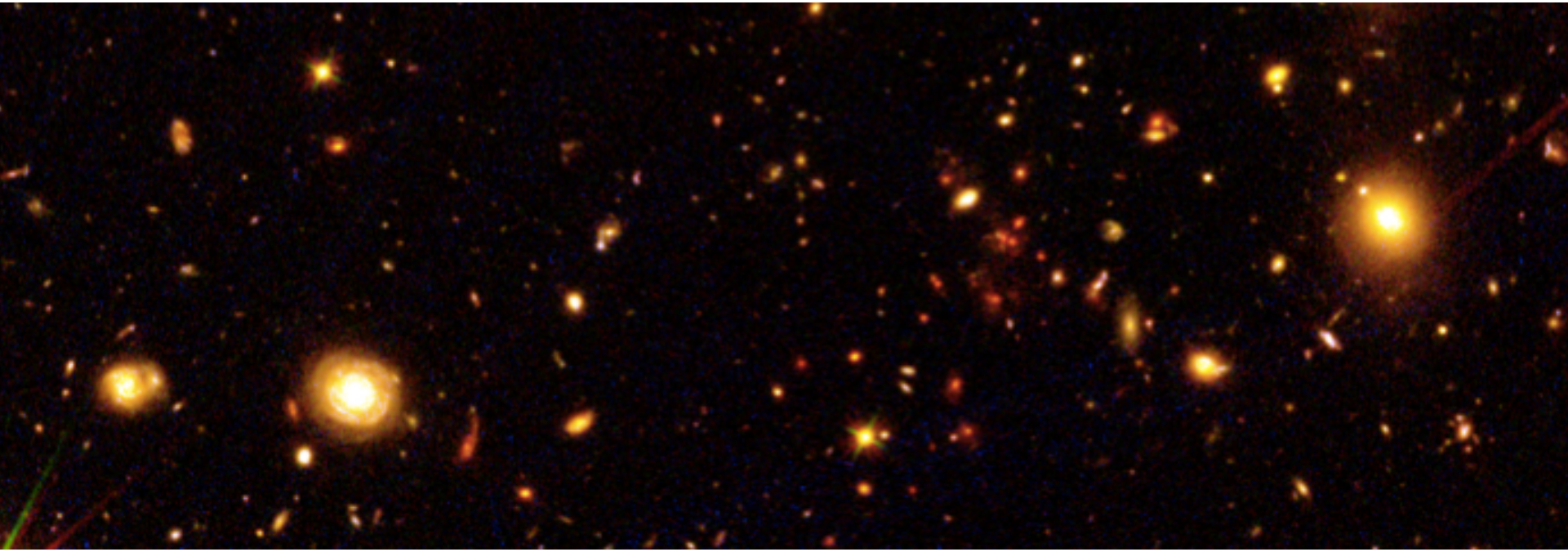
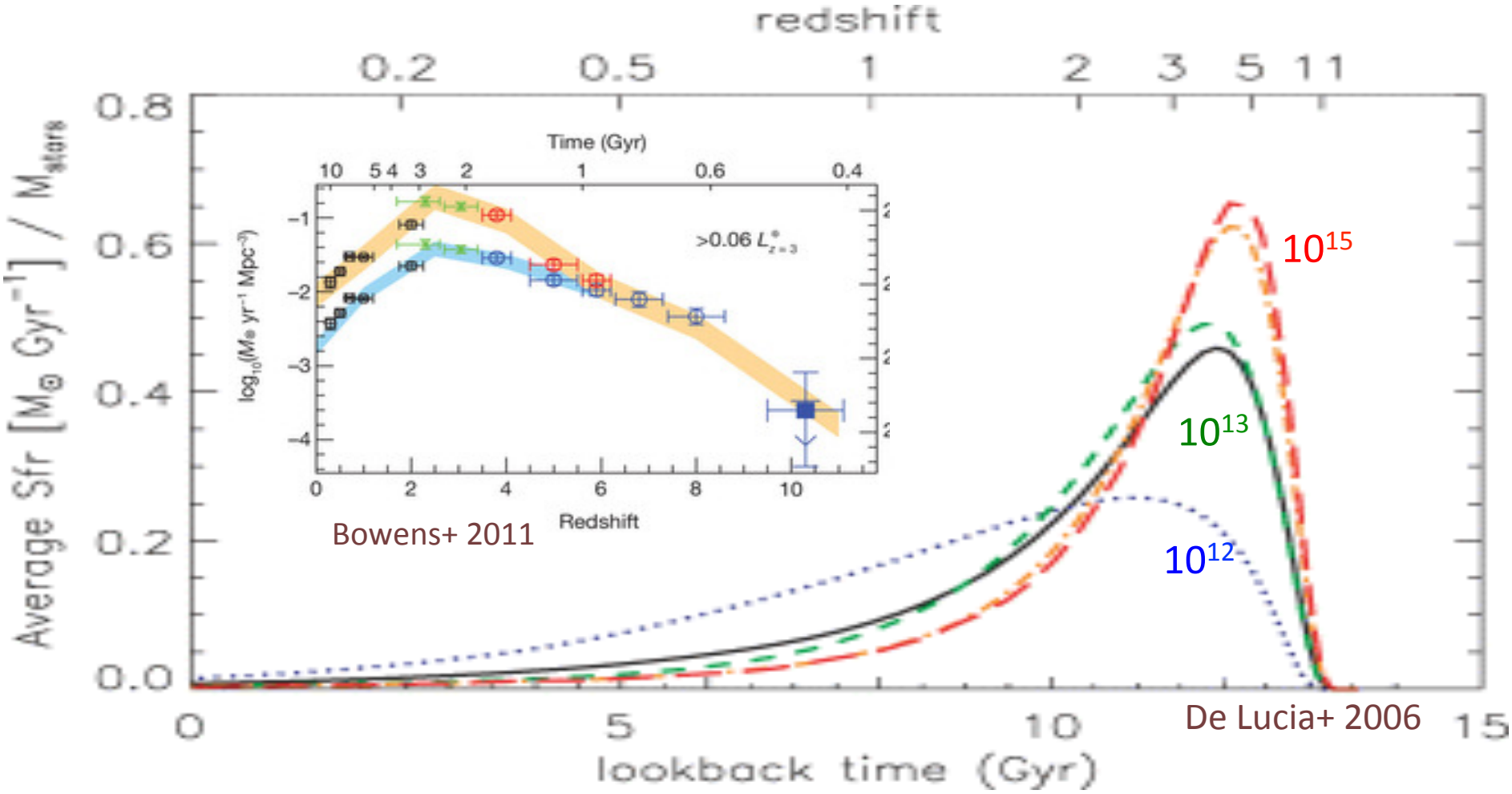
Early-type galaxies in a cluster at z=2



Veronica Strazzullo
(CEA Saclay)

with R. Gobat, E. Daddi
and M. Onodera, M. Carollo, M. Dickinson, A. Renzini,
N. Arimoto, A. Cimatti, A. Finoguenov, R.R. Chary

… why going to redshift 2



Cl J1449+0856

- "IRAC selected" (3.6-4.5μm), with a strong overdensity of red (Y-K>2) galaxies Gobat et al. 2011
- now spectroscopically confirmed at z=2 with >20 spectroscopic members Gobat et al. 2013
- an a-posteriori 3.5σ detection of extended X-ray emission Gobat et al. 2011
- a sub-$10^{14} M_{\odot}$ system, evolving into a typical massive cluster today
- wide multi-wavelength coverage including Subaru/VLT/HST/Spitzer optical/NIR, XMM, Chandra, Spitzer MIPS, Herschel PACS and SPIRE, APEX LABOCA, ALMA, JVLA, GMRT

