Mock Challenge for eBOSS Quasar Clustering

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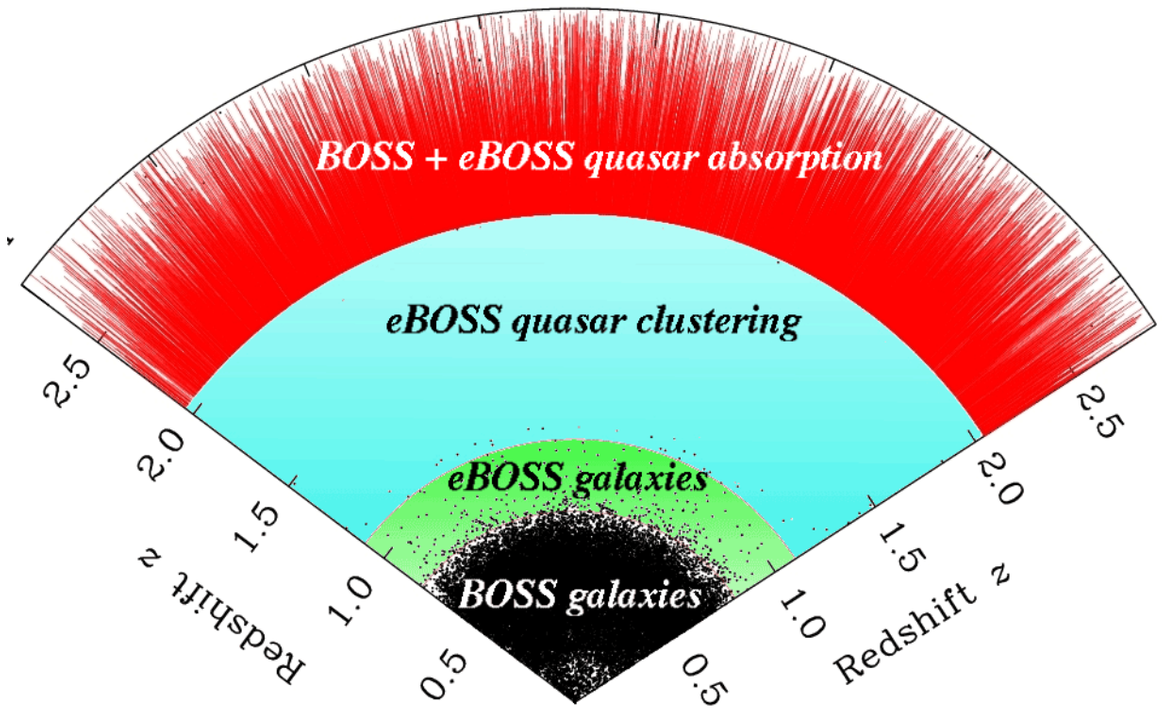
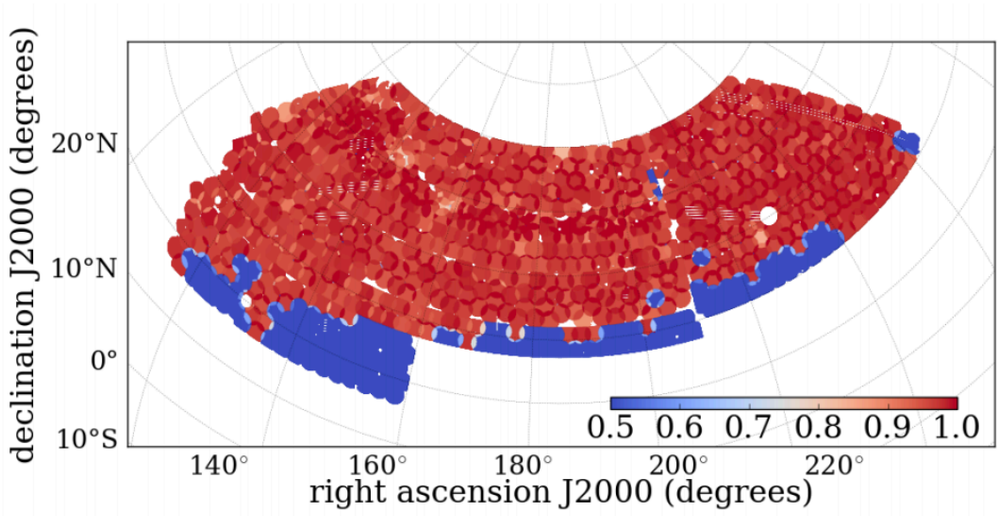
Outline

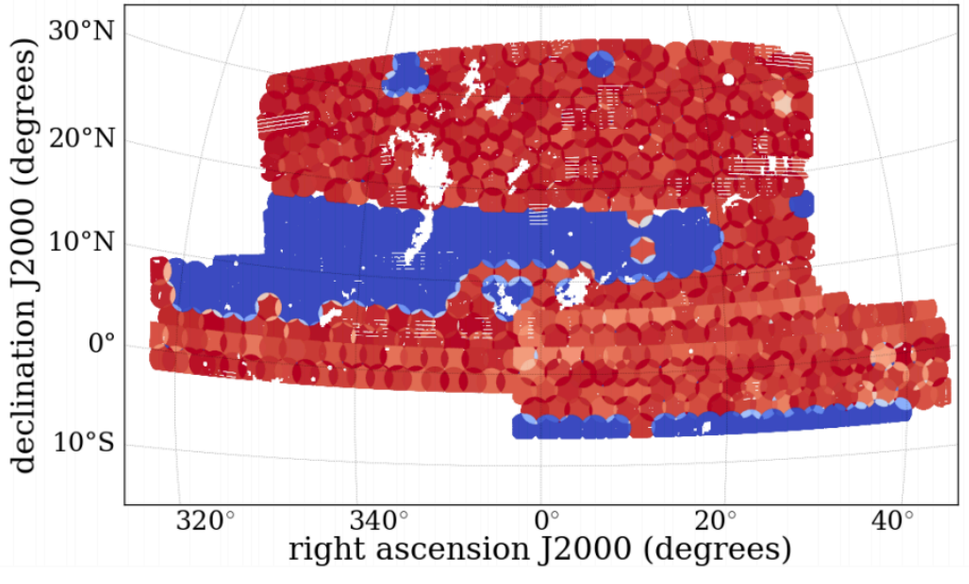
- eBOSS QSOs
- Motivation for mock challenge
- Non-blind OuterRim HOD mocks
- Fits to clustering using CLPT
- Creating blind mocks (method of Mead & Peacock 2014)
- Conclusions

eBOSS QSO sample

- Quasars in redshift range 0.8 < z < 2.2 used as direct tracers of matter density field
- In DR16, 340,000 QSOs, over 4,700 sq deg
- Fills in missing redshift range in BOSS
- Measure growth of structure at z_{eff} = 1.5







