



Geometric and growth rate tests of gravity with the linearised galaxy distribution

Michael J. Wilson

Collaborators: J. Peacock, A. Taylor, S. de la Torre

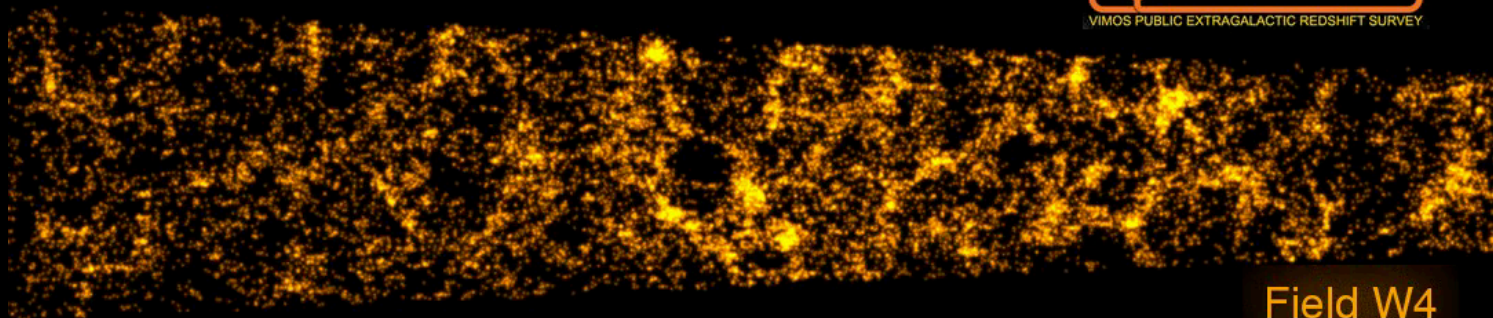
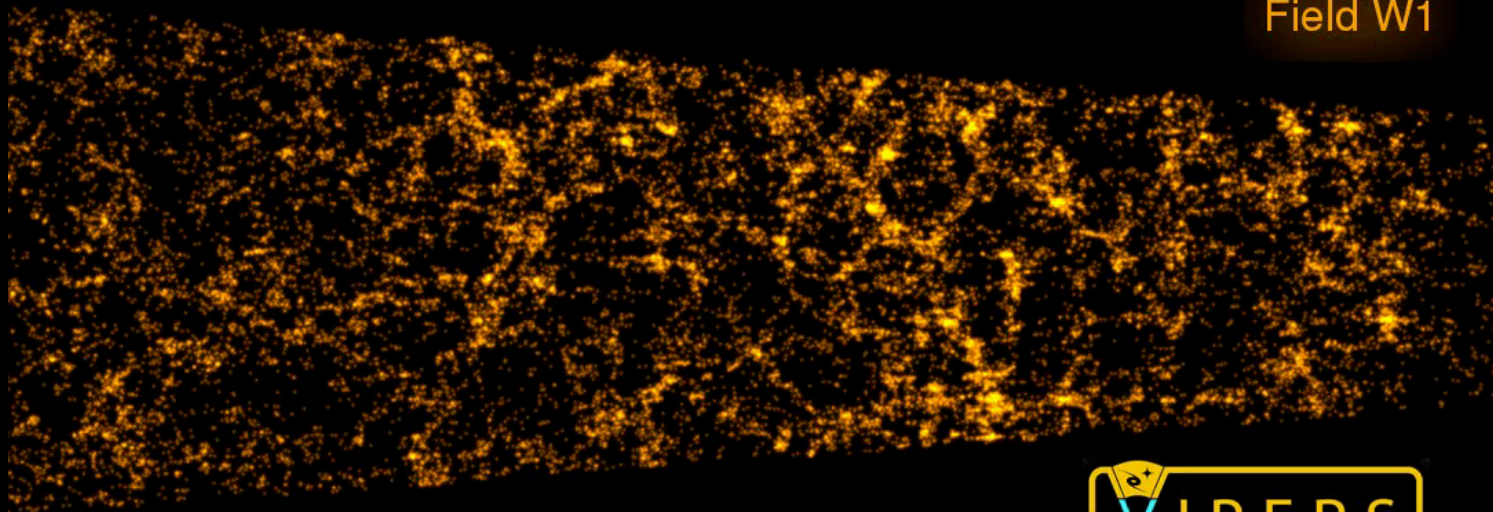




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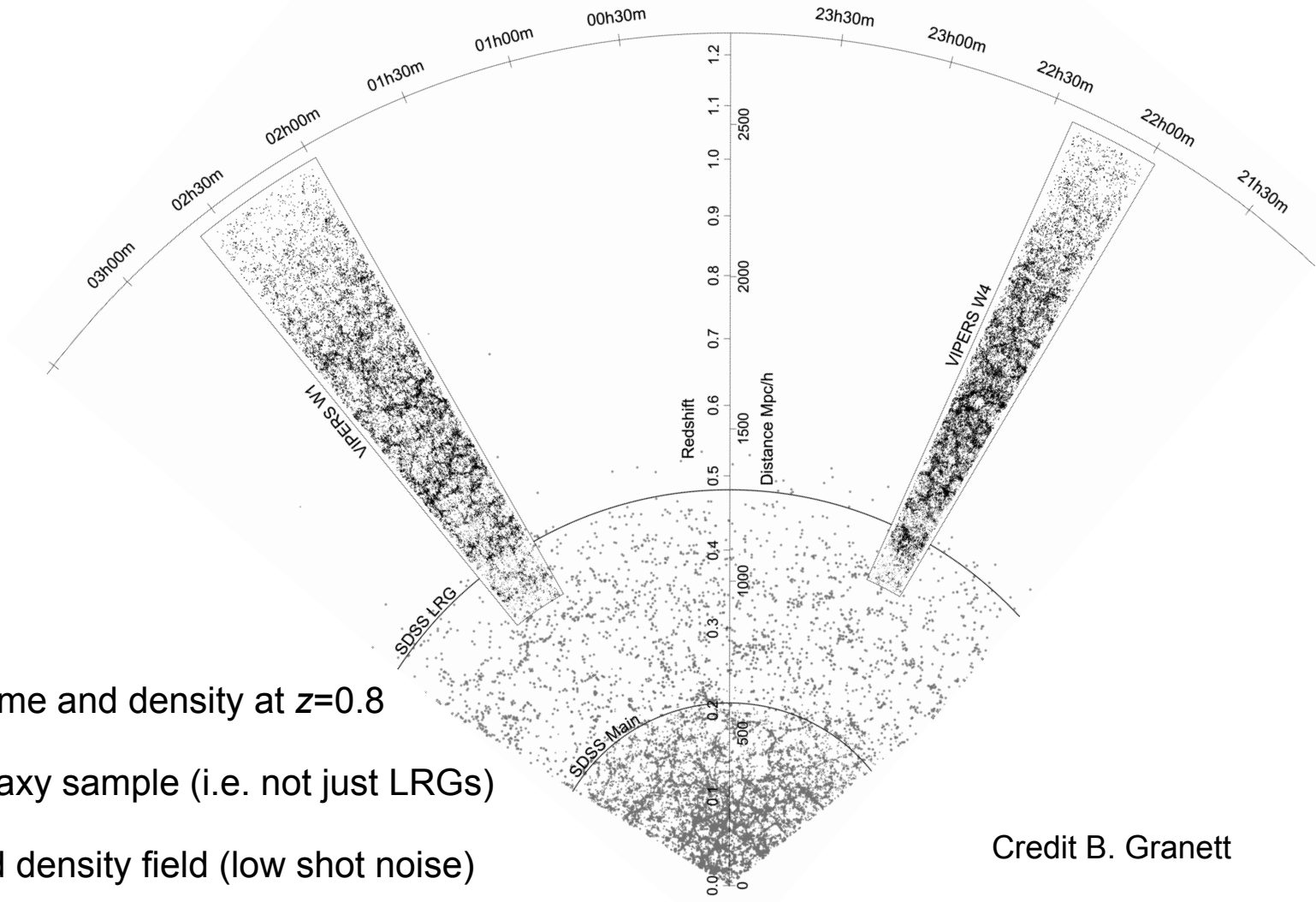
Field W1



Field W4

Scodeggio et al. (2016)

Guzzo et al. (2014)

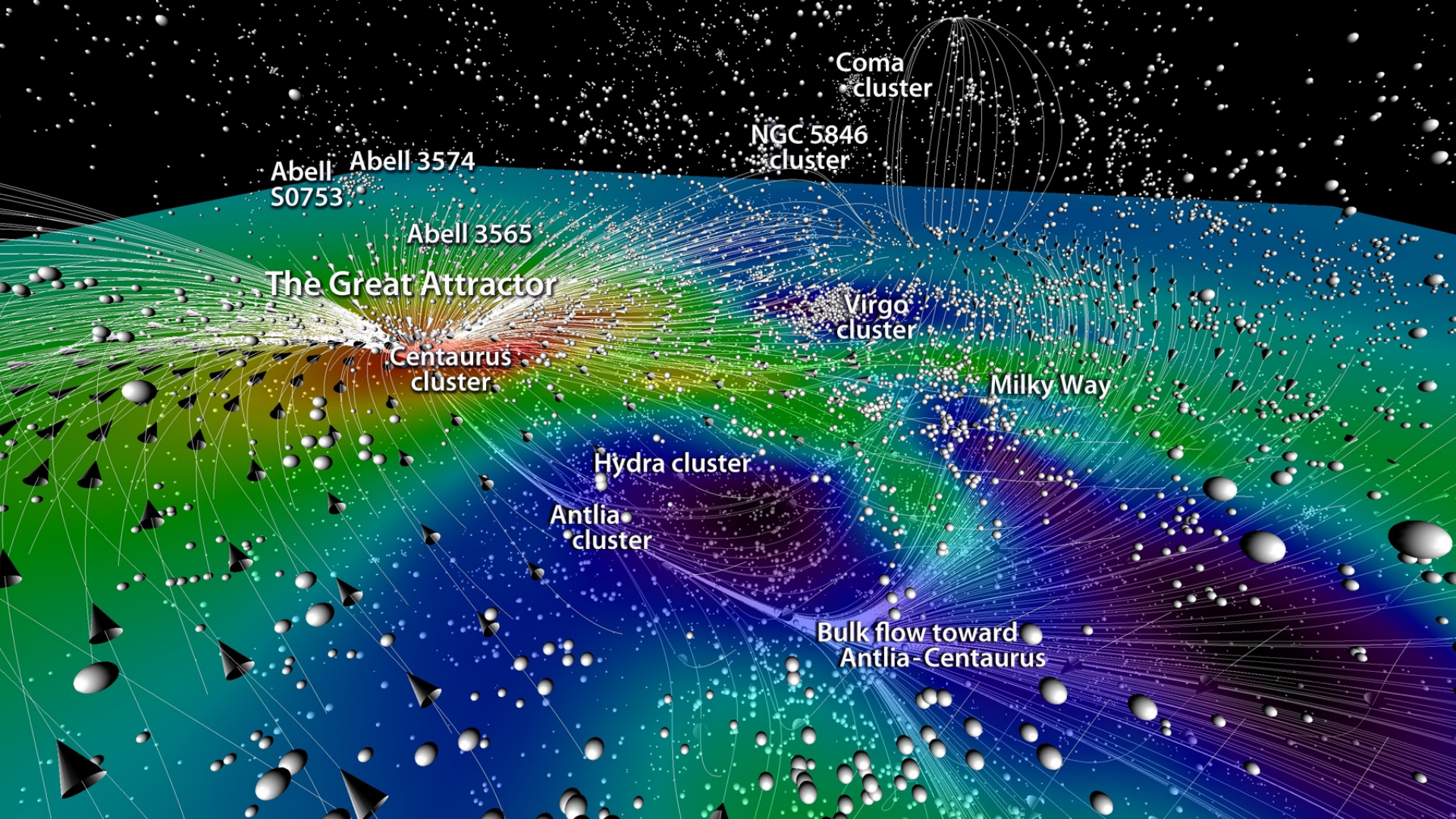


- 2dF-GRS volume and density at $z=0.8$
- ‘Complete’ galaxy sample (i.e. not just LRGs)
- Well-estimated density field (low shot noise)

Credit B. Granett

A broad range of science goals:

- Growth rate and clustering at $z=0.8$
- *Evolution and non-linearity of galaxy biasing*
- *Combined clustering and tomographic weak gravitational lensing*
- Evolution of the luminosity and stellar mass functions
- Evolution of colours and environmental effects
- Groups and clusters



Abell 50753

Abell 3574

Abell 3565

The Great Attractor

Centaurus cluster

Hydra cluster

Antlia cluster

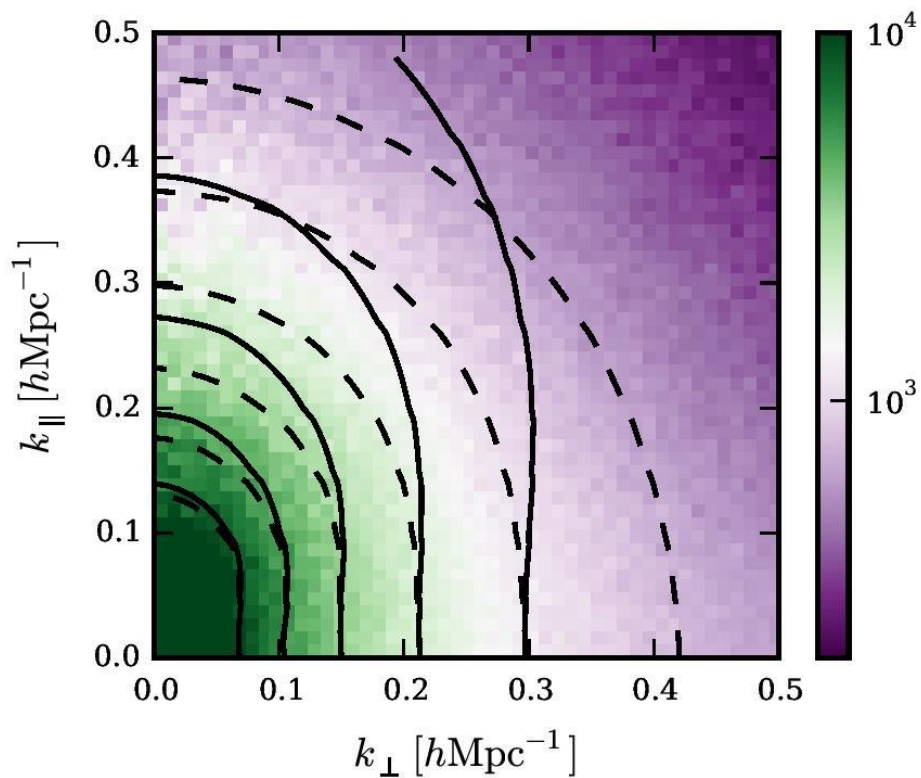
NGC 5846 cluster

Coma cluster

Virgo cluster

Milky Way

Bulk flow toward Antlia-Centaurus



$$P_s(k, \mu) = \frac{(1 + \beta\mu^2)^2}{1 + \frac{1}{2}k^2\mu^2\sigma_p^2} P_g(k).$$

$$\beta = (f/b).$$

$$f(a) = \Omega_m(a)^\gamma \quad (\text{Linder \& Cahn, 2007})$$

$$\gamma = 0.545, 0.68, 0.4$$

For: General Relativity,
Dvali-Gabadadza-Poratti (DGP) and
Hu & Sawicki $f(R)$ gravity respectively

$$\rho_v c^2 = 2 \int_0^\Lambda \frac{\hbar \omega}{2} \frac{d^3 k}{(2\pi)^3},$$

$$\mapsto 10^{120}$$

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$$\mapsto 10^{120}$$

- Cut-off is not a Lorentz invariant
- $w = (1/3)$ rather than $w = -1$

~~$$\rho_v c^2 = 2 \int_0^\Lambda \frac{\hbar \omega}{2} \frac{d^3 k}{(2\pi)^3},$$~~

