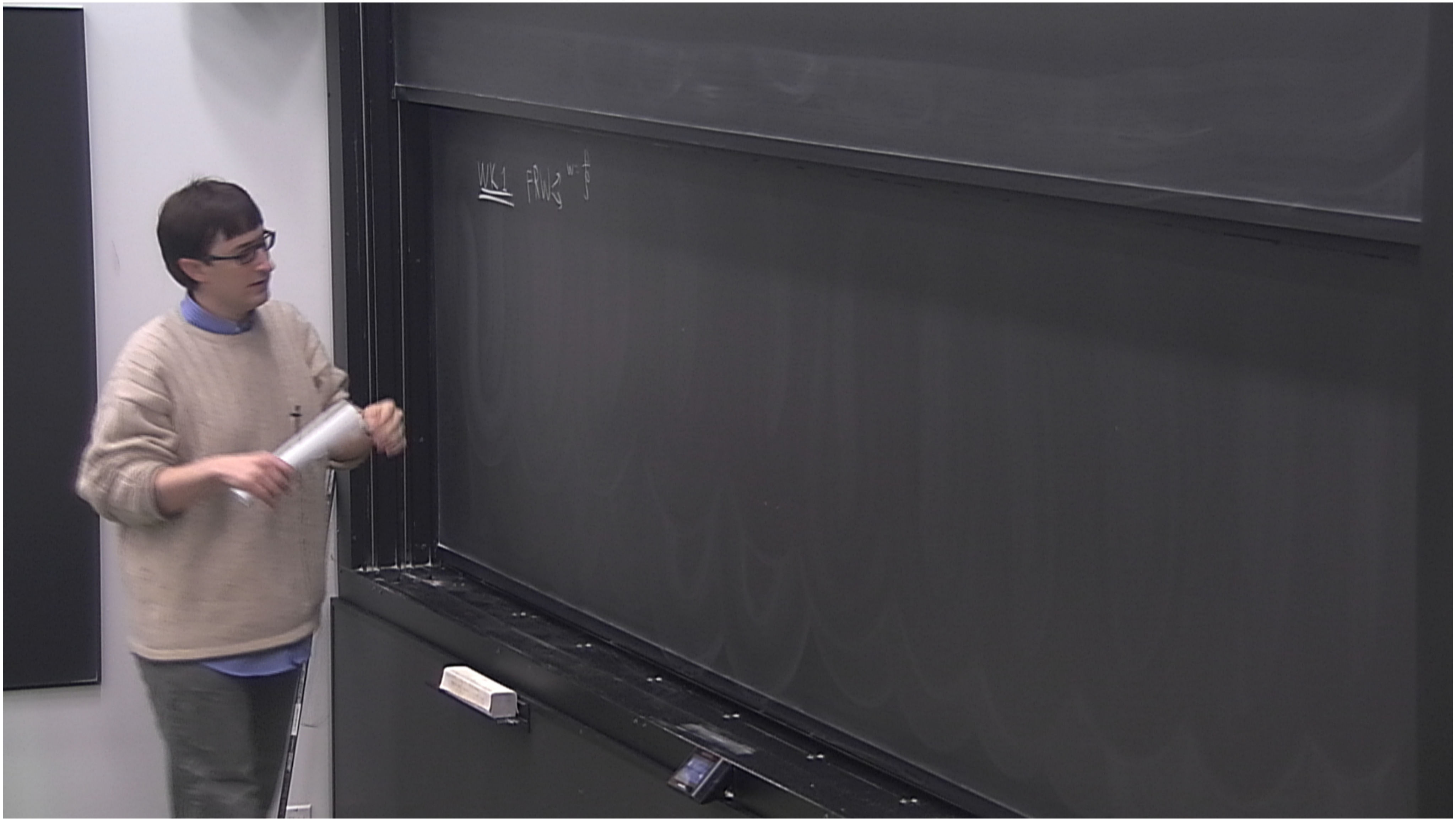
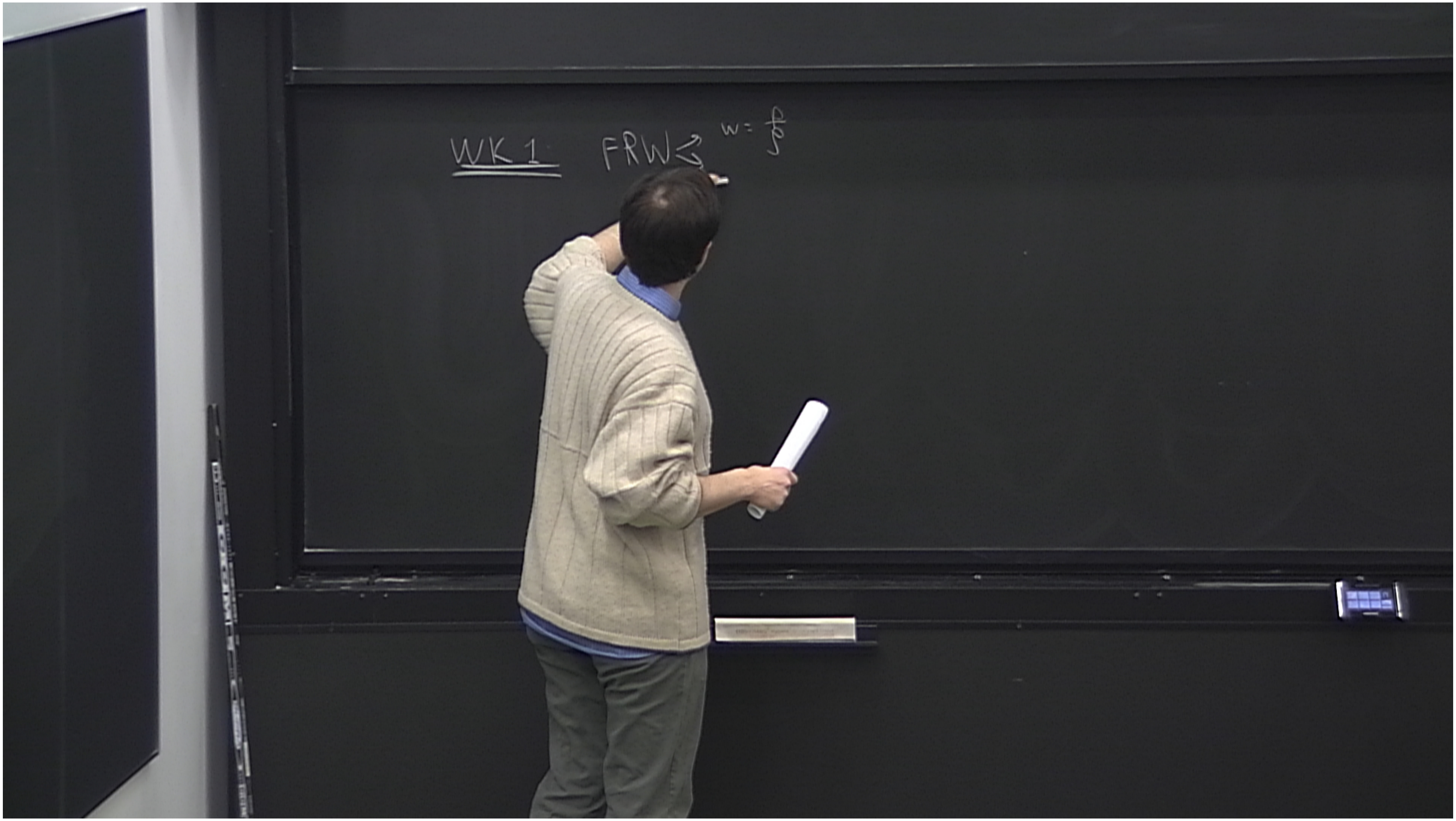
Title: 13/14 PSI - Cosmology Review - Lecture 9

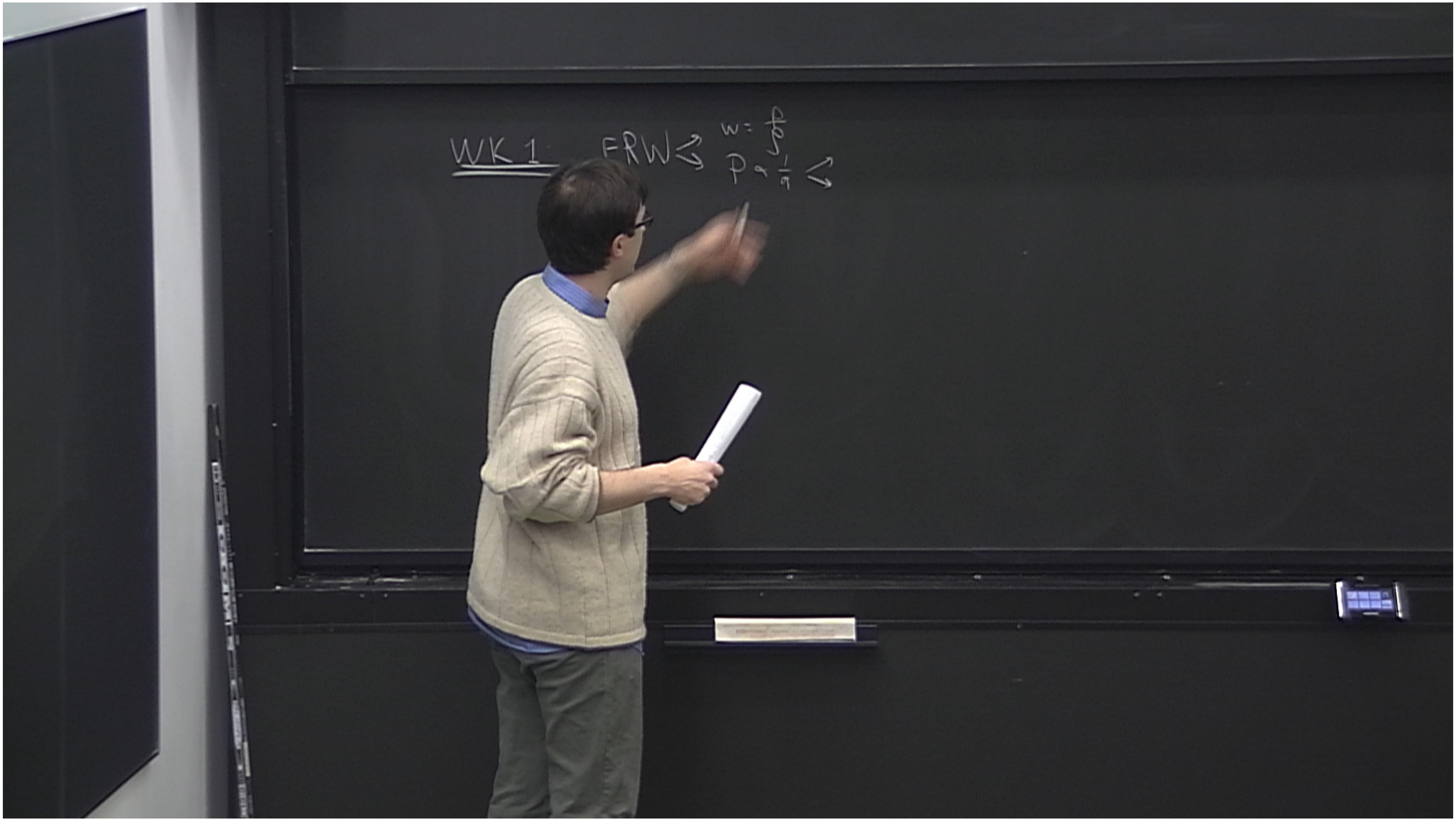
Date: Feb 10, 2014 11:30 AM

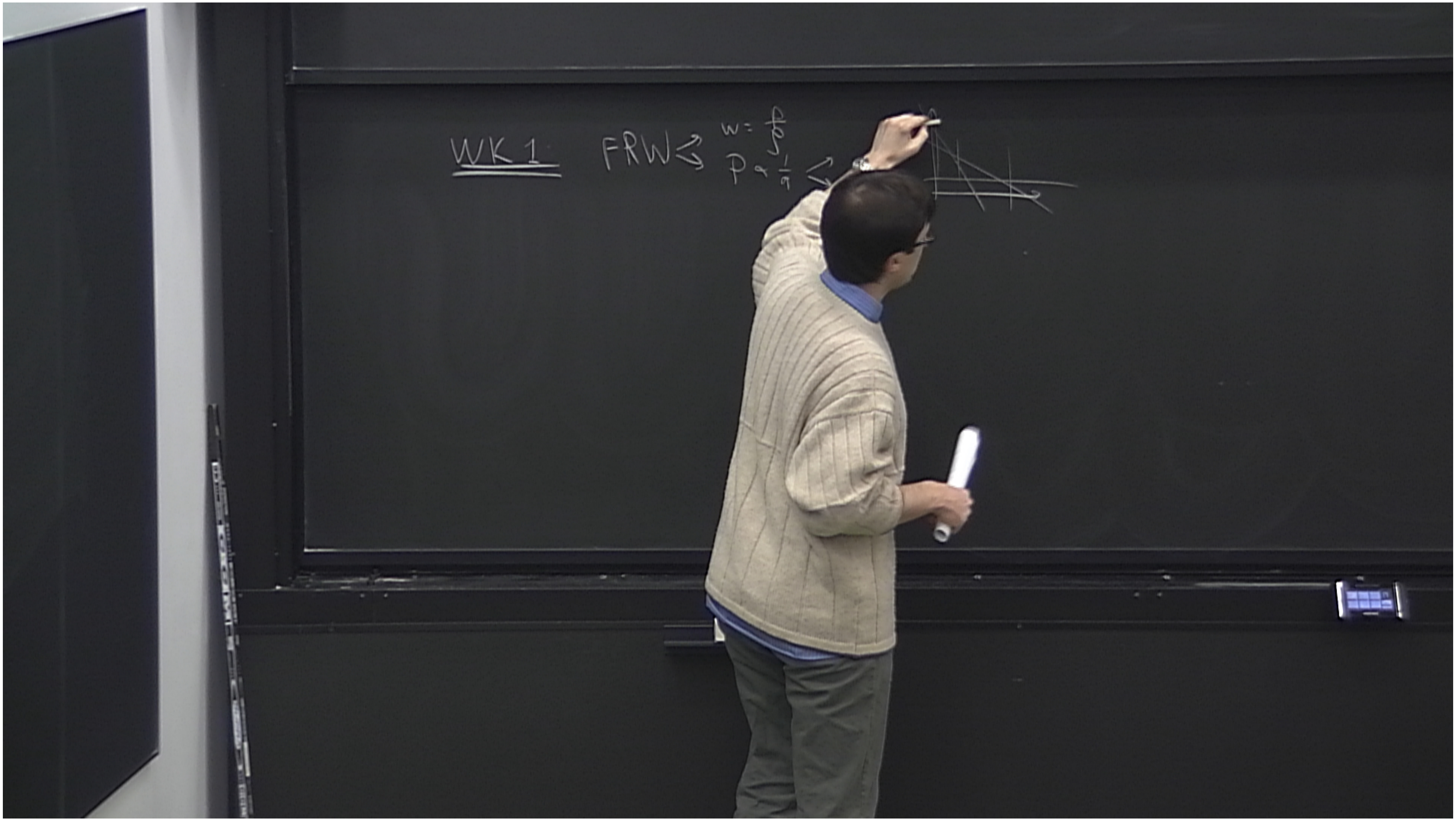
URL: http://pirsa.org/14020017

Abstract:

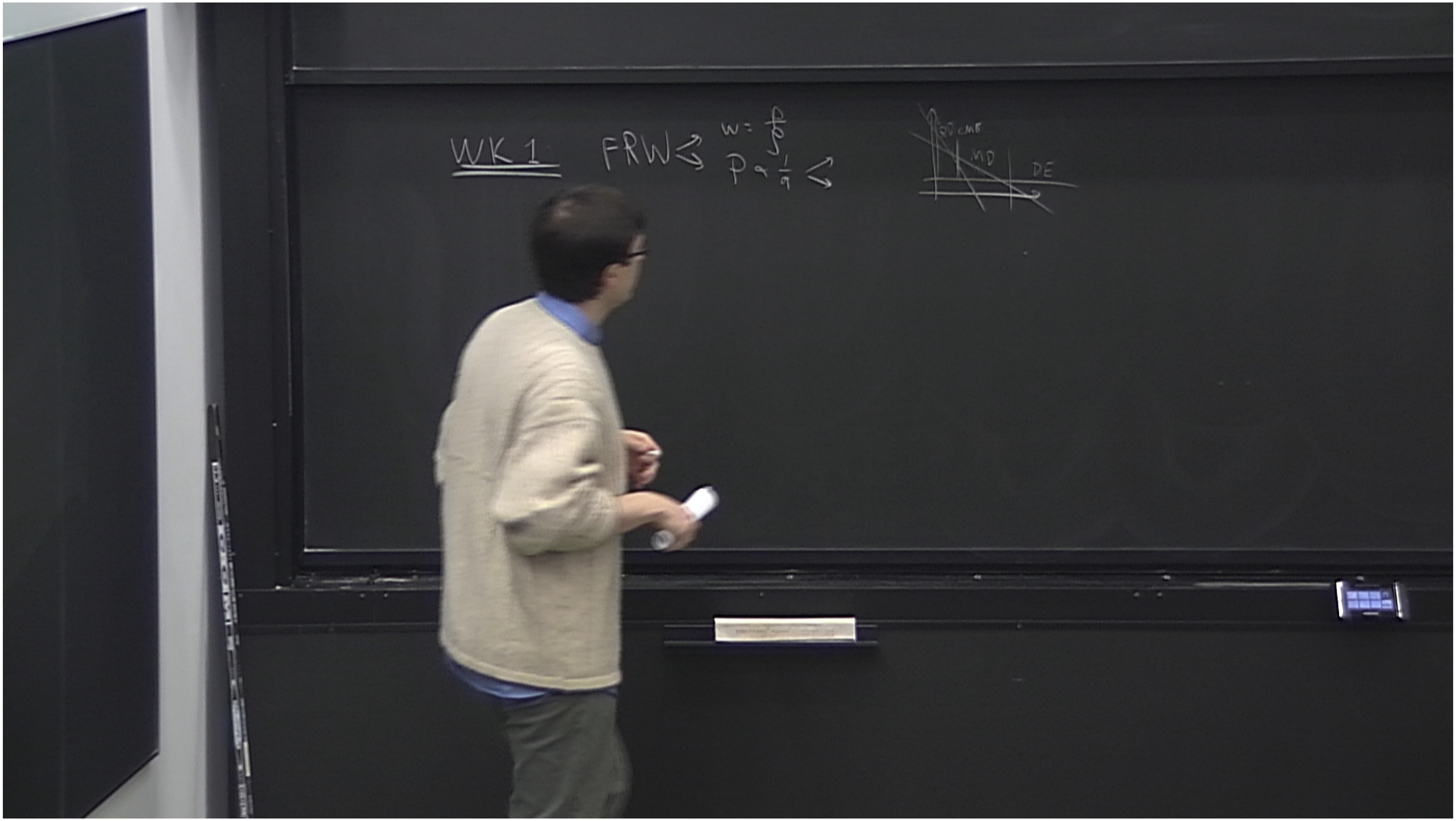

WK 1 FRW

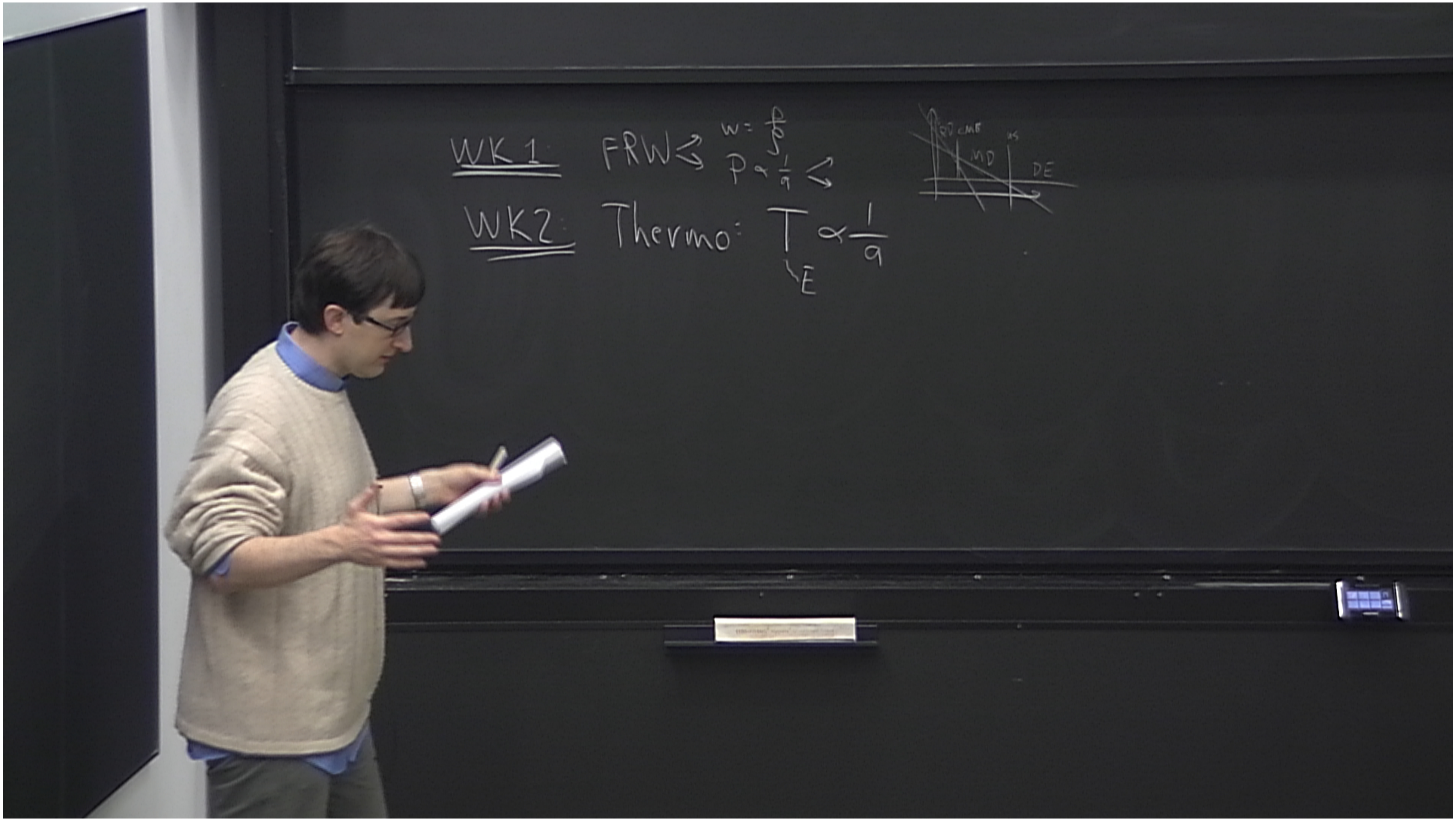

WK 1
FRW
w = p/ρ

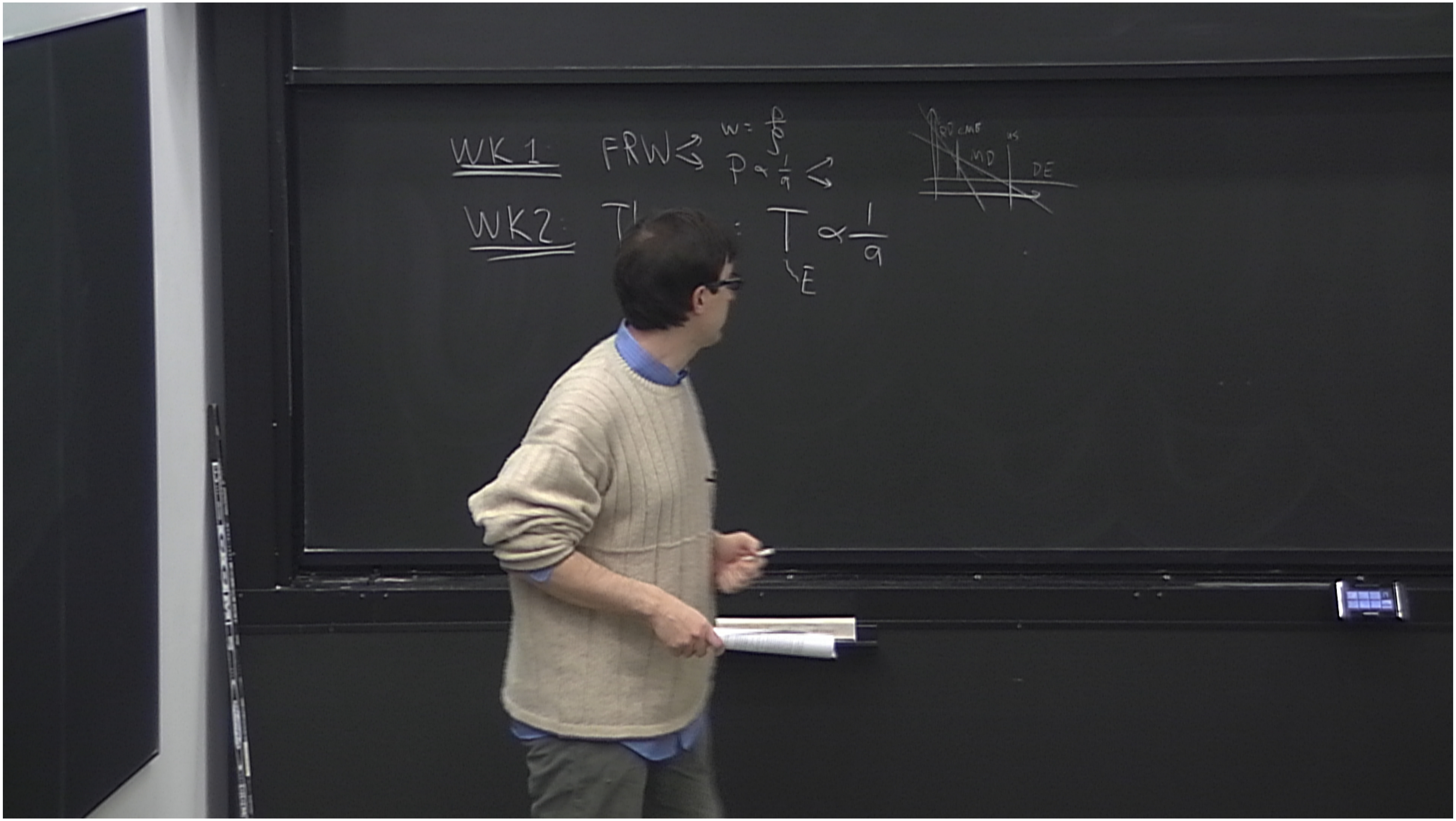

WK 1
FRW

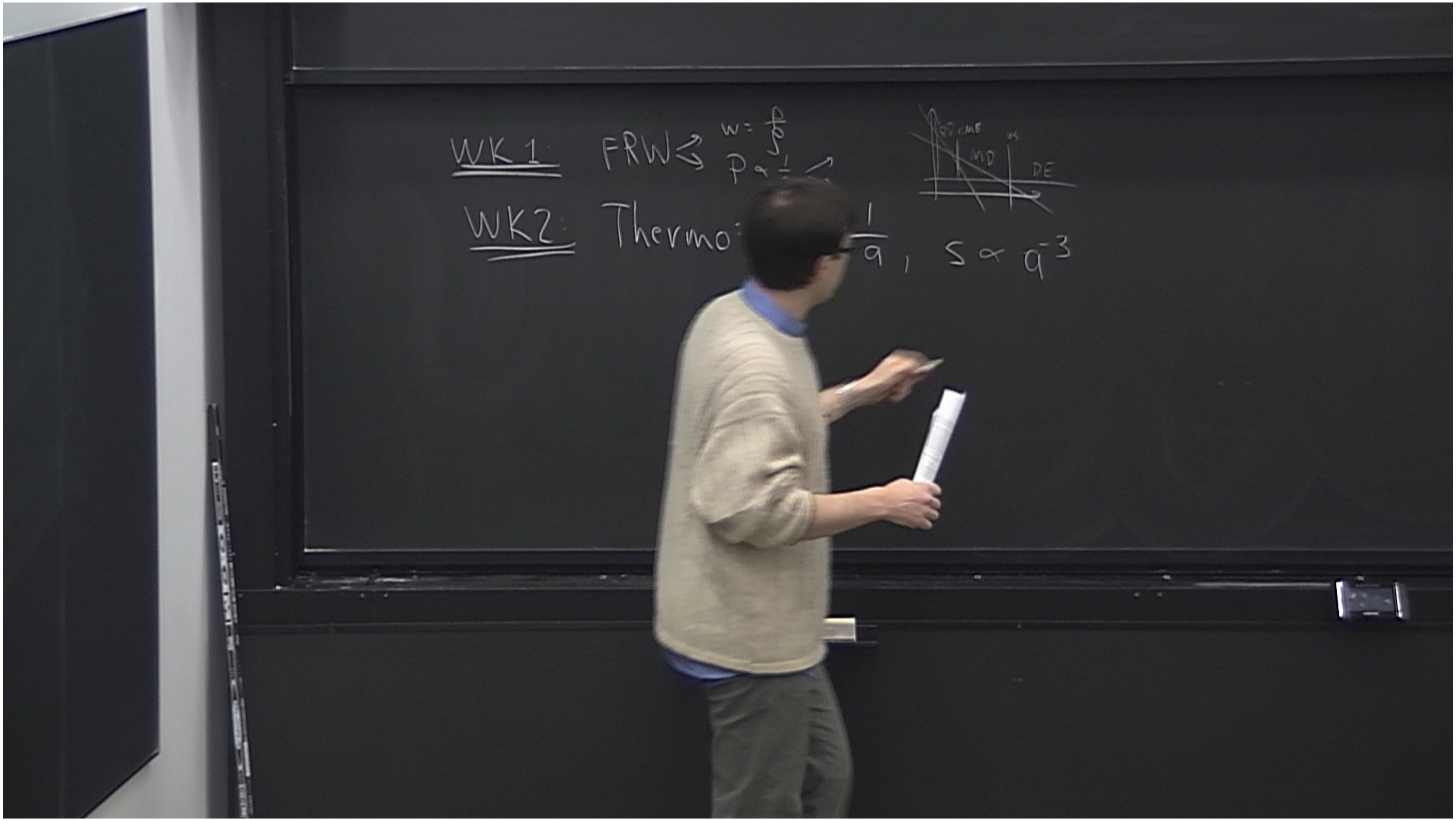


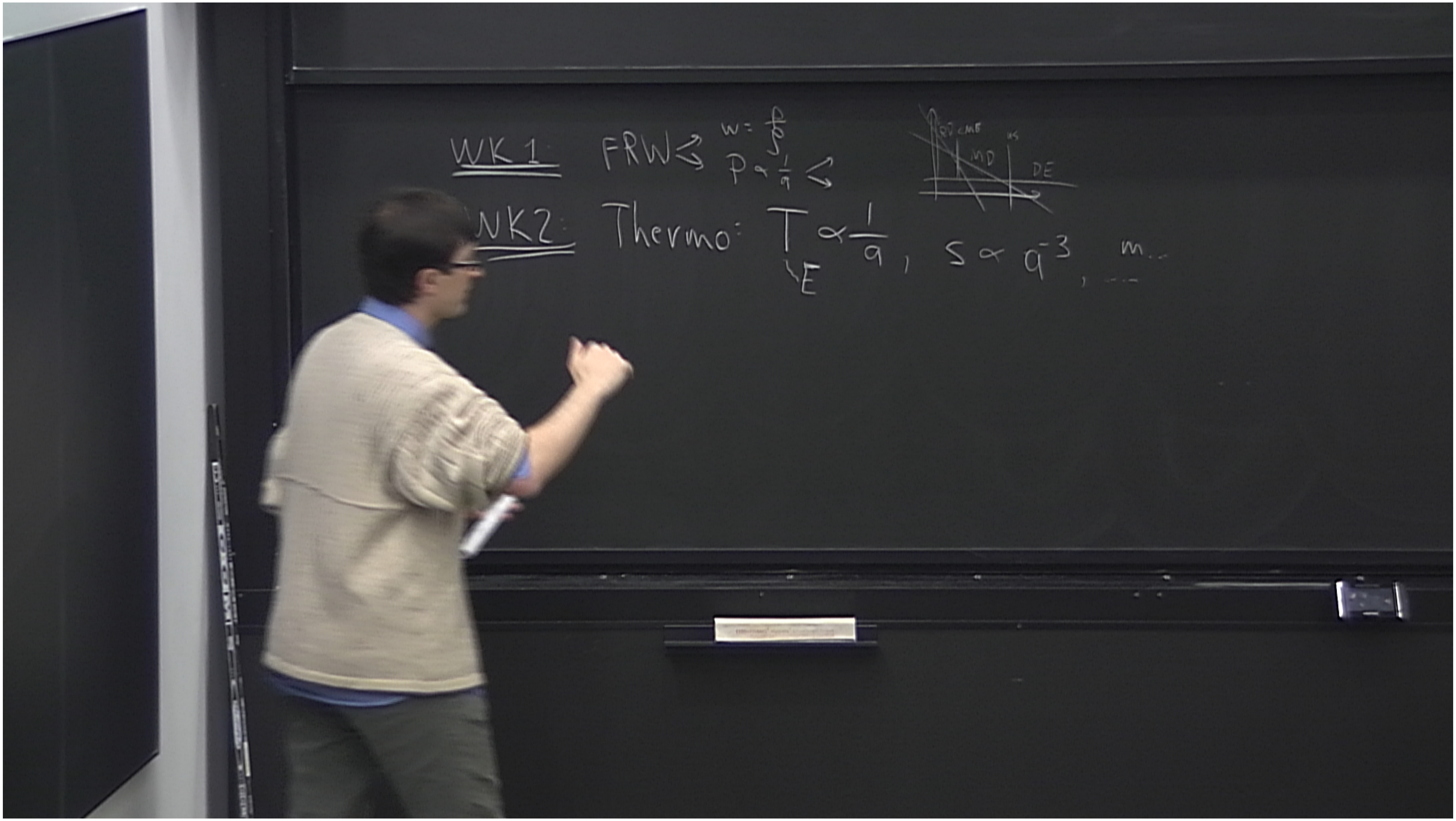
WK 1
FRW
w = p/ρ
ρ ∝ 1/a

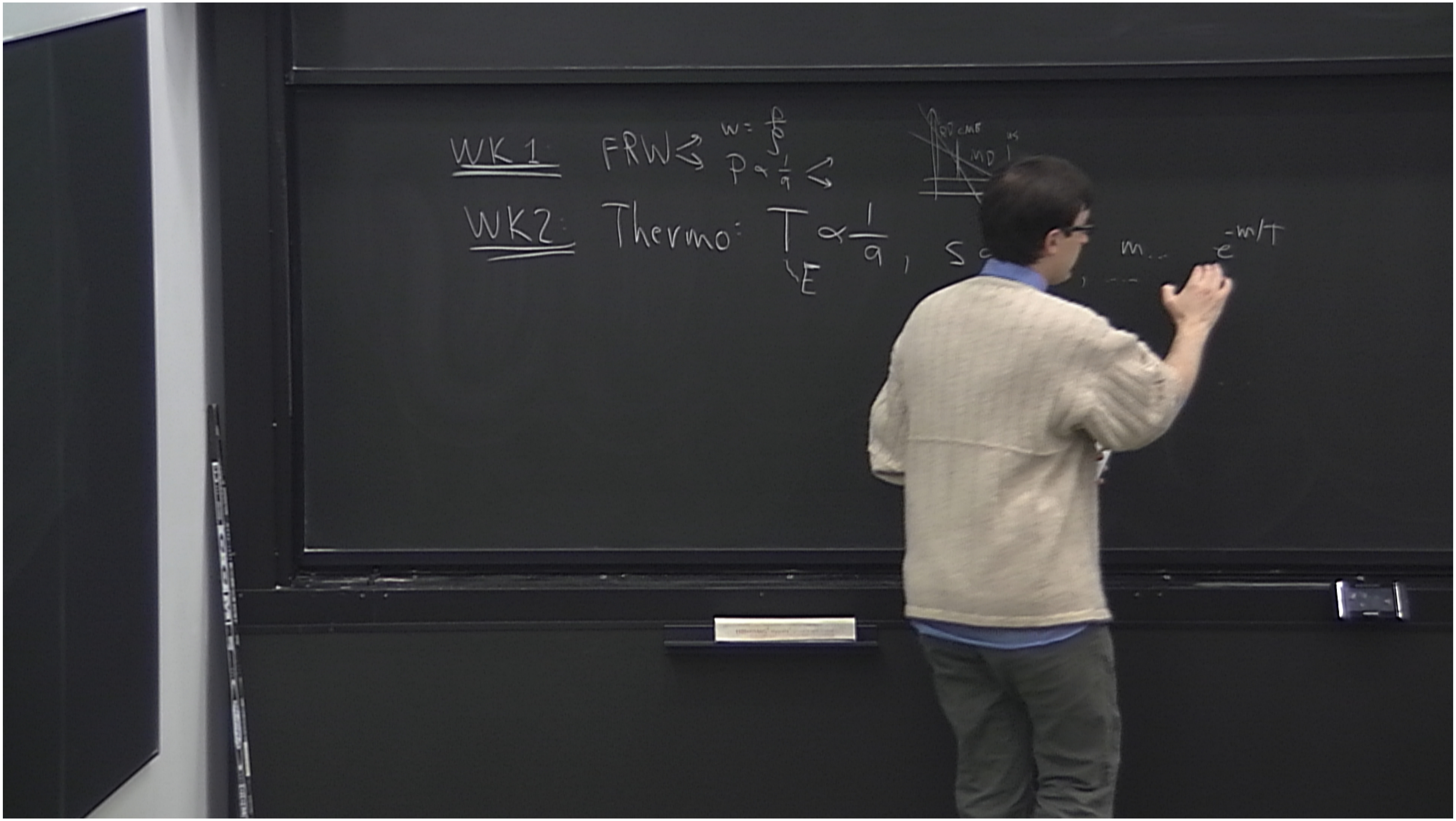

WK 1
FRW
w = p/ρ
ρ ∝ 1/a
CMB
MD
DE

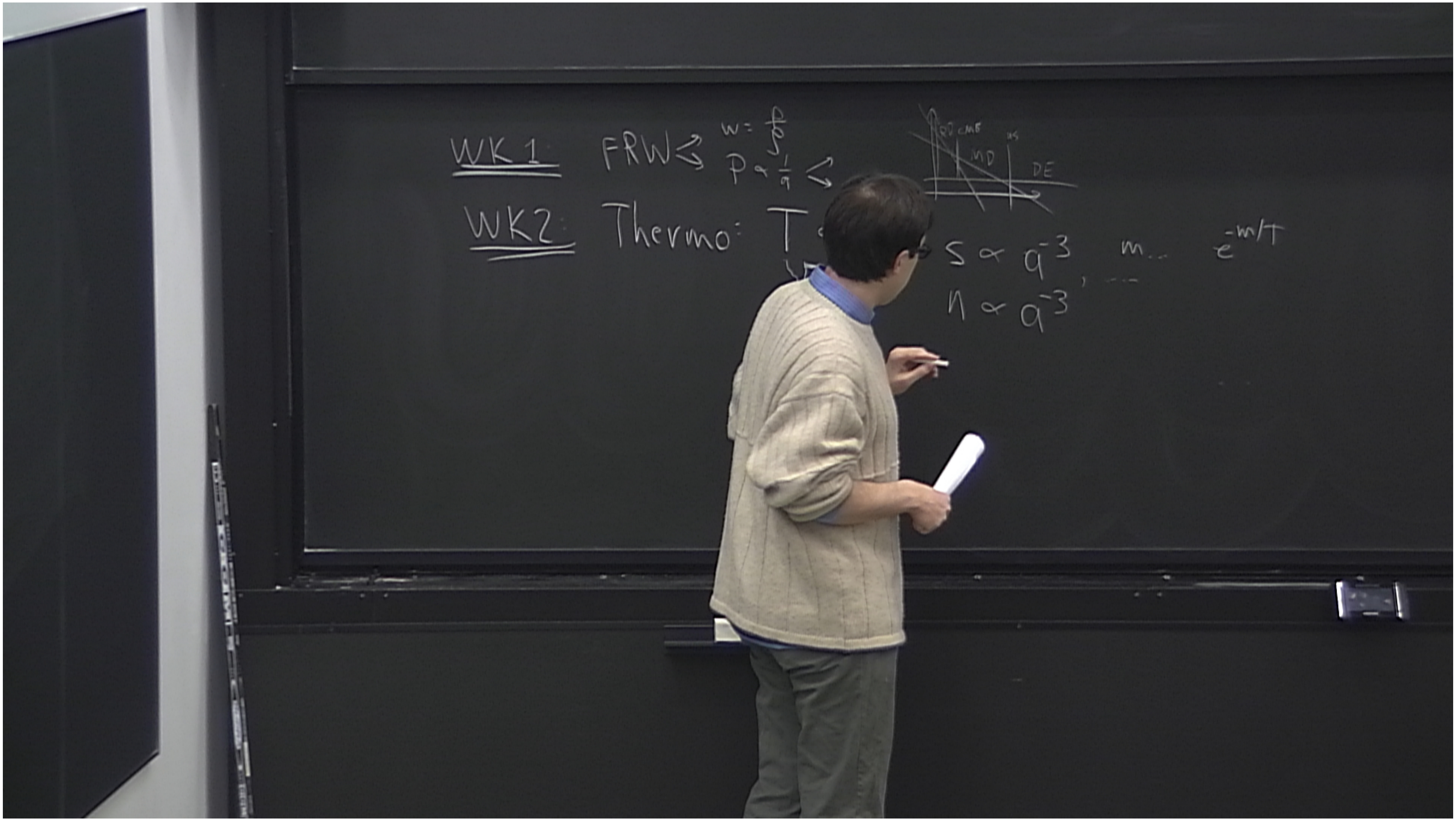

WK 1
FRW
w = P/ρ
ρ ∝ 1/a
WK2
Thermo:
T ∝ 1/a
E
MD
DE

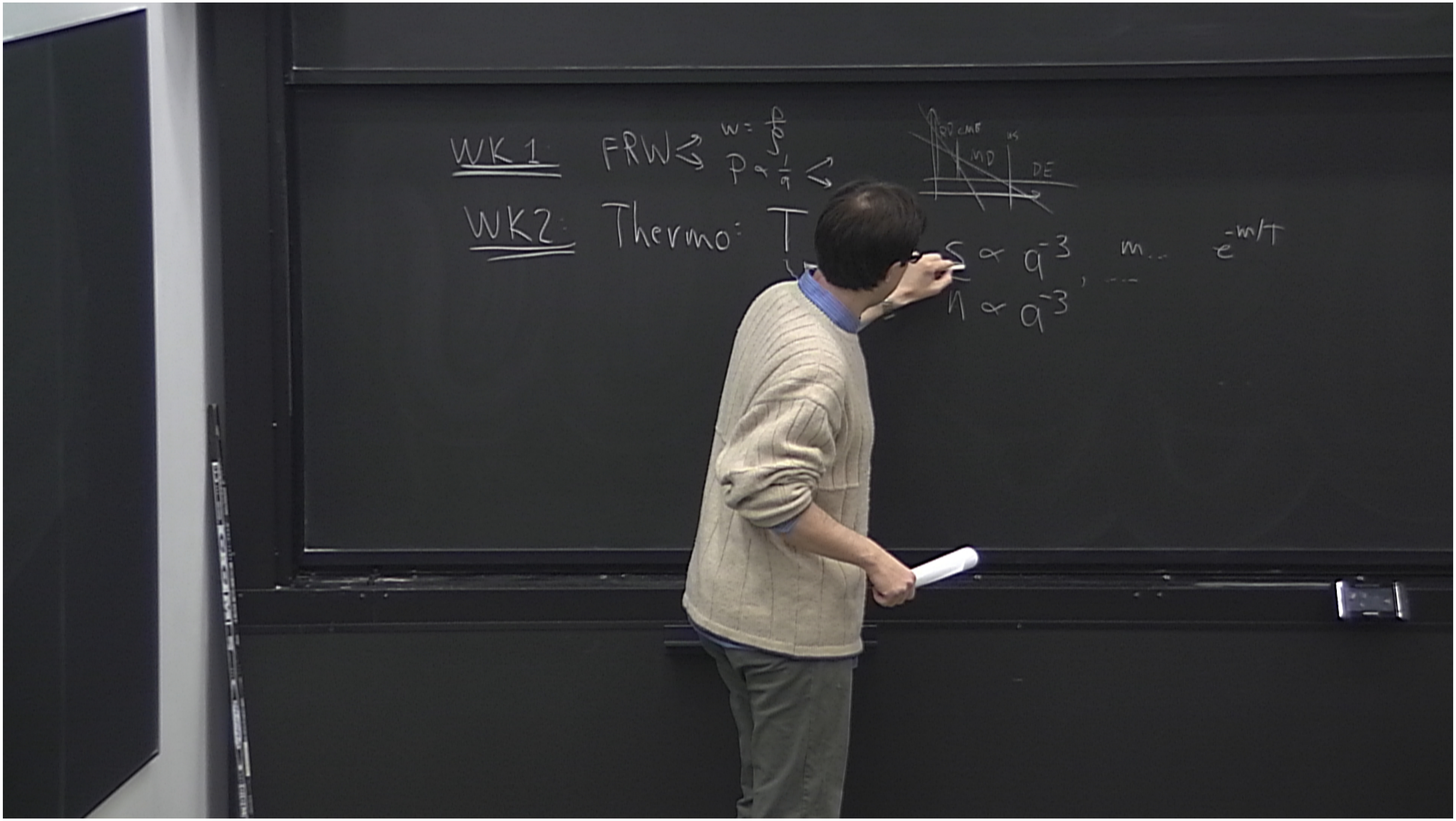

WK 1 FRW
w = p/ρ
ρ ∝ 1/a
WK2 T ∝ 1/a
E
RD CMB
MD
DE

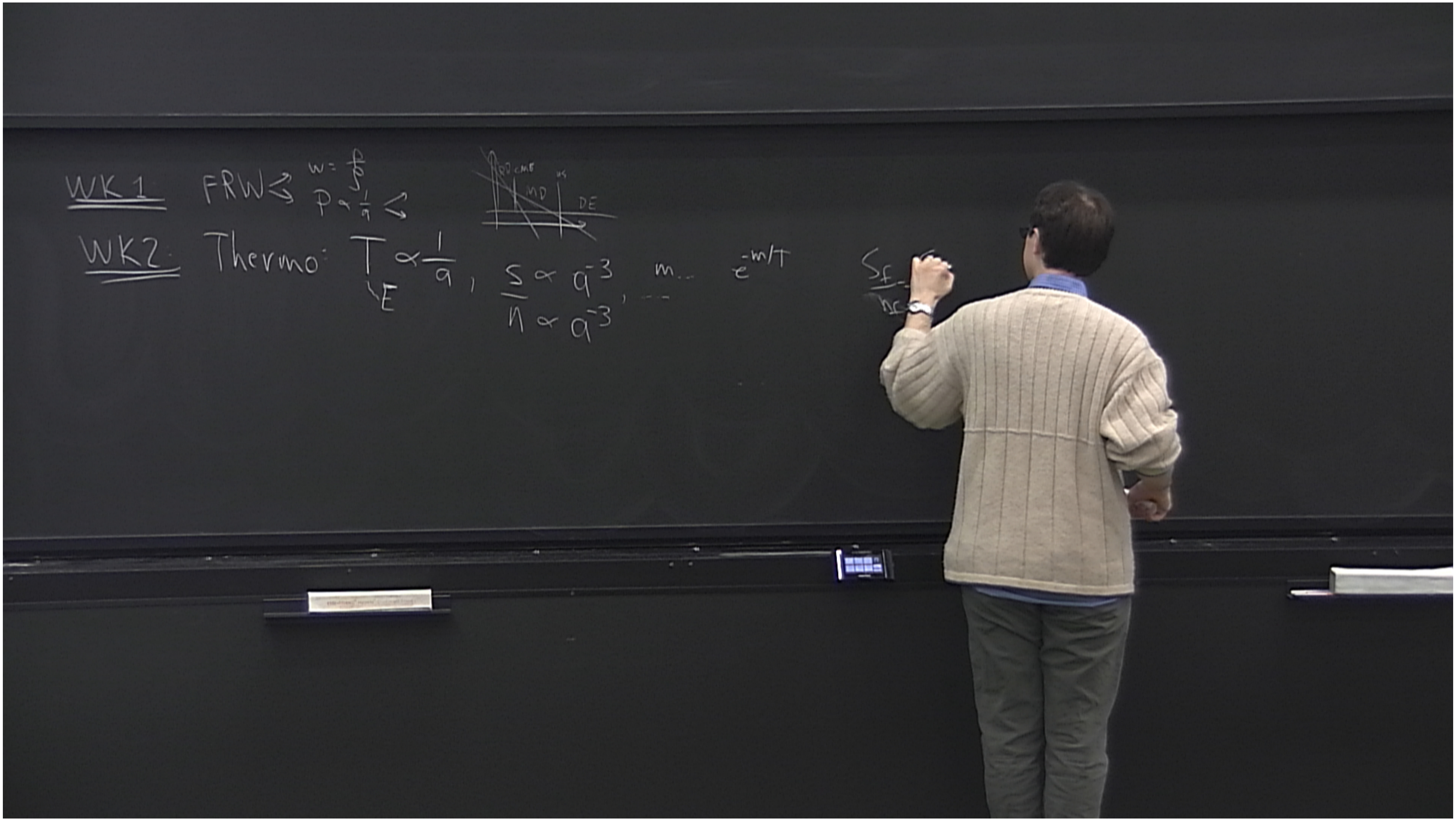

WK1: FRW
WK2: Thermo

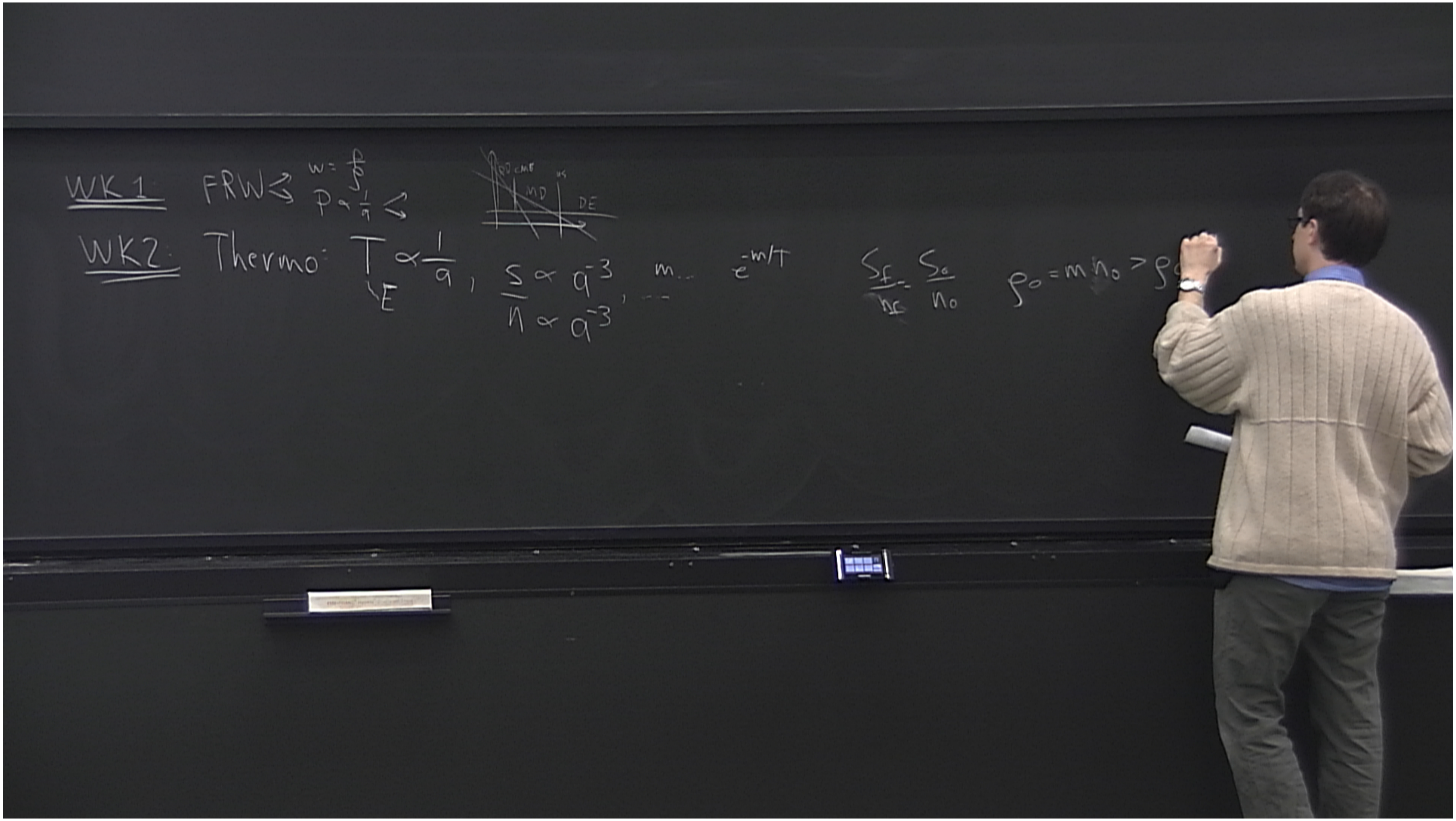

WK1 FRW
$w = \frac{p}{\rho}$
$\rho \propto \frac{1}{a}$
MD
DE
WK2 Thermo: $T \propto \frac{1}{a}$, $s \propto a^{-3}$
E


WK 1
FRW
WK2
Thermo:

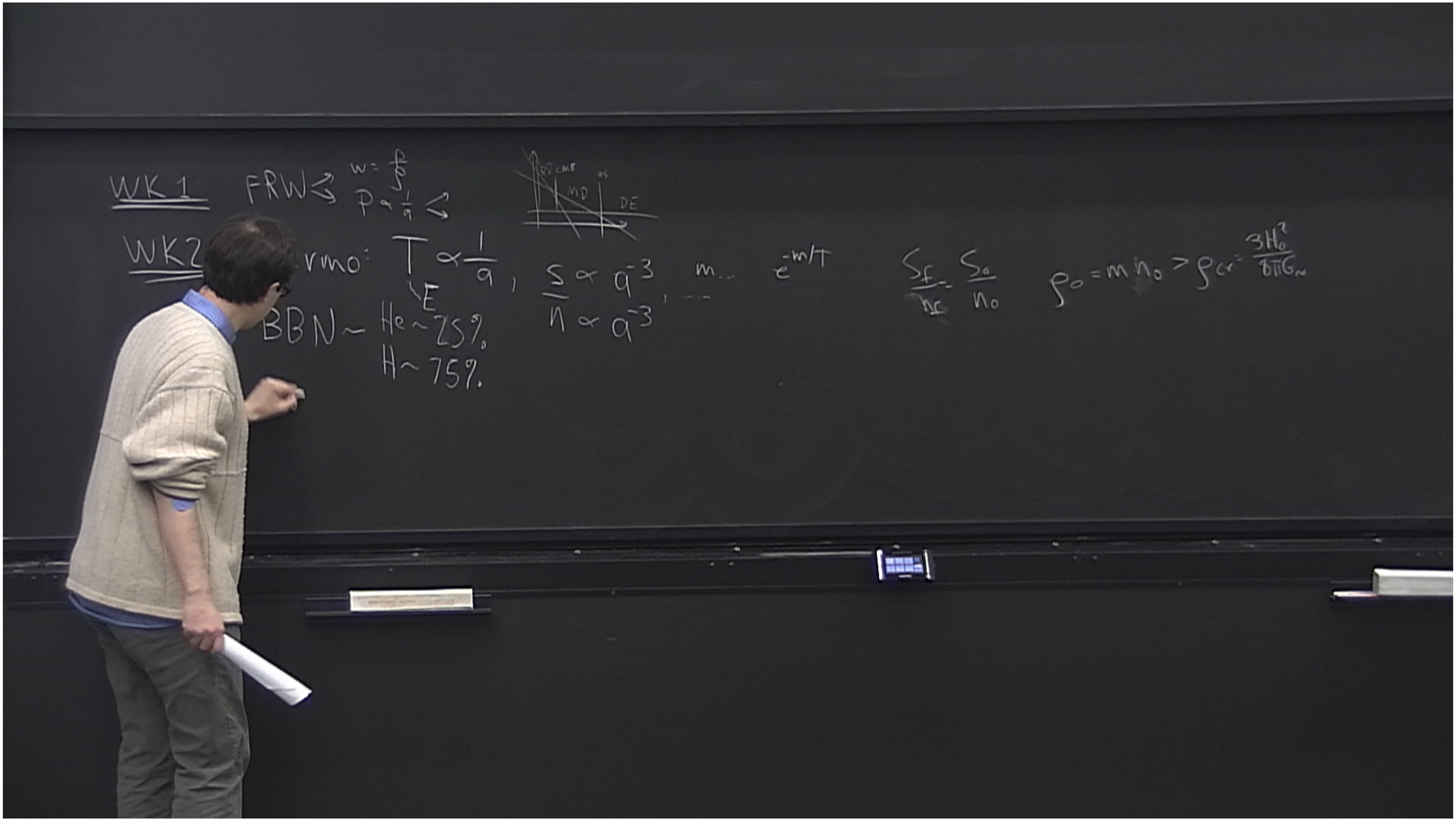

WK 1
FRW
WK2: Thermo: T
MD
DE
s ∝ a^-3
n ∝ a^-3
e^-m/T

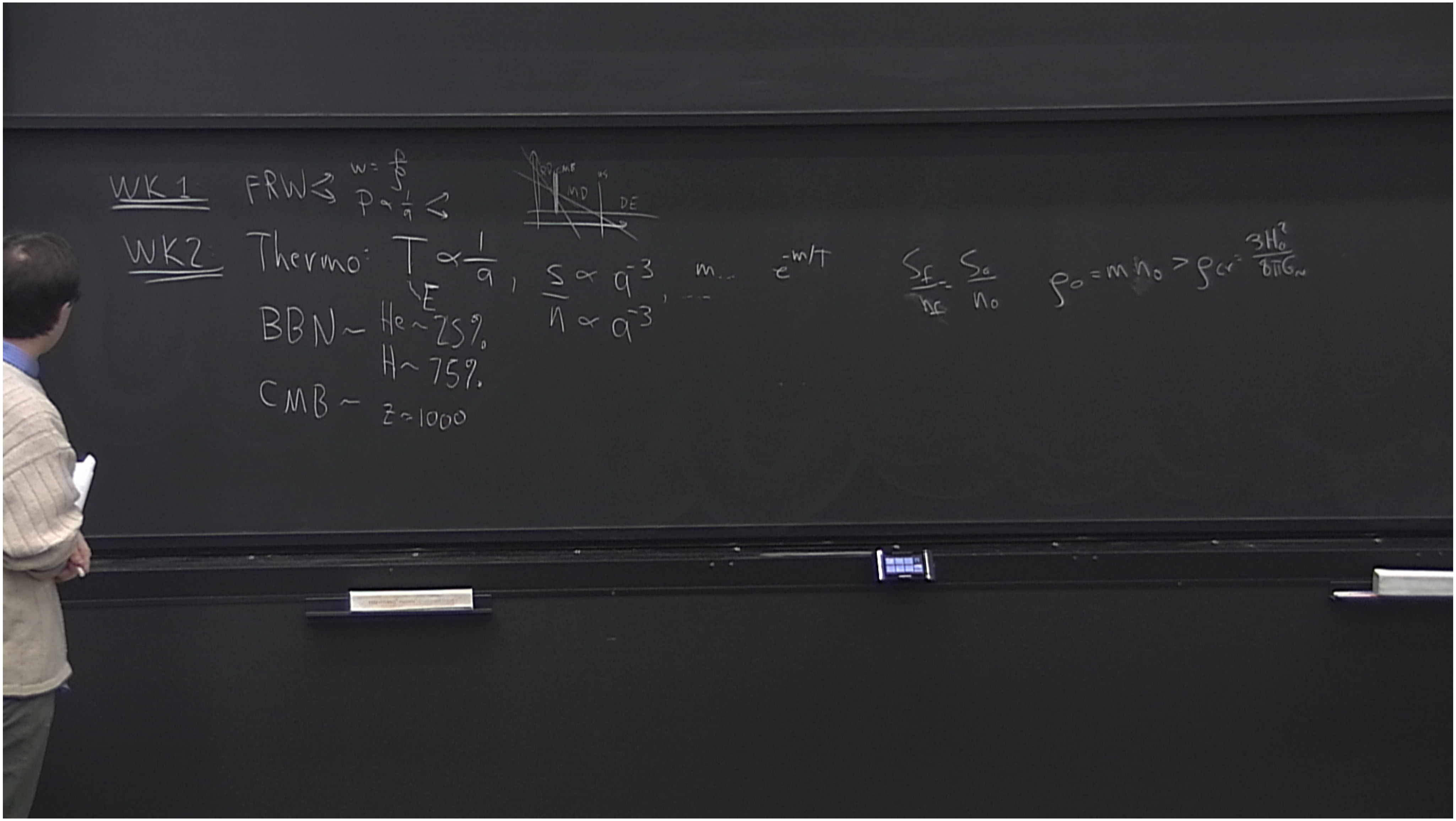

WK 1 FRW
WK2 Thermo:
DE

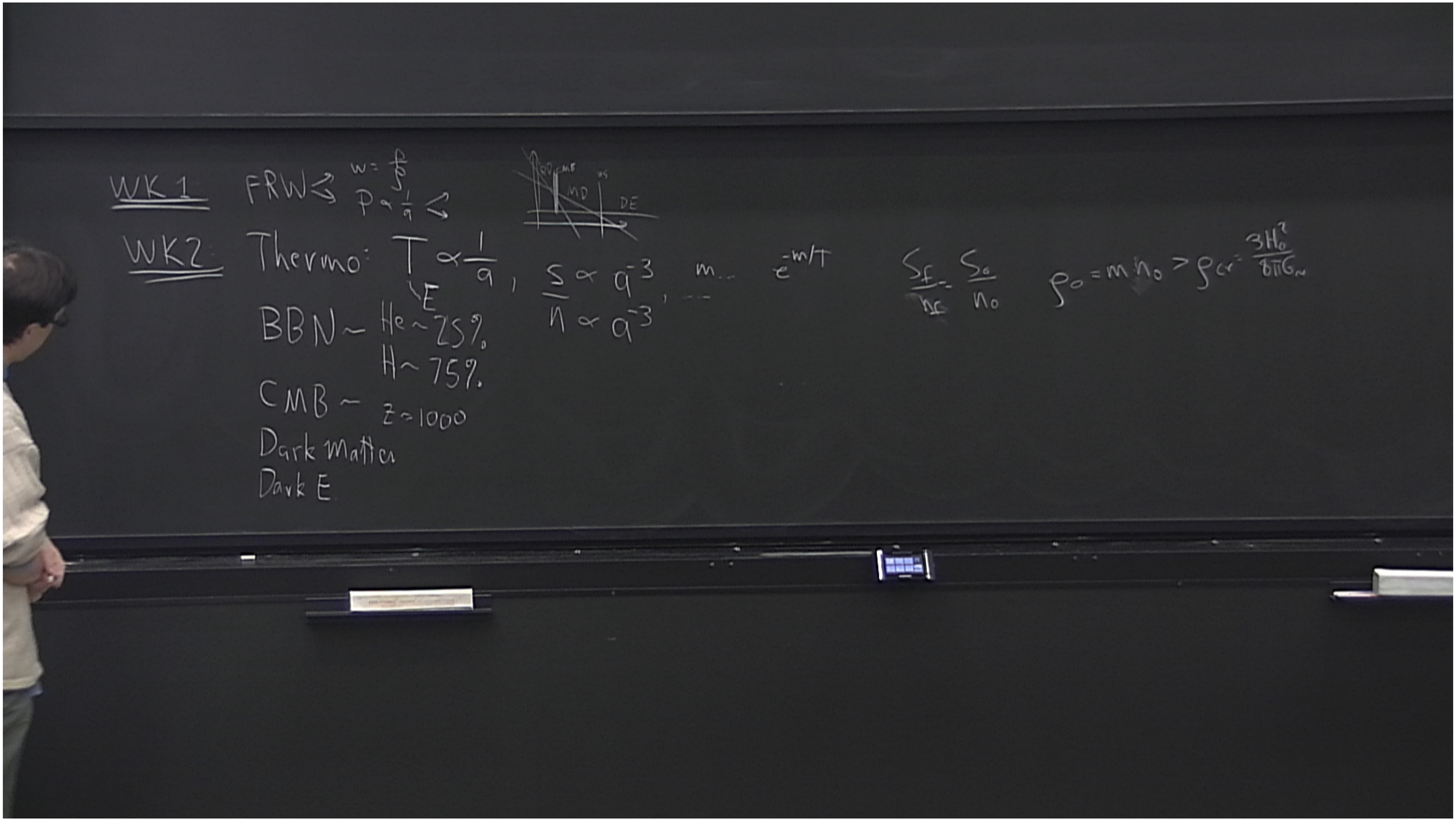

WK 1
FRW
WK2
Thermo
DE
MD

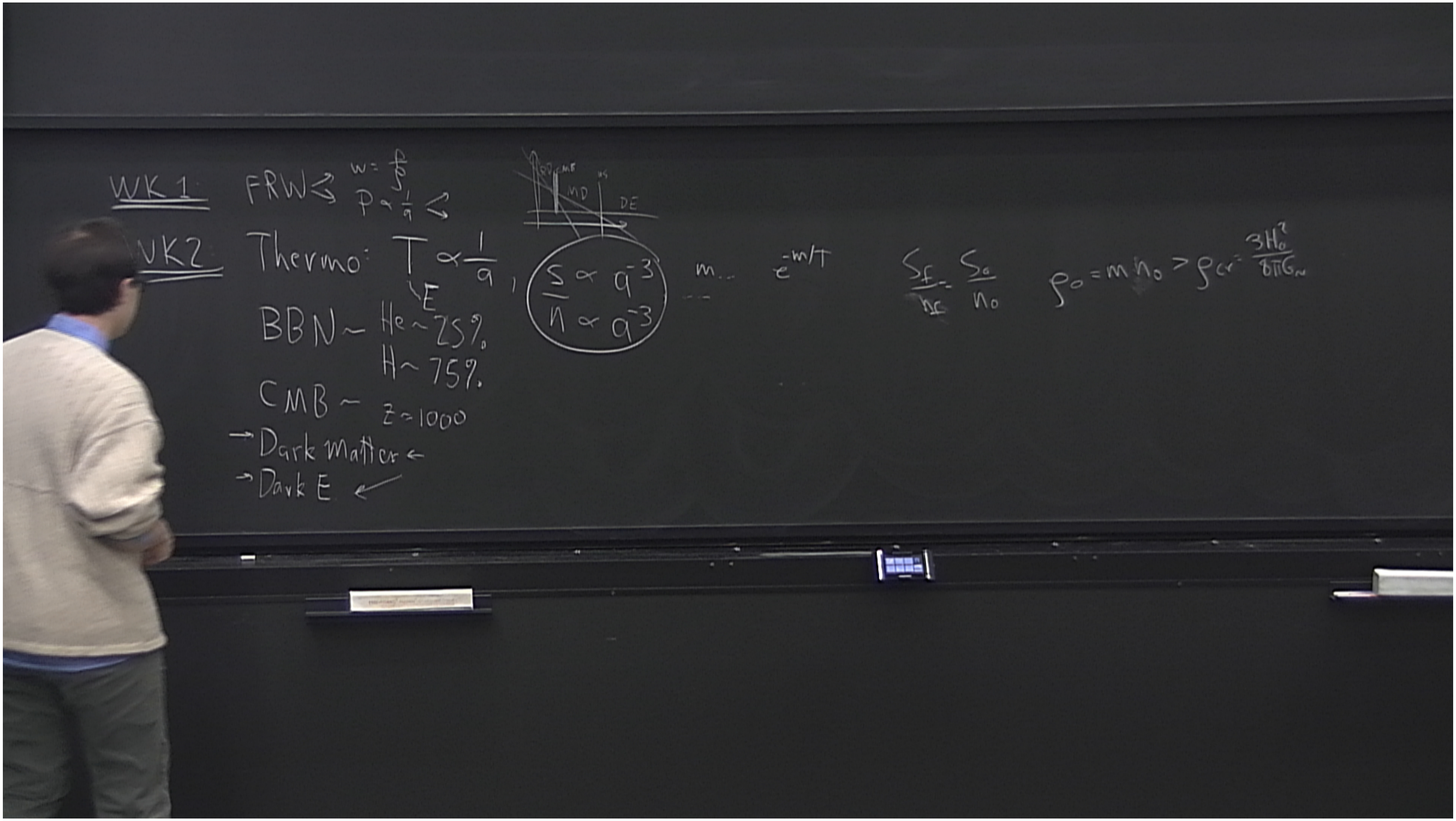


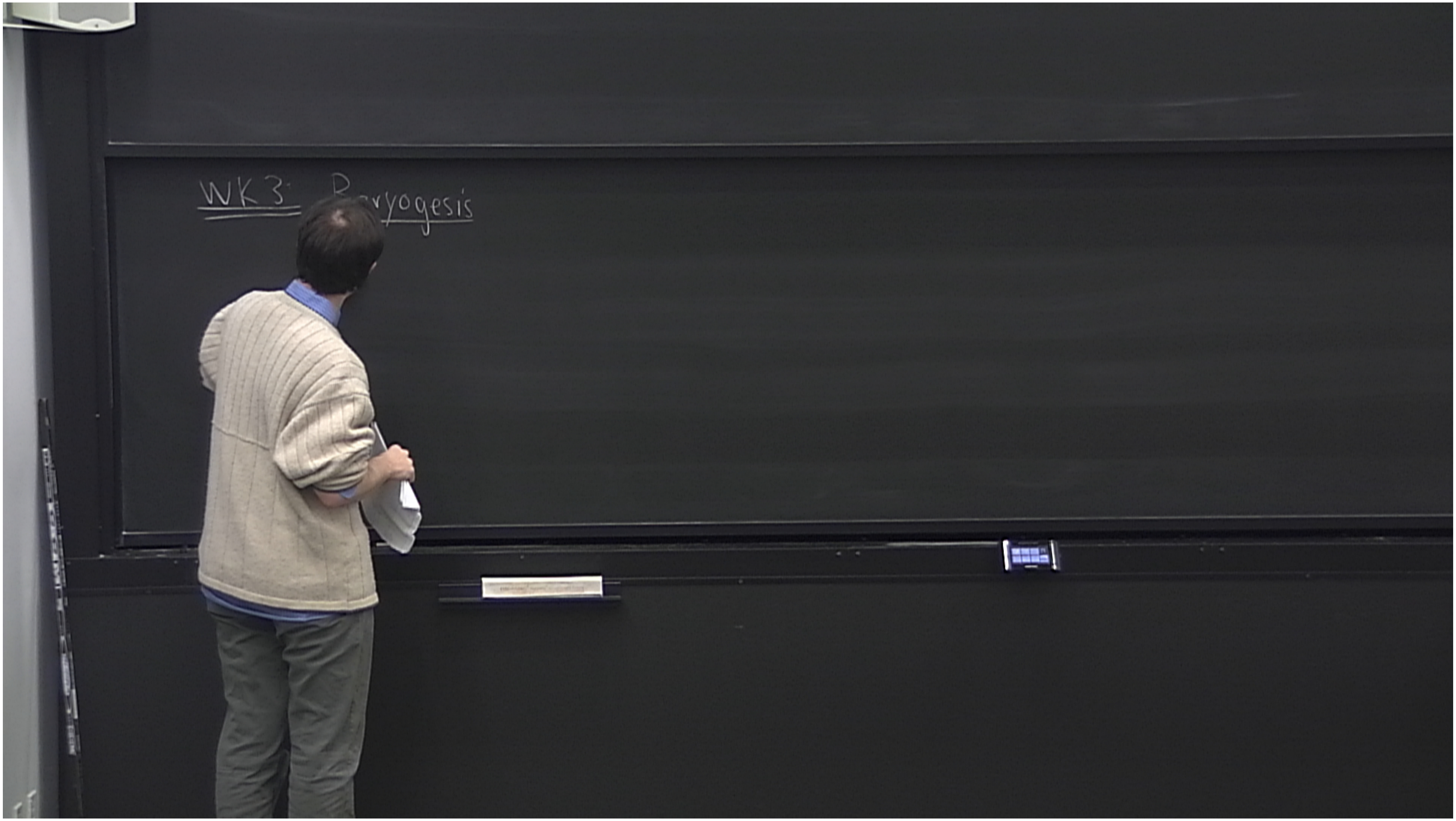
WK 1 FRW
WK2 Thermo
DE
MD

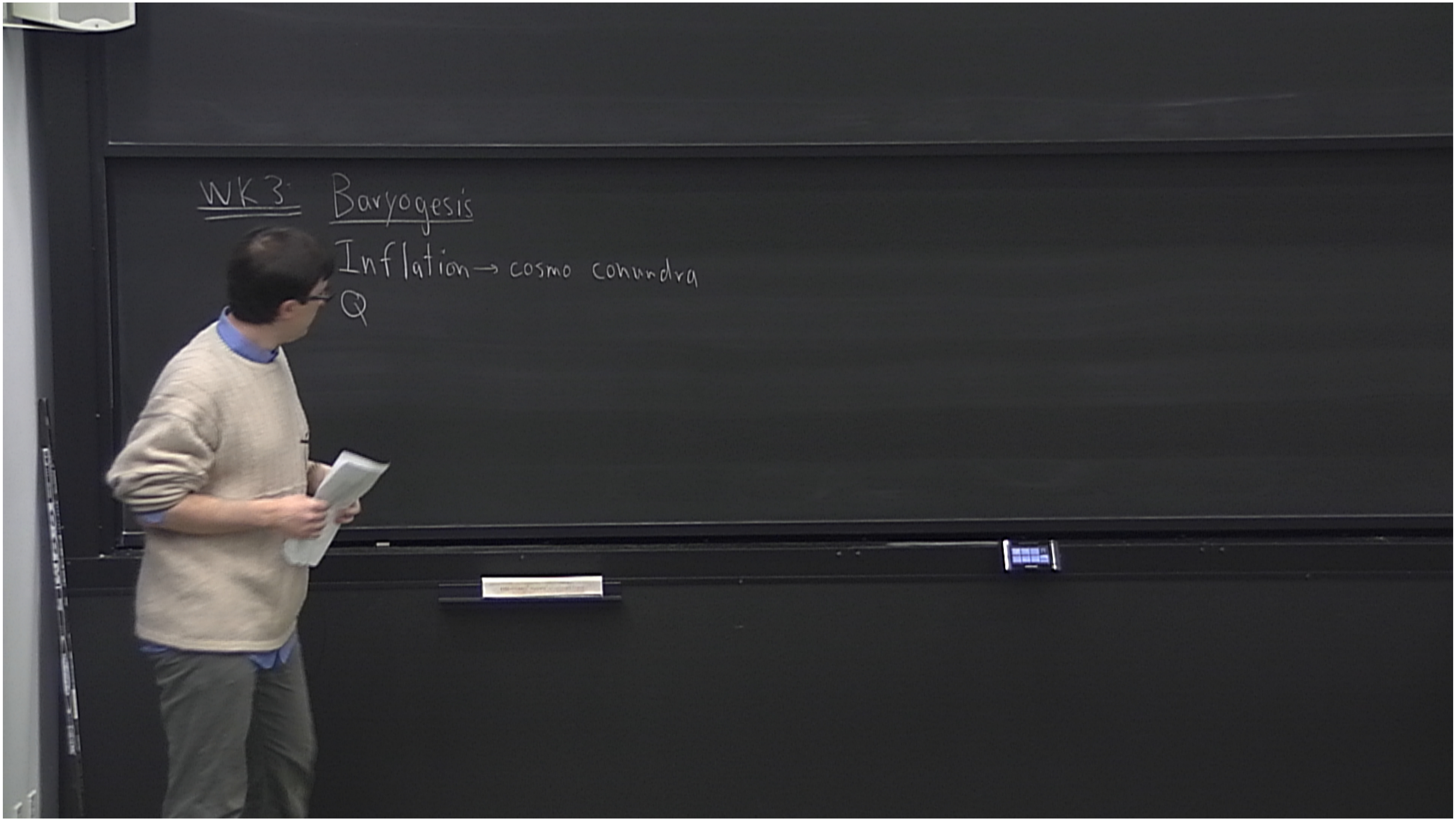

WK1 FRW
w = P/ρ
ρ ∝ 1/a
MD
DE
WK2
rmo: T ∝ 1/a , s ∝ a^-3 , ...
E
m... e^-m/T
n ∝ a^-3
S_f/n_f = S_0/n_0
ρ_0 = m n_0 > ρ_cr = 3H_0^2/8πG_N
BBN ~ He ~ 25%
H ~ 75%

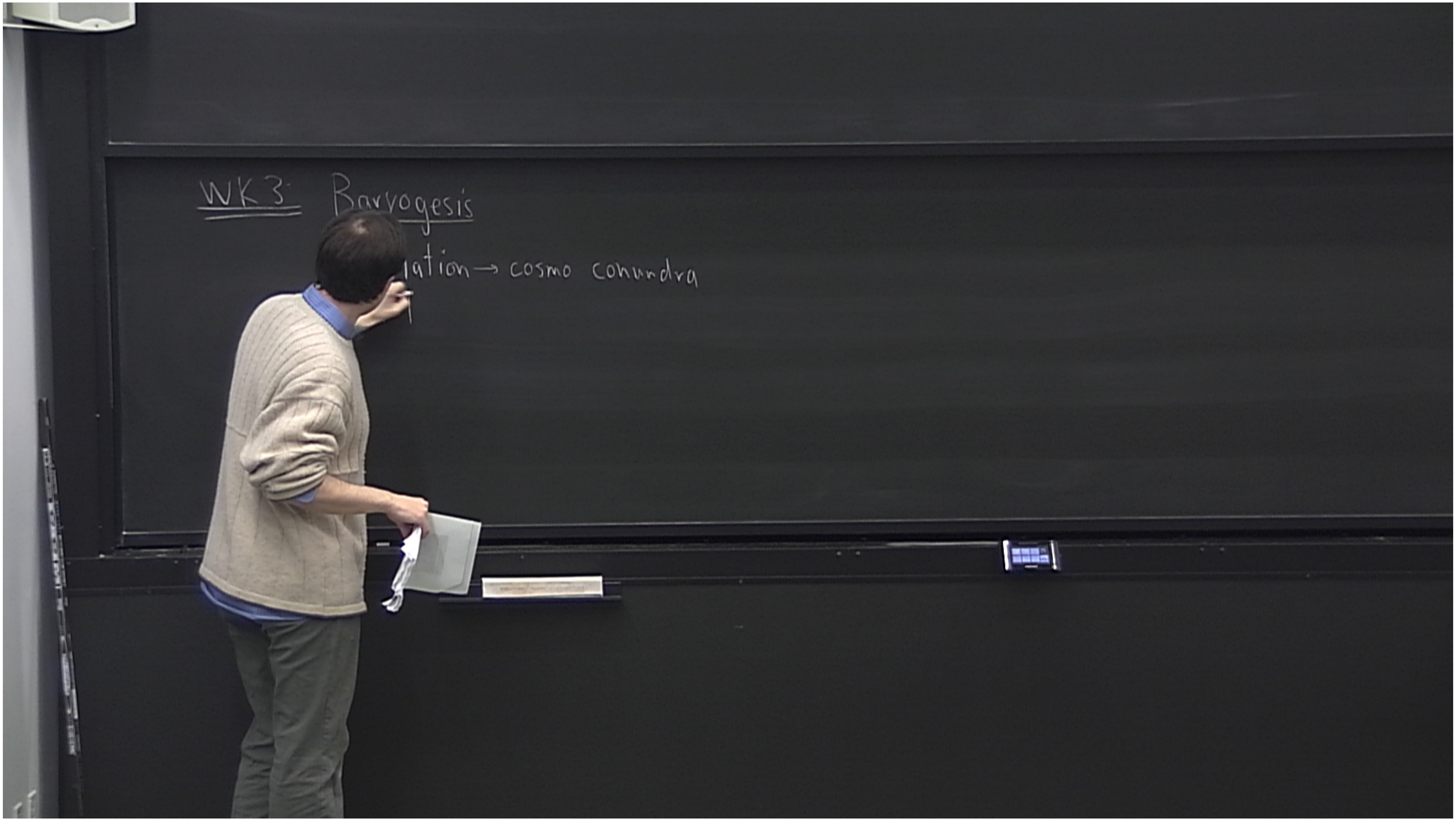

WK1 FRW
w = p/ρ
ρ ∝ 1/a
MD
DE
WK2 Thermo: T ∝ 1/a, s ∝ a^-3, ...
E
n ∝ a^-3
m
e^-m/T
S_f/n_f = S_0/n_0
ρ_0 = m n_0 > ρ_cr = 3H_0^2/8πG_N
BBN ~ He ~ 25%
H ~ 75%
CMB ~ z ~ 1000

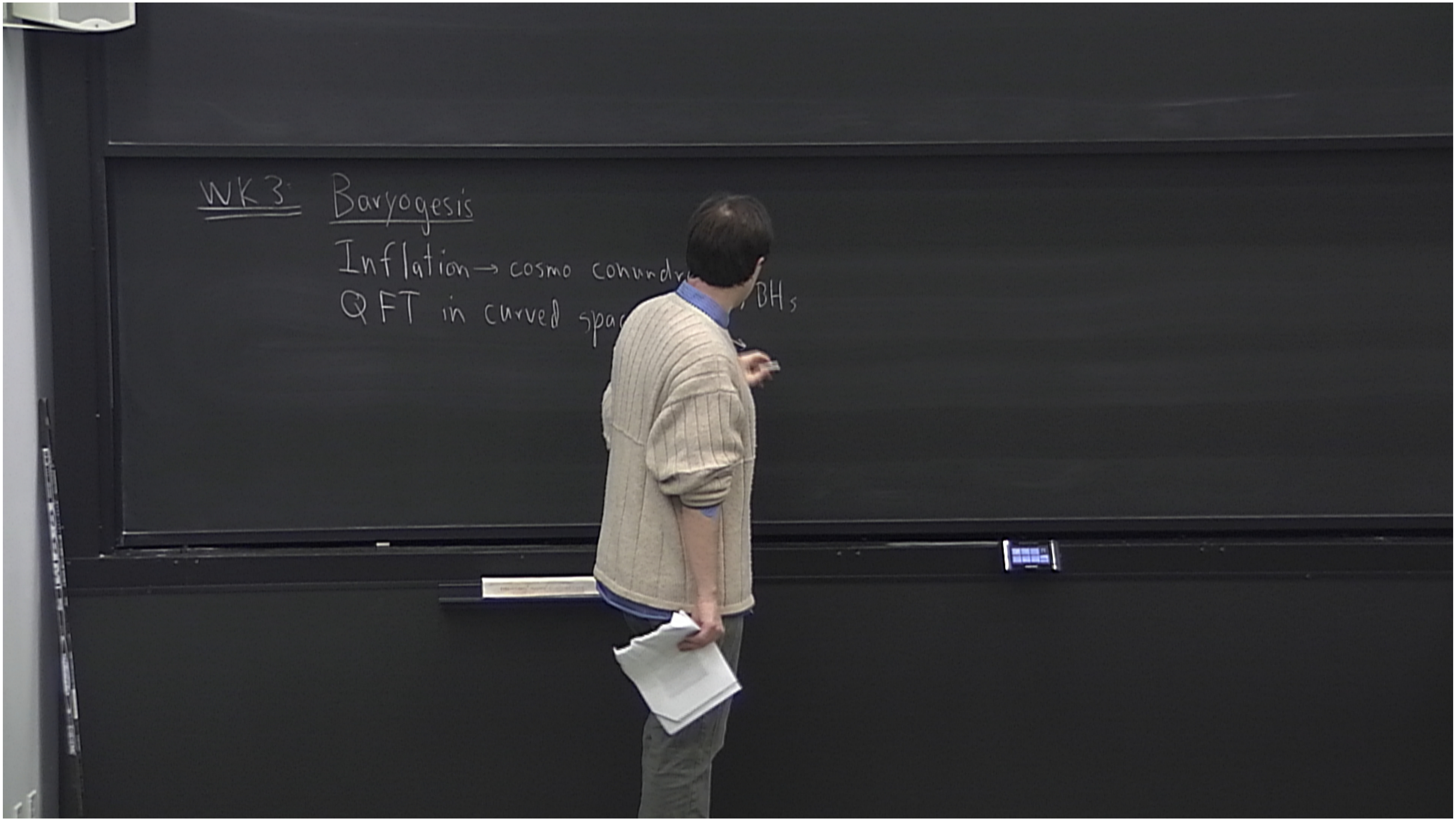

WK 1
FRW
$w = \frac{p}{\rho}$
$\rho \propto \frac{1}{a}$
MD
DE
WK2
Thermo: $T \propto \frac{1}{a}$, $\frac{s}{n} \propto a^{-3}$, $n \propto a^{-3}$
E
m
$e^{-m/T}$
$\frac{s_f}{n_f} = \frac{s_0}{n_0}$
$\rho_0 = m n_0 > \rho_{cr} = \frac{3H_0^2}{8\pi G_N}$
BBN ~ He ~ 25%
H ~ 75%
CMB ~ z ≈ 1000
Dark matter
Dark E

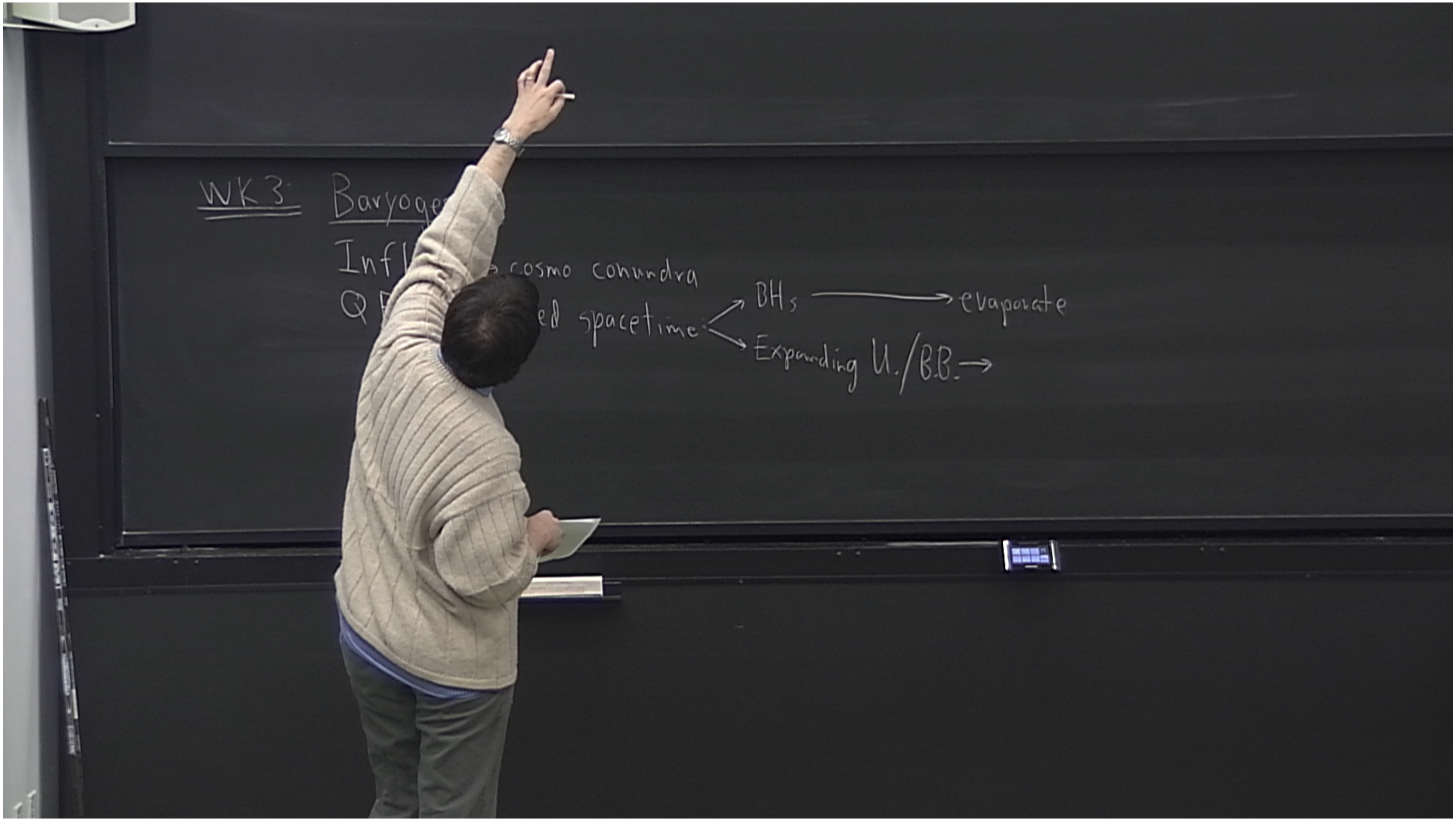

WK 1 FRW
w = p/ρ
ρ ∝ 1/a
WK2 Thermo: T ∝ 1/a
E
s ∝ a^-3
n ∝ a^-3
m
e^-m/T
S_f/n_f = S_0/n_0
ρ_0 = m n_0 > ρ_cr = 3H_0^2/8πG_N
BBN ~ He ~ 25%
H ~ 75%
CMB ~ z ≈ 1000
→ Dark matter ←
→ Dark E ←
MD
DE

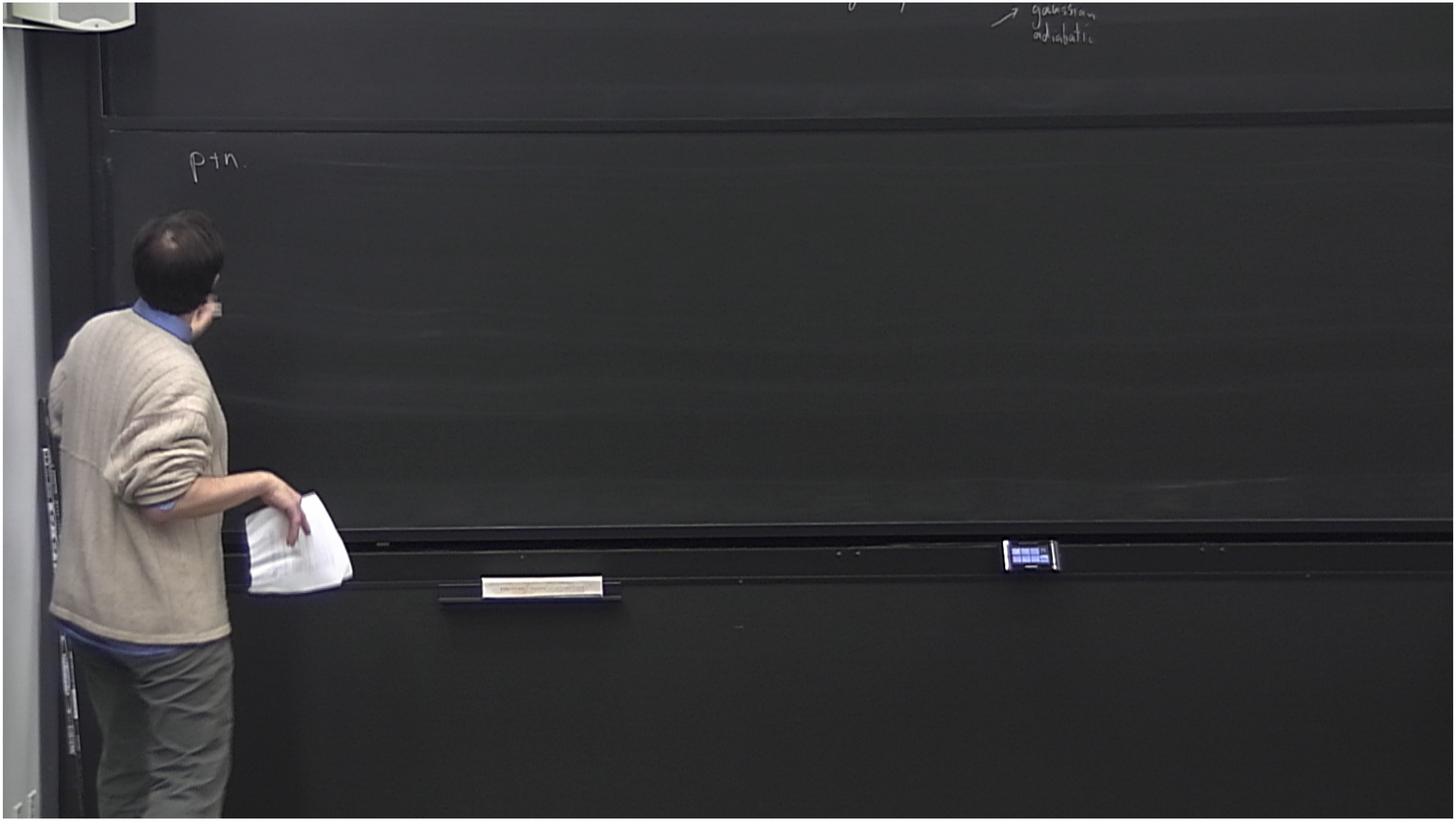

WK3:

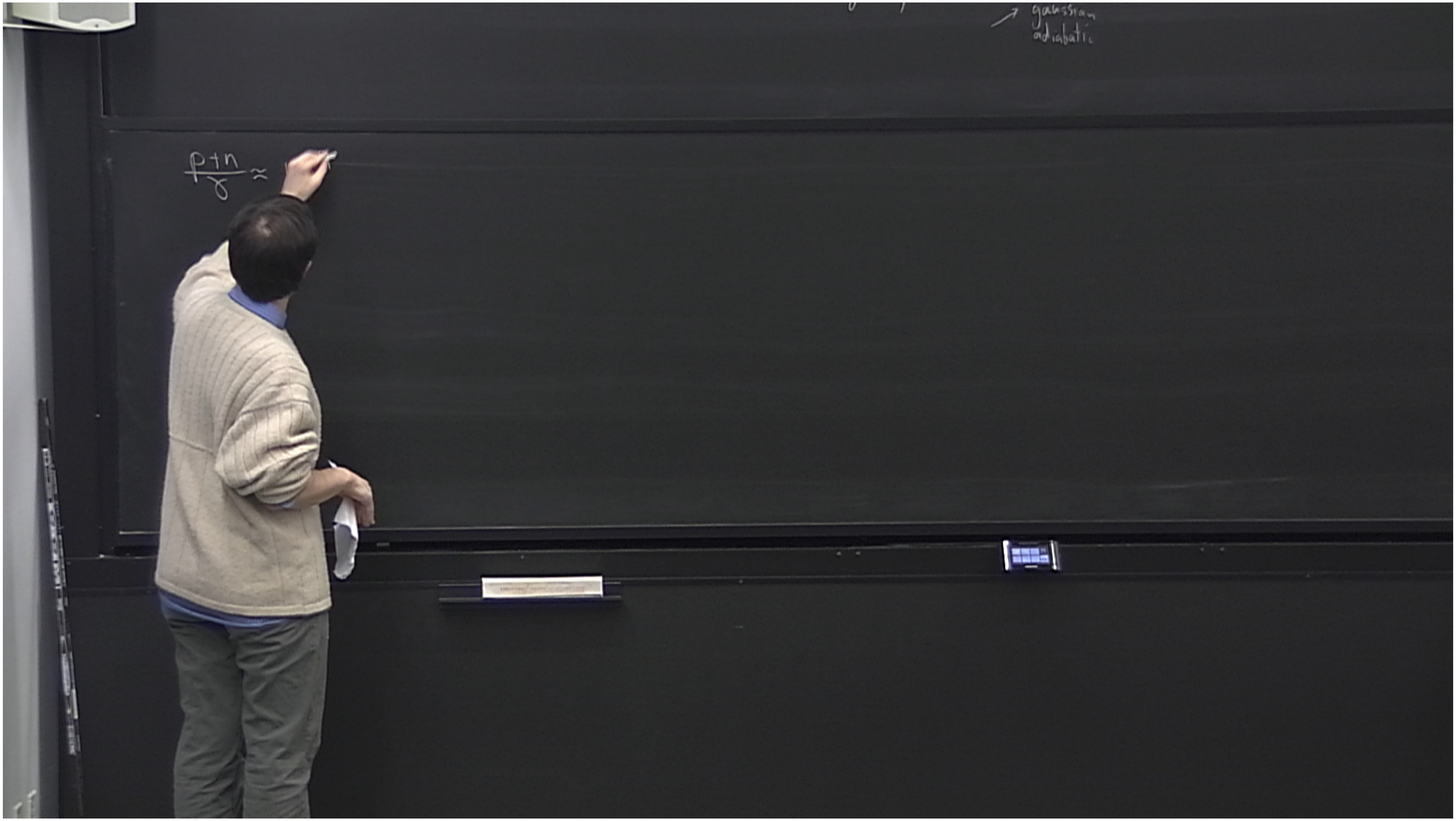

WK3: Baryogesis
Inflation → cosmo conundra
Q

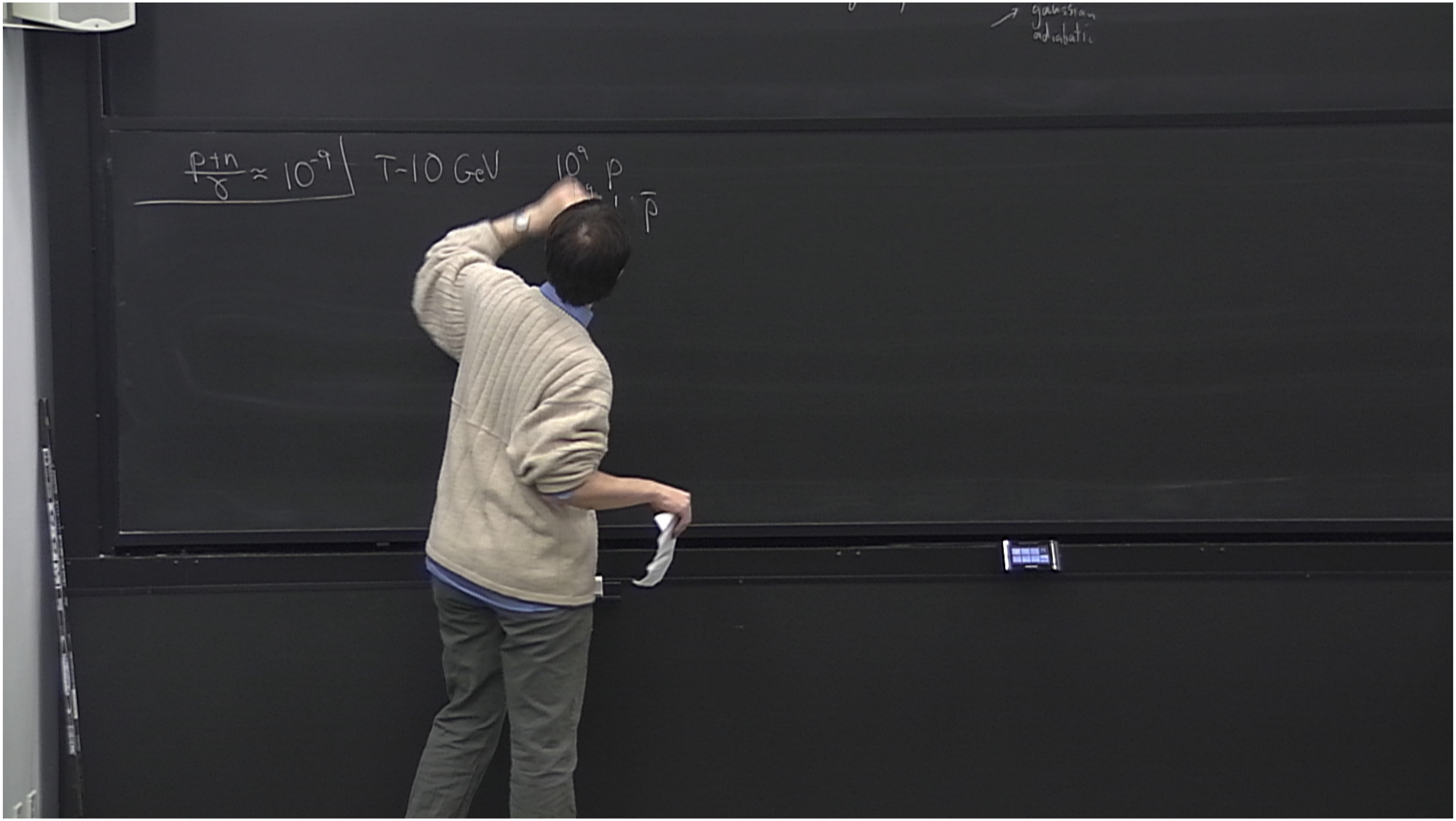

WK 3: Baryogesis
iation → cosmo conundra

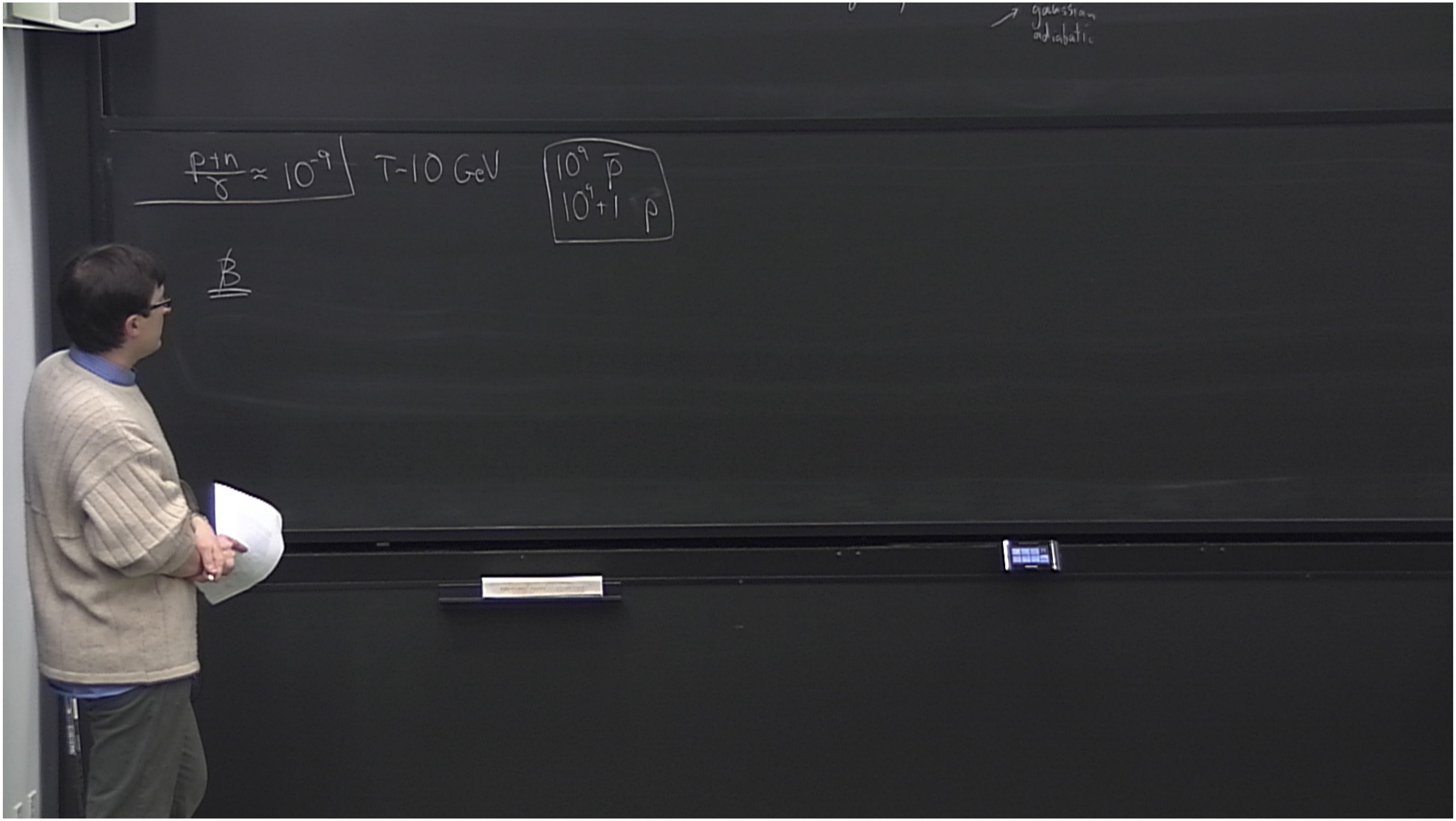

WK 3:
Baryogesis
Inflation → cosmo conundr
BHs
QFT in curved spa

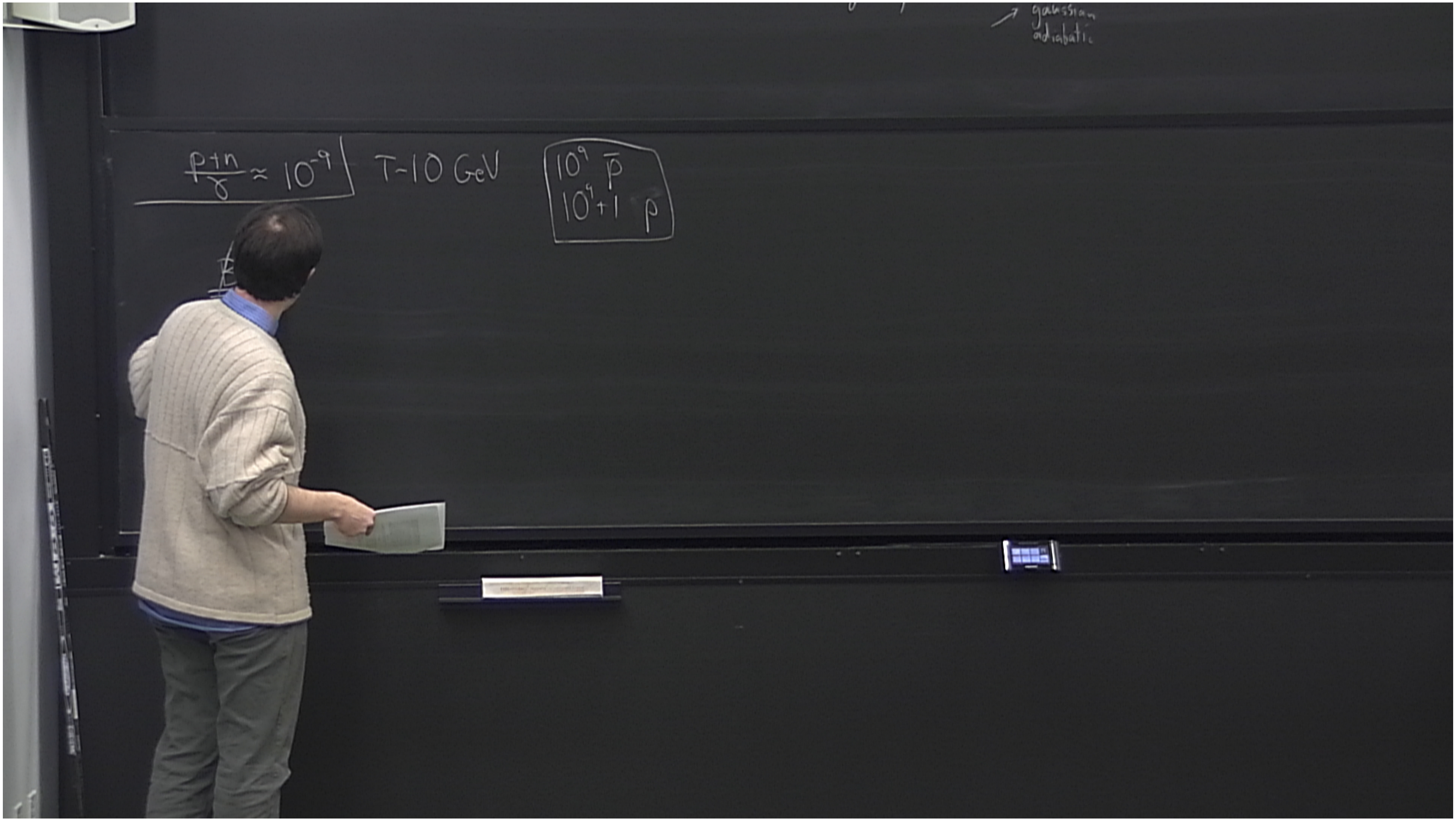

WK3: Baryoge
Infl cosmo conundra
Q ed spacetime
BHs → evaporate
Expanding U./B.B. →

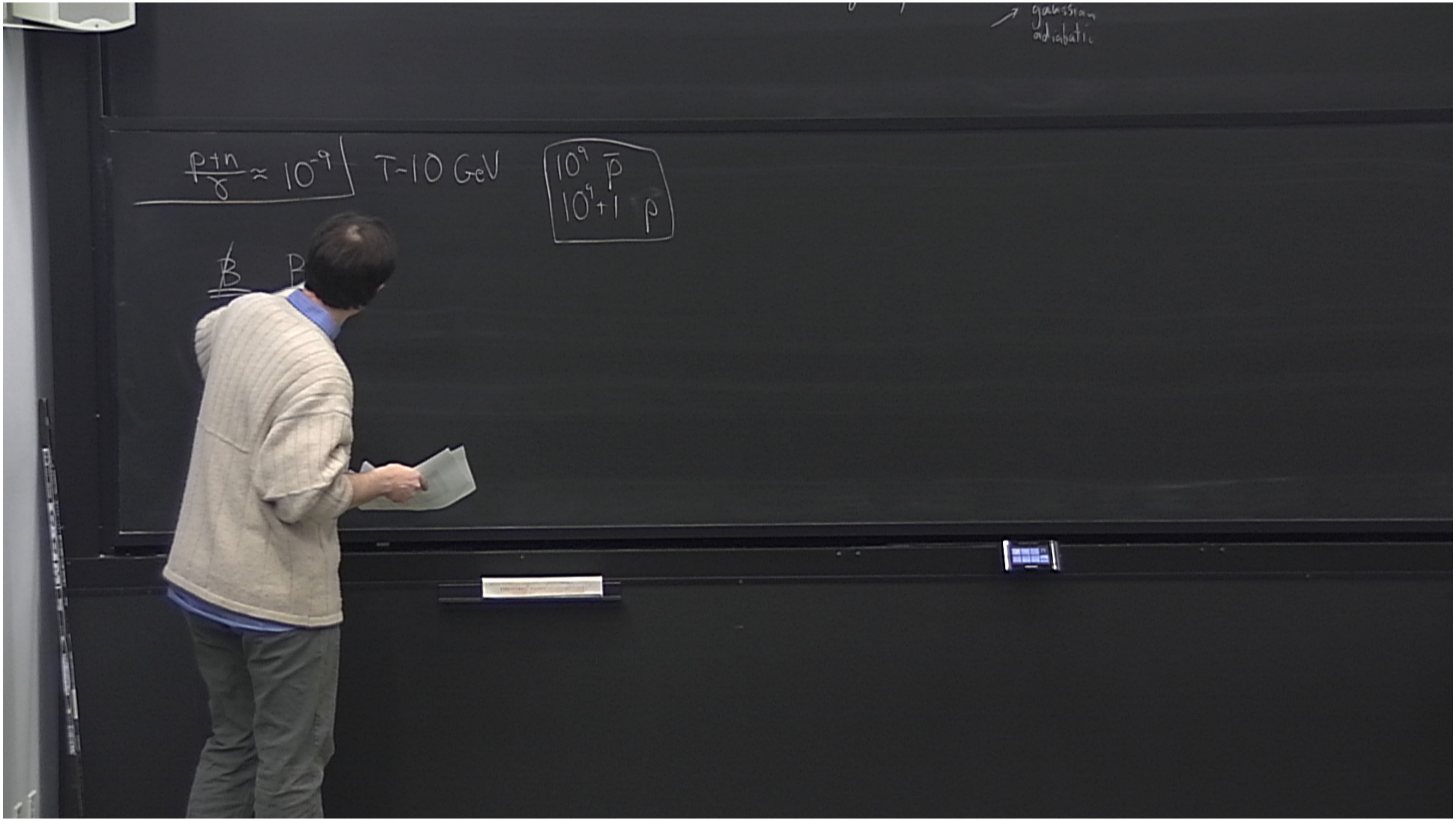

gaussian
adiabatic
p+n.

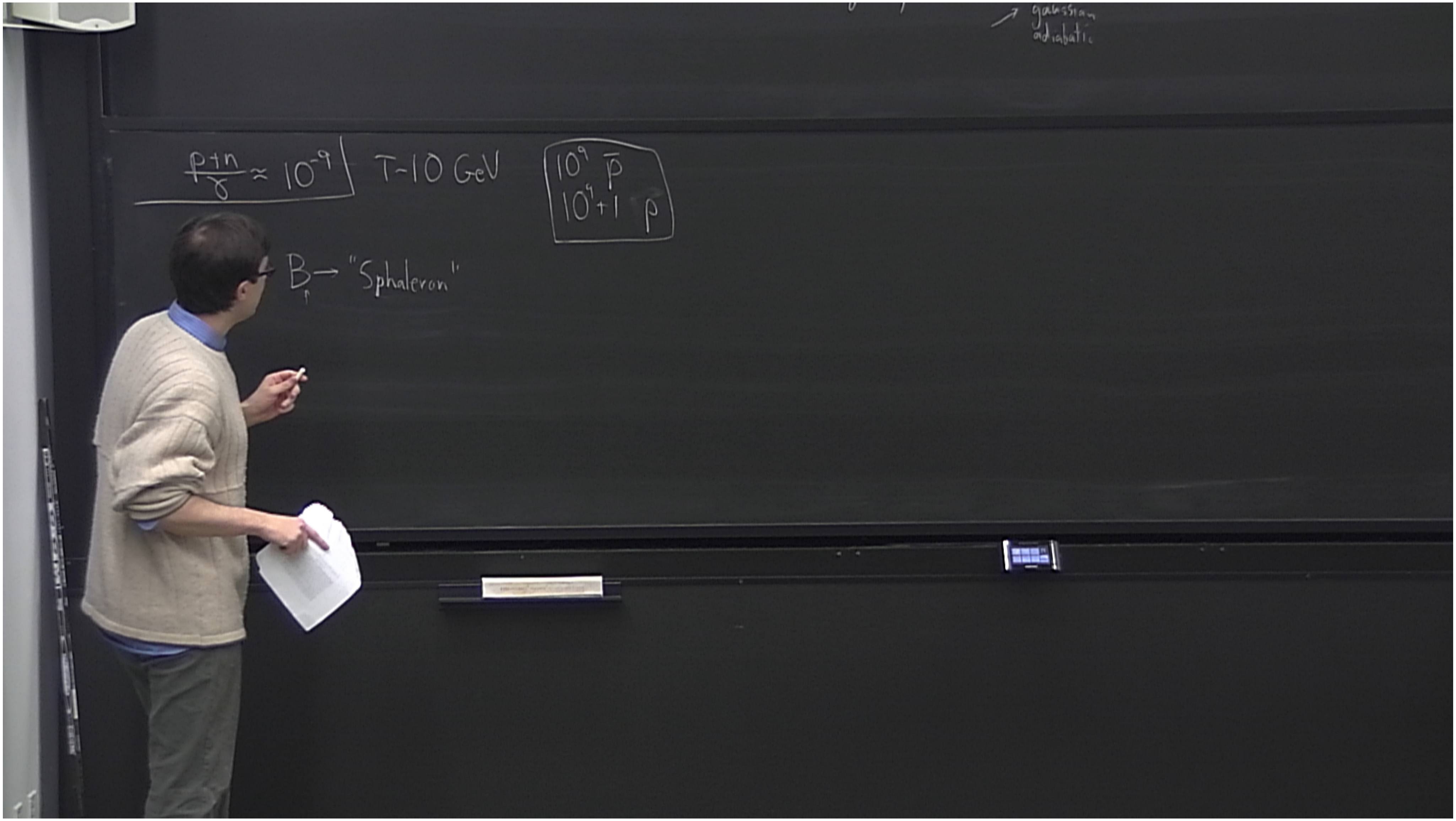

gaussian
adiabatic
$\frac{p+n}{\gamma} \approx$

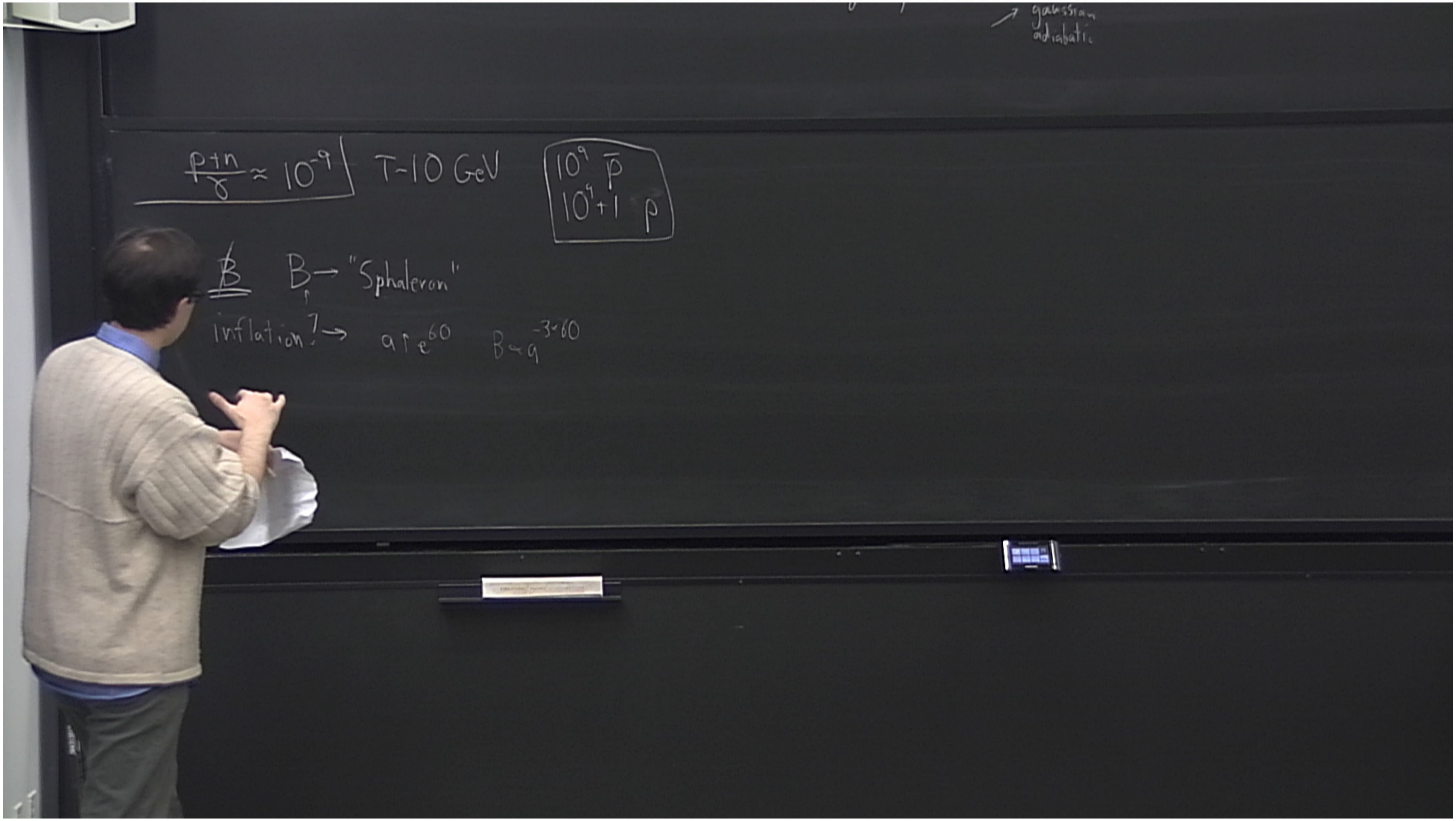

gaussian
adiabatic
$\frac{p+n}{\gamma} \approx 10^{-9}$
T~10 GeV
10^9 p
$\bar{p}$

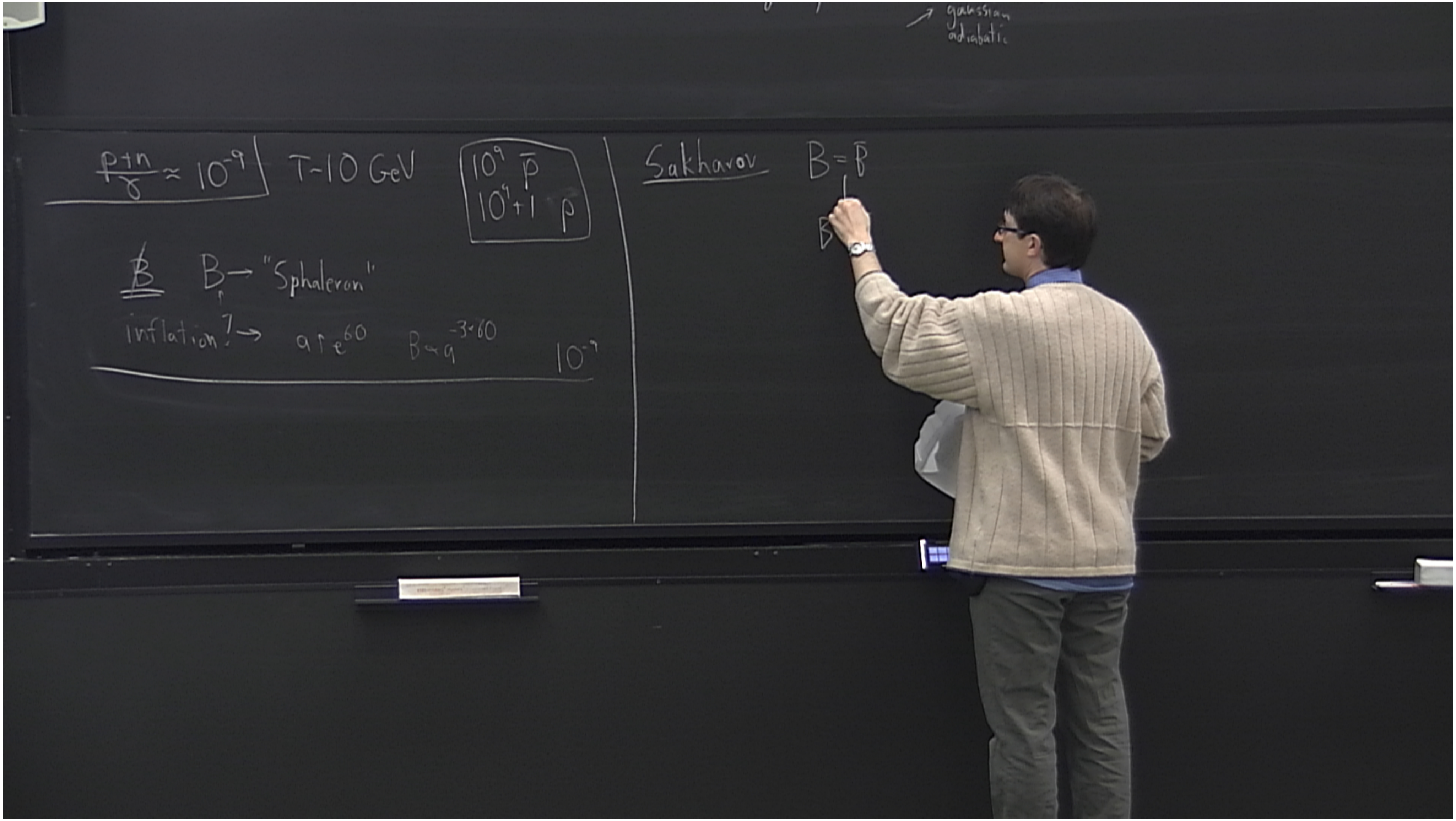

gaussian
adiabatic
$\frac{p+n}{\gamma} \approx 10^{-9}$
$T \sim 10$ GeV
10^9 $\bar{p}$
10^9+1 p
$\not{B}$

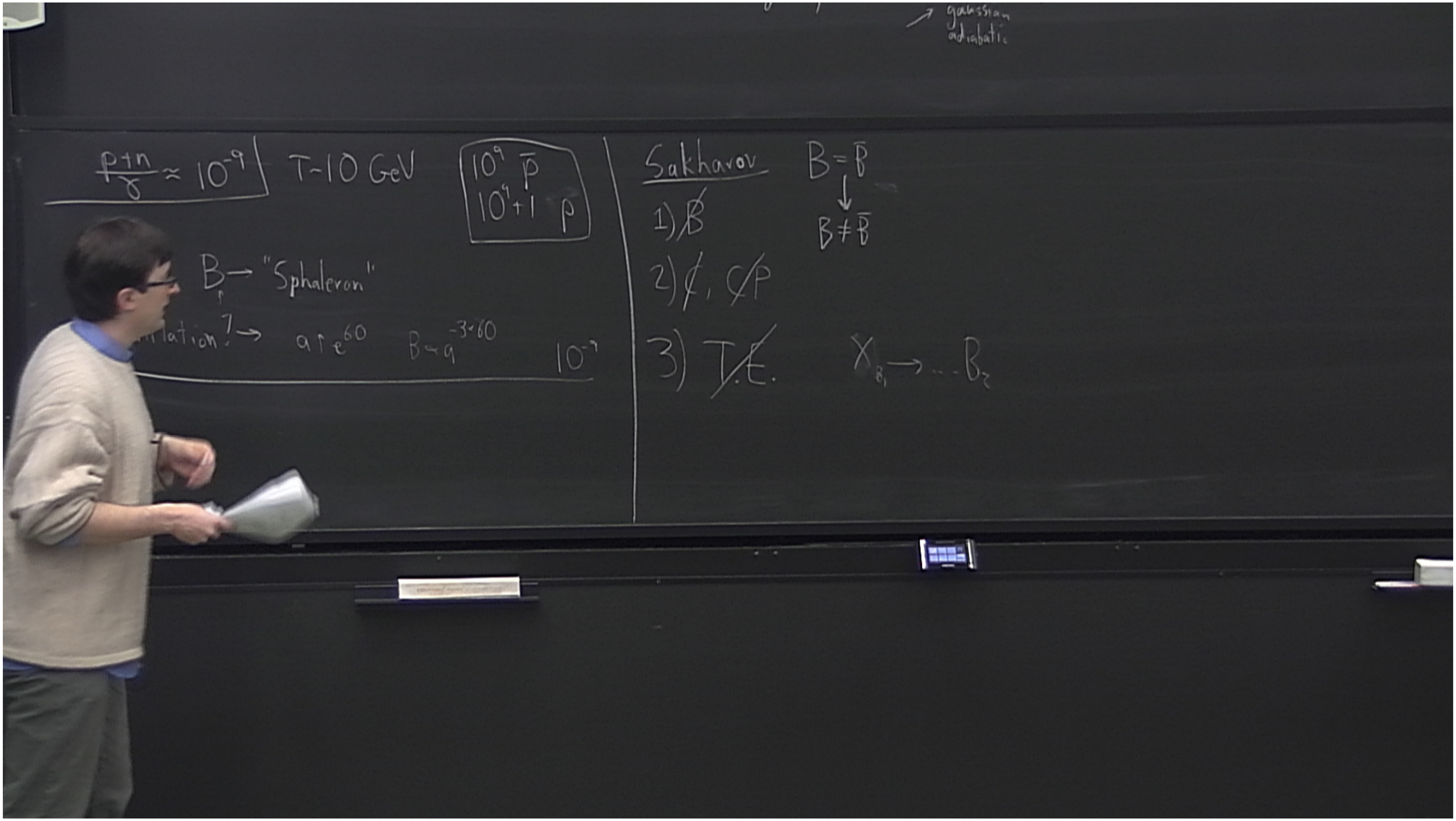

gaussian
adiabatic
$\frac{p+n}{\gamma} \approx 10^{-9}$
T~10 GeV
$10^{9}\ \bar{p}$
$10^{9}+1\ p$

