Fourier space clustering analysis of the DR16 eBOSS quasar sample

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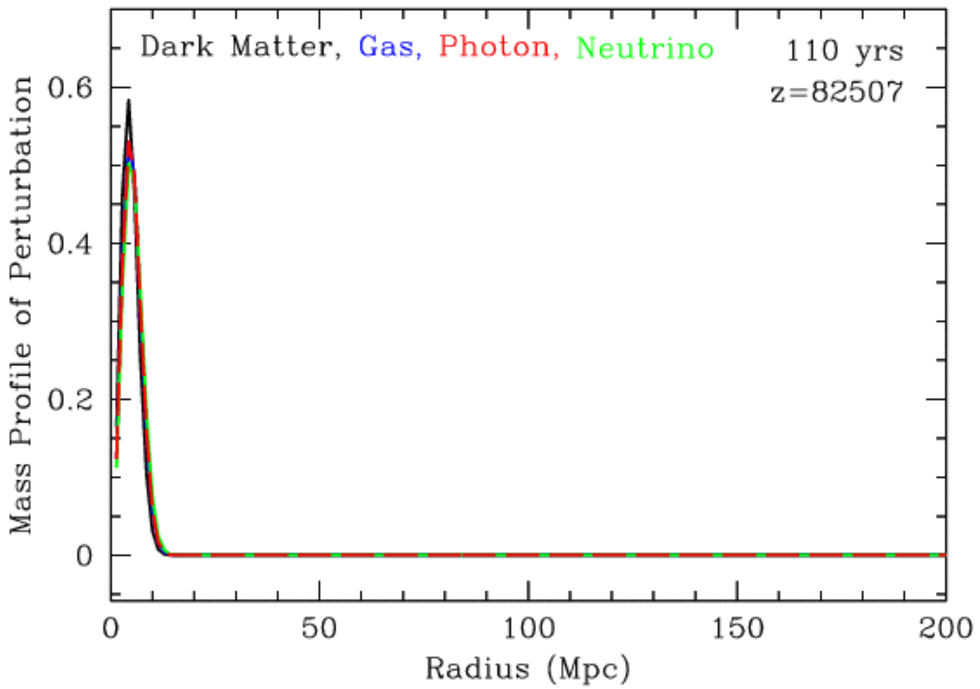
Baryon Acoustic Oscillations



From Eisenstein et al. (2014)

- Measurement of the position of the BAO peak (wiggles) in the correlation function (power spectrum) of the matter density field

$$\alpha_{iso} = \frac{D_V(z) r_{drag}^{fid}}{D_V^{fid}(z) r_{drag}}$$

or

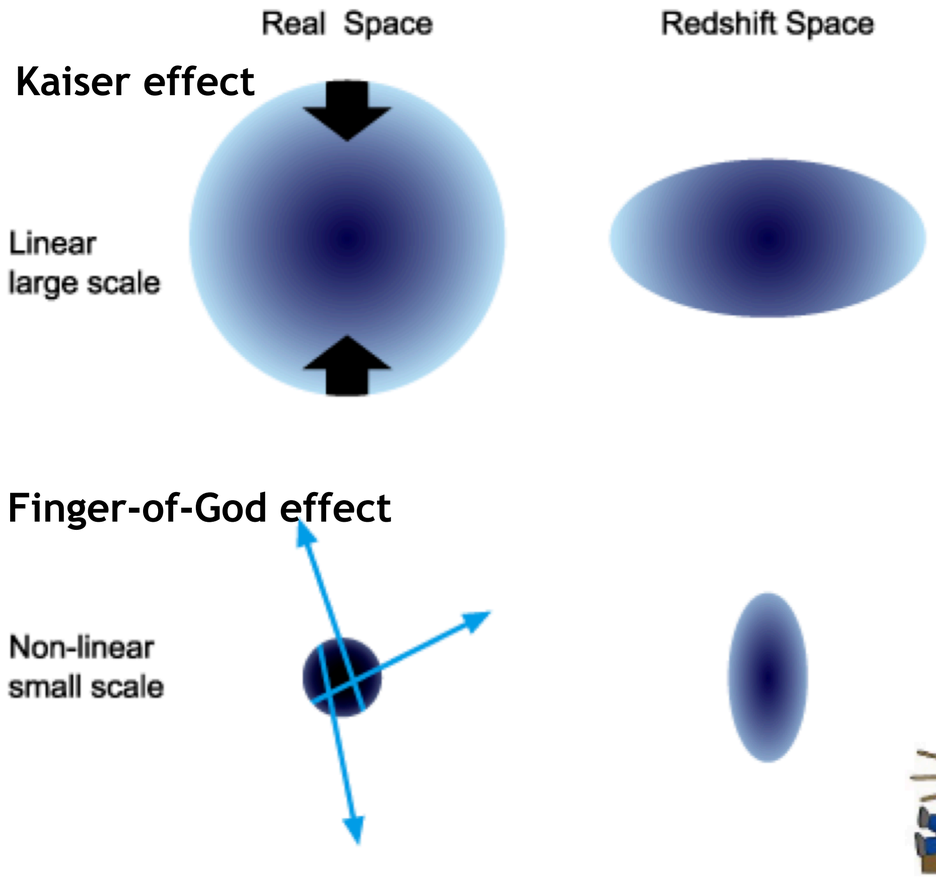
$$\alpha_{\parallel} = \frac{D_H(z) r_{drag}^{fid}}{D_H^{fid}(z) r_{drag}} \qquad \alpha_{\perp} = \frac{D_M(z) r_{drag}^{fid}}{D_M^{fid}(z) r_{drag}}$$