Mock Challenge

- Fitting RSD models to measured clustering allows measurements of

$$f(z)\sigma_8(z) \qquad \alpha_{\parallel} = \frac{H^{\rm fid}(z) r_s^{\rm fid}}{H(z) r_s} \qquad \alpha_{\perp} = \frac{D_A(z) r_s^{\rm fid}}{D_A^{\rm fid}(z) r_s}$$

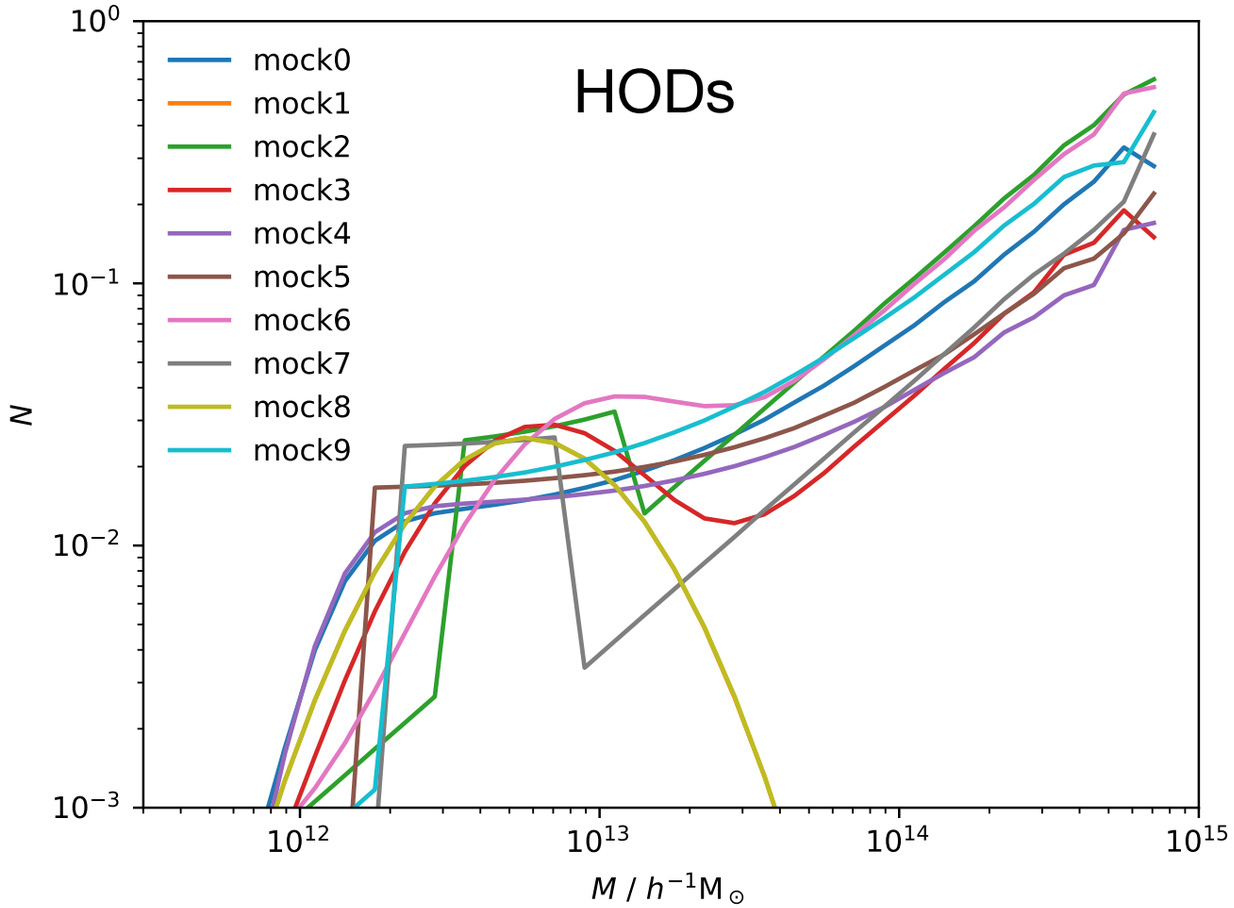
- Aim to validate models, quantify systematics
- Can do this with a mock challenge
- Run analysis on mocks where cosmology is known
- Non-blind and blind mocks

