The 3D clustering of SDSS-III BOSS DR9 galaxies

(and the construction of mock catalogues)

Marc Manera (ICG, Portsmouth)

On behalf of the SDSS-III BOSS Collaboration

Modern Cosmology Workshop, Benasque, August 2012

The clustering of galaxies in the SDSS-III BOSS survey:

Anderson et al. arXiv:1203.6594
Ross et al. arXiv:1203.6499&1208.1491
Manera et al. arXiv:1203.6609
Reid et al. arXiv:1203:6641
Tojeiro et al. arXiv:1203.6565
Sanchez et al. arXiv:1203.6616
Samushia et al. arXiv:1206.5309

Lauren Anderson[1], Eric Aubourg[2], Stephen Bailey[3], Dmitry Bizyaev[4], Michael Blanton[5], Adam S. Bolton[6], J. Brinkmann[4], Joel R. Brownstein[6], Angela Burden[7], Antonio J. Cuesta[8], Luiz N. A. da Costa[9,10], Kyle S. Dawson[6], Roland de Putter[11,12], Daniel J. Eisenstein[13], James E. Gunn[14], Hong Guo[15], Jean-Christophe Hamilton[2], Paul Harding[15], Shirley Ho[3,14], Klaus Honscheid[16], Eyal Kazin[17], D. Kirkby[18], Jean-Paul Kneib[19], Antione Labatie[20], Craig Loomis[21], Robert H. Lupton[14], Elena Malanushenko[4], Viktor Malanushenko[4], Rachel Mandelbaum[14,21], Marc Manera[7], Claudia Maraston[7], Cameron K. McBride[13], Kushal T. Mehta[22], Olga Mena[11], Francesco Montesano[23], Demetri Muna[5], Robert C. Nichol[7], Sebastián E. Nuza[24], Matthew D. Olmstead[6], Daniel Oravetz[4], Nikhil Padmanabhan[8], Nathalie Palanque-Delabrouille[25], Kaike Pan[4], John Parejko[8], Isabelle Pâris[26], Will J. Percival[7], Patrick Petitjean[26], Francisco Prada[27,28,29], Beth Reid[3,30], Natalie A. Roe[3], Ashley J. Ross[7], Nicholas P. Ross[3], Lado Samushia[7,31], Ariel G. Sánchez[23], David J. Schlegel[*3], Donald P. Schneider[32,33], Claudia G. Scóccola[34,35], Hee-Jong Seo[36], Erin S. Sheldon[37], Audrey Simmons[4], Ramin A. Skibba[22], Michael A. Strauss[21], Molly E. C. Swanson[13], Daniel Thomas[7], Jeremy L. Tinker[5], Rita Tojeiro[7], Mariana Vargas Magaña[2], Licia Verde[38], Christian Wagner[12], David A. Wake[39], Benjamin A. Weaver[5], David H. Weinberg[40], Martin White[3,41,42], Xiaoying Xu[22], Christopher Yeche[25], Idit Zehavi[15], Gong-Bo Zhao[7,43]

The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey:

Baryon Acoustic Oscillations in the Data Release 9 Spectroscopic Galaxy Sample (Anderson et al. 2012)

Analysis of potential systematics (Ross et al. 2012)

A large sample of mock galaxy catalogues (Manera et al. 2012)

Measurements of the growth of structure and expansion rate at z=0.57 from anisotropic clustering (Reid et al. 2012)

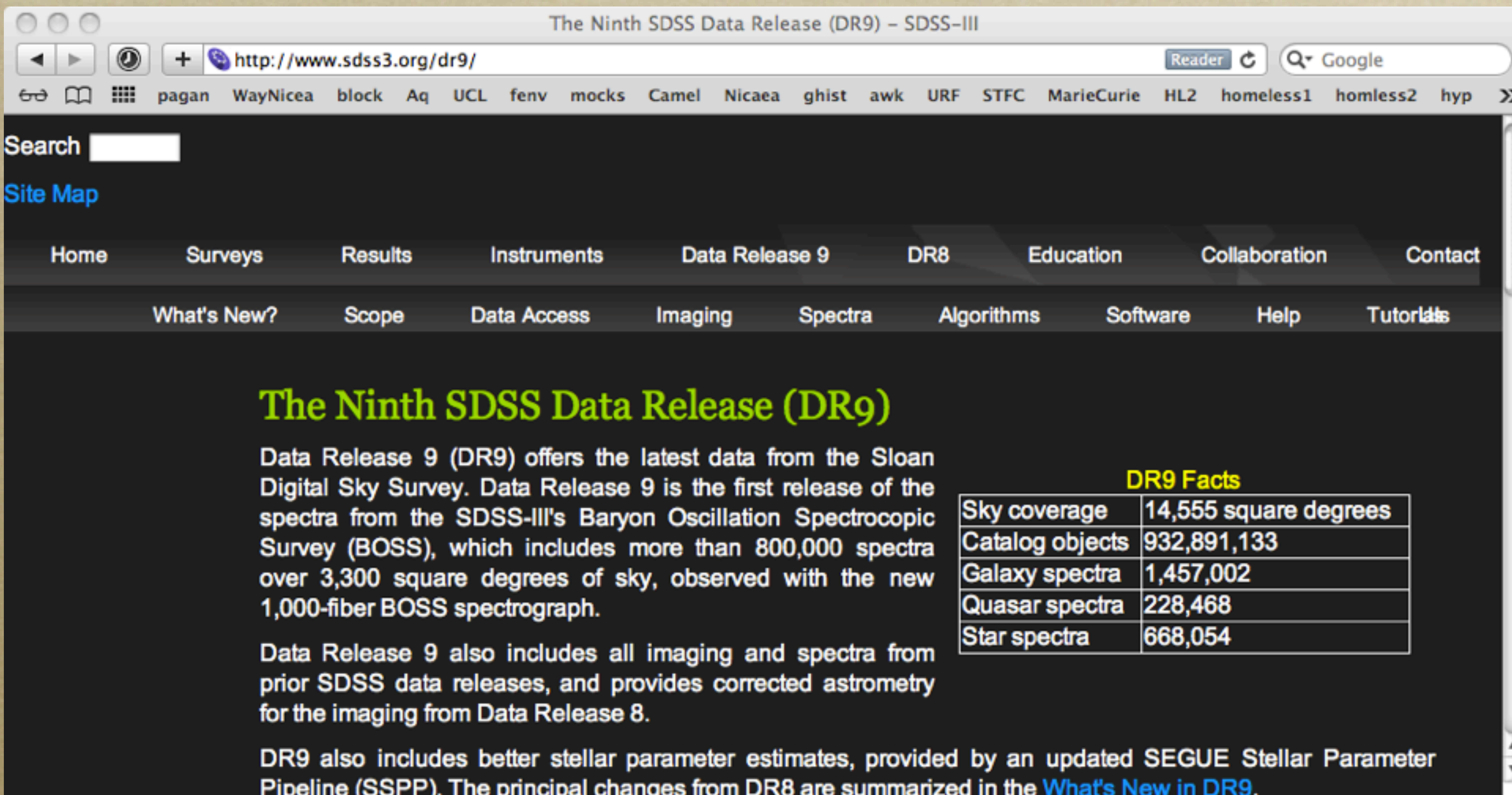
Testing Deviations from Λ and General Relativity using anisotropic clustering of galaxies (Samushia et al. 2012)

Cosmological implications of the large-scale two-point correlation function (Sánchez et al. 2012)

Measuring structure growth using passive galaxies (Tojeiro et al. 2012)

Baryon Oscillation Spectroscopic Survey: Constraints on Primordial Non-Gaussianity (Ross et al 2012)

BOSS DR9 data available:


The Ninth SDSS Data Release (DR9) – SDSS-III

http://www.sdss3.org/dr9/

pagan WayNicea block Aq UCL fenv mocks Camel Nicaea ghist awk URF STFC MarieCurie HL2 homeless1 homless2 hyp

Search

Site Map

Home Surveys Results Instruments Data Release 9 DR8 Education Collaboration Contact

What's New? Scope Data Access Imaging Spectra Algorithms Software Help Tutorials

The Ninth SDSS Data Release (DR9)

Data Release 9 (DR9) offers the latest data from the Sloan Digital Sky Survey. Data Release 9 is the first release of the spectra from the SDSS-III's Baryon Oscillation Spectrocopic Survey (BOSS), which includes more than 800,000 spectra over 3,300 square degrees of sky, observed with the new 1,000-fiber BOSS spectrograph.

Data Release 9 also includes all imaging and spectra from prior SDSS data releases, and provides corrected astrometry for the imaging from Data Release 8.

DR9 Facts

Sky coverage	14,555 square degrees
Catalog objects	932,891,133
Galaxy spectra	1,457,002
Quasar spectra	228,468
Star spectra	668,054

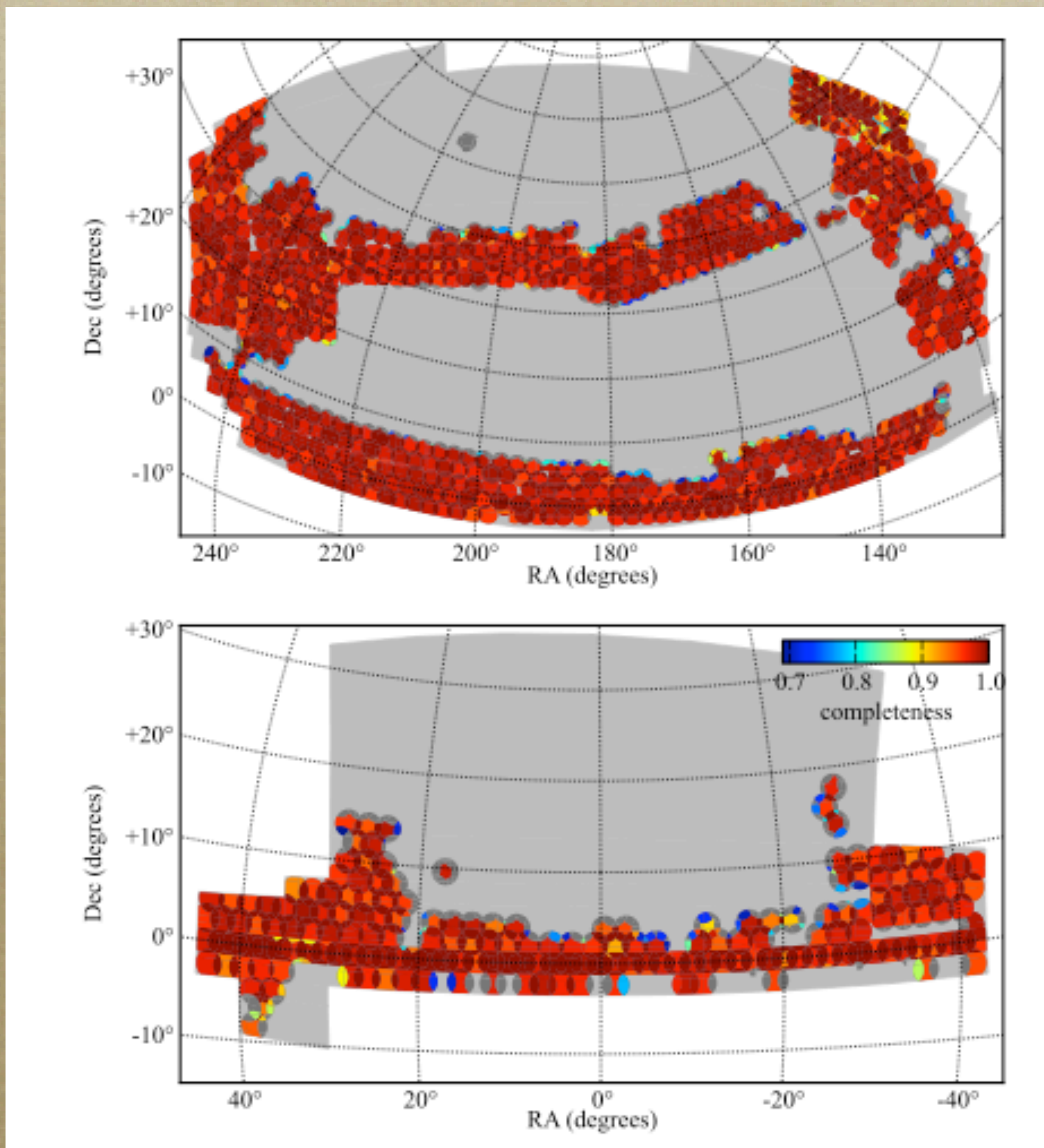
DR9 also includes better stellar parameter estimates, provided by an updated SEGUE Stellar Parameter Pipeline (SSPP). The principal changes from DR8 are summarized in the What's New in DR9.

OUTLINE

I. BOSS DR9 galaxies
II. BAO Measurements, and
II. Systematics and Statistical Errors
III. Results (monopole)
IV. Mock galaxy catalogues
V. Other Results from BOSS

I. BOSS DR9 galaxies

CMASS DR9 galaxy sample



BOSS 1.5 million galaxies
over 10000 sq. deg

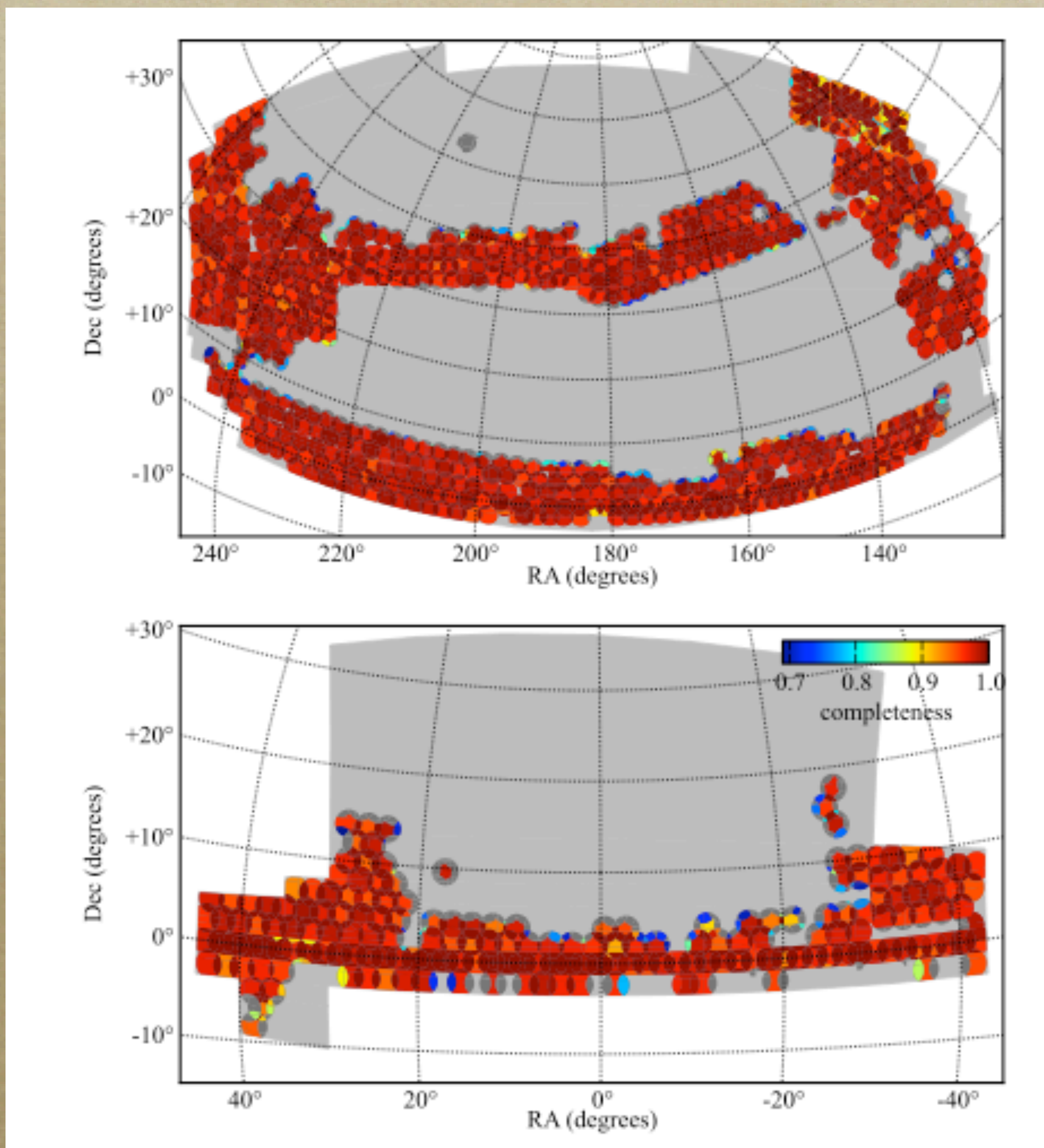
CMASS 270,000+
redshifts $0.43 < z < 0.7$

DR9 footprint 3345 sq. deg
2635 in the NGC
709 in the SGC

CMASS sample targets
massive luminous galaxies

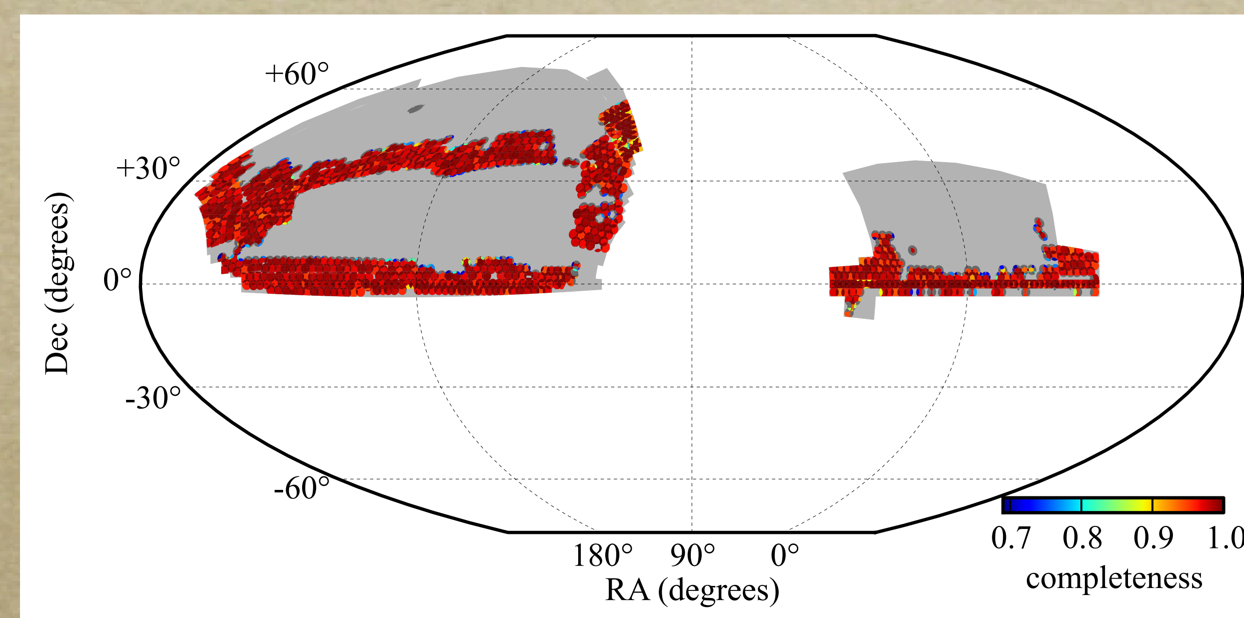
Public July 2012

CMASS DR9 galaxy sample



BOSS 1.35 million galaxies
over 10000 sq. deg

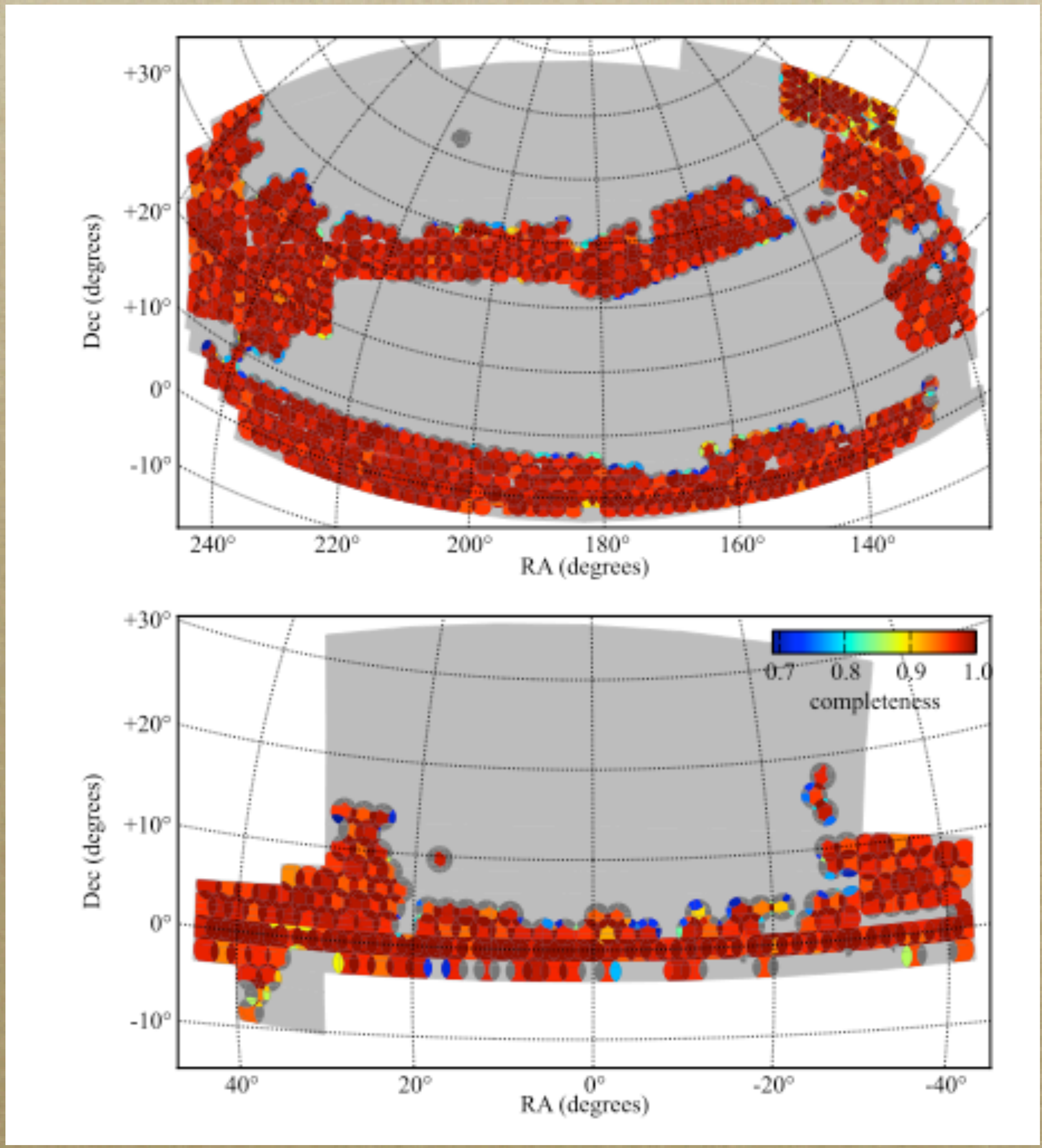
270,000+ redshifts 0.43<z< 0.7



Public July 2012

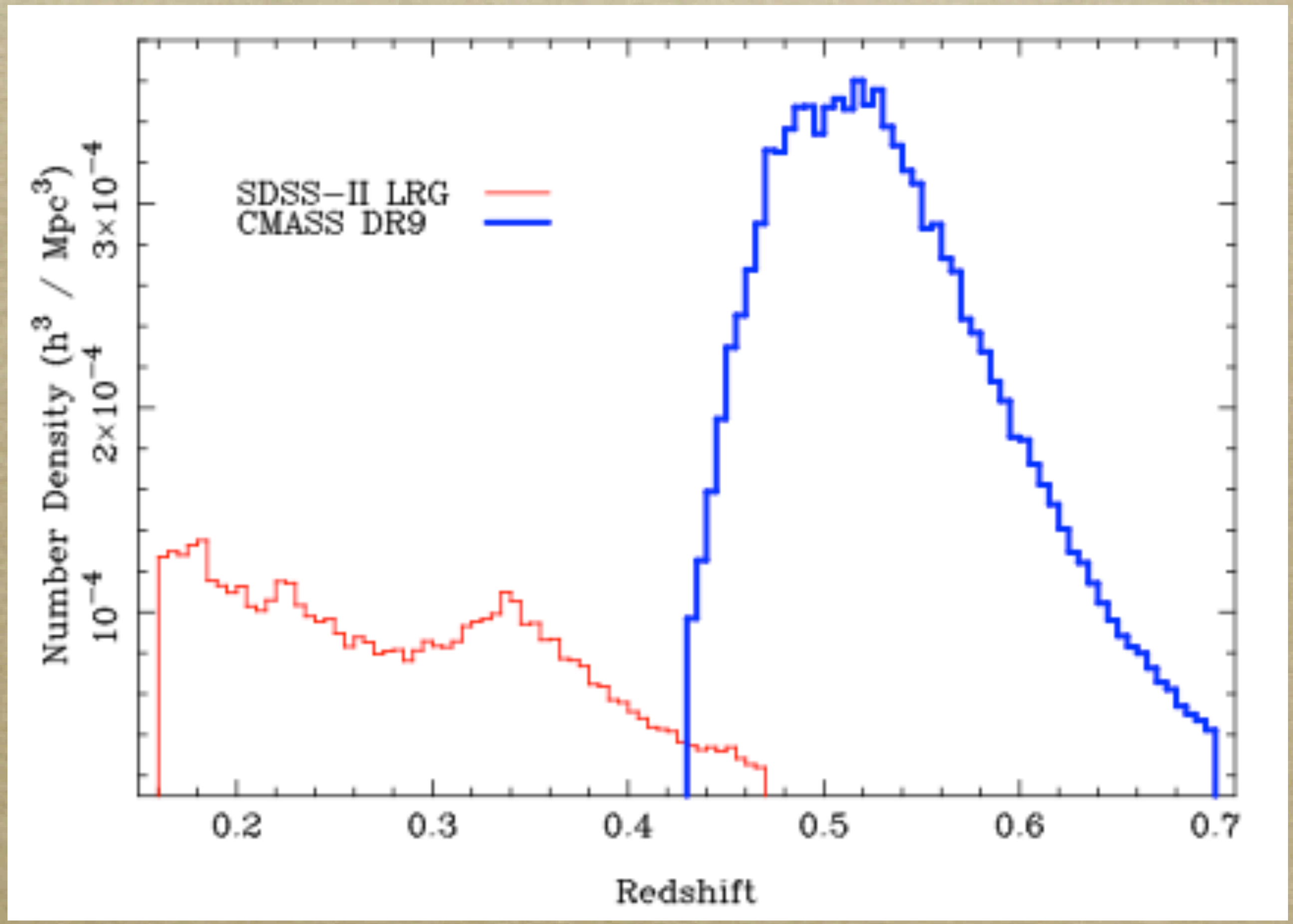
Modern Cosmology Workshop, Benasque, August 2012

