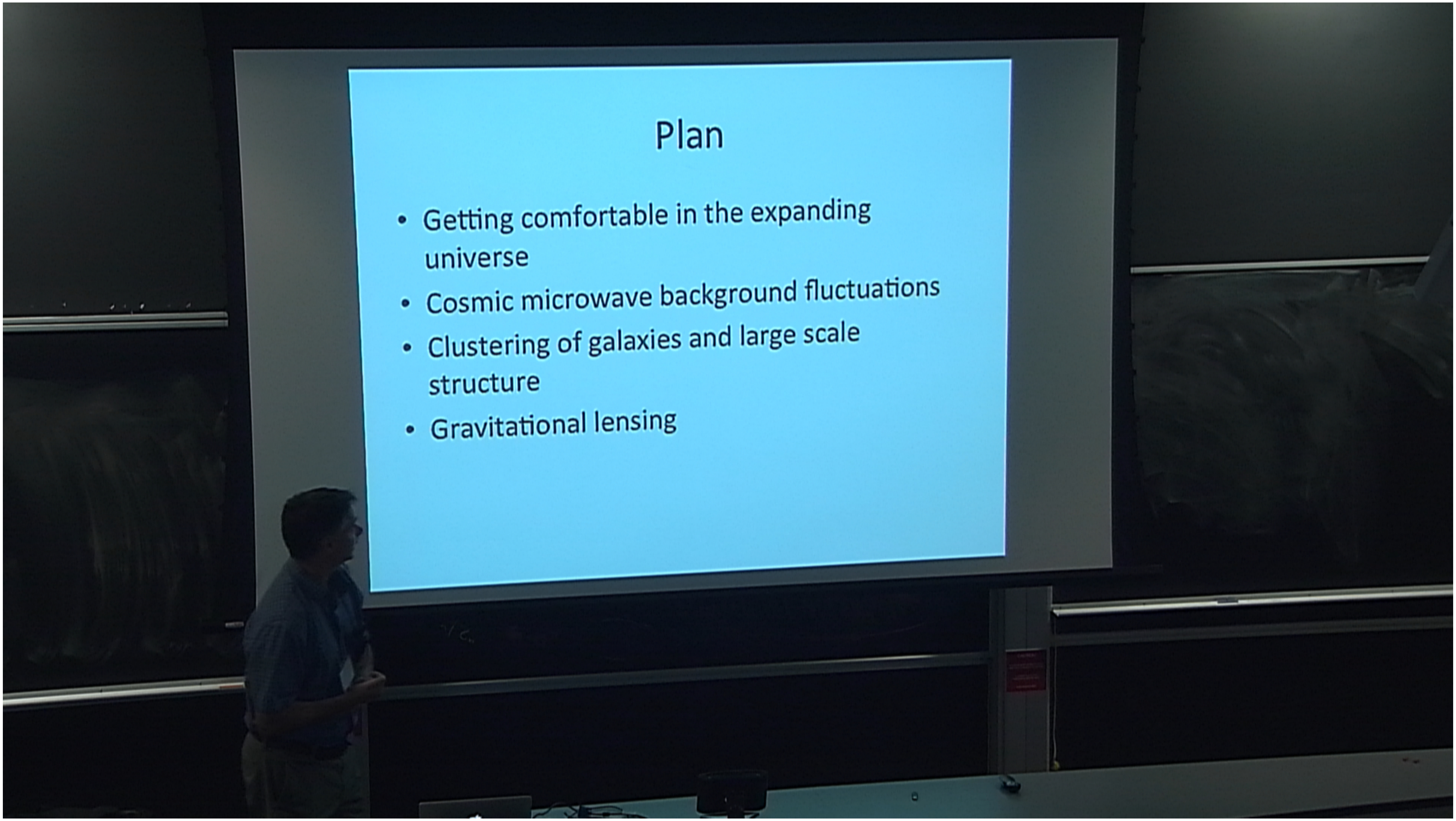
Title: Cosmology â€“ Observations: Observables in an expanding universe

Date: Jul 13, 2015 11:45 AM

URL: http://pirsa.org/15070038

Abstract:


Plan
• Getting comfortable in the expanding universe
• Cosmic microwave background fluctuations
• Clustering of galaxies and large scale structure
• Gravitational lensing

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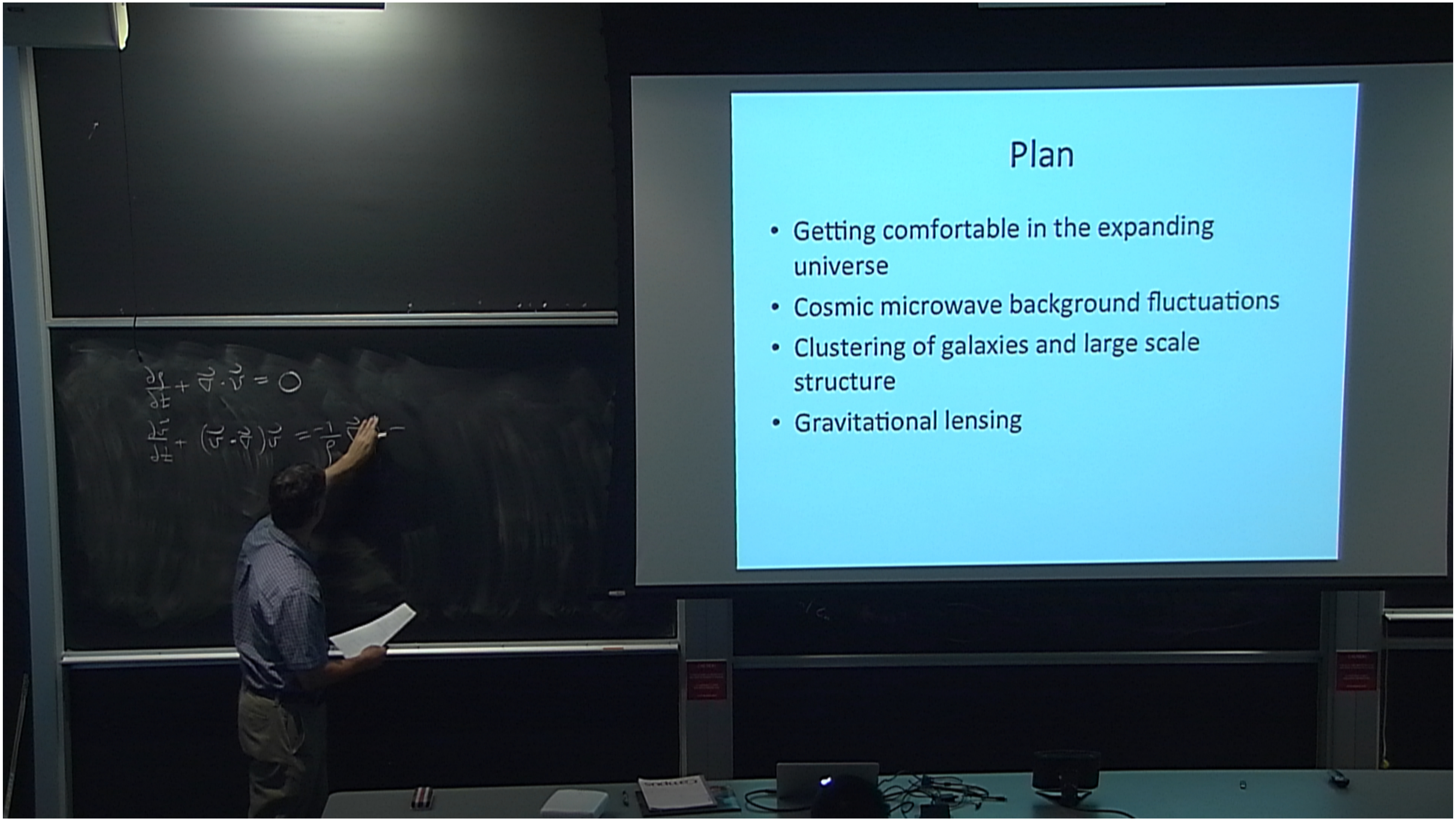
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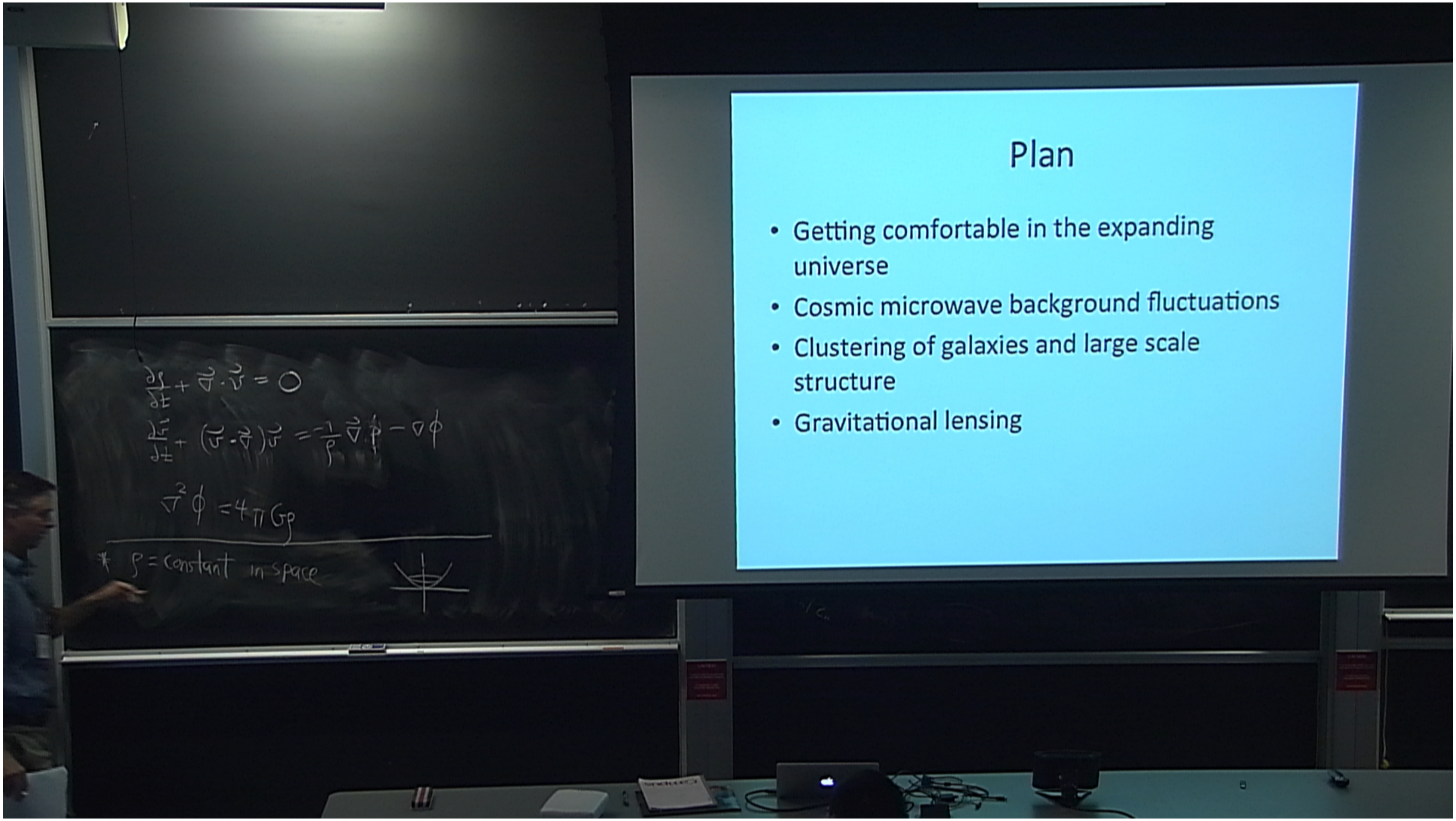
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* ρ = constant in space

