Measuring RSD in deep redshift surveys

Rossana Ruggeri
Collaborators: Will J. Percival, Héctor Gil Marín et al.
ICG, Portsmouth

April 5, 2017

Outline of my talk

Observational cosmology

- The galaxy power spectrum
- Observational effects
- Redshift space distortions

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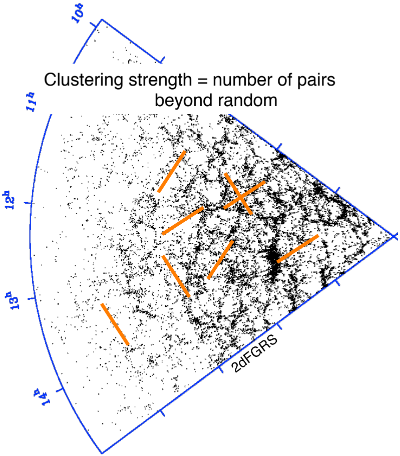
Measuring the redshift space distortions in eBOSS

- Redshift binning vs redshift weights
- Optimal redshift weights
- Preliminary results

Observational cosmology: what does clustering mean?



$$dP = \rho^2 \left[1 + \xi(r)\right] dV_1 dV_2 \qquad (1)$$

Observational cosmology: formal clustering definitions

- the "probability of seeing structure" can be recast in terms of the overdensity
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- The correlation function of the field,
$$\xi(r) = \langle \delta(\mathbf{x})\delta(\mathbf{x} + \mathbf{r}\ )\rangle \tag{3}$$
or its Fourier analogue, the power spectrum,
$$P(k) = \int d^3\mathbf{r}\, \xi(r) e^{-i\mathbf{k}\cdot\mathbf{r}} \tag{4}$$
which describes the amplitude of the fluctuations as a function of scale k.

Observational cosmology: the galaxy power spectrum

$$P_{gal}(k, \mu, z) = k^n T^2(k) D^2(z)[b(z) + f(z)\mu^2]^2$$
$$\mu = \mathbf{k} \cdot \hat{\mathbf{n}}/\mathrm{k}; \quad \hat{\mathbf{n}} = \mathrm{line-of-sight} \tag{5}$$

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- k^n (standard inflation)
- $T^2(k) \to \Omega_m,\ m_\nu$ ..

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- galaxy bias $\to P_g = b(z)P_{dm}$
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Observational effects $\leftrightarrow k, \mu, f(z)$

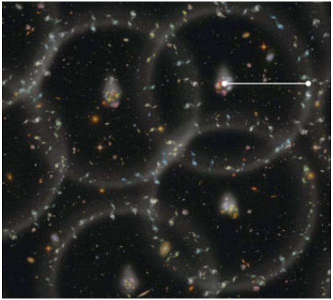
- Redshift Space Distortions (RSD)
- Alcock-Paczynksy effect
- (Baryonic acoustic oscillations)

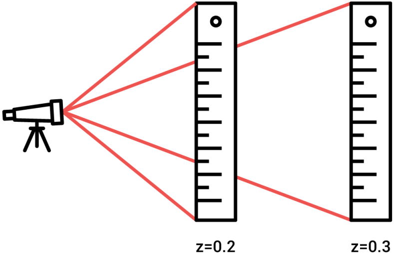
The Baryonic Acoustic Oscillation: standard ruler

BAO as a standard ruler to better understand the nature of the acceleration.

$$r_s = (1/H_0\Omega_m^{1/2}) \int_0^{a_*} da \frac{c_s}{(a + a_{eq})^{1/2}};$$

$$k_{bao} = 2\pi/r_s \sim 0.06h/Mpc;$$





The Alcock-Paczynksy test

Galaxy distances are inferred from galaxy redshifts: using a wrong set of fiducial cosmological parameters to convert redshifts into distances introduces artificial anisotropy!

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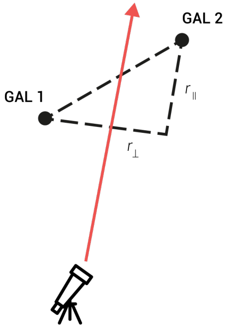
Known as Alcock-Paczynski distortion, (Alcock & Paczynski 1979).

