Title: Cosmic Flows with the Baryon Oscillation Spectroscopic Survey (BOSS)

Date: Aug 12, 2015 09:30 AM

URL: http://pirsa.org/15080001

Abstract: I will present results from the SDSS-III BOSS-DR11 analysis. In this talk I will focus on the analysis of the power spectrum multipoles, which allows to constrain the growth of structure through redshift-space distortions. Such measurements can be used to test GR and measure the sum of the neutrino masses. Beside RSD we also constrain the geometry of the Universe through the Alcock-Paczynski effect and Baryon Acoustic Oscillations.

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Cosmic flows in the Baryon Oscillation Spectroscopic Survey (BOSS)

Florian Beutler

on behalf of the BOSS collaboration

August, 2015

Lawrence Berkeley National Lab

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Outline of the talk

- The Baryon Oscillation Spectroscopic Survey (BOSS).
- BOSS measurements of Baryon Acoustic Oscillations.
- BOSS measurements of Redshift-space distortions.

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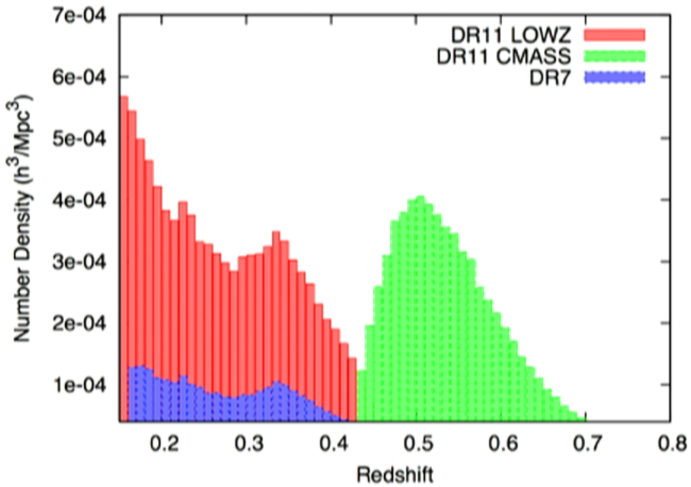
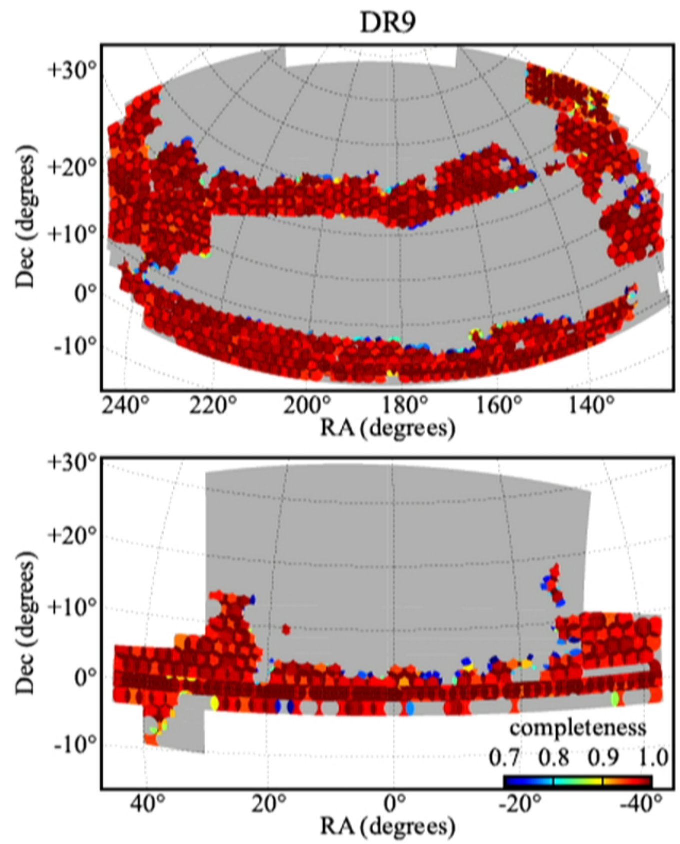
The BOSS galaxy survey

- Third version of the Sloan Digital Sky Survey (SDSS-III).
- Spectroscopic survey optimized for the measurement of Baryon Acoustic Oscillations (BAO).
- The galaxy sample is divided in a high redshift part, CMASS ($0.43 < z < 0.7$) and a low redshift part, LOWz (< 0.43).
- The effective volume is $6\,\mathrm{Gpc}^3$ for CMASS and $2.4\,\mathrm{Gpc}^3$ for LOWz.
- About 1 million redshifts for CMASS and LOWz.

The BOSS galaxy survey

- DR11 covered 8509.6 deg^2 and DR12 has about 10 000 deg^2.
- The survey is divided in a north galactic patch and a south galactic patch.





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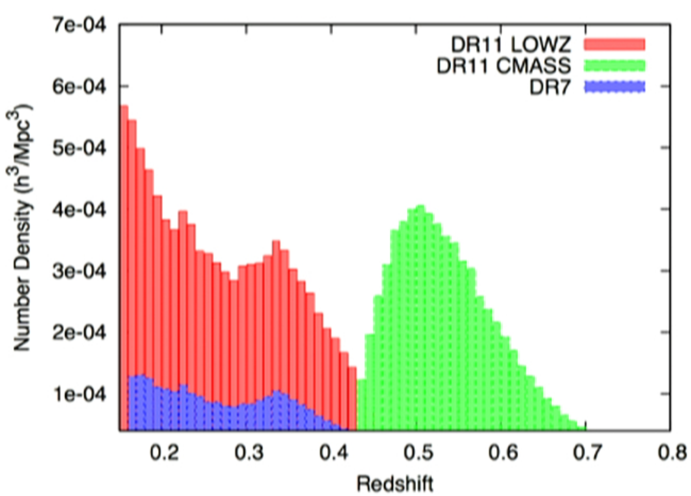

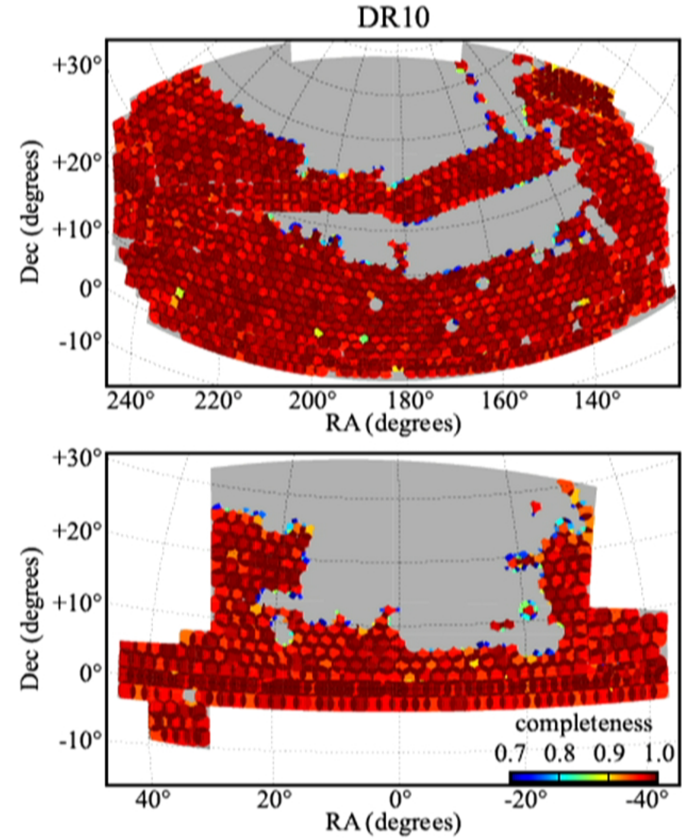

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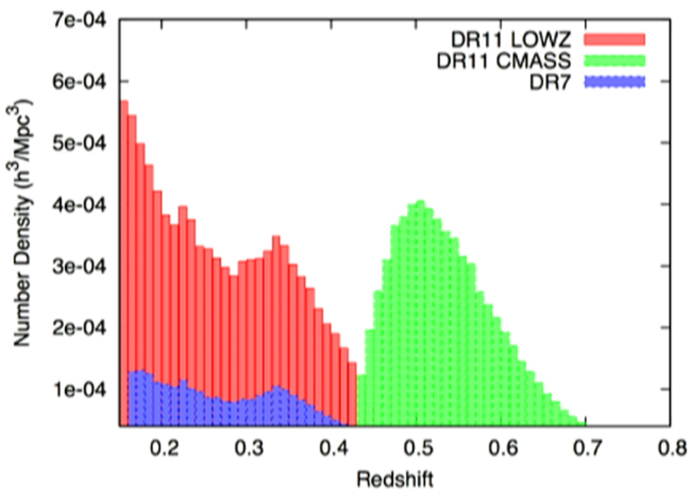

