The benefit of a joint 2- and 3- point clustering analysis

Alfonso Veropalumbo, Barolo Astroparticle Meeting, 09/09/2021

Collaborators: Iñigo Sáez Casares, Enzo Branchini, Benjamin R. Granett, Luigi Guzzo, Federico Marulli, Michele Moresco, Lauro Moscardini, Andrea Pezzotta, Sylvain de la Torre

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Summary

- Introduction: galaxy clustering
- The case for a joint two and three point correlation analysis
- Application to the VIPERS survey
- Conclusions & outlook

Galaxy clustering

Cosmology from large-scale structure

- Galaxy spatial distribution encodes important cosmological information; the relevant quantity is the mass density contrast:

$$\delta(\vec{x}) = \frac{\rho(\vec{x}) - \rho_b}{\rho_b}.$$

- **Statistical description** of the large-scale structure
  - For a **gaussian** field:
    Two-point correlation function (2PCF): $\xi(r) = \left\langle \delta(\vec{x})\delta(\vec{x} + \vec{r}) \right\rangle.$
  - If the field is **non gaussian, higher orders** correlation functions contains significant information :

    Three-point correlation function (3PCF): $\zeta(r_1, r_2, r_3) = \left\langle \delta(\vec{x})\delta(\vec{x} + \vec{r})\delta(\vec{x} + \vec{s}) \right\rangle.$
- Study of 2PCF and 3PCF allows to investigate all **sources of non gaussianities** and to **remove parameter degeneracies** of two-point only correlation analysis.

Sources of three-point signal

1. Non-gaussianities in the primordial density distribution.

2. Growth of structures entering non-linear regimes (perturbation theory approach):

$$\delta_M(\overrightarrow{x}) = \delta_0 + \delta_1 + \delta_2 + \ldots$$

3. Local and deterministic galaxy bias:

$$\delta_g = \sum_{m=0} \frac{b_m}{m!} \delta^m \equiv b\left(\delta + \gamma\delta^2/2 + \ldots\right)$$

4. Non-linear redshift distortion along the line of sight:

$$\delta_s(r,\mu) = \delta_r(r) - \mu^2 \nabla \cdot \overrightarrow{v}$$

Linear theory: $$\nabla \cdot \overrightarrow{v} = -\frac{\partial \log D(t)}{\partial \log a(t)} \delta = -f\delta$$

Breaking parameter degeneracies

1. In linear limit, 2PCF depends on ***combinations*** of cosmological parameters:

$$\xi_g(s,\mu) = \left(b\sigma_8 + f\sigma_8\mu^2\right)^2 \xi_M(r)$$

2. The same holds for 3PCF:

$$\zeta_g(r_{12}, r_{13}, r_{23}; f, \gamma) = b^3\sigma_8^4\zeta(r_{12}, r_{13}, r_{23}; f, \gamma)$$

3. Joint 2PCF-3PCF analysis in non-linear regime allows to remove degeneracies, constraining:
   - b_1: the linear bias;
   - f: the linear growth rate;
   - $\gamma \equiv b_2/b_1$: the second order bias;
   - σ_8: the amplitude of density fluctuations;

4. Compared to a 2PCF analysis only, adding 3PCF doesn't require extra information. The only cost is in the computational requirement (==time needed to *estimate* clustering probes)

