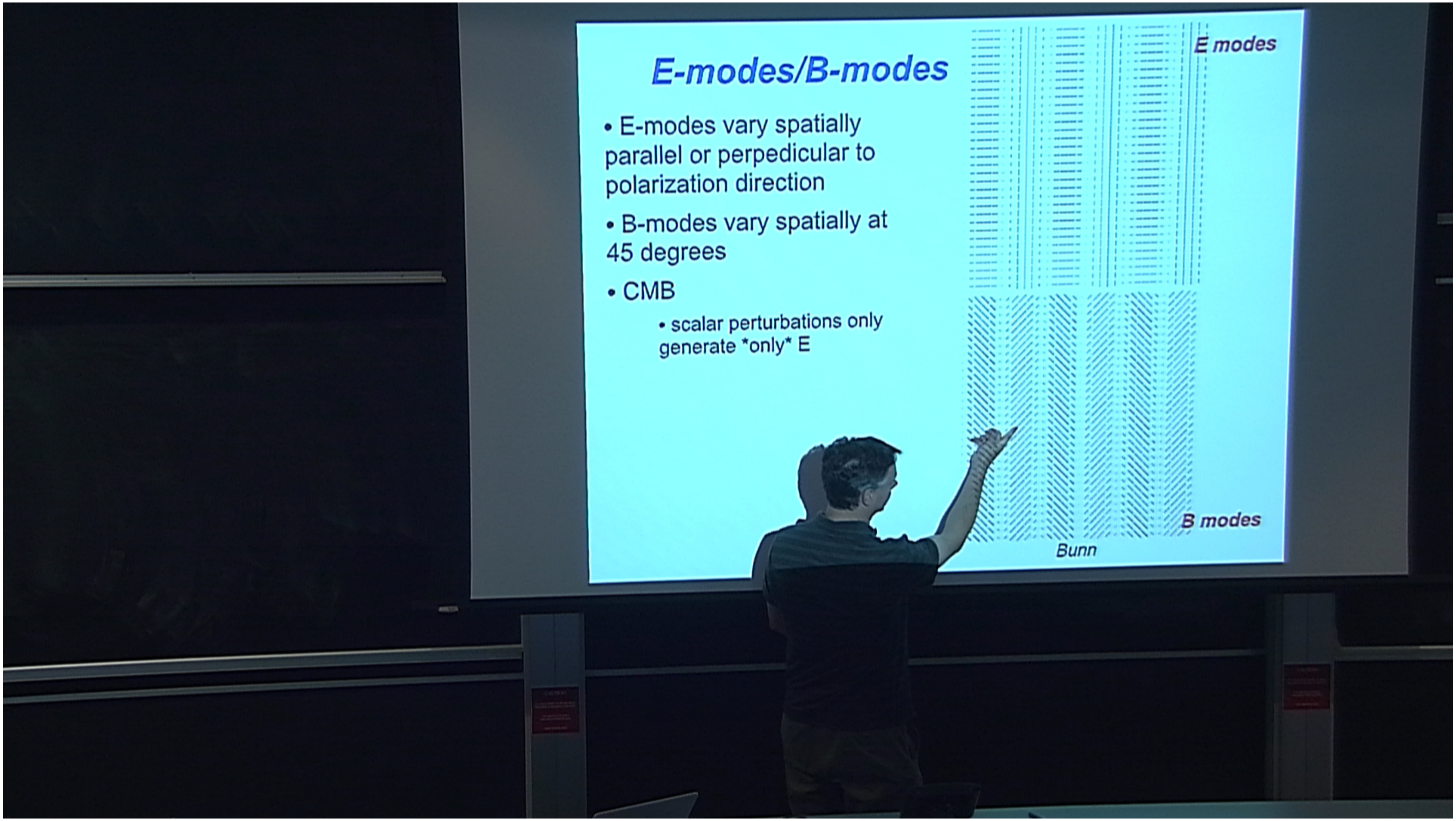
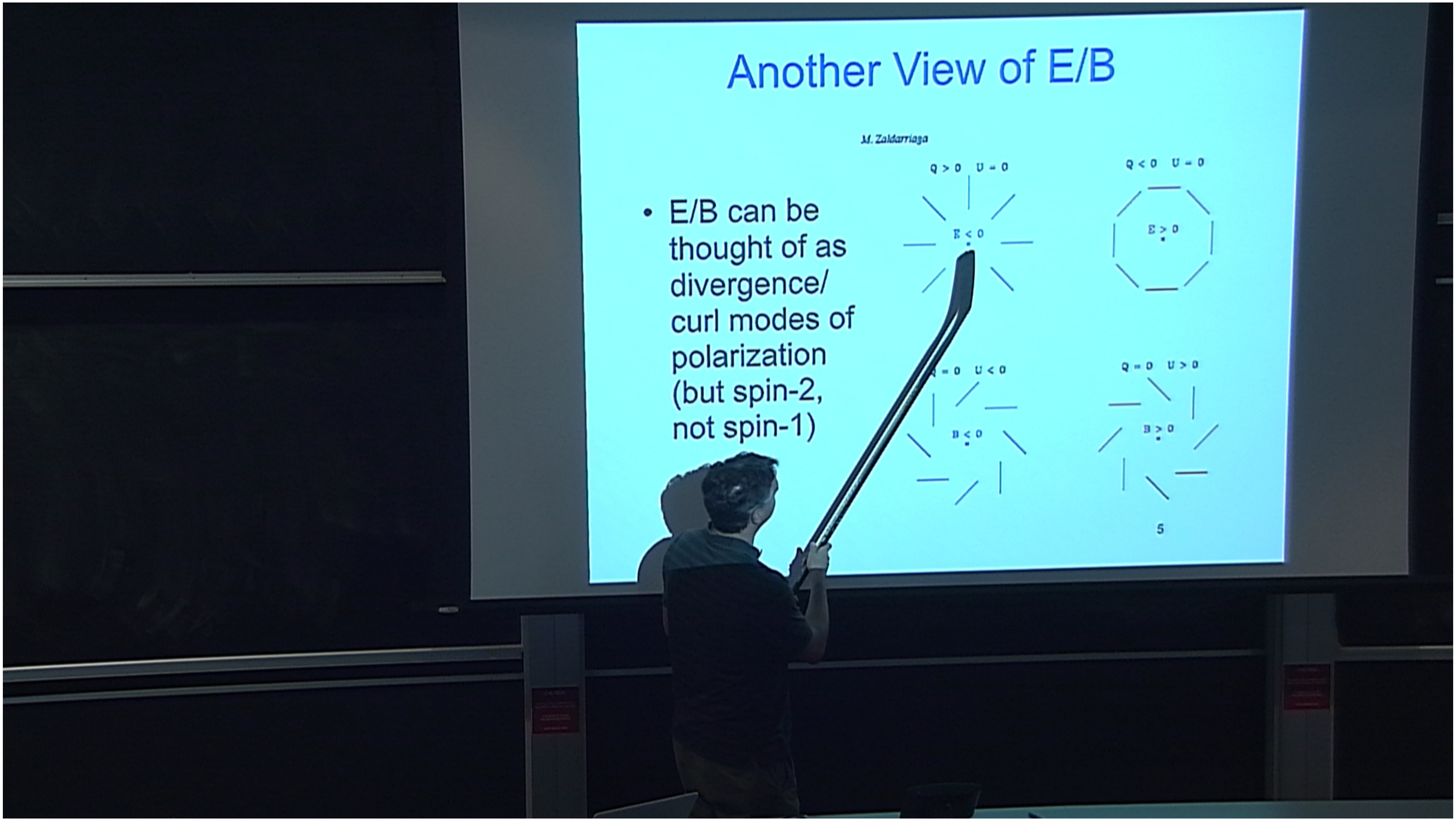
Title: Cosmology â€“ Observations: Galaxy clustering

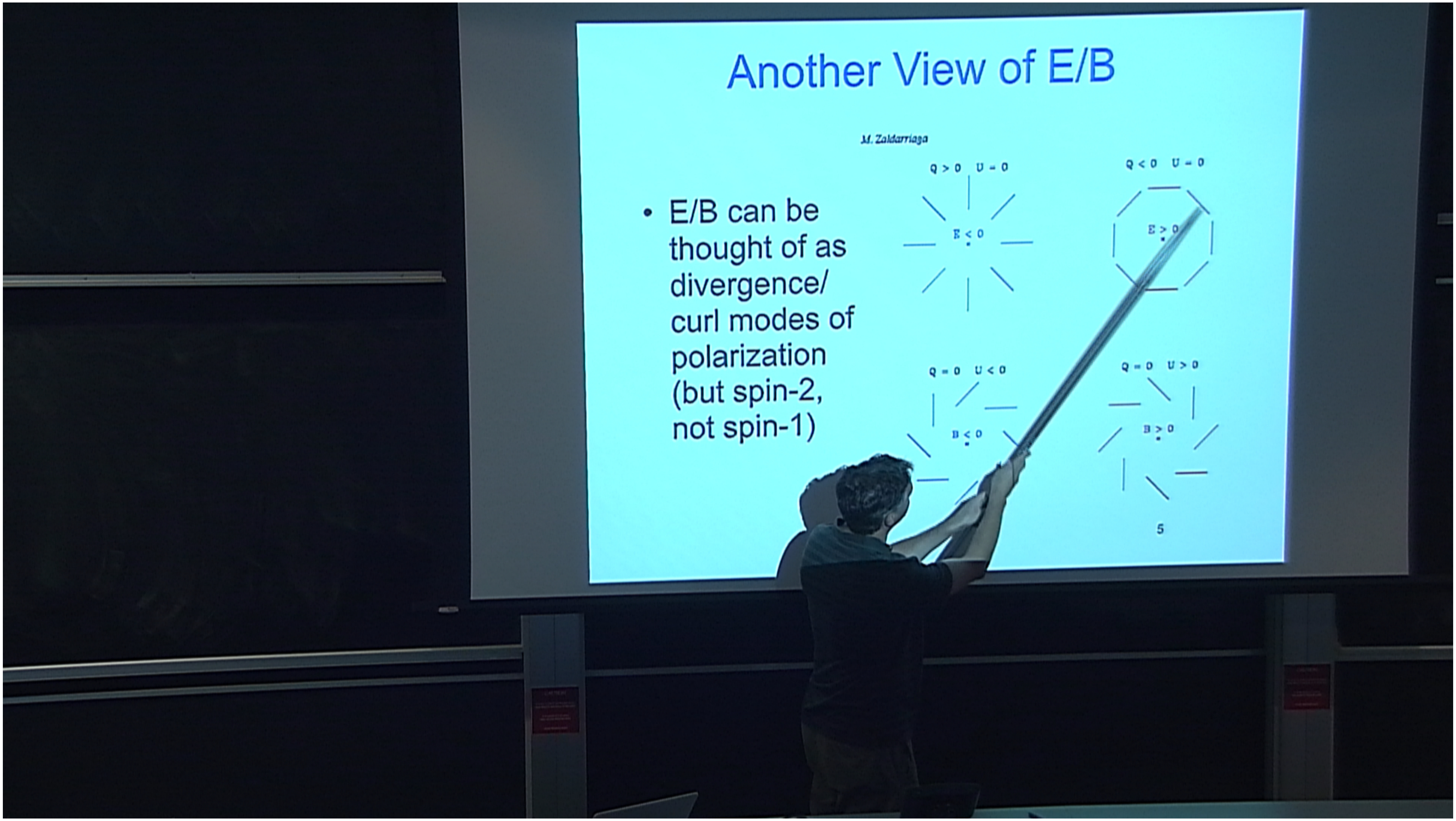
Date: Jul 15, 2015 11:45 AM

URL: http://pirsa.org/15070049

Abstract:


E-modes/B-modes
• E-modes vary spatially parallel or perpedicular to polarization direction
• B-modes vary spatially at 45 degrees
• CMB
• scalar perturbations only generate *only* E
E modes
B modes
Bunn


Another View of E/B
M. Zaldarriaga
• E/B can be thought of as divergence/ curl modes of polarization (but spin-2, not spin-1)
Q > 0 U = 0
E < 0
Q < 0 U = 0
E > 0
U < 0
B < 0
Q = 0 U > 0
B > 0
5



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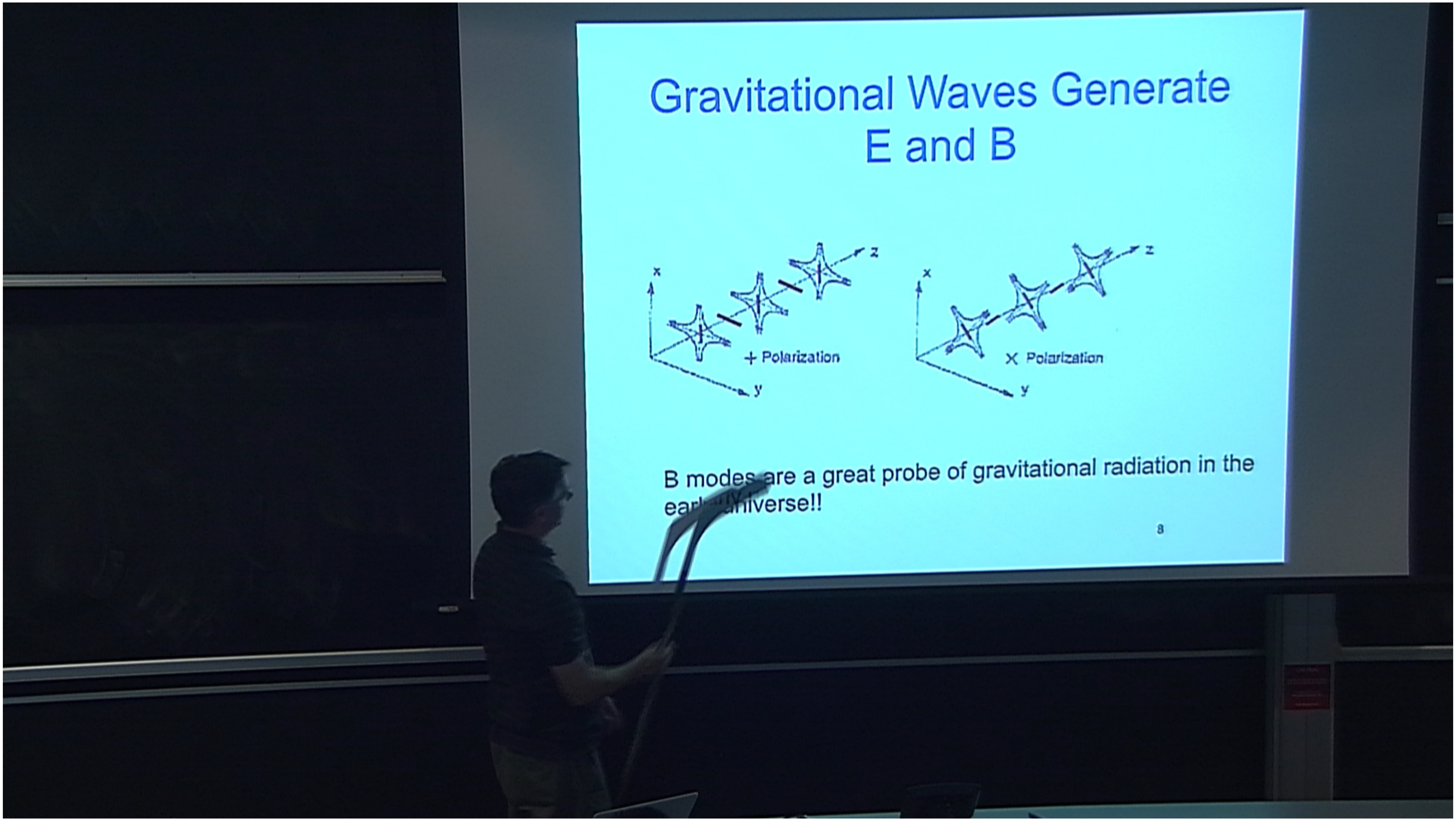
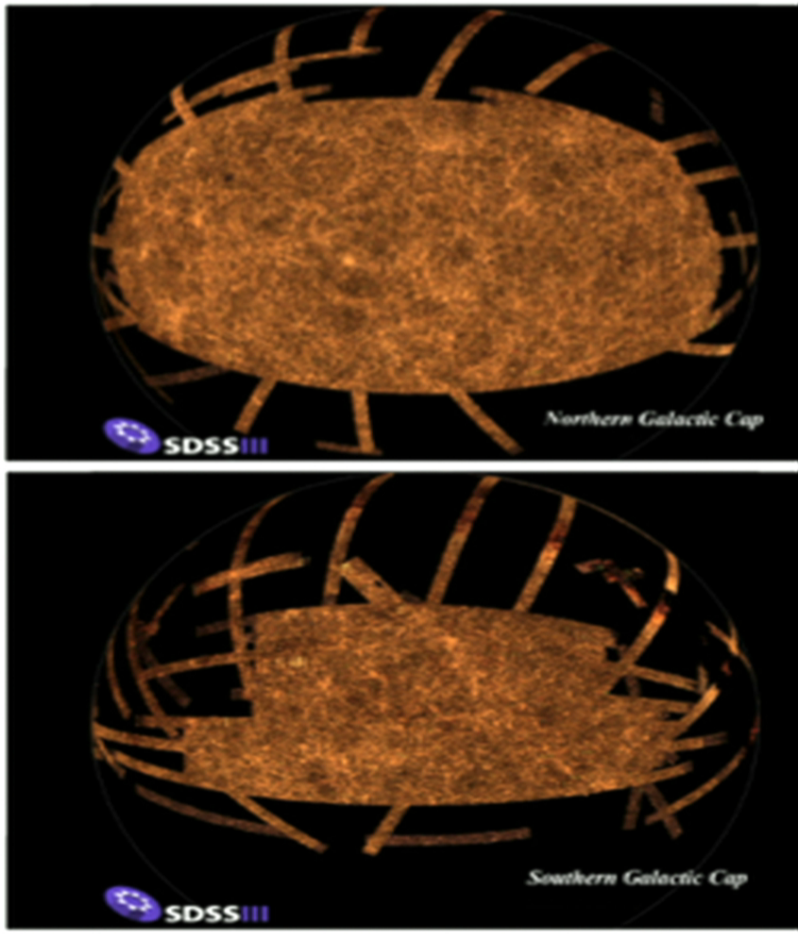

Gravitational Waves Generate
E and B
x
y
z
+ Polarization
x
y
z
X Polarization
B modes are a great probe of gravitational radiation in the
iverse!!
8


Galaxy Surveys
• look at a patch of extragalactic sky, count up galaxies
https://archive.stsci.edu/cgi-bin/dss_form

Is the galaxy distribution random?

- hard to say, looks sort of random…
- survey geometry pretty clear
- looks a bit too wispy and splotchy to be random?



