Title: Panel on Precision Cosmology

Date: Apr 11, 2005 04:45 PM

URL: http://pirsa.org/05040053

Abstract:

The CBI Collaboration

Caltech Team: **Tony Readhead (Principal Investigator), John Cartwright, Clive Dickinson, Alison Farmer, Russ Keeney, Brian Mason, Steve Miller, Steve Padin (Project Scientist), Tim Pearson, Walter Schaal, Martin Shepherd, Jonathan Sievers, Pat Udomprasert, John Yamasaki.**
Operations in Chile: **Pablo Altamirano, Ricardo Bustos, Cristobal Achermann, Tomislav Vucina, Juan Pablo Jacob, José Cortes, Wilson Araya.**
Collaborators: **Dick Bond (CITA), Leonardo Bronfman (University of Chile), John Carlstrom (University of Chicago), Simon Casassus (University of Chile), Carlo Contaldi (CITA), Nils Halverson (University of California, Berkeley), Bill Holzapfel (University of California, Berkeley), Marshall Joy (NASA's Marshall Space Flight Center), John Kovac (University of Chicago), Erik Leitch (University of Chicago), Jorge May (University of Chile), Steven Myers (National Radio Astronomy Observatory), Angel Otarola (European Southern Observatory), Ue-Li Pen (CITA), Dmitry Pogosyan (University of Alberta), Simon Prunet (Institut d'Astrophysique de Paris), Clem Pryke (University of Chicago).**

The CBI Project is a collaboration between the **California Institute of Technology**, the **Canadian Institute for Theoretical Astrophysics**, the **National Radio Astronomy Observatory**, the **University of Chicago**, and the **Universidad de Chile**. The project has been supported by funds from the National Science Foundation, the California Institute of Technology, Maxine and Ronald Linde, Cecil and Sally Drinkward, Barbara and Stanley Rawn Jr., the Kavli Institute, and the Canadian Institute for Advanced Research.

The Instrument

- 13 90-cm Cassegrain antennas
  - 78 baselines
- 6-meter platform
  - Baselines 1m – 5.51m
- 10 1 GHz channels 26-36 GHz
  - HEMT amplifiers (NRAO)
  - Cryogenic 6K, Tsys 20 K
- Single polarization (R or L)
  - Polarizers from U. Chicago
- Analog correlators
  - 780 complex correlators
- Field-of-view 44 arcmin
  - Image noise 4 mJy/bm 900s

The CBI Adventure…

CBI located at 5080 meters in Atacama desert, Chile.

Area is used by NASA as a proxy for Mars for testing/developing equipment.

Land mines along border w/ Bolivia

Steve Padin wearing the cannular oxygen system

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- Volcan Lascar (~30 km away)

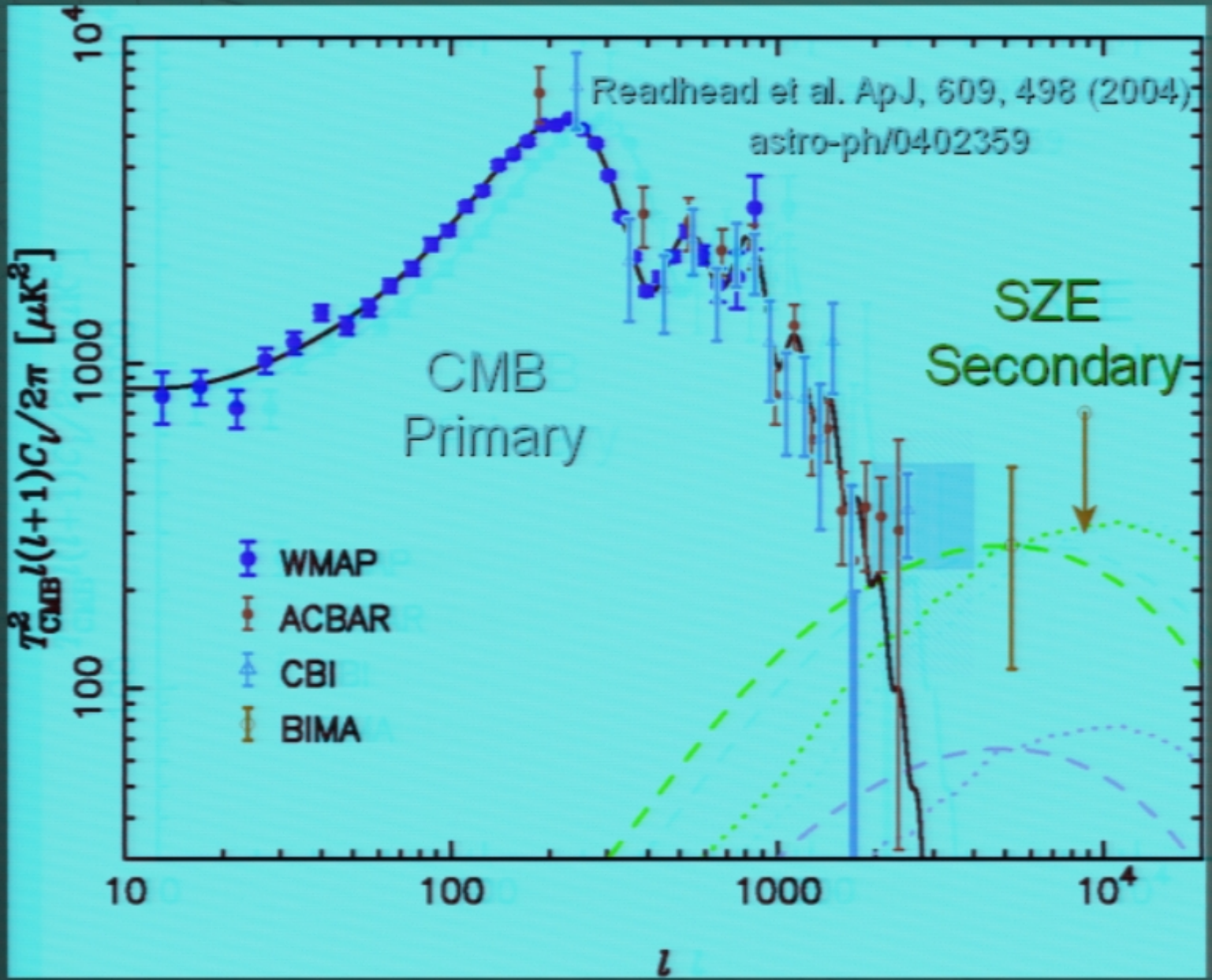
CMB Interferometers

Interferometers are a very clean way of measuring CMB. Robust with respect to instrumental systematics.

- Interferometers directly measure Fourier Plane
  - Resolution set by field of view
- Interferometers do not pick up large scale power
  - Gain fluctuations don't see monopole/dipole

- Polarization:
  - Directly Measure E and B (modulo FOV)
  - Correlate circular electric fields to directly measure linear pol'n
  - Do *not* subtract two nearly equal signals

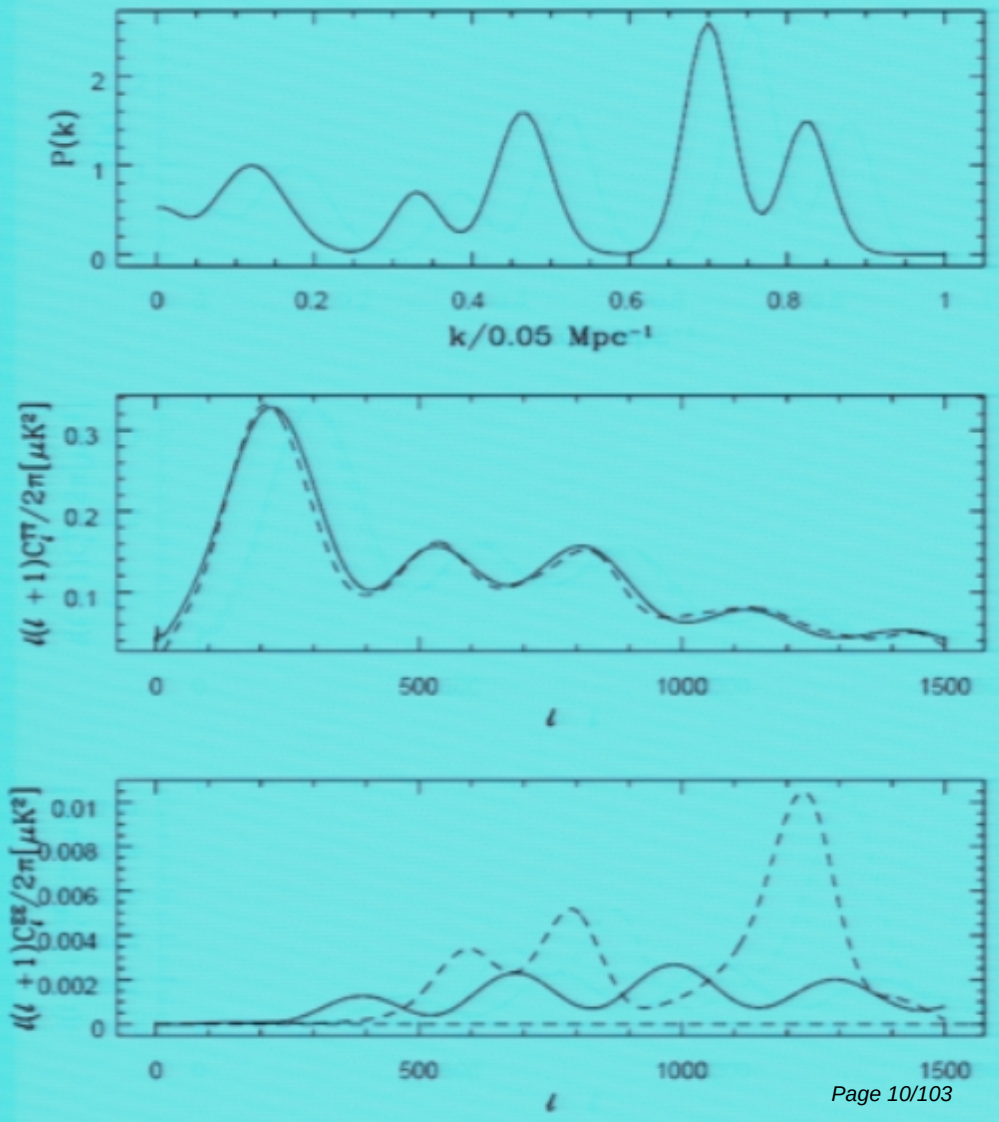
CBI 2000+2001 (TT), WMAP, ACBAR, BIMA



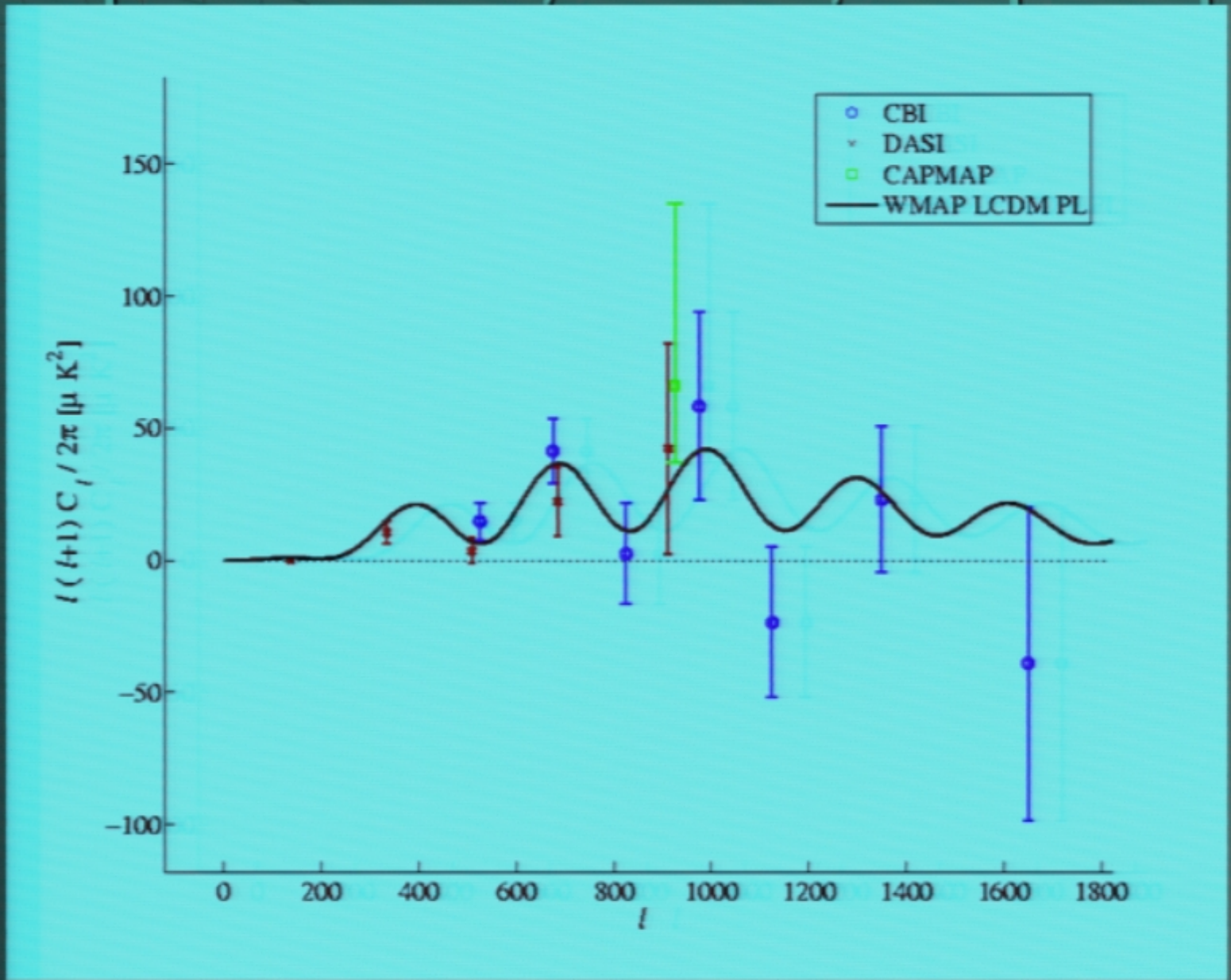
EE – A Separate View

Excellent check on consistency of standard cosmological model.

One example: pathological primordial spectra with very different params can mimic TT. However, EE changes dramatically.



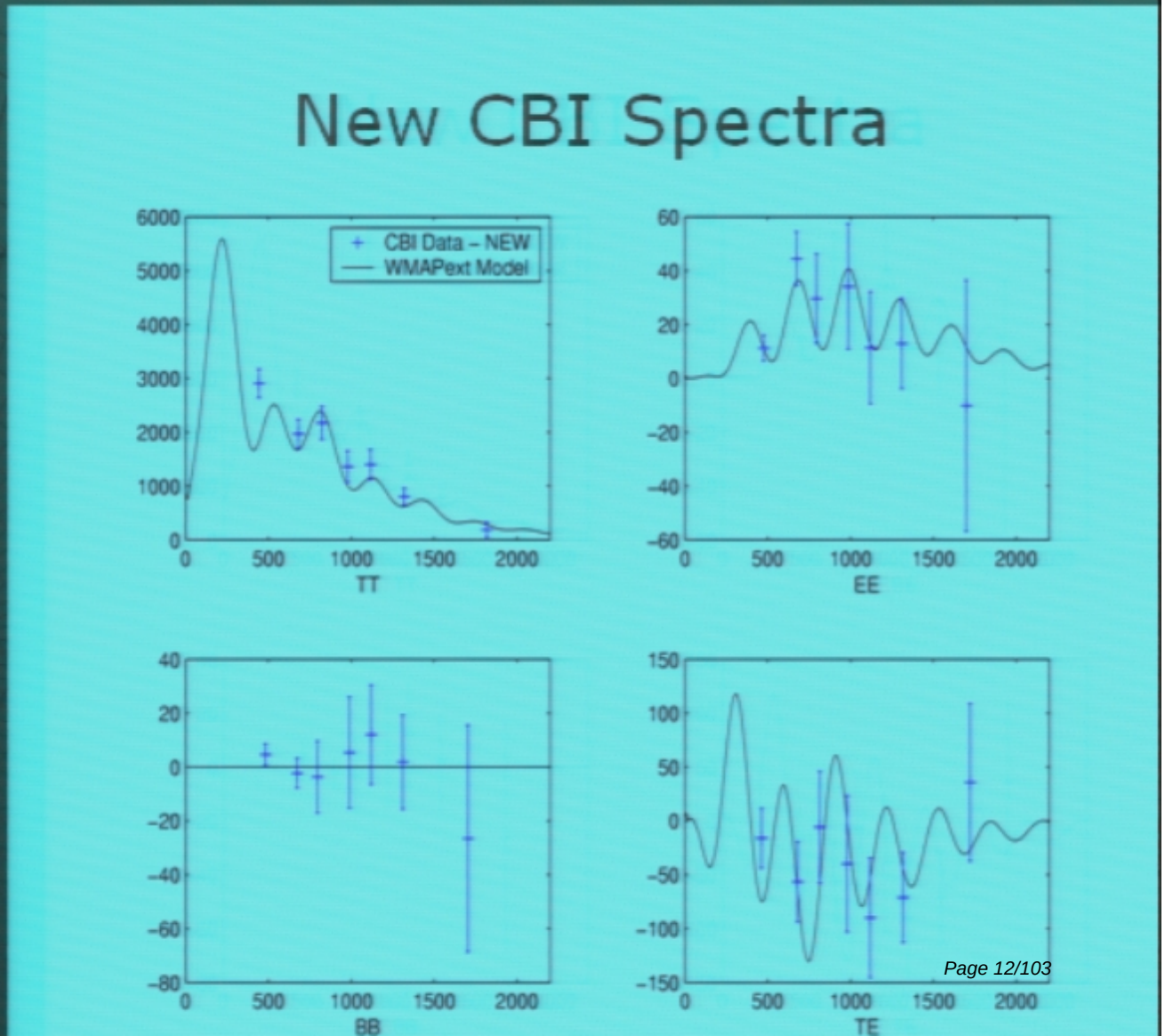
Sep '04: CBI, DASI, Capmap



CBI Polarization Power Spectra

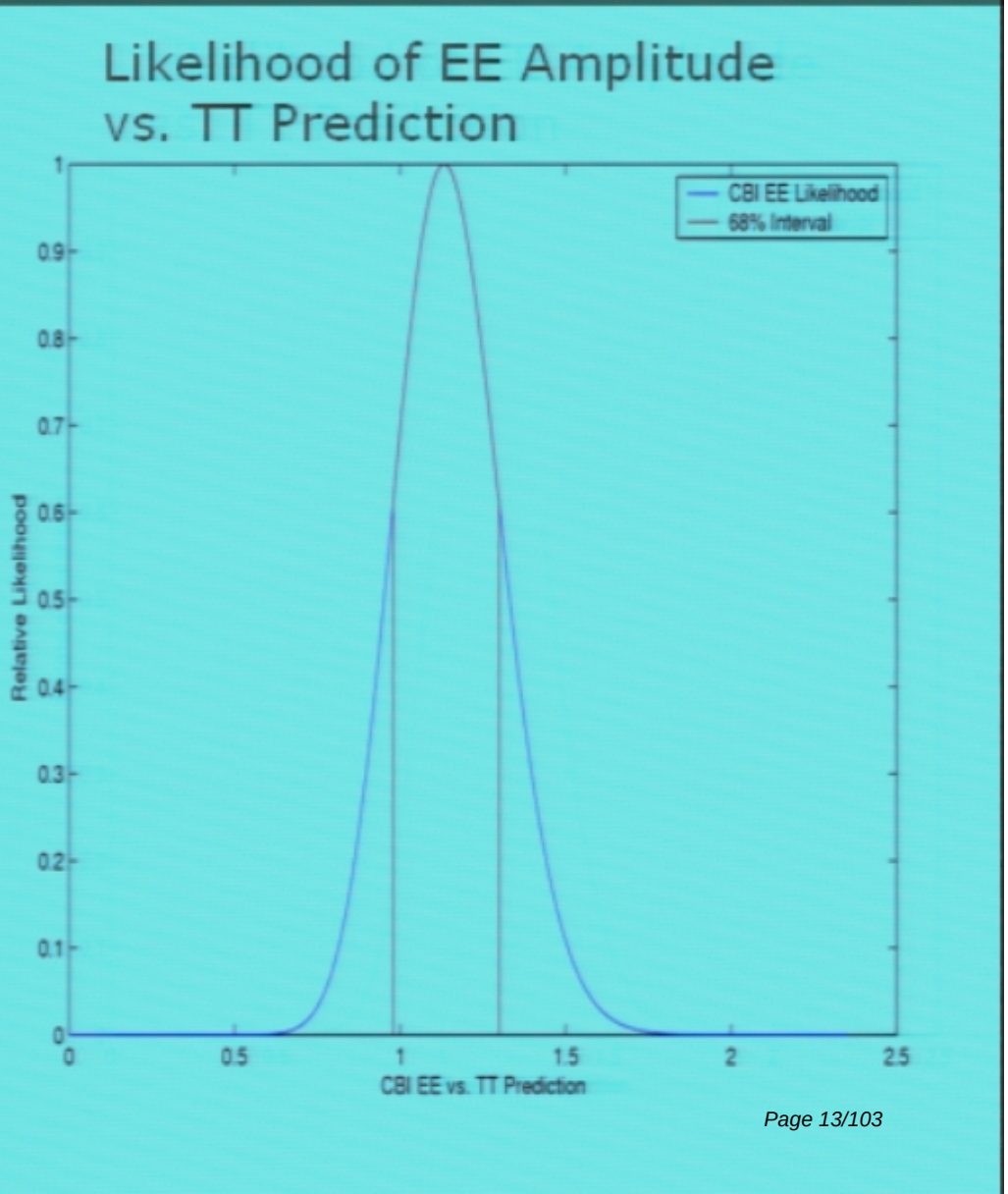
Previously published pol'n detection – *Science* 306,836
NEW DATA – 40% increase presented here

- 7-band fits (Δl = 150 for $600<l<1200$)
- 7-band spectra consistent with WMAPext model (TT from WMAP, ACBAR, 2000 + 2001 CBI)
- Consistent with old pol'n data, errors smaller



Shaped C_l Fit

- Use WMAP'03 best-fit C_l in signal covariance matrix
  - bandpower relative to fiducial PS
  - compute for single band encompassing all l
- Results for new CBI pol'n data
  - EE q_B = 1.13 ± 0.17 (68%)
  - EE likelihood vs. zero : equivalent significance 10.7 σ
  - TE q_B = 1.00 ± 0.28
  - BB q_B = 1.9 ± 2.2 μK^2
    - No evidence for foregrounds



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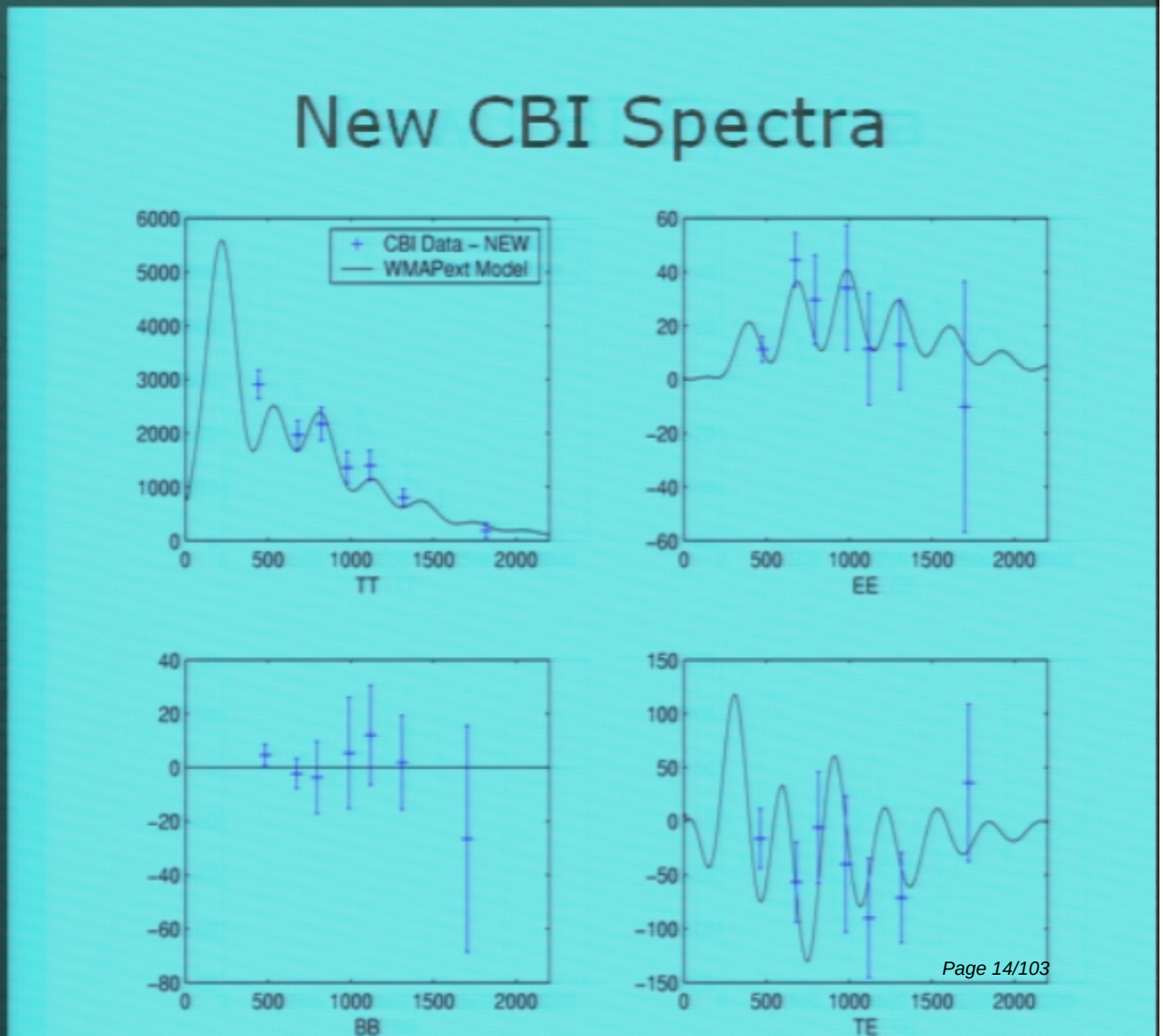

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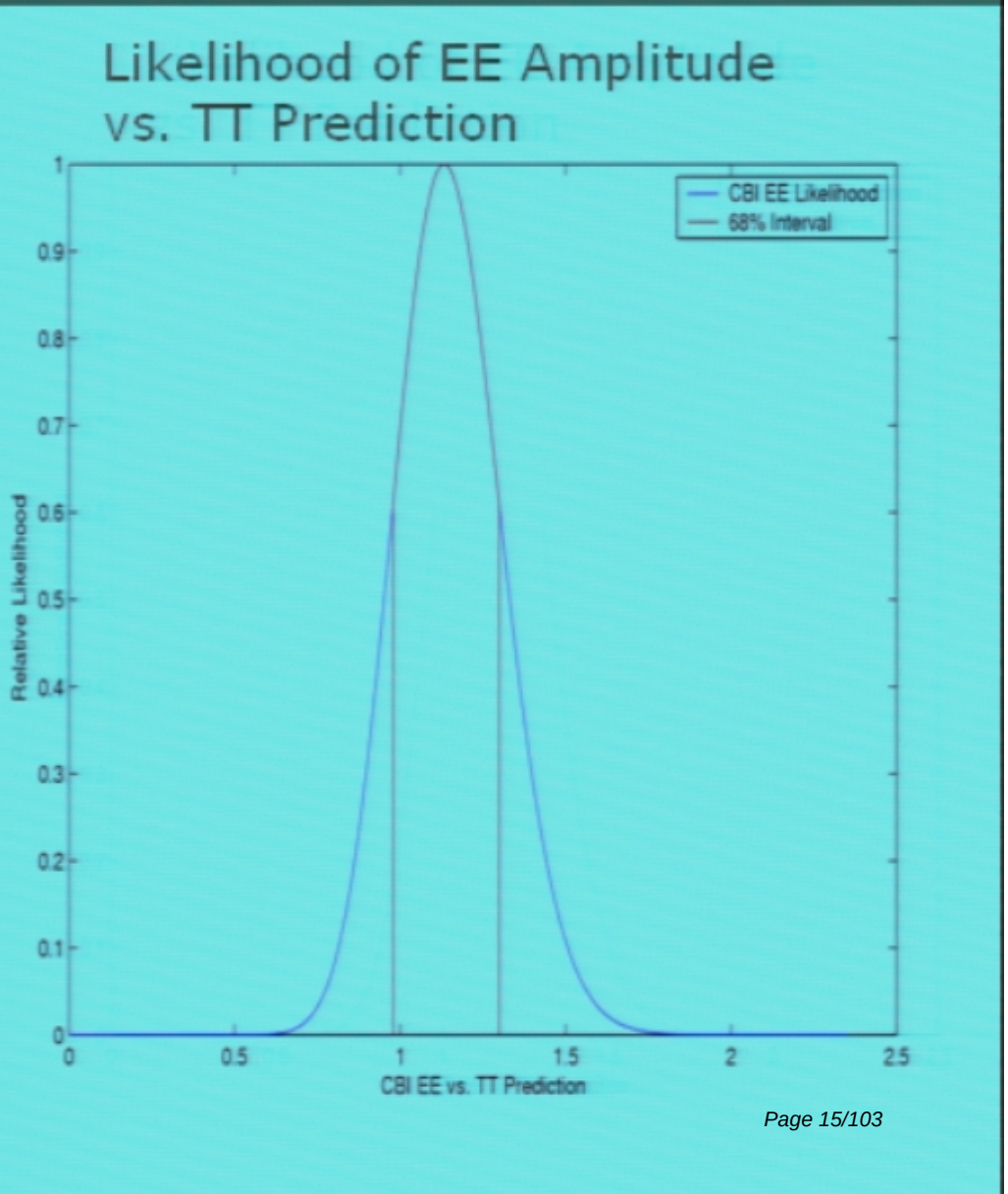
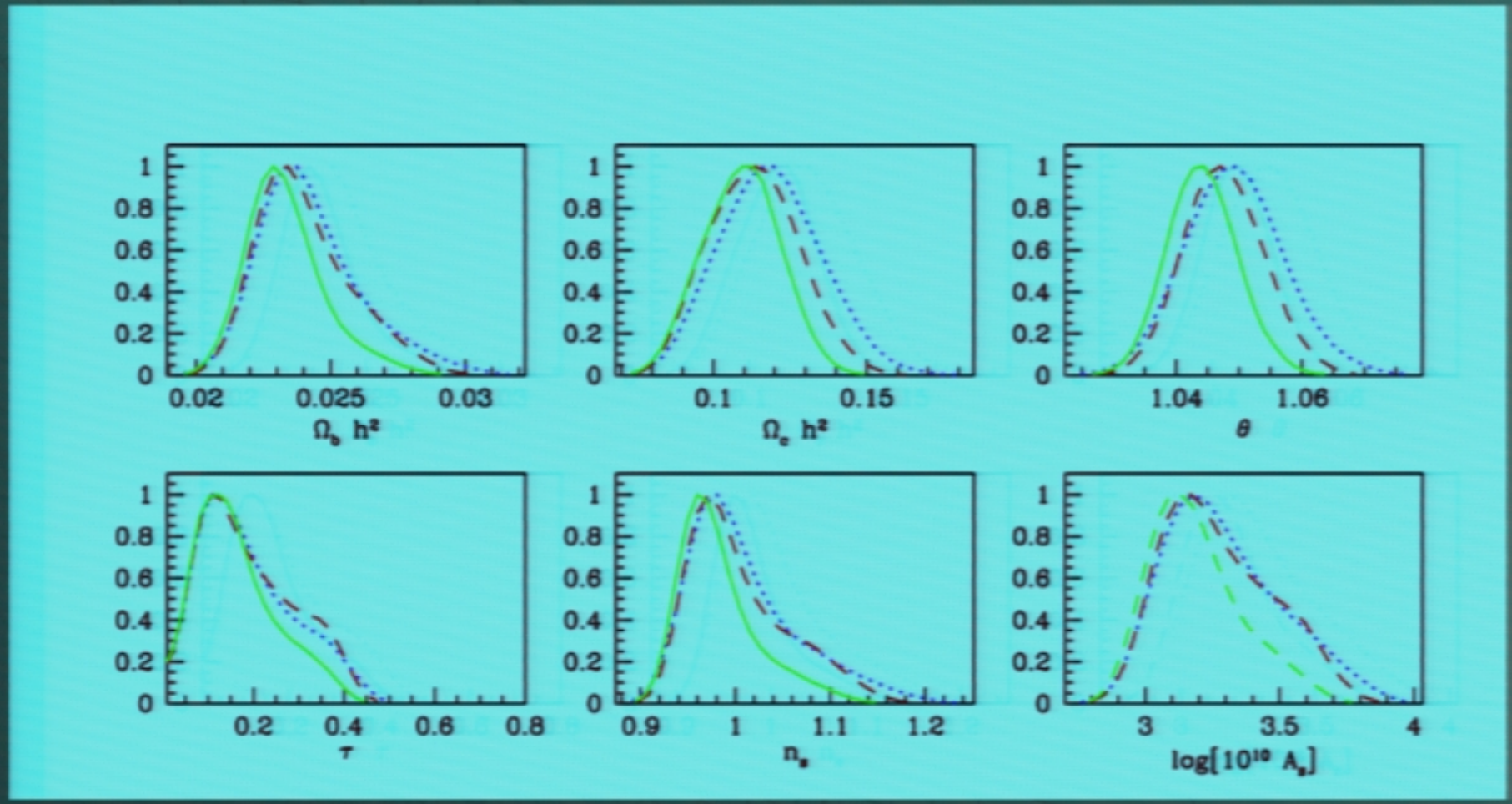


Parameters w/CBI

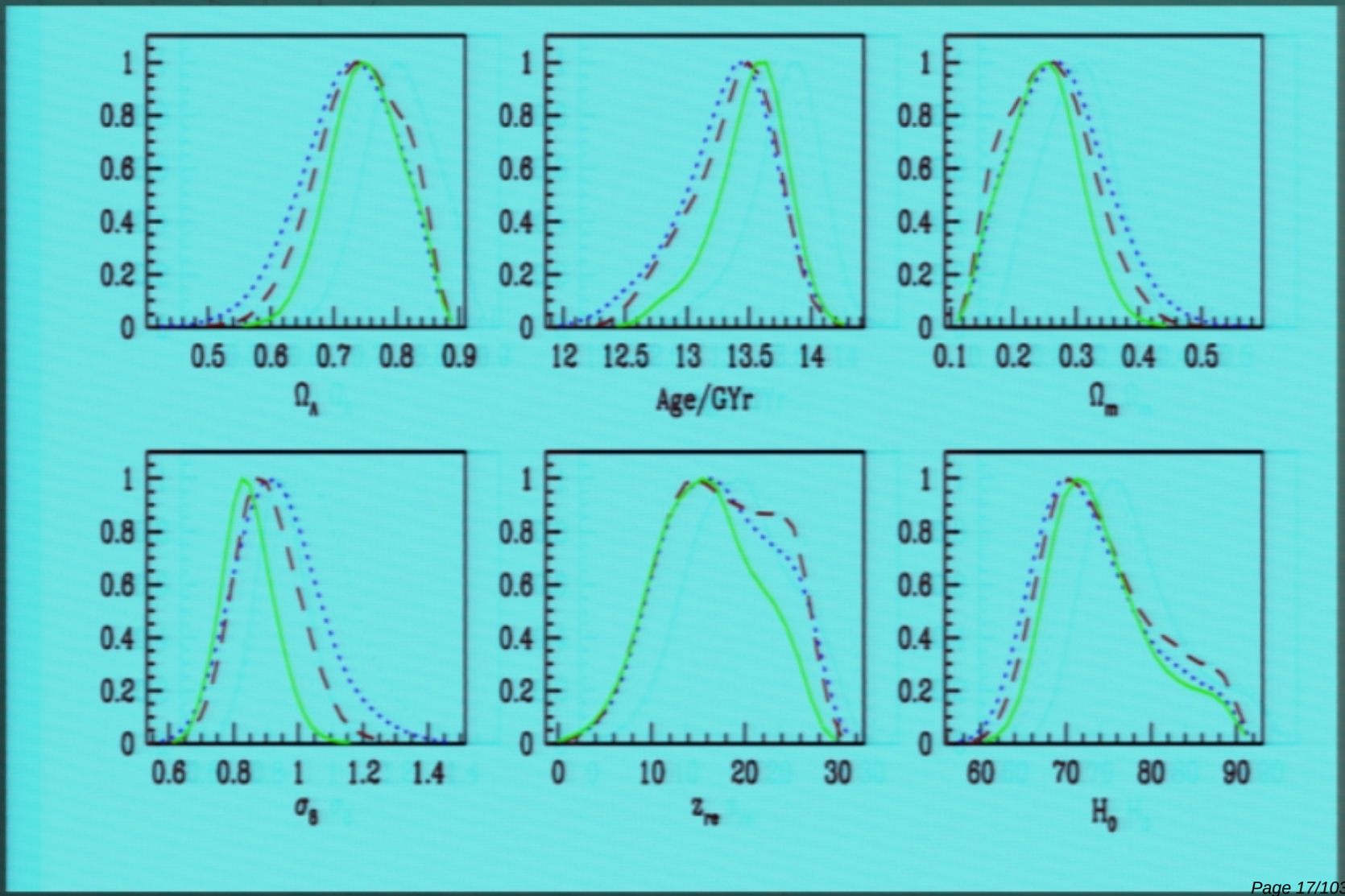


Blue=WMAP

Red=WMAP+Sep '04 (Working on new data)

