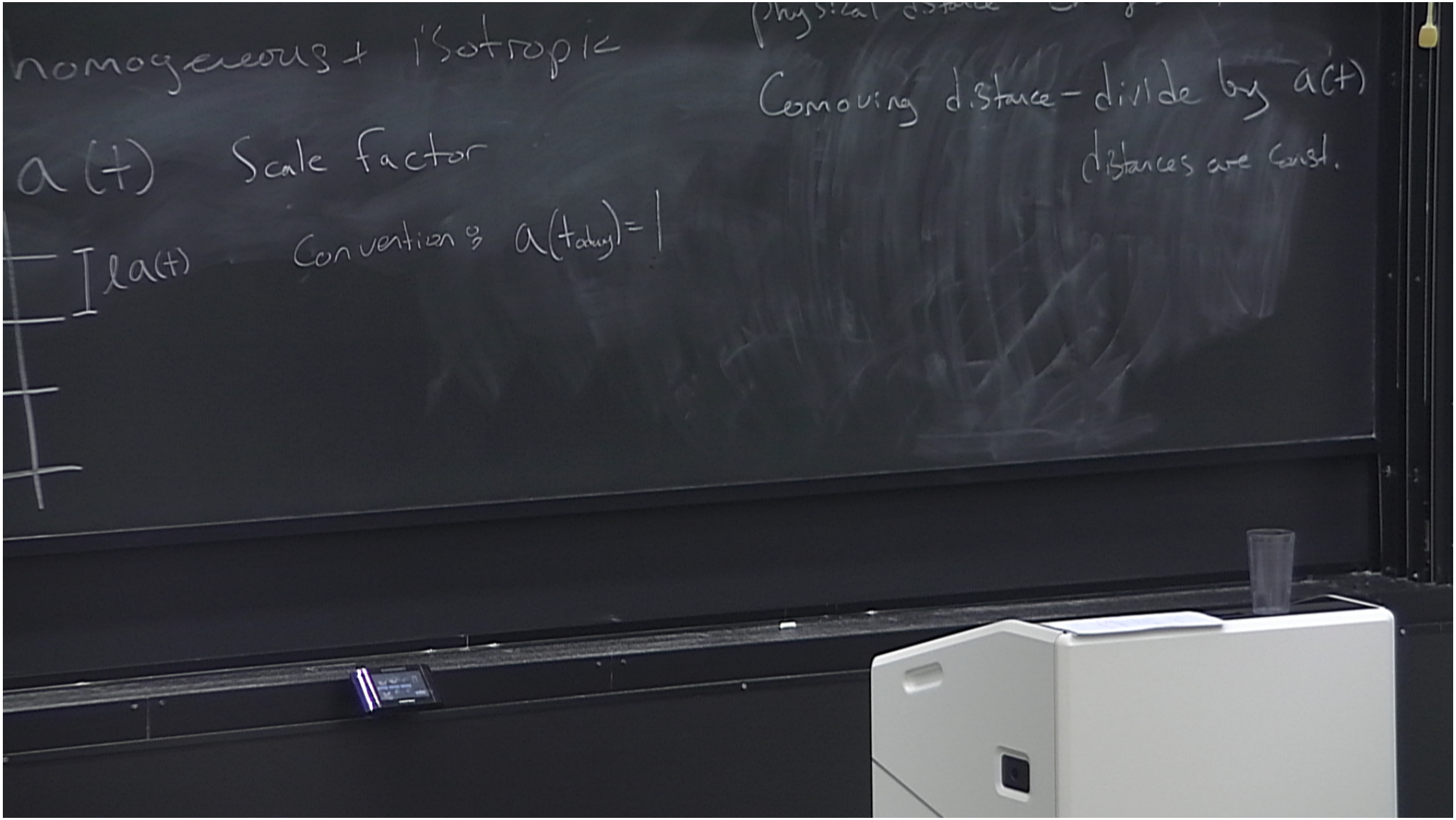
λ_{obs} / 10 Mpc

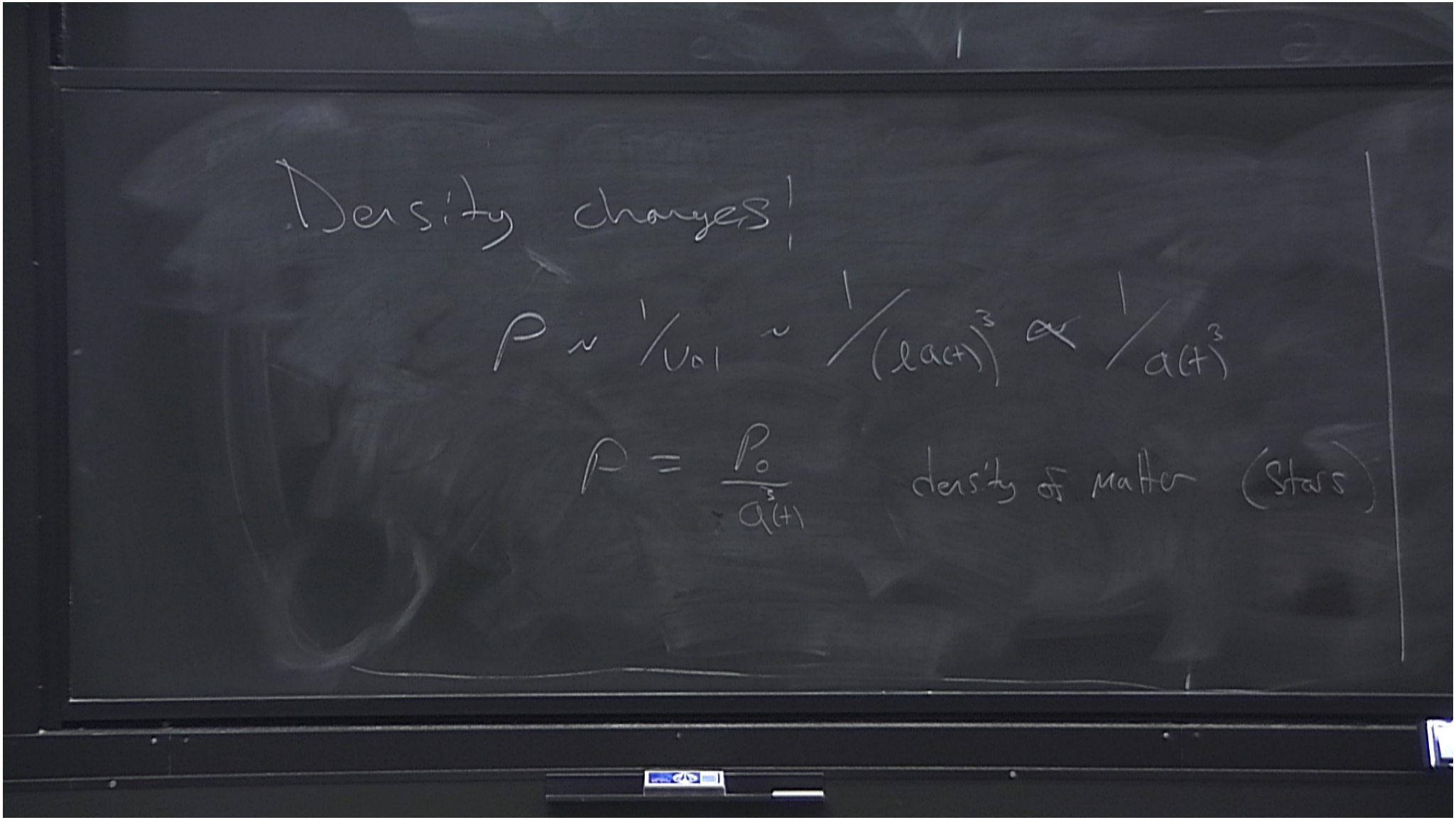
On large Scales, Universe is homogeneous + isotropic

