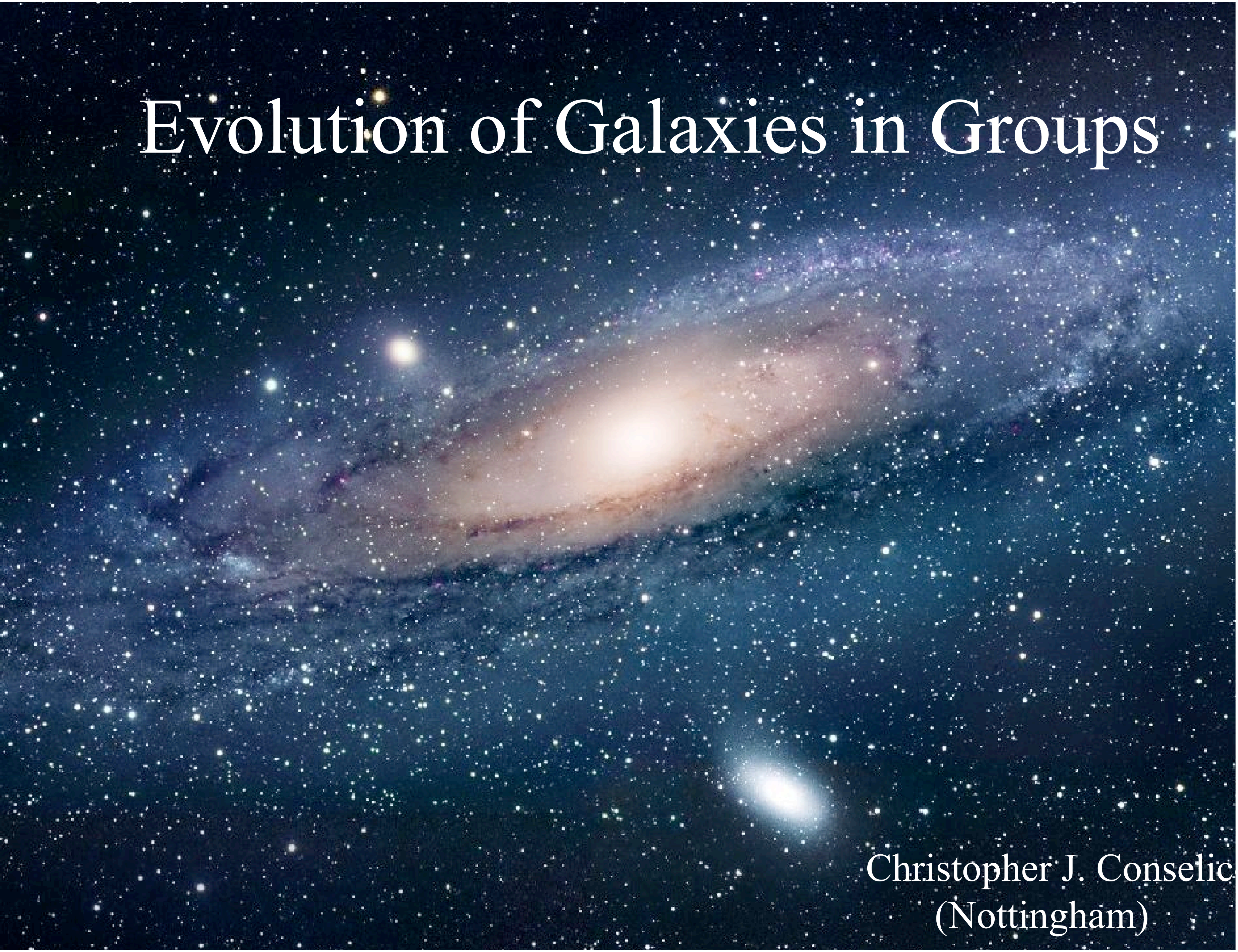


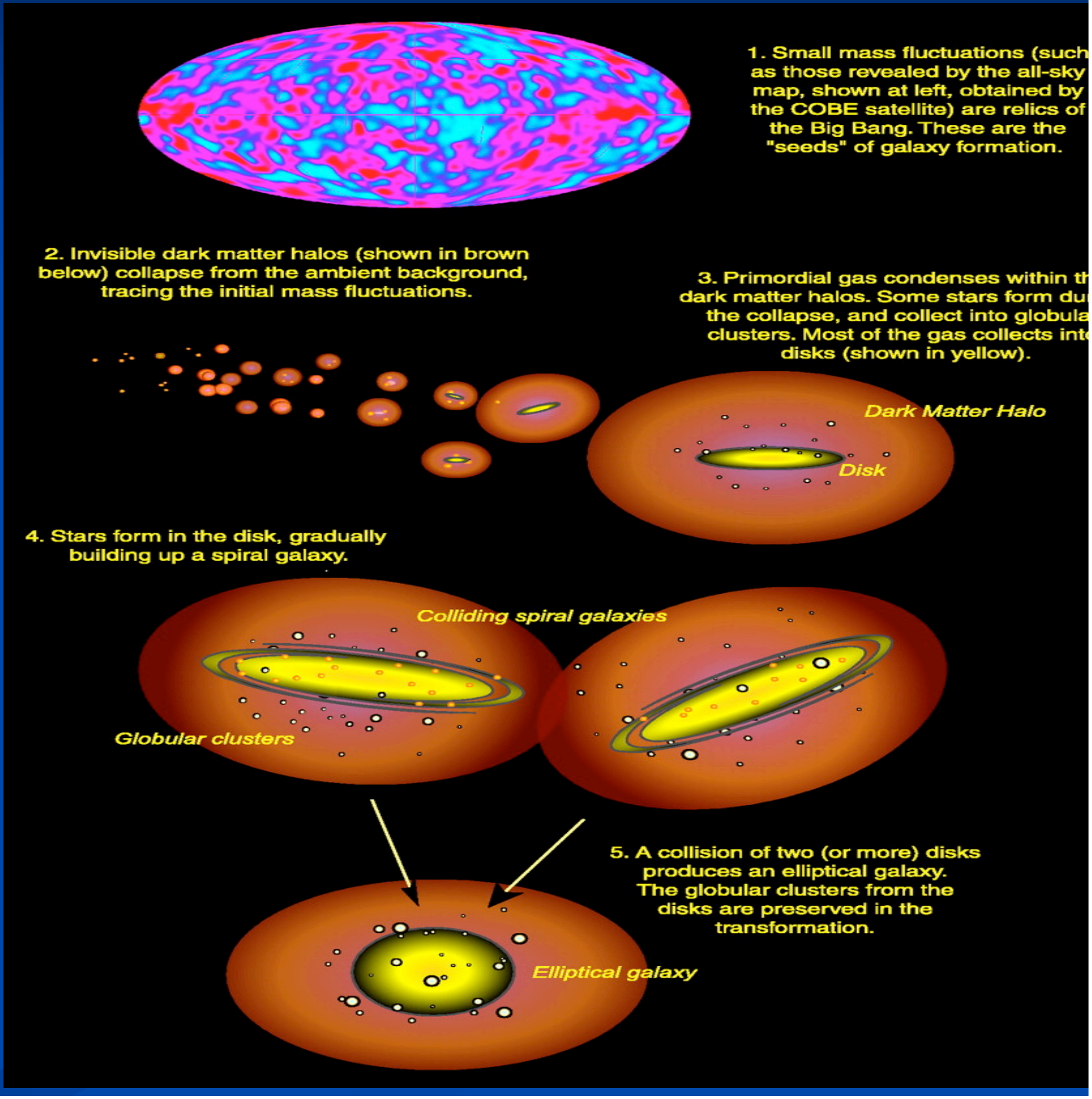
Evolution of Galaxies in Groups

Christopher J. Conselice
(Nottingham)

How we think galaxies form

Role of environment
in driving this evolution,
as opposed to internal
processes is currently
unknown

However, most evolution and merging likely occur in group-like environments



1. Small mass fluctuations (such as those revealed by the all-sky map, shown at left, obtained by the COBE satellite) are relics of the Big Bang. These are the "seeds" of galaxy formation.

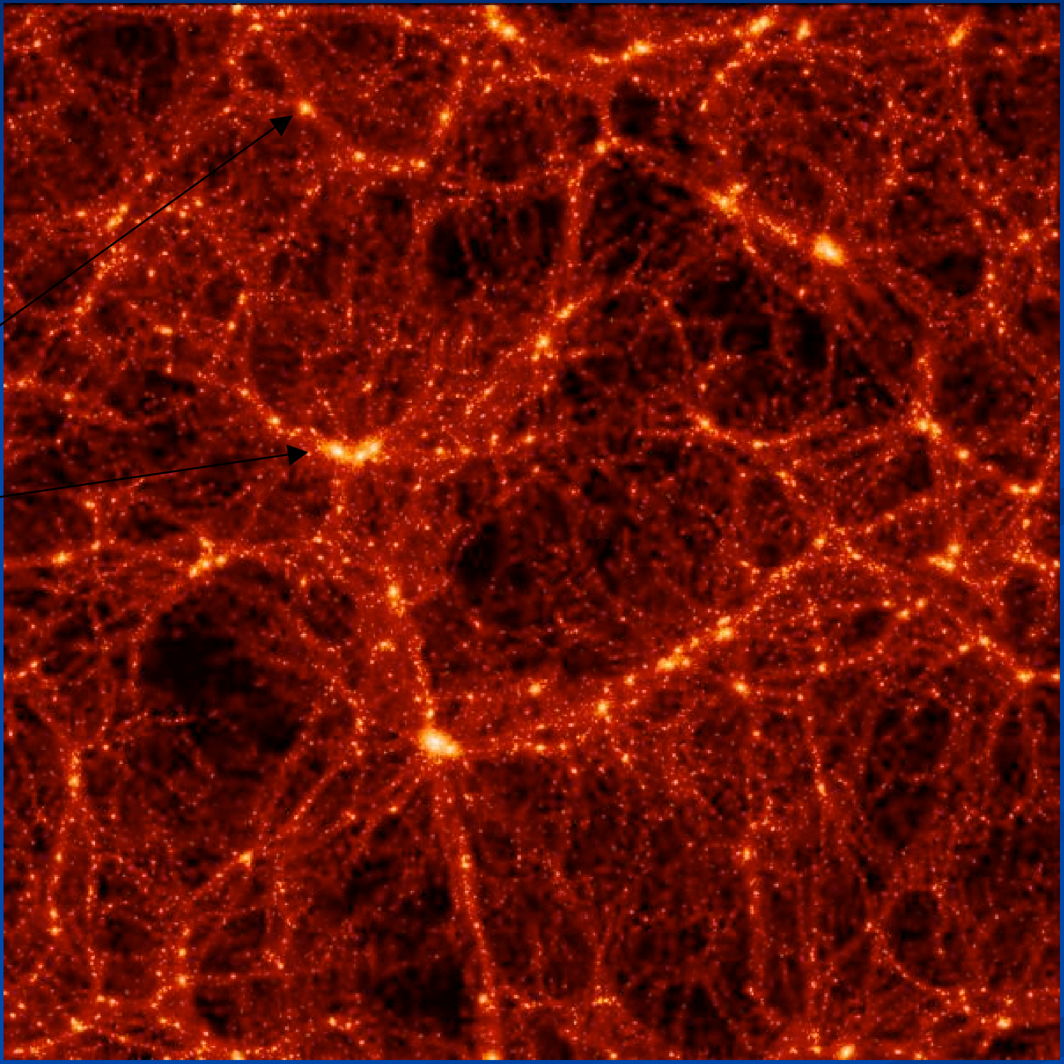
2. Invisible dark matter halos (shown in brown below) collapse from the ambient background, tracing the initial mass fluctuations.

3. Primordial gas condenses within th
dark matter halos. Some stars form du
the collapse, and collect into globula
clusters. Most of the gas collects int
disks (shown in yellow).

4. Stars form in the disk, gradually building up a spiral galaxy.

5. A collision of two (or more) disks produces an elliptical galaxy. The globular clusters from the disks are preserved in the transformation.

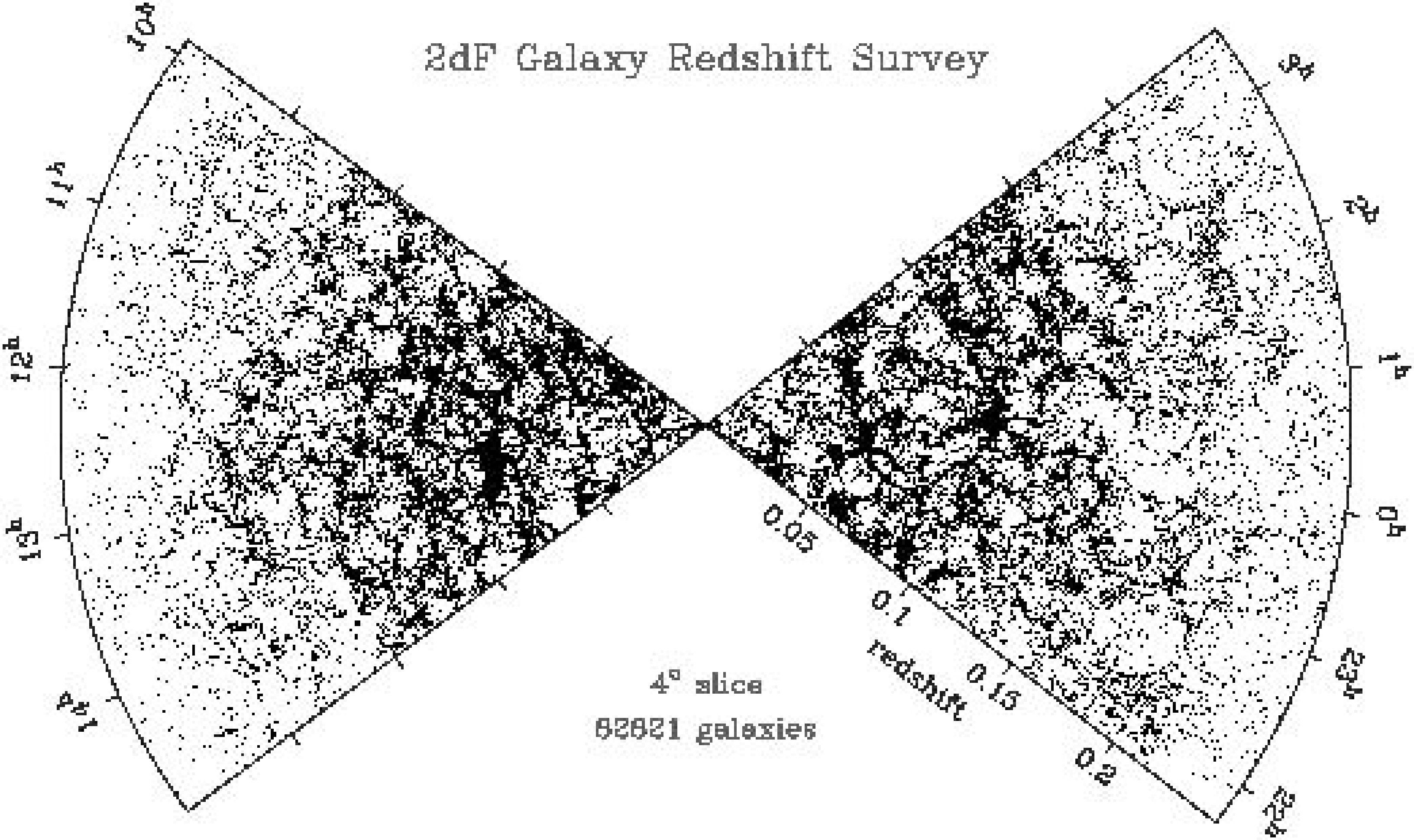
Within Cold Dark Matter theory galaxies strongly cluster



Forming groups
and clusters

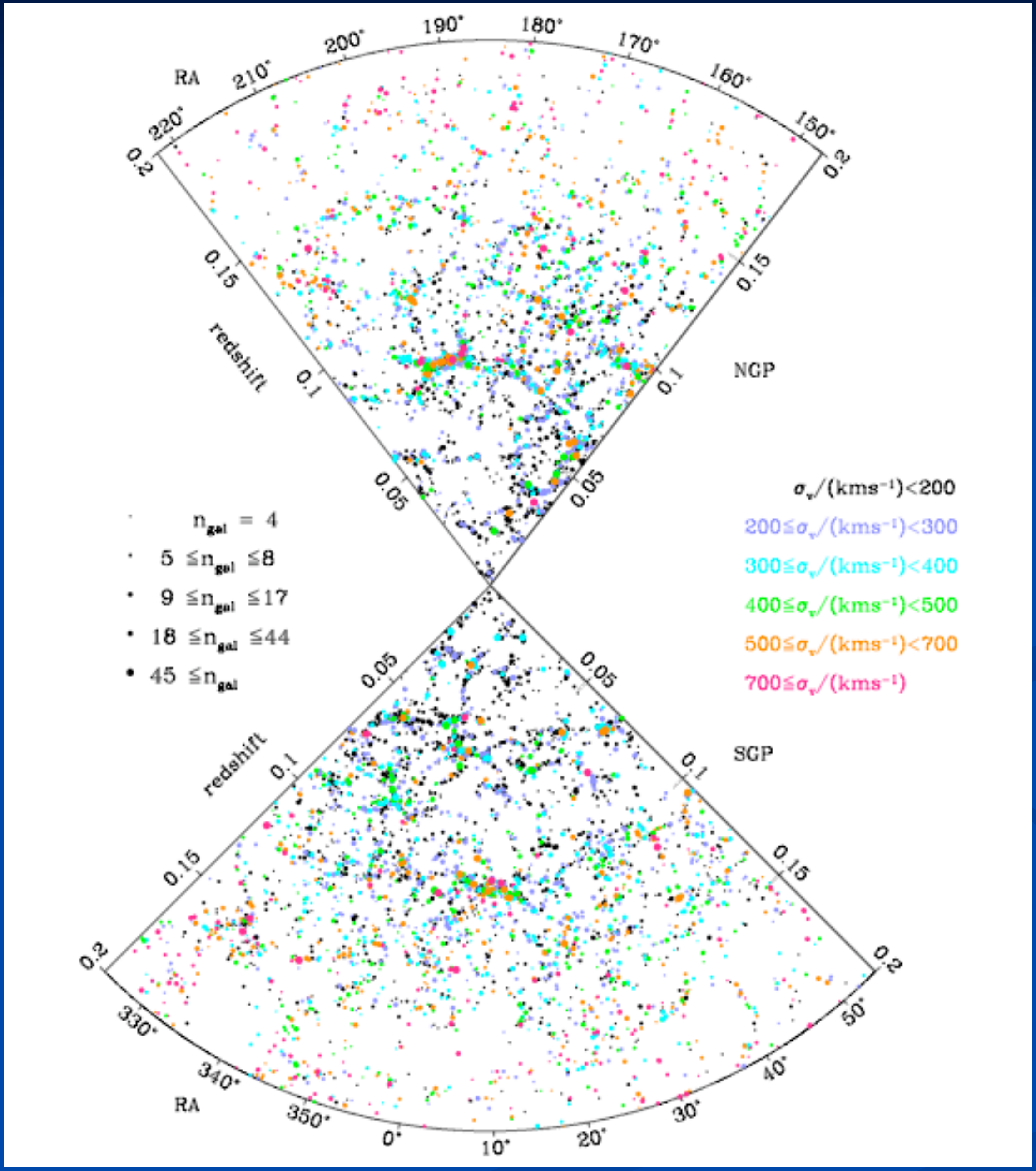
Virgo consortium simulation (Jenkins et al. 1998)

This clustering is directly observable and agrees with CDM models to a high degree



See this type of structure at low redshifts up to z~0.2 in the 2dFGRS and in Sloan

Most of this clustering is due to groups of galaxies



Eke et al. (2004)

Galaxy groups in the 2dFGRS

Properties of Galaxy Groups

a) Sizes ~ 0.5-2 Mpc with < 50 members

b) Velocity dispersions from ~100 km/s to ~400 km/s
with total halo masses between 10^{13} and 10^{14} M_0

c) Group morphology - varies from cluster like to field-like

d) > 50% of all galaxies in nearby universe are in groups
and thousands of groups can now be studied

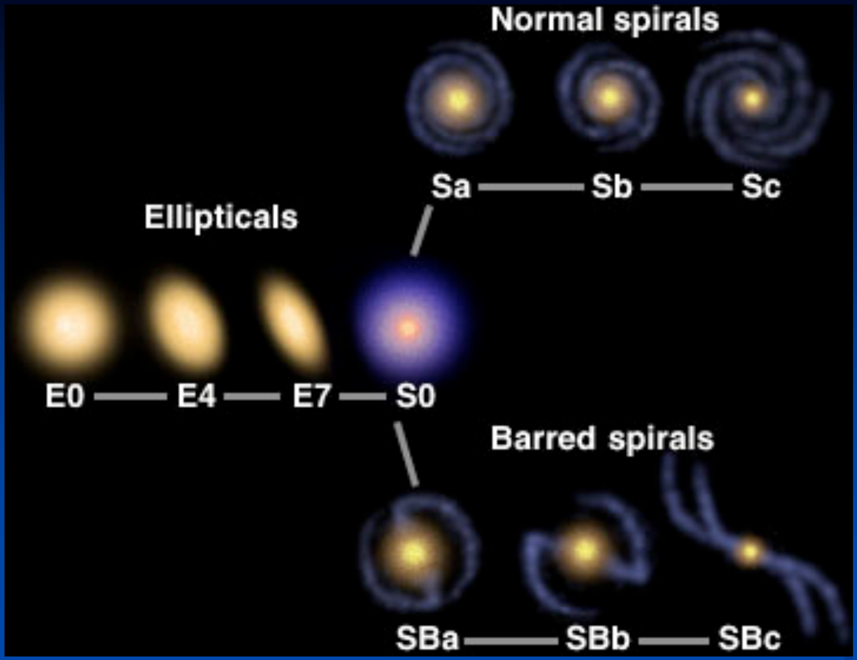
e) Source of pairwise velocity dispersion and 2-point correlation
function (Davis & Peebles 1983)

HOW DO GALAXIES IN GROUPS EVOLVE?