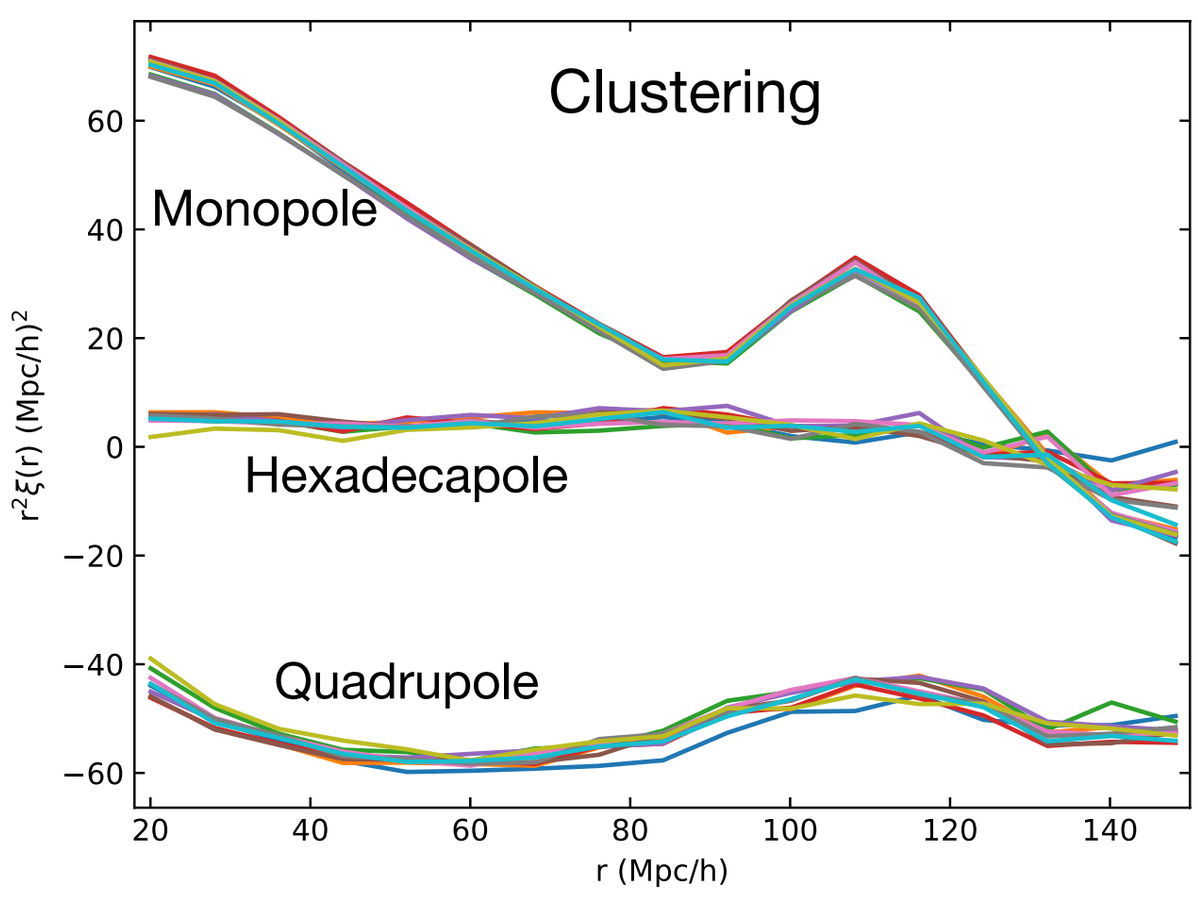
OuterRim mocks

- OuterRim simulation (3 Gpc/h box, WMAP7 cosmology) snapshot at z=1.433
- Populated with 20 different HODs, 100 mocks for each
- HODs tuned to approximately give same large scale clustering
- Central quasars: assigned position and velocity of halo
- Satellite quasars: either assigned pos/vel of particle, or randomly positioned following NFW profile, with random velocity
- Mocks contain ra, dec, z of objects in cubic box
- Periodic replications of box used to take into account objects that move in/out of the box in redshift space

HOD models

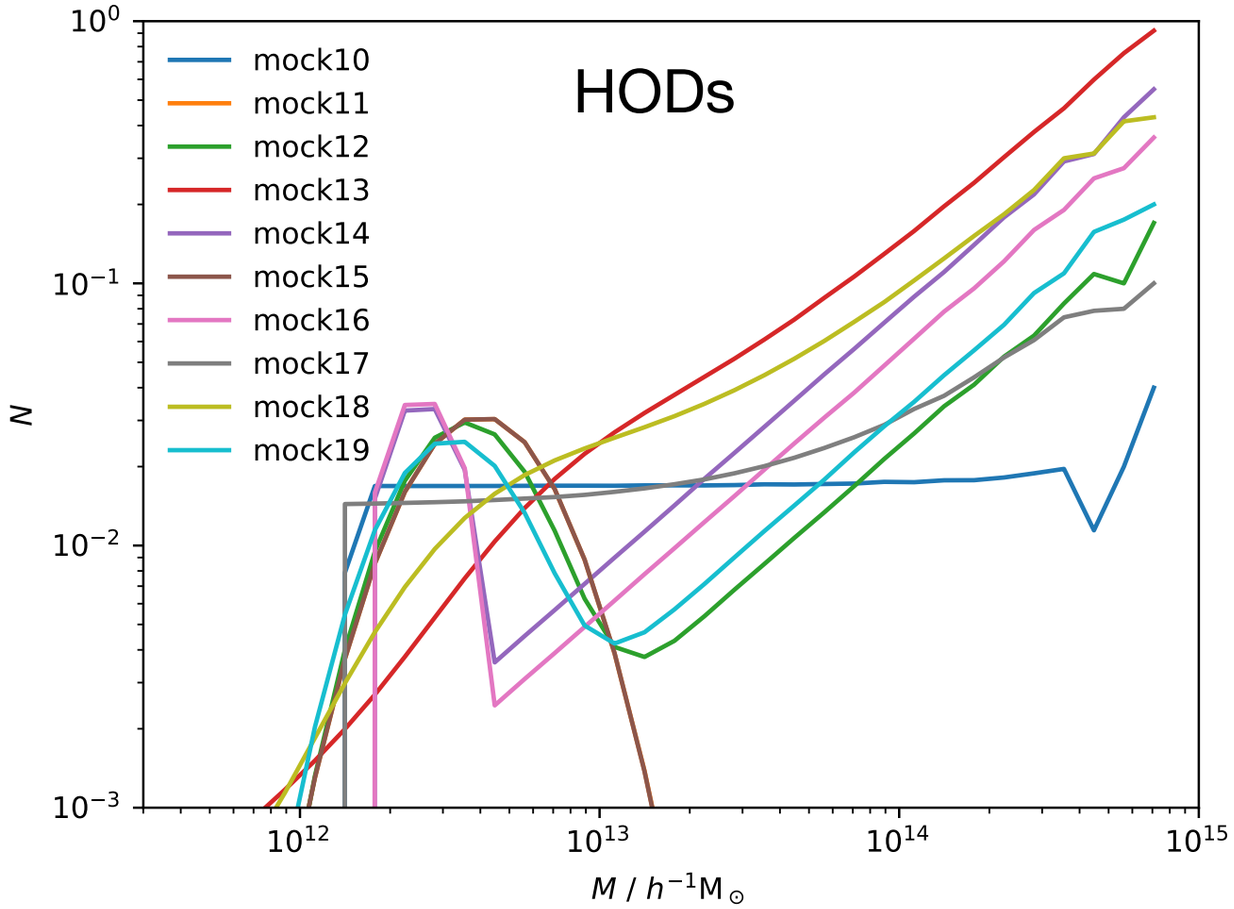
	mock0	mock1	mock2	mock3	mock4	mock5	mock6	mock7	mock8	mock9
HOD	Smooth step + PL	Gaussian	Top hat + PL	Gaussian + PL	Smooth step + PL	Sharp step + PL	Gaussian + PL	Top hat + PL	Gaussian	Sharp step + PL
Satellite positions	Particles	NFW	NFW	Particles	NFW	NFW	NFW	Particles	NFW	NFW
Satellite %	19 %	7 %	60 %	21 %	8 %	17 %	56 %	24 %	100 %	42 %