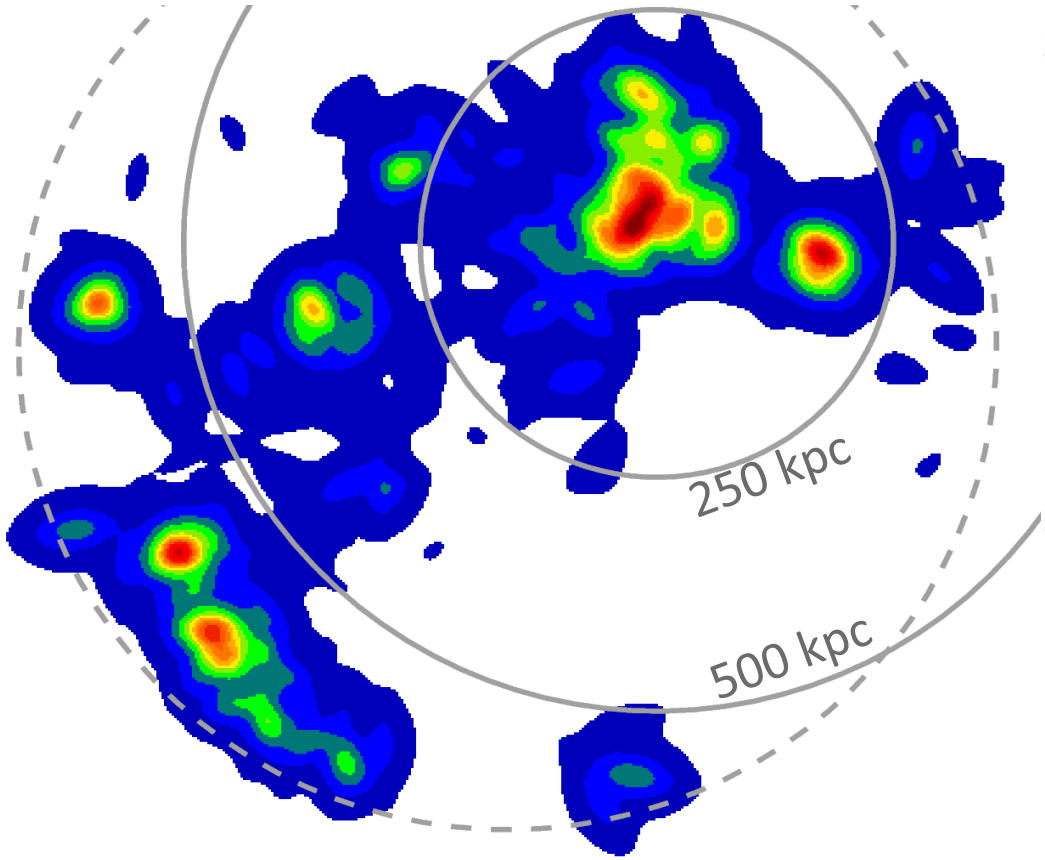
Results presented here based on optical/NIR Imaging.

