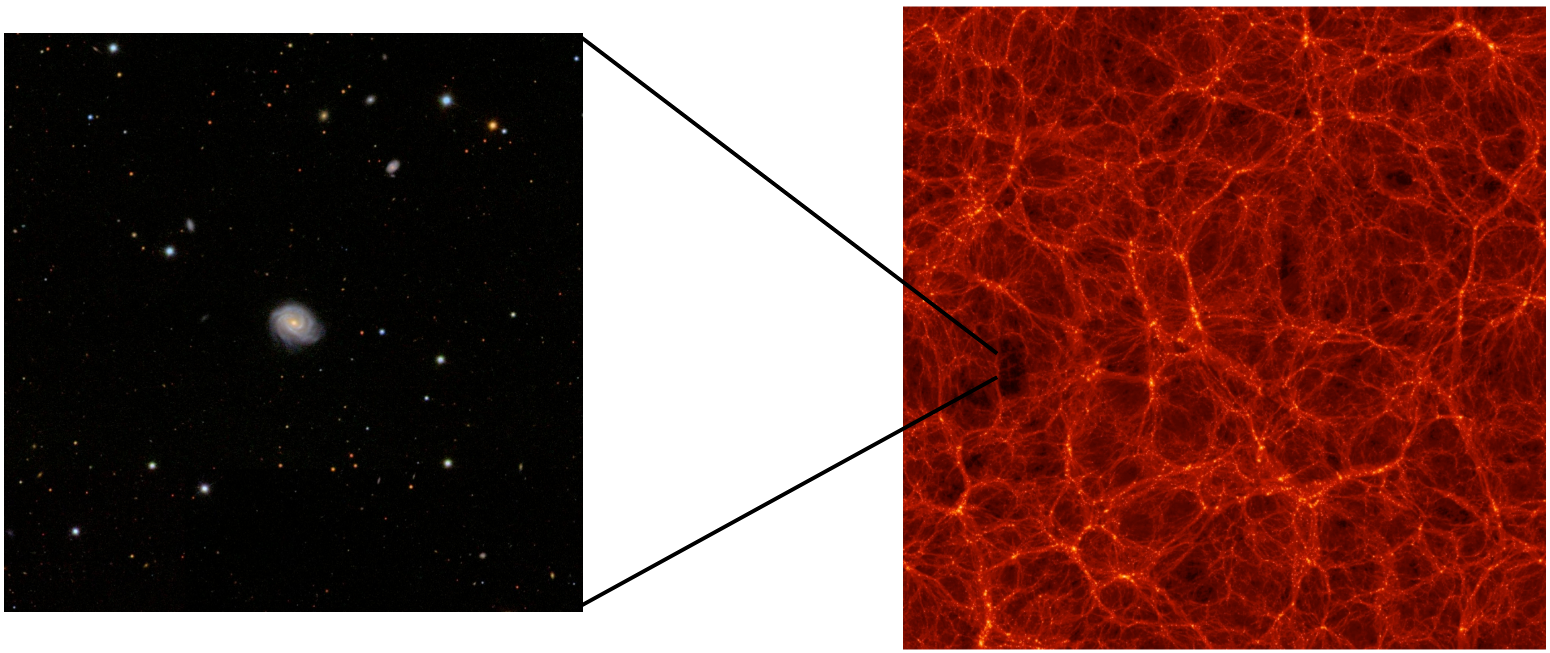
the galaxy-halo connection from abundance matching: simplicity and complications

Risa Wechsler



with Peter Behroozi, Michael Busha, Rachel Reddick (KIPAC/Stanford)
& Charlie Conroy (Harvard/CfA)

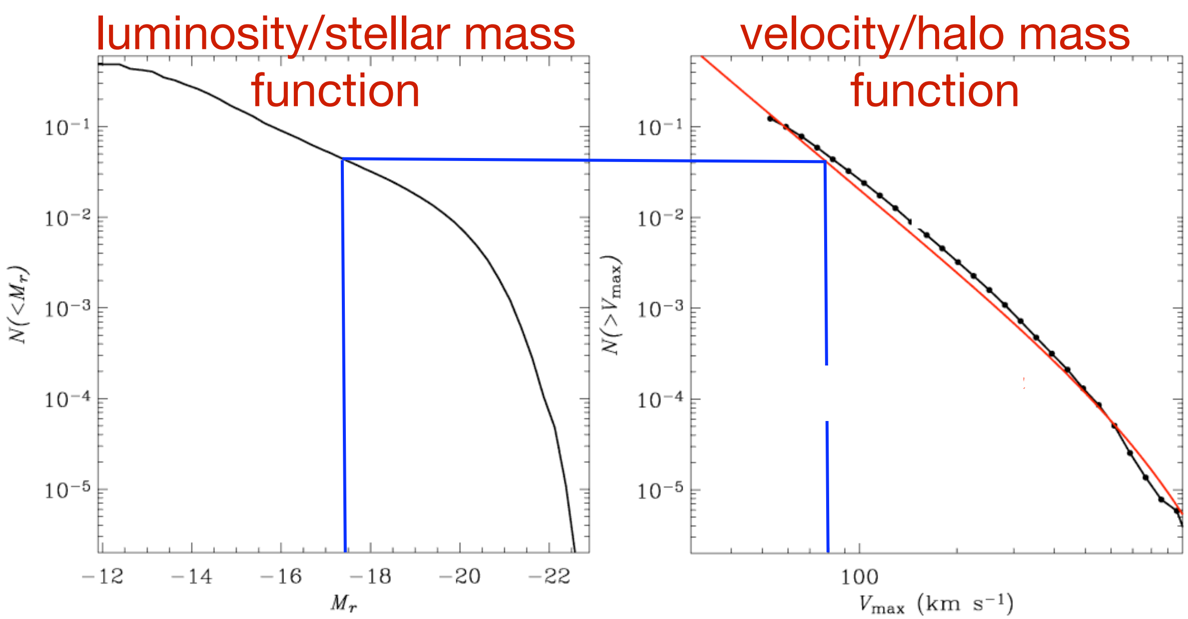
subHalo abundance matching

- The basic idea:
  - Galaxies live in halos (including subhalos)
  - There is a property of halos (e.g. mass) that is tightly correlated with some property of galaxies (e.g. stellar mass, luminosity)
- Some details matter:
  - which property, what is the scatter?
  - proper treatment of satellite galaxies: stripping, star formation once halos become substructures
- Very powerful idea:
  - the mass of a dark matter halo is the primary determinant of its properties.
  - detailed tests of the model can test both LCDM and galaxy formation physics
- Results to date:
  - matching stellar mass/or luminosity to the maximum mass/v_{max} its halo ever had (current mass(v_{max}) for central galaxies; mass at accretion for satellites), with a small amount of scatter, works very well.
  - excellent agreement with a wide range of galaxy statistics, including two-point clustering, three-point clustering, lensing, etc.
  - data are getting good enough to test the details, and infer some physics.