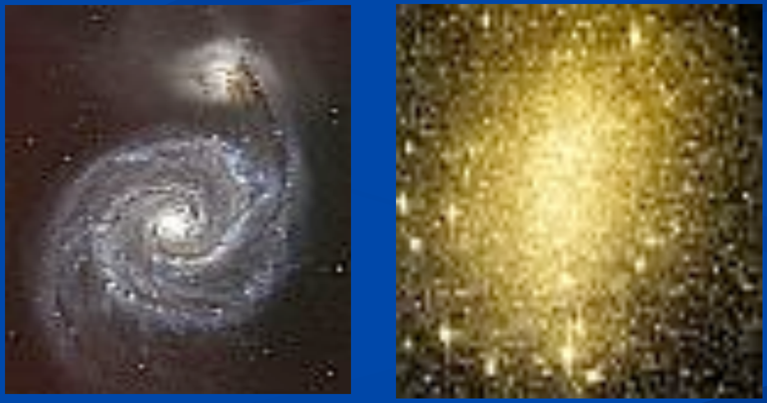
Clues from nearby galaxies

98% of all nearby bright galaxies can be placed into a Hubble type

Hubble types are the z = 0 final state of bright galaxy evolution



Ellipticals have old stellar populations, spirals have both old and young components while irregulars are dominated by young stars



Old stars

Young stars

No/little cold gas or star formation

Cooling gas with star formation

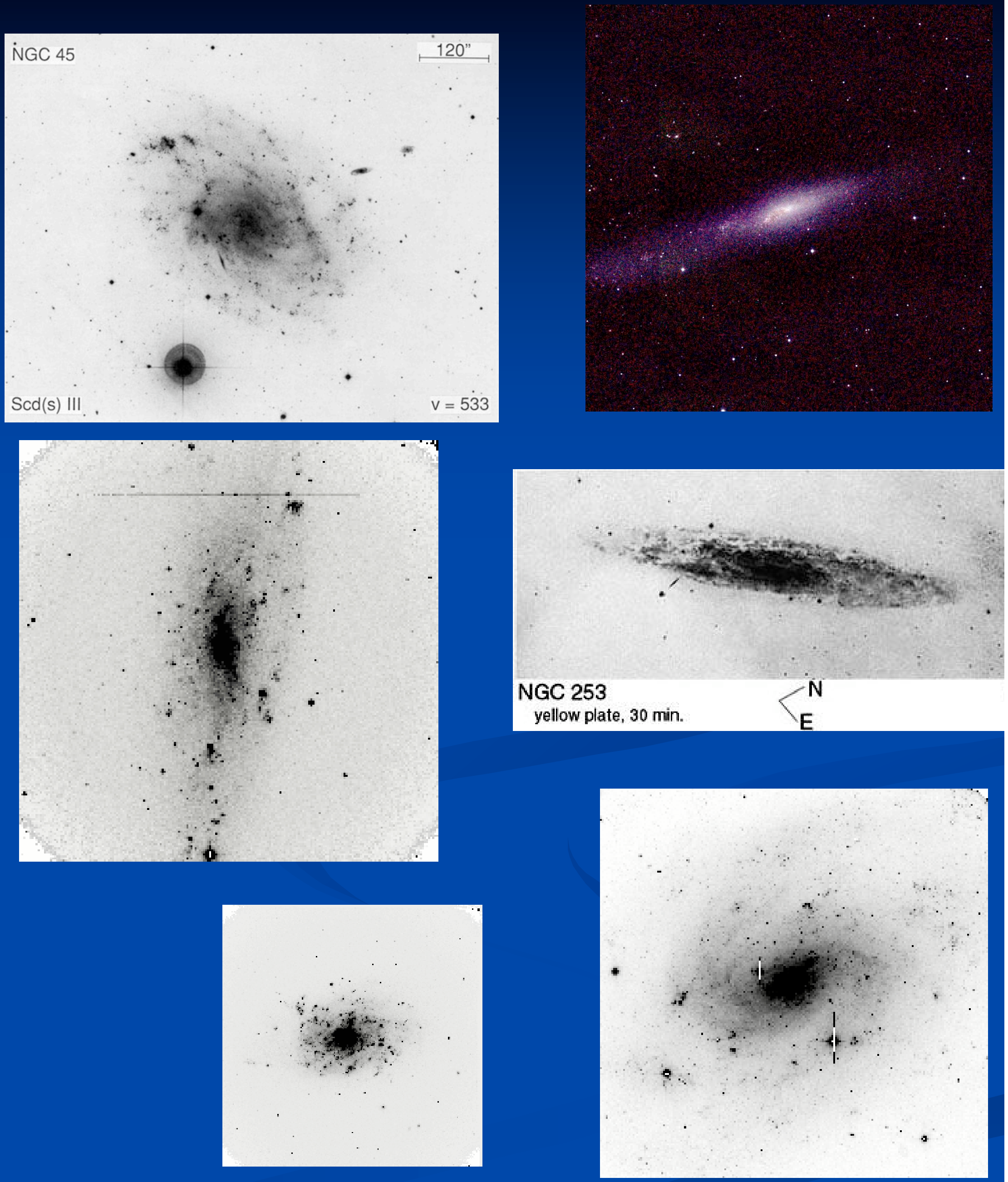
What are the properties of galaxies in nearby groups?

Figure 18.17 These are the galaxies of the Local Group, arranged to represent their actual physical relationships to the Milky Way http://universe.colorado.edu/fig/18-17.html

(1) Milky Way
(2) Draco
(3) Ursa Minor
(4) SMG
(5) LMG
(6) Carina
(7) Sextans
(8) Ursa Major
(9) Pegasus
(10) Sculptor
(11) Fornax
(12) Leo I
(13) Leo II
(14) Maffei
(15) NGC 185
(16) NGC 147
(17) NGC 205
(18) M32
(19) Andromeda I
(20) Andromeda II
(21) Andromeda (M3
(22) M33
(23) LGS 3
(24) IC 1613
(25) NGC 6822
(26) Sextans A
(27) Leo A
(28) IC 10
(29) DDO 210
(30) Wolf-Lundmark-Melotte
(31) IC 5152

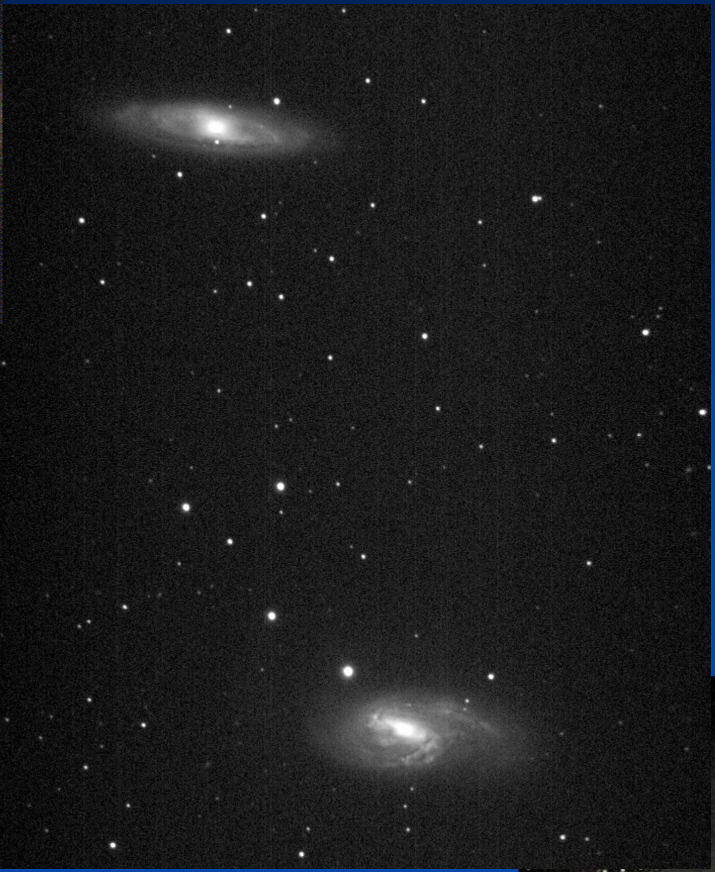
Some examples

M66 Group



Sculptor Group members

M65

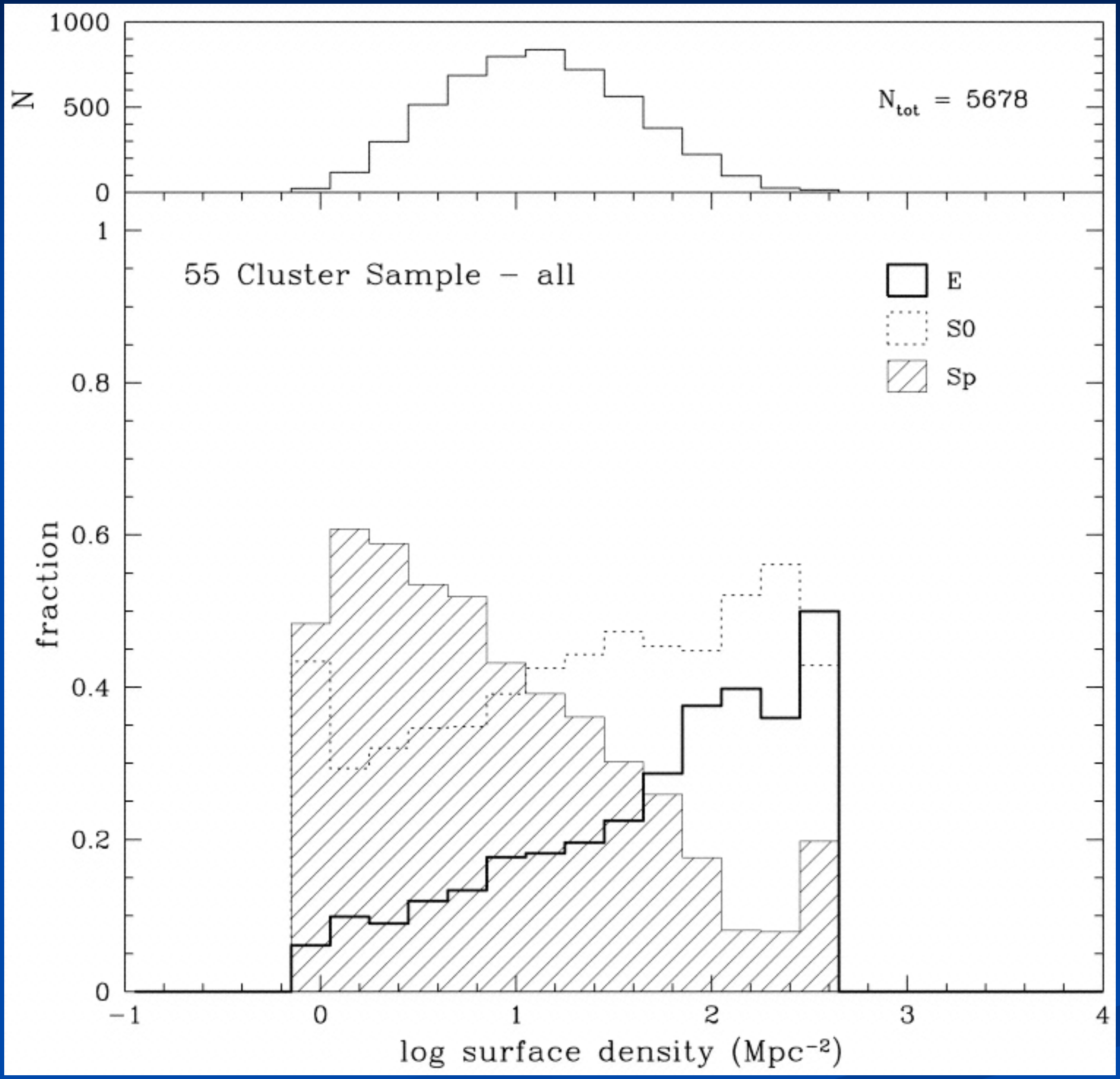


M66

Galaxy interactions can also be seen in nearby groups

What types of galaxies exist in groups?

The morphological distribution in groups may reveal the physical processes responsible for galaxy evolution



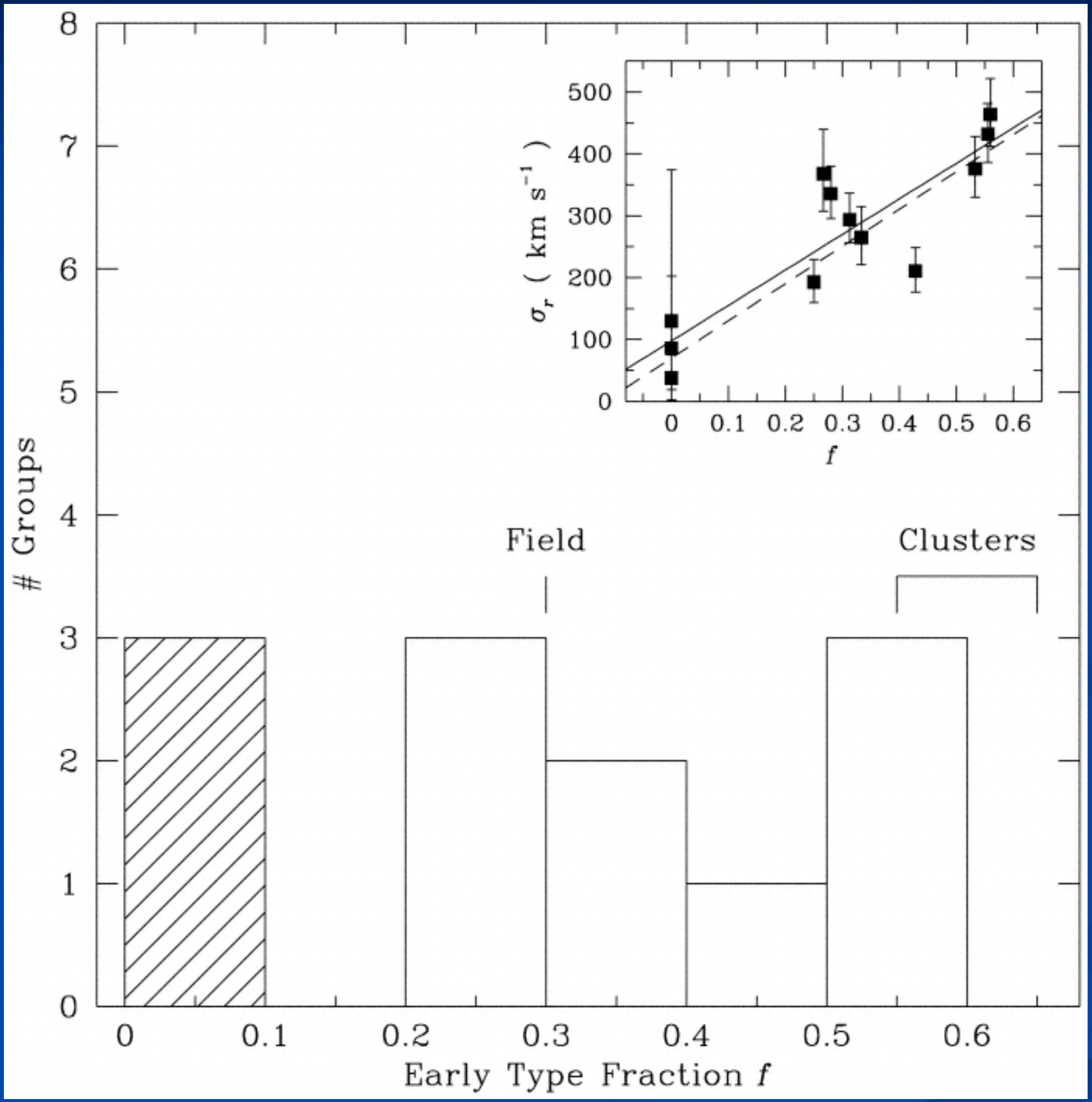
Dressler (1980)

Morphology/density relation: higher fraction of late type galaxies in lower density environments

Some groups still have a large total early type fraction

These early types are found among the higher velocity dispersion groups

Most of the‘red’ galaxies are found towards the centers of groups



Zabludoff & Mulchaey (1998)

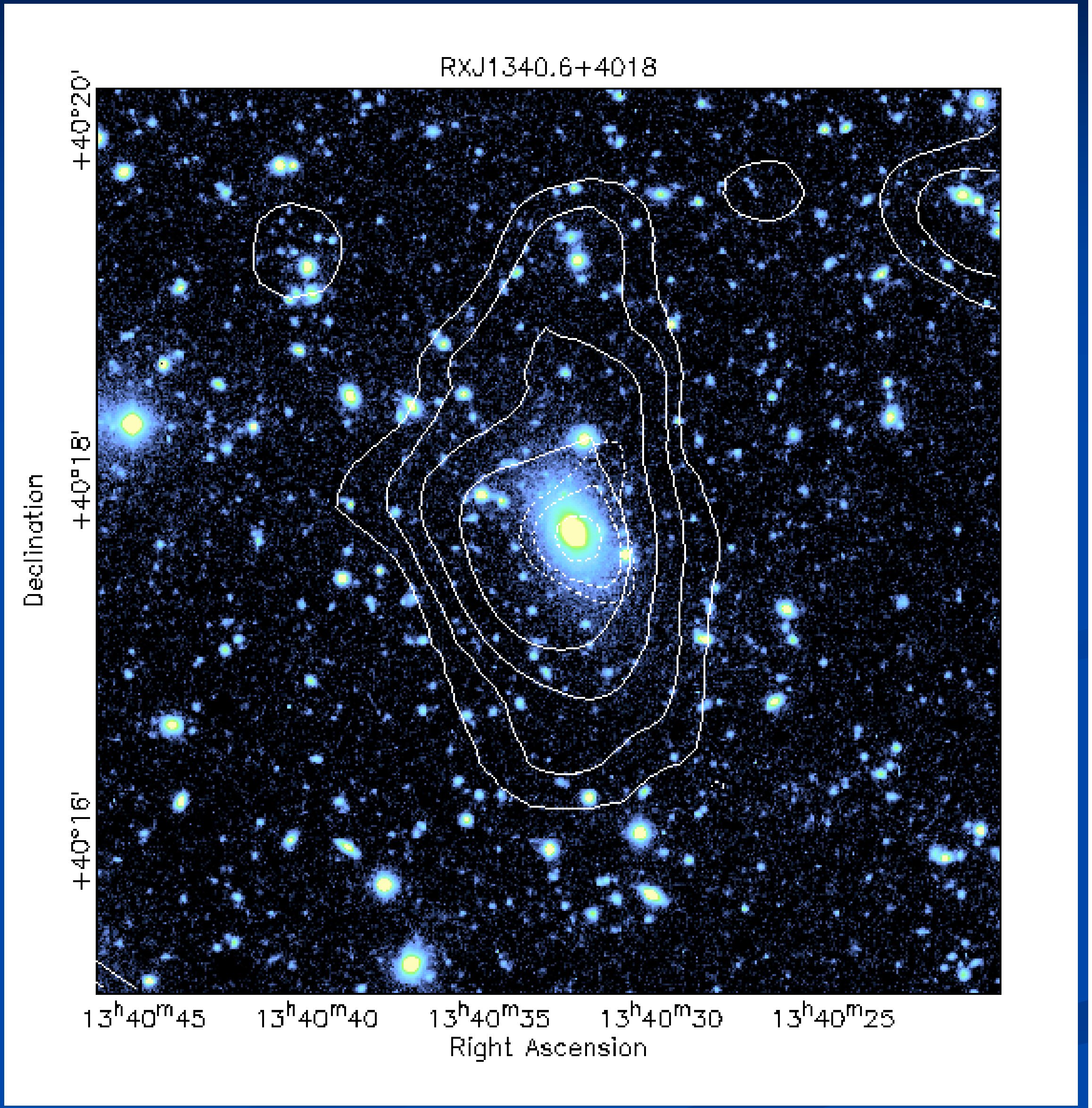
COMPACT GROUPS -- GALAXIES IN RAPID EVOLUTION?

Seyfert's Sextet

Fossil Groups - merger remnants?

Also 'ghost groups' and the AWM groups may have a similar origin

All are single luminous early types without other bright nearby galaxies and often have luminous X-ray emission



Ponman et al. (1993)

These systems are however rare(?)

How/when do galaxies in groups evolve?

Some questions

a. Do galaxies in groups evolve by themselves? That is, without much influence from other galaxies.

