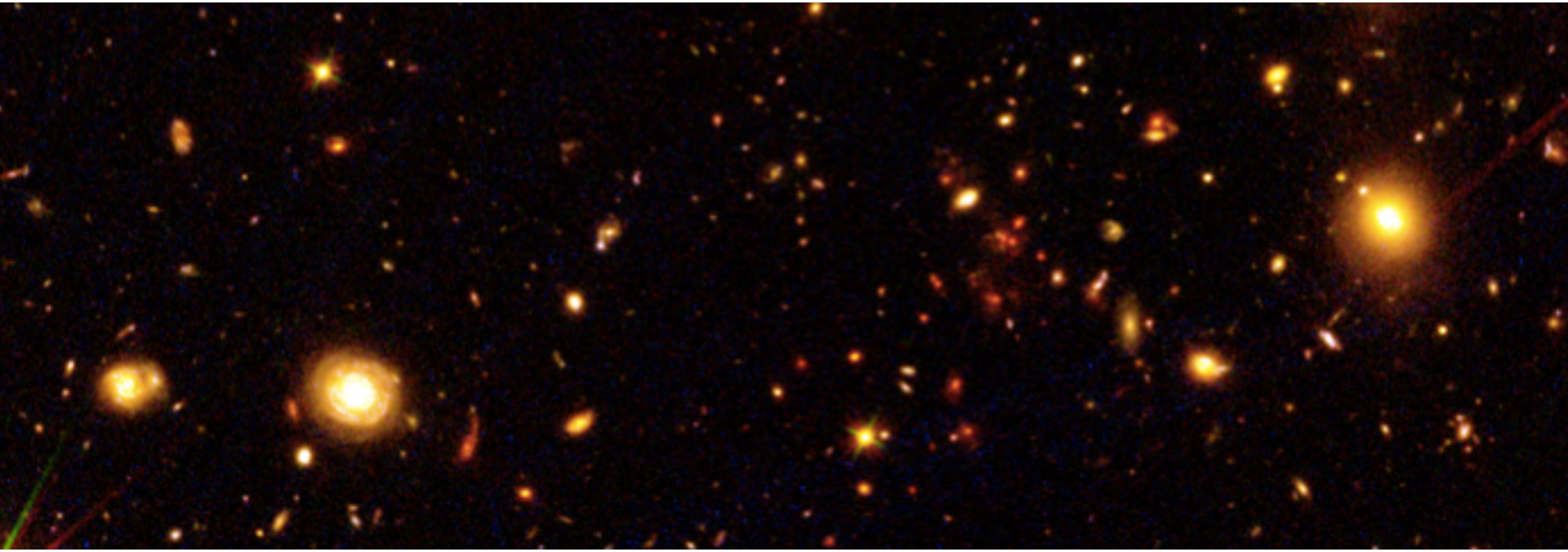
Stellar populations and morphologies of very distant cluster galaxies

A study in Cl J1449+0856 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

Deconstructing Galaxies: Structure and Morphology in the Era of Large Surveys, Santiago 2013

Cl J1449+0856

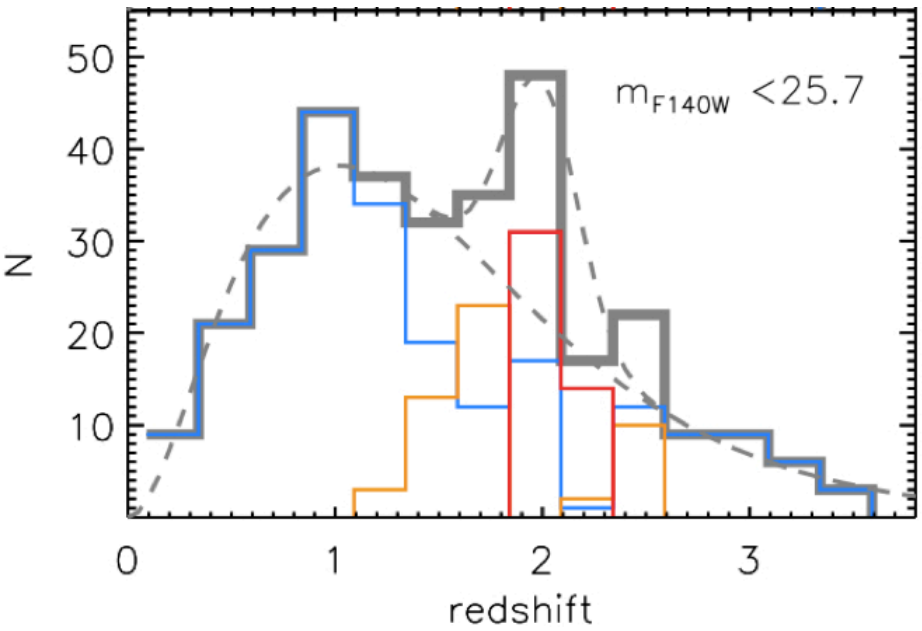
- "IRAC selected" (3.6-4.5μm), with a strong overdensity of red (Y-K>2) galaxies Gobat et al. 2011
- now spectroscopically confirmed at z=2 with >20 spectroscopic members Gobat et al. 2013
- an a-posteriori 3.5σ detection of extended X-ray emission Gobat et al. 2011
- a sub-$10^{14} M_{\odot}$ system, 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

Gobat+2011,2013, Strazzullo+2013

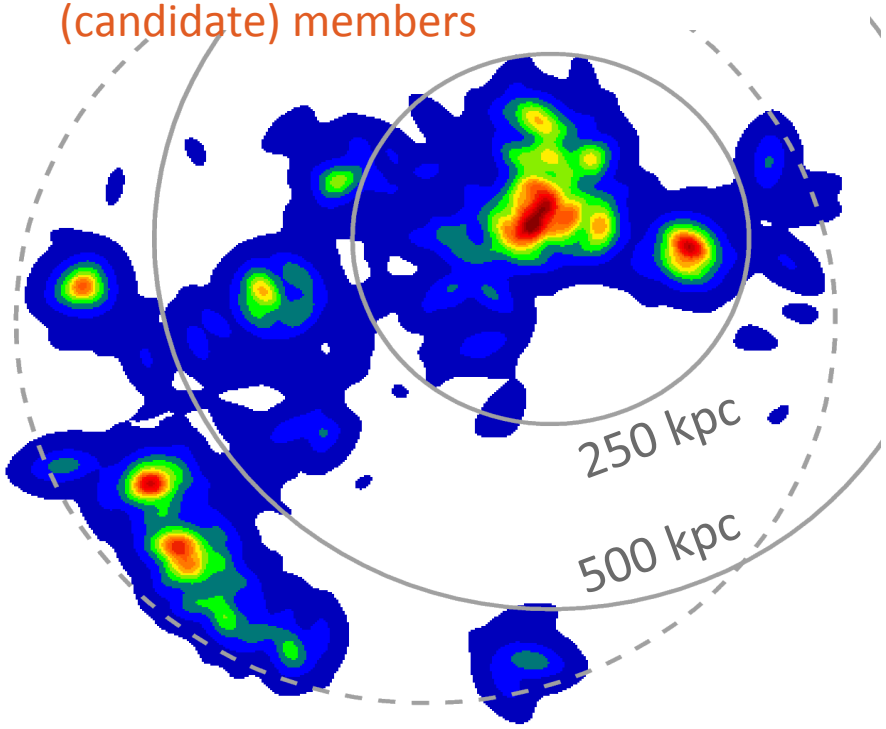
A (photometric) study of cluster galaxies

