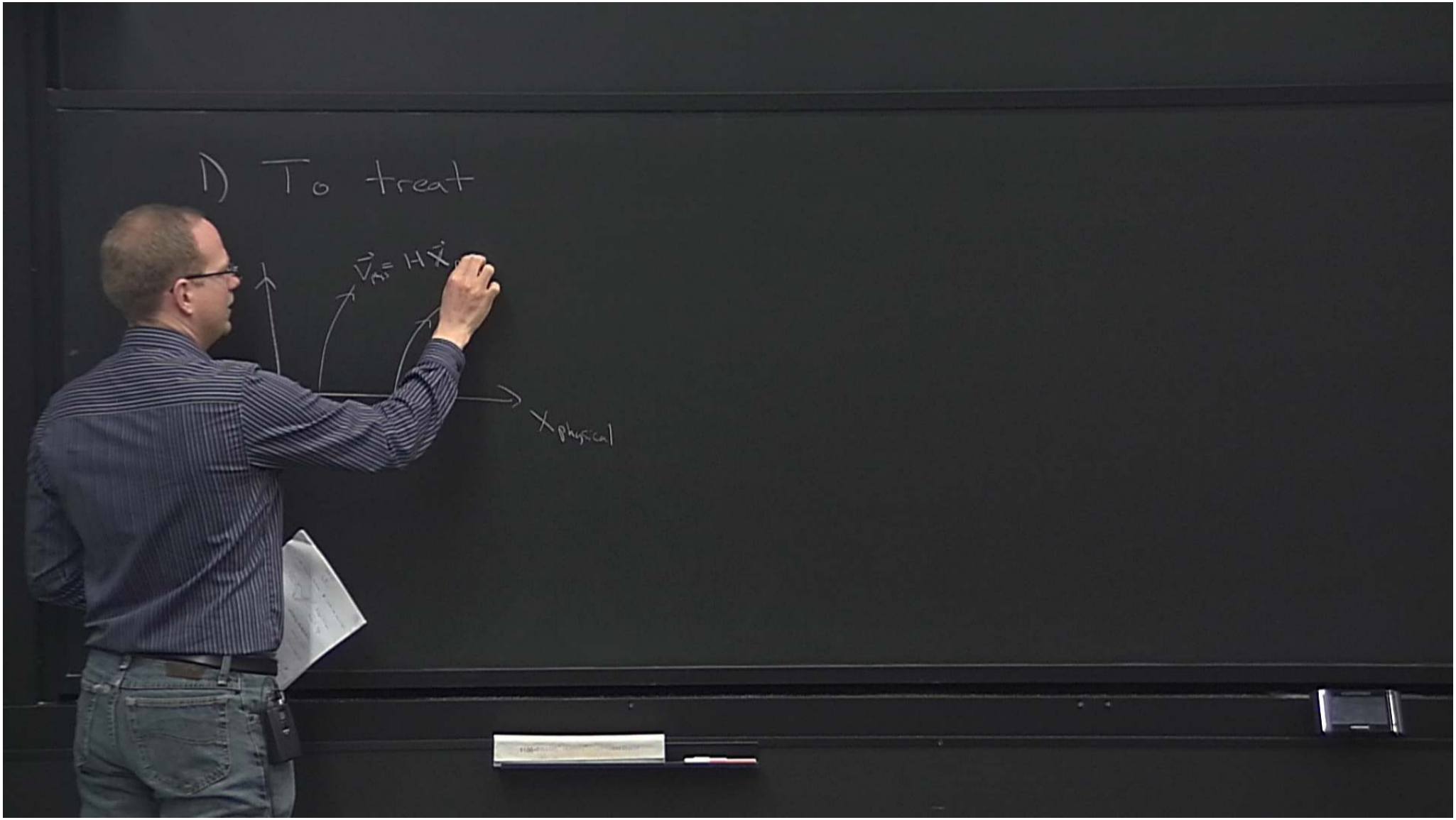
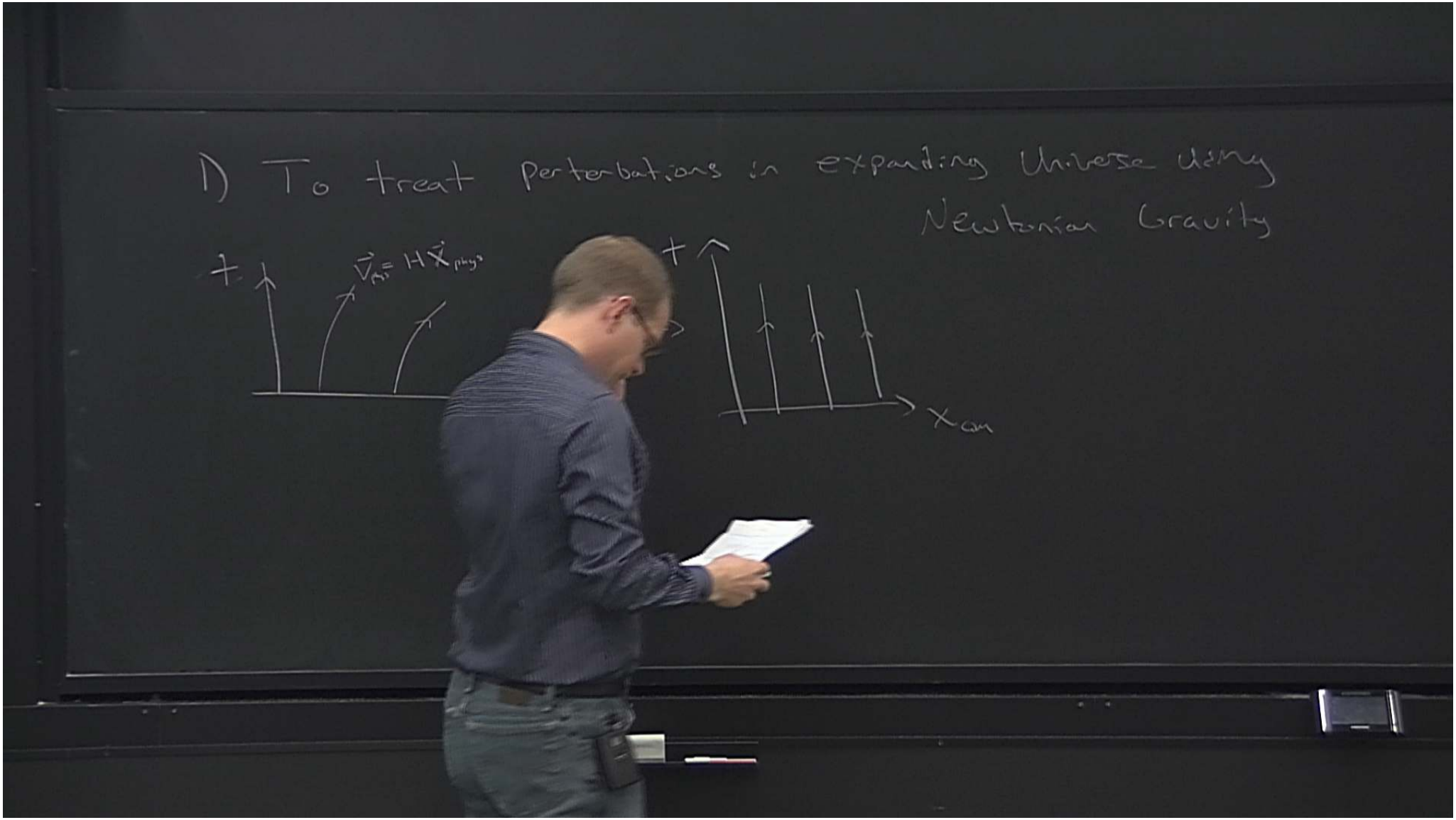
Title: 13/14 PSI - Explorations in Cosmology - Lecture 3

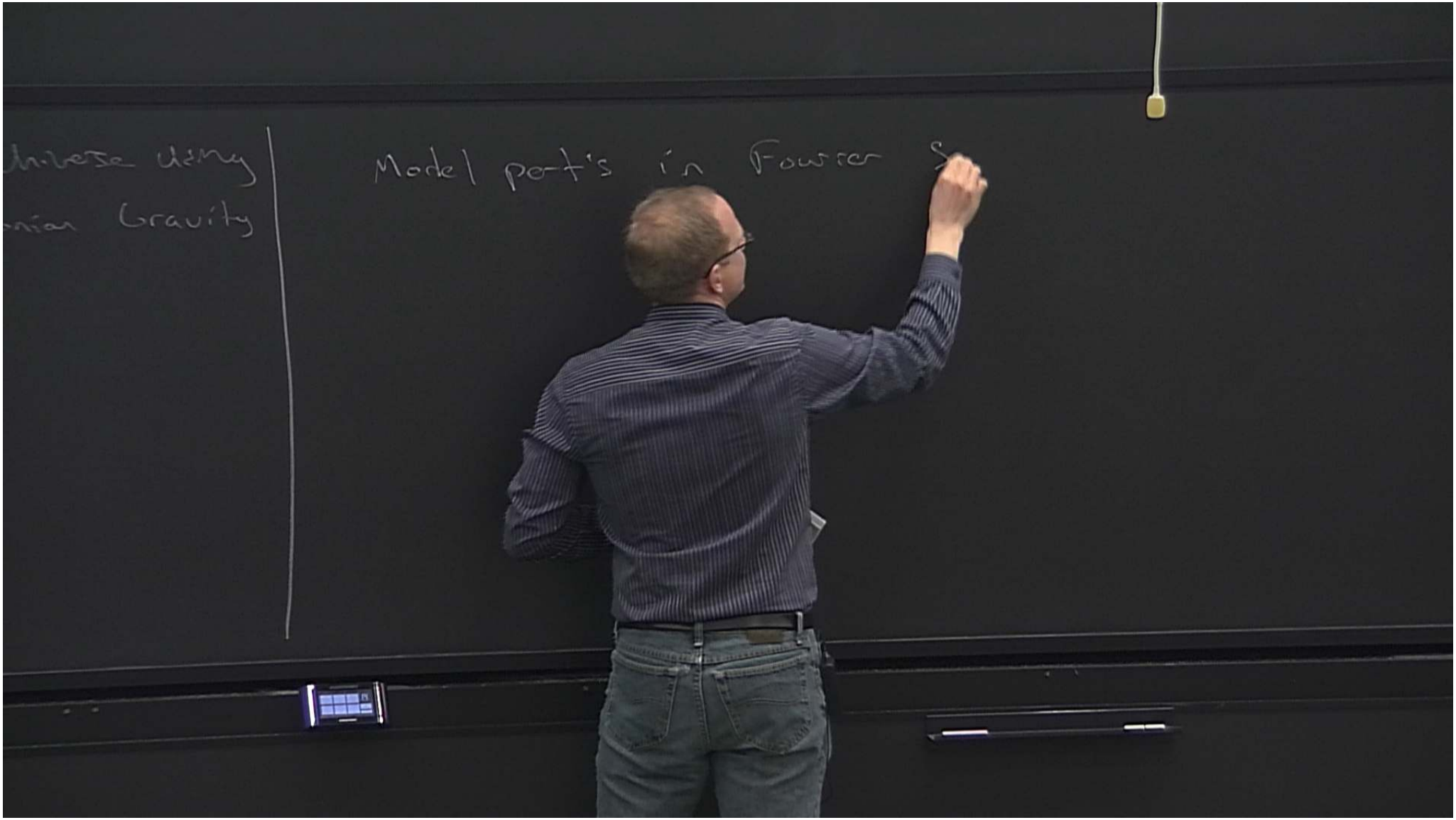
Date: Apr 09, 2014 10:15 AM

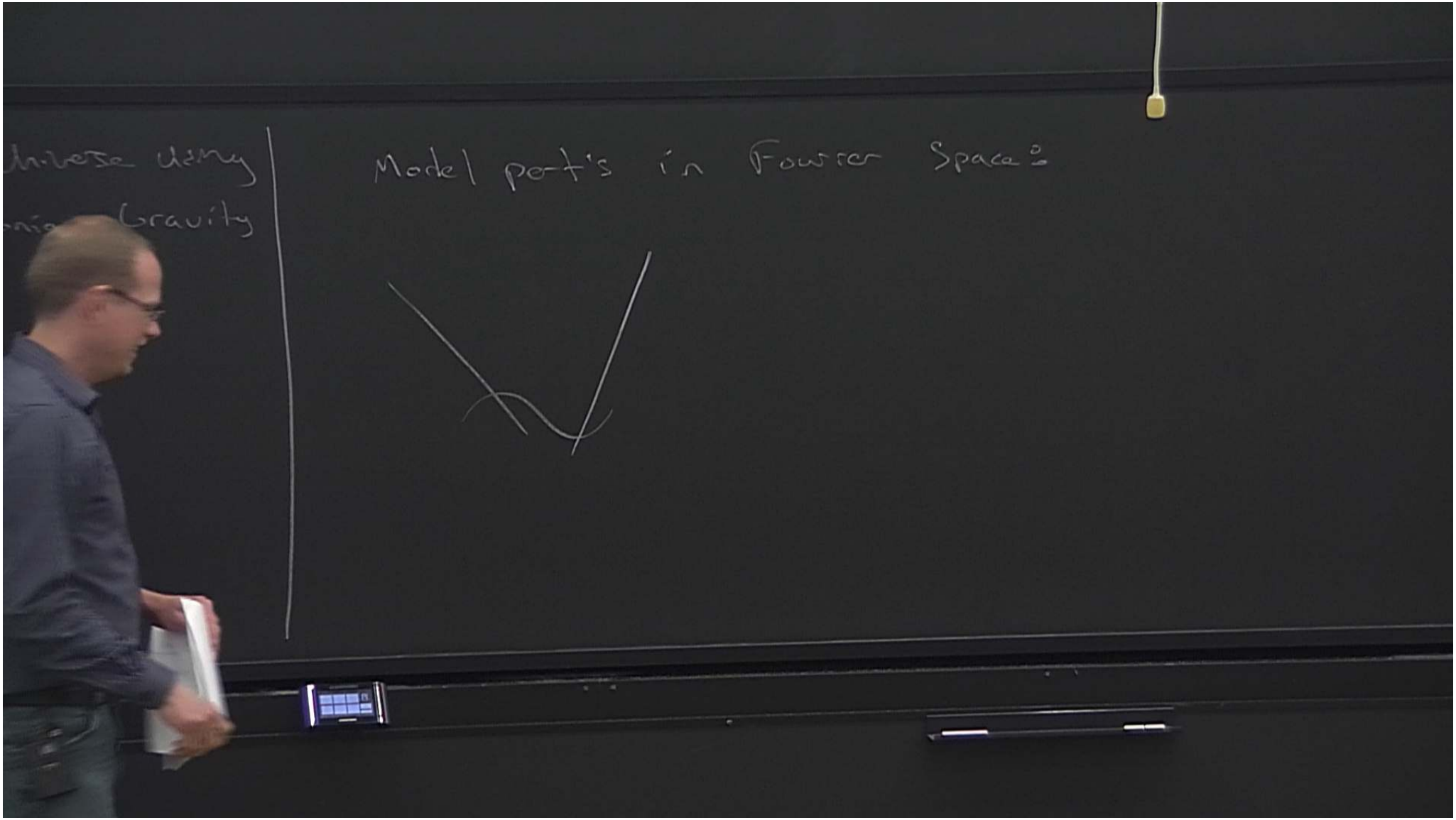
URL: http://pirsa.org/14040043

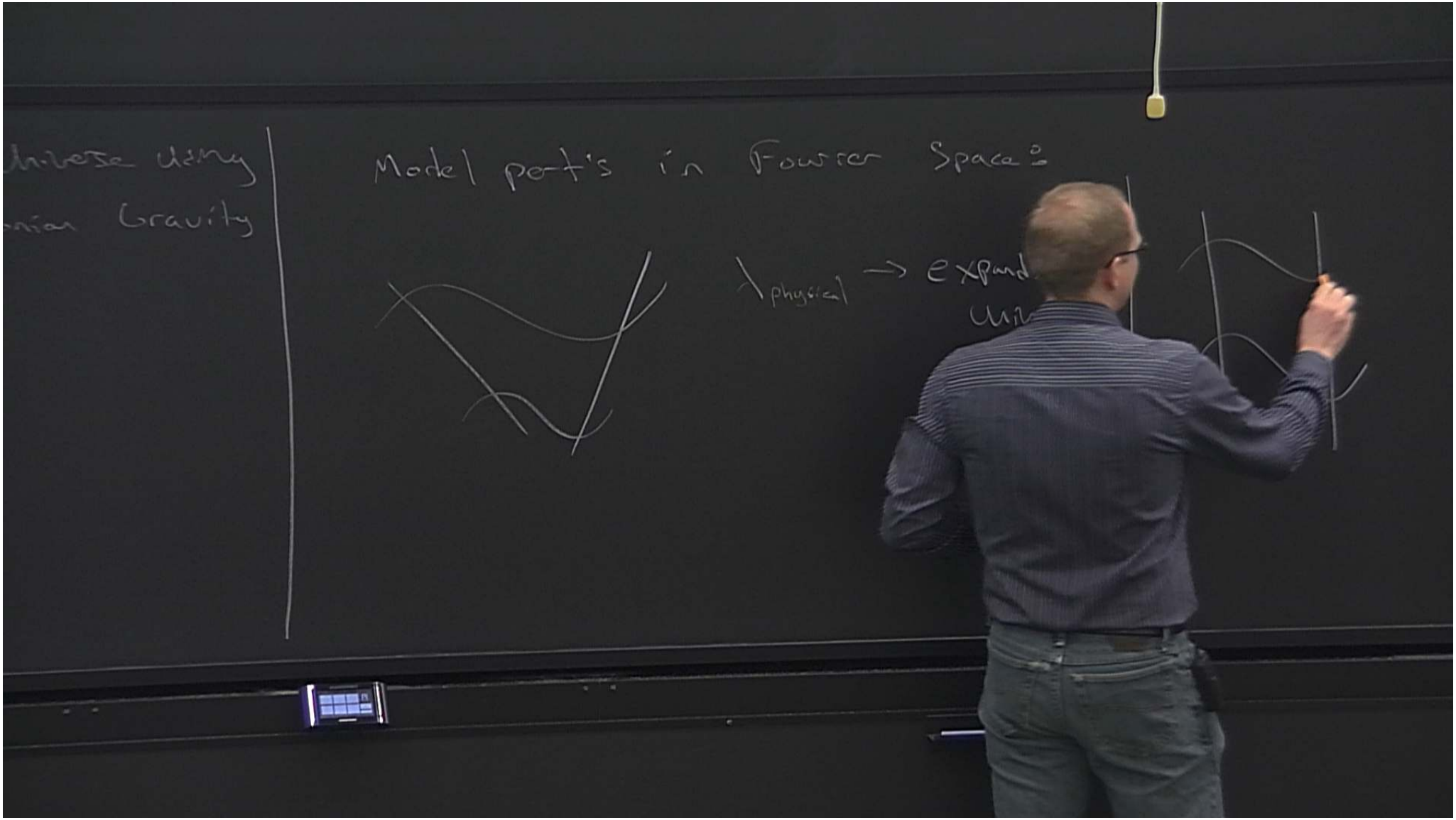
Abstract:

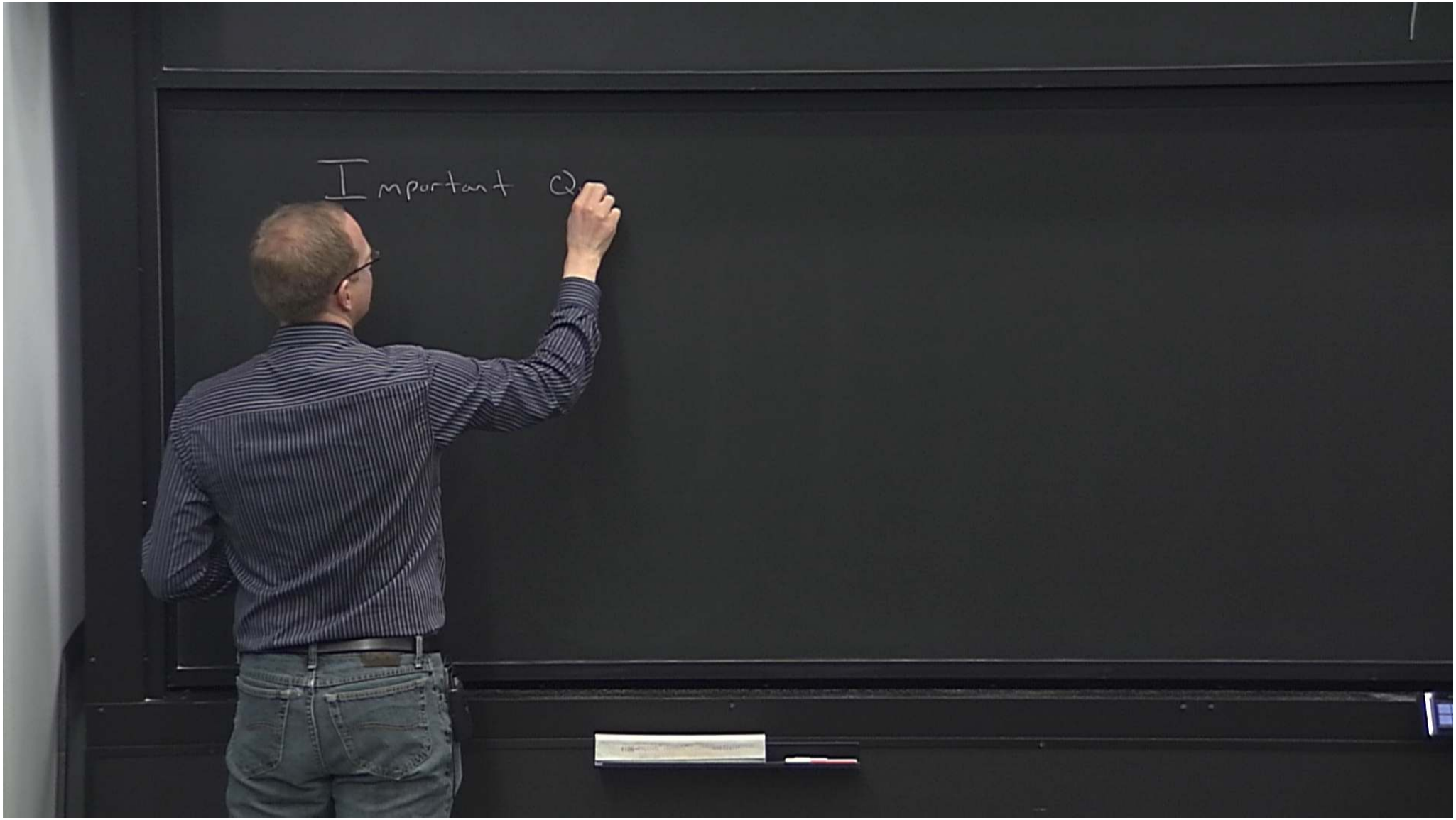

1) To treat
x physical

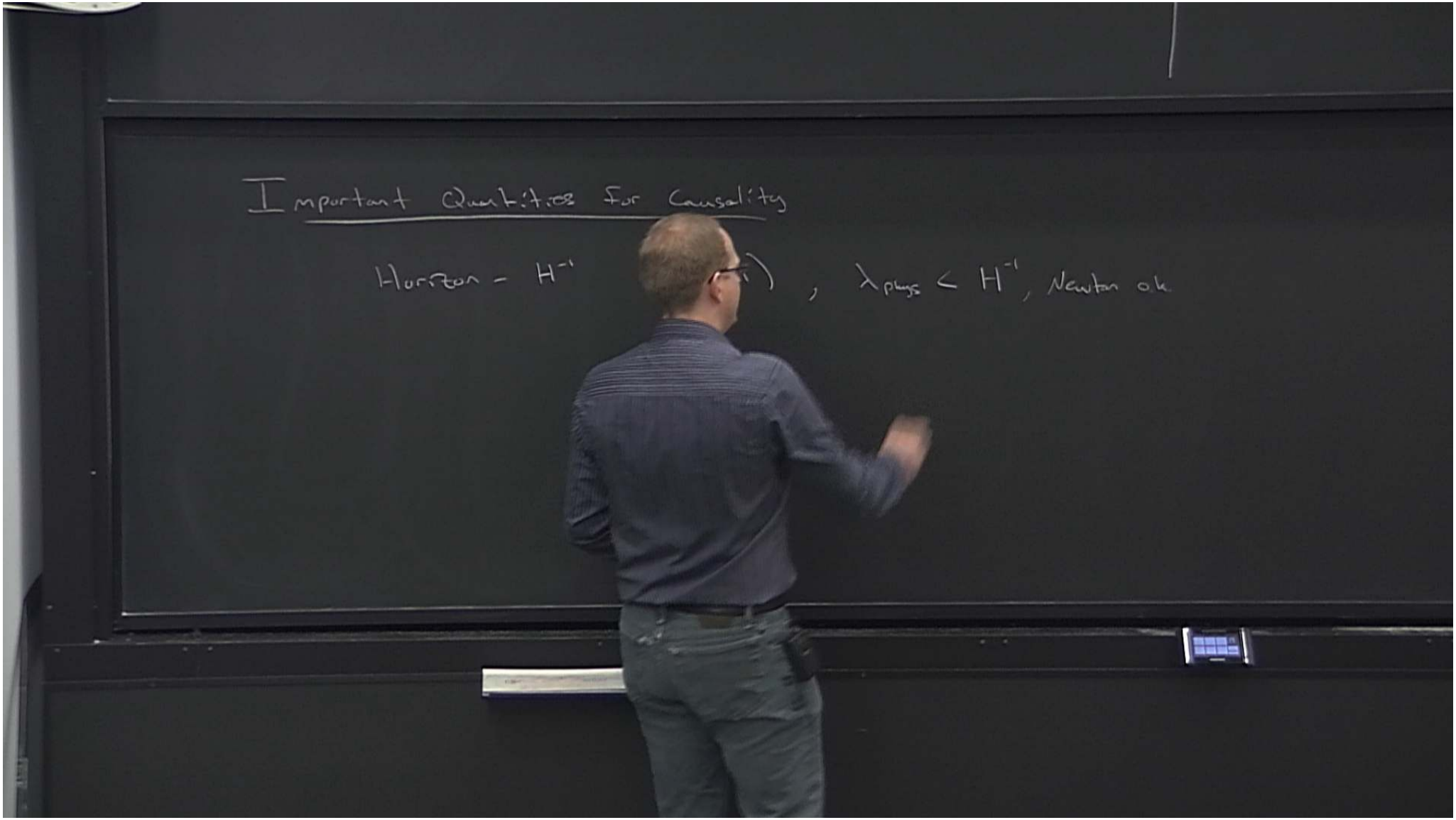

1) To treat perterbations in expanding Universe using
Newtonian Gravity
t
$\vec{V}_{Ai} = H\vec{X}_{phys}$
t
x_{com}

