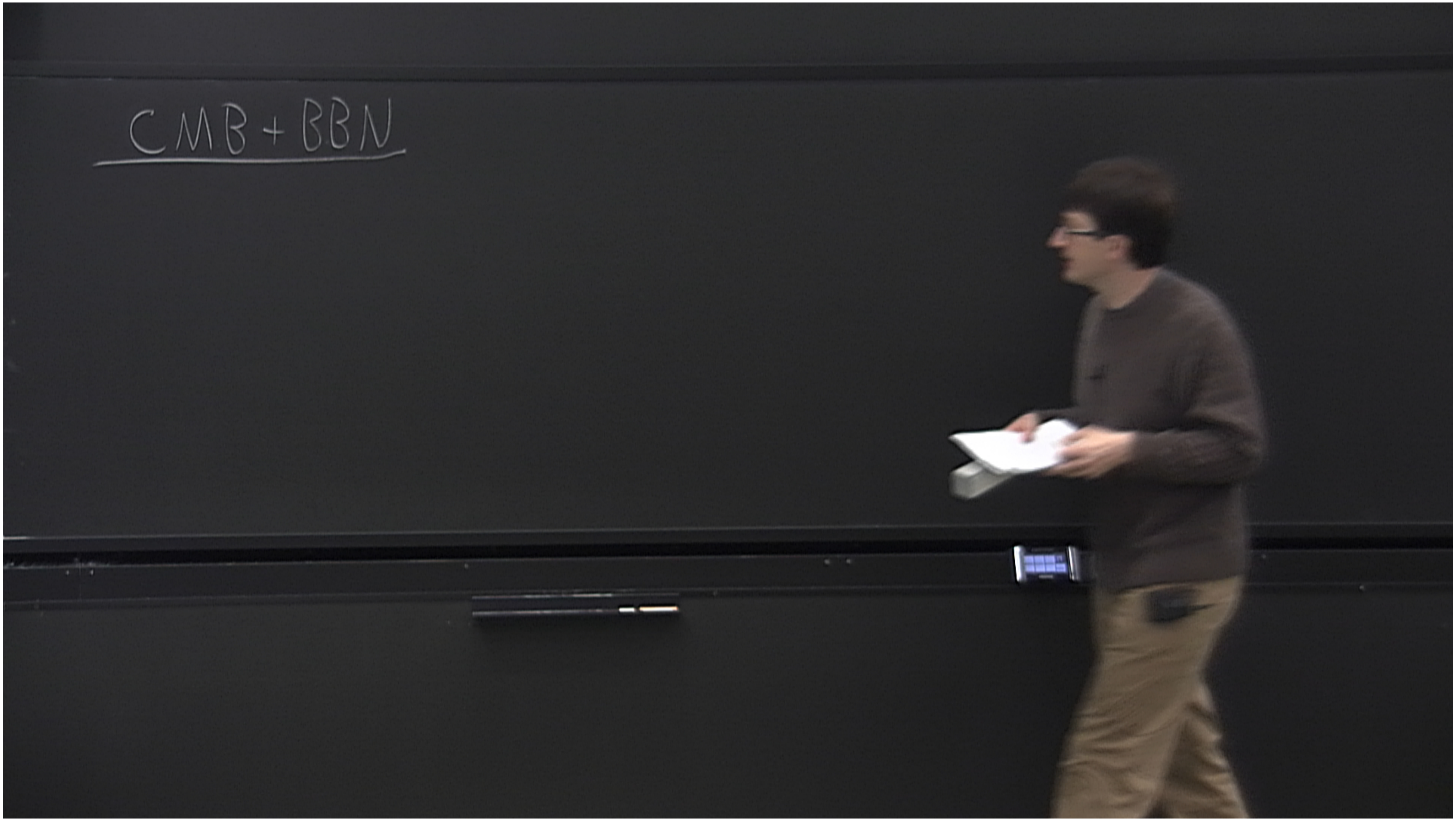
Title: 12/13 PSI - Cosmology Review Lecture 9

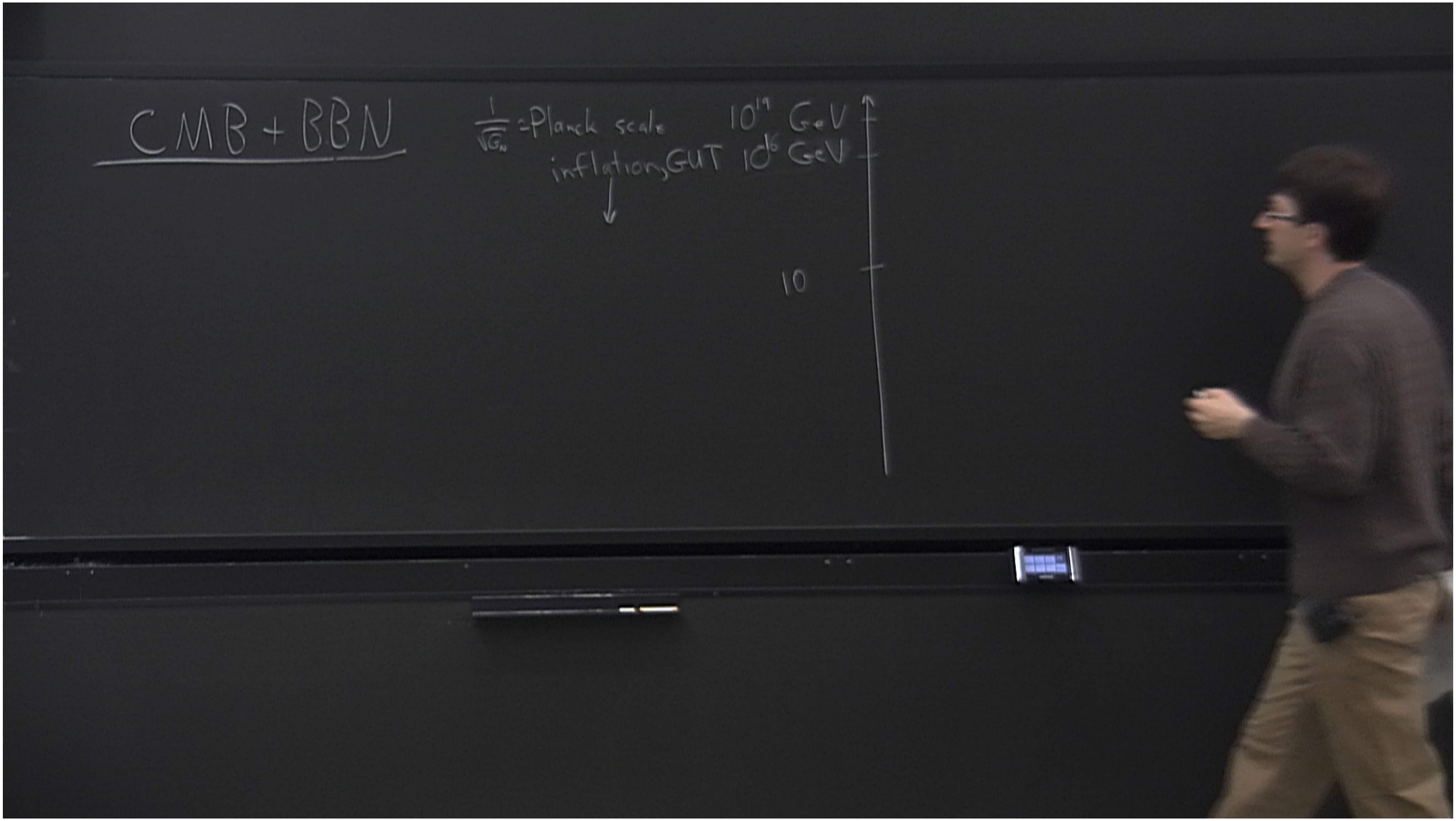
Date: Mar 01, 2013 11:30 AM

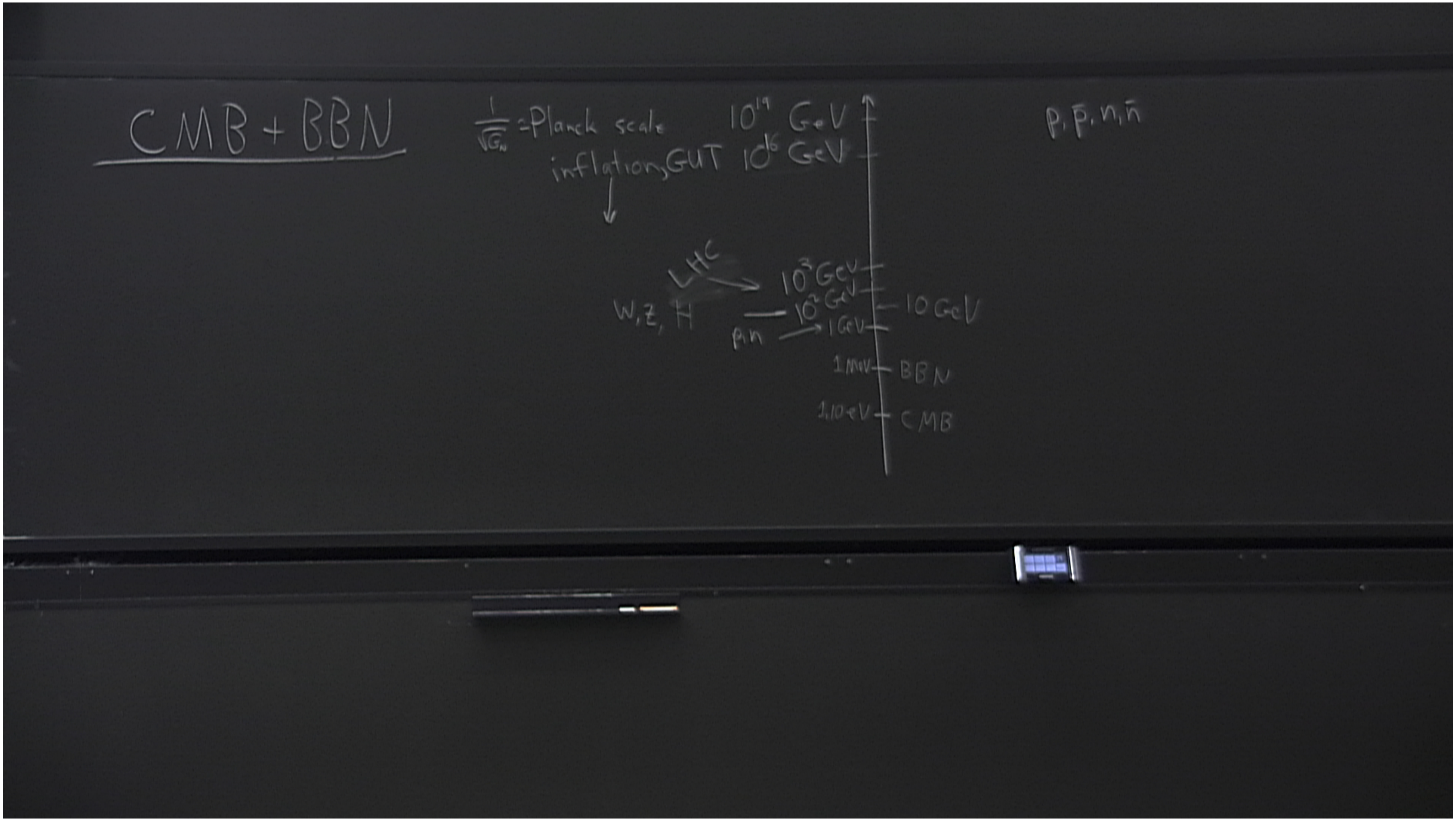
URL: http://pirsa.org/13030038

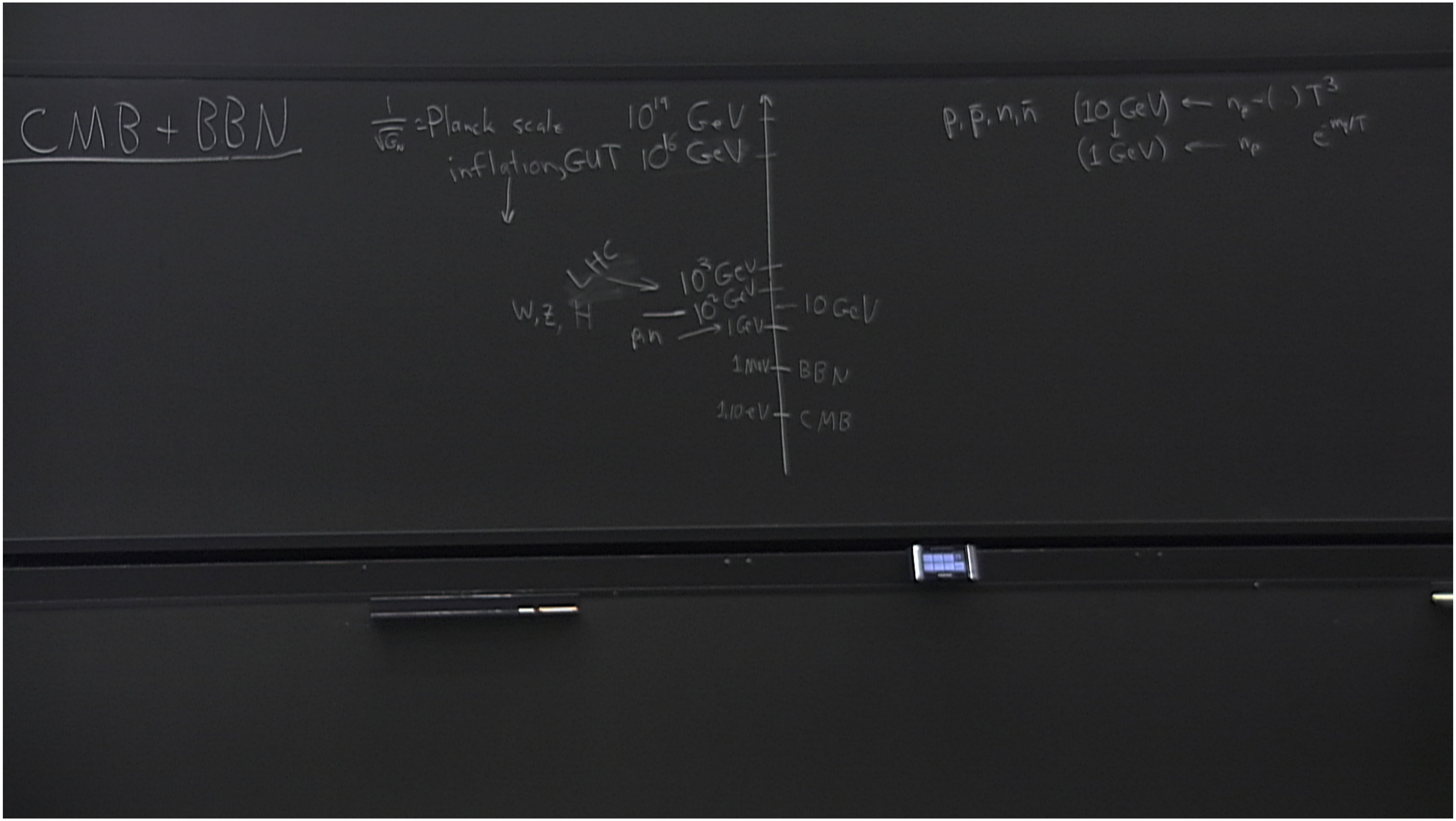
Abstract:

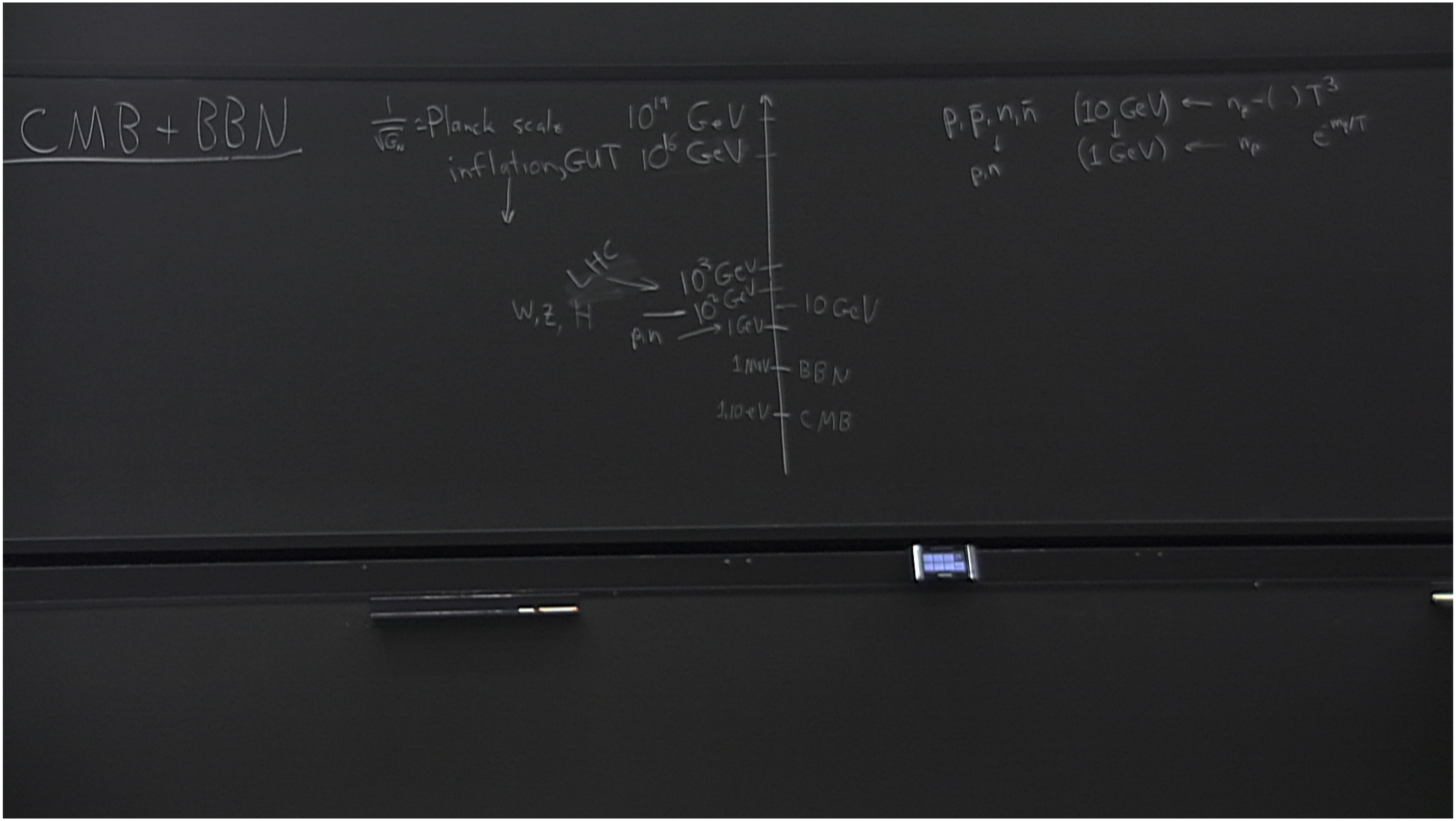

CMB + BBN

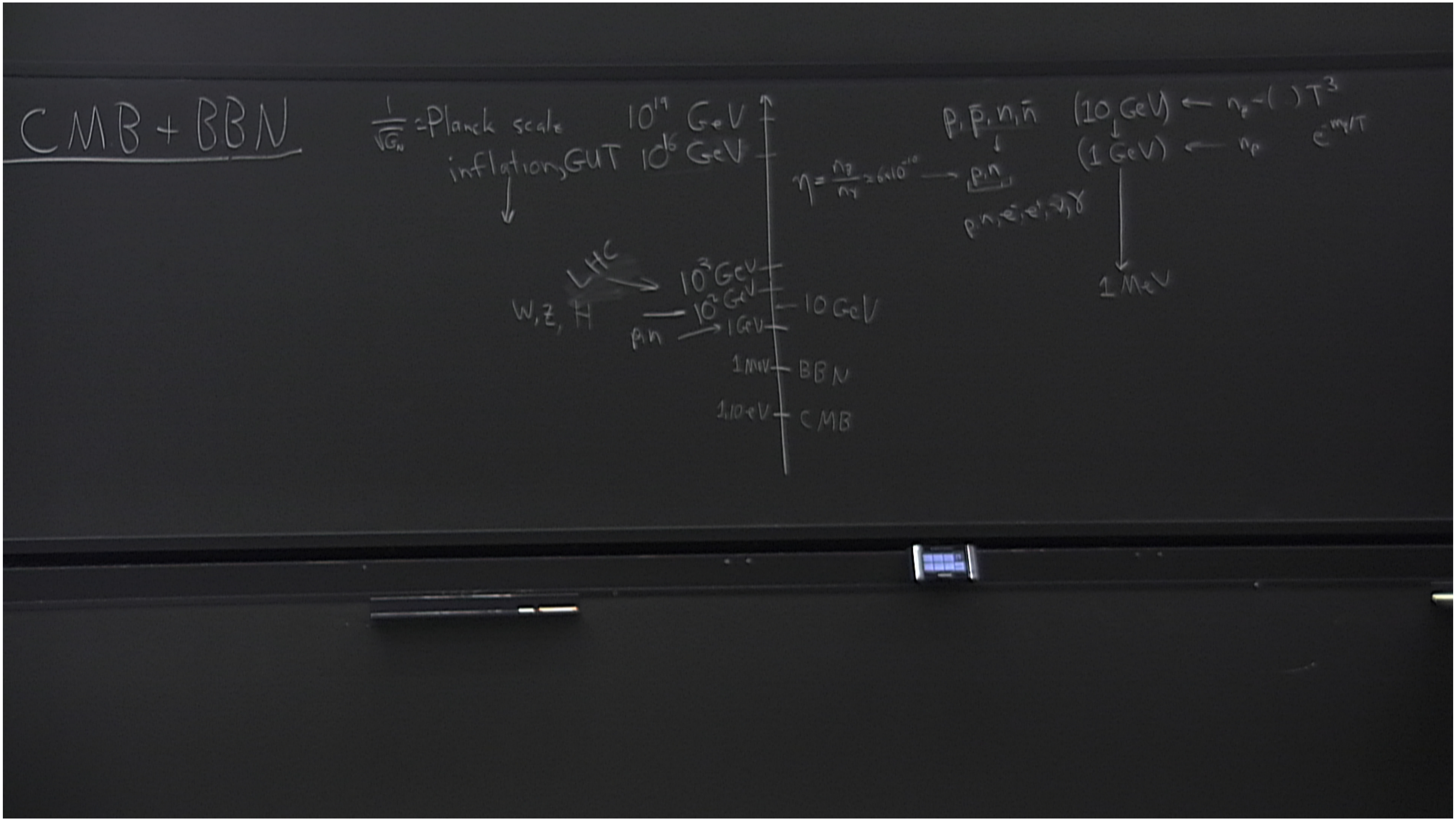

CMB + BBN
1/√G_N = Planck scale
10^19 GeV
10^6 GUT

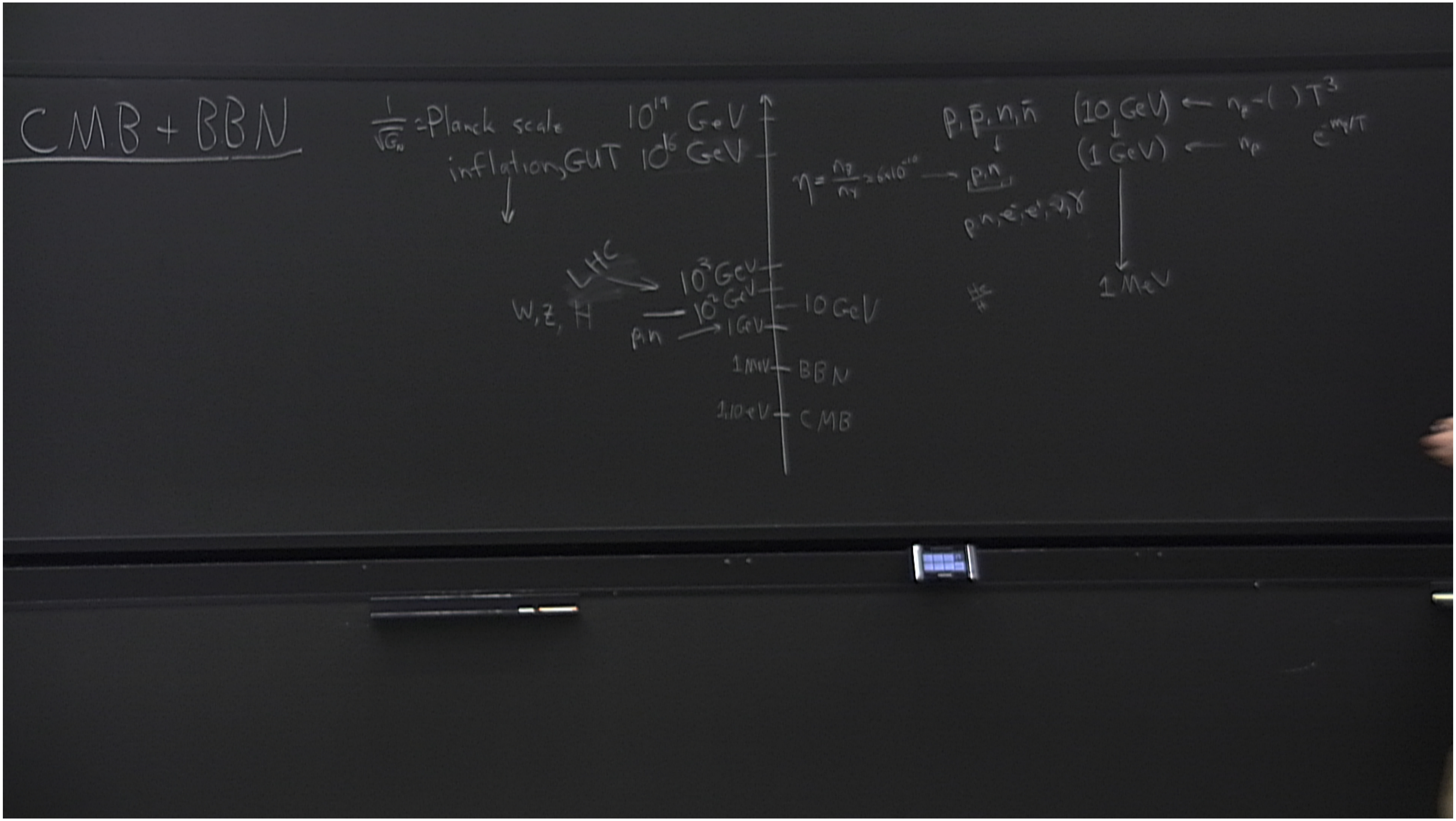

CMB + BBN
1/√G_N = Planck scale 10^19 GeV
inflation, GUT 10^16 GeV
10

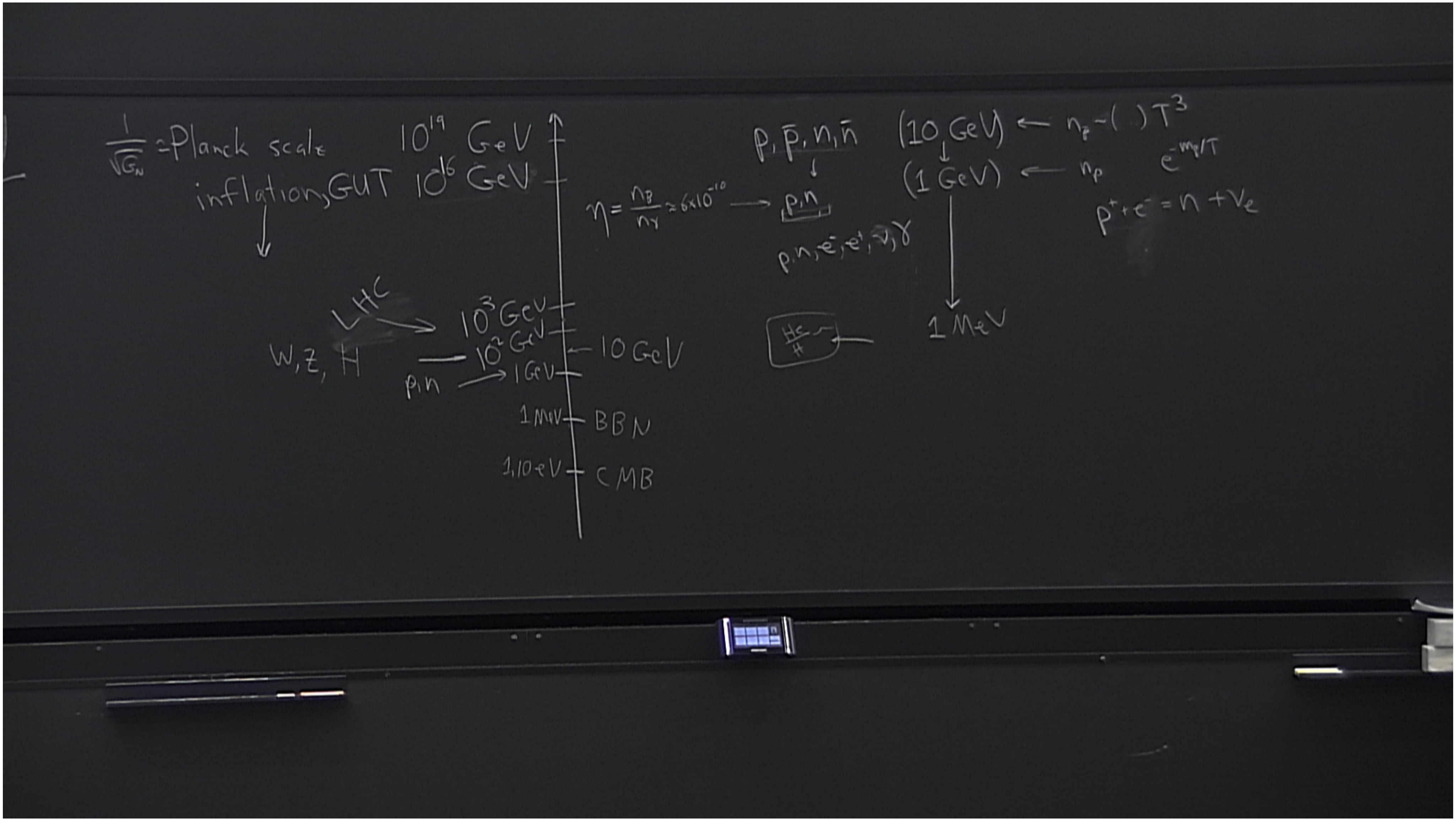

CMB + BBN
1/√G_N = Planck scale 10^19 GeV
inflation, GUT 10^16 GeV
LHC
10^3 GeV
W, Z, H
10^2 GeV
10 GeV
p, n
1 GeV
1 MeV
BBN
CMB
p, p̄, n, n̄


CMB + BBN
1/√G_N = Planck scale
10^19 GeV
inflation, GUT
10^16 GeV
LHC
10^3 GeV
W, Z, H
10^2 GeV
10 GeV
p, n
1 GeV
1 MeV
BBN
CMB
p, p̄, n, n̄
(10 GeV)
(1 GeV)
T^3

