Probing Structural and Stellar Population Evolution out to the Densest Environments

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and The ACS Team and The GOODS Team

Nature and Nurture:
an holistic approach

1. *Compare size evolution of massive ETGs in cluster and field environments from z~0 to z~1.*

2. *Study the evolution of their stellar populations*

Introduction: Cluster vs. Field

- A long-standing prediction of hierarchical models is that early-type galaxies (ETG) in the field are younger for a given mass than those in cluster cores(Diaferio+01, De Lucia+06)

- Fundamental Plane (FP) or fossil record data at z~0 suggest that star formation in low density environments was delayed by 1-2 Gyr (Bernardi+06, Thomas+05, Clemens+06)

- FP studies at z~1 have shown that massive ETG in field and in clusters ($M>3 \times 10^{11}$ $M_\odot$) share the same fundamental plane.
(van der Wel+ 05, di Serego-Alighieri+05, Treu+ 05, Van dokkum et al 2007)

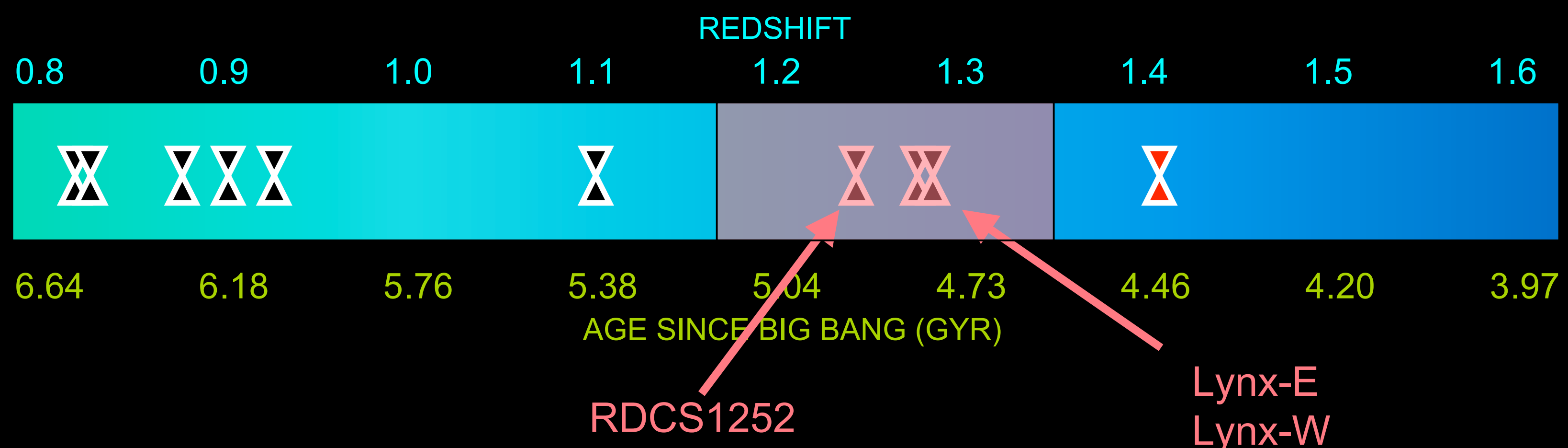
Important test:

at high redshifts and in the highest density sites this evolutionary clock delay should become more apparent.

We aim at measuring the environmentally driven effects on galaxy morphology and galaxy stellar populations at $1.0 < z < 1.5$

ACS GTO Cluster Survey

(P.I. Holland Ford)

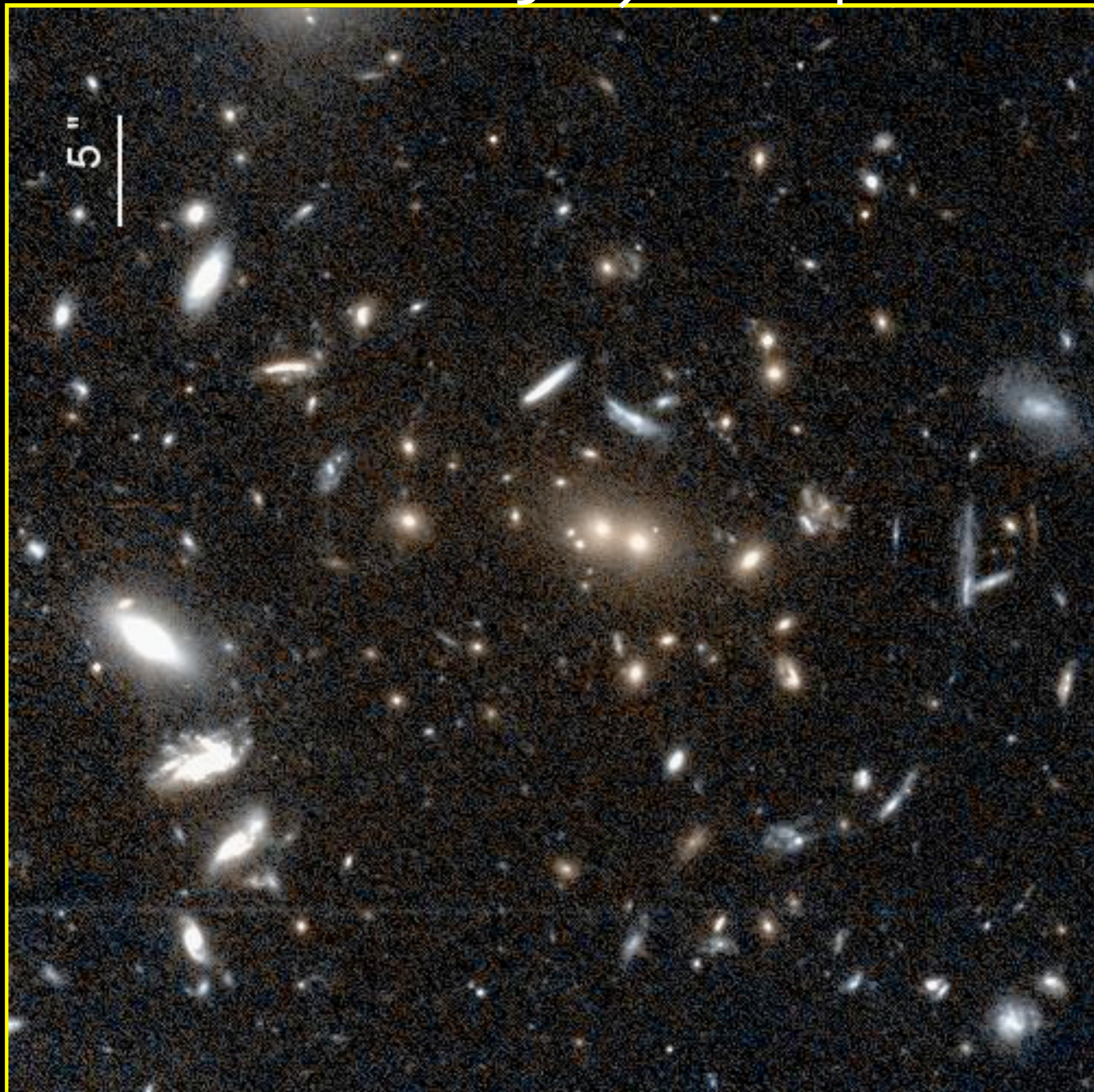


- **10 massive galaxy clusters in the range *0.8 < z < 1.4***
- ***ACS imaging + ancillary data***
- CM relation of cluster ellipticals at z=1 is indistinguishable from local (Blakeslee et al. 2003, 2006, Mei et al. 2009)
- Mass distribution largely in place (Jee et al. 2005)
- No strong morphological evolution of massive galaxies (Postman et al. 2005)

Datasets

- Cluster (RDCS1252-29, z=1.24)
  (CL0848+4453, z=1.26)
  (CL0849+4452, z=1.27)
- Field (CDFS, 1.25 ± 0.10)

