Large-Scale Structure with Galaxy Clusters

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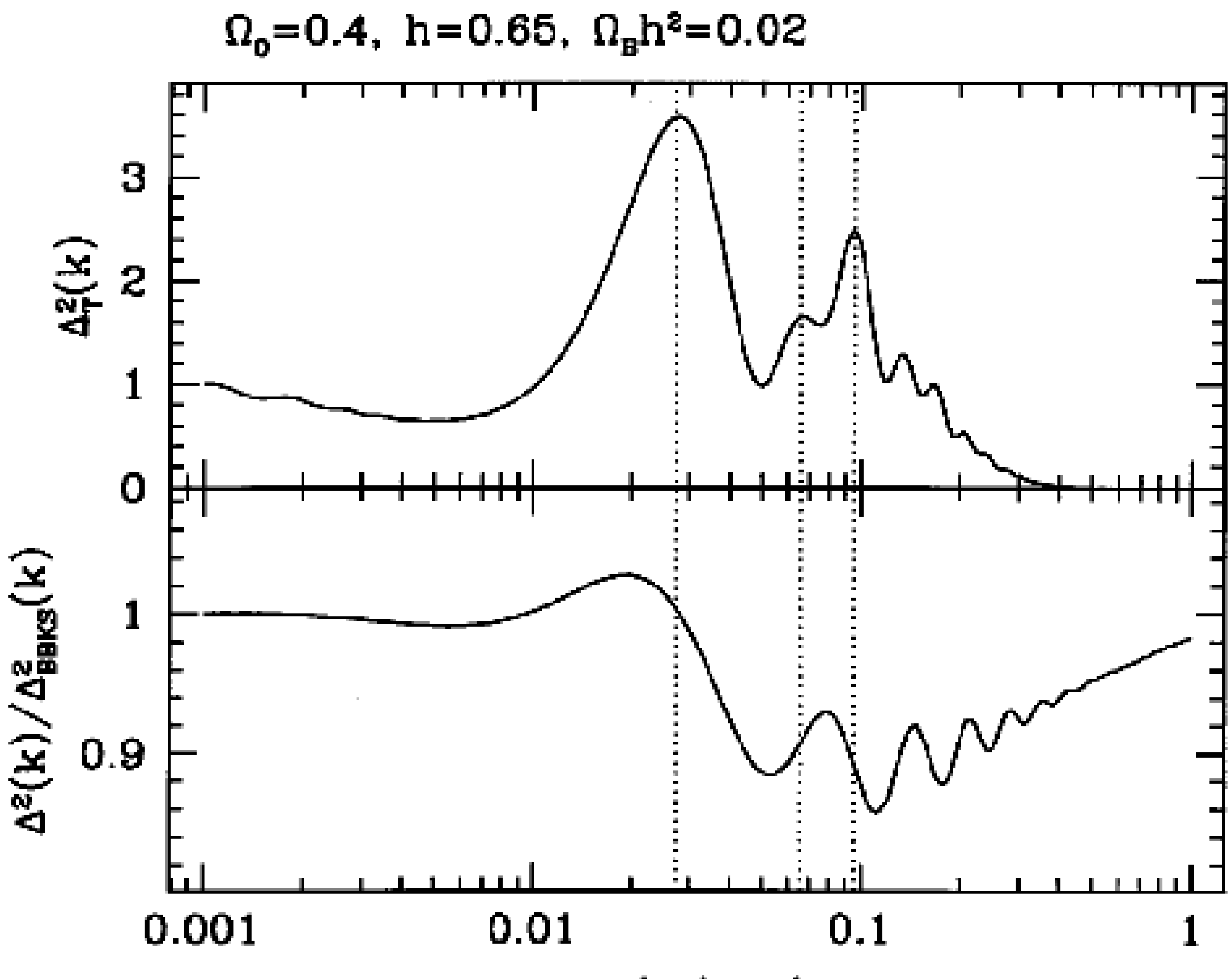
Baryonic Acoustic Oscillations

Simulated Power Spectra of Clusters of Galaxies

Application to Dark Energy

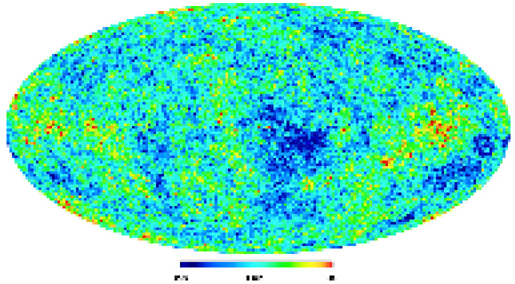
Ringberg - October 2005

Dark Energy with Acoustic Oscillations

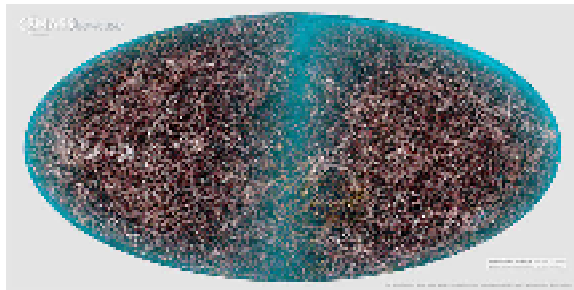


Analytic model: Meiksin, M. White & Peacock (1999)

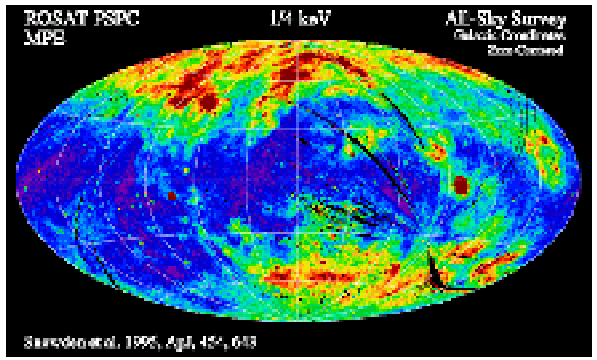
WMAP: CMB T-Anisotropies
Spergel et al. (2003)



2MASS galaxies
Jarret et al. (2002)



RASS: Voges et al. (1999)



Baryonic Acoustic Oscillations: Physics

Metric ruler : sound horizon at drag epoch

$$s = \int_0^{t(z_\mathrm{d})} c_\mathrm{s}\,(1+z)\,dt\,, \qquad c_\mathrm{s} \quad \text{sound speed}$$