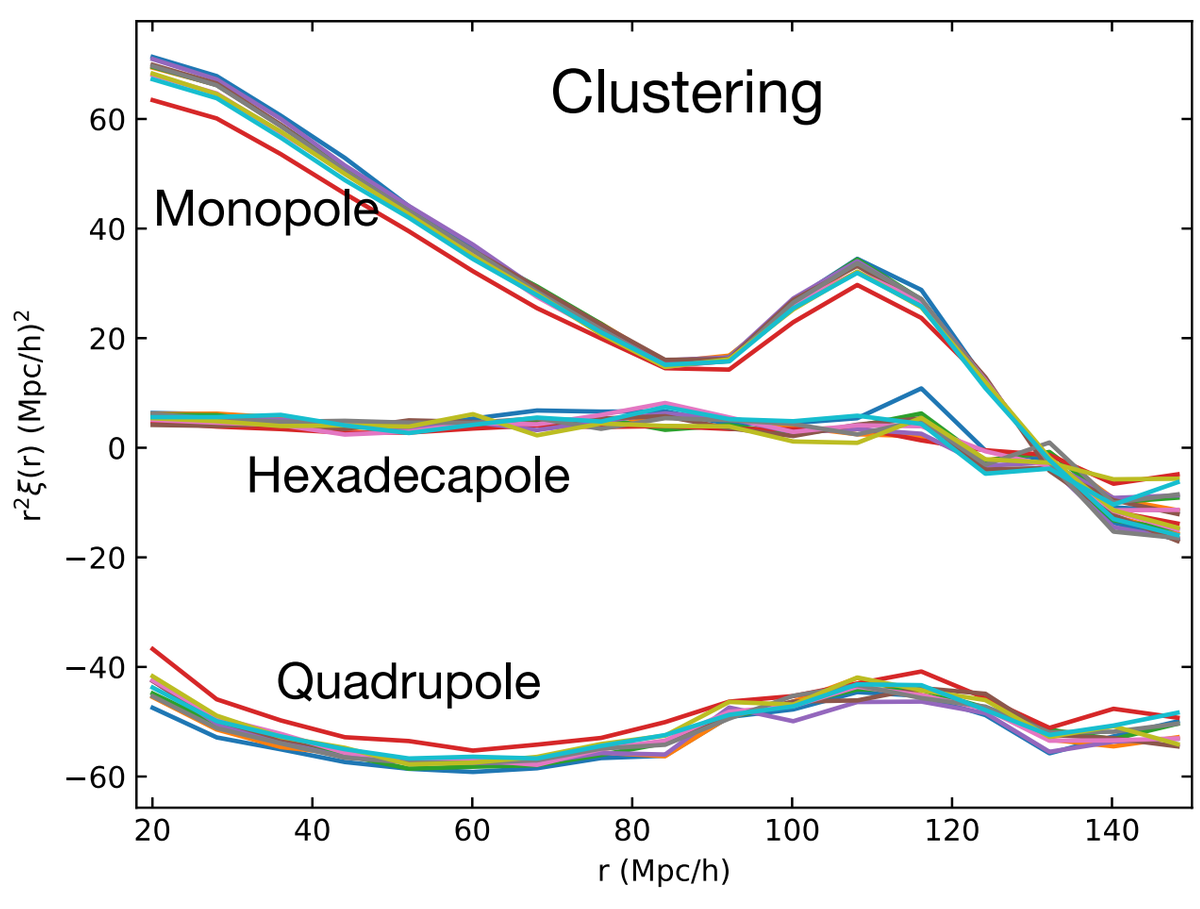




HOD models

	mock10	mock11	mock12	mock13	Mock14	mock15	mock16	mock17	mock18	Mock19
HOD	Sharp step + PL	Gaussian	Gaussian + PL	Smooth step + PL	Top hat + PL	Gaussian	Top hat + PL	Sharp step + PL	Smooth step + PL	Gaussian + PL
Satellite positions	Particles	NFW	NFW	NFW	Particles	Particles	NFW	NFW	NFW	Particles
Satellite %	0.2 %	10 %	5 %	73 %	17 %	50 %	12 %	4 %	36 %	7 %





Redshift Smearing

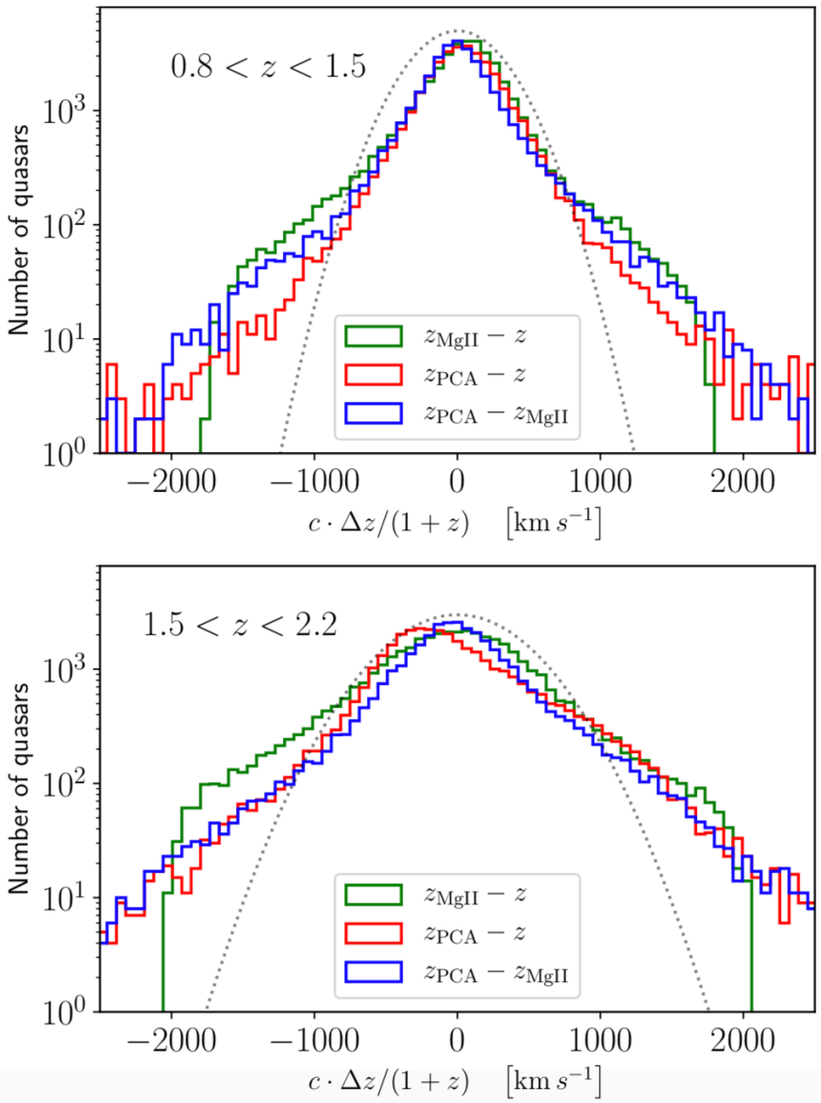
- Uncertainties in measured redshift
  - QSOs have broad emission lines
  - Systematic shifts in measured redshift due to outflows
- Shift in redshift, Δz, between different redshift estimates, and re-observations of the same quasar
- Can be written as a shift in velocity $\Delta v = \frac{c\Delta z}{1+z}$
- For each quasar, Δv is randomly drawn from a distribution (Gaussian or double-Gaussian)

