Measuring the growth rate of structure around cosmic voids in VIPERS

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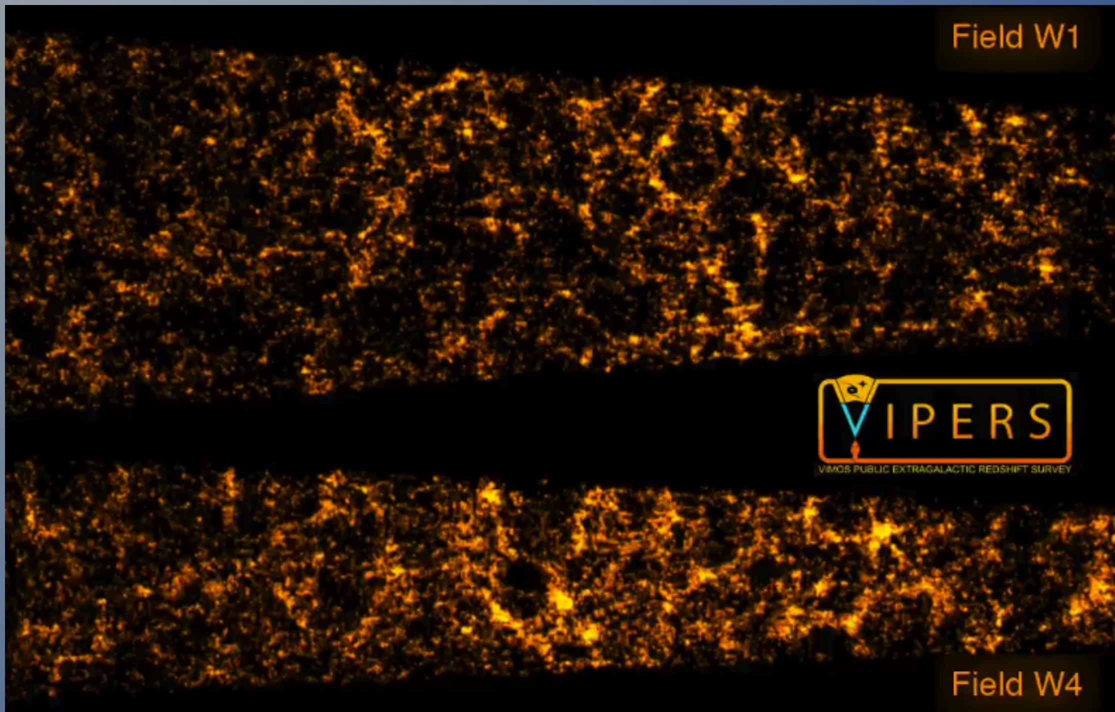
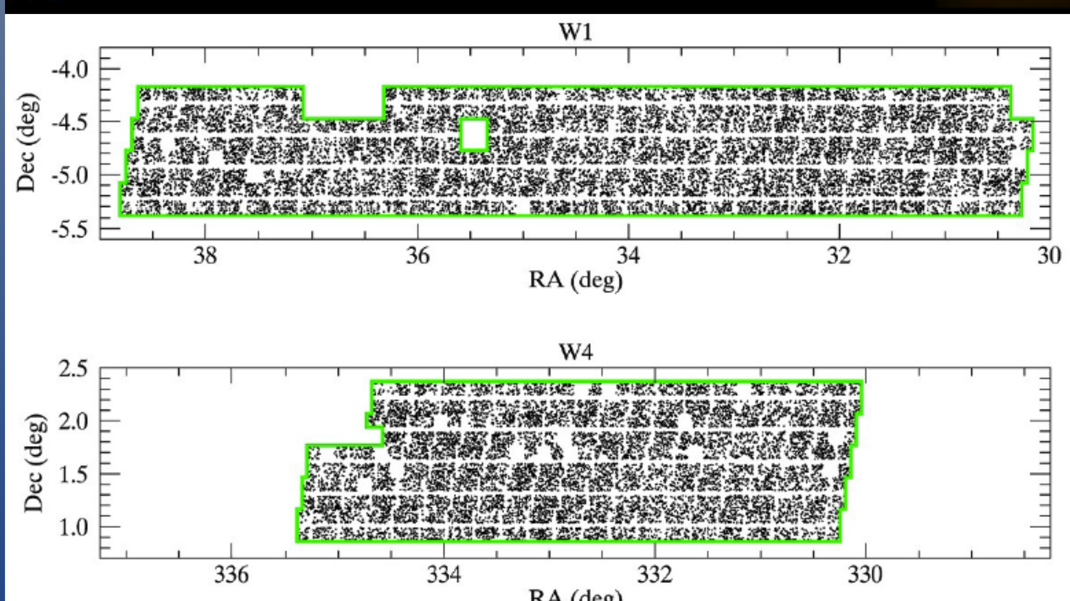
Micheletti et al. (submitted), Hawken et al. (in prep)

Summary

- We have developed a simple void finding algorithm based on empty spheres.
- We used this to search for voids in VIPERS and to produce a void catalogue.
- Using this catalogue we measured the void-galaxy cross correlation function.
- The cross-correlation function is anisotropic – demonstrating the effect of linear redshift space distortions.
- By fitting a model of the correlation function to the data we can obtain an estimate of the growth parameter $f(\Omega) = d \ln D / d a$.
- There are many other pieces of science that we would like to do with this catalogue.

VIMOS Public Extragalactic Redshift Survey





The current public data release contains 57204 spectra.

Eventually VIPERS should collect ~100,000 redshifts out to z~1 covering 24 sq deg.