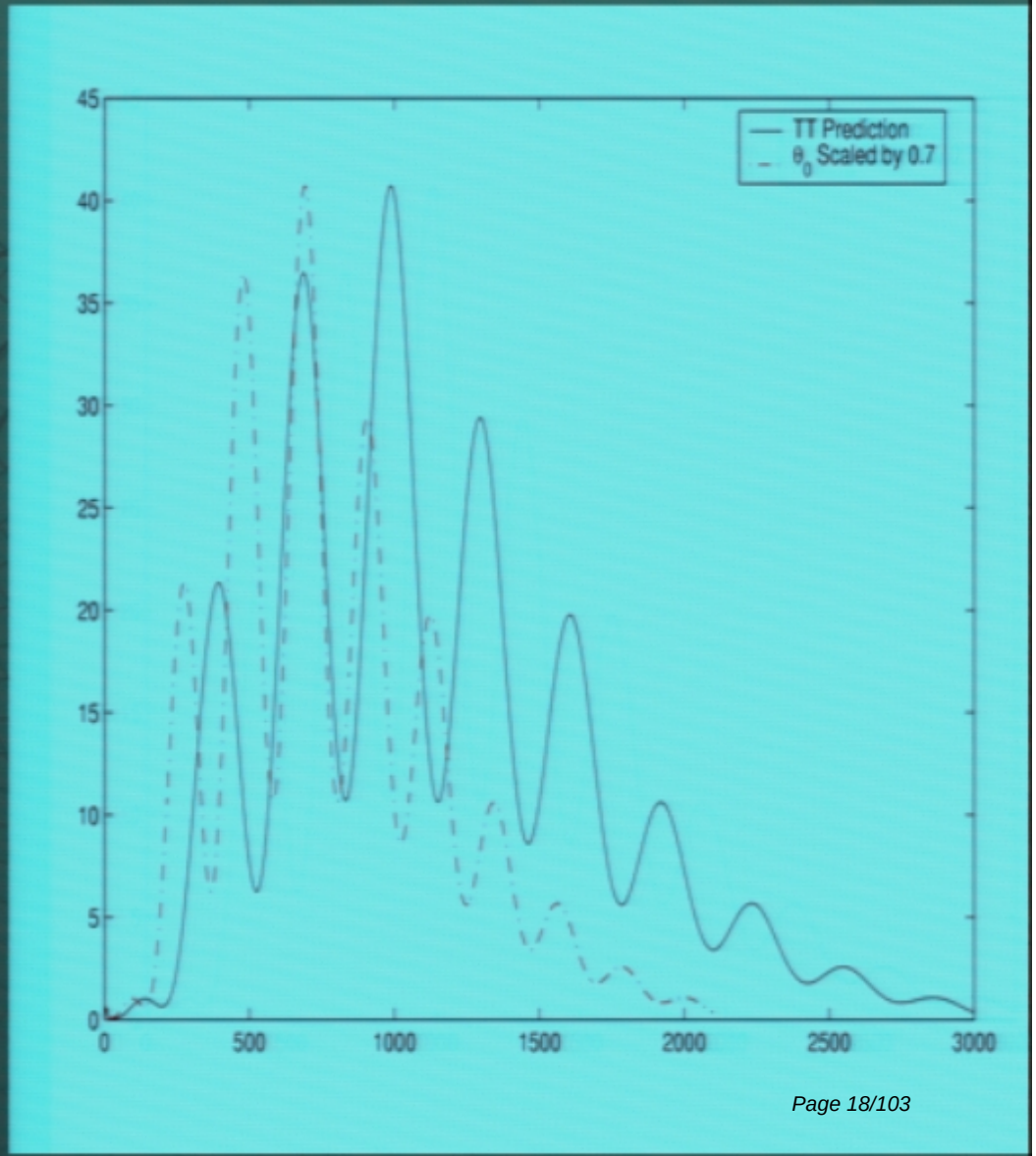
Green=WMAP+Sep '04+CBI7 high-ℓ

Params, contd…

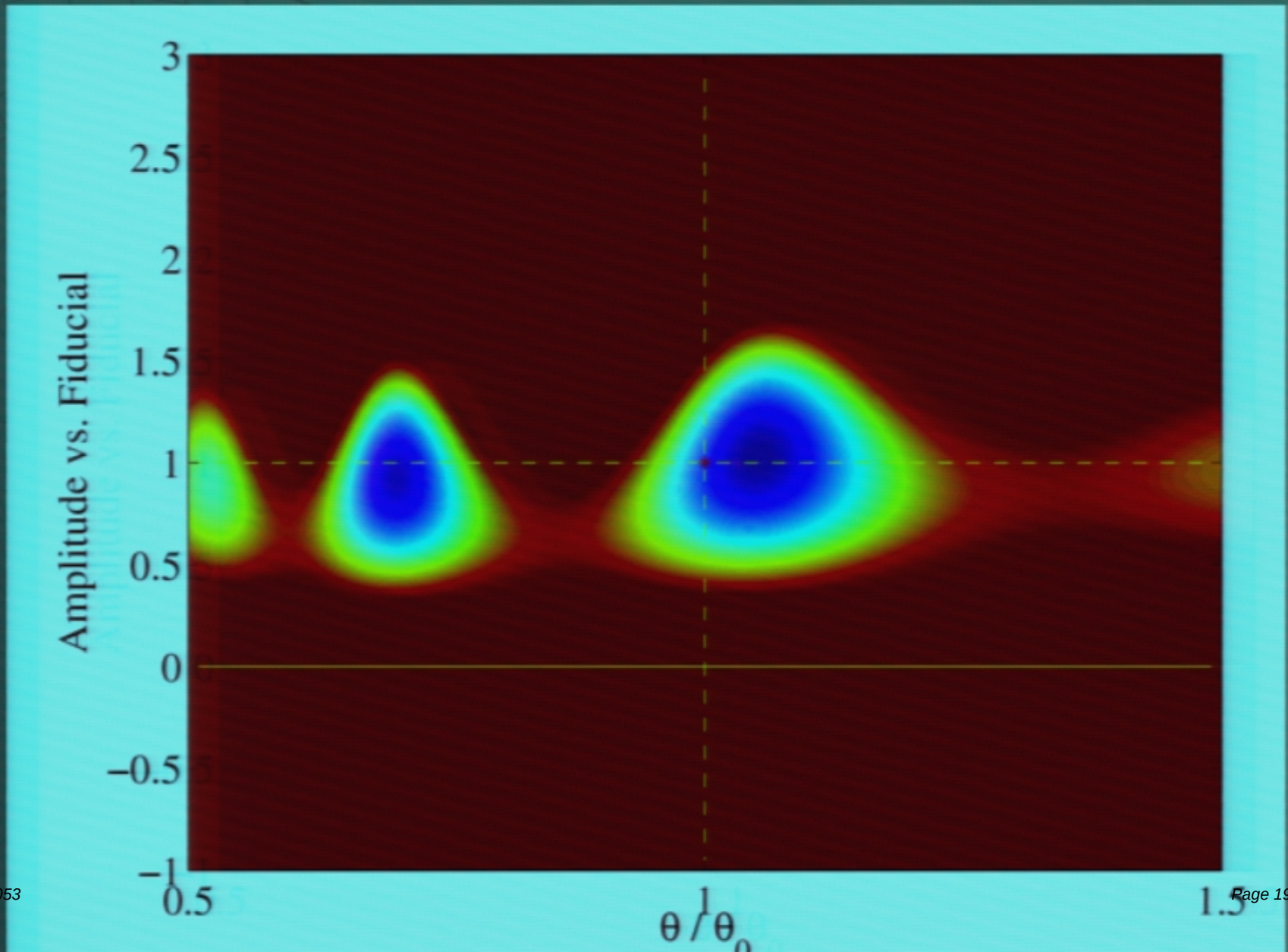


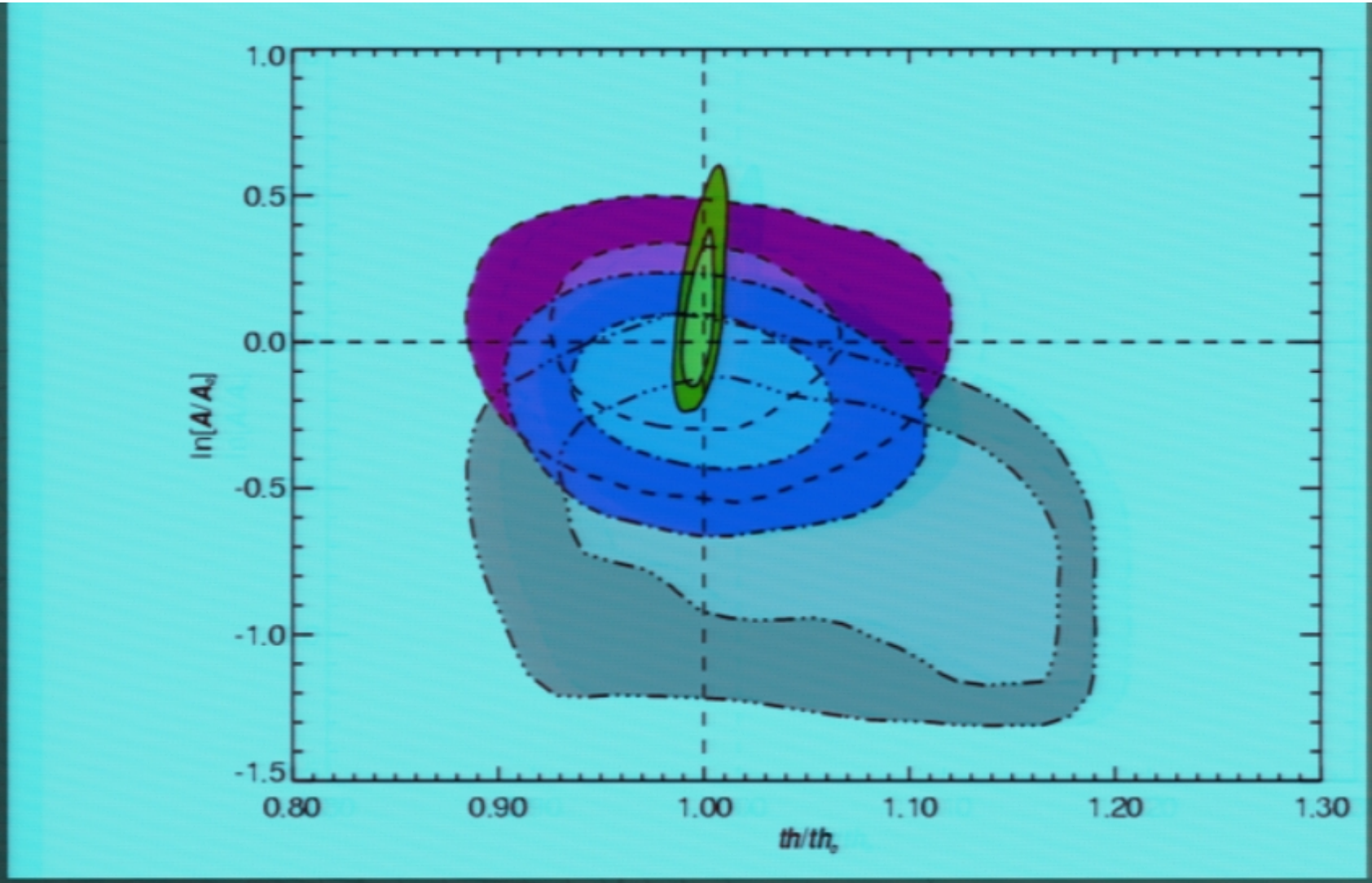
θ/θ_0

- Angular size of sound horizon at LSS should be same for TT and EE.
- CBI only has multiple solutions (shift spectrum by one peak).
- DASI removes degeneracy, but less sensitive.
- CBIold+DASI give scale vs. TT of 1.02 +/- 0.03.



CBI θ/θ_0





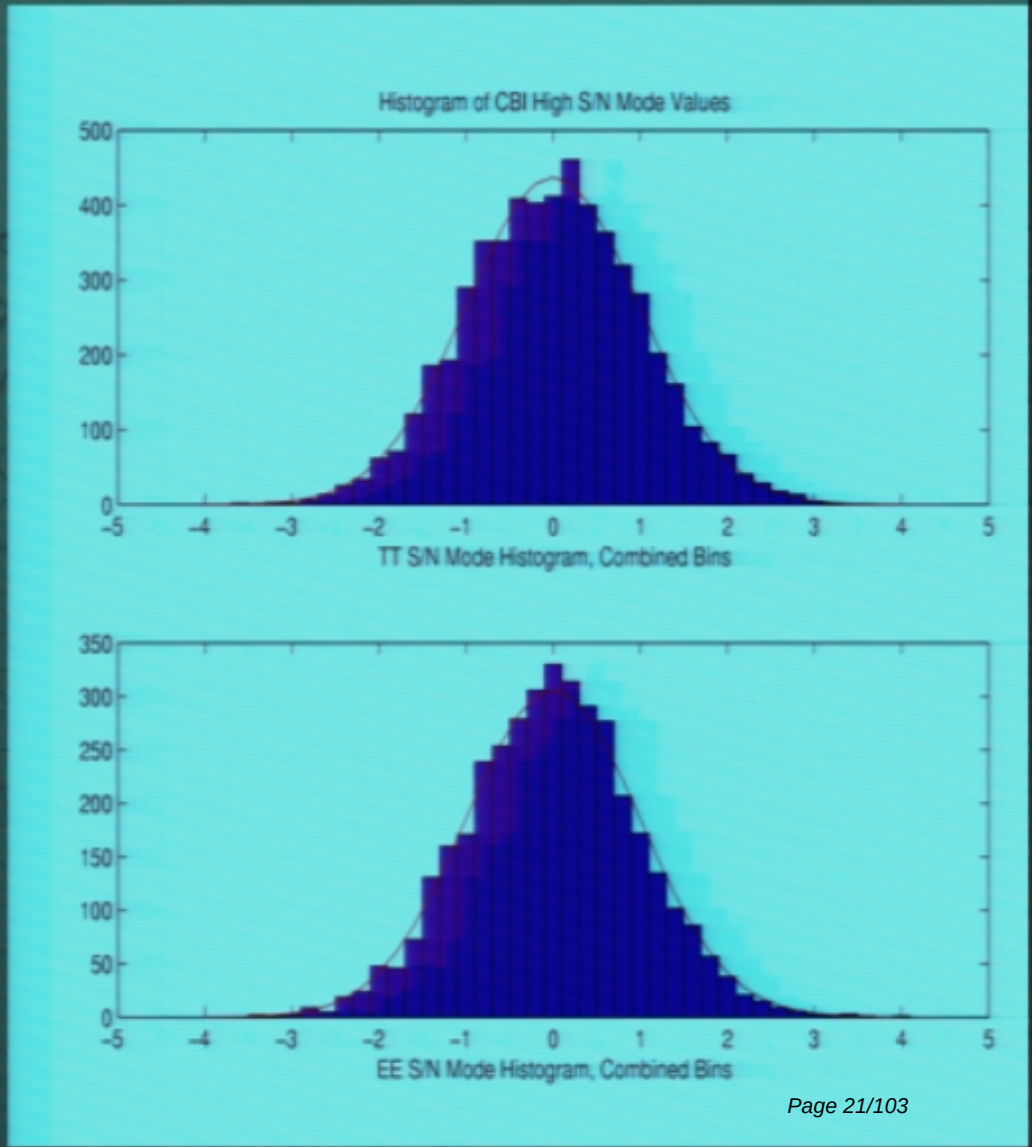
pattern shift parameter 0.998 +- 0.005 WMAP1+CBIpol TT/TE/EE

Evolution: Jan00 11% Jan02 1.2% Jan03 0.9% Mar03 0.4%

EE ONLY: 4% phase check of EE cf. TT pk/dip locales, amp too

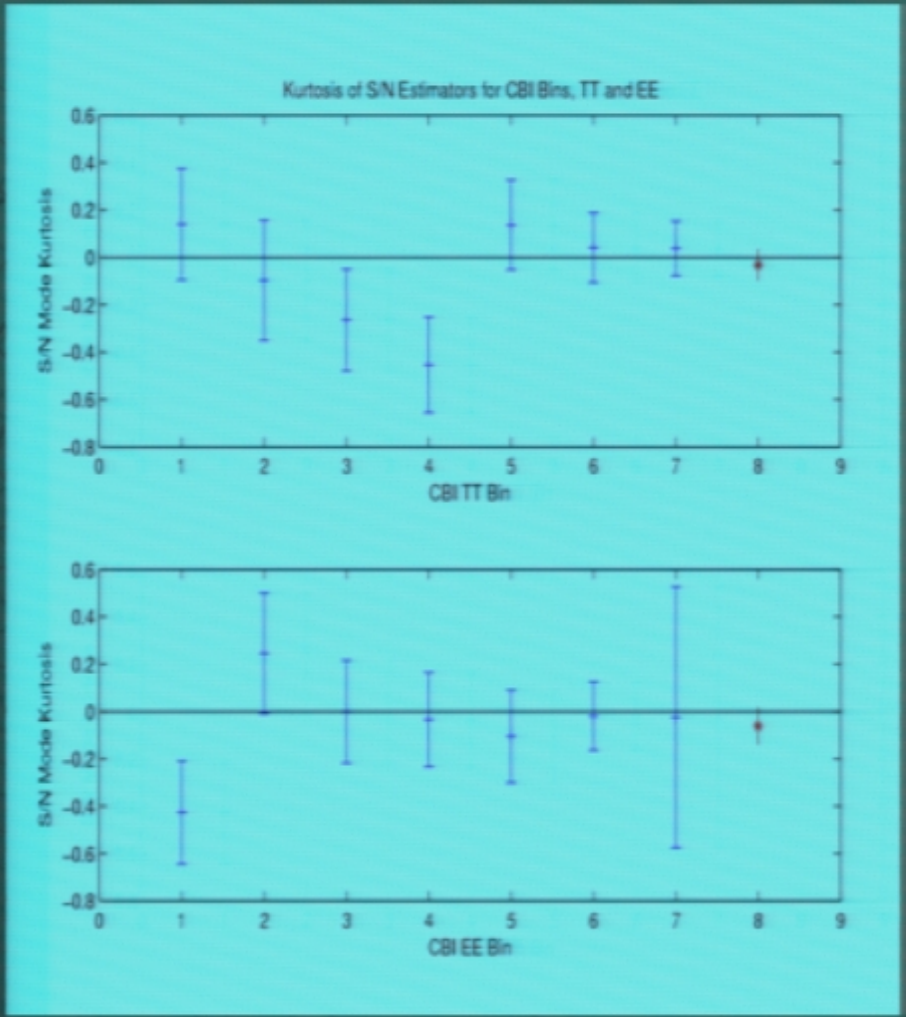
Non-Gaussianity

- Decompose data into uncorrelated S/N eigenmodes for each bin.
- Pick out modes expected to have signal
- Check distribution for non-Gaussianity
- Keep total of 5500 modes TT, 3800 EE – everything consistent with Gaussian
- First check of EE Gaussianity!
- More tests coming…



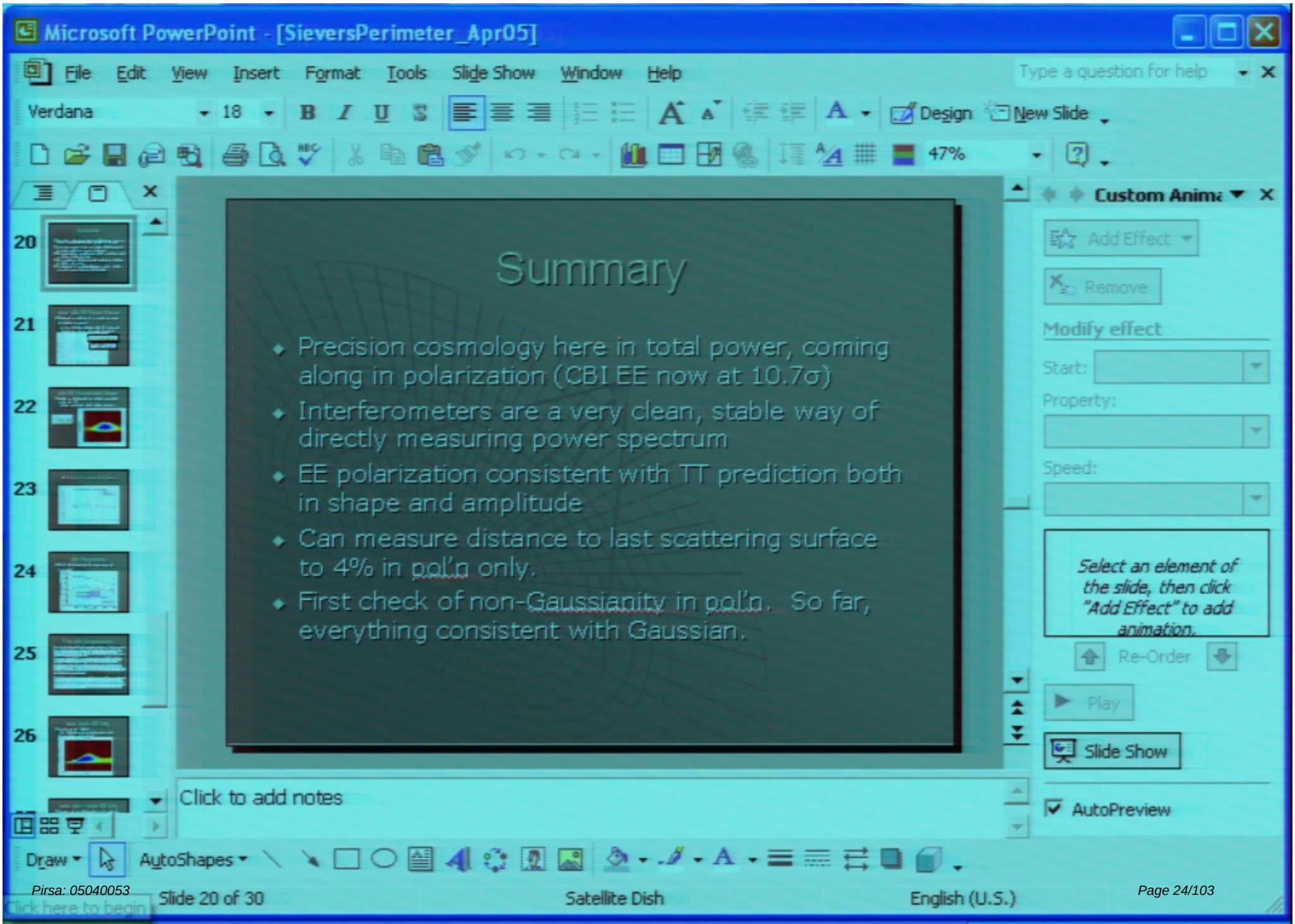
Non-Gaussianity *cont.*

- Check non-Gaussianity in each bin
- Might show l-dependent effect (such as foreground)
- Individual bins consitent with Gaussian.



Summary

- Precision cosmology here in total power, coming along in polarization (CBI EE now at 10.7σ)
- Interferometers are a very clean, stable way of directly measuring power spectrum
- EE polarization consistent with TT prediction both in shape and amplitude
- Can measure distance to last scattering surface to 4% in pol'n only.
- First check of non-Gaussianity in pol'n. So far, everything consistent with Gaussian.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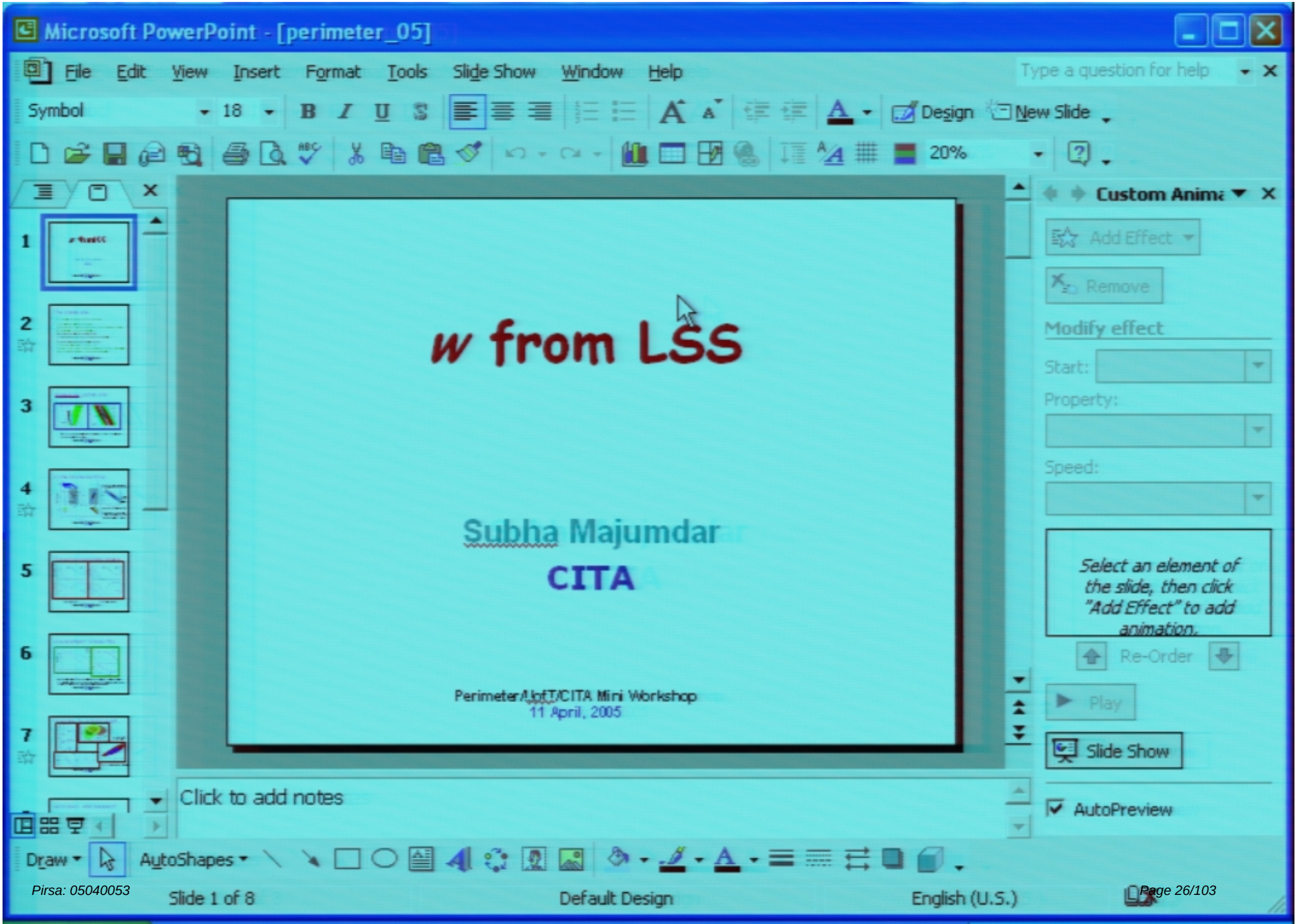
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Subha Majumdar

CITA

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- Baryonic oscillations in galaxy P(k)
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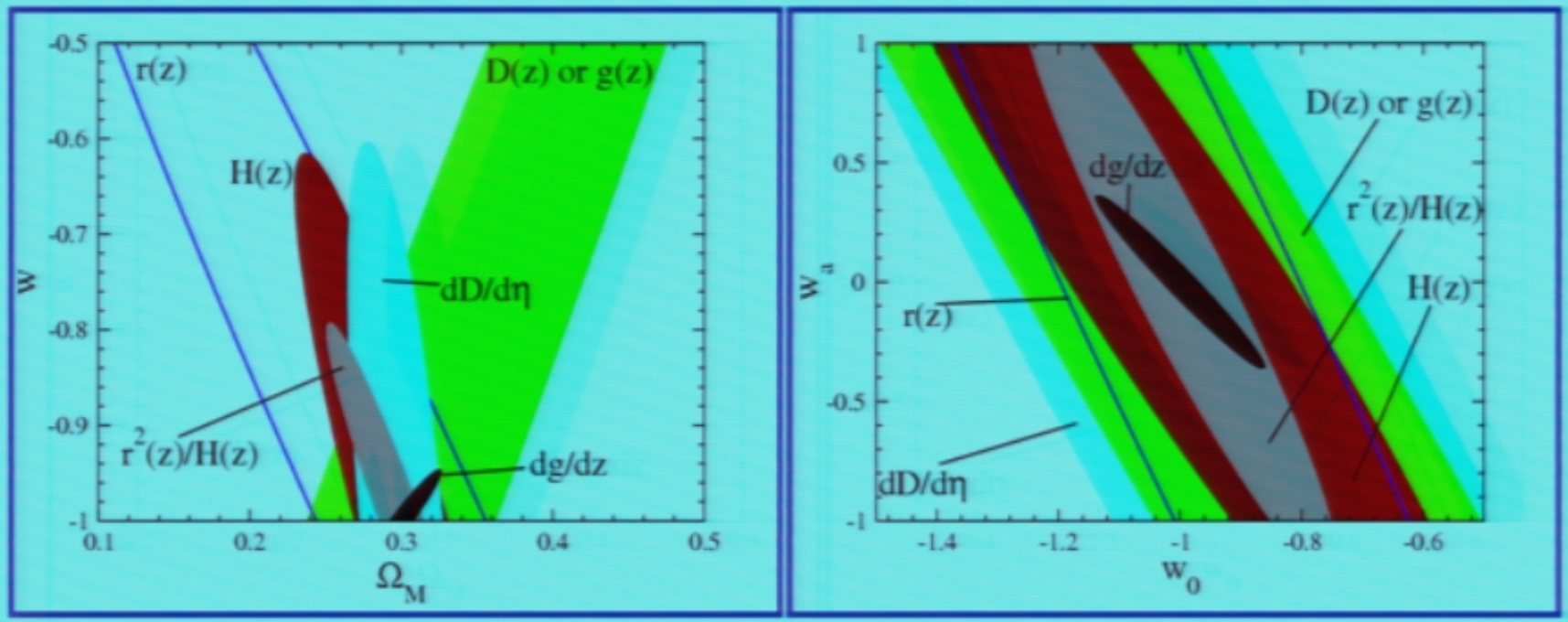
- Redshift distribution of galaxy clusters
- Cross-correlation of ISW with LSS
- Others: Redshift distribution of galaxies (HOD fn); Lookback time to galaxy clusters; Alcock-Paczynski test

‘Underlying’ probes of *w*...



10% error on expansion history, distance, volume, growth and rates of change of growth

A little bit of everything...

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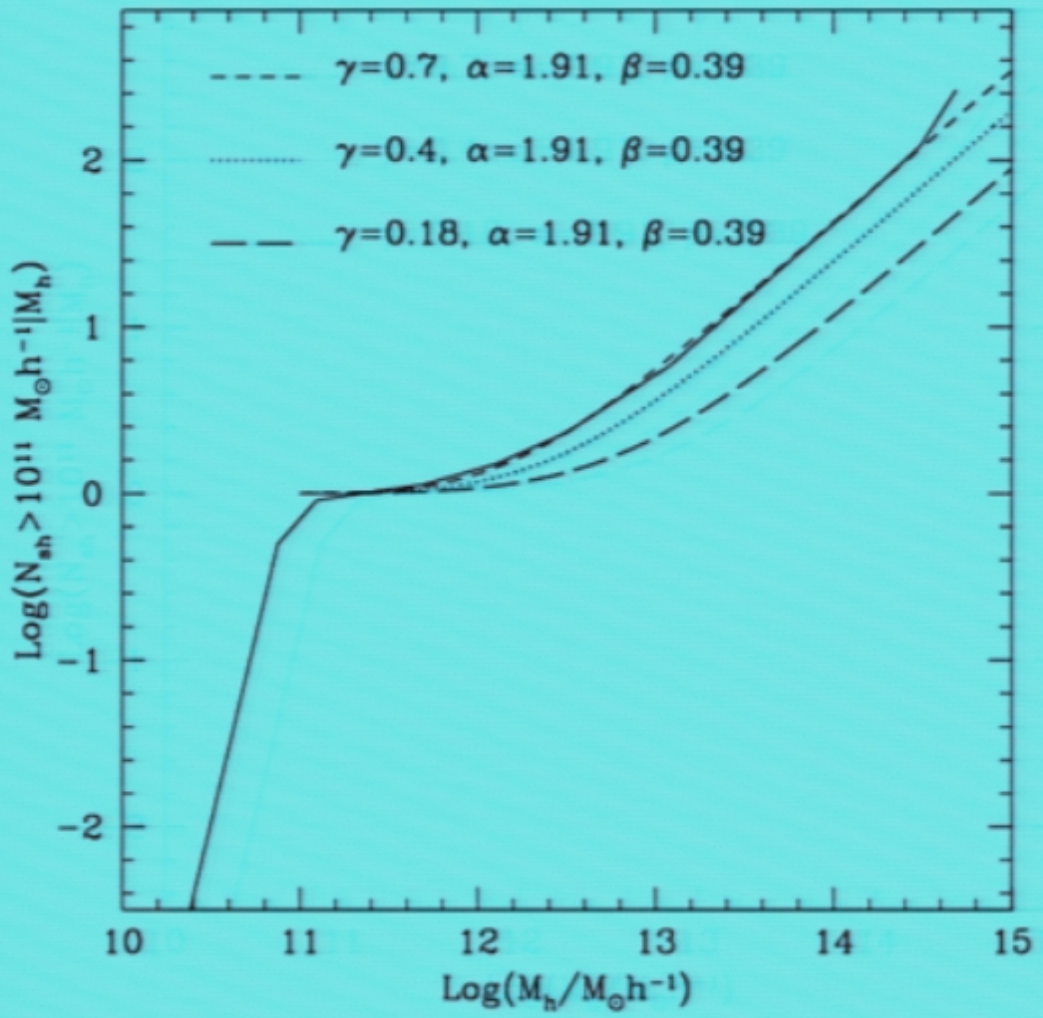
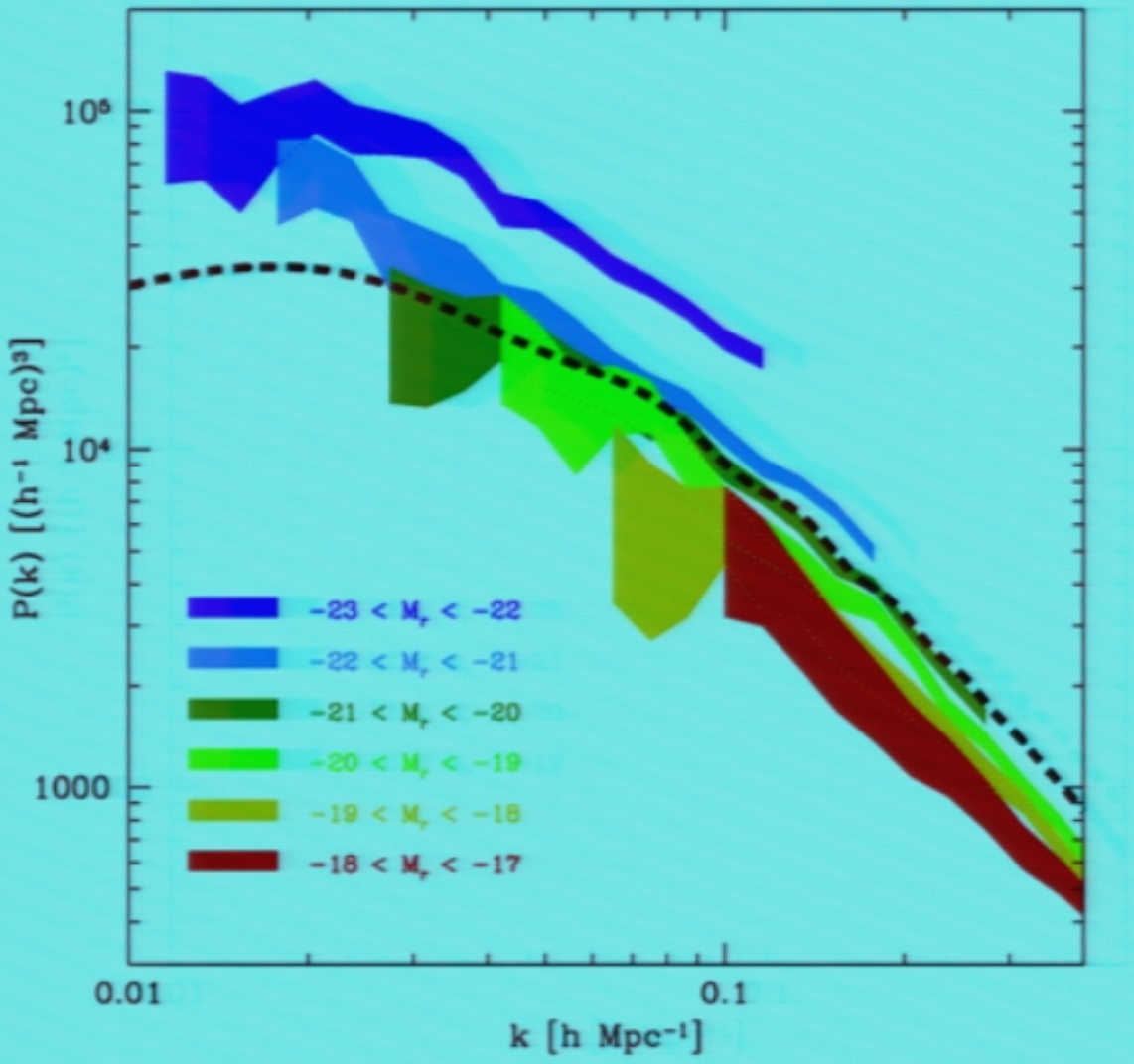


Galaxy redshift distribution (comparison with HOD from Simulations)

A little bit of everything…



Galaxy power spectrum:
Shape (turnover), amplitude.
Different galaxies biased
Differently; Need to estimate
P(L;M)