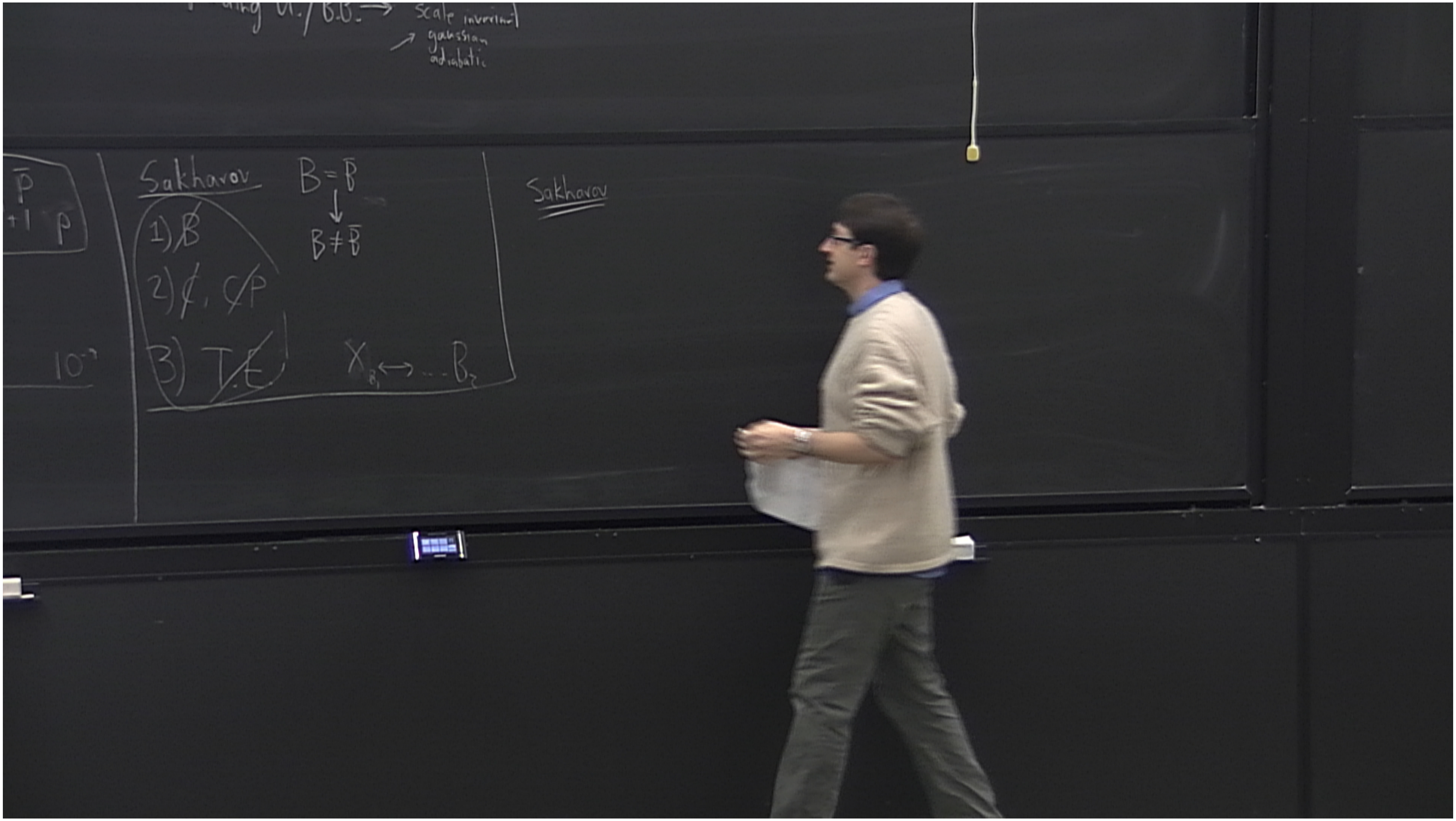

gaussian
adiabatic
p+n / γ ≈ 10^-9
T~10 GeV
10^9 p̄
10^9+1 p
B̸ B

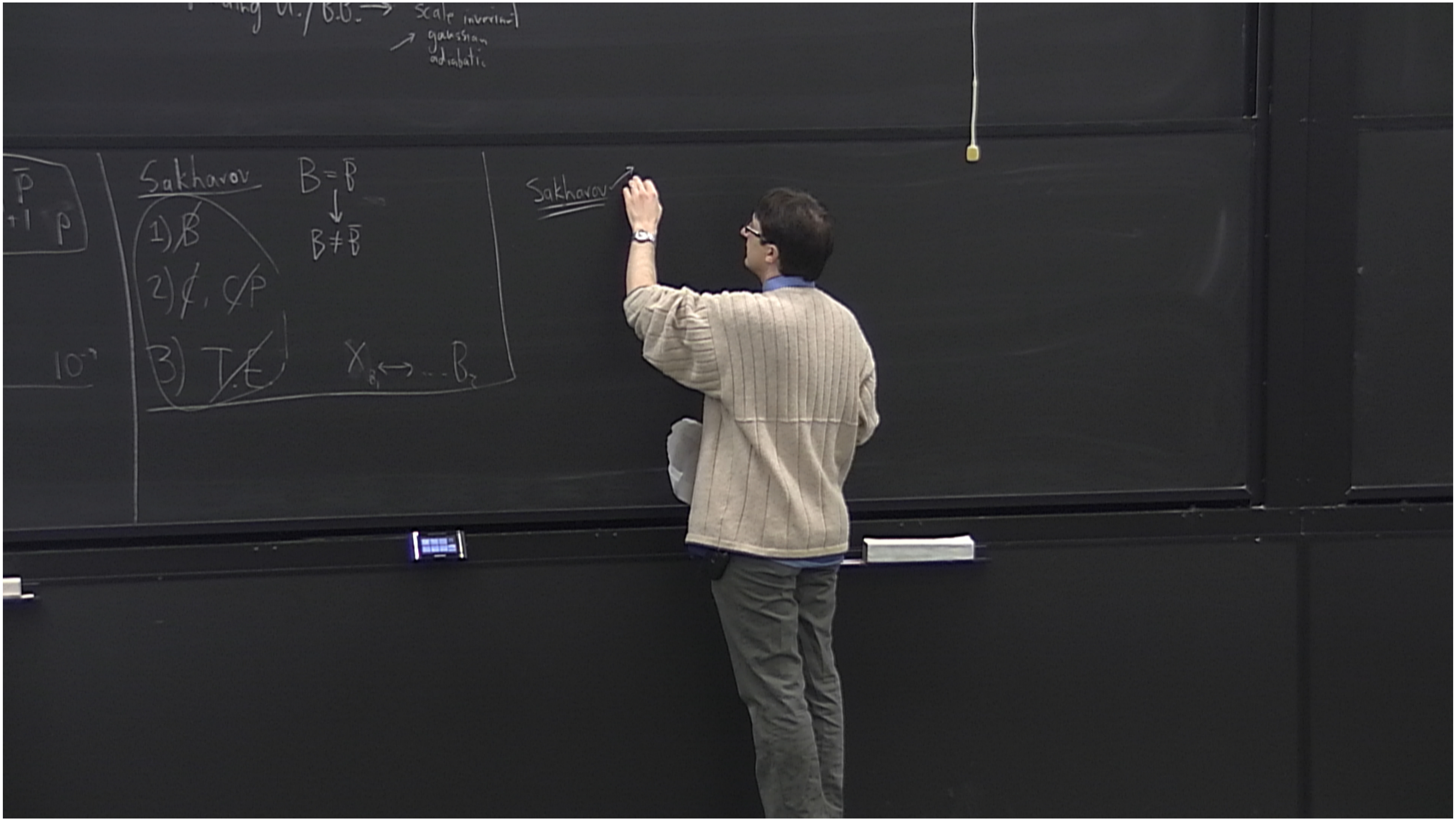

gaussian
adiabatic
$\frac{p+n}{\gamma} \approx 10^{-9}$
$T \sim 10$ GeV
10^9 $\bar{p}$
10^9+1 p
B → "Sphaleron"

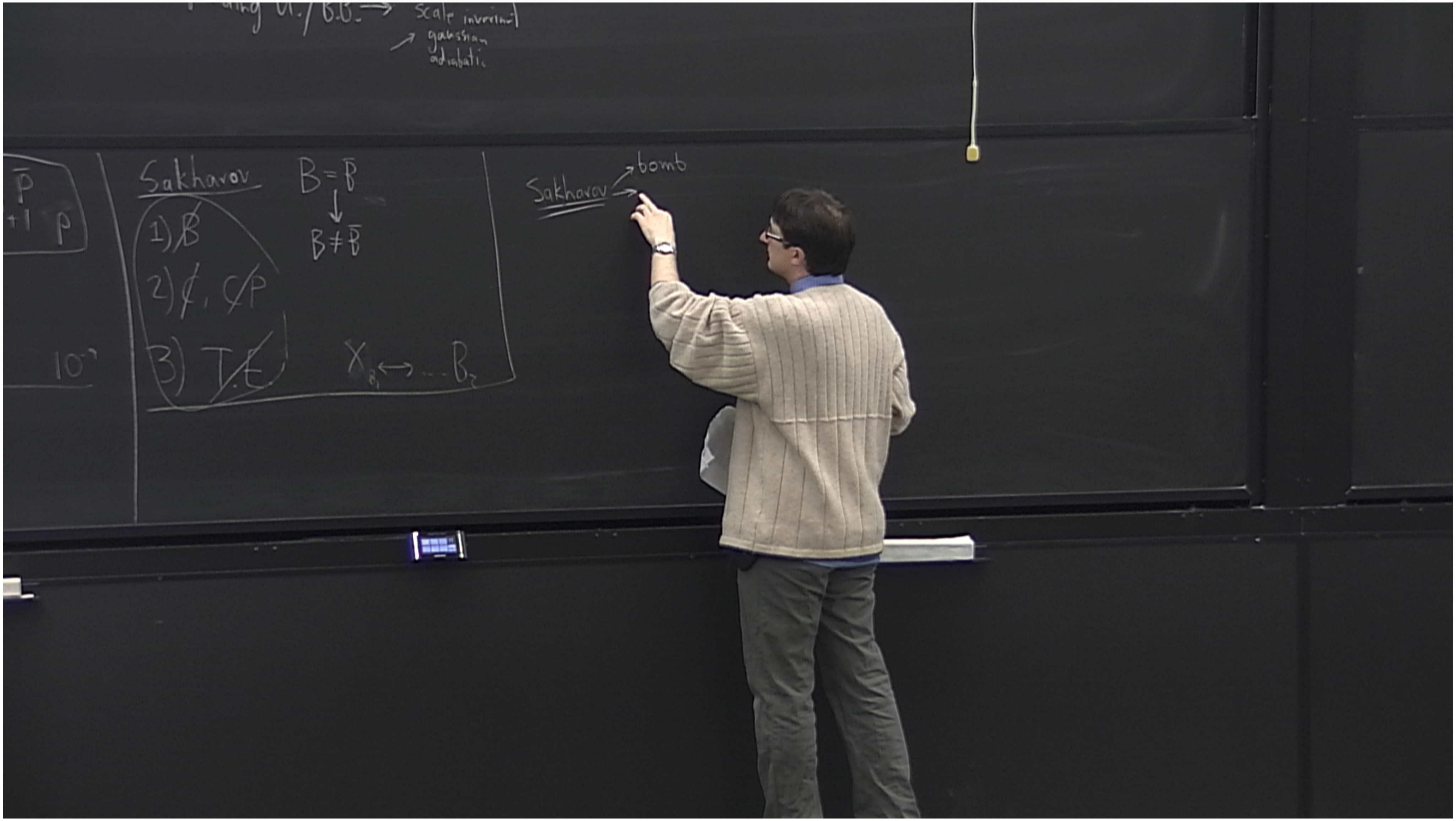

gaussian
adiabatic
(p+n)/γ ≈ 10^-9
T~10 GeV
10^9 p̄
10^9+1 p
"Sphaleron"
inflation?
a ↑ e^60
B ~ a^-3·60

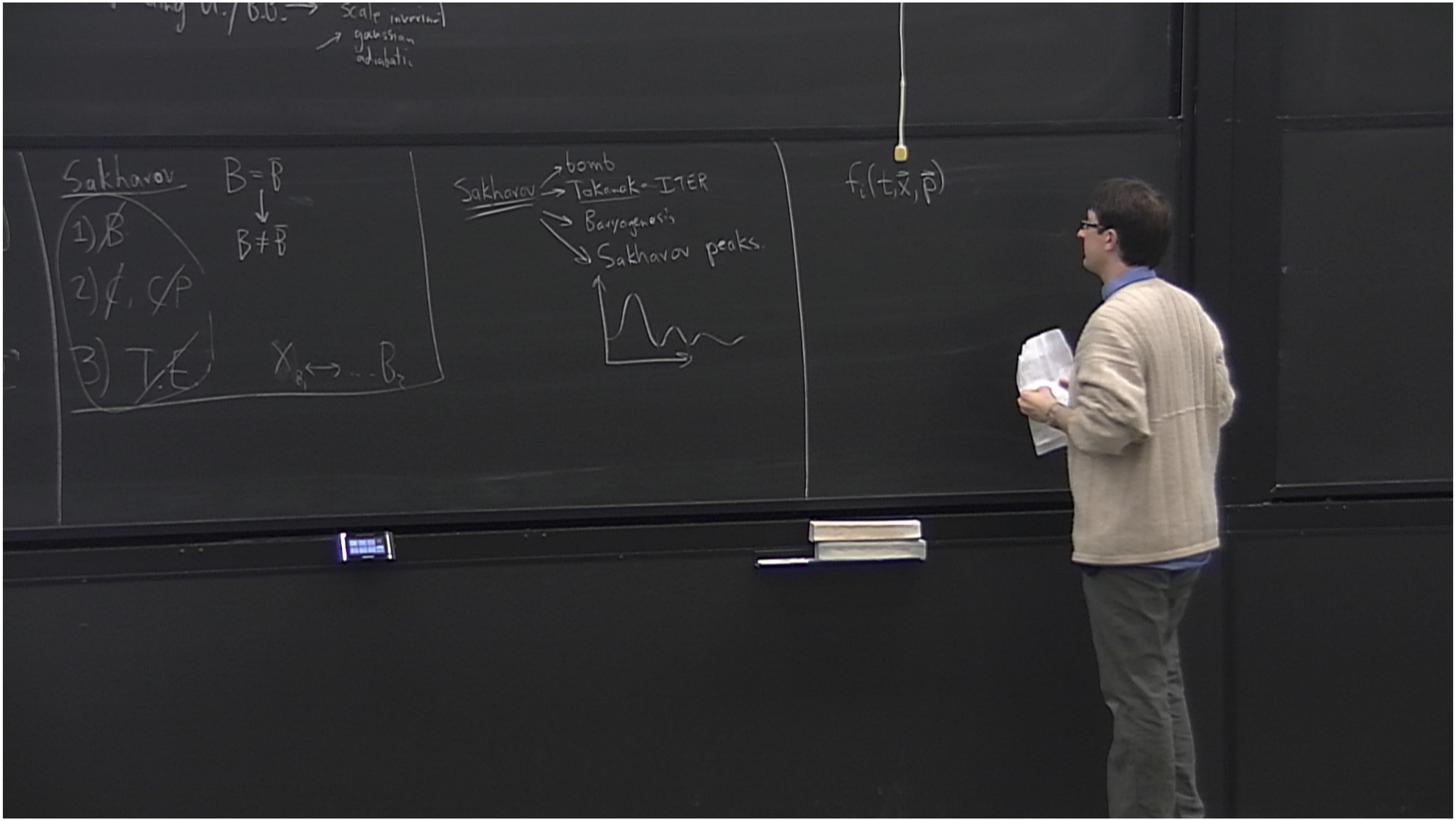

gaussian
adiabatic
p+n / γ ≈ 10^-9
T~10 GeV
10^9 p̄
10^9+1 p
"Sphaleron"
inflation?
a ↑ e^60
10^-9
Sakharov
B = B̄

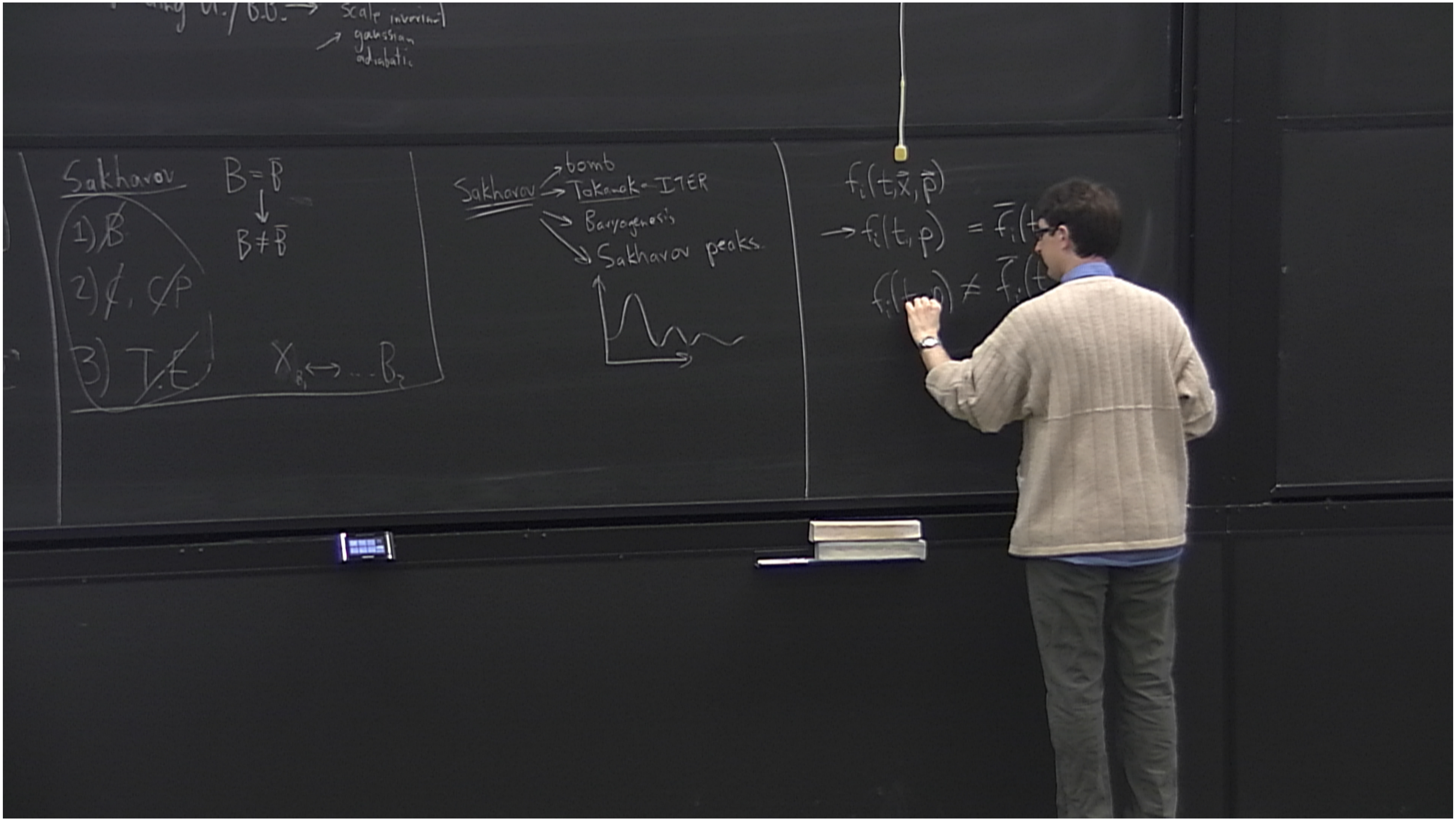

gaussian
adiabatic
p+n / γ ≈ 10^-9
T~10 GeV
10^9 p̄
10^9+1 p
B → "Sphaleron"
lation? → a ↑ e^60
B ~ a^-3·60
10^-9
Sakharov
B = B̄
B ≠ B̄
1) B̸
2) C̸, CP̸
3) T.E.
X_B1 → ... B_2

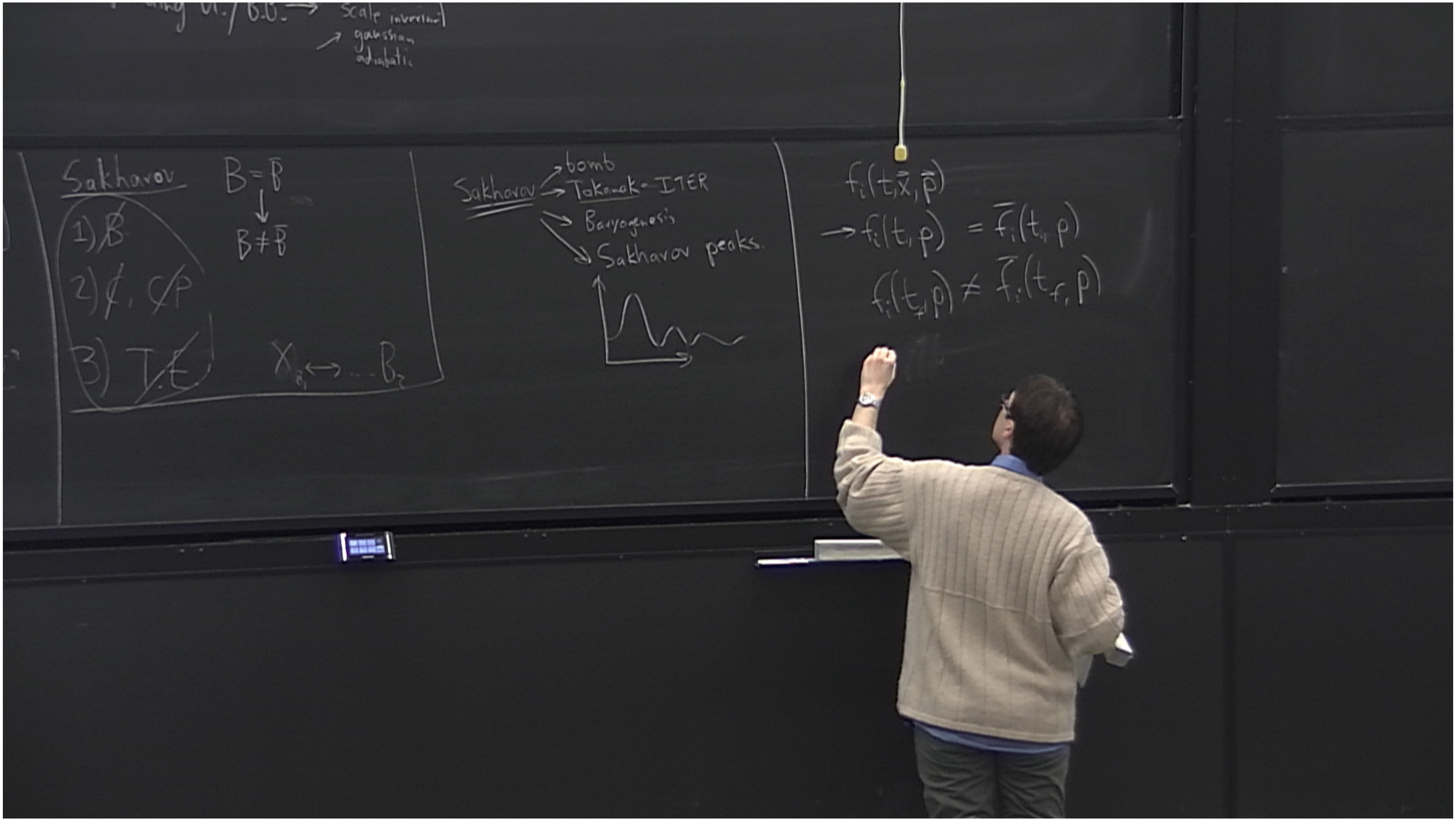

scale invariant
gaussian
adiabatic
Sakharov
B = B̄
B ≠ B̄
1) B̸
2) C̸, C̸P
3) T.E.
Sakharov

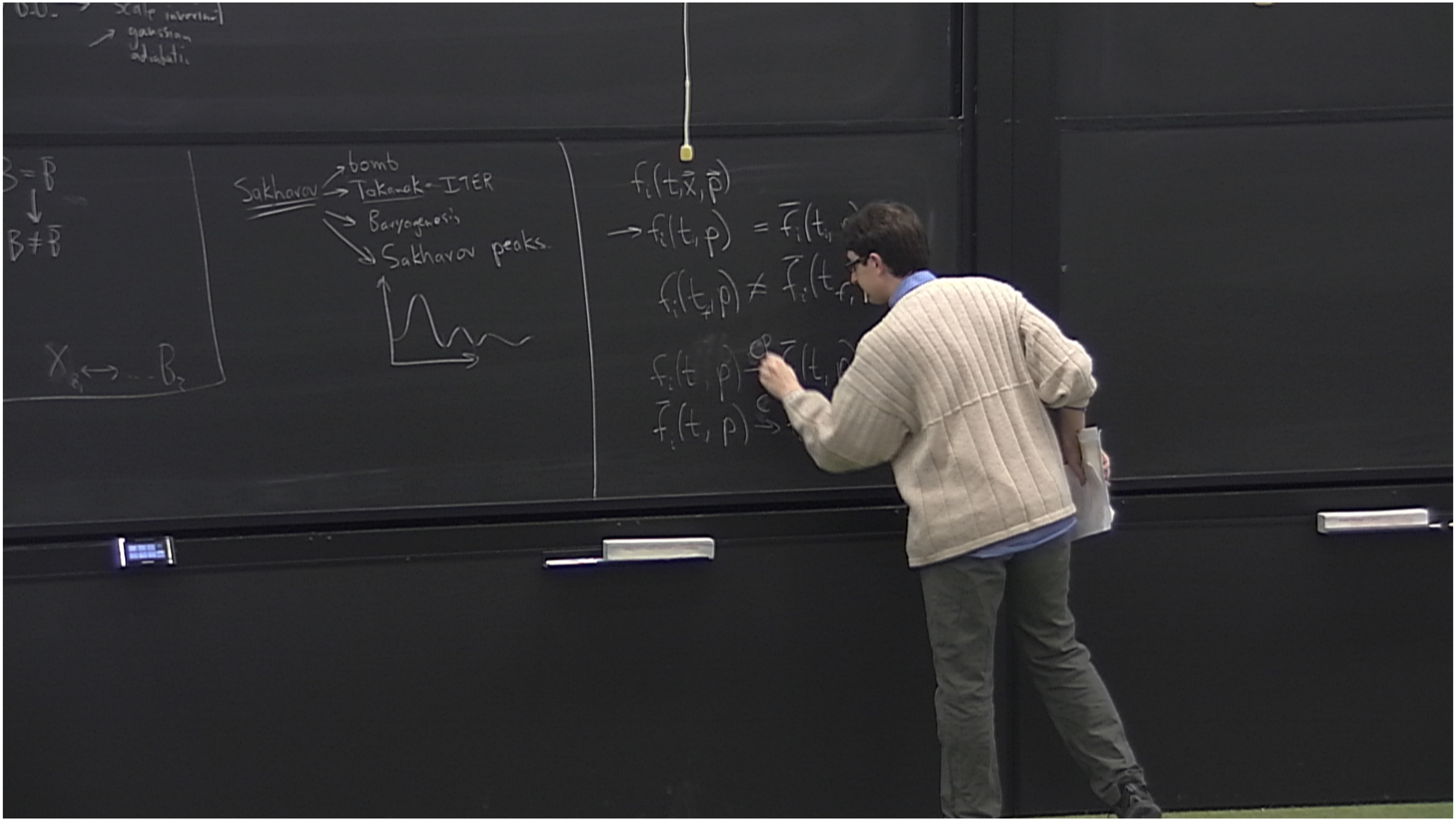

scale invariant
gaussian
adiabatic
Sakharov
1) B̸
2) C̸, C̸P
3) T.E.
B = B̄
B ≠ B̄
Sakharov


scale invariant
gaussian
adiabatic
Sakharov
1) B
2) C, CP
3) T.E.
B = B̄
B ≠ B̄
Sakharov
bomb

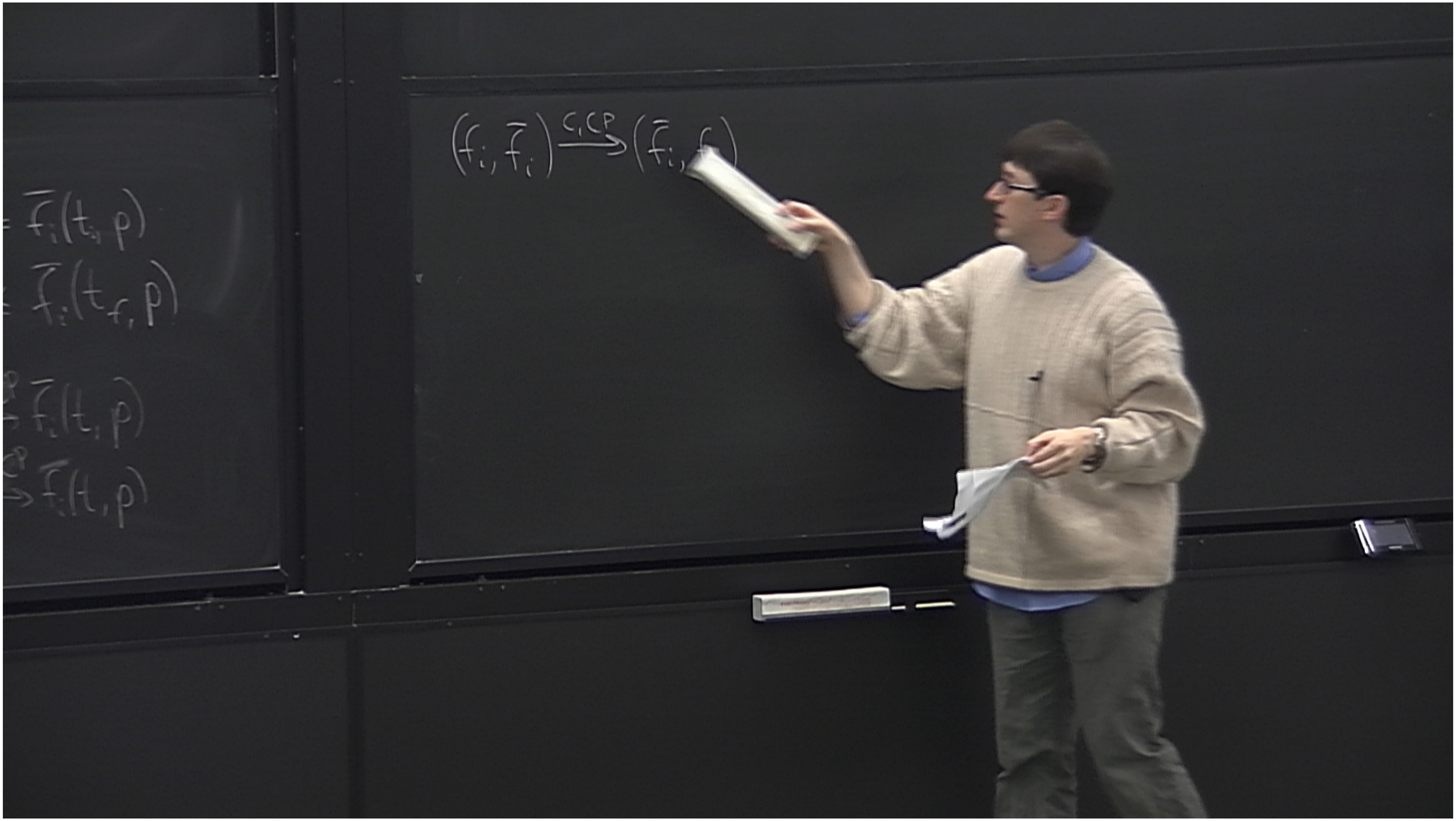

scale invariant
gaussian
adiabatic
Sakharov
1) B
2) C, CP
3) T.E.
B = B̄
B ≠ B̄
Sakharov
bomb
Tokamak - ITER
Baryogenesis
Sakharov peaks.
f_i(t, x⃗, p⃗)

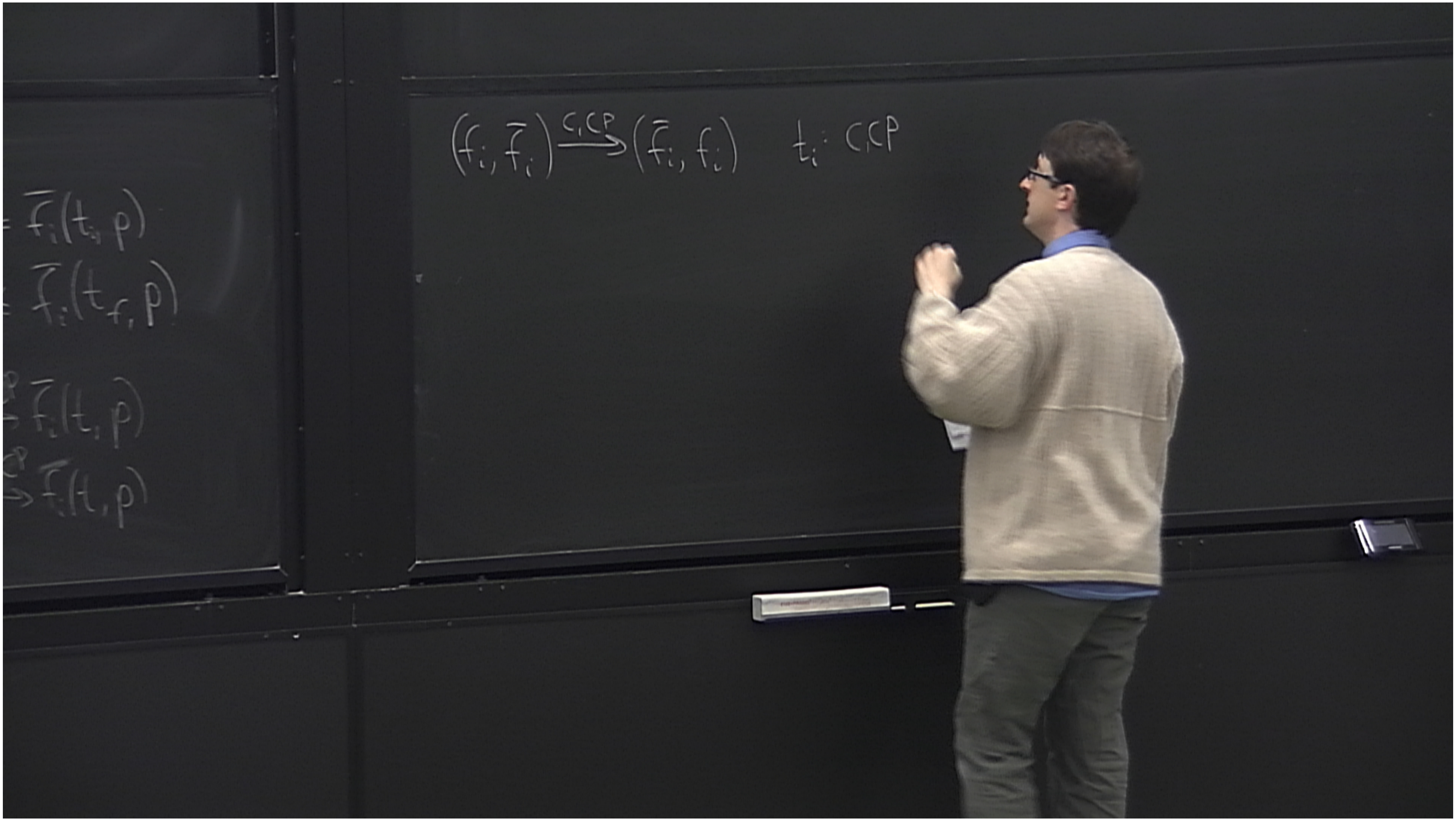

Scale invariant
gaussian
adiabatic
Sakharov
B = B̄
B ≠ B̄
1) B
2) C, CP
3) T.E.
Sakharov
bomb
Tokamak - ITER
Baryogenesis
Sakharov peaks.

