Improving reconstruction of the baryon acoustic peak : the effect of local environment

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CAASTRO ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

Arxiv:**1507.03584**, IA & C. Blake

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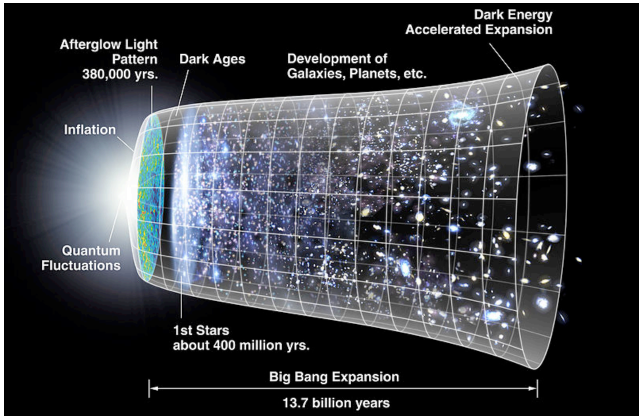
Motivations

Hierarchical scenario

- Initial perturbations to cosmic web
- Displacement of proto-halos

a. Easier to model

b. Can be linked to galaxy positions



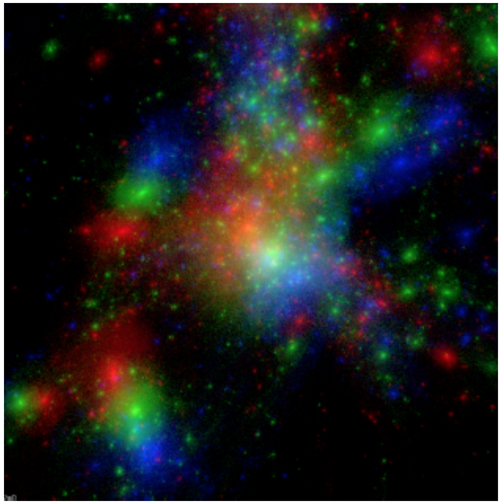
CMB fluctuations related to galaxies we observe. Credit: wikimedia

Why?

- Theoretical prediction of NL clustering

(M. Kopp, C. Uhlemann & IA in prep)

- New cosmological probes
- BAO reconstruction



DM density field for different DE models. Credit: DEUS consortium courtesy of Y. Rasera

Outlines

1- How accurately can we predict the displacement of halos?

2-Does the displacement depend on the environment ?

Unbiased case study:
prediction of halos positions at z=0 from the initial DM velocities
Reconstruction study:
Infer the initial positions of proto-halos from z=0 halo density field

3-Can we use this to improve BAO reconstruction ?

New estimator for the reconstructed correlation function

1^{st} (ZA) and 2^{nd} LPT approximations

Displacement field of mass element M(Rs):

$$\mathbf{x}(R_S) = \mathbf{q}(R_S) + \mathbf{\Psi}(\mathbf{q}, R_S)$$

$$\mathbf{\Psi} \simeq \mathbf{\Psi}^{(1)} + \mathbf{\Psi}^{(2)}$$

$$\mathbf{\Psi} \simeq -D\nabla\phi^{(1)} - 3/7 D^2 \nabla\phi^{(2)}$$

Potential equations:

$$\nabla^2\phi^{(1)}(R_S) = \delta_0(R_S)$$

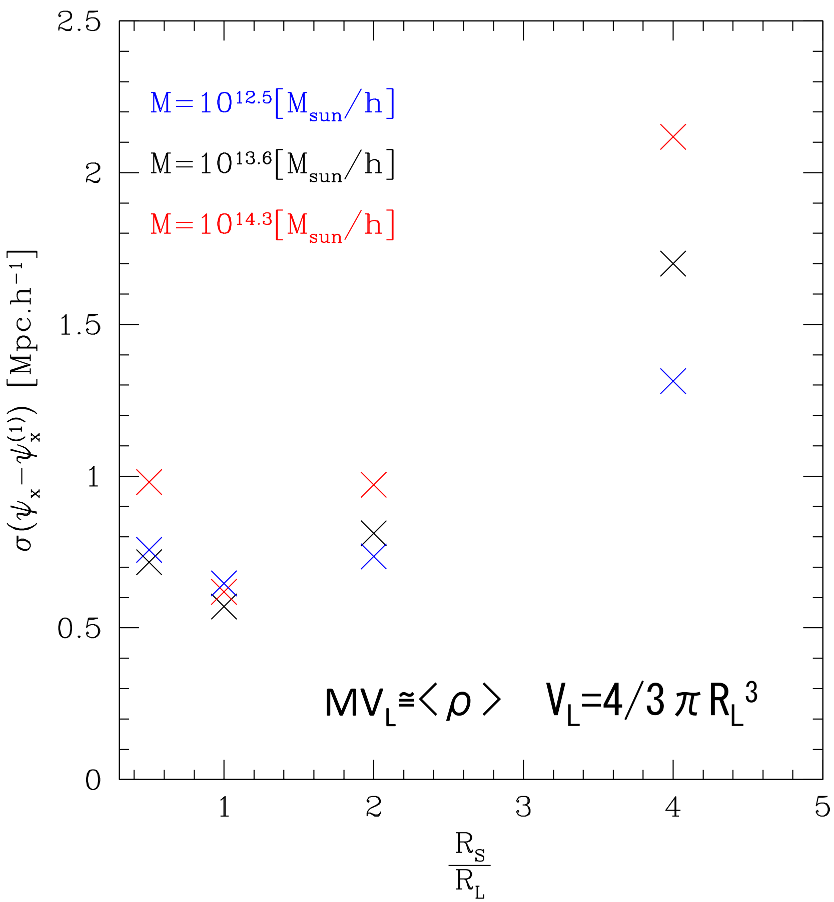
$$\nabla^2\phi^{(2)}(R_S) = -1/2\mathcal{G}_2(\phi^1)$$

Input required:

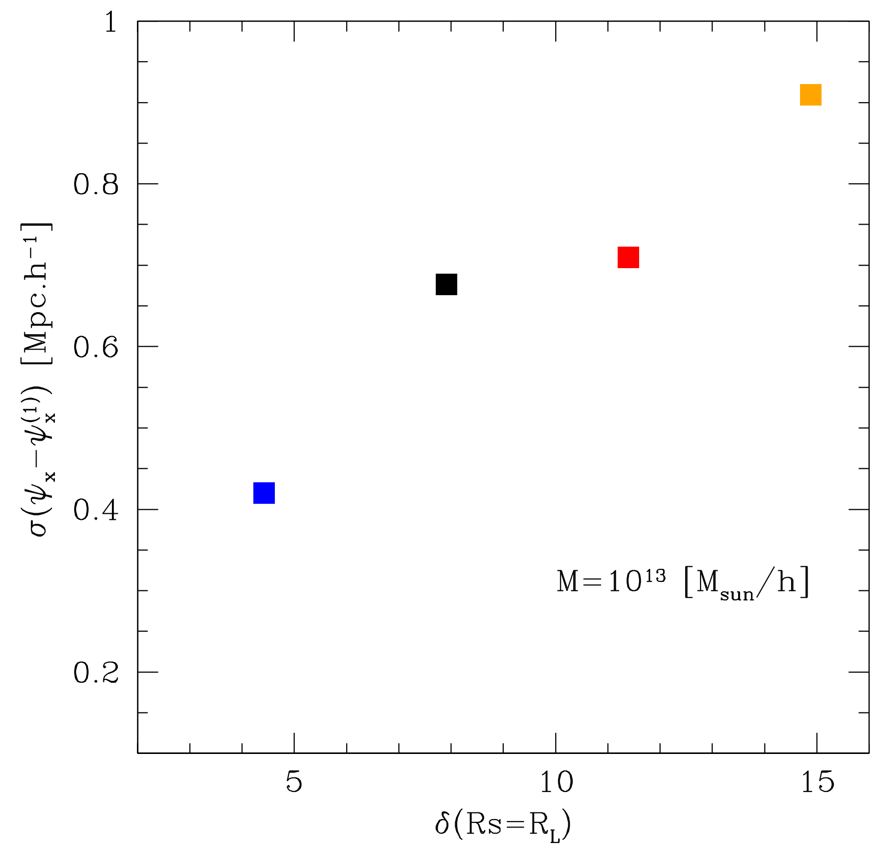
- Local density $\delta_0(R_s)$ or
- Local velocity field $\mathbf{v}(R_s)$ + continuity equation

