assembly history of massive galaxies and clusters

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Shogo Masaki, Naoki Yoshida, and the HSC collaboration

outline

- assembly history of massive galaxies: fixed cumulative number density selection
  - stellar mass growth history of brightest cluster galaxies (BCGs)
  - occurrence of active galactic nucleus (AGN) phases throughout the lifetime of massive galaxies
- assembly bias of massive structures
  - non-detection at galaxy scales
  - idea for studying assembly bias at cluster scales?
- useful tool for galaxy-halo connection studies (?)
  - inferring halo mass from counts of neighboring galaxies

assembly history of BCGs

bigger than big

UGC 10214 - "The Tadpole"

Disturbed spiral galaxy with a very long tail
Distance: 420,000,000 LY
Total length: 300,000 LY

NGC 1316 - "Fornax A"

Dusty elliptical galaxy
Distance: 62,000,000 LY
Diameter: 220,000 LY

NGC 908

Starbursting galaxy with
disturbed spiral arms
Distance: 65,000,000 LY
Diameter: 75,000 LY

Hercules A

Giant elliptical galaxy with powerful radio jets
(shown in pink) powered by a supermassive
black hole at the galaxy's center
Distance: 2,100,000,000 LY
Diameter: 1,500,000 LY (jets)

M87

A giant elliptical at the center of the Virgo Cluster.
At its center, material falling onto a supermassive
black hole is emitting powerful jets.
Distance: 53,000,000 LY
Diameter: 980,000 LY

M100

Spiral galaxy in the Virgo Cluster
Distance: 55,000,000 LY
Diameter: 160,000 LY

NGC 4921

A spiral galaxy in the Coma Cluster. It has lost much
of its gas and can no longer form many new, blue stars,
giving it an unusually pale appearance
Distance: 320,000,000 LY
Diameter = 230,000 LY

Arp 87

Two merging galaxies
Distance: 260,000,000 LY
Diameter: 200,000 LY

M31 - "Andromeda"

Nearby spiral in our Local Group
About as massive as the Milky Way
It's headed straight for us ! Collision in about 4 billion years
Distance: 2,500,000 LY
The main stellar disc is about the same size as the Milky Way
but an extended, fainter disc spans about 220,000 LY

NGC 1365

Barred spiral galaxy in the Fornax Cluster
Distance: 61,000,000 LY
Diameter: 200,000 LY

IC 1101

Largest known galaxy. Contains about 100,000,000,000,000 stars.
Lives in the center of the Abell 2029 cluster. Probably became so
monstrously large by eating its neighbours
Ridiculously distant
No suitable images exist due to its great distance. This image is
a modification of M87, a similar (though much smaller) elliptical
galaxy
Distance: 1,000,000,000 LY
Diameter: 6,000,000 LY

NGC 7049

Elliptical galaxy with an unusual dust ring
Distance: 90,000,000 LY
Diameter: 150,000 LY

Malin 1

Arguably the largest spiral
Normal stellar disc embedded in a huge, very faint halo
Distance: 1,400,000,000 LY
Diameter: 303,000 LY (inner disc)
Diameter: 650,000 LY (outer disc)
(Image is an original artist's impression, not a real observation
of Malin 1)

Hoag's Object

Elliptical galaxy surrounded by a ring of blue stars
Distance: 600,000,000 LY
Diameter: 120,000 LY (of outer ring)

NGC 6670

Two interacting galaxies seen edge-on
Distance: 400,000,000 LY
Diameter: 120,000 LY

M33 - "Triangulum"

Smaller spiral in our Local Group
Distance: 2,700,000 LY
Diameter: 50,000 LY

NGC 6872

Claimant for title of largest spiral galaxy
Disturbed by recent interactions with IC 4970
Distance: 220,000,000 LY
Diameter: 520,000 LY

The Milky Way

It's us !
Diameter about 100,000 LY
Artist's impression (Nick Risinger)

ESO 507-070

Merger remnant of two galaxies
Distance: 300,000,000 LY
Diameter: 240,000 LY

Cygnus A

Elliptical galaxy with bright radio jets
(shown in red, image from NRAO)
Distance: 760,000,000 LY
Diameter: 500,000 LY (of jets)

M104 - "Sombrero"

Spiral galaxy with a prominent
bulge and dust ring
Distance: 28,000,000 LY
Diameter: 50,000 LY

ESO 350-40 - "Cartwheel"

Everyone's favourite ring galaxy
(well, probably)
Distance: 500,000,000 LY
Diameter: 150,000 LY

Centaurus A

Elliptical galaxy with a prominent dust lane
It also possesses radio jets (not shown) of a
similar size to those of Hercules A
Distance: 13,000,000 LY
Diameter: 97,000 LY

100,000 LY

One light year is the distance light travels in a year.
1 light year = 9,426,000,000,000 km or 5,879,000,000,000 miles

30,000 pc

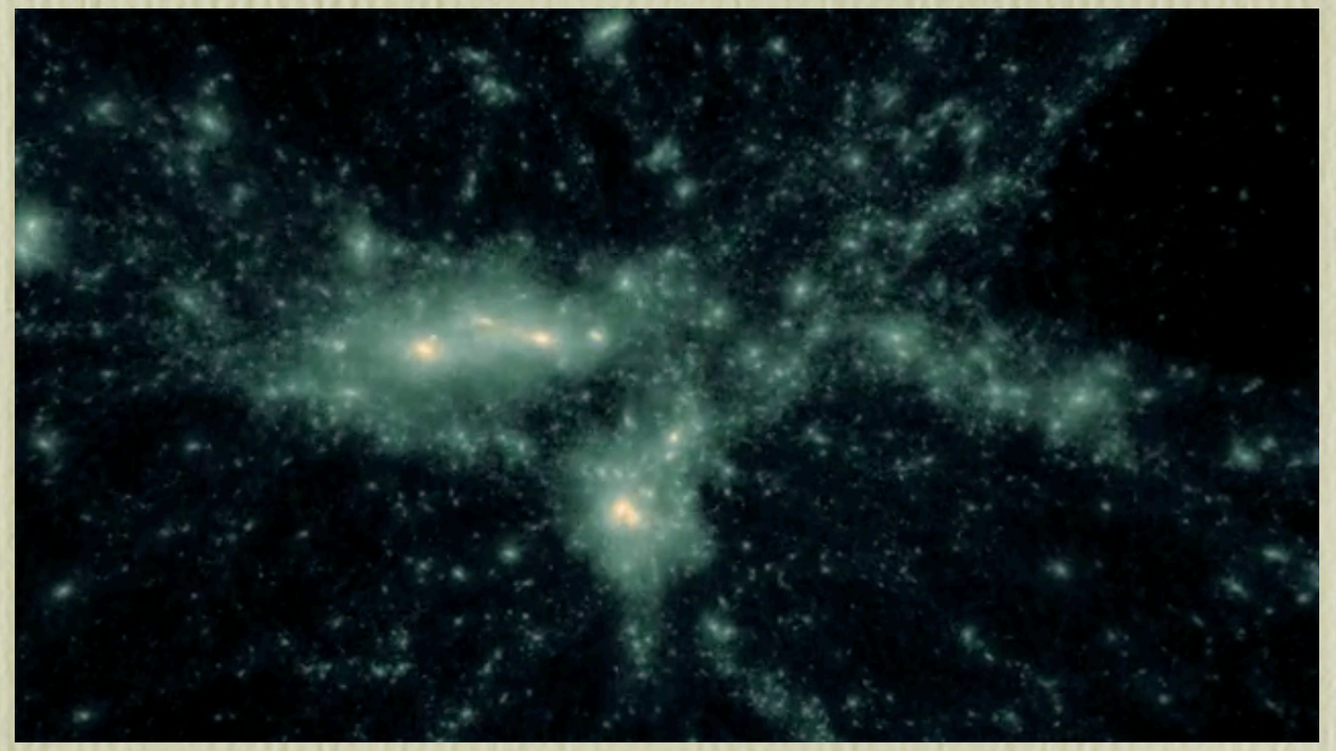
One parsec is the distance at the Sun that spans one
second of arc (1/3600th of a degree)
1 pc = 3.26 LY

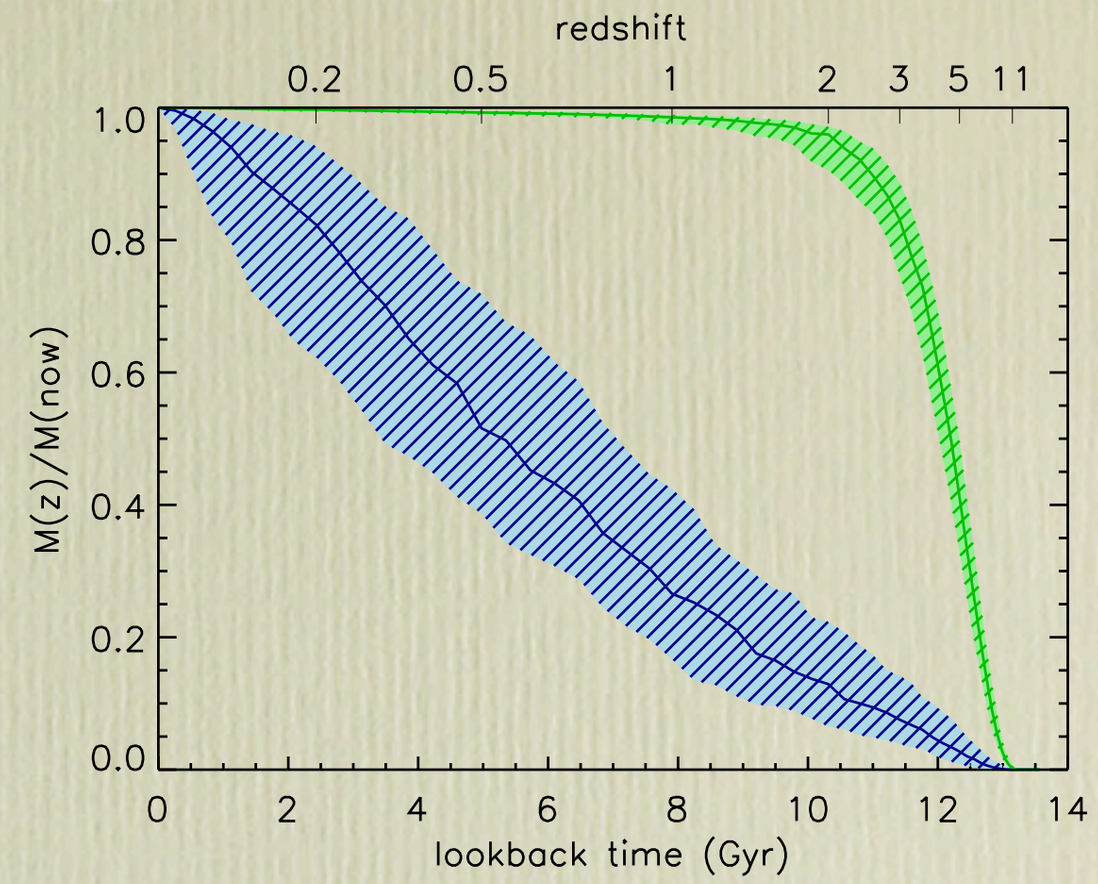
ABOUT THE IMAGE

The image was assembled by Rhys Taylor using public domain images from NASA and ESA.
The images have in many cases been processed to remove annoying foreground stars, so may
contain artifacts. Measurements of size and distance are subject to considerable uncertainty.
www.rhysty.net

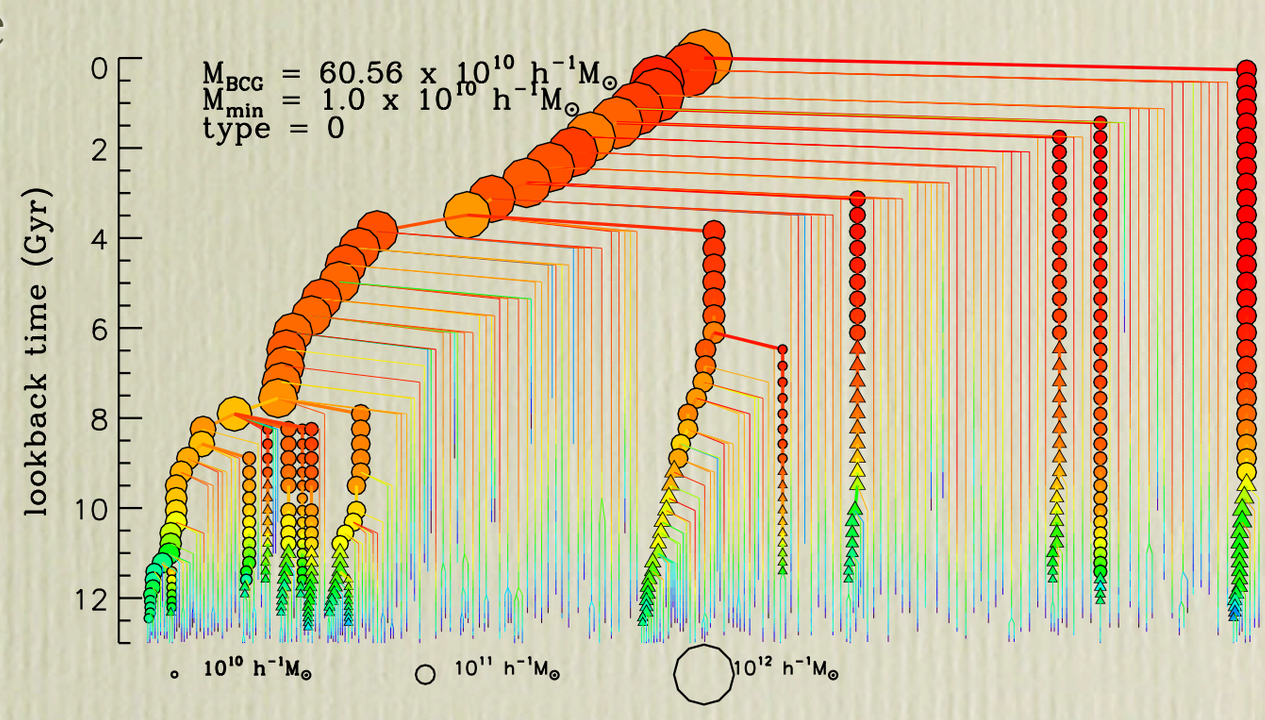
R. Taylor

the challenge



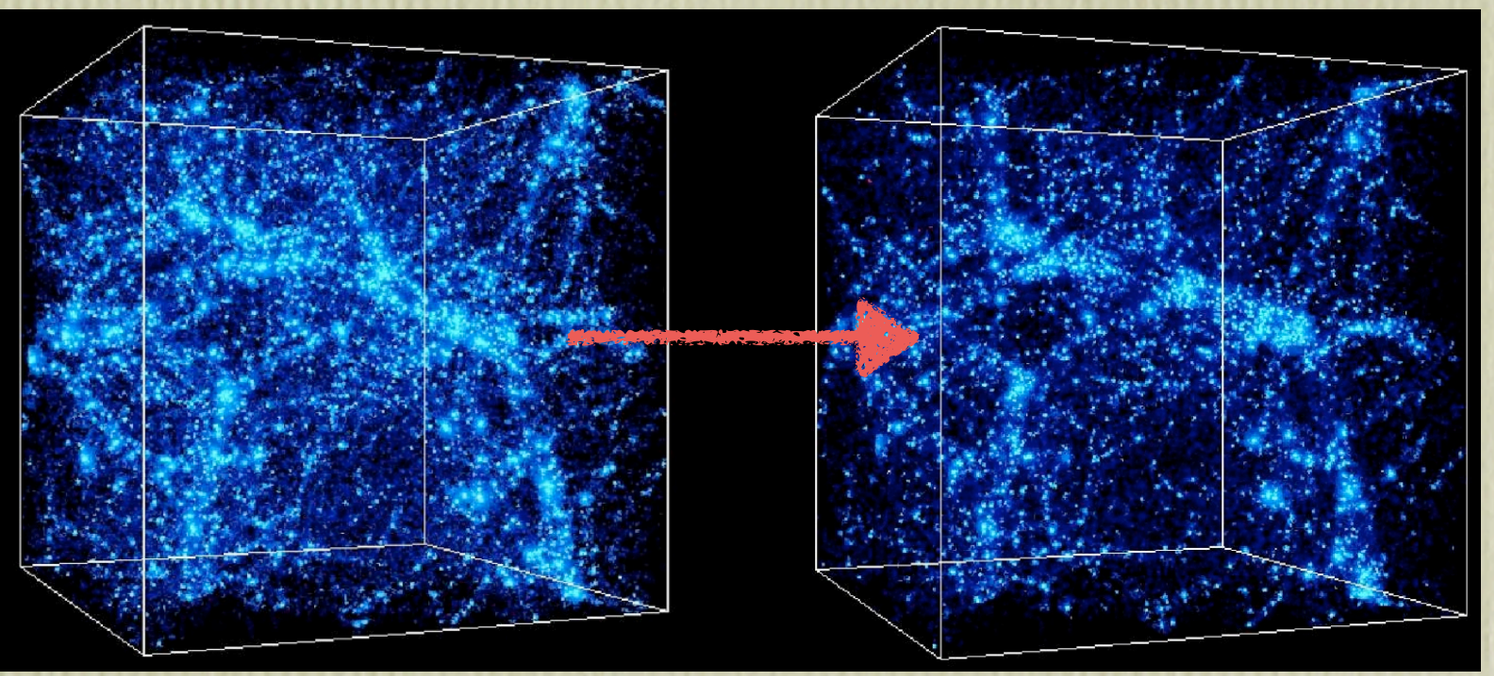


- the many mergers occurring in the centers of massive halos make the central regions continue to grow
- need to built merger trees for observed BCGs for fair comparison with theoretical predictions



R. Wechsler; De Lucia & Blaizot 07

top N selection of halos



Remaining Fraction (%)

initial z	final z (no scatter)			final z (25% scatter)		
	0.83	0.68	0.45	0.83	0.68	0.45
0.98	86	76	66	62	67	58
0.83	–	86	–	–	64	–
0.68	–	–	79	–	–	58

A. Kravtsov

- Ansatz: given comoving volume, the most massive N halos will remain among the most massive N at a later time
- tests with large N-body simulations suggest above holds to ~60-70% (including scatter in mass-observable relation), even with $\Delta z \sim 0.6$
- tests with semi-analytic models show good recovery of galaxy population
- similar in spirit to the fixed cumulative number density selection for field galaxies

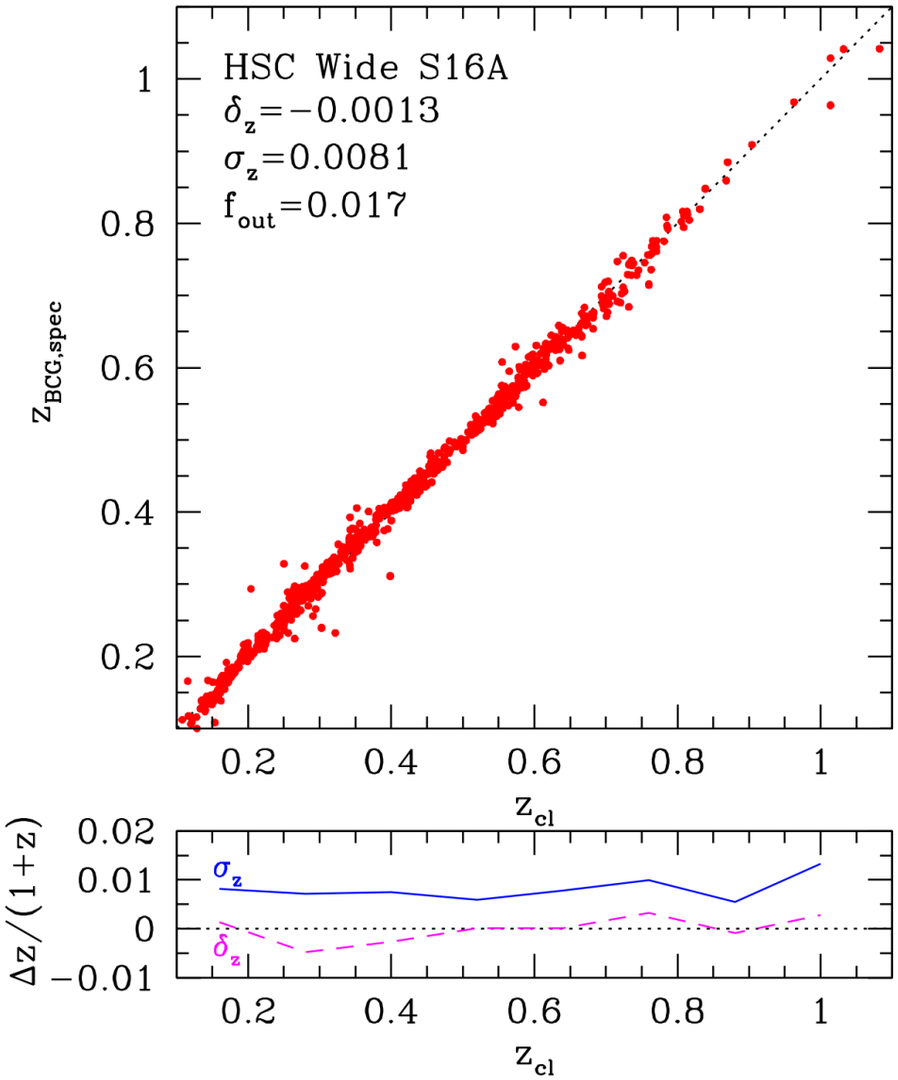
Inagaki, Lin et al. (2015)

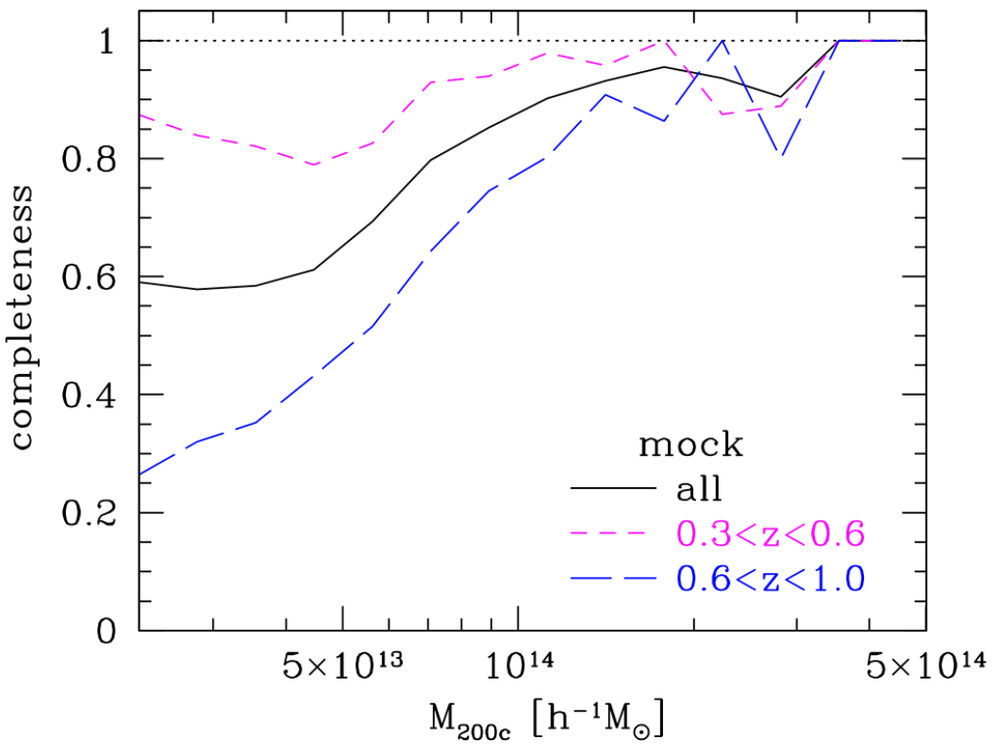
the HSC cluster survey

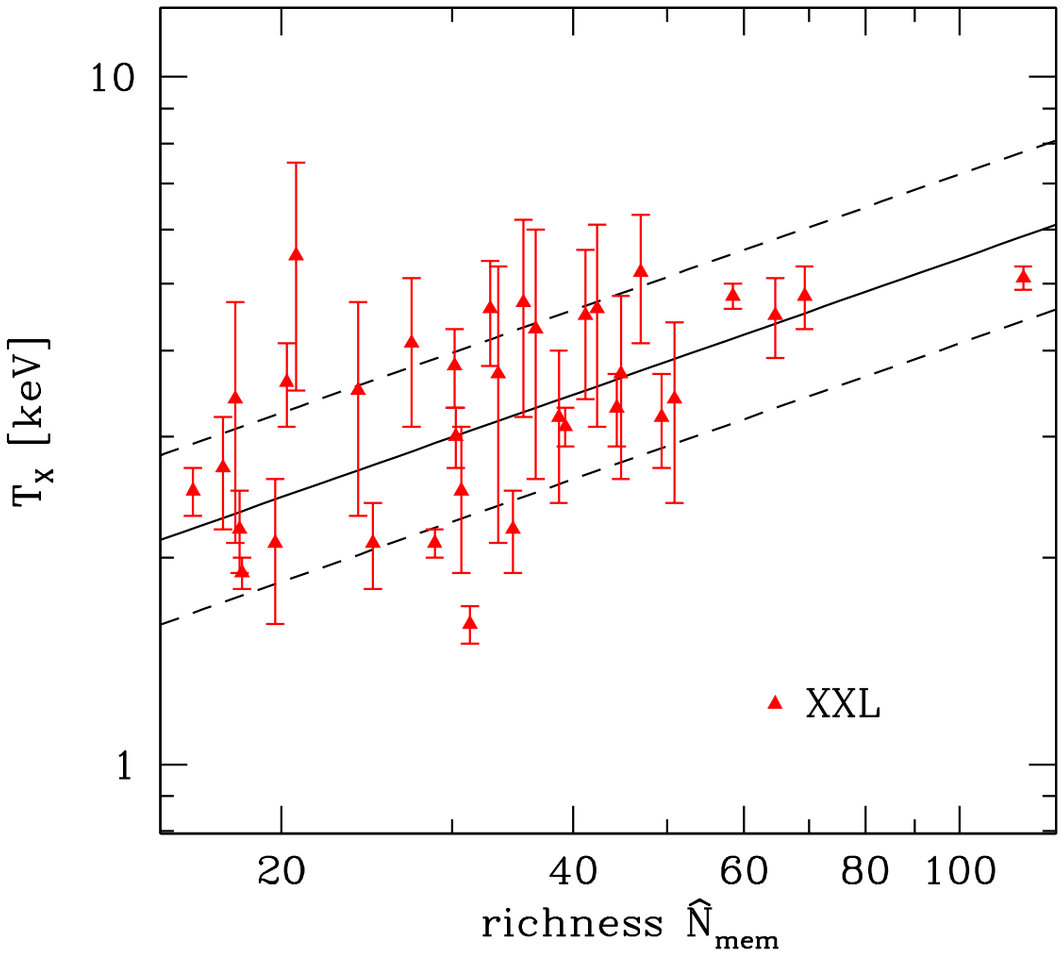
targeting clusters with prominent red sequence, *camira* (**c**luster finding **a**lgorithm based on **m**ulti-band **i**dentification of **r**ed sequence g**a**laxies) has found ~1900 clusters at z=0.1-1.1 over 230 deg² with richness N≥15 in the HSC survey

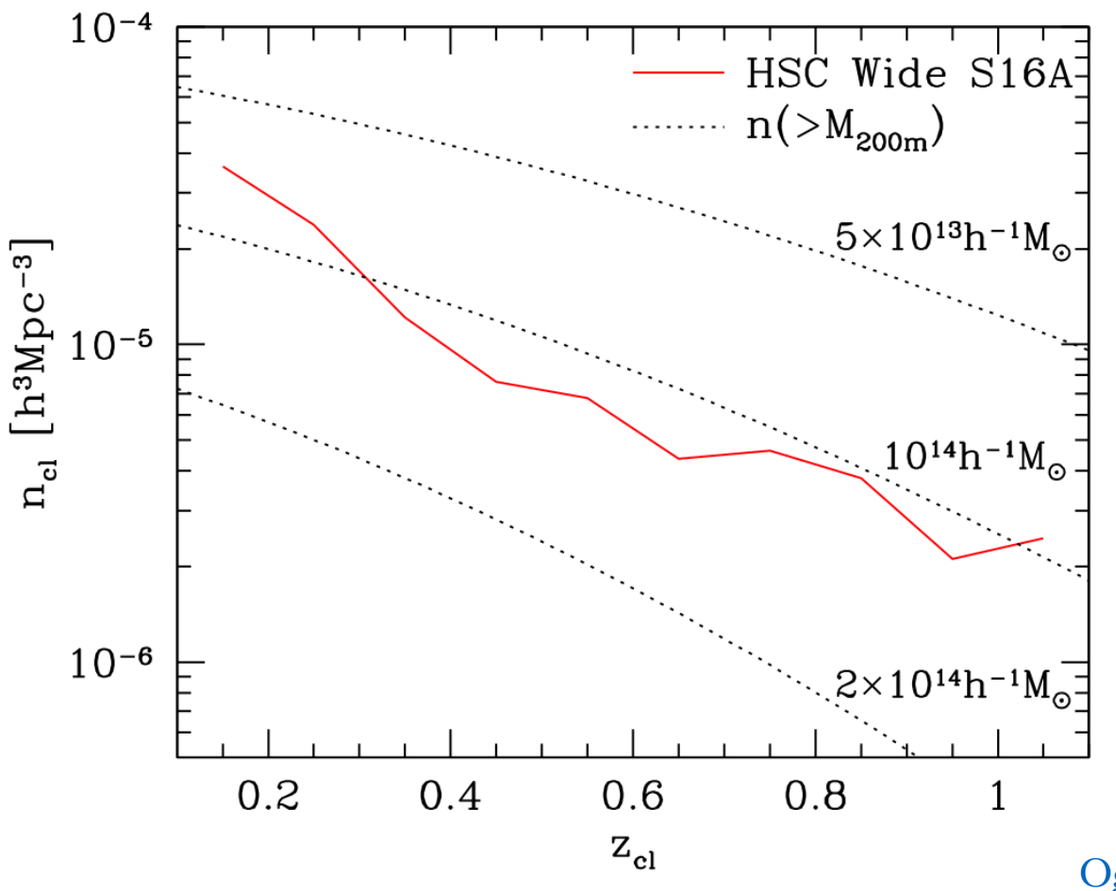
Oguri+17

Oguri, Lin et al. (arxiv:1701.00818)


HSC Wide S16A
δ_z=−0.0013
σ_z=0.0081
f_{out}=0.017
$z_{BCG,spec}$
z_{cl}
$\Delta z/(1+z)$
σ_z
δ_z


completeness
mock
all
0.3<z<0.6
0.6<z<1.0
M_{200c} [$h^{-1}M_\odot$]

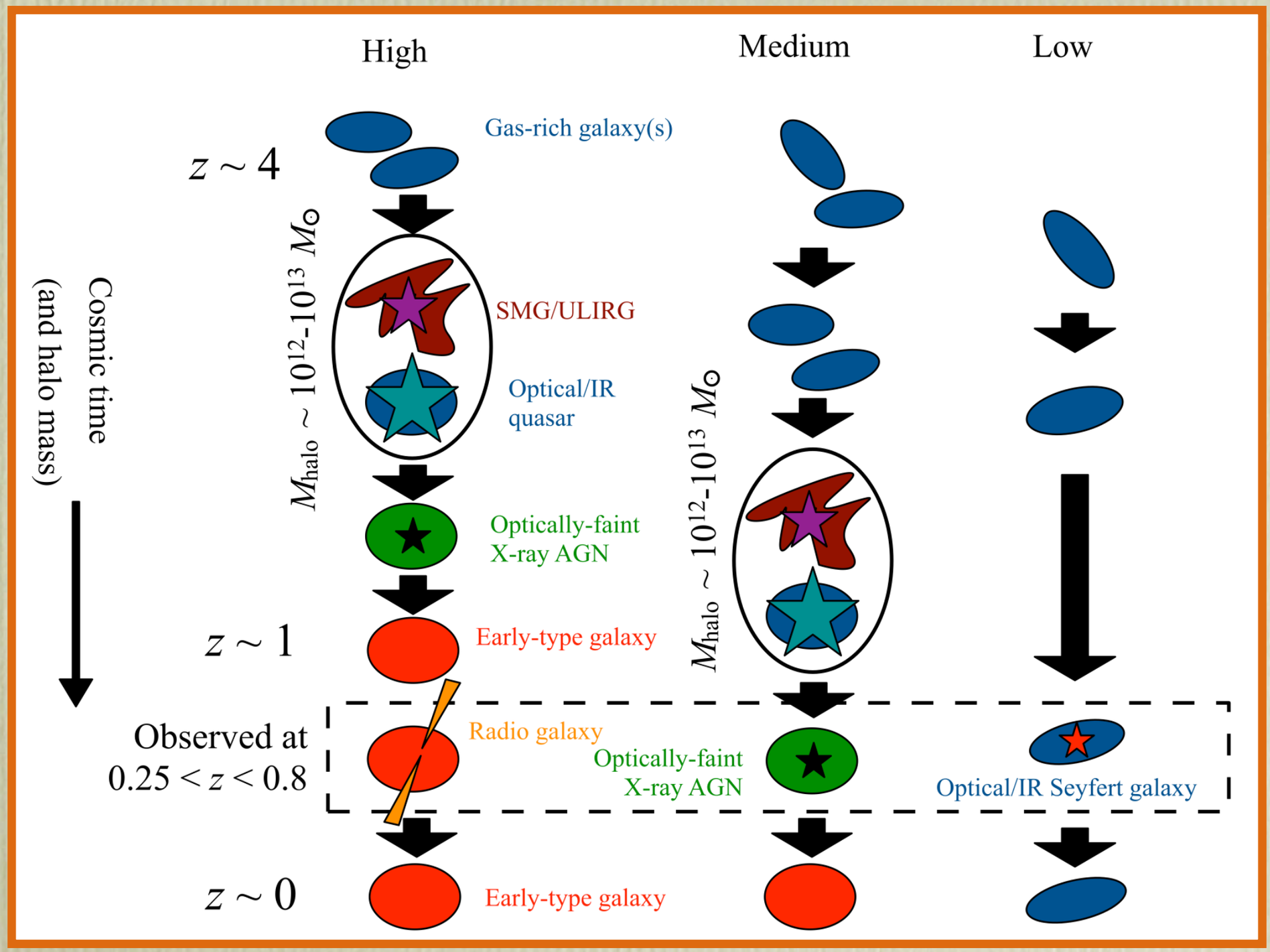

T_x [keV]
XXL
richness $\hat{N}_{mem}$


HSC Wide S16A
n(>M_{200m})
$5\times10^{13}h^{-1}M_\odot$
$10^{14}h^{-1}M_\odot$
$2\times10^{14}h^{-1}M_\odot$
n_{cl} [h^3Mpc^{-3}]
z_{cl}

Oguri+17

AGN phases in the lifetime of massive galaxies

halo mass dependence on AGN occurrence?



Hickox+09

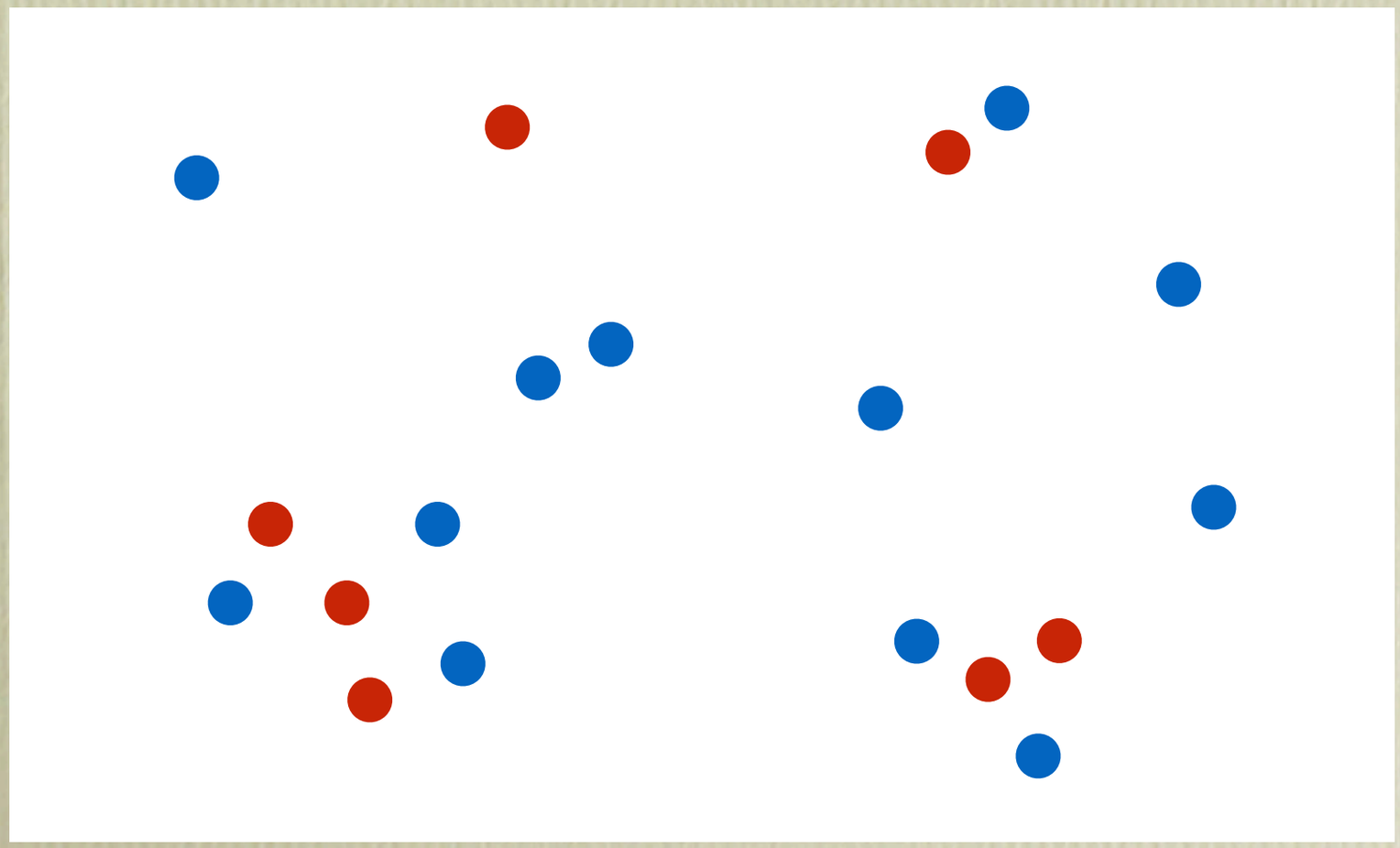
AGN occurrence ⊗ number density selection

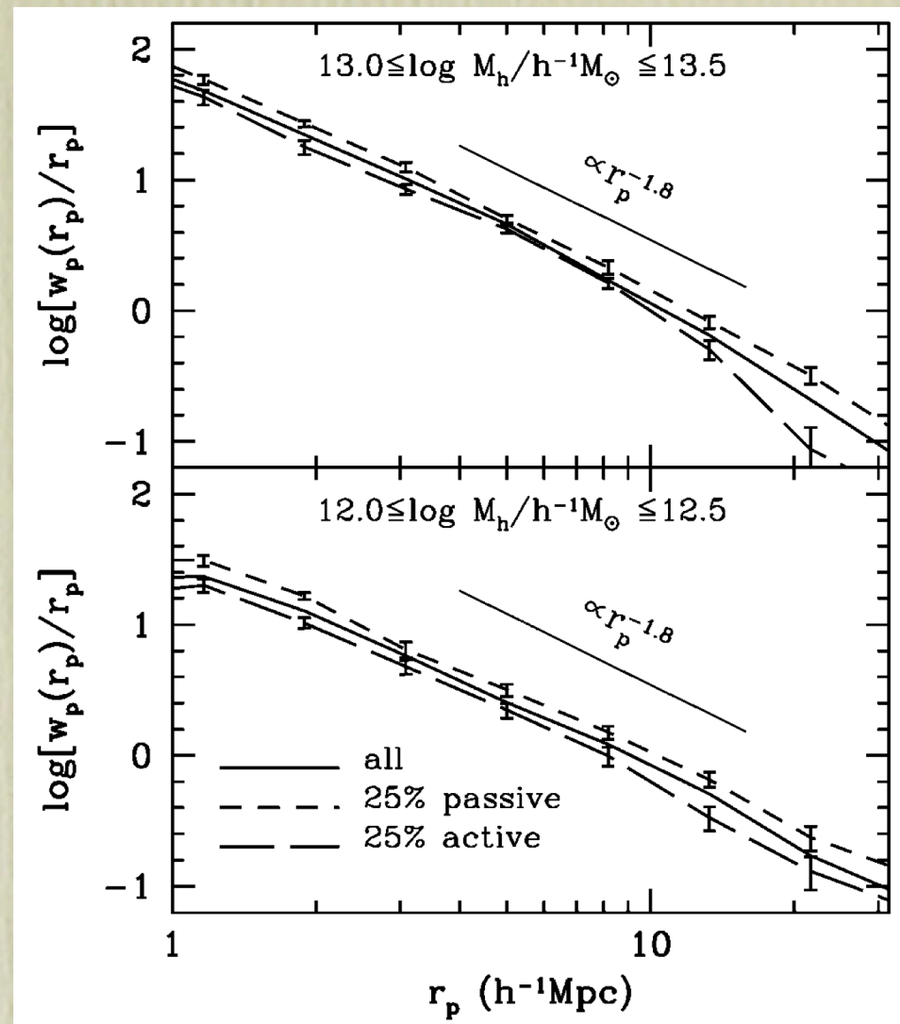
- fixed cumulative number density selection has been widely used in linking progenitor galaxy populations to descendants
  - inside-out growth: sizes, stellar masses, SFR, etc
- could be used to examine the Hickox picture
- COSMOS data
  - Laigle+16 photometric catalog
  - X-ray (Chandra), Radio (VLA), IR (Spitzer+Herschel)
- re-derive stellar mass by including AGN components in SED fitting with MAGPHYS (Y.-Y. Chang et al. in prep.)
- in 5 redshift bins, we select number density thresholds to statistically link the galaxy populations
  - do this for 3 different thresholds, to get galaxies living in halos of different masses

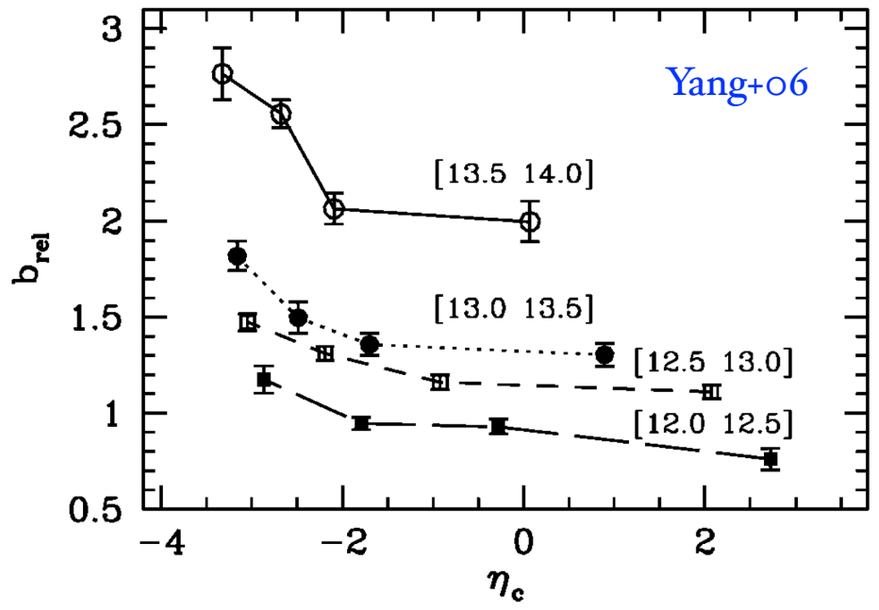
assembly bias in galaxy scale halos

wasn't this detected long ago?

- Yang+06 first claimed detection
  - a catalog that classifies galaxies into single and multiple galactic systems
  - designation of central vs satellite galaxies
  - halo mass *assigned* to each system à la abundance matching technique







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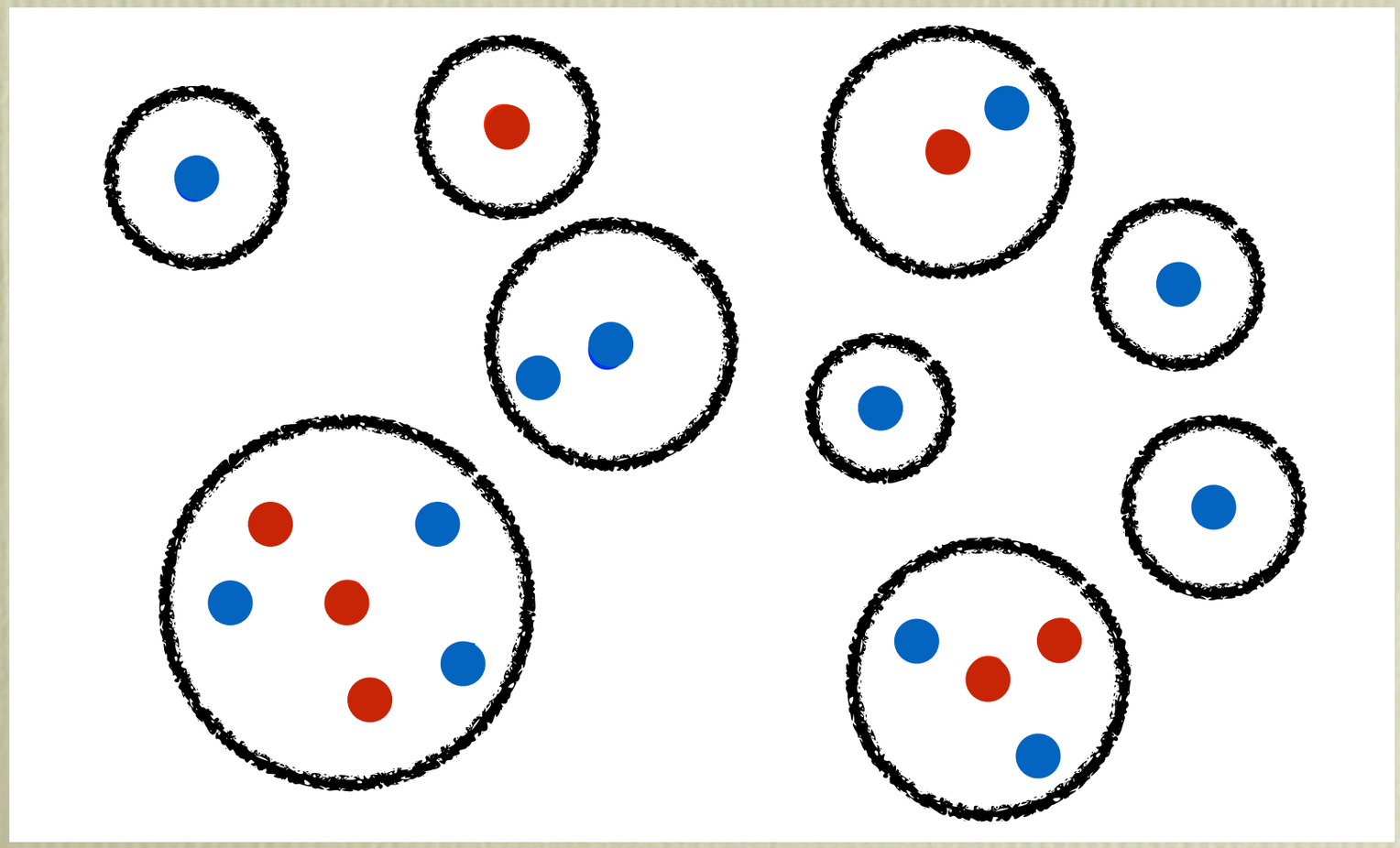

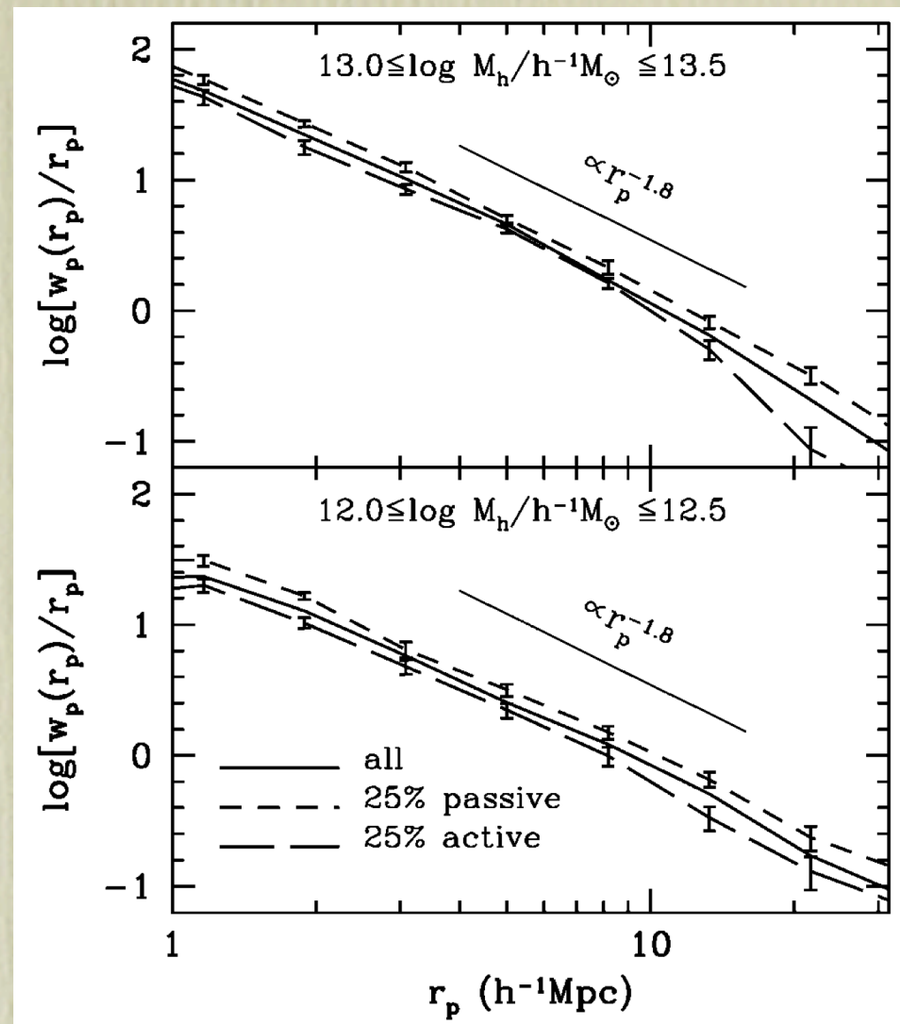

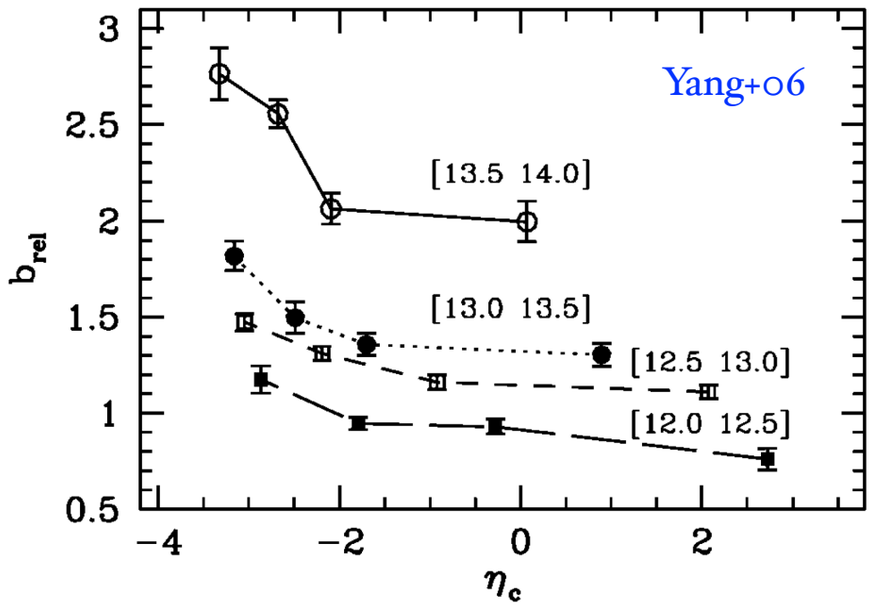

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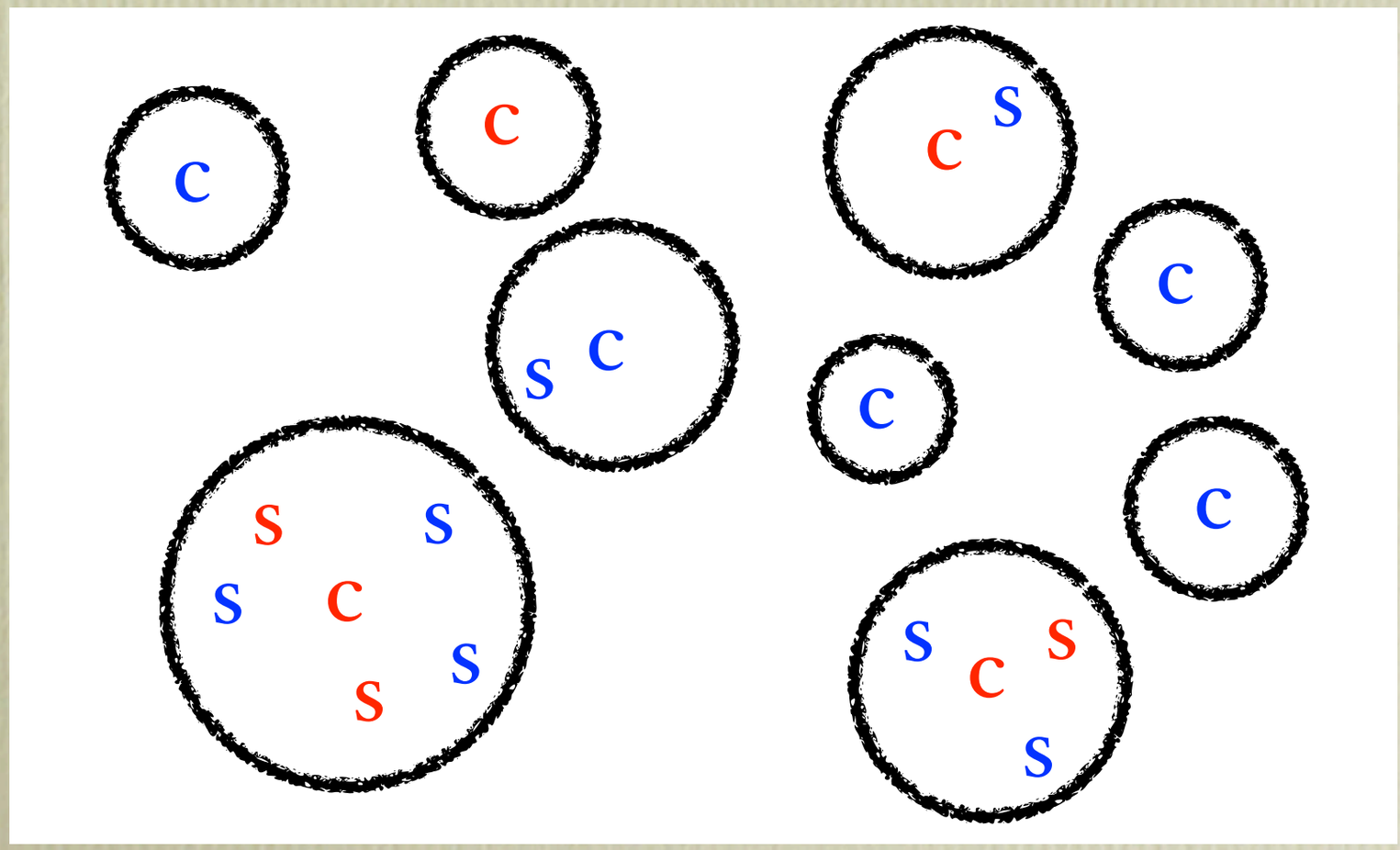
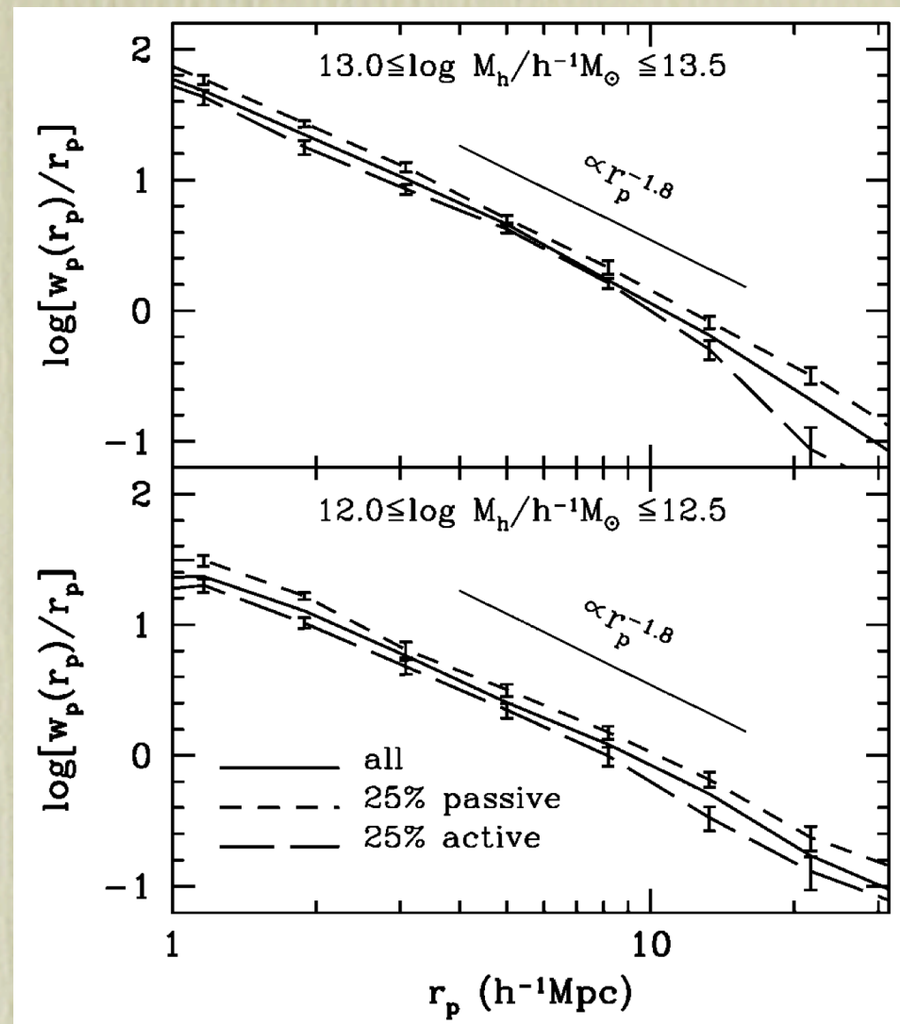
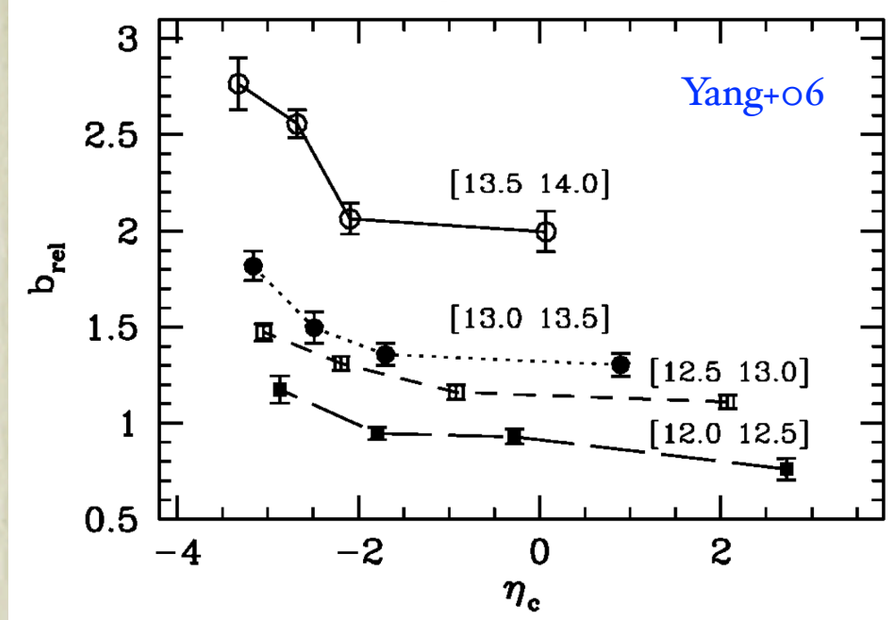
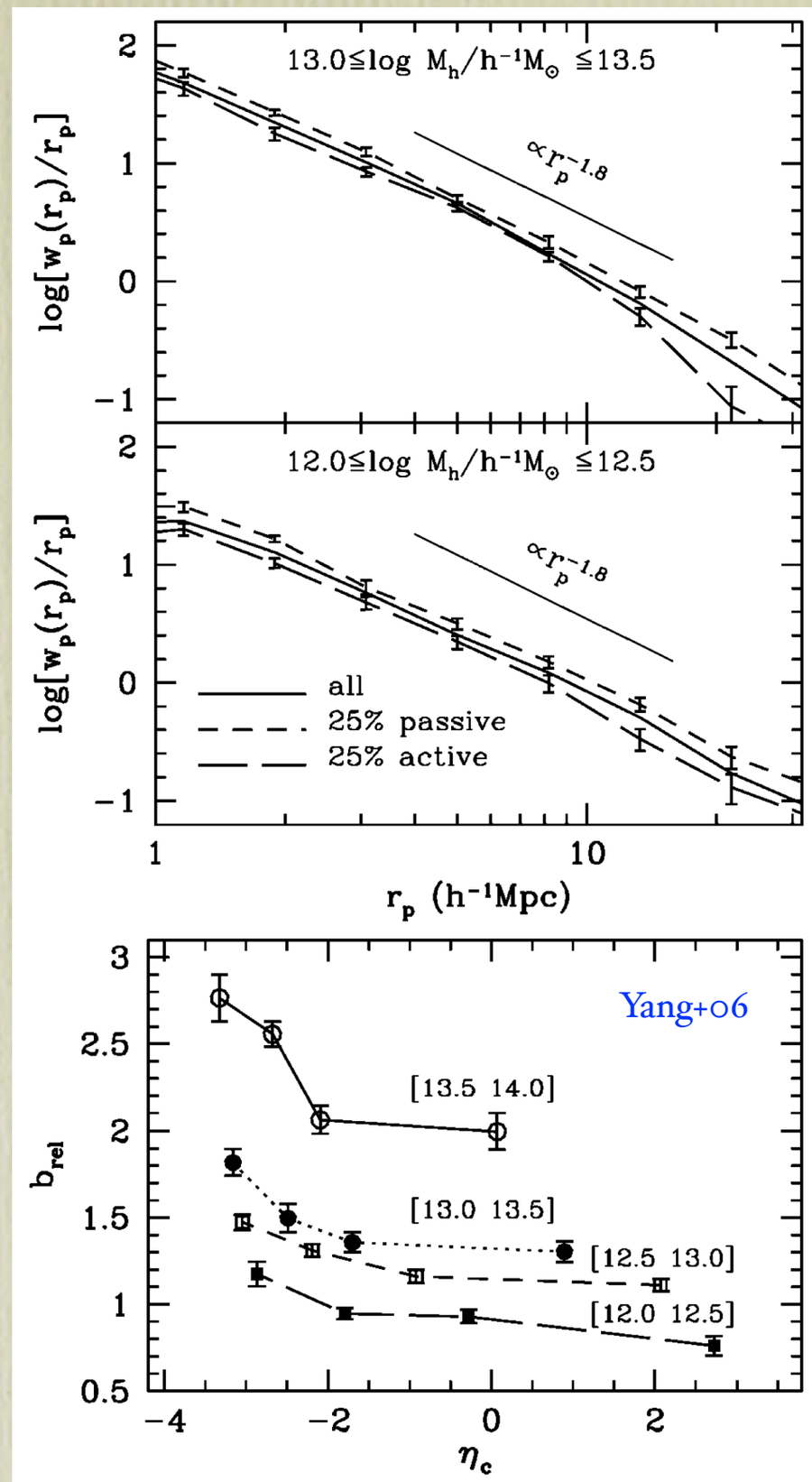






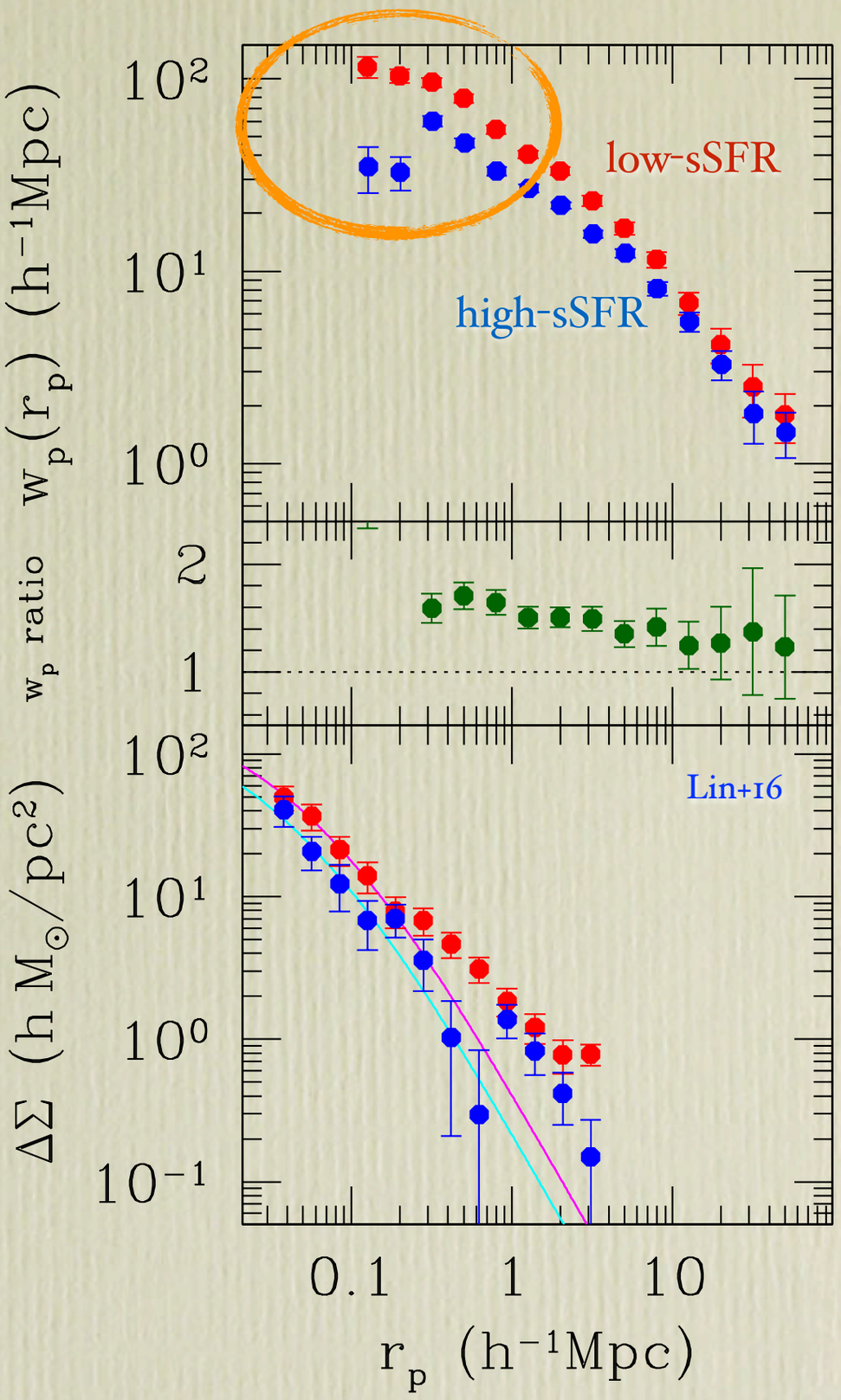
wasn't this detected long ago?

- Yang+06 first claimed detection
  - a catalog that classifies galaxies into single and multiple galactic systems
  - designation of central vs satellite galaxies
  - halo mass *assigned* to each system à la abundance matching technique
- formation history of central galaxies *assumed* to be closely related to that of the halos
- Yang+06 found that halos with currently passive centrals have larger bias than those with star-forming centrals of the *same* halo mass
  - if passive ↔ old, star-forming ↔ young, then this indicated assembly bias



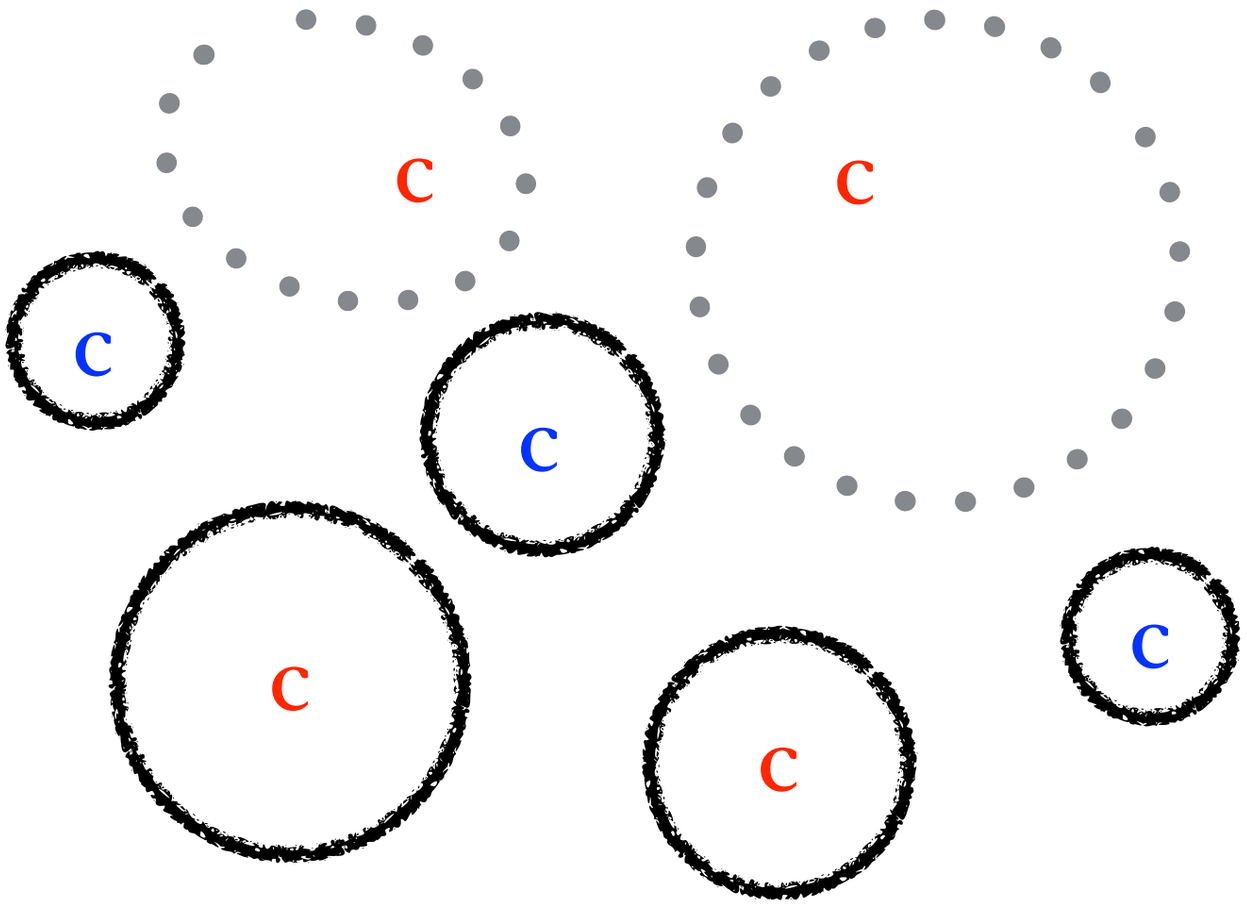
or was it?

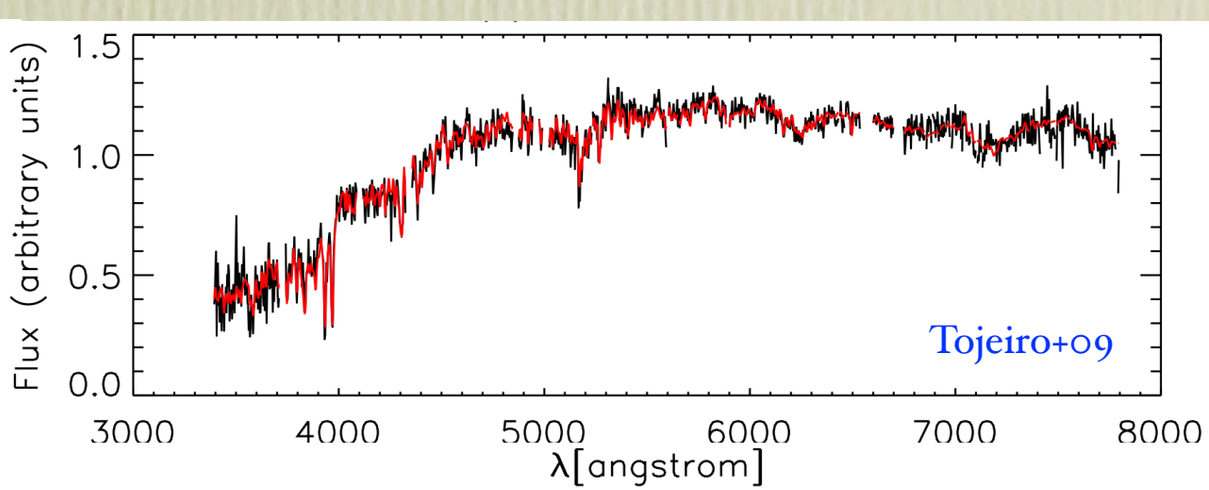
- using SDSS data, we follow the Yang+06 approach and confirm that low-sSFR centrals do cluster more strongly than high-sSFR ones
- however, the difference in bias may be explained by the difference in the mean masses of the two samples, as indicated by stacked weak lensing
- the previous claim of detection likely false
- Yang et al halo mass assignment not reliable
- serious contamination from satellite galaxies also seen

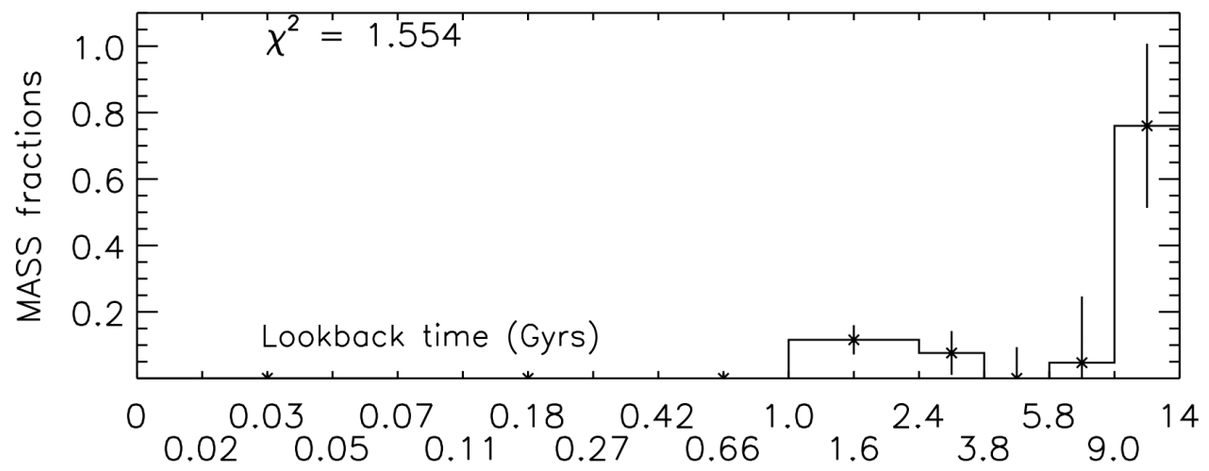


our approach

- still use Yang's central galaxy catalog
  - trim off satellites via a friends-of-friends algorithm
  - use weak lensing to ensure samples of early- and late-forming centrals have similar mean masses
- use resolved star formation history from VESPA algorithm to define early- and late-forming central galaxy samples

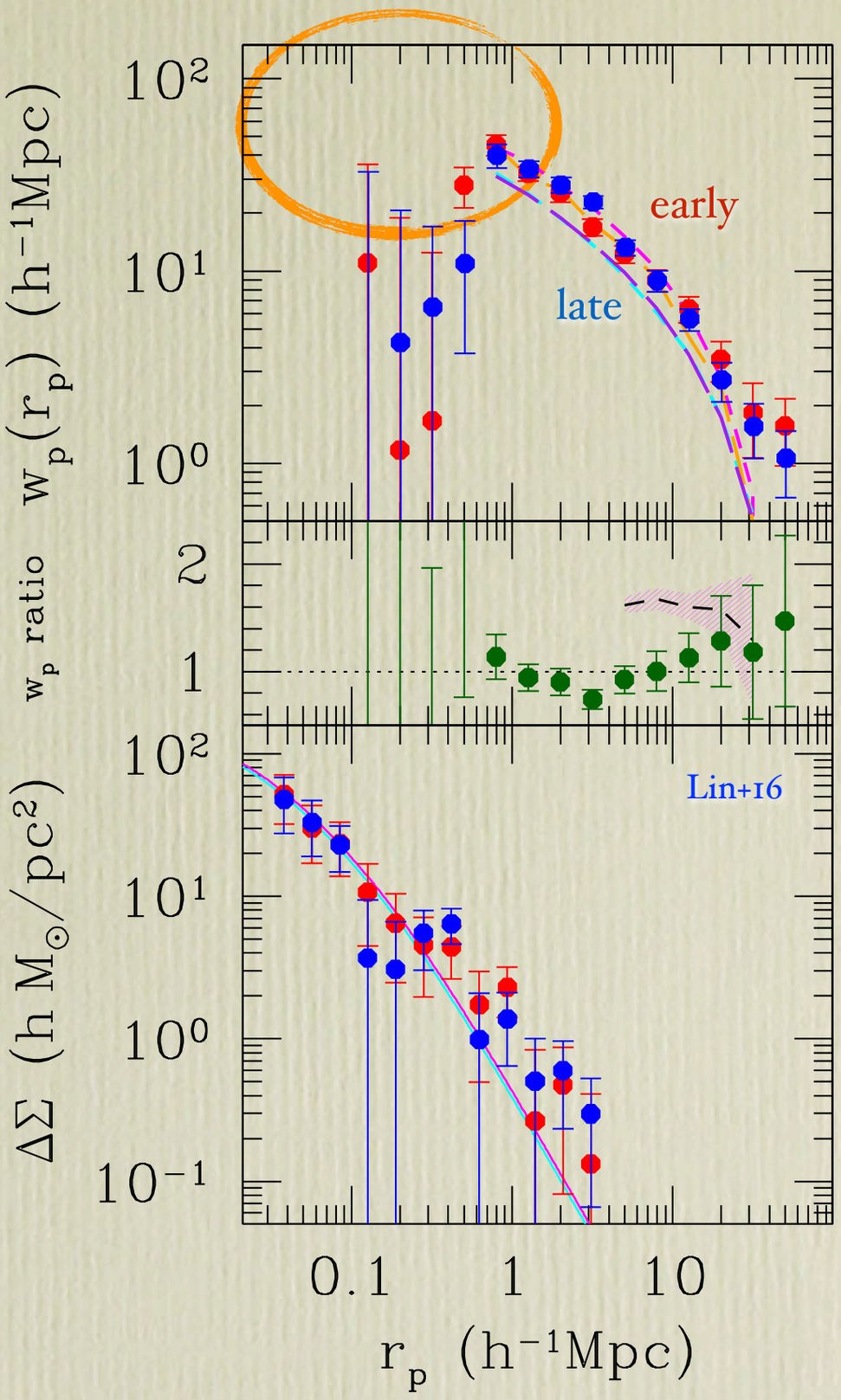






non-detection of assembly bias

- we have constructed a pair of early- and late-forming central samples for which the satellite contamination is minimal
- masses are $(9\pm2)\times10^{11}h^{-1}M_{sun}$ and $(8\pm2)\times10^{11}h^{-1}M_{sun}$
- theoretical expectation derived from high resolution N-body simulations, taking into account uncertainties in halo mass distribution
  - log-normal form assumed
  - probable values of centroid & width allowed by measured lensing signal
- probability for theory to be consistent with observation is 2×10^{-6}



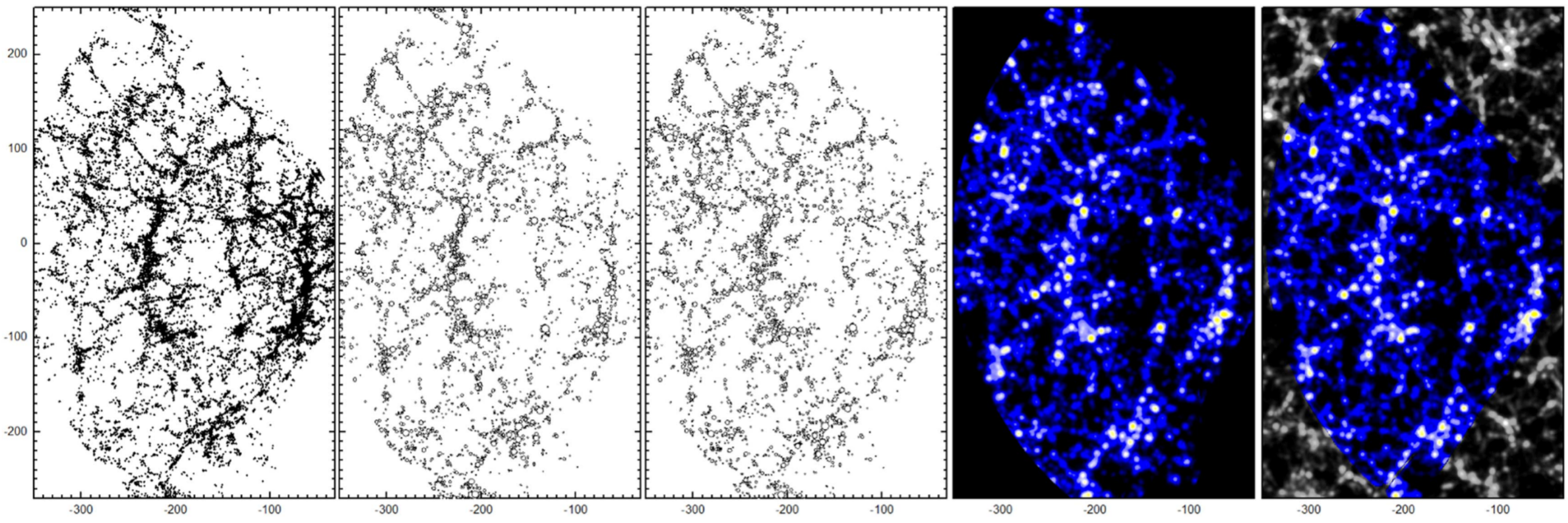
implications

- galaxy formation processes render magnitude of assembly bias small?
  - not according to Guo+11 semi-analytic model
- *VESPA*-based SFH not good enough for subtle effect like assembly bias?
  - may need higher S/N spectral data from future surveys
  - will try other algorithms such as STARLIGHT
- how tightly coupled is central galaxy formation history to that of the halos?
  - actually, quite tight, according to the Guo+11 model
- better proxy for halo formation time?
  - z_{mah} derived for SFH or mean stellar age
  - look at extrema of the distributions
  - concentration?

assembly bias at cluster scales?

- what is the best proxy/indicator for the halo formation time?
- $R_{mem,3D}$ works, but difficult to measure in practice
- what if we have the mass growth history (MGH) of the clusters?
- using the group catalog of Yang et al., H.-Y. Wang et al. (2016) have run a constrained simulation (CS) of the local Universe (SDSS DR7, z<0.12)

Wang+16



assembly bias at cluster scales?

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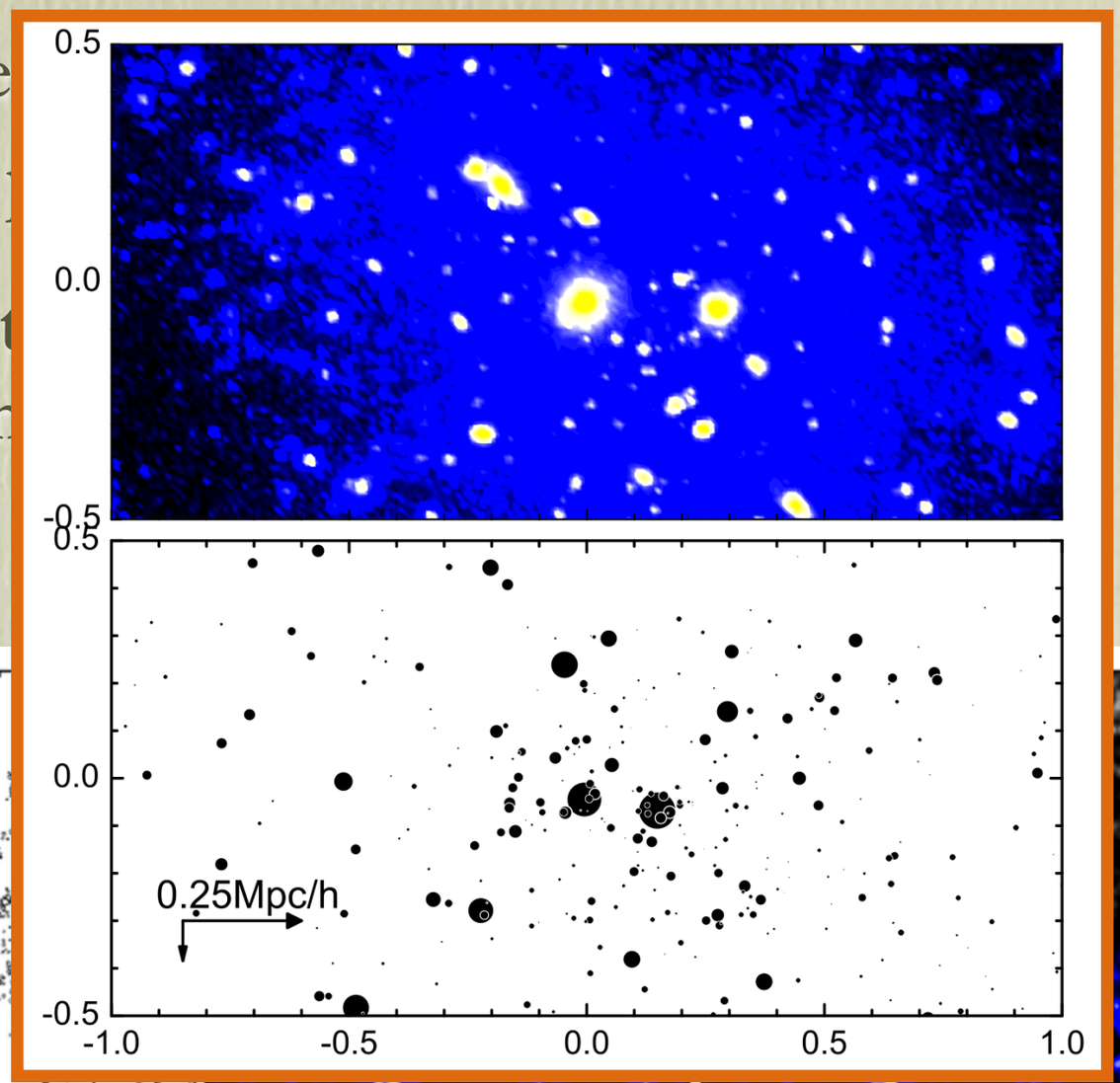
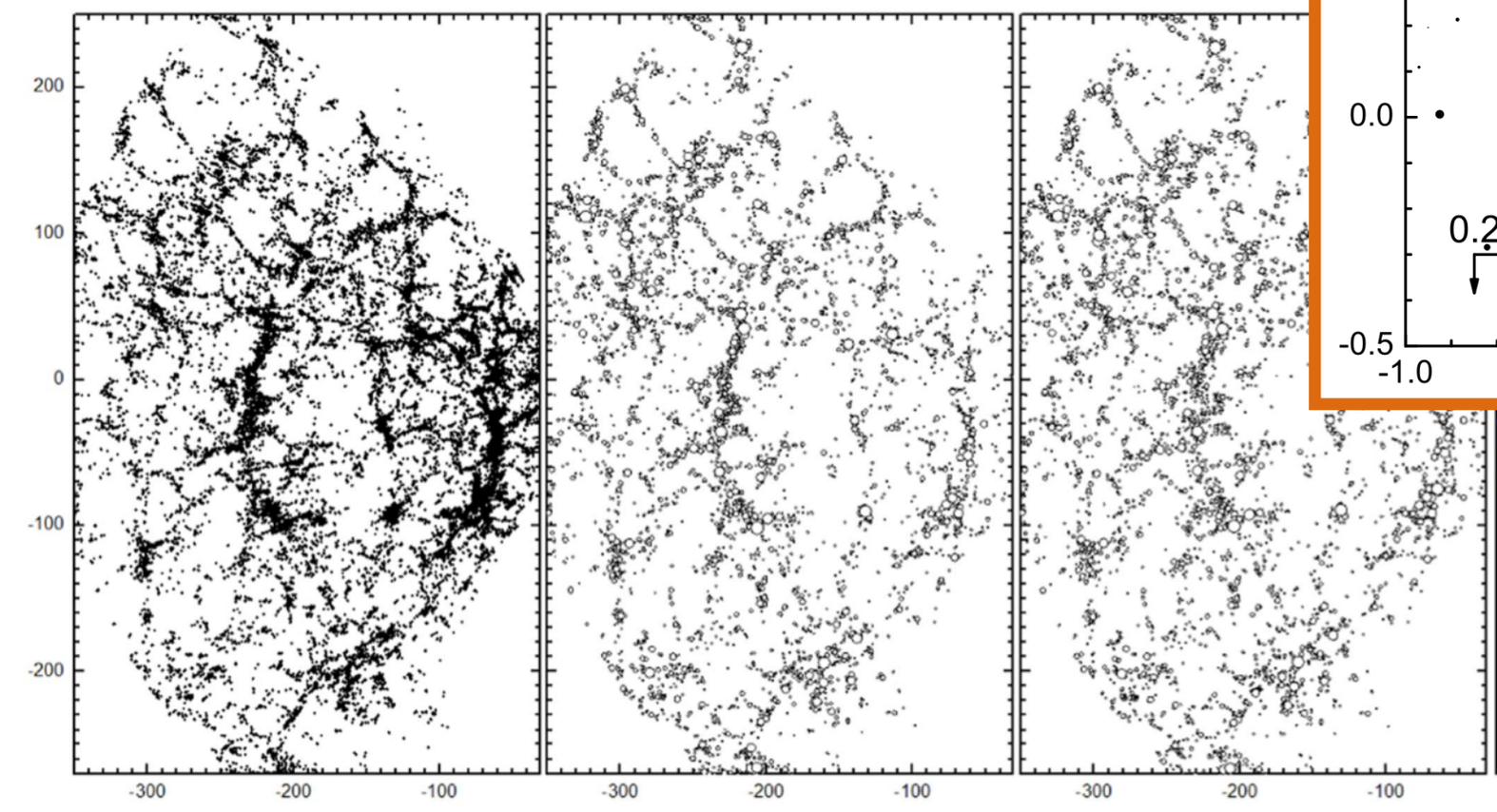
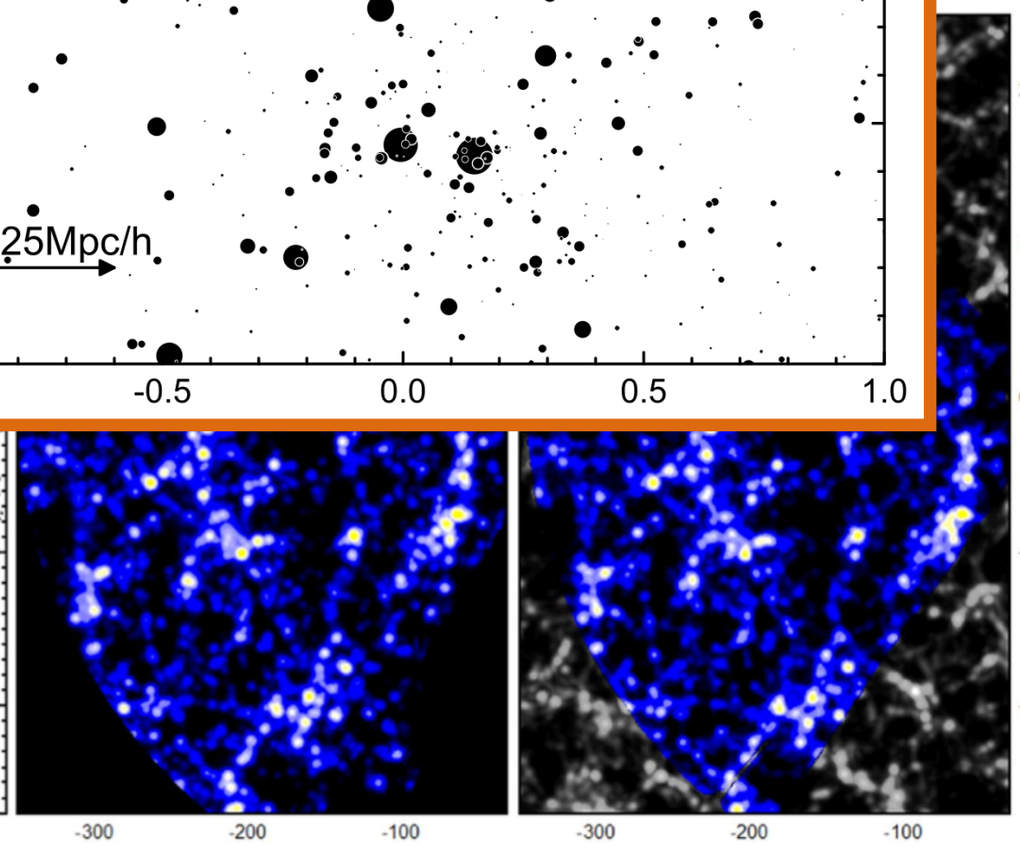






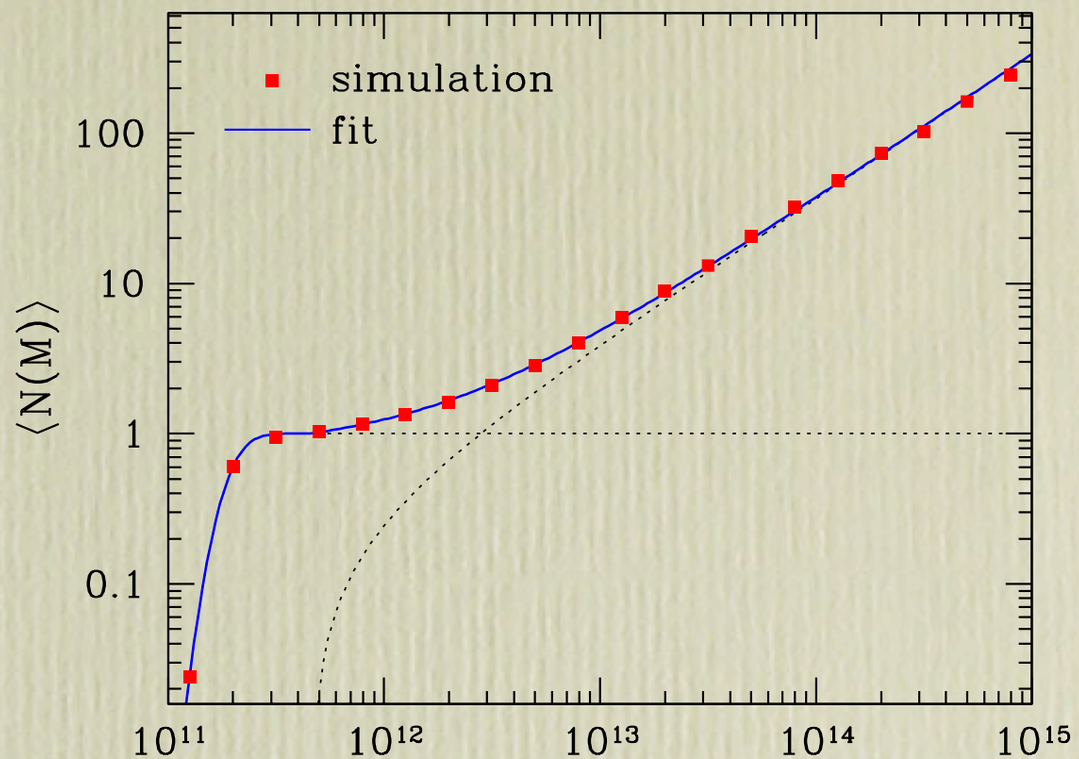
assembly bias at cluster scales?

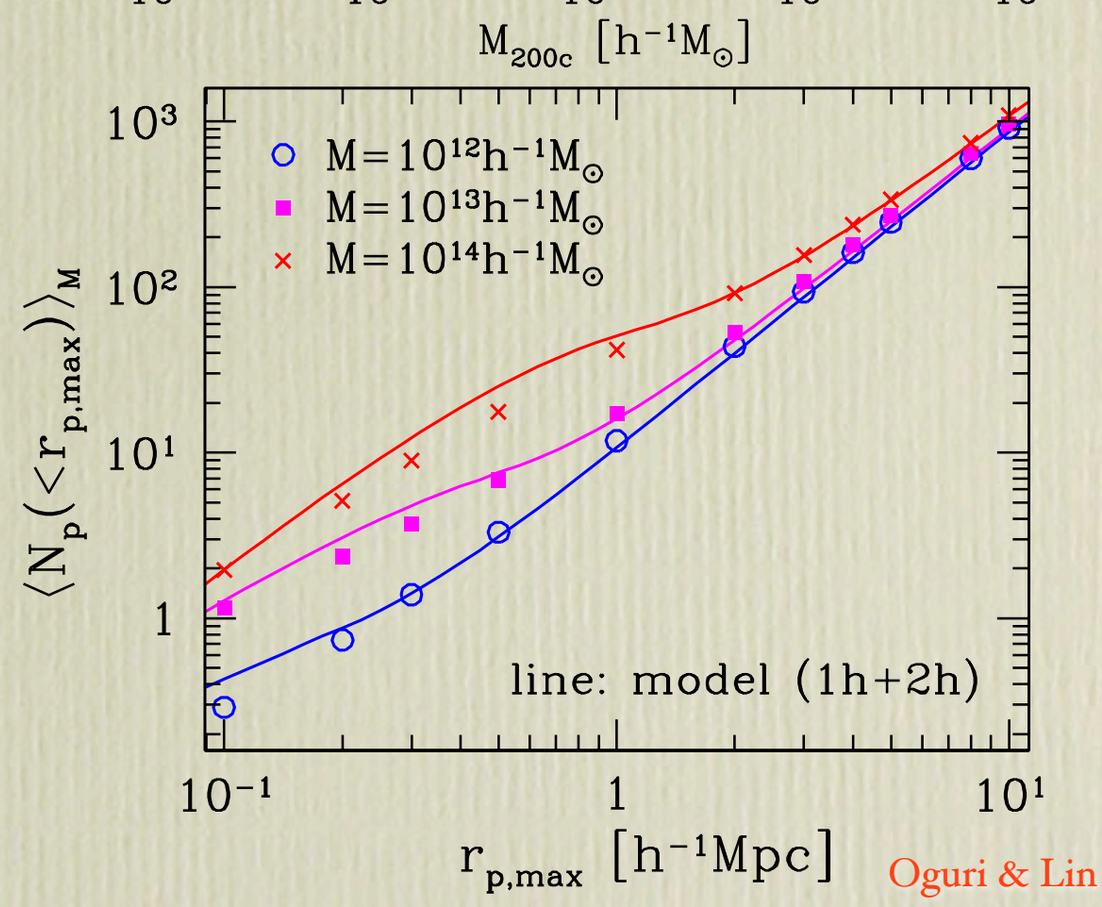
- what is the best proxy/indicator for the halo formation time?
- $R_{mem,3D}$ works, but difficult to measure in practice
- what if we have the mass growth history (MGH) of the clusters?
- using the group catalog of Yang et al., H.-Y. Wang et al. (2016) have run a constrained simulation (CS) of the local Universe (SDSS DR7, z<0.12)
- for structures larger than ~2Mpc/h, there is very good correspondence between SDSS LSS and CS structures
- we have selected top 600 most massive clusters at z<0.12 from Yang's catalog
- MGH for each cluster is given by the counterpart halo in the CS

halo mass from galaxy counting

new mass estimator: neighbor counts

- estimating halo masses is hard!
- most of existing methods give halo mass in a statistical sense (e.g., satellite kinematics, WL)
- for a given galaxy sample, we can infer its halo occupation distribution (HOD), in particular the halo occupation number
- for this sample, we can then infer the number of neighboring galaxies *within the same galaxy sample*
- analytical calculations within the HOD framework, separately for central and satellite galaxies, and for one- and two-halo terms





Oguri & Lin 15

halo mass probability distribution

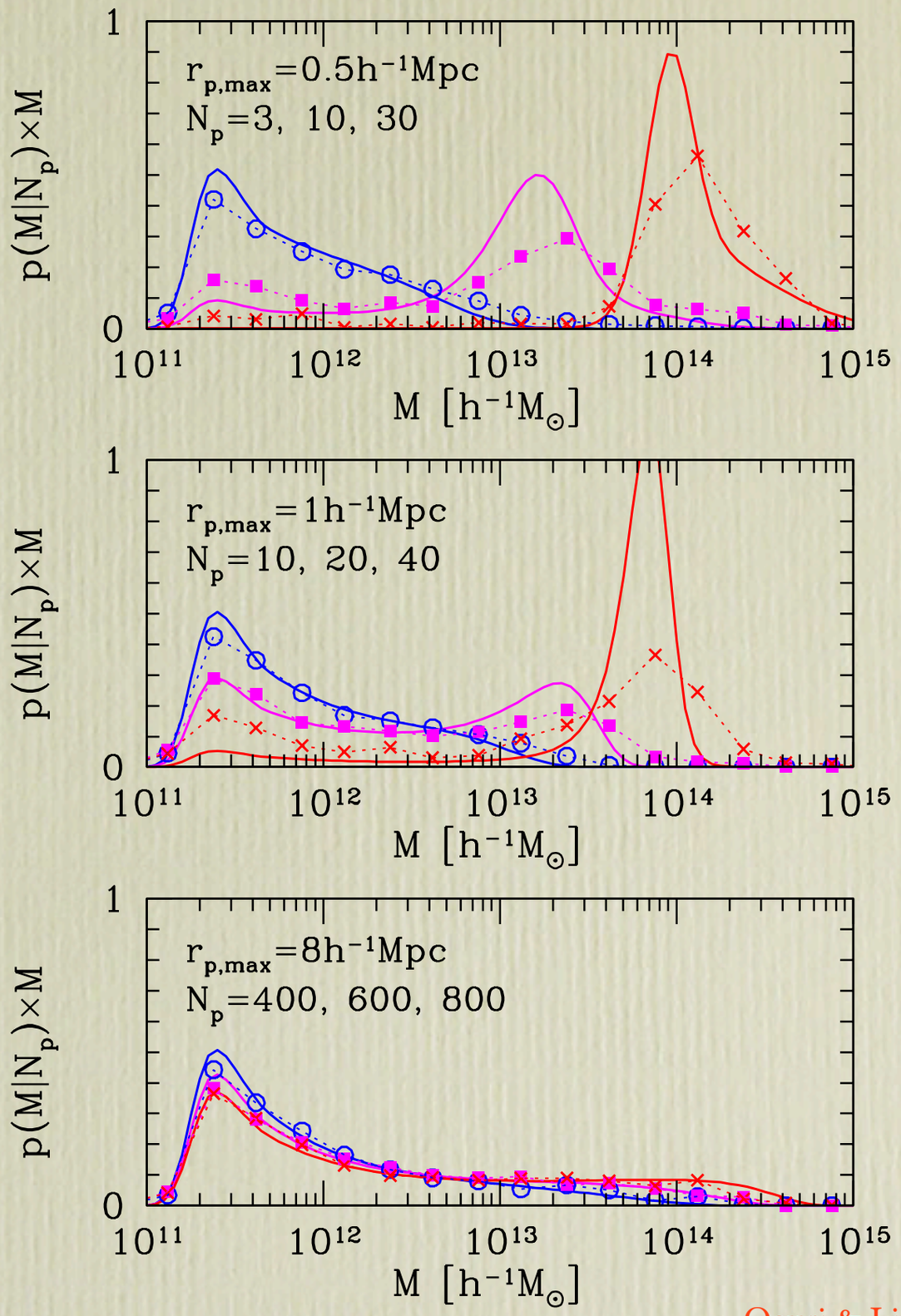
- use Bayes' theorem to infer halo mass probability distribution function (pdf)

$$p(M|N) \propto p(N|M)p(M)$$

- model predictions match well with the mock results

- pdf often bimodal, due to uncorrelated large scale structures
- also gives probability of being a central

- working on extending the method to high redshifts ⇒ high-z galaxy-halo connection!



Oguri & Lin 15

summary

- BCG stellar mass assembly history from HSC survey consistent with previous results
- first application of fixed cumulative number density selection technique in exploring AGN-galaxy-halo connection
- non-detection of assembly bias at low mass halo scales: better proxy of halo age needed?
- exploring a way to detect assembly bias at cluster scales using constrained local Universe simulation
- inferring halo mass pdf from neighboring galaxy counts may be useful for high-z studies