Enhancing Dark Energy Constraints from Redshift-Space Galaxy Clustering

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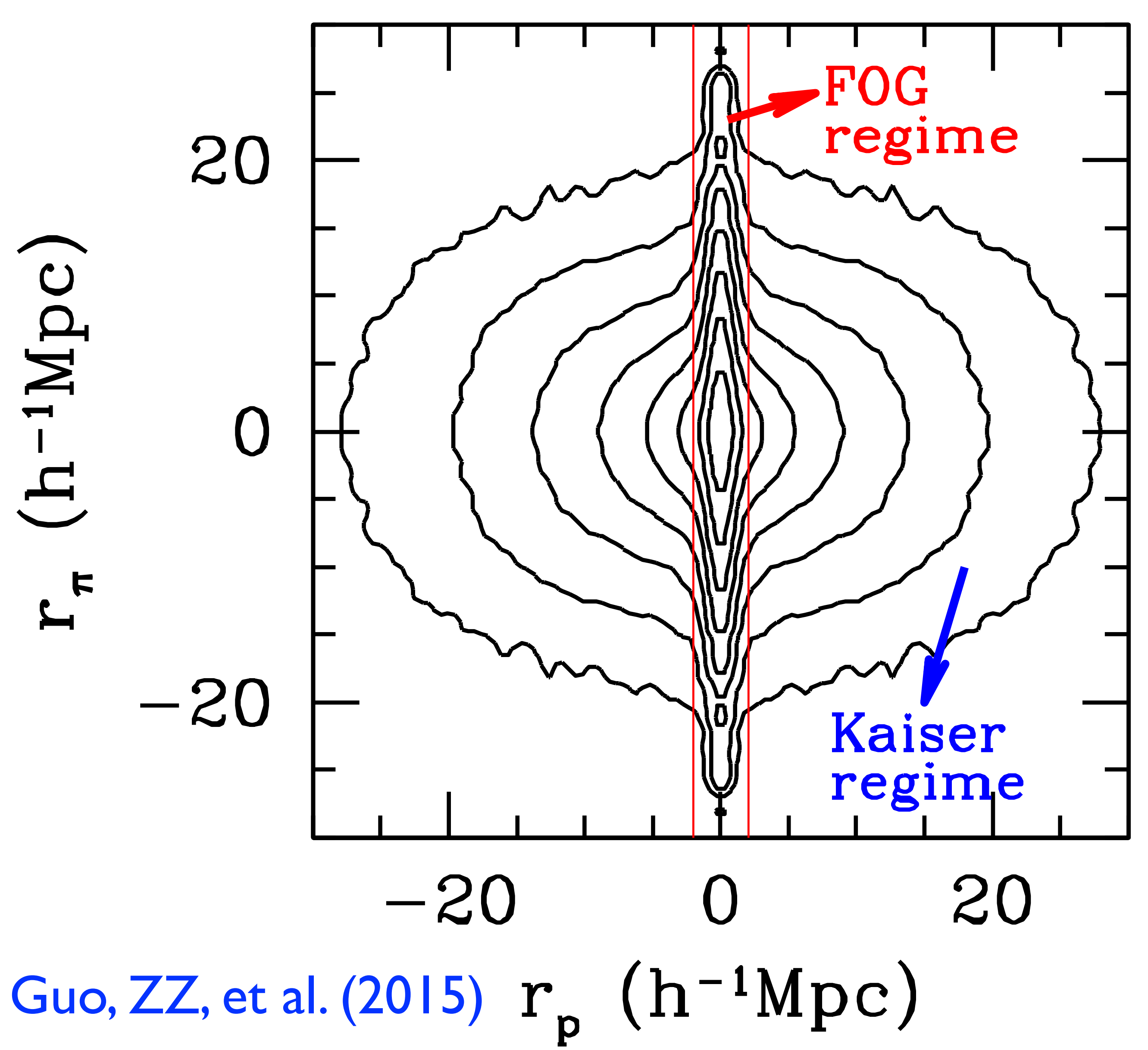
Enhancing Dark Energy Constraints from Redshift-Space Galaxy Clustering

- Redshift-space distortions (RSD) in galaxy clustering and constraints on structure growth rate
- Accurate and efficient halo modeling of (intermediate- and small-scale) galaxy clustering
- Investigating potential theoretical systematics in the (halo-based) modeling

Redshift-Space Galaxy Clustering

Small scales: FoG
[Fingers-of-God]
galaxy kinematics inside virtualized structures (halos)

Large scales: Kaiser effect
structure growth rate
(gravity, dark energy)



Guo, ZZ, et al. (2015)

Redshift-Space Galaxy Clustering

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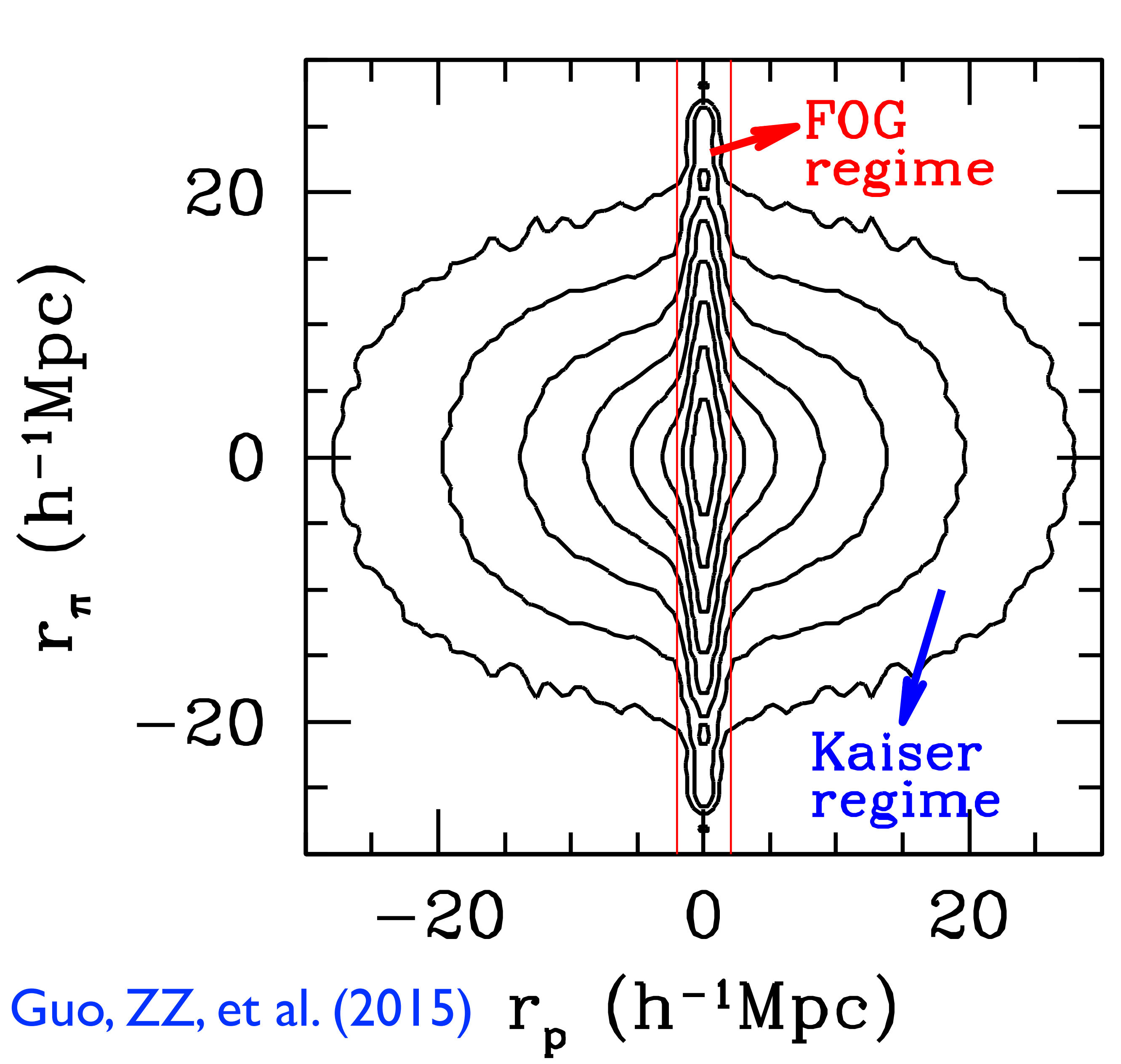
[Fingers-of-God]
galaxy kinematics inside virtualized structures (halos)

Large scales: Kaiser effect
structure growth rate
(gravity, dark energy)

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

(continuity)



Guo, ZZ, et al. (2015)

Redshift-Space Galaxy Clustering

Large-scale RSD

amplitude => $b\sigma_8$

shape => f/b

$$\left.\begin{array}{l} \text{amplitude} \Rightarrow b\sigma_8 \\ \text{shape} \Rightarrow f/b \end{array}\right\} \Rightarrow f\sigma_8$$

Probe combination of structure growth rate and fluctuation amplitude (gravity, dark energy)

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

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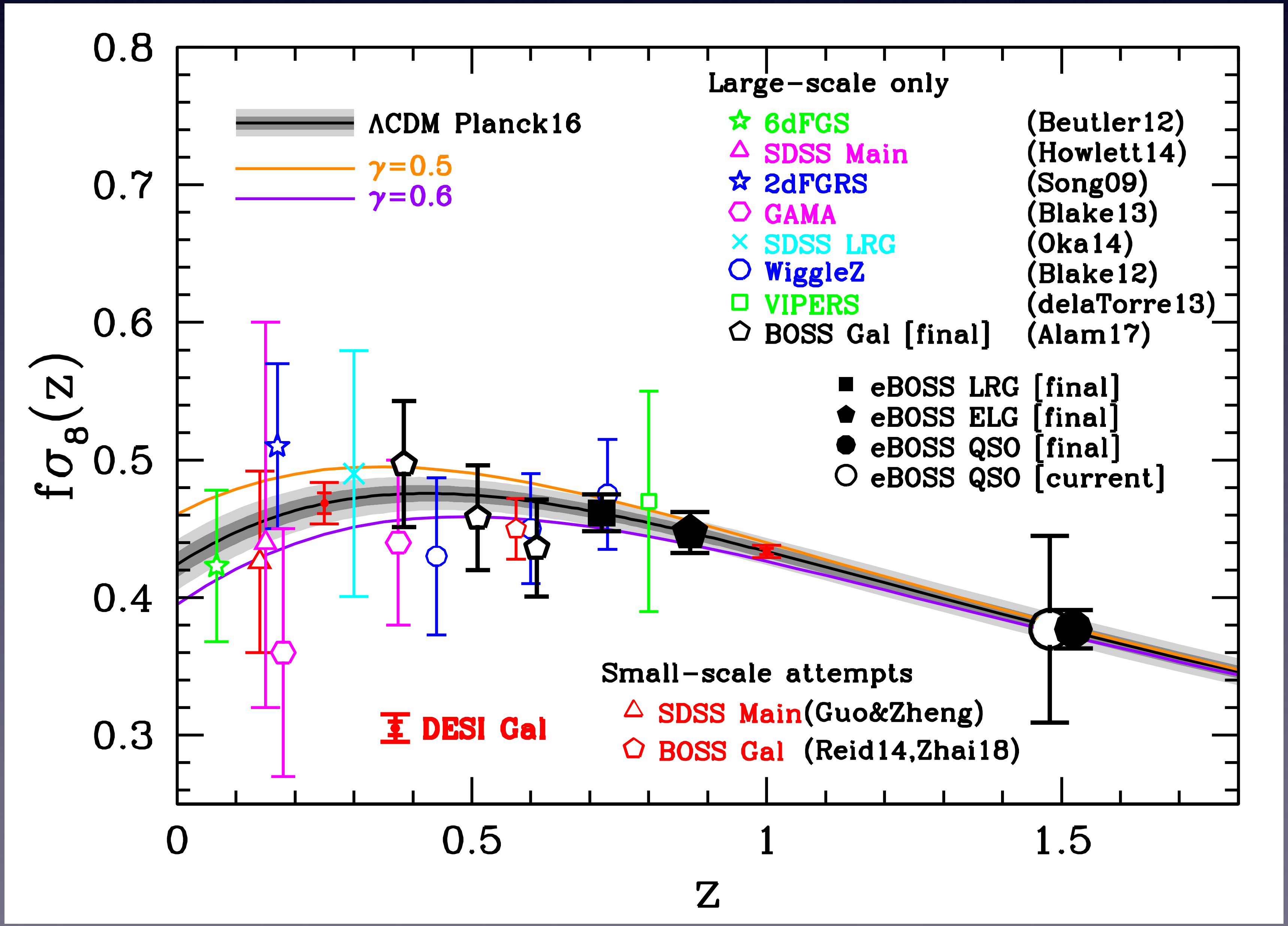

Redshift-Space Galaxy Clustering

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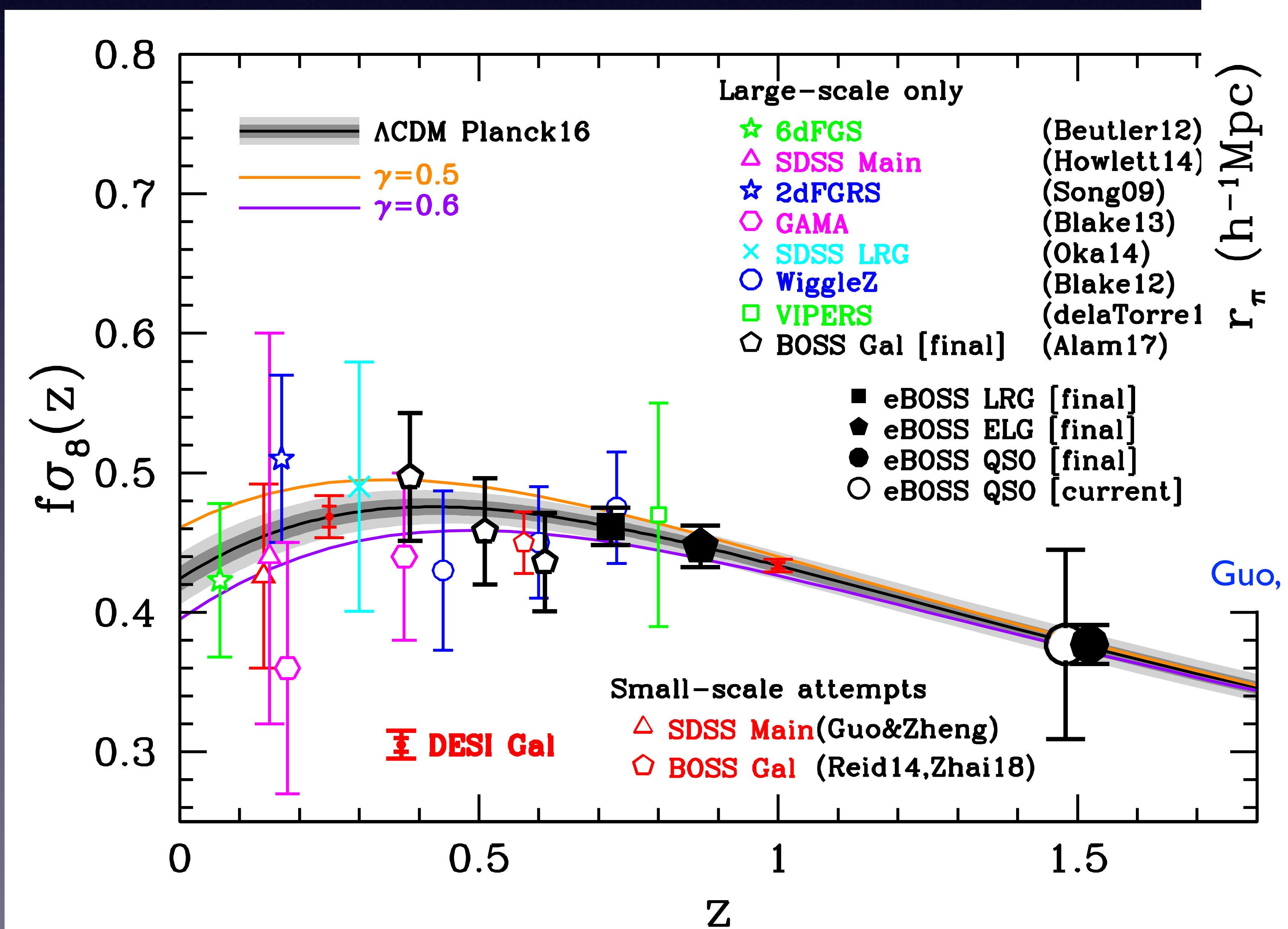

