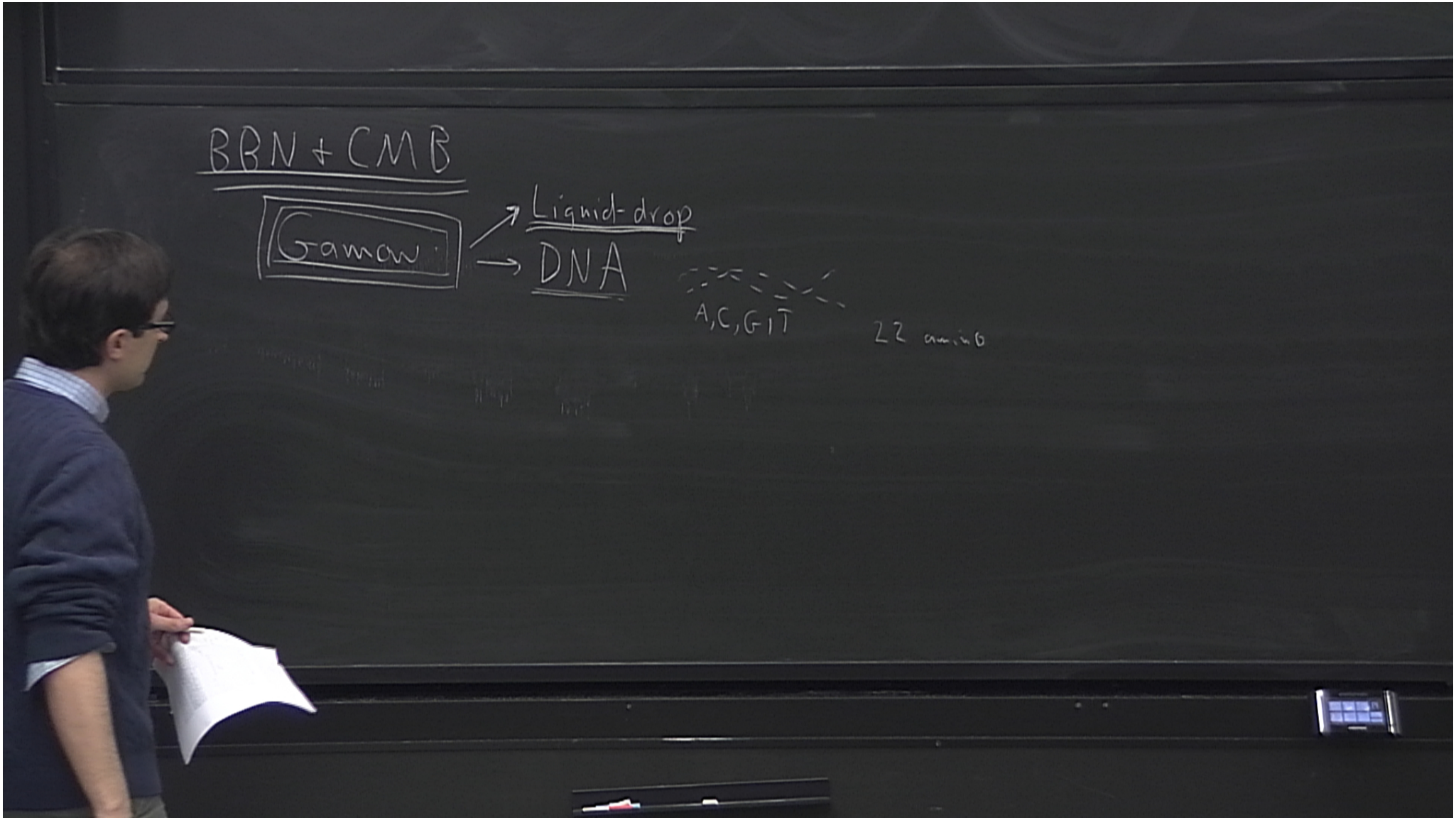
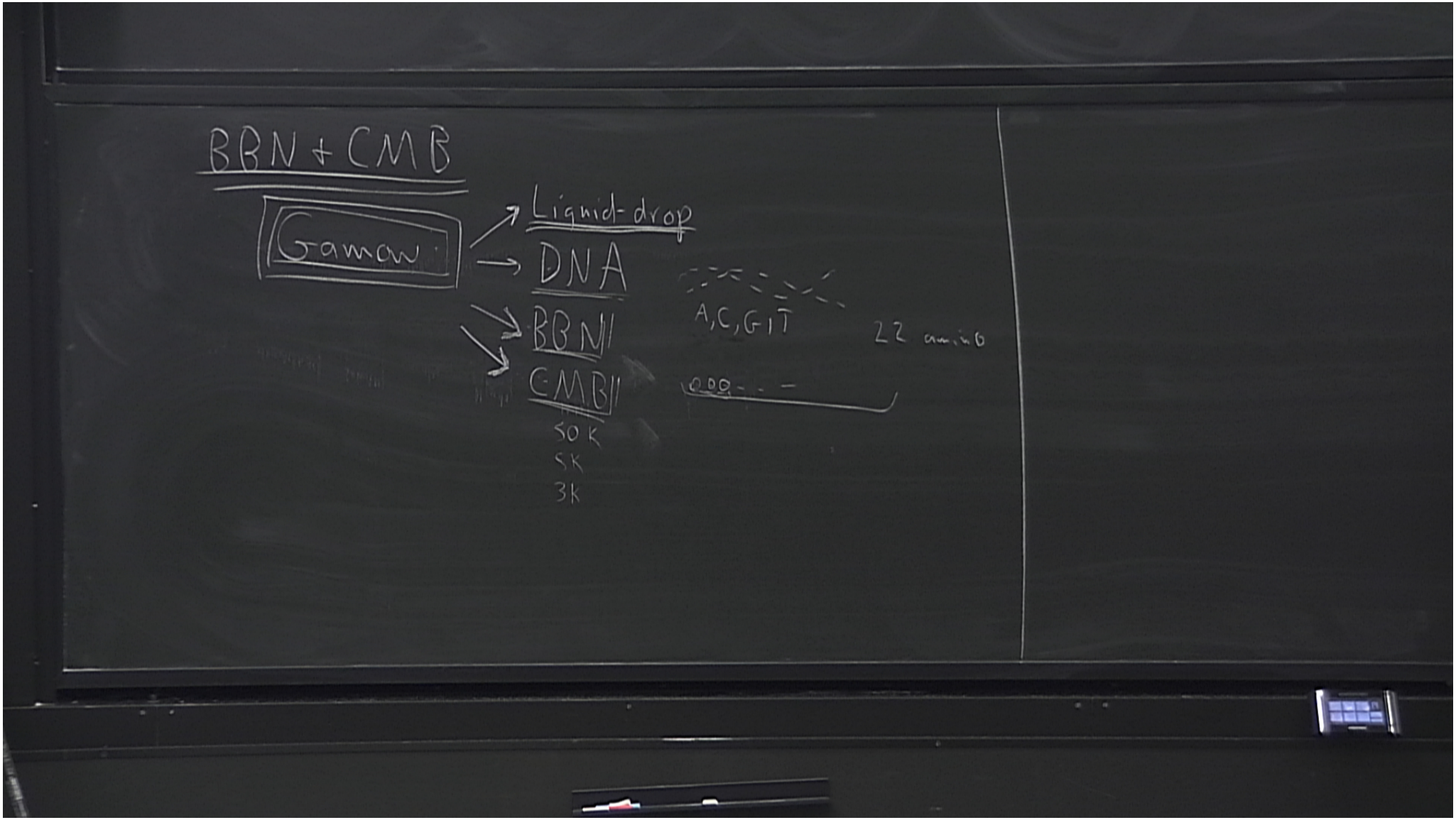
Title: 13/14 PSI - Cosmology Review - Lecture 6

