Title: PSI 17/18 - Cosmology - Lecture 9

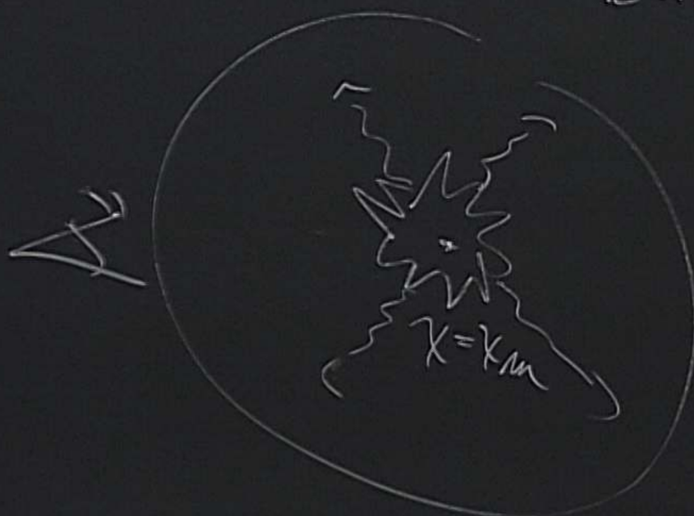
Date: Feb 06, 2018 11:30 AM

URL: http://pirsa.org/18020097

Abstract:

DARK ENERGY

- IF NO DE => SOME STARS OLDER THAN UNIVERSE.
- SUPERNOVAE EXPLOSIONS



$$F = \frac{L}{4\pi} \frac{a^2}{a_0^4 S_k^2(\chi_{em})}$$

AIM: WRITE IN TERMS OF z

- C

• COSMOLOGICAL REDSHIFT

$$\frac{a_0}{a} = \frac{\omega}{\omega_0} = z+1 \,, \quad dz = -\frac{a_0}{a} H\,dt$$

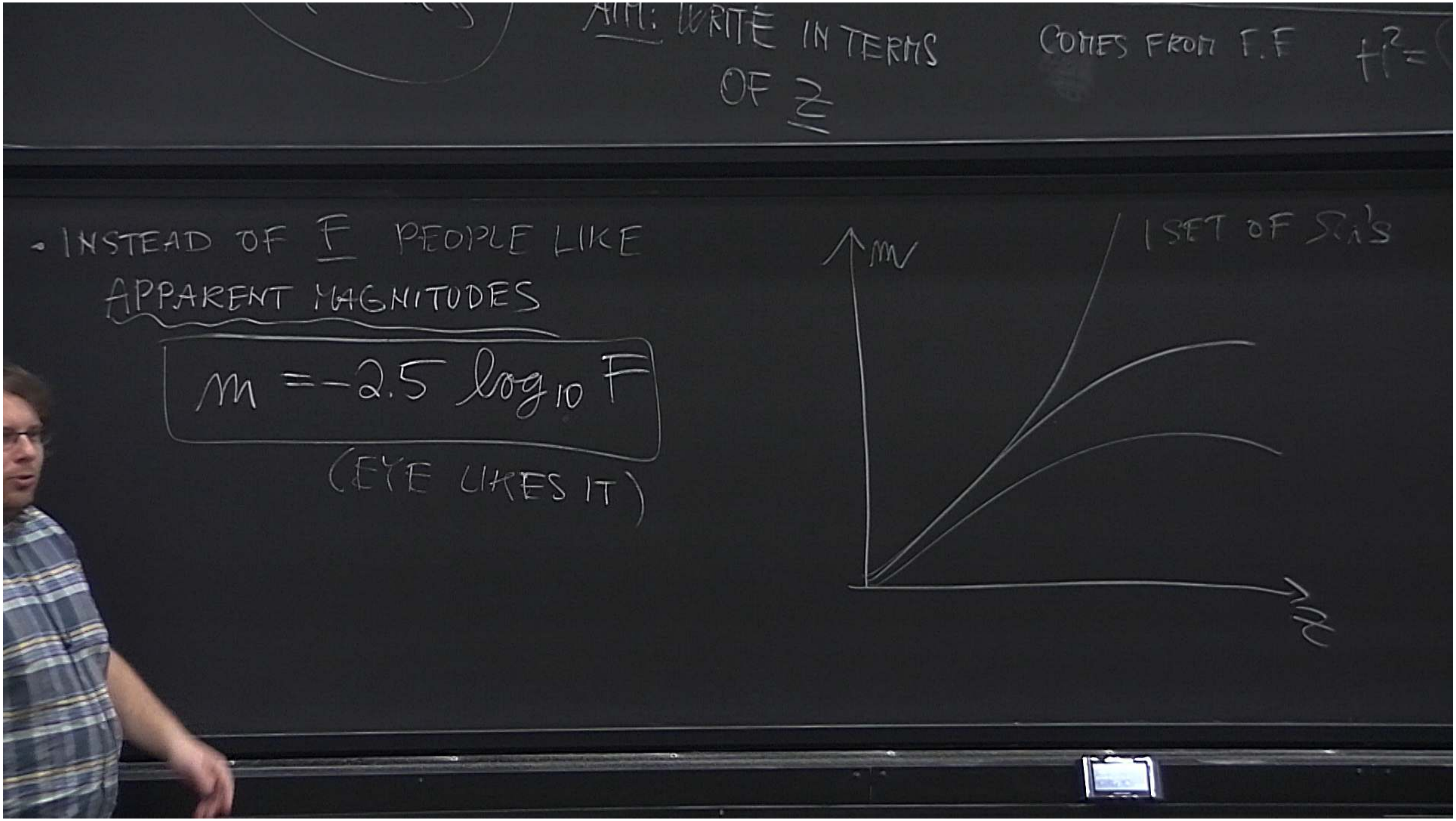
$$\chi_{em}(z) = -\int_{em}^{0} d\chi = \int_{em}^{0} d\eta = \int_{em}^{0} \frac{dt}{a(t)} = \frac{1}{a_0}\int_0^z \frac{dz}{H(z)}$$

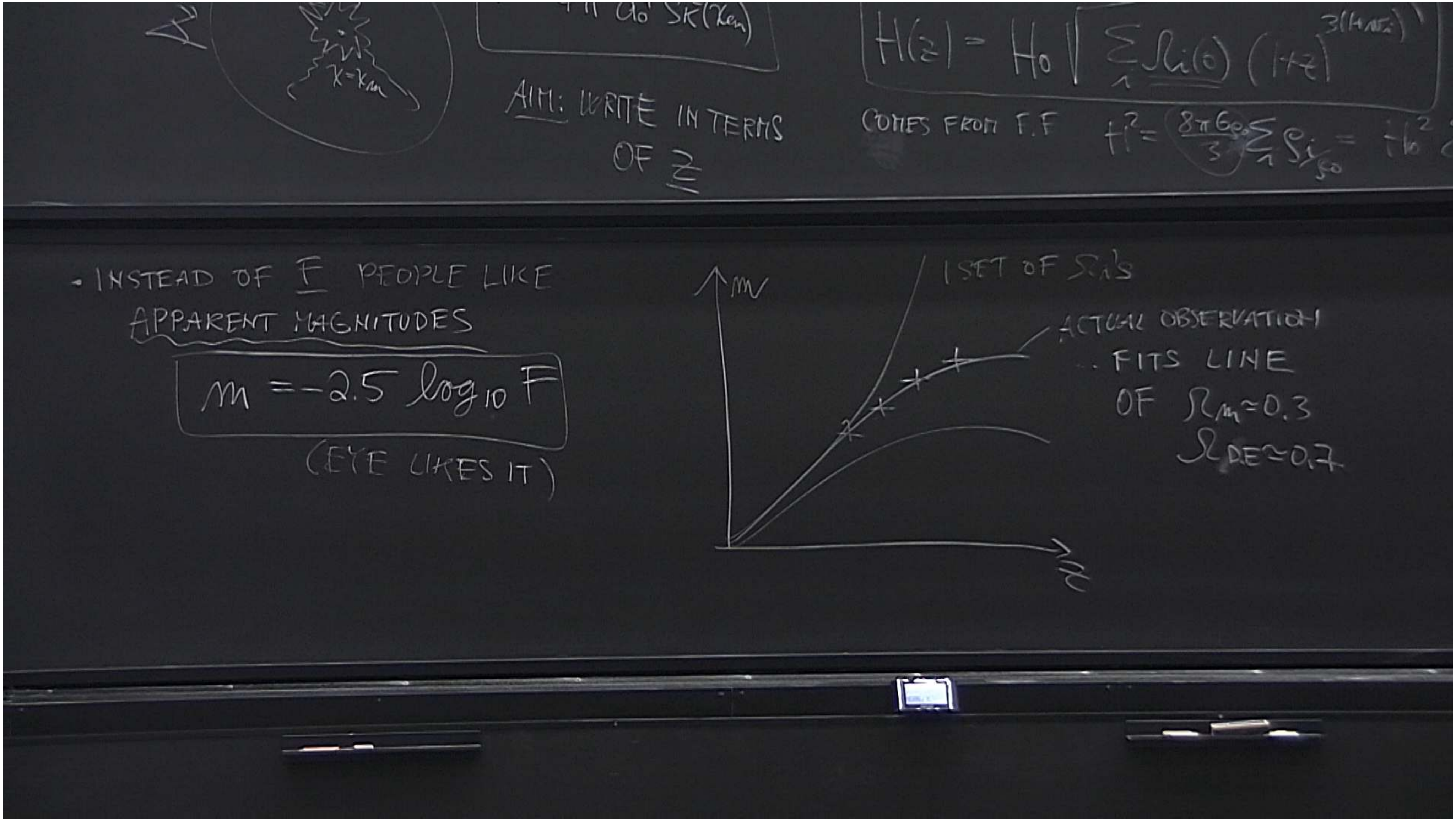
$$\boxed{H(z) = H_0 \sqrt{\sum_i \Omega_i(0)\,(1+z)^{3(1+w_i)}}}$$

