Halo model versus simulations

Uros Seljak

ICTP/Princeton

Trieste, June 2005

Outline

Halo model: basics

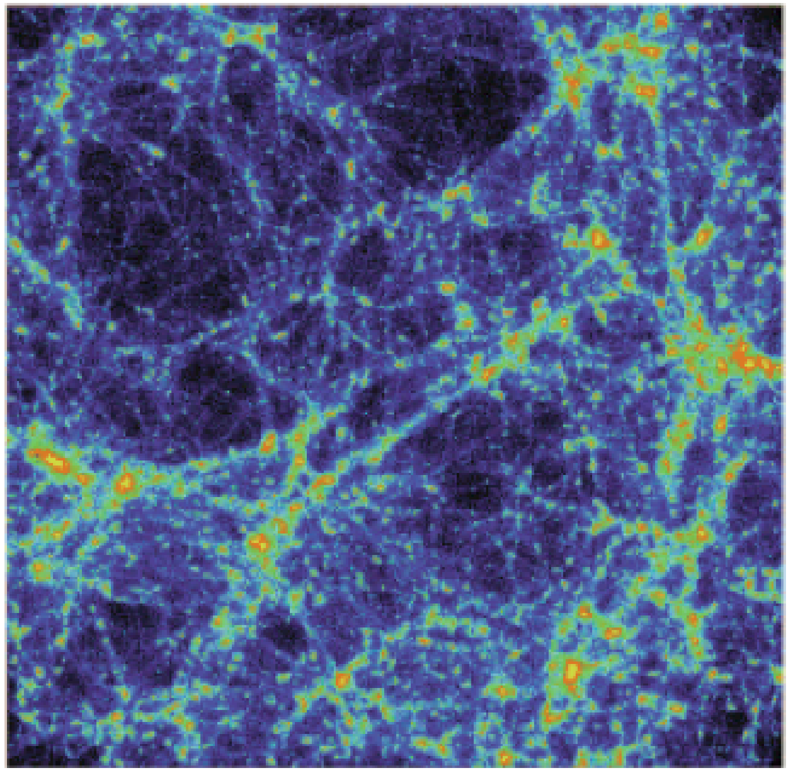
Main physics ingredients: mass function, halo bias and halo profile

Gastrophysics: Halo occupation distribution

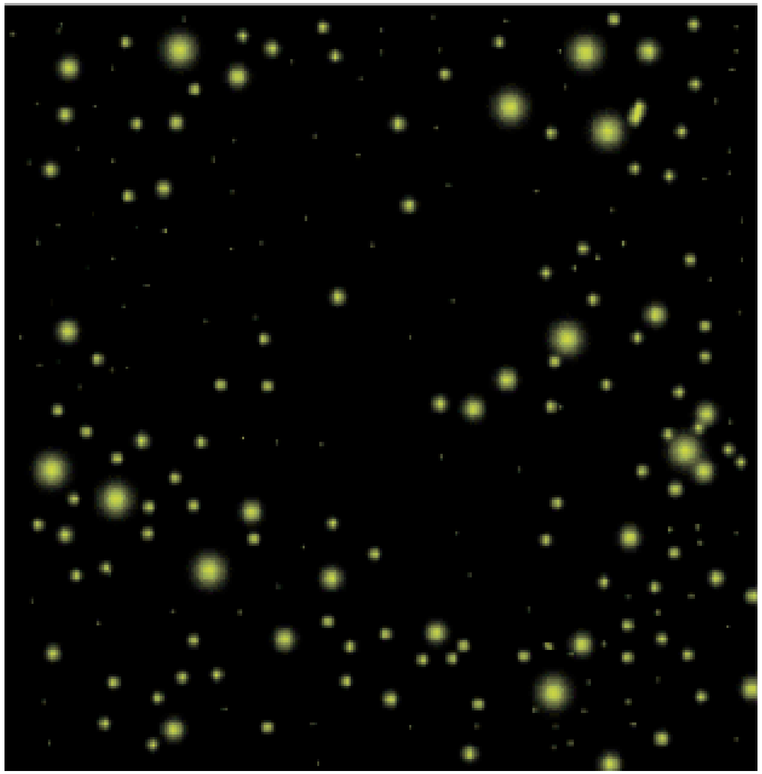
Application: galaxy-galaxy lensing

Halo Approach to Large Scale Structure

"poor man's approximation to simulations"



Complex View



Simplified View

Review article in Physics Reports (Cooray & Sheth 2002)

Halo Approach to Large Scale Structure

Dark matter halo model for clustering

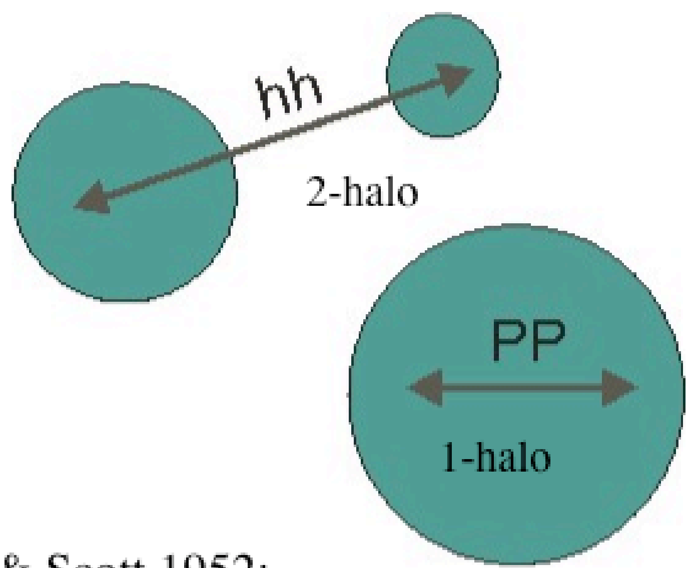
Basic idea:

1. All dark matter in halos

2. Correlation functions can be described through correlations within and between halos

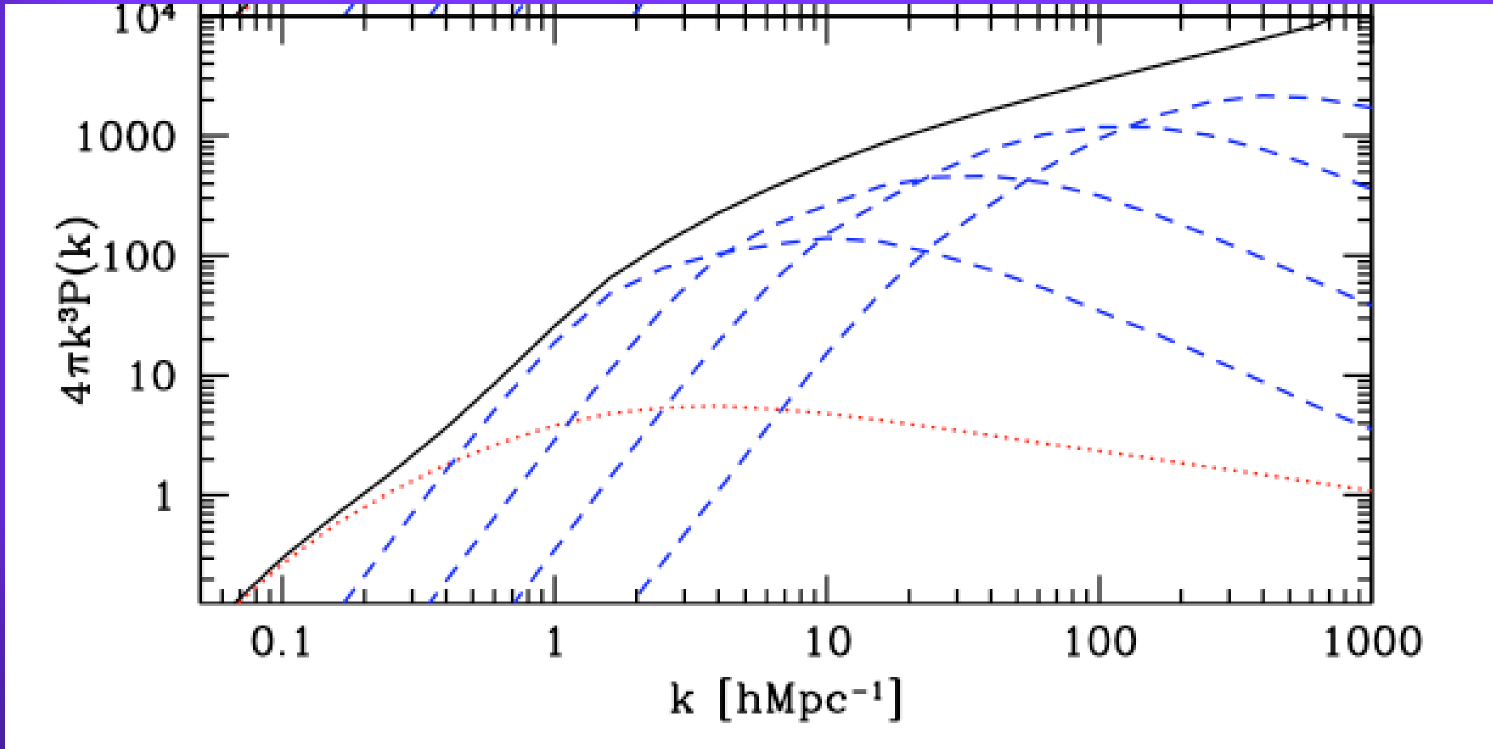
3. Ingredients:
   dark matter profile
   (NFW or variants)
   Mass function
   (Press-Schechter or variants)
   Halo bias model

Two point function



Neyman & Scott 1952;
Peebles 1974; Scherrer & Bertschinger 1991;
Seljak 2000; Ma & Fry 2000;
Scoccimarro et al 2000;
Cooray, Hu, Miralda-Escudé 2000;

Dark matter power spectrum



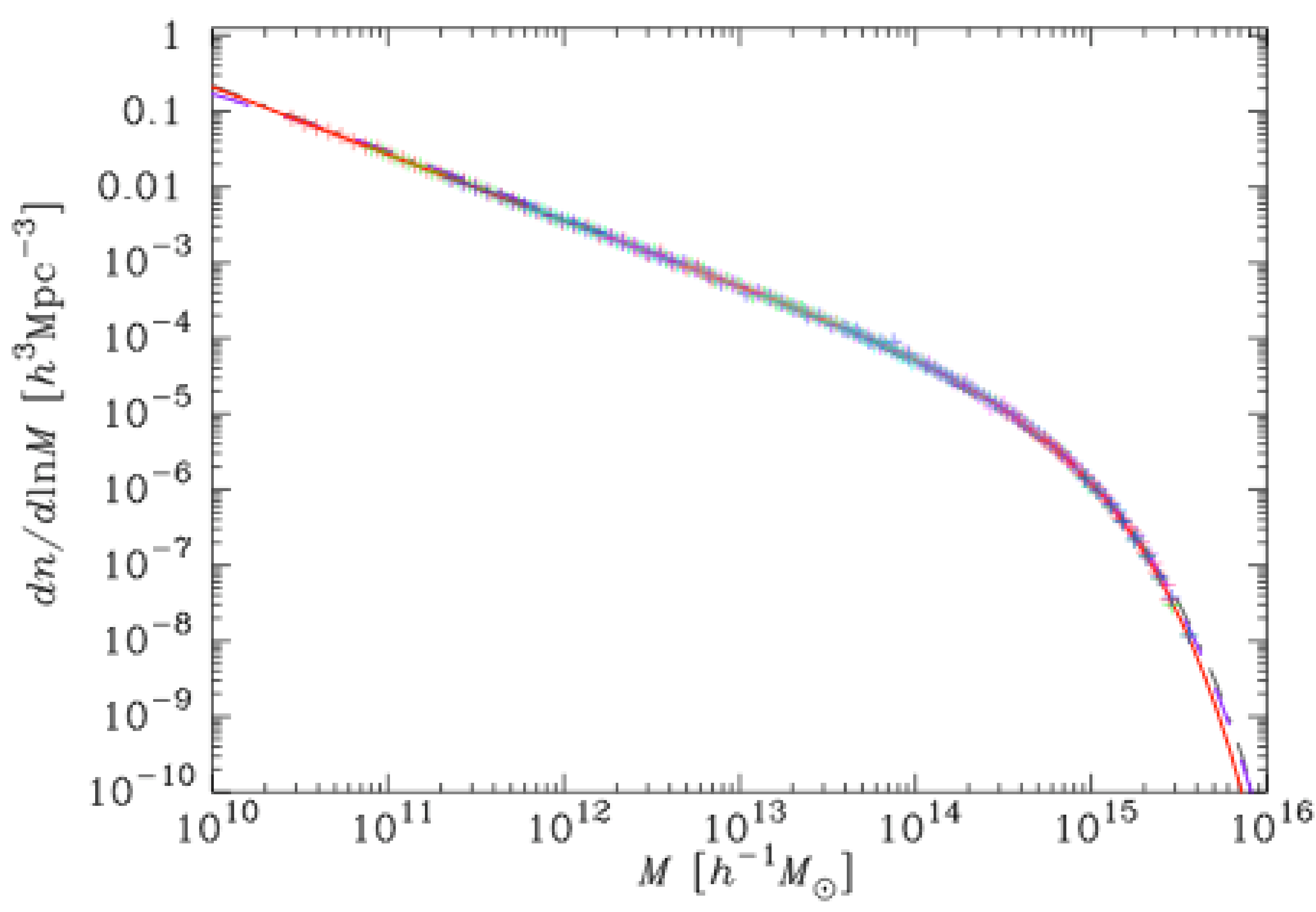
Seljak

2000

Agrees well with N-body simulations

Provides analytic understanding of nonlinear clustering

Mass function from Warren etal (see poster):
Sheth and Tormen fit good, but with modified parameters: a=0.75, p=0.1



