Title: Large-scale structure from the Sloan Digital Sky Survey

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Abstract:

Large-scale structure from the Sloan Digital Sky Survey

(with emphasis on the Lyman-α forest)

Pat McDonald

(CITA)

More importantly, everyone who worked on SDSS

Perimeter Institute, October 24, 2005

Outline

- Intro to SDSS
- Four SDSS measurements
- Cosmological parameters
- Future

Conclusions

- Non-Gaussianities as probe of something non-minimal going on
- Two classes of models
  1) Non minimal inflaton Lagrangian
  2) Additional light fields during inflation
- Equilateral shape VS local shape
- WMAP data analysis for the two shapes
  1) Factorizable equil. shape
  2) Linear piece in the estimator
- No detection! Tightest limit on NG parameters

  $-27 < f_{NL}^{local} < 121$ at 95% C.L.

  $-366 < f_{NL}^{equil} < 238$ at 95% C.L.
- Future

  WMAP 4 yrs: 30% improvement

  WMAP 8 yrs: 60% improvement

  PLANCK: factor of 4 (additional factor 1.6 from polarization)
- Non-minimal models will be ruled out

Goals of observational cosmology

- Matter components (neutrino mass?), nature of dark matter
- Nature of dark energy
- Nature of creation of structure in the universe (inflation or something else?)

These are fundamental physics goals, in addition to this we also want to know how the universe got to how it looks today

SDSS

Apache Point Observatory (APO) New Mexico

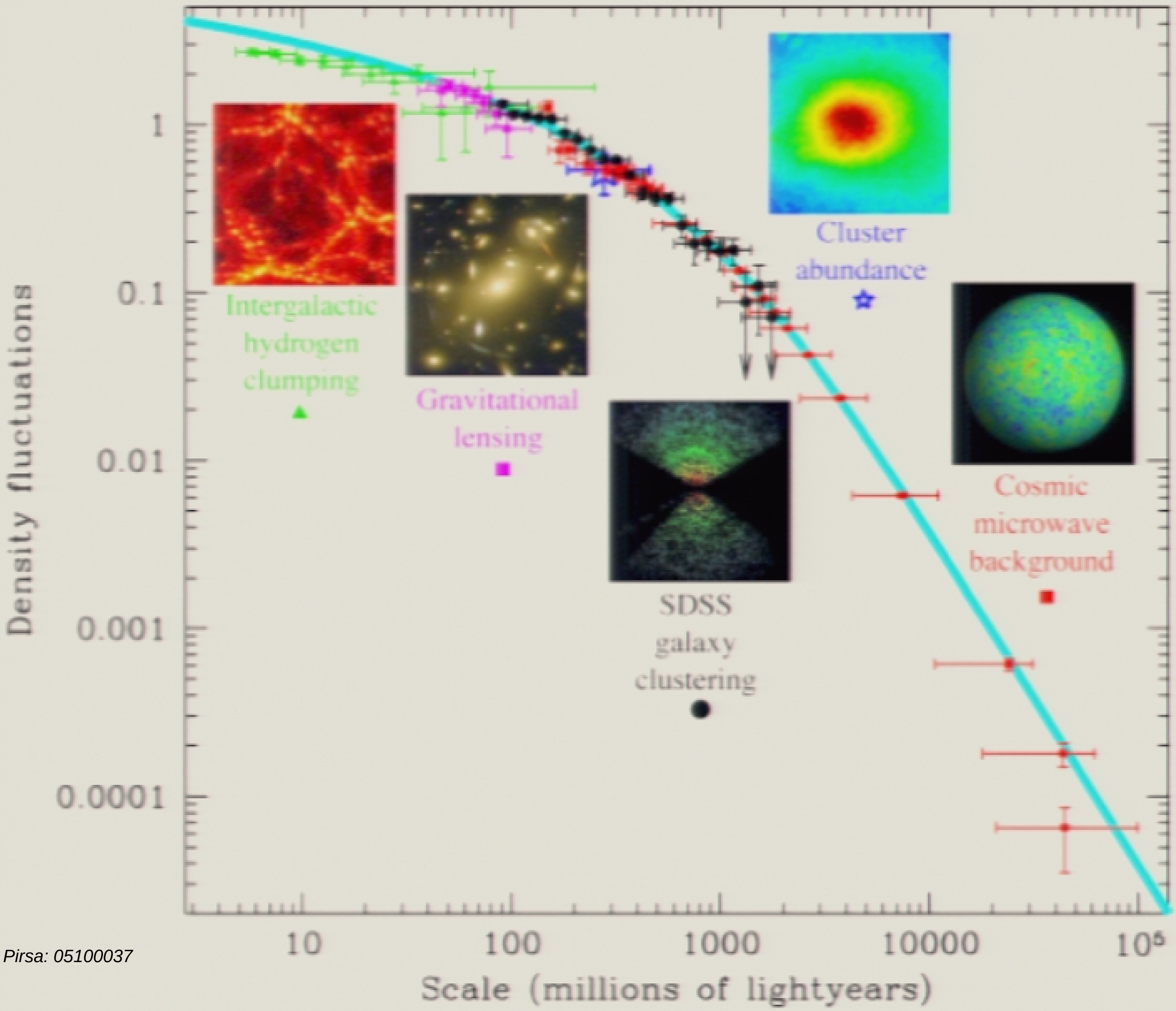
SDSS Basics

- 2.5 meter telescope
- 3 degree field of view
- Drift-scan imaging camera
- 5 photometric bands
- Target: 10000 square degrees
- 640 fiber spectrograph
- Target: spectra of 100000 quasars, 1 million galaxies

Several ways SDSS maps LSS

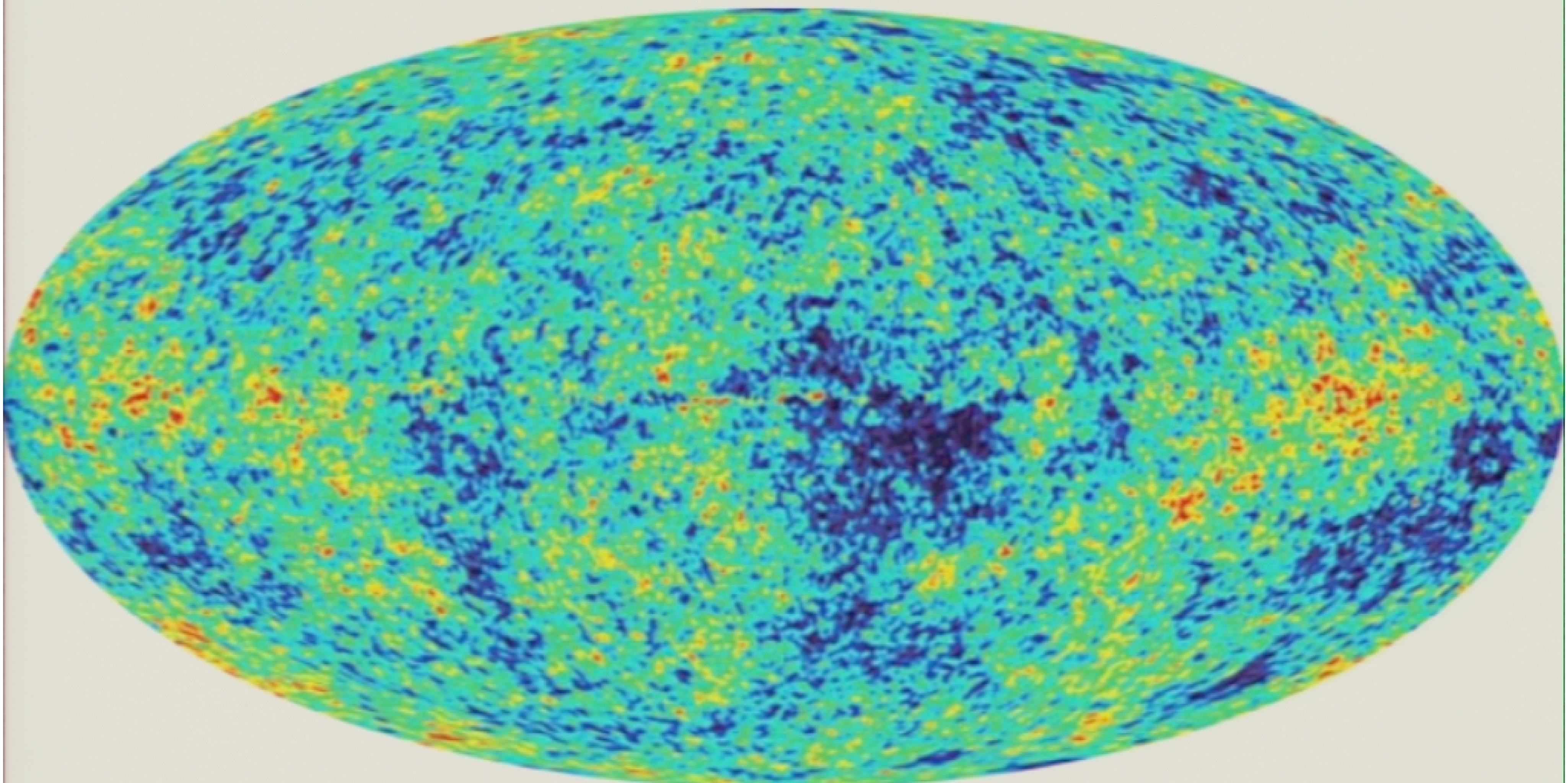
- Main galaxy power spectrum
  - Tegmark et al. 2004
- Galaxy-galaxy lensing to determine bias
  - Seljak et al. 2005
- Lyman-alpha forest
  - McDonald et al. 2005
- Luminous Red Galaxy (LRG) correlation function
  - Eisenstein et al. 2005
- Others less useful so far for cosmological parameters

Scales of various LSS probes

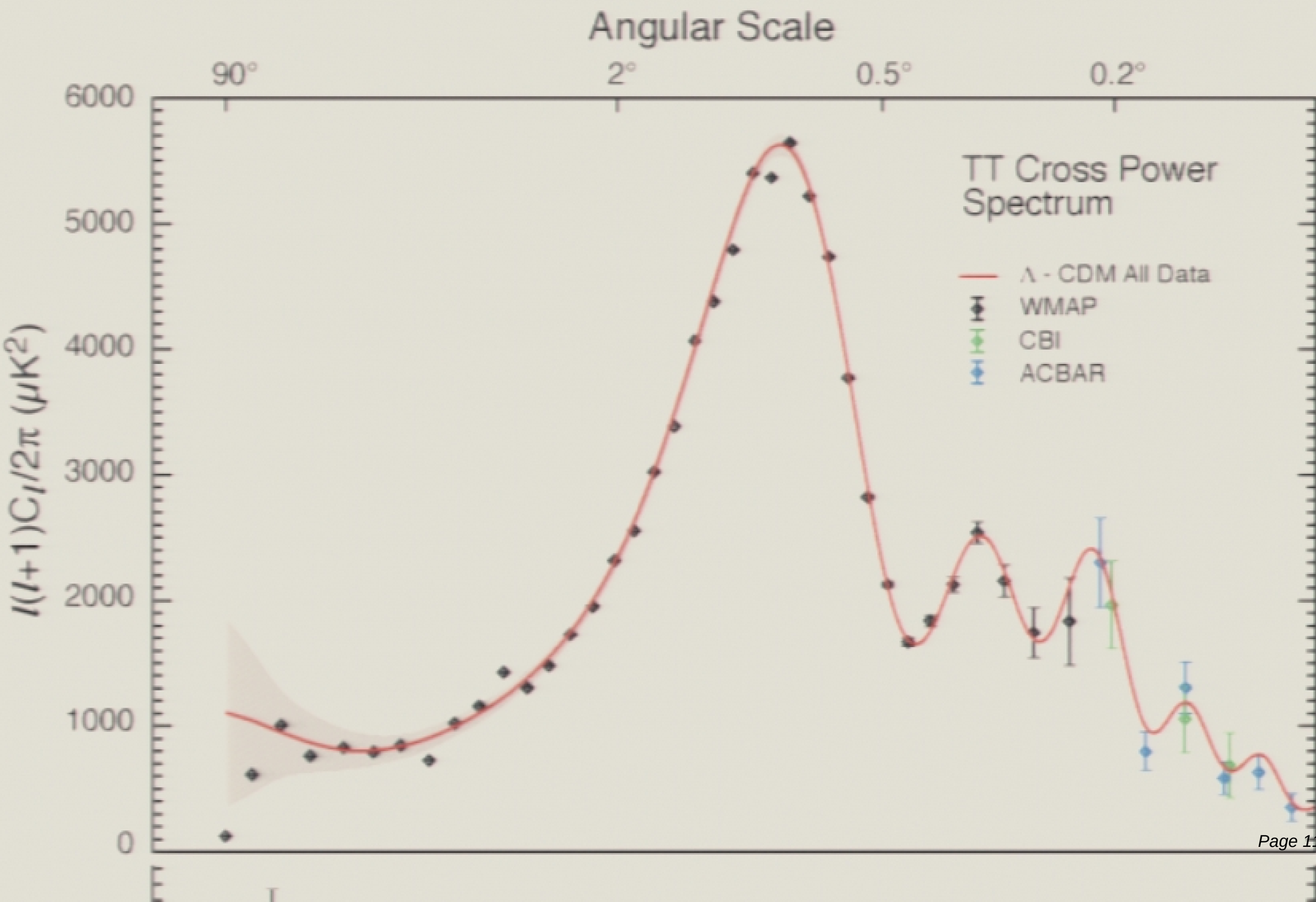


(figure by Max Tegmark)