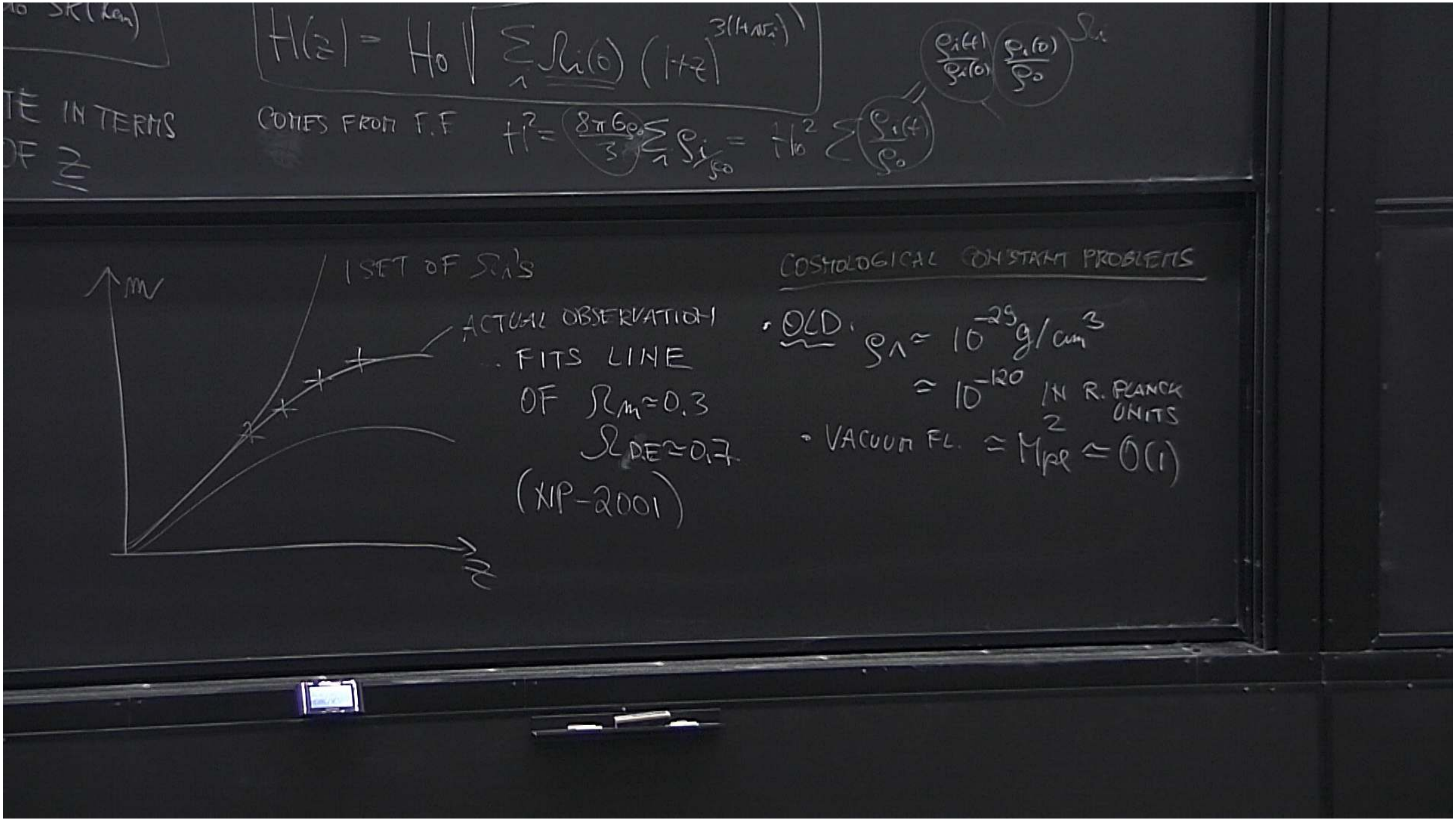
ERMS

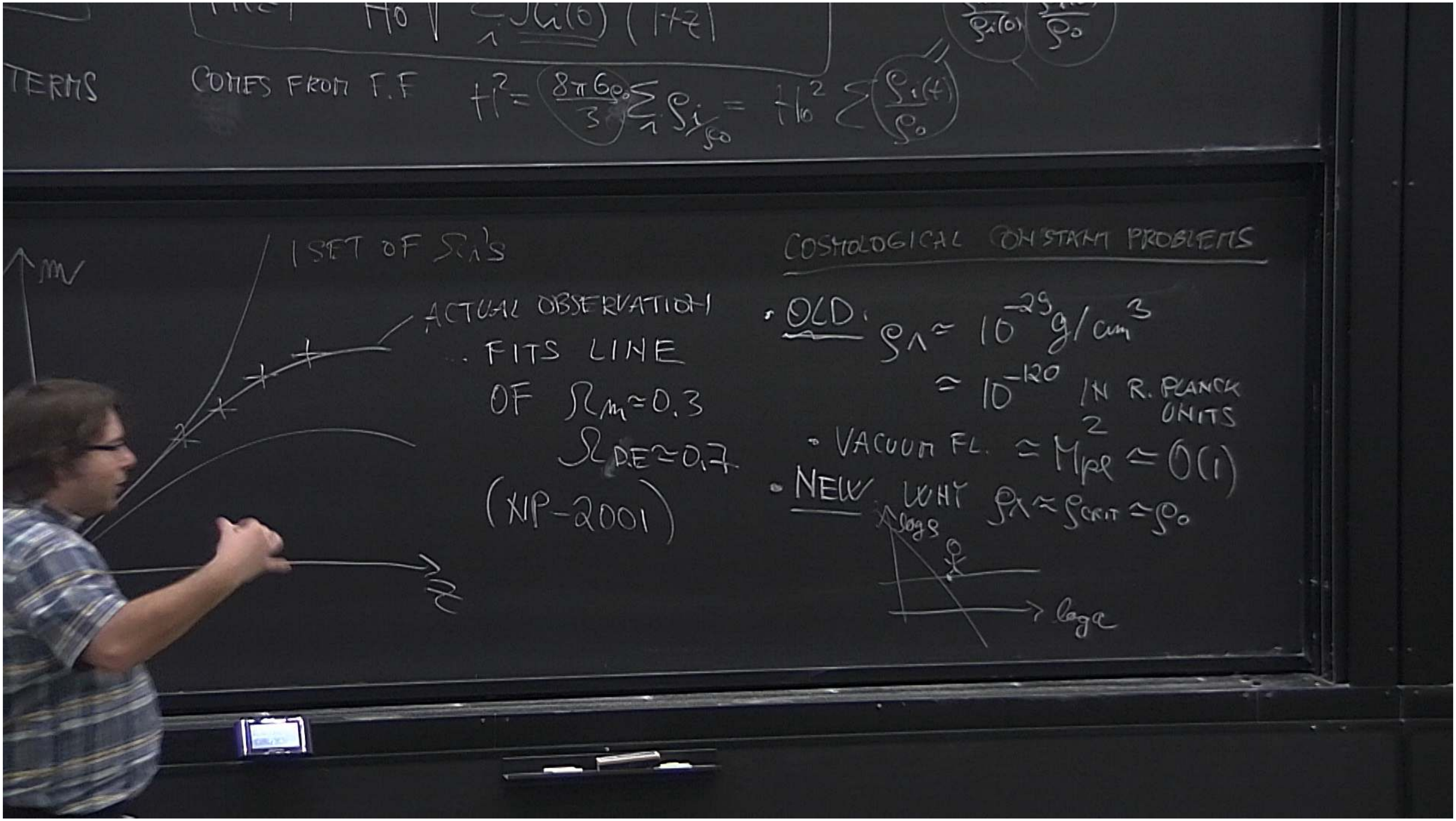
COMES FROM F.E $\quad H^2 = \frac{8\pi G\rho_0}{3}\sum_i \rho_i/\rho_0 = H_0^2 \sum \frac{\rho_i(t)}{\rho_0}$