Halo bias as a function of halo mass

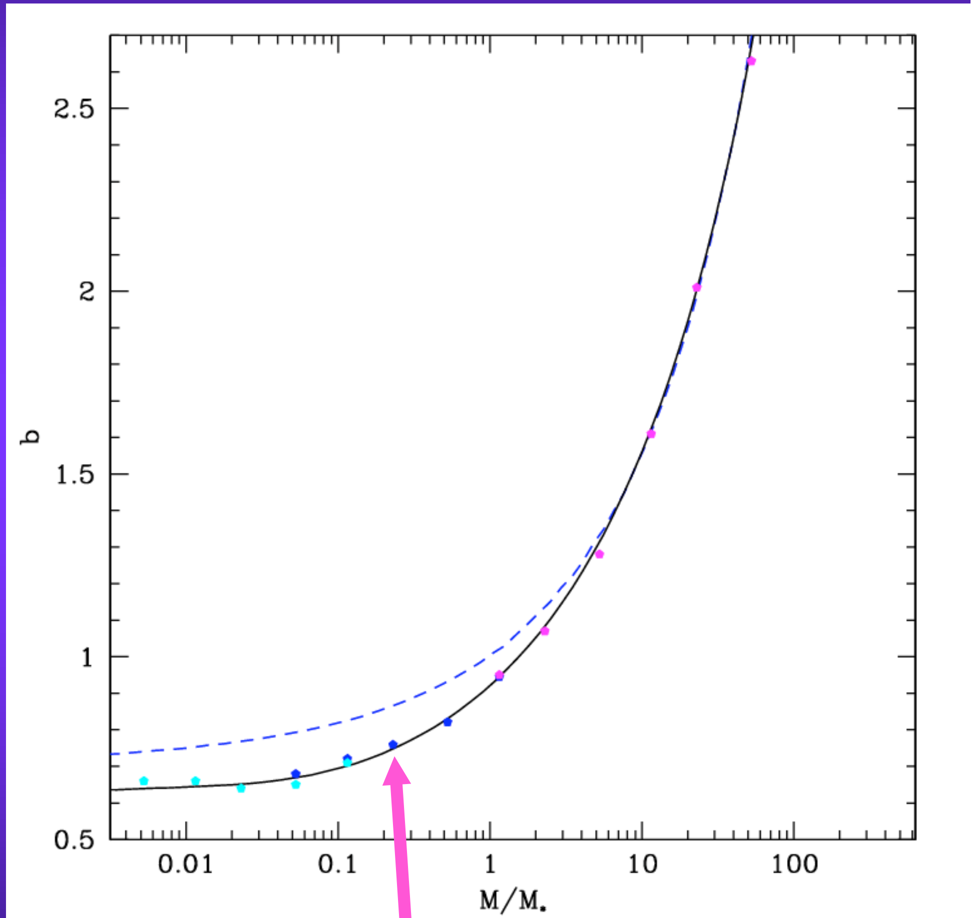
High mass halos strongly biased

Low mass halos antibiased, b=0.7

Theory is in reasonable agreement with simulations (Sheth and Tormen 1999; Jing 1999, US and Warren 2004)

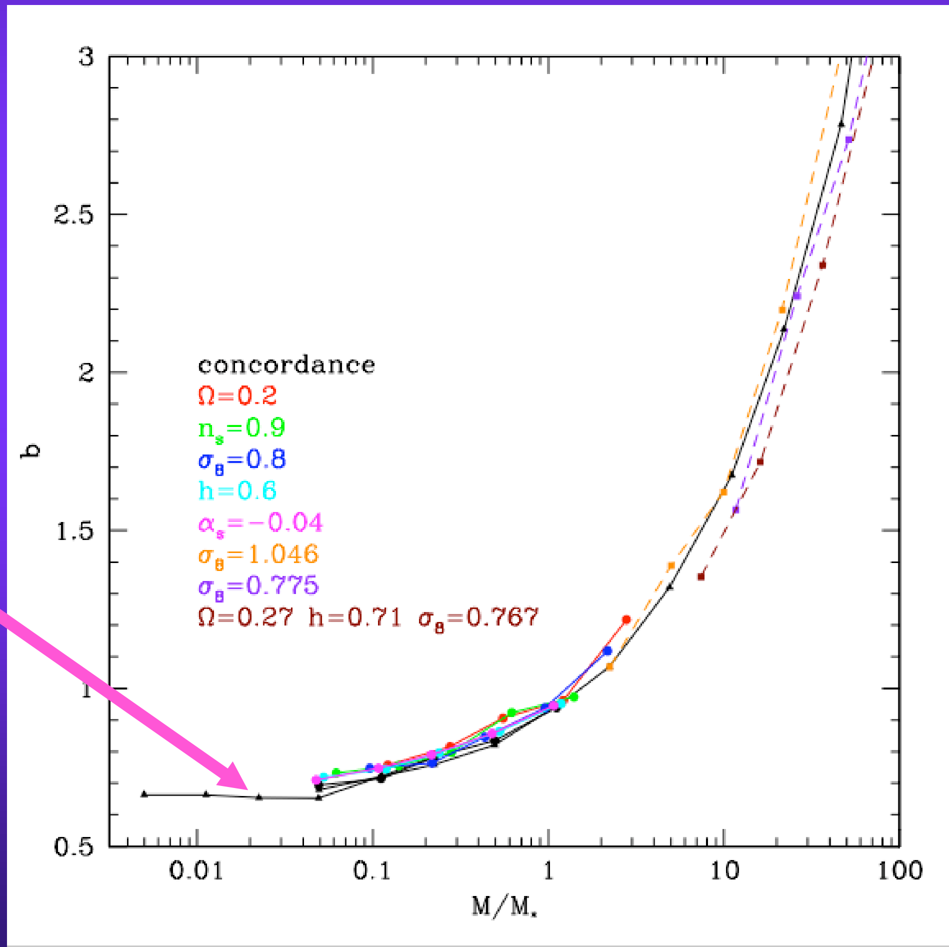
Best ST fit gives a=0.7, p=0.15, in reasonable agreement with mass function: peak-background split works!