A (spec-aided) **photo-z selection** of cluster *candidate* members

Cluster clearly appears both in projected density and redshift space.



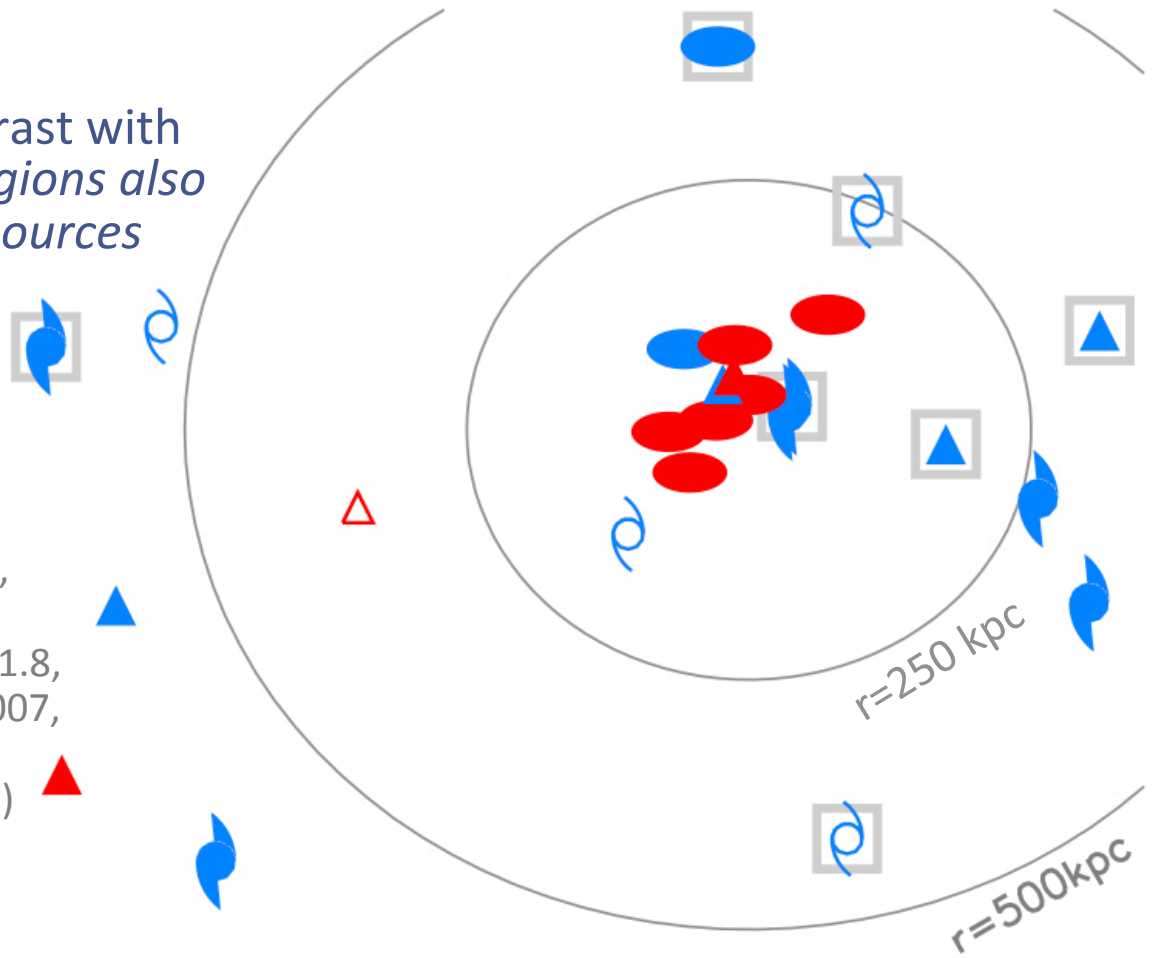
projected Σ_3 density of m_{140}<25.7 (candidate) members



A concentration of passive early-types in cluster core - already at z=2

- quiescent and morphologically early-type galaxies are both effectively segregated in the cluster central region (<200kpc)

- at the same time – and in contrast with z<1.5 cluster cores – *central regions also host still actively star forming sources*



see also e.g. Kurk+ 2009, Papovich+ 2010, 2012, Tanaka+ 2010, 2012, Raichoor and Andreon 2012, Newman+ 2013 at z≈ 1.6-1.8, as well as e.g. Steidel+ 2005, Kodama+ 2007, Tanaka+ 2010, Hatch+ 2011, Zirm+ 2012, Spitler+ 2012, Galametz+2013 for (proto-) clusters at z≥2.