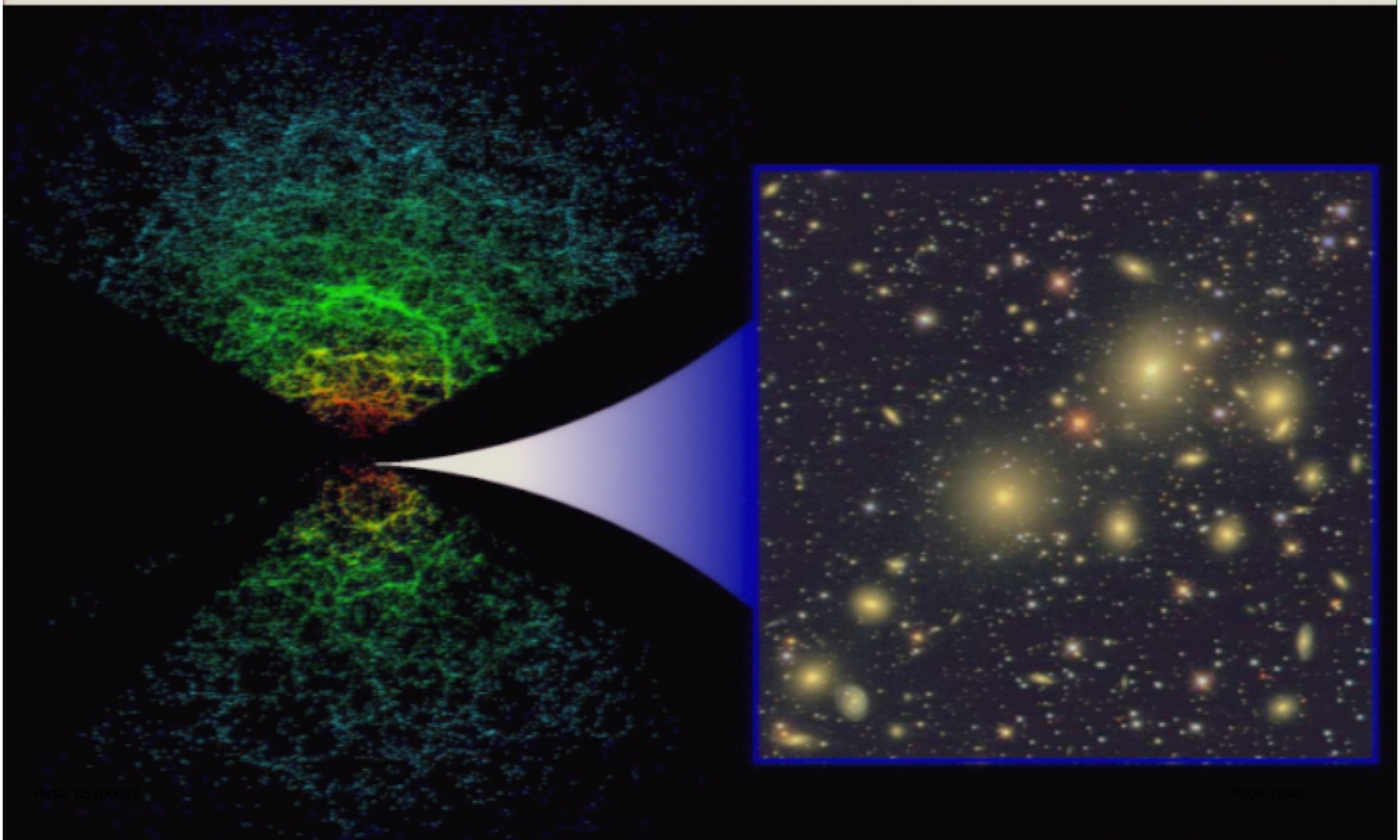
WMAP CMB map



WMAP CMB power spectrum



SDSS Galaxy map

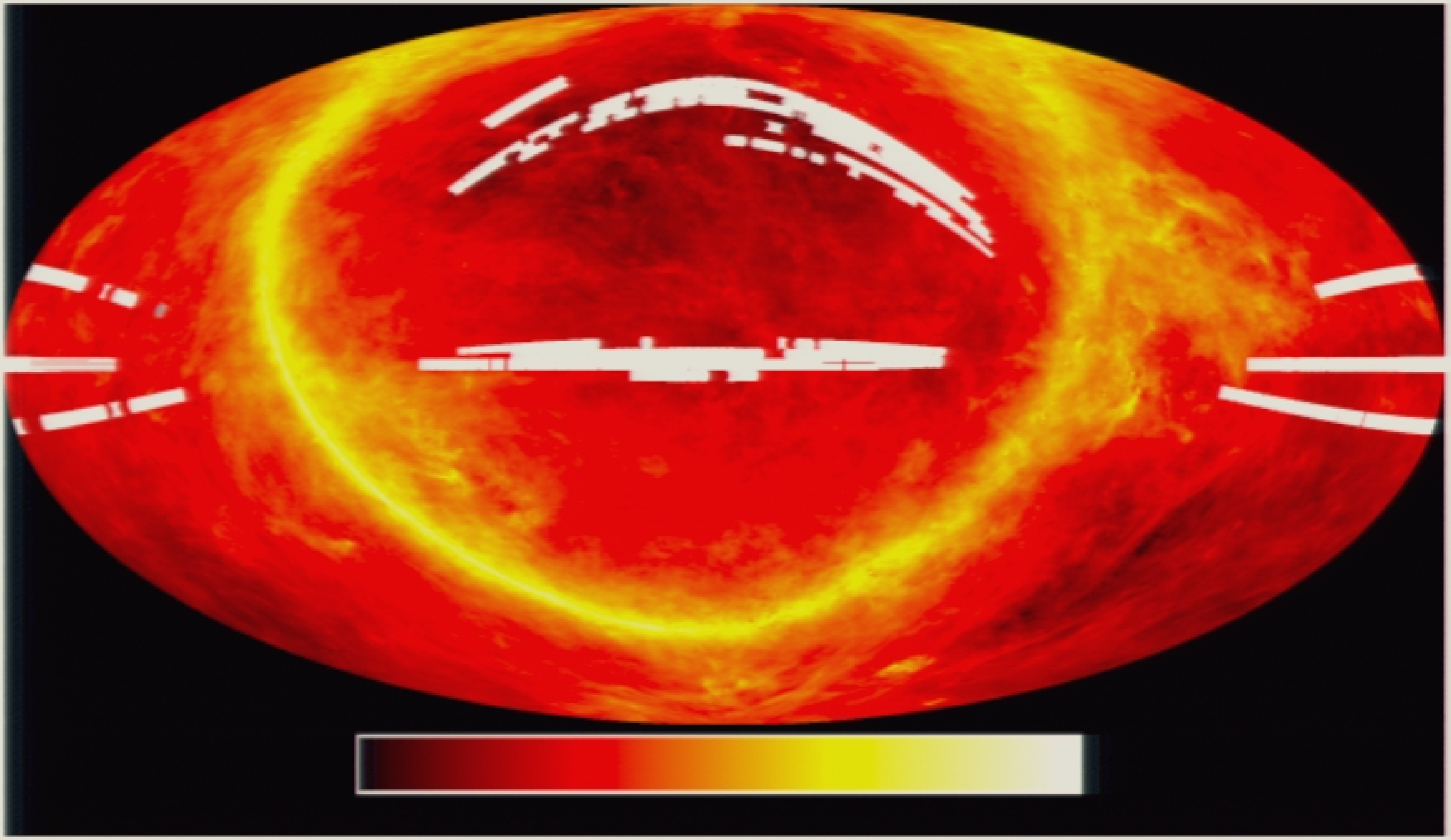


SDSS main galaxy power spectrum

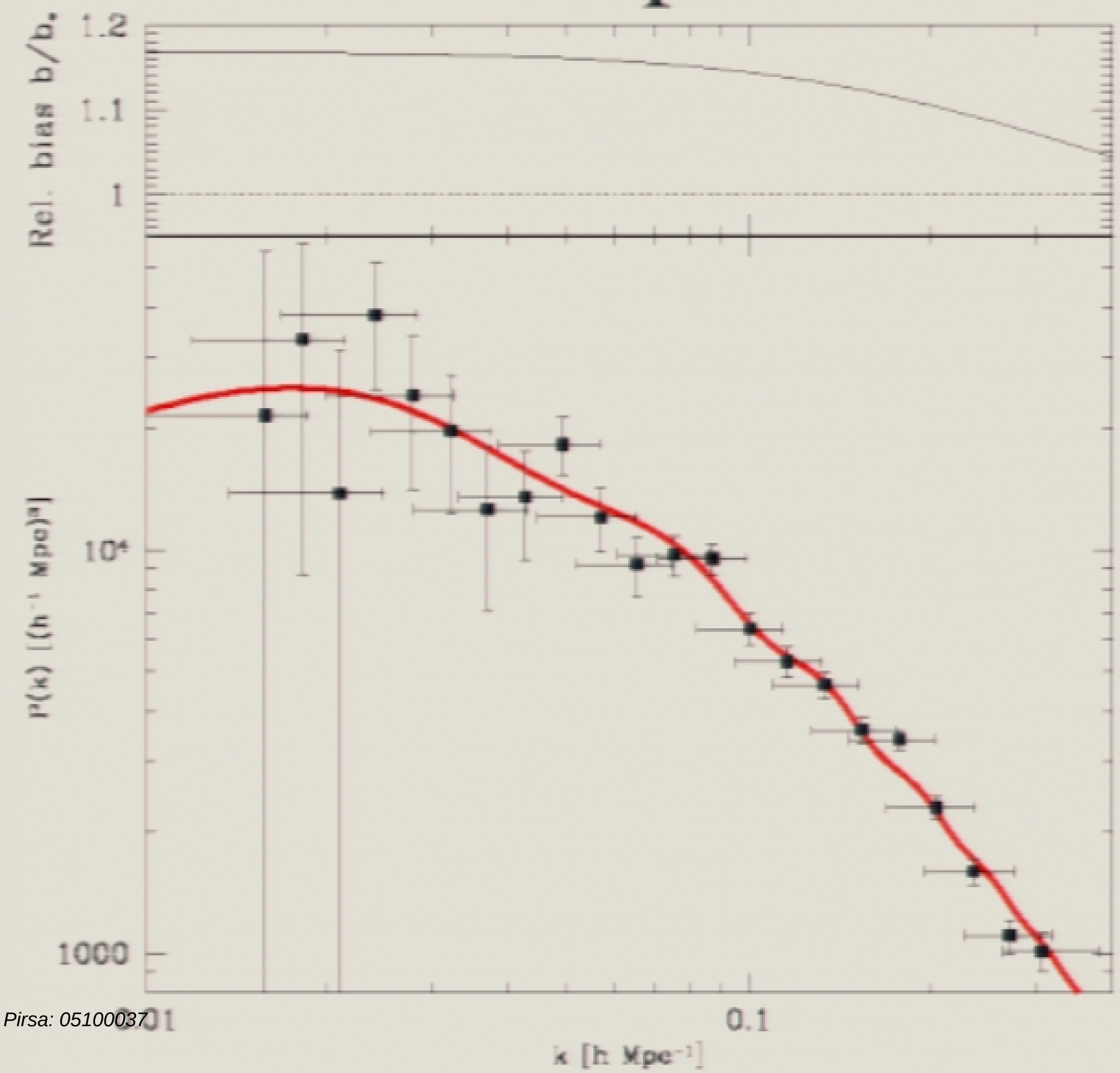
(Tegmark, Blanton, Strauss, et al. 2004, ApJ, 606, 702)

- 205443 galaxies
- 2417 square degrees
- Mean z=0.1
- http://space.mit.edu/home/tegmark/sdsspower.html

Tegmark et al. (2004) sky coverage (~6%)



SDSS main galaxy power spectrum



Complications:

- Bias
- Redshift-space distortions
- Non-linearity

Tegmark et al. 2004

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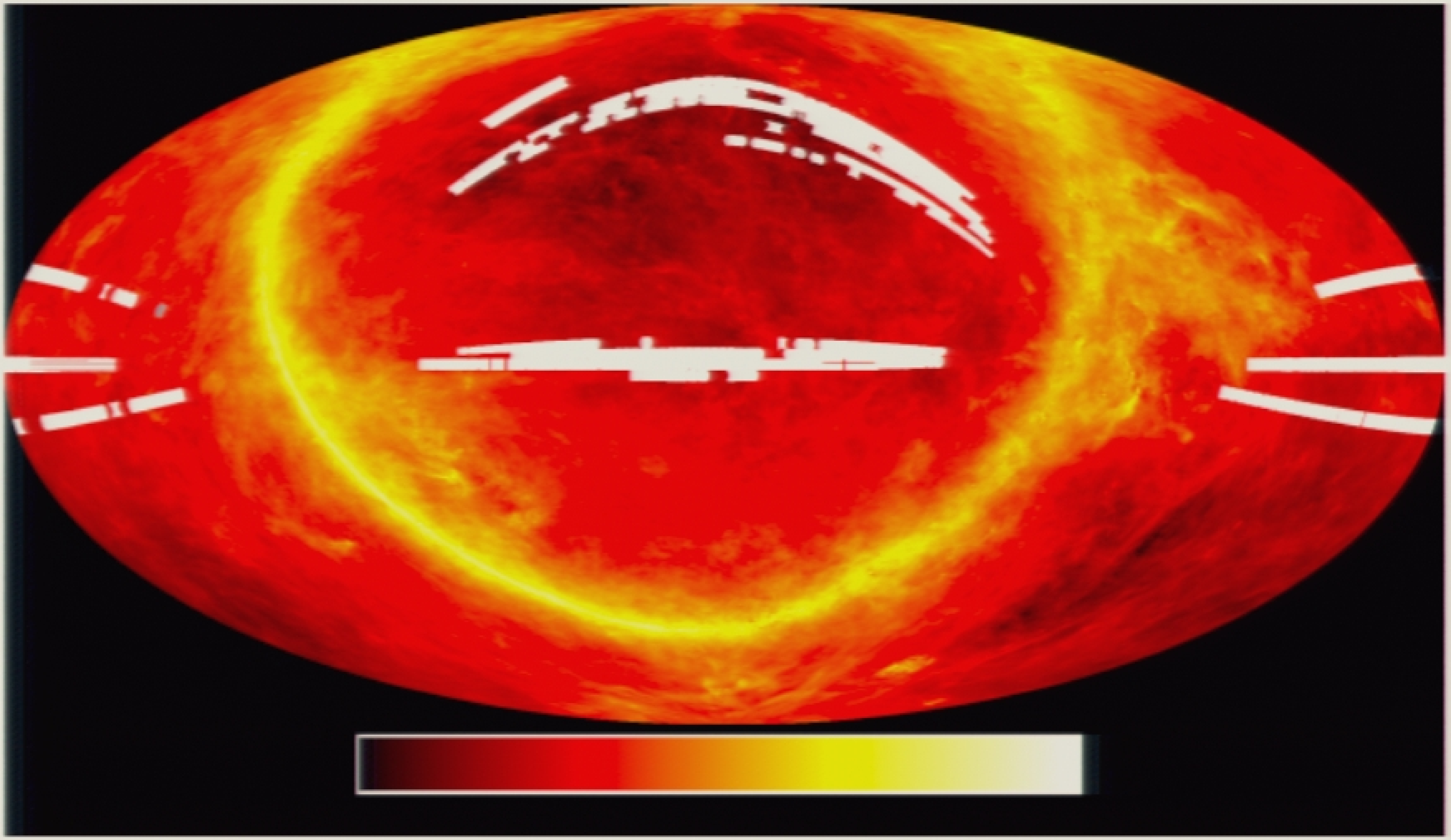
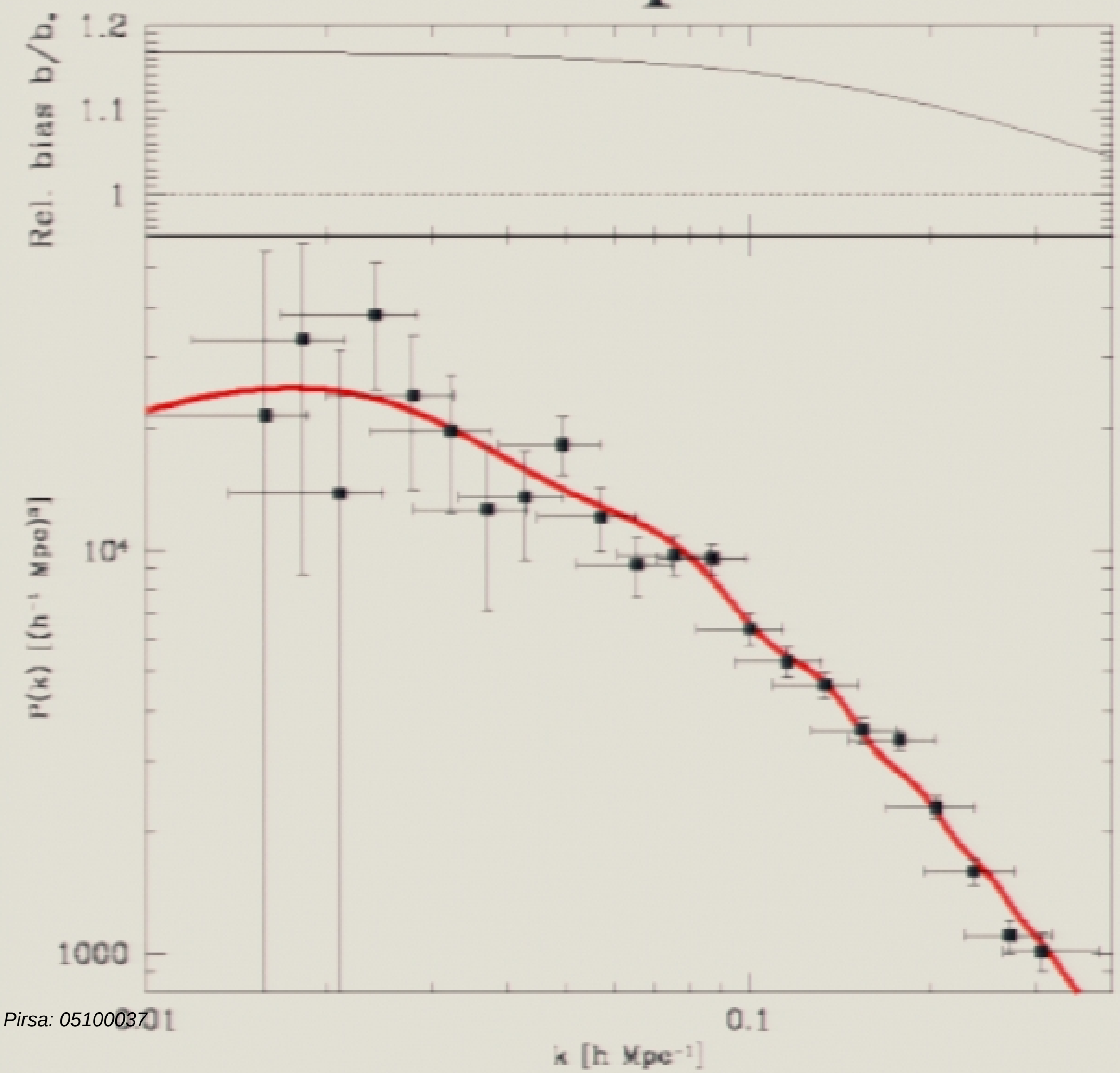


