Sloan Digital Sky Survey DR7: New Results
arXiv:0907.1660* BAO
arXiv:0907.1659 LRG P(k)
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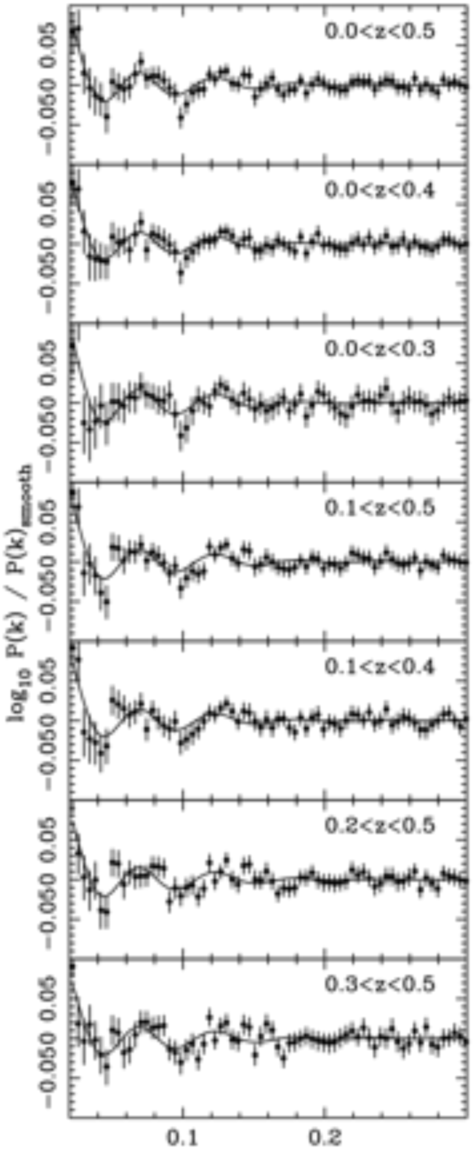
BAO in SDSS DR7 + 2dFGRS power spectra

- Combine 2dFGRS, SDSS DR7 LRG and Main Galaxies
- Assume a fiducial distance-redshift relation and measure spherically-averaged P(k) in redshift slices
- Fit spectra with model comprising smooth fit × damped BAO
- To first order, isotropically distributed pairs depend on

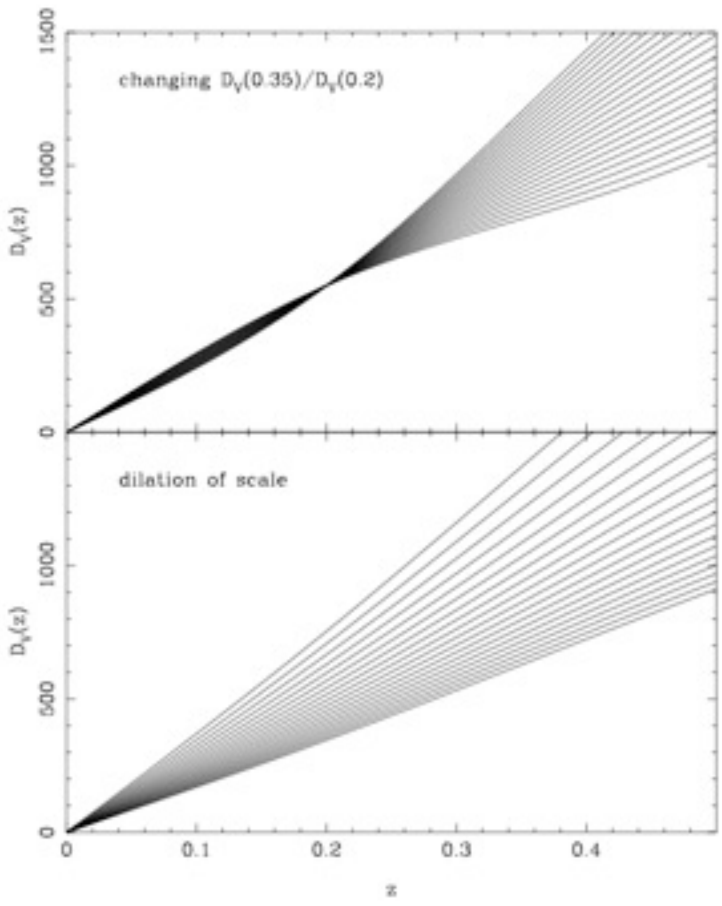
$$D_V(z) = \left[(1+z)^2 D_A^2(z) \frac{cz}{H(z)}\right]^{1/3}$$