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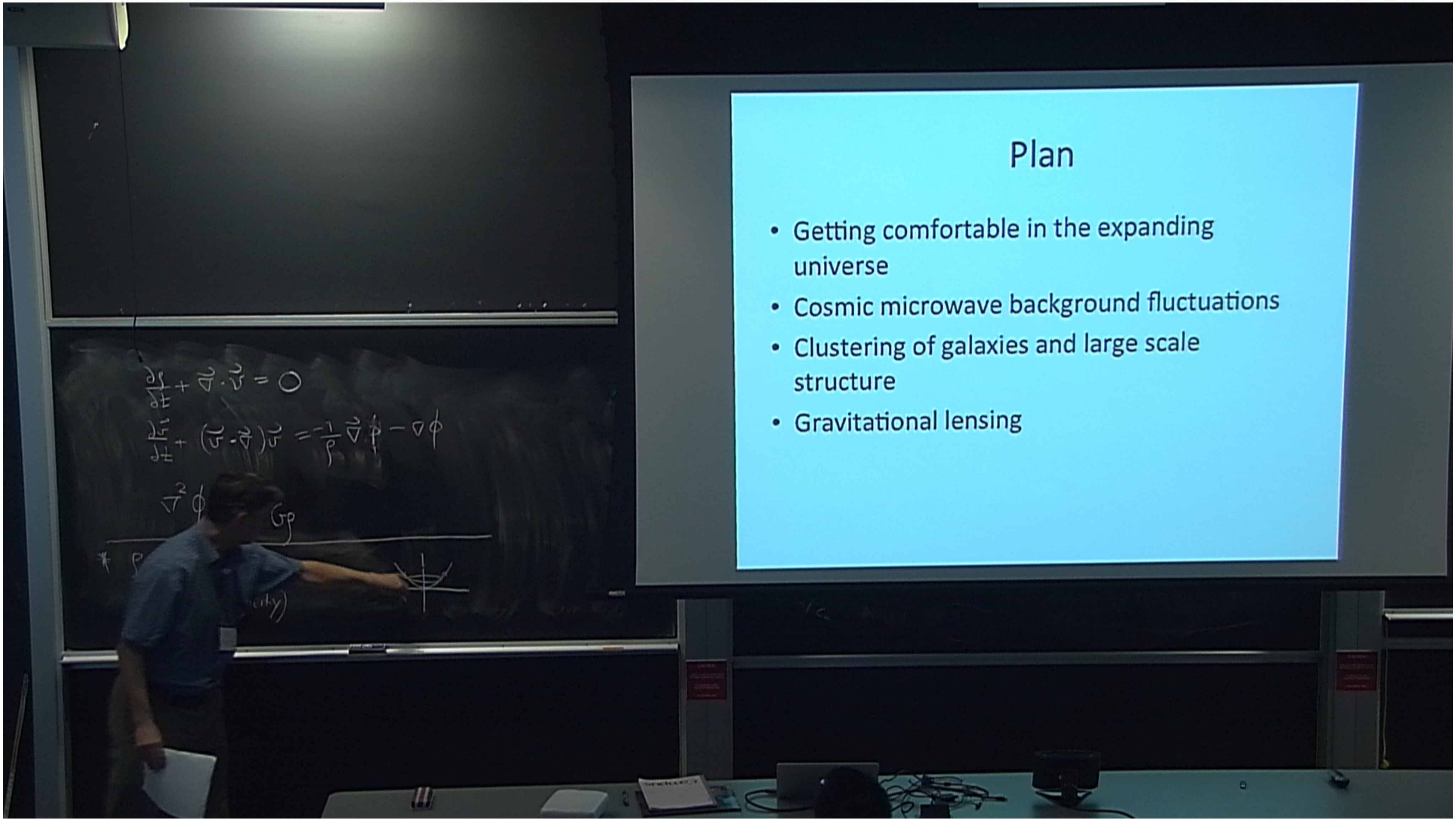
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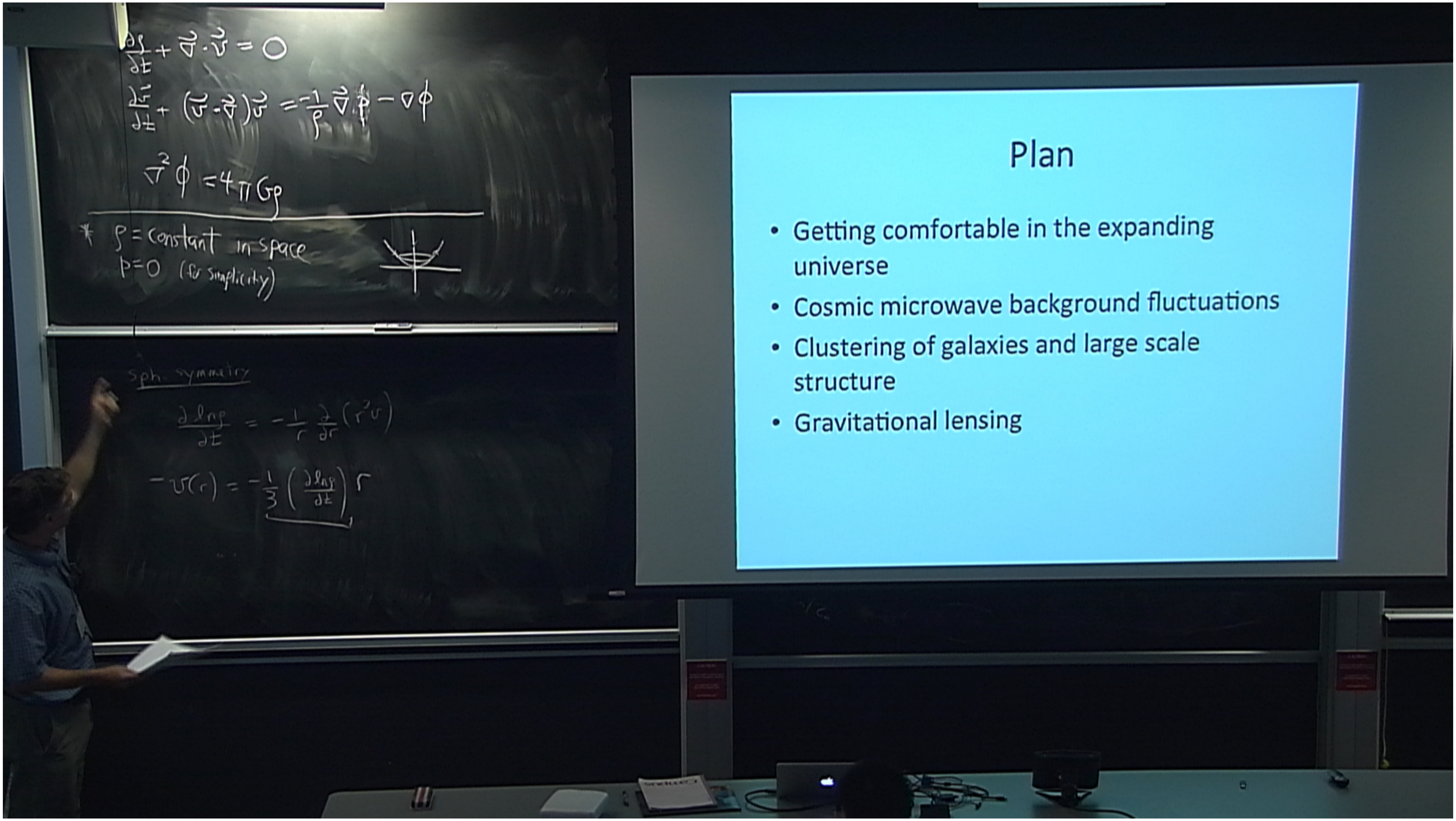
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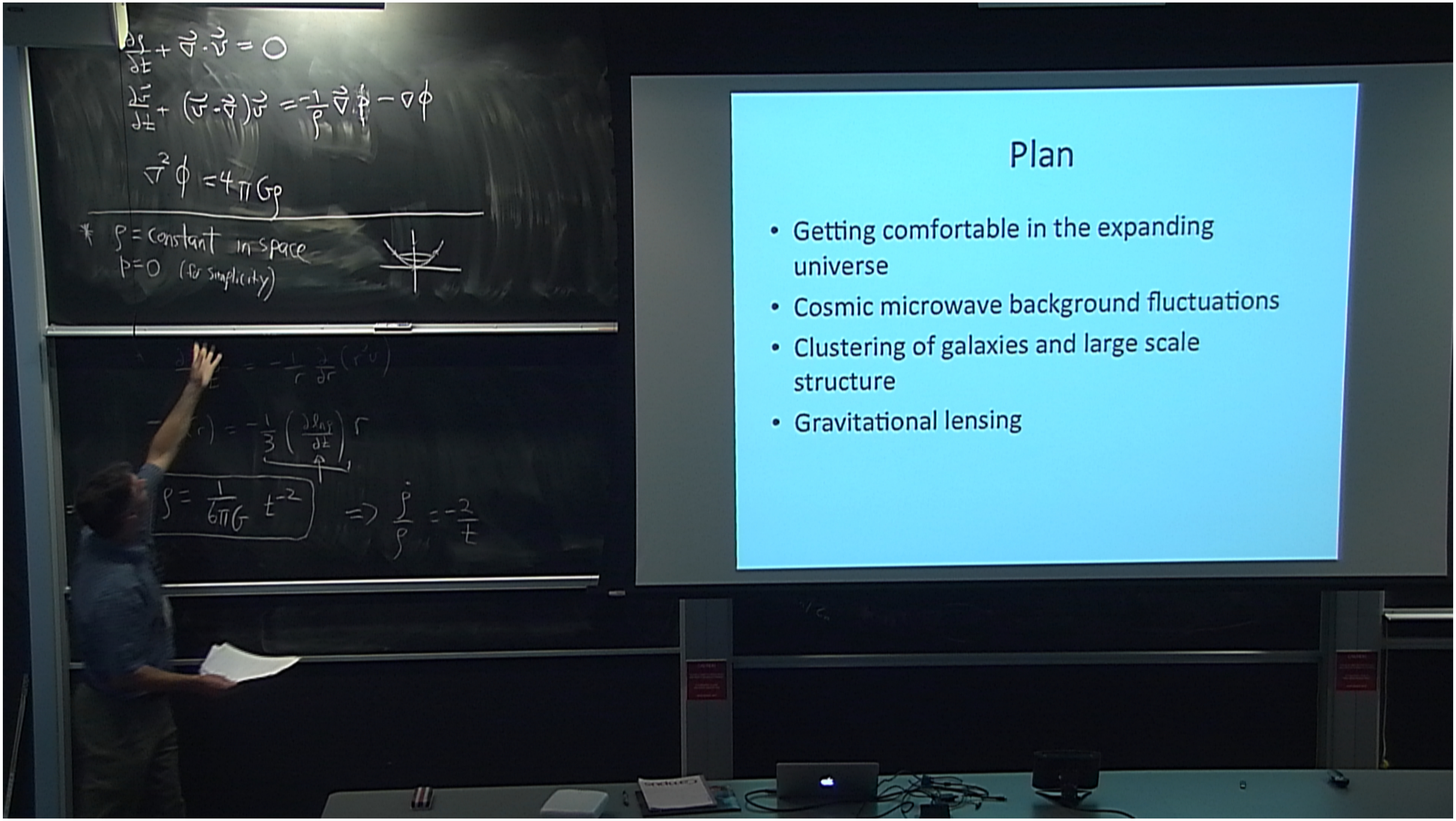
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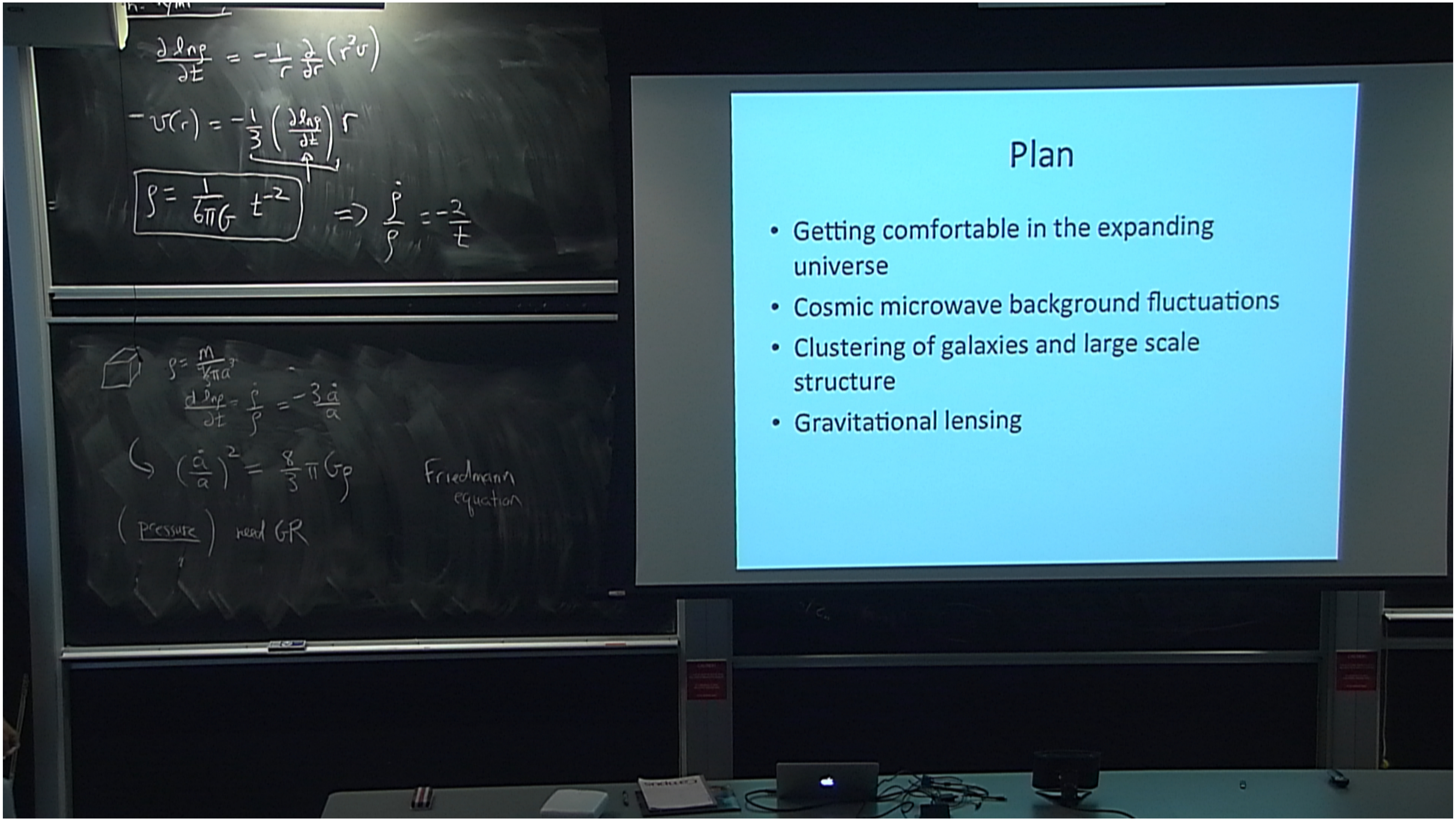
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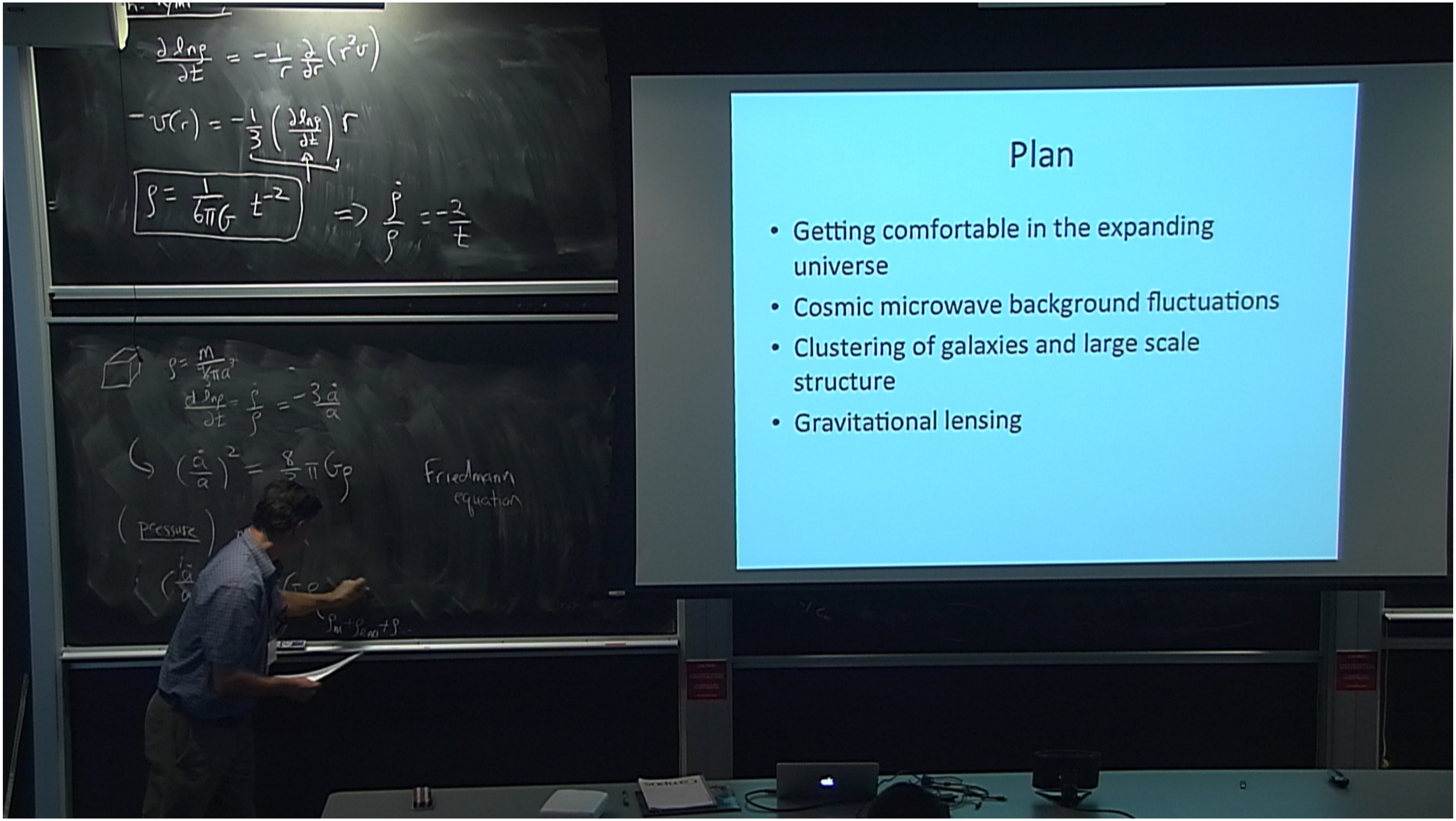