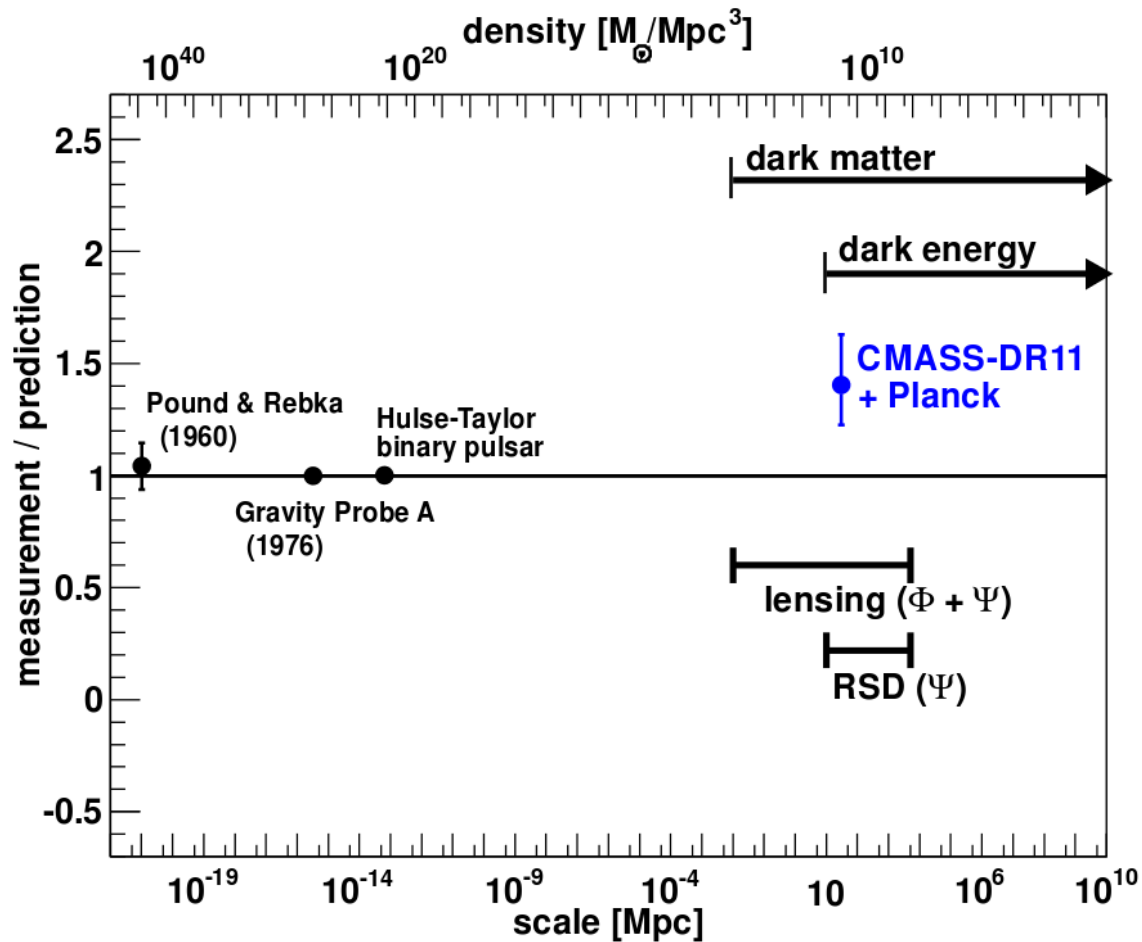
~~$$\mapsto 10^{120}$$~~

$$\mapsto 10^{56}$$

Koksma and Prokopec (2011)

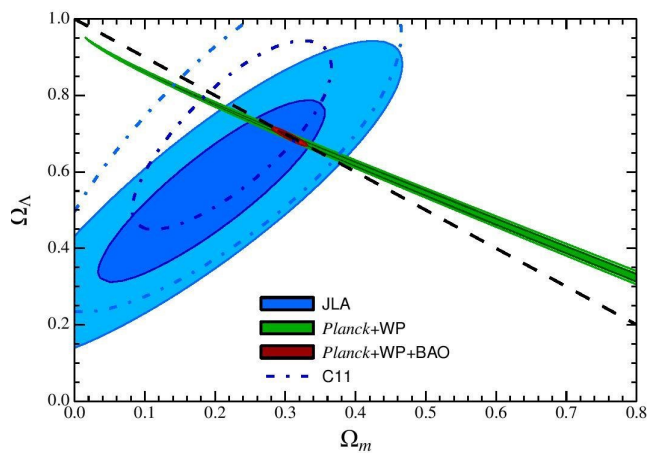
(When the most massive elementary particle is the top quark)

- Cut-off is not a Lorentz invariant
- $w = (1/3)$ rather than $w = -1$

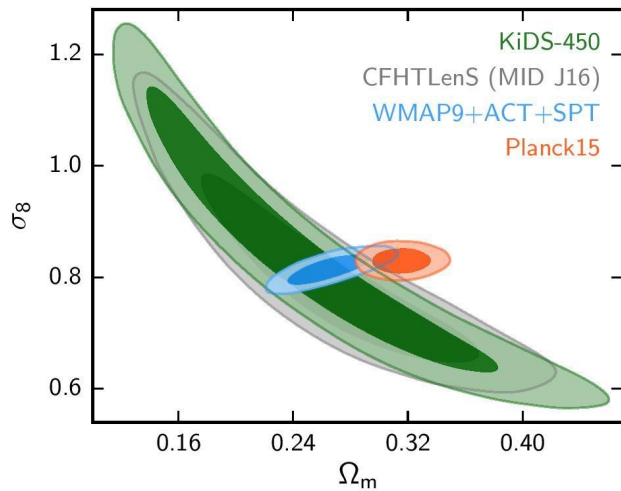
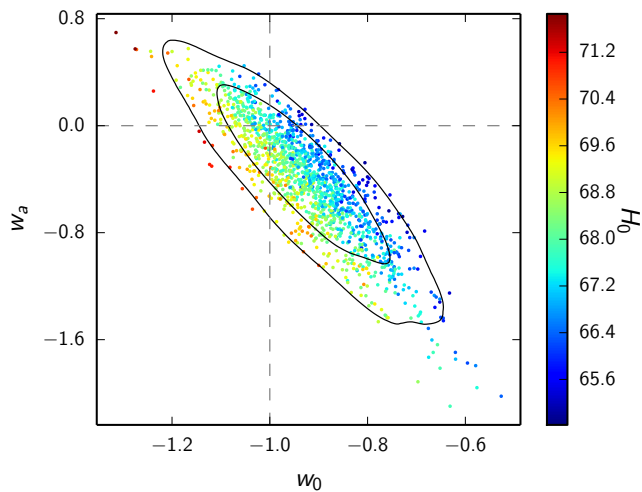


Beutler et al. (2011)

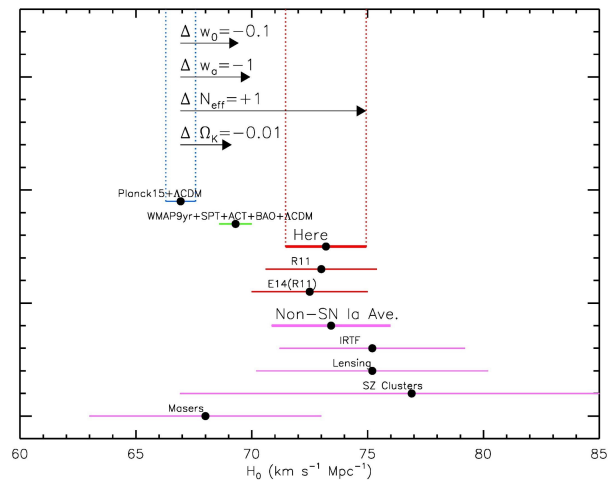
$$R - 2\Lambda ?$$



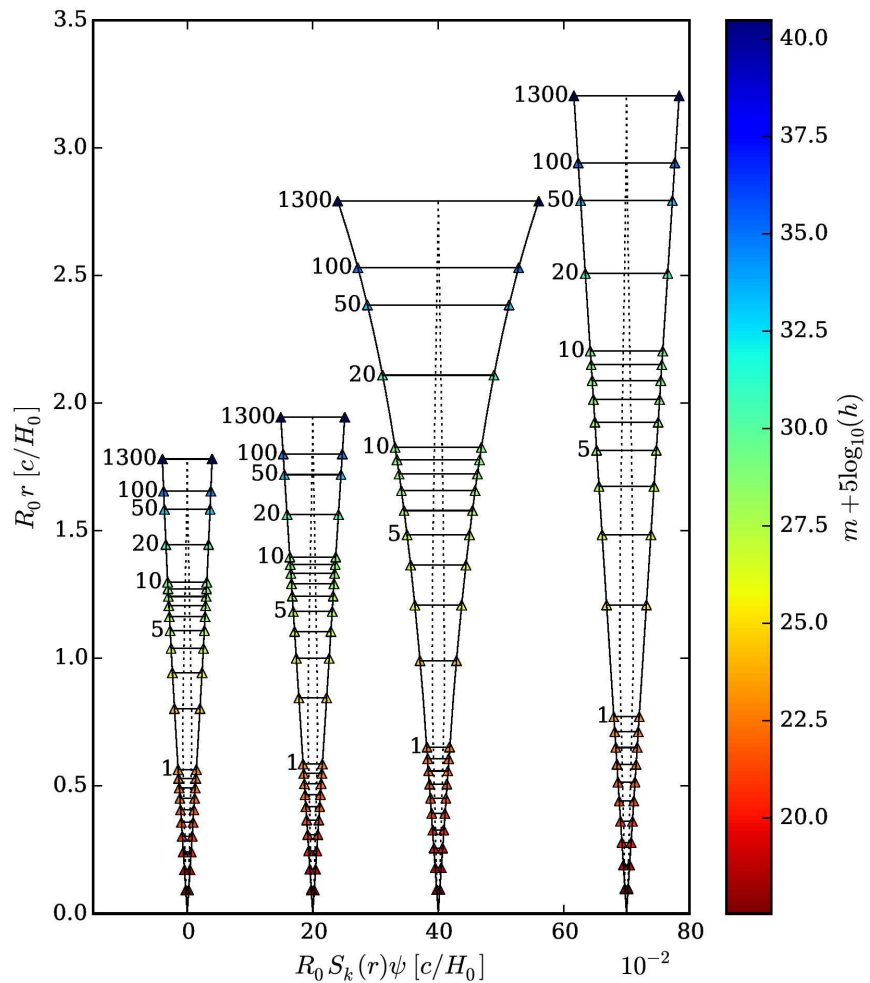
Planck collaboration (2015)



Hildebrandt et al. (2016, KIDS)

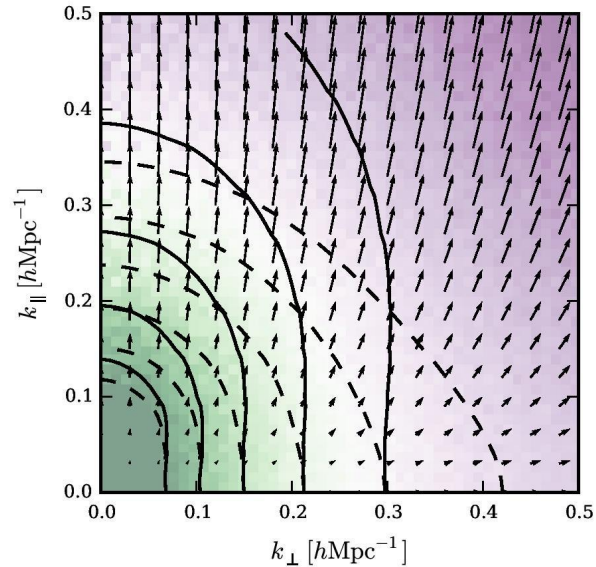
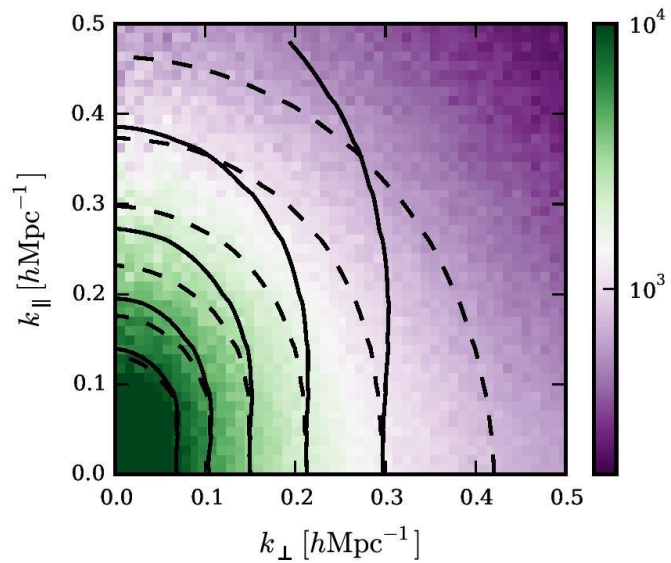


Riess et al. (2016)



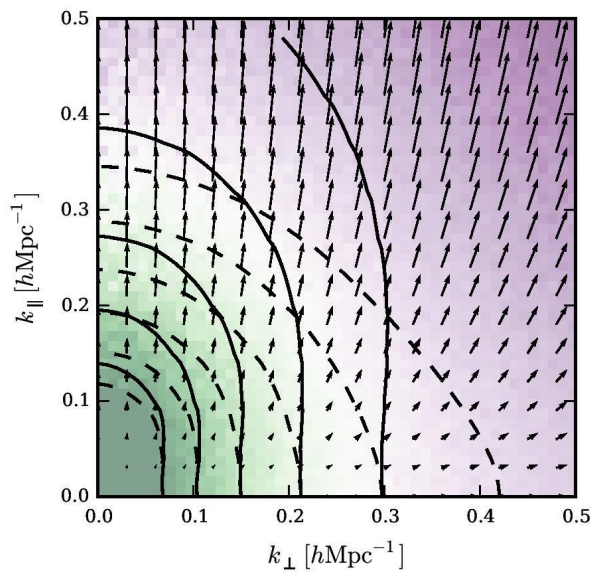
$$\left(\frac{H^2}{H_0^2} \right) = \Omega_r a^{-4} + \Omega_m a^{-3} + \Omega_k a^{-2} + \Omega_\Lambda$$