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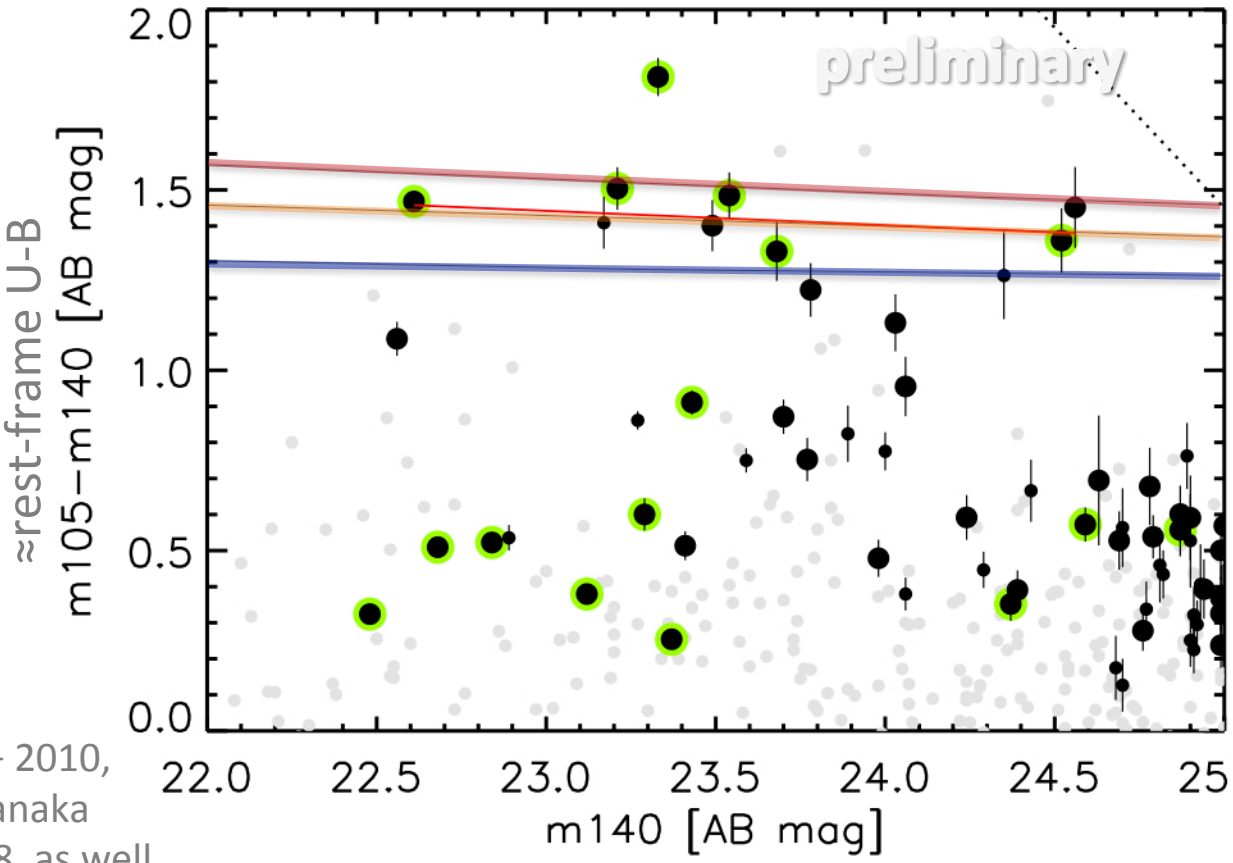
The red sequence at redshift two

The CMD in Cl J1449:

passive galaxies already on a red sequence

- mainly in cluster center
- mainly early-types, but SF contaminants



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spec members

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

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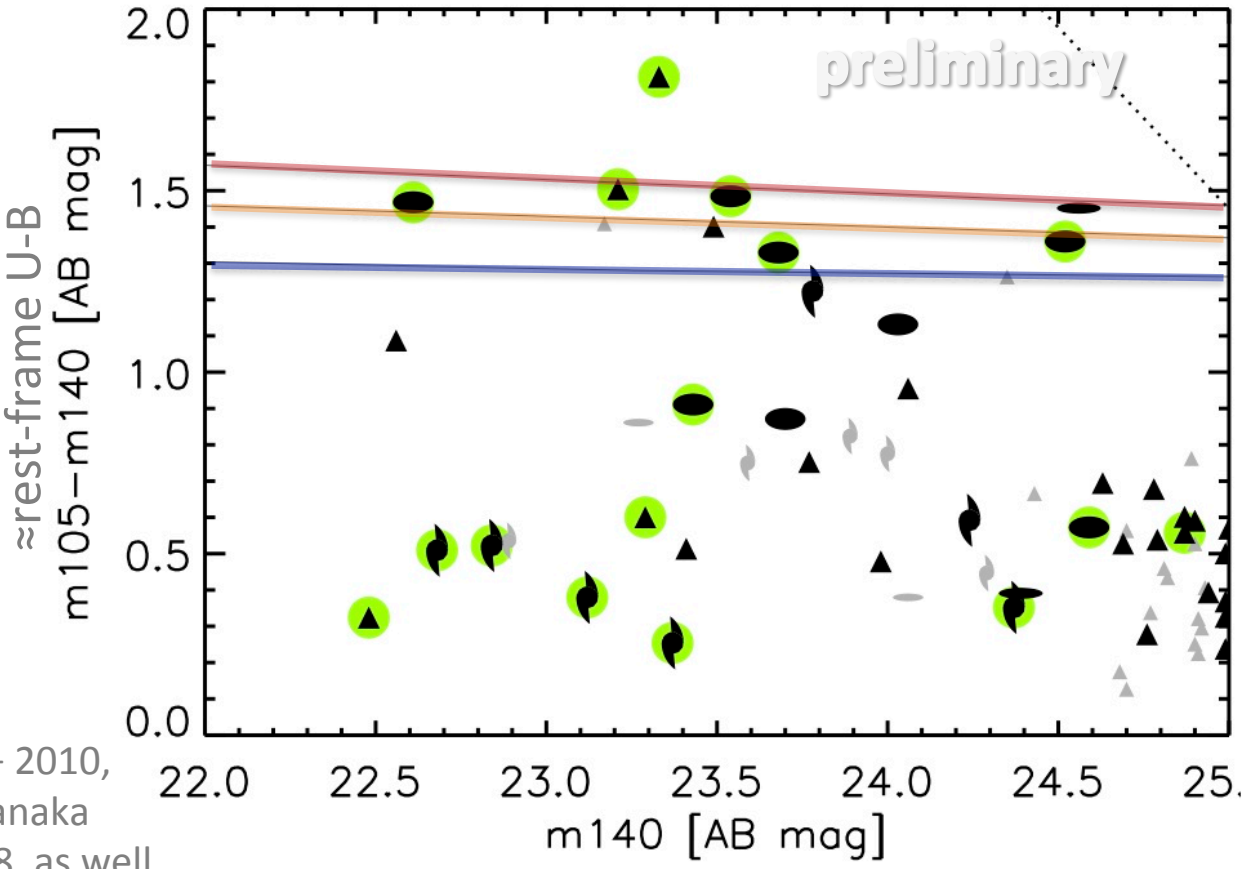