Accuracy tests for unbiased DM field using N-body simulations*

Sensitivity to the smoothing scale



Sensitivity to the environments

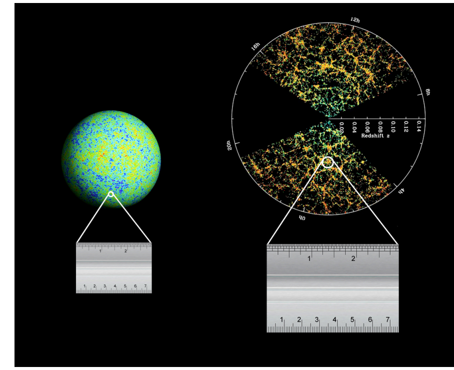


$$\Psi^{(1)}(q, z, R_S) = \frac{\mathbf{v}_i(R_S)D(z)}{a_i H(a_i) f(a_i) D(z_i)}$$

*www.deus-consortium.org

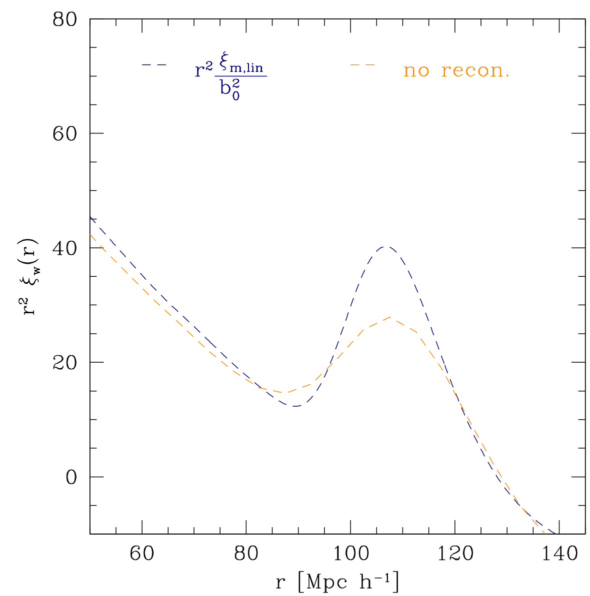
Application to the BAO peak reconstruction

Baryon Acoustic Oscillations:
- Excess of matter on scale R~110 Mpc/h
- Use as standard rulers



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

Non-linear effects:
- Blur & Shift the BAO peak



*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 *)*

Other effects:
- Redshift space distortions
- Biased tracers

Restoring the BAO peak

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

1- Measure local density around each halo at z=0

$$\delta_m(R_S) = \delta_h(R_S)/b$$

2- Compute the corresponding ``displacement field''