We used a volume limited sample of galaxies

$0.55 < z < 0.9$

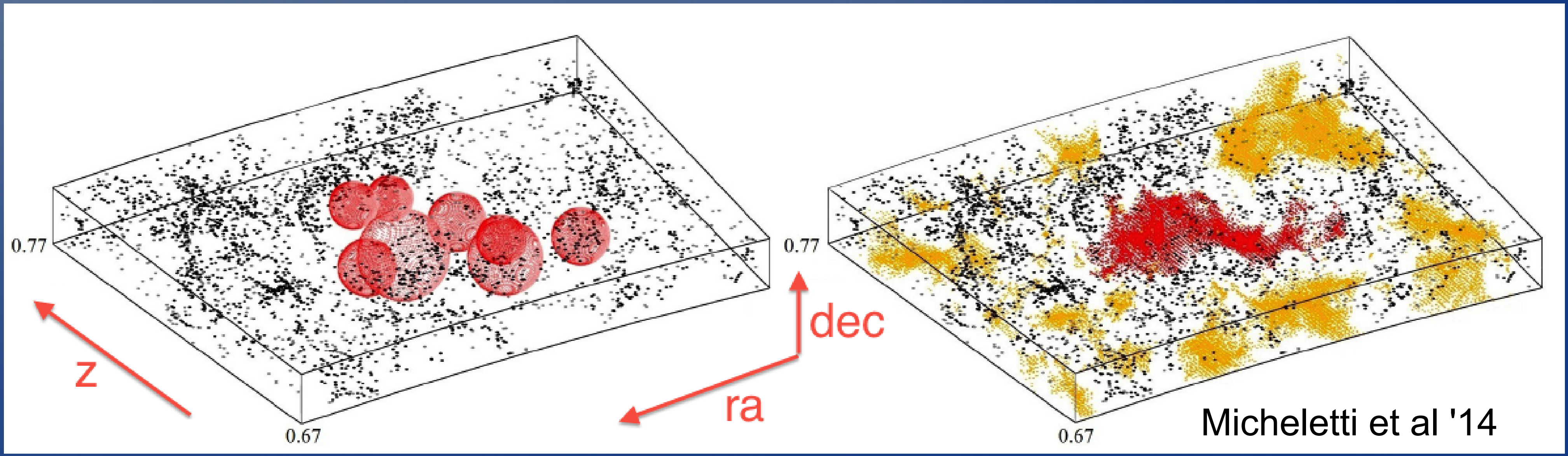
from the VIPERS internal data release four

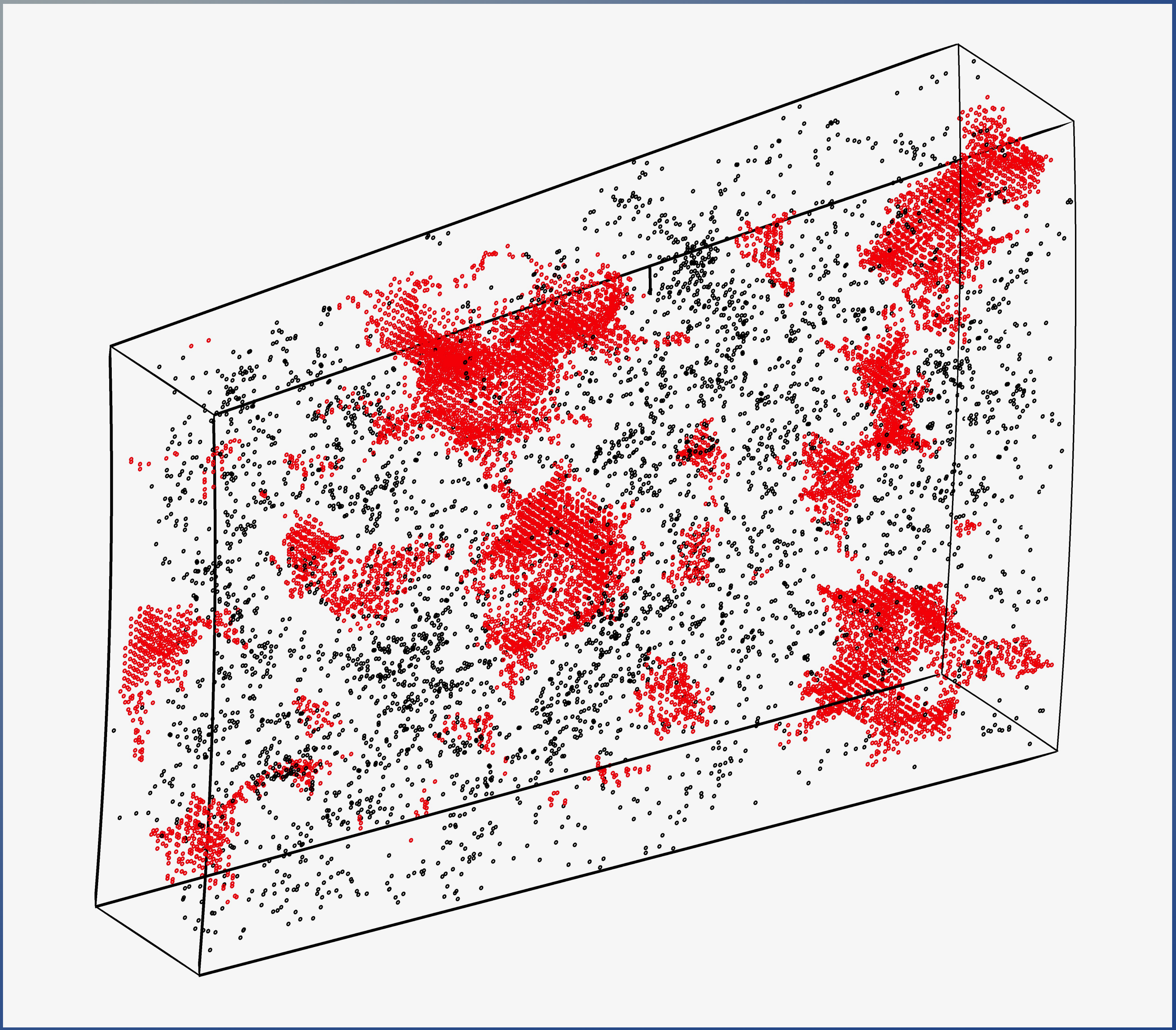
VIPERS is very thin in declination.

It has a complicated mask with gaps and holes which can cause problems when trying to look for voids.

Void finding algorithm

- Remove the most isolated galaxies from the catalogue to increase the contrast between the high and low density regions.
- Look for empty spheres using a regular grid.
- 'maximal spheres' are defined as the subset of statistically significant non-overlapping empty spheres.
- 'voids' are regions connected by overlapping statistically significant spheres.





To avoid finding spurious under densities caused by the mask, we only select the most significant empty spheres.

R ~ 15 Mpc

The cutoff radius is slightly redshift dependant because our galaxy catalogue is not perfectly volume limited and because the significance of the gaps changes with redshift.