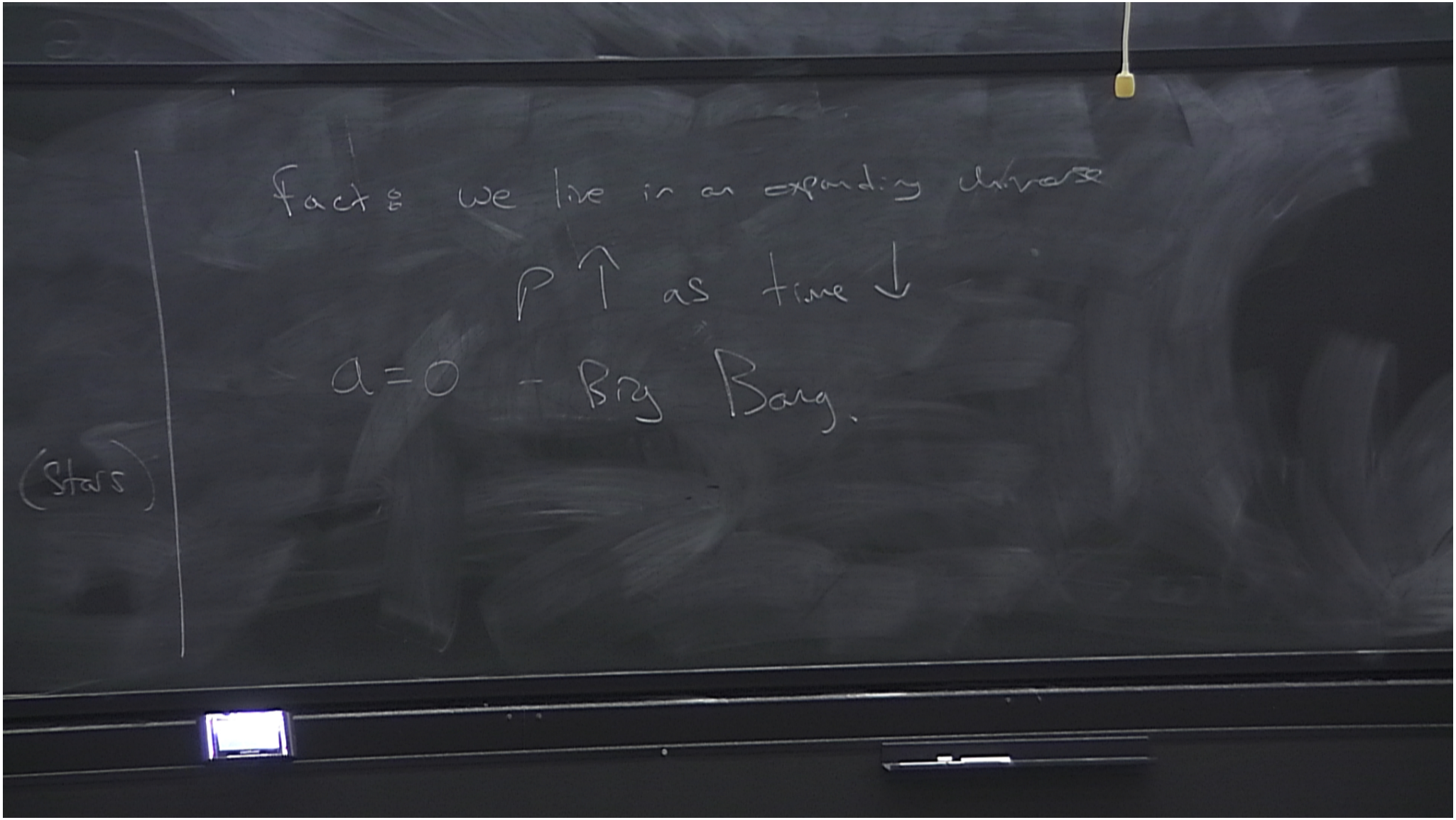
Described by a Scale : $a(t)$ Scale factor