SDSS main galaxy power spectrum



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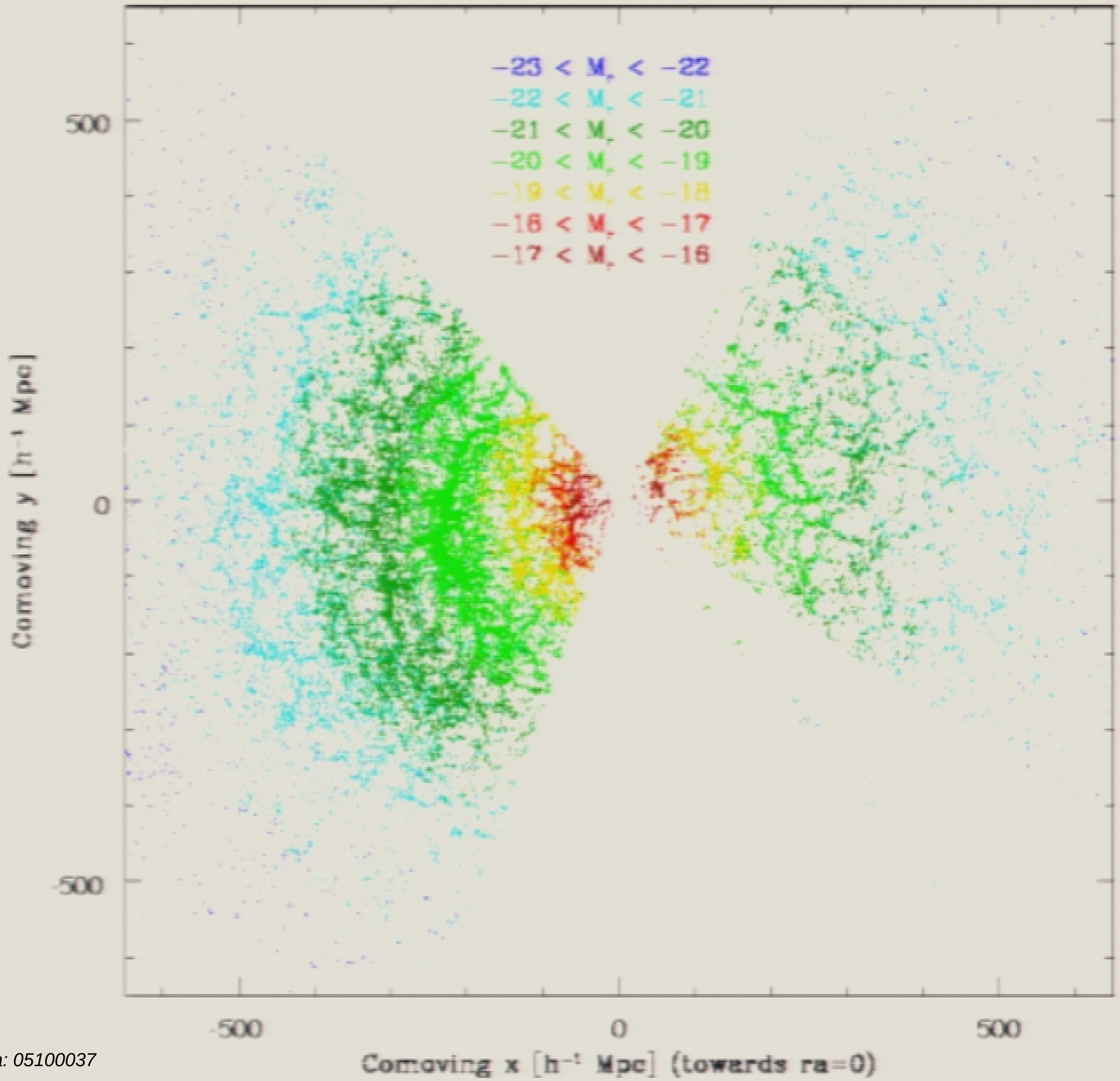
Tegmark et al. 2004

SDSS main galaxy survey



SDSS galaxy-galaxy lensing bias determination

(Seljak, Makarov, Mandelbaum, et al. 2005, PRD, 71, 043511)

$$b^2(k) = \frac{P_{gg}(k)}{P_{dm}(k)}$$

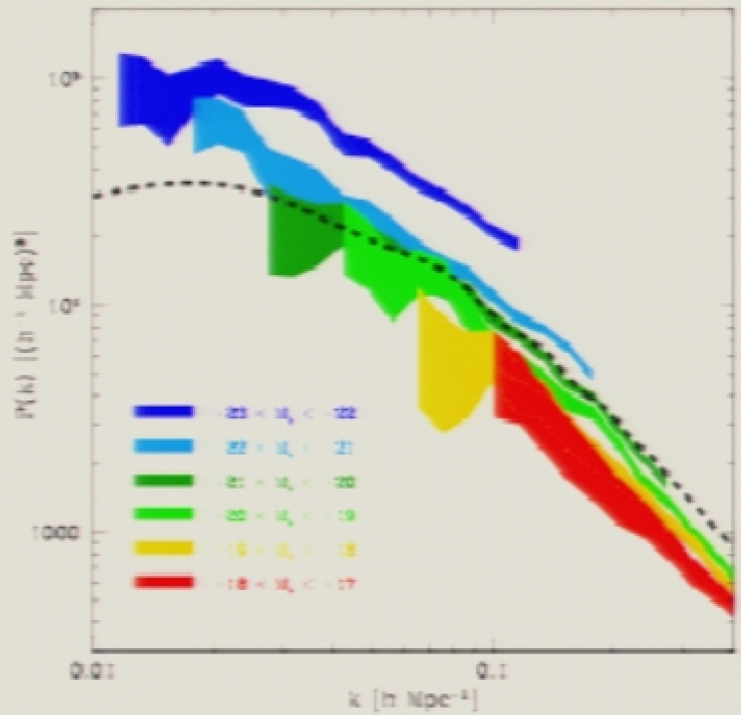
•Galaxies are biased tracers of dark matter; the bias is believed to be scale independent on large scales (k<0.1-0.2/Mpc)

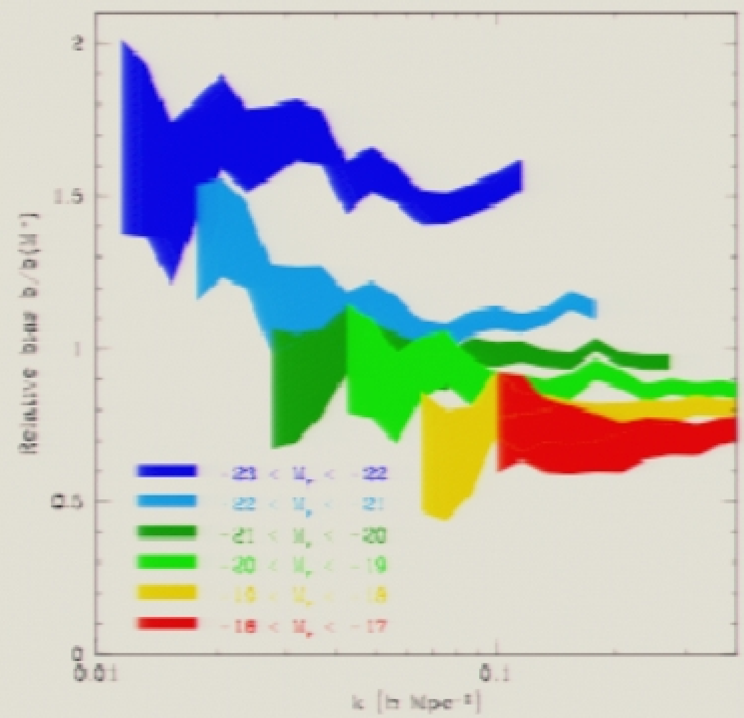
•If we can determine the bias we can use galaxy power spectrum to determine amplitude of dark matter spectrum σ8

•High accuracy determination of σ8 is important for neutrino mass and dark energy constraints

•Existing methods have poor statistics (>10% error)

Galaxy clustering: luminosity dependence of linear amplitude





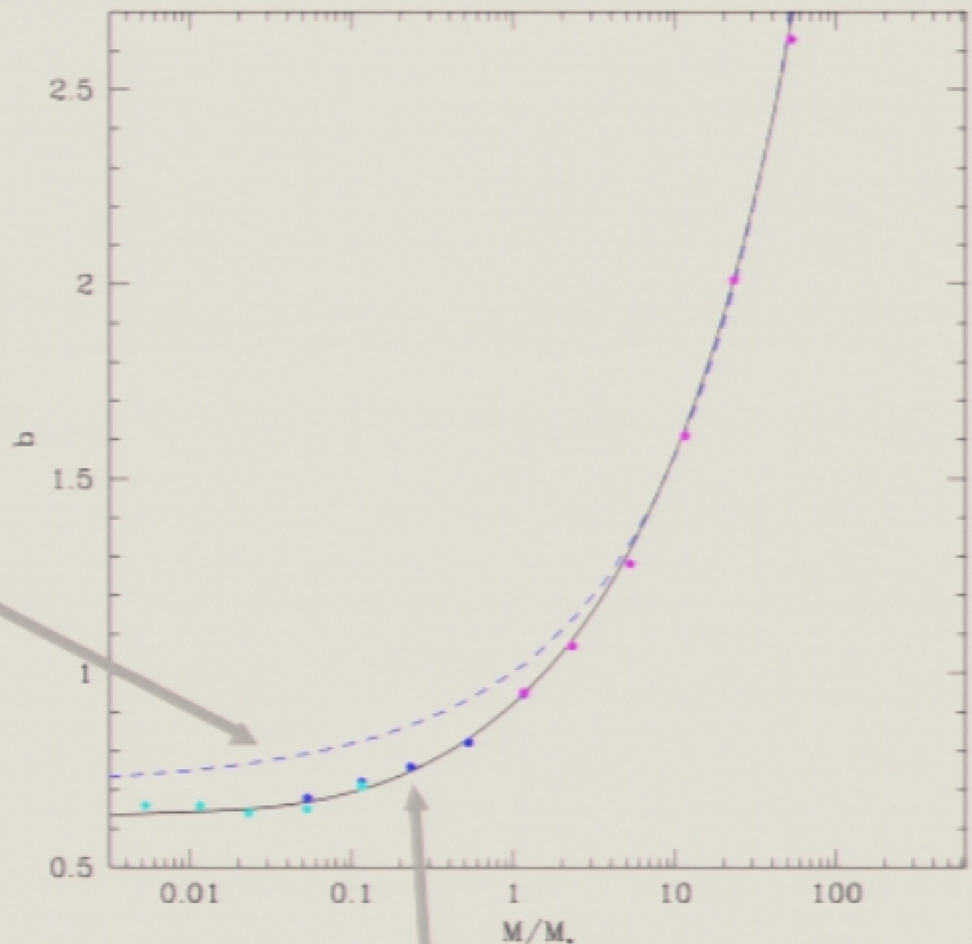
Bias relative to L* changes from 0.75 to 1.7 (Tegmark etal 2004), in agreement with previous attempts at smaller scales (Norberg etal, Zehavi etal)