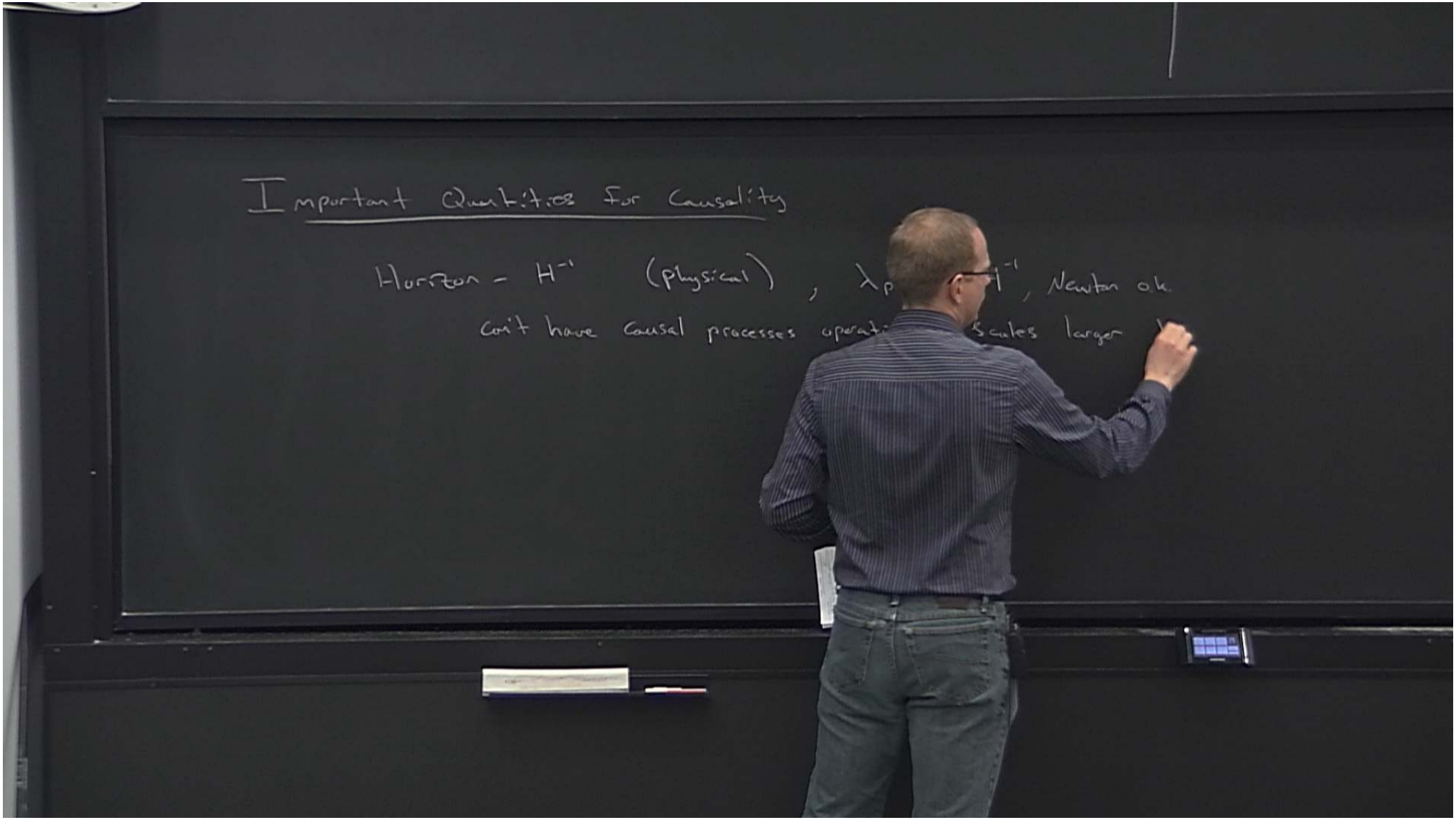

Model pot's in Fourier

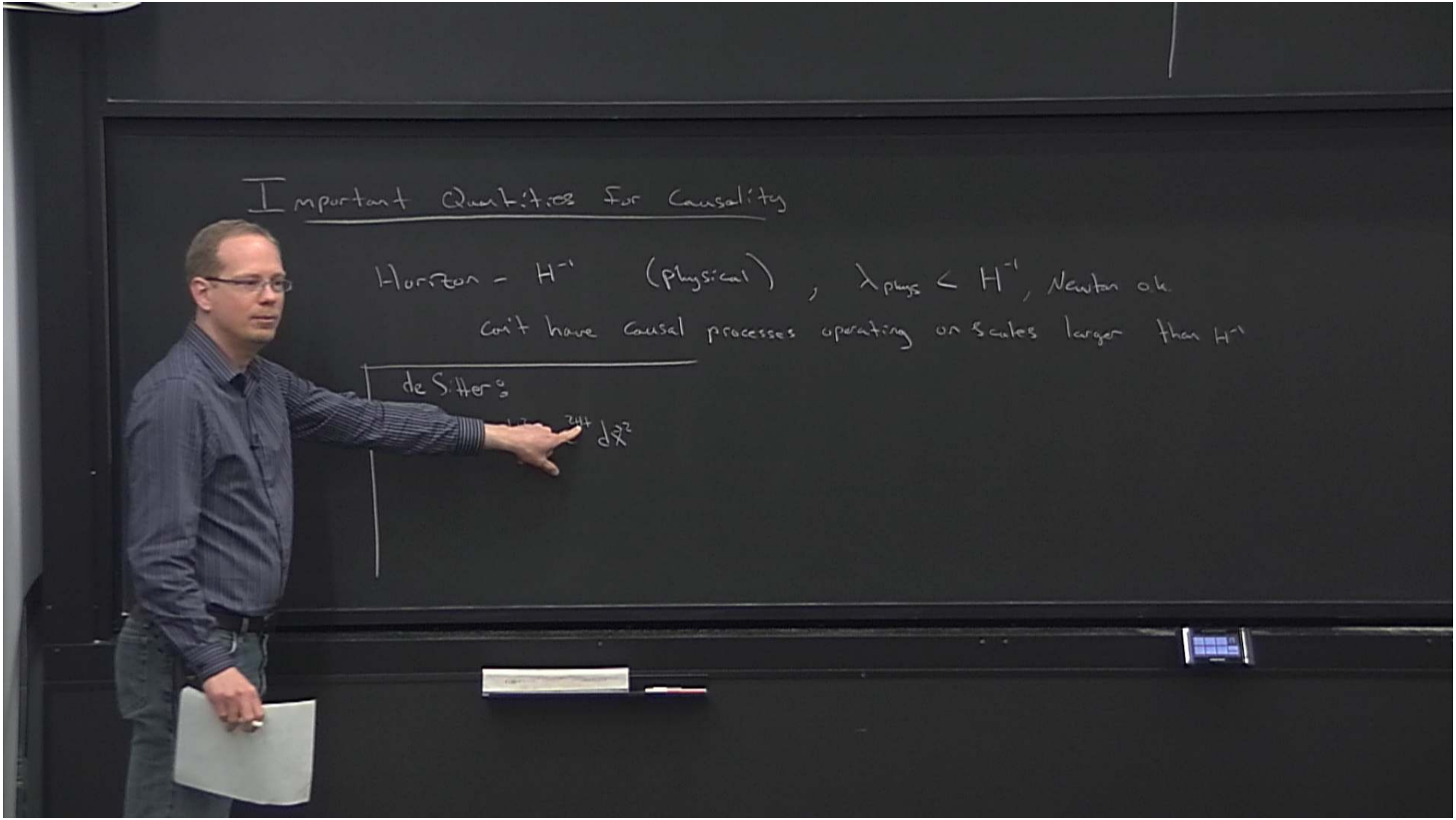

Model pdf's in Fourier Space

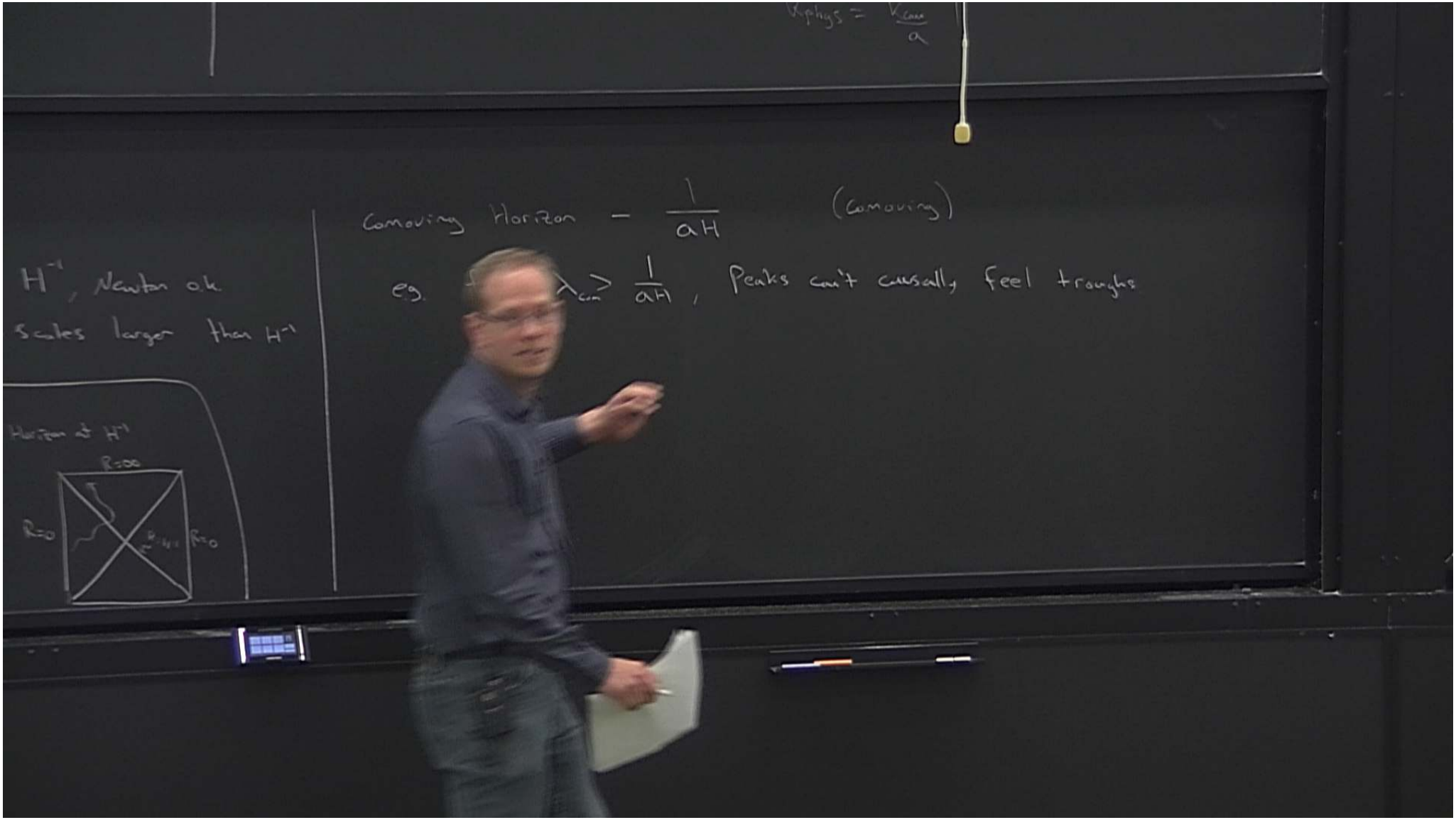

Model pert's in Fourier Space:
physical

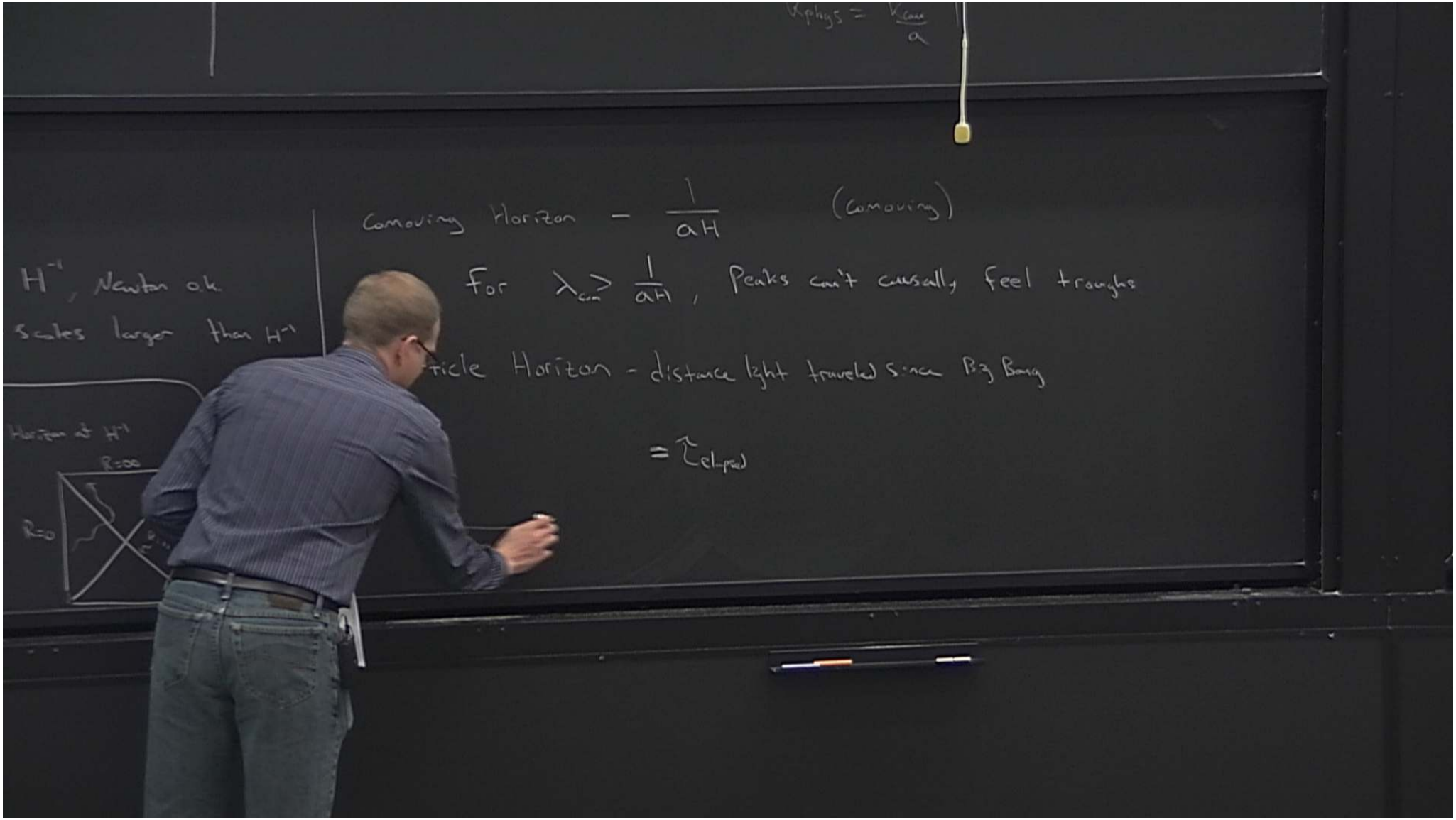

Important

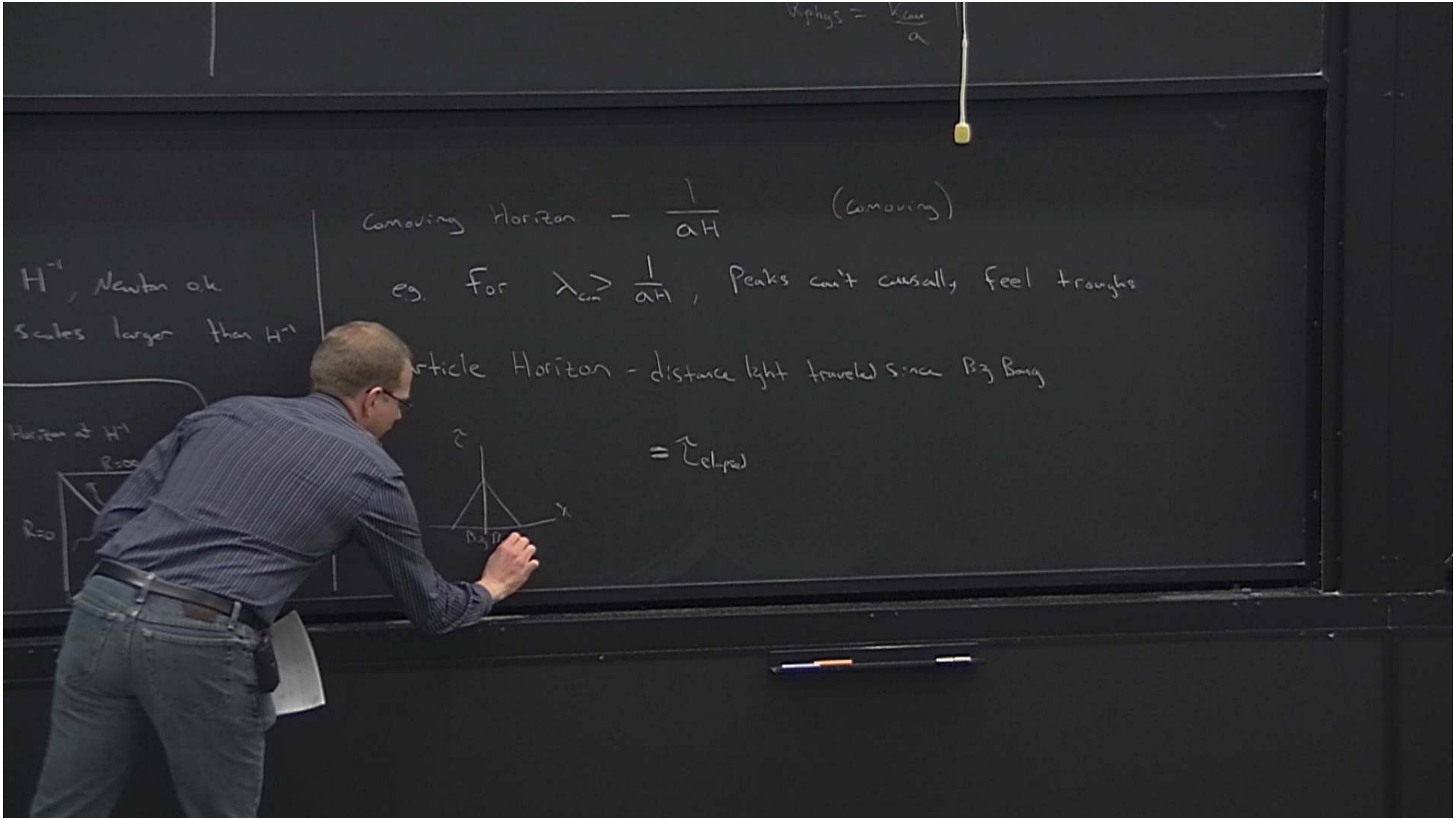

Important Quantities for Causality
Horizon - H^{-1}
$\lambda_{phys} < H^{-1}$, Newton o.k.


Important Quantities for Causality
Horizon - H^{-1} (physical)
can't have causal processes operat
scales larger


Important Quantities for Causality
Horizon - H^{-1} (physical), $\lambda_{phys} < H^{-1}$, Newton ok
can't have causal processes operating on scales larger than H^{-1}
de Sitter's
dx^2


Comoving Horizon $\sim \frac{1}{aH}$ (Comoving)
H^{-1}, Newton o.k.
scales larger than H^{-1}
eg. $\lambda_{com} > \frac{1}{aH}$, Peaks can't causally feel troughs
Horizon at H^{-1}
R=∞
R=0
R=0


$k_{phys} = \frac{k_{comov}}{a}$
Comoving Horizon $= \frac{1}{aH}$ (comoving)
H^{-1}, Newton o.k.
scales larger than H^{-1}
for $\lambda_{com} > \frac{1}{aH}$, Peaks can't causally feel troughs
ticle Horizon - distance light traveled since Big Bang
$= \tau_{cl-pol}$
Horizon at H^{-1}
R=∞
R=0