$(\Omega_m, \Omega_v) = (1.3, 0.0), (1.0, 0.0), (0.3, 0.0)$ and $(0.3, 0.7)$



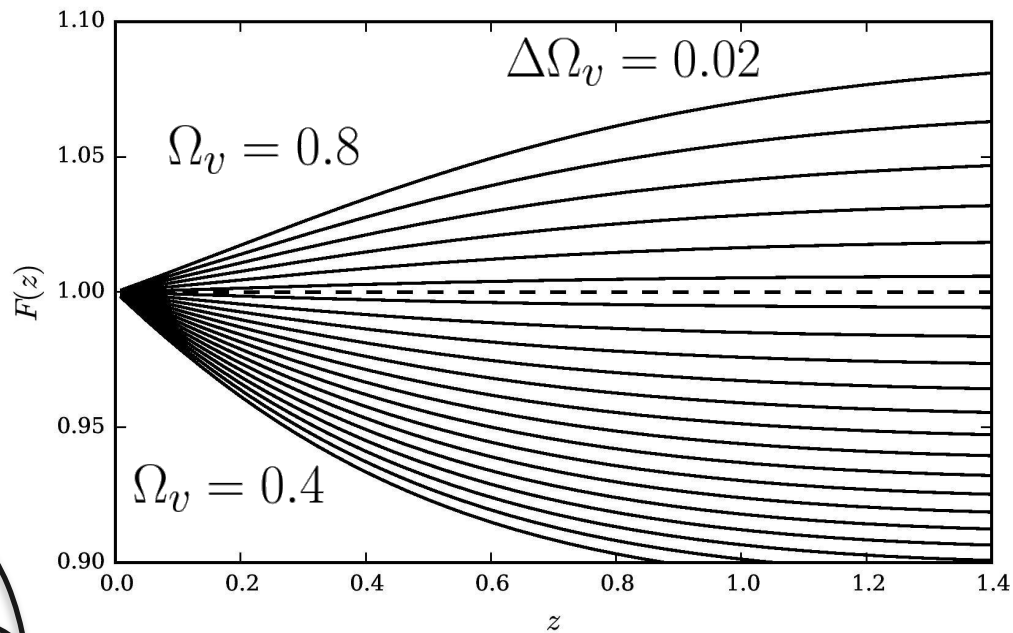
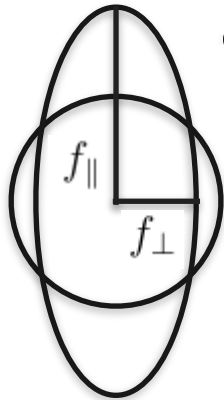
$$k'_{\perp} = f_{\perp} k_{\perp} = \left(\frac{D_A}{D'_A} \right) k_{\perp},$$

$$k'_{\parallel} = f_{\parallel} k_{\parallel} = \left(\frac{H'}{H} \right) k_{\parallel},$$



$$k'_\perp = f_\perp k_\perp = \left(\frac{D_A}{D'_A} \right) k_\perp,$$

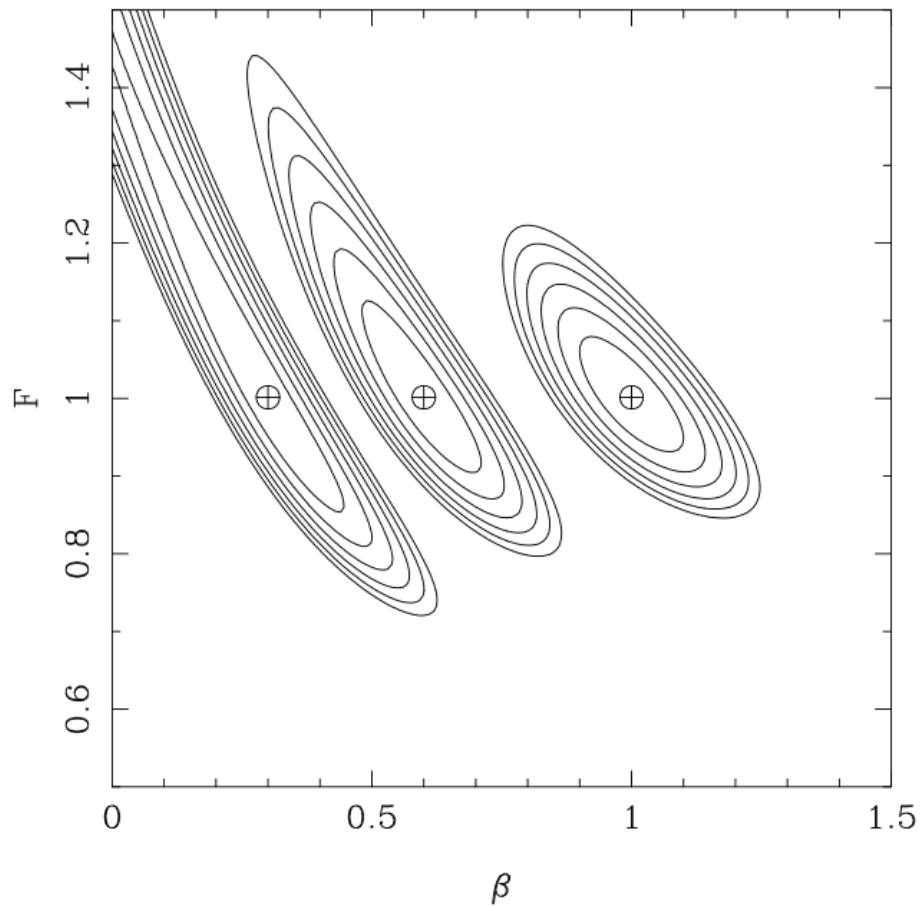
$$k'_\parallel = f_\parallel k_\parallel = \left(\frac{H'}{H} \right) k_\parallel,$$



$$F = \frac{f_\parallel}{f_\perp} = \left(\frac{H'}{H} \right) \left(\frac{D'_A}{D_A} \right),$$

$$F_{AP} \equiv (1+z)D_A \left(\frac{H}{c} \right) = (1+z)D'_A \left(\frac{H'}{c} \right) \left(\frac{1}{F} \right).$$

Expansion history



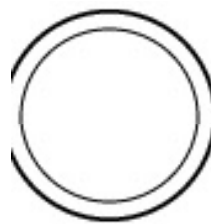
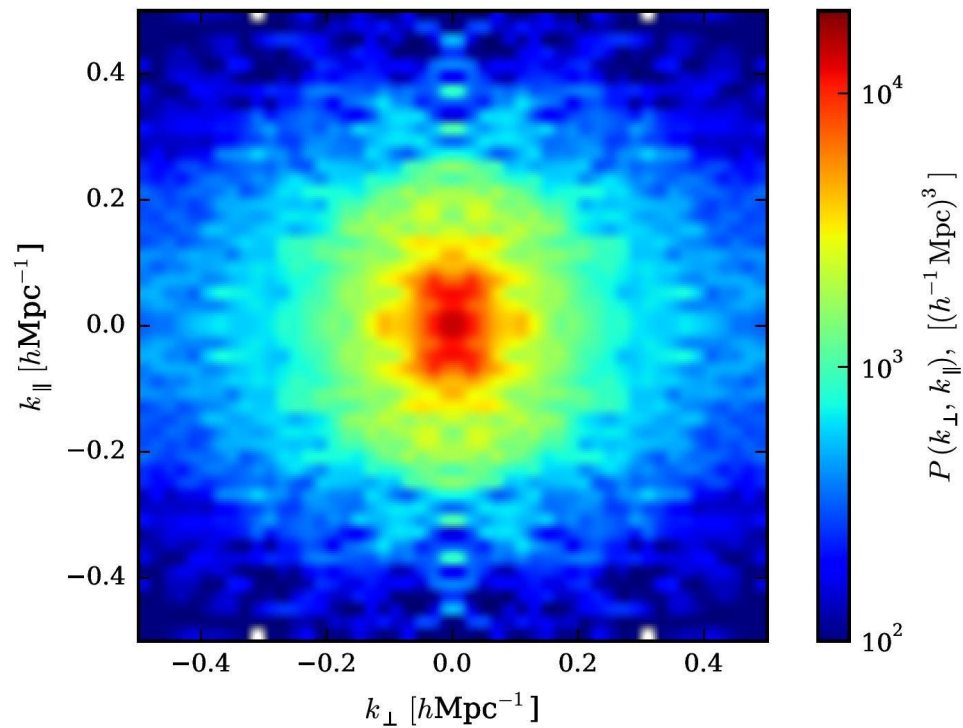
Large-scale gravitational collapse

Ballinger, Peacock & Heavens (1996)

Padmanabhan & White (2008)

Ruiz & Huterer (2015)

Linder (2016)



Monopole



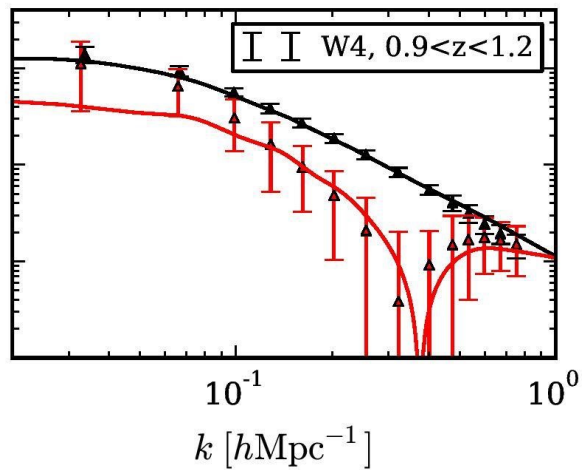
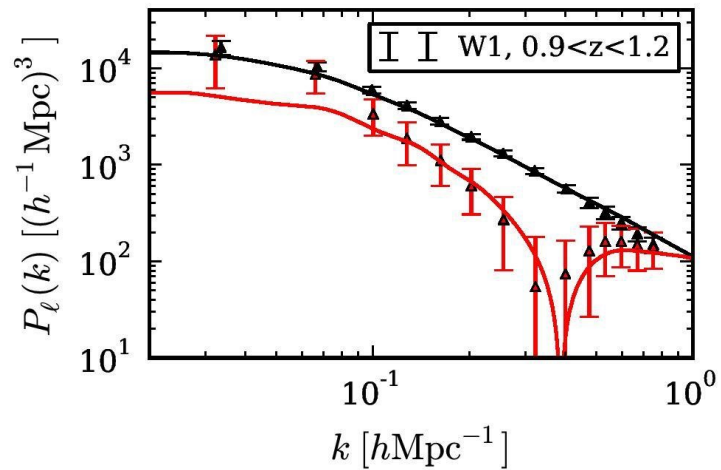
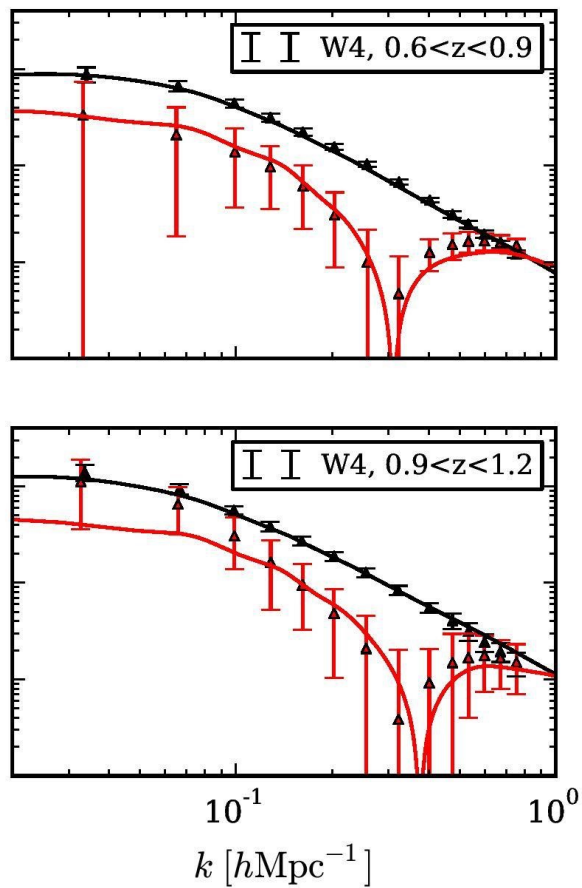
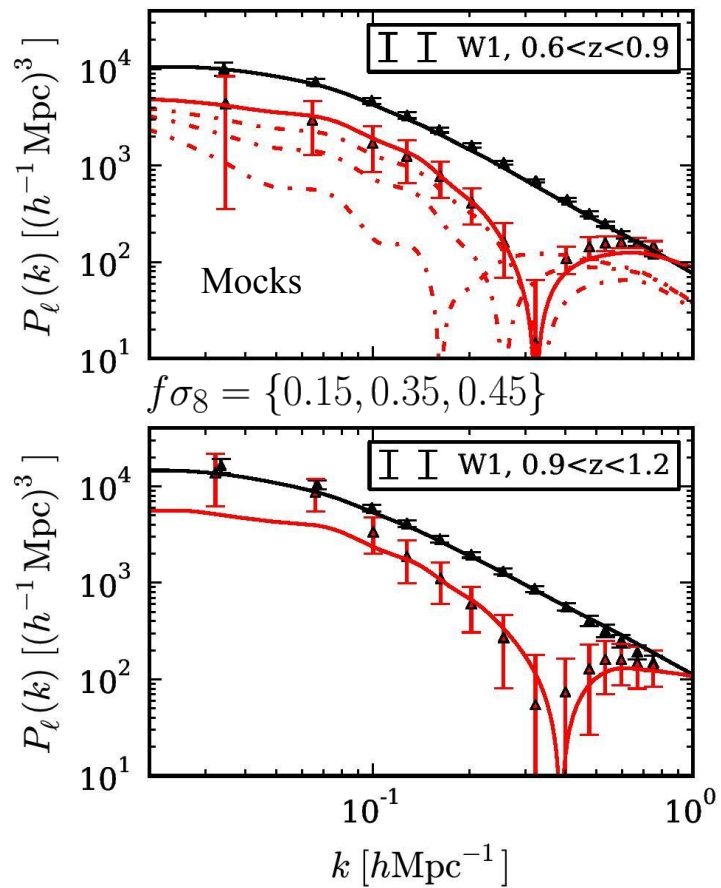
Quadrupole



Hexadecapole

$$P(k, \mu) = \sum P_{\ell}(k) L_{\ell}(\mu)$$

VIPERS PDR-2 W1: $0.6 < z < 0.9$

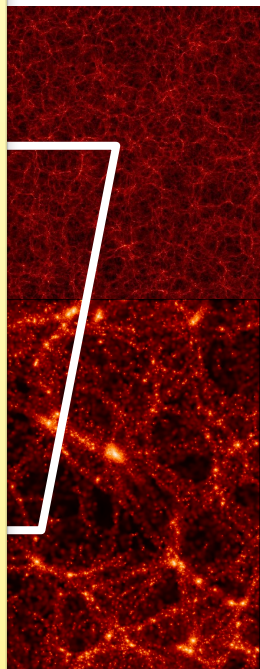


fit to luminosity dependent clustering?