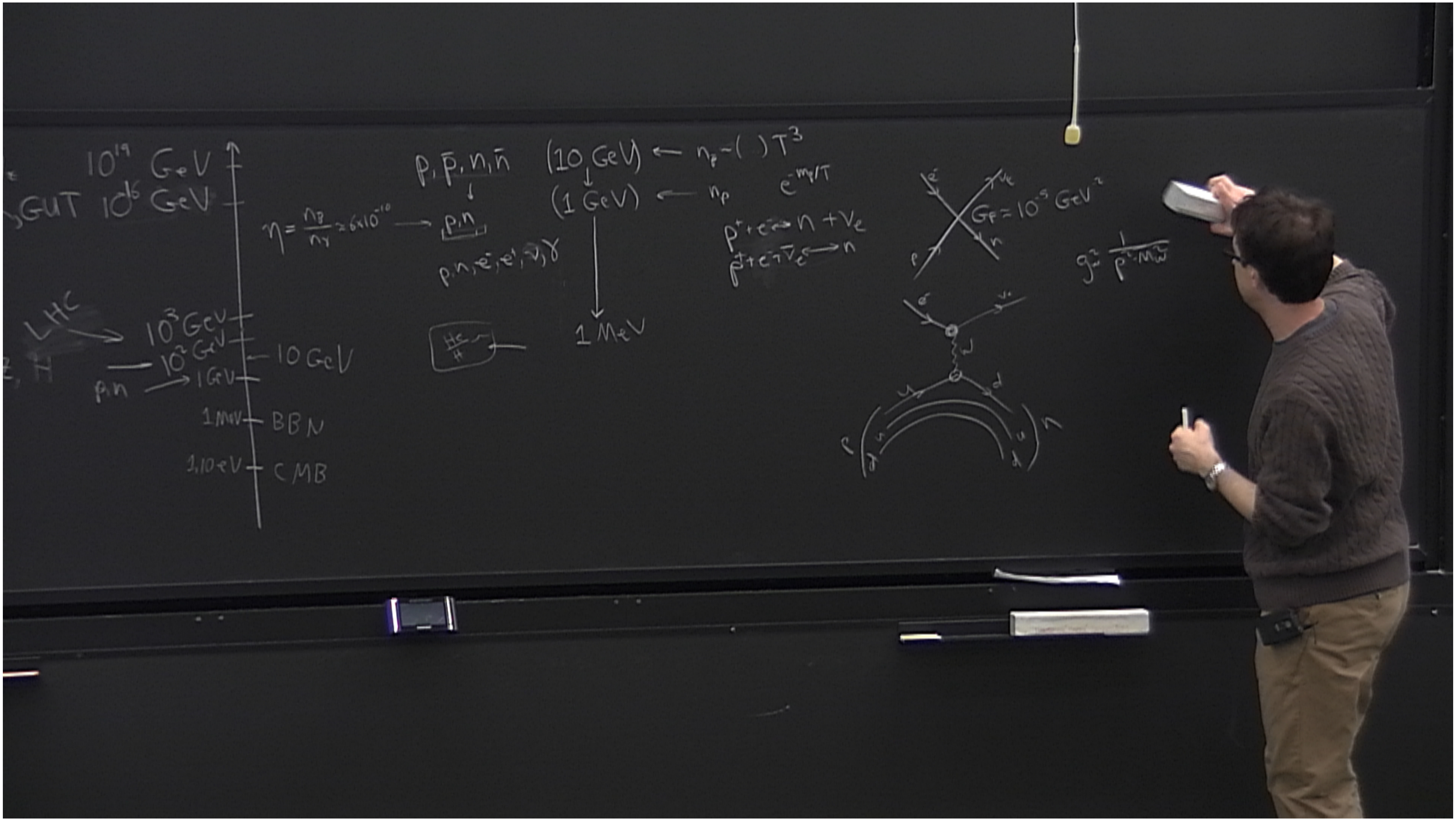

CMB + BBN
Planck scale
10^19 GeV
inflation, GUT
10^16 GeV
LHC
10^3 GeV
10^2 GeV
W, Z, H
10 GeV
p, n
1 GeV
1 MeV
BBN
CMB
p, p̄, n, n̄
(10 GeV)
(1 GeV)

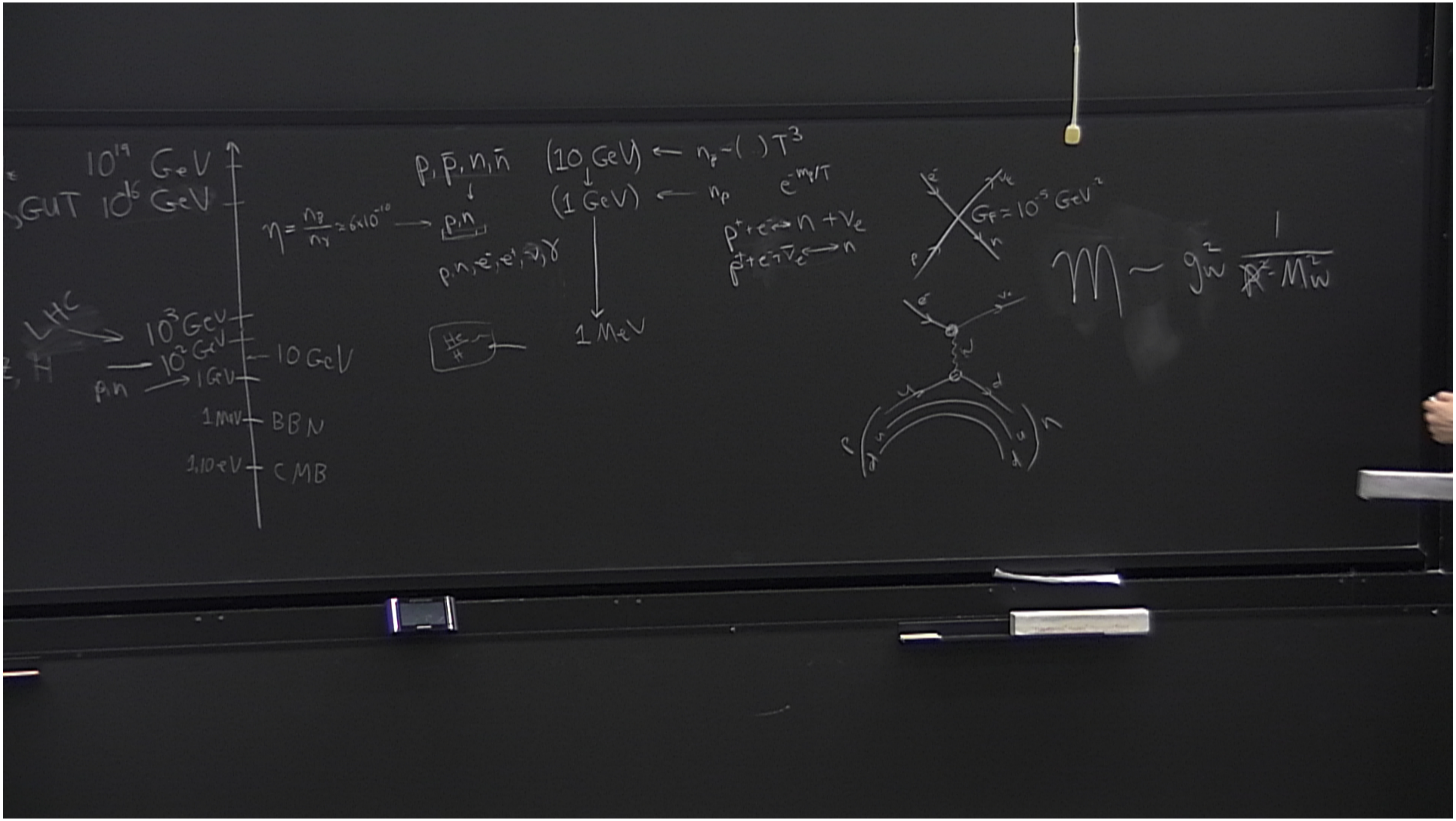

CMB + BBN
1/√G_N = Planck scale 10^19 GeV
inflation, GUT 10^16 GeV
LHC
10^3 GeV
W, Z, H
10^2 GeV
10 GeV
p, n
1 GeV
1 MeV
BBN
CMB
η = n_B/n_γ ≈ 6×10^-10
p, p̄, n, n̄
p, n
(10 GeV)
(1 GeV)
1 MeV

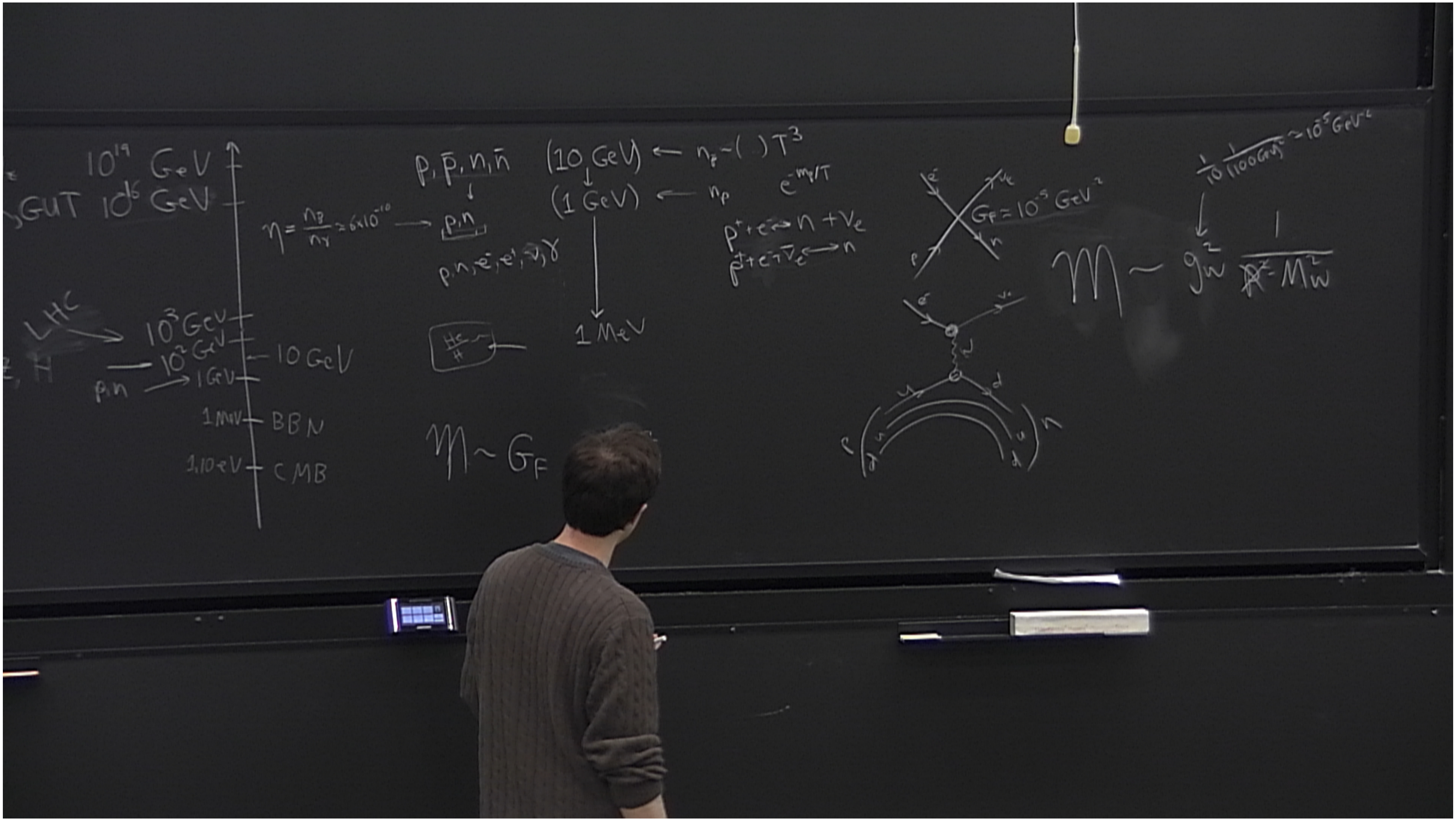

CMB + BBN
Planck scale 10^19 GeV
inflation, GUT 10^16 GeV
LHC
10^3 GeV
W, Z, H
10^2 GeV
10 GeV
p, n
1 GeV
1 MeV
BBN
CMB
p, p̄, n, n̄
p, n
(10 GeV)
(1 GeV)
1 MeV

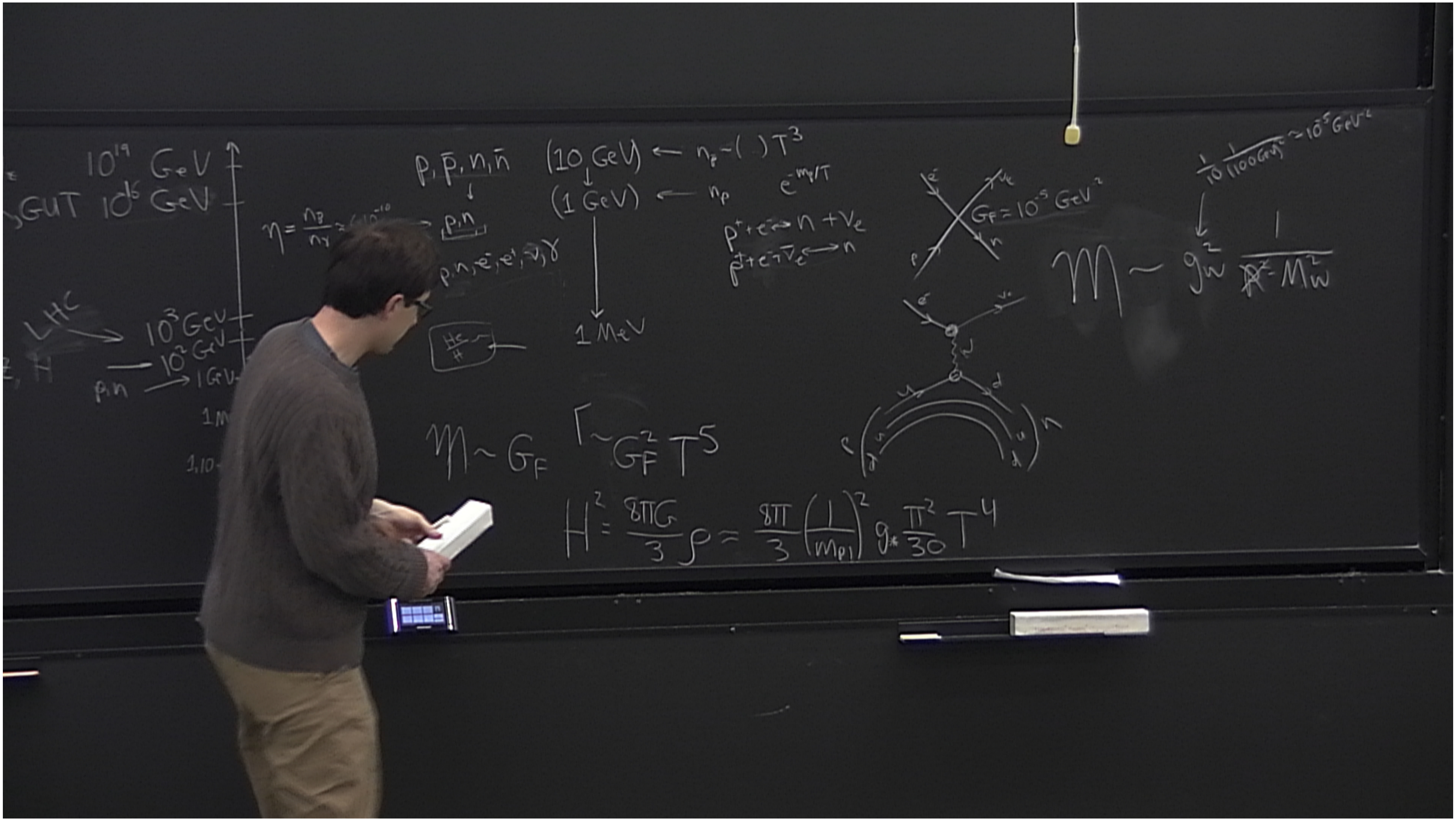


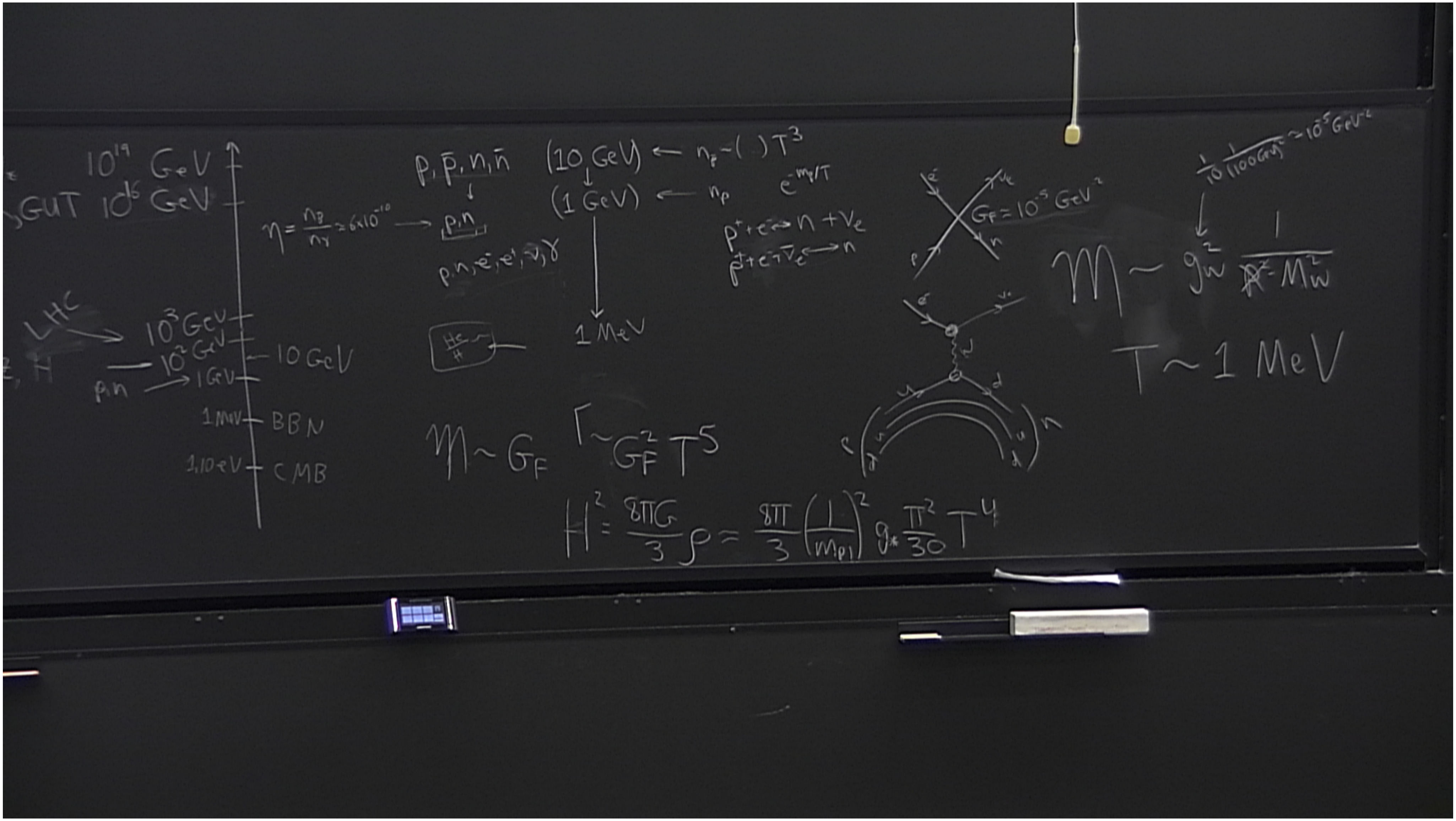
= Planck scale 10^19 GeV
inflation, GUT 10^16 GeV
LHC
10^3 GeV
W, Z, H
10^2 GeV
10 GeV
p, n
1 GeV
1 MeV
BBN
1,10 eV
CMB
η = n_B / n_γ ≈ 6×10^-10
p, p̄, n, n̄
(10 GeV)
(1 GeV)
p, n
p, n, e-, e+, ν, γ
1 MeV
p+ + e- = n + ν_e