- The effect scales differently along and perpendicular to the line-of-sight direction

$$\alpha_\parallel \propto \frac{H^{\rm fid}(z)}{H(z)}, \qquad \alpha_\perp \propto \frac{D_A(z)}{D_A^{\rm fid}(z)} \tag{6}$$

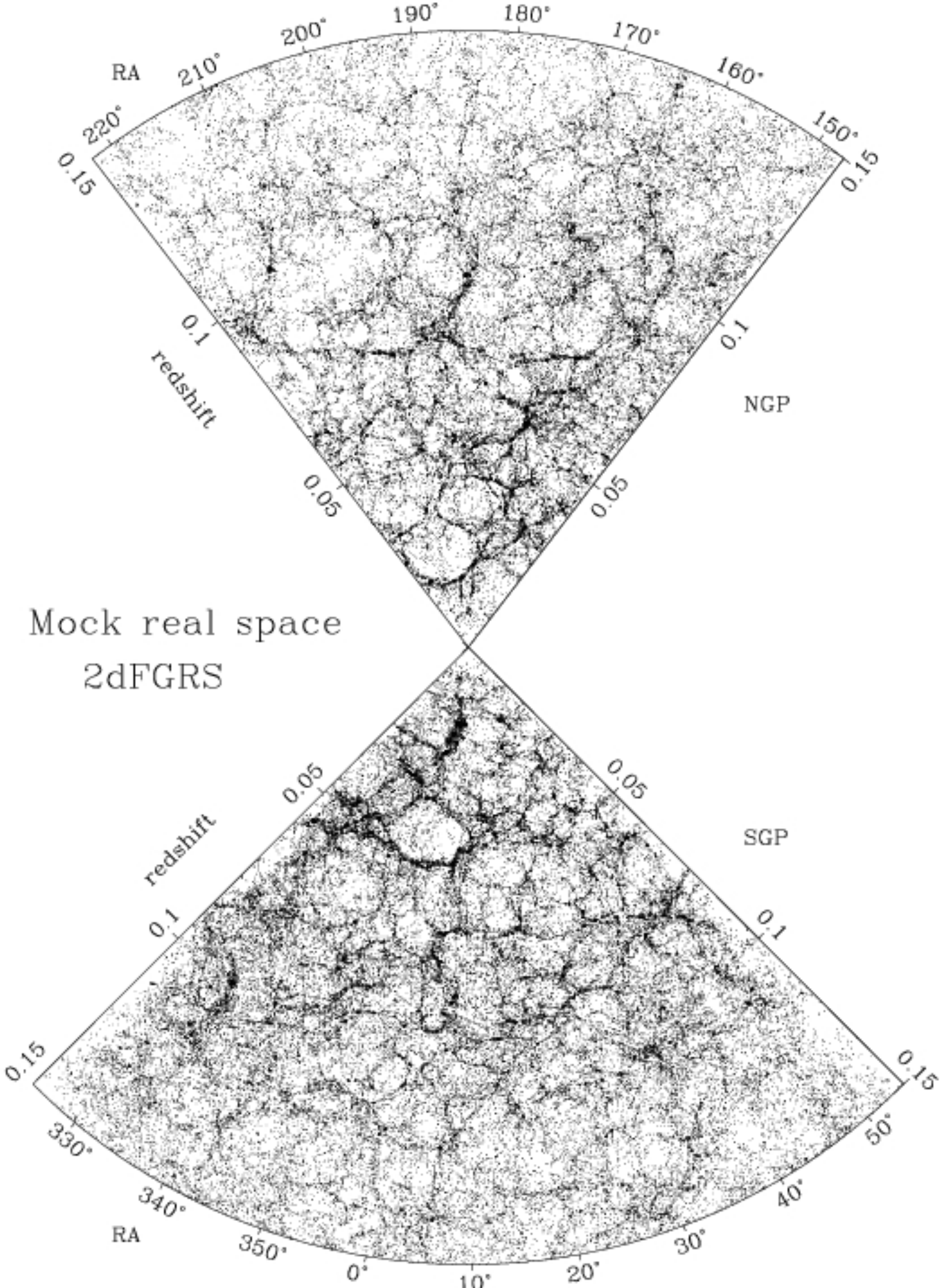
The Redshift Space distortions

When making a 3D map of the Universe the radial distance is obtained from observed redshift.