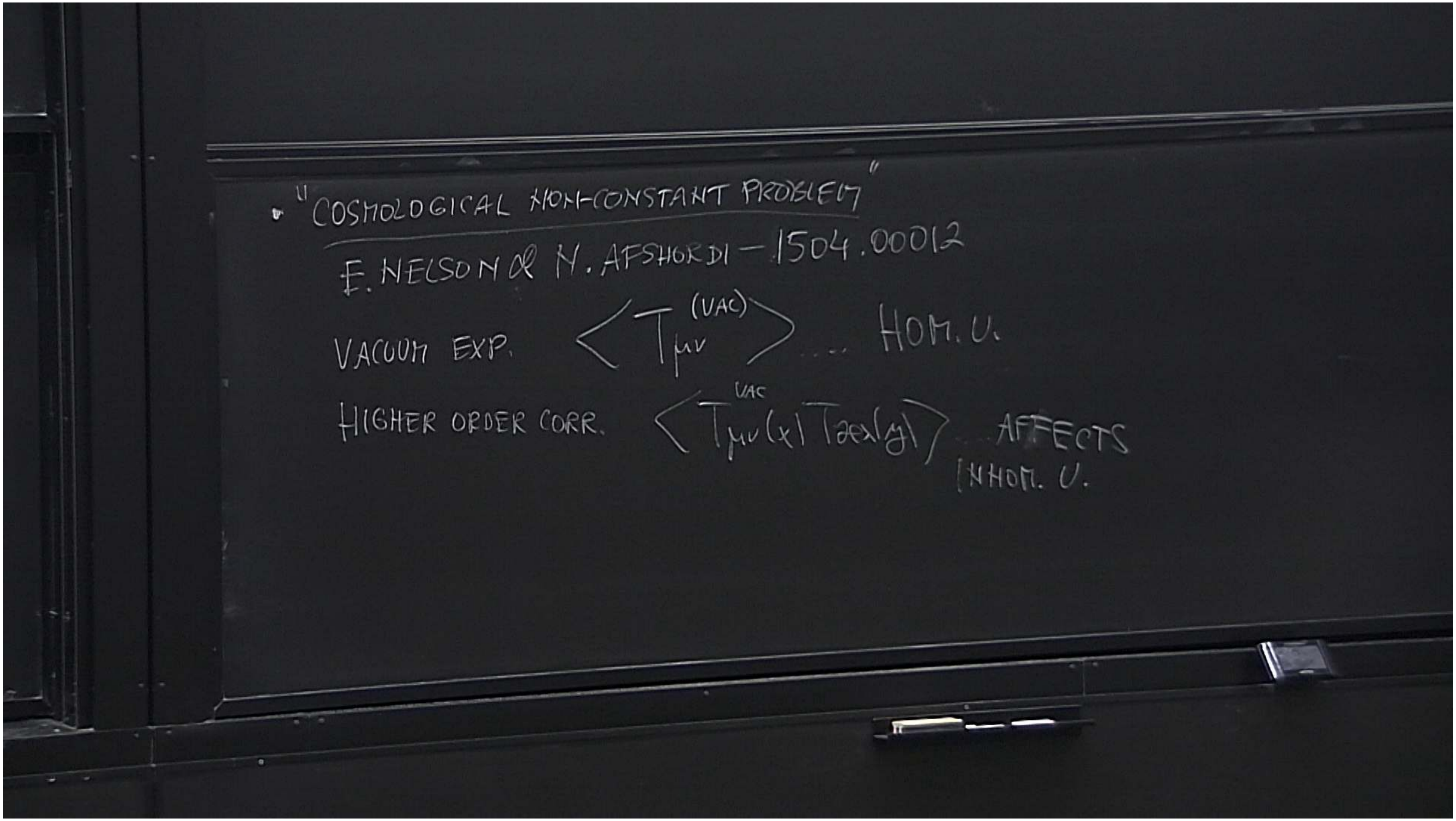
$$\frac{\rho_i(t)}{\rho_i(0)}\,\frac{\rho_i(0)}{\rho_0} \qquad \Omega_i$$

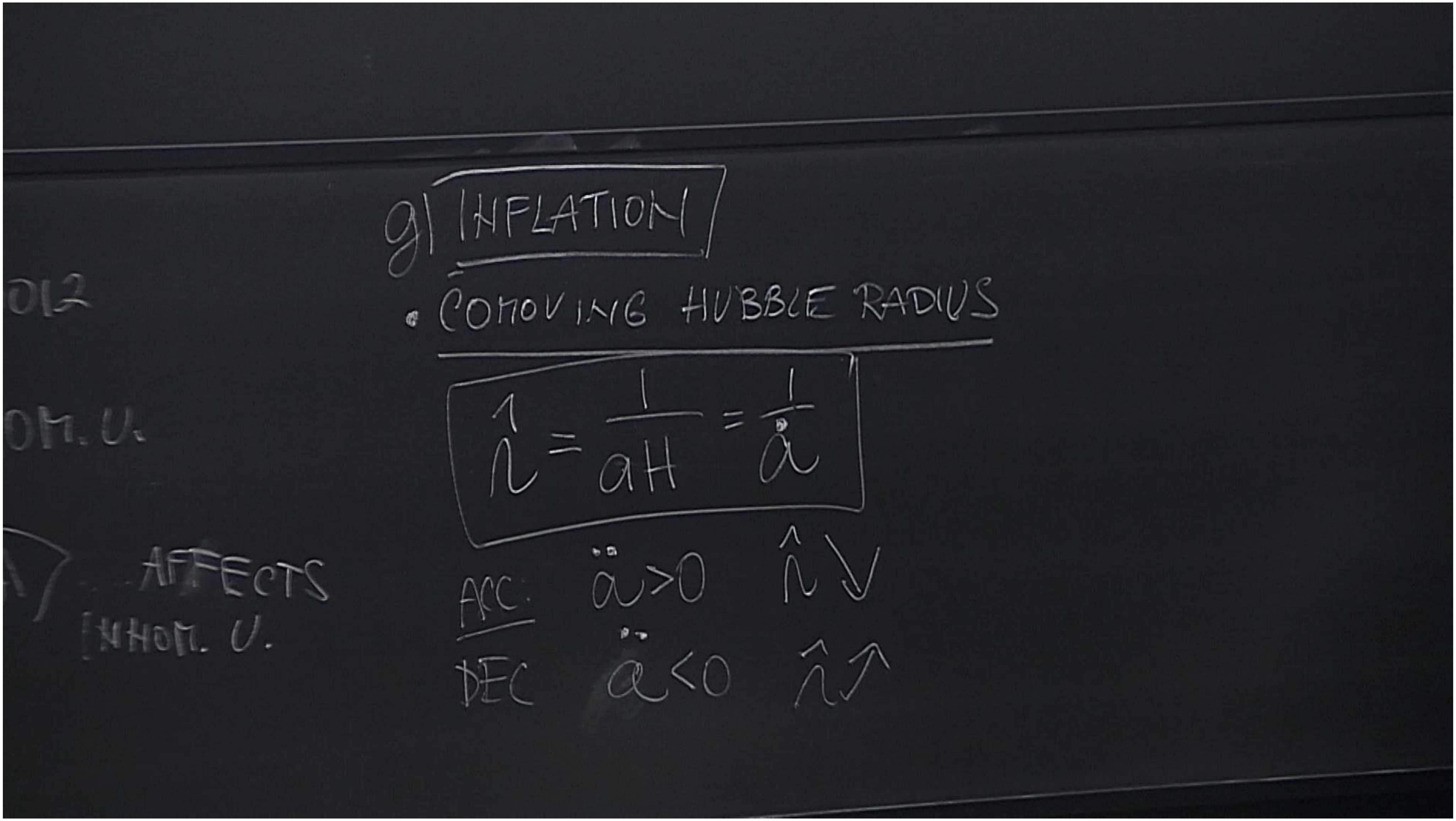

AIM: WRITE IN TERMS
OF z
COMES FROM F.F
INSTEAD OF F PEOPLE LIKE
APPARENT MAGNITUDES
m = -2.5 log10 F
(EYE LIKES IT)
m
1 SET OF Ω's
z

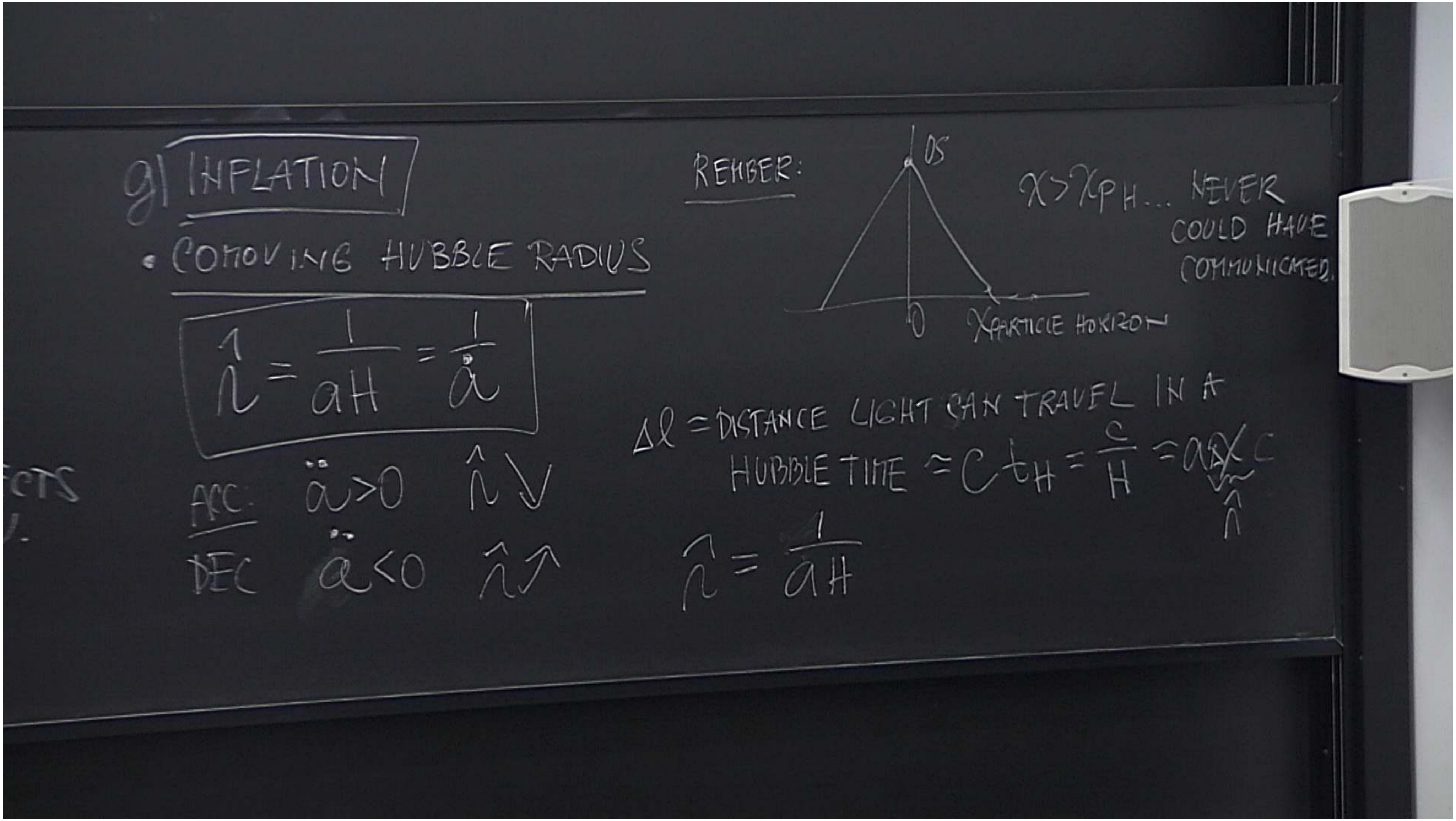

AIM: WRITE IN TERMS OF z
H(z) = H0 √(Σ Ωi(0) (1+z)^3(1+wi))
COMES FROM F.F
• INSTEAD OF F PEOPLE LIKE APPARENT MAGNITUDES
m = -2.5 log10 F
(EYE LIKES IT)
1 SET OF Ωi's
ACTUAL OBSERVATION
.. FITS LINE OF Ωm ≃ 0.3
ΩDE ≃ 0.7
m
z