$k_{phys} = \frac{k_{comov}}{a}$
Comoving Horizon $= \frac{1}{aH}$ (comoving)
H^{-1}, Newton o.k.
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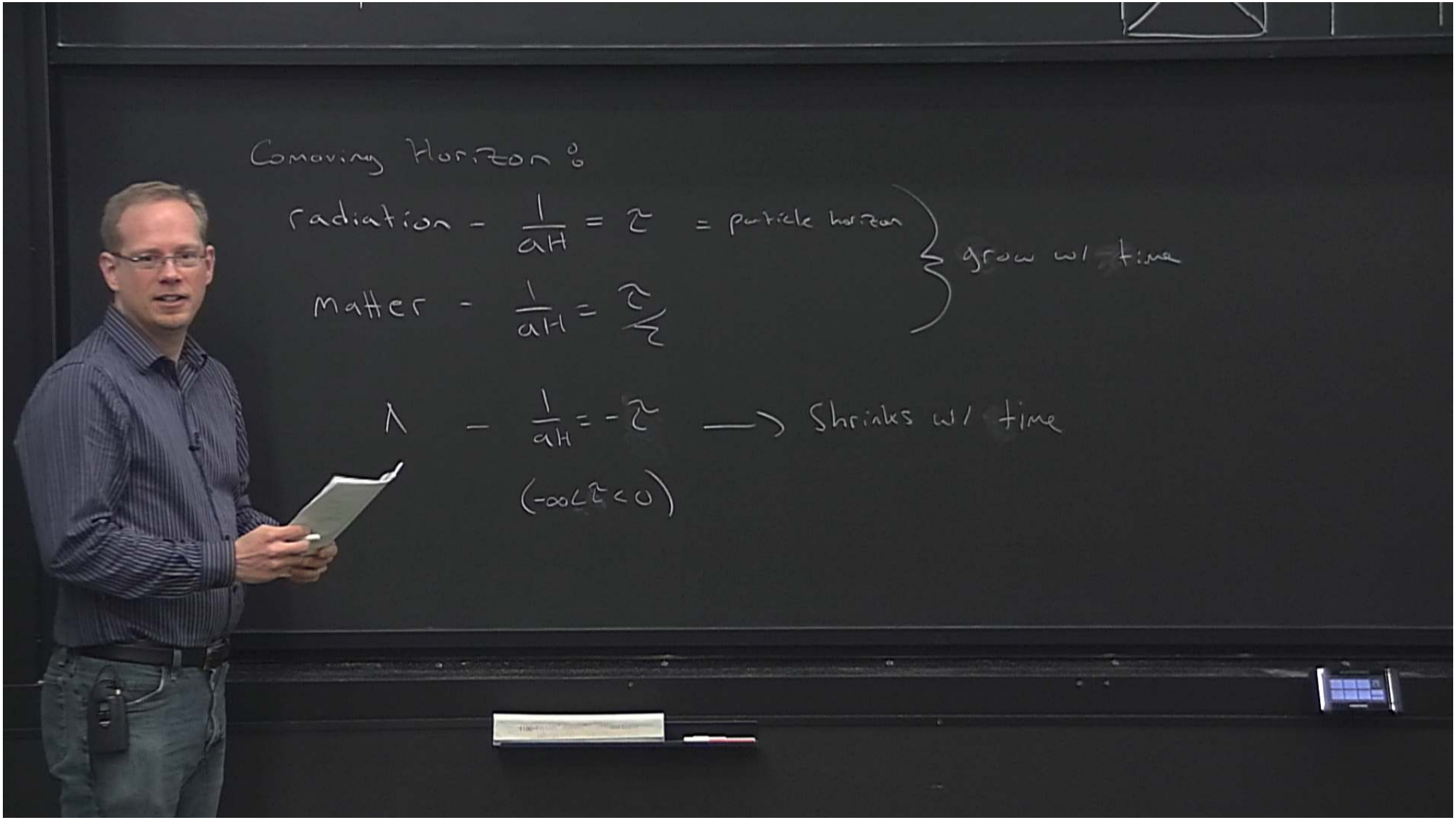
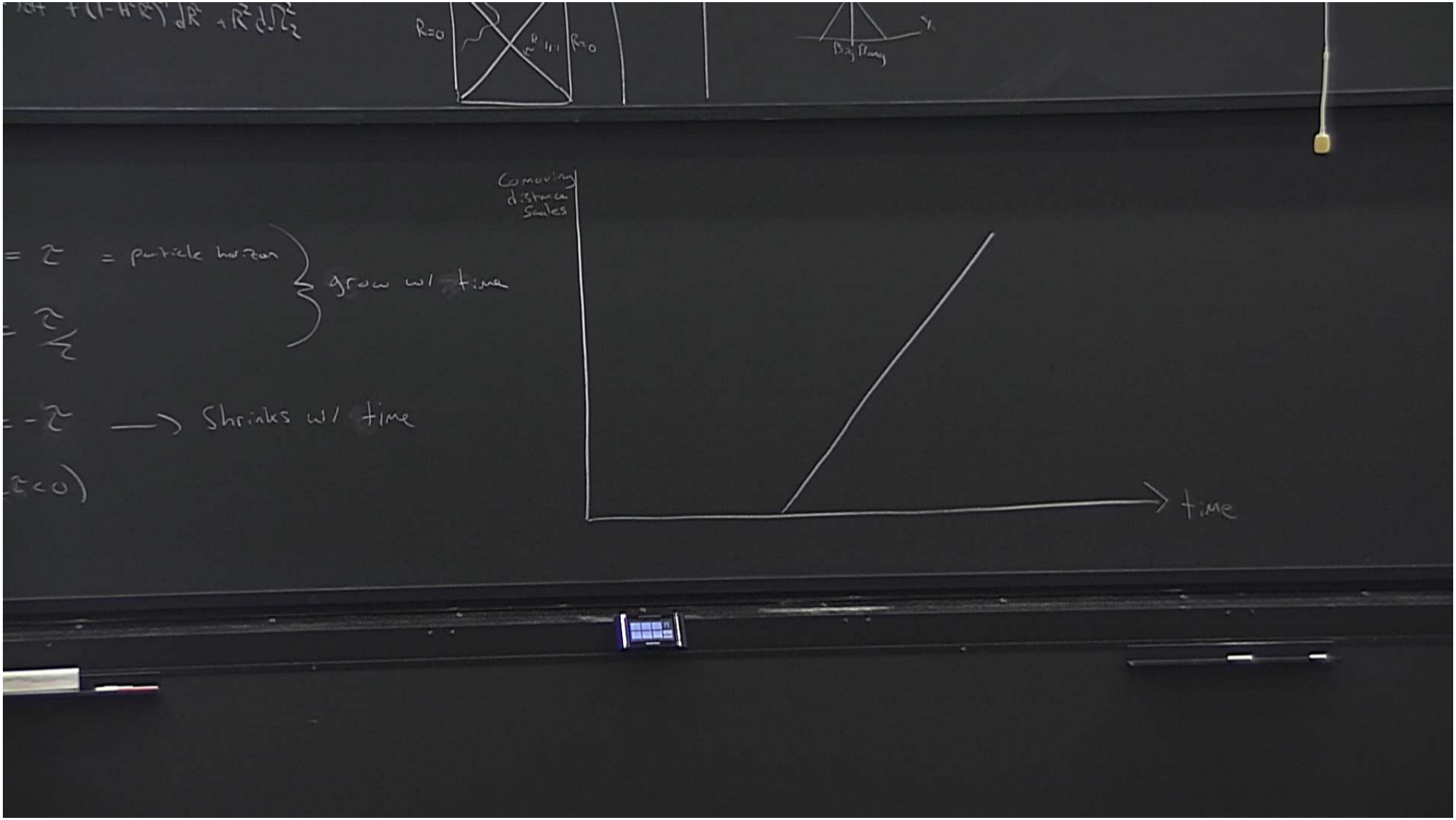
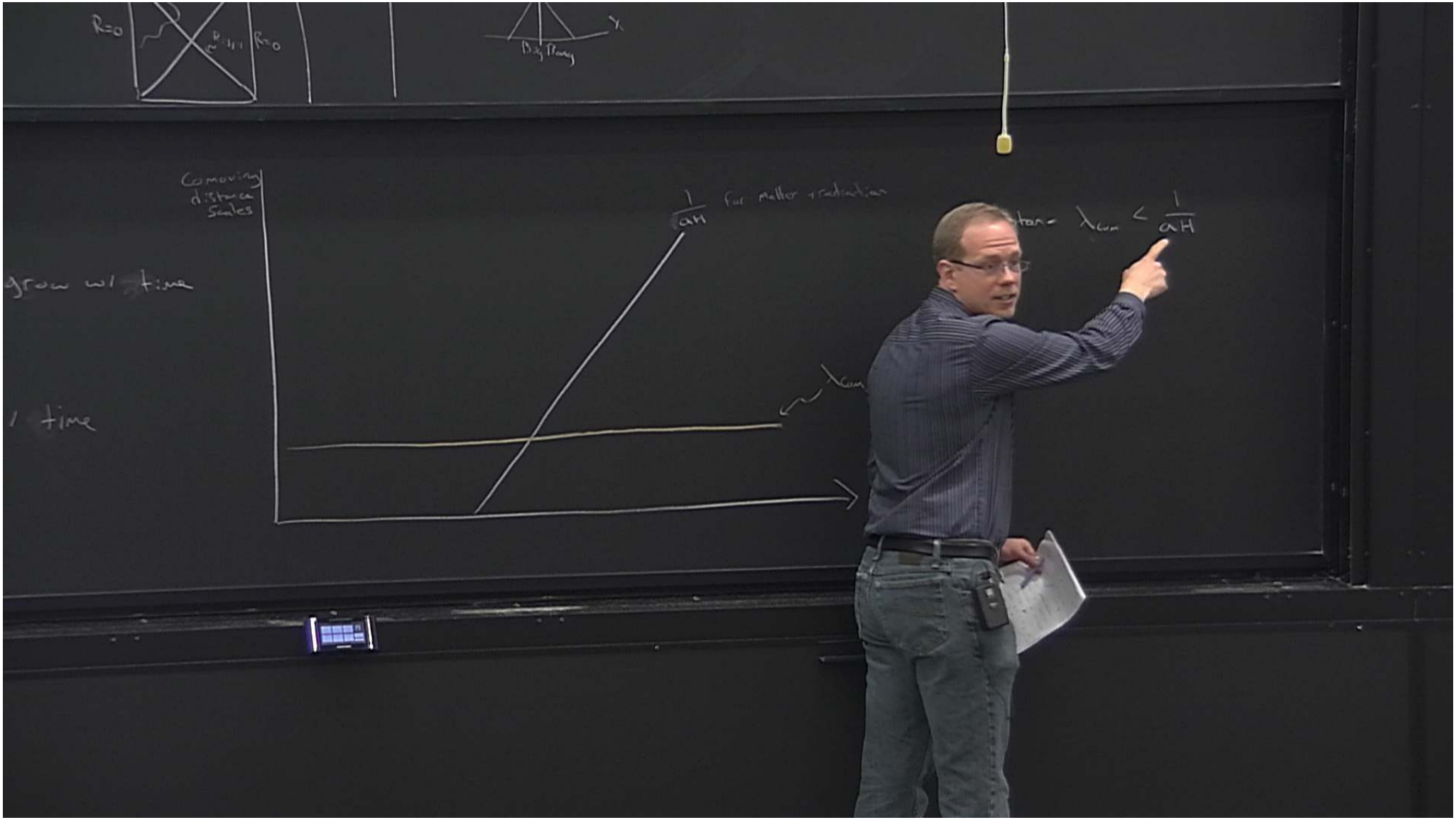
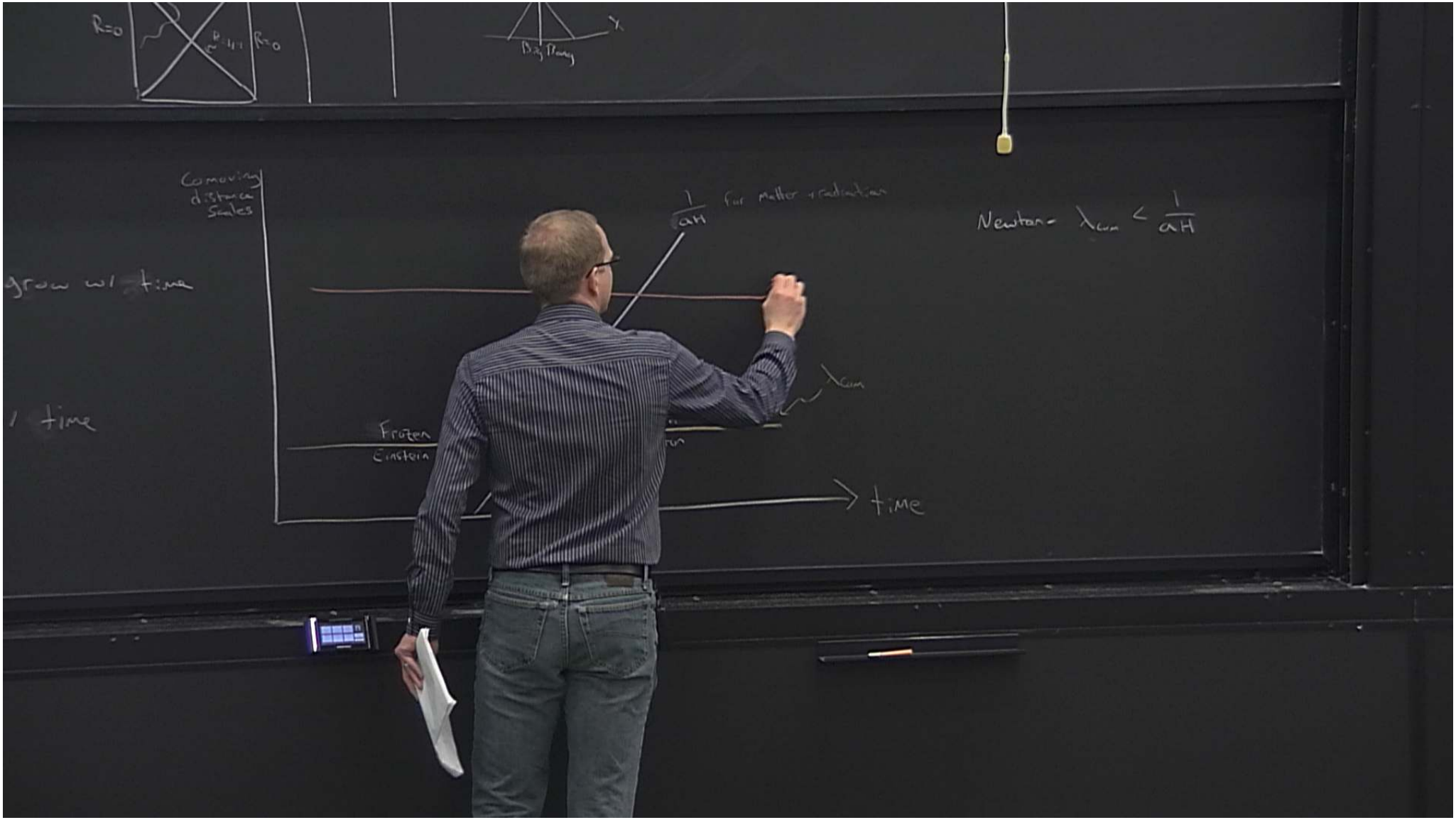
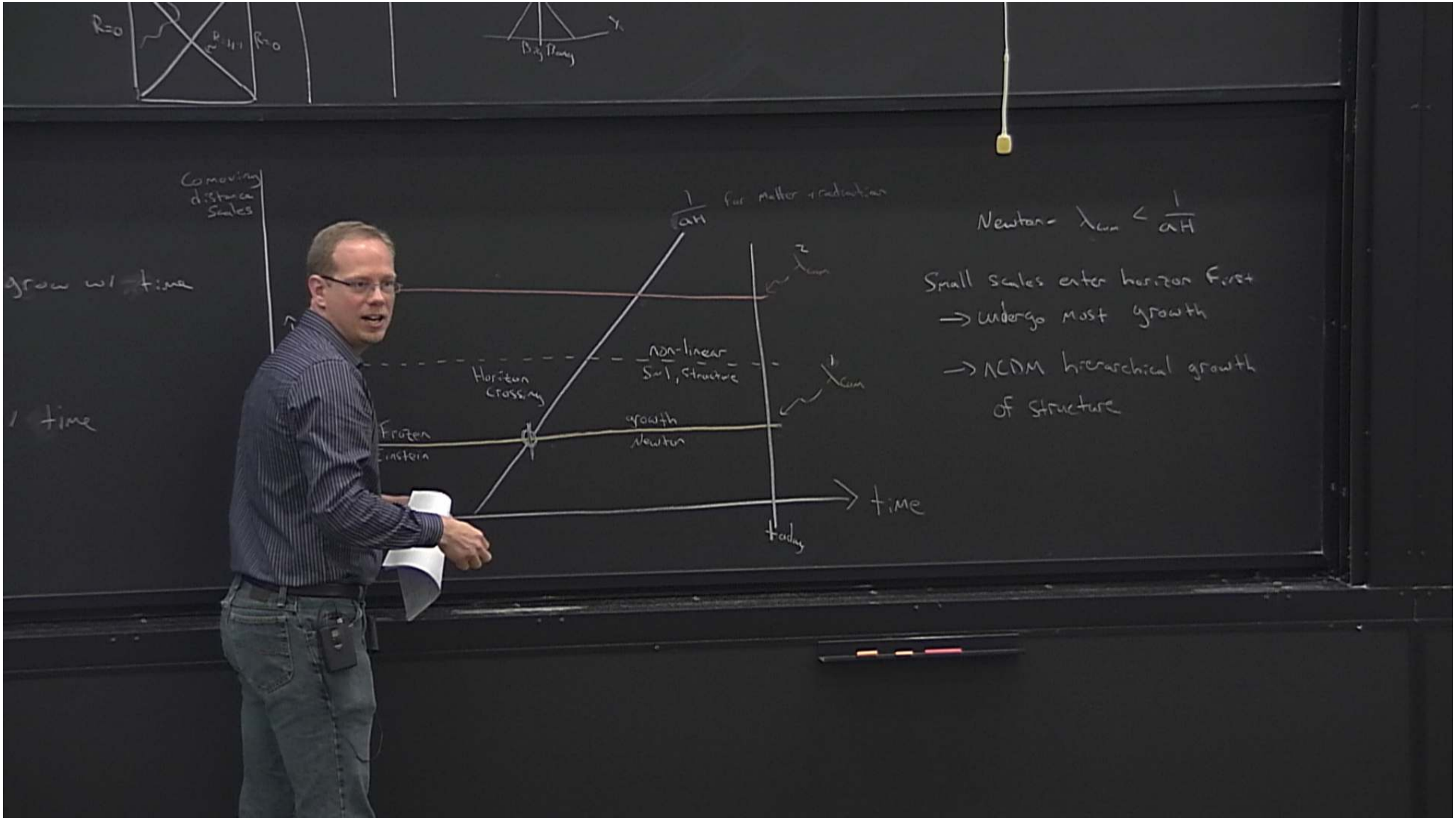
eg. for $\lambda_{com} > \frac{1}{aH}$, Peaks can't causally feel troughs
rticle Horizon - distance light traveled since Big Bang
$= \tau_{el-pol}$
Horizon at H^{-1}
$R=0$
τ
x

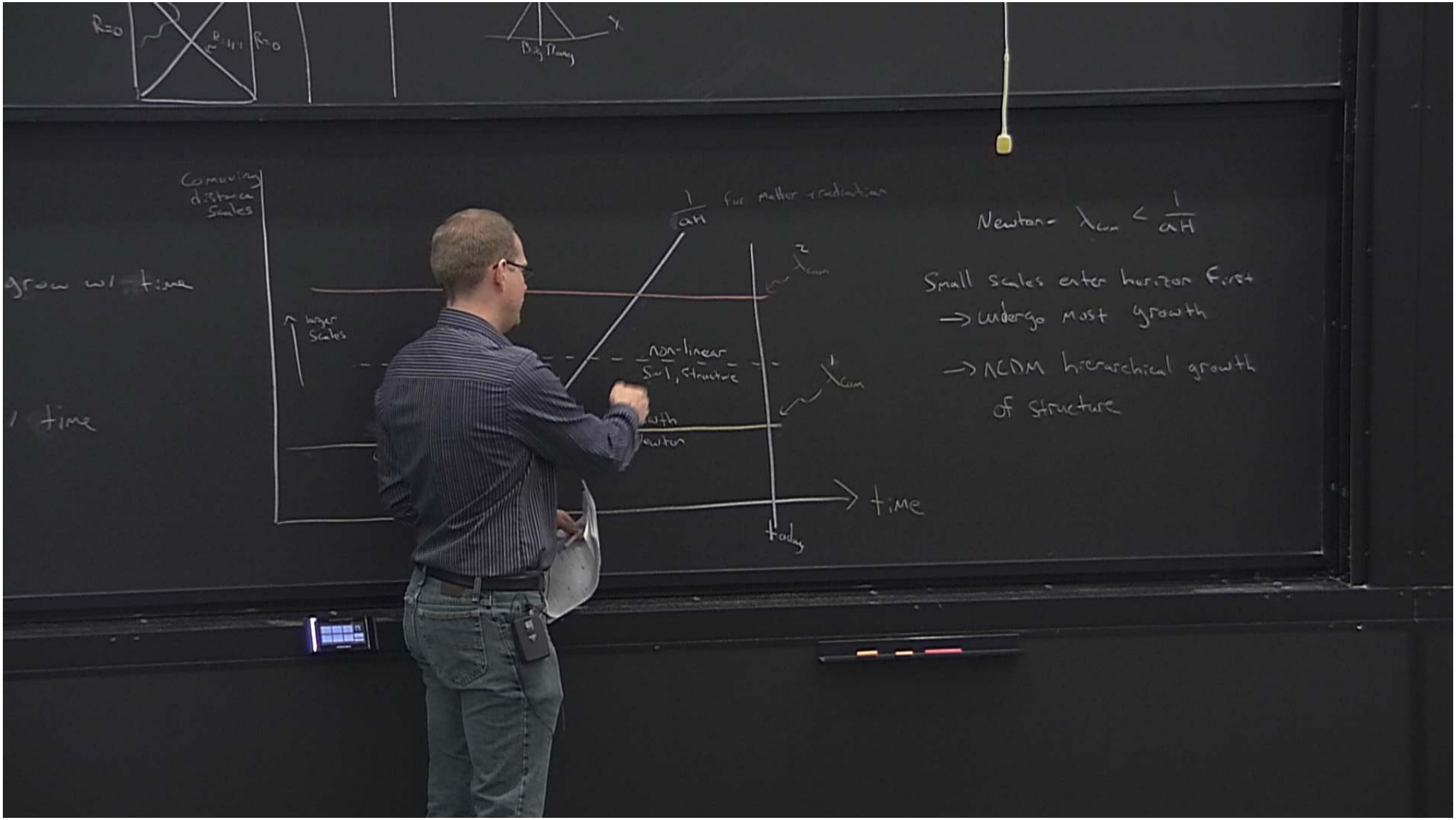

Comoving Horizon:
radiation - $\frac{1}{aH} = \tau$ = particle horizon
matter - $\frac{1}{aH} = \frac{\tau}{2}$
grow w/ time
Λ - $\frac{1}{aH} = -\tau$ ⟶ Shrinks w/ time
$(-\infty < \tau < 0)$

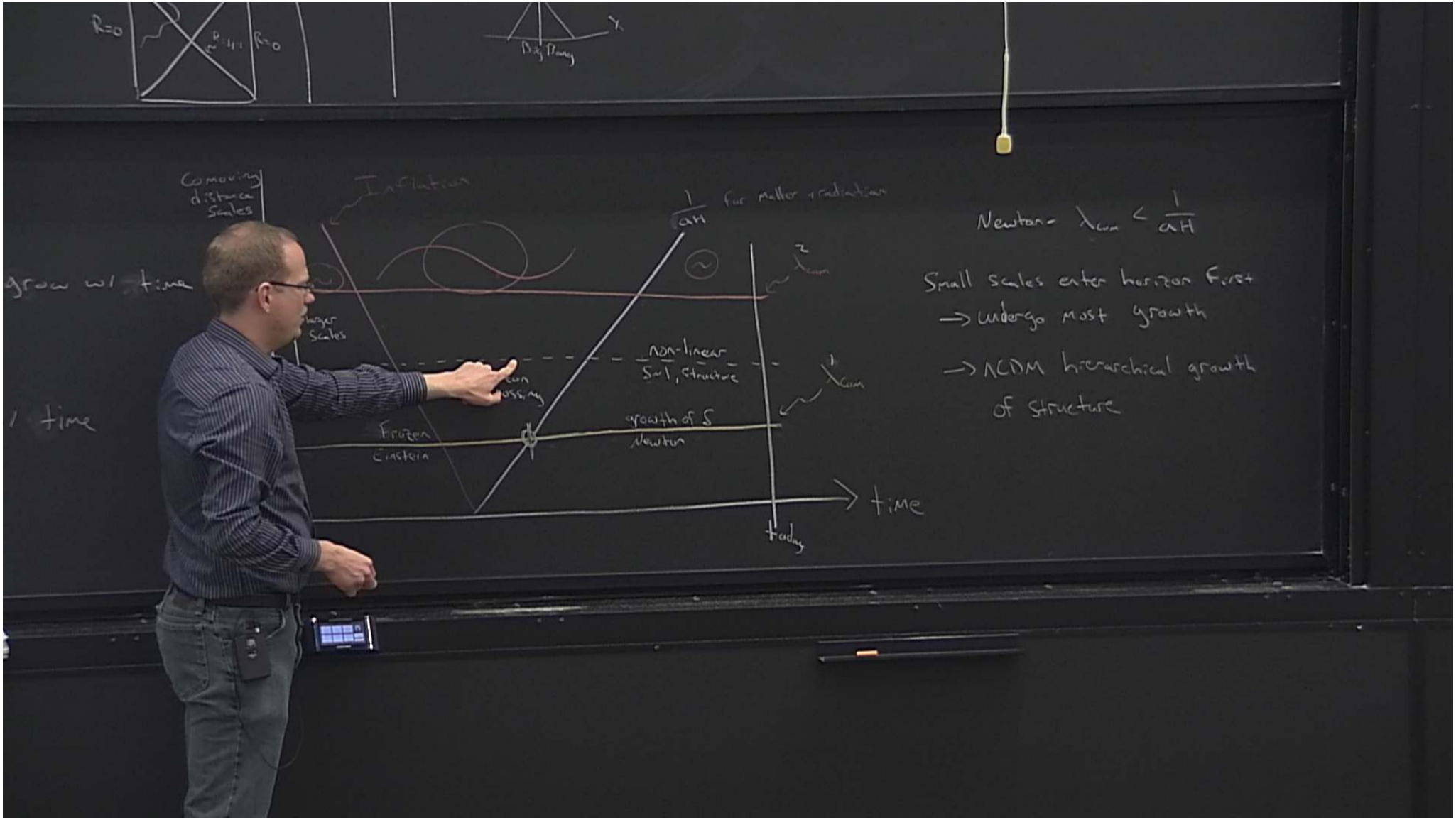

R=0
R=0
Big Bang
Comoving distance scales
= τ = particle horizon
grow w/ time
= τ/2
= -τ → Shrinks w/ time
(τ<0)
time