Some interesting questions

- How much scatter is there in the galaxy-halo connection?
  - What is it due to?
- How does the halo occupation evolve?
- Does the model extend to low masses?

abundance matching technique

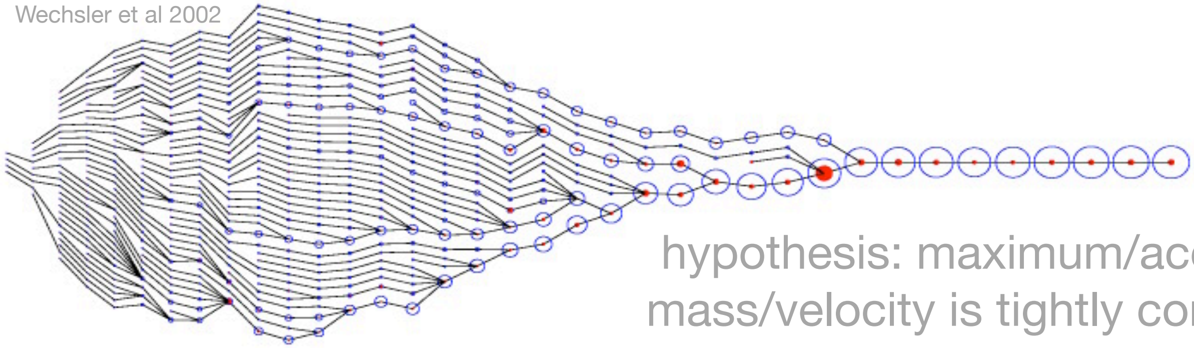


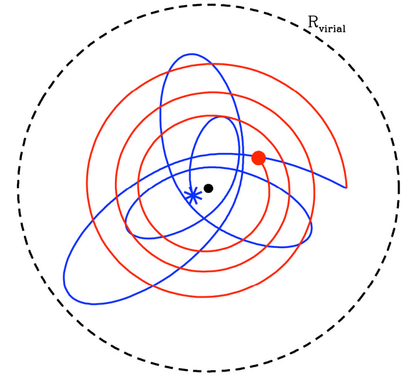
assign galaxies to halos velocities by matching n(>M*) to n(>M) (assume the most massive galaxy lives in the most massive halo)

key assumptions: one galaxy per dark matter clump; galaxy mass/luminosity tightly correlated with halo mass/velocity
required high-res cosmological simulations to properly test

e.g. Kravtsov, Berlind, Wechsler, et al 2004; Conroy, Wechsler & Kravtsov 2006; Conroy & Wechsler 2008 see also Vale & Ostriker 2006, 2007

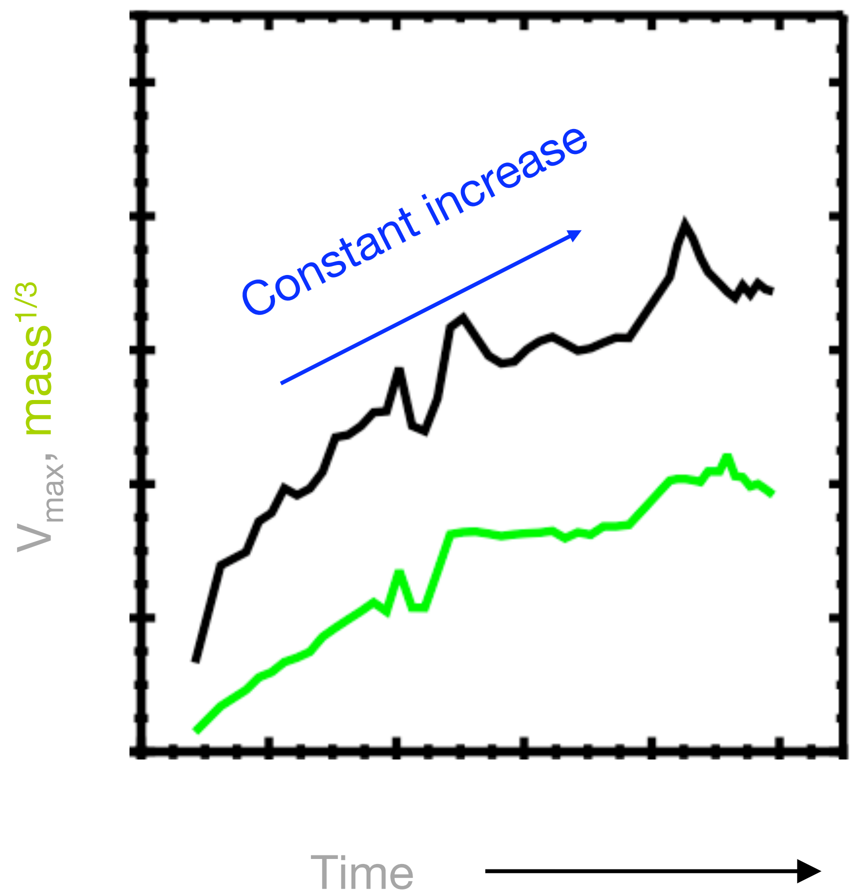
Wechsler et al 2002



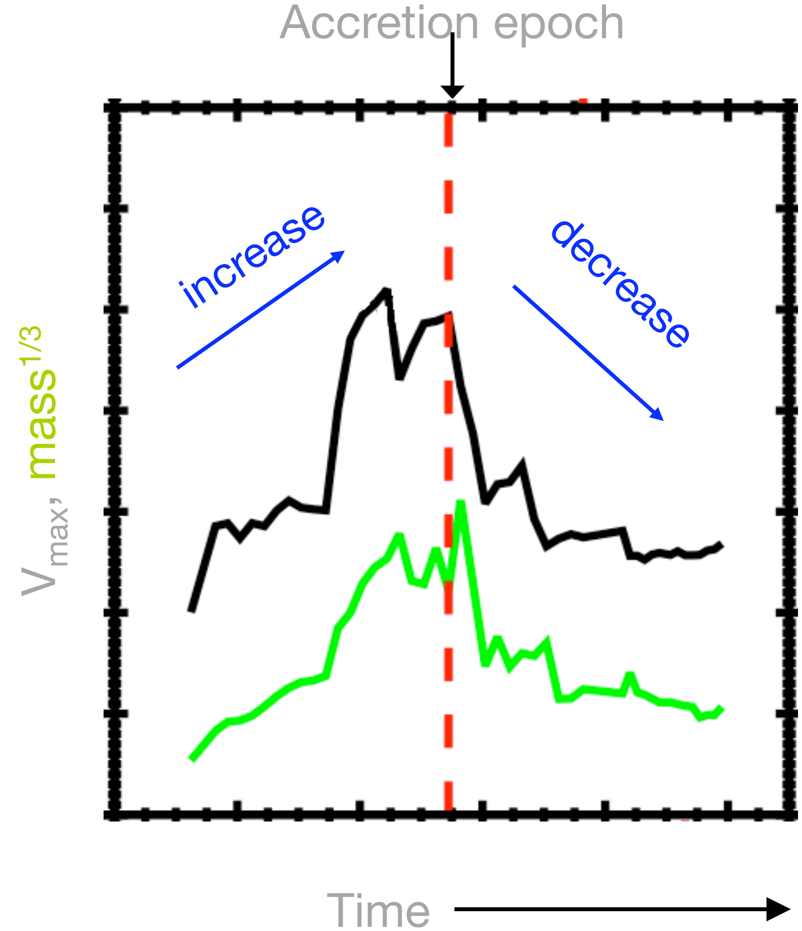


hypothesis: maximum/accretion mass/velocity is tightly correlated with stellar mass/total luminosity