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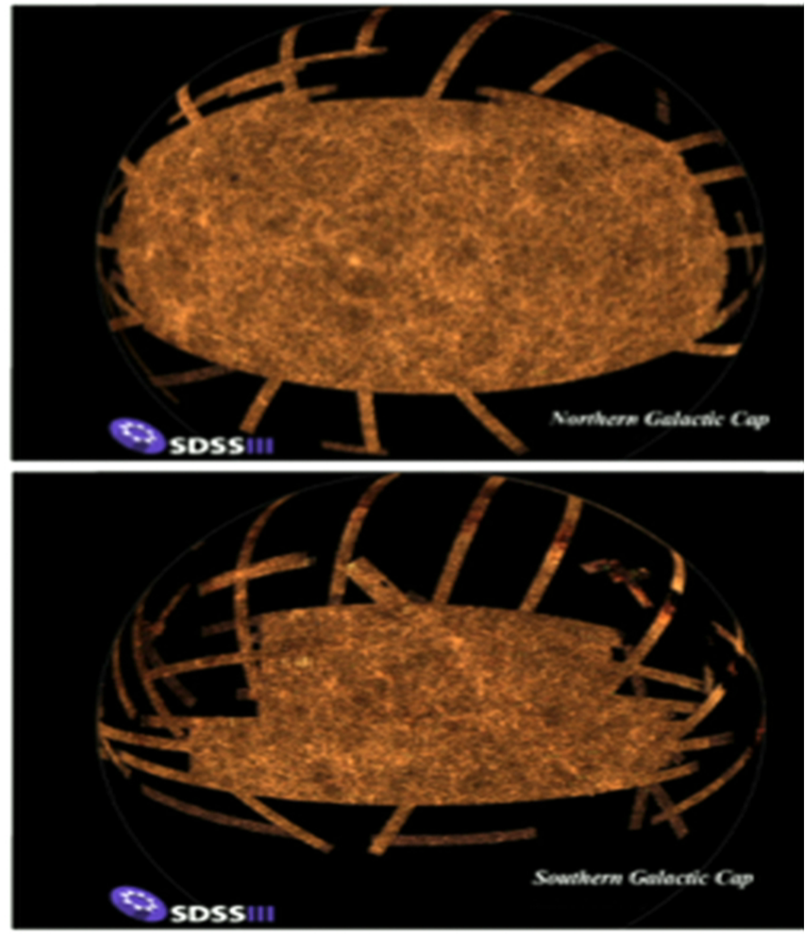

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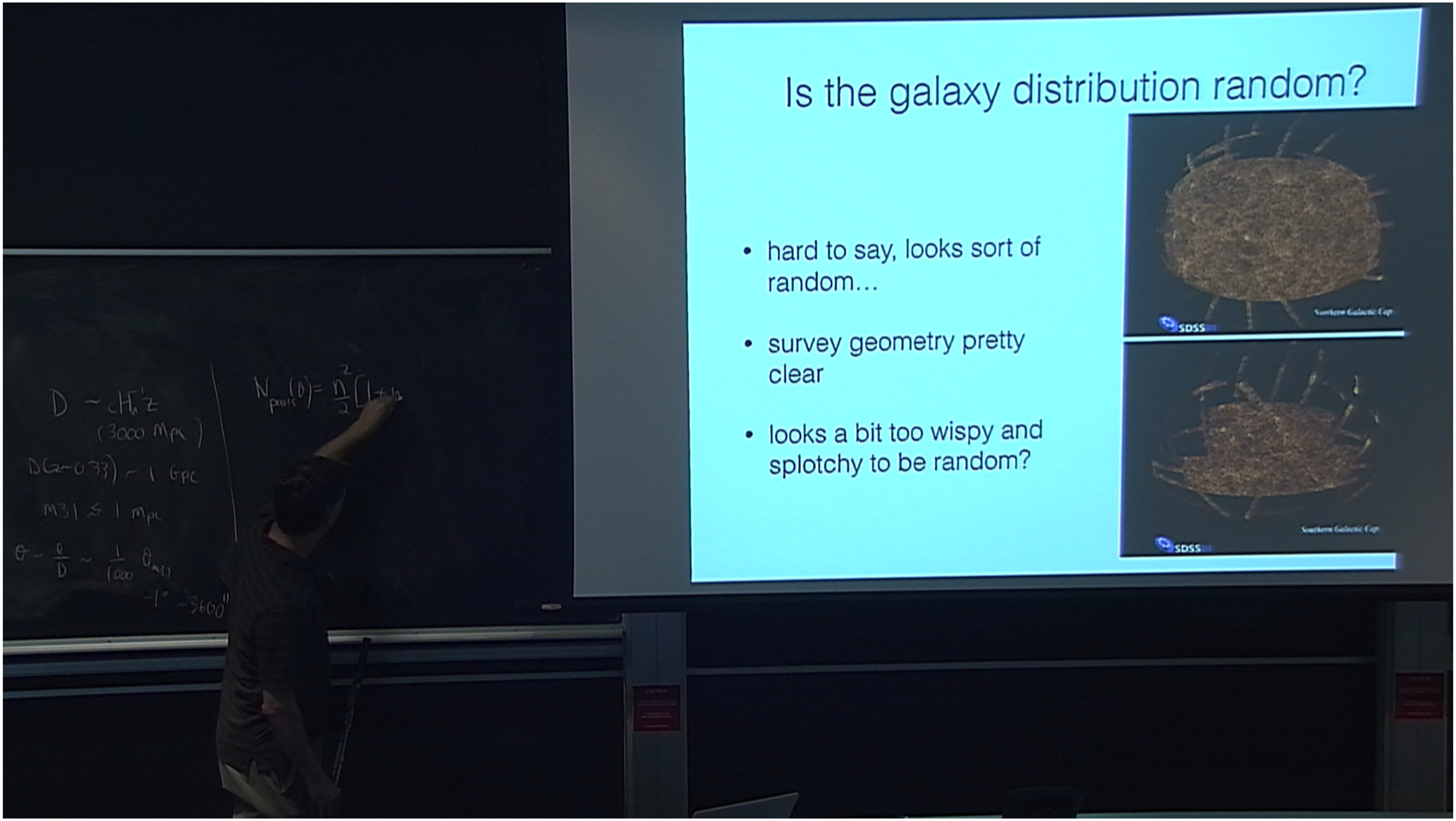
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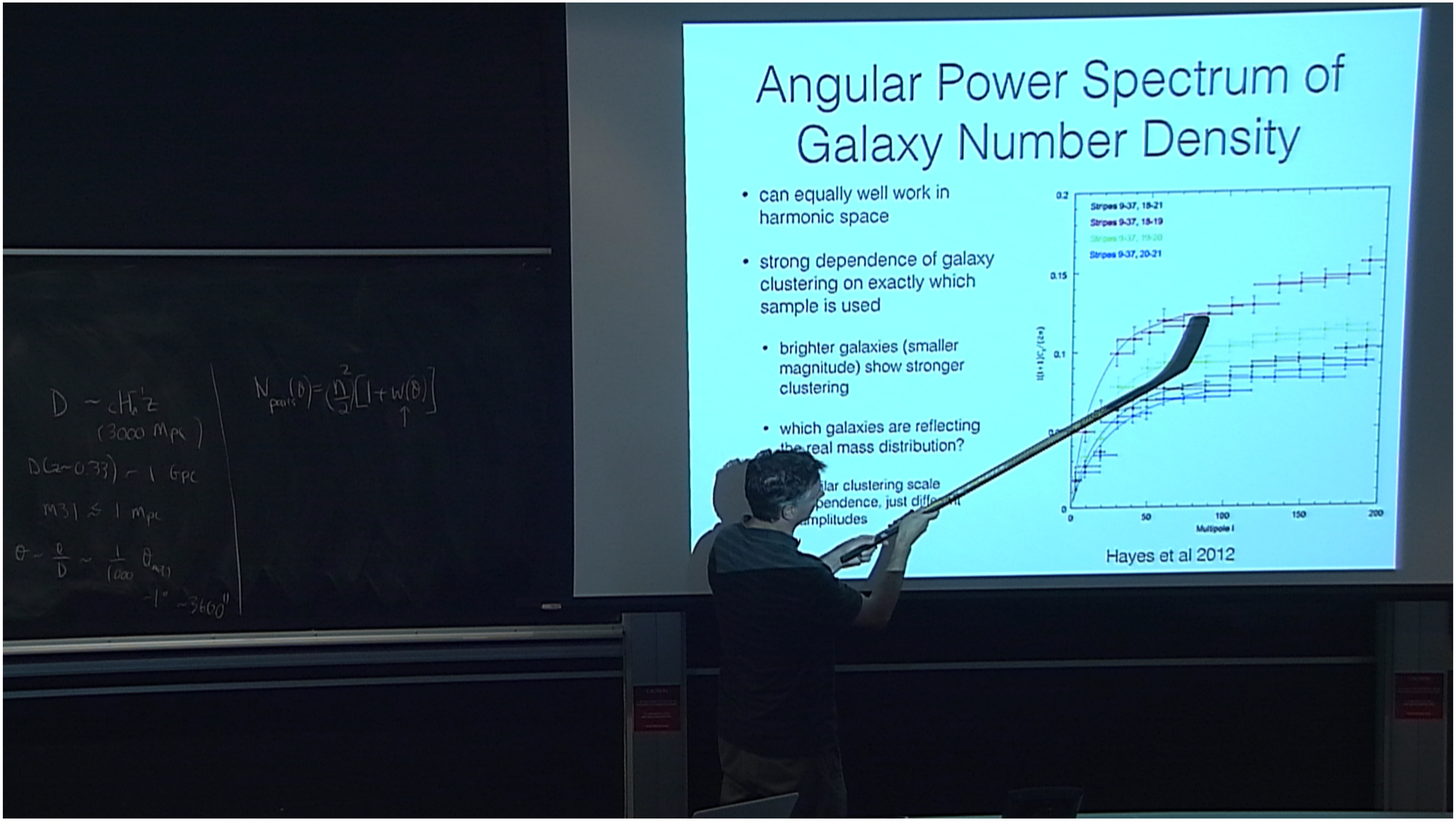
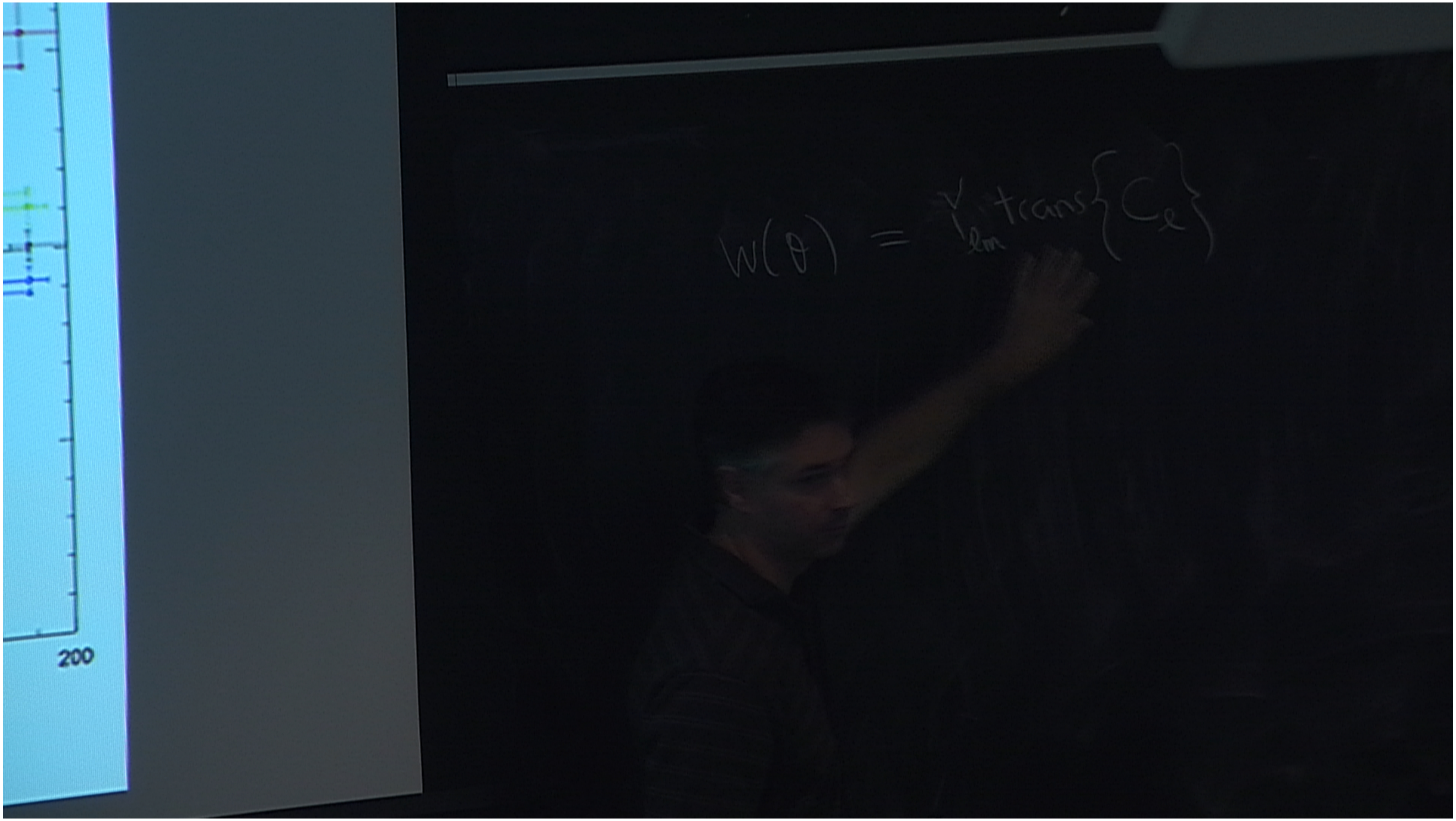
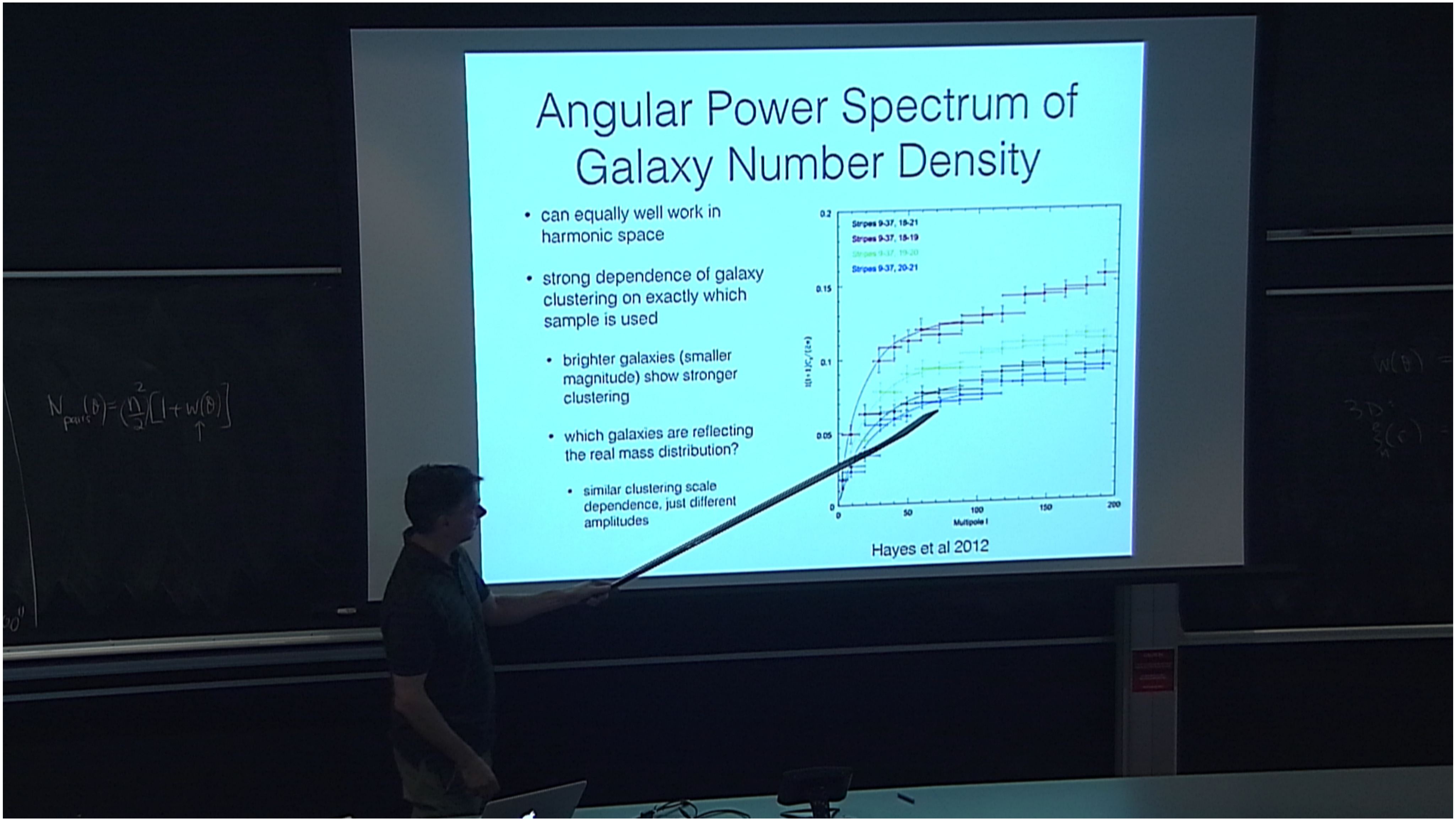
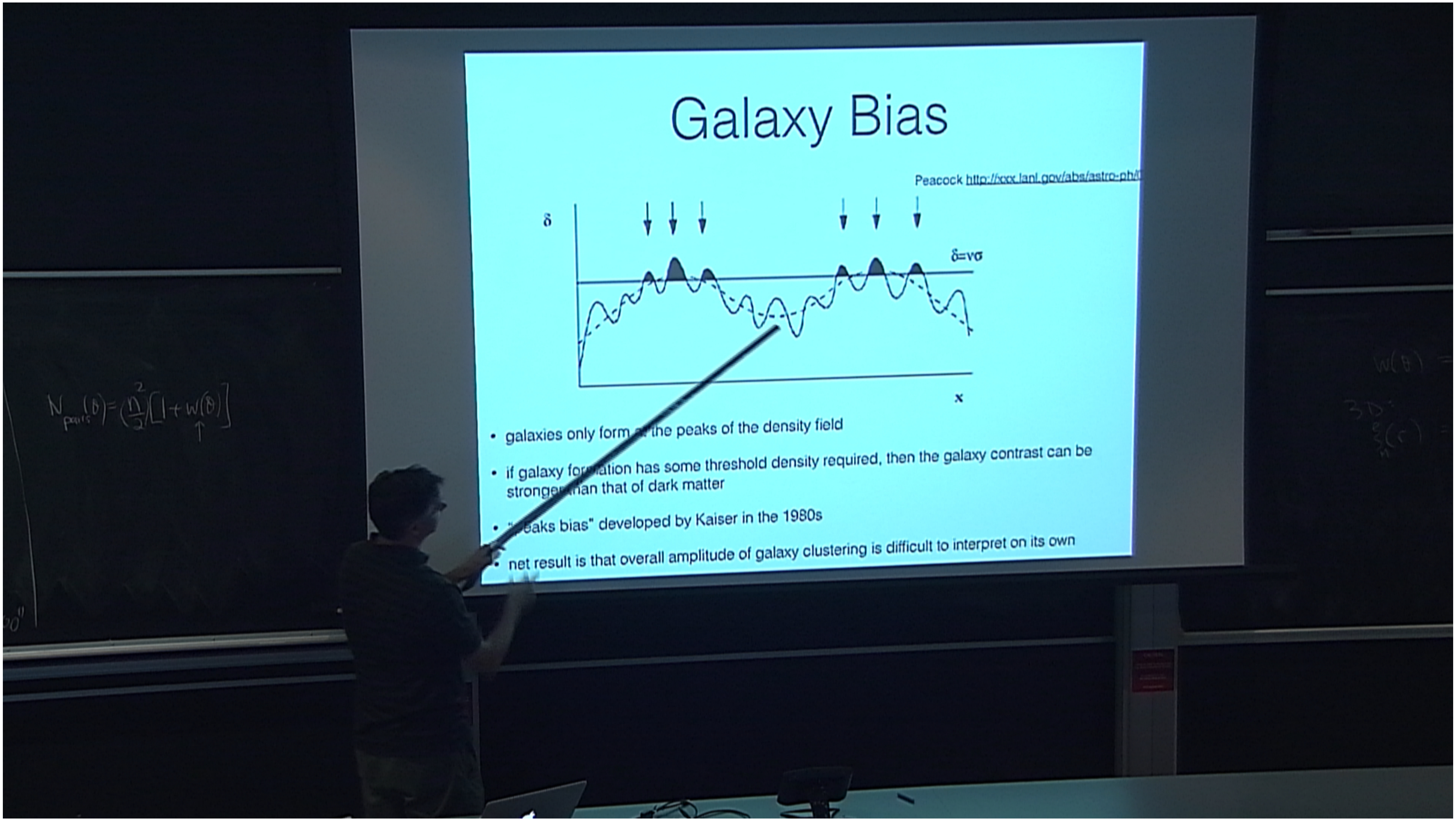
SDSS
SDSS