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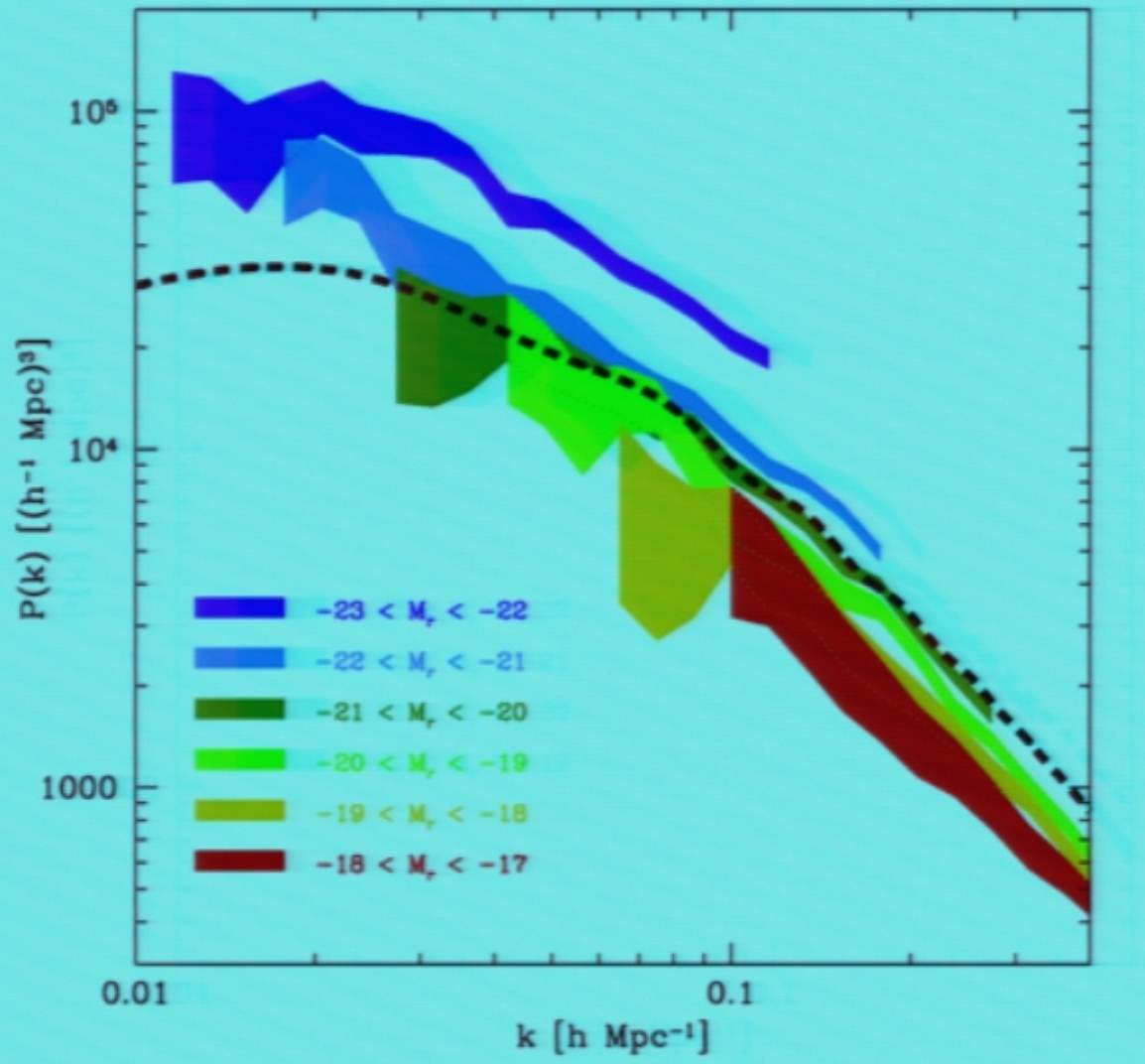

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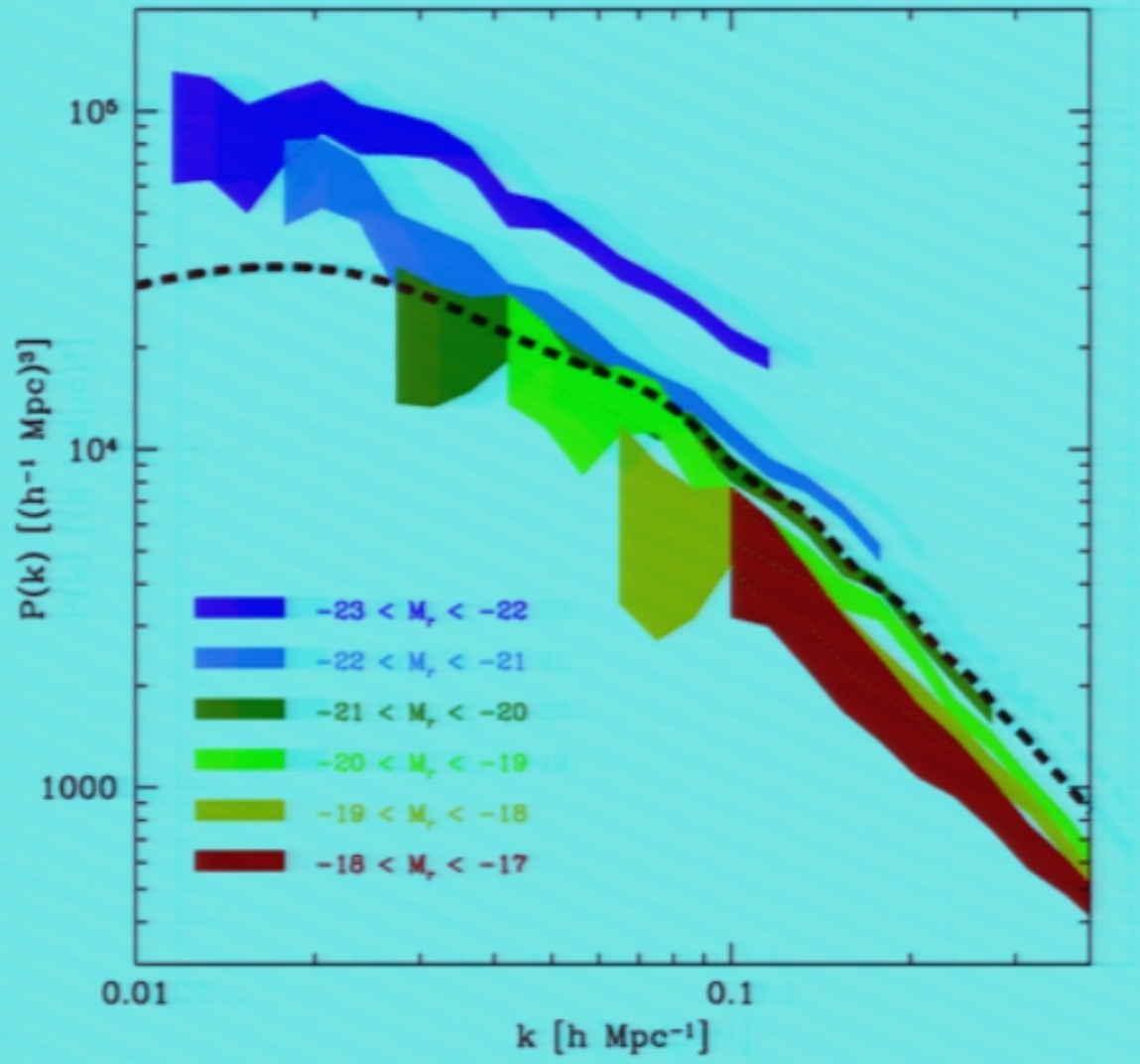

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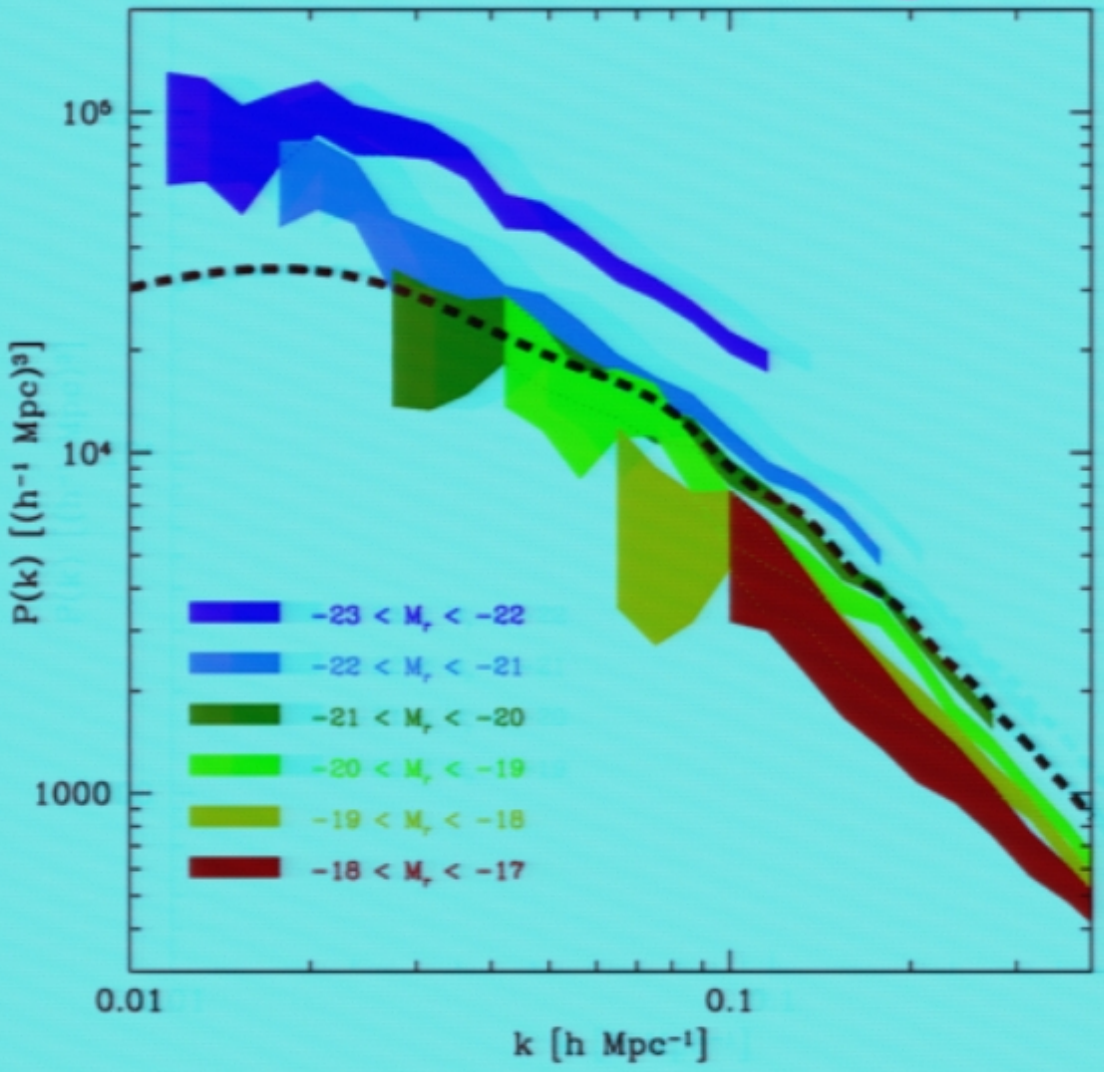

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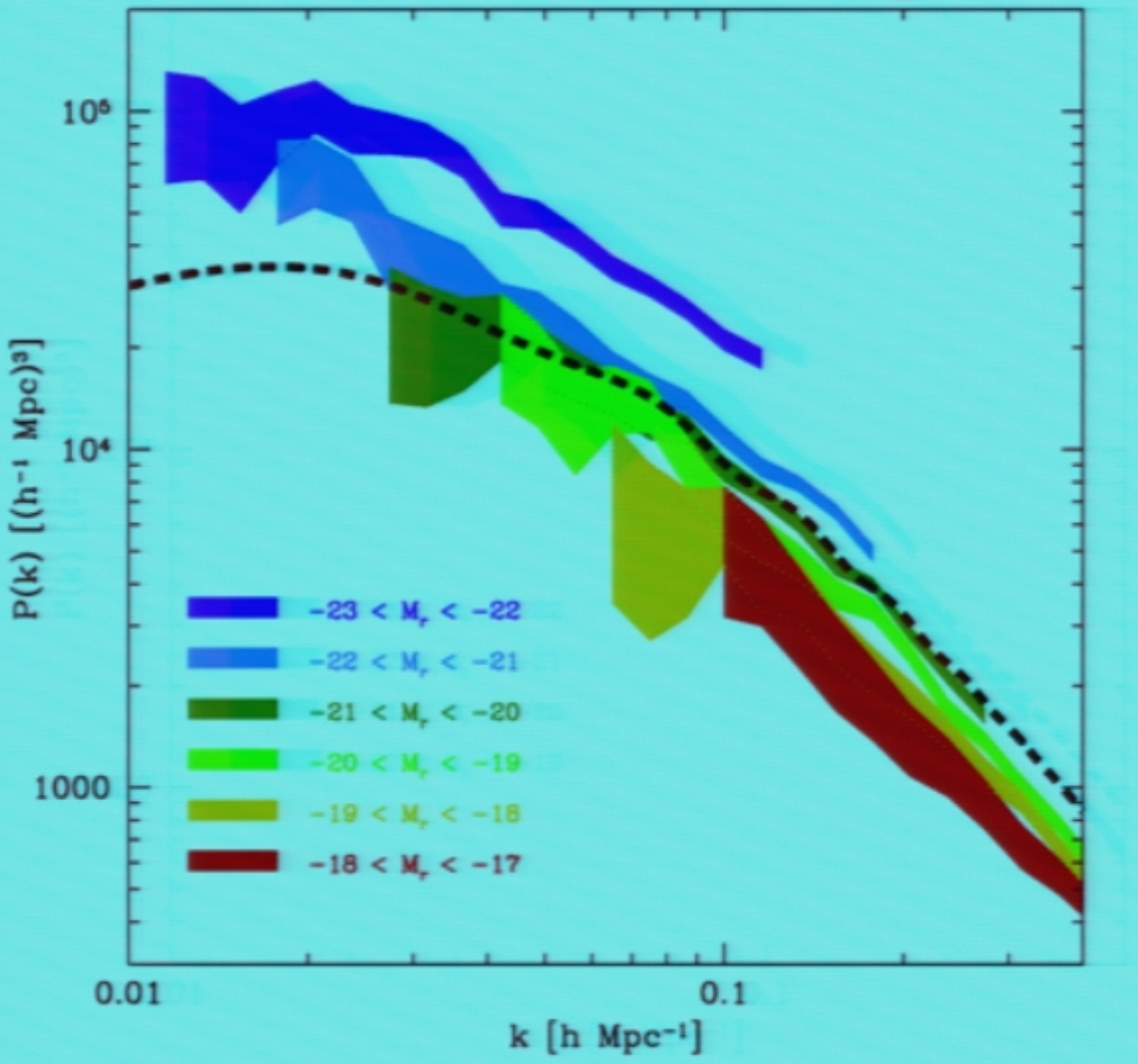

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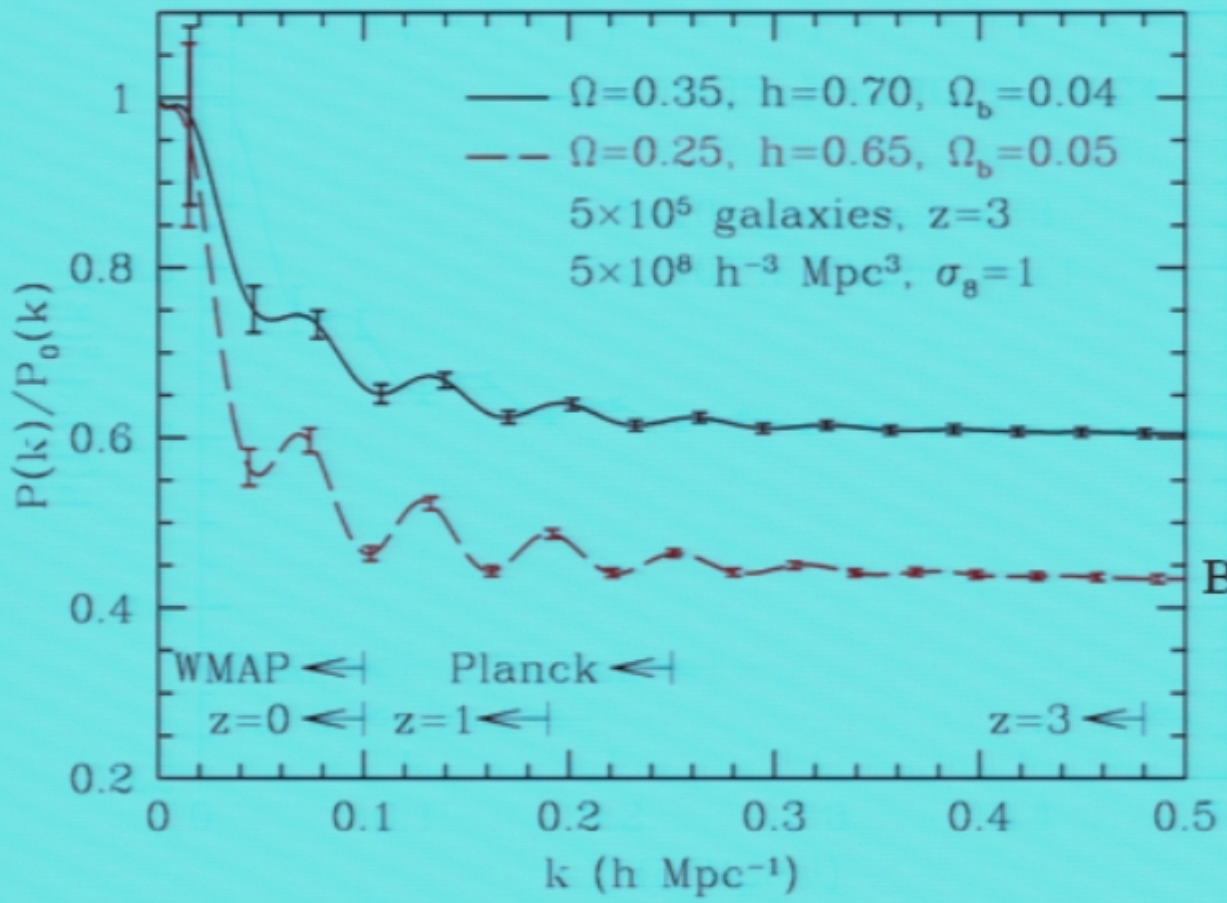
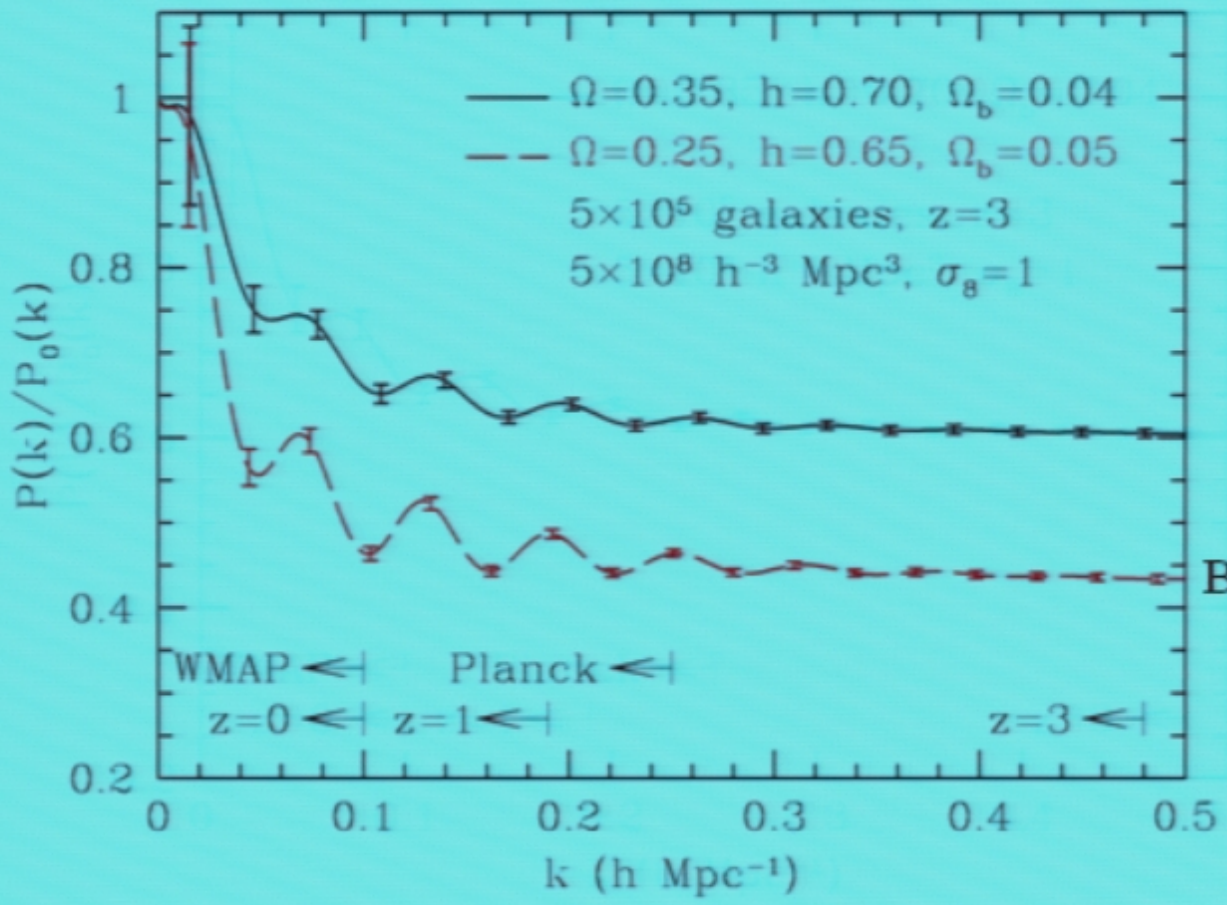


Baryonic oscillations in P(k)

A little bit of everything...



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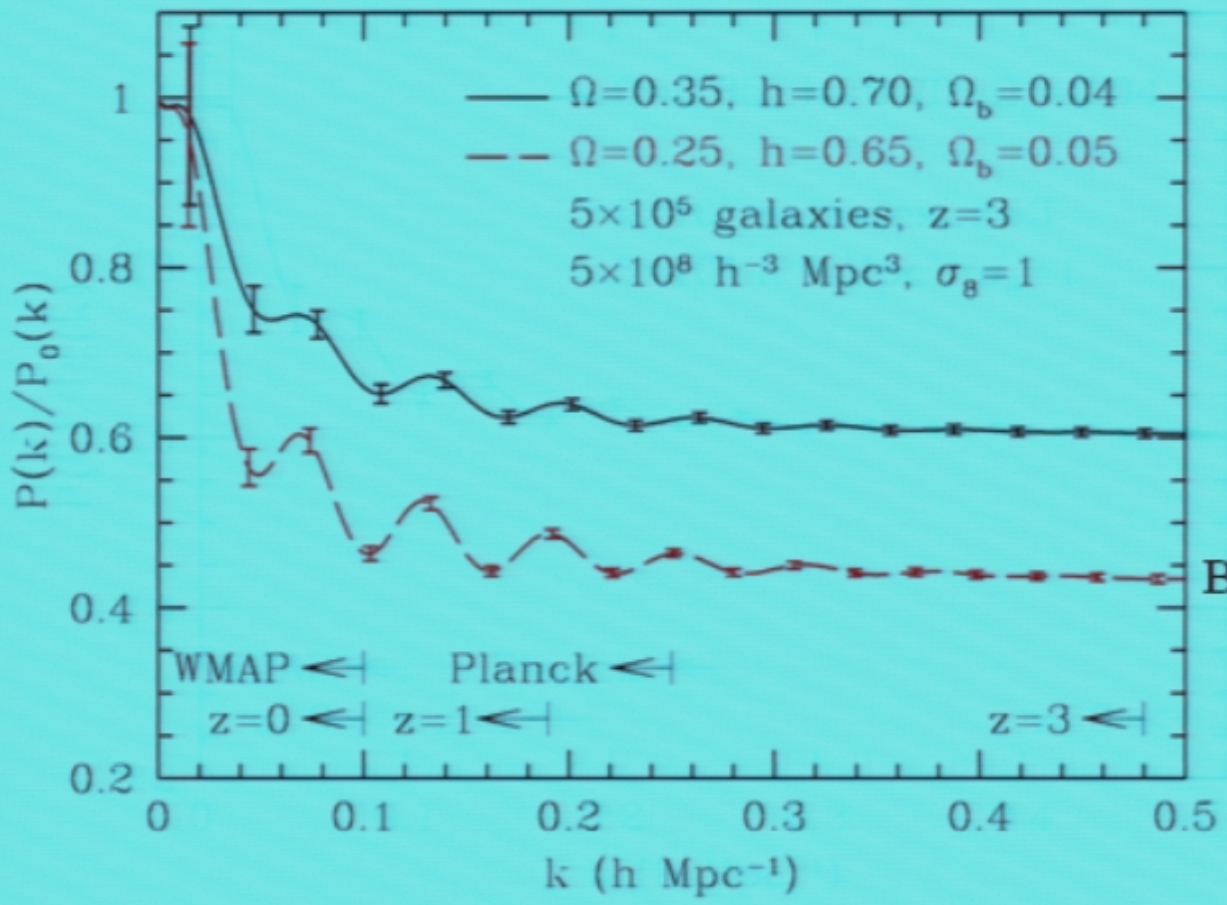

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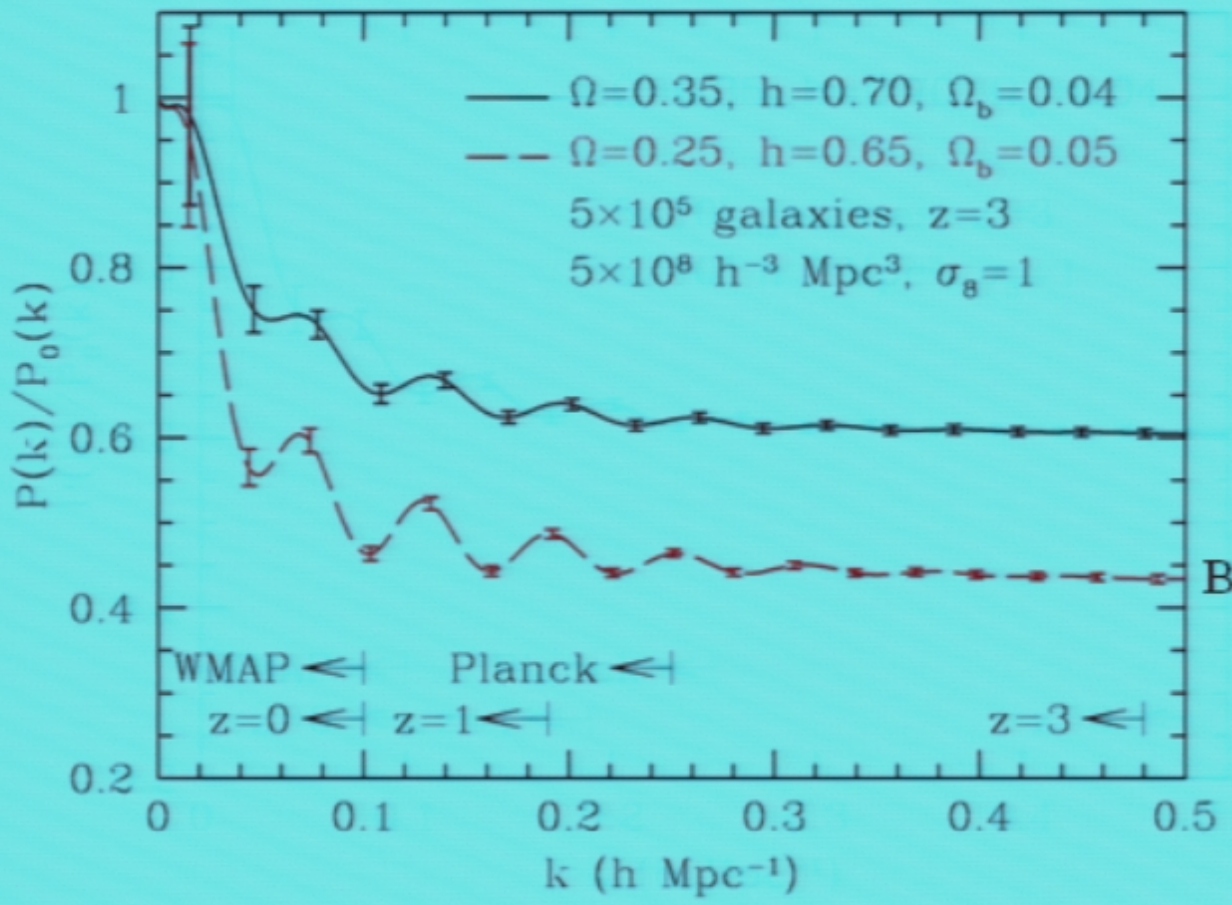

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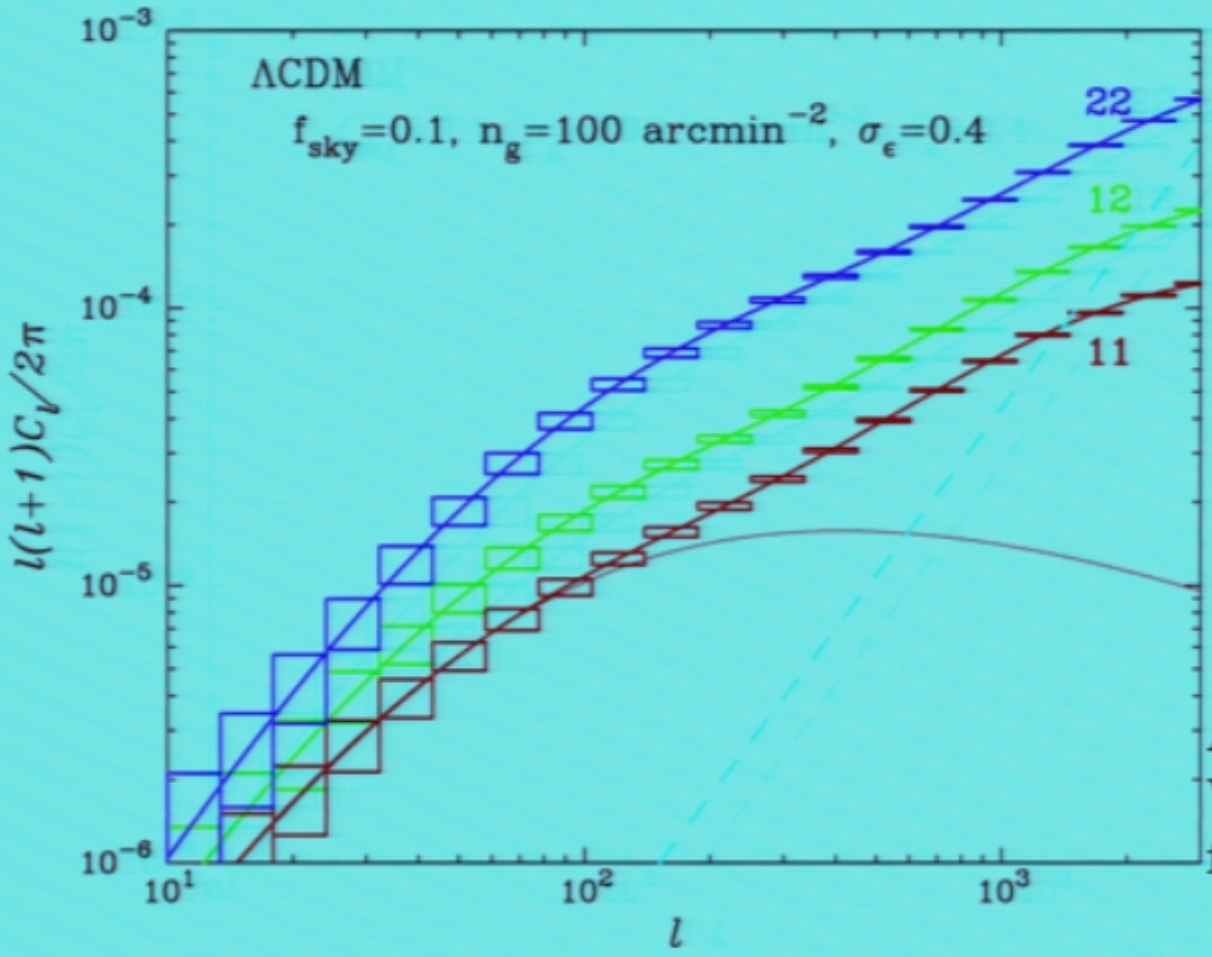

Auto and cross correlating
Weak lensing power spectrum
from galaxies at diff. Z-range

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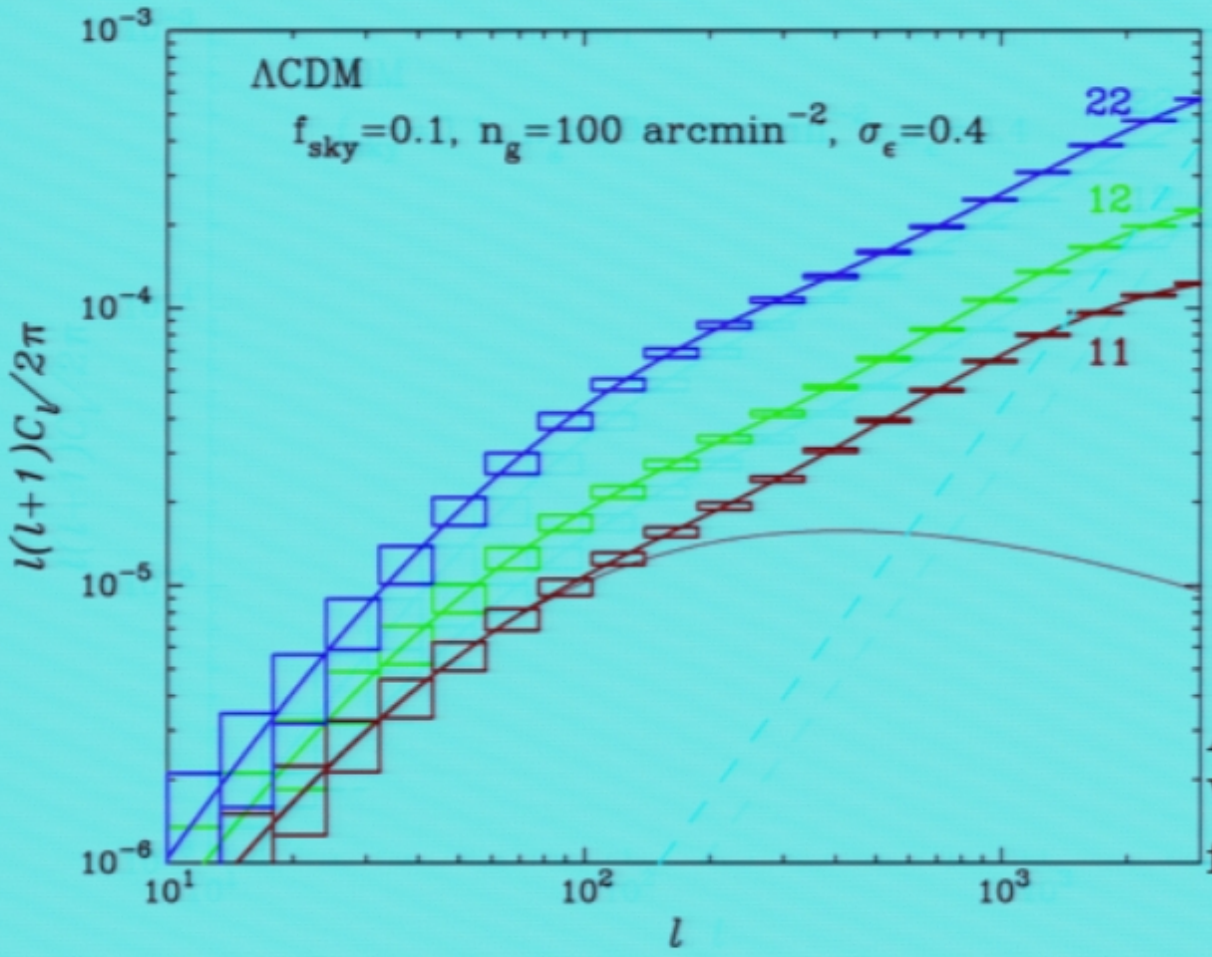

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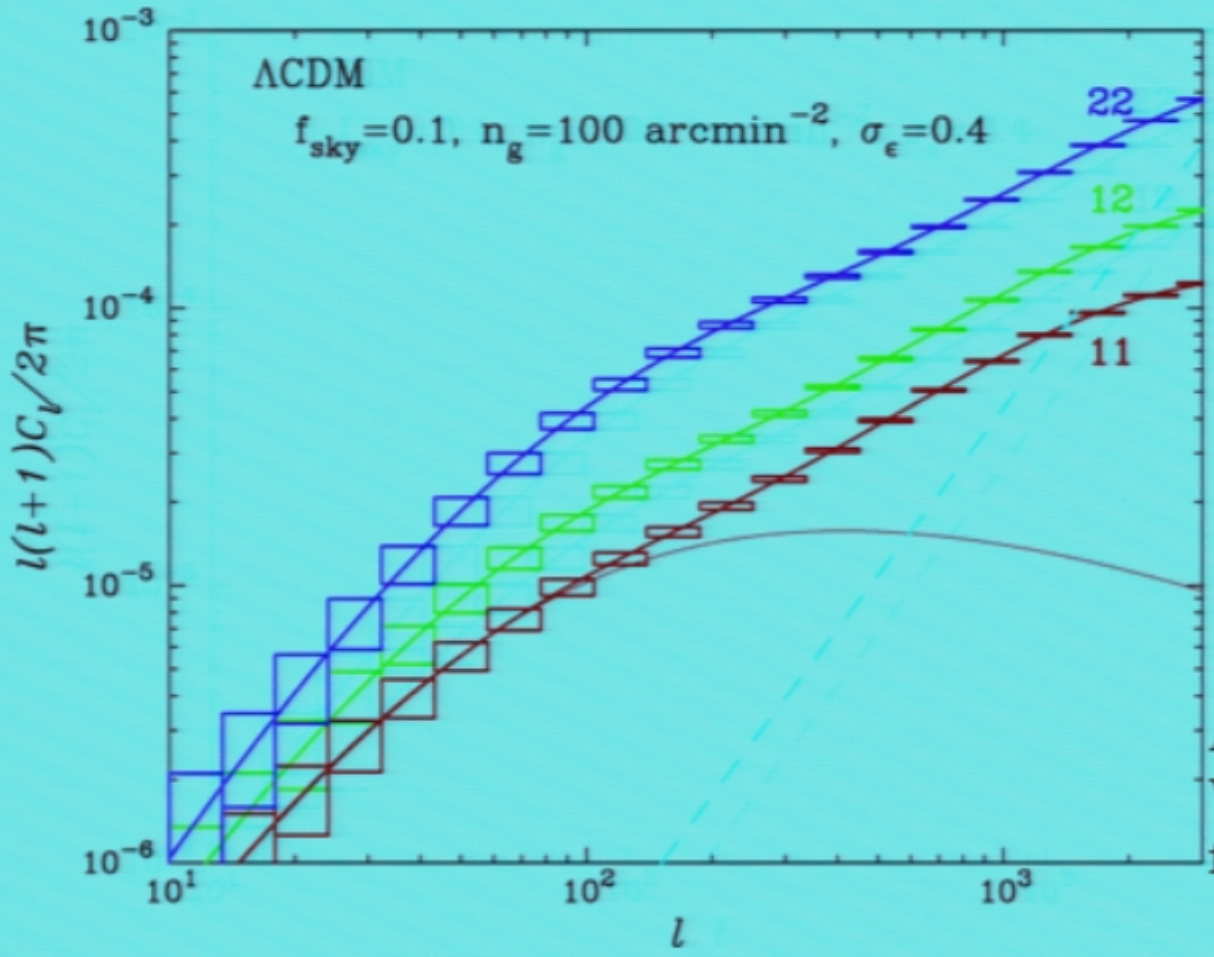