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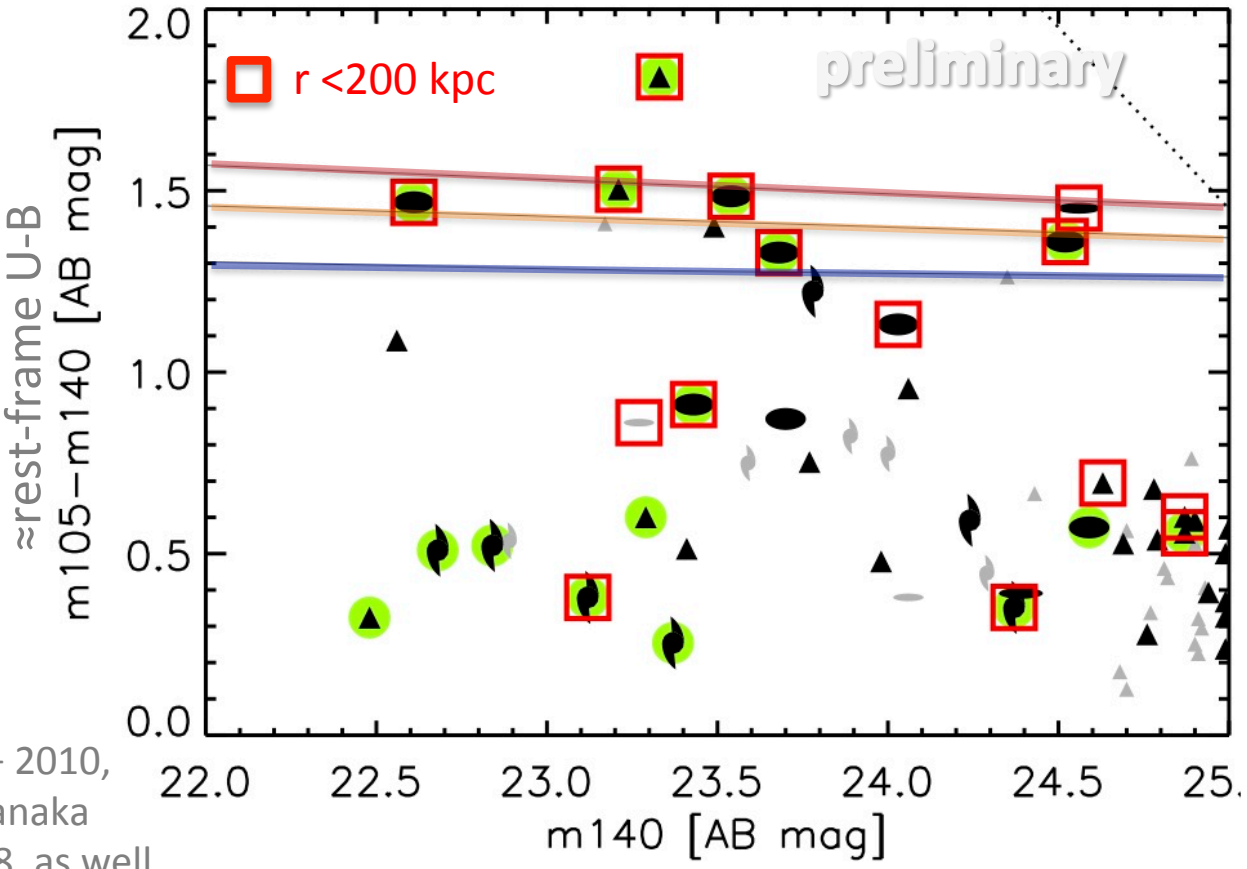

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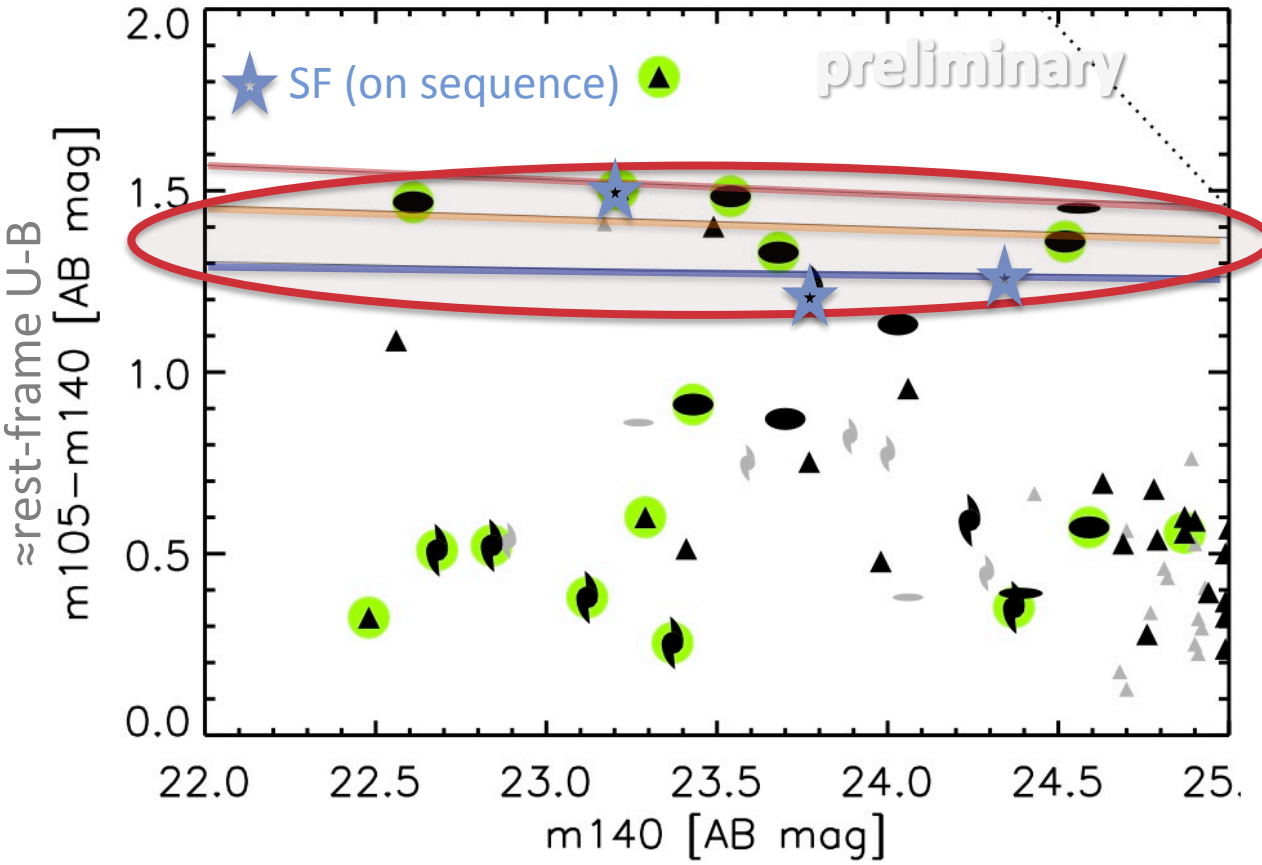