Halo bias as a function of halo mass

High mass halos strongly biased

Low mass halos antibiased, b=0.7

Theory is in reasonable agreement with simulations (Sheth and Tormen 1999; Jing 1999, Seljak and Warren 2004)



Seljak and Warren 2004

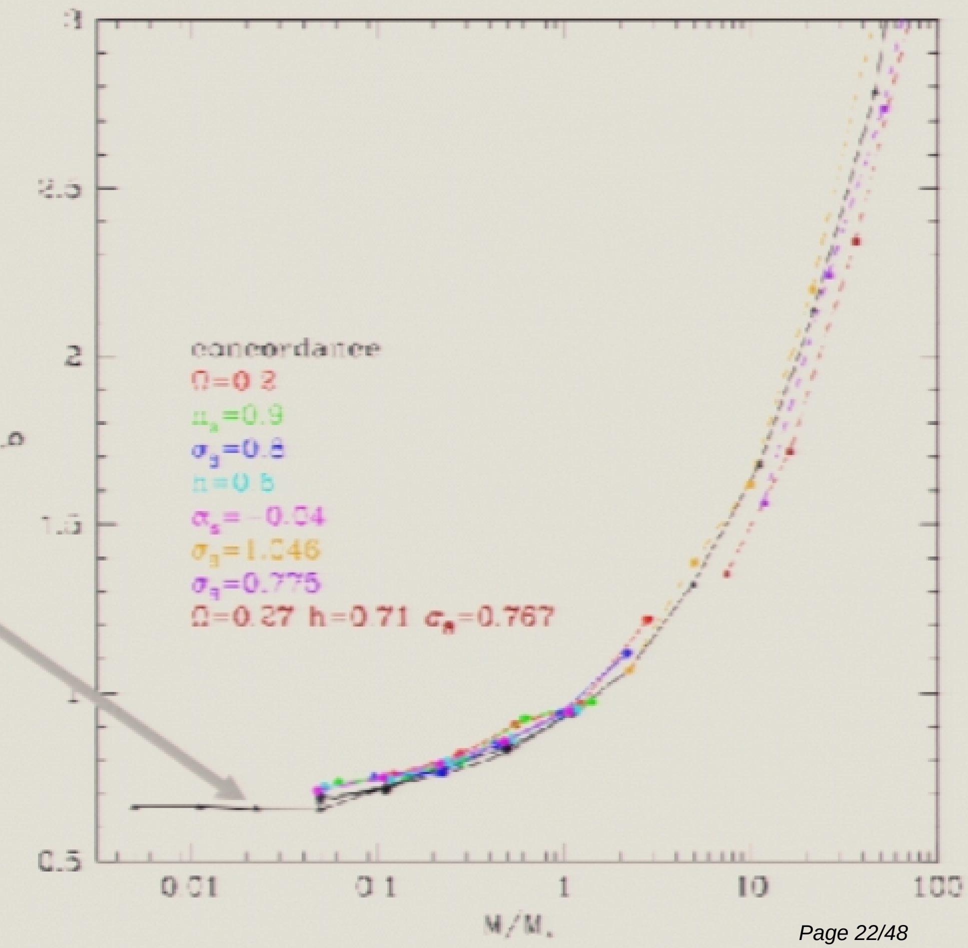
Bias mass relation is nearly universal if mass is in units of nonlinear mass (mass within the sphere with rms 1.68)

Nonlinear mass grows with amplitude of power spectrum and matter density

If we could establish halo clustering at low mass end we would have determined the amplitude of fluctuations (cf lensing)

We do not observe halos, but galaxies

Seljak and Warren 2004



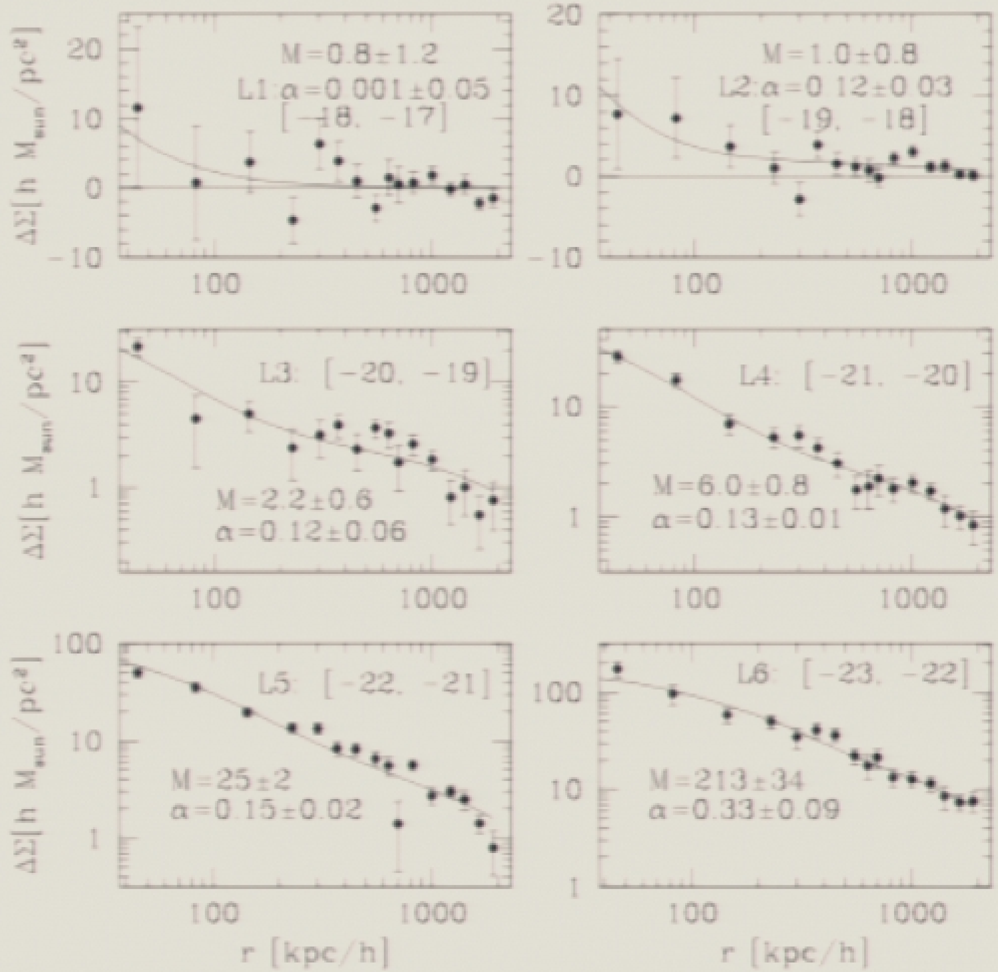
halo mass probability distribution p(M;L) from galaxy-galaxy lensing

Goal: lensing determines halo masses (in fact, full mass distribution, since galaxy of a given L can be in halos of different mass)

If halo mass is low compared to nonlinear mass bias is less than one, otherwise more than one…

Halo model: galaxies can be halo hosts or satellites (Guzik and Seljak 2002), parametrized as the halo mass of central component and fraction of galaxies that are non-central

G-g lensing least model dependent, but used to have poor statistics, no longer the case



Seljak etal 2004

Bias determination

$$b(L) = \int b(M)\, p(M;L)\, dM$$

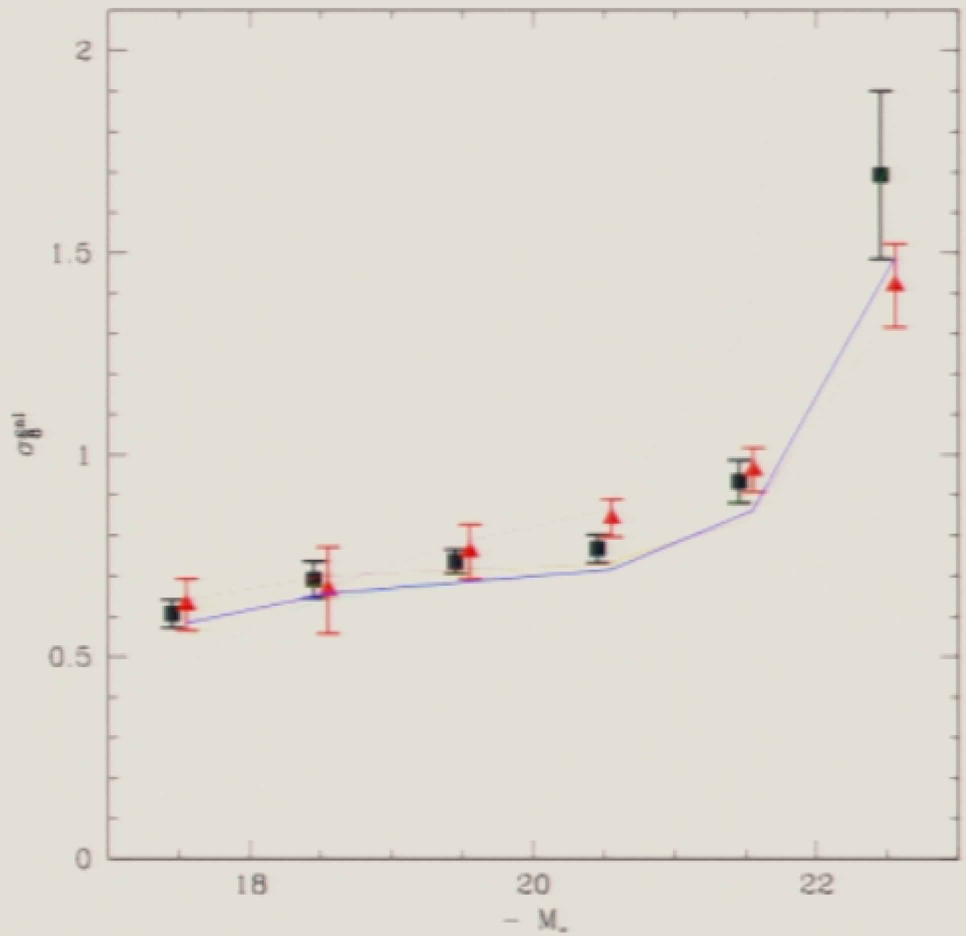
For any cosmological model we can determine b(L) from above

Theoretical halo bias is confirmed!

We also measure b(L) from galaxy clustering

Only cosmological models where the two constraints agree are acceptable

Robust: 20% error in lensing gives only 0.03 error in bias

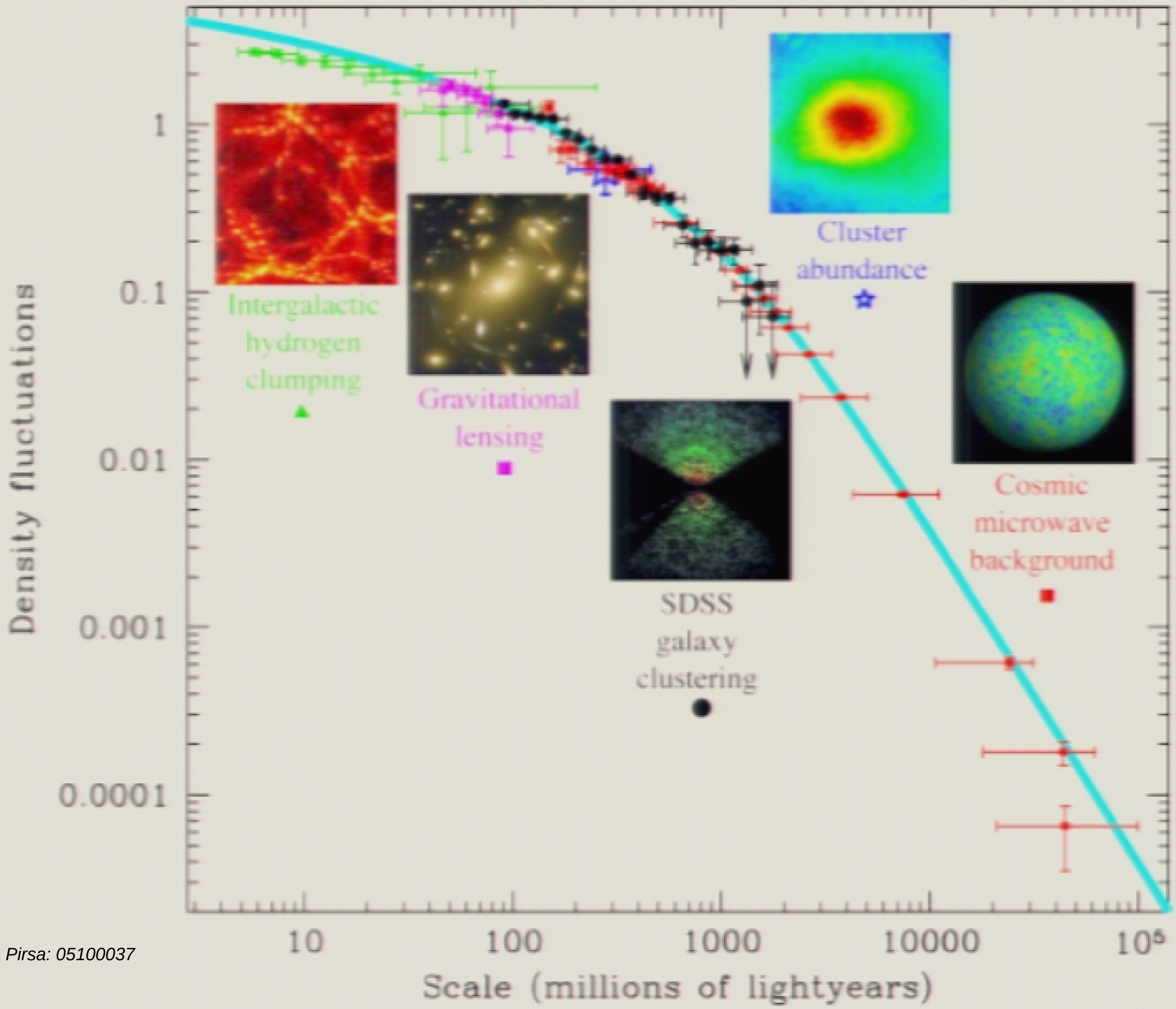


SDSS Lyman-alpha forest

(McDonald, et al. 2005, ApJ, in press, astro-ph/0405013 and astro-ph/0407377)

- 3300 quasars
- $2.1<z<4.3$
- Chi^2 code (input linear power at z=3, output LyaF chi^2)
  - http://www.cita.utoronto.ca/~pmcdonal/code.html

Scales of various LSS probes



The Lyα forest is great for determining the running of the spectral index, $\alpha \equiv \frac{dn}{d\ln k}$, because it extends our knowledge to small scales