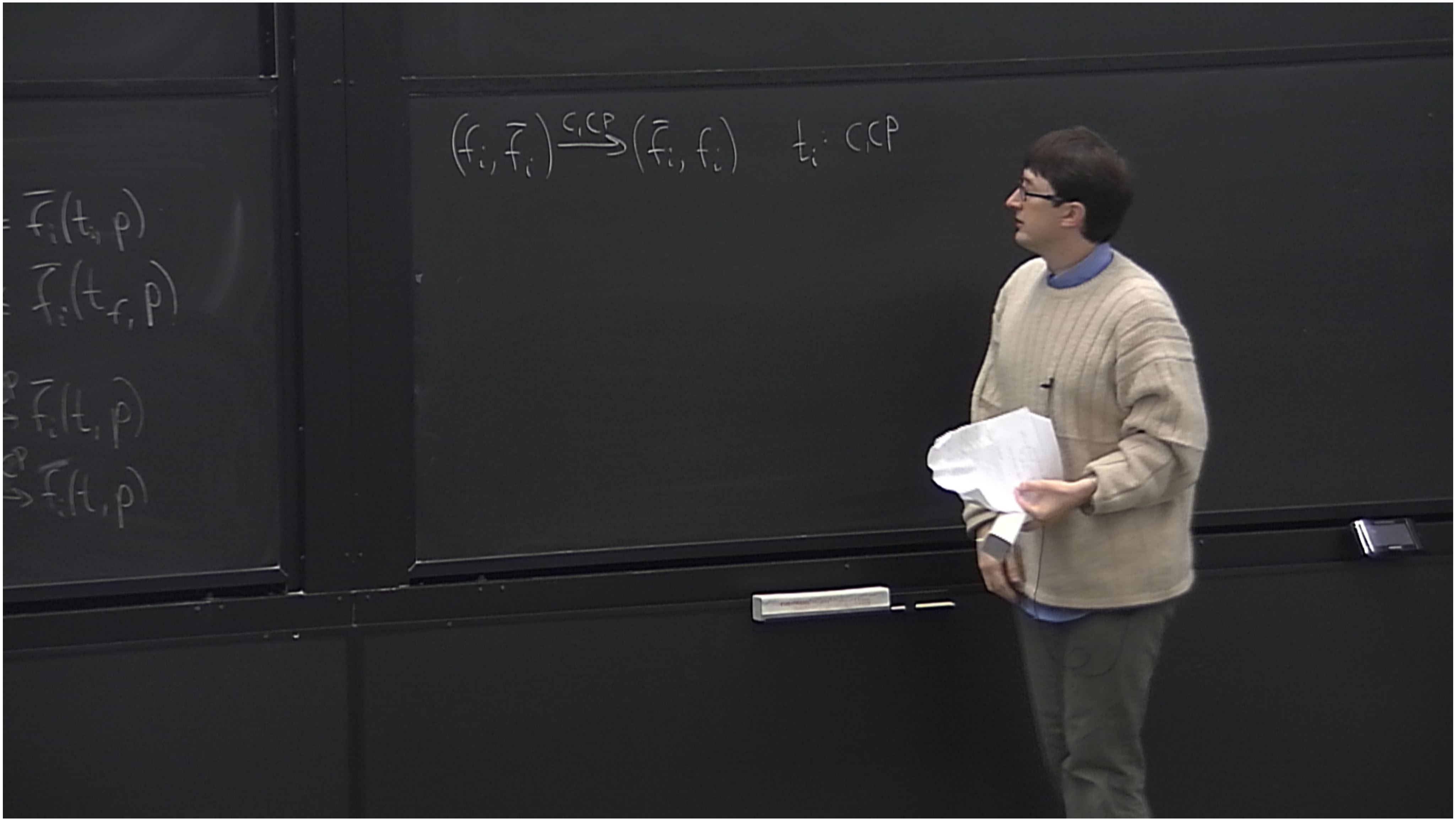

scale invariant
gaussian
adiabatic
Sakharov
1) $\cancel{B}$
2) $\cancel{C}$, $\cancel{CP}$
3) T.E.
$B = \bar{B}$
$B \neq \bar{B}$
Sakharov
bomb
Tokamak - ITER
Baryogenesis
Sakharov peaks.
$f_i(t, \vec{x}, \vec{p})$
$\to f_i(t_i, p) = \bar{f}_i(t_i, p)$
$f_i(t_f, p) \neq \bar{f}_i(t_f, p)$

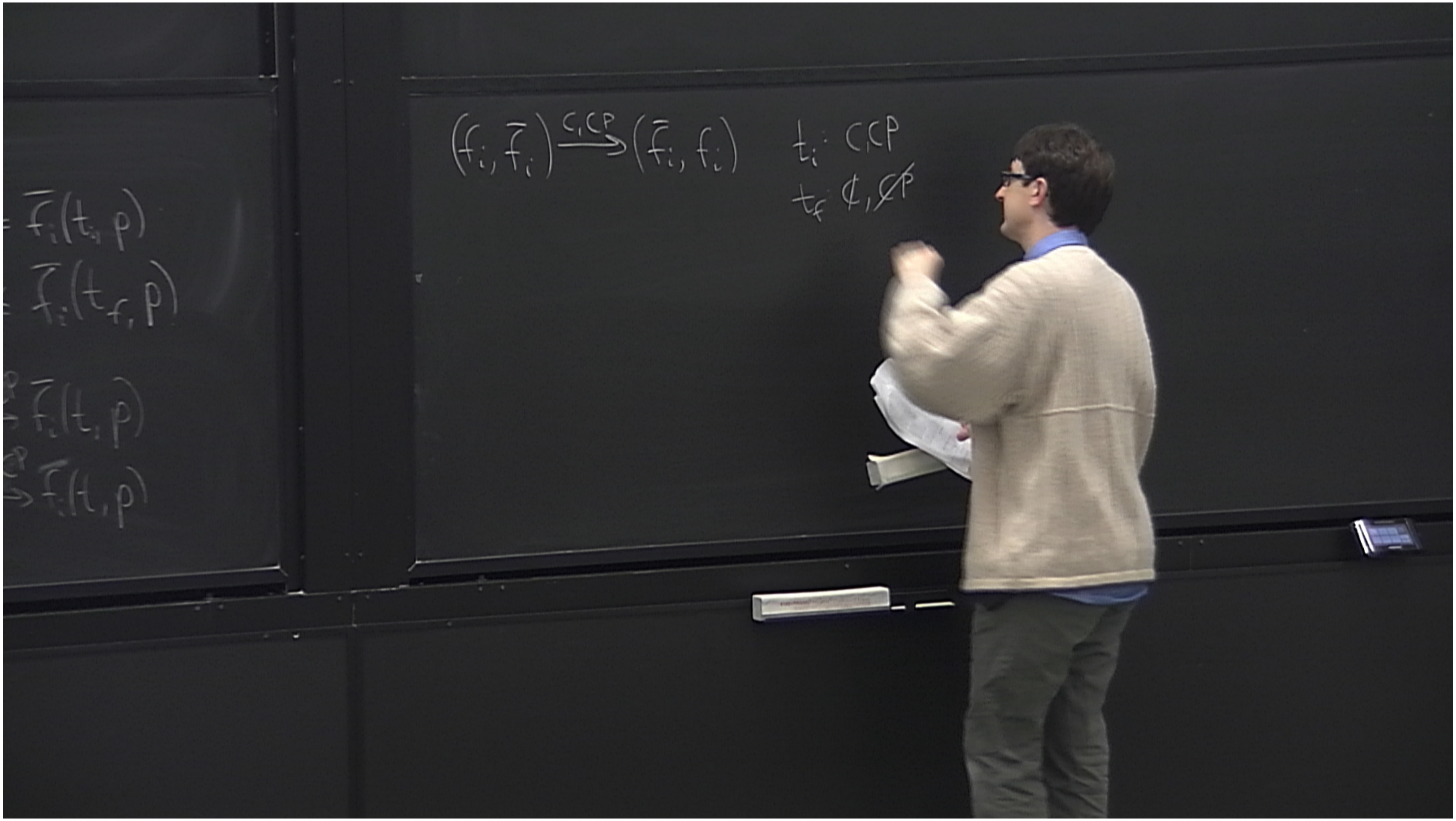


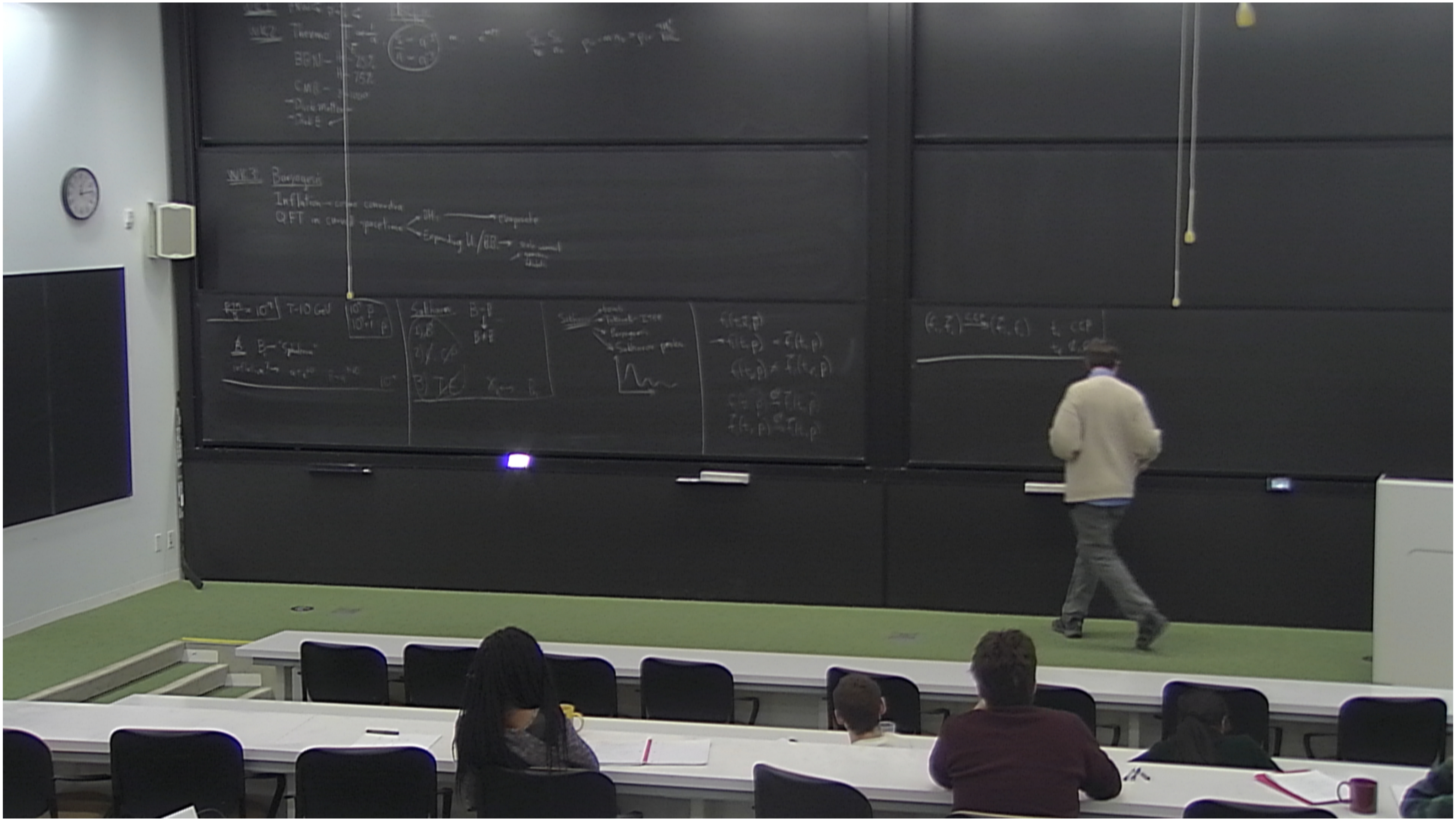
Sakharov
bomb
Tokamak - ITER
Baryogenesis
Sakharov peaks.


$(f_i, \bar{f}_i) \xrightarrow{C, CP} (\bar{f}_i, f_i)$
$\bar{f}_i(t_i, p)$
$\bar{f}_i(t_f, p)$
$\bar{f}_i(t, p)$
$\bar{f}_i(t, p)$


$(f_i, \bar{f}_i) \xrightarrow{C, CP} (\bar{f}_i, f_i)$
t_i: C, CP


$(f_i, \bar{f}_i) \xrightarrow{C,CP} (\bar{f}_i, f_i)$ $t_i \cdot C,CP$


$(f_i, \bar{f}_i) \xrightarrow{C, CP} (\bar{f}_i, f_i)$
t_i: C, CP
t_f: $\cancel{C}$, $\cancel{CP}$



$= \bar{f}_i(t_i, p)$

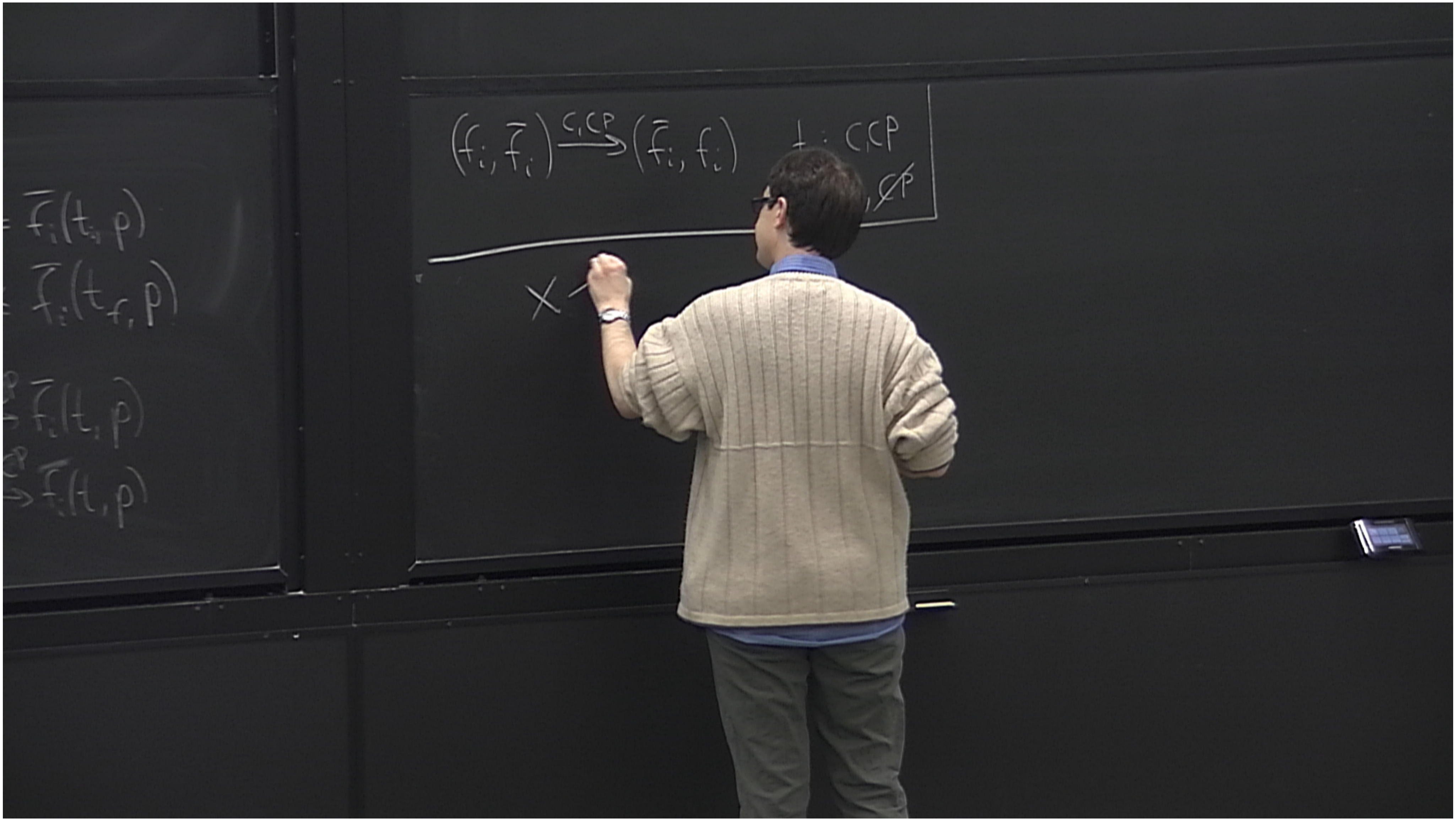
$= f_i(t_f, p)$

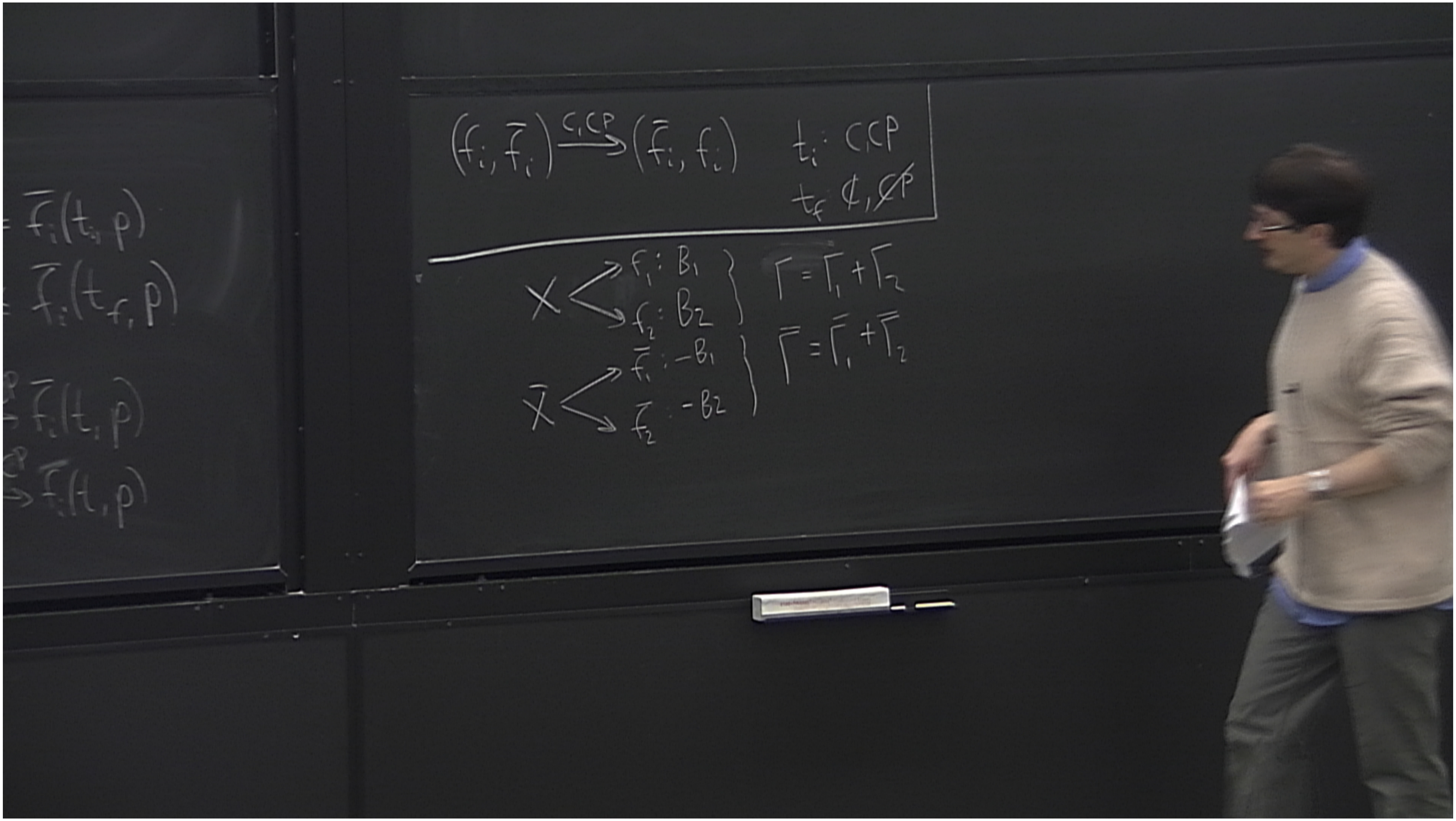
$\xrightarrow{CP} \bar{f}_i(t, p)$

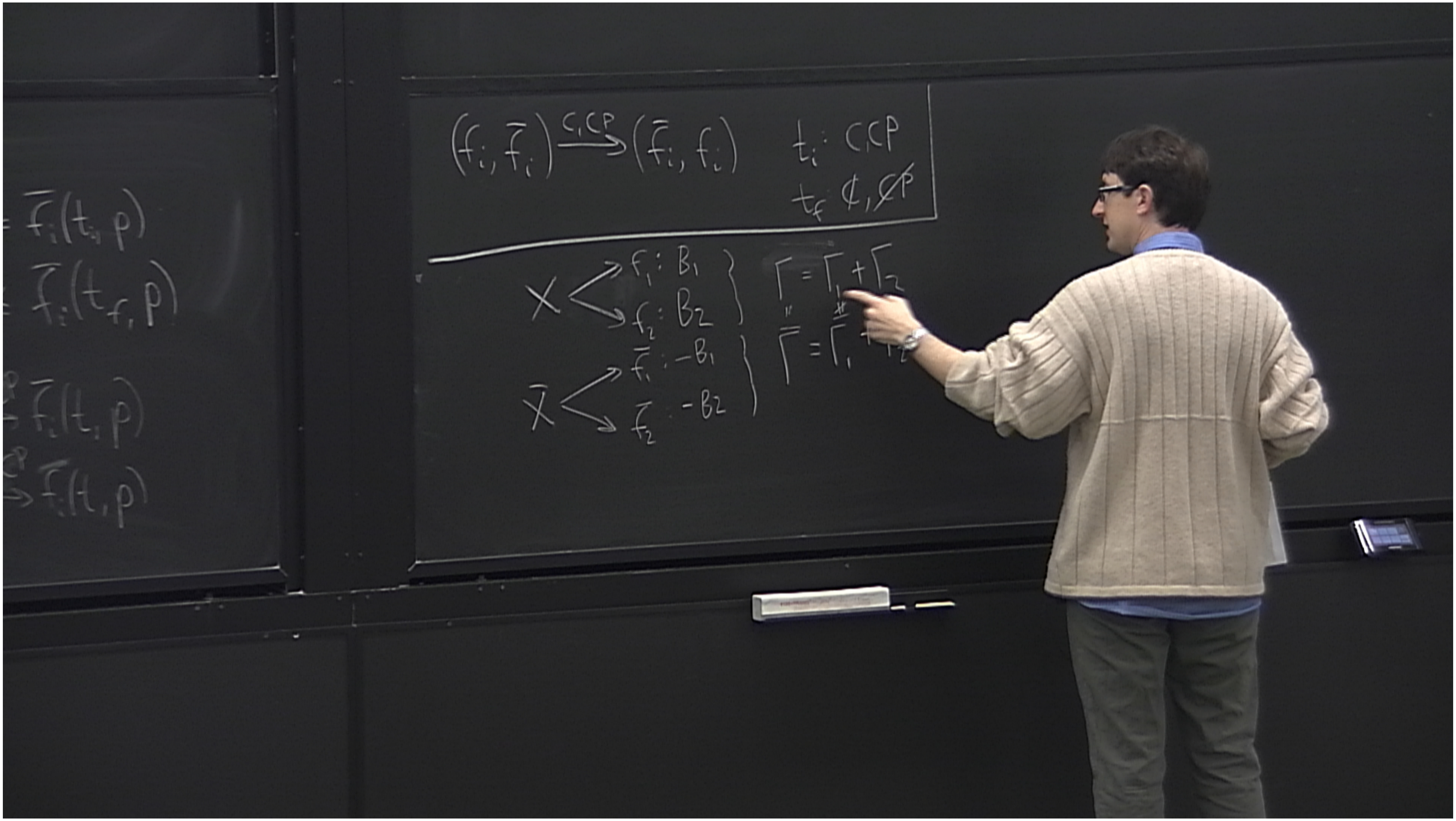
$\xrightarrow{CP} \bar{f}_i(t, p)$

$$(f_i, \bar{f}_i) \xrightarrow{C, CP} (\bar{f}_i, f_i) \qquad t_i : C, CP$$

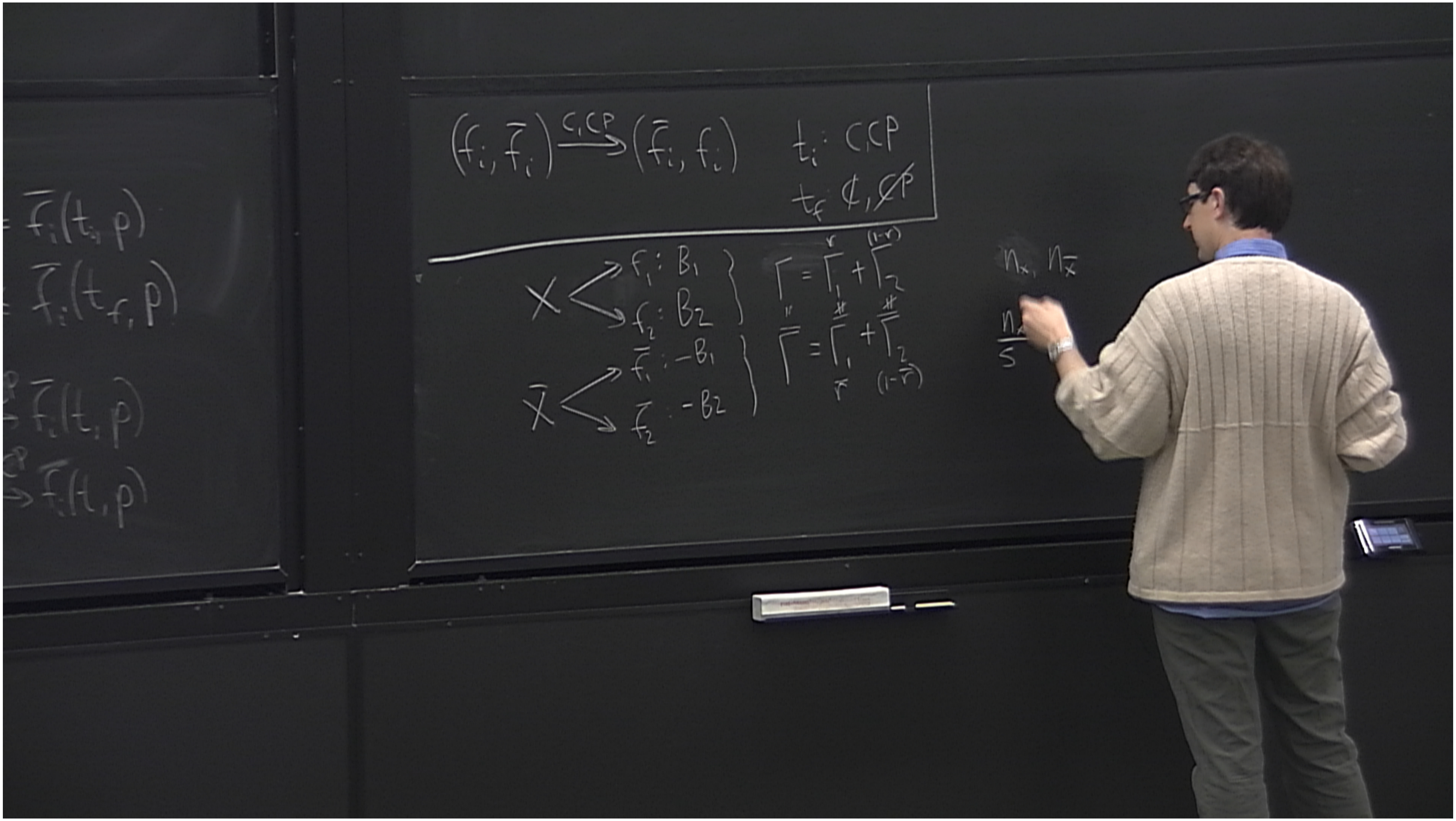
$$t_f : \cancel{C}, \cancel{CP}$$

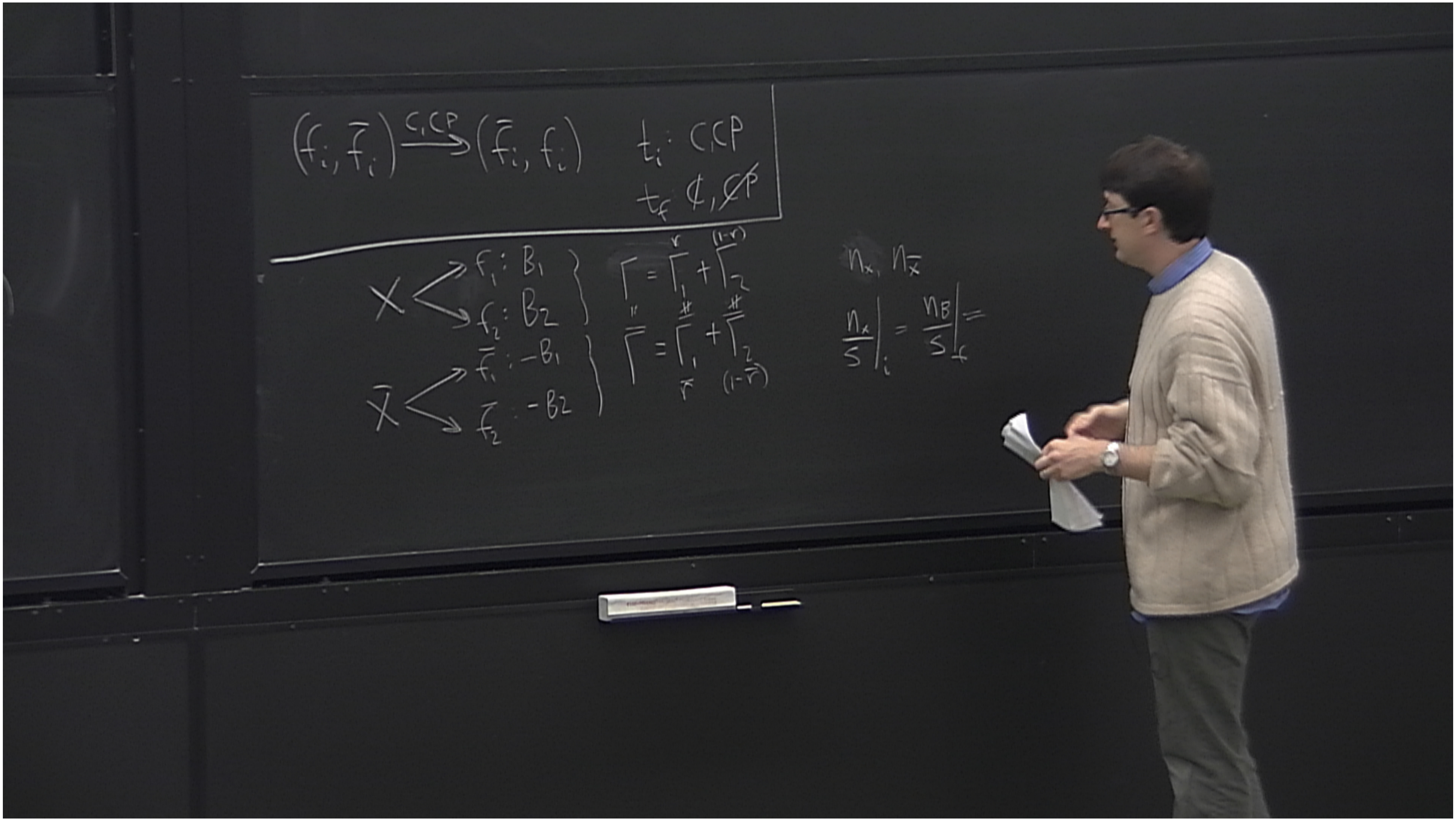

$(f_i, \bar f_i) \xrightarrow{C, CP} (\bar f_i, f_i)$
$\bar f_i(t_i, p)$
$\bar f_i(t_f, p)$
$\bar f_i(t, p)$
$\bar f_i(t, p)$