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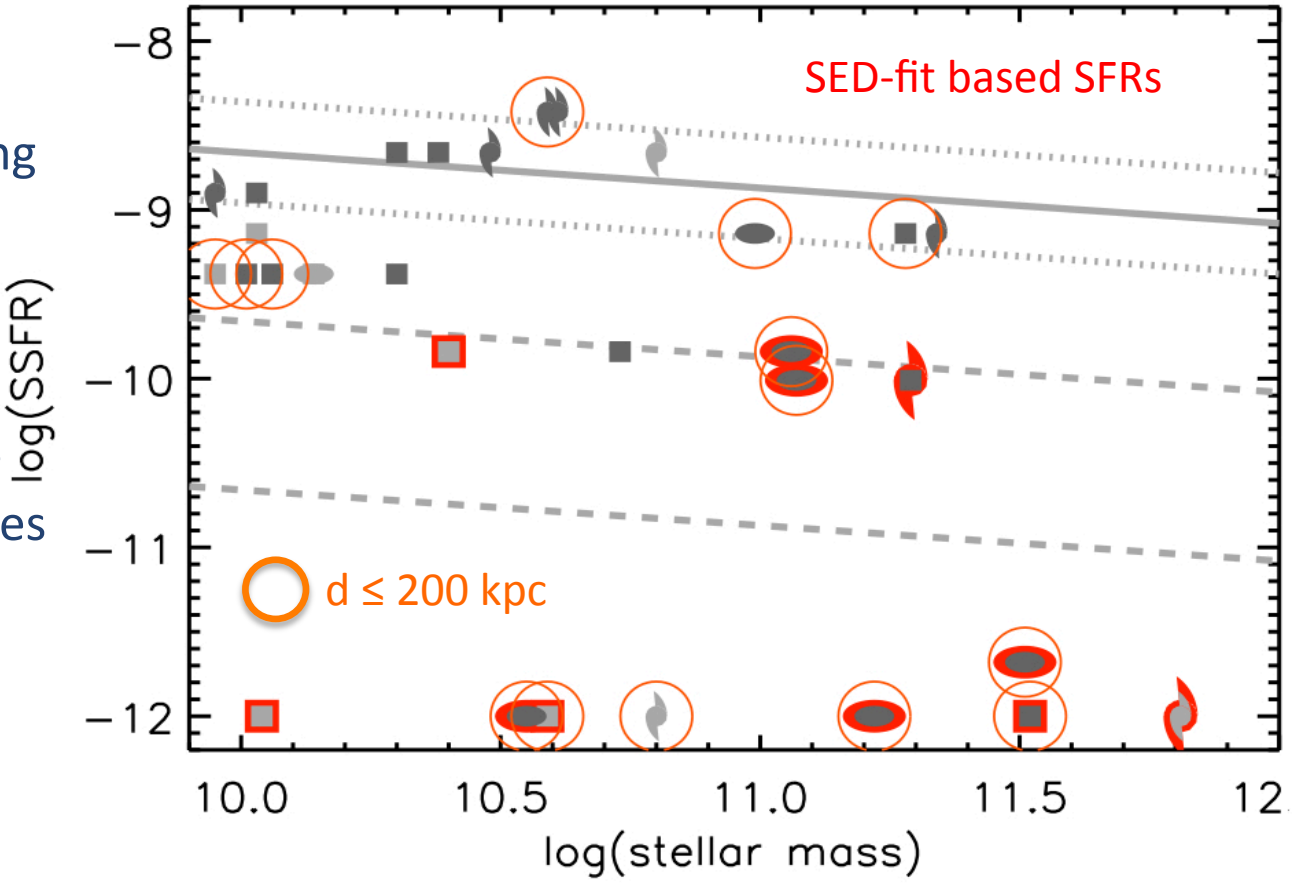
Red sequence vs Main sequence

Star formation and quenching in Cl J1449:

- difficult to identify *quenching* galaxies
- need high-resolution dust-unbiased SFR tracer reaching typical SF galaxies down to $10^{10} M_{\odot}$ (ALMA follow-up approved in cycle one but yet not observed)



Environmental signatures, 10 billion years ago…

quiescent fraction is already enhanced in the most dense regions

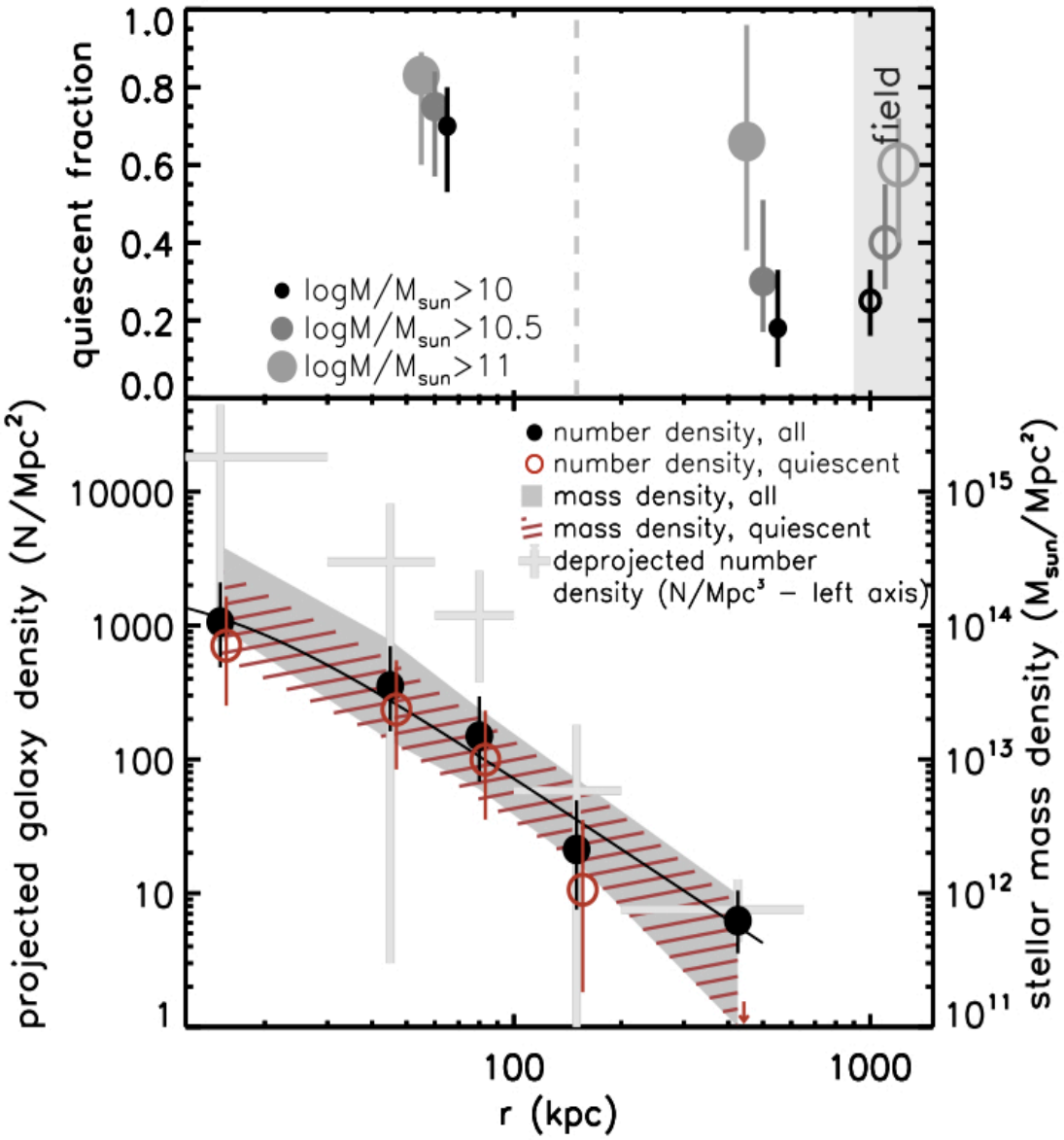
Quiescent fractions lower than in z≈1 clusters (e.g. Muzzin+ 2012, but …) but at >$10^{11}M_{\odot}$ - already similar quiescent fraction for most massive core galaxies?

also e.g. Raichoor & Andreon 2012, Newman+ 2013 at z=1.8

Quiescent fraction depends on mass

(from ≈15% 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,…



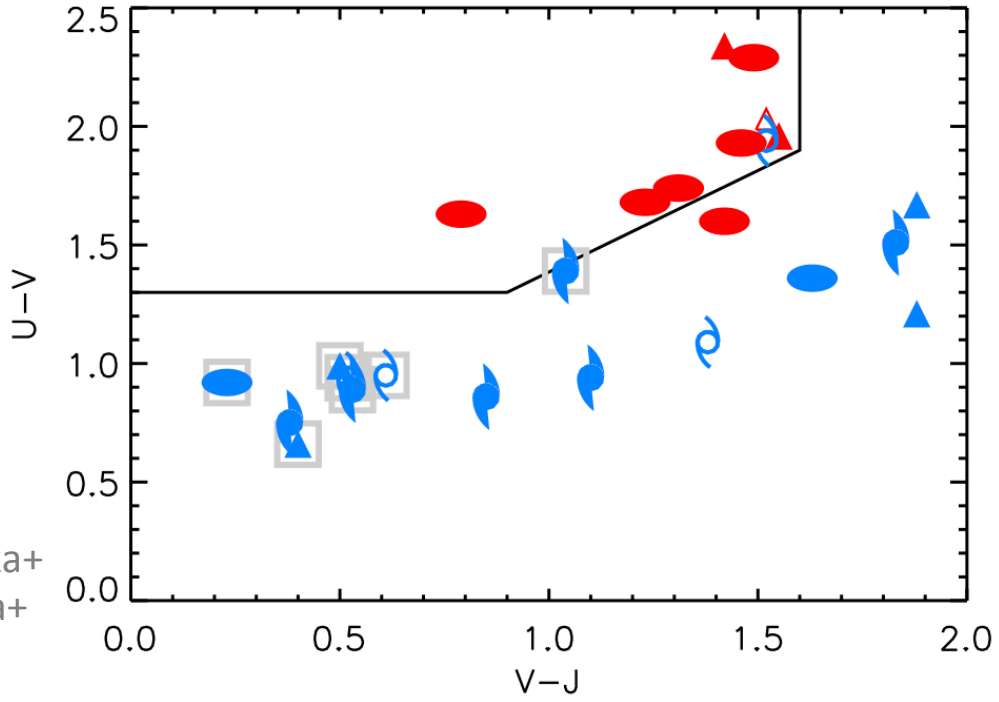
A clear correlation between galaxy structure and stellar populations

Already at z=2, morphological appearance is clearly correlated with stellar population properties – *as in the field*

@log(M/$M_\odot$)>10.4, ≈70%($^{+10}_{-20}$) of passive galaxies are early-types, *both in cluster and field samples*, wrt ≈10% ($^{+20}_{-4}$) of SF members (and viceversa).

as 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



Passive cluster early-types (wrt z=2 field and local reference)

Cluster (and field) early-types at z≈2 lie below the local ETG mass-size relation