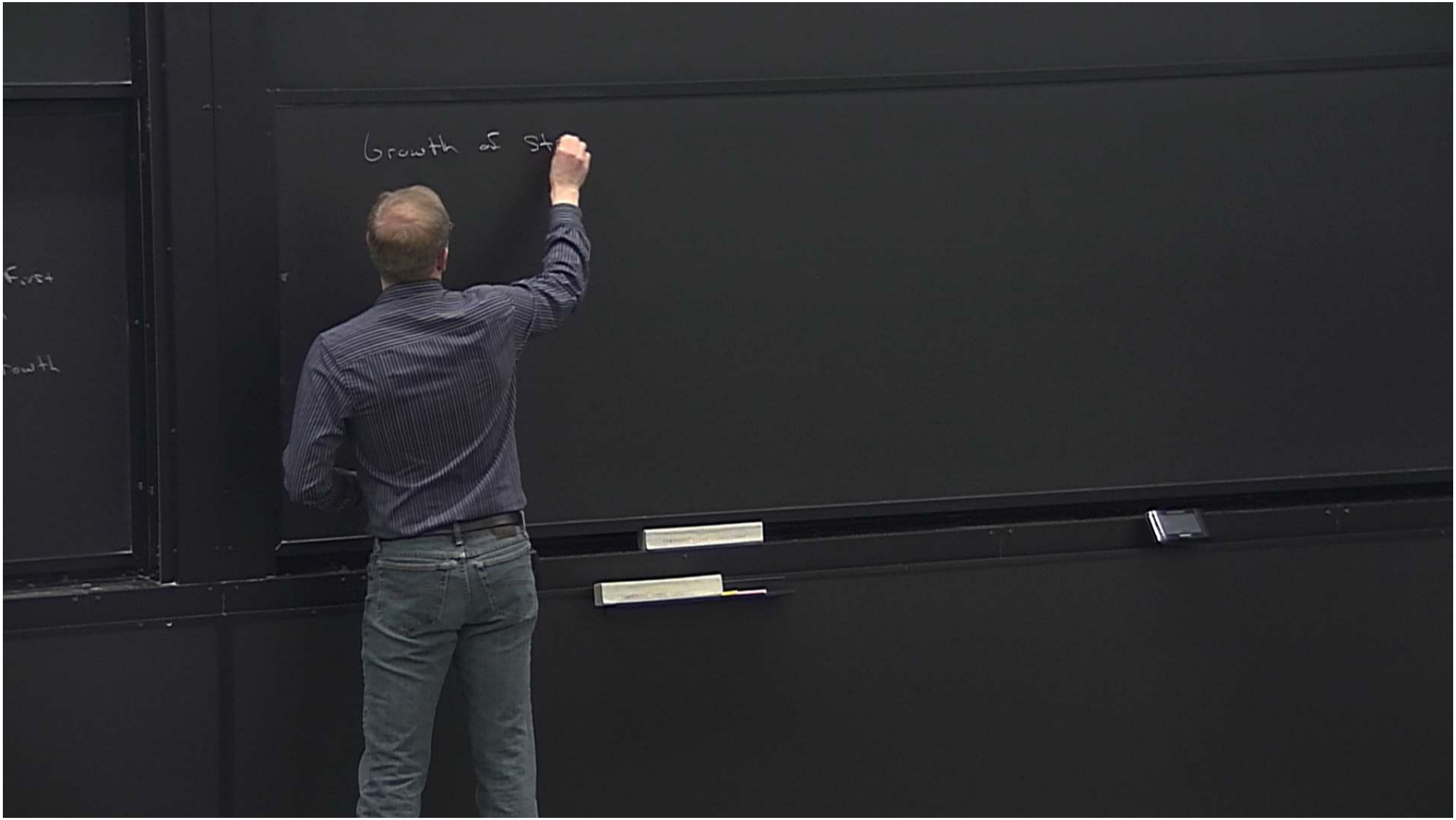

R=0
R=0
Big Bang
Comoving distance Scales
grow w/ time
/ time
1/aH for matter + radiation
λcom < 1/aH

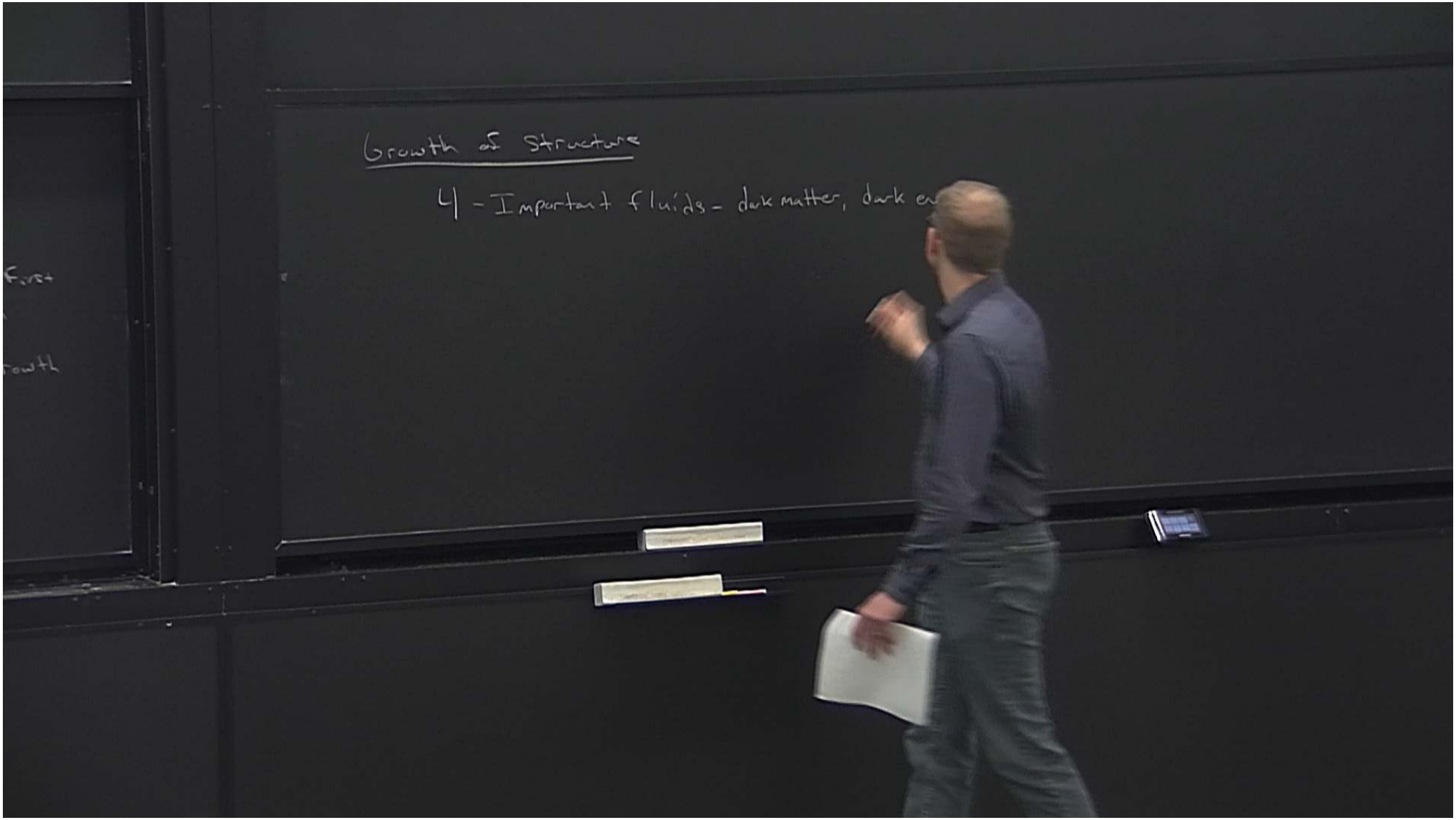

R=0
R=0
Big Bang
Comoving distance Scales
grow w/ time
time
Frozen
Einstein
time
for matter + radiation
Newton - $\lambda_{com} < \frac{1}{aH}$
λ_{com}

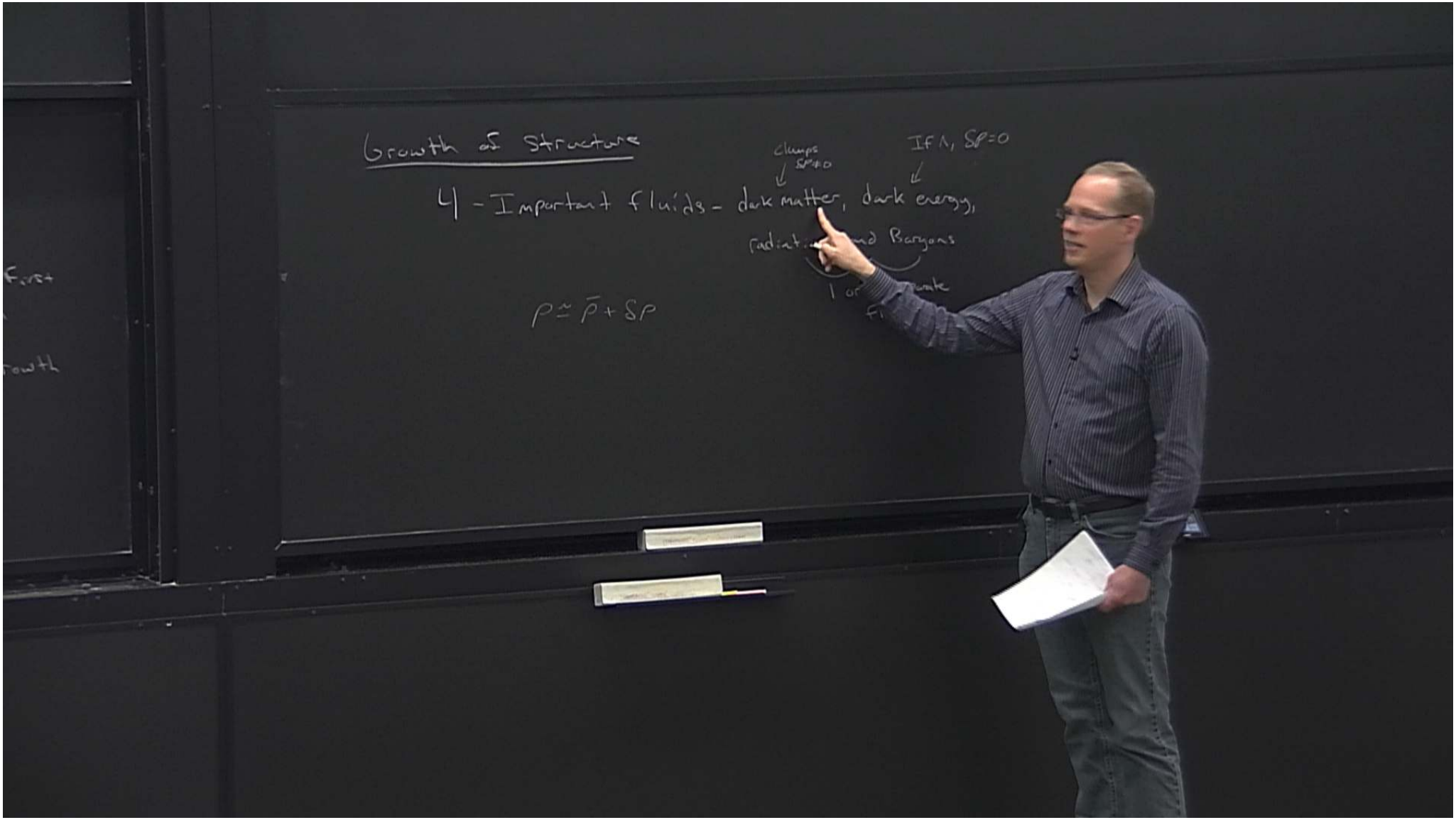

Comoving distance Scales
grow w/ time
time
Big Bang
for matter + radiation
Horizon crossing
non-linear
Frozen
Einstein
growth
Newton
time
today
Newton - $\lambda_{com} < \frac{1}{aH}$
Small scales enter horizon first
→ undergo most growth
→ ΛCDM hierarchical growth of structure

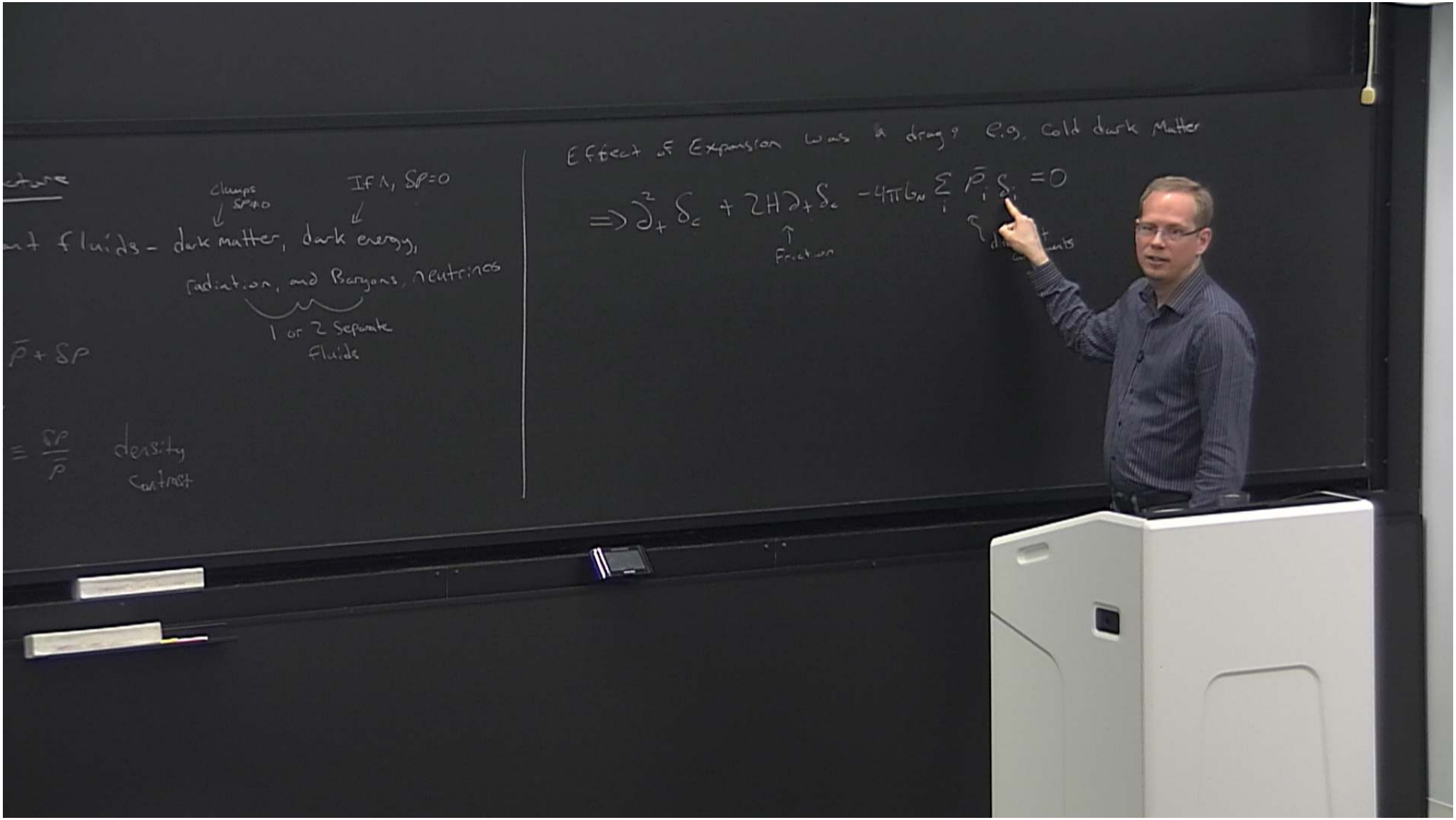

Big Bang
Comoving distance Scales
grow w/ time
larger Scales
time
for matter + radiation
non-linear
S~1, structure
Newton
time
today
Newton - $\lambda_{com} < \frac{1}{aH}$
Small scales enter horizon first
→ undergo most growth
→ ΛCDM hierarchical growth of structure