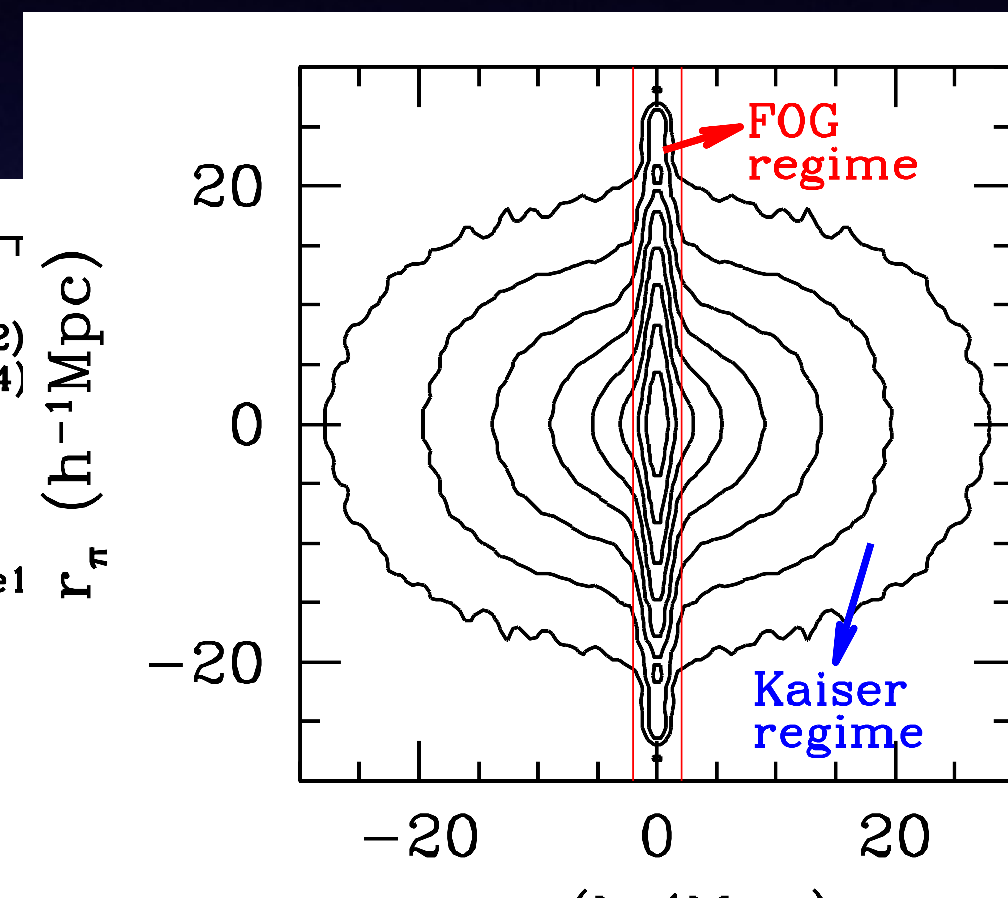

Guo, ZZ, et al. (2015)

Current constraints mainly use scales > ~40Mpc/h with perturbation theories.

Redshift-Space Galaxy Clustering

Intermediate and Small-scale RSD

high statistical power
but difficult to model accurately and efficiently

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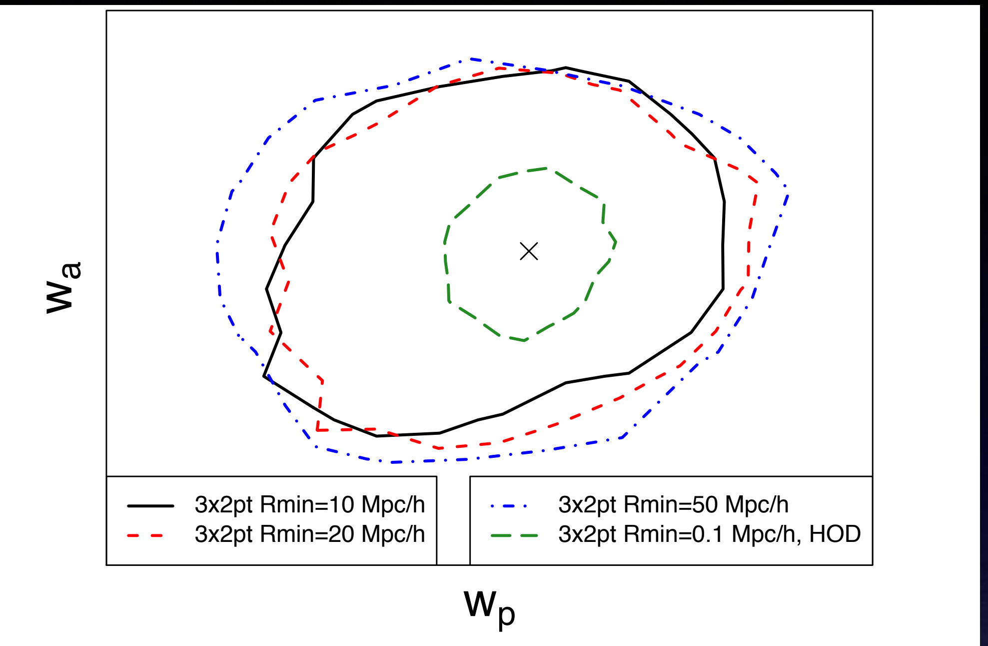

Krause & Eifler (2017)

Redshift-Space Galaxy Clustering

Intermediate and Small-scale RSD

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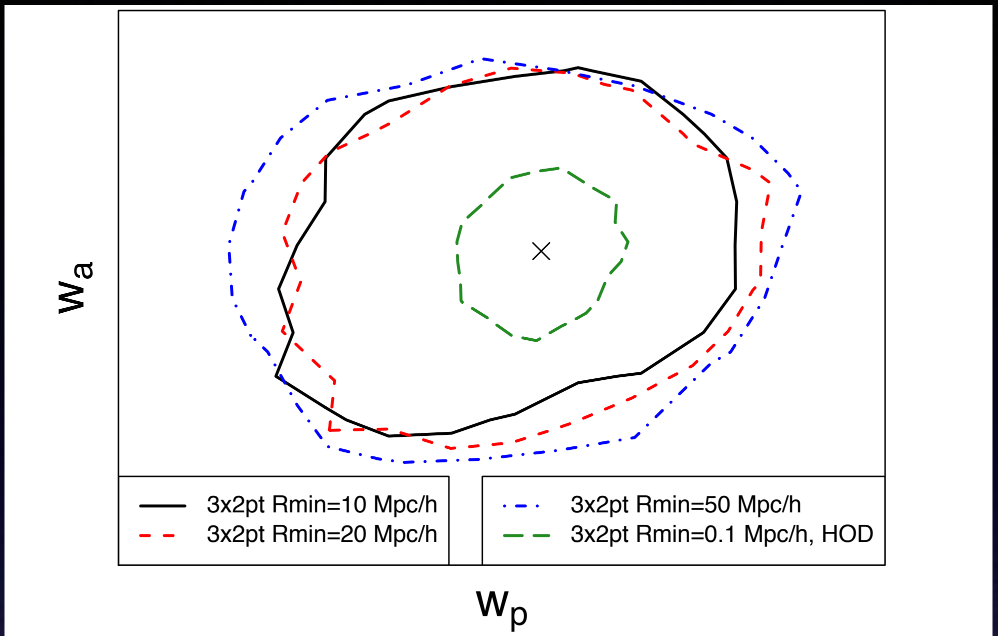
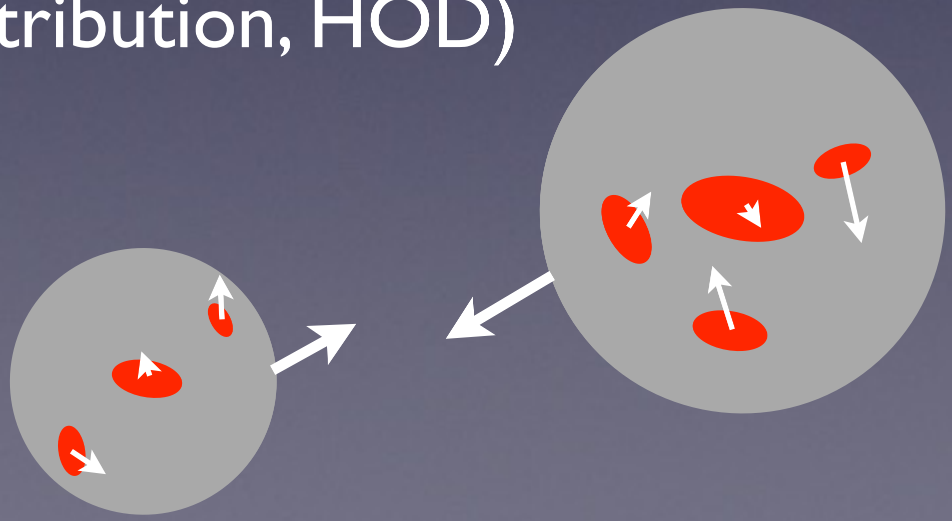


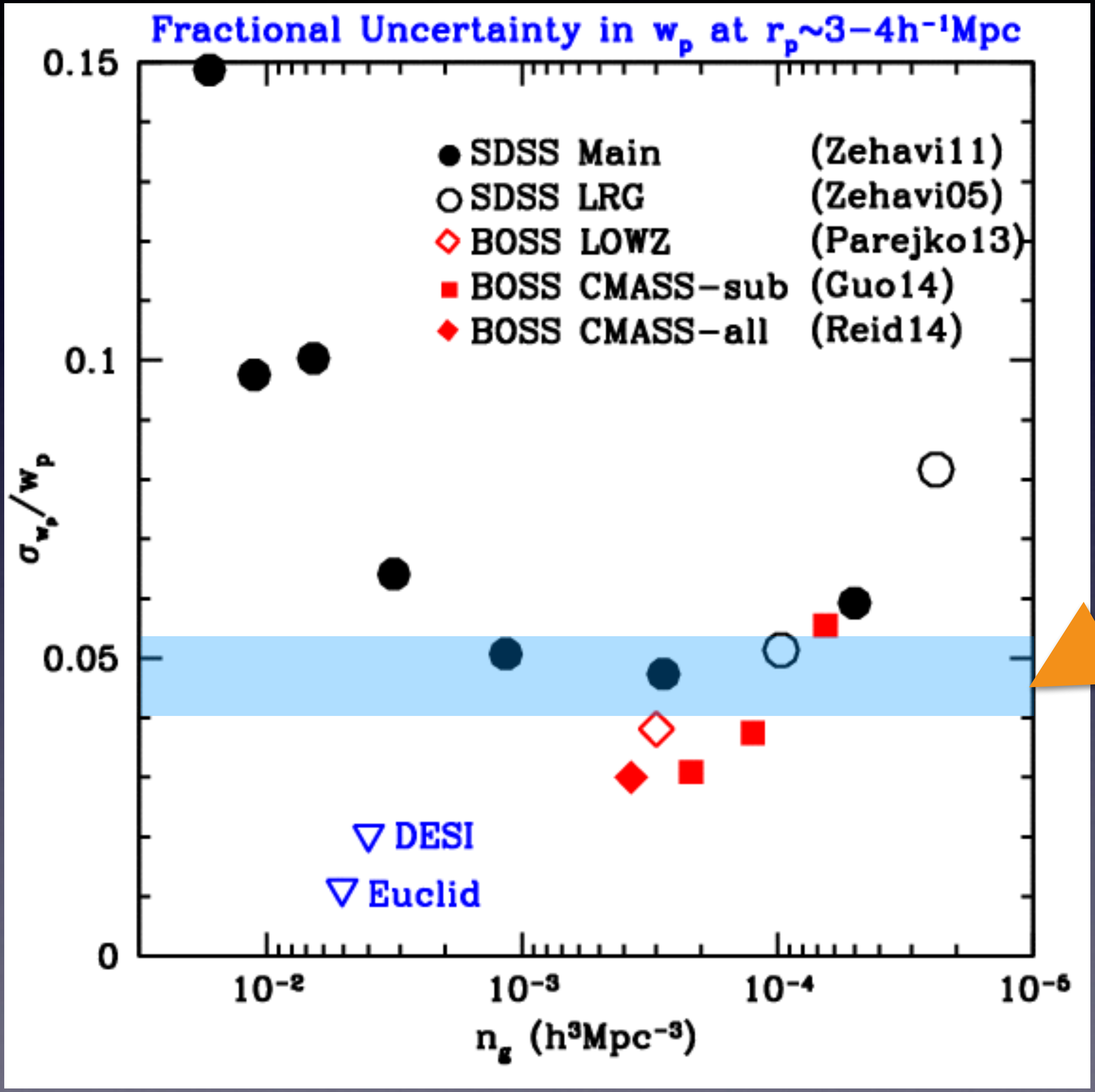
Krause & Eifler (2017)

Halo model

connecting galaxies to dark matter field through galaxy-halo relation
(e.g., Halo Occupation Distribution, HOD)

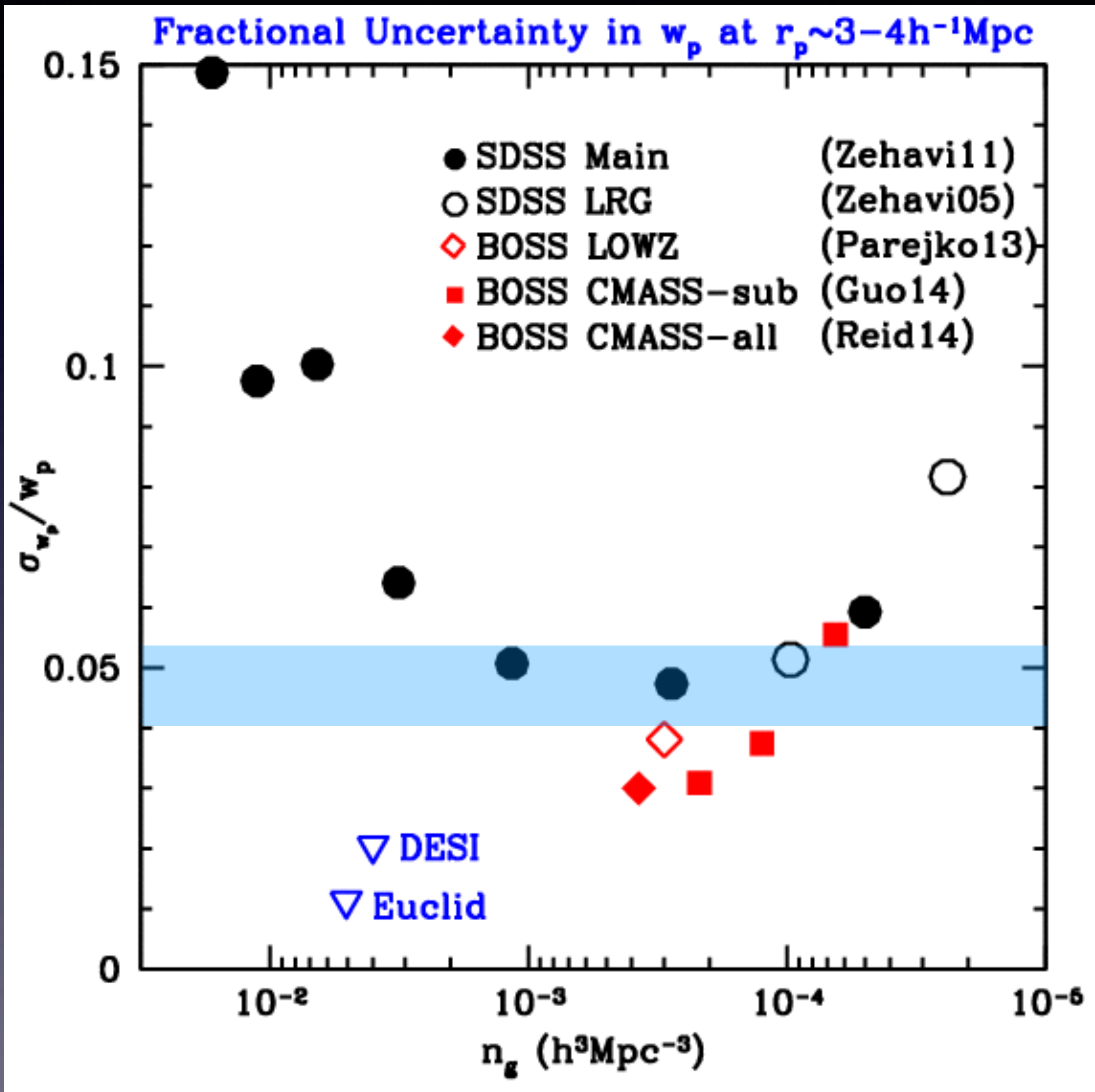


High Precision Galaxy Clustering Measurements



~ 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
- …

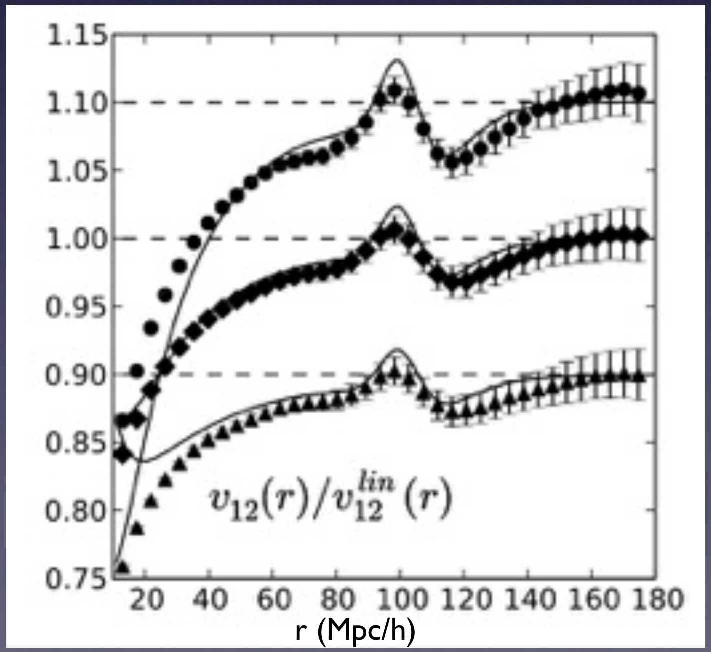
(Zheng04, Tinker+05, van den Bosch+13)