Turn around: assuming bias is a derivative of MF gives a precise way of measuring MF from bias



Seljak and Warren 2004

Seljak and Warren 2004



Bias mass relation is nearly universal if mass is in units of nonlinear mass (mass within the sphere with rms 1.68)

Ingredients: dark matter

- Halo clustering: halo bias
- Linear correlation function
- Halo abundance: halo mass function
- Average halo dark matter profile

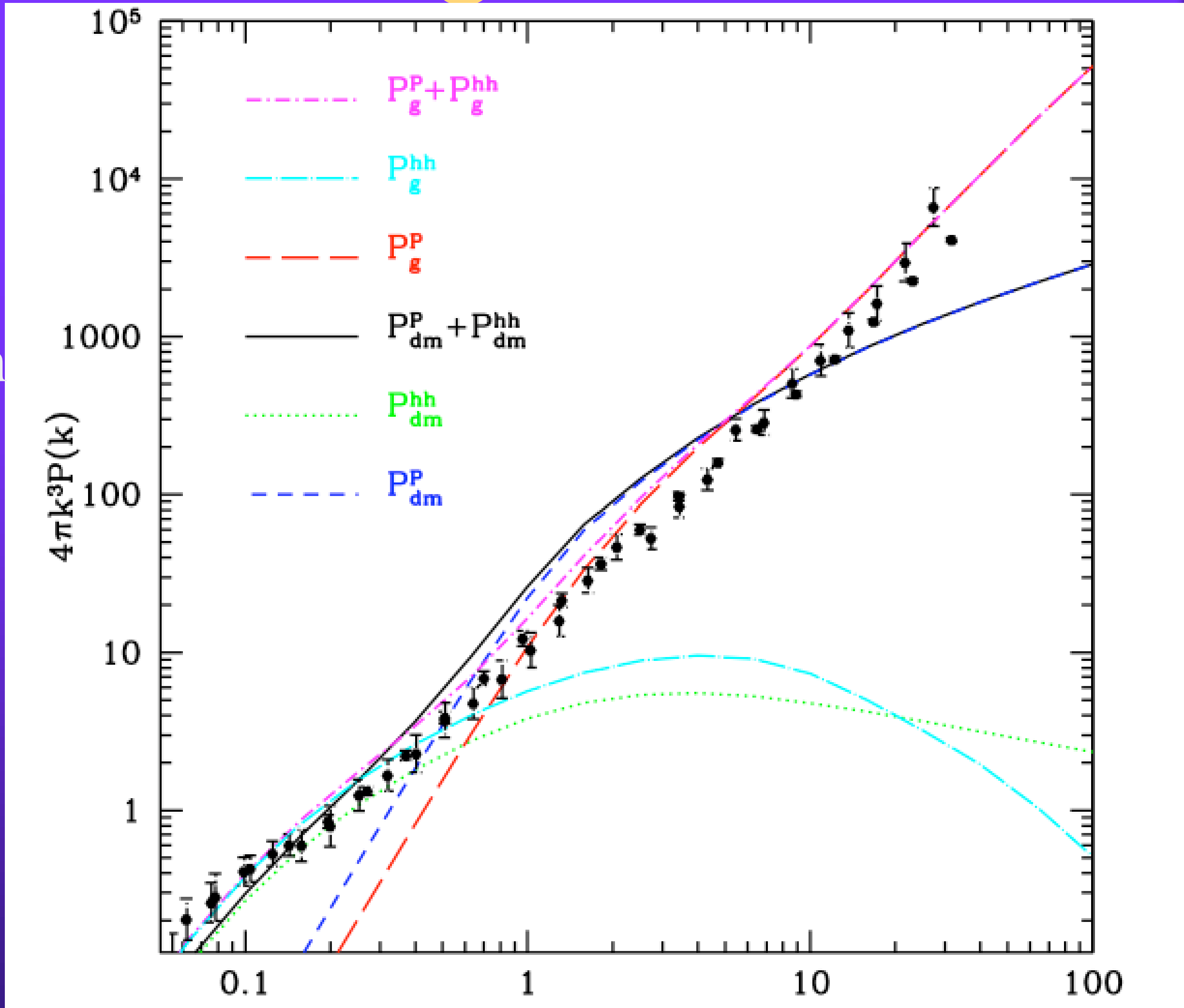
Galaxy clustering

Seljak 2000

Need to populate galaxies inside halos

Specify galaxy occupation <N(M)> or <N(N-1)(M)>

Can explain power law in galaxy clustering for appropriate halo occupations, but these need to be pulled out of simulations



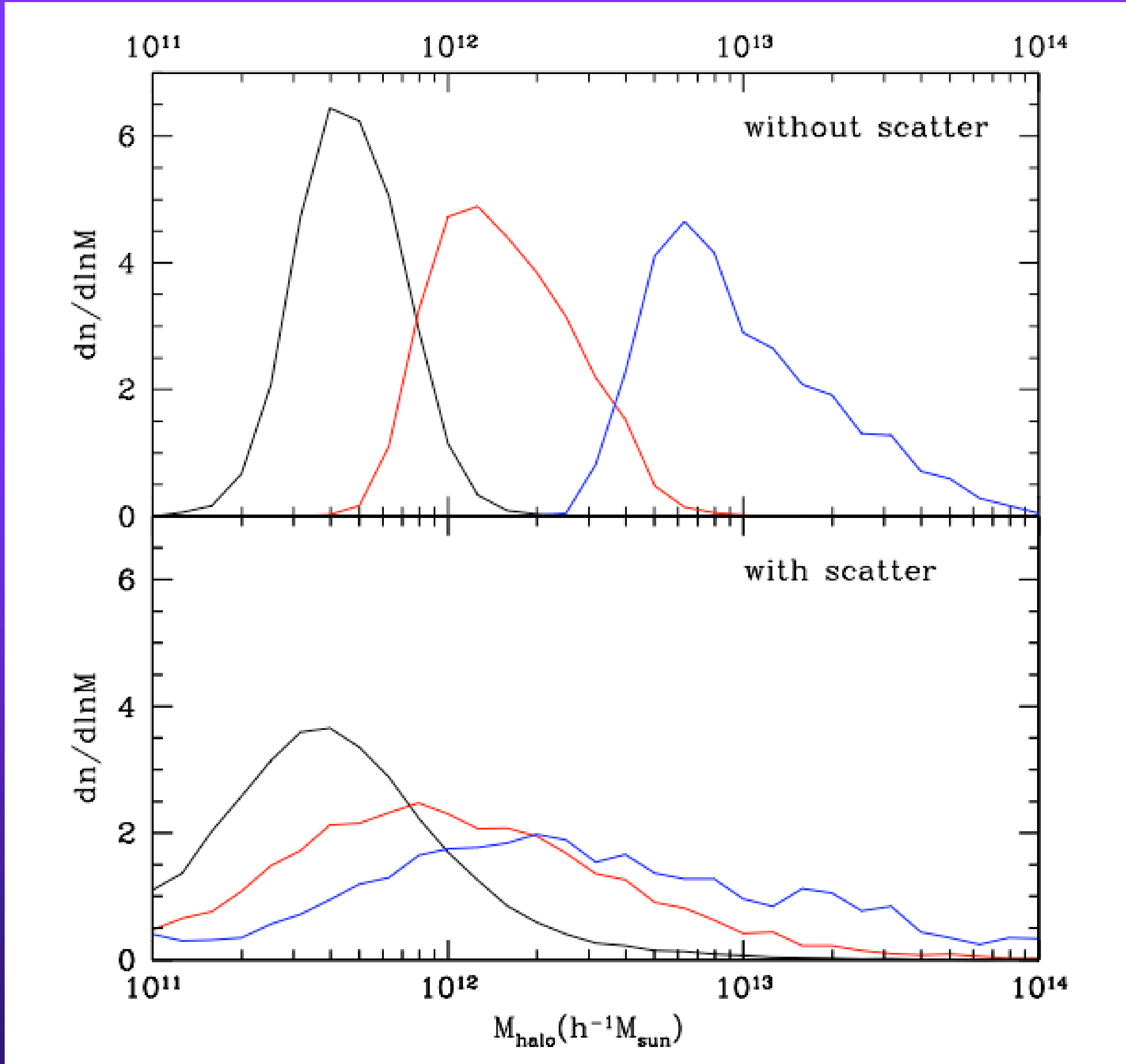
New paradigm

Guzik & Seljak 2001, Kravtsov etal 2004, Zhang etal 2005

- Split galaxies into central and non-central
- Central galaxies: tight relation between luminosity and mass: at a given L mass distribution narrow: M_c

Central galaxy mass distribution can be narrow, unless there is a lot of scatter

Important to find a tight tracer of halo mass (stellar mass etc)

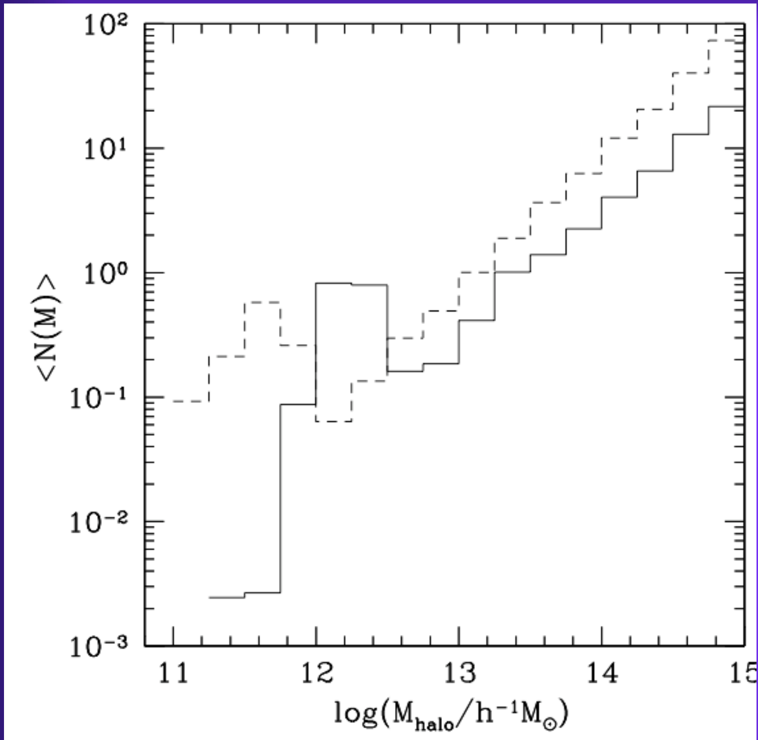


Mandelbaum etal

New paradigm

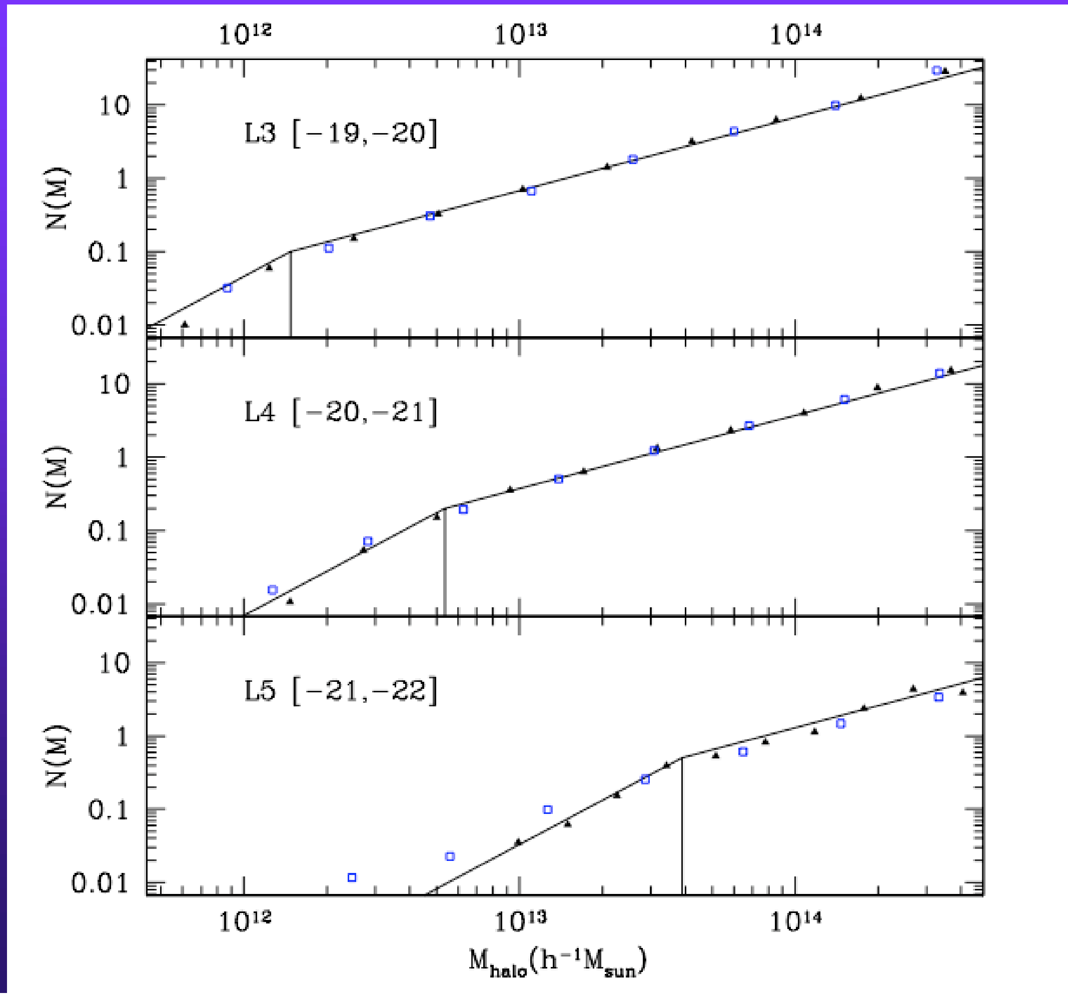
Guzik & Seljak 2001, Kravtsov etal 2004, Zhang etal 2005

- Split galaxies into central and non-central
- Central galaxies: tight relation between luminosity and mass: at a given L mass distribution narrow: M_c
- Noncentral galaxies or satellites: N(M;L) proportional to M for $M>3M_c$, the simplest possibility
- Can be used to model galaxy properties as a function of luminosity

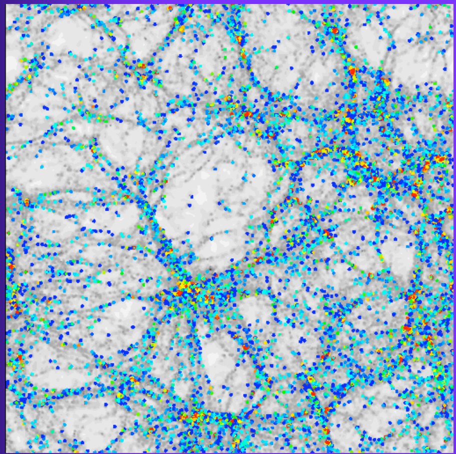


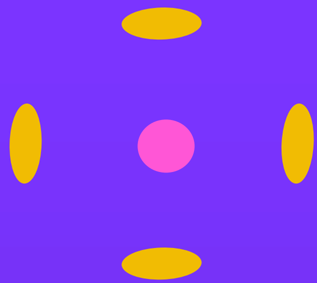
SAM GIF simulations
Guzik and Seljak 2001

Mandelbaum,
Tasitsiomi,
Seljak,
Kravtsov,
Wechsler
2005



Weak lensing in SDSS: galaxy-galaxy lensing





$$R = r_L \Theta$$

$$\gamma_T = \frac{\Delta\Sigma(R)}{\Sigma_{\rm crit}}$$

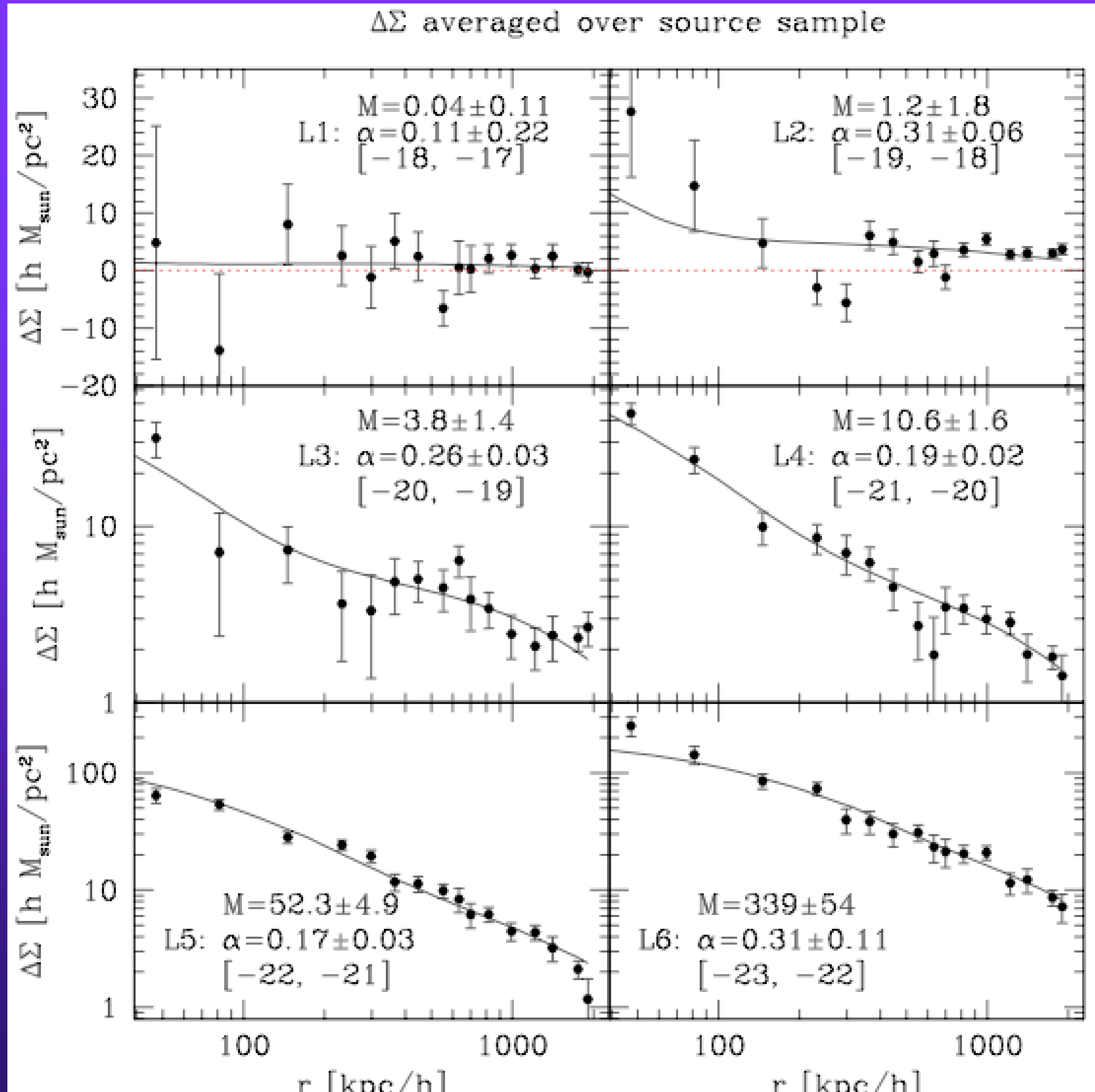
$$\Delta\Sigma(R) = \bar{\Sigma}(R) - \Sigma(R)$$