Mostly from Strazzullo+ 2013, ApJ, 772, 1185

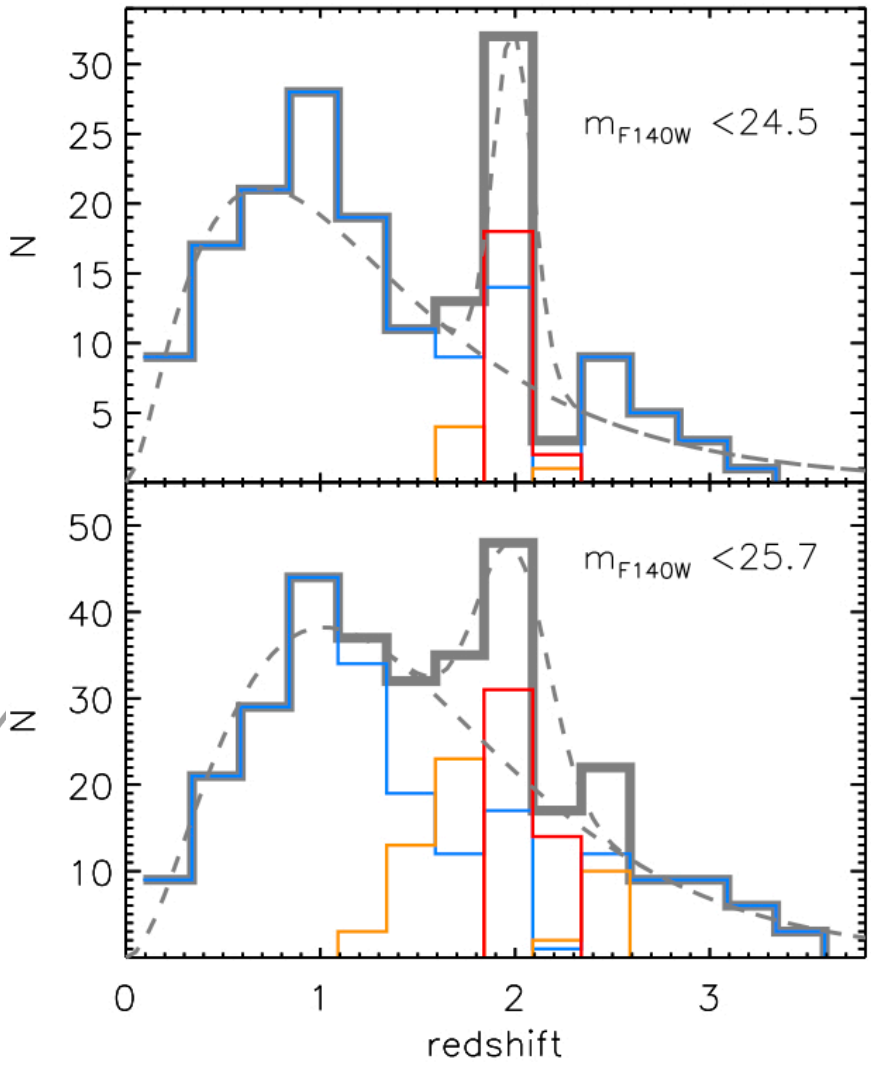
Cl J1449 as described by its galaxies

- a clear projected overdensity of (candidate) members

projected Σ_3 density of m_{140}<25.7 (candidate) members



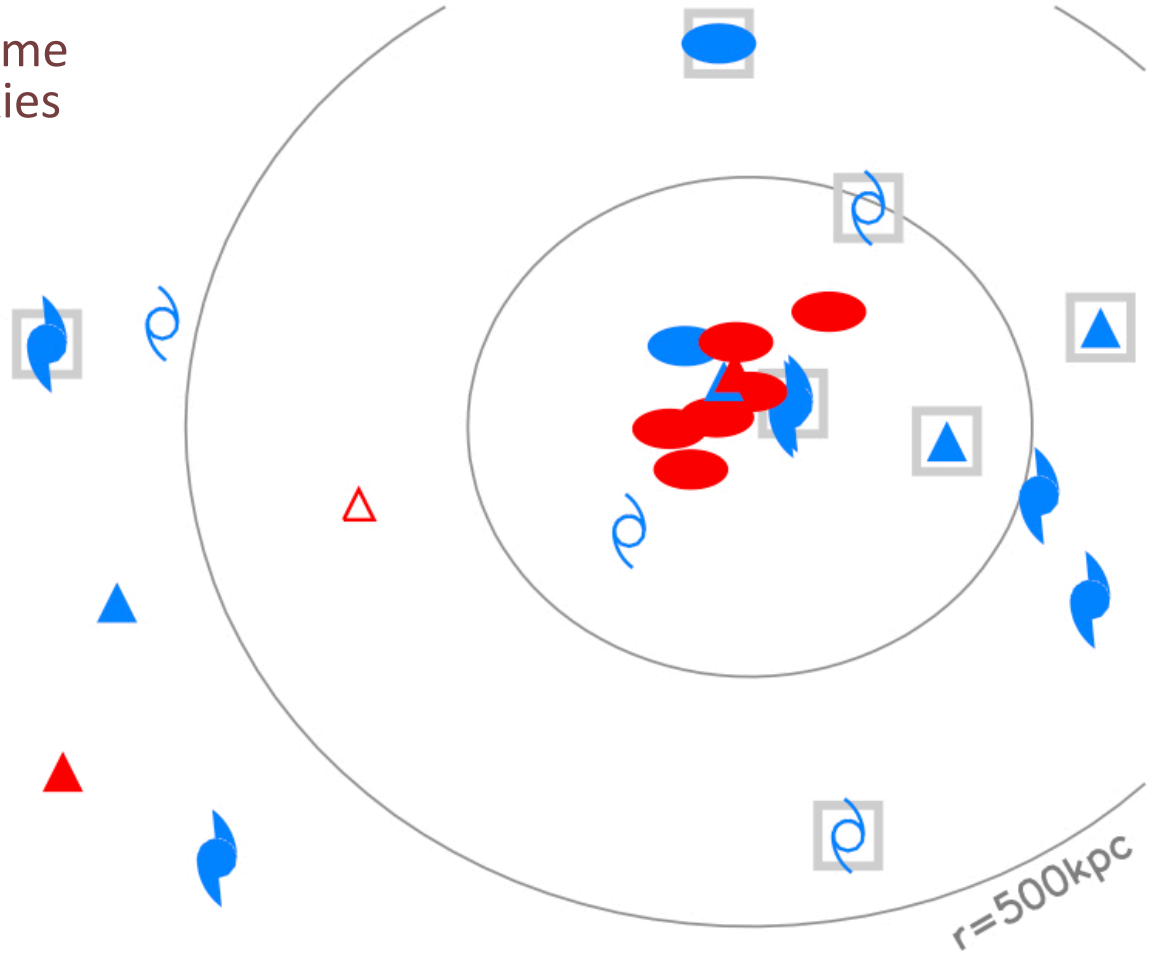
- a clear overdensity in redshift space



Cluster galaxies at redshift two

- a population of massive, quiescent early-type galaxies in the cluster core
- ***but*** cluster core hosts at the same time still actively forming galaxies

e.g. Kurk+ 2009, Papovich+ 2010, 2012, Tanaka+ 2010, 2012 at z≈ 1.6, as well as e.g. Steidel+ 2005, Kodama+ 2007, Tanaka+ 2010, Hatch+ 2011, Zirm+ 2012, Spitler+ 2012 for (proto-)clusters at z≥2.



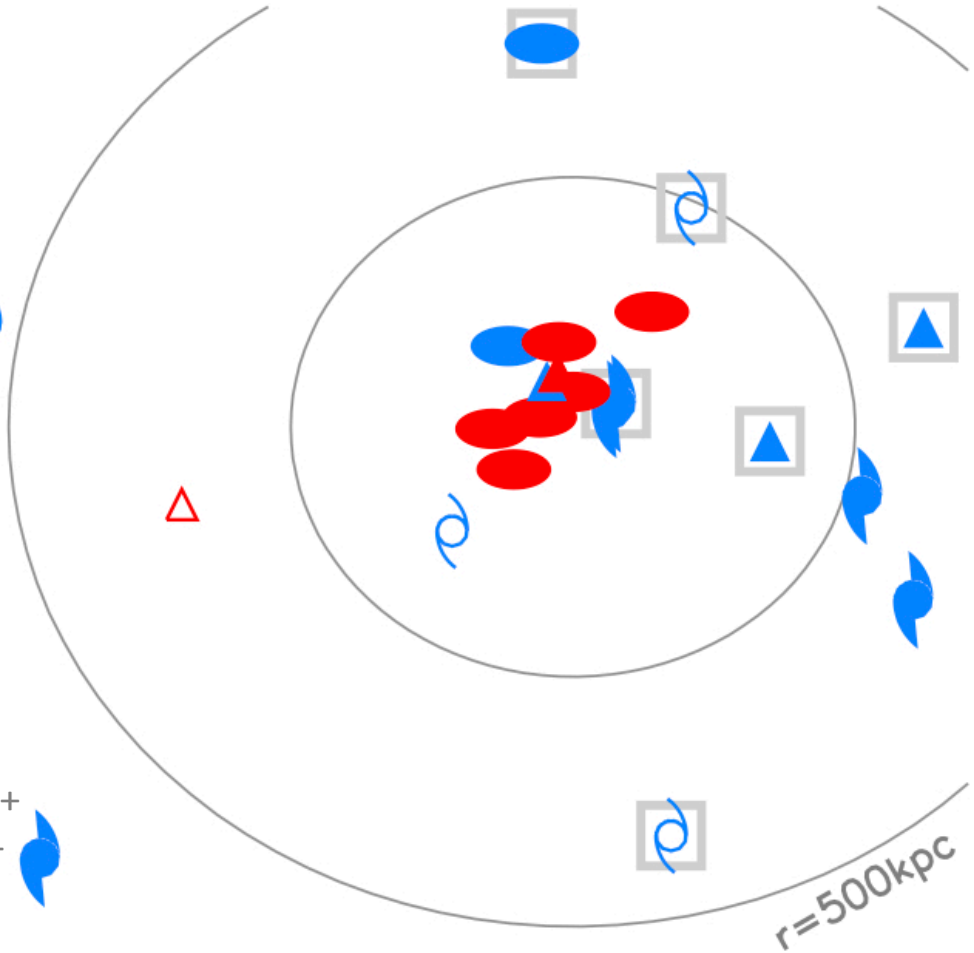
Cluster galaxies at redshift two

- a population of massive, quiescent early-type galaxies in the cluster core
- ***but*** cluster core hosts at the same time still actively forming galaxies
- galaxy structure and stellar populations are already well correlated (as observed also in the field)

@log(M/$M_\odot$)>10.4, ≈70% ($^{+10}_{-20}$) of passive (candidate) members have n>2 (similar in the field passive sample), wrt ≈10% ($^{+20}_{-4}$) of SF members. In turn, ≈75% ($^{+9}_{-20}$) of early-type (candidate) members are passive.