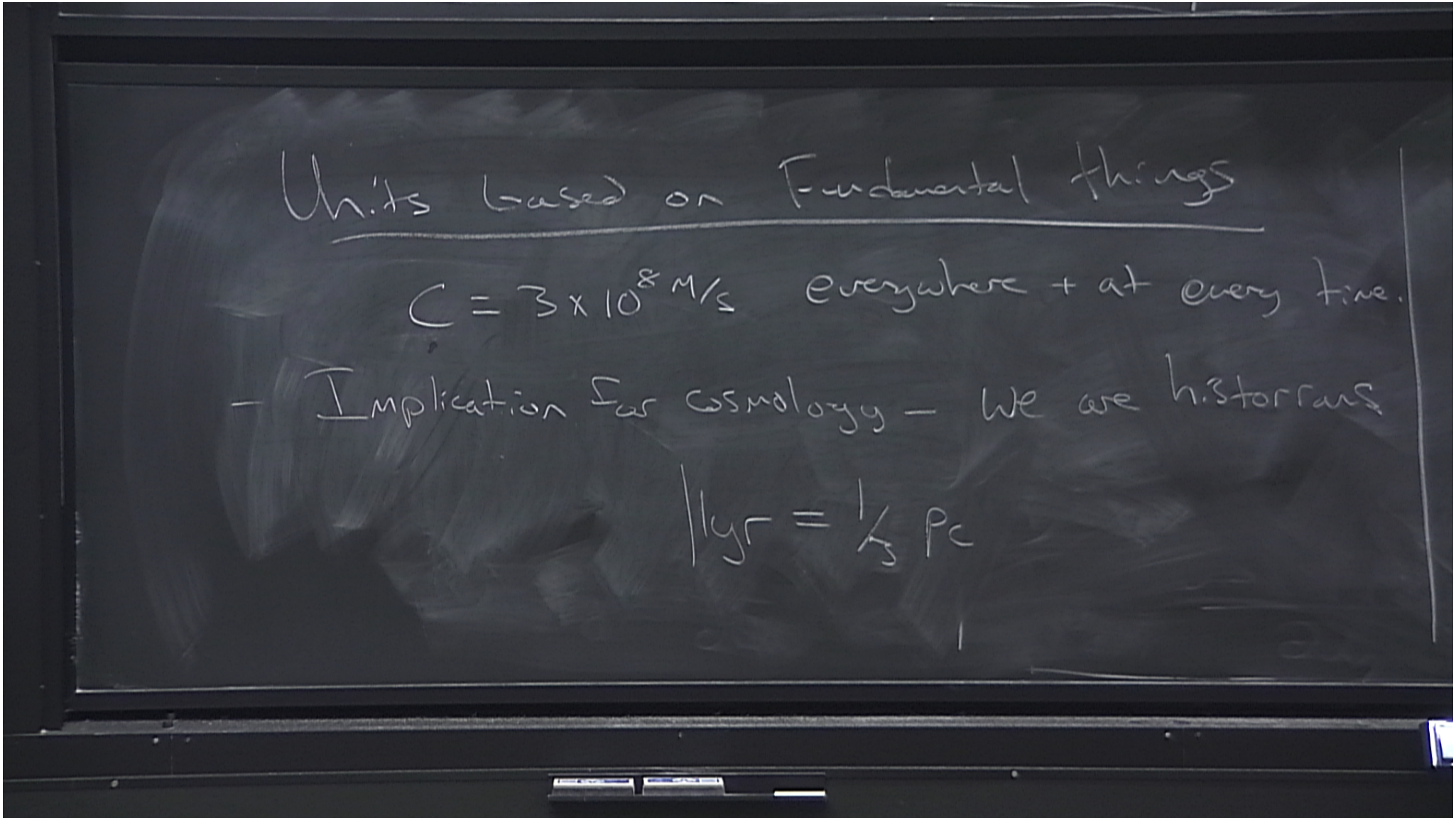


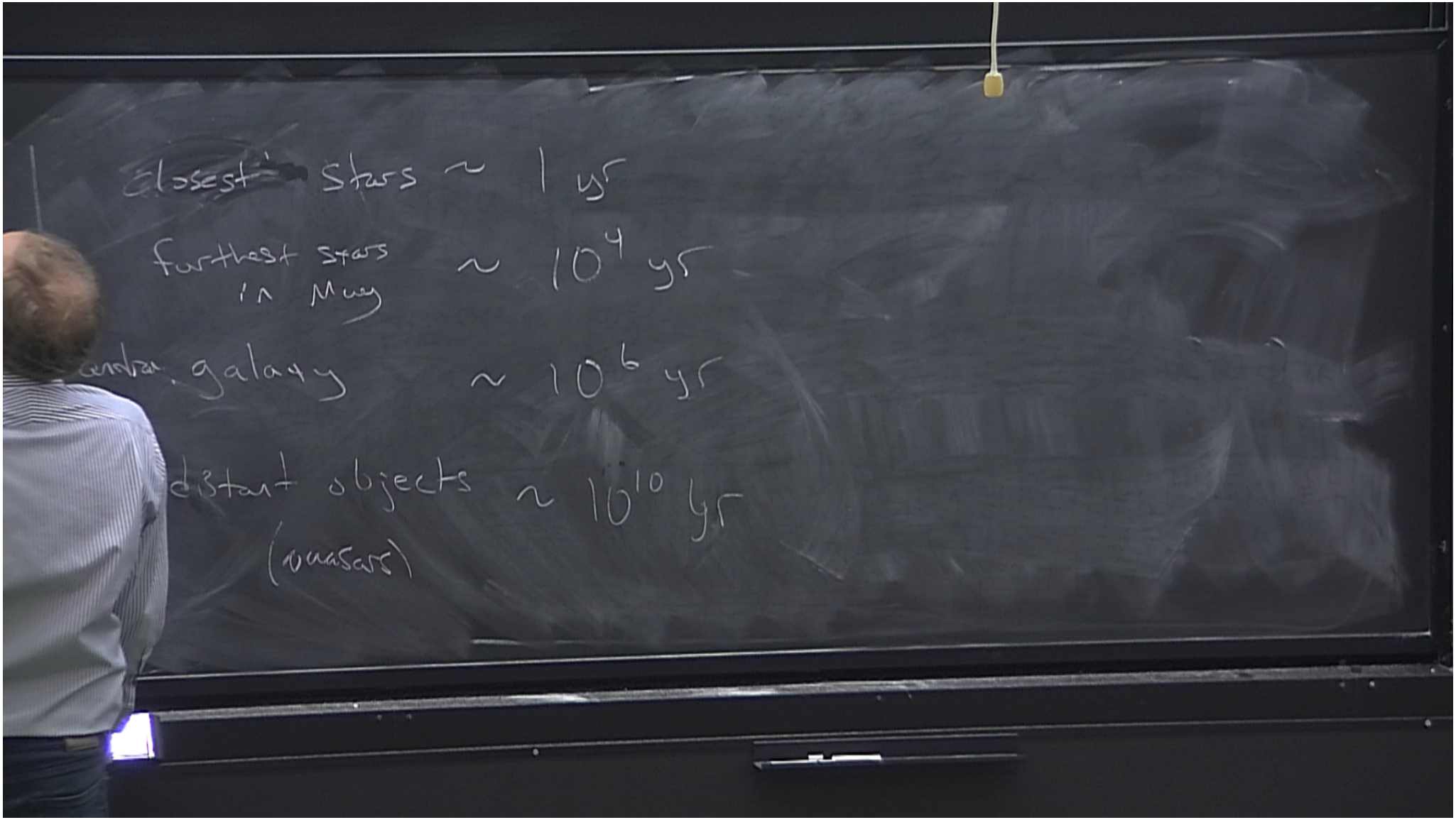
Convention: $a(t_{today}) = 1$

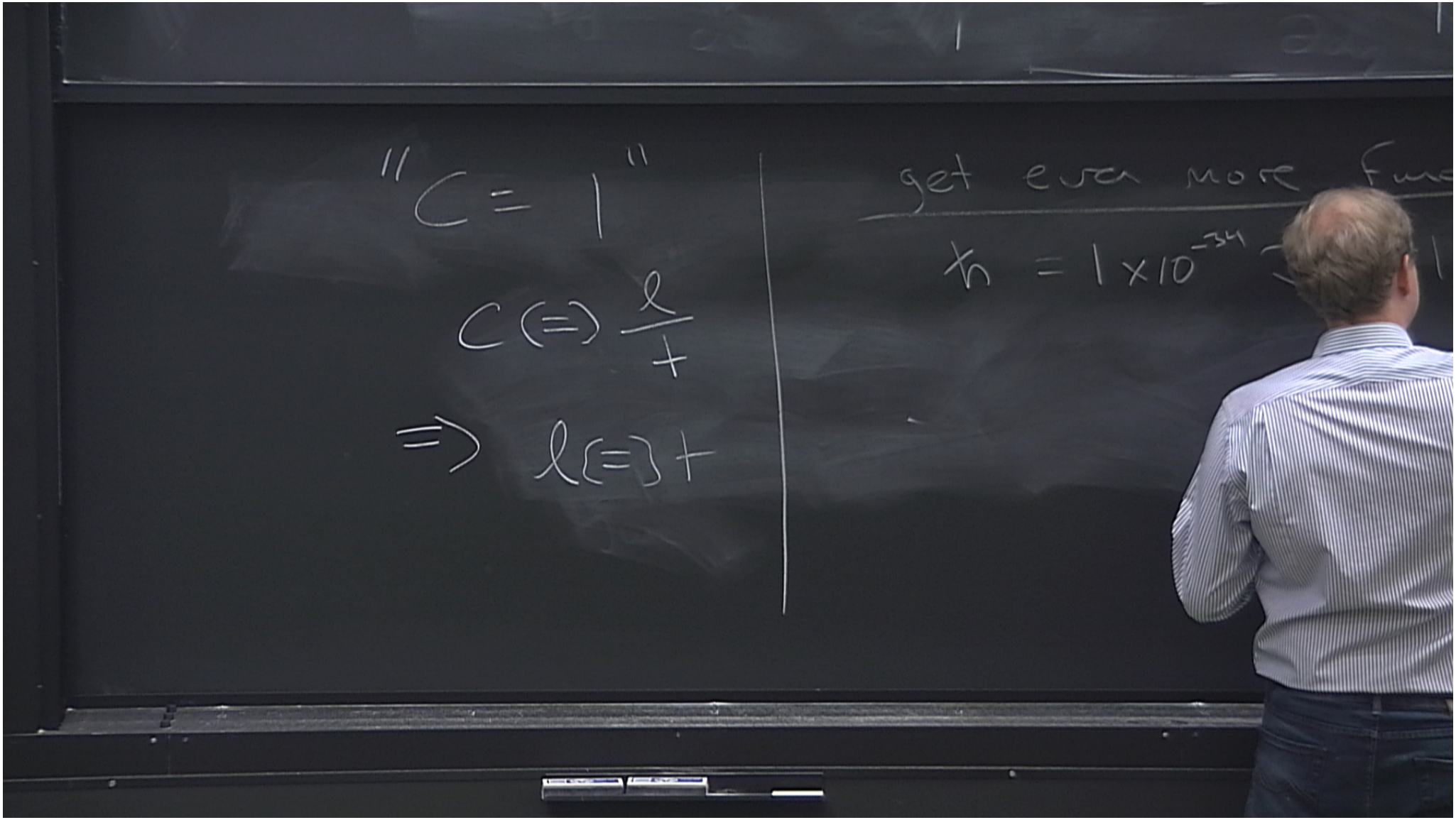

homogeneous + isotropic
a(t) Scale factor
1 a(t)
Convention: a(t today) = 1
Comoving distance - divide by a(t)
distances are const.


Density changes!
$\rho \sim 1/V_{01} \sim 1/(l\,a(t))^3 \propto 1/a(t)^3$
$\rho = \frac{\rho_0}{a^3(t)}$
density of matter (stars)


fact: we live in an expanding universe
ρ ↑ as time ↓
a=0 - Big Bang.
(Stars)


Units based on Fundamental things
$C = 3 \times 10^8$ m/s everywhere + at every time.
- Implication for cosmology - We are historians