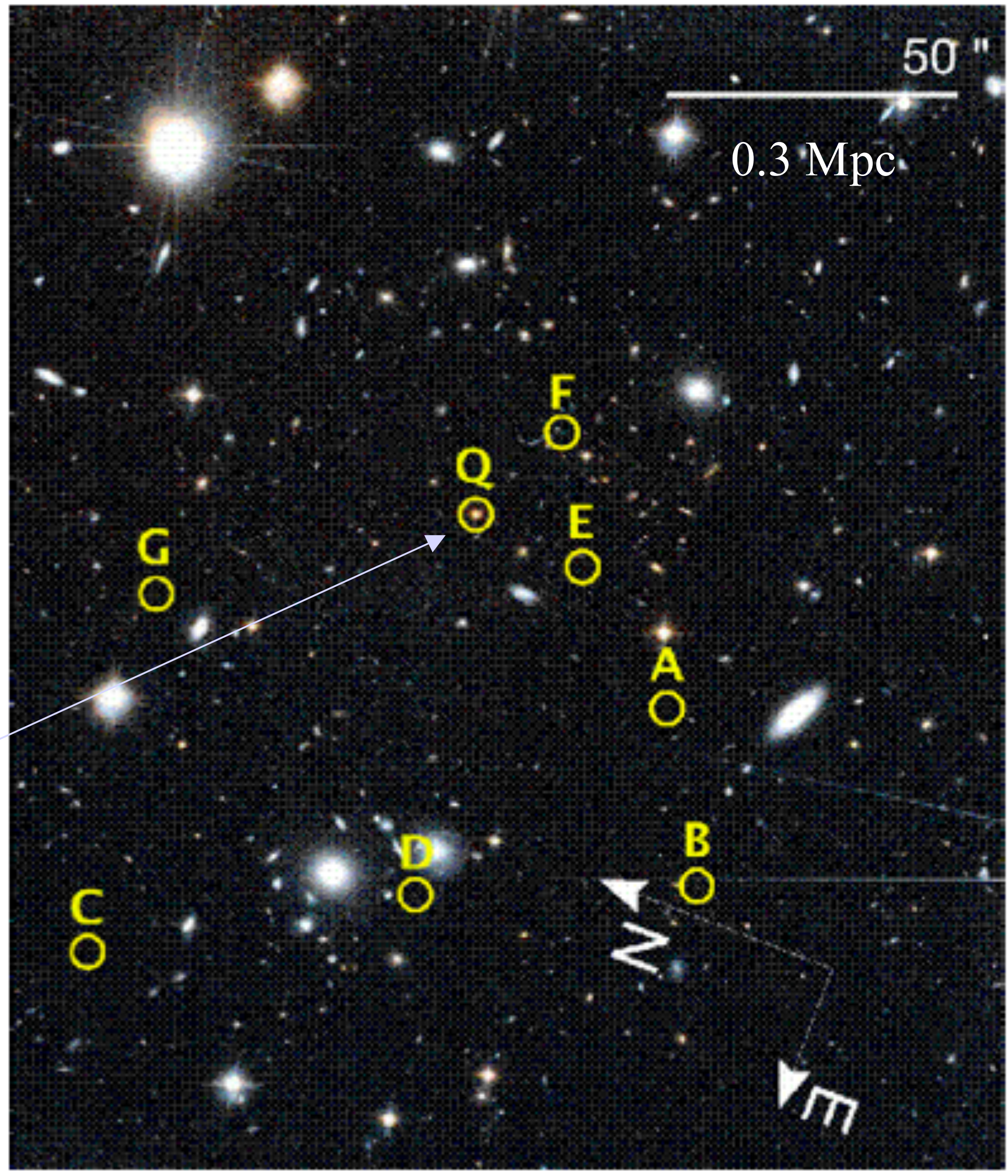
b. Do galaxy groups survive? Are they rebuilt over time?

c. What is the role of galaxy mergers in the evolution of galaxy groups?

d. Does the environment of a group change its evolution?

e. When do group galaxies form their stars, as opposed to their mass?

Do groups exist at high redshifts?



Most certainly!

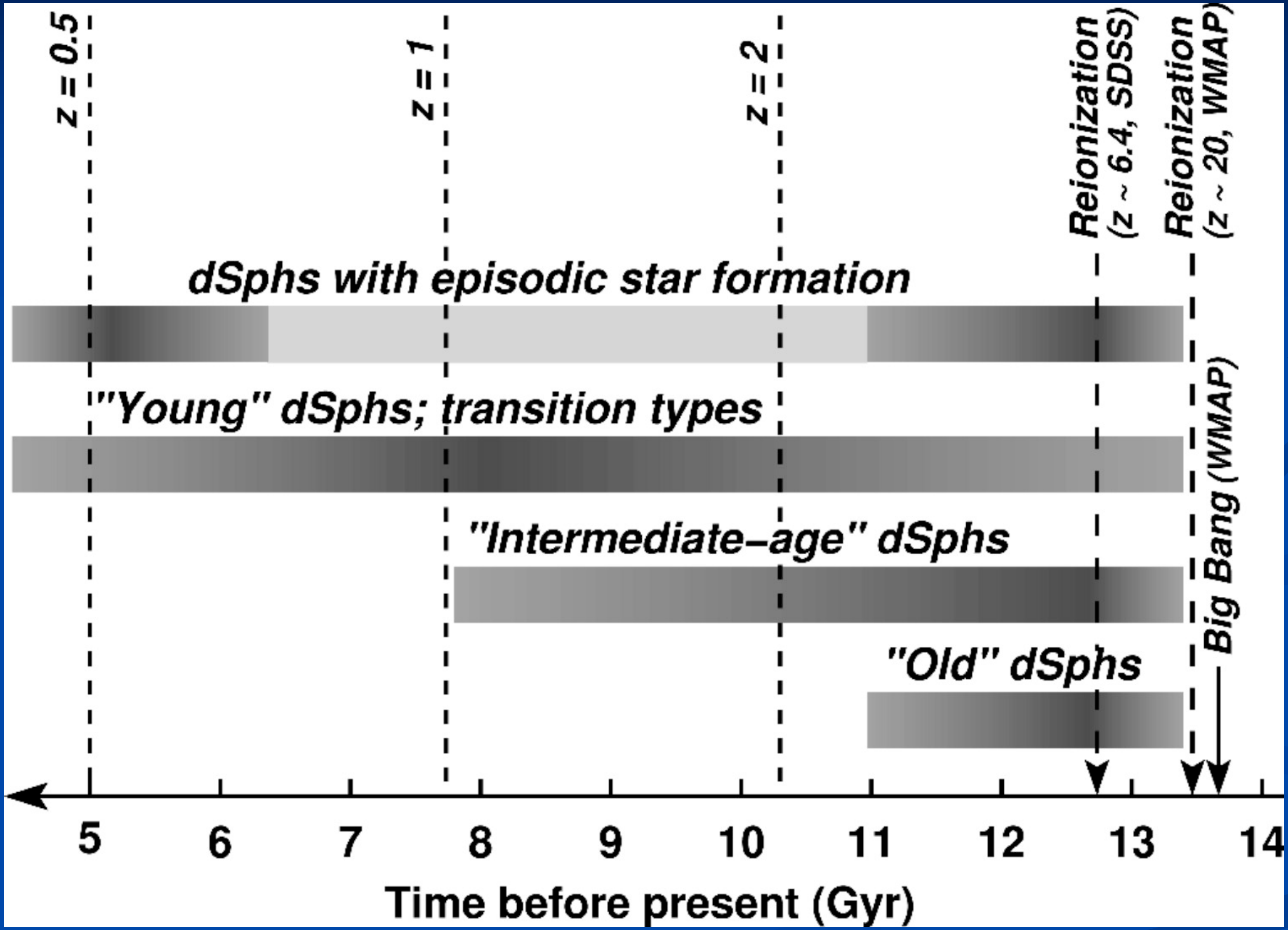
Find clustering at the highest redshifts we can probe

z~6 Sloan QSO

Labeled systems are
at similar redshifts
based on (i-z) colors

Zheng et al. (2005)

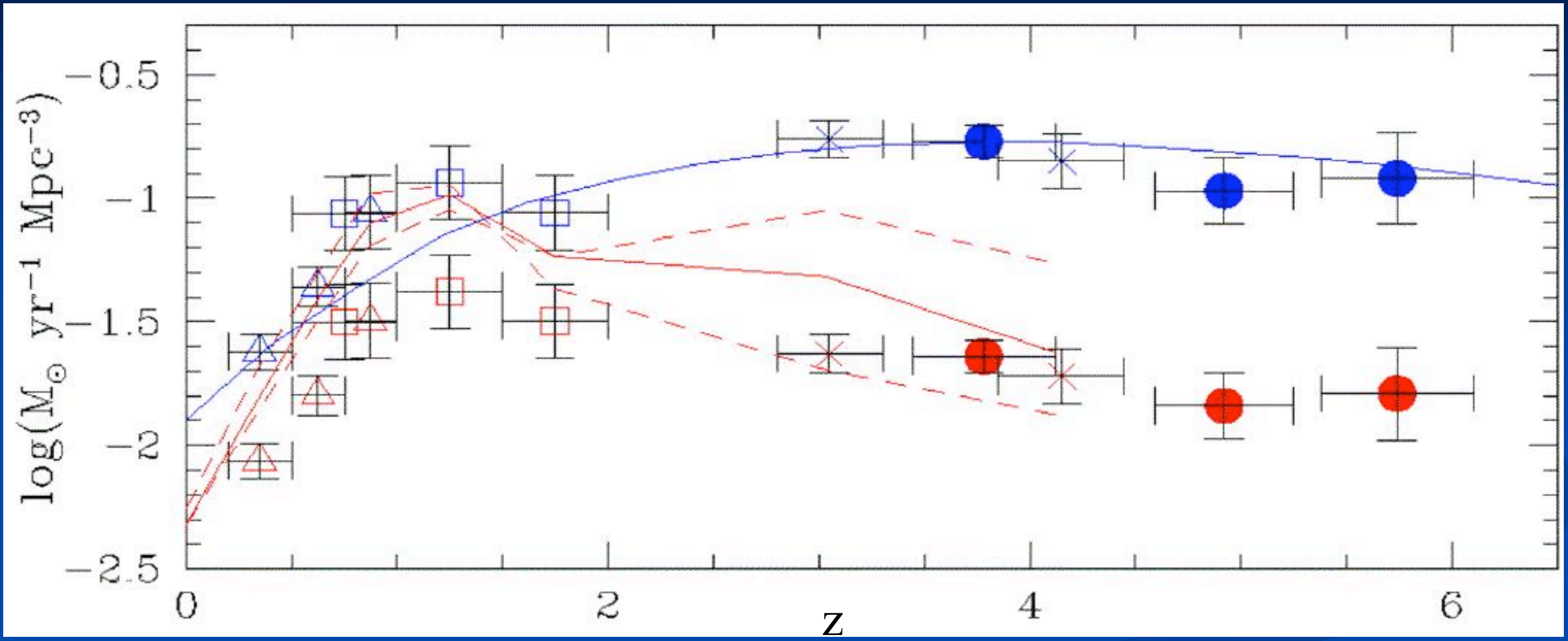
Star formation history for Local Group dSphs



Grebel & Gallagher (2004)

Complicated history with star formation at all epochs.

THE TOTAL STAR FORMATION HISTORY



Giavalisco et al. (2004)

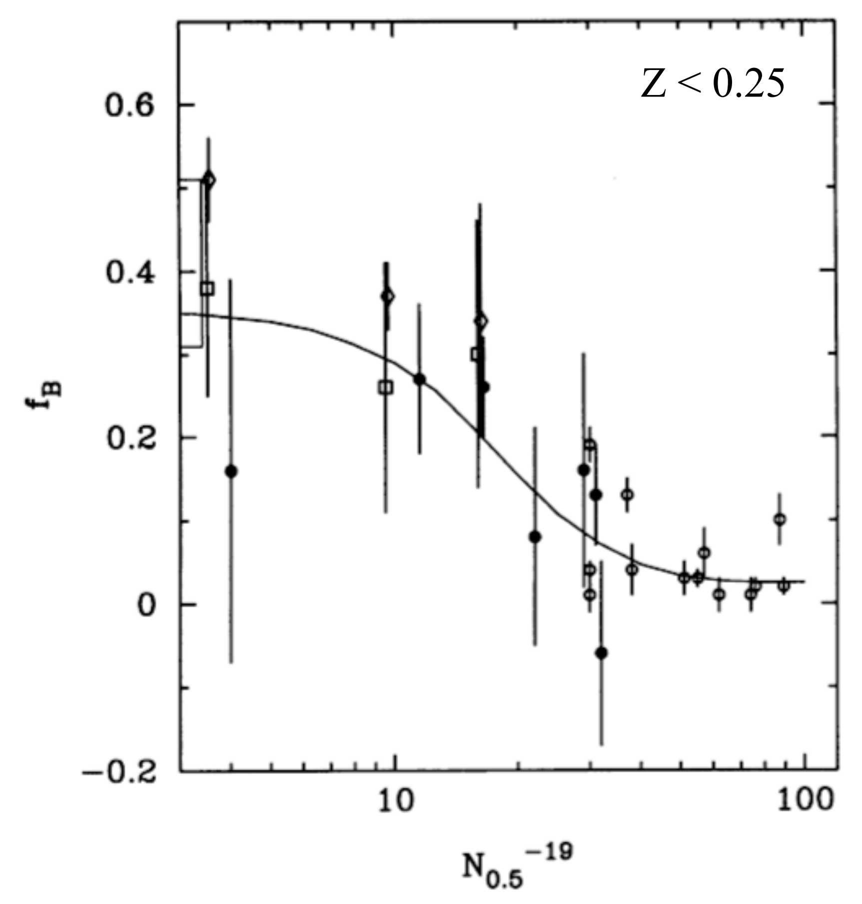
Star formation is observed to be more common in the past than today – Qualitatively consistent with old stellar populations in the nearby universe.

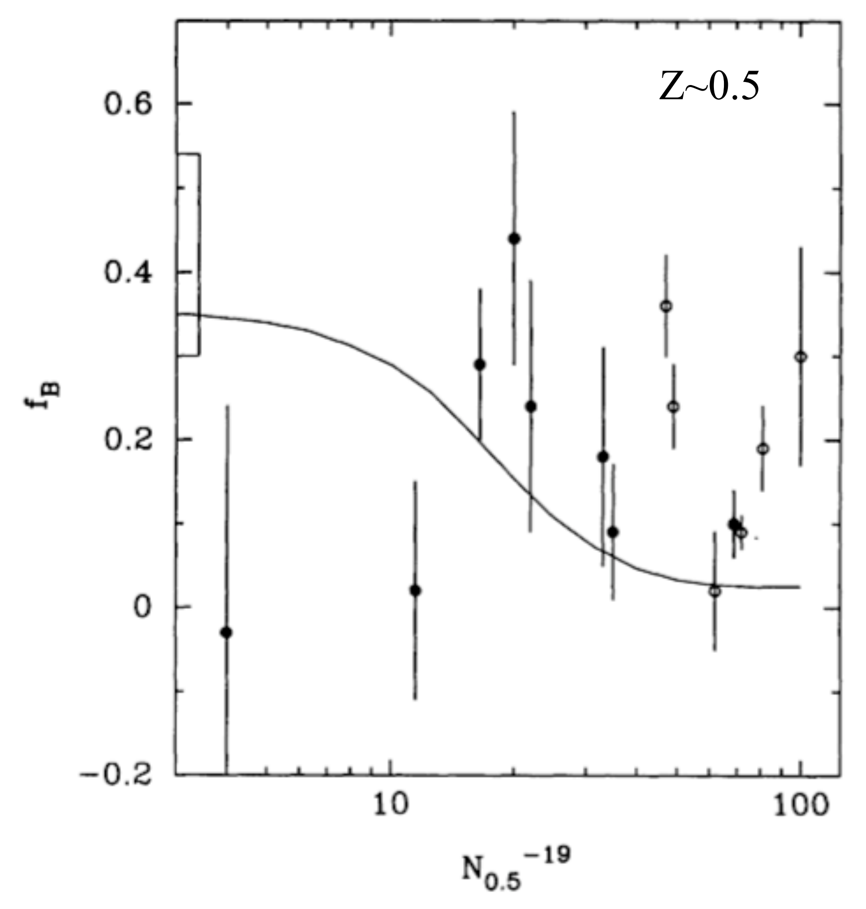
This tells us *when* galaxies formed, but not *how* or in *which types*

Do galaxies in groups evolve?

(or how do galaxies in high redshift groups differ from modern groups?)

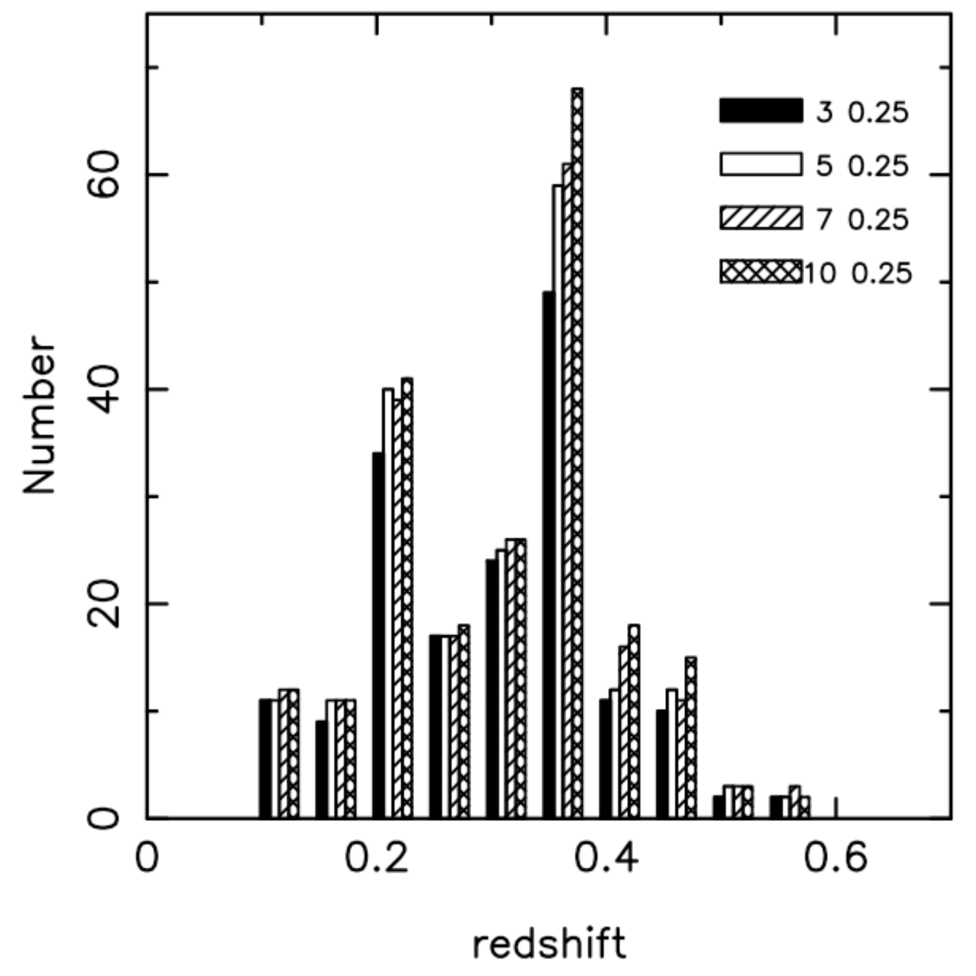
Radio selected groups show evolution (Allington-Smith et al. 1993)



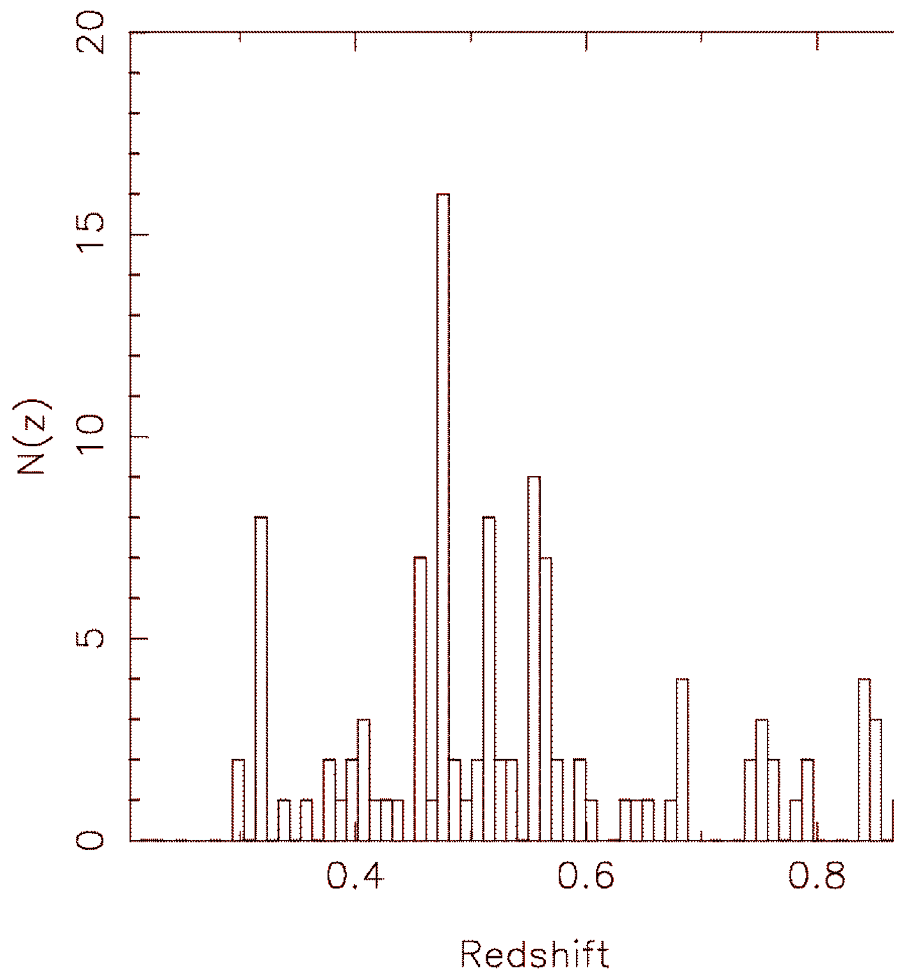


The blue fraction increases at lower values of group richness and higher redshift systems are bluer at a given richness