“performed an analytic HOD modelling of the projected correlation function for different samples selected in luminosity and redshift that we will present in Section 6”

Gpc^3; 306 VIPERS mocks, lot of overlap?

colour dependence



MultiDark (Planck)

de la Torre et al. (2013)

- Halo occupation distribution:

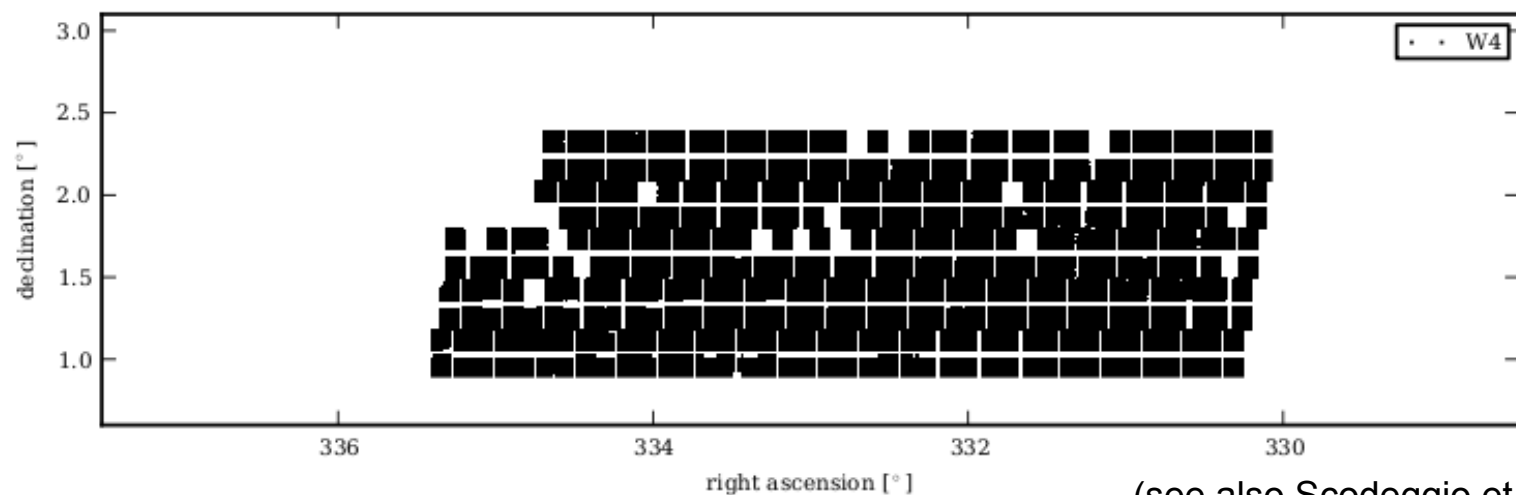
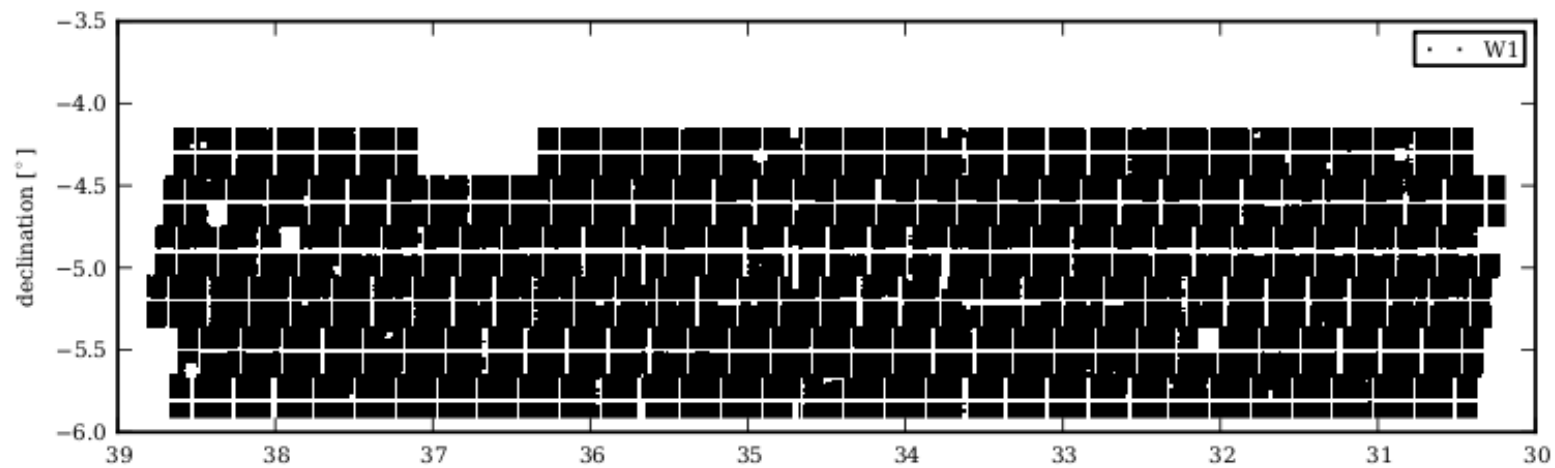
$$\langle N_{cen} | m \rangle = \frac{1}{2} \left[1 + \operatorname{erf} \left(\frac{\log m - \log M_{\min}}{\sigma_{\log m}} \right) \right],$$

$$\langle N_{sat} | m \rangle = \left(\frac{m - M_0}{M_1} \right)^\alpha.$$

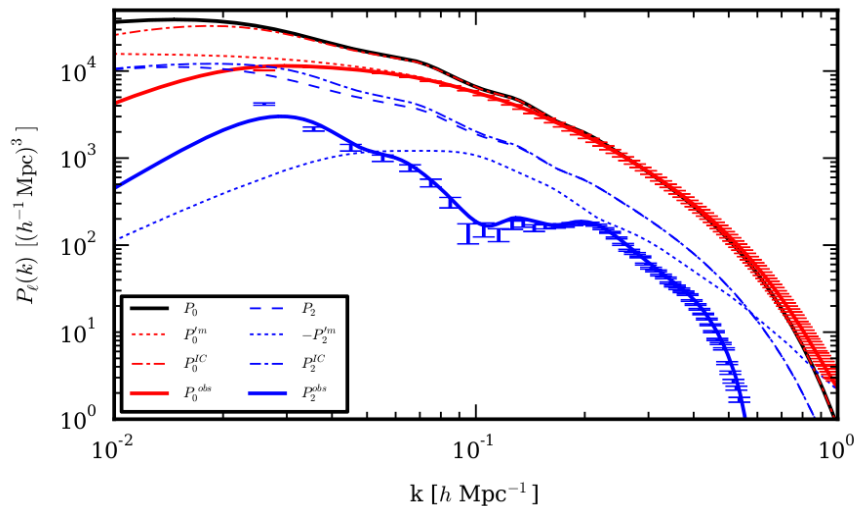
Seljak (2000)

Zheng et al. (2005)

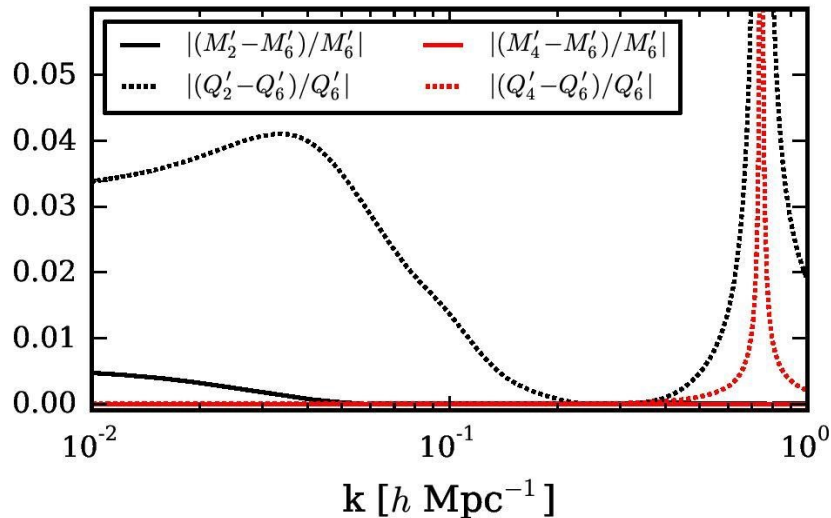
- Repopulated below the mass limit
(de la Torre and Peacock, 2013)
- Halo-model fit to projected clustering
- Placed into redshift space
- Realistic survey selection



(see also Scodeggio et al., 2016)



MJW, J. Peacock, A. Taylor, S. de la Torre (2016):



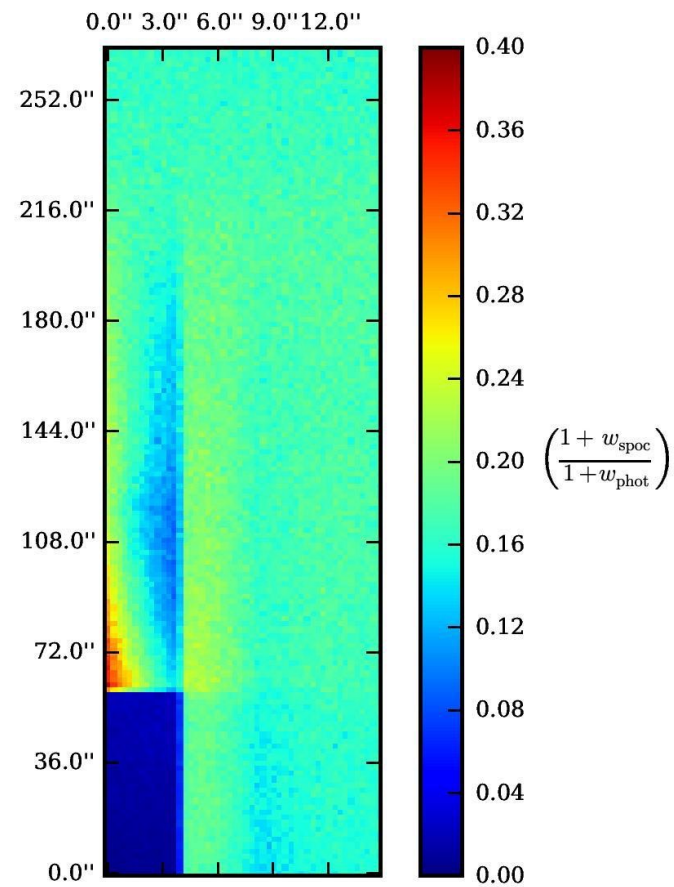
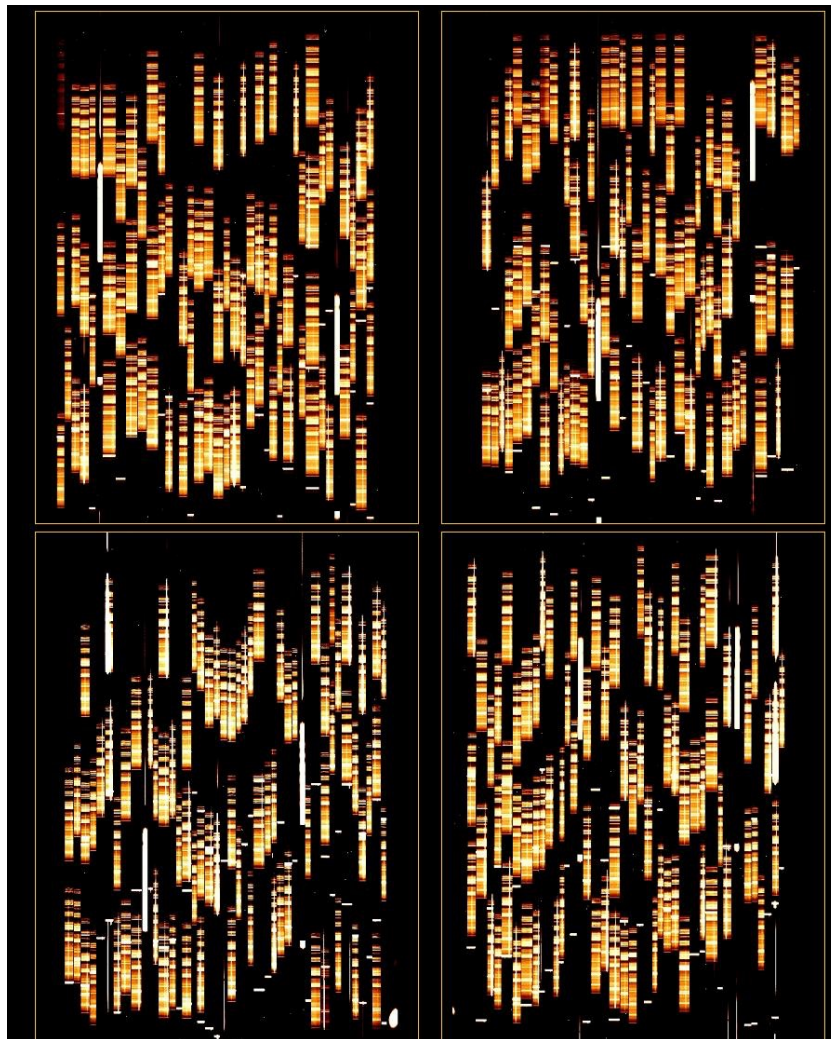
— $10^3 - 10^4 \times$ faster

— (Much) greater wavenumber resolution

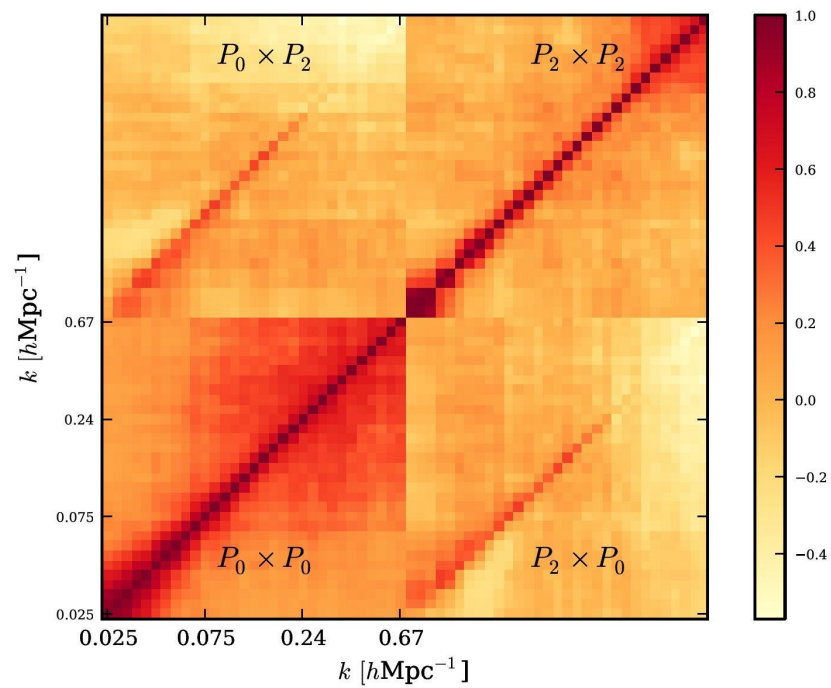
— Sub-percent accuracy (requirement for eBOSS etc.)