Gravitational compression vs. radiation pressure

Velocity fluctuations more important than density fluctuations

$$v_\mathrm{b} \sim C_A(k)\,\sin(kr_s)$$

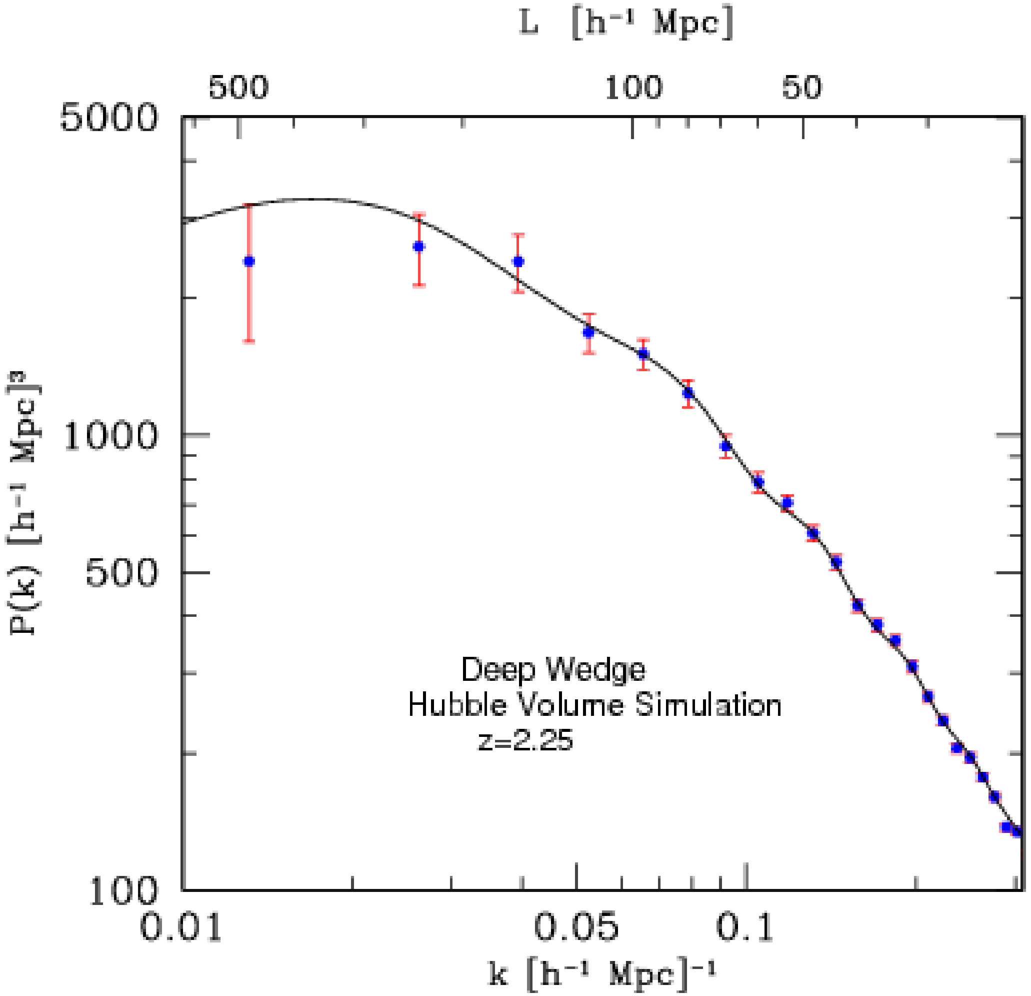
Transfer function , power spectrum , phases

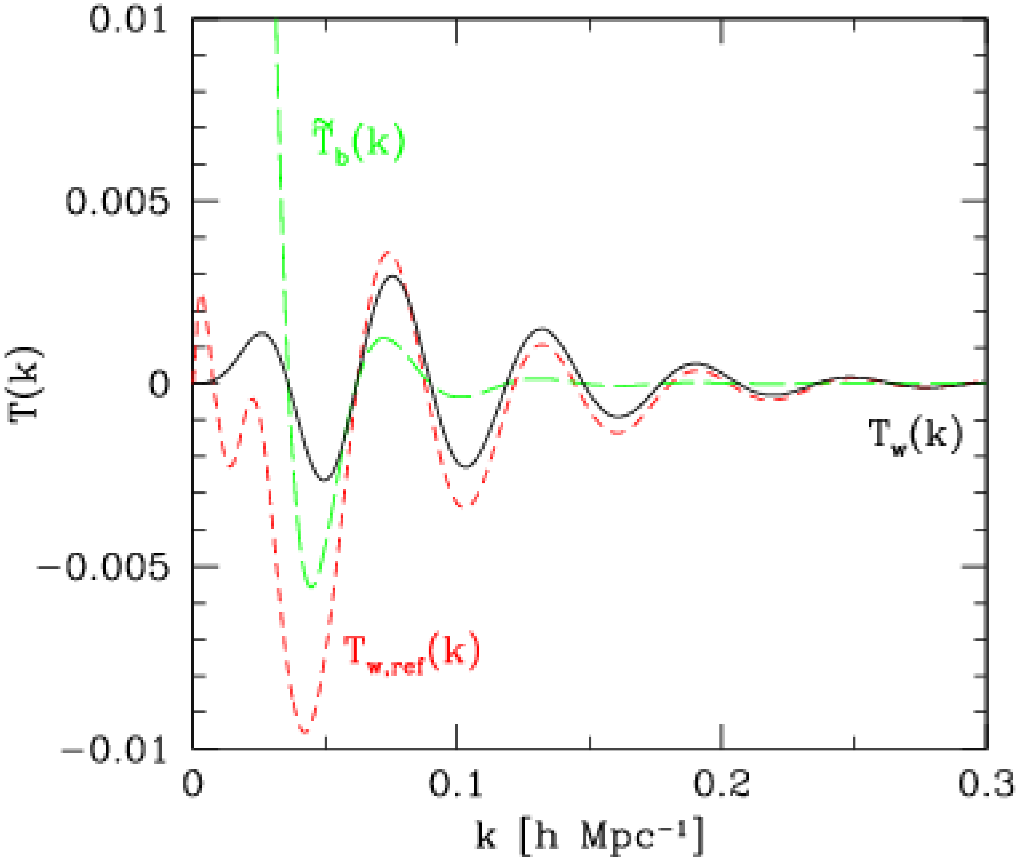
$$T_b \sim \sin(ks)\,, \qquad P(k) \sim k^n\,T^2(k)\,, \qquad k_{\mathrm{b},n}\cdot s(\eta_d) = (n - \frac{1}{2})\pi$$

Silk damping : $T_b(k) \sim \dfrac{\sin(ks)}{ks}\,\mathcal{D}(k)\,, \quad \mathcal{D}(k) = \exp\left(-k/k_\mathrm{Silk}\right)^{m_s}$

Baryonic Acoustic Oscillations: Metric Ruler

$$\sqrt{\frac{P_{\rm obs}(k,z)}{k^n}} - \left[\sqrt{\frac{P_{\rm obs}(k,z)}{k^n}}\right]_{\rm smoothed} = G(k,z)\,\frac{\alpha_{\rm b}\; j_0(k\tilde{s})\, e^{-(k/k_{\rm Silk})^{m_s}}}{1+(\beta_{\rm b}/ks)^3}$$





Baryonic Acoustic Oscillations: Comoving Coordinates

Comoving coordinate $\quad x \sim \int_0^z \frac{dz}{H(z)}$

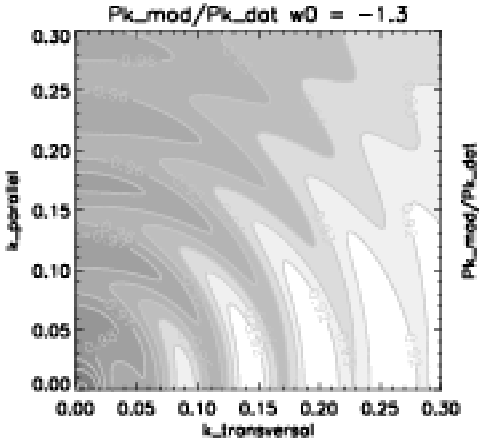
$$H^2(z) \sim \Omega_{\rm m}(1+z)^3 + (1-\Omega_{\rm m})\exp\left\{3\int_0^z [1+w_{\rm DE}(z)]d\ln(1+z)\right\}$$

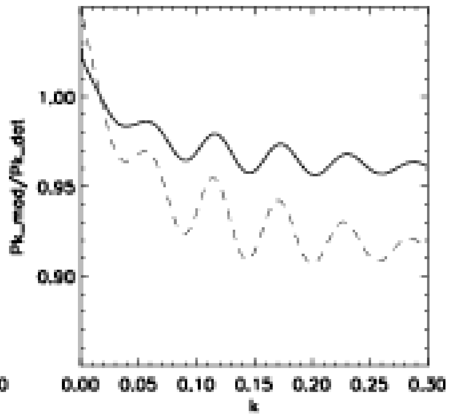
Compare reference cosmology with new cosmology

