Exploring the dependence of the three-point correlation function on stellar mass, luminosity, and redshift

A paper by M. Moresco et al using data from the VIMOS Public Extragalactic Redshift Survey (VIPERS)

Sten Delos

Department of Physics and Astronomy
UNC-Chapel Hill

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Outline

The 3-point correlation function

The survey

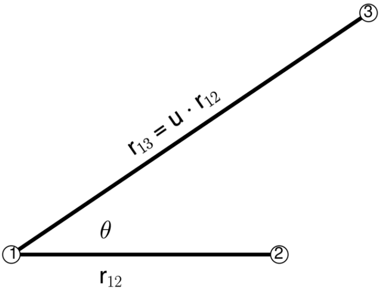
Data and methods

Results

3-point correlation function

Probability of finding triplets of objects at vertices of triangle:

$$dP = \bar{n}^3[1 + \xi(r_{12}) + \xi(r_{13}) + \xi(r_{23}) + \zeta(r_{12}, r_{13}, r_{23})]dV_1 dV_2 dV_3$$



- Parameterize with r_{12}, u, θ
- Fix $u \sim 2$ to exclude collapsed triangles (two vertices close together)
- Study variation with angle θ and scale r_{12}

Reduced 3-point correlation function

Scale symmetry implies

$$\zeta(r_{12}, r_{13}, r_{23}) \propto \xi(r_{12})\xi(r_{13}) + \xi(r_{12})\xi(r_{23}) + \xi(r_{13})\xi(r_{23})$$

and similar relations for higher correlations.

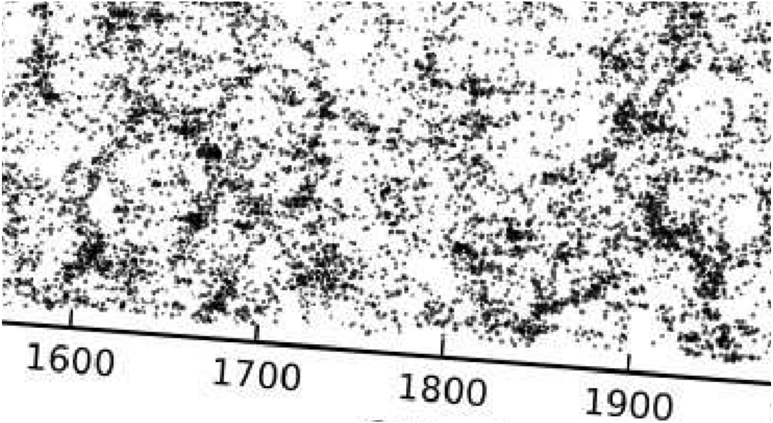
Introduce reduced 3PCF as proportionality factor to study deviations:

$$Q(r_{12}, r_{13}, r_{23}) = \frac{\zeta(r_{12}, r_{13}, r_{23})}{\xi(r_{12})\xi(r_{13}) + \xi(r_{12})\xi(r_{23}) + \xi(r_{13})\xi(r_{23})}$$

This function is also easier to study because it remains close to 1 at all scales.

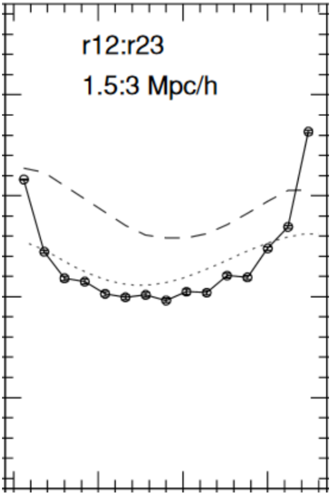
Interpretation

- Fingers of god small past 5-10 Mpc
- Filaments and walls can be much larger

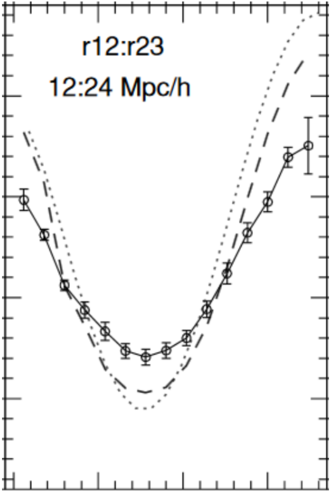


Interpretation

Small scales: U shape due to velocity dispersion



Large scales: V shape due to real structure



Simulation/theory results as displayed by Gaztañaga and Scoccimarro 2005

Why study the 3PCF

Probe nonlinear evolution of structure (2PCF only probes Gaussian statistics)