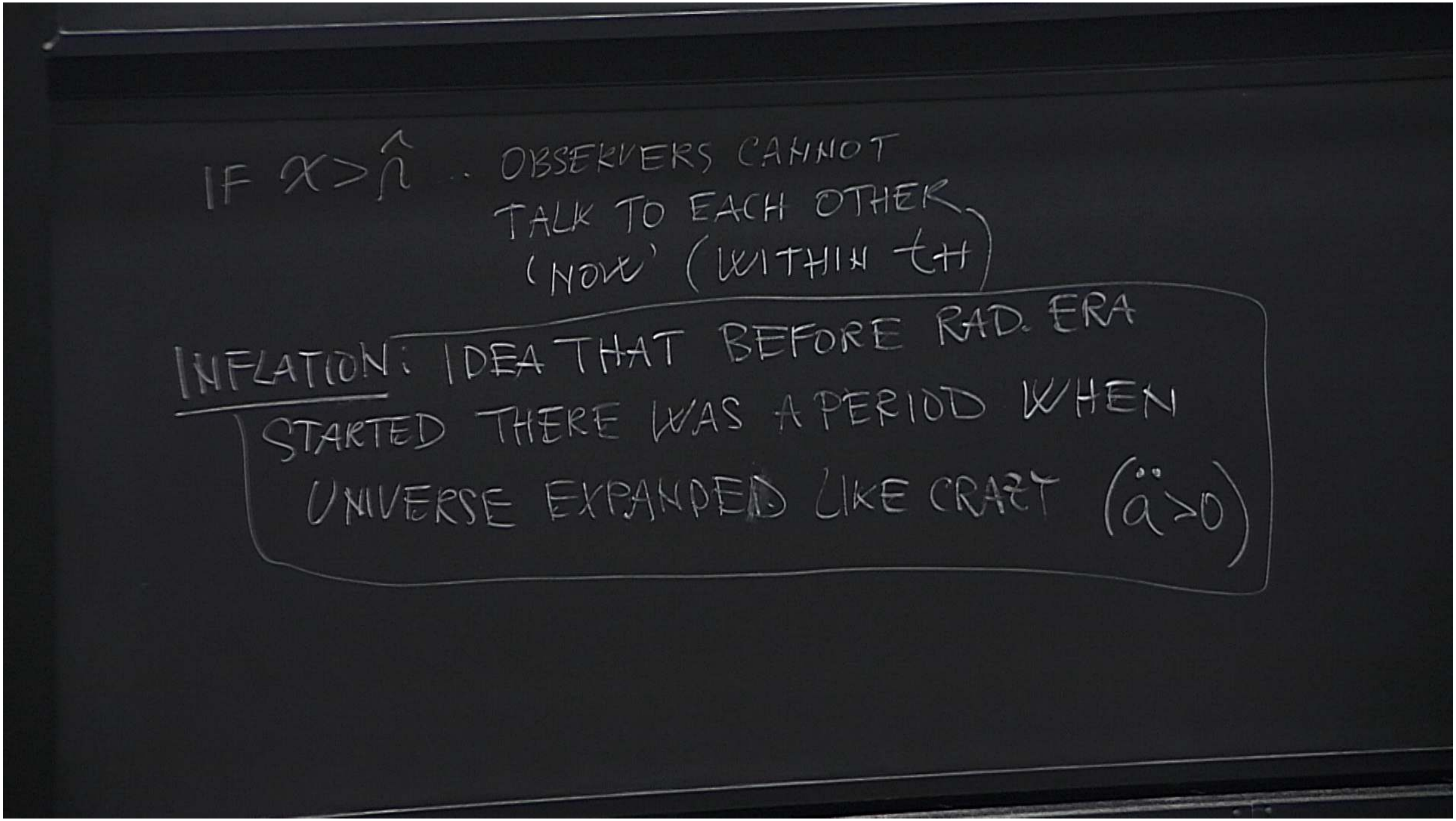

H(z) = H0 √ Σ Ωi(0) (1+z)^3(1+wi)
COMES FROM F.F
H² = 8πGρ0/3 Σ ρi/ρ0 = H0² Σ ρi(t)/ρ0
TE IN TERMS
OF z
1 SET OF Ωi's
m
z
ACTUAL OBSERVATION
FITS LINE
OF Ωm ≃ 0.3
ΩDE ≃ 0.7
(NP-2001)
COSMOLOGICAL CONSTANT PROBLEMS
OLD: ρΛ ≃ 10^-29 g/cm³
≃ 10^-120 IN R. PLANCK UNITS
VACUUM FL. ≃ Mpl² ≃ O(1)

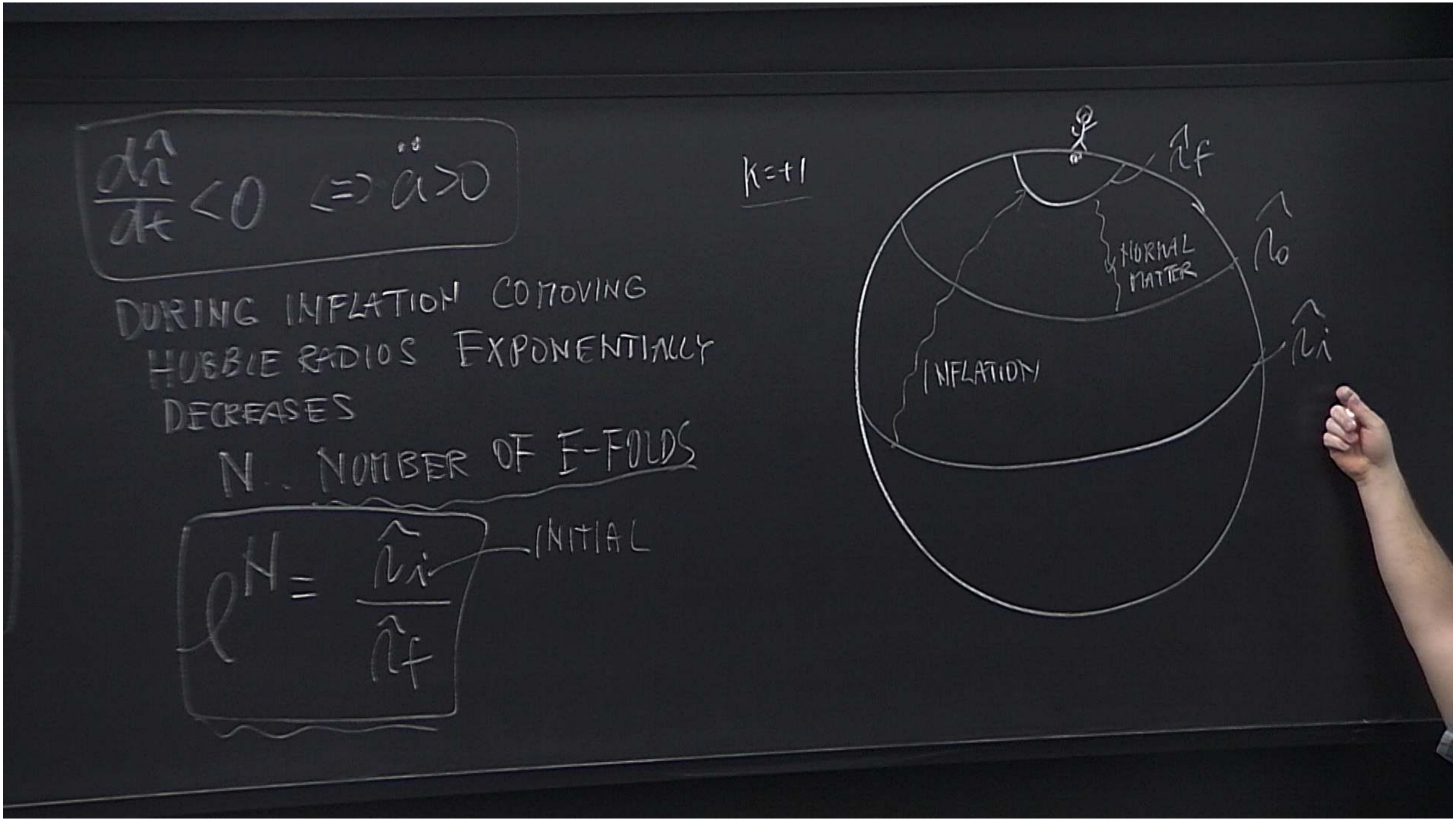

TERMS
COMES FROM F.F
1 SET OF Ω's
ACTUAL OBSERVATION
FITS LINE
OF Ωm ≃ 0.3
ΩDE ≃ 0.7
(NP-2001)
COSMOLOGICAL CONSTANT PROBLEMS
OLD:
ρΛ ≃ 10^-29 g/cm^3
≃ 10^-120 IN R. PLANCK UNITS
VACUUM FL. ≃ M_pl^2 ≃ O(1)
NEW WHY ρΛ ≃ ρCRIT ≃ ρ0
log ρ
log a


"COSMOLOGICAL NON-CONSTANT PROBLEM"
E. NELSON & N. AFSHORDI – 1504.00012
VACUUM EXP. $\langle T_{\mu\nu}^{(VAC)} \rangle$ ... HOM. U.
HIGHER ORDER CORR. $\langle T_{\mu\nu}(x) T_{\alpha\lambda}(y) \rangle^{VAC}$ ... AFFECTS INHOM. U.