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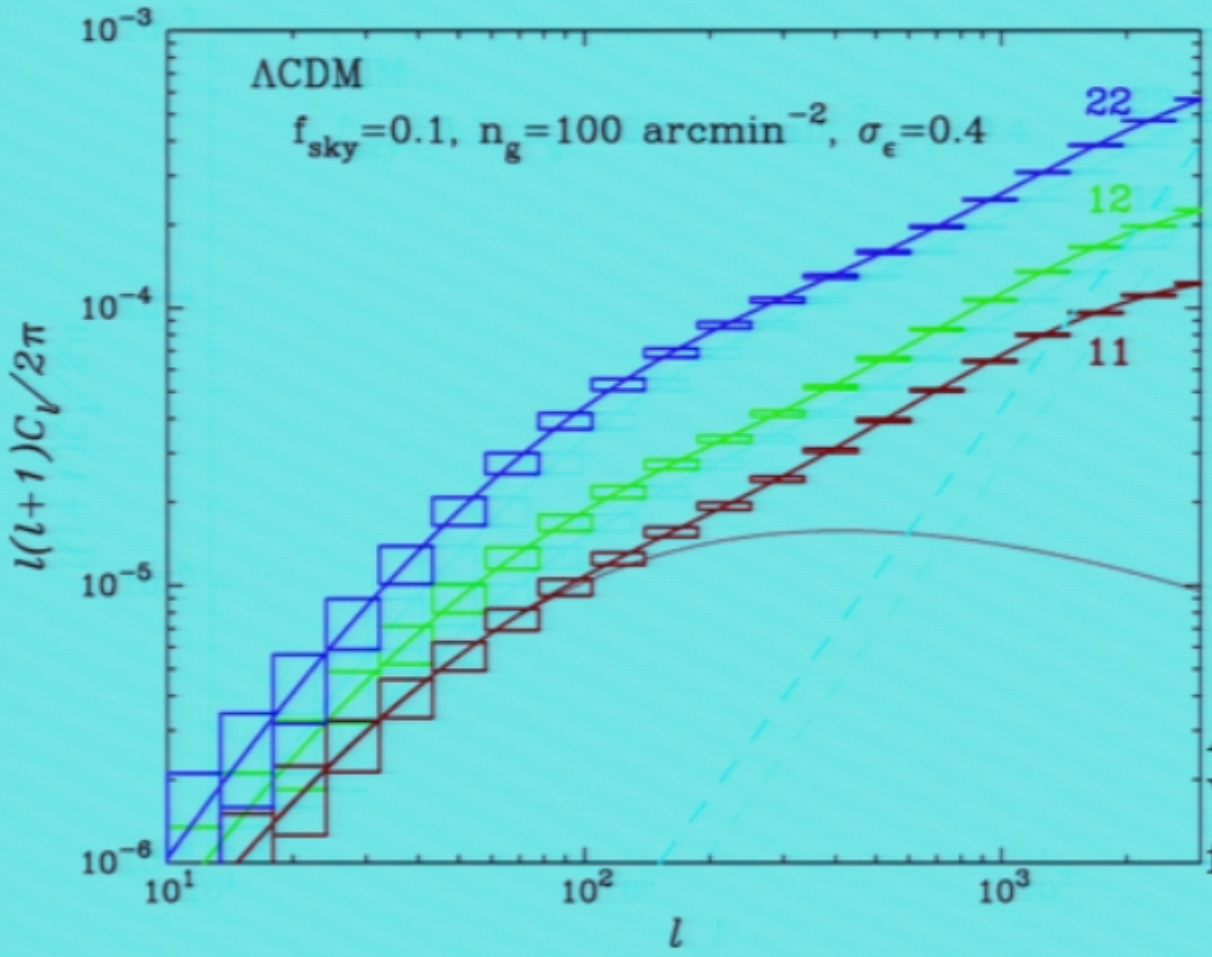

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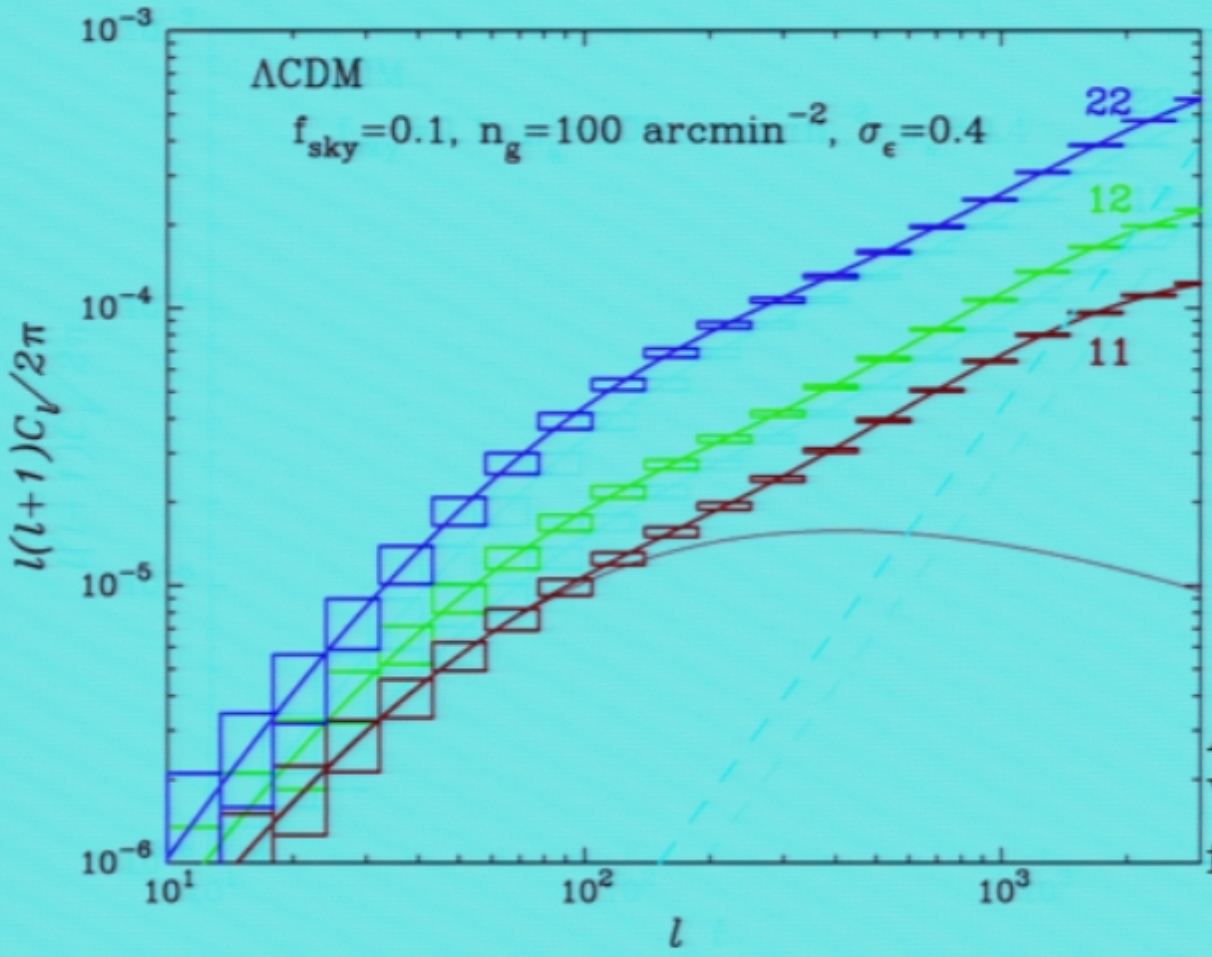

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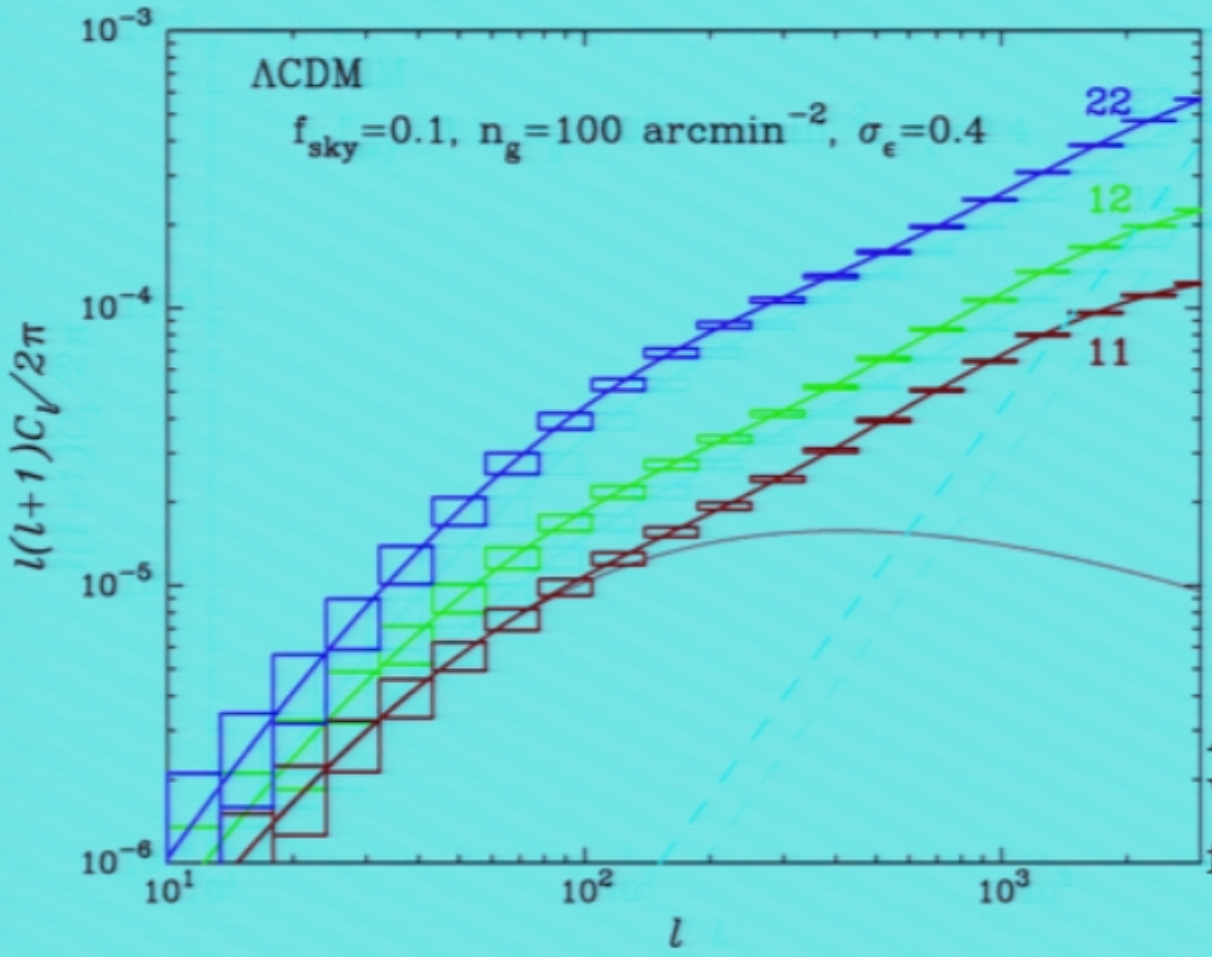

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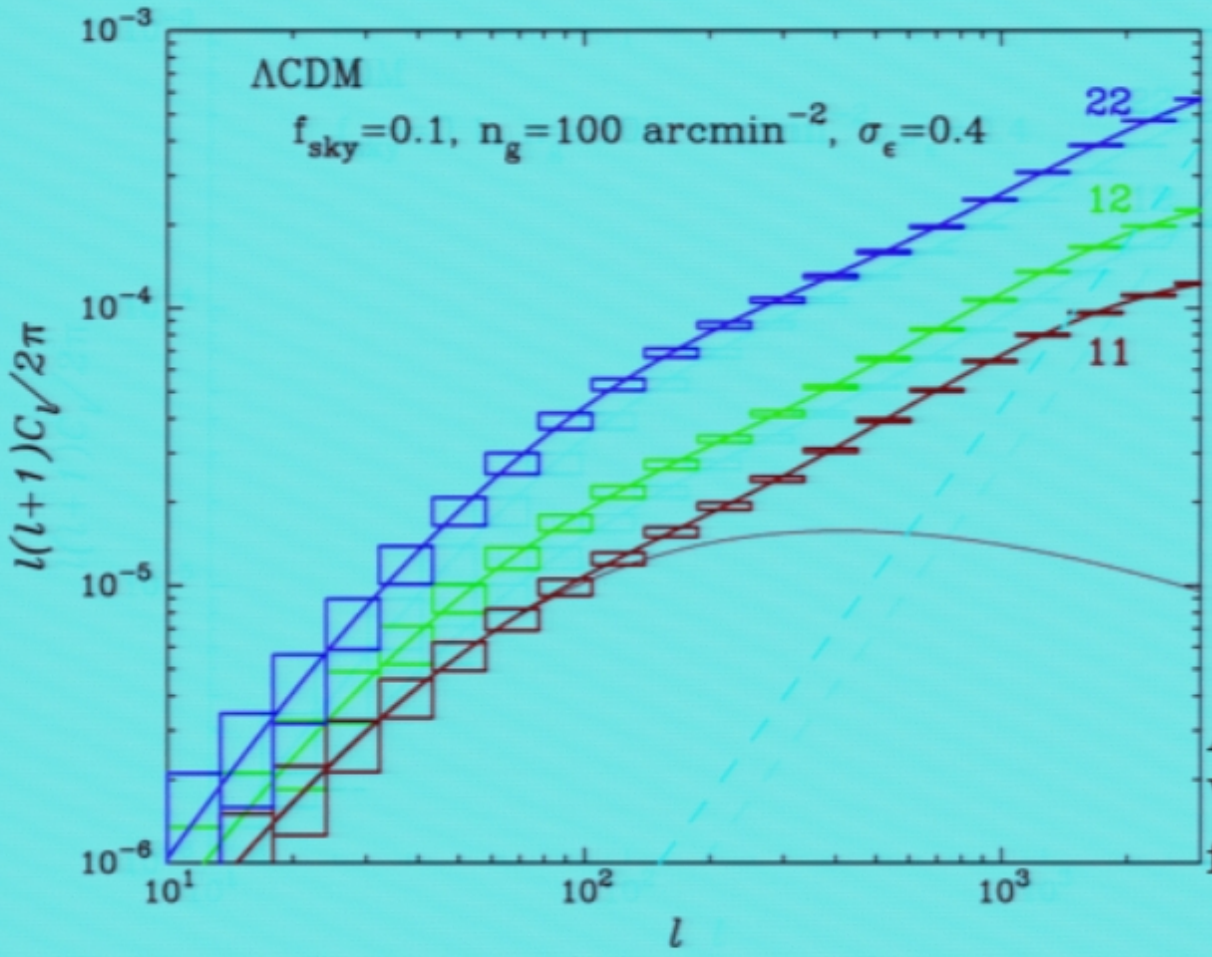

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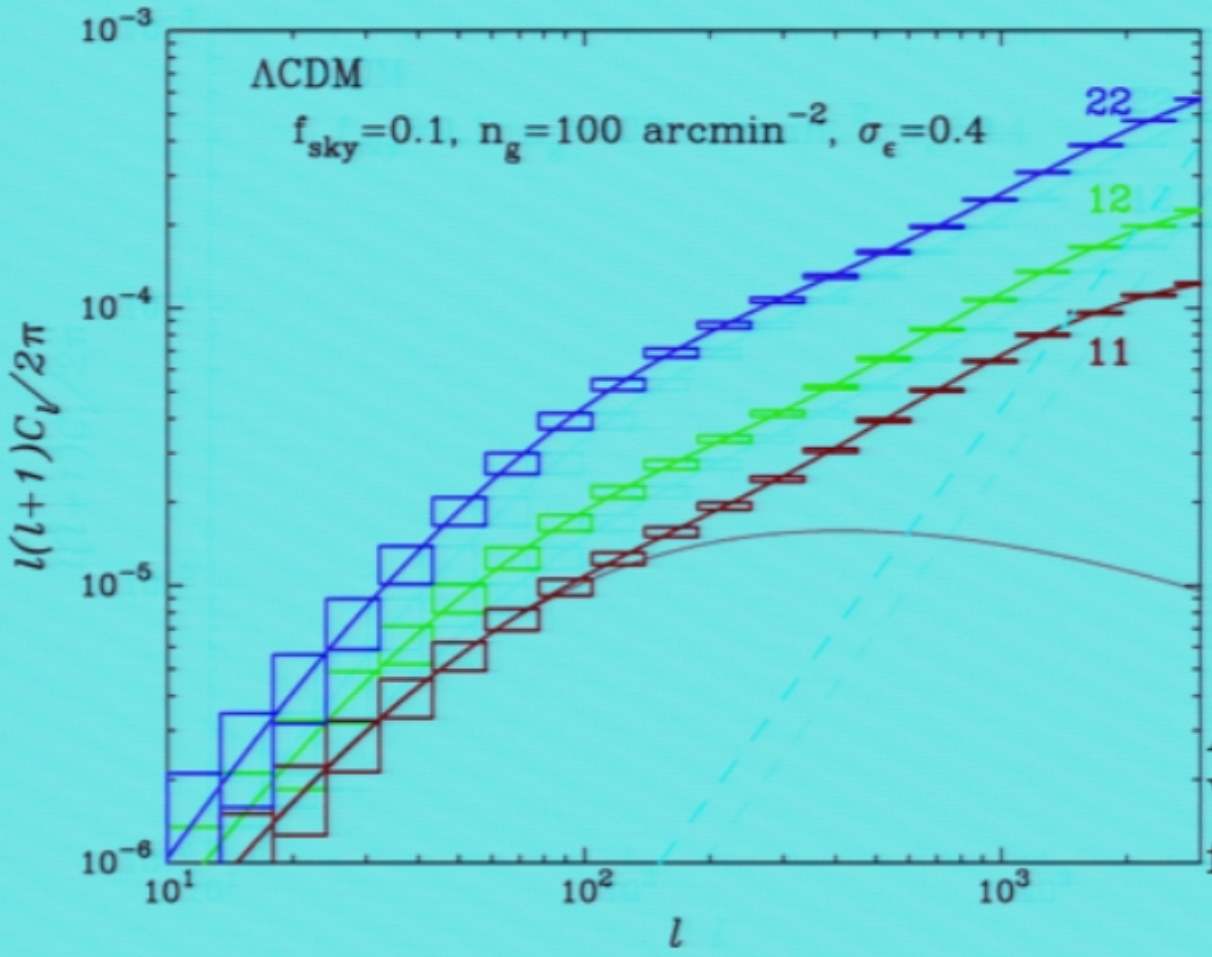

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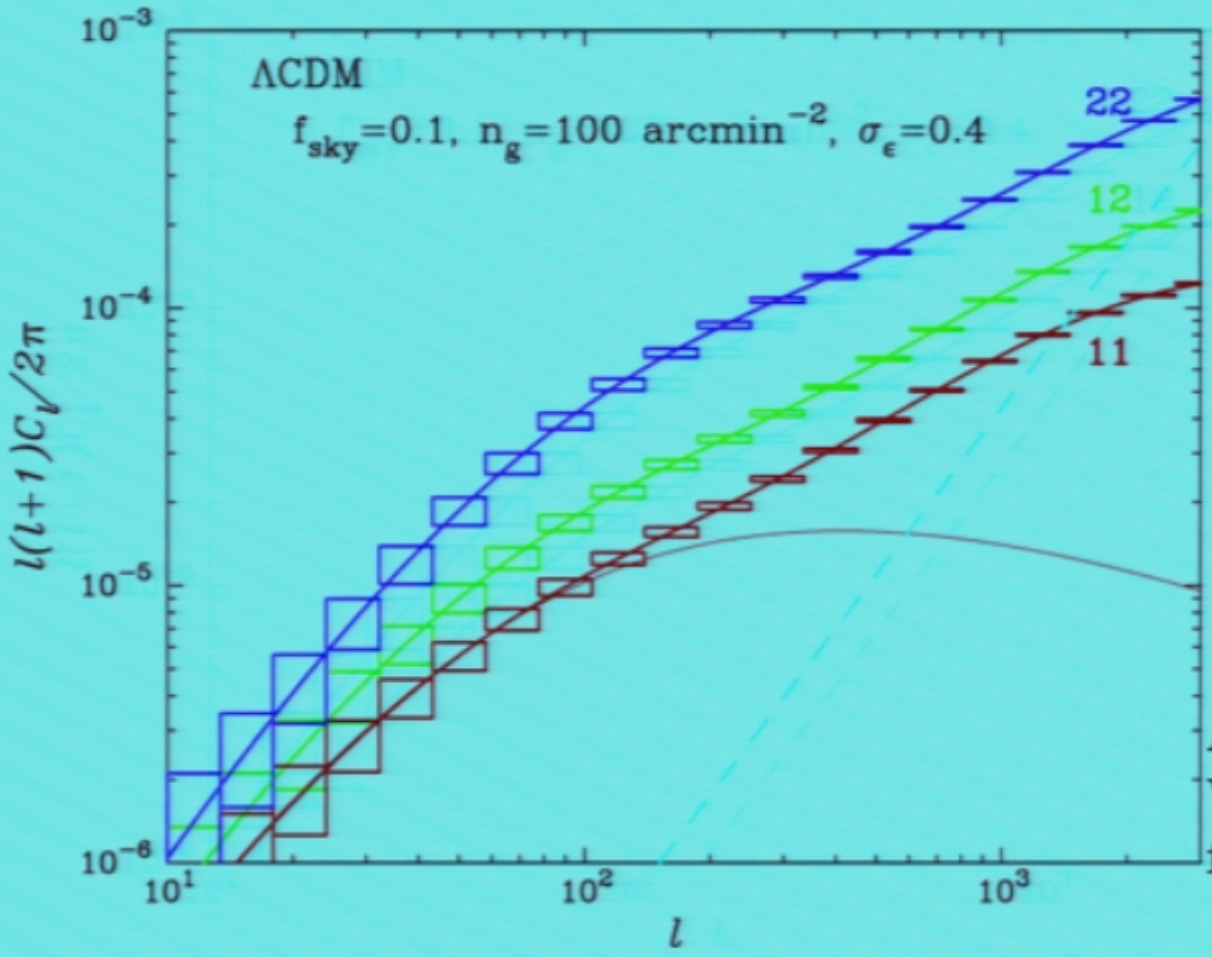

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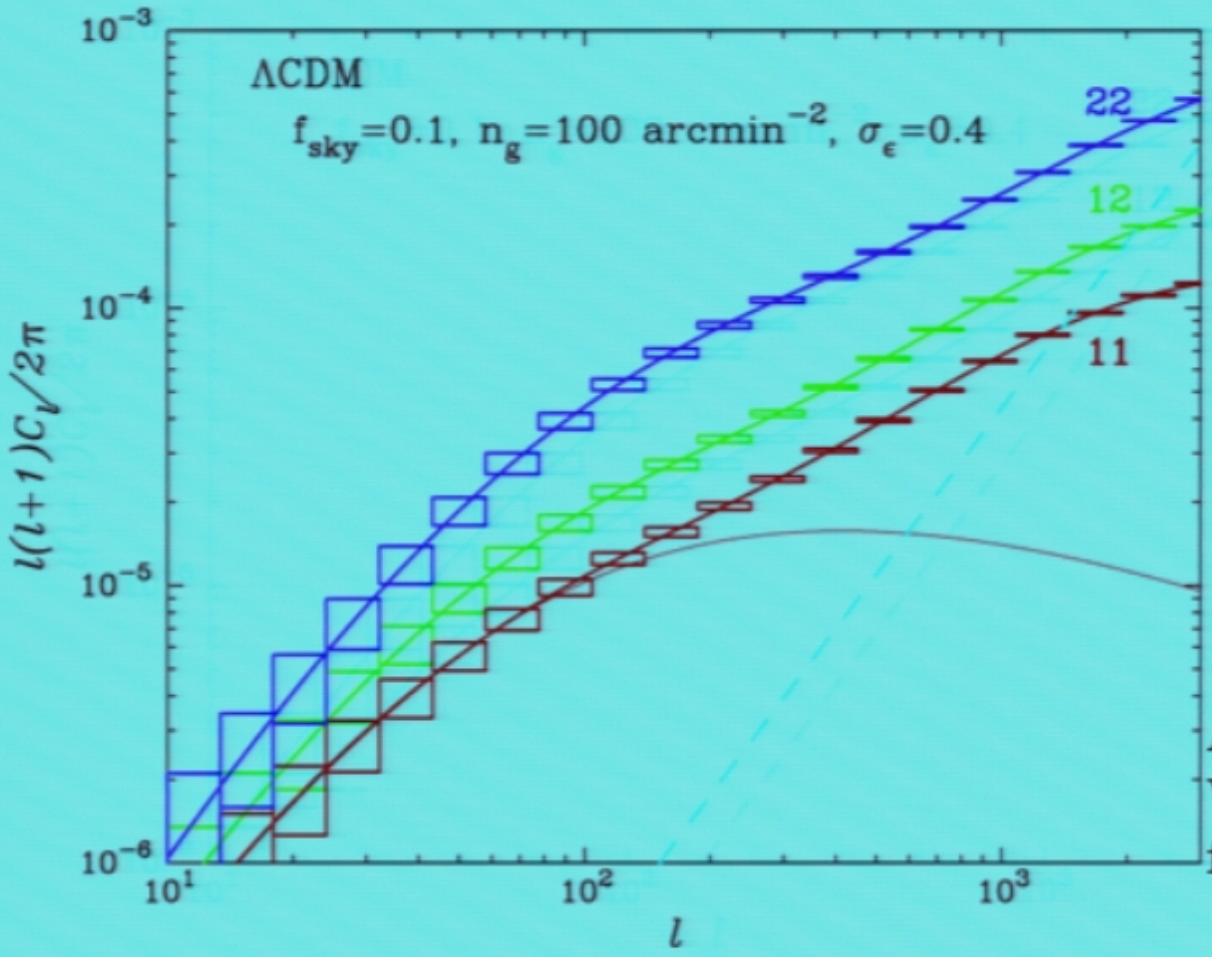

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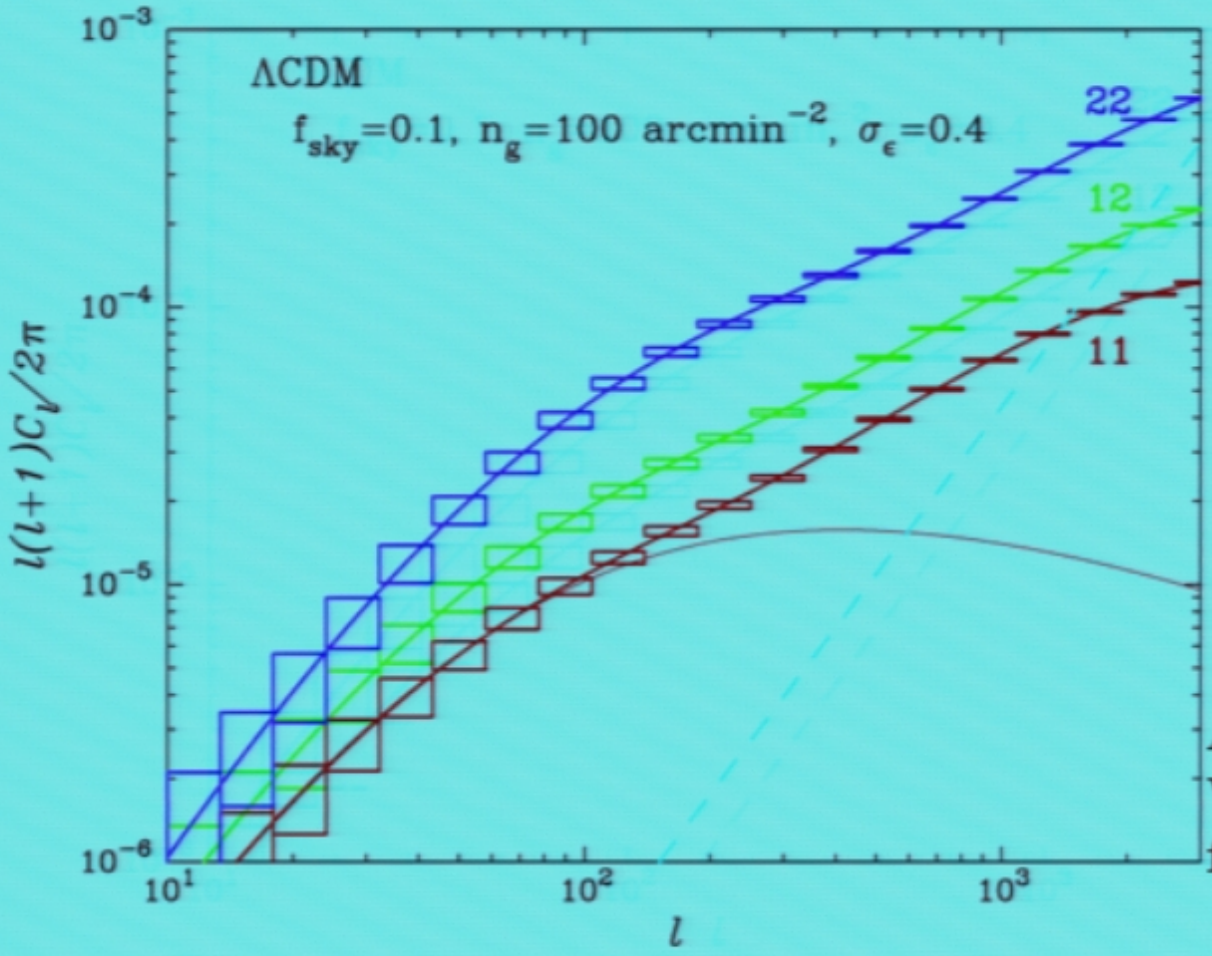

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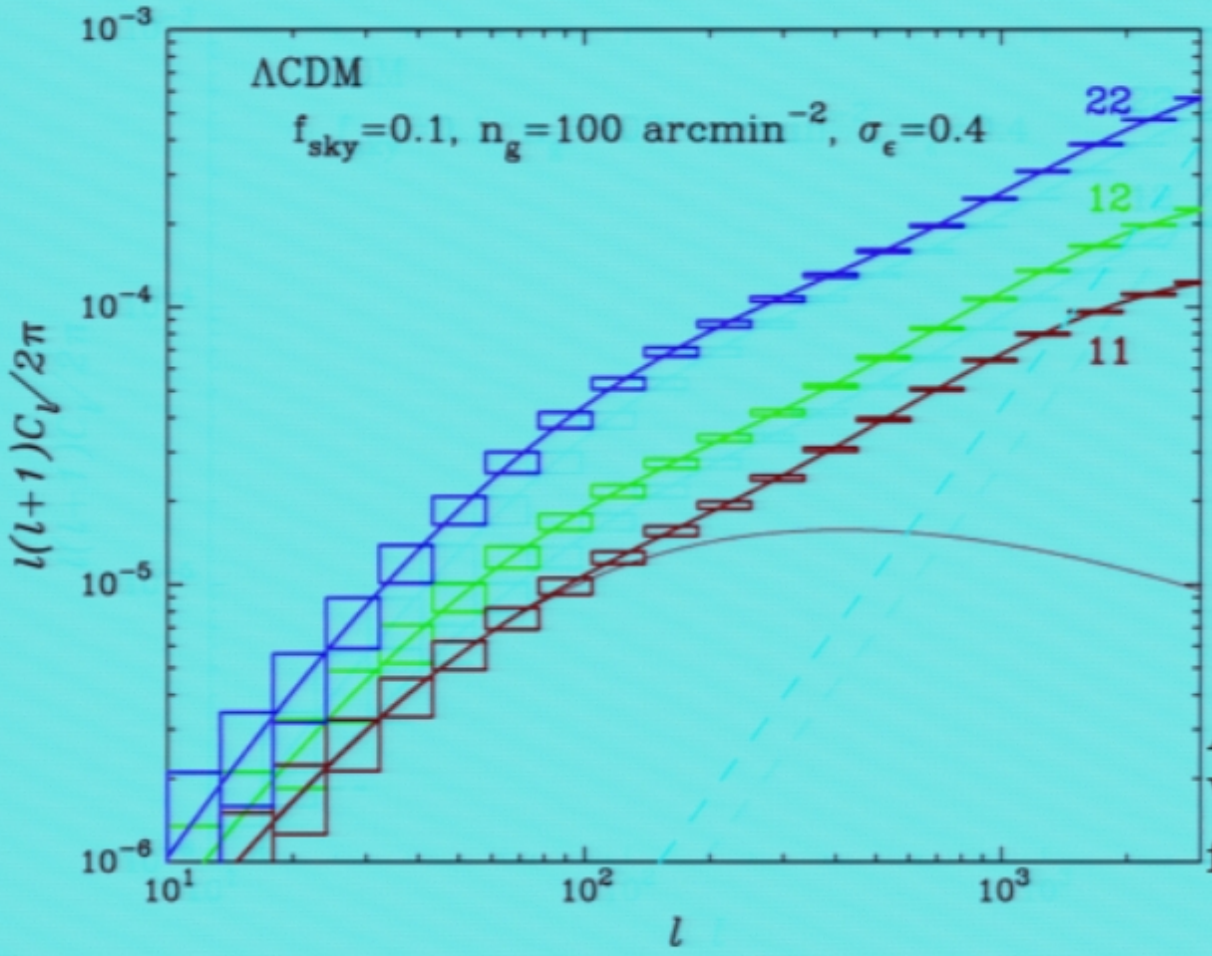

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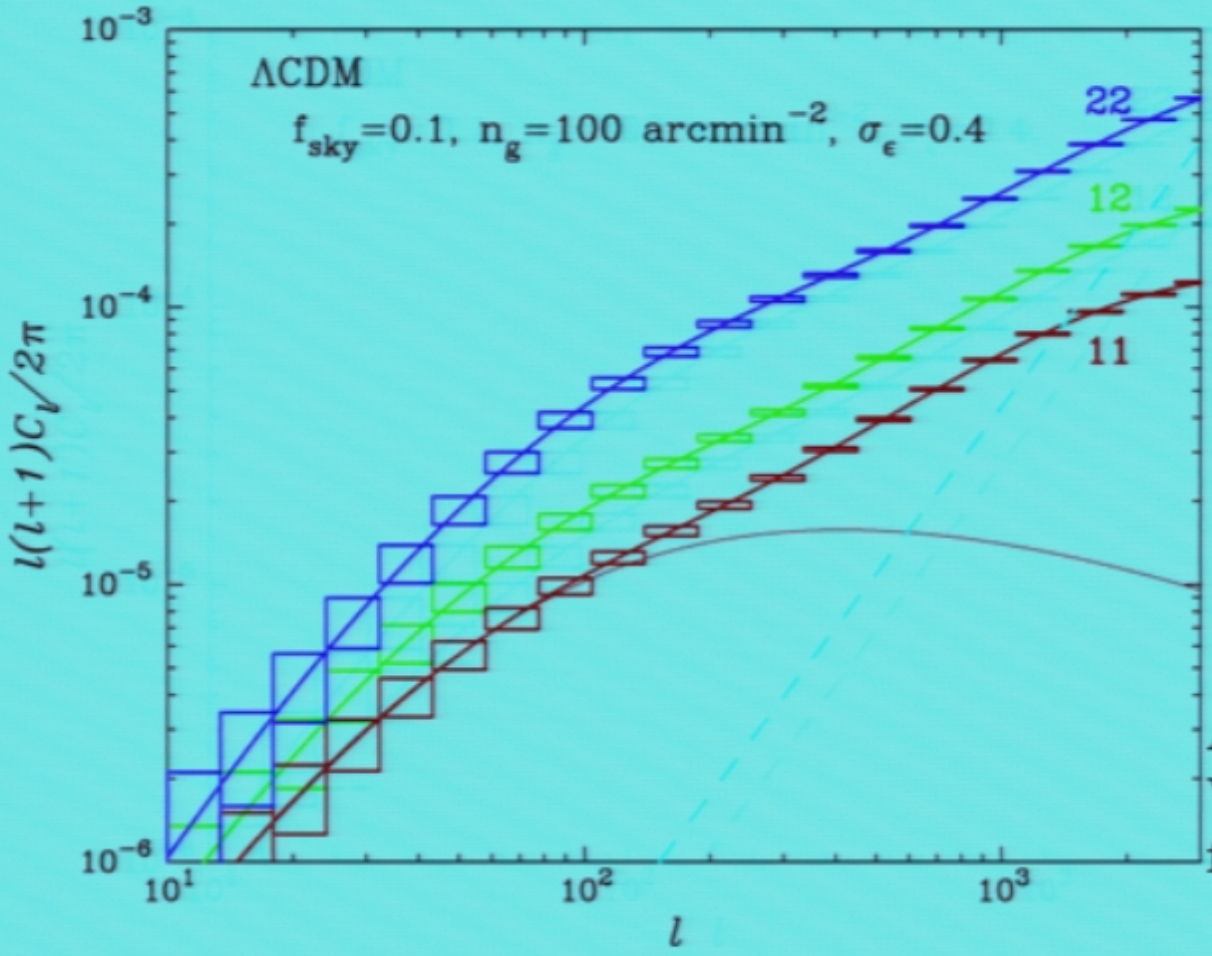