$$\Sigma_{\rm crit} = \frac{c^2}{4\pi G} \frac{r_S}{(1+z_L) r_L r_{LS}}$$

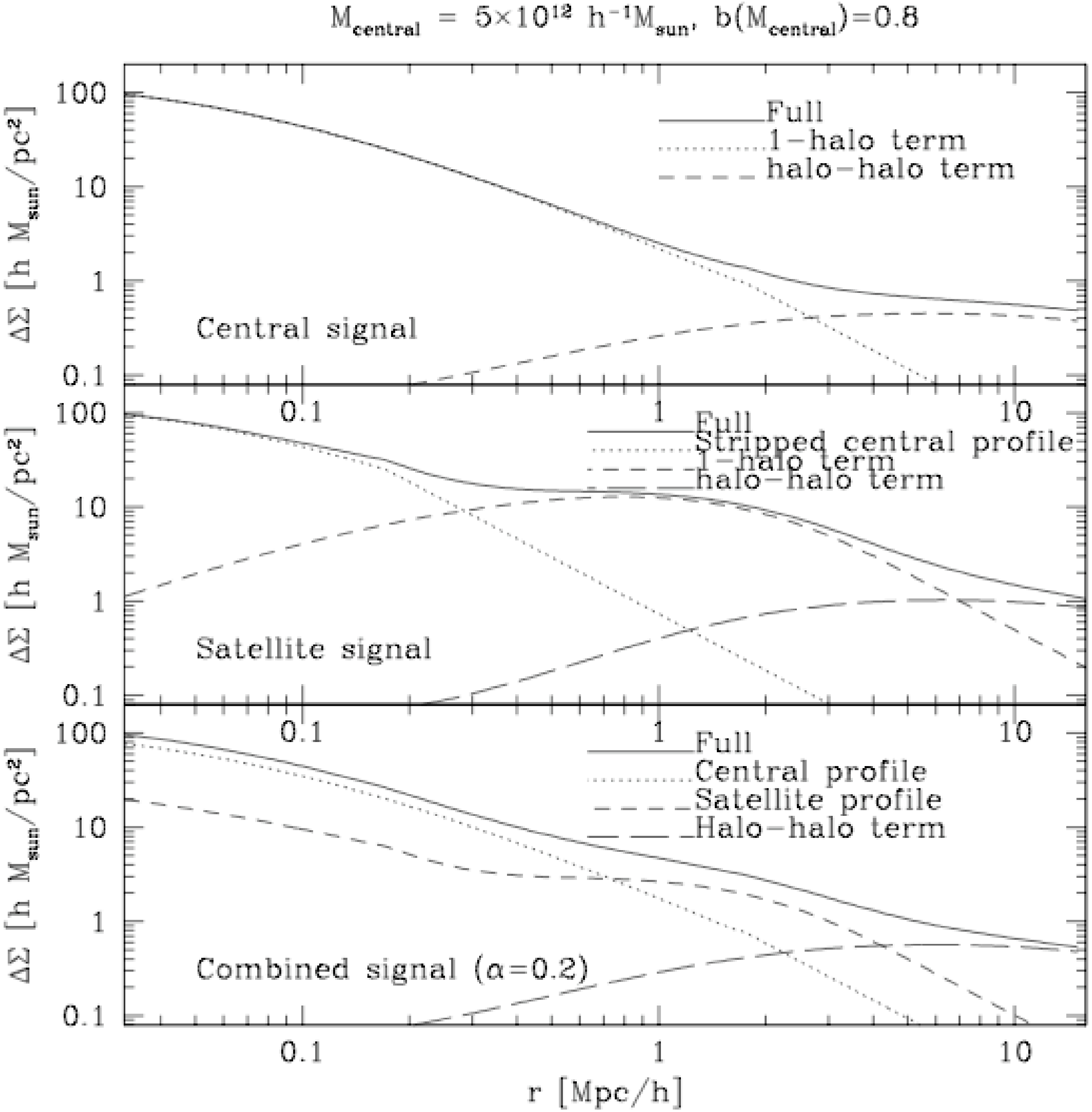
- dark matter around galaxies induces tangential distortion of background galaxies: extremely small, 0.1%
- ♦Important to have redshifts of foreground galaxies: SDSS (McKay etal 02, Sheldon etal 03,04, Seljak etal 04)
- ♦Express signal in terms of projected surface density and transverse r
- ♦Signal as a function of galaxy luminosity

Application to galaxy-galaxy lensing

- Motivation: lot's of data from SDSS: SDSS has the highest lensing S/N=50 to date
- 5-d simulation grid not practical
- Halo model useful if calibrated on simulations



Seljak etal 2005

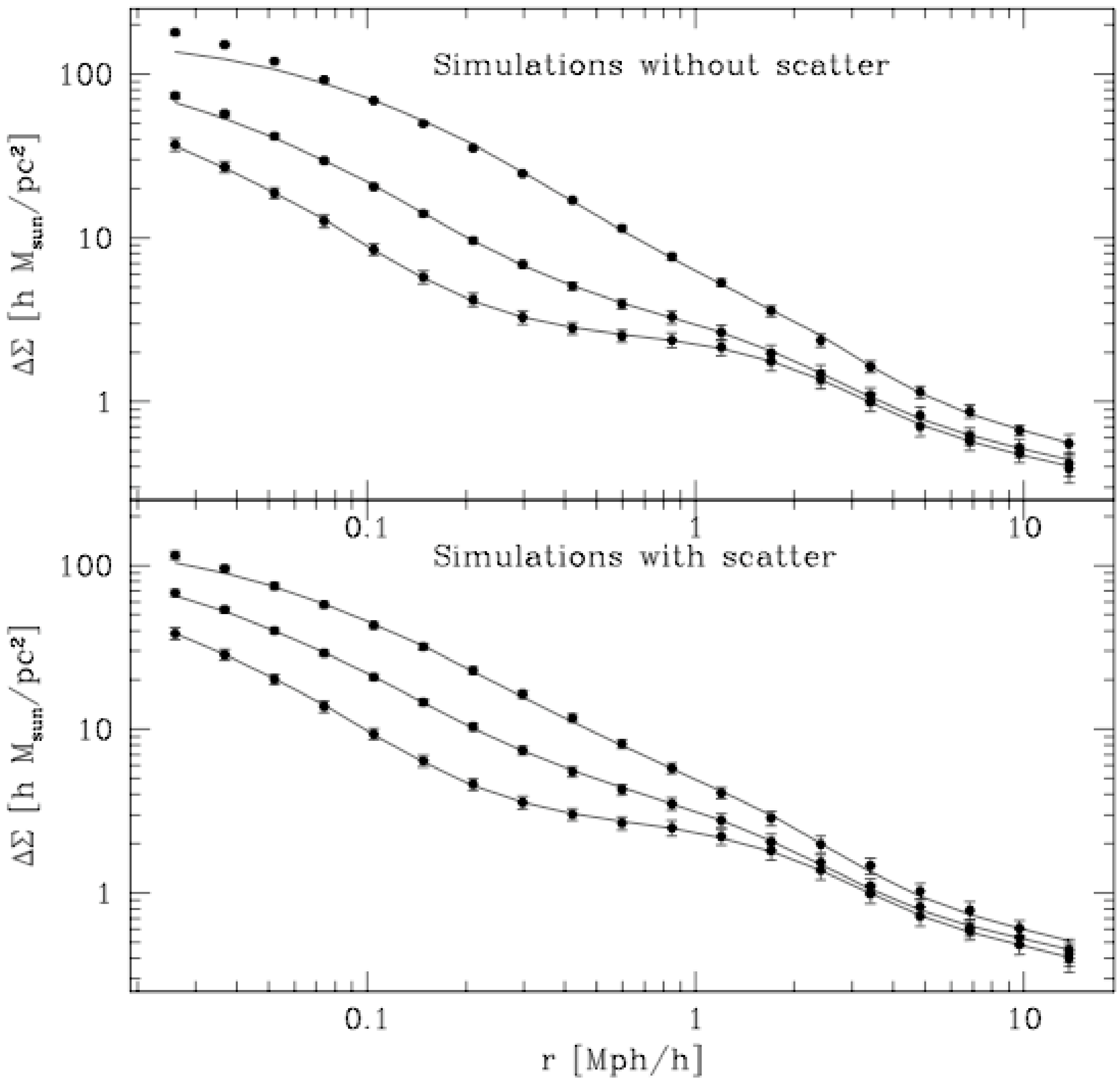


M_central = 5×10^12 h^-1 M_sun, b(M_central)=0.8
ΔΣ [h M_sun/pc²]
Full
1-halo term
halo-halo term
Central signal
Stripped central profile
Satellite signal
Central profile
Satellite profile
Halo-halo term
Combined signal (α=0.2)
r [Mpc/h]