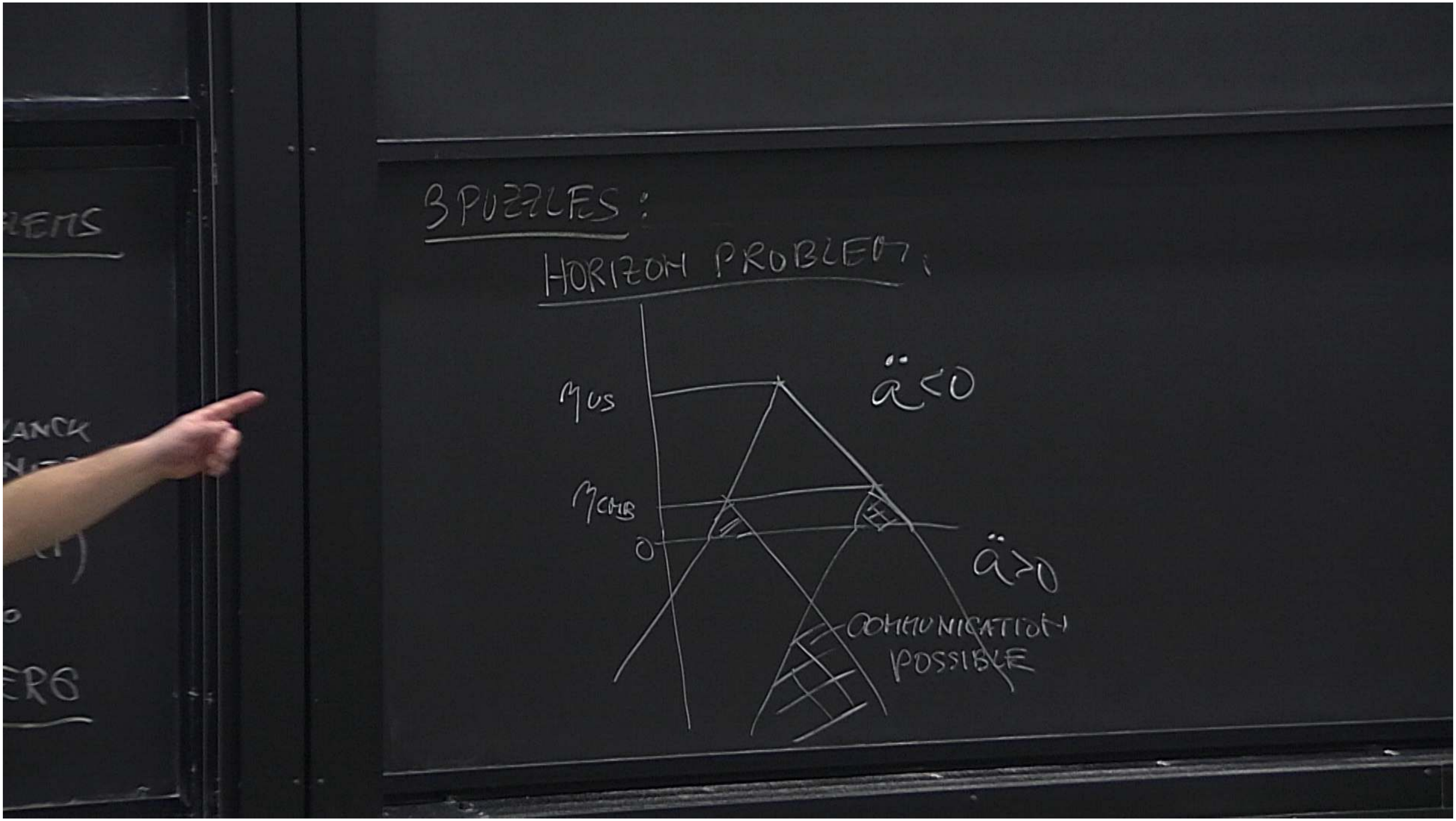

g) INFLATION
• COMOVING HUBBLE RADIUS
$\hat{r} = \frac{1}{aH} = \frac{1}{\dot{a}}$
ACC: $\ddot{a} > 0$ $\hat{r} \downarrow$
DEC $\ddot{a} < 0$ $\hat{r} \uparrow$
AFFECTS
INHOM. U.

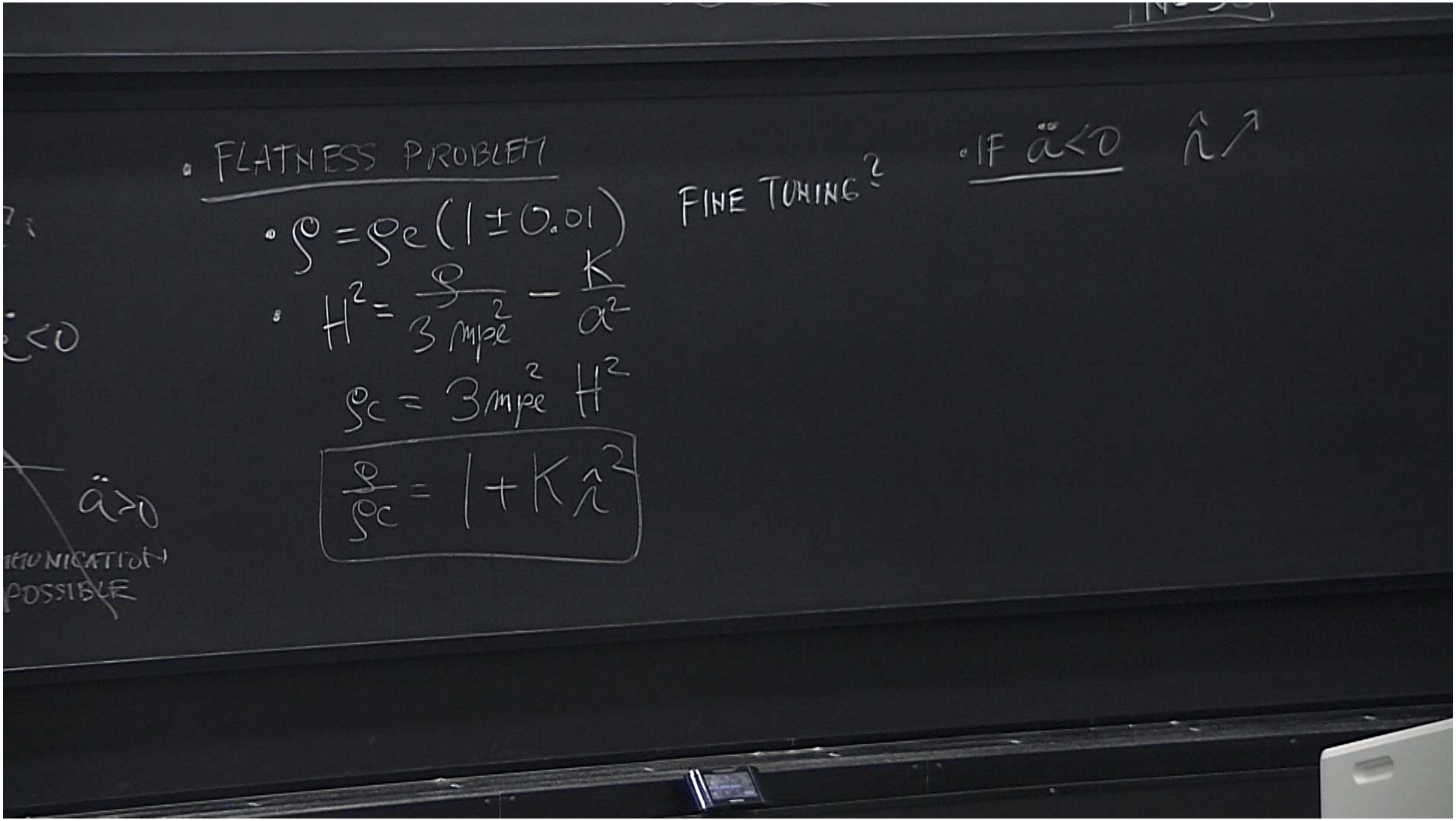

g) INFLATION
• COMOVING HUBBLE RADIUS
ACC.
DEC
REMBER:
OS
O
XPARTICLE HORIZON
X > XPH... NEVER COULD HAVE COMMUNICATED.
Δl = DISTANCE LIGHT CAN TRAVEL IN A HUBBLE TIME