• Gravitational lensing
Friedmann equation
pressure
need GR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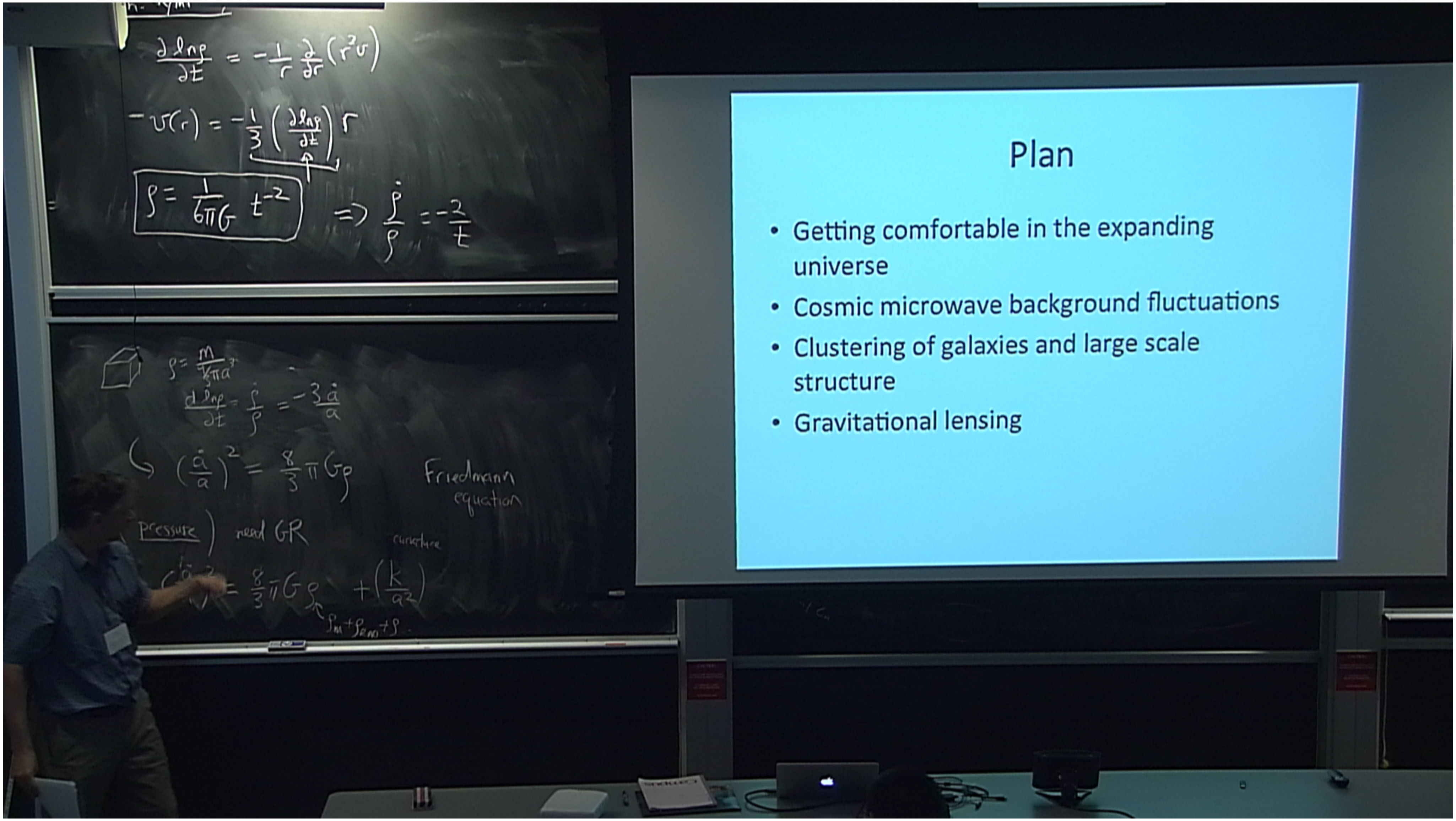
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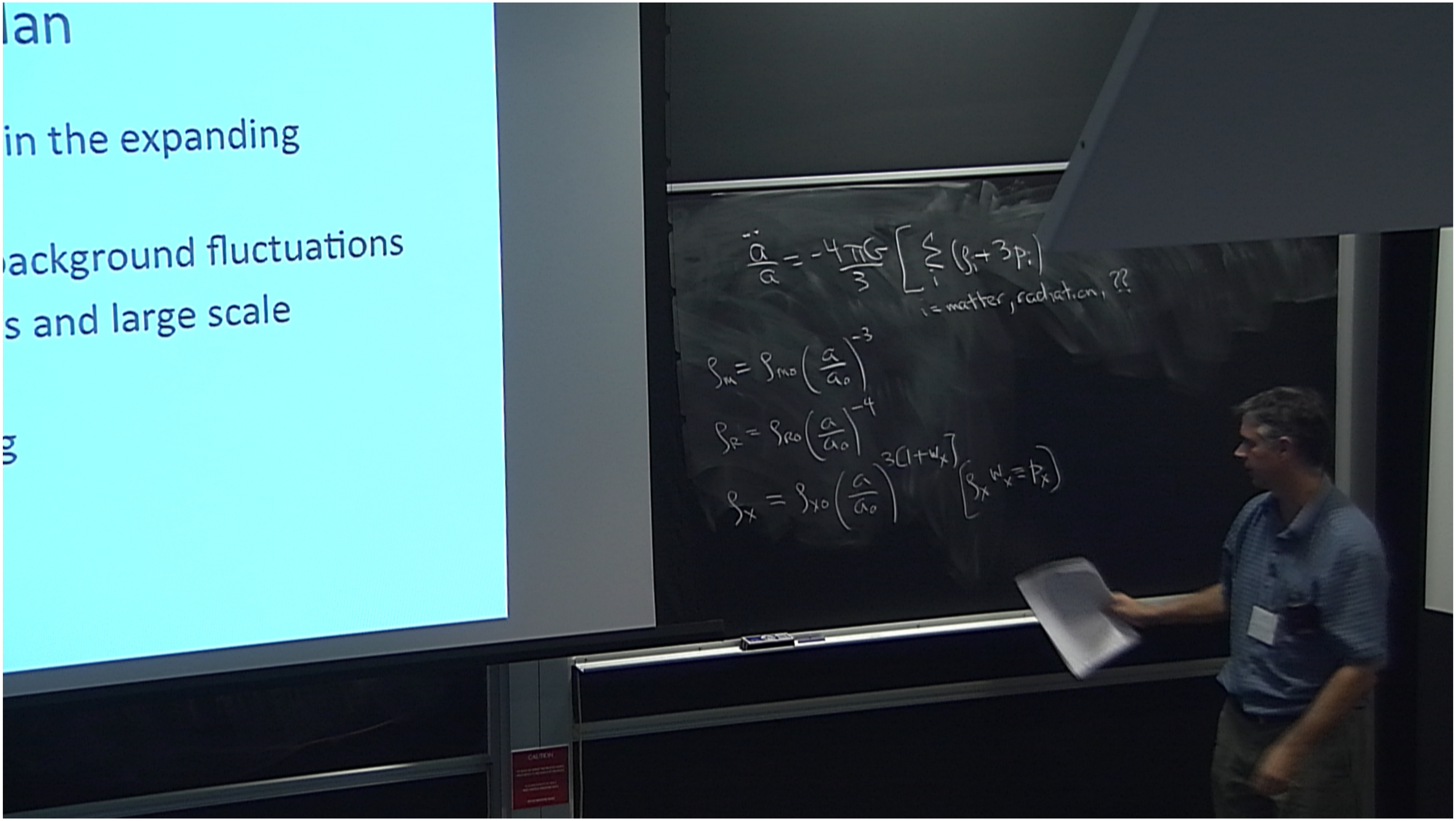
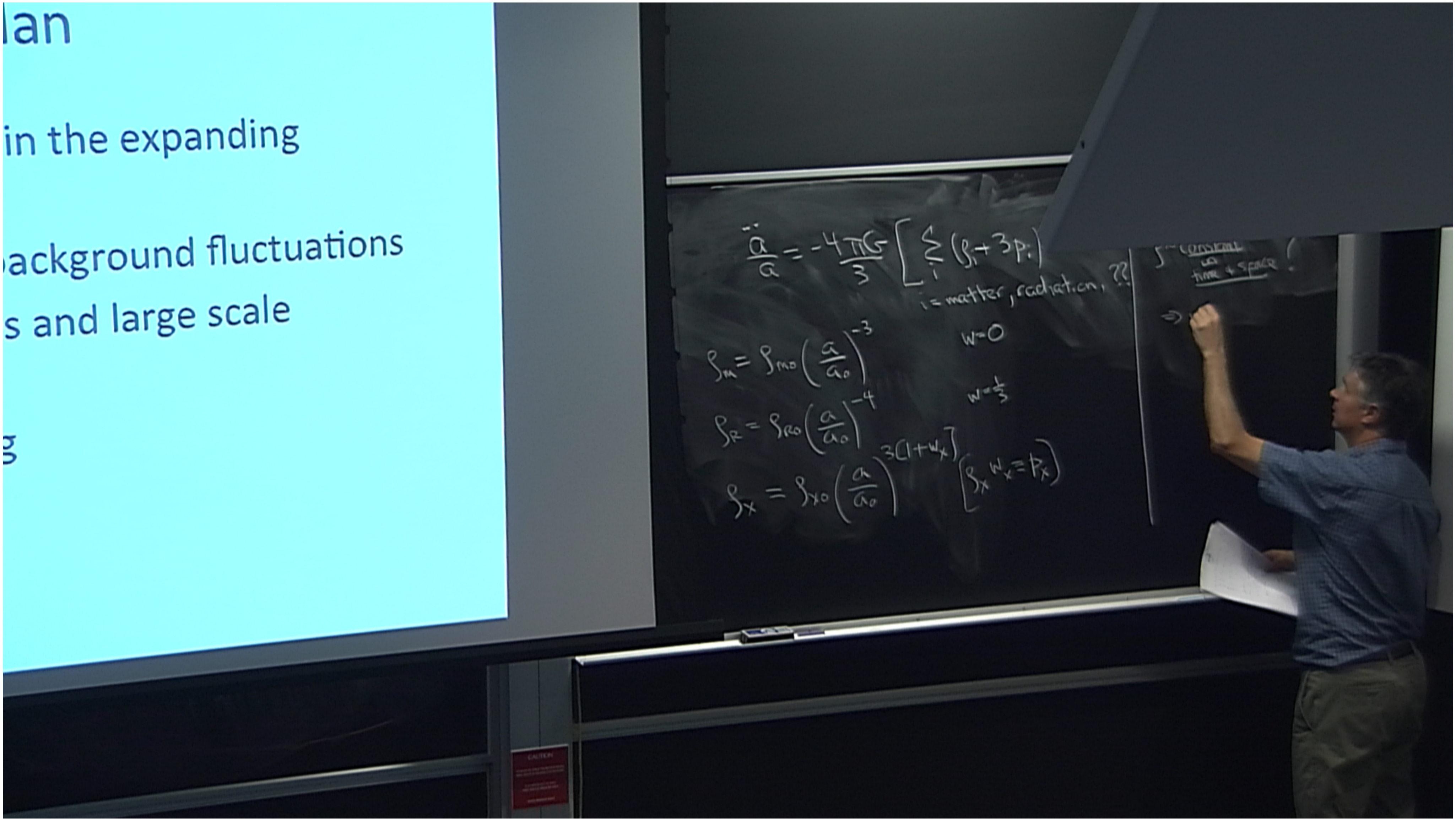
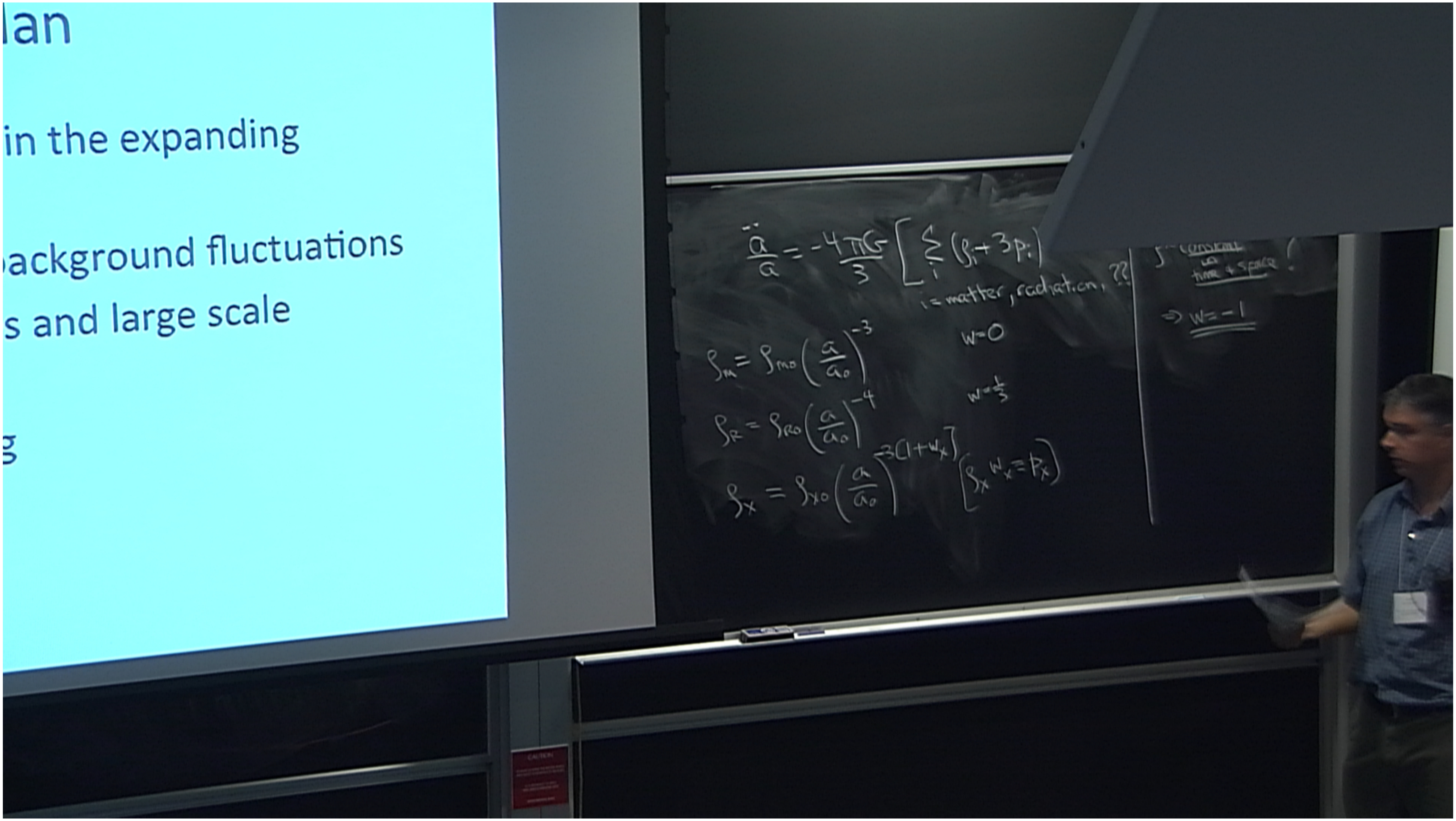
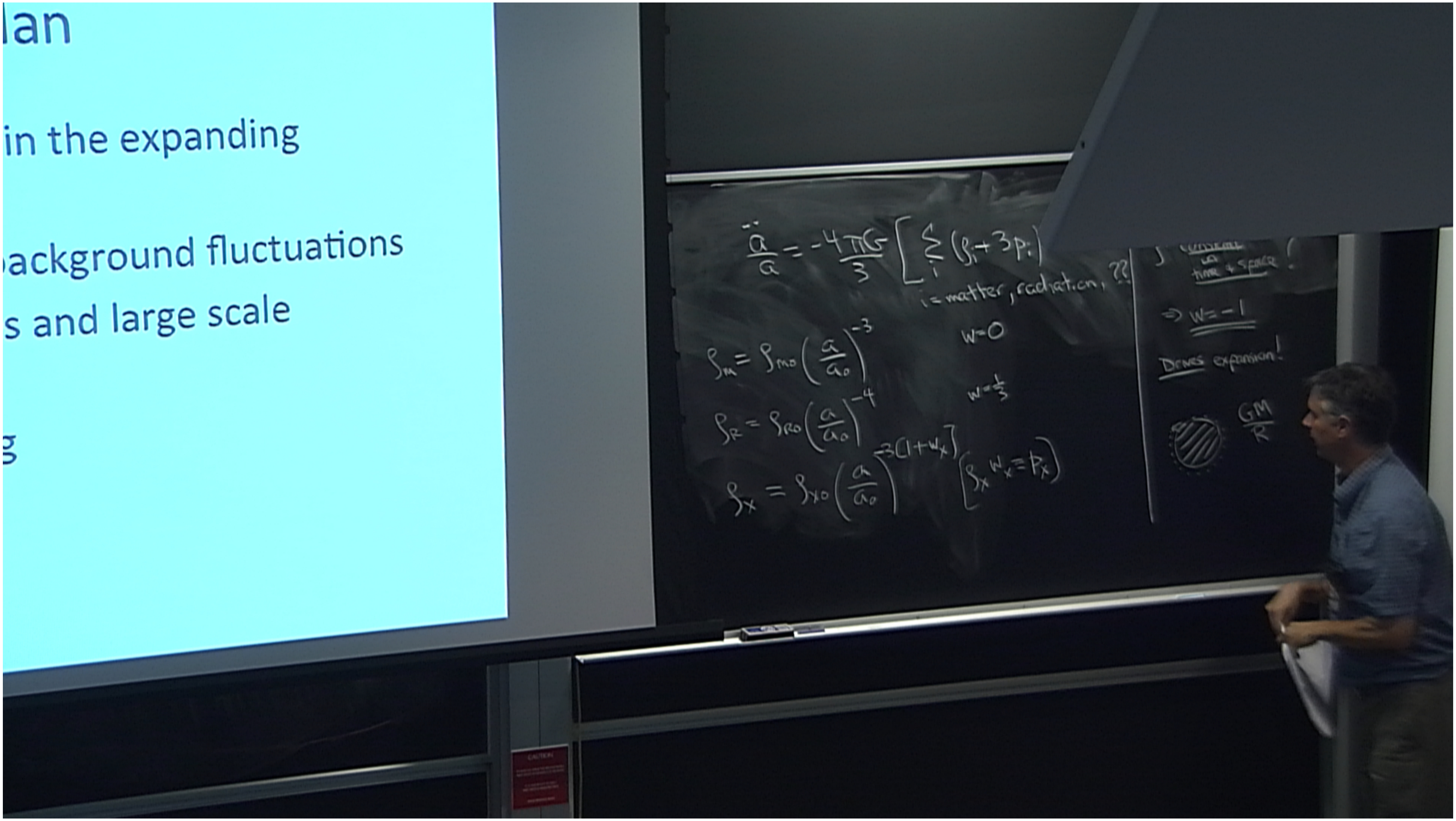
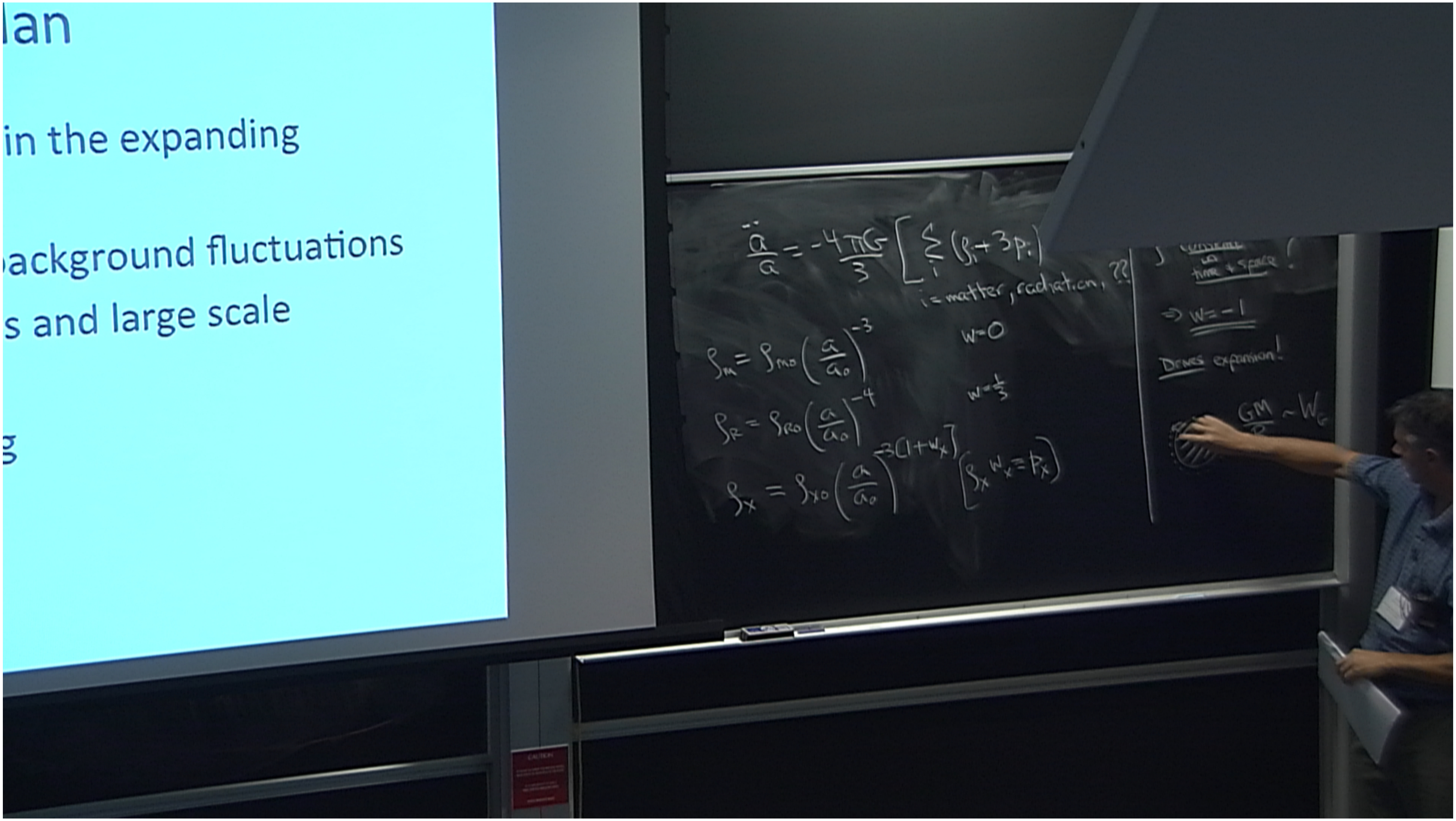