2 free parameters: central halo mass and satellite fraction

Halo model can reproduce simulations to high accuracy

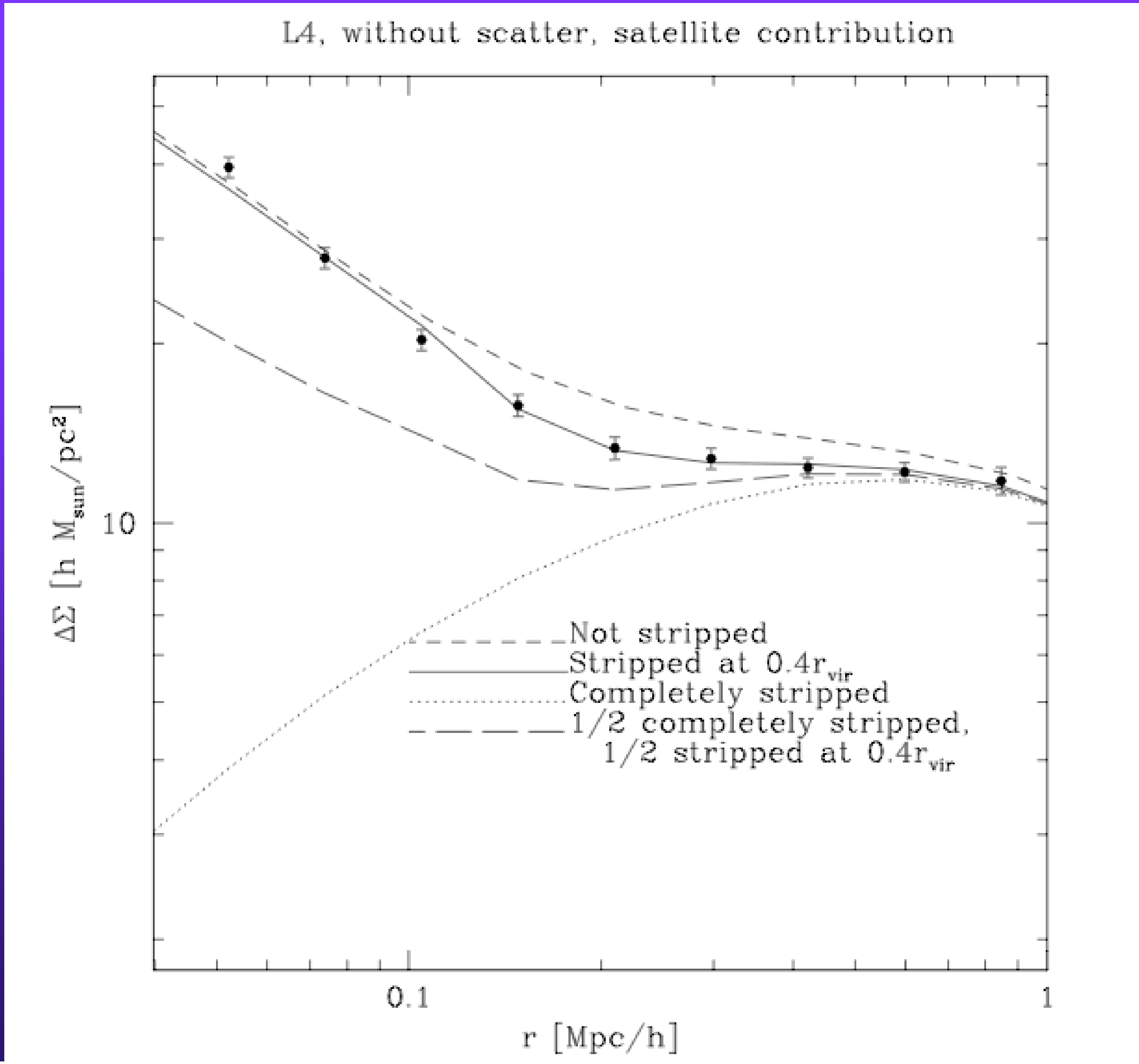
Mandelbaum etal 2005



Halo stripping of satellites

Seen in simulations of g-g lensing

Can be measured if a satellite sample is selected



Application: bias determination

$$b(L) = \int b(M)\, p(M;L)\, dM$$

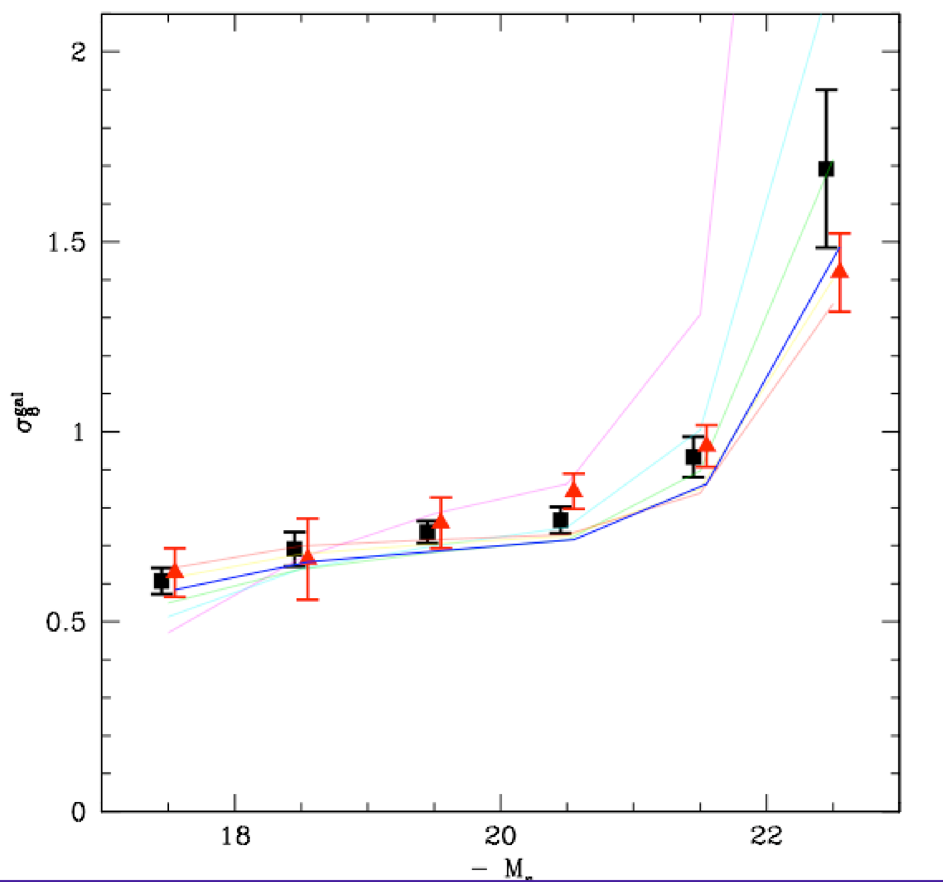
For any cosmological model we can determine b(L) from above

Theoretical halo bias is confirmed!

We also measure b(L) from galaxy clustering

Only cosmological models where the two constraints agree are acceptable

Robust: 20% error in lensing gives only 0.03 error in bias



Conclusions

- Halo model is a simple and well motivated description of galaxy and dark matter clustering
- In simplest model 2 free parameters: halo mass of central galaxies and satellite fraction
- It agrees with simulations to high accuracy, once this is established it can be used on its own
- High precision cosmology application: g-g lensing (SDSS), leading to bias and sigma8 determination