- Absorb cosmological dependence of the distance-redshift relation into the window function applied to the model P(k)
- Report model-independent constraint on $r_s/D_V(z_i)$



Percival et al. (2009, arXiv:0907.1660)

modeling the distance-redshift relation



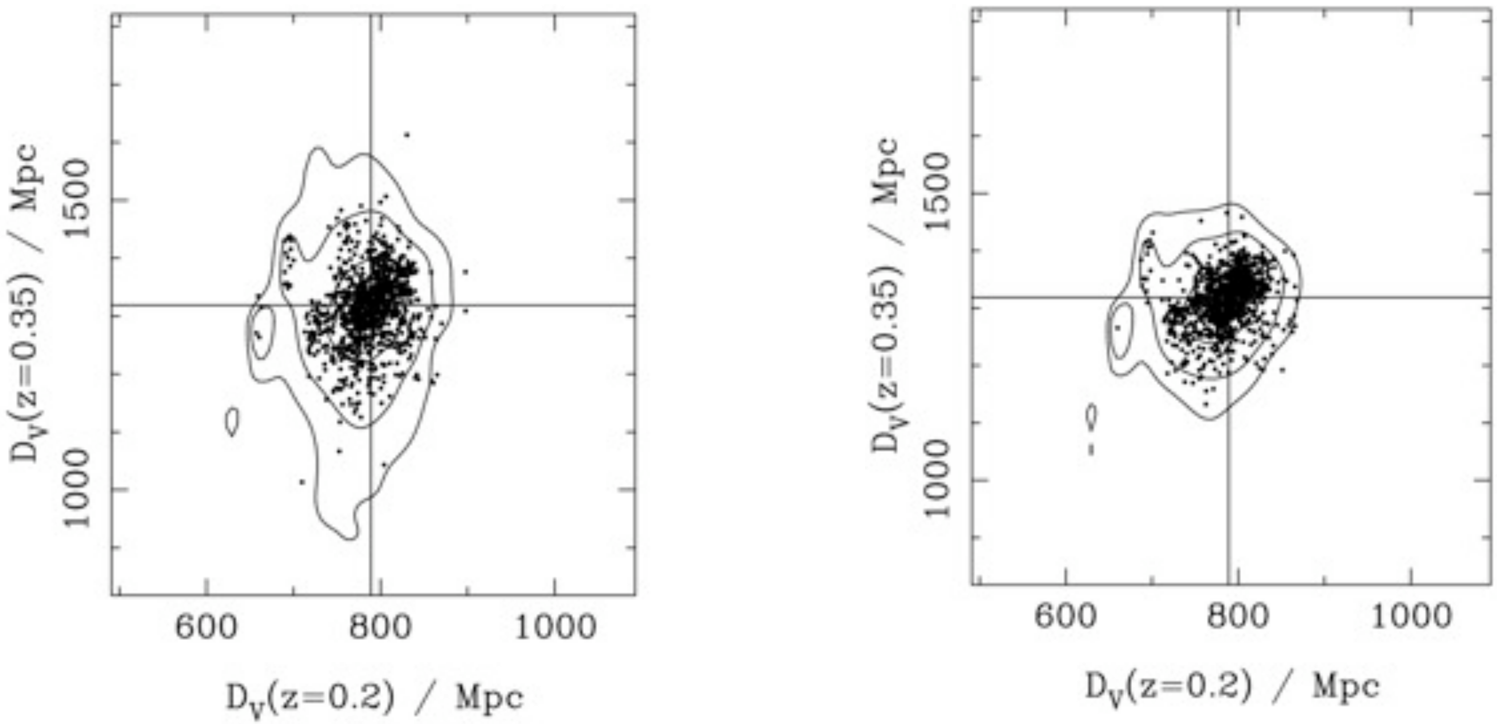
Parameterize distance-redshift relation by smooth fit: can then be used to constrain multiple sets of models with smooth distance-redshift relation