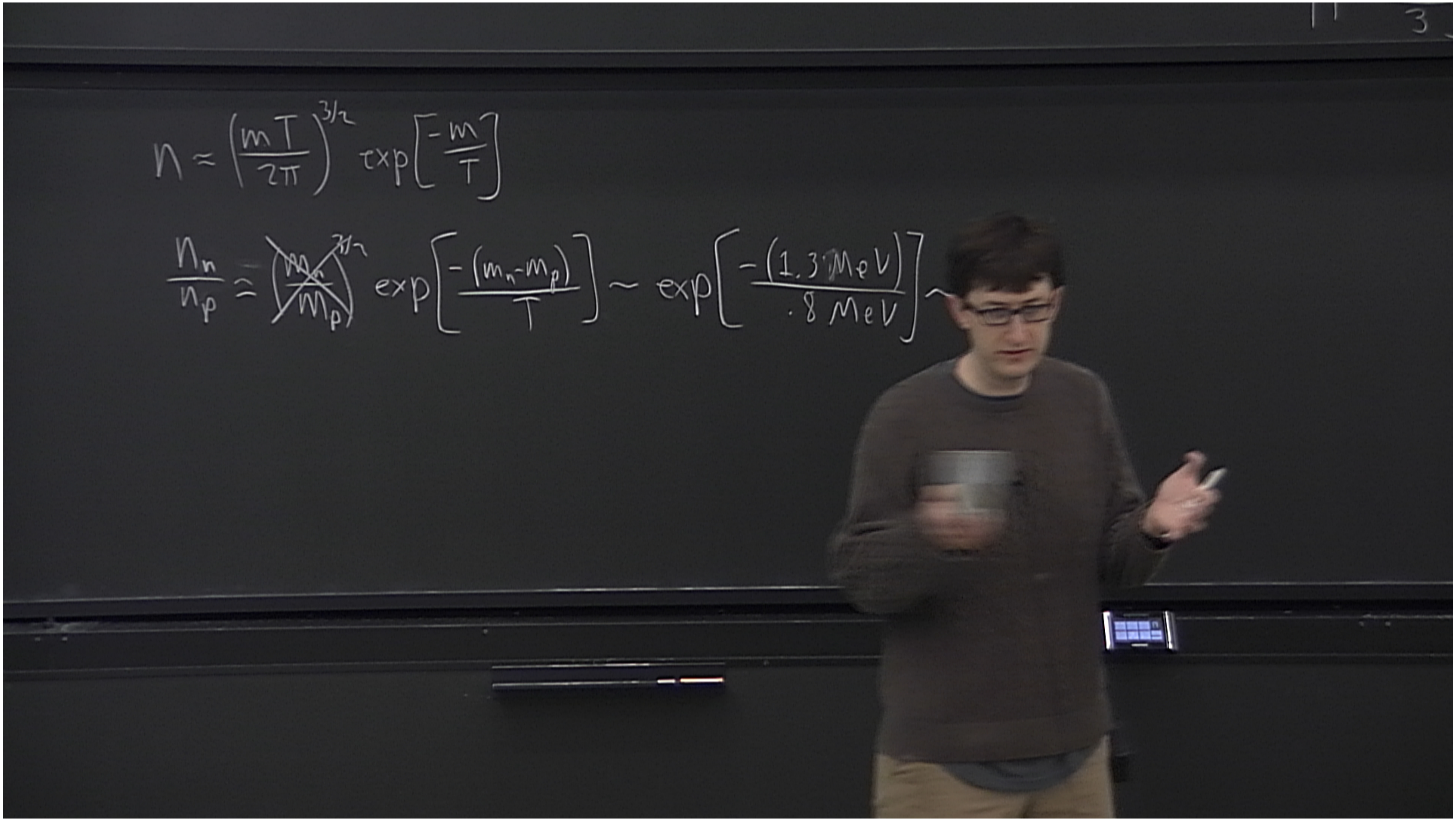


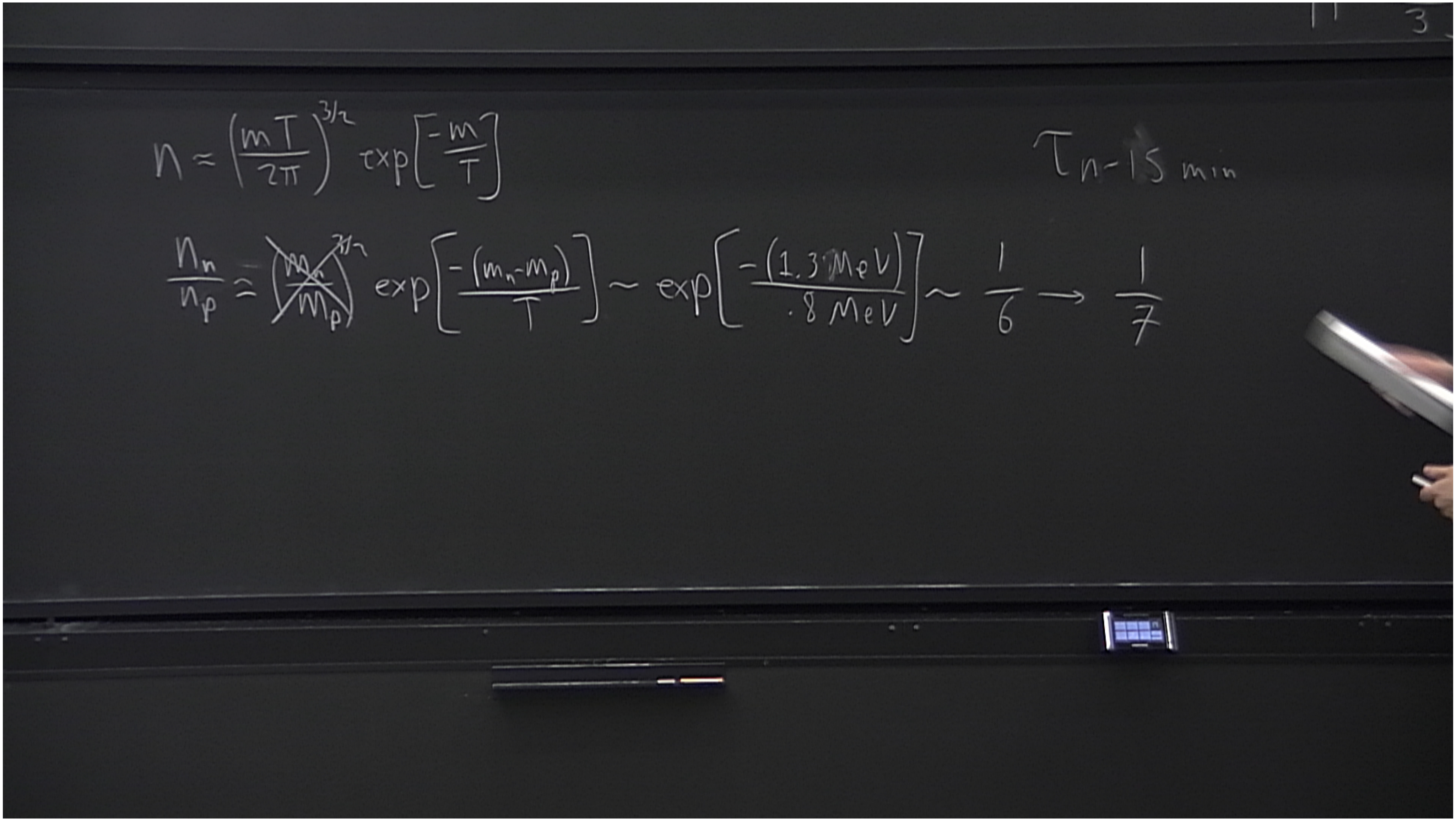

10^19 GeV
GUT 10^16 GeV
LHC
10^3 GeV
10^2 GeV
10 GeV
p, n
1 GeV
1 MeV
BBN
CMB
η = n_B/n_γ ≈ 6×10^-10
p, p̄, n, n̄
p, n
p, n, e⁻, e⁺, ν, γ
(10 GeV) ← n_p ~ ( ) T^3
(1 GeV) ← n_p e^{-m_p/T}
1 MeV
p⁺ + e⁻ ⟷ n + ν_e
G_F = 10^-5 GeV^-2
M ~ g_W^2 1/(p^2 - M_W^2)

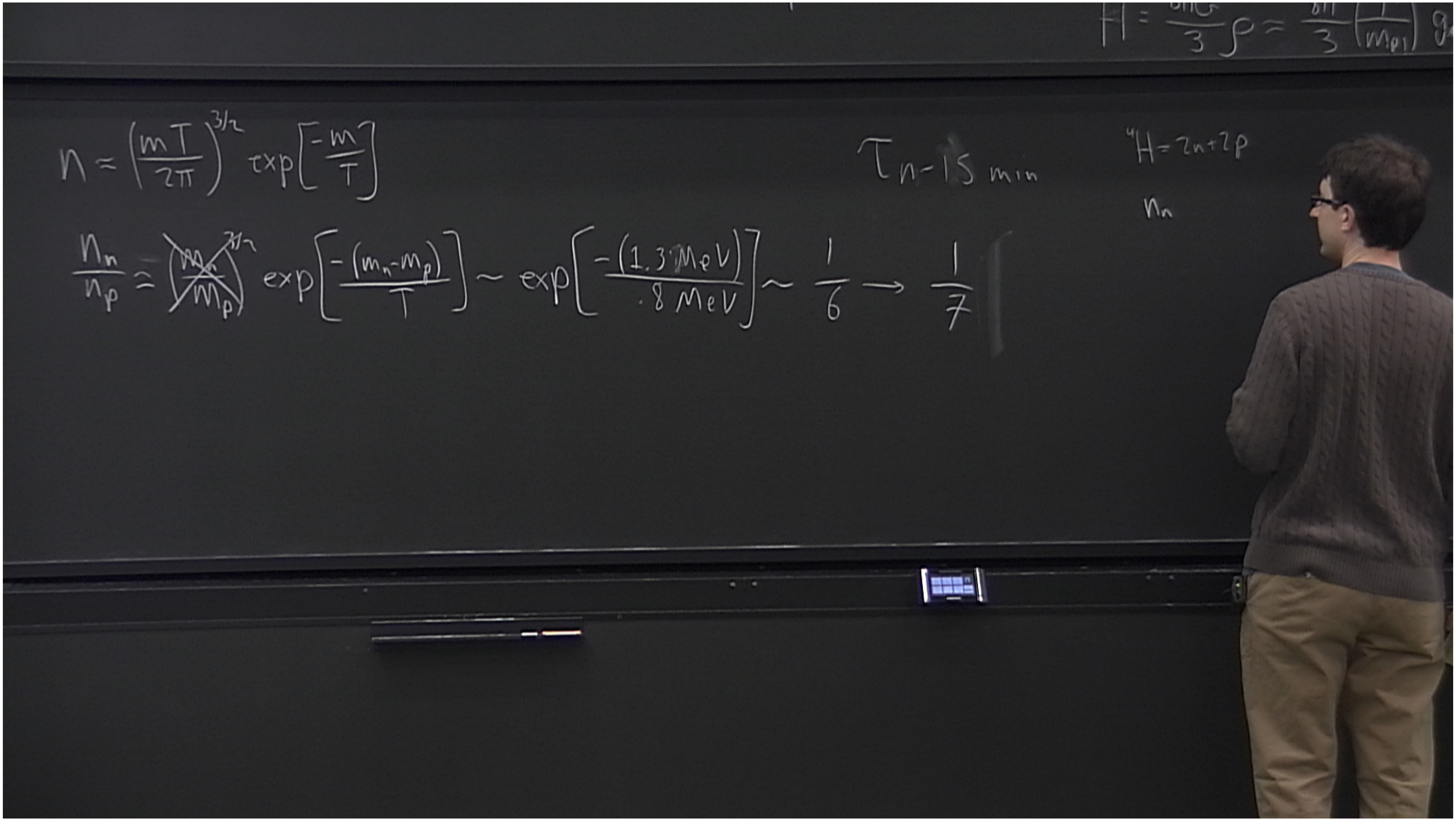


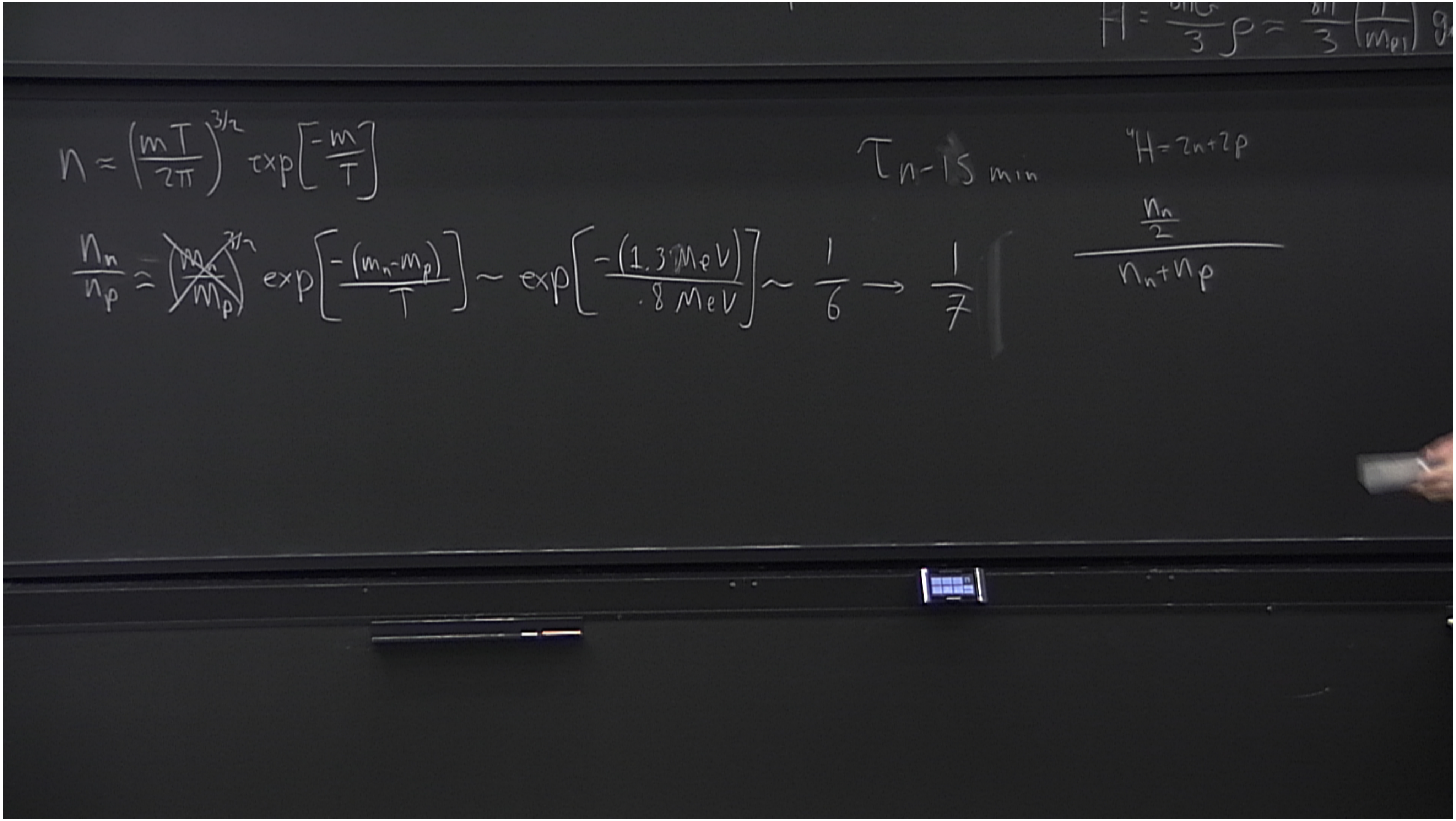

10^19 GeV
GUT 10^16 GeV
LHC
10^3 GeV
10^2 GeV
1 GeV
p, n
p, p̄, n, n̄
p, n
p, n, e⁻, e⁺, ν, γ
(10 GeV)
(1 GeV)
1 MeV
G_F = 10^-5 GeV^-2
M ~ G_F
Γ ~ G_F^2 T^5
H^2 = 8πG/3 ρ = 8π/3 (1/m_Pl)^2 g* π^2/30 T^4

