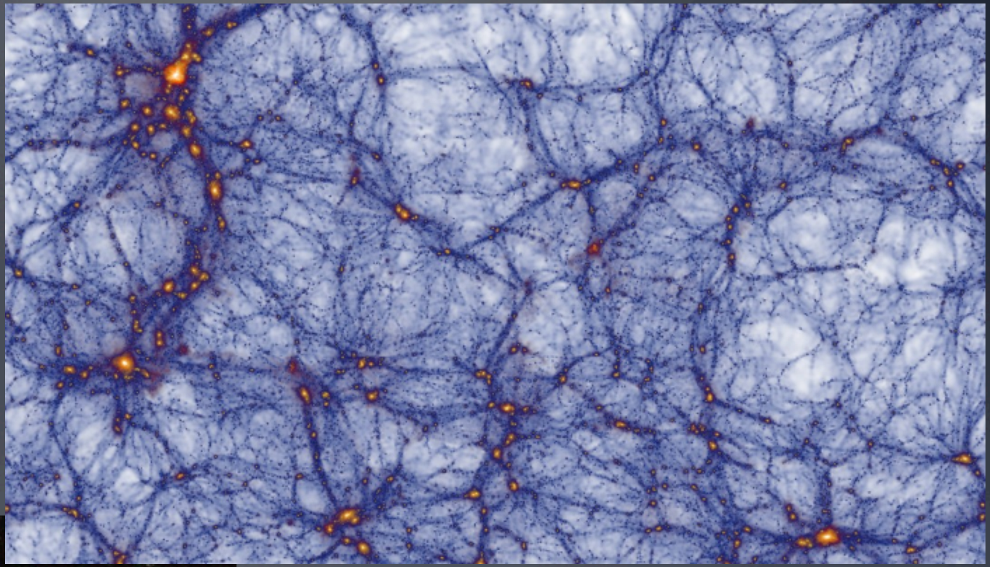
Observational review:
The galaxy-halo connection

Rachel Mandelbaum
Carnegie Mellon University
May 15, 2017



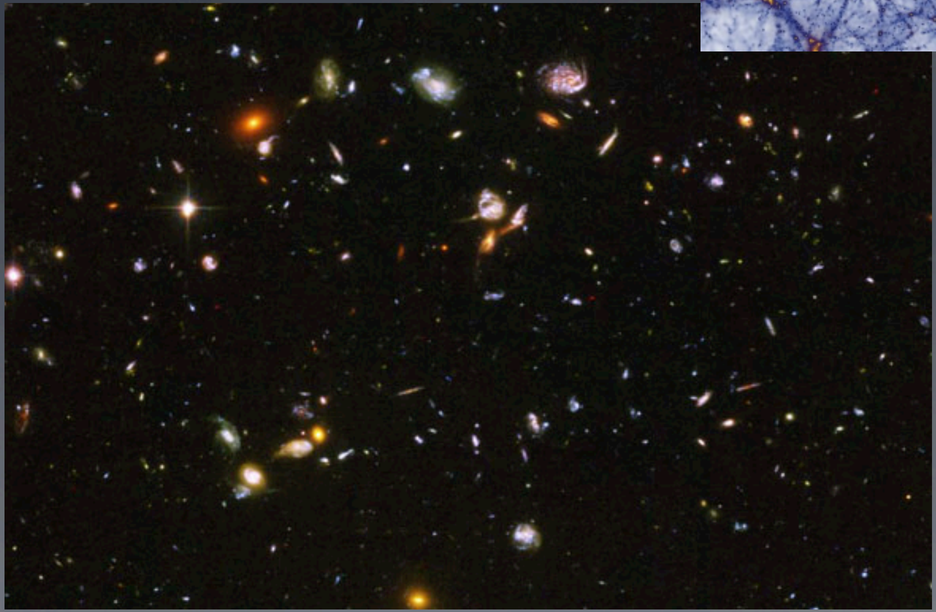


Image credits: NASA, ESA, S. Beckwith (STScI), the HUDF Team

What kinds of observational results could I talk about?

Galaxies and their halos to lowest order: Halo ma luminosity/st

1^{st} order: type dependence and/or color dependence

Estimated talk length: 3 hours

Galaxy clusters: mass-observable relation

halo mass

Galaxy bias beyond halo mass: assembly bias

Other cool stuff about clusters: splashback radius of halos, ...

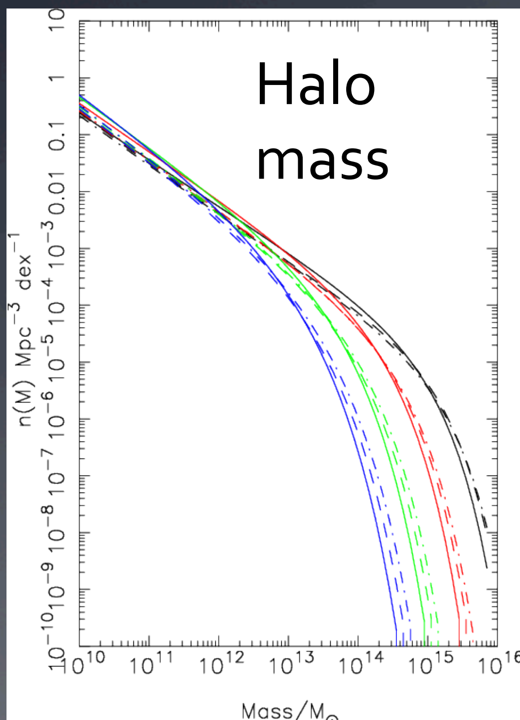
What I will actually talk about

Galaxies and their halos to lowest order: Halo mass vs. luminosity/stellar mass

→ 1st order: ~~type dependence and/or~~ color dependence

Galaxy bias beyond halo mass: assembly bias

Baseline mass-observable relation



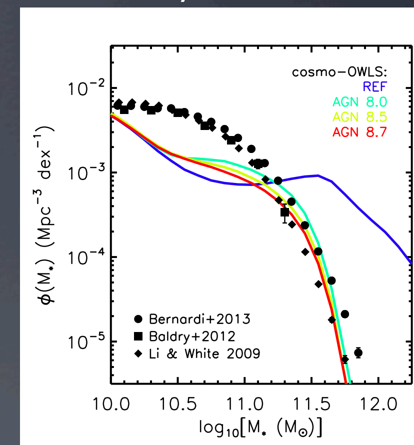
Eales (2015)

Mean relationship

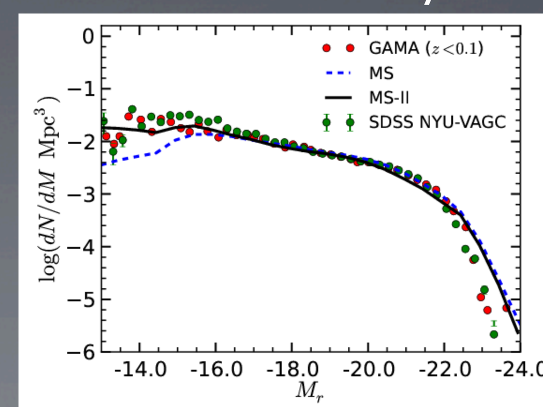
Scatter

McCarthy et al (2016)

Stellar mass



Luminosity



Guo et al (2013)

Color-dependent mass-observable relation

Halo mass

Mean relationship

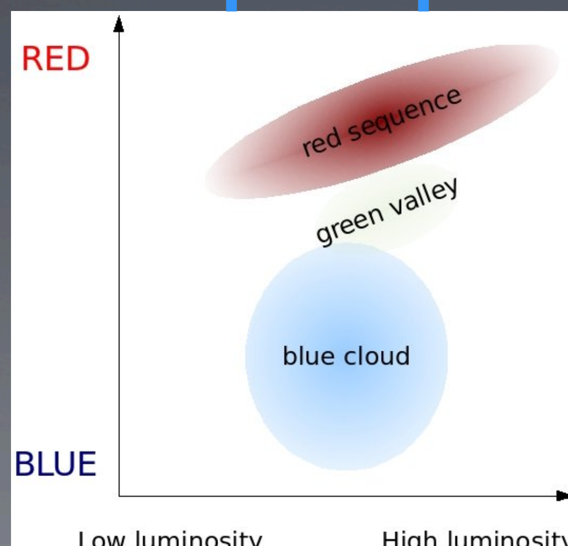
Scatter

Stellar mass

Luminosity

??

