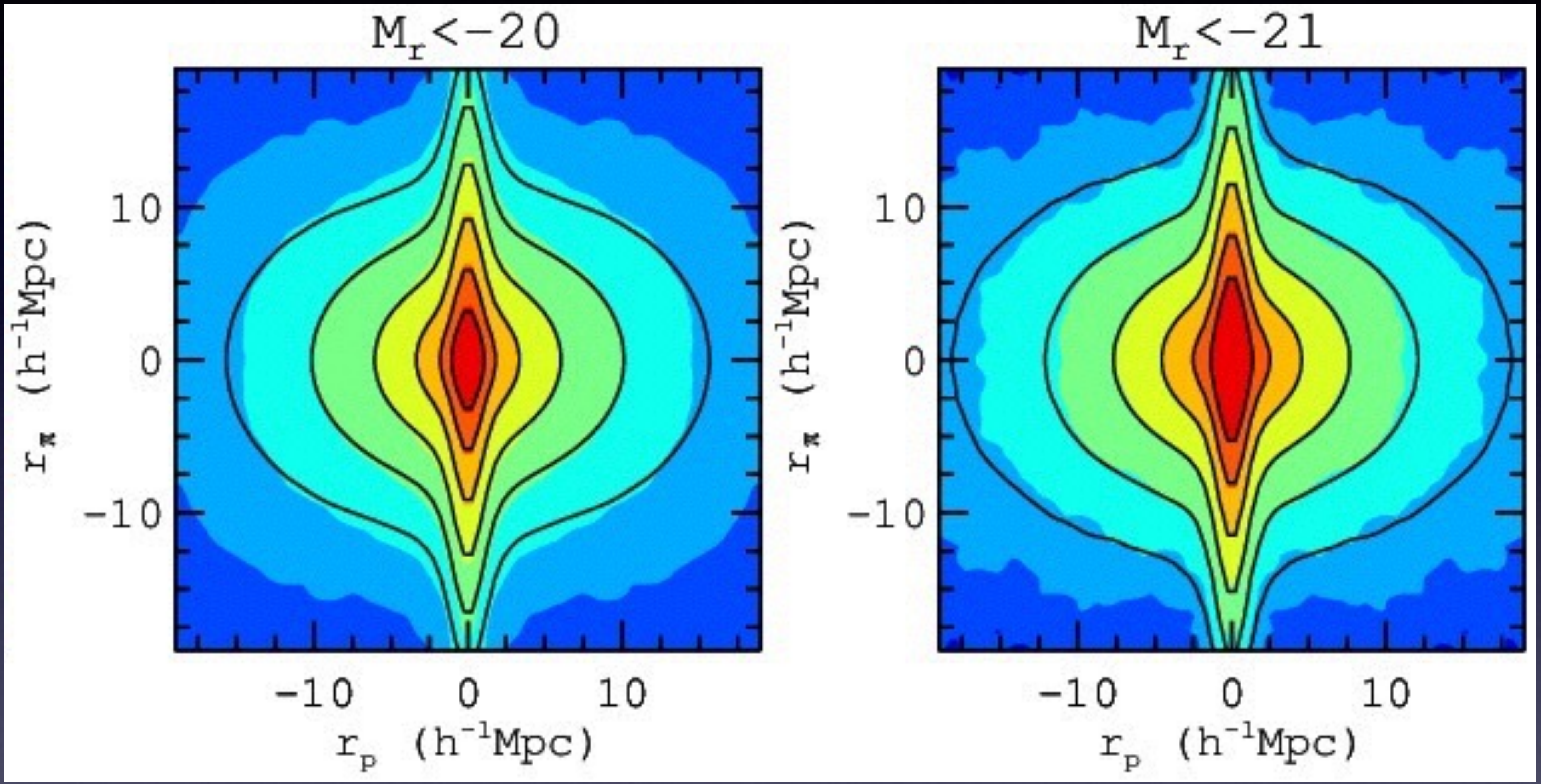
Redshift-Space Galaxy Clustering:

Accurate Modeling, Velocity Bias, and Assembly Effect



Zheng Zheng

University of Utah

Hong Guo (SHAO), Jia-Ni Ye (SHAO), Idit Zehavi (CWRU), Kevin McCarthy (Utah), Xiaoju Xu (Utah)

Redshift-Space Galaxy Clustering

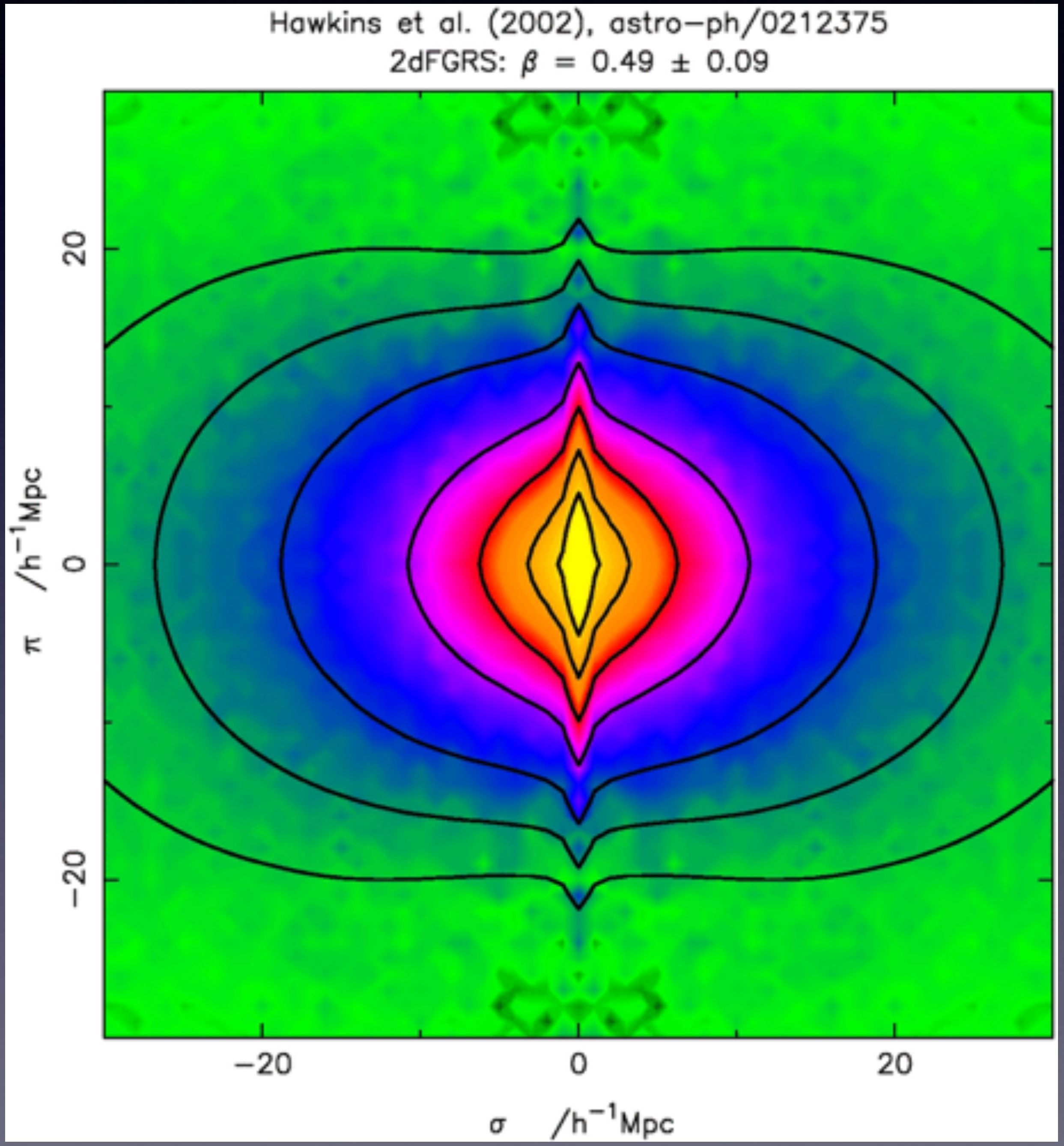
Small scales: FoG

galaxy kinematics inside virtualized structures (halos)

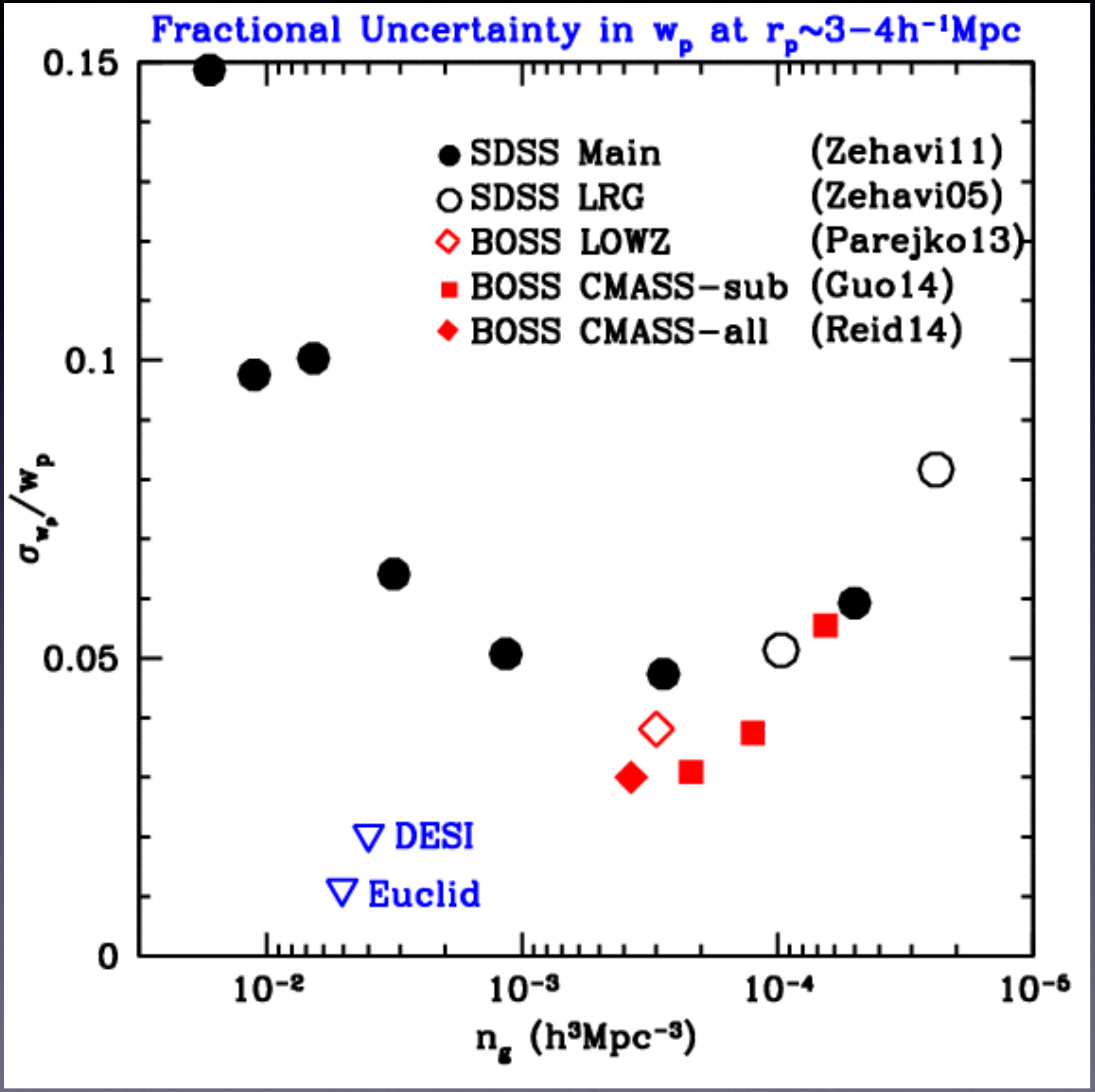
Large scales: Kaiser effect

structure growth rate

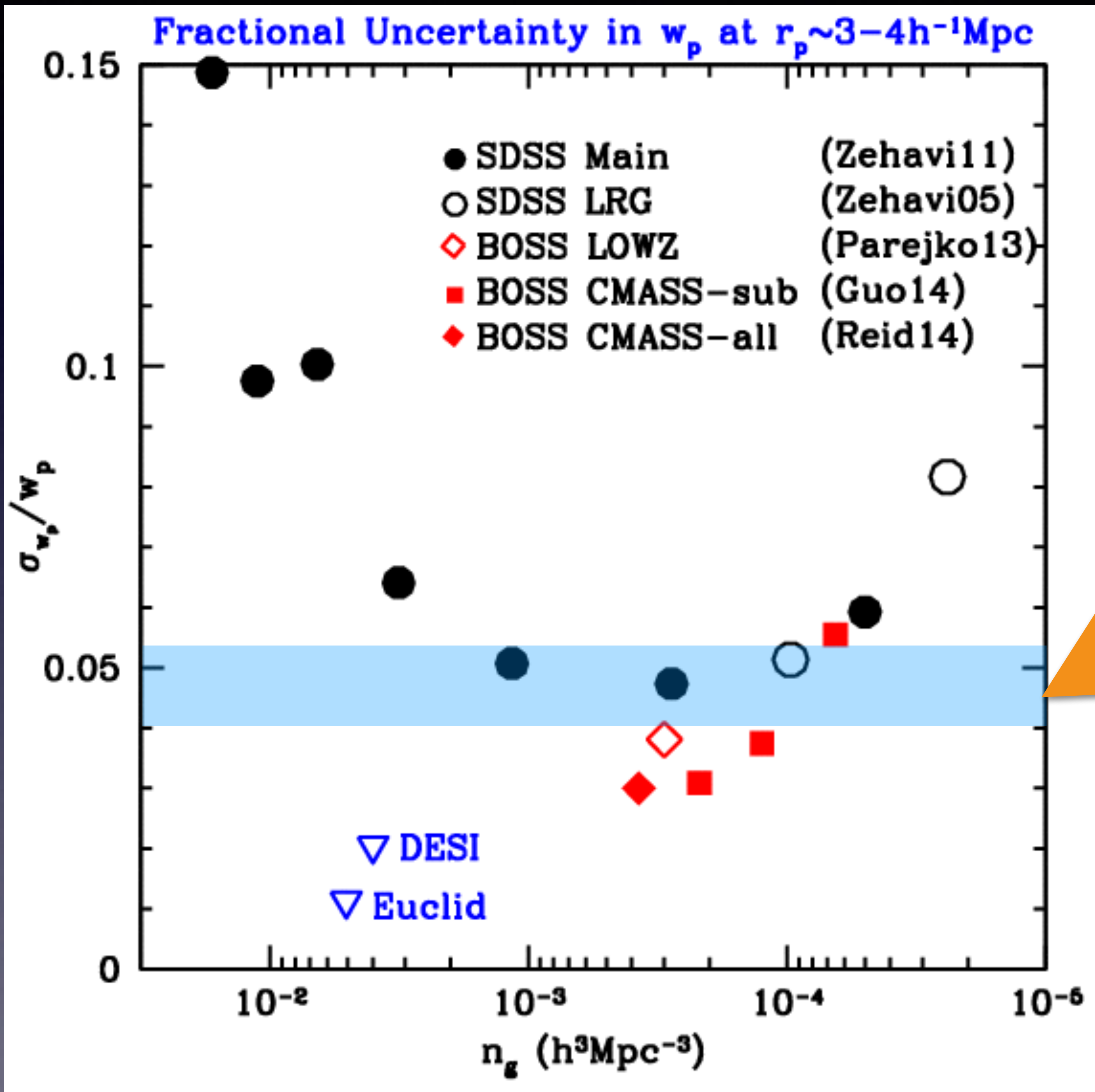
The simple model is not accurate.