— VIPERS PDR-1 systematic analysis

— Foundation to Beutler et al., Zhao et al. (BOSS DR12)



(see also Pezzotta et al., 2016)



better introduction of weights: N_{ESR}

z interval	W1			
	$N_{\text{gal}}/10^4$	$N_{\text{ESR}}/10^4$	$V/(h^{-1}\text{Gpc})^3$	$V_{\text{eff}}/(h^{-1}\text{Gpc})^3$
0.6 – 0.9	2.82	7.37	6.5×10^{-3}	6.4×10^{-3}
0.9 – 1.2	0.74	2.21	9.1×10^{-3}	7.6×10^{-3}

z interval	W4			
	$N_{\text{gal}}/10^4$	$N_{\text{ESR}}/10^4$	$V/(h^{-1}\text{Gpc})^3$	$V_{\text{eff}}/(h^{-1}\text{Gpc})^3$
0.6 – 0.9	1.41	3.76	3.1×10^{-3}	3.1×10^{-3}
0.9 – 1.2	0.33	1.00	4.4×10^{-3}	3.6×10^{-3}

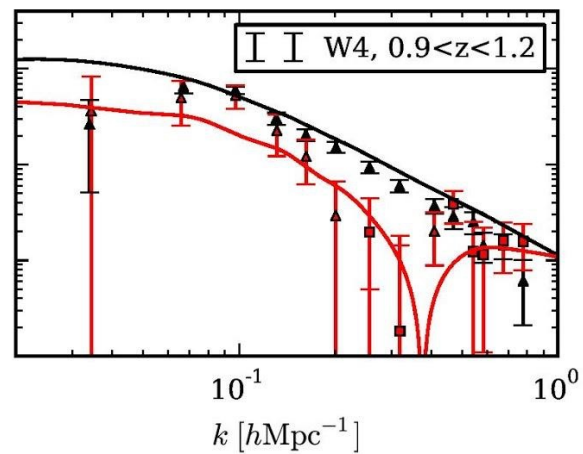
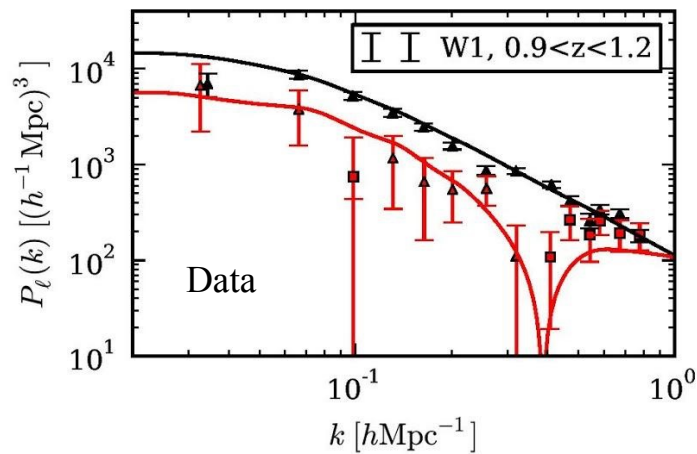
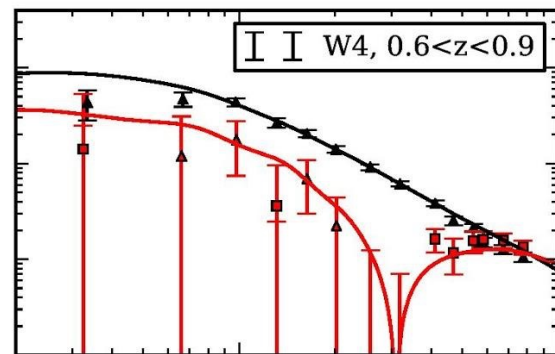
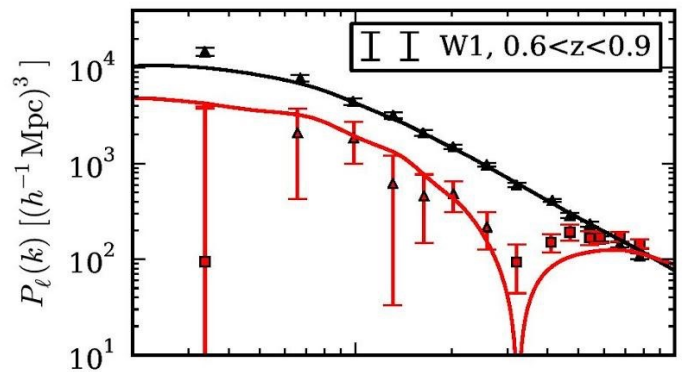
VIPERS PDR-2:

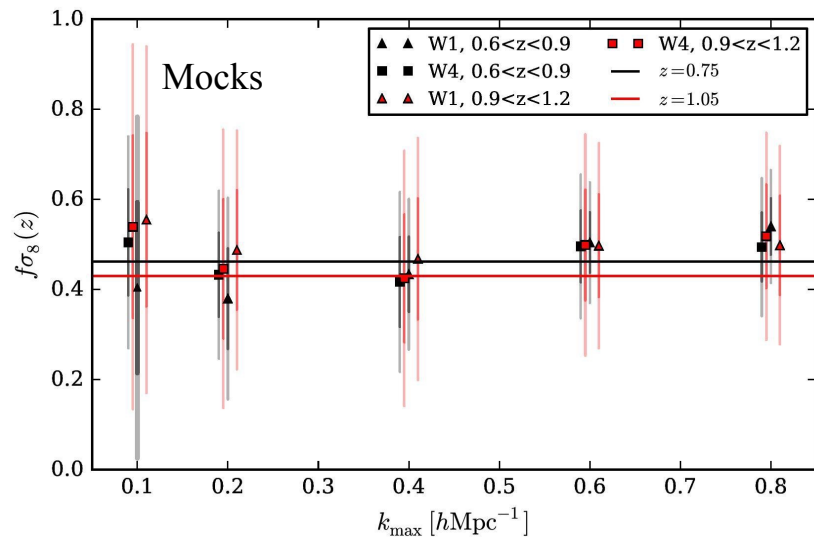
— 95% have reliable spec- z

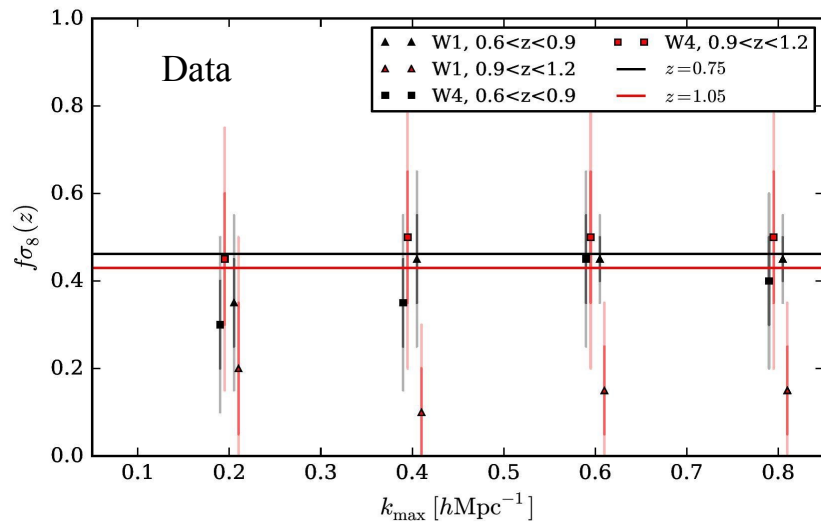
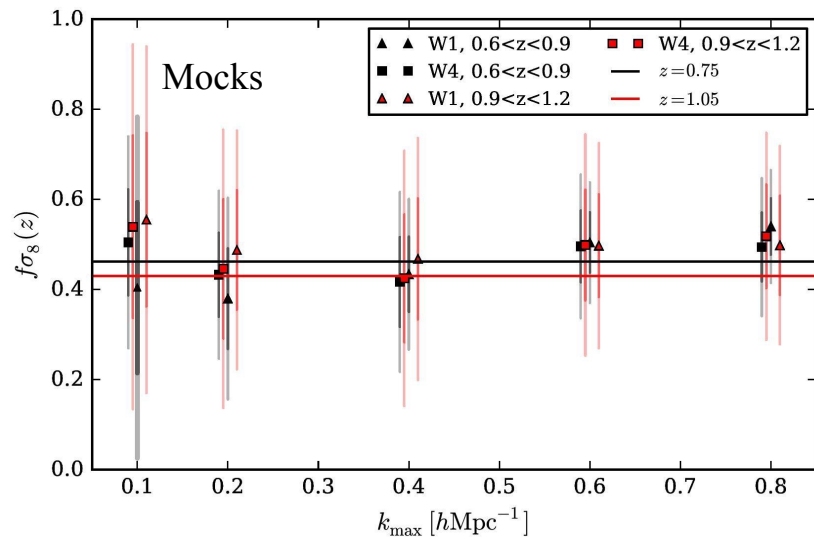
— 2.3% stellar contamination

— $\langle n \rangle \sim 10^{-2} h^3 \text{ Mpc}^{-3}$

$$5.3 \times 10^4, \quad (8.8 \times 10^4)$$



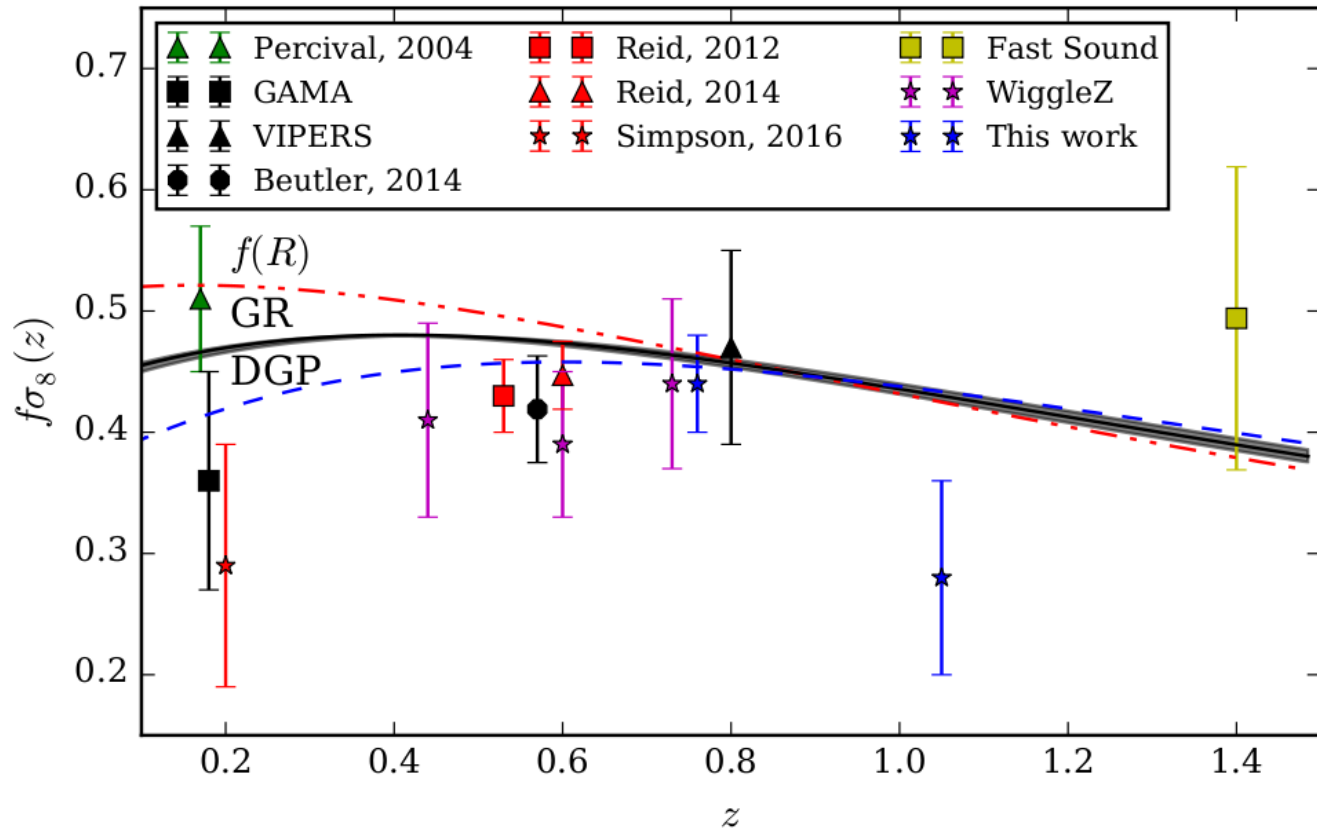


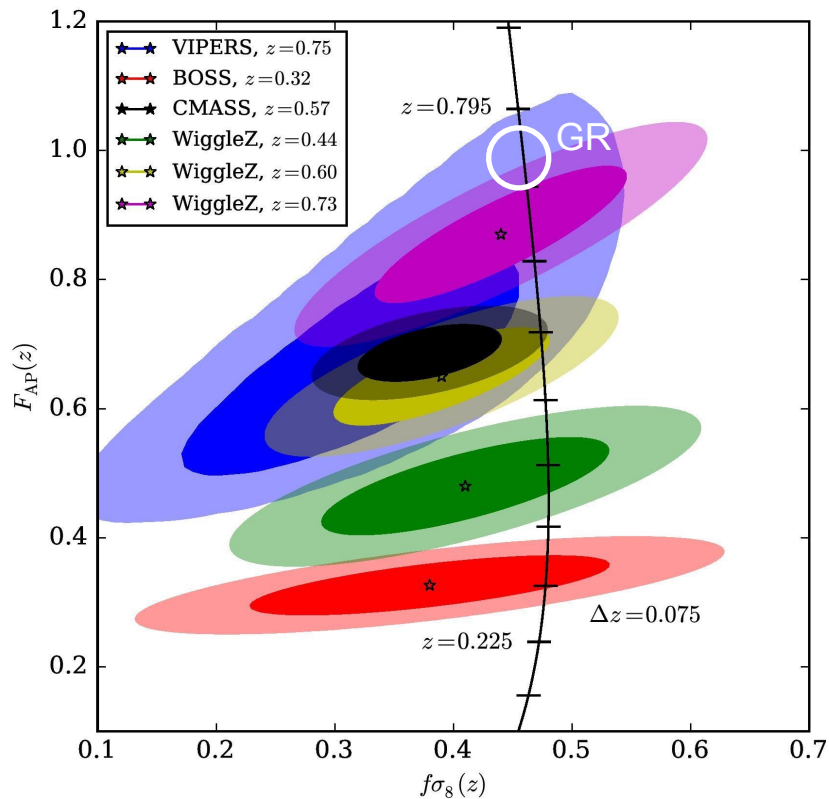


$k_{\text{max}}[h\text{Mpc}^{-1}]$	y_{best}	χ^2	min. $P(\nu = 3)$
0.2	0.718	1.55	0.50
0.4	0.732	7.40	0.05
0.6	0.899	6.77	0.05
0.8	0.881	6.63	0.05

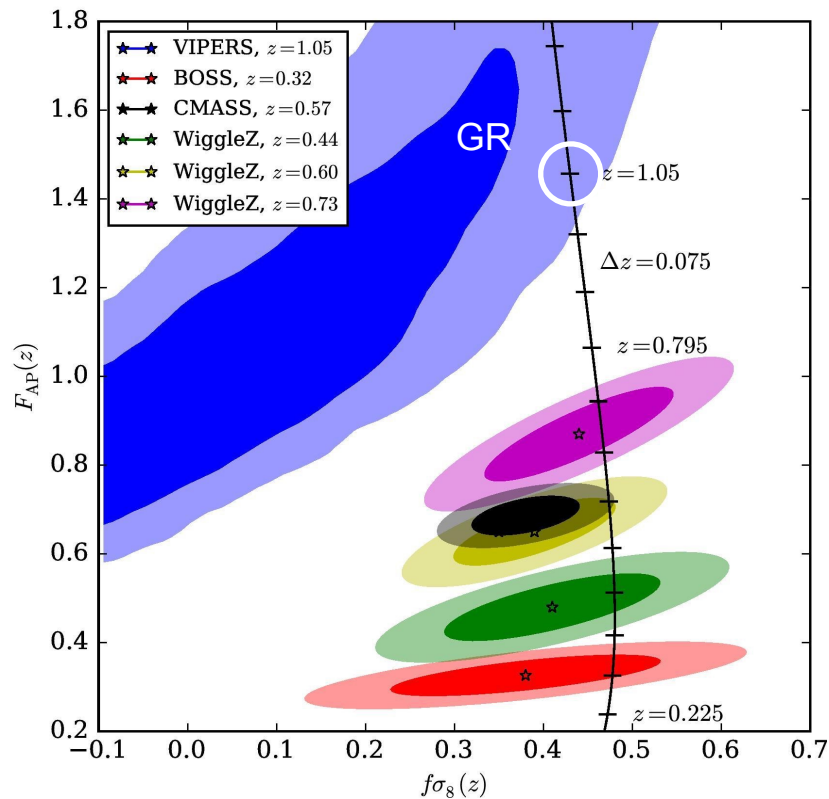
$$y = \frac{f\sigma_8(z)}{\langle f\sigma_8(z) \rangle}, \quad y_{\text{best}} = \frac{\sum_i w_i y_i}{\sum_i w_i},$$