For SDSS+2dFGRS analysis, choose nodes at z=0.2 and z=0.35, for fit to D_V

$$D_V(z) = \left[(1+z)^2 D_A^2(z) \frac{cz}{H(z)}\right]^{1/3}$$

Percival et al. (2009, arXiv:0907.1660)

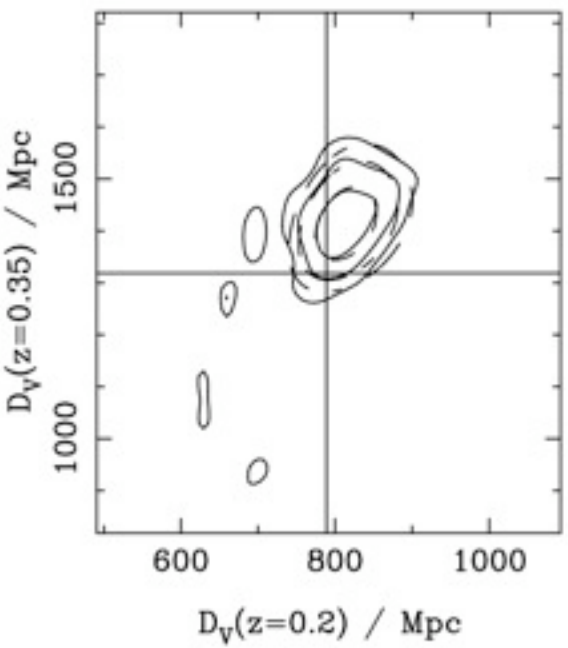
Testing the errors



Tests comparing parameters and errors recovered for mock data against the true cosmology, show we need to increase the errors. Gaussian realisations of power spectra show this is caused by the non-Gaussian nature of the Likelihood

Percival et al. (2009, arXiv:0907.1660)

BAO in SDSS DR7 + 2dFGRS power spectra



- results can be written as independent constraints on a distance measure to z=0.275 and a tilt around this

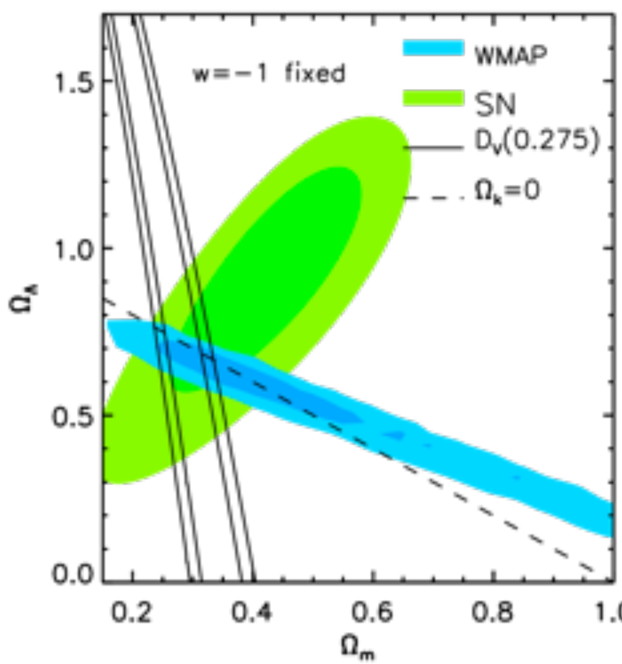
$$
\begin{aligned}
r_s(z_d)/D_V(0.275) &= 0.1390 \pm 0.0037 \quad (2.7\%) \\
D_V(0.37)/D_V(0.2) &= 1.736 \pm 0.065
\end{aligned}
$$

- consistent with ΛCDM models at 1.1σ when combined with WMAP5
- Reduced discrepancy compared with DR5 analysis
  – more data
  – revised error analysis (allow for non-Gaussian likelihood)
  – more redshift slices analyzed
  – improved modeling of LRG redshift distribution

Percival et al. (2009, arXiv:0907.1660)