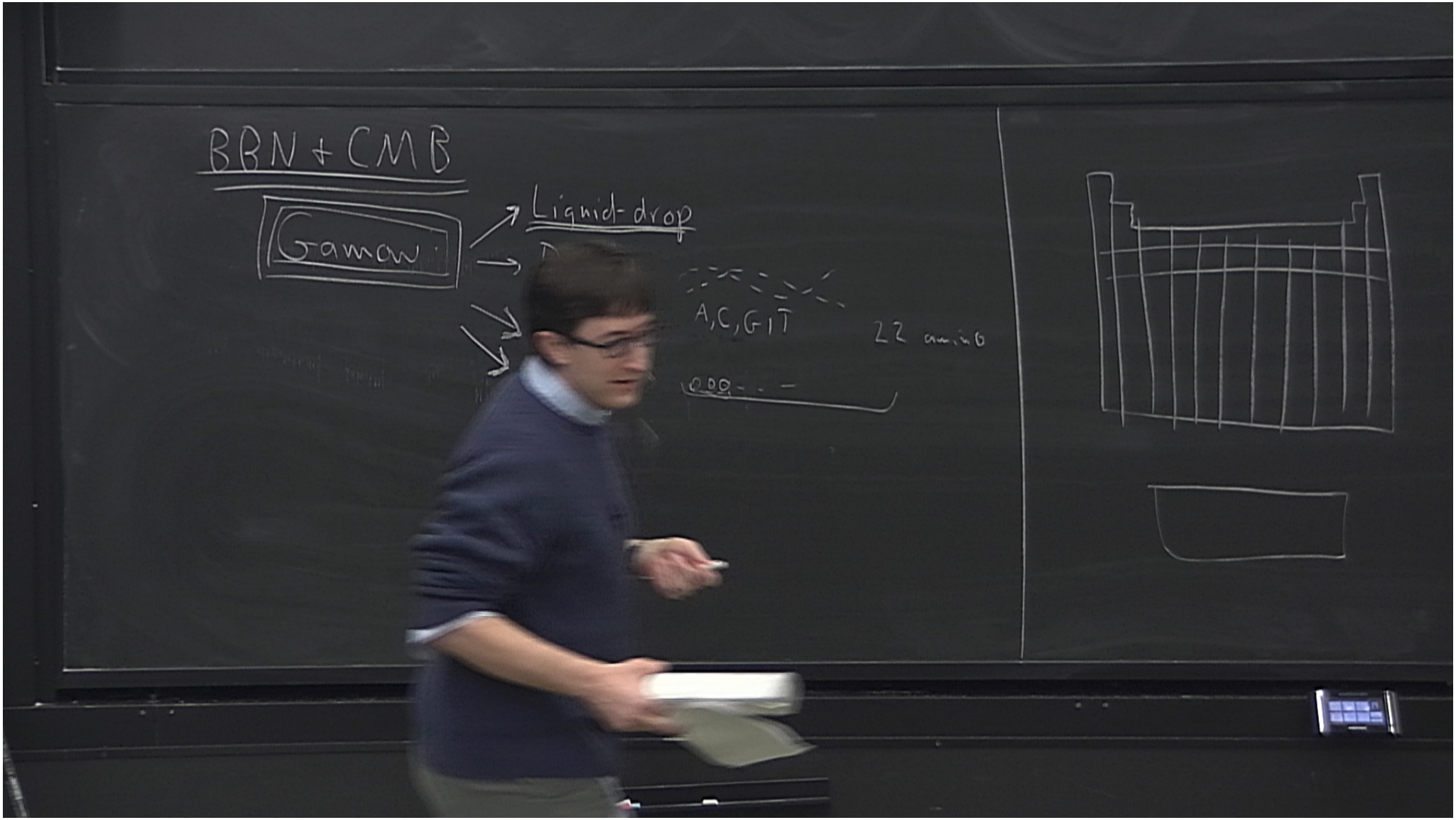
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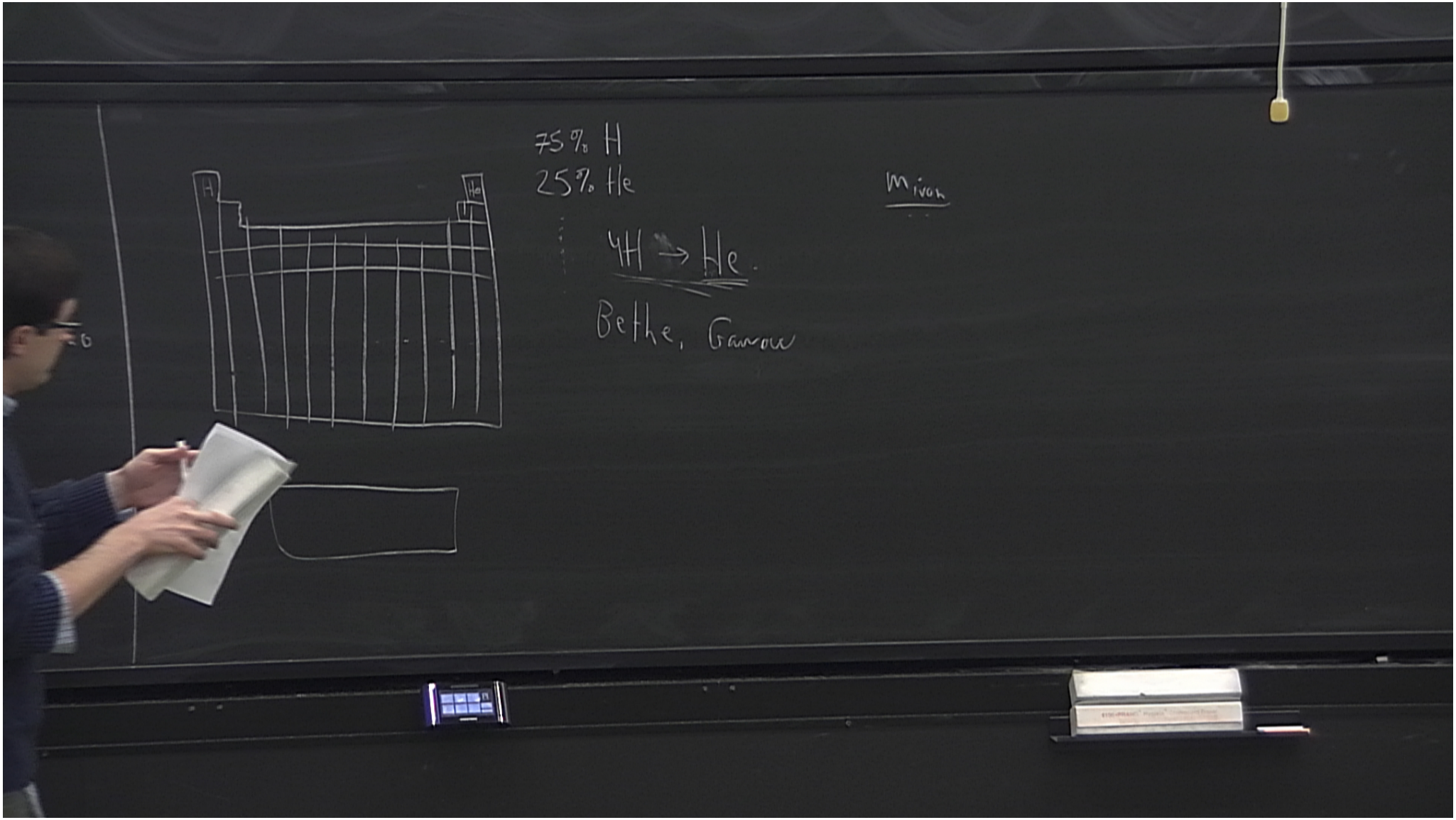
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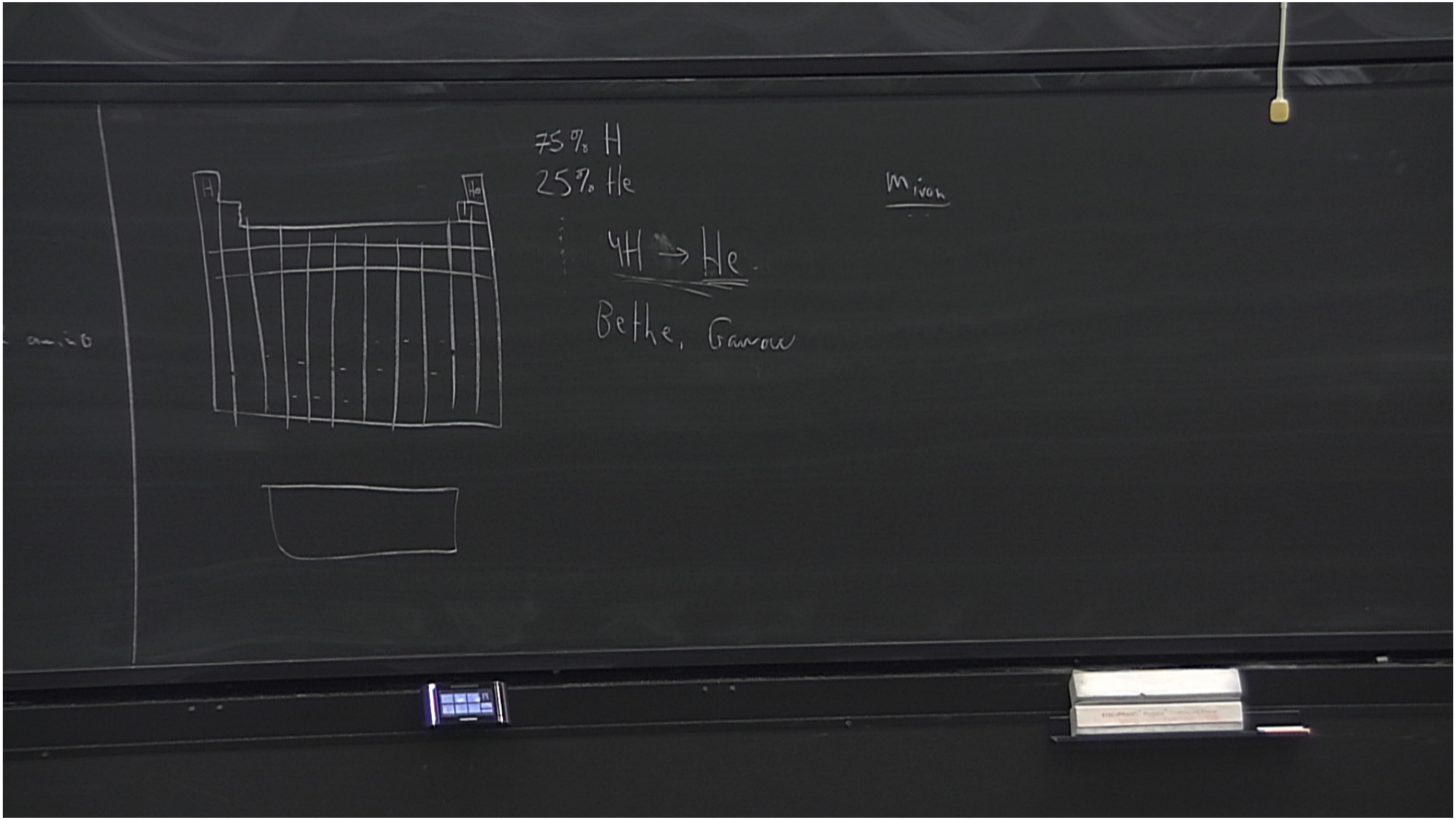
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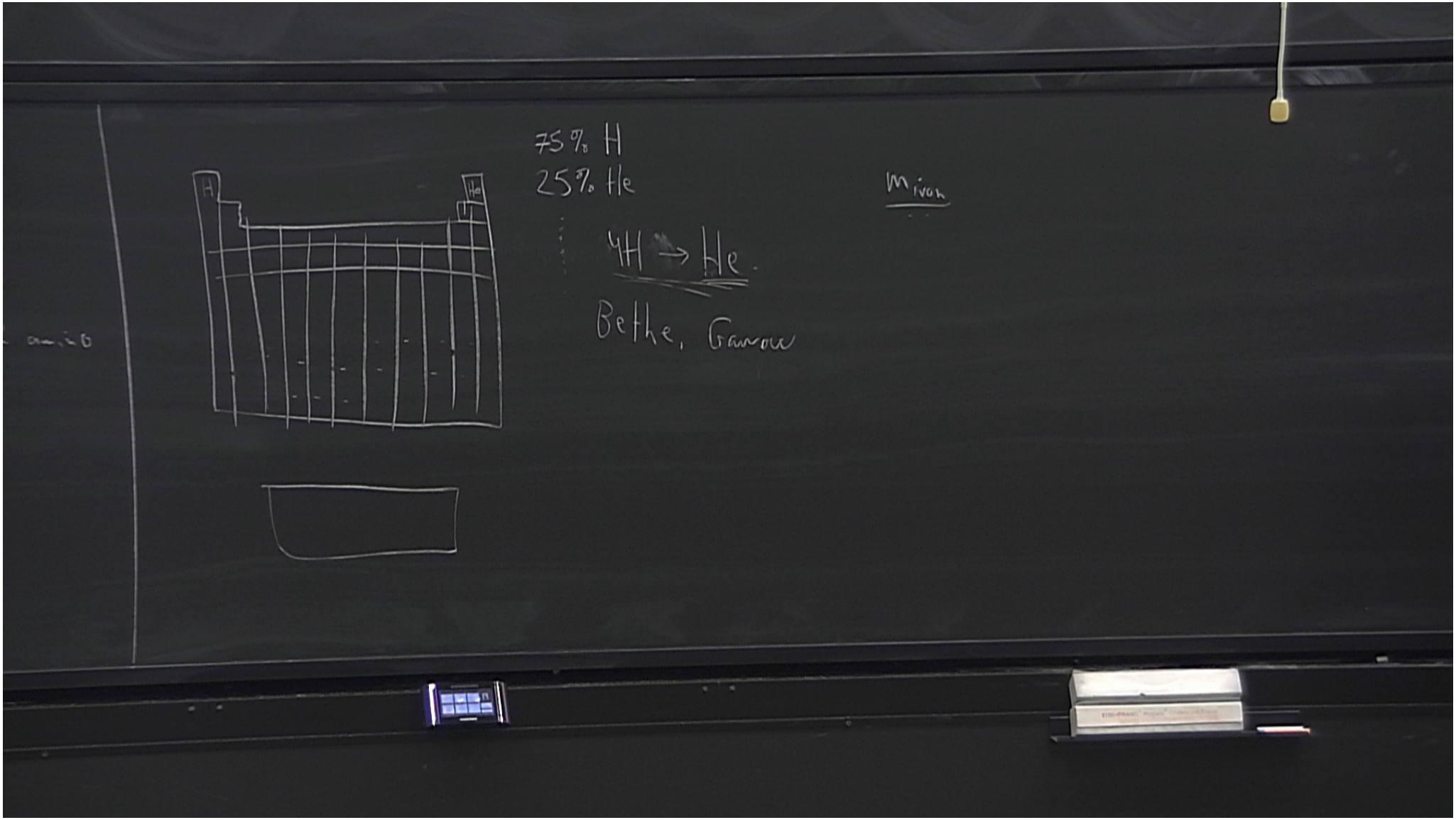