1 lyr = 1/3 pc


closest stars ~ 1 yr
furthest stars in Muy ~ 10^4 yr
andra galaxy ~ 10^6 yr
distant objects ~ 10^{10} yr
(quasars)

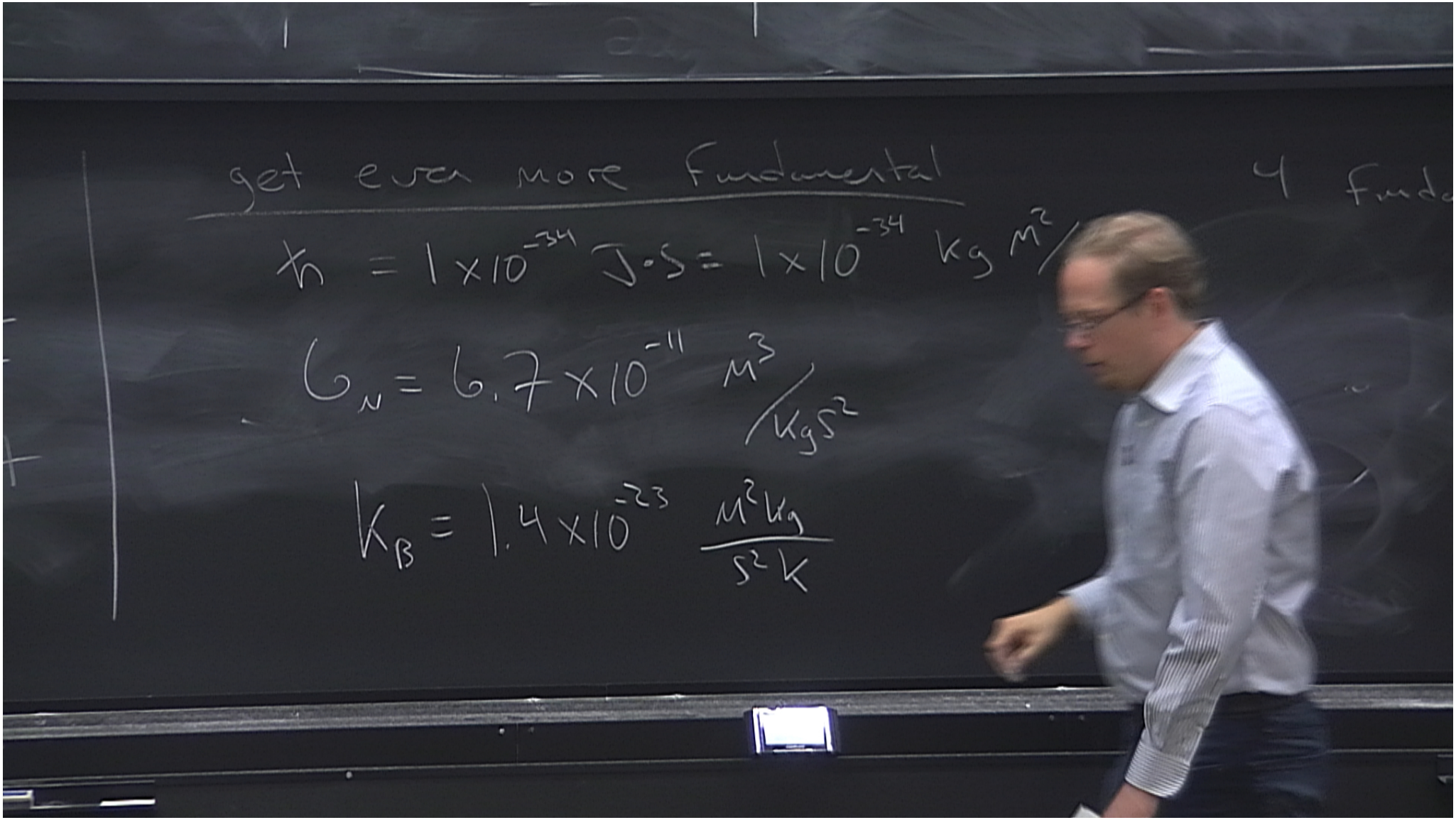

"c = 1"
c (=) l/t
=> l (=) t
get even more
ħ = 1 x 10^-34

get even more fundamental

$\hbar = 1 \times 10^{-34}\ J \cdot s = 1 \times 10^{-34}\ kg\ m^2/s$

$G_N = 6.7 \times 10^{-11}\ m^3/kg\,s^2$

$k_B = 1.4 \times 10^{-23}\ \frac{m^2 kg}{s^2 K}$


get even more fundamental
4 fund
$\hbar = 1 \times 10^{-34}\ J \cdot s = 1 \times 10^{-34}\ kg\ m^2/$
$G_N = 6.7 \times 10^{-11}\ m^3/kg\,s^2$
$k_B = 1.4 \times 10^{-23}\ \frac{m^2 kg}{s^2 K}$