Probe galaxy bias

- Galaxies are a "biased tracer" of matter distribution:

$$\delta = b_1 \delta_m + \frac{b_2}{2} \delta_m^2 + \dots$$

- Probe with 2PCF:

$$\xi(r) \approx b_1^2 \xi_m(r)$$

  Compare with dark matter theory, but degeneracy with σ_8
- Reduced 3PCF: σ_8 dependence cancels

$$Q \approx \frac{1}{b_1} \left(Q_m + \frac{b_2}{b_1} \right)$$

Constrain other cosmological parameters (σ_8, BAO)

This work

- Preliminary exploration of the behavior of the 3PCF at high redshift
- More rigorous analysis left to subsequent papers

Outline

The survey

The instrument

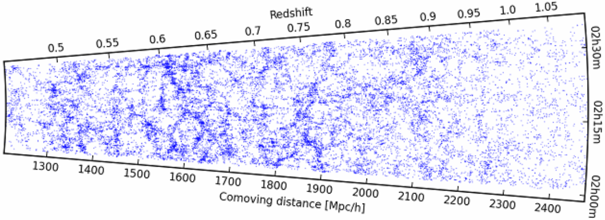
- VIsible Multi-Object Spectrograph (VIMOS)
- European Southern Observatory's Very Large Telescope (Chile)

The survey

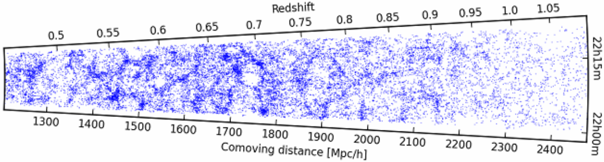
- VIMOS Public Extragalactic Redshift Survey (VIPERS)
- High redshift: $0.5 < z < 1.1$ (5-8 billion years ago)
- Area: 24 deg^2 split between two fields W1 and W4
- Large volume: $5 \times 10^7 (h^{-1}\mathrm{Mpc})^3$
- Magnitude limited: $i_{AB} < 22.5$
- PDR1: 54756 galaxies (entire W4, half of W2)
- (Final data release: $\sim$ 90000 galaxies, Nov 18)

Survey volume

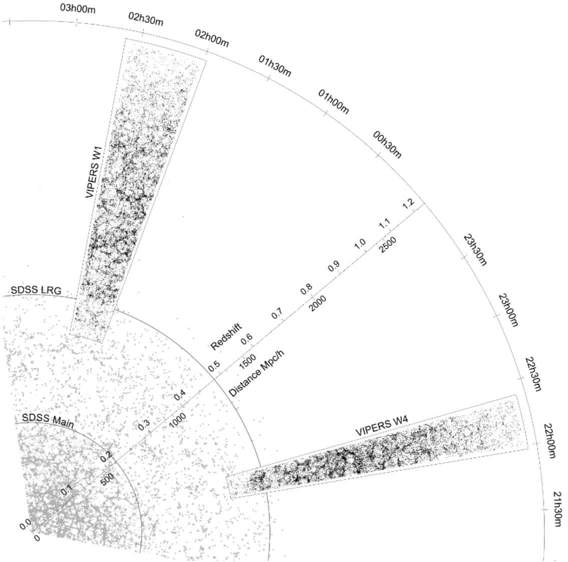
W1 field



W4 field



Survey volume



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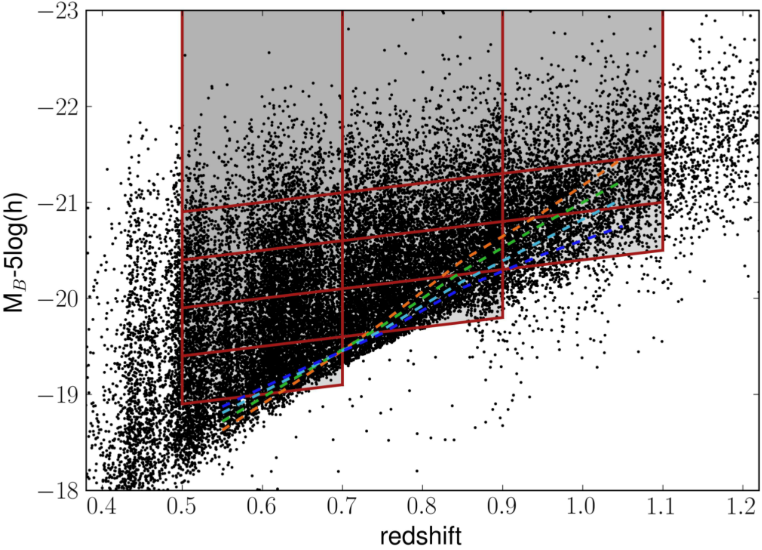
Split into three redshift ranges:

- $z \in [0.5, 0.7]$
- $z \in [0.7, 0.9]$
- $z \in [0.9, 1.1]$

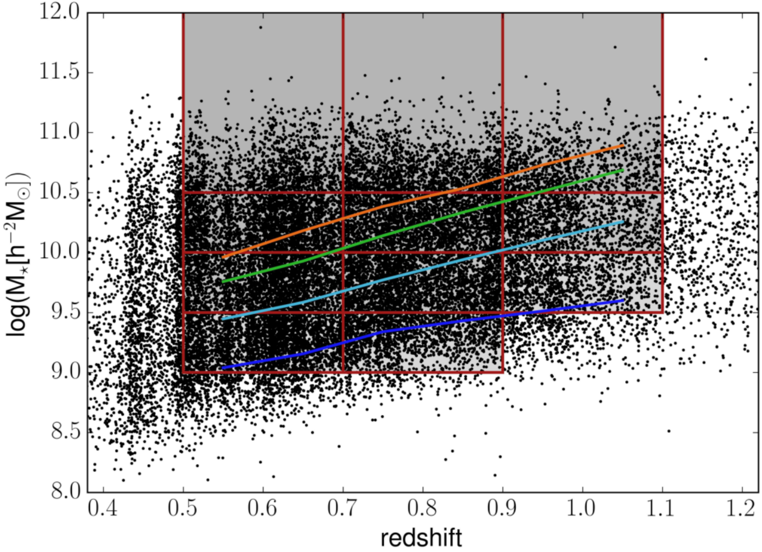
Create equally spaced mass and luminosity bins that follow the redshift evolution:

- Mass bins constant (approximately true for $z \lesssim 1$)
- Luminosity bins increasing with z (dimming with time)
- Idea: compare similar classes of galaxy at different redshift

Luminosity bins



Mass bins



12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
redshift
log(M⋆[h⁻²M⊙])

Data selection

Most luminosity bins are volume-limited

- Redder objects start to fall out of the survey at high redshift

Mass bins suffer incompleteness

- Effect studied by Marulli et al 2013
- Mainly affects small scales ($\lesssim 1 h^{-1}\mathrm{Mpc}$)

Computation

Use Szapudi-Szalay estimator for 3PCF:

$$\hat{\zeta}(r_{12}, u, \theta) = \frac{DDD - 3DDR + 3DRR - RRR}{RRR}$$

and Landy-Szalay estimator for 2PCF:

$$\hat{\xi}(r) = \frac{DD - 2DR + RR}{RR}$$

Random sample for each bin

- 60 times as many objects
- Redshifts drawn from smoothed data distribution

Apply weights to account for sampling rate effects (minor)

Error estimation

Mock catalogues from previous work (de la Torre et al 2013)

- Create 26 halo catalogues using MultiDark dark matter N-body simulation
- Populate with galaxies and their absolute magnitudes
  - Based on HOD formalism calibrated on VIPERS data
  - Use for luminosity-selected 3PCF
- Separately populate with galaxies and their stellar masses.
  - Based on SHMR (stellar-to-halo mass relation) formalism
  - Use for stellar mass-selected 3PCF
- Apply survey selection function