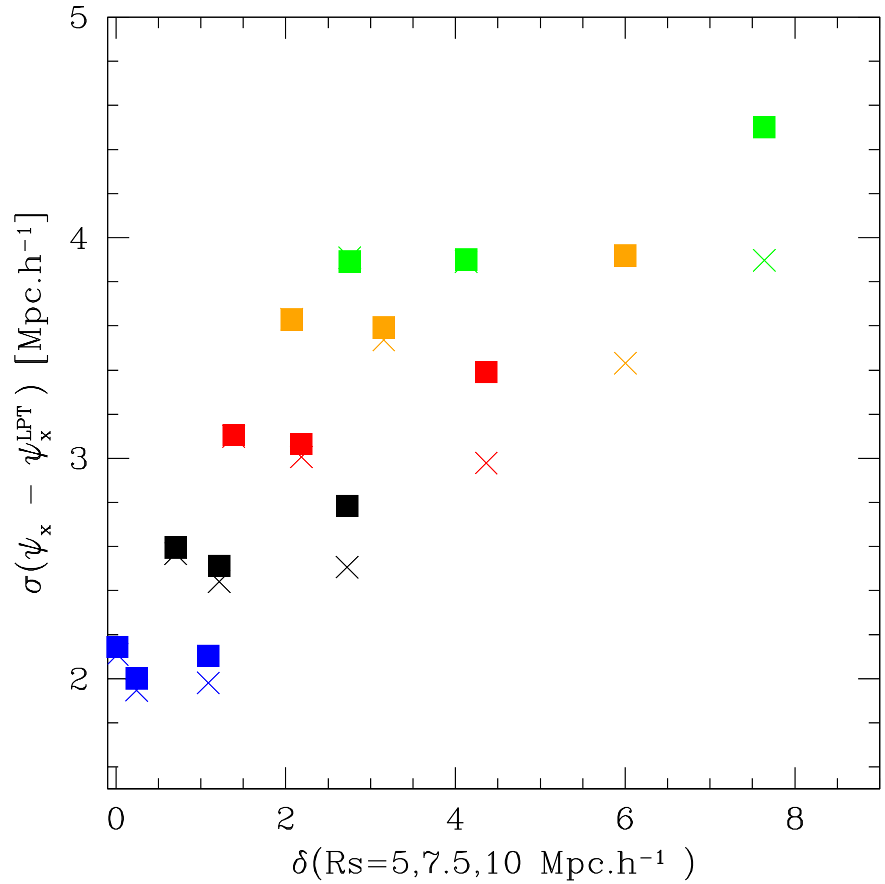
$$\text{div}\,\boldsymbol{\Psi} = -\delta_m(Rs)$$

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

if no biased tracers & no NL **q**=**x**-Ψ

Performance of the reconstruction

- Low sensitivity to the smoothing scale
- High sensitivity to the environment, independent of the LPT orders
- Need to add up 2LPT for Rs<7.5 Mpc/h



The reconstruction method breaks down on dense environments where NL effects become important.

Reconstructed correlation function in different environments

Landy-Szalay estimator:

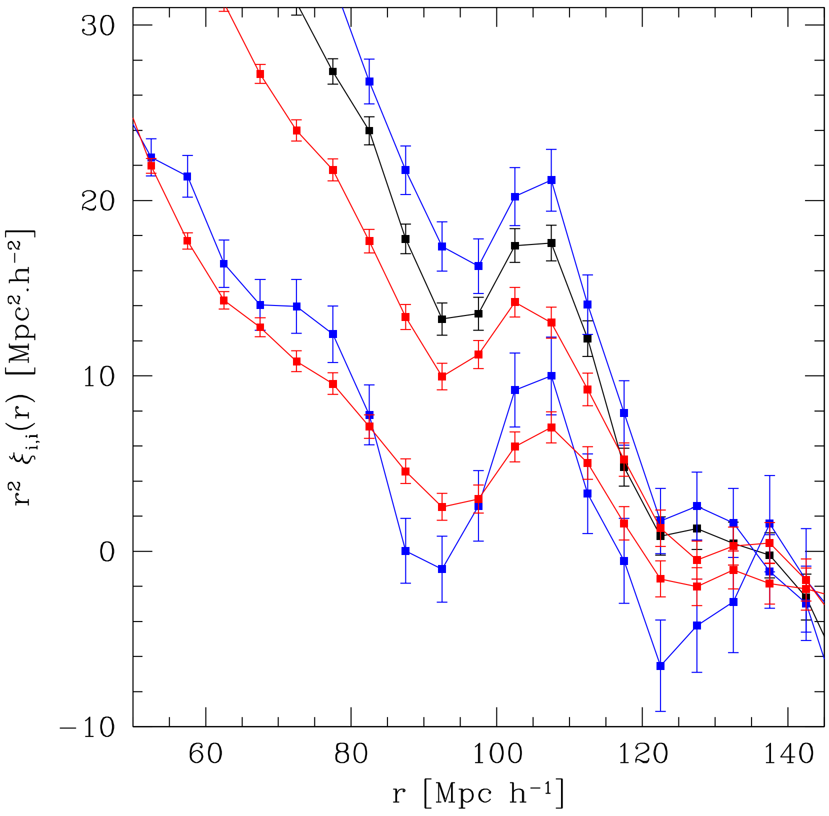
$$\xi_{E_iE_j} = \frac{DD_{ij}}{RR_{ij}}\frac{nR_i nR_j}{nD_i nD_j} - \frac{DR_{ij}}{RR_{ij}}\frac{nR_i}{nD_i} - \frac{DR_{ji}}{RR_{ij}}\frac{nR_j}{nD_j} + 1$$