Redshift surveys - Groups to z ~ 1



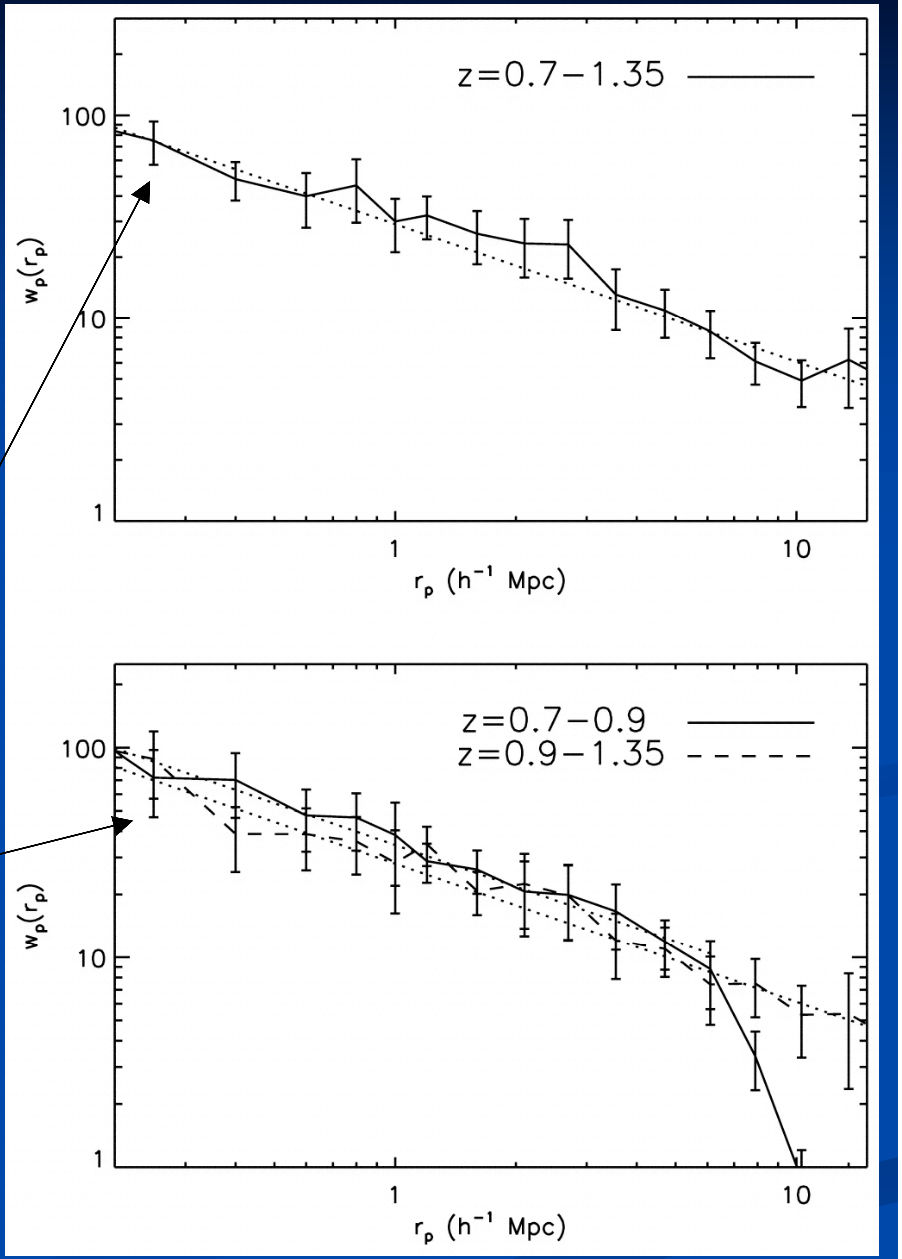
CNOC2 - Carlberg et al. (2001)



HDF - Cohen et al. (1999)

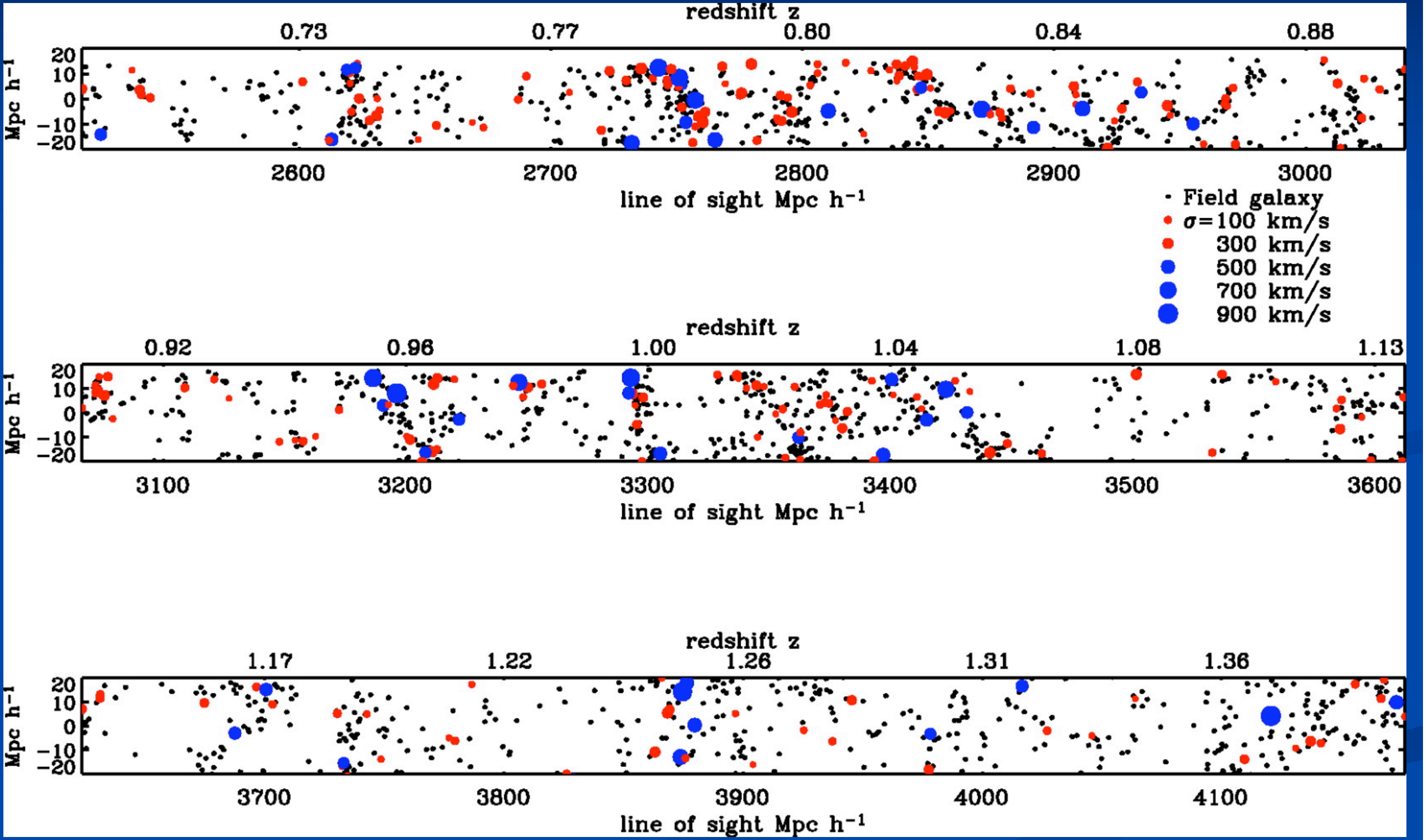
Using thousands of redshifts between z=0.7-1.35 with DEEP2 we can characterize the galaxy population

Correlation functions show that at z~1 there is significant galaxy clustering, especially on small scales



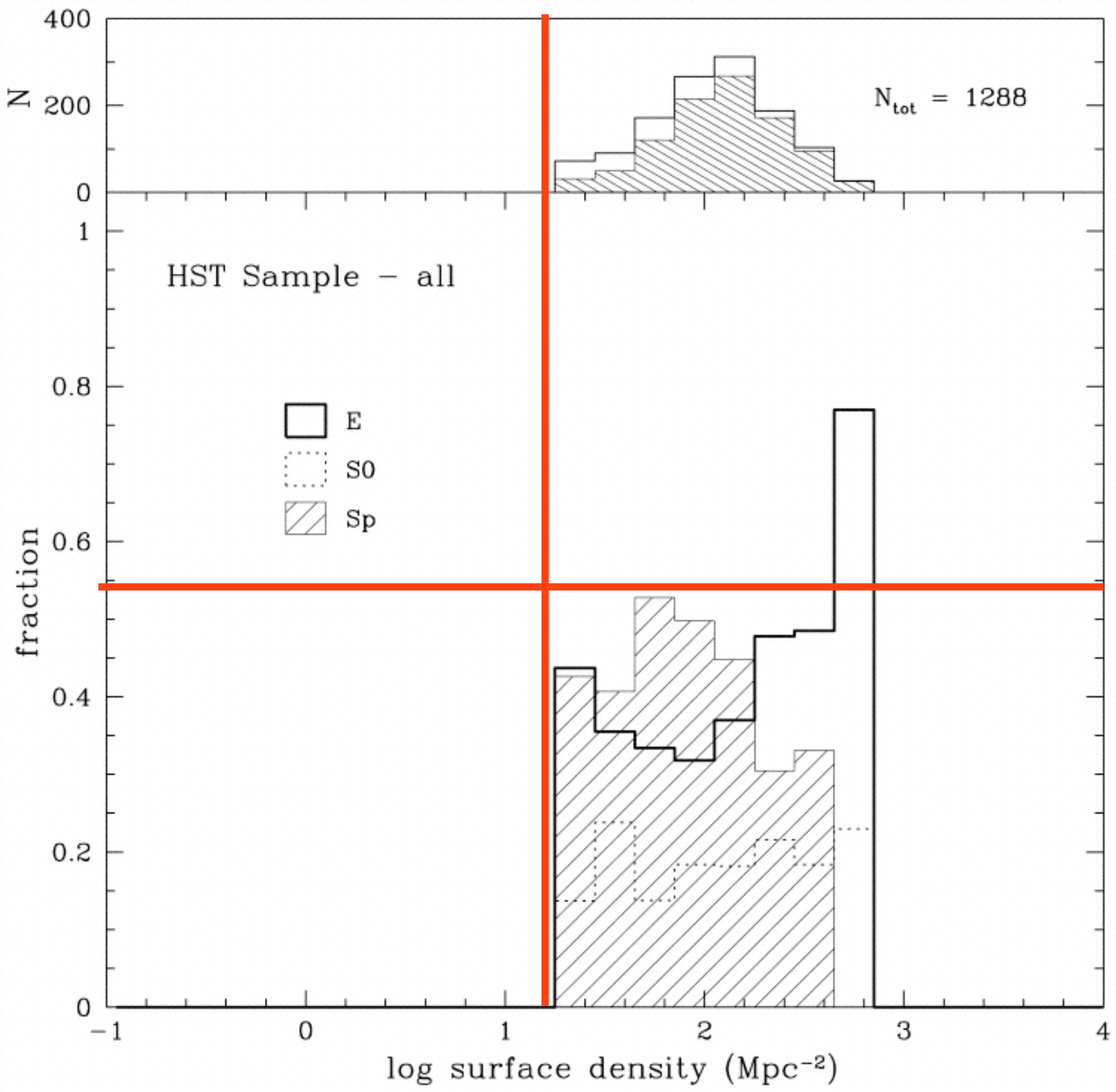
Coil et al. (2004)

This clustering is produced by groups of galaxies with velocity dispersions 100-500 km/s out to z = 1.4



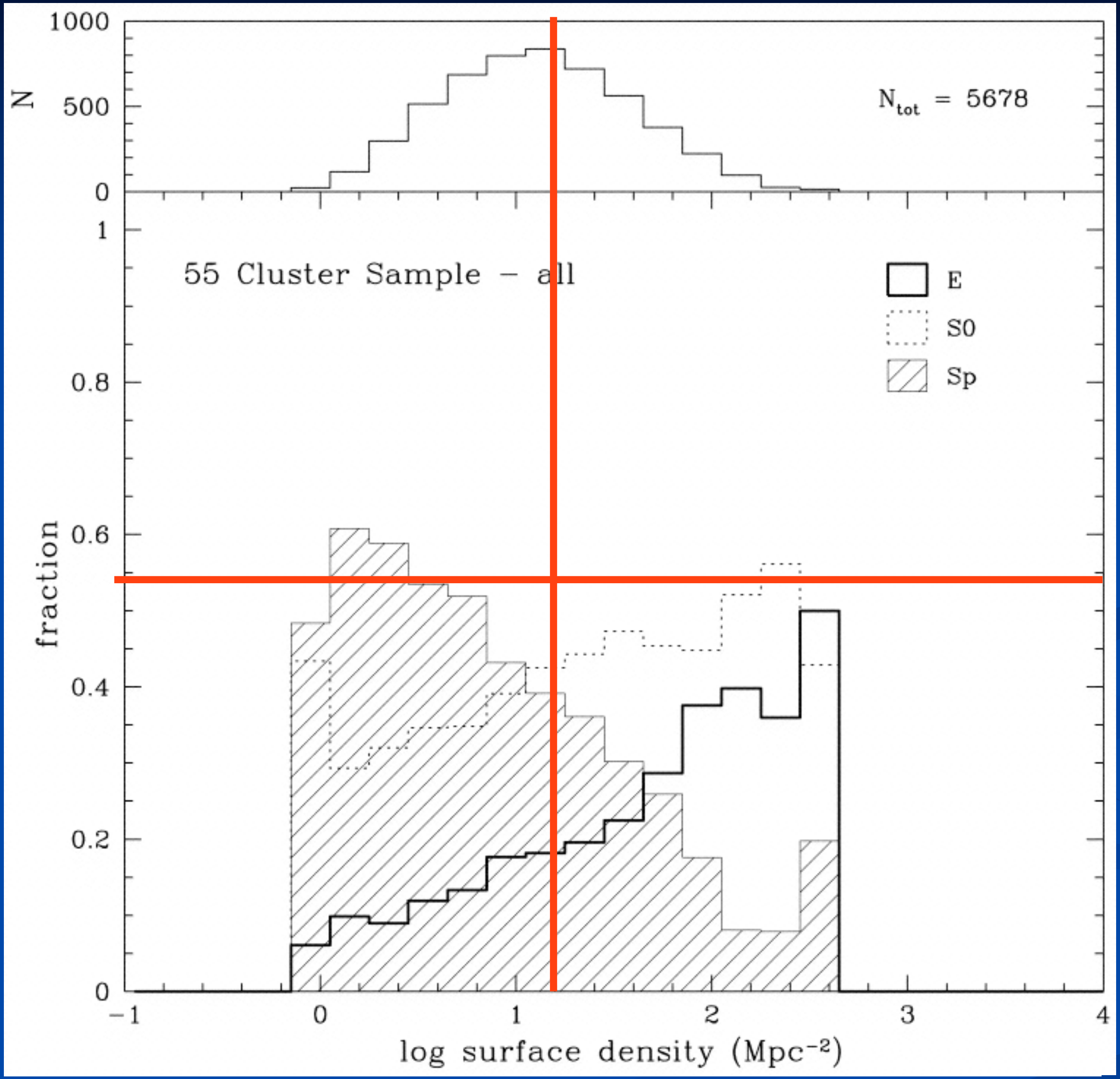
Gerke et al. (2005)

What type of galaxies exist in different environments at higher-z?



z > 0.5 clusters

Dressler et al. (1997)



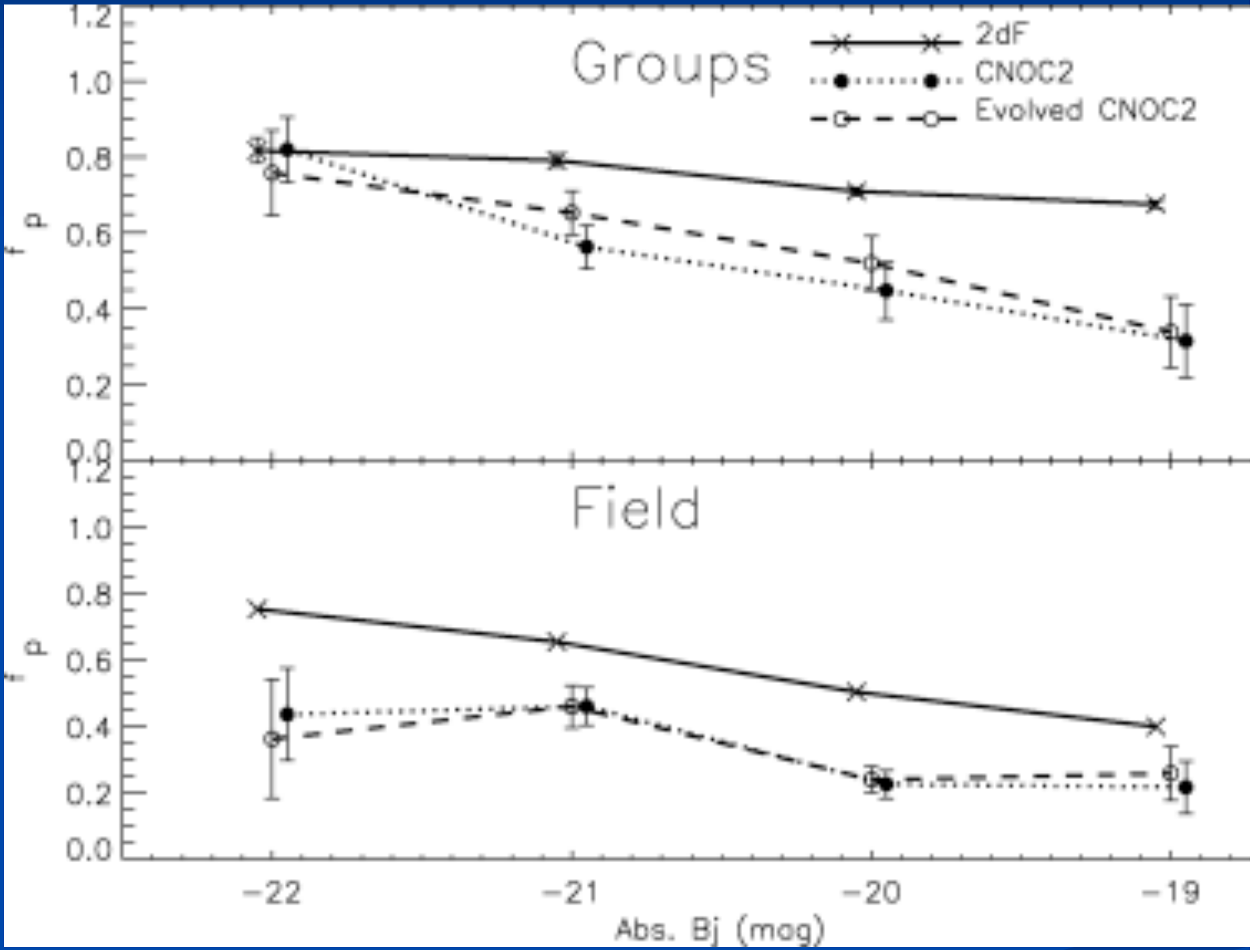
z = 0
clusters

Higher spiral fraction at high redshifts (early times)

FRACTION OF PASSIVE GALAXIES IN GROUPS AND THE FIELD AT Z~0.5 AND Z~0

Also see this in groups at z=0.5

1. There are more star forming galaxies in both environments at z~0.5 than at z~0
2. Similar increase in active galaxies up to z~0.5
3. There are more passive galaxies in groups at all redshifts



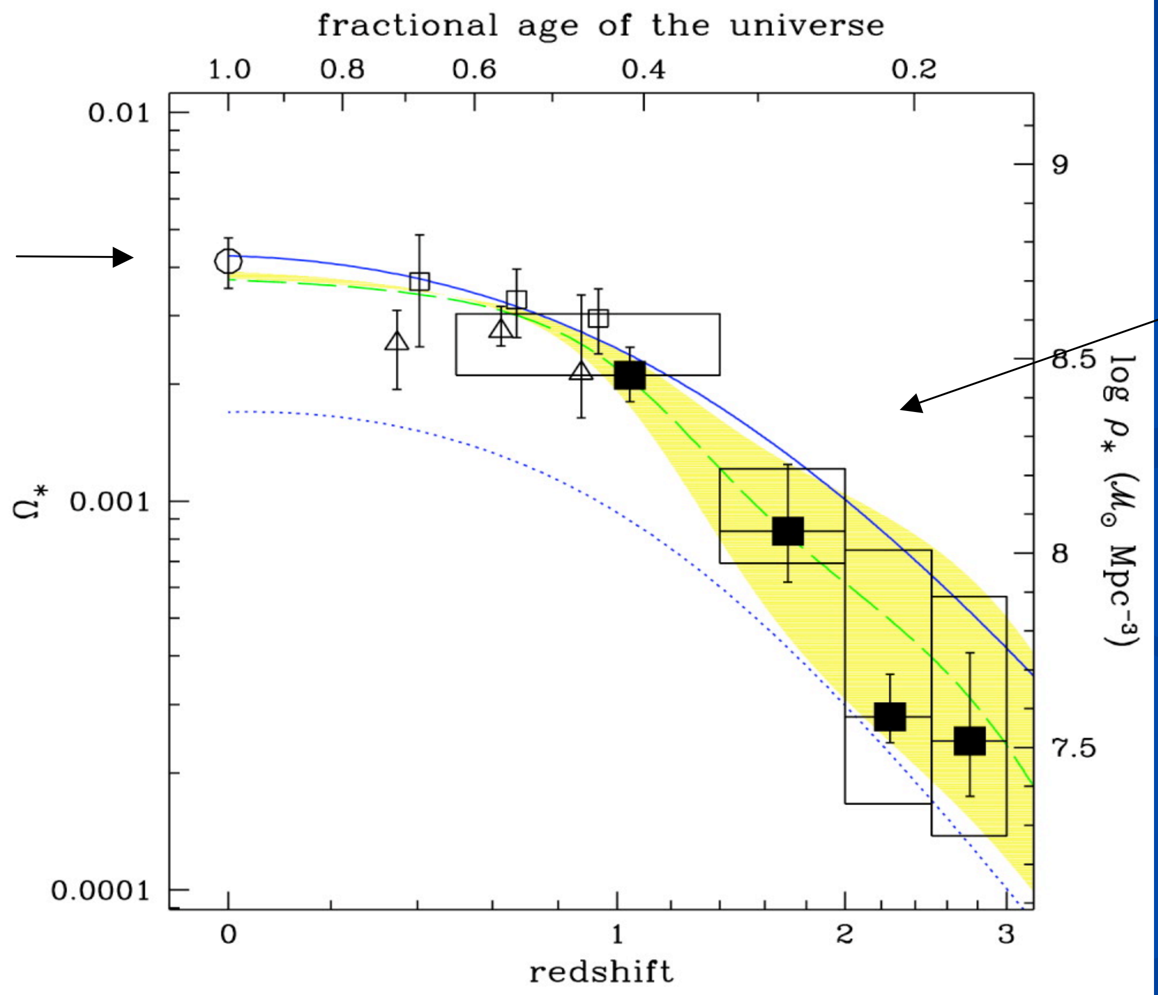
<u>Similar evolution in field and groups</u>

Wilman et al. (2005)

When do galaxies in groups form?