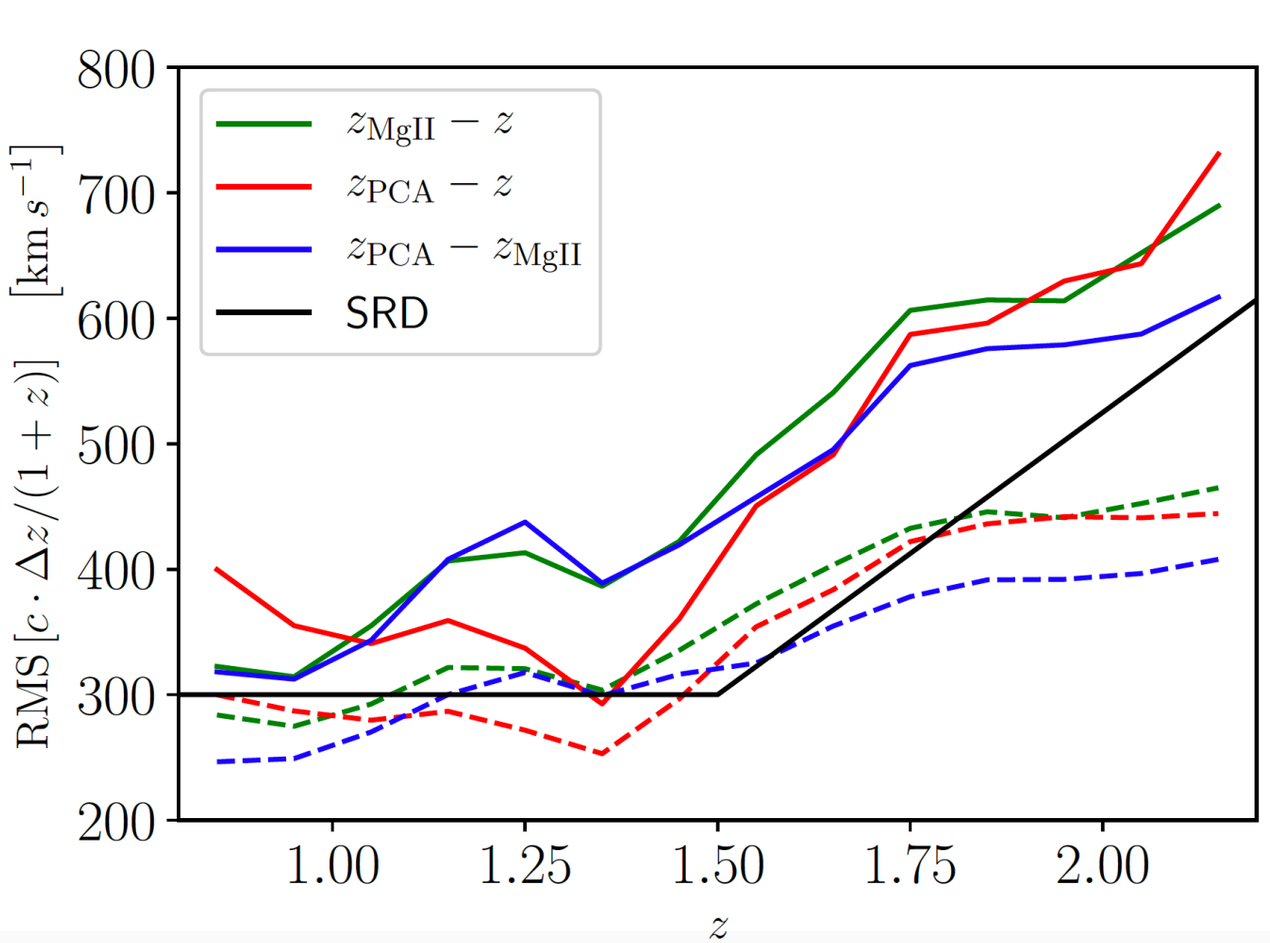
Redshift Smearing

- Gaussian smearing

$$\Delta v = \frac{c\Delta z}{1+z} \qquad z < 1.5 \qquad \sigma_{\rm v} = 300 \text{ km/s}$$