Application to the VIPERS survey

The VIPERS survey

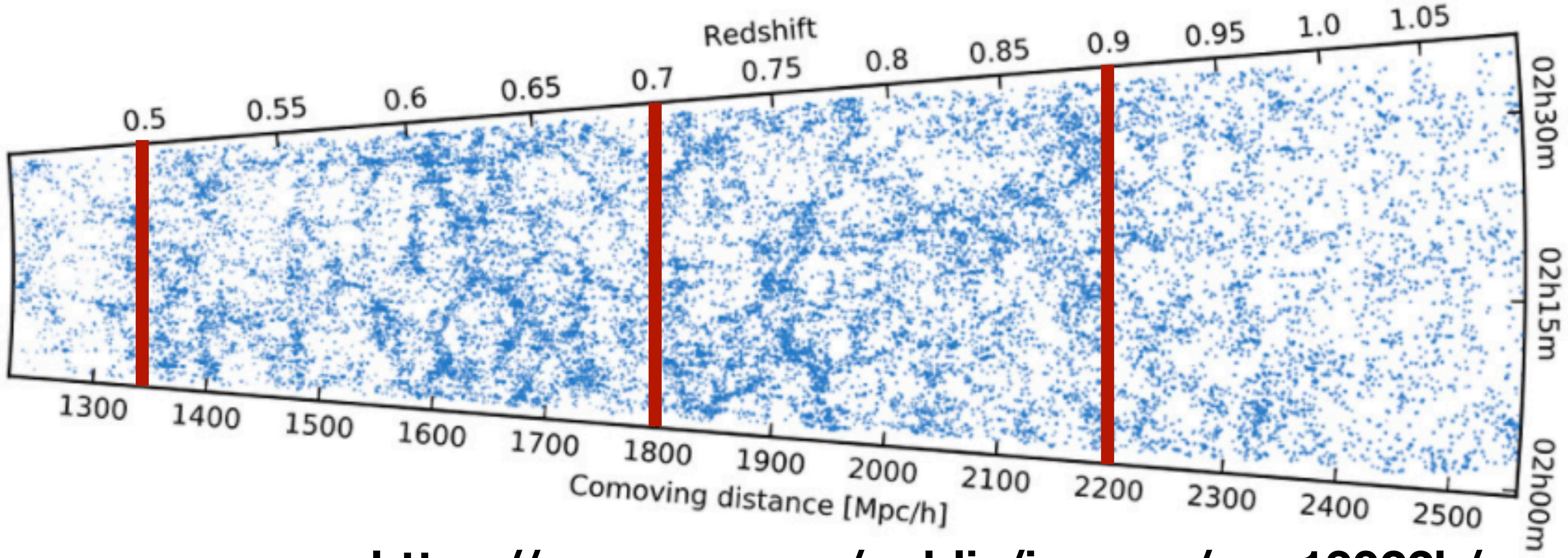
- **We've performed the first joint analysis of 2PCF and 3PCF in configuration space.**
- We choose the VIPERS survey (Public Data Release 2, Scodeggio et al 2018) as it probes high redshift density field with a number density of objects large enough to keep shot-noise under control.

Density: $\bar{n} = 5 \times 10^{-3} h^3 \mathrm{Mpc}^{-3}$.

Area: $24\,\deg^2$ **in two fields (W1, W4).**

Redshift range: $0.5 < z < 1.2$.

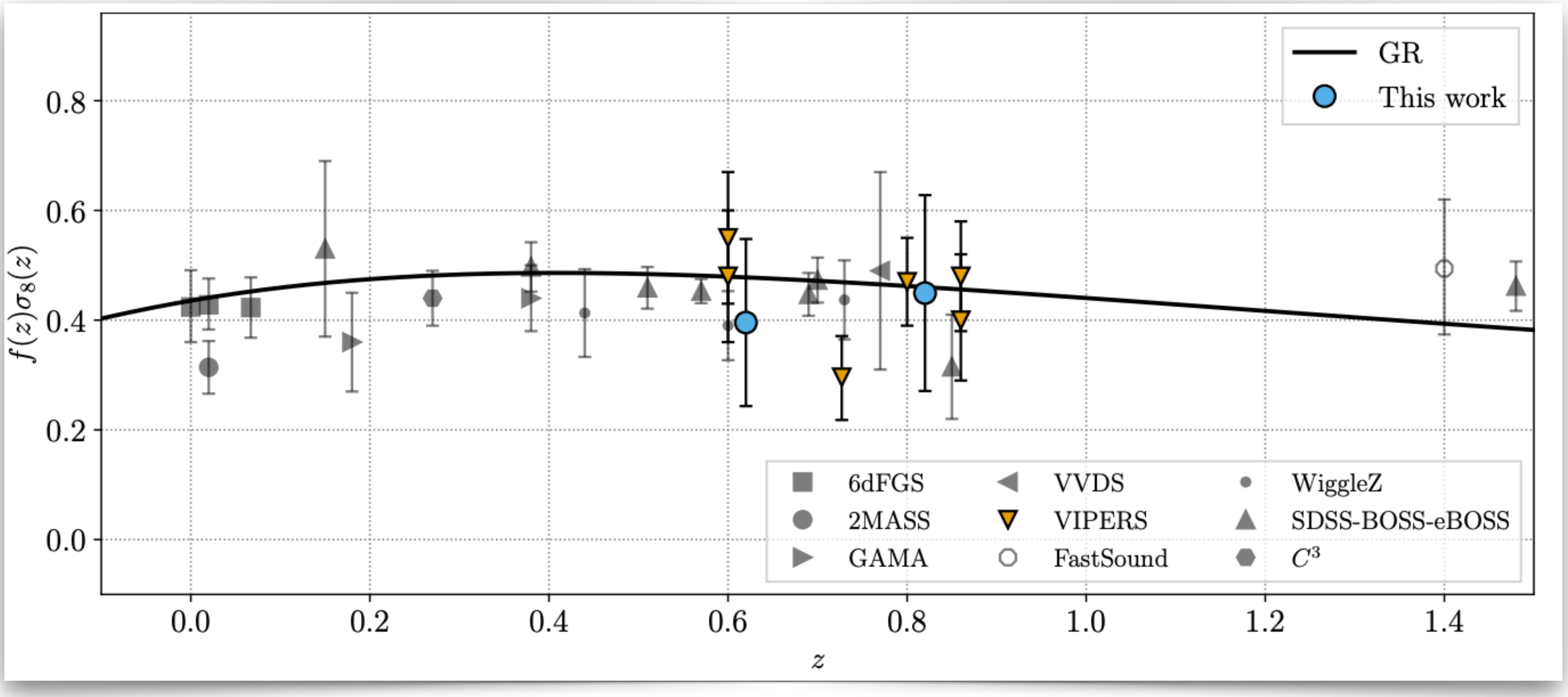
Spectroscopic redshift.