We only report an amplitude and slope *no band powers*

(figure by Max Tegmark)

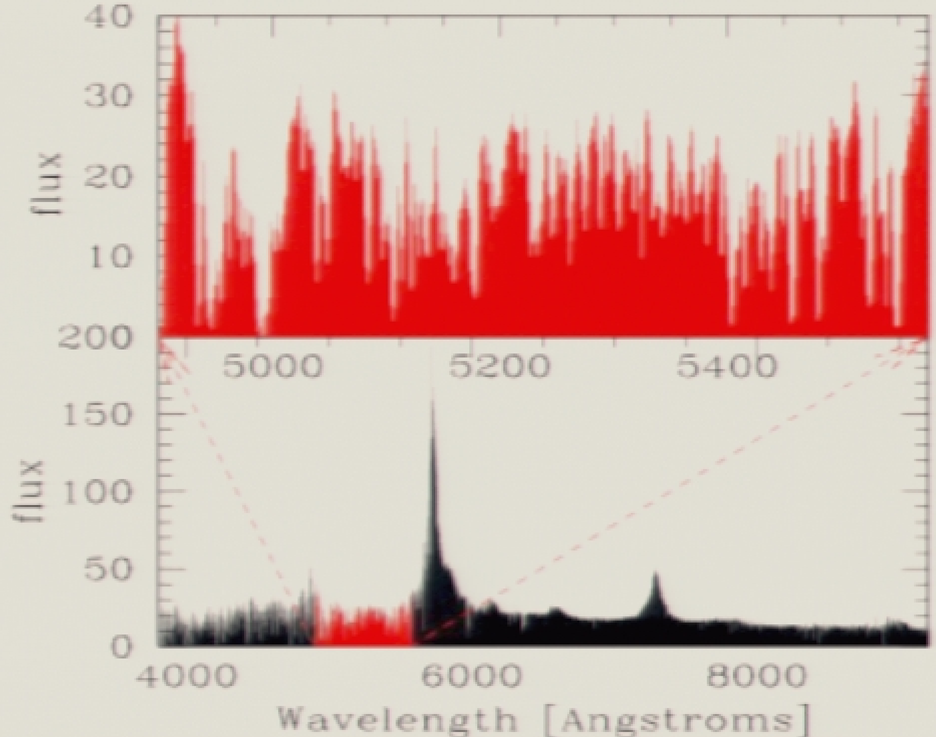
What can we learn from Ly-alpha?

- Dark matter fluctuations on relatively small (few Mpc) scales: amplitude, slope, curvature of the linear power spectrum
- Growth of fluctuations over $2<z<4$
- More leverage when combined with the CMB
- Improve neutrino mass limits, and cosmological parameters in general

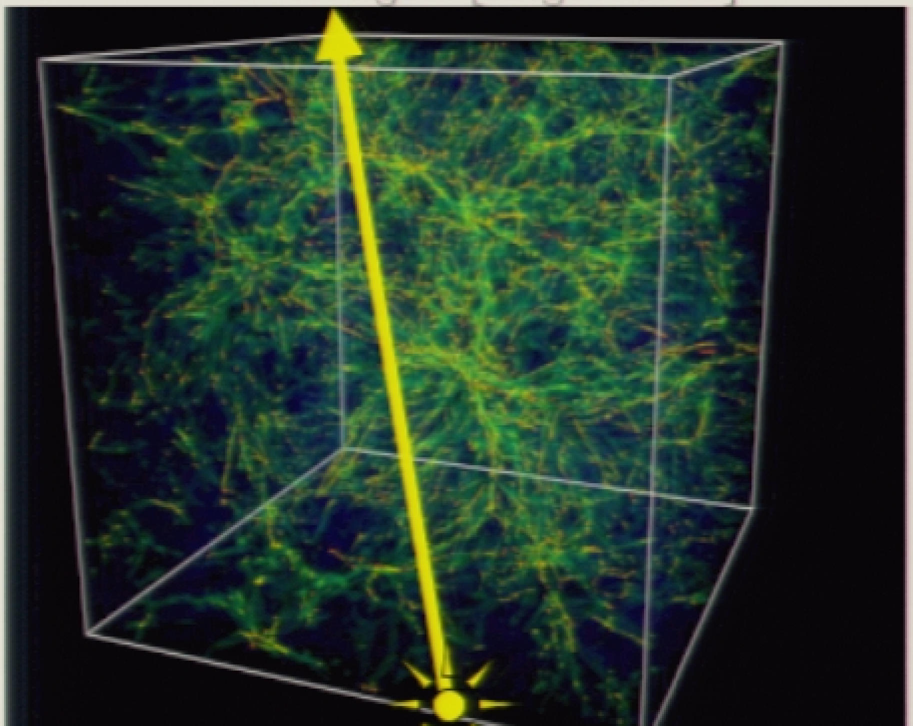
The Lyman-α forest is the Lyα absorption by neutral hydrogen in the intergalactic medium (IGM) observed in the spectra of high redshift quasars

Ly-alpha forest

SDSS quasar spectrum



Cen simulation of the IGM (neutral hydrogen)