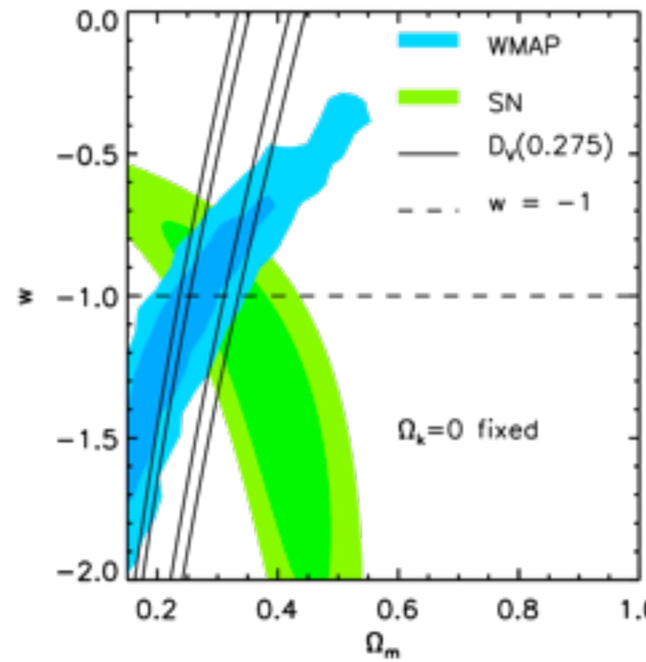
Comparing BAO constraints against different data

ΛCDM models with curvature



Percival et al. (2009: arXiv:0907.1660)

flat wCDM models



Percival et al. (2009: arXiv:0907.1660)