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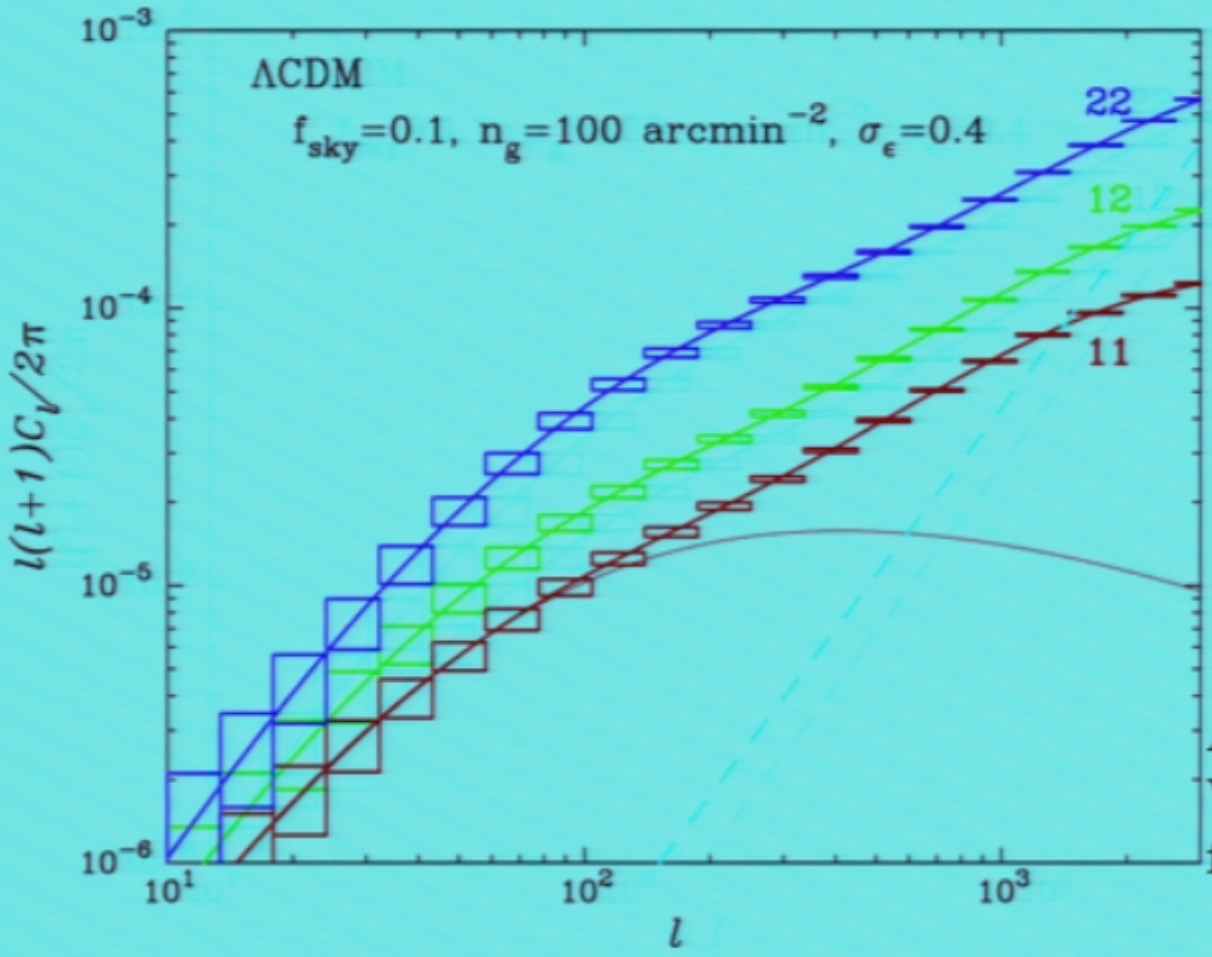

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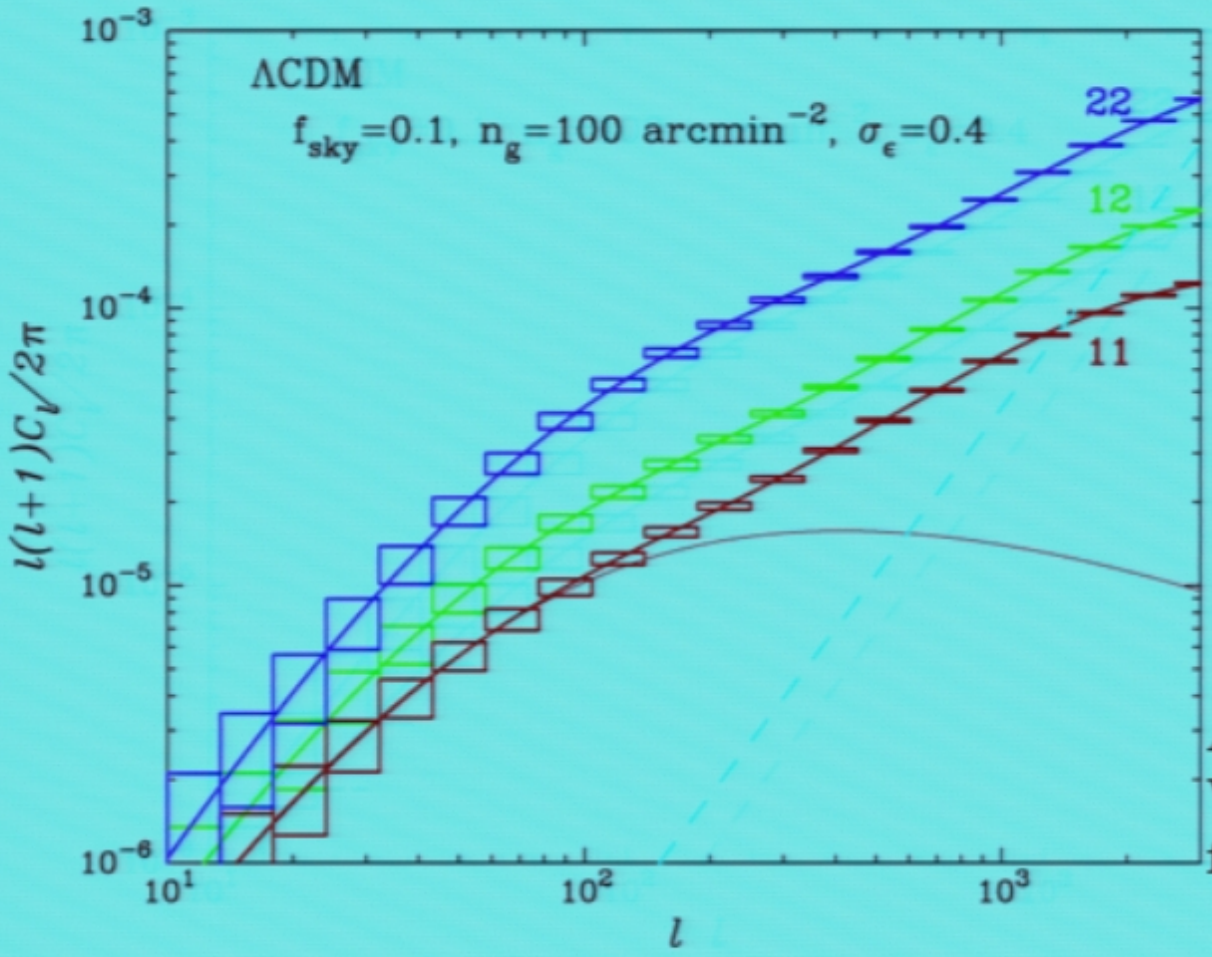

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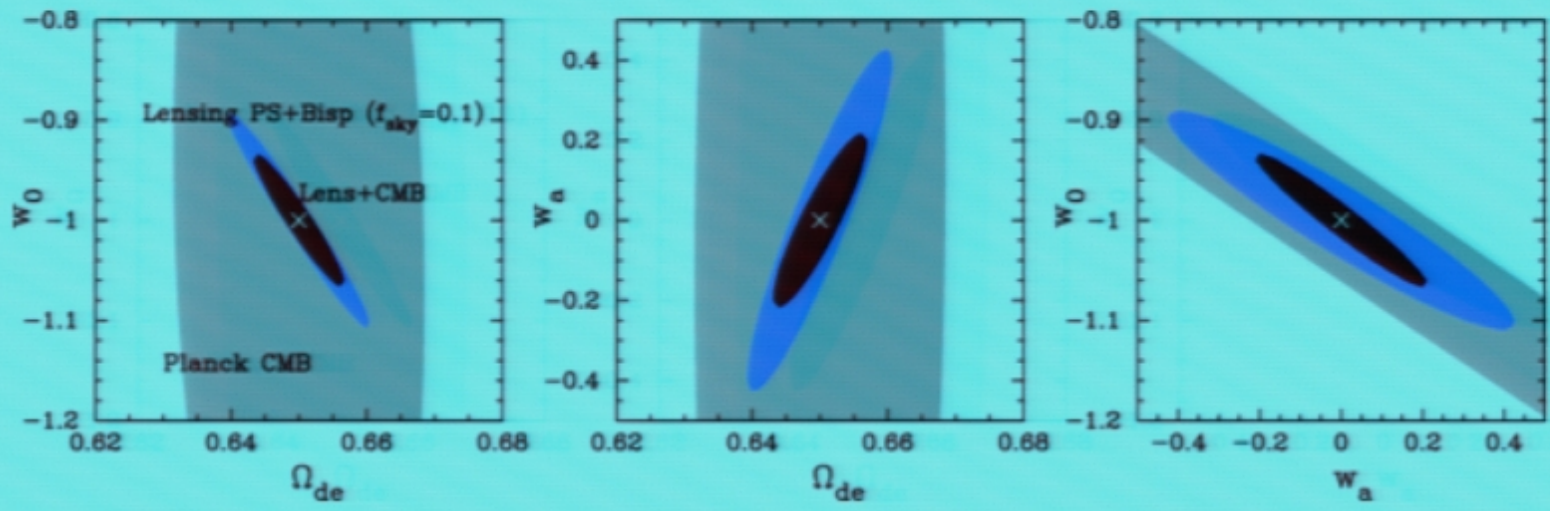

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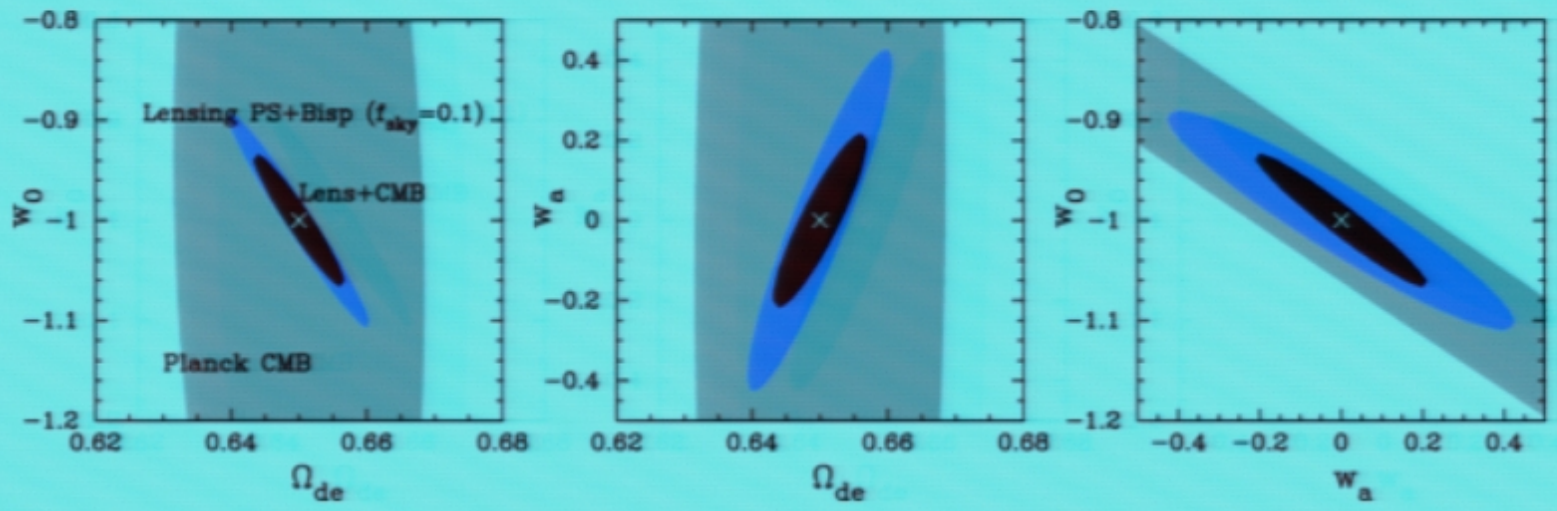

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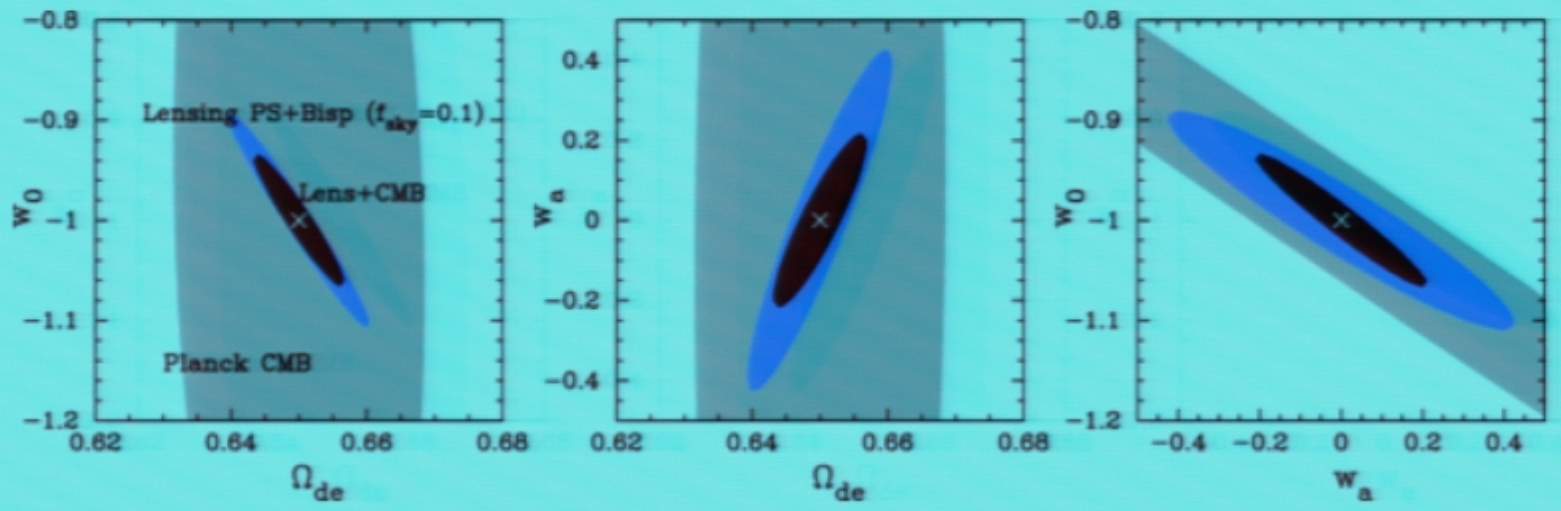

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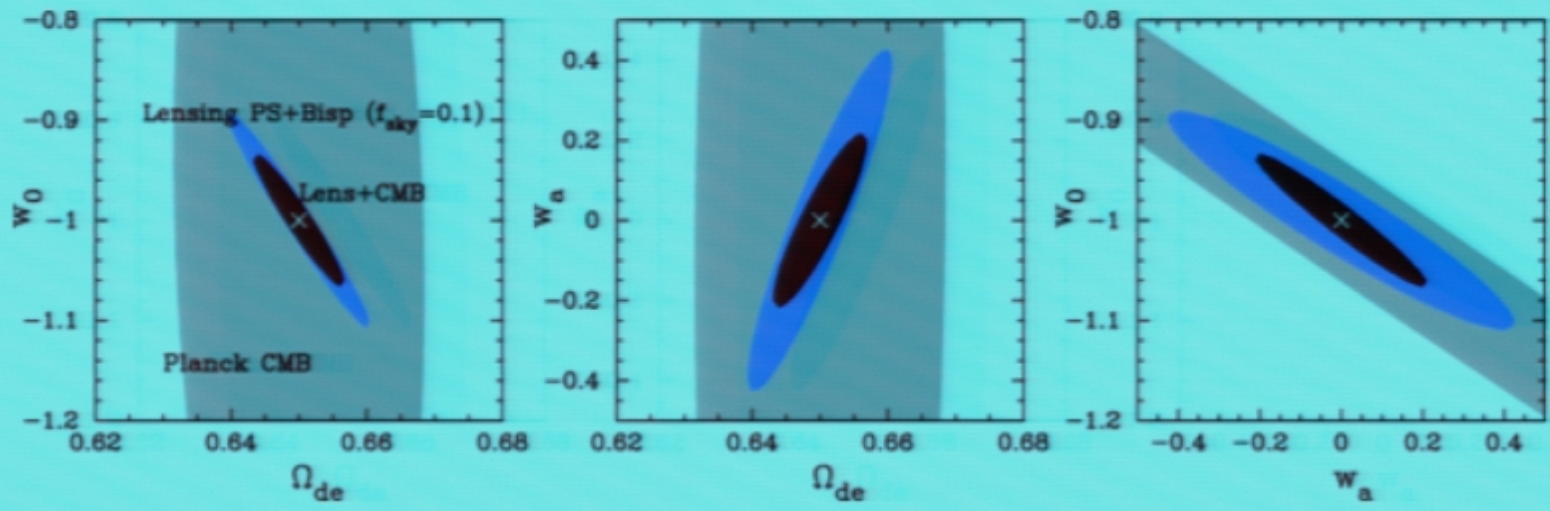

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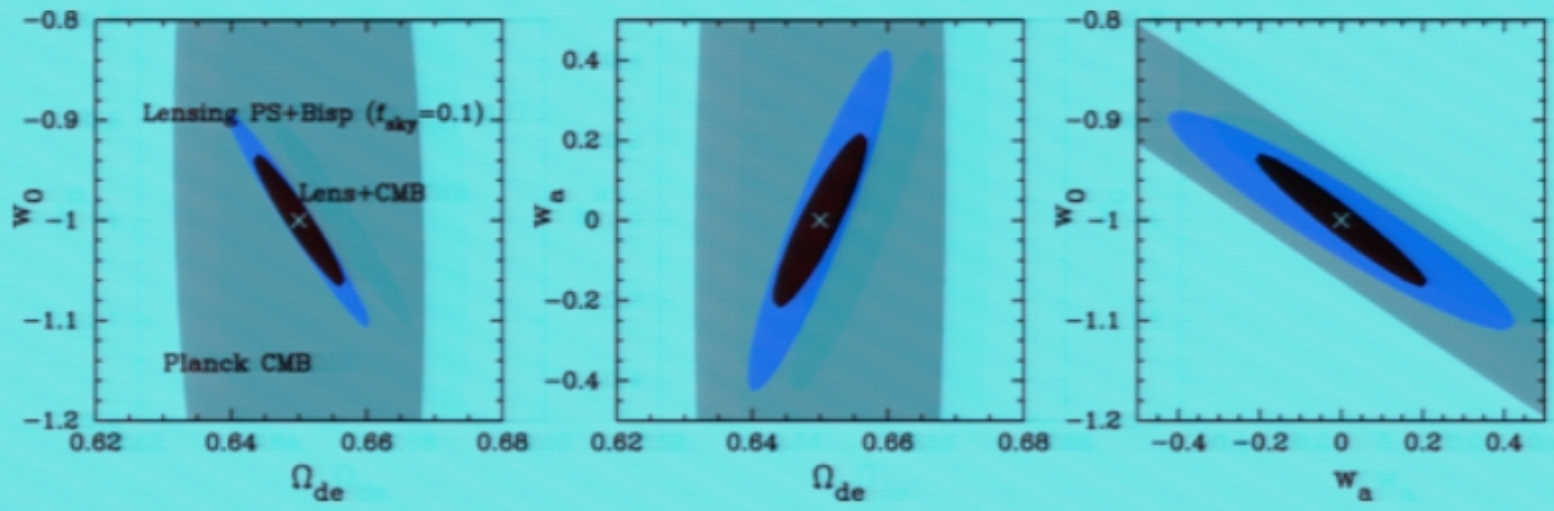

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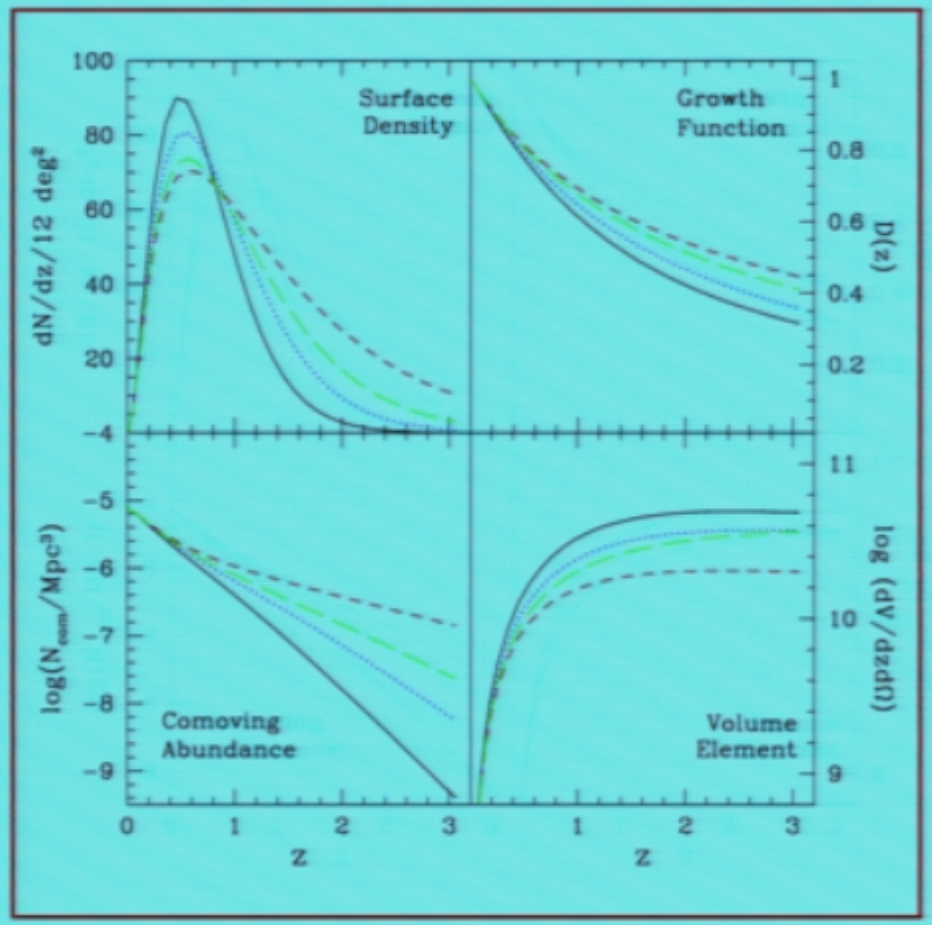
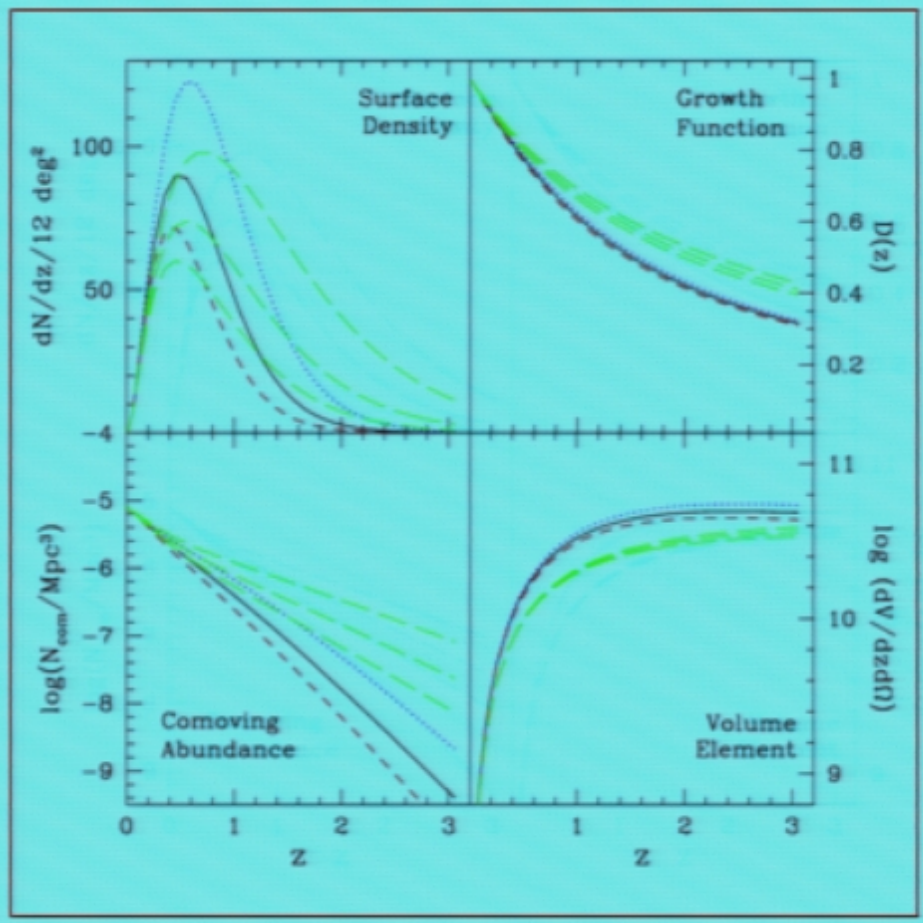
Focussing on one probe:Clusters...



w-dependence



Ω_M-dependence

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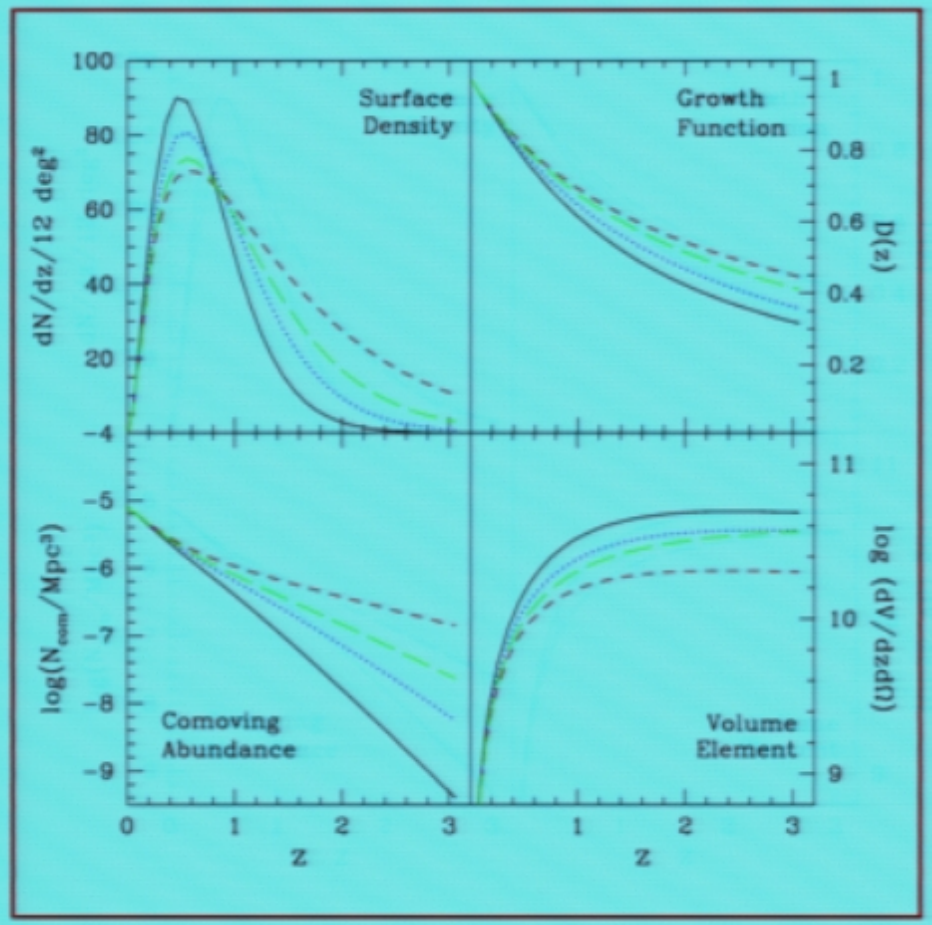

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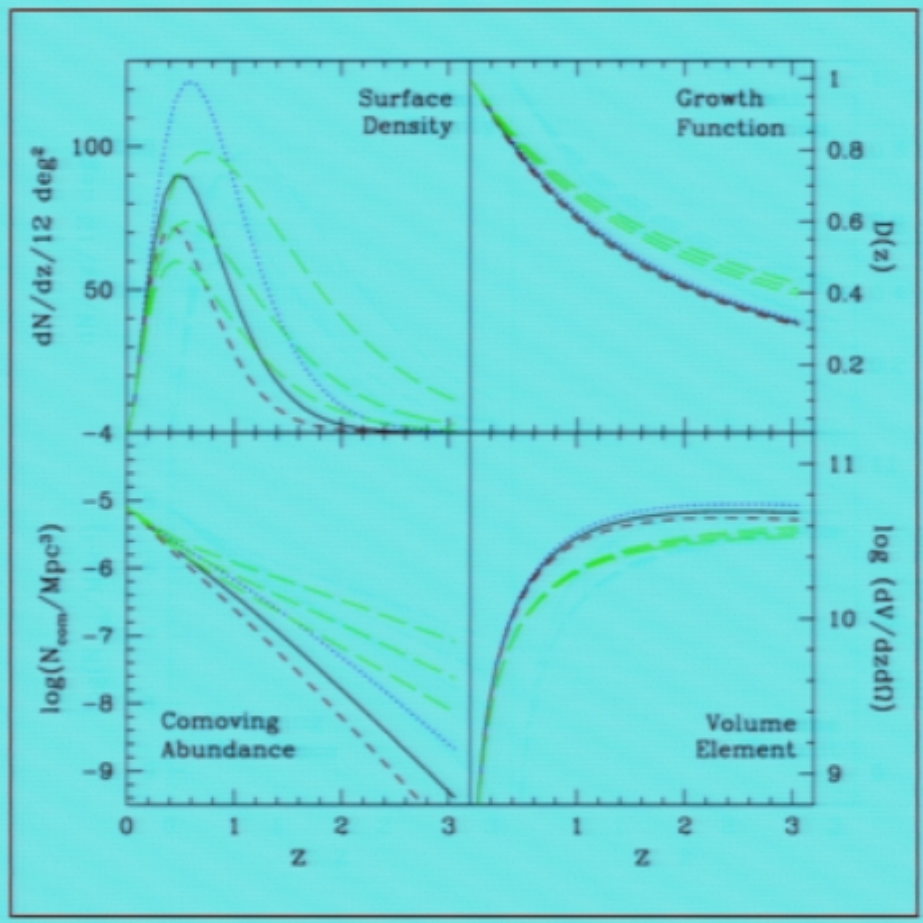

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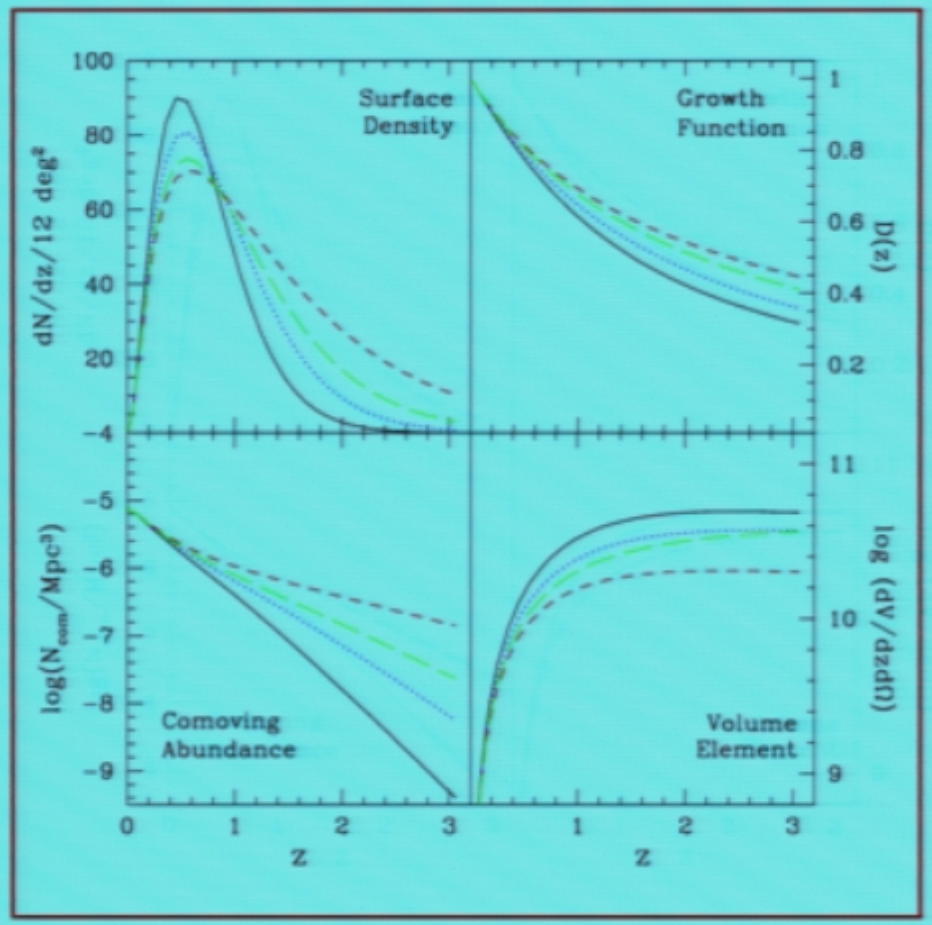

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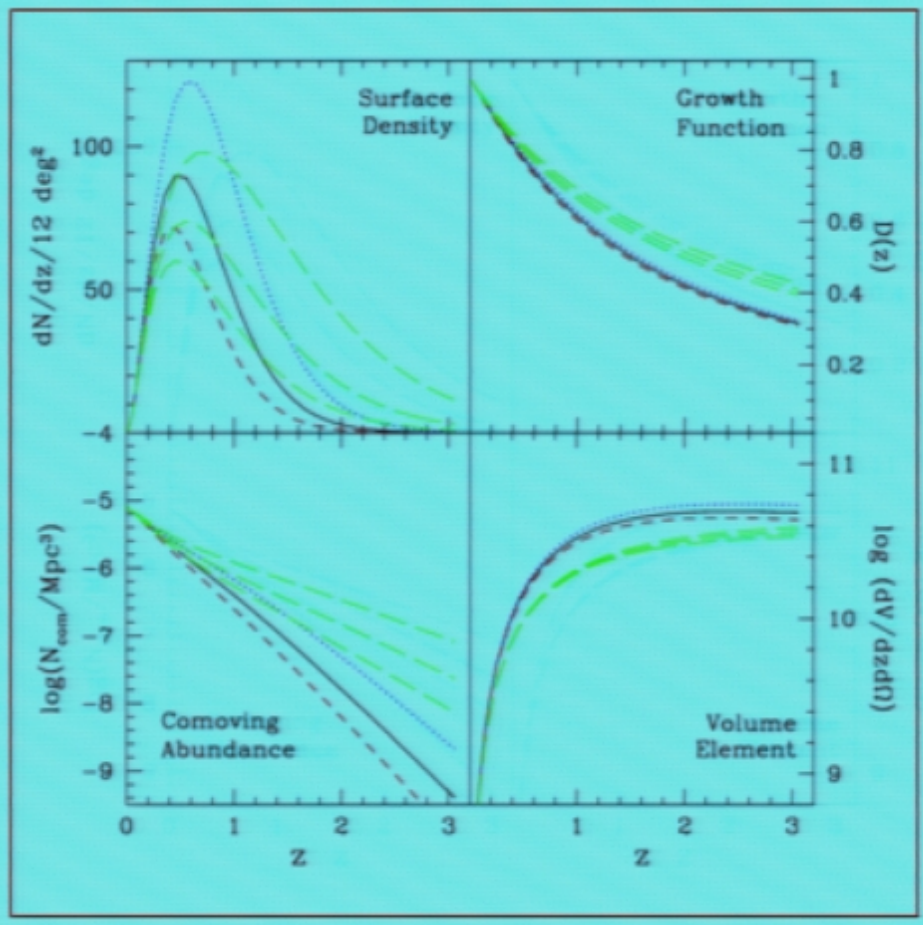

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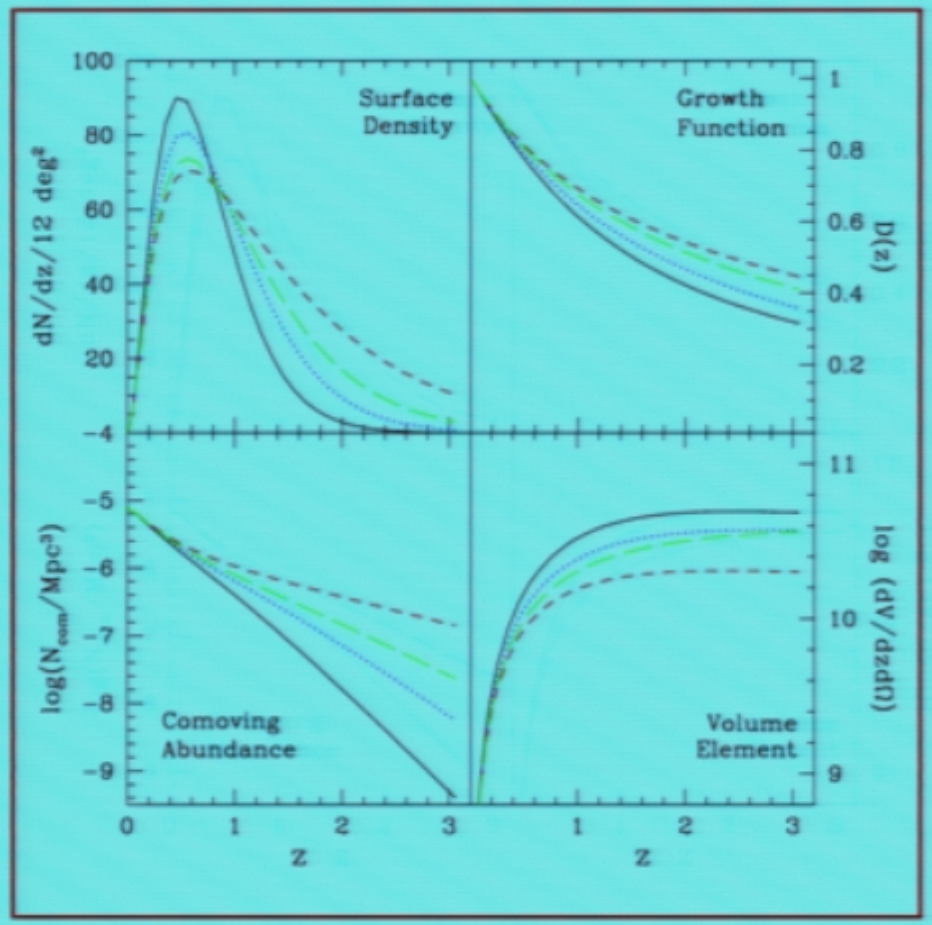

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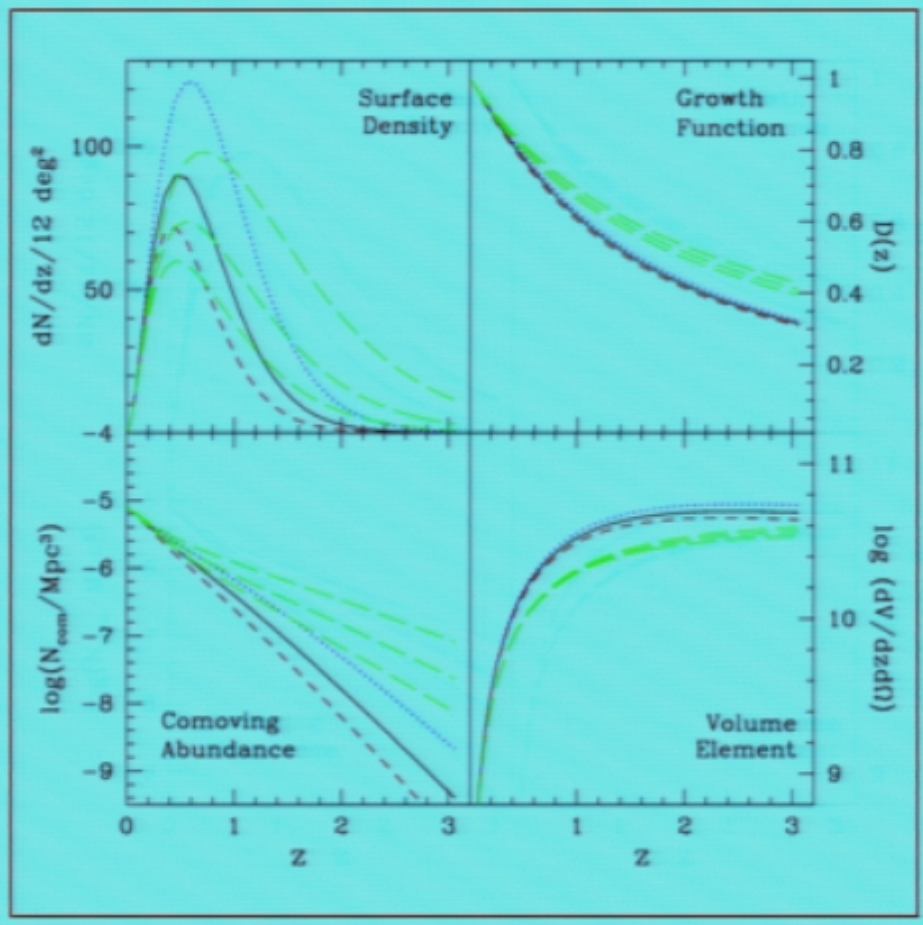

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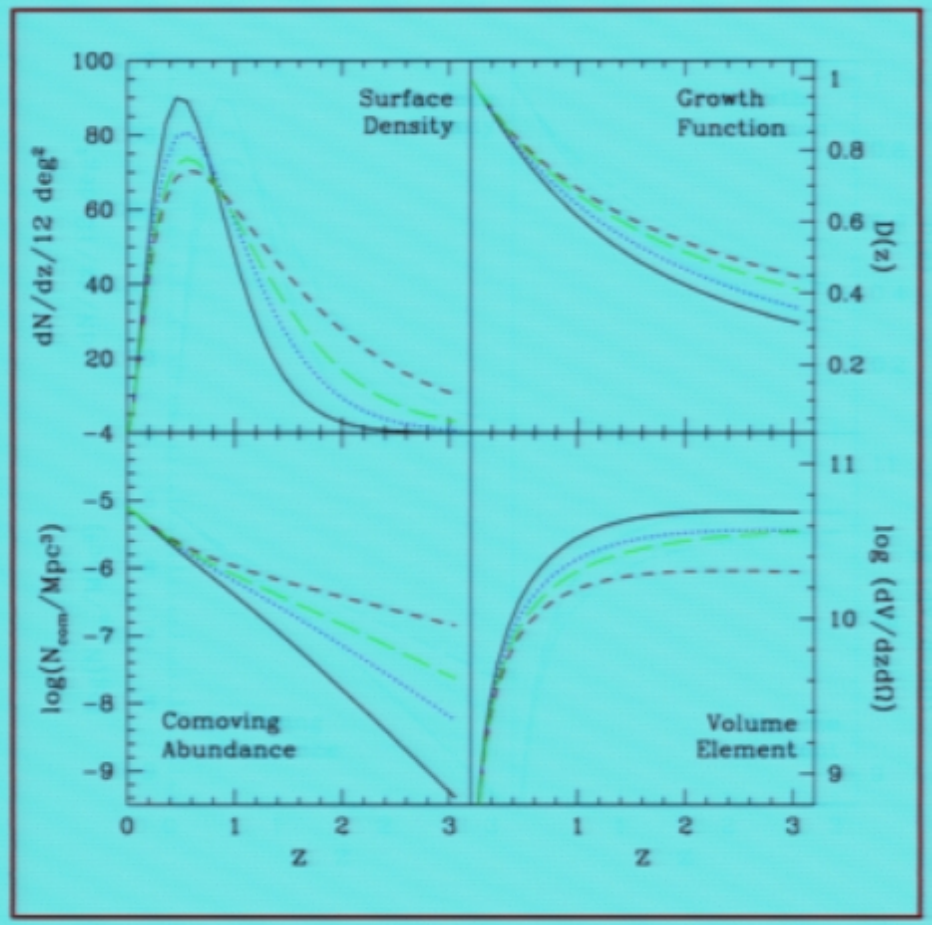

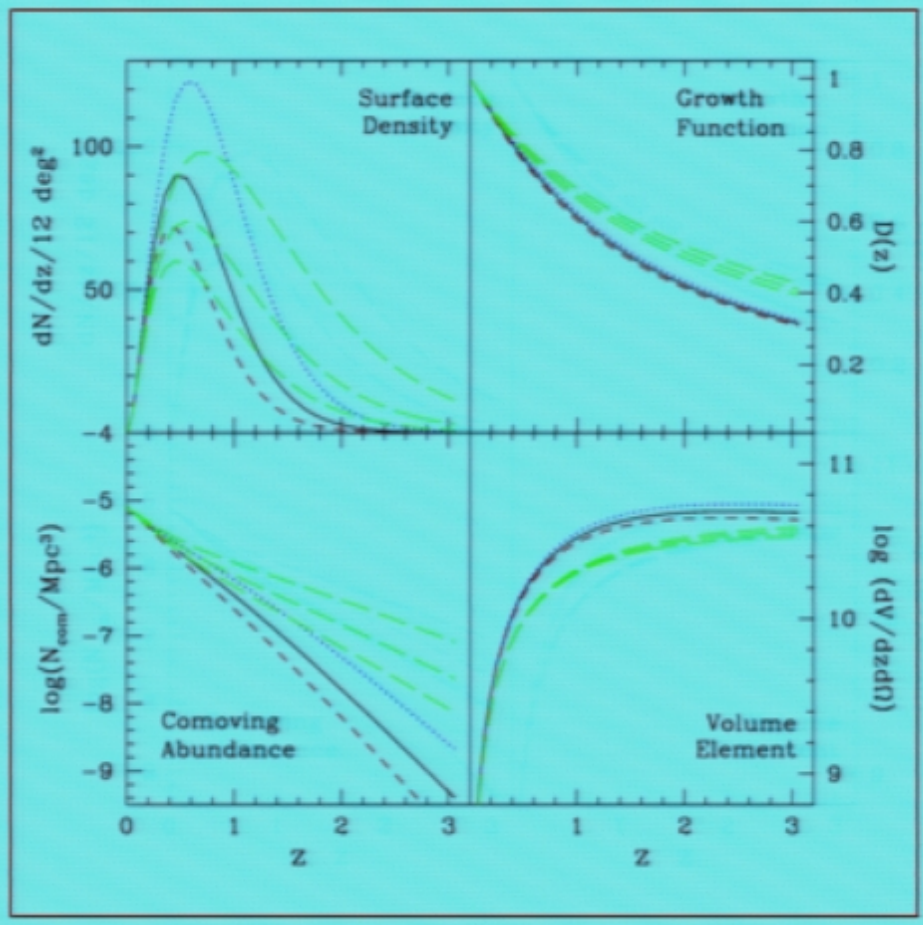

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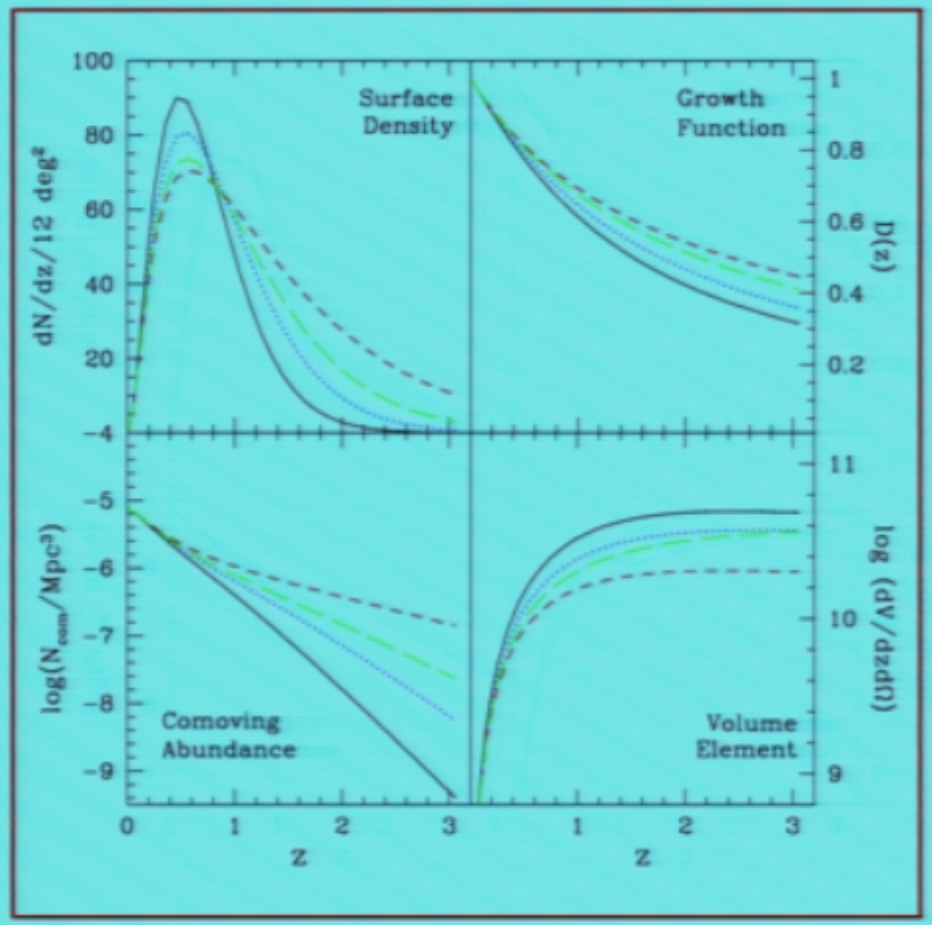

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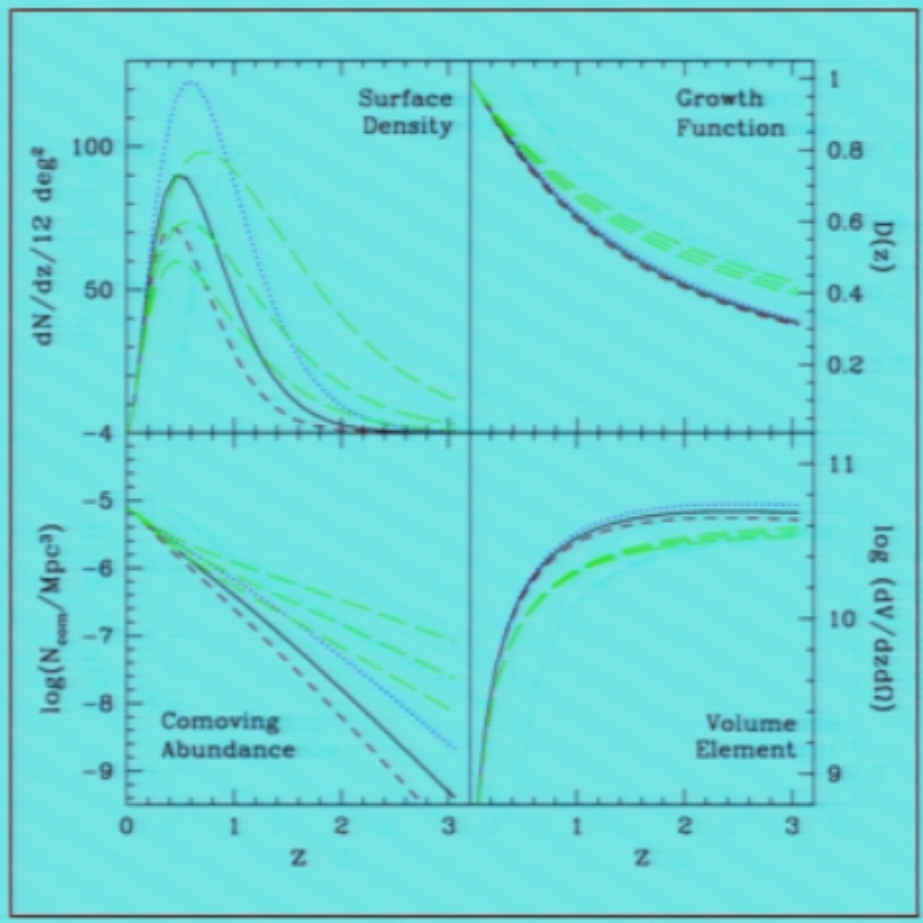

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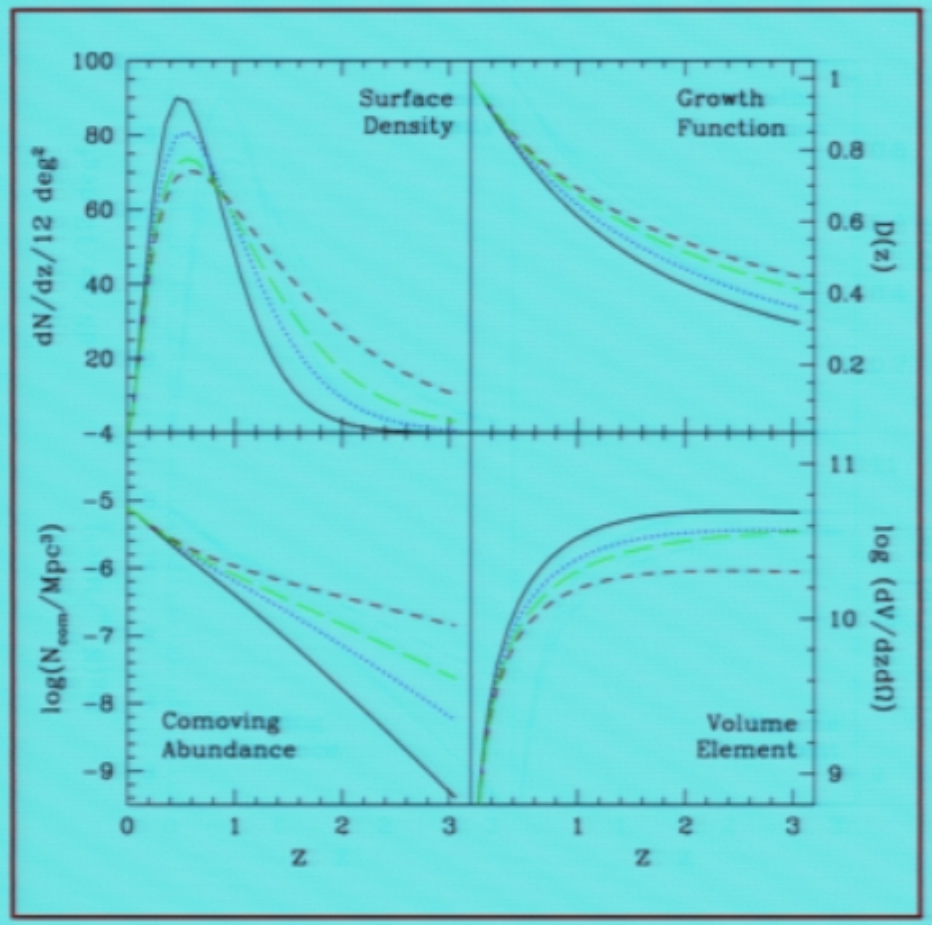

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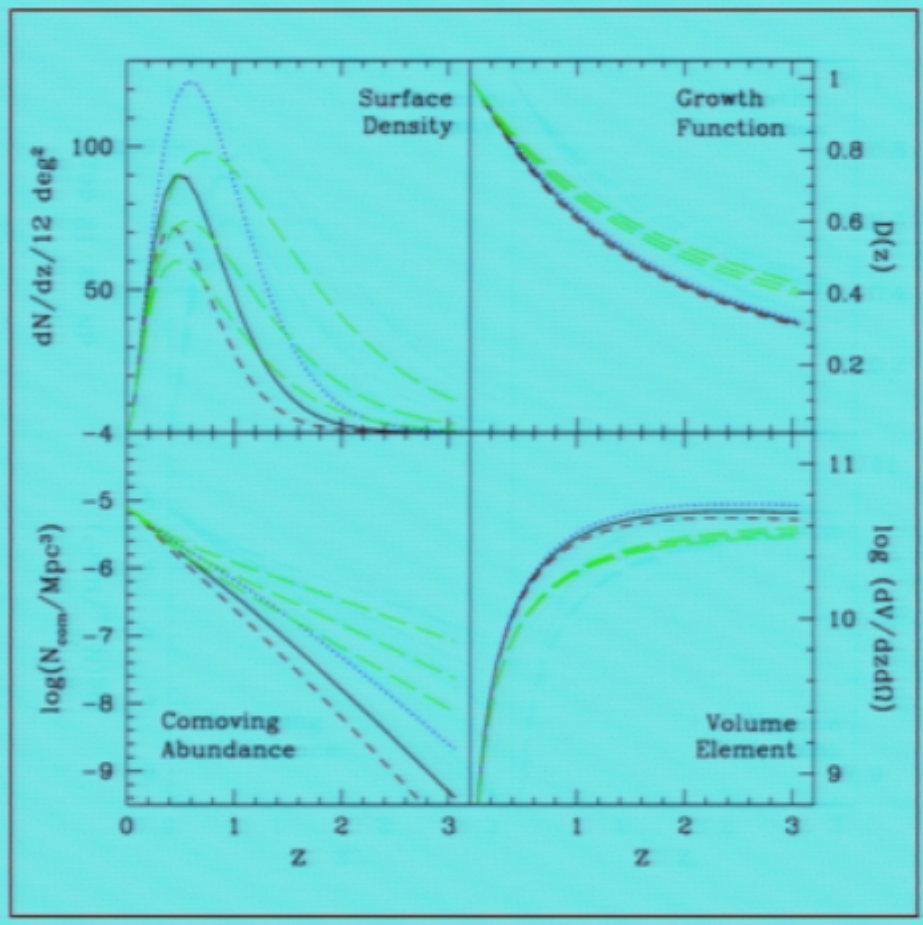

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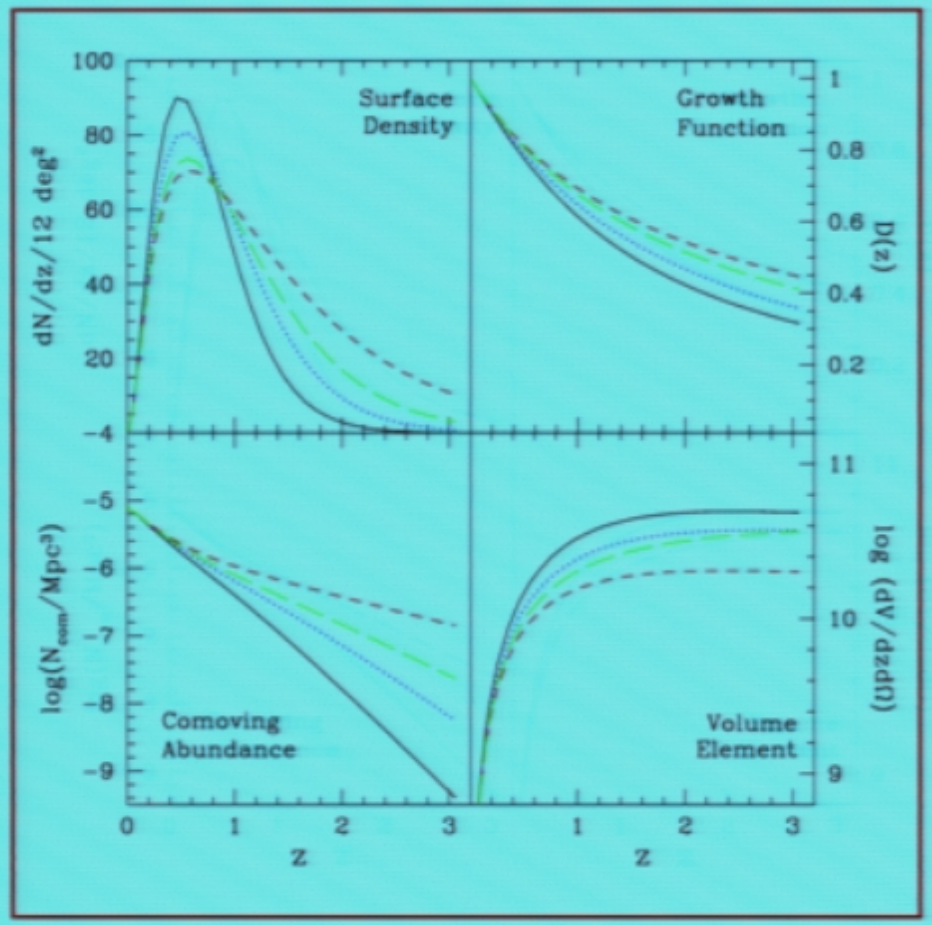

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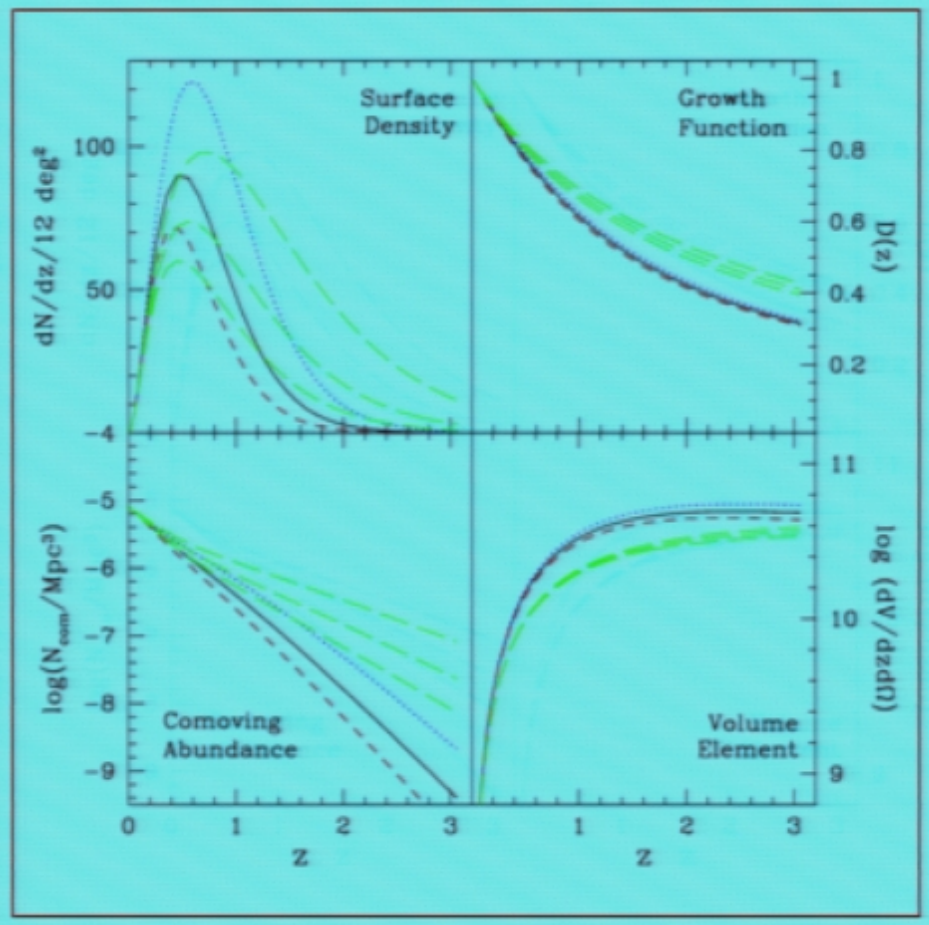

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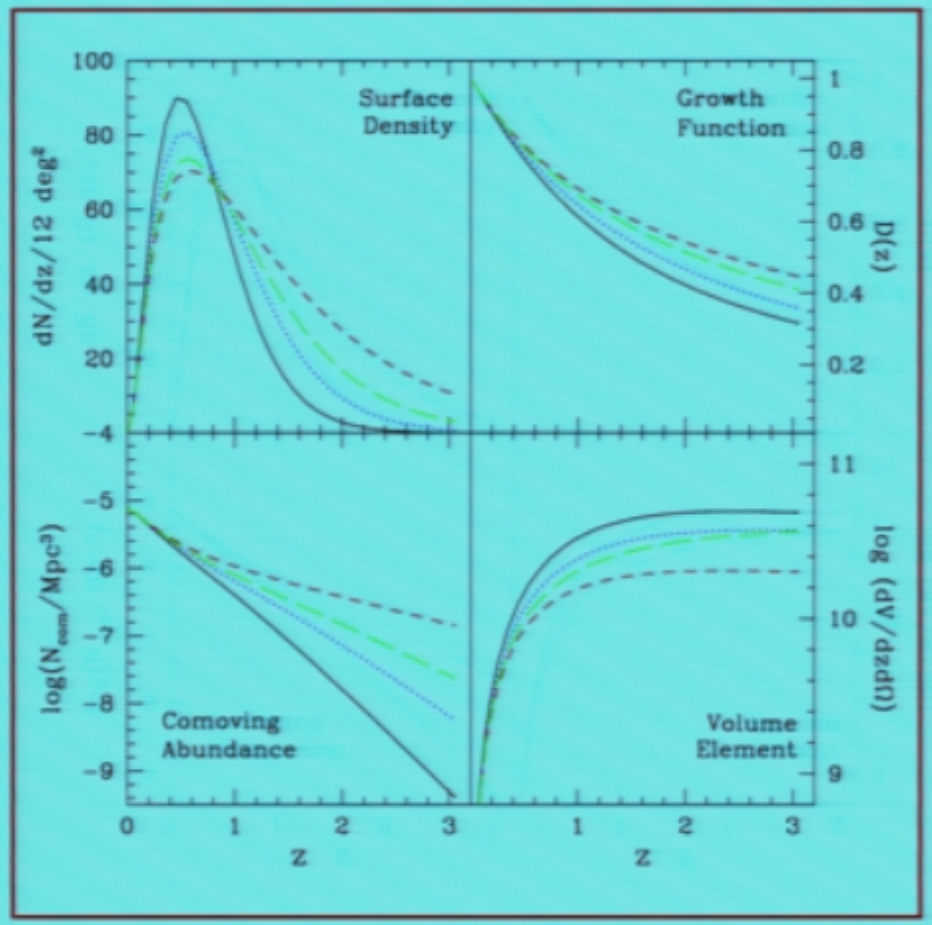

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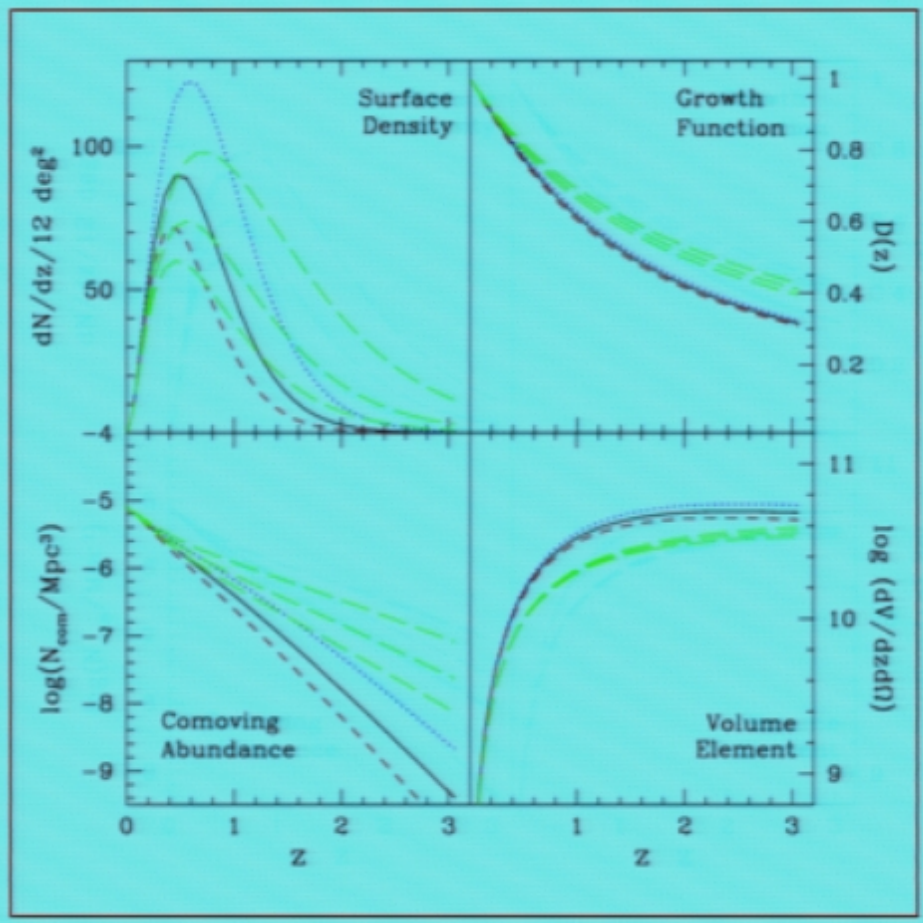

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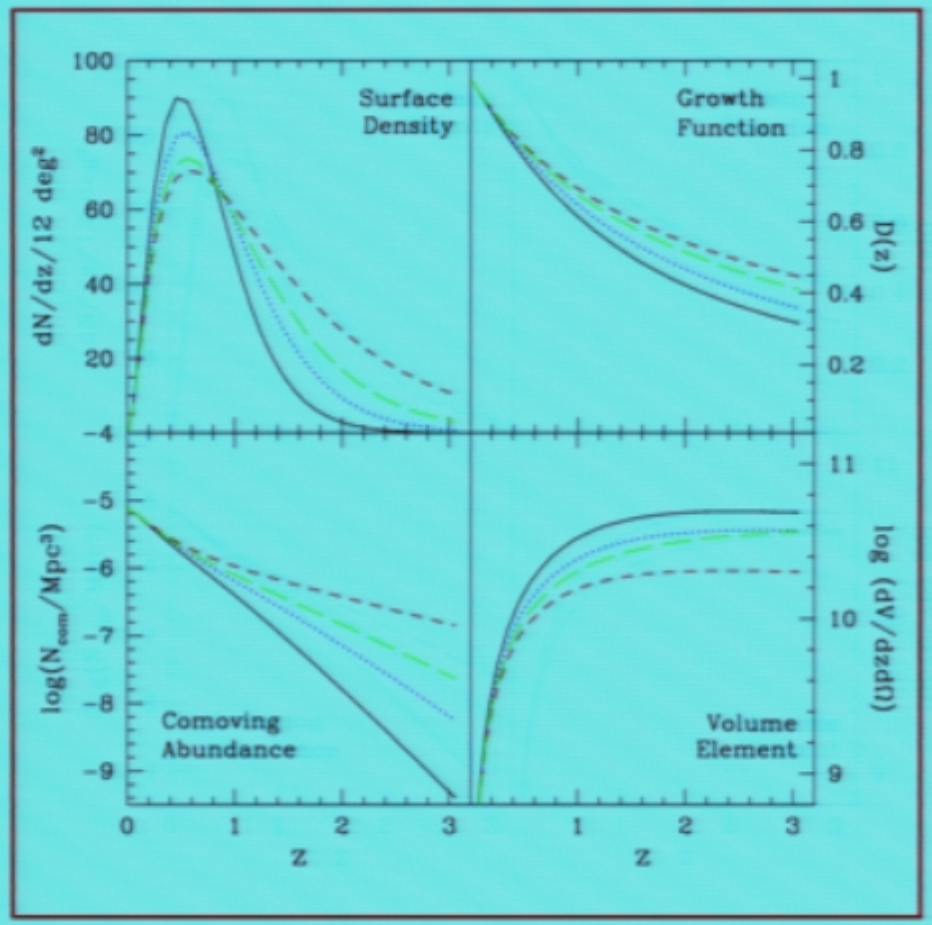

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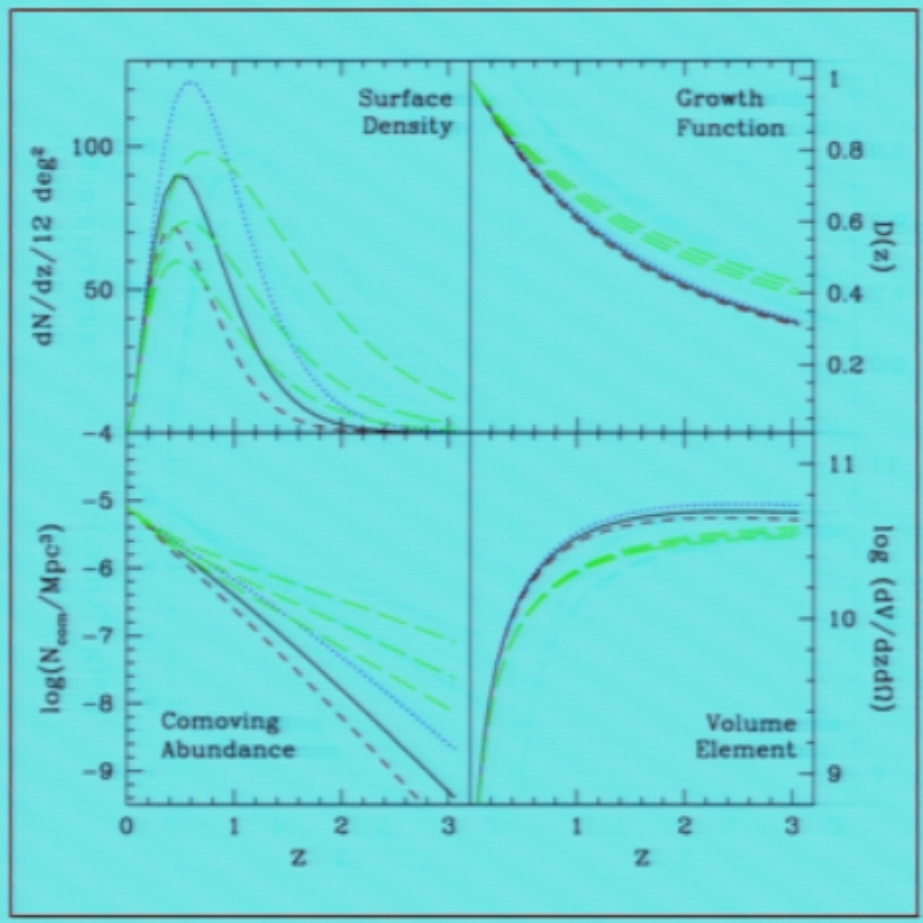
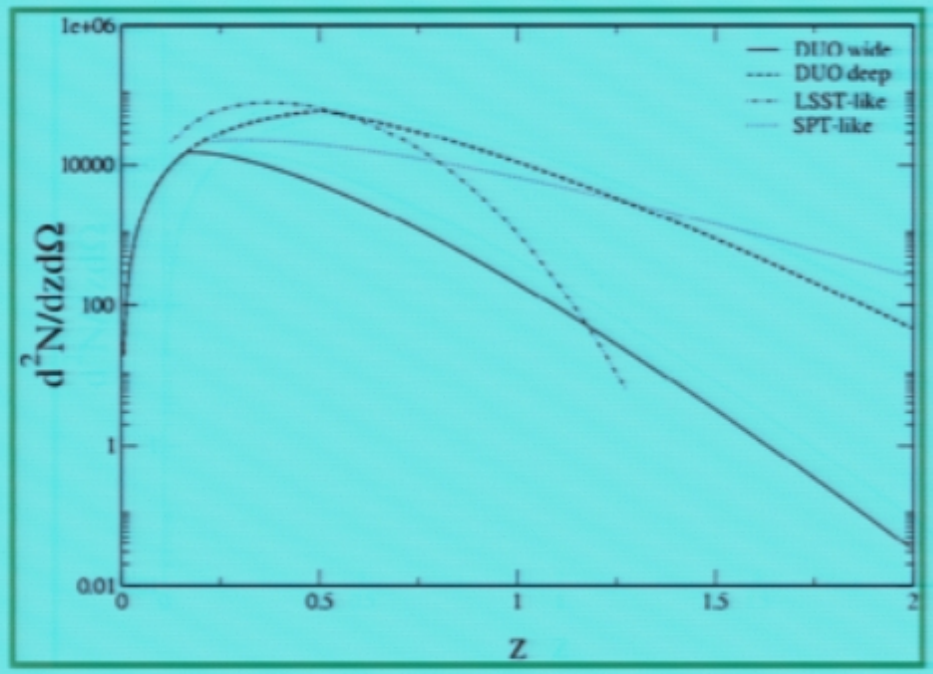
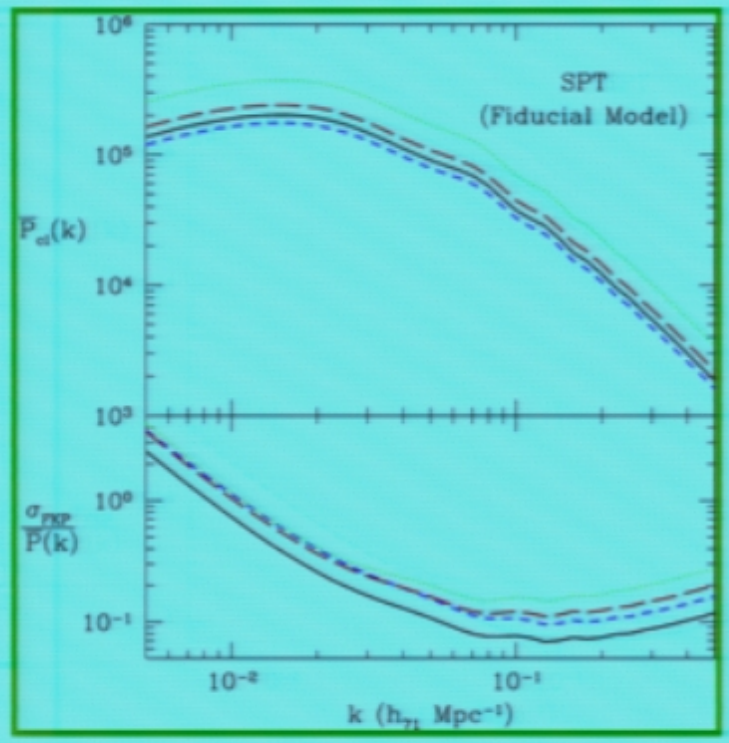


Ω_M-dependence

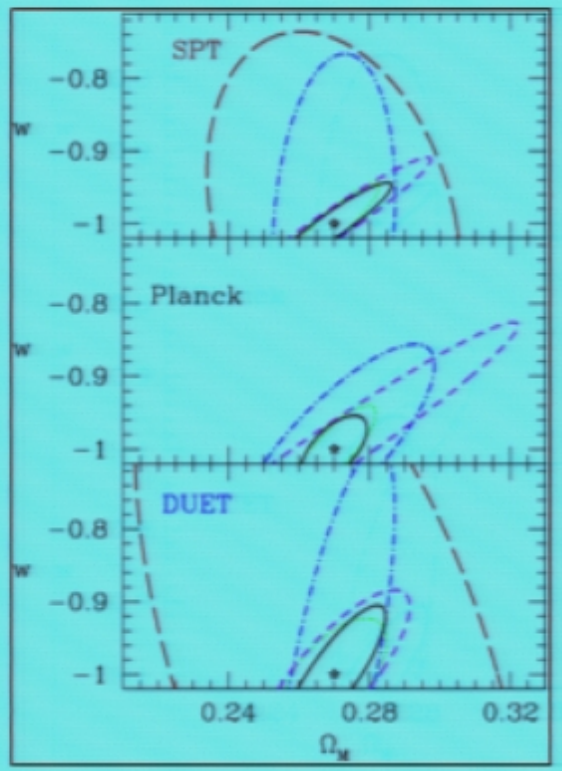
Cluster dNdz + Cluster P(k)...





Many planned/funded SZ surveys: potentially very powerful; probes upto high-z; Also capable to detect tens of thousands of clusters; SZ cleaner than Xray flux and Is a better proxy for mass. Add P(k) as additional constraints.

Forecasts for w from clusters...



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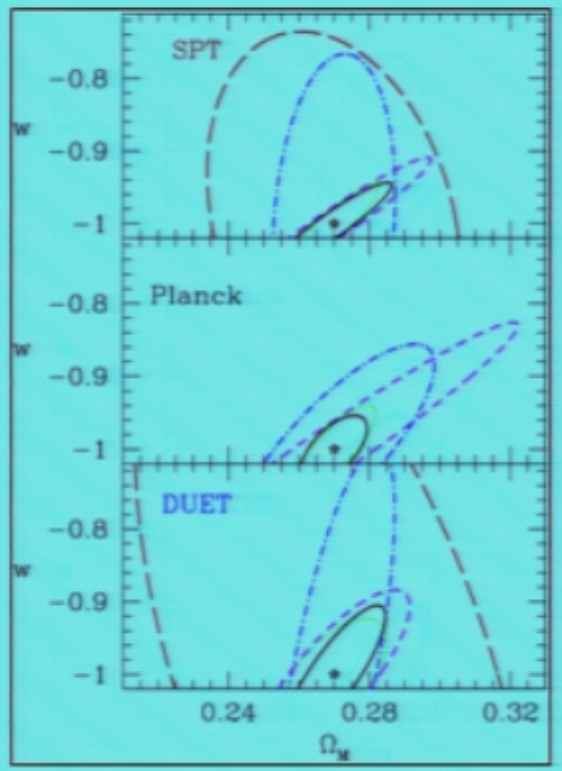

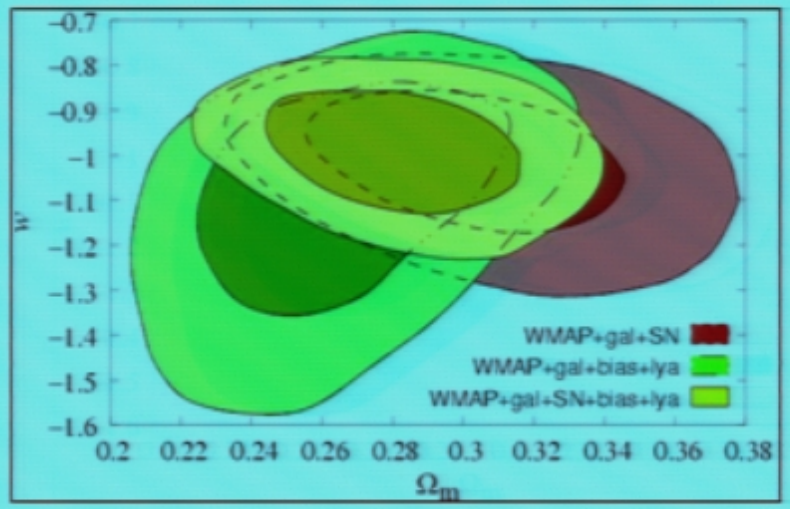

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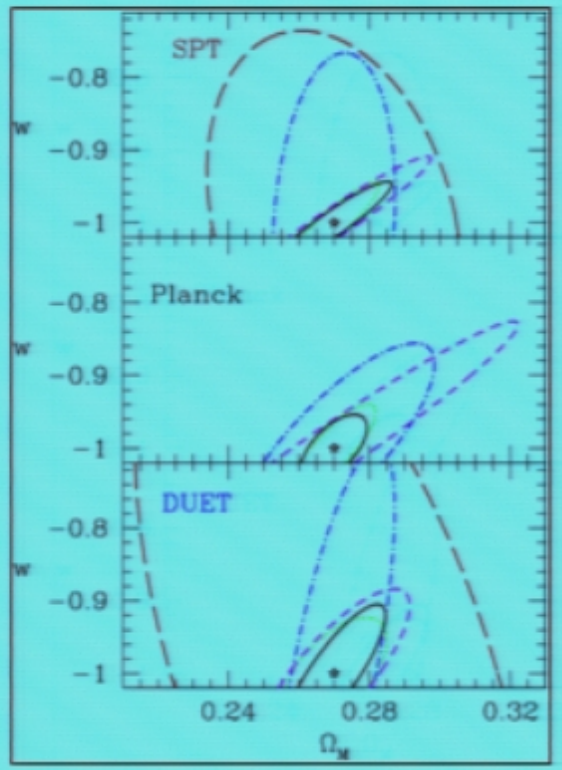

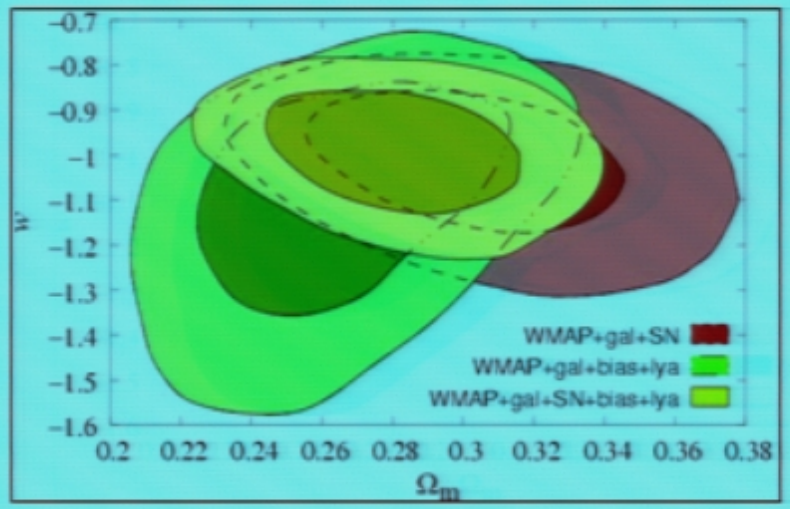

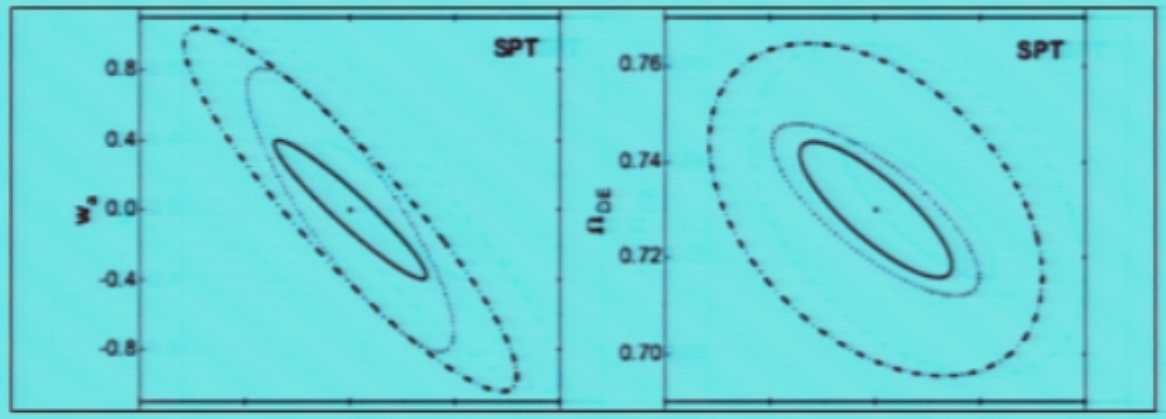

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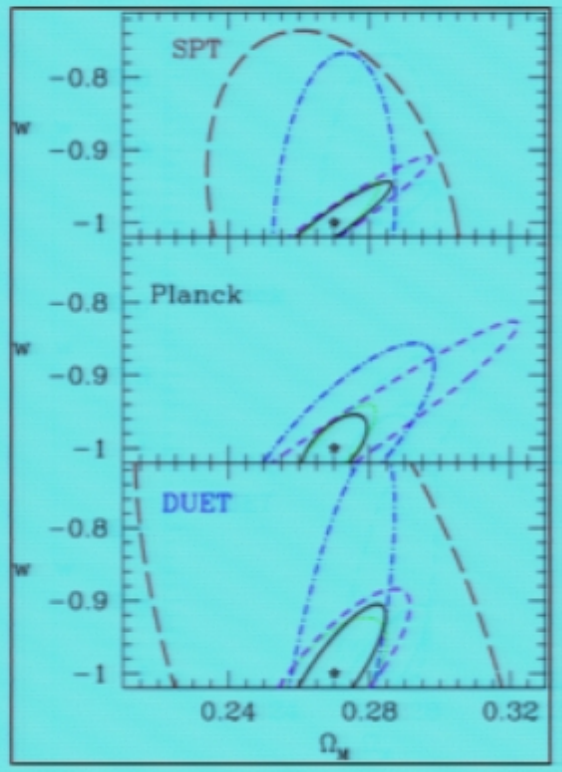

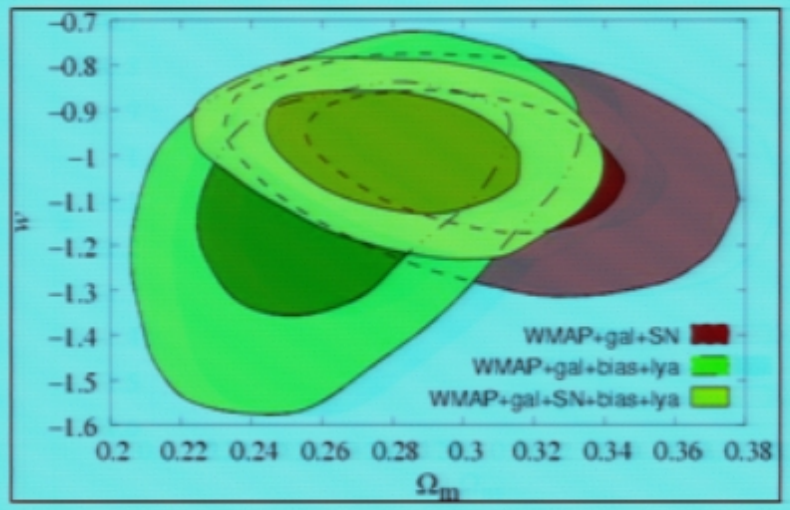

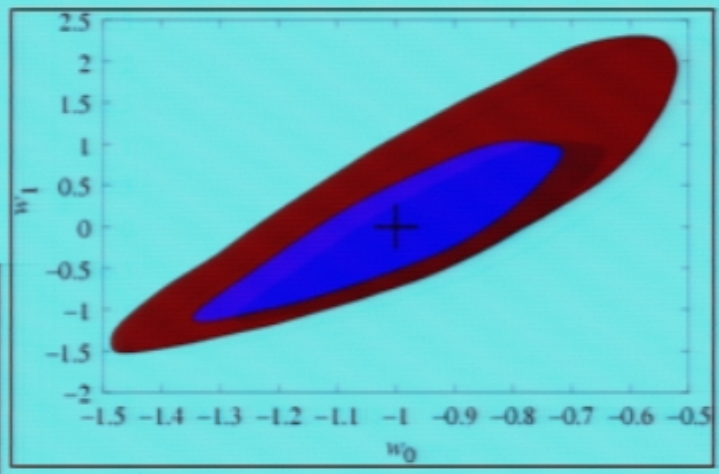

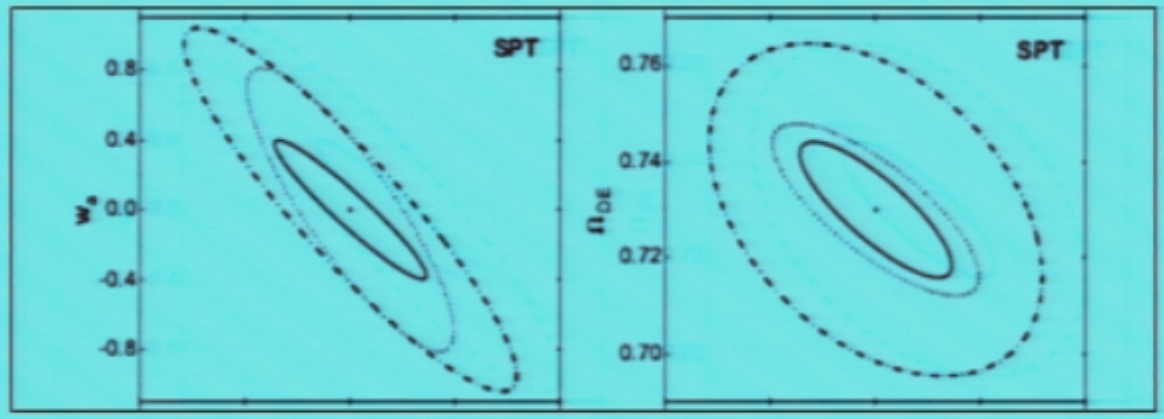

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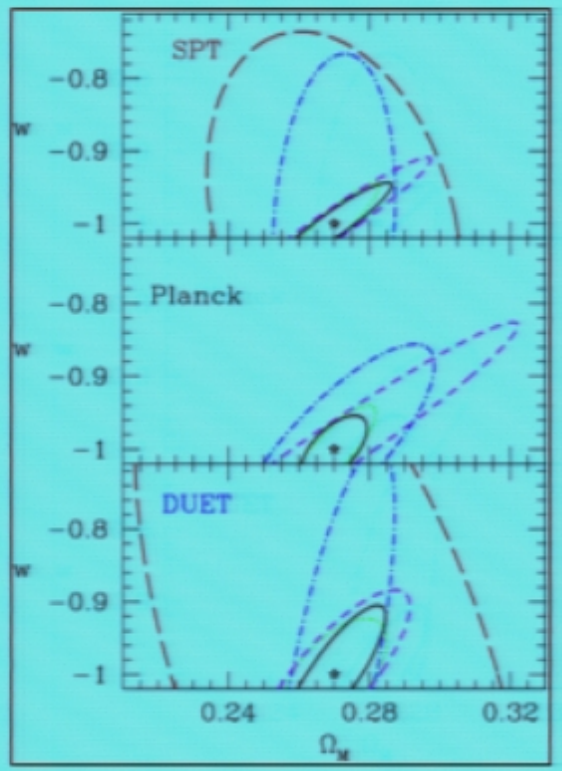

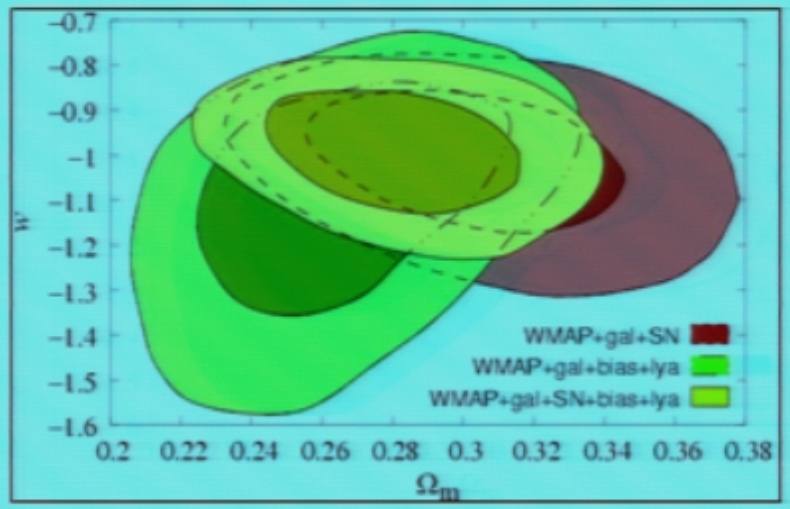

$\sigma(w0) = 20\%$

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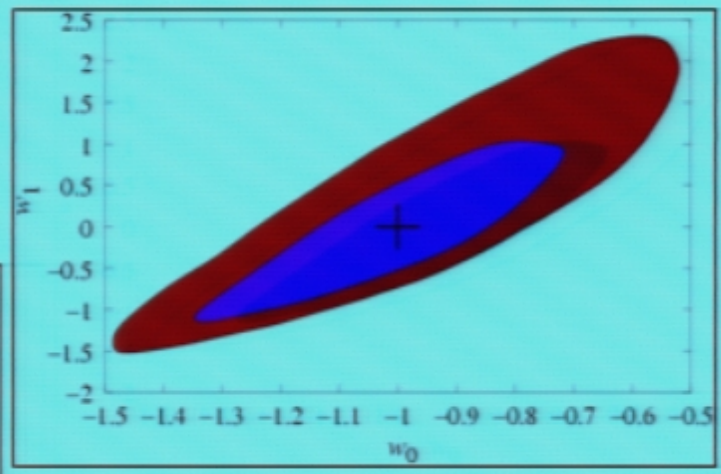

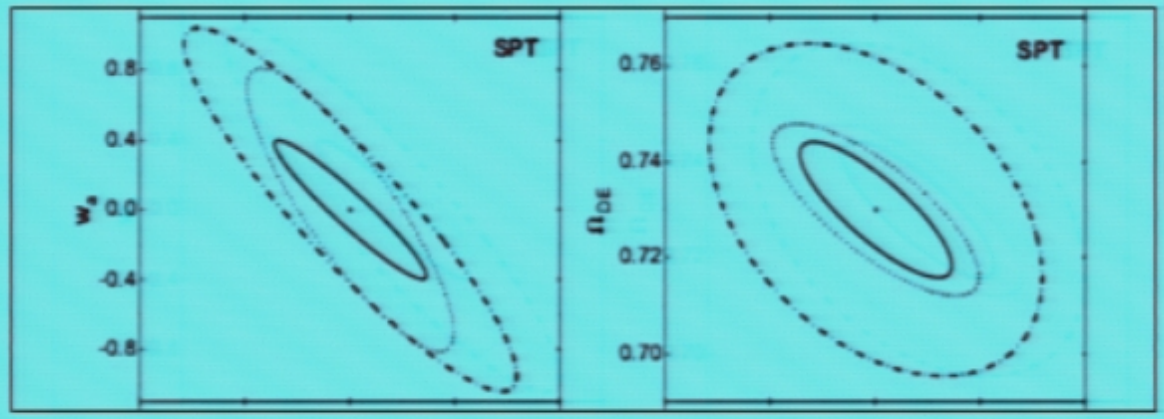

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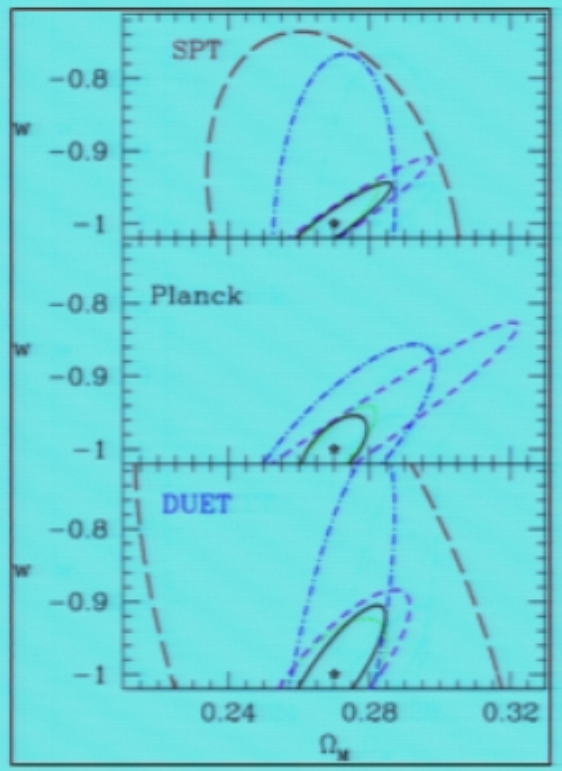

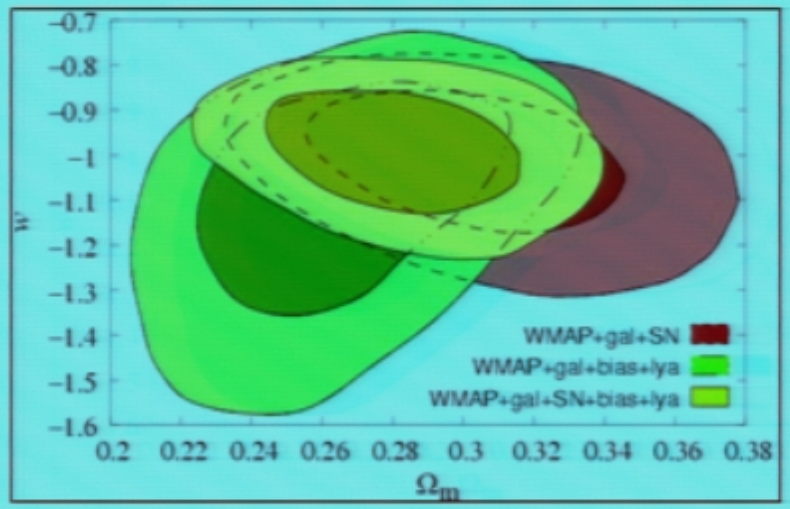

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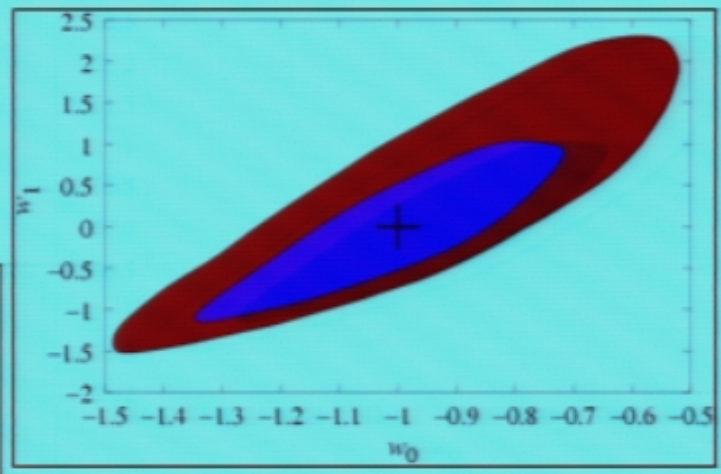

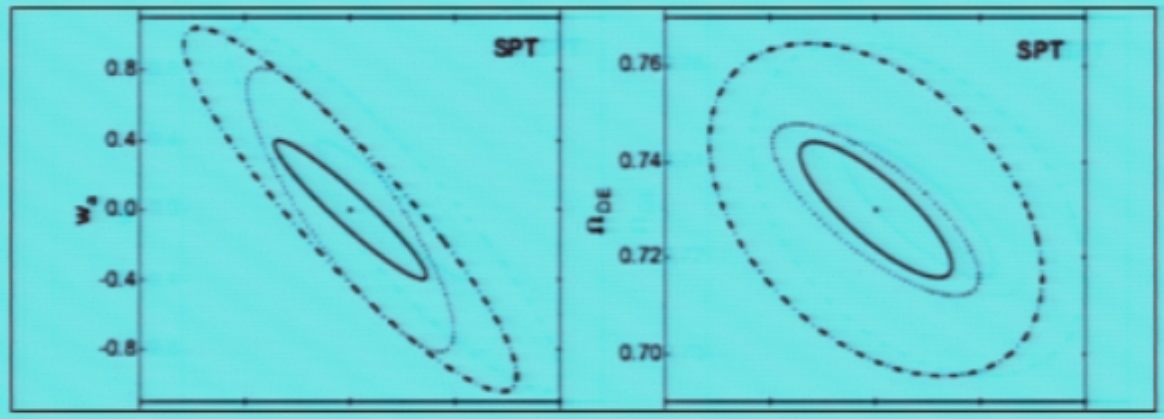

Expect 3-4 times improvement!!

Conclusion: what to expect?

A Promising example: SPT (4000 deg SZ survey) + DES (4000 deg optical followup)
Time Scale: 2007 – 2009 – 2014

Cluster SZ dNdz + (Cluster optical dNdz) + Cluster power spectrum + Galaxy power Spectrum + Galaxy P(k) wiggles + Weak lensing + SNe.

(If systematics & cosmology-gastronomy goofups can be sufficiently controlled, then)
Each can optimally determine $w_0 \sim 5\%$ and $w_a > 20\%$
Combined, we can probably aim at 1-2% on w_0 and ~10% on w_a!

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(If systematics & cosmology-gastronomy goofups can be sufficiently controlled, then)
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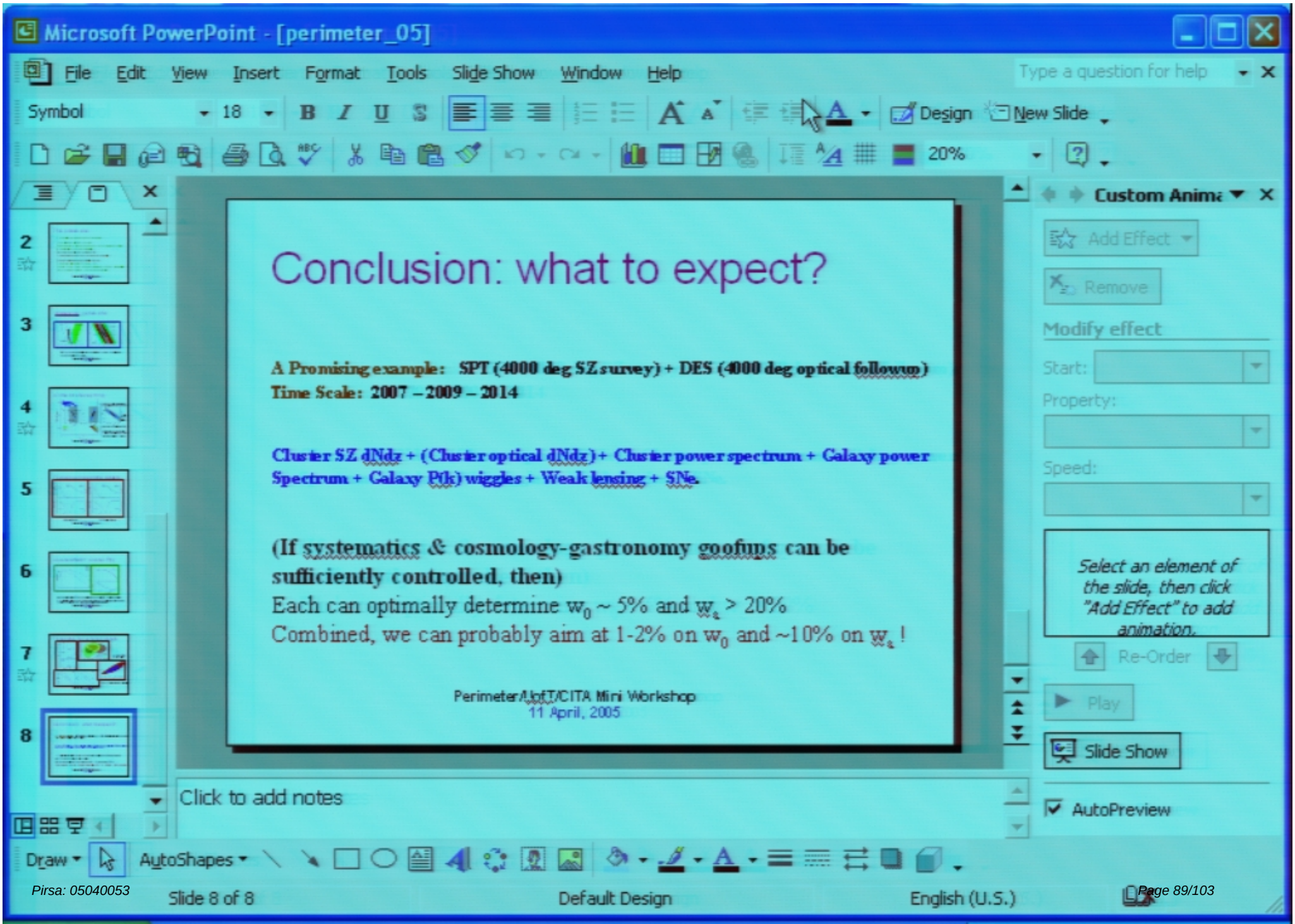
Combined, we can probably aim at 1-2% on w_0 and ~10% on w_a !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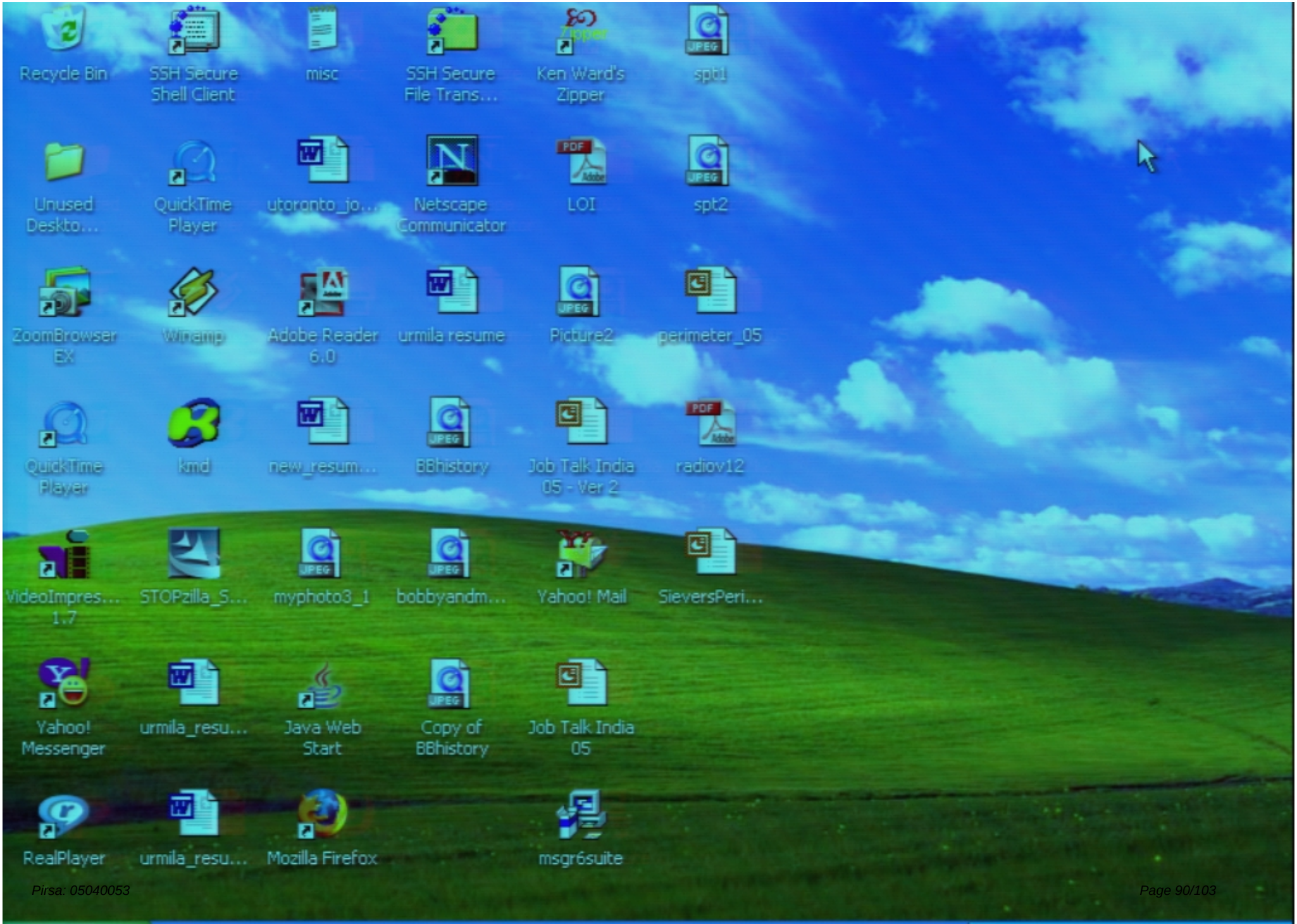
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Unused Deskto...
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Netscape Communicator
LOI
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ZoomBrowser EX
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EOS in the very early Universe

D. Podolsky, G. Felder, L. Kofman, M. Peloso

CITA, Landau ITP, University of Minnesota, Smith College

We discuss dynamics of matter fields during the stage realized immediately after the end of inflation

This stage is important for cosmology:

1. It defines initial conditions for the Hot Universe stage: reheating temperature, cosmological particle relics etc.
2. It defines the relation between the number of inflationary efoldings and physical wavelength of perturbations from inflation