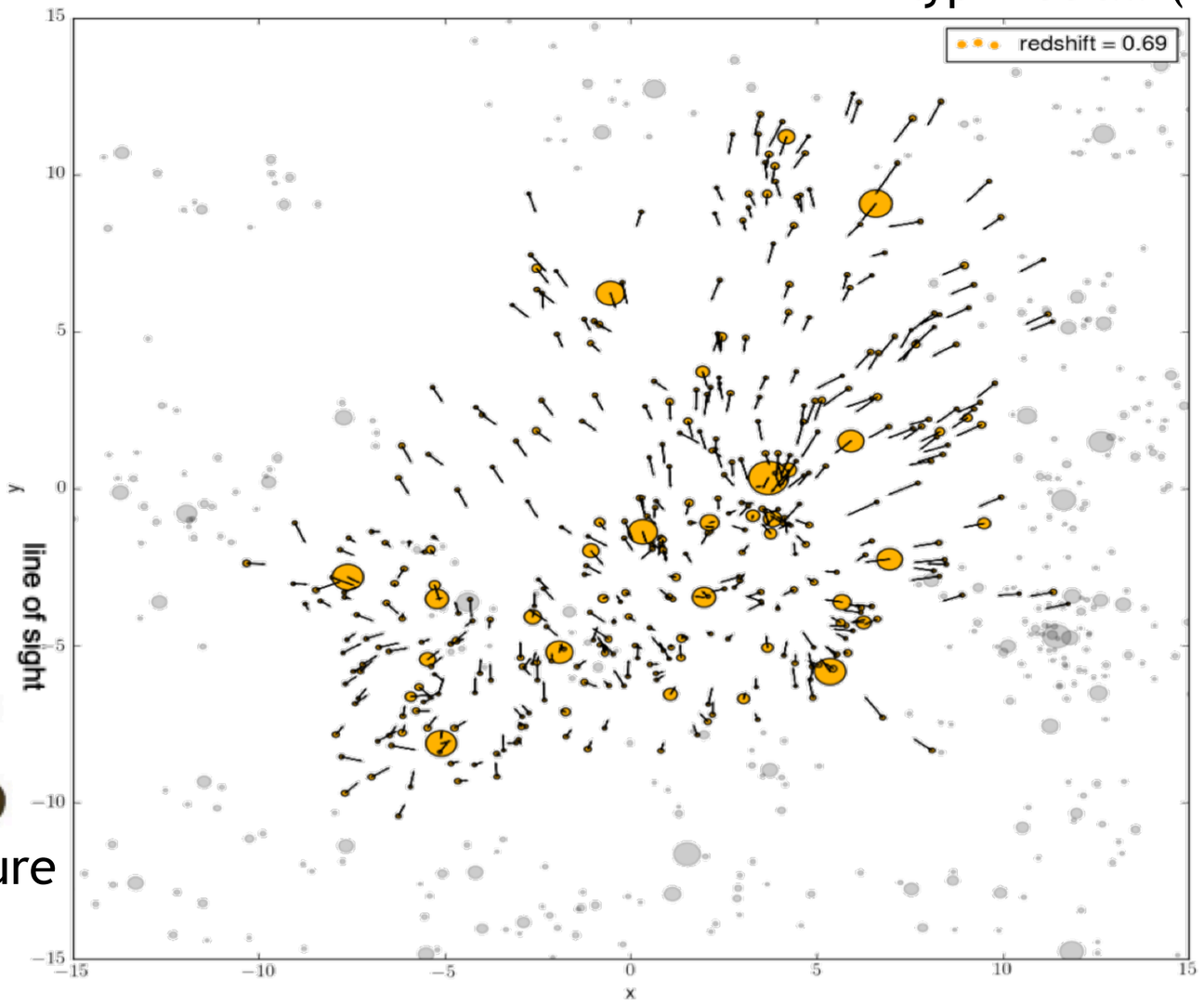
r_{drag} : Sound horizon at the end of the baryon drag epoch
D_V : Volume averaged distance
D_H : Hubble distance
D_M : Transverse comoving distance
‘fid’ : Quantities determined within fiducial cosmology

Redshift-Space Distortions

From MultiDark N-Body simulation Dark Matter only $M_{halo}>10^{12}M_{sun}$
Klypin et al. (2014)

- Effect along the line of sight due to **peculiar velocities** (Doppler effect)





Related to the linear growth rate of structure
$\Delta \cdot v = -f\delta$ (in linear theory)

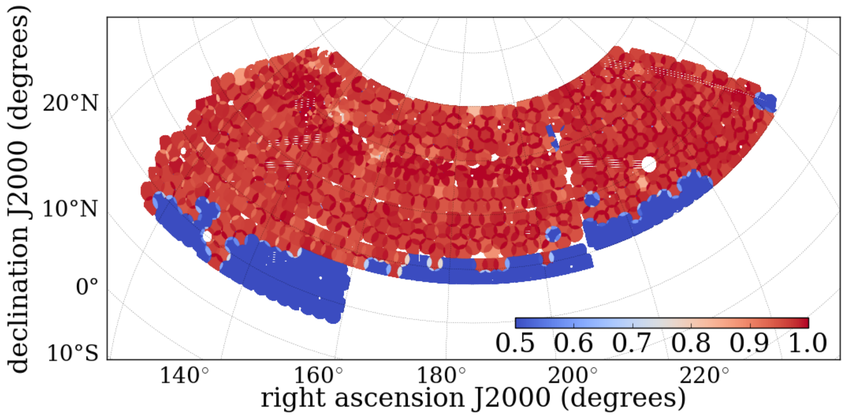
Data

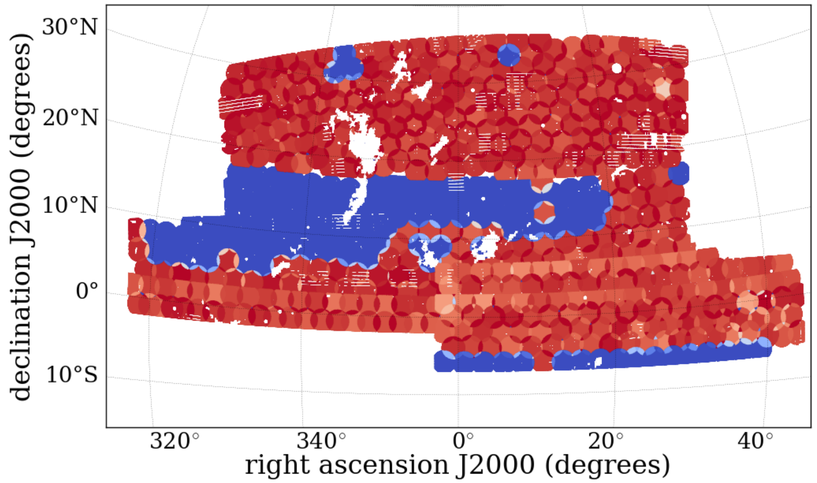
DR16 eBOSS quasar catalog

- Mean N(z) $[h/Mpc]^3$ ~ 1.74 10^{-5} (NGC) & 1.58 10^{-5} (SGC)
- Mean redshift ~ 1.48 [0.8, 2.2]
- ~340,000 quasars observed

Survey area [deg²]

	NGC	SGC	Total
DR14	1215	898	2213
DR16	2860	1839	4699





Data

Simulations

Nbody simulation : OuterRim

- L = 3 Gpc/h
- 10243^3 particles of 1.82 10^9 $M_\odot$
- Snapshot at z = 1.433

- 15 Different Halo Occupation Distribution (HOD)
- Different fractions of satellite
- 3 redshift smearing case:
    - No smearing
    - Gaussian smearing
    - “Realistic” smearing

+ Blind mock
(https://github.com/amjsmith/rescale-cosmology)

Mock challenge to test the model

EZ mocks (Effective Zel’dovich approximation)

- Same geometry as the data
- Much faster than Nbody simulation to compute
- 1000 realisations