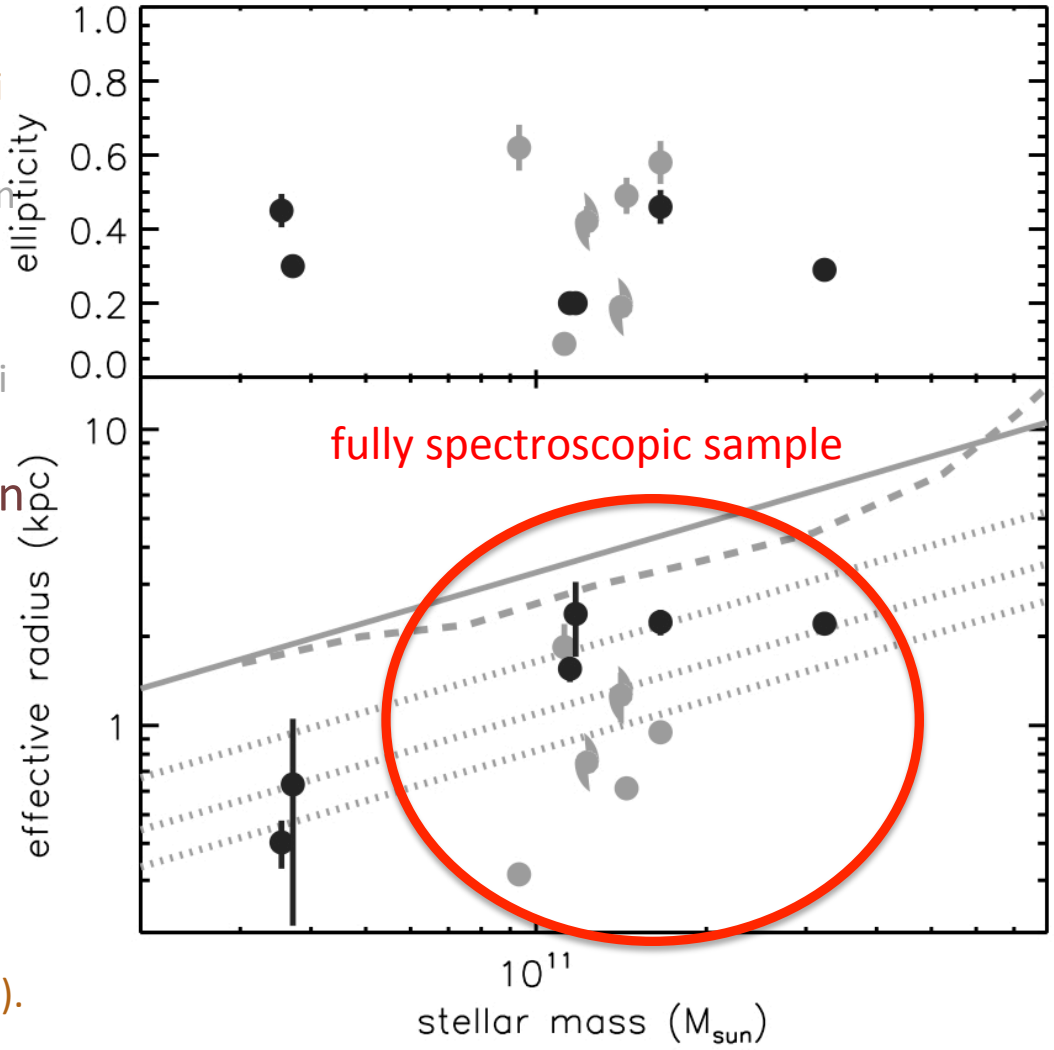
(for cluster galaxies, by a factor 2-3 wrt Shen +2003 with BC03, but can be ≤2 wrt Valentinuzzi +2010, or with M05)

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

Cluster early-types might be larger than z≈2 field early-types of similar mass.

see Papovich+2012, Zirm+ 2012, Tanaka+ 2013, Lani+2013 - but see also Raichoor et al. 2012, Newman+2013 – more controversial results in lower redshift groups, e.g. Cooper+ 2012, Huertas-Company+ 2013

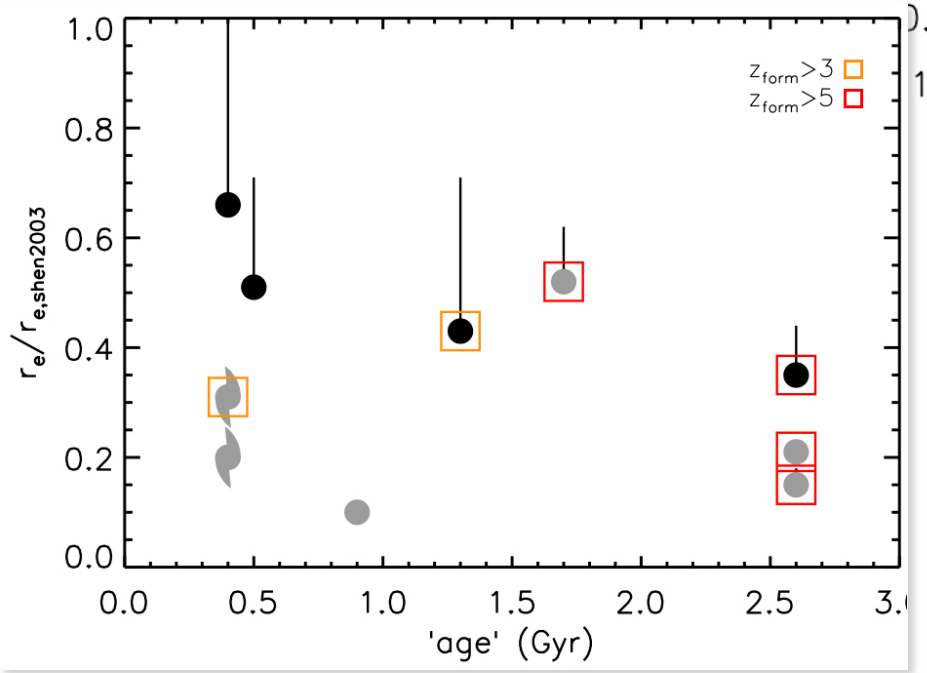
Median ellipticity of cluster early-types close to low-z values (≈0.3, e.g. Holden+ 2009).

