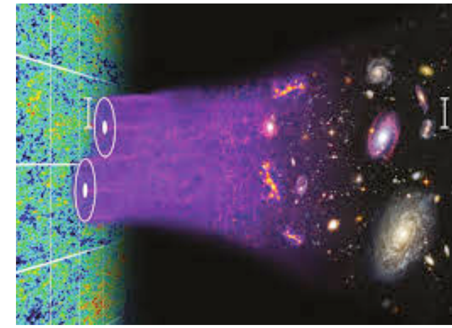
CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

What can we learn from averaging Cosmological Observables in different environments?

Ixandra Achitouv – Diving into the dark July 16

SWINBURNE UNIVERSITY OF TECHNOLOGY

Motivations



- Improving systematic errors: BAO

Additional information washed out by averaging over all environments?

- Screening mechanisms: suppress grav. forces in underdense regions

Upcoming surveys: high volume, so why not?

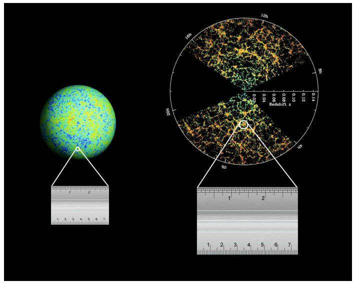
Outlines

- Improving the BAO scale measurement using environmental correlation function

- Testing the consistency of the growth rate measurement in different environments with 6dFGS

Improving the BAO scale measurement using environmental weighting

BAO peak reconstruction



(Images courtesy NASA's Wilkinson Microwave Anisotropy Probe, left, and Sloan Digital Sky Survey, right)

- **Baryon Acoustic Oscillations:**

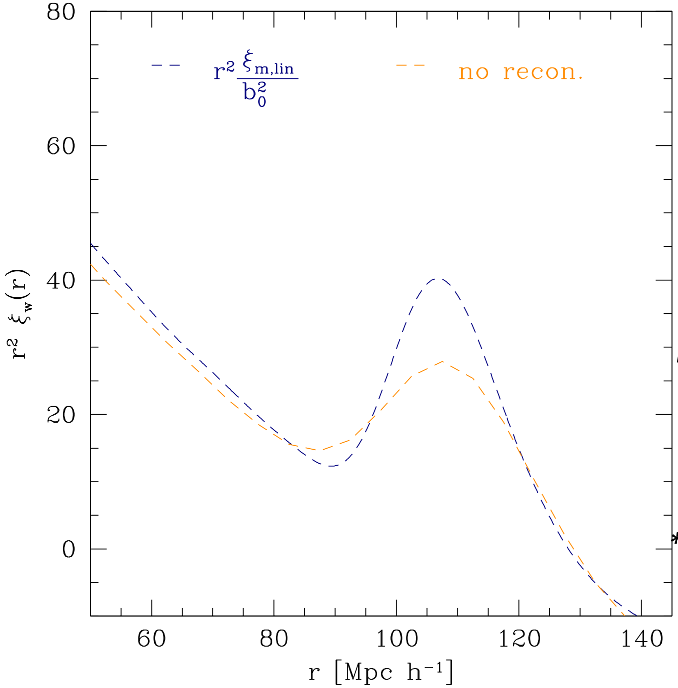
Excess of matter on scale R~110 Mpc/h
(peak in the matter correlation function)
Use as standard ruler

- **Non-linear effects:**

Blur & Shift the BAO peak

- **Other effects:**

Redshift space distortions
Biased tracers



*Measured correlation functions in 1000 COLA^ simulations**
^COmoving Lagrangian Acceleration method
(Tassev et al. 2013 JCAP 0636)
** Simulations Run by J. Koda* (Kazin et al 2014 MNRAS Vol. 441 I4 *)*

Restoring the BAO peak

Standard reconstruction in simulations *(Eisenstein et al. 2006)*:

1- Measure local density around each galaxy

2- Compute the corresponding ``displacement field''

$$\mathrm{div}\, \mathbf{\Psi} = -\delta_m(Rs)$$

3- Move each galaxy position **x** by **x**-Ψ

If no biased tracers & no NL $\mathbf{q} = \mathbf{x} - \Psi$

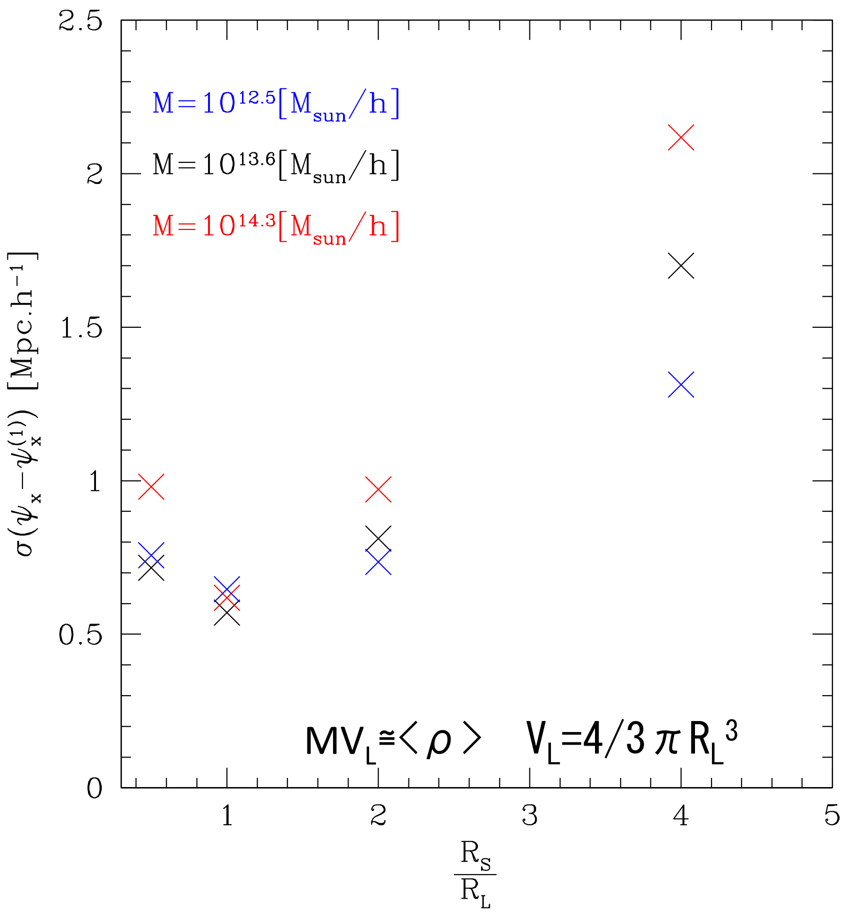
Displacement of halos:

Achitouv & C. Blake ArXiv: 1507.03584 M. Kopp,C. Ulman& I. Achitouv ArXiv: 1606.02301

- 1st order LPT approx:

$$\Psi^{(1)}(q,z,R_S) = \frac{\mathbf{v}_i(R_S)D(z)}{a_i H(a_i) f(a_i) D(z_i)}$$

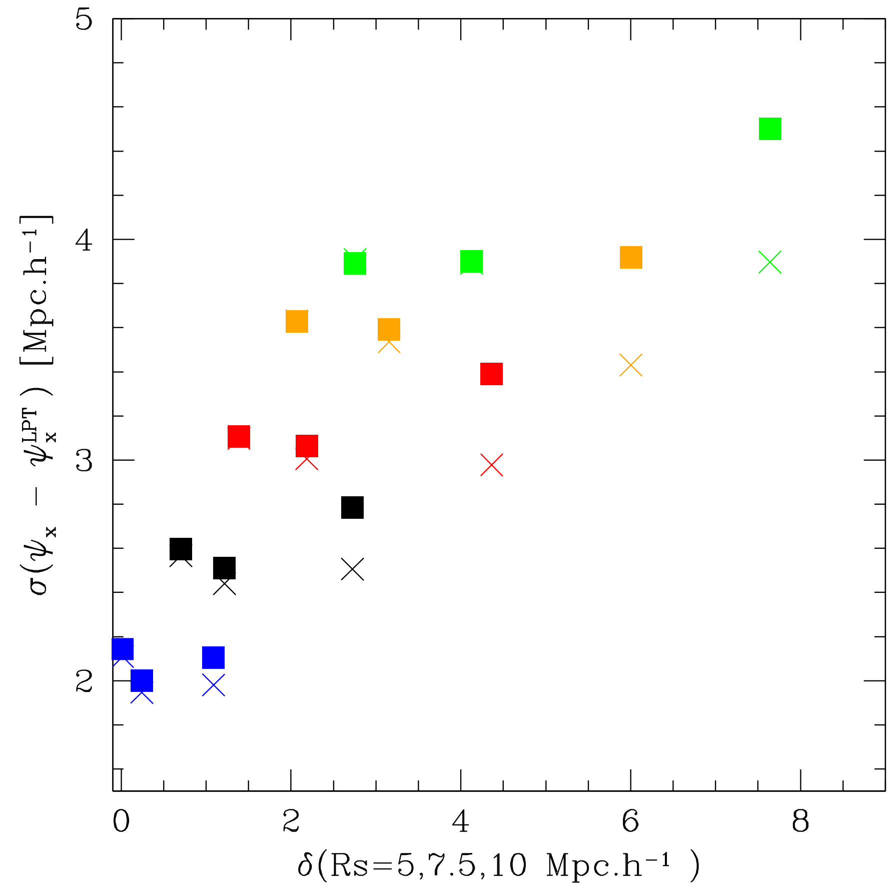
Optimal smoothing scale = initial size of the proto-halo



Performance of the reconstruction for different environments:

- Low sensitivity to the smoothing scale
- High sensitivity to the environment, independent of the LPT orders

The reconstruction efficiency decreases in dense environments where NL effects become important.



I. Achitouv & C. Blake ArXiv: 1507.03584

Reconstructed correlation function in different environments:

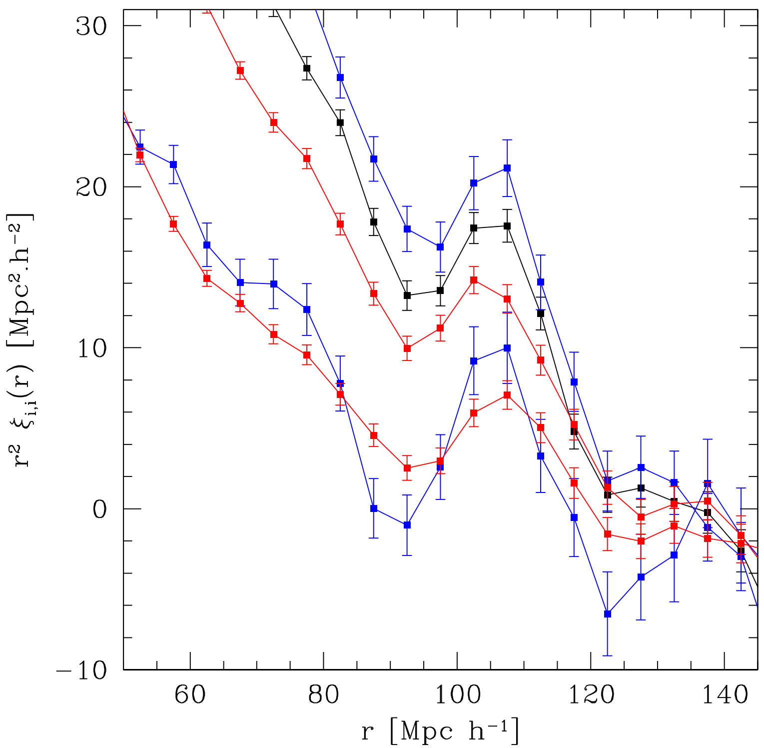
- **Landy-Szalay estimator:**

$$\xi_{E_iE_j} = \frac{DD_{ij}}{RR_{ij}}\frac{nR_i nR_j}{nD_i nD_j} - \frac{DR_{ij}}{RR_{ij}}\frac{nR_i}{nD_i} - \frac{DR_{ji}}{RR_{ij}}\frac{nR_j}{nD_j} + 1$$

- **Sharper peak in underdense environment**
  less NL effects
  reconstruction more accurate

- **The total correlation function can be expressed as**

$$\xi_{\rm tot} = \frac{\sum_{ij}\left(\alpha_{ij}\, RR_{ij}\, \xi_{ij} + \beta_{ij}\right)}{\sum_{ij} RR_{ij}}$$



I. Achitouv & C. Blake ArXiv: 1507.03584

Can we build a new estimator of ξ_{tot} which improves the reconstruction of the BAO peak?

Weighting the reconstructed correlation function:

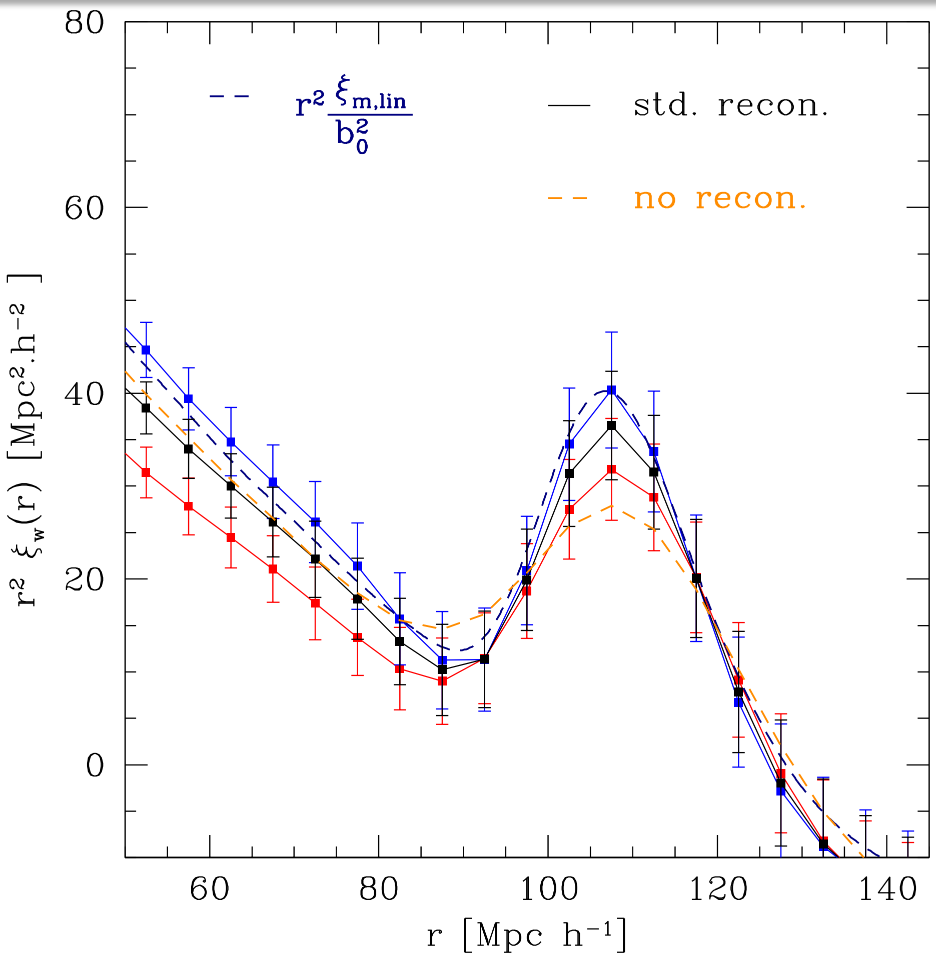
- **Simple idea:**

$\xi_{ij} \rightarrow w_{ij}\, \xi_{ij}$ & $w_{ij}=(w_i\, w_j)^{1/2}$

reproduce linear correlation function shape at the BAO scale

$$\xi_{\rm weighted} = \frac{\sum_{ij} w_{ij}\,(\alpha_{ij}\, RR_{ij}\, \xi_{ij} + \beta_{ij})}{\sum_{ij} w_{ij}\, RR_{ij}}$$

Weighting+ 2LPT + $R_s \rightarrow R_L$
~8% improvement on the measurement of the BAO scale



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Testing the consistency of the growth rate in different environments with the 6dF galaxy survey

Linear Perturbation theory :

- Evolution of the linear density fluctuations:

$$\frac{\partial^2 \delta}{\partial t^2} + 2\frac{\dot{a}}{a}\frac{\partial \delta}{\partial t} = 4\pi G \rho_b \delta.$$

- Linear growth rate for a ΛCDM universe:

$$f(\Omega_m) \equiv \frac{1}{H}\frac{\dot{D}}{D} = \frac{d\ln D}{d\ln a} \approx \Omega_m^{0.6}.$$

Sensitive to the background expansion

Depends on gravitational forces

- Peculiar velocities of galaxies are sourced by the gravitational potential

$$\vec{\nabla} \cdot \mathbf{v} = -a\frac{\partial \delta}{\partial t} = -a\delta\frac{\dot{D}}{D} = -a\delta H f(\Omega_m)$$

Probing the linear growth rate in different environments:

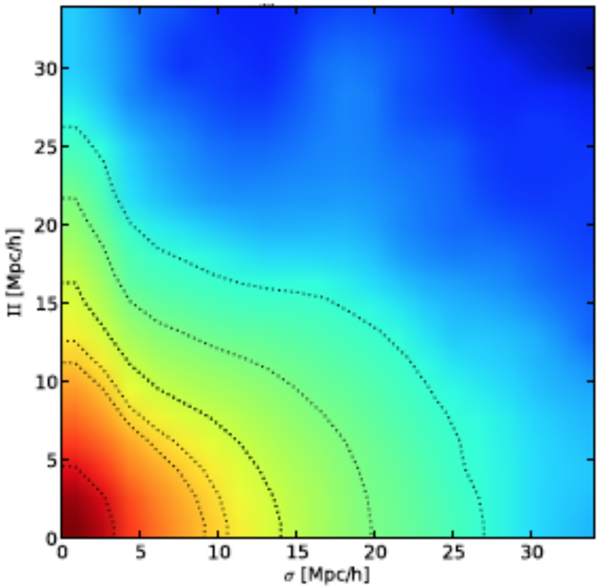
- Redshift space distortions:

Asymmetry of the correlation function due to peculiar velocities of galaxies.

$$\xi_{gg}(\sigma,\pi) = \int \xi^l(\sigma, \pi - \frac{v}{H_0})P(v)dv$$

Large scales: coherent infall/ outflow due to density fluctuation (Kaiser effect) sensitive to the growth rate

Small scales: random motion of galaxies within group (FoG)



I. Achitouv & C. Blake Arxiv: 1606.03092

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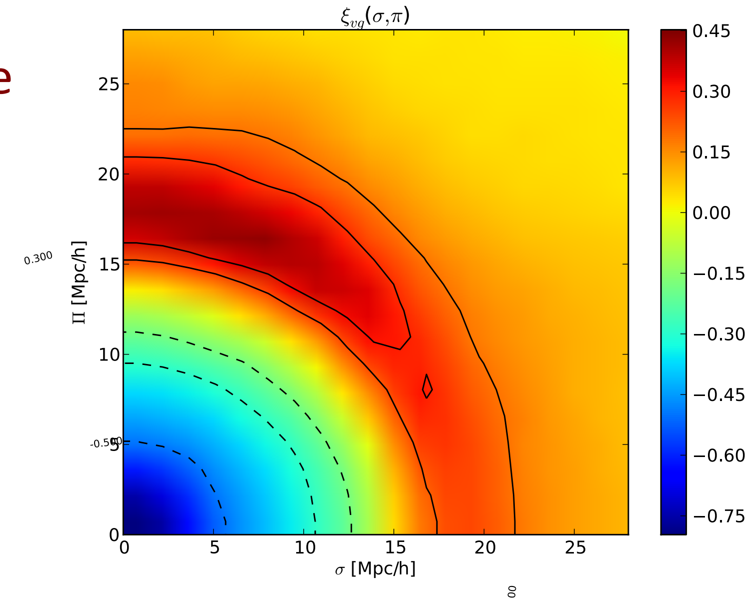
Probing the linear growth rate in different environments:

- The galaxy-void correlation function in RS: outflow motion of the galaxies sensitive to the growth rate

$$v_p(r) = -\frac{1}{3} H_0 r \Delta(r) f.$$

$$\Delta(r) = \frac{3}{r^3} \int_0^r \xi_{v-\mathrm{DM}}(y) y^2 dy.$$

Small scales Virial motion of the galaxies P(v)dv



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6dF Galaxy Survey:

http://www.6dfgs.net/

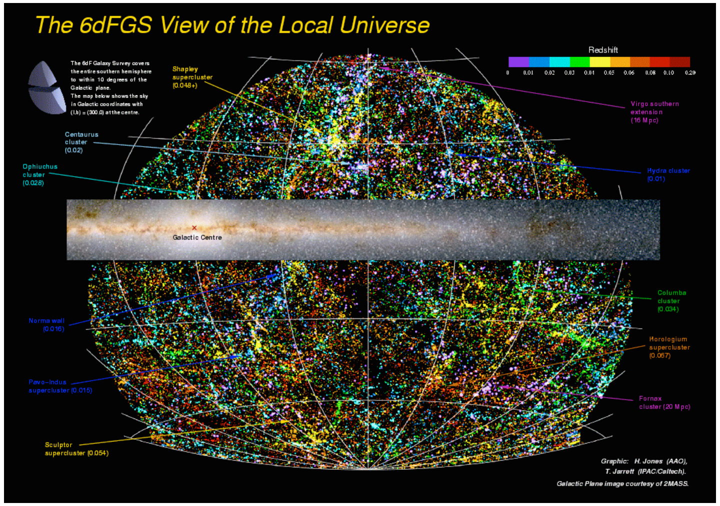
- Low redshift survey z~0.1

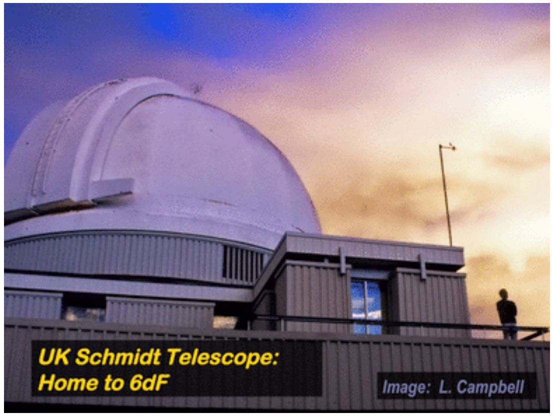
- Sensitive to the late-time accelerated expansion of the universe (DE)

- Mapped nearly half the sky (southern hemisphere)

- Large volume that can probe large voids

- Catalogue of ~ 100,000 galaxies and measurement of ~8,000 peculiar velocities.



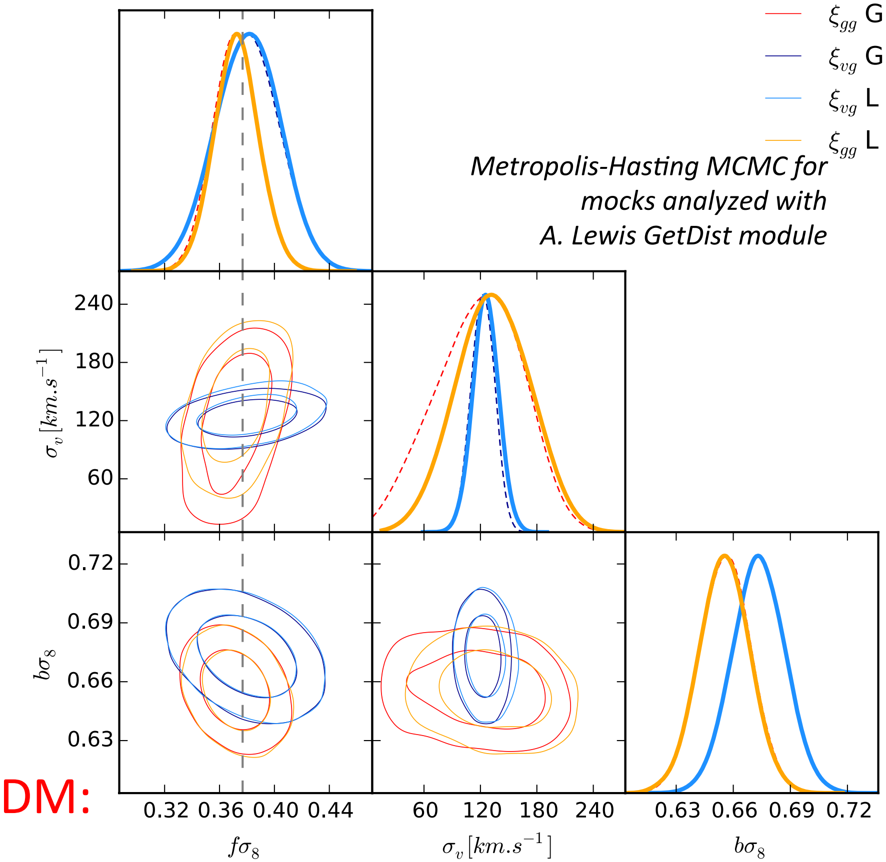


Consistency of the growth rate

Assumptions:

- ΛCDM cosmology
- Linear bias
- Constant velocity dispersion (nuisance parameter)
- we find voids using density criteria*
- We performed a χ^2 of the 2D void-galaxy, galaxy-galaxy correlation functions using errors from the standard deviation of the mocks.

*I.Achitouv, in prep



Metropolis-Hasting MCMC for mocks analyzed with A. Lewis GetDist module

We found for 6dFGS a consistency with ΛCDM:
$f\sigma_8 = 0.36 \pm 0.06$ for gal-gal RSD
and $f\sigma_8 = 0.39 \pm 0.11$ for the gal-void RSD

I. Achitouv & C. Blake Arxiv: 1606.03092

Conclusion

- Looking at different environments can be helpful to:

1-Improve current cosmological probes ~ 8% for BAO

2-Challenge the ΛCDM picture of our universe / GR model

- With 6dFGS we find consistency with LCDM but:

-Large statistical errors that will become lower with upcoming surveys giving a good opportunity to perform such analyses.

- Interesting to test for different models of gravity and DE

The alpha fit

The distortion factor:

- X^2 (α) estimate

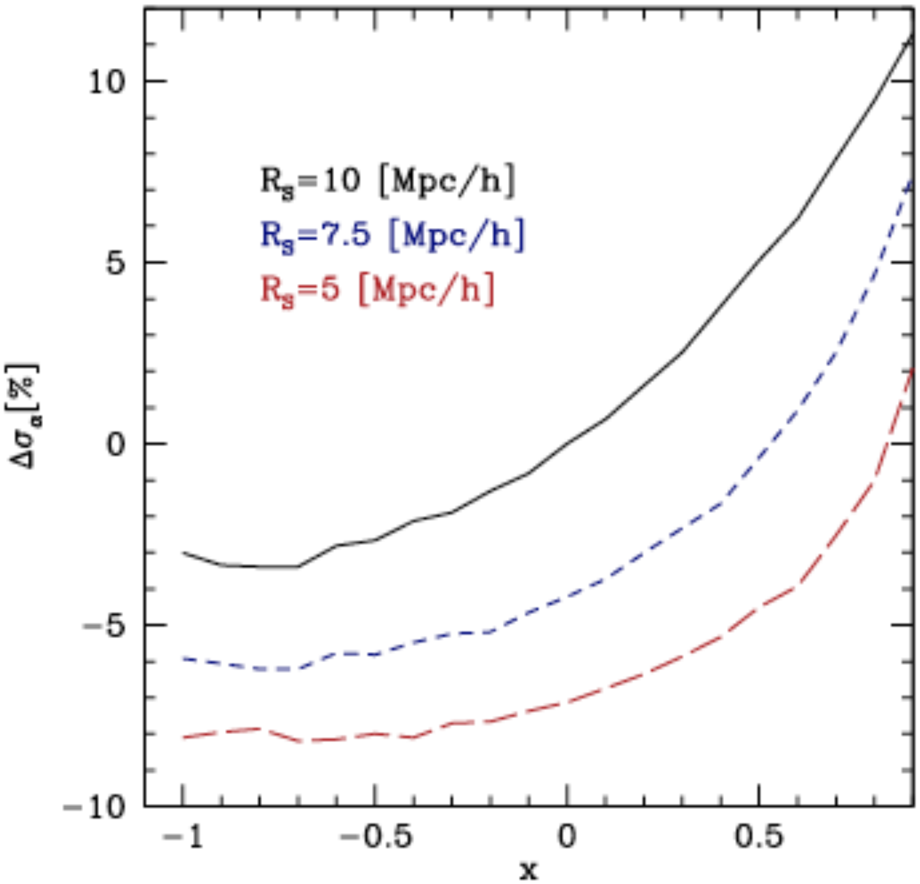
$$\xi^{\rm flt}(r) = B^2 \xi_m(\alpha r) + A(r)$$

- α=1 no shift in BAO peak
- σ_α over 1000 boxes = error in BAO scale measurement

Standard reconstruction:

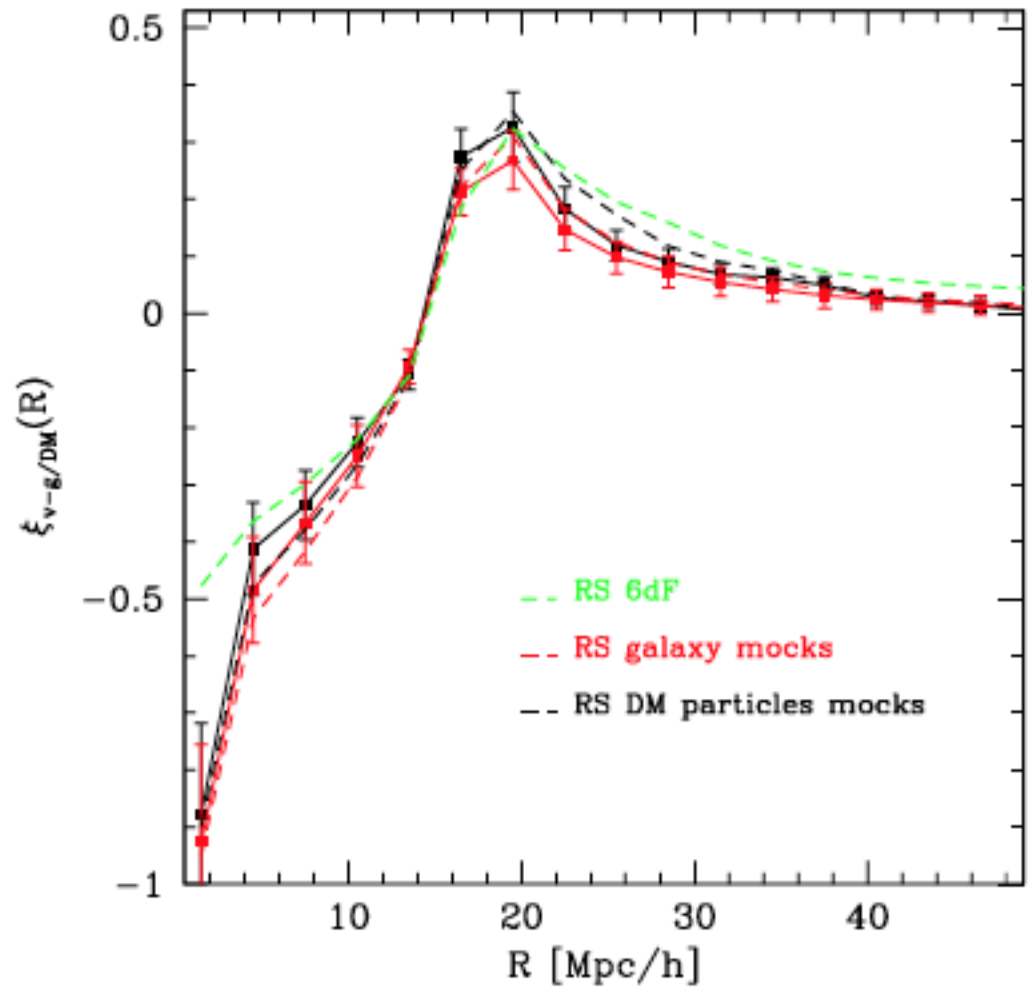
- R_S=10Mpc/h and x=0
- Zel'dovitch approximation