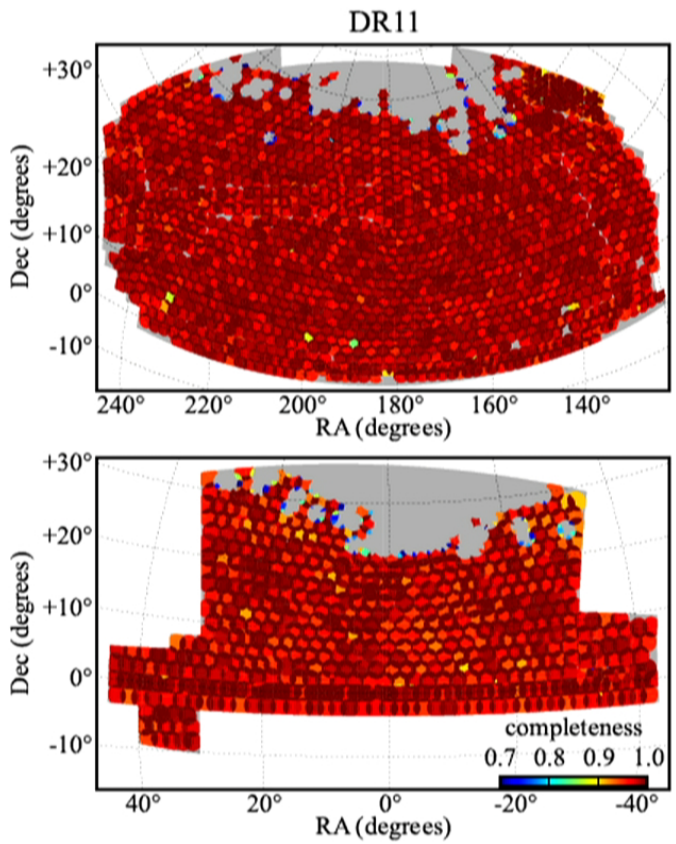

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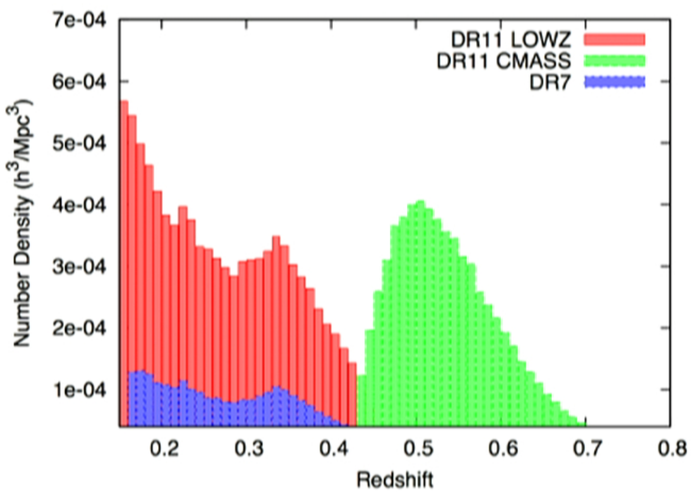

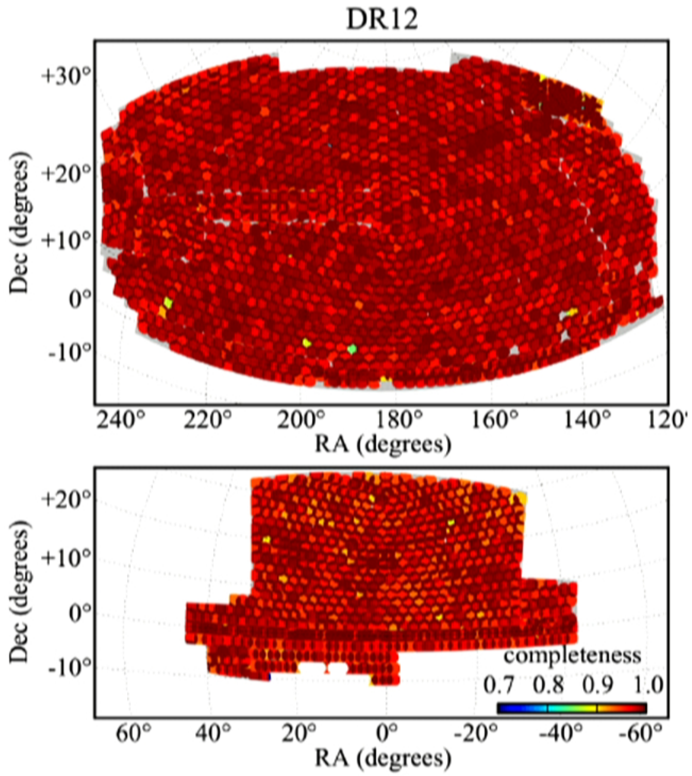

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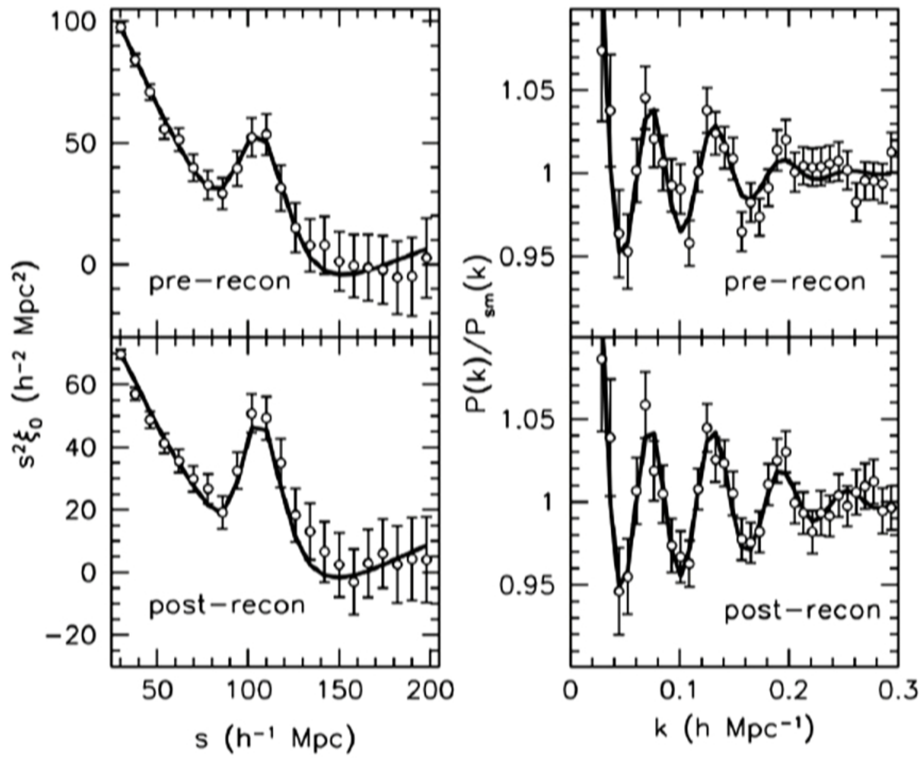
BOSS & BAO