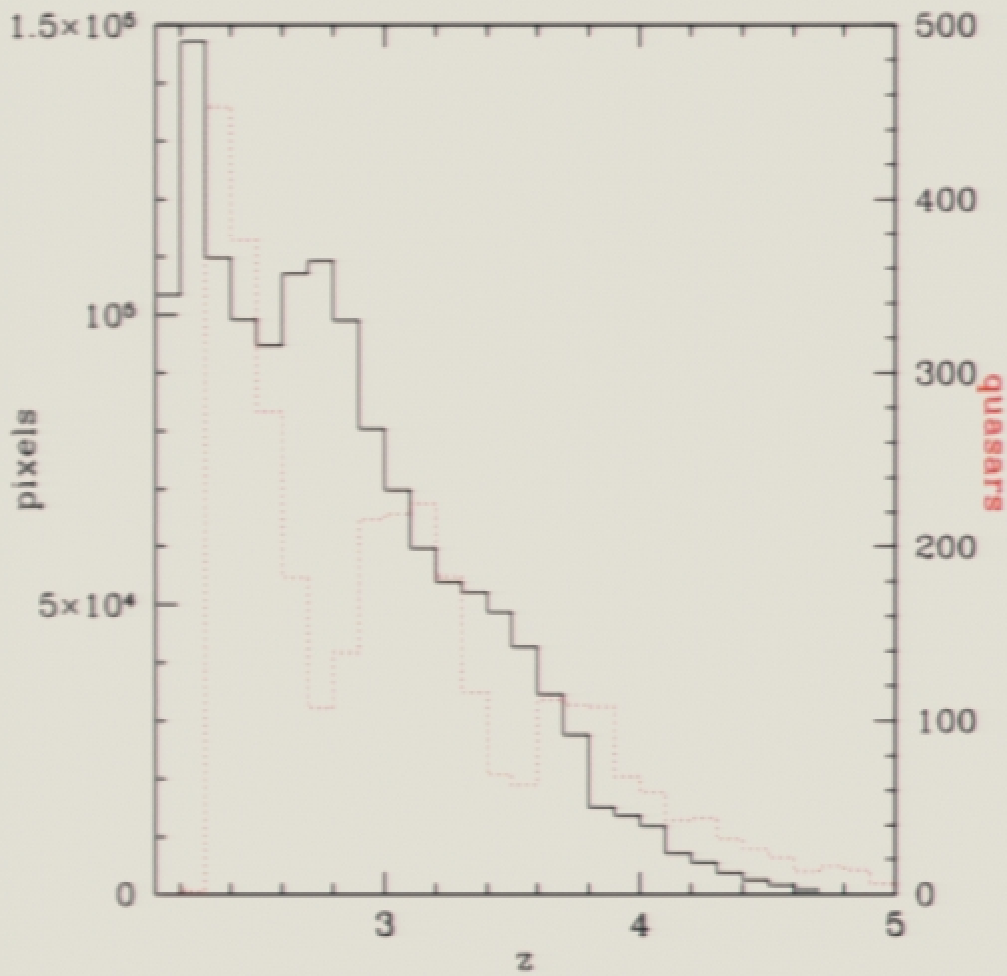
z = 3.7 quasar

Absorption by gas at redshift z appears in a quasar spectrum at wavelength

$$\lambda_{\text{observed}} = \lambda_{\alpha}(1 + z_{\text{gas}})$$

$$\lambda_{\alpha} = 1216\ \text{Å} = 121.6\ \text{nm}$$

SDSS Data



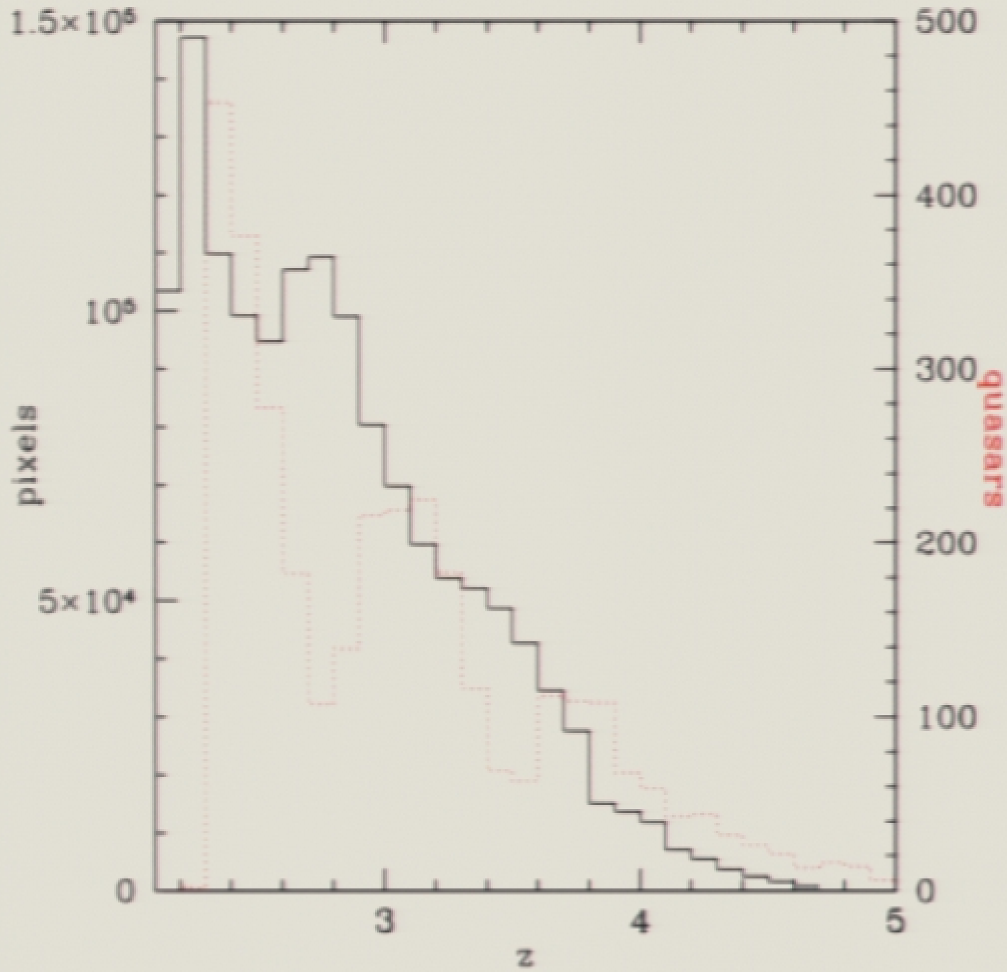
3300 spectra with z_{qso}>2.3

.... redshift distribution of quasars

1.4 million pixels in the forest

—— redshift distribution of Lyα forest pixels

SDSS Data



3300 spectra with $z_{qso}>2.3$

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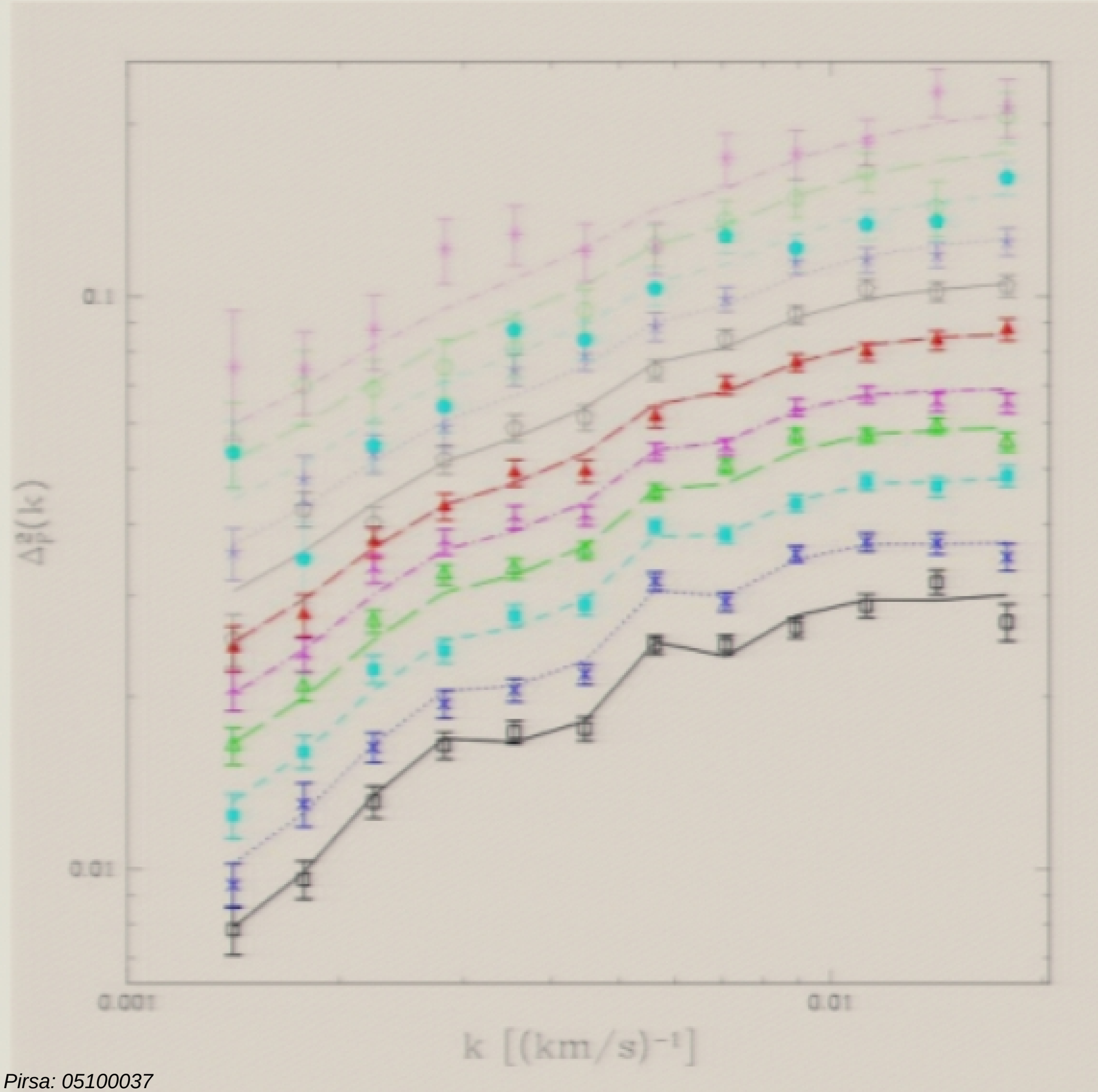
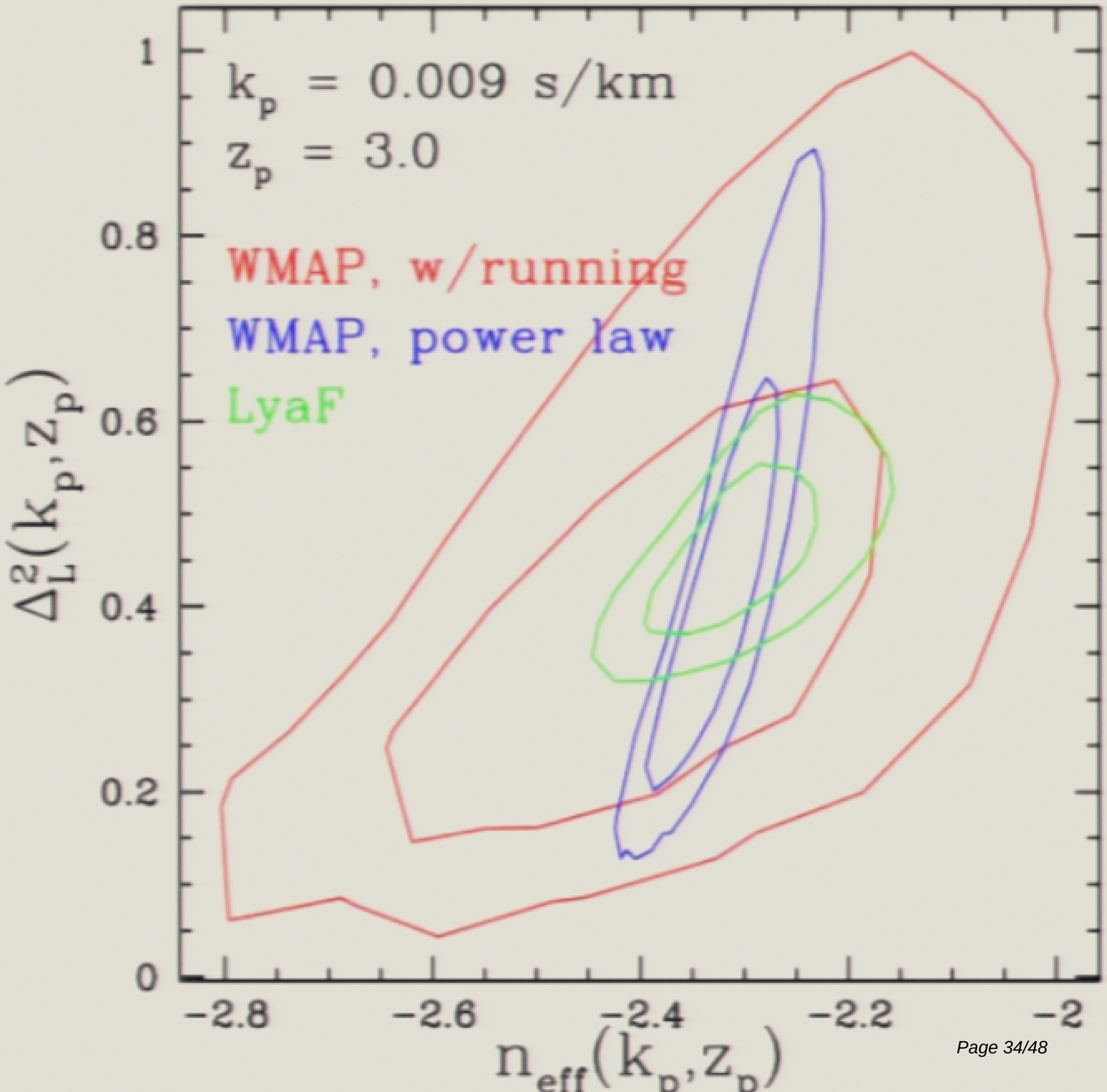


Ly-alpha forest power

- $\Delta^2(k) = \pi^{-1} k P(k)$ (0.01 s/km ~ 1 h/Mpc)
- Colors correspond to redshift bins centered at z = 2.2, 2.4, …, 4.2 (from bottom to top)
- $1041 < \lambda_{rest} < 1185$ Å
- Computed using optimal weighting
- Noise subtraction
- Resolution correction
- Background subtraction using regions with $\lambda_{rest} > 1268$ Å
- Error bars from bootstrap resampling
- Code tested on semi-realistic mock spectra
- HIRES/VLT data probes smaller scales

Constraints in the natural LyaF plane from WMAP, minimal model, with and without running



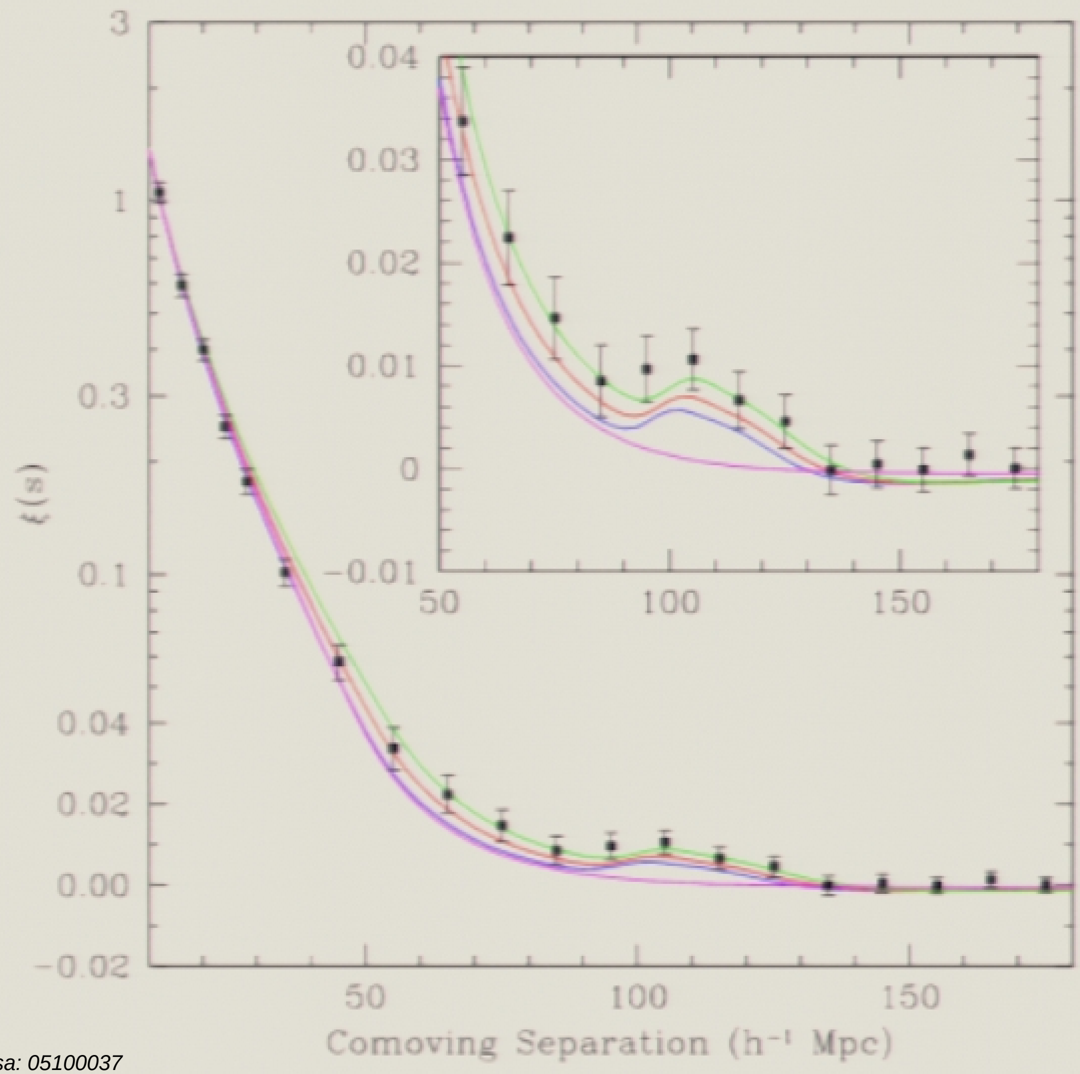
LRGs (Luminous Red Galaxies)

(Eisenstein, Zehavi, Hogg, et al. 2005, astro-ph/0501171)

- Measure baryon acoustic oscillation scale
- 46748 galaxies
- 3816 square degrees
- $0.16<z<0.47$
- 0.72 (Gpc/h)^3
- http://cmb.as.arizona.edu/~eisenste/acousticpeak/

Large-scale Correlations

(Eisenstein et al. 2005)



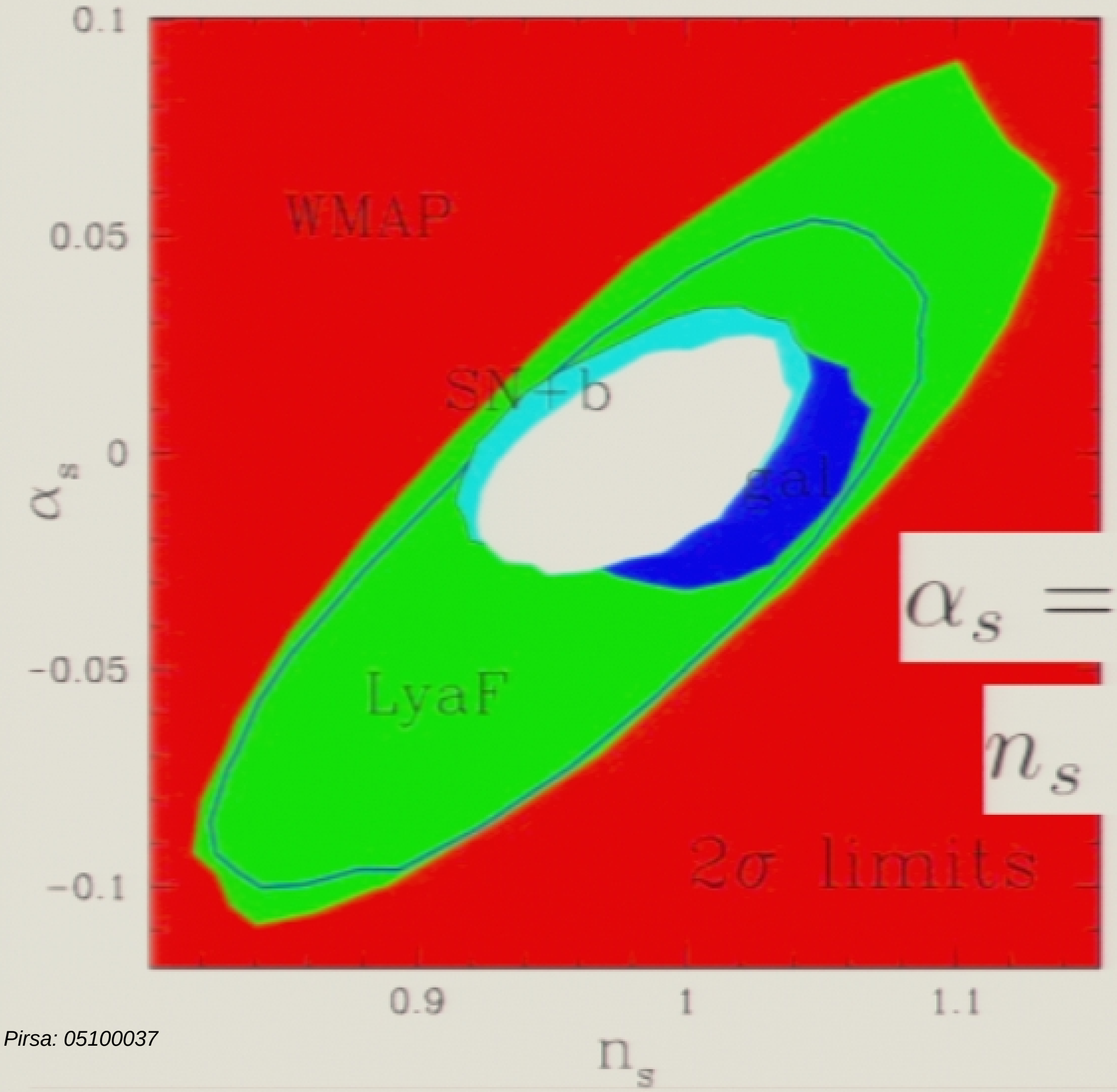
Before recombination:

–Universe is ionized, Photon pressure

–Perturbations oscillate as acoustic waves.