BBN + CMB
Gamow
Liquid-drop
DNA
A,C,G,T
22 amino

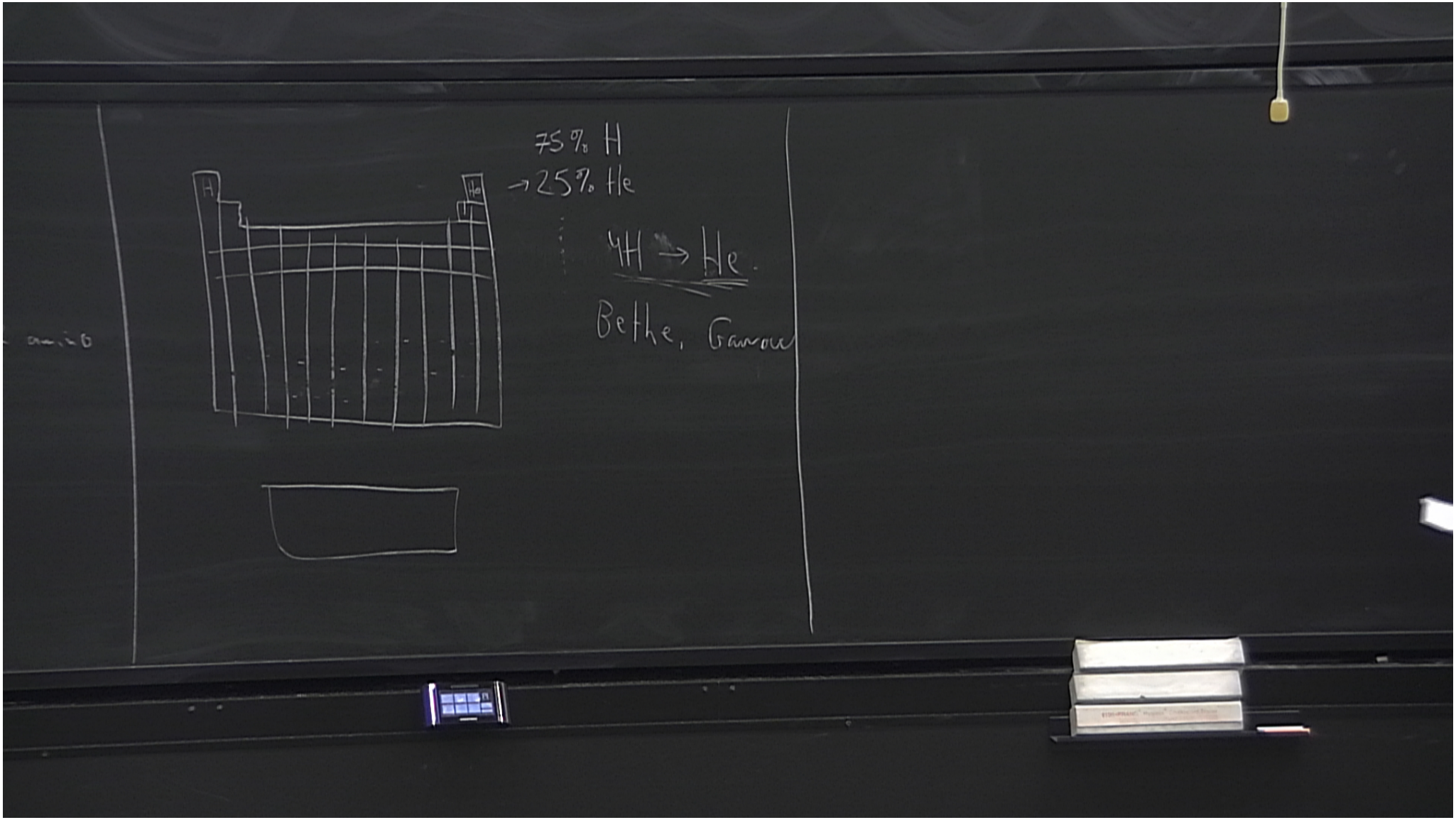

BBN + CMB
Gamow
Liquid-drop
DNA
BBN
CMB
50 K
5K
3k
A,C,G,T
22 amino

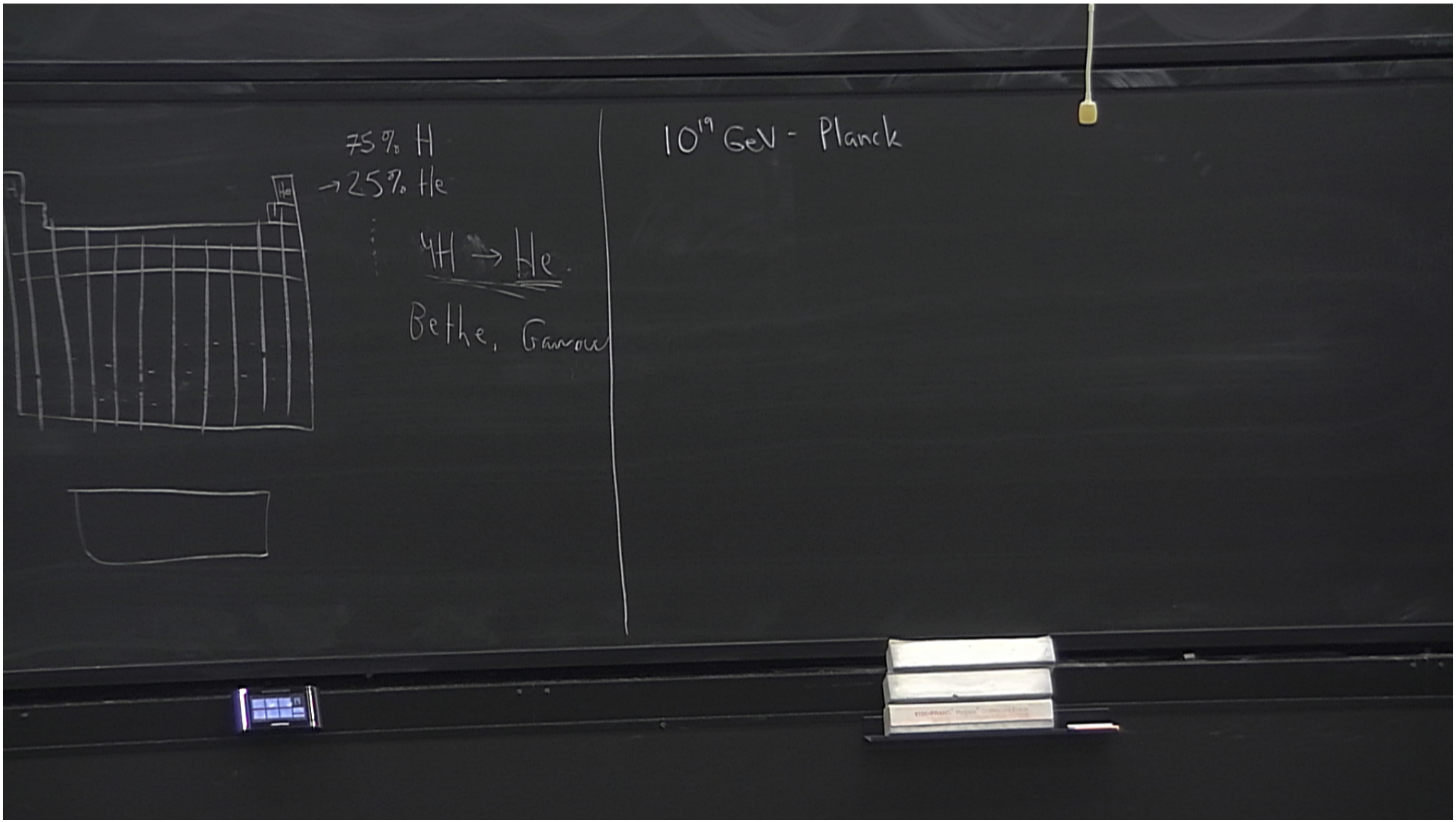

BBN + CMB
Gamow
Liquid-drop
A,C,G,T
22 amino

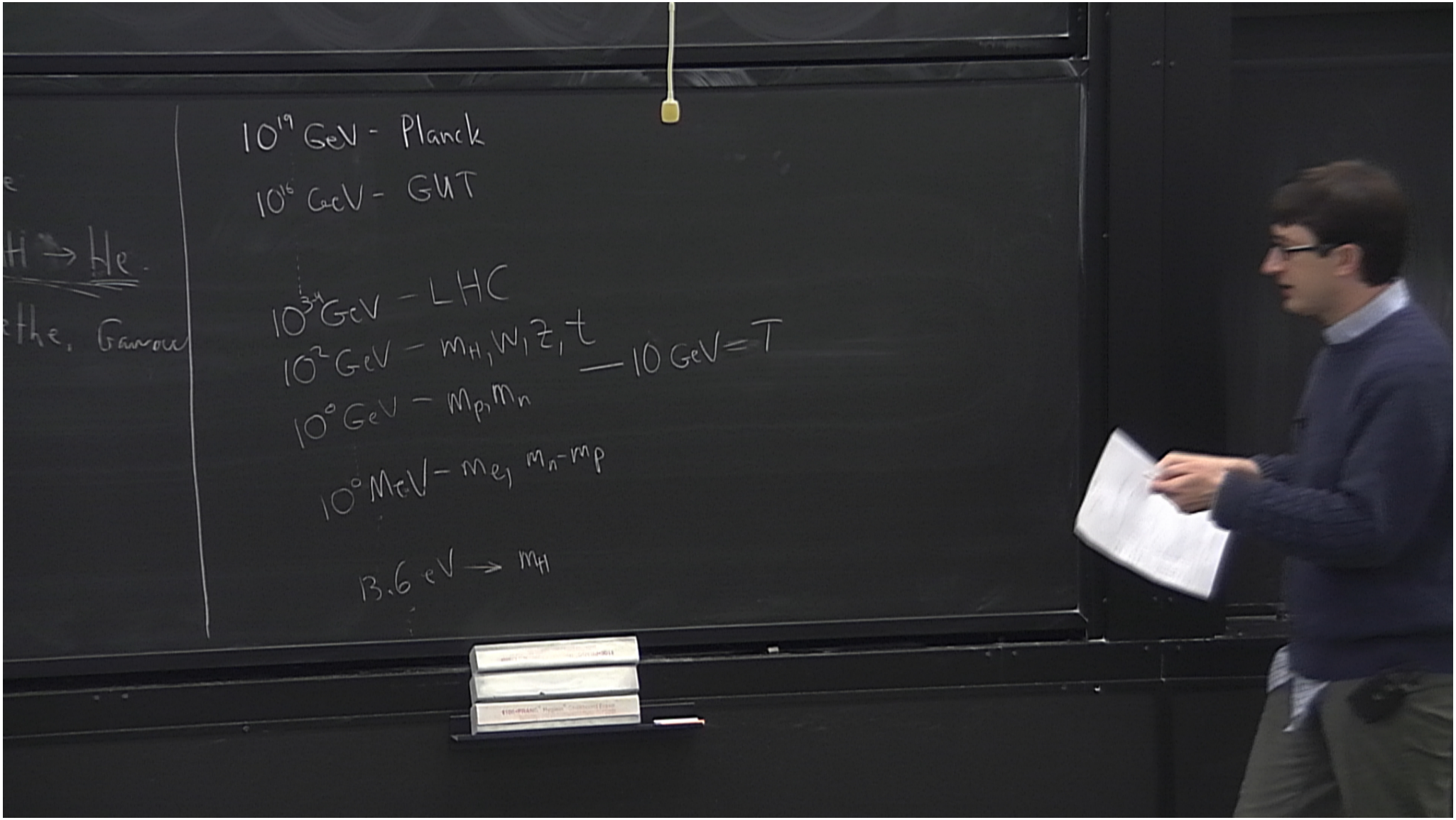

75% H