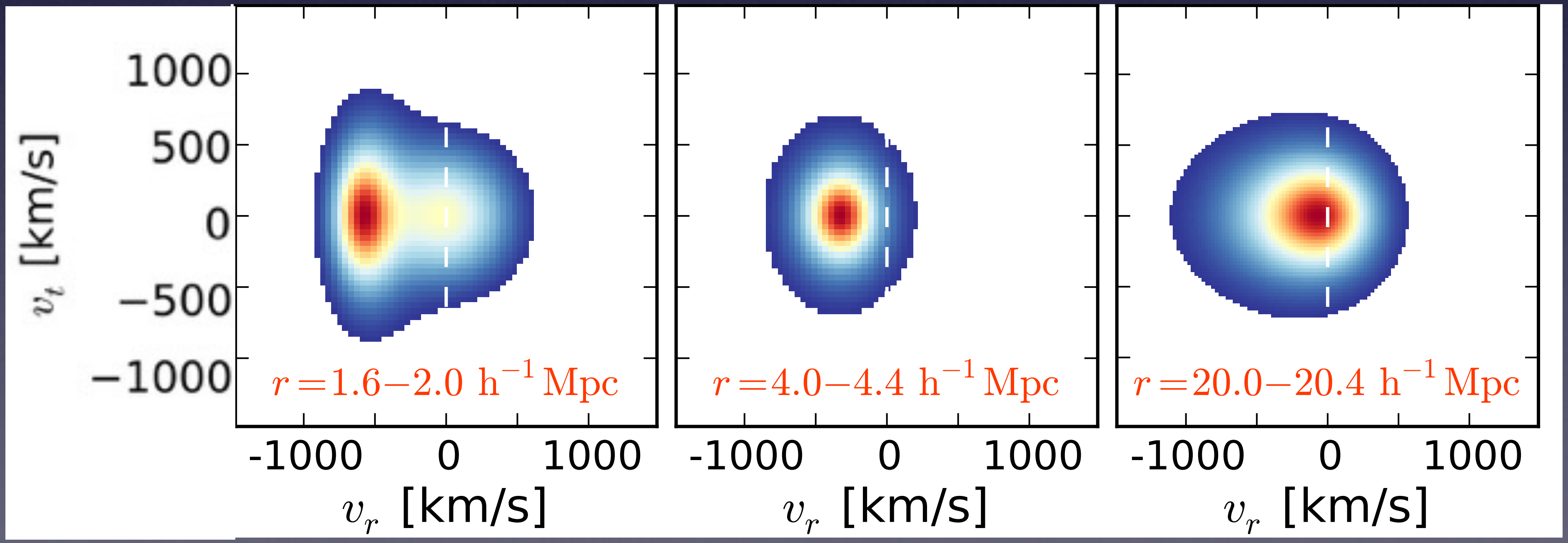
Difficulties in Developing Accurate Models of Galaxy Clustering

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

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

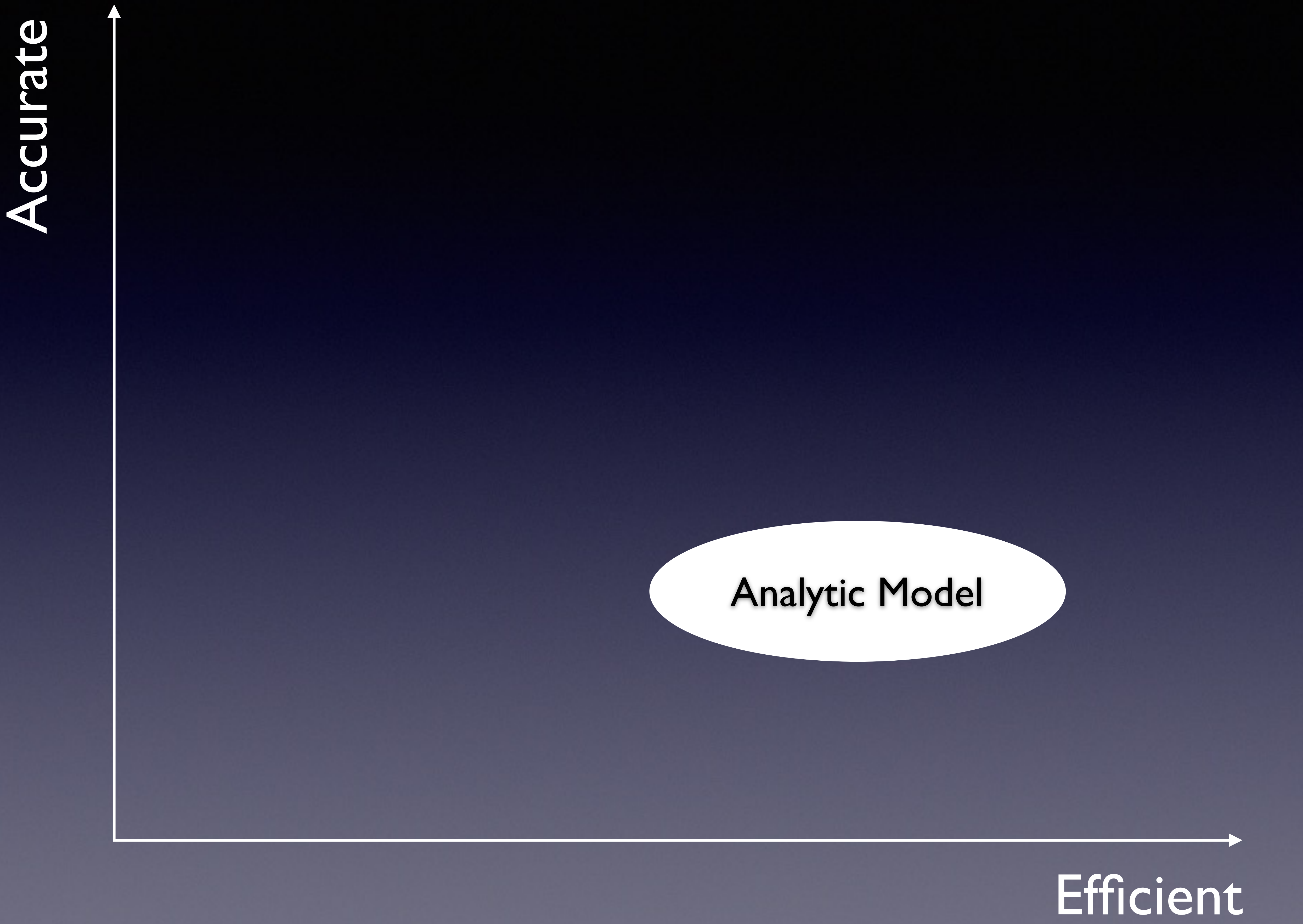
(e.g., Tinker 2007, Reid & White 2011, Zu & Weinberg 2013)





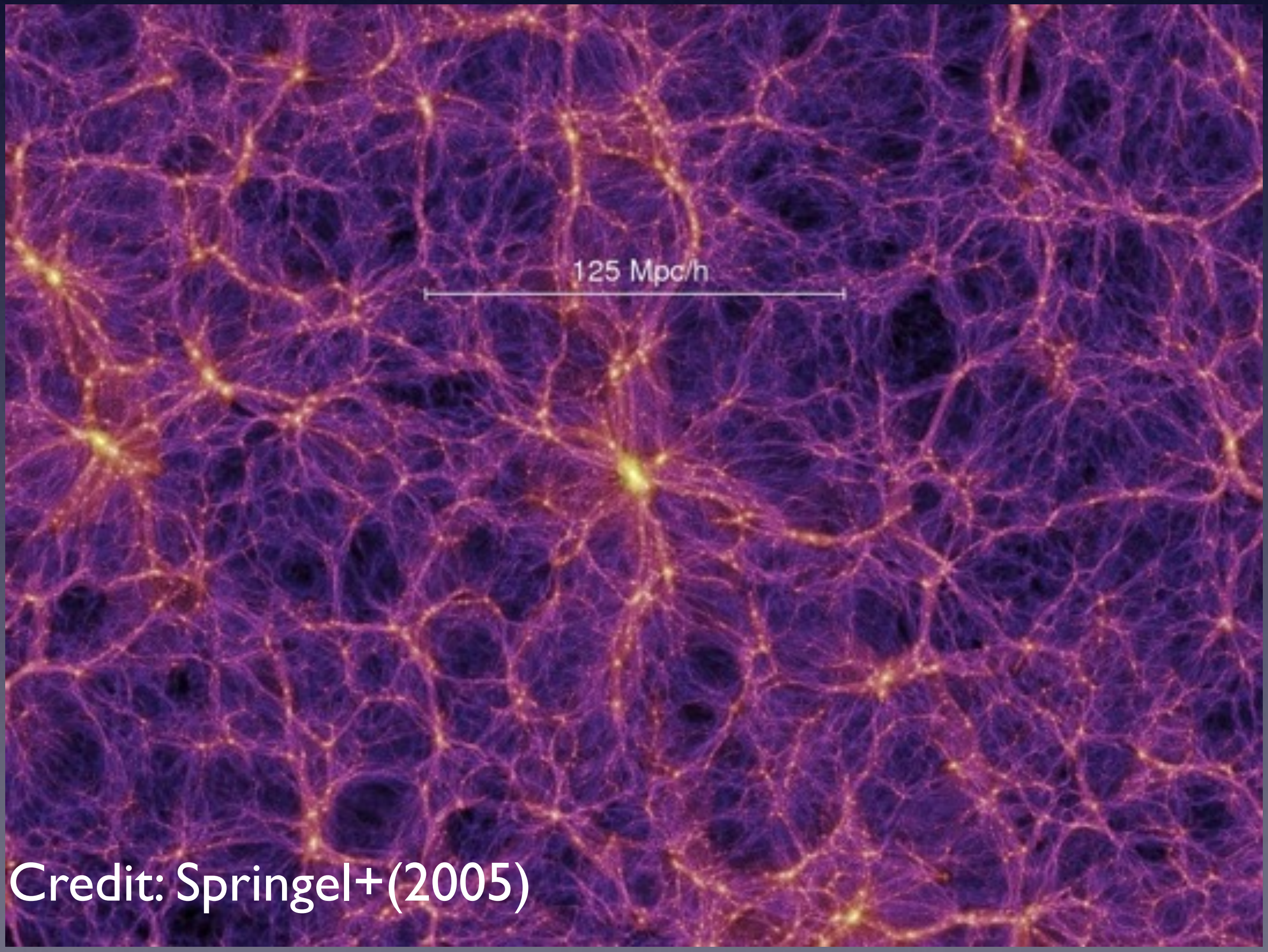
Reid & White (2011)

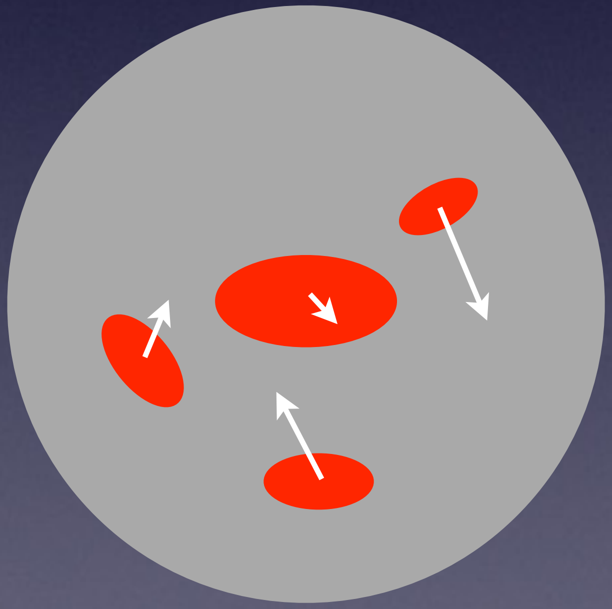
Zu & Weinberg (2013)


Accurate
Analytic Model
Efficient

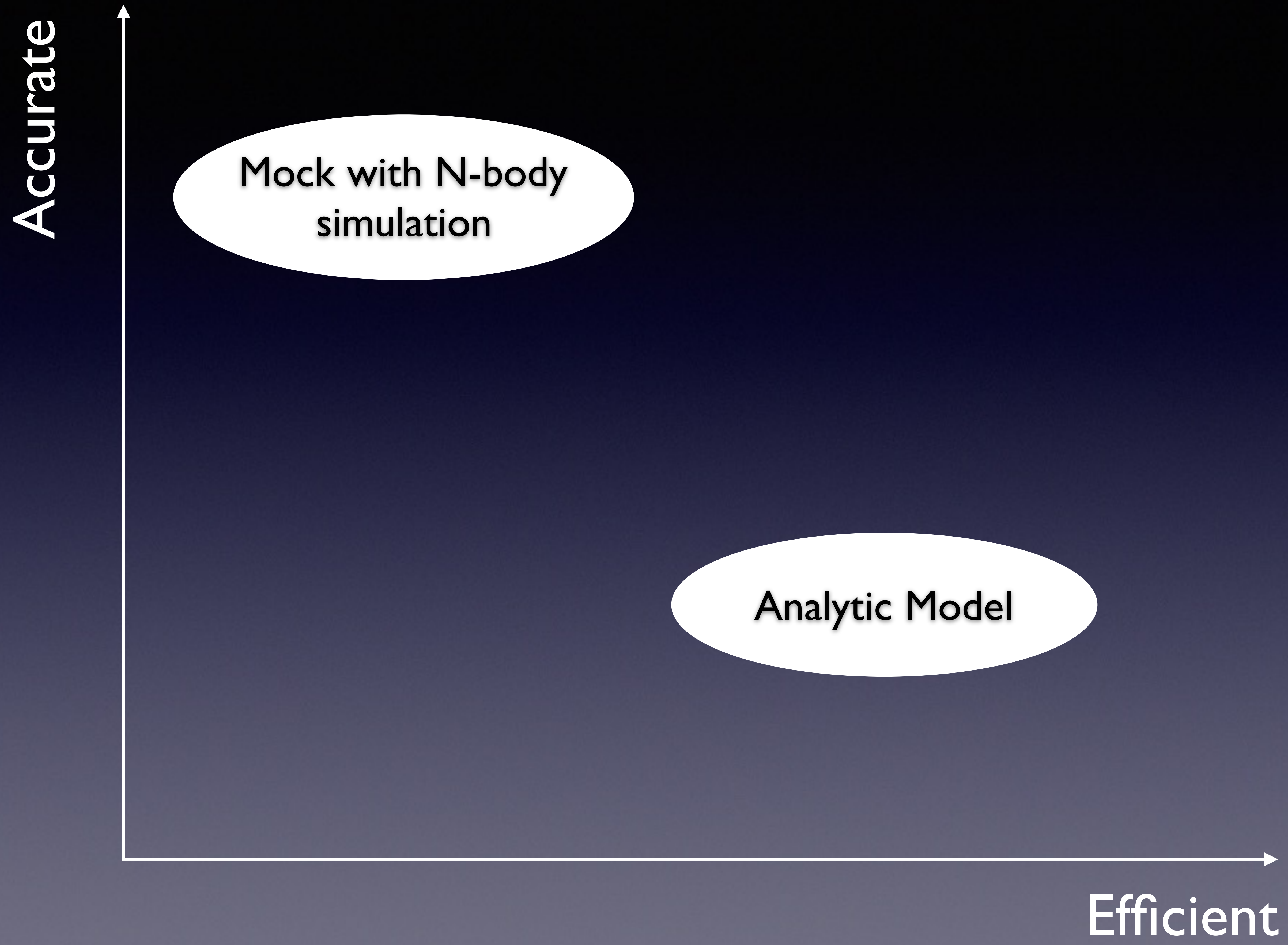
Model Galaxy Clustering with N-body Simulations

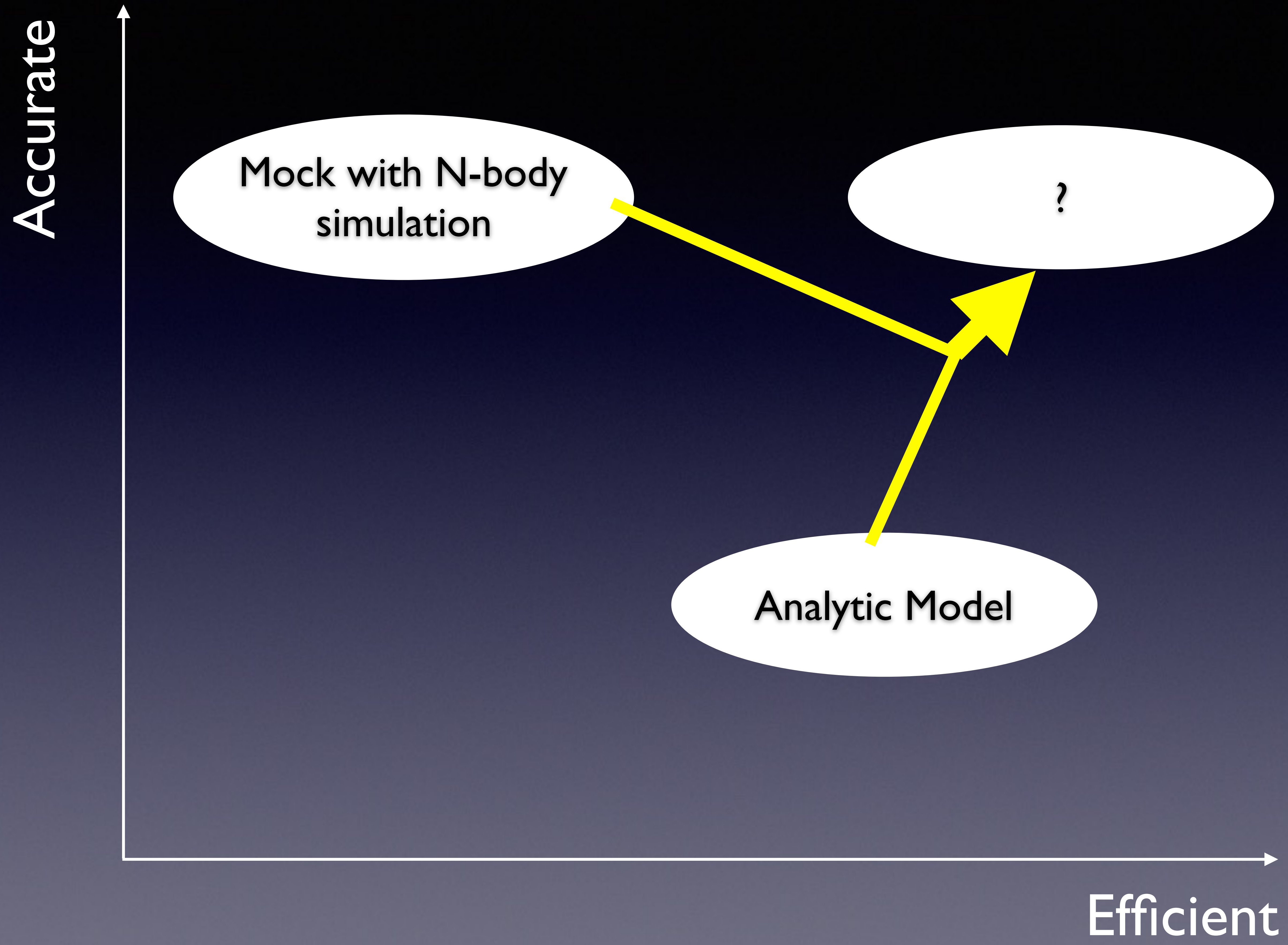
Populate halos with galaxies according to HOD/CLF to form mock
Measure 2PCFs from the mock as the model prediction





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


Accurate
Mock with N-body simulation
Analytic Model
Efficient


Accurate
Mock with N-body simulation
?
Analytic Model
Efficient

More Efficient Simulation-Based Clustering Modeling

HOD Halo Properties

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

Mass Function

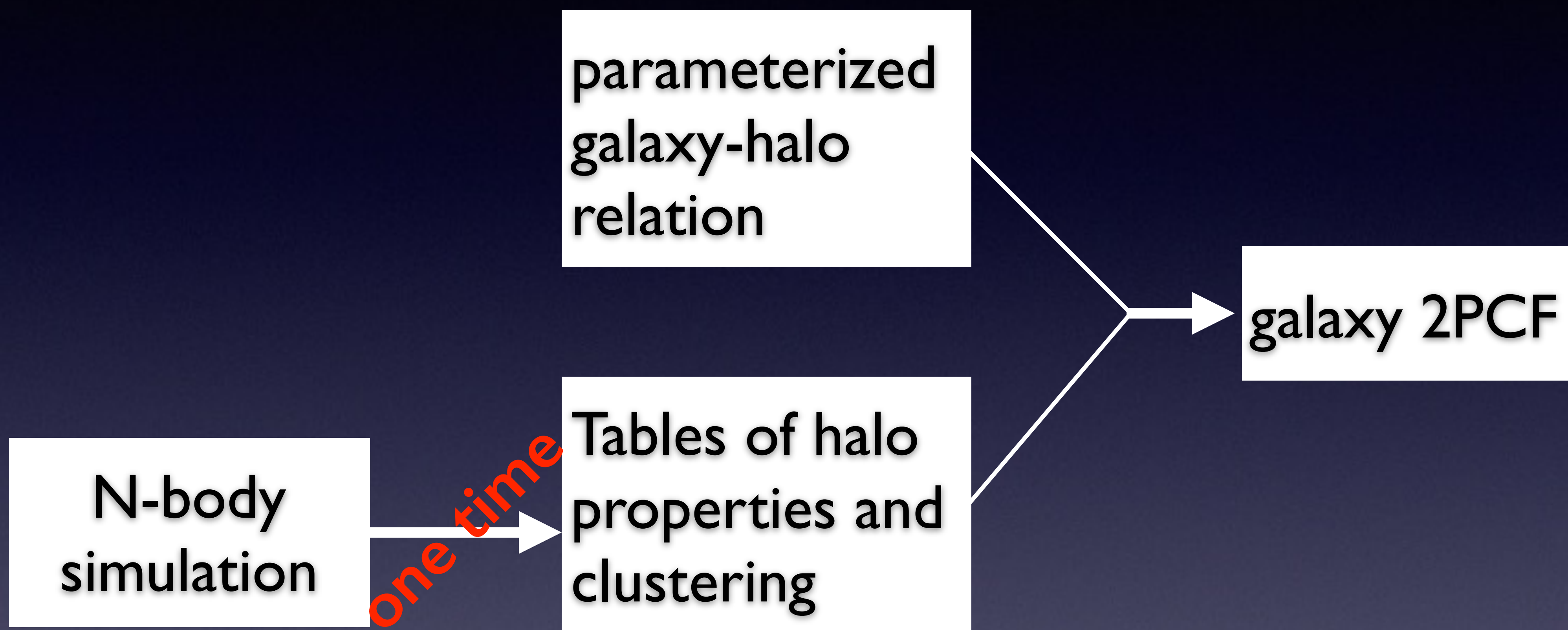
$$1 + \xi_{\rm gg}^{\rm 1h}(\mathbf{r}) = \sum_i 2 \frac{\bar{n}_i}{\bar{n}_g^2} \langle N_{\rm cen}(M_i) N_{\rm sat}(M_i) \rangle f_{\rm cs}(\mathbf{r}; M_i)$$
$$+ \sum_i \frac{\bar{n}_i}{\bar{n}_g^2} \langle N_{\rm sat}(M_i) [N_{\rm sat}(M_i) - 1] \rangle f_{\rm ss}(\mathbf{r}; M_i)$$

Profile

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

Clustering

Accurate and Efficient Simulation-Based Modeling



3840^3 particles
~1.2TB

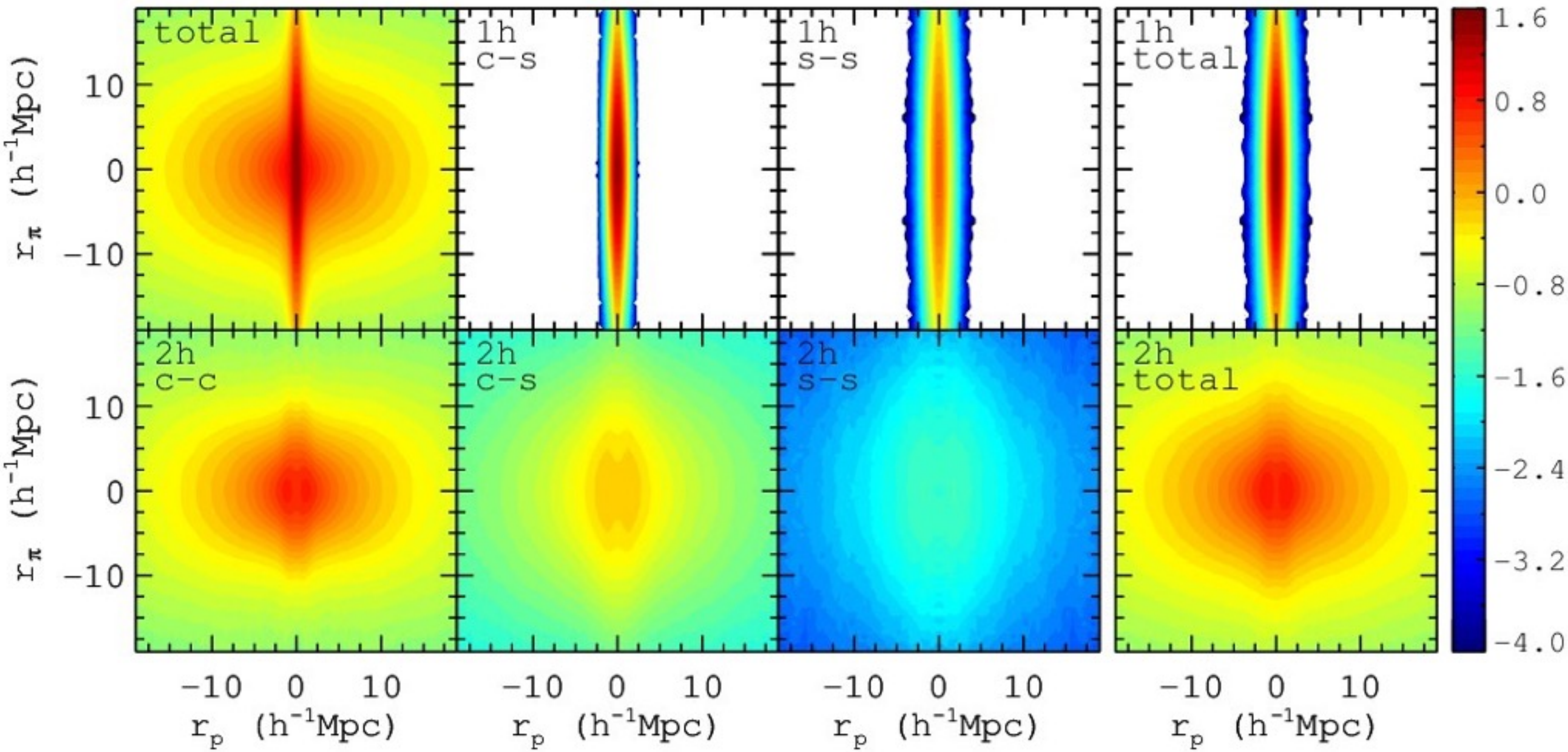
~300 mass bins
wp+RSD multiples 4x15 scales
cen/sat velocity bias 10x10
~3GB

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)

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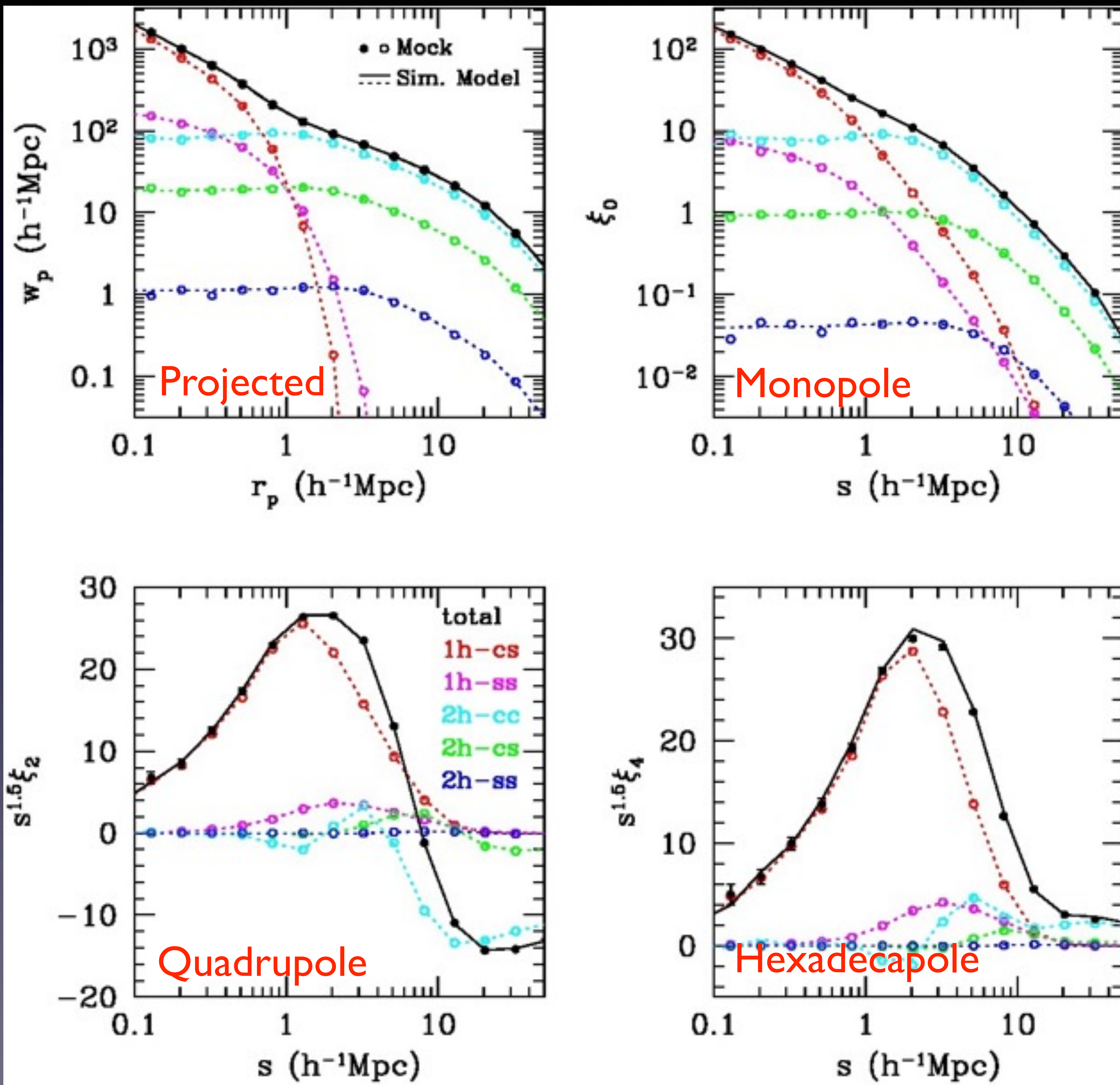

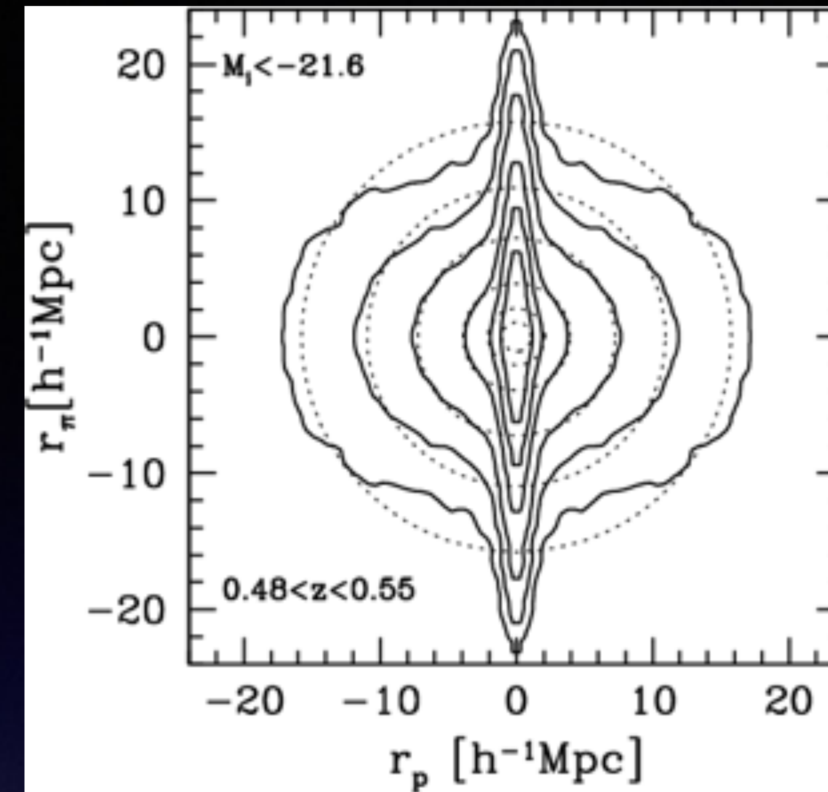

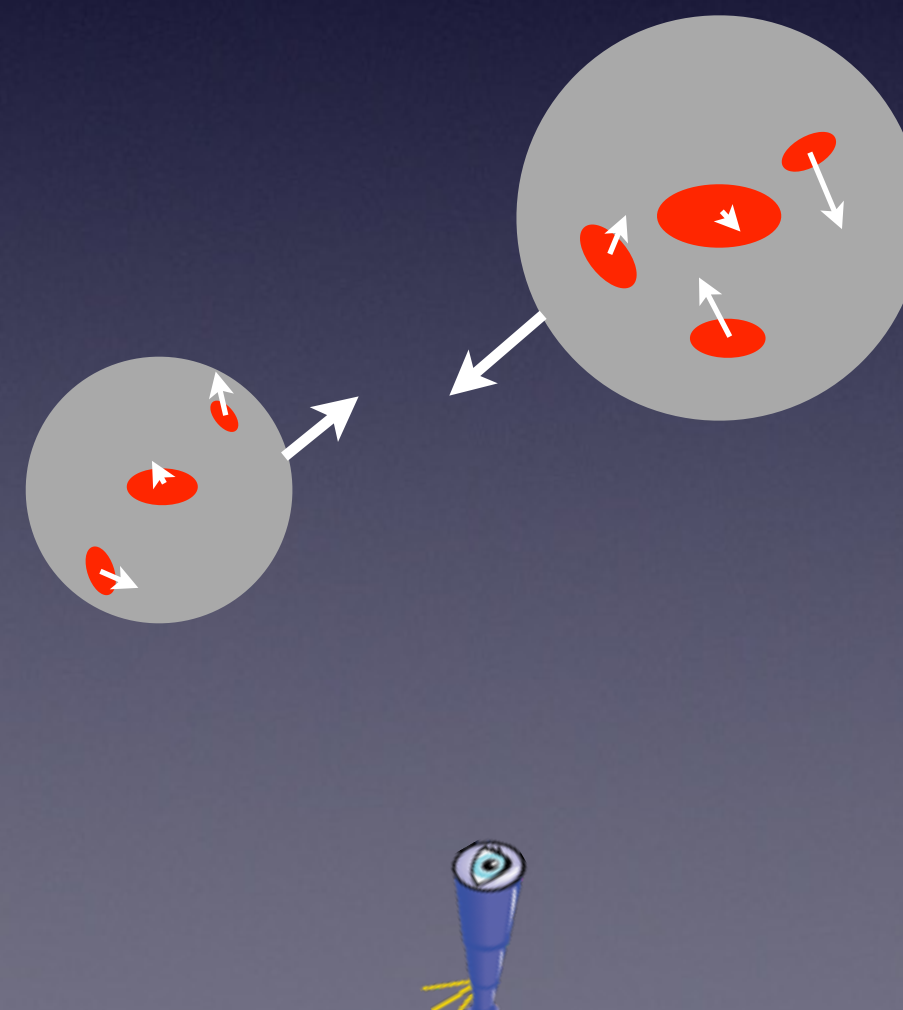

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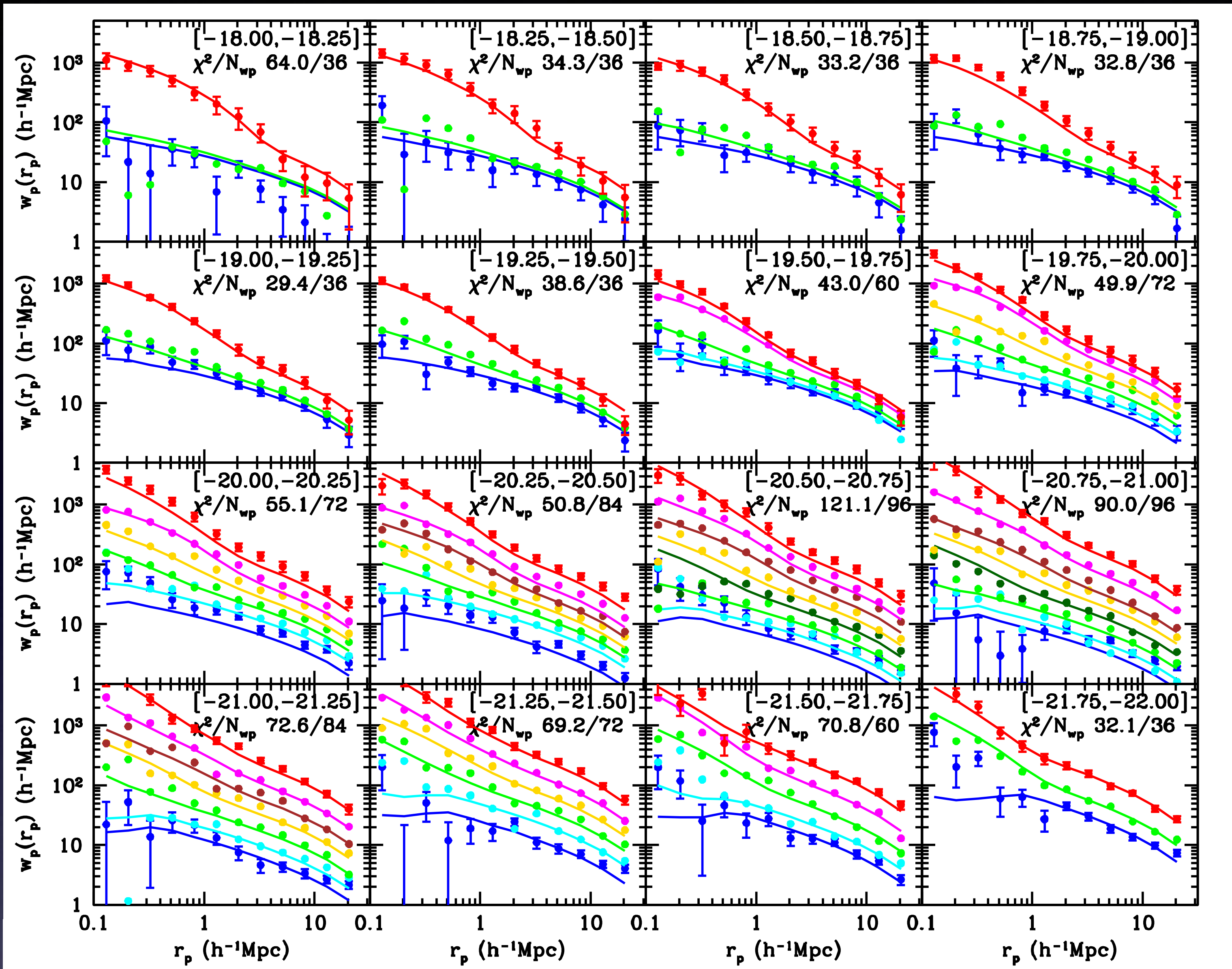
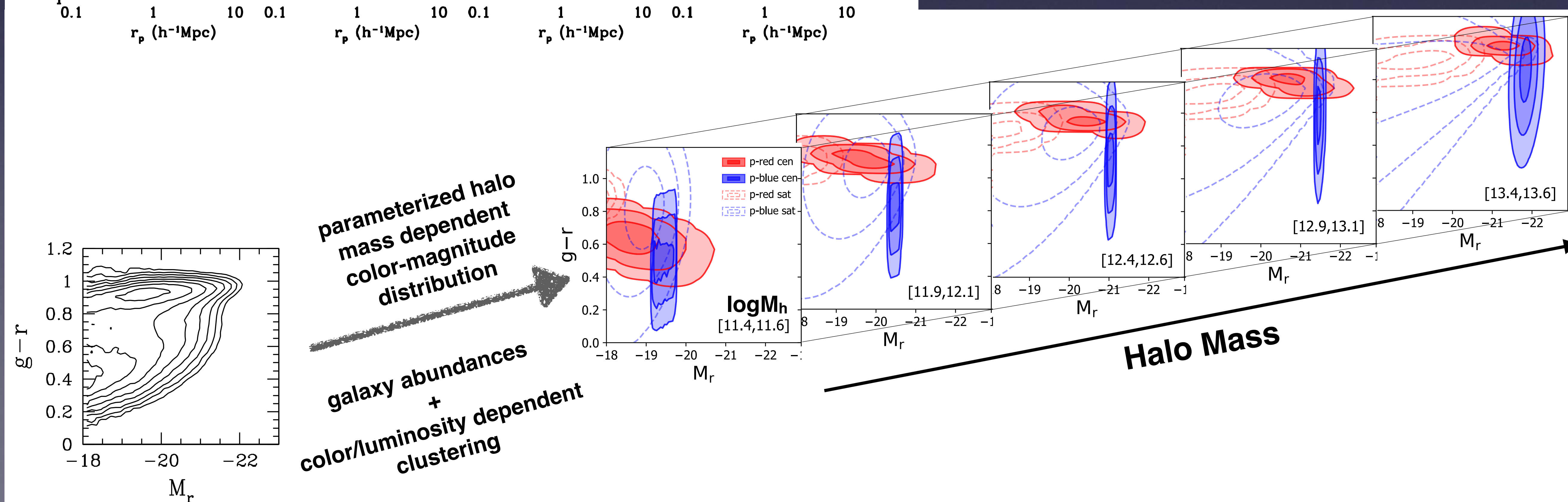
Accurate and Efficient Model



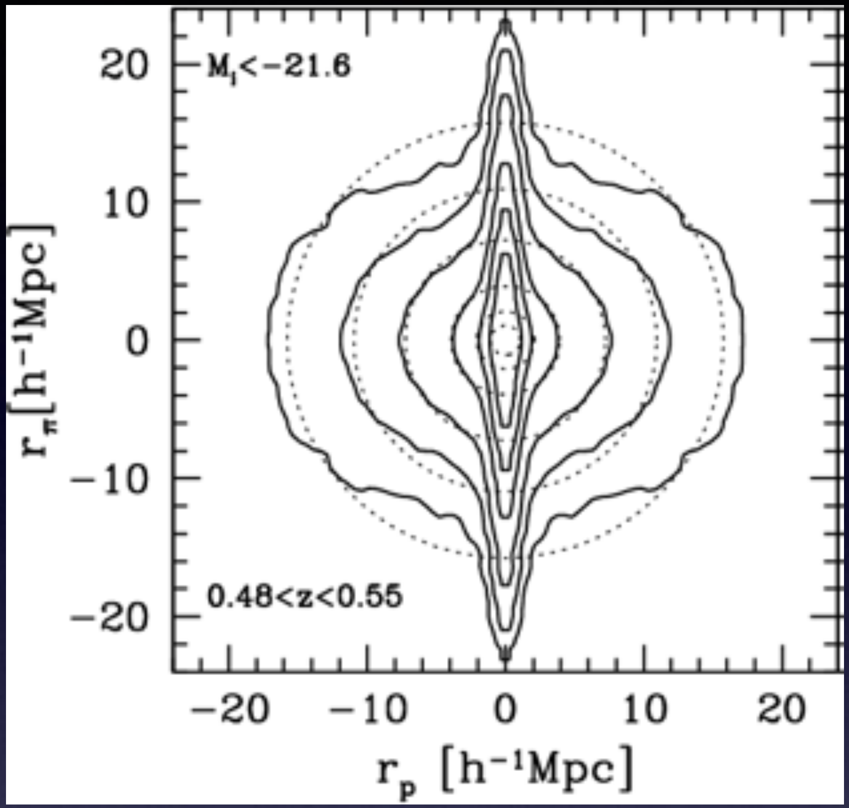
Application Example -

simultaneously modeling the clustering of ~80 SDSS galaxy samples in fine color-magnitude bins to obtain detailed relation between galaxy color/luminosity and halo mass

Xu, Zheng, et al. (2018)

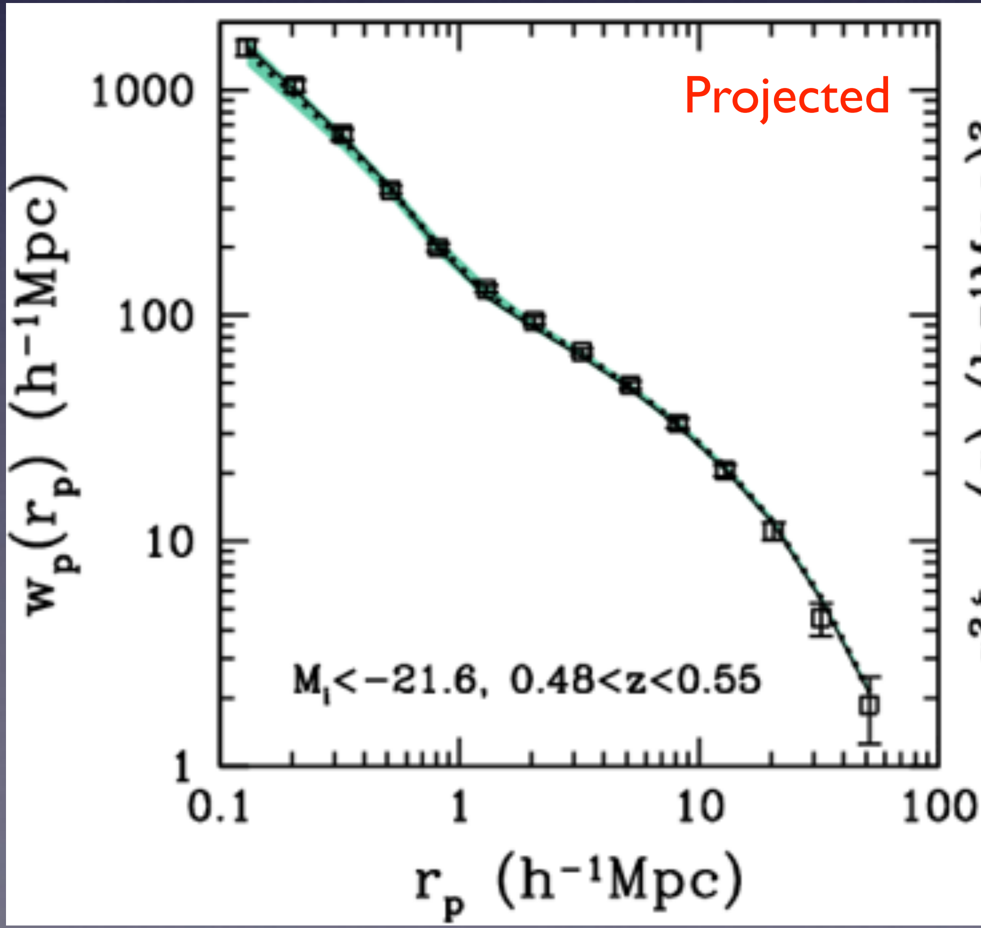


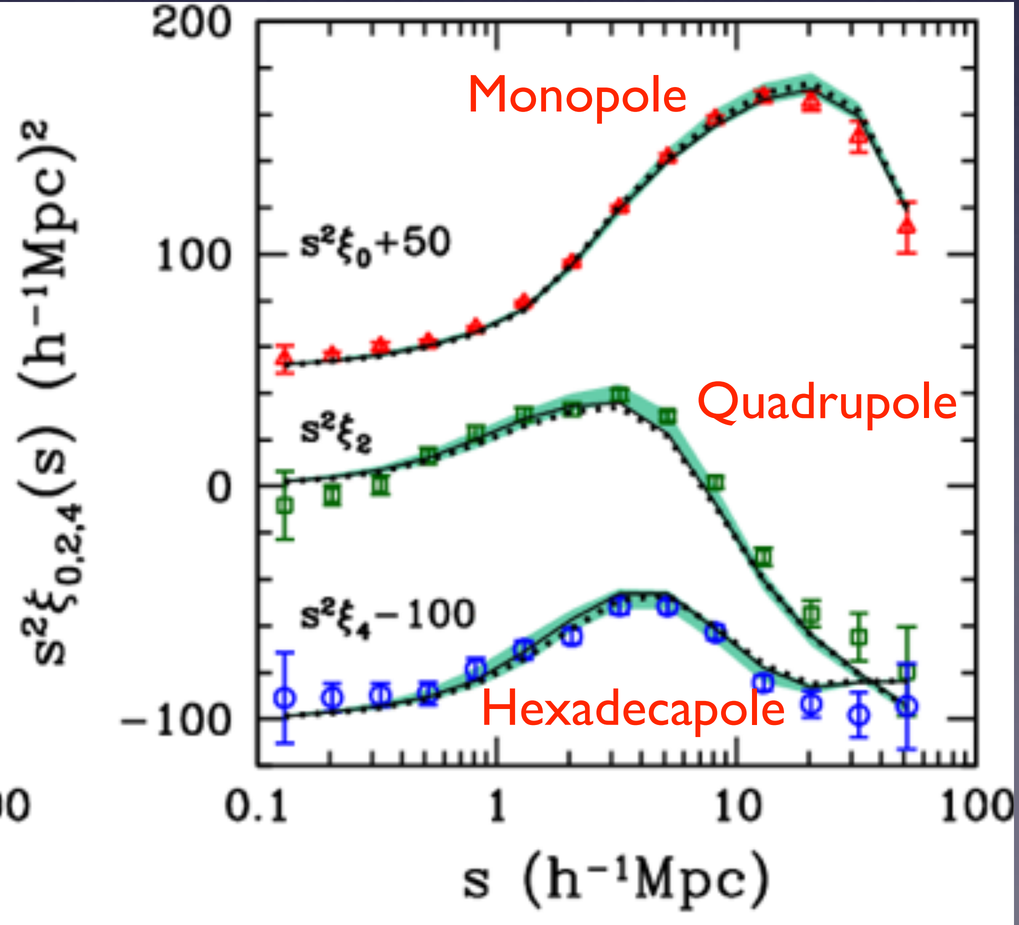
Modeling the Redshift-Space Galaxy Clustering



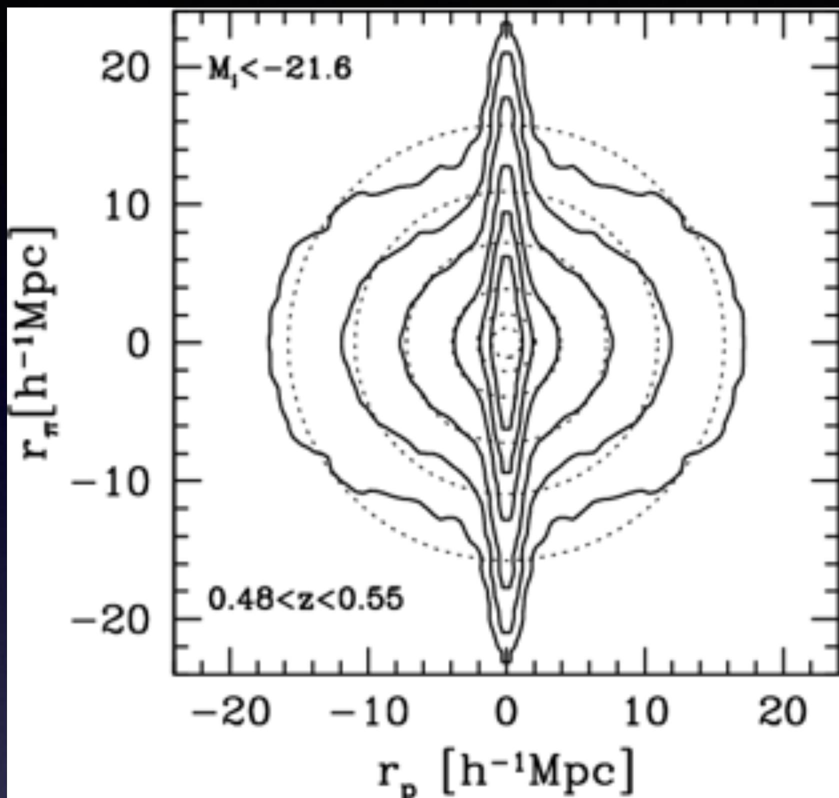
BOSS Galaxies
z~0.5

Guo, ZZ, et al. (2015a)





Modeling the Redshift-Space Galaxy Clustering



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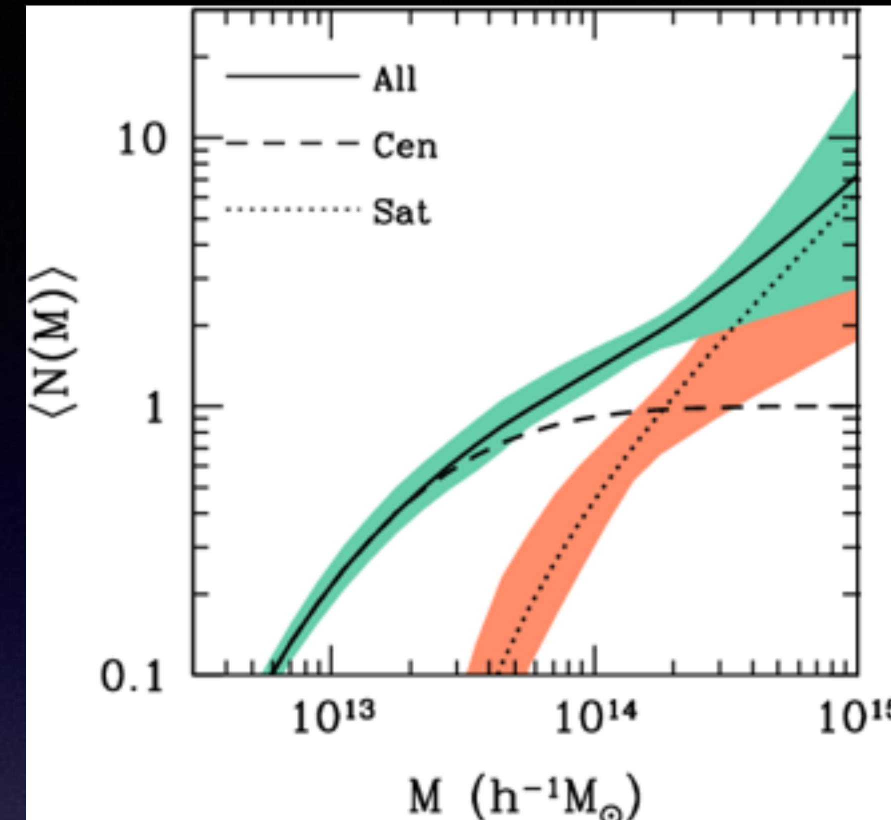
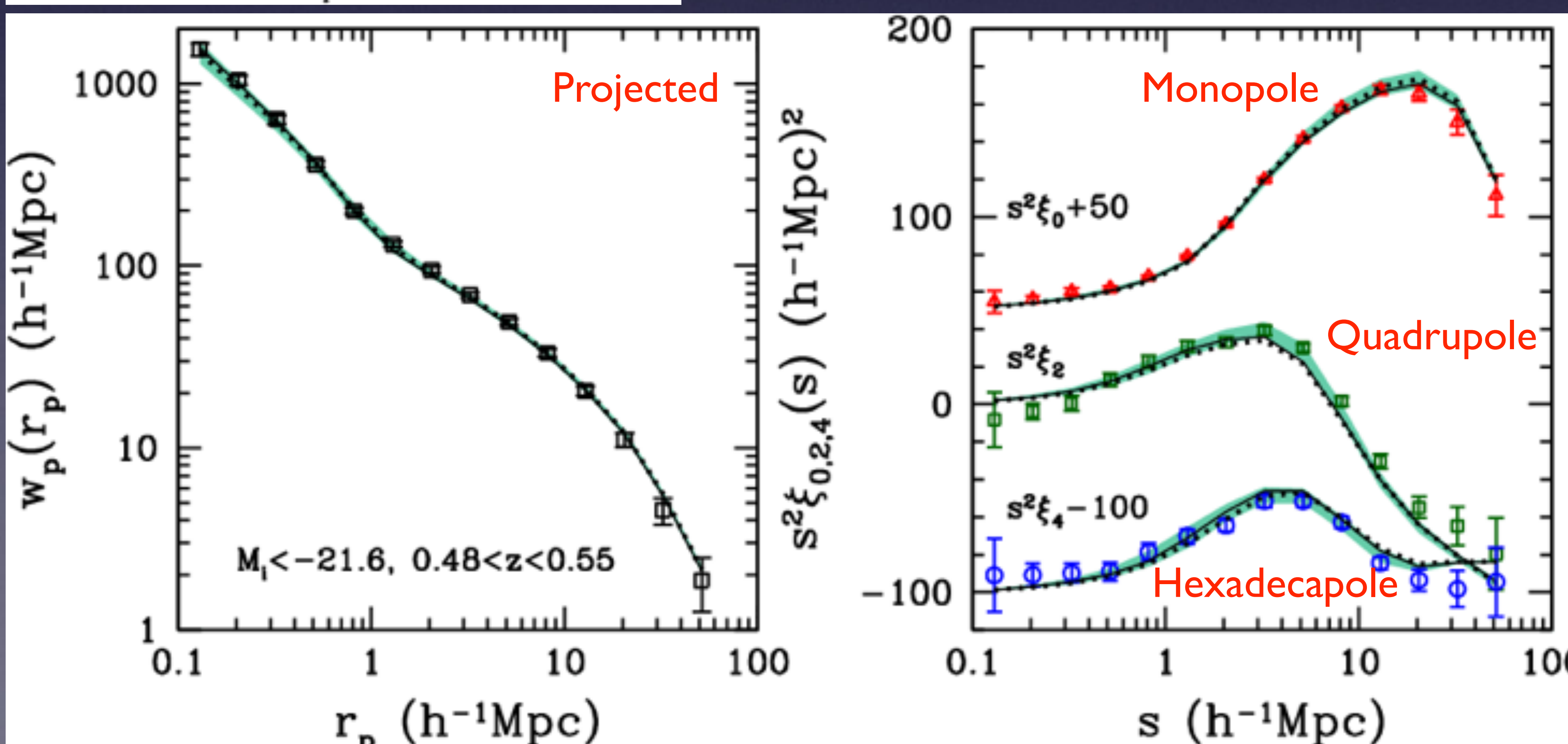
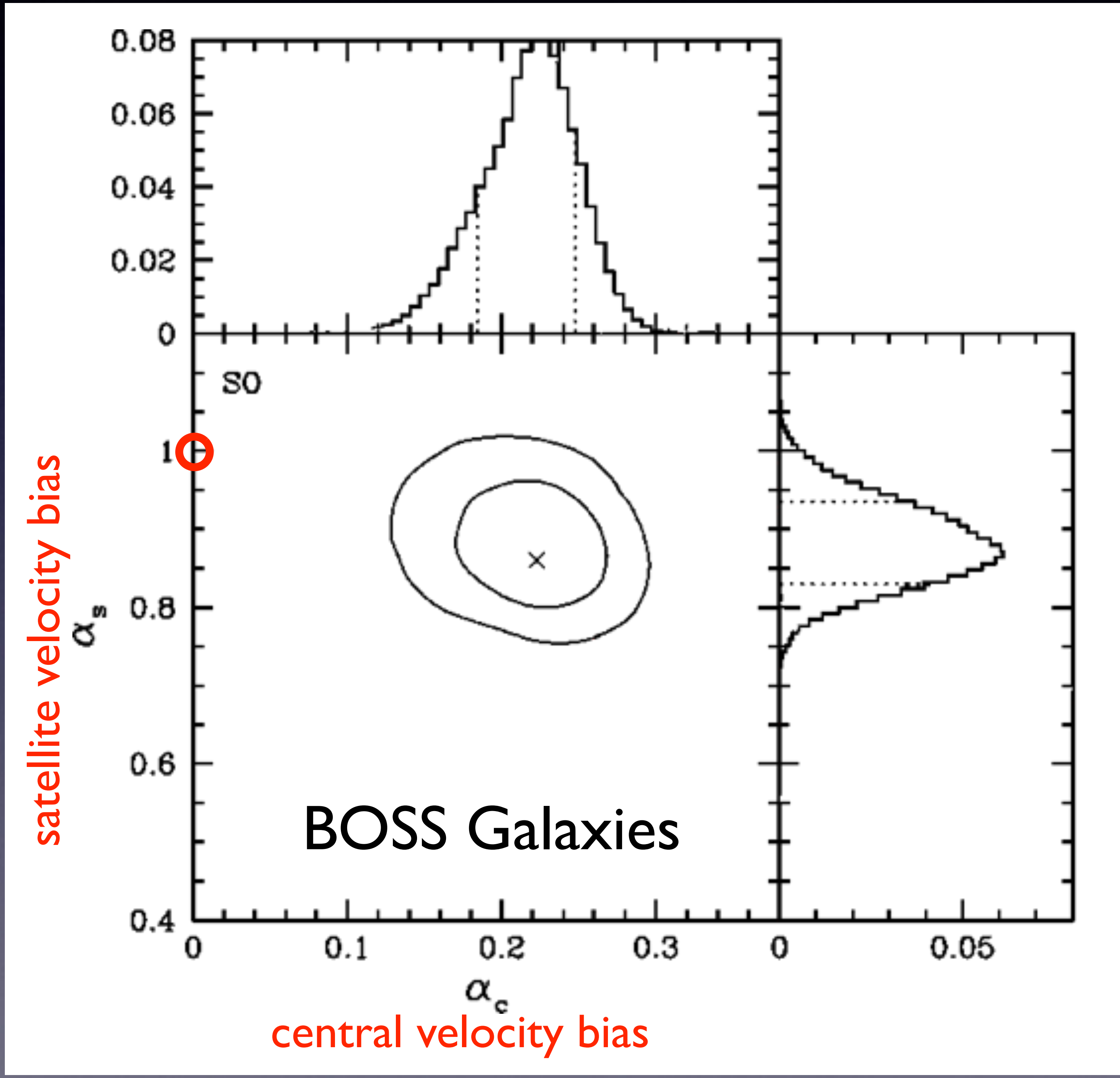


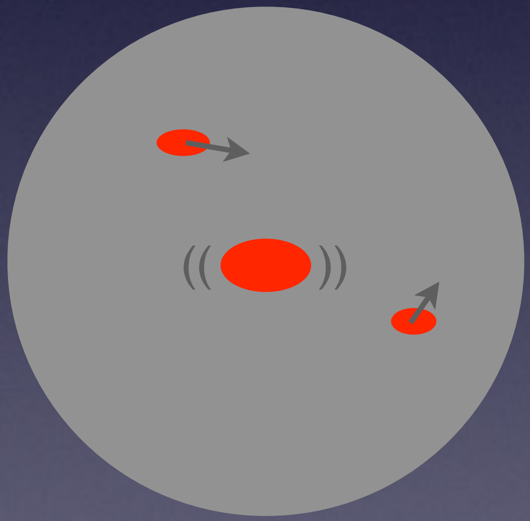
Guo, ZZ, et al. (2015a)



Galaxy Kinematics inside Halos



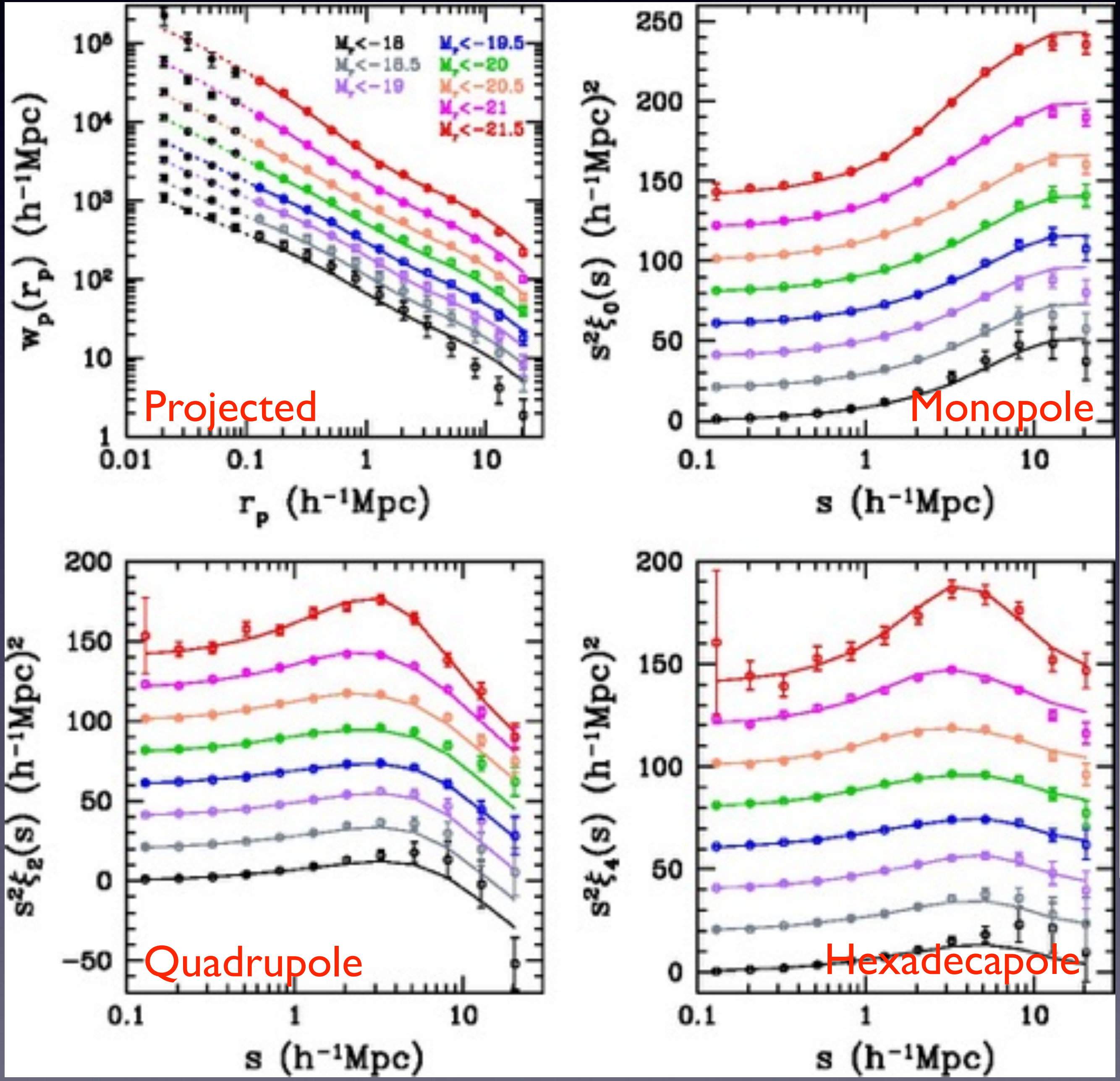
important ingredient to remove uncertainties in cosmological constraints

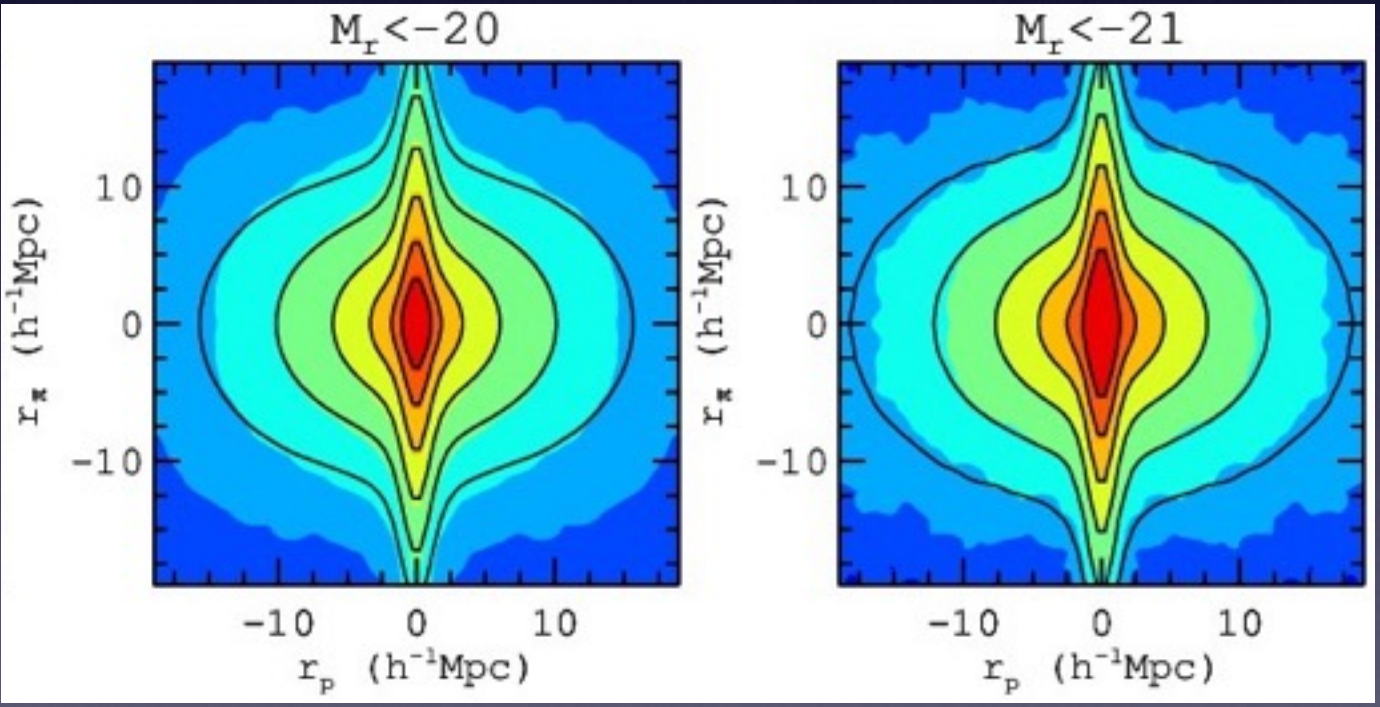


The central galaxy in a halo is not at rest w.r.t. the halo.

Guo, ZZ, et al. (2015a)

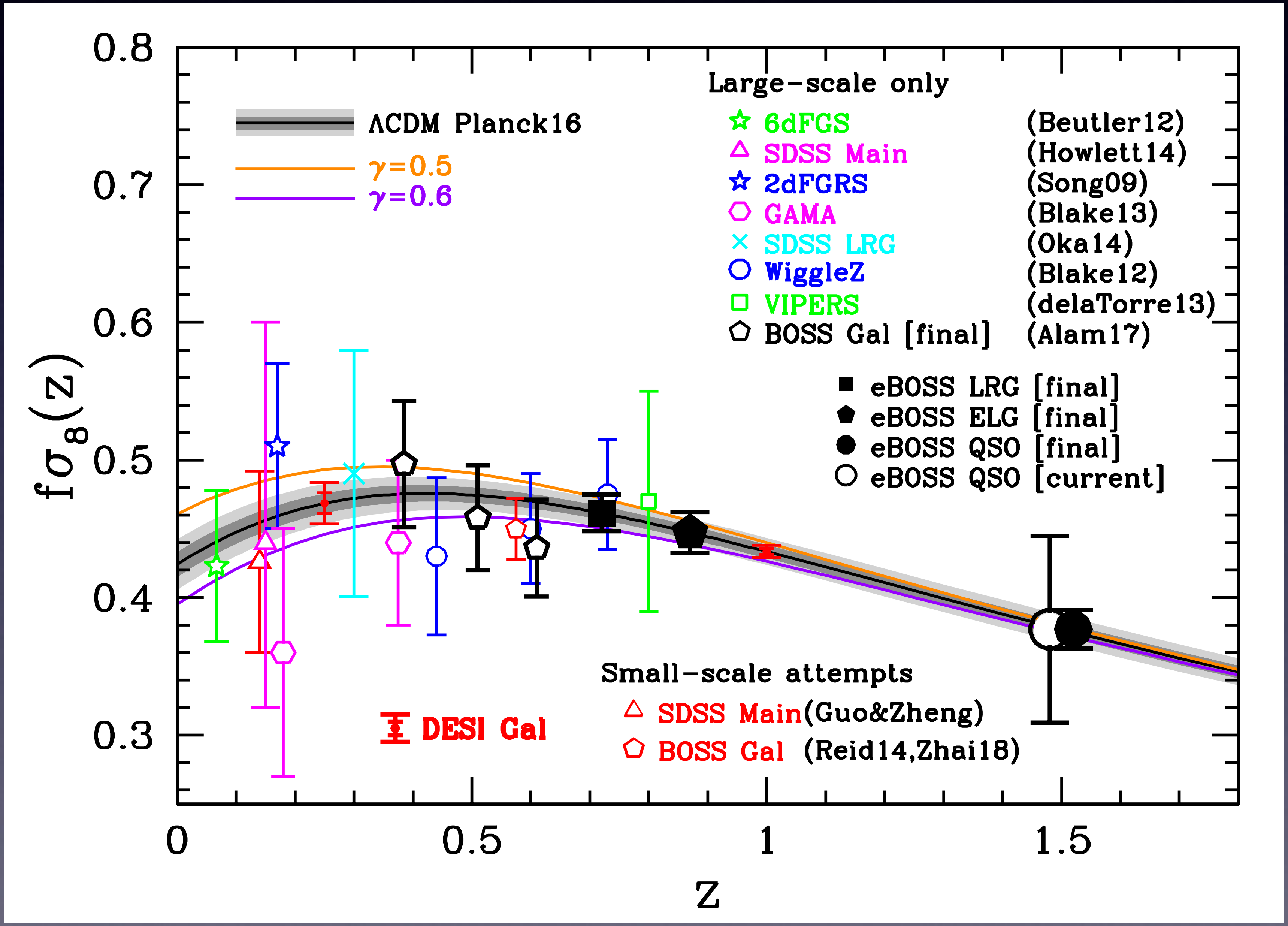
SDSS Main Galaxy Sample (z~0.1)





Guo, ZZ, et al. (2015c)

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



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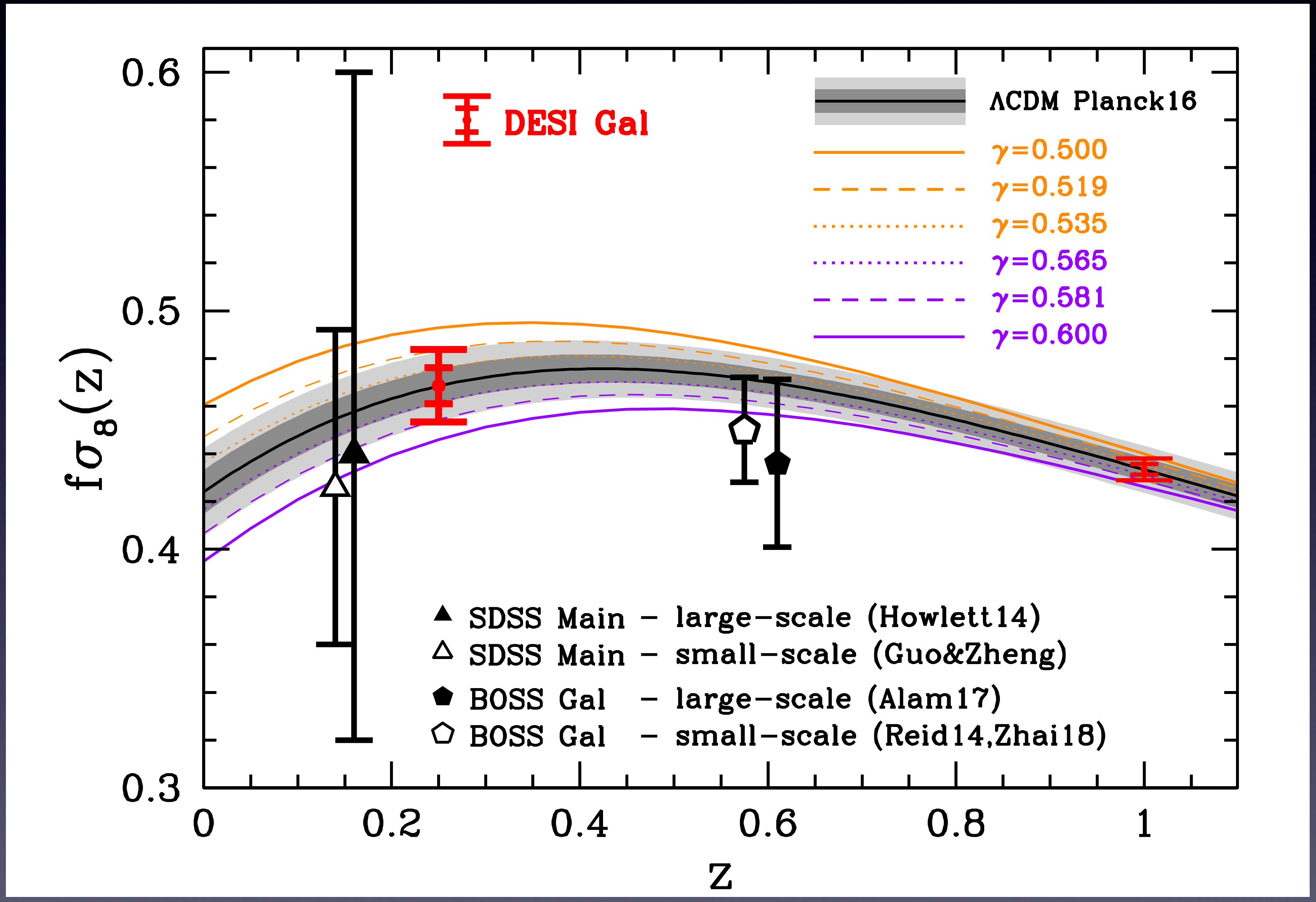


Substantial Gain
like a survey with **4x** volume!

Comparison with large-scale-only constraints,
2x improvement in $f\sigma_8$
1.5% with DESI BGS (z~0.25)
0.5% with DESI ELGs (z~1.0)

comparable to or better than the Planck prediction

Potential Theoretical Systematics

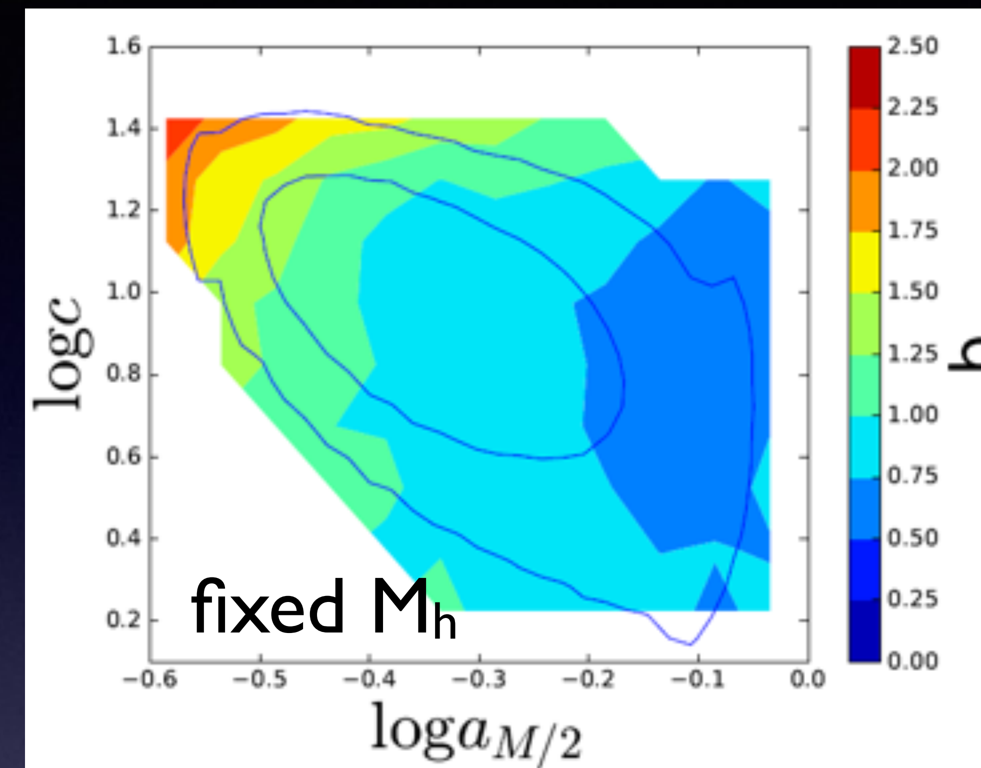
Basic halo model of galaxy clustering (e.g., HOD) assumes that galaxy content in a halo only depend on halo mass.

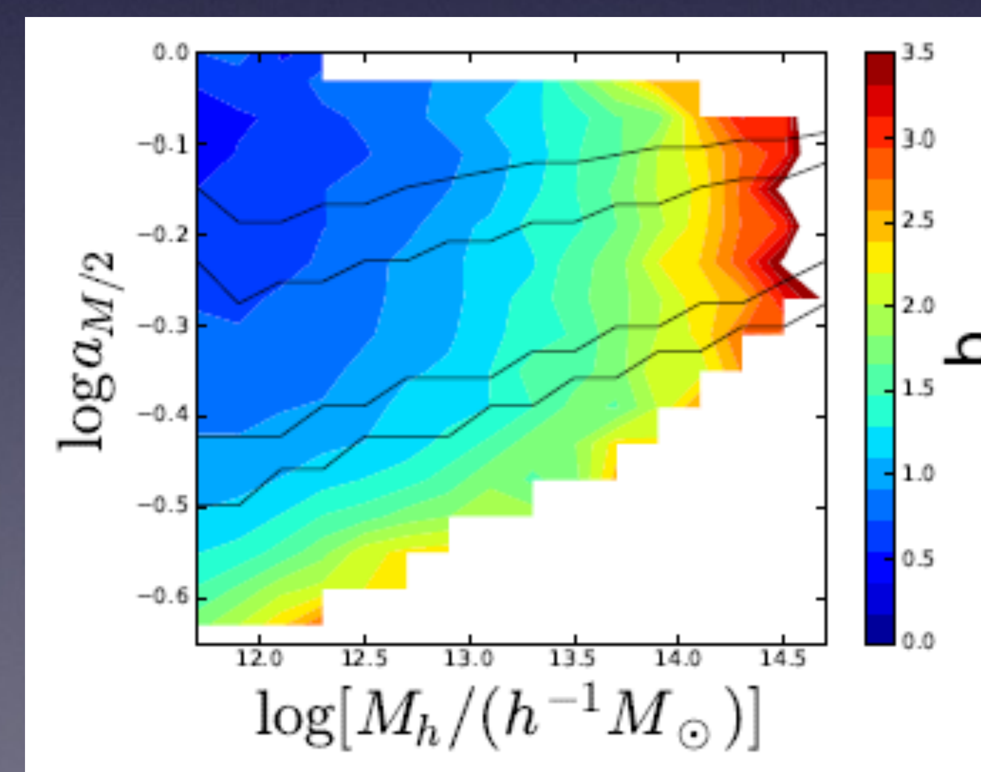
However, halo clustering at fixed halo mass is found to depend on halo assembly history and environment (halo assembly bias; e.g. , Gao+2005).