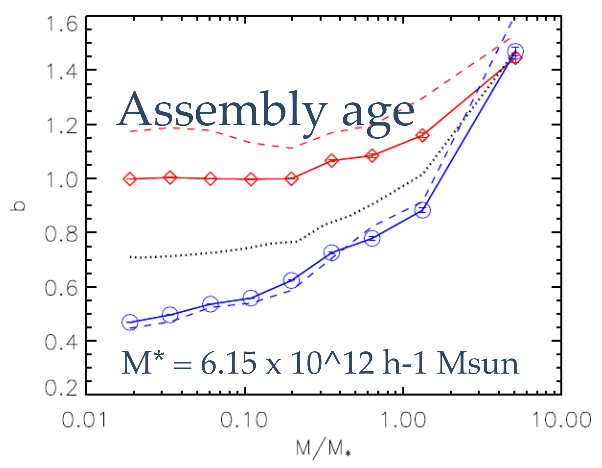
??



Beyond halo mass

- Do observable galaxy properties depend on some halo property besides halo mass?
- Assembly bias: does galaxy clustering amplitude depend on some quantity other than halo mass?

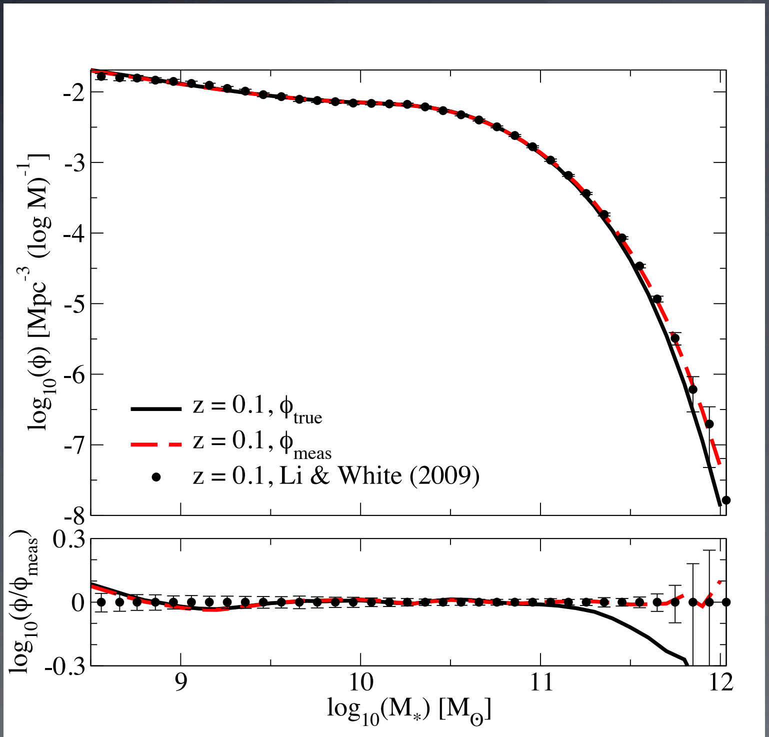
Gao et al. (2005)

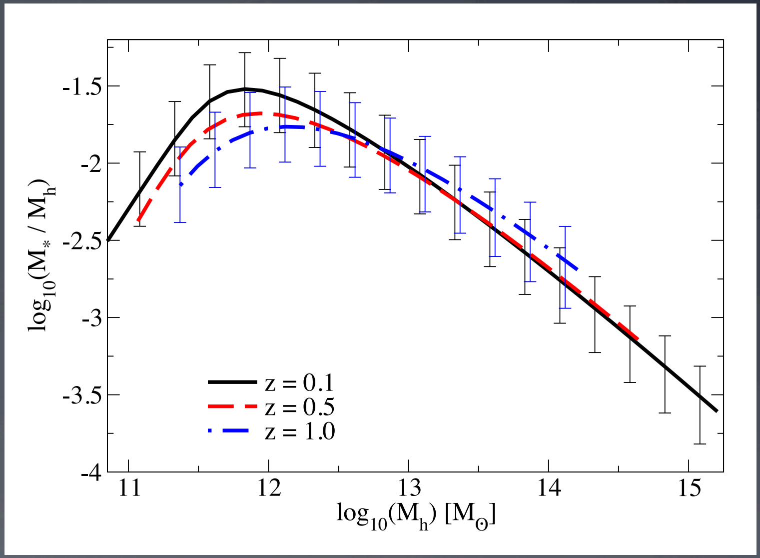


Halo assembly bias is a robust prediction of LCDM (see Mao+17, Villarreal+17). Galaxy assembly bias is not.

Observational methods

Number counts



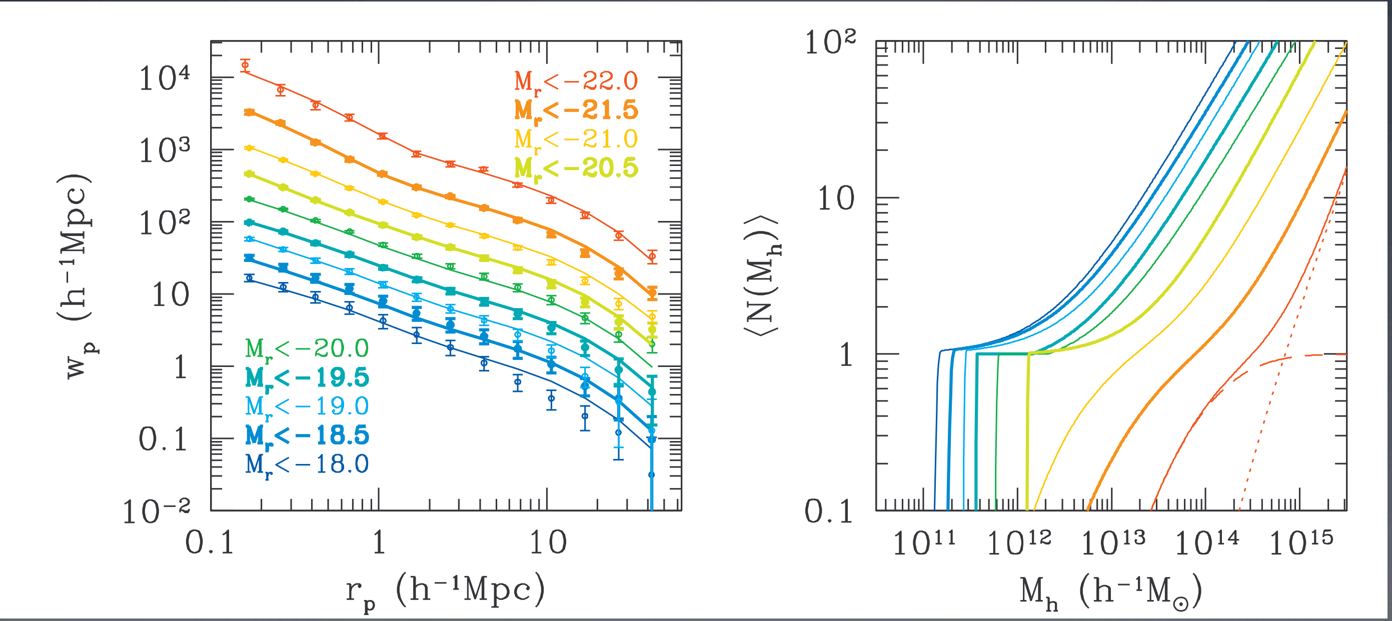


Behroozi et al (2010)

Challenge: no direct access to halo mass, satellites, model degeneracies

Galaxy clustering

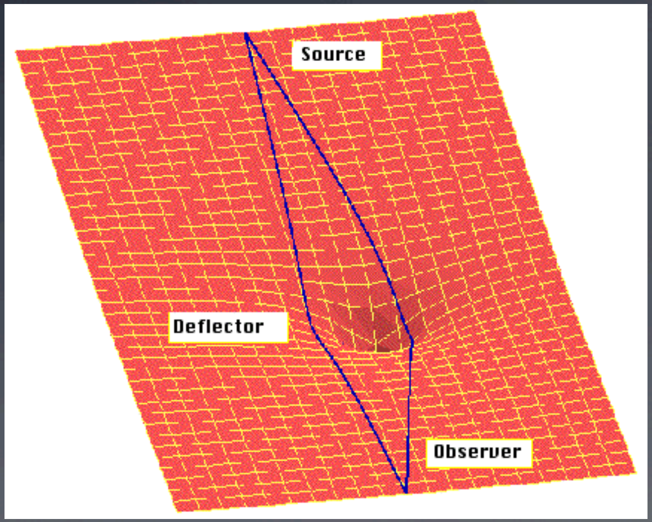
Excess pair counts: $dN = n\,(1+\xi(r))\,dV$



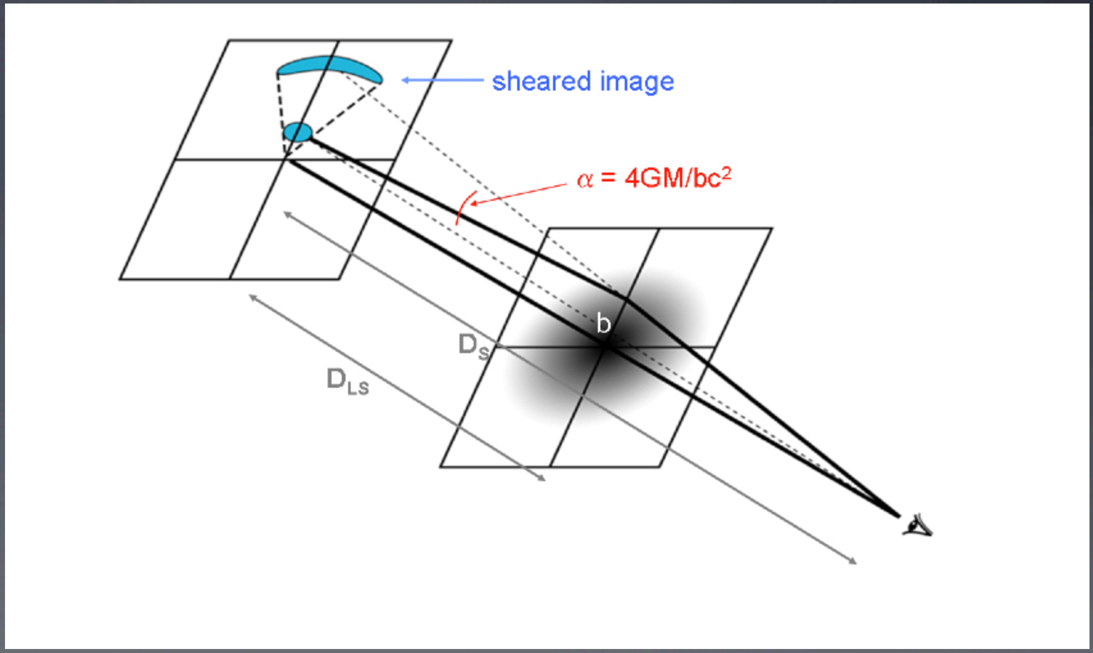
Zehavi et al. (2011)

Challenge: model degeneracies, cosmology-dependence, CV for small volumes

Gravitational lensing



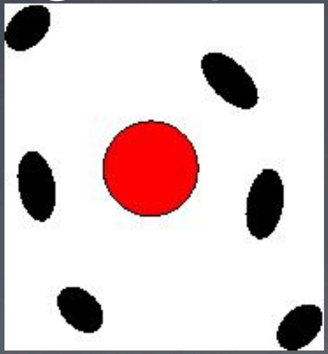
Directly sensitive to **all** projected mass



Picture credit: LSST Science Book

Galaxy-galaxy lensing

Cross-correlation: Lens galaxy positions versus source galaxy shapes

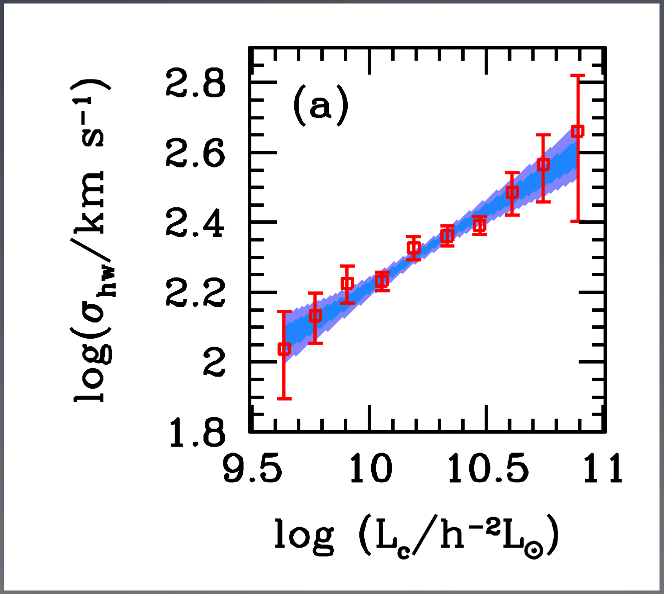


Reveals ***total*** matter distribution around lens galaxies (galaxy-mass correlation)

Challenge: interpreting stacked measurements, central/satellite terms

Stacked kinematics

Satellites orbit in host halo potential well



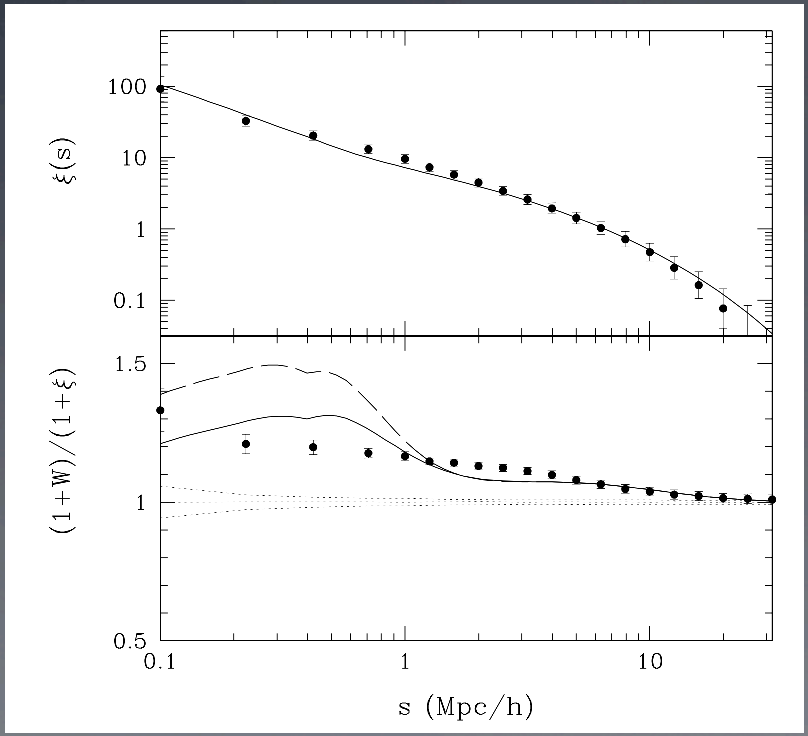
More et al (2011)

Challenges: central/satellite identification, modeling of stacked distributions

Marked correlation functions

Like clustering measurements, but weighted by some "mark" (color, ...)

$$M(s) \equiv \frac{1+W(s)}{1+\xi(s)}$$

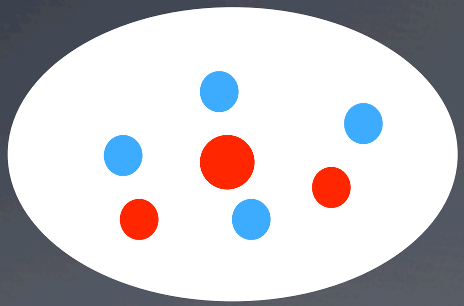


But note M. White (2016): density-marked correlation function as discriminator of gravity?

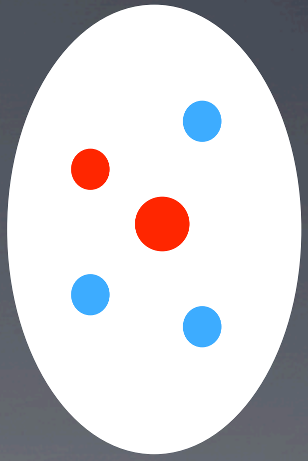
Sheth et al (2005), Skibba et al (2006)

Conformity (special case of marked CF?)

Correlation between star formation rates / colors of nearby galaxies



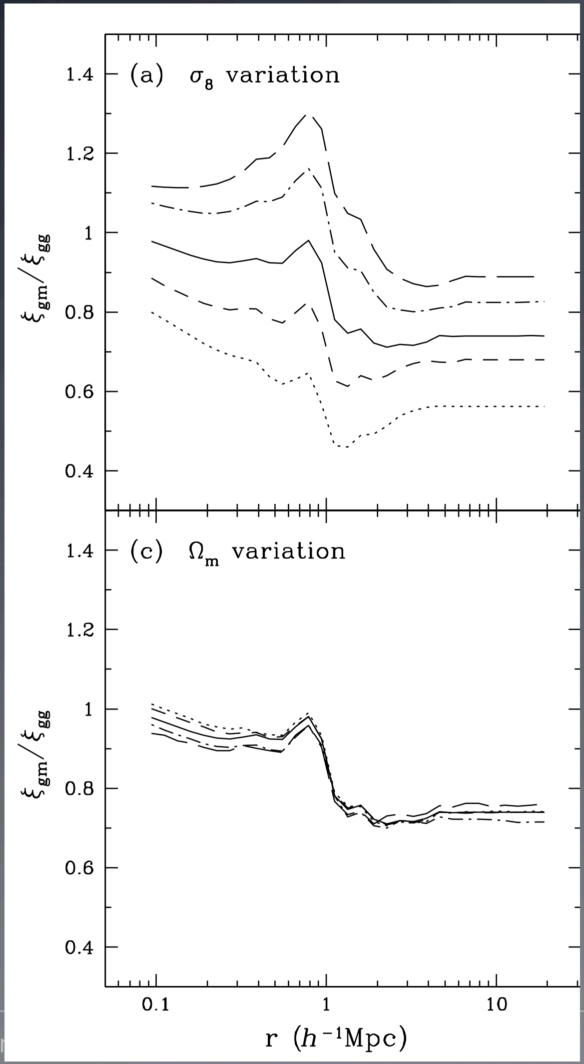
Note, 1-halo and 2-halo conformity, and central-central vs. central-satellite, give different information



Challenge: robustly identifying centrals vs. satellites and/or interpreting results statistically

Joint results

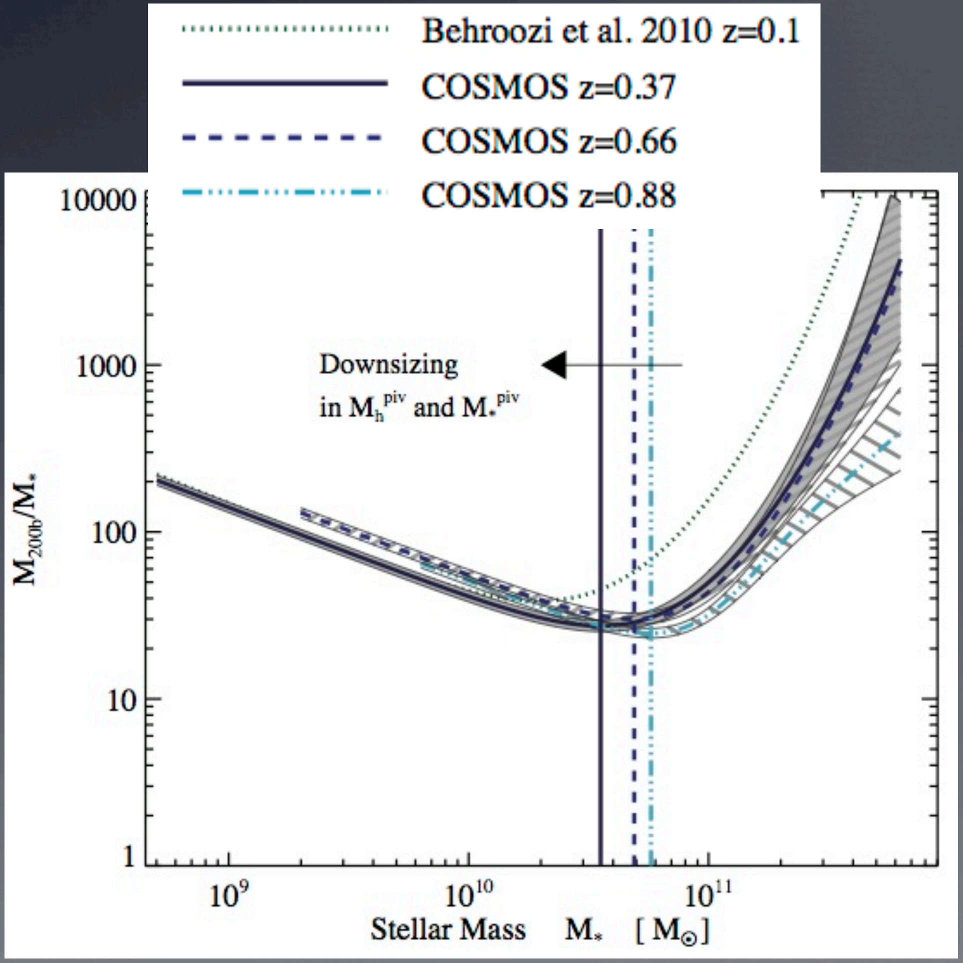
Yoo et al (2006)



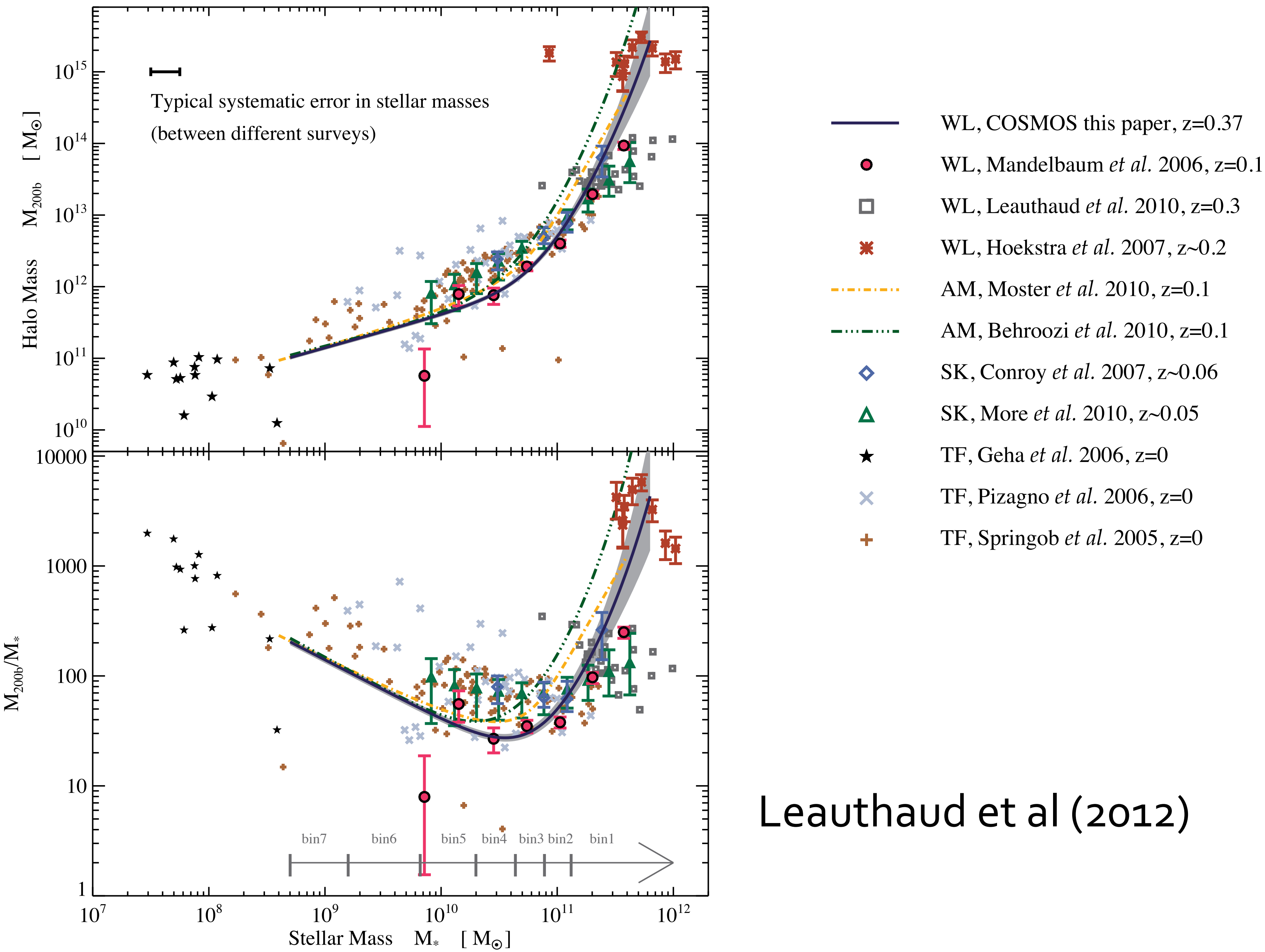
- Combining clustering, lensing, number counts enables better model constraints by reducing degeneracies
- Watch out for cosmology dependence! See e.g. More (2013)
- McEwen & Weinberg (2016) showed lensing+clustering joint constraints can be insensitive to assembly bias if using cross-correlation coefficient

Basic results: average relationships

COSMOS (Leauthaud et al. 2012)

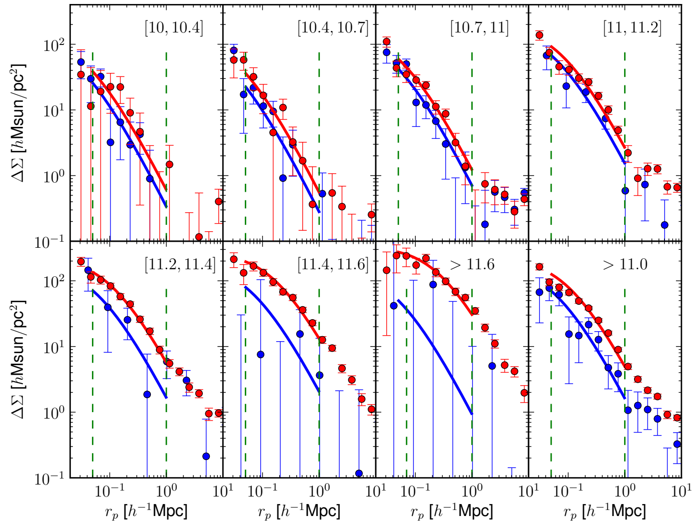


- Self-consistent halo modeling of lensing, galaxy clustering, abundance
- No early vs. late type split
- Evolution with redshift for parameterized $M_{halo}/M*$ relation

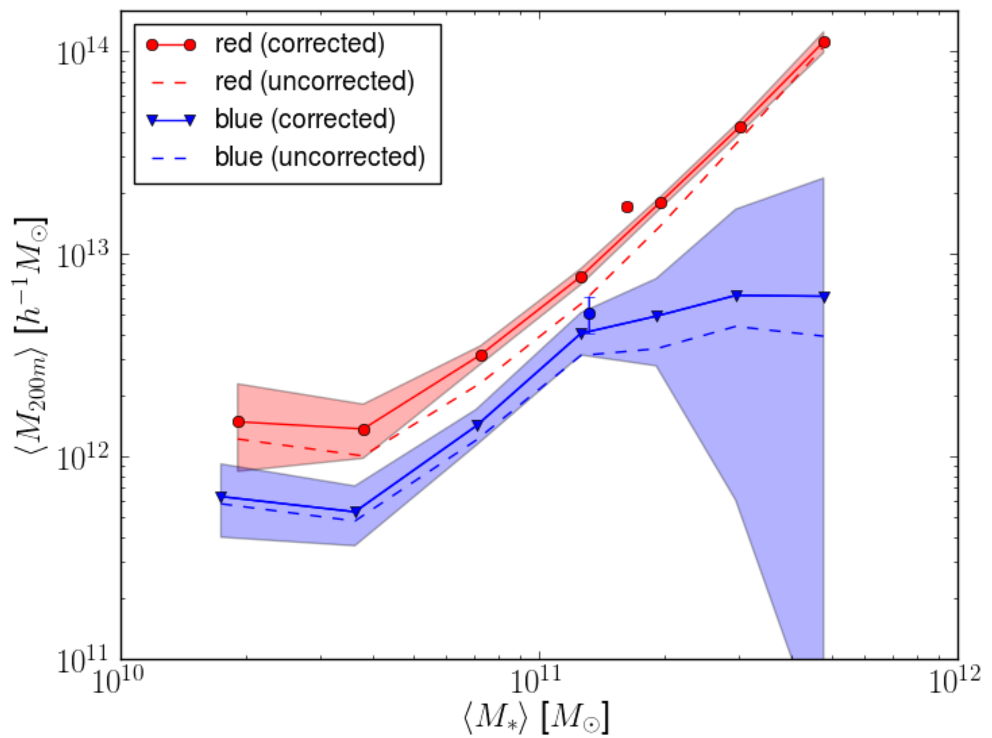


Leauthaud et al (2012)

Type-dependent results

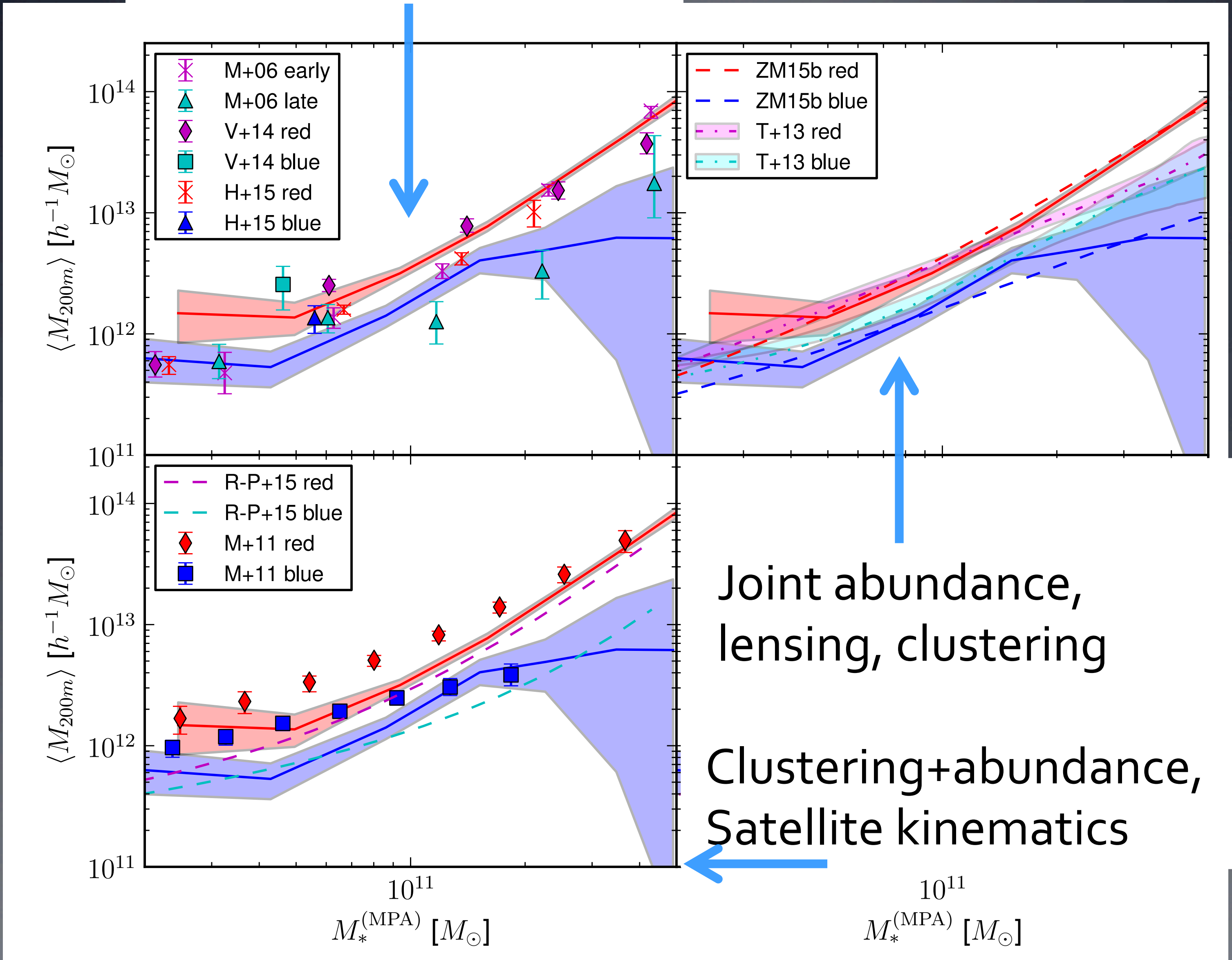


RM+16



These are constraints on the mean relations. Intrinsic scatter is larger.

Previous lensing results



Joint abundance, lensing, clustering

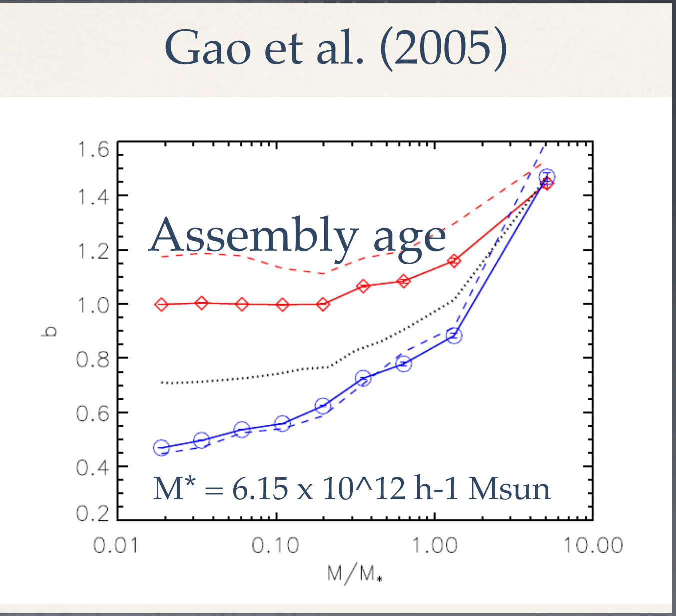
Clustering+abundance, Satellite kinematics

Lessons so far

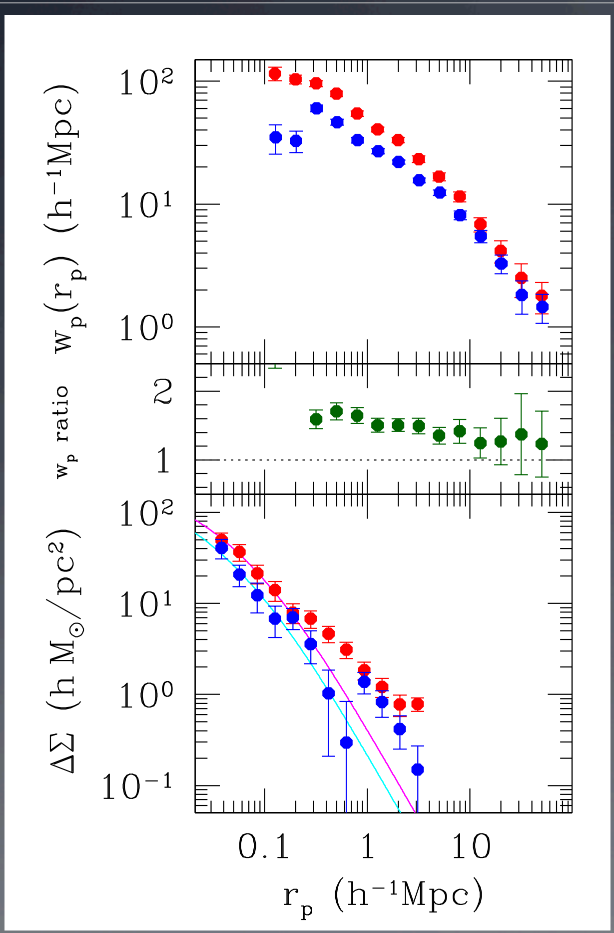
- Lensing tells us that **early-type central galaxies live in halos that are ~2-3x more massive than those hosting late-type central galaxies**
- Kinematics and lensing agree on this point, though with different normalization at low M*
- Clustering+abundance results agree, though high-mass normalization differs (modeling assumptions?)
- Joint lensing+clustering+abundance results agree, though SDSS and COSMOS give different results at high mass (model differences, cosmic variance in COSMOS?)

Galaxy assembly bias

- To detect *directly*, find two samples of galaxies. They must:
  - **Have the same underlying halo mass distribution.**
  - Differ in some observable property that correlates with dark matter halo properties.
- Measure their clustering, and look for differences

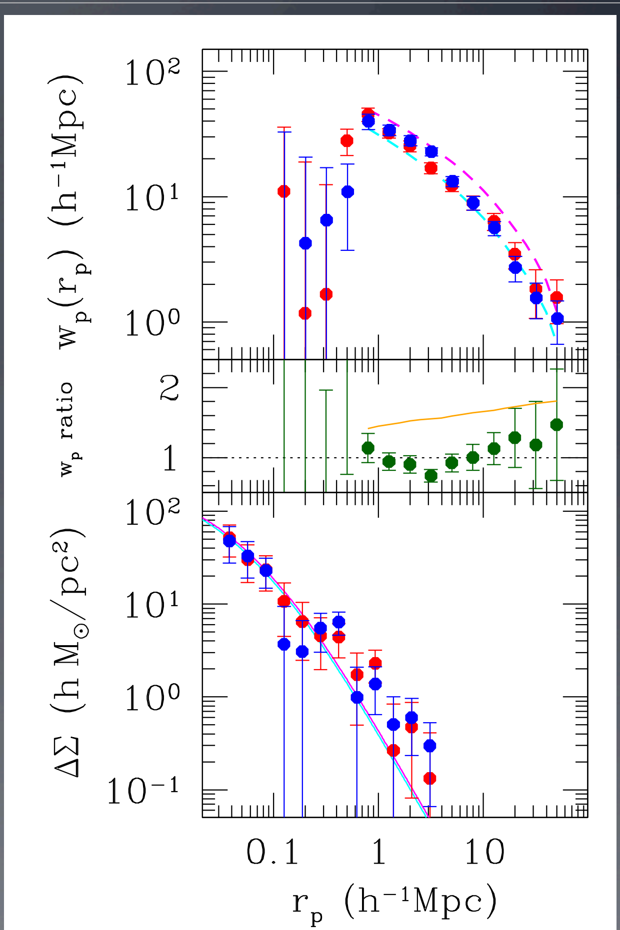


Galaxy assembly bias



Clustering of red, blue centrals from Yang et al group catalog: not assembly bias! (mass, satellites)

Split by star formation rate at fixed halo mass: No clustering difference, upper limit on AB.

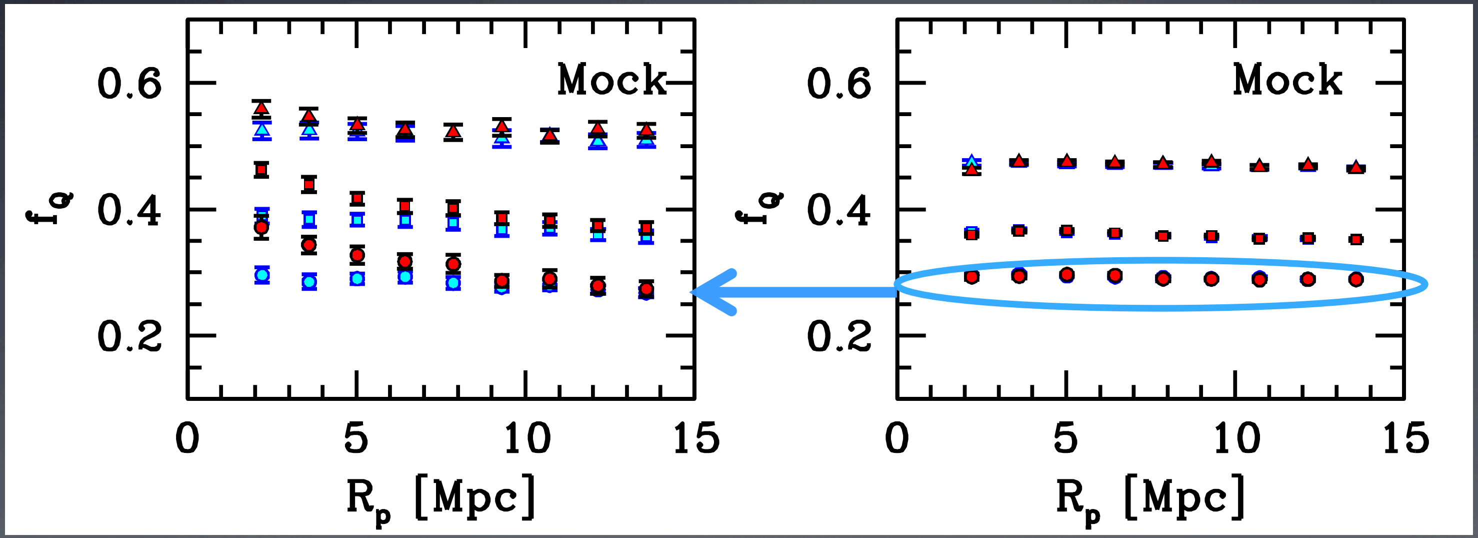


Lin et al (2016)

Galaxy assembly bias

- Conclusions from direct detection attempts
  - Controlling for halo mass distribution and removing satellites from “central” sample are critical, and hard
  - After addressing both issues, we only get upper limits on AB
- Possible causes for these results:
  - There is no galaxy assembly bias, only halo assembly bias
  - We need a better optical tracer of halo formation time to identify the galaxy assembly bias directly
- Could also consider indirect detection

Conformity

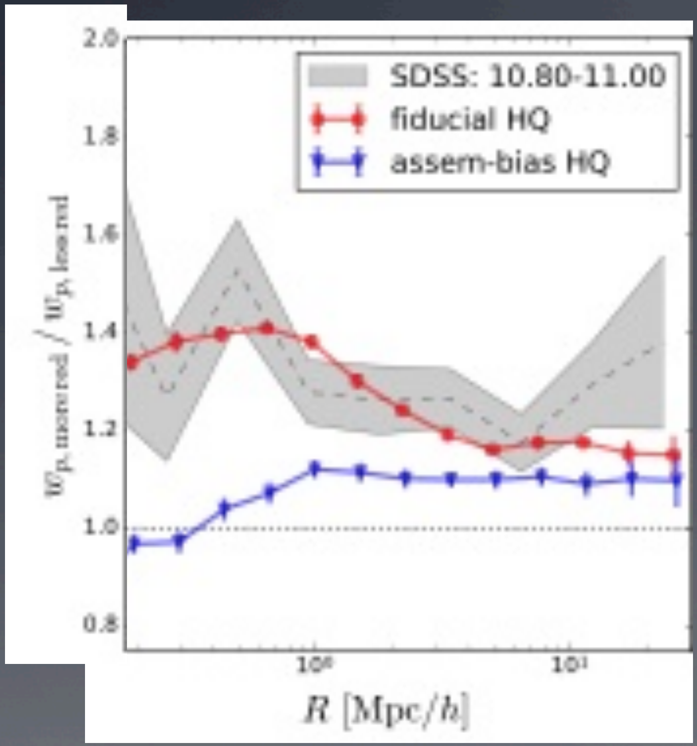


Tinker et al (2017) identified difficulty in 2-halo conformity: quenched fraction of central galaxies around other centrals can acquire a false signal due to central/satellite confusion