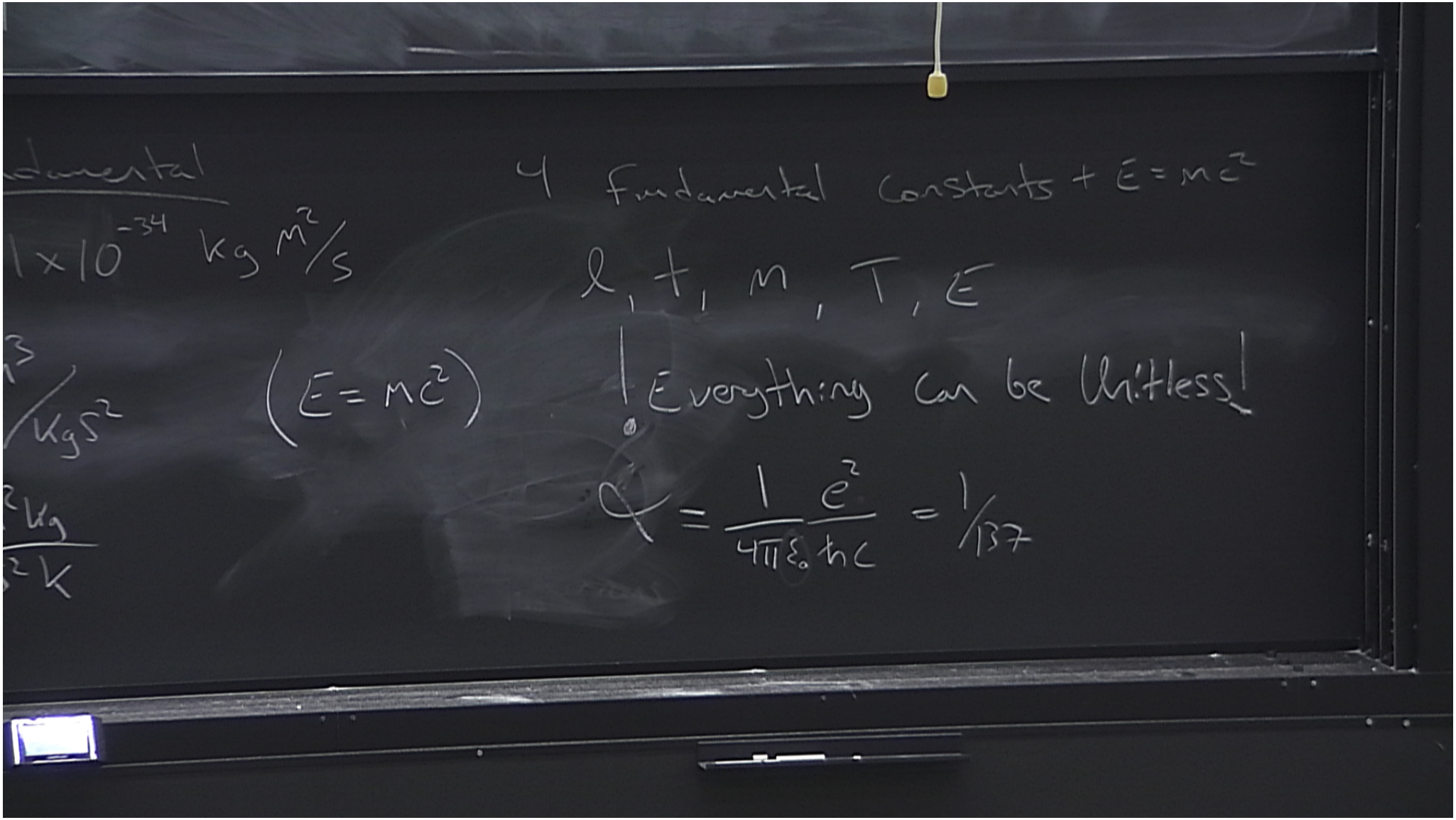
get even more fundamental

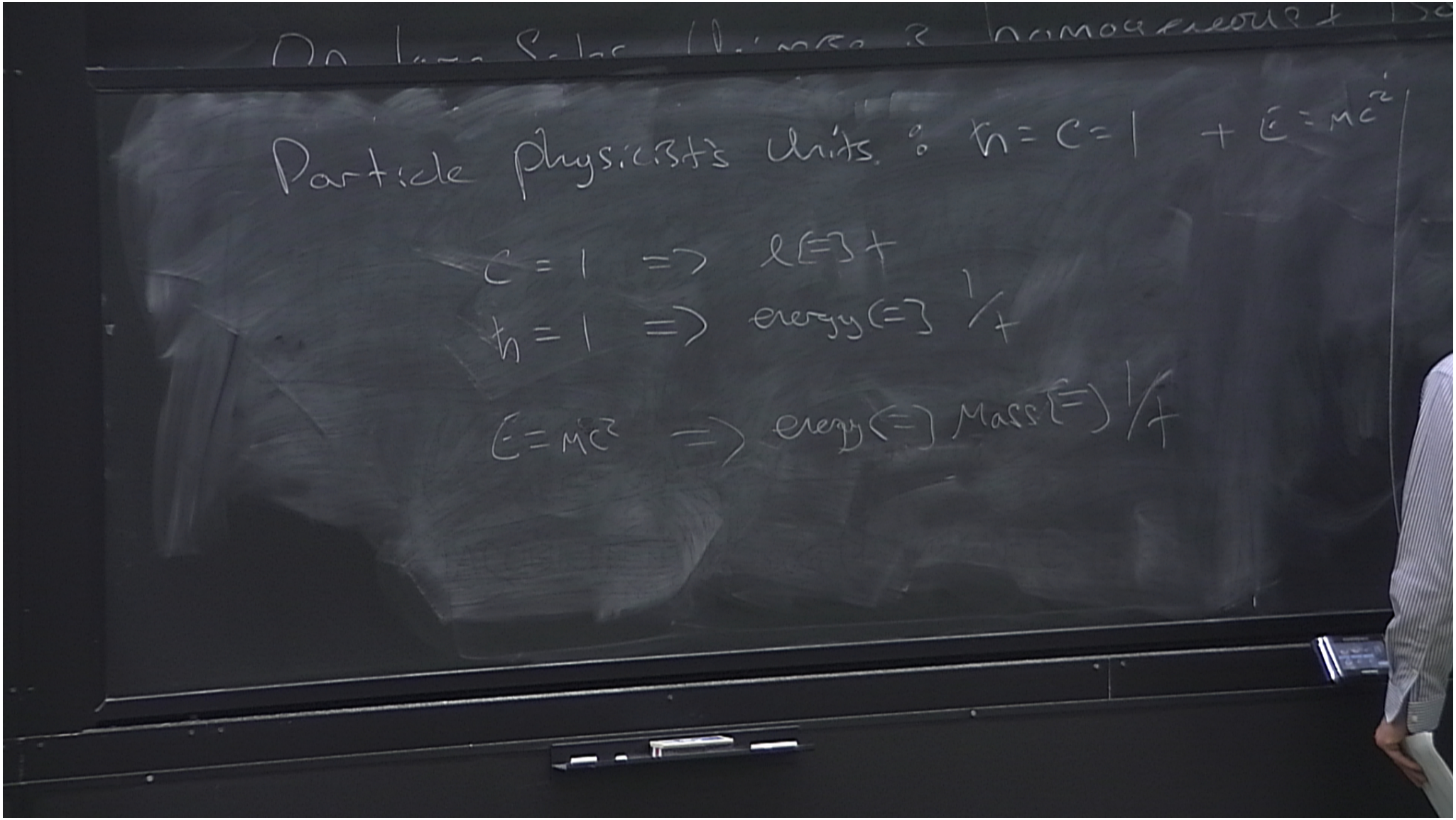
4 fund

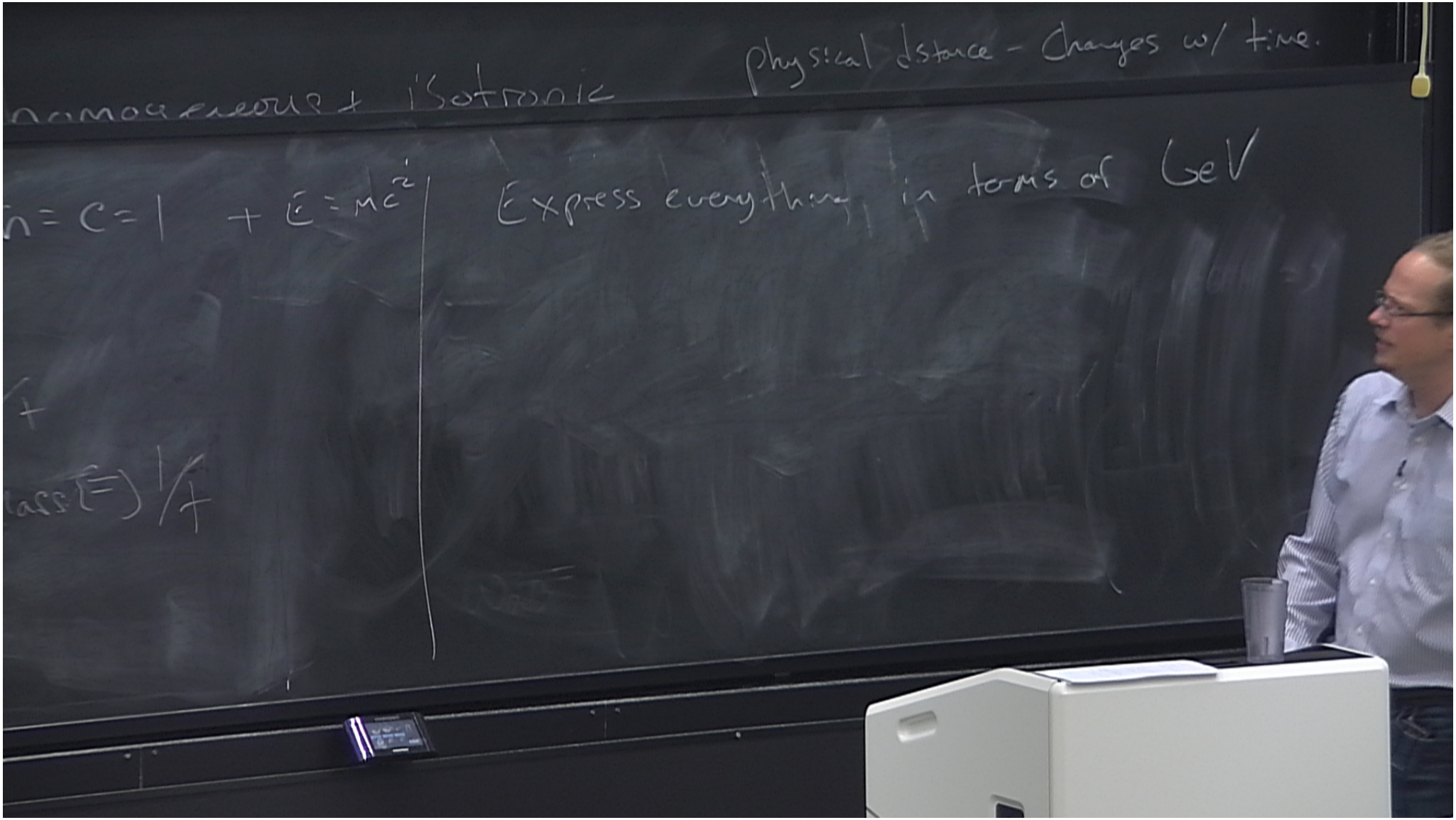
$\hbar = 1 \times 10^{-34}\ J \cdot s = 1 \times 10^{-34}\ kg\ m^2/s$

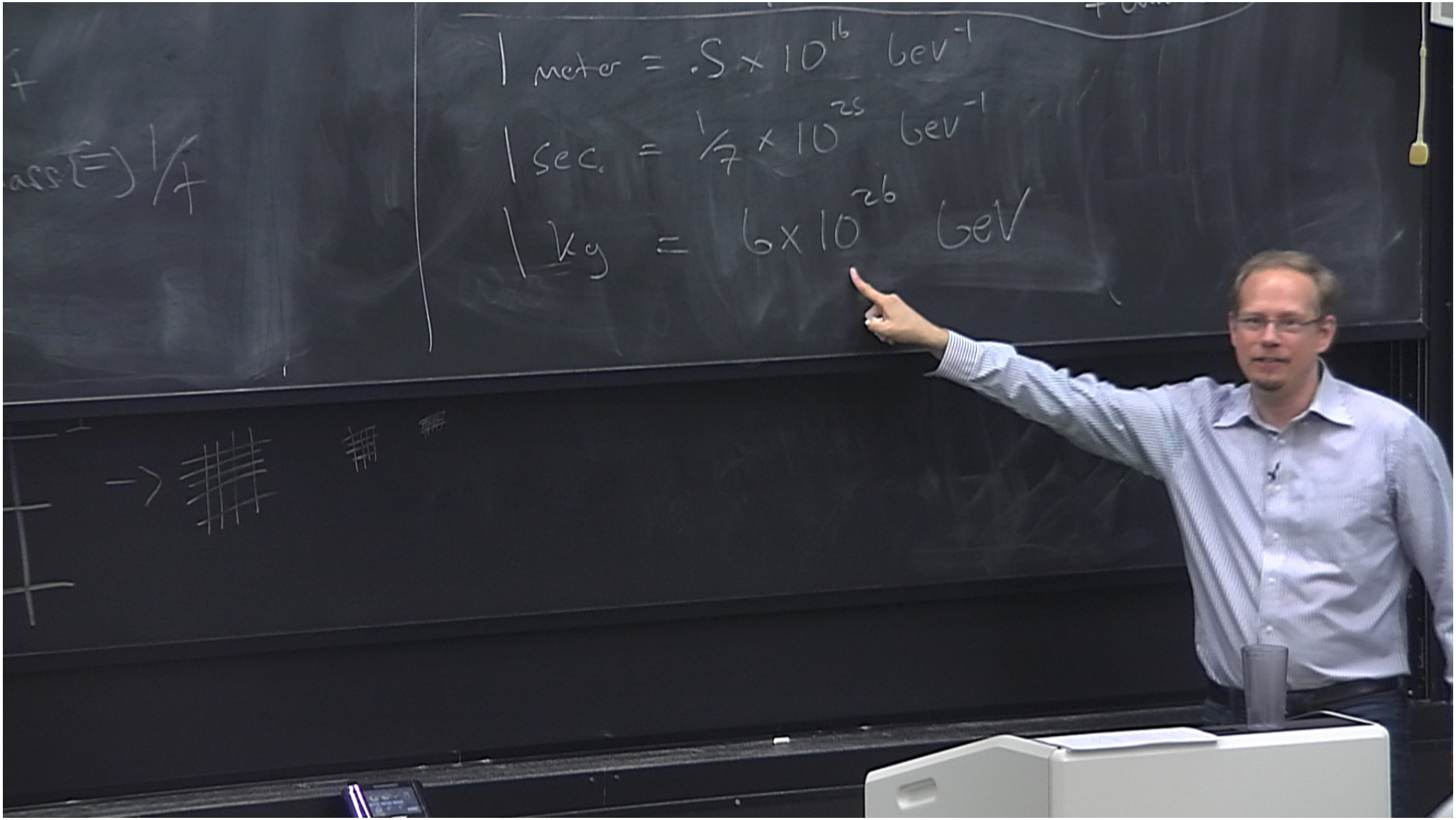
$G_N = 6.7 \times 10^{-11}\ m^3/kg\,s^2$ $\quad (E = mc^2)$