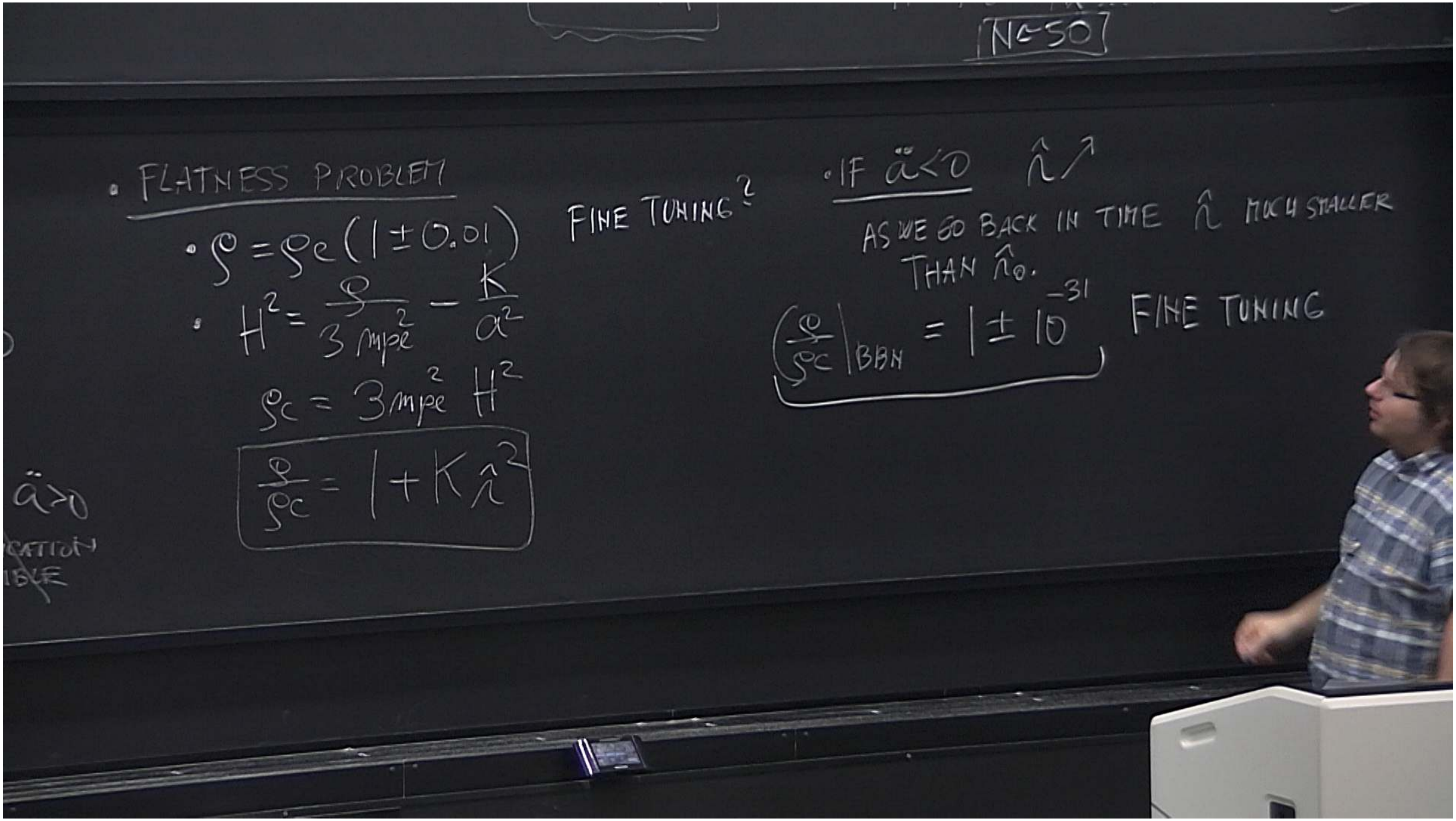

IF x > r̂ .. OBSERVERS CANNOT
TALK TO EACH OTHER
'NOW' (WITHIN tH)
INFLATION: IDEA THAT BEFORE RAD. ERA
STARTED THERE WAS A PERIOD WHEN
UNIVERSE EXPANDED LIKE CRAZY (ä>0)

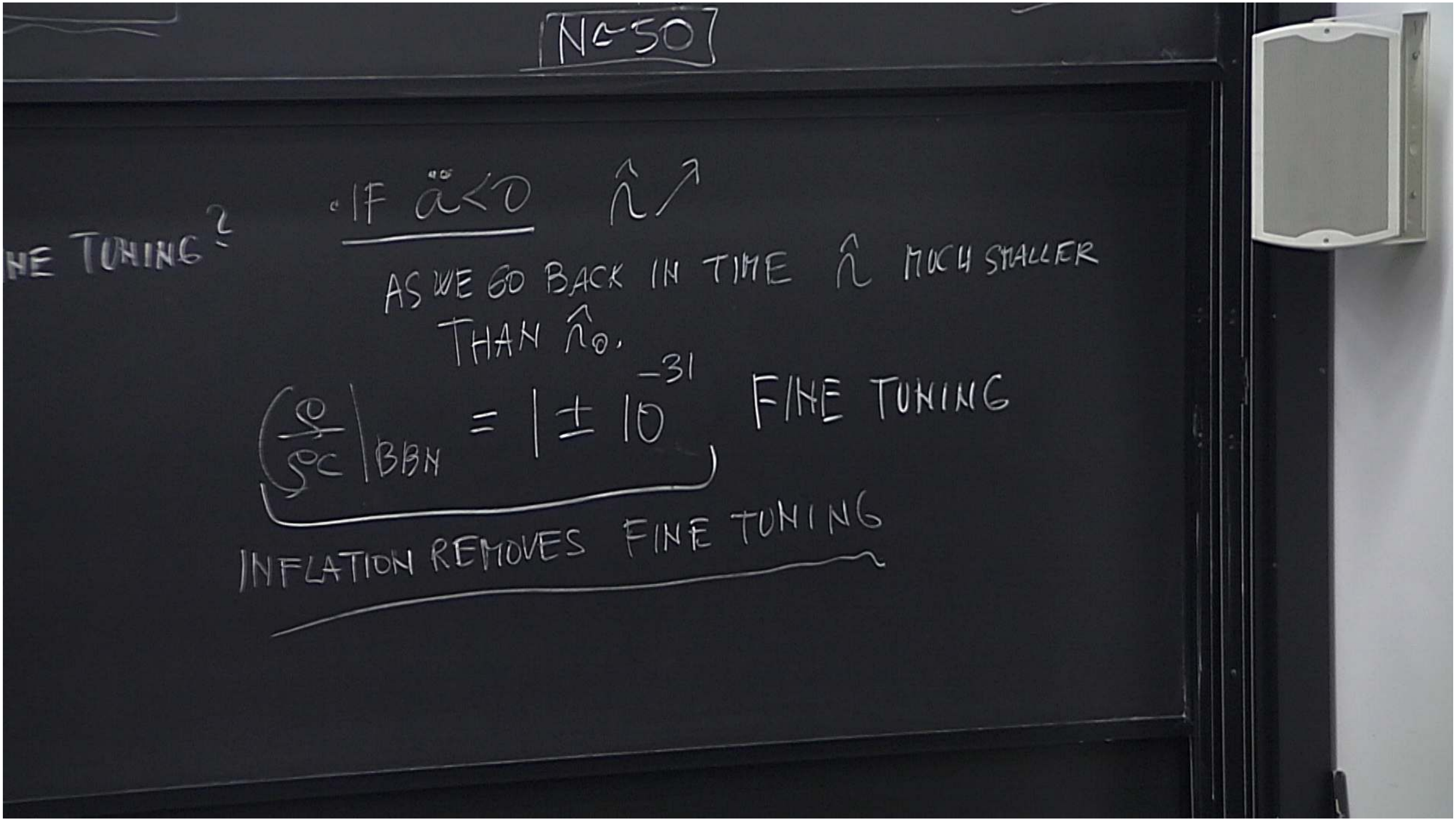


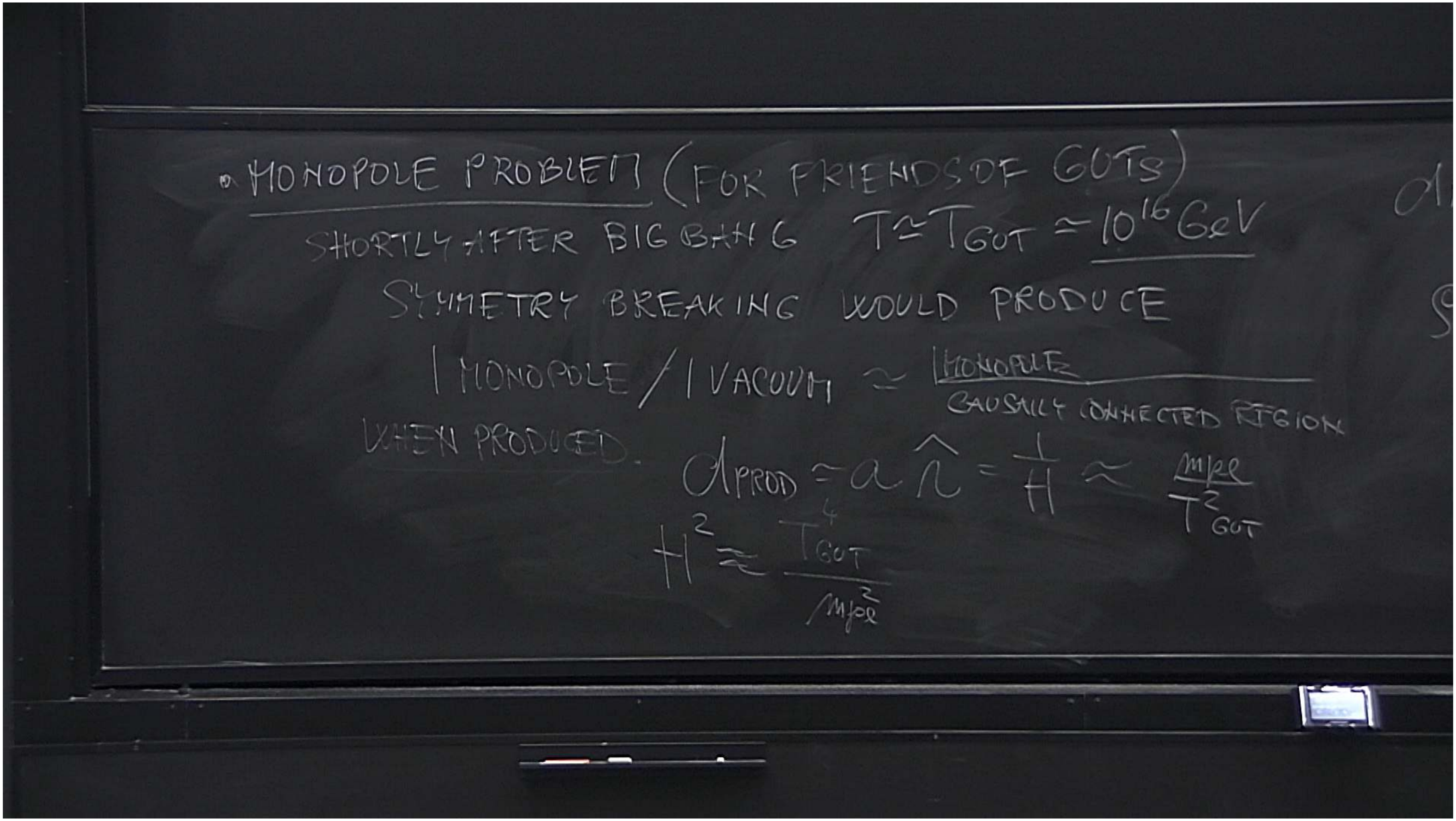
$\frac{d\hat{r}}{dt} < 0 \iff \ddot{a} > 0$
DURING INFLATION COMOVING
HUBBLE RADIUS EXPONENTIALLY
DECREASES
N .. NUMBER OF E-FOLDS
$e^N = \frac{\hat{r}_i}{\hat{r}_f}$
INITIAL
k=+1
$\hat{r}_f$
$\hat{r}_0$
$\hat{r}_i$
NORMAL MATTER
INFLATION