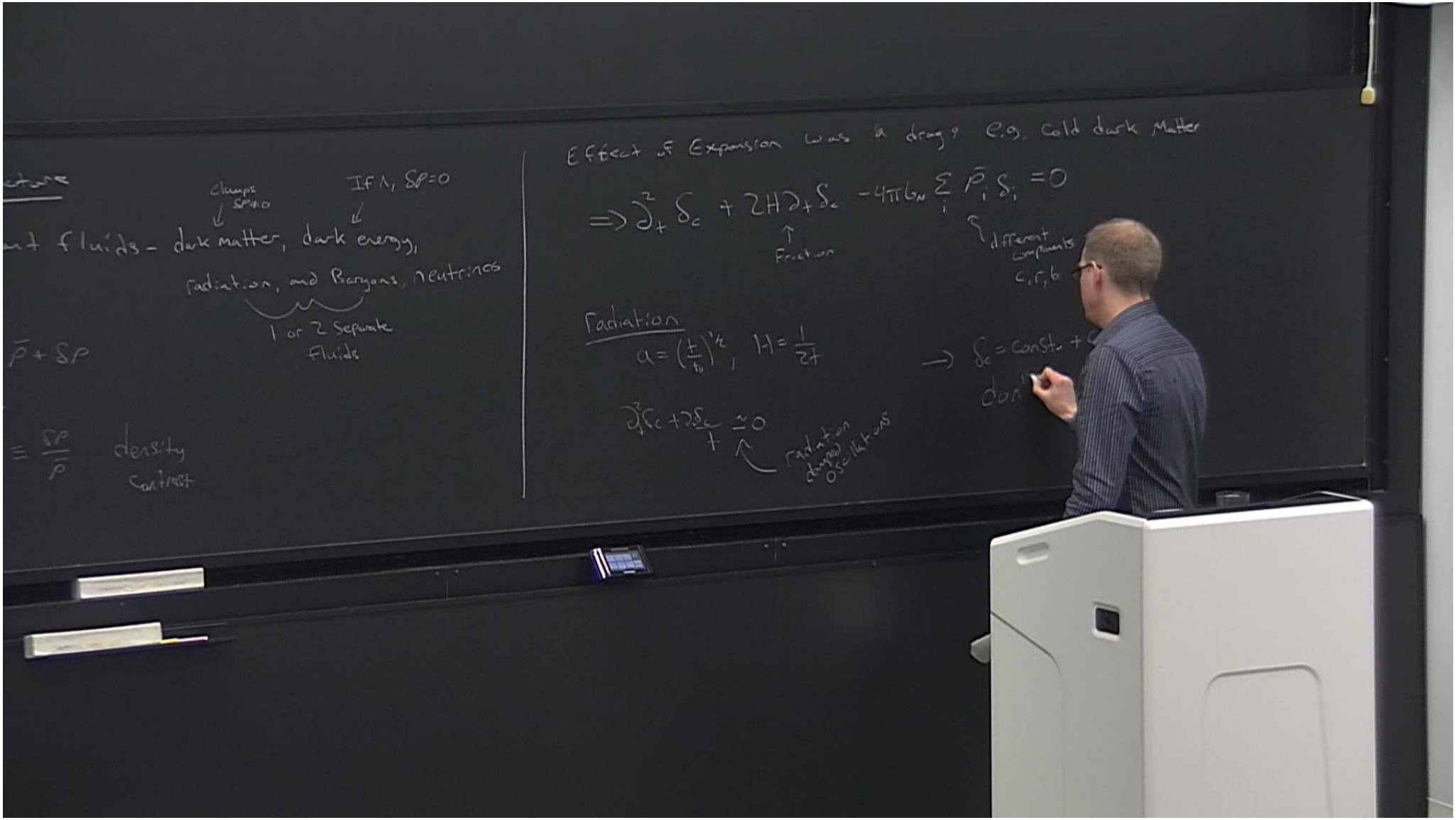

Comoving distance Scales
Inflation
grow w/ time
time
Frozen Einstein
non-linear
growth of δ
Newton
time
today
Newton - $\lambda_{com} < \frac{1}{aH}$
Small scales enter horizon first
→ undergo most growth
→ ΛCDM hierarchical growth of structure

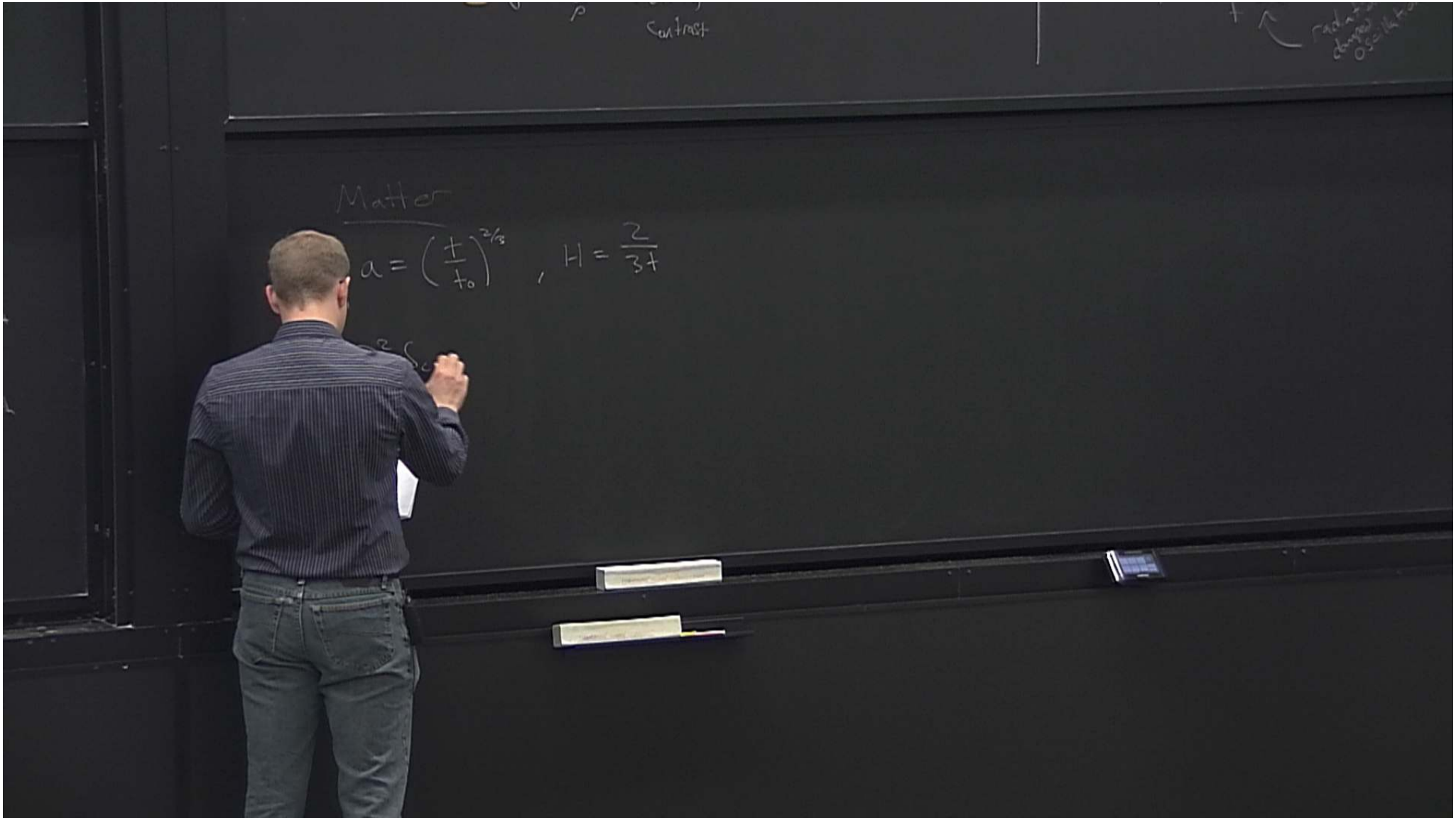

Growth of St

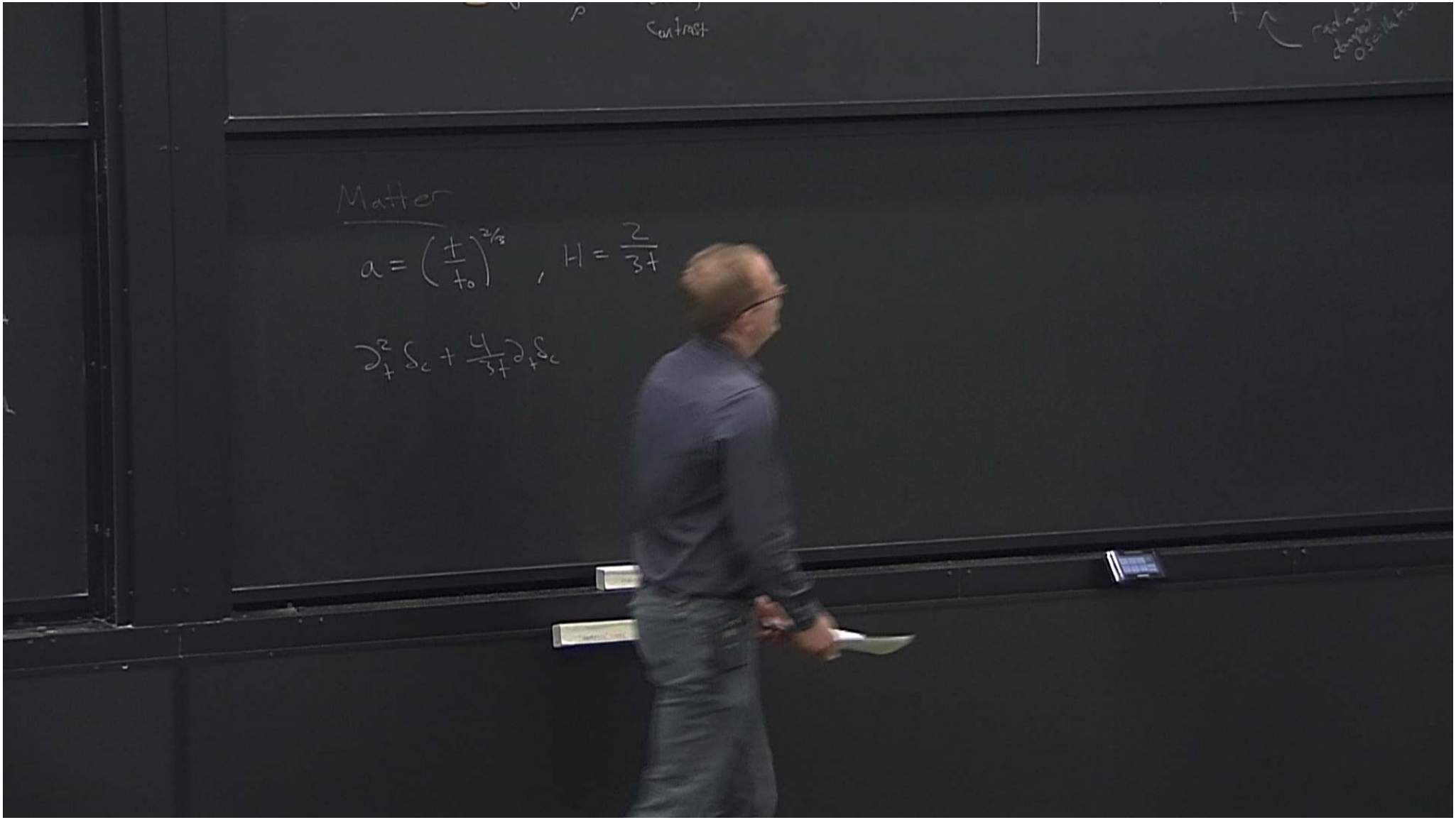

Growth of Structure
4 - Important fluids - dark matter, dark

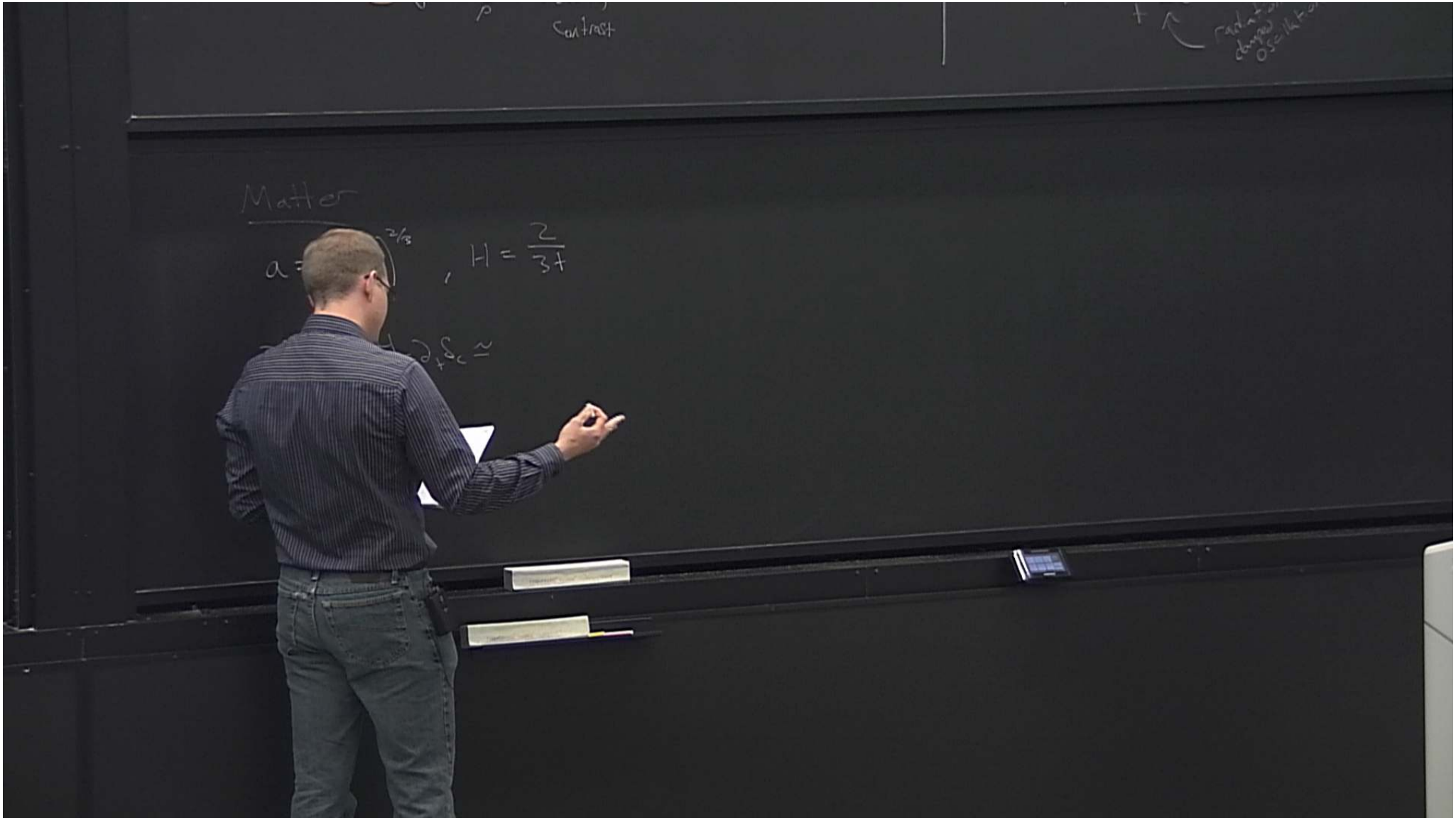

Growth of Structure
4 - Important fluids - dark matter, dark energy,
clumps
IF Λ, δP=0
$\rho \simeq \bar{\rho} + \delta P$

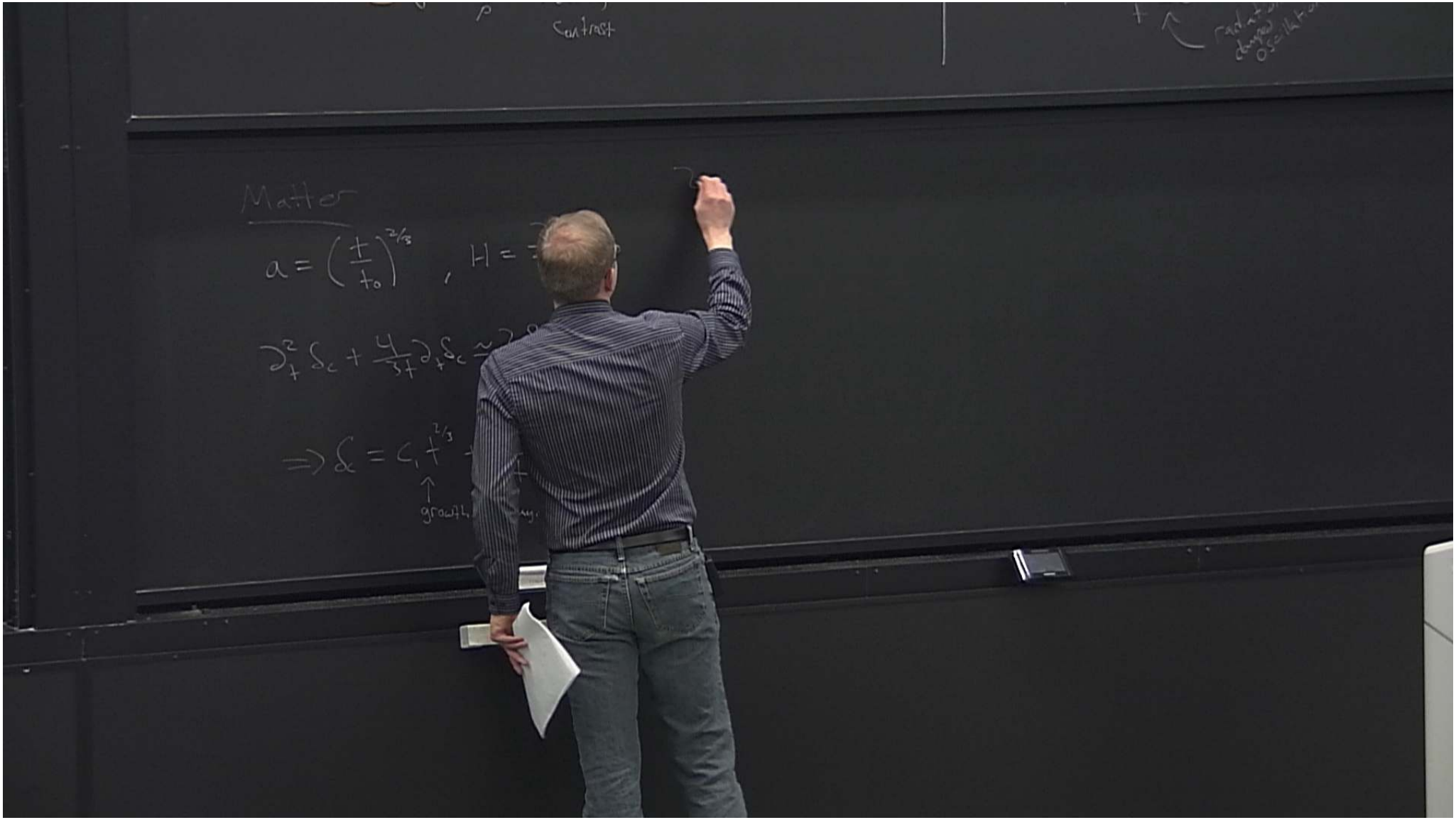

Effect of Expansion Was a drag? e.g. Cold dark Matter
$\Rightarrow \partial_+^2 \delta_c + 2H\partial_+ \delta_c - 4\pi G_N \sum_i \bar{\rho}_i \delta_i = 0$
Friction
Clumps $\delta P \neq 0$
If Λ, $\delta P = 0$
fluids - dark matter, dark energy,
radiation, and Baryons, neutrinos
1 or 2 Separate fluids
$\bar{\rho} + \delta P$
$= \frac{\delta P}{\bar{\rho}}$ density contrast