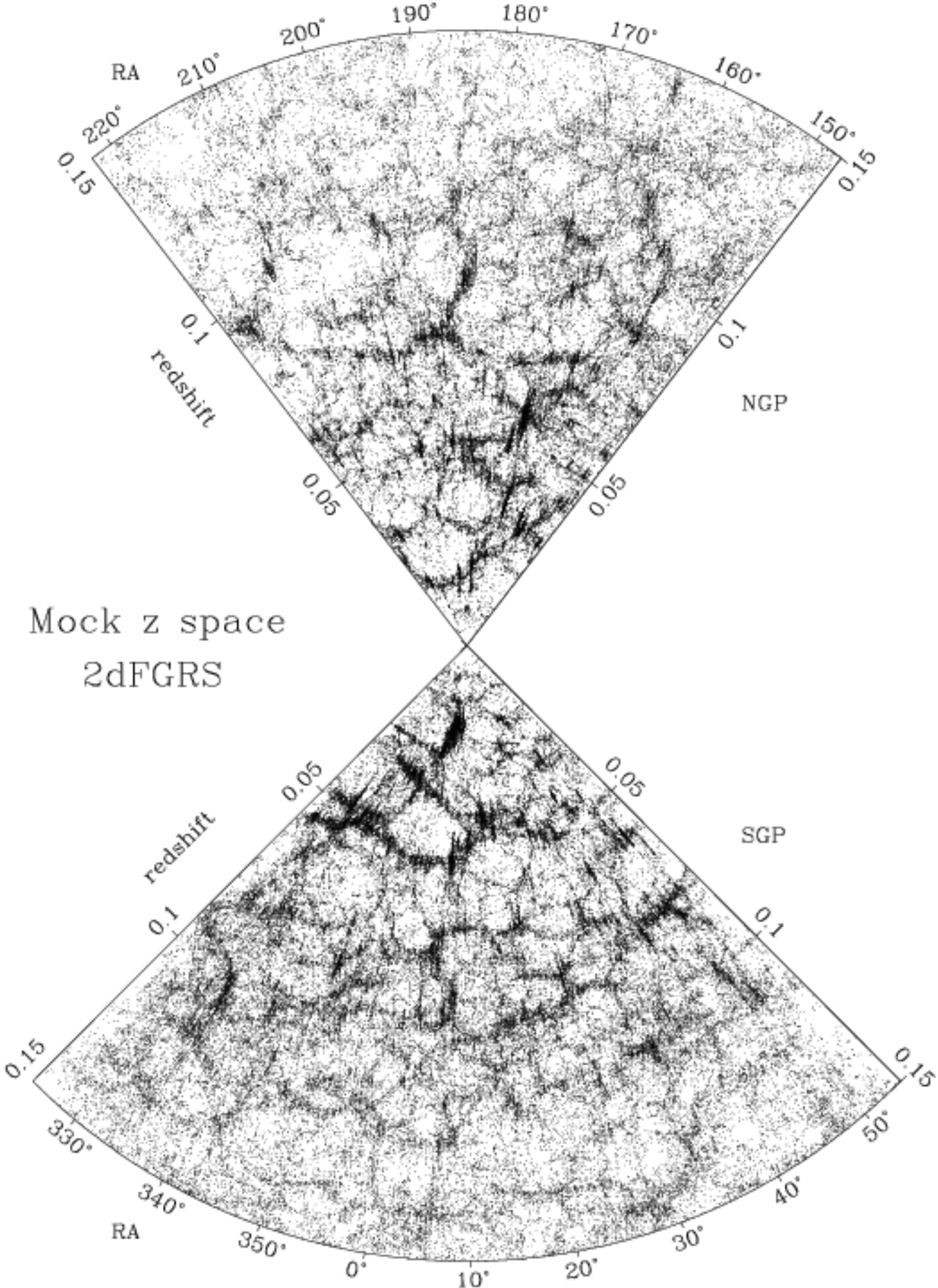


Observed redshift has two components: the Hubble expansion and peculiar motion of galaxies, $s(r) = \mathbf{r} - v_r(r)\ \hat{\mathbf{r}}$.