1-in-20 for a frequentist

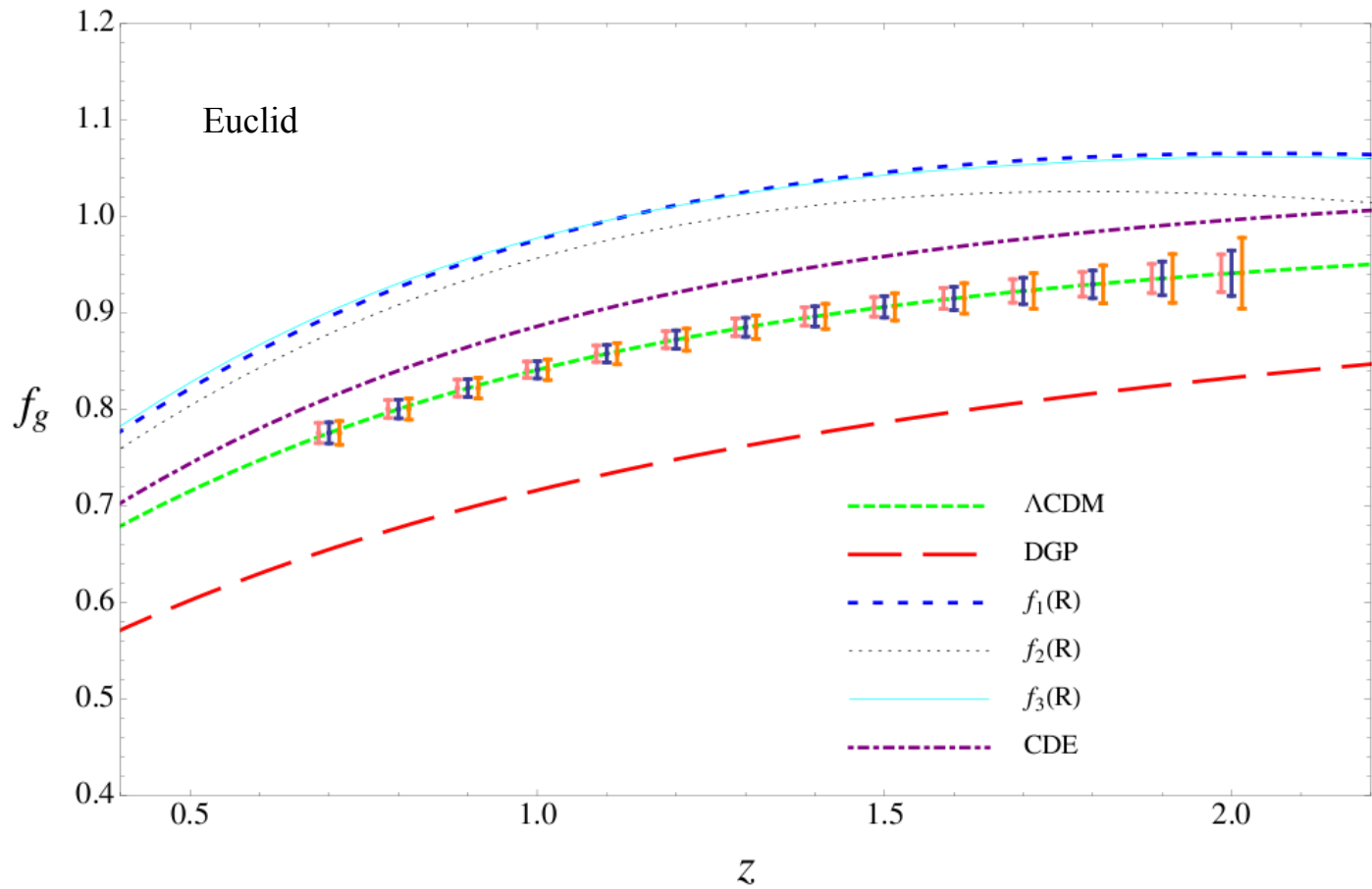


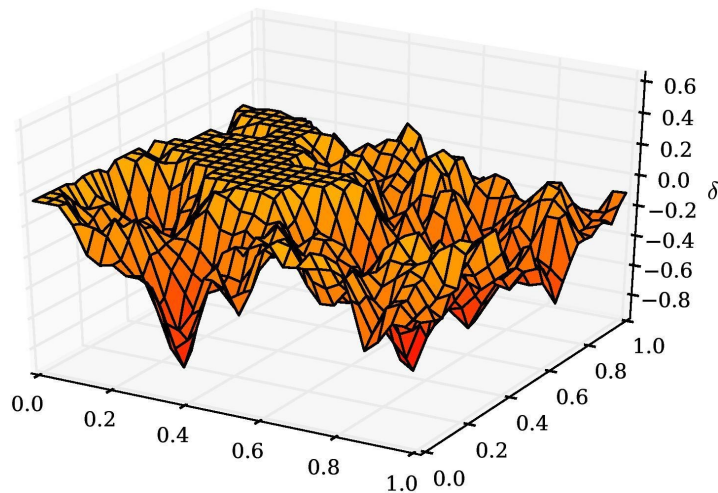
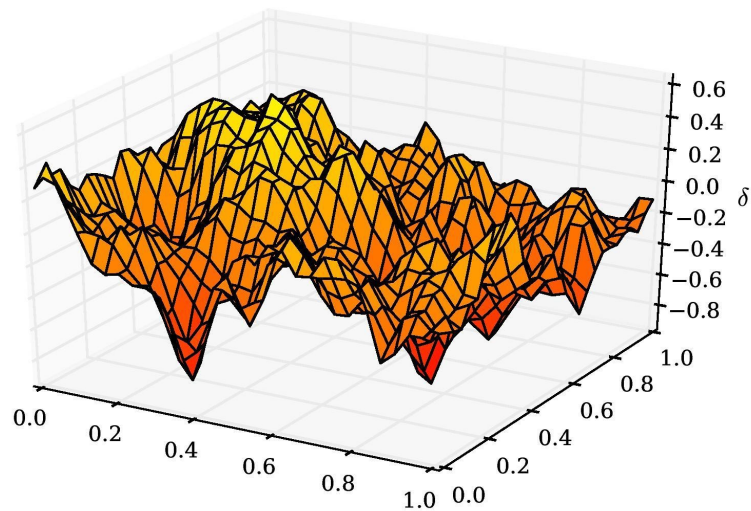


Large-scale gravitational collapse



$$F_{AP} \equiv (1+z)D_A \left(\frac{H}{c} \right) = (1+z)D'_A \left(\frac{H'}{c} \right) \left(\frac{1}{F} \right).$$





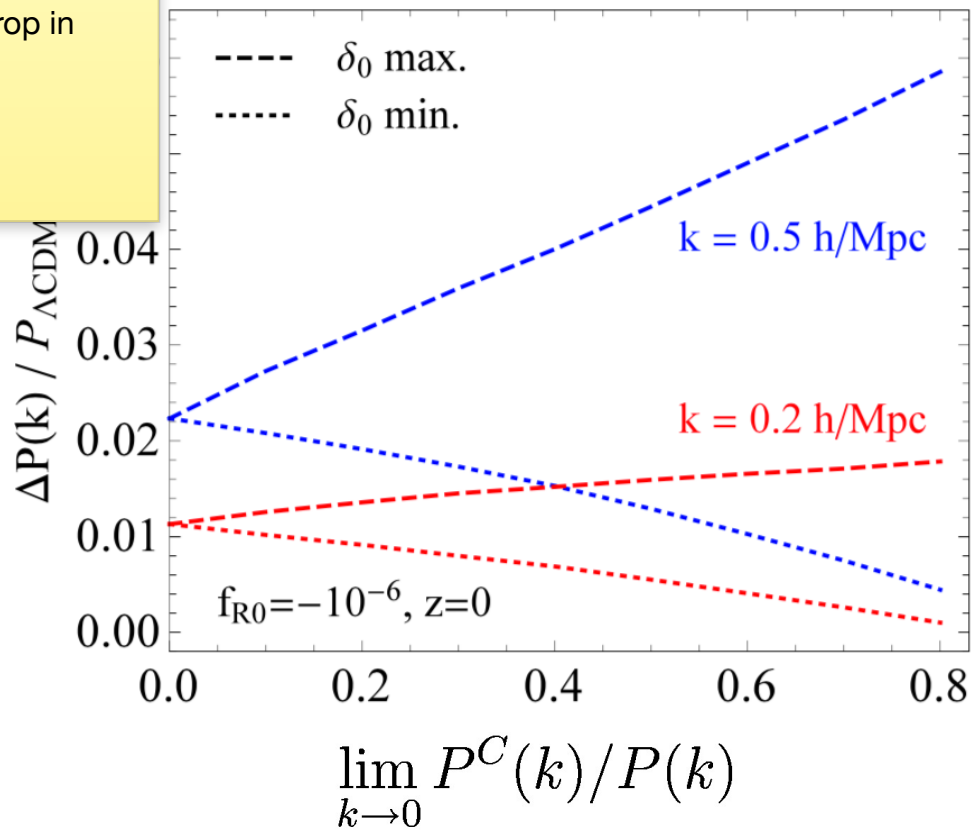
$$\delta \mapsto \delta \quad \text{if } \delta \leq \delta_0,$$

$$\delta \mapsto \delta_0 \quad \text{otherwise,}$$

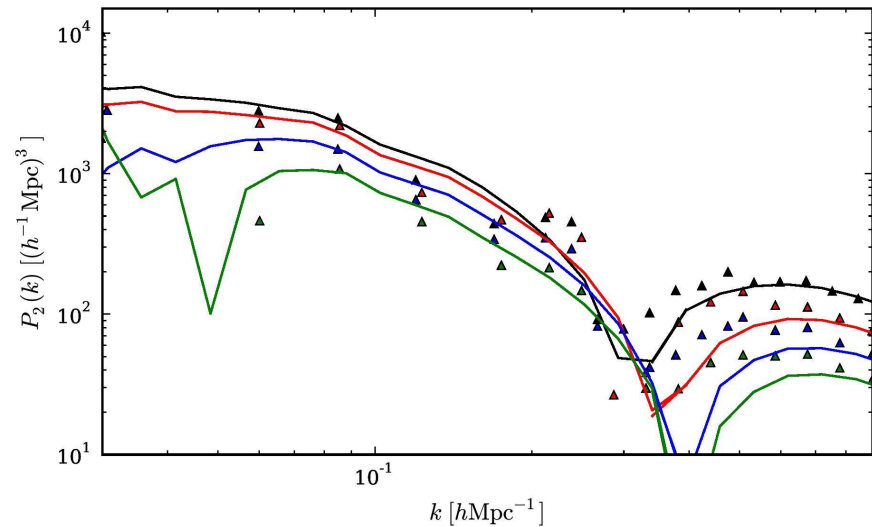
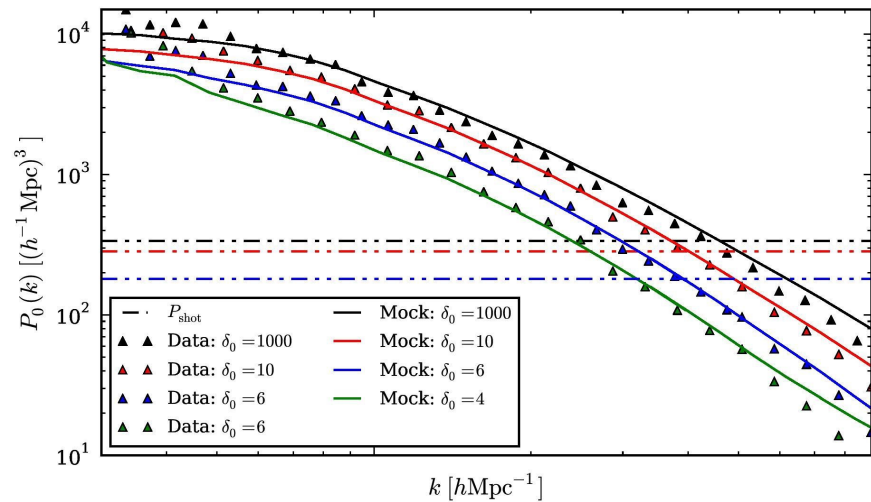
Simpson et al. (2016)
Wilson et al. (in prep.)

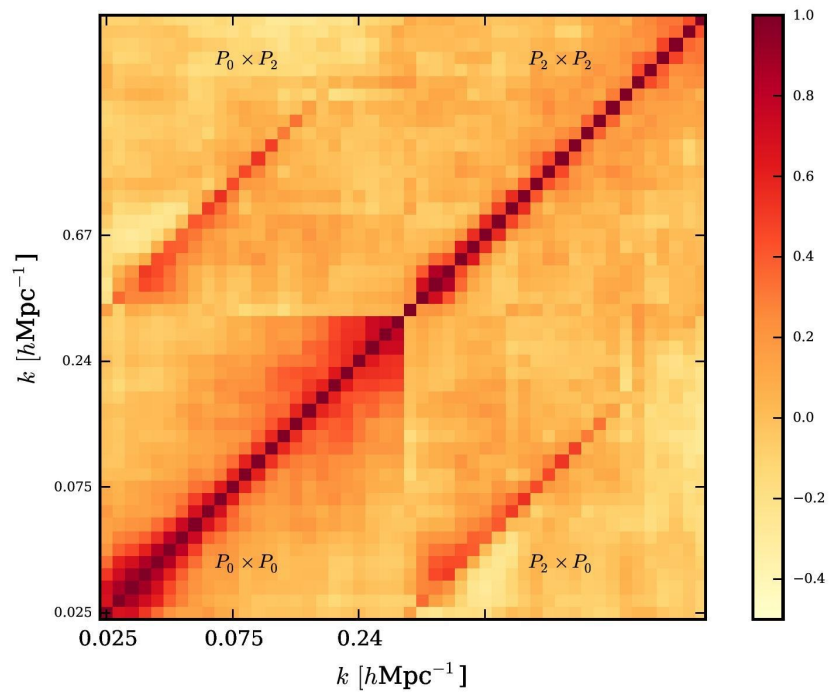
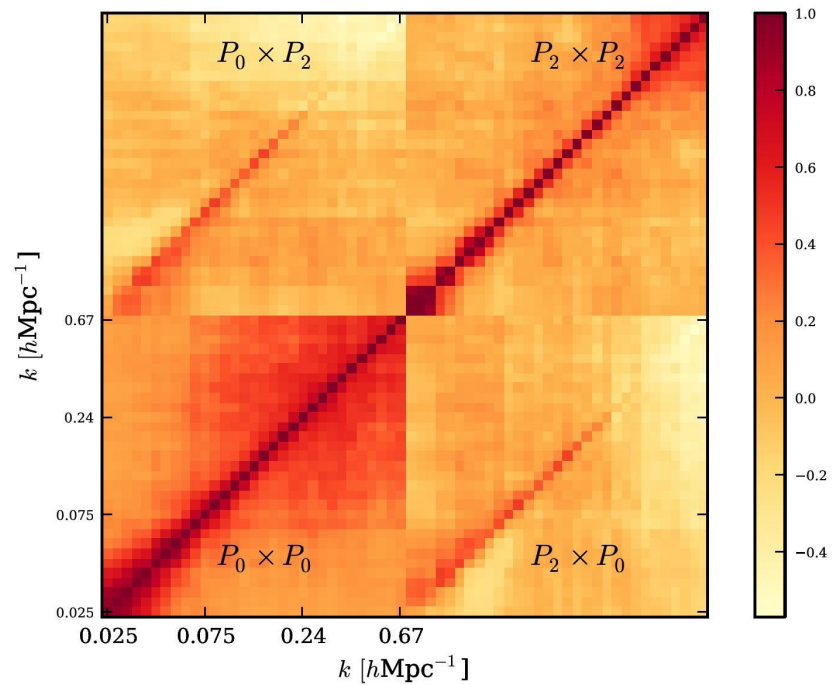
clipping strength compare to δ_0 ?