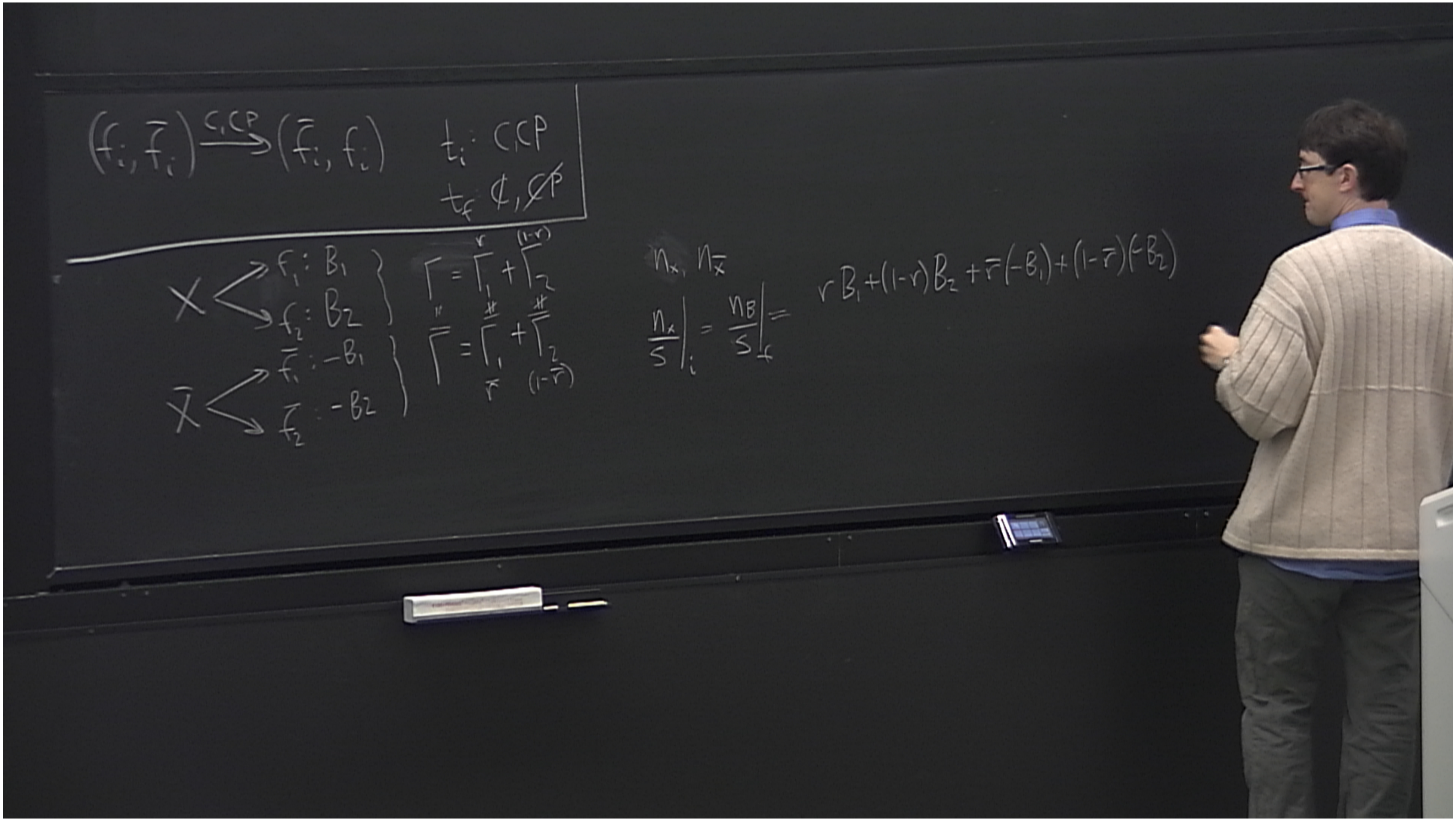

$(f_i, \bar{f}_i) \xrightarrow{C, CP} (\bar{f}_i, f_i)$
t_i : C, CP
t_f : ¢, C̸P
X → f_1 : B_1, f_2 : B_2
$\Gamma = \Gamma_1 + \Gamma_2$
$\bar{X}$ → $\bar{f}_1$: $-B_1$, $\bar{f}_2$: $-B_2$
$\bar{\Gamma} = \bar{\Gamma}_1 + \bar{\Gamma}_2$



(f_i, f̄_i) → (f̄_i, f_i)
C, CP
t_i: C, CP
t_f: ¢, ȻP
f_1: B_1
f_2: B_2
Γ = Γ_1 + Γ_2
f̄_1: −B_1
f̄_2: −B2
Γ̄ = Γ̄_1


(f_i, f̄_i) →CCP (f̄_i, f_i)
t_i: CCP
t_f: ¢, C̸P̸
X → f_1: B_1, f_2: B_2
X̄ → f̄_1: −B_1, f̄_2: −B2
Γ = Γ_1 + Γ_2
Γ̄ = Γ̄_1 + Γ̄_2
n_x, n_x̄


C, CP
t_i : CCP
t_f : ¢, C̸P
f_1 : B_1
f_2 : B2
f̄_1 : −B_1
f̄_2 : −B2
n_X, n_X̄


(f_i, f̄_i) C,CP → (f̄_i, f_i)
t_i: C, CP
t_f: C̸, C̸P̸
X → f_1: B_1 ; f_2: B_2
Γ = Γ_1 + Γ_2 (r, 1−r)
X̄ → f̄_1: −B_1 ; f̄_2: −B_2
Γ̄ = Γ̄_1 + Γ̄_2 (r̄, 1−r̄)
n_X, n_X̄
n_X/s |_i = n_B/s |_f = r B_1 + (1−r) B_2 + r̄(−B_1) + (1−r̄)(−B_2)

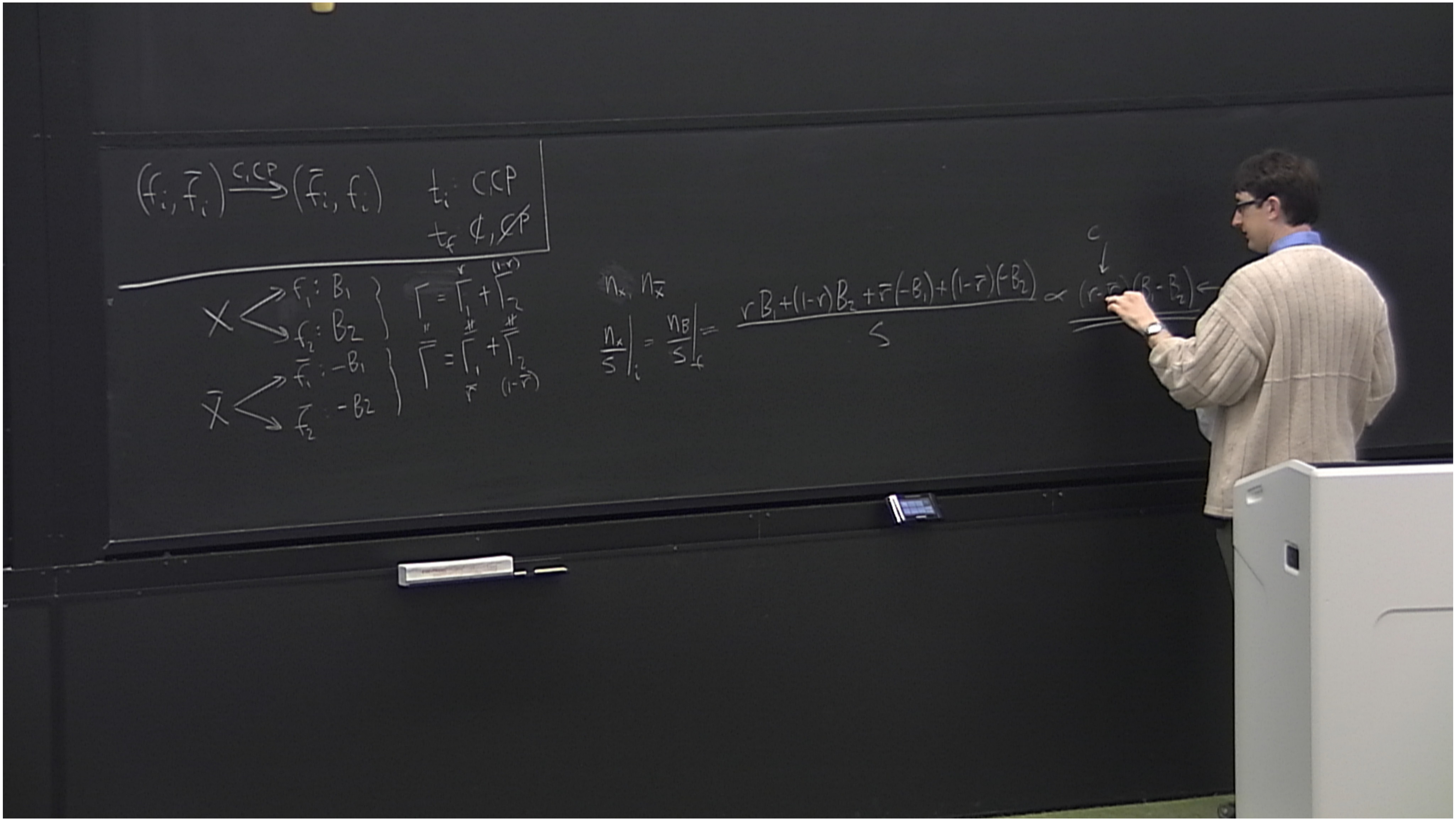
$$(f_i, \bar{f}_i) \xrightarrow{C,\,CP} (\bar{f}_i, f_i) \qquad t_i : C, CP \qquad t_f : \cancel{C}, \cancel{CP}$$

$$X \to \begin{cases} f_1 : B_1 \\ f_2 : B_2 \end{cases} \qquad \Gamma = \overset{r}{\Gamma_1} + \overset{(1-r)}{\Gamma_2}$$

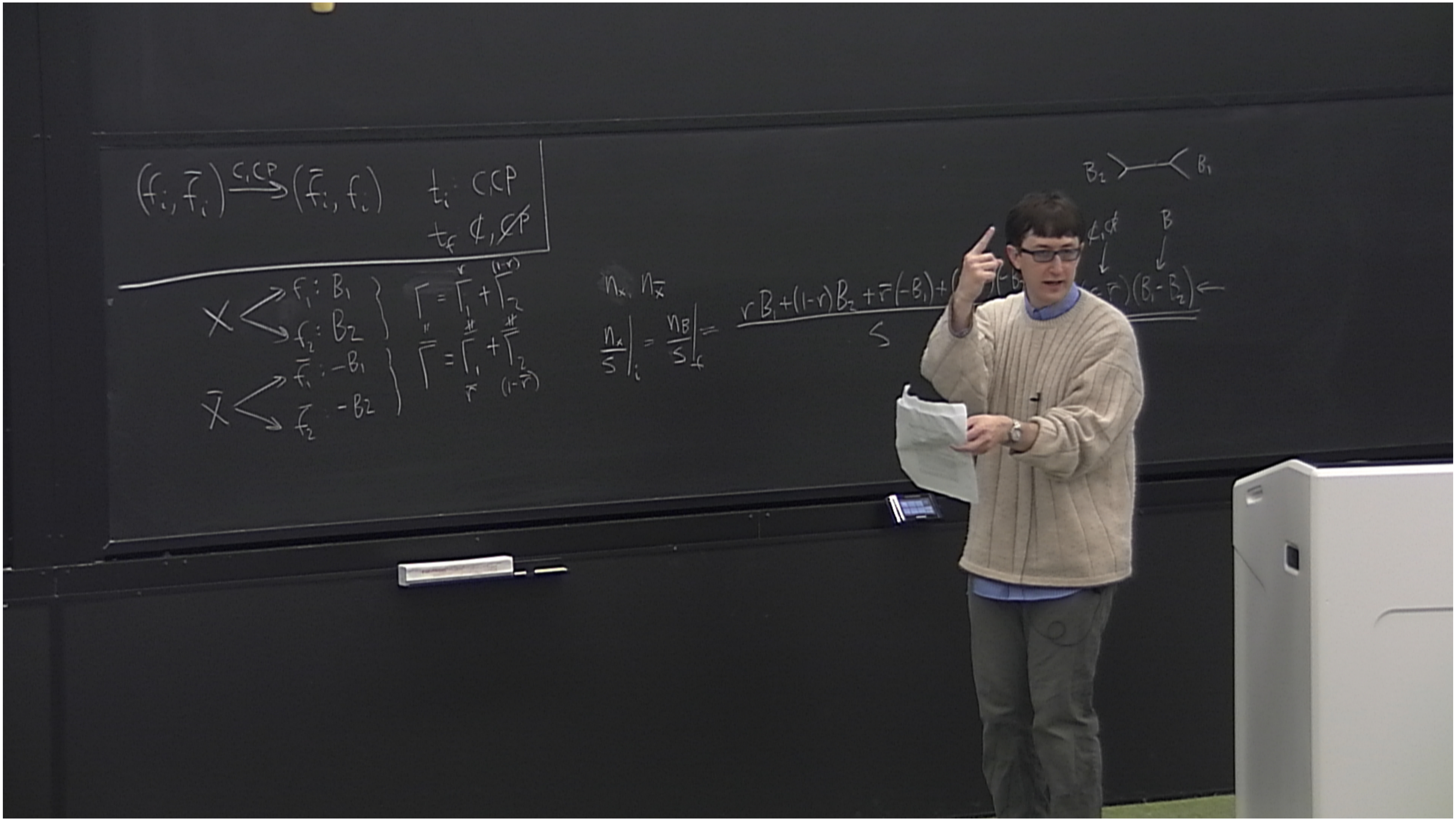
$$\bar{X} \to \begin{cases} \bar{f}_1 : -B_1 \\ \bar{f}_2 : -B_2 \end{cases} \qquad \bar{\Gamma} = \underset{\bar{r}}{\bar{\Gamma}_1} + \underset{(1-\bar{r})}{\bar{\Gamma}_2}$$

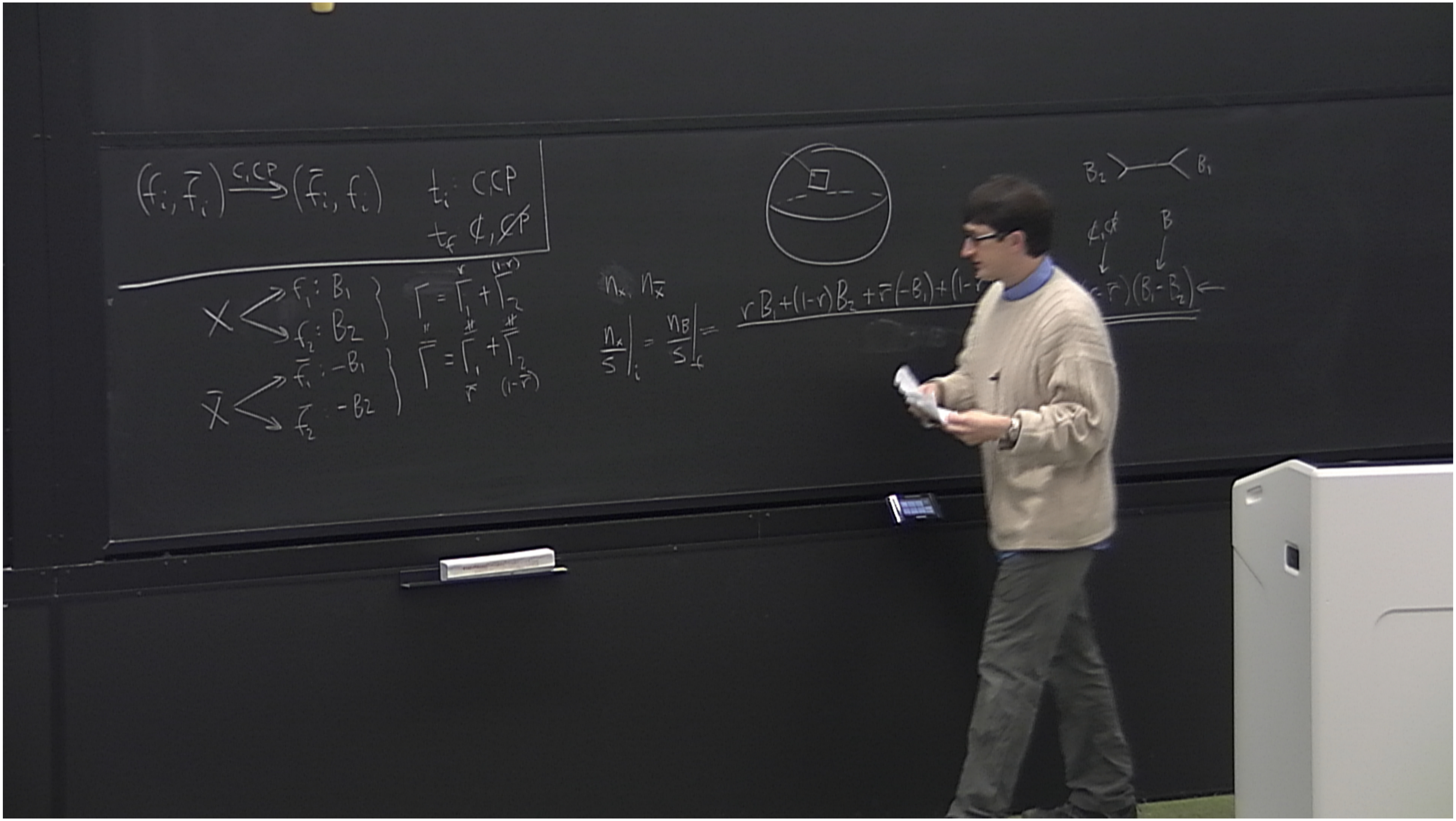
$$n_X, \; n_{\bar{X}}$$

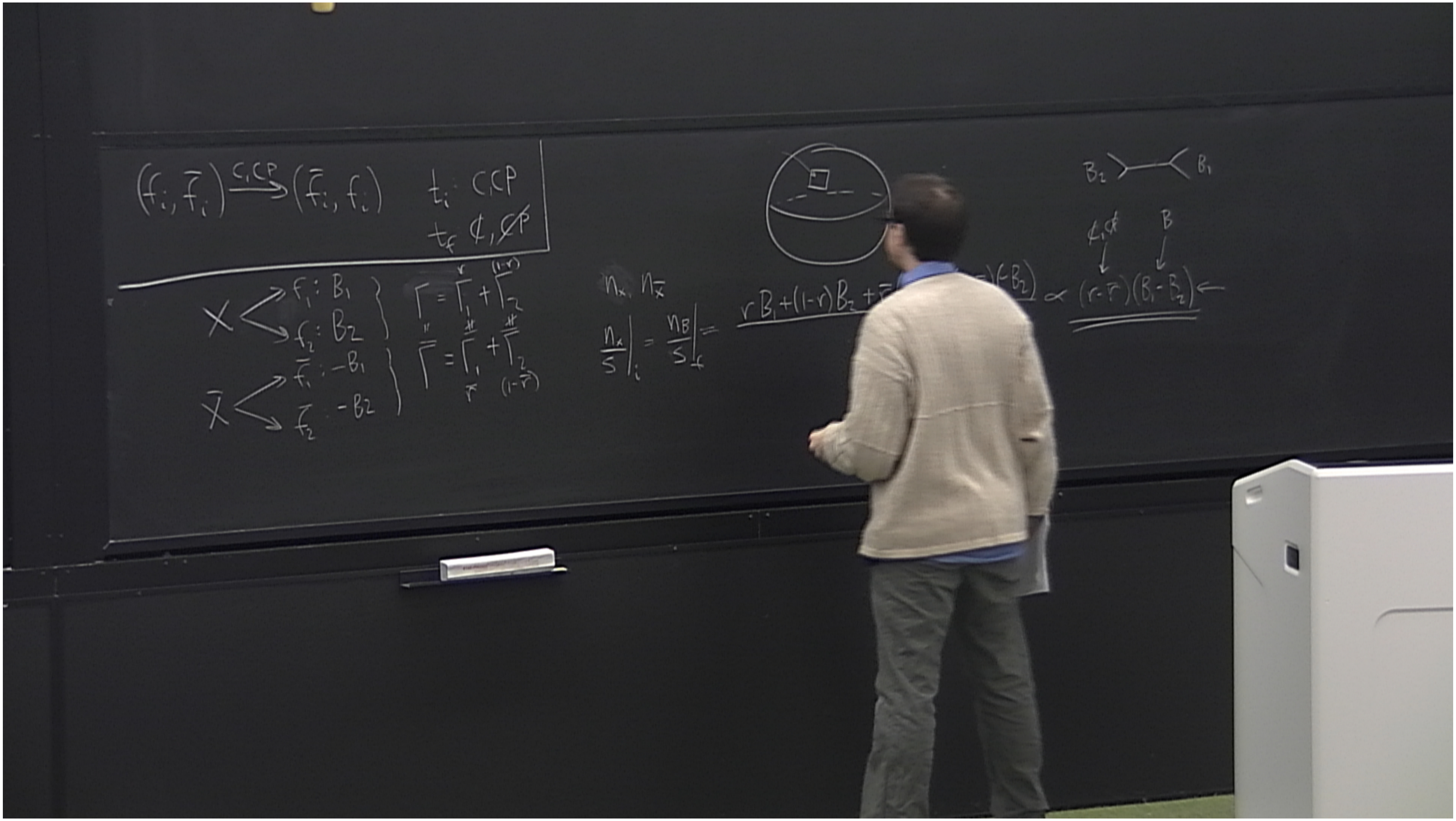
$$\left.\frac{n_X}{S}\right|_i = \left.\frac{n_B}{S}\right|_f = \frac{rB_1 + (1-r)B_2 + \bar{r}(-B_1) + (1-\bar{r})(-B_2)}{S}$$

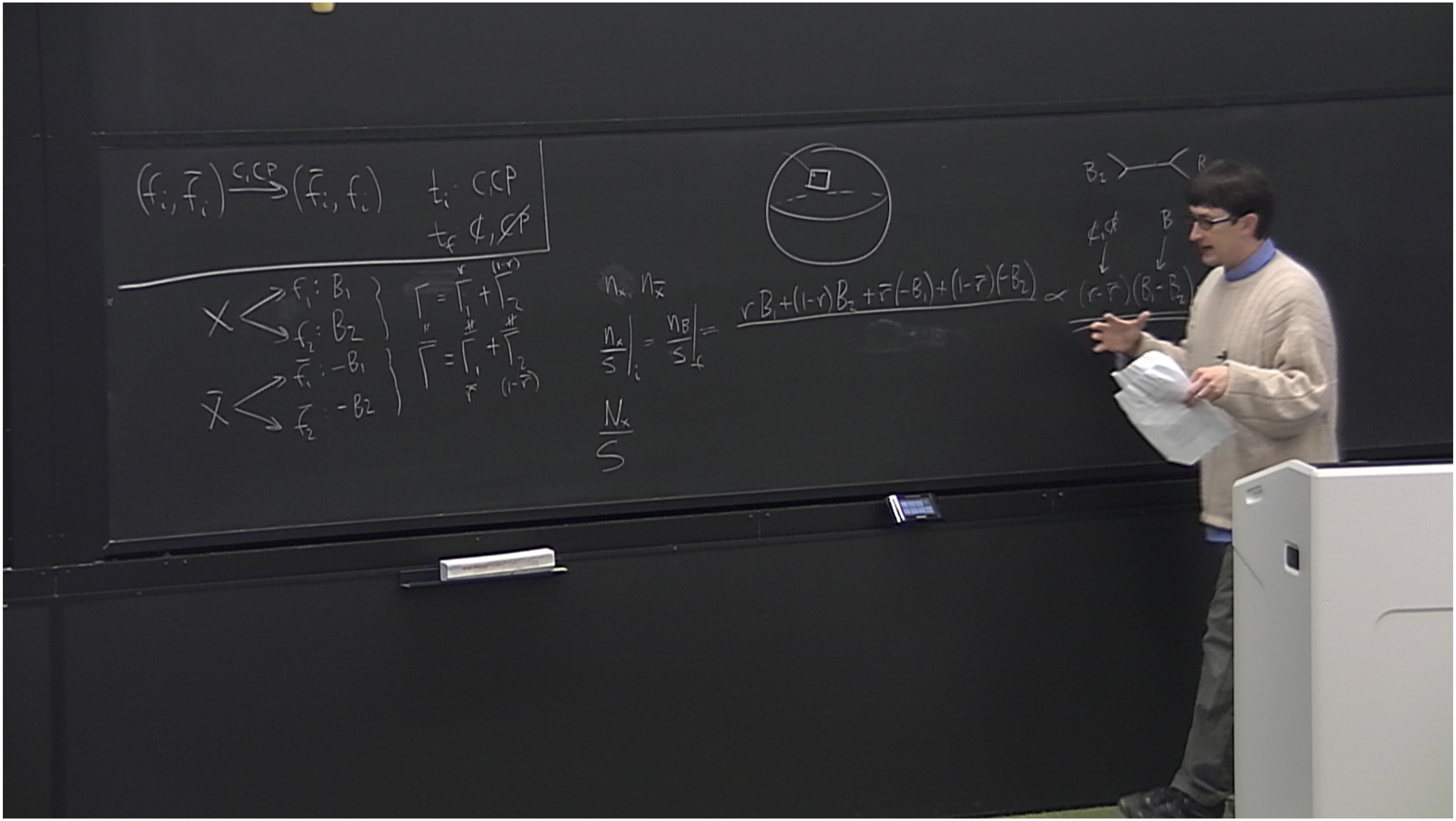


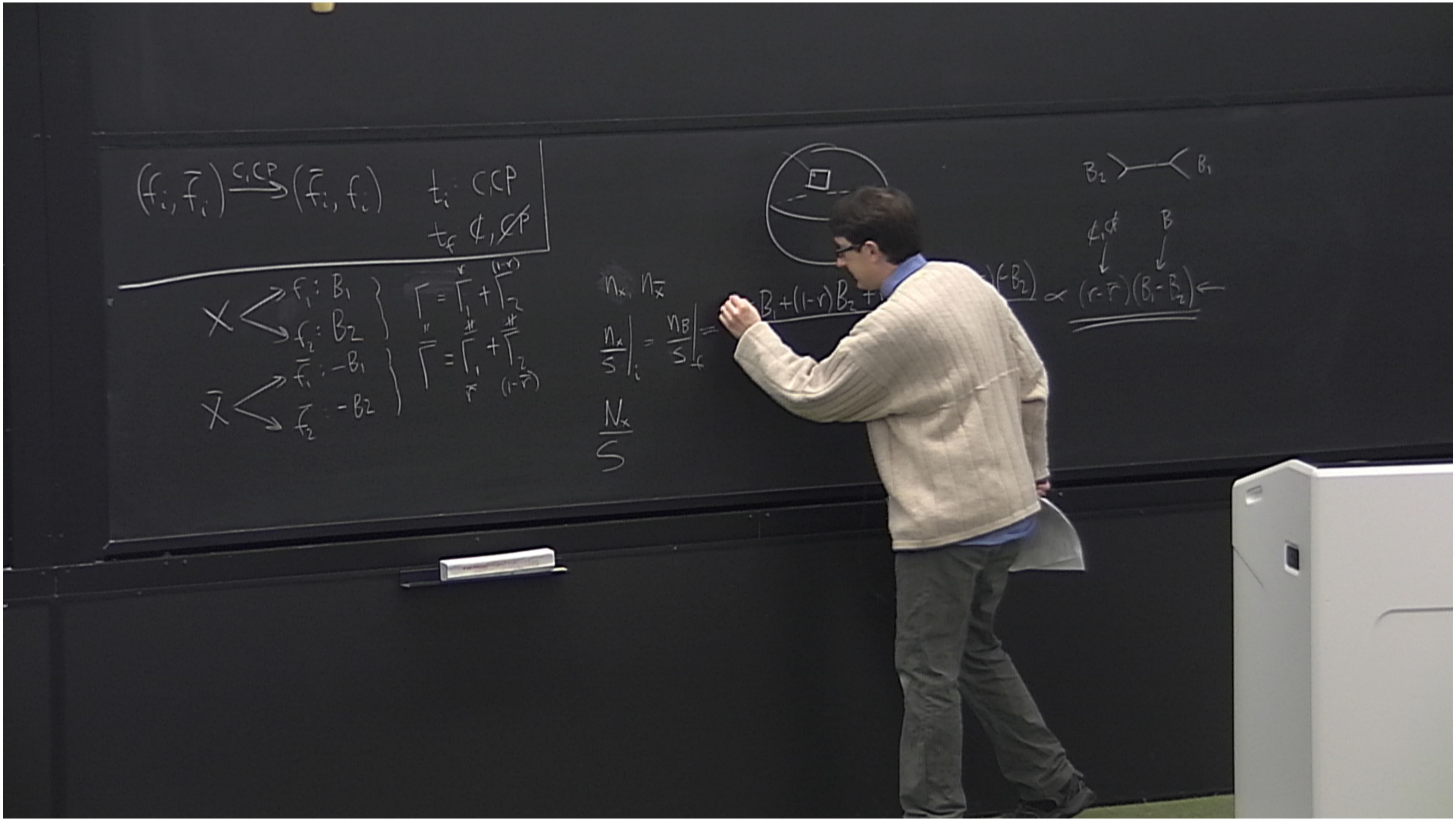
(f_i, f̄_i) C,CP → (f̄_i, f_i)
t_i: C, CP
t_f: ¢, ȻP
f_1: B_1
f_2: B_2
f̄_1: −B_1
f̄_2: −B_2
Γ = Γ_1 + Γ_2
Γ̄ = Γ̄_1 + Γ̄_2
n_x, n_x̄
n_x/s|_i = n_B/s|_f = (r B_1 + (1−r) B_2 + r̄(−B_1) + (1−r̄)(−B_2))/s ∝ (r−r̄)(B_1 − B_2)

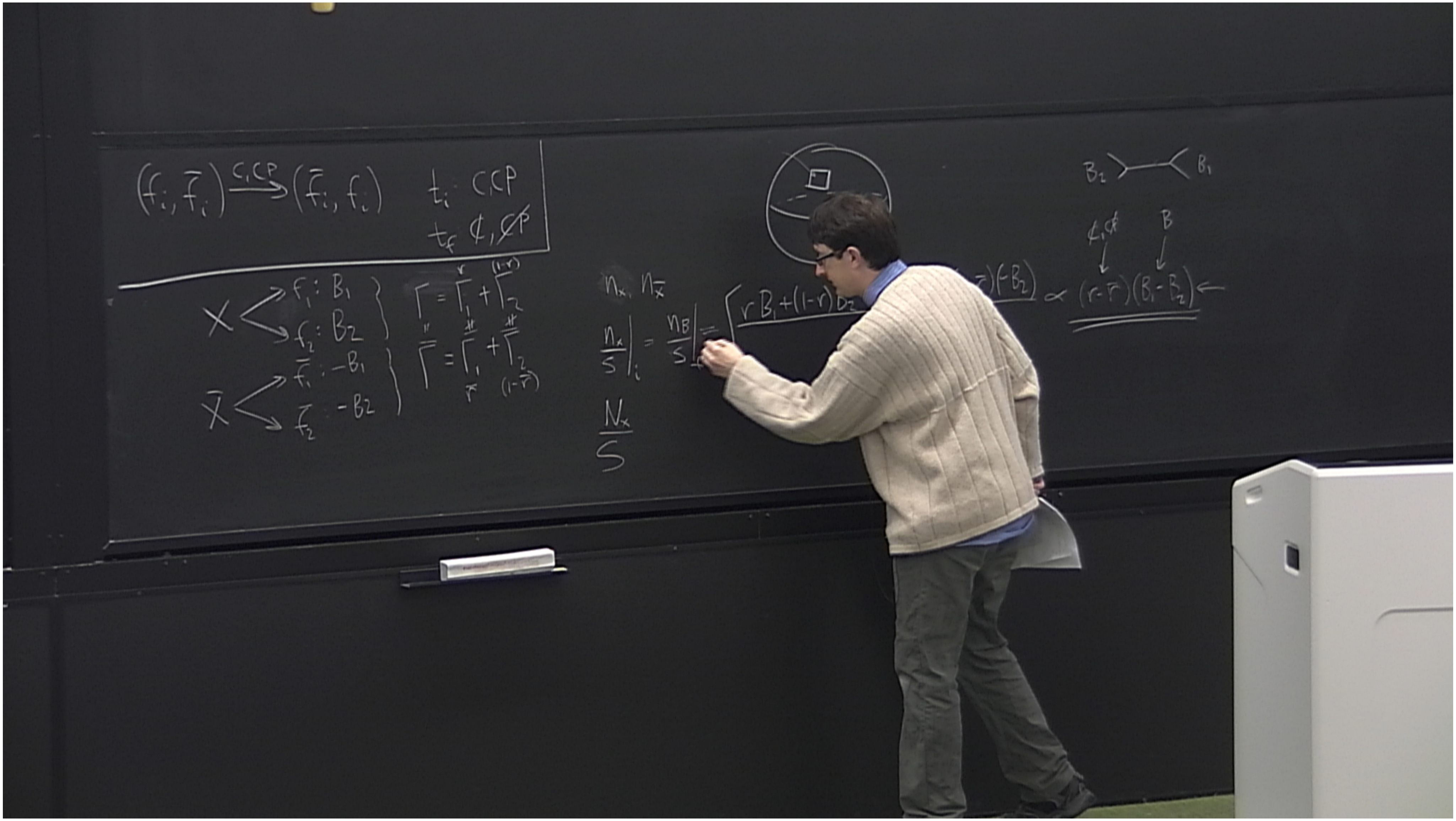

$(f_i, \bar{f}_i) \xrightarrow{C, CP} (\bar{f}_i, f_i)$
t_i: C, CP
t_f: $\cancel{C}$, $\cancel{CP}$
B_2 B_1
n_x, $n_{\bar{x}}$
$\frac{n_x}{s}\Big|_i = \frac{n_B}{s}\Big|_f = \frac{rB_1 + (1-r)B_2 + \bar{r}(-B_1) + \ldots}{s}$
$(B_1 - B_2)$