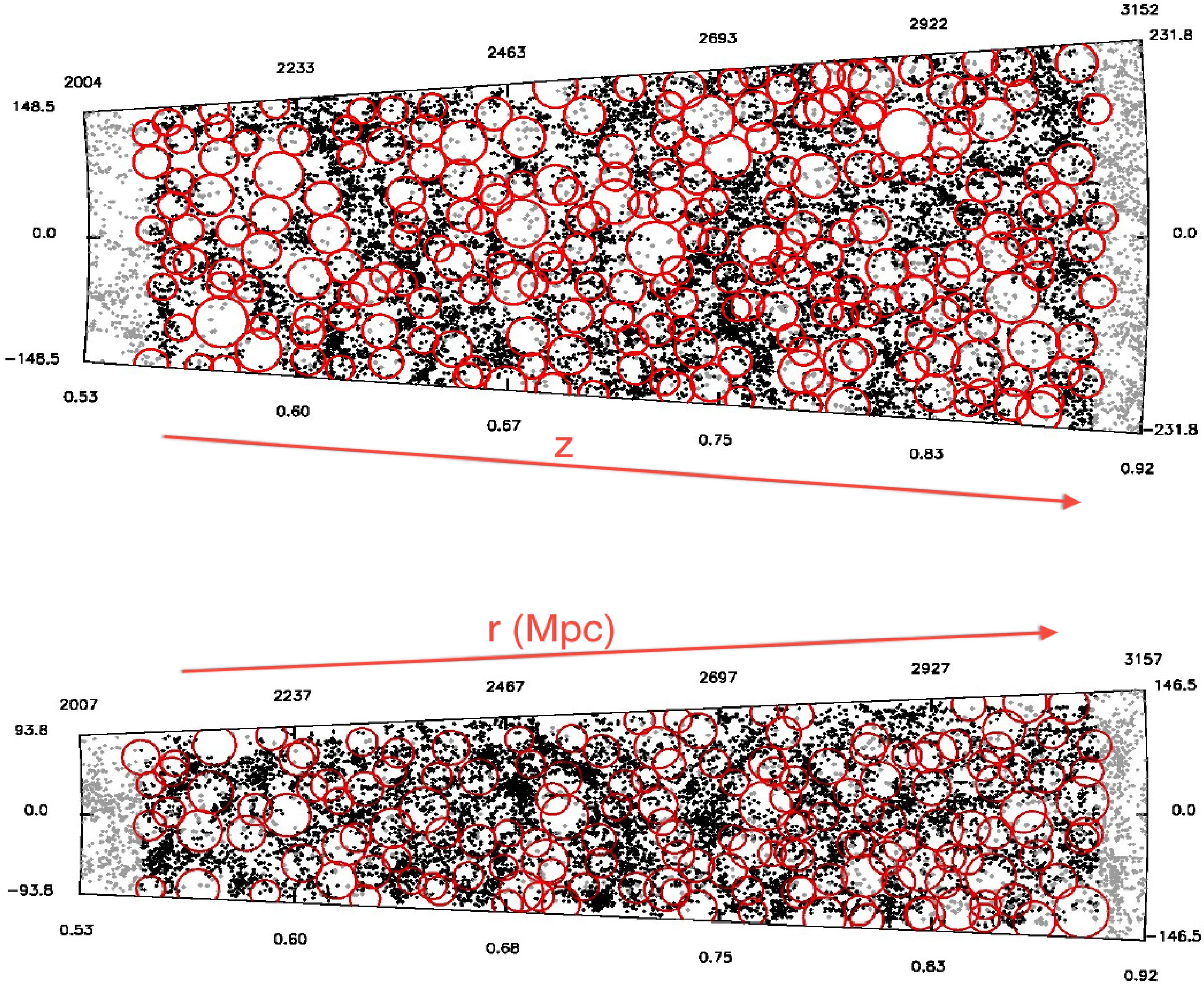
We are not just restricted to finding spherical voids.

Our voids are defined as points on a regular grid bounded by a density threshold:

$$\delta_g < \frac{1-\bar{n}}{V(r_c)\bar{n}}$$

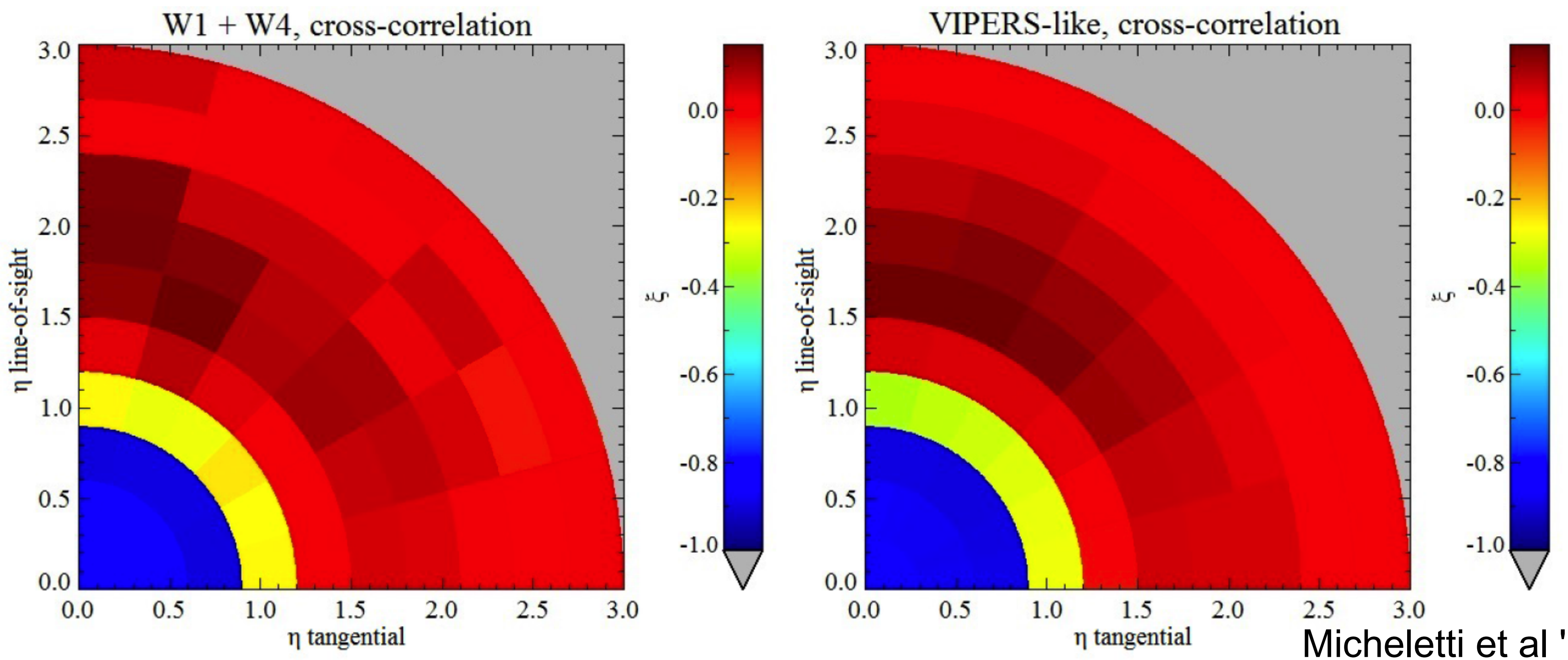
W1 : 229 maximal spheres in 145 voids

W4 : 159 maximal spheres in 100 voids



Micheletti et al '14

The void-galaxy cross correlation function



Micheletti et al '14

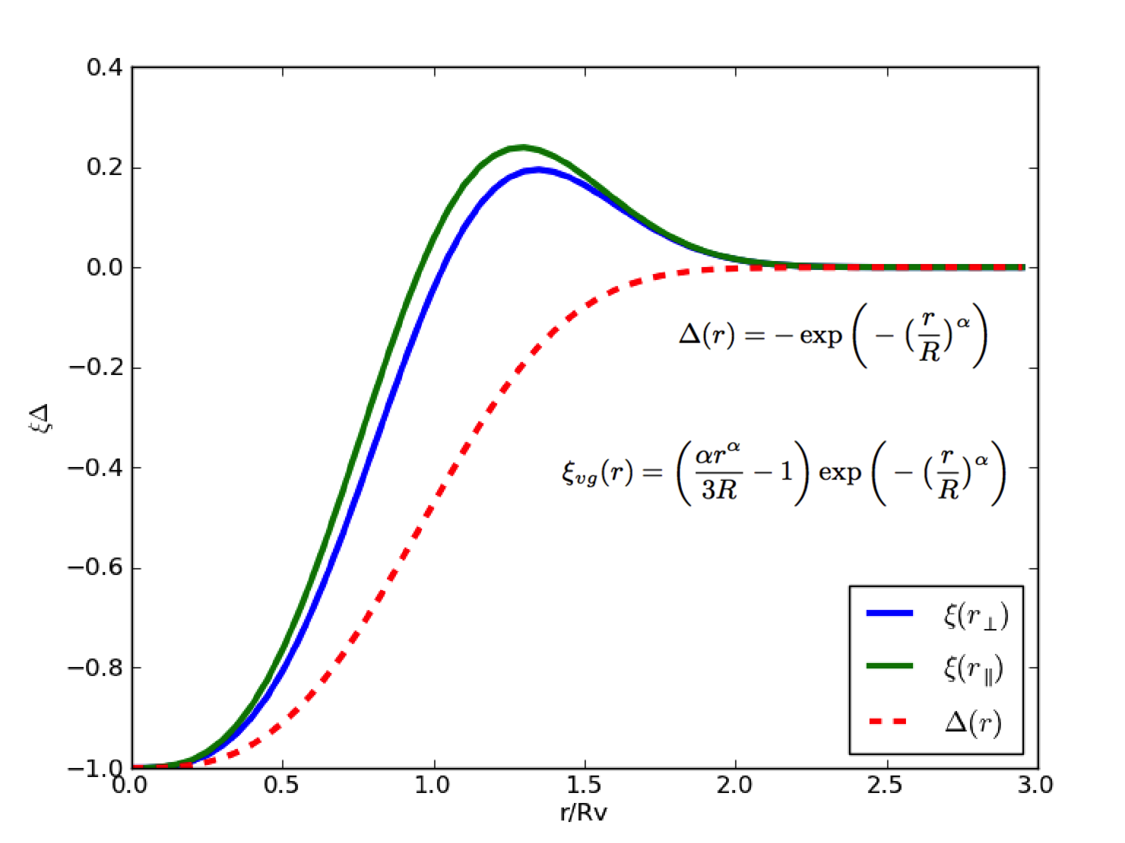
$$\xi(\eta,\alpha) = \frac{N_R}{N_g}\frac{DD(\eta,\alpha)}{DR(\eta,\alpha)} - 1$$

We apply the Davis & Peebles estimator to VIPERS to estimate the anisotropic cross-correlation function.

Any observed enhancement along the line of sight should be caused by coherent outflows.

The rate at which material is evacuating from the voids is an indicator of the strength of gravity.

The effect of redshift space distortions



The void-galaxy cross correlation function carries the same information as the density profile.

The void galaxy cross-correlation function also provides information on the dynamics of galaxies in voids and in the structure around them.

Because the densities of the environments we are considering are small, the relationship between density and velocity is pretty much linear.

$$v(r) \approx -Hr\Delta(r)\frac{f(\Omega_m)}{3}$$

$$\xi_{vg}(r) = \frac{1}{3r^2}\frac{\mathrm{d}}{\mathrm{d}r}(r^3\Delta(r))$$

$$1 + \xi(\sigma,\pi) = \int \frac{\mathrm{d}w_3}{\sqrt{2\pi}\sigma_v}\exp\left(-\frac{(w_3 - v(r)\frac{r_3}{r})^2}{2\sigma_v}\right)[1+\xi(r)]$$