Line-of-sight selects out a special direction and breaks rotational symmetry of underlying correlations.



RA
220°
210°
200°
190°
180°
170°
160°
150°
0.15
0.1
0.05
redshift
NGP
Mock real space
2dFGRS
SGP
0.05
0.1
0.15
redshift
330°
340°
350°
0°
10°
20°
30°
40°
50°
RA



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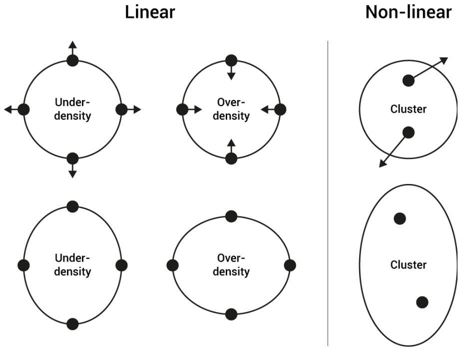
Linear regime $\rightarrow$ Coherent infall over-dense regions *squashed* and under-dense regions *stretched* along the line of-sight.

Non Linear regime $\rightarrow$ random (thermal) motion, (fingers-of-god)



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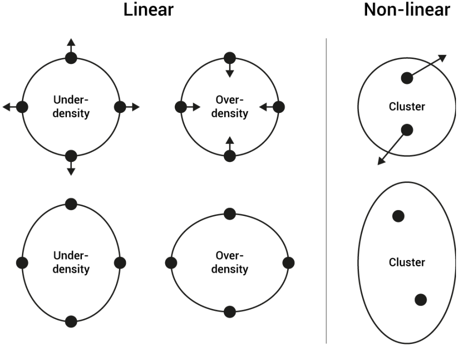

At large scale the galaxies move because cosmological structure is growing through gravity. This growth is the dominant source of RSD.

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- Linear perturbation theory

$$\begin{aligned} \partial\delta/\partial t + \theta = 0; \quad \theta = \nabla\mathbf{u}\ \ (\mathit{mass\ conservation}) \\ \partial\mathbf{u}/\partial t + \mathcal{H}\mathbf{u} = -\nabla\phi\ \ (\mathit{momentum\ conservation}) \end{aligned} \tag{7}$$

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It is convenient to expand the angular dependence on Legendre Polynomials, e.g. $P_0(k) = \left(b^2 + \frac{2}{3}bf + \frac{1}{5}f^2\right) P(k)$,

Modelling the RSD in the galaxy power spectrum: beyond linear approximation;

- Full mapping;
- Non linear perturbation theory

$$\partial\delta/\partial t + \theta = -\int \mathrm{d}^3\mathbf{k}_1 \mathrm{d}^3\mathbf{k}_2 \delta_D(\mathbf{k}-\mathbf{k}_{12})\alpha(\mathbf{k}_1,\mathbf{k}_2)\theta(\mathbf{k}_1,t)\delta(\mathbf{k}_2,ts)$$

$$\partial\theta/\partial t + \mathcal{H}\theta + 3/2\Omega_m H^2\delta = -\int \mathrm{d}^3\mathbf{k}_1 \mathrm{d}^3\mathbf{k}_2 \delta_D(\mathbf{k}-\mathbf{k}_{12}) \times \beta(\mathbf{k}_1,\mathbf{k}_2)\theta(\mathbf{k}_1,\tau)\theta(\mathbf{k}_2,\tau)$$

expand density and velocity fields about the linear solutions;

$$\delta_n(\mathbf{k}) = \int \mathrm{d}^3\mathbf{q}_1 ... \int \mathrm{d}^3\mathbf{q}_n\, \delta_D(\mathbf{k}-\mathbf{q}_{1..n}) F_n(\mathbf{q}_1,...,\mathbf{q}_n)\delta_1(\mathbf{q}_1)..\delta_1(\mathbf{q}_n),$$