Anderson et al 2014

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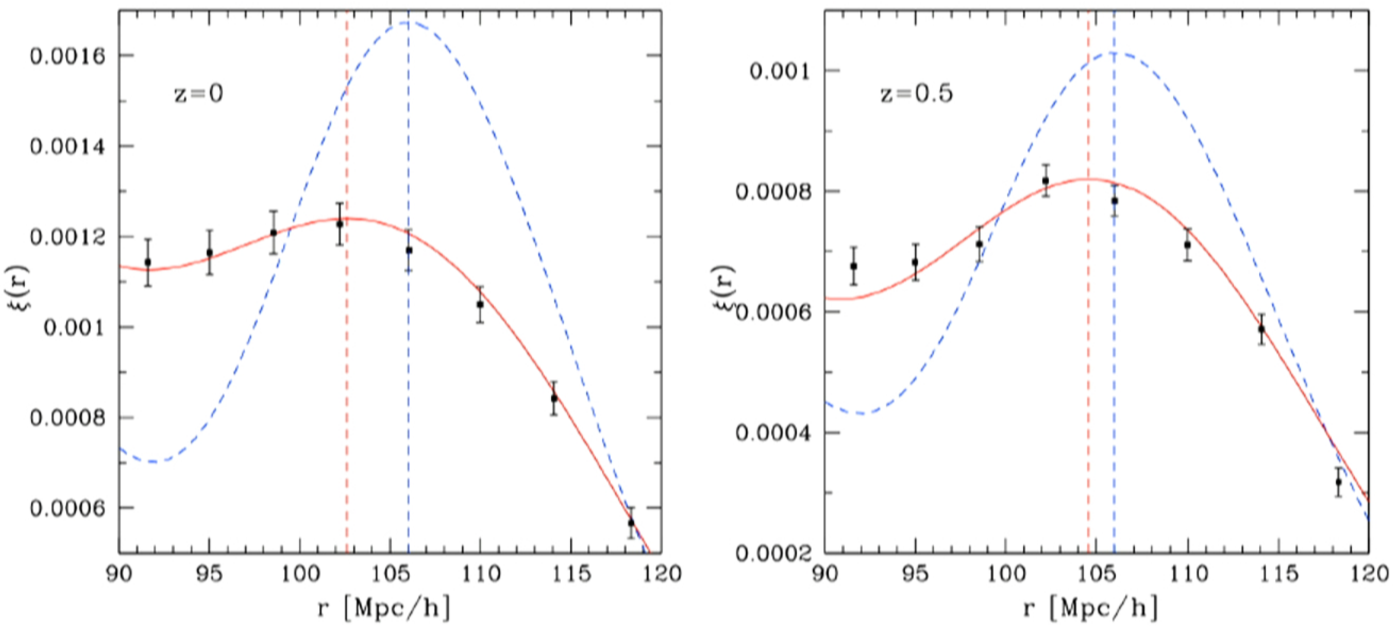
Density field reconstruction



$$\xi(r,z) = [e^{-r^2/\sigma^2} * \xi_0](r,z) + \xi_{\mathrm{MC}}(r,z)$$

Crocce & Scoccimarro 2008

Density field reconstruction

- Smooth the density field to filter out high k non-linearities.

$$\delta'(\vec{k}) \rightarrow e^{-\frac{k^2R^2}{4}}\delta(\vec{k})$$

- Solve the Poisson eq. to obtain the gravitational potential

$$\nabla^2\phi = \delta$$

- The displacement (vector) field is given by

$$\Psi = \nabla\phi$$

- Now we calculate the displaced density field by shifting the original particles.

Eisenstein et al (2007), Padmanabhan et al. (2012)

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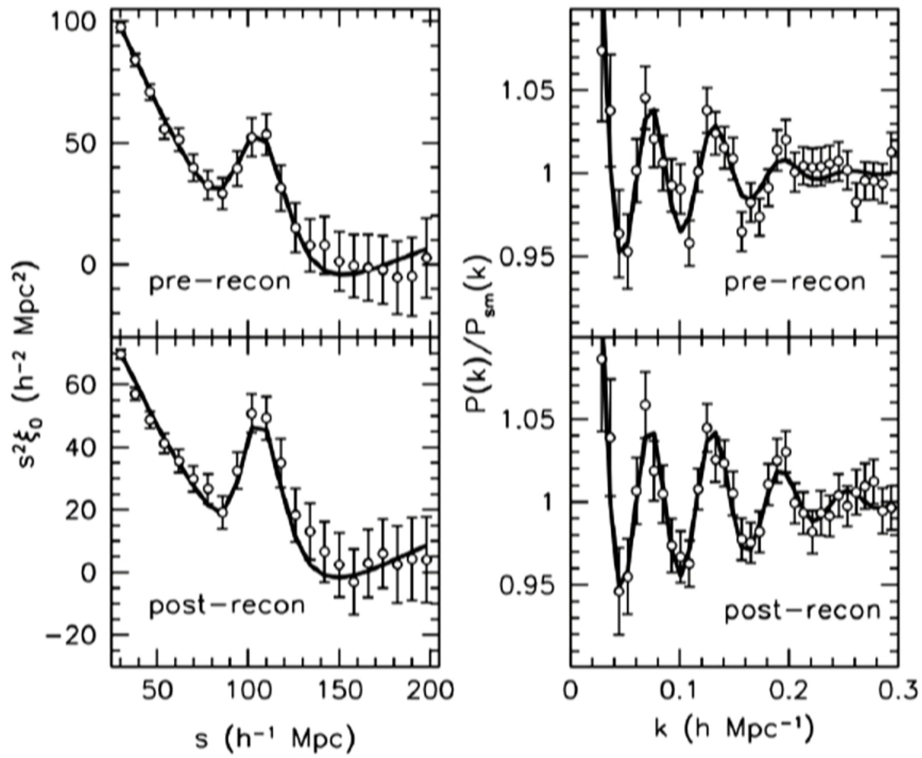
BOSS & BAO



Anderson et al 2014

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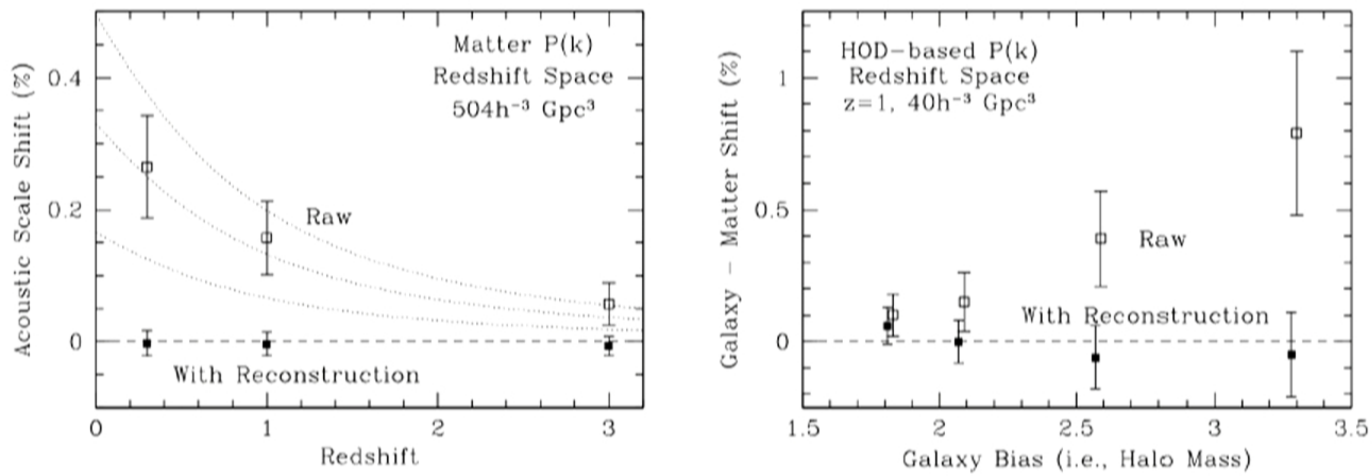
Density field reconstruction

- Density field reconstruction increases the BAO signal and improves the distance constraint by a factor of ~ 2 which corresponds to a increase in survey volume by a factor of ~ 4 (Padmanabhan et al. 2012).
- One can show that reconstruction removes the shift due to the mode coupling term (see e.g. Seo et al. 2010, Mehta et al 2011).