also e.g. Cimatti+ 2008, Kurk+ 2009, Wuyts+ 2011, Cameron+ 2011, Bell+ 2012, Papovich+ 2012, Tanaka+ 2012, Patel+ 2012, Wang+ 2012, Lee+ 2013, Cassata+ 2013 … at similar redshift and in different environments

quiescent or **star-forming** cluster members (phot or spec), m_{140}<24.5

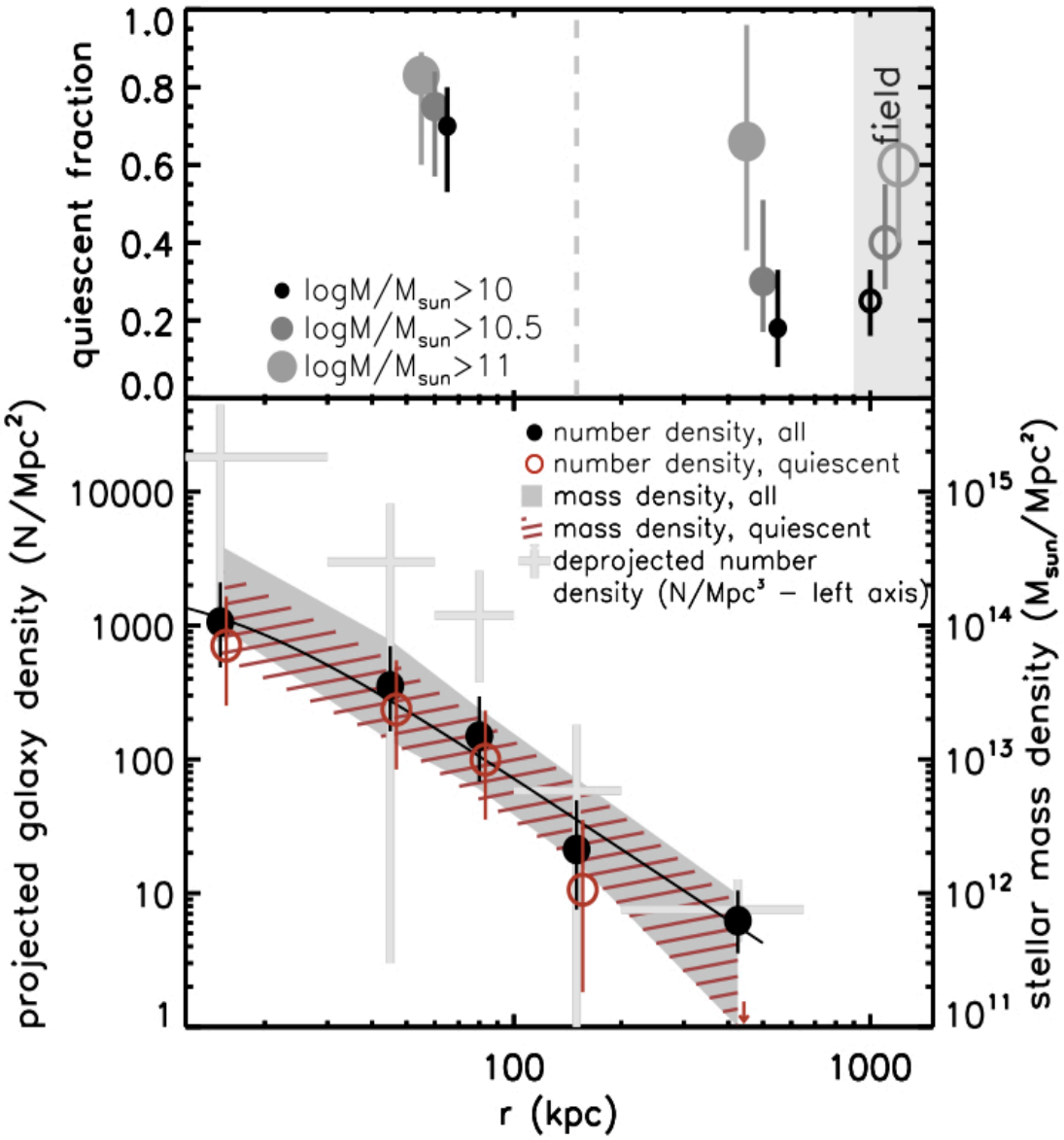


Cluster galaxies at redshift two

- quiescent fraction is already enhanced in the most dense regions

Compared to z≈1 clusters (e.g. Muzzin+ 2012) quiescent fractions appear to be lower (but beware of caveats!), at least for $<10^{11}M_{\odot}$ galaxies. Already similar quiescent fraction for most massive core galaxies (see also e.g. Raichoor & Andreon 2012).

Quiescent fraction ≈15% ($^{+15}_{-5}$) at log(M/$M_{\odot}$)<10.5, increasing to ≈30% at log(M/$M_{\odot}$)≈10.5-11, and ≈80% beyond $10^{11}M_{\odot}$ (also e.g. Kodama+ 2004, De Lucia+ 2007, Rudnick+ 2012,…)



Early-type galaxies in Cl J1449

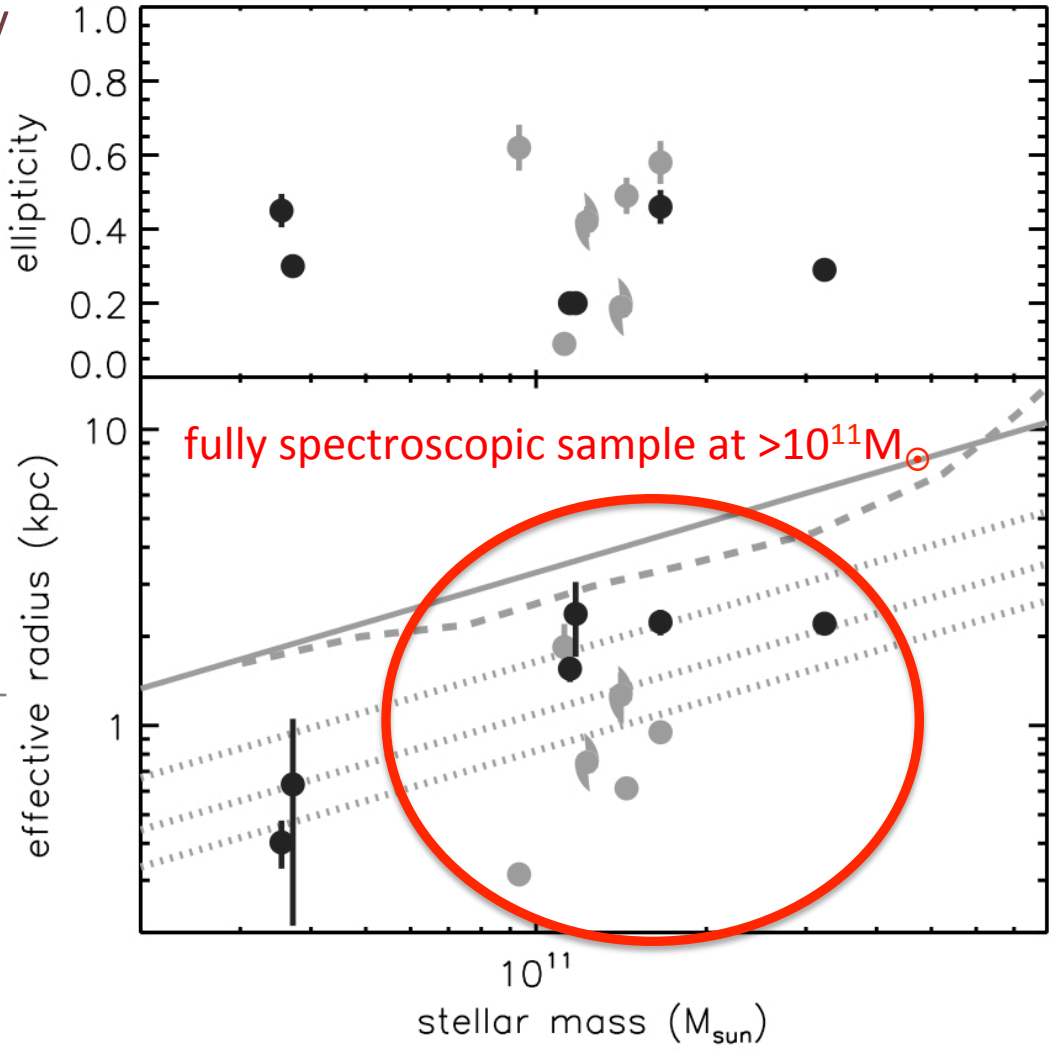
- cluster early-types appear smaller (by a factor 2-3) than z≈0 similarly massive early-types

(among many others, Daddi+ 2005, Trujillo +2006, Zirm+ 2007, van der Wel+ 2008, Williams+2010, van Dokkum+ 2010, Cassata+ 2011, Damjanov+ 2011, Cameron+ 2011, Cimatti+ 2012 … – see als0 e.g. Saracco+2009, Onodera+ 2010, Mancini+ 2010 …)

- cluster early-types might be *larger (≈2x) than z≈2 field* early-types of similar mass

(see also Papovich+2012, Zirm+ 2012, Tanaka+ 2012 – perhaps more controversial results in lower redshift groups, e.g. Cooper+ 2012, Huertas-Company+ 2013)

Median ellipticity of cluster early-types close to low-z values (≈0.3, e.g. Holden+ 2009).

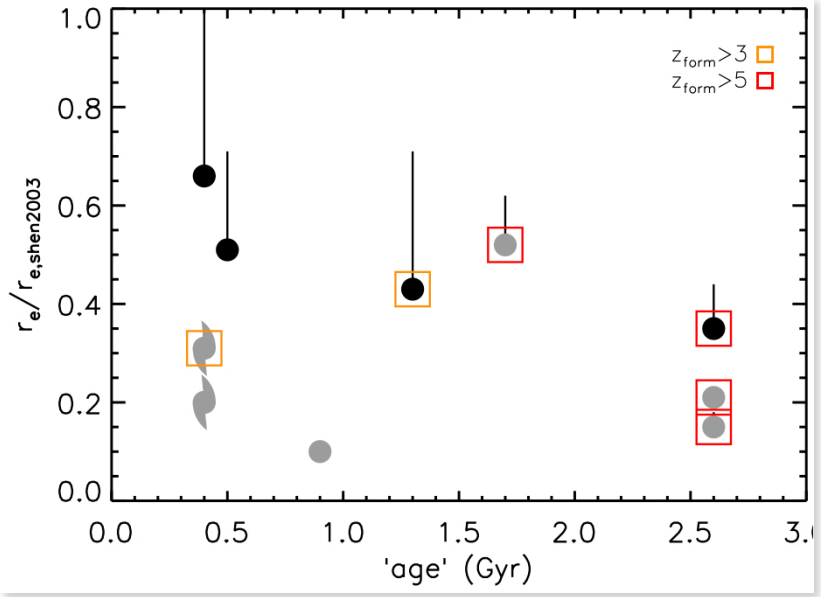


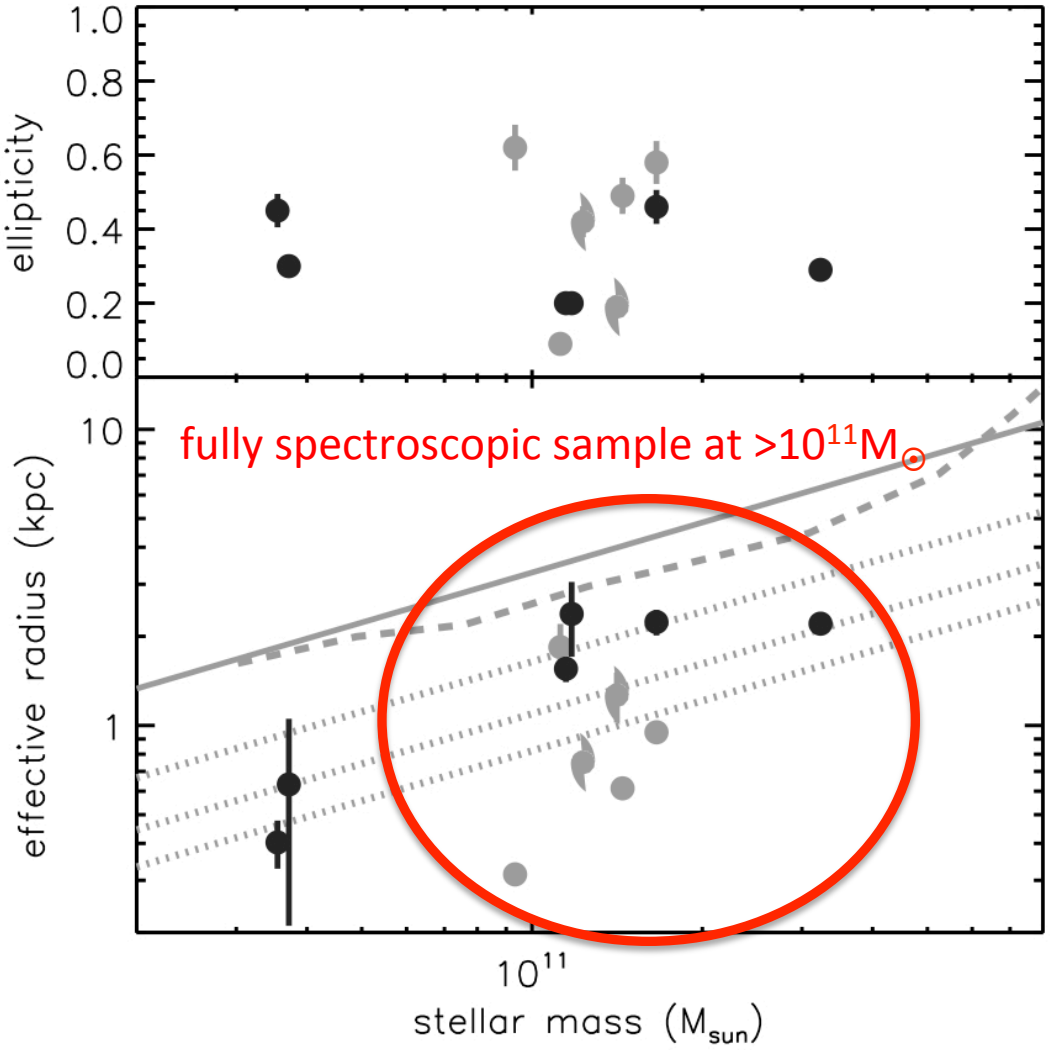
Early-type galaxies in Cl J1449

- size difference between cluster and field early-types doesn't seem to be due to systematic age differences (at face value...!)

see also spectral analysis Gobat+ 2013

e.g. Bernardi+ 2010, Valentinuzzi+ 2010, Saracco+ 2011... but see also e.g. Cimatti +2012, Onodera+ 2012, Whitaker+ 2012)