Sharper peak in underdense environment

- less NL effects
- reconstruction more accurate

The total correlation function can be expressed as

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



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

Weighting the reconstructed correlation function

Simple idea:

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

- we can reproduce linear correlation function shape at the BAO scale

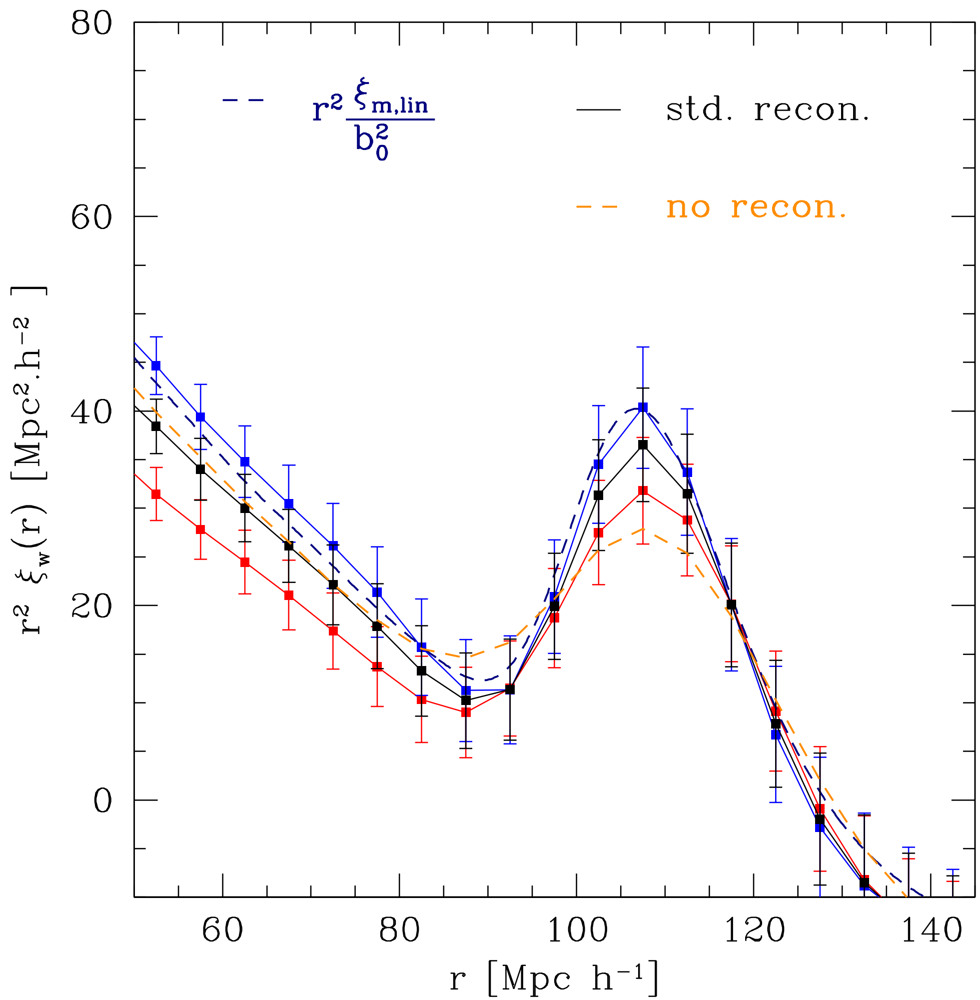
- too large choices of parameters to systematically test the improvement.