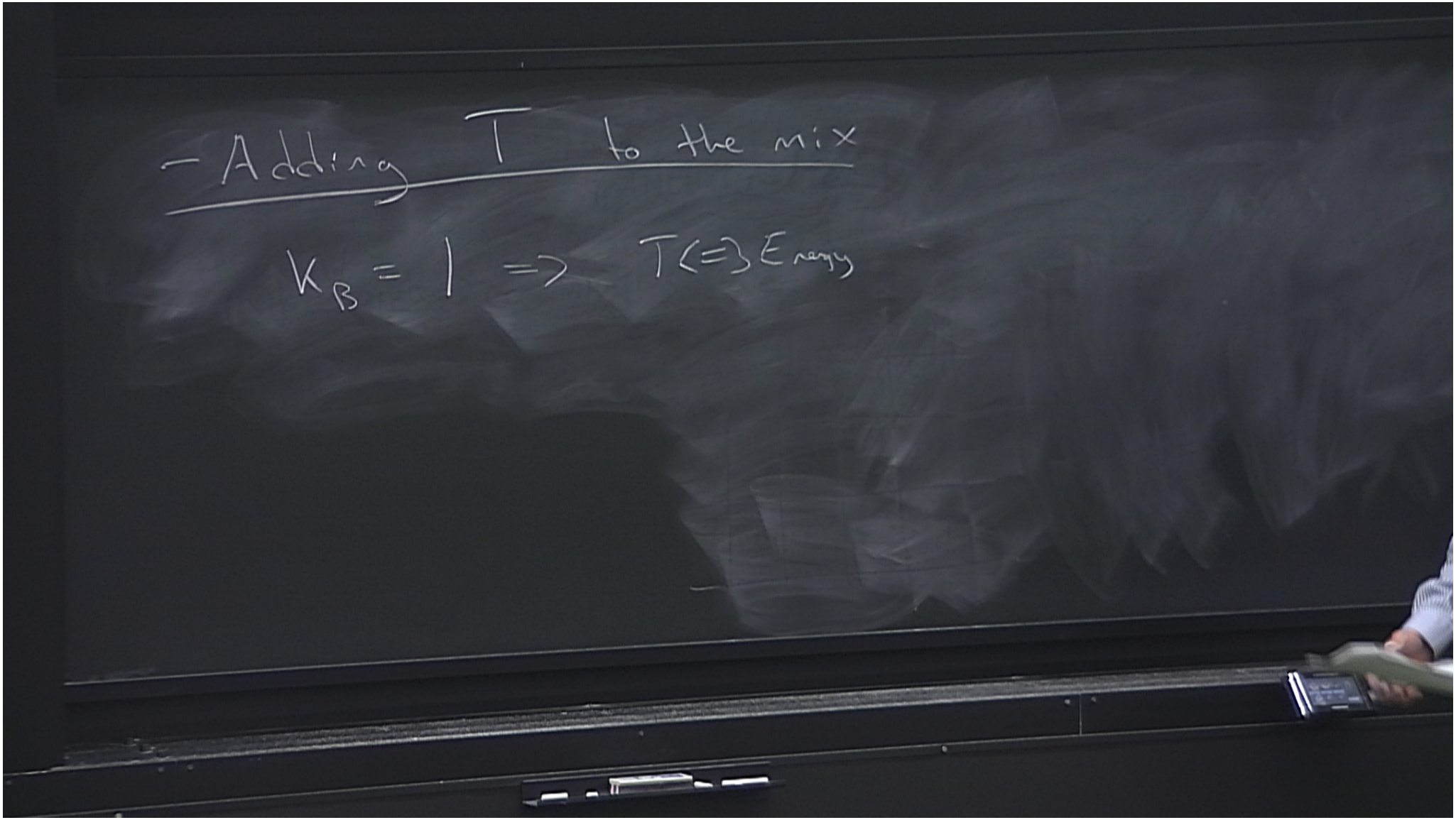
$k_B = 1.4 \times 10^{-23}\ \frac{m^2 kg}{s^2 K}$

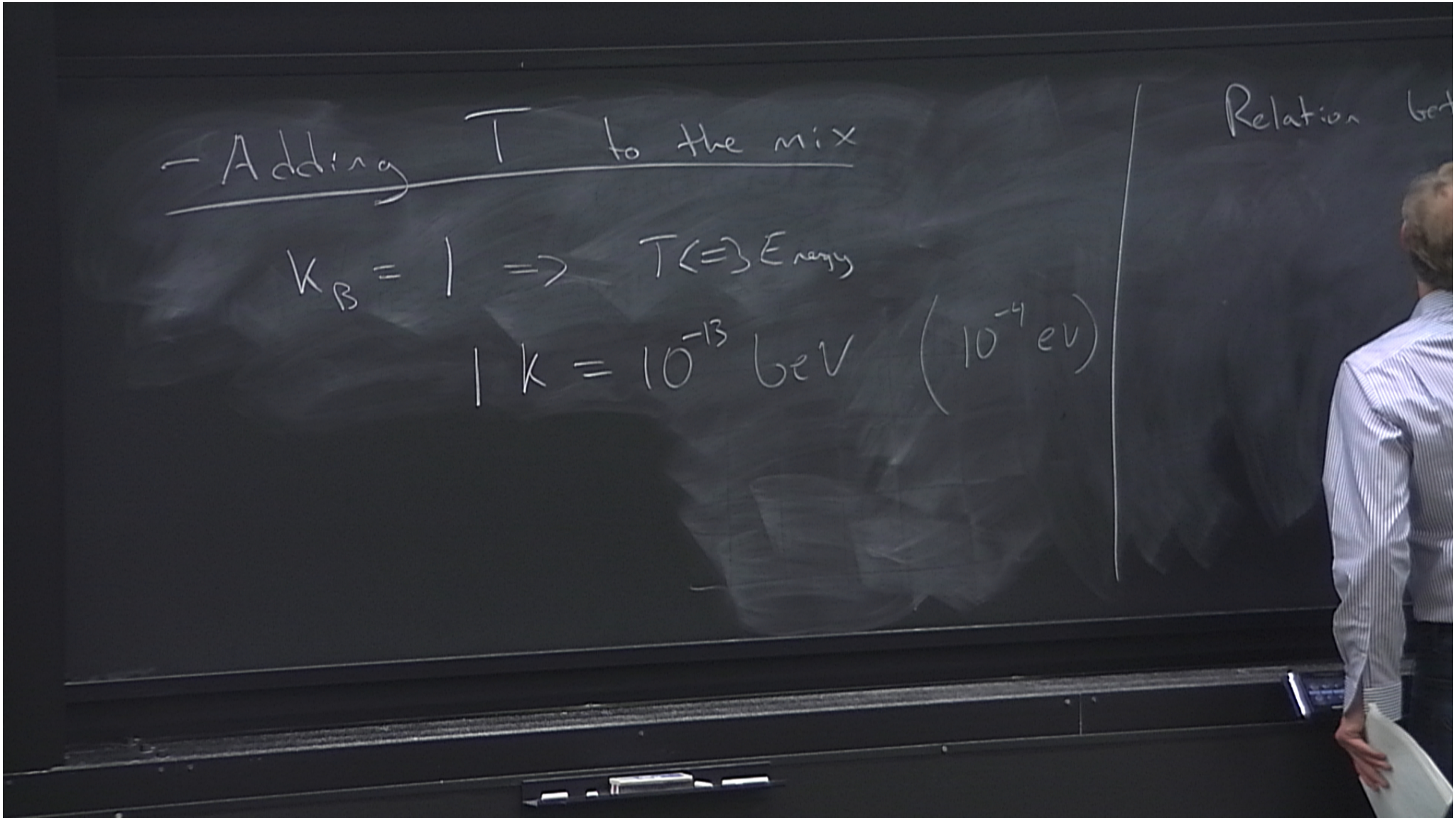

damental
1×10^{-34} kg m²/s
$(E = mc^2)$
4 fundamental constants + $E = mc^2$
ℓ, t, m, T, E
Everything can be Unitless!
$\alpha = \frac{1}{4\pi\varepsilon_0} \frac{e^2}{\hbar c} = 1/137$