At high redshift there is a rapid decline in the stellar mass density over all galaxy environments

Local 2dF/
2MASS

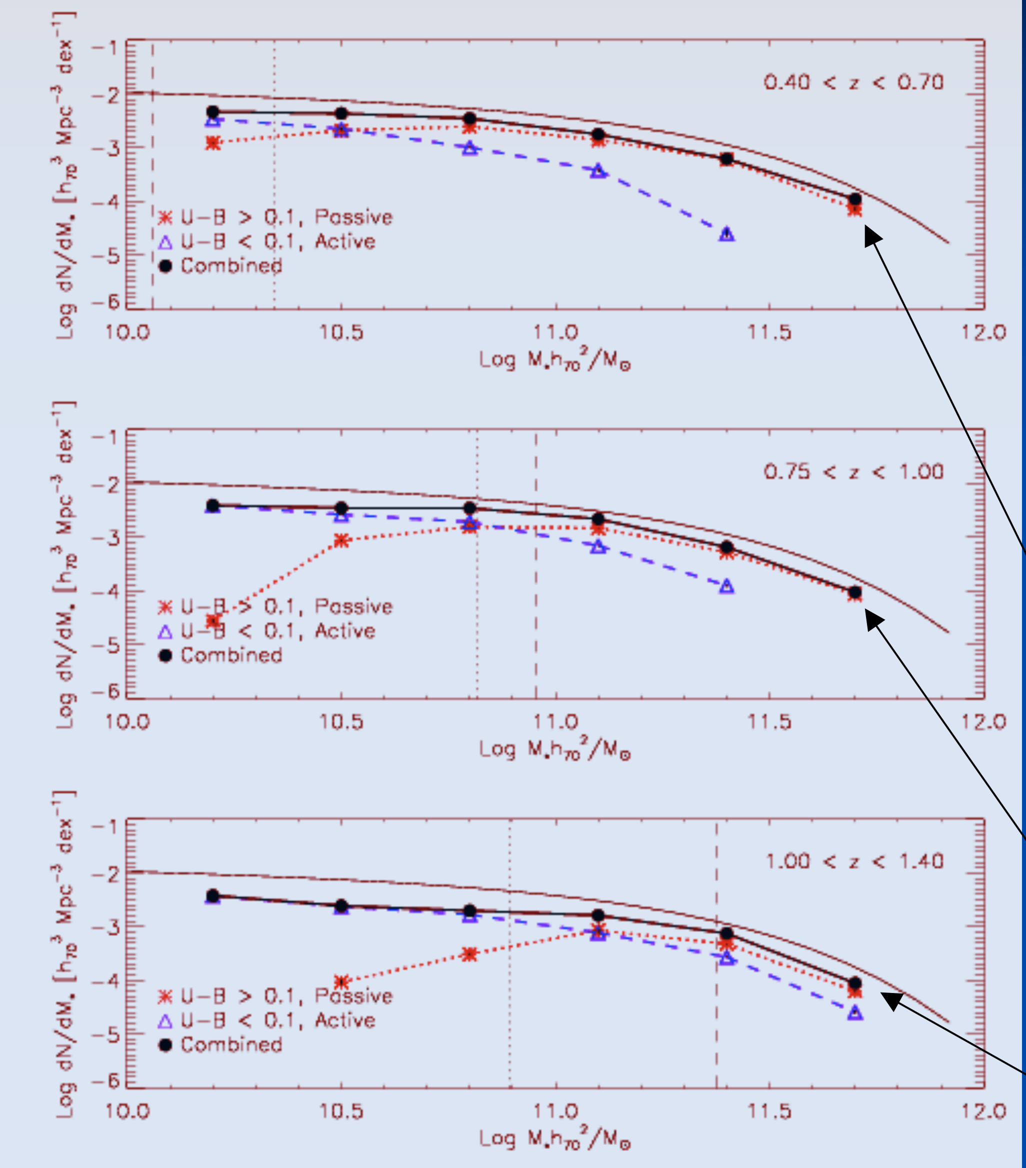


Hubble Dee
Field

Dickinson et al. (2003)

Only 10% of stellar mass formed by z~3

STELLAR MASS FUNCTIONS OF ALL GALAXIES TO Z=1.4



Bundy et al. (2006)

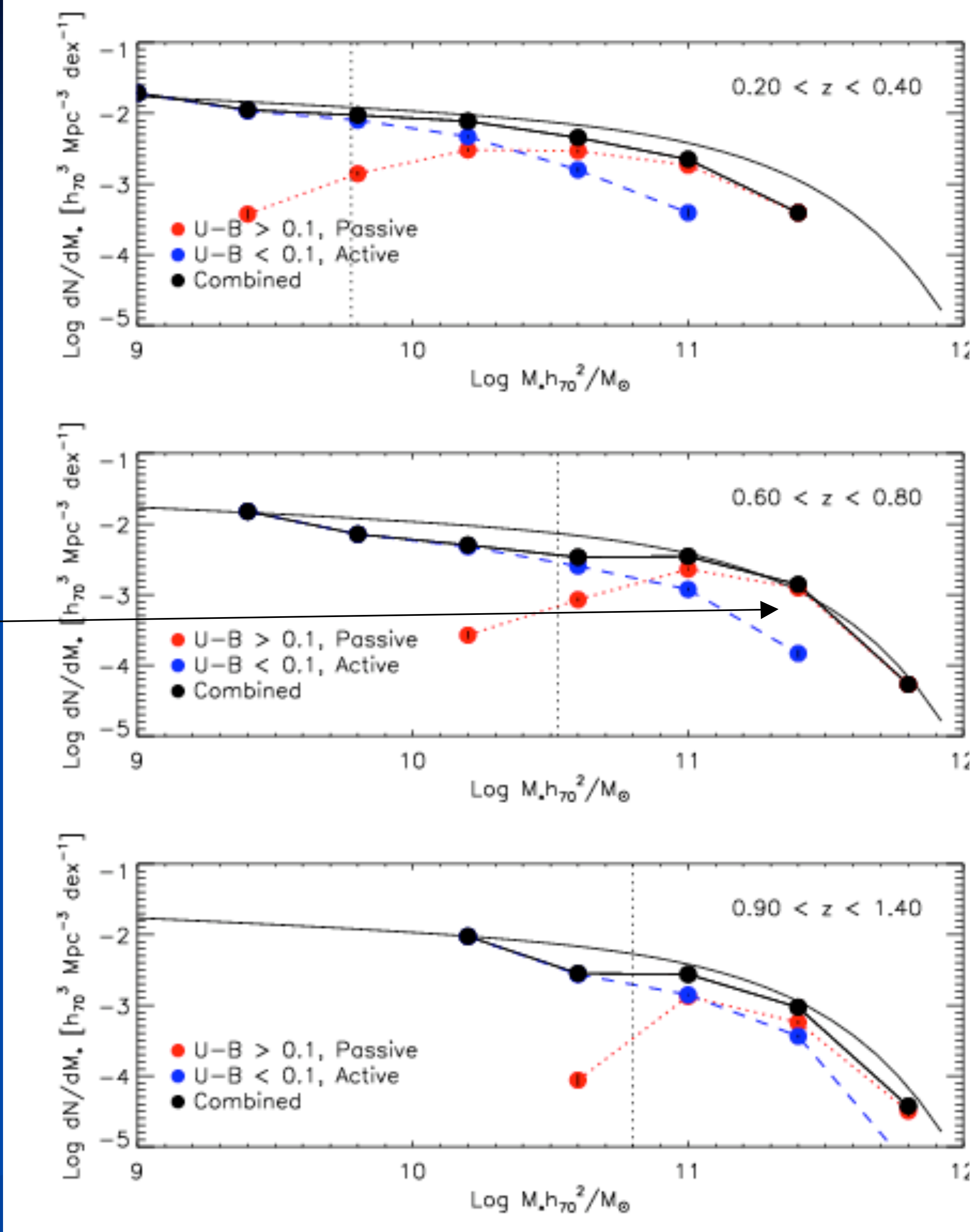
The stellar mass function can
be computed at redshifts up to z~1.

Using large area fields ~2 sq. degre
we find that the most massive gala
are already formed by z~1.

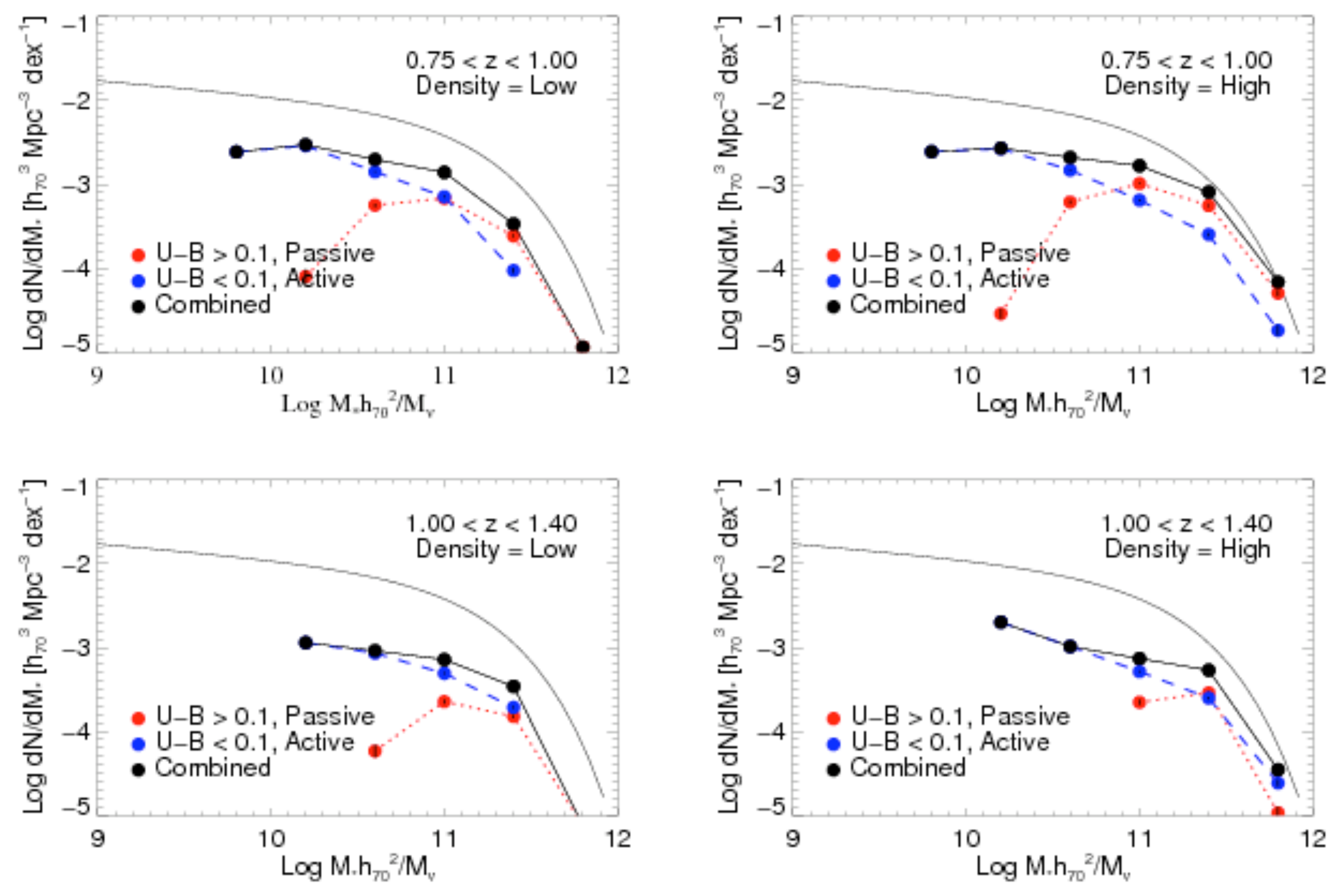
Massive galaxies formed by z~1, lower mass systems form later

Stellar mass functions divided into different colors

Massive red galaxies are nearly fully formed by z~1



See no or little environmental dependence



Most of the stellar mass in dense and low density environments is in place by z~1

How do group galaxies form/evolve?

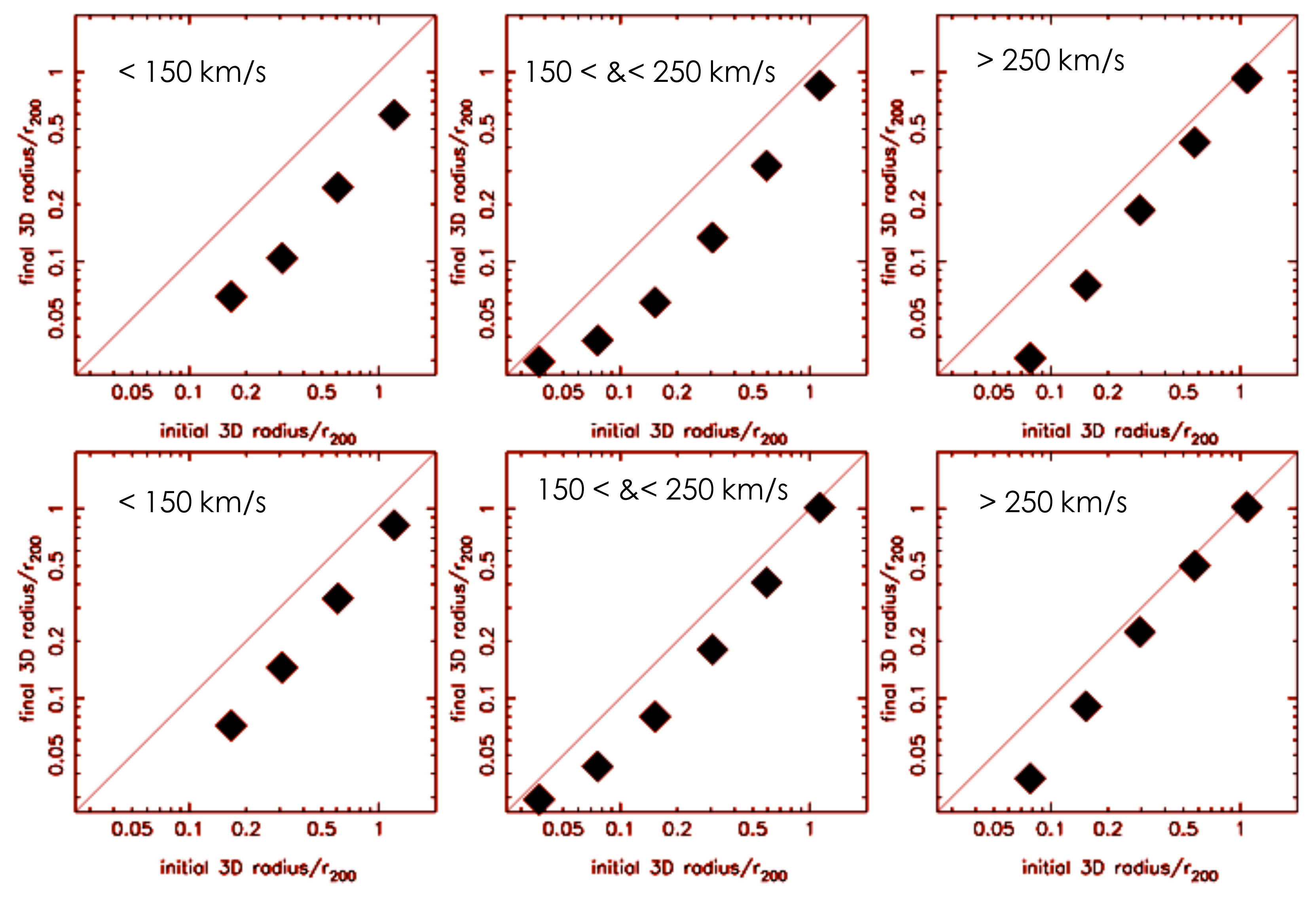
Possible Physical Processes

- Mergers - two or more galaxies colliding to form a more massive system - should be common
- Harassment - high speed galaxy interactions removing mass (Moore et al. 1999) - unlikely to be important with low relative velocities
- Strangulation - removal of hot gas - halts star formation - not likely, star formation is common
- Ram pressure stripping - removing gas from disks due to traveling in an intragroup medium unlikely, depends upon (group σ)^2 - also halts star formation
- Non-gravitational processes (AGN, SNe) - likely important, hard to constrain observationally

Galaxy Mergers

- Should be common - dynamical friction time-scale evolves as (group $\sigma)^3$
- ~250 km/s upper limit for dragging galaxies into center of a group over a Hubble time
- Low redshift merger rate expected to be low, around 2% of galaxies in groups merge per Gyr
- At higher redshift the mass density increases as $H^2 \sim (1+z)^3$. Results in a higher merger rate of $\sqrt{(\rho)} \sim (1+z)^{1.5}$

Evolution of cluster galaxies due to dynamical friction

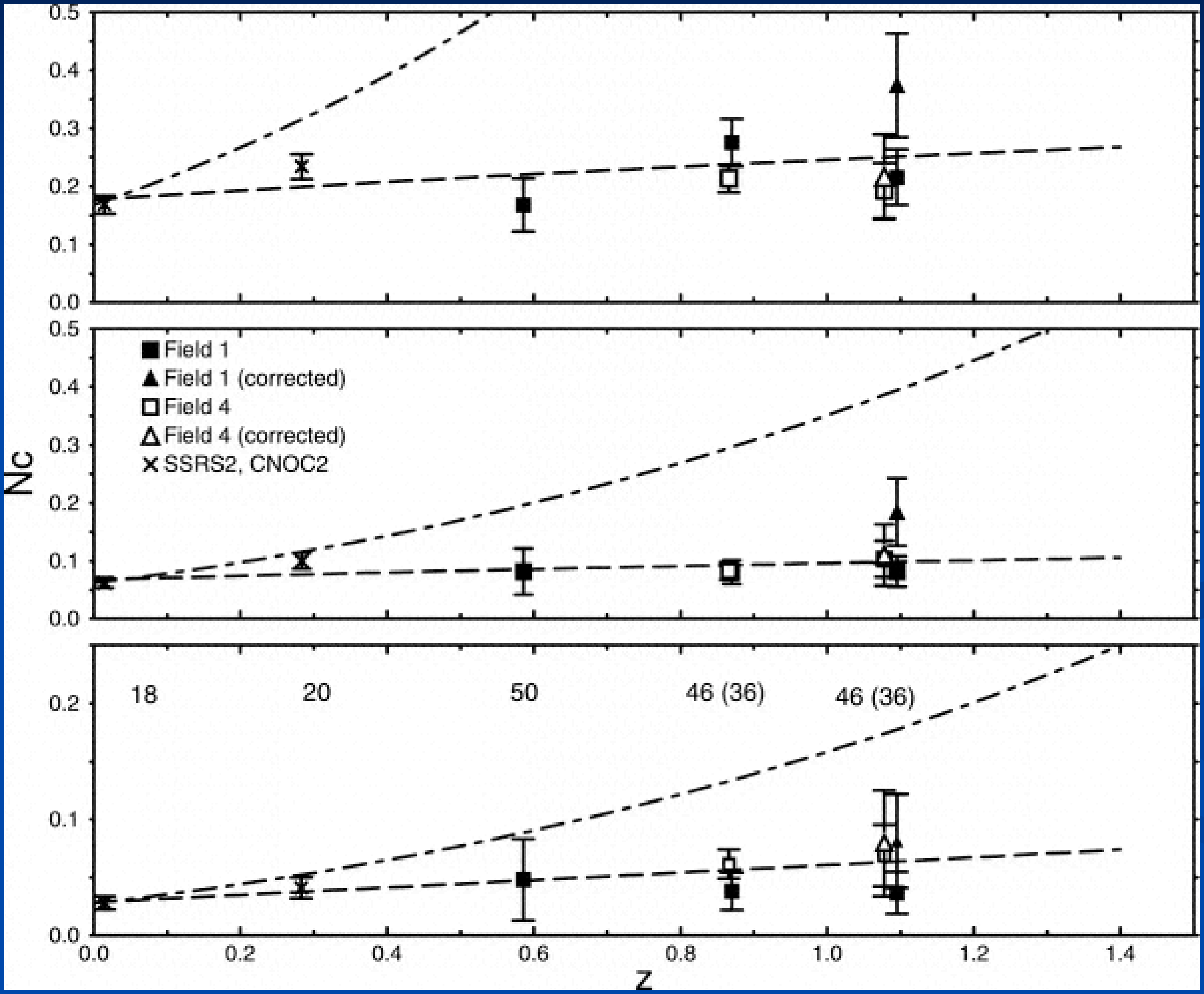


Initial position decreases by a factor of two over 5 Gyrs

Carlberg (2004)

Mergers are unlikely a dominant process at z < 1

Mergers are not common at $z < 1$



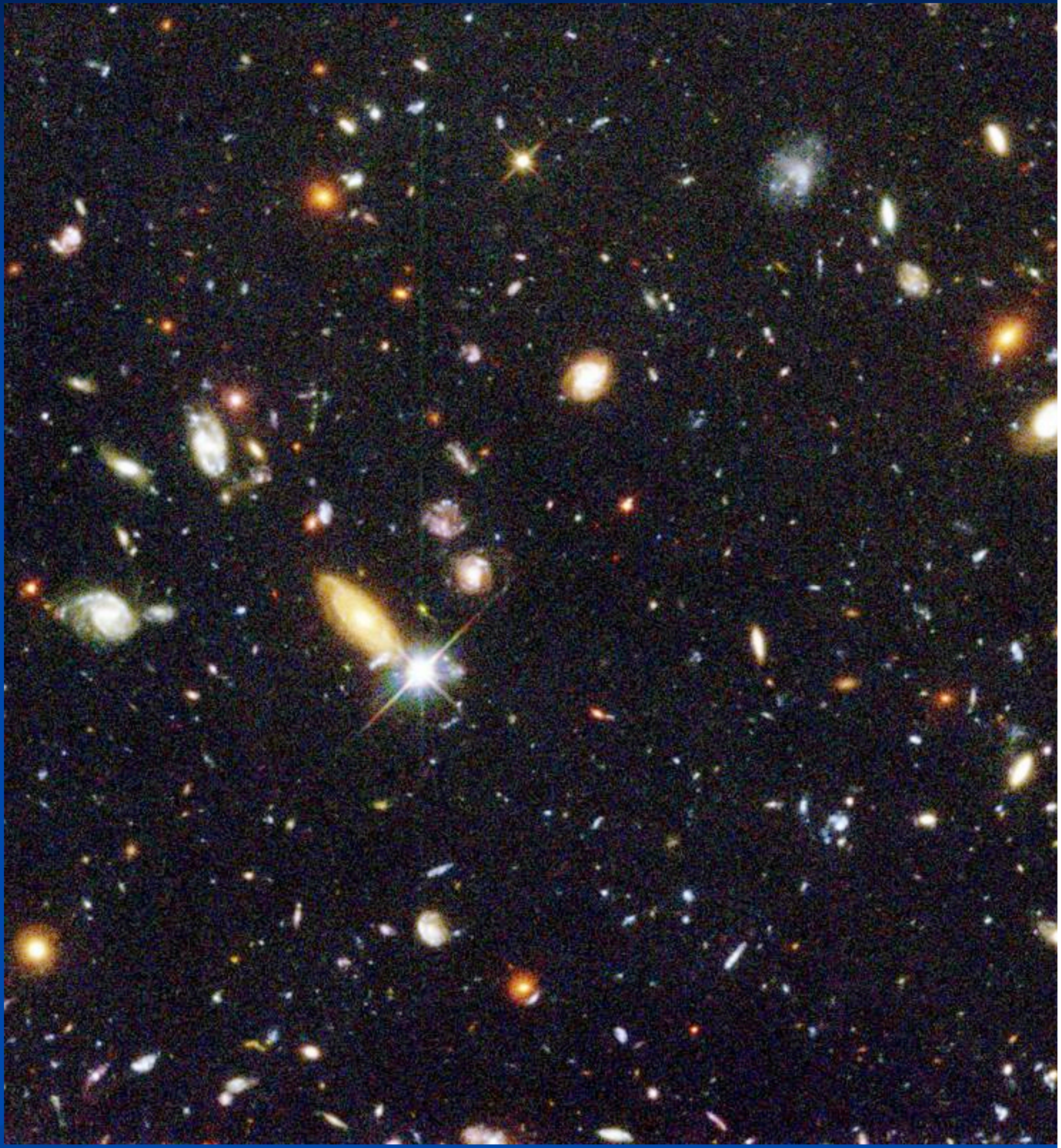
Lin et al. (20

Pair fraction does not evolve much at $z < 1$

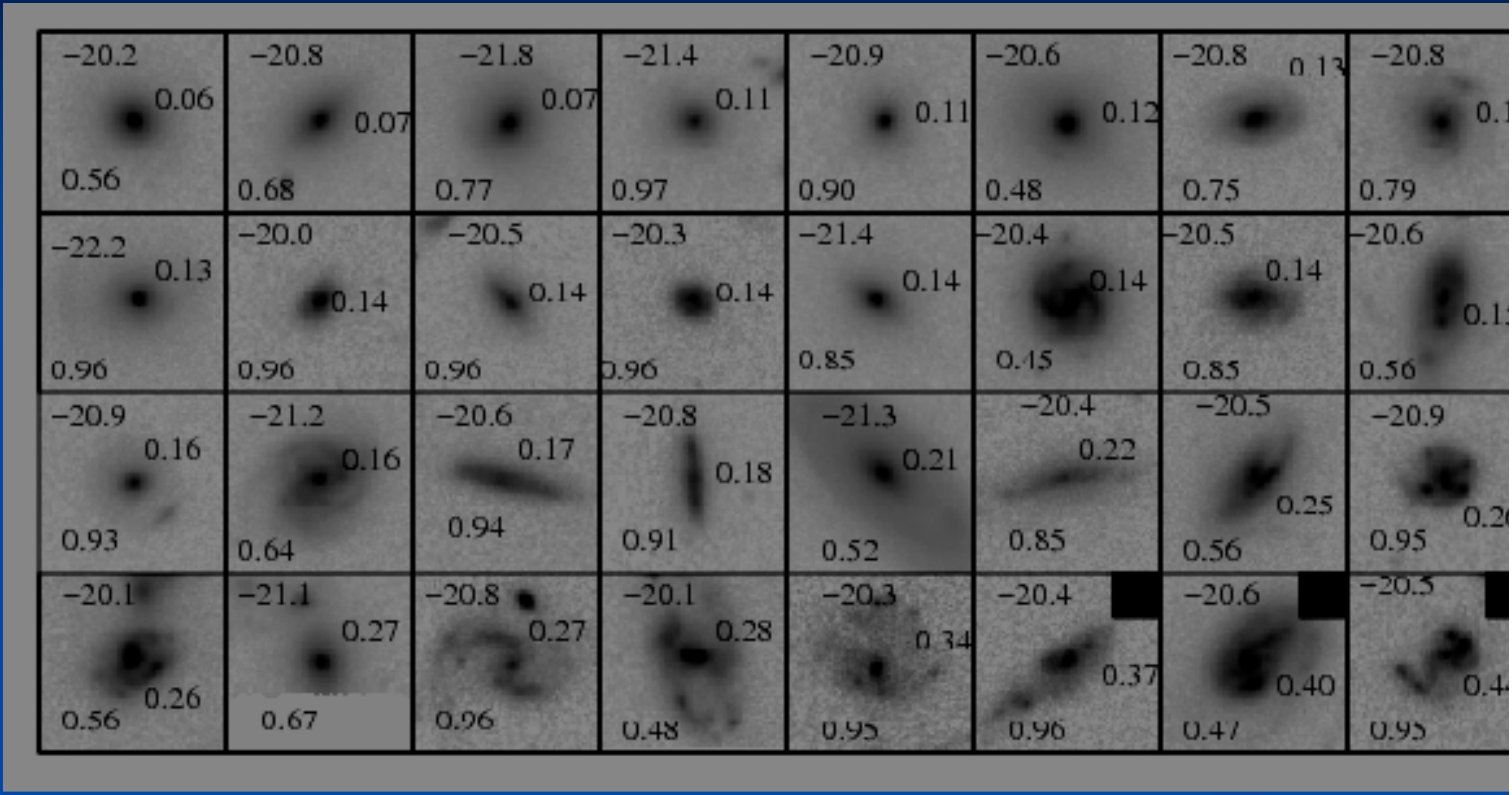
WHAT ABOUT HIGHER REDSHIFTS?

The Hubble Deep Field observed with NICMOS in the NIR gives us a rest-frame view of z > 1 galaxies

Its resolution allows galaxy structures to be studied up to z~5 (~1 Gyr after Big Bang) and thus can be used to determine how galaxies formed



Rest-frame optical observations of high redshift galaxie

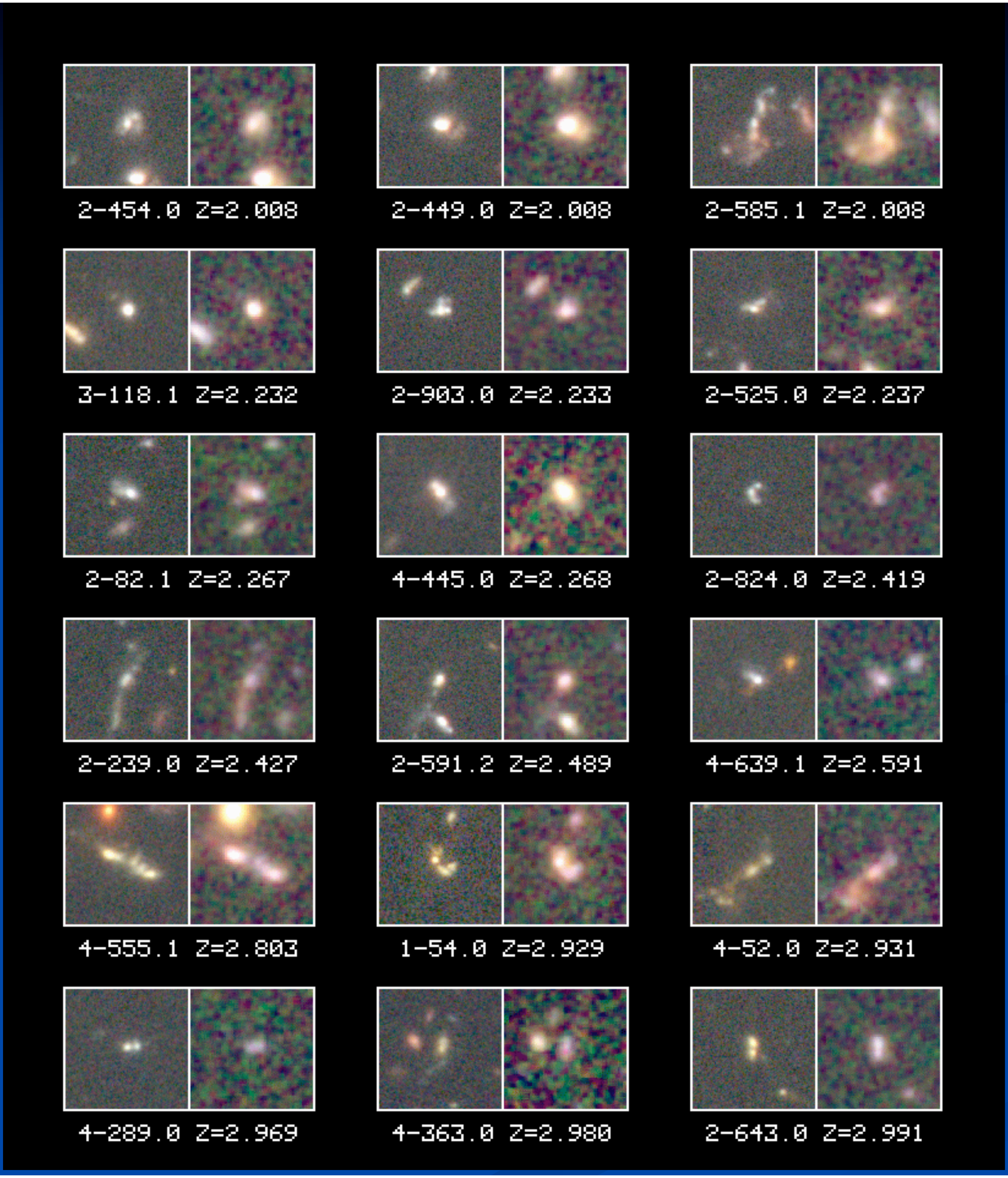


Galaxies at z < 1 - Includes group galaxies

Hubble Sequence in place

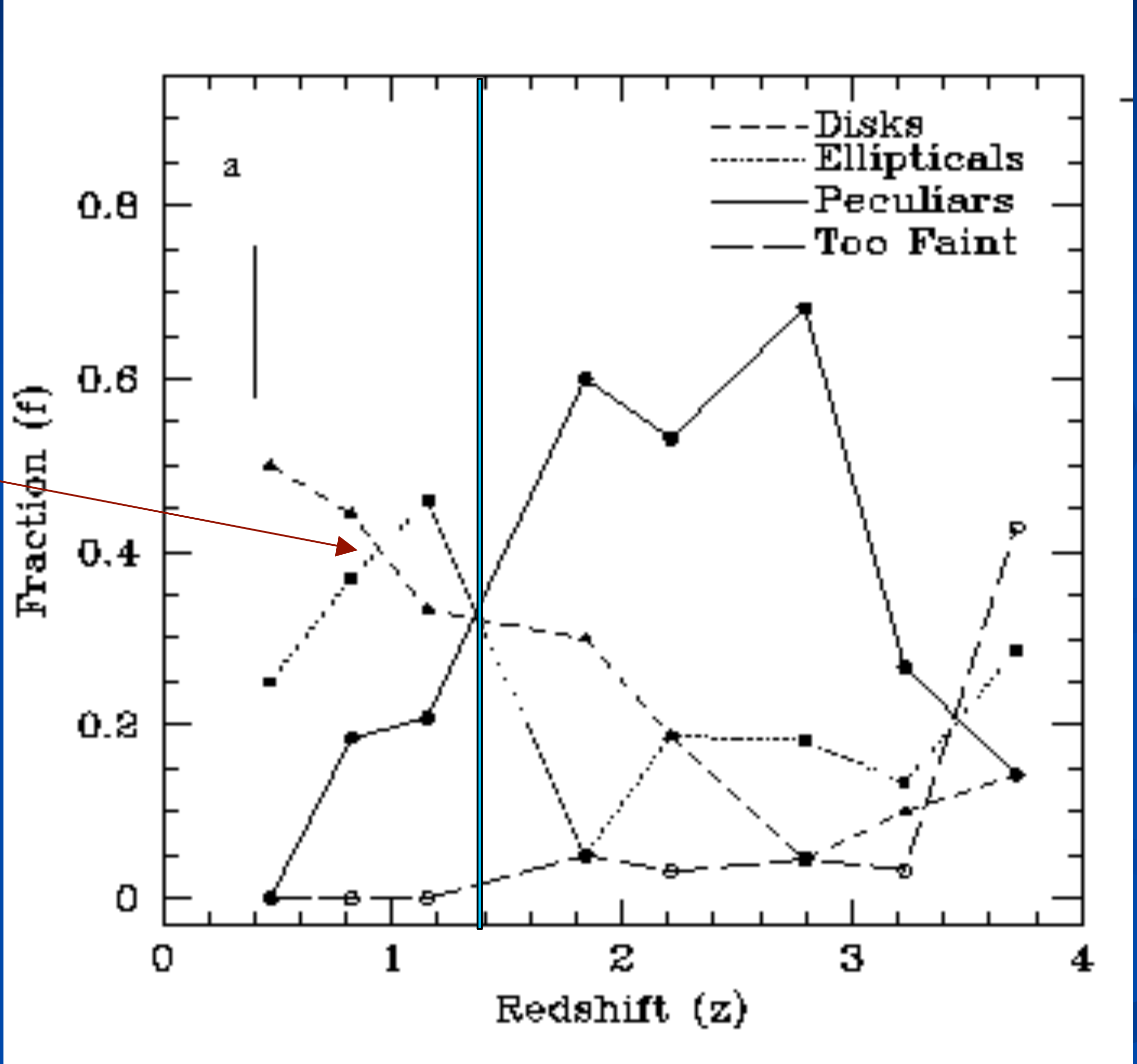
Galaxies at z >

Not 'Hubble Types'



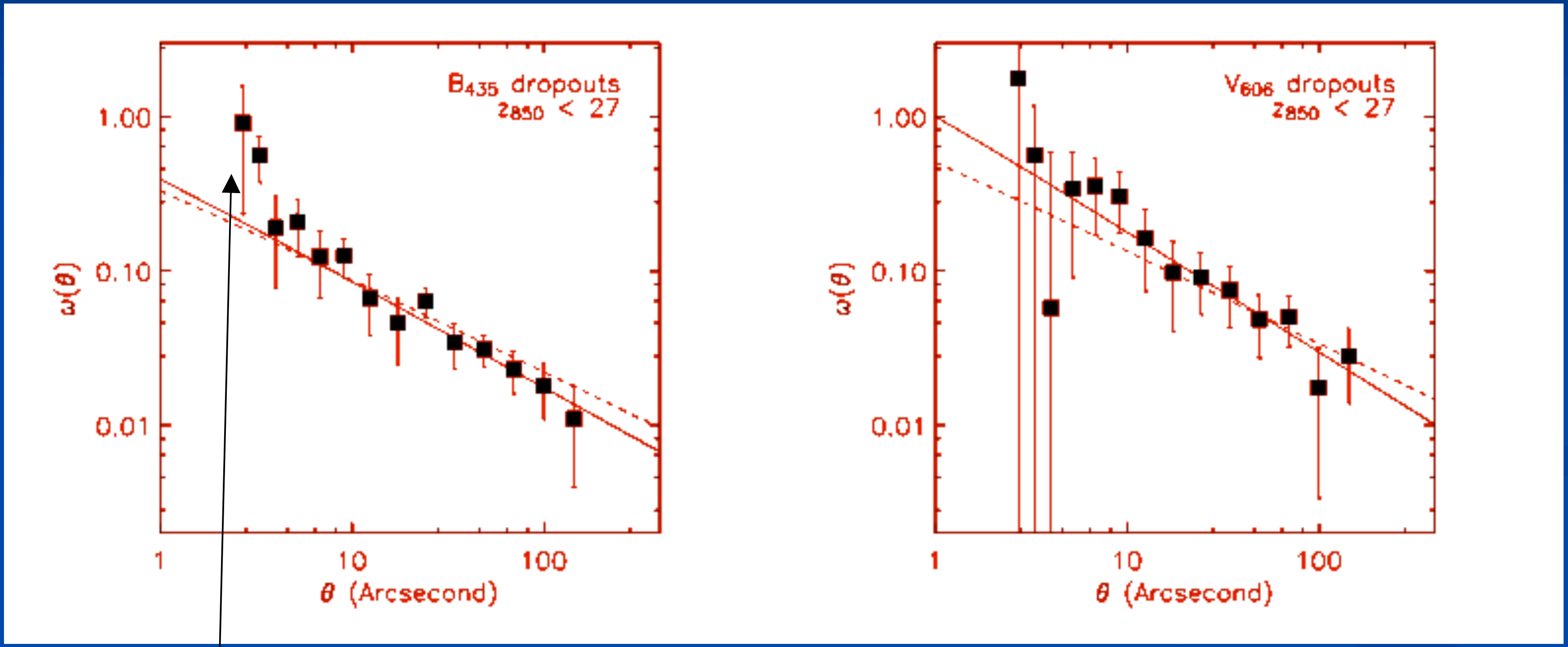
Evolution in the relative fractions of Hubble Types

Normal galaxies dominate at lower redshifts; phase transition at z ~ 1.4



Characterizing the population : What kind of galaxies exist?

Angular correlation function w(Θ) for B (z~4) and V (z~5) drop-outs in the GOODS fields

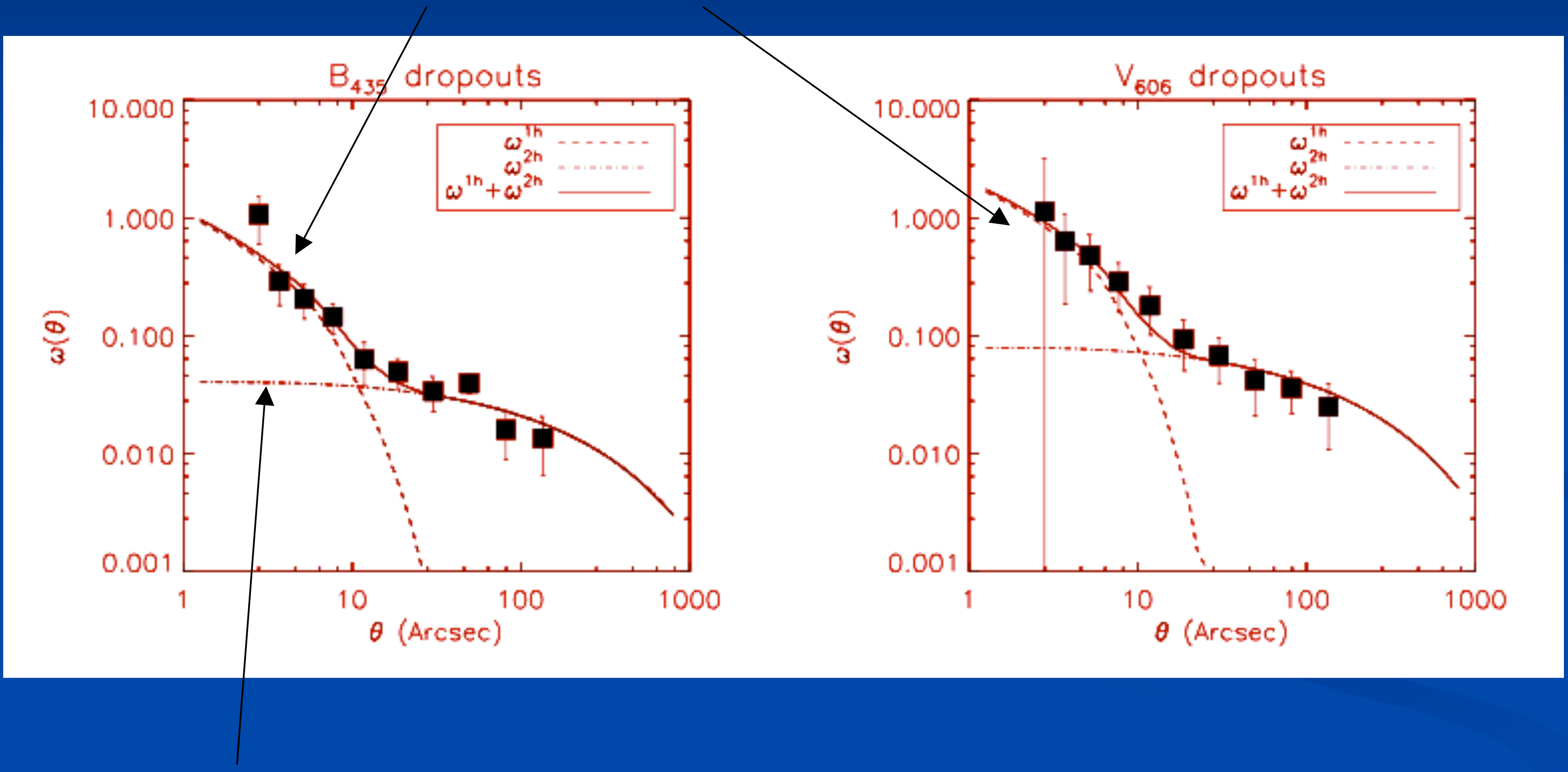


Lee et al. (2005)

A large departure from the fit power-law form at separations < 10 arcsec

This excess at small scales can be accounted for by multipl galaxies in the same halo

Two halo contribution

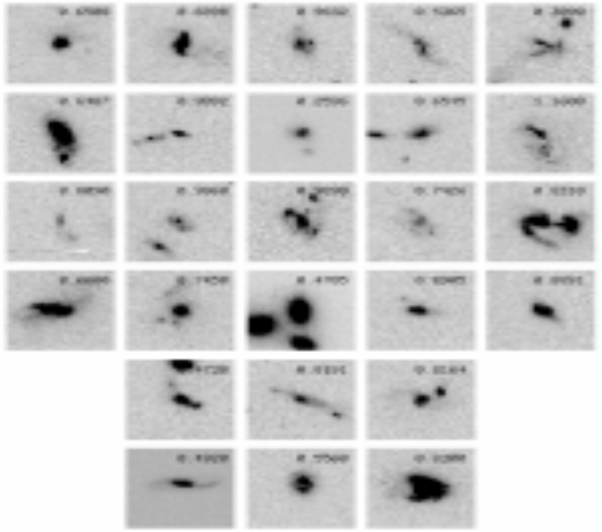


One halo contribution

Halo occupation distributions

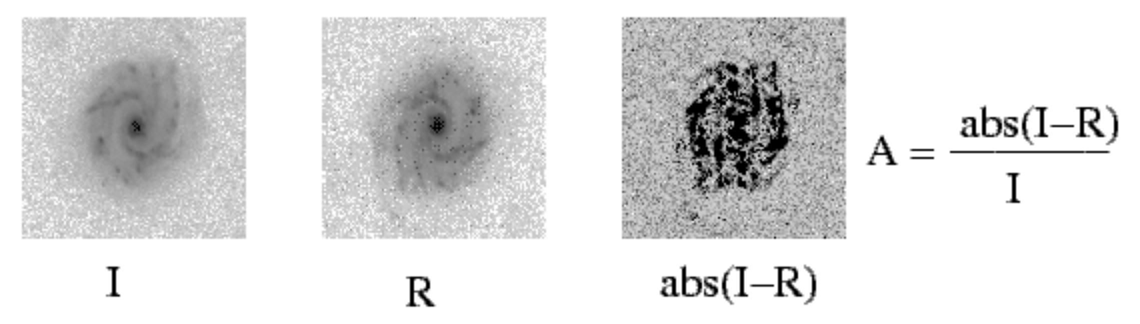
ARE HIGH REDSHFIT (Z > 2) 'GROUP' GALAXIES UNDERGOIN RAPID MERGING?

Traditional method for finding mergers is to use pairs



LeFevre et al. (2000)

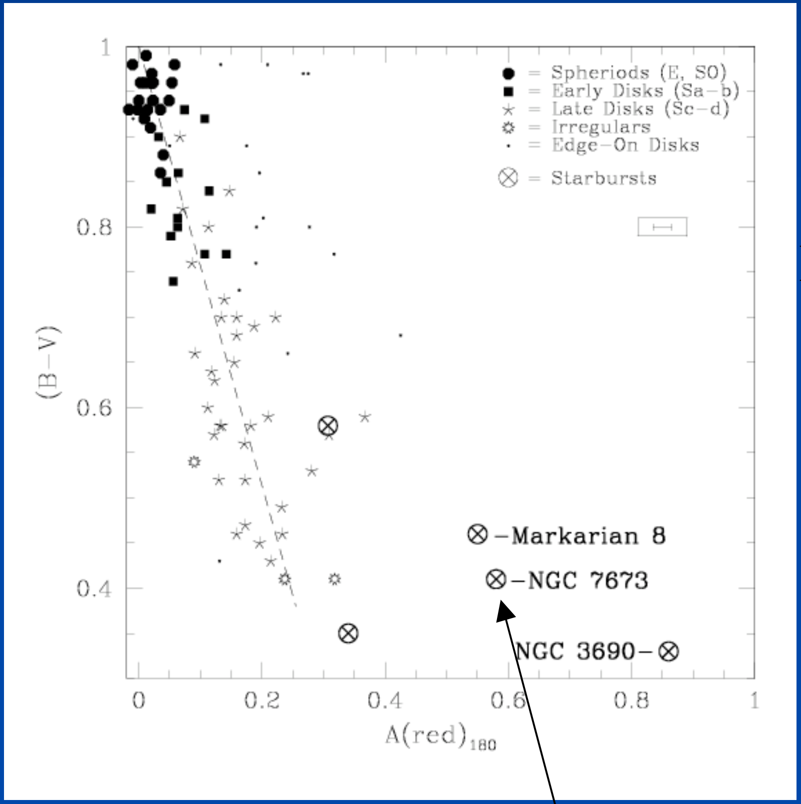
Morphological method finds objects that have already merged



$$A = \frac{\mathrm{abs}(I-R)}{I}$$

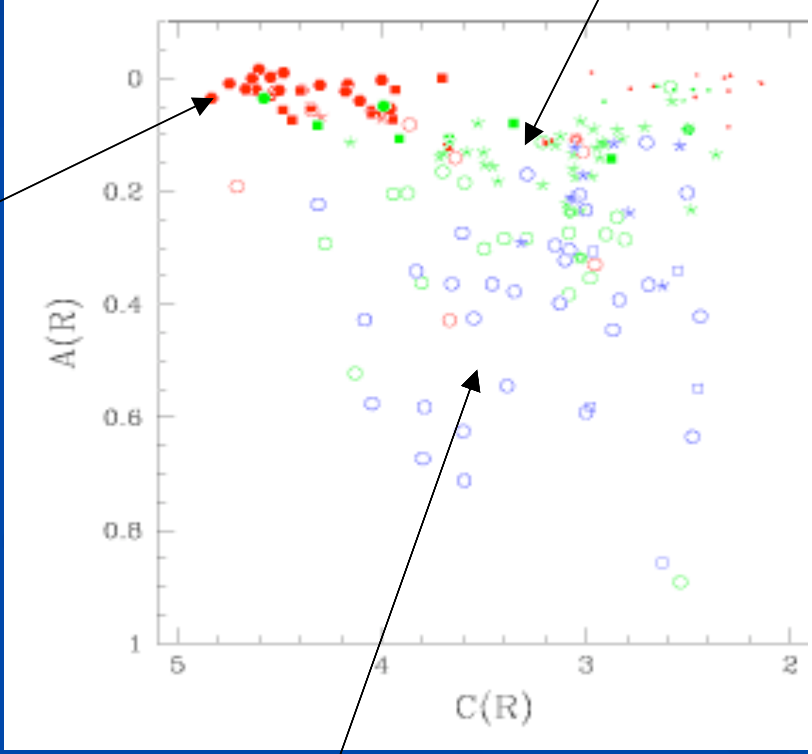
Rotate and subtract and image and quantify the residuals as a number

We can use the value of the asymmetry index to determine whether a galaxy is undergoing a merger



Ellipticals

Disk galaxies

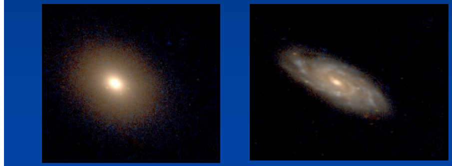


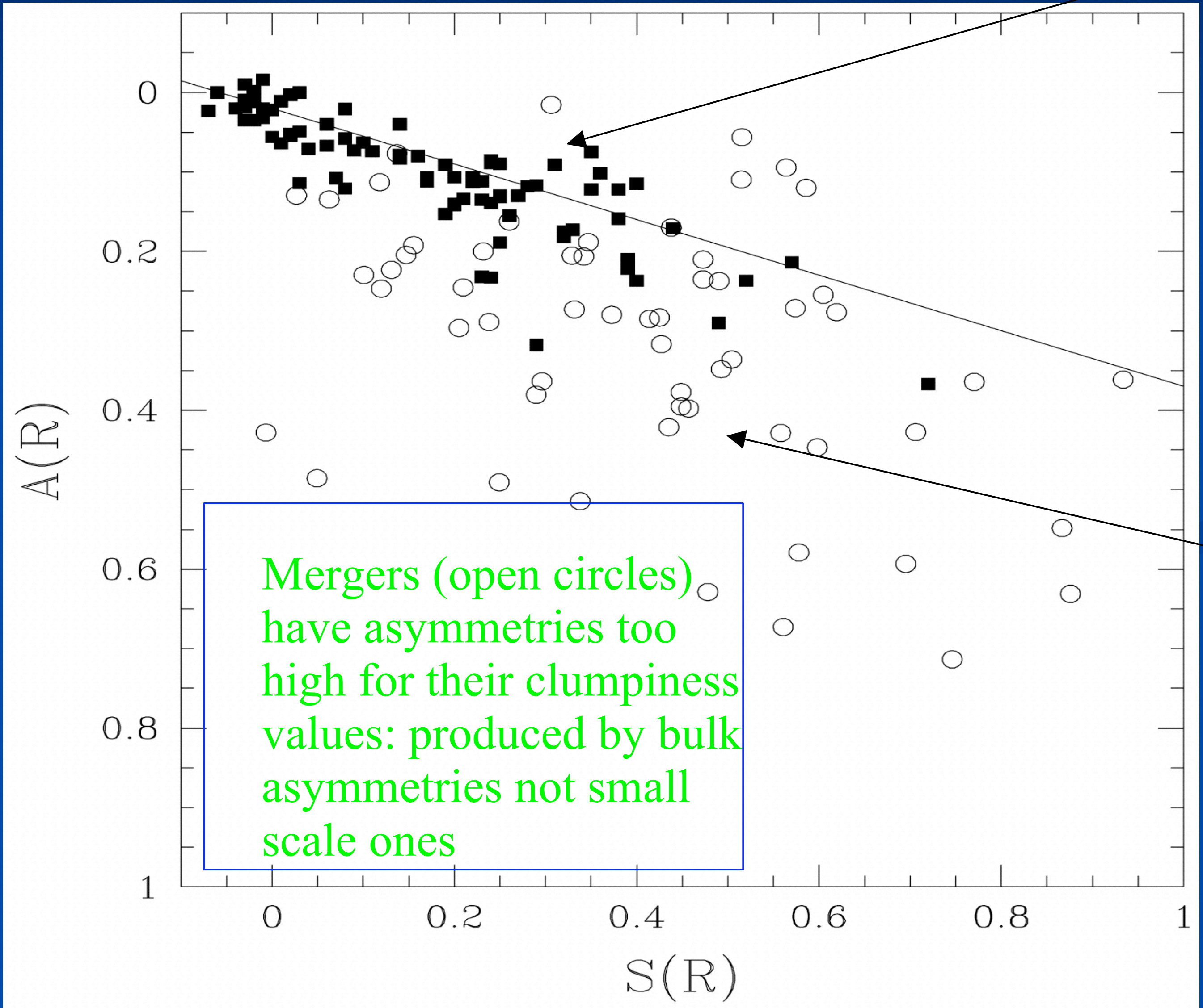
High A galaxies with blue colors are merger induced starbursts

High A(R) galaxies are mergers

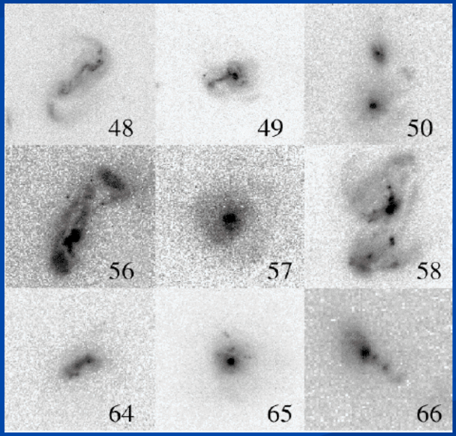
How to identify a merger – asymmetries

Clumpy light produces sma
asymmetries for normal
star forming galaxies

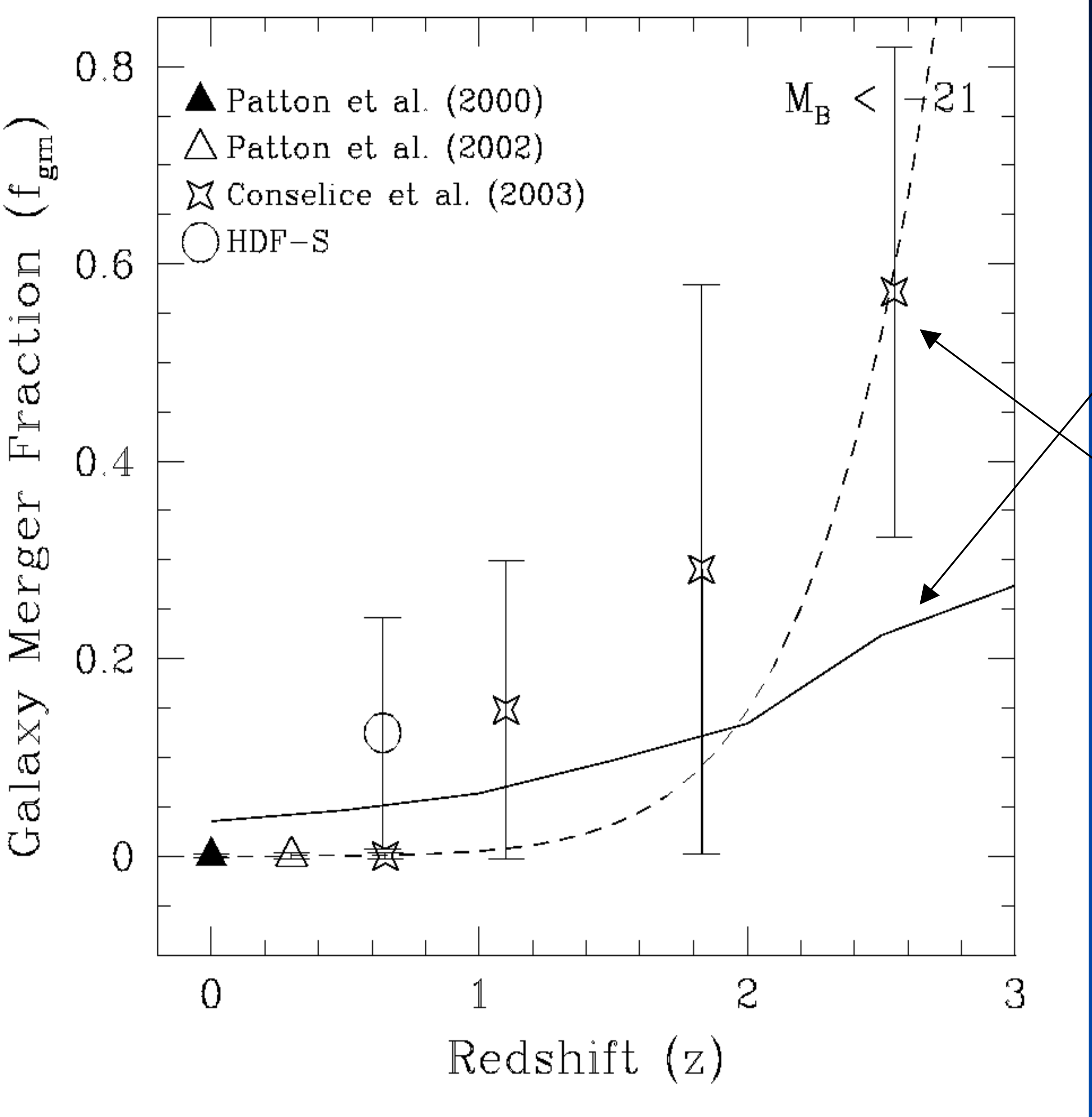




Mergers (open circles) have asymmetries too high for their clumpiness values: produced by bulk asymmetries not small scale ones



Can use the number of mergers at various redshifts to determine the history of merging

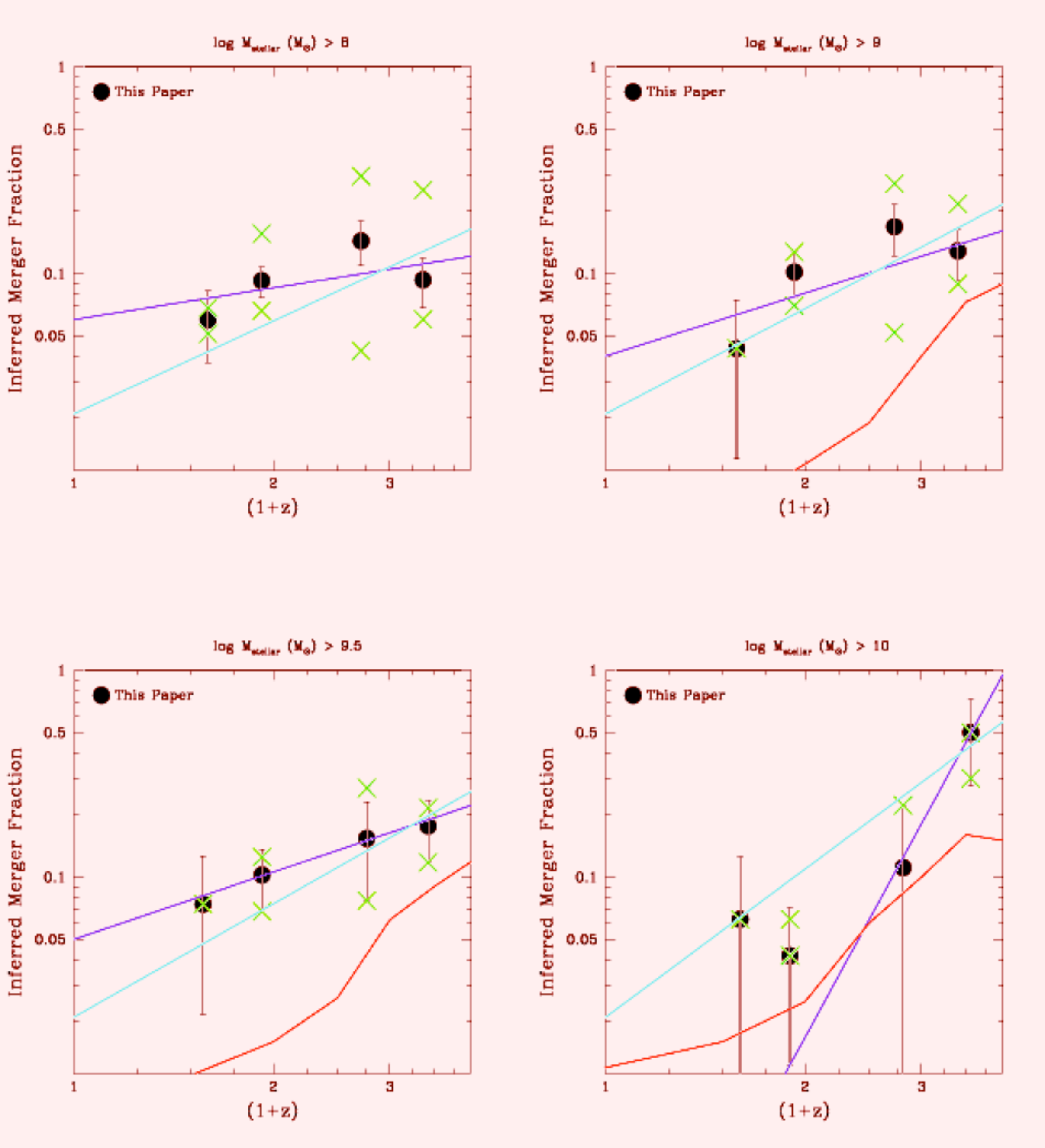


CDM semi-analytic model predictions from Benson et al. (20

Merger fractions computed as a function of redshift and upper magnitude limit

The brightest and most massive galaxies are those undergoing the most merging at high redshift with 60% involved in a merger