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Modelling the RSD in the galaxy power spectrum: beyond linear approximation;

$$P^s(k) = [P_{\delta\delta} + 2f\mu^2 P_{\delta\theta} + f^2\mu^4 P_{\theta\theta} + A(k\mu) + B(k\mu)] D_{\rm FOG}[k\mu f\sigma_v];$$

(see Scoccimarro 2004; Taruya 2010;)
More improvements,

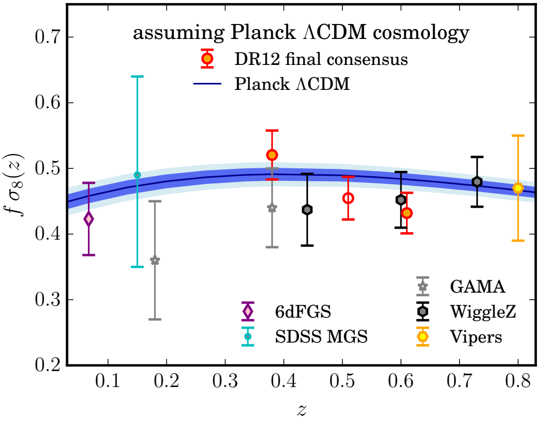
- non linear and non local galaxy bias (see Chan 2012)
- beyond standard perturbation theory

Future and current surveys analysis goals

- Improve the methodology used to analyse data
- Development of fast method to measure anisotropic signal
- **How to combine data from different volumes within the surveys.**

Current constrains from RSD on $f(z)$, $D(z)$, $b(z)$...

Constrain from different redshift bin of redshift evolving quantities



(S. Alam et al. 2016)

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Optimal redshift weights as smoother windows on data,

- compression of the information in the redshift direction
- sensitivity to evolution with redshift
- Fisher prediction $\sim 30\%$ better than actual results
- decrease computational effort for large data sets

The search for optimal weights

Linear compression of a data-set $\mathbf{x}$, Gaussian distributed, with mean μ and covariance C,

$$y = \mathbf{w}^T \mathbf{x}. \tag{9}$$

For a single parameter θ_i,

$$F_{ii} = \frac{1}{2} \left(\frac{\mathbf{w}^T C_{,i} \mathbf{w}}{\mathbf{w}^T C \mathbf{w}} \right)^2 + \frac{\left(\mathbf{w}^T \mu_{,i}\right)^2}{\mathbf{w}^T C \mathbf{w}}, \tag{10}$$

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We maximise F_{ii} w.r.t $\mathbf{w}$ assuming C a priori, $C_{,i} = 0$ and the only non-trivial eigenvector is

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For $P(k)$, $\mathbf{x}$ is formed by measurements of δ^2.

Cosmological model

- We investigate the $\Omega_m(z)$ relation about ΛCDM model

$$\frac{\Omega_m(z)}{\Omega_{m,\mathrm{fid}}(z)} = q_0(1 + q_1 y(z) + \frac{1}{2} q_2 y(z)^2), \tag{12}$$

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Redshift weighting assuming unknown distance-redshift relation

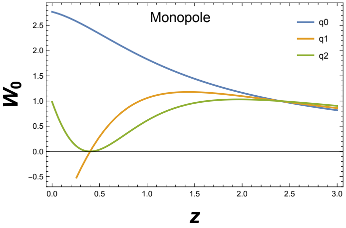
- combining AP effect with RSD ($\alpha_{\parallel}$, $\alpha_{\perp}$, b, σ_8, f)

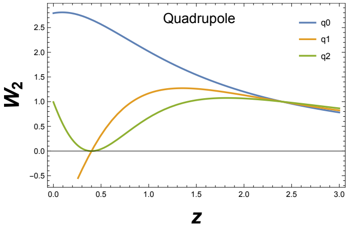
Power Spectrum weights, when D_A is assumed known (b, σ_8, f)

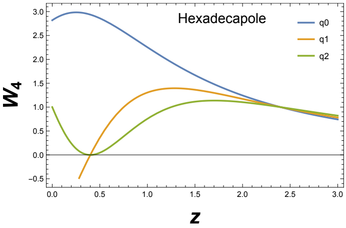
$$P^s(\mathbf{k}) = (b + f\mu_{\mathbf{k}}^2)^2 P(k) \quad (13)$$