Compute the covariance matrix
Test the observational systematic effects

Clustering analysis

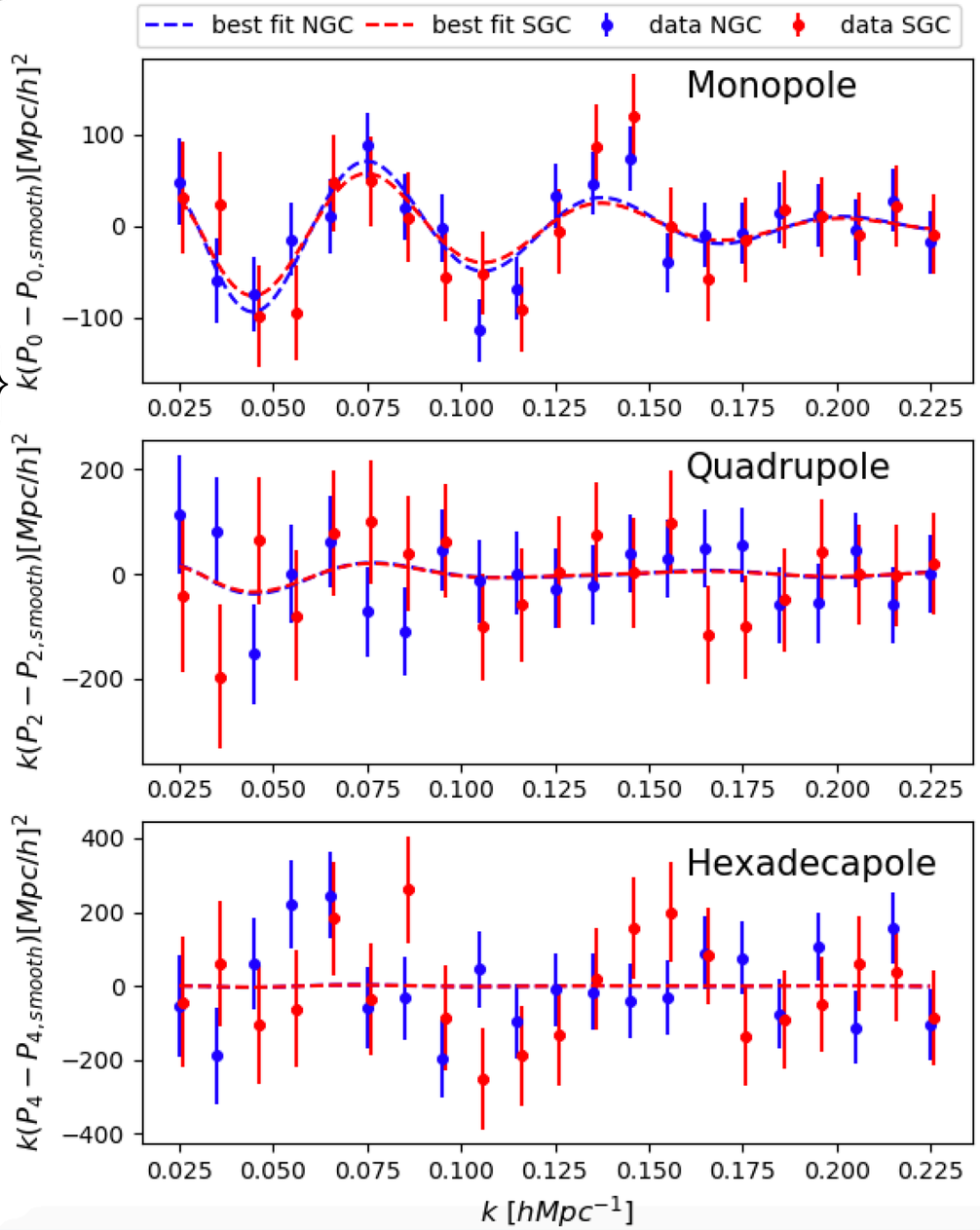
BAO modelling

Anisotropic

- k-range = [0.02,0.23] $[h\,.\,Mpc^{-1}]$
- Based on Bautista et al. 2017

$$P(k,\mu) = \frac{b^2[1+\beta\mu^2]^2}{1+\frac{(k\mu\Sigma_s)^2}{2}} \left\{ P_{sm}(k,\mu) + P_{peak}(k(\alpha_{\parallel,\perp}),\mu(\alpha_{\parallel,\perp}))e^{-k^2\Sigma_{nl}^2} \right\}$$

- Work with multipole l=0,2,4 of power spectrum
- The sigmas are fixed from mock challenge
- 18 free parameters
  - 2 dilation scale parameters $\alpha_\perp$, $\alpha_\parallel$
  - 2 bias (1 per cap)
  - 18 broadband terms (3 per multipole and per cap)



Clustering analysis

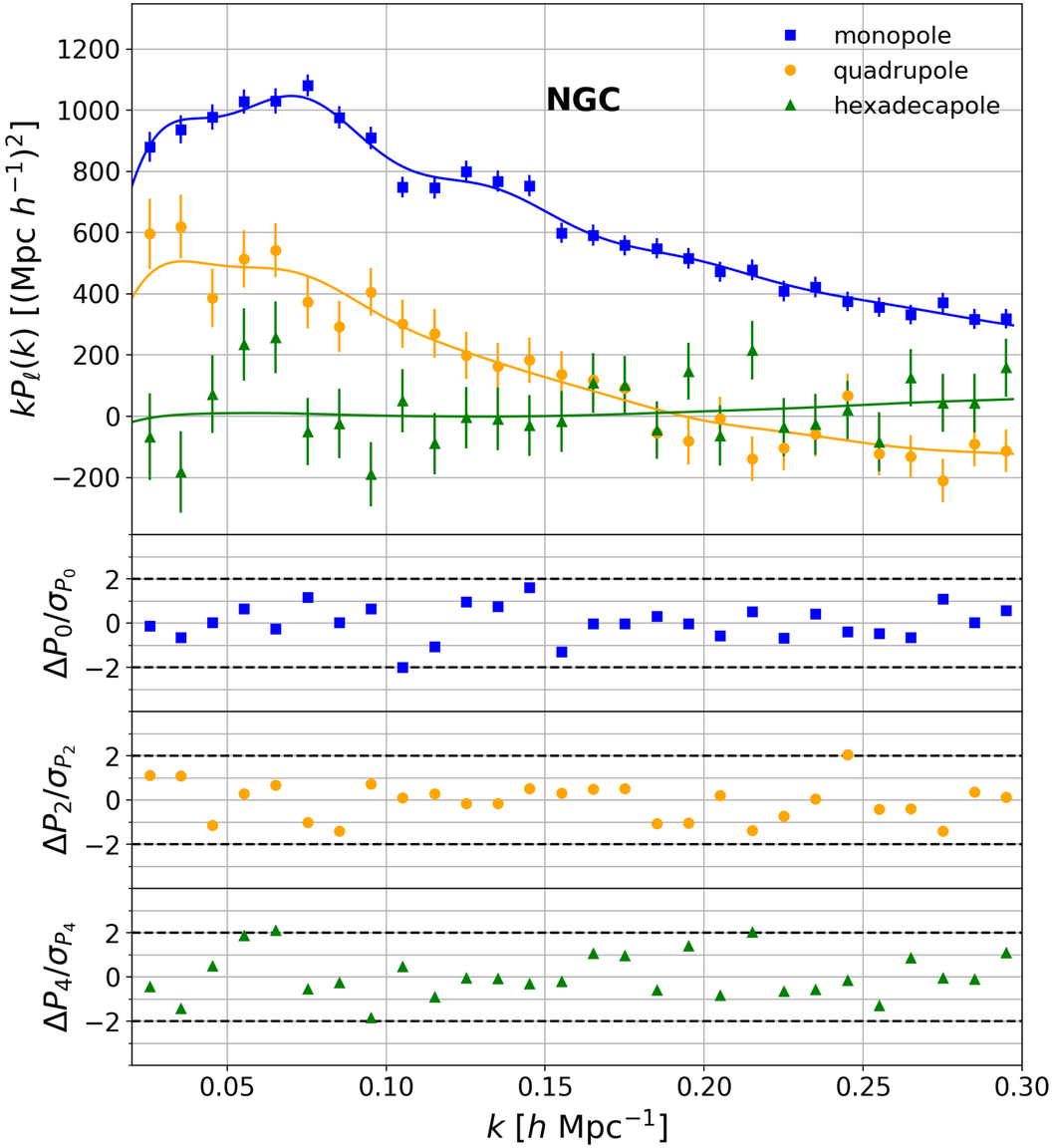
Full shape modelling

Model: (https://github.com/adematti)

- TNS model (based on Beutler et al. 2016)
- RegPT at 2loop
- Window function (Wilson et al. 2015)
- Wide angle correction (Beutler et al. 2018)
- Radial Integral Constraints (de Mattia et al. 2019)

Parameters:

- Linear growth rate of structure : f
- Alcock-Paczynski : $\alpha_\perp$, $\alpha_\parallel$
- Finger-of-God and redshift smearing : σ_v , a_{vir}
- Bias : b_1 , b_2
- Shot noise : A_g



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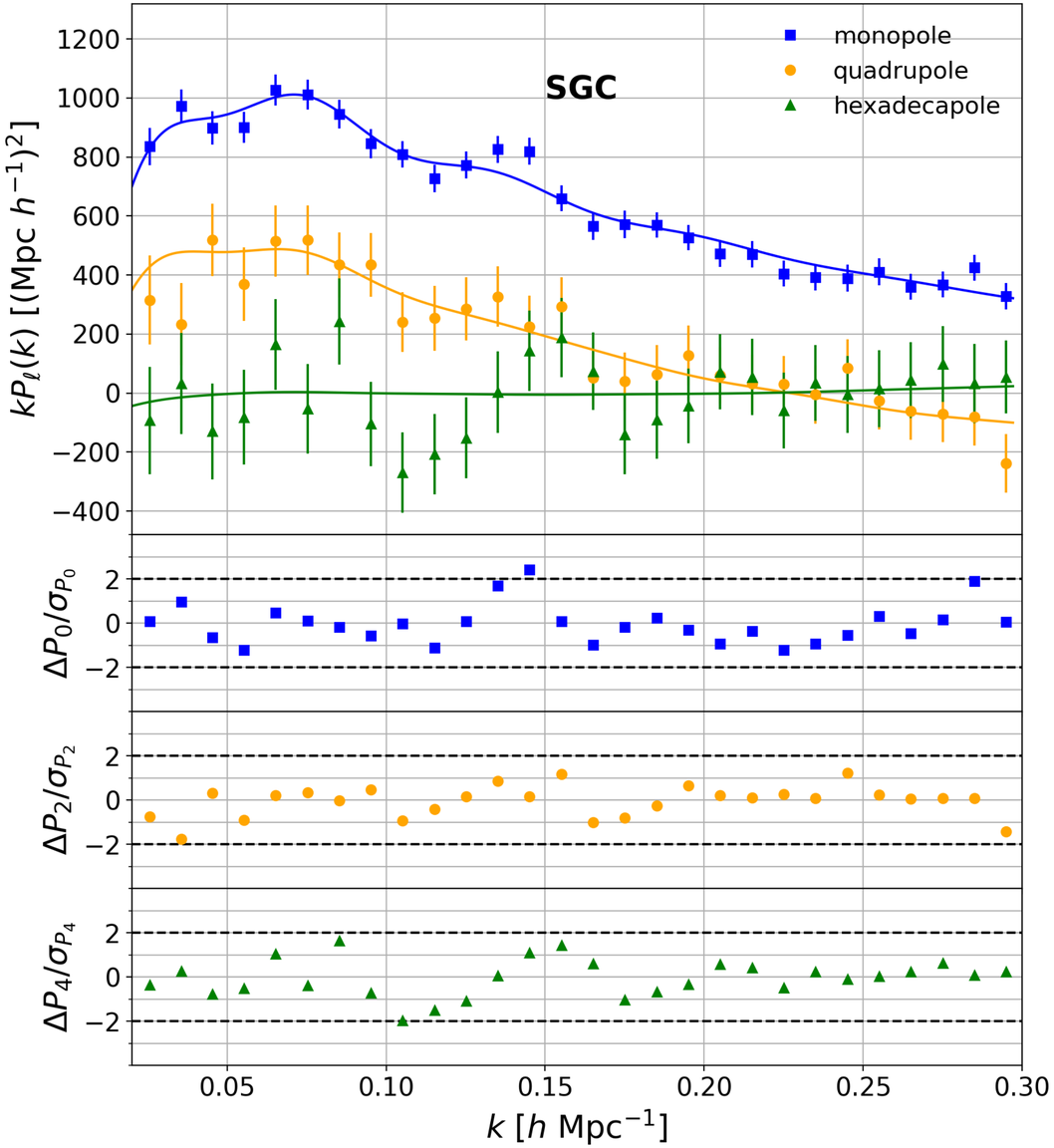
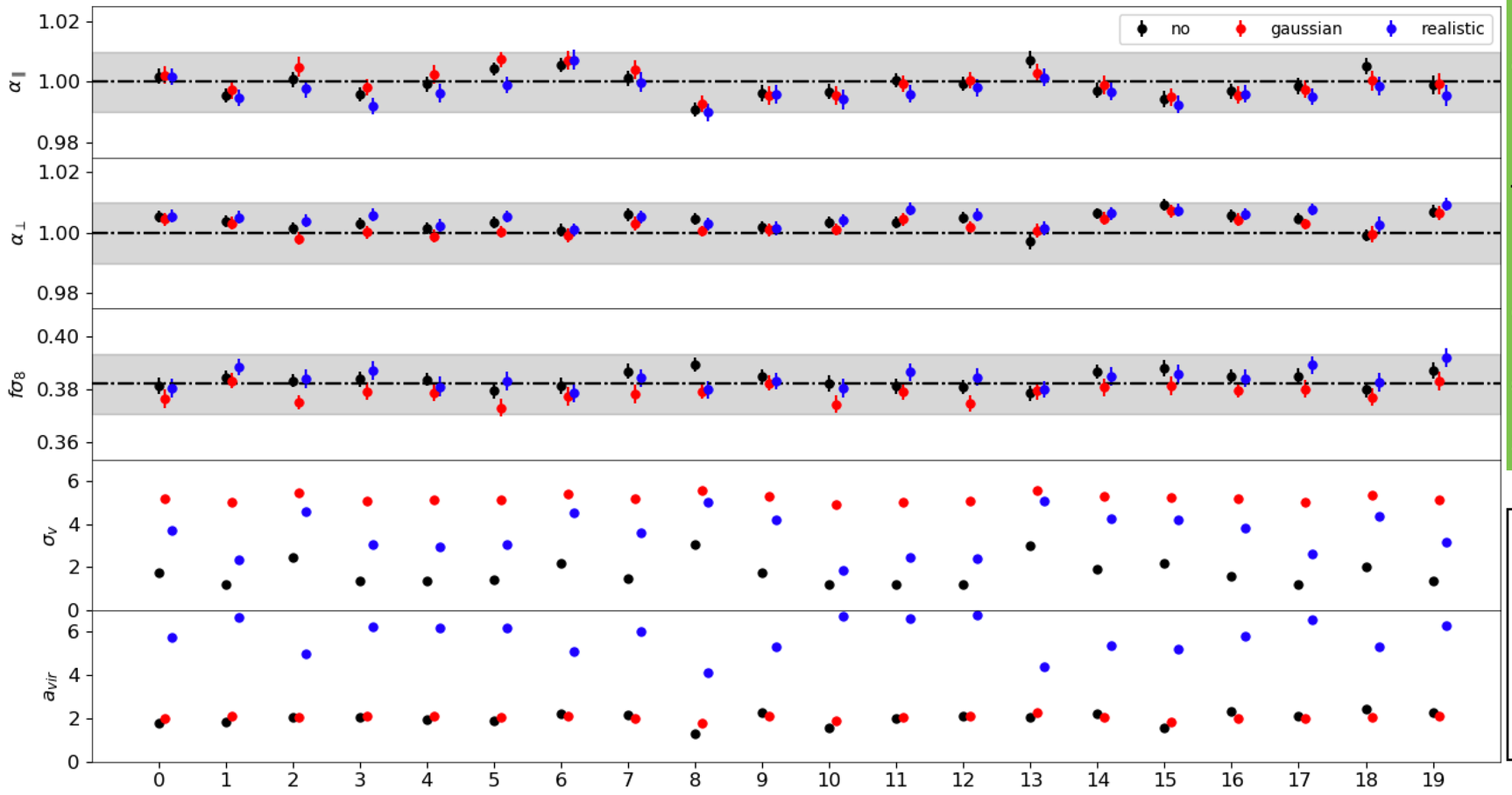


Mock challenge

Non-blind mocks

Shaded areas :
$\pm 1\,\%$ for the alphas
$\pm 3\,\%$ for $f\sigma_8$
Dash-dotted lines :
Expected values

- 20 versions of 100 mocks with different HOD (Halo Occupation Distribution)
- Each version with 3 **redshift** smearing case :



The Finger-of-God terms takes account of the redshift smearing:

$$\frac{1}{\sqrt{1+(k\,.\,\mu\,.\,a_{vir})^2}}\, e^{-\frac{(k\,.\,\mu\,.\,\sigma_v)^2}{1+(k\,.\,\mu\,.\,a_{vir})^2}}$$

σ_v : Gaussian part of the smearing

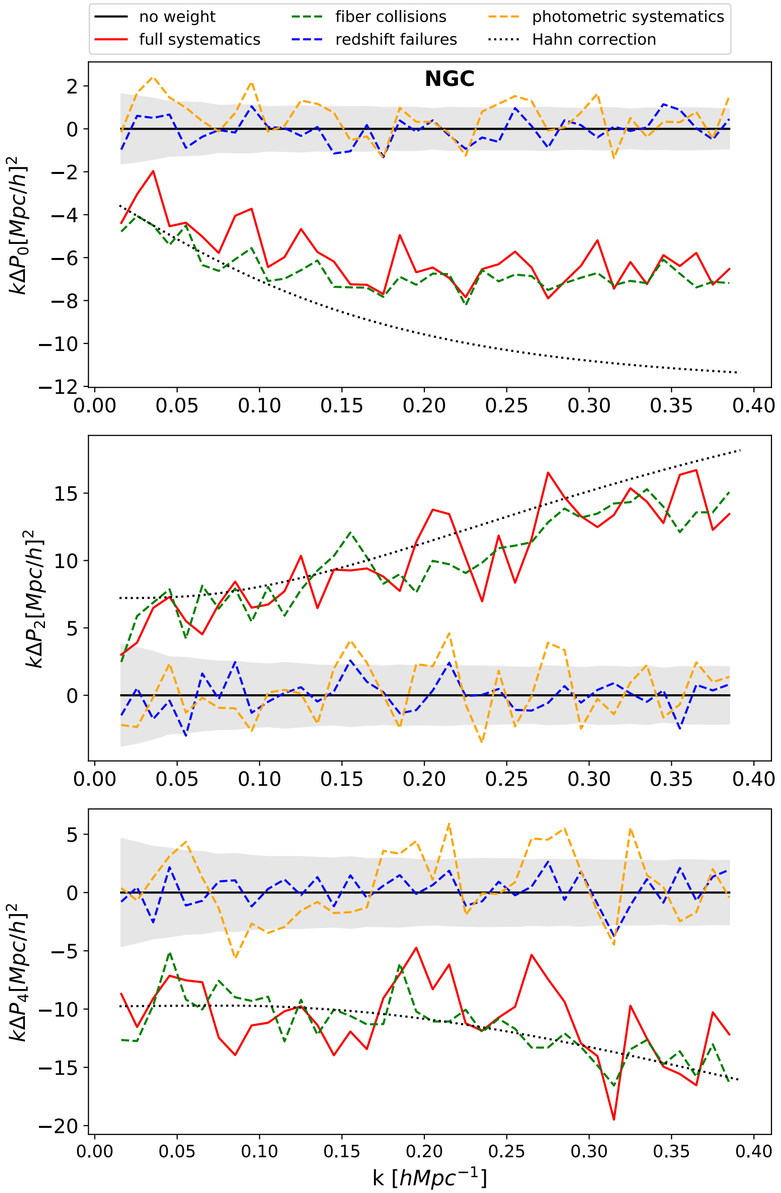
a_{vir} : non-Gaussian part of the smearing