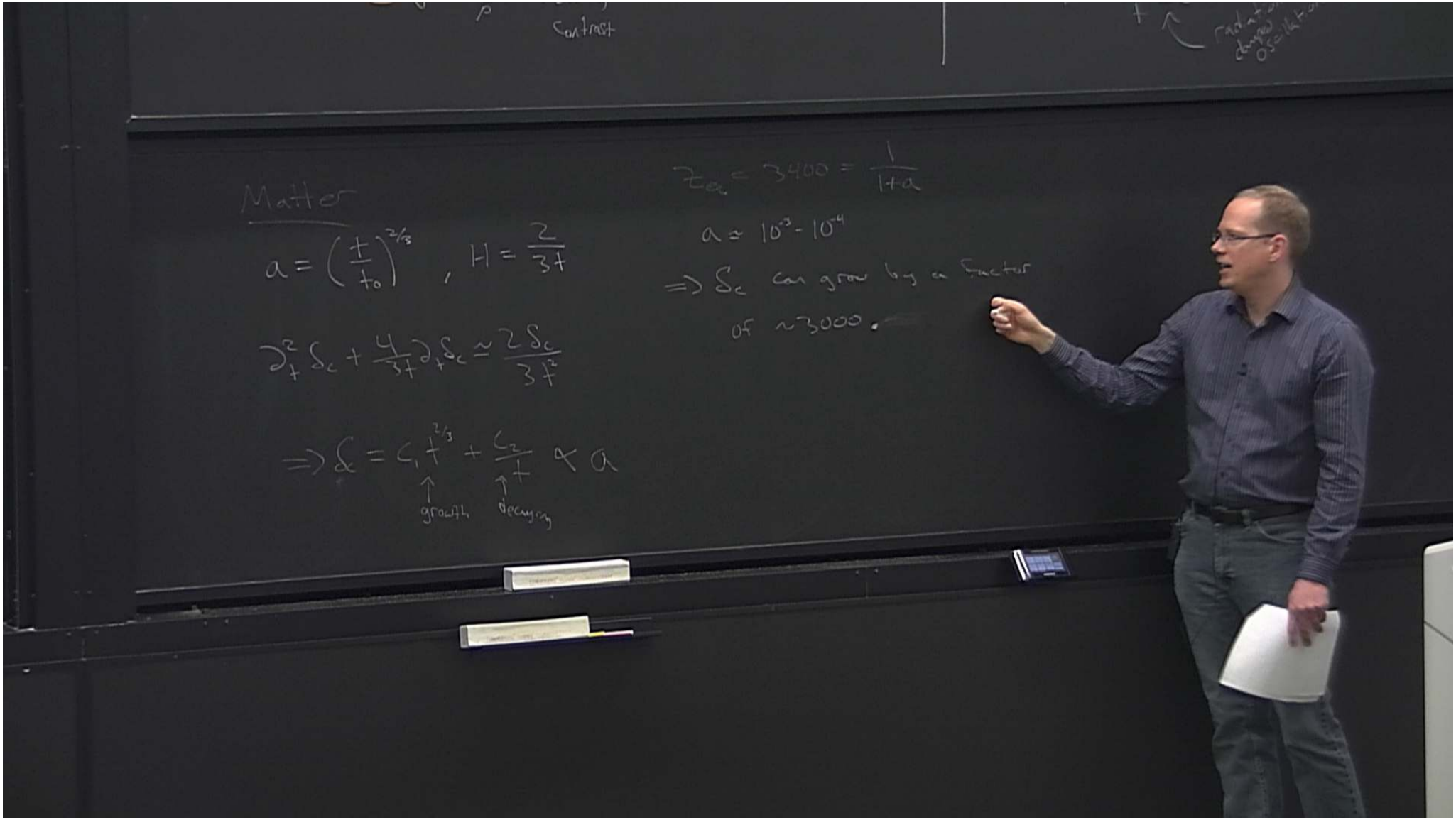

Effect of Expansion was a drag? e.g. Cold dark Matter
clumps δρ≠0
If Λ, δρ=0
fluids - dark matter, dark energy,
radiation, and Baryons, neutrinos
1 or 2 Separate fluids
density contrast
Friction
different components
c, r, b
radiation
radiation damped oscillations

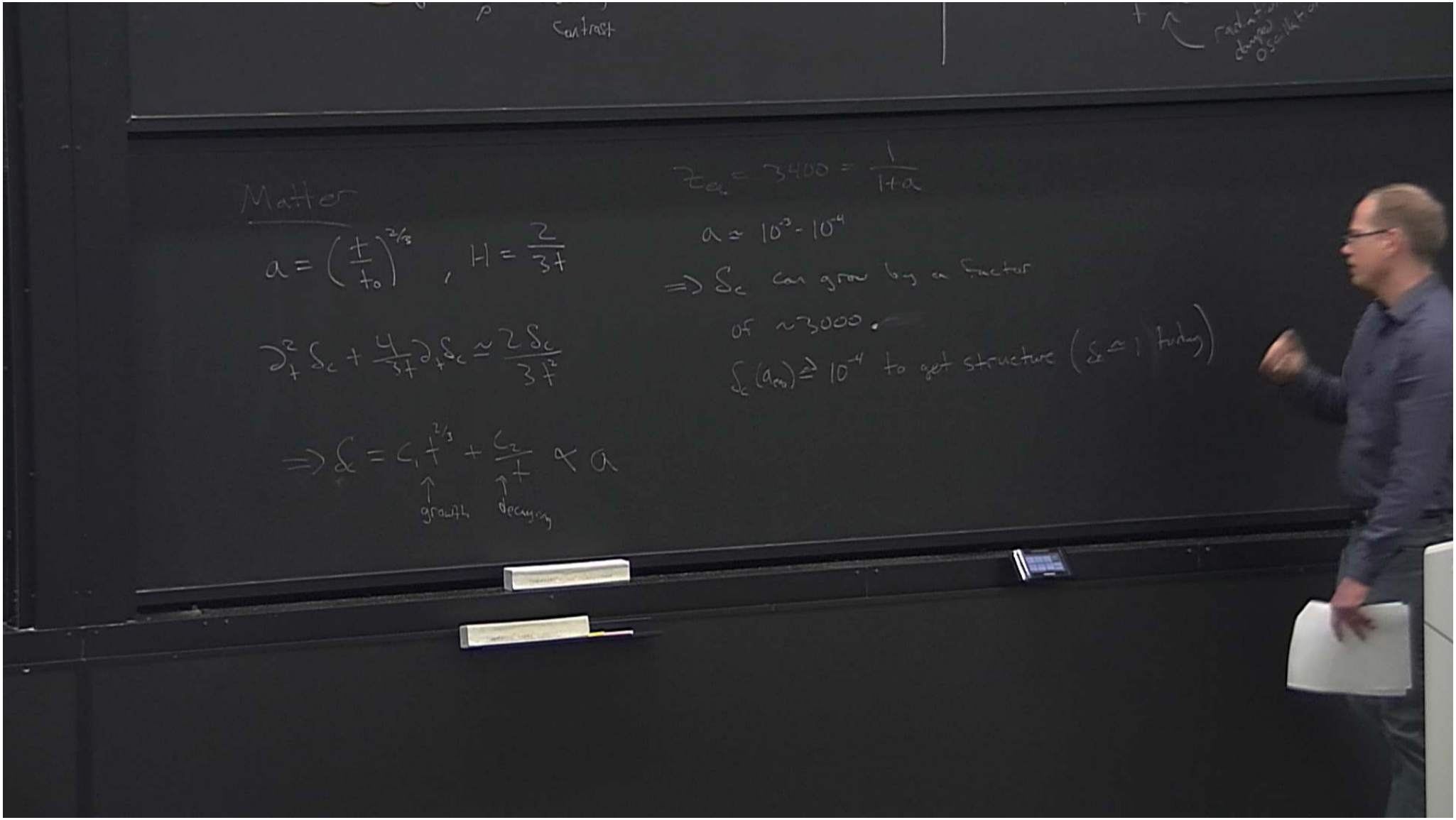

Contrast
Matter
$a = \left(\frac{t}{t_0}\right)^{2/3}$, $H = \frac{2}{3t}$


Contrast
Matter
$a = \left(\frac{t}{t_0}\right)^{2/3}$, $H = \frac{2}{3t}$
$\partial_t^2 \delta_c + \frac{4}{3t}\partial_t \delta_c$


Contrast
Matter
$H = \frac{2}{3t}$


Contrast
Matter
$a = \left(\frac{t}{t_0}\right)^{2/3}$
$\partial_t^2 \delta_c + \frac{4}{3t}\partial_t \delta_c \approx$
$\Rightarrow \delta = C_1 t^{2/3}$
growth


Contrast
Matter
$a = \left(\frac{t}{t_0}\right)^{2/3}$, $H = \frac{2}{3t}$
$\partial_t^2 \delta_c + \frac{4}{3t}\partial_t \delta_c \simeq \frac{2\delta_c}{3t^2}$
$\Rightarrow \delta = c_1 t^{2/3} + \frac{c_2}{t} \propto a$
growth
decaying
$z_{eq} = 3400 = \frac{1}{1+a}$
$a \simeq 10^{-3} - 10^{-4}$
$\Rightarrow \delta_c$ can grow by a factor
of ~3000.


Contrast
Matter
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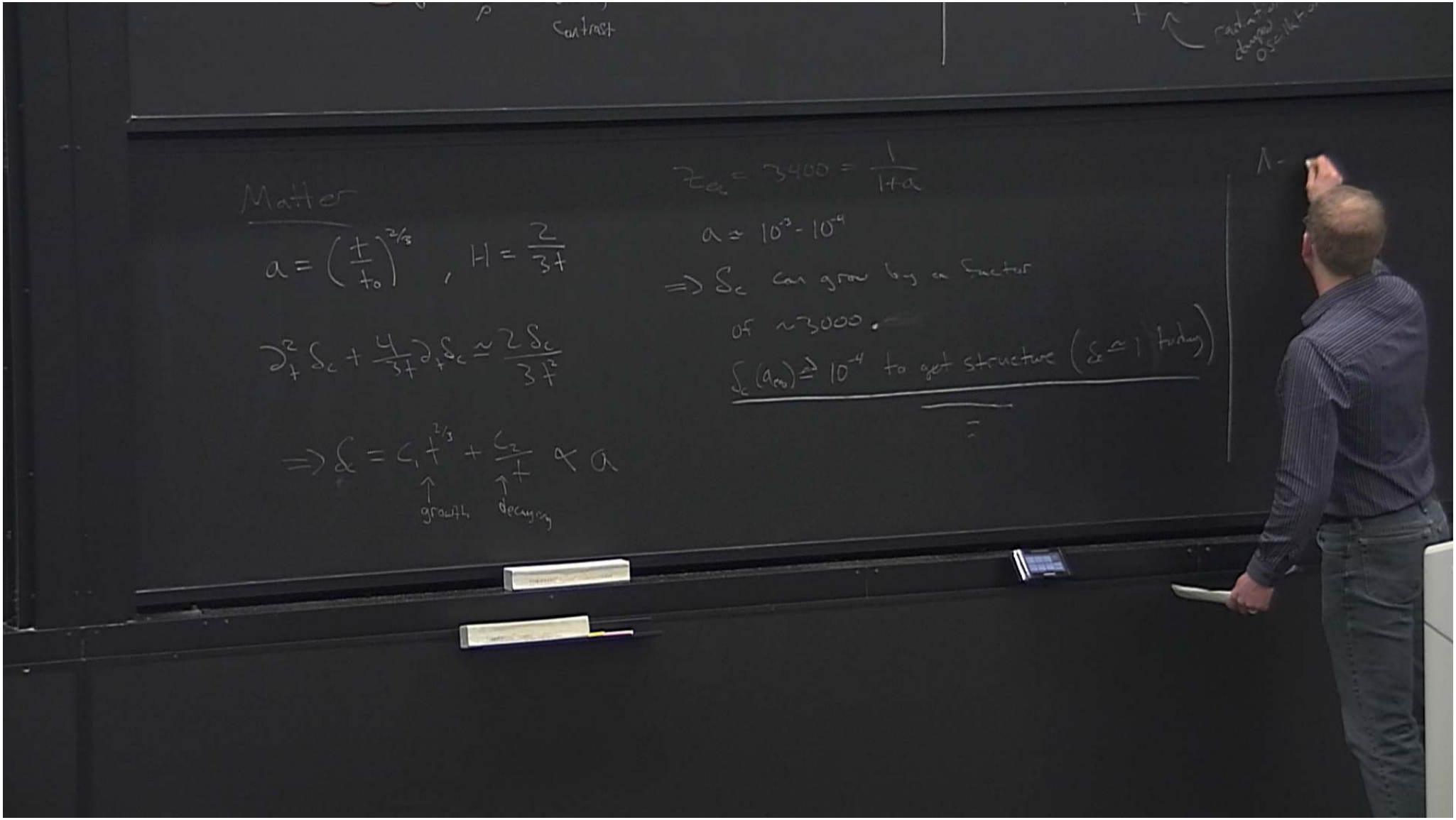
growth
decaying
$z_{eq} = 3400 = \frac{1}{1+a}$
$a \simeq 10^{-3} - 10^{-4}$
$\Rightarrow \delta_c$ can grow by a factor
of ~3000.
$\delta_c(a_{eq}) \geq 10^{-4}$ to get structure ($\delta_c \simeq 1$ today)