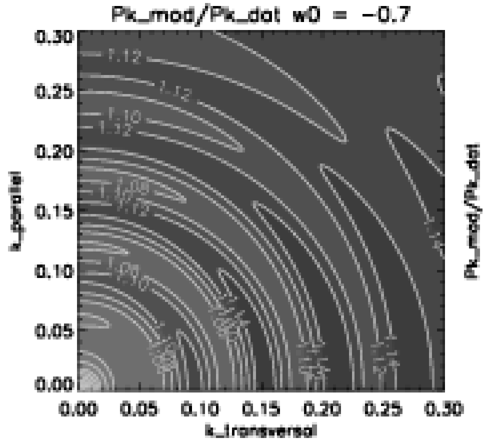
Radial coordinates $\quad x_{\rm rad} = \int_{z_1}^{z_2} \frac{dx}{dz}dz \Rightarrow \quad x'_{\rm rad} = \frac{dx'}{dx}x_{\rm rad}$

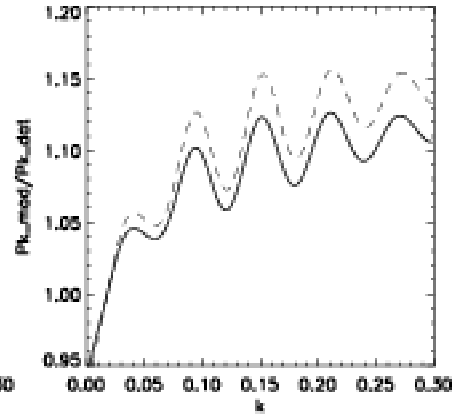
Transversal coordinates $\quad x_{\rm trans} = \theta \int_0^z \frac{dx}{dz}dz \Rightarrow \quad x'_{\rm trans} = \frac{x'}{x}x_{\rm trans}$

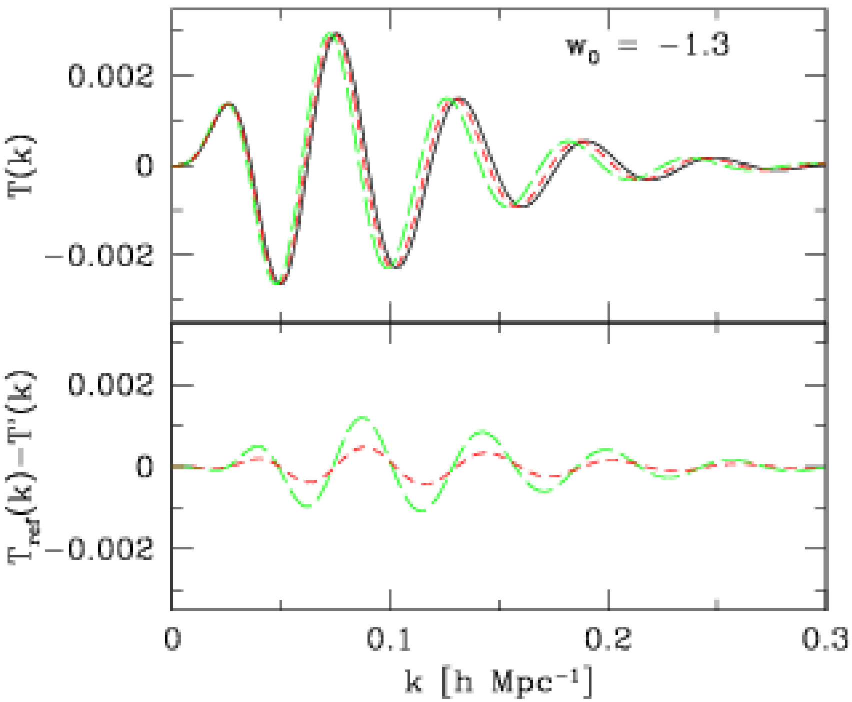
Baryonic Acoustic Oscillations: w Dependency