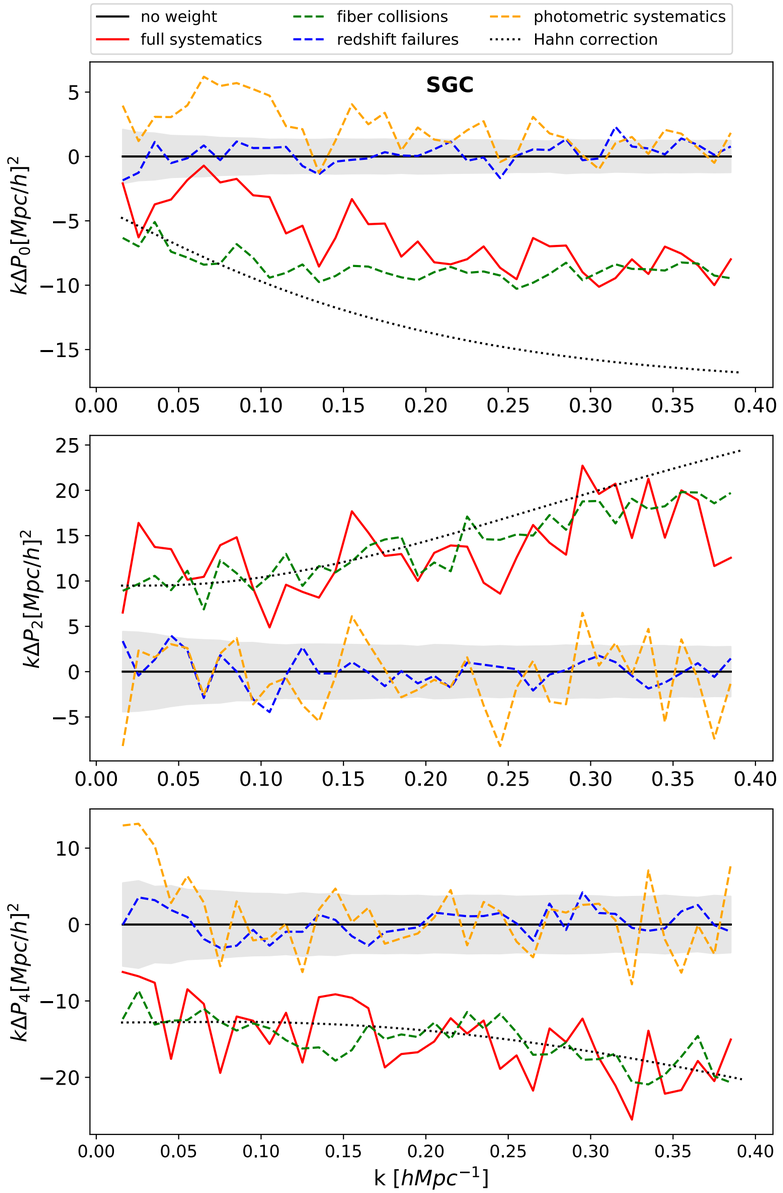
Systematic errors from non-blind mock:

$$\sigma(\alpha_\parallel) = 0.0036$$
$$\sigma(\alpha_\perp) = 0.0042$$
$$\sigma(f\sigma_8) = 0.0081$$

Observational systematics

Ezmocks





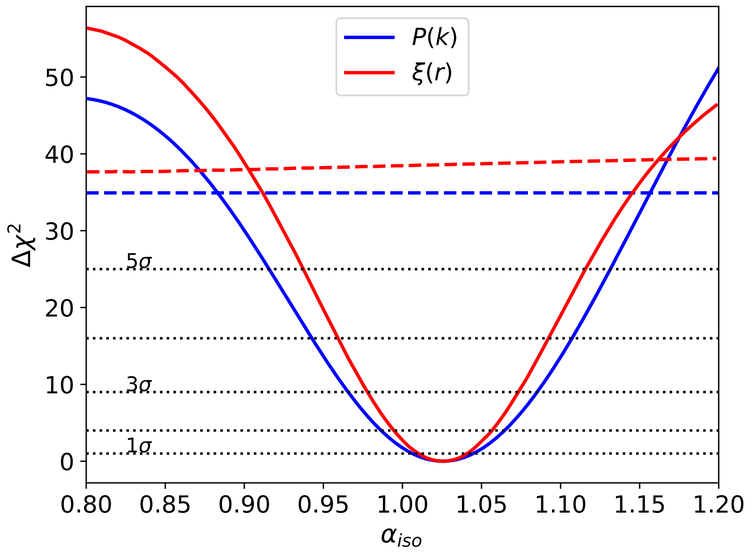
- Redshift failures and photometric systematics are enough corrected and have a low impact on the power spectrum (yellow and blue lines)
- Standard correction of fiber collisions is not sufficient (green lines)
- The top-hat window function modelling (based on Hahn et al. 2017) correct well this effect on all multipoles and all scale except for l=0 at small scale but this a minor shift compared to the amplitude of the power spectrum (black dotted lines)

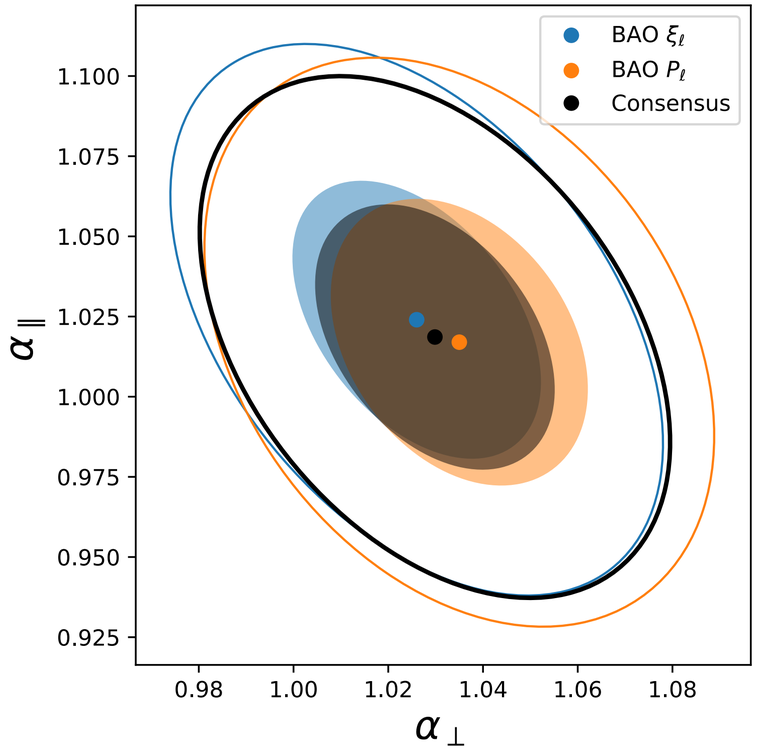
Results

BAO results

	$\alpha_\parallel$	$\alpha_\perp$
Observational	0.0037	0.0036
Modelling	0.0098	0.0055
Damping	0.005	0.001
Total systematics	0.012	0.007
Statistical error	0.045	0.029
Fraction	27%	24%