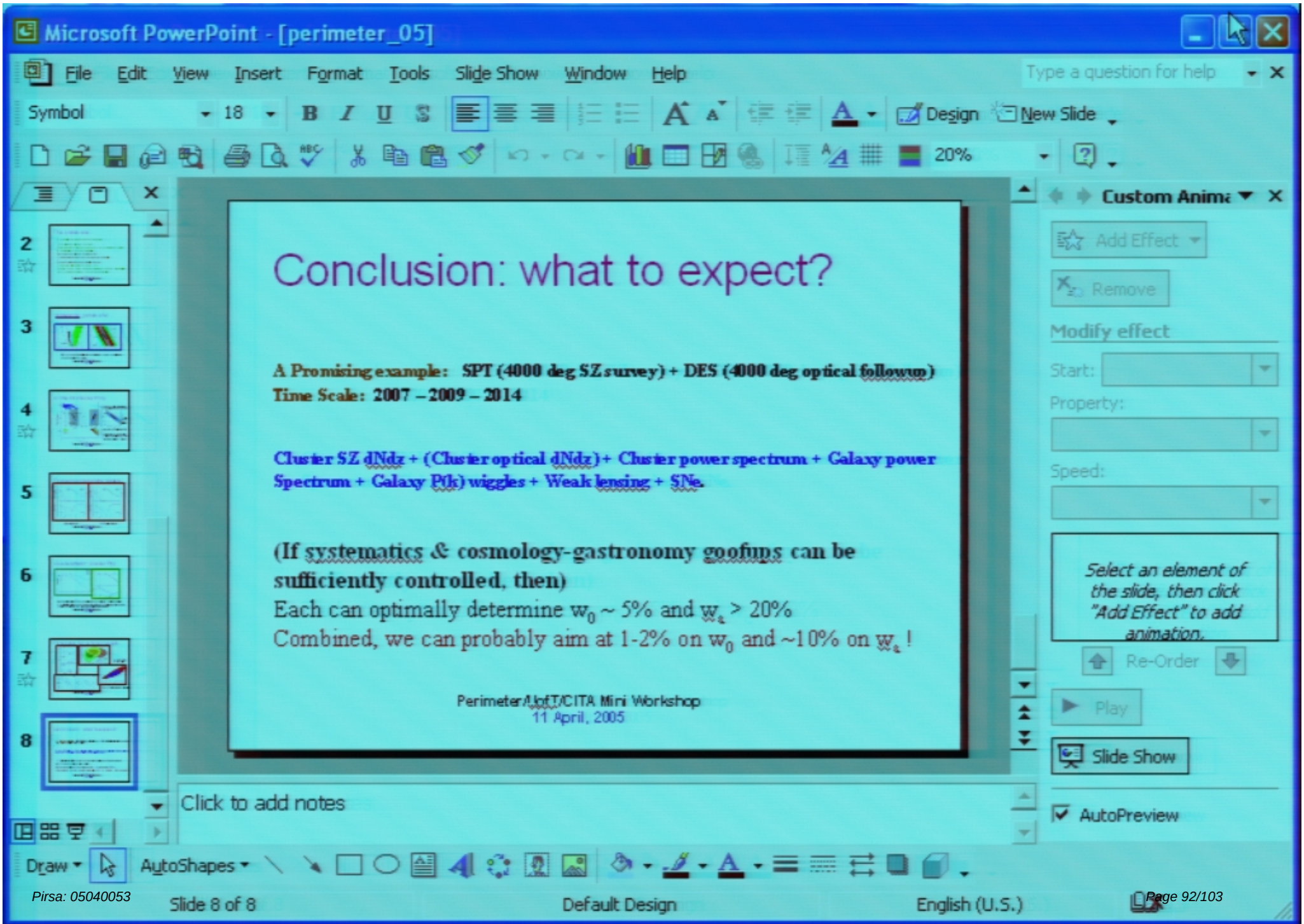
$$\log\left(\frac{0.01 Mpc^{-1}}{k}\right) = 68 - N + \Delta$$

last term Δ is defined by physics after inflation

3. Modulated fluctuations
4. ETC

It could be very interesting for field and string theorists because

1. adequate language for describing physics during this stage is non-equilibrium quantum field theory
2. Main features of field dynaimcs during this stage are related with non-perturbative effects in non-equilibrium QFT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Model

$$L = -\frac{1}{16\pi G}R + \frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{2}m^2\phi^2 + \frac{1}{2}(\partial_\mu\chi)^2 - \frac{1}{2}g^2\phi^2\chi^2$$

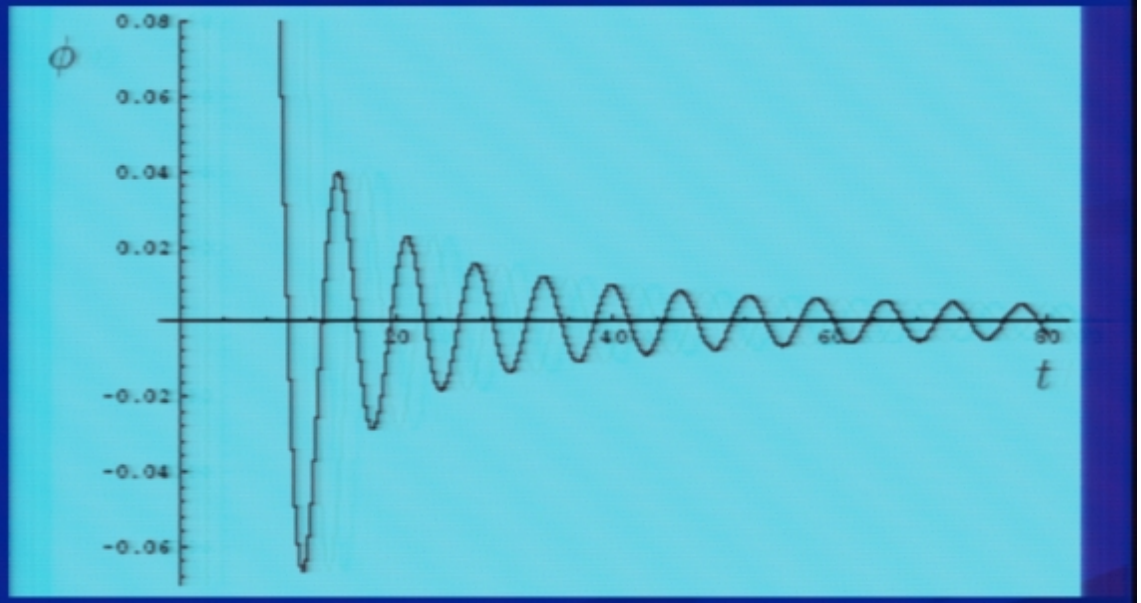
gravity inflaton matter

Inflation and reheating

$$H^2 = \frac{8\pi}{3M_P^2}\left(\frac{1}{2}\dot{\phi}^2 + \frac{1}{2}m^2\phi^2\right)$$

$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$

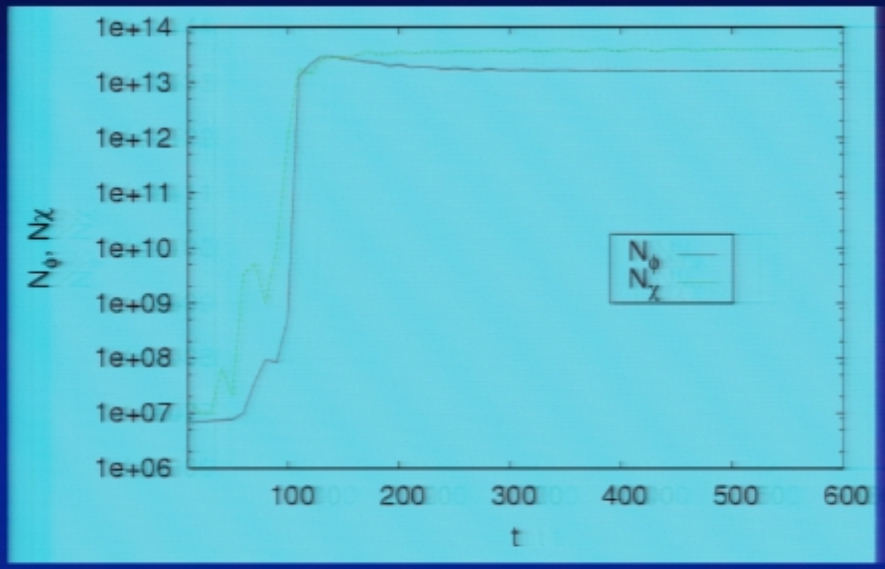
At $\phi \sim \frac{M_P}{2}$ inflation ends

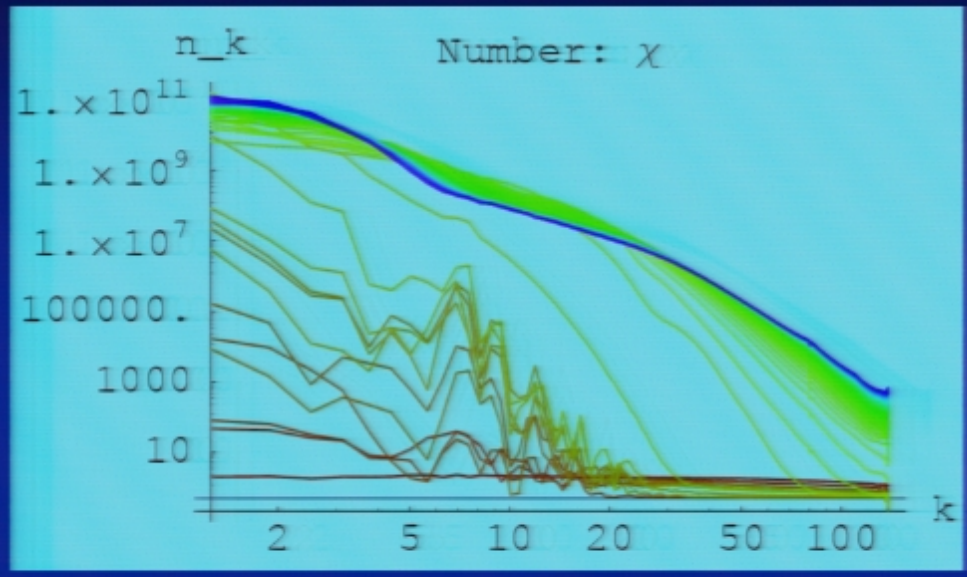


Oscillations of inflaton near the minimum of potential energy, effective mass for χ oscillates as well --- parametric resonance

Three stages of non-equilibrium dynamics after inflation

total number density





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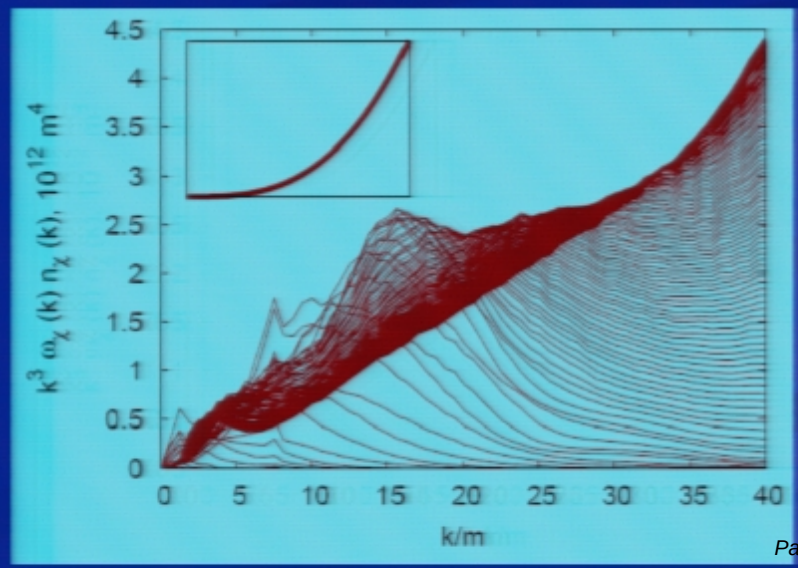
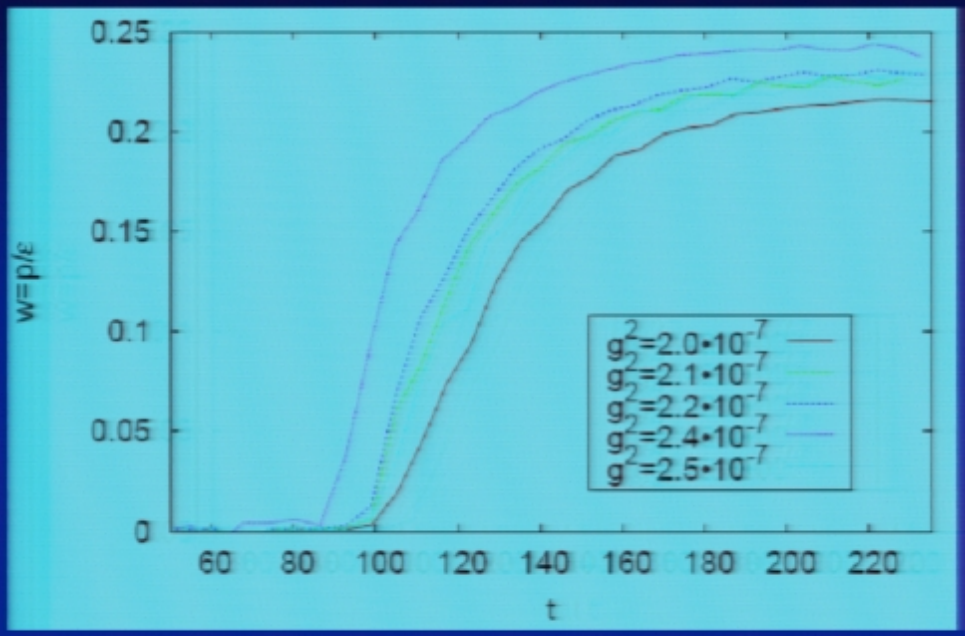
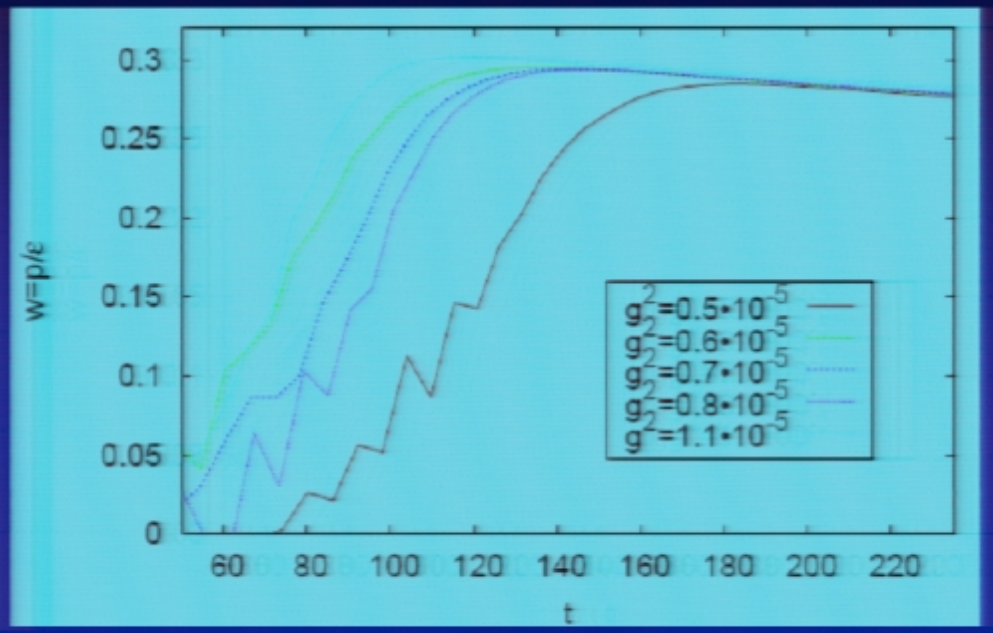


EOS and Prethermalization





Prethermalization:

- some "integral" quantities like EOS are thermalized quickly while distribution functions are far from thermal in the UV
- IR modes are thermalized quickly, UV are cascading

Change of paradigm:

soon after the end of reheating spectra are thermal at all physically interesting $k < 10^{12}$ Gev; characteristic temperatures are high: $T \sim 10^{14}$ Gev

Consequences:

huge overproduction of gravitinos etc.

$k < m = 10^{12}$ GeV

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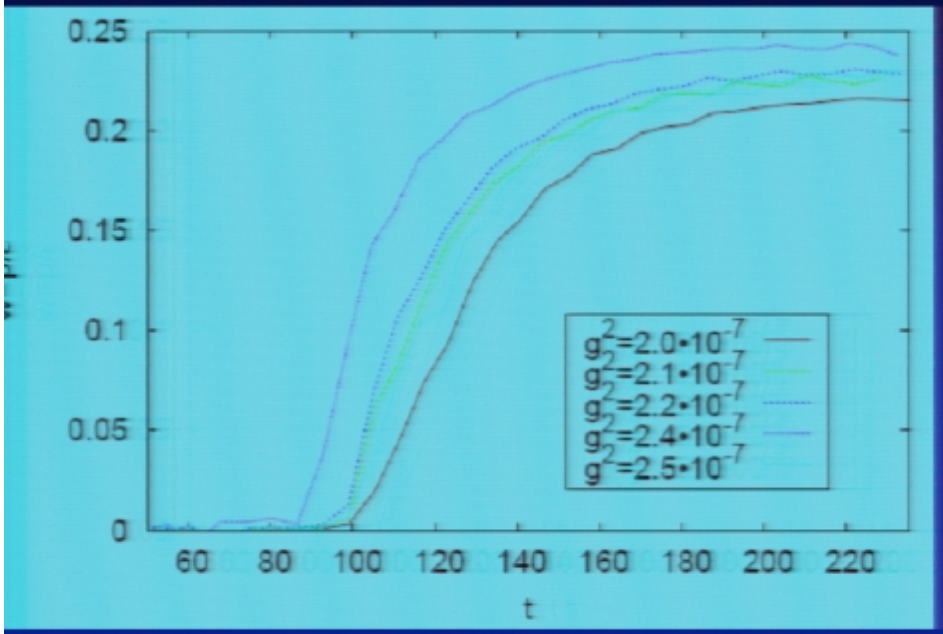

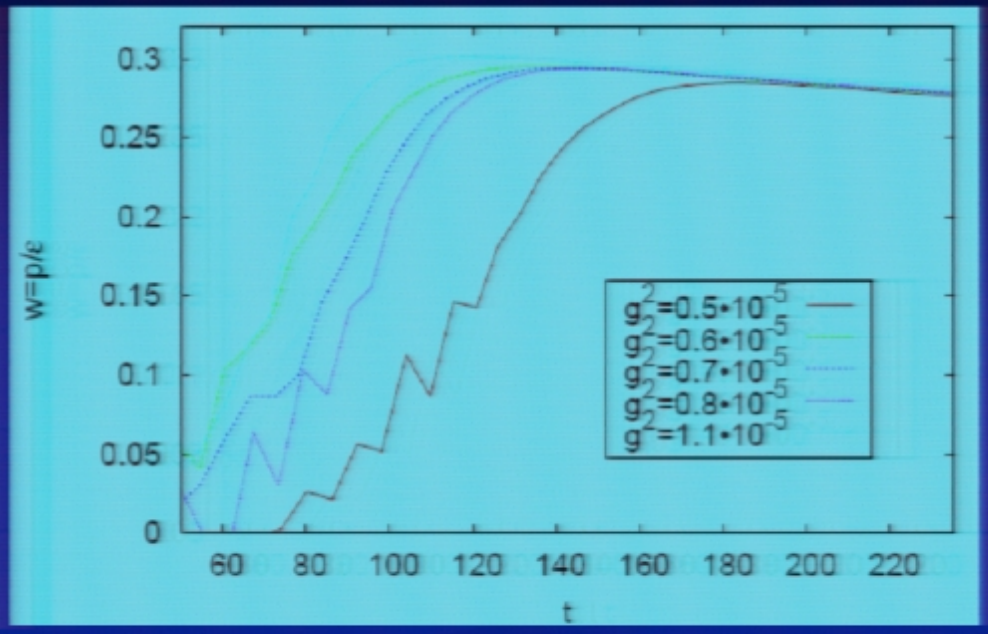

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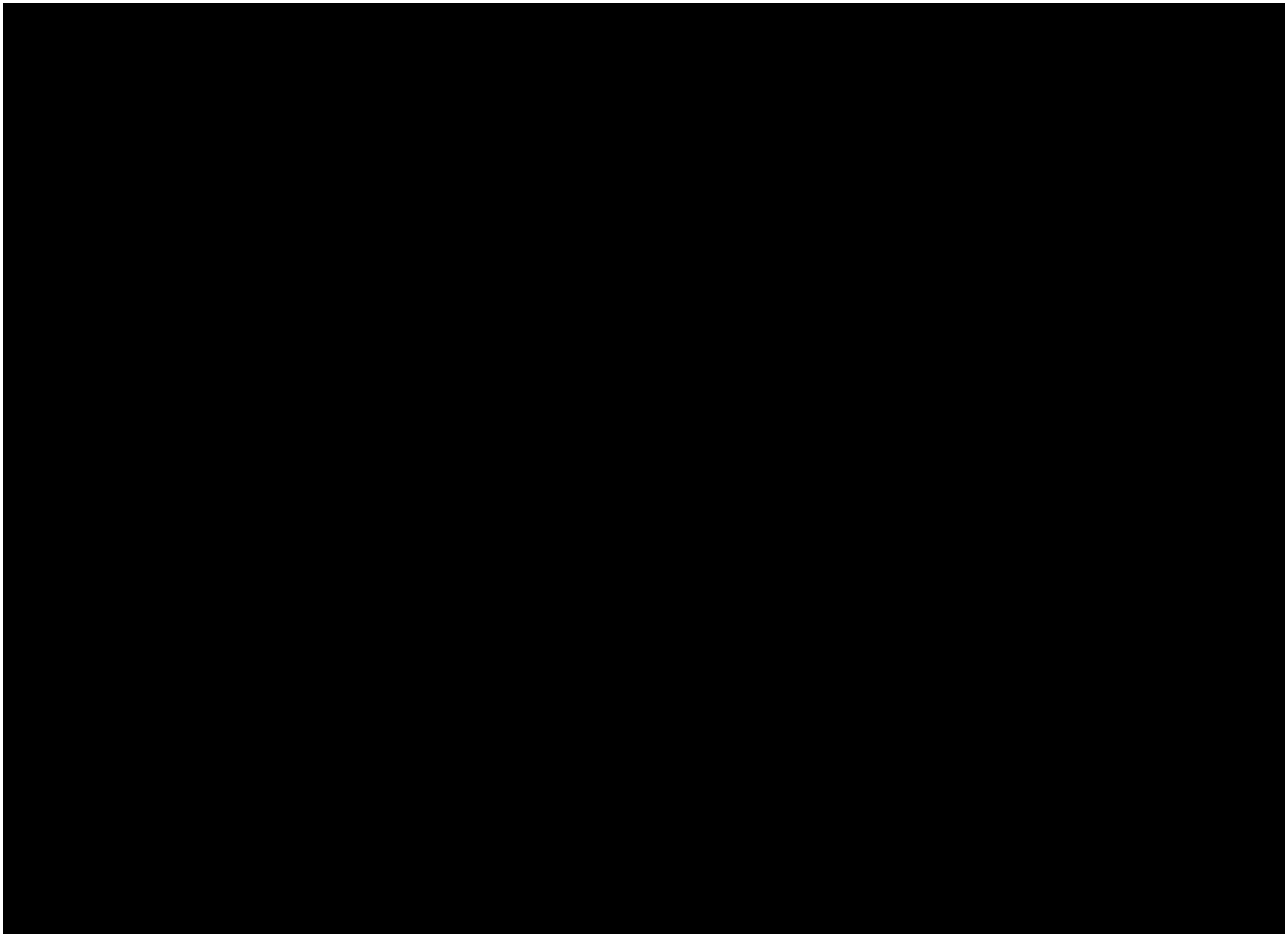

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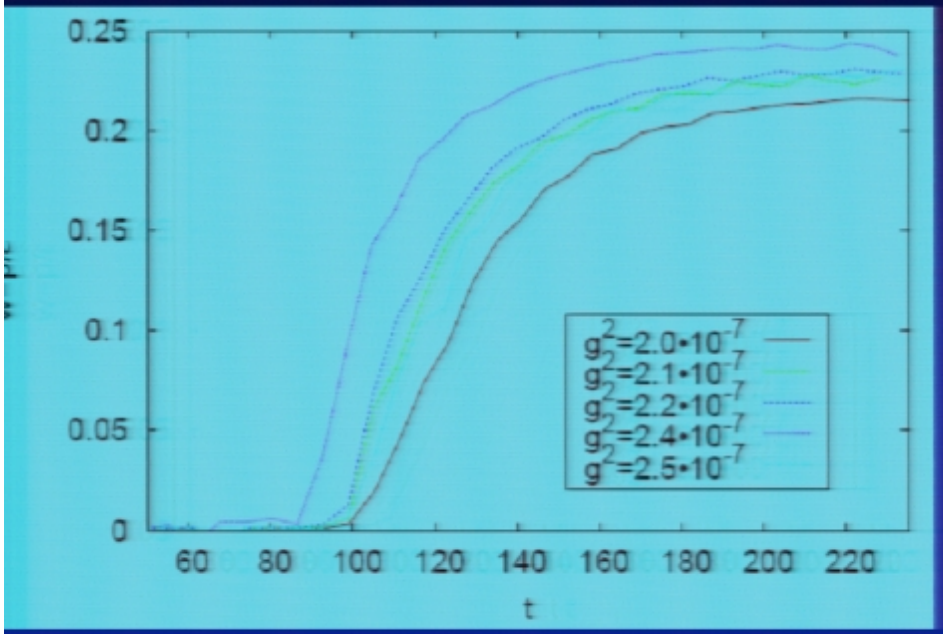

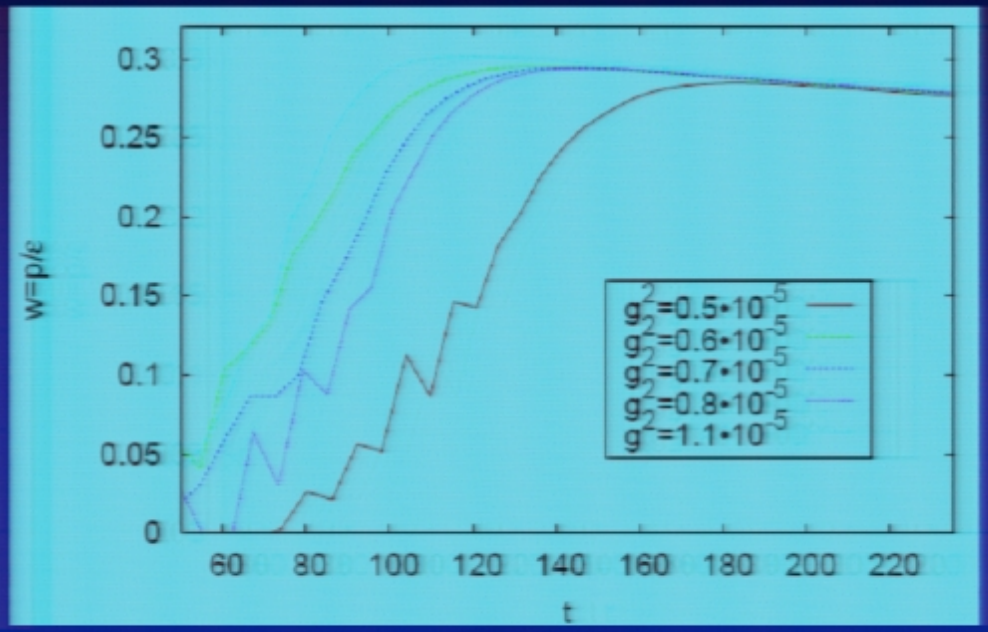

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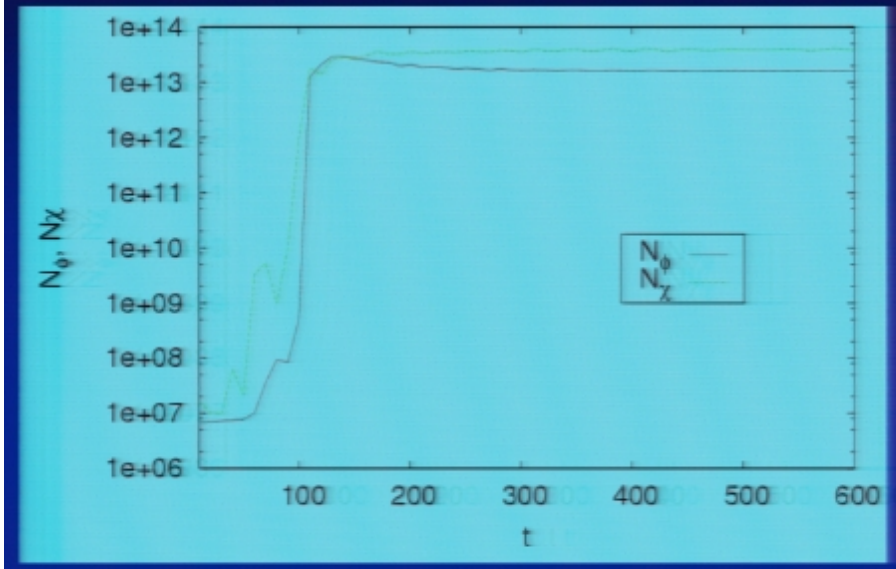

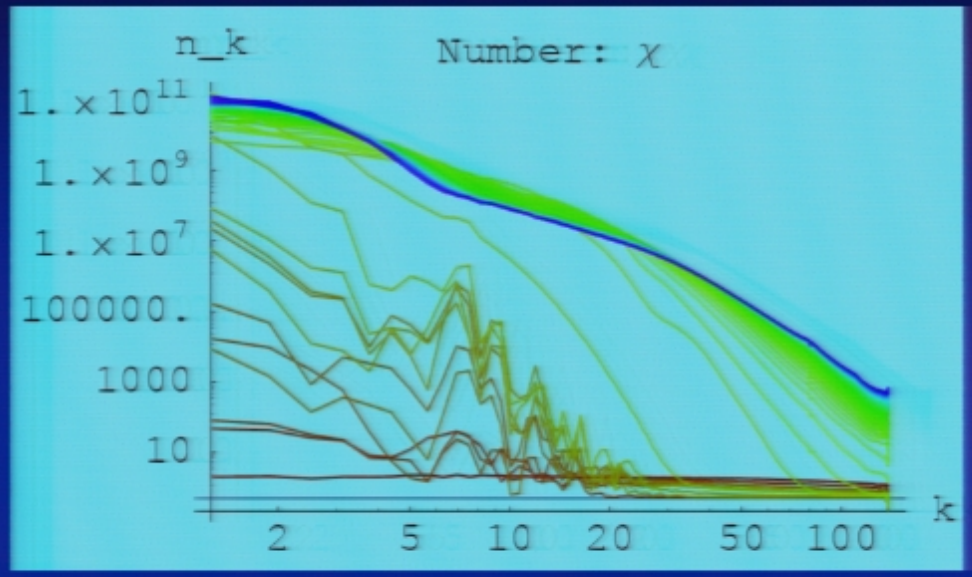

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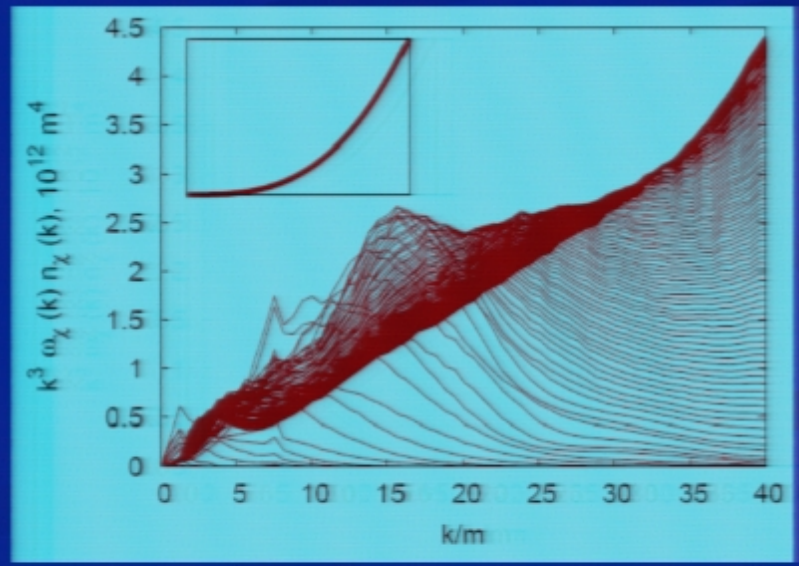

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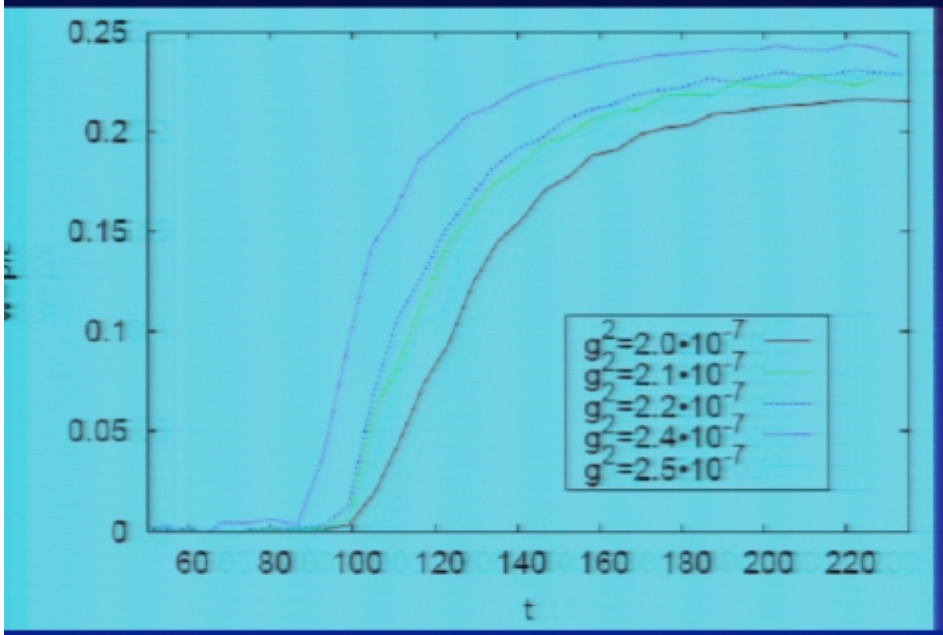

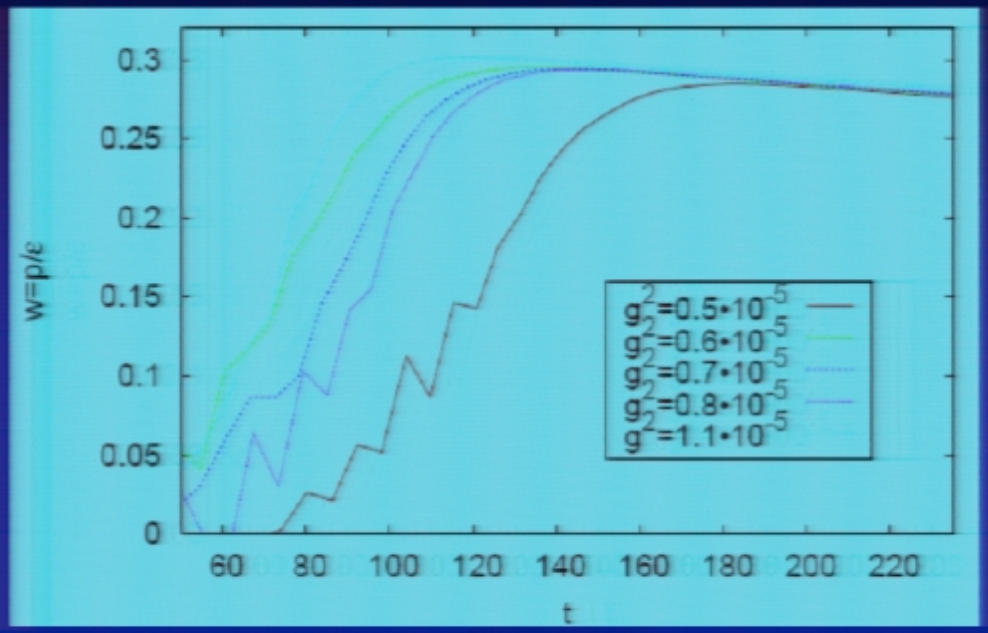

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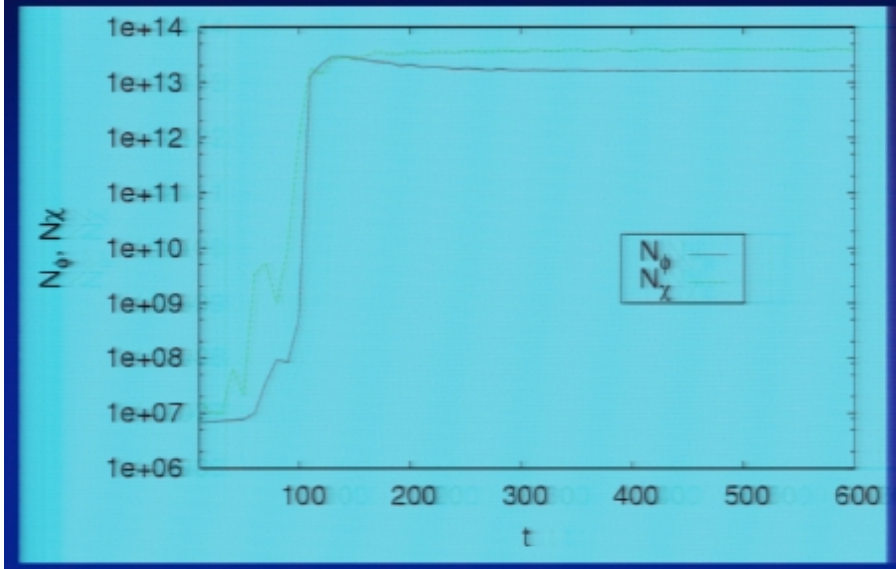

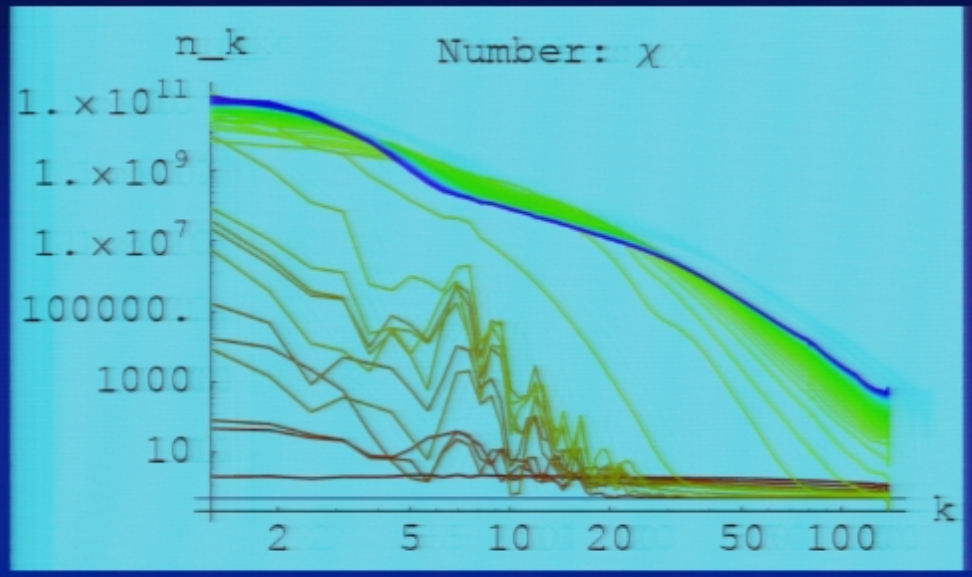

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