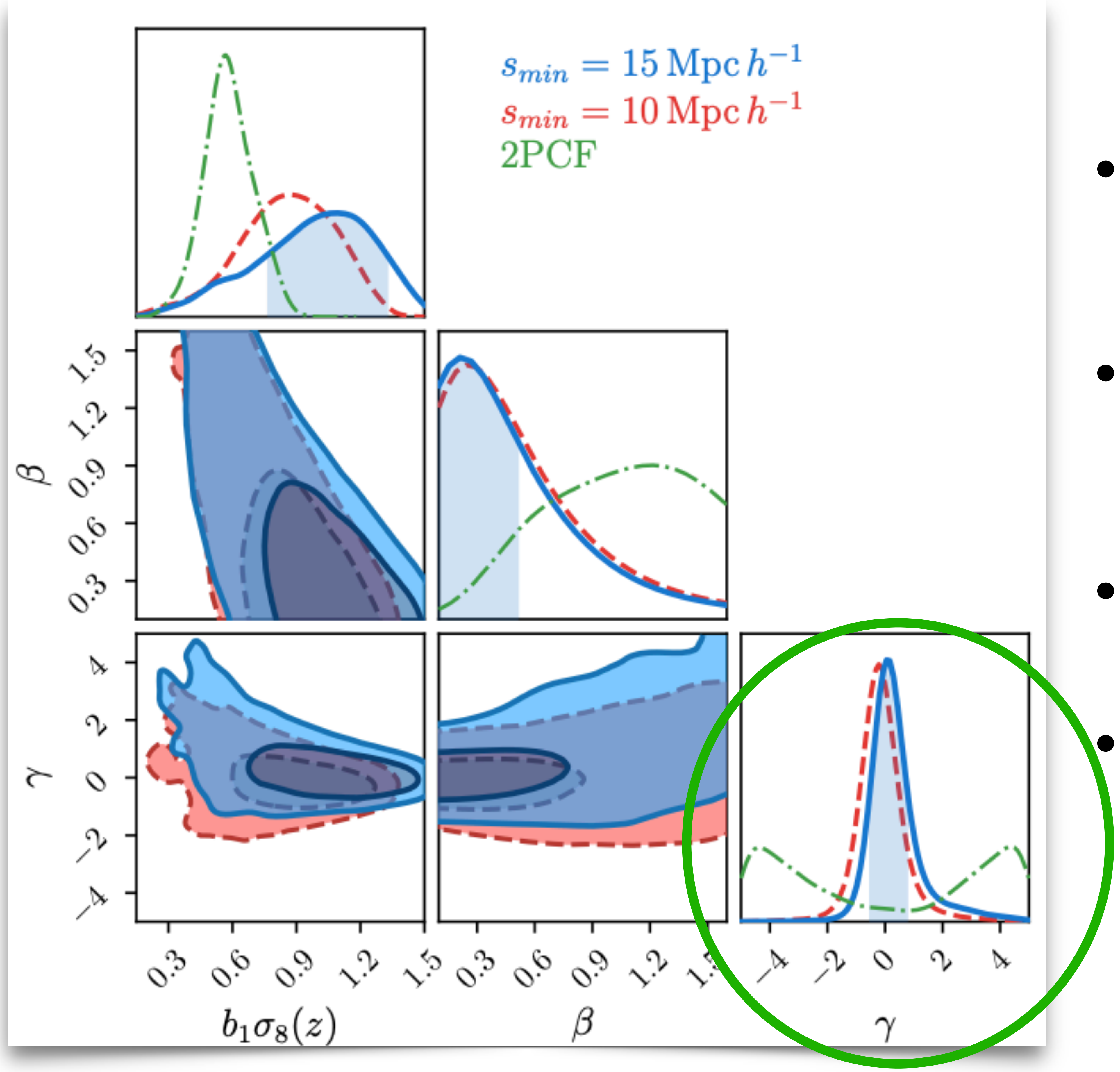
https://www.eso.org/public/images/ann13022b/