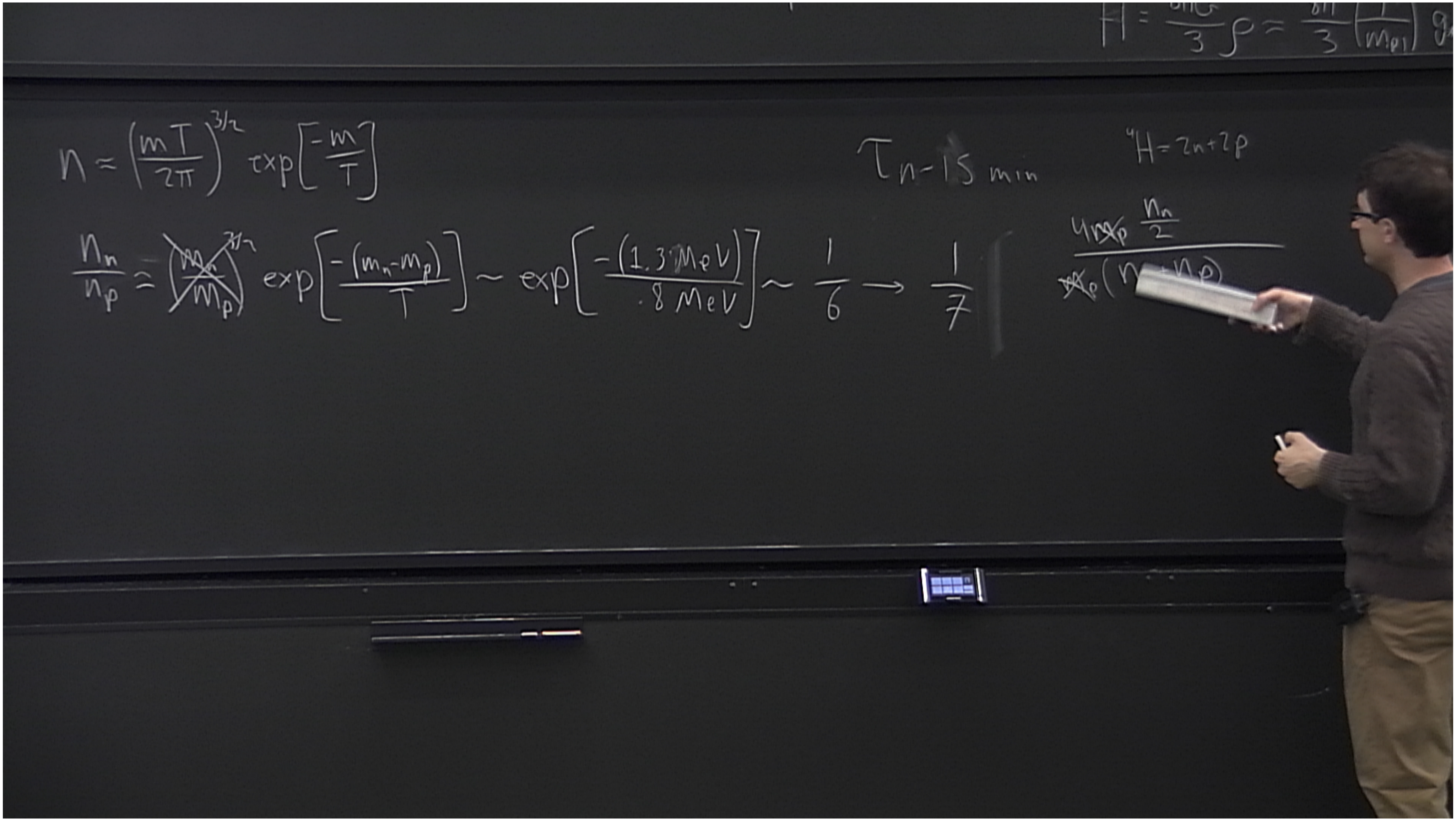

10^19 GeV
GUT 10^16 GeV
LHC
10^3 GeV
10^2 GeV
1 GeV
10 GeV
p, n
1 MeV BBN
CMB
p, p̄, n, n̄
(10 GeV)
(1 GeV)
1 MeV
η = n_B / n_γ ≈ 6×10^-10
p, n
G_F = 10^-5 GeV^-2
M ~ G_F
Γ ~ G_F^2 T^5
H^2 = 8πG/3 ρ = 8π/3 (1/M_Pl)^2 g_* π^2/30 T^4
M ~ g_W^2 1/(p^2 - M_W^2)
T ~ 1 MeV

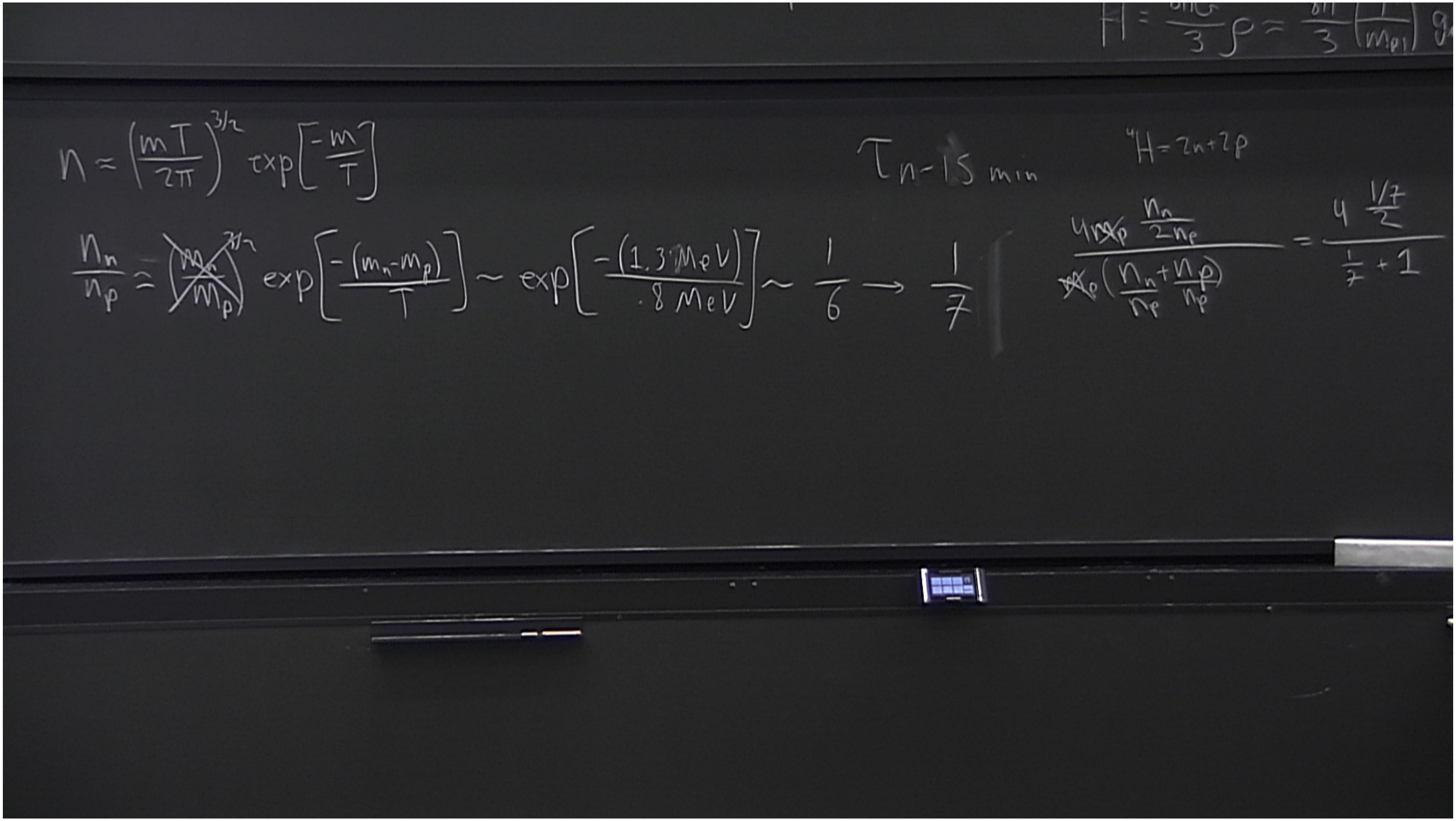

$n \simeq \left(\frac{mT}{2\pi}\right)^{3/2} \exp\left[\frac{-m}{T}\right]$
$\frac{n_n}{n_p} \simeq \left(\frac{m_n}{m_p}\right)^{3/2} \exp\left[\frac{-(m_n - m_p)}{T}\right] \sim \exp\left[\frac{-(1.3\, MeV)}{.8\, MeV}\right] \sim$

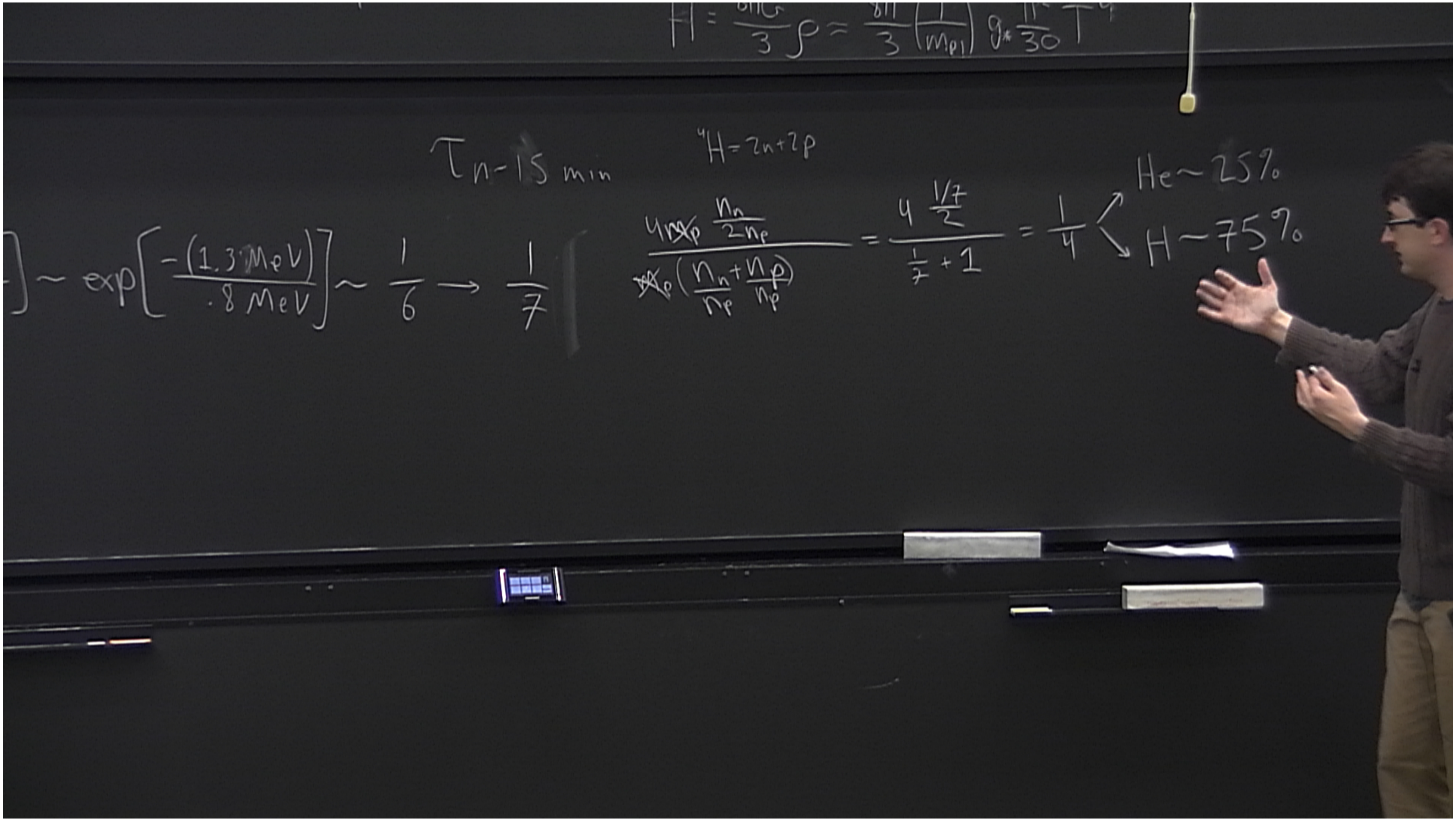

$n \simeq \left(\frac{mT}{2\pi}\right)^{3/2} \exp\left[\frac{-m}{T}\right]$
$\tau_n \sim 15$ min
$\frac{n_n}{n_p} \simeq \left(\frac{m_n}{m_p}\right)^{3/2} \exp\left[\frac{-(m_n - m_p)}{T}\right] \sim \exp\left[\frac{-(1.3\ \mathrm{MeV})}{.8\ \mathrm{MeV}}\right] \sim \frac{1}{6} \rightarrow \frac{1}{7}$


$n \simeq \left(\frac{mT}{2\pi}\right)^{3/2} \exp\left[\frac{-m}{T}\right]$
$\tau_n \sim 15$ min
$^4H = 2n + 2p$
n_n
$\frac{n_n}{n_p} \simeq \left(\frac{m_n}{m_p}\right)^{3/2} \exp\left[\frac{-(m_n - m_p)}{T}\right] \sim \exp\left[\frac{-(1.3\,MeV)}{.8\,MeV}\right] \sim \frac{1}{6} \rightarrow \frac{1}{7}$

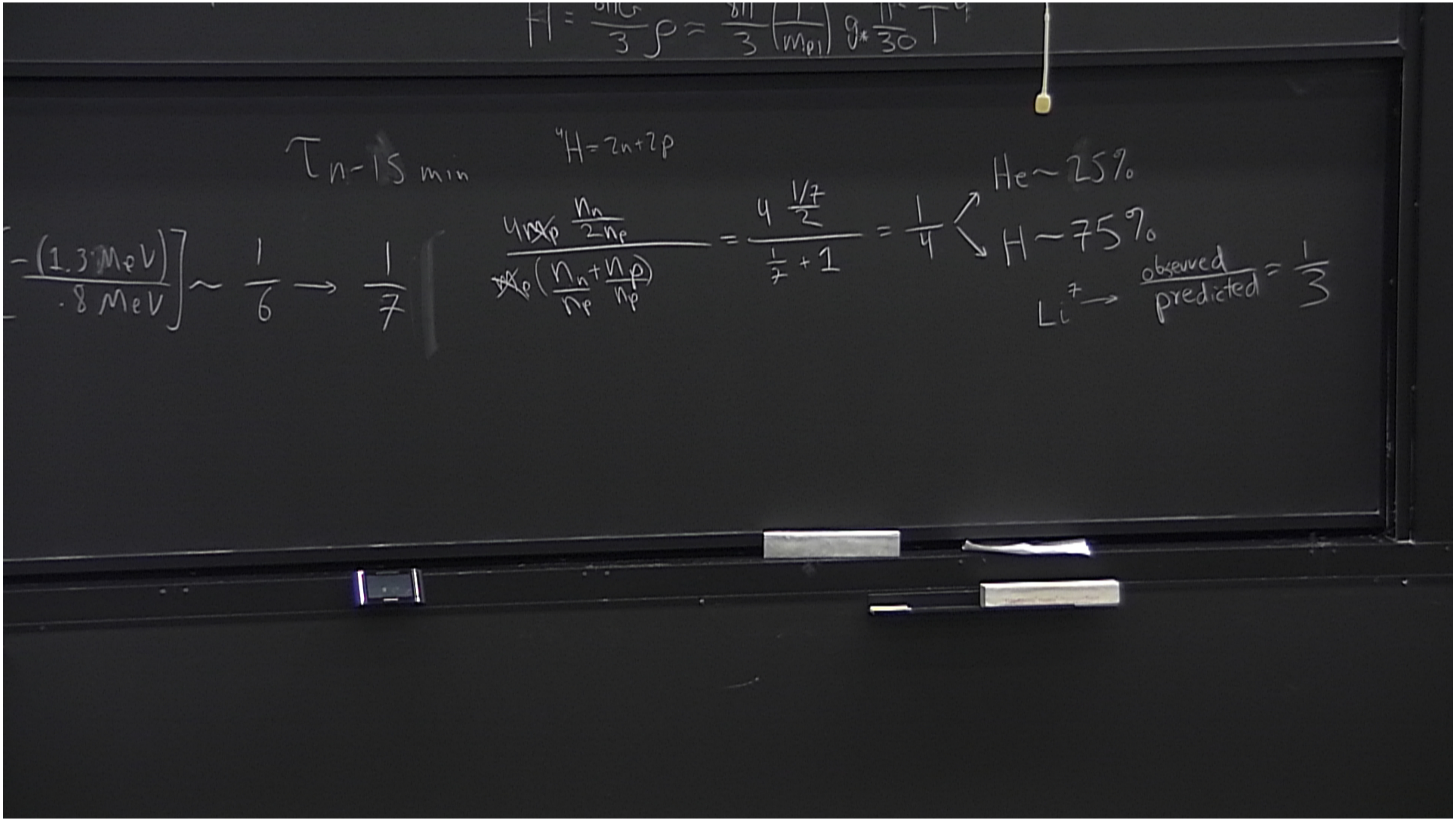

n ≃ (mT/2π)^3/2 exp[−m/T]
τn ~ 15 min
4He = 2n + 2p
nn/np ≃ (mn/mp)^3/2 exp[−(mn − mp)/T] ~ exp[−(1.3 MeV)/.8 MeV] ~ 1/6 → 1/7
(nn/2)/(nn + np)

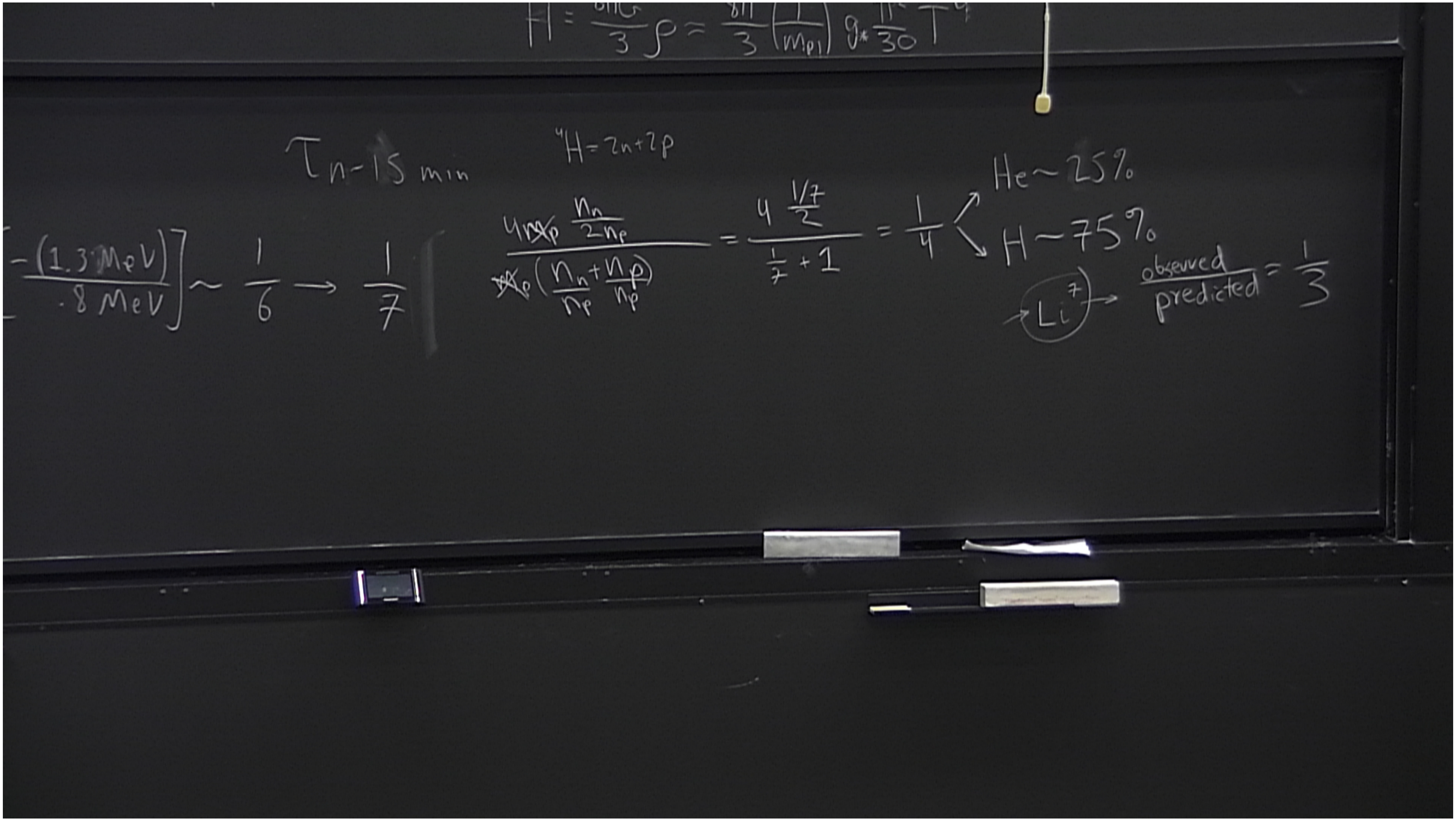

$n \simeq \left(\frac{mT}{2\pi}\right)^{3/2} \exp\left[\frac{-m}{T}\right]$
$\tau_n \sim 15$ min
${}^4H = 2n + 2p$
$\frac{n_n}{n_p} \simeq \left(\frac{m_n}{m_p}\right)^{3/2} \exp\left[\frac{-(m_n - m_p)}{T}\right] \sim \exp\left[\frac{-(1.3\,MeV)}{.8\,MeV}\right] \sim \frac{1}{6} \rightarrow \frac{1}{7}$

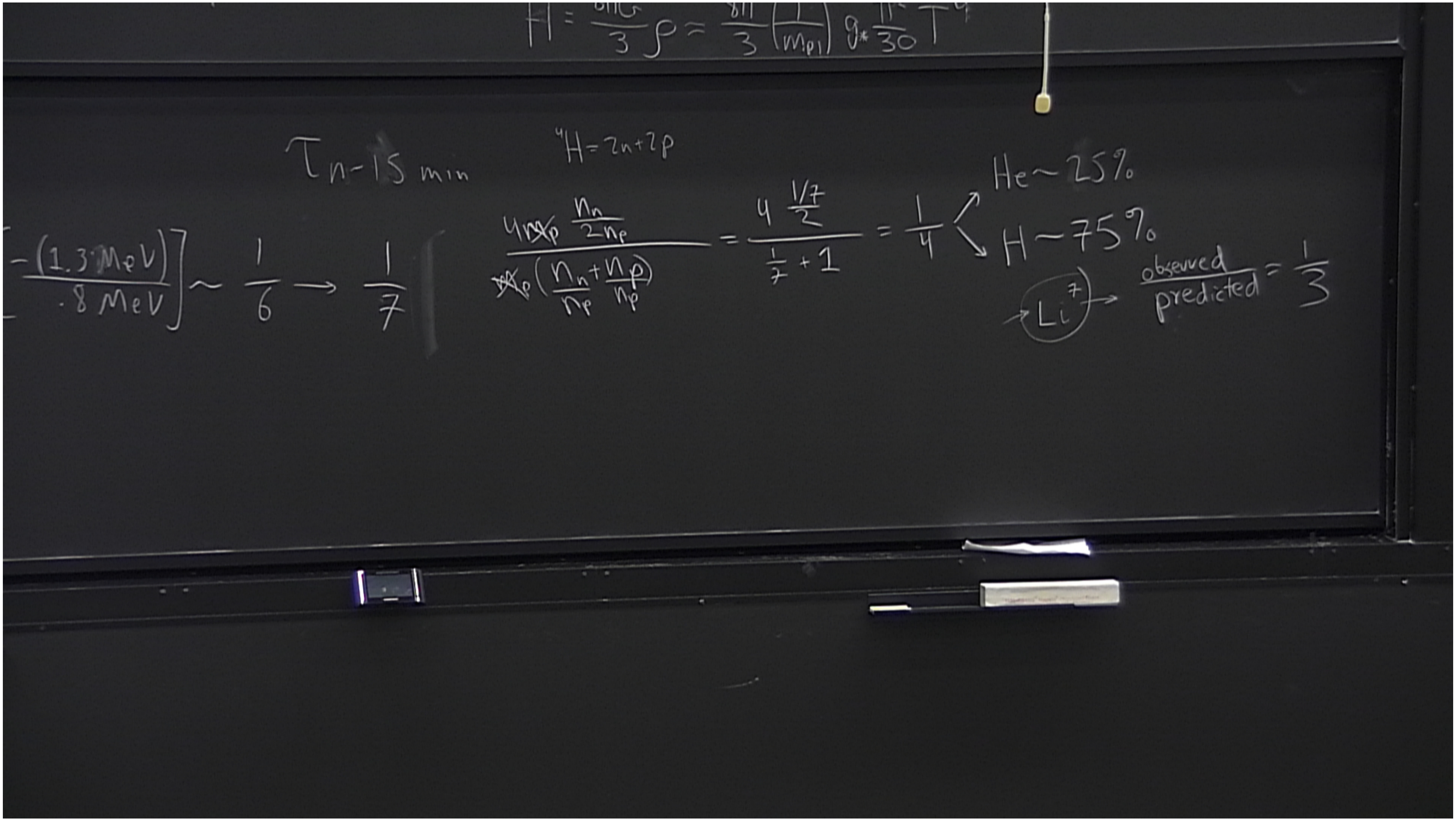

n ≃ (mT/2π)^{3/2} exp[−m/T]
τ_n ~ 15 min
^4He = 2n + 2p
n_n/n_p ≃ (m_n/m_p)^{3/2} exp[−(m_n − m_p)/T] ~ exp[−(1.3 MeV)/.8 MeV] ~ 1/6 → 1/7
= (4 1/7 / 2) / (1/7 + 1)



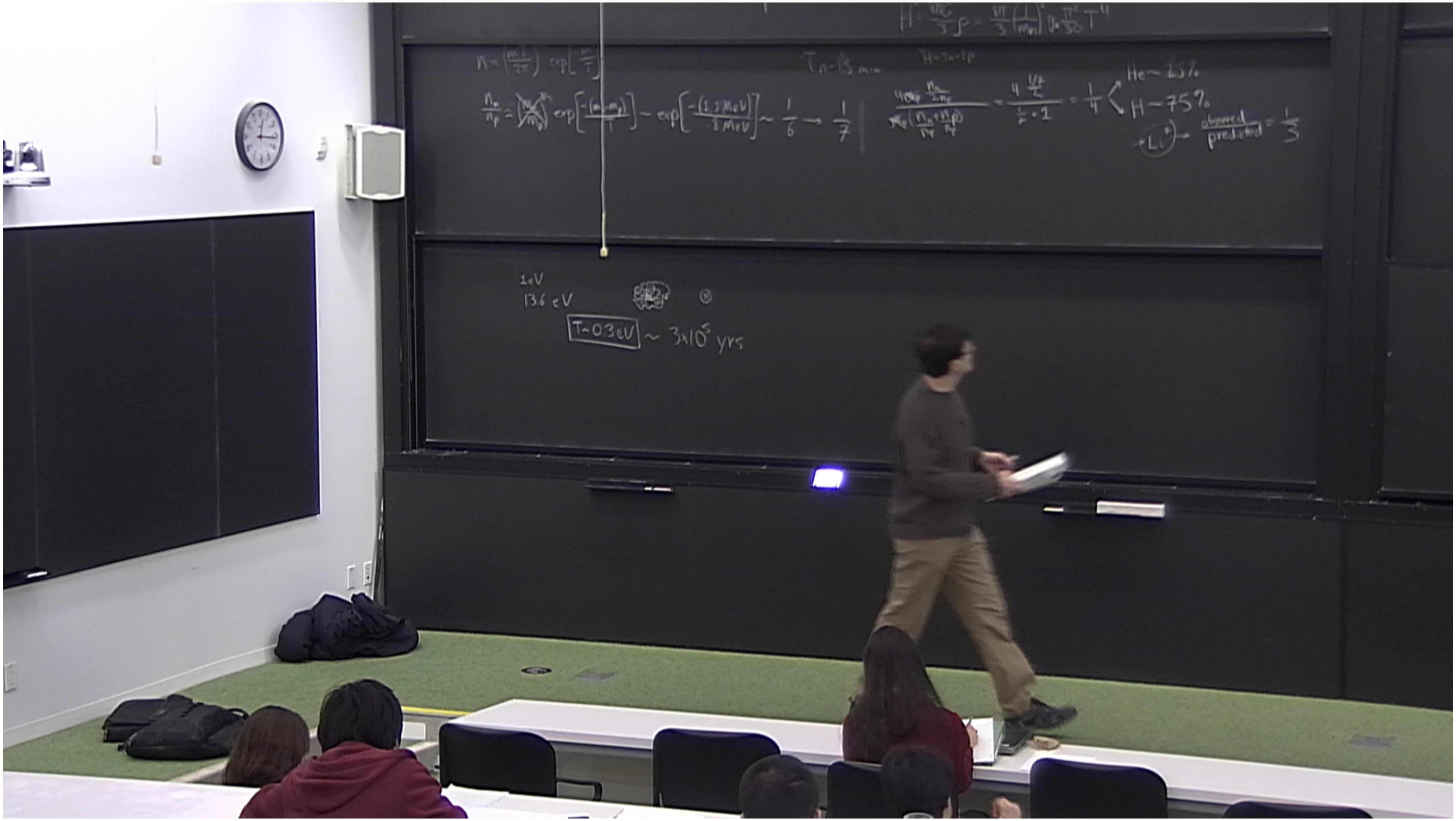
τn ~ 15 min
4H = 2n+2p
He ~ 25%
H ~ 75%

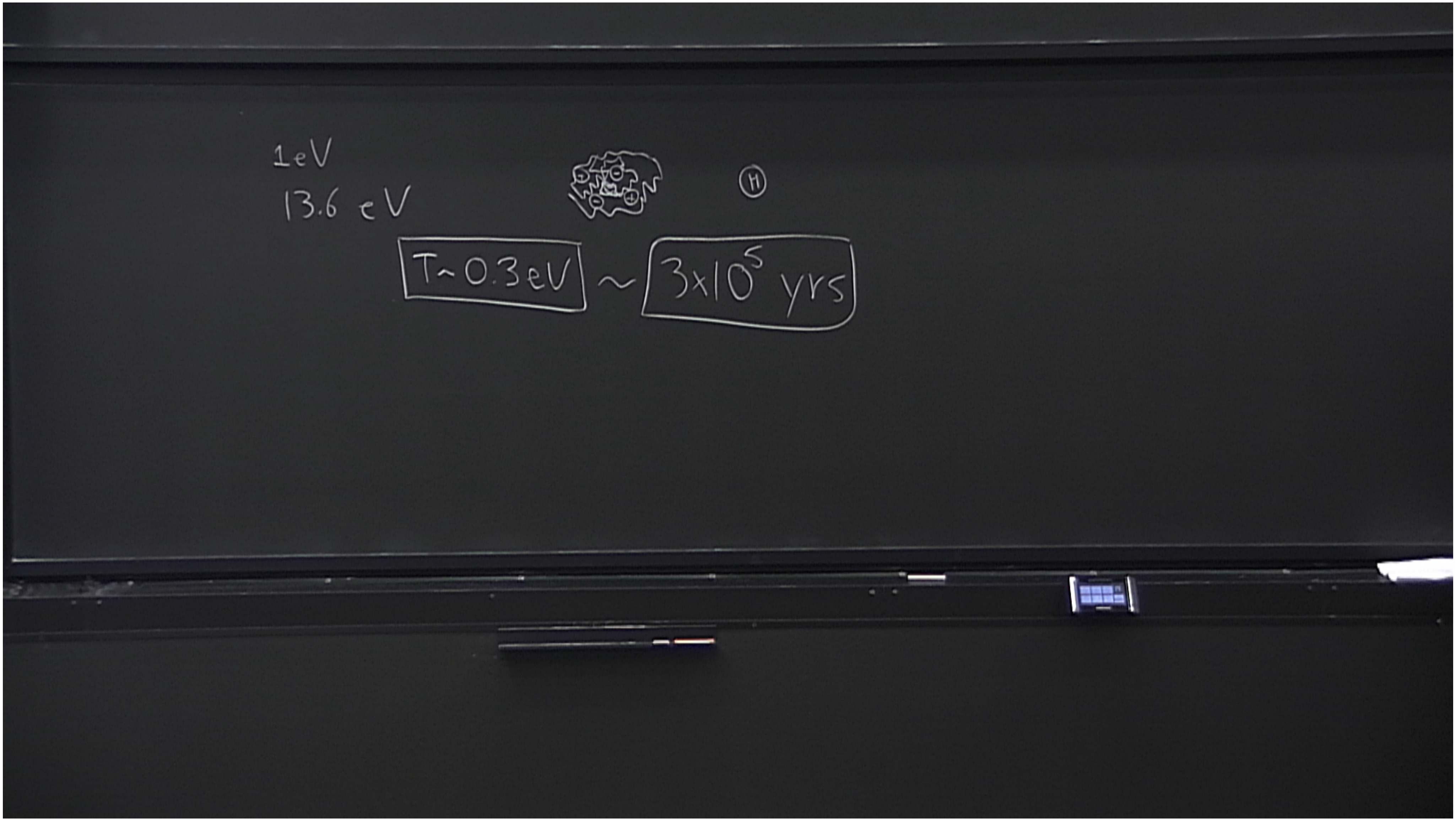

H = 8πG/3 ρ = 8π/3 (1/m_Pl) g* π²/30 T⁴
τn ~ 15 min
⁴H = 2n+2p
He ~ 25%
H ~ 75%
(1.3 MeV) / .8 MeV ~ 1/6 → 1/7
= 1/4
observed / predicted = 1/3
Li⁷ →

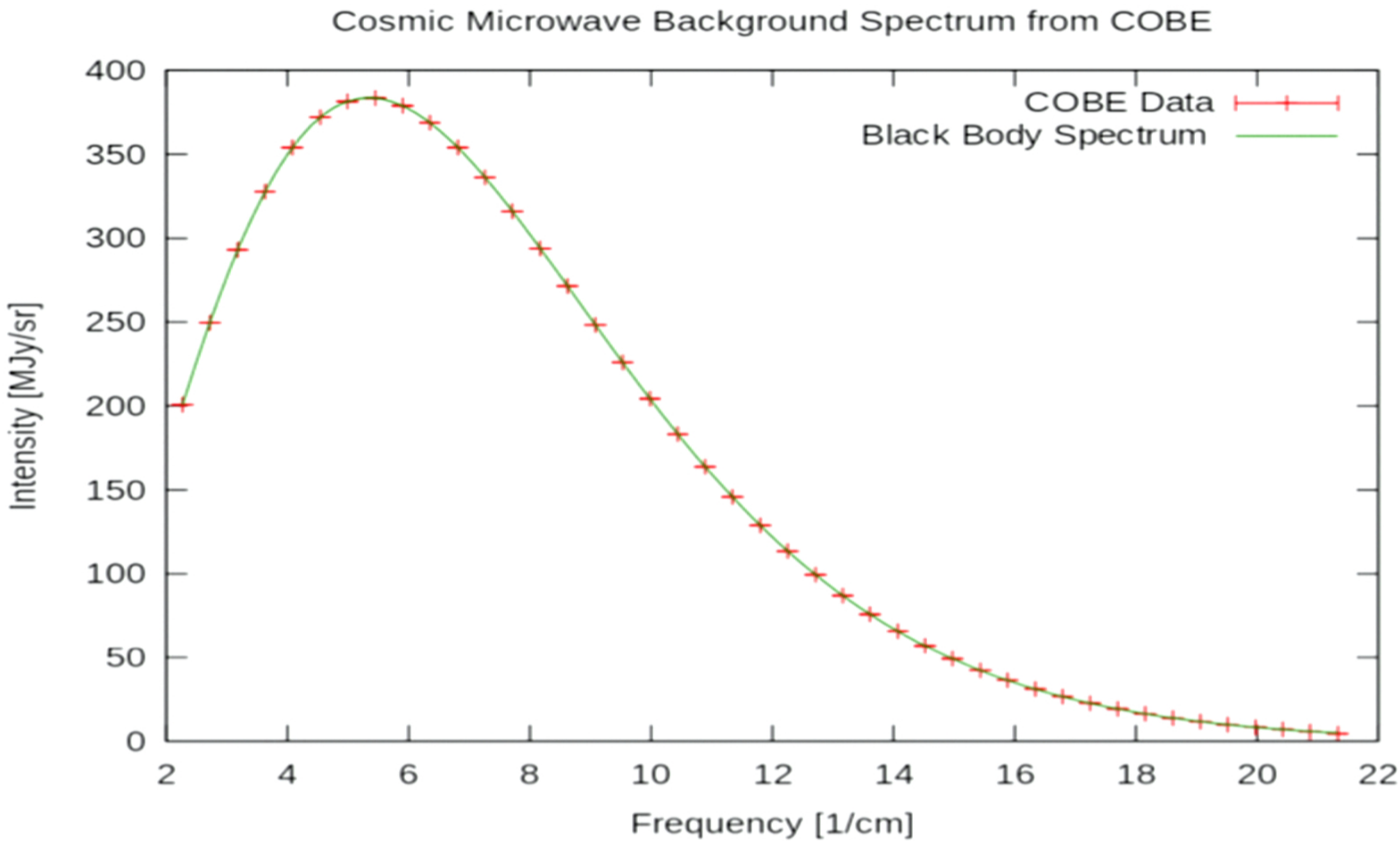

τn ~ 15 min
4He = 2n+2p
He ~ 25%
H ~ 75%
Li7
observed / predicted = 1/3
(1.3 MeV)
.8 MeV
~ 1/6 → 1/7
= 1/4

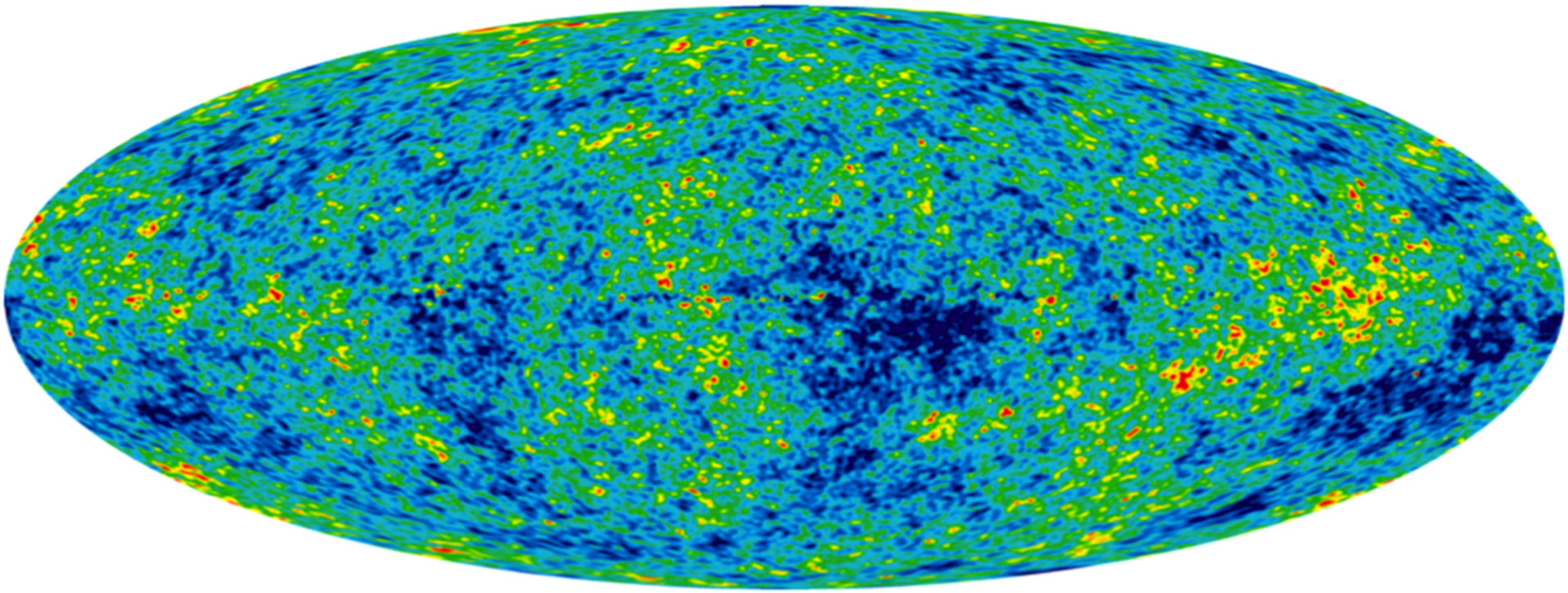

$\tau_n \sim 15$ min
$^4H = 2n + 2p$
He ~ 25%
H ~ 75%
(1.3 MeV)
.8 MeV
~ 1/6 → 1/7
= 1/4
Li^7
observed / predicted = 1/3

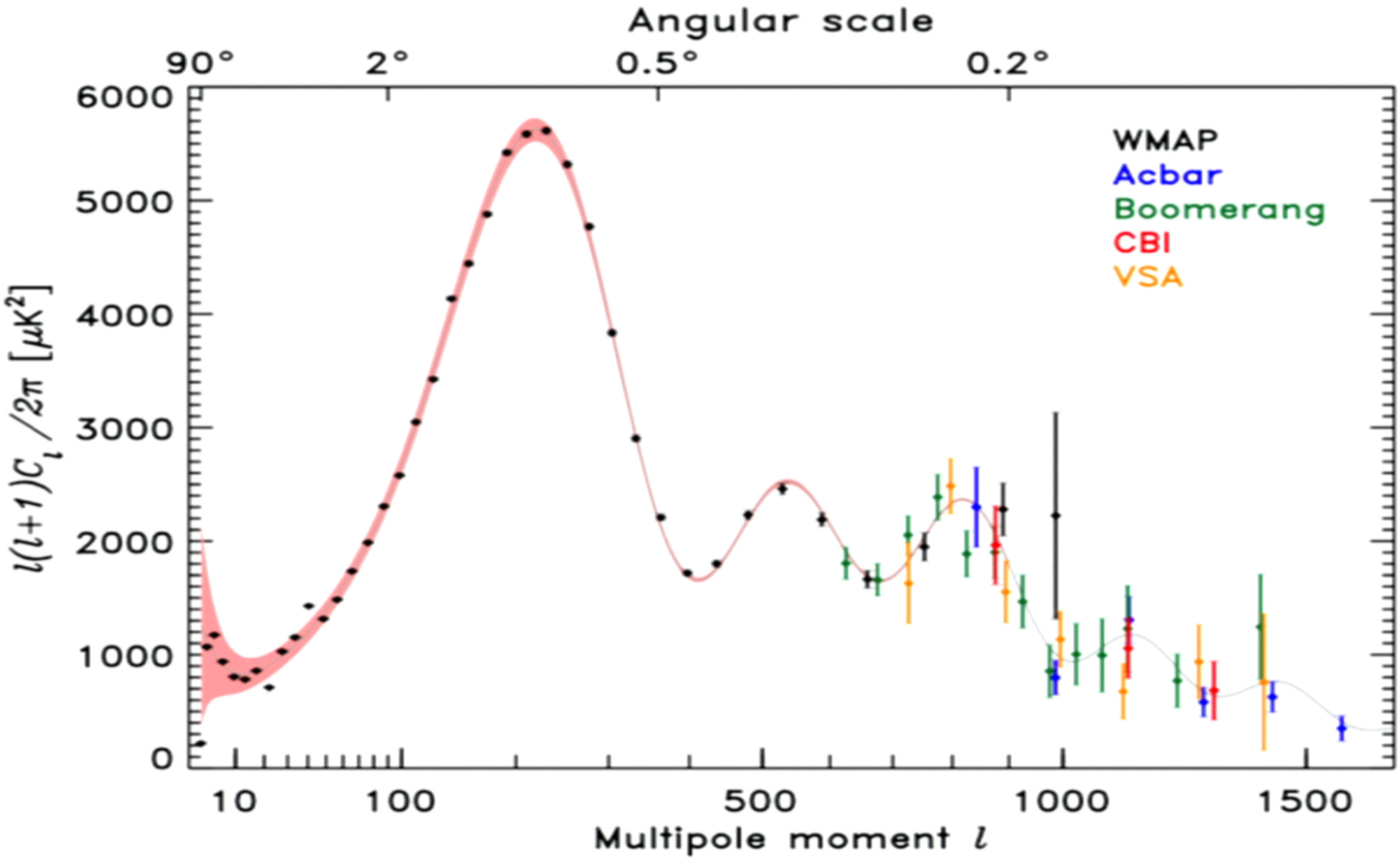
$m(2n+2p) > m_{He^4}$

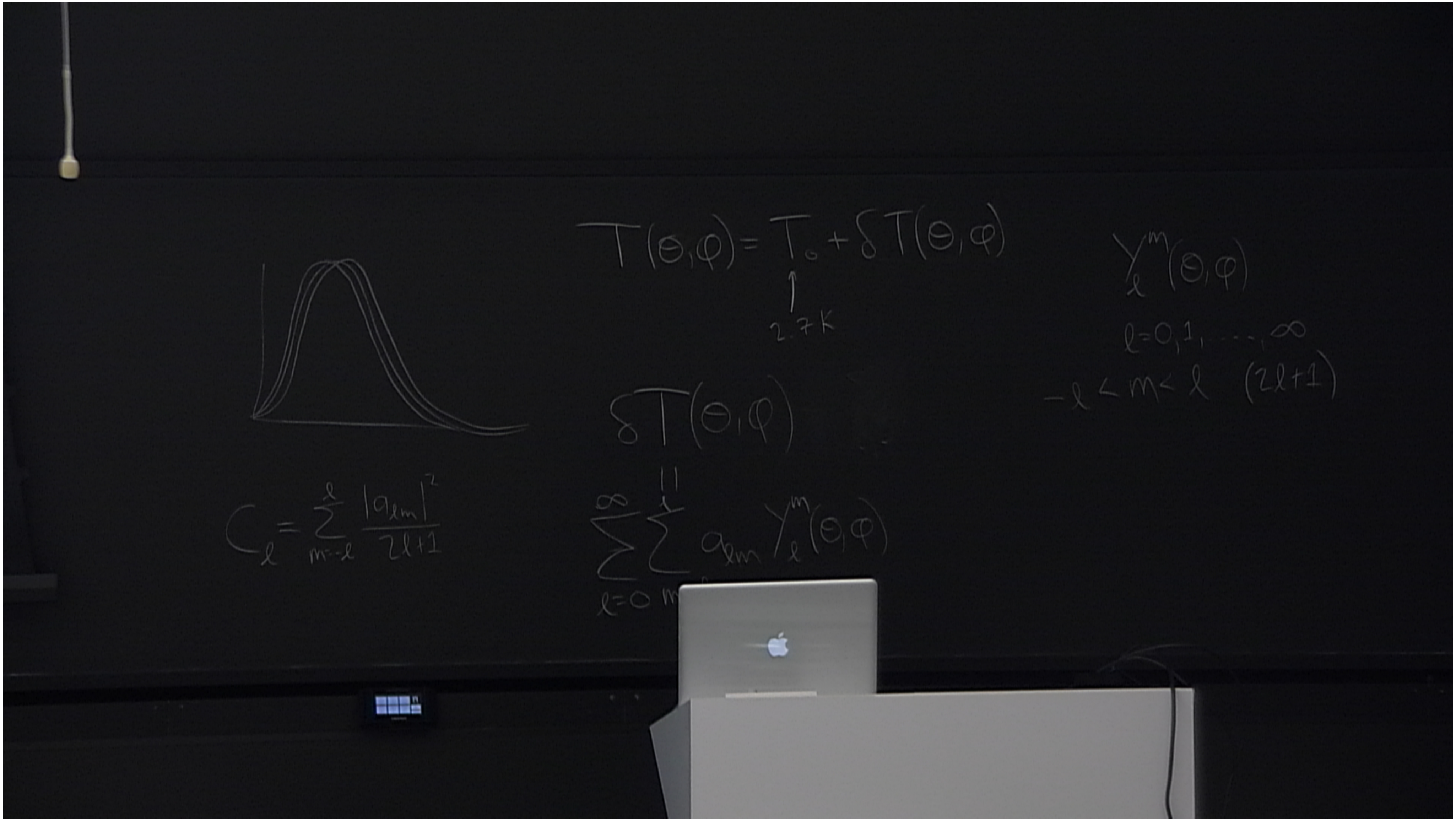


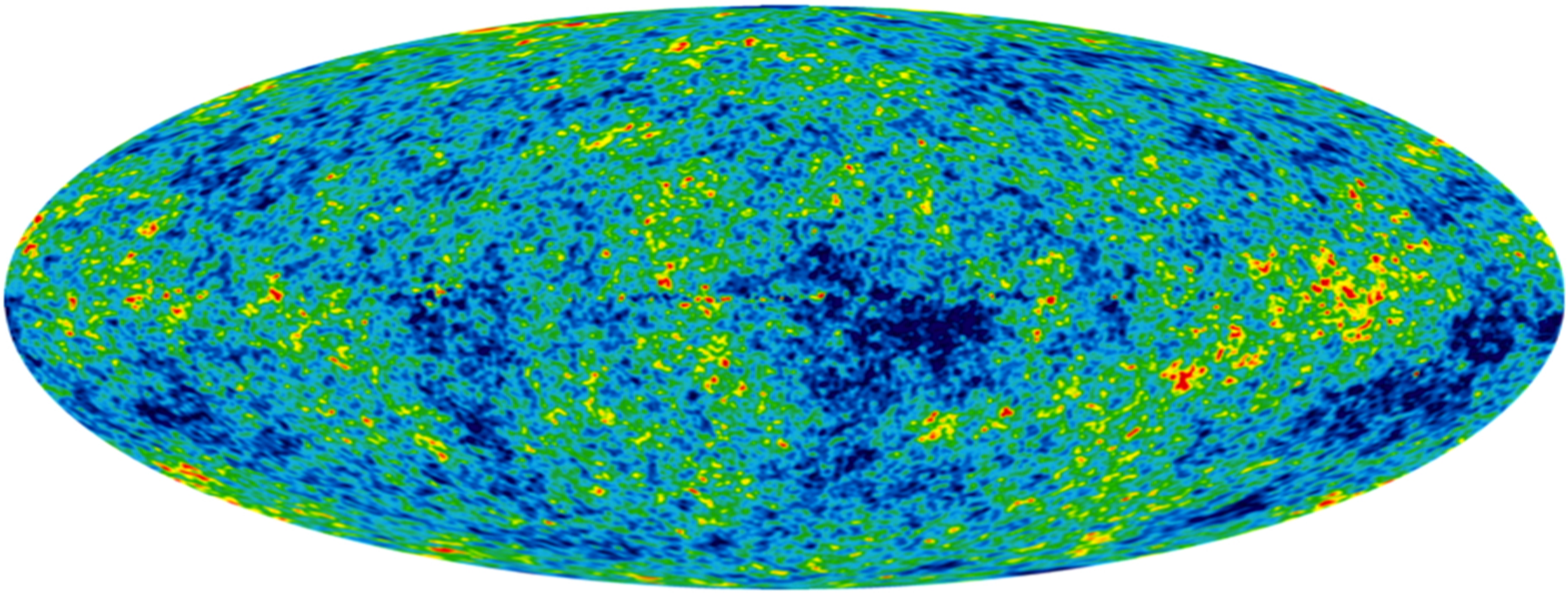

1eV
13.6 eV
H
T~0.3eV ~ 3x10^5 yrs

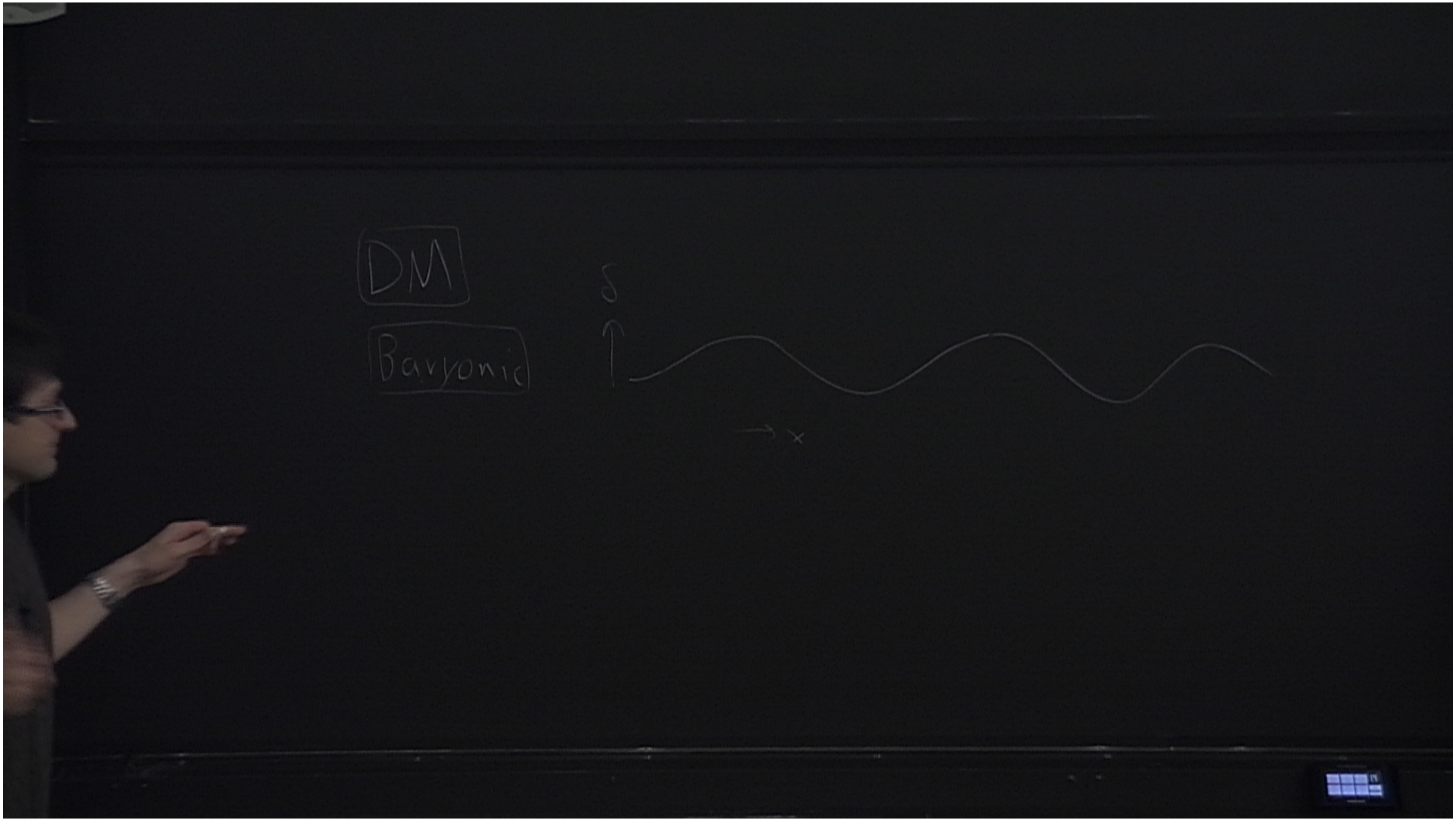

Cosmic Microwave Background Spectrum from COBE
COBE Data
Black Body Spectrum
Intensity [MJy/sr]
Frequency [1/cm]
0
50
100
150
200
250
300
350
400
2
4
6
8
10
12
14
16
18
20
22

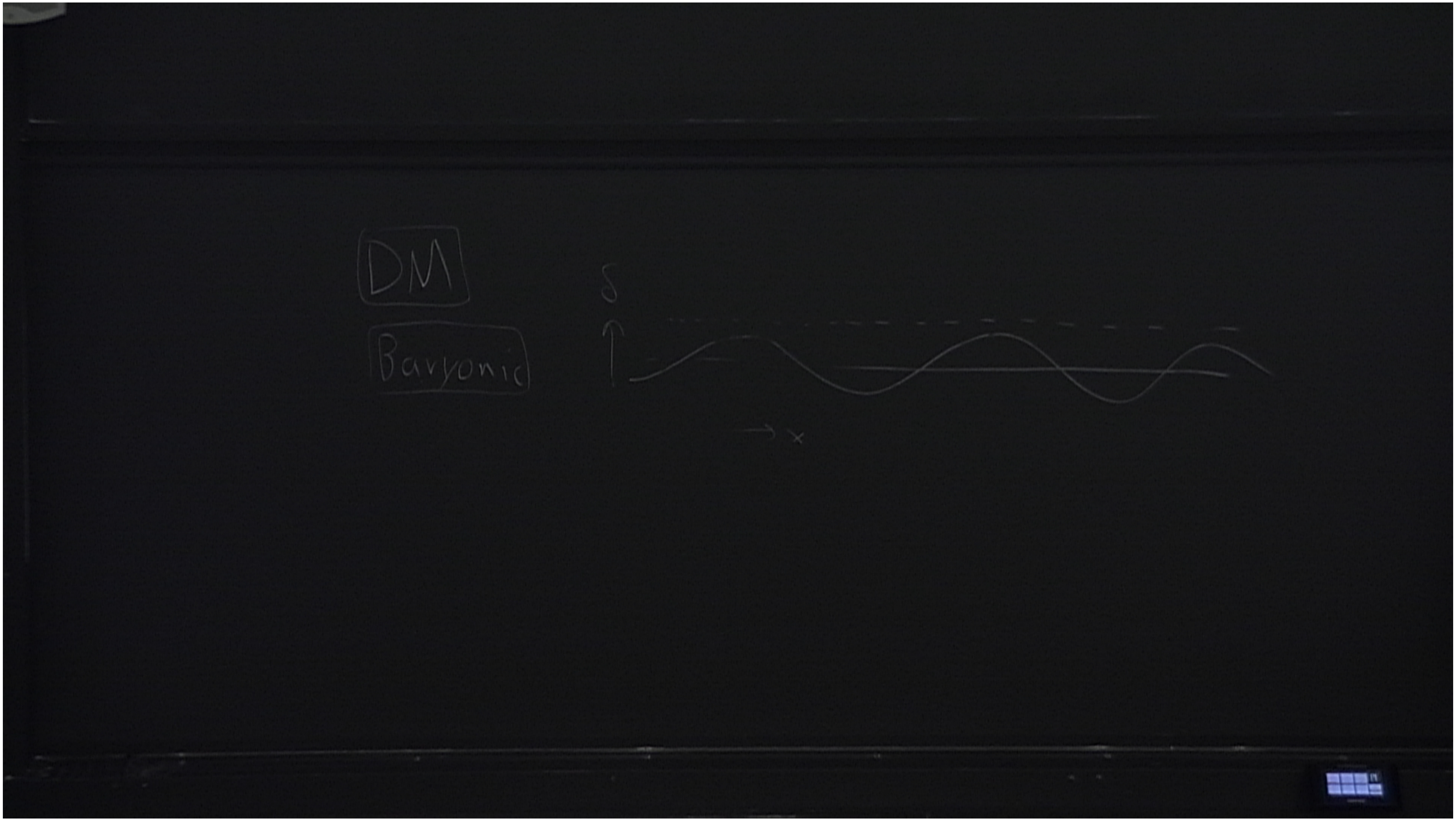


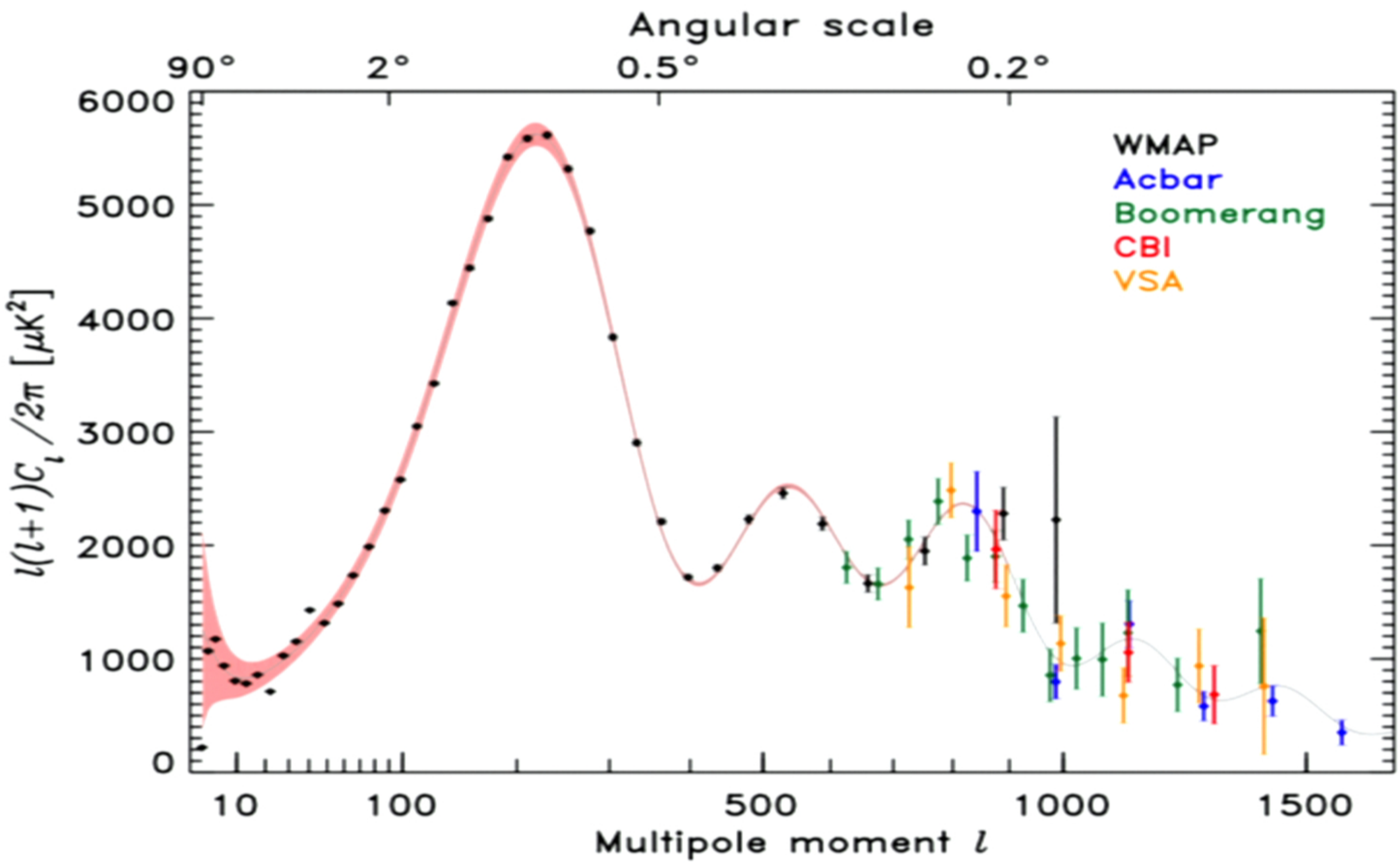

Angular scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
WMAP
Acbar
Boomerang
CBI
VSA
l(l+1)C_l /2π [μK²]
10
100
500
1000
1500
Multipole moment l


$T(\theta,\varphi) = T_0 + \delta T(\theta,\varphi)$
2.7K
$Y_\ell^m(\theta,\varphi)$
$\ell = 0, 1, \ldots, \infty$
$-\ell < m < \ell \quad (2\ell+1)$
$\delta T(\theta,\varphi) = \sum_{\ell=0}^{\infty} \sum_{m}^{\ell} a_{\ell m} Y_\ell^m(\theta,\varphi)$
$C_\ell = \sum_{m=-\ell}^{\ell} \frac{|a_{\ell m}|^2}{2\ell+1}$




DM
Baryonic
δ
x


DM
Baryonic
δ
x


Angular scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi\ [\mu K^2]$
WMAP
Acbar
Boomerang
CBI
VSA
10
100
500
1000
1500
Multipole moment l