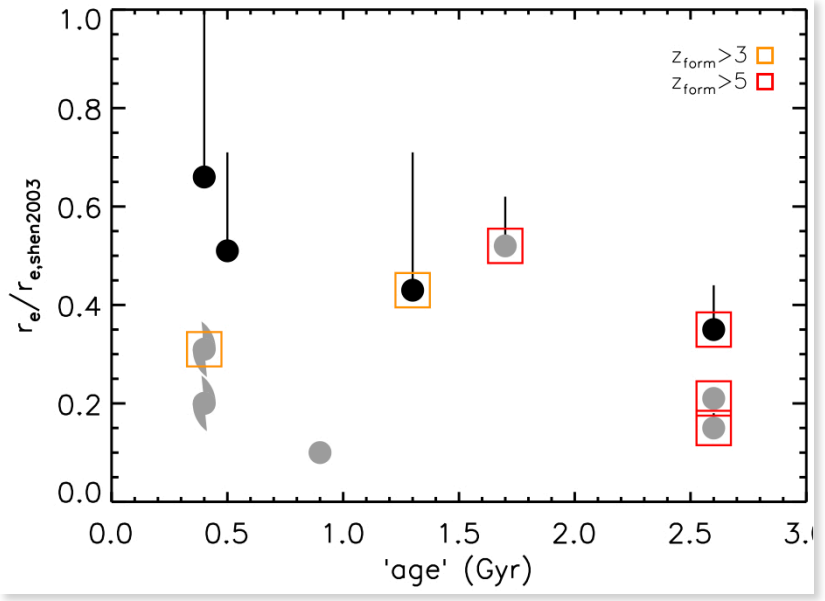


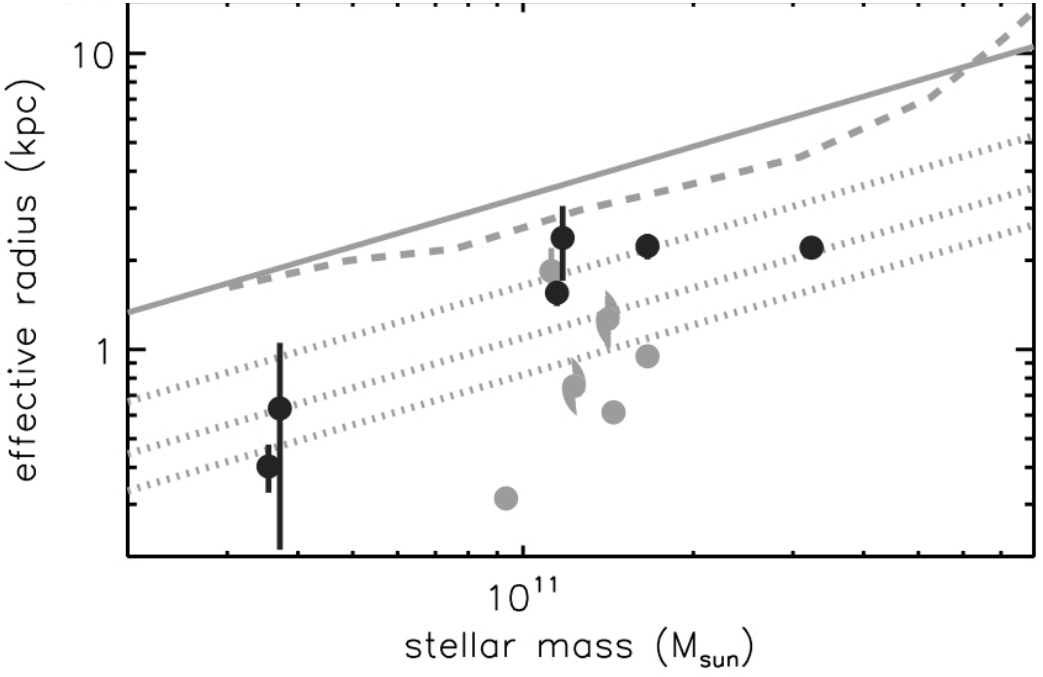
Early-type galaxies in Cl J1449

In principle, size evolution might indicate further structural evolution at later times, but… too many caveats to discuss here, including:

- local reference
- "progenitor bias"
- biases in stellar masses and sizes

(e.g. Franx+ 2008, van der Wel+ 2009, Pannella+ 2009, Mancini+ 2010, Valentinuzzi+ 2010, Bernardi+ 2010, Hopkins+ 2010, Williams+ 2010, Saracco+ 2009 ,2010, 2011, Cassata + 2011, Newman+ 2012, Poggianti+ 2012, Cassata+ 2013, Carollo+ 2013, …)





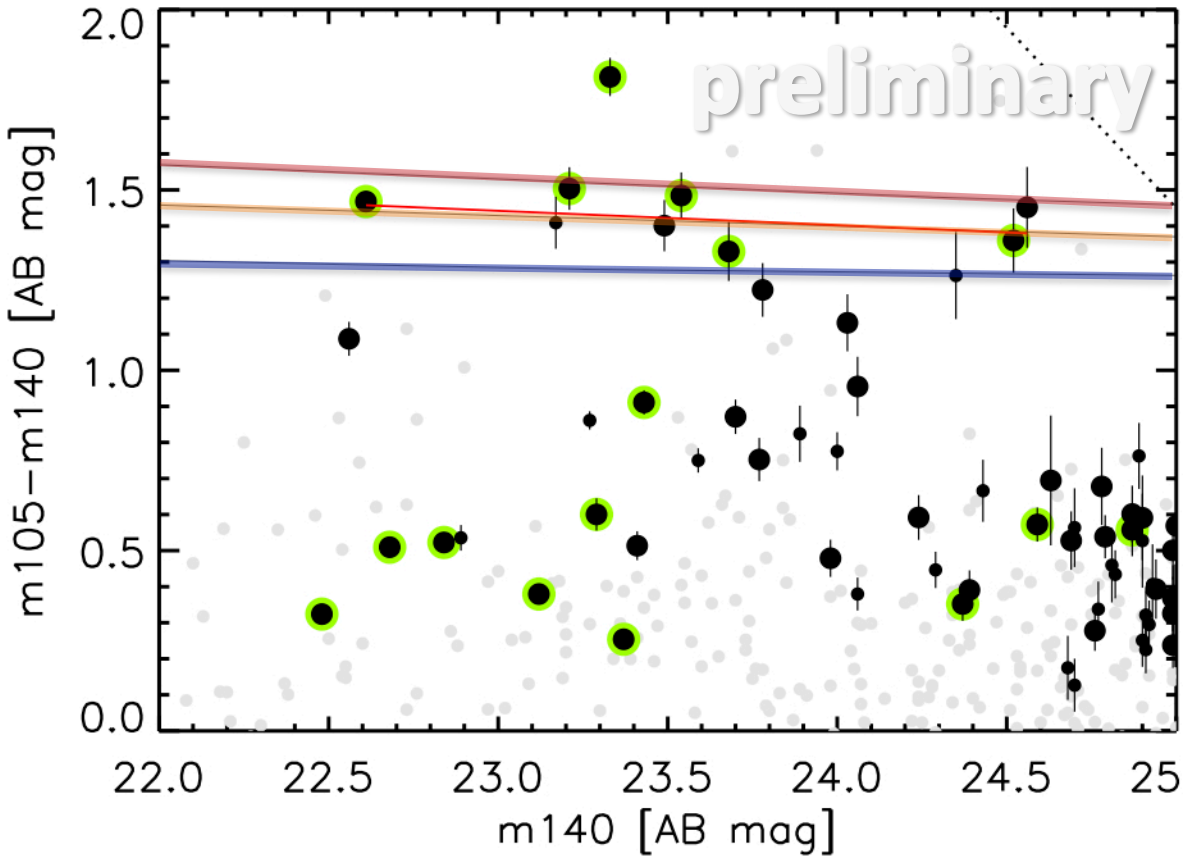
The red sequence at z=2

New WFC3 F105W observations

Observed F105-F140 probes rest-frame U-B

● = spec members

Kodama & Arimoto (1997) models (zf=3,5,10)