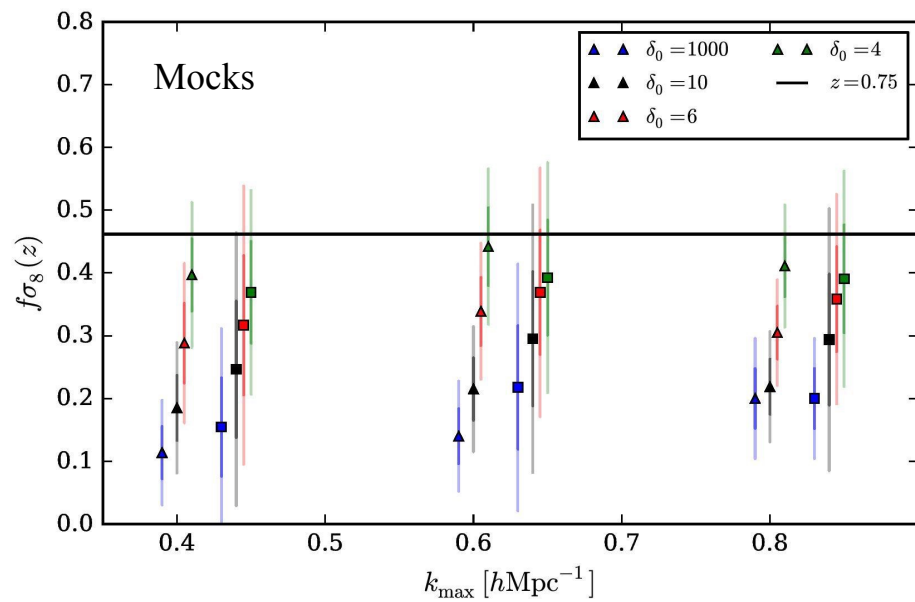
clipping strength: large-scale drop in amplitude

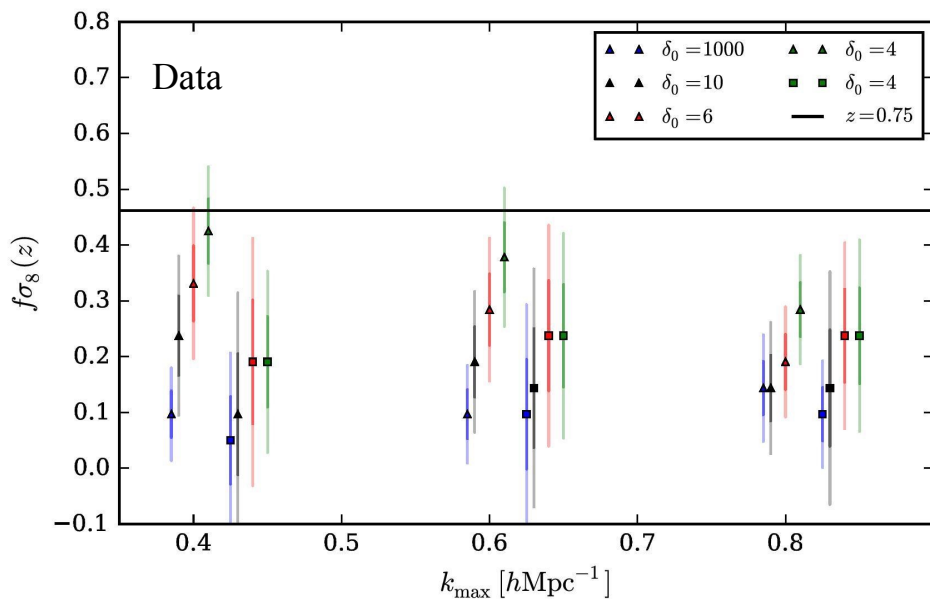
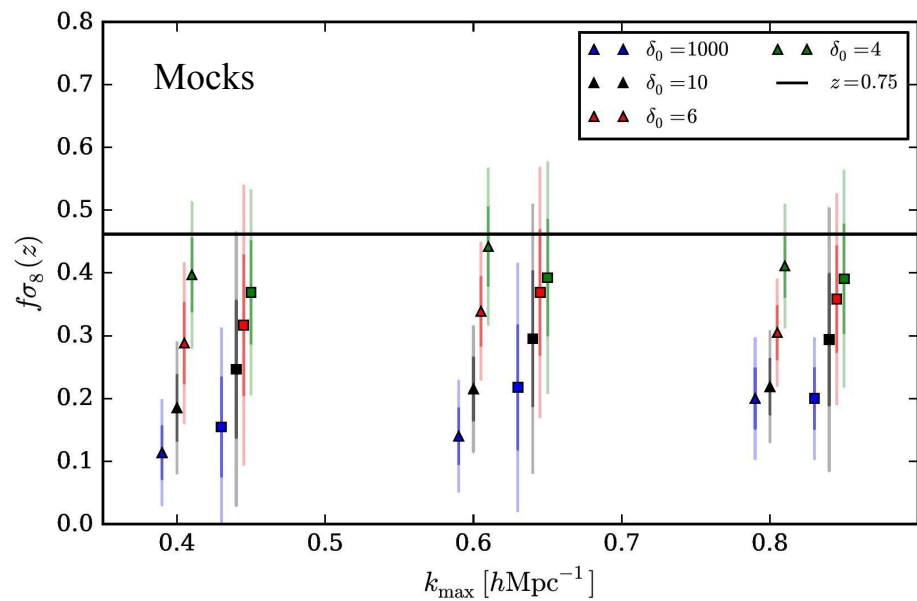


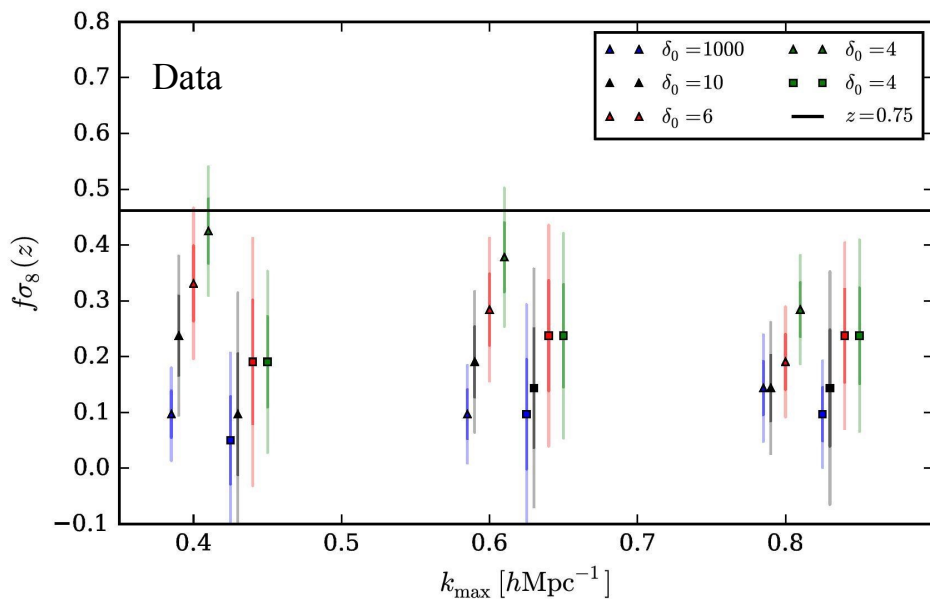
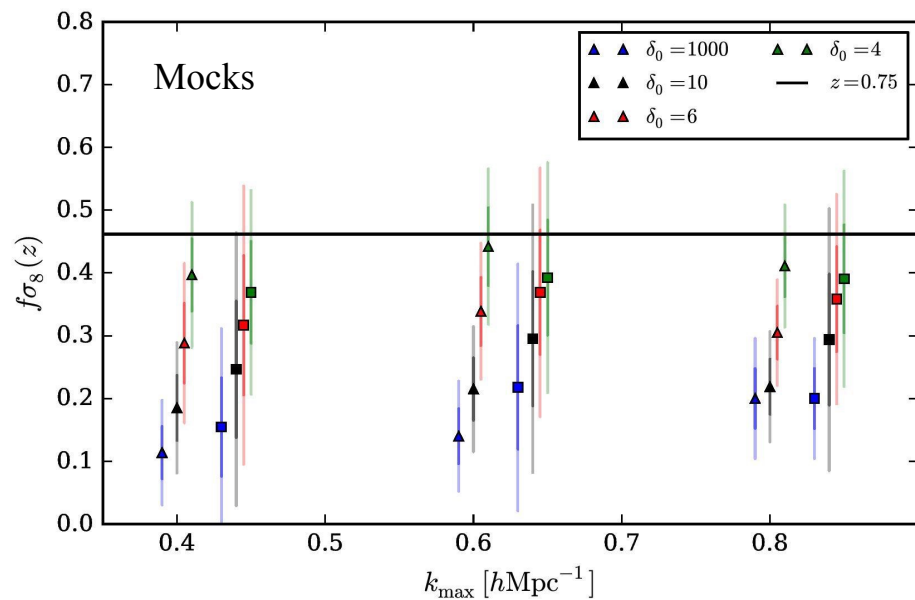
Lombriser et al. (2015)
White (2016)











Higher order statistic — physically motivated
superior to the bispectrum?



VIPERS PDR-2: 18th Nov. 2016

all spectra and redshifts @ www.vipers.inaf.it

Wilson et al.

(Density-weighted)
Power spectrum

Pezzotta et al.

RSD $\xi(\mathbf{s})$

de la Torre et al.

RSD +
galaxy-galaxy lensing

Mohammad et al.

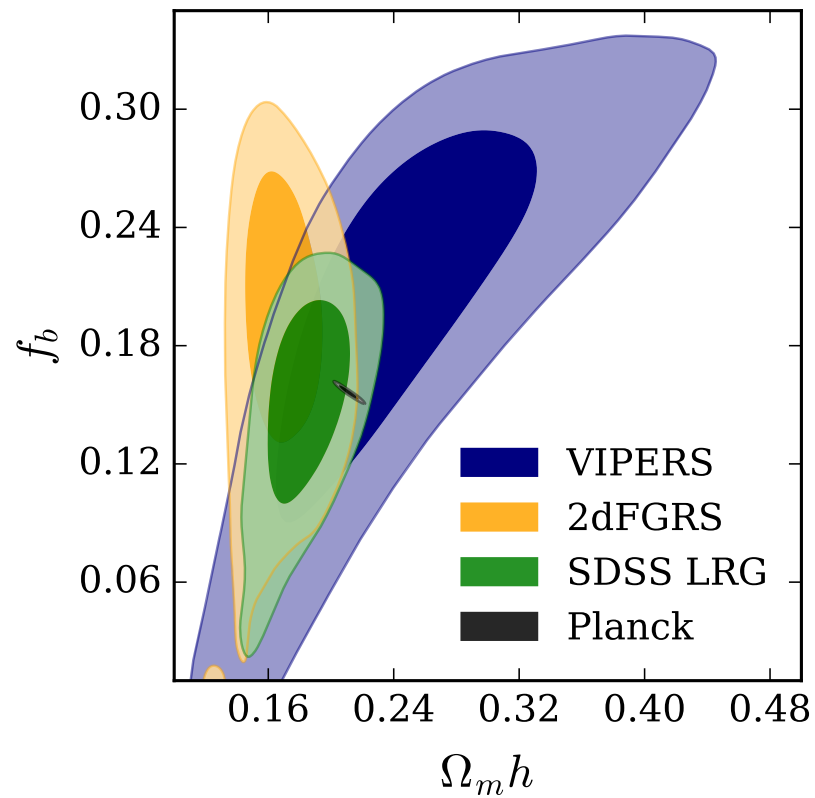
Multi-tracer RSD

Hawken et al.

Void-galaxy RSD

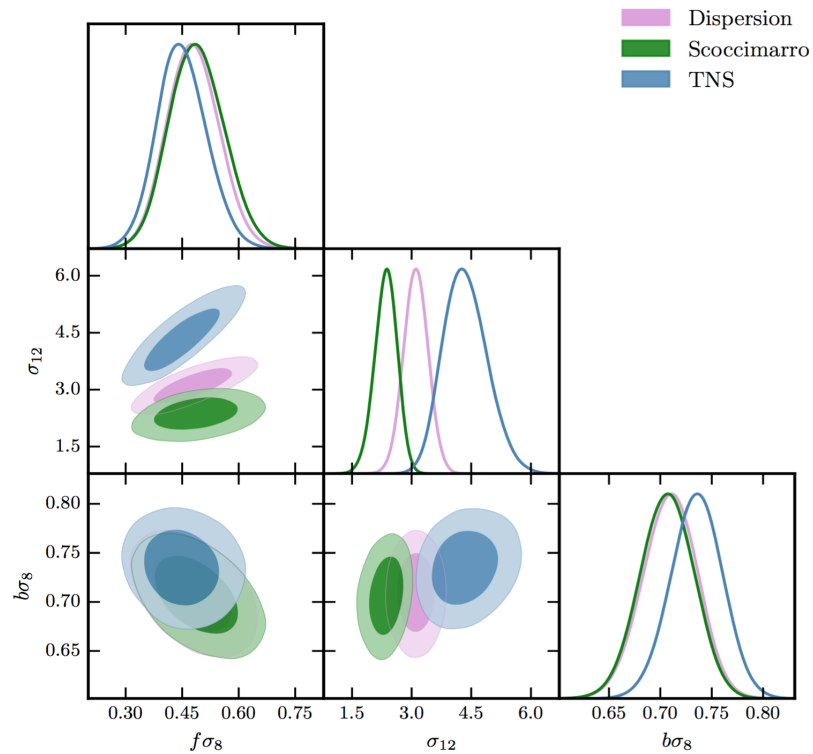
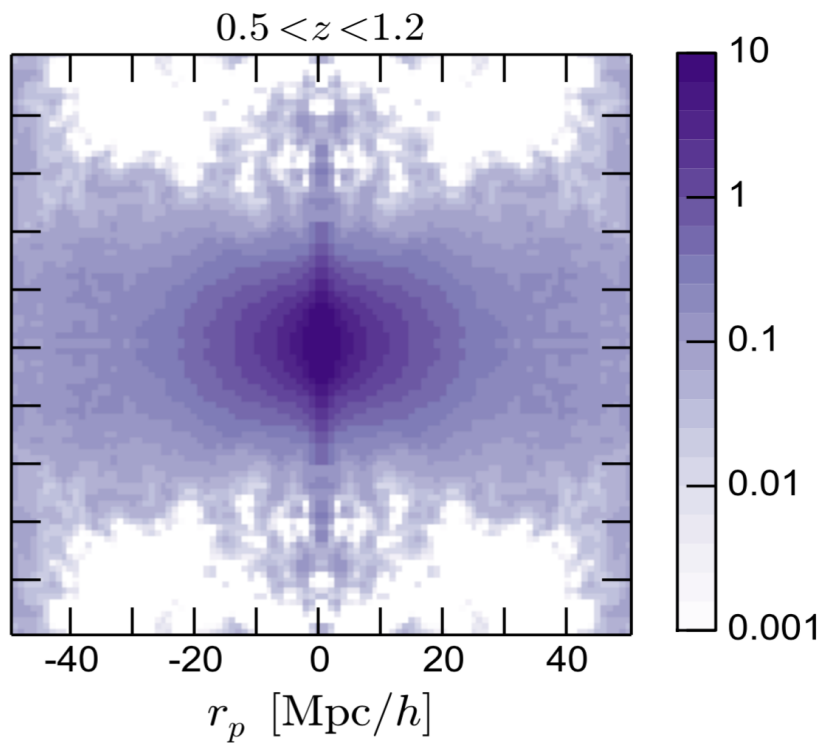
Rota et al.