If galaxy-halo relation depends on variables other than halo mass, we would have galaxy assembly bias, which may possibly lead to bias in cosmological constraints (e.g., Zentner+2014).

Extending the halo model by effectively including assembly bias prescription (Xu&Zheng 2018, 2019)

Assembly Bias

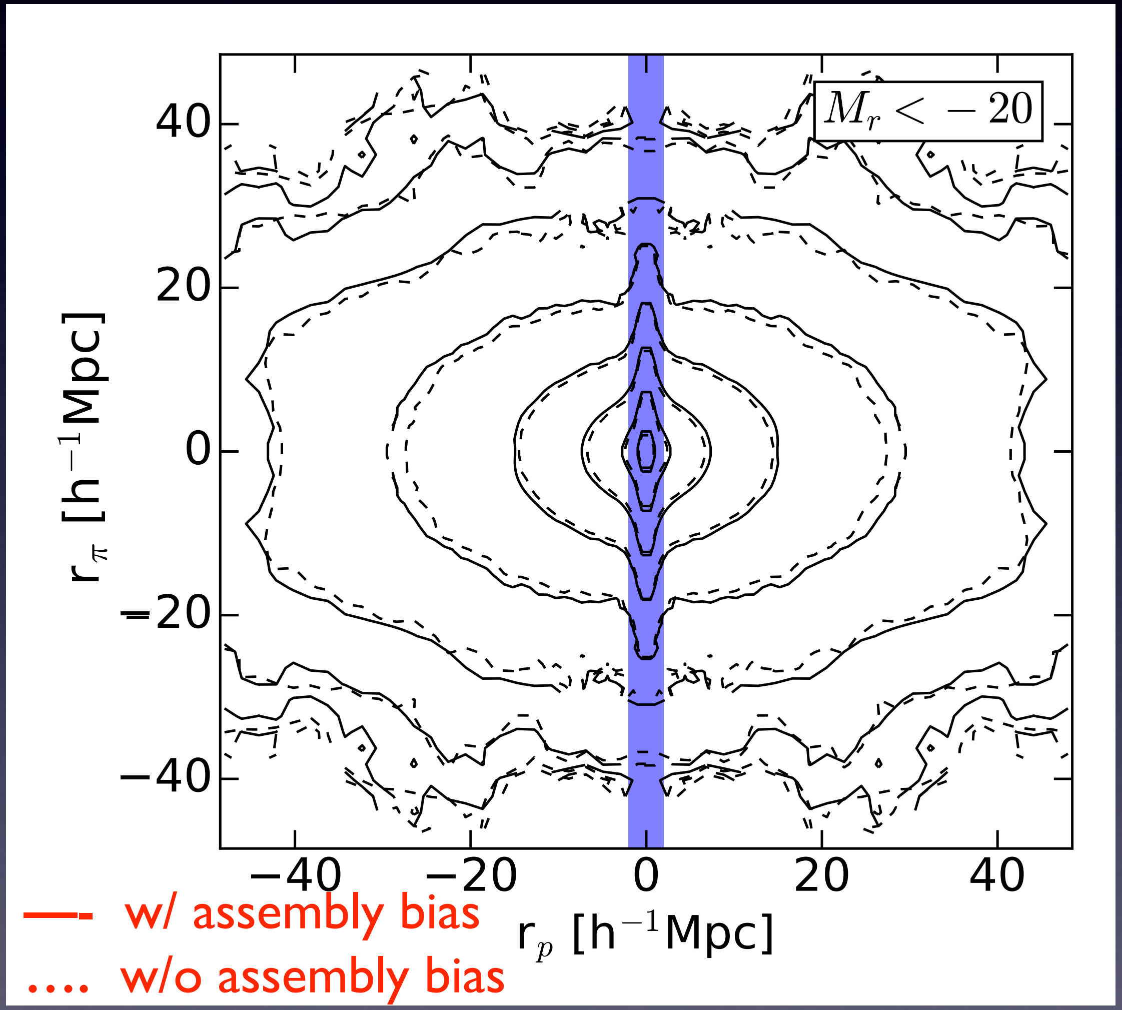




Xu & Zheng (2018)

Potential Theoretical Systematics

Assembly Bias



McCarthy&Zheng (2019)

large-scale 3D redshift 2PCF

amplitude => $b\sigma_8$

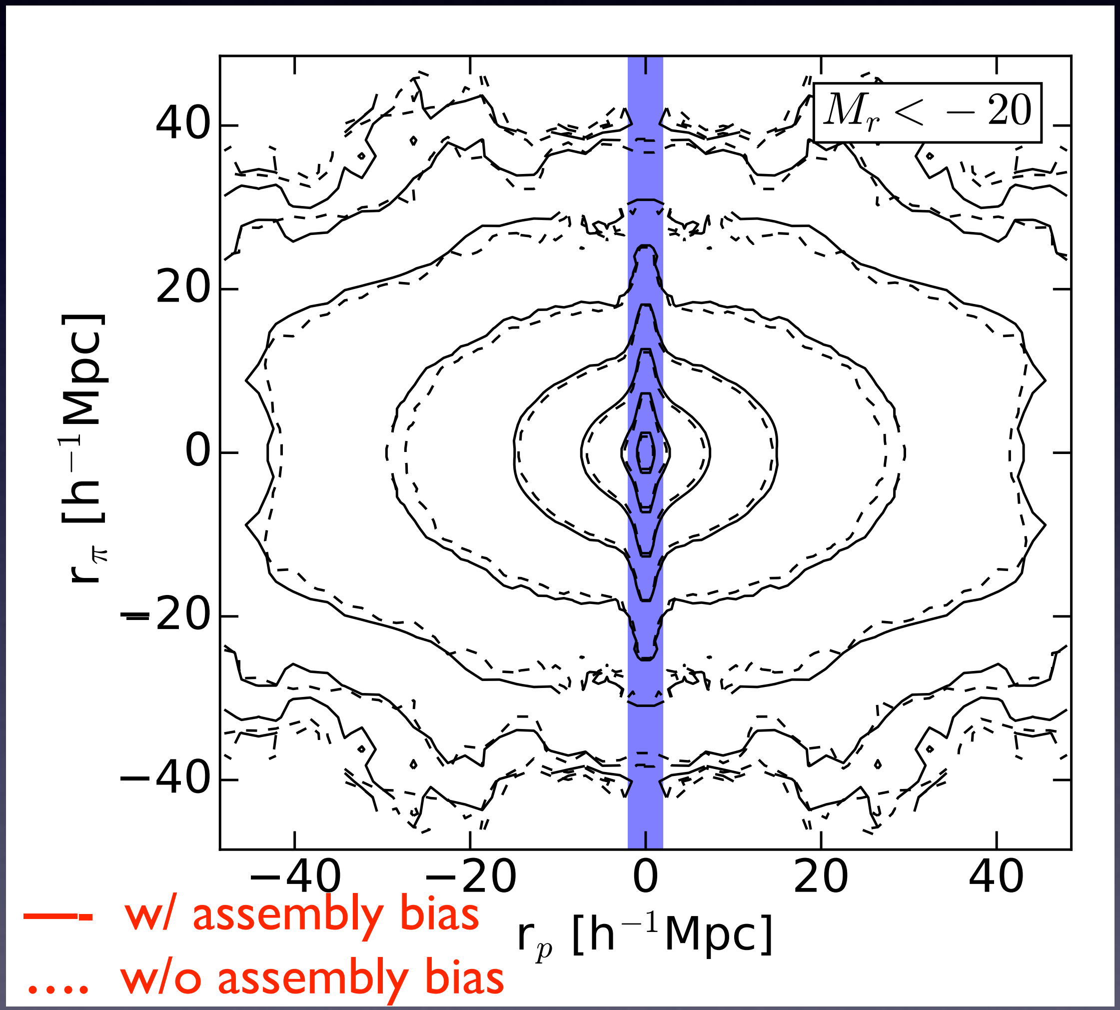
shape => $\frac{f}{b}$

$\Big\}$ => $f\sigma_8$

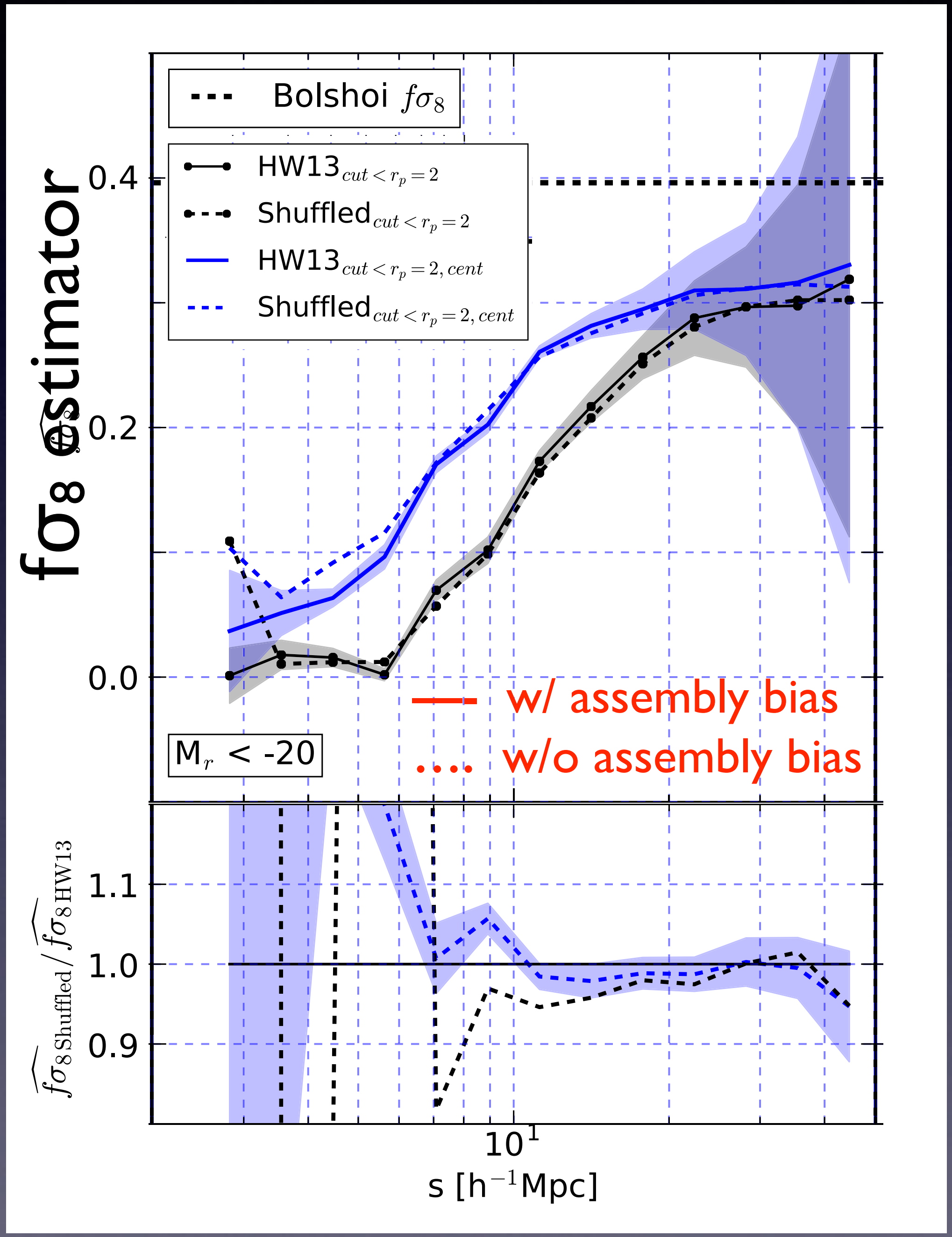
insensitive to assembly bias

Potential Theoretical Systematics

Assembly Bias



McCarthy&Zheng (2019)

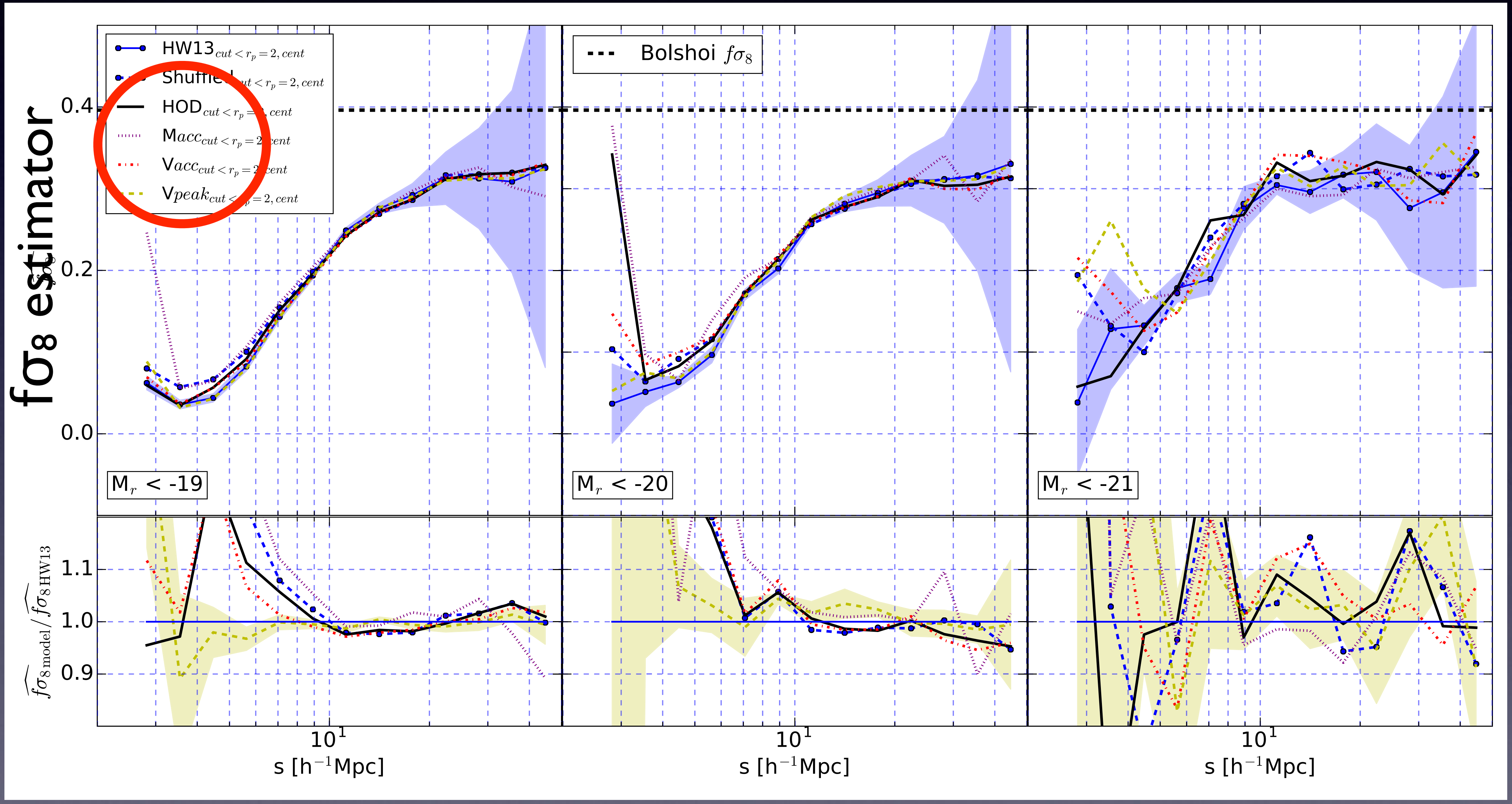


How about intermediate/small scales?

Potential Theoretical Systematics

Assembly Bias

McCarthy&Zheng (2019)



With RSD down to scales ~8Mpc/h for a sample of central galaxies, halo models with no or incorrect assembly bias prescription can still give the correct $f\sigma_8$.

Summary

- Accurate and efficient modeling of small- and intermediate-scale redshift-space galaxy clustering by tabulating necessary information of halos in N-body simulations
- Successful applications to model the RSD of SDSS galaxies to constrain galaxy kinematics inside halos

  potential gain in tightening $f\sigma_8$ constraints
  (~4x survey volume; low investment, high return)

- Potential theoretical systematics from assembly bias

  encouraging message from preliminary investigations
  more studies needed to quantify any bias in cosmological constraints