3 PUZZLES:
HORIZON PROBLEM:
ηUS
ηCMB
0
ä<0
ä>0
COMMUNICATION POSSIBLE


FLATNESS PROBLEM
$\rho = \rho_c (1 \pm 0.01)$
$H^2 = \frac{\rho}{3 m_{pl}^2} - \frac{K}{a^2}$
$\rho_c = 3 m_{pl}^2 H^2$
$\frac{\rho}{\rho_c} = 1 + K \hat{r}^2$
FINE TUNING?
IF $\ddot{a} < 0$ $\hat{r} \nearrow$
$\ddot{a} > 0$
POSSIBLE


N≃50
• FLATNESS PROBLEM
• ρ = ρc (1 ± 0.01)
• H² = ρ / 3 mpl² − K / a²
ρc = 3 mpl² H²
ρ / ρc = 1 + K r̂²
FINE TUNING ?
• IF ä < 0 r̂ ↗
AS WE GO BACK IN TIME r̂ MUCH SMALLER THAN r̂₀.
(ρ / ρc)|BBN = 1 ± 10⁻³¹
FINE TUNING
ä > 0


N≃50
NE TUNING?
• IF ä<0 r̂ ↗
AS WE GO BACK IN TIME r̂ MUCH SMALLER
THAN r̂₀.
(ρ/ρc)|BBN = 1 ± 10^-31 FINE TUNING
INFLATION REMOVES FINE TUNING

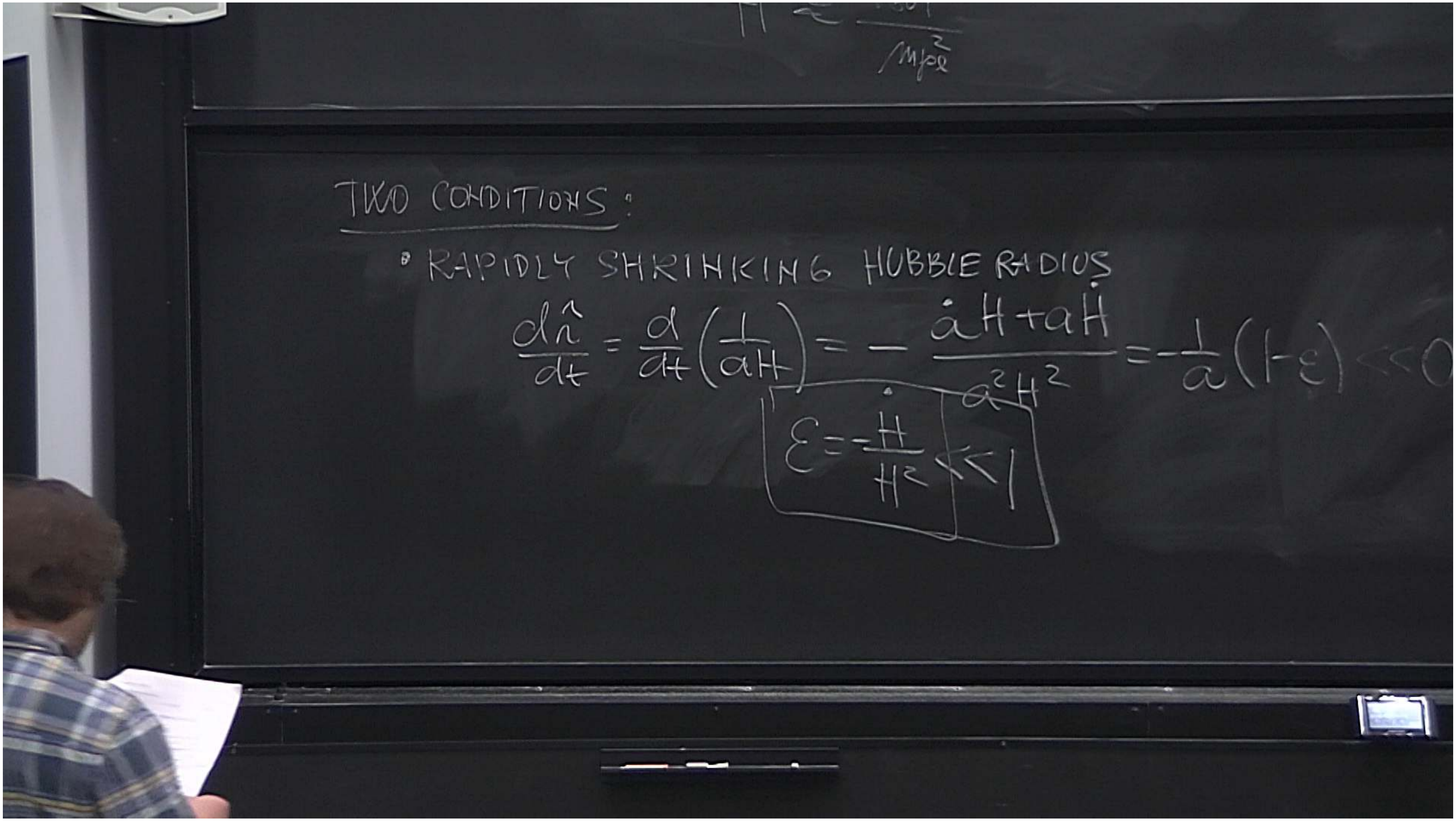

• MONOPOLE PROBLEM (FOR FRIENDS OF GUTs)
SHORTLY AFTER BIG BANG $T \simeq T_{GUT} \simeq 10^{16}$ GeV
SYMMETRY BREAKING WOULD PRODUCE
1 MONOPOLE / 1 VACUUM ≃ 1 MONOPOLE / CAUSALLY CONNECTED REGION
WHEN PRODUCED.
$d_{PROD} \simeq a\hat{r} = \frac{1}{H} \simeq \frac{m_{pl}}{T^2_{GUT}}$
$H^2 \simeq \frac{T^4_{GUT}}{m^2_{pl}}$

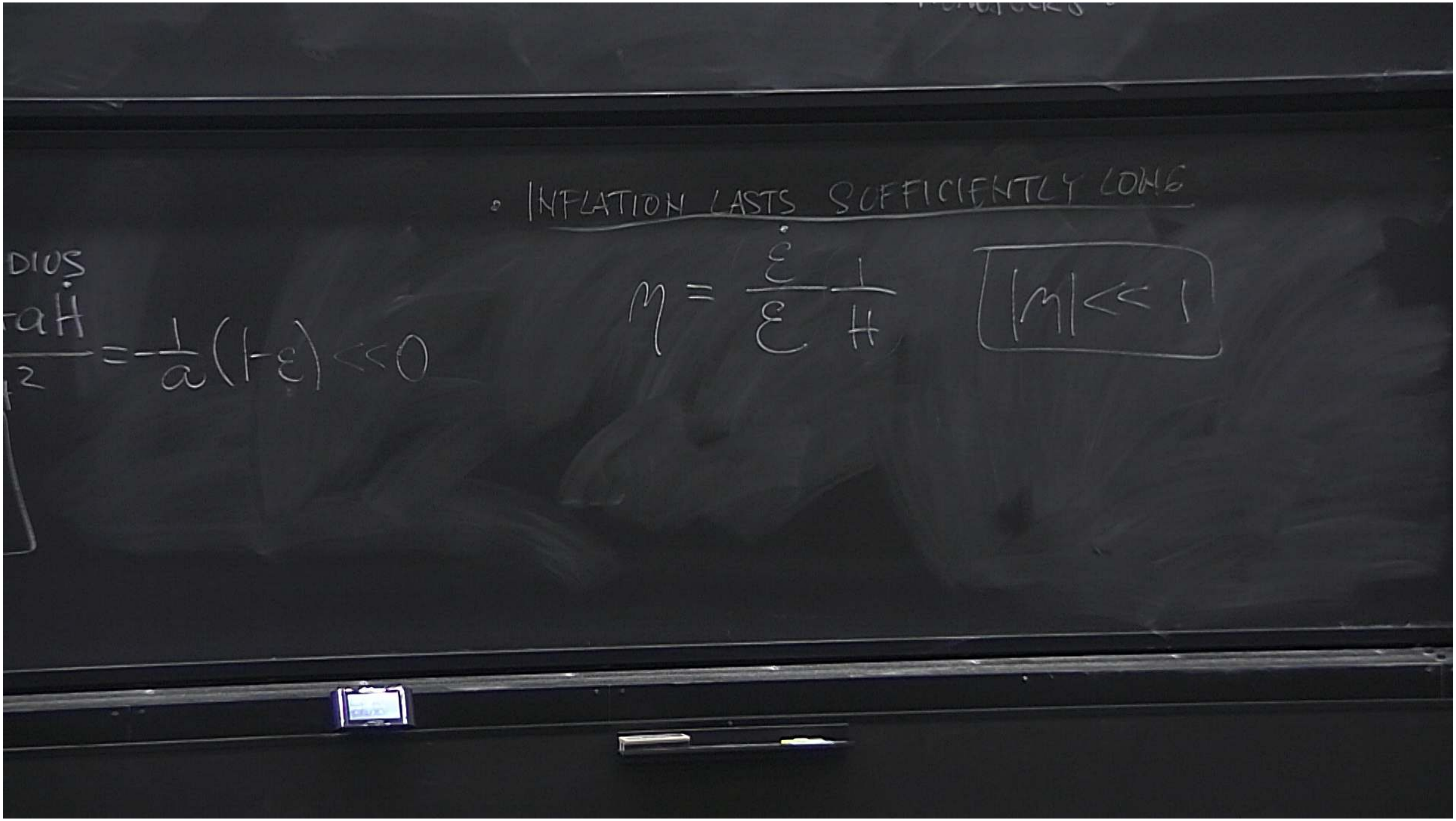
$$d_{NOW} = \frac{T_{GUT}}{T_{CMB}} d_{PROD} \simeq \frac{m_{pl}}{T_{GUT} T_{CMB}} \simeq 10^4 \text{ km}.$$