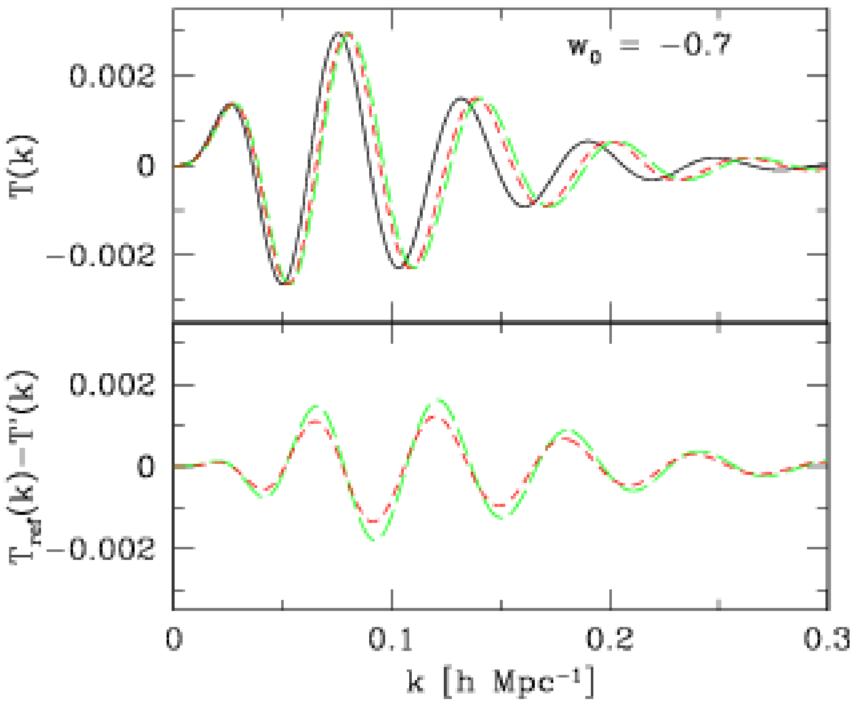




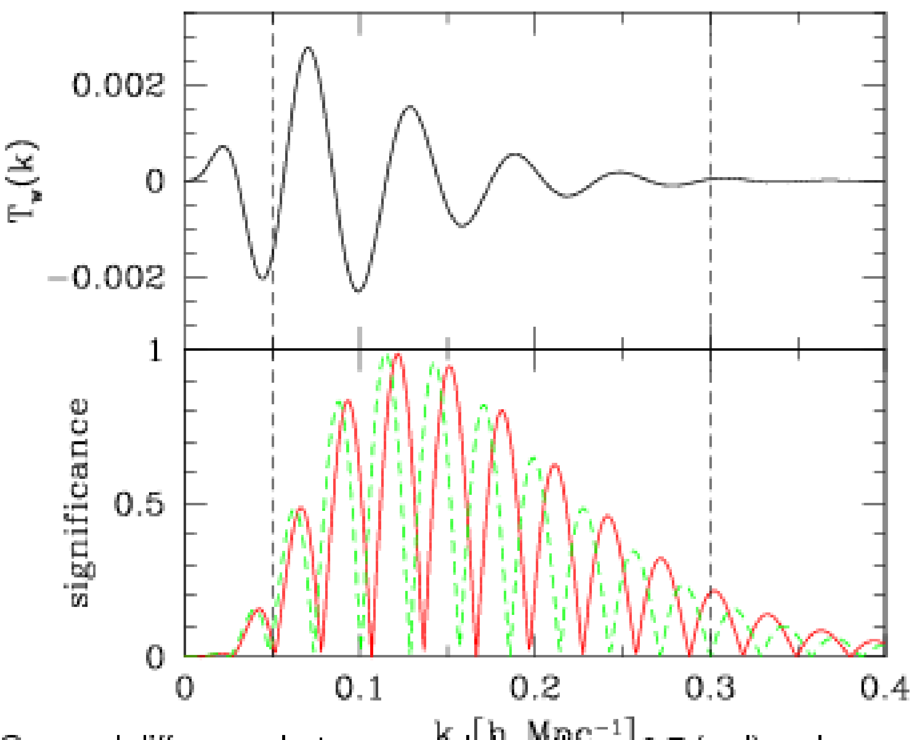




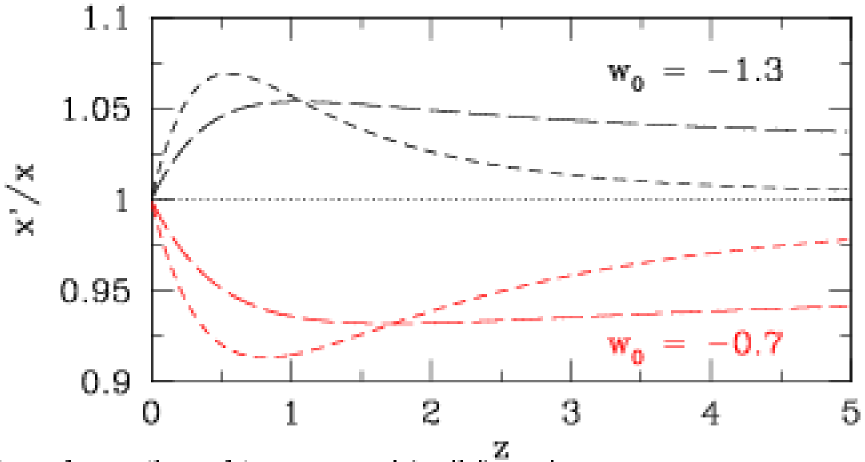




Baryonic Acoustic Oscillations: Highest Sensitivities



Squared difference between models with w=-0.7 (red) and w=-1.2 (green) compared to a cosmological constant.

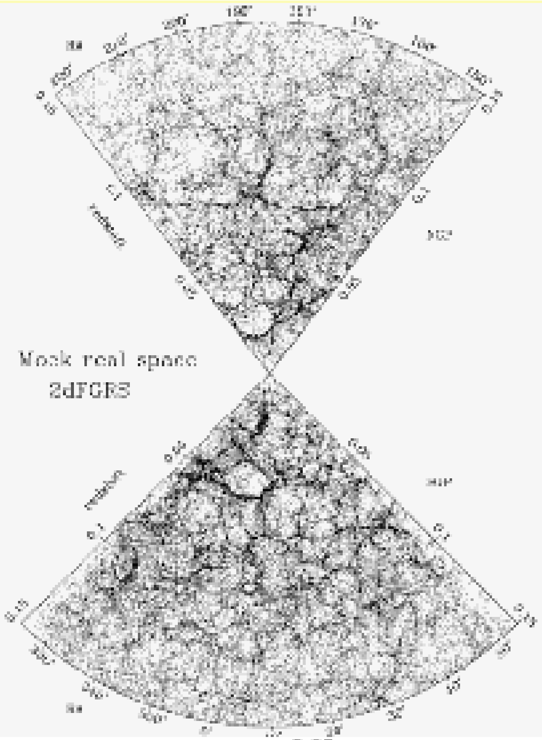


Transformation of transversal (solid) and radial (dashed) distances in comparison to the concordance model

Baryonic Acoustic Oscillations: Real Space vs. Redshift Space

Mock 2dFGRS from Hubble volume

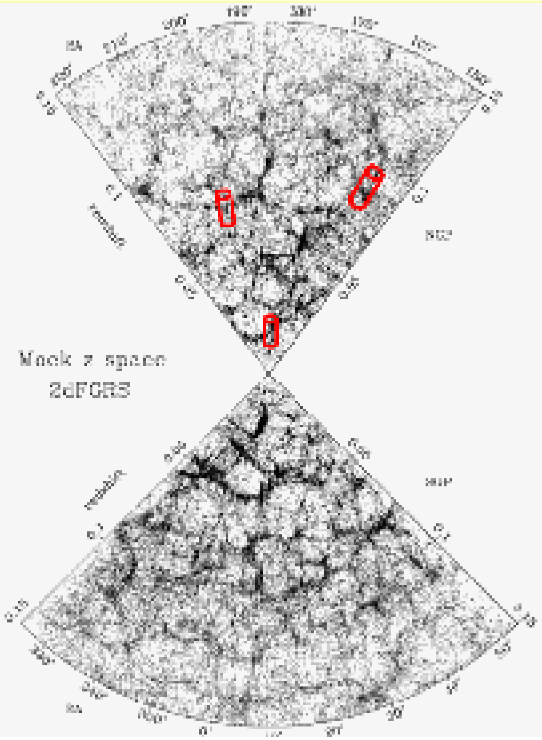
real space



Eke, Frenk, Cole, Baugh –
2dFGRS 2003

Mock 2dFGRS from Hubble volume

z-space



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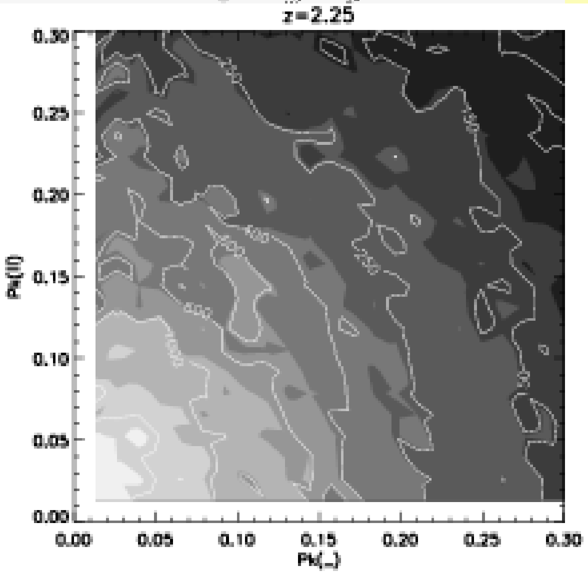
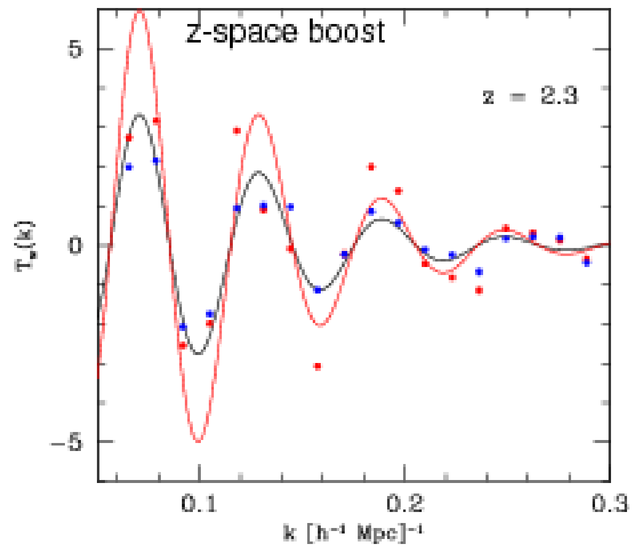
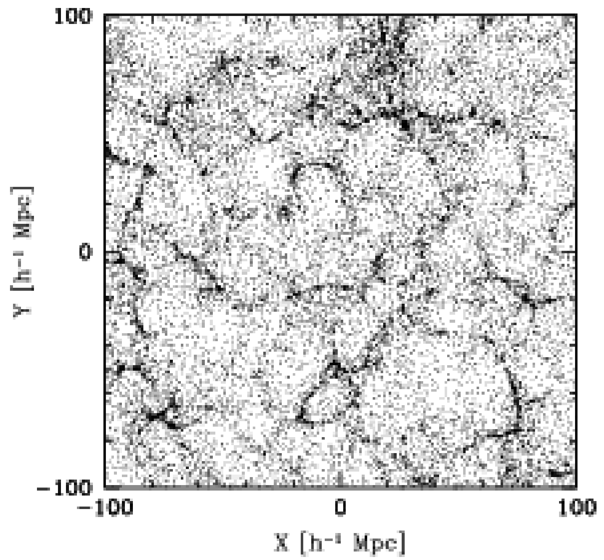




