Reconstruction of density field for BAO

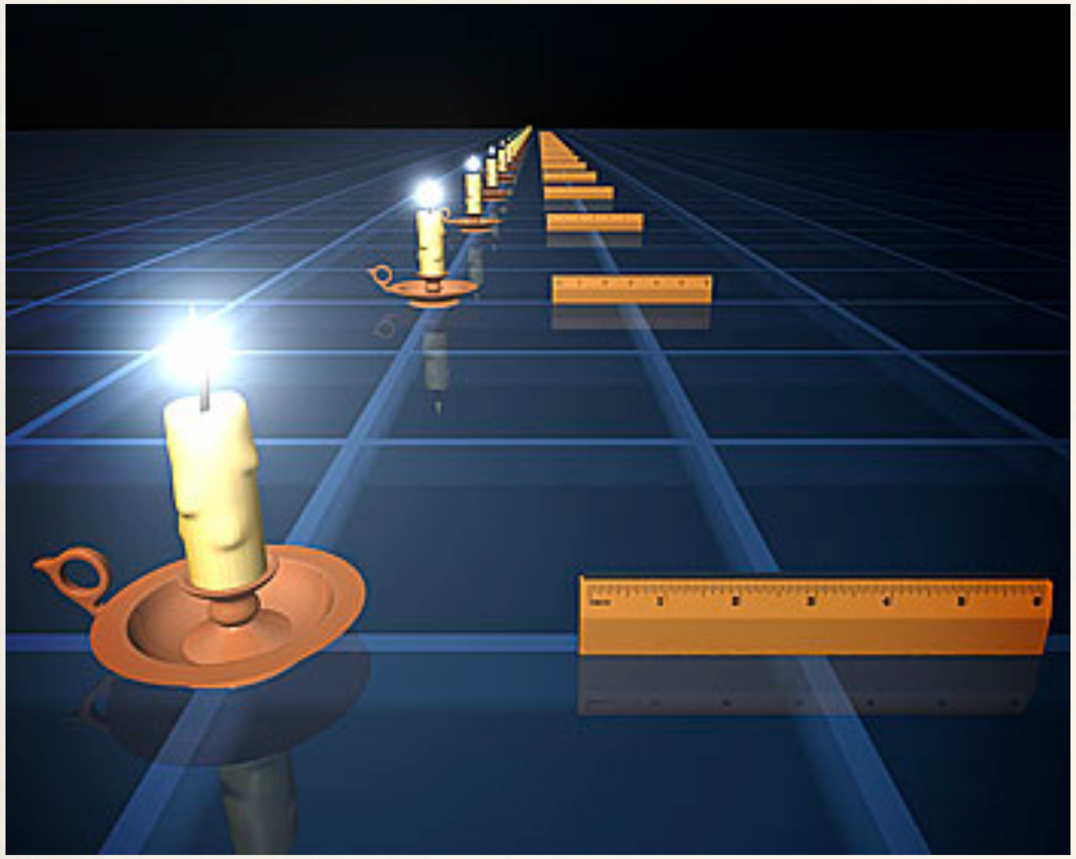
Mariana Vargas-Magaña

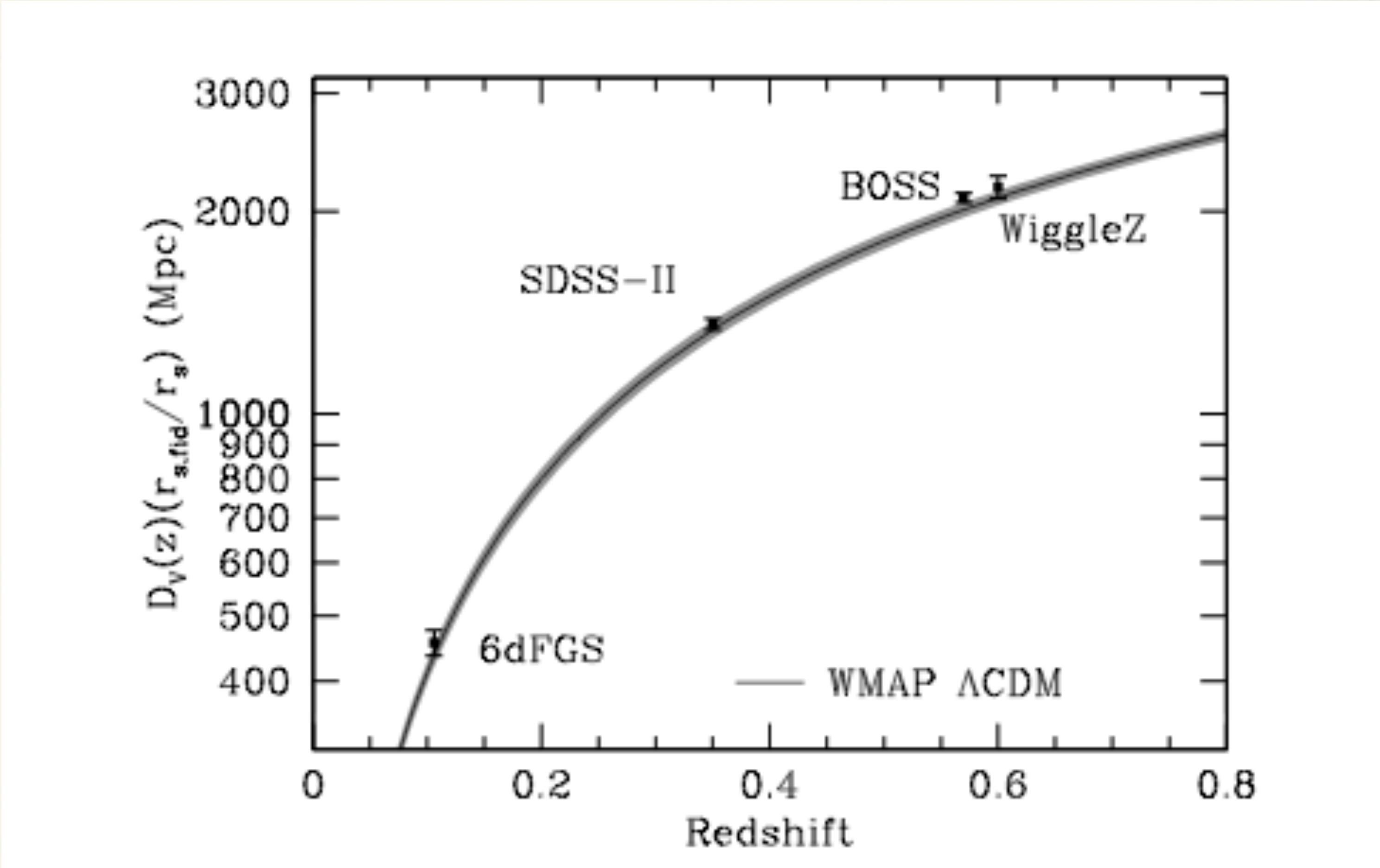
Xiaoying.Xu ,Shirley.Ho, Hy. Trac, Yu. Feng,+A.Cuesta, N. Padmanabham, A. Burden, W. Percival, A. Sanchez+ Ashley. Ross+Beth. Reid, M. White, M. Manera,Cameron, Jeremy Tinker, +**BOSS collaborators**

Outline

- Introduction
- Realistic mocks: PTHALOS
- Towards improvement.

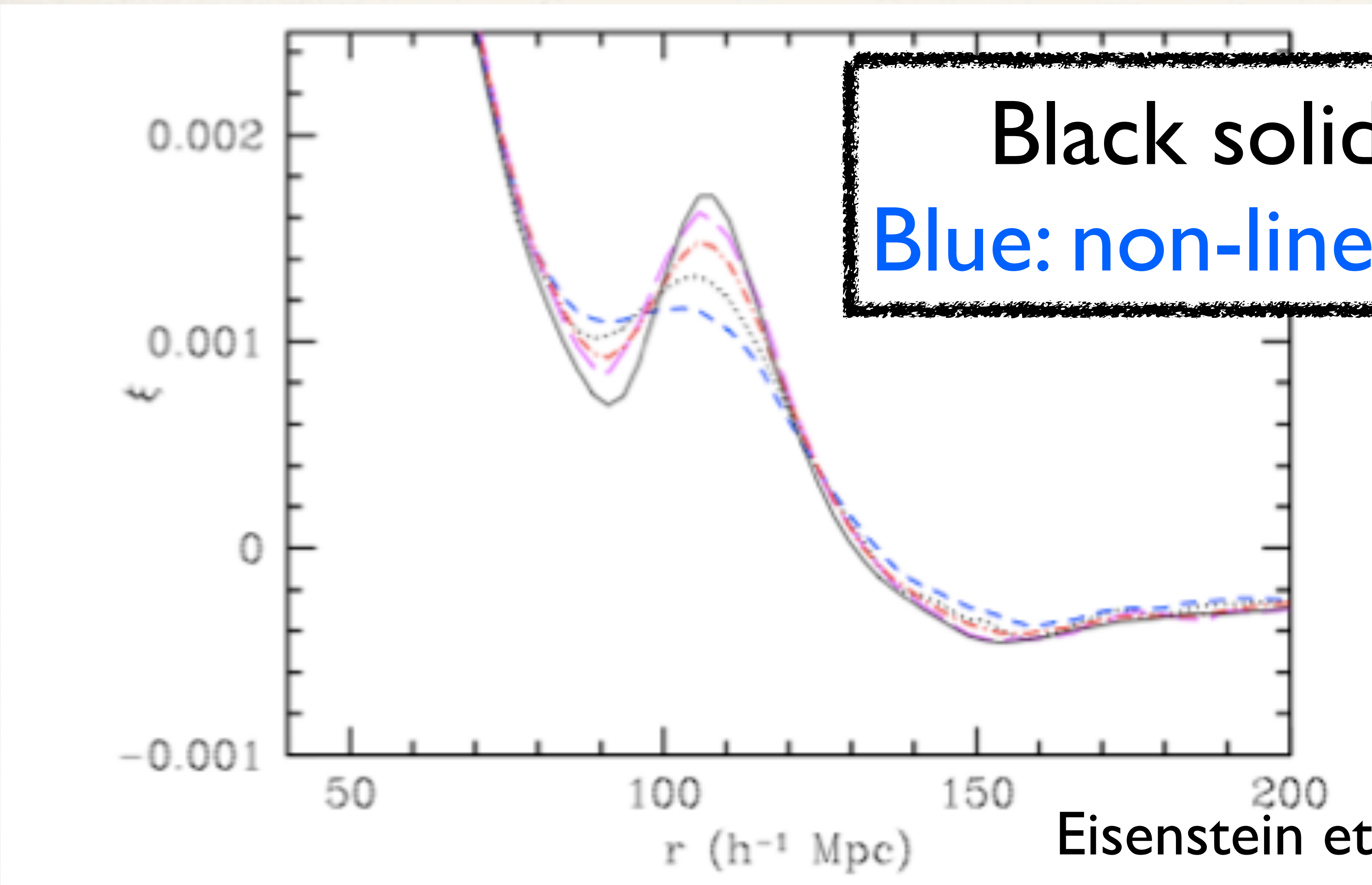
Baryonic Acoustic Oscillations





The measurement of distances between between objects on cosmic scales over a range of redshift provides a map of the expansion history. BAO are used as standard rulers for learning about cosmology.

Introduction



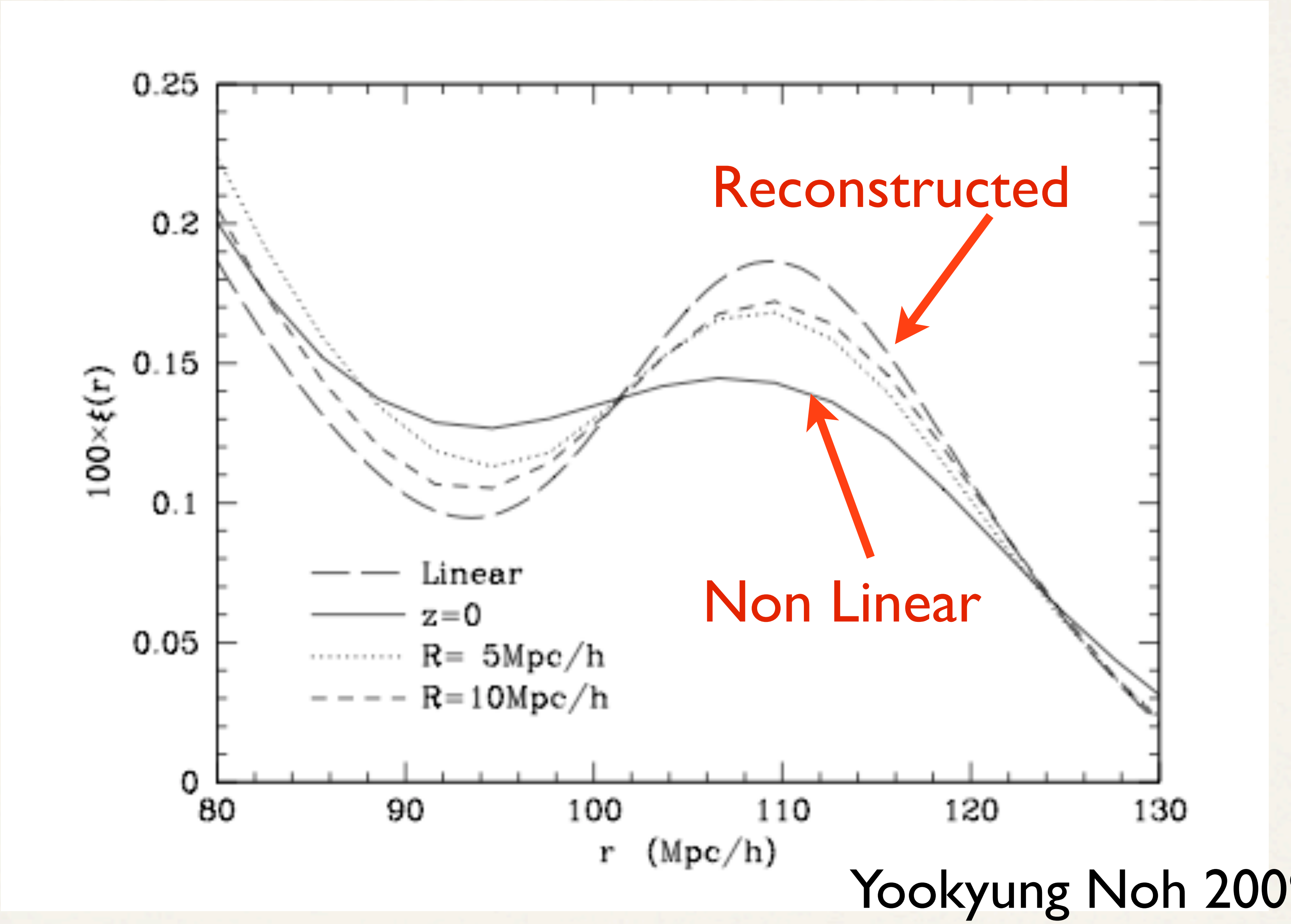
Black solid = linear at z=49

Blue: non-linear z-space observed

Eisenstein et al 2006

Dominant effect of **non linear evolution** of density is BAO **smoothing**. Smoothing reduce contrast BAO, increasing error distance measurement.

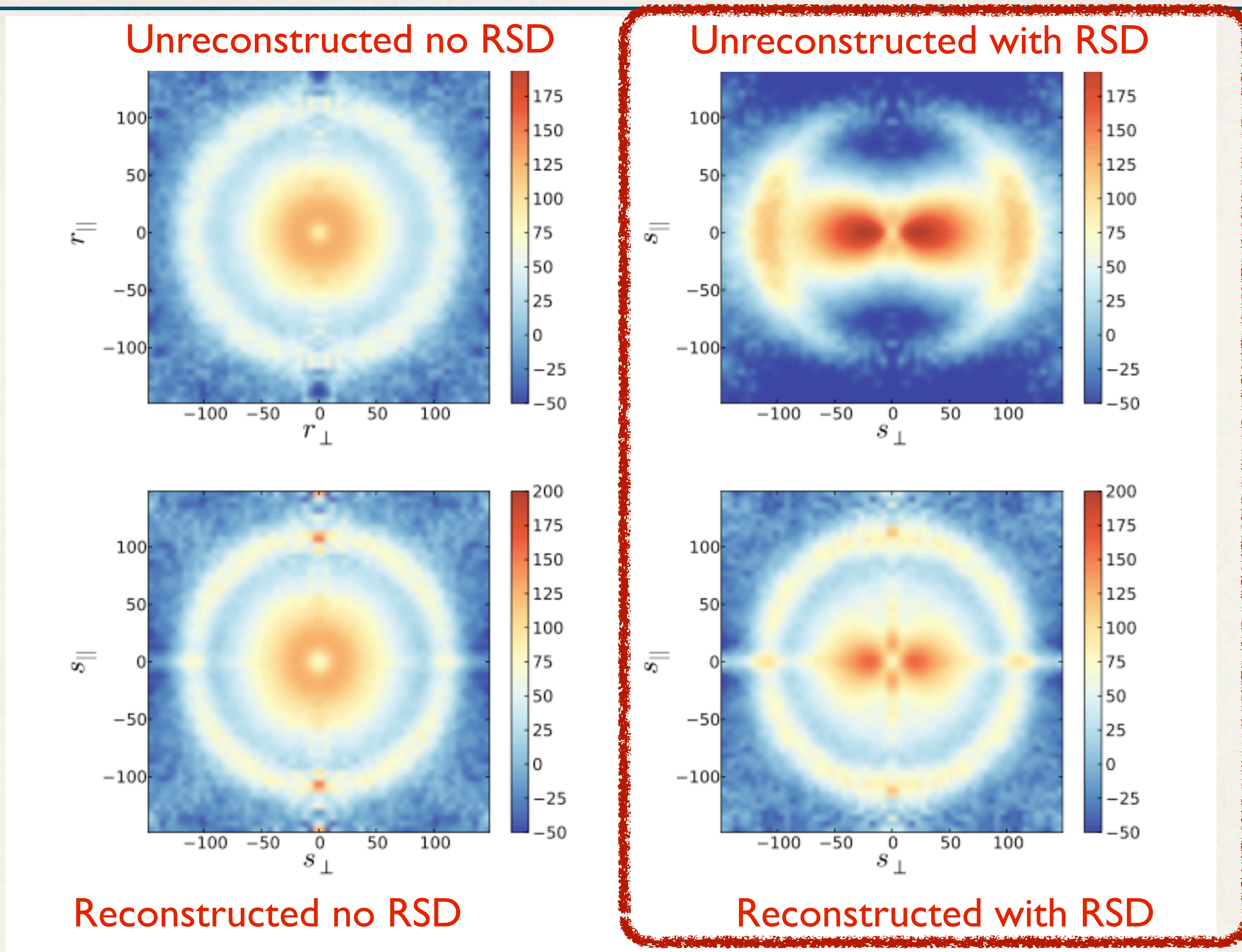
Introduction



Yookyung Noh 2009

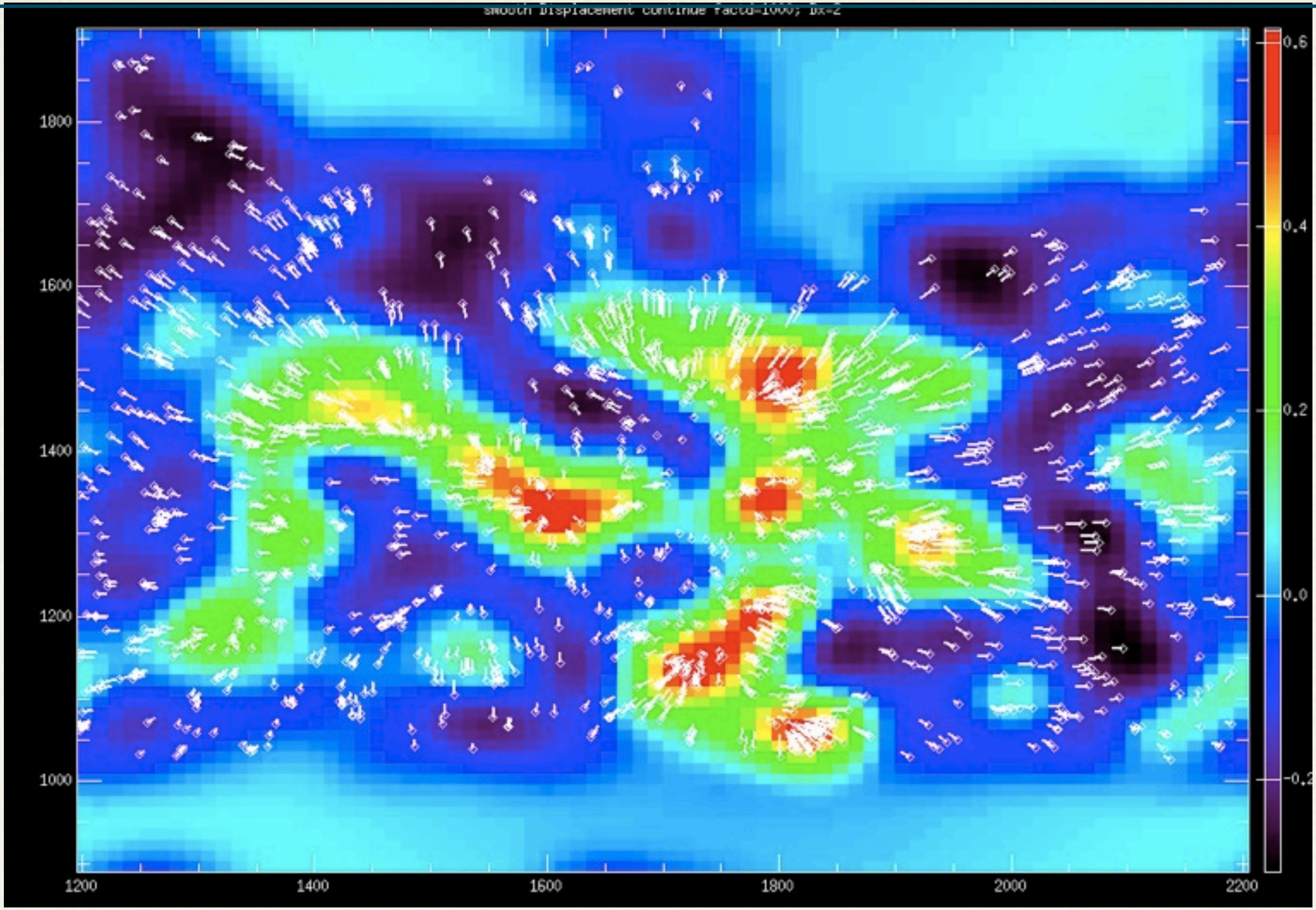
Reconstruction sharpens the BAO feature in the angle averaged galaxy correlation function, this traduces to **better constrains on the distance measurement.**

Introduction



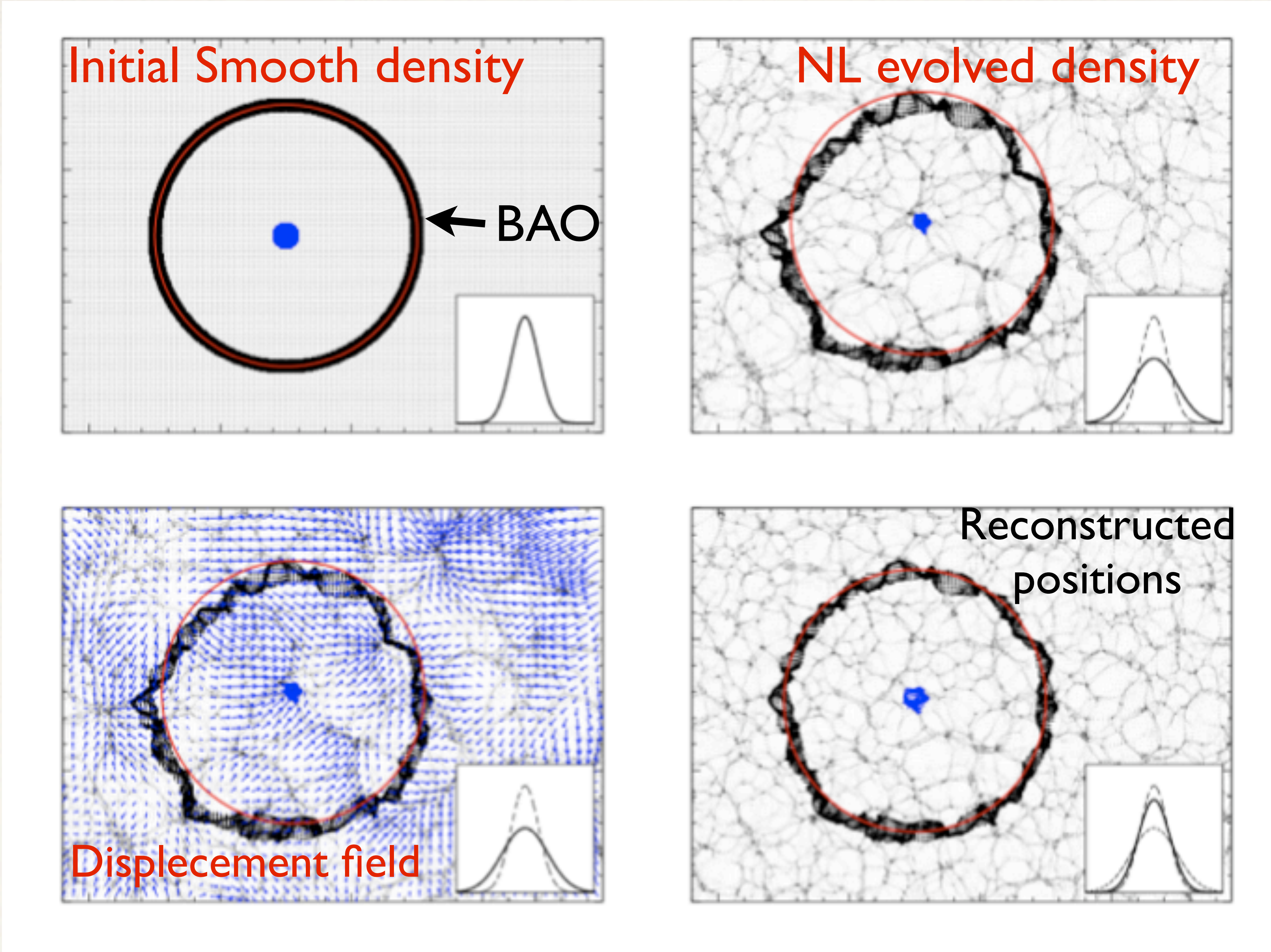
Reduces the effects of redshift-space distortions at the BAO scale, isotropizing the correlation function (if case we are interested in do it).

Introduction



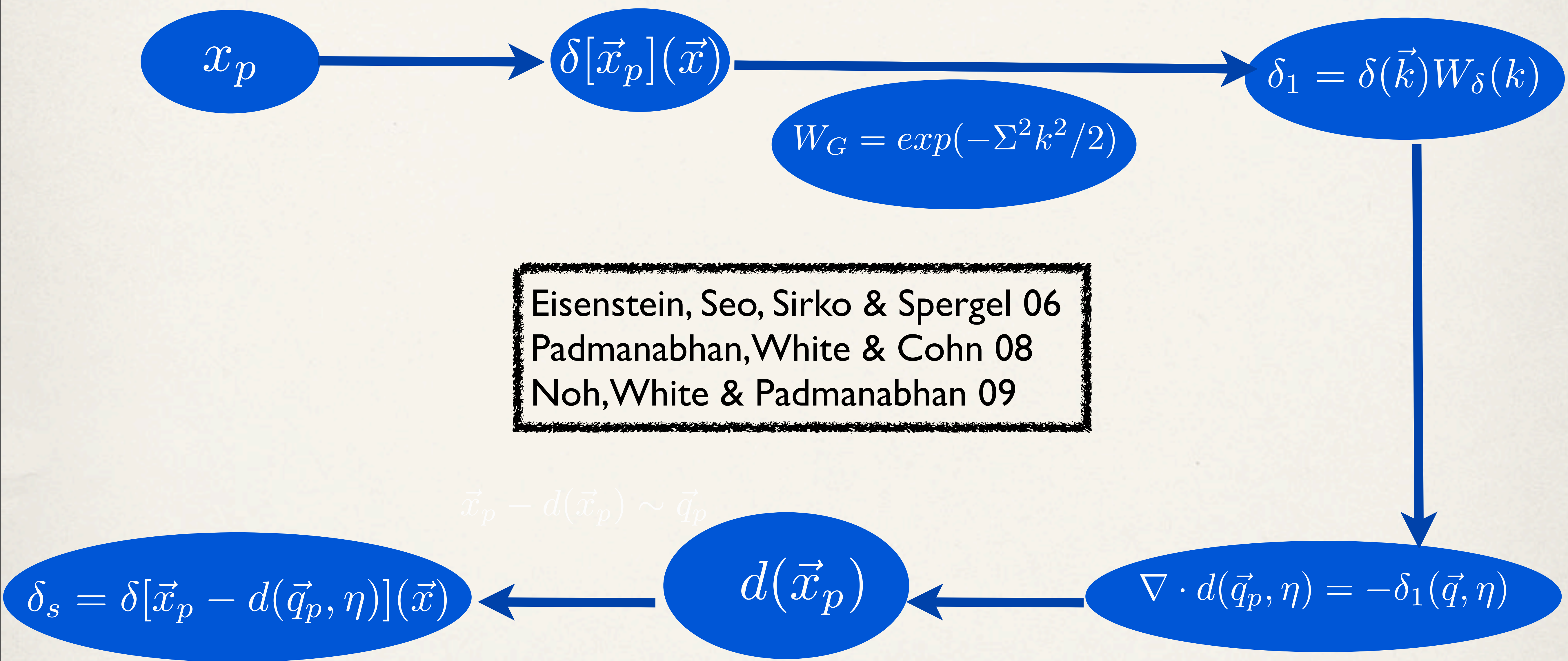
Density field maps the structure that generates these bulk flows, this information is used to reverse smoothing

Introduction



Density field maps the structure that generates these bulk flows, this information is used to reverse smoothing

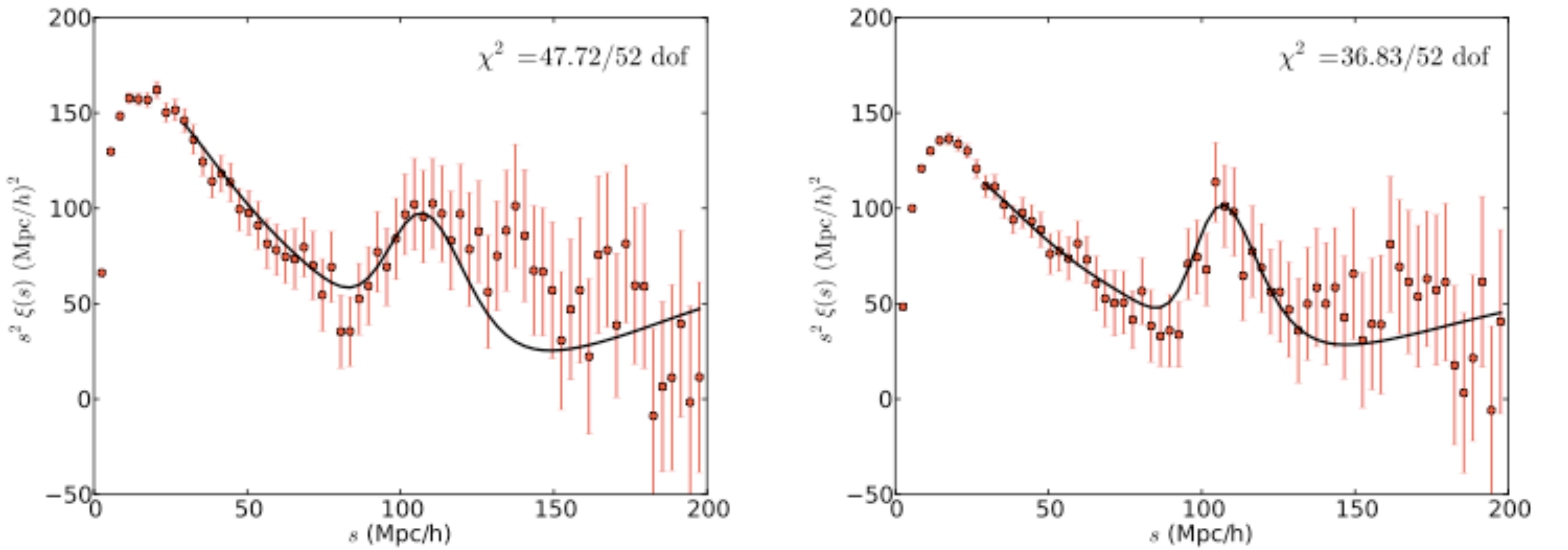
Basic Algorithm



Eisenstein, Seo, Sirko & Spergel 06
Padmanabhan, White & Cohn 08
Noh, White & Padmanabhan 09

First Reconstruction with SDSS I-II Galaxy samples DR7

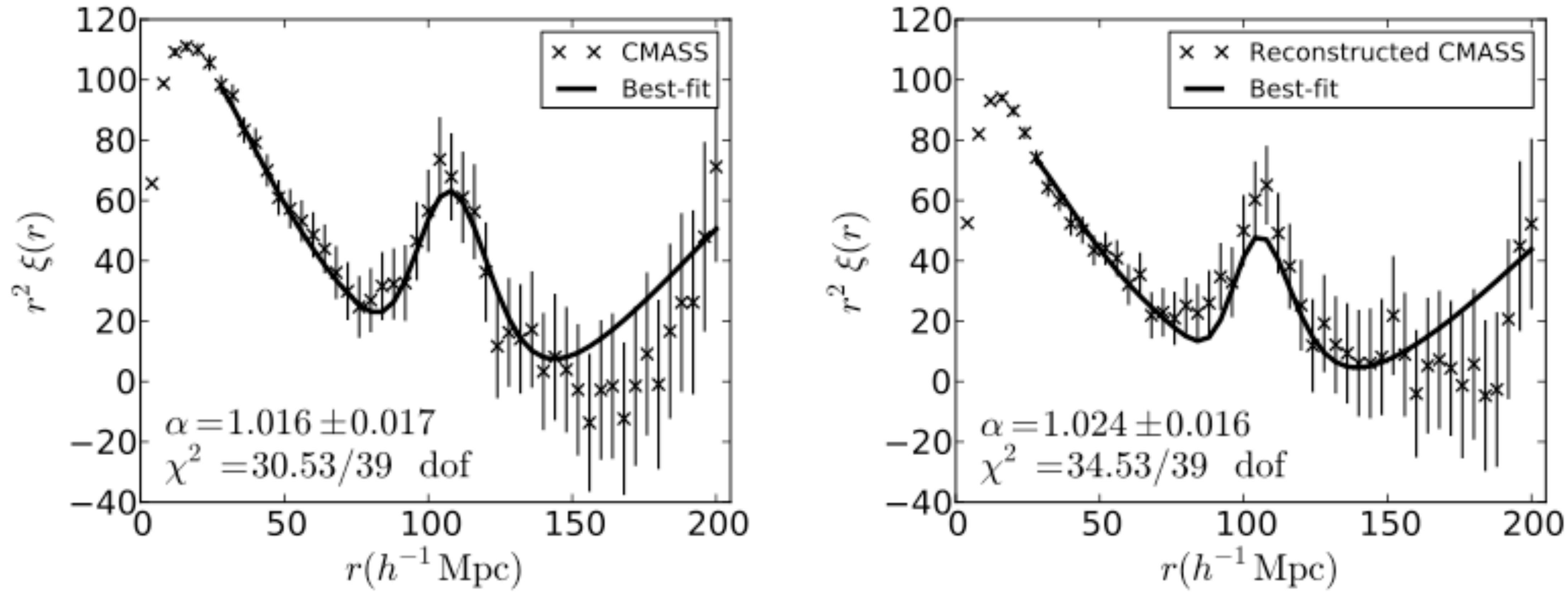
Padmanabham et al 2012



- Reduces error from **3.5% to 1.9%** in the measurement of the distance to z=0.35 **equivalent to a survey with three times the volume of SDSS.**
- **Improves significance** of the BAO feature from 3.3 sigma to 4.2 sigma.

Reconstruction on BOSS DR9

Anderson et al 2012



- CMASS DR9, reconstruction has **not significantly improved our measurement of the acoustic scale.** Shift in the acoustic scale from the CMASS DR9 data α = 1.016±0.017 before reconstruction and α = 1.024 ± 0.016 after reconstruction.

Reconstruction on BOSS DR10/ DR11 CMASS Galaxies

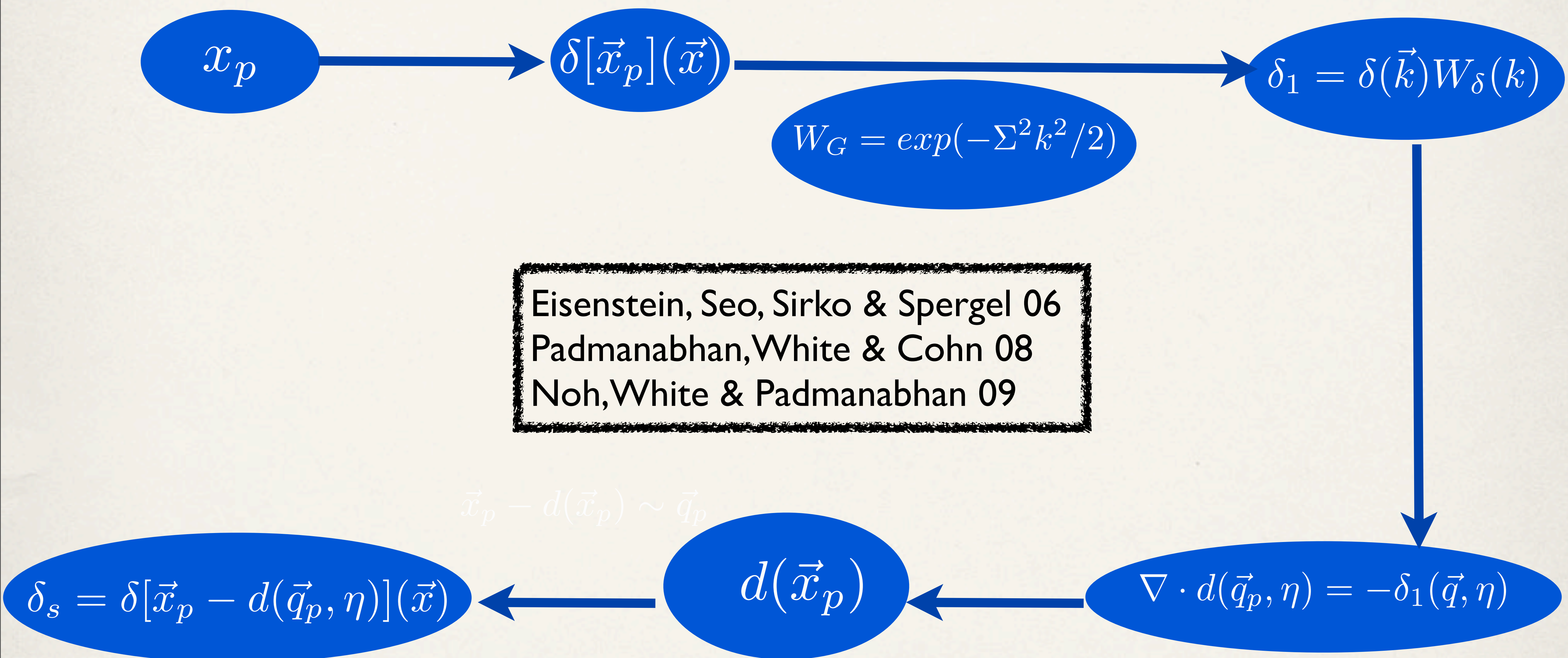
coming soon !!

- Reconstruction have proven to be successful in decreasing the error in distance measurement!!
- Still a technique that needs to be explored, specially the analysis need to be extended to the anisotropic clustering as currently these studies are focus on isotropic clustering.
- Exploring reconstruction have important implications for current and future surveys as all of these surveys have assumed some level of reconstruction for their projected constraints.

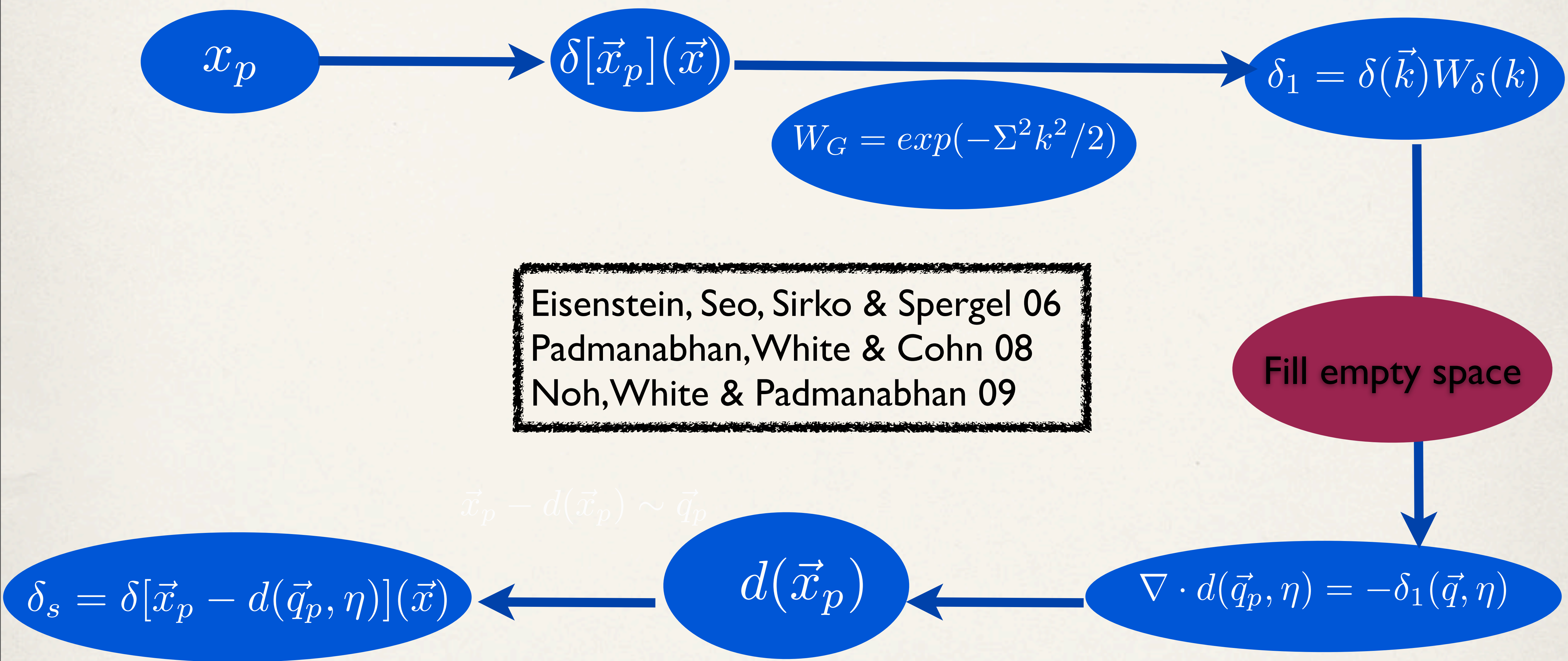
Outline

- Introduction
- **Results with simulations.**
- Towards improvement.

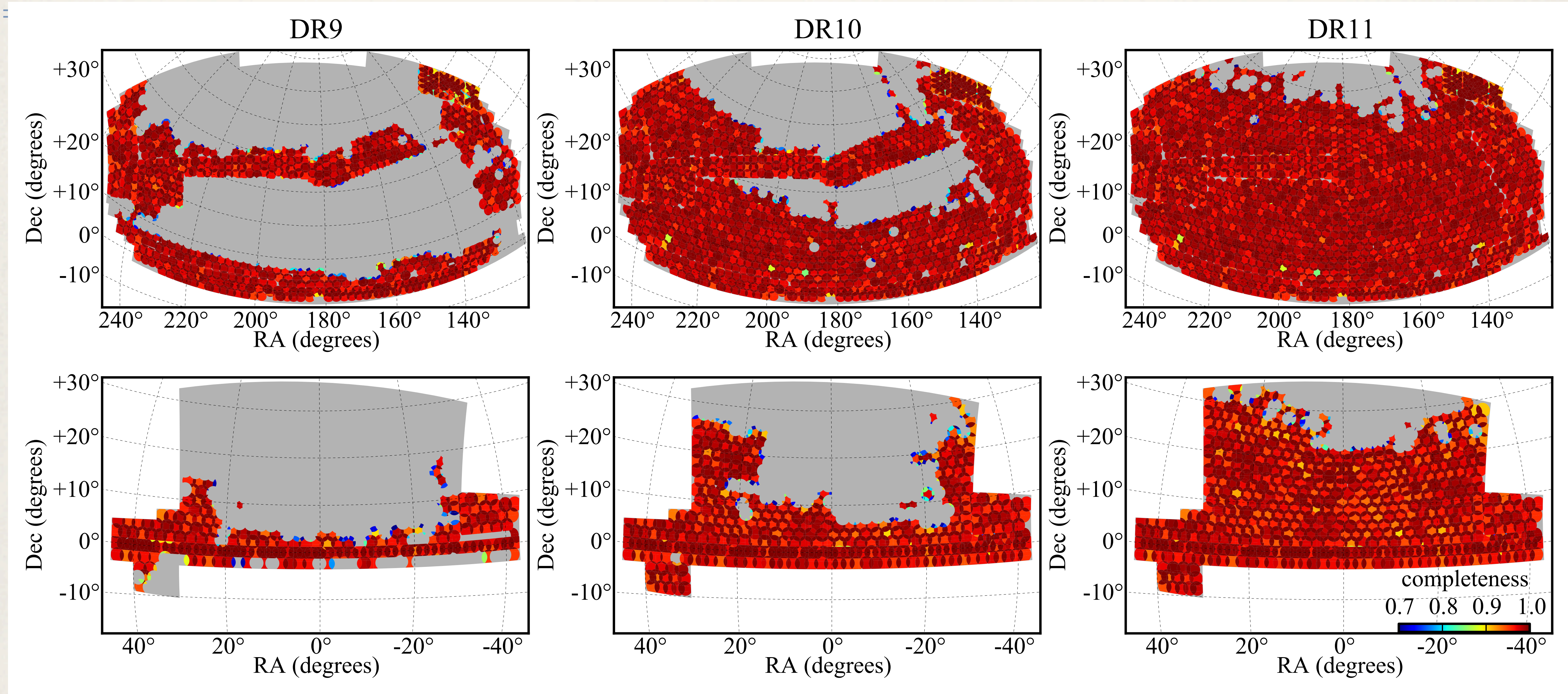
Basic Algorithm

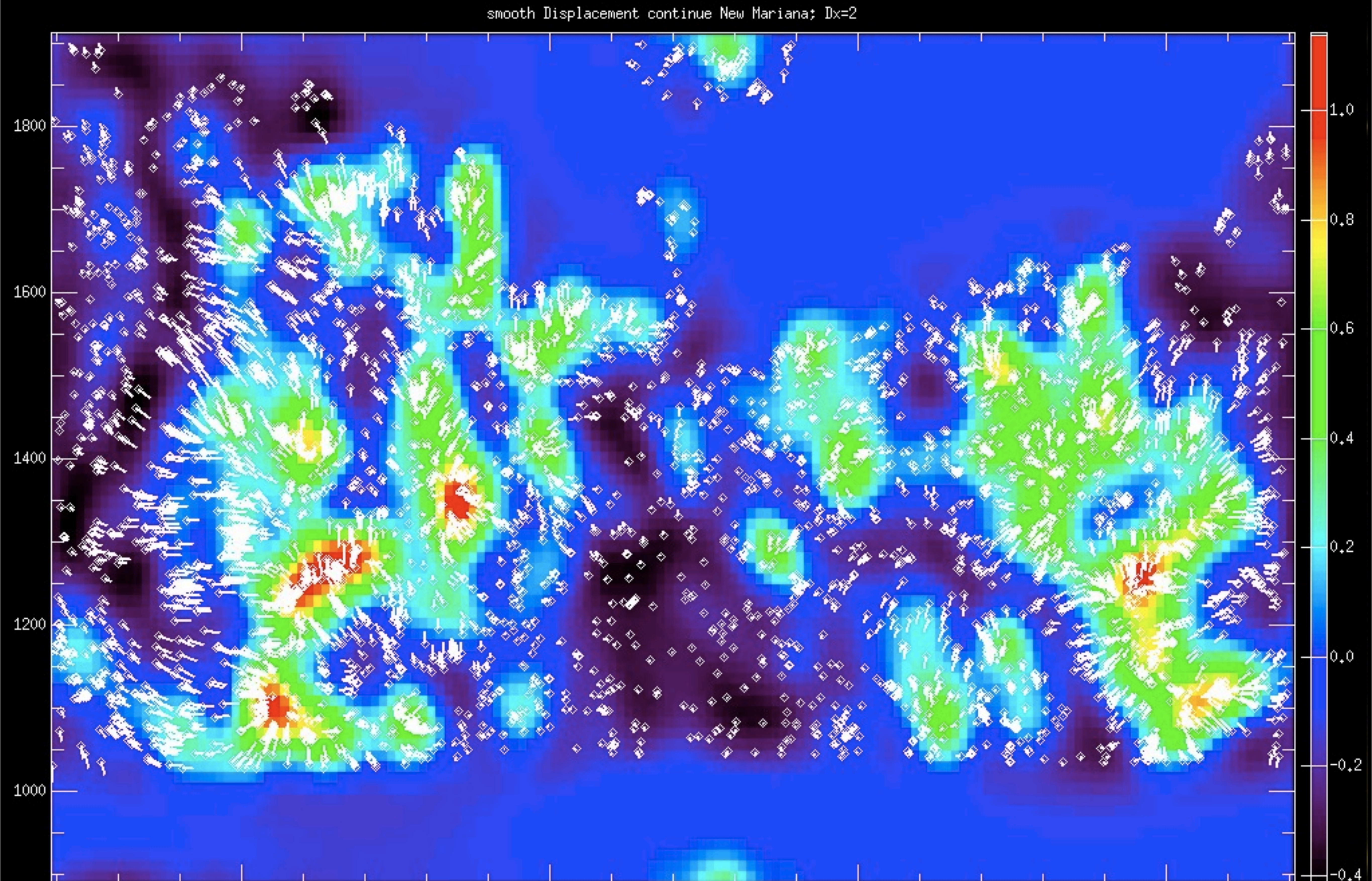


Basic Algorithm



Edges and masks(radial and angular)





smooth Displacement continue New Mariana; Dx=2
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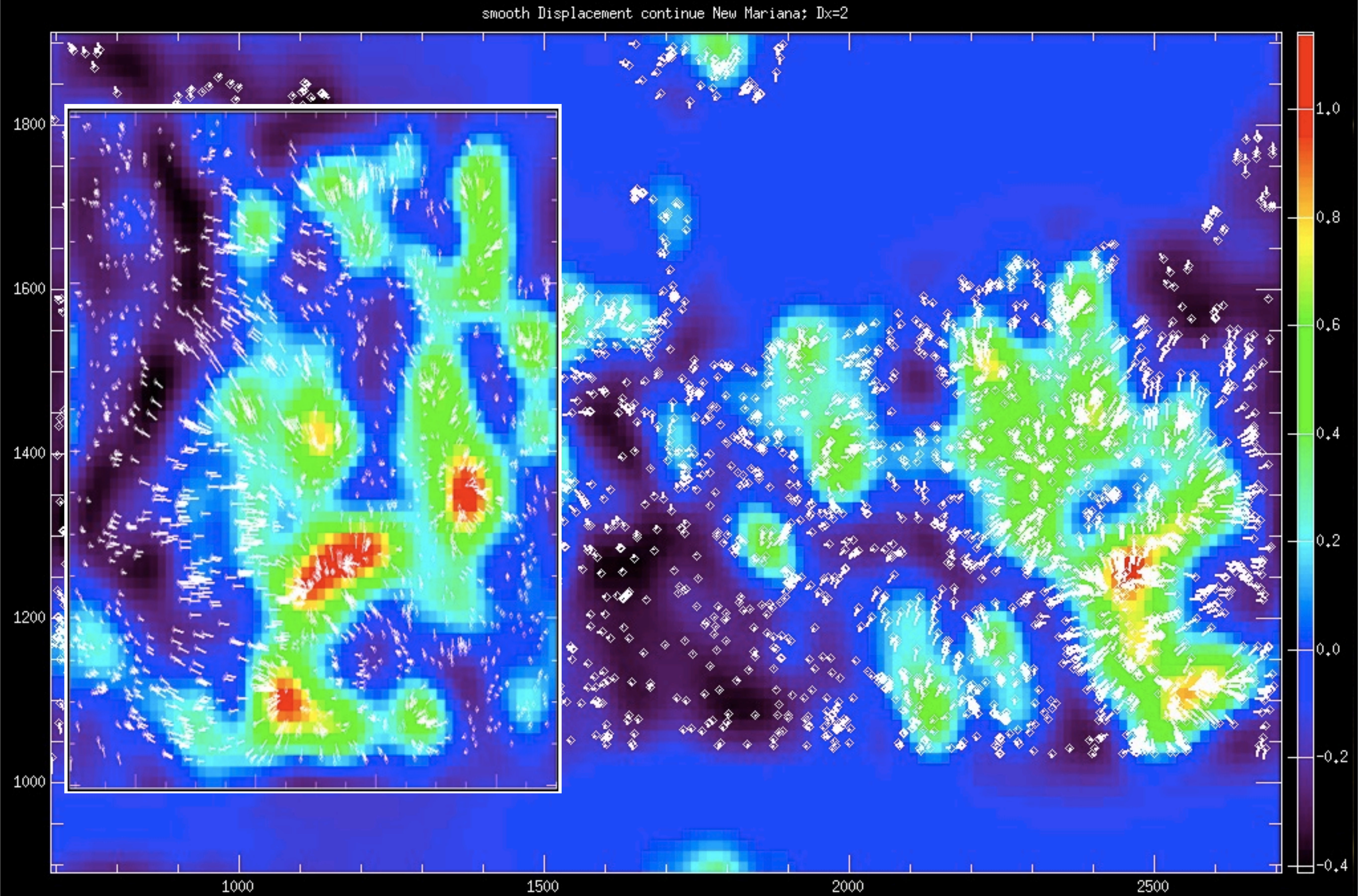
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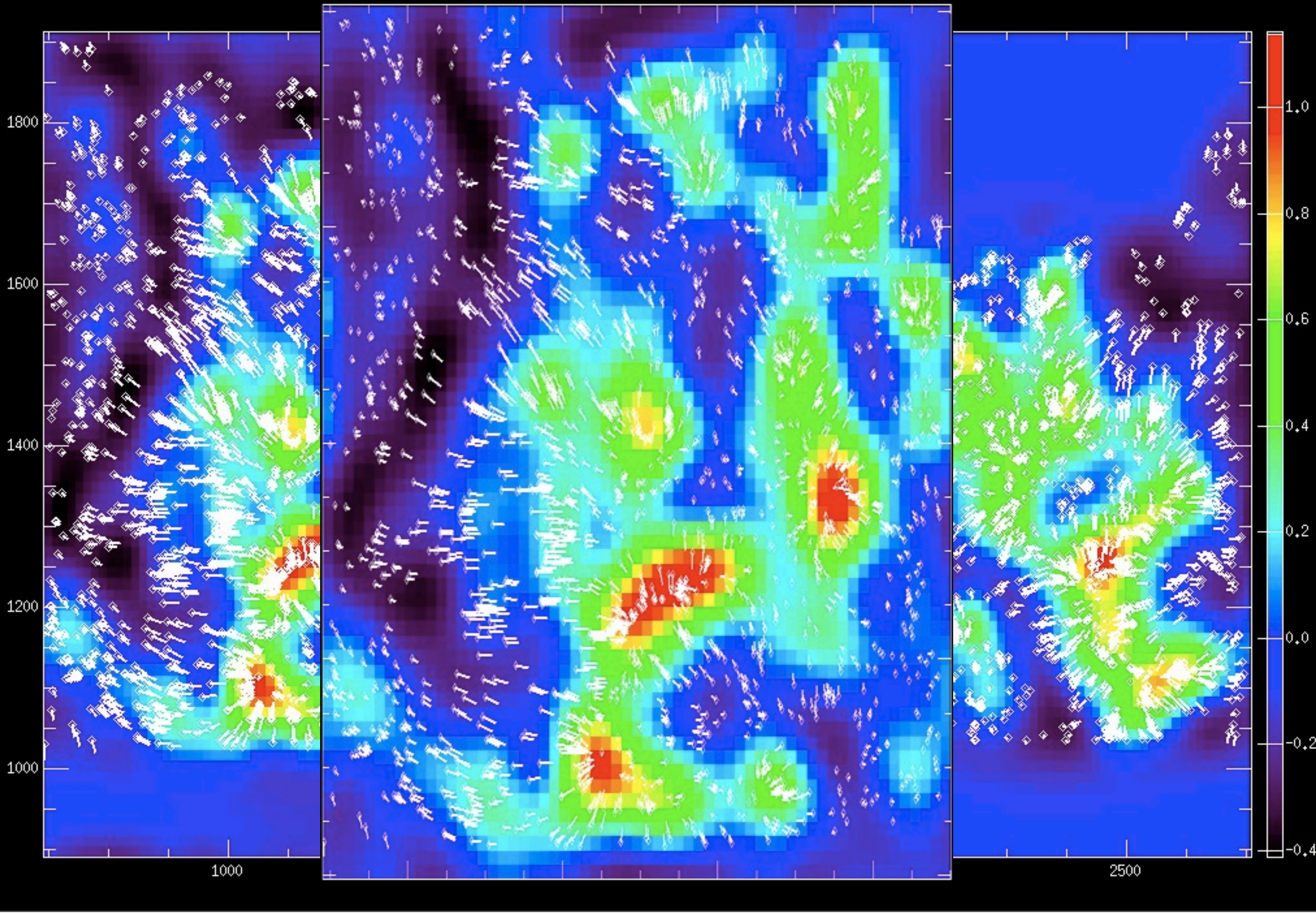
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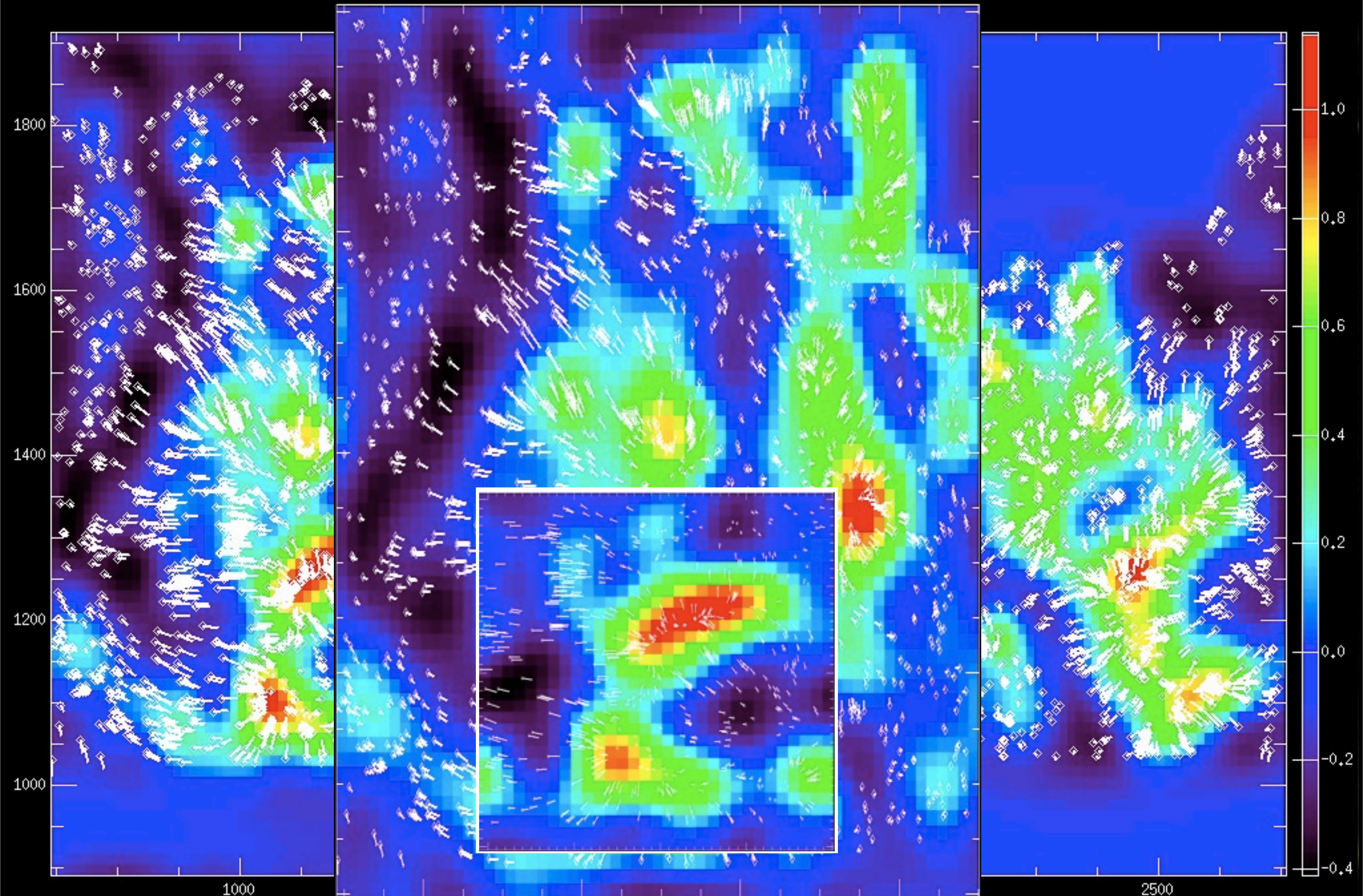

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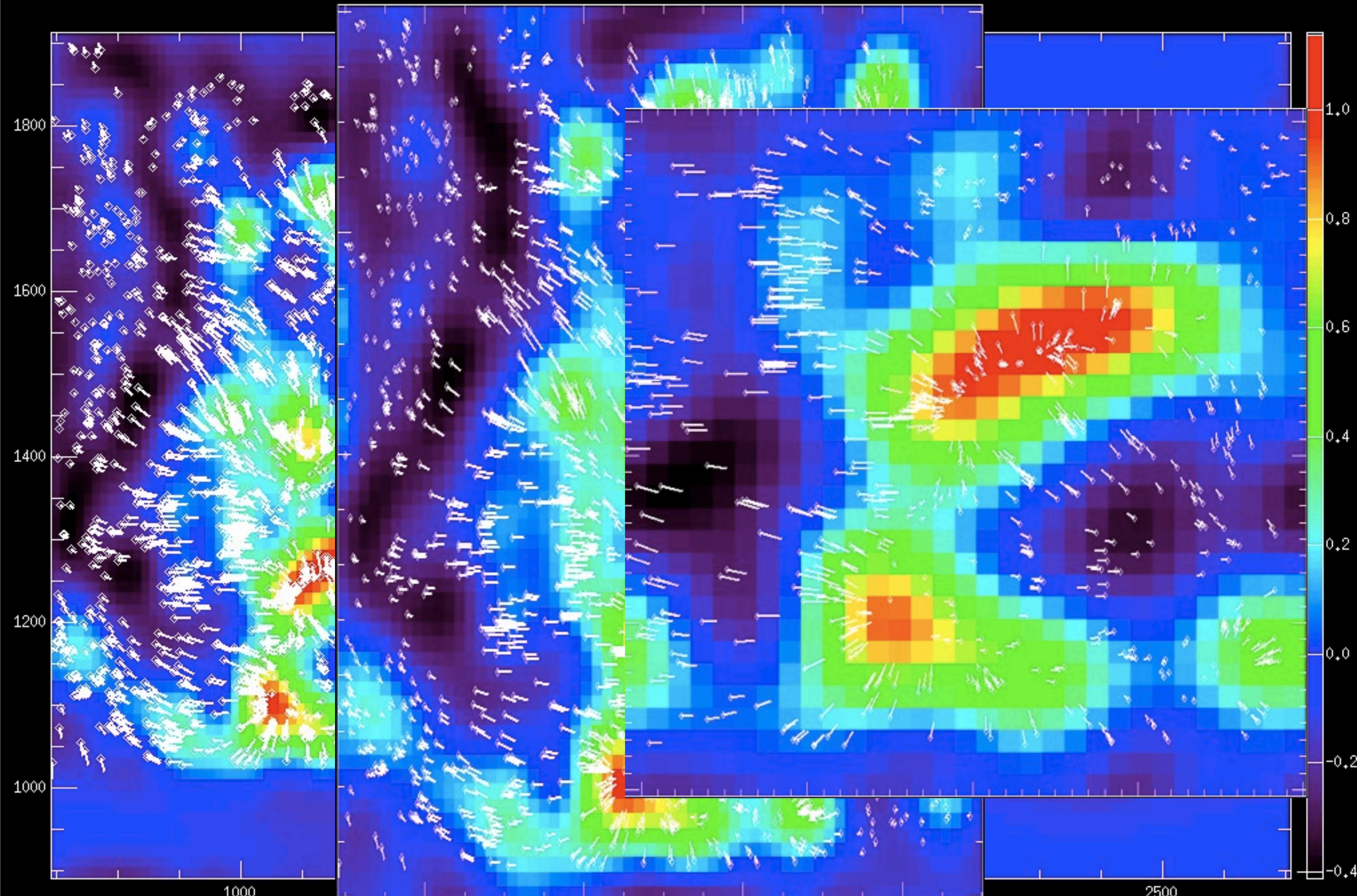

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PTHALOS Simulations

- Based on the 2LPT theory matter field and halo occupation function.
- 610 realizations .
- Cosmology: h=0.7, Ωm=0.274, Ω_Λ=0.726, $\Omega bh2$=0.0224, $\sigma 8$=0.8, and ns=0.97.

Tests

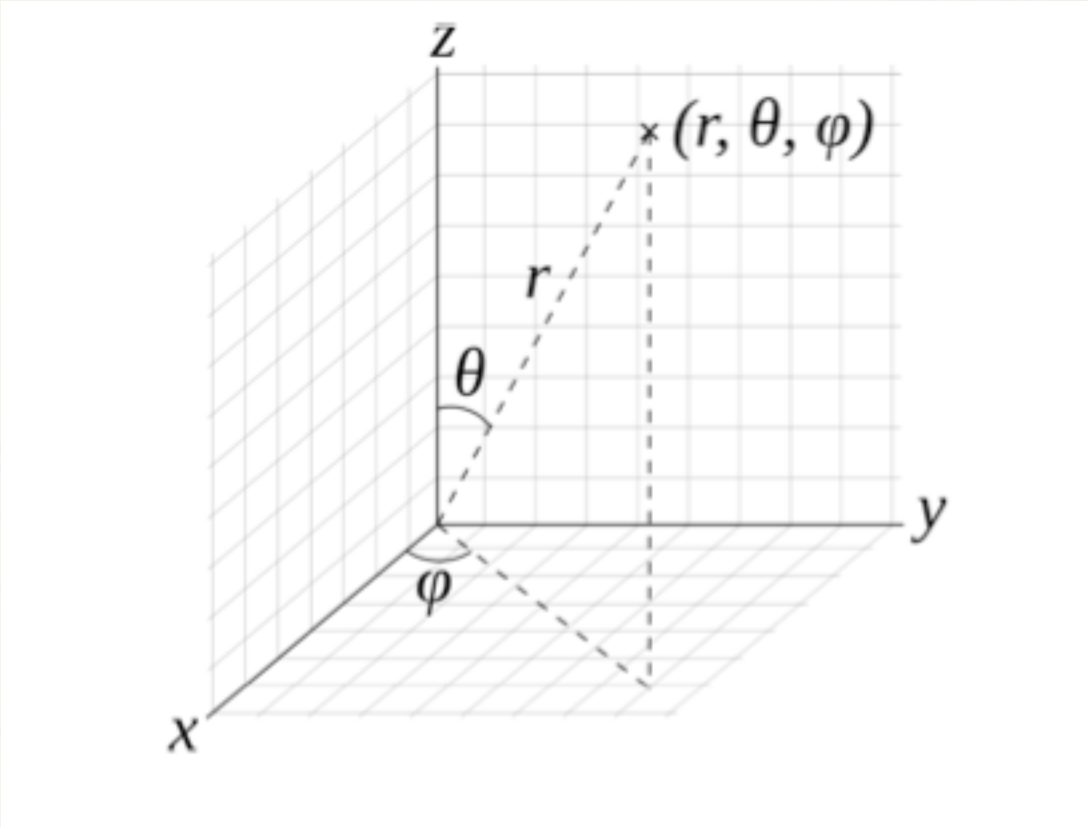
I. **Displacement Field.**
II. Multipoles.
III. Anisotropic Clustering.

I. Displacements Maps & distributions

$$\hat{r} = sin\theta cos\phi\hat{x} + sin\theta sin\phi\hat{y} + cos\theta\hat{z}$$

$$\hat{\theta} = cos\theta cos\phi\hat{x} + cos\theta sin\phi\hat{y} - sin\theta\hat{z}$$

$$\hat{\phi} = -sin\phi\hat{x} + cos\phi\hat{y}$$



Results with simulations

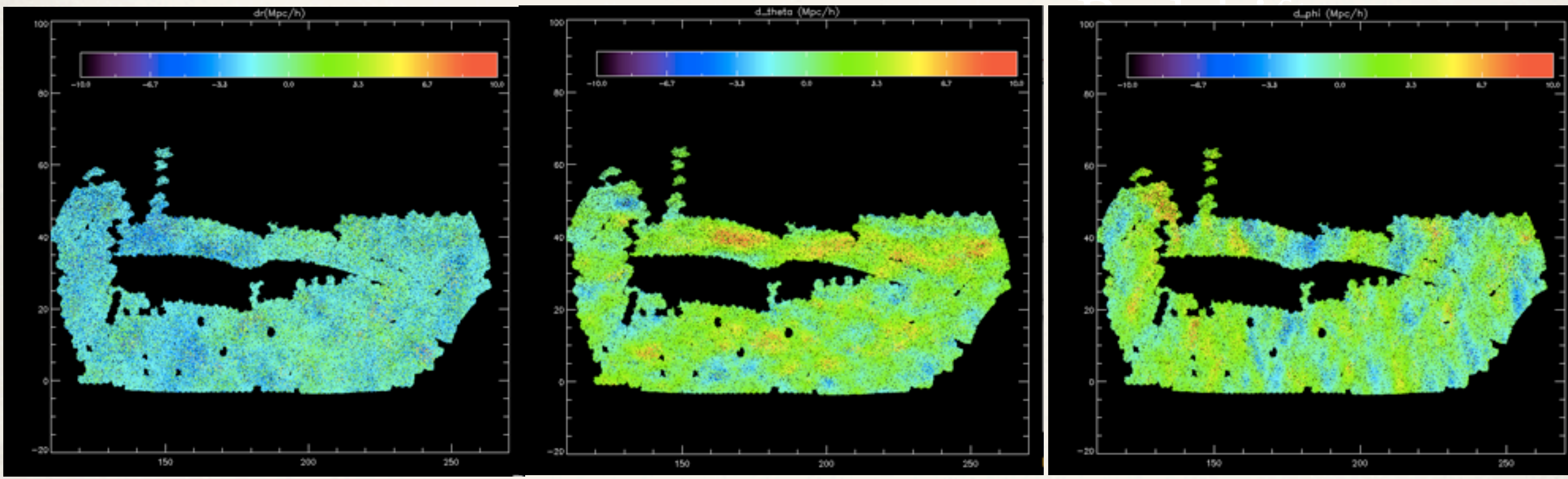
Real space

We expect gaussian distributions centered in zero (not preferred direction)

Redshift space

When correcting for redshift distortions, there is a larger displacement correction along one of the axes, making the overall distribution wider.

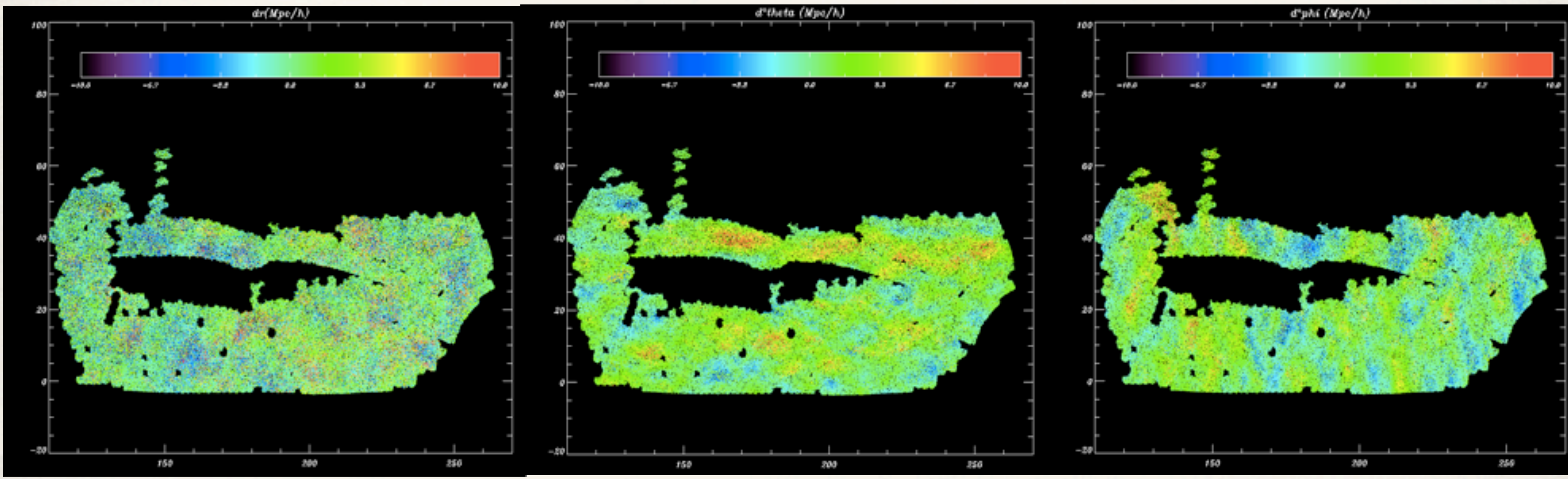
Real space



dr $\quad d\theta \quad d\phi$

We expect gaussian distributions centered in zero (not preferred direction)

Redshift space

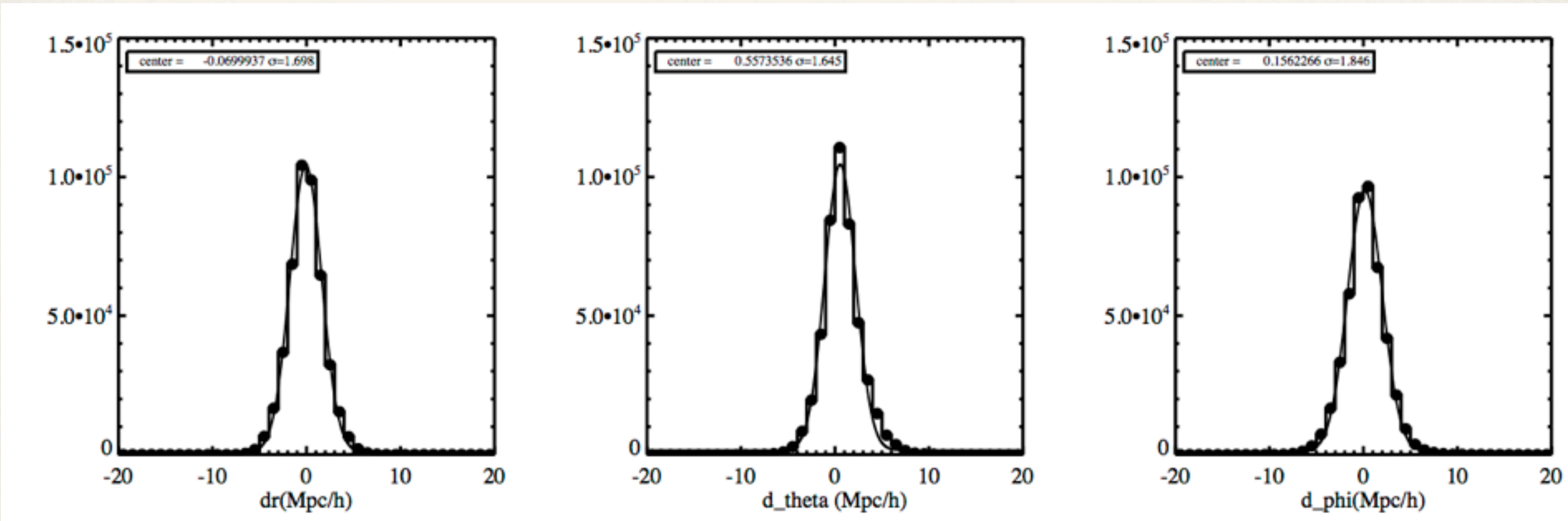


dr $\quad d\theta \quad d\phi$

When correcting for redshift distortions there is a preferred direction.

Mock 0 (real space)

dr $d\theta$ $d\phi$

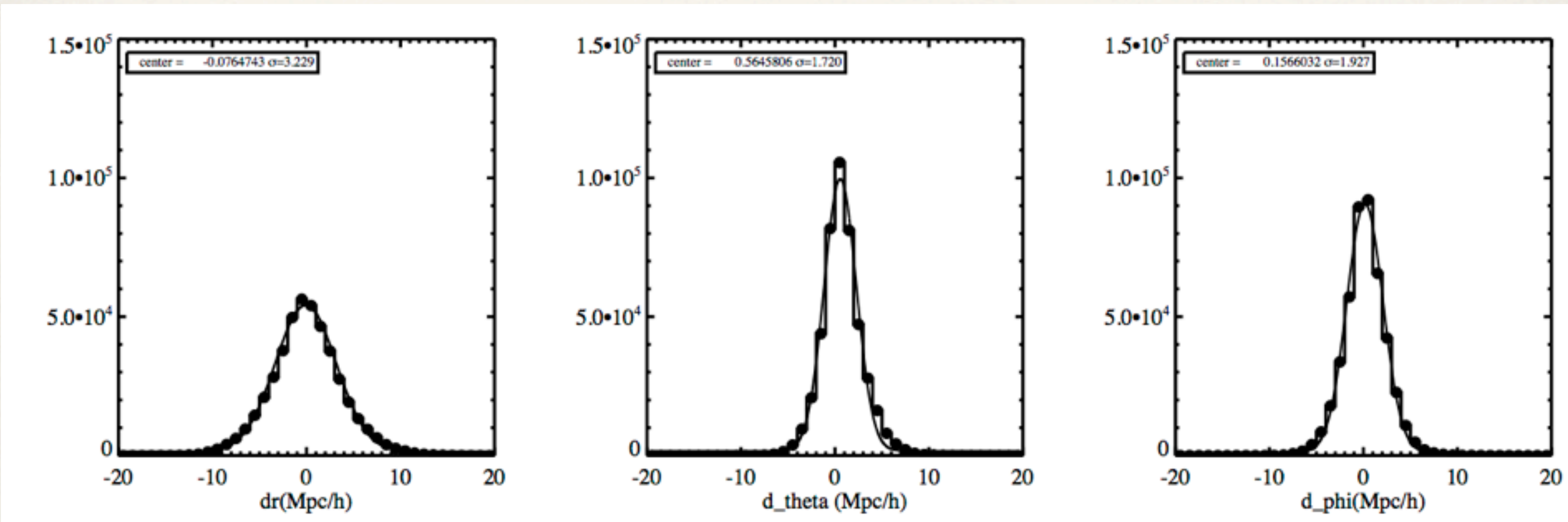


~2.0

They should all center at 0, with similar width in all directions (no preferred directions).

Mock 0 (redshift space)

dr $d\theta$ $d\phi$



~4.1 ~2.4 ~2.2

For redshift space distortion, we correct for it also, so there is a larger displacement correction along one of the axes, making the overall distribution wider.

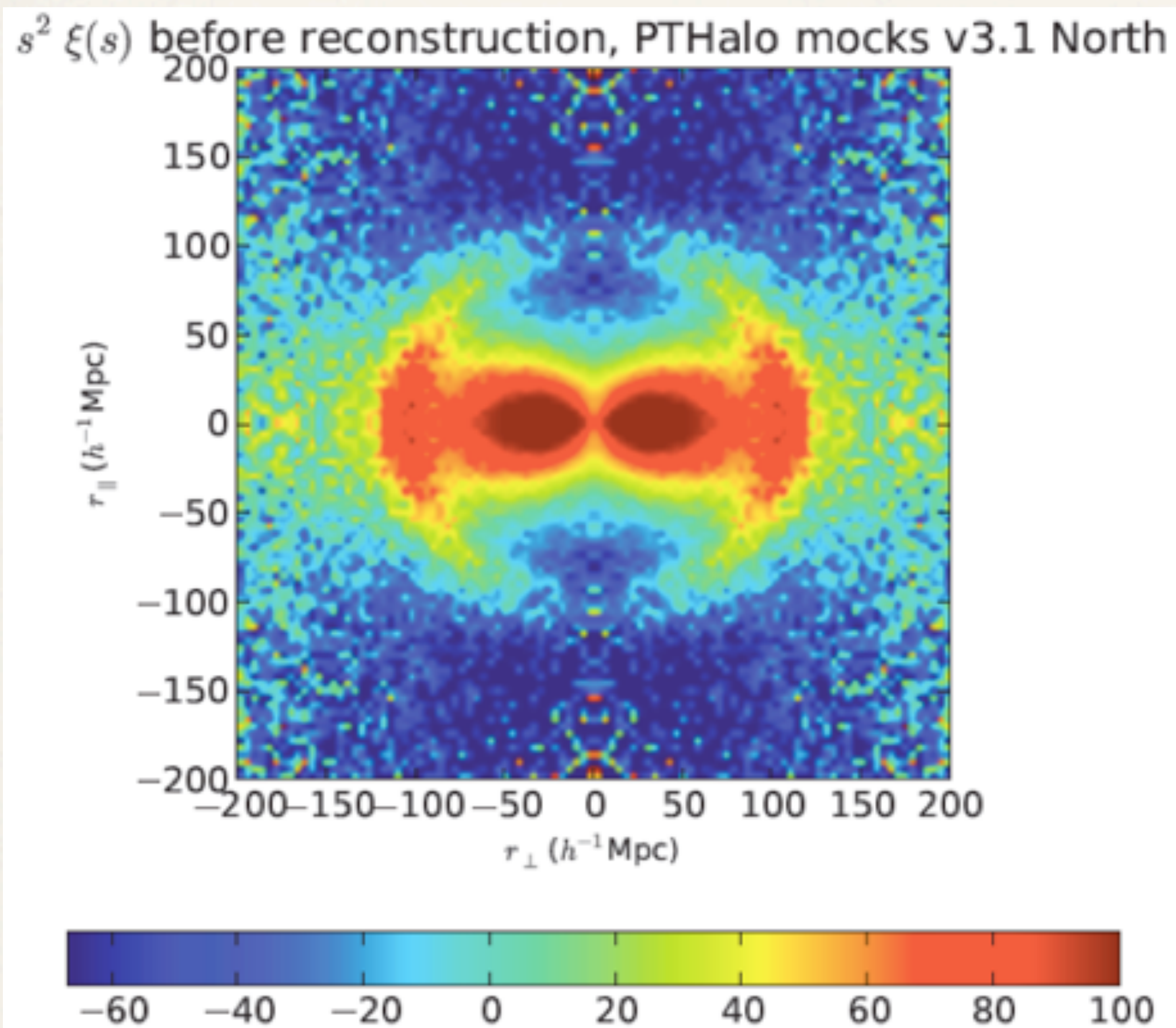
Tests

I. Displacement Field.

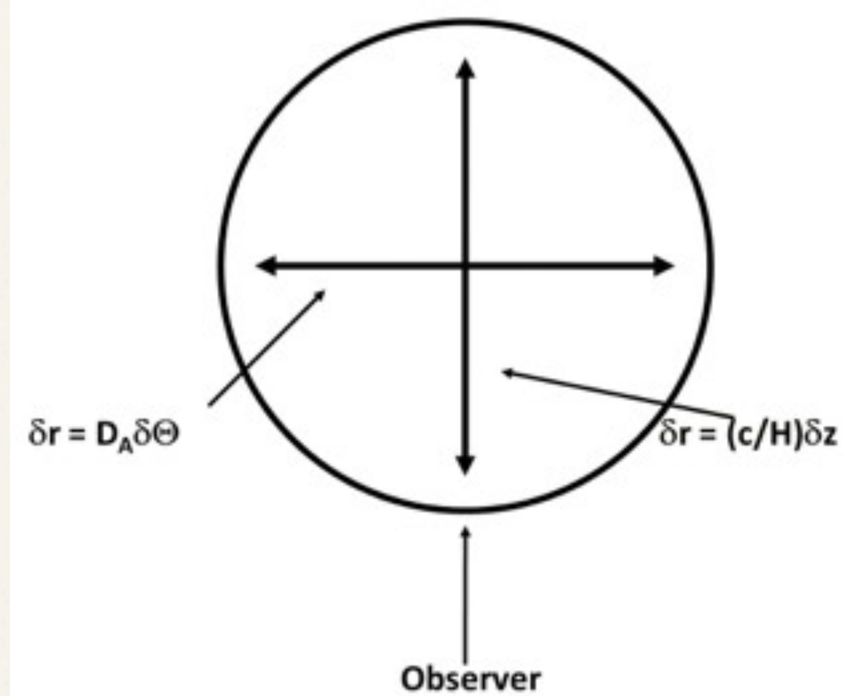
II. Multipoles.

III. Anisotropic Clustering.

- Correlation Function definitions



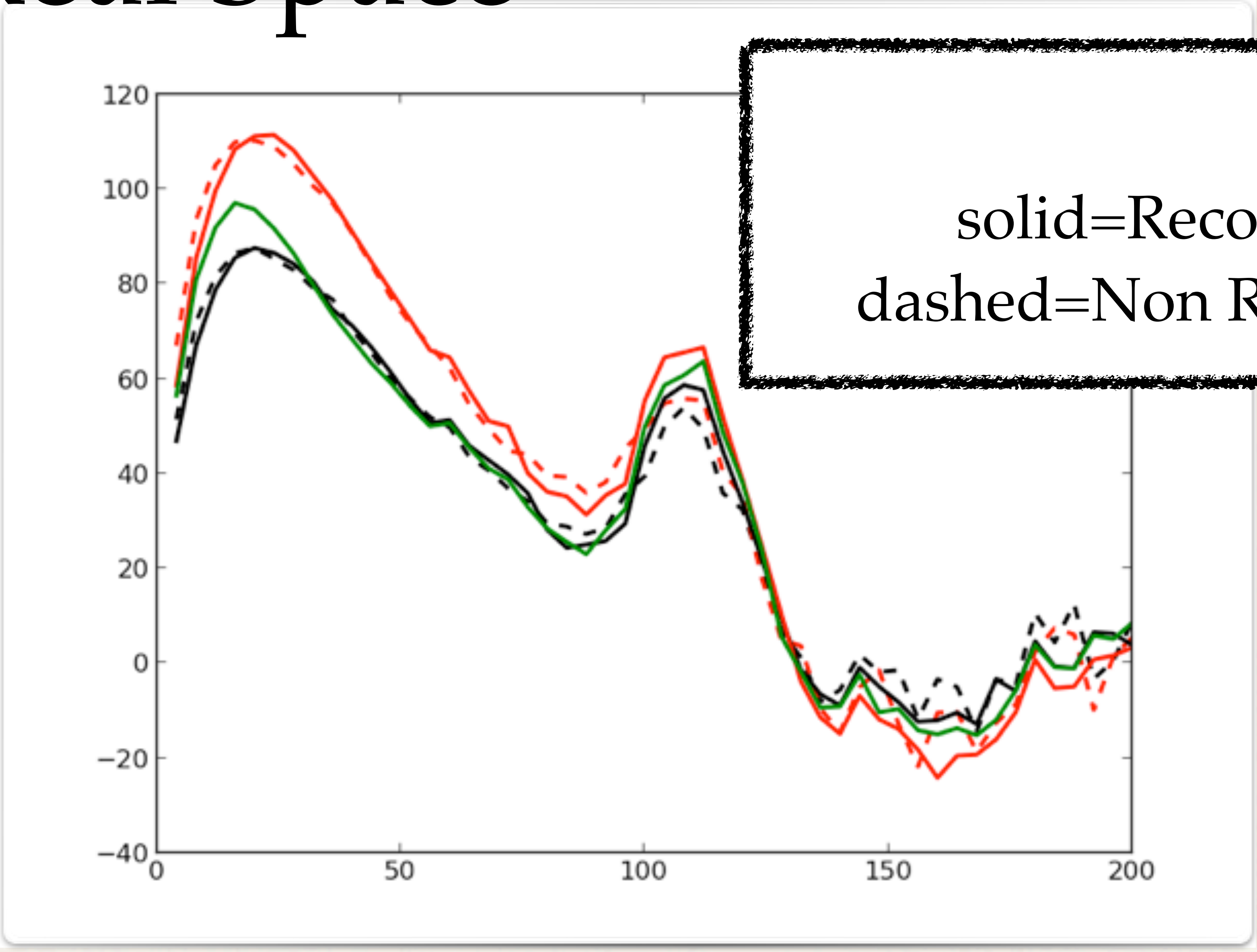
$$\xi(\boldsymbol{r}') = \sum_{\ell'=0}^{\infty} \xi_{\ell'}(r')L_{\ell'}(\mu'),$$



Monopole

Cubic Mocks

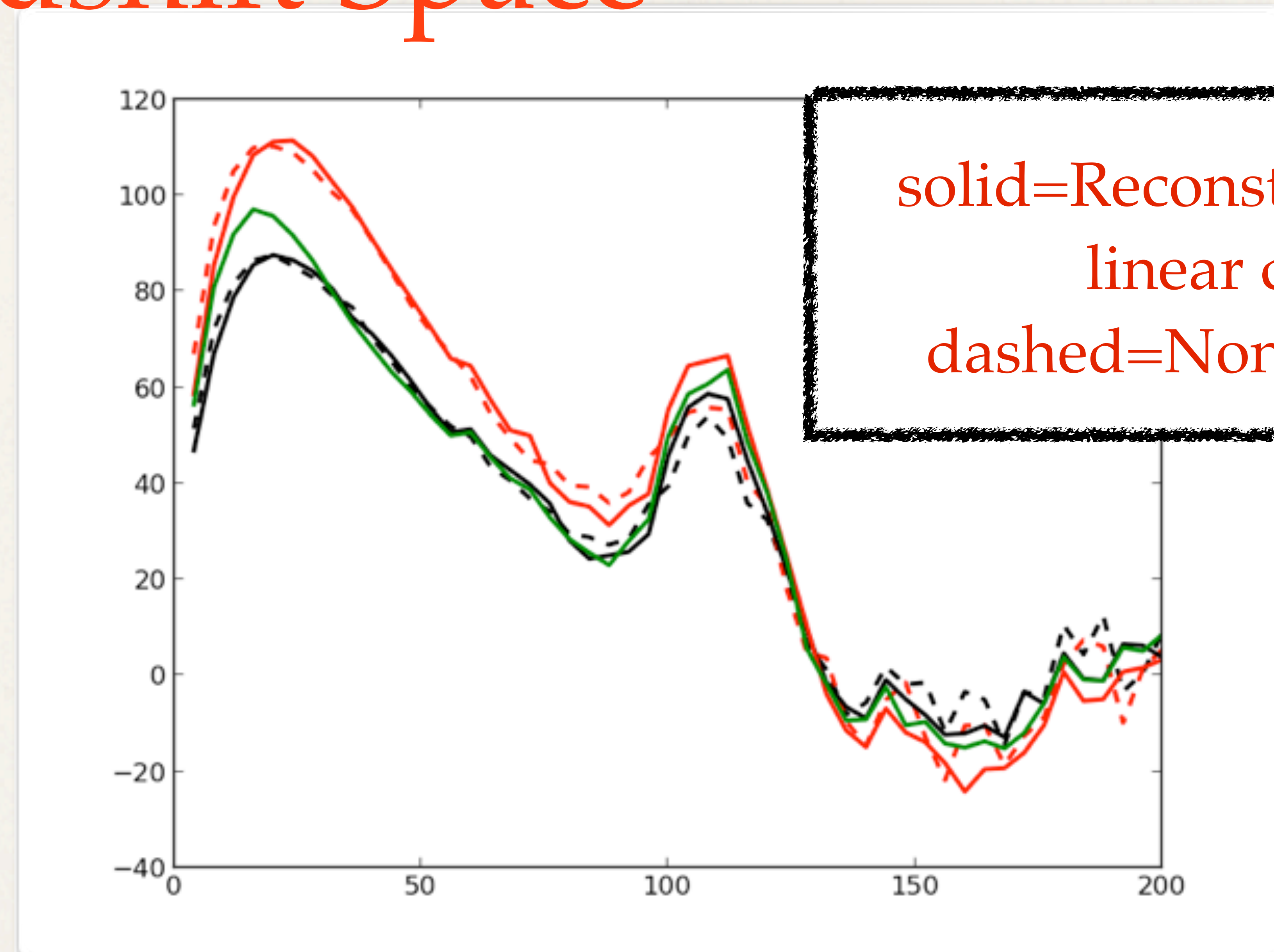
Real Space



solid=Reconstructed
dashed=Non Reconstructed

with reconstruction, the solid black line gives a sharper peak than the (no recon) dashed black line.This however only corrects for non-linearities.

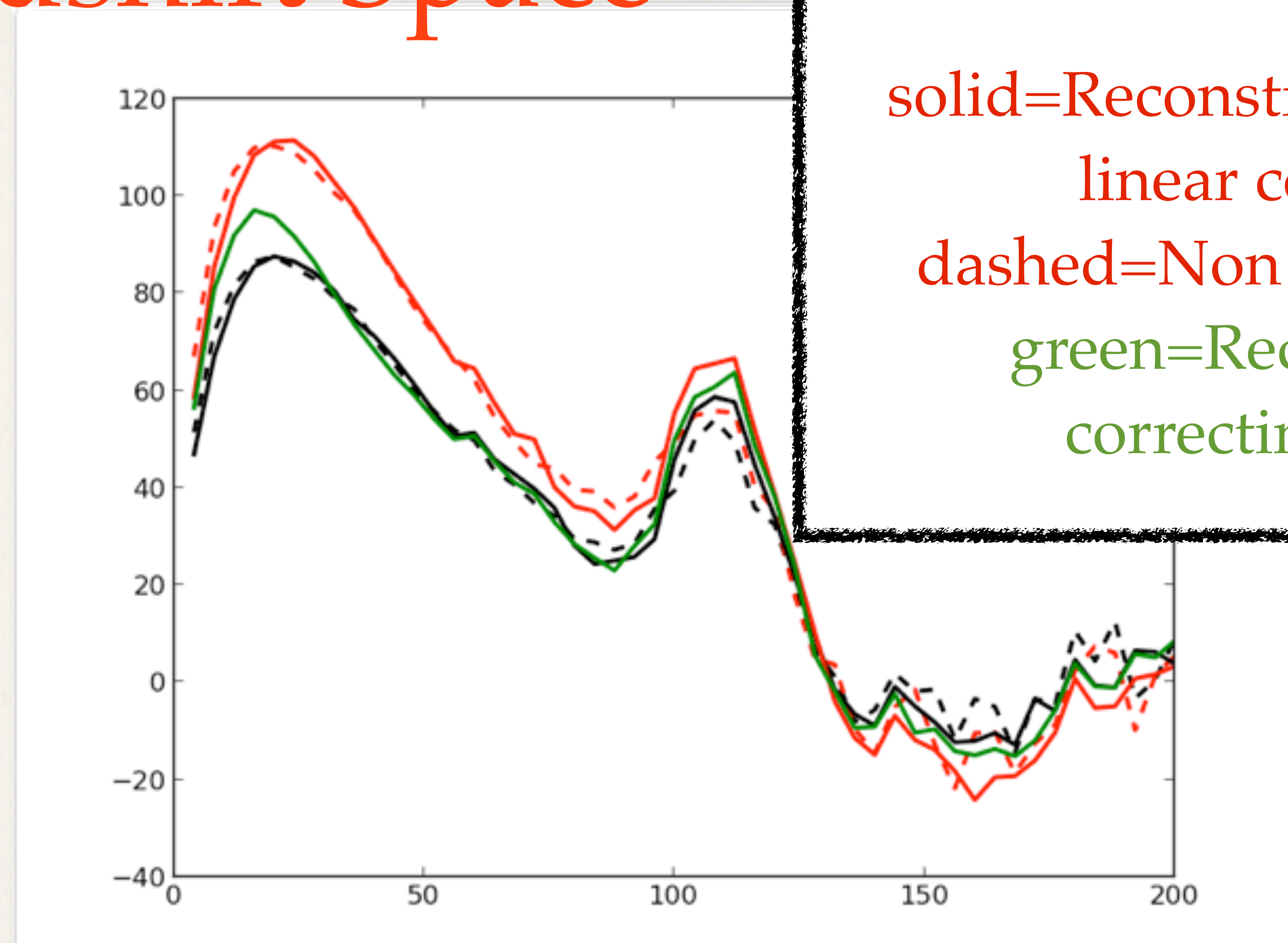
Redshift Space



solid=Reconstructed only non linear correction
dashed=Non Reconstructed

with reconstruction, the solid **red** line gives a sharper peak than the (no recon) **dashed red line**.This however only corrects for non-linearities.

Redshift Space

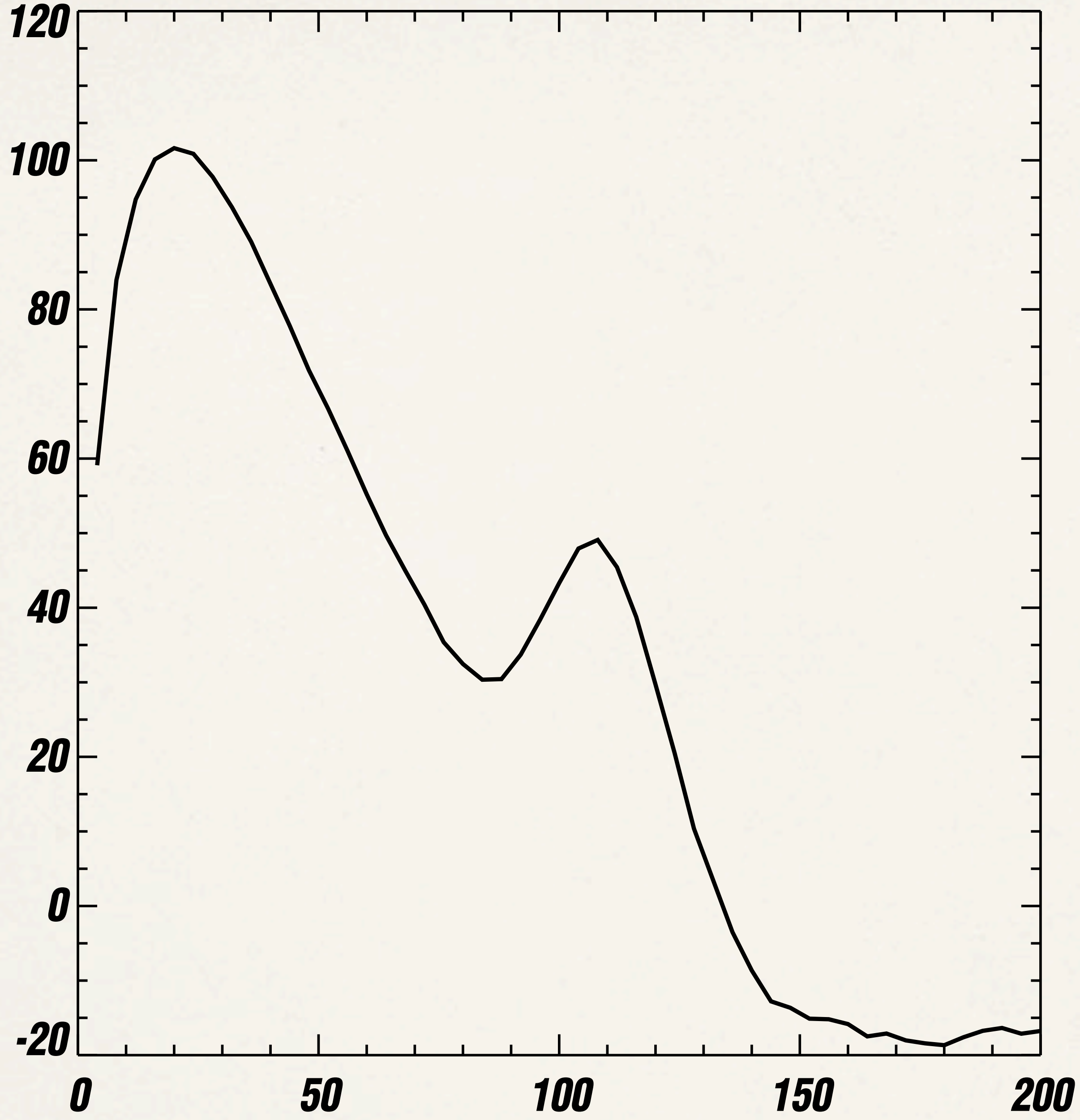


solid=Reconstructed only non linear correction
dashed=Non Reconstructed
green=Reconstructed correcting for RD

If we included correction for redshift space distortions: with reconstruction, the solid green line gives a sharper peak than the (no recon) **red line** approaching to the reconstructed real space correlation function **black solid line.**

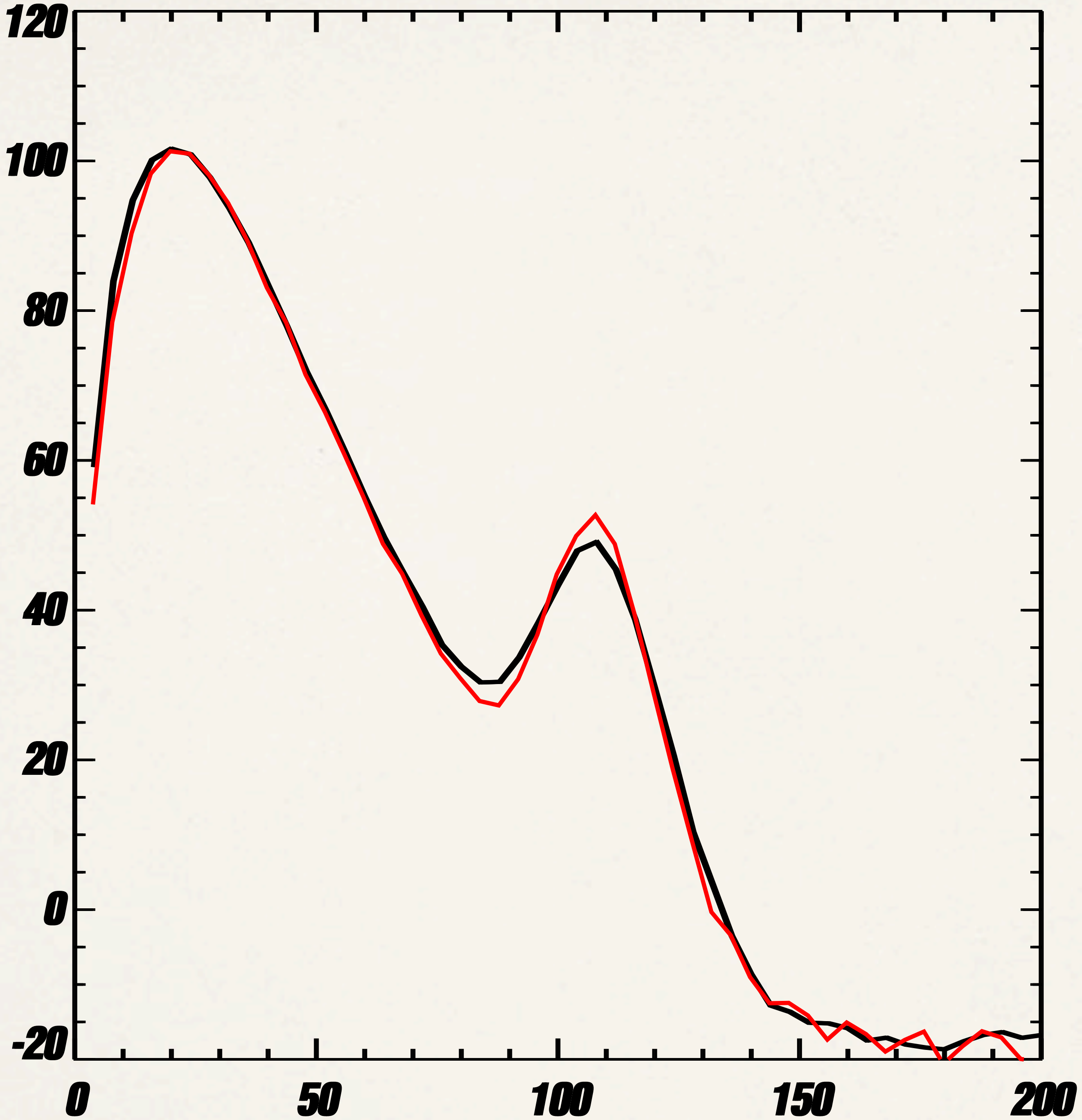
Realistic Mocks

Results with simulations



Black: No reconstruction

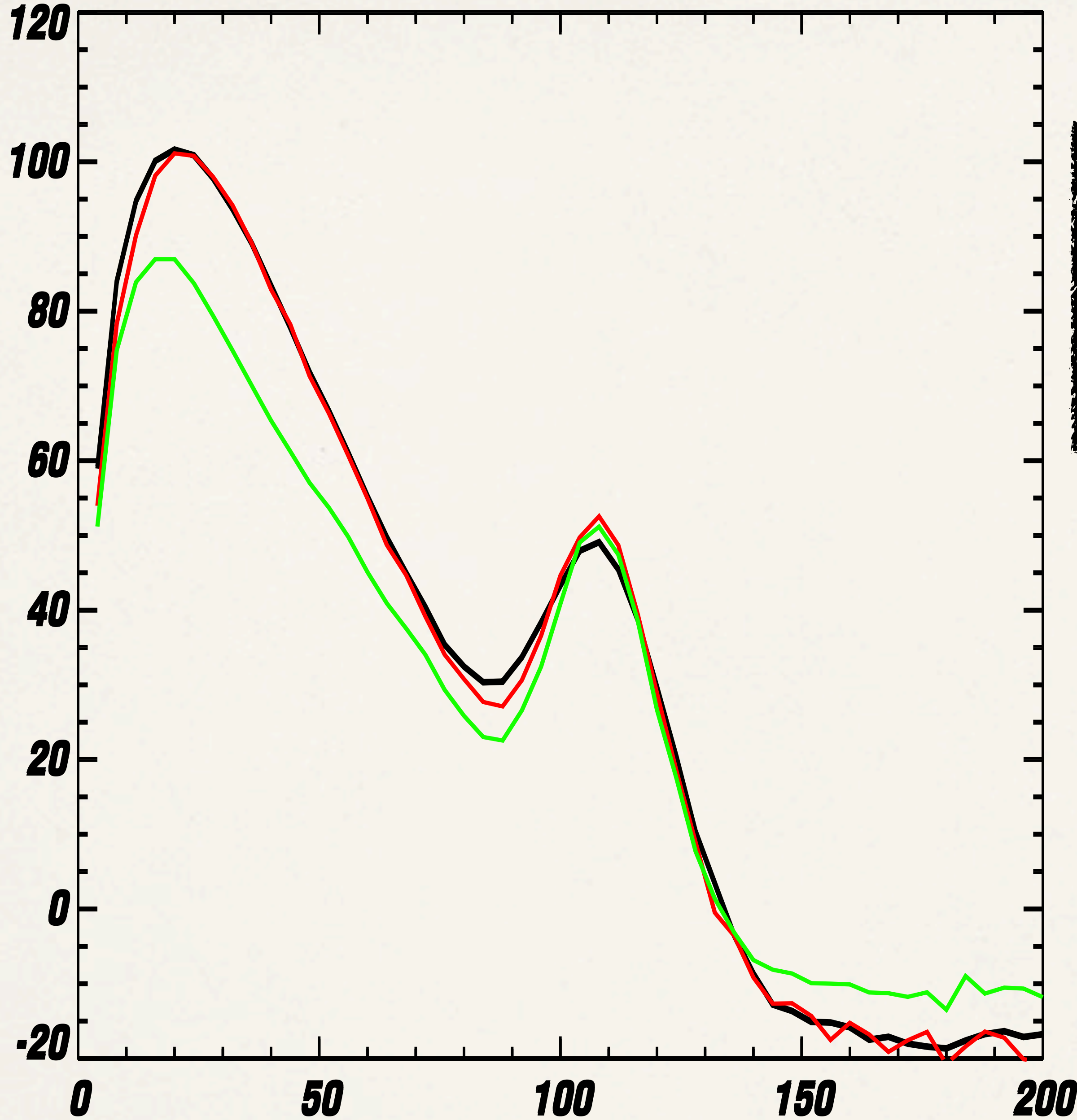
Results with simulations



Red: Reconstruction
(non linear only)

with reconstruction, the **solid red line** gives a sharper peak than the (no recon) black line.This however only corrects for non-linearities, not redshift space distortions itself.

Results with simulations



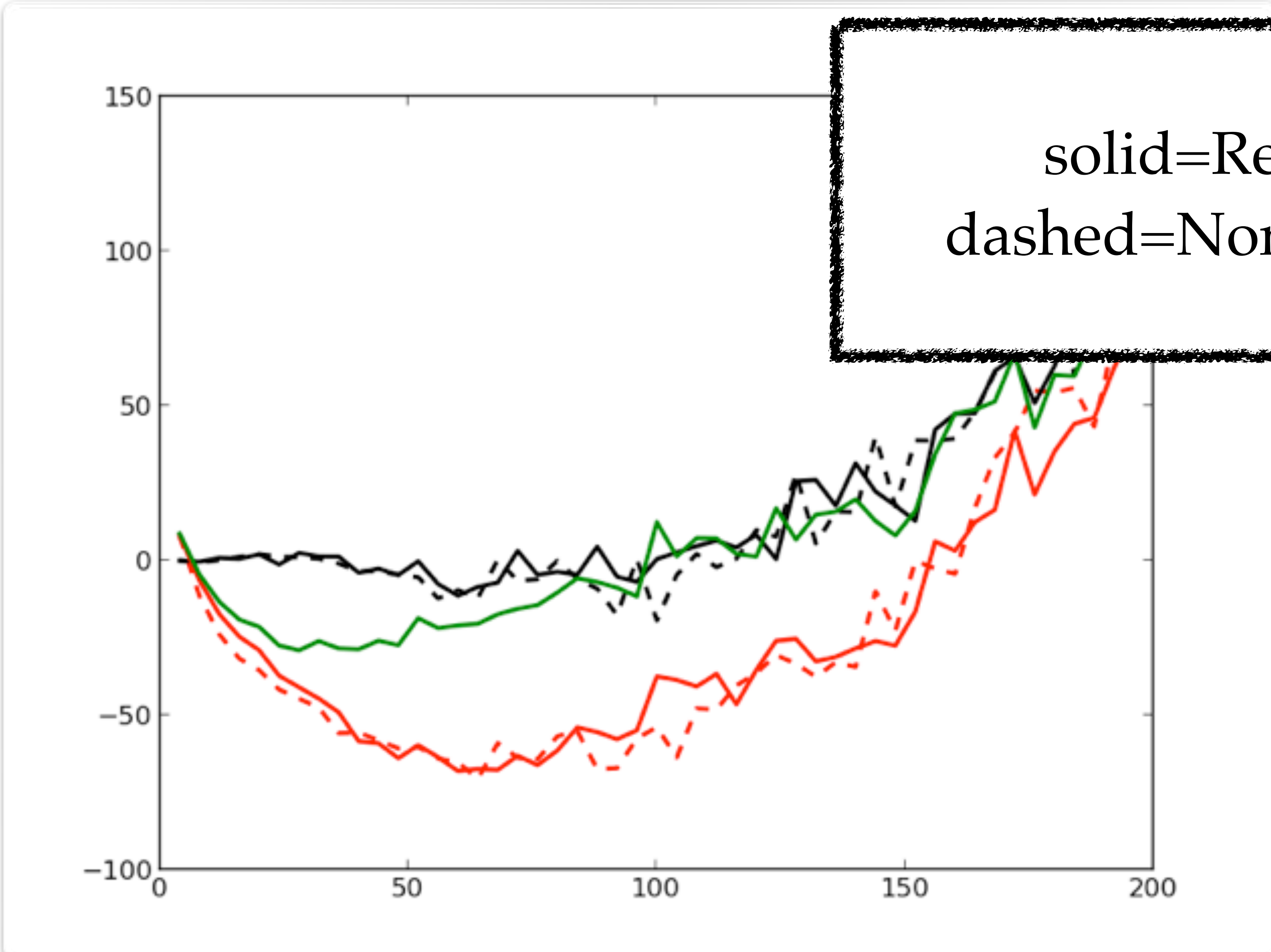
Black: No recon
Red: Recon(non linear only)
Green : Recon correcting RD

If we included correction for redshift space distortions: with reconstruction, the solid **green line** gives a sharper peak than the (no recon) black line approaching to the real space correlation function

Quadrupole

Cubic Mocks

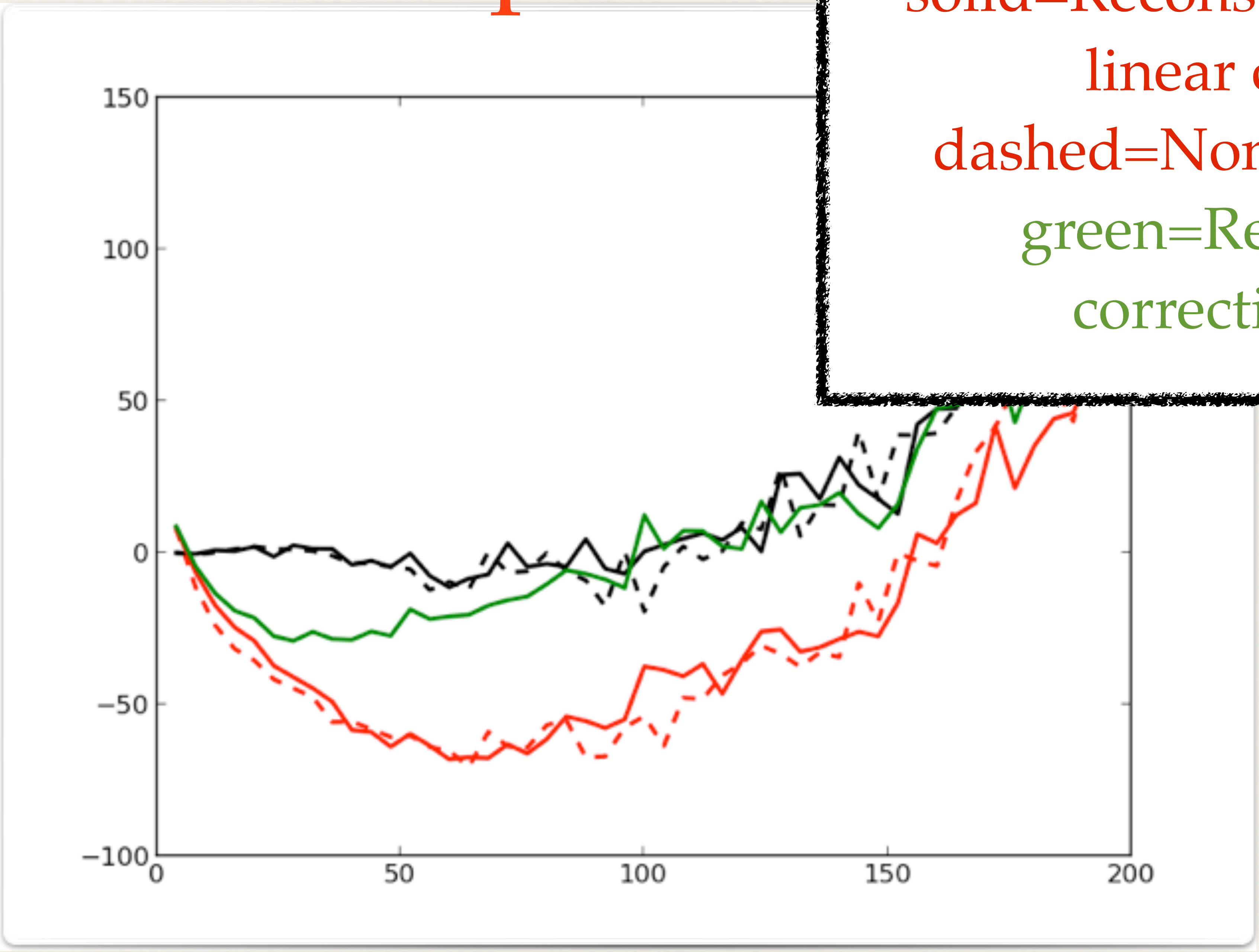
Real Space



solid=Reconstructed
dashed=Non Reconstructed

Results with simulations

Redshift Space

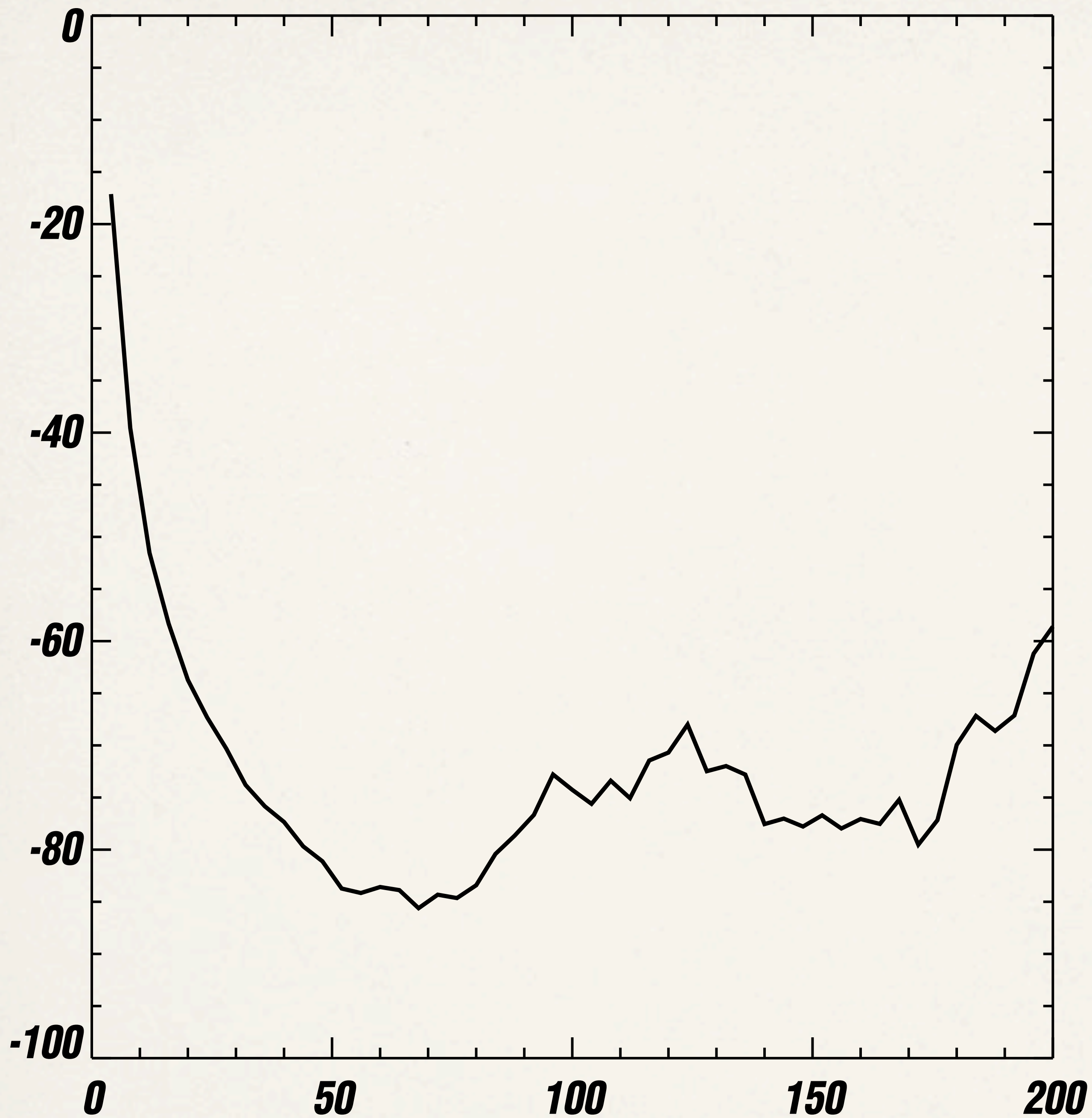


solid=Reconstructed only non linear correction
dashed=Non Reconstructed
green=Reconstructed correcting for RD

With reconstruction, the **solid green line** (reconstructed redshift space quadrupole) approach the black solid line(real space with reconstruction).

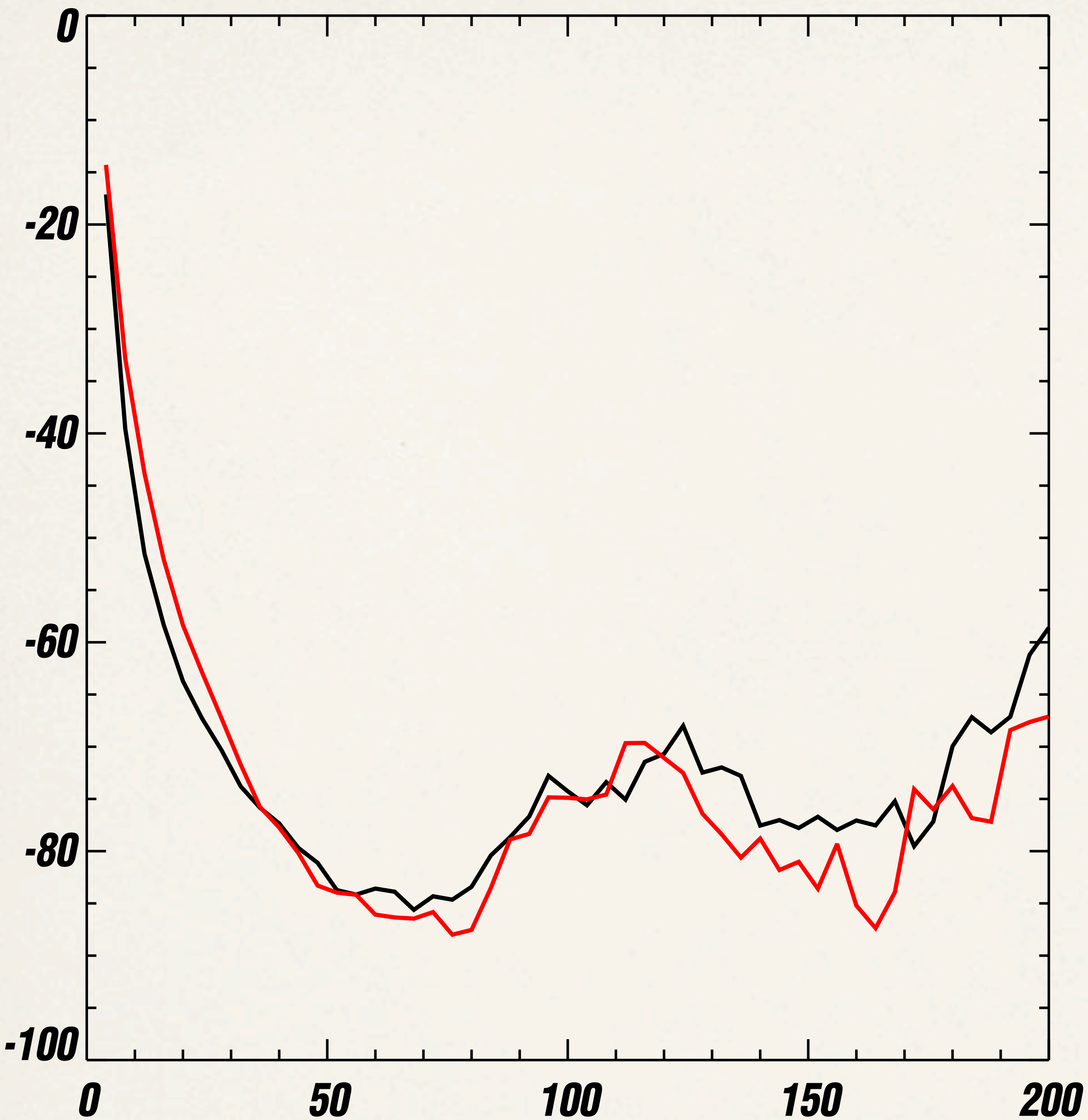
Realistic Mocks

Results with simulations



Black: No reconstruction

Results with simulations



Red: Reconstruction
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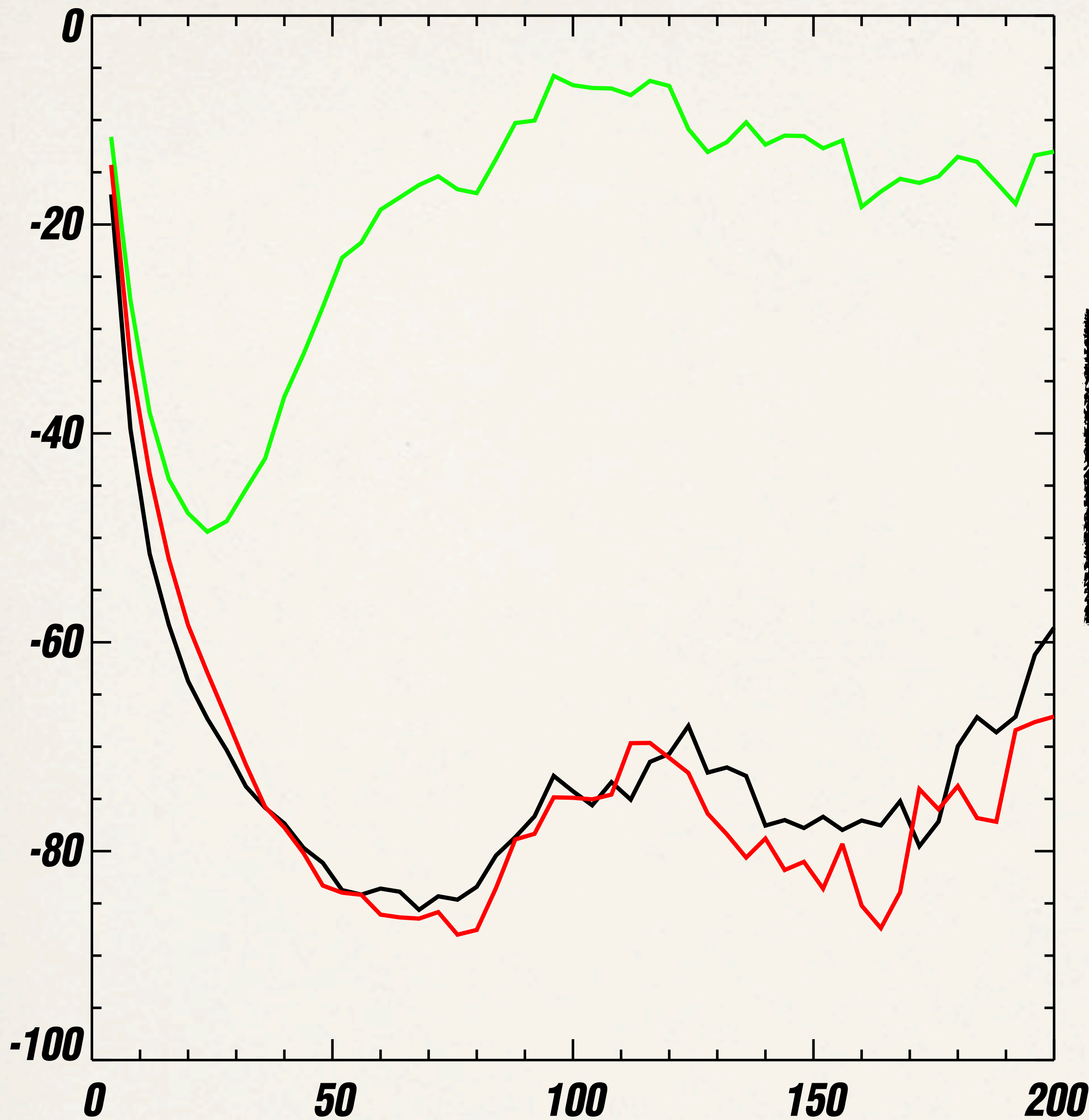
Results with simulations



Black: No recon
Red: Recon(non linear only)
Green : Recon correcting RD

with reconstruction, the **solid green line** (reconstructed redshift space quadrupole) will approach the real space reconstructed quadrupole .

Tests

I. Displacement Field.
II. Multipoles.
III. Anisotropic Clustering.

Fitting Multipoles

Following X. Xu, N.P et al 2013, where it is defined and isotropic shift α and an anisotropic shift ε.

$$\alpha = \alpha_{\perp}^{2/3}\alpha_{||}^{1/3}$$

$$1+\epsilon = \left(\frac{\alpha_{||}}{\alpha_{\perp}}\right)^{1/3}.$$

Shift in transverse direction constraints the angular diameter distance relative to the sound horizon and the radial direction constraints the relative Hubble parameter

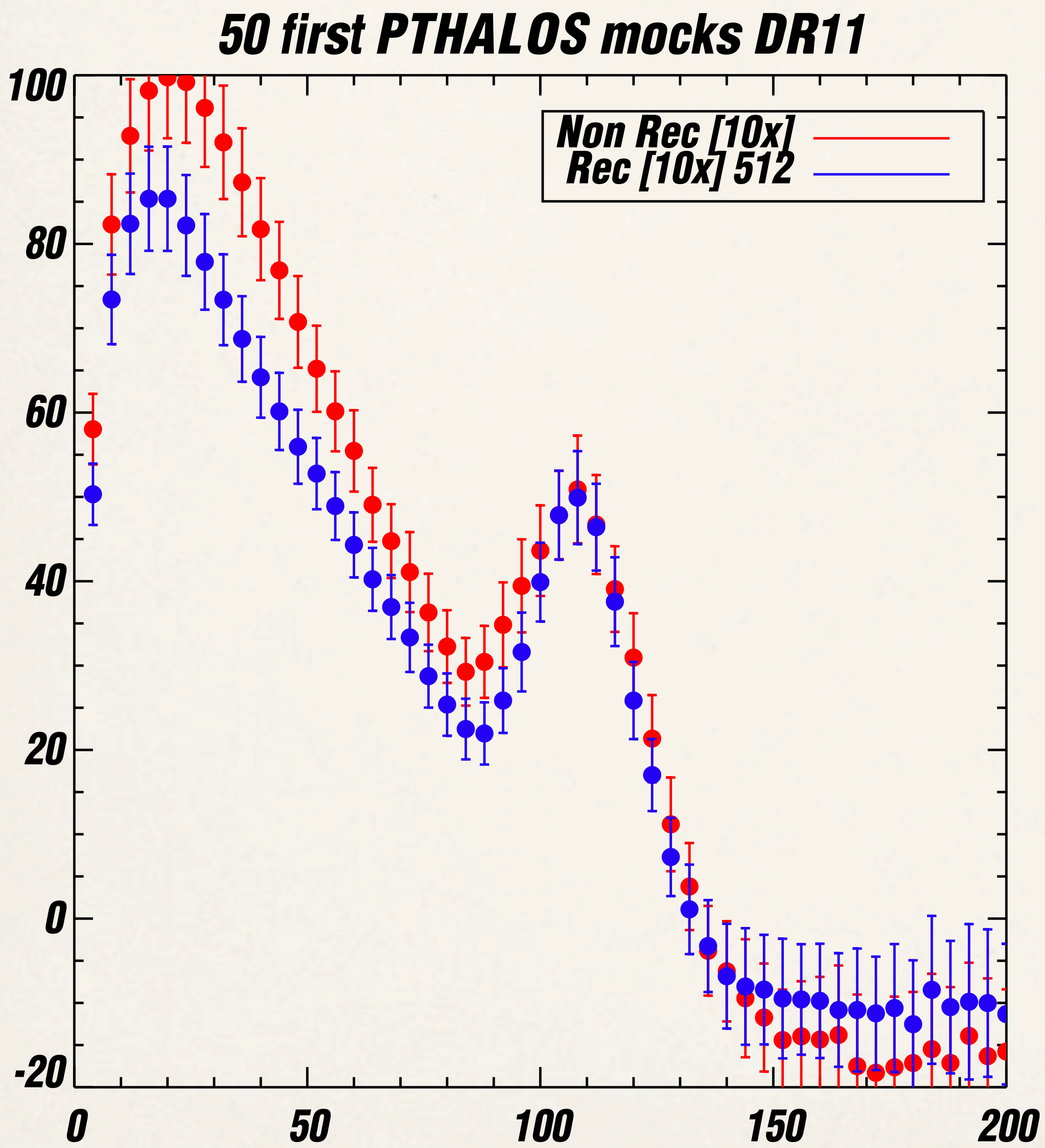
$$\alpha_{\perp} = \frac{D_A(z) r_s^{\rm fid}}{D_A^{\rm fid} r_s},$$

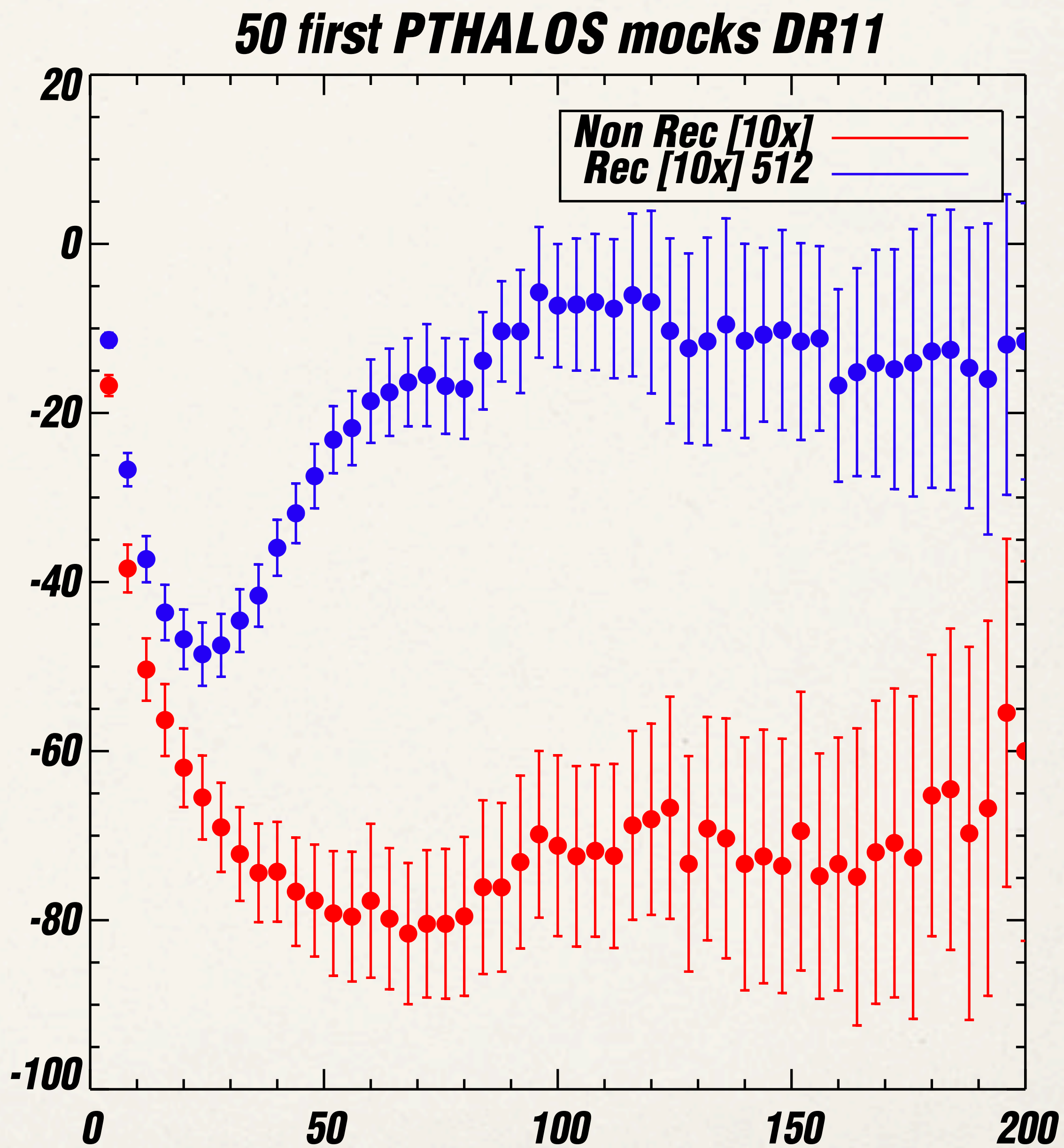
$$\alpha_{||} = \frac{H^{\rm fid}(z) r_s^{\rm fid}}{H(z) r_s}.$$

For the fiducial cosmological model:

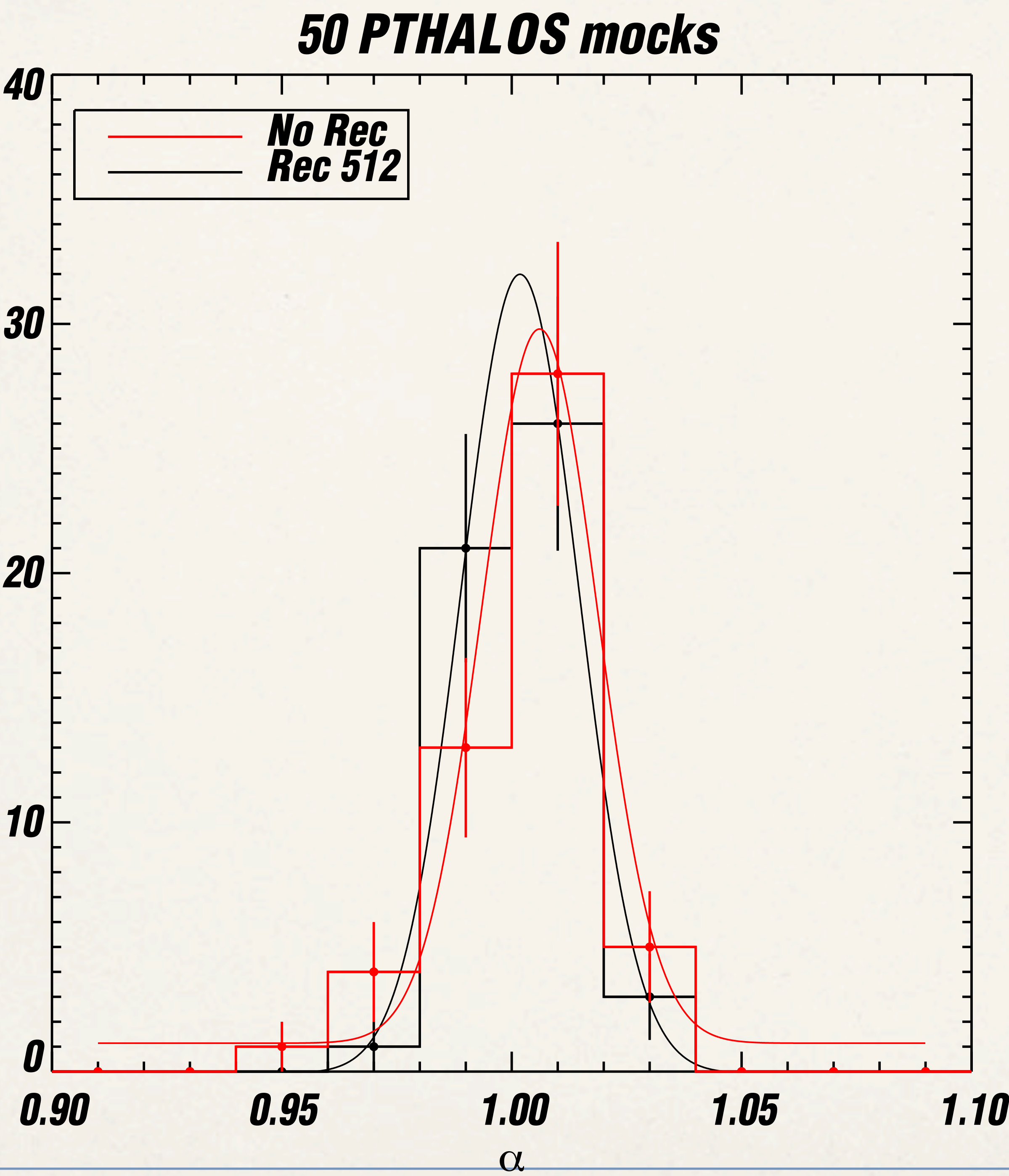
$$\alpha = \alpha_{\perp} = \alpha_{||} = 1 \qquad \epsilon = 0.$$