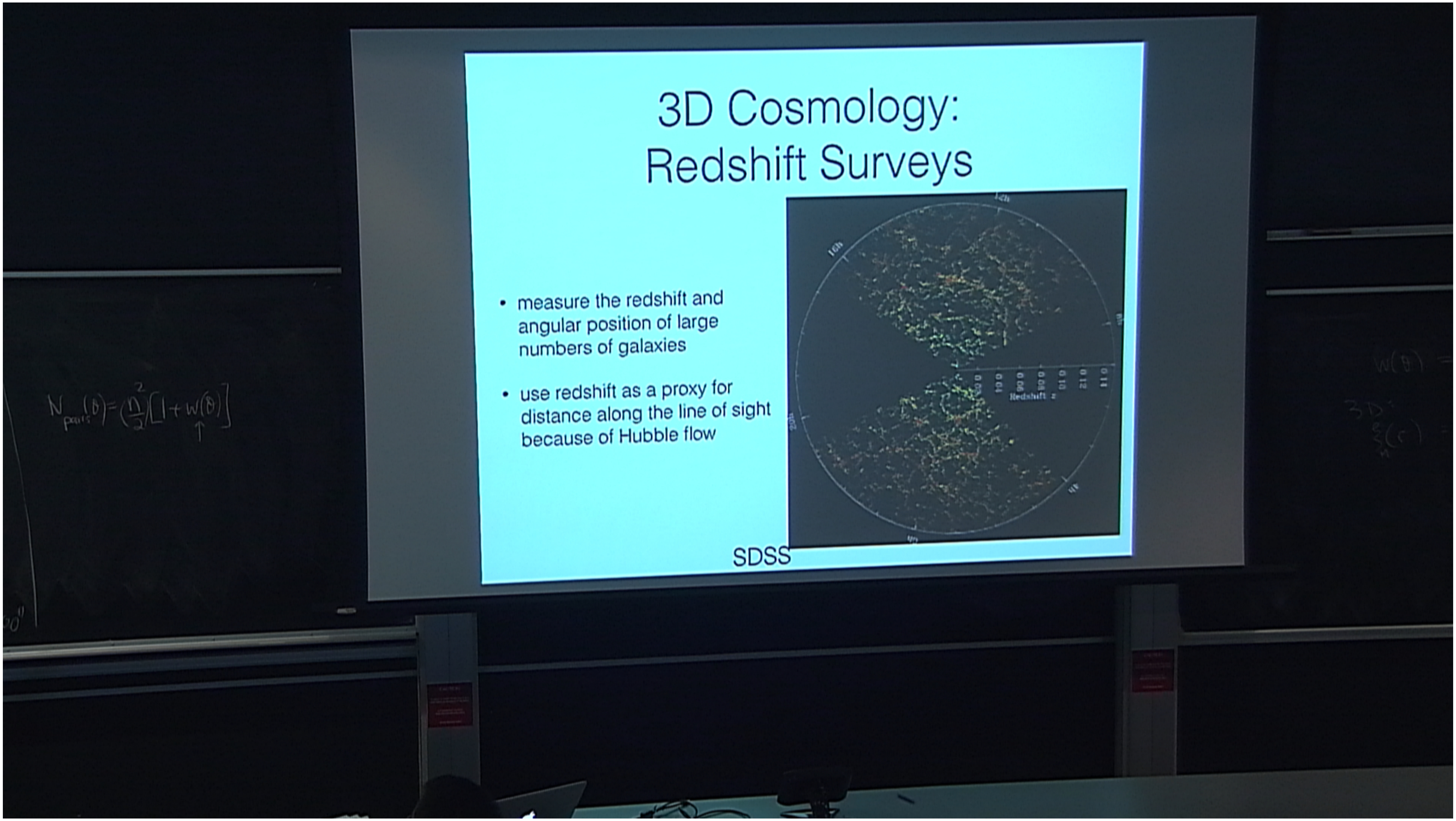


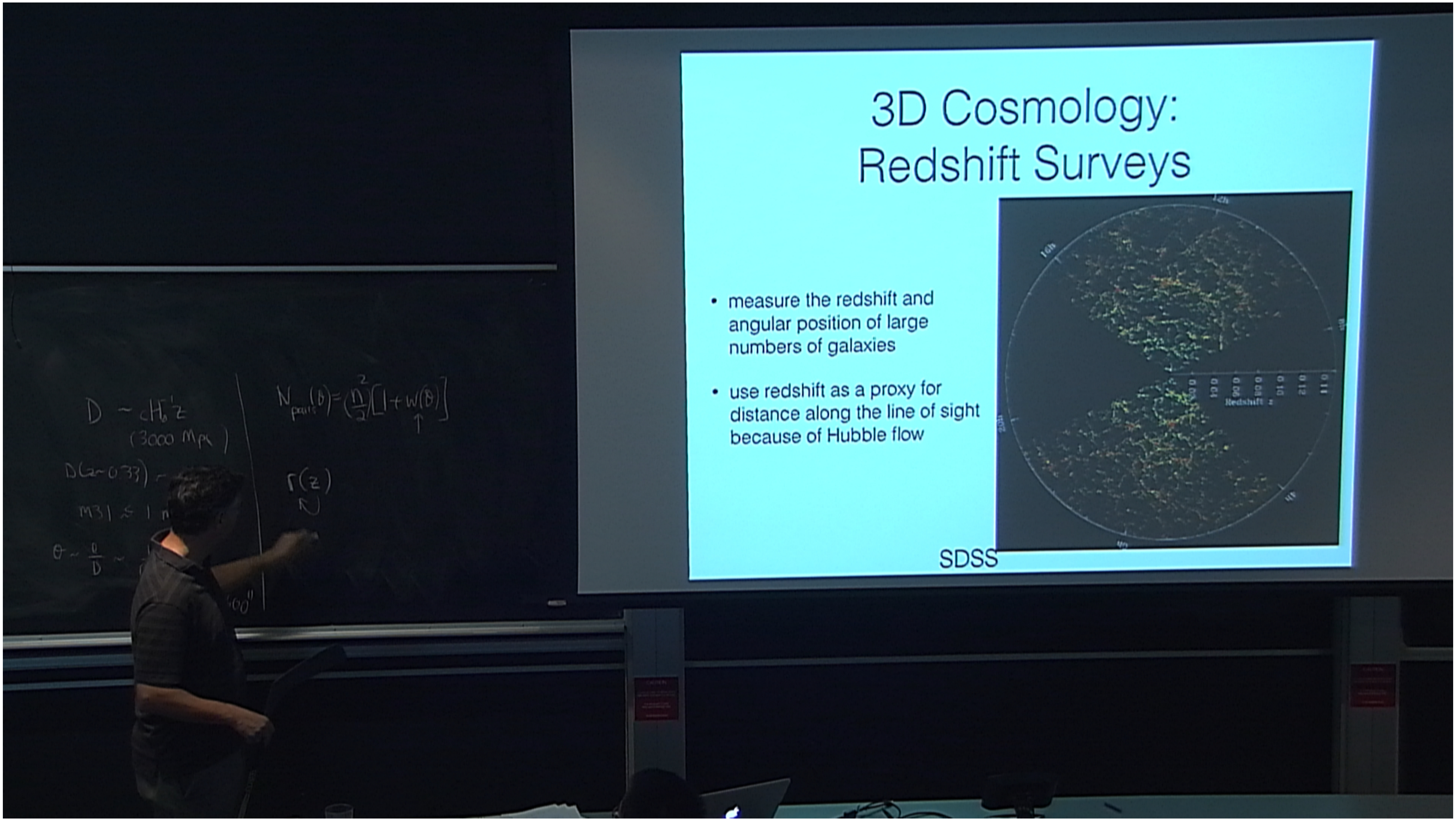
Angular Power Spectrum of Galaxy Number Density
can equally well work in harmonic space
strong dependence of galaxy clustering on exactly which sample is used
brighter galaxies (smaller magnitude) show stronger clustering
which galaxies are reflecting the real mass distribution?
Stripes 9-37, 18-21
Stripes 9-37, 18-19
Stripes 9-37, 19-20
Stripes 9-37, 20-21
Multipole l
Hayes et al 2012


200
W(θ) = Y_lm trans{C_ℓ}


Angular Power Spectrum of Galaxy Number Density
• can equally well work in harmonic space
• strong dependence of galaxy clustering on exactly which sample is used
• brighter galaxies (smaller magnitude) show stronger clustering
• which galaxies are reflecting the real mass distribution?
• similar clustering scale dependence, just different amplitudes
Multipole l
Hayes et al 2012


Galaxy Bias
Peacock http://xxx.lanl.gov/abs/astro-ph/
δ
δ=νσ
x
• galaxies only form at the peaks of the density field
• if galaxy formation has some threshold density required, then the galaxy contrast can be stronger than that of dark matter
• "peaks bias" developed by Kaiser in the 1980s
• net result is that overall amplitude of galaxy clustering is difficult to interpret on its own


3D Cosmology:
Redshift Surveys
• measure the redshift and angular position of large numbers of galaxies
• use redshift as a proxy for distance along the line of sight because of Hubble flow
SDSS



3D Cosmology:
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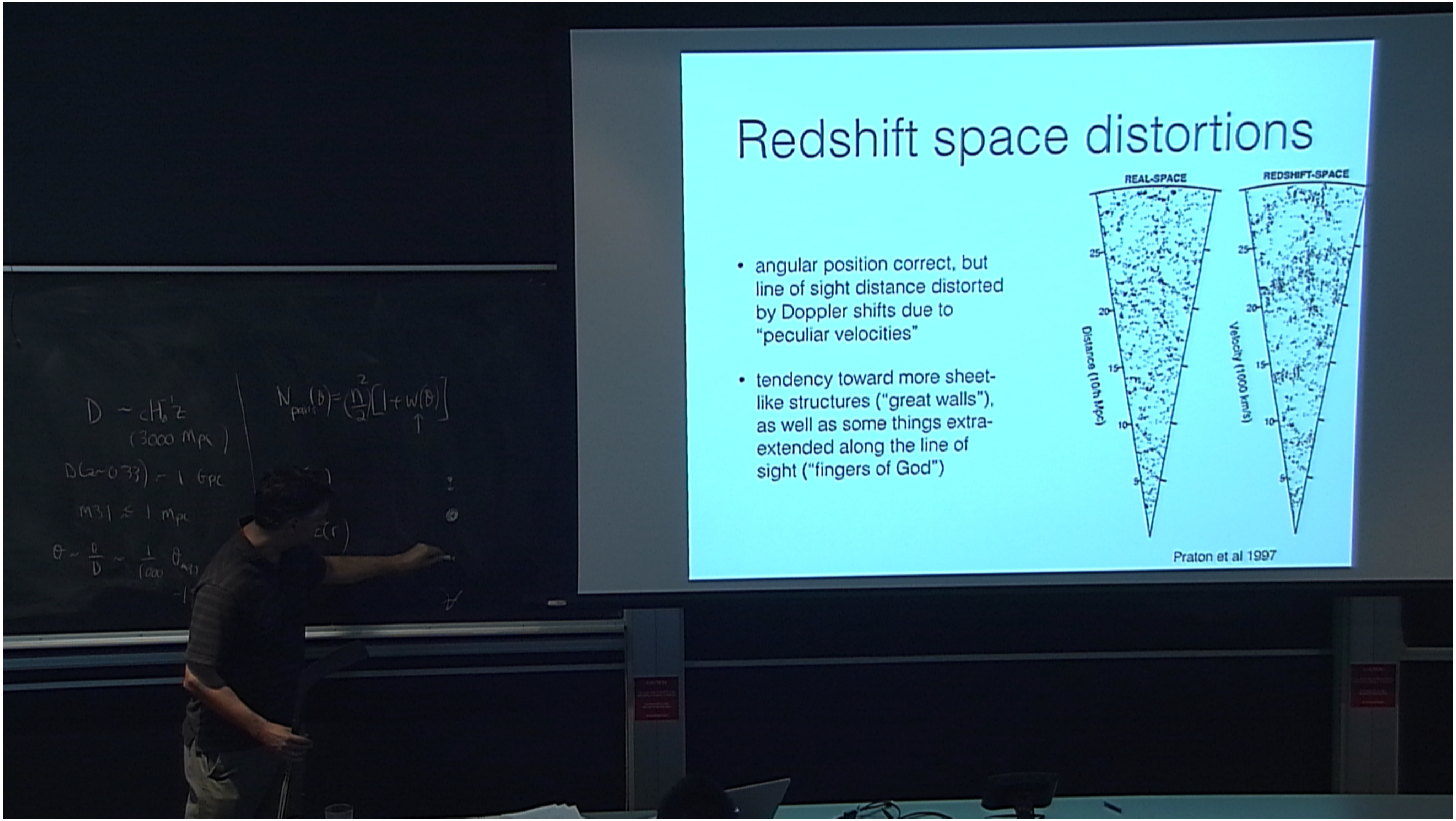
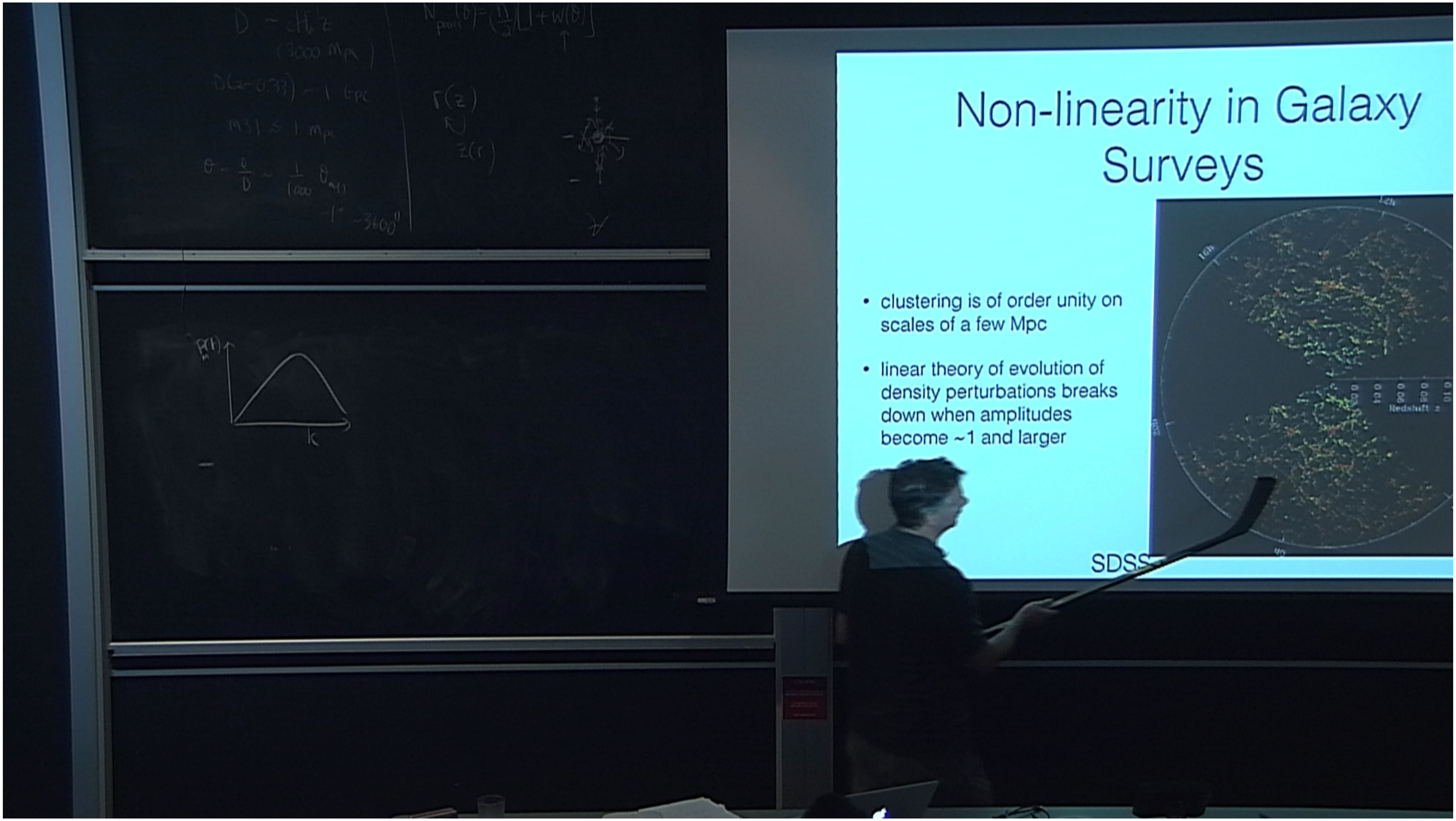
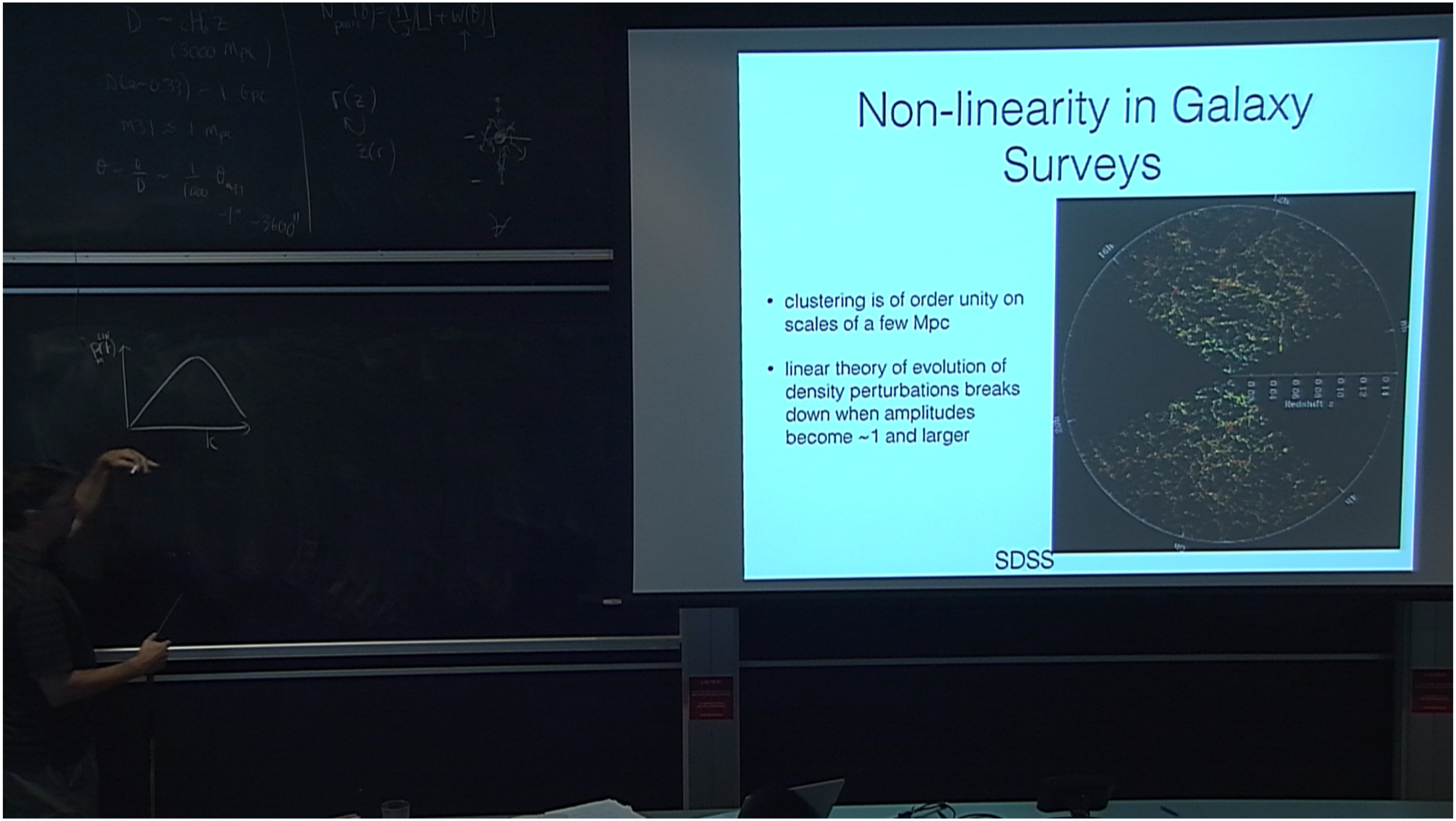
Redshift z
SDSS