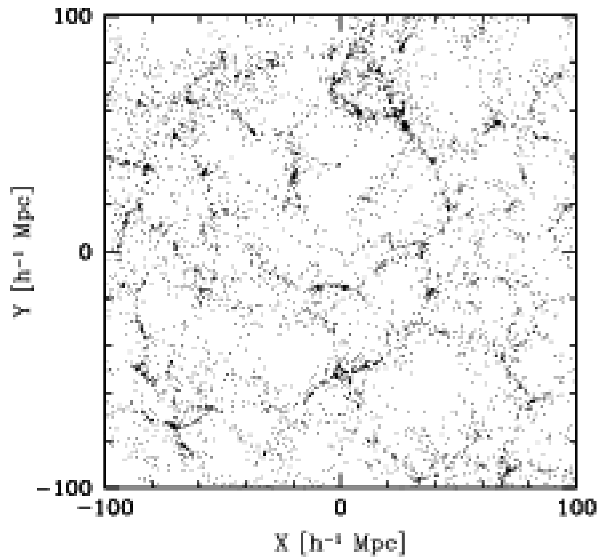
Peculiar velocities boost baryonic wiggles

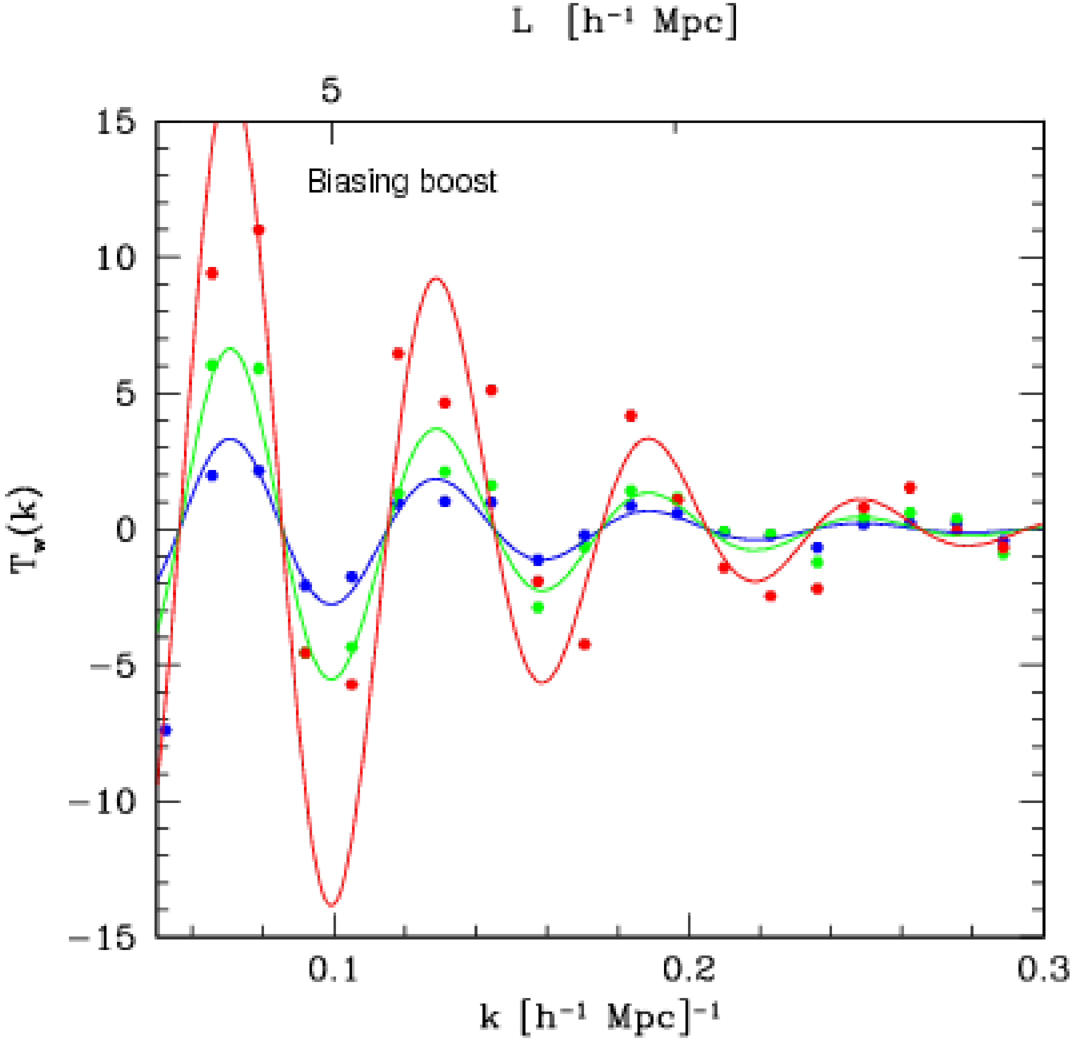
Baryonic Acoustic Oscillations: Biasing

z = 0.6
Matter distribution



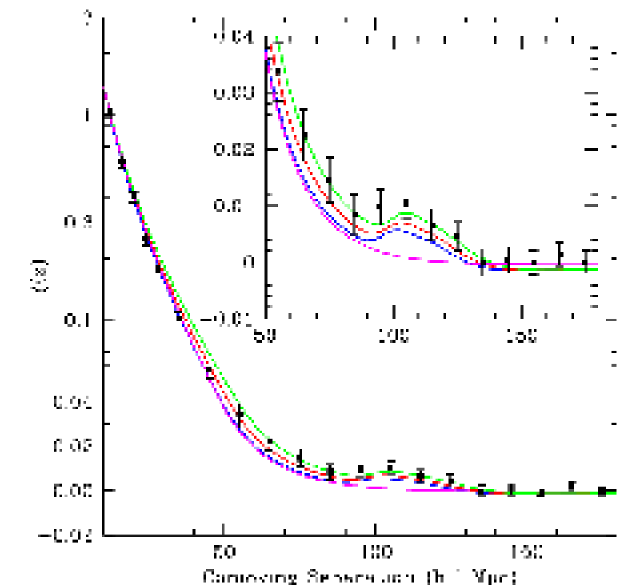
z = 0.6
Biased distribution

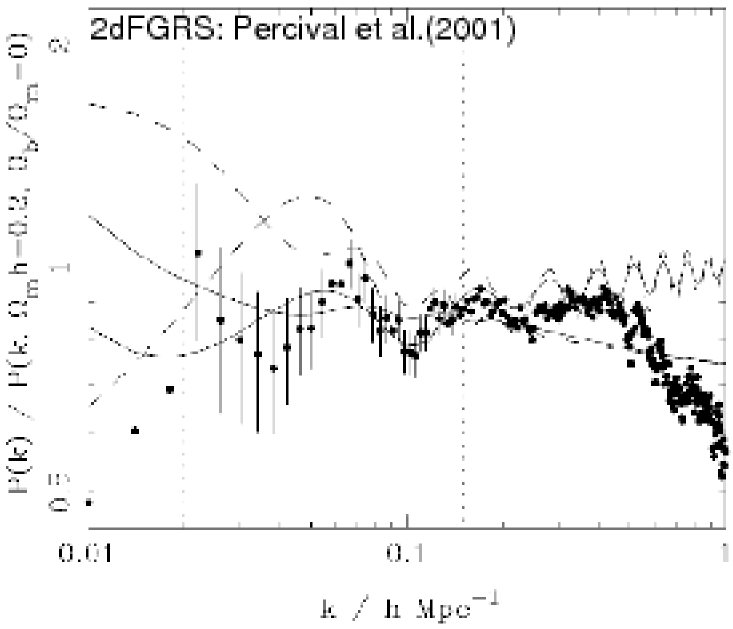