Seo et al. 2010 / Mehta et al 2011

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Fitting the BAO

- Start with linear $P(k)$ and separate the broadband shape, $P^{\rm sm}(k)$, and the BAO feature $O^{\rm lin}(k)$. Include a damping of the BAO feature:

$$P^{\rm sm,lin}(k) = P^{\rm sm}(k)\left[1 + (O^{\rm lin}(k/\alpha) - 1)e^{-k^2\Sigma_{\rm nl}^2/2}\right]$$

- add broadband nuisance terms

$$A(k) = a_1 k + a_2 + \frac{a_3}{k} + \frac{a_4}{k^2} + \frac{a_5}{k^3}$$

- Marginalize to get P(α)

$$P^{\rm fit}(k) = B^2 P^{\rm sm,lin}(k/\alpha) + A(k)$$

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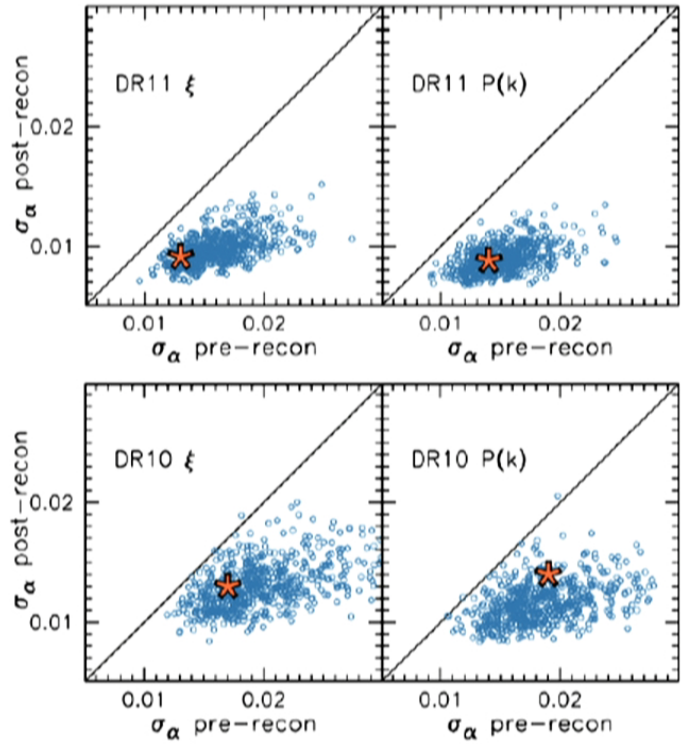
Fitting the BAO in mocks



Anderson et al. (2014)

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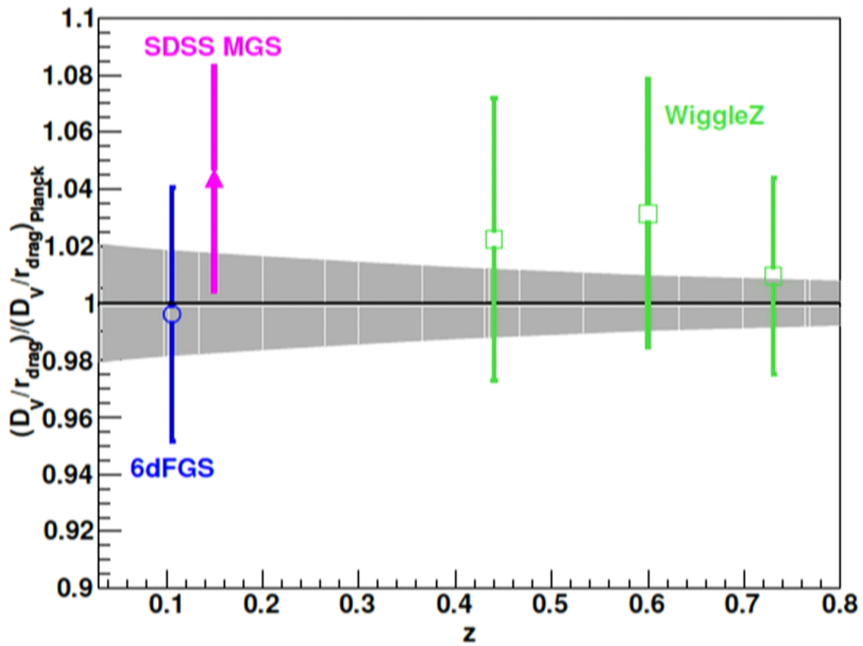
BAO constraints before BOSS



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

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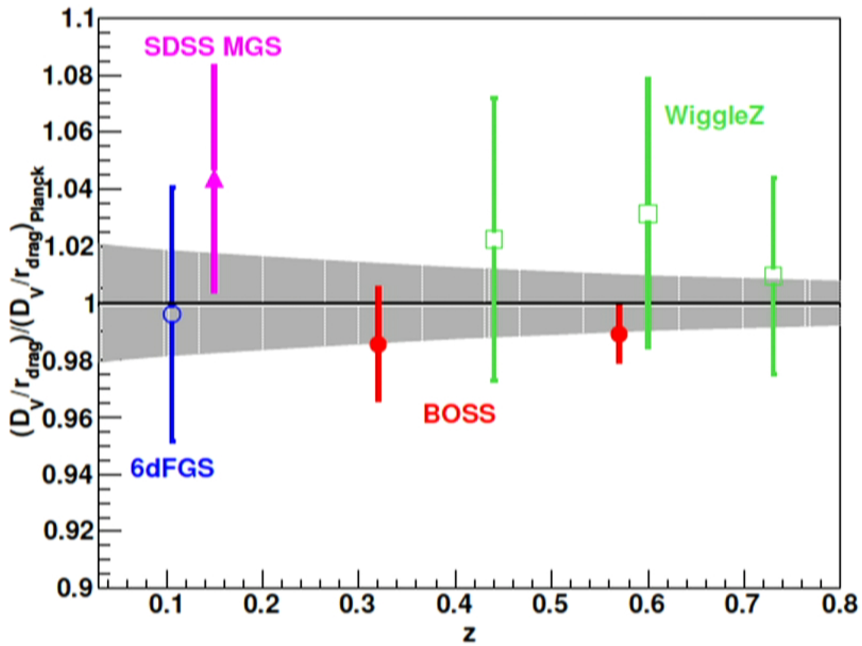
BAO constraints including BOSS



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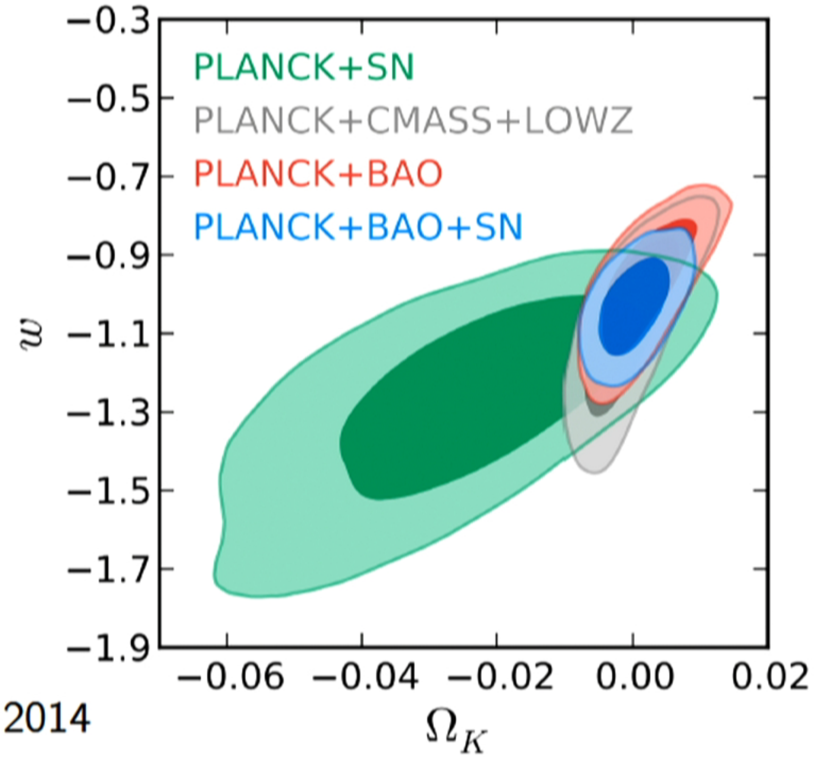
Constraining cosmological parameters