Baryon fraction



Rota, Granett et al. (in prep.)

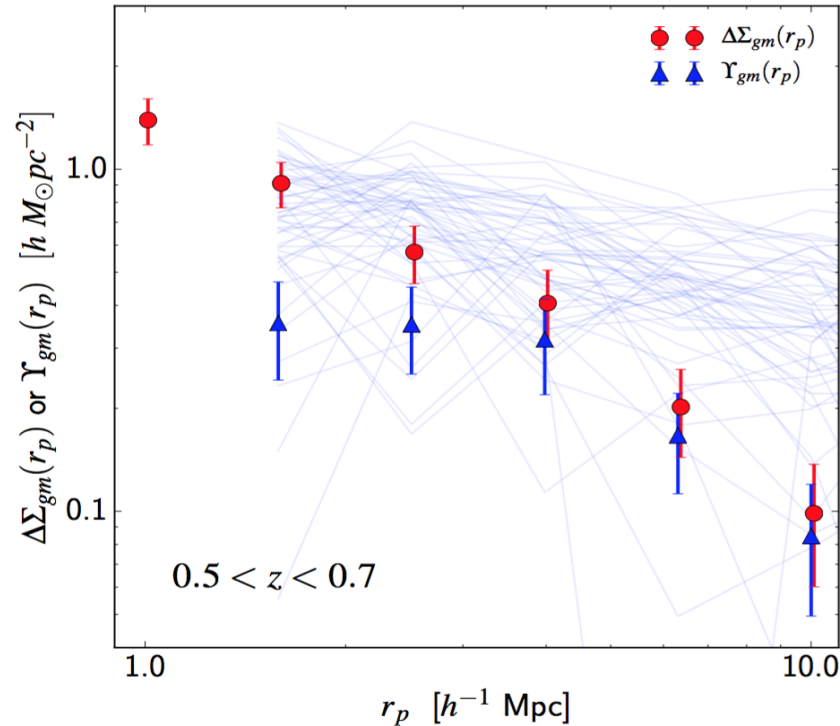
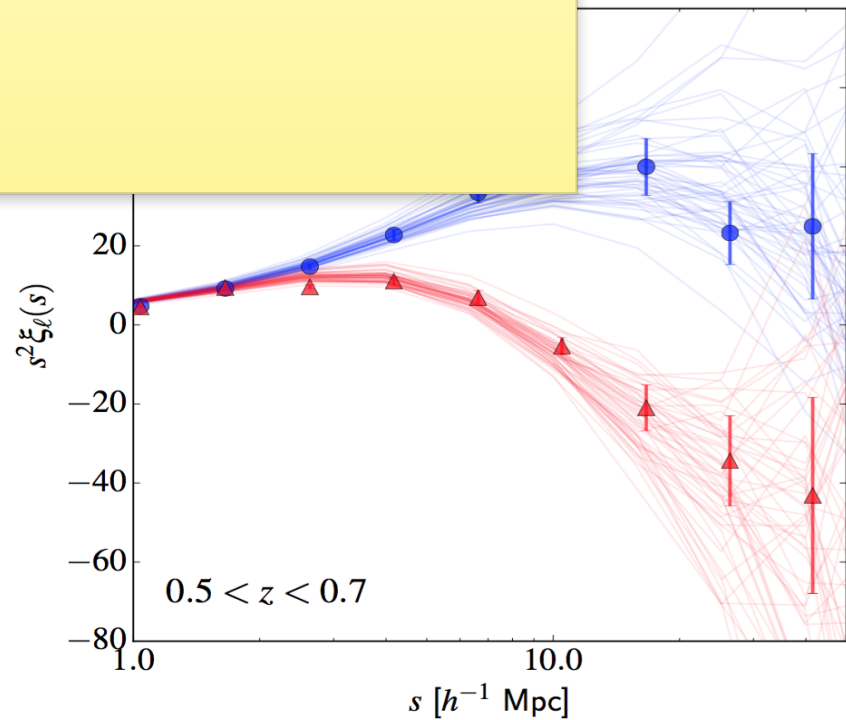
Cole (2005) at $z=0.8$



Pezzotta et al. (in prep.)

PDR-2 repeat of de la Torre (2013)

E_G



de la Torre et al. (2016)
Mandelbaum et al. (2013) — with a focus on f

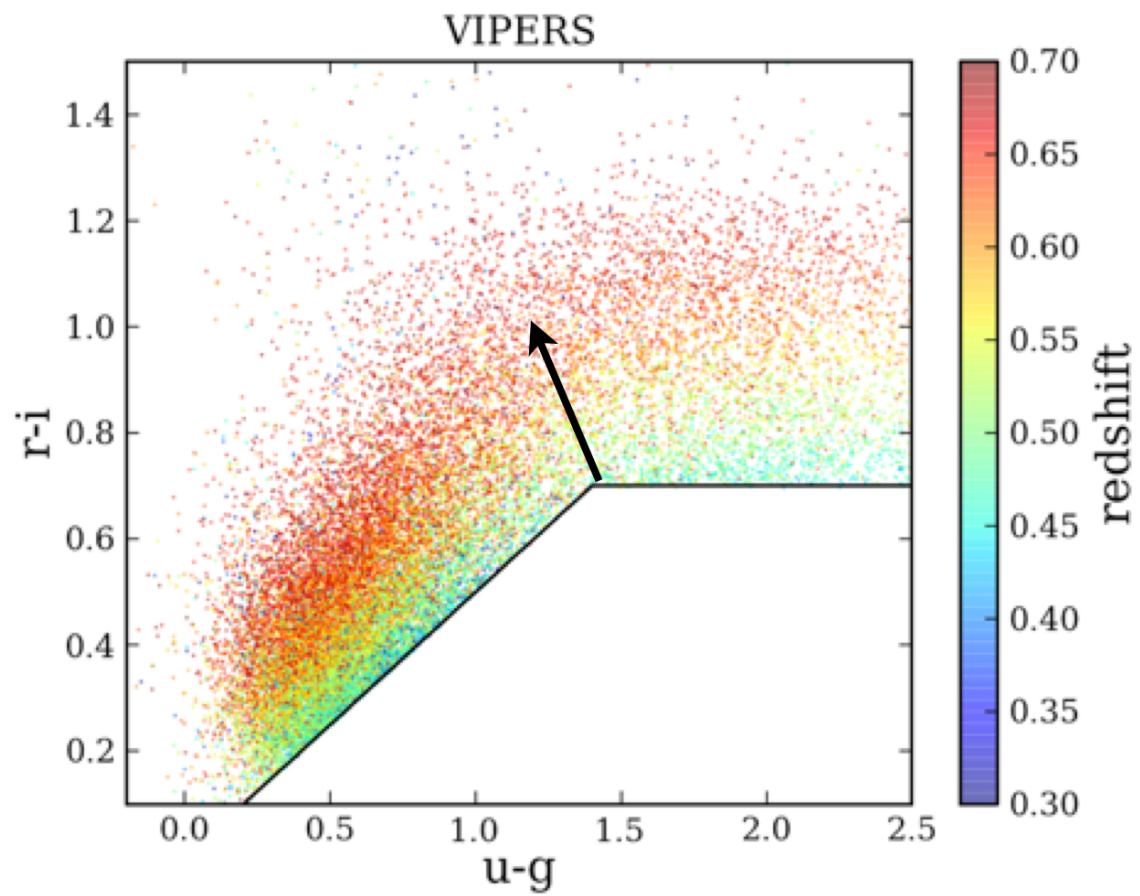


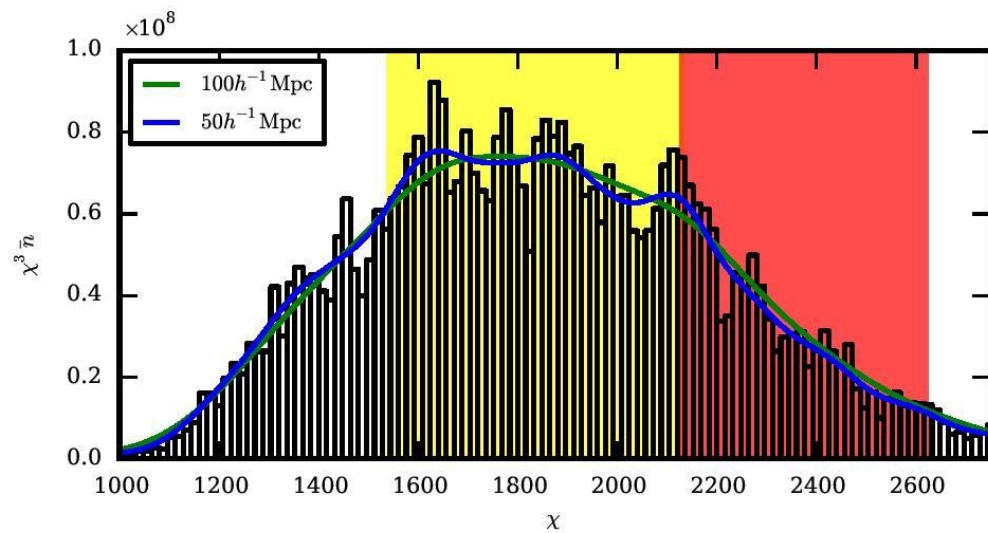
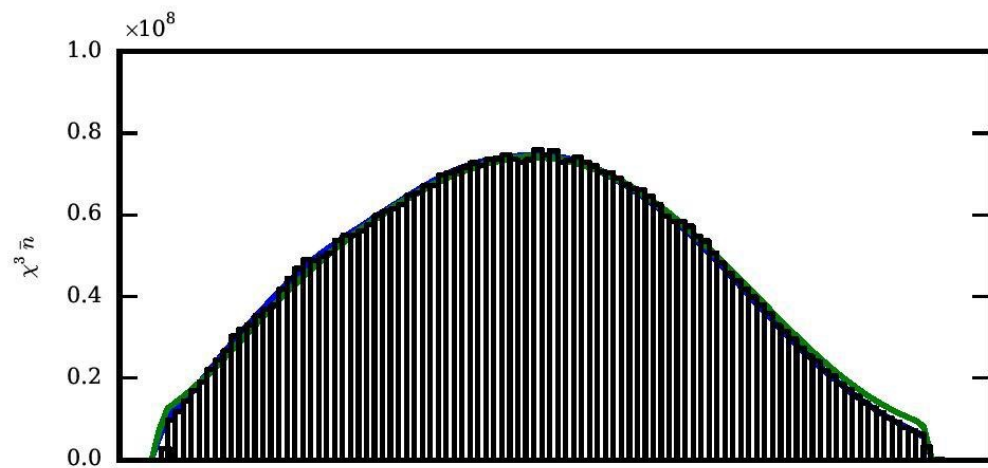
Thank you

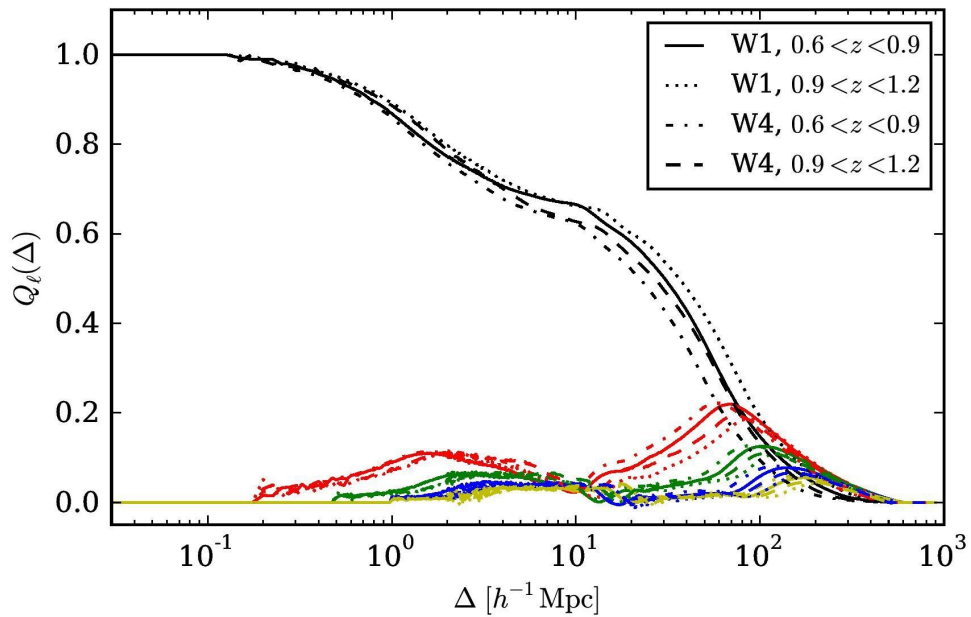
mjw@roe.ac.uk

<http://www.roe.ac.uk/~mjw/>

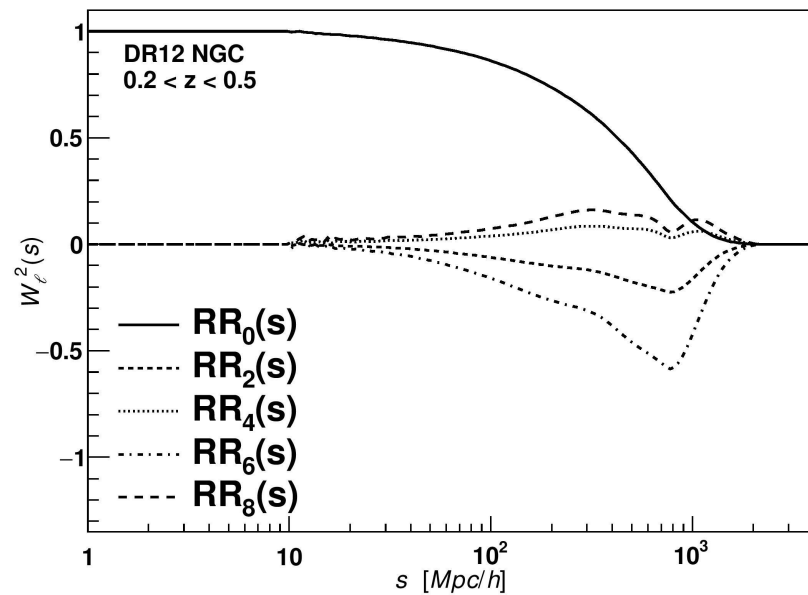
(BCCP common desks)







VIPERS PDR-2



BOSS DR12 - Beutler et al. (2016)

Zhao et al. (2016)