High Precision Galaxy Clustering Measurements

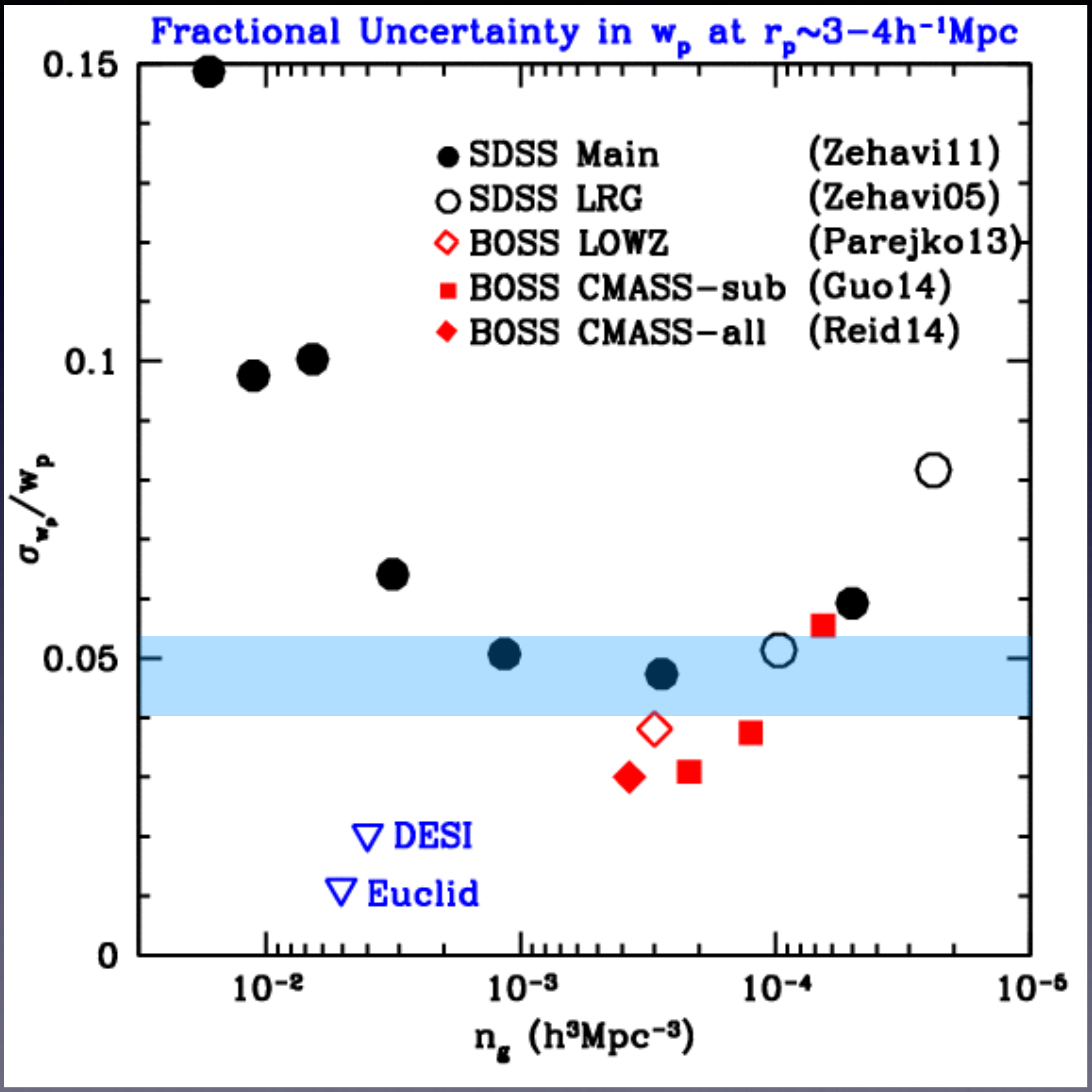


High Precision Galaxy Clustering Measurements



~ accuracy of analytic models of real-space 2PCFs (e.g., Tinker+05, van den Bosch+13)

Difficulties in Developing Accurate Models of Galaxy Clustering



- non-linear evolution of matter power spectrum
- scale dependence of halo bias
- halo exclusion effect
- nonsphericity of halos
- halo alignment
- …

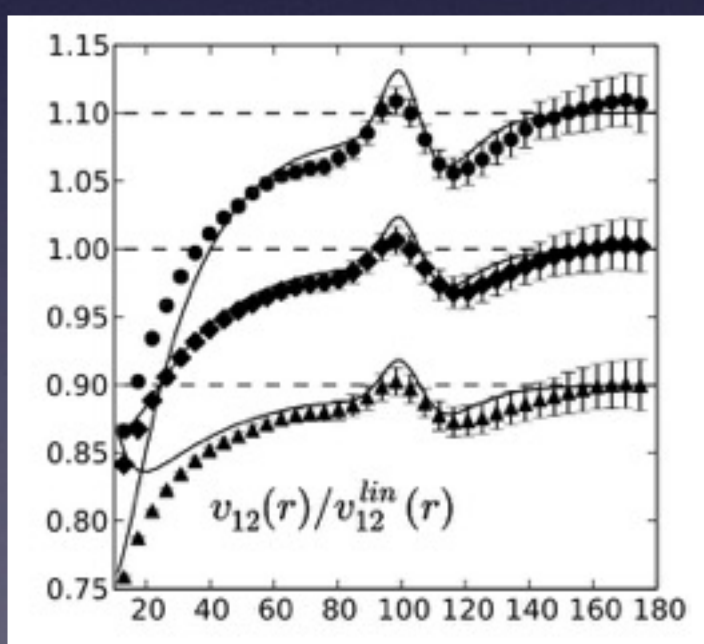
(Zheng04, Tinker+05, van den Bosch+13)

Difficulties in Developing Accurate Models of Galaxy Clustering

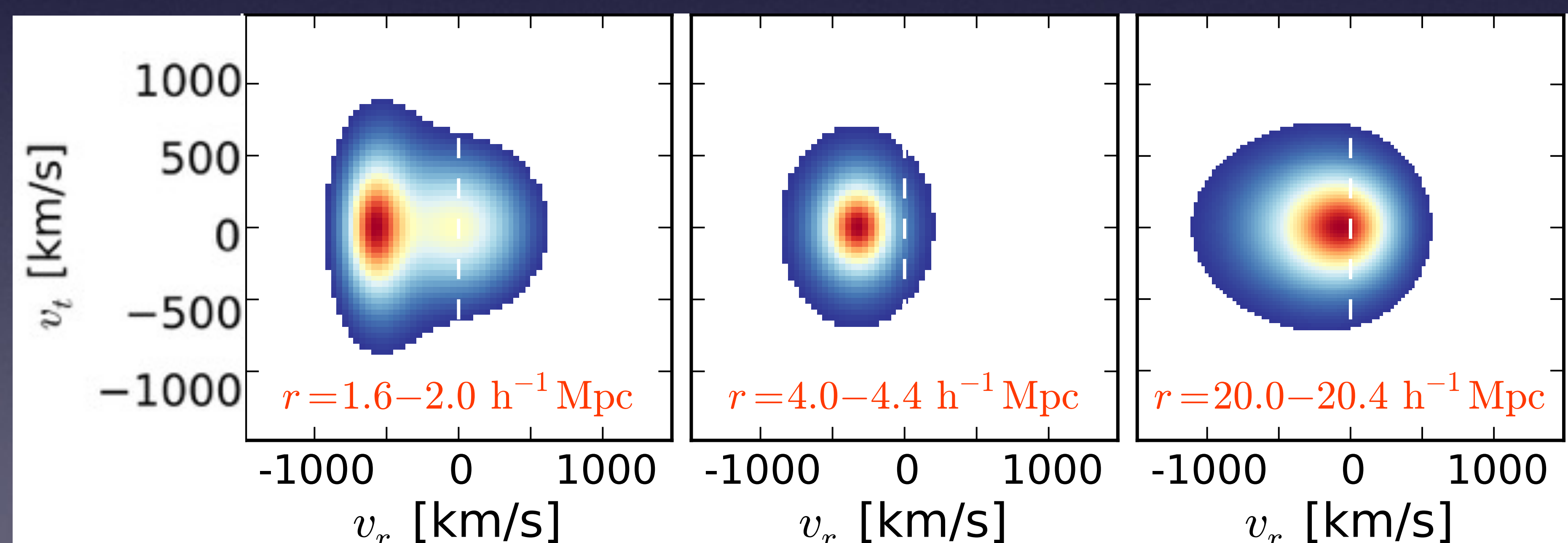
$$P(v_r, v_t | r, M_1, M_2)$$

Distribution of halo-halo (radial and transverse) pairwise velocity

(e.g., Tinker 2007, Reid & White 2011, Zu & Weinberg 2013)



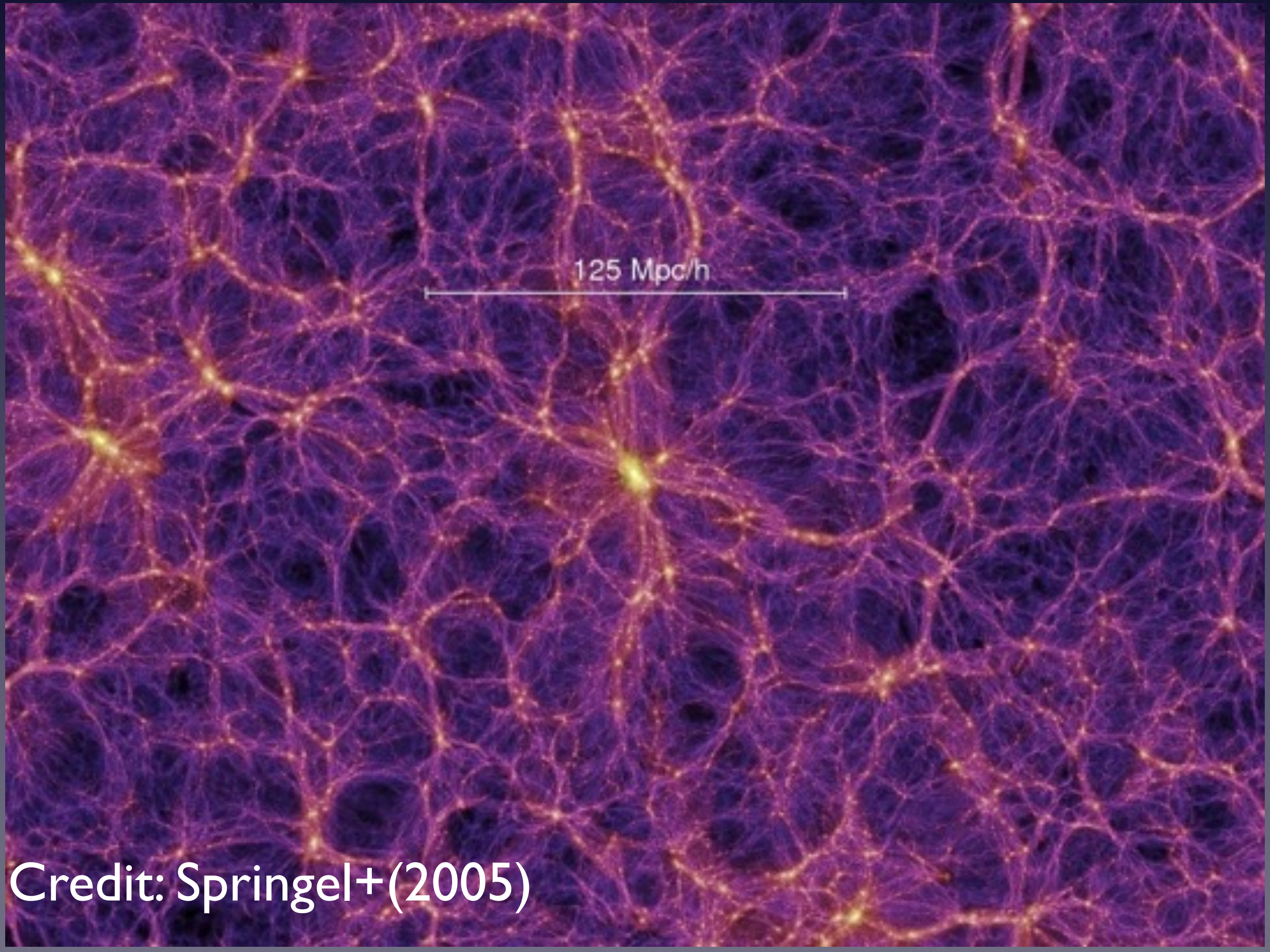
Reid & White (2011)

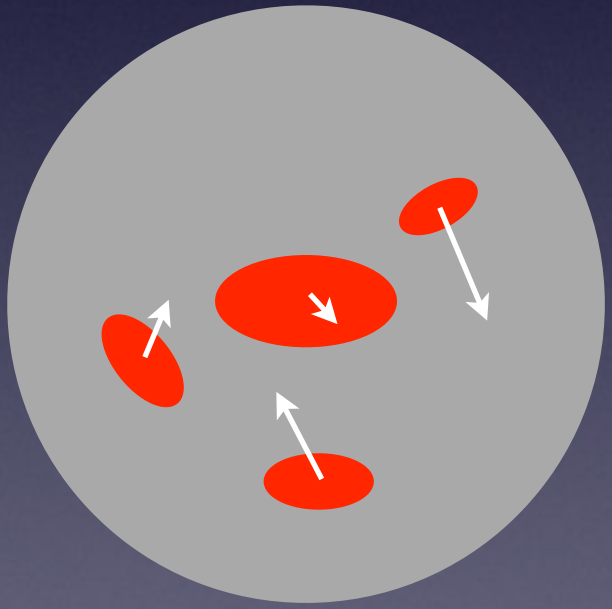


Zu & Weinberg (2013)

Model Galaxy Clustering with N-body Simulations

Populate halos with galaxies according to HOD/CLF to form mock
Measure 2PCFs from the mock as the model prediction





e.g., White+(2011), Parejko+(2013)
halotools (Hearin+2016)

More Efficient Simulation-Based Clustering Modeling

HOD — Halo Properties

$$\bar{n}_g = \sum_i [\langle N_{\rm cen}(M_i)\rangle + \langle N_{\rm sat}(M_i)\rangle]\bar{n}_i$$

Mass Function

$$1+\xi^{\rm 1h}_{\rm gg}(\mathbf{r}) = \sum_i 2\frac{\bar{n}_i}{\bar{n}_g^2}\langle N_{\rm cen}(M_i)N_{\rm sat}(M_i)\rangle f_{\rm cs}(\mathbf{r};M_i) + \sum_i \frac{\bar{n}_i}{\bar{n}_g^2}\langle N_{\rm sat}(M_i)[N_{\rm sat}(M_i)-1]\rangle f_{\rm ss}(\mathbf{r};M_i)$$

Profile

$$\xi^{\rm 2h}_{\rm gg}(\mathbf{r}) = \sum_{i\neq j}\frac{\bar{n}_i\bar{n}_j}{\bar{n}_g^2}\langle N_{\rm cen}(M_i)\rangle\langle N_{\rm cen}(M_j)\rangle \xi_{\rm hh,cc}(\mathbf{r};M_i,M_j) + \sum_{i\neq j}2\frac{\bar{n}_i\bar{n}_j}{\bar{n}_g^2}\langle N_{\rm cen}(M_i)\rangle\langle N_{\rm sat}(M_j)\rangle \xi_{\rm hh,cs}(\mathbf{r};M_i,M_j) + \sum_{i\neq j}\frac{\bar{n}_i\bar{n}_j}{\bar{n}_g^2}\langle N_{\rm sat}(M_i)\rangle\langle N_{\rm sat}(M_j)\rangle \xi_{\rm hh,ss}(\mathbf{r};M_i,M_j)$$