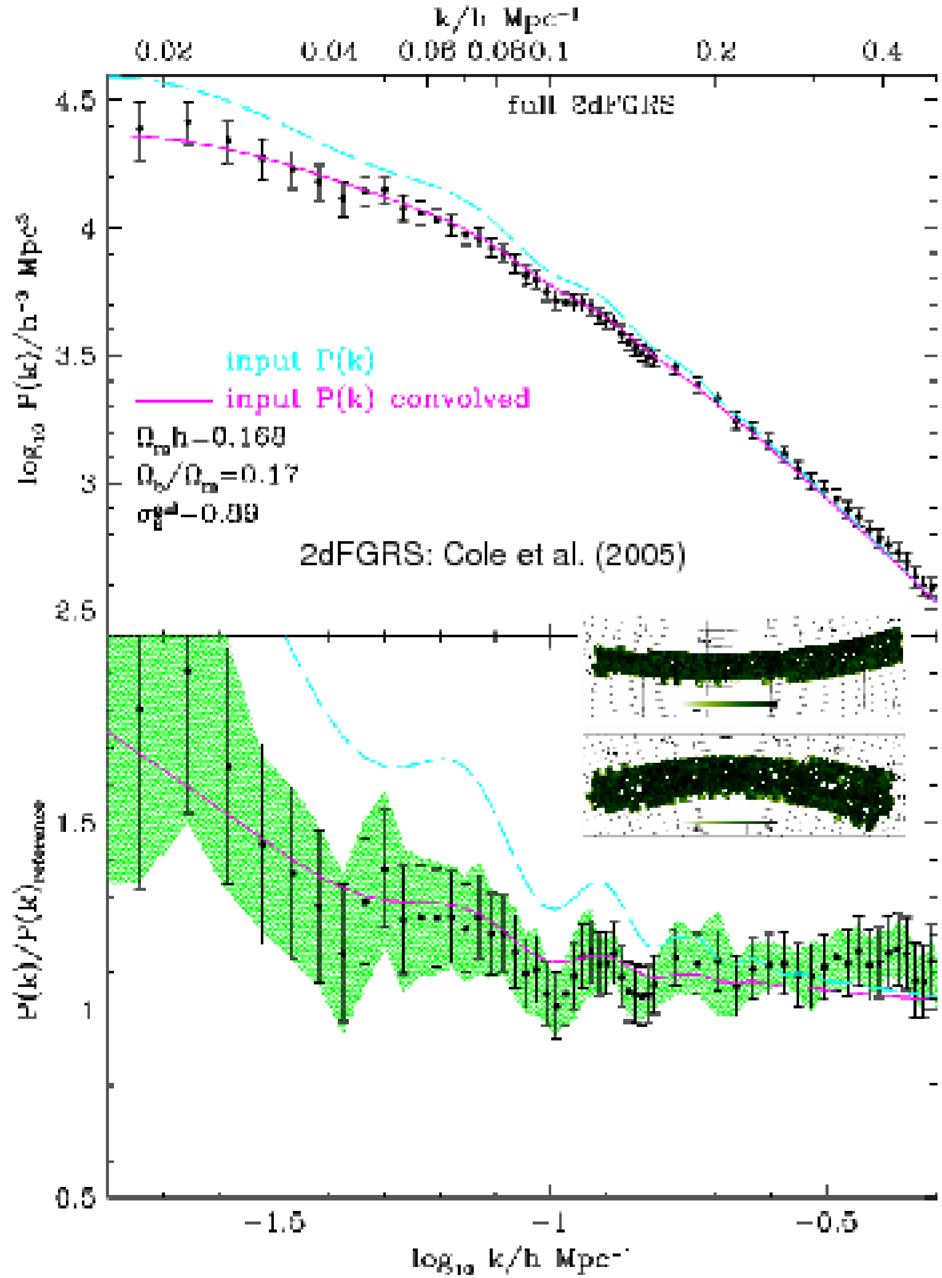


Biasing boosts baryonic wiggles

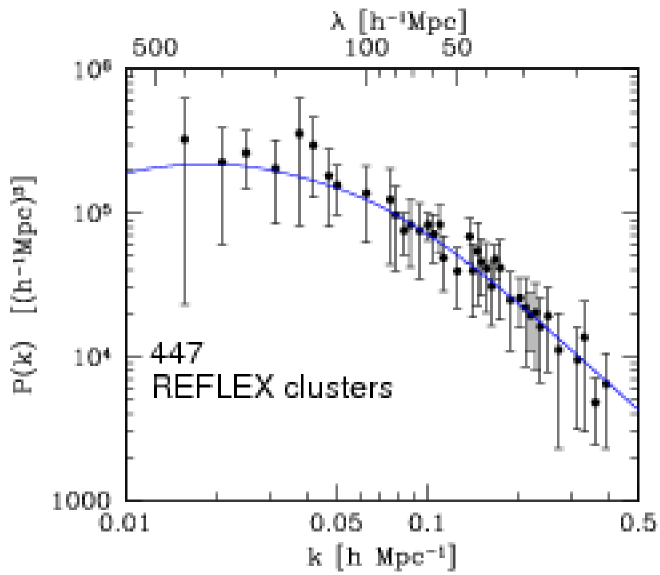
Baryonic Acoustic Oscillations: Observations at Low z

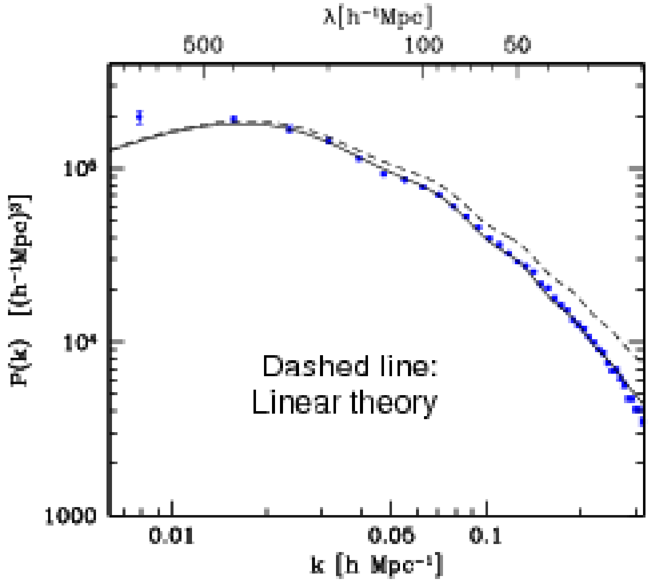






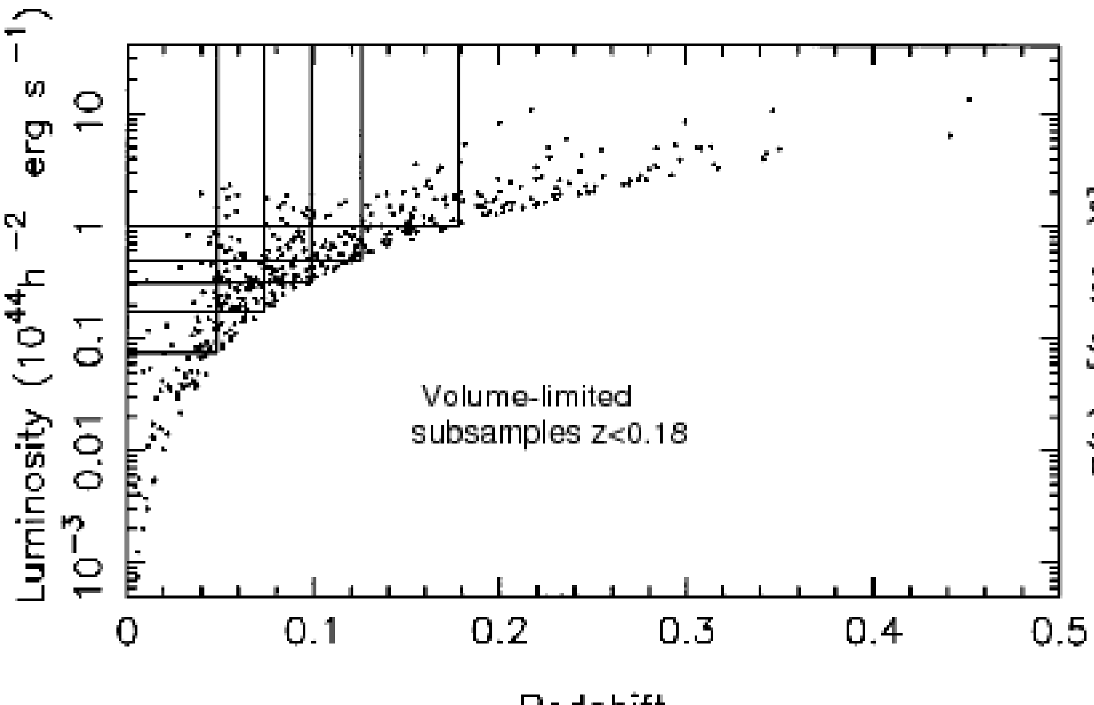
Power Spectra: REFLEX vs. Simulated Clusters