Calculate covariance matrix on these mocks:

$$C_{ij} = \frac{1}{N-1} \sum_{k=1}^{N} (Q_i^k - \bar{Q}_i)(Q_j^k - \bar{Q}_j)$$

Due to small number of mocks, only use diagonal elements:

$$\sigma_i = \sqrt{C_{ii}}$$

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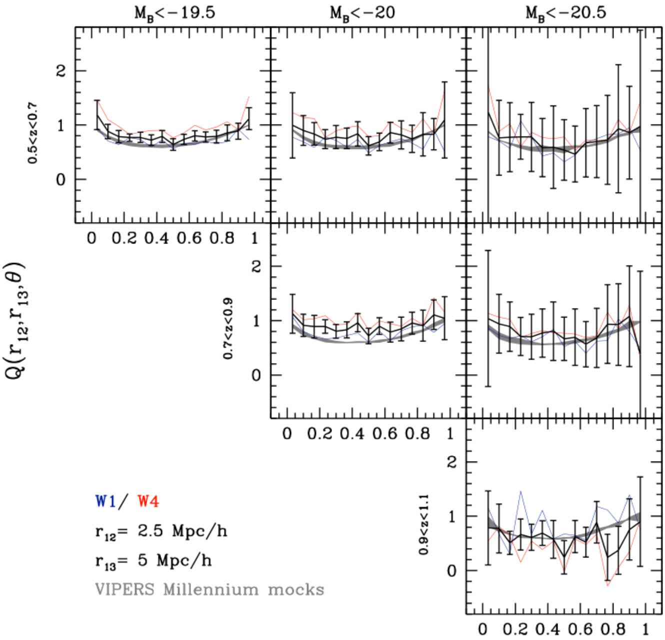
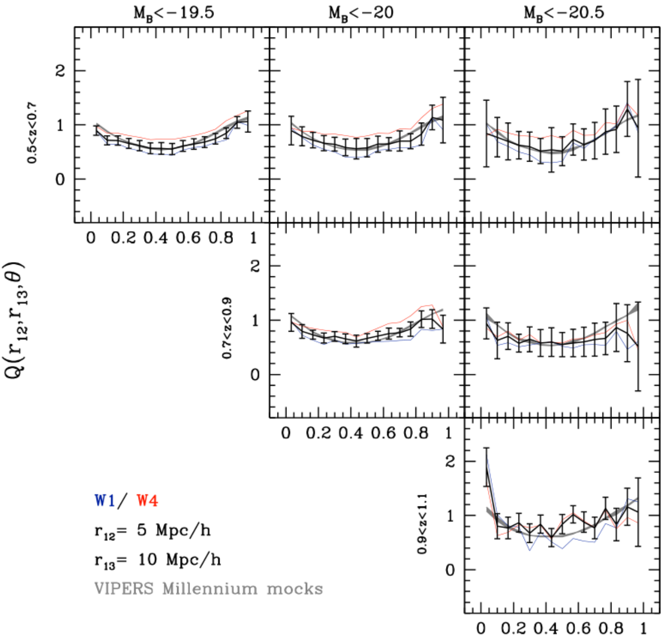
Redshift and scale dependence, luminosity bins