Paz et al '13, Padilla et al '05

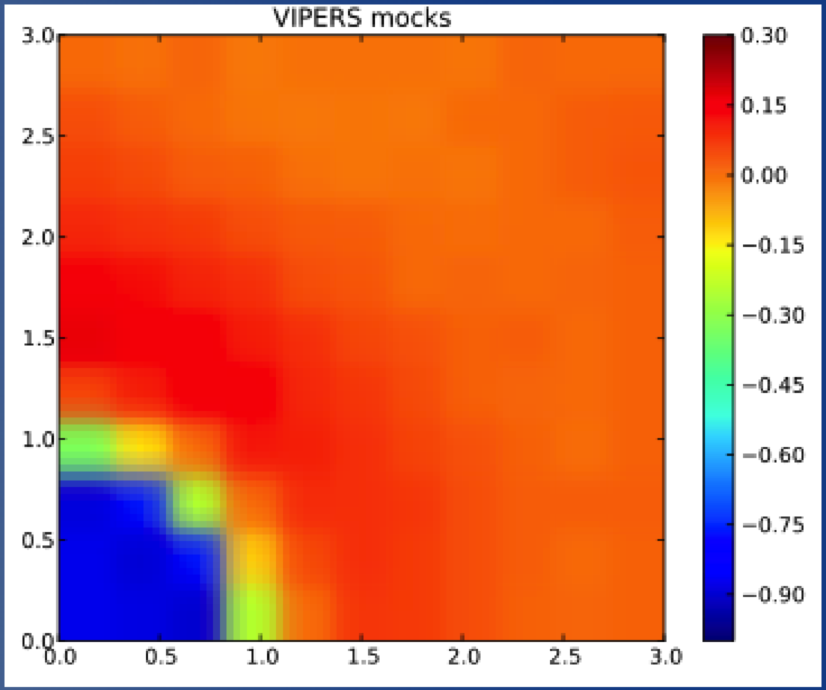
Comparison to mocks

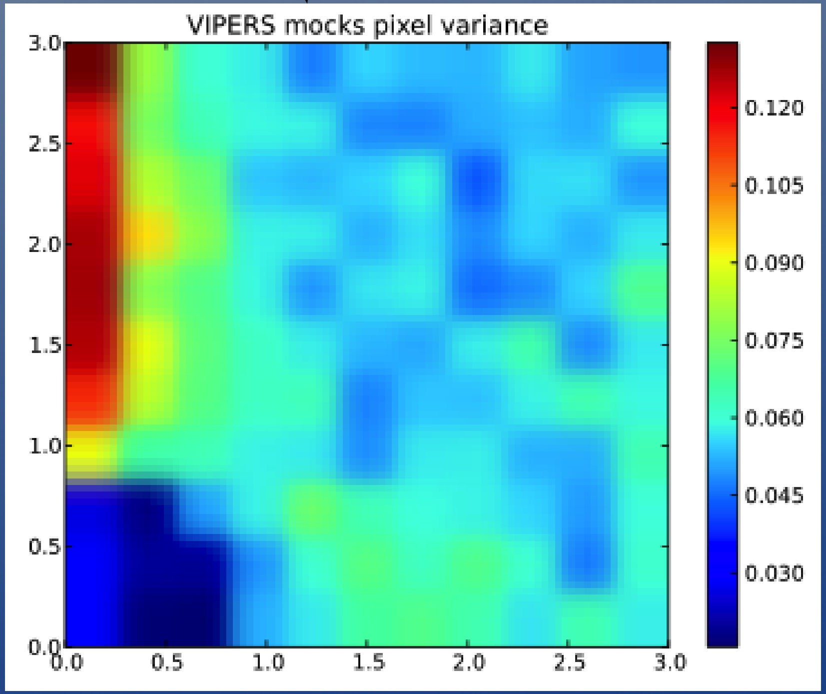
57 mock VIPERS-like catalogues (de la Torre et al 2013)

produced from the MultiDark N-body simulations (Prada et al 2012)

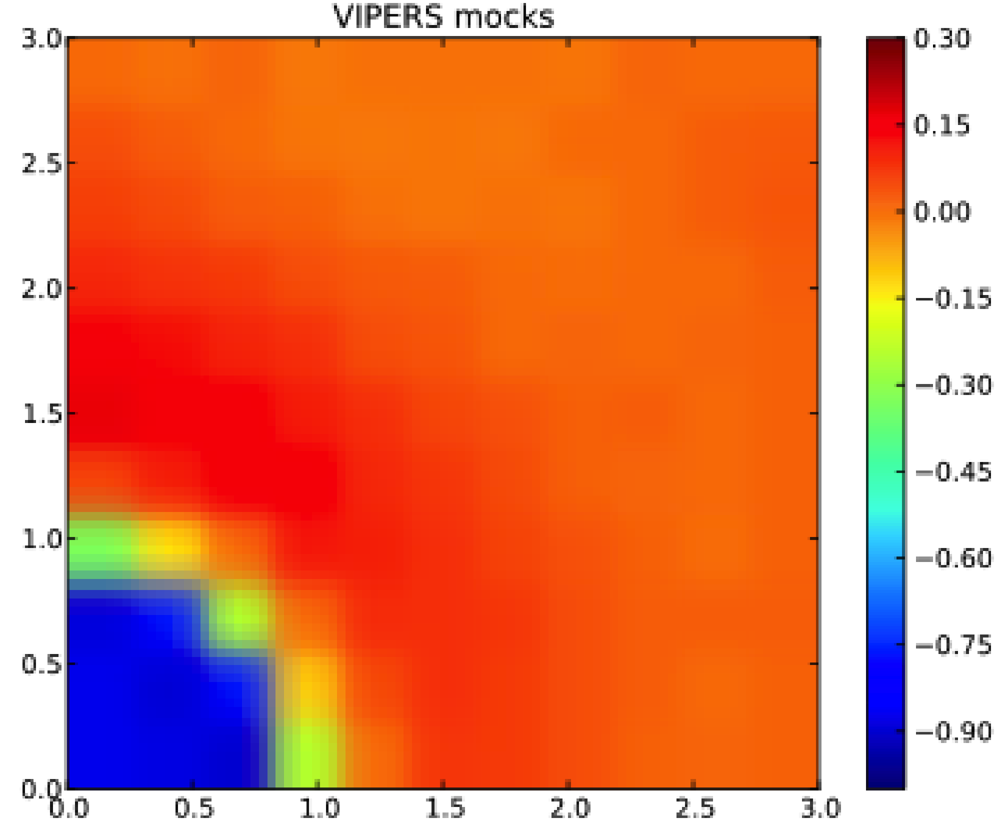
Combined mock correlation function

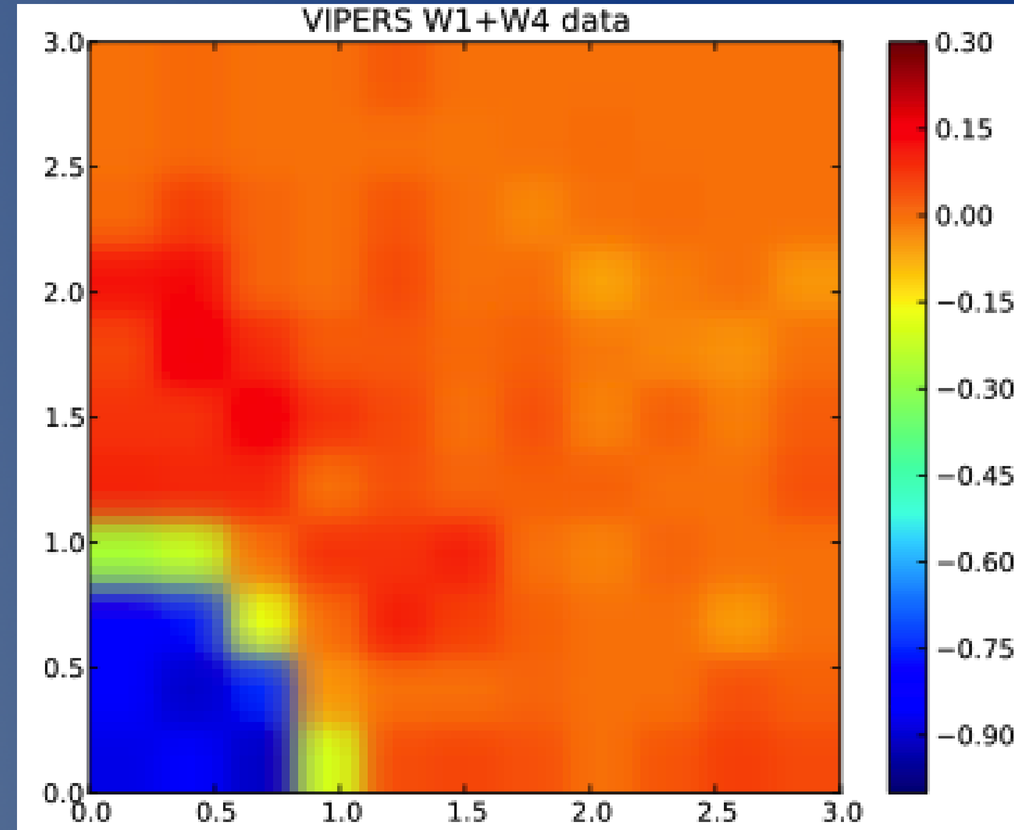
Variance of the mocks





$$
\begin{aligned}
\Omega_m &= 0.27 \\
\Omega_b &= 0.0469 \\
\Omega_\Lambda &= 0.73 \\
H_0 &= 70 \mathrm{km\,s^{-1}\,Mpc^{-1}} \\
n_s &= 0.95 \\
\sigma_8 &= 0.82
\end{aligned}
$$