$$z > 1.5 \qquad \sigma_{\rm v} = 450(z-1.5) + 300 \text{ km/s}$$

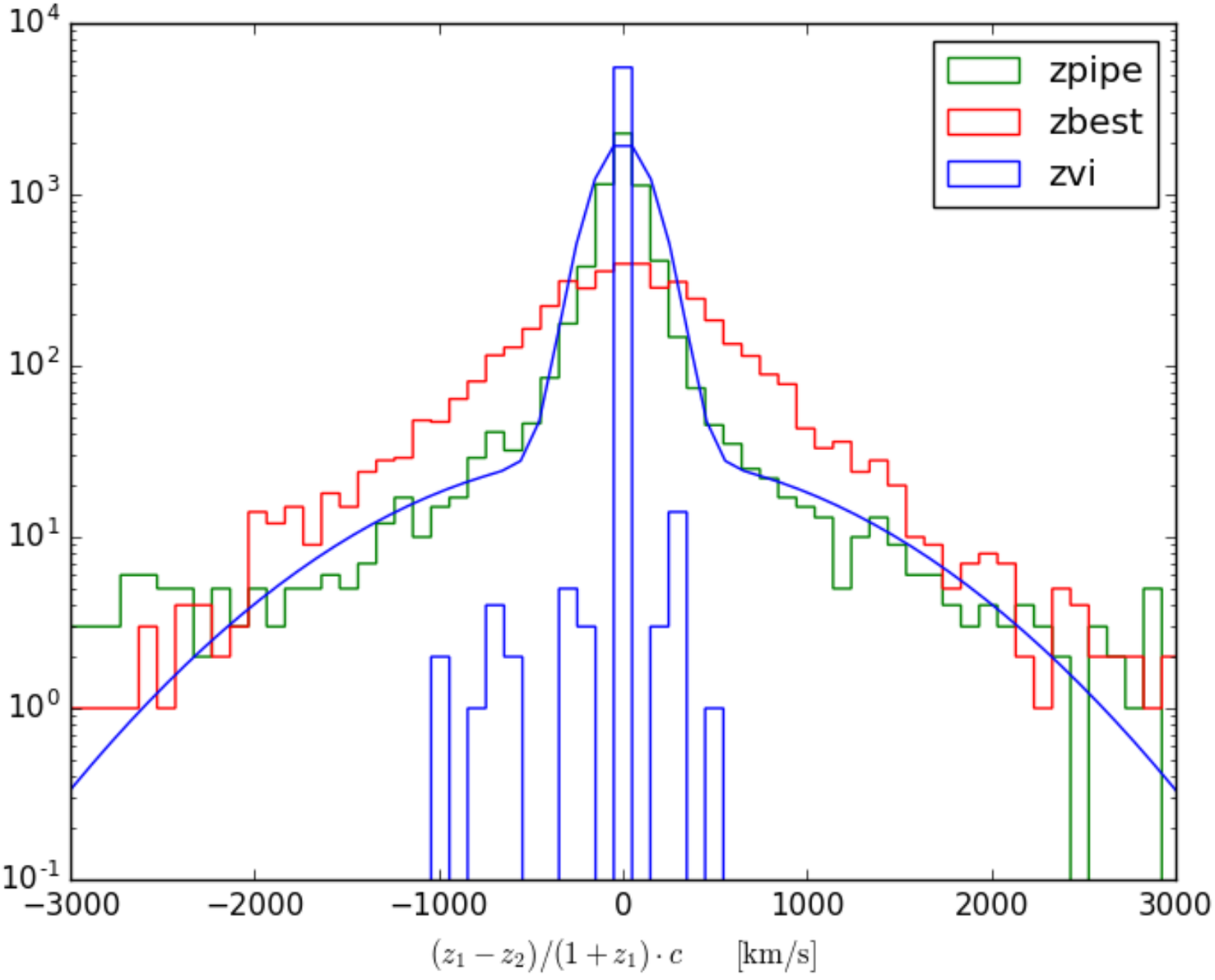




Zarrouk 2018

Redshift Smearing

- ‘Realistic’ smearing
- Double Gaussian, from duplicate observations of the same object



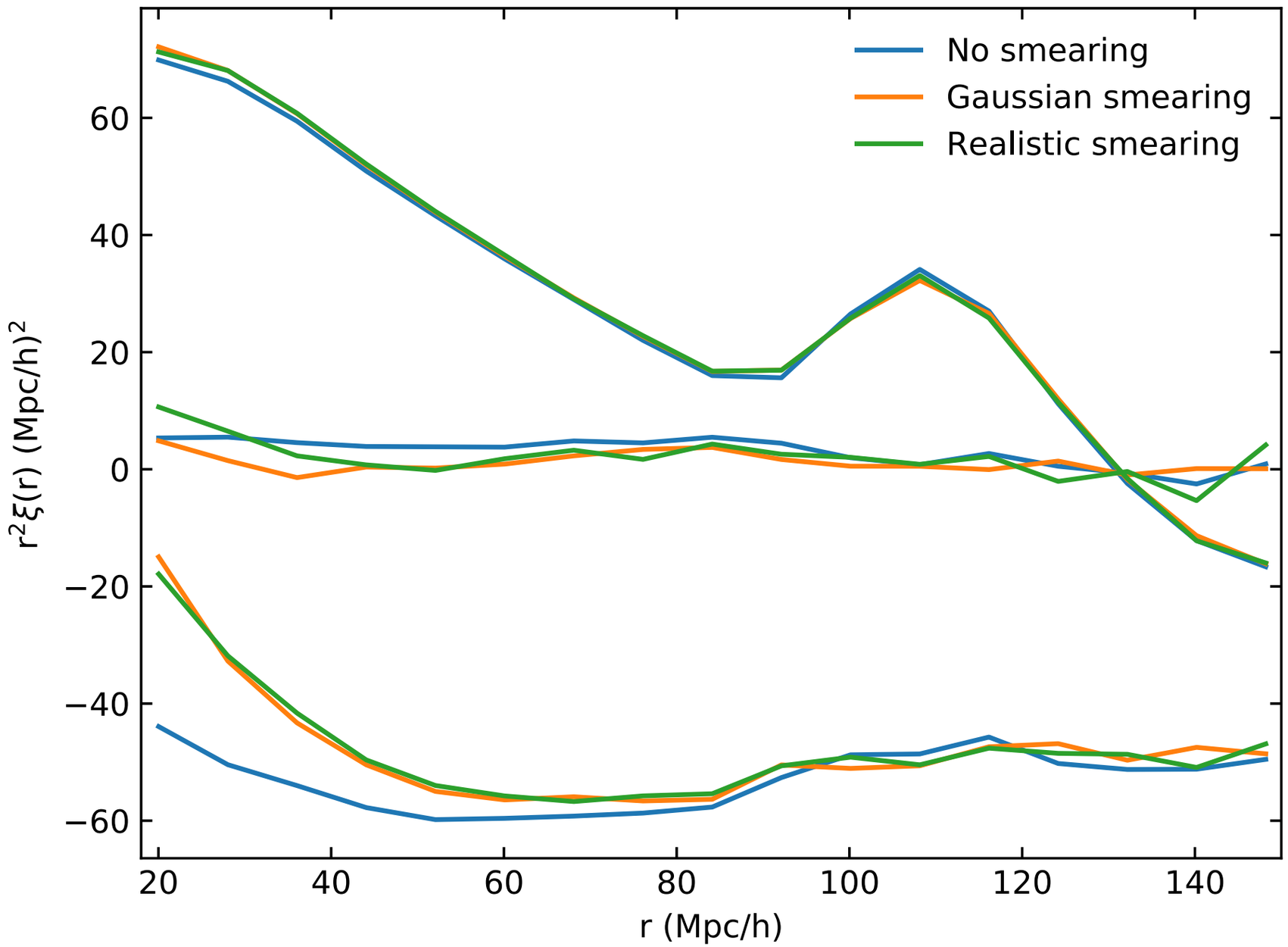
$$N_1 \exp\left(\frac{-\Delta v^2}{2\sigma_1^2}\right) + N_2 \exp\left(\frac{-\Delta v^2}{2\sigma_2^2}\right)$$