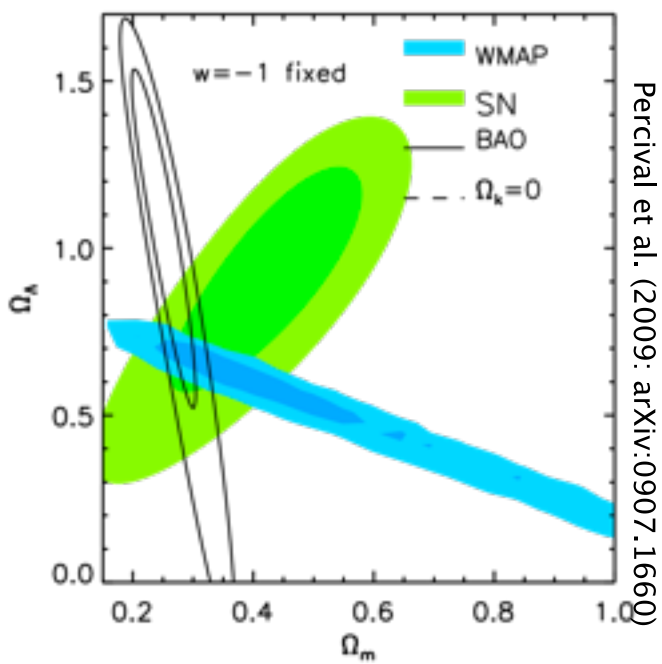
Union supernovae

WMAP 5year

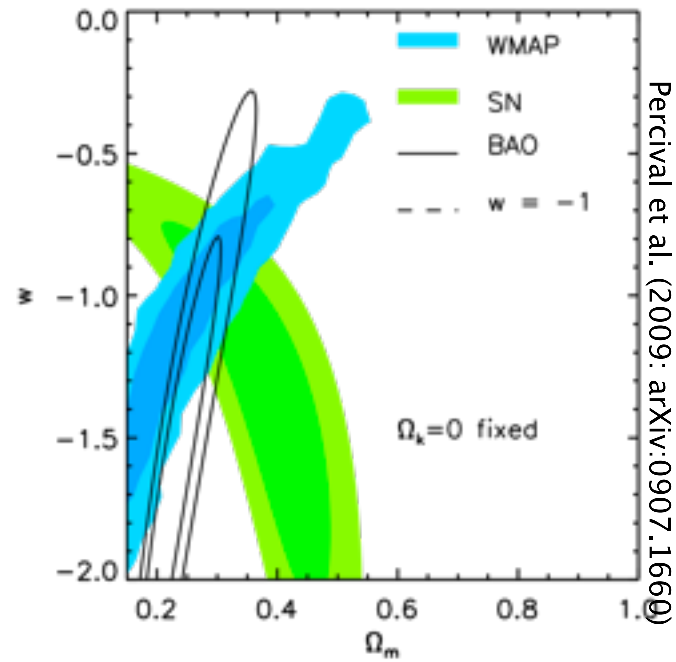
BAO Constraint on $r_s(z_d)/D_V(0.275)$

Cosmological Constraints

ΛCDM models with curvature



flat wCDM models



Union supernovae

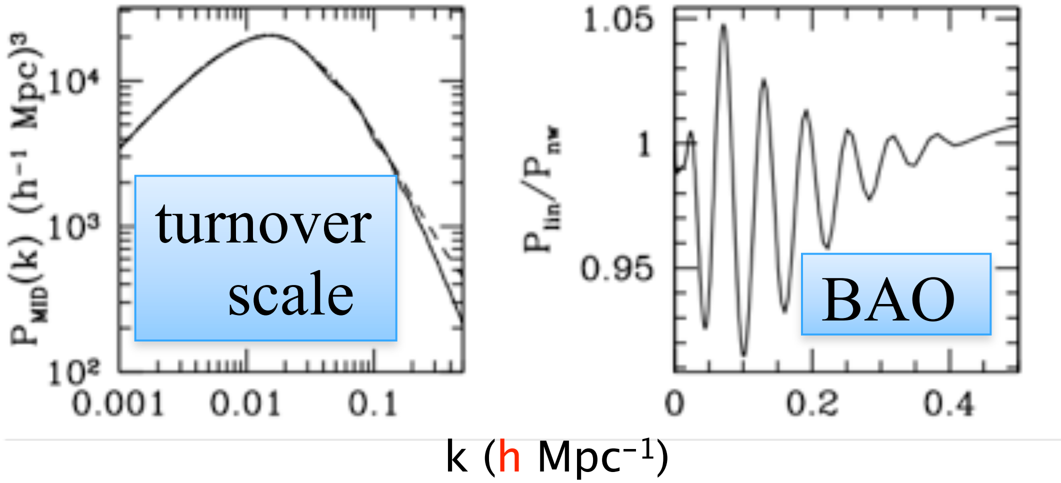
WMAP 5year

$r_s(z_d)/D_V(0.2)$ & $r_s(z_d)/D_V(0.35)$

WMAP5+BAO ΛCDM:
$\Omega_m = 0.278 \pm 0.018$, $H_0 = 70.1 \pm 1.5$
WMAP5+BAO+SN wCDM + curvature:
$\Omega_{tot} = 1.006 \pm 0.008$, $w = -0.97 \pm 0.10$