Two-Point correlation function

- Measure of the multipoles of the **VIPERS** polar **2PCF,** in two redshift bins.
- VIPERS 2PCF has been extensively used for astrophysical and cosmological analysis.
- Results are fully consistent with similar previous works (Pezzotta et al. 2017, De la Torre et al 2017).

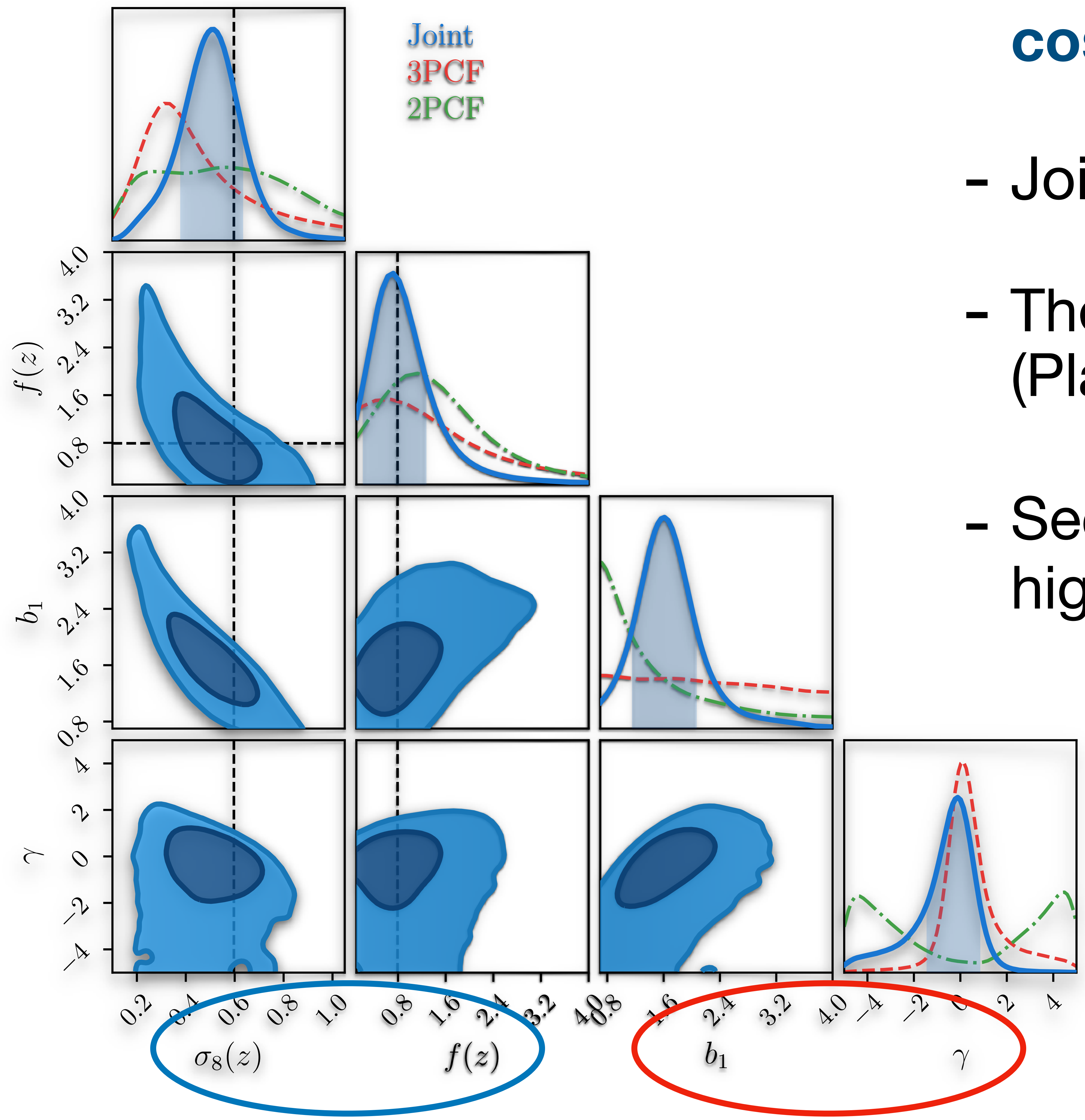


Three-Point correlation function



- Measure of the monopole of the VIPERS 3PCF, in two redshift bins.