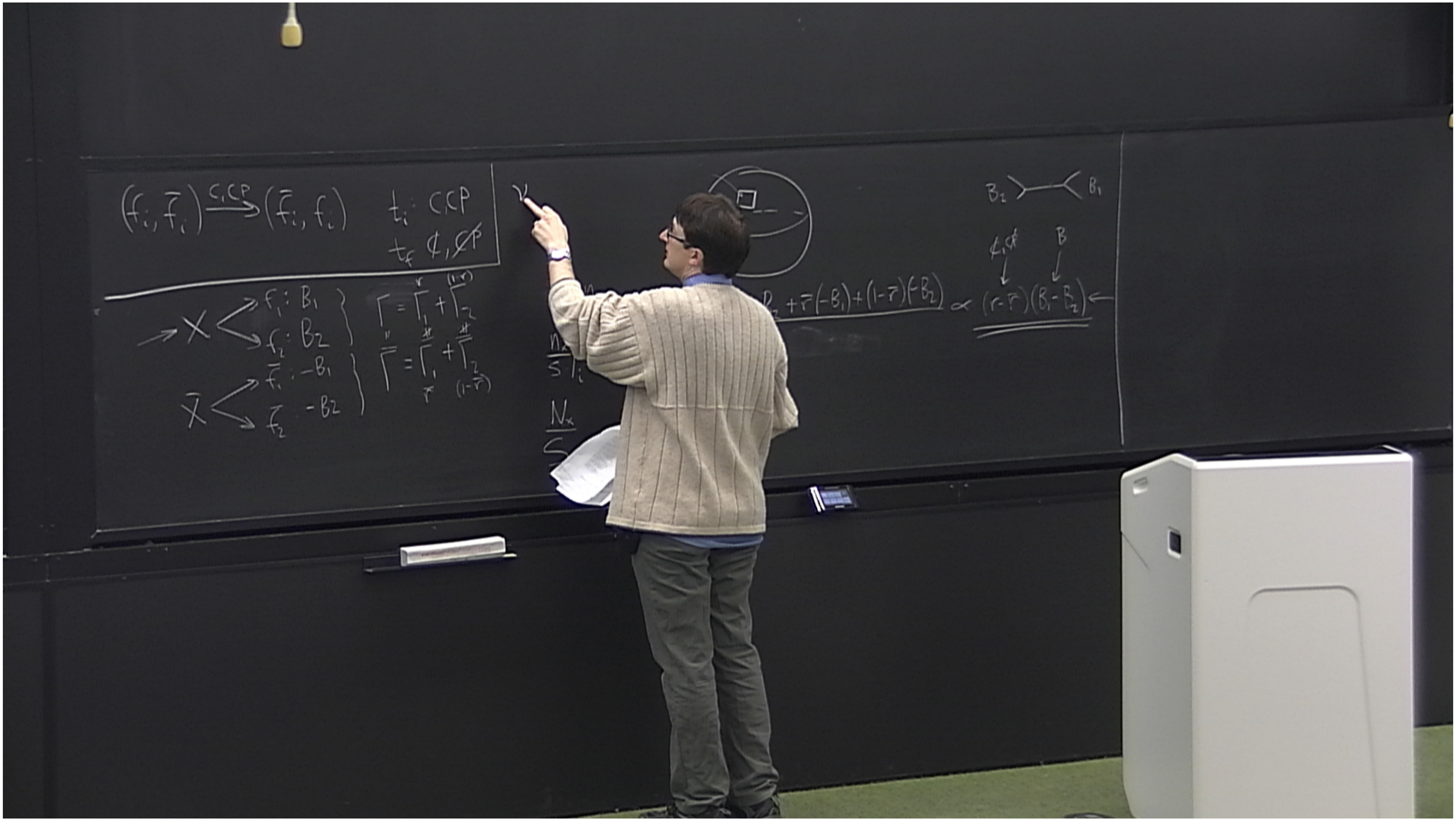


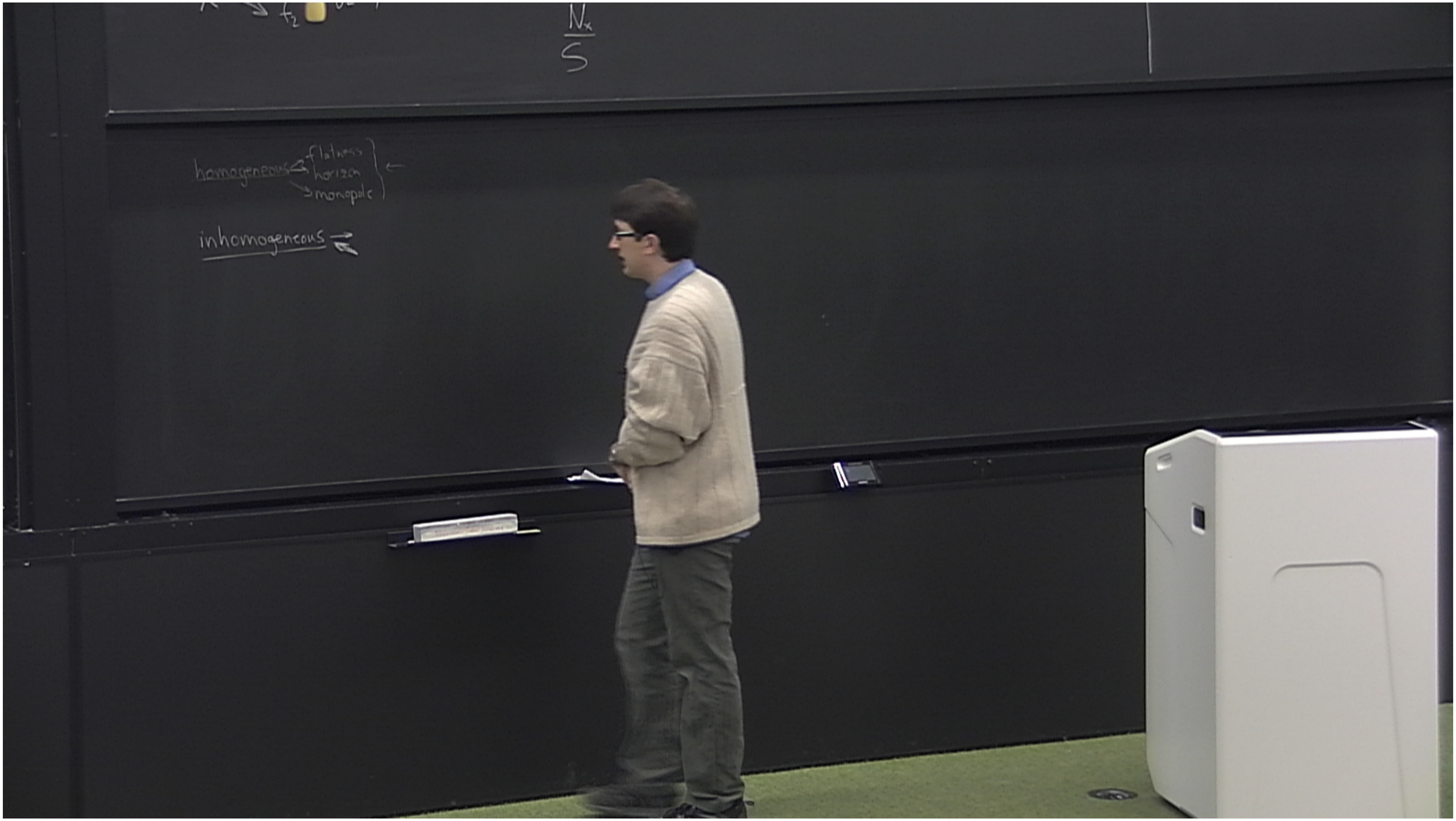



(f_i, f̄_i) → C, CP → (f̄_i, f_i)
t_i : C, CP
t_f : C̸, C̸P̸
X → f_1 : B_1, f_2 : B_2
Γ = Γ_1 + Γ_2
X̄ → f̄_1 : −B_1, f̄_2 : −B_2
Γ̄ = Γ̄_1 + Γ̄_2
n_X, n_X̄
n_X/s |_i = n_B/s |_f =
r B_1 + (1−r) B_2 + r̄ (−B_1) + (1−r̄)(−B_2) ∝ (r−r̄)(B_1−B_2)
N_X/S
C̸, C̸P̸
B

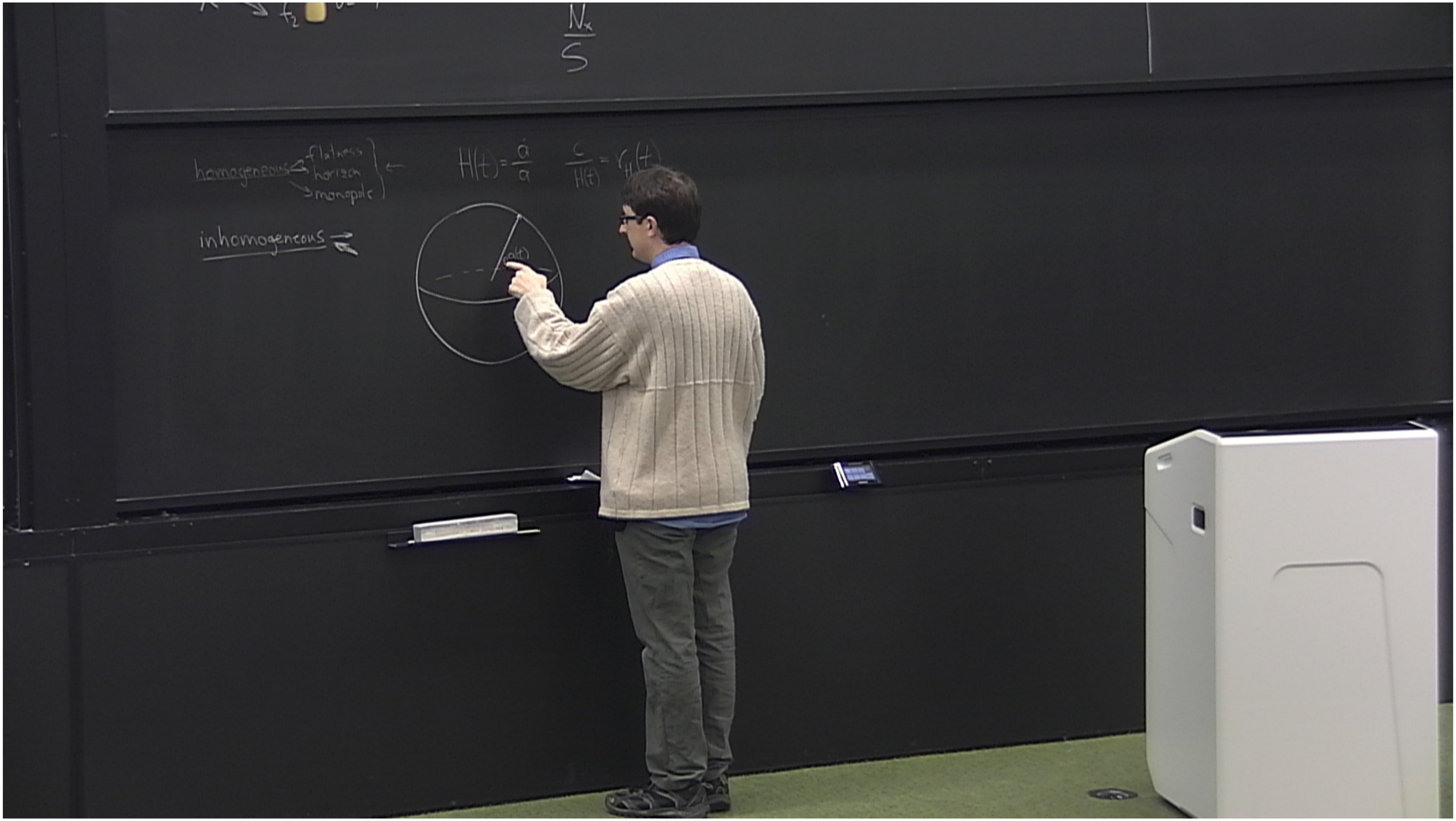

t_i : CCP
t_f : ¢, ¢P
X → f_1 : B_1 ; f_2 : B_2
X̄ → f̄_1 : −B_1 ; f̄_2 : −B_2
n_X, n_X̄
N_X / S
B_2 ≻—≺ B_1

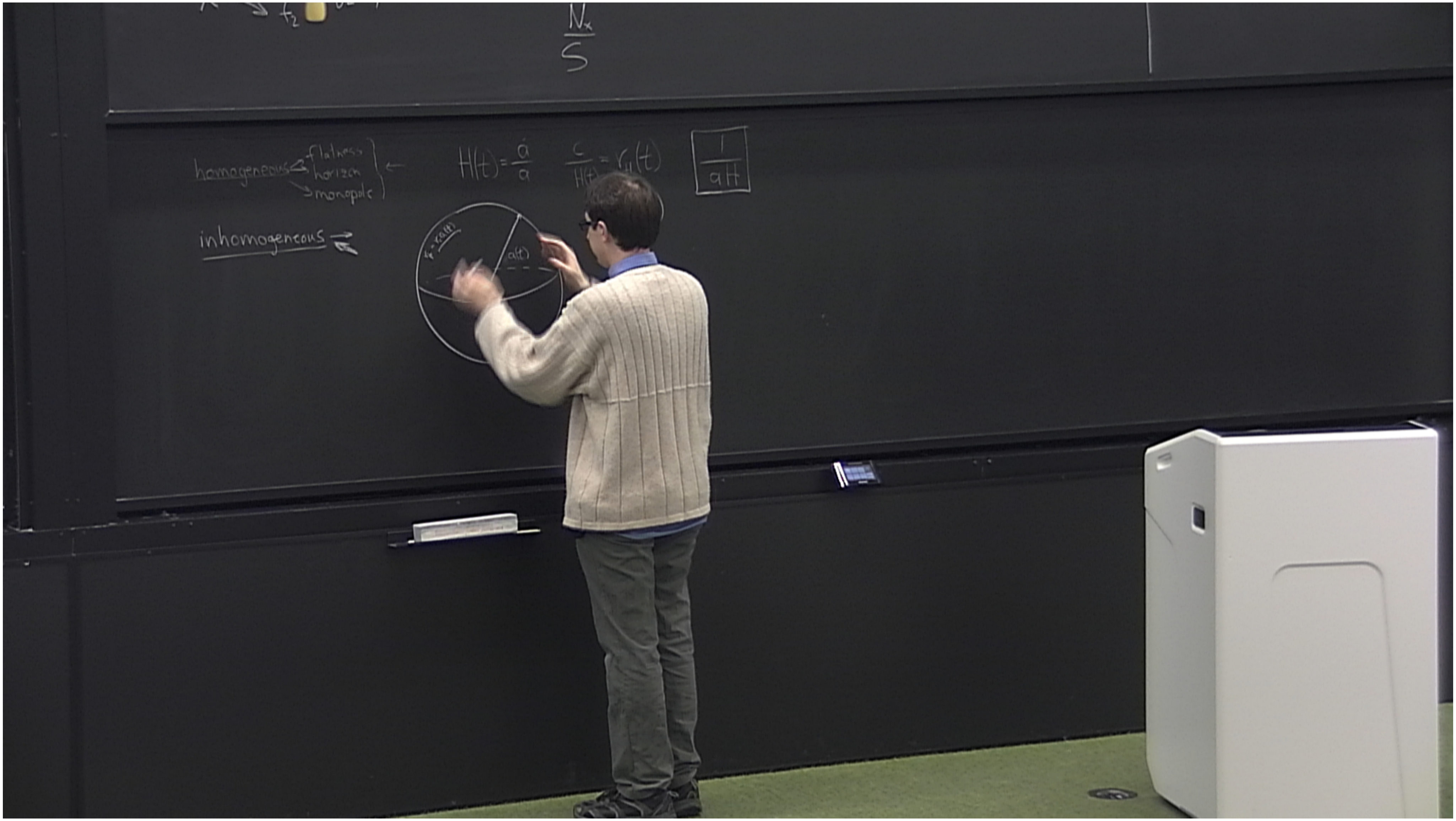




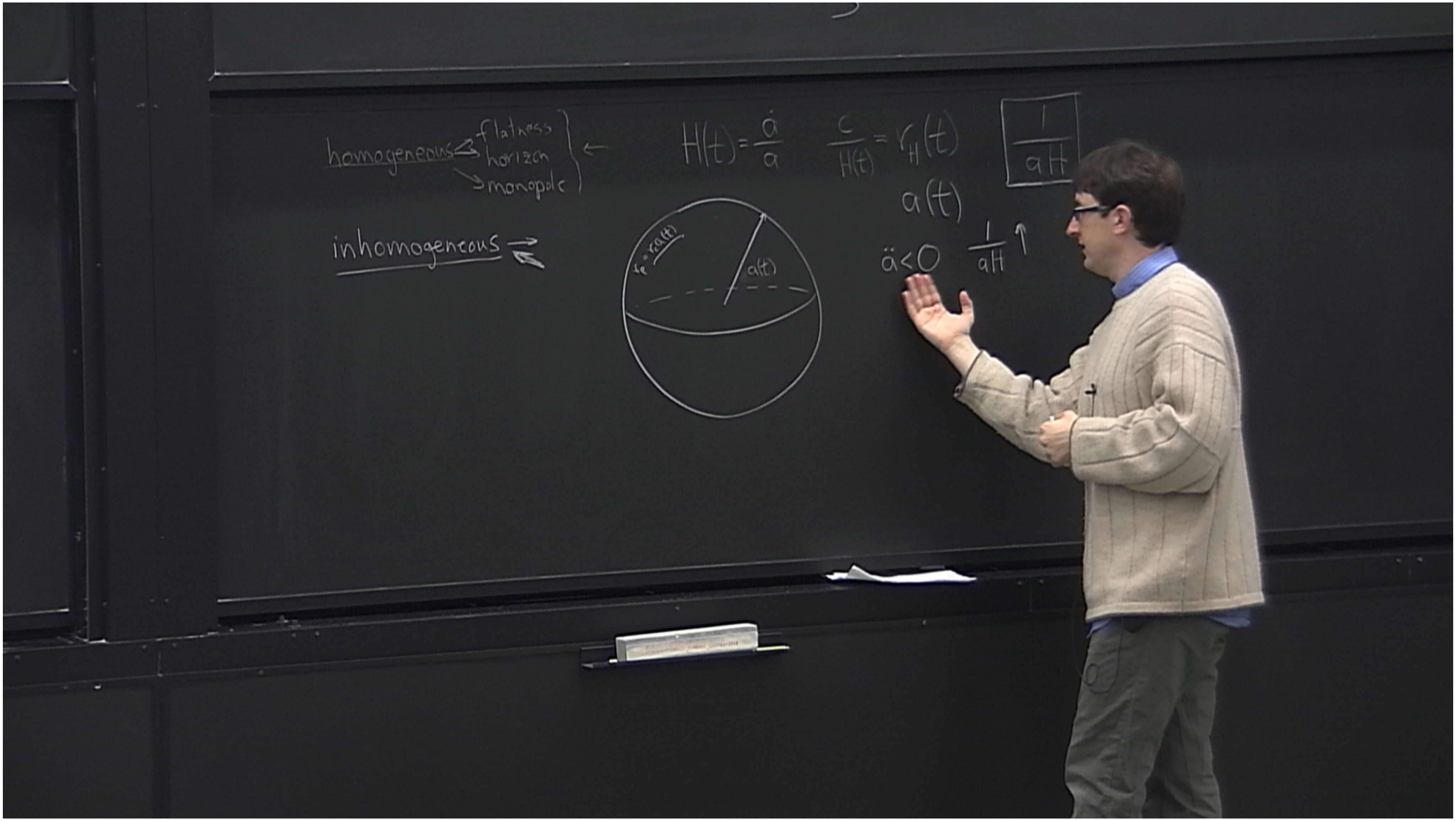


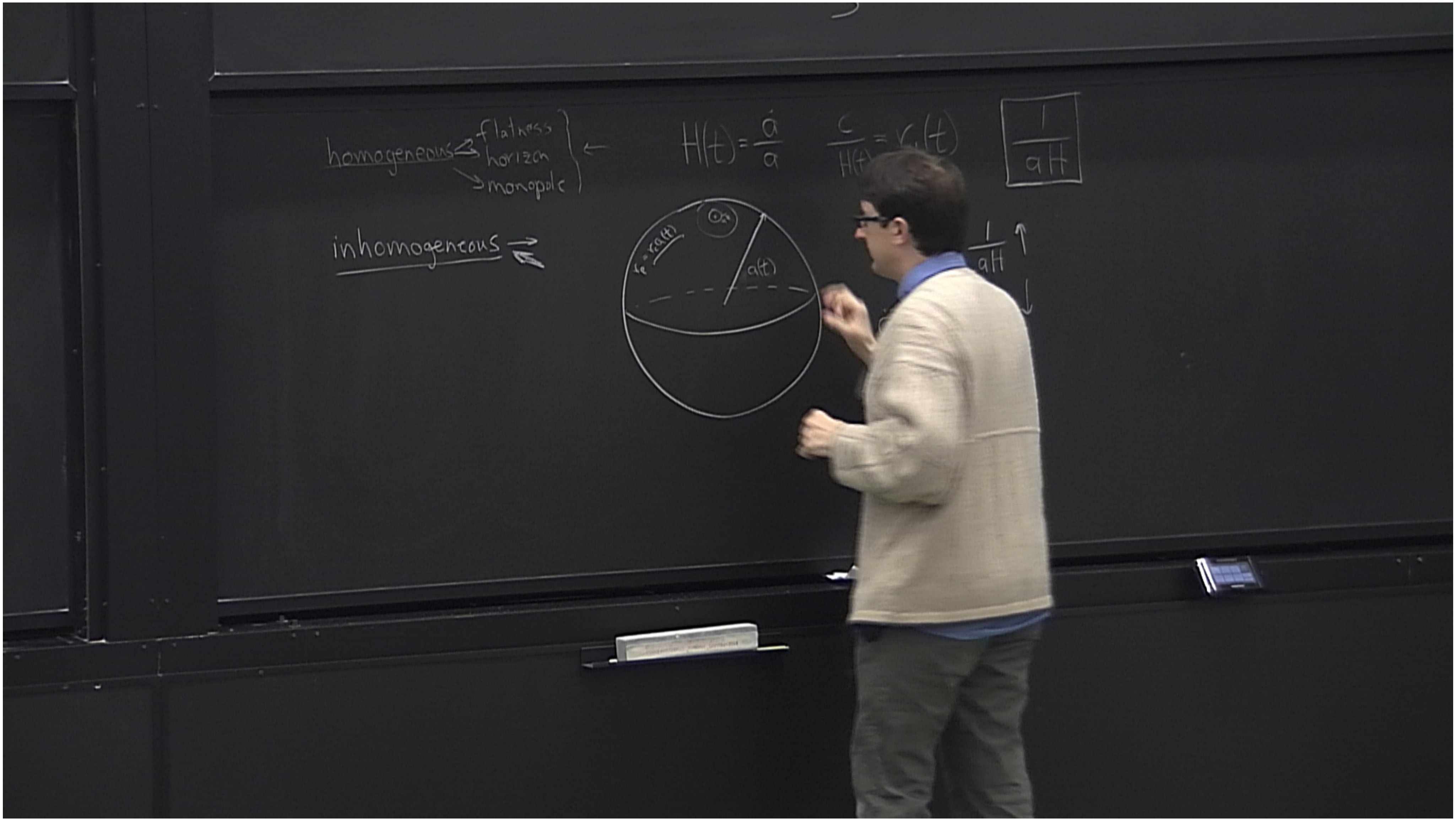
N_x
S
homogeneous
flatness
horizon
monopole
inhomogeneous

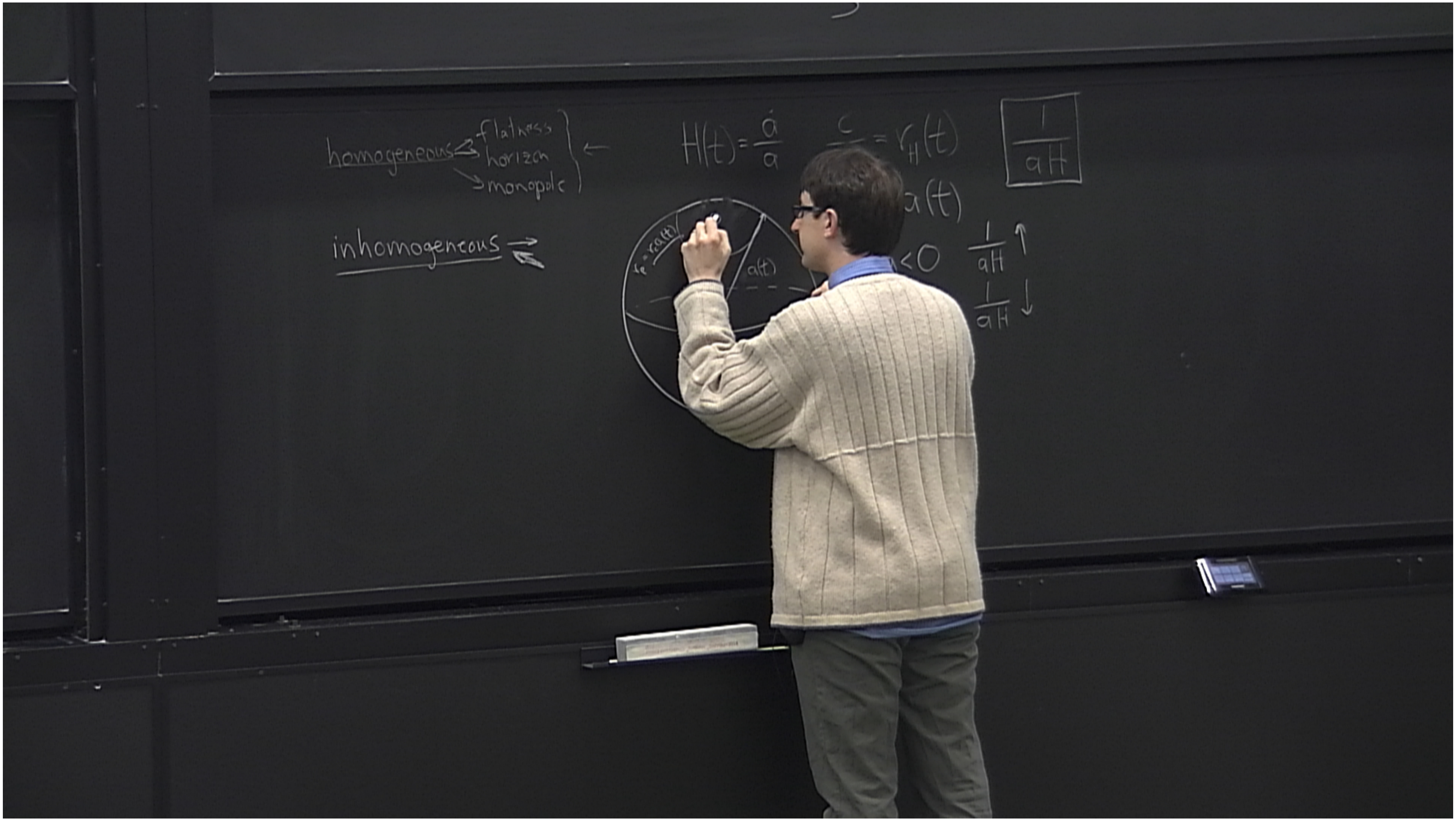

homogeneous
flatness
horizon
monopole
inhomogeneous
H(t) = ȧ/a
c/H(t) = r_H(t)
a(t)
N_x/S



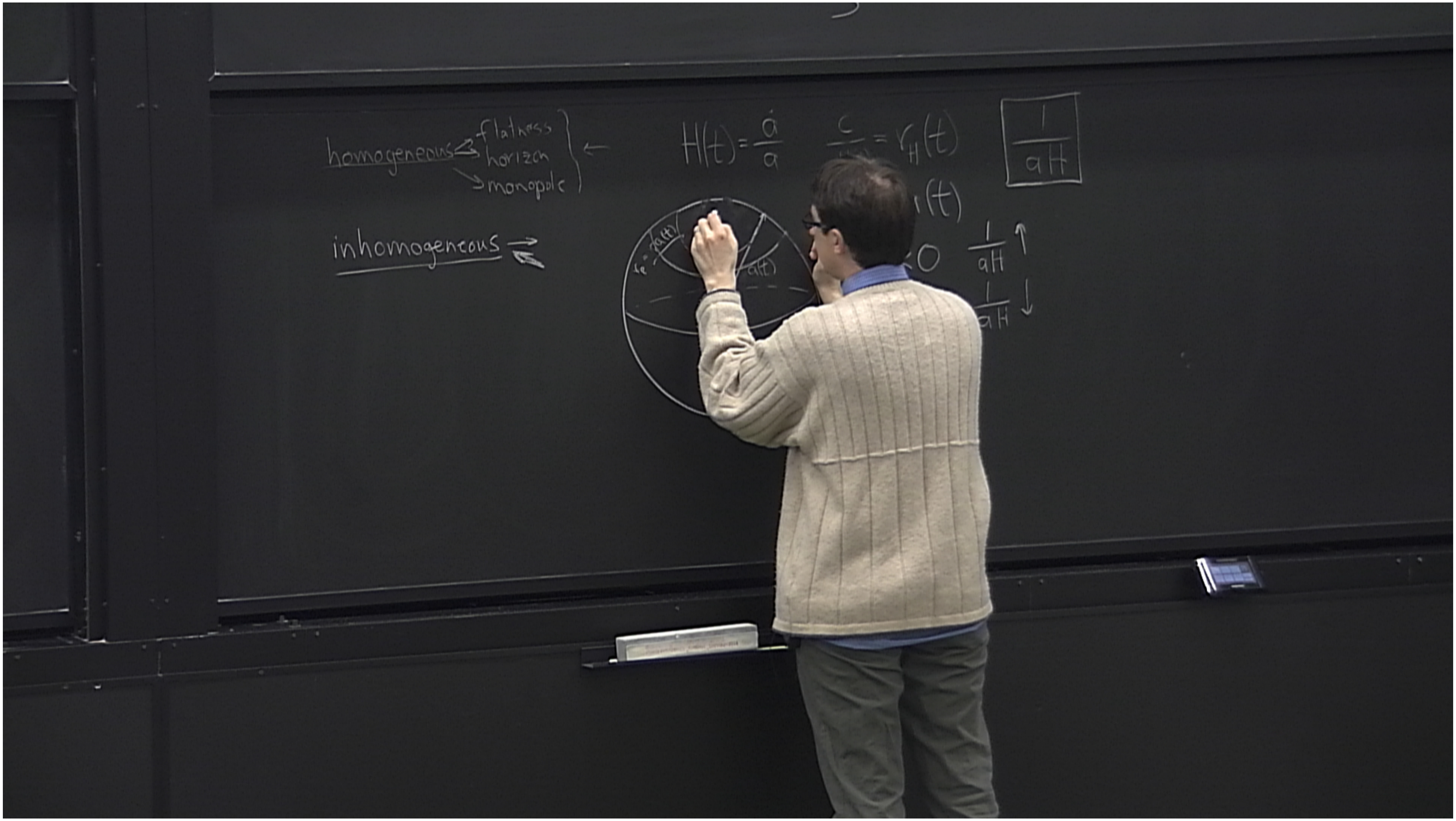
homogeneous
flatness
horizon
monopole
inhomogeneous
H(t) = ȧ/a
c/H(t) = r_H(t)
1/aH
a(t)


homogeneous
flatness
horizon
monopole
inhomogeneous
$H(t) = \frac{\dot{a}}{a}$
$\frac{c}{H(t)} = r_H(t)$
$\boxed{\frac{1}{aH}}$
$a(t)$
$\ddot{a} < 0$
$\frac{1}{aH} \uparrow$
a(t)


homogeneous
flatness
horizon
monopole
$H(t) = \frac{\dot{a}}{a}$
$\frac{c}{H(t)}$
$\boxed{\frac{1}{aH}}$
inhomogeneous
a(t)
$\frac{1}{aH}$



homogeneous
flatness
horizon
monopole
inhomogeneous
$H(t) = \frac{\dot{a}}{a}$
$\frac{c}{\ } = r_H(t)$
$\boxed{\frac{1}{aH}}$
a(t)
<0
$\frac{1}{aH}\uparrow$
$\frac{1}{aH}\downarrow$
a(t)


homogeneous
flatness
horizon
monopole
inhomogeneous
$H(t) = \frac{\dot{a}}{a}$
$\frac{1}{aH}$