25% He
4H → He.
Bethe, Gamow
H
He

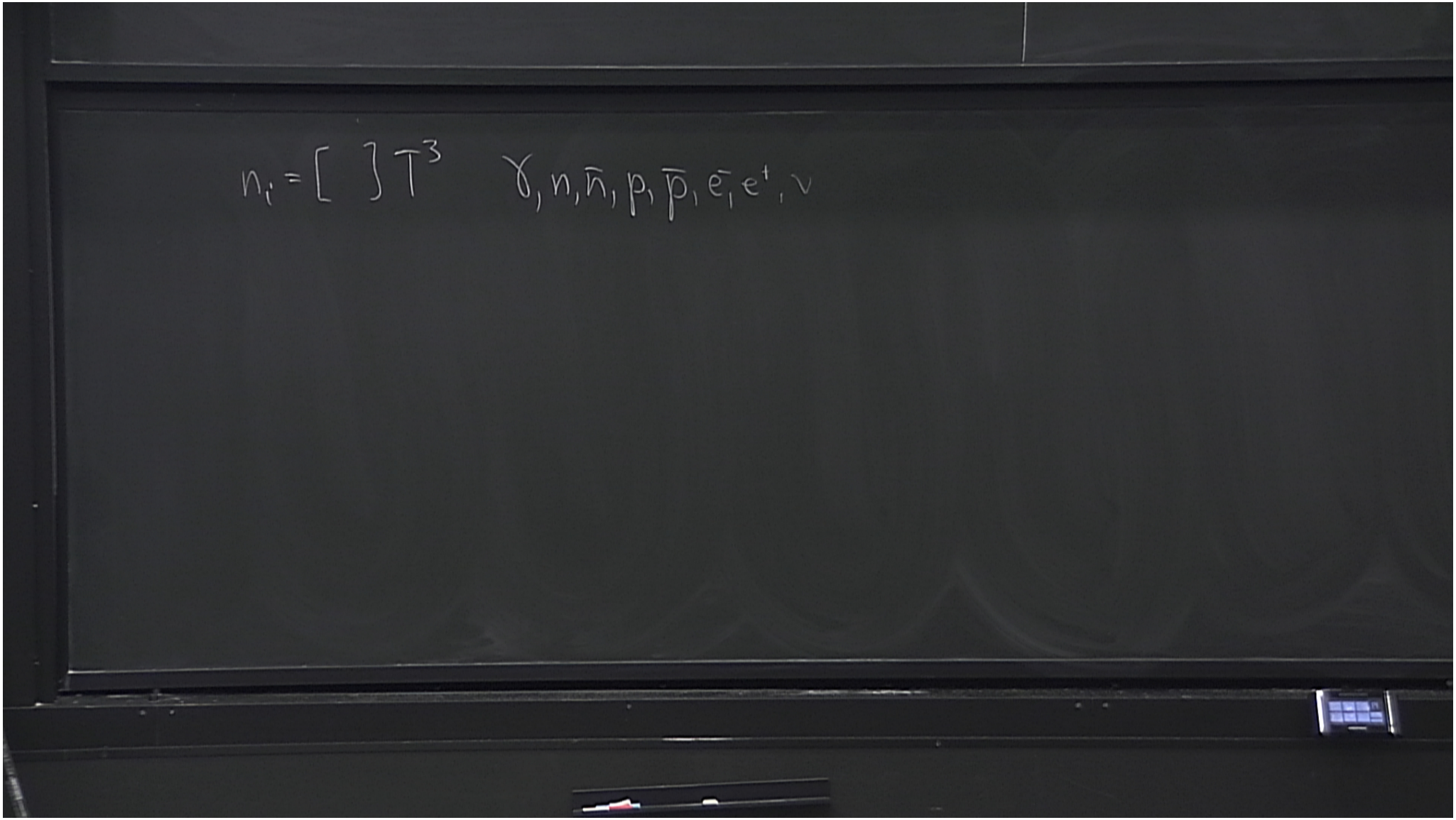

75% H
25% He
m_{ivan}
$4H \rightarrow He$.
Bethe, Gamow

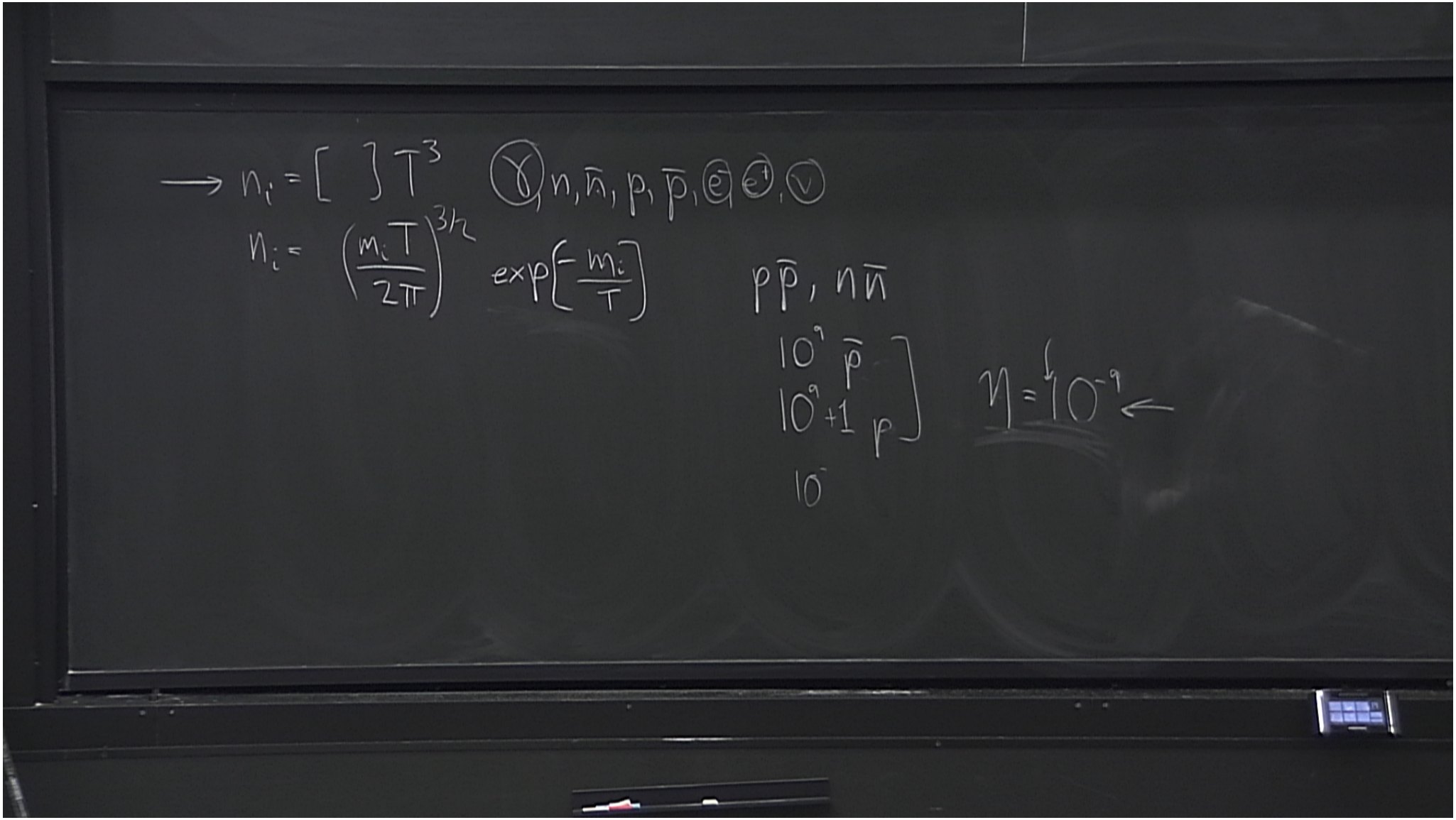

75% H
25% He
m_{ivan}
4H → He.
Bethe, Gamow

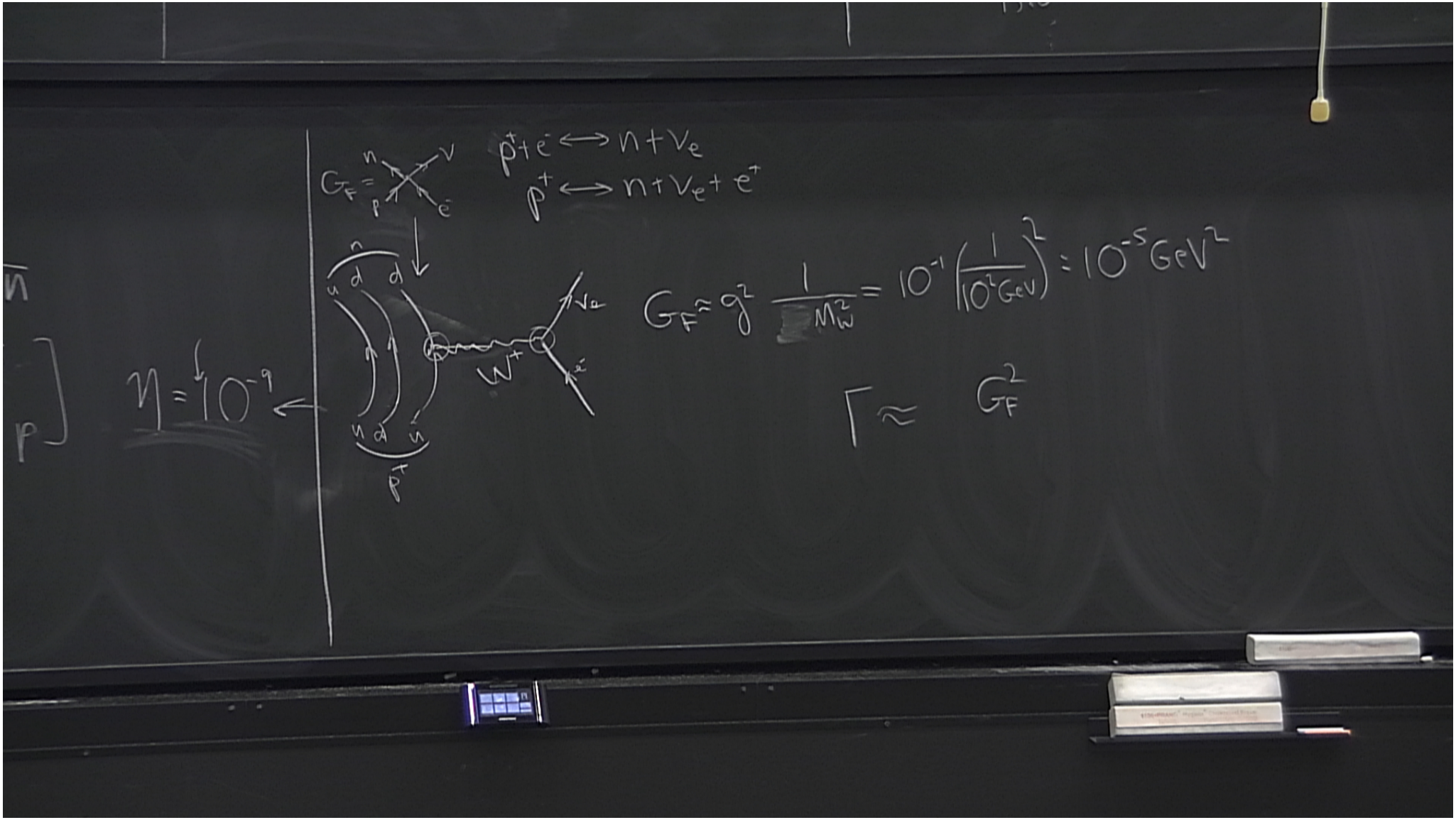

75% H
→ 25% He
4H → He.
Bethe, Gamow