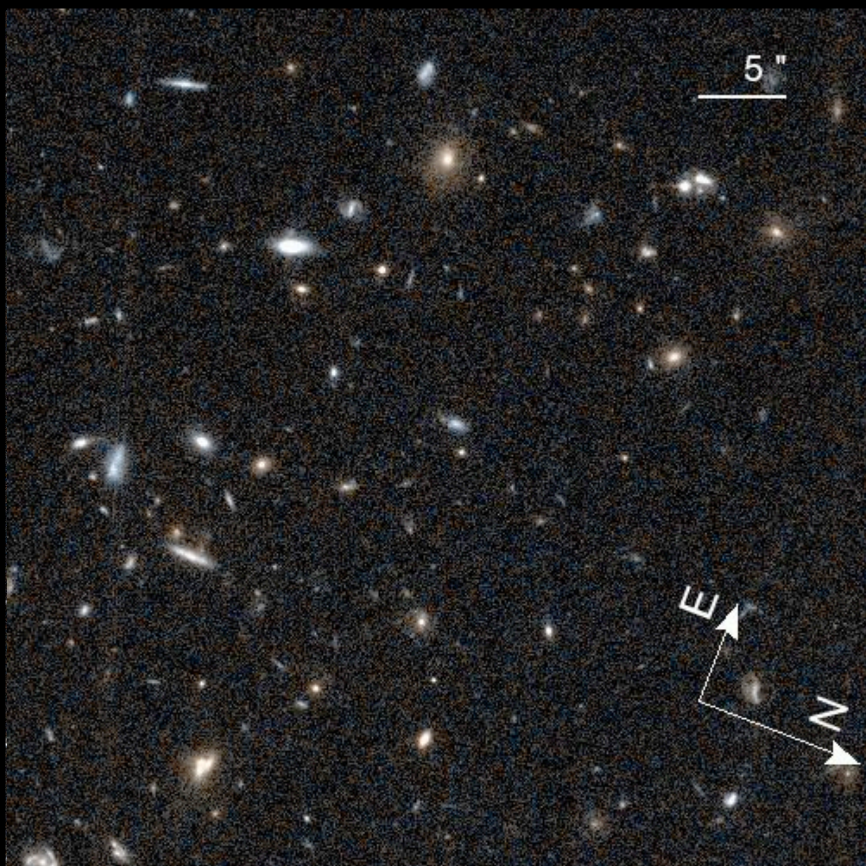
RDCS 1252-29 z=1.24

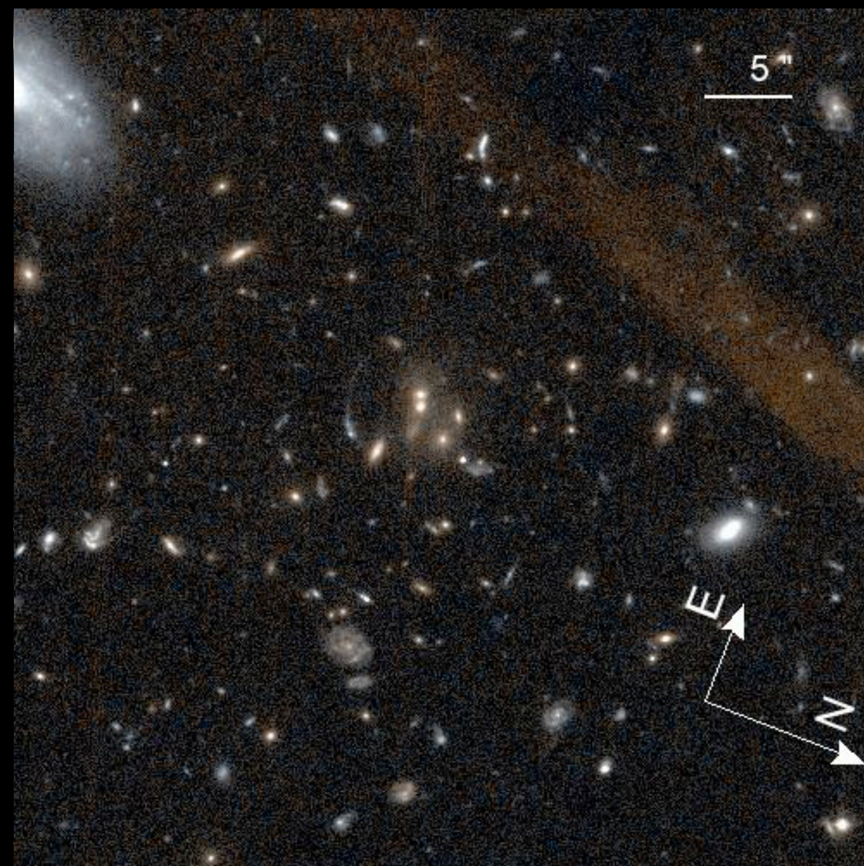


250+
Redshifts

38 cluster
Members

CL0848 @ z = 1.26 - CL0849@ z=1.27





200+ Redshifts

50 cluster Members

Datasets

- Cluster (RDCS1252-29, z=1.24)
  (CL0848+4453, z=1.26)
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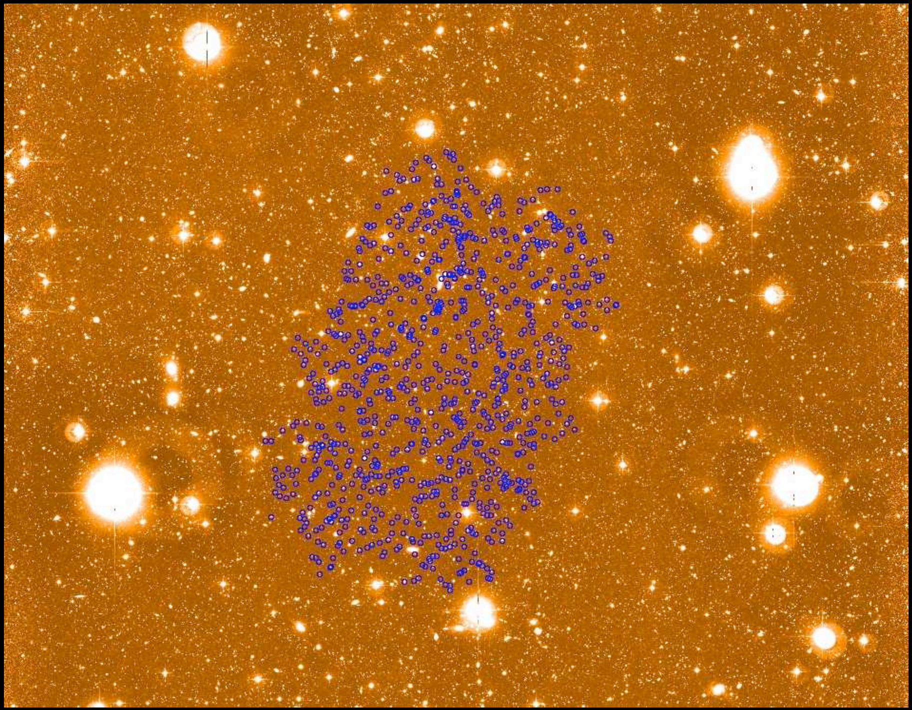
- Field (CDFS, z=1.25 ± 0.1)

FIELD : CDFS GOODS/FORS2 Mass-selected Sample



Imaging:

Xray Imaging (Chandra/XMM)

Deep Optical Imaging (ACS/HST),

Near Infrared Imaging (ISAAC),

Mid-Infrared Imaging (IRAC/Spitzer).