–Sound horizon at recombination ~100 Mpc/h

No evidence for departure from scale-invariance n=1, dn/dlnk=0



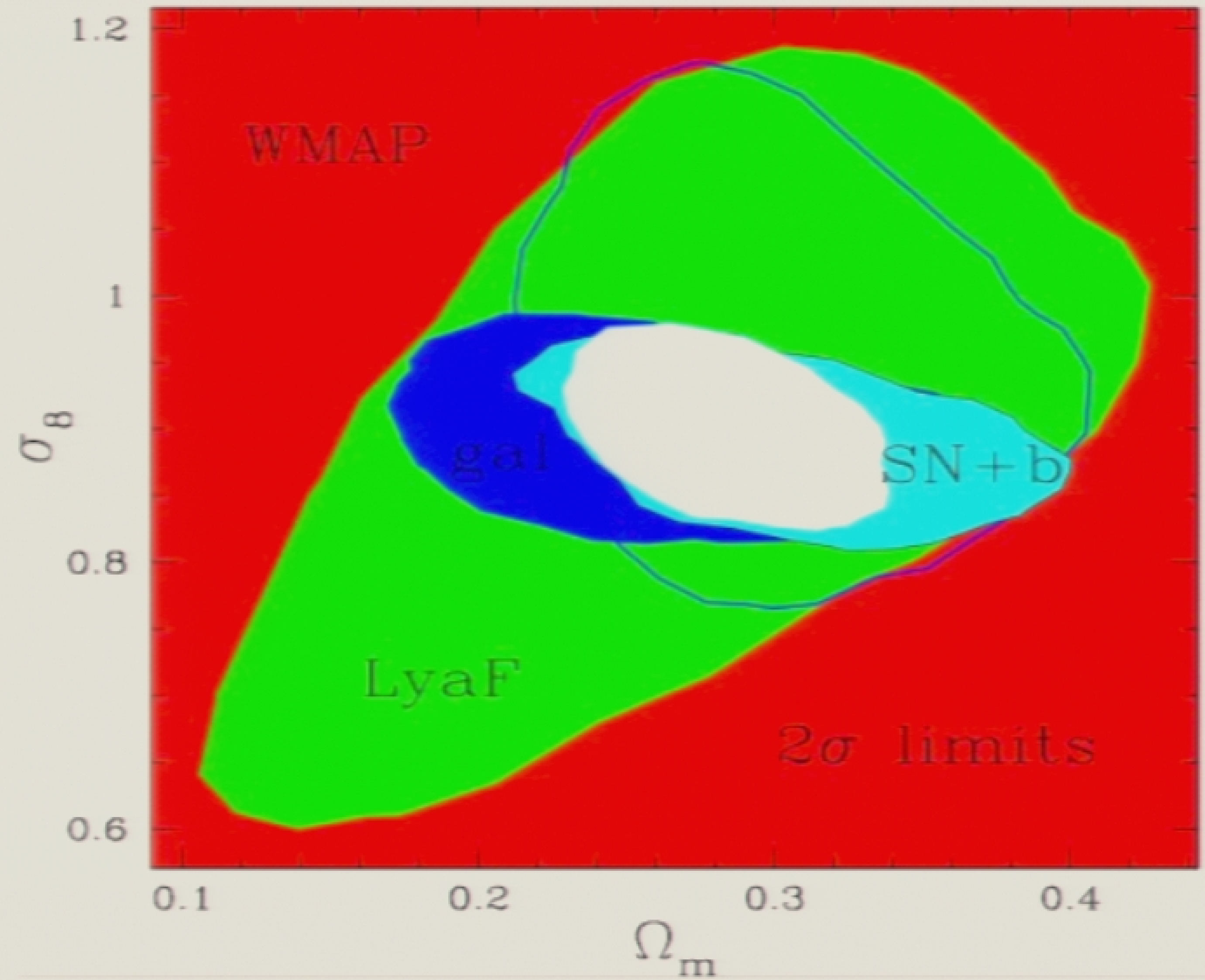
3-fold reduction in errors on alpha_s

Very large running ruled out

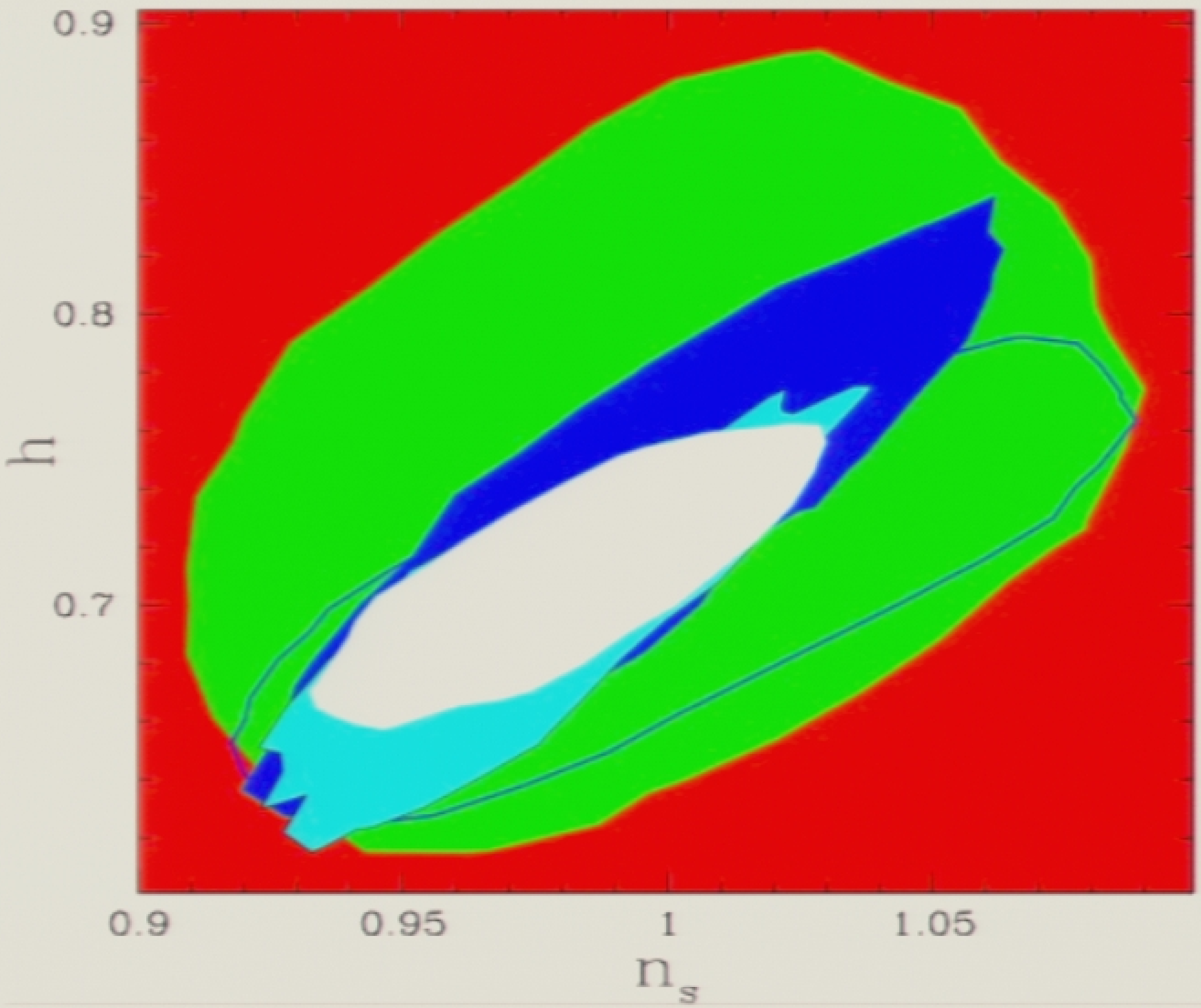
$$\alpha_s = -0.003^{+0.011\ +0.024}_{-0.010\ -0.018}$$

$$n_s = 0.977^{+0.025\ +0.052}_{-0.021\ -0.040}$$

$$\Omega_m = 0.281 \pm 0.022$$
$$\sigma_8 = 0.897 \pm 0.032$$



$$n = 0.980 \pm 0.020$$
$$h = 0.709 \pm 0.021$$



Basic six parameter model

$$\Omega_m = 0.281 \pm 0.022$$

$$\sigma_8 = 0.897 \pm 0.032$$

$$h = 0.709 \pm 0.021$$

$$n = 0.980 \pm 0.020$$

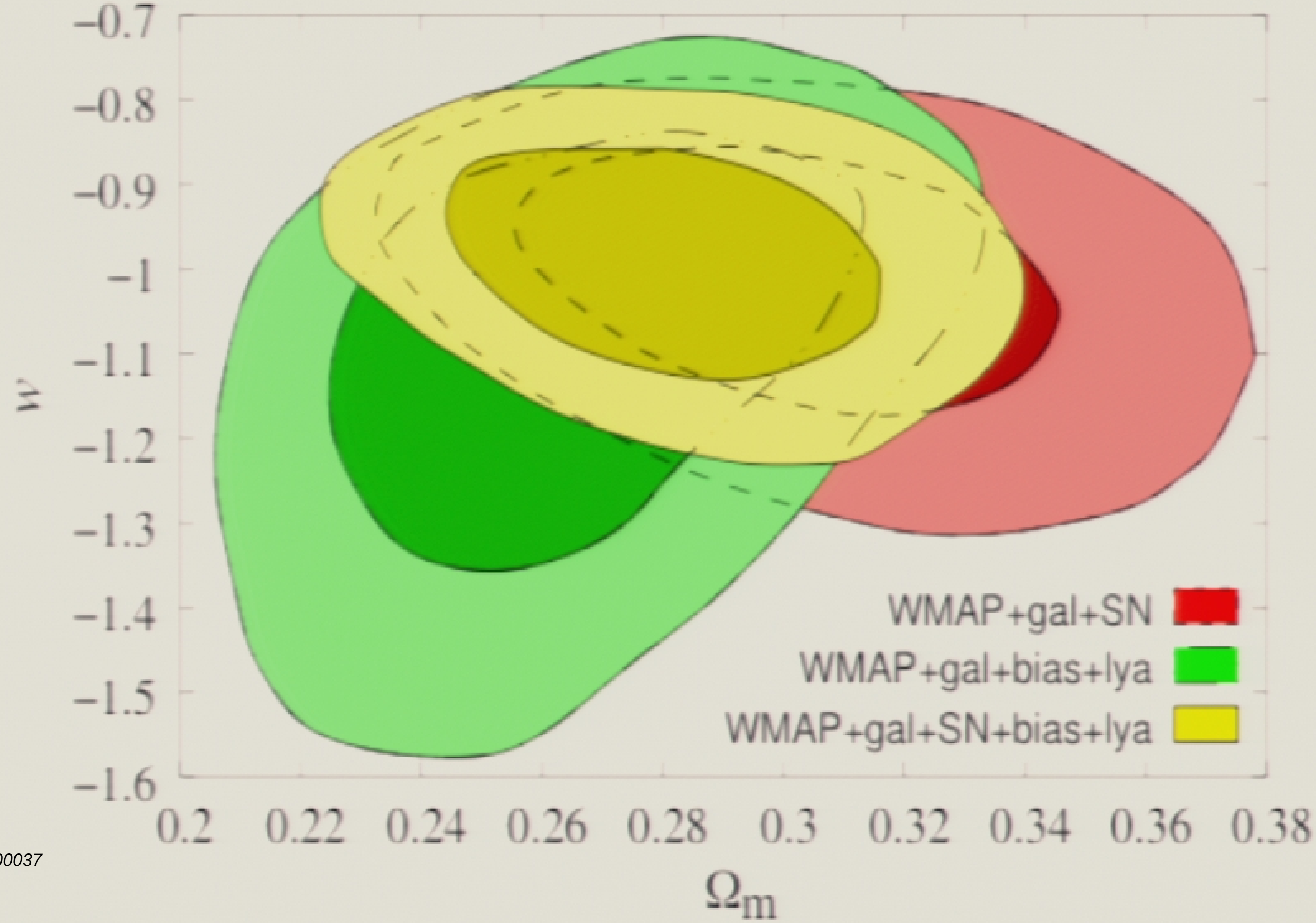
$$\Omega_b h^2 = 0.0233 \pm 0.0009$$

$$\tau = 0.160 \pm 0.041$$

WMAP, Lya, SDSS gal (w/gg lensing determination of bias), SN1a

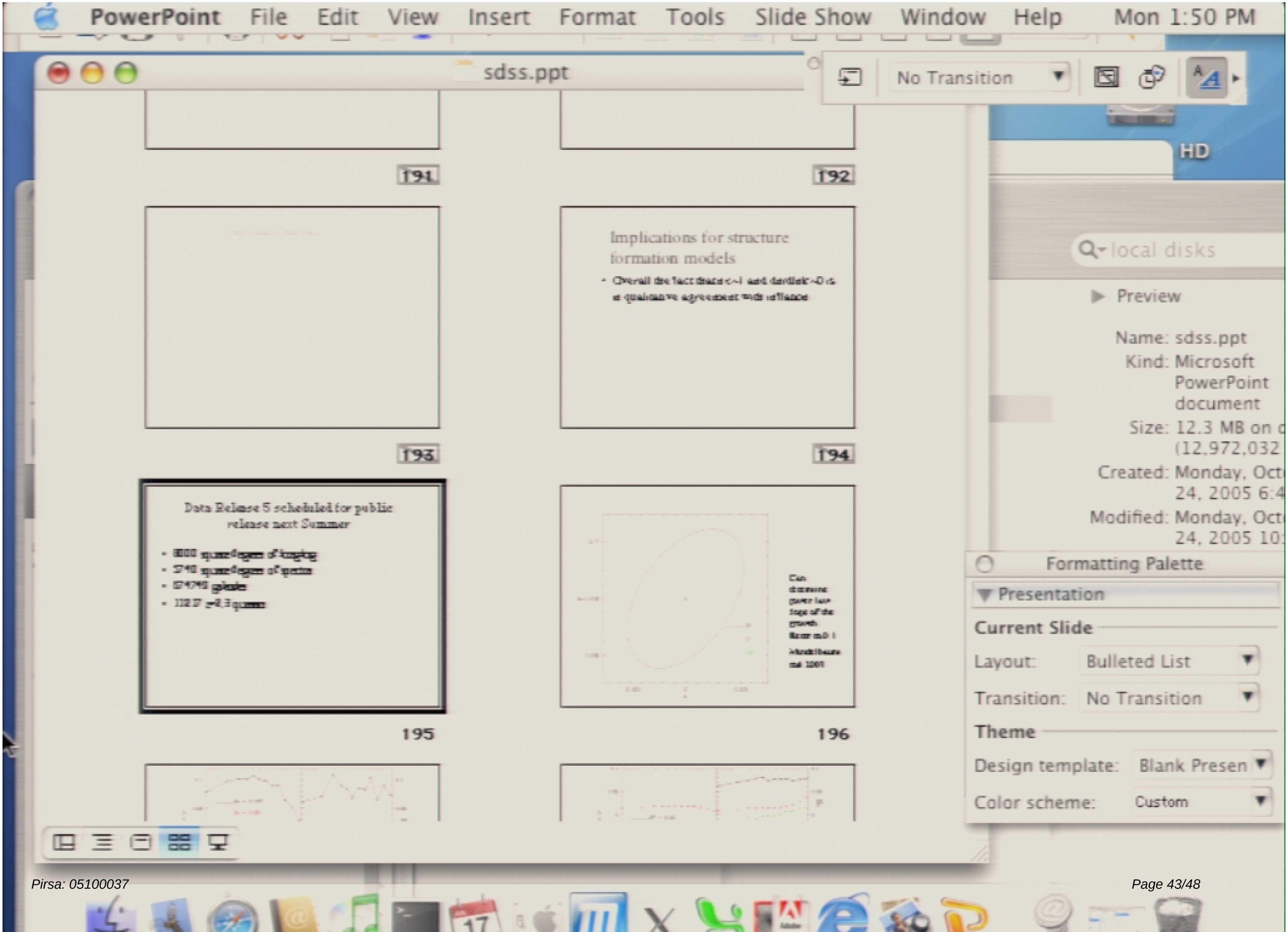
$$w = -0.99 \pm 0.09$$

$$w < -0.85 \ (95\%)$$



Data Release 5 scheduled for public release next Summer

- 8000 square degrees of imaging
- 5740 square degrees of spectra
- 674749 galaxies
- 11217 z>2.3 quasars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Implications for structure formation models
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Data Release 5 scheduled for public release next Summer
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local disks
Preview
Name: sdss.ppt
Kind: Microsoft PowerPoint document
Size: 12.3 MB on
Created: Monday, Oct 24, 2005
Modified: Monday, Oct 24, 2005
Formatting Palette
Presentation
Current Slide
Layout: Bulleted List
Transition: No Transition
Theme
Design template: Blank Presen
Color scheme: Custom