lan
in the expanding
ackground fluctuations
s and large scale
g
ä/a = -4πG/3 [Σ_i (ρ_i + 3p_i)]
i = matter, radiation, ??
ρ_m = ρ_m0 (a/a_0)^-3
ρ_R = ρ_R0 (a/a_0)^-4
ρ_x = ρ_x0 (a/a_0)^3(1+w_x)
[ρ_x w_x = p_x]


lan
in the expanding
ackground fluctuations
s and large scale
g
i = matter, radiation, ??
w=0
w=1/3
time + space


lan
in the expanding
ackground fluctuations
s and large scale
i = matter, radiation, ??
w=0
w=-1


lan
in the expanding
ackground fluctuations
s and large scale
g
i = matter, radiation, ??
w=0
⇒ w = -1
Drives expansion!
GM
R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i = matter, radiation, ??
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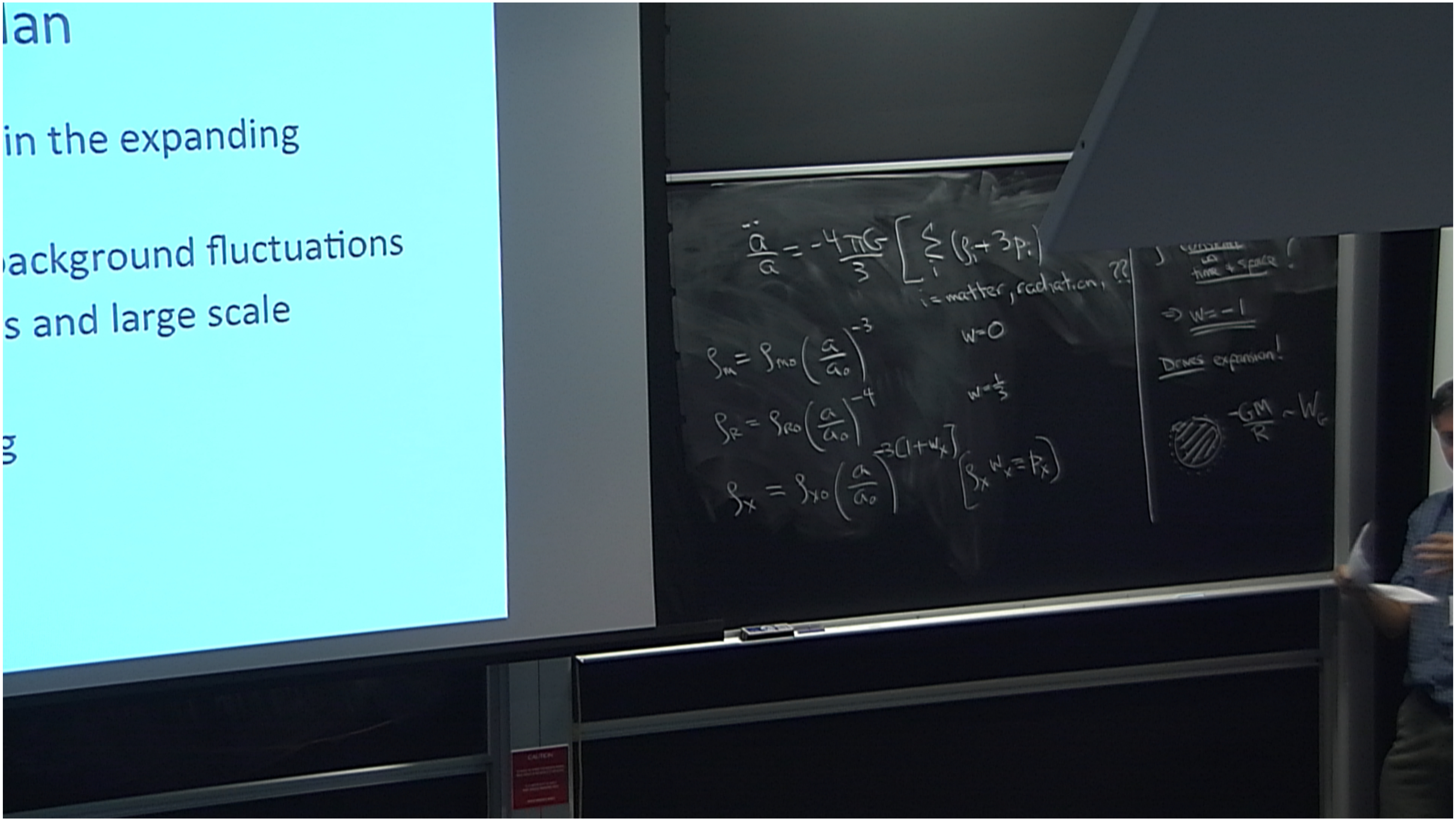
⇒ w = −1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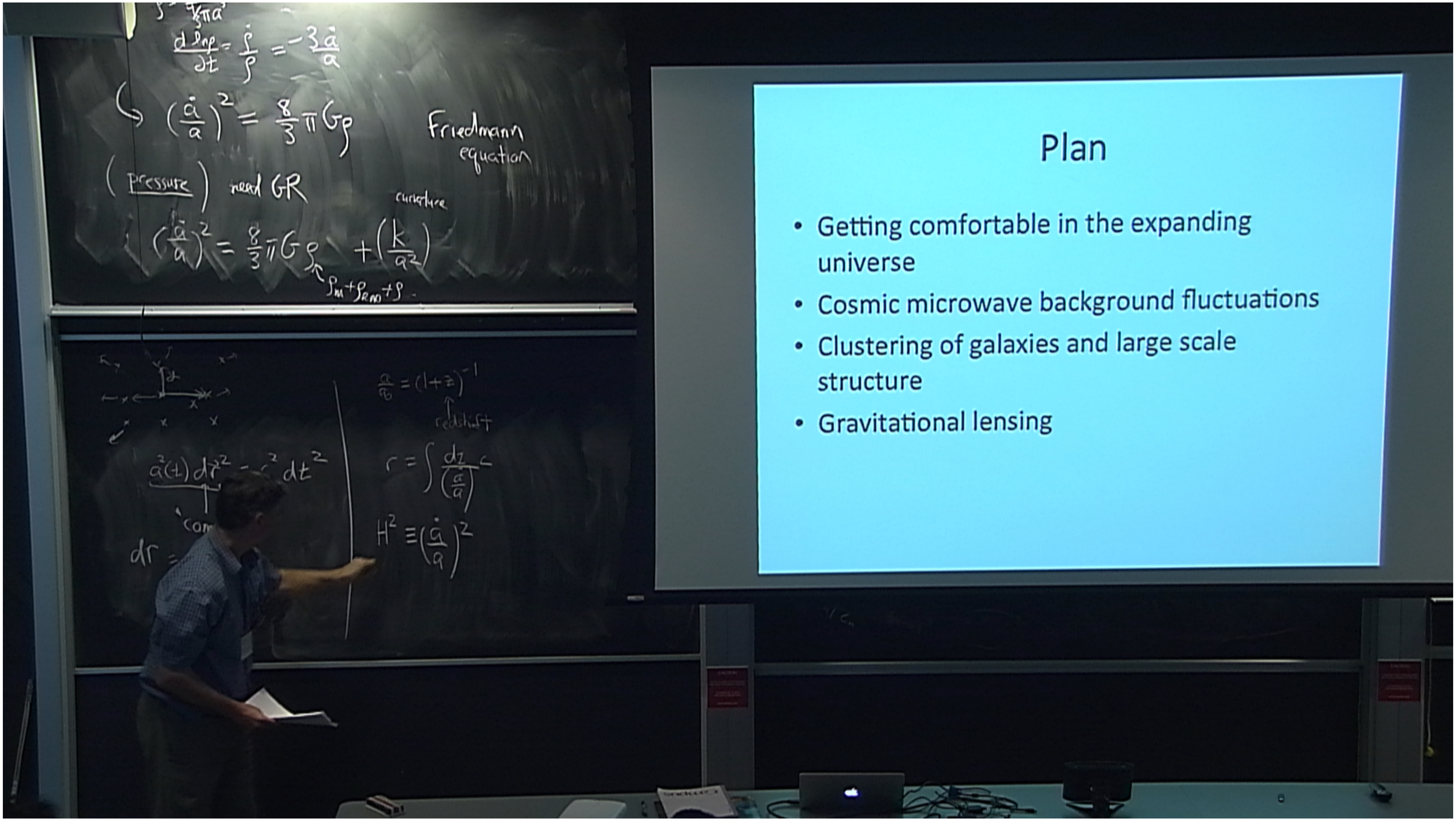
i = matter, radiation, ??
w=0
Drives expansion!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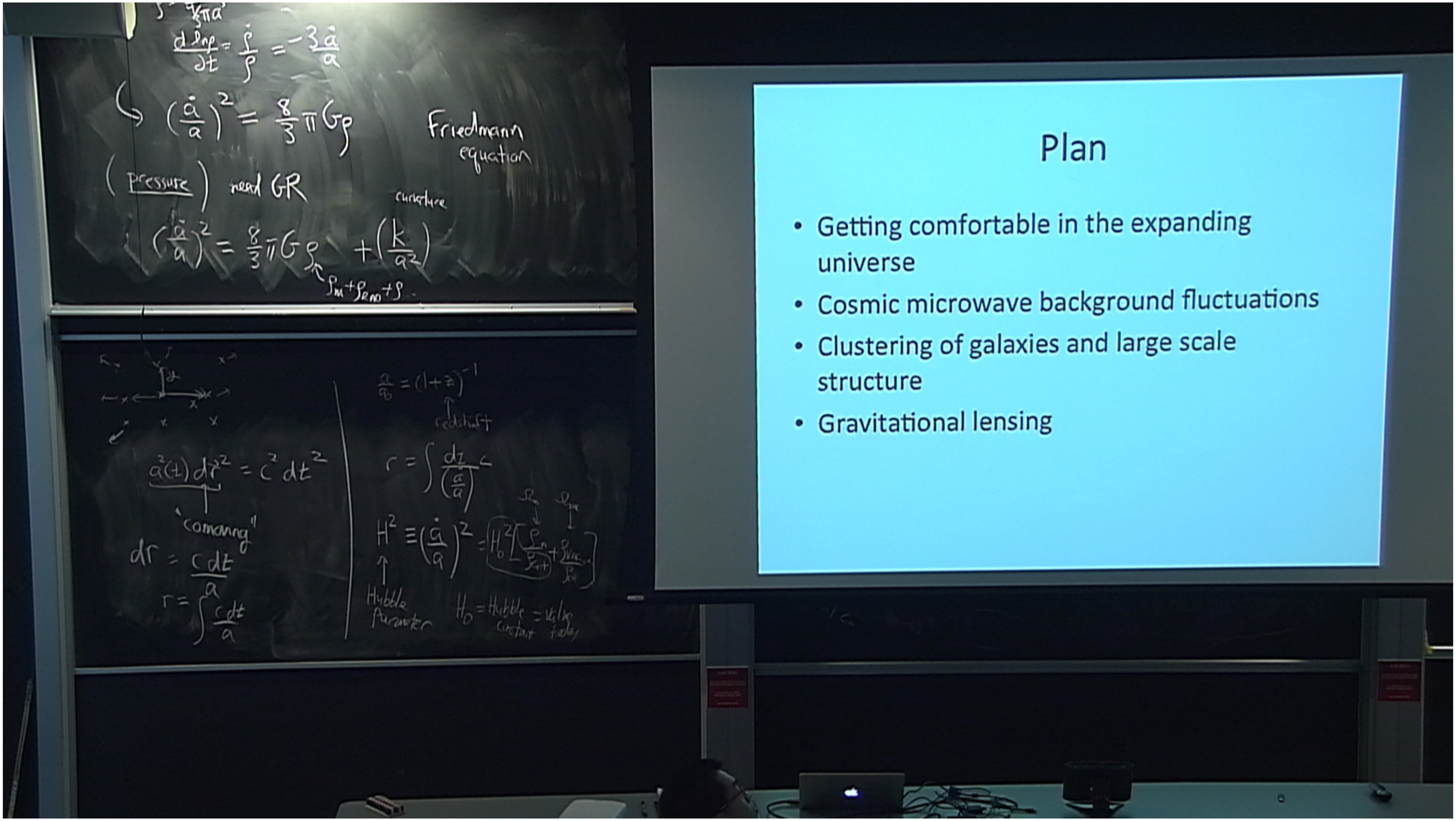
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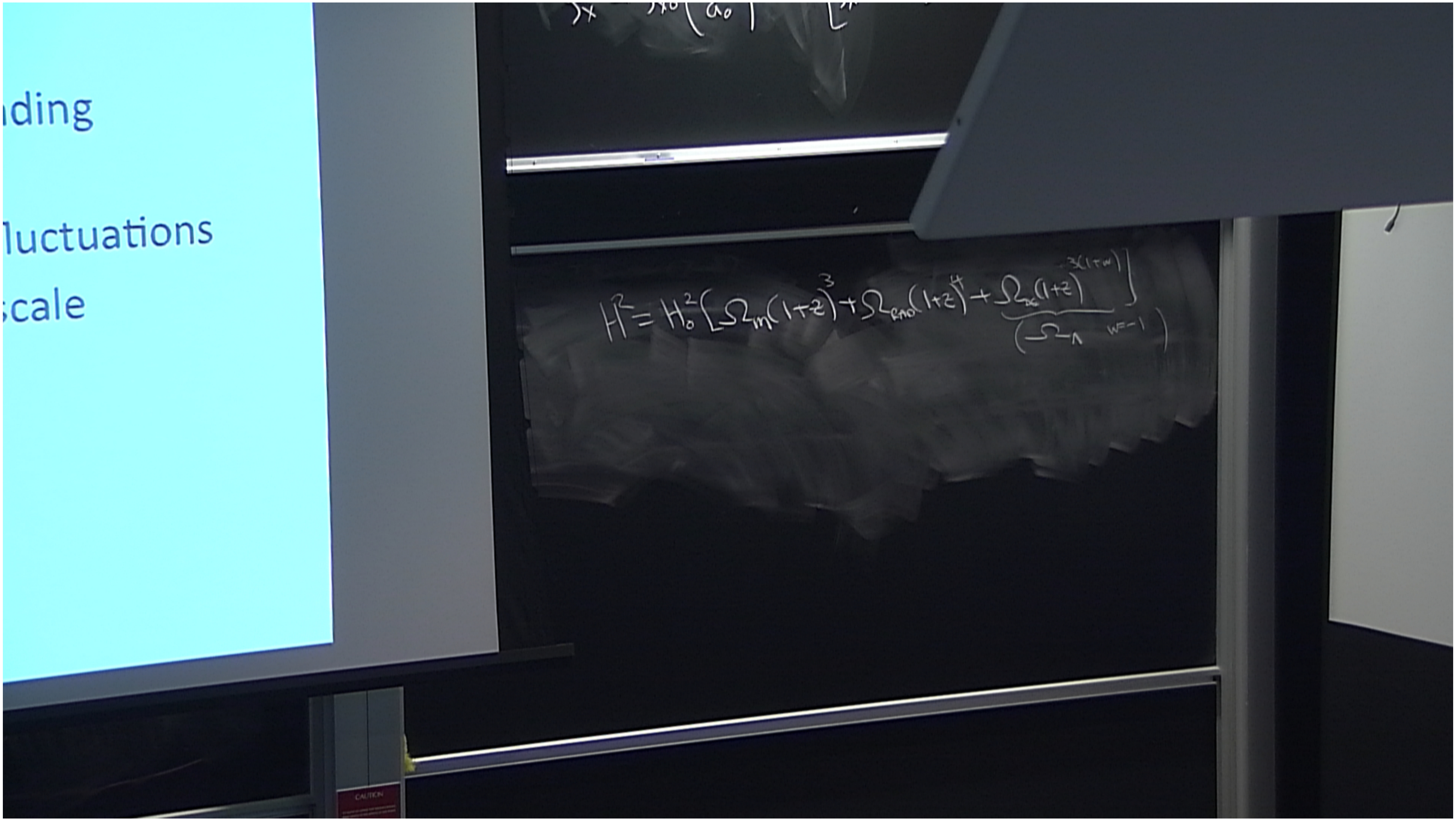
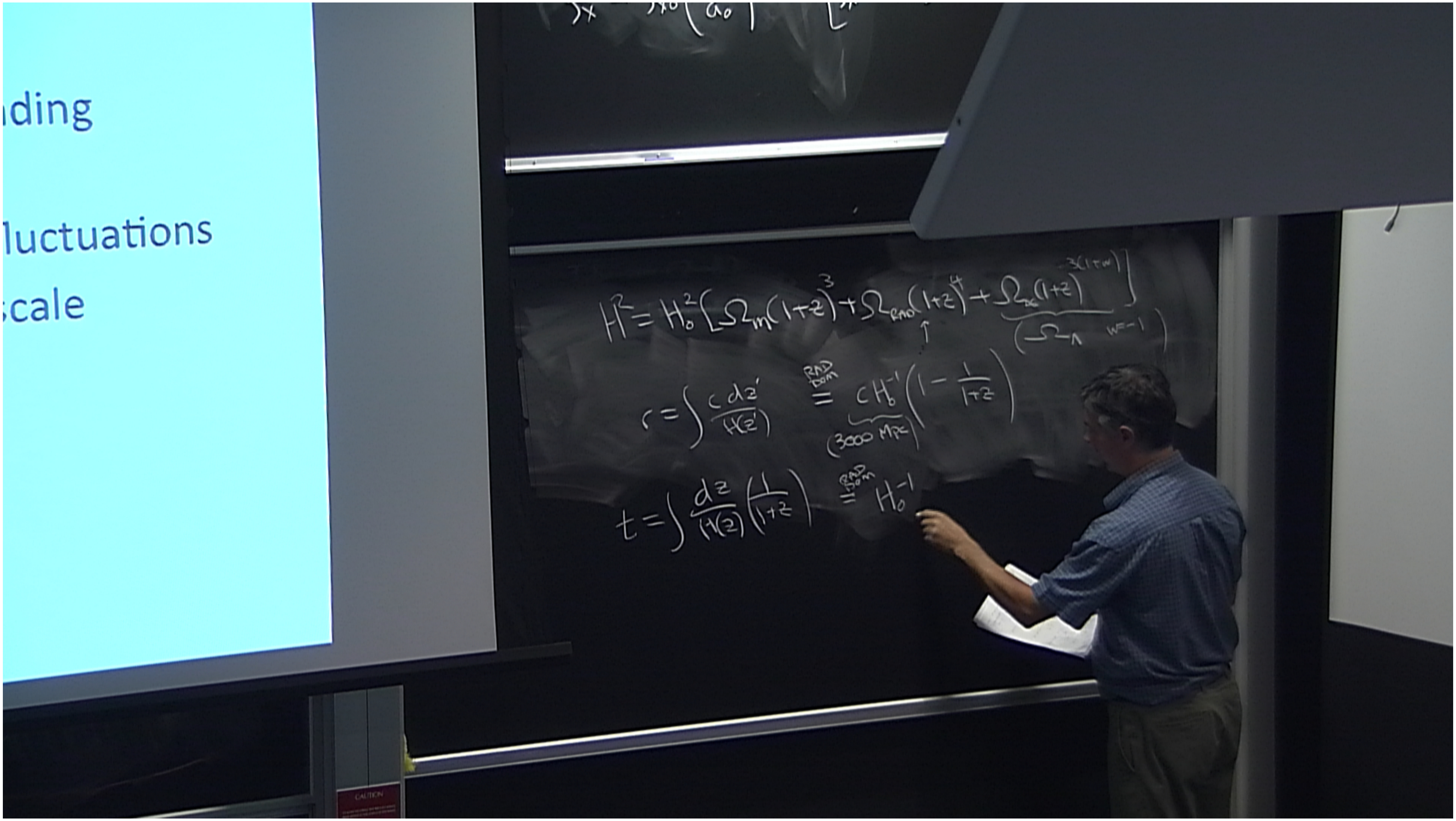