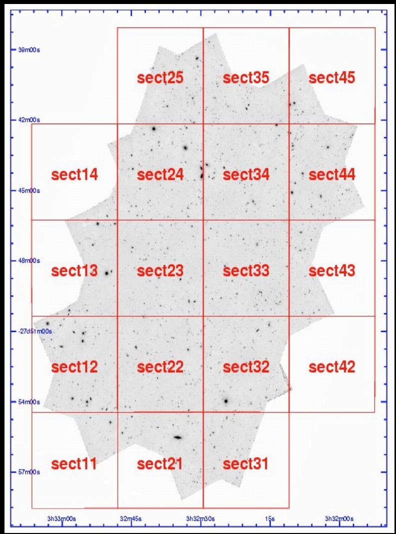
Spectroscopy of > 600 sources:

ESO/GOODS (Vanzella+,2005,2006)

K20 (Cimatti+02, Mignoli+05)

For this project:

We selected ~30 ETG (spectroscopic classification) with $M > 5 \times 10^{10} M_\odot$ at $z = 1.25 \pm 0.1$



- We use CDFS as a control Field to contrast X-ray Cluster properties and probing environmental effects.

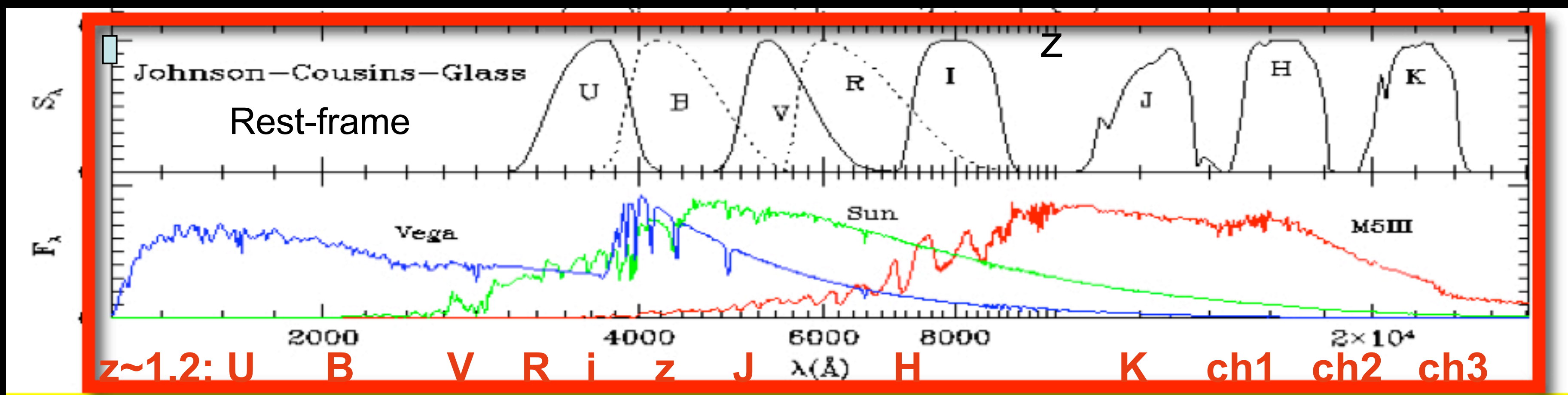
Similarly Mass-selected sample, comparable photometric and spectroscopic completeness.

What a detailed study of stellar populations can tell us about the Nature and Nurture of ETGs?

- Global SED fitting
  - Measure Mass
  - Formation Epochs
  - SFHs

Modelling "entire" galaxy Spectral Energy Distribution (SED)

UV *Optical* *Infrared*



Obs. Frame ← **HST / ACS** → ← **VLT / ISAAC** → ← **Spitzer / IRAC** →

- We perform χ^2 minimisation SED fitting over a large range of:
  - CSP Models [PEGASE.2, BC03, M05, CB07]
  - Ages
  - Masses
  - SFR(t) $\propto e^{(-t/\tau)}$; $0.05 < \tau < 5$ Gyr
  - Dust extinction; $0.0 < E(B-V) < 0.4$
  - Assuming Solar Metallicity & Salpeter IMF

Stellar Population Ages of CSP models

We assume SFH to be exponentially-declining "tau" models:

$$\Psi(T-t',\tau) = e^{-\frac{T-t'}{\tau}} \cdot \frac{M_\odot}{yr},$$

0.05< tau <5Gyr

We can then define Star Formation Weighted Ages as

$$\bar{t}(T-t',\tau) \equiv \frac{\int_0^T (T-t')\Psi(T-t',\tau)dt'}{\int_0^T \Psi(T-t',\tau)dt'}$$

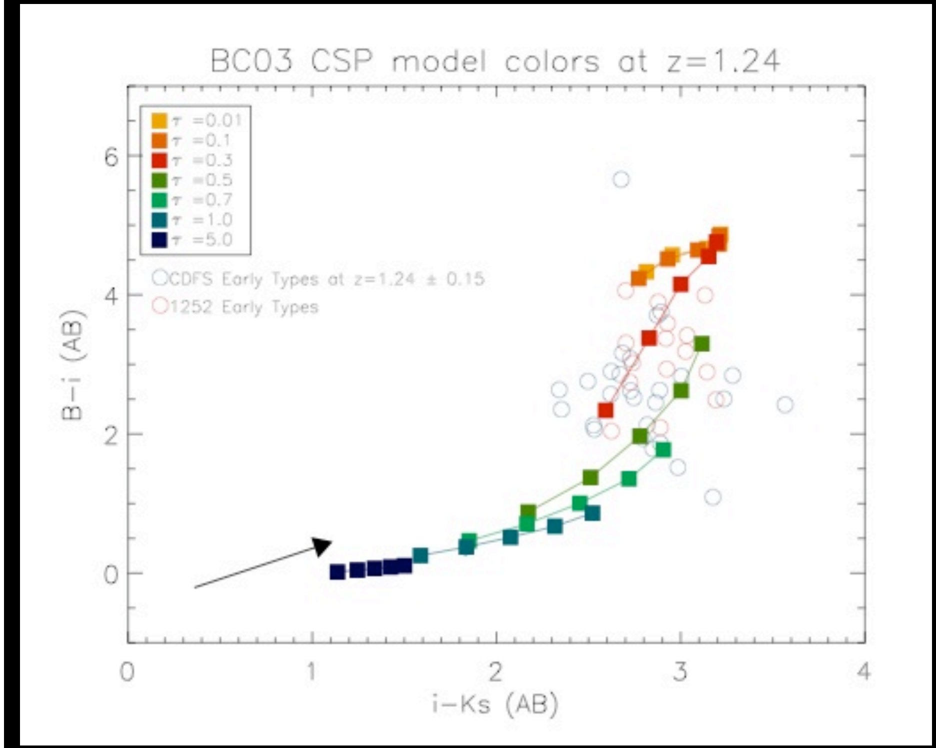
Assuming $\Psi(T-t',\tau)$ as in Eq. 3 we obtain,

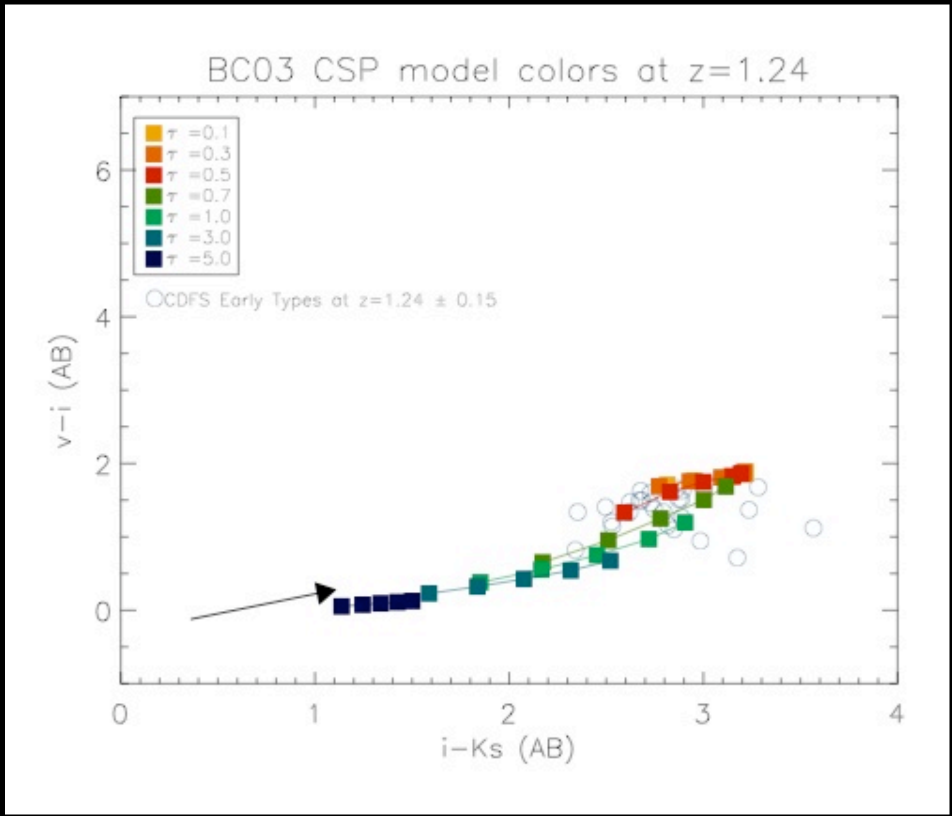
$$\bar{t} = \tau \cdot e^{-\frac{T-t'}{\tau}} + (T-t') + \tau.$$

Where *T* is the cosmic time at which we compute the average age of the stellar populations, and *(T-t')* is the age of the stellar populations formed at time t' at a SFR, Ψ (T-t').

this value measure the average age of the bulk of the stars in the galaxy.

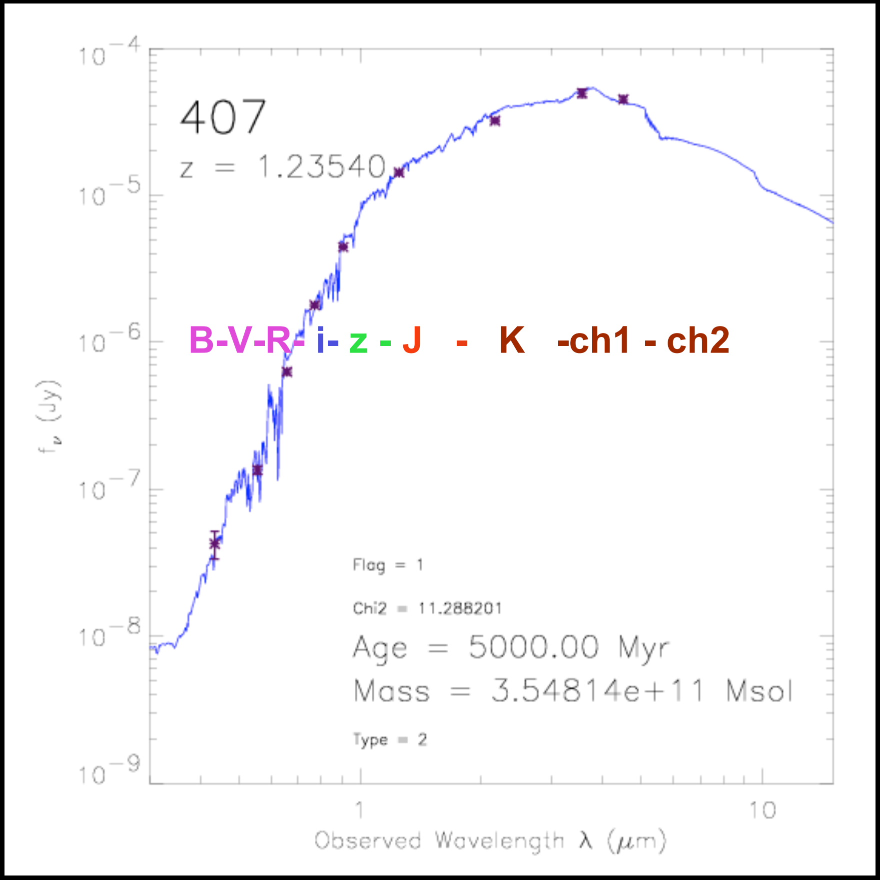
Need of UV to break the SFH-age degeneracy

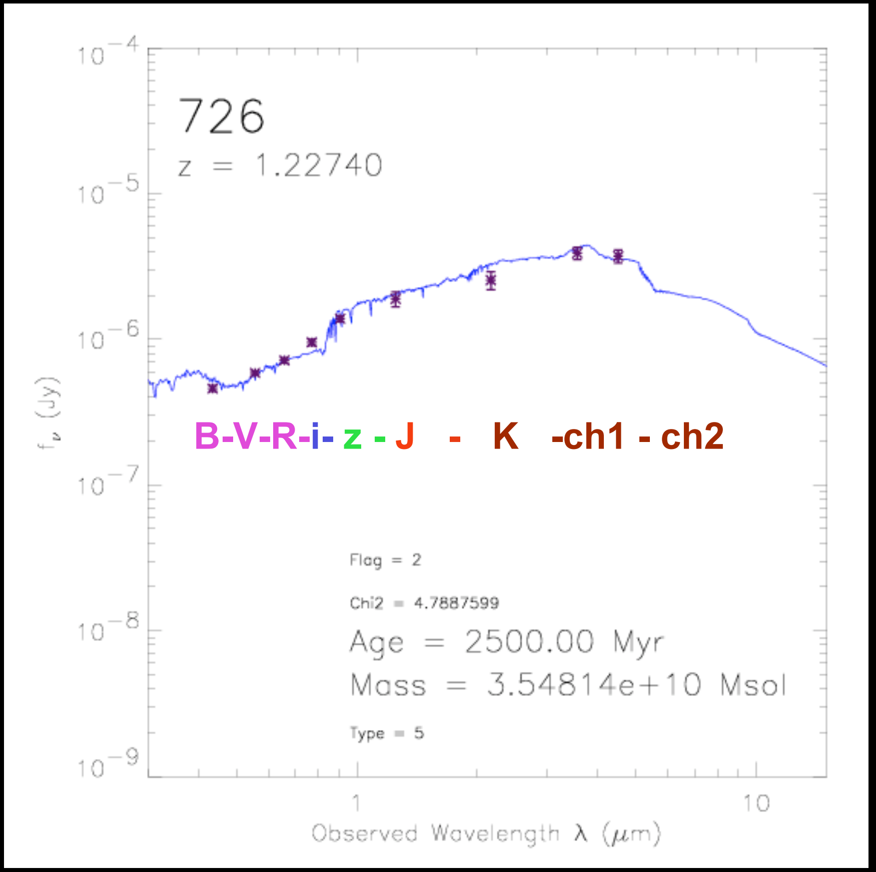




Rettura+ 2008

CLUSTER SAMPLE: Global SED Fitting





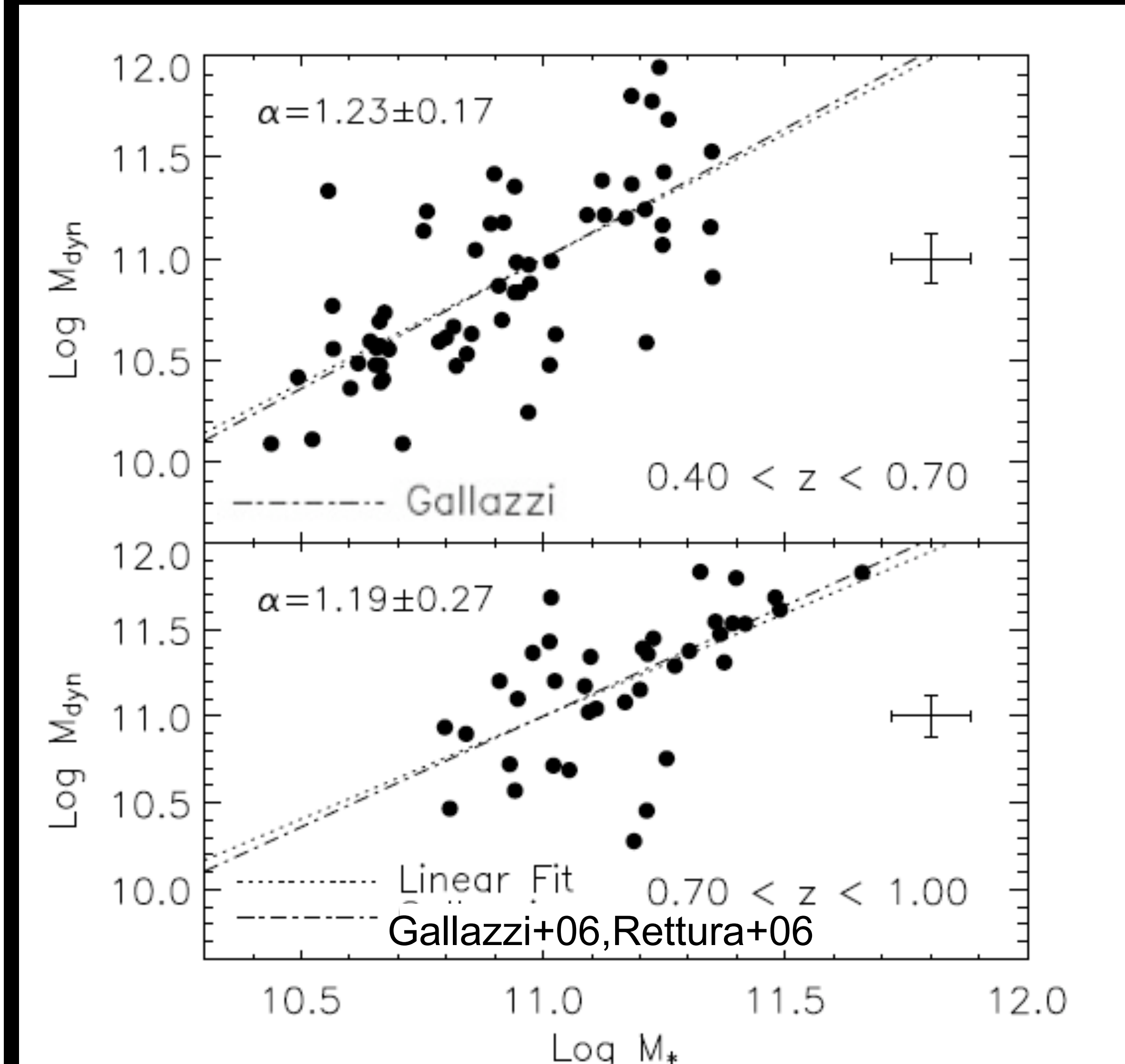
Early type

Late type

The importance of photometric stellar masses

- Global SED fitting
- Stellar Population Ages
- Dynamical vs. Photometric Stellar Masses

Dynamical and photometric-stellar mass estimates of ETG from z~0 to z~1.3



Bundy et al. 2007

Independent studies:

Rettura+06 (z~1)

Mdyn ~ Mphot $^{1.25\pm0.08}$

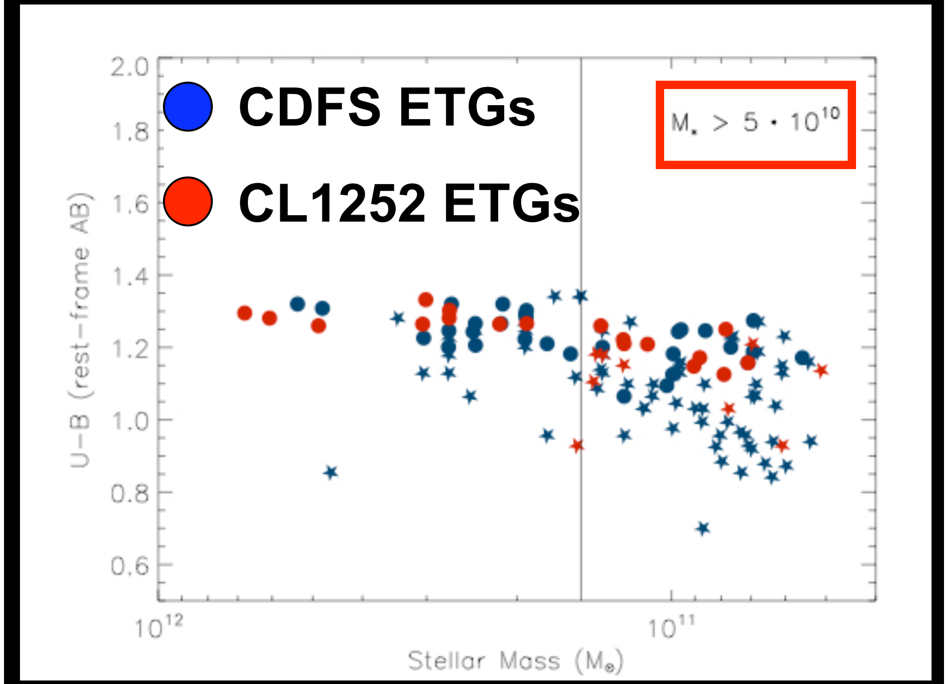
Gallazzi+06 (z~0)

Bundy+07 (0.4<z<1.0)

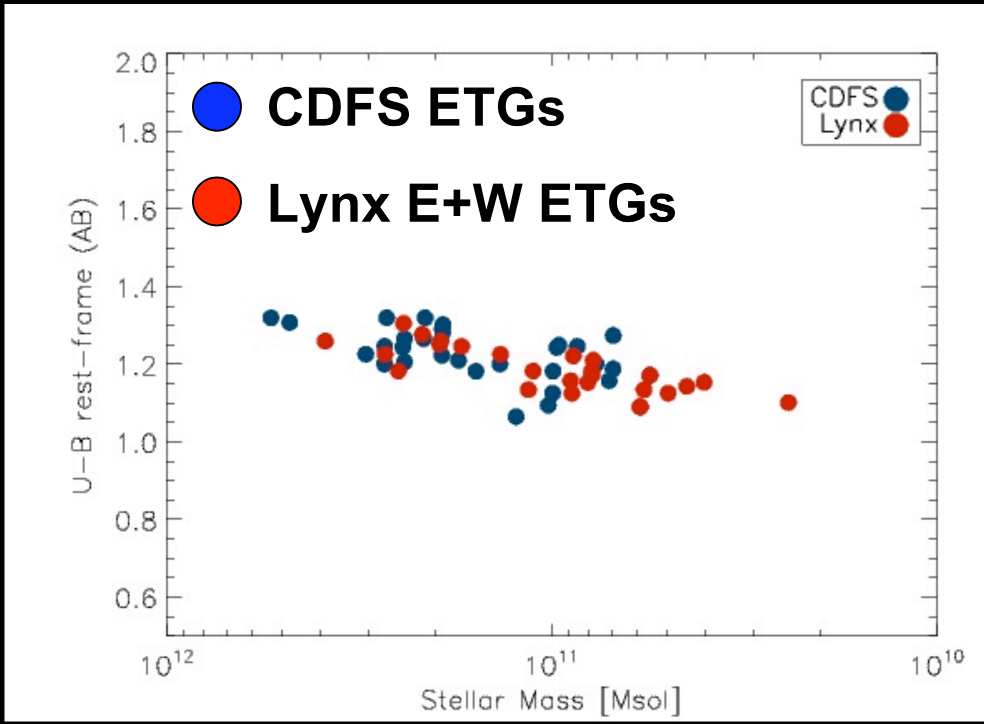
The agreement between independent measurements confirms that at least out to z~1 dynamical and photometric estimates match

(see also di Serego-Alighieri+05, van der Wel+06, Holden+06)

Mass-Selected samples: Color vs. Stellar-Mass diagram



Rettura et al.,2008



Rettura et al.,2009, in prep.