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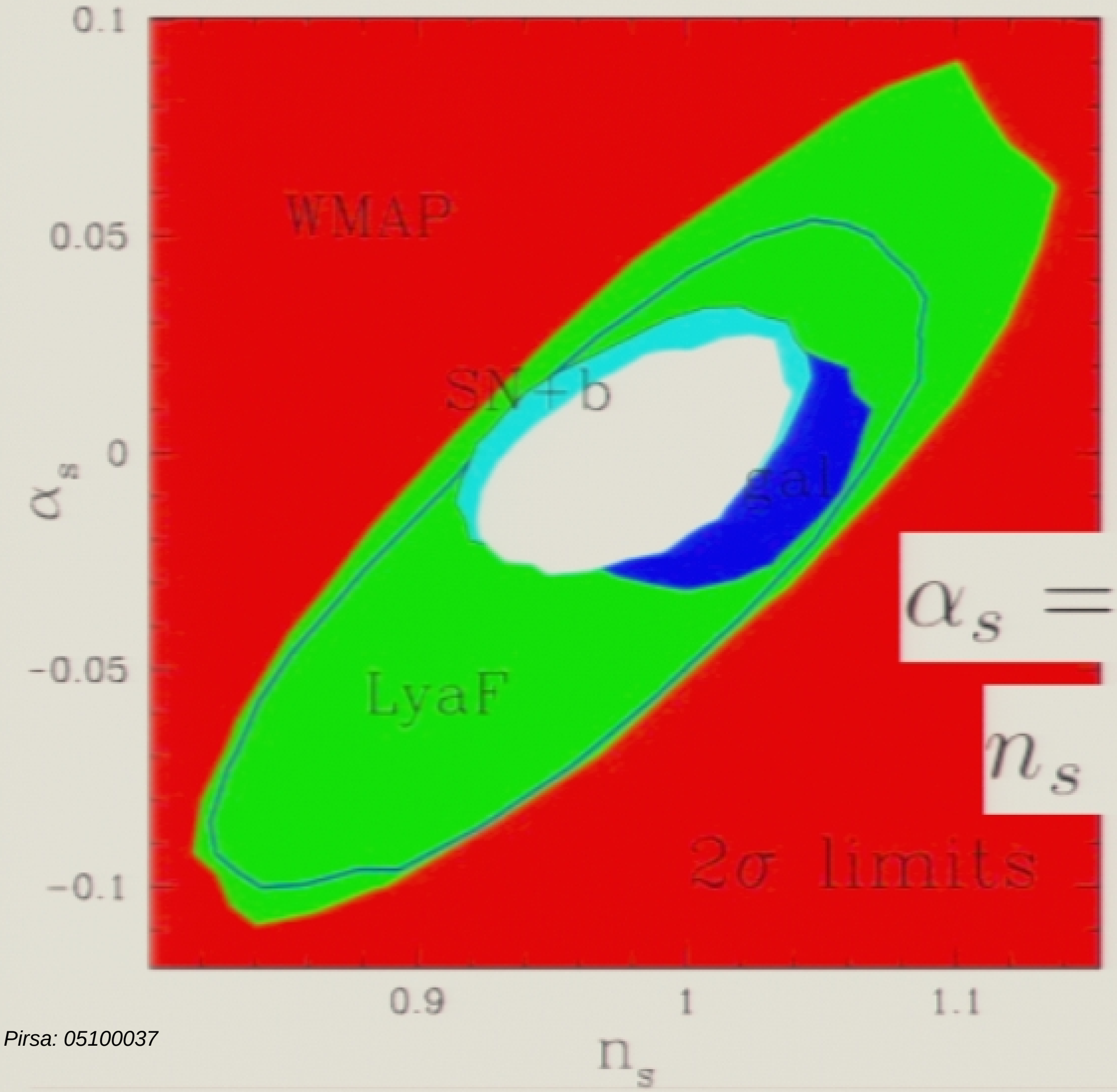

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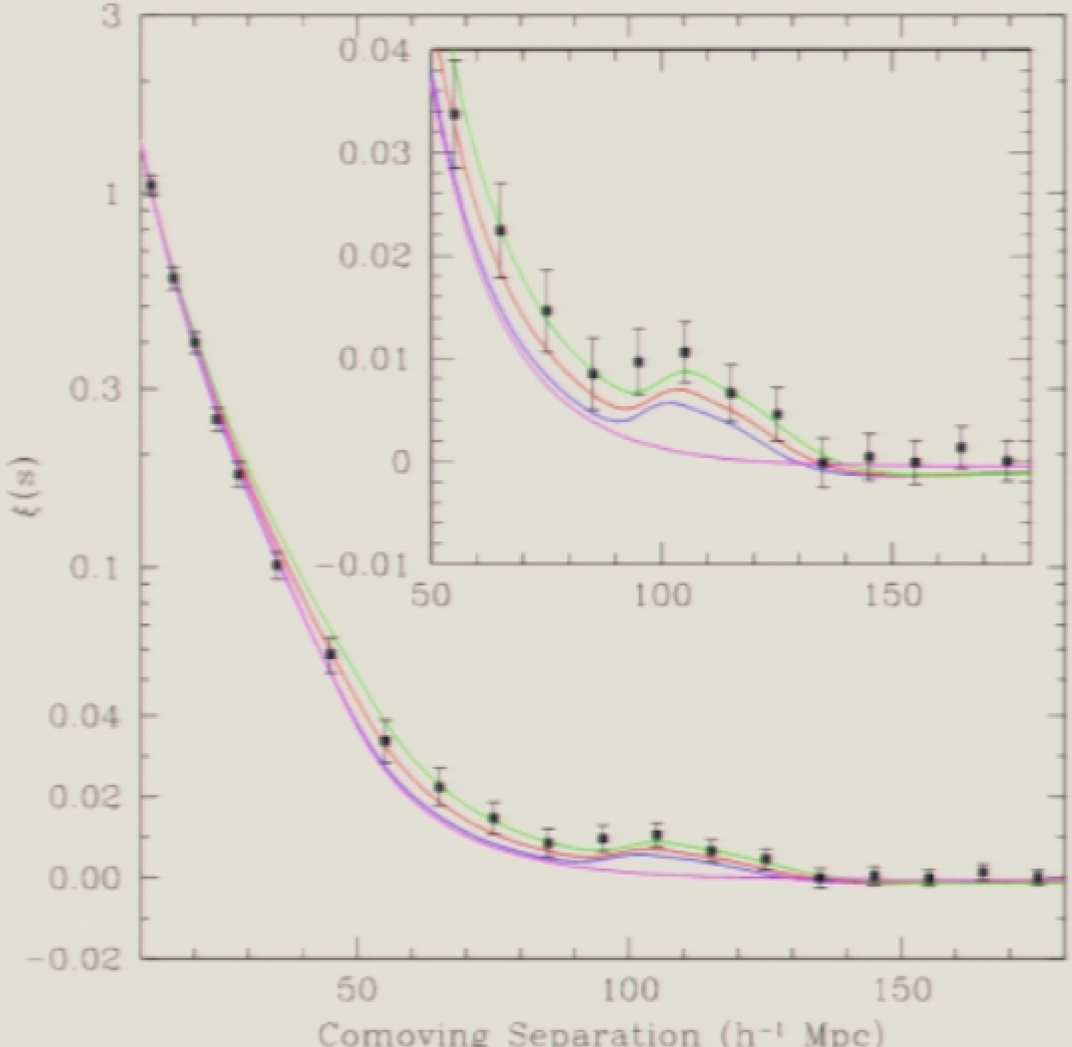
(Eisenstein et al. 2005)



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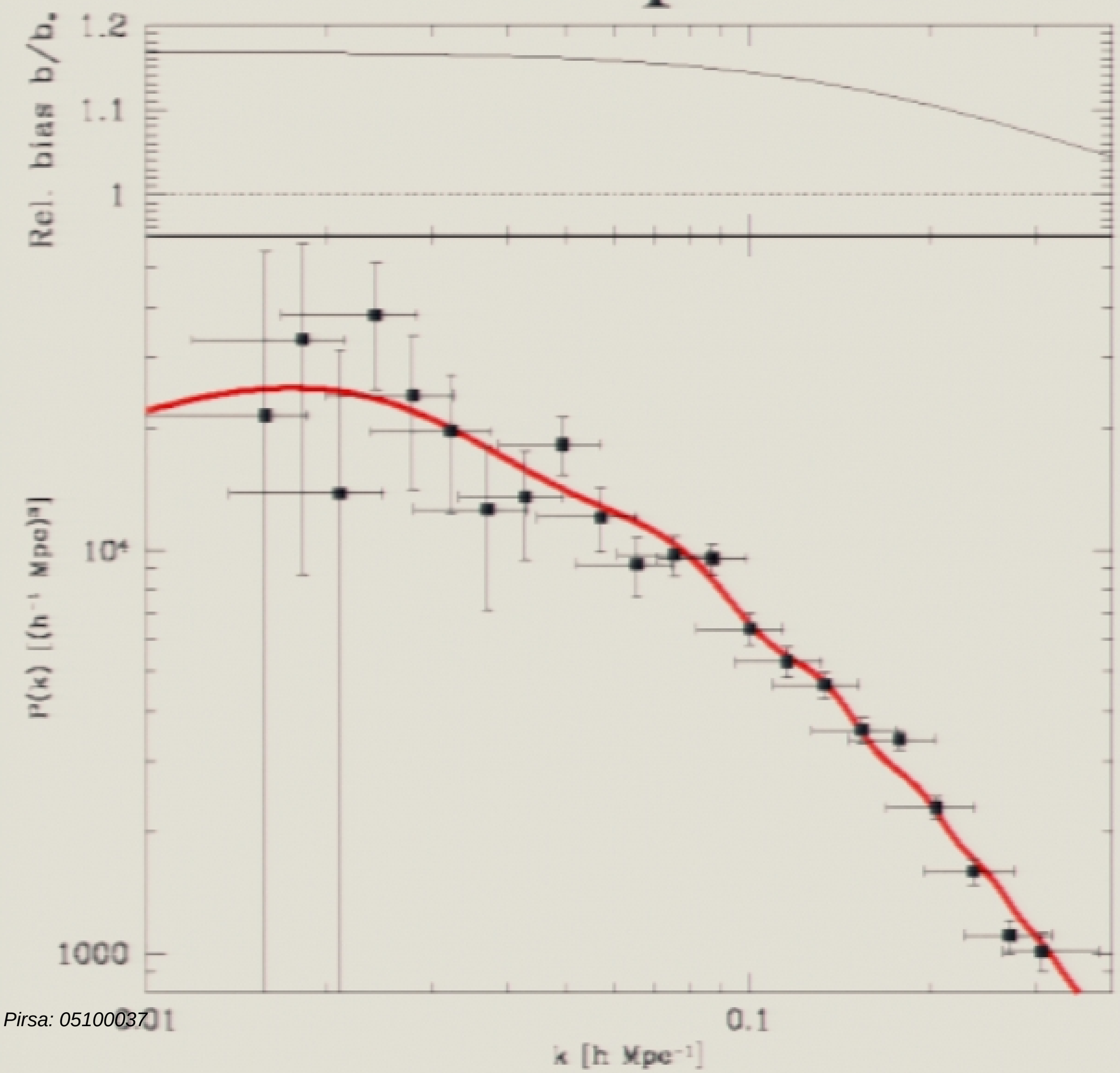

Complications:

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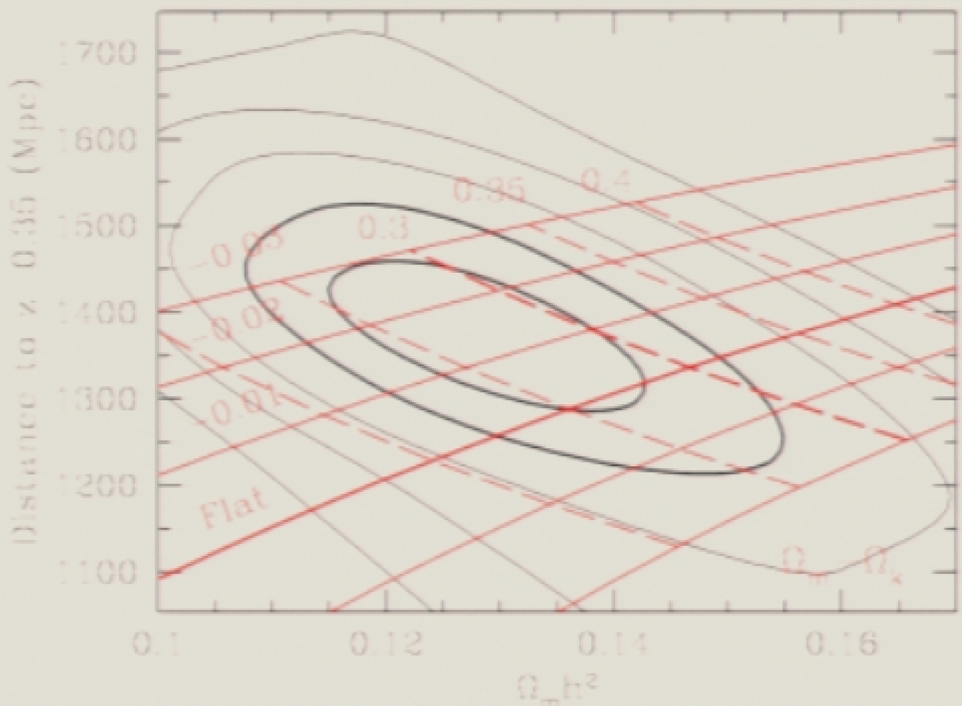
Tegmark et al. 2004

Λ+ Curvature

(Eisenstein et al. 2005)



- Common distance scale to low and high redshift yields a powerful constraint on spatial curvature:

$$\Omega_K = -0.010 \pm 0.009 \quad (w = -1)$$