PTHALOS DR11





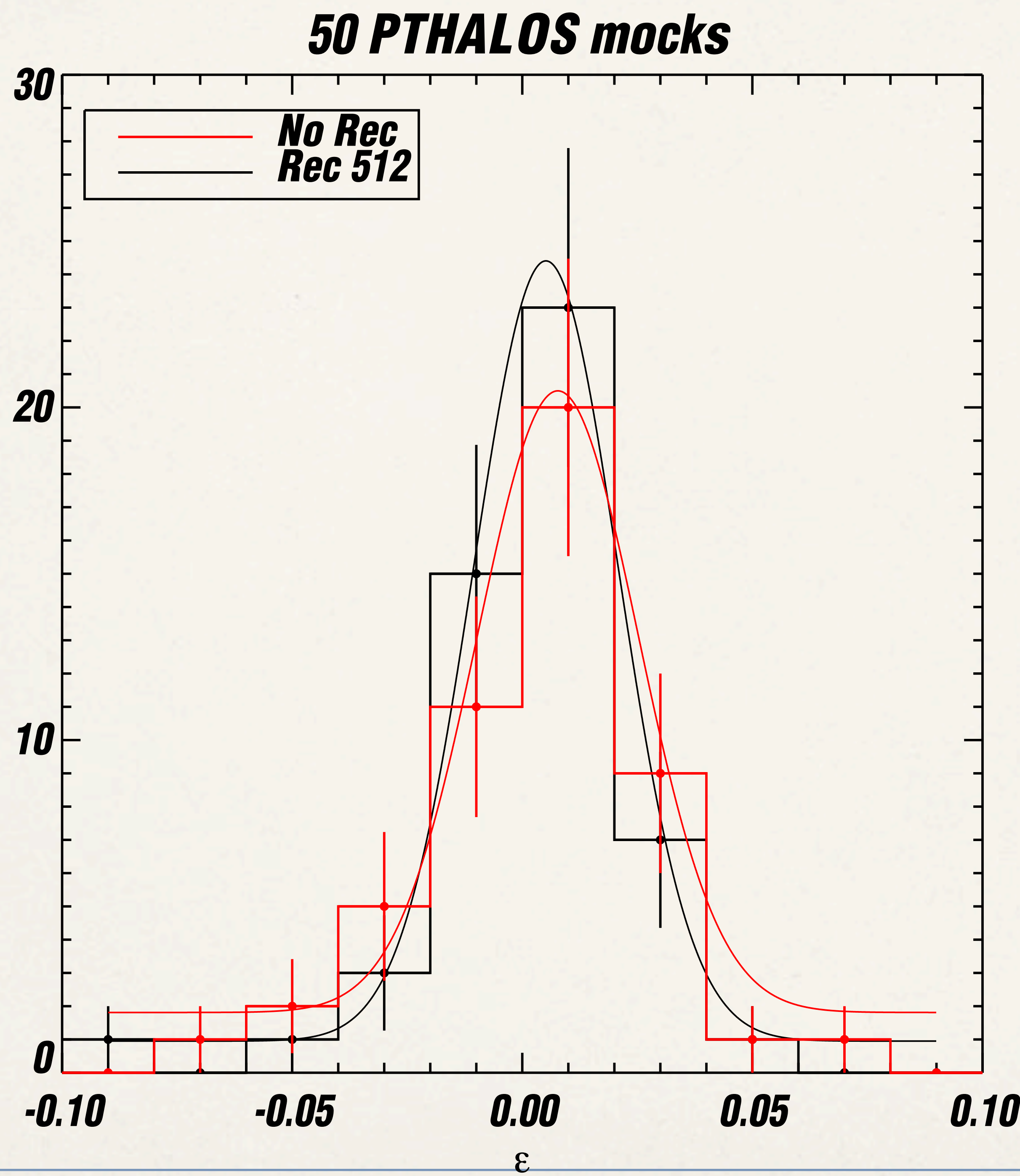
PTHALOS DR11



Reconstructed

Non Reconstructed

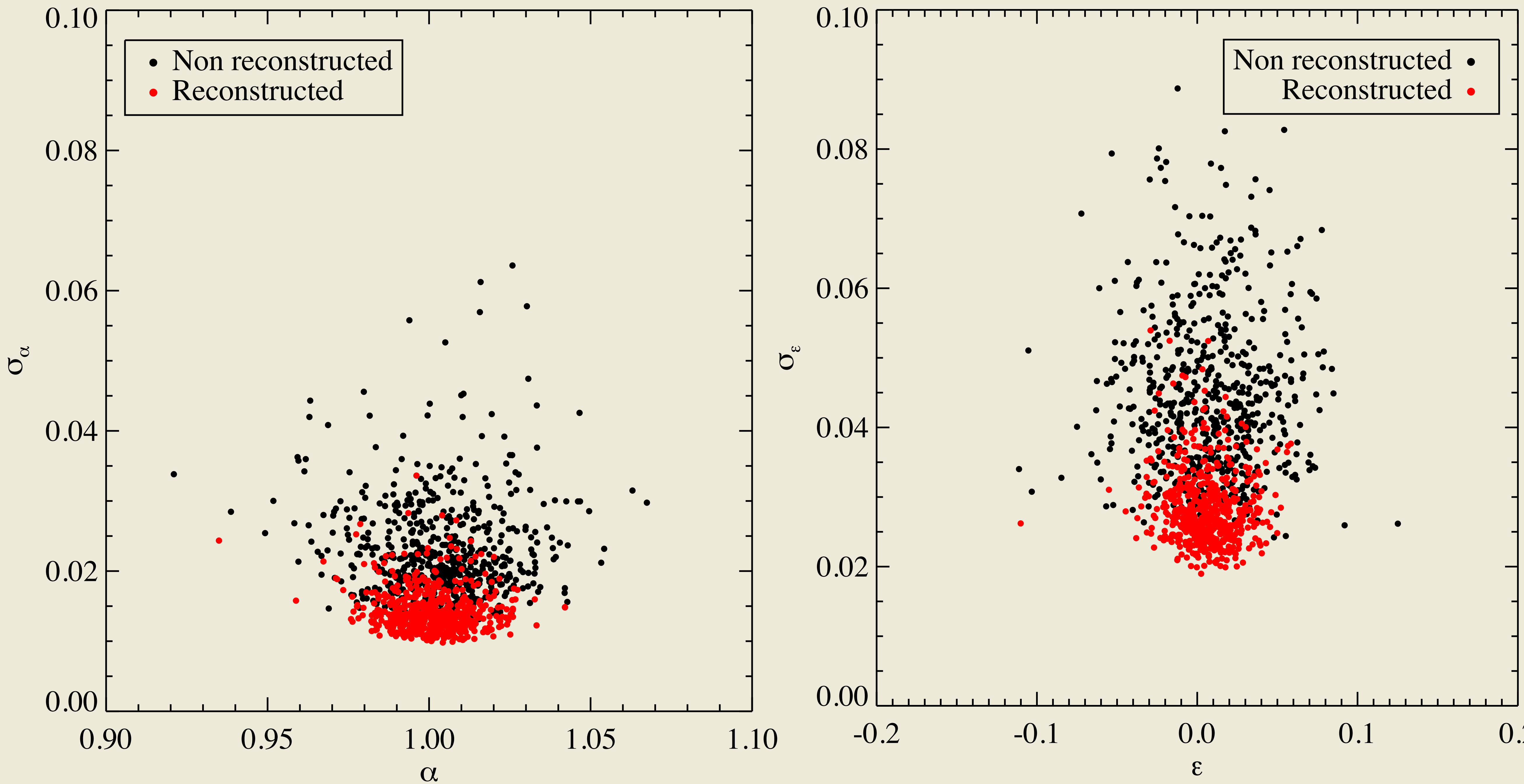
PTHALOS DR11



Reconstructed

Non Reconstructed

Results with simulations



Tests

I. Displacement Field. ✔
II. Multipoles. ✔
III. Anisotropic Clustering. ✔

Outline

- Introduction
- Results with simulations.
- **Towards improvement.**

Optimal Reconstruction.

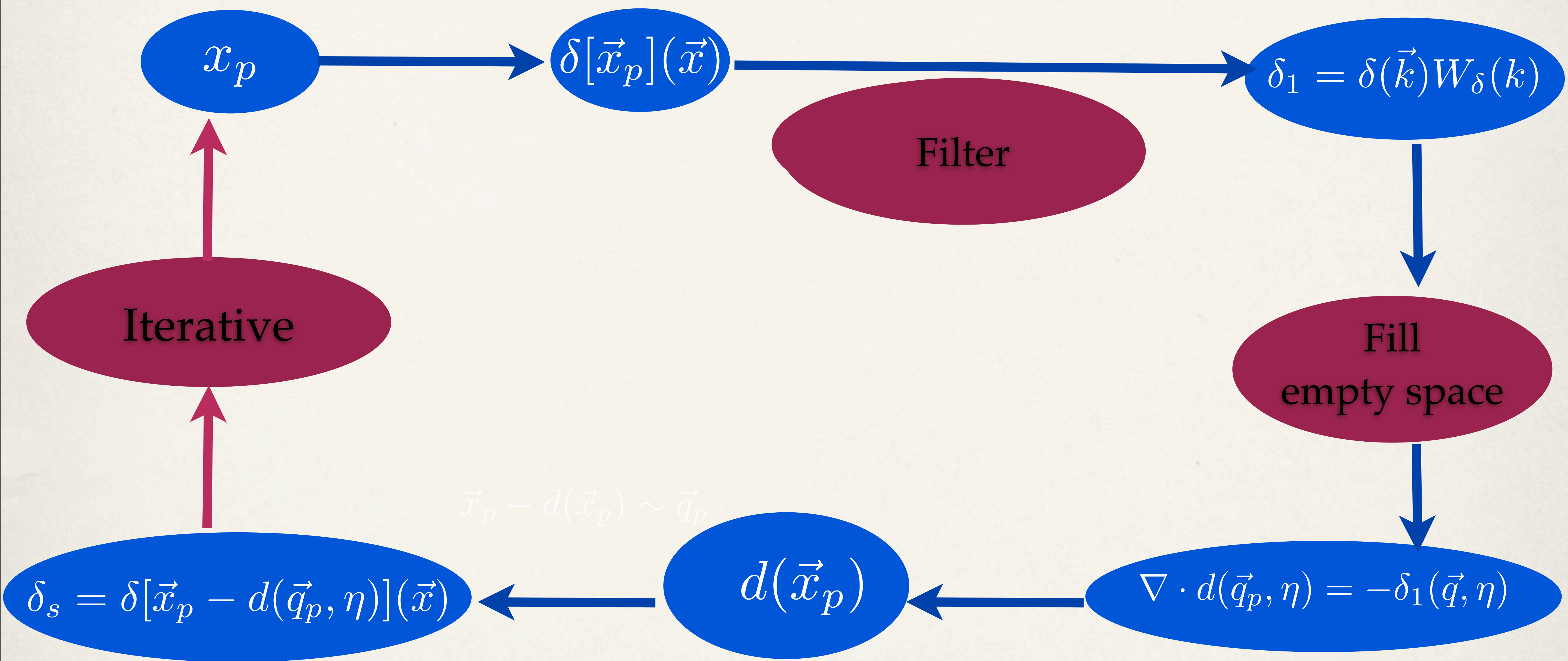
2 stage reconstruction , considering a **model for the mildly non linear regime** (LPT inspired)

1 "backward" reconstruction (match initial conditions) → Wiener filter → **first guess** displacement field

2 "forward" reconstruction (match evolved density) → match non lineal density with $\delta[s_z]$, maximizing the likelihood → final displacement field.

Svetlin Tassev and Matias Zaldarriaga, "Towards an Optimal Reconstruction of Baryon Oscillations", 2012, arXiv:1203.6066

In which directions we can improve?



Search for an optimal Filter

SR: Gaussian Filter

$$W_G = exp(-\Sigma^2 k^2/2)$$

Wiener Filter from MNL model for density*

$$W_\delta(k) = \frac{< \delta(\vec{k})\delta_1^*(\vec{k}) >}{< |\delta(\vec{k})|^2 >}$$

*Svetlin Tassev and Matias Zaldarriaga, "Towards an Optimal Reconstruction of Baryon Oscillations", 2012, arXiv:1203.6066

Model for non linear density in the mildly non linear regime*

$$\delta(\vec{k}) = R_\delta(k)\delta_1(\vec{k}) + \delta_{MC}(\vec{k})$$

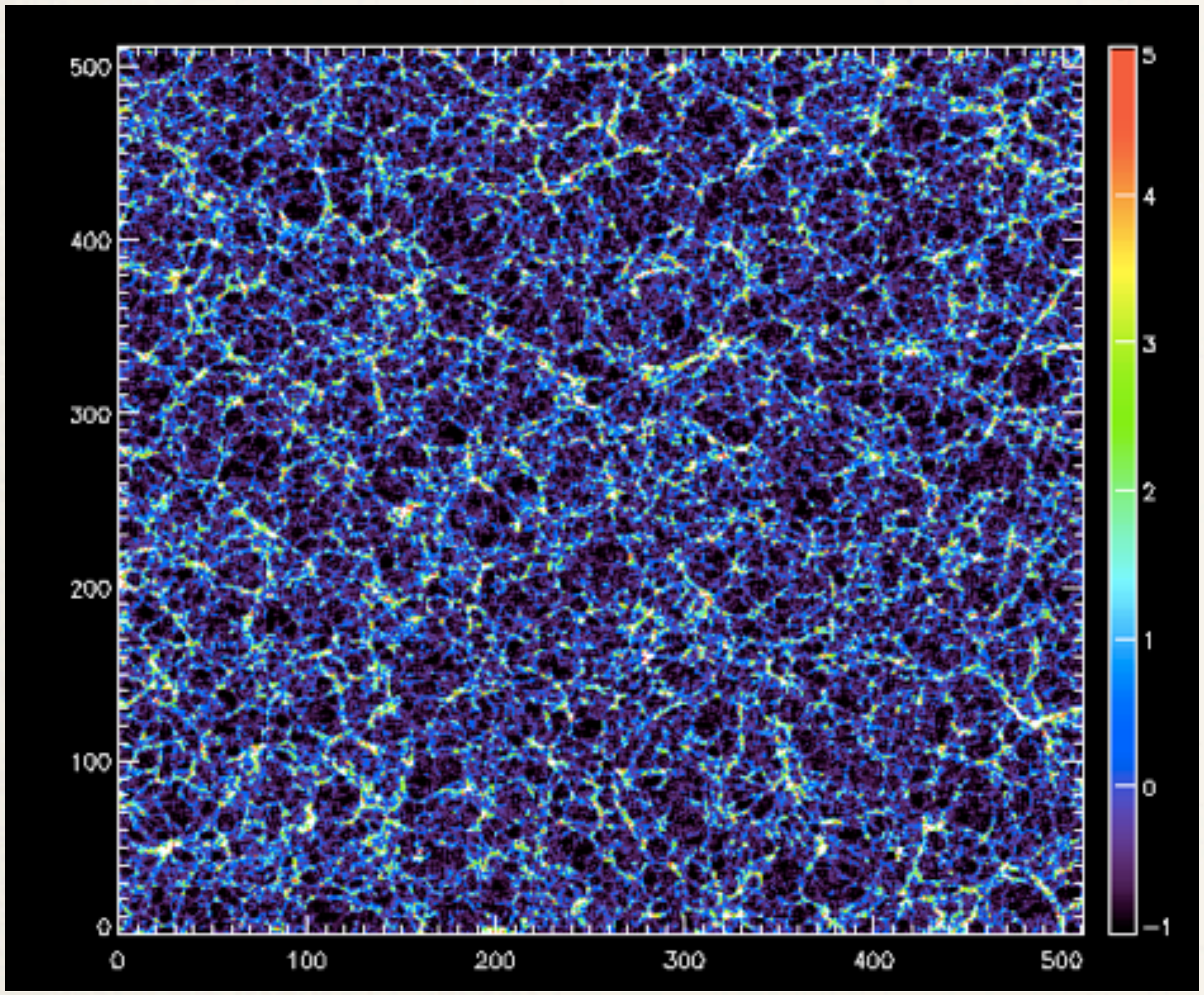
$$\delta_1 \equiv \delta[\vec{x}_p = \vec{q}_p + (R_z * s_z)(\vec{q}_p))]$$

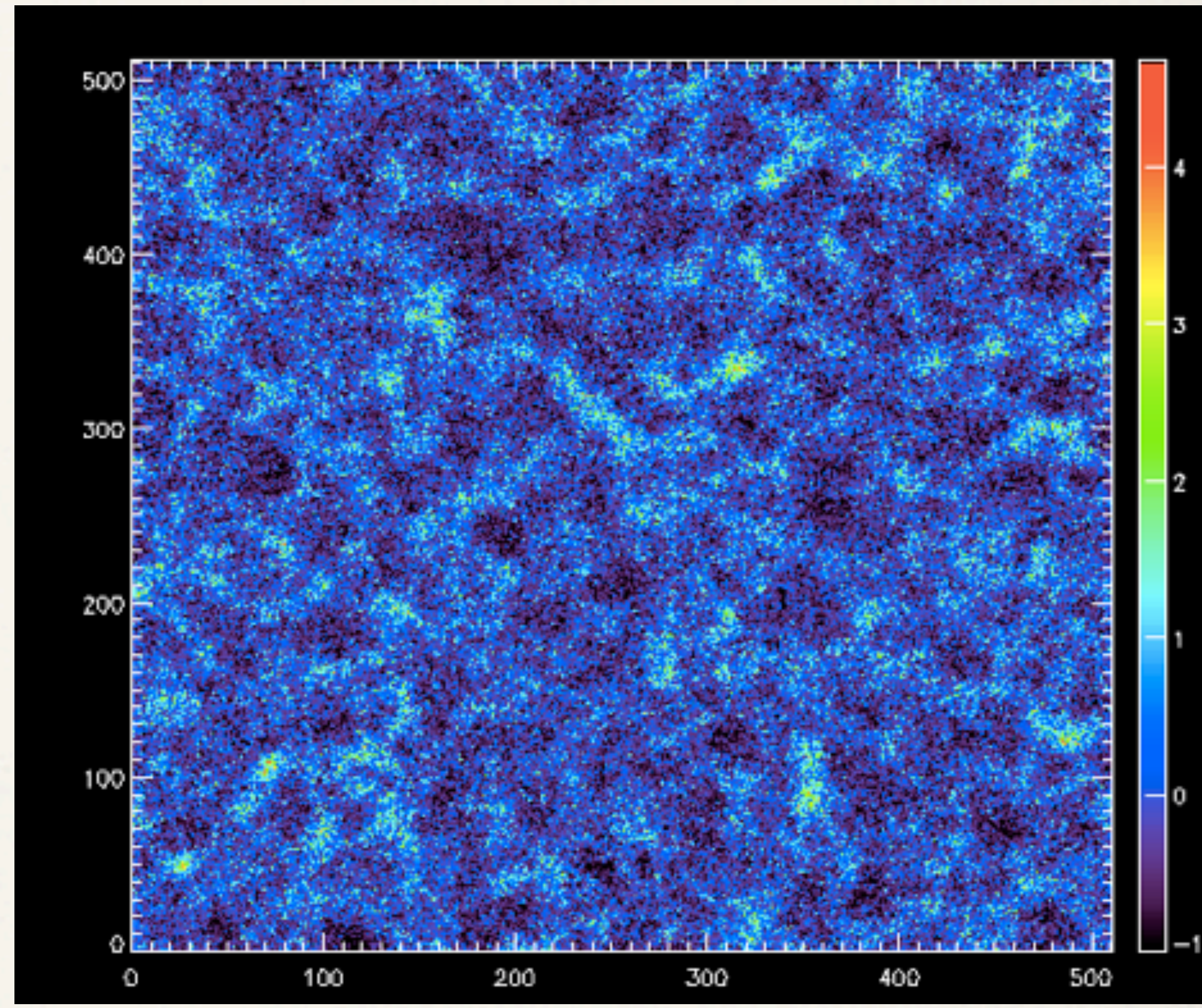
$$R_\delta(k) = \frac{\delta(\vec{k})\delta_1^*(\vec{k})}{< |\delta_1(\vec{k})|^2 >}$$

$$R_z(\kappa) = \frac{s_z(\vec{\kappa}) \cdot s_z^*(\vec{\kappa})}{< |s_z(\vec{\kappa})|^2 >}$$

Svetlin Tassev and Matias Zaldarriaga, "Towards an Optimal Reconstruction of Baryon Oscillations", 2012, arXiv:1203.6066

Filter Calibration





$$R_\delta(k) = \frac{\delta(\vec{k})\delta_1^*(\vec{k})}{< |\delta_1(\vec{k})|^2 >}$$

Conclusions

- Reconstruction has shown to make **significative improvement** in the **precision of the BAO distance** measurements

- Reconstruction has become a **standard tool clustering analysis.** Exploring reconstruction have important implications for current and **future surveys** as all of these surveys have **assumed some level of reconstruction** for their projected constraints.

- We are exploring **different "metrics" to study performance** of reconstruction. We are also extending the current studies mostly focus on **isotropic clustering to the anisotropic** BAO signal.

- Now, testing with simulations and real data. Reconstruction is also being **applied to the next data release SDSS-III/BOSS (DR10/DR11)** coming very soon!!

- Ongoing work on improving standard reconstruction, testing filters, iterative reconstruction and a different method for filling empty space.