Measuring $P_{gal}(k)$: Motivation

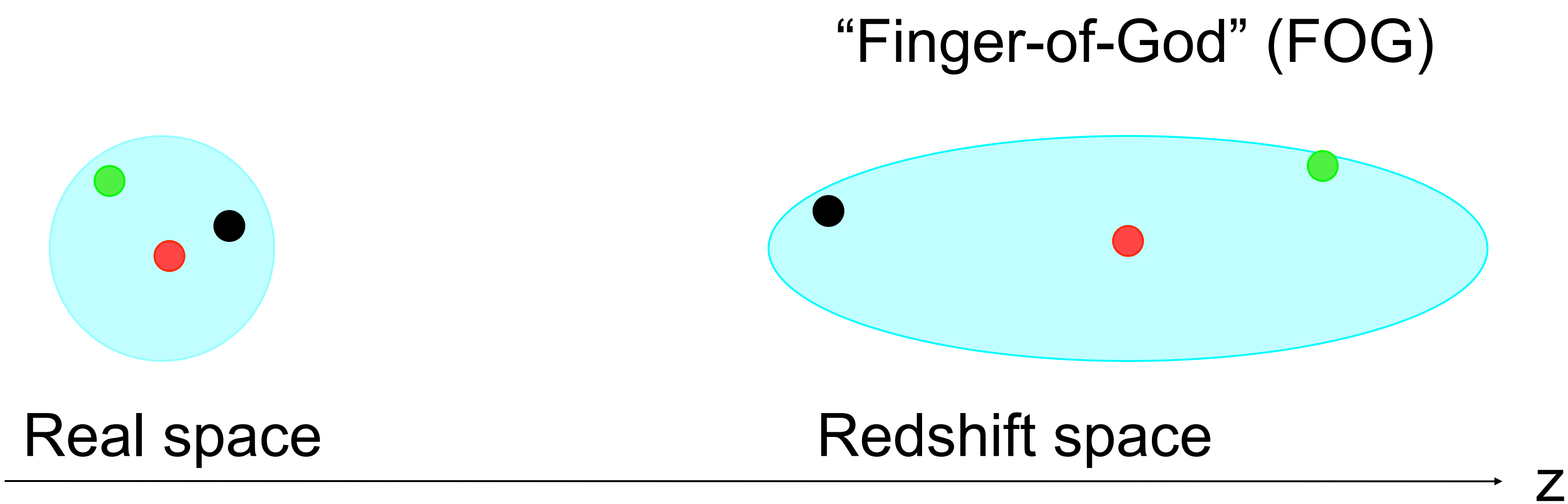
- CMB fixes in **Mpc^{-1}** through $\Omega_{c/b}h^2$, independent of θ_{CMB}



- Independent probe of the matter transfer function and primordial power spectrum: $\Omega_m h^2$, n_s
- Excellent probe of cosmological neutrinos
  - N_{rel}, the number of relativistic species in early universe; affects turnover and BAO scales differently
  - $\Sigma\, m_\nu$, sum of neutrino massives; k-dependent power suppression

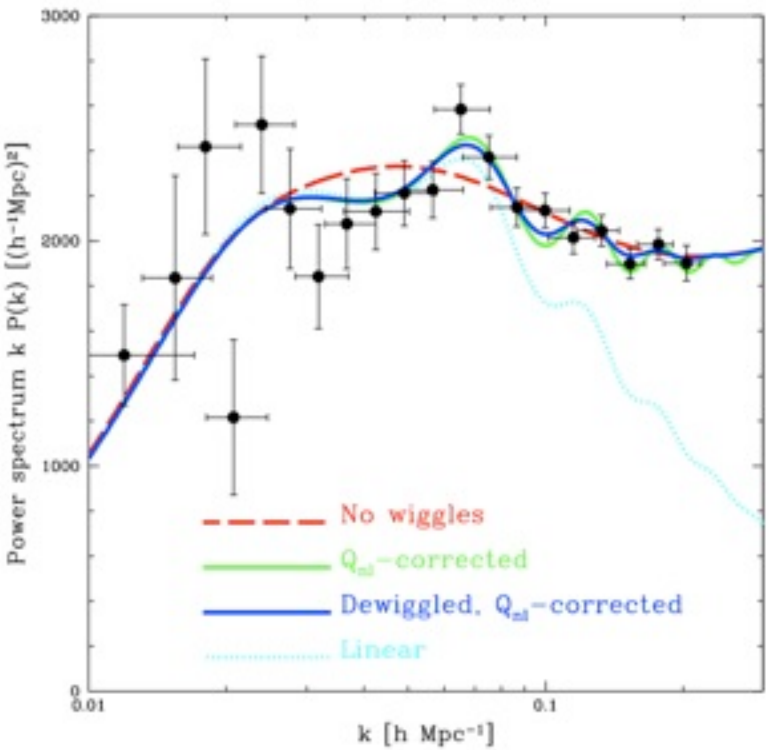
Measuing $P_{gal}(k)$: Challenges

- density field goes nonlinear
- uncertainty in the mapping between galaxy and matter density fields
- galaxy positions observed in redshift space