The red sequence at z=2

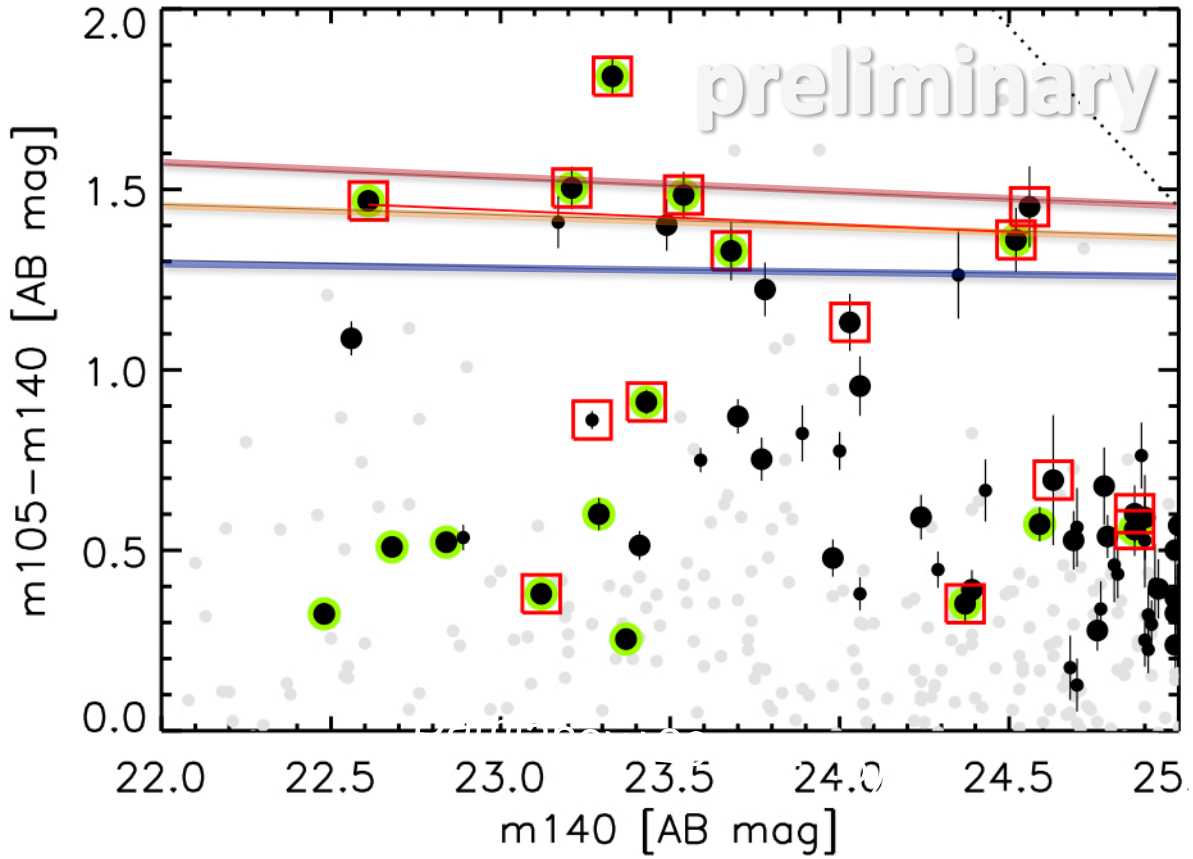
New WFC3 F105W observations

Observed F105-F140 probes rest-frame U-B

● = spec members

□ = d ≤ 200 kpc

Kodama & Arimoto (1997) models (zf=3,5,10)



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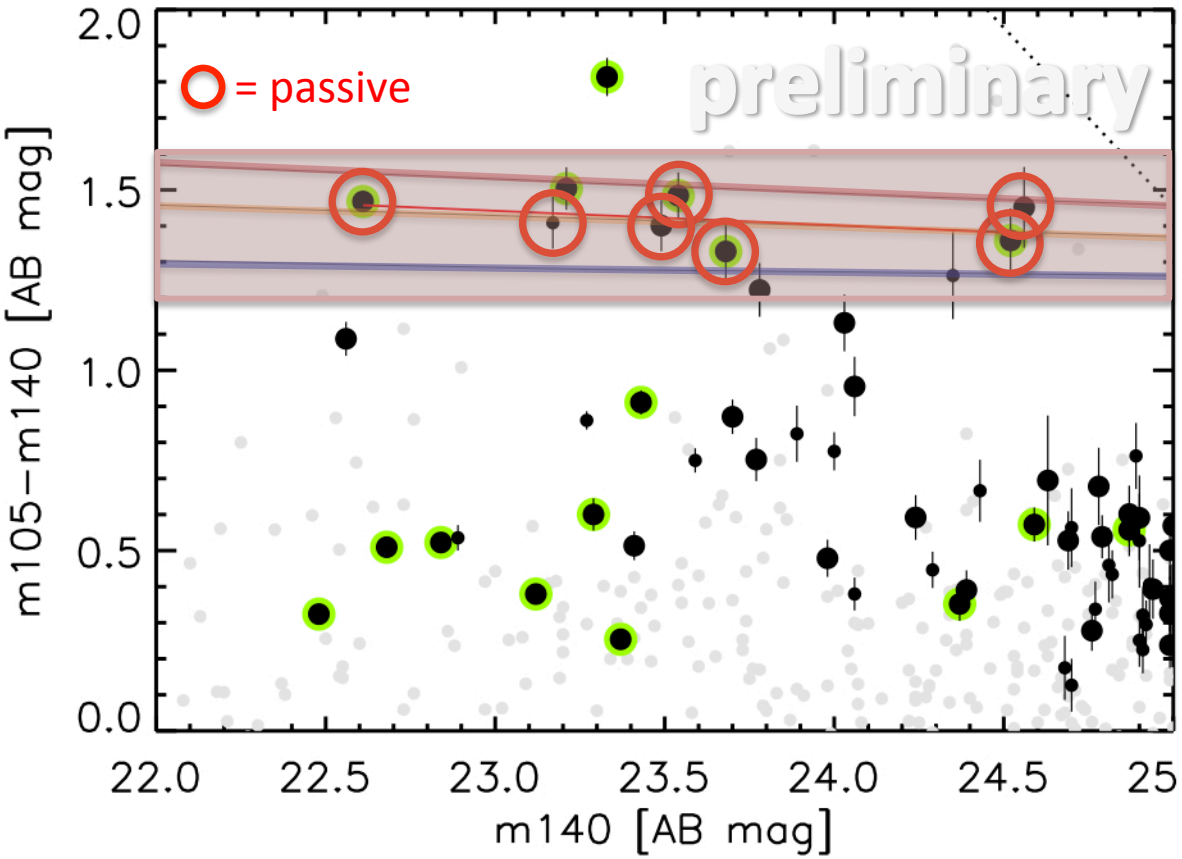
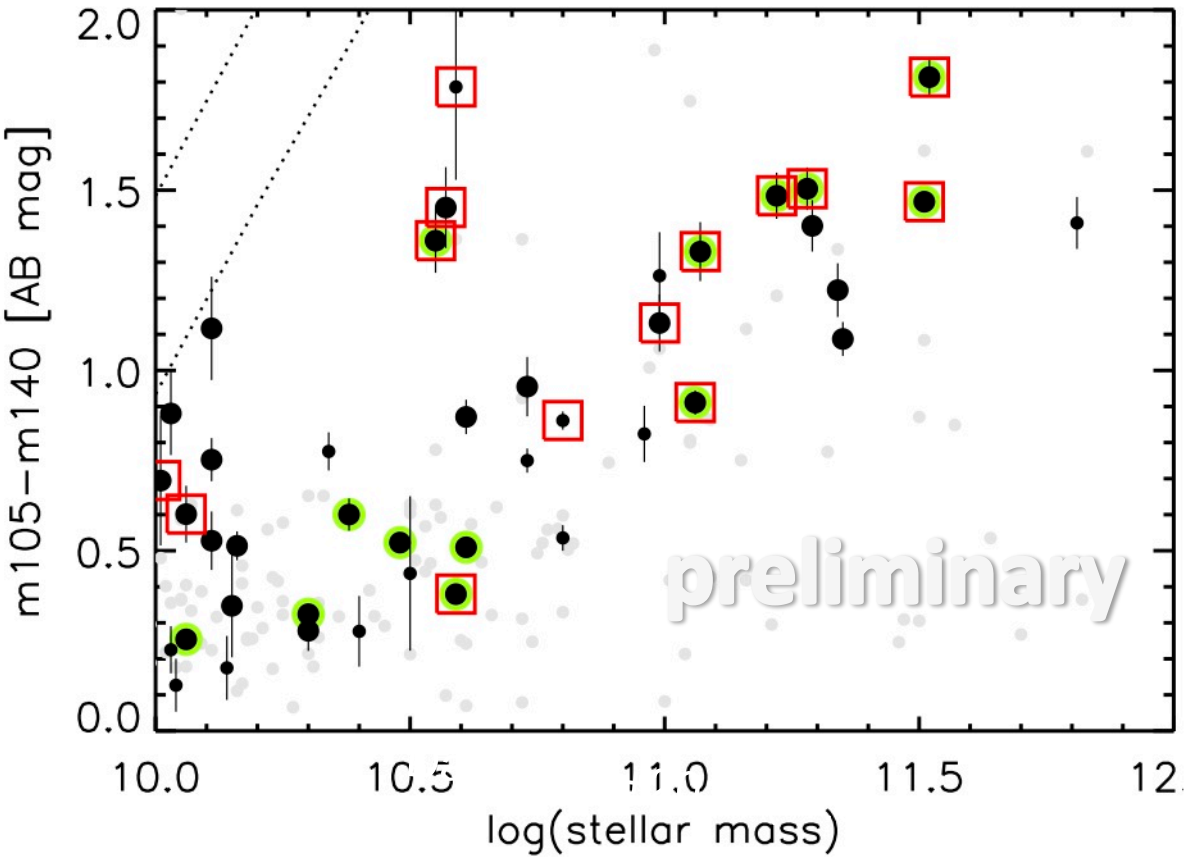
Some "red sequence" galaxies are likely dusty SF (as expected)