(Kaiser, 1987)

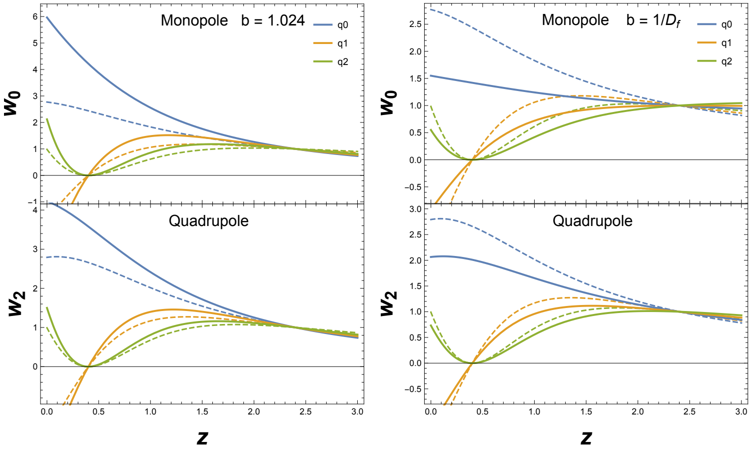
$$\Omega_m(z, q_0, q_1, q_2)$$





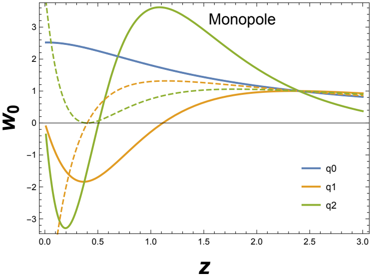


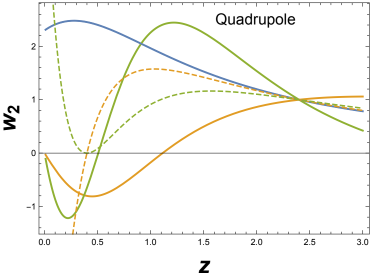
The dependence on the fiducial bias model

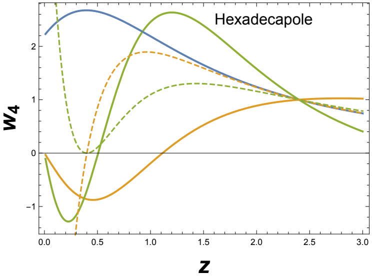


Power Spectrum weights, when D_A is unknown

$$P_\ell(k) = \frac{2\ell + 1}{2} \int_{-1}^{1} d\mu \, P(k^t, \mu^t) \mathcal{L}_\ell(\mu) \tag{14}$$







eBOSS analysis

The quasar sample represents an important sample-test to investigate the improvements possible through the optimal weights. Characterized by a wide redshift range, $(0.9 - 2.2)$, and lower density $82.6/\mathrm{deg}^2$;

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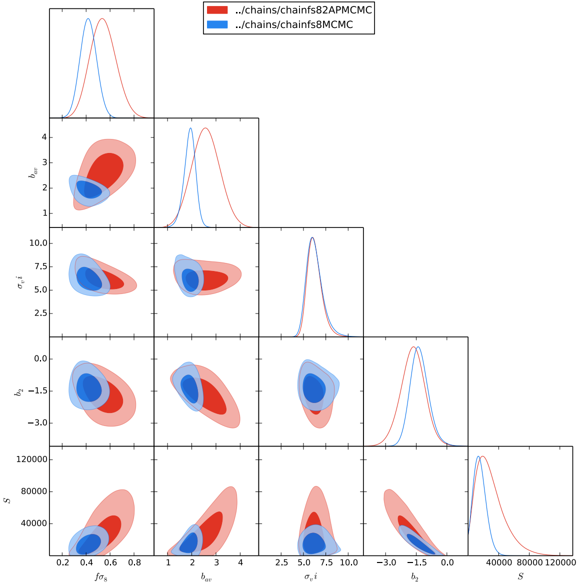
The extended Baryon Oscillation Spectroscopic Survey (eBOSS): testing redshift space distortions at $z \sim 1.55$ on the QSO optimally weighted multipoles.