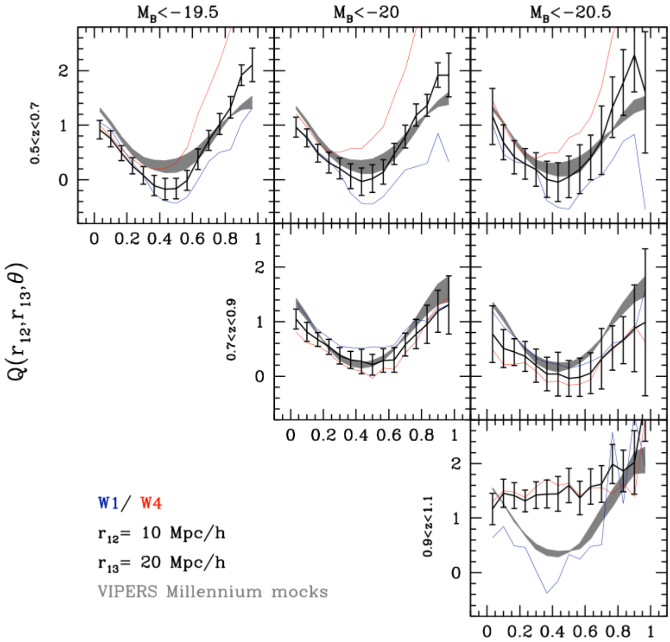
Small scale

Redshift and scale dependence, luminosity bins



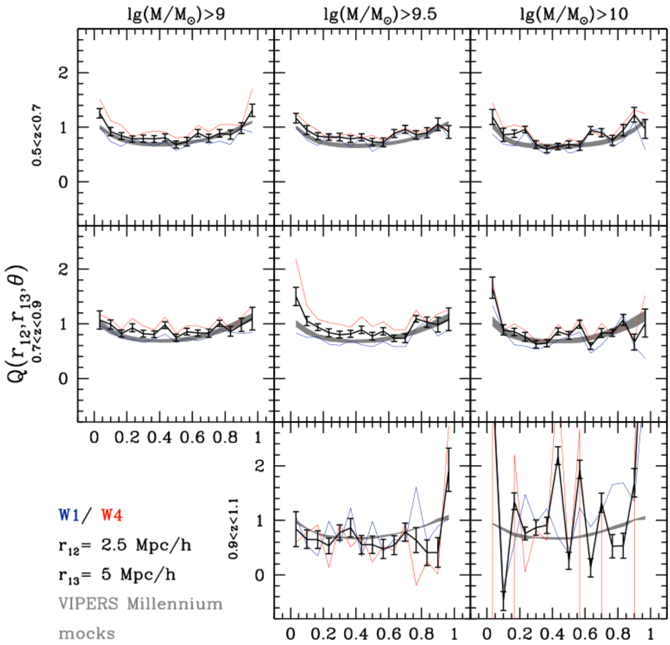
Intermediate scale

Redshift and scale dependence, luminosity bins



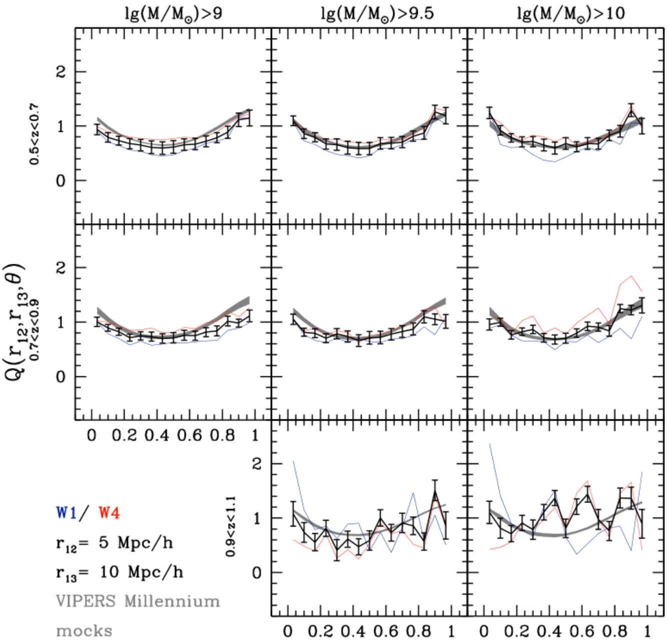
Large scale

Redshift and scale dependence, mass bins



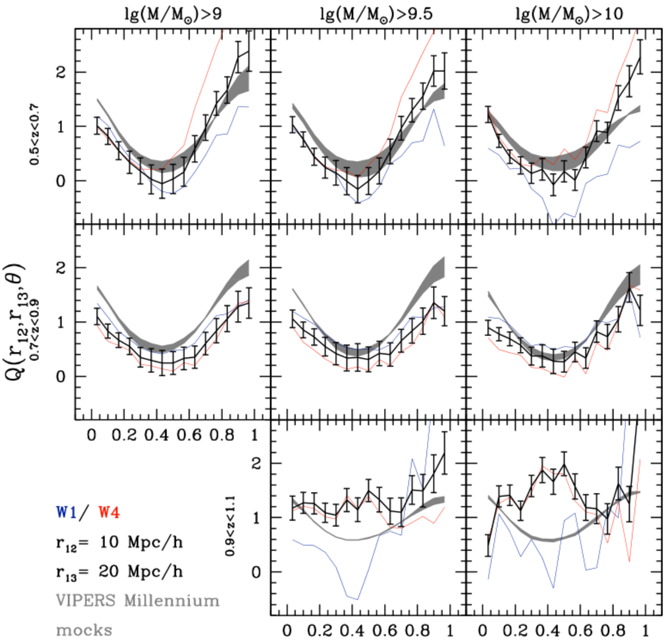
Small scale

Redshift and scale dependence, mass bins



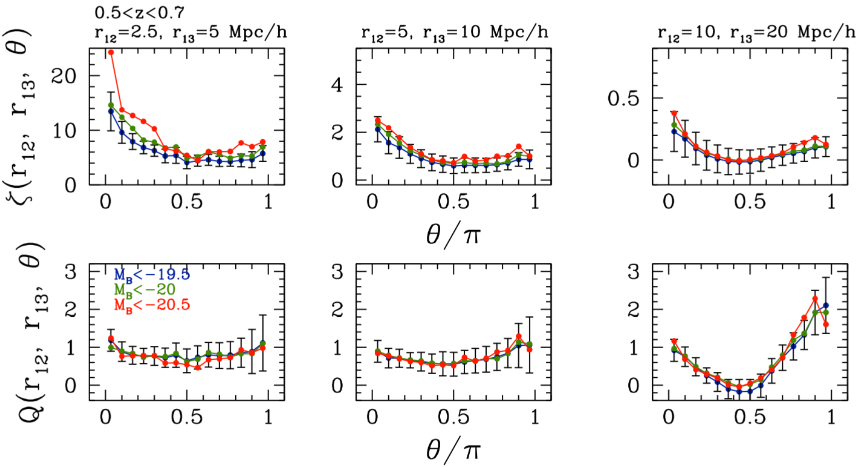
Intermediate scale

Redshift and scale dependence, mass bins



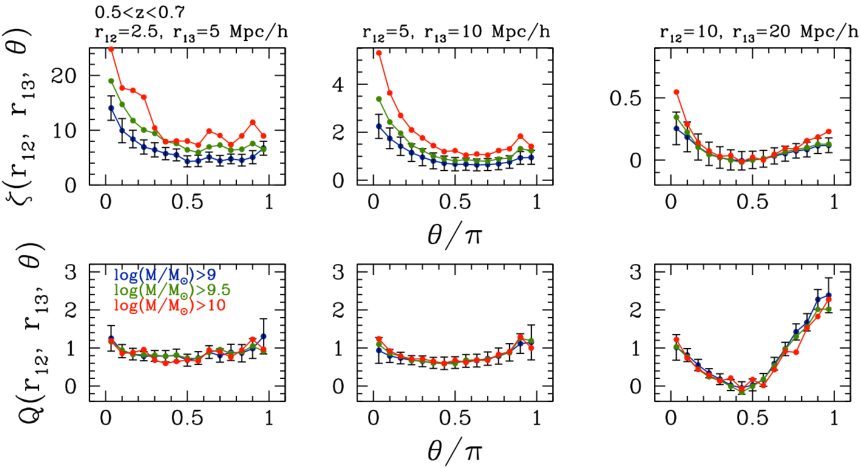
Large scale

Luminosity dependence



Colors indicate the low ([−20, −19.5]), intermediate ([−20.5, −20]), and high ([−21, −20.5]) luminosity bins.

Mass dependence



Colors indicate the low ([9, 9.5]), intermediate ([9.5, 10]), and high ([10, 10.5]) log stellar mass bins.

Conclusions

- Q(θ) shows prominent anisotropy at large scale: indicates dominance of filamentary structure
- Large scale Q(θ) flatter at higher redshift: reflects evolution of structure
- More massive/luminous galaxies more clustered
- Q minimally dependent on mass/luminosity, despite linear bias dependence (2PCF work): suggests nonlinear contribution to bias
- Theoretical models consistently underestimate Q at small scales: failing to reproduce nonlinear bias?
- Poor agreement with theory at high redshift: possibly underestimated error from using only diagonal elements of covariance matrix

M. Moresco et al
The VIMOS Public Extragalactic Redshift Survey (VIPERS). Exploring the dependence of the three-point correlation function on stellar mass and luminosity at $0.5 < z < 1.1$
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The VIMOS Public Extragalactic Redshift Survey (VIPERS). Luminosity and stellar mass dependence of galaxy clustering at $0.5 < z < 1.1$
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The VIMOS Public Extragalactic Redshift Survey (VIPERS). Galaxy clustering and redshift-space distortions at $z \simeq 0.8$ in the first data release
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VIPERS Home Page
http://vipers.inaf.it

E. Gaztañaga and R. Scoccimarro
The three-point function in large-scale structure: redshift distortions and galaxy bias
MNRAS,361(3):824–836, 2005.