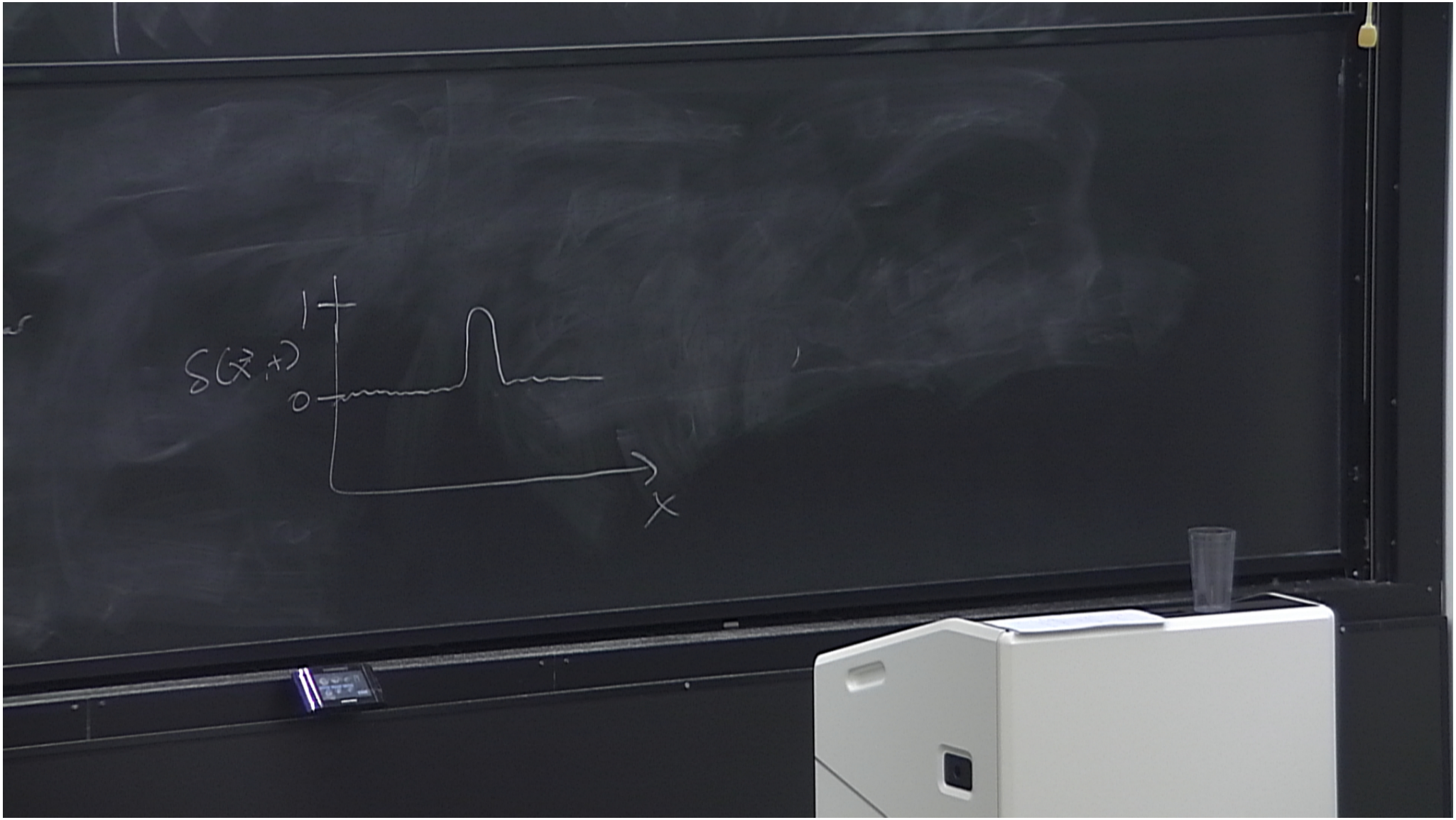

Particle physicists's Units: $\hbar = c = 1$ + $E = mc^2$
$c = 1 \Rightarrow$ length $[=]$ time
$\hbar = 1 \Rightarrow$ energy $[=]$ $1/\text{time}$
$E = mc^2 \Rightarrow$ energy $[=]$ Mass $[=]$ $1/\text{time}$

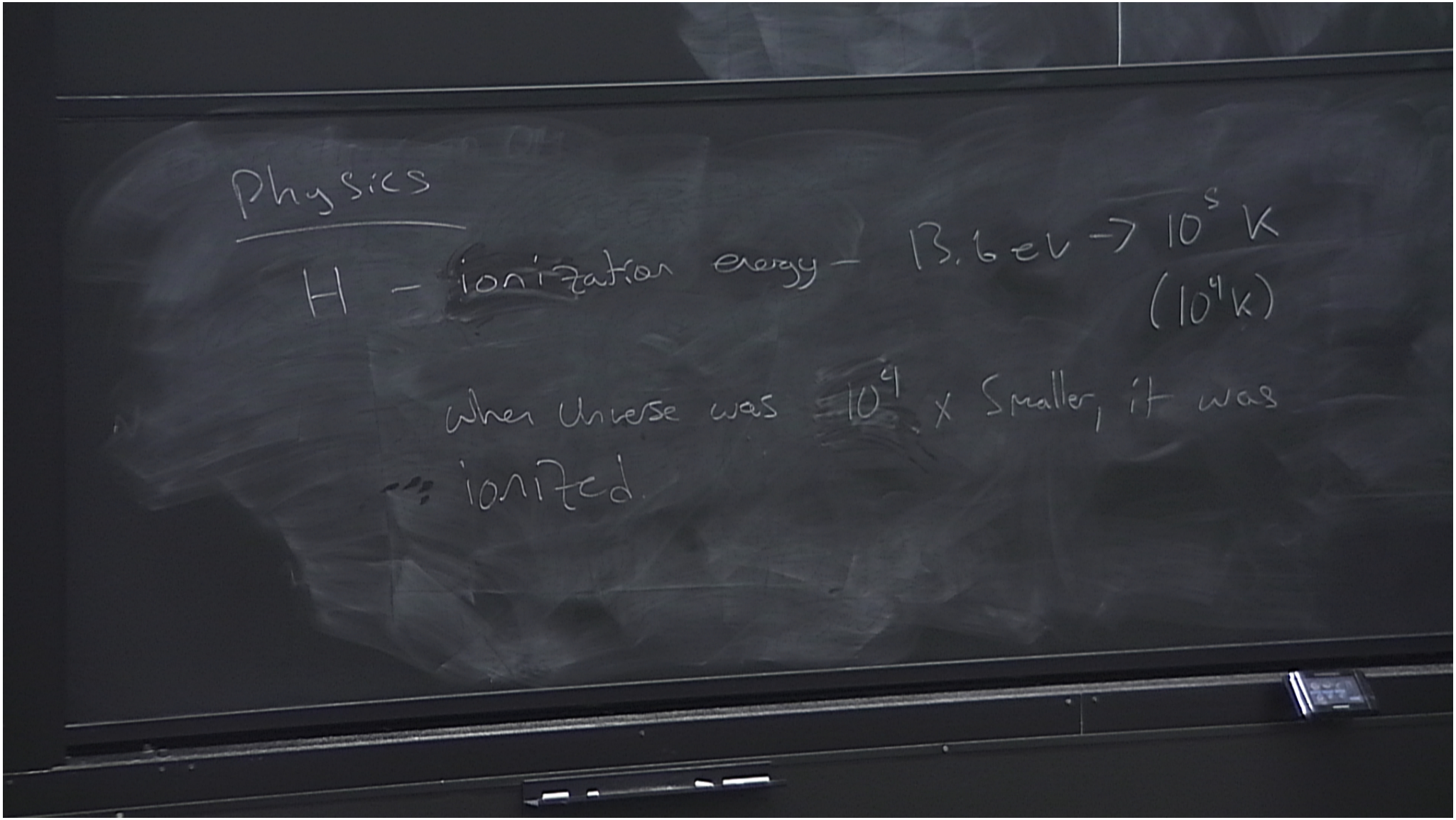

isotropic
physical distance - changes w/ time.
$\hbar = c = 1$ + $E = mc^2$
Express everything in terms of GeV