$N_1 = 2000$ $\sigma_1 = 150\text{km/s}$

$N_2 = 67$ $\sigma_2 = 1000\text{km/s}$

Redshift Smearing

- Effect of different types of smearing on mock0 clustering (average of 100 mocks)



CLPT-GS Model

- Langrangian framework $\vec{x}(\vec{q},t) = \vec{q} + \vec{\Psi}(\vec{q},t)$
- Convolution Lagrangian Perturbation Theory (CLPT) uses perturbative expansion of $\vec{\Psi}$ to calculate $\xi(r)$ in real space

- Redshift space - Gaussian streaming (GS) model
- Convolve real space $\xi(r)$ with Gaussian

$$1 + \xi(s_\perp, s_\parallel) = \int d^3r \left[1 + \xi(r)\right] G(s_\parallel - r_\parallel, v_{12}, \sigma_{12})$$

- Models probability pair with real space separation $r_\parallel$ will be observed with separation $s_\parallel$
- Gaussian centred on $\mu v_{12}(r)$ and depends on pairwise infall velocity, v_{12}, and dispersion, σ_{12} .

Modifying Gaussian Streaming

- Convolve real space $\xi(r)$ with two Gaussians

$$1 + \xi(s_\perp, s_\parallel) = \frac{[1 + \xi(r)] * G_1 + \nu[1 + \xi(r)] * G_2}{1 + \nu}$$

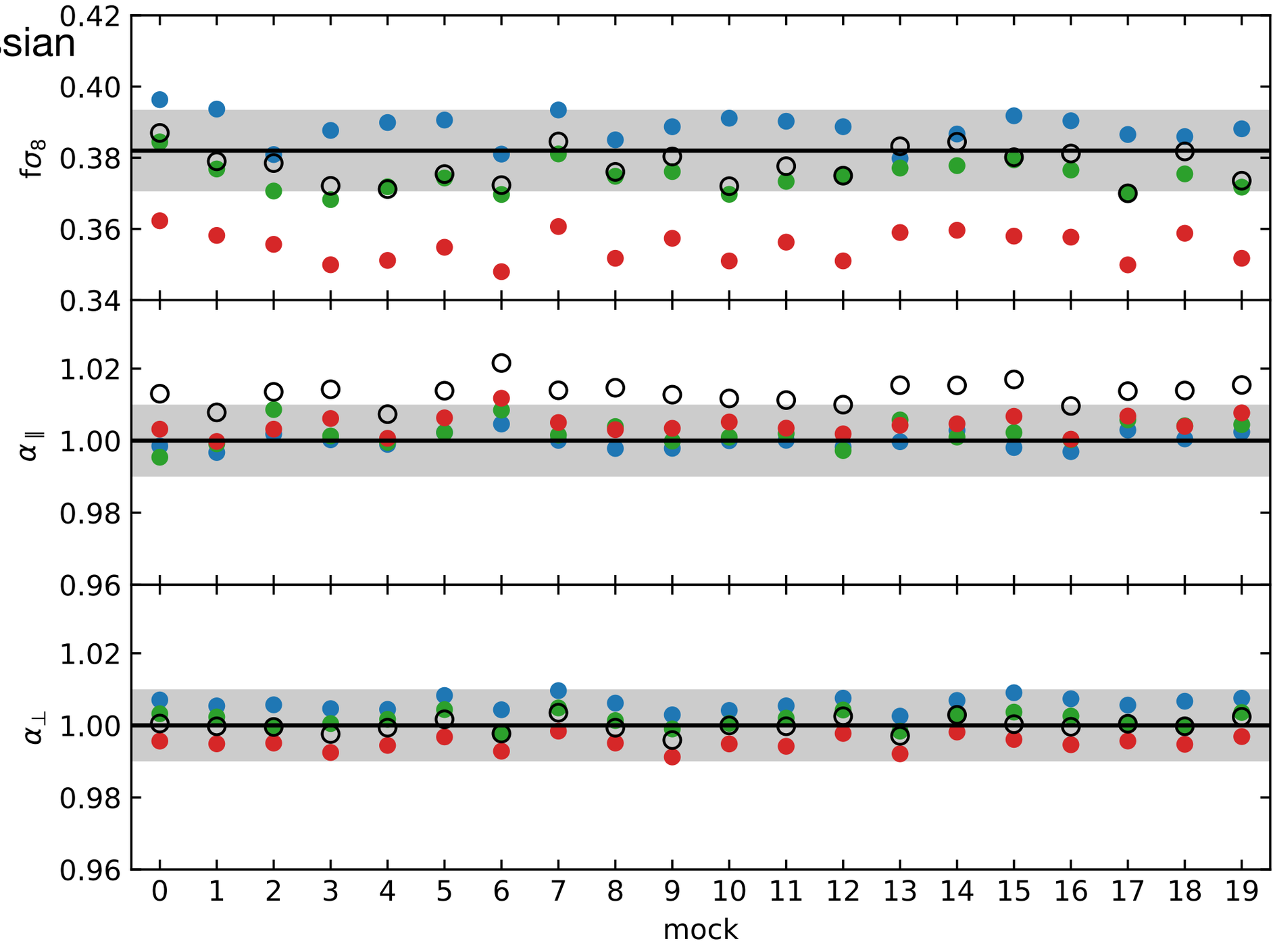
- G_1 and G_2 have same centre
- G_1 narrow Gaussian with $\sigma_{\rm narrow}$,
  G_2 wide gaussian with $\sigma_{\rm wide}$
- v sets the ratio of the two Gaussians
- Set v=0.1