Anderson et al 2014

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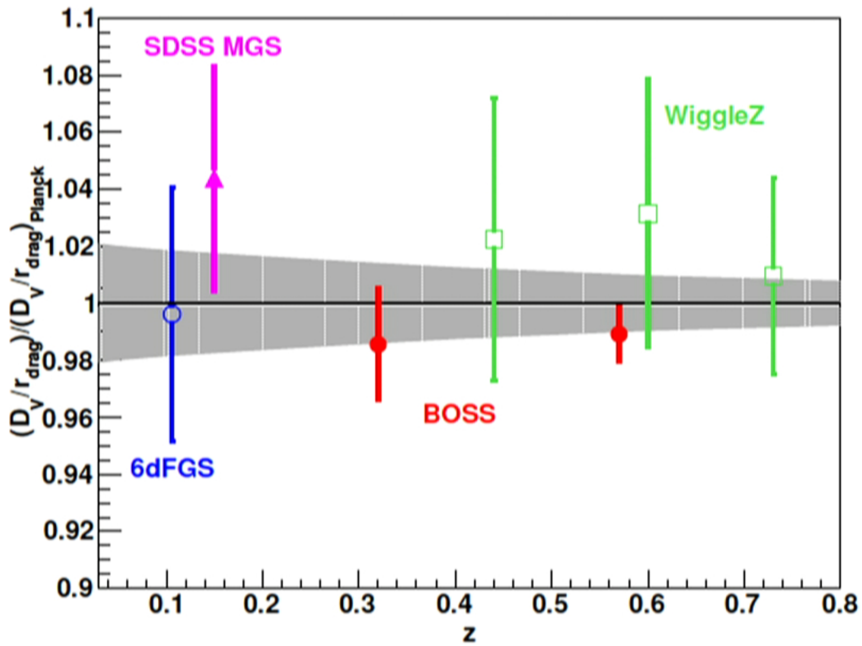
BAO constraints including BOSS



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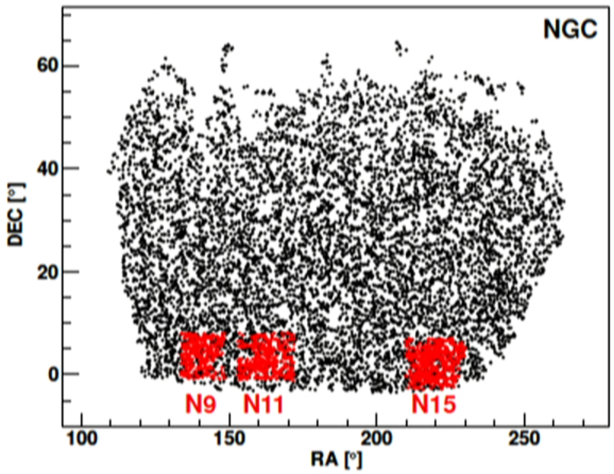
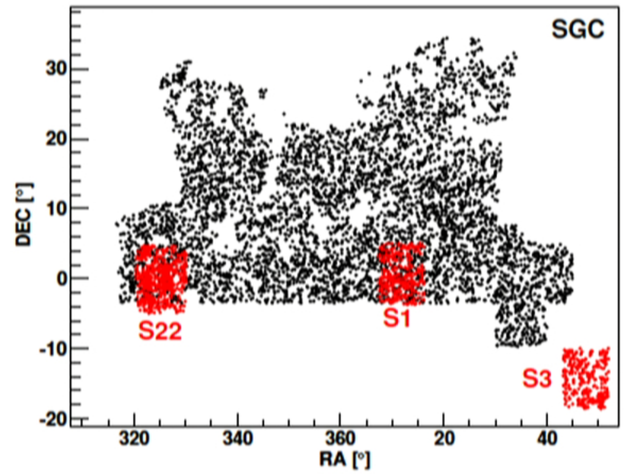
About BOSS and WiggleZ





Beutler et al (2015)

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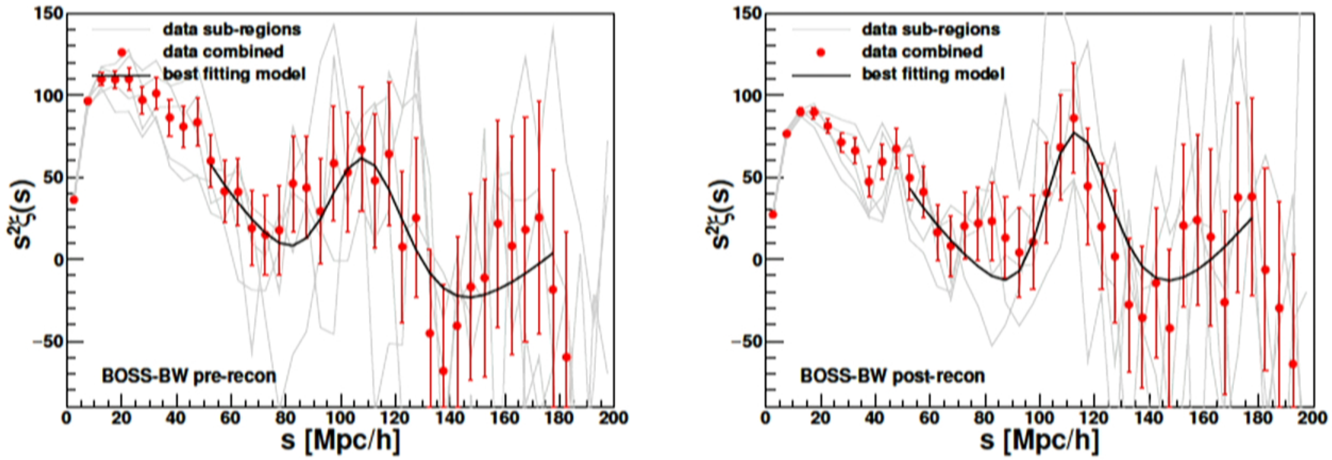
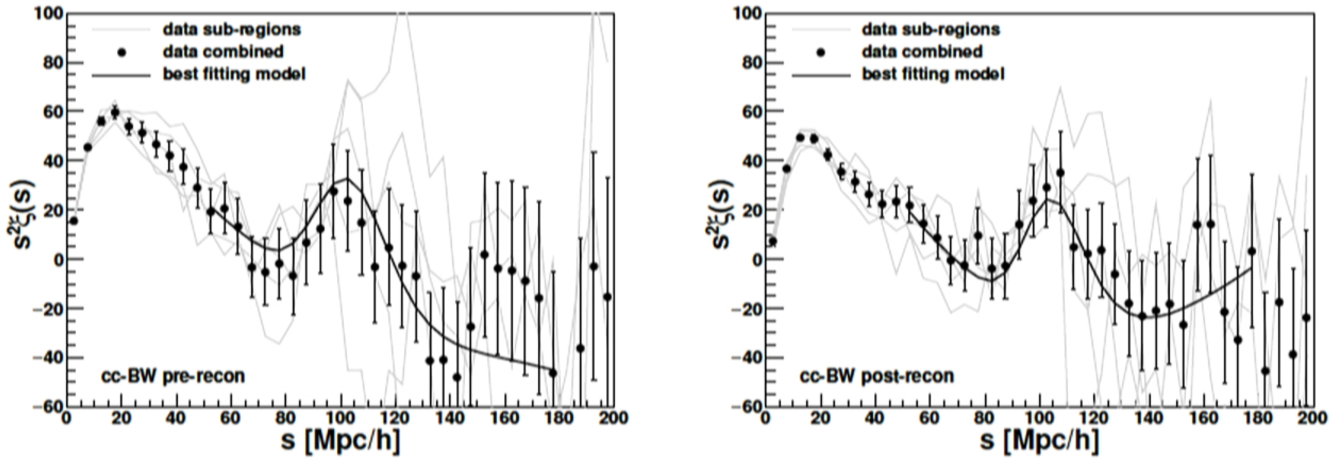


$$D_V/r_s = 2100^{+220}_{-170}\,Mpc \qquad \text{(pre-recon)}$$
$$D_V/r_s = 1970 \pm 45\,Mpc \qquad \text{(post-recon)}$$