Redshift space distortions
• angular position correct, but line of sight distance distorted by Doppler shifts due to "peculiar velocities"
• tendency toward more sheet-like structures ("great walls"), as well as some things extra-extended along the line of sight ("fingers of God")
REAL-SPACE
REDSHIFT-SPACE
Distance (10/h Mpc)
Velocity (1000 km/s)
Praton et al 1997


Non-linearity in Galaxy Surveys
• clustering is of order unity on scales of a few Mpc
• linear theory of evolution of density perturbations breaks down when amplitudes become ~1 and larger
SDSS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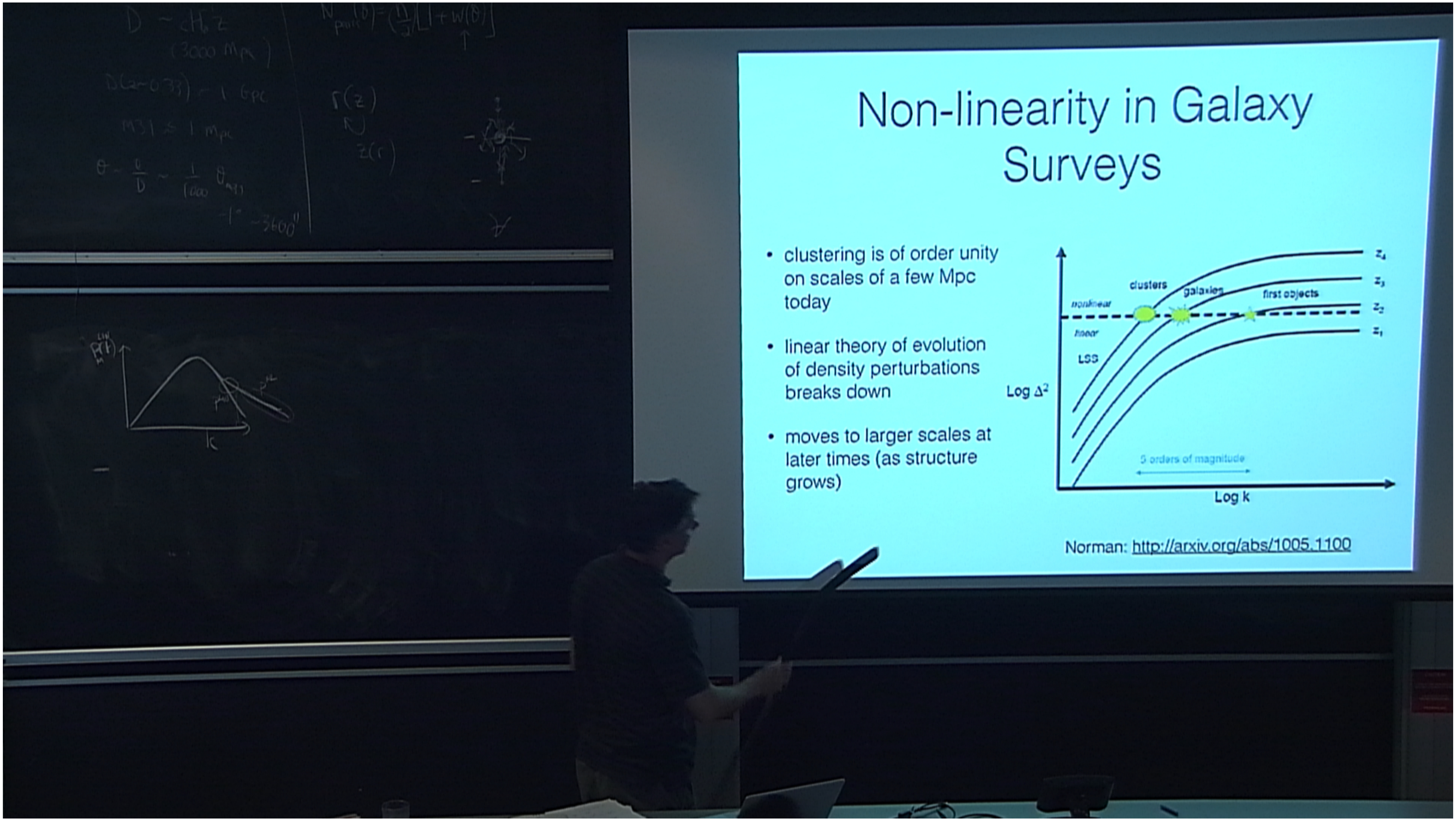
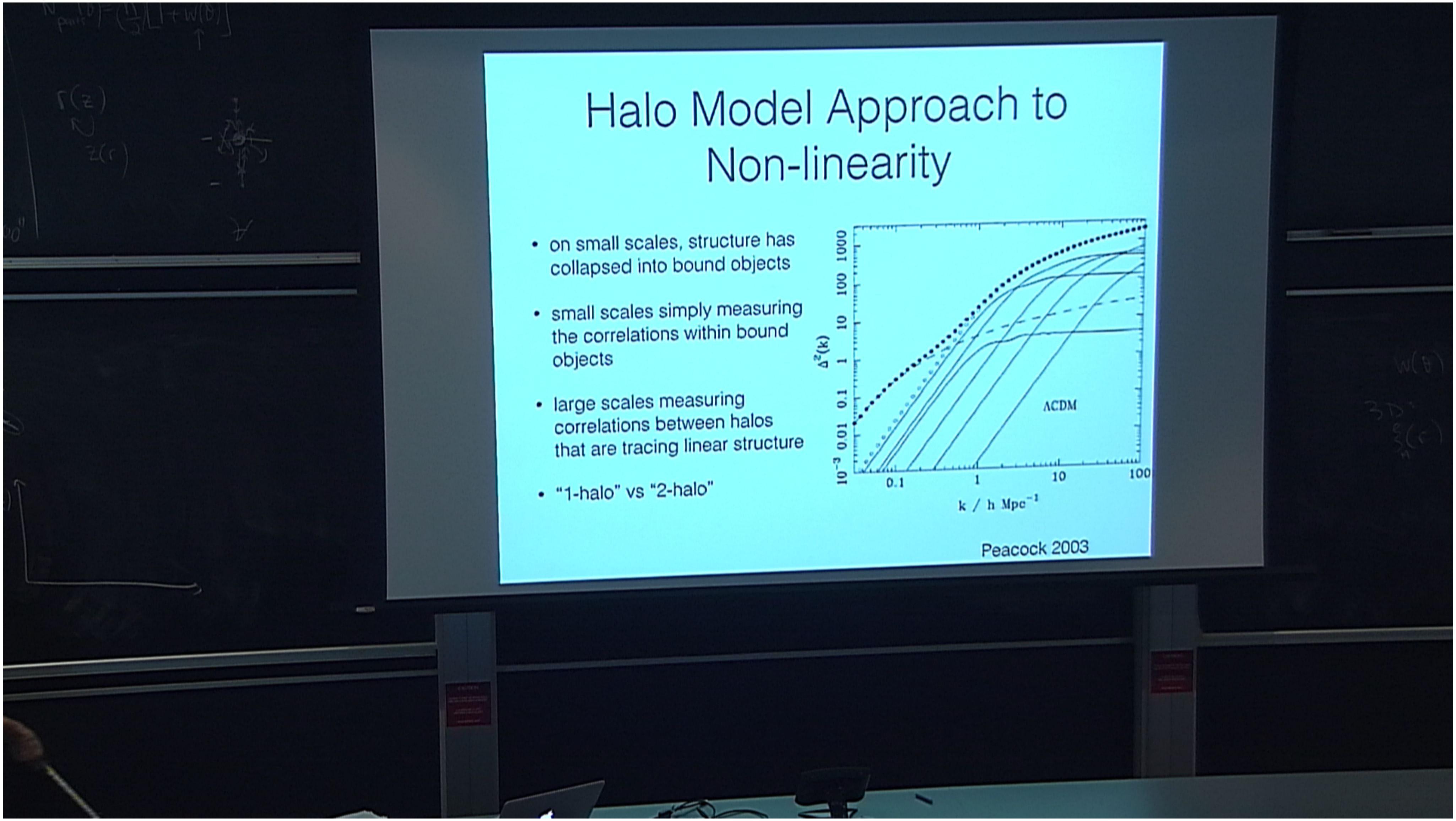
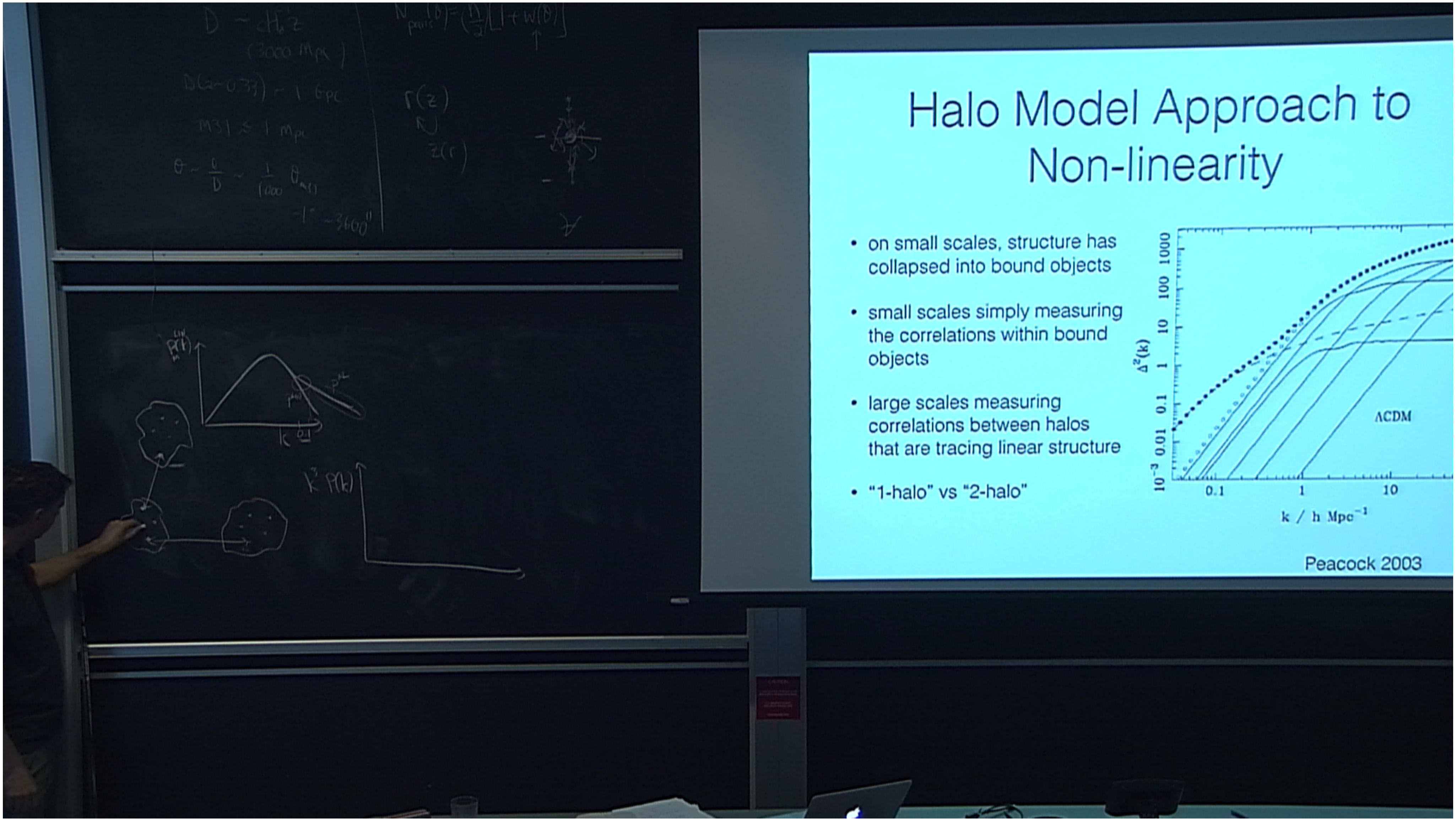

Non-linearity in Galaxy Surveys
• clustering is of order unity on scales of a few Mpc today
• linear theory of evolution of density perturbations breaks down
• moves to larger scales at later times (as structure grows)
clusters
galaxies
first objects
nonlinear
linear
LSS
Log Δ²
Log k
5 orders of magnitude
Norman: http://arxiv.org/abs/1005.1100