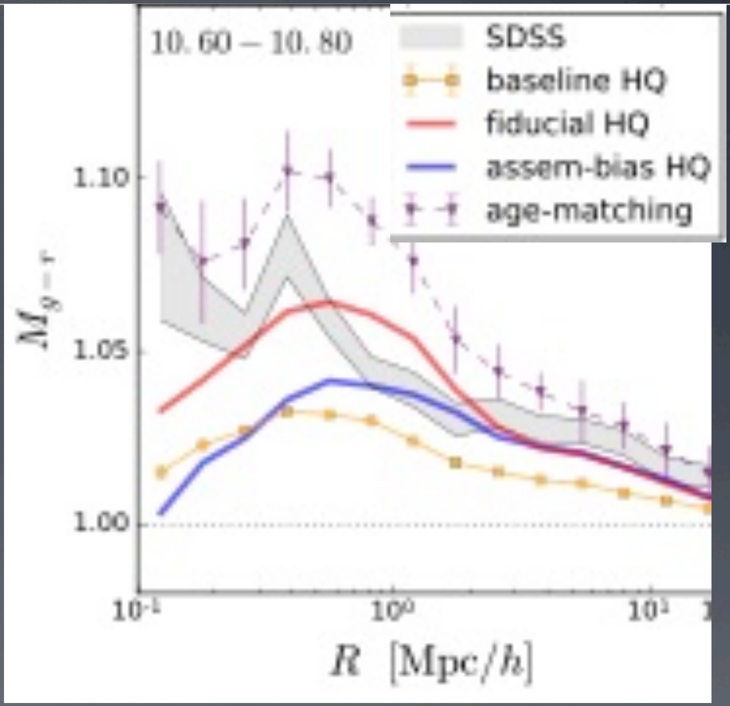
Joint analysis

- Zu & RM (2017) demonstrated self-consistent joint modeling of red+blue+overall galaxy 2-point correlations:
  - Galaxy-galaxy lensing
  - Galaxy clustering
- We make mock catalogs with galaxy colors at fixed stellar mass determined in 3 ways:
  - Randomly within red sequence / blue cloud OR
  - Based on halo mass within red sequence / blue cloud OR
  - Concentration at fixed halo mass (proxy for formation time)
- Compare various measurements in the data vs. mocks

Joint analysis



Halo mass-dependence of colors at fixed stellar mass needed to explain strong clustering ratios for more/less red samples



Without assembly bias, can explain the mark correlation functions: dense environments have more massive halos and hence more red galaxies

Key take-aways

- We can explain the various two-point statistics (lensing, clustering) plus marked correlations, quenching fractions with a model that relates quenching to halo mass… without assembly bias
- This model still exhibits some non-trivially interesting environmental effects in the marked correlations
  - Observed environmental effects do not automatically imply assembly bias!
- But these results do not rule out AB as a *secondary* effect on galaxy colors
  - See also decorated HODs (Hearin+15, Zentner+16)

The future…

HYPER SUPRIME-CAM

LSST
Large Synoptic Survey Telescope

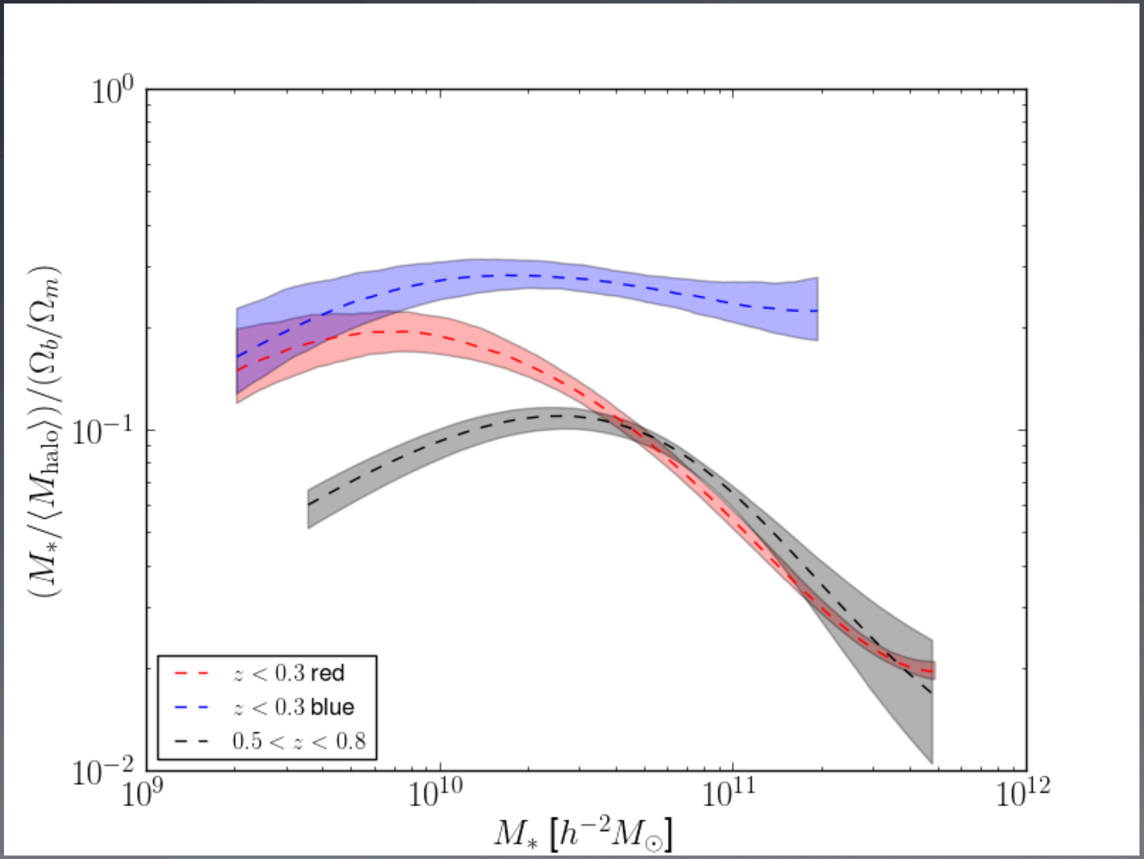
KiDS
The Kilo-Degree Survey

DARK ENERGY SURVEY

euclid

WFIRST
Wide Field Infrared Survey Telescope

Evolution? Lower mass?



0.5<z<0.8 results from Coupon et al (2015)

Conclusions

- A variety of observations have been very informative about the galaxy-halo connection
- Ongoing and future surveys will
  - open up a richer range of questions,
  - enable extension of past results to new regimes,
  - Enable cleaner measures of conformity, assembly bias
- Challenges such as understanding observed quantities, the importance of modeling assumptions, and cosmological parameter-dependence becoming important
- Lots to do – let’s do it!