- Fast computation, thanks to Spherical Harmonics Decomposition method (Slepian & Eisenstein, 2015).
- Strong constraint on non-linear bias γ (w.r.t. 2PCF).
- Constraints on $b\sigma_8(z)$ parameters in slight tension with 2PCF results. This possibly point to systematics in the model of the same order of magnitude of statistical error.

Joint analysis



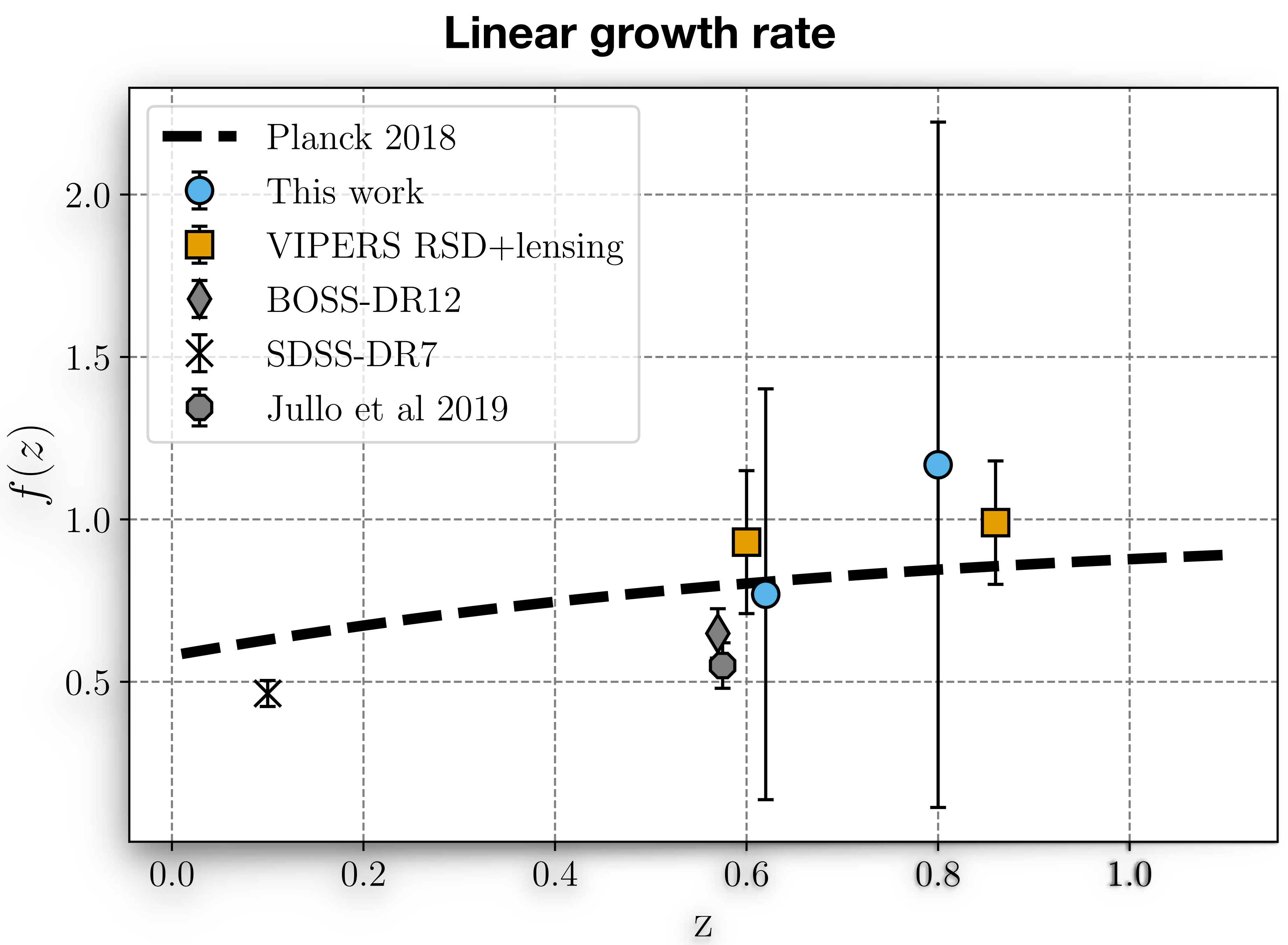
Cosmological information **Galaxy Bias**