Conselice et al. (2003); Conselice (2006)



Conselice et al. (2003)

Can fit merger fraction evoluti
as a powerlaw

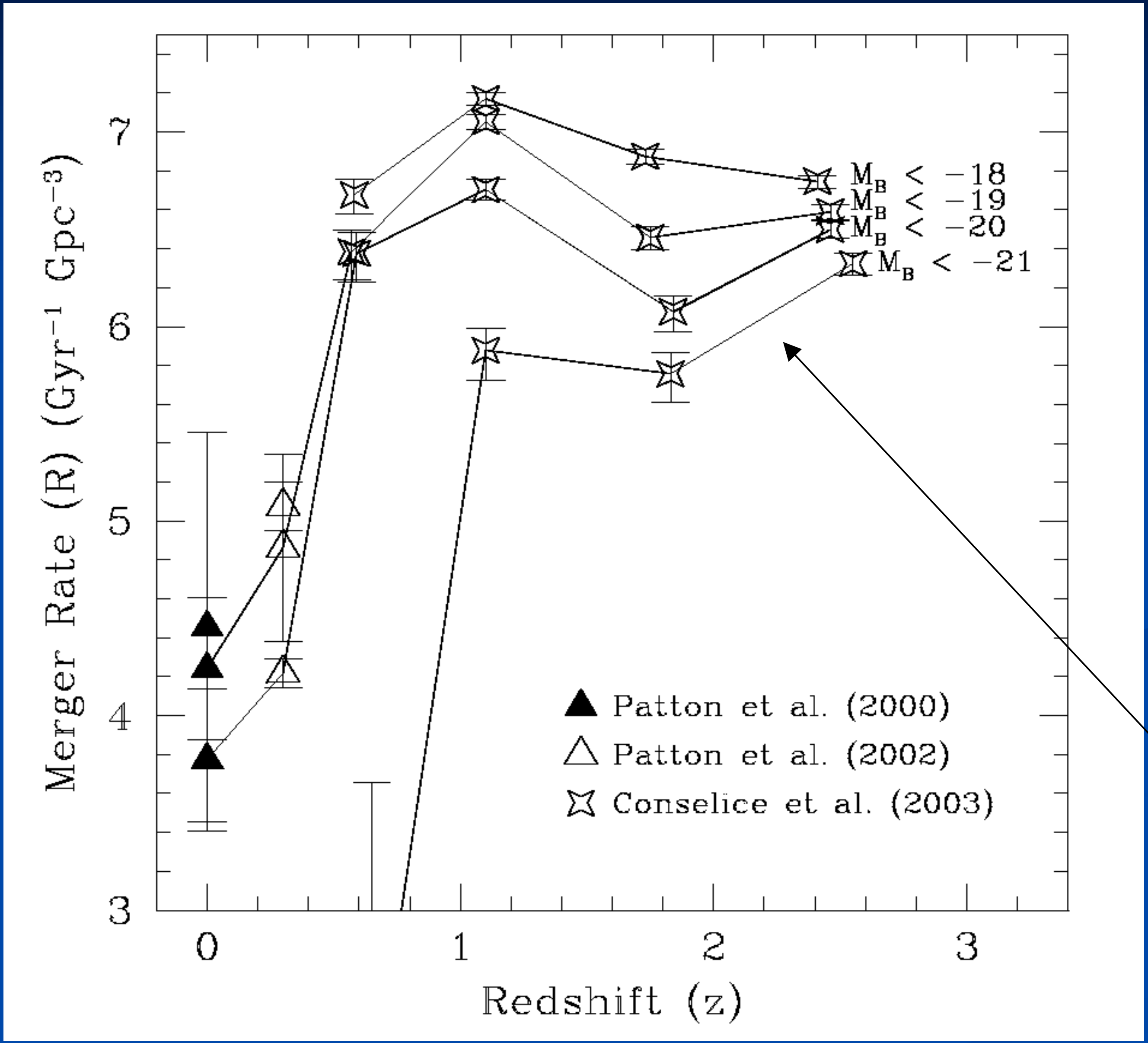
$$fm = f_0 * (1 + z)^{m}$$

From z ~0 to z~3

For objects with Mb > -21 or
log (Mstellar) < 10 ---- m ~

For objects with Mb < -21 or
log (Mstellar) > 10 ---- m ~

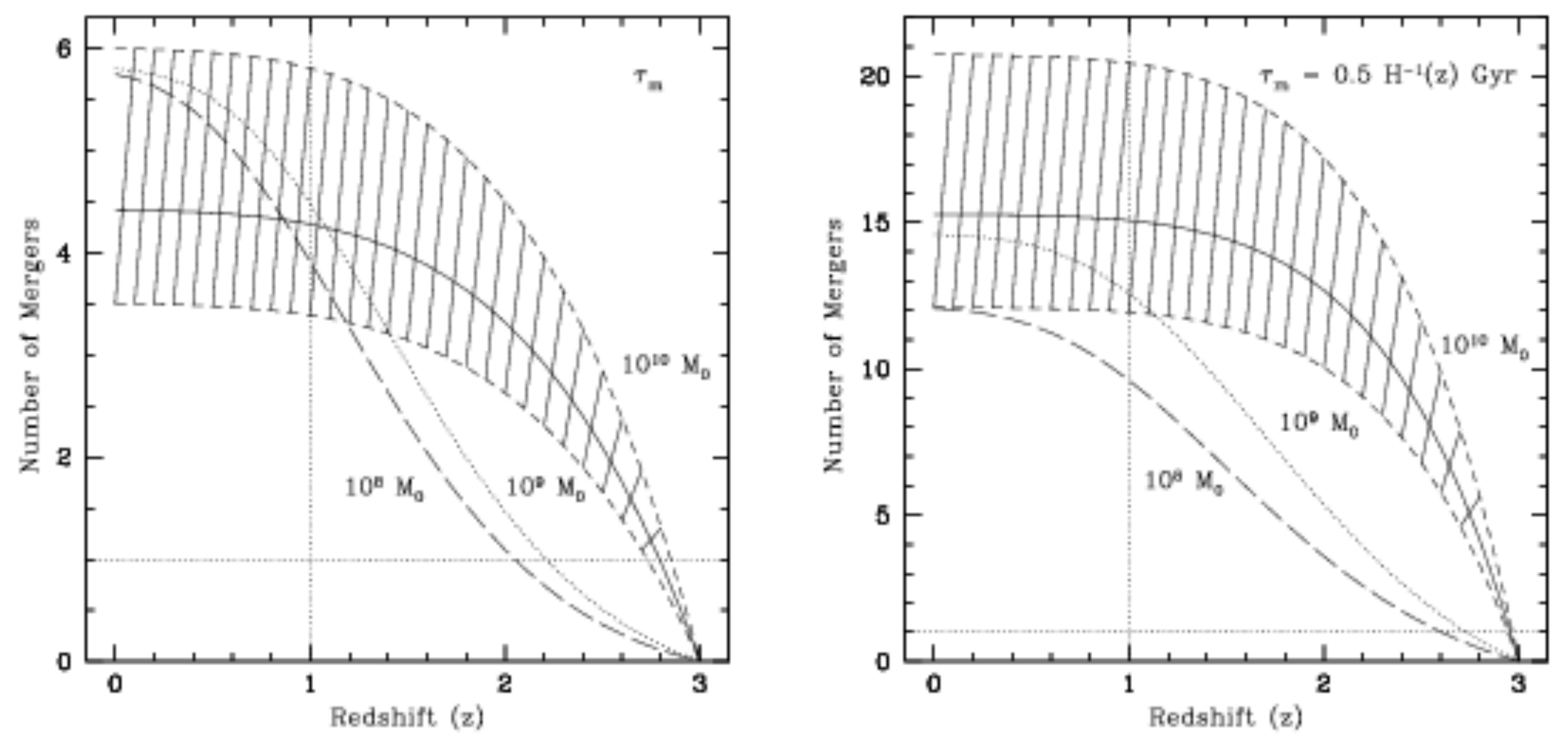
Merger Rates



From the merger time scale, we can compute the merger rate – that is the number densities of mergers occurring pe unit time as a function o redshift

Merger rate is high at z > 1, but declines rapidly at lower redshifts. Consistent with an early formation of galaxies and a lambda dominated universe

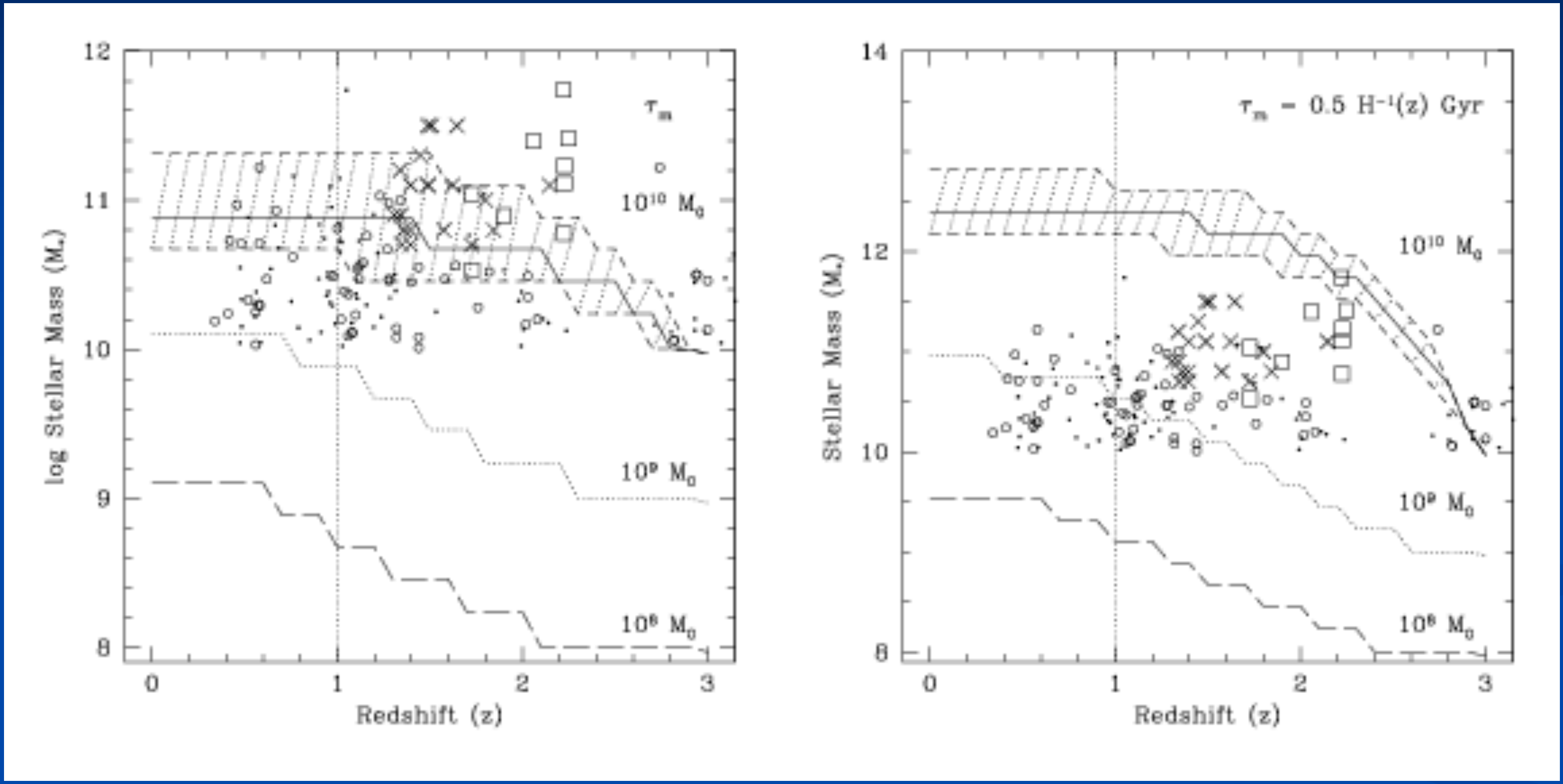
From the merger rate, can calculate the average number of mergers a typical galaxy at z~3 undergoes before it reaches z~0



$$N_{\rm m} = \int_{z_1}^{z_2} \frac{f_{\rm gm}(z)}{\tau_{\rm m}} {\rm d}t = \int_{z_1}^{z_2} t_H \left(\frac{f_0}{\tau_{\rm m}}\right) (1+z)^{{\rm m_A}-1} \frac{{\rm dz}}{{\rm E}(z)}$$

On average, a massive z~3 galaxy undergoes $4.4^{+1.6}_{-0.9}$ major mergers

The mass accretion history can also be calculated by adding in star formation produced by the merger and the mass from the merger



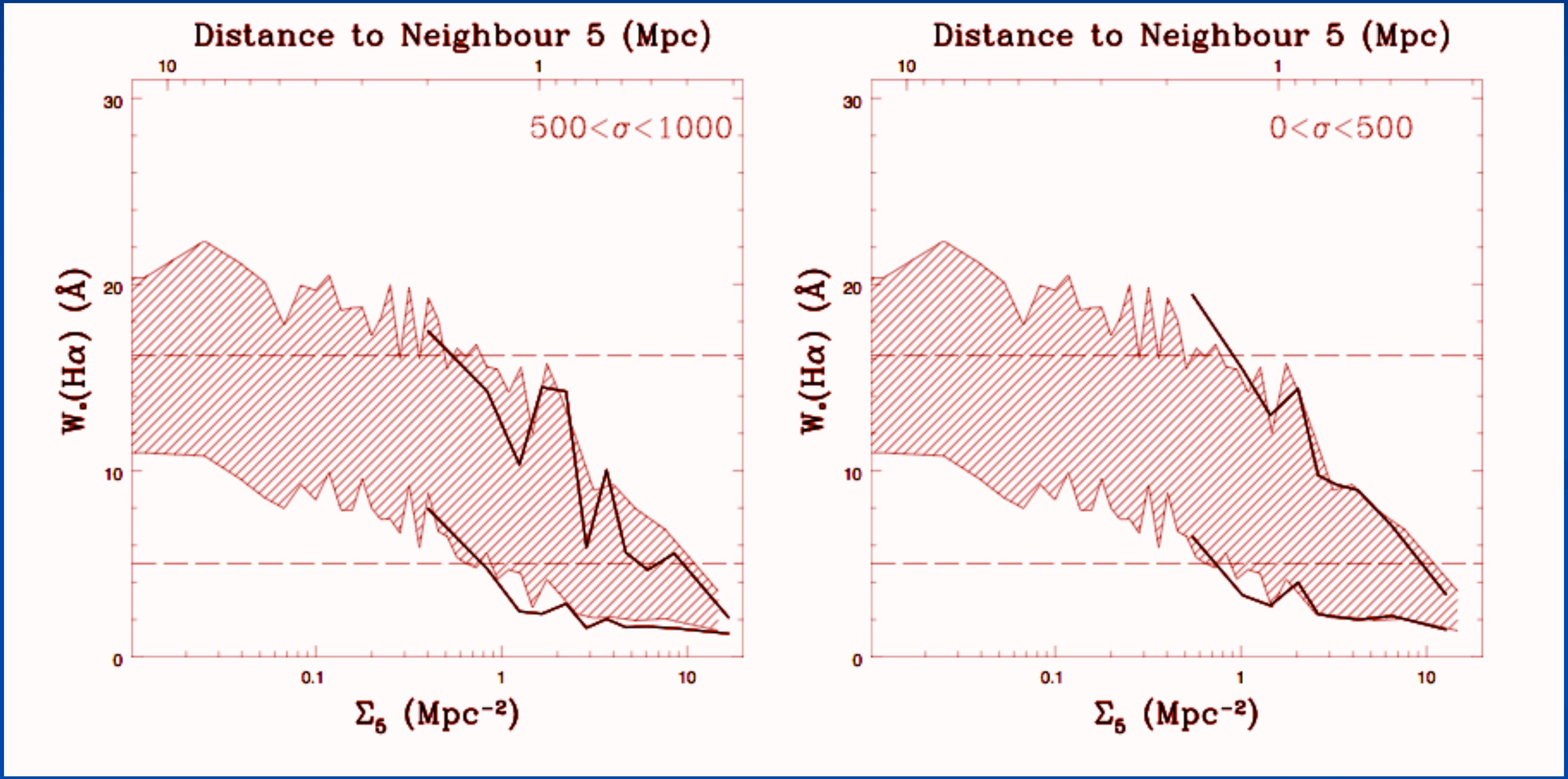
$$\delta \mathrm{M_{msf}} = \int_{z_1}^{z_2}\int_{0}^{t_\mathrm{m}} t_H \left(\frac{f_0}{\tau_\mathrm{m}}\right)(1+z)^{\mathrm{m_A}-1}\frac{\mathrm{dz}}{\mathrm{E}(z)} \times \Psi_0 \mathrm{exp}(-t/\tau_\mathrm{sf})\mathrm{dt}$$

z~3 galaxies increase in mass by a factor of 100 – enough to become today's massive galaxies

Conselice (200

Open questions

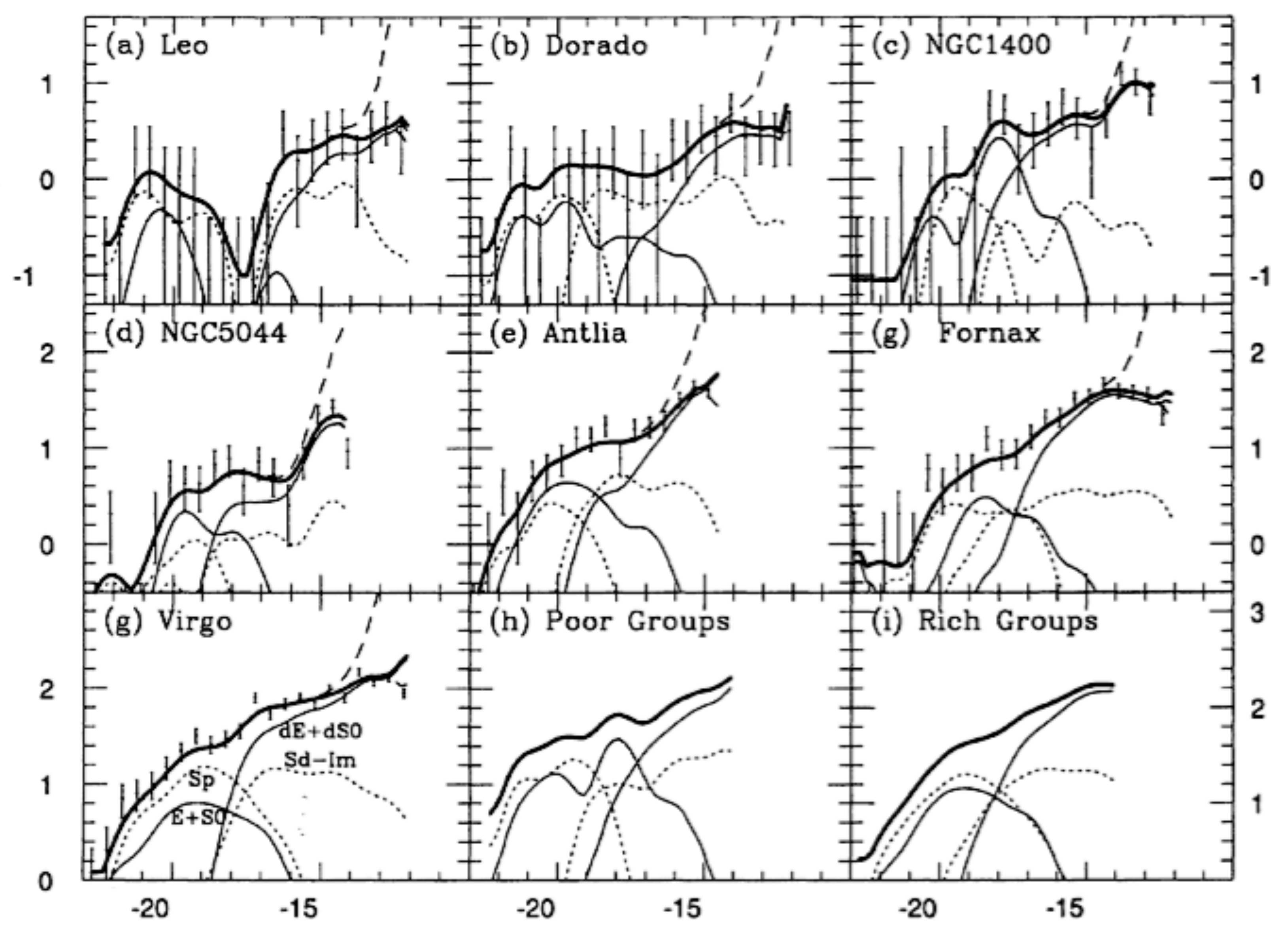
Star formation rate is independent of global environment



Balogh et al. (200

Ongoing star formation only depends on the local density

Low luminosity and dwarf galaxies in groups



There are more dwarfs per giant in richer environments - why?

Summary

1. Galaxy ‘group’ evolution can be studied in various ways out to when the first galaxies are found

2. Low redshift galaxy groups reveal that multiple galaxy formation modes have occurred

3. Groups, in a traditional sense, can be identified and are common out to z~1.4, when the universe was less than half its current age

4. Galaxies in groups evolve in a similar manner as the field, although groups tend to have a more evolved population at a redshifts thus far probed

5. At higher redshifts, evidence exists for ‘groups’ in the form o strong galaxy clustering and merging to form larger galaxies