- The amount of systematic error is reasonable
- Fourier and configuration space are in agreement
- The consensus does not improve much the precision





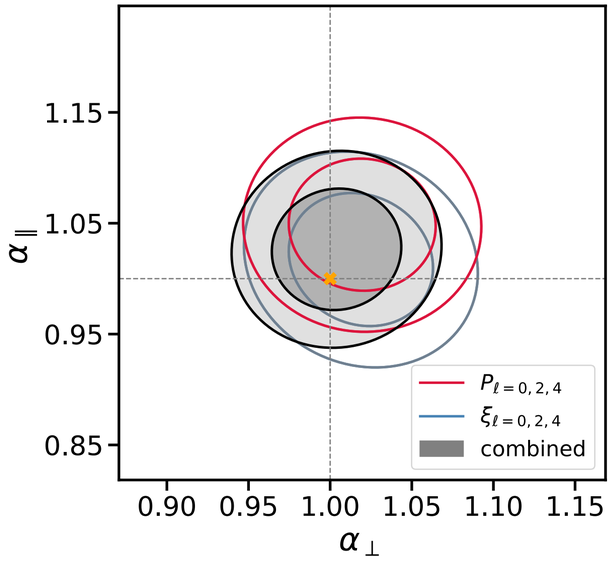
	$D_H(z_{eff})/r_{drag}$	$D_M(z_{eff})/r_{drag}$	$D_V(z_{eff})/r_{drag}$
Fourier space	13.34 ± 0.60	30.60 ± 0.90	26.50 ± 0.55
Configuration space	13.22 ± 0.58	30.82 ± 0.85	26.52 ± 0.44
BAO-only consensus	13.26 ± 0.55	30.69 ± 0.80	26.51 ± 0.42

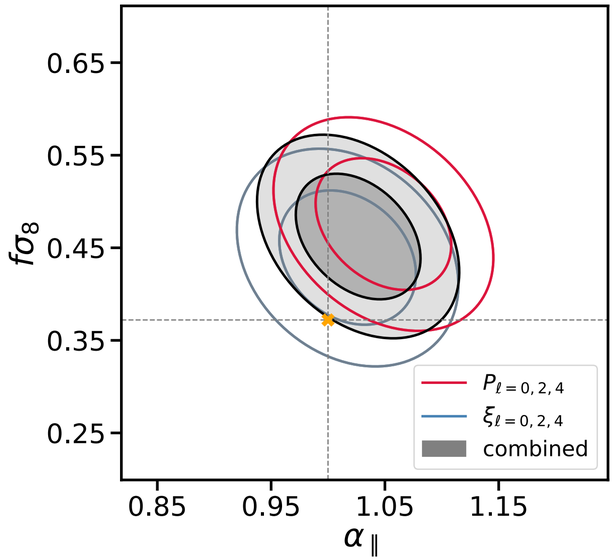
Results

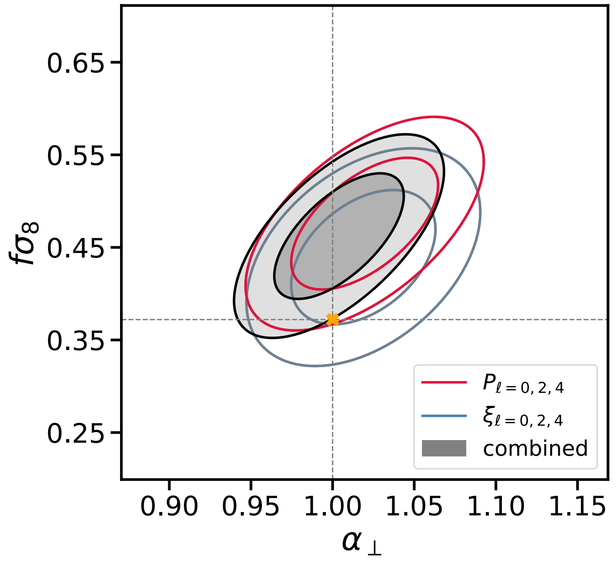
Full shape results

	$\alpha_\parallel$	$\alpha_\perp$	$f\sigma_8$
Photometry(Δ_1)	±0.0030	±0.0024	±0.0028
$\Delta(f_s) = 10\%(\Delta_2)$	±0.0017	±0.0011	±0.0021
Fibre collisions (Δ_3)	$+0.0040$	-0.0018	±0.0020
Total observational	0.0053	0.0032	0.0040
Redshift smearing	0.0036	0.0042	0.0081
Blind challenge	0.0091	0.0051	0.0093
Total modelling	0.0098	0.0066	0.0123
Total systematics	0.0111	0.0073	0.0129
Statistical error	0.0378	0.0289	0.0447
Fraction	30%	25%	29%

- The amount of systematic error is reasonable
- Fourier and configuration space are in agreement
- The consensus does not improve much the precision