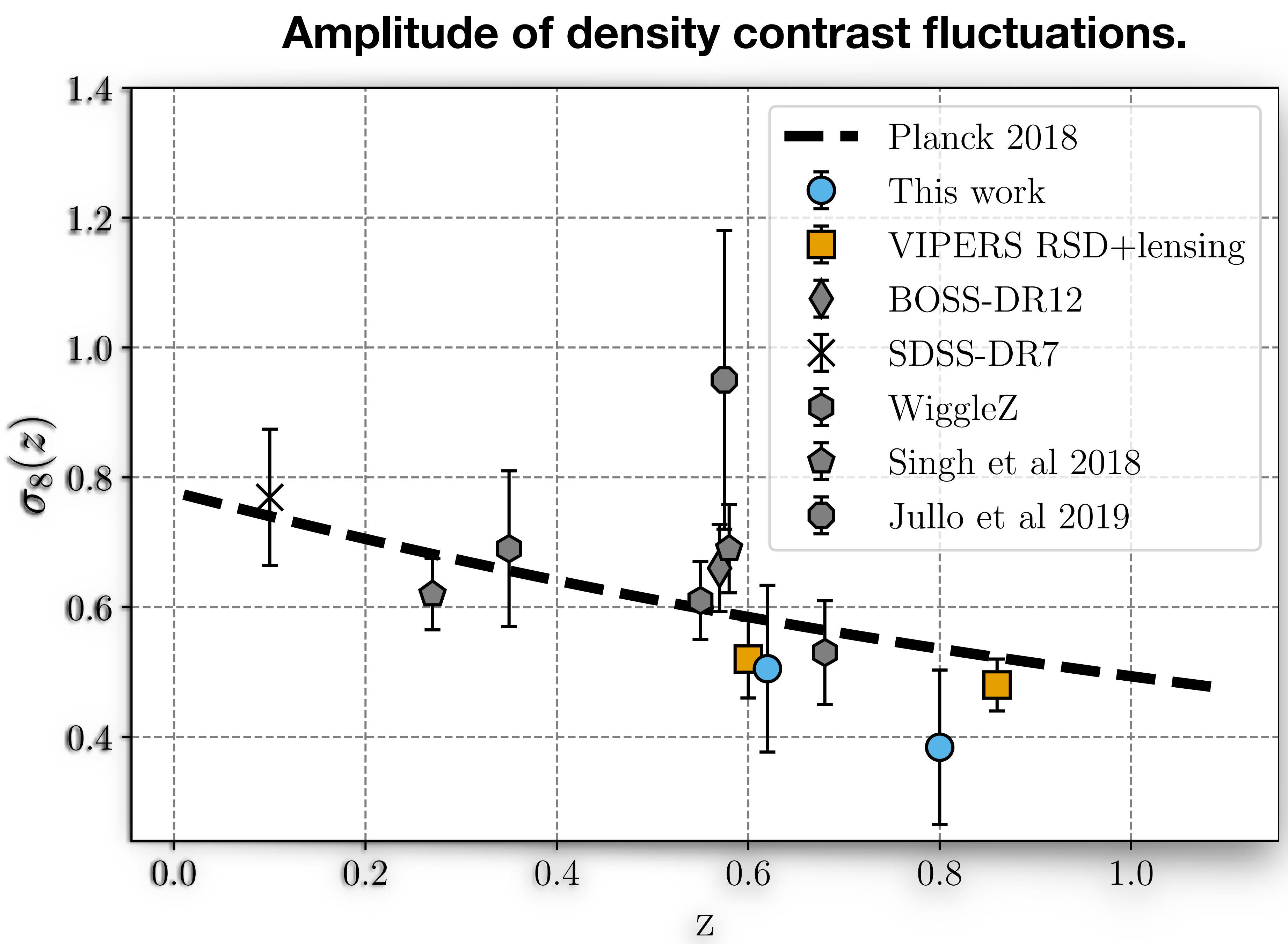
- We perform a joint fit of clustering probes, aimed at constraining **cosmological information** (σ_8, f) and **bias relation** (b_1, γ)

- Joint analysis **breaks** parameter degeneracy.