Beutler et al (2015)

About BOSS and WiggleZ



$$D_V/r_s = 2180^{+110}_{-140}\,Mpc \qquad \text{(pre-recon)}$$
$$D_V/r_s = 2132 \pm 65\,Mpc \qquad \text{(post-recon)}$$

Beutler et al (2015)

About BOSS and WiggleZ

- We use mock catalogues to quantify the correlation between BOSS and WiggleZ.
- Additional information from the cross-correlation function.

$$C^{-1}_{\mathrm{DR11}} = \begin{pmatrix} 250.47 & & \\ -3.48 & 35.11 & \\ 0.09 & -6.50 & 3.70 \end{pmatrix} \times 10^{-5}.$$

with the data vector
$D = (\text{CMASS-DR11}, \text{cc-BW}, \text{WiggleZ-BW}) = (2056, 2132, 2100)\,\text{Mpc}.$

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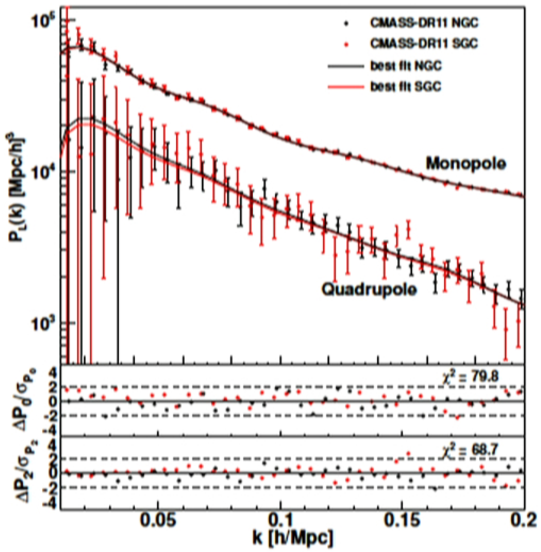
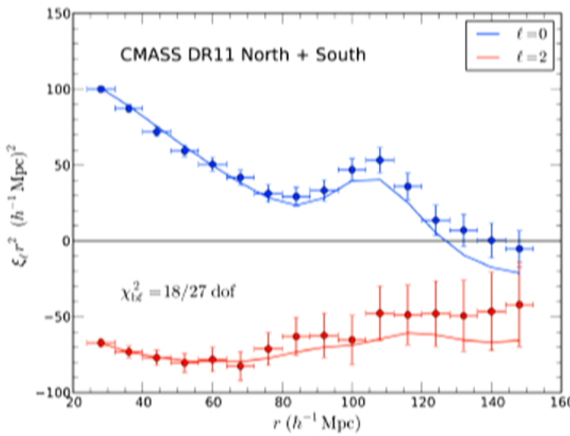
2D clustering

$$P_\ell(k) = \frac{2\ell+1}{2}\int_{-1}^{1} d\mu\, P(k,\mu)\mathcal{L}_\ell(\mu) \qquad \xi_\ell(r) = \frac{2\ell+1}{2}\int_{-1}^{1} d\mu\, \xi(r,\mu)\mathcal{L}_\ell(\mu)$$



Beutler et al. (2014)



Samushia et al. (2014)

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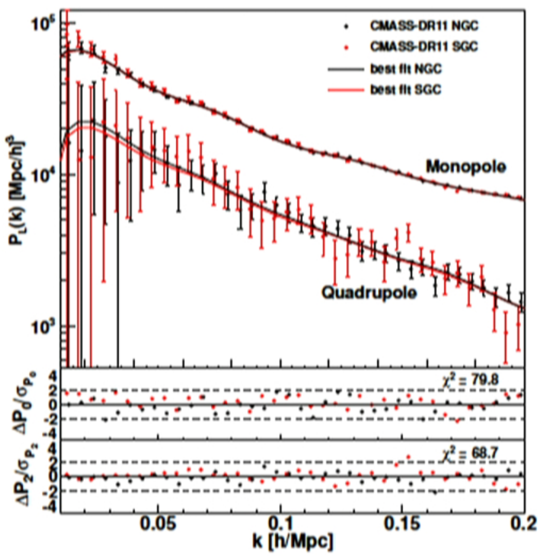
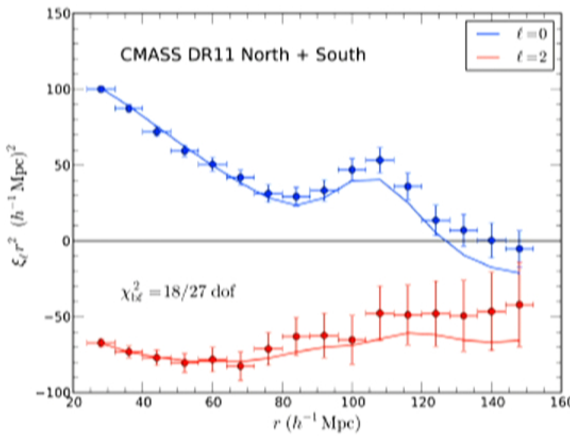


Beutler et al. (2014)



Samushia et al. (2014)

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Modeling the power spectrum

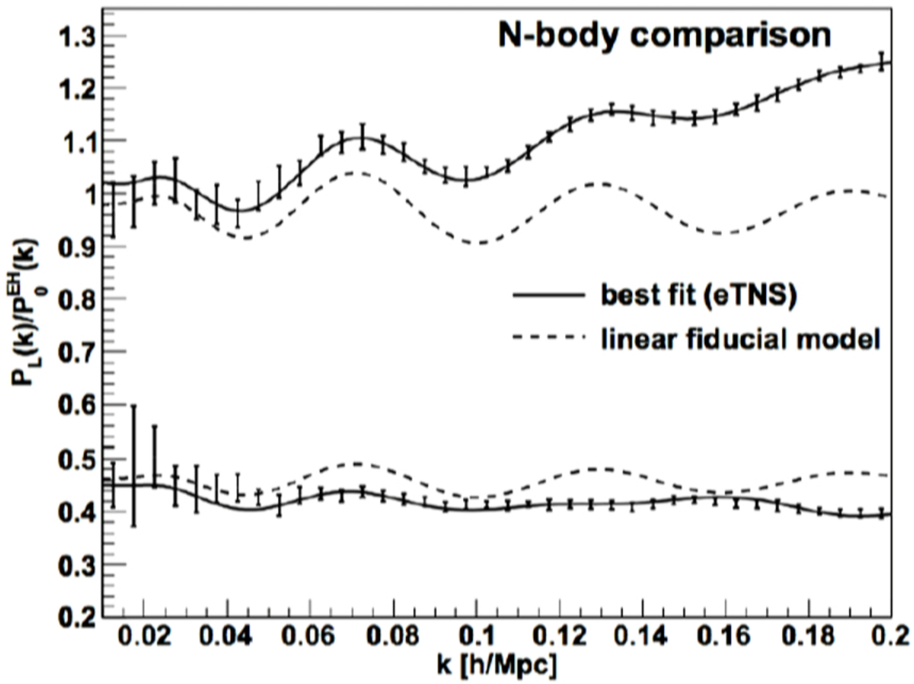
Our power spectrum model is based on renormalized perturbation theory (Taruya et al. 2011, McDonald & Roy 2009, Saito et al. 2014)

$$\begin{aligned} P_{\rm g}(k,\mu) = \exp\left\{-(fk\mu\sigma_v)^2\right\}\big[&P_{{\rm g},\delta\delta}(k) \\ &+ 2f\mu^2 P_{{\rm g},\delta\theta}(k) + f^2\mu^4 P_{\theta\theta}(k) \\ &+ b_1^3 A(k,\mu,\beta) + b_1^4 B(k,\mu,\beta)\big], \end{aligned}$$

with

$$\begin{aligned} P_{{\rm g},\delta\delta}(k) = \; & b_1^2 P_{\delta\delta}(k) + 2b_2 b_1 P_{b2,\delta}(k) + 2b_{s2} b_1 P_{bs2,\delta}(k) \\ & + 2b_{3\rm nl} b_1 \sigma_3^2(k) P_{\rm m}^{\rm L}(k) + b_2^2 P_{b22}(k) \\ & + 2b_2 b_{s2} P_{b2s2}(k) + b_{s2}^2 P_{bs22}(k) + N, \\ P_{{\rm g},\delta\theta}(k) = \; & b_1 P_{\delta\theta}(k) + b_2 P_{b2,\theta}(k) + b_{s2} P_{bs2,\theta}(k) \\ & + b_{3\rm nl}\sigma_3^2(k) P_{\rm m}^{\rm lin}(k), \end{aligned}$$

