The galaxy population of an X-ray luminous cluster at z~1: *the HST/ACS colour-magnitude relation*

Joana Santos (OATS-INAF)

P. Rosati, R.Gobat, C.Lidman (ESO)

I.Balestra, H.Boehringer (MPE)

Outline

INTRO:

- Formation and evolution of early-type galaxies
- Tools to study ETGs
- State-of-the-art on studies of high-z clusters

XMMUJ1229, z=0.975 (J.S. Santos et al 2009 A&A)

Photometric, morphological & spectral properties of the cluster galaxies

- XMM1229 dataset
- X-ray analysis
- Colour-Magnitude Relation (CMR)
- Structural analysis: fitting SB models, visual morphological class.
- Spectral Energy Distribution (SED) fitting
- Brightest Cluster Galaxies (BCG)
- Conclusions

Formation & evolution of ETGs

- Scenarios of galaxy formation & evolution:

1) Monolithic collapse model Eggen, Lynden-Bell & Sandage 1962
Massive galaxies formed in a single event at high-z

2) Hierarchical merging model Toomre 1977
ETGs form and evolve through mergers

- Early-type galaxies (ETGs, ellipticals & S0s):

- found in massive clusters, 60% of the stellar mass
see review by Renzini 06
- Passive, i.e., negligible ongoing star formation
- Compact, bulge-dominated

Surface brightness:

de Vaucouleurs $I(r) = I_0 \exp [(r/r_e)^{1/4}]$

Sersic $I(r) = I_0 \exp [(r/r_e)^{1/n} -1]$

Formation & evolution of ETGs

- Observational Thomas 05 & Theoretical De Lucia 06 studies show that SFH is mass dependent:

massive galaxies have higher formation redshift @ z~5

"downsizing" Cowie 1996

STUDY THE EVOLUTION OF ETGs:

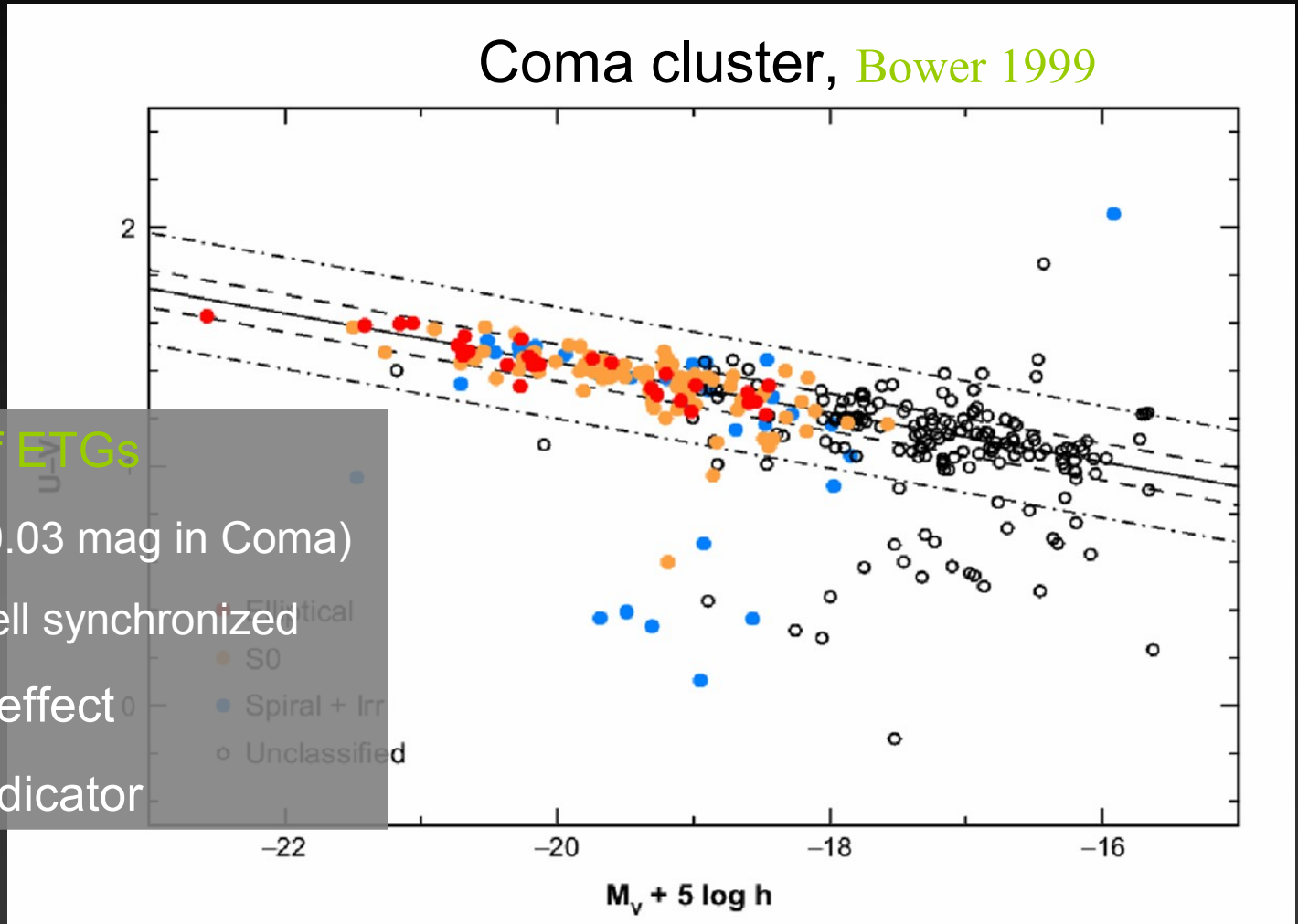
1) Fossil record: low-z studies

2) Directly investigate high-z ETG population

Local CMR

CMR scaling relation Baum 1959

Coma cluster, Bower 1999



Red-sequence of ETGs

small Scatter (~ 0.03 mag in Coma)

-> SFH of ETGs well synchronized

Slope metallicity effect

Zero point age indicator

Spectrophotometric tools

Modelling Spectral Energy Distribution (SED) of galaxies and spectra

- Simple stellar population synthesis models

or Composite stellar population models: star formation, $\psi(t) = t/\tau\ e^{-t/\tau}$

e.g. Bruzual & Charlot 2003, Maraston 2005

- Initial Mass Function

  $\Phi(m) \propto m^{-2.35}$ Salpeter 1955

  top-heavy IMF Kroupa 01, Chabrier 03

Fitting the SEDs

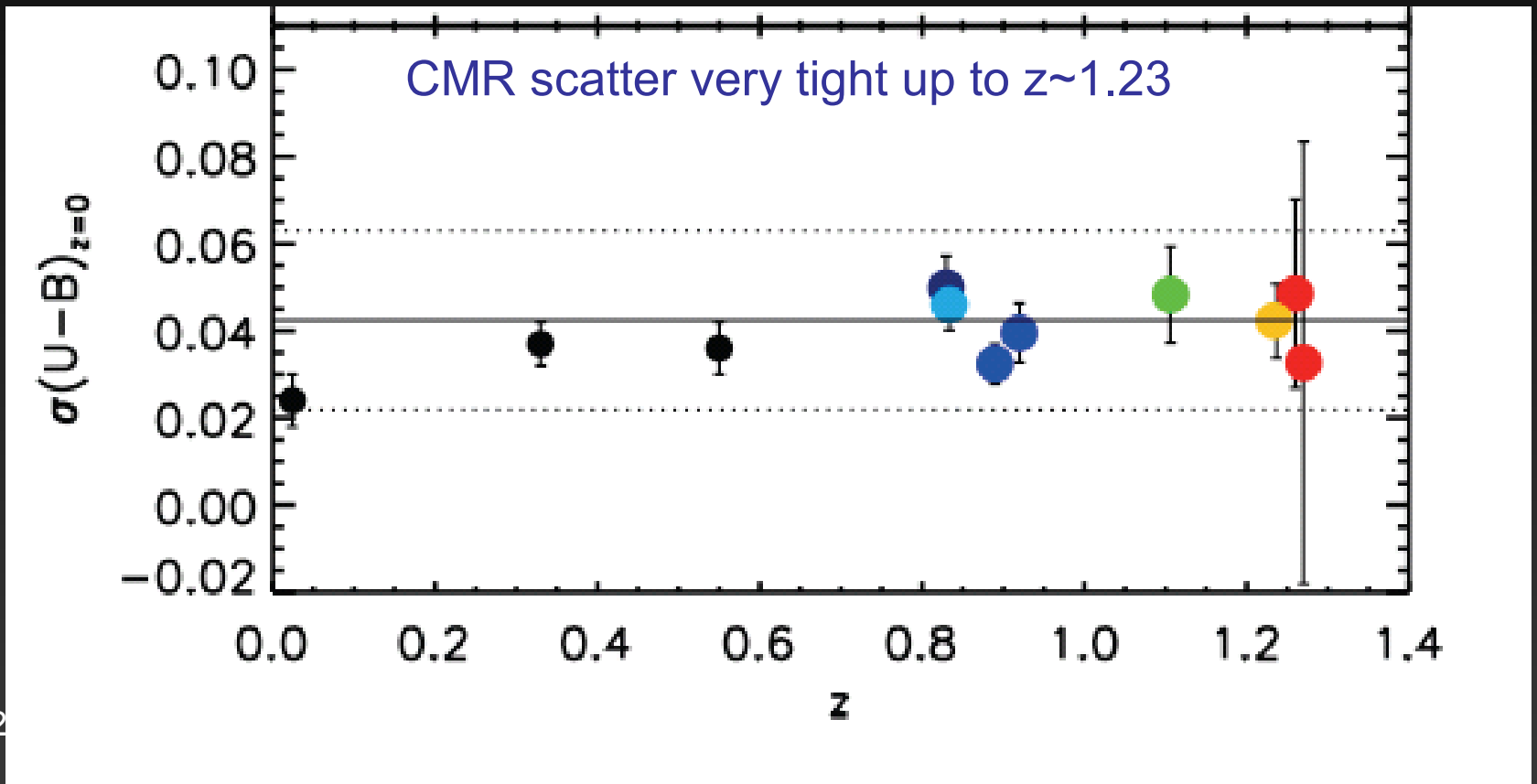
- photometric data
- obtain stellar ages, masses