Halo Model Approach to Non-linearity
• on small scales, structure has collapsed into bound objects
• small scales simply measuring the correlations within bound objects
• large scales measuring correlations between halos that are tracing linear structure
• "1-halo" vs "2-halo"
Δ²(k)
10⁻³
0.01
0.1
1
10
100
1000
0.1
1
10
100
ΛCDM
k / h Mpc⁻¹
Peacock 2003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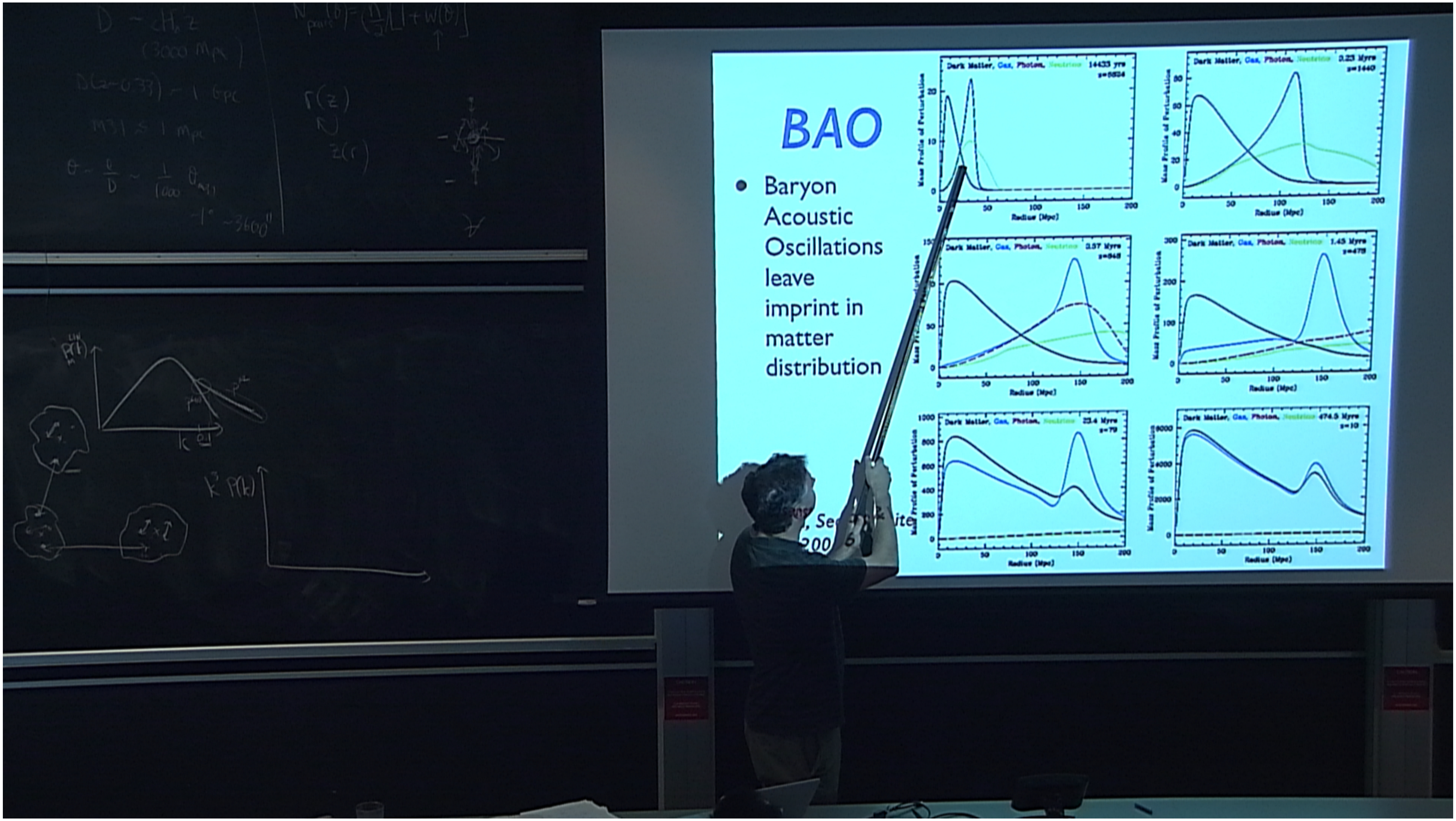
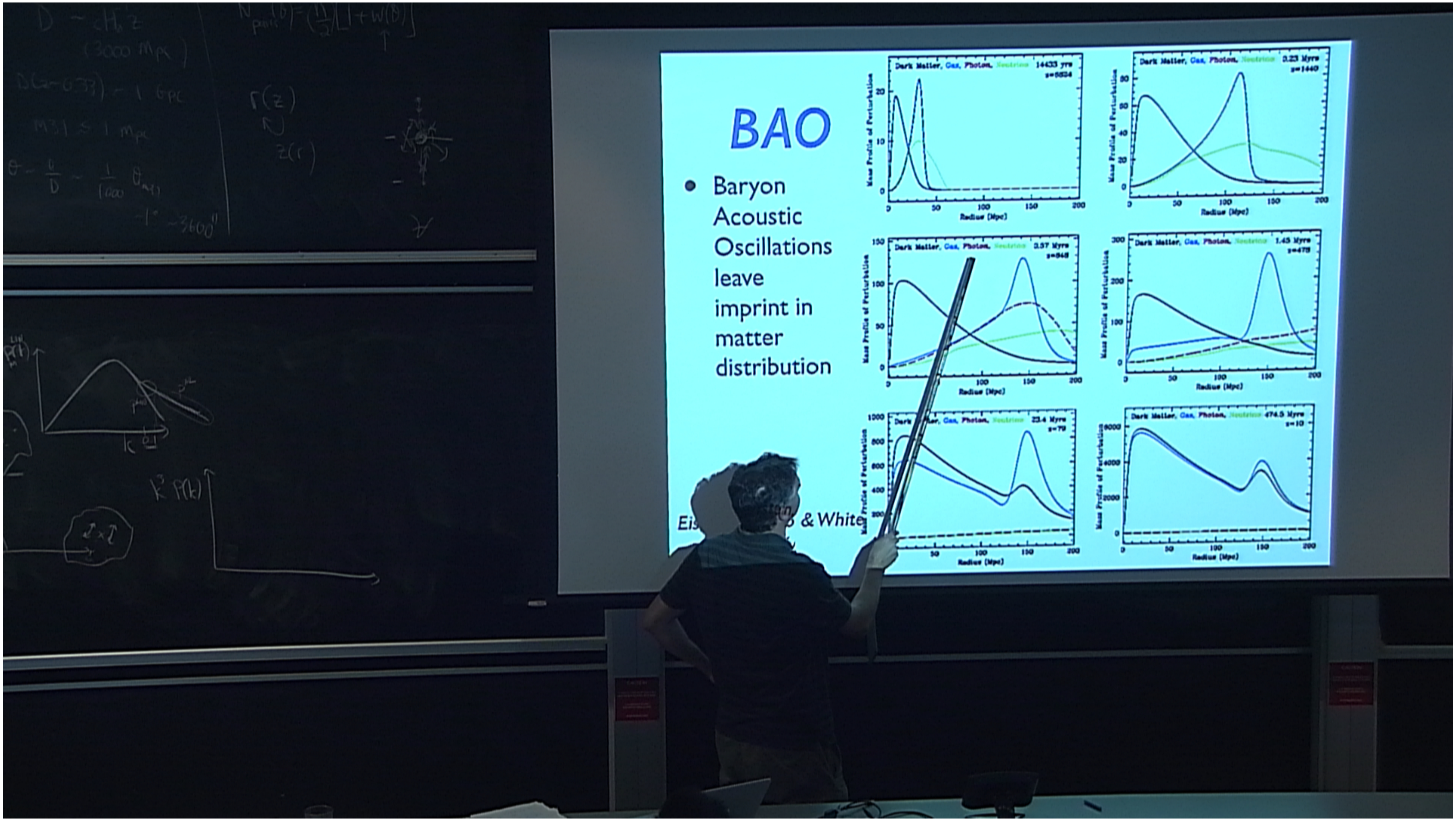
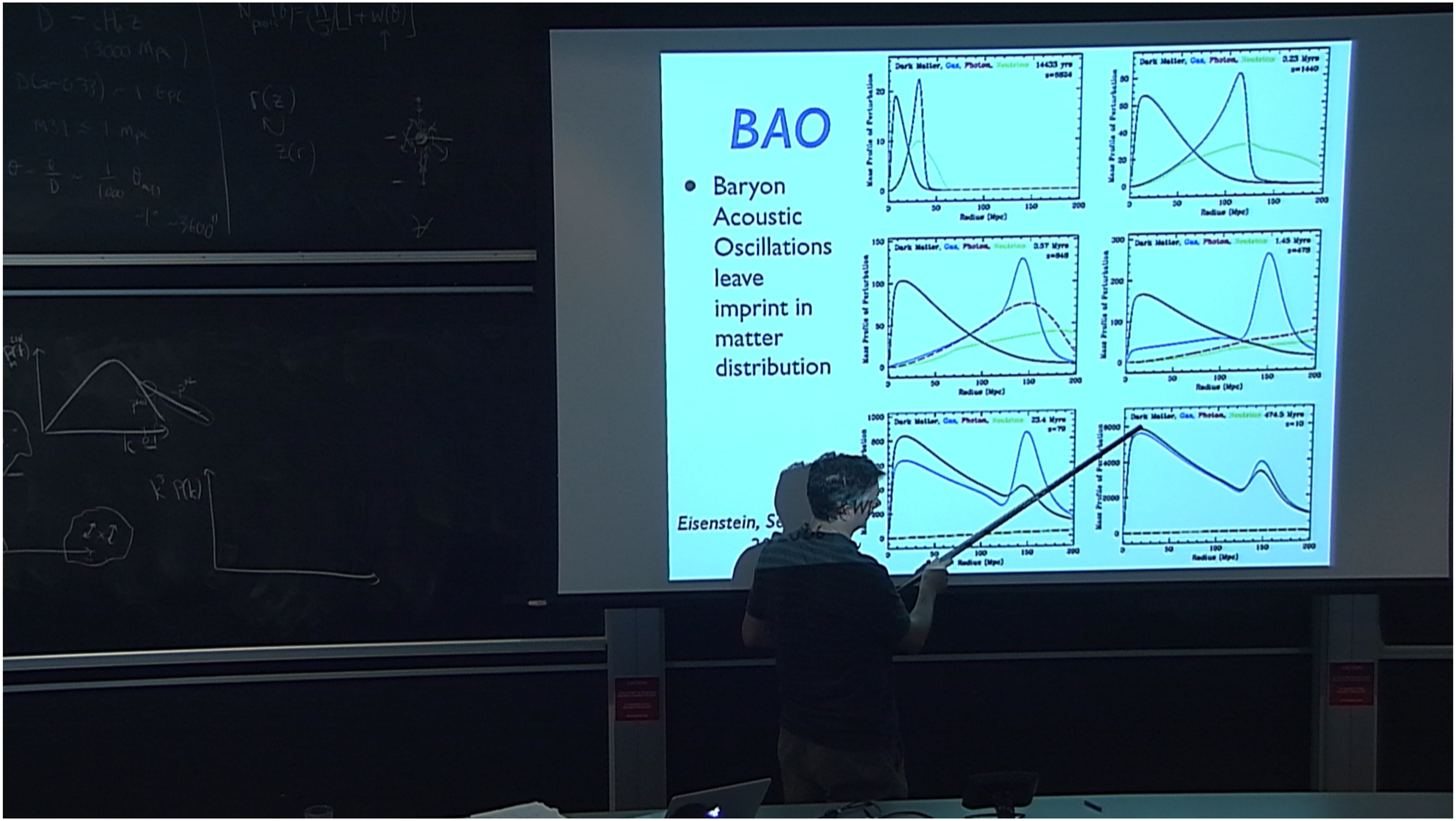
$\Delta^2(k)$
10^{-3} 0.01 0.1 1 10 100 1000
0.1 1 10
k / h Mpc^{-1}
ΛCDM
Peacock 2003


BAO
Baryon Acoustic Oscillations leave imprint in matter distribution
Dark Matter, Gas, Photon, Neutrino
Radius (Mpc)
Mass Profile of Perturbation


BAO
Baryon Acoustic Oscillations leave imprint in matter distribution
& White
Dark Matter, Gas, Photon, Neutrino
Radius (Mpc)
Mass Profile of Perturbation



BAO
Baryon Acoustic Oscillations leave imprint in matter distribution
Eisenstein, Se
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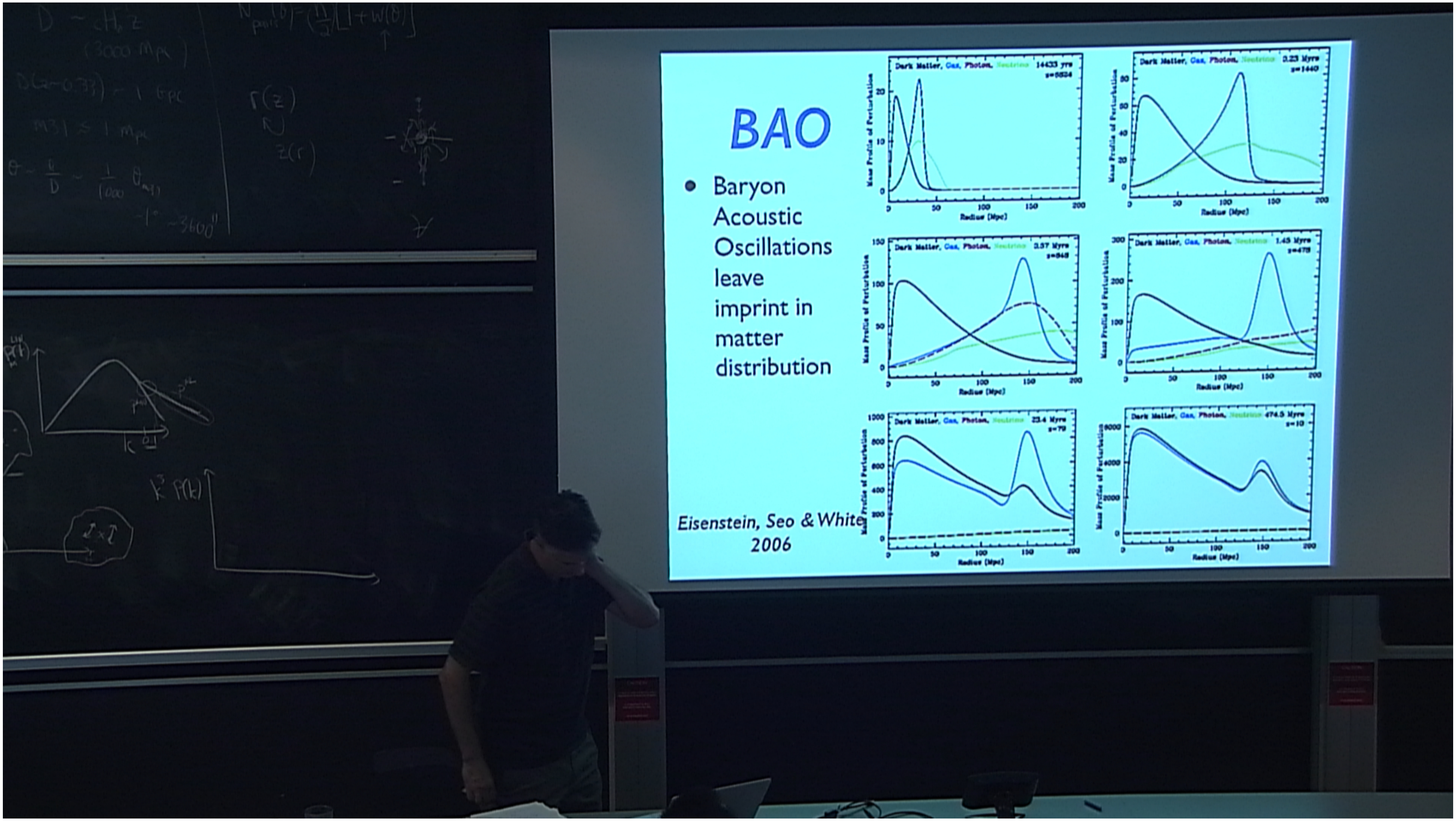

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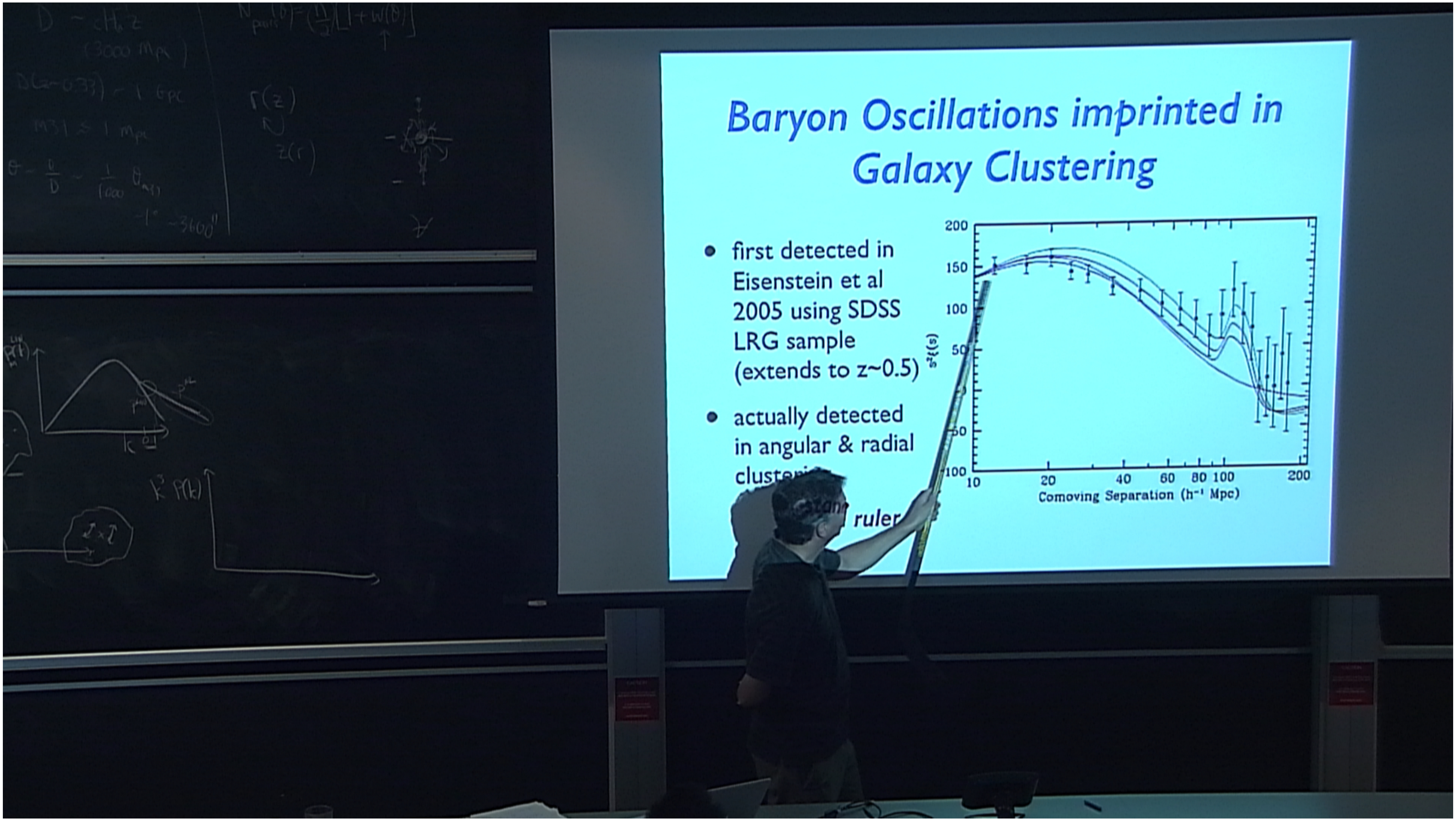
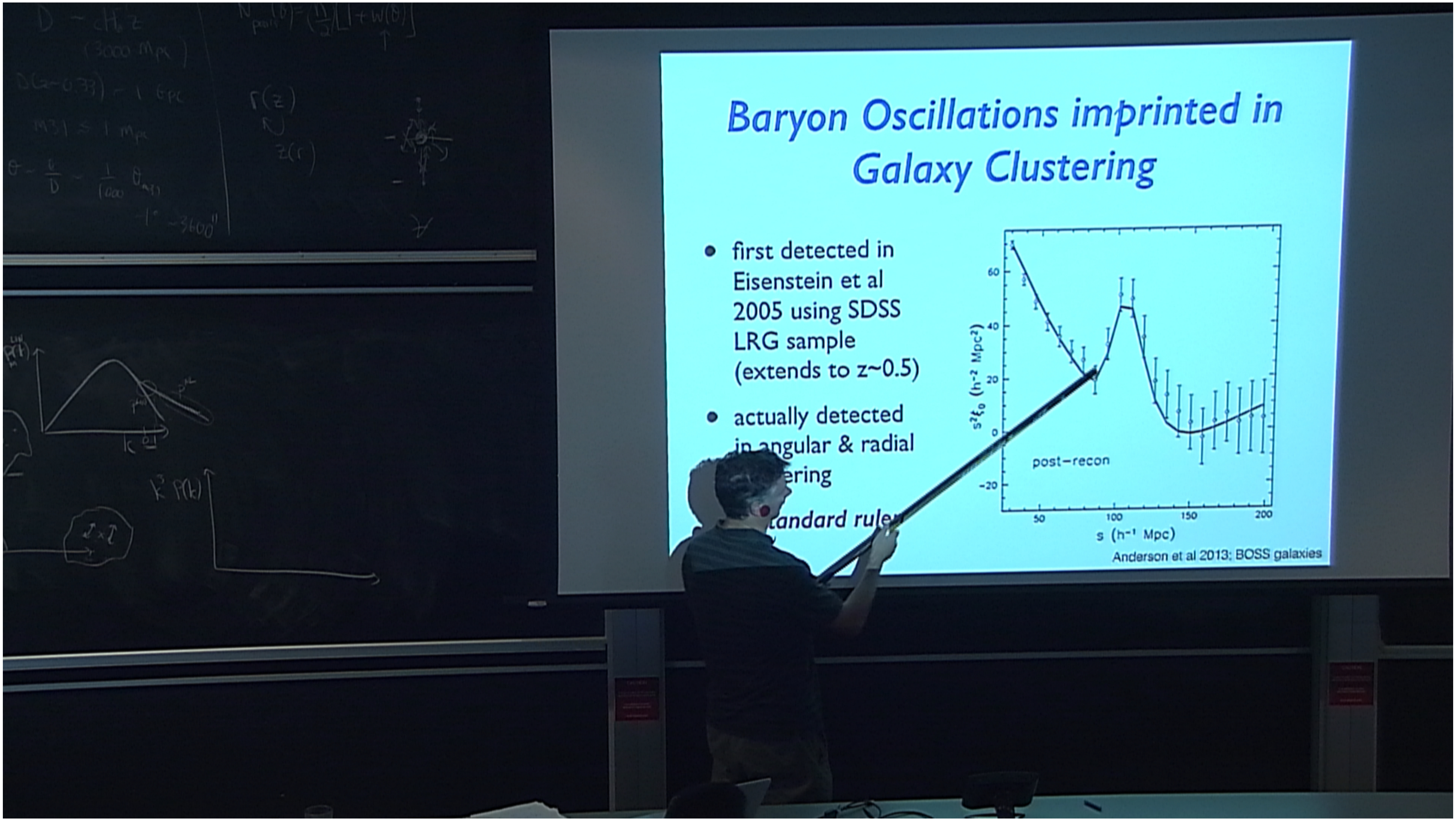
Eisenstein, Seo & White 2006