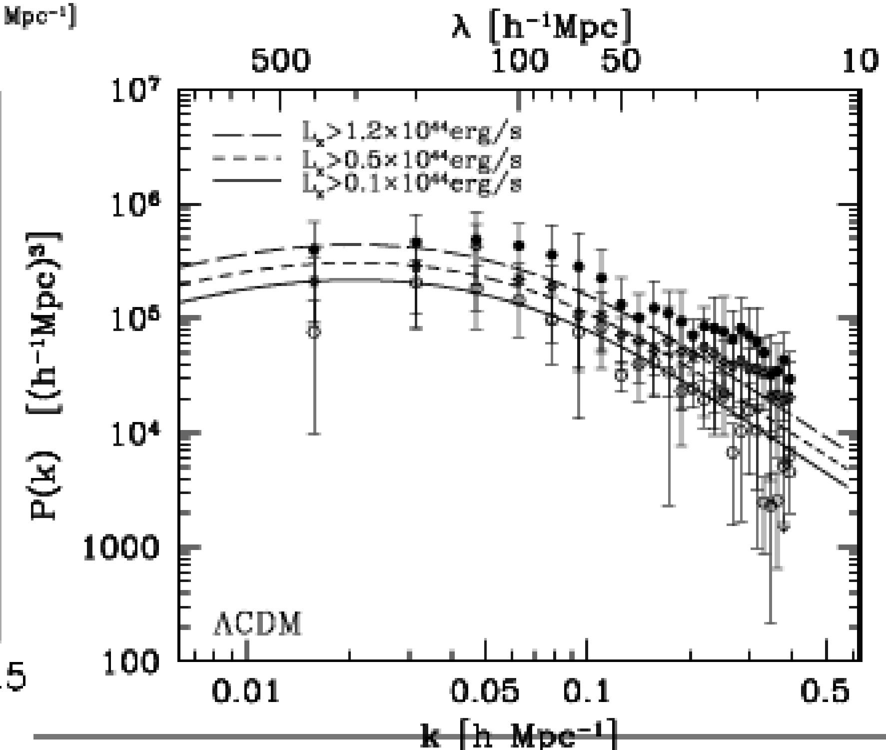




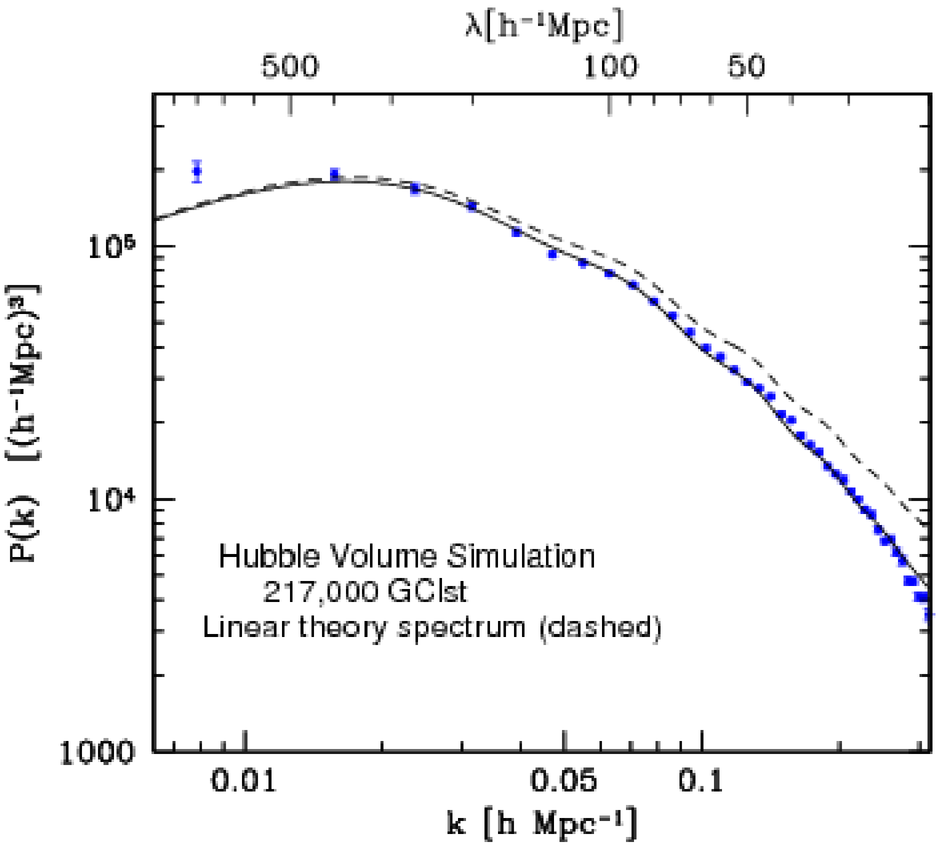
Hubble Volume Simulations
217,000 galaxy clusters
z < 0.5