- There is a good with expectation extrapolated from CMB data (Planck collaboration et al. 2020).

- Second order bias ($\gamma \equiv b_2/b_1$) is constrained by higher order information only.





- Results in good agreement with Planck at both redshifts and previous analysis, both using VIPERS or other (larger) surveys at similar redshifts.

- VIPERS probes a relatively small volume: large error bars w.r.t. others surveys

- $20\,\%$ errors for σ_8, competitive with same results obtained with different approaches (2PCF + lensing information).

- Systematic shift for $\sigma_8(z)$: due to non-linear effects not properly modelled at the scale considered for the analysis (see next talk!)

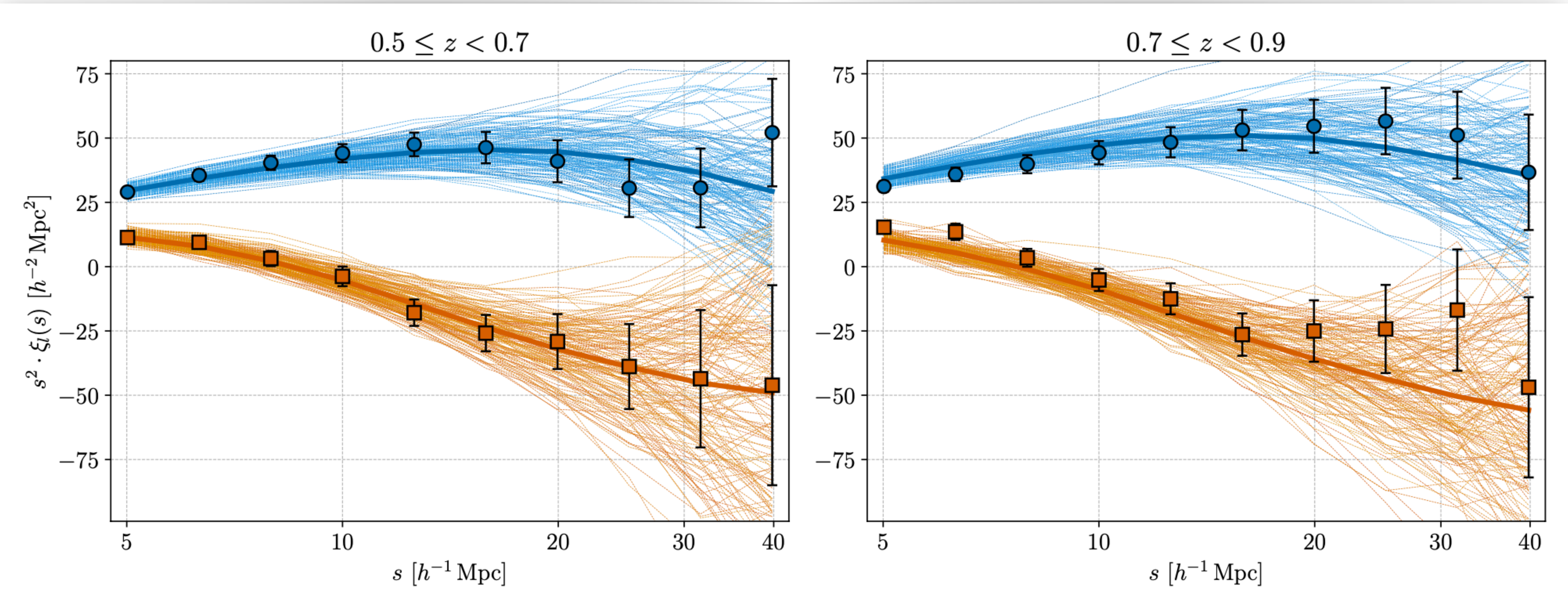
Conclusions & outlook

Conclusions and future challenges

- Clustering is a powerful way to obtain precise constraints on cosmological parameters.
- The joint analysis of 2PCF and 3PCF has the ability to break parameter degeneracy, allowing a direct measure for $b - f - \sigma_8$.
- When applied to VIPERS survey, we get $20\,\%$ on σ_8, large error bars on $f(z)$ since we only use isotropic information for 3PCF
- Next generation galaxy surveys will provide an unprecedented view of our Universe.
- To account for millions of galaxies, extremely **efficient algorithms for clustering should be developed**.
- Statistical errors will be of the same order of magnitude of theoretical systematics, **model must be improved** (see next talk by Massimo Guidi).