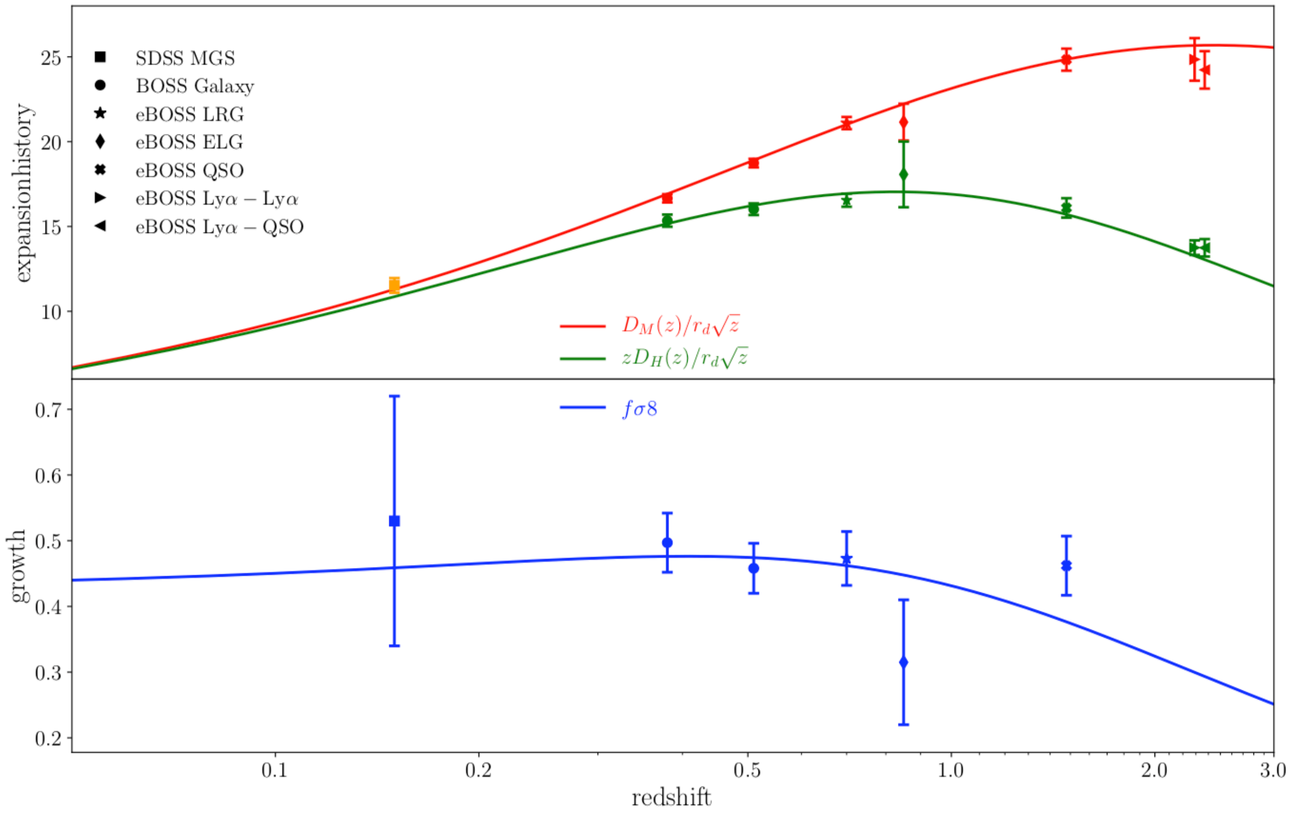
	$D_H(z_{eff})/r_{drag}$	$D_M(z_{eff})/r_{drag}$	$f\sigma_8$
Fourier space	13.52 ± 0.51	30.68 ± 0.90	0.476 ± 0.047
Configuration space	13.11 ± 0.52	30.66 ± 0.88	0.439 ± 0.048
Full shape consensus	13.23 ± 0.47	30.21 ± 0.79	0.462 ± 0.045

Results

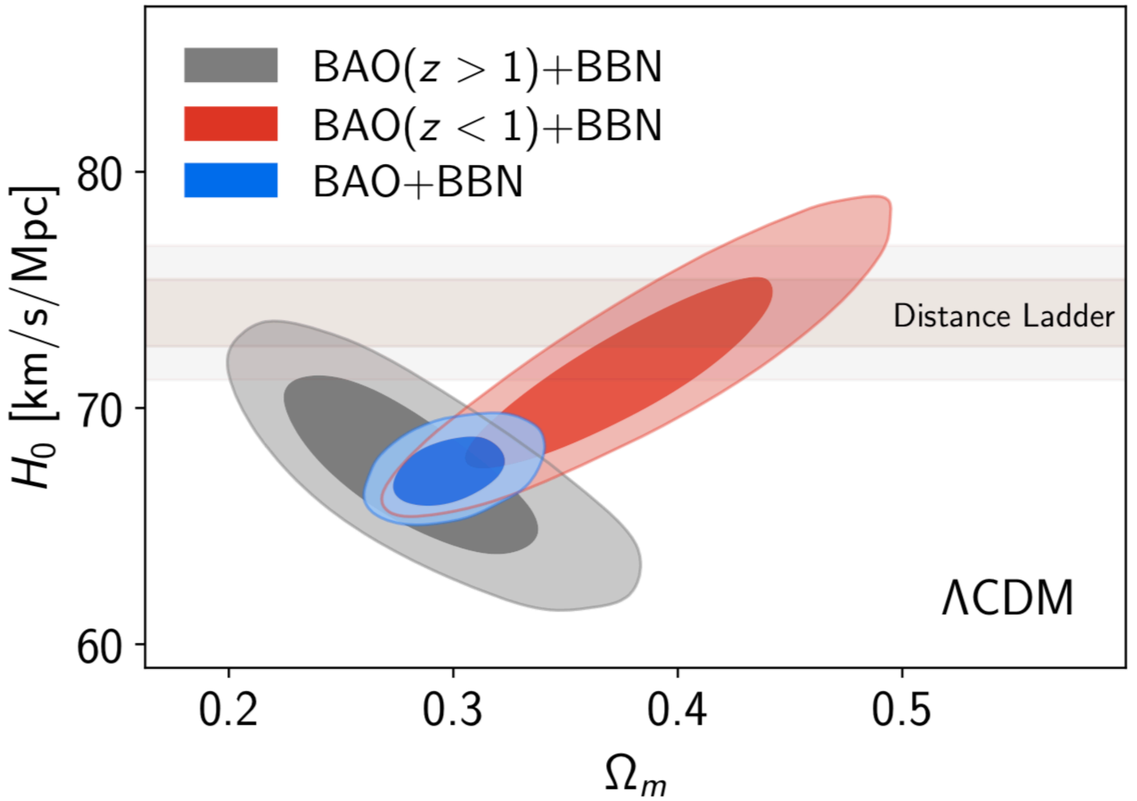
Cosmological parameter

Combined with all final eBOSS data release, the quasar DR16 eBOSS sample brings constraints on the expansion history and the growth rate of structure.

In particular, the high redshift clustering analysis (quasar+Lyman-α) break degeneracy on $H_0 - \Omega_m$ plane



From eBOSS collaboration 2020 https://arxiv.org/pdf/2007.08991.pdf



Summary

1. BAO-only and Full shape clustering analysis with ~340,000 quasars

2. Systematic study
    1. Model with non-blind and blind mock challenge (see Alex Smith's talk on Thursday)
        - Validate the model
        - Study the Finger-of-God term
    2. Observational systematics with mocks
        - Validate the weighting scheme
        - Add correction for the fiber collisions effect
    3. Systematic errors keep below 30% of the statistical error

3. Results
    1. Quasar consensus results: $f\sigma_8 = 0.462 \pm 0.045$, $D_{\rm M}(z_{\rm eff})/r_{\rm drag} 30.21 \pm 0.79$, $D_{\rm H}(z_{\rm eff})/r_{\rm drag} = 13.23 \pm 0.47$
    2. Combined with other SDSS samples: constraints expansion history from z=0.15 to 1.5
    3. High redshift clustering analysis (z>1) break degeneracy of the clustering constraints on the $H_0 - \Omega_m$ plane