CMASS DR9 galaxy sample



BOSS 1.35 million galaxies over 10000 sq. deg

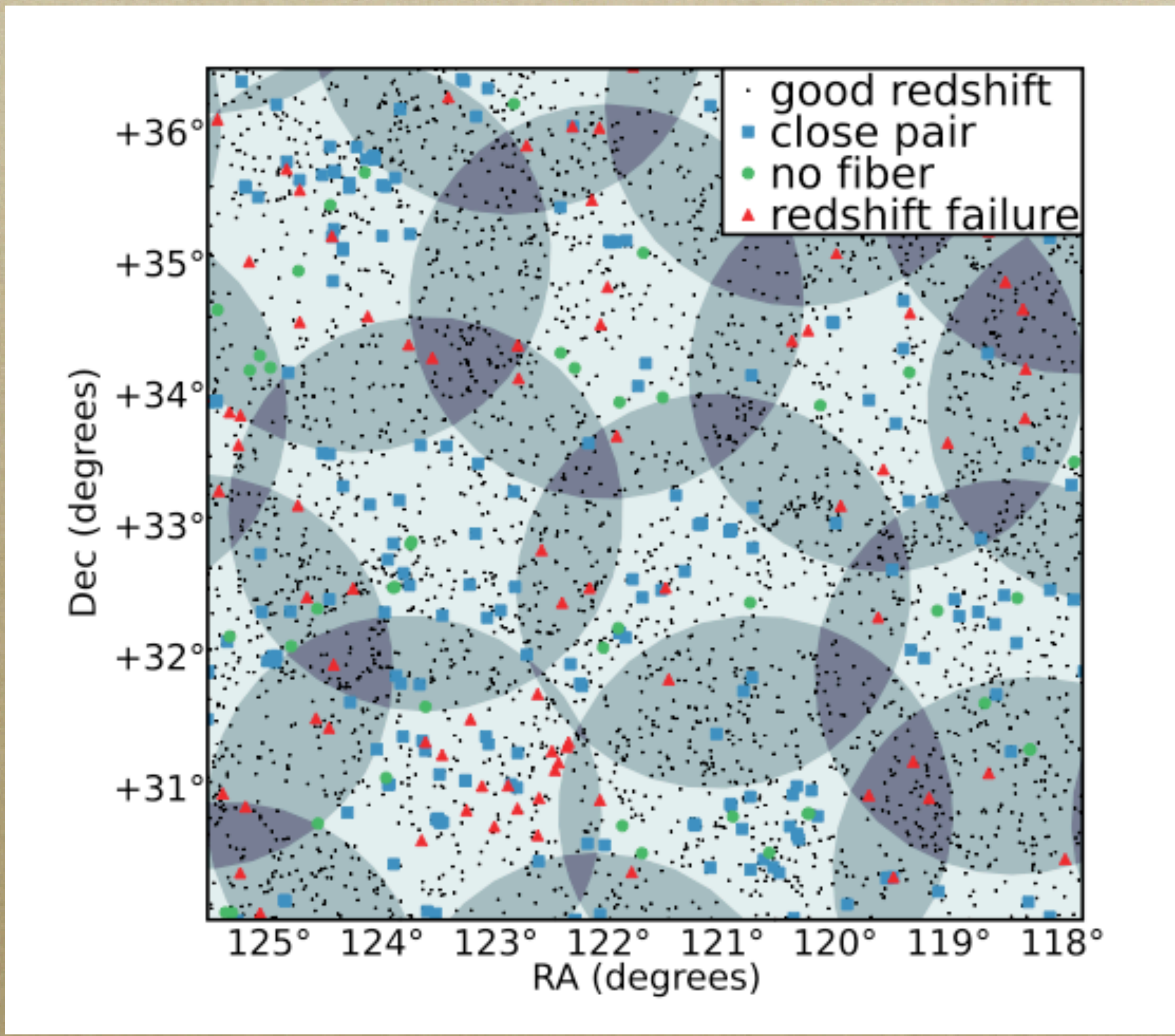
270,000+ redshifts 0.43<z< 0.7



Public July 2012

Modern Cosmology Workshop, Benasque, August 2012

CMASS complenteness



Landy-Szalay

$$\xi(r) = \frac{DD - 2DR + RR}{RR}$$

completeness

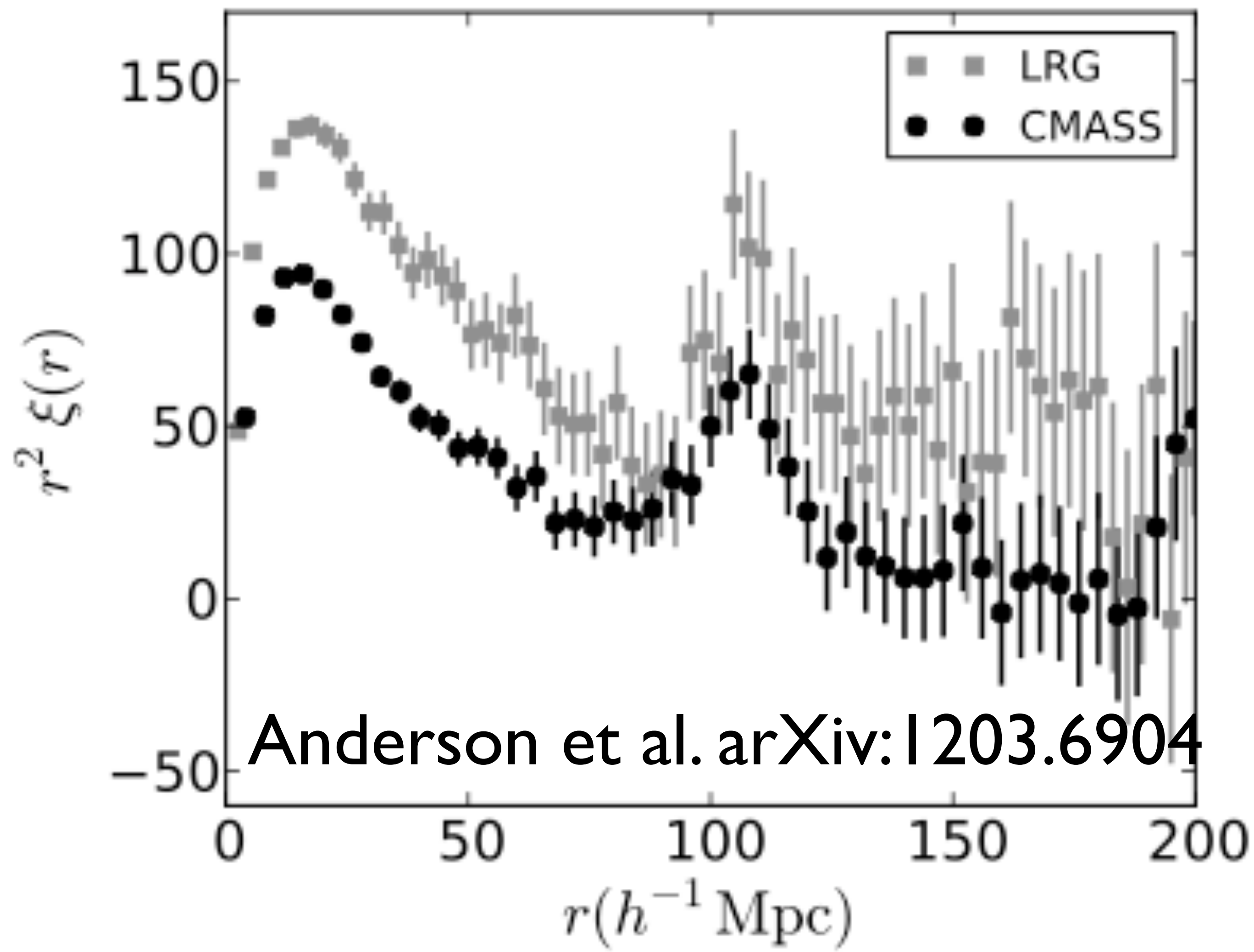
$$C_{\rm red} = \frac{N_{\rm gal}}{N_{\rm obs} - N_{\rm star}}.$$

$$C_{\rm BOSS} = \frac{N_{\rm obs} + N_{\rm cp}}{N_{\rm targ} - N_{\rm known}},$$

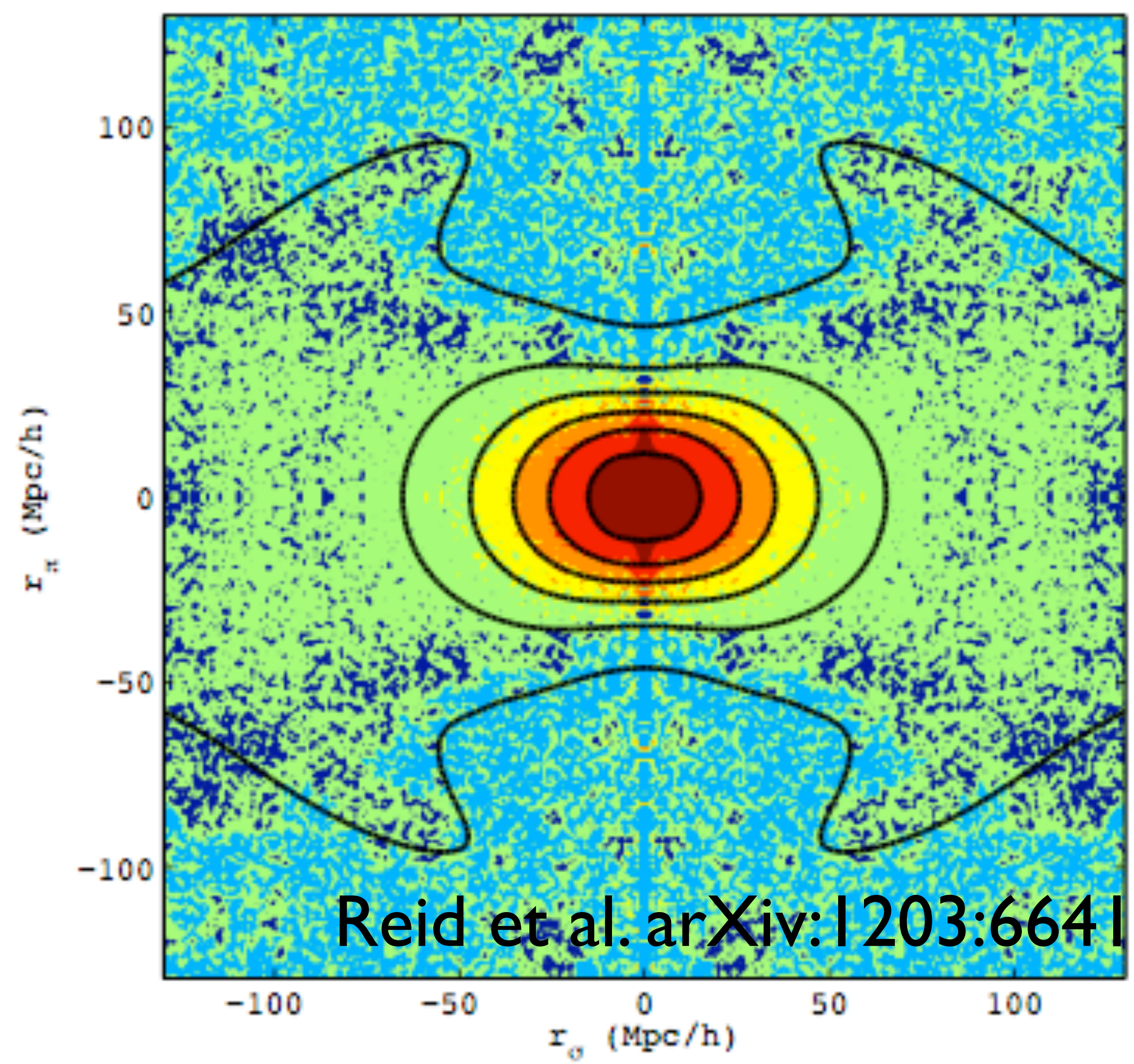
II. Measurements and Errors

CMASS DR9 CLUSTERING

- Largest effective volume of any individual sample 2.2 Gpc^3
- Covariance from 600+ PThalos galaxy mock catalogs (Manera et al. 1203.6609)
- Demands thorough investigation of systematics (Ross et al. 1203.6499)