Rossana Ruggeri[1]*, Will J. Percival [1], Héctor Gil-Marín, Eva-Maria Mueller[1] et eBOSS friends

[1] *Institute of Cosmology & Gravitation, University of Portsmouth, Dennis Sciama Building, Portsmouth, PO1 3FX, UK*

Preliminary results: $[f\sigma_8]_{av}$ and b_{av}



Preliminary results: q_0, q_1, q_2, σ_v and b

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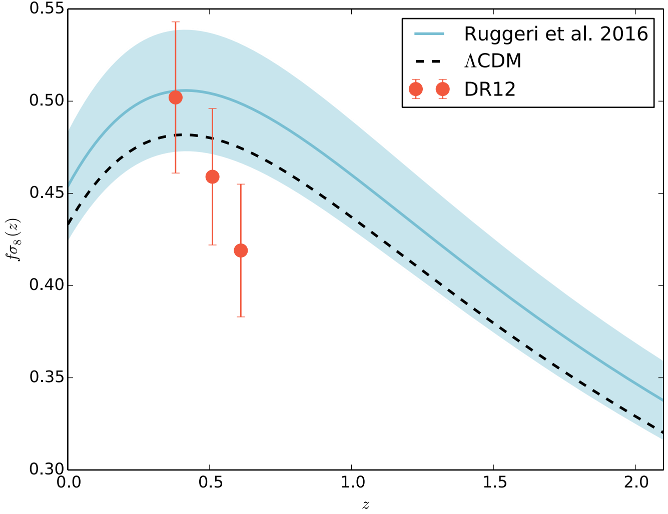

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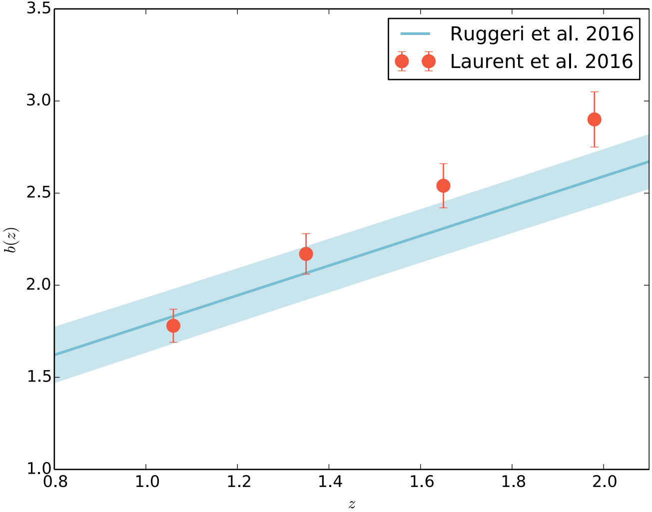
$$b(z) = b(z_p) + \frac{\partial b}{\partial z}\Big|_{z_p}(z - z_p)$$



Conclusion

- We investigate departures in $\Omega_m(q_i, z)$ about Λ CDM.
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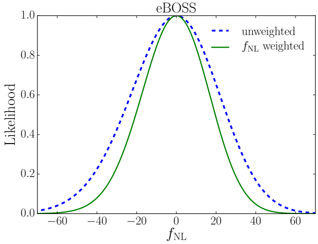
DESI/EUCLID

- 20 - 30 million objects, $0.5 < z < 3.5$; 15-18,000 deg^2;
- Traditional analysis: e.g for DESI, to be repeated on 35 redshift bins, neglecting cross correlation between different volumes.
- Optimal weights technique, as a more efficient and accurate alternative would enhance S/N, considering all galaxy pairs.
- Weighting scheme: the method is flexible and works for other sets of parameters;

Alternative parametrization: Primordial non-Gaussianity from LSS

Scale dependent halo bias $b_{tot} = b + \Delta b$, $\Delta b(k) \propto f_{NL}/\alpha(k)$ (e.g. Dalai et al. 2008)
Very sensitive at large scales $\rightarrow$ Splitting the survey volume decreases the S/N at large scales
$30 - 40\%$ of improvements for eBOSS



Mueller, Percival & Ruggeri (2017)