Backup

Two-point correlation function



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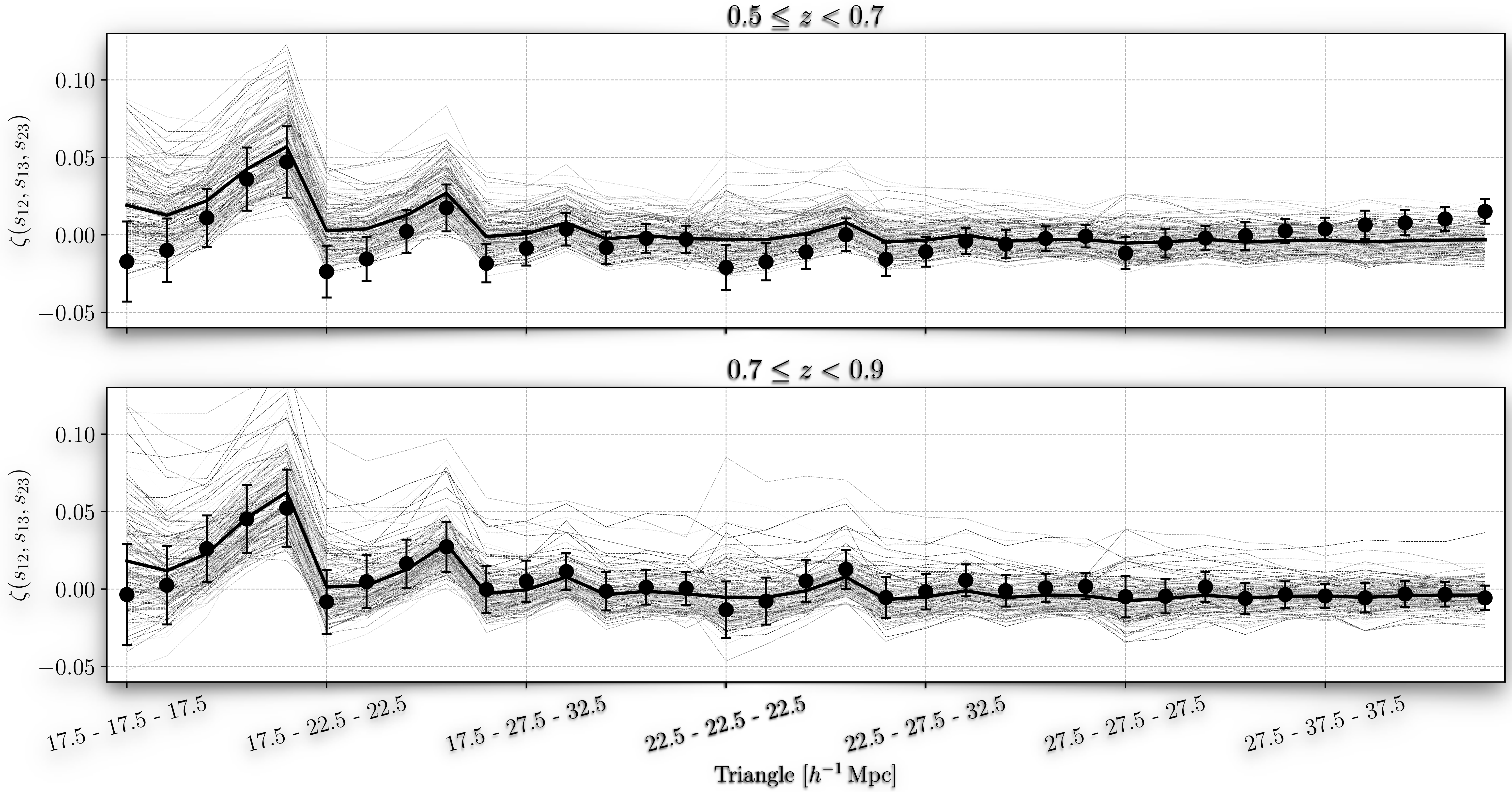
- Fully consistent with measurements from previous works (Pezzotta et al. 2017, De la Torre et al 2017).

Three-Point correlation function



- 3PCF signal rapidly vanishes as scales increase.