ding
luctuations
scale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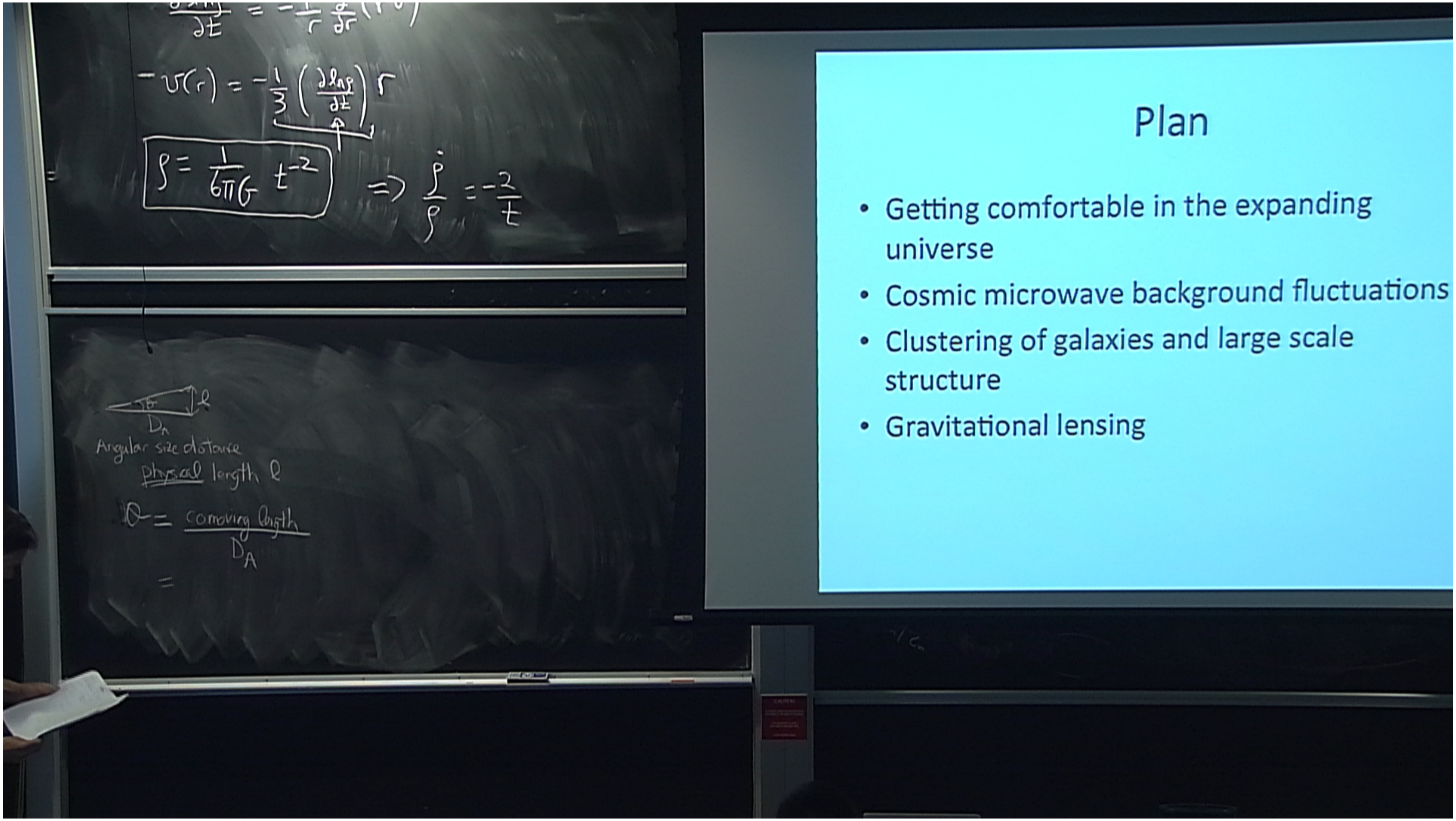
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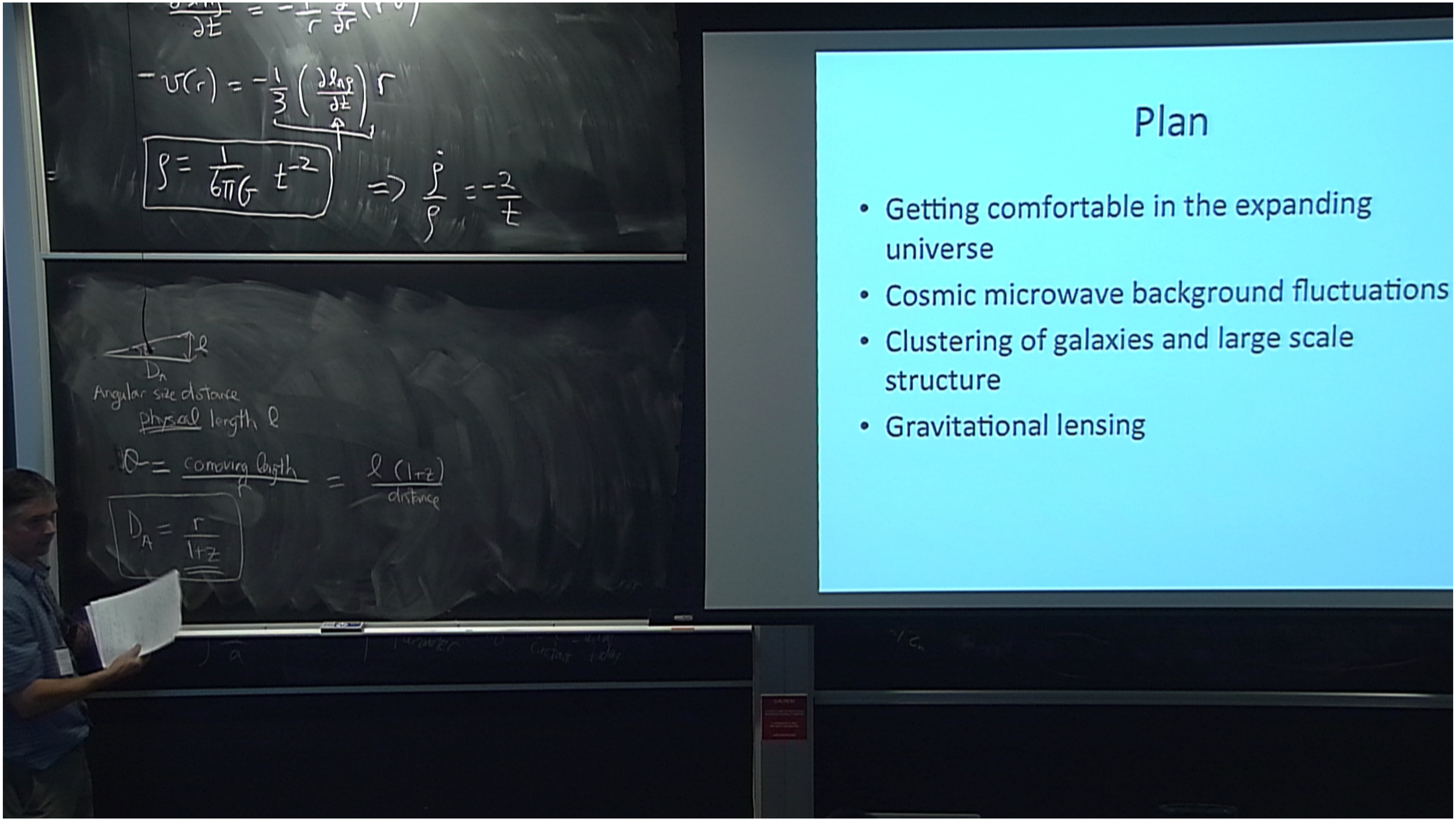
• Gravitational lensing
Angular size distance
physical length l


Plan
Getting comfortable in the expanding universe
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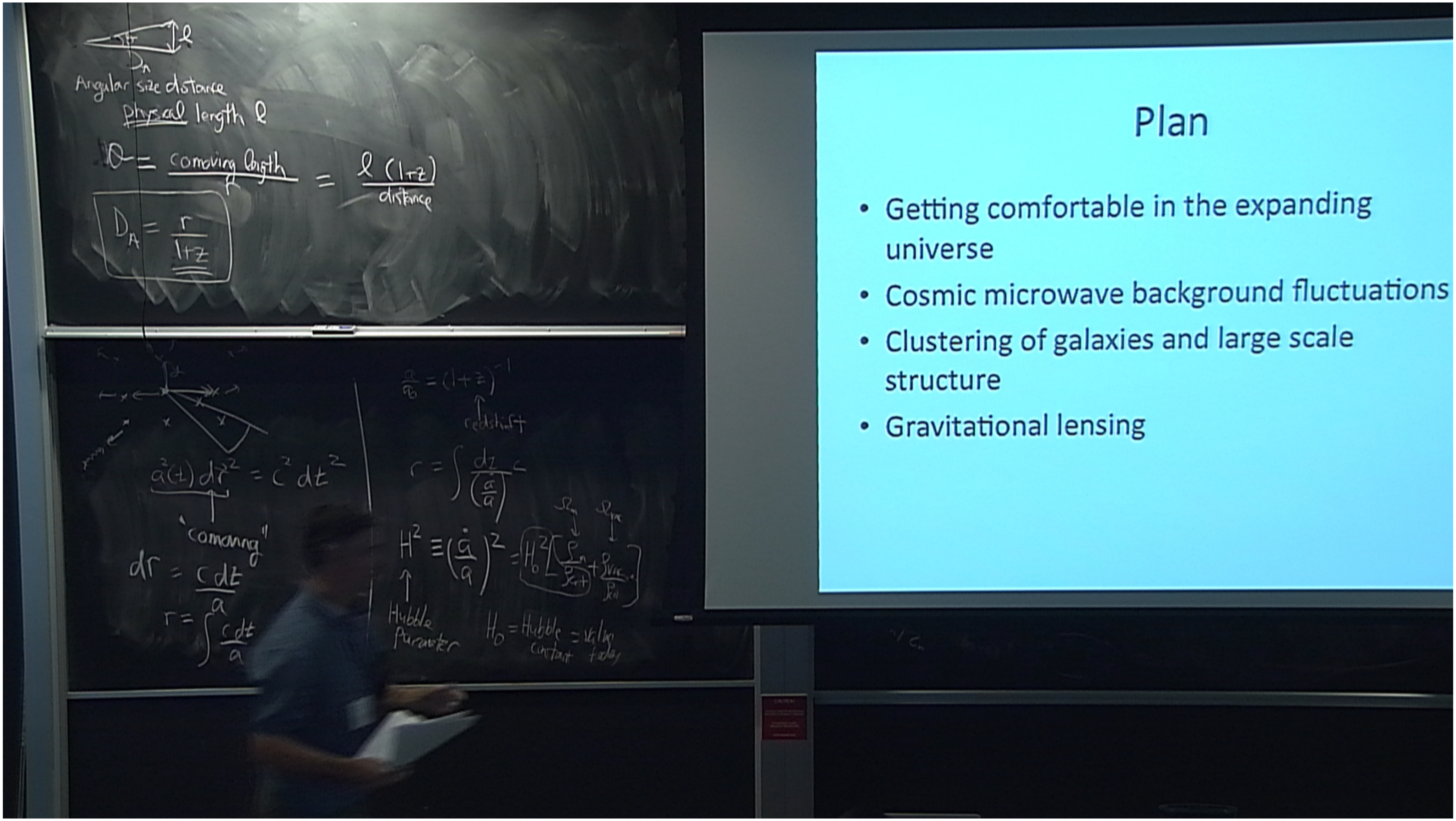
Clustering of galaxies and large scale structure
Gravitational lensing
Angular size distance
physical length l
comoving length


Angular size distance
physical length
Plan
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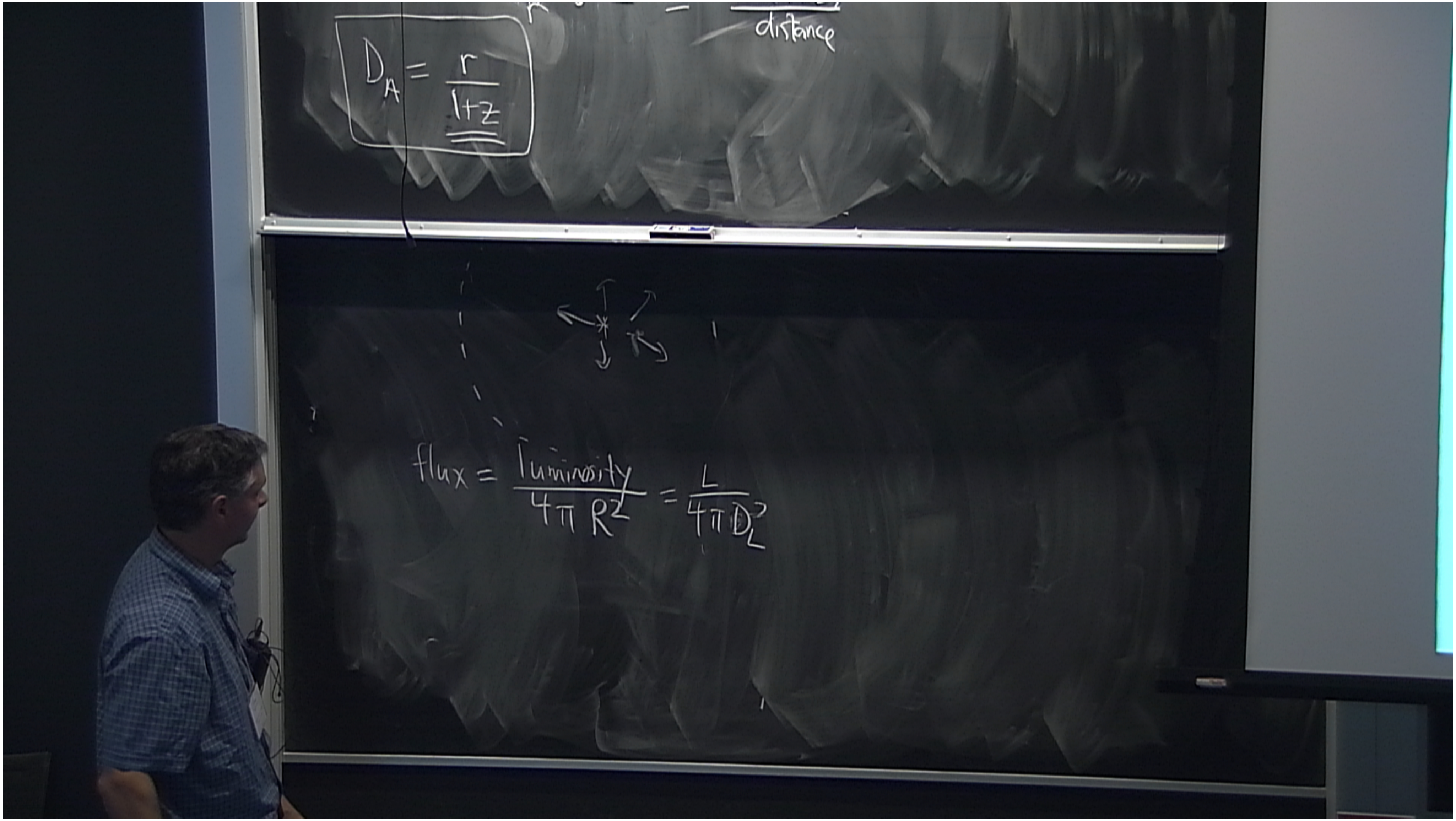
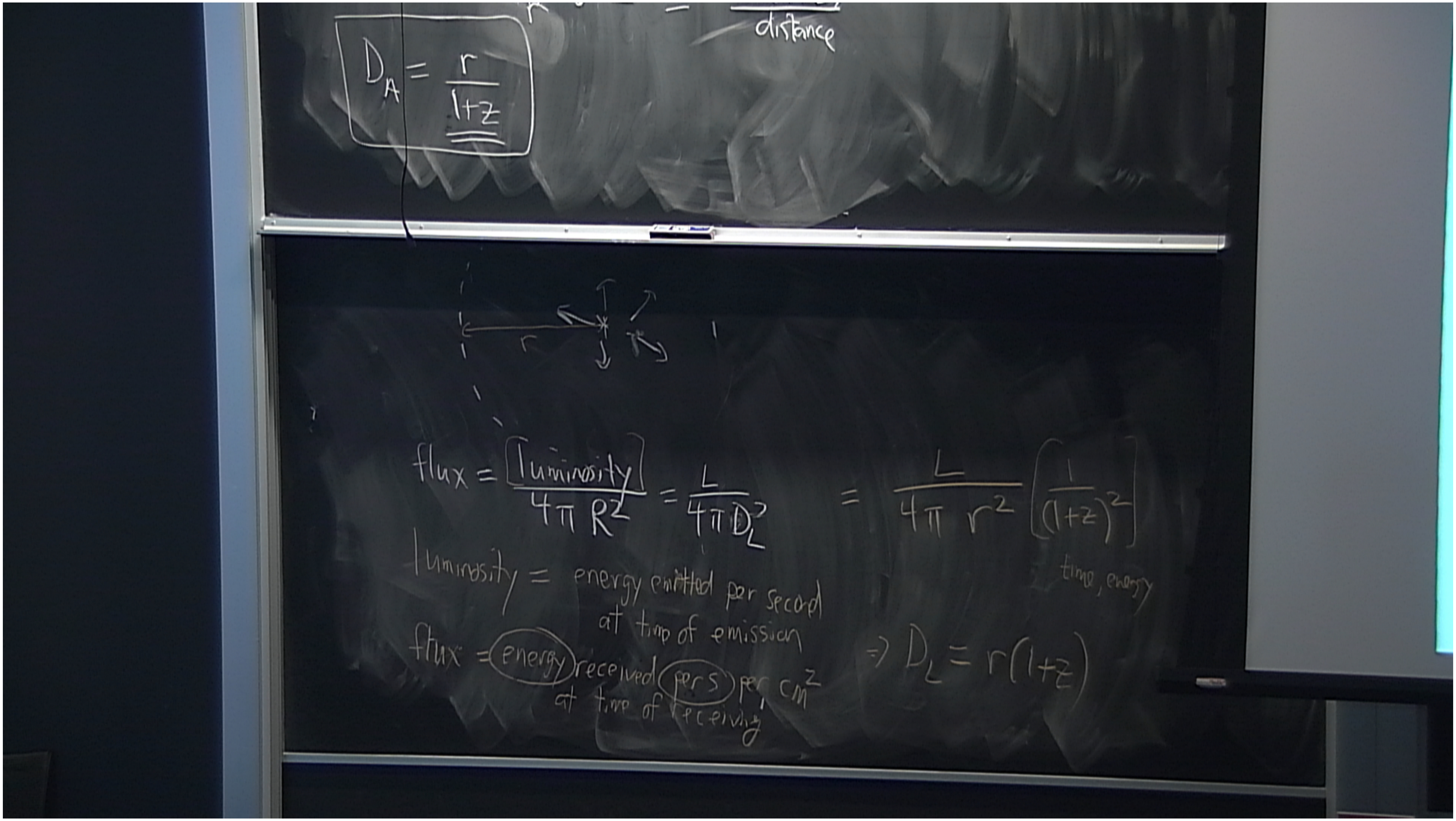
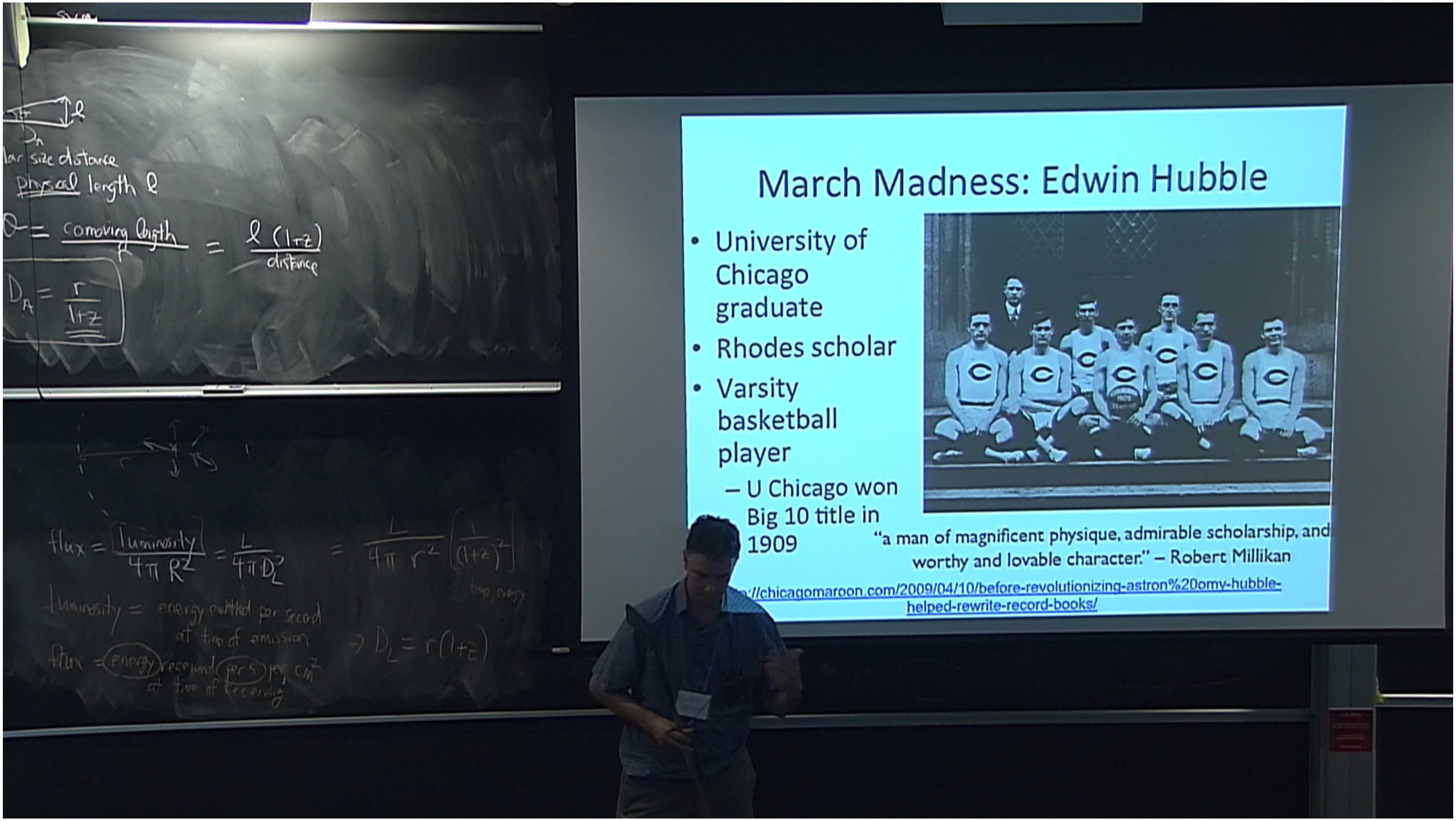
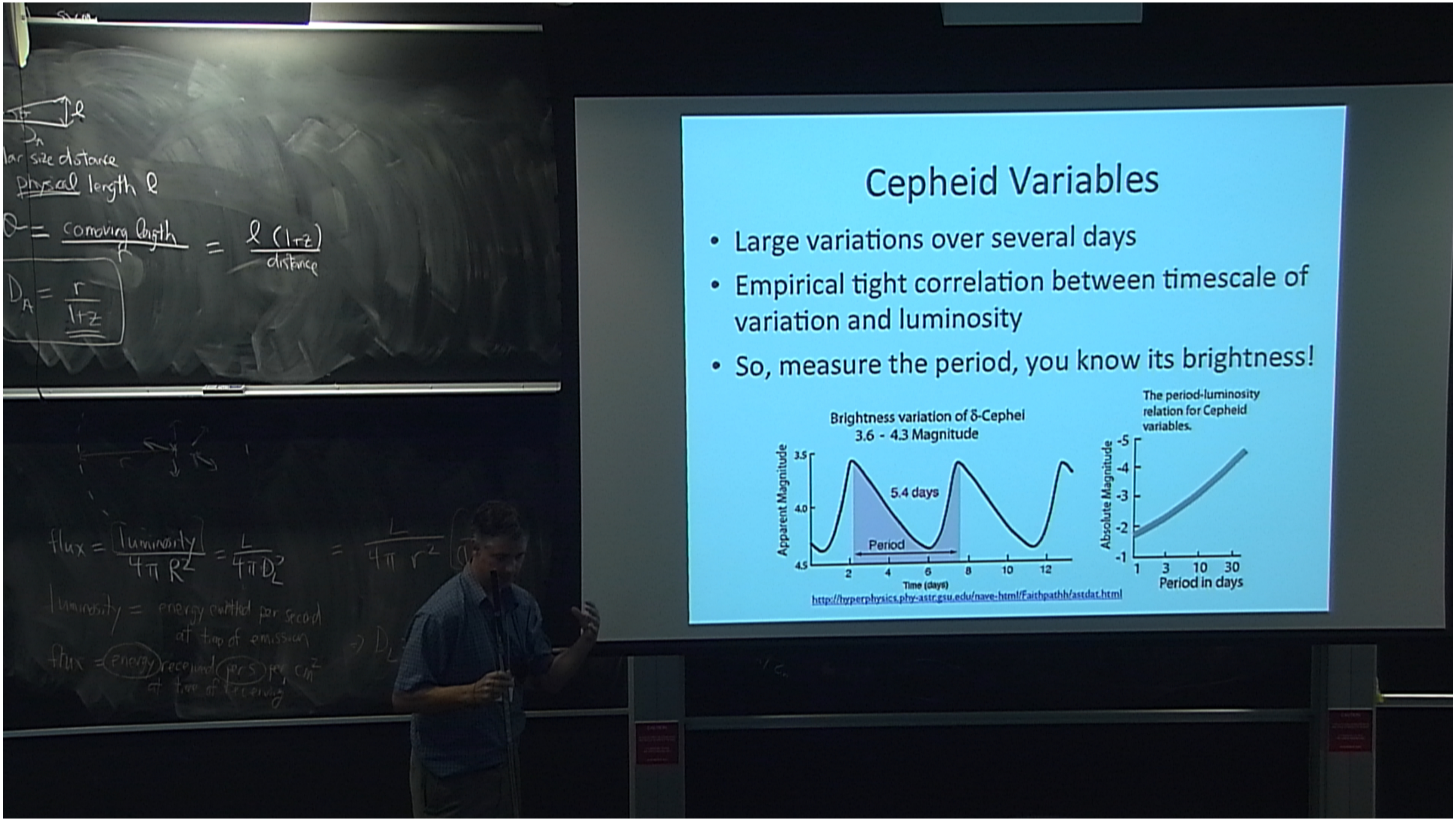
Clustering of galaxies and large scale structure
Gravitational lensing
redshift
"comoving"
Hubble Parameter