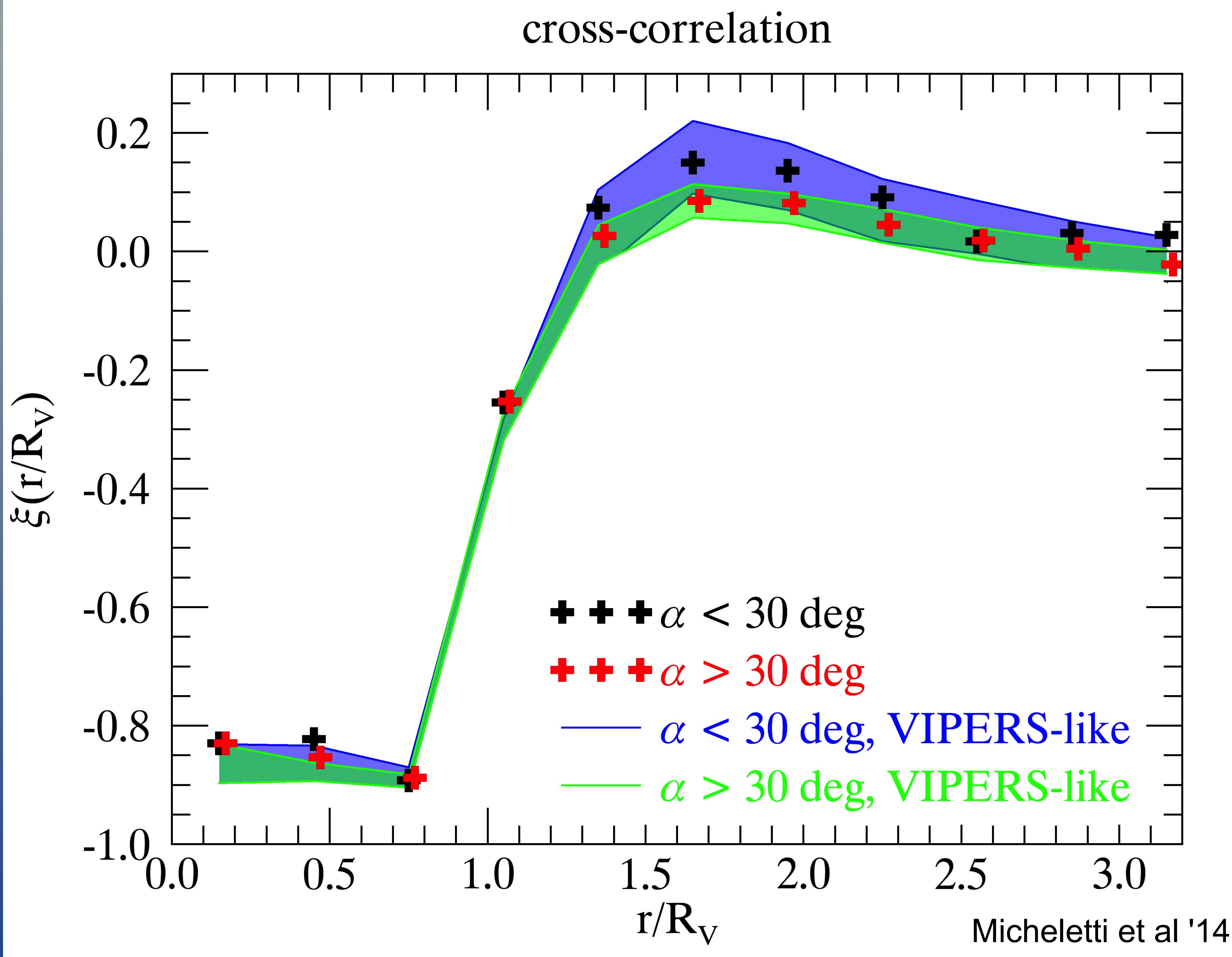


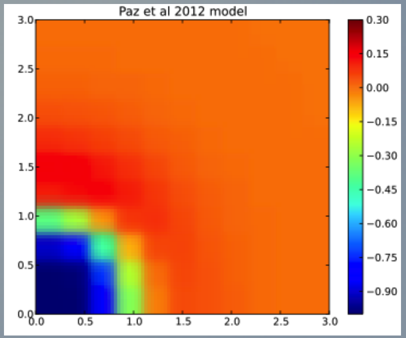


The observed void-galaxy cross correlation function is in good agreement with the mocks.

$$\chi^2 = 0.437$$

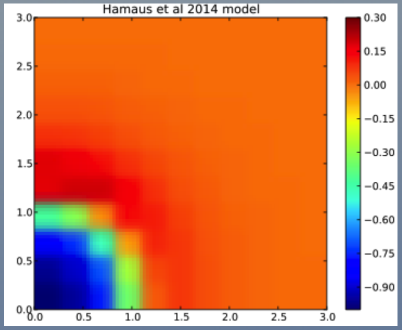
From this we can safely say that there is no conflict with LCDM


cross-correlation
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
$\xi(r/R_V)$
0.0
0.5
1.0
1.5
2.0
2.5
3.0
r/R_V
α < 30 deg
α > 30 deg
α < 30 deg, VIPERS-like
α > 30 deg, VIPERS-like
Micheletti et al '14



$$\Delta(r) = \frac{1}{2}[\mathrm{erf}(S\ln(\eta)) - 1] + P\exp\left(-\frac{\ln^2(\eta)}{2\Theta^2}\right)$$