Distinct Halo Evolution



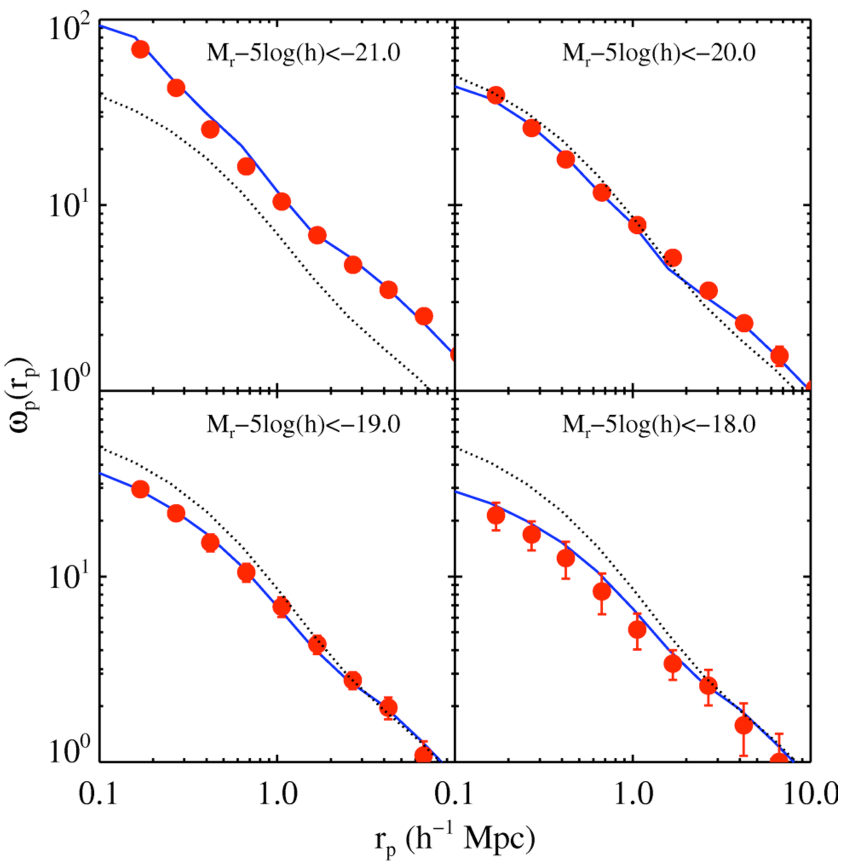
Subhalo Evolution



initial comparisons to clustering measurements

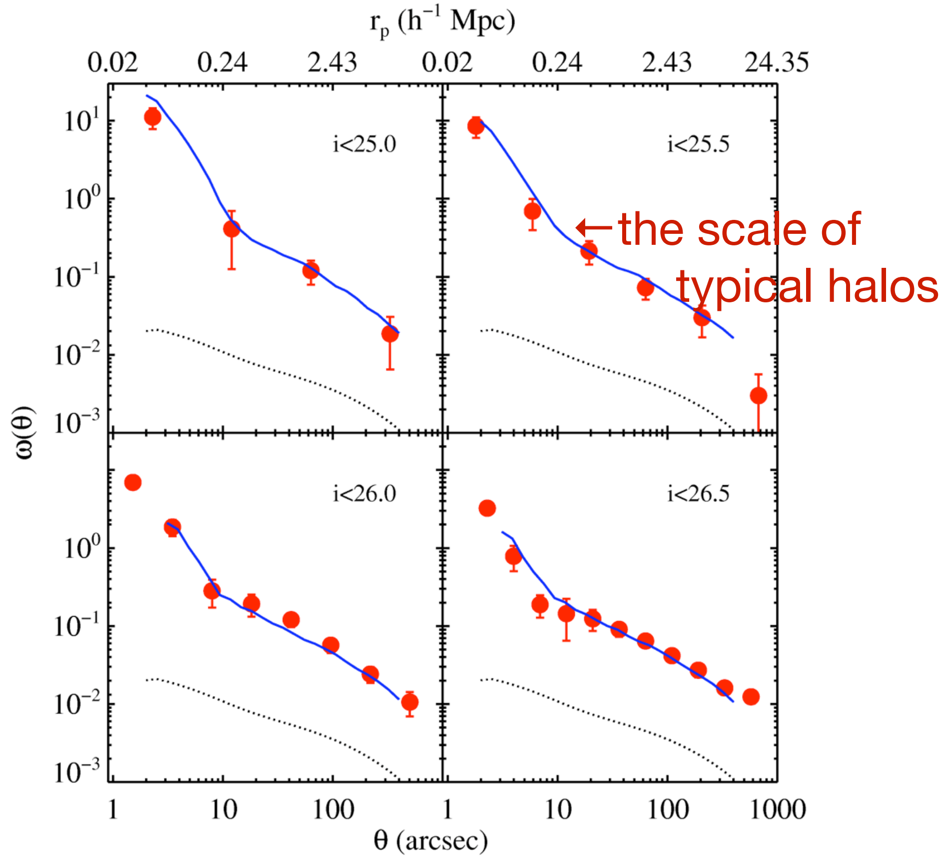
SDSS, z=0

data: Zehavi et al 2004



Subaru, z=4-5

data: Ouchi et al 2005

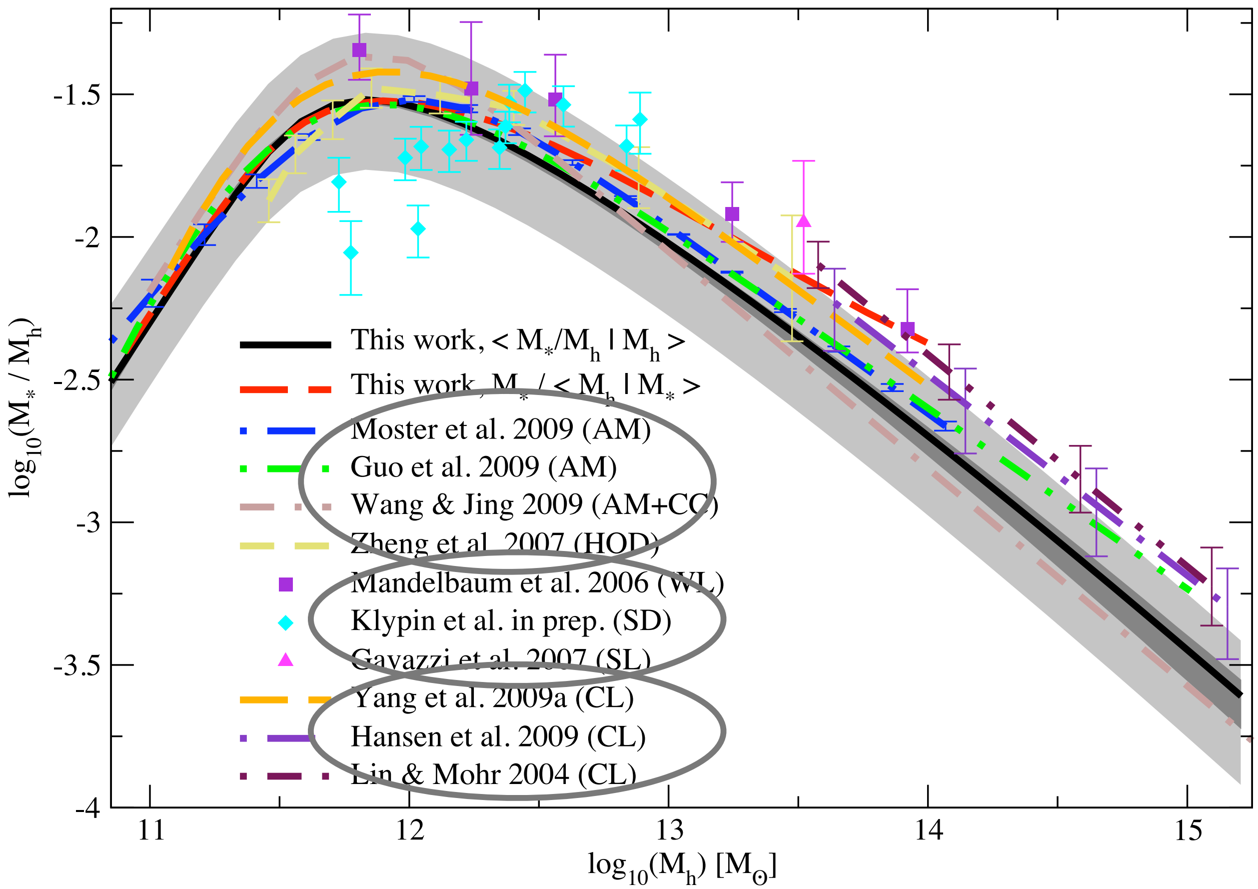


the scale & luminosity dependence of galaxy clustering at high z are very well explained by this simple approach!

Conroy, Wechsler, & Kravtsov 2006

The galaxy-halo connection at z=0

Behroozi, Conroy & RW 2010



constraints from abundance & clustering

mass measurements from lensing/dynamics

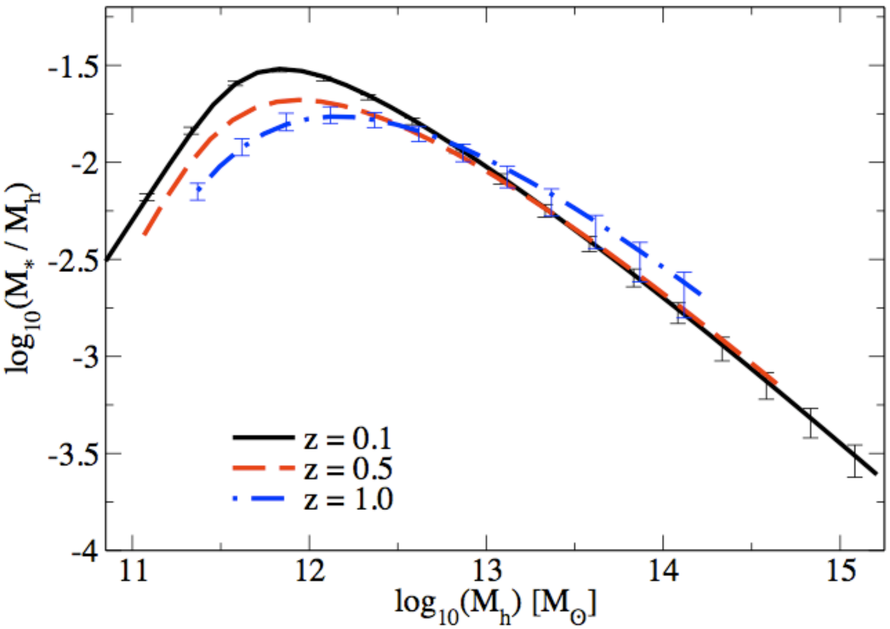
galaxy content of clusters

How well is the galaxy-halo connection constrained?

consider errors in: mass function, stellar mass function, scatter, cosmology, matching algorithm

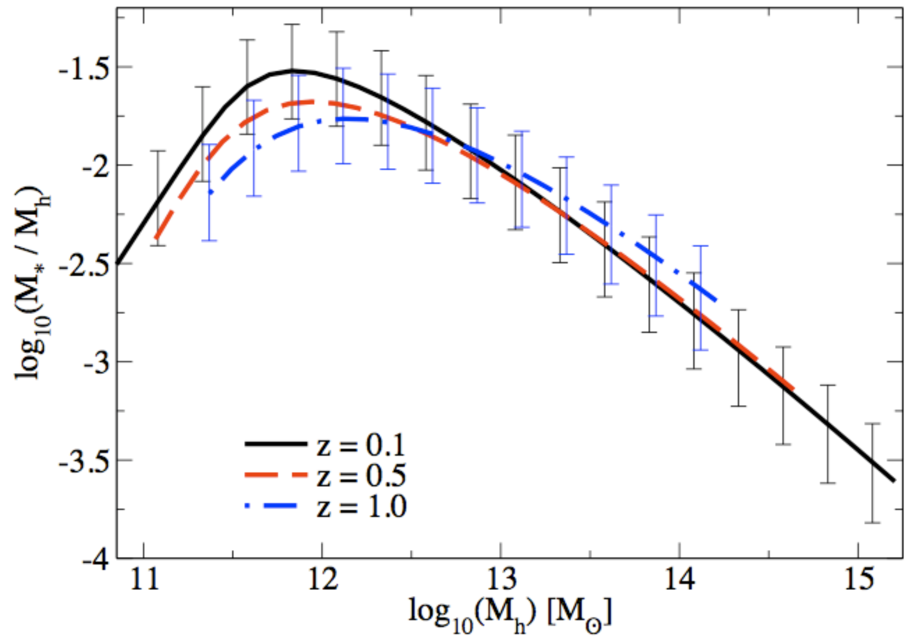
Behroozi, Conroy & RW 2010

statistical errors only



includes poisson and sample variance errors,
uncertainty due to scatter in M*-M

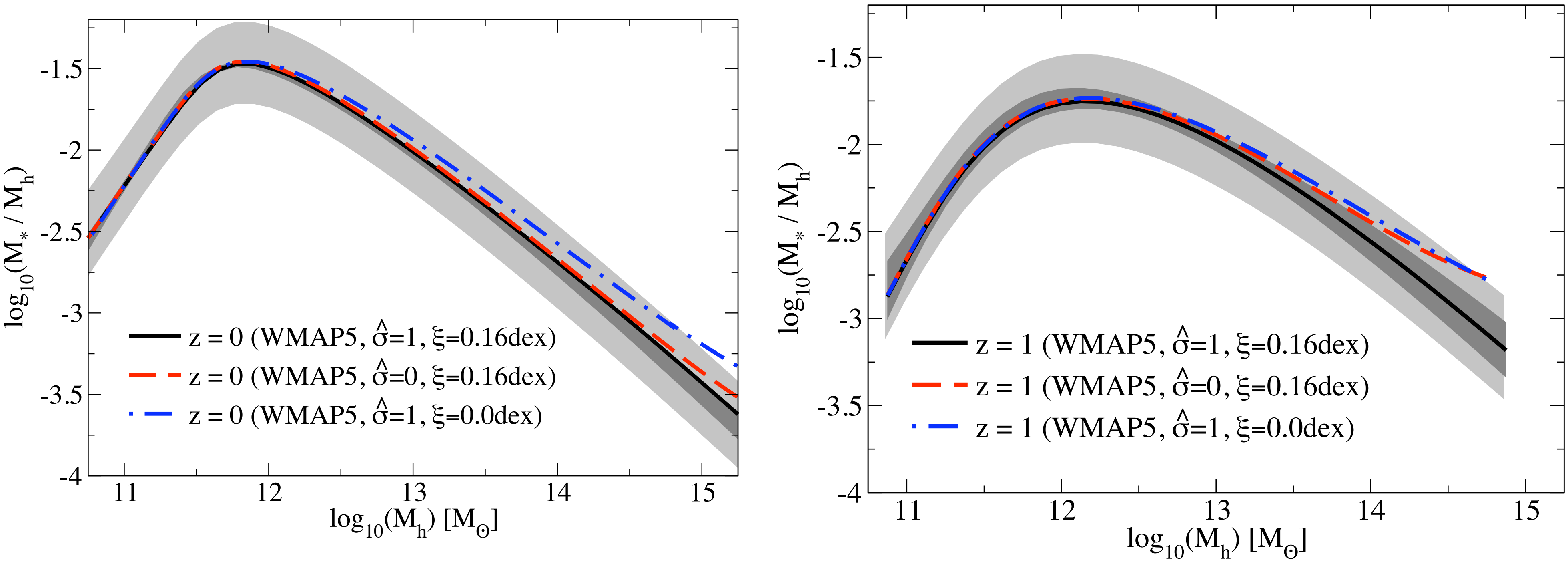
systematic errors



includes random errors in stellar masses, possible systematic errors in the stellar mass function

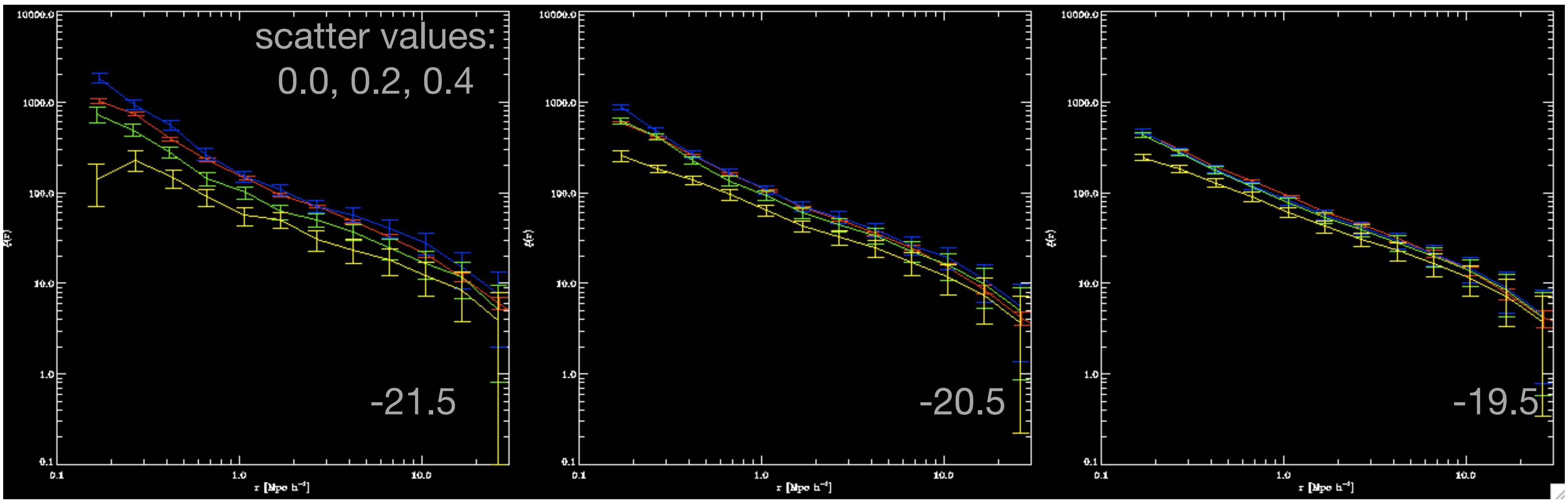
current uncertainty due to cosmological model is smaller than systematic errors in stellar mass function

Uncertainty due to scatter in M*-M



...but this can be constrained by clustering

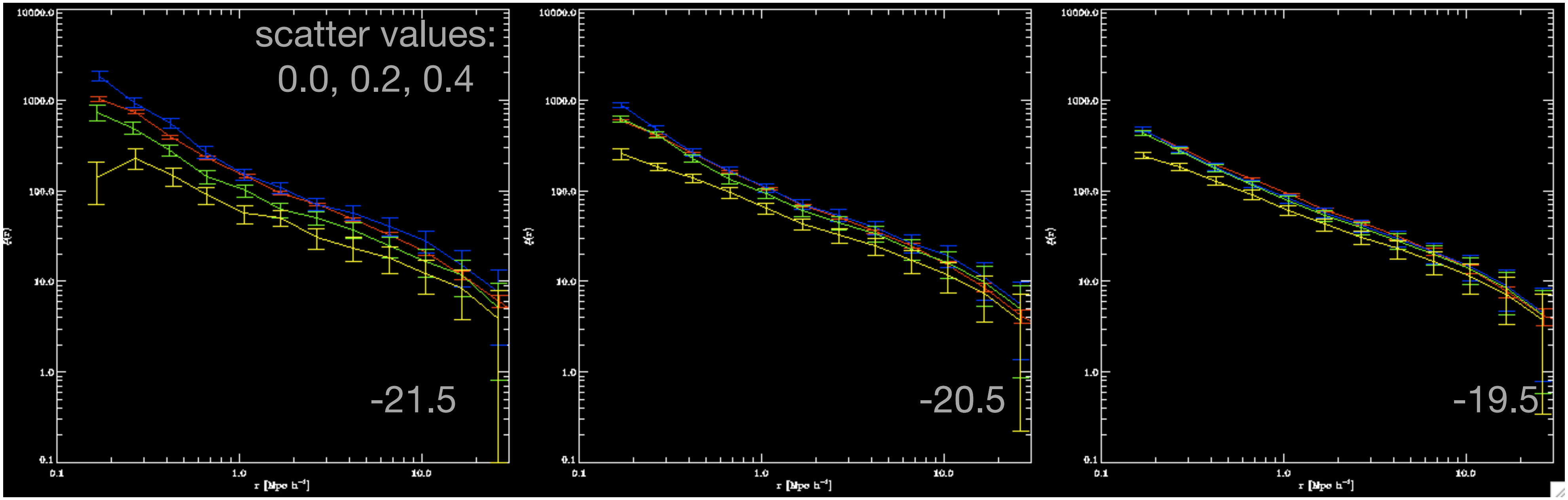
Distinguishing scatter between mass and luminosity with clustering statistics



- data: Zehavi et al 2010 SDSS DR7
- model: Bolshoi simulation, merger trees created by Peter Behroozi
  - assign L-v_{max} for centrals; L-v_{acc} for satellites

Distinguishing scatter between mass and luminosity with clustering statistics

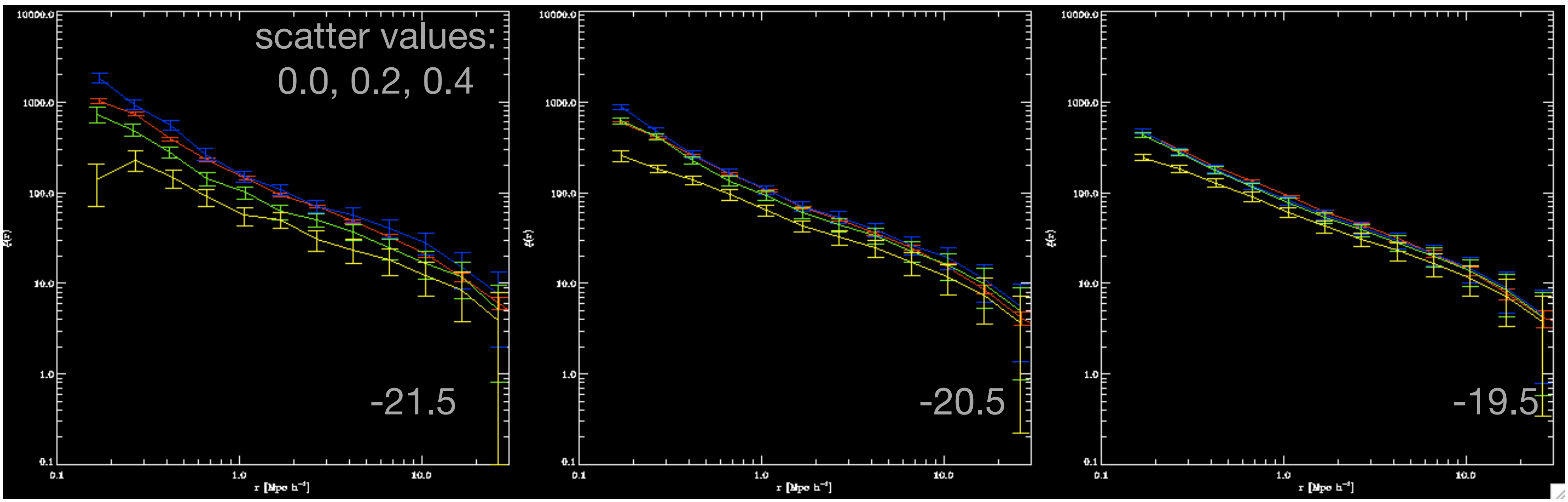
L-v_{max} for centrals; L-v_{acc} for satellites



- for a one parameter (scatter) model, already very strong constraints, even for one magnitude below L*
- scatter is small: ~0.15-0.2 dex in L at a given M

Distinguishing scatter between mass and luminosity with clustering statistics

L-v_{max} for centrals; L-v_{acc} for satellites



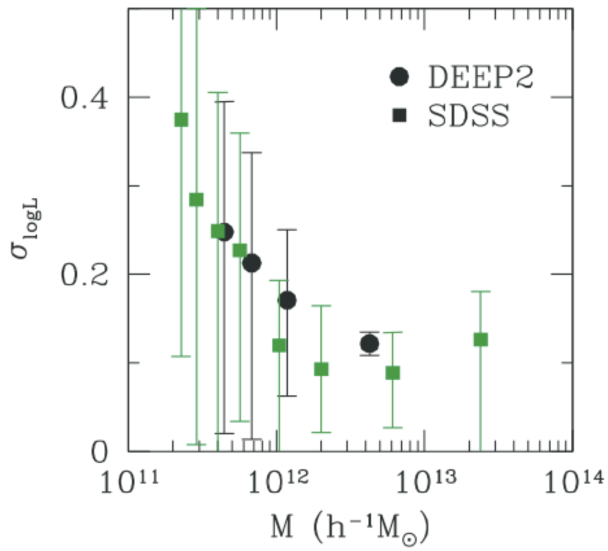
what controls the clustering:

data is so good that conclusions are sensitive to simulation details inc halo finding and merger trees

- scatter in the mass-luminosity relation
- satellite fraction (what does the sat luminosity do after accretion?)
- cosmological model

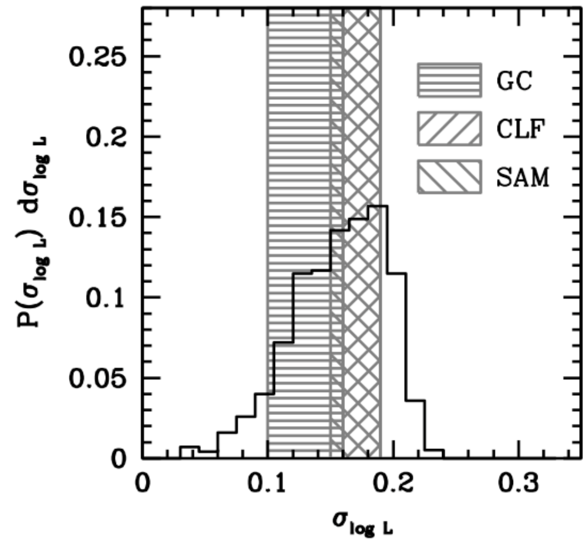
Consistent picture with other measurements

HOD constraints from 2 point clustering



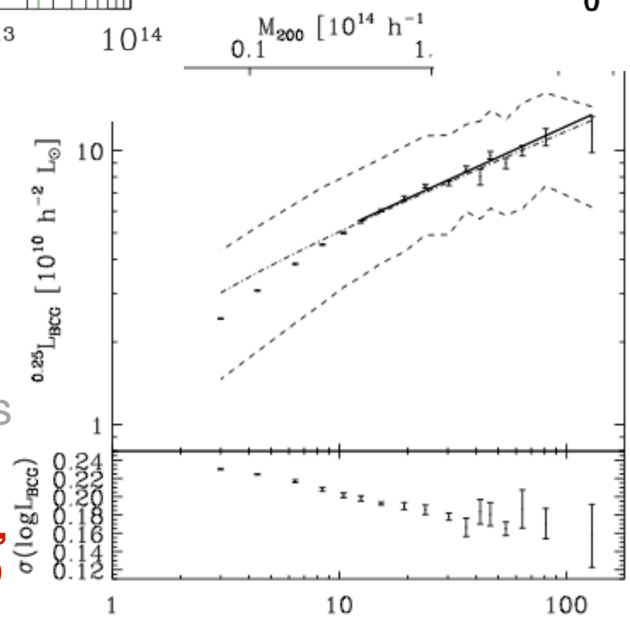
Zheng, Coil & Zehavi 07

constraints from satellite dynamics



More et al 09

constraints from BCGs



Hansen, Sheldon, RW & Koester 09

+ T-F relation
(Trujillo-Gomez talk)

0.15-0.2 dex scatter

How much scatter just from accretion histories?

- a simple model: assume SFR(M,z) with no scatter. (Conroy & Wechsler 09)
- follow star formation history along merger trees in a cosmological box.
- what is the resulting scatter in stellar mass at a given halo mass?

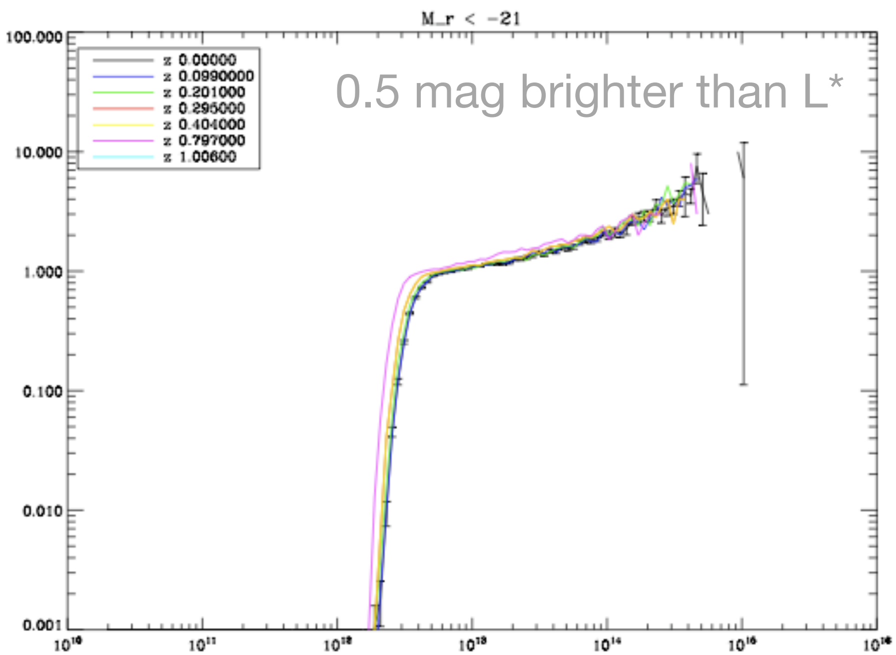
result: ~ 0.1 dex scatter

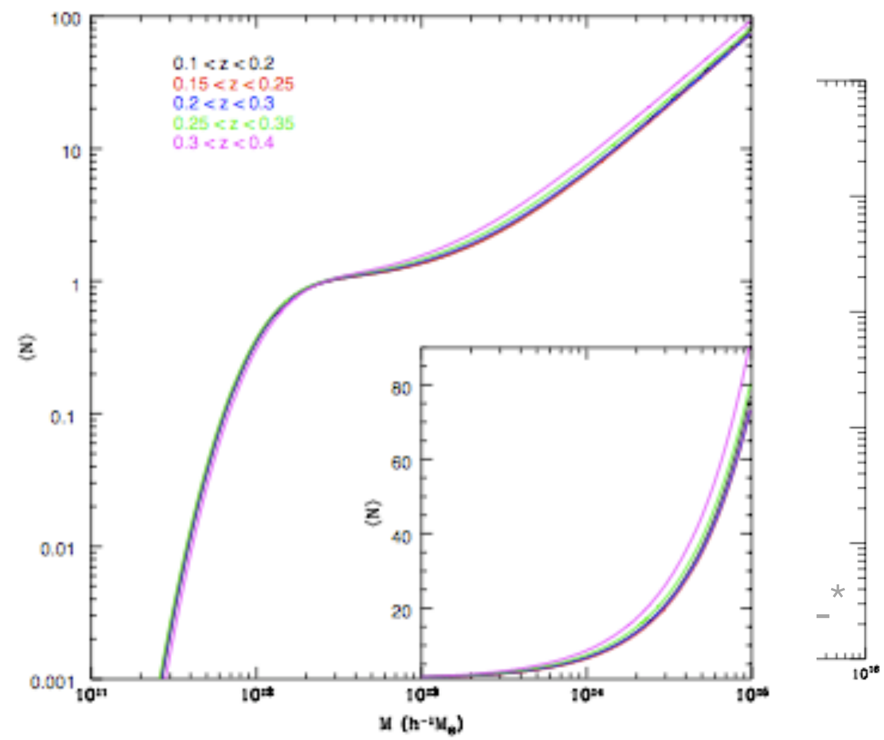
- given measurement errors in SM and HM, this is consistent with 50-100% of scatter in M*-M due to differences in mass accretion histories

evolution of halo occupation

Reddick et al in prep
based on Bolshoi sim + Behroozi merger trees

halo occupation for galaxies (subhalos) with a fixed number density:
nearly constant from z ~ 1 to z ~ 0





in very good agreement with recent observational estimates
(e.g. Ross et al 2010), but conclusions are sensitive to photo-z errors

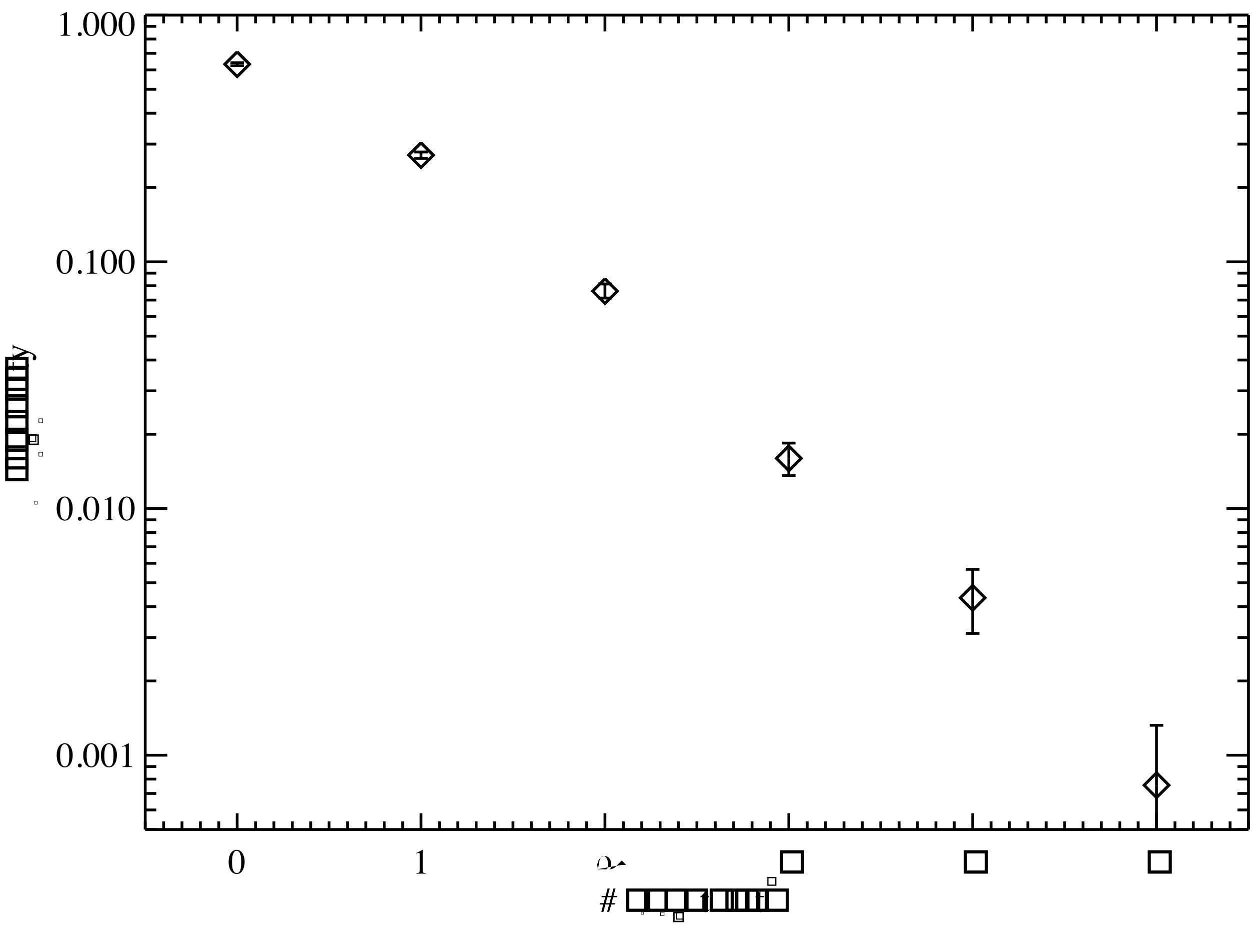
under the assumption of LCDM, all galaxies should live in halos and subhalos.

this means that fitting to a standard HOD model does not use all of the available information

Can we extend this to lower masses?

How many Magellanic Cloud like galaxies do we expect around MW like halos in LCDM?

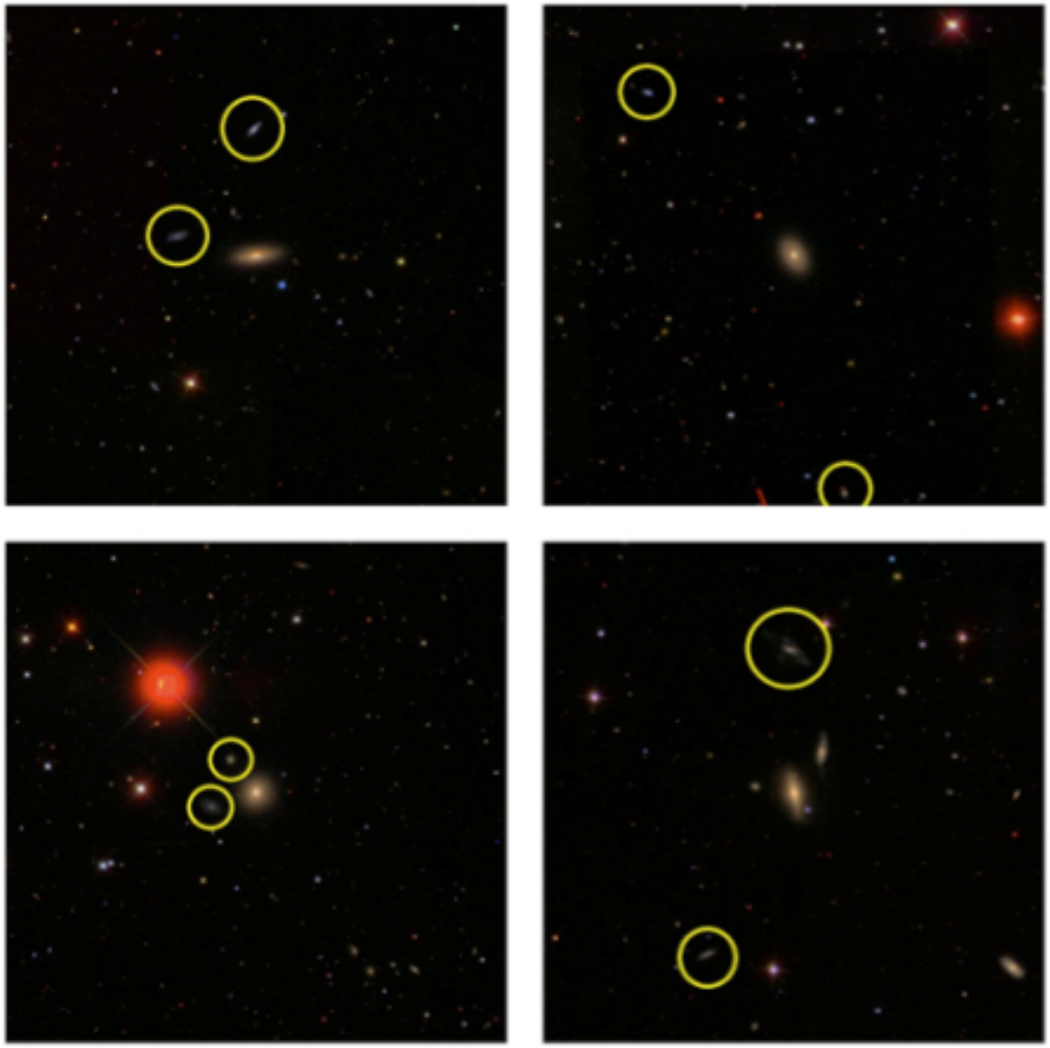
Busha et al in prep
based on Bolshoi simulation



statistics of satellites 2-4 mags dimmer than hosts

only ~10% of halos have 2 or more satellites!

How many Magellanic Cloud like galaxies do we observe around MW like halos?



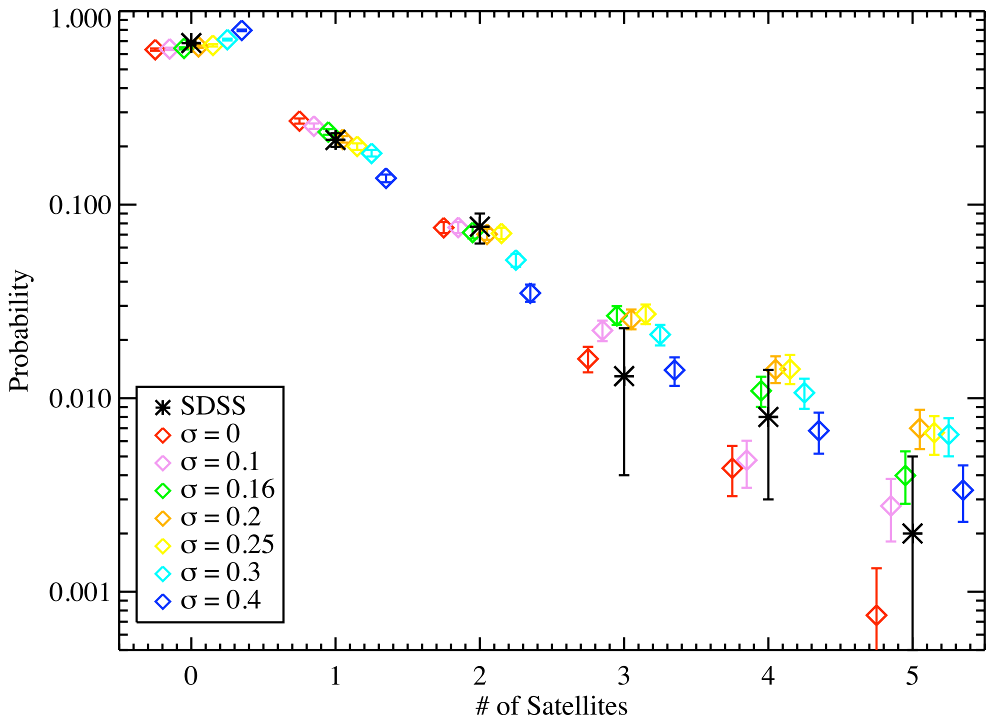
Liu, Gerke, RW et al in prep

four example MW-like halos with exactly two satellites

investigate the statistics of photometrically selected satellite galaxies around spectroscopically selected host galaxies using SDSS data

How many Magellanic Cloud like galaxies do we observe around MW like halos?

Busha et al in prep
halos from Bolshoi simulation



Liu et al in prep
(see Gerke talk for details)
observational results based on SDSS: spectroscopically selected host galaxies, photometrically selected satellite galaxies 2-4 mags fainter

- most MW like halos have no satellites; the MW has more MC-like satellites than ~90% of galaxies of its luminosity.
- the *statistics* of the distribution of satellite number match almost perfectly between LCDM prediction & SDSS, as long as the scatter in L-v is relatively small (<0.3 dex)

Highlights

- scatter between galaxy luminosity & halo mass is small: ~0.15-0.2dex
- good agreement between several approaches: 2-point clustering, Tully-Fisher relation, measuring luminosities for central galaxies, satellite dynamics
- ~ 50-100% of the scatter comes from halo mass accretion histories

- HOD of galaxies of a given number density is predicted to be roughly constant from z=0-1. Good agreement with observations but more robust tests are necessary.

- simple L-M correspondence with low scatter appears to hold down to ~ SMC masses
  - MW has more MC-like satellites than ~90% of galaxies of its luminosity.
  - P(Nsat) predicted from LCDM agrees with new measurements from SDSS

simple model works very well.
but data & sims are now good enough to test the details.