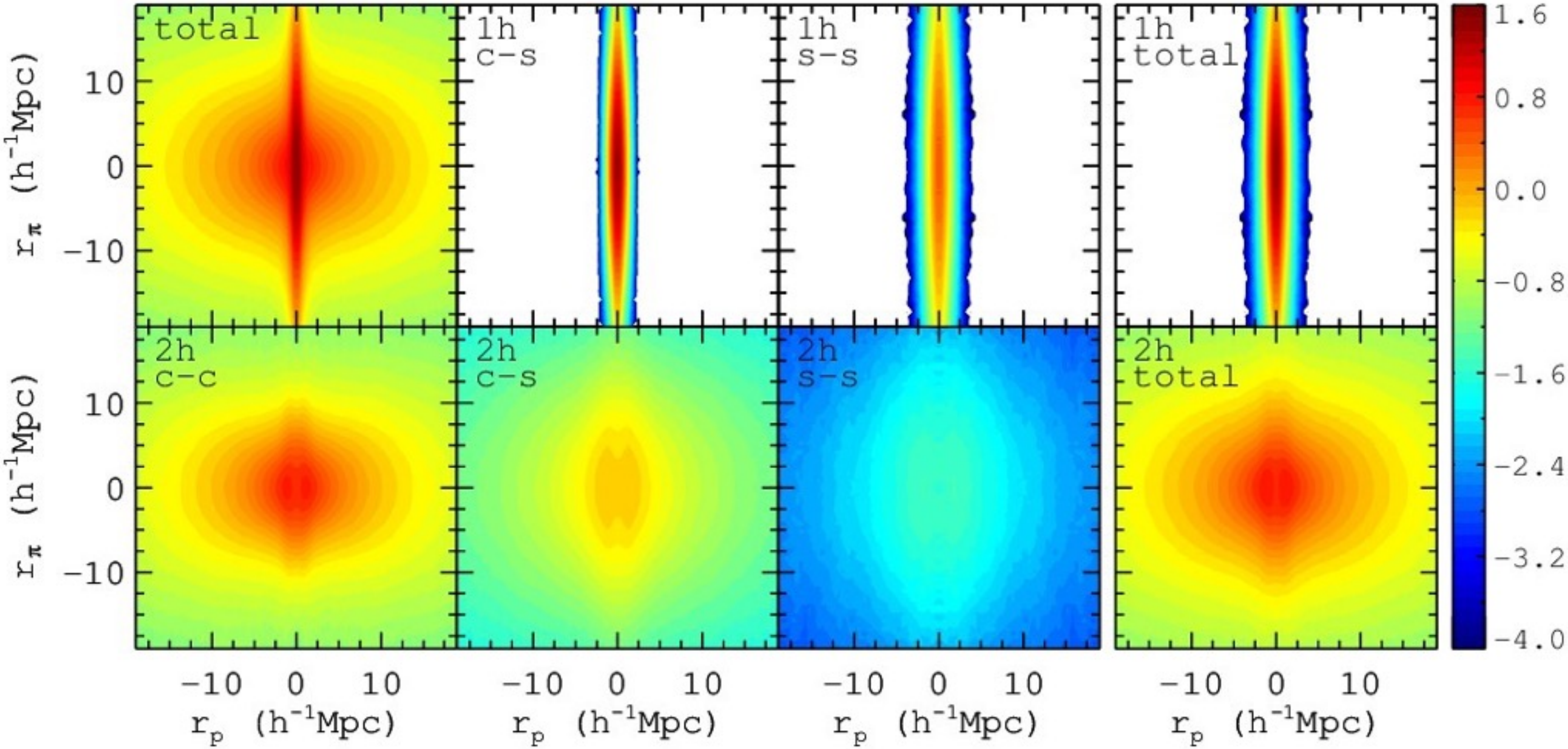
Clustering

Accurate and Efficient Halo-Based Galaxy Clustering Modeling with Simulations

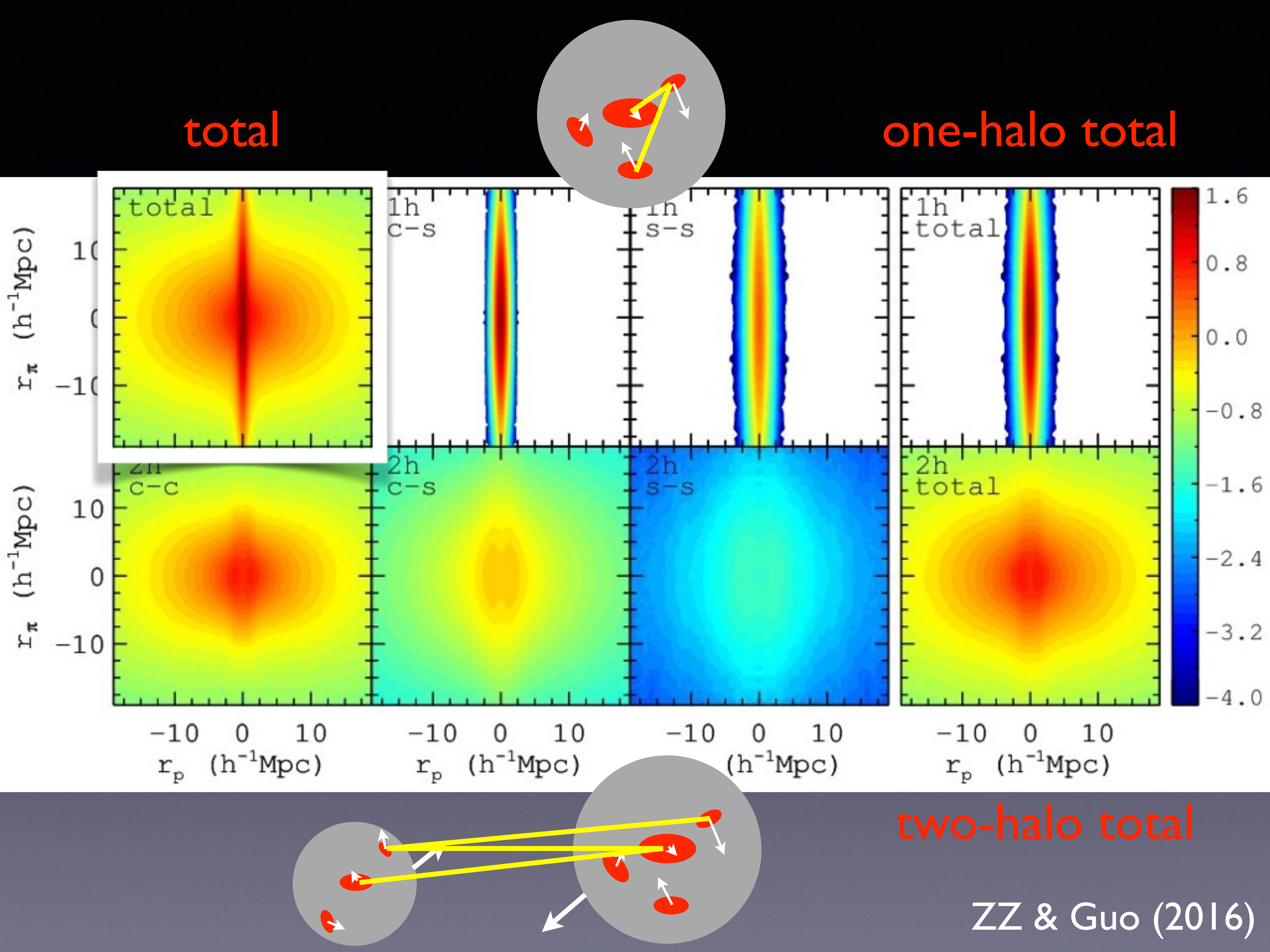
- **Accurate**
  - equivalent to populating galaxies into dark matter halos and using the (mean) mock 2PCF measurements as the model prediction
  - no finite-bin-size effect (same binning and integration scheme as measurements); residual RSD automatically accounted for
- **Efficient**
  - no need for the construction of mocks and the measurement of the 2PCF from the mocks
  - independent of simulation size
  - efficient exploration of the parameter space (e.g., MCMC)
- **Extension to subhalos (SCAM), halo variables other than mass, and other clustering statistics**

(Neostein+2011, Neistein & Khochfar2012, Zheng & Guo 2016, Guo+2015)

An Accurate and Efficient Simulation-based Model for Redshift-Space Galaxy Two-Point Correlation Function



ZZ & Guo (2016)



total
one-halo total
two-halo total
total
1h c-s
1h s-s
1h total
2h c-c
2h c-s
2h s-s
2h total
r_π (h^{-1}Mpc)
r_p (h^{-1}Mpc)
-10
0
10
1.6
0.8
0.0
-0.8
-1.6
-2.4
-3.2
-4.0
ZZ & Guo (2016)

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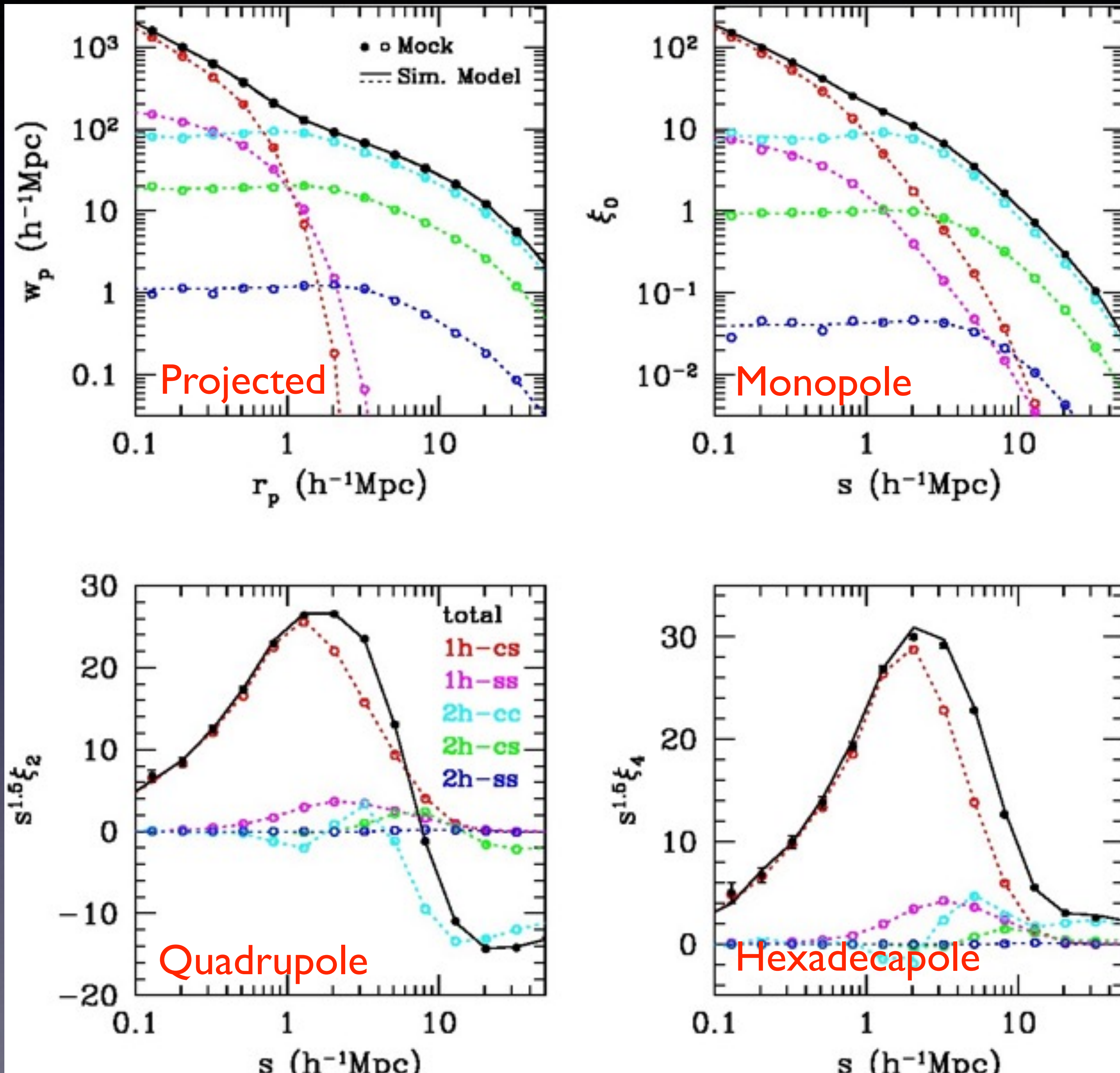

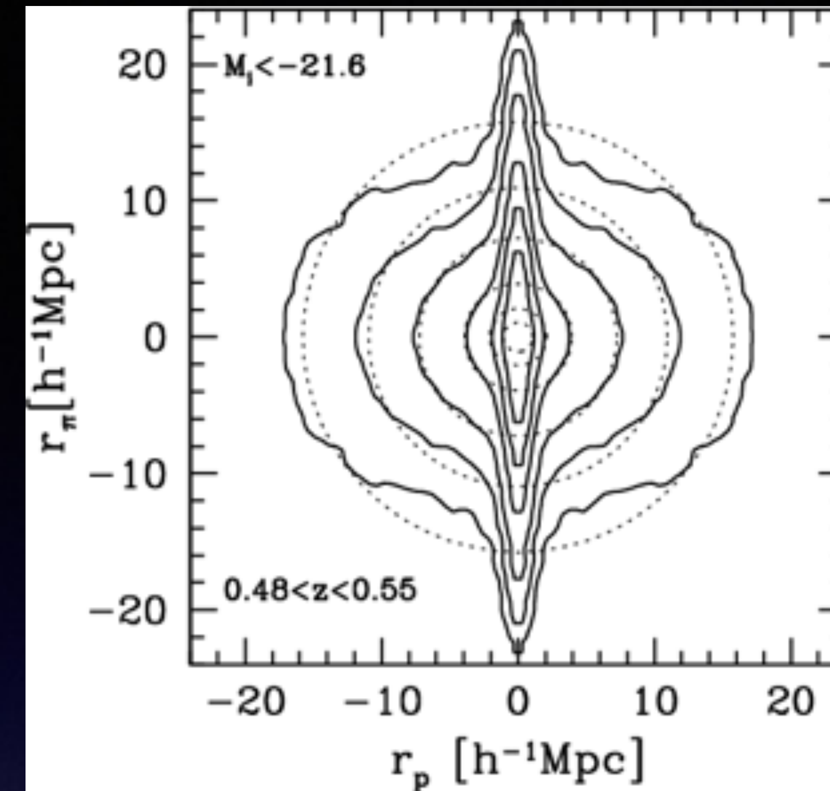

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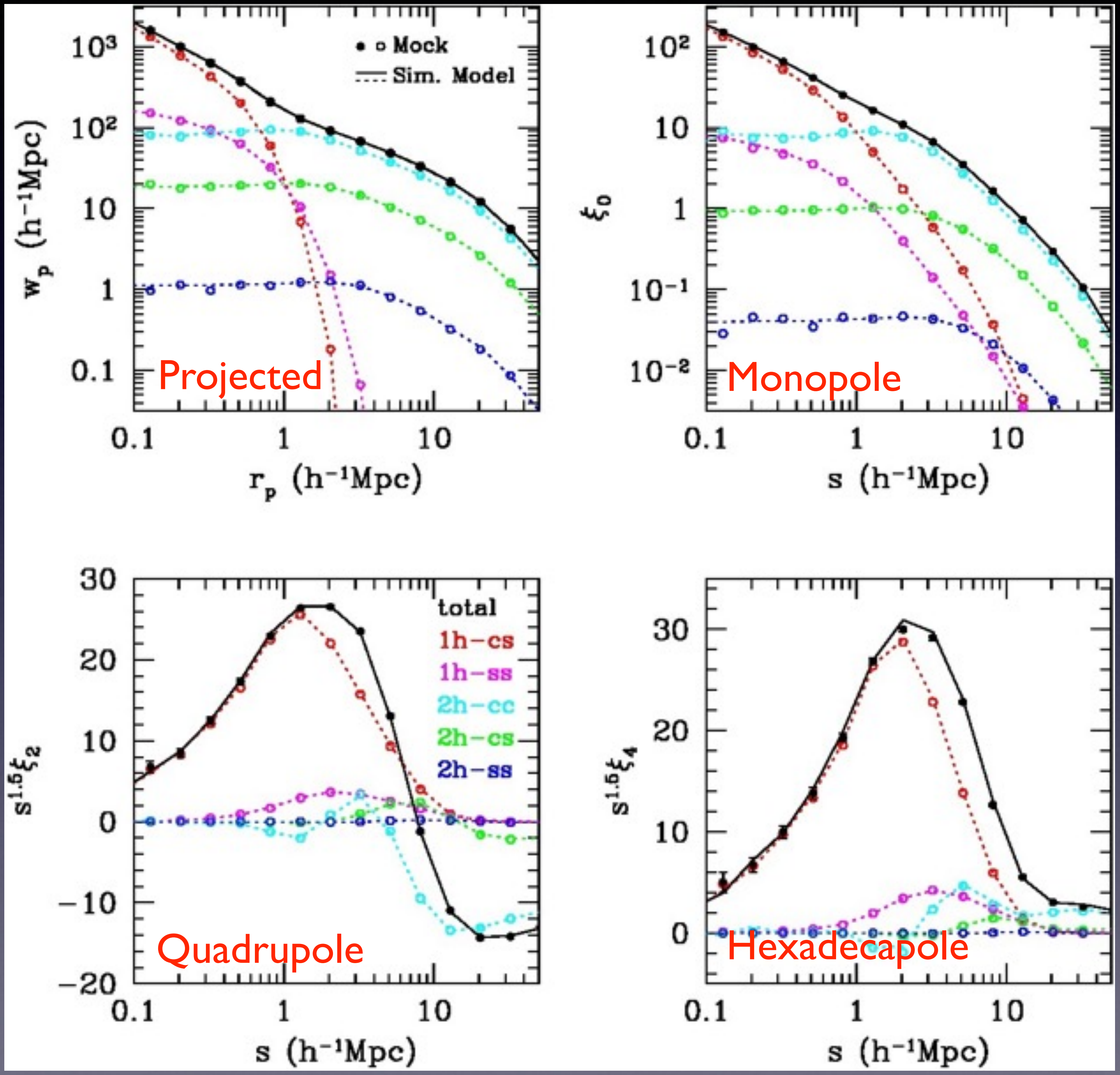
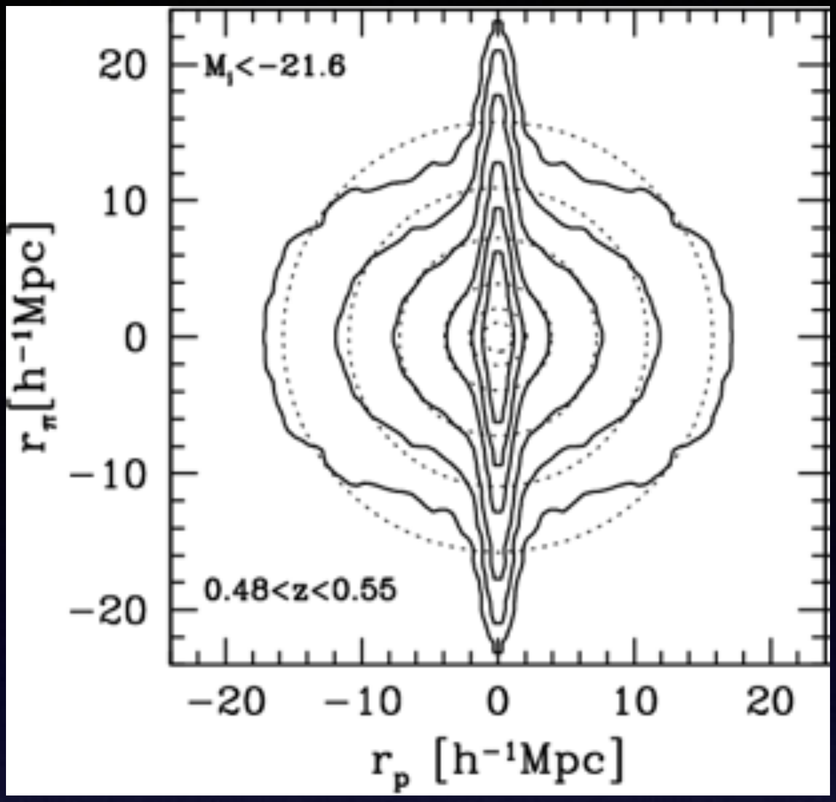
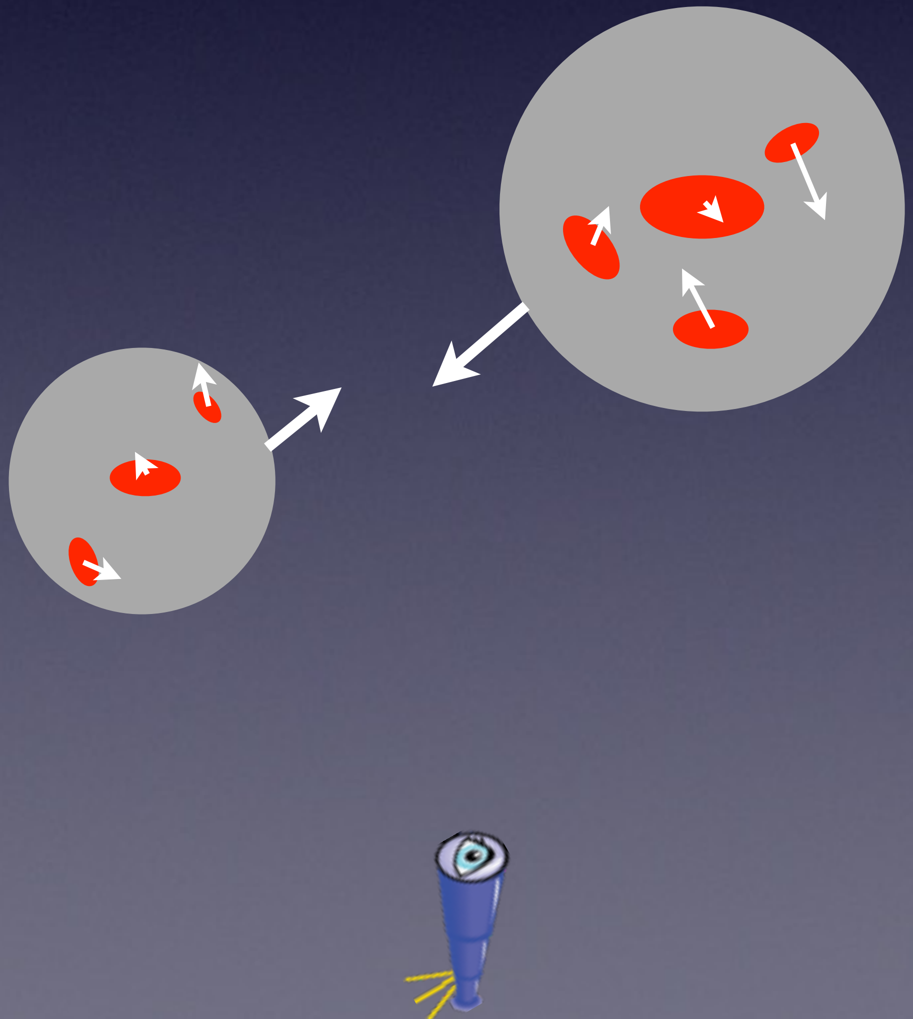






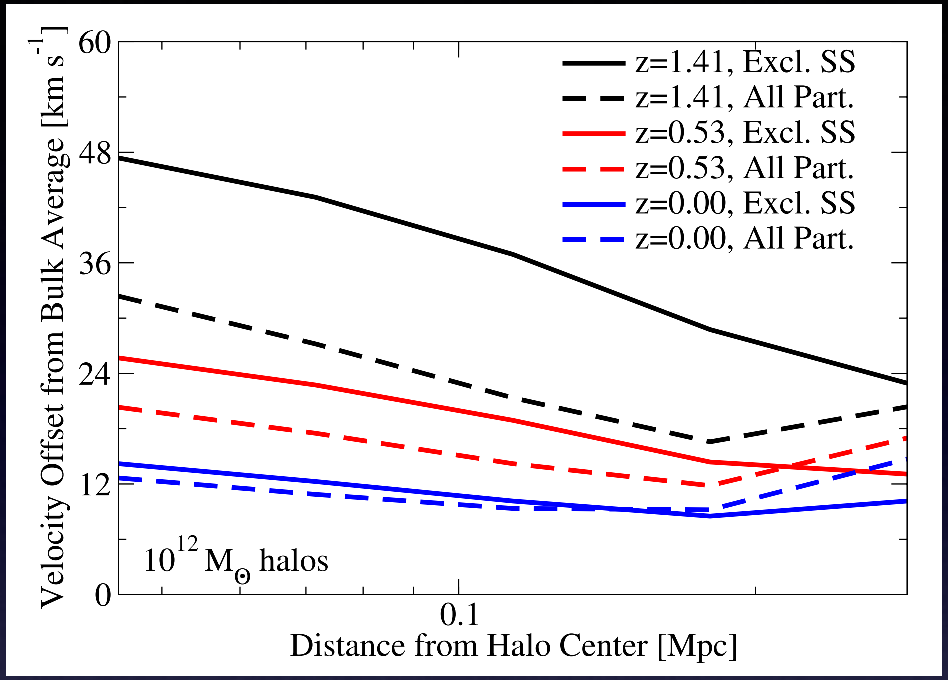
ZZ & Guo (2016)

Modeling Redshift-Space Galaxy Clustering

- Choose the reference frame to define galaxy velocity bias

  - halo core frame

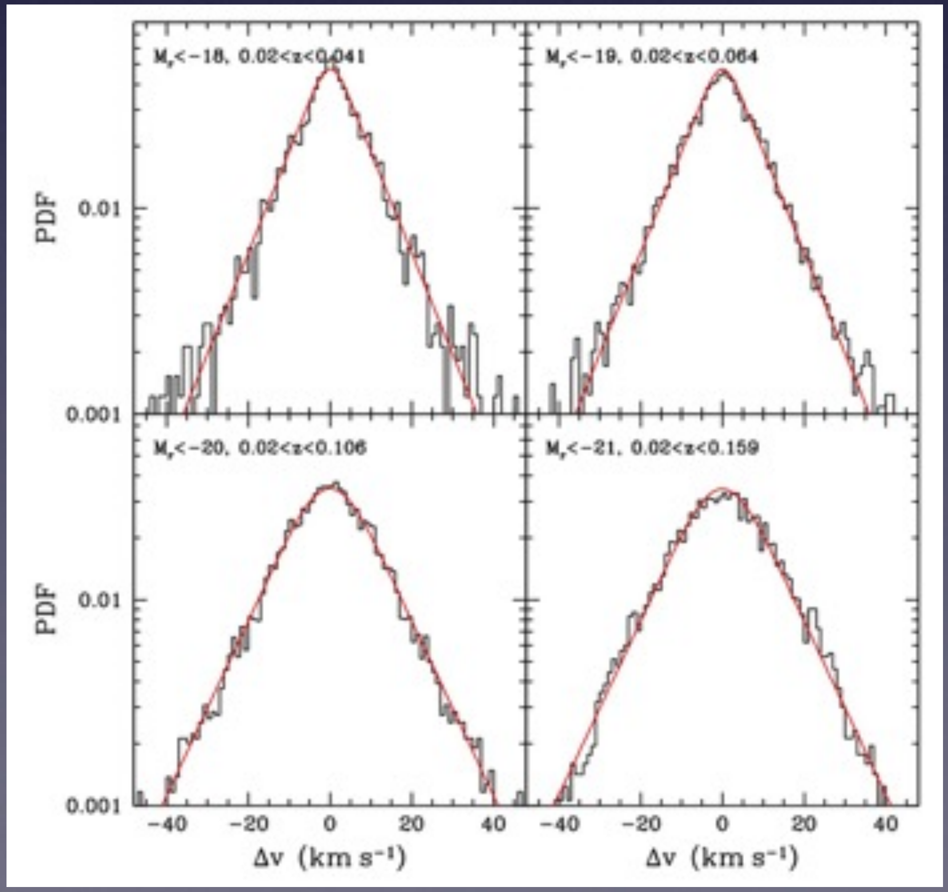
  - halo bulk velocity frame
    (more appropriate for large, low-res simulations)



Behroozi et al. (2013)

- Account for galaxy redshift errors

  (Gaussian-Convolved Laplace Distribution)



Guo, ZZ, et al. (2015c)

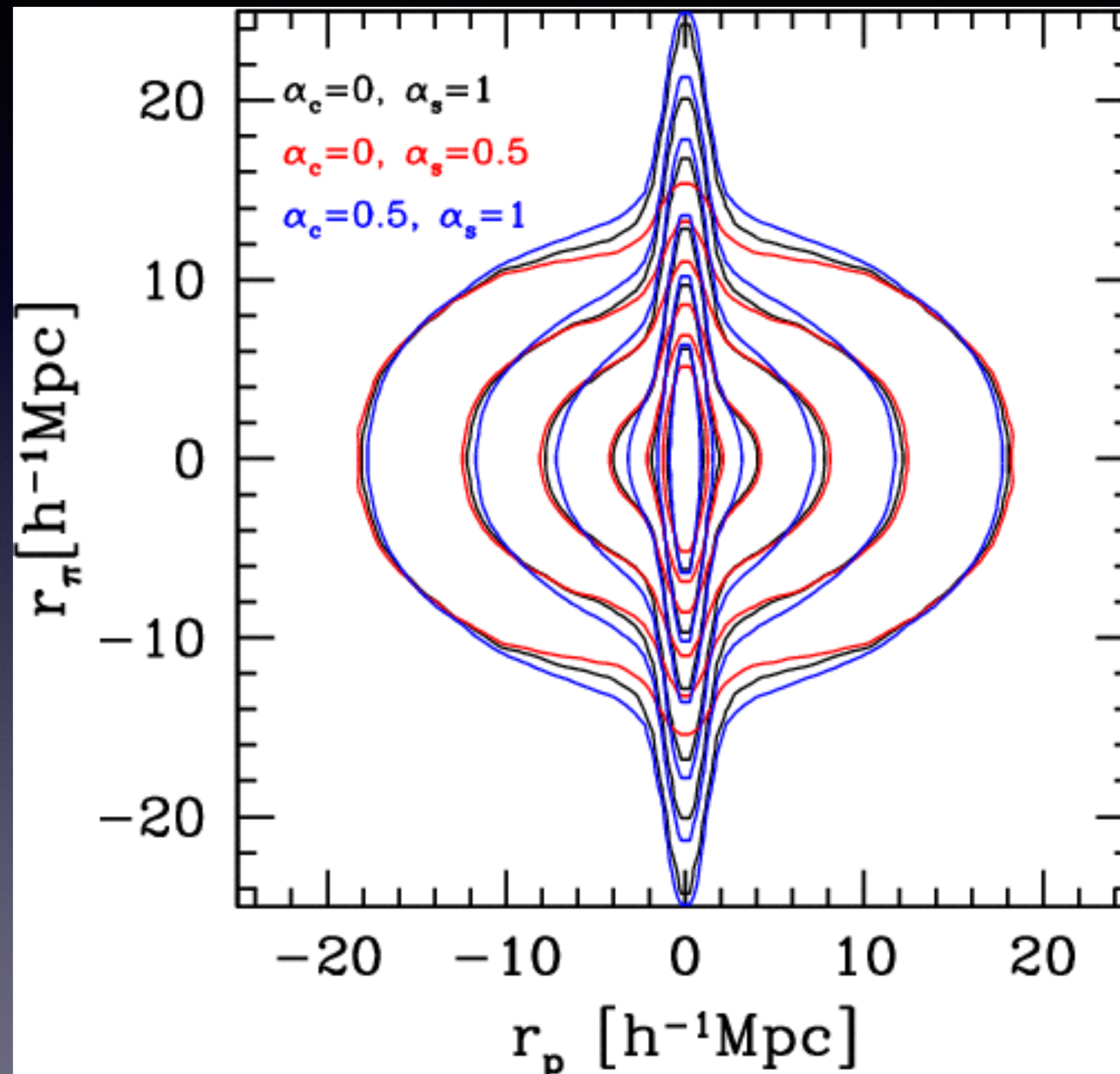
Constraining Galaxy Kinematics inside Halos

Velocity bias

In the halo frame

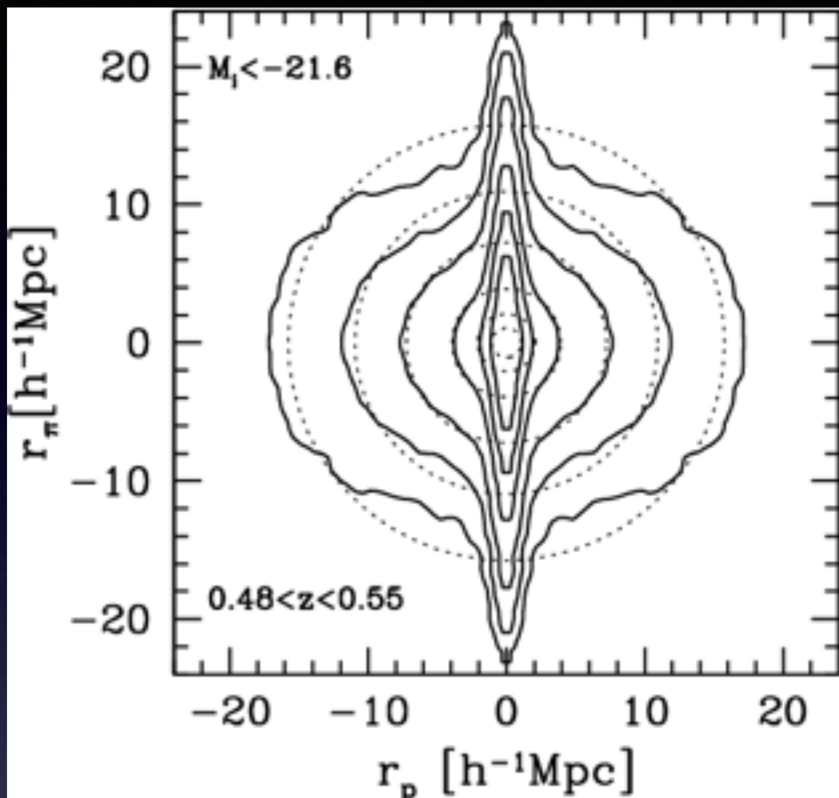
$$\alpha_c = \frac{v_{\rm cen}}{\sigma_{\rm DM}}$$

$$\alpha_s = \frac{\sigma_{\rm sat}}{\sigma_{\rm DM}}$$



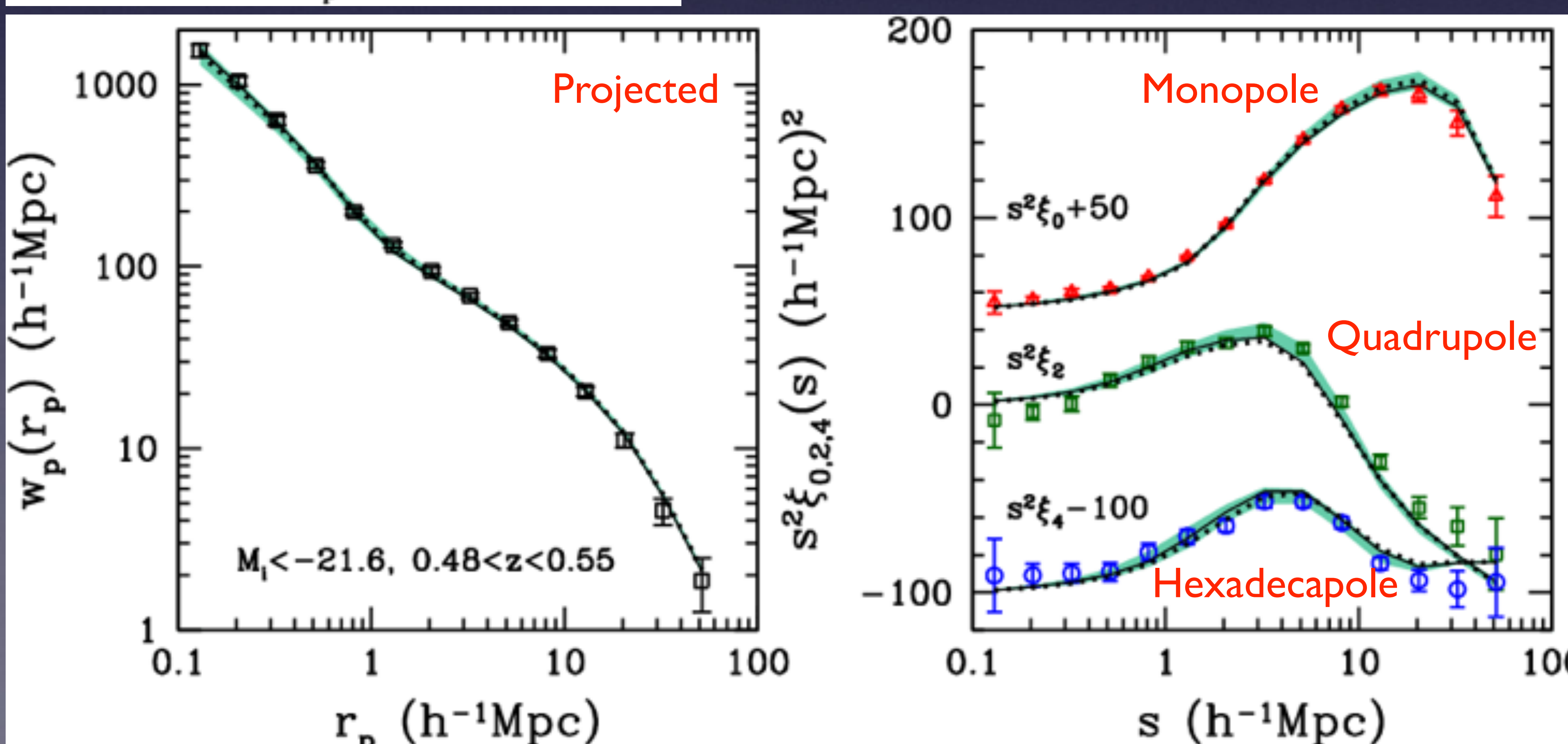
Guo, ZZ, et al. (2015a)

Measuring and Modeling the Redshift-Space Galaxy Clustering

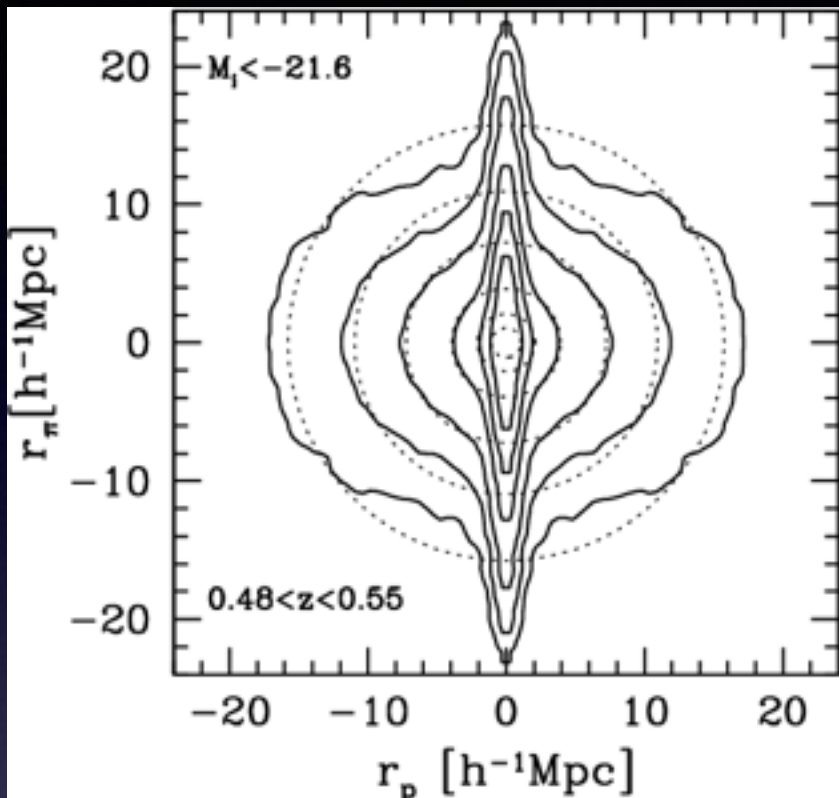


BOSS Galaxies
z~0.5

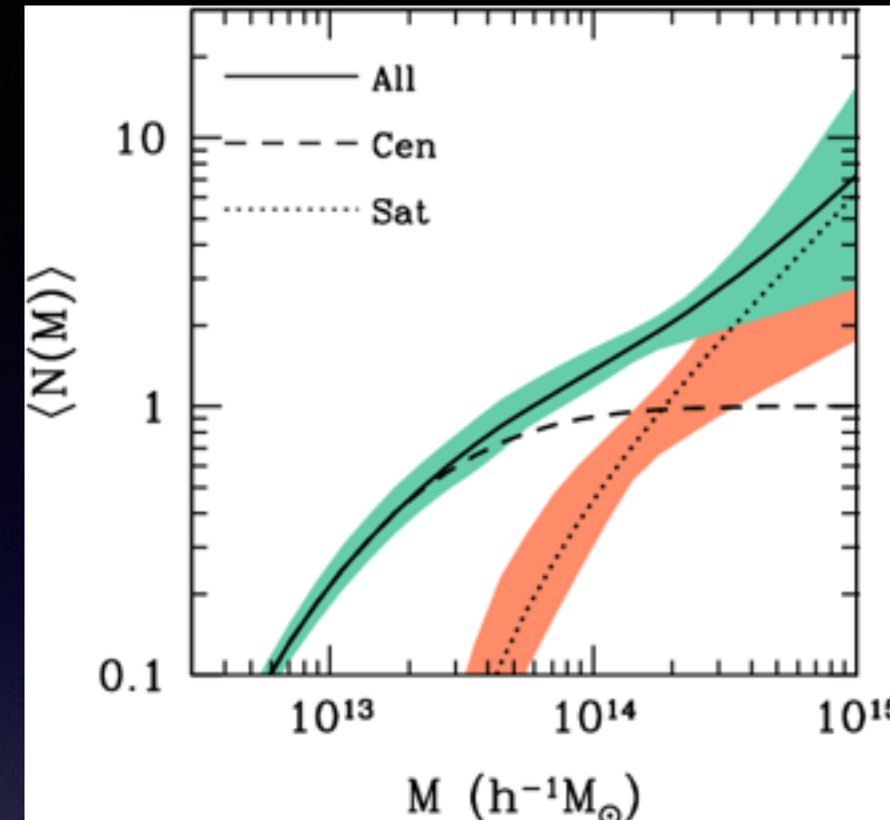
Guo, ZZ, et al. (2015a)



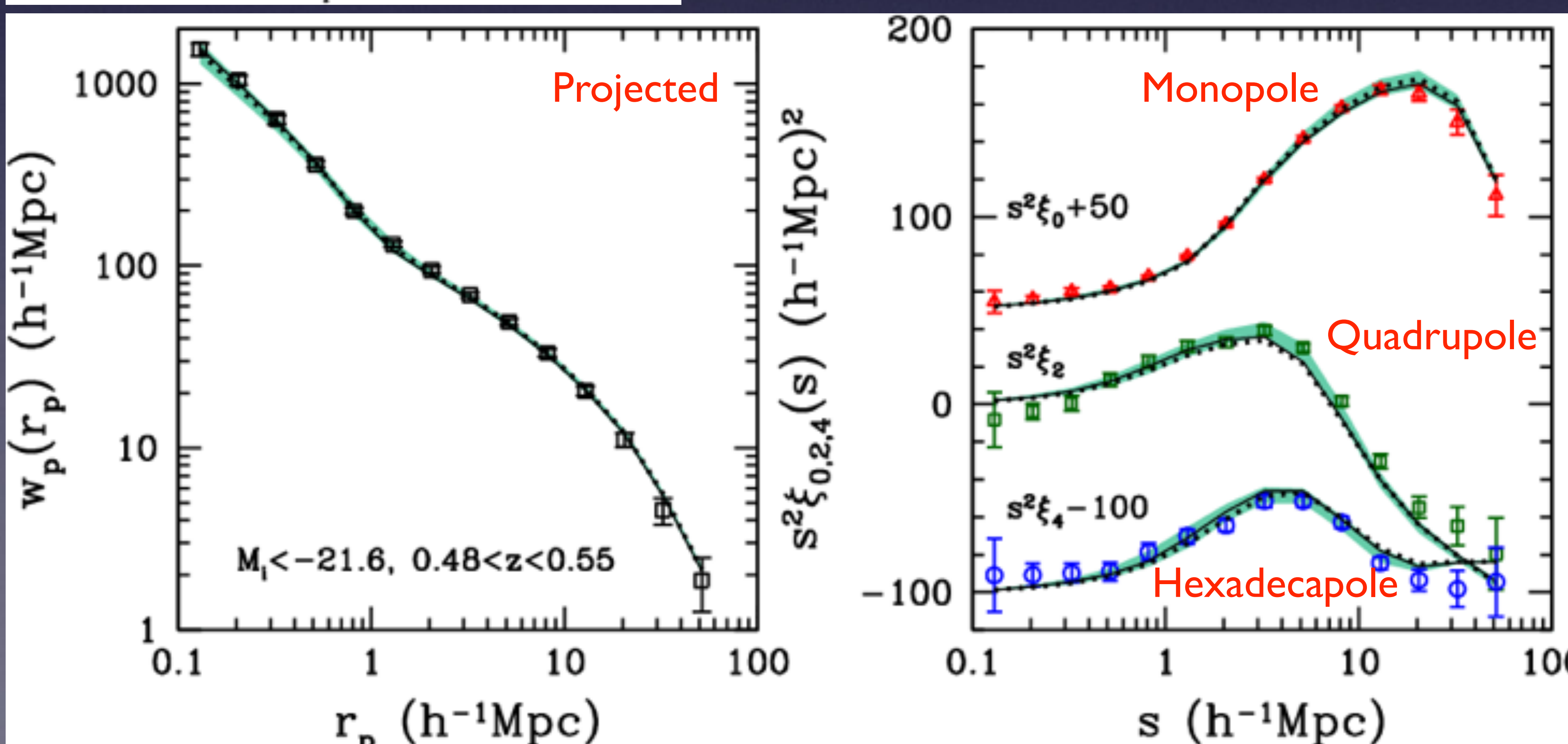
Measuring and Modeling the Redshift-Space Galaxy Clustering



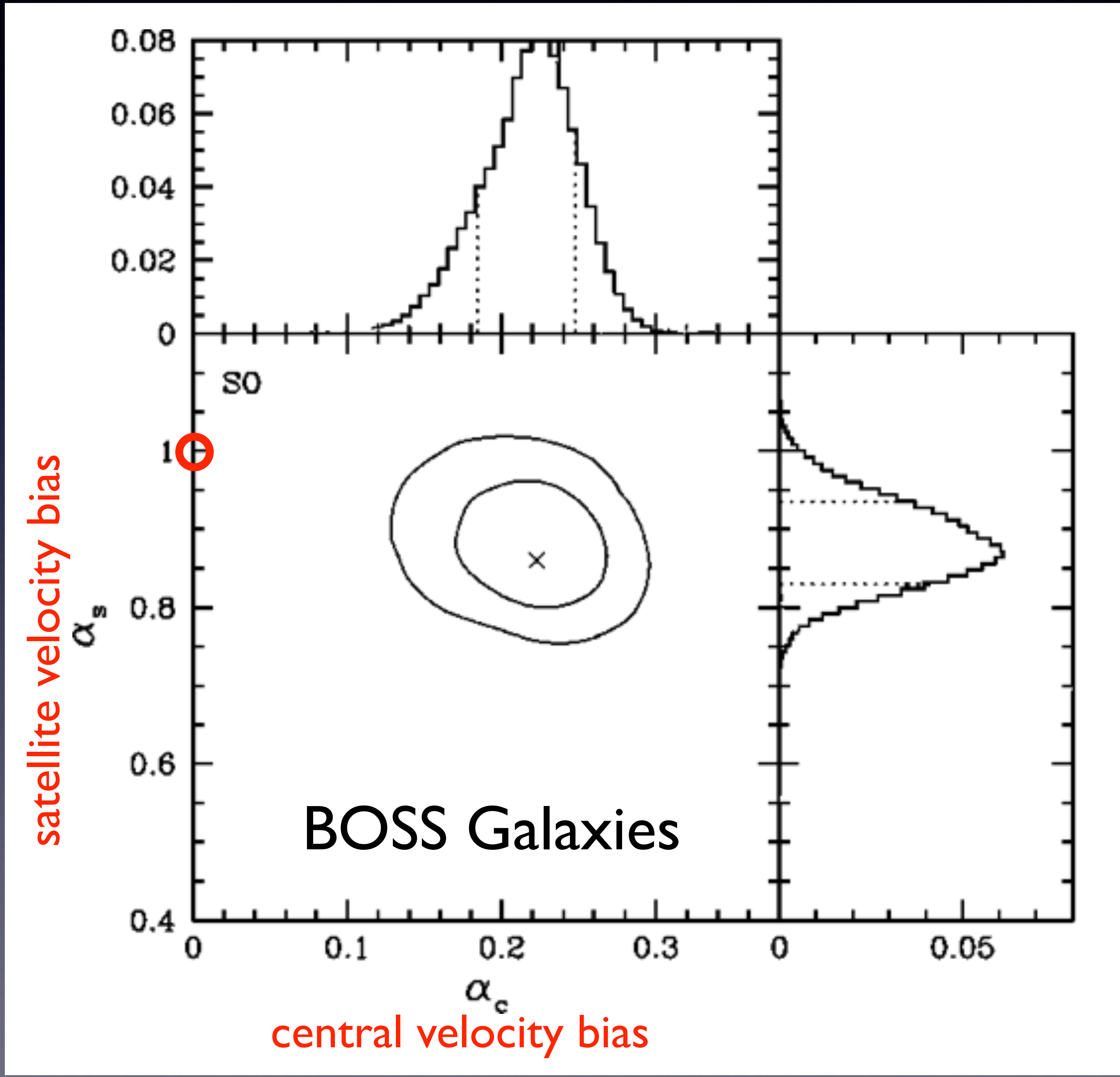
BOSS Galaxies
z~0.5



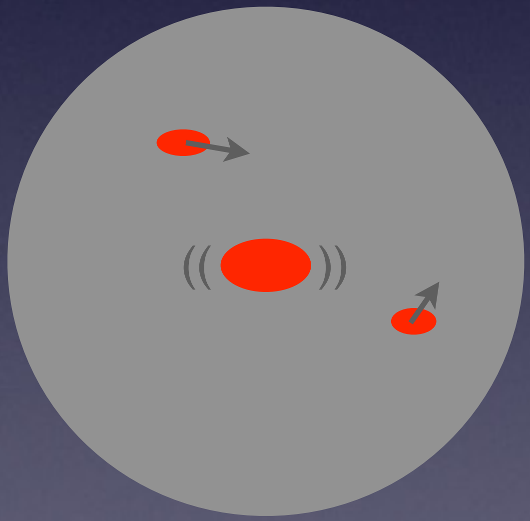
Guo, ZZ, et al. (2015a)



Galaxy Kinematics inside Halos

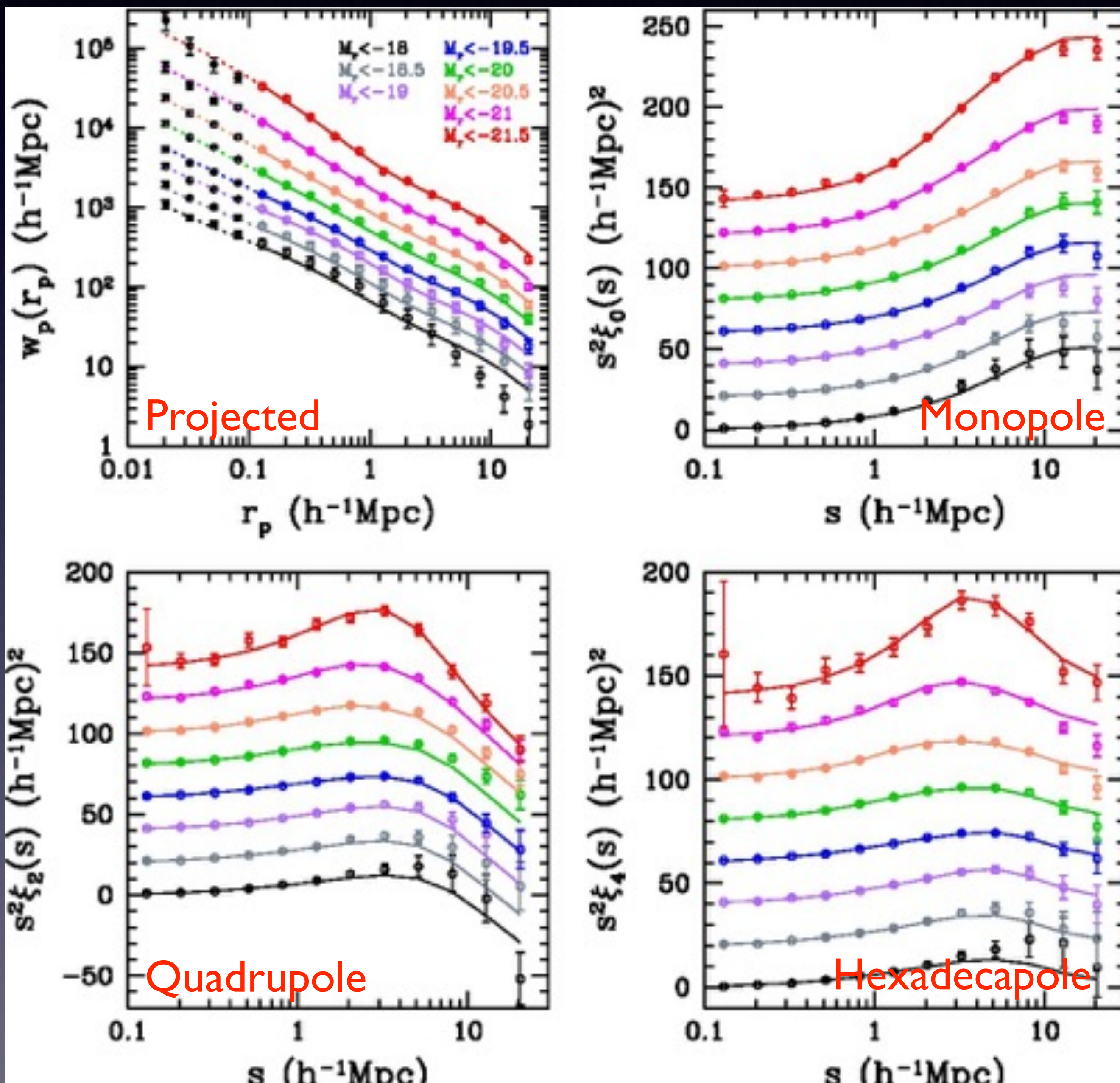


Guo, ZZ, et al. (2015a)



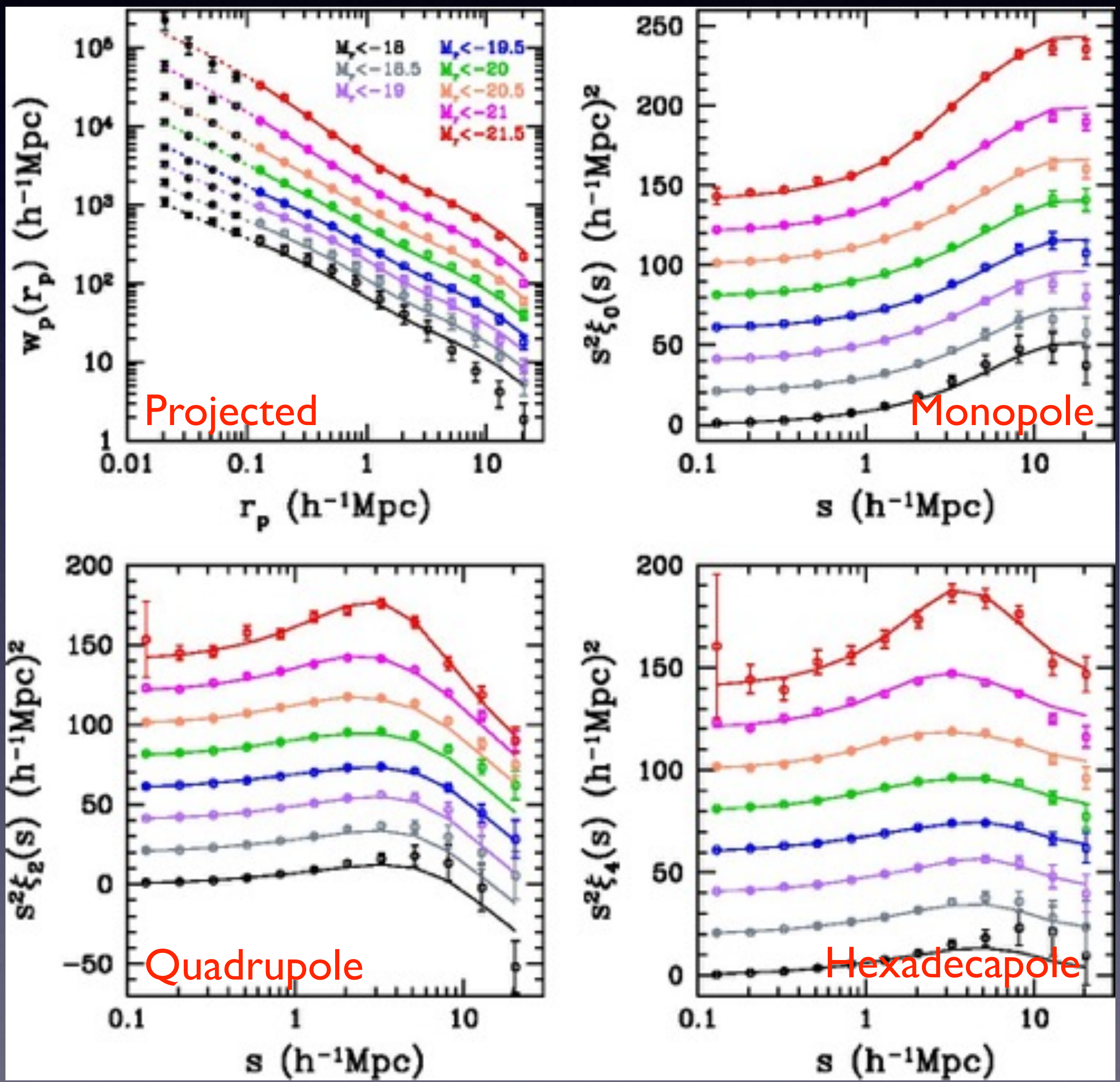
The central galaxy in a halo is not at rest w.r.t. the halo.

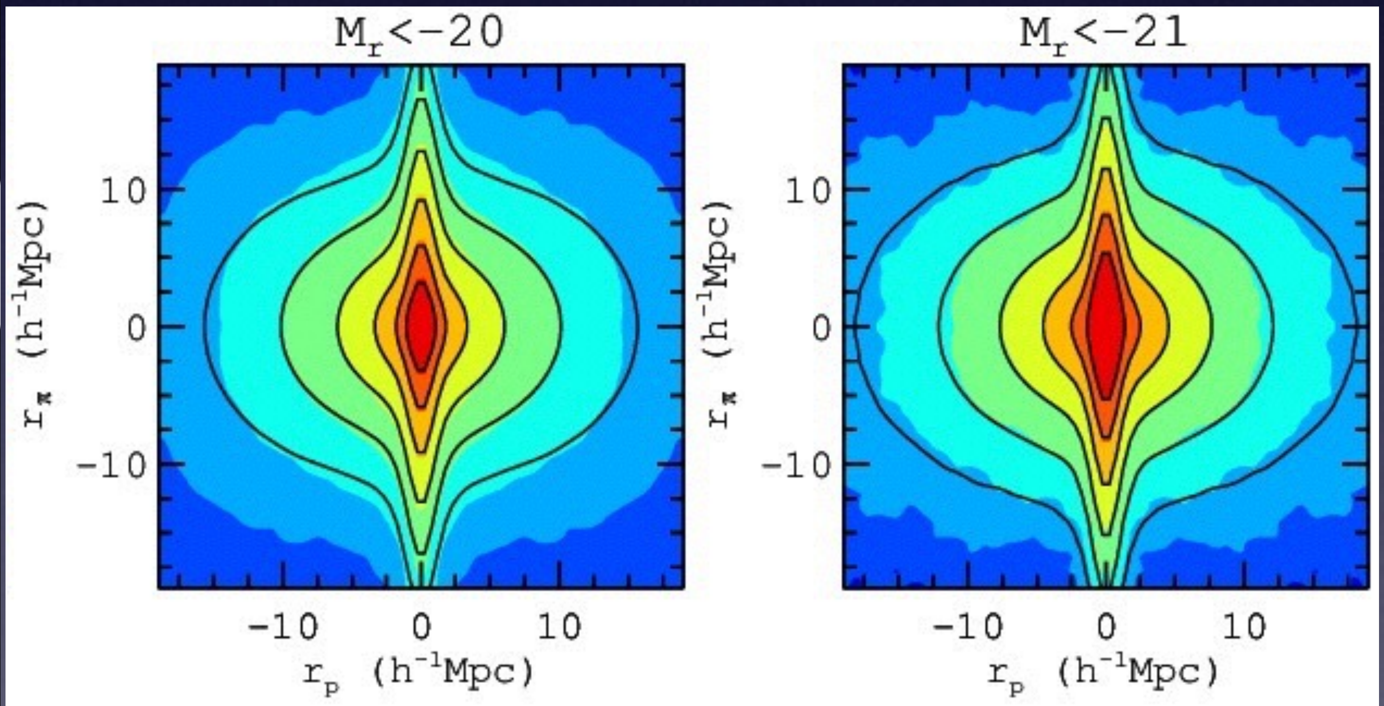
SDSS Main Galaxy Sample (z~0.1)



Guo, ZZ, et al. (2015c)

SDSS Main Galaxy Sample (z~0.1)

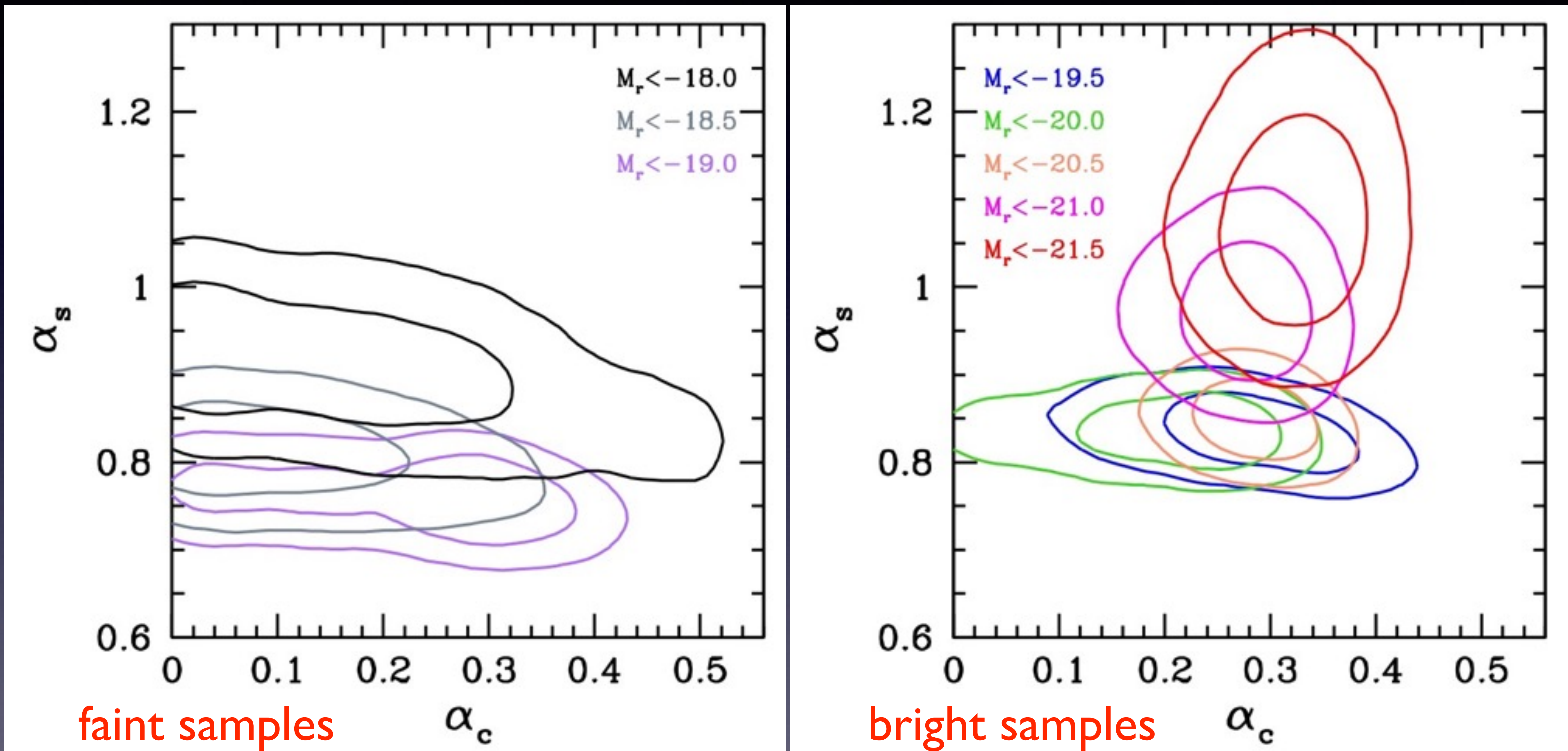




Guo, ZZ, et al. (2015c)

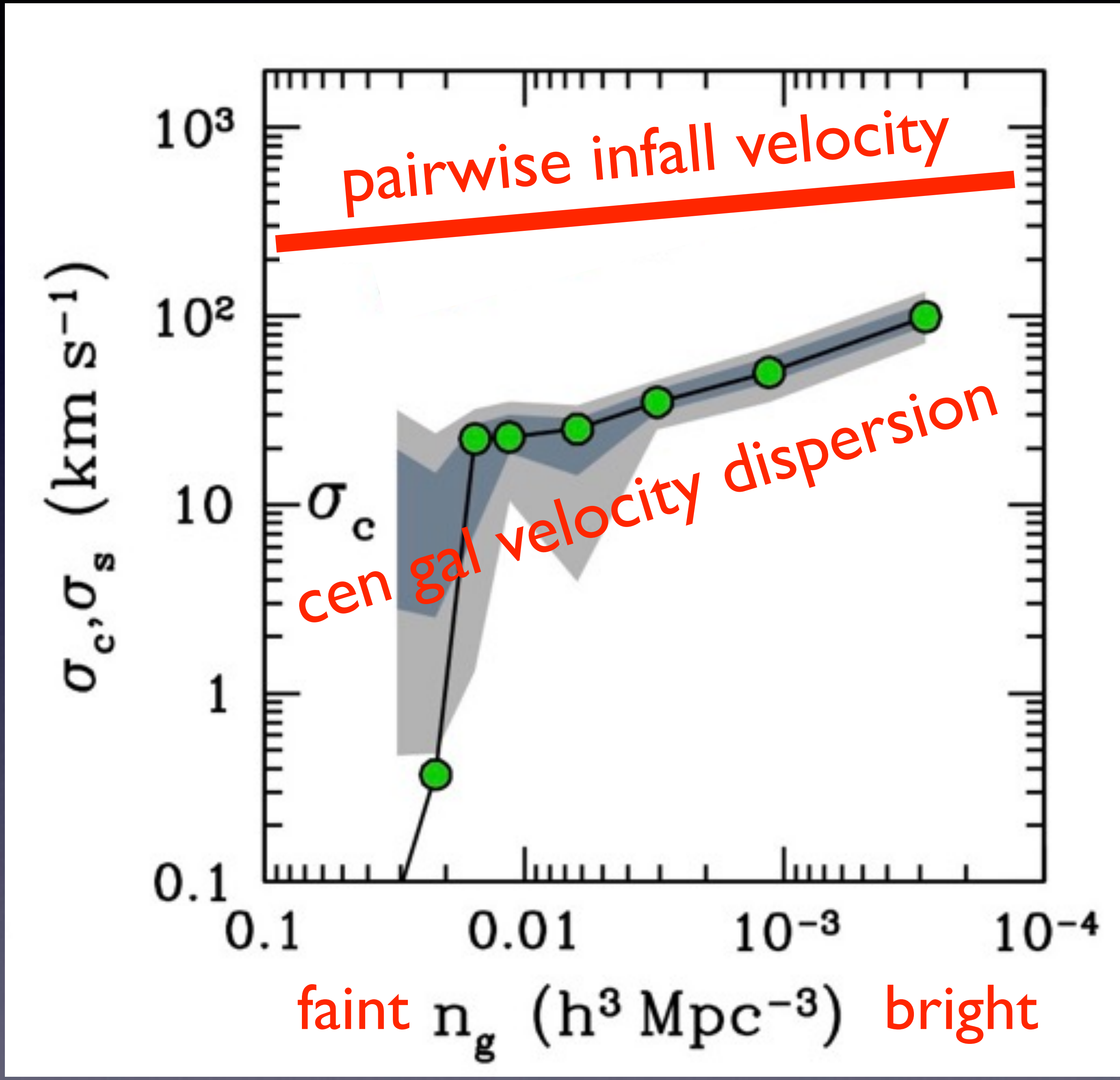
Velocity Bias of SDSS Main Galaxies (z~0.1)

Guo, ZZ, et al. (2015c)



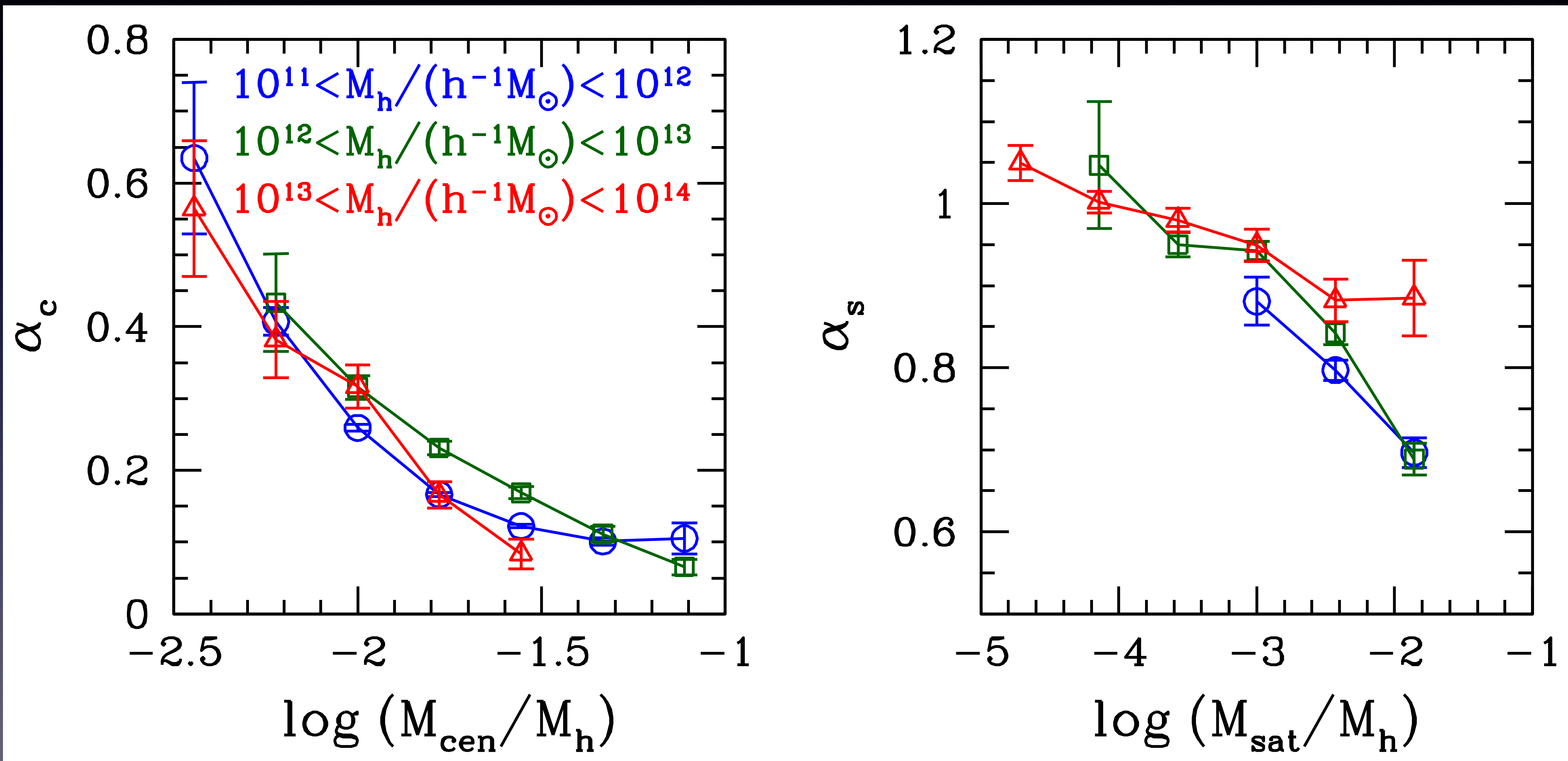
In broad agreement with results based on galaxy groups (van den Bosch+2005; Skibba+ 2011)

Velocity Bias of SDSS Main Galaxies (z~0.1)



In lower mass halos, central galaxies and halos are more mutually relaxed, consistent with an overall earlier formation and thus more time for relaxation.

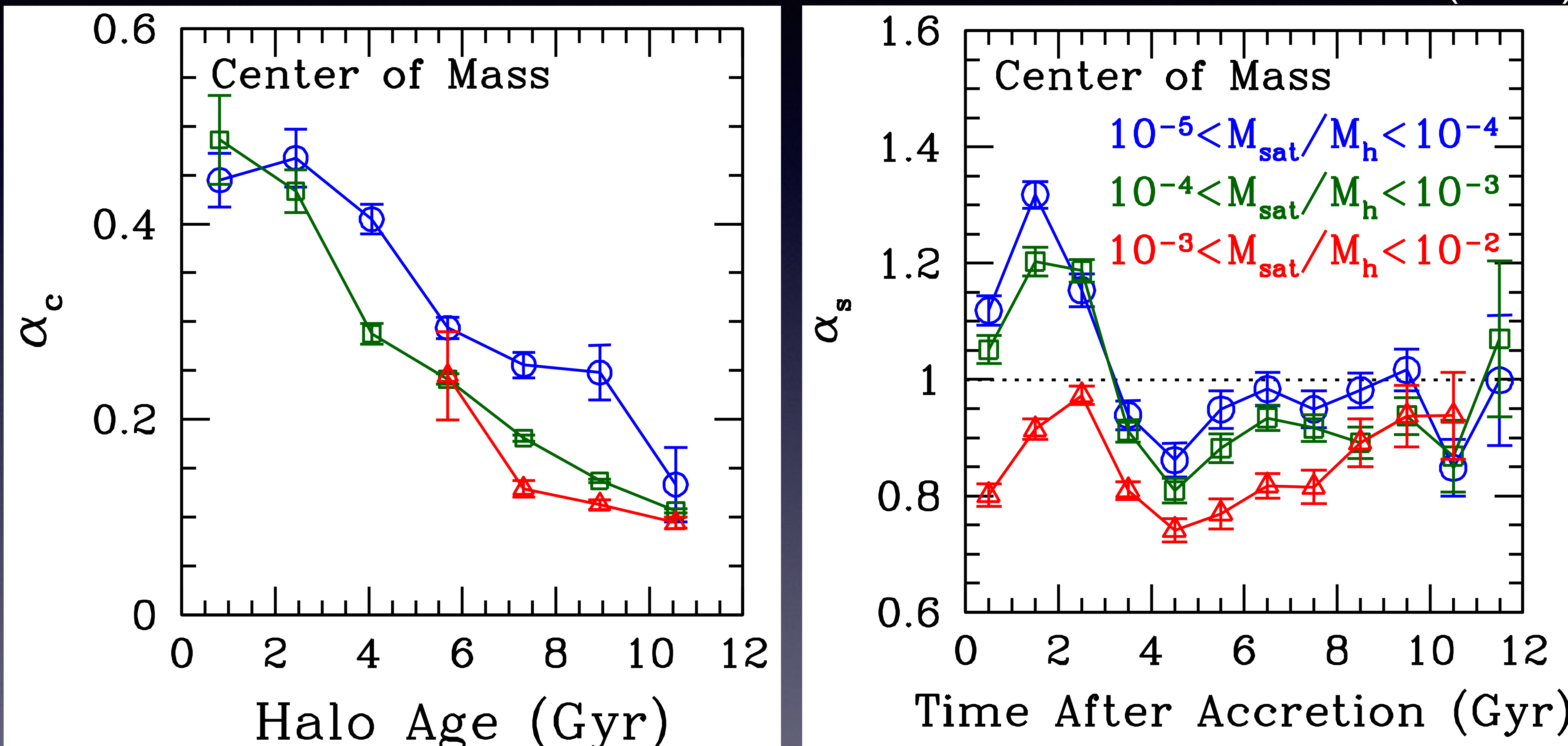
Velocity Bias in the Illustris Simulation



Ye, Guo, ZZ, & Zehavi (2017)

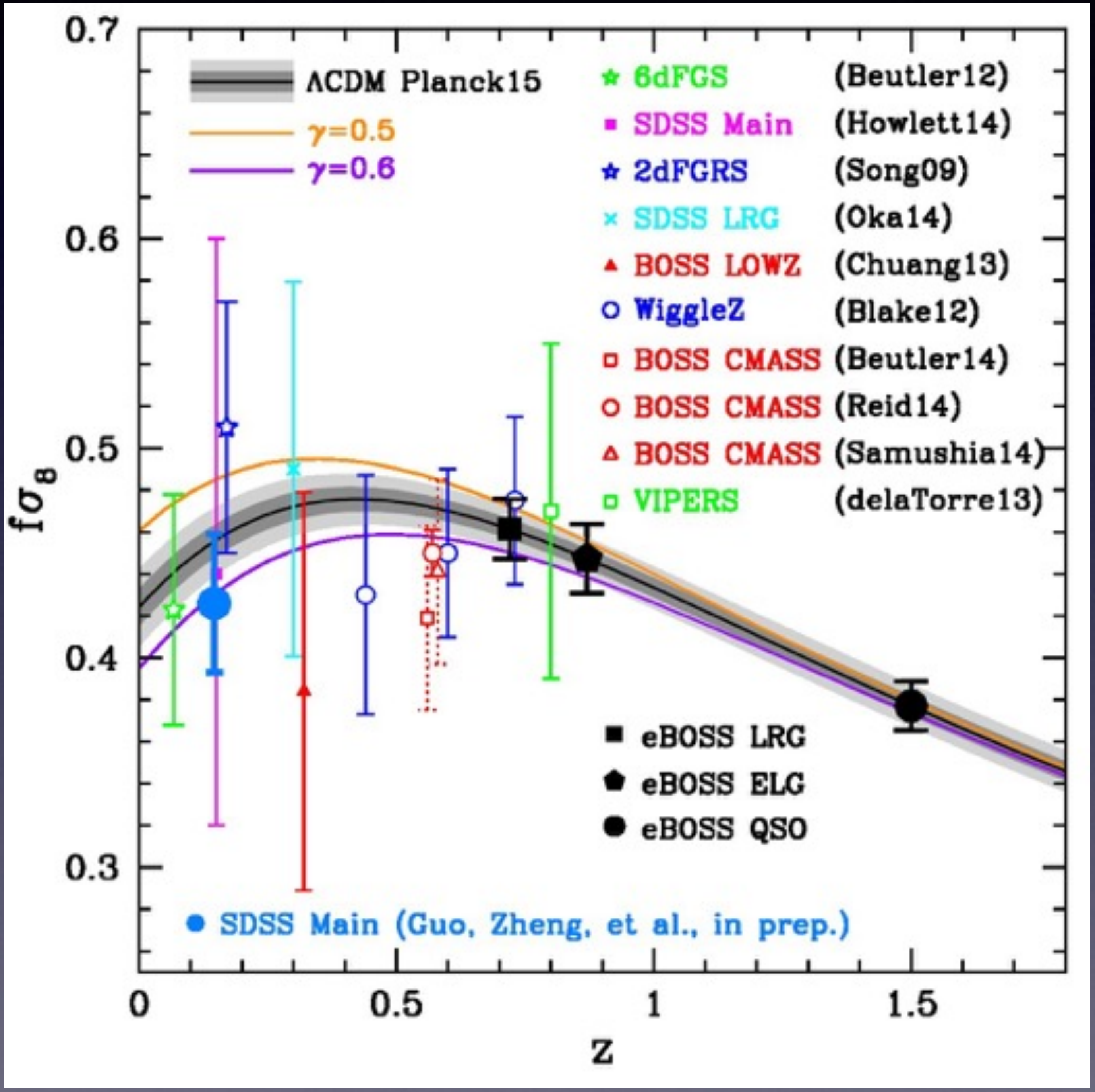
Velocity Bias in the Illustris Simulation

Ye, Guo, ZZ, & Zehavi (2017)



cen v bias	**sat v bias**
more affected by halo accretion/merger	more affected by dynamics inside halos

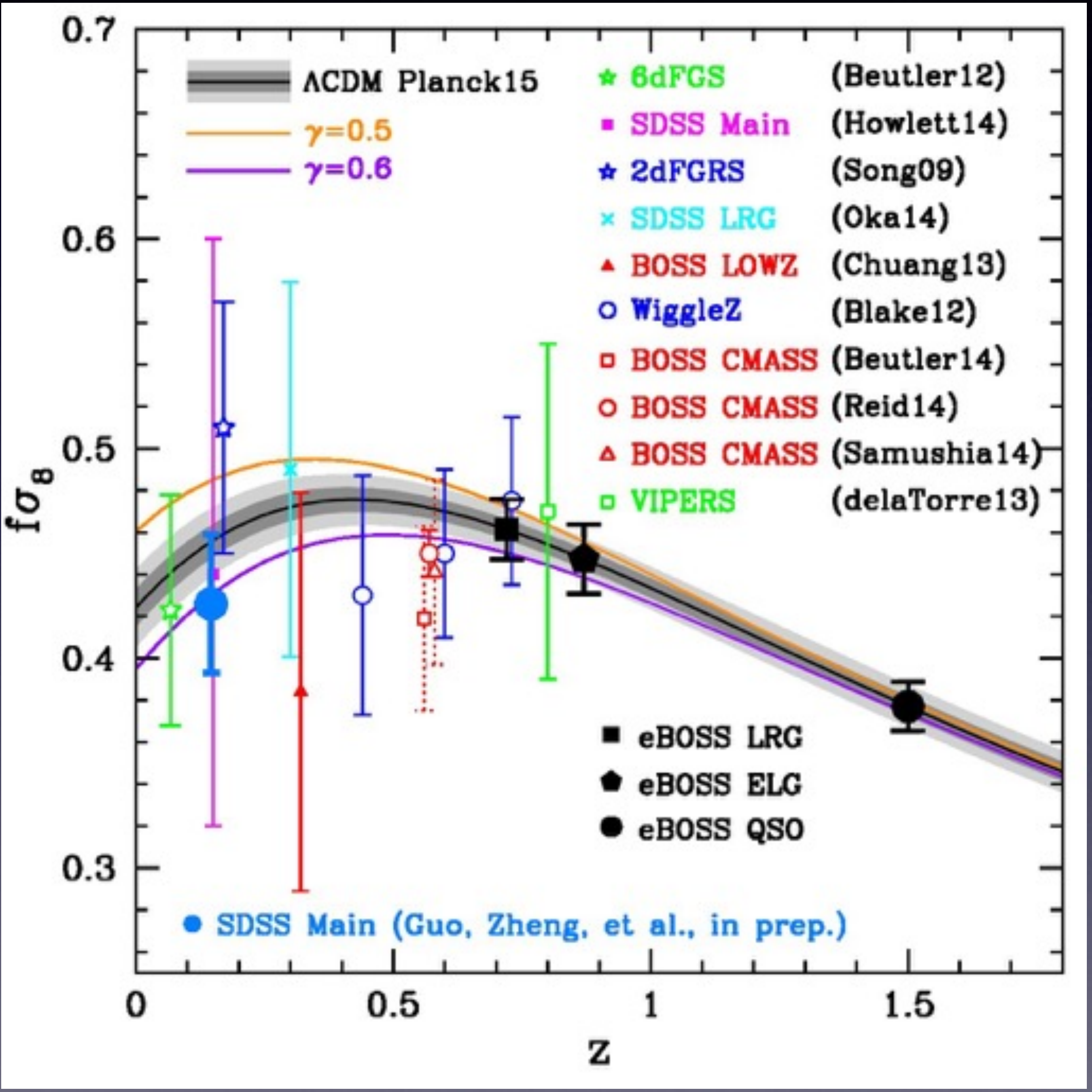
Tightening Cosmological Constraints from Small- and Intermediate-Scale Redshift-Space Distortions



$$\dot{\delta} + \frac{1}{a}\nabla \cdot \mathbf{v} = 0$$ (continuity)

Dawson, et al. (2015)

Tightening Cosmological Constraints from Small- and Intermediate-Scale Redshift-Space Distortions

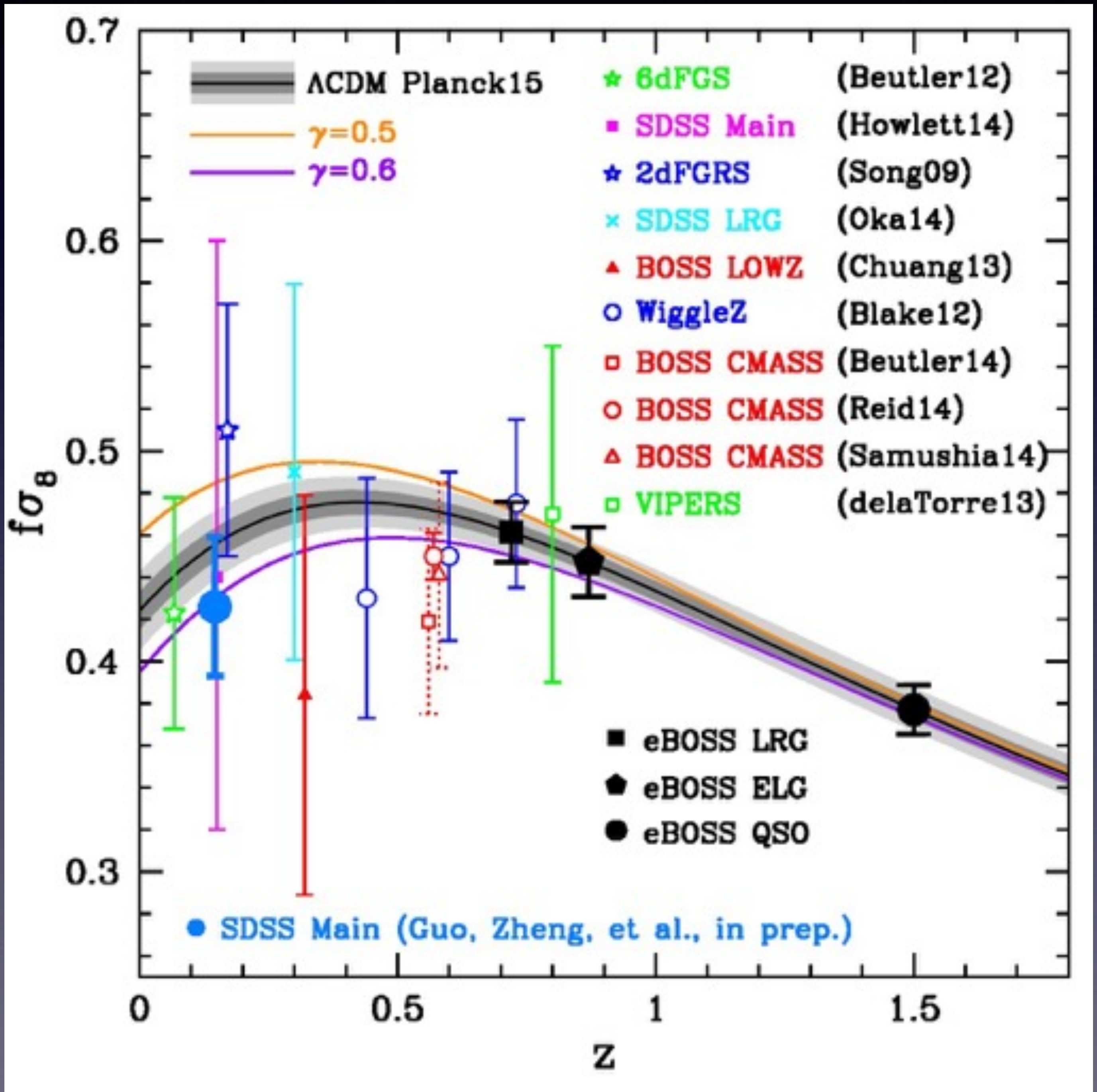


$$\dot{\delta} + \frac{1}{a}\nabla \cdot \mathbf{v} = 0 \quad \text{(continuity)}$$

- Probe structure growth rate
- Test theories of gravity
- Constrain dark energy

Dawson, et al. (2015)

Tightening Cosmological Constraints from Small- and Intermediate-Scale Redshift-Space Distortions



$$f \equiv \frac{d \ln D}{d \ln a}$$

large-scale 3D redshift 2PCF

amplitude => $b\sigma_8$

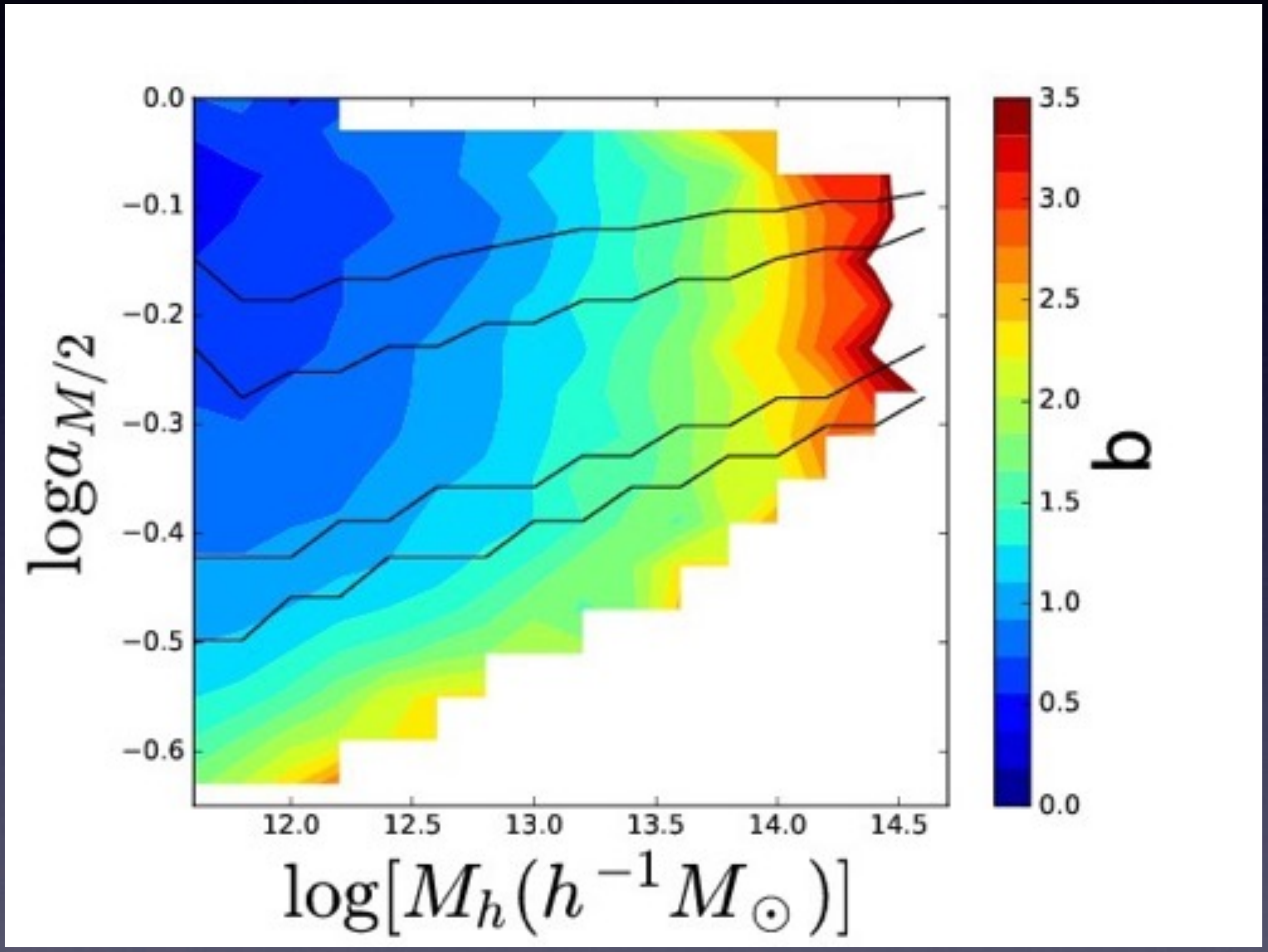
shape => $\frac{f}{b}$

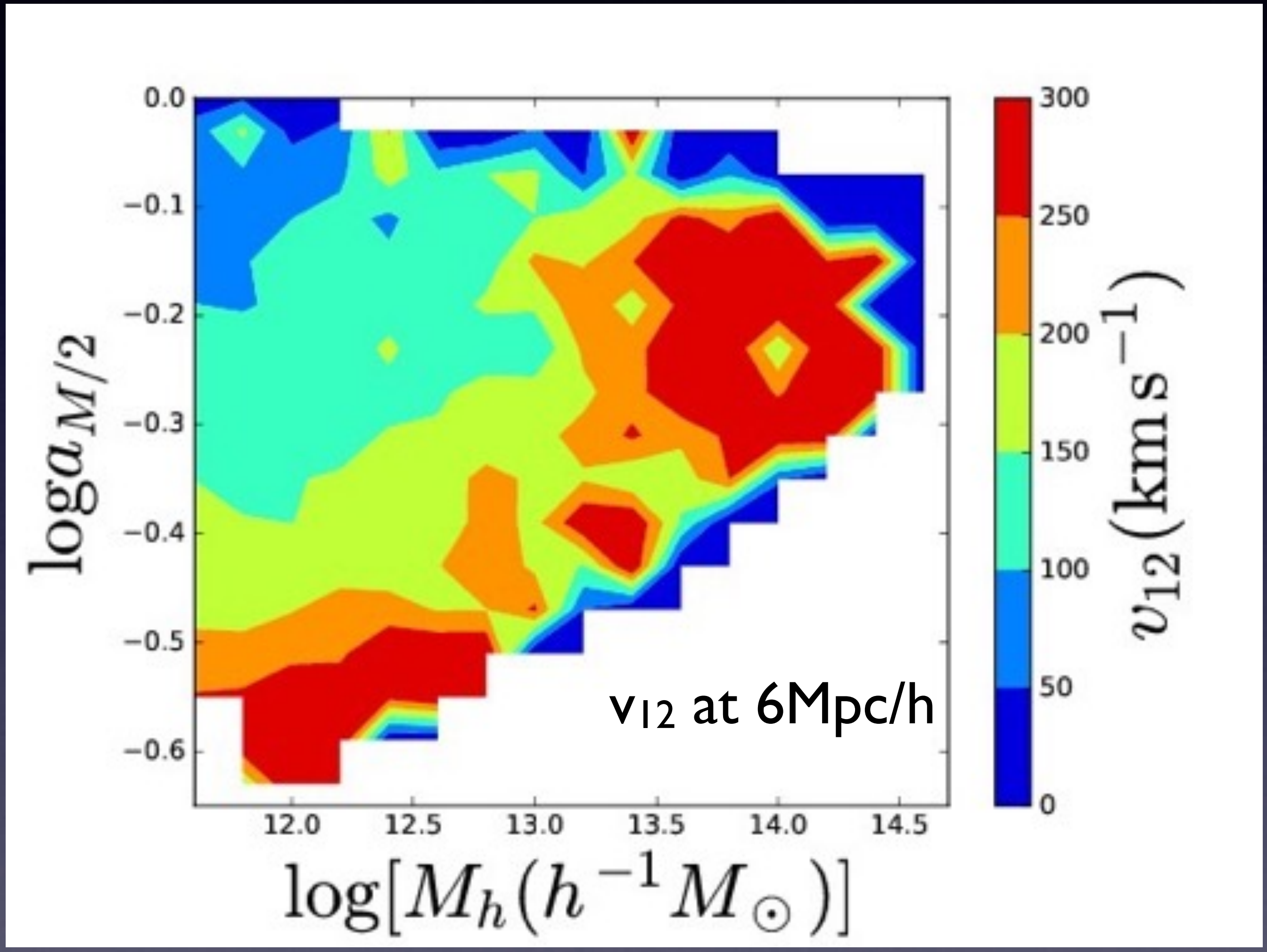
} => $f\sigma_8$

insensitive to assembly bias

Dawson, et al. (2015)

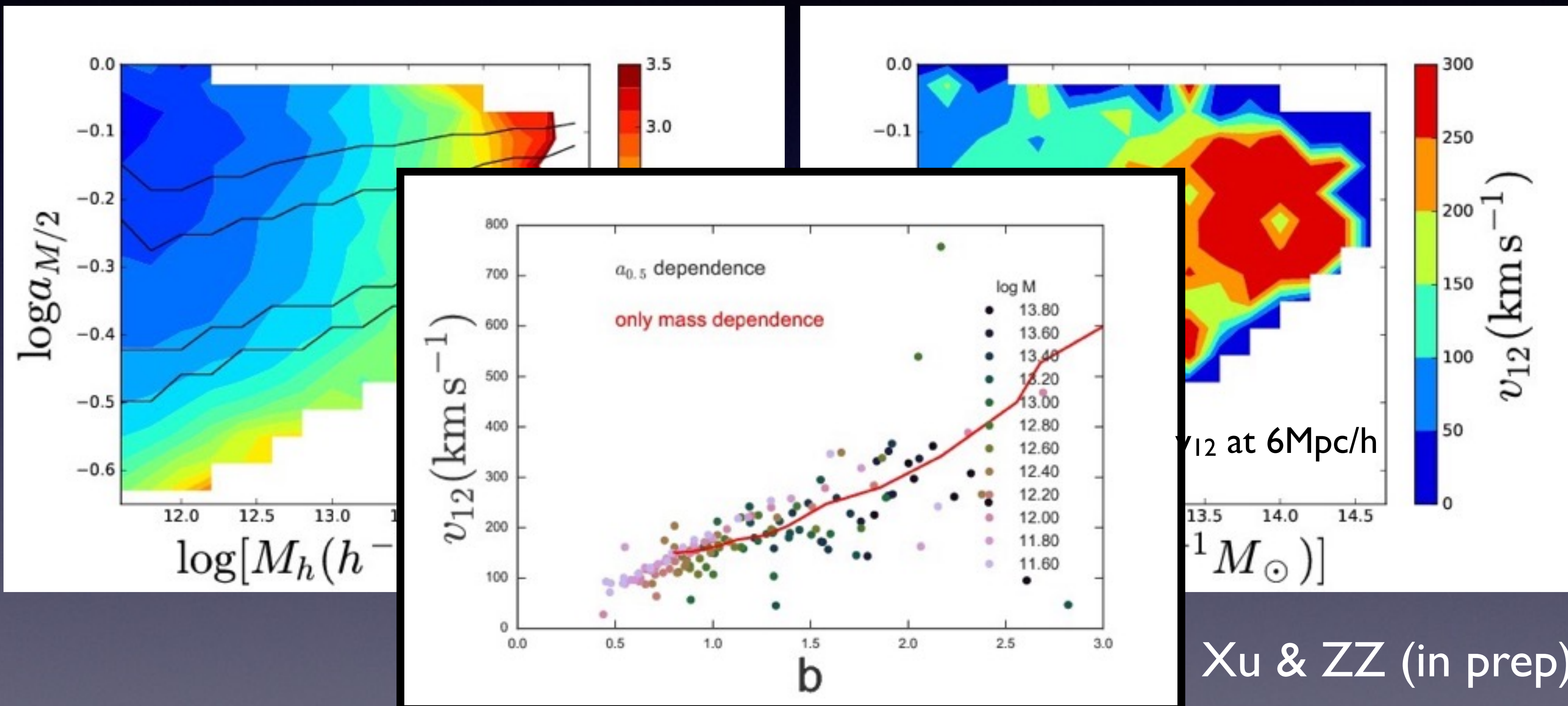
Assembly Effect on Halo Clustering and Kinematics





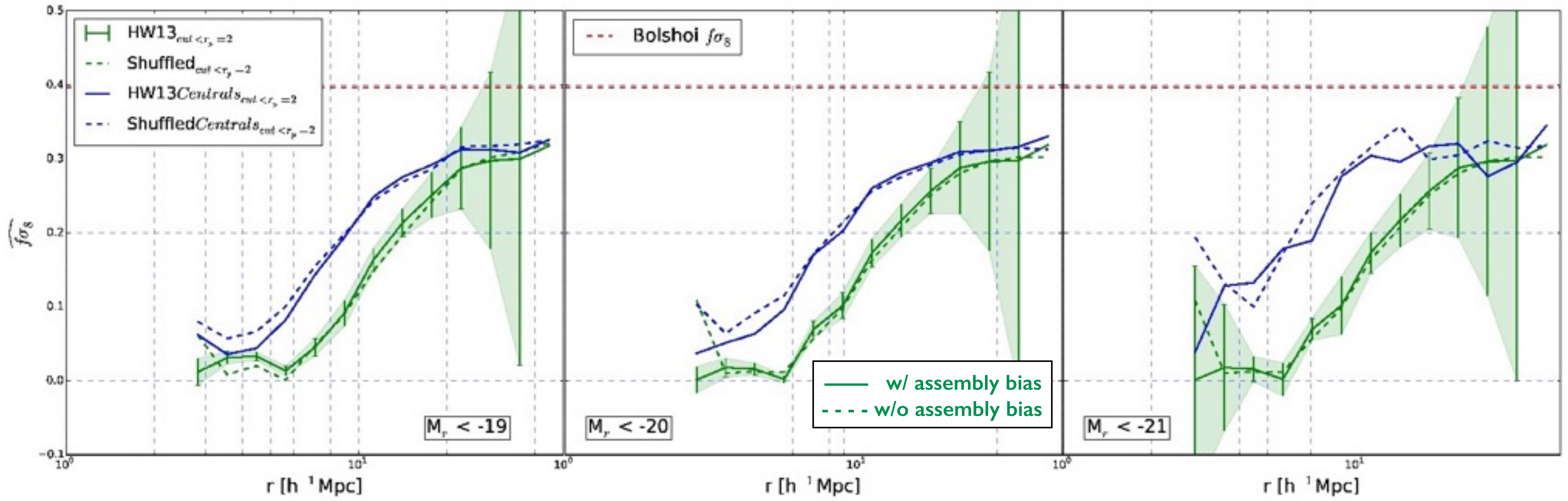
Xu & ZZ (in prep)

Assembly Effect on Halo Clustering and Kinematics



Xu & ZZ (in prep)

Assembly Effect on $f\sigma_8$ Constraint from Small Scales



McCarthy & ZZ (in prep)

[McEwen & Weinberg (2016) on matter correlation from galaxy correlation function and galaxy lensing]

Summary

- accurate and efficient modeling of small- and intermediate-scale redshift-space galaxy clustering by tabulating necessary information of halos in N-body simulations
- redshift-space clustering modeling of BOSS CMASS and SDSS Main galaxies to constrain galaxy kinematics inside halos (and tighten $f\sigma_8$ constraints), with inferred velocity bias in broad agreement with predictions of hydro simulations
- influence of assembly bias on $f\sigma_8$ constraints and halo assembly on both halo clustering and kinematics