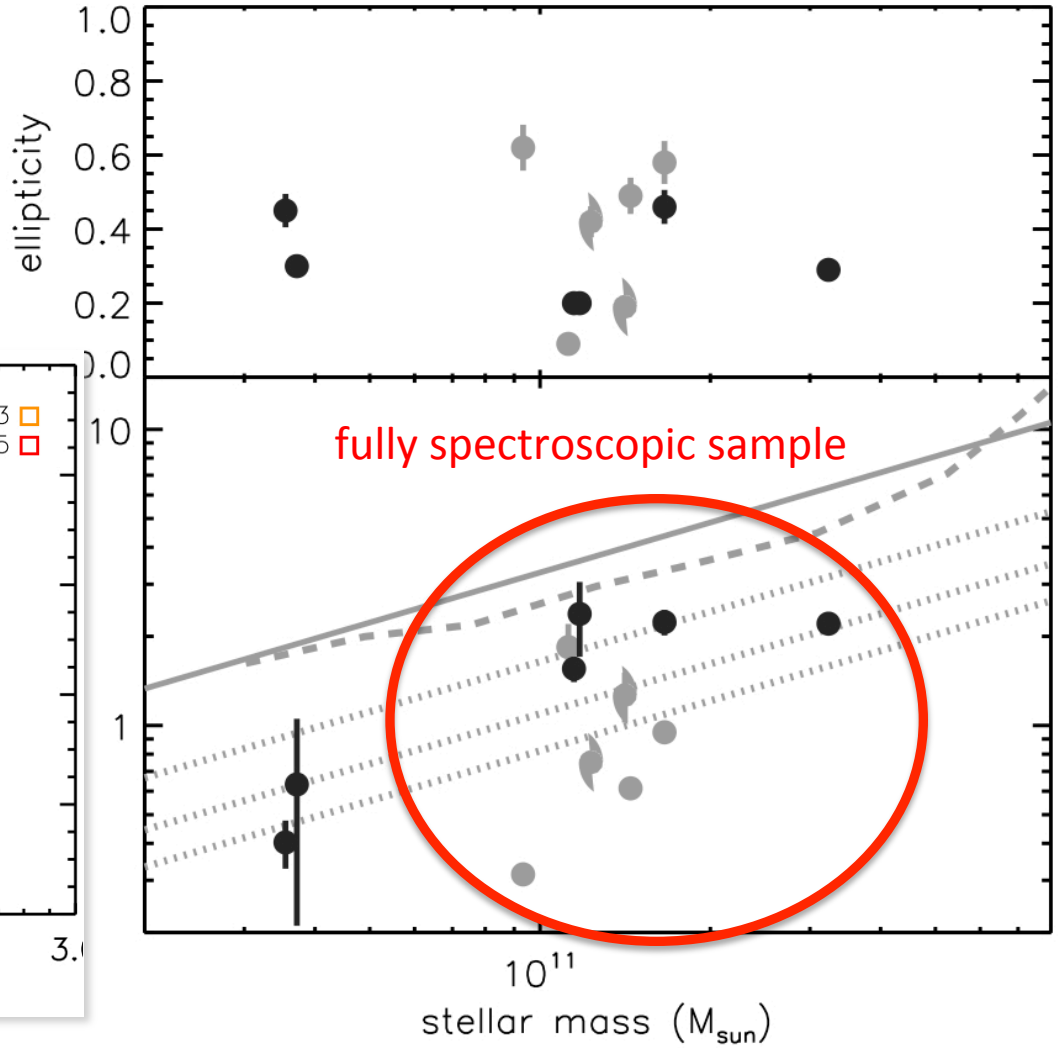


Passive cluster early-types (wrt z=2 field and local reference)

Size difference doesn't seem to be due to systematic age differences (at face value...! Also supported by spec analysis, Gobat+2013)

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

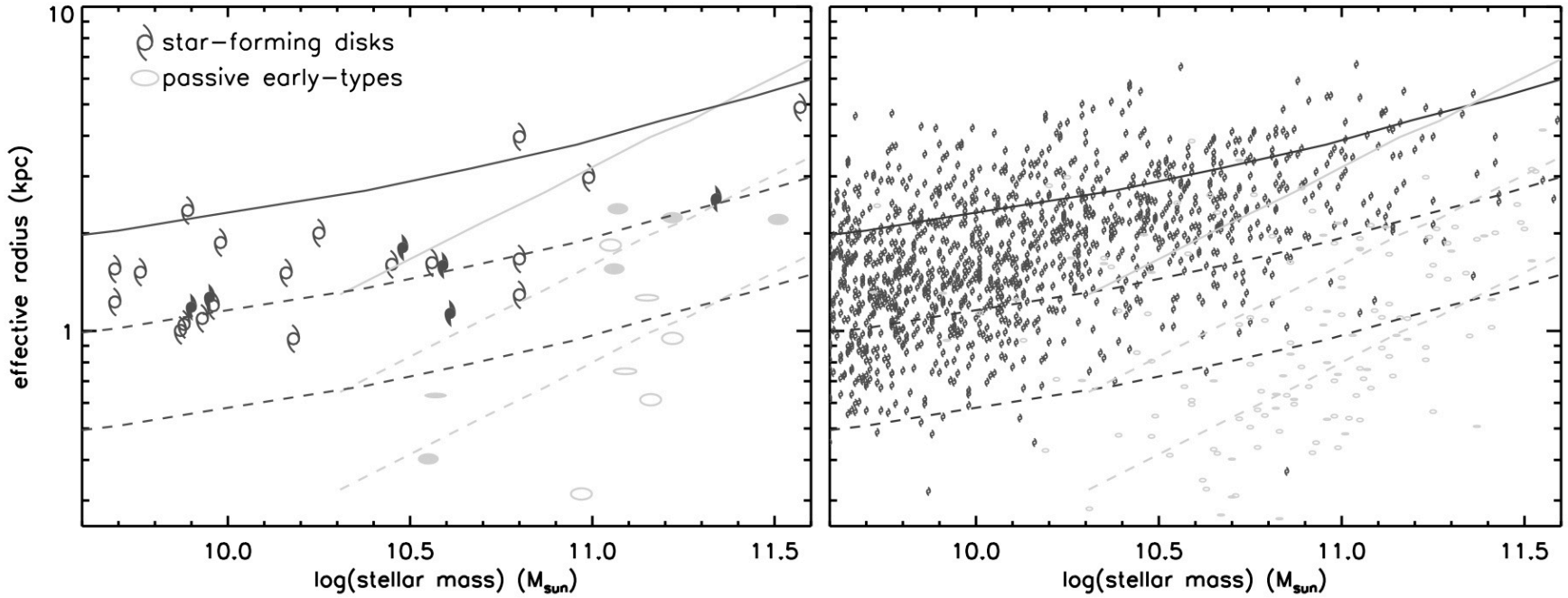




… and star-forming late-types (wrt z=2 field and local reference)

Average size of star-forming late types is within a factor≈2 of the local reference.

With current (poor) statistics, no significant size difference between cluster and field star-forming disks.



Our cluster (filled) and field (empty) samples

CANDELS GOODS-S
Structural parameters from van der Wel+2012
Photo-zs, masses and UVJ colors courtesy of Maurilio Pannella

a rough summary

- Galaxy clusters at z≈2 still rare, and hard to find – but there are a few examples!
  Cl J1449 may be considered as a progenitor of an average nearby cluster. This structure shows that, 10 billion years ago and very close to the epoch of cluster formation:
  - **most dense regions may 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:
  - uncertainties, systematics, selection effects, very poor statistics, still hamper these first conclusions
  - likely large cluster-to-cluster differences at this epoch need to be explored with (possibly complementary selections of) much larger cluster samples
- (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)