Weighting+ 2LPT + $R_s \rightarrow R_L$
~8% improvement



Identifying voids:
I. Achitouv, in prep

Density criteria to identify voids of size Rv=20Mpc/h



Motivations

- **Simple idea:**

$\xi_{ij} \rightarrow wij\ \xi_{ij}$ & $wij=(wi\ wj)^{1/2}$

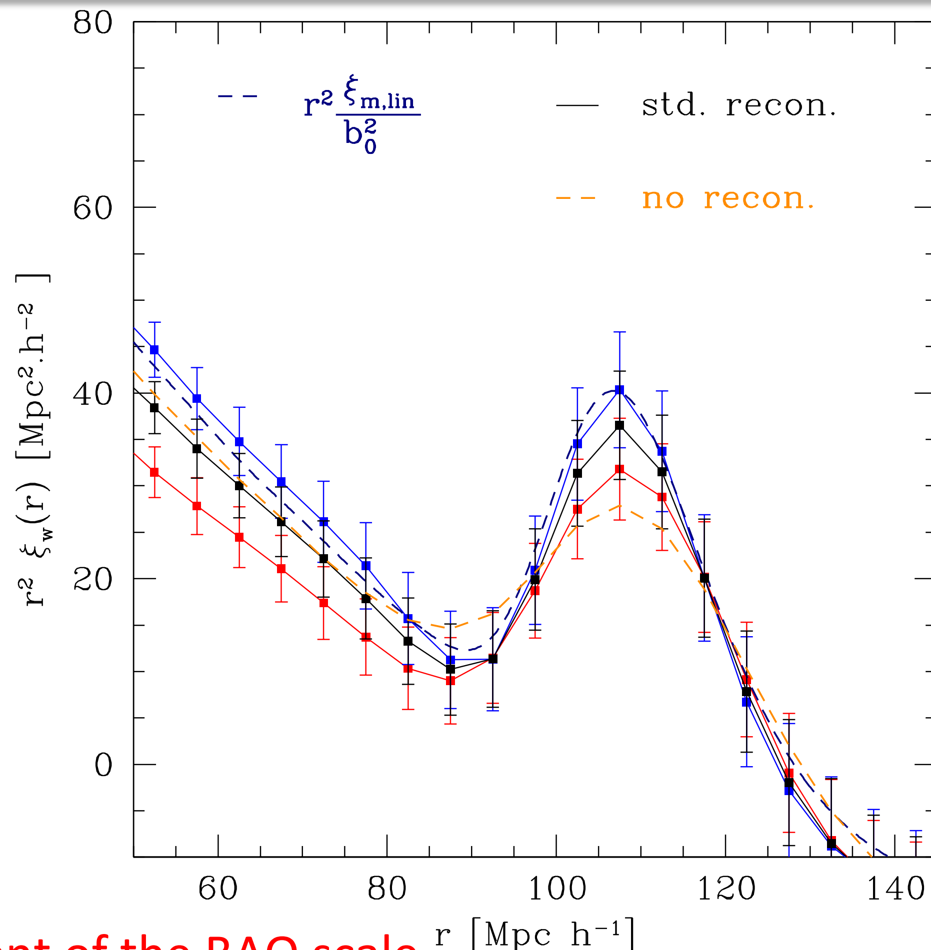
reproduce linear correlation function shape at the BAO scale

broad choices of parameters

- **Elaborated idea:**

$$\xi_{\mathrm{weighted}} = \frac{\sum_{ij} w_{ij}\,(\alpha_{ij}\, RR_{ij}\, \xi_{ij} + \beta_{ij})}{\sum_{ij} w_{ij}\, RR_{ij}}$$

$wi=1+(i-i_{av})\,x/(i_{max}-i_{av})$ $x=[-1,1]$



Weighting+ 2LPT + $R_s \rightarrow R_L$

~8% improvement on the measurement of the BAO scale