Combine stack spectra + photometry of ETGs

constrain star formation histories

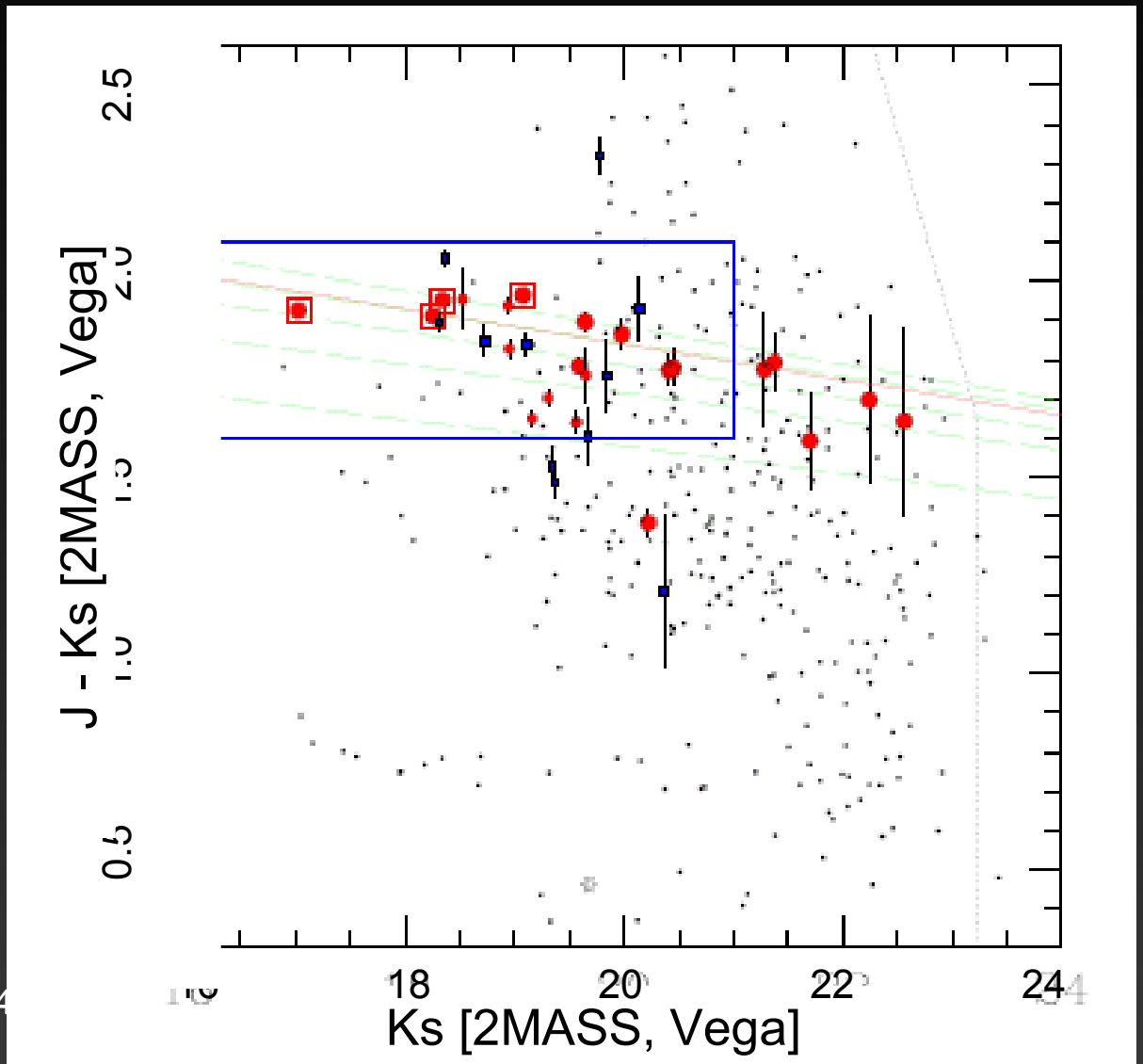
State-of-the-art: high-z cluster studies

- ACS Intermediate Redshift Cluster survey, 8 clusters $0.8 < z < 1.2$ Blakeslee 03+06, Homeier 05, Holden 06, Mei 06+09
- RDCS1252 z=1.23 Demarco 07



State-of-the-art: high-z cluster studies