Baryon Oscillations imprinted in Galaxy Clustering
first detected in Eisenstein et al 2005 using SDSS LRG sample (extends to z~0.5)
actually detected in angular & radial
ruler
Comoving Separation (h⁻¹ Mpc)



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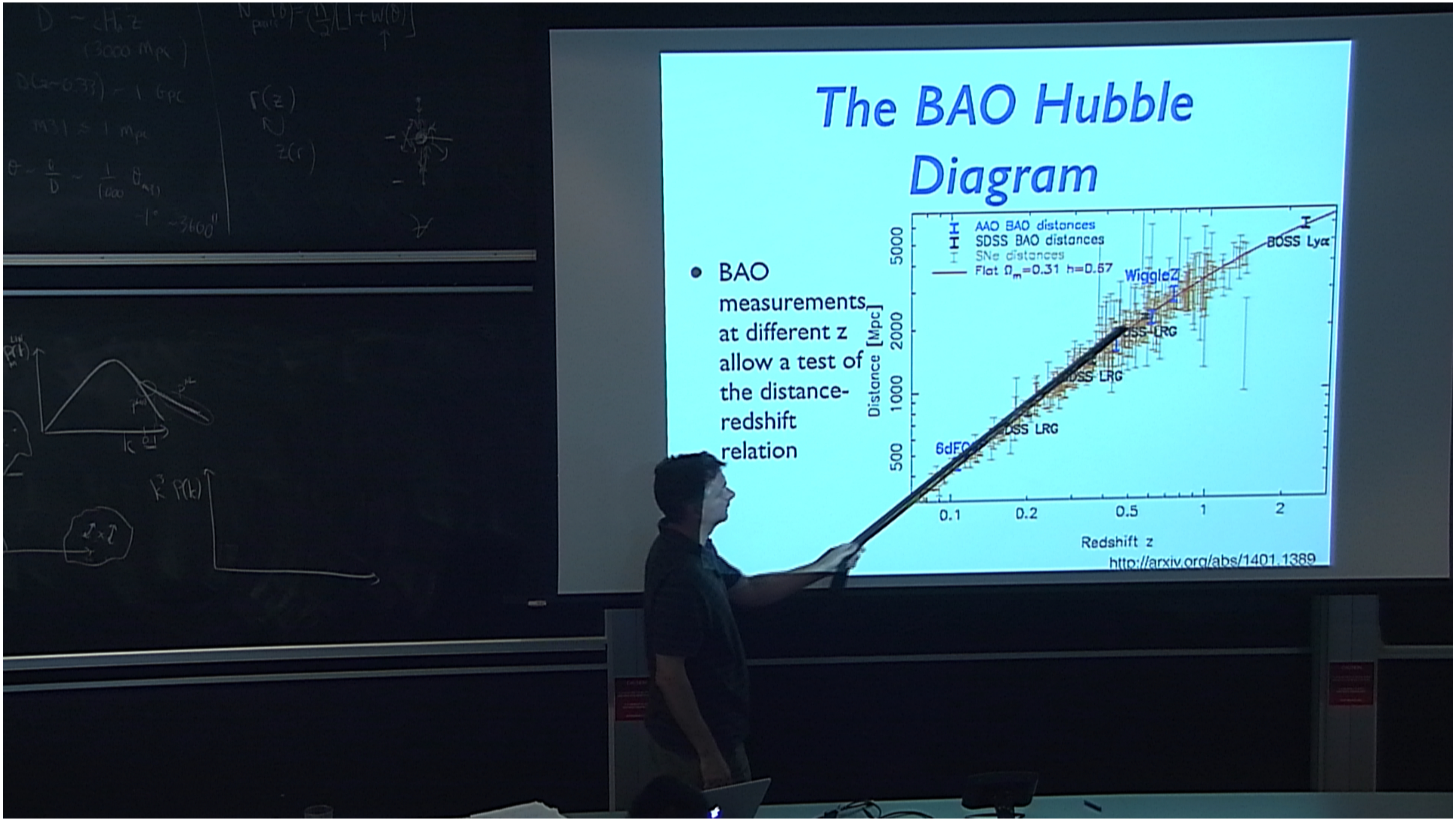
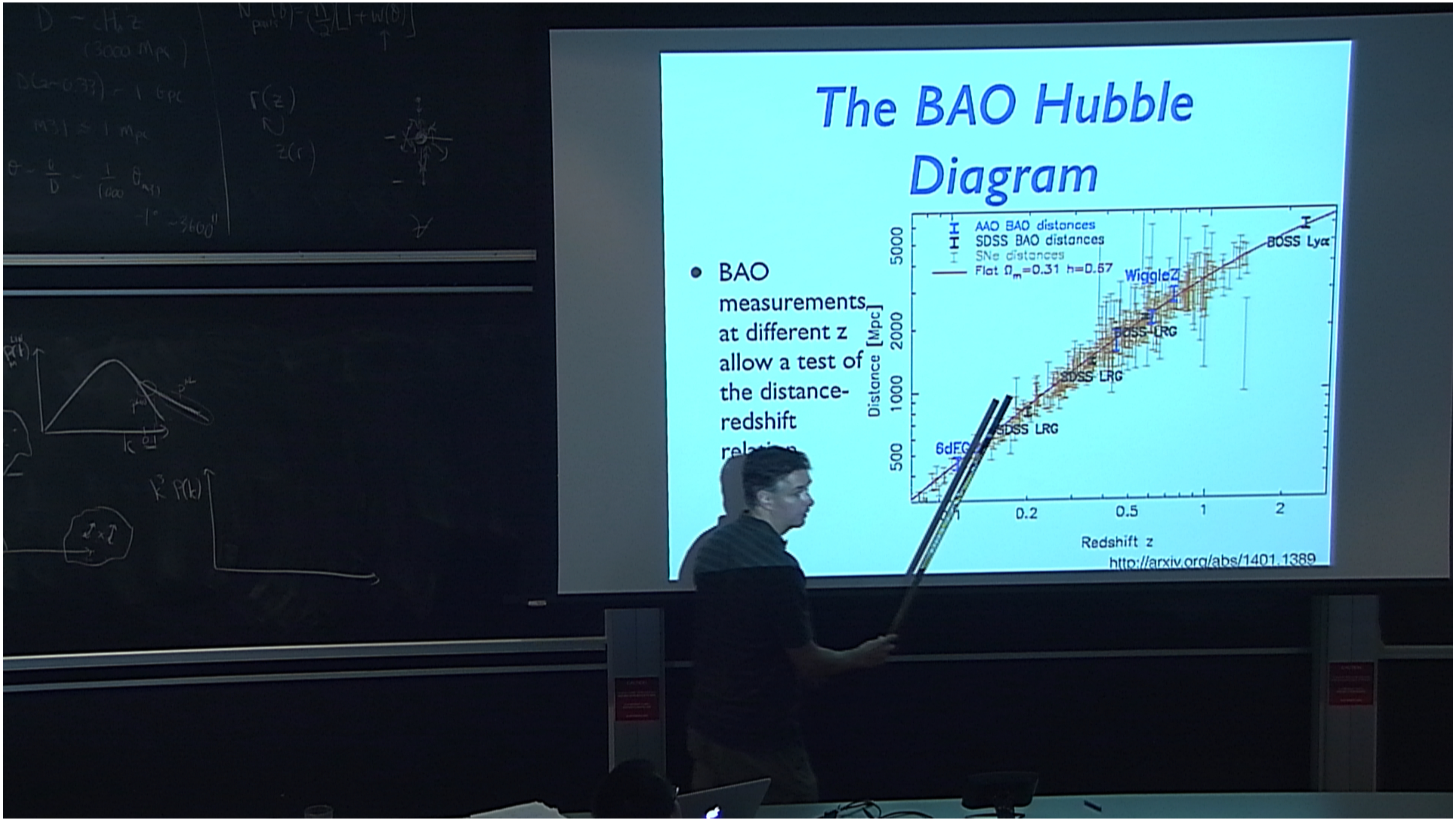
tandard rule
post−recon
s (h⁻¹ Mpc)
Anderson et al 2013; BOSS galaxies


The BAO Hubble Diagram
BAO measurements at different z allow a test of the distance-redshift relation
AAO BAO distances
SDSS BAO distances
SNe distances
Flat Ωm=0.31 h=0.67
WiggleZ
BOSS Lyα
SDSS LRG
6dFGS
Distance [Mpc]
Redshift z
http://arxiv.org/abs/1401.1389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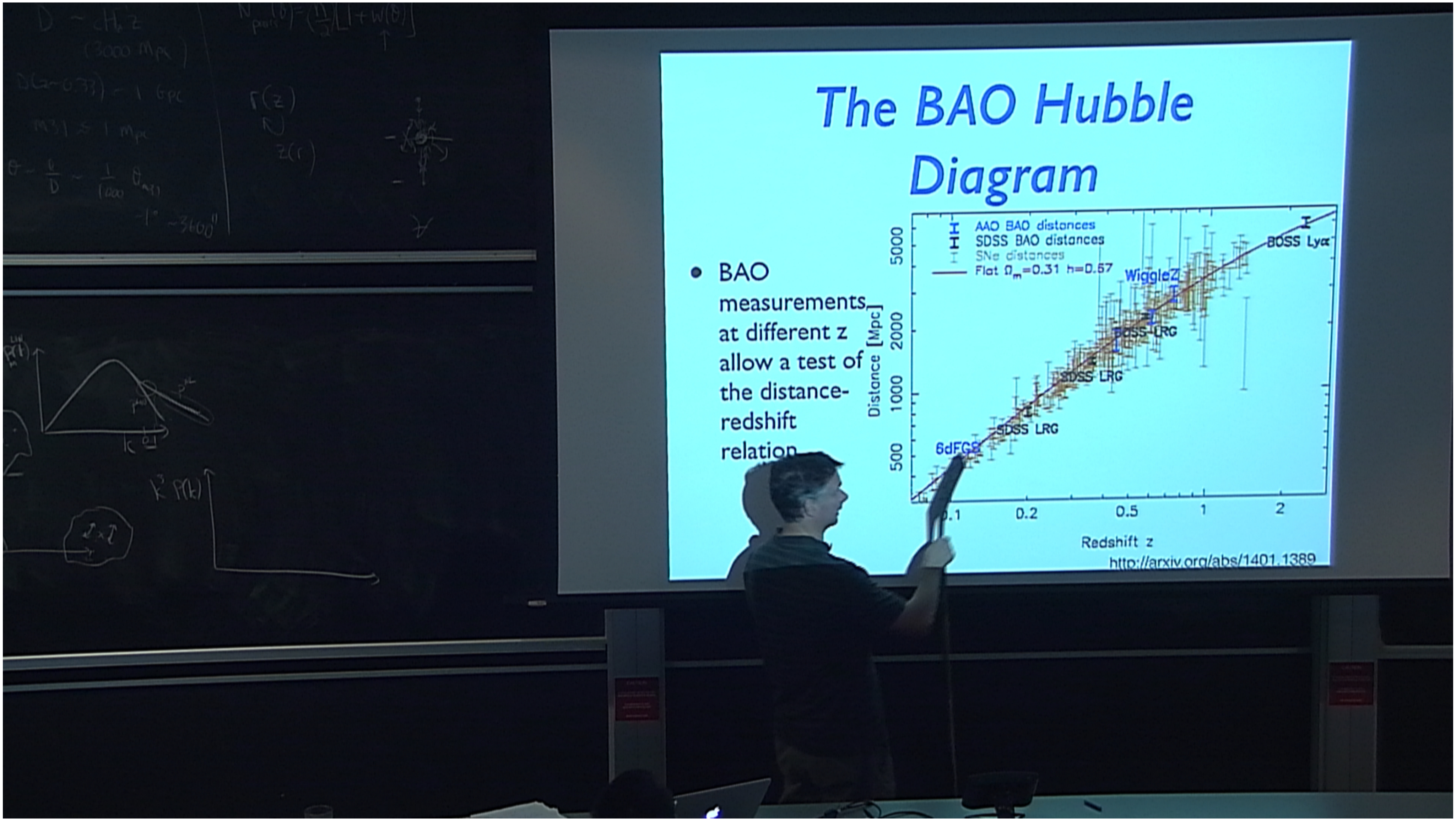
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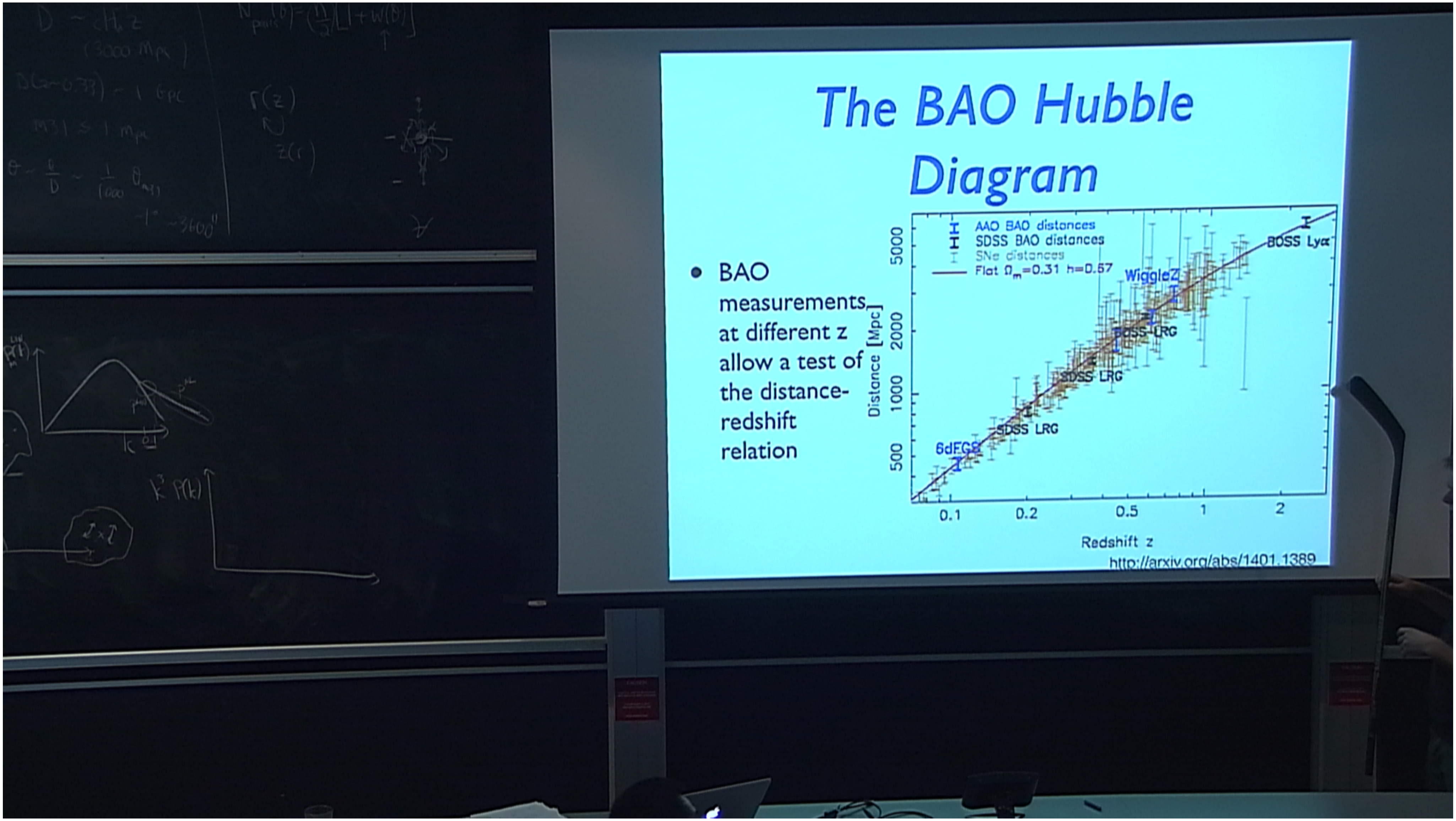