Paz et al '13

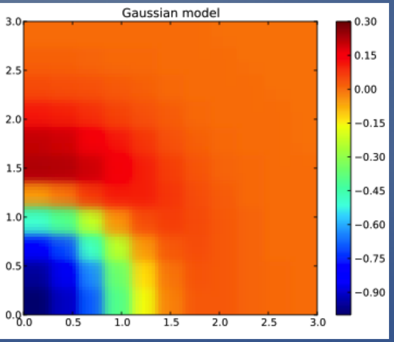


$$\xi_{vg}(r) = \delta_c \frac{1-(r/r_s)^\alpha}{1+(r/r_v)^\beta}$$

Hamaus et al '14

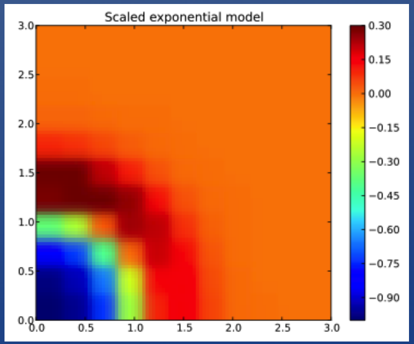
$$\xi_{vg}(r) = \left(\frac{r^2}{3\sigma^2}-1\right)\exp\left(-\frac{r^2}{2\sigma^2}\right)$$

Gaussian density profile



$$\xi_{vg}(r) = \left(\frac{\alpha r^\alpha}{3R}-1\right)\exp\left(-\left(\frac{r}{R}\right)^\alpha\right)$$

Exponential power law

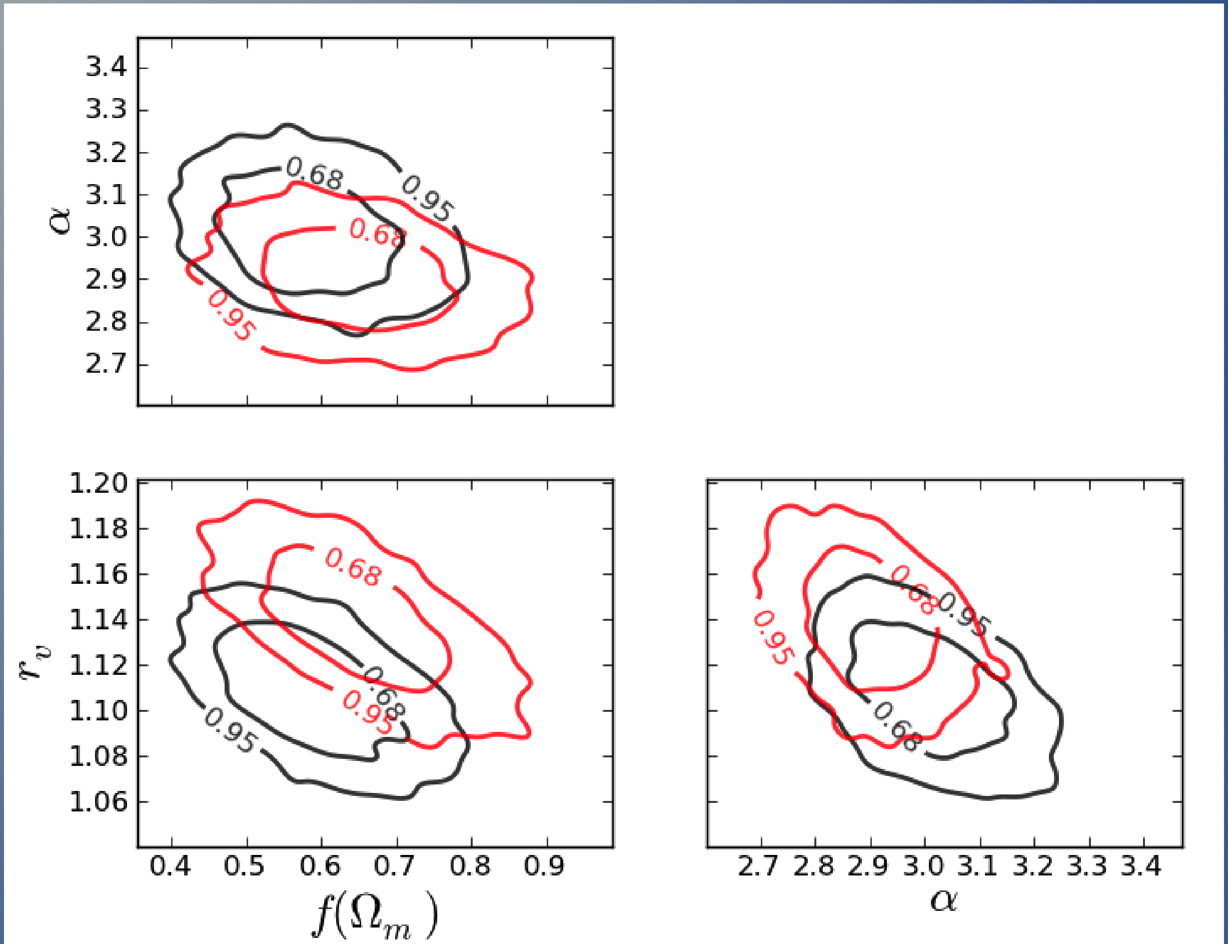


The most general models for the density profile, which have been shown to fit both simulations and data well, allow for a compensating ridge around the void.

Our voids, which are much larger than many of the voids characterised in other studies, do not appear to have this ridge.

However, this could be because of smoothing. (Marius suggested this yesterday).

The simplest exponential power law profile provides a good fit to our correlation function.



We found the best fitting correlation function (with RSD) using an MCMC chain, varying the profile shape parameters and the growth rate.