Reddening of P(k):
Flux-limited sample
over large z-range



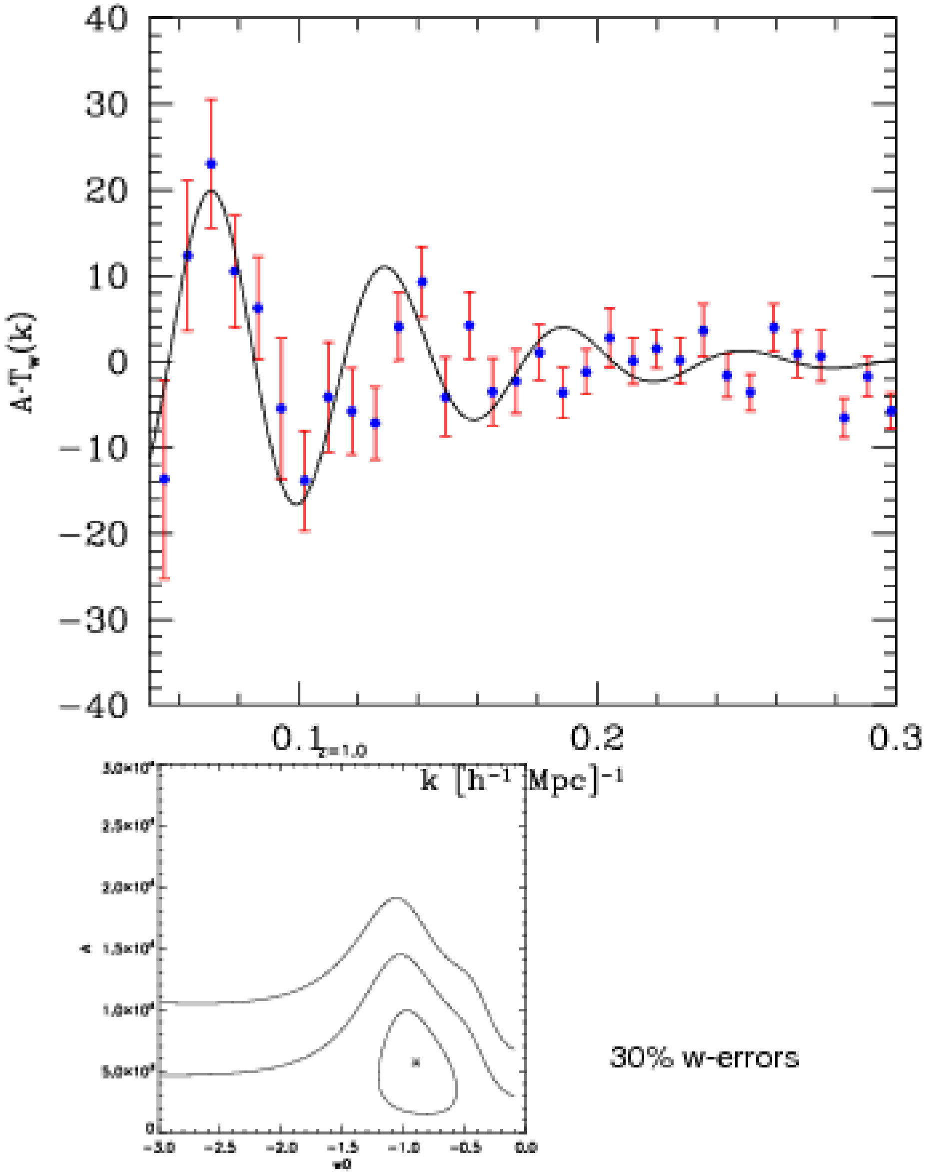


Baryonic Acoustic Oscillations: X-Ray Clusters



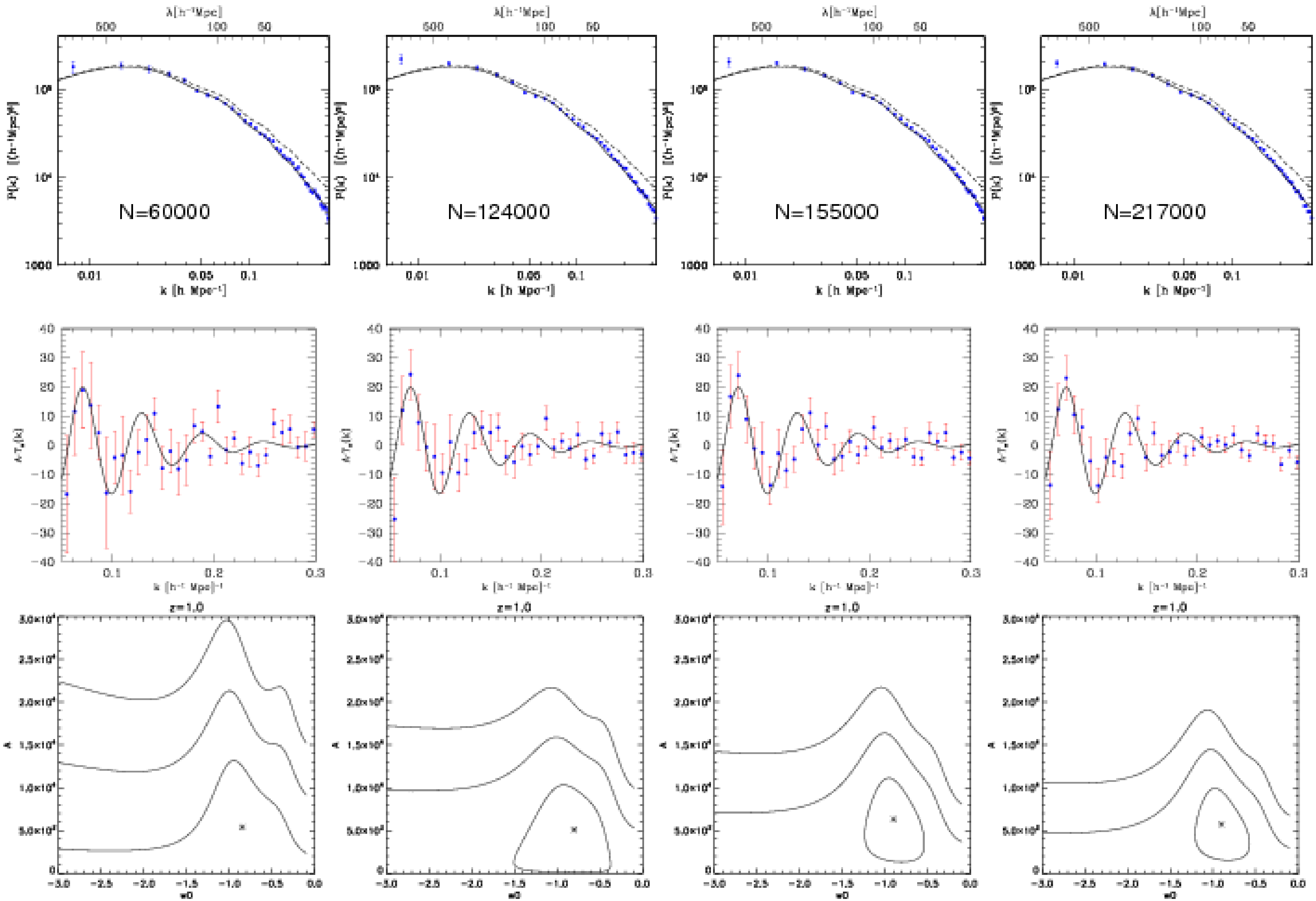
Continuum subtraction with
non-oscillating
fit function

Summarizes all effects
(redshift/real space, bias)
without explicit modelling

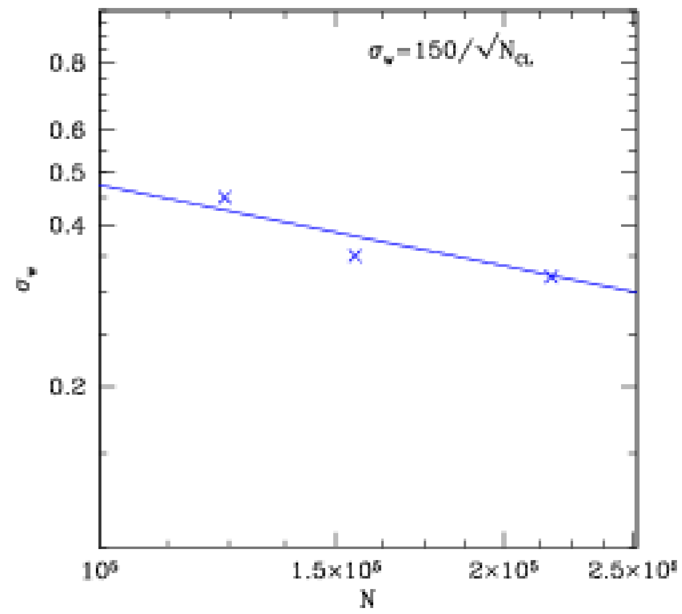


30% w-errors

Baryonic Acoustic Oscillations: X-Ray Clusters



Baryonic Acoustic Oscillations: X-Ray Clusters



Errors on redshift-independent part of w:

Decrease slowly with square root of number of clusters

More than 2 Mio. clusters necessary to get errors on the 10%-level (basically all clusters in the Universe)

Observational challenge to identify all these clusters

Probably with photometric redshift surveys

G. Huetsi draws more optimistic conclusions (astro-ph/0505441)

R. Angulo et al. (2005, MNRAS, 362, L25) use continuum

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