$$\rho_{MON} = \frac{M_{GUT}}{d^3_{NOW}} = 10^{17} \rho_c$$

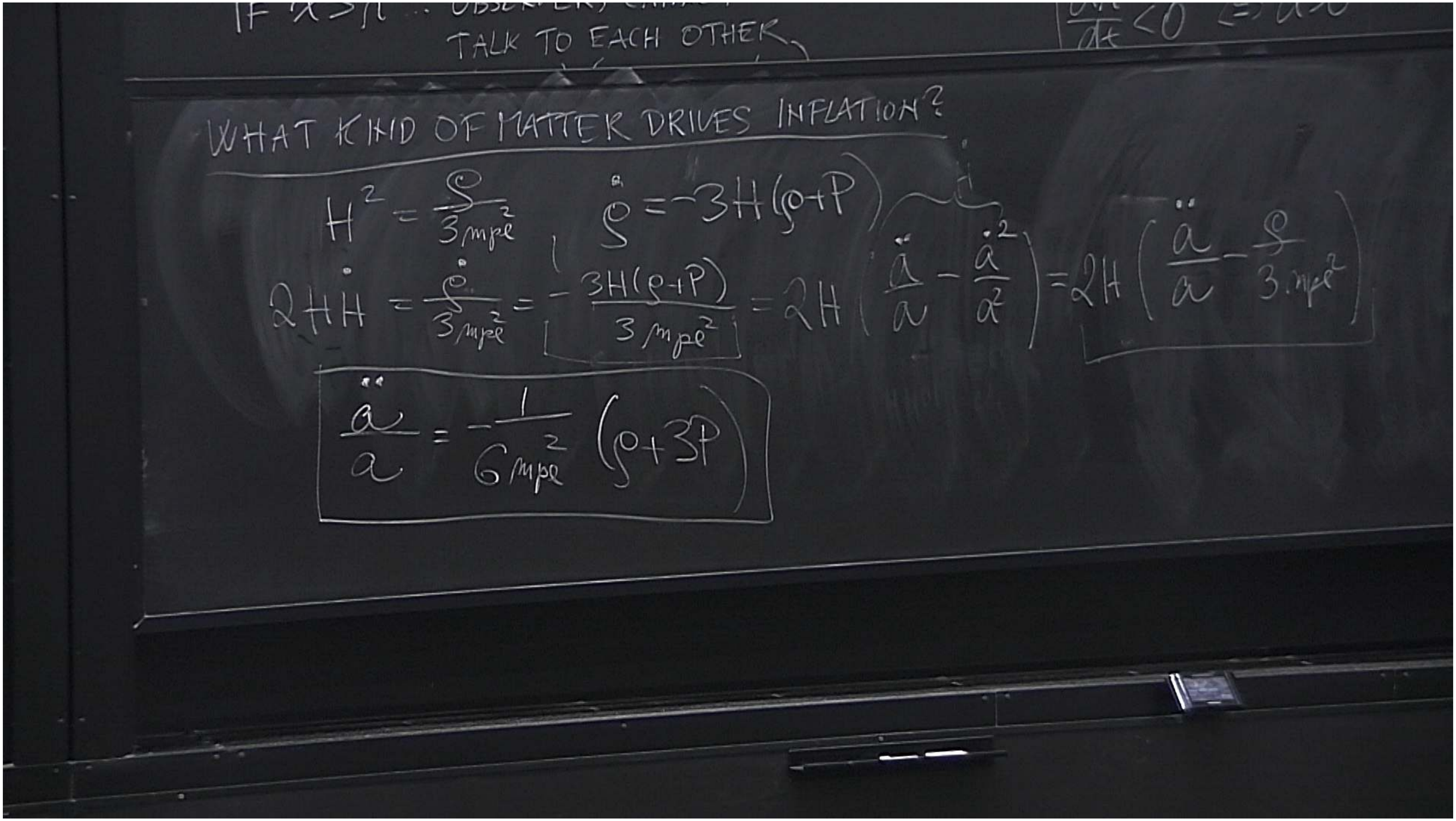
EGION

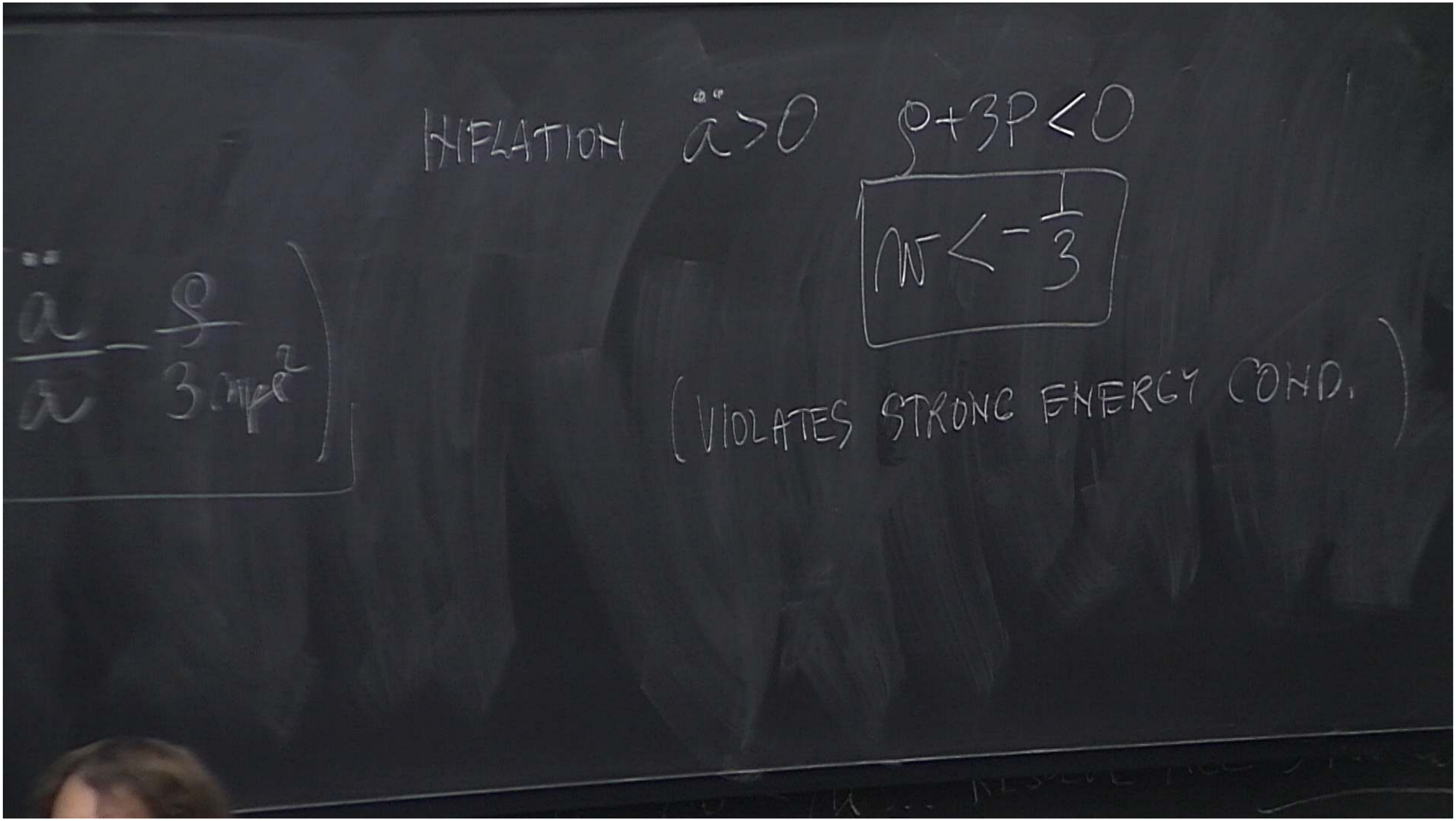
UNIVERSE WOULD COLLAPSE LONG TIME AGO.


TWO CONDITIONS:
• RAPIDLY SHRINKING HUBBLE RADIUS
$\frac{d\hat{r}}{dt} = \frac{d}{dt}\left(\frac{1}{aH}\right) = -\frac{\dot{a}H + a\dot{H}}{a^2H^2} = -\frac{1}{a}(1-\varepsilon) << 0$
$\varepsilon = -\frac{\dot{H}}{H^2} << 1$



INFLATION LASTS SUFFICIENTLY LONG
$\eta = \frac{\dot{\varepsilon}}{\varepsilon}\frac{1}{H}$
$|\eta| << 1$
DIUS
$= -\frac{1}{a}(1-\varepsilon) << 0$


TALK TO EACH OTHER
WHAT KIND OF MATTER DRIVES INFLATION?
H² = ρ / 3mpl²   ρ̇ = −3H(ρ+P)
2HḢ = ρ̇ / 3mpl² = − 3H(ρ+P) / 3mpl² = 2H(ä/a − ȧ²/a²) = 2H(ä/a − ρ/3mpl²)
ä/a = − 1/6mpl² (ρ+3P)


INFLATION ä>0 ρ+3P<0
w<-1/3
(VIOLATES STRONG ENERGY COND.)