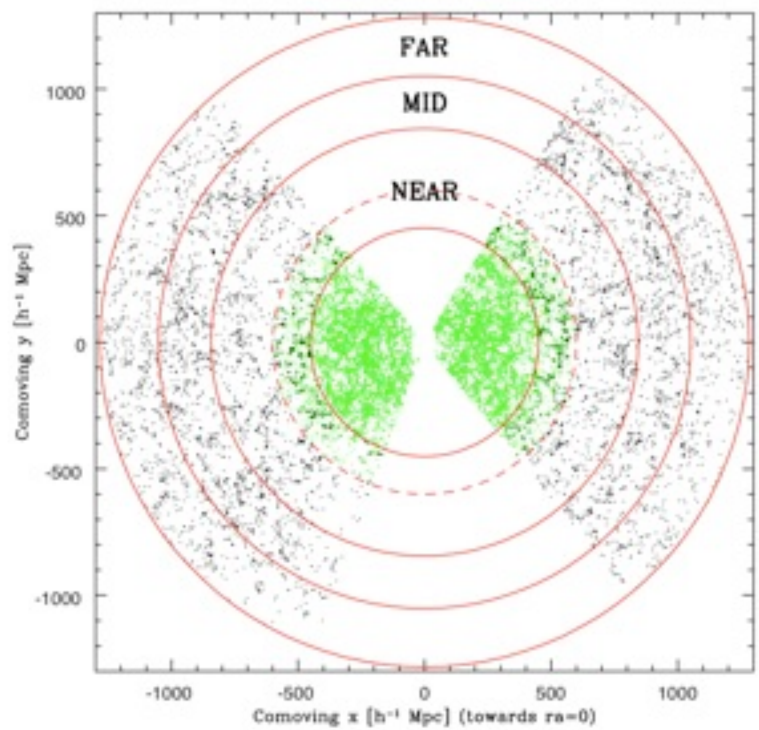


Luminous Red Galaxies

- DR5 analysis: huge deviations from $P_{lin}(k)$
- nP ~ 1 to probe largest effective volume
  - Occupy most massive halos ⟶ large FOG features
  - Shot noise correction important



Tegmark et al. (2006, PRD 74 123507)



Tegmark et al. (2006, PRD 74 123507)

DR7: What's new?

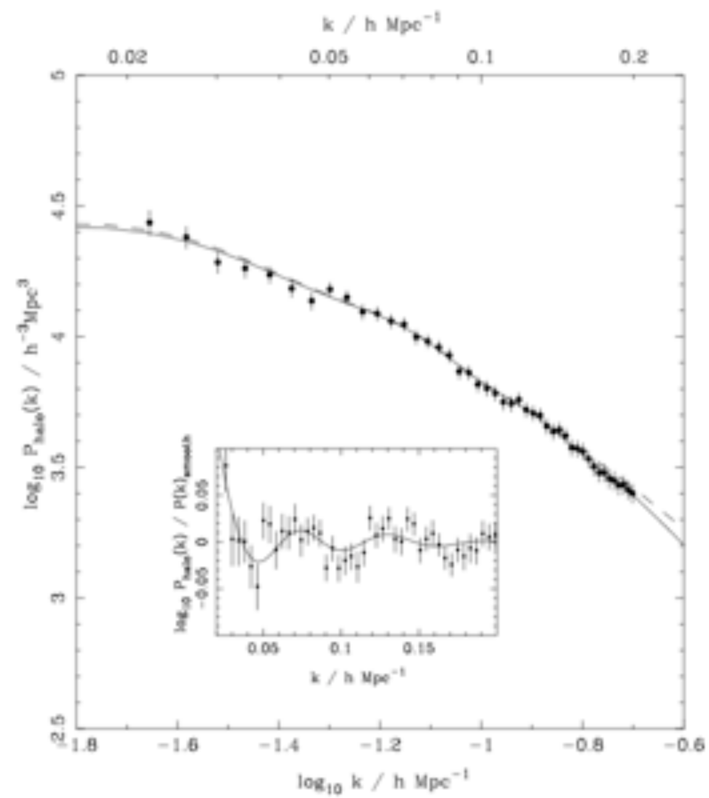
- n_{LRG} small $\longrightarrow$ find "one-halo" groups with high fidelity
  - –Provides observational constraint on FOGs and "one-halo" excess shot noise
- NEW METHOD TO RECONSTRUCT HALO DENSITY FIELD
  - –Better tracer of underlying matter P(k)
  - –Replace heuristic nonlinear model (Tegmark et al. 2006 DR5) with cosmology-dependent, nonlinear model calibrated on accurate mock catalogs and with better understood, smaller modeling systematics
  - –Increase k_{max} = 0.2 h/Mpc; 8x more modes!