Contrast
radiation damped Oscillations
Matter
$a = \left(\frac{t}{t_0}\right)^{2/3}$, $H = \frac{2}{3t}$
$\partial_t^2 \delta_c + \frac{4}{3t}\partial_t \delta_c \simeq \frac{2\delta_c}{3t^2}$
$\Rightarrow \delta = C_1 t^{2/3} + \frac{C_2}{t} \propto a$
growth
decaying
$z_{eq} = 3400 = \frac{1}{1+a}$
$a \simeq 10^{-3} - 10^{-4}$
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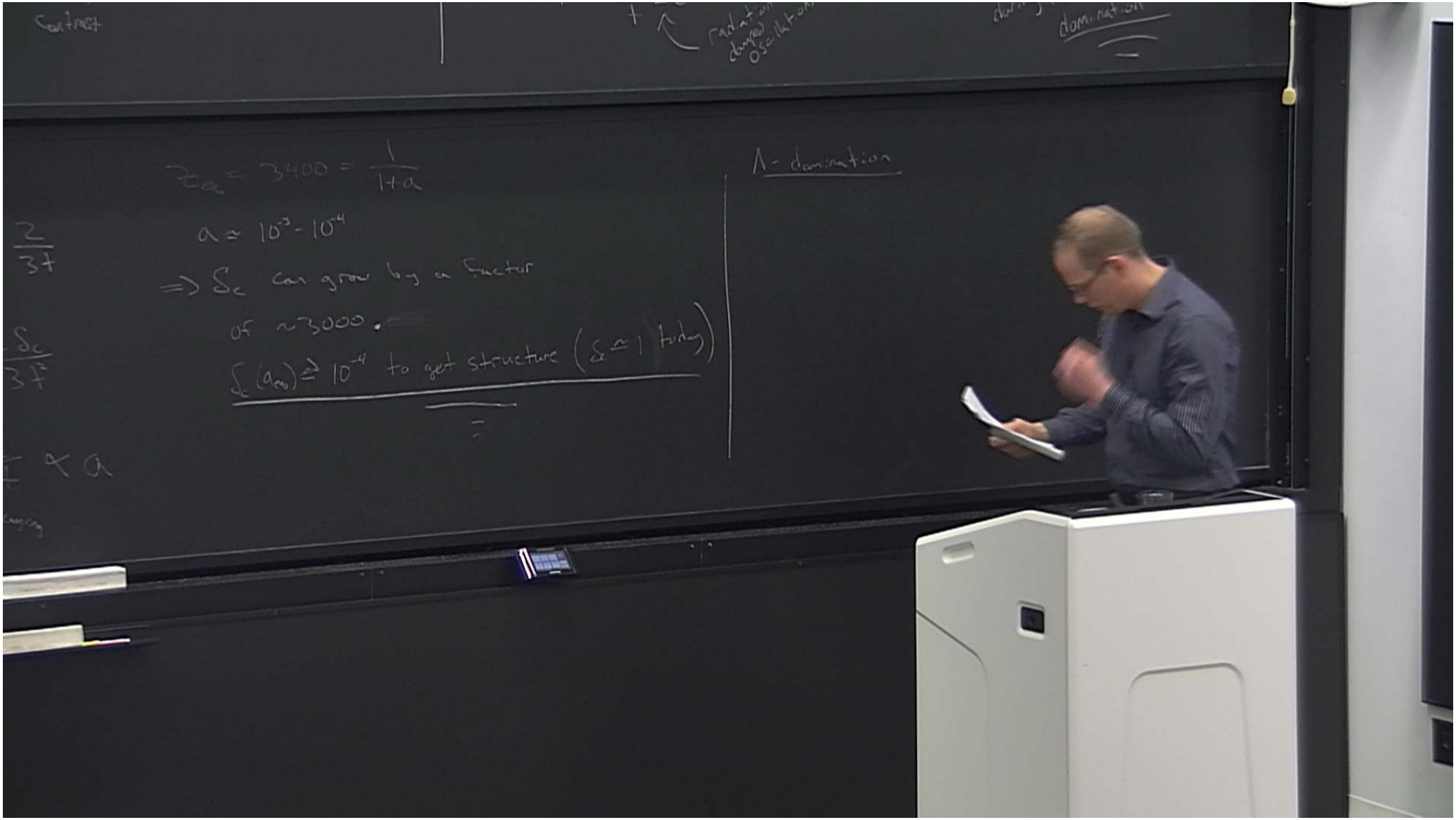
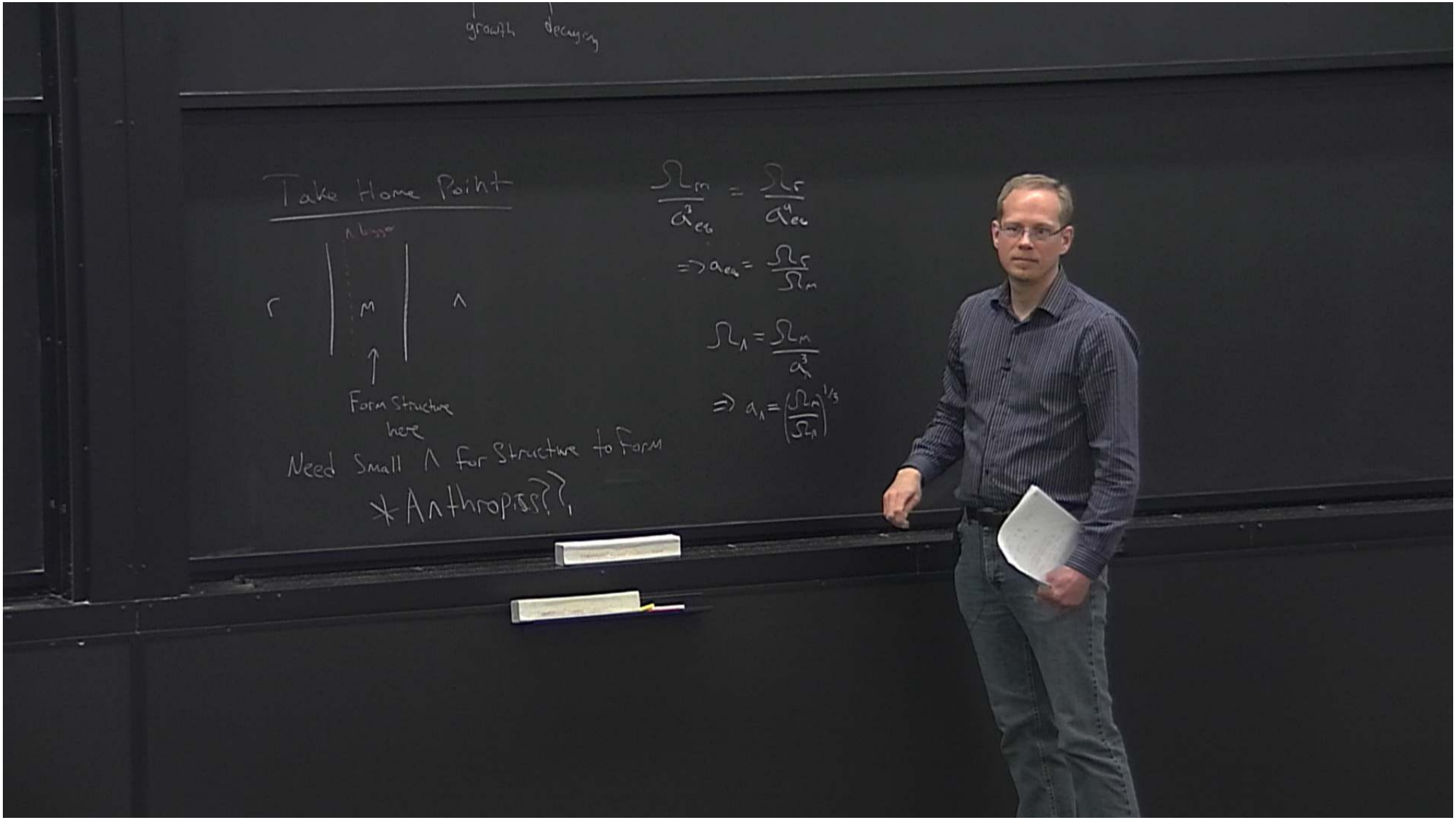
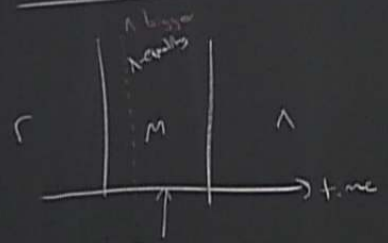
$\delta_c(a_{eq}) \geq 10^{-4}$ to get structure ($\delta \simeq 1$ today)
Λ-


Contrast
radiation
damped
oscillation
domination
$z_{eq} = 3400 = \frac{1}{1+a}$
$a \simeq 10^{-3} - 10^{-4}$
$\Rightarrow \delta_c$ can grow by a factor
of ~3000.
$\delta_c(a_{eq}) \simeq 10^{-4}$ to get structure ($\delta_c \simeq 1$ today)
Λ- domination
$\frac{2}{3t}$
$\frac{\delta_c}{3t^2}$
$\propto a$


growth
decay
Take Home Point
$\frac{\Omega_m}{a_{eq}^3} = \frac{\Omega_r}{a_{eq}^4}$
$\Rightarrow a_{eq} = \frac{\Omega_r}{\Omega_m}$
$\Omega_\Lambda = \frac{\Omega_m}{a^3}$
$\Rightarrow a_\Lambda = \left(\frac{\Omega_\Lambda}{\Omega_\Lambda}\right)^{1/3}$
r
M
Λ
Form Structure here
Need Small Λ for Structure to Form
*Anthropics??

growth decaying

Take Home Point



$$\frac{\Omega_m}{a_{eq}^3} = \frac{\Omega_r}{a_{eq}^4}$$

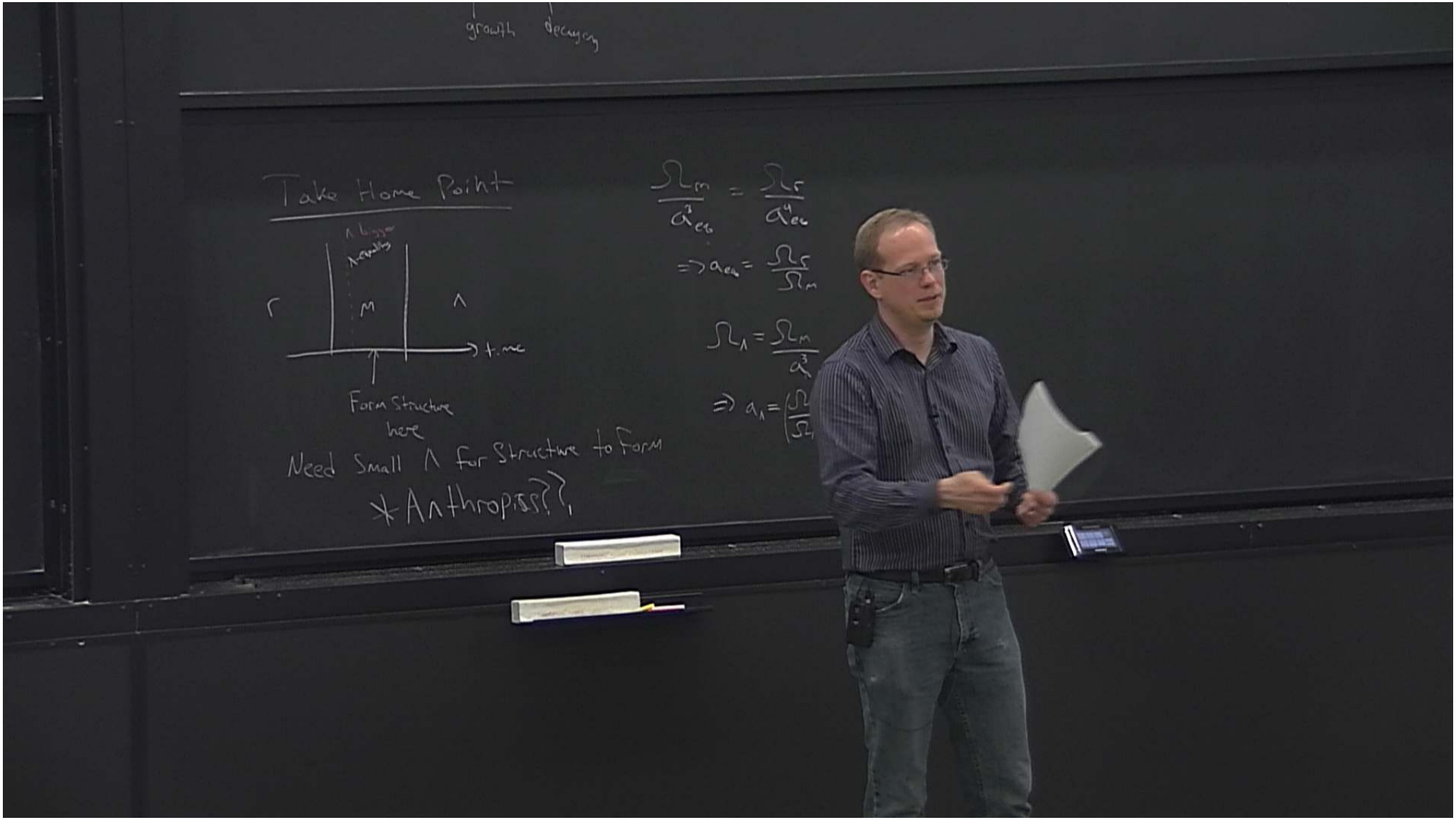
$$\Rightarrow a_{eq} = \frac{\Omega_r}{\Omega_m}$$

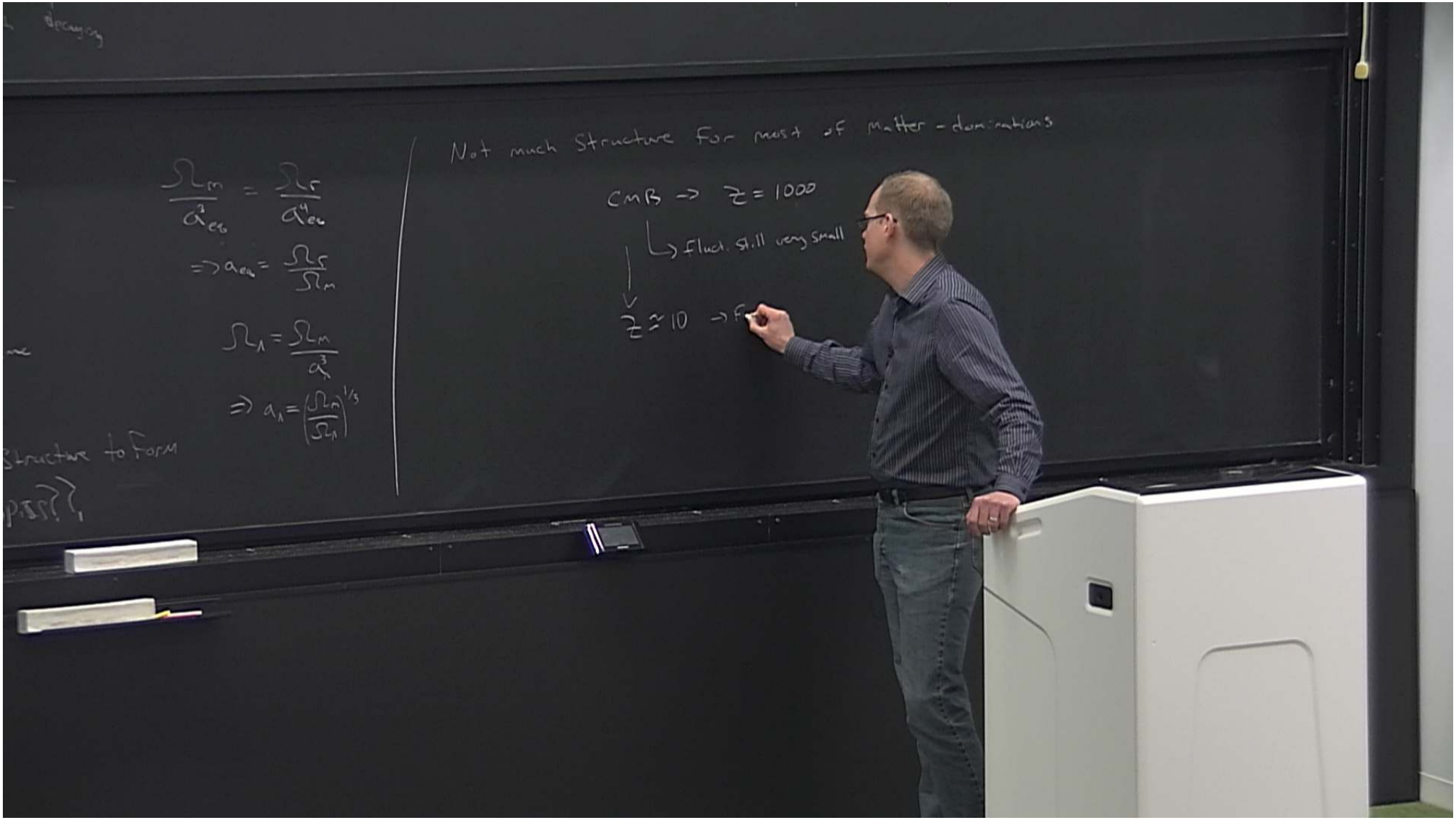
$$\Omega_\Lambda = \frac{\Omega_m}{a_\Lambda^3}$$

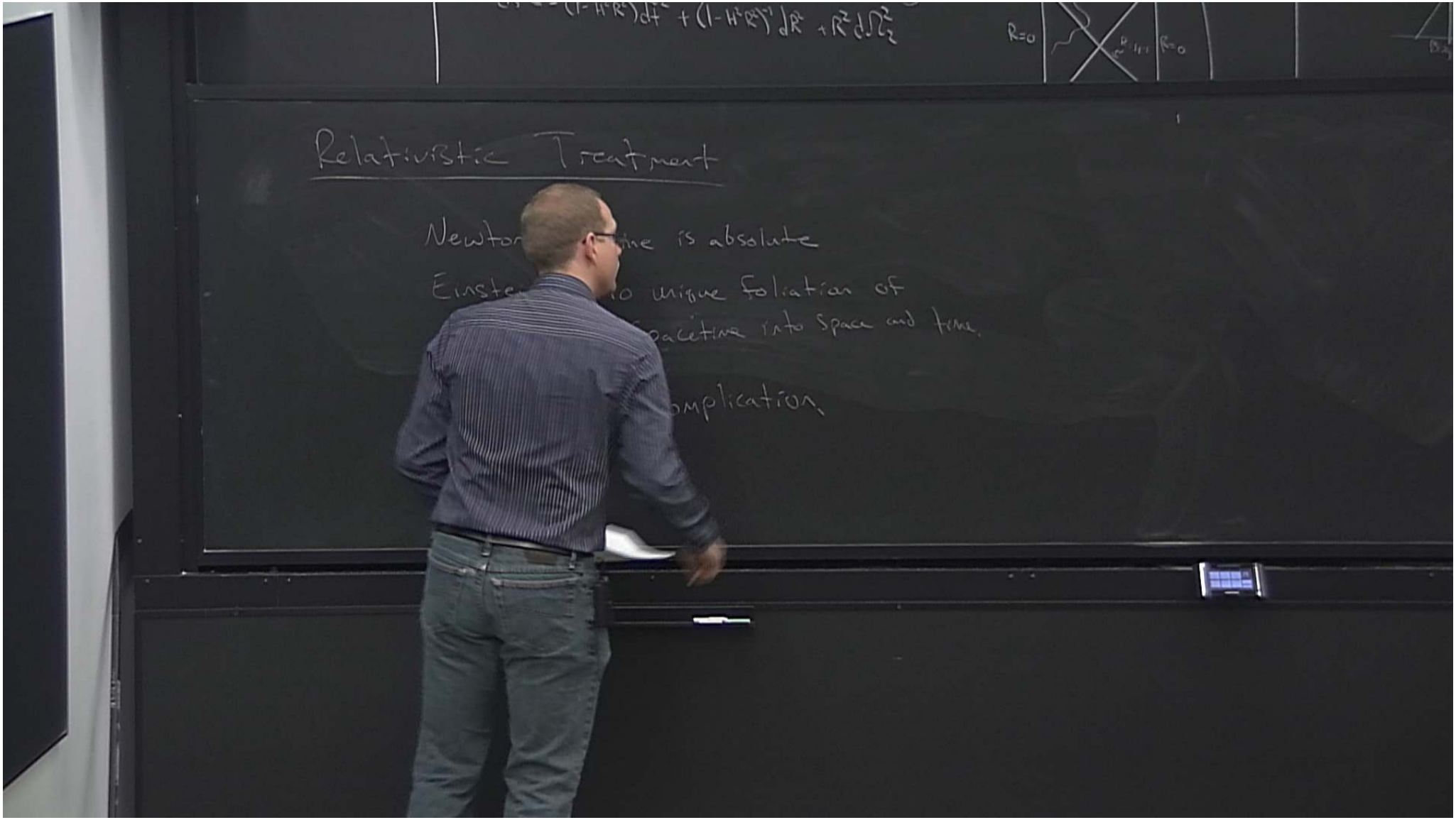
$$\Rightarrow a_\Lambda = \left(\frac{\Omega_m}{\Omega_\Lambda}\right)^{1/3}$$

Need Small Λ for Structure to Form

*Anthropics??


growth
decaying
Take Home Point
Λ begins dominating
r
M
Λ
time
Form Structure here
Need Small Λ for Structure to Form
*Anthropic??
$\frac{\Omega_m}{a_{eq}^3} = \frac{\Omega_r}{a_{eq}^4}$
$\Rightarrow a_{eq} = \frac{\Omega_r}{\Omega_m}$
$\Omega_\Lambda = \frac{\Omega_m}{a^3}$
$\Rightarrow a_\Lambda = \frac{\Omega_m}{\Omega_\Lambda}$


Not much Structure for most of matter-dominations
CMB -> z = 1000
fluct. still very small
z ≈ 10


Relativistic Treatment
is absolute
unique foliation of
into space and time.
R=0