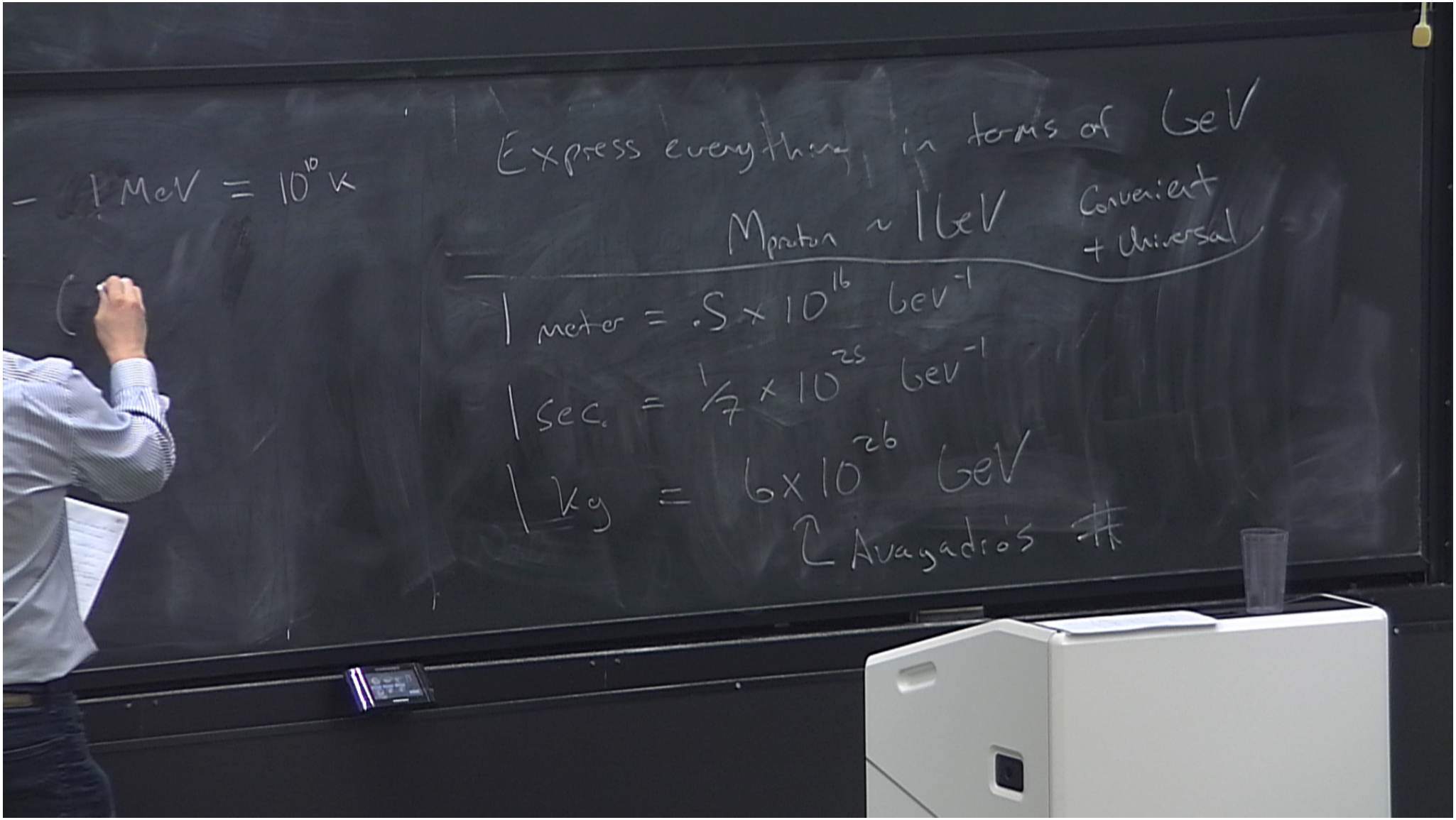

1 meter = .5 × 10^16 GeV^-1
1 sec. = 1/7 × 10^25 GeV^-1
1 kg = 6 × 10^26 GeV

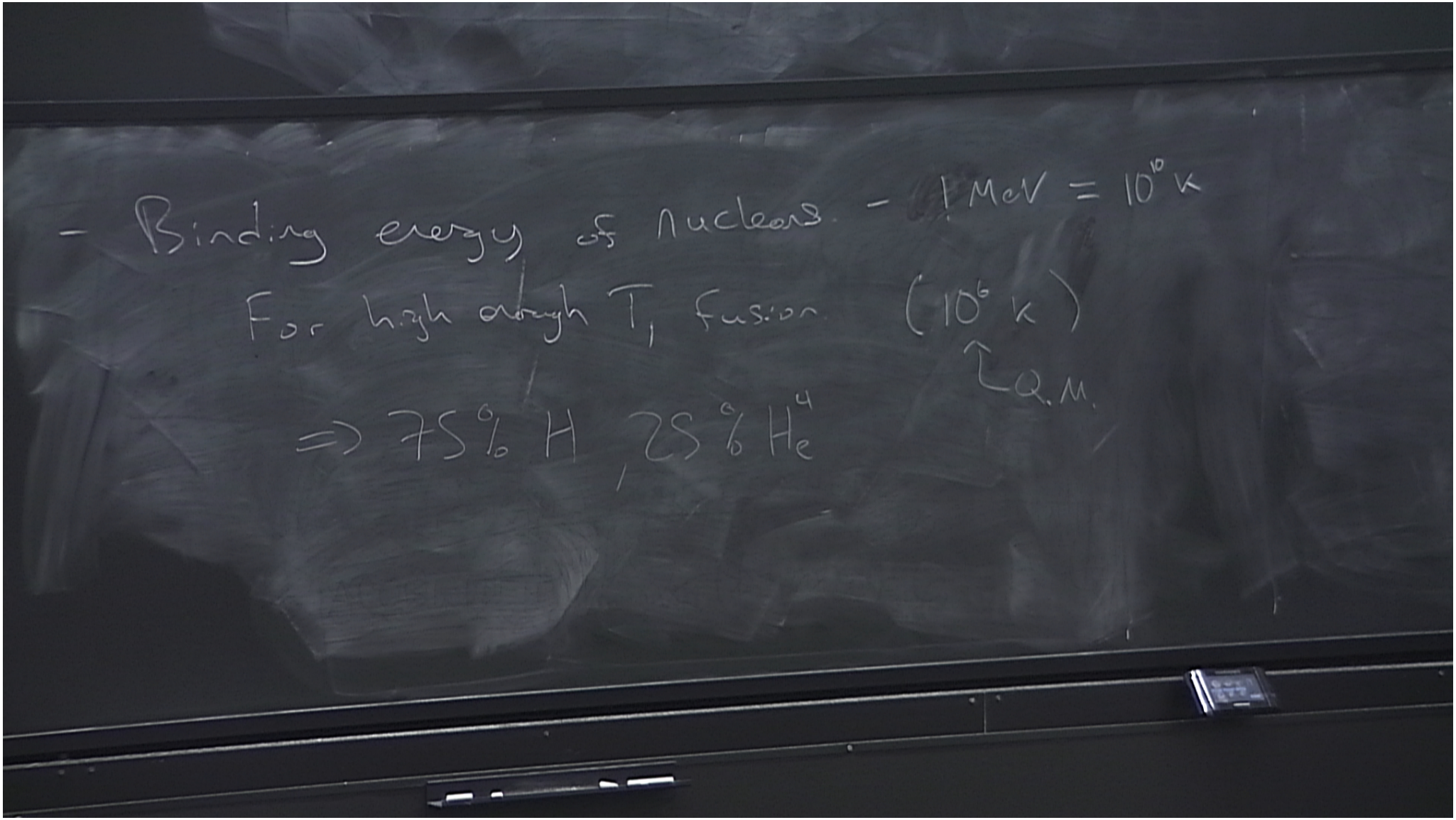

- Adding T to the mix
$k_B = 1 \Rightarrow T \langle = \rangle Energy$

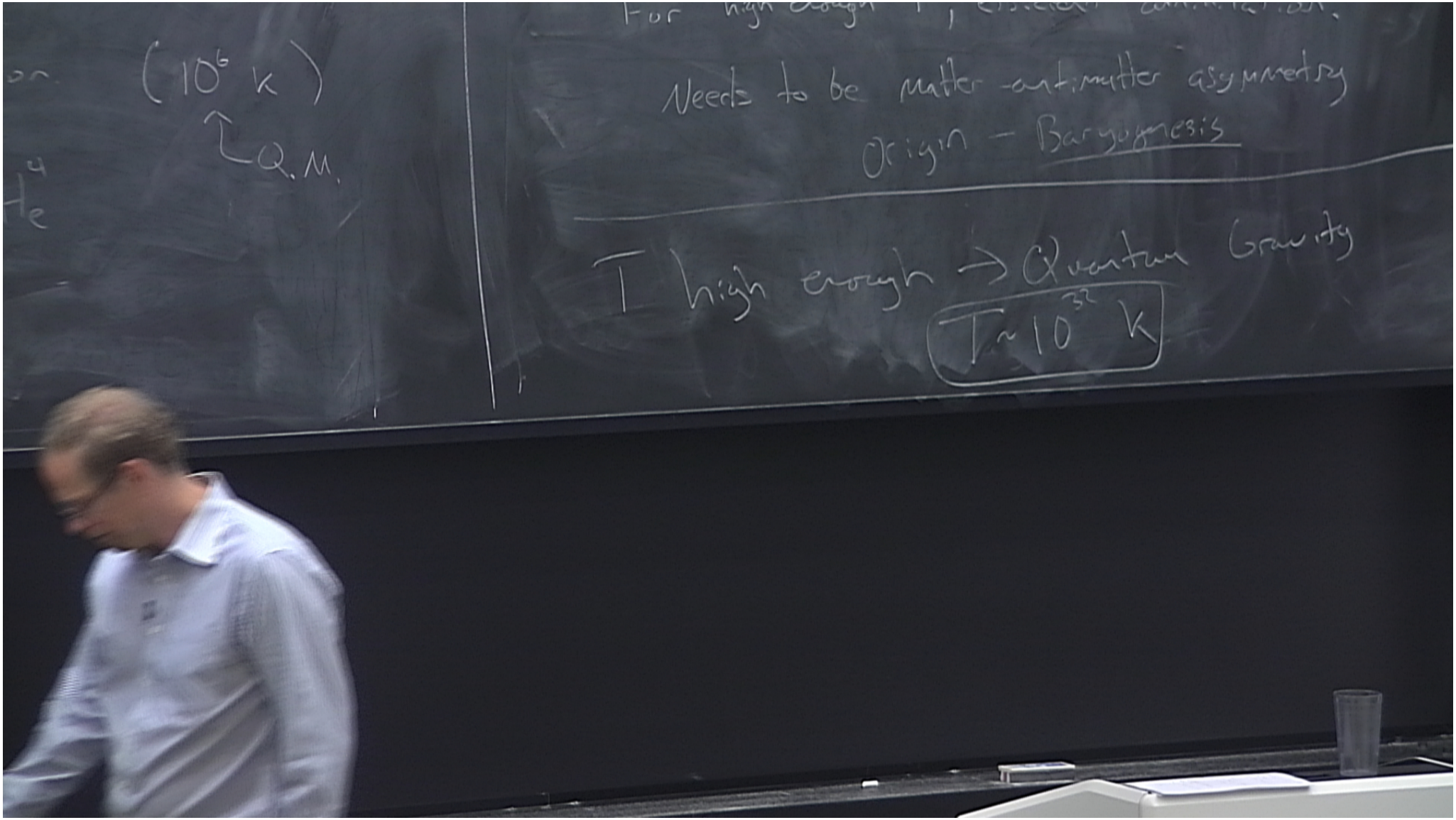

- Adding T to the mix
$k_B = 1 \Rightarrow T \langle = \rangle$ Energy
$1\,k = 10^{-13}$ GeV $(10^{-4}$ eV)
Relation bet


S(x,t)
1
0
x


Physics
H - ionization energy - 13.6 eV -> 10^5 K
(10^9 K)
when Universe was 10^9 x smaller, it was
ionized.


1 MeV = 10^{10} K
Express everything in terms of GeV
$M_{proton} \sim 1$ GeV
Convenient + Universal
1 meter = $.5 \times 10^{16}$ GeV^{-1}
1 sec. = $\frac{1}{7} \times 10^{25}$ GeV^{-1}
1 kg = 6×10^{26} GeV
2 Avagadro's #


- Binding energy of Nucleons - 1 MeV = 10^{10} K
For high enough T, fusion (10^6 K)
Σ Q.M.
$\Rightarrow$ 75% H, 25% He^4


$(10^6 K)$
$\sim$ Q.M.
Needs to be matter-antimatter asymmetry
Origin - Baryogenesis
T high enough $\rightarrow$ Quantum Gravity
$T \sim 10^{32} K$