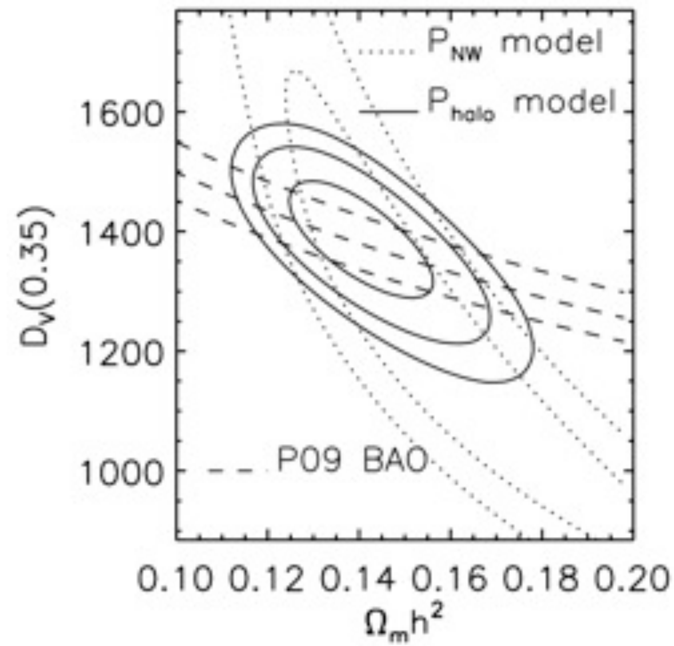
Reid et al. (2009, arXiv:0907.1659)

$P_{halo}(k)$ Results

- Constrains turnover ($\Omega_m h^2 D_V$) and BAO scale (r_s/D_V)

$$D_V(z) = \left[(1+z)^2 D_A(z)^2 \frac{cz}{H(z)}\right]^{1/3}$$





$\Omega_m h^2 (n_s/0.96)^{1.2} = 0.141 \pm 0.011$

$D_V(z=0.35) = 1380 \pm 67$ Mpc

WMAP+$P_{halo}(k)$ Constraints: Neutrinos in ΛCDM

- $P_{halo}(k)$ constraints tighter than P09 BAO-only
- Massive neutrinos suppress P(k)
  - WMAP5: $\Sigma m_\nu < 1.3$ eV (95% confidence)
  - WMAP5+LRG: $\Sigma m_\nu < 0.62$ eV
  - WMAP5+BAO: $\Sigma m_\nu < 0.73$ eV
- Effective number of relativistic species N_{rel} alters turnover and BAO scales differently
  - WMAP5: $N_{rel} = 3.046$ preferred to $N_{rel} = 0$ with > 99.5% confidence
  - WMAP5+LRG: $N_{rel} = 4.8 \pm 1.8$

Reid et al. (2009, arXiv:0907.1659)

Summary & Prospects

- BAOs provide tightest geometrical constraints
  - consistent with ΛCDM models at 1.1σ when combined with WMAP5
  - improved error analysis, n(z) modeling, etc.
- DR7 P(k) improvement: We use **reconstructed halo density field** in cosmological analysis
  - Halo model provides a framework for quantifying systematic uncertainties
- Result: 8x more modes, improved neutrino constraints compared with BAO-only analysis
- Likelihood code available here:
  - http://lambda.gsfc.nasa.gov/toolbox/lrgdr/
- Shape information comes "for free" in a BAO survey!

Looking towards the future…

- Extend halo model modeling to redshift space distortions to constrain growth of structure and test GR or dark coupling (e.g., Song and Percival 2008)
- Apply BAO reconstruction (Eisenstein, Seo, Sirko, Spergel 2007)
- Extract P(k), BAO, & redshift distortion information simultaneously?
  - improvement in estimating covariance matrices
  - use of new two-point statistics (Padmanabhan, White, Eisenstein 2007)