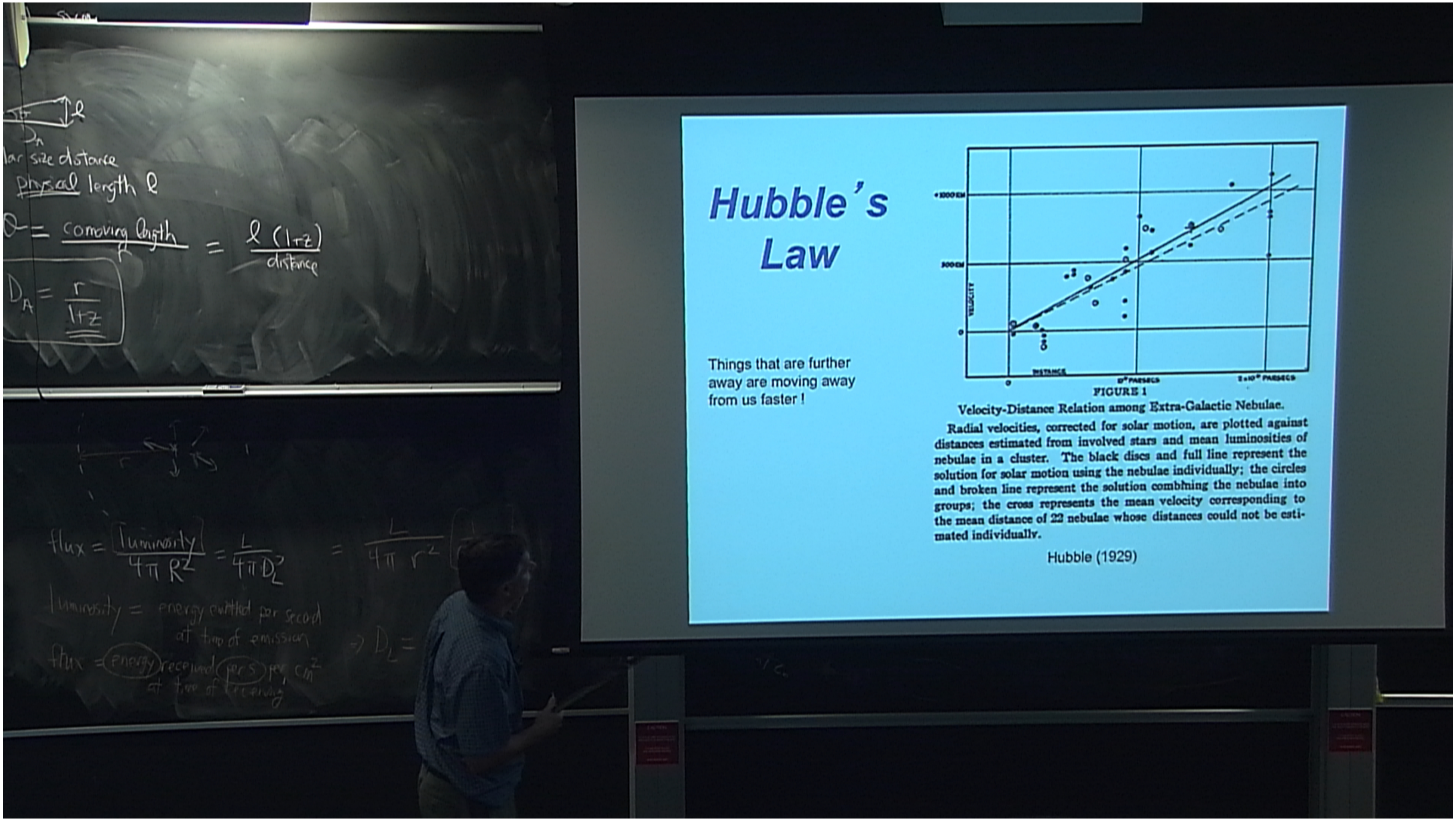

distance
D_A = r / 1+z
flux = luminosity / 4π R^2 = L / 4π D_L^2


distance
D_A = r / (1+z)
r
flux = luminosity / 4π R^2 = L / 4π D_L^2 = L / 4π r^2 · 1/(1+z)^2
luminosity = energy emitted per second
at time of emission
time, energy
flux = energy received per s per cm^2
at time of receiving
⇒ D_L = r(1+z)

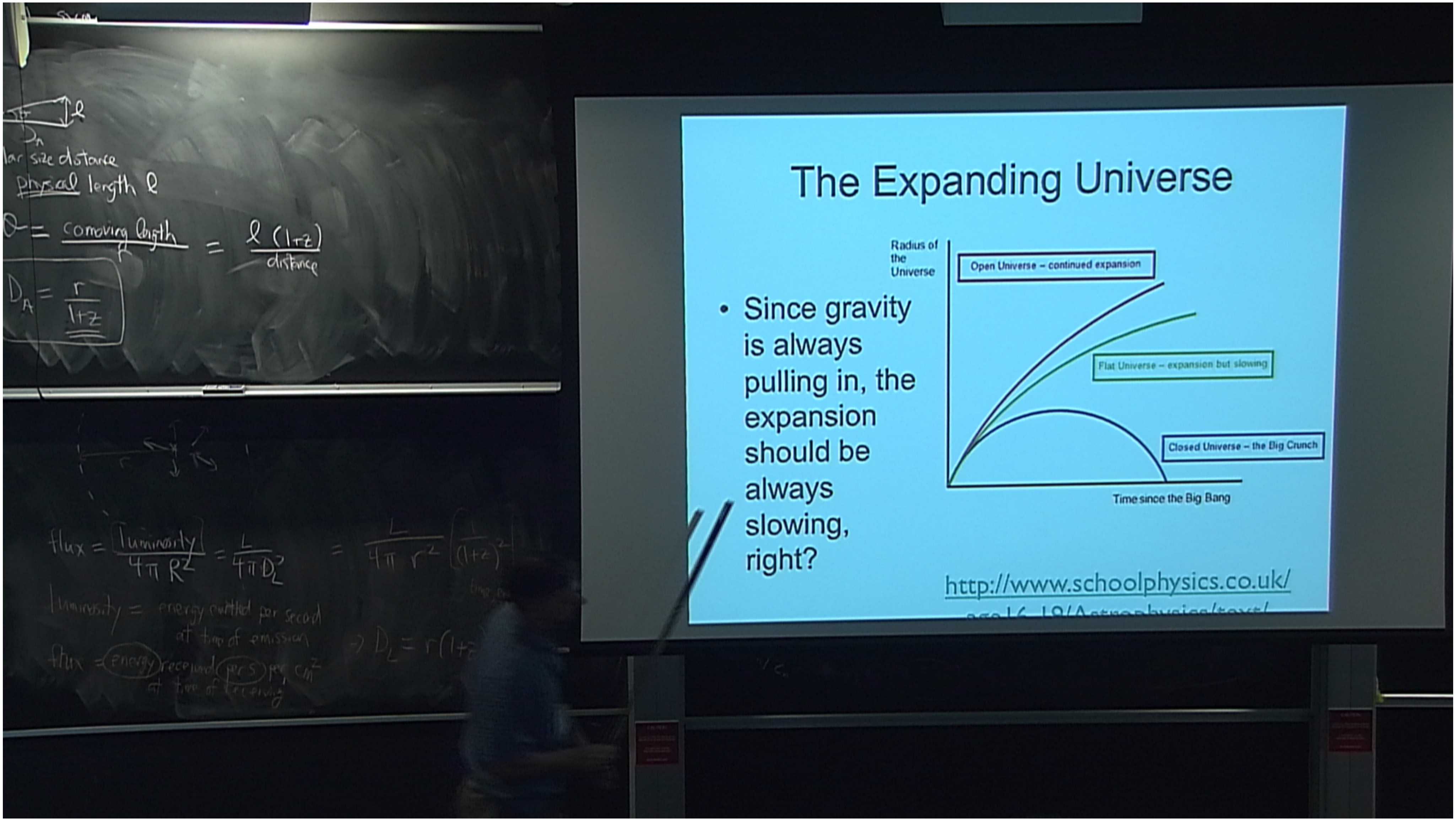

March Madness: Edwin Hubble
• University of Chicago graduate
• Rhodes scholar
• Varsity basketball player
– U Chicago won Big 10 title in 1909
"a man of magnificent physique, admirable scholarship, and worthy and lovable character." – Robert Millikan
//chicagomaroon.com/2009/04/10/before-revolutionizing-astron%20omy-hubble-helped-rewrite-record-books/

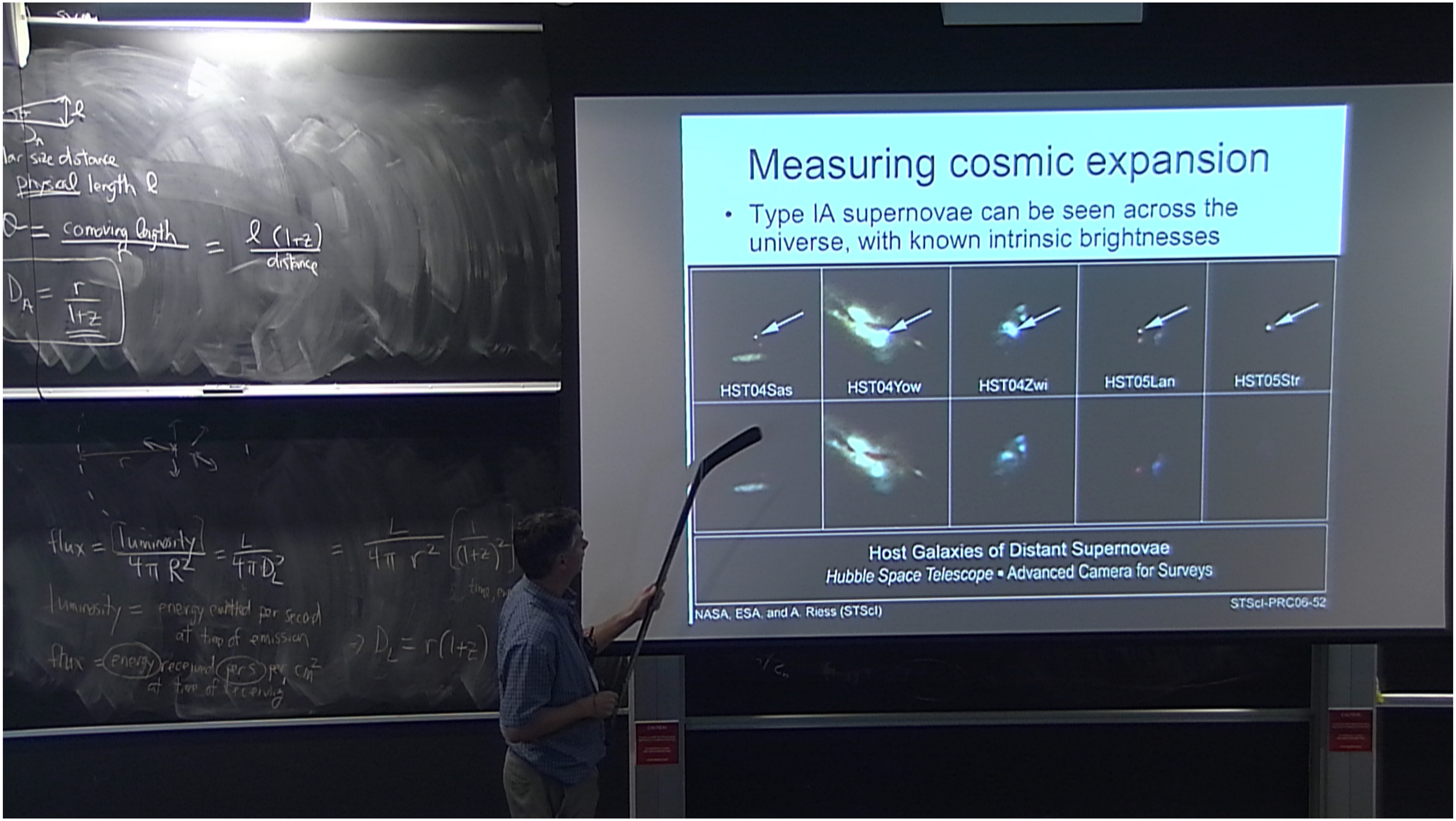


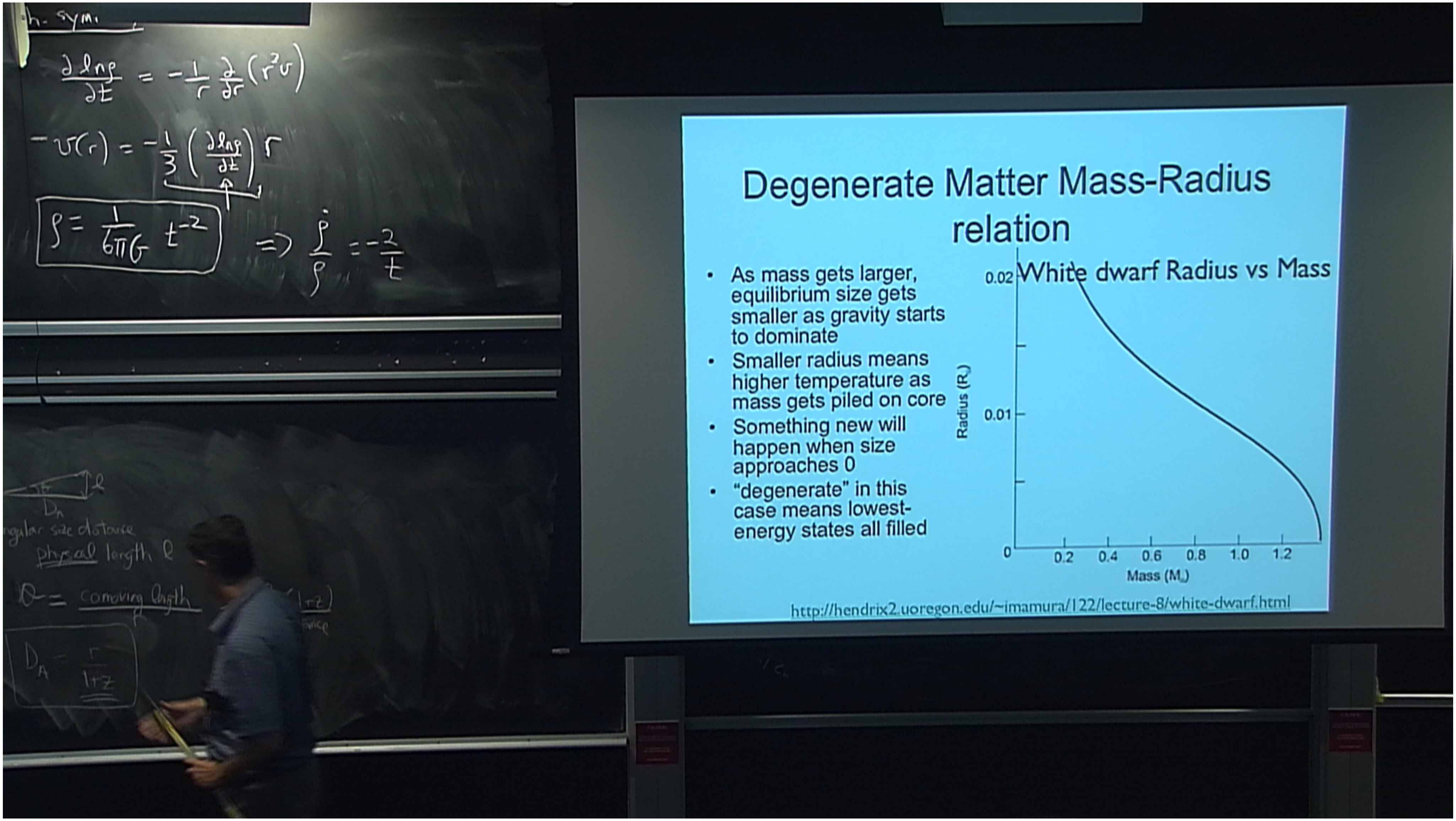
Cepheid Variables
• Large variations over several days
• Empirical tight correlation between timescale of variation and luminosity
• So, measure the period, you know its brightness!
Brightness variation of δ-Cephei
3.6 - 4.3 Magnitude
5.4 days
Period
Apparent Magnitude
Time (days)
The period-luminosity relation for Cepheid variables.
Absolute Magnitude
Period in days
http://hyperphysics.phy-astr.gsu.edu/nave-html/Faithpathh/astdat.html