Clustering measurements – power spectrum



Beutler et al. (2014)

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Clustering measurements – power spectrum

- Since the survey window multiplies the configuration density field, it results in a convolution in Fourier-space.
- To account for the window function effect we can deconvolve the data or convolve the model.
- The convolution integral is

$$P^{\rm conv}(\vec{k}) = \int d\vec{k}' P^{\rm true}(\vec{k}')|W(\vec{k}-\vec{k}')|^2 - \frac{|W(\vec{k})|^2}{|W(0)|^2}\int d\vec{k}' P^{\rm true}(\vec{k}')|W(\vec{k}')|^2$$

- A straight forward calculation of this integral would have the complexity $\mathcal{O}(N^2_{\rm modes})$. But if the window function is compact, this can be simplified considerably.

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Clustering measurements – power spectrum

- We can express the window function convolution in terms of the power spectrum multipoles as:

$$P_\ell^{\rm conv}(k) = 2\pi \int dk' k'^2 \sum_L P_L^{\rm true}(k') |W(k,k')|^2_{\ell L}$$
$$- 2\pi \frac{|W(k)|^2_\ell}{|W(0)|^2_0} \int dk' k'^2 \sum_L P_L^{\rm true}(k') |W(k')|^2_L \frac{2}{2L+1}$$

- The equation above only contains the mode amplitude $|\vec{k}|$ instead of the mode vector.
- The integral constraint comes from the fact that we assumed that the mean density of the survey is equal to the mean density of the Universe. Sample variance tells us that this is wrong...
- Therefore our measured power spectrum has the condition $P(k \to 0) = 0$ by design.
- The window function couples the $k = 0$ mode with larger modes, depending on the width of the window function.

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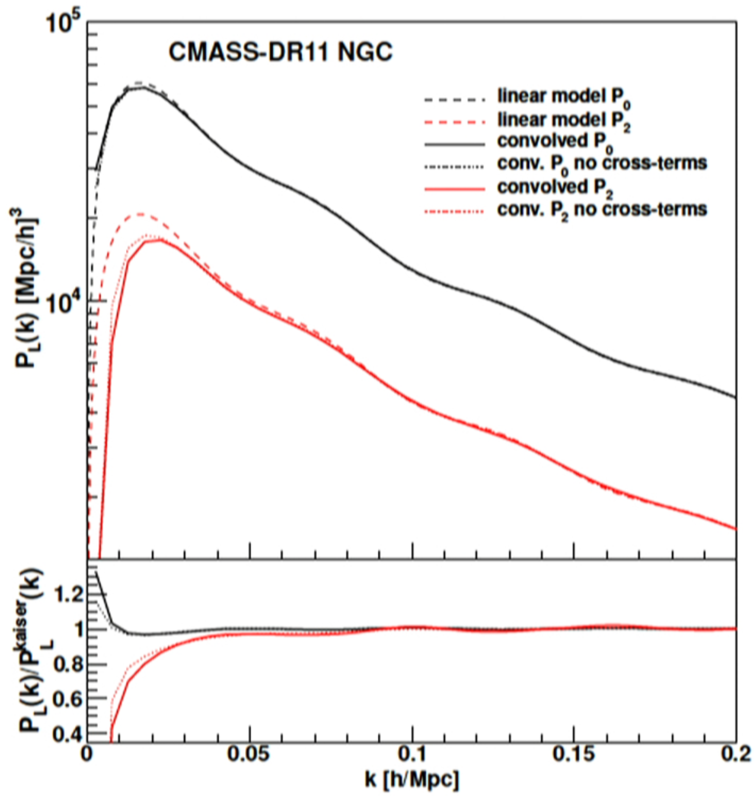
Clustering measurements – power spectrum



Beutler et al. (2014)

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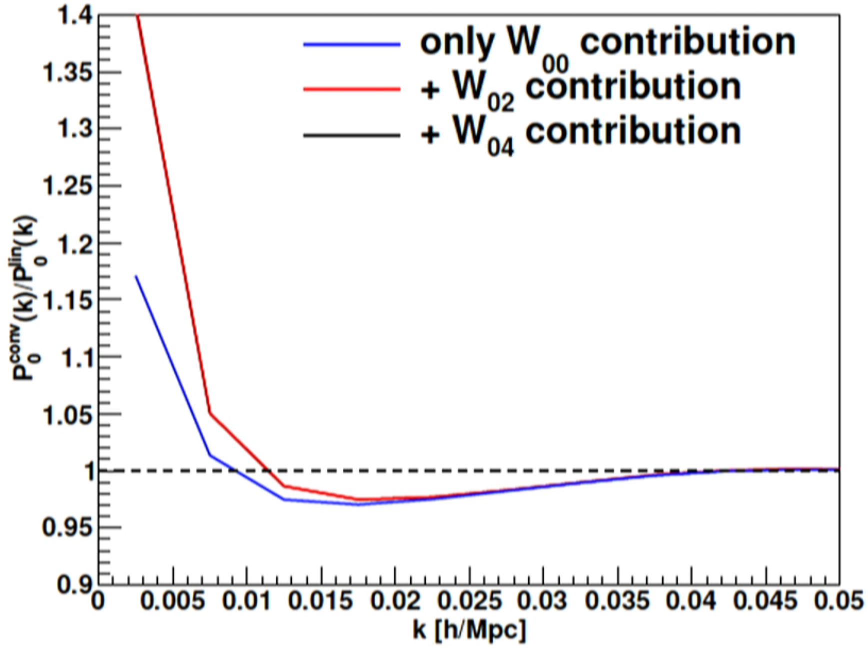
Clustering measurements – power spectrum

Ignoring the window function can lead to biased constraints



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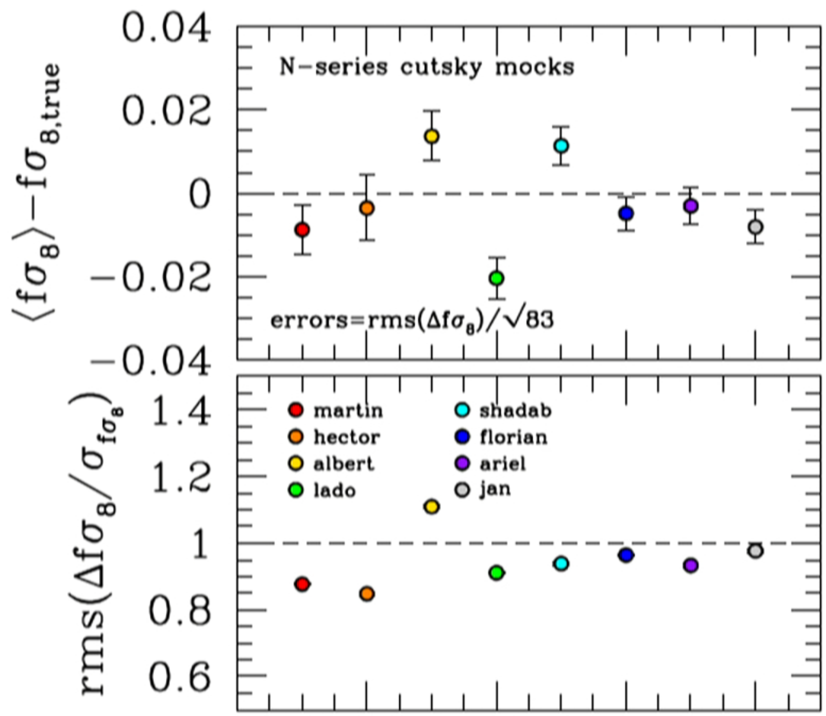
Clustering measurements – blind mock challenge