Elaborated idea:

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

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

$x=[-1,1]$

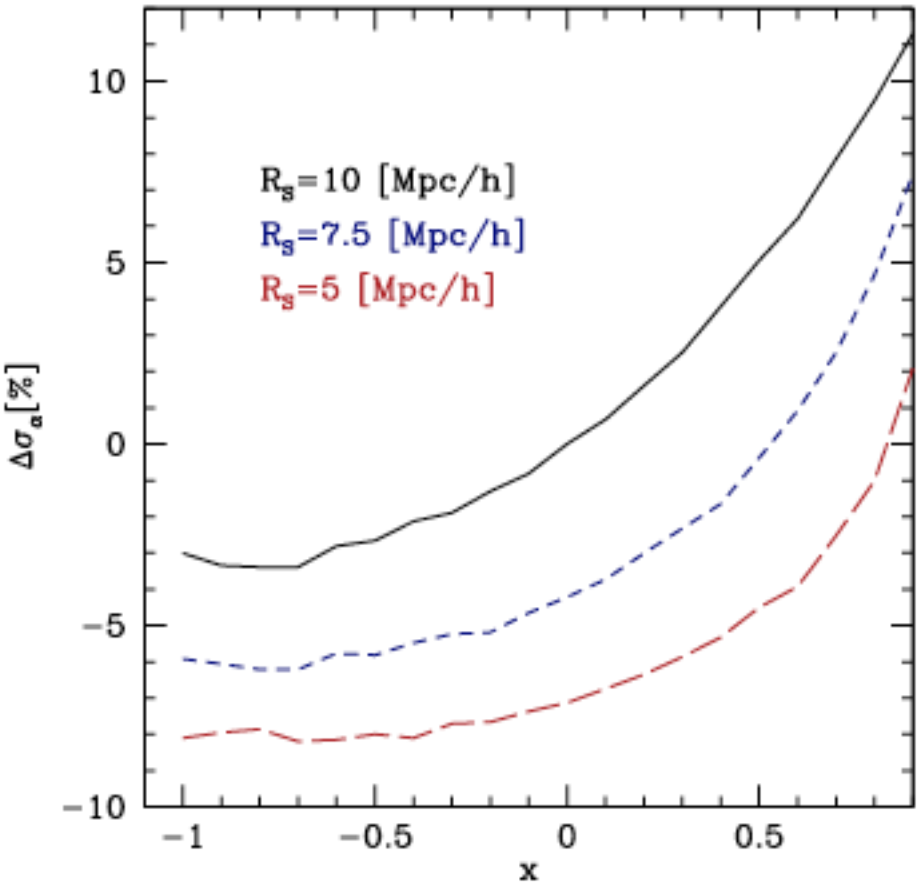


The distortion factor:

- 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 → R_L
~8% improvement

Conclusions

The weighting by environment sharpens the BAO peak and improves the measurement of the standard ruler.

Our estimate for the reconstructed correlation function can be optimized (e.g. weighting parameterization).

Can we probe cosmology by measuring the environmental correlation functions at different cosmic times?

To be continued…