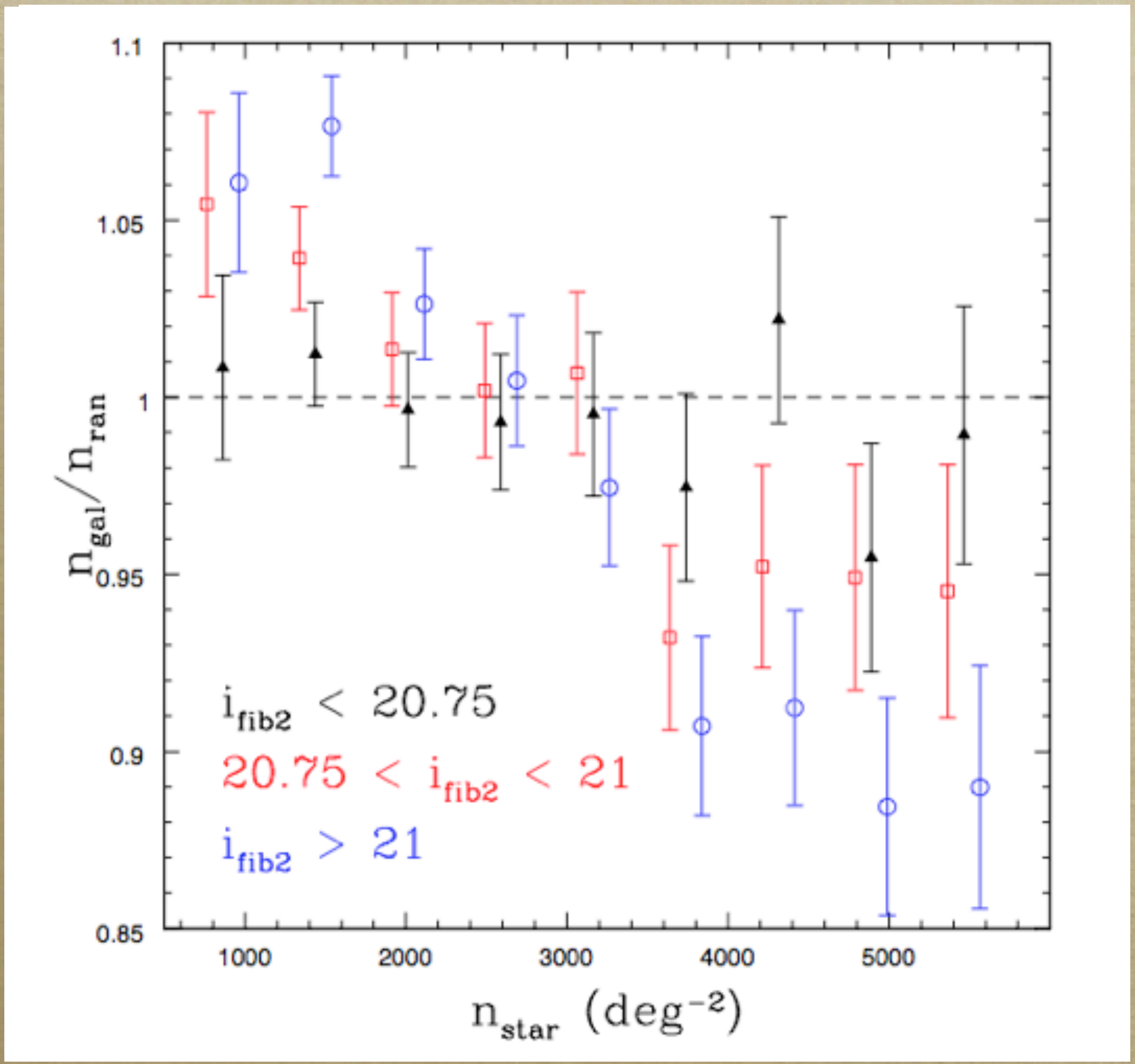


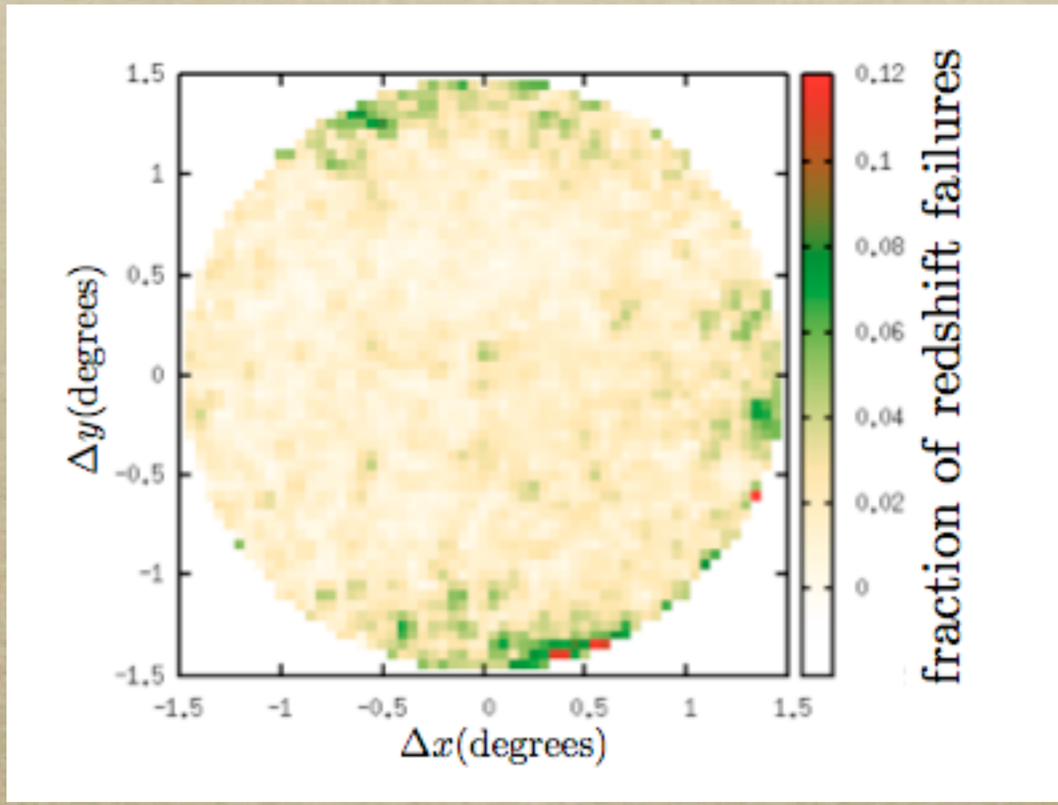
Anderson et al. arXiv:1203.6904



Reid et al. arXiv:1203:6641

SYSTEMATIC ANALYSIS

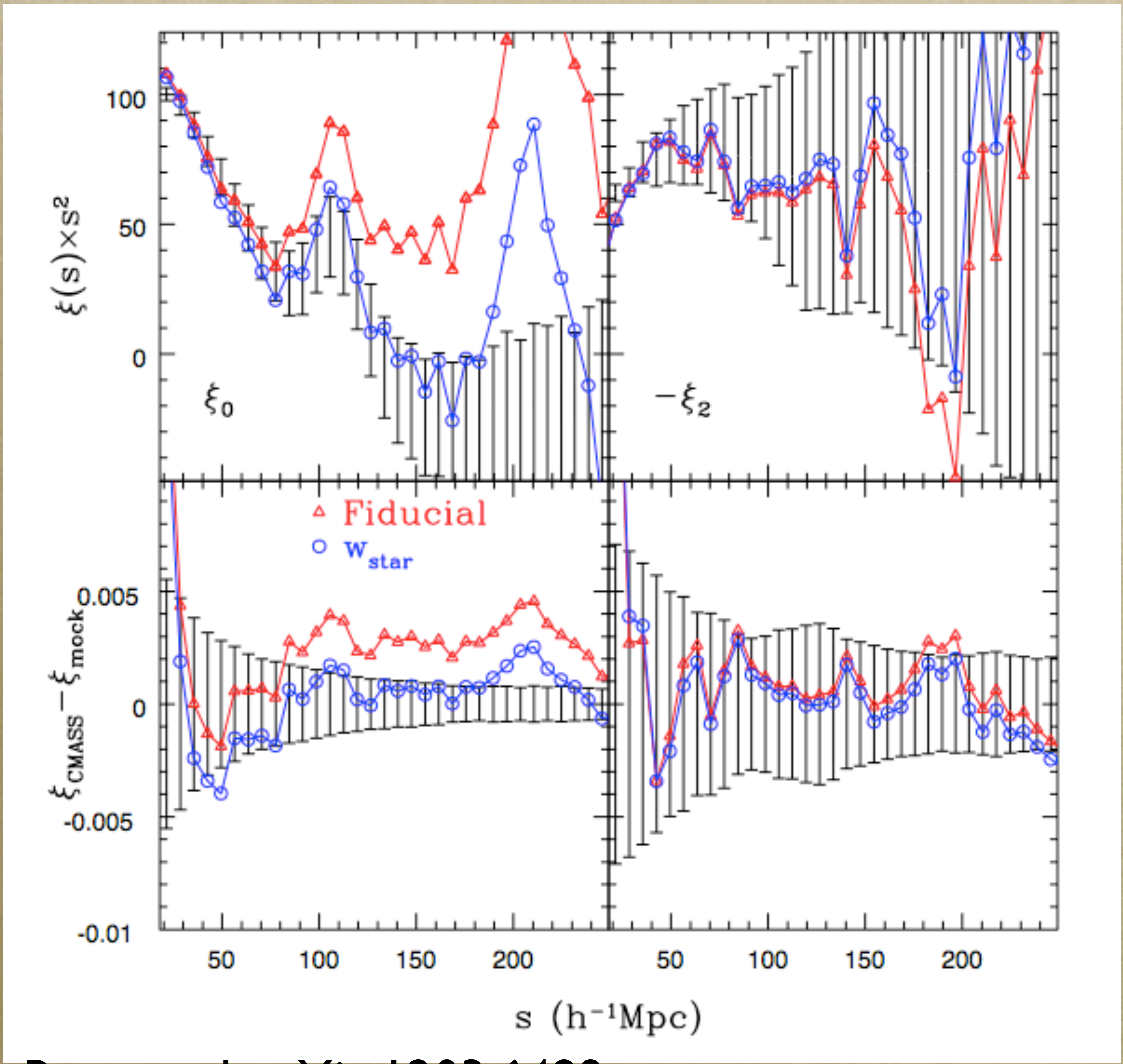




Ross et al. arXiv:1203.6499

Thorough vetting of potential systematics Ross et al. 1203.6499

SYSTEMATIC ANALYSIS

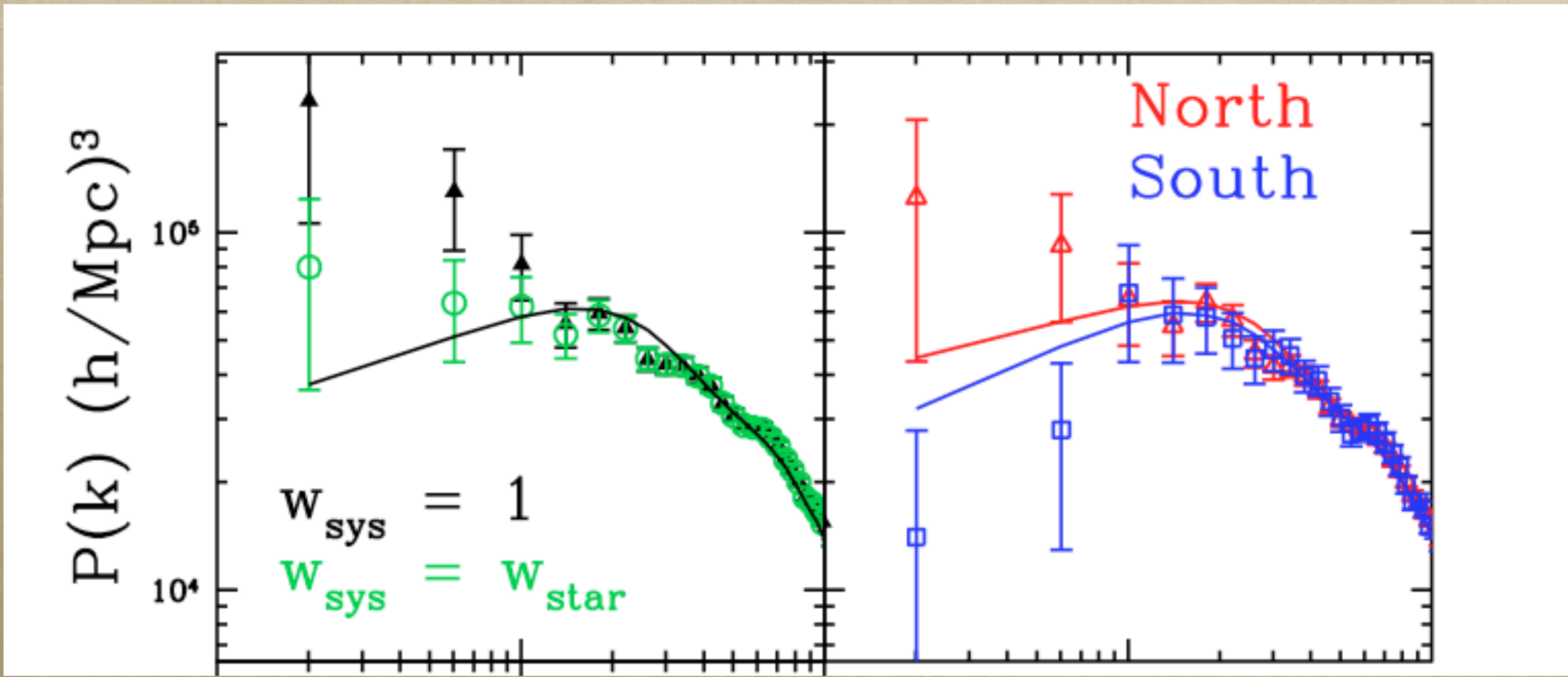


Ross et al. arXiv:1203.6499

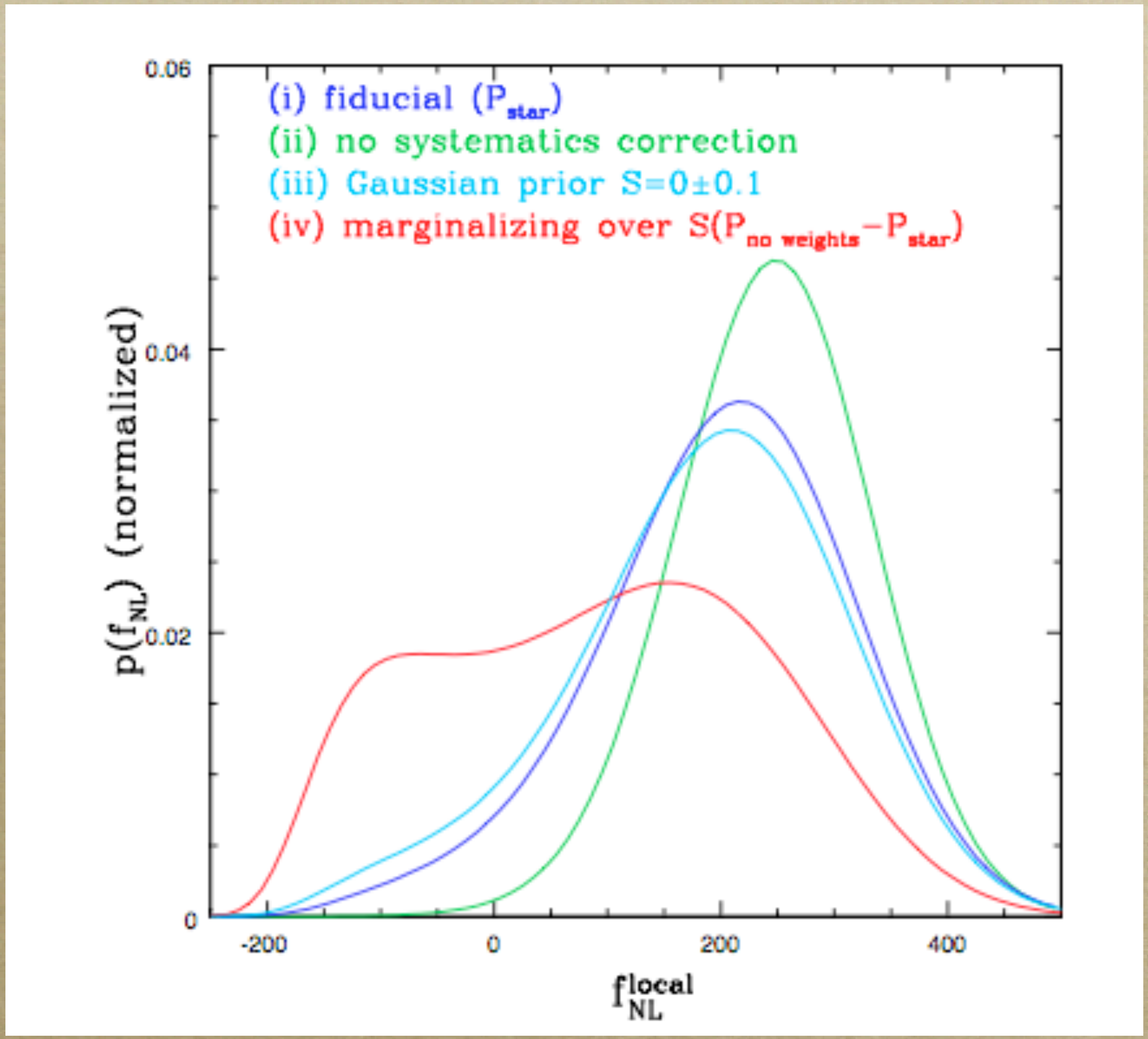
- Most important: Correct for presence of stars via weights linear fit to $n_g(n_{star})$ relationship

Thorough vetting of potential systematics Ross et al. 1203.6499

SYSTEMATIC ANALYSIS



Ross et al. arXiv:1203.6499



Ross et al. 2012

PTHalos galaxy mocks - Executive Summary

goal: covariance matrices for LSS

method: (Manera et al. arXiv:1203.6609)

generate 2LPT dark matter field

populate the DM field with halos
and halos with HOD galaxies

halo clustering matching NBody simulations at 10%
HOD is chosen by fitting xi(r) from boss galaxies

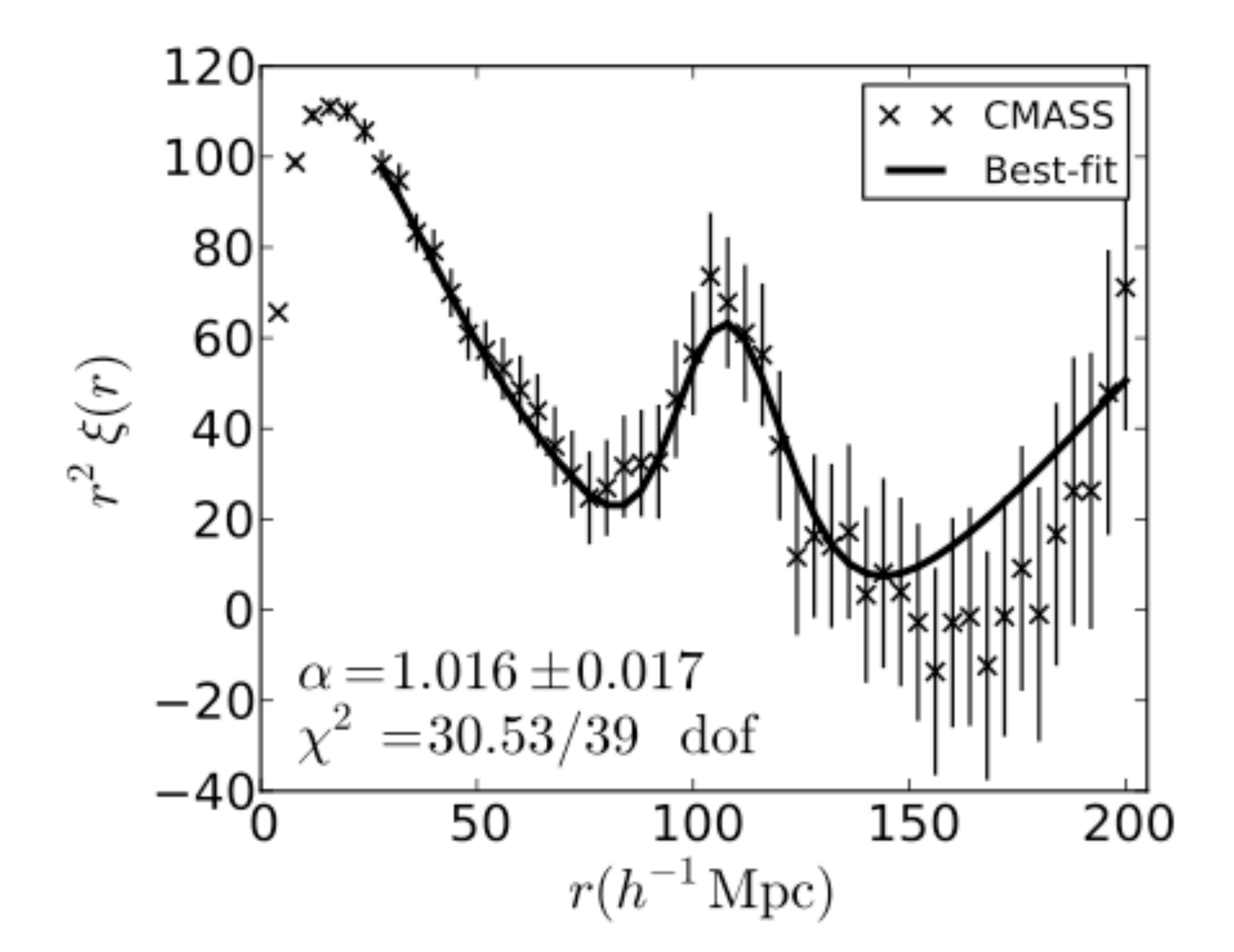
apply latest CMASS mask and n(z)

status: *600* 'version3'

IV.Results (monopole)

RESULTS

Anderson et al. arXiv:1203.6594



$$\xi(r) = \xi(\alpha\, r)_{fid} \qquad \alpha = \frac{(D_V/r_s)}{(D_V/r_s)_{fid}} \qquad D_V \equiv \left[\frac{cz(1+z)^2 D_A^2}{H(z)}\right]^{1/3}$$

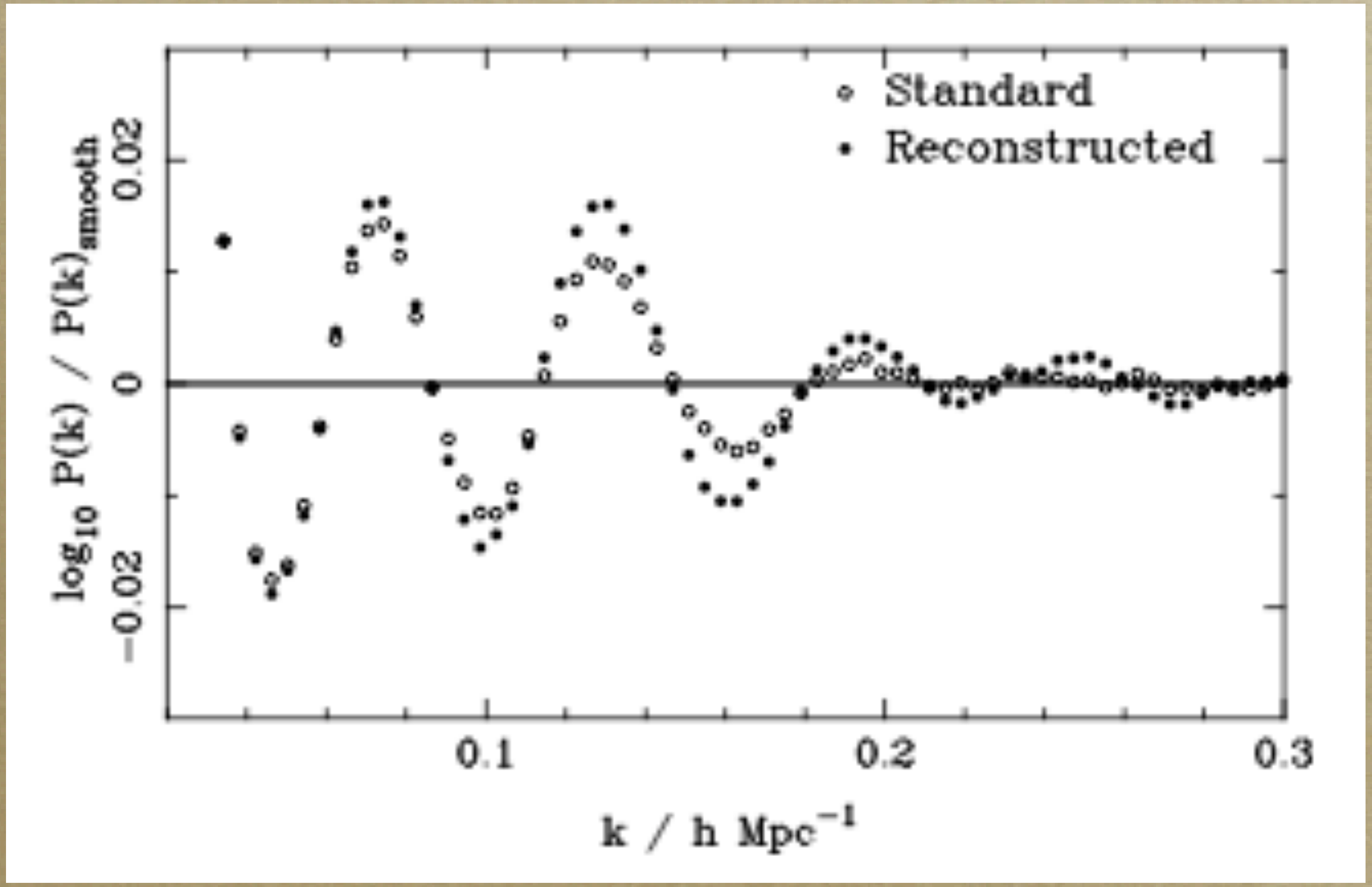
Modern Cosmology Workshop, Benasque, August 2012

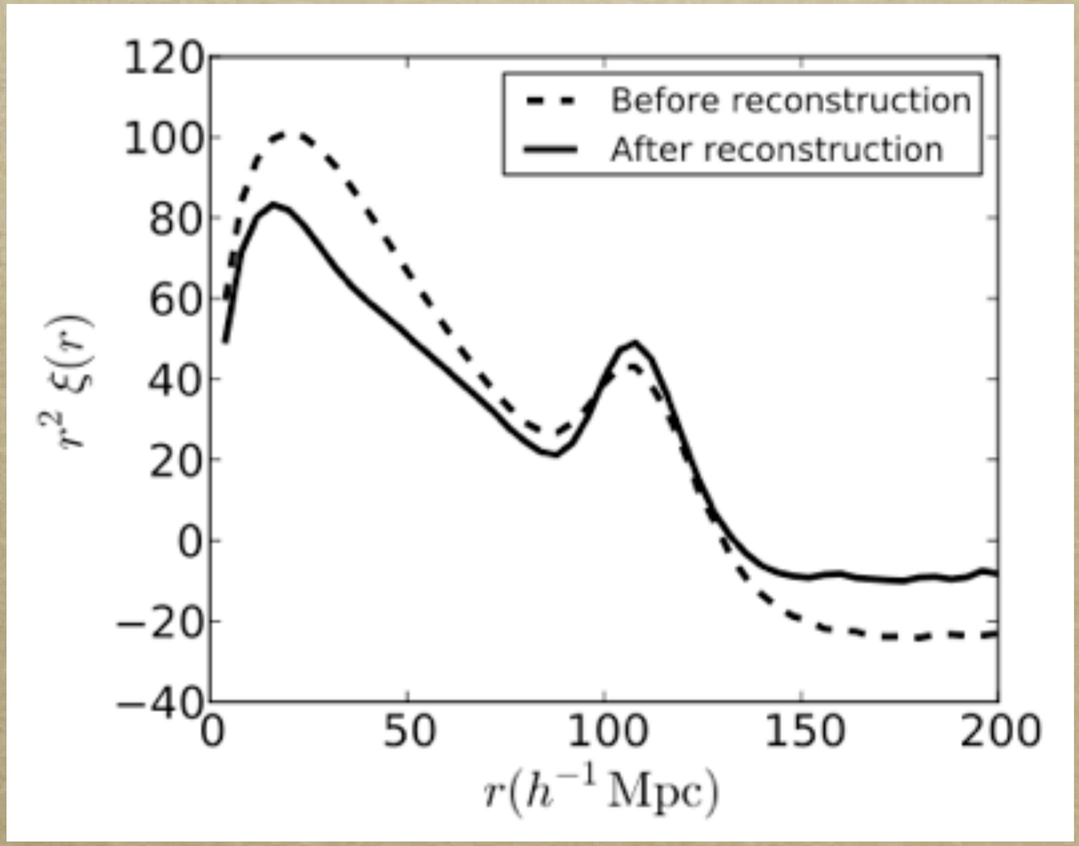
Reconstruction

- Attempts to move density field back in time and sharpen peak(s)
  see Eiseinstein et al. 2007, Padmanabhan 2012

- Small improvement for CMASS, 5%, but 50% on average for mocks

- Agrees in context of mock results





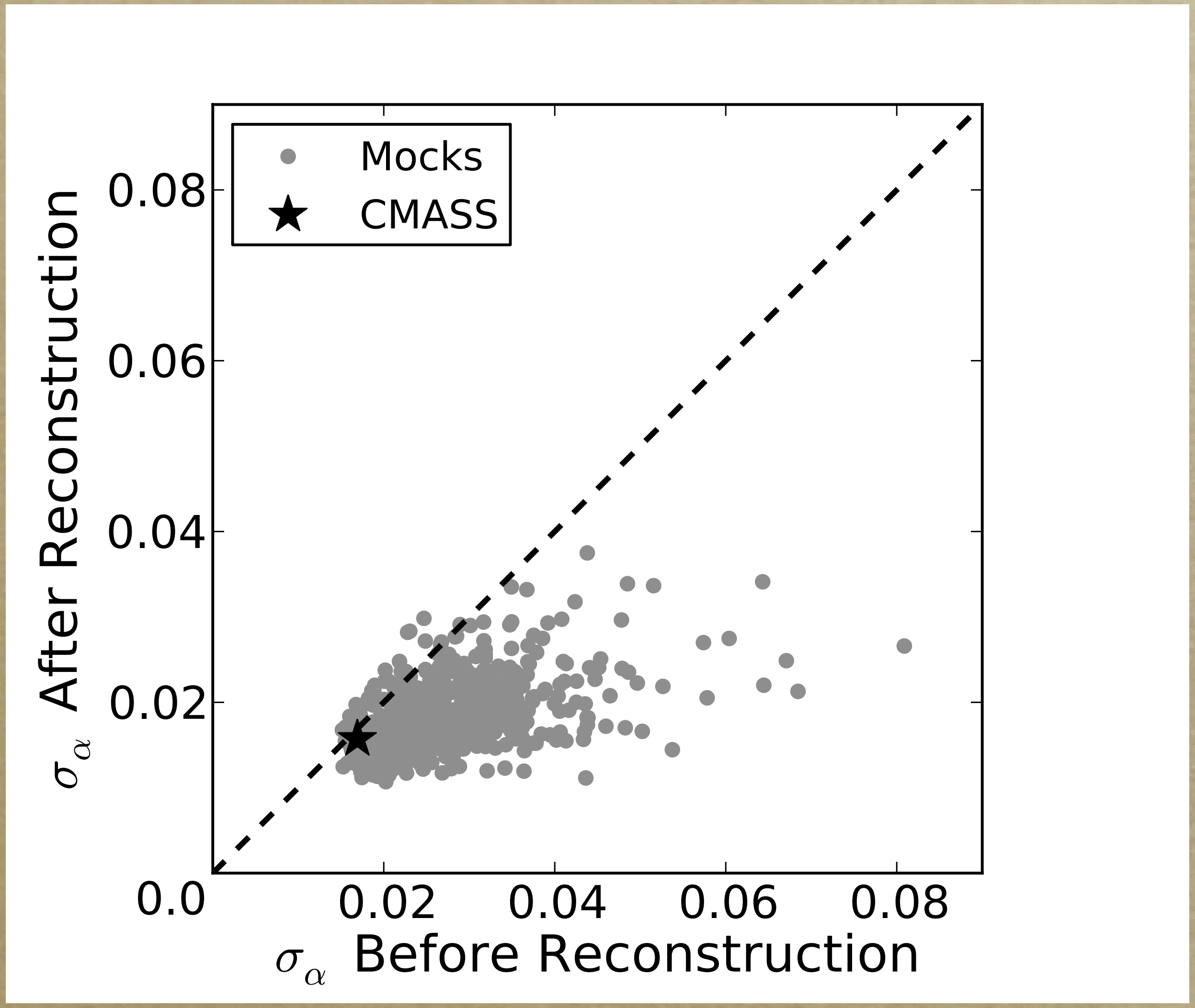
Anderson et al. arXiv:1203.6594

Reconstruction

- Attempts to move density field back in time and sharpen peak(s)
  see Eiseinstein et al. 2007, Padmanabhan 2012

- Small improvement for CMASS, 5%, but 50% on average for mocks

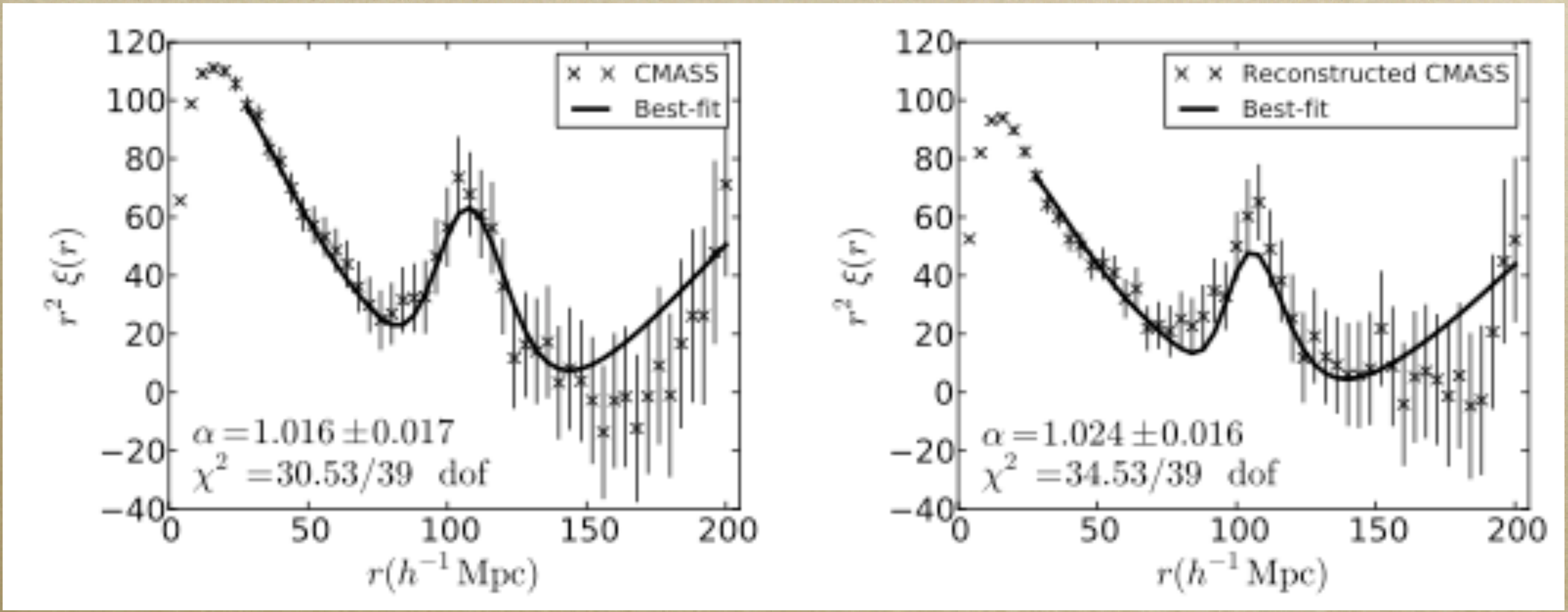
- Agrees in context of mock results



Anderson et al. arXiv:1203.6594

RESULTS

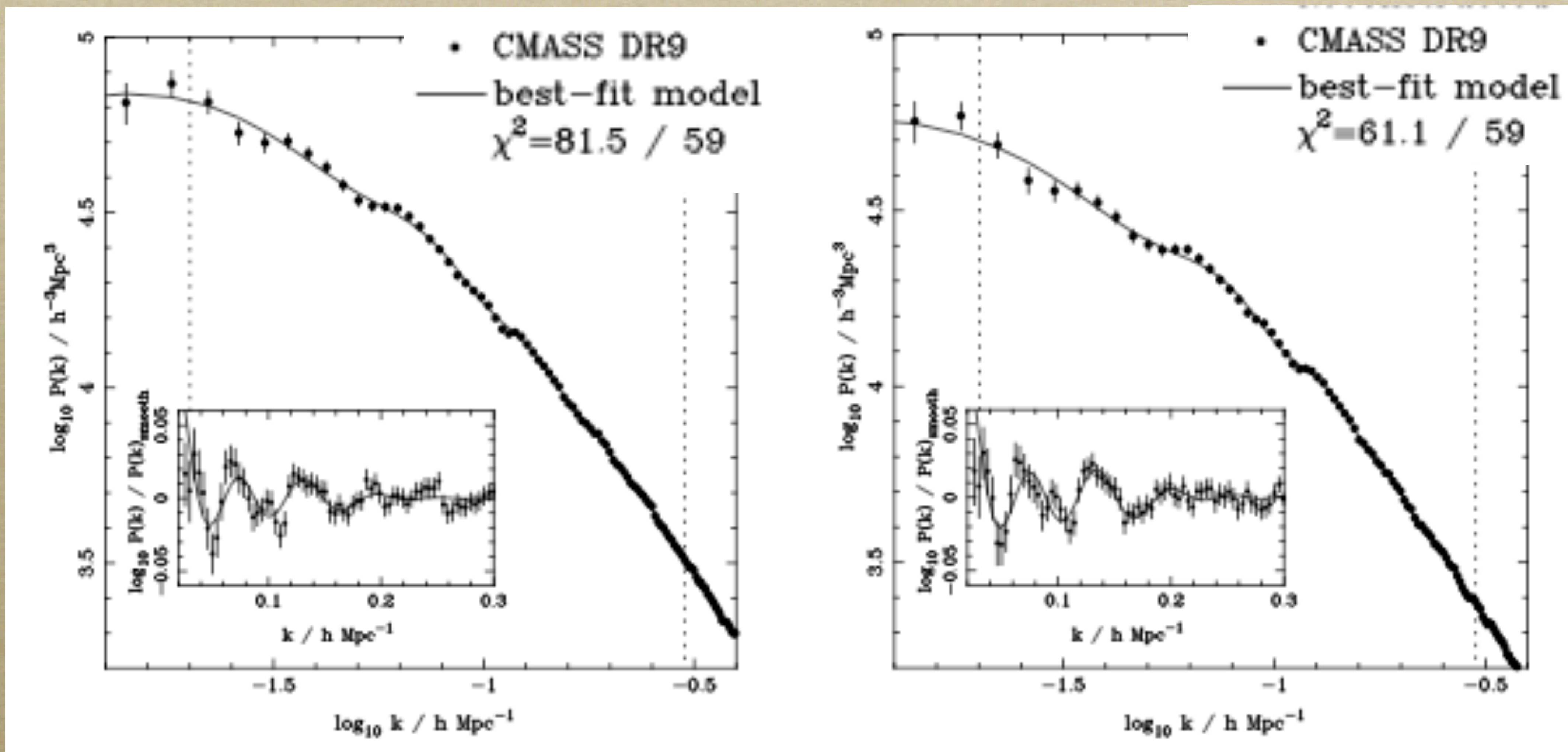
Anderson et al. arXiv:1203.6594



Modern Cosmology Workshop, Benasque, August 2012

RESULTS

Anderson et al. arXiv:1203.6594

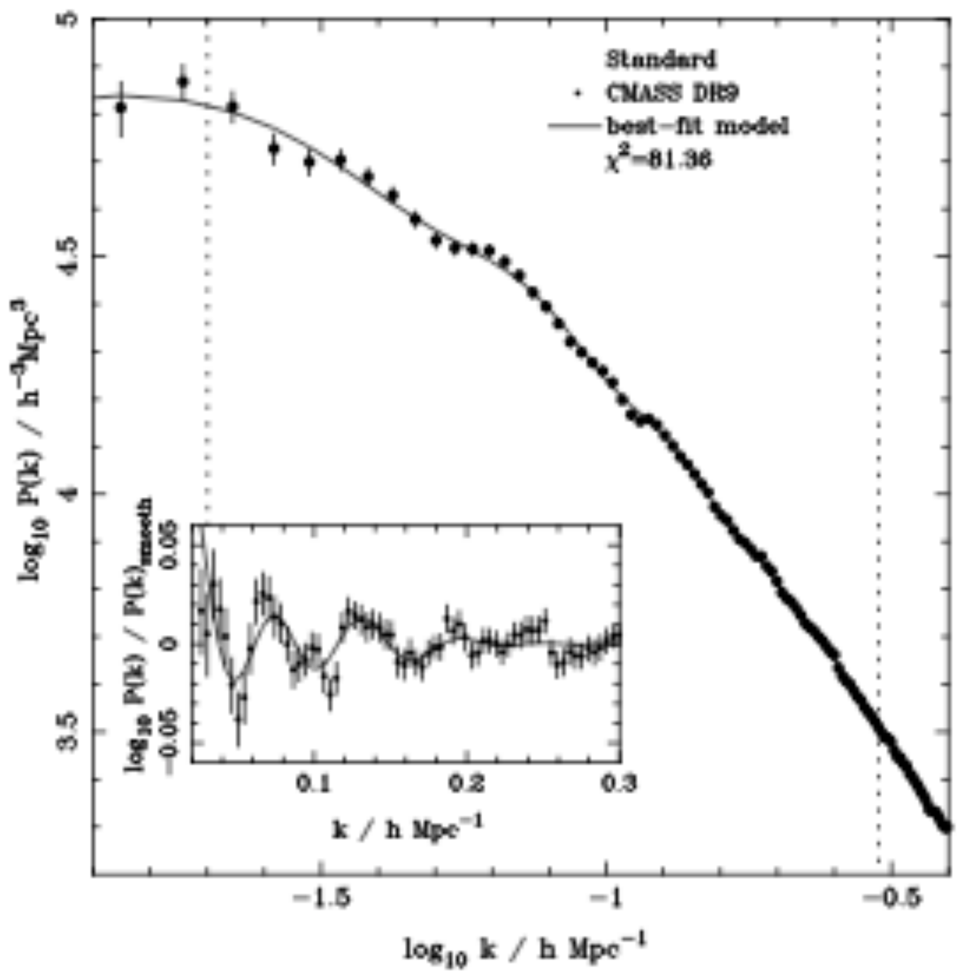


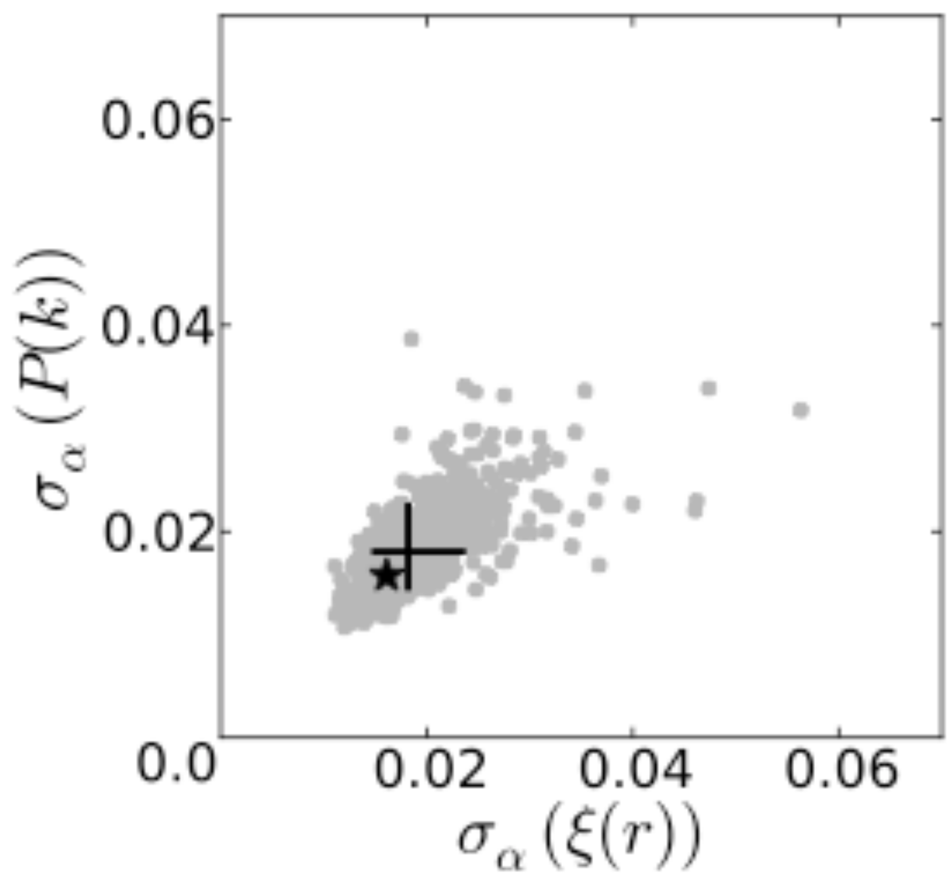
$\alpha = 1.022 \pm 0.017$ $\alpha = 1.042 \pm 0.016$

Modern Cosmology Workshop, Benasque, August 2012

RESULTS

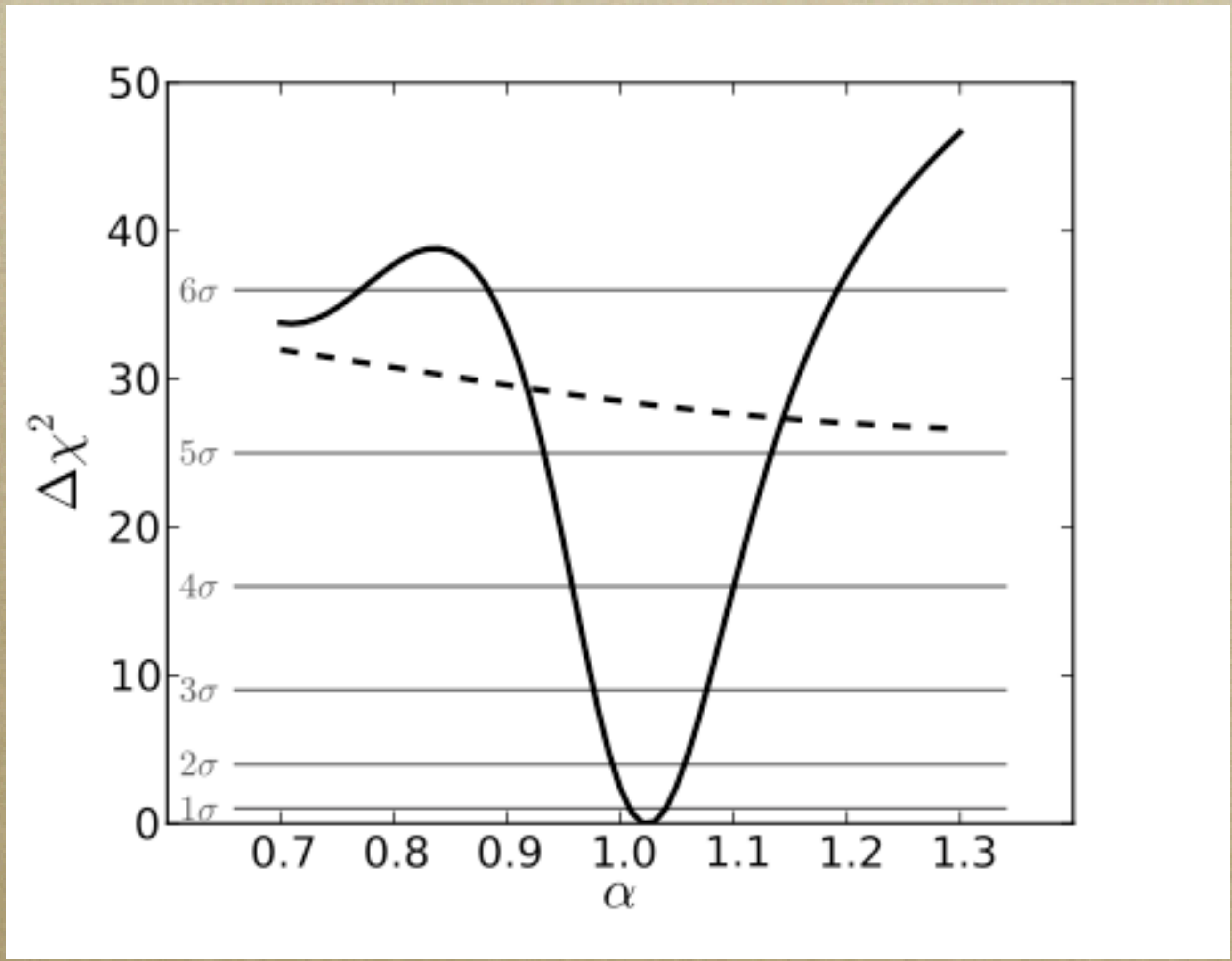
Anderson et al. arXiv:1203.6594





Modern Cosmology Workshop, Benasque, August 2012

RESULTS: BAO SCALE



$$\chi^2(\alpha) = [\vec{d} - \vec{m}(\alpha)]^T C^{-1} [\vec{d} - \vec{m}(\alpha)],$$

- Anderson et al. 1203:6594
- 5σ detection!
- <2% uncertainty on BAO position measurements
- Robust to systematics: ignore corrections; < 0.1σ change
- Differences between P an xi consistent with expectations from mocks
- Consensus:

$$\alpha = 1.033 \pm 0.017$$

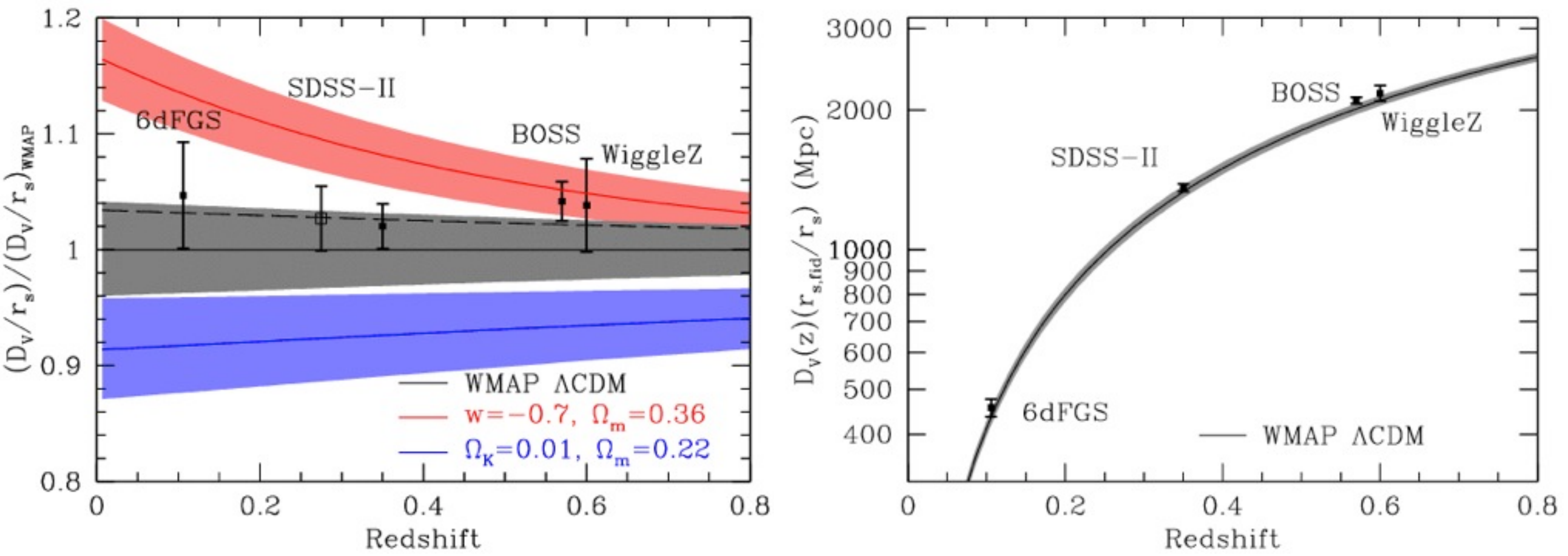
$$D_V(0.57)/r_s = 13.67 \pm 0.22$$

$$D_V(0.57) = 2094 \pm 0.34$$

Modern Cosmology Workshop, Benasque, August 2012

$$\Omega_M = 0.274 \quad \Omega_L = 0.726 \quad \Omega_b = 0.0457$$

$$h = 0.7 \quad \sigma_8 = 0.8 \quad n_s = 0.95$$

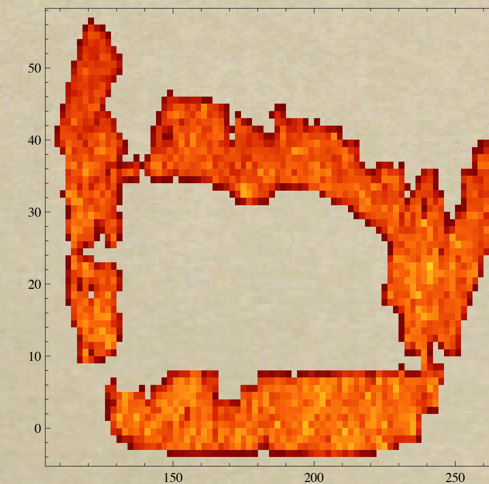


Anderson et al. arXiv:1203.6594

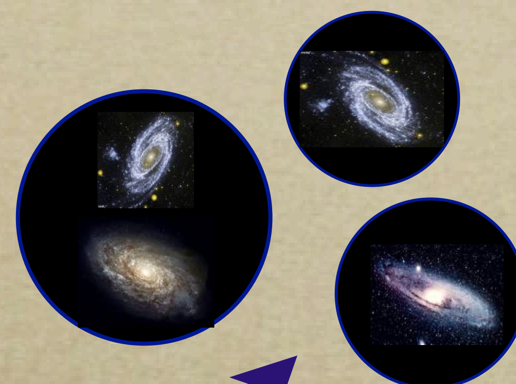
Modern Cosmology Workshop, Benasque, August 2012

VI.Mock galaxy catalogues

Galaxy Mocks In Steps

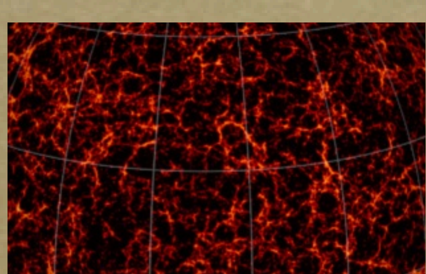


Mask and geometry



Galaxy field

Halo field



Dark Matter field

matter: 2LPT

- 2LPT is very fast (< 5min per run)
- Better than linear, good at large scales.
- We are trading accuracy versus number of runs
- Already used to generate mocks

  (see first PTHalo paper Scoccimarro & Sheth 2002)

- We use initial P(k) from CAMB
- Shell crossing reduced by means of a cut off inspired by RPT.
- 600+ runs
- $N=1280^3$ L=2400 Mpc/h

- We can compare with simulations to calibrate.

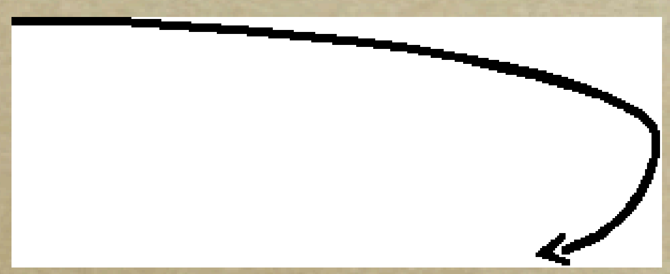
KRAKEN, Tennesse

SCIAMA, Portsmouth

2LPT *2nd Order Lagrangian Perturbation Theory*

- 

$$\vec{x} = \vec{q} + \vec{\Psi}(\vec{q})$$

- 

$$\vec{\Psi} = \vec{\Psi}^{(1)} + \vec{\Psi}^{(2)} + \ldots$$

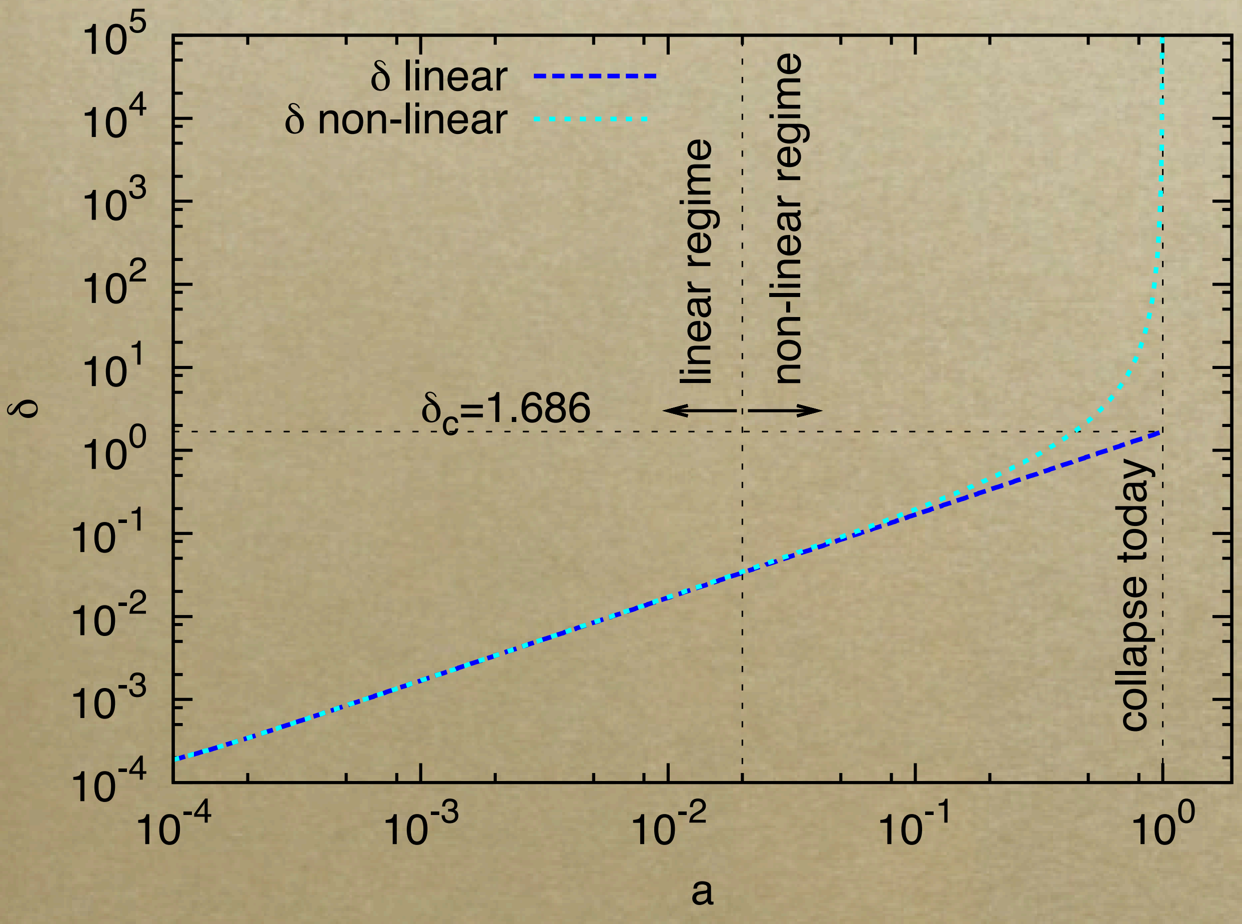
solve it at second order

• *Note: 2LPT used to set IC for N-Body simulations. Relevant because otherwise transients have a significant effect in both P(k) and n(m).*

$$\frac{d^2 x}{dr^2} + \mathcal{H}(\tau)\frac{dx}{dr} = \nabla\Phi$$

Clustering in 2LPT is different than N-Body

Eulerian (NBody)



$$\delta_l = 1.686 \rightarrow \delta_{NL} = 200$$

Lagrangian (2LPT)

$$\vec{x} = \vec{q} + \vec{\Psi}(\vec{q})$$

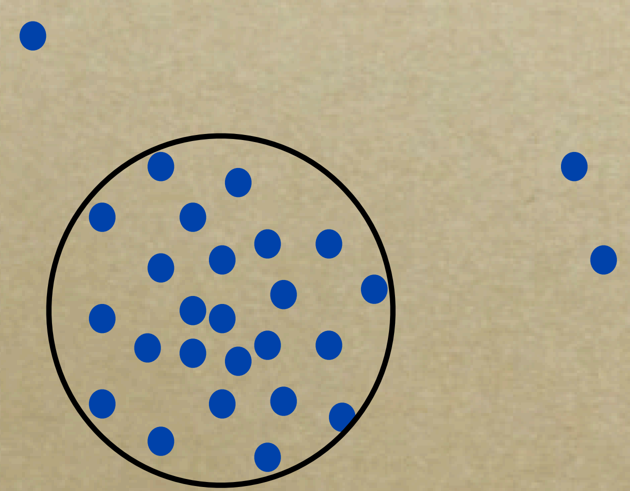
$$\delta_{2LPT} = \frac{1}{Det\left(1 + \frac{\partial \Psi}{\partial q_j}\right)} - 1$$

$$\delta_{2LPT} = \frac{1}{1 - \frac{\delta_0}{3}(D_1 - \frac{\delta_0}{3} D_2)} - 1$$

$$\delta_l = 1.686 \rightarrow \delta_{NL} = 34$$

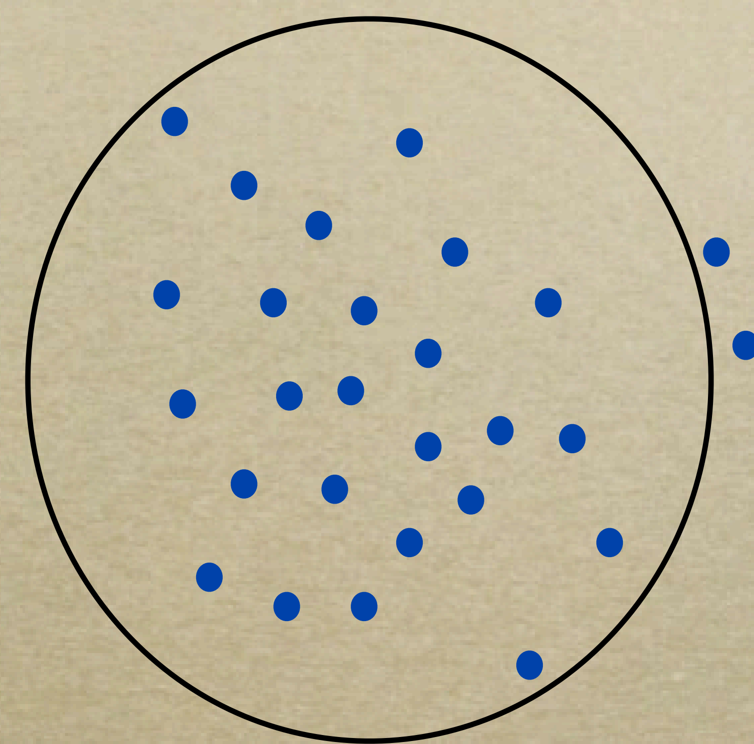
Clustering in 2LPT is different than N-Body

Eulerian (NBody)



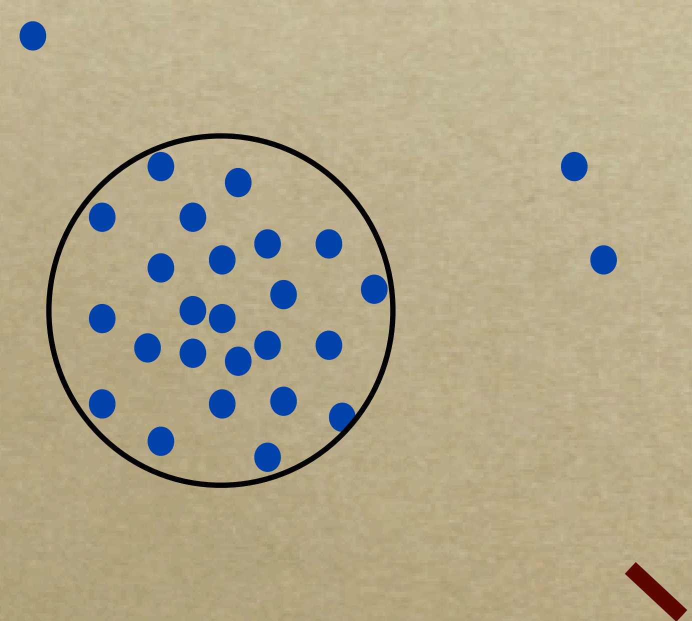
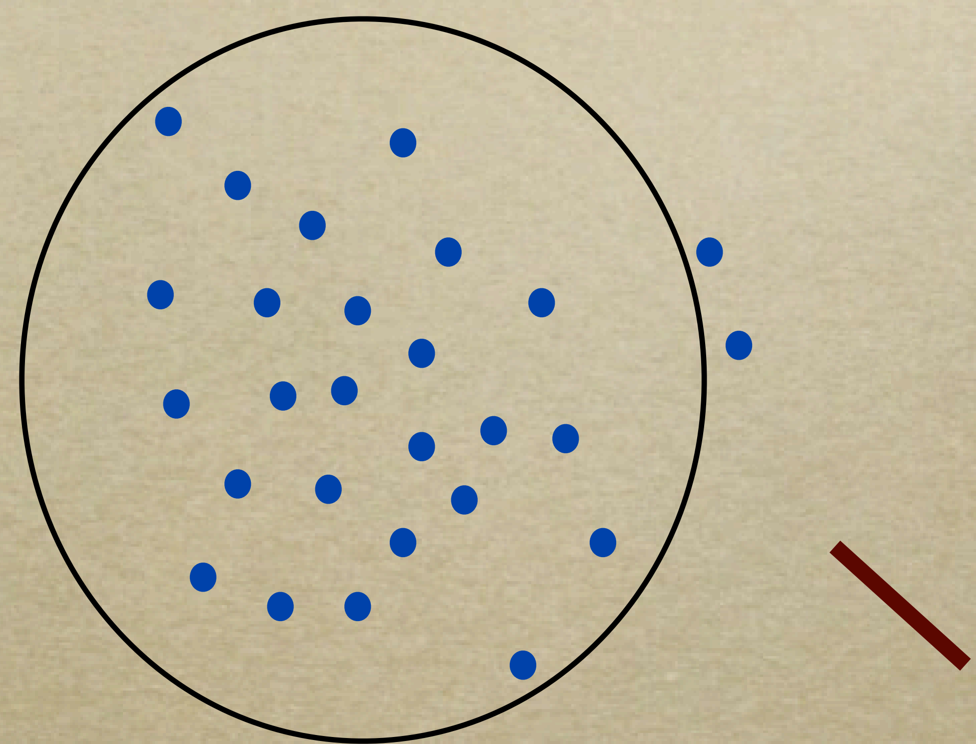
$$\delta_l = 1.686 \rightarrow \delta_{NL} = 200$$

Lagrangian (2LPT)



$$\delta_l = 1.686 \rightarrow \delta_{NL} = 34$$

Clustering in 2LPT is different than N-Body

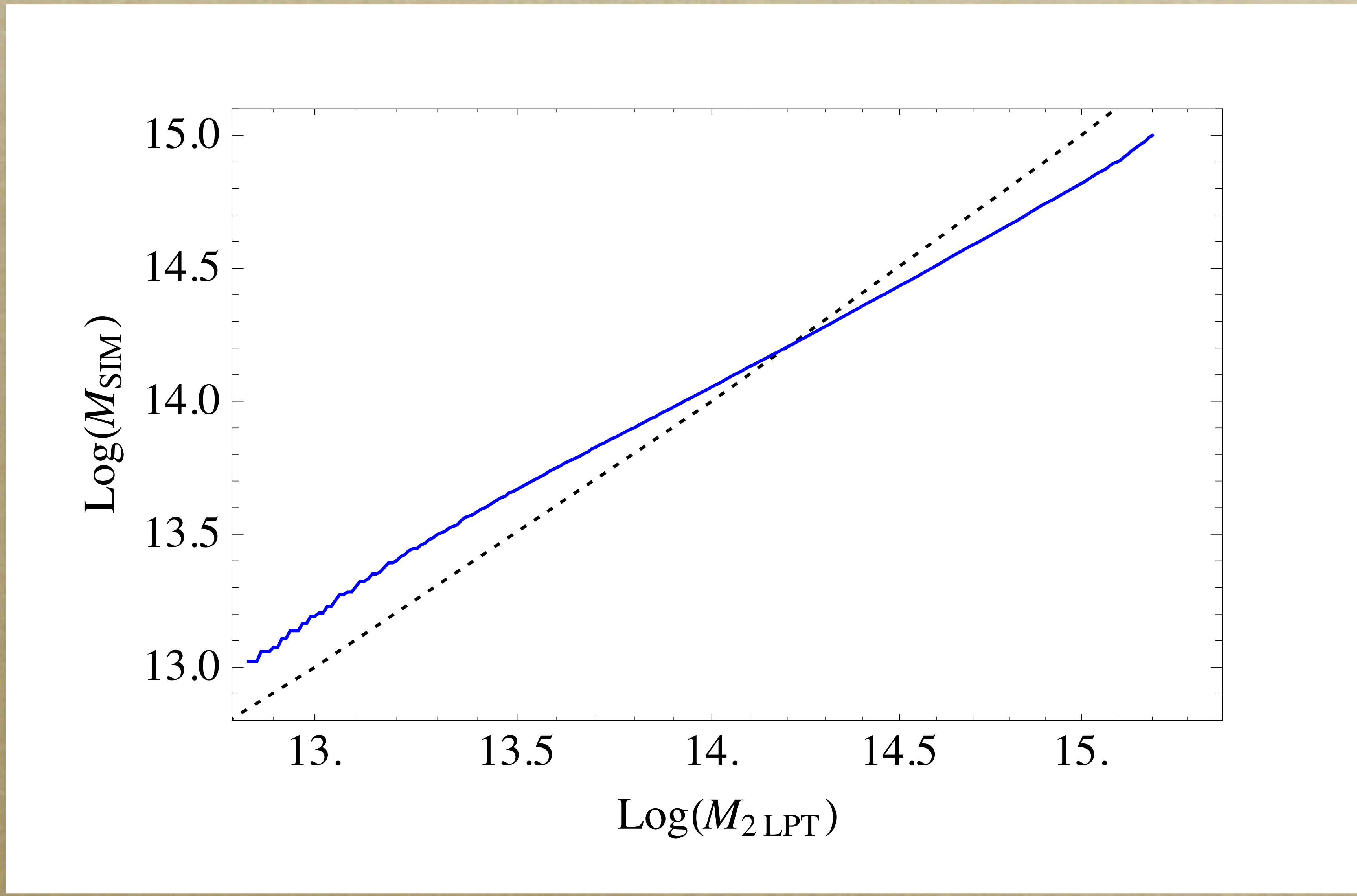
Eulerian (NBody)	*Lagrangian (2LPT)*
	
$\delta_l = 1.686 \rightarrow \delta_{NL} = 200$	$\delta_l = 1.686 \rightarrow \delta_{NL} = 34$
b=0.2	*b=0.38*

PTHalos: populating DM with Halos

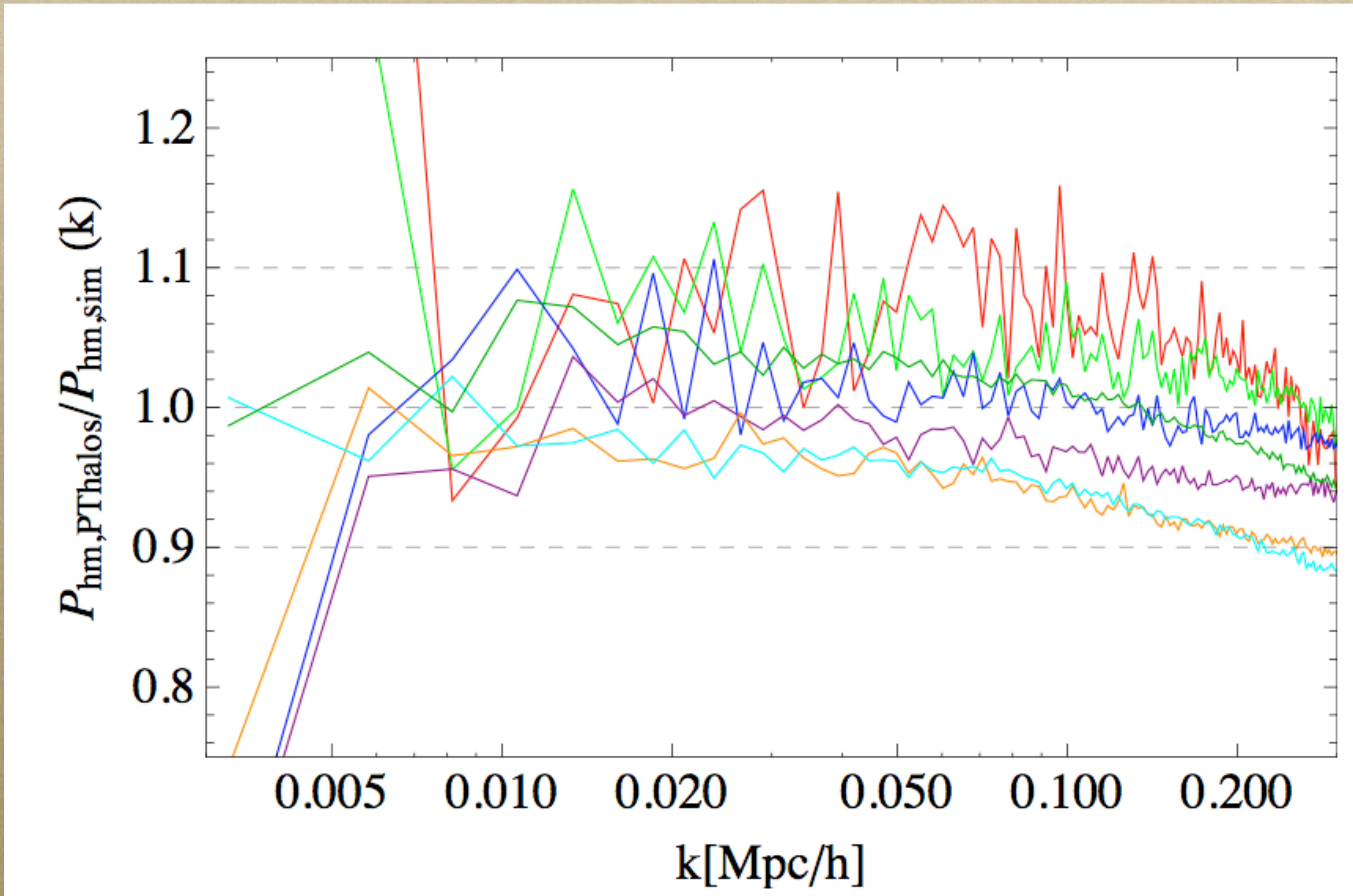
- Halos are found by Friends of Friends with $b=0.38$
- Masses are set to match a given mass function

PTHalos: populating DM with Halos

- *Halos are found by Friends of Friends with b=0.38*
- *Masses are set to match a given mass function*

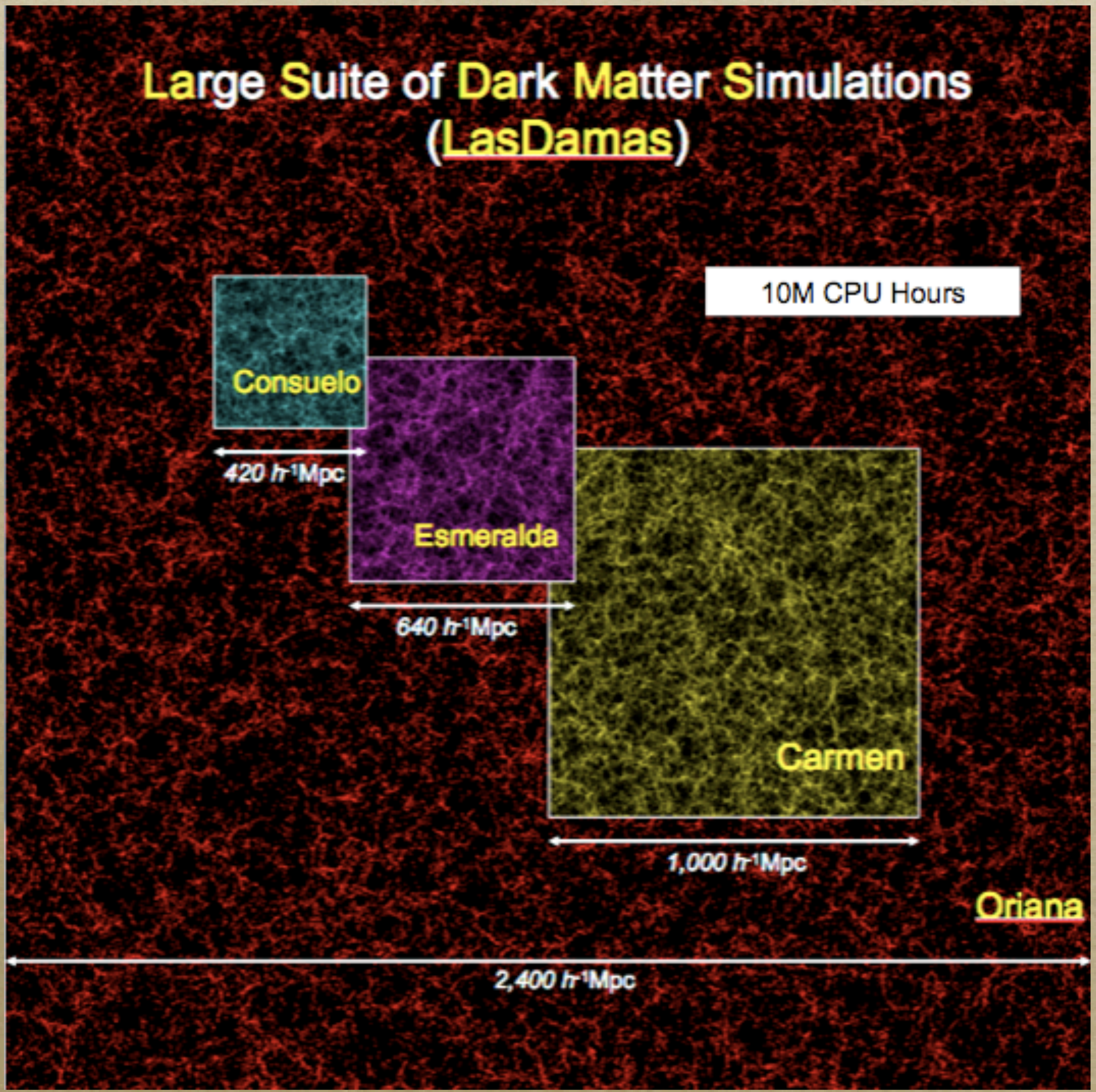


method: finding halos



Halos from N-Body found with FoF b=0.2 , 2LPT b=0.38

LasDamas Simulations



http://lss.phy.vanderbilt.edu/lasdamas/overview.html

VANDERBILT U.
Andreas Berlind
HARVARD
Cameron McBride
-
ITP ZURICH
Michael Busha
SLAC
Risa Wechsler
-
YALE
Frank van den Bosch
-
NYU
Roman Scoccimarro
ICG
Marc Manera

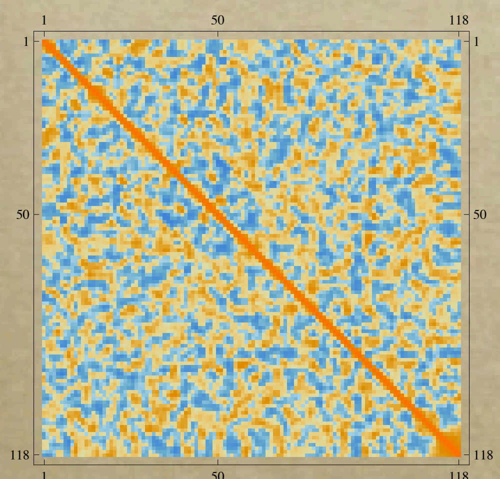
$\Omega_b = 0.04$ $n_s = 1$

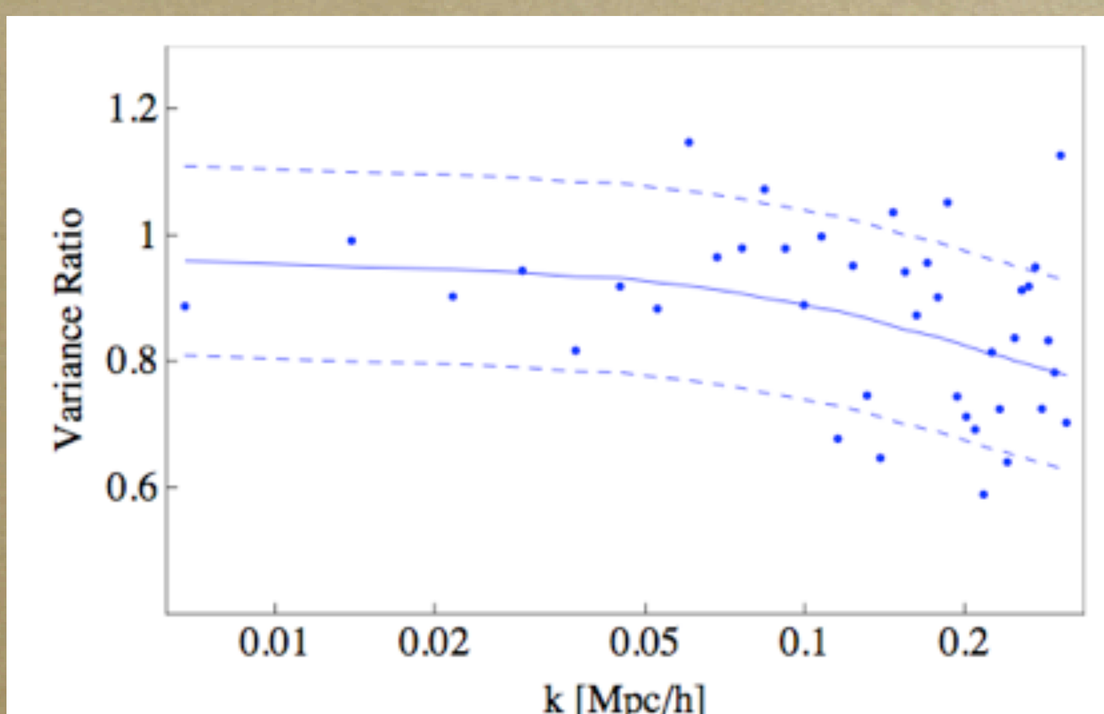
$\Omega_\Lambda = 0.75$ $h = 0.7$

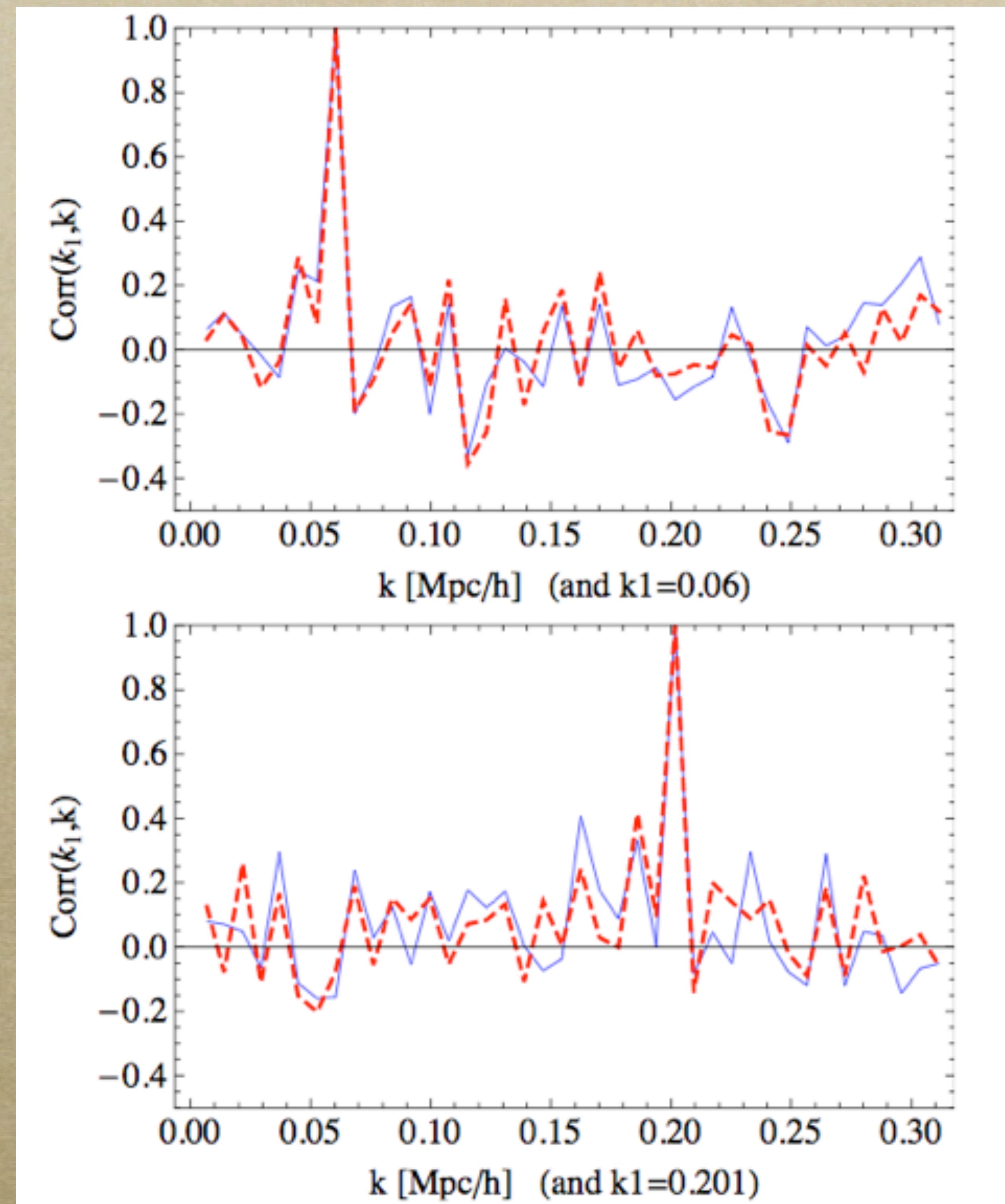
$\Omega_m = 0.25$ $\sigma_8 = 0.8$

method: finding halos

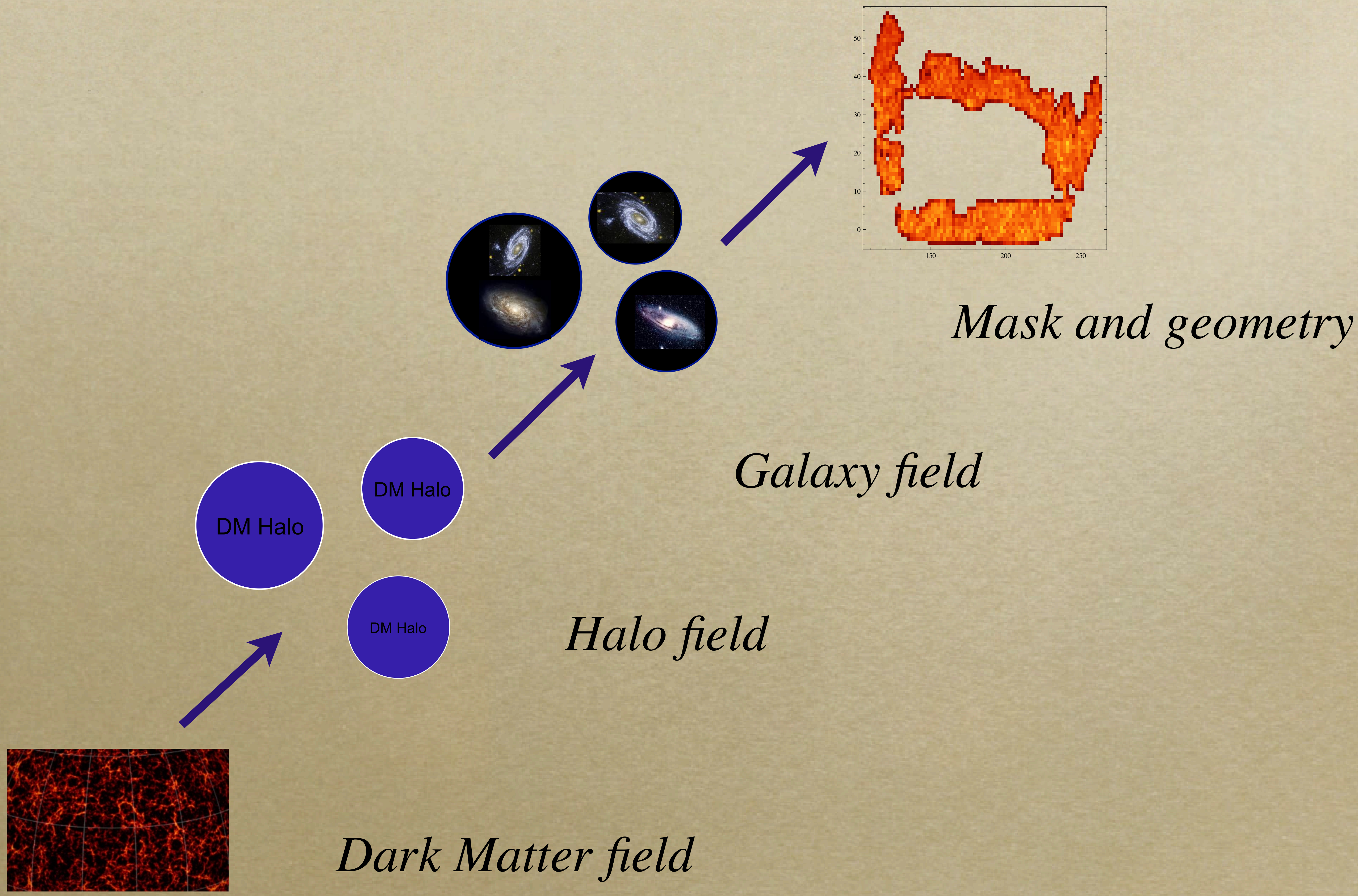
$$Corr(k_1, k_2) = \frac{< (P_{hm} - \bar{P}_{hm})_{k_1} (P_{hm} - \bar{P}_{hm})_{k_2} >}{\sigma(k_1)\sigma(k_2)}$$







Galaxy Mocks In Steps



Geometry

1. Cubic Box

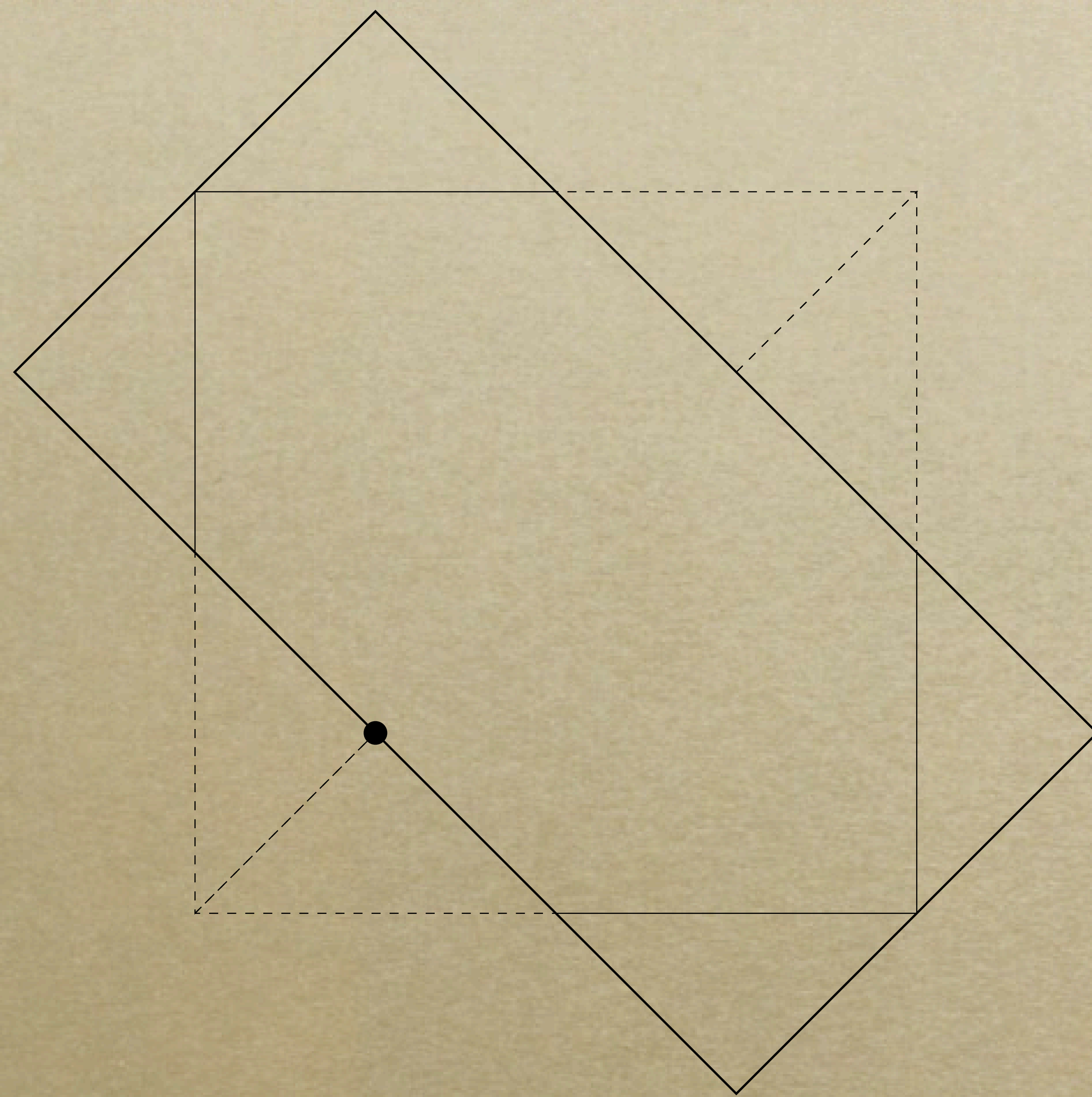
L=2400 Mpc/h

Geometry

L = 2400 Mpc h

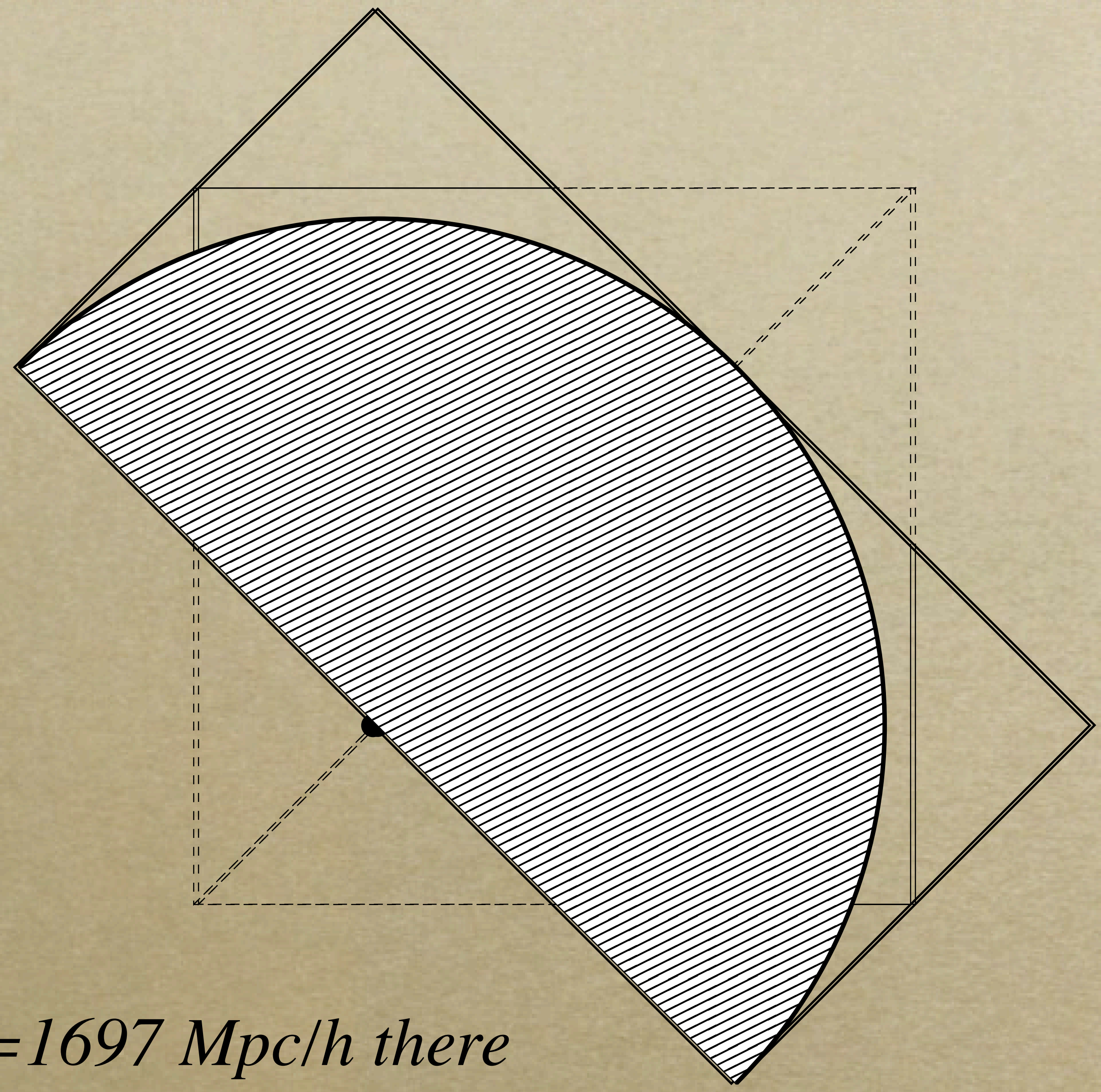
1. *Cubic Box*
2. *Reshape Box*

Geometry



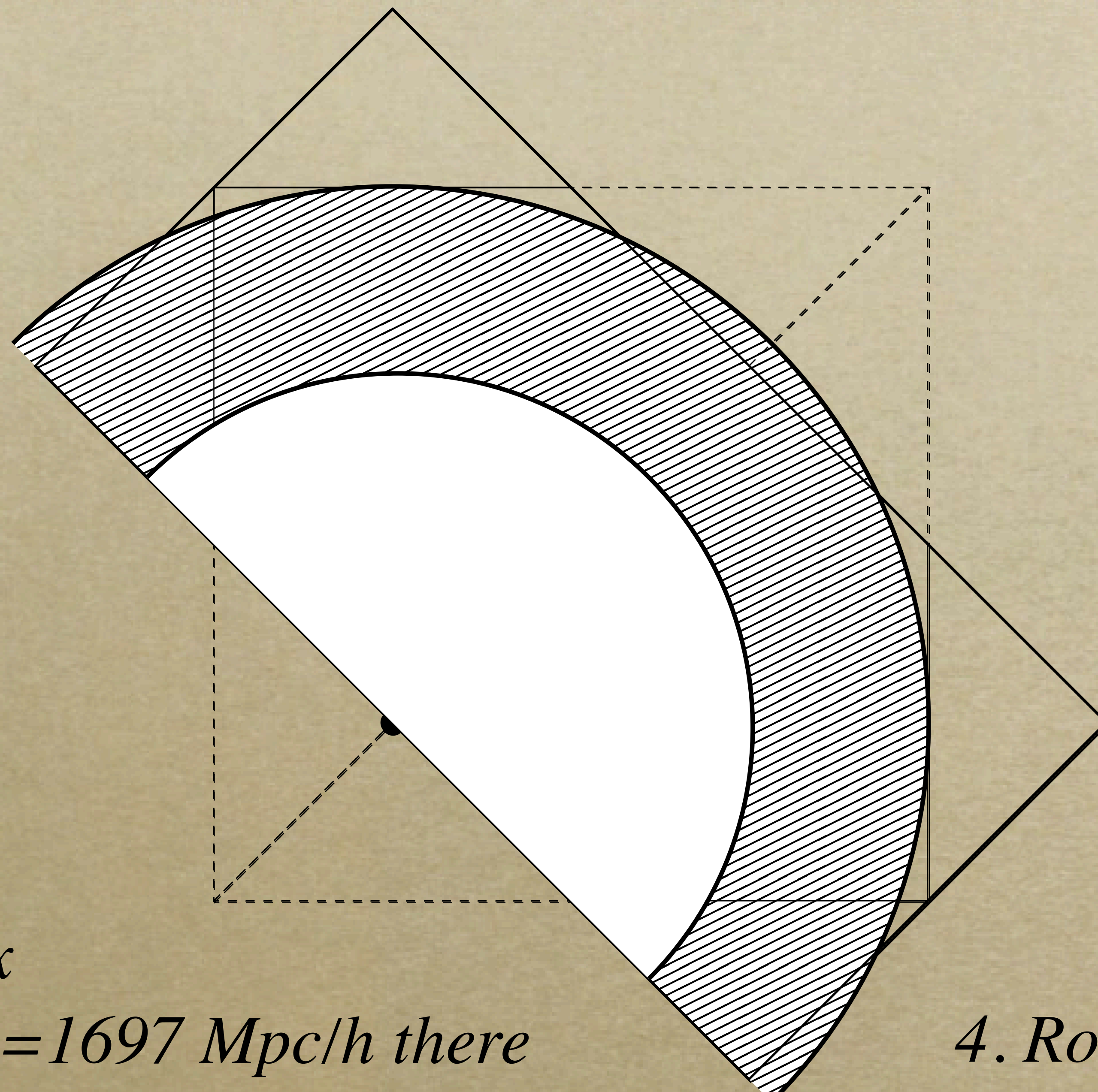
1. Cubic Box
2. Reshape Box

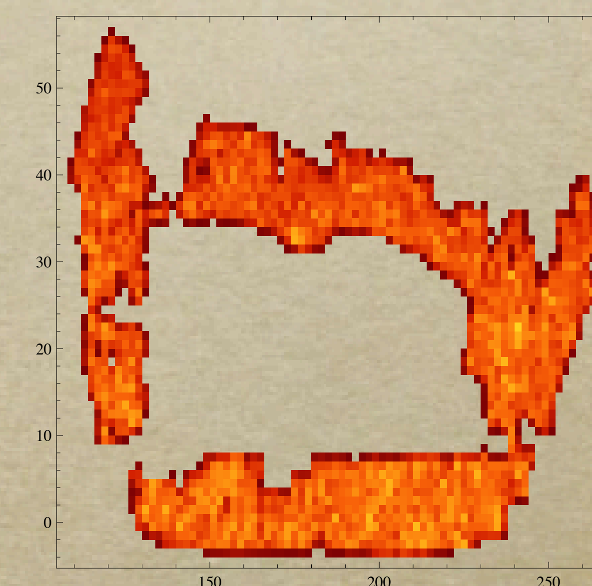
Geometry



1. Cubic Box
2. Reshape Box
3. Now, until r=1697 Mpc/h there is a quarter of the sky accessible without repetition of the underlying matter.

Geometry





1. Cubic Box
2. Reshape Box
3. Now, until r=1697 Mpc/h there is a quarter of the sky accessible without repetition of the underlying matter.

4. Rotate to fit survey
5. Because of the DR9 mask, z=0.7 (r=1777 Mpc/h) still has no repetition

Mask

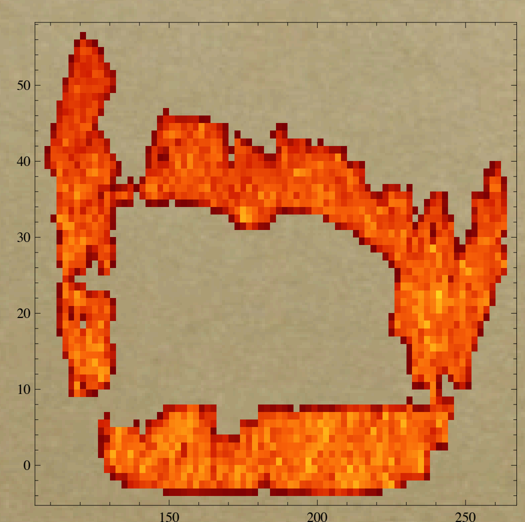
a) We subsample our galaxies to match DR9 splined n(z)

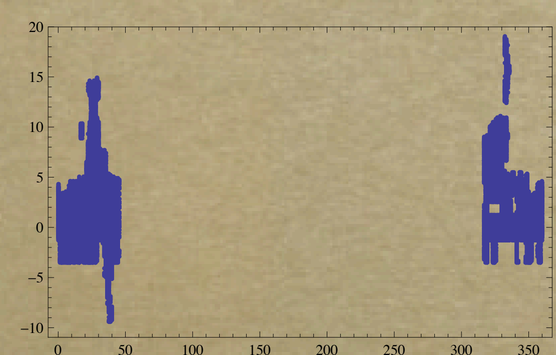
- matching total number of galaxies with good redshifts (flags 1 & 6)

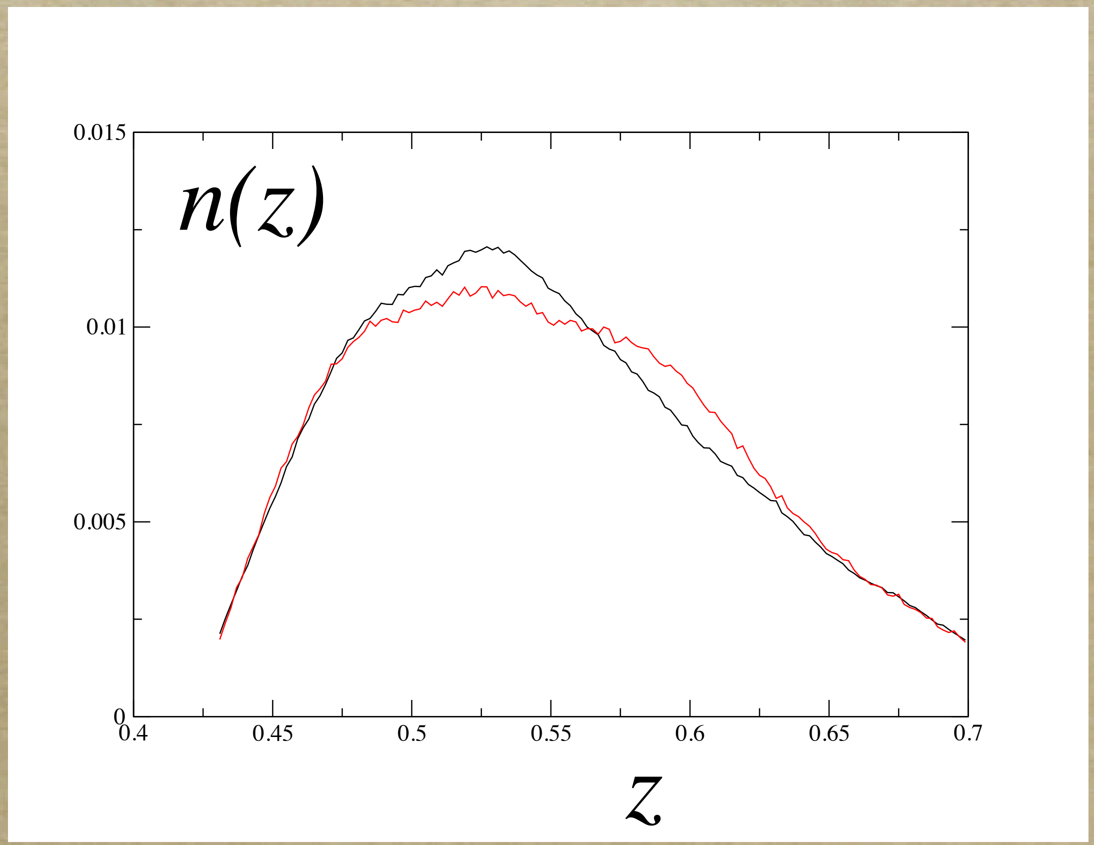
b) North and South are treated each with its own n(z)

c) Completeness applied sector by sector.

$$com(sec) = \frac{n_{gal} + n_{stars} + n_{zfail}}{n_{gal} + n_{stars} + n_{ffail} + n_{zfail} + n_{cp}} \; \frac{n_{gal}}{n_{gal} + n_{zfail}}$$







fiducial cosmology

LasDamas http://lss.phy.vanderbilt.edu/lasdamas/

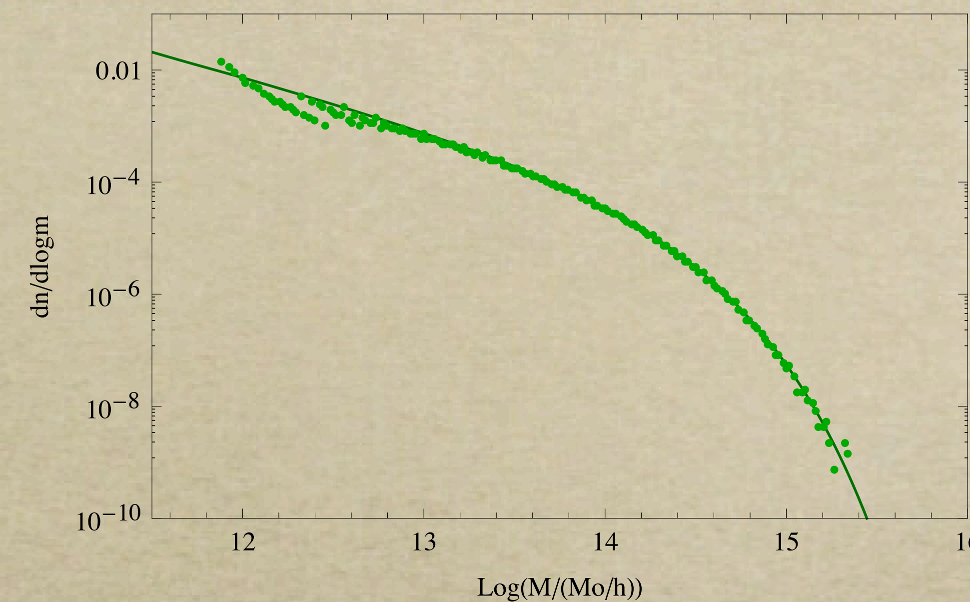
$$\Omega_M = 0.25 \quad \Omega_L = 0.75 \quad \Omega_b = 0.04$$

$$h = 0.7 \quad \sigma_8 = 0.8 \quad n_s = 1$$

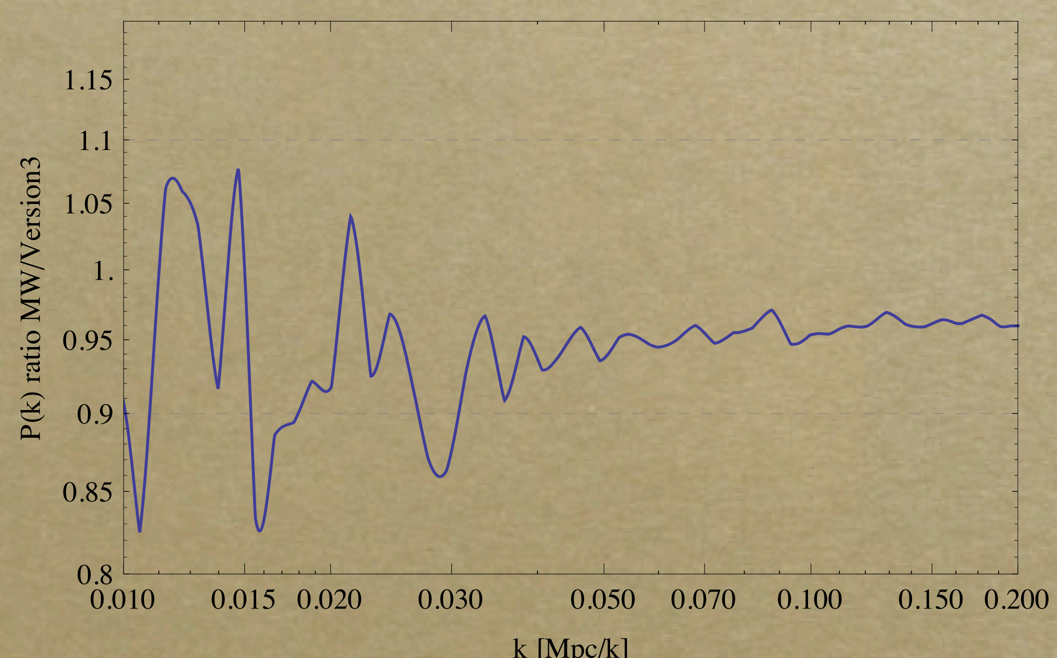
New Fiducial *(as in White et al 2010)*

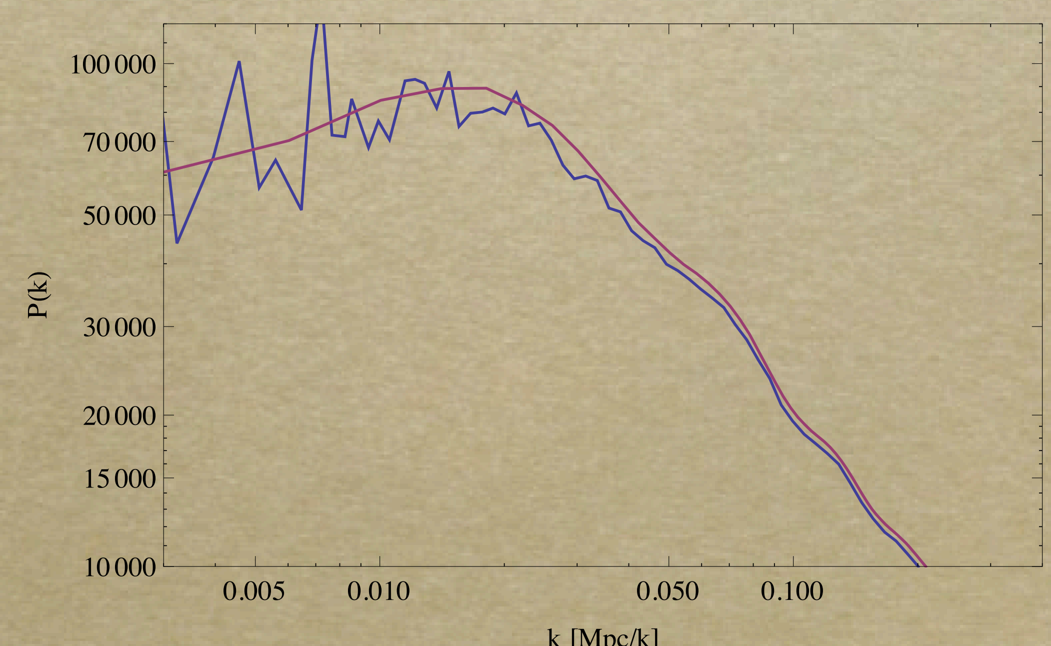
$$\Omega_M = 0.274 \quad \Omega_L = 0.726 \quad \Omega_b = 0.0457$$

$$h = 0.7 \quad \sigma_8 = 0.8 \quad n_s = 0.95$$

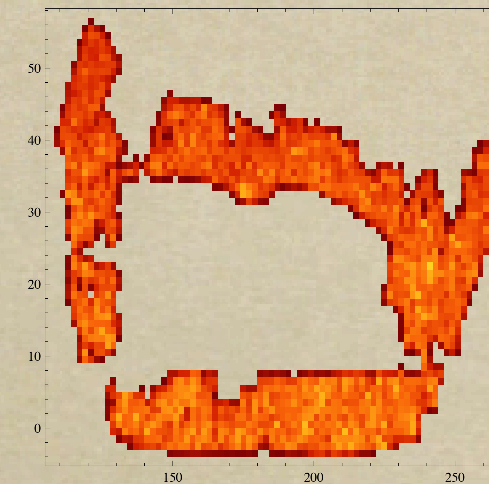


we use Tinker et al 2010 mass function

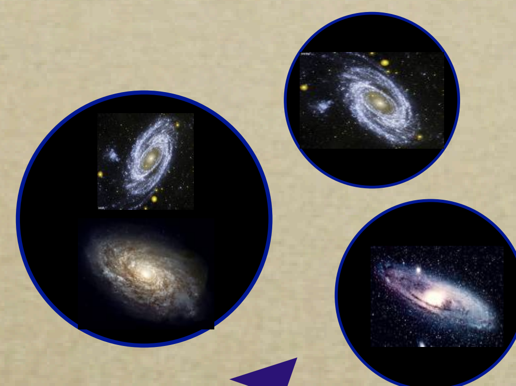




Galaxy Mocks In Steps

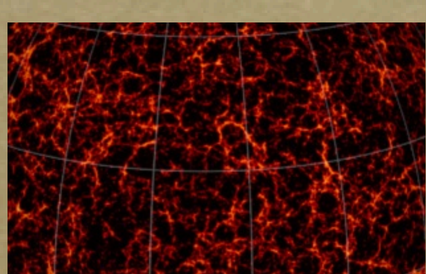


Mask and geometry



Galaxy field

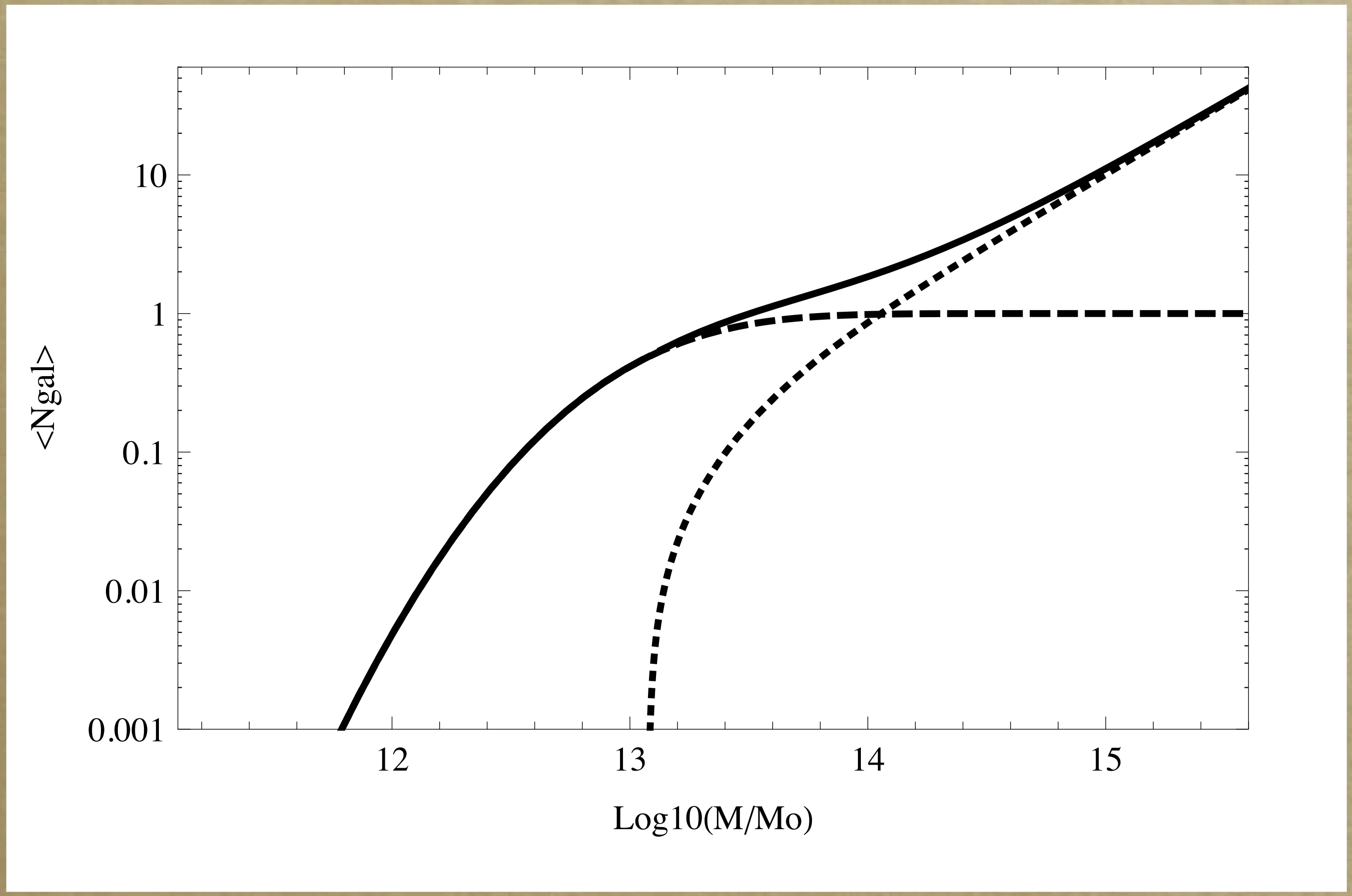
Halo field



Dark Matter field

HOD fit

- HOD of 5 parameters.
- We use an octant of the sky and compute xi(r), including RSD
- The run of the fit is chosen to be closest to the mean.
- The covariance matrix of the fit is from version2
- We fit against measured xi(r) from DR9, range 30-80 Mpc/h



Zheng et at 2005 functional form

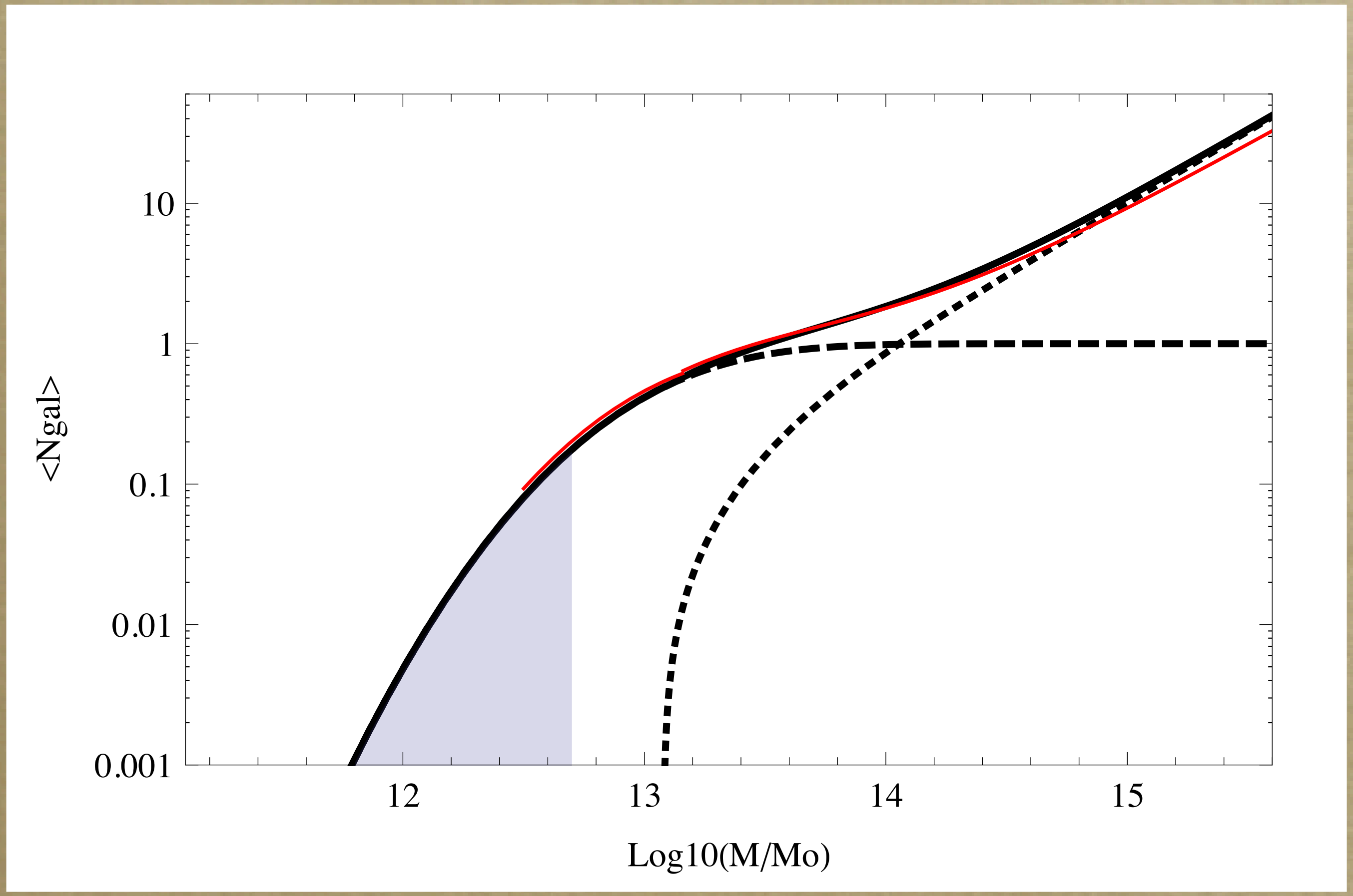
$$< N(M) > = < N_{cen} > + < N_{sat} >$$

$$< N_{cen} >= \frac{1}{2}\left[1 + erf\left(\frac{logM - logM_{min}}{\sigma_{logM}}\right)\right]$$

$$< N_{sat} >=< N_{cen} > \left(\frac{M - M_0}{M_1}\right)^{\alpha}$$

HOD fit

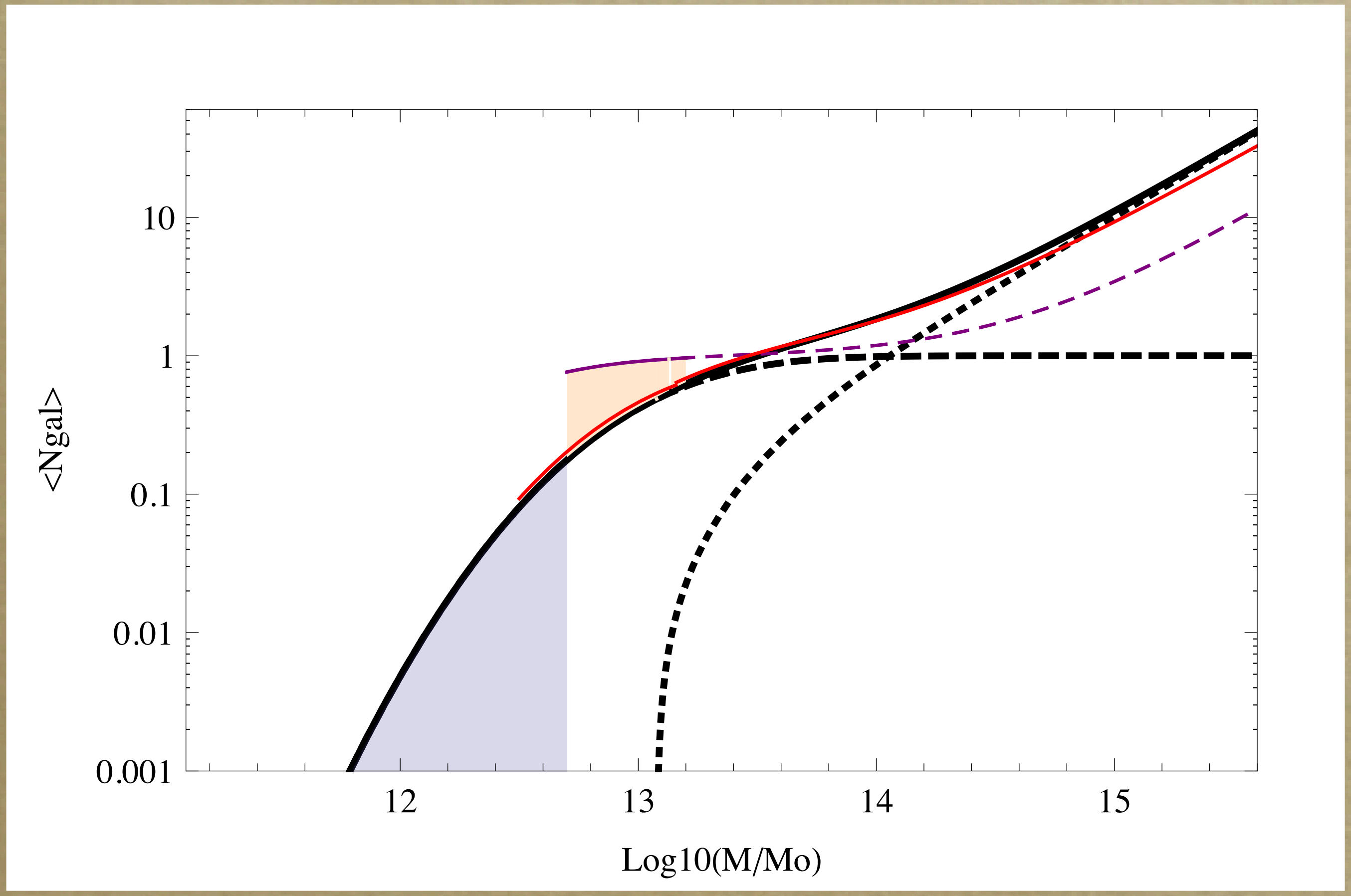
- HOD of 5 parameters.
- We use an octant of the sky and compute xi(r), including RSD
- The run of the fit is chosen to be closest to the mean.
- The covariance matrix of the fit is from version2
- We fit against measured xi(r) from DR9, range 30-80 Mpc/h



- We use the Simplex method, starting with an HOD that fits N-Body simulations.
- About 50% of galaxies would in halos below our M_{min}. They are drawn from the dark matter particles.

HOD fit

- HOD of 5 parameters.
- We use an octant of the sky and compute xi(r), including RSD
- The run of the fit is chosen to be closest to the mean.
- The covariance matrix of the fit is from version2
- We fit against measured xi(r) from DR9, range 30-80 Mpc/h



- We use the Simplex method, starting with an HOD that fits N-Body simulations.
- About 50% of galaxies would in halos below our M_{min}. They are drawn from the dark matter particles.

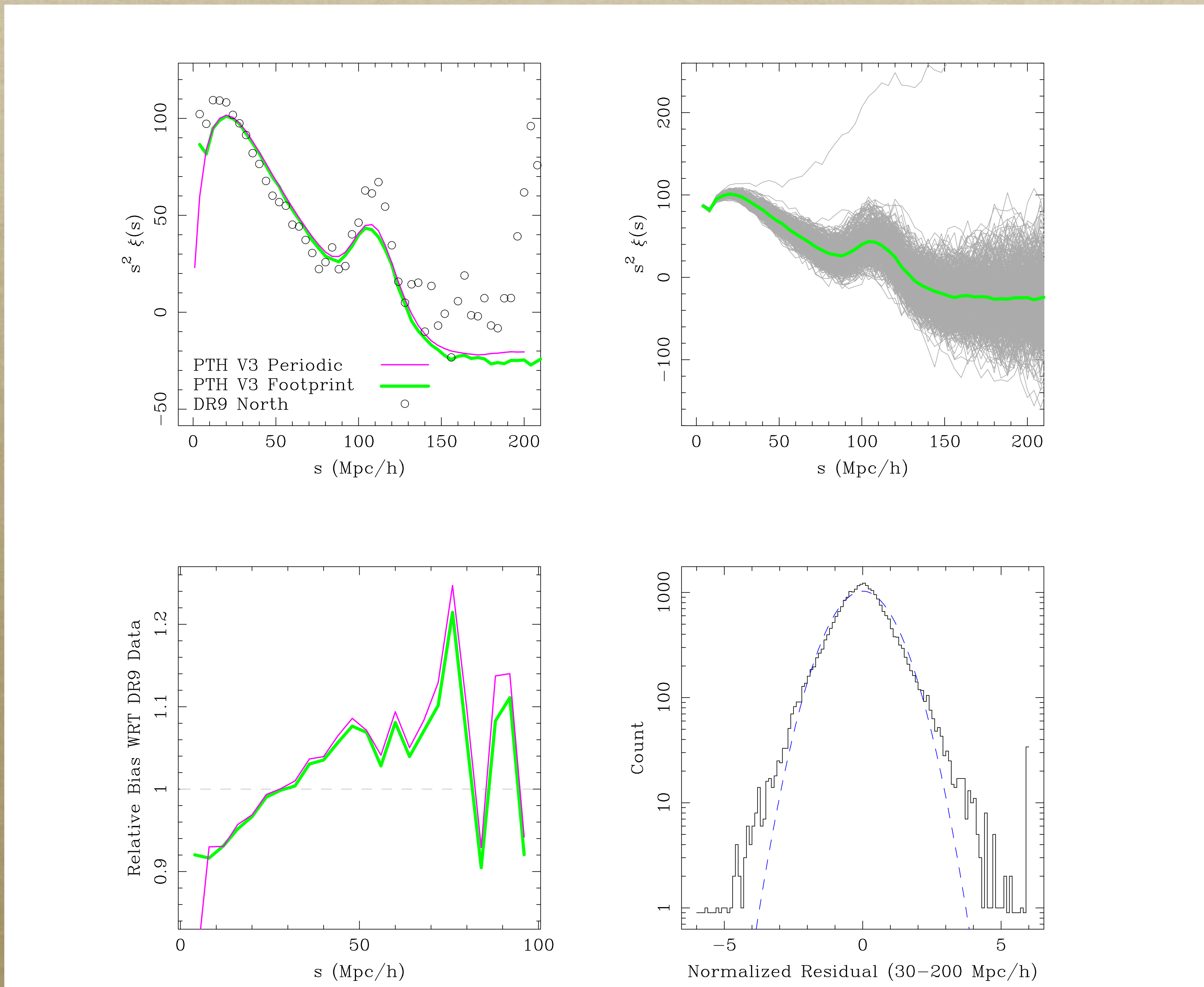
Galaxies

- NFW profile to assign galaxies within an halo
  - we use Mass-concentration from Prada et al 2001
  - we include dispersion in this relation.

$$\rho(r) = \frac{4\rho_s}{\frac{r}{r_s}(1+\frac{r}{r_s})^2} \qquad c = \frac{R_{Vir}}{r_s}$$

- Galaxy velocities within an halo from the Virial Theorem.
  - peculiar velocity = v_cm + v_g
  - these velocities are used when including Redshift Space Distortions

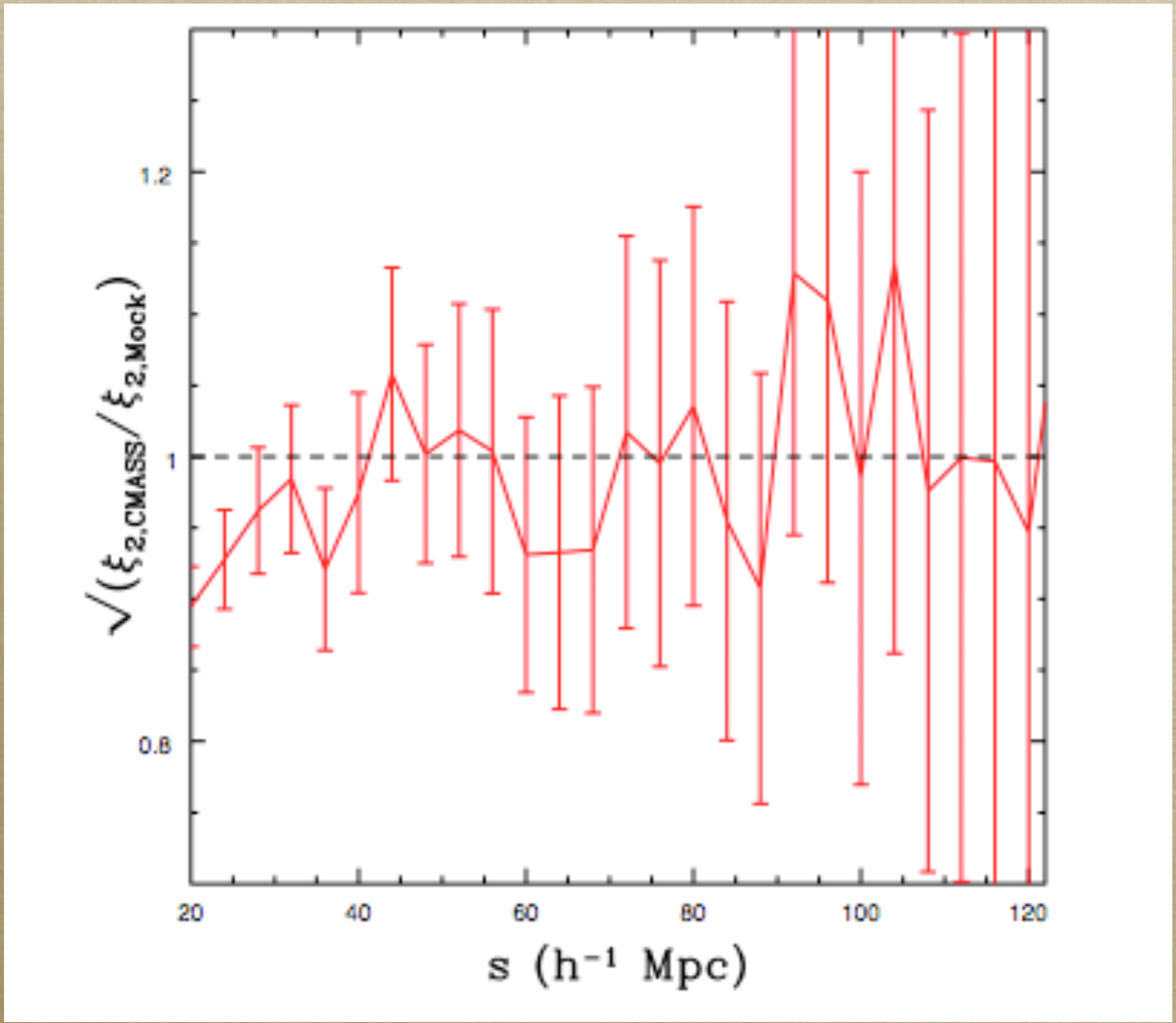
Comparison with DR9



courtesy
Cameron McBride

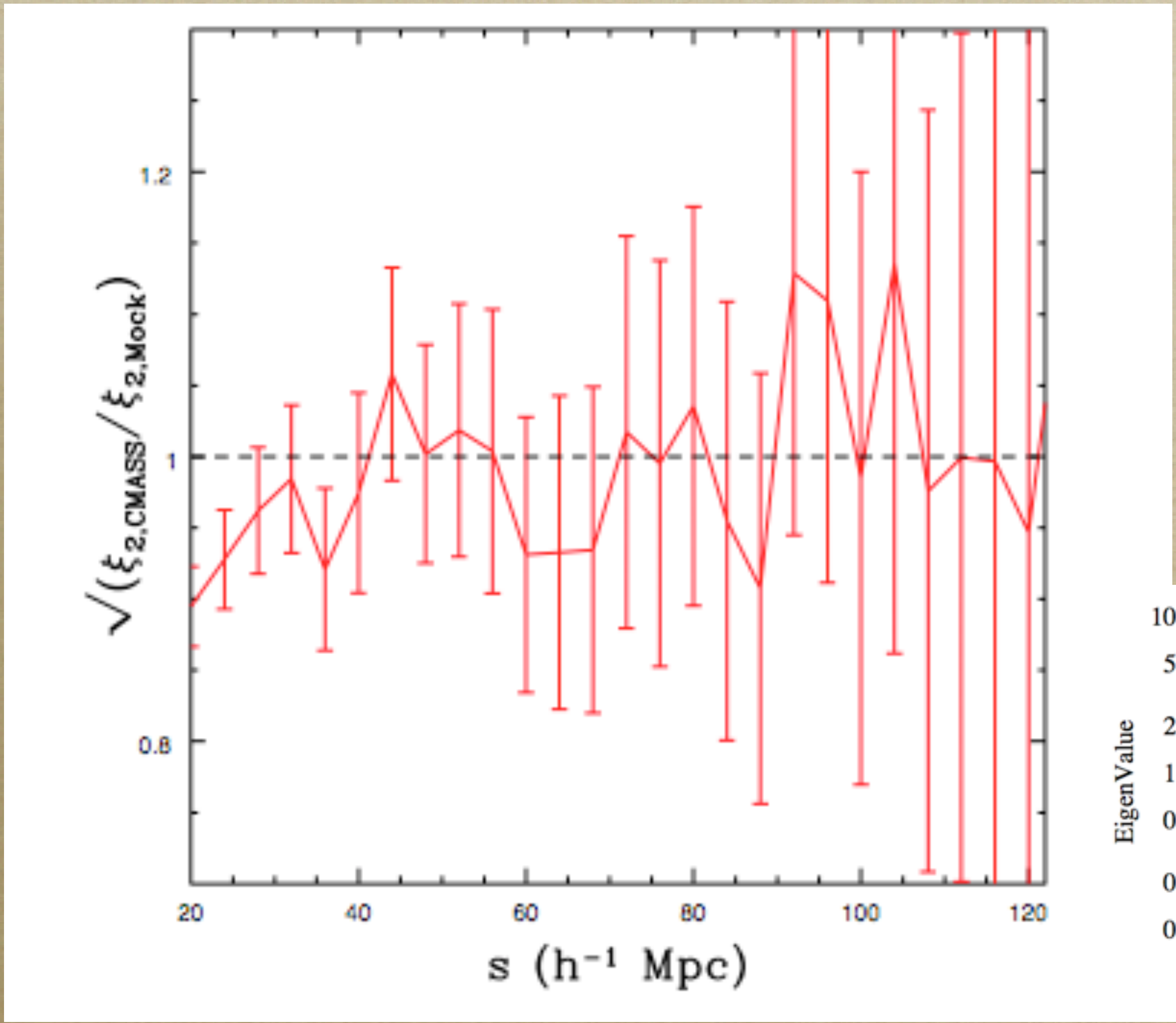
galaxy mocks

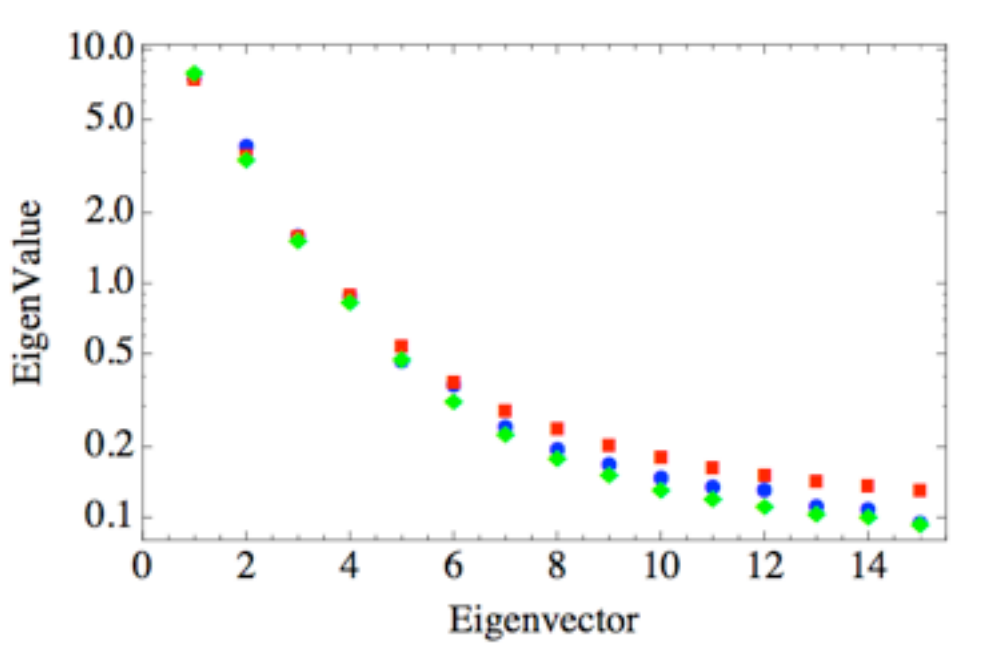
Manera et al. arXiv:1203.6609



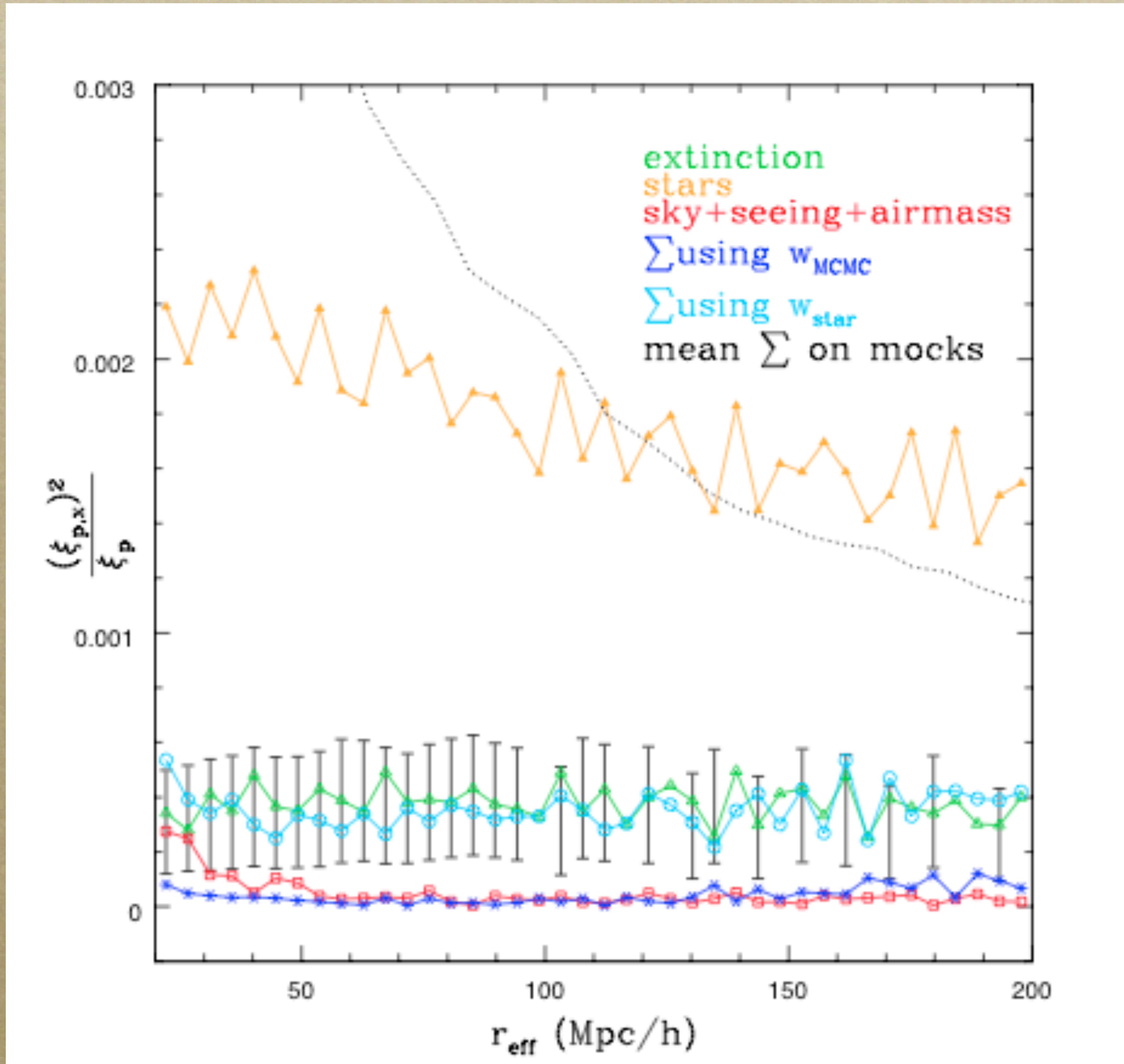
galaxy mocks

Manera et al. arXiv:1203.6609

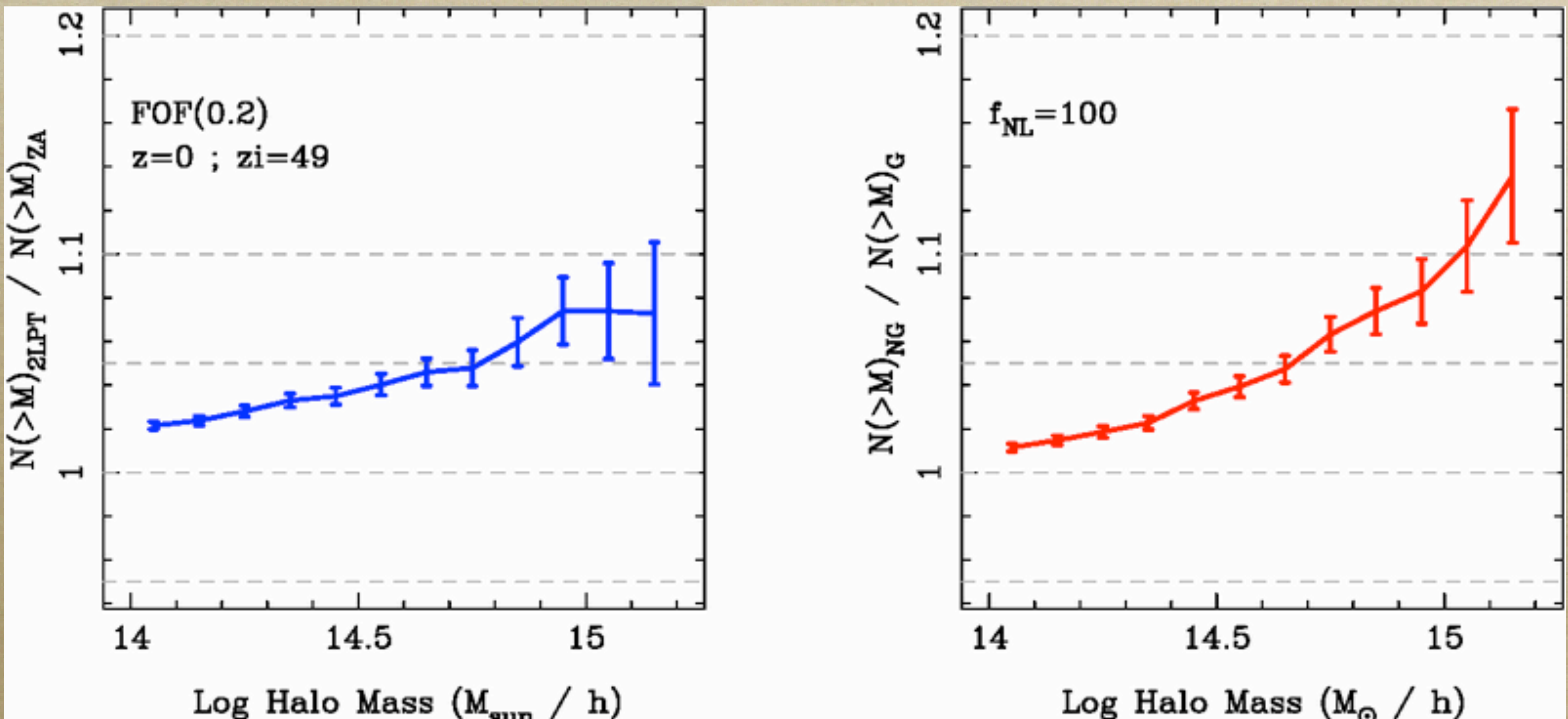


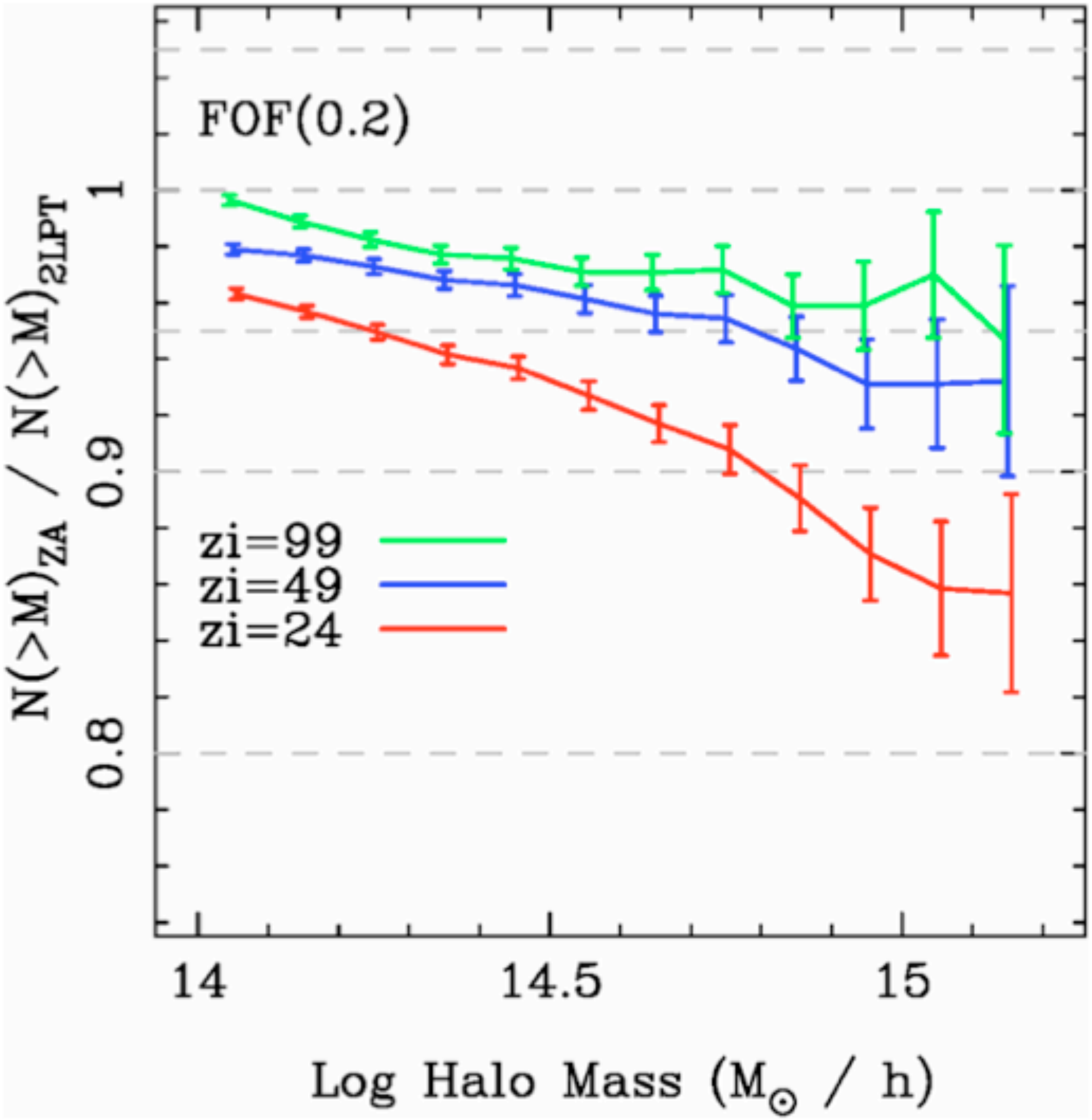


Using mocks: expected statistic uncertainty



extra slide: why 2LPT





ZA initial conditions converge very slowly, use 2LPT always!!

This is true also for SO halos

plot from LasDamas Collaboration, (McBride et al in prep)

Conclusions

- BAO peak detected at 5-sigma

Most precise constraint ever obtained of the BAO scale from a galaxy survey (1.7% error)

- Systematics are relevant

most relevant: star density correlates with galaxy density

- Mock galaxy catalogues are crucial to understand errors

PTHalos: 1- fast method to generate mocks useful for LSS analysis
2- clustering of halos is recovered at 10%
3- galaxies included to mimic survey clustering
4- 600 mock catalogues and covariance matrices / available
5- used in reconstruction, systematics, optimisation of estimators,... and obviously, LSS clustering.

- Companion papers on anisotropic clustering and full shape of the correlation function.

Conclusions

PTHalos mock galaxy catalogues	Manera et al. arXiv:1203.6609
Systematics	Ross et al. arXiv:1203.6499
BAO scale, alphabetical	Anderson et al. arXiv:1203.6594
Anisotropic clustering	Reid et al. arXiv:1203:6641
Growth from passive galaxies	Tojeiro et al. arXiv:1203.6565
Full shape of the correlation function	Sanchez et al. arXiv:1203.6616

Thank you for your attention