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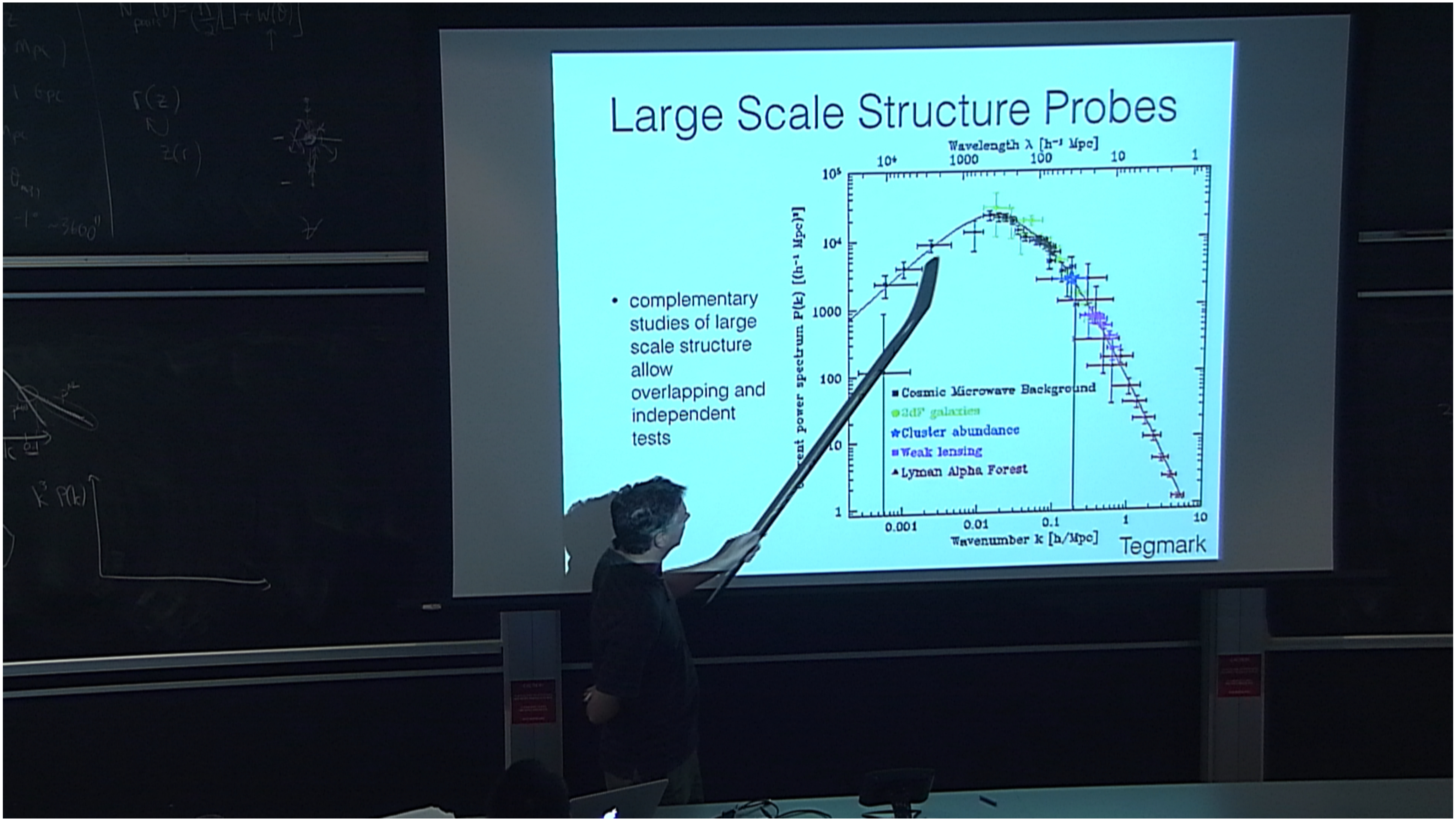
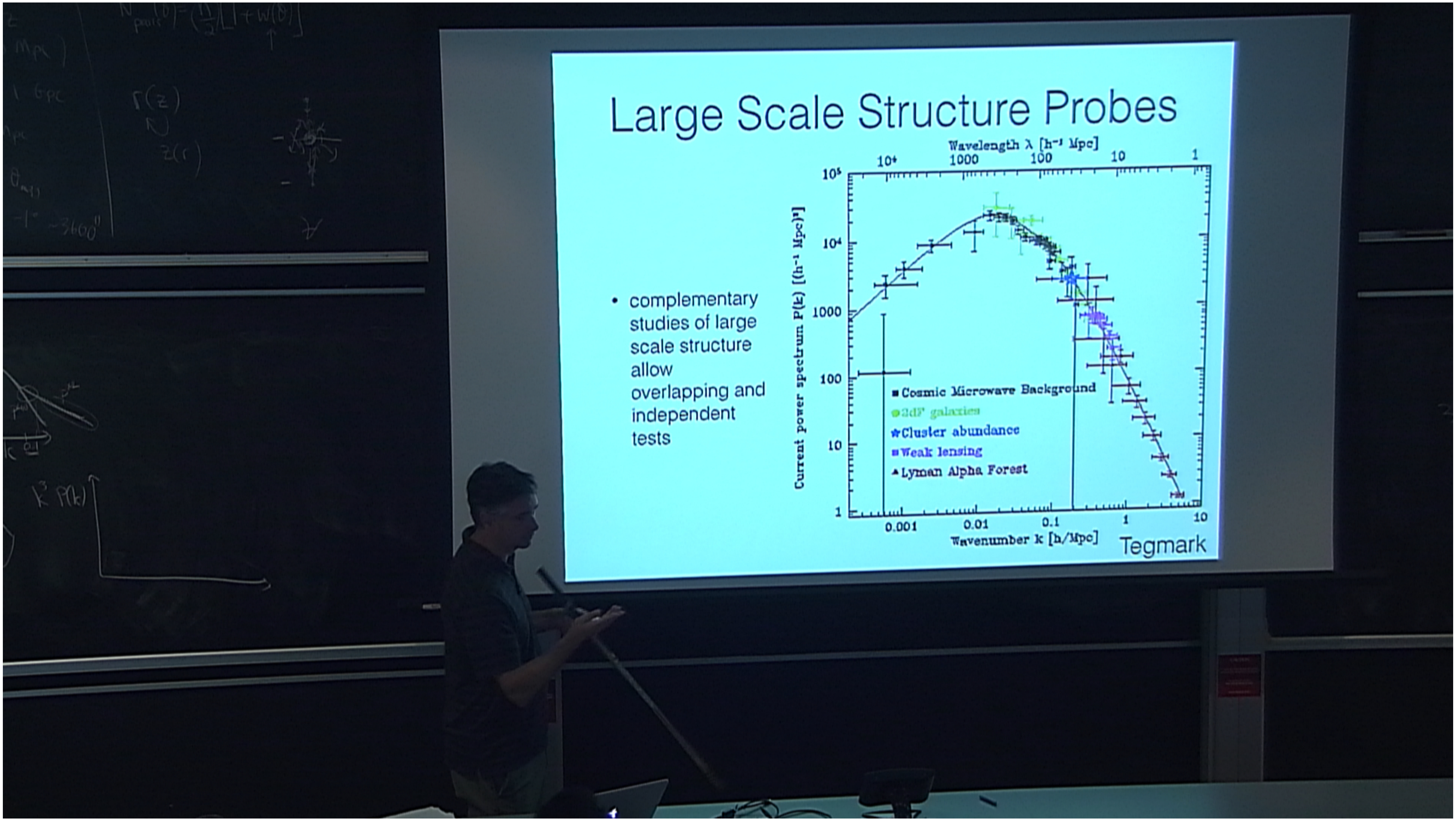


Large Scale Structure Probes
complementary studies of large scale structure allow overlapping and independent tests
Wavelength λ [h⁻¹ Mpc]
Cosmic Microwave Background
2dF galaxies
Cluster abundance
Weak lensing
Lyman Alpha Forest
Wavenumber k [h/Mpc]
Tegmark



Large Scale Structure Probes
• complementary studies of large scale structure allow overlapping and independent tests
Wavelength λ [h⁻¹ Mpc]
Current power spectrum P(k) [(h⁻¹ Mpc)³]
Cosmic Microwave Background
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Cluster abundance
Weak lensing
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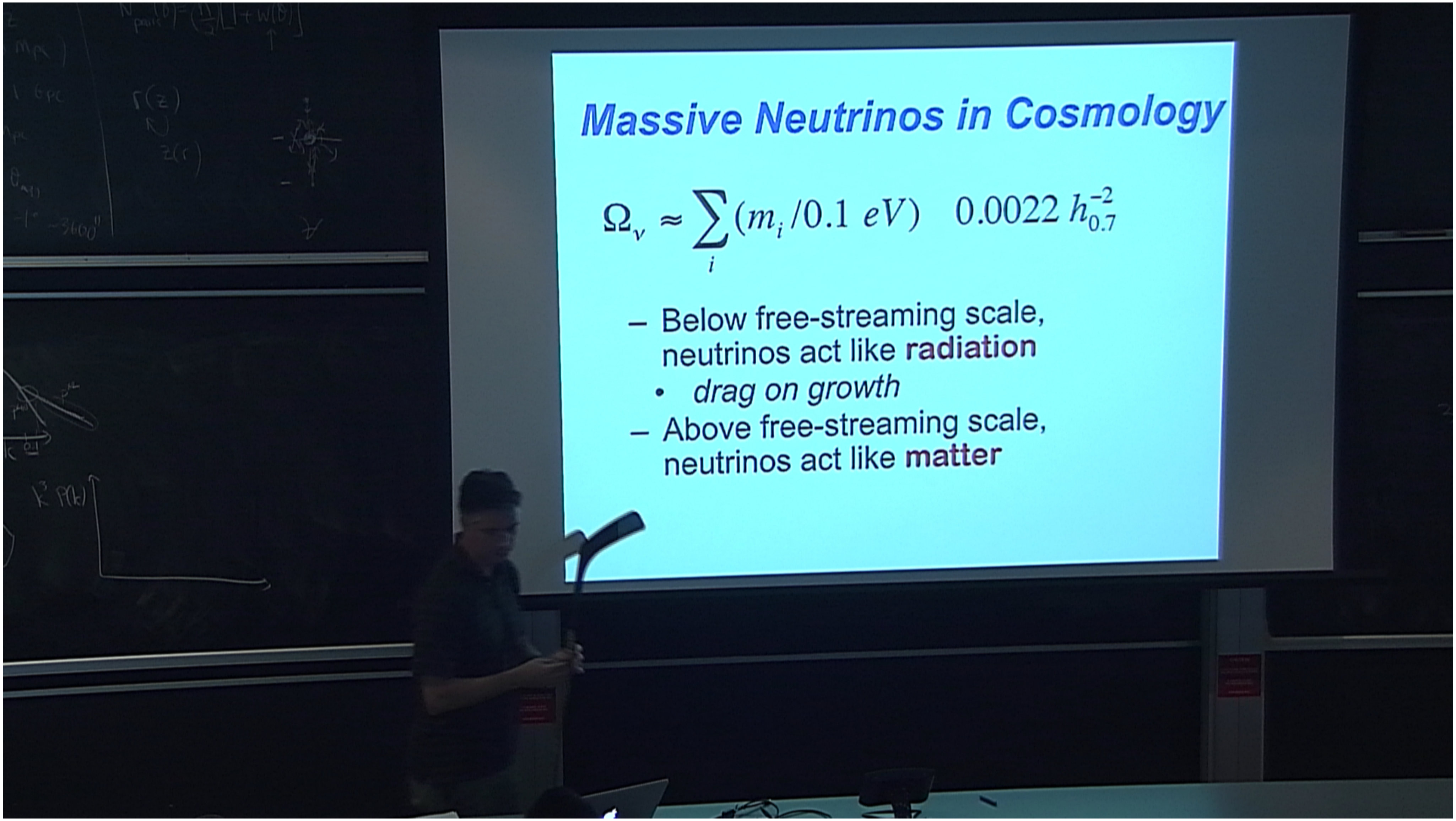
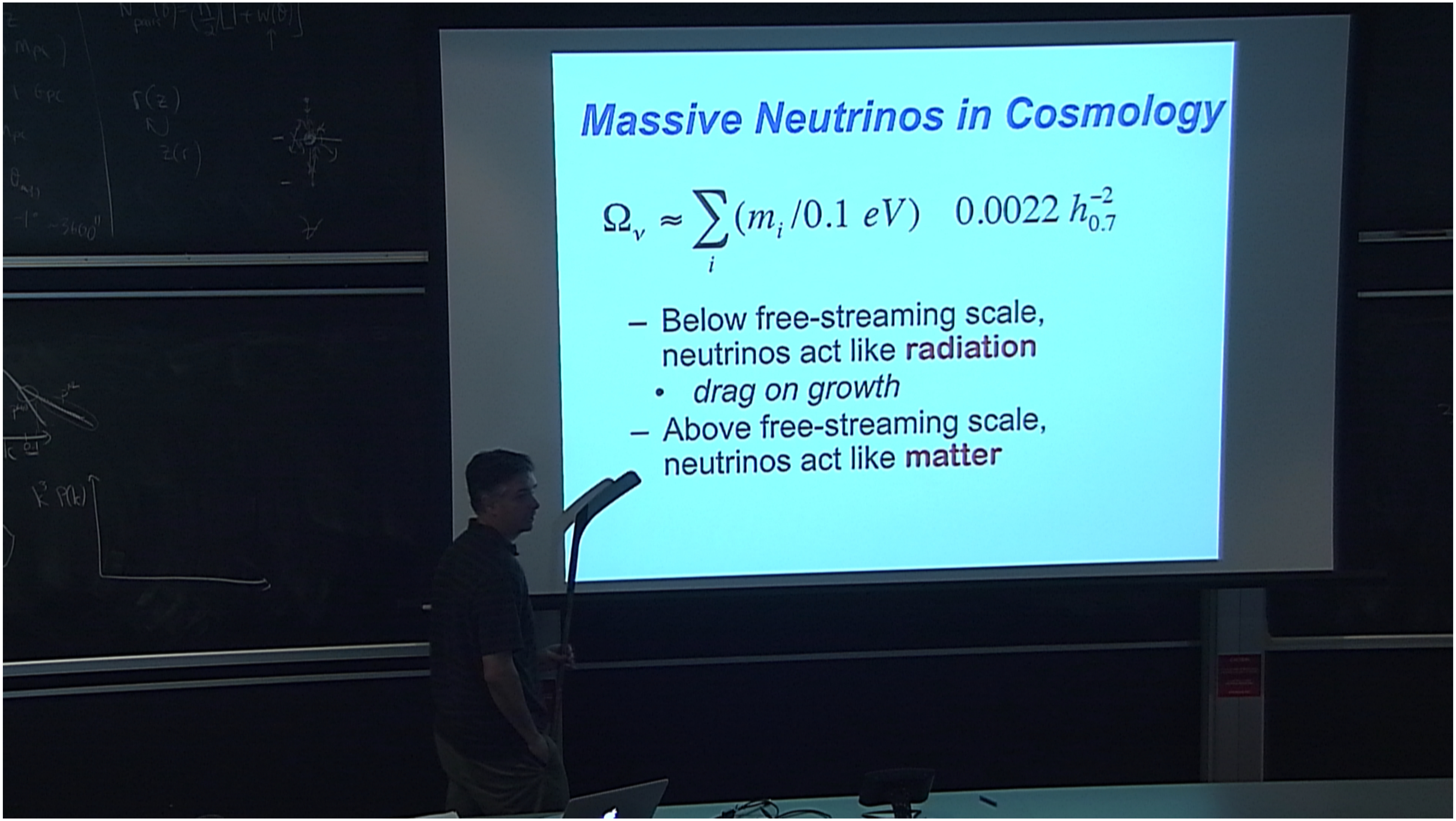

