The Impact of Theoretical Systematics on Cosmological Parameter Constraints from Galaxy Clustering

Is the current halo model accurate enough?

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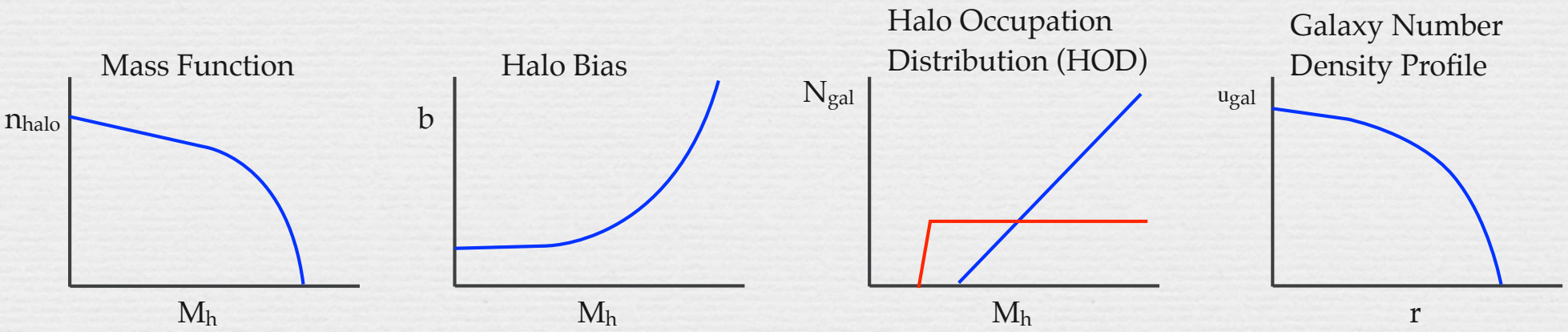
Halo Model for Galaxy Power Spectrum

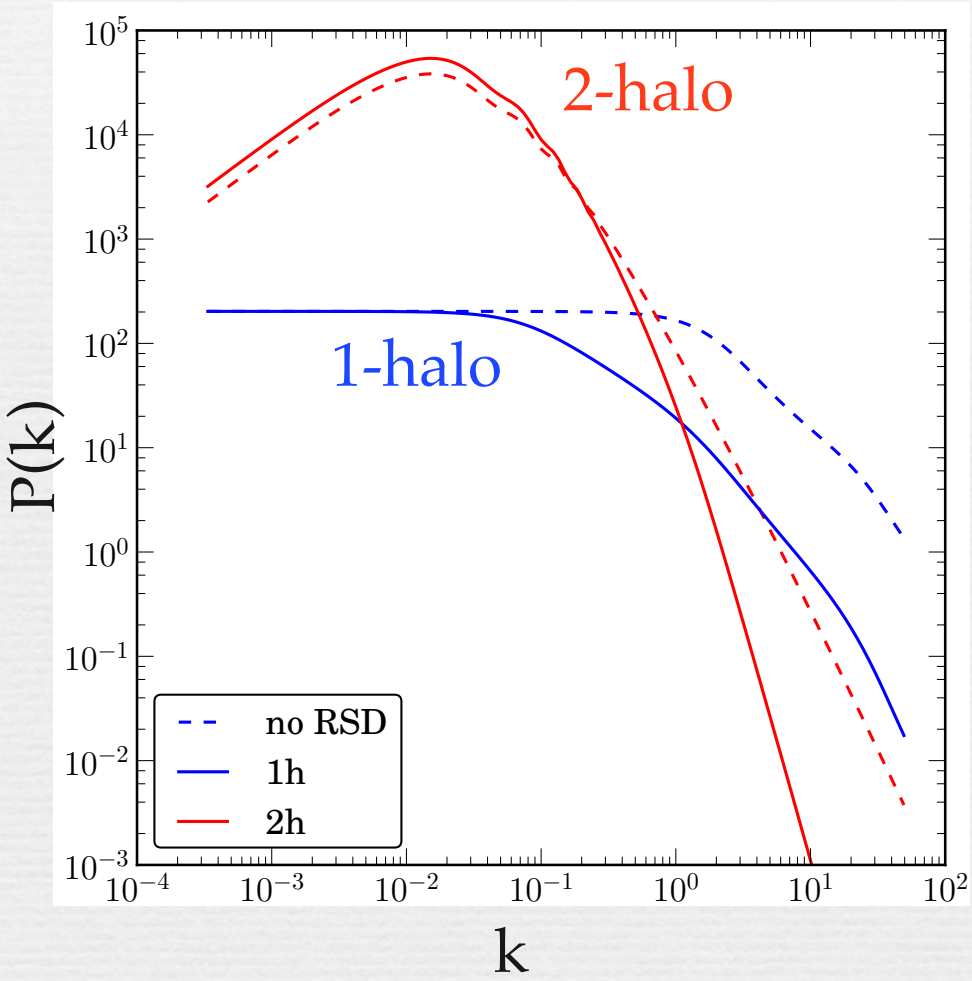
Sherrer & Bertschinger '91 (also see Cooray & Sheth '02 for a review)
Ingredients:

- Distribution of dark matter halos: n(M) and b(M)
- Number of galaxies in a halo: N_{gal} (M)
- Distribution of galaxies in halos: $u_{gal}(r)$ or $u_{gal}(k)$



$$b = \frac{\delta_{halo}}{\delta_{DM}}$$

Halo Model for Galaxy Power Spectrum



Counting pairs:

- 1-halo term: pairs in the same halo
- 2-halo term: pairs in two different halos

$$P_{\rm gal}(k) = P^{1h}_{\rm gal}(k) + P^{2h}_{\rm gal}(k), \quad \text{where}$$

$$P^{1h}_{\rm gal}(k) = \int {\rm d}m\, n(m) \frac{\langle N_{\rm gal}(N_{\rm gal}-1)|m\rangle}{\bar{n}^2_{\rm gal}} |u_{\rm gal}(k|m)|^p \ ,$$

$$P^{2h}_{\rm gal}(k) \approx P^{\rm lin}(k) \left[\int {\rm d}m\, n(m)\, b_1(m) \frac{\langle N_{\rm gal}|m\rangle}{\bar{n}_{\rm gal}} u_{\rm gal}(k|m) \right]^2 .$$

Redshift-space distortion

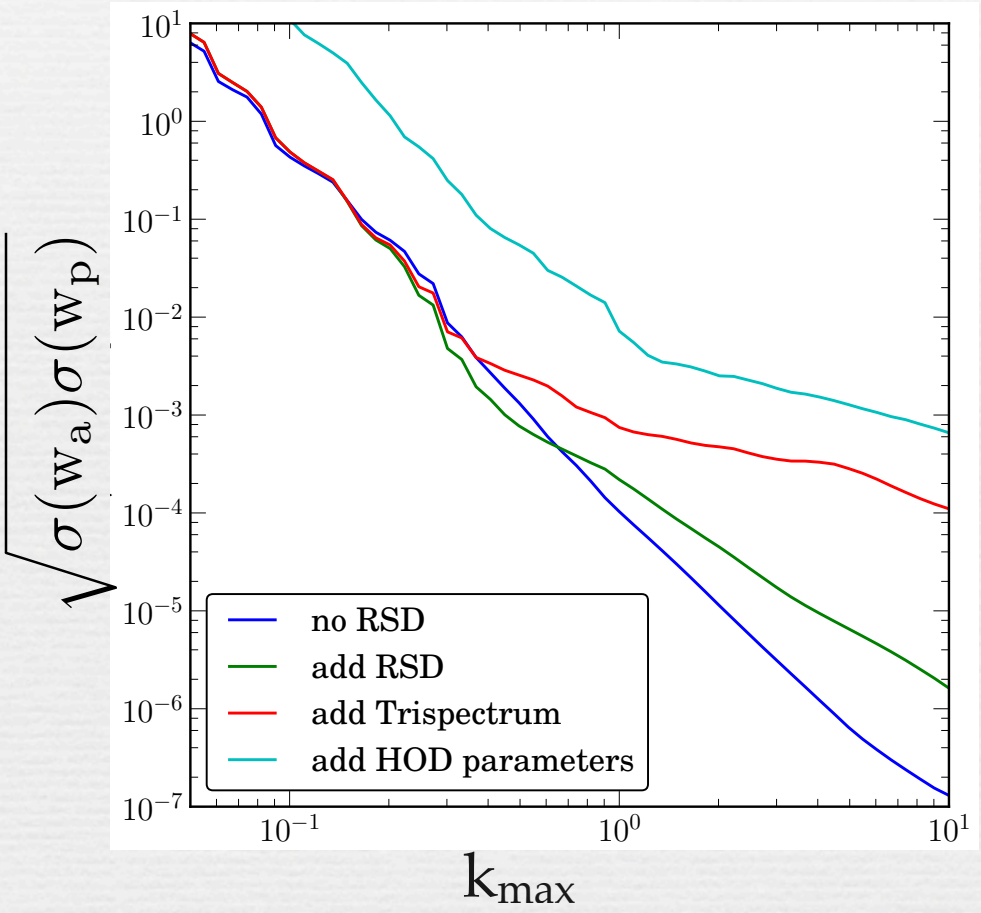
- Small scale: virial motion inside a halo suppresses power

$$\delta^z_g(\mathbf{k}) = \delta_g e^{-(k\sigma\mu)^2/2}$$

- Large scale: Kaiser effect boosts power

$$\delta^z_g(\mathbf{k}) = \delta_g(\mathbf{k}) + \delta_v \mu^2$$

Likelihood Function for P(k)