CLPT fits to mocks

Blue: no smearing
Green: Gaussian smearing
Red: double Gaussian

Black: double Gaussian with modified Gaussian streaming

Using Gaussian covariance matrix



Shaded regions:
±3% in $f\sigma_8$,
±1% in alphas

Scaling the Cosmology

- Method of Mead & Peacock 2014 to rescale OuterRim cosmology
- First part of method: scale position/mass/z to match σ(M) in new cosmology
- Scale comoving positions by factor s $\quad L' = sL$
- Since $M = \frac{4}{3}\pi R^3 \bar{\rho}$, scale masses by $\quad M' = s_{\rm m} M; \quad s_{\rm m} \equiv s^3 \frac{\Omega'_{\rm m}}{\Omega_{\rm m}}$
- Need to find scaling factor s, and redshift, z, of original simulation snapshot
- Minimize $\quad \delta^2_{\rm rms}(s, z \mid z') = \frac{1}{\ln(R'_2/R'_1)} \int_{R'_1}^{R'_2} \frac{{\rm d}R}{R} \left[1 - \frac{\sigma(R/s, z)}{\sigma'(R, z')}\right]^2$

Scaling the Cosmology

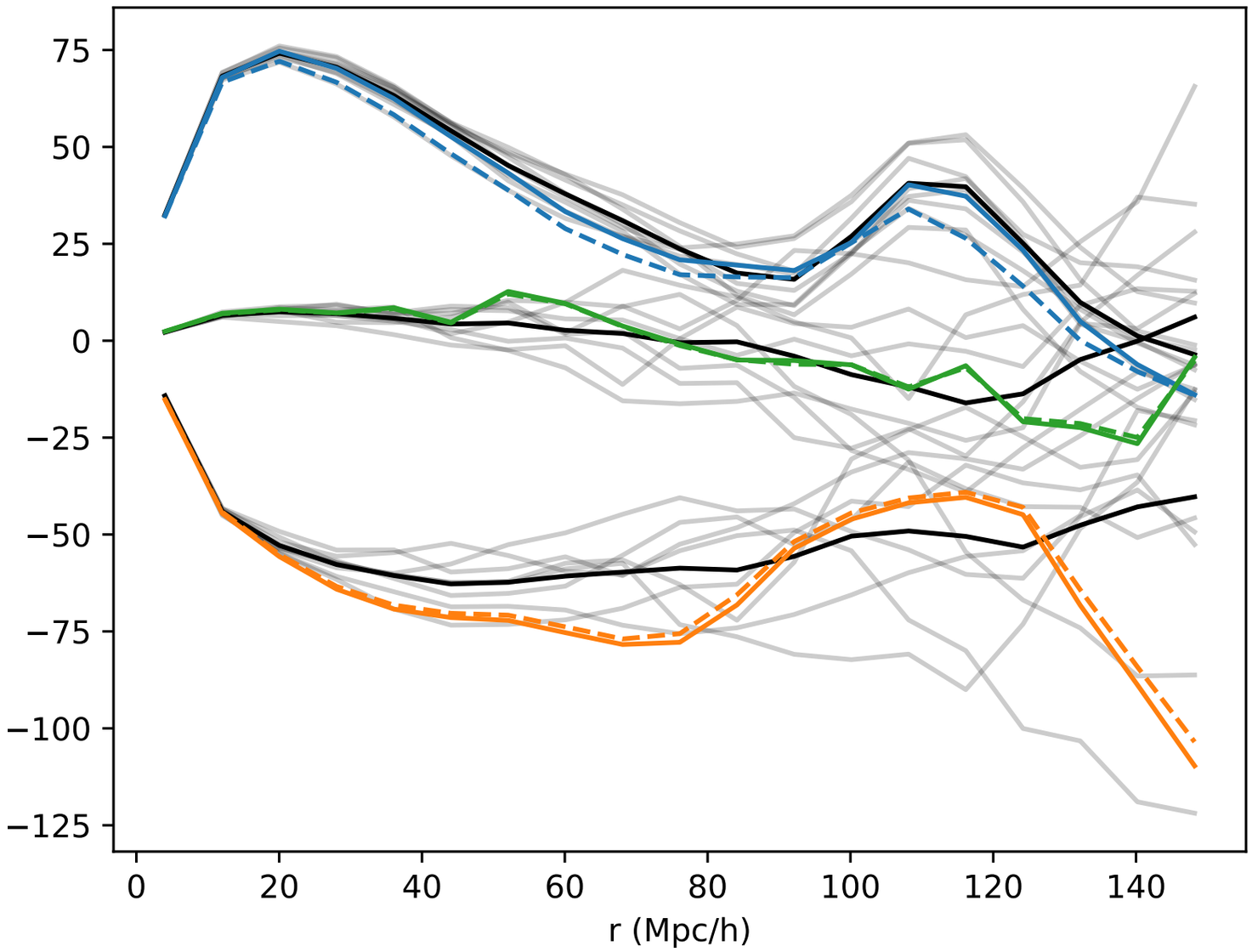
- Second part of method: displace halo positions/velocities
- Calculate displacement field, ***f***, from overdensity of haloes
- Change in ***f*** due to different cosmology

$$\delta \boldsymbol{f}_{k'} = \left[\sqrt{\frac{\Delta'^2_{\rm lin}(k', z')}{\Delta^2_{\rm lin}(sk', z)}} - 1 \right] \boldsymbol{f}_{k'}$$

- Adjust positions by $\boldsymbol{x}' = \boldsymbol{x} + \delta \boldsymbol{f}$
- To get right mass-dependent bias, multiply displacement by b(M)
- Also apply scaling and displacements to halo velocities

Clustering After Displacements

- Test method by rescaling MDPL2 simulation to MXXL cosmology (simulations have the same mass definition)



- **Black**: average of MXXL
- **Grey**: MXXL sub-volumes (same volume as scaled MDPL2)
- **Coloured**: MDPL2
- Dashed: after scaling
- Solid: with additional displacements

Blind Mocks

- Mead & Peacock method used to rescale snapshots either side of z=1.433 to new cosmologies at z=1.433
- Modify Ω_{m} to change f
- Modify $h,\ \sigma_8, n_s$, so that redshift matches simulation snapshot
- Populated with HODs from non-blind mock challenge
- First 10 sets of 100 mocks have been produced, analysis in progress
- Python implementation of Mead & Peacock method on GitHub https://github.com/amjsmith/rescale-cosmology

Summary

- OuterRim simulation used to create eBOSS QSO mocks
- Non-blind challenge:
  - 20 different HODs, wide range of satellite fractions
  - Approx same large-scale clustering
  - Included effects of redshift smearing
- Blind challenge:
  - Rescaled OuterRim cosmology using method of Mead & Peacock
  - Verified code by scaling MDPL2 to MXXL
  - Code available on GitHub