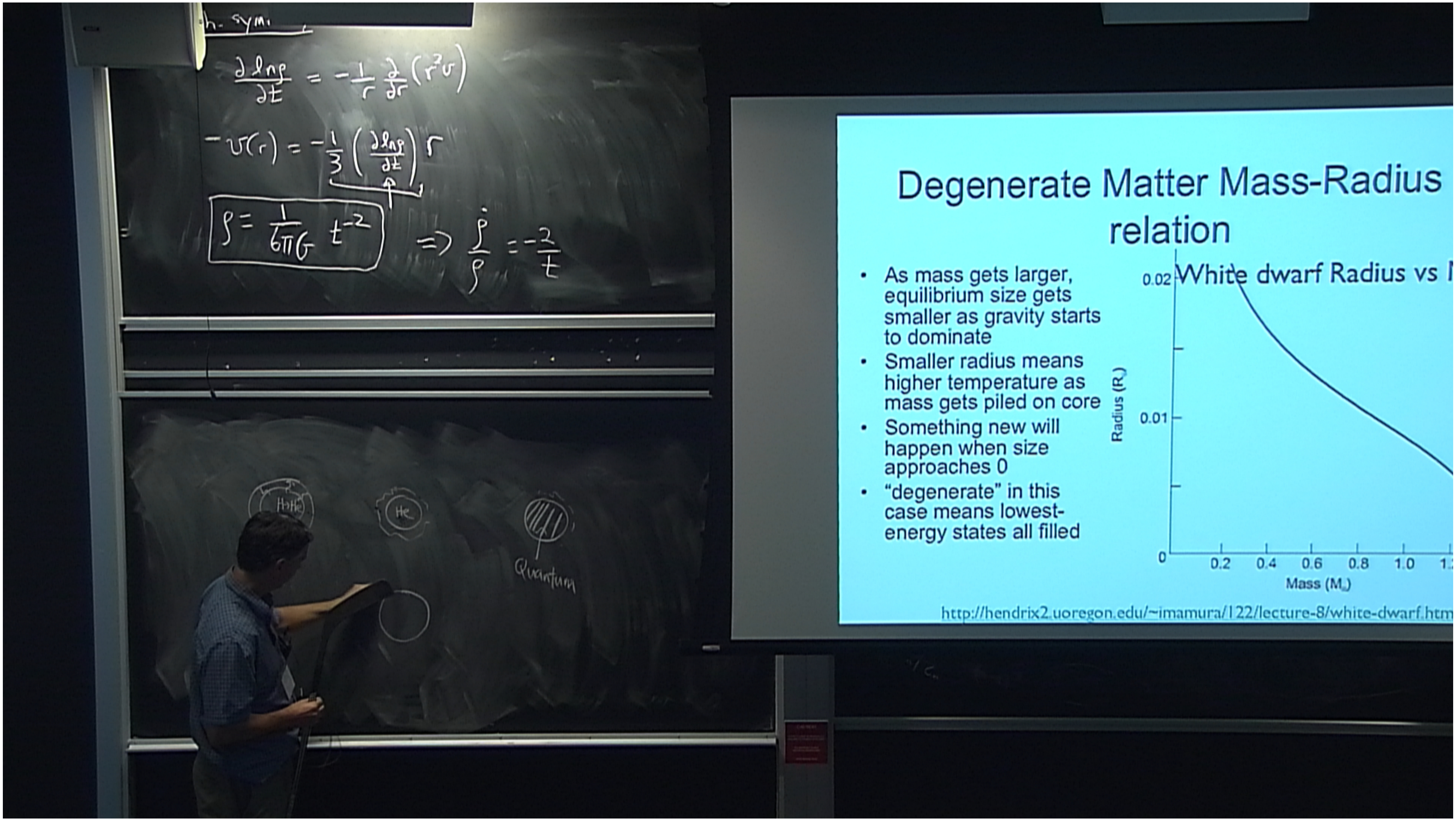


Hubble's Law
Things that are further away are moving away from us faster !
FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.
Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.
Hubble (1929)


The Expanding Universe
Since gravity is always pulling in, the expansion should be always slowing, right?
Radius of the Universe
Open Universe – continued expansion
Flat Universe – expansion but slowing
Closed Universe – the Big Crunch
Time since the Big Bang
http://www.schoolphysics.co.uk/


Measuring cosmic expansion
• Type IA supernovae can be seen across the universe, with known intrinsic brightnesses
HST04Sas
HST04Yow
HST04Zwi
HST05Lan
HST05Str
Host Galaxies of Distant Supernovae
Hubble Space Telescope • Advanced Camera for Surveys
NASA, ESA, and A. Riess (STScI)
STScI-PRC06-52


Degenerate Matter Mass-Radius relation
As mass gets larger, equilibrium size gets smaller as gravity starts to dominate
Smaller radius means higher temperature as mass gets piled on core
Something new will happen when size approaches 0
"degenerate" in this case means lowest-energy states all filled
White dwarf Radius vs Mass
0.02
0.01
0
Radius (R☉)
0.2
0.4
0.6
0.8
1.0
1.2
Mass (M☉)
http://hendrix2.uoregon.edu/~imamura/122/lecture-8/white-dwarf.html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Radius (R⊙)
0.02
0.01
0
0.2
0.4
0.6
0.8
1.0
Mass (M⊙)
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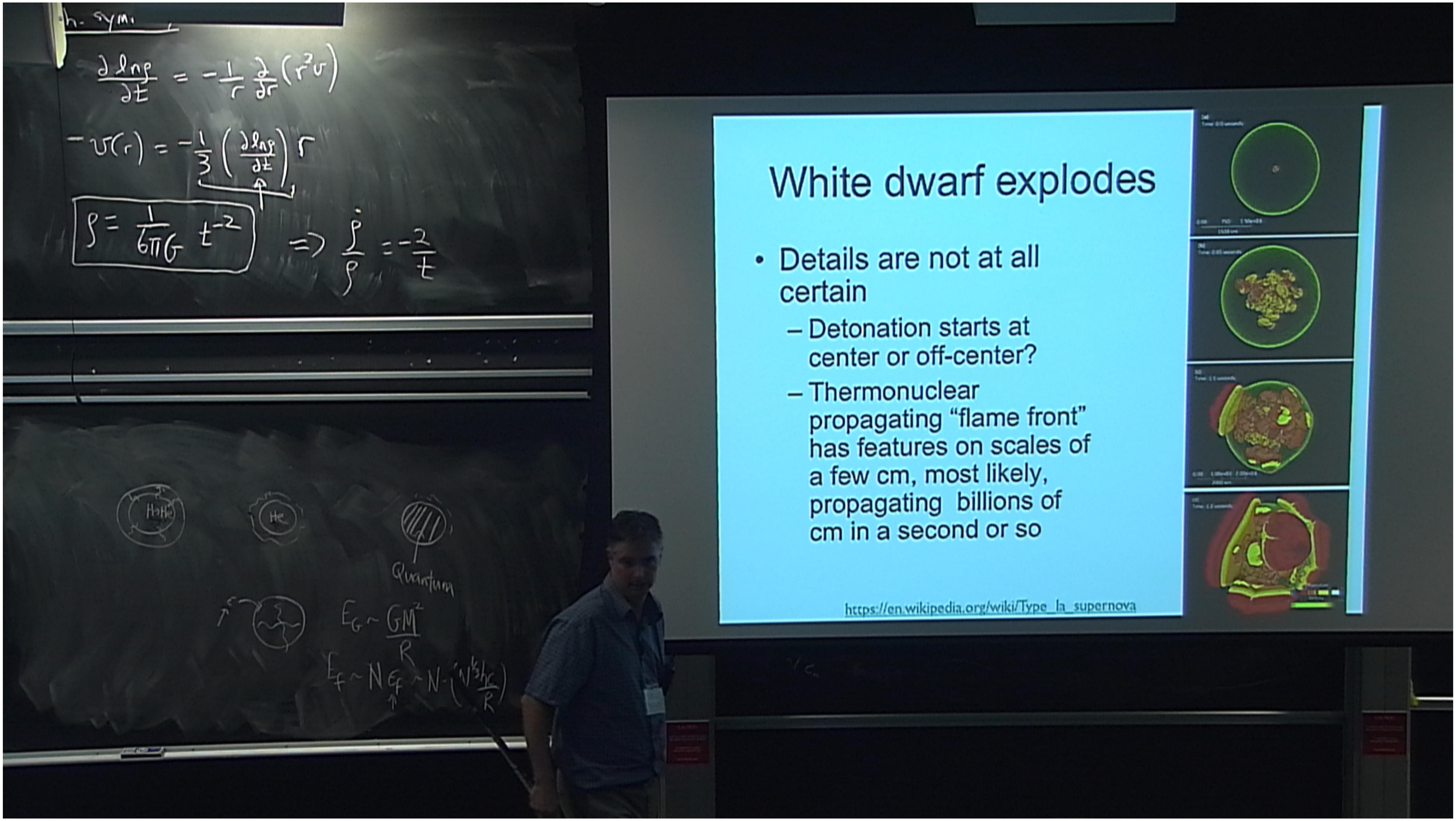
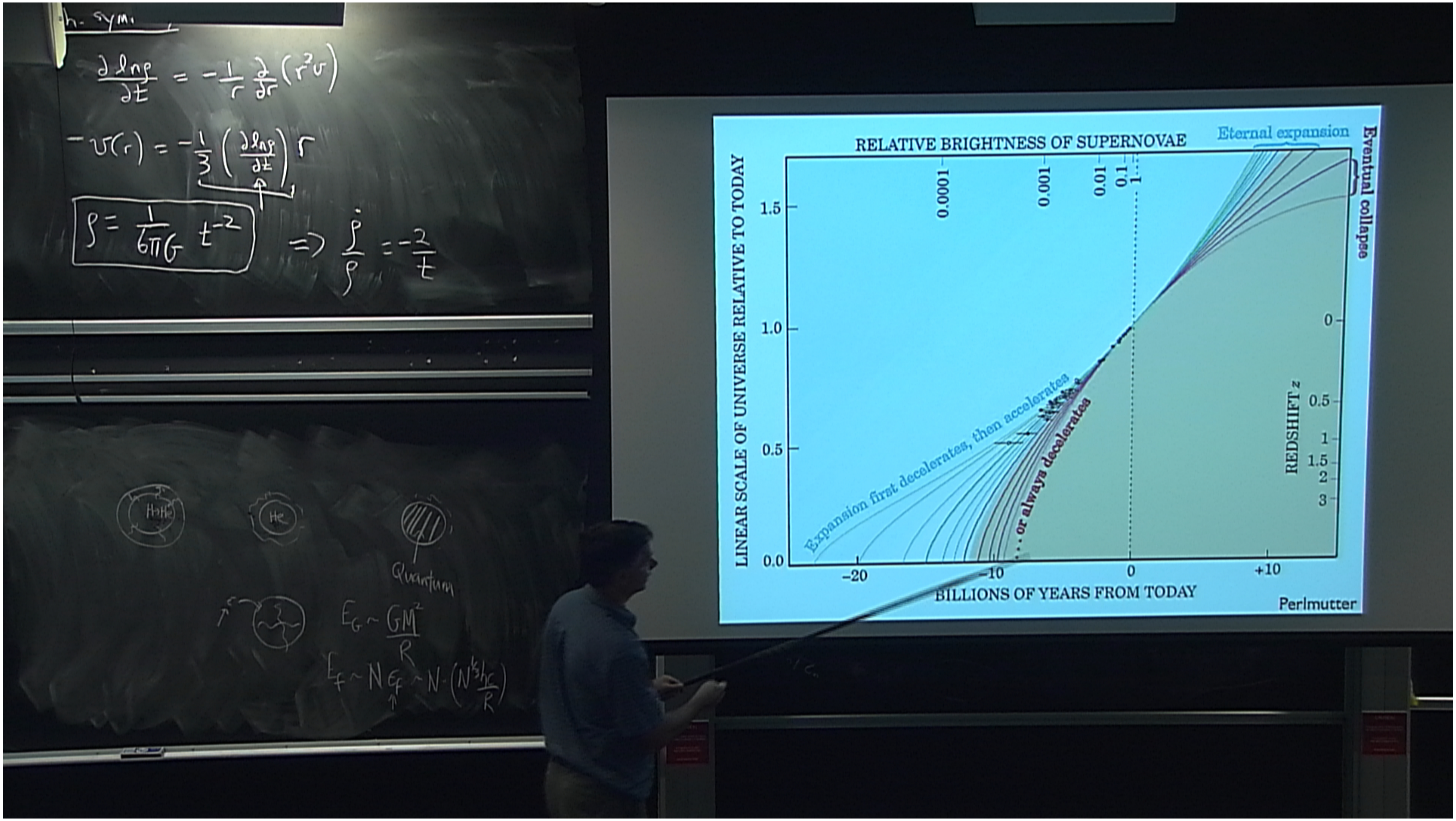
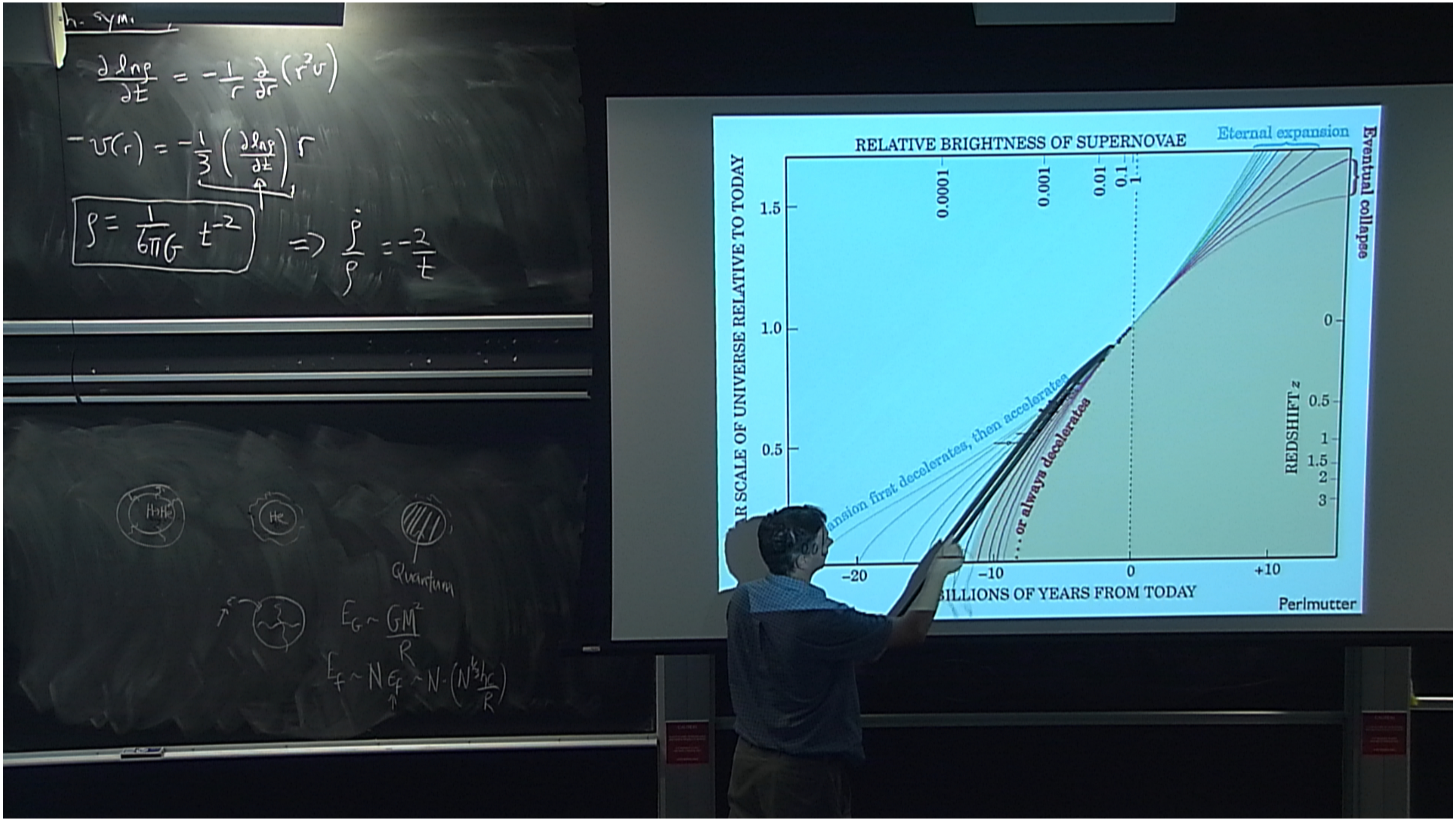
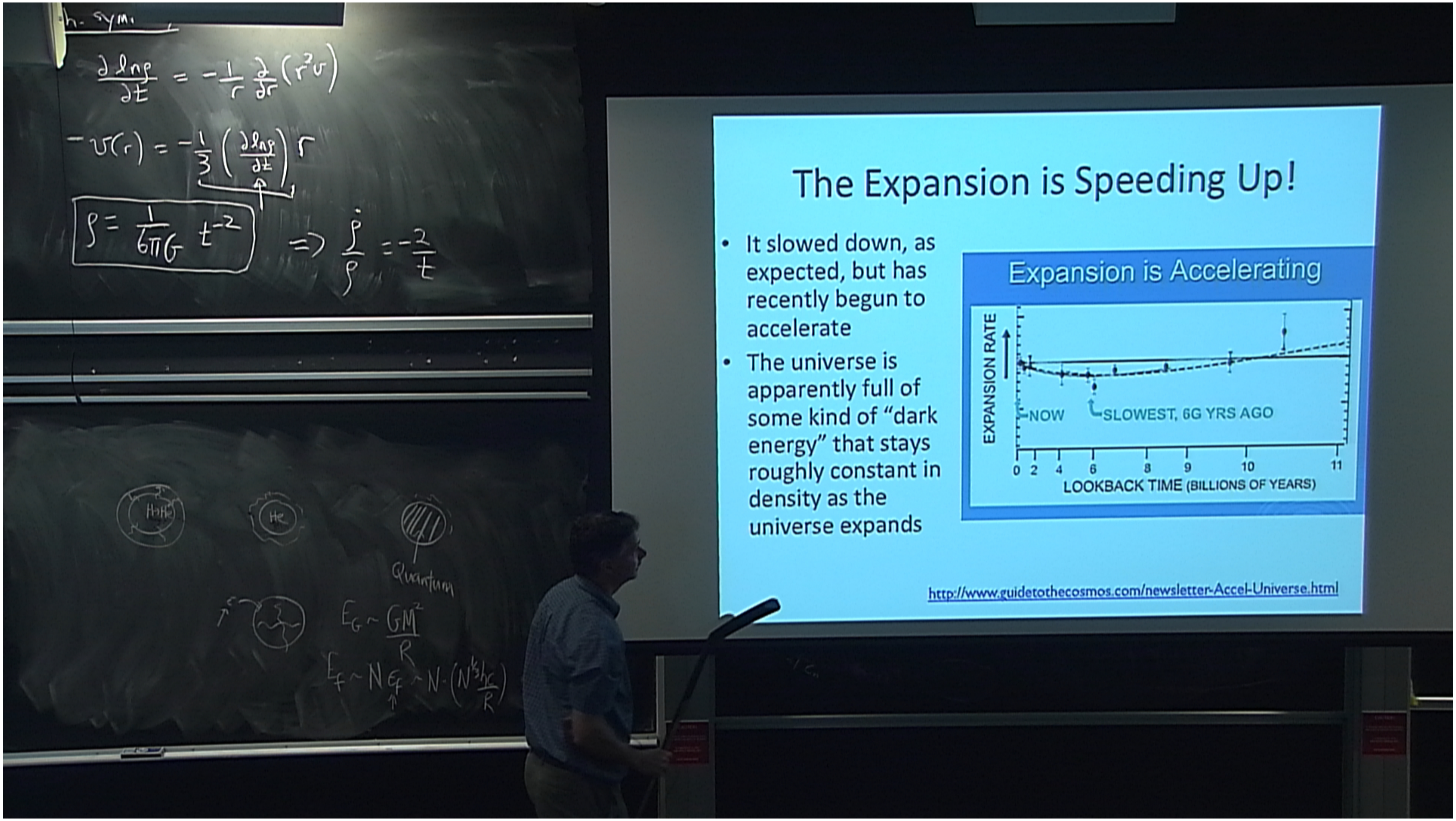
Quantum