The red sequence at z=2

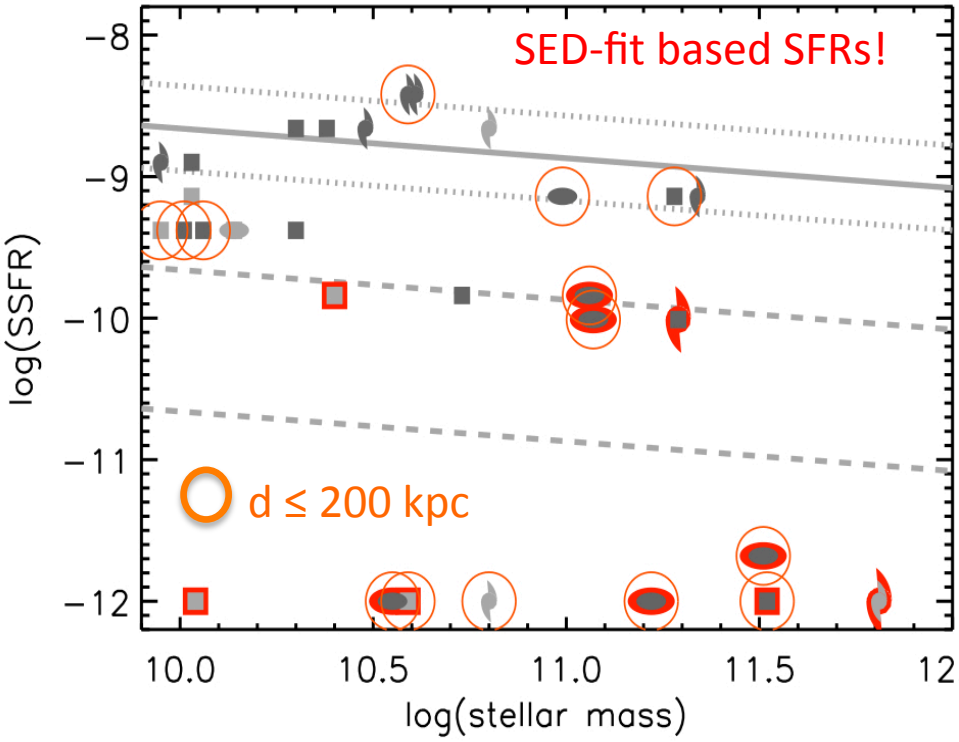


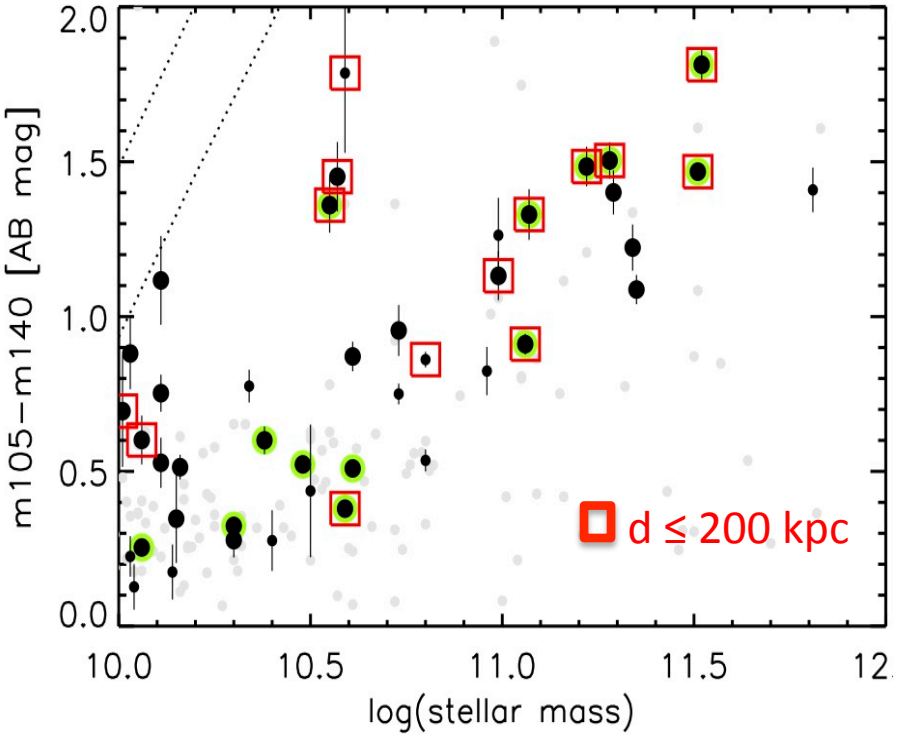
= spec members

= d ≤ 200 kpc

Red sequence vs Main sequence

Star formation and quenching in Cl J1449





- Not quite there yet…
- In both plots, difficult to identify **quenching galaxies**
- need dust-unbiased SFR tracer reaching close to $10^{10} M_{\odot}$…

summary

- Only few galaxy clusters discovered at z≈2. Cl J1449 may be an example of typical cluster progenitor at this redshift. We likely see what we might expect:
  - **most dense regions already host a concentration of massive passive galaxies**
  - **these share the cluster core with younger siblings still in their very active age**
  - **their structure might be more evolved than in the field**
- BUT:
  - beware of the **(tons of) caveats!** (uncertainties, systematics, selection effects, very poor statistics, ….)
  - likely large cluster-to-cluster differences at this epoch
- (among the) other things we are looking for:
  - **an accurate mapping of star formation**, to constrain the "reversal of fortune"
  - **cold gas reservoirs**, fueling star formation and affecting structural evolution
  - **structural vs stellar population evolution**
  - **the early red sequence and the drop off the main sequence** (ongoing quenching, and constraints on the early formation of first cluster early-types)