Galaxy Pairs and Clusters in ΛCDM: Bridging Simulations and Observation

Joel Berrier
UC Irvine

CENTER FOR COSMOLOGY
UNIVERSITY OF CALIFORNIA, IRVINE

UC Berkeley
May 13, 2008

Collaborators

James Bullock,
Elizabeth Barton,
Heather Berrier,
Jeff Cooke,
Kyle Stewart,
Chris Purcell (UC Irvine)

Andrew Zentner (U Pittsburgh)
Risa Wechsler (Stanford)

Outline

I. Close Galaxy Pairs
II. Cluster Assembly

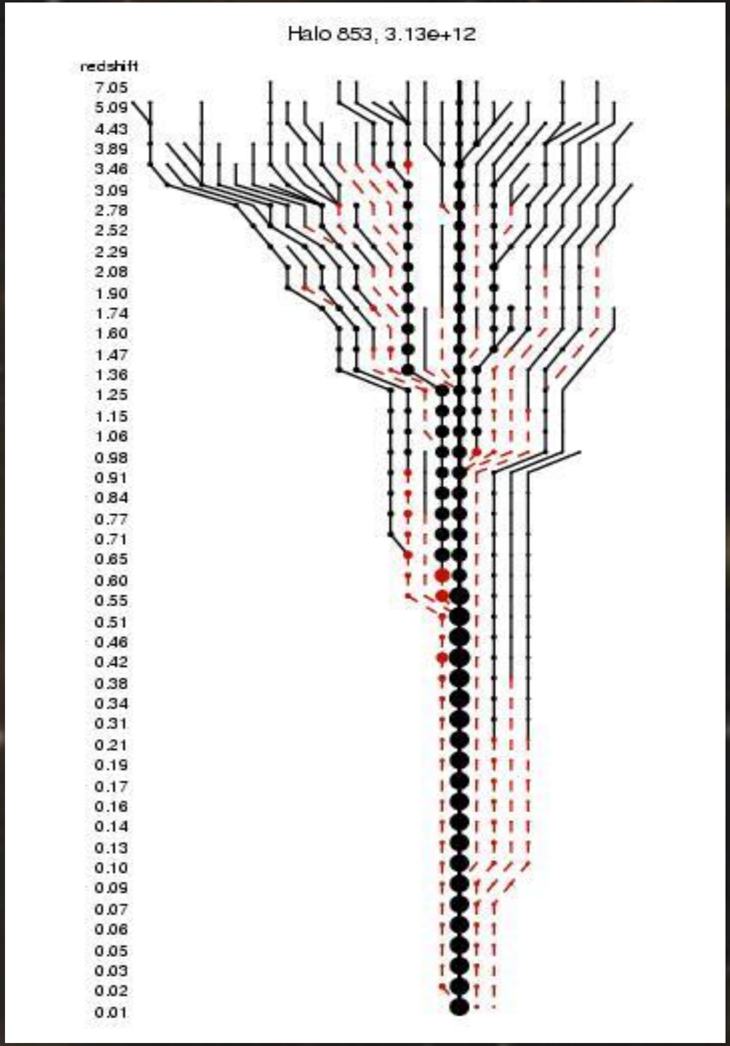
Outline

I. Close Galaxy Pairs
II. Cluster Assembly

Hierarchical Formation

Many small halos in the early universe merge together to form the larger halos today.

- Several small halos at high z form larger, more massive halos at low z.
- Circle size represents size/mass of halo.



Stewart et al. 2007

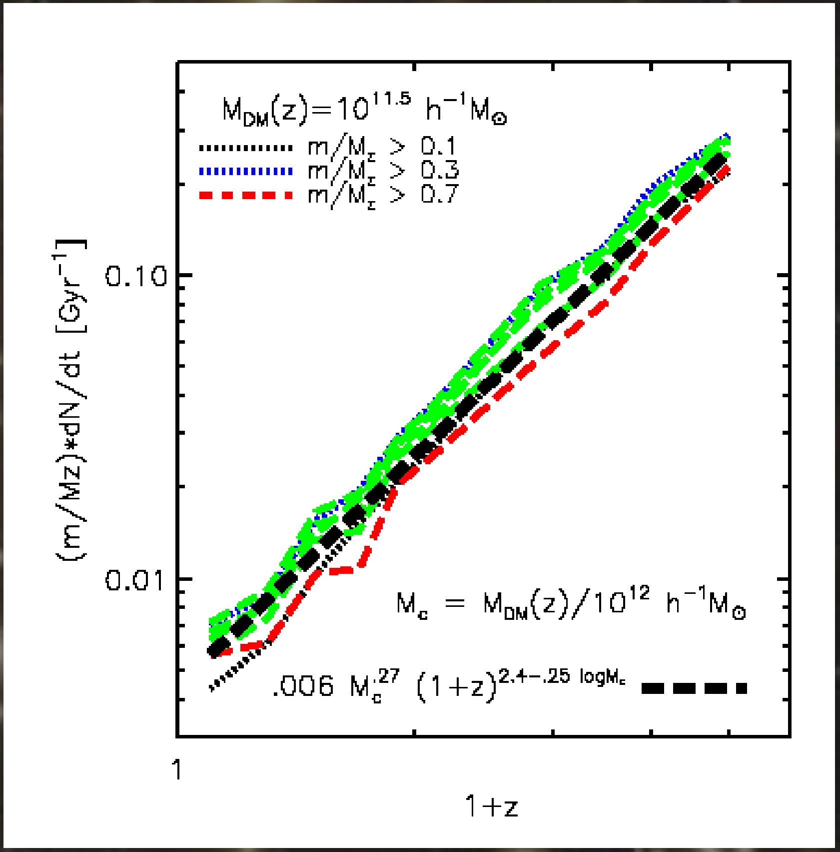
Theoretical Expectations of Hierarchical Merging

Predicted values of the merger rate, R_{mg}, from analytic arguments and from simulation results show

$$R_{mg} \propto (1+z)^m$$

where $2.5 \leq m \leq 3.5$.

(e.g. Governato et al. 1999; Gottlöber et al. 2001; Stewart et al. 2008)



Stewart et al. 2008, in prep

Close Galaxy Pairs

The expectation:

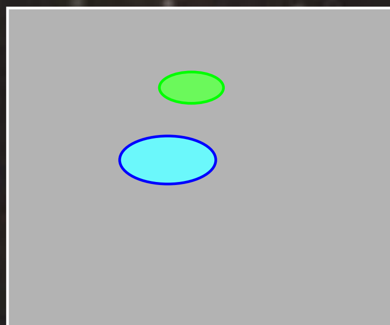
- As galaxies are merging so are their dark matter halos.
- Provide candidates for merger events.
- Evolution of close pairs fraction measures the merger rates.

We define a close pair of galaxies to have:

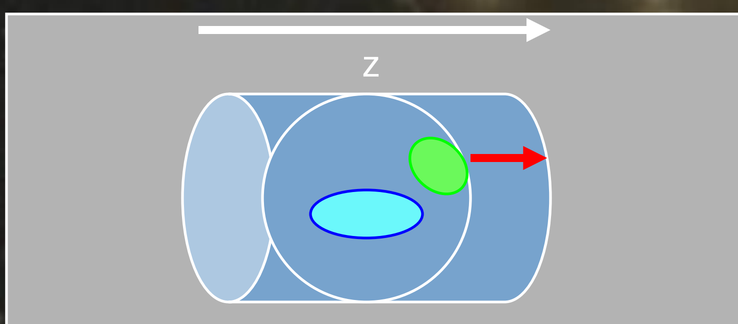
- Separation between $R_{min} = 10\ h^{-1}$ kpc and $R_{max} = 50\ h^{-1}$ kpc in the comoving coordinates.
- A line of sight velocity separation of $|\Delta V_{max}| \leq 500$ km s^{-1}.

The close pair fraction, N_c, is the number density of pairs with respect to the number density of galaxies in the sample.

Close-Pairs

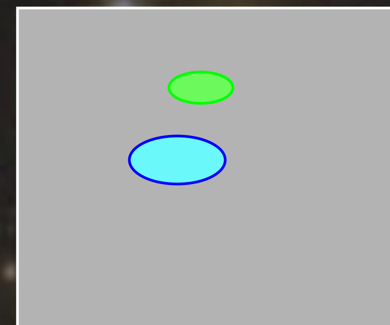


As seen on sky

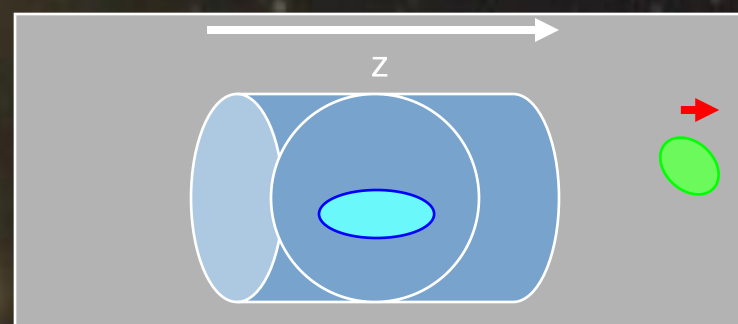


Edge on

False-Pairs (Projection effect)



As seen on sky



Edge on

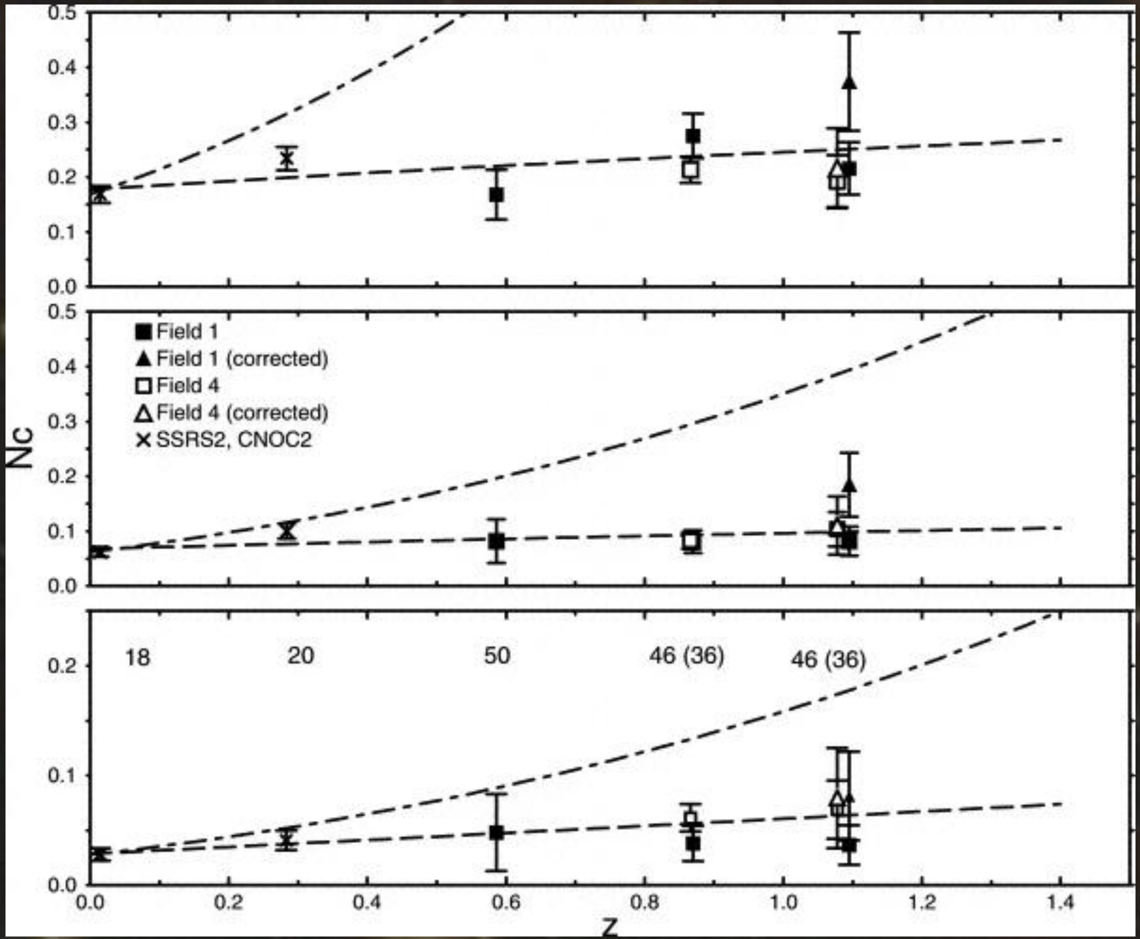
Measurements of Close Pairs

Several surveys have been used to calculate N_c, e.g.:

- CNOC2
- SSRS2
- DEEP2
- RCS-1

(Zepf & Koo 1989; Burkey et al. 1994; Carlberg et al. 1994; Woods et al. 1995; Yee & Ellingson 1995; Carlberg et al. 2000; Bundy et al. 2004; Le Fèvre et al. 2000; Patton et al. 2002,1997; Neuschafer et al. 1997, Lin et al. 2004, Cooke et al. 2005, Hsieh et al. 2008, Lin et al. 2008)