Chuang et al. (2014), Sanchez et al. (2014), Wang et al. (2014), Shadab et al. (2015)

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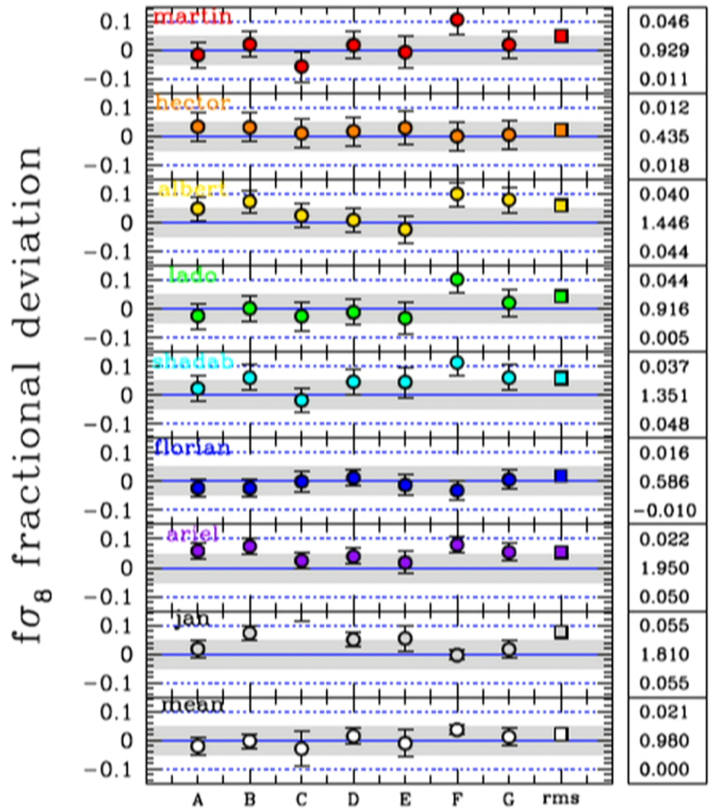
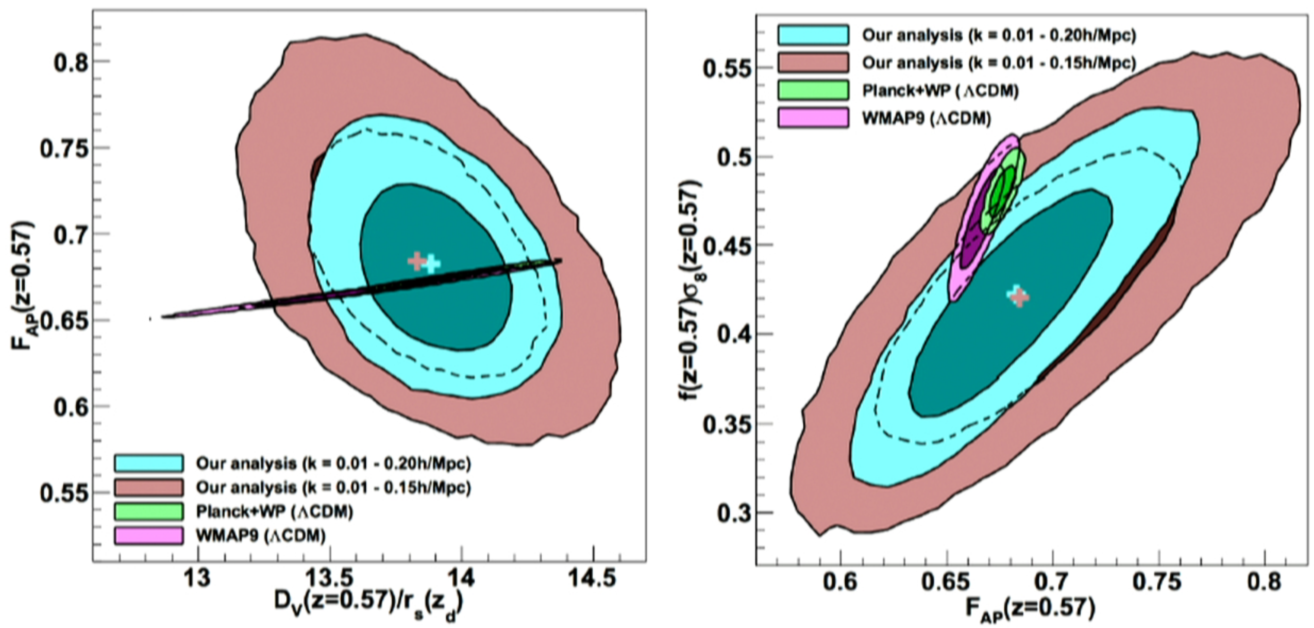


Tinker et al. (in prep.)

2D clustering



Beutler et al. (2014)

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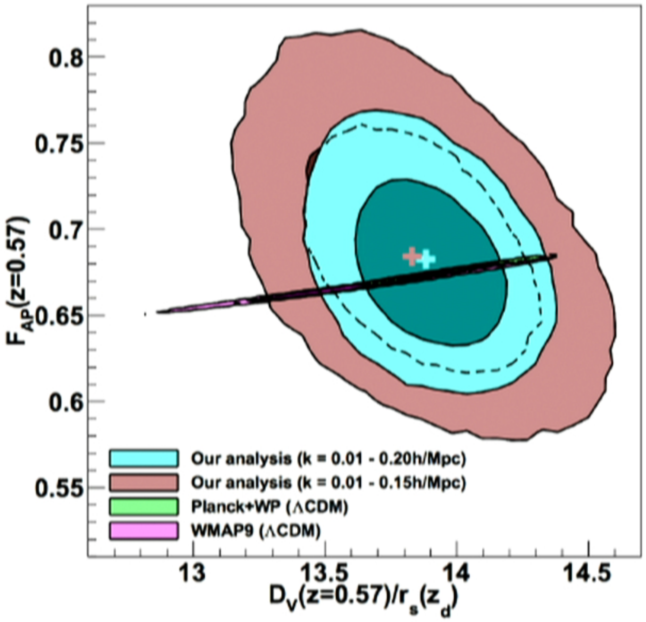
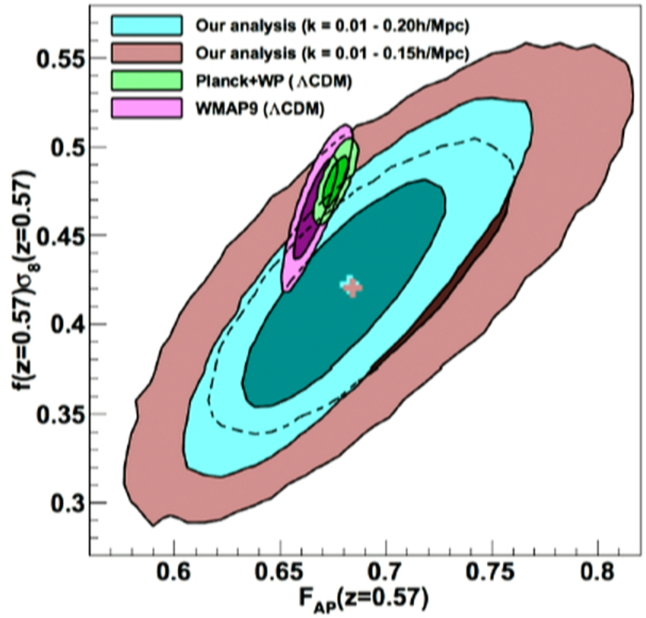
2D clustering





Beutler et al. (2014)