Mass-selected samples of Spectroscopic ETG

(with comparable phot. and spec. completeness)

18 ETG in 1252

27 ETG in CDFS

28 ETG in Lynx E+W

Typical Mass errors= 40%= 0.15 dex

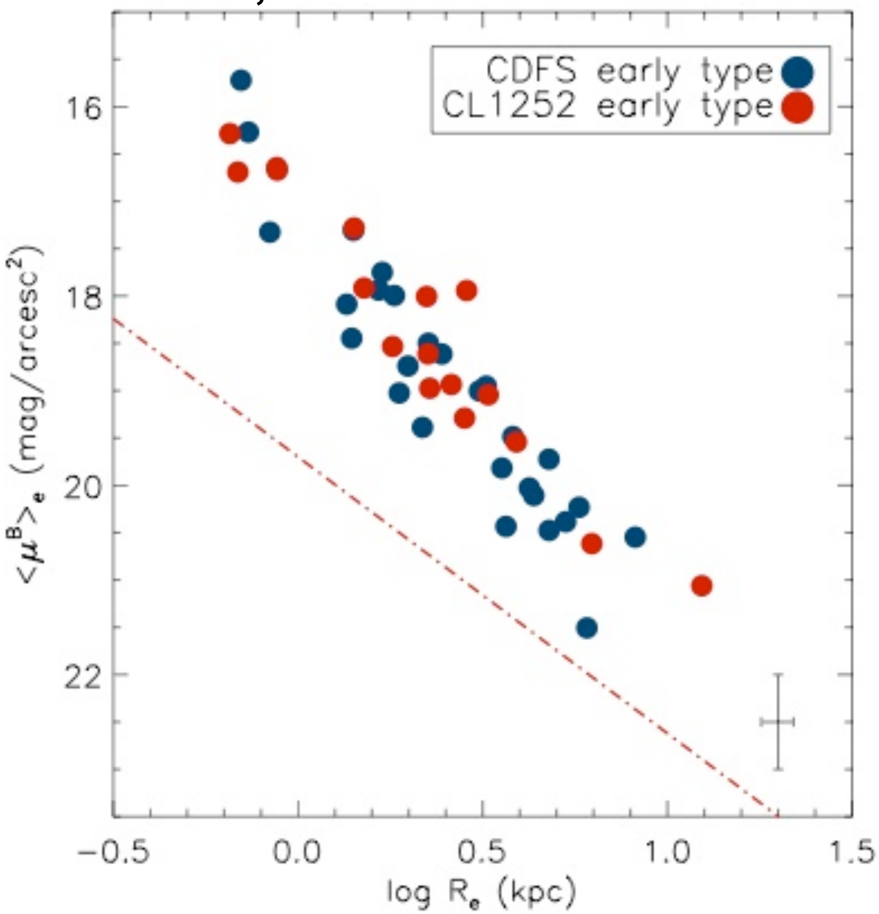
Results

1. *Are there Environmentally driven effects on the morphology of ETG ?*

Cluster vs. Field ETGs morphologies : Kormendy Relation

•Sersic surface brightness profiles fit for both samples z-band images (GIM2D)

Rettura et al.,2008



•z~0 relation from LaBarbera+03 (Coma Cl.)

•ETGs are 1-2mag brigther then z~0

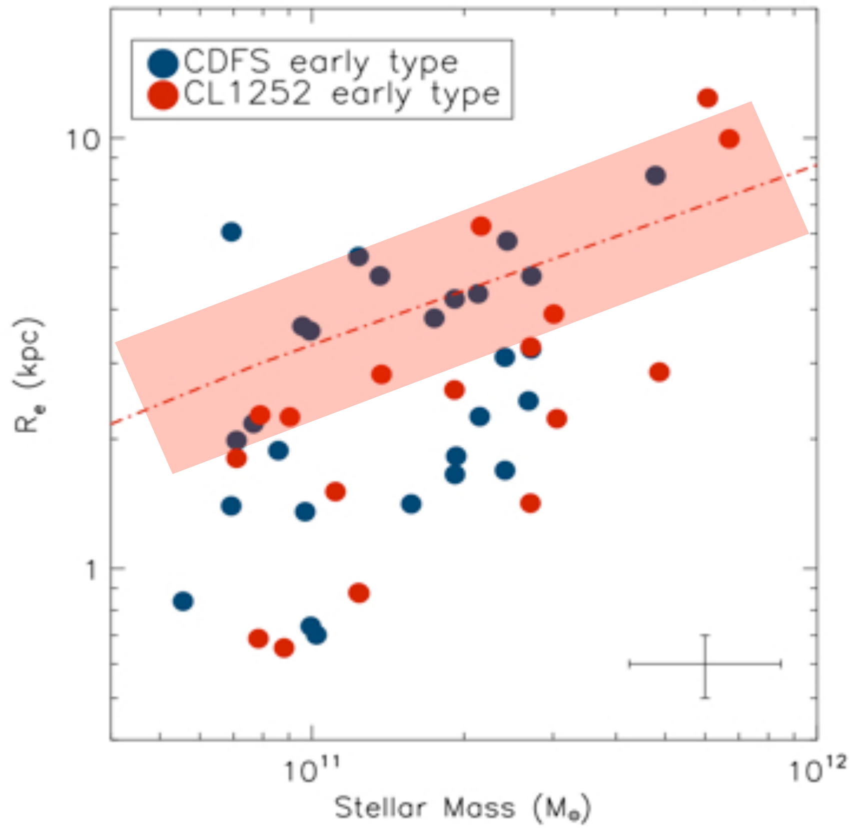
•Cannot be explained by pure luminosity evolution

(Longhetti et al. 2007, Cimatti et al. 2008, di Serego Alighieri et al. 2005)

Cluster vs. Field ETGs morphologies : size evolution

•Sersic surface brightness profiles fit for both samples z-band images (GIM2D)

Rettura et al.,2008

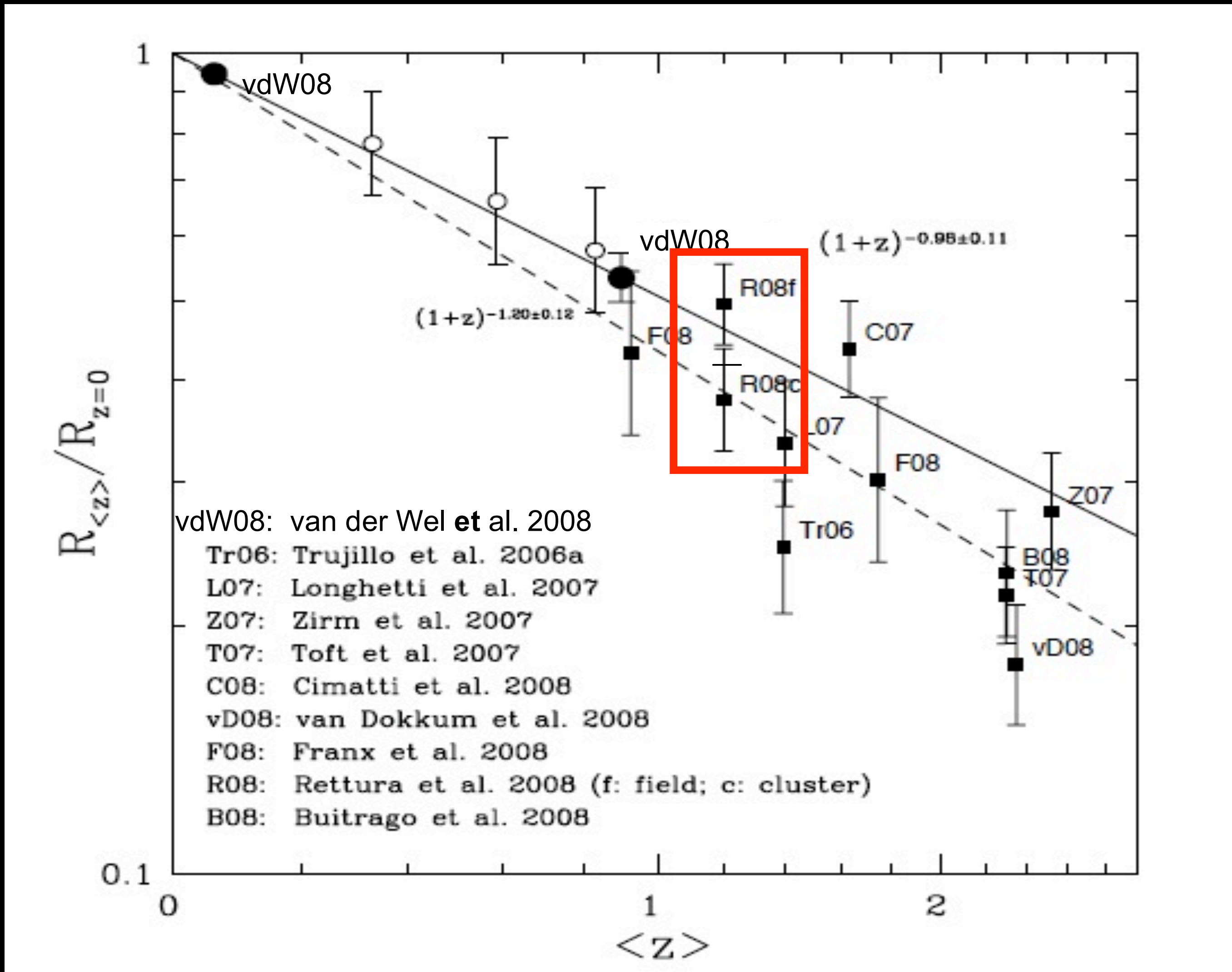


- z~0 relation from SDSS (Shen+03)

•Strong size evolution:

~ a factor of ~2 per unit mass

Size evolution with redshift



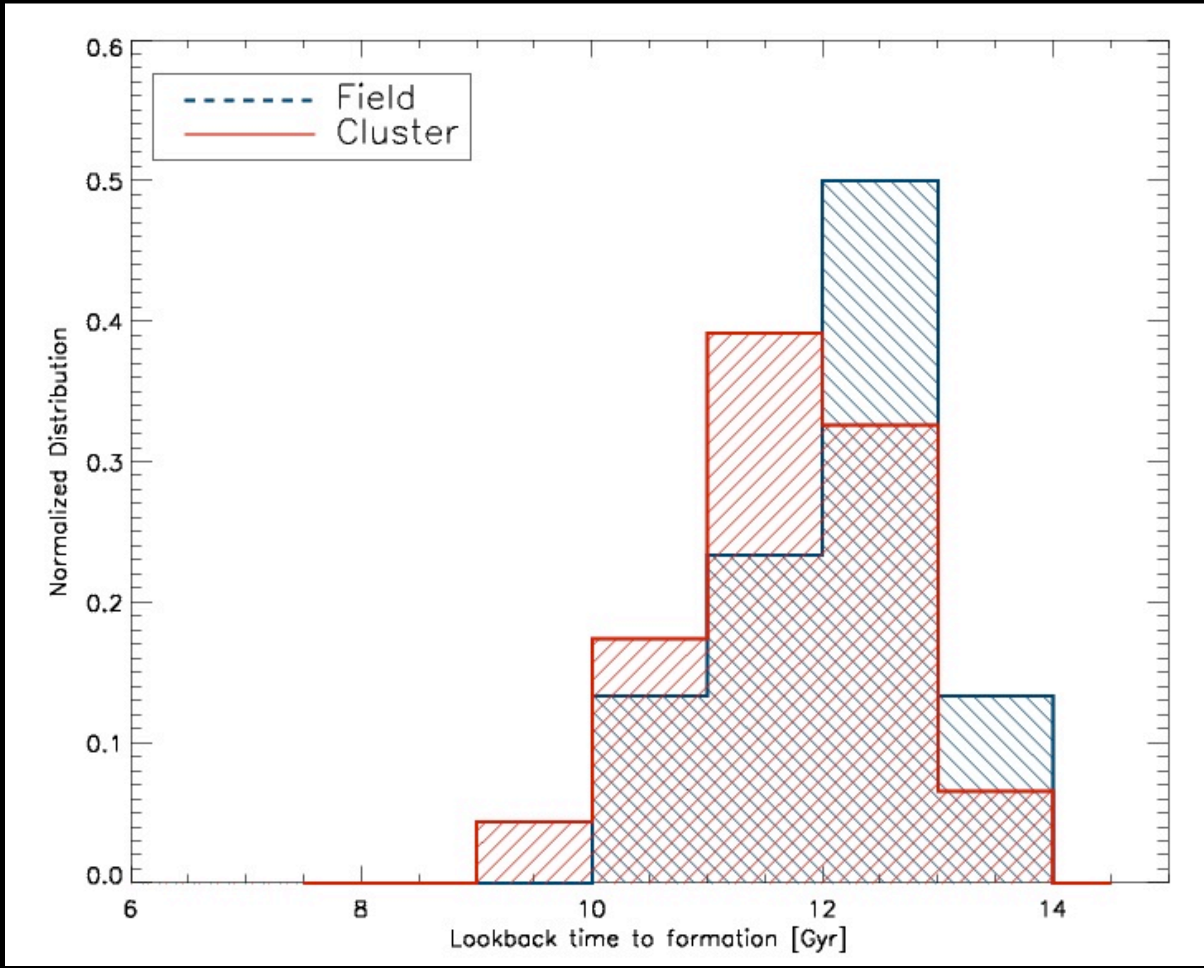
- Size evolution of a factor of 2 from z~1 to z~0
- Dissipationless "dry" merger of gas poor systems (Khochfar&Burkert 03)

van der Wel et al. 08

Results

2. *Are there Environmentally driven effects on stellar population properties ?*

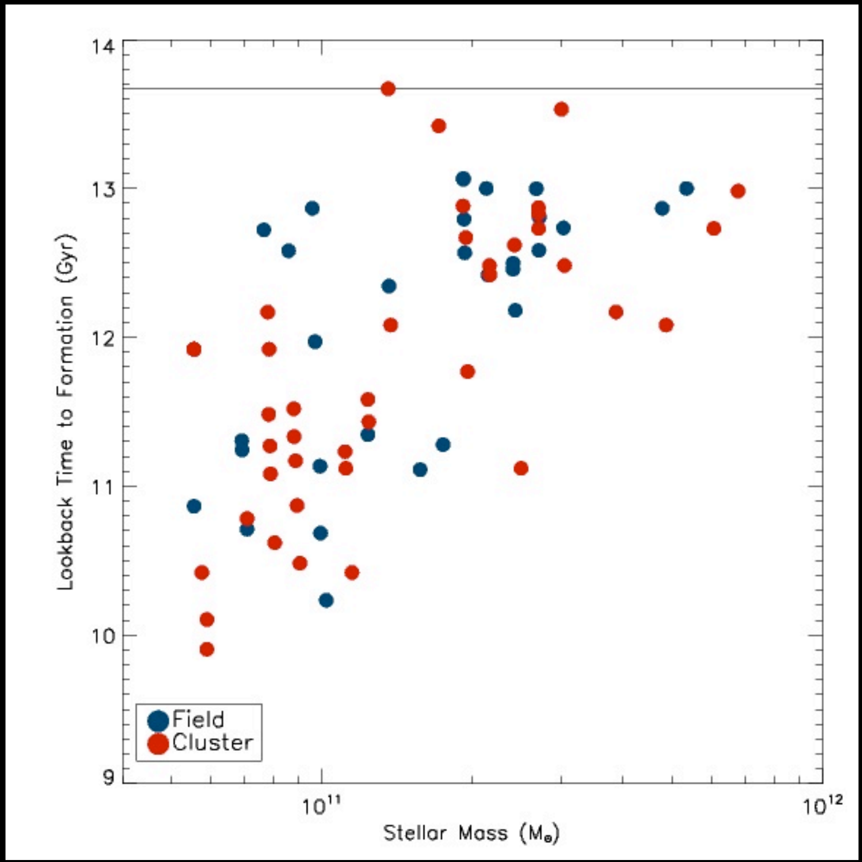
Formation Epoch of Cluster vs. Field galaxies : *timing*



Typical Mass errors= 40%= 0.15 dex
Typical Age errors= 0.5 Gyr

FP studies (Van dokkum + 07, di Serego-Alighieri (ERRATUM)+ 07) have also shown that massive ETG in field and in clusters ($M>3 \times 10^{11} M_{\odot}$) at z ~ 1.0 have similar formation epochs.