Fisher matrix

$$F_{\alpha\beta} = \sum_z \frac{V_{survey}}{(2\pi)^3} \sum_i \sum_j \frac{\partial P_i}{\partial \theta_\alpha} \left[\frac{2P_i^2}{4\pi k_i^3 \delta \ln k} \delta_{ij} + T_{ij} \right]^{-1} \frac{\partial P_j}{\partial \theta_\beta}$$

Survey assumption:

Full sky, z_{max}=1; 5 redshift bins;

magnitude limit -18

Nuisance parameters:

5 parameters for HOD; piecewise

continuous for 5 mass bins

The Impact of Theoretical Systematics

1. Concentration-mass relation
2. Distribution of galaxies in a halo: NFW?
3. Galaxy number in a cluster: Poisson?
4. Velocity dispersion

✓ How do they lead to errors in P(k) and w?

✓ What is the smallest scale (highest k_{max}) we can use?

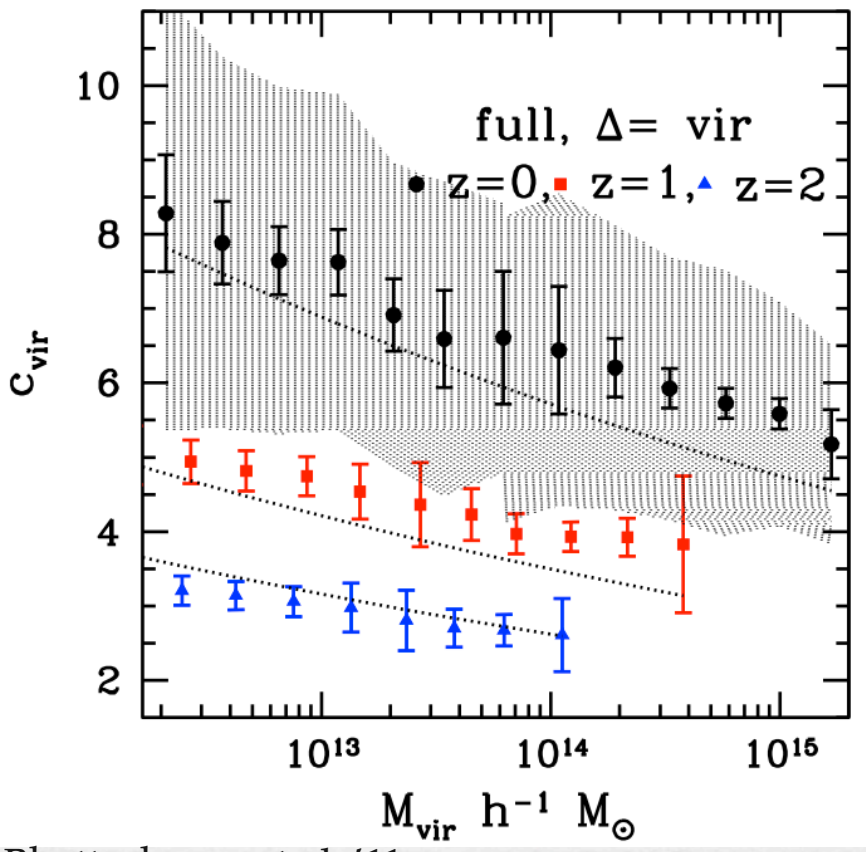
✓ What is the required theoretical accuracy if we want to use information in higher k?

Systematic Effect 1: Concentration-Mass Relation

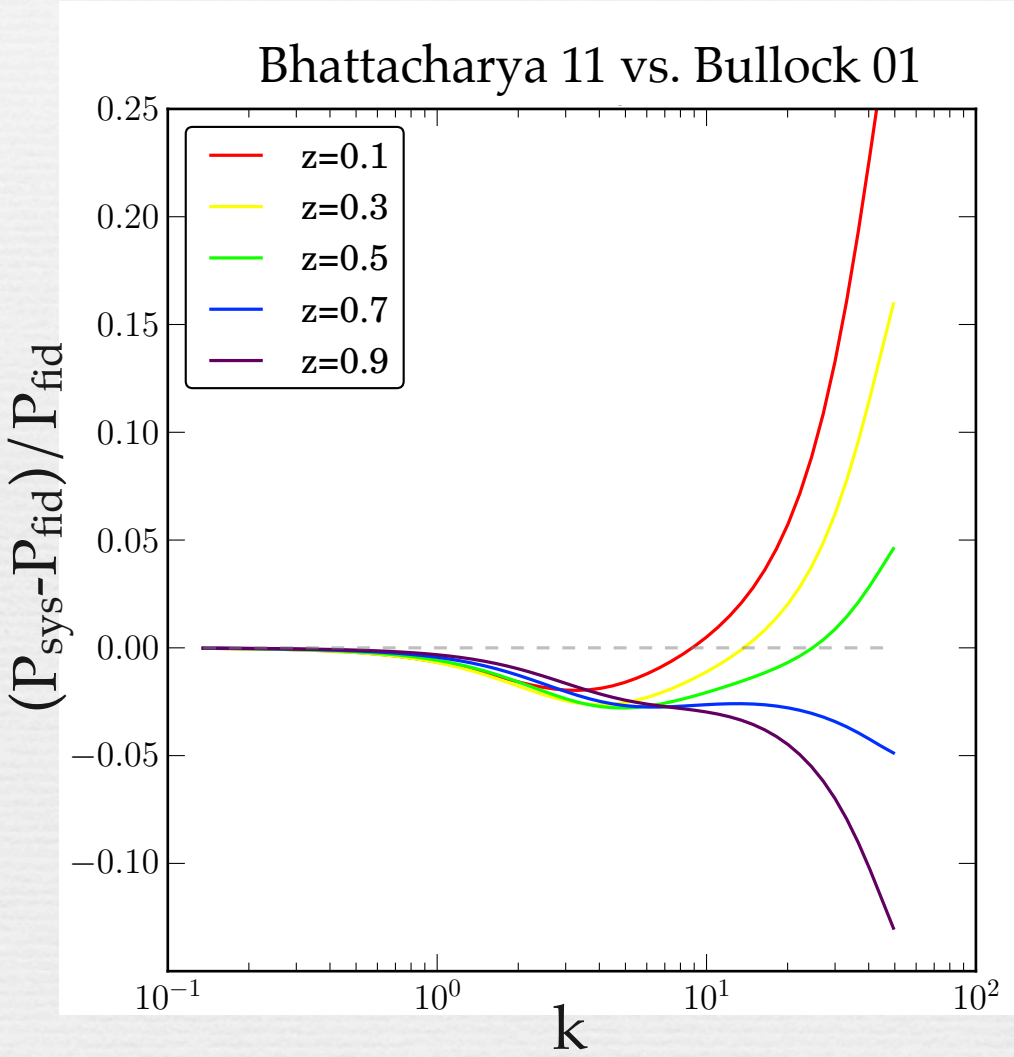
$$P^{1h}_{\rm gal}(k) = \int {\rm d}m\, n(m)\, \frac{\langle N_{\rm gal}(N_{\rm gal}-1)|m\rangle}{\bar{n}^2_{\rm gal}}\, |u_{\rm gal}(k|m)|^p$$

$$c_{\rm vir} = R_{\rm vir}/r_s$$

$$\rho_{\rm NFW} \propto (r/r_s)^{-1}(1+r/r_s)^{-2}$$

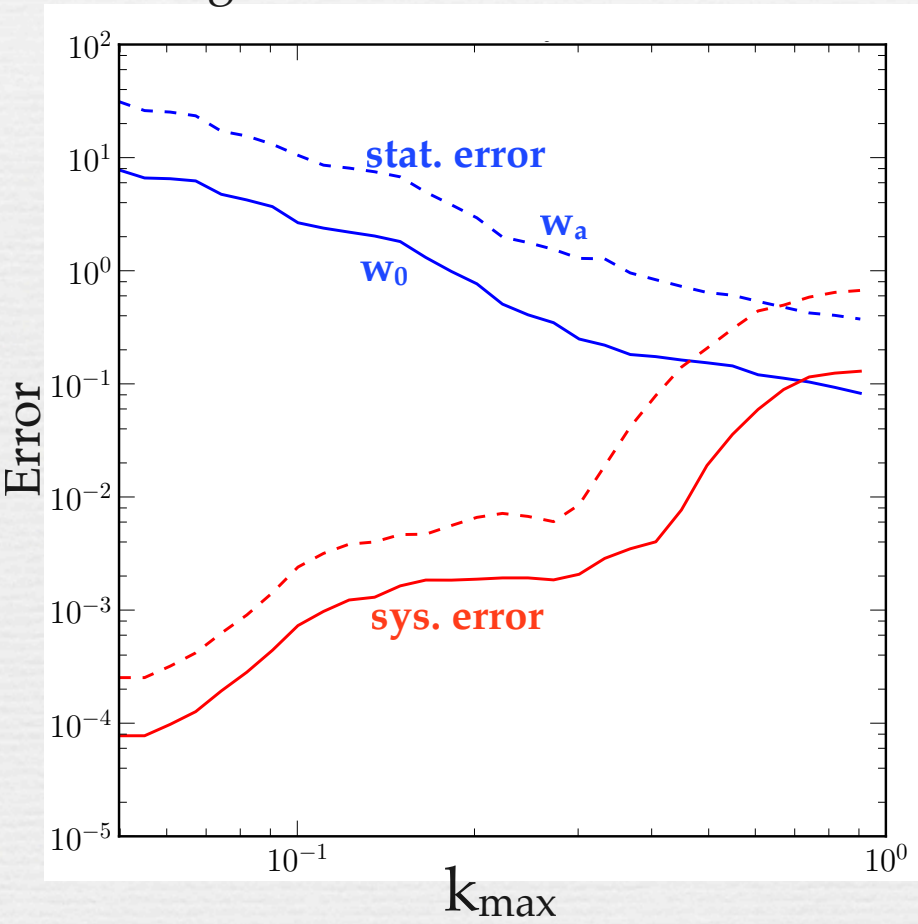


Bhattacharya et al. '11



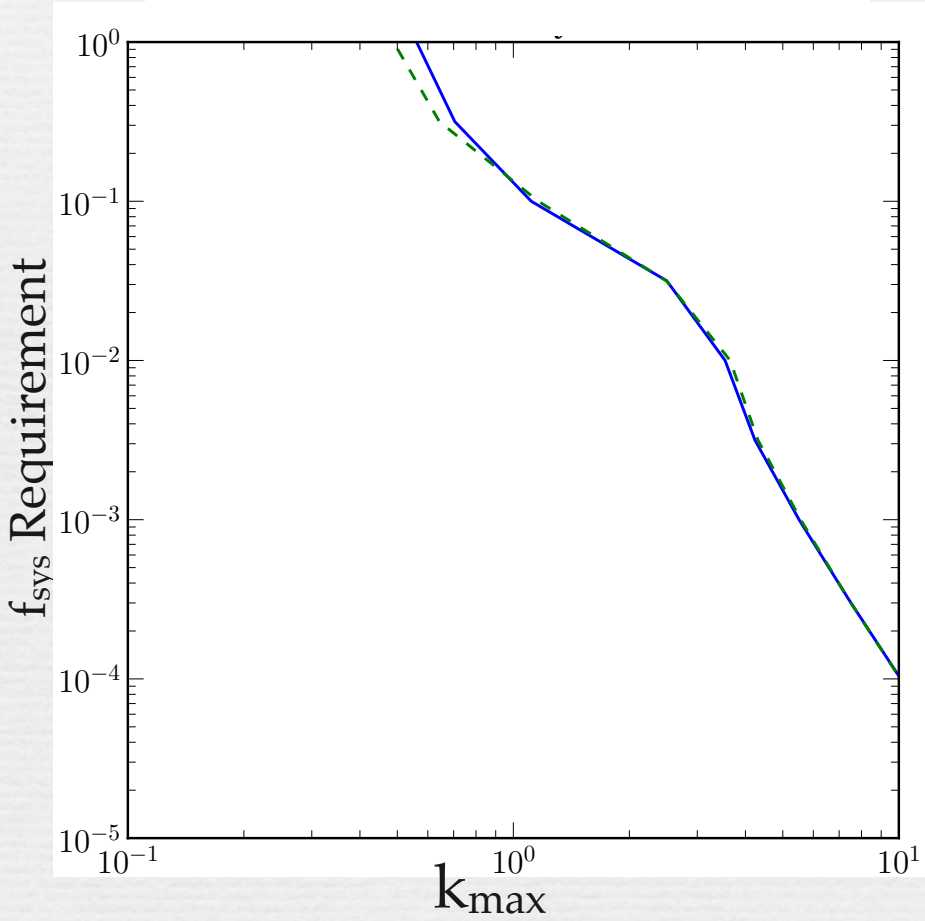
Systematic Effect 1: Concentration-Mass Relation

The effect of full systematics:
If we require $\Delta w_0/\sigma(w_0) < 0.3$, the limiting scale is $k_{max} = 0.6$



How much should we reduce the systematics?

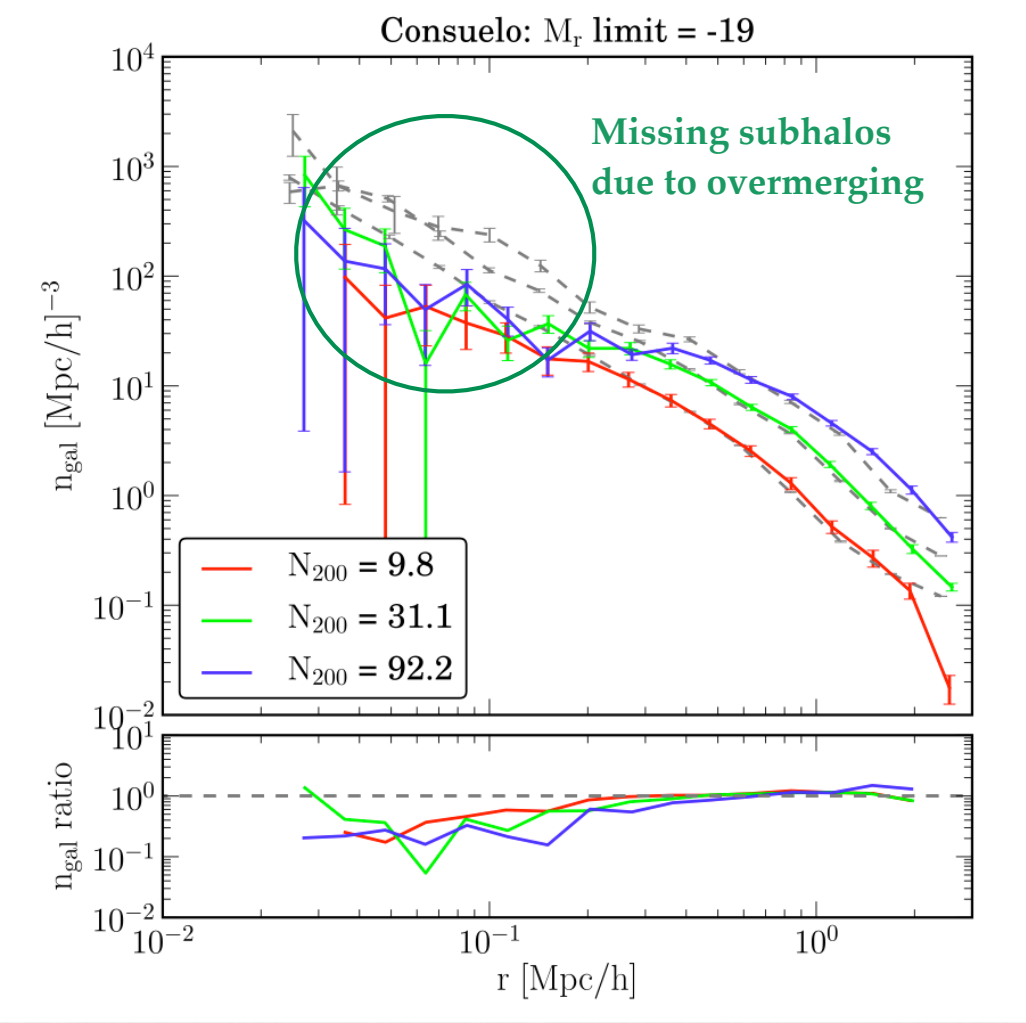
$$P_{sys}(k) = P_{fid}(k) + f_{sys}(P^{full}_{sys}(k) - P_{fid}(k))$$



Systematic Effect 1: Concentration-Mass Relation

	Systematic Difference	k_{max} allowed by current systematics	$k_{max} = 0.1$			$k_{max} = 1$		
			$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction	$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction
C-M	Bullock 01 vs. Battacharya 11	0.6	10^{-6}	0.0003	none	0.002	2	0.2

Systematic Effect 2: Number Density Profiles



Consuelo simulation; Wu et al. (in prep.)

$$P_{\rm gal}^{1h}(k) = \int {\rm d}m\, n(m)\, \frac{\langle N_{\rm gal}(N_{\rm gal}-1)|m\rangle}{\bar{n}_{\rm gal}^2}\, |u_{\rm gal}(k|m)|^p$$

Does galaxy distribution follow NFW profile?

$$\rho_{\rm NFW} \propto ({\rm r}/{\rm r_s})^{-1}(1+{\rm r}/{\rm r_s})^{-2}$$

N-body simulations found that galaxy distribution is systematically shallower than NFW in cluster center. The deviation depends on

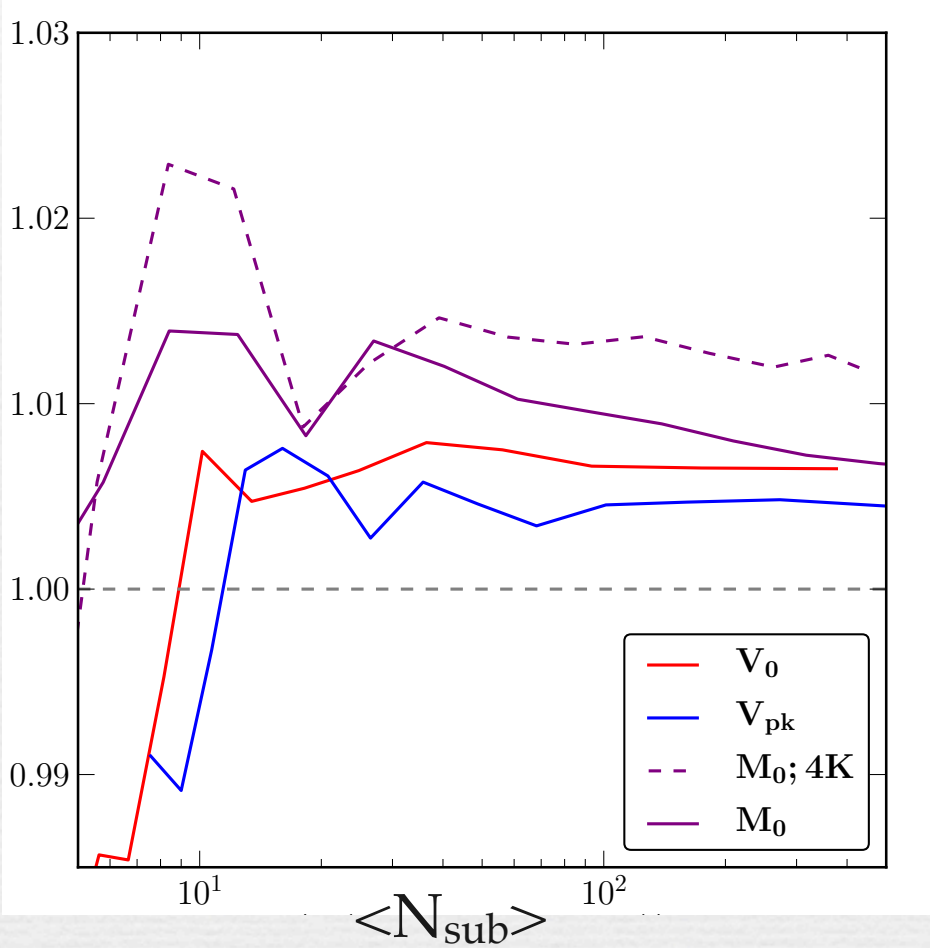
- mass of clusters
- luminosity of galaxies
- resolution

("Overmerging"? Need for "Orphan Galaxies"?)

Systematic Effect 2: Number Density Profiles

	Systematic Difference	k_{max} allowed by current systematics	$k_{max} = 0.1$			$k_{max} = 1$		
			$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction	$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction
Number density profile	NFW vs. overmerging	0.5	10^{-6}	0.0005	none	0.003	4	0.1

Systematic Effect 3: Poisson Distribution



Rhapsody simulation; Wu et al. (in prep.)

Does P(N | M) follow Poisson distribution?

$$P^{1h}_{\rm gal}(k) = \int {\rm d}m\, n(m) \frac{\langle N_{\rm gal}(N_{\rm gal}-1)|m\rangle}{\bar{n}^2_{\rm gal}} |u_{\rm gal}(k|m)|^p$$

$$\alpha = \frac{\sqrt{\langle N(N-1)\rangle}}{\langle N\rangle}$$

α =1 for Poisson distribution

In N-body simulations, α depends on

- selection method (red, blue, purple)
- selection threshold (x-axis)
- resolution (solid vs. dash)