Massive Neutrinos in Cosmology
$\Omega_\nu \approx \sum_i (m_i/0.1\ eV) \quad 0.0022\, h_{0.7}^{-2}$
– Below free-streaming scale, neutrinos act like radiation
• drag on growth
– Above free-streaming scale, neutrinos act like matter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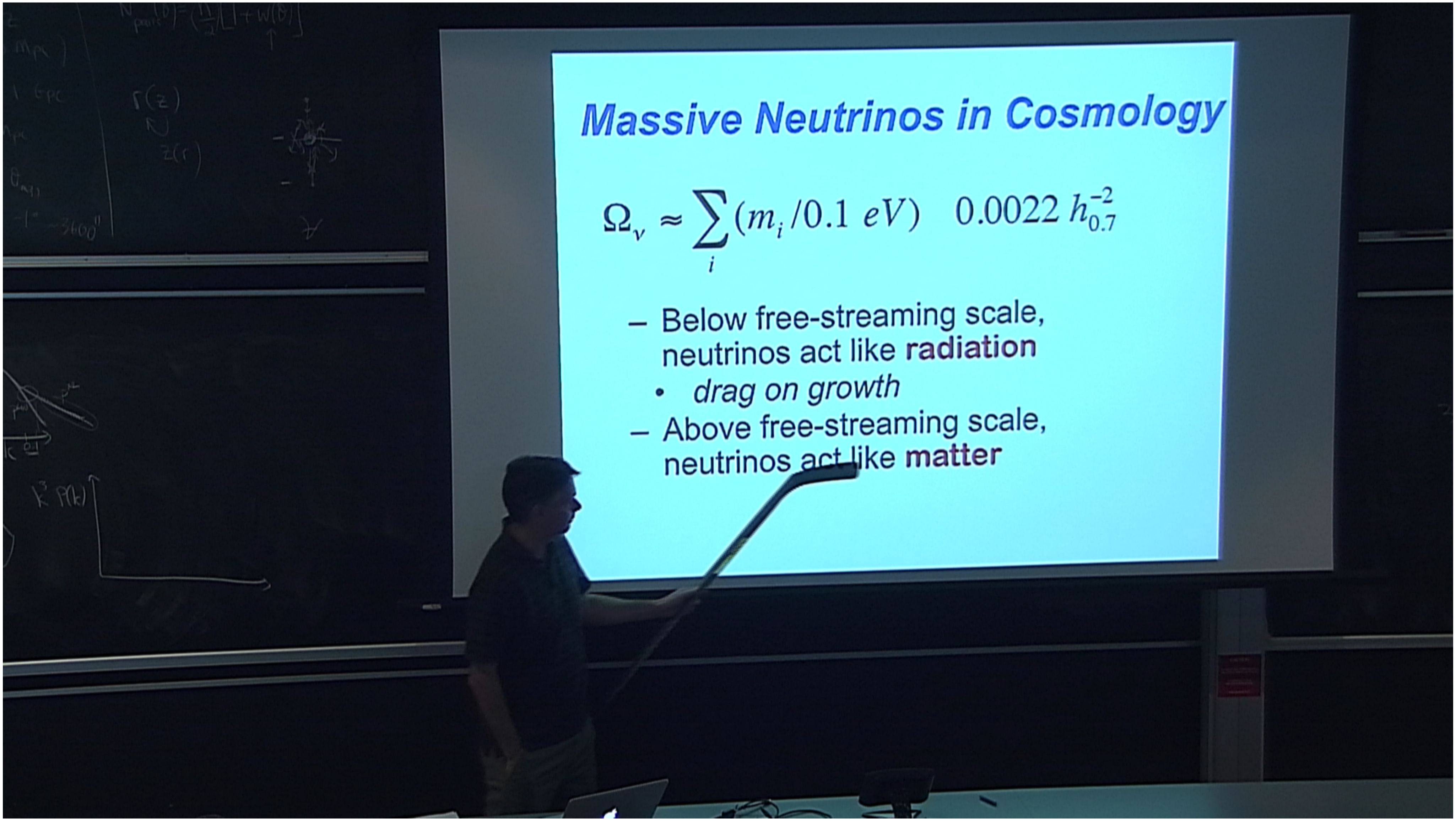
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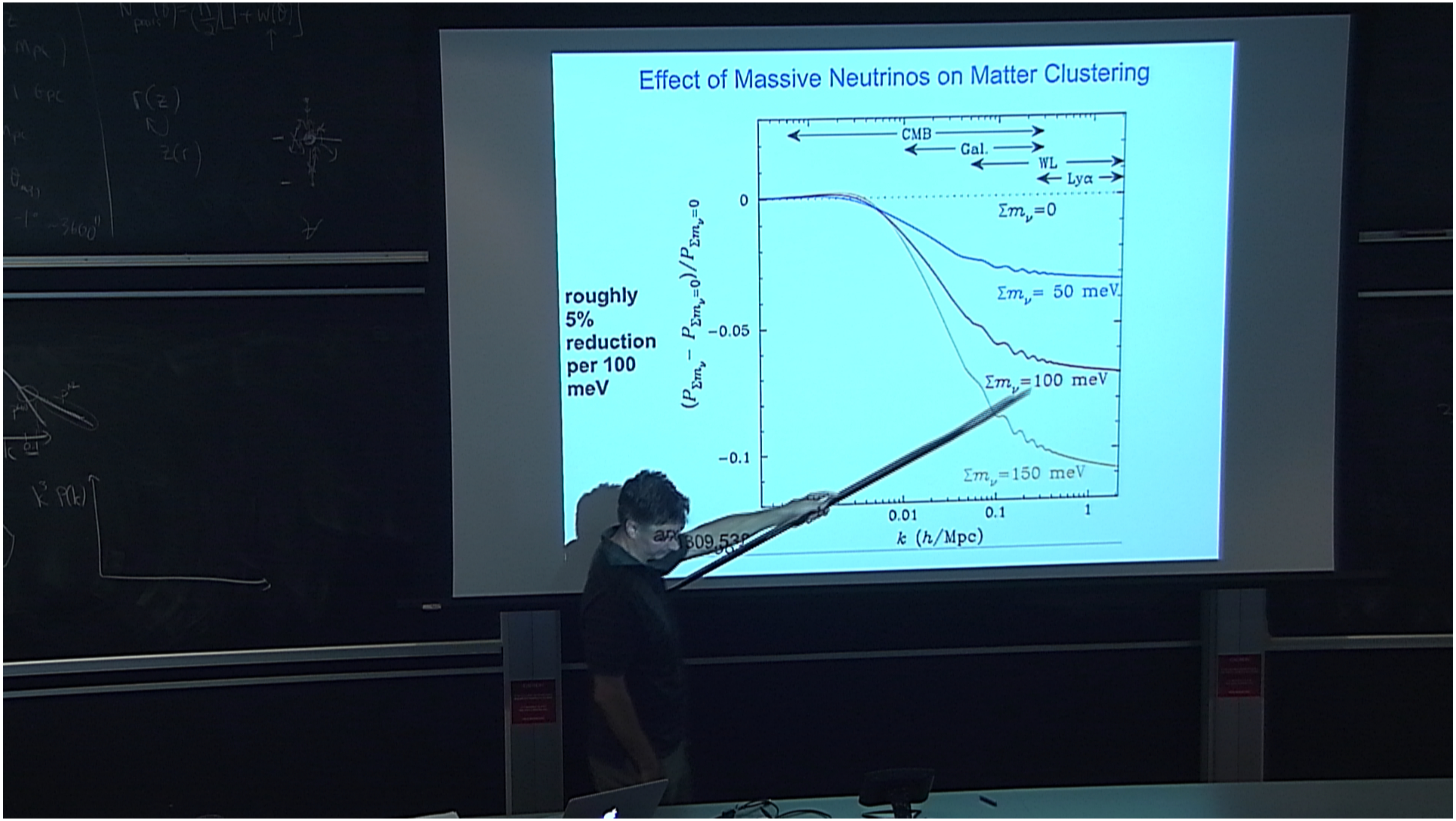
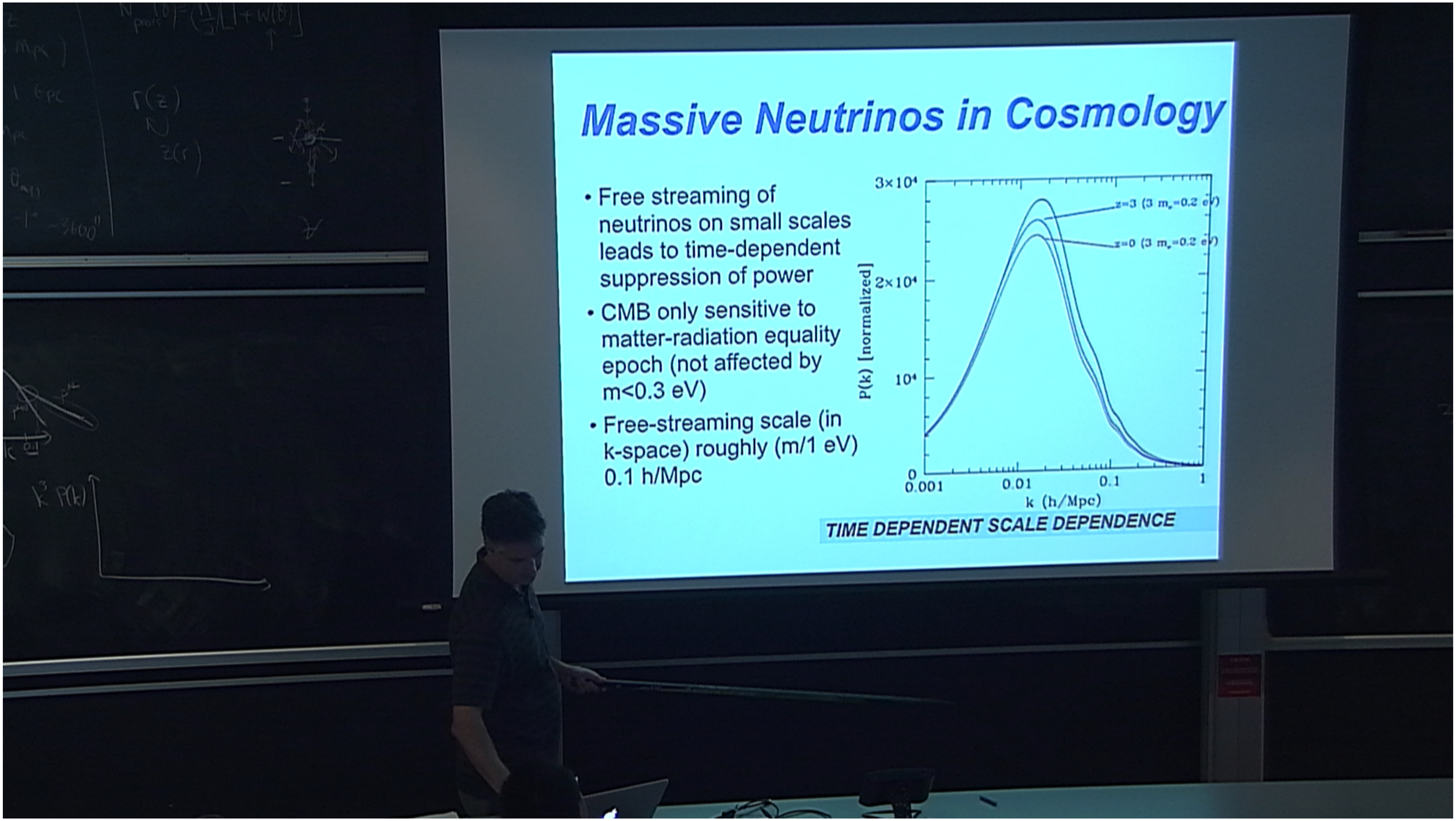
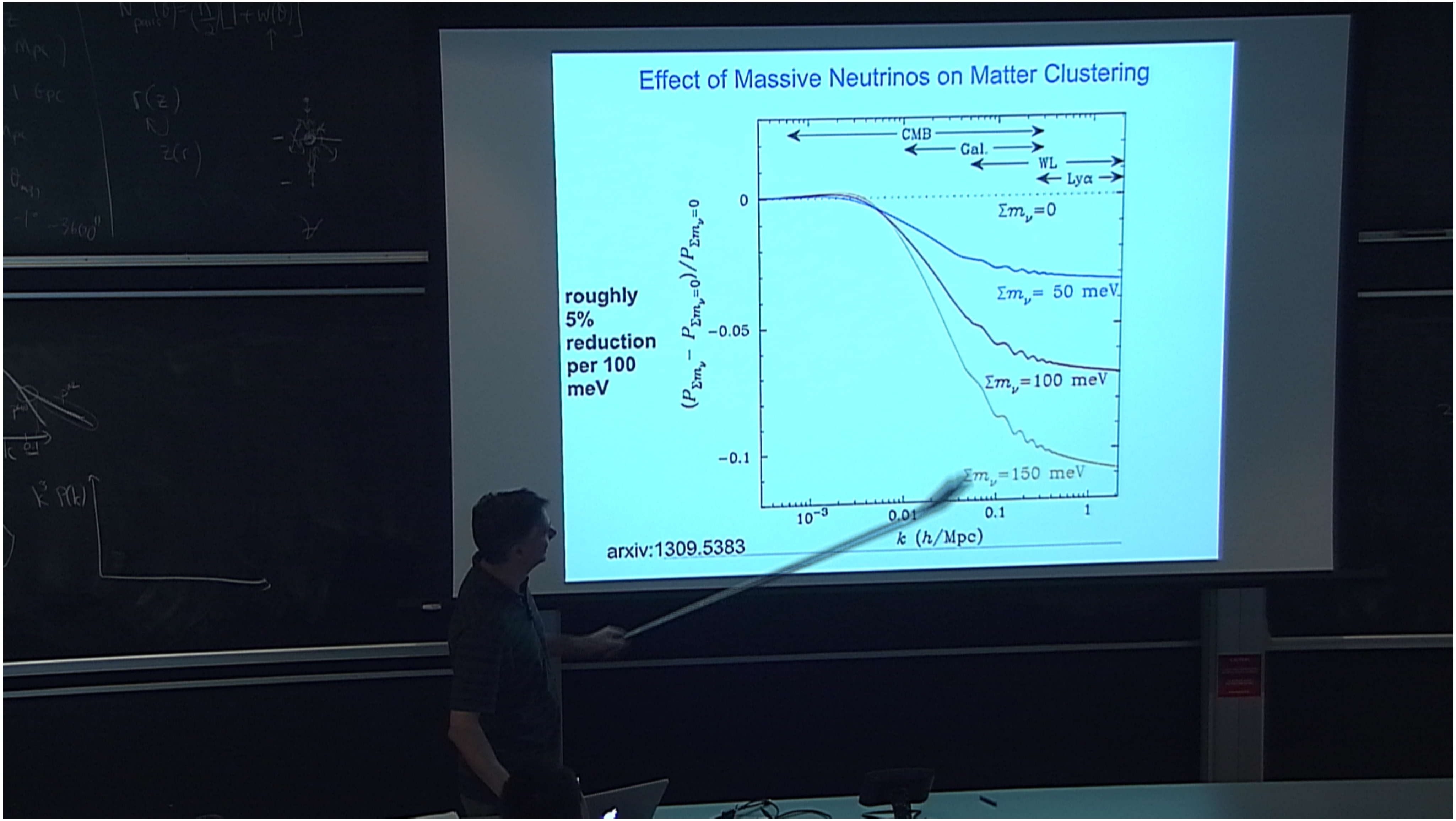


Effect of Massive Neutrinos on Matter Clustering
roughly 5% reduction per 100 meV
CMB
Gal.
WL
Lyα
$\Sigma m_\nu=0$
$\Sigma m_\nu=$ 50 meV
$\Sigma m_\nu=$100 meV
$\Sigma m_\nu=$150 meV
$(P_{\Sigma m_\nu} - P_{\Sigma m_\nu=0})/P_{\Sigma m_\nu=0}$
0
−0.05
−0.1
0.01
0.1
1
k (h/Mpc)


Massive Neutrinos in Cosmology
• Free streaming of neutrinos on small scales leads to time-dependent suppression of power
• CMB only sensitive to matter-radiation equality epoch (not affected by m<0.3 eV)
• Free-streaming scale (in k-space) roughly (m/1 eV) 0.1 h/Mpc
3×10⁴
2×10⁴
10⁴
0
P(k) [normalized]
z=3 (3 mν=0.2 eV)
z=0 (3 mν=0.2 eV)
0.001
0.01
0.1
1
k (h/Mpc)
TIME DEPENDENT SCALE DEPENDENCE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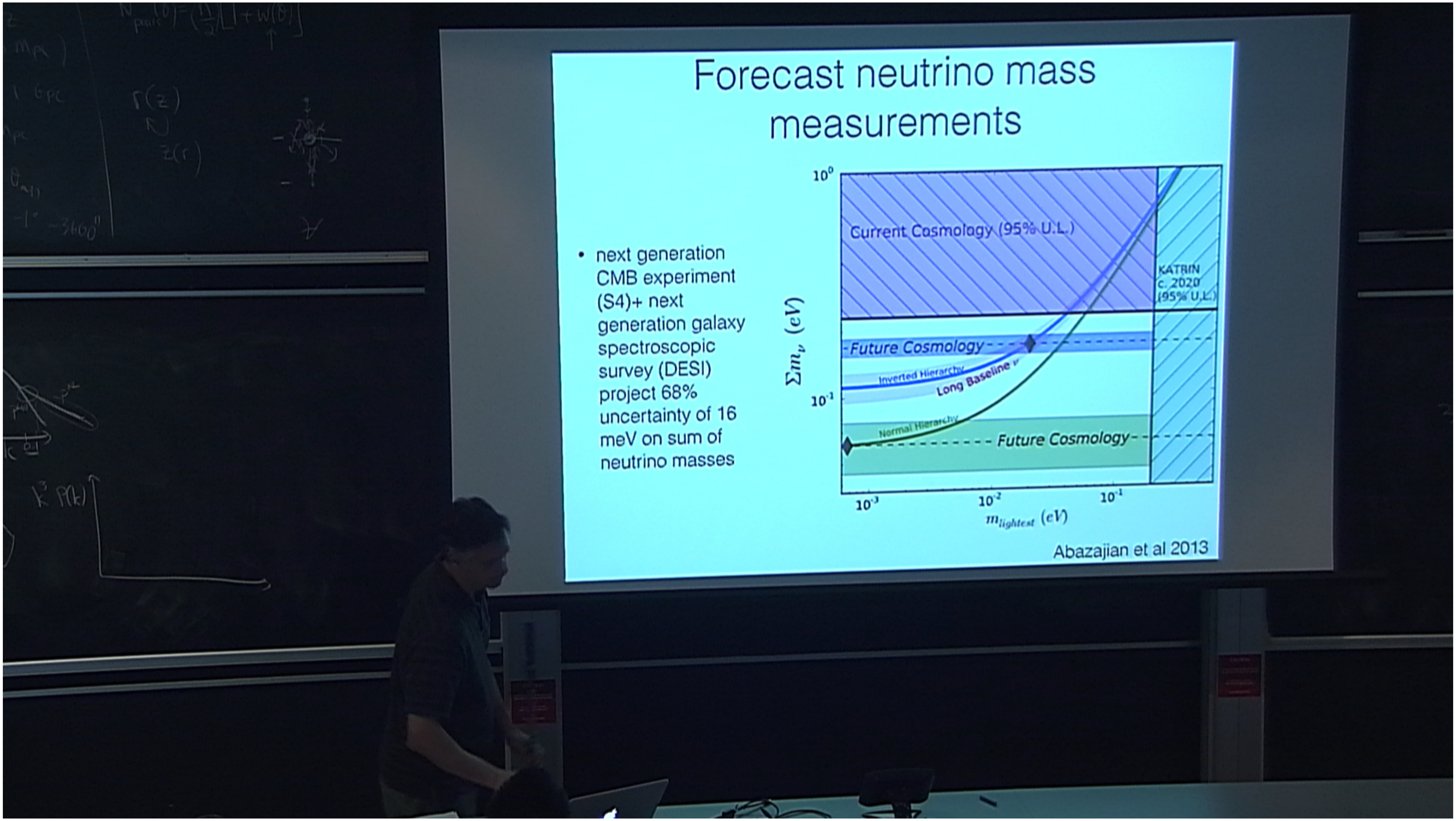
$\Sigma m_\nu=$150 meV
0
−0.05
−0.1
10^{-3}
0.01
0.1
1
$k\ (h/\mathrm{Mpc})$
$(P_{\Sigma m_\nu} - P_{\Sigma m_\nu=0})/P_{\Sigma m_\nu=0}$
arxiv:1309.5383


Forecast neutrino mass measurements
• next generation CMB experiment (S4)+ next generation galaxy spectroscopic survey (DESI) project 68% uncertainty of 16 meV on sum of neutrino masses
Current Cosmology (95% U.L.)
KATRIN c. 2020 (95% U.L.)
Future Cosmology
Inverted Hierarchy
Long Baseline ν
Normal Hierarchy
Future Cosmology
Σm_ν (eV)
m_lightest (eV)
Abazajian et al 2013