White dwarf explodes
• Details are not at all certain
– Detonation starts at center or off-center?
– Thermonuclear propagating “flame front” has features on scales of a few cm, most likely, propagating billions of cm in a second or so
https://en.wikipedia.org/wiki/Type_Ia_supernova


RELATIVE BRIGHTNESS OF SUPERNOVAE
Eternal expansion
Eventual collapse
LINEAR SCALE OF UNIVERSE RELATIVE TO TODAY
Expansion first decelerates, then accelerates
or always decelerates
BILLIONS OF YEARS FROM TODAY
REDSHIFT z
Perlmutter


RELATIVE BRIGHTNESS OF SUPERNOVAE
Eternal expansion
Eventual collapse
0.0001
0.001
0.01
0.1
1
1.5
1.0
0.5
0
0.5
1
1.5
2
3
REDSHIFT z
ansion first decelerates, then accelerates
or always decelerates
R SCALE OF UNIVERSE RELATIVE TO TODAY
-20
-10
0
+10
BILLIONS OF YEARS FROM TODAY
Perlmutter
Quantum



The Expansion is Speeding Up!
It slowed down, as expected, but has recently begun to accelerate
The universe is apparently full of some kind of "dark energy" that stays roughly constant in density as the universe expands
Expansion is Accelerating
EXPANSION RATE
NOW
SLOWEST, 6G YRS AGO
0 2 4 6 8 9 10 11
LOOKBACK TIME (BILLIONS OF YEARS)
http://www.guidetothecosmos.com/newsletter-Accel-Universe.html

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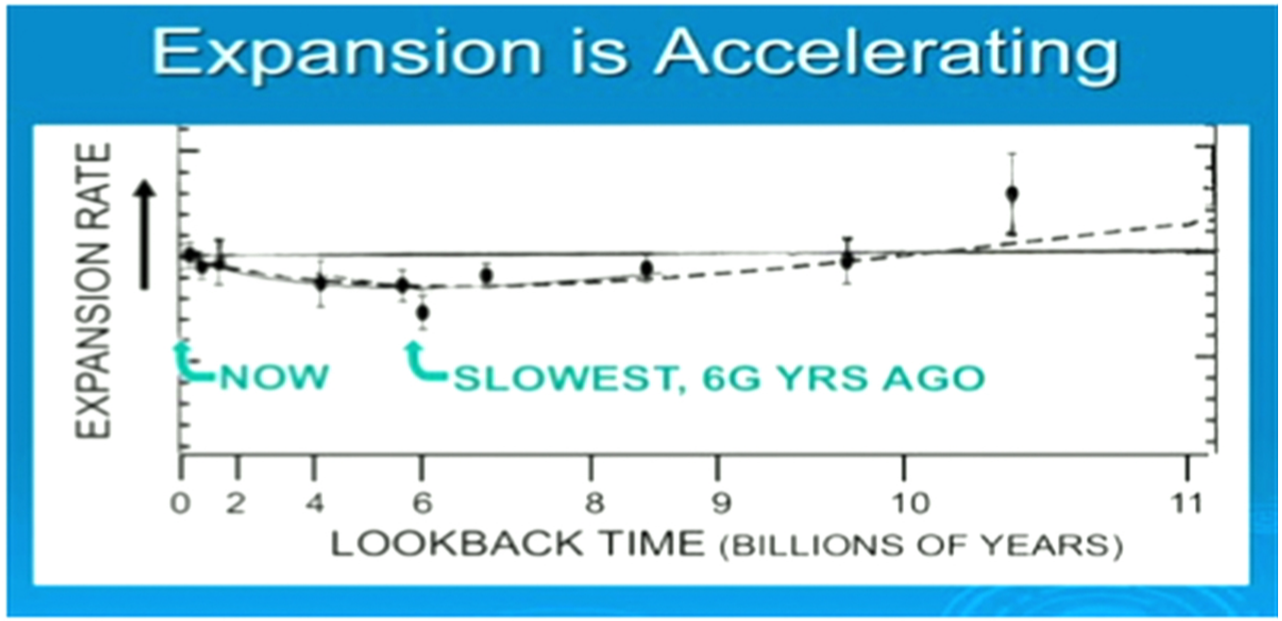

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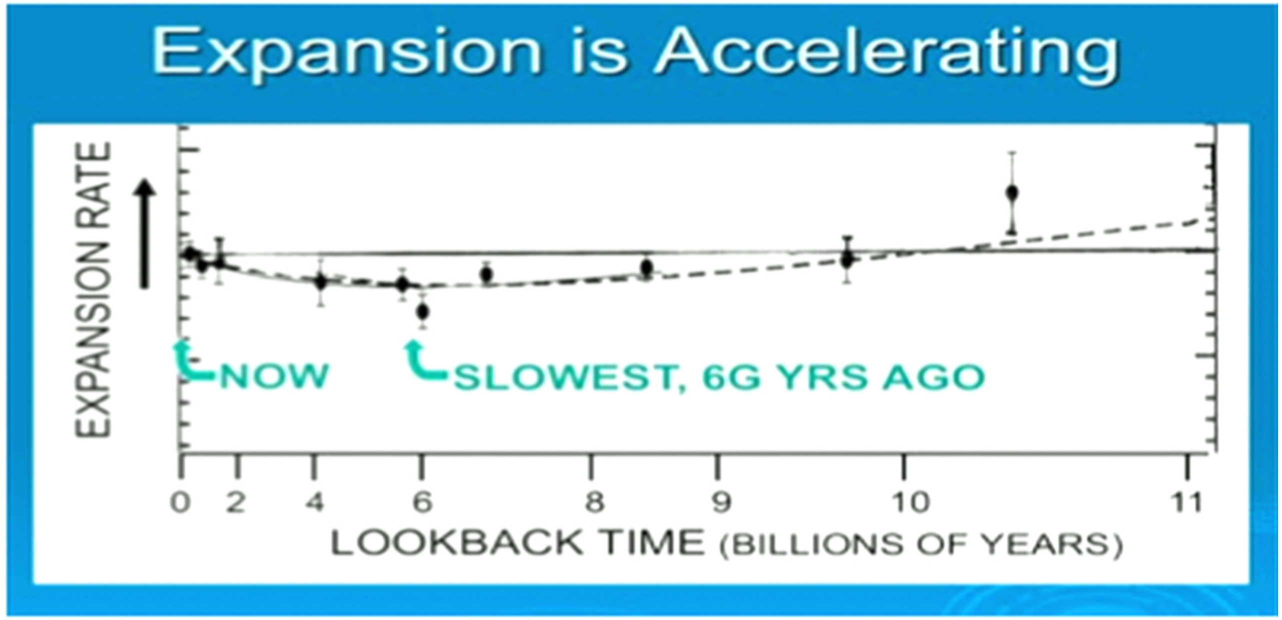

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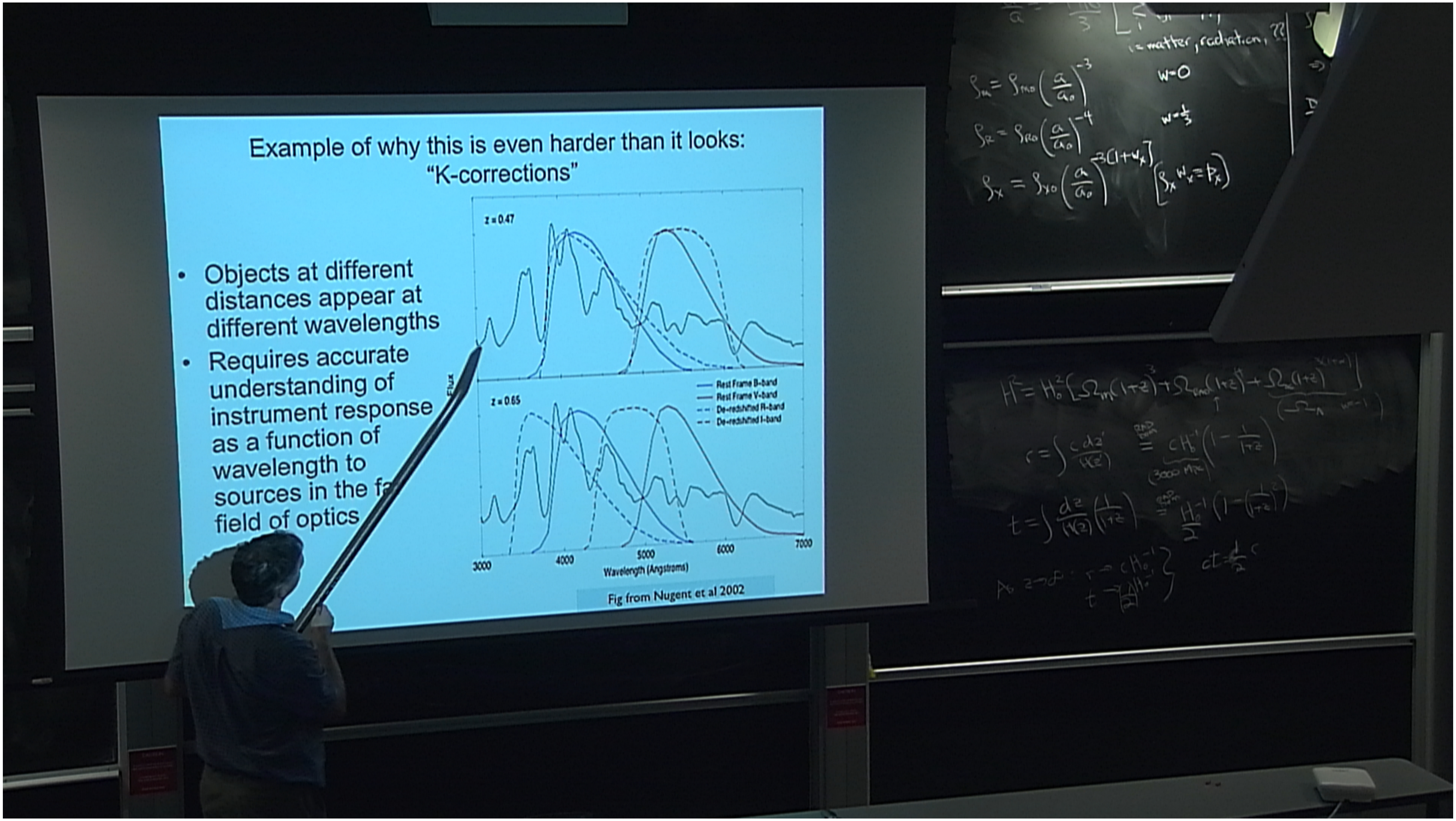
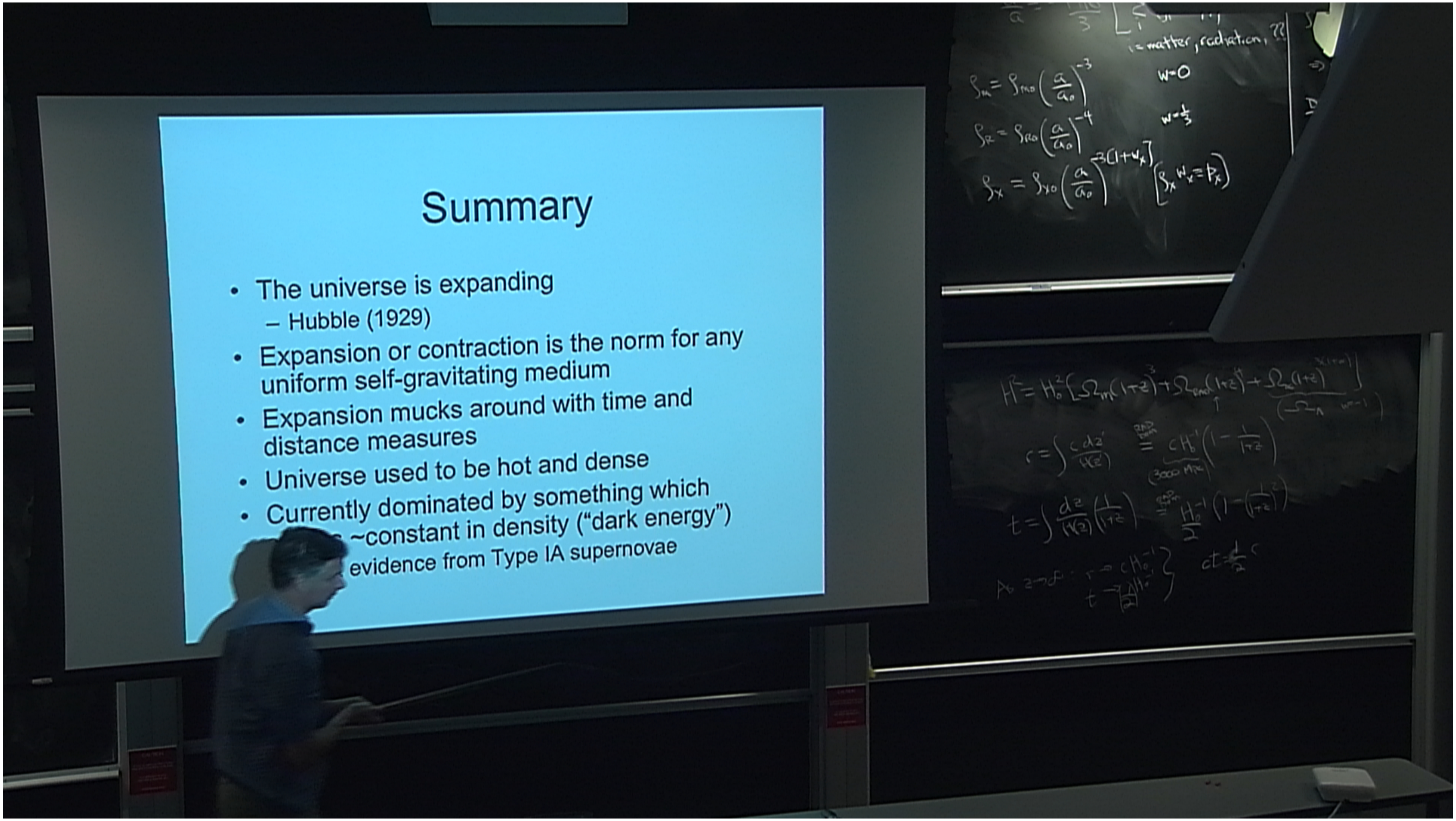


Example of why this is even harder than it looks:
"K-corrections"
• Objects at different distances appear at different wavelengths
• Requires accurate understanding of instrument response as a function of wavelength to sources in the fa field of optics
z = 0.47
z = 0.65
Flux
Rest Frame B-band
Rest Frame V-band
De-redshifted R-band
De-redshifted I-band
3000
4000
5000
6000
7000
Wavelength (Angstroms)
Fig from Nugent et al 2002


Summary
• The universe is expanding
– Hubble (1929)
• Expansion or contraction is the norm for any uniform self-gravitating medium
• Expansion mucks around with time and distance measures
• Universe used to be hot and dense
• Currently dominated by something which
~constant in density ("dark energy")
evidence from Type IA supernovae