Formation Epochs of Cluster and Field galaxies : *downsizing*



Typical Mass errors= 40%= 0.15 dex
Typical Age errors= 0.5 Gyr

- The sites of active star formation shift from high-mass galaxies at early epochs, to low-mass galaxies as a function of cosmic time.
- No dependence on environment

Rettura et al.,2008, 2009

Star Formation Histories of Cluster and Field galaxies: *timescales*

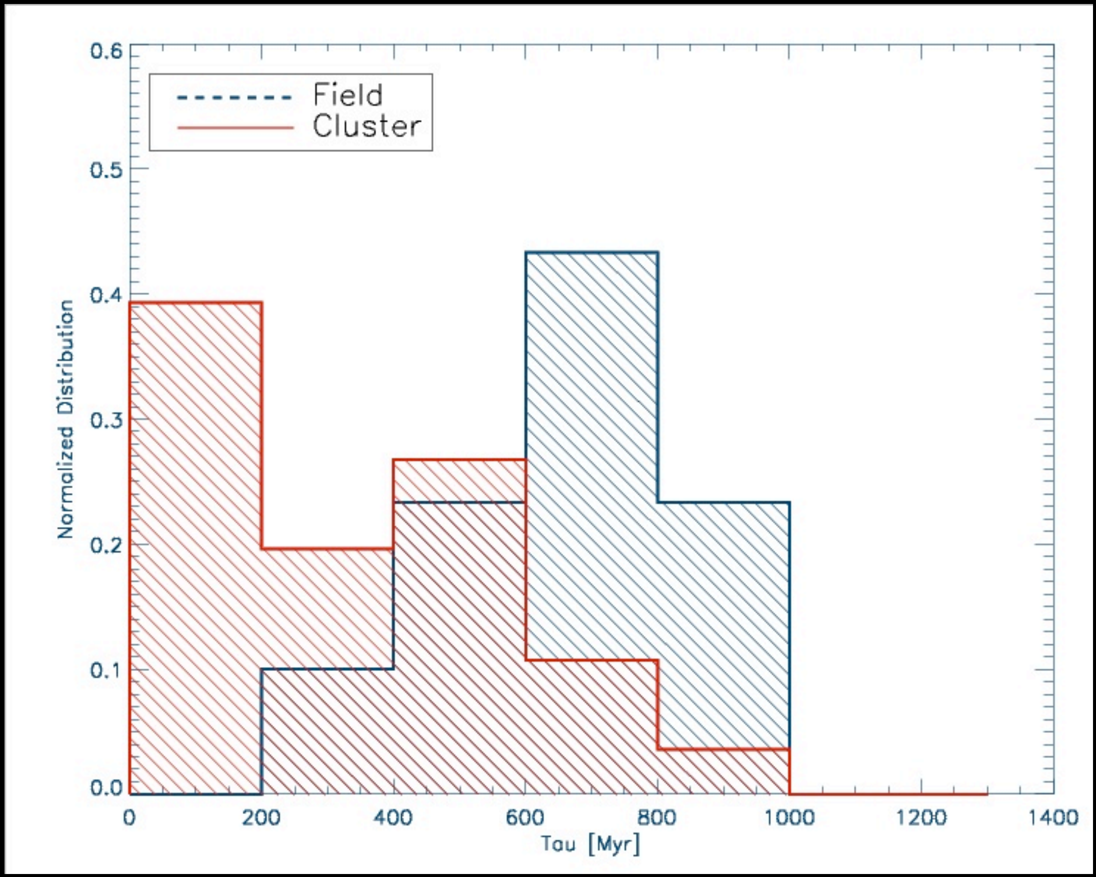
Despite of the fact that formation epochs are found to be similar, it could still be possible that the timescales of SFH are different.

Rettura+08, +09

See also

Gobat+08

Menci+08

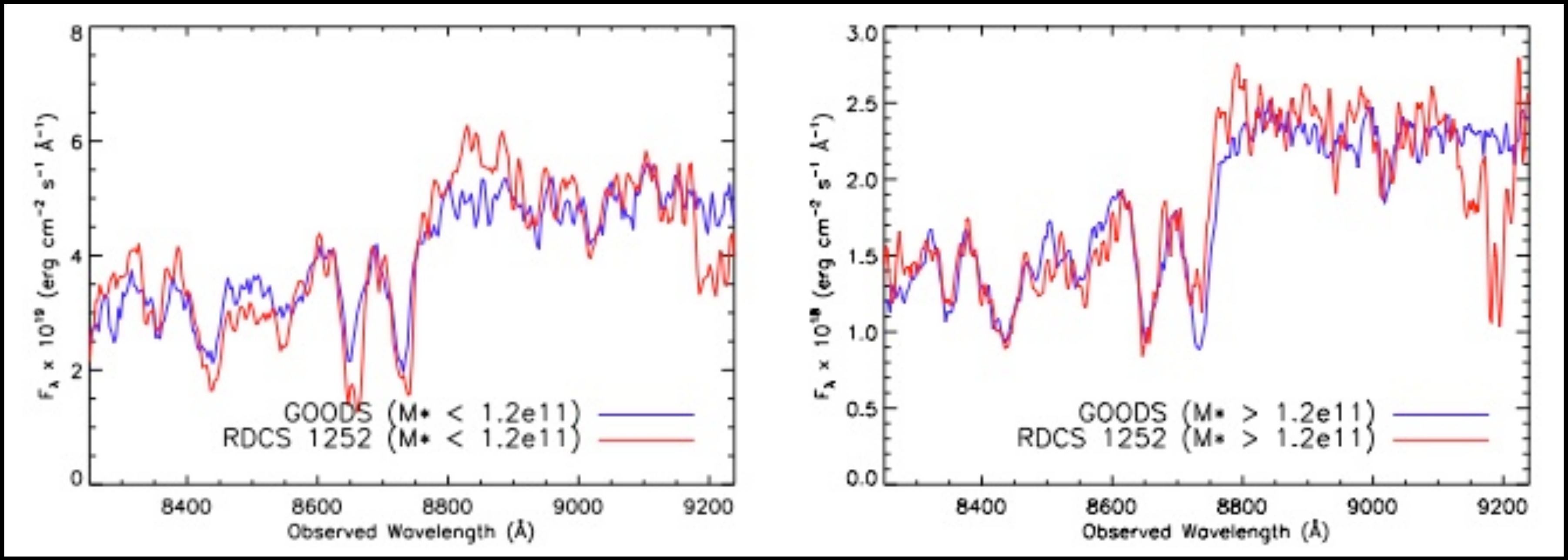


Typical Tau errors= 0.2 Gyr

- Implying that the last episode of star formation must have happened more recently in the field than in the cluster

Differences between stacked spectra of Cluster and Field ETGs:

4000 A break strenght



Gobat et al.,2008

Conclusions

- Complete sample of mass-selected ETG (46 Cluster and 27 Field)
- Cluster and field ETGs at z~1.3 lie on the same Color-magnitude sequence although field galaxies have a larger scatter.
- No dependence on the environment of the *size vs. stellar mass* and *Kormendy* relations.
  - Our results indicate a strong size evolution in both environments
- Mass-selected samples of galaxies (>~$5\times10^{10}M_{\odot}$) in cluster and field at z~1.3 have roughly similar Formation epochs.
  - independently of the actual SP code
  - consistent with FP studies at $z \leq 1.0$
  - consistent with down-sizing scenario
- Field ETGs best-fit models span a longer range of timescales than their cluster contemporaries, which are found to have formed with the shortest tau at any given mass.
- Mass regulates the *timing* of formation epoch of ETG (Nature), while environment mildly regulates the *timescales* of assembly process (Nurture).