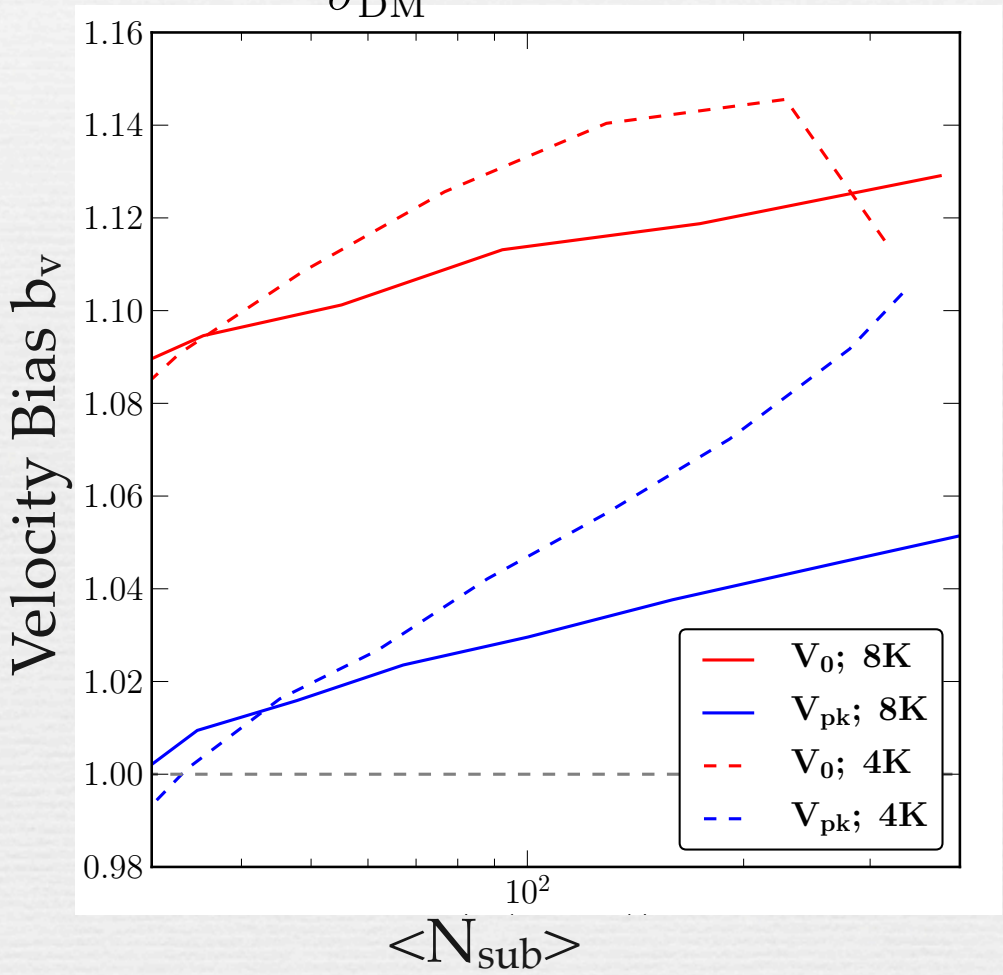
Assuming α =1.02 (Boylan-Kolchin 09)

Systematic Effect 3: Poisson Distribution

	Systematic Difference	k_{max} allowed by current systematics	$k_{max} = 0.1$			$k_{max} = 1$		
			$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction	$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction
P(N)	Poisson vs. α=1.02	0.2	0.0003	0.10	none	0.01	21	0.03

Systematic Effect 4: Velocity Bias

$$b_v = \frac{\sigma_{gal}}{\sigma_{DM}}$$



Rhapsody simulation; Wu et al. (in prep.)

$$\delta_g^z(\mathbf{k}) = \delta_g e^{-(k\sigma u)^2/2}$$

σ_{gal} is approximated by σ_{sub} in simulations;

σ_{sub} depends on

- selection method (blue vs. red)
- selection threshold (x-axis)
- resolution (solid vs. dash)
- baryonic physics (see Lau '10 for hydro simulations)

Assuming $b_v = 1.15$

Systematic Effect 4: Velocity Bias

	Systematic Difference	k_{max} allowed by current systematics	$k_{max} = 0.1$			$k_{max} = 1$		
			$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction	$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction
Velocity bias	bv = 1 vs. 1.15	0.06	0.015	5	0.09	0.1	290	0.003

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			$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction	$\Delta P/P$	$\Delta w_0/\sigma(w_0)$	Required sys reduction
C-M	Bullock 01 vs. Battacharya 11	0.6	10^{-6}	0.0003	none	0.002	2	0.2
Number density profile	NFW vs. overmerging	0.5	10^{-6}	0.0005	none	0.003	4	0.1
P(N)	Poisson vs. α=1.02	0.2	0.0003	0.10	none	0.01	21	0.03
Velocity bias	$b_v = 1$ vs. 1.15	0.06	0.015	5	0.09	0.1	290	0.003

✓ **Velocity bias** could be the dominant source of error limiting the smallest scale we can use. It may need to be calibrated from observation rather than simulation.