Results from DEEP2



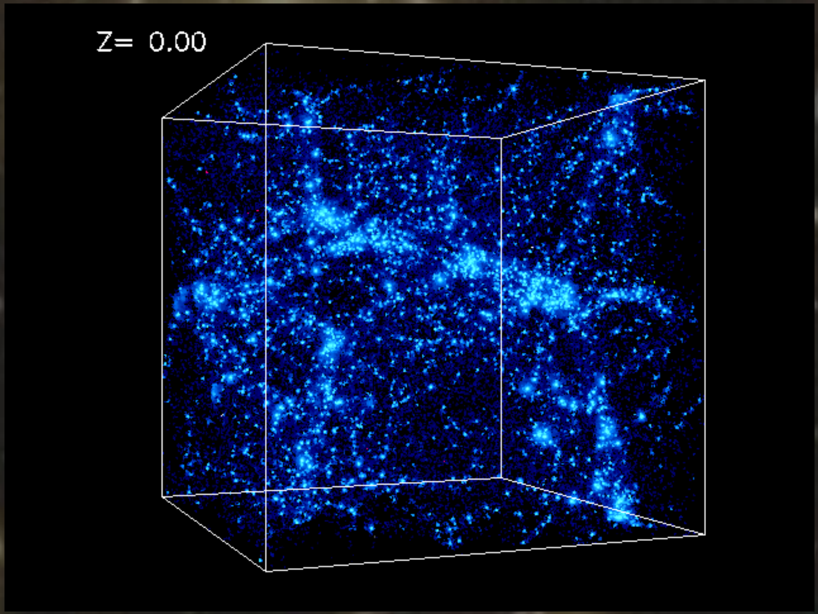
- The evolution of N_c
- Shows little growth
- m = 0.51±0.28.

$$N_c = N_0(1+z)^m$$

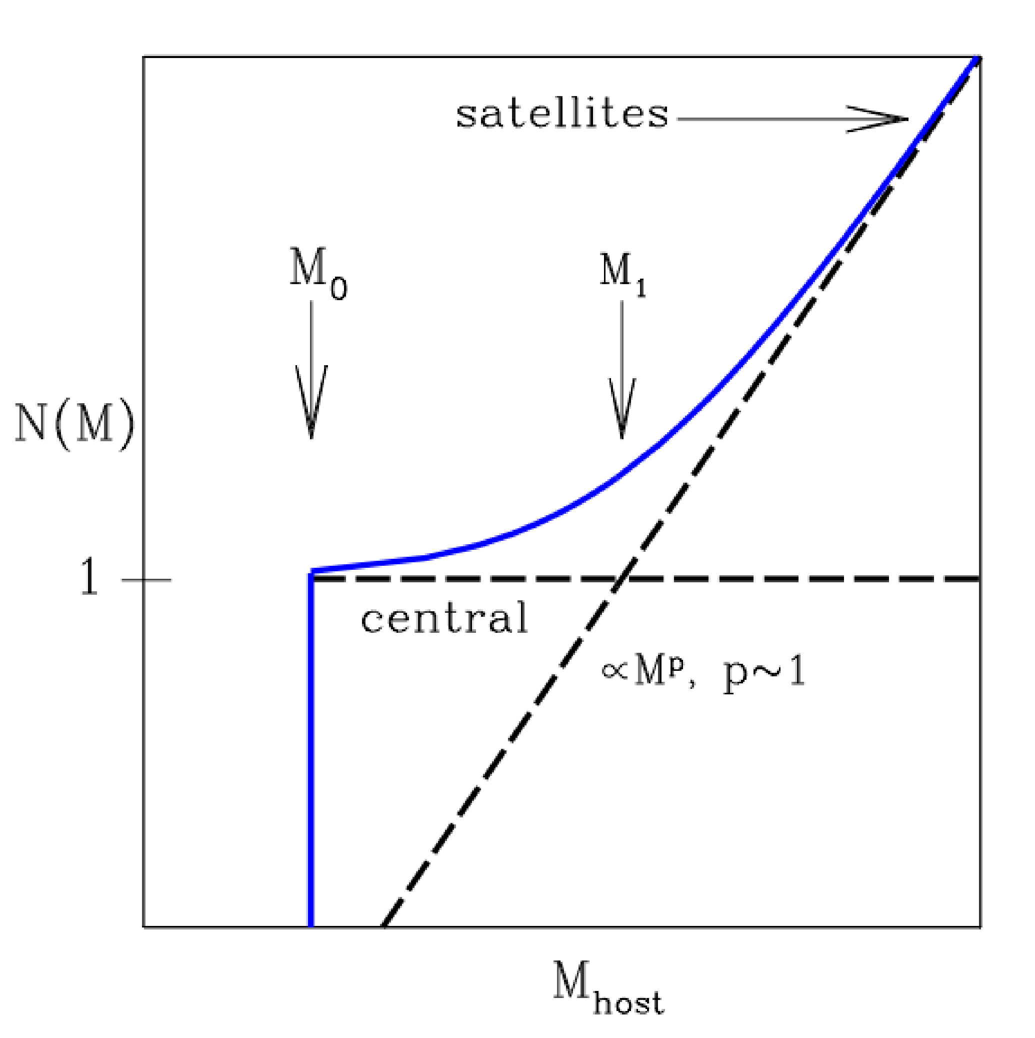
Lin et al. (2004)

Simulations & Model

- Our model uses an N-body simulation for Host halos and an analytic model for subhalos.
- Large scale structure (host halos) -- very well predicted.
- Box is 120 h^{-1} Mpc on a side in comoving coordinates.
- Analytic model provides substructure -- with virtually unlimited resolution. (The N-Body code does not have accurate resolution on its own.)
- For details on the substructure code see Zentner et al. 2005. It has been tested and refined against high-resolution simulations.



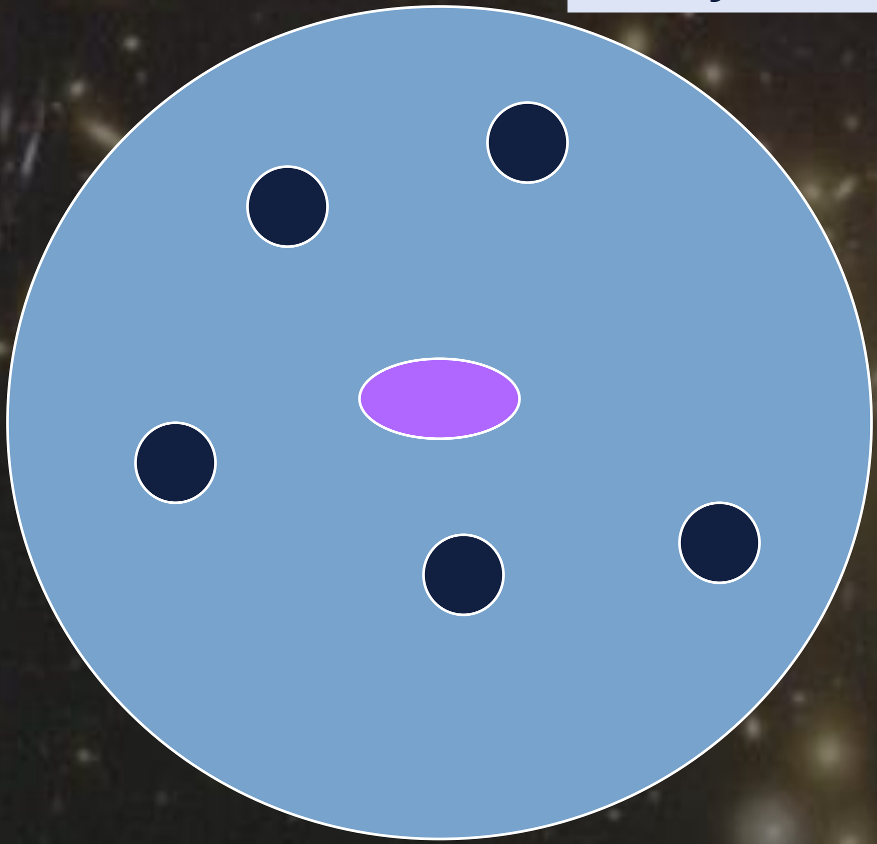
The Halo Occupation Distribution

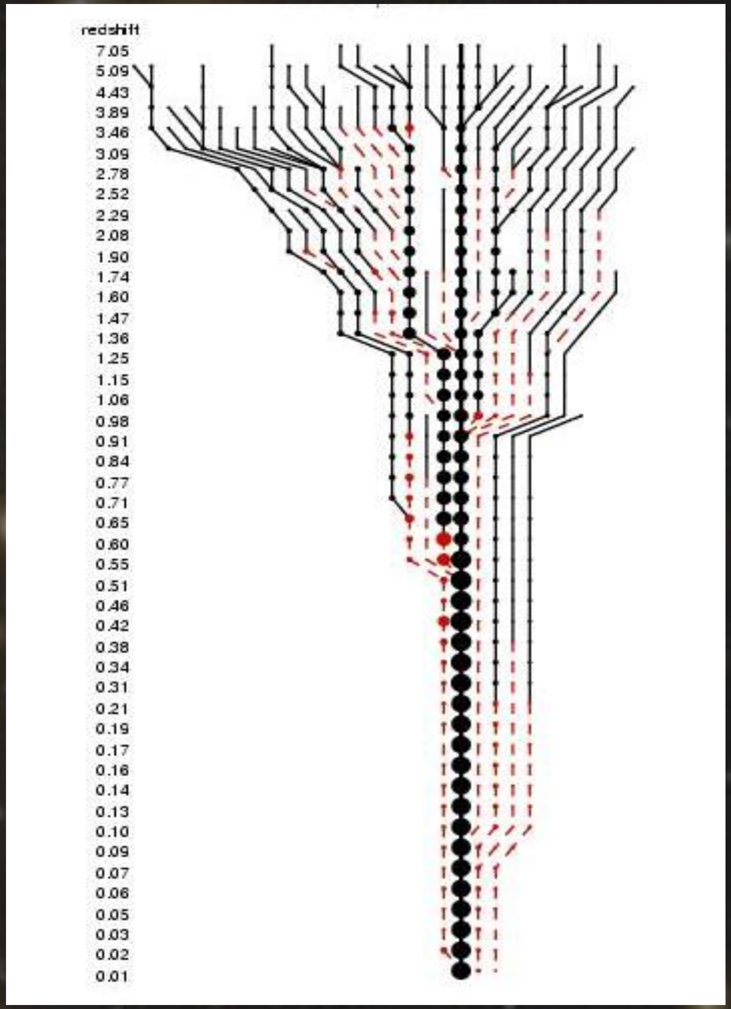


- All galaxies live in "host dark matter halos".
- Host halos are not contained within another, larger halo
- Hosts a central galaxy + satellites.
- Describes number of subhalos in a host halo of a given mass.
- Predicted (not fit)

Host halo
(central galaxy)

Subhalos
(galaxies)
Zentner semi-
analytic model





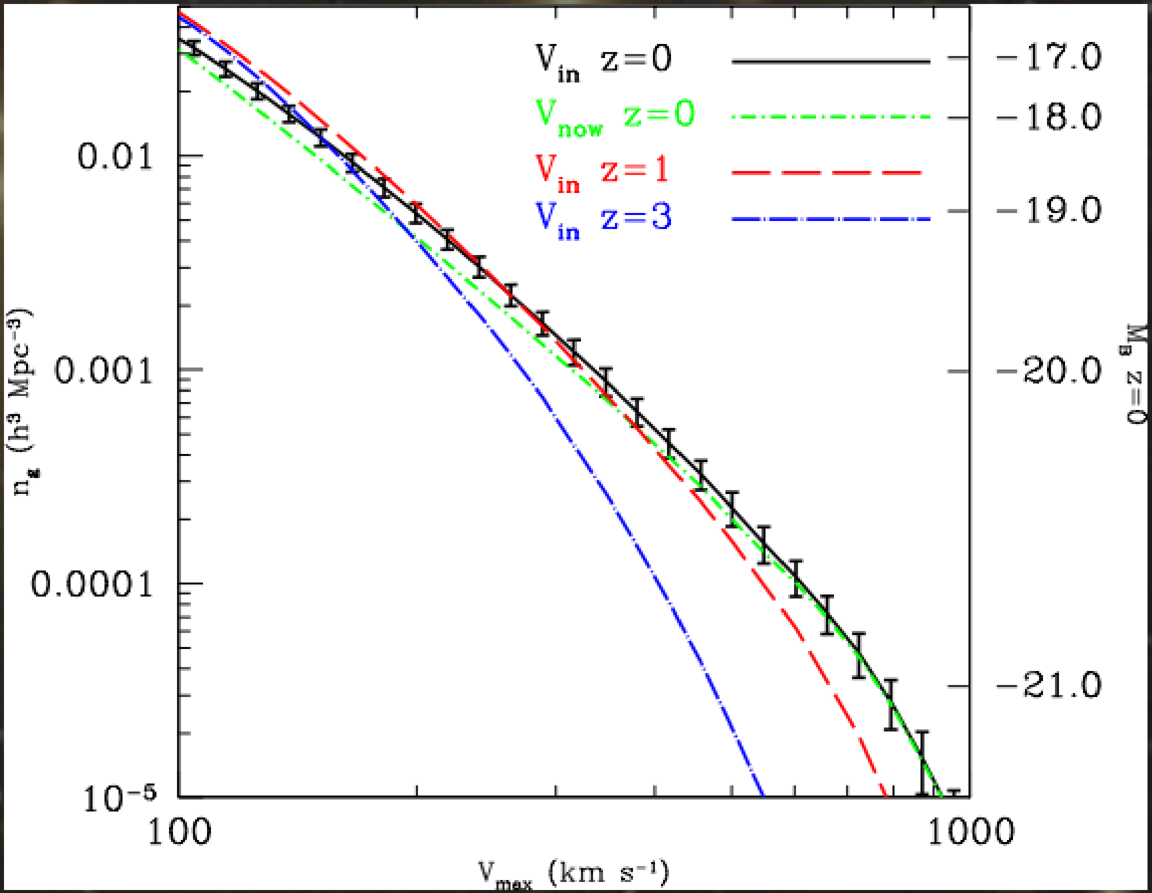
- V_{max} is the velocity at the peak of the circular velocity profile.

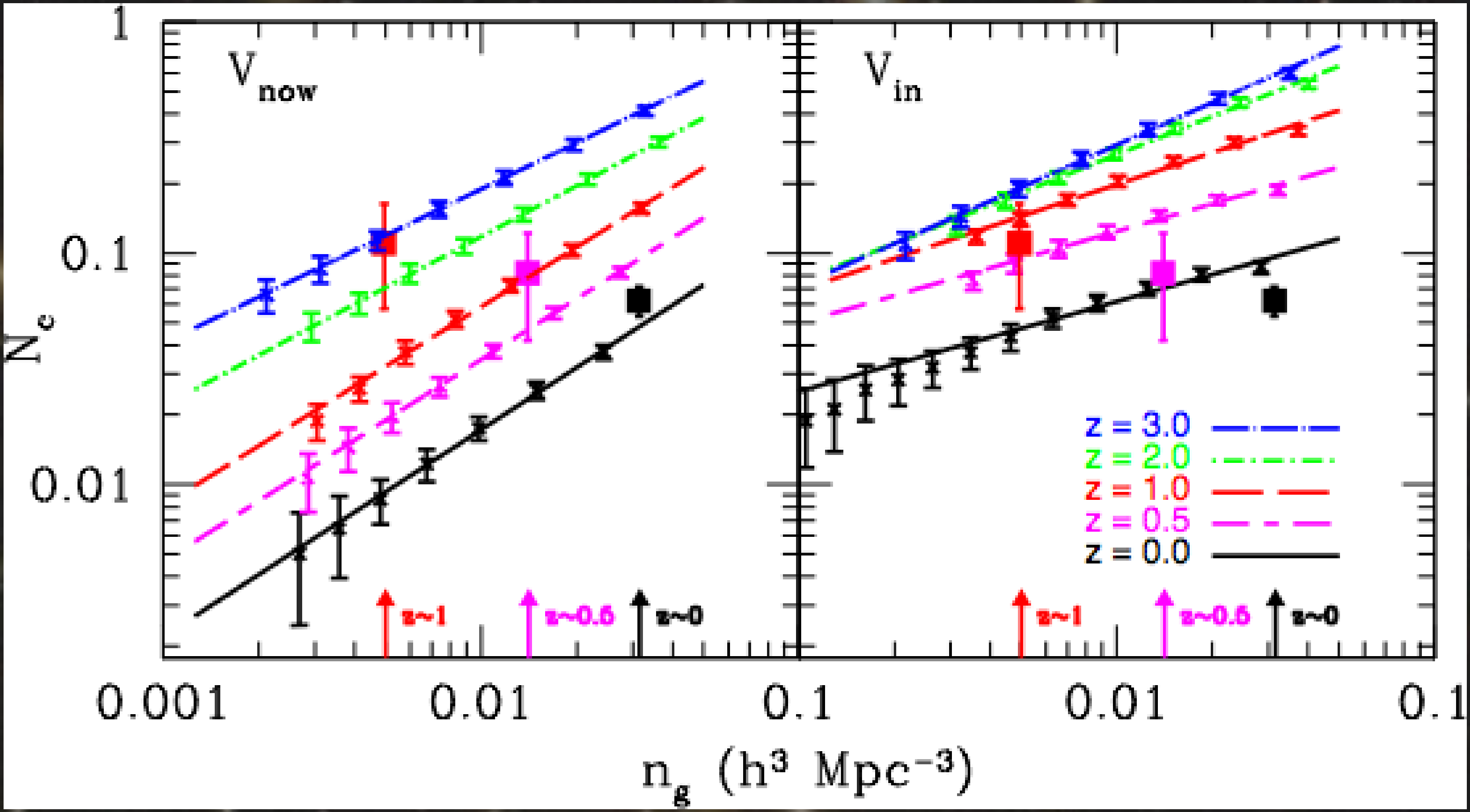
$$V_{\max} = \max\left\{\sqrt{\frac{GM(<r)}{r}}\right\}$$

- V_{now} model: uses the maximum circular velocity of the halo at the current epoch.
- V_{in} model: uses the maximum circular velocity of a subhalo before it is accreted into host.

Associating dark matter subhalos with galaxies…

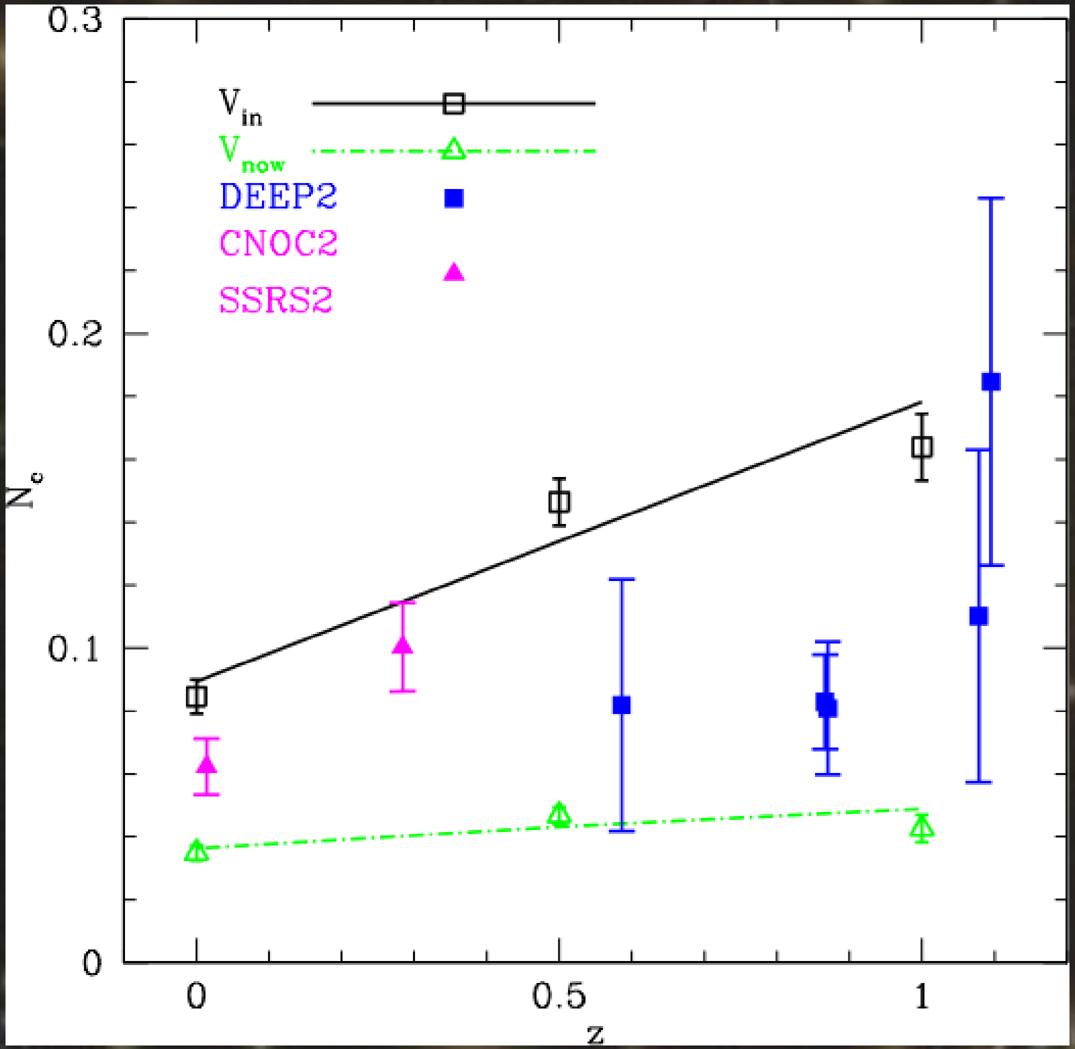
- We pick a simple one-to-one association between dark matter halos and galaxies based upon the V_{circ} of the halo.
- Number densities of halos are matched to the number densities of galaxies in the observational sample.
- V_{in} and V_{now} models produce different samples.





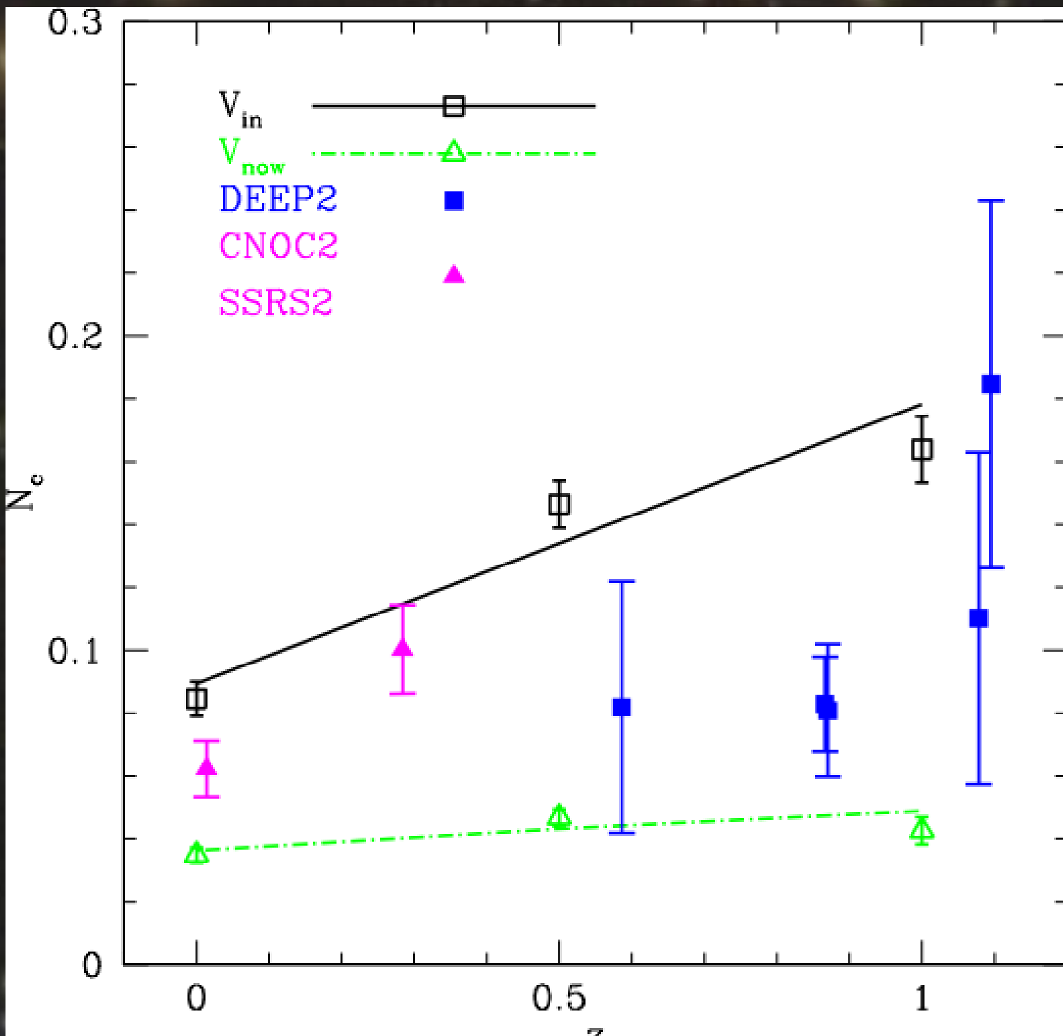
General Predictions for N_c with both number density and redshift.

Our model compared to DEEP2

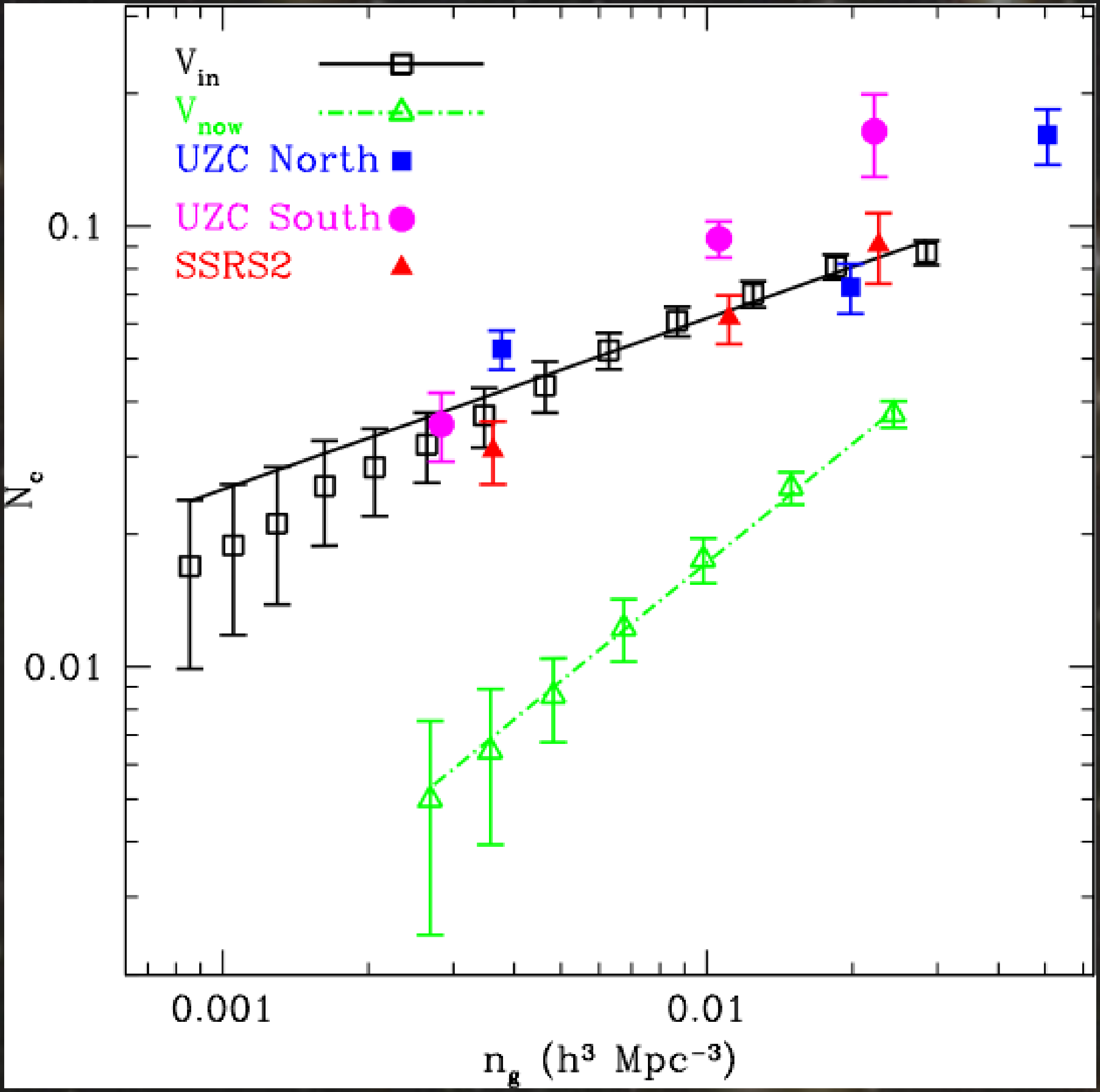


- Models predict weak evolution!
- DEEP2 Results are bracketed by models.

Our model compared to DEEP2

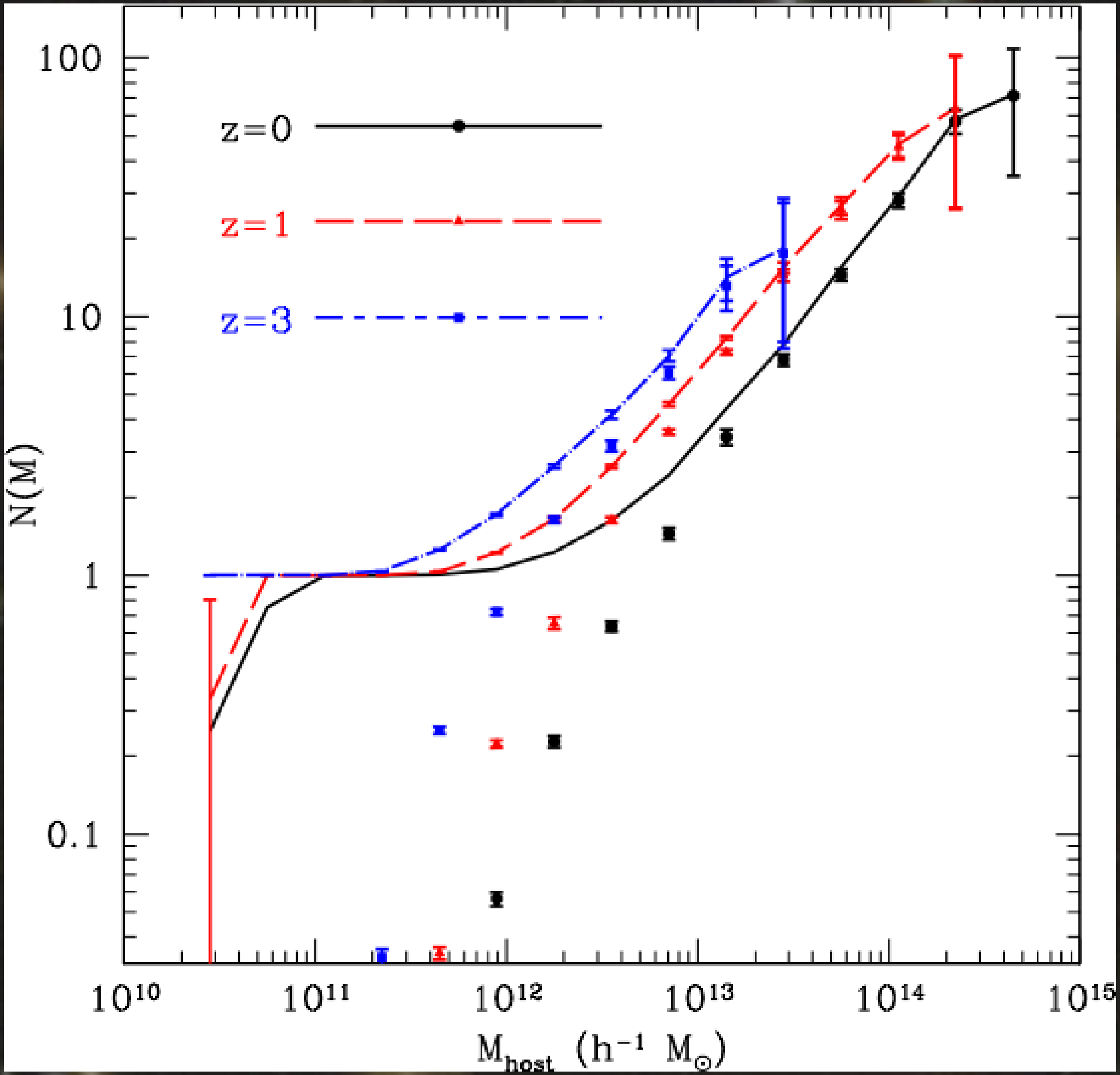


- Number densities matched to DEEP2 results.
- Both models show mild evolution
- V_{in} model has $m=0.99\pm0.14$
- V_{now} model has $m=0.42\pm0.17$

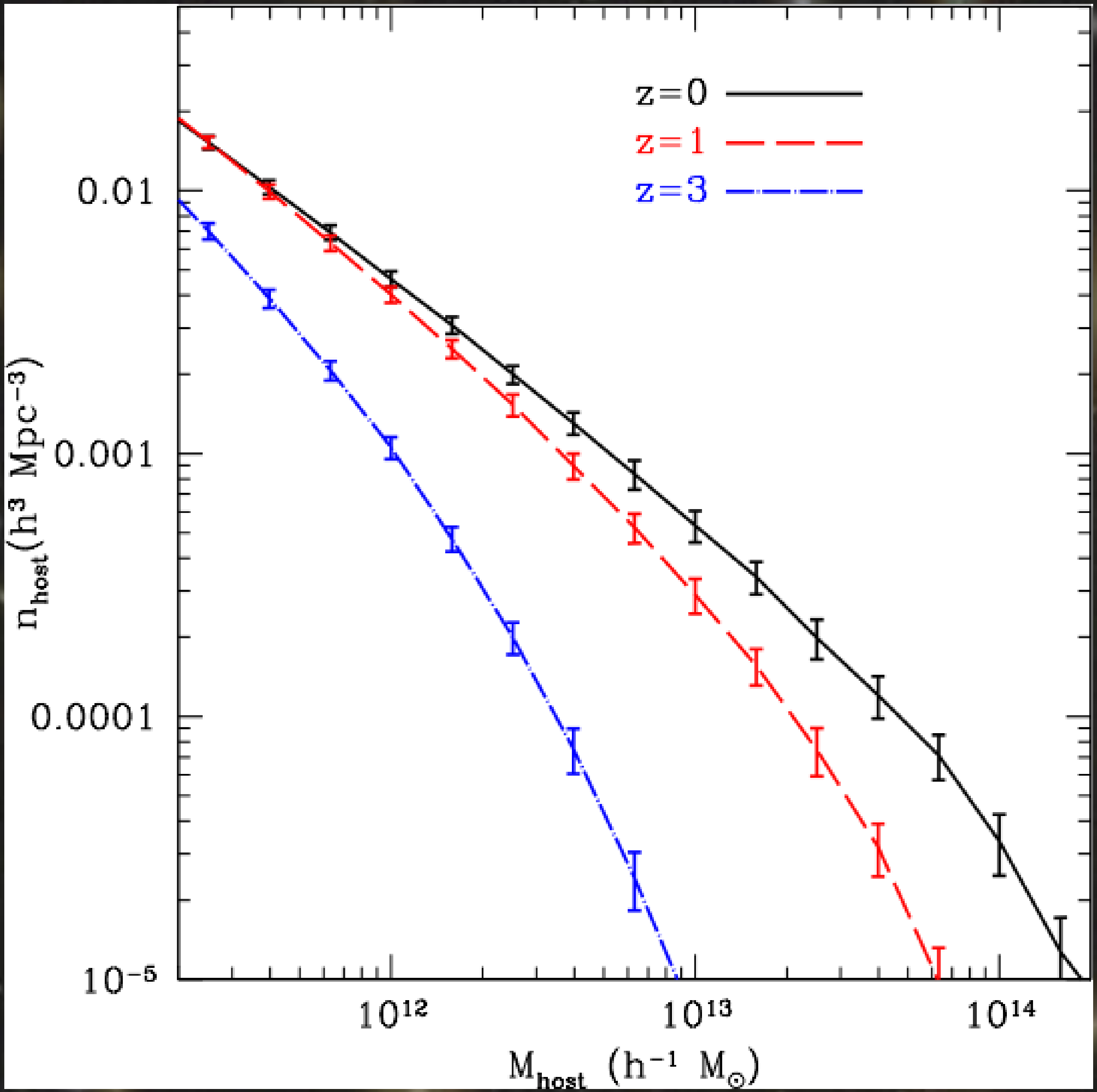


Test prediction that
Pair fraction should
Vary with n_g:
Compare to z=0 data.

Remarkable agreement!
V_{in} model favored.

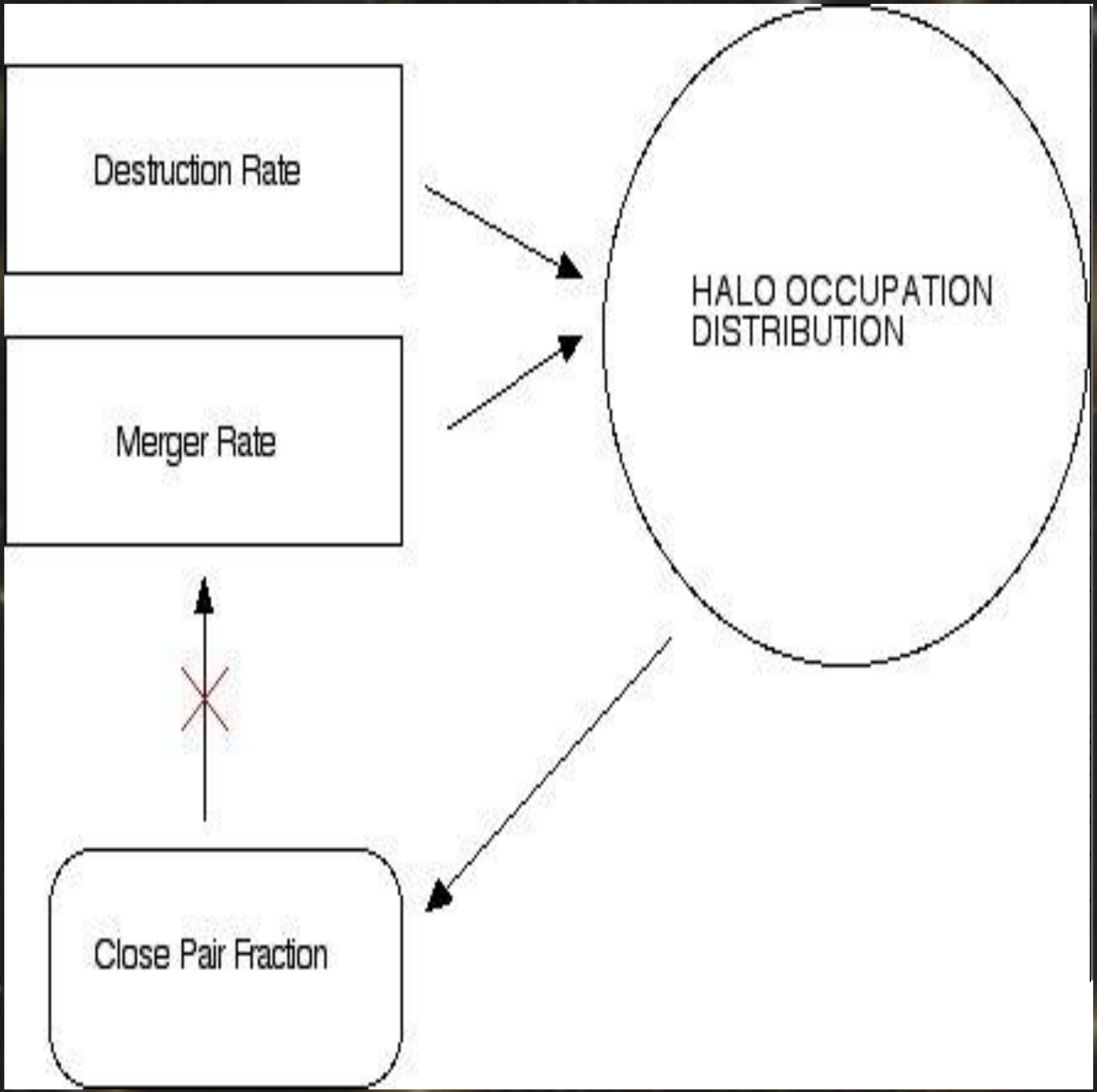


- Lines indicate the total distribution.
- Points indicate substructure only.
- Evolved to redshifts of 1 and 3.



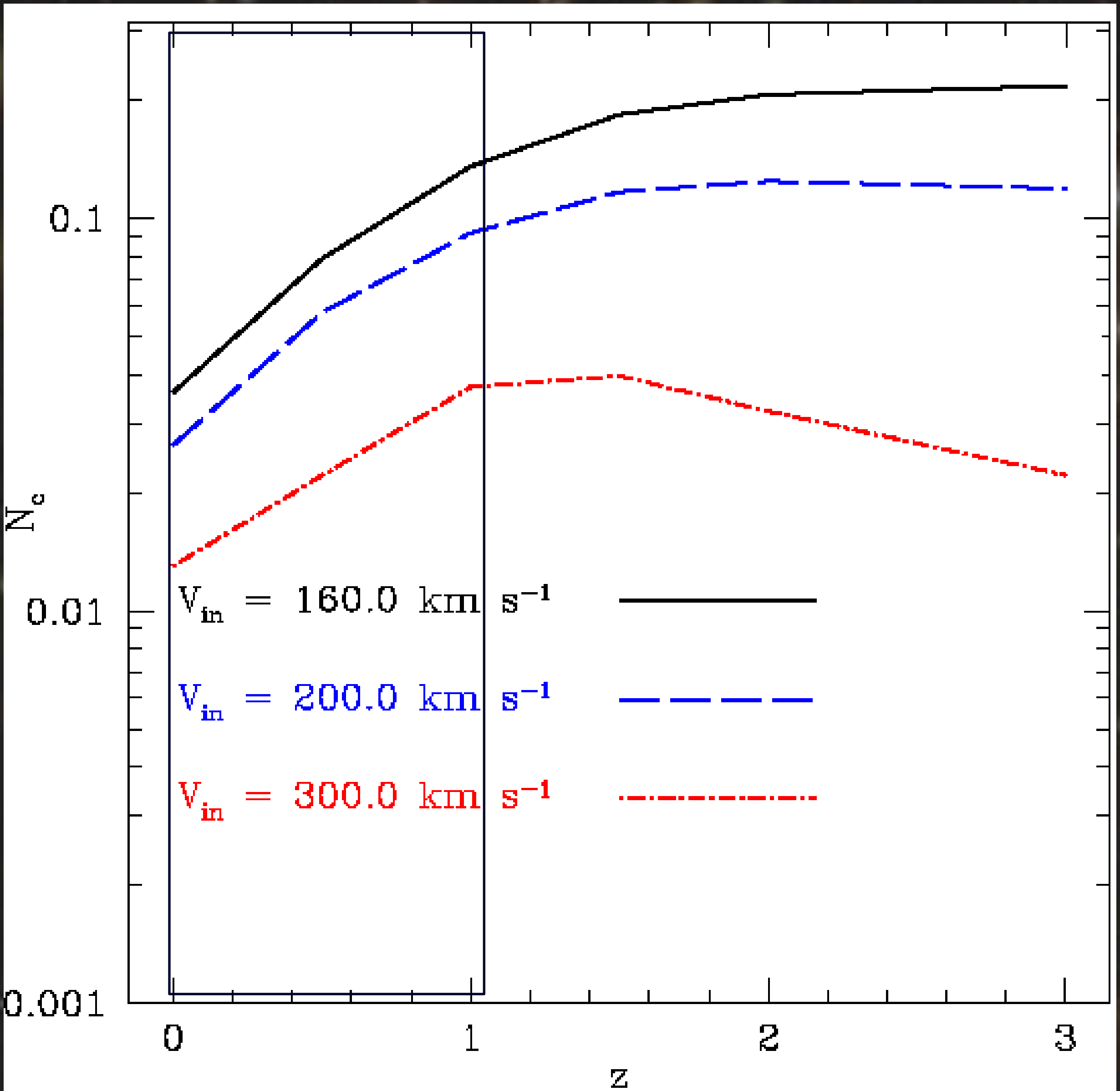
There is a greater amount of substructure at high z but fewer halos to host this substructure.

Close Pairs are set by the HOD, which is determined by two competing effects. They are the rate of accretion onto a host, and the rate of destruction of its substructure.



There is a greater amount of substructure at high z but fewer halos to host this substructure.

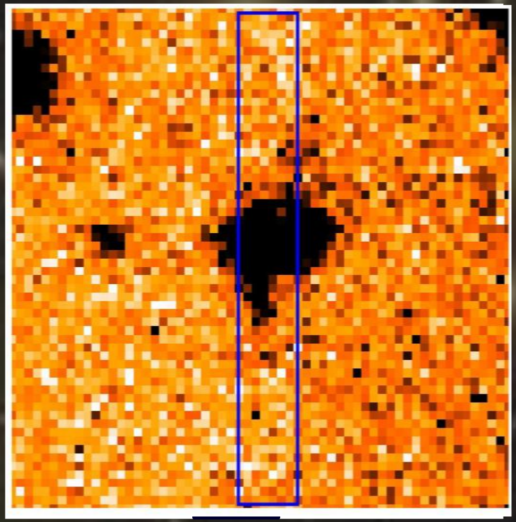
Close Pairs are set by the HOD, which is determined by two competing effects. They are the rate of accretion onto a host, and the rate of destruction of its substructure.



- Evolution using sample with fixed V_{in}
- Selects same kinds of object over all redshift bins

Measure z=3 lbgs

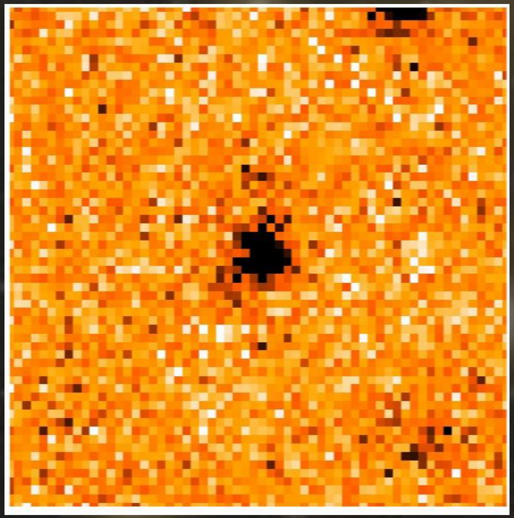
- Sample galaxies selected based on colors.
- Confirmed z~3 objects have spectra taken using long slits
- Simulations have parameters set by observational sample
- Total pair fractions for cylinders and slits are calculated.

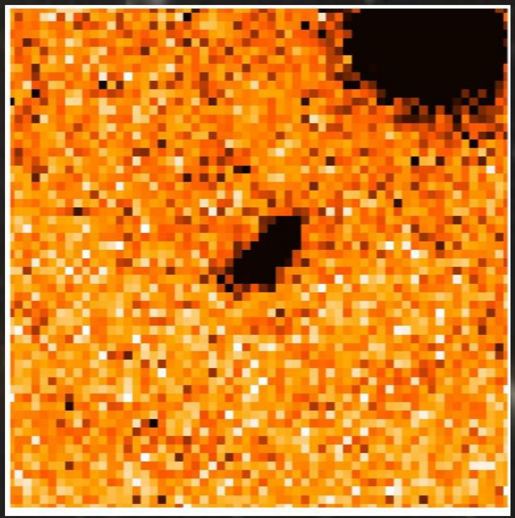


UCSD LBG-DLA z~3 survey

- Cooke et al. 2005 calibrated u'BVRI
- Instruments and telescopes - LRIS on Keck, COSMIC imager on Palomar
- Comparable to Steidel sample, calibrated UnGRI, Redshift distribution virtually identical between the two samples
- Photo-selection function is arguably better defined

- Typical Method





UCSD LBG-DLA z~3 survey

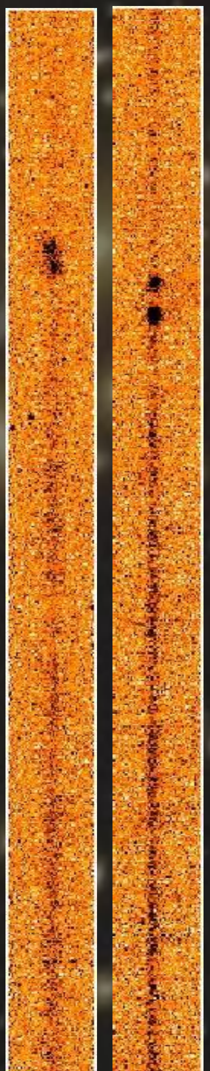
- Fields = 9
- DLAs = 11
- u'BVRI color selected z~3 R < 25.5 LBGs = 796
- Follow-up spectra = 329
- Confirmed z~3 LBGs = 211
- Pairs = 10

- n_{LBG} R < 25.5 ~ 4 x 10^{-3} h^3 Mpc^{-3}

- Luminosity functions of Sawicki & Thompson (Keck Deep fields II) and Steidel 1999, n_{LBG}=1 x 10^{-3} for R = 25.5 z~3 LBGs.

- Average dark matter mass of R < 25.5 LBGs at z ~3 determined from clustering is ~10^11.5 h^{-1} M_{sun}.

- Suggests V_{in} > 200 km/s

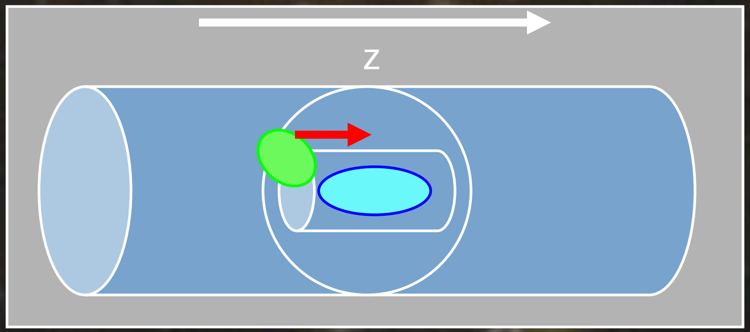


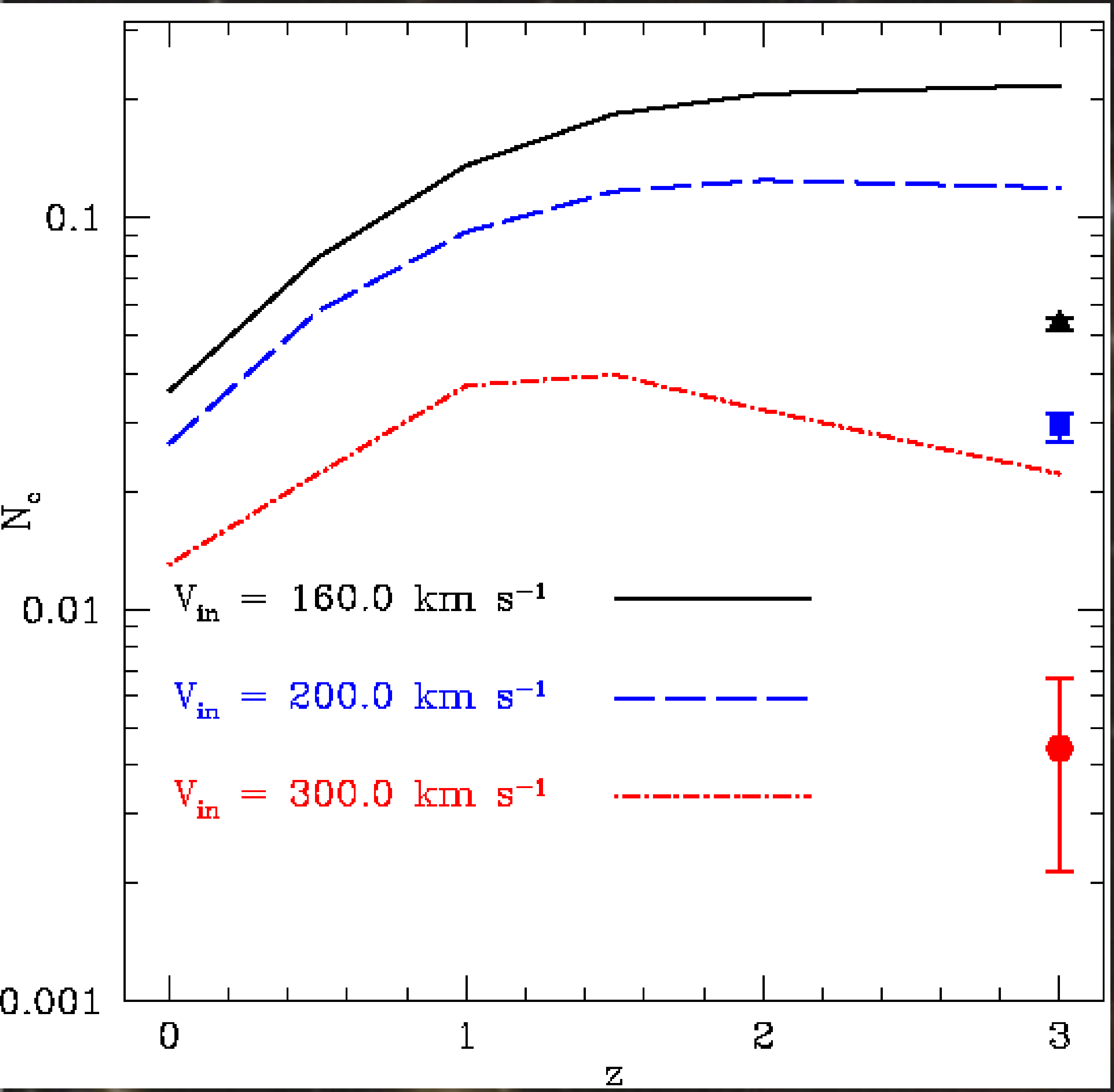
Simulating Observations of z=3 Pairs

- Simulations compared with high redshift pairs of LBG's at z=3.

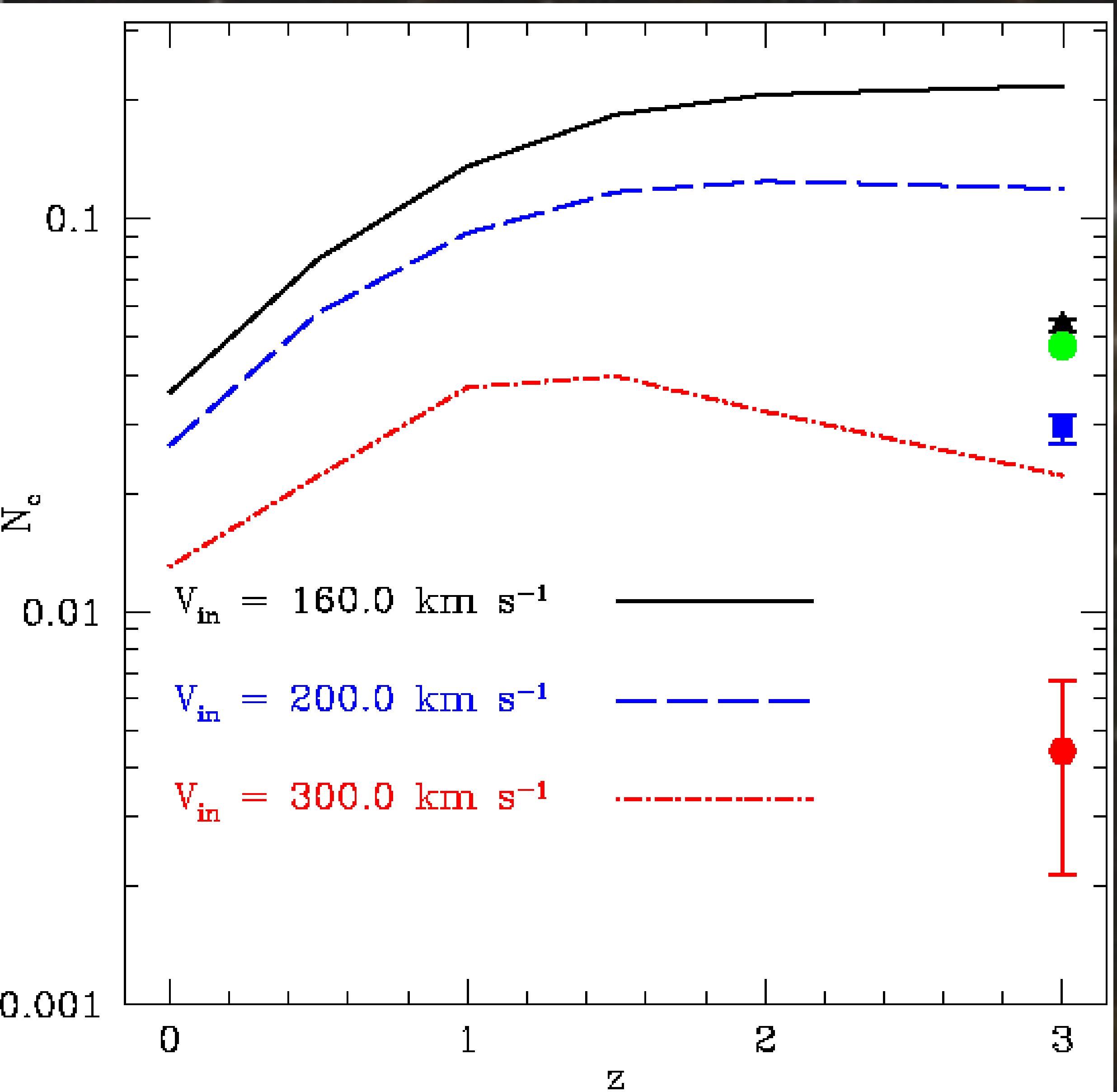
- Uses different set of parameters.

- between R_{min} = 3.85 h^{-1} kpc and R_{max} = 35 h^{-1} kpc physically.
- A line of sight velocity separation of $|\Delta V_{max}| \leq 550$ km s^{-1}.
- If object has $R < R_{min}$ we accept if $|\Delta V_{max}| > 100$ km s^{-1}



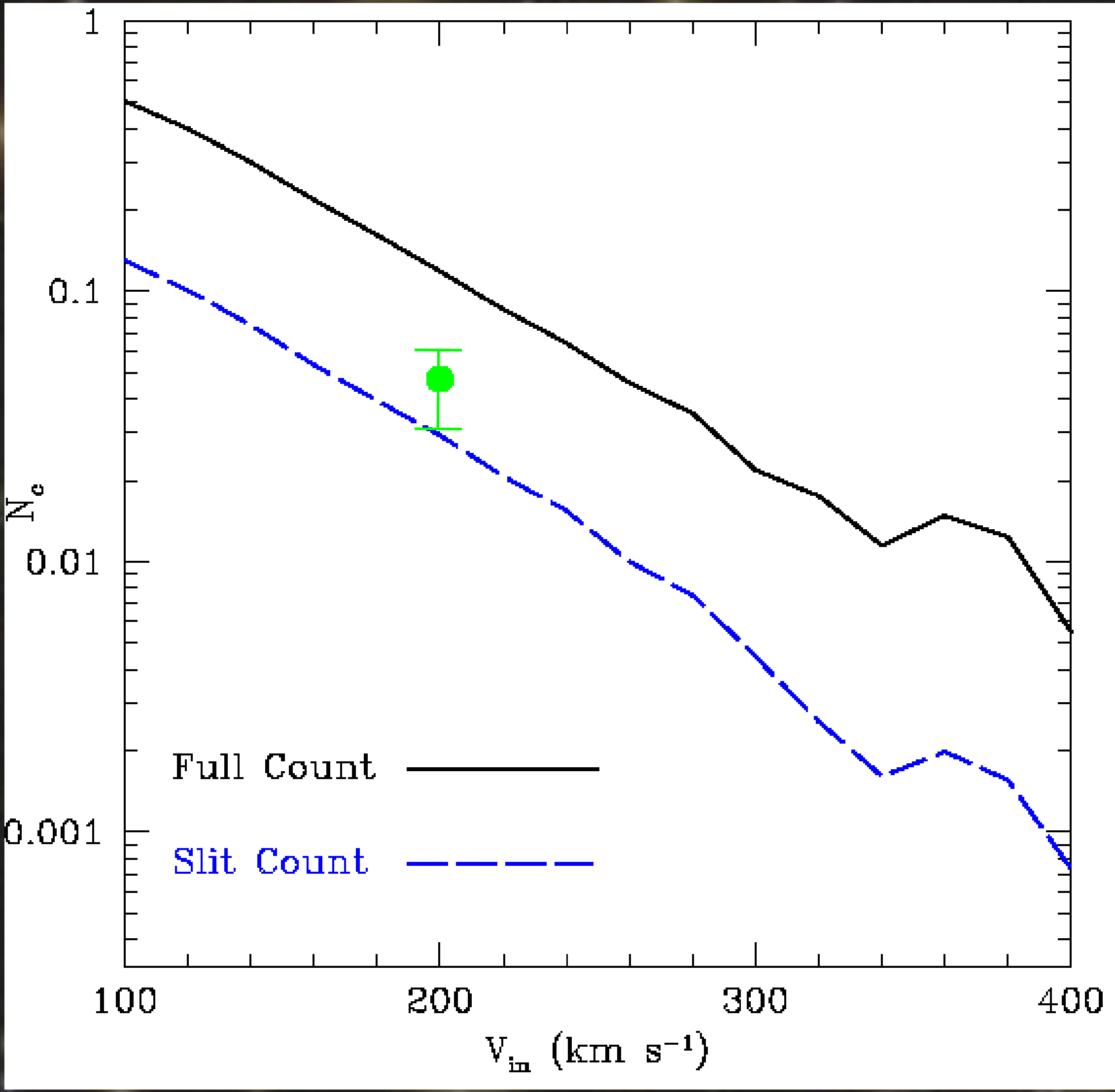


- Sample evolution using spectroscopic sample parameters.
- Points are simulation predictions for samples seen in randomly oriented slits at z=3.



- Sample evolution using spectroscopic sample parameters.
- Points are simulation predictions for samples seen in randomly oriented slits at z=3.
- Green point is observational sample
- Slits in observations were not randomly oriented

Z=3 Galaxy Pairs predictions



Pair Fraction evolution with V_{in}

Conclusions for the Study of Pairs

- Models naturally produce the "weak" evolution observed.
- V_{in} model favored by observational results from SSRS2 and UZC surveys.
- N_c does not track distinct dark matter halo mergers.
- Close Pair statistics provide a constraint on the galaxy HOD, by providing a test for models of galaxy formation on scales <100 kpc.

Conclusions for the Study of Pairs

- Model predicts the z=3 lbg pair fraction!
- Observed slit pair fractions ~5% => Measured pair fraction of ~20%
- z=0 Pair fraction for similar sample ~4% => factor of 5 increase at z=3.

Outline

I. Close Galaxy Pairs

II. Cluster Assembly

Origin of Morphology-Density Relation in Clusters?

- ~60% of cluster galaxies are early type galaxies, only 30% early type galaxies in the field (value depends on mass and density).

- Current results for where this trend is set, in the group scale or in the cluster itself, are conflicting (Ellingson et al. 2001, Zabludoff 2002).

- Possible processes which may set this relation:
    - Preprocessing in groups
    - Major mergers
    - Cluster processes (e.g. Harassment, ram pressure stripping)

Postman et al. 2005, Oemler 1974, Butcher and Oemler 1978, Dressler 1980, Dressler et al. 1997, Poggianti et al. 2006, Capak et al. 2007

Simulations

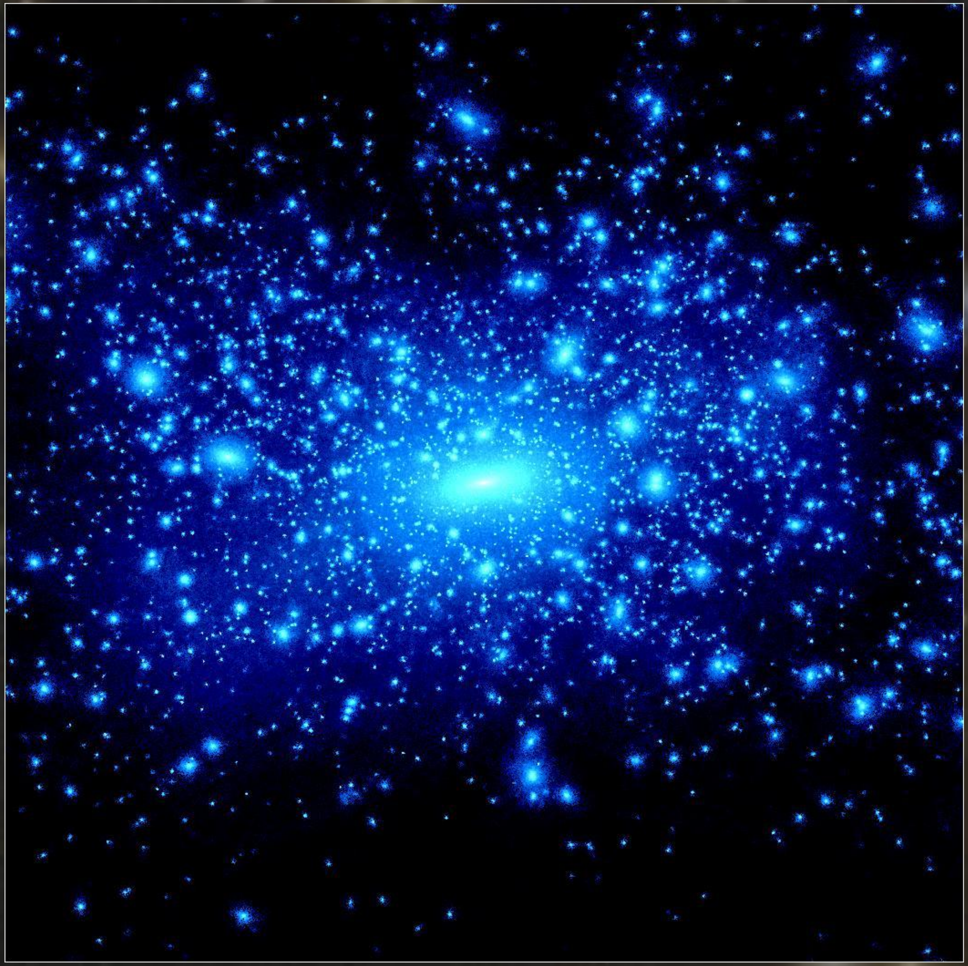


Image Courtesy of A. Klypin http://astronomy.nmsu.edu/aklypin/

We use well understood N-body CDM simulations to track the merger histories of cluster sized halos.

Standard Cosmology
$\Omega_m=1-\Omega_\Lambda=0.3$
$\sigma_8=0.9$
$h=0.7$

$120\ h^{-1}$ Mpc
$80\ h^{-1}$ Mpc

512^3 particles

Study the assembly of 53 clusters with masses between $10^{14} - 10^{14.76}\ h^{-1}\ M_{sun}$

Sample is complete to $10^{11}\ h^{-1}\ M_{sun}$

Associating dark matter subhalos with galaxies…

- Sample of 53 cluster sized halos

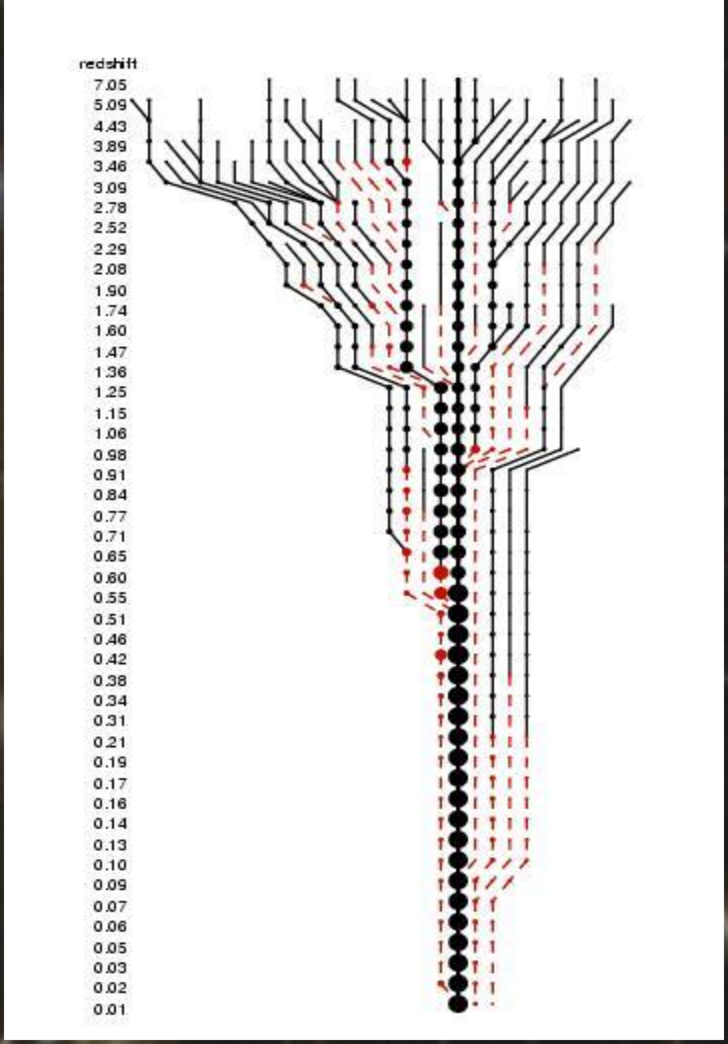
- Assume a simple one-to-one association between dark matter halos and galaxies.

- Association based upon the mass of the dark matter subhalo and the number density of halos.

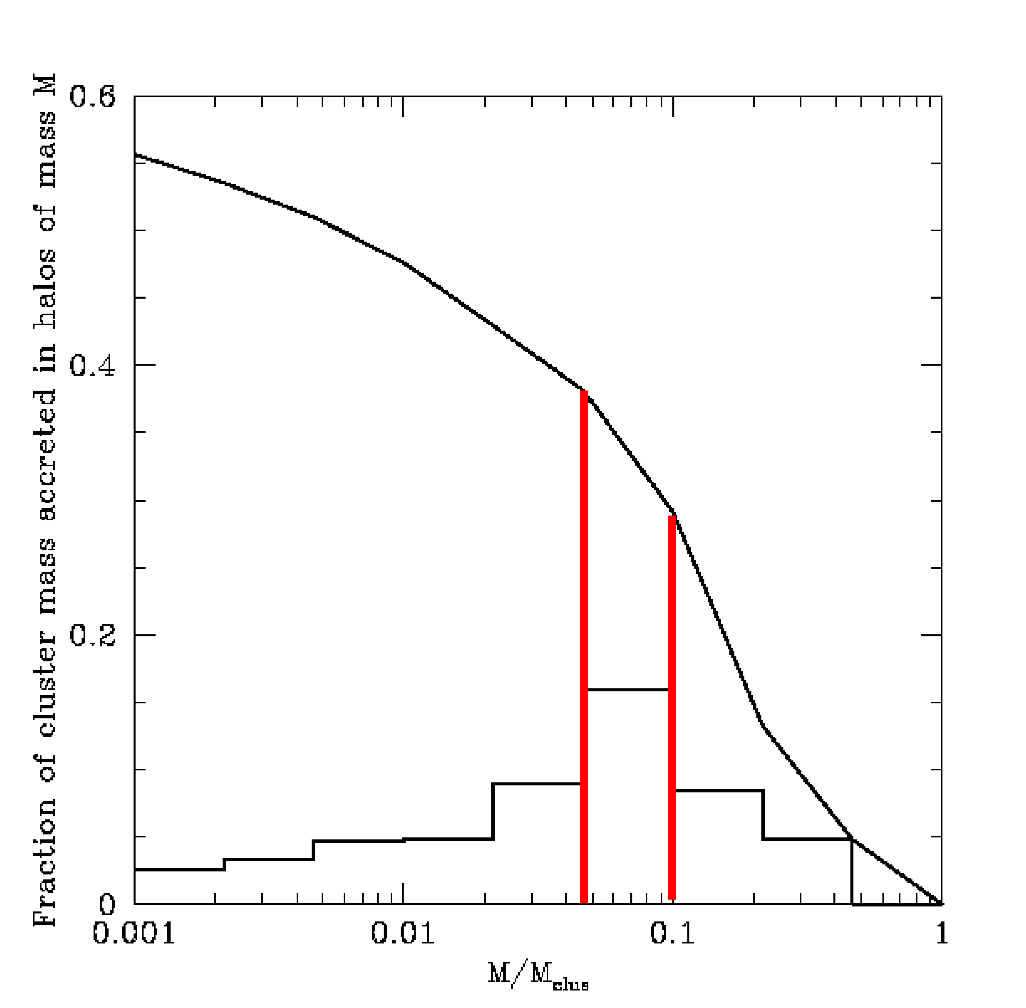
- Luminosities >= 0.1 L*.

- Track the merger histories

- Halos in sample must have an infall mass, $M_{in} \geq 10^{11.5}\ h^{-1}\ M_{sun}$ and have a final mass $M_{crit} \geq 10^{11}\ h^{-1}\ M_{sun}$.



Stewart et al 2007



Well known that the majority of a dark matter halos mass accreted from objects ~5-10% of the final dark matter halo size.

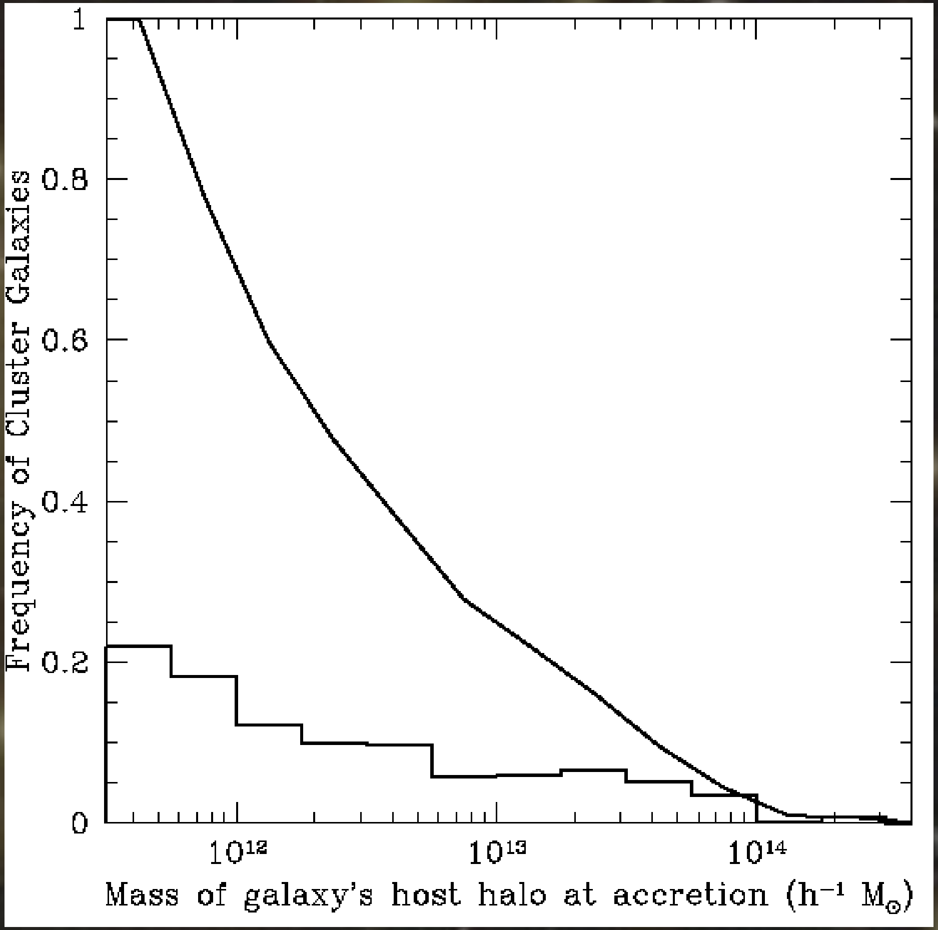
e.g. a 10^{14} h^{-1} M_{sun} cluster builds mass from 10^{13} h^{-1} M_{sun} groups.

Do we expect similar results for the cluster galaxies themselves?

Lacey and Cole 1993, Zentner and Bullock 2003, Purcell et al 2007, Stewart et al 2007

How were cluster galaxies accreted?

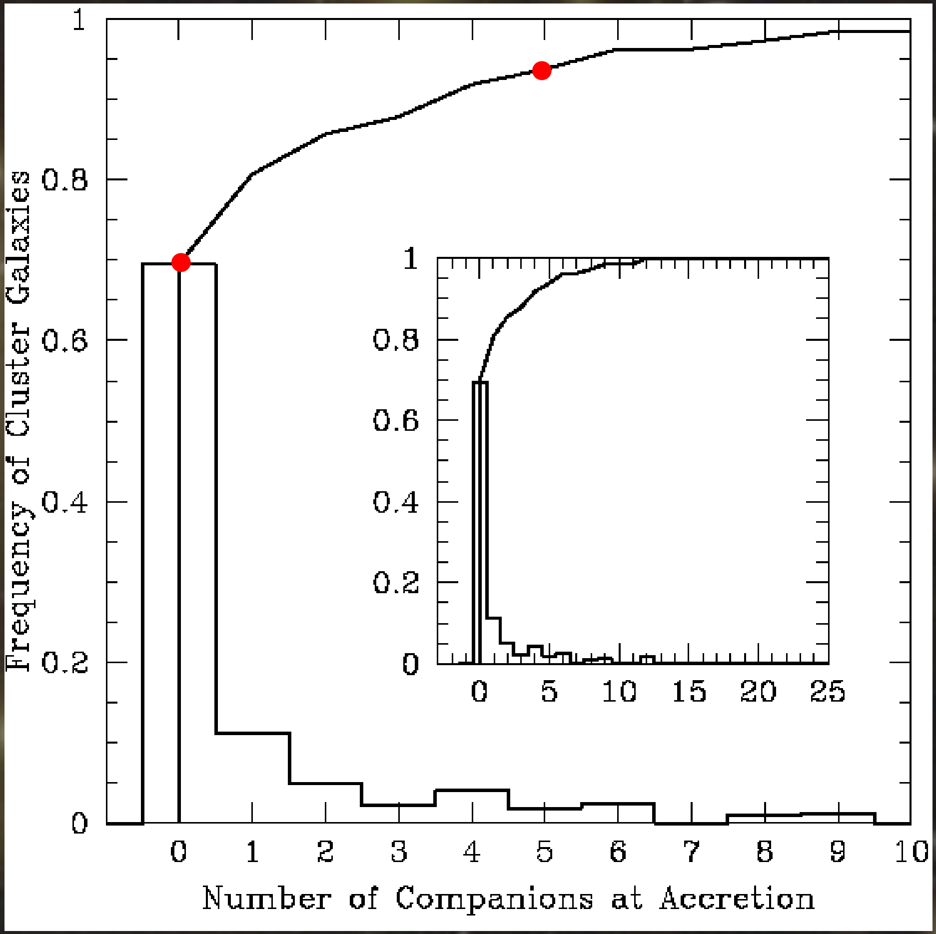
- Only 25% accreted from group mass objects



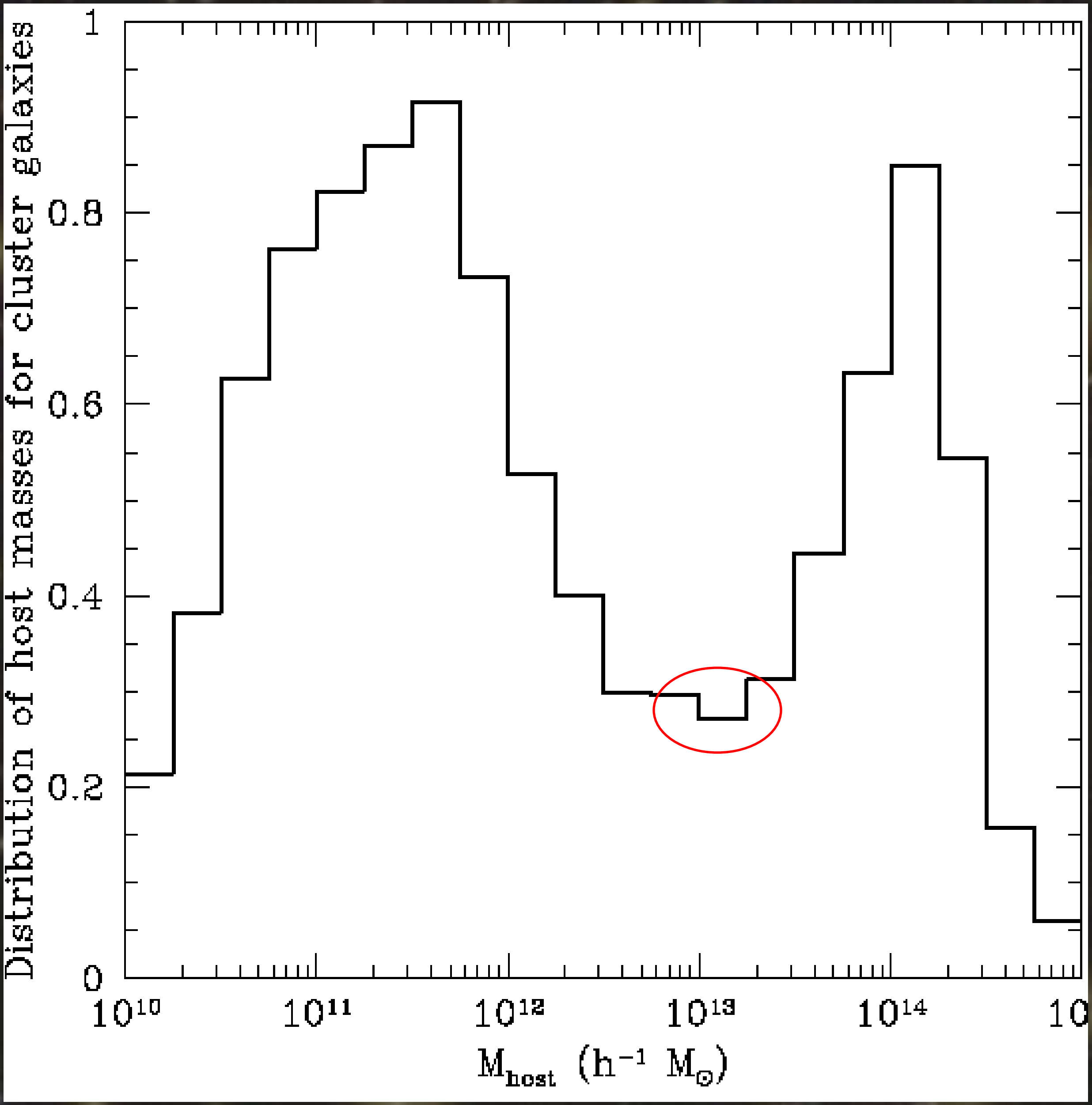
Mass comes from groups.
Galaxies come from field.

How were cluster galaxies accreted?

- Only 25% accreted from group mass objects
- ~ 70% accreted from field
- ~ 93% accreted with 5 or fewer companions.



Mass comes from groups.
Galaxies come from field.



Fraction of cluster galaxies in our sample which have spent any time in the given mass regime.

Note that most galaxies have not spent any time in the group mass region.

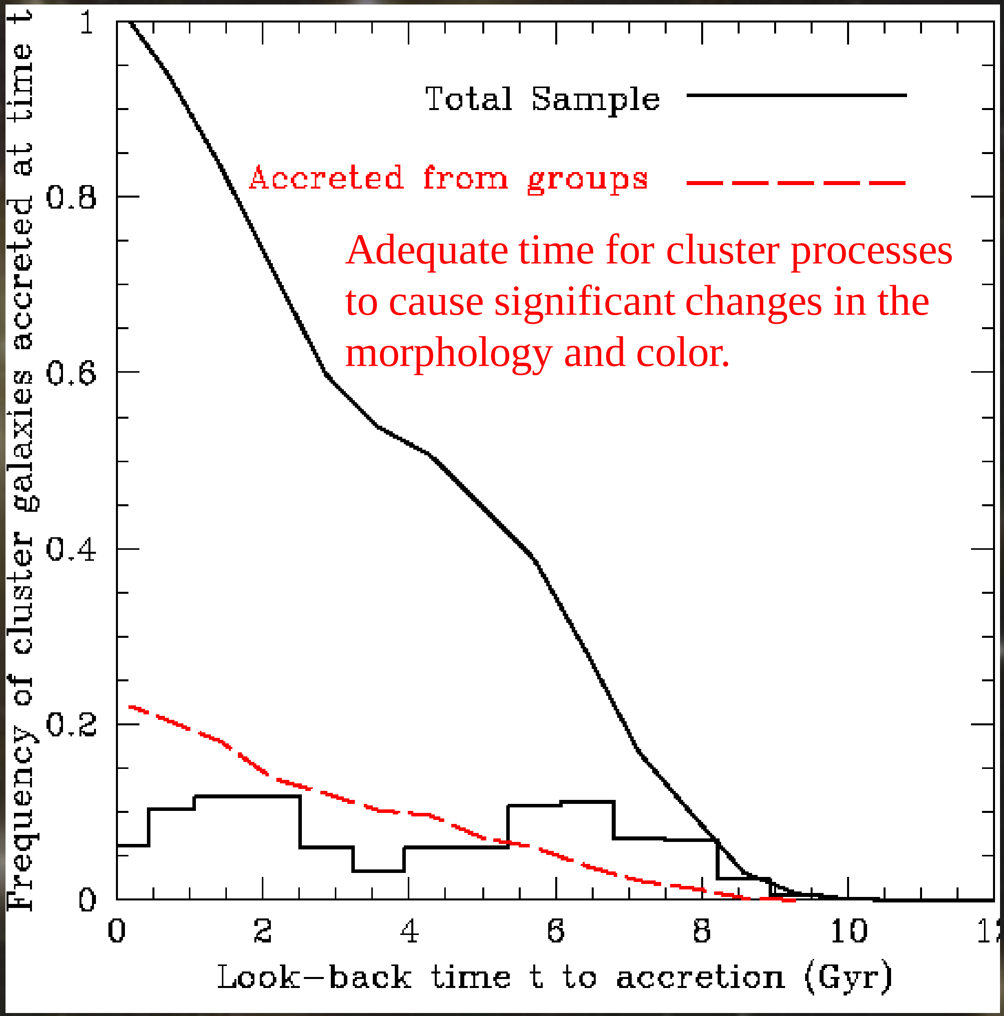
Accretion time

- The cluster galaxies have a uniform accretion history.

- ~40% of cluster galaxies were accreted over 6 Gyr ago.

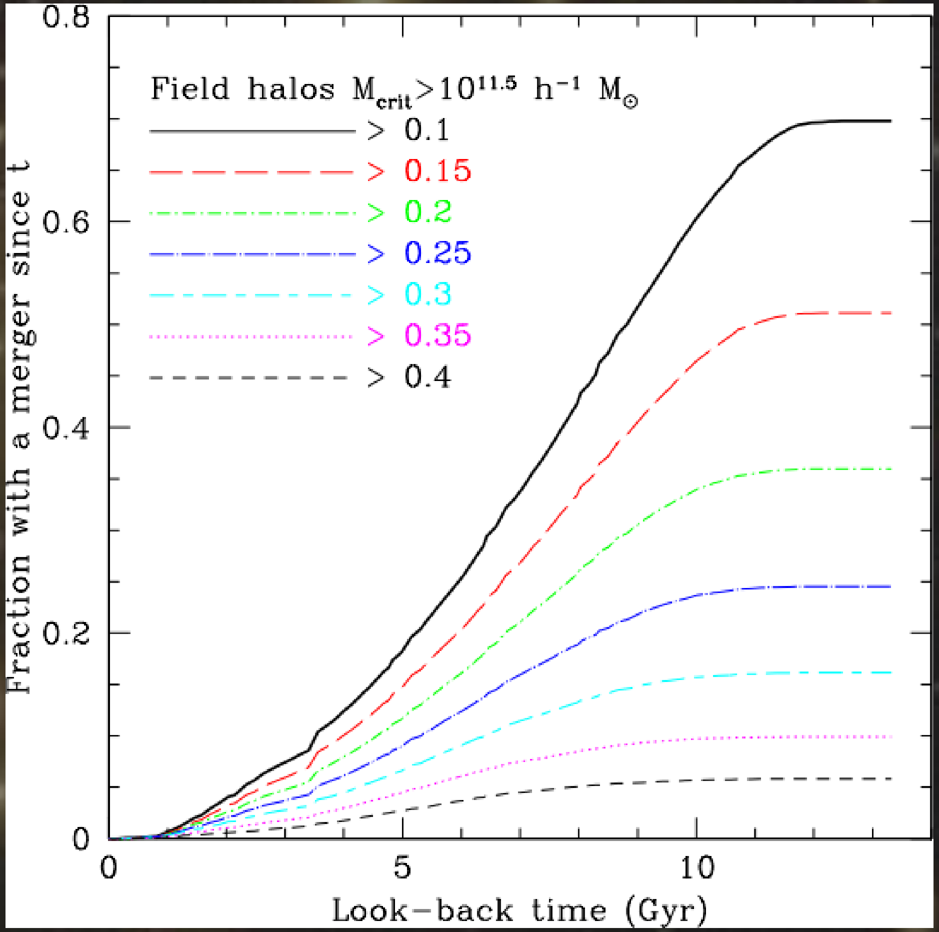
- Median accretion time is ~4 Gyr ago.

- ~25% of galaxies accreted from groups



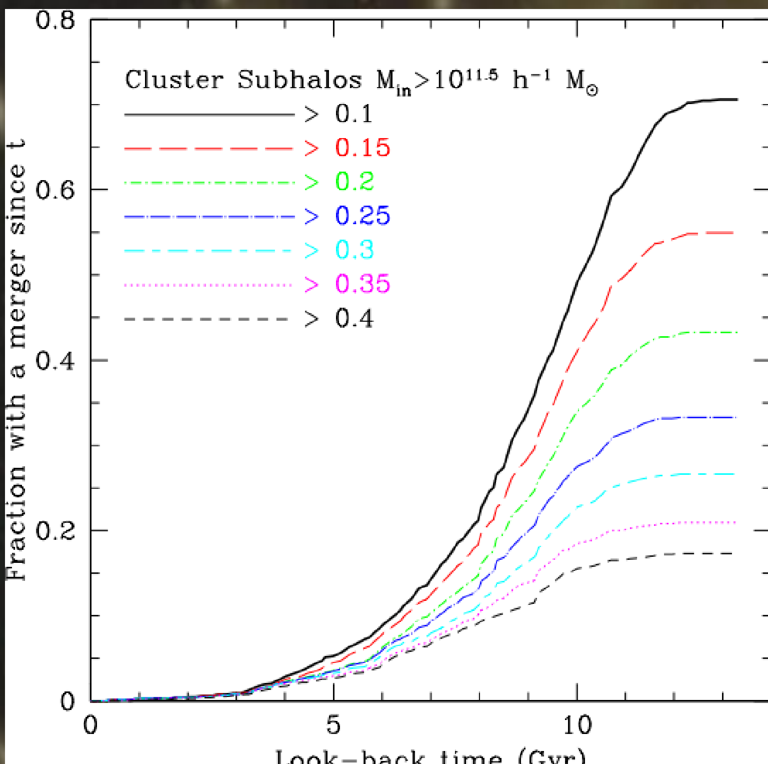
Are mergers more common in clusters than in the field

Possible to associate the early types in the field with 1/10 mergers in last 6 Gyr.

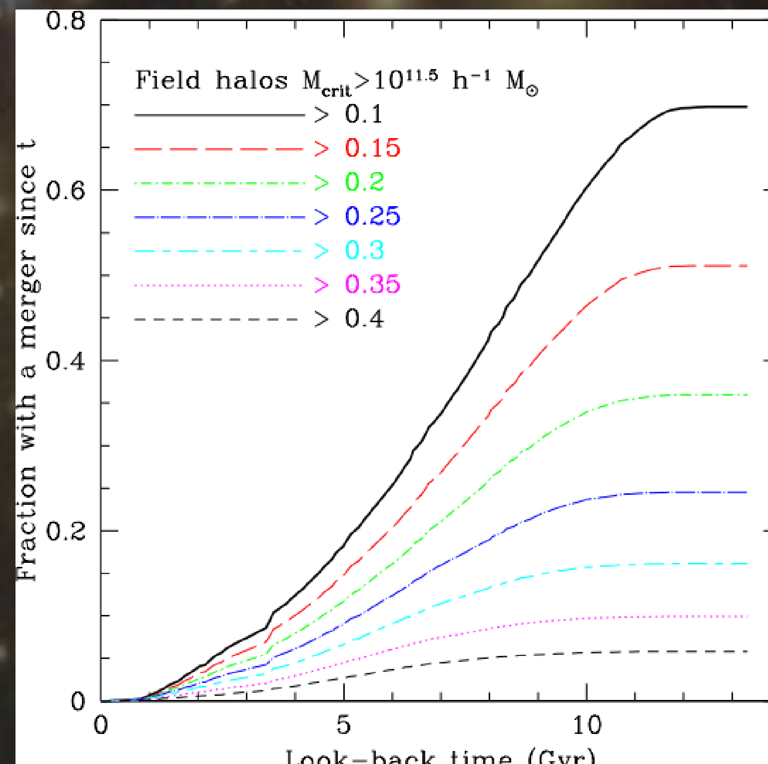


Are mergers more common in clusters than in the field

Cluster galaxies experience fewer mergers.



Suggests mergers don't drive morphology-density relation.



Conclusions for the study of Cluster Assembly

The literature suggests that 60% of cluster galaxies are early type.

By examining the accretion histories of clusters in high resolution N-body simulations we have found:

- On average ~70% of cluster galaxies fall into the cluster from the field.
- Only ~25% of cluster galaxies spend any time in groups.
- ~93% of cluster galaxies were accreted with fewer than 5 companions.
  - Suggests little preprocessing in group environments.
- Cluster galaxies less likely to have mergers
  - Suggests merger don’t drive morphology-density relations in clusters.
- Uniform accretion history with median accretion ~4 Gyr ago
  - Ample time for cluster processes to affect galaxies (harassment, stangulation, ram-pressure, etc).

This work supports a model in which the morphology-density relation is set in the cluster environment.