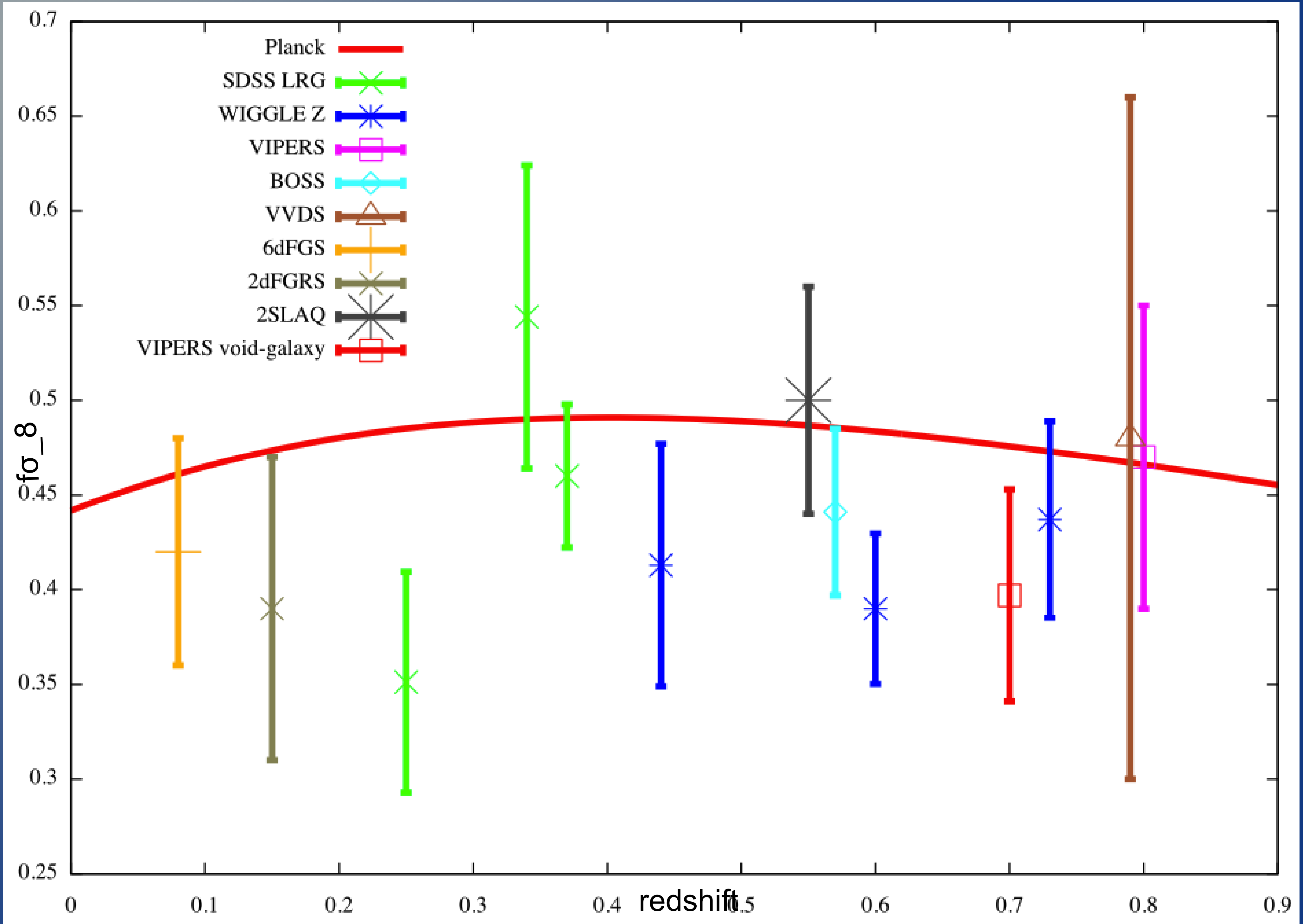
First we fit to the mocks (red) and then to the VIPERS data (black).

The results are consistent with each other.

$$\xi_{vg}(r) = \left(\frac{\alpha r^{\alpha}}{r_v} - 1\right)\exp\left(-\left(\frac{r}{r_v}\right)^{\alpha}\right)$$

However, this is an underestimate of the growth rate measured on the same mocks using conventional methods.

This bias needs to be understood before we can be truly confident of the result.


0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
fσ_8
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
redshift
Planck
SDSS LRG
WIGGLE Z
VIPERS
BOSS
VVDS
6dFGS
2dFGRS
2SLAQ
VIPERS void-galaxy

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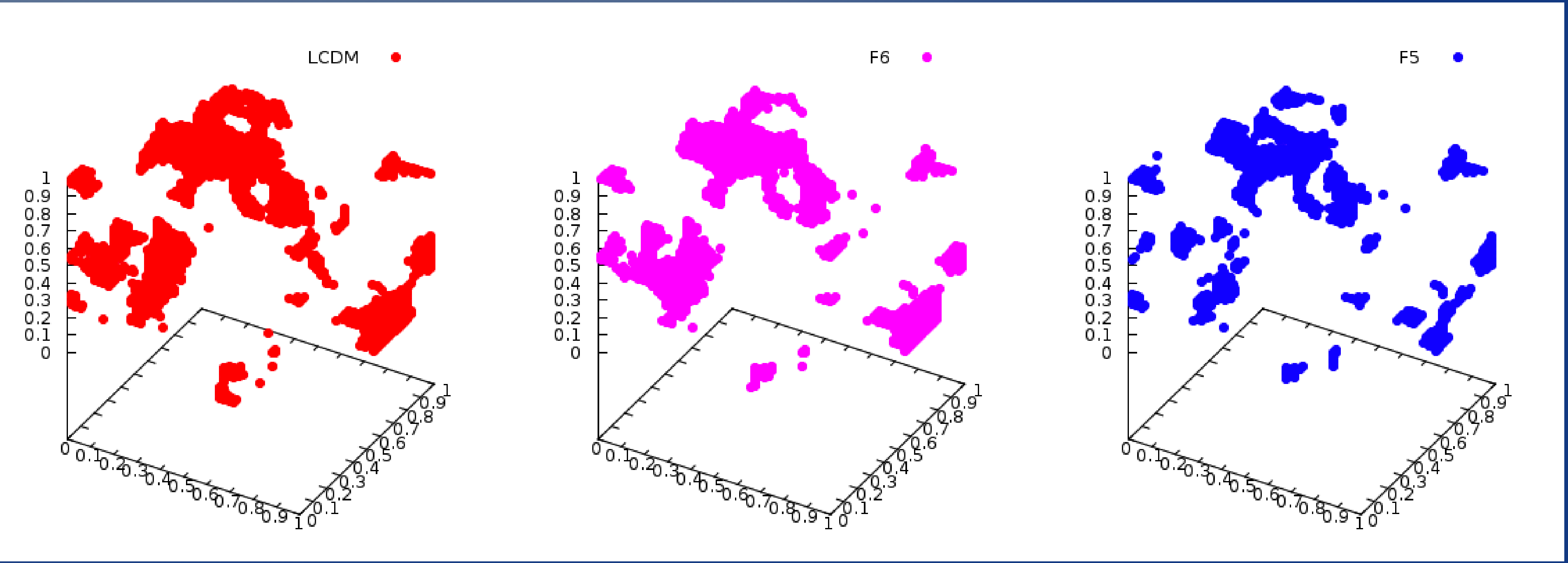
- We have developed a simple void finding algorithm based on empty spheres.
- We used this to search for voids in VIPERS and to produce a void catalogue.
- Using this catalogue we measured the void-galaxy cross correlation function.
- The cross-correlation function is anisotropic – demonstrating the effect of linear redshift space distortions.
- By fitting a model of the correlation function to the data we can obtain an estimate of the growth parameter f(Ω).
- The systematics in this method need to be investigated and understood.
- There are many other pieces of science that we would like to do with this catalogue.

Tänan tähelepanu! :)



LCDM
F6
F5