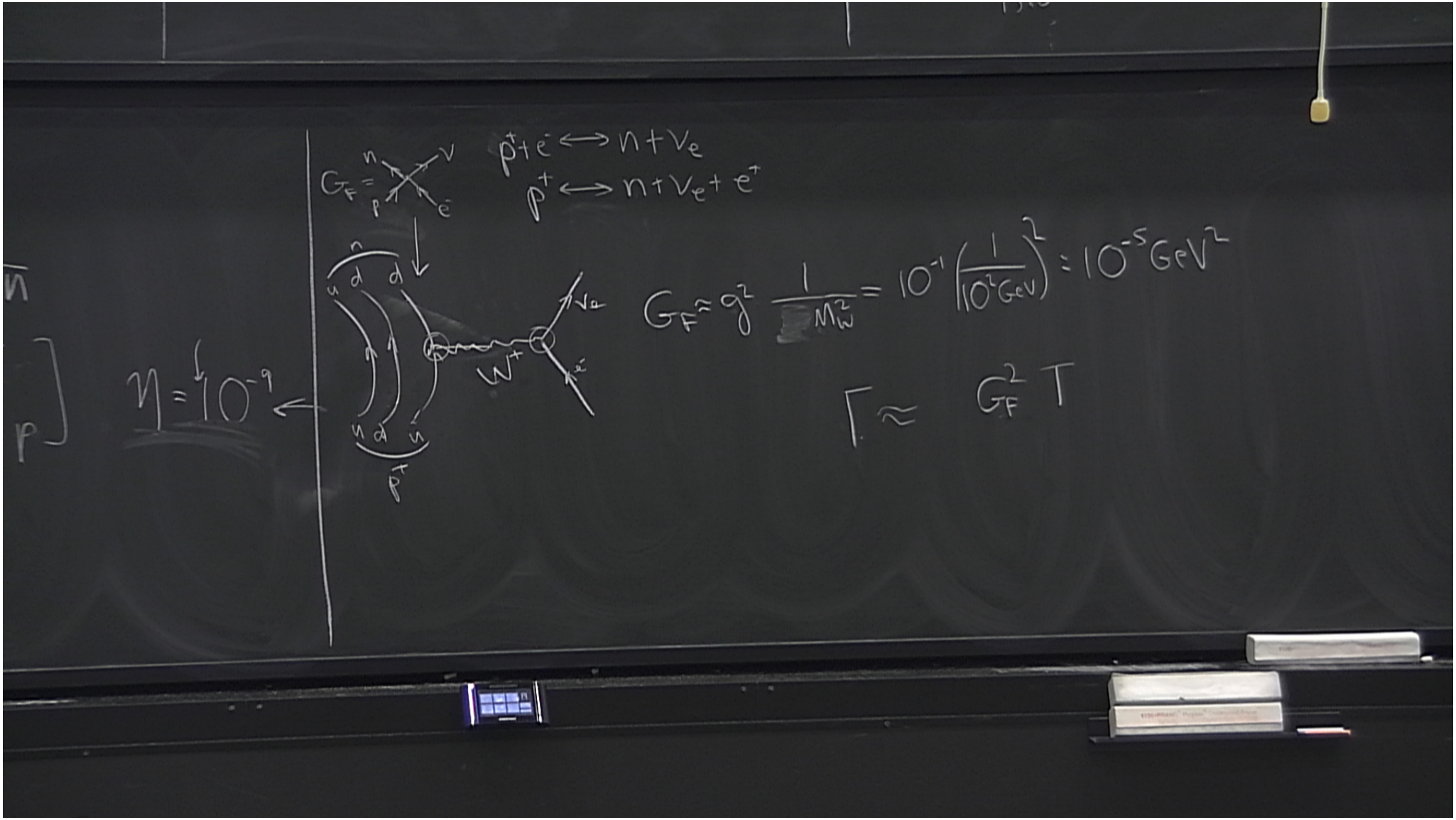

75% H
→ 25% He
4H → He
Bethe, Gamow
10^19 GeV - Planck

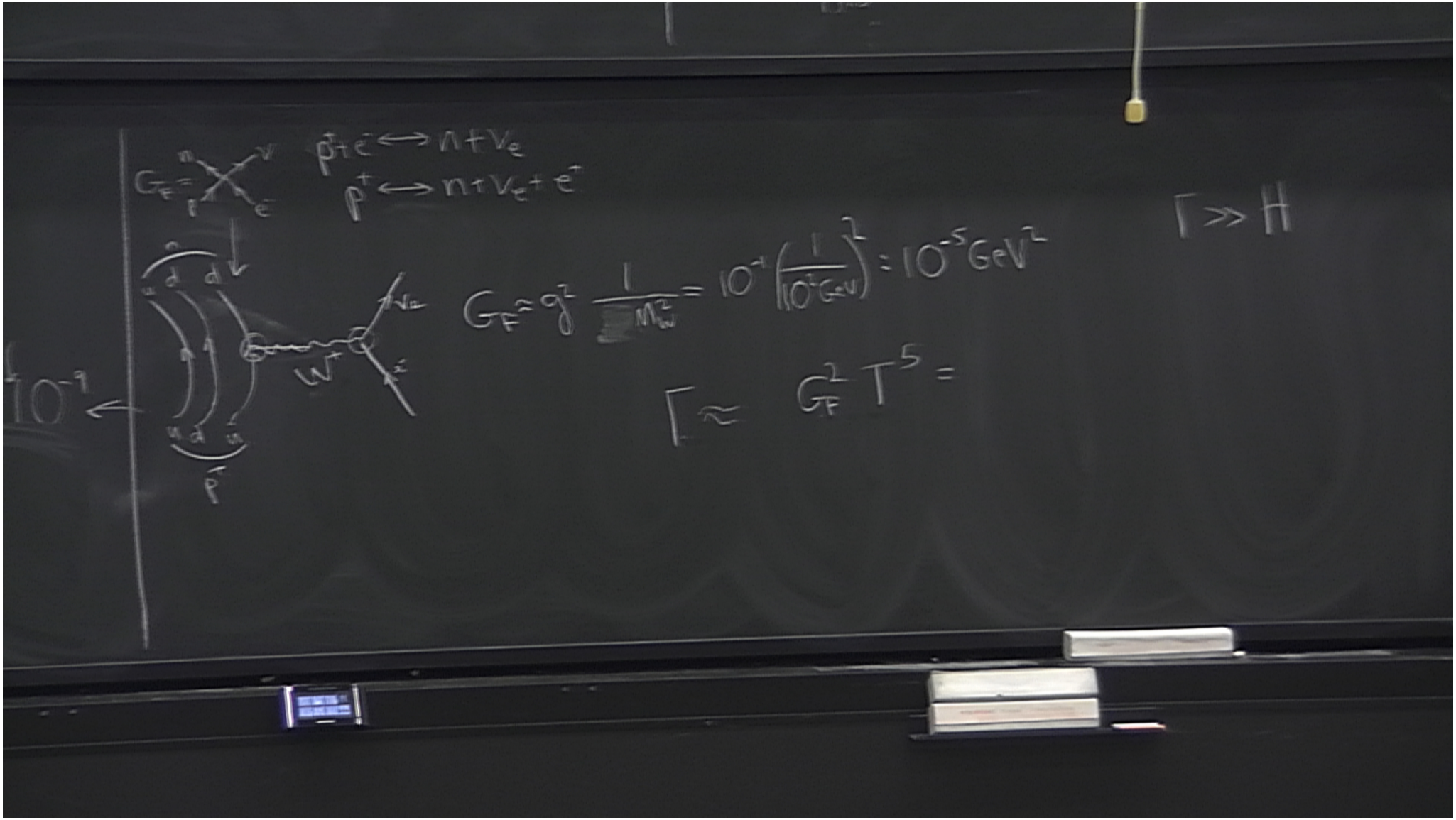

10^{19} GeV - Planck
10^{16} GeV - GUT
10^{3} GeV - LHC
10^{2} GeV - m_H, W, Z, t
10^{0} GeV - m_p, m_n
10^{0} MeV - m_e, $m_n - m_p$
13.6 eV → m_H
— 10 GeV = T

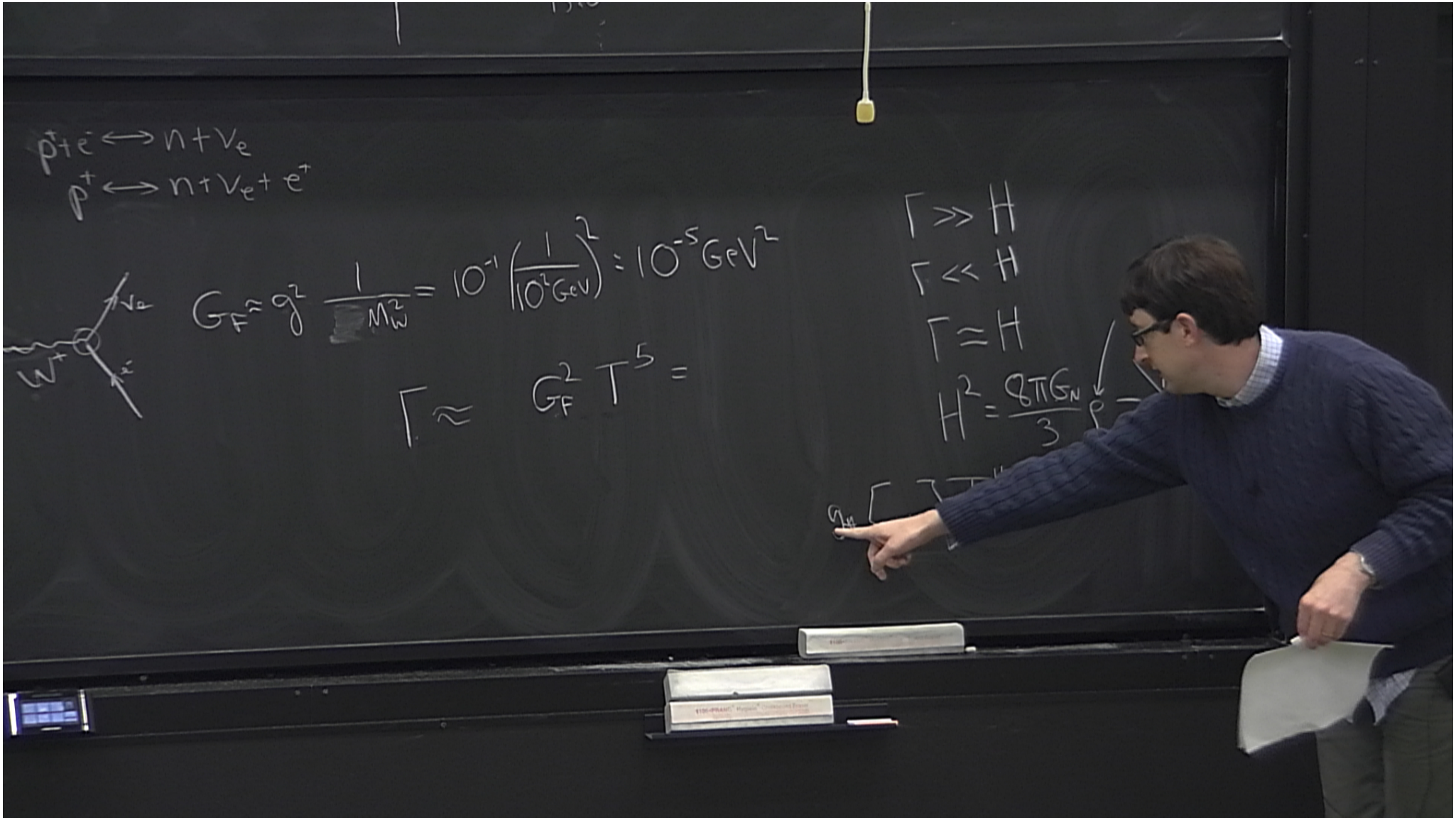

$n_i = [\ ]\, T^3$ $\gamma, n, \bar{n}, p, \bar{p}, e^-, e^+, \nu$


$\rightarrow n_i = [\ ]\, T^3$ $\gamma, n, \bar{n}, p, \bar{p}, e^-, e^+, \nu$
$n_i = \left(\frac{m_i T}{2\pi}\right)^{3/2} \exp\left[-\frac{m_i}{T}\right]$
$p\bar{p}, n\bar{n}$
$10^9\ \bar{p}$
$10^9+1\ p$
10^{-}
$\eta = \frac{1}{10^9}$


$G_F =$
n
ν
p
e
$p^+ + e^- \leftrightarrow n + \nu_e$
$p^+ \leftrightarrow n + \nu_e + e^+$
u d d
u d
W^+
ν_e
e^+
u d u
p^+
$G_F \approx g^2 \frac{1}{M_W^2} = 10^{-1} \left(\frac{1}{10^2 GeV}\right)^2 \approx 10^{-5} GeV^{-2}$
$\Gamma \approx G_F^2$
$\eta = \frac{1}{4} 10^{-9}$

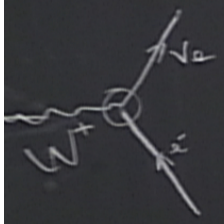

$p^+ + e^- \leftrightarrow n + \nu_e$
$p^+ \leftrightarrow n + \nu_e + e^+$
$G_F \approx g^2 \frac{1}{M_W^2} = 10^{-1} \left(\frac{1}{10^2\,GeV}\right)^2 \approx 10^{-5}\,GeV^{-2}$
$\Gamma \approx G_F^2 T$
$\eta = \frac{1}{4} 10^{-9}$
W^+
ν_e
e^+


G_F
$p + e^- \leftrightarrow n + \nu_e$
$p^+ \leftrightarrow n + \nu_e + e^+$
$G_F \approx g^2 \frac{1}{M_W^2} = 10^{-1} \left(\frac{1}{10^2 GeV}\right)^2 = 10^{-5} GeV^{-2}$
$\Gamma \gg H$
$\Gamma \approx G_F^2 T^5 =$
10^{-9}
W^+
ν_e
e^+
u d d
u d u
p^+


$p^+ e^- \longleftrightarrow n + \nu_e$
$p^+ \longleftrightarrow n + \nu_e + e^+$
W^+
ν_e
e^+
$G_F \approx g^2 \frac{1}{M_W^2} = 10^{-1} \left(\frac{1}{10^2 GeV}\right)^2 = 10^{-5} GeV^{-2}$
$\Gamma \approx G_F^2 T^5 =$
$\Gamma \gg H$
$\Gamma \ll H$
$\Gamma \simeq H$
$H^2 = \frac{8\pi G_N}{3} \rho$

$p + e^- \longleftrightarrow n + \nu_e$

$p^+ \longleftrightarrow n + \nu_e + e^+$



$G_F \approx g^2 \frac{1}{M_W^2} = 10^{-1}\left(\frac{1}{10^2\,GeV}\right)^2 \approx 10^{-5}\,GeV^{-2}$

$\Gamma \approx G_F^2 T^5 = H \approx () \frac{T^2}{m_{Pl}}$

$T_* \sim 1\,MeV$

$\Gamma \gg H$

$\Gamma \ll H$

$\Gamma \simeq H$

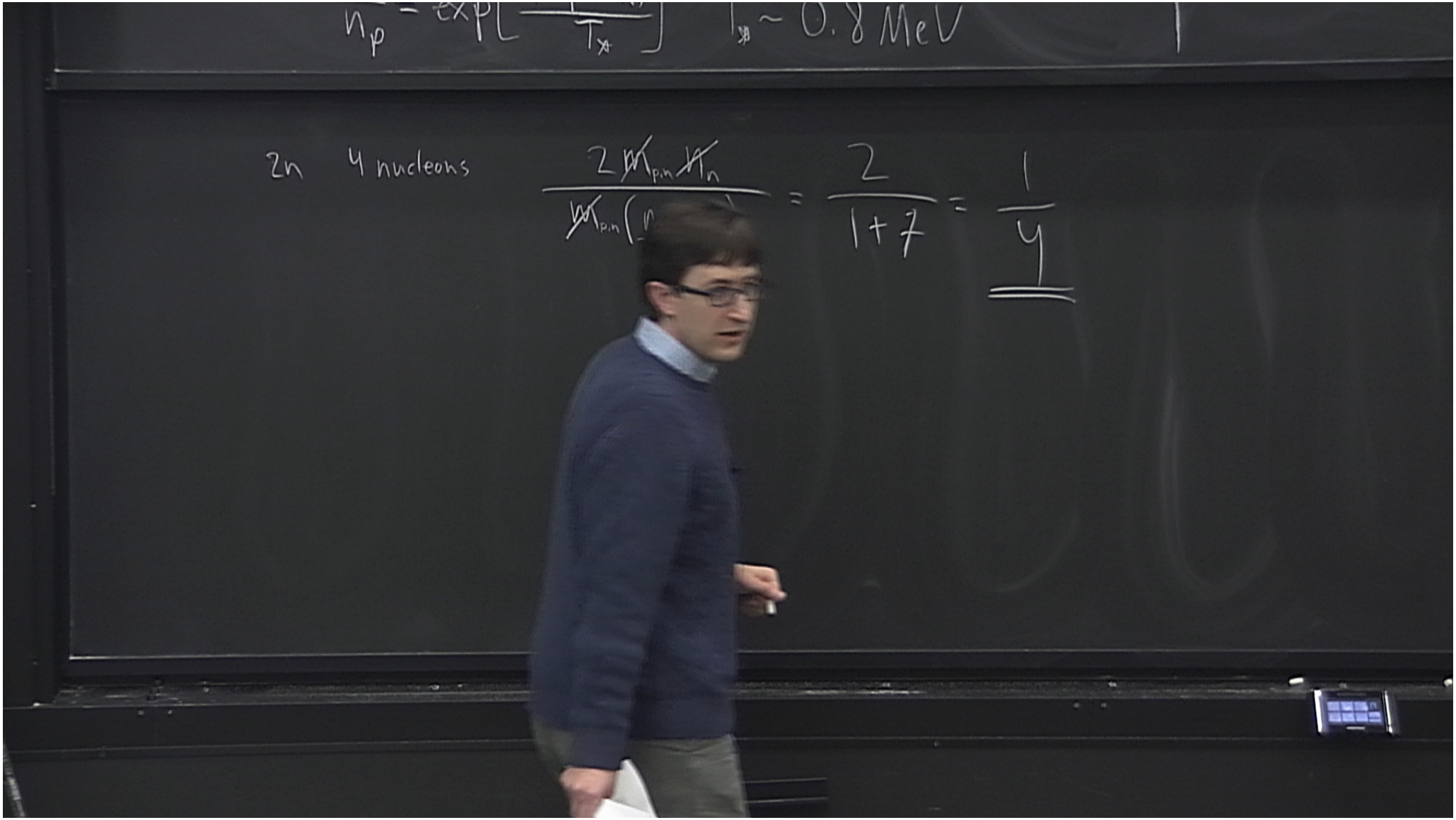
$\hbar = c = 1$

$G_N = \frac{1}{m_{Pl}^2}$

$H^2 = \frac{8\pi G_N}{3}\rho - \frac{k}{a^2}$

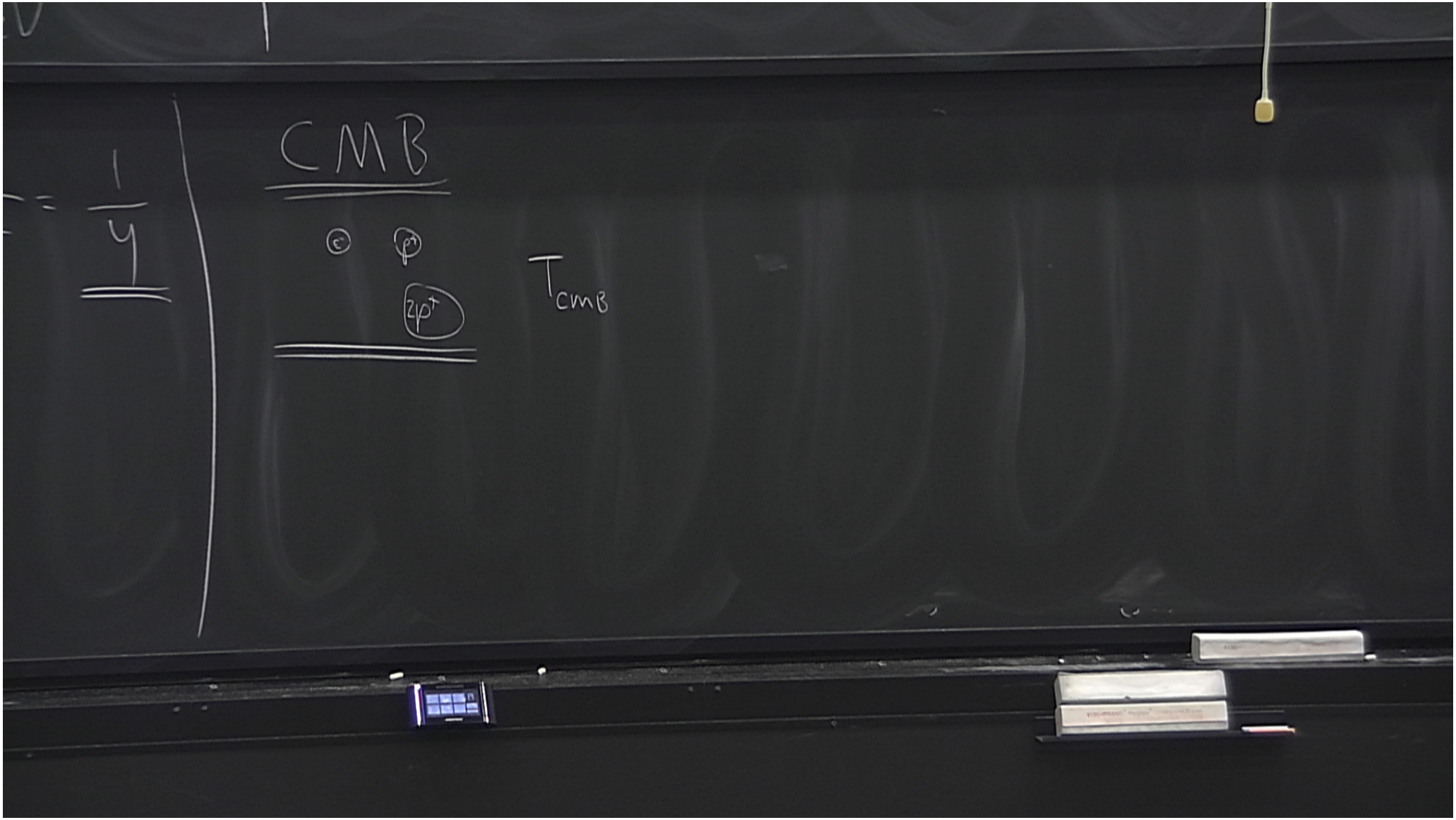
$g_* [\,] T^4$

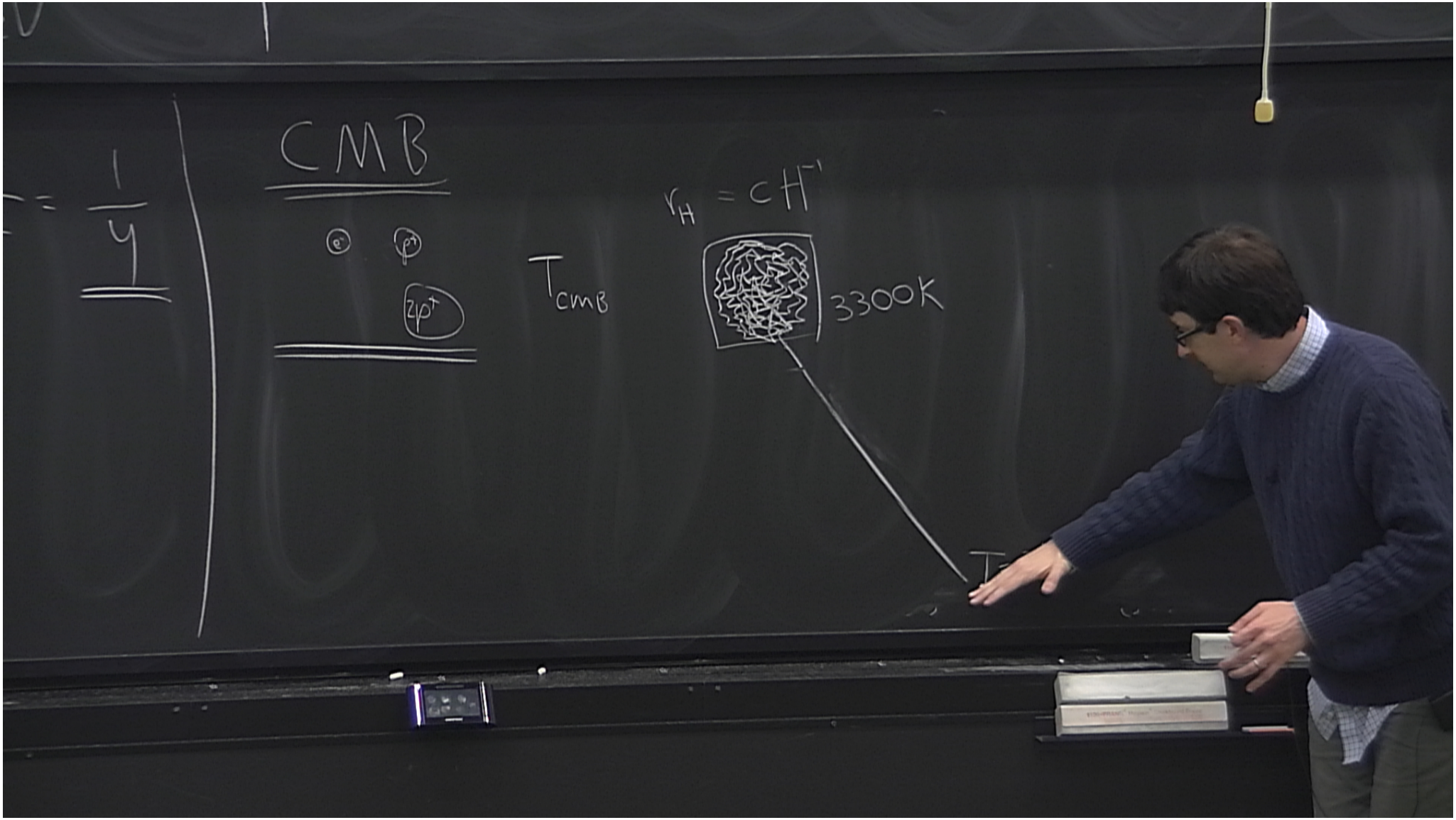
$H \sim [\,] \frac{T^2}{m_P}$

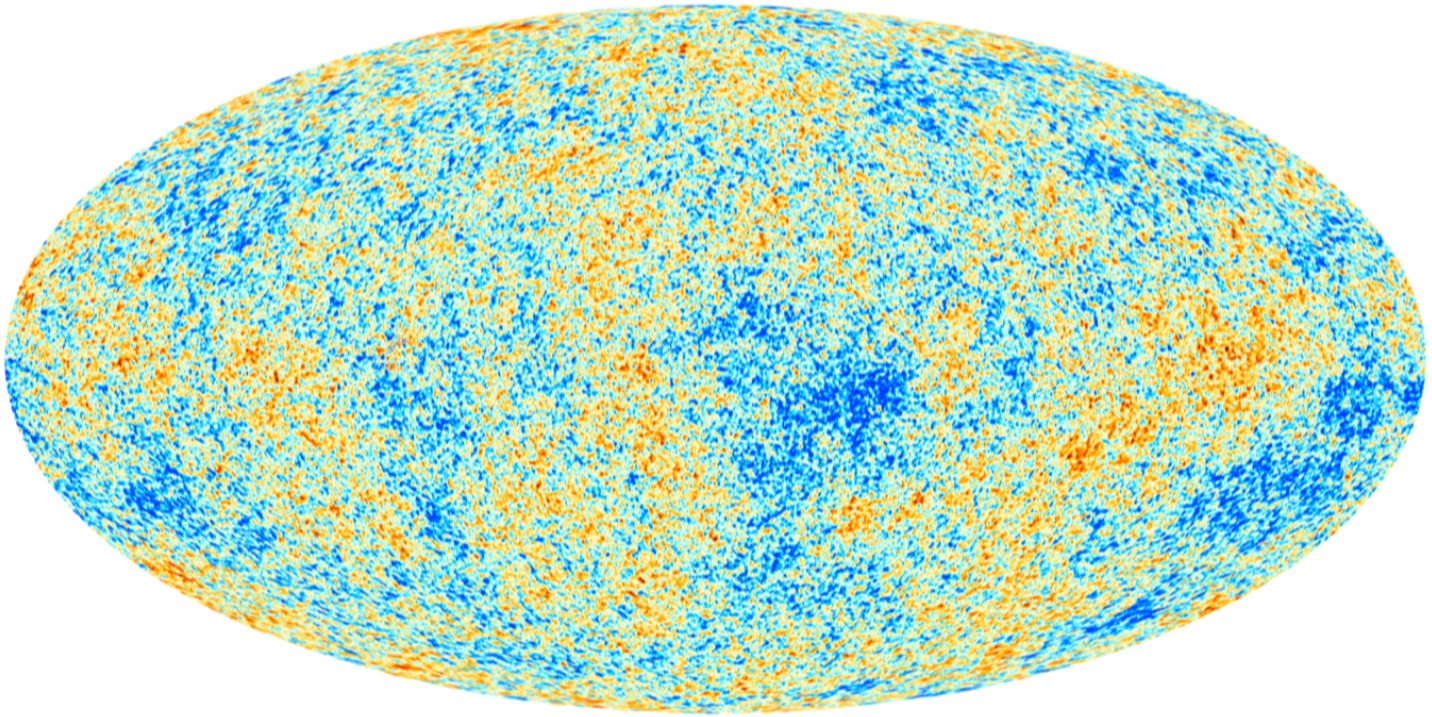

$n_p = \exp\left[\frac{\quad}{T_*}\right]$
$T_* \sim 0.8\,\mathrm{MeV}$
2n 4 nucleons
$\frac{2\mu_{p,n}\mu_n}{\mu_{p,n}(n} = \frac{2}{1+7} = \frac{1}{4}$

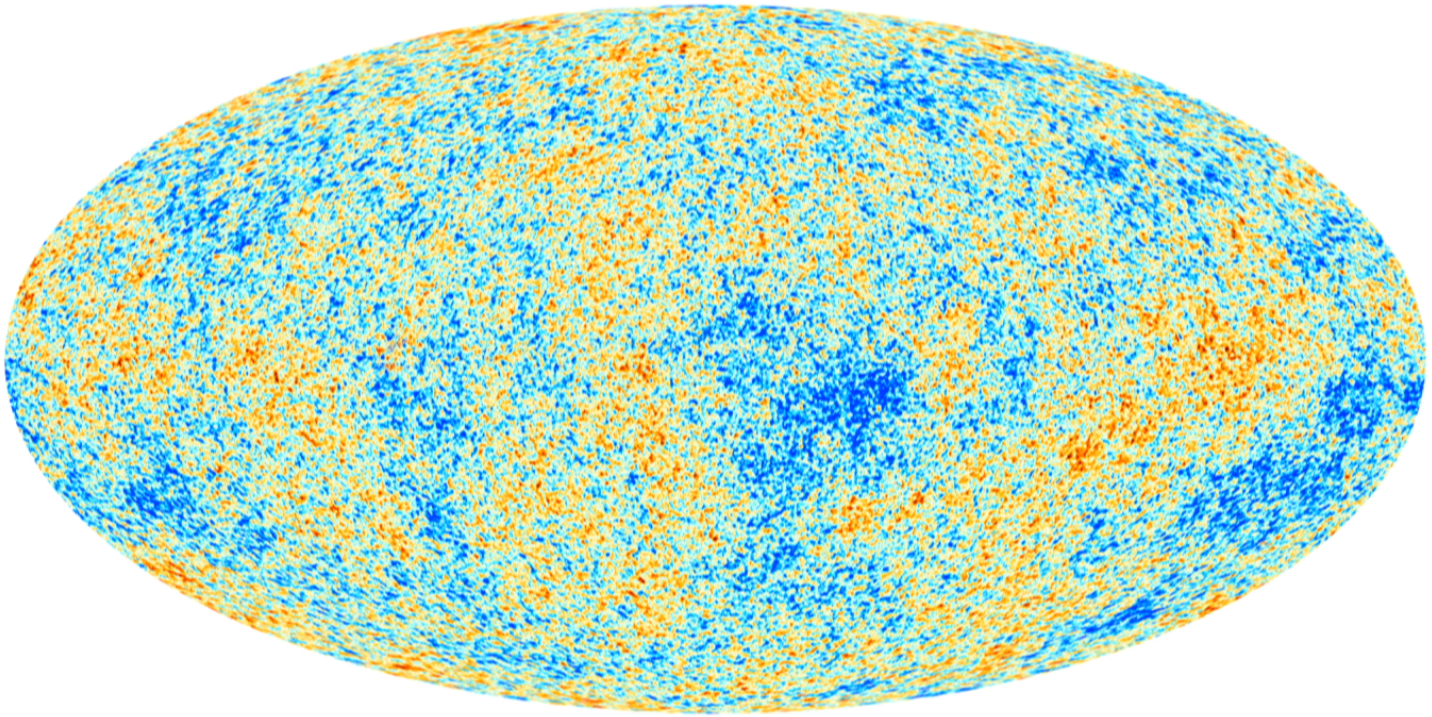
$n_p = \exp\left[\frac{\quad}{T_*}\right]$ $T_* \sim 0.8\,\mathrm{MeV}$

2n 4 nucleons $\quad \frac{2\cancel{n_{p,n}}\cancel{n_n}}{\cancel{n_{p,n}}\left(\frac{n_p}{n_n} + \cancel{1}\right)} = \frac{2}{1+7} = \underline{\underline{\frac{1}{4}}}$


CMB
T_{cmb}


CMB
$r_H = cH^{-1}$
T_{cmb}
3300K





$n_p = \exp\left[\frac{\quad}{T_*}\right]$ $T_* \sim 0.8\,\mathrm{MeV}$

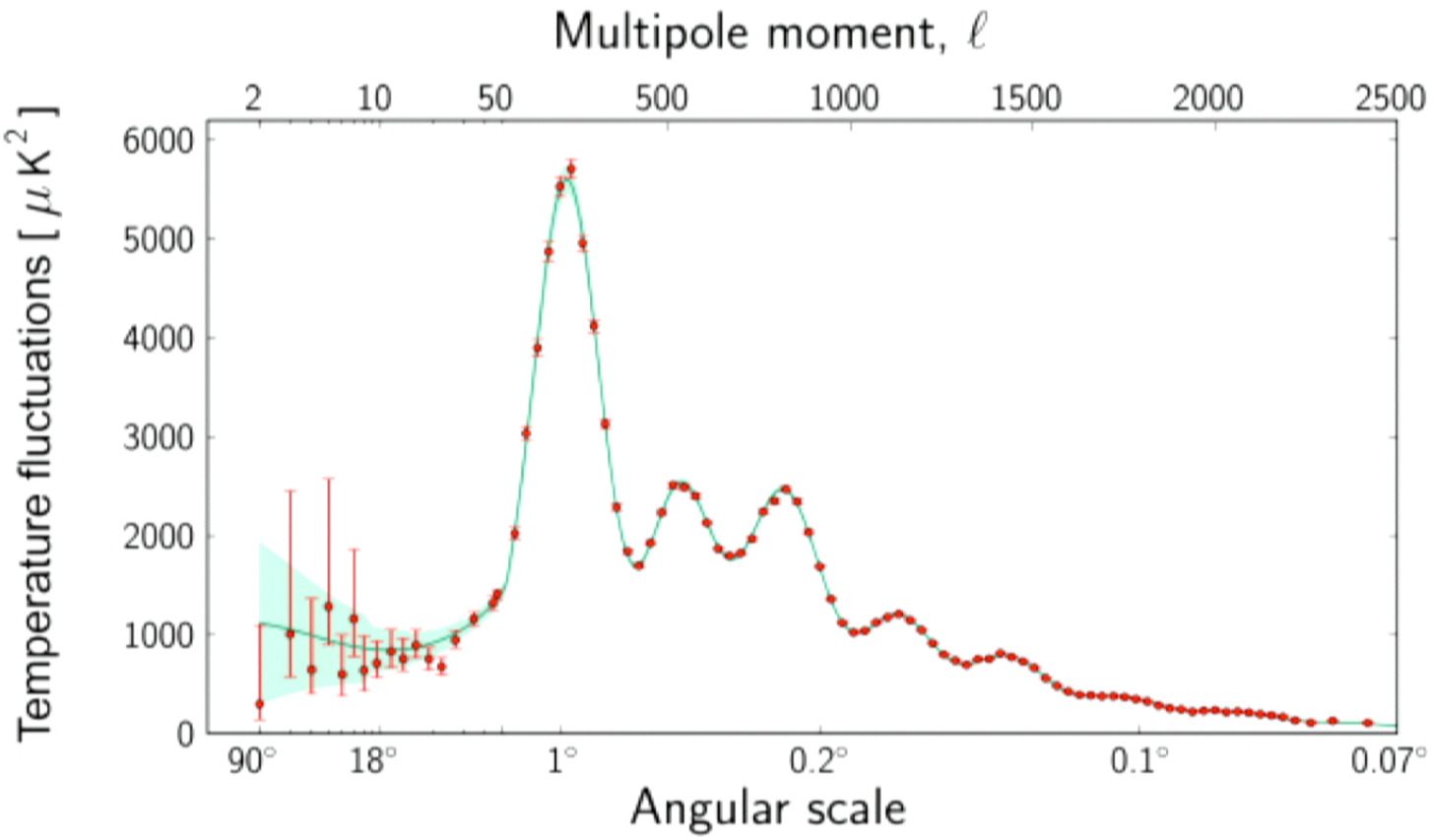
2n 4 nucleons $\frac{2 n_{pn} n_n}{n_{pn}\left(\frac{n_p}{n_n} + n_n\right)} = \frac{2}{1+z} = \frac{1}{y}$

$$T(\theta,\varphi) = \sum_{l=0}^{\infty} \sum_{m=-l}^{l} a_{lm} Y_{l,m}(\theta,\varphi)$$

$$\langle a_{lm} a^*_{l'm'} \rangle = C_l \delta_{l,l'} \delta_{m,m'} \qquad C_l = \frac{1}{2l+1} \sum_{m=-l}^{l} |a_{lm}|^2$$

fixed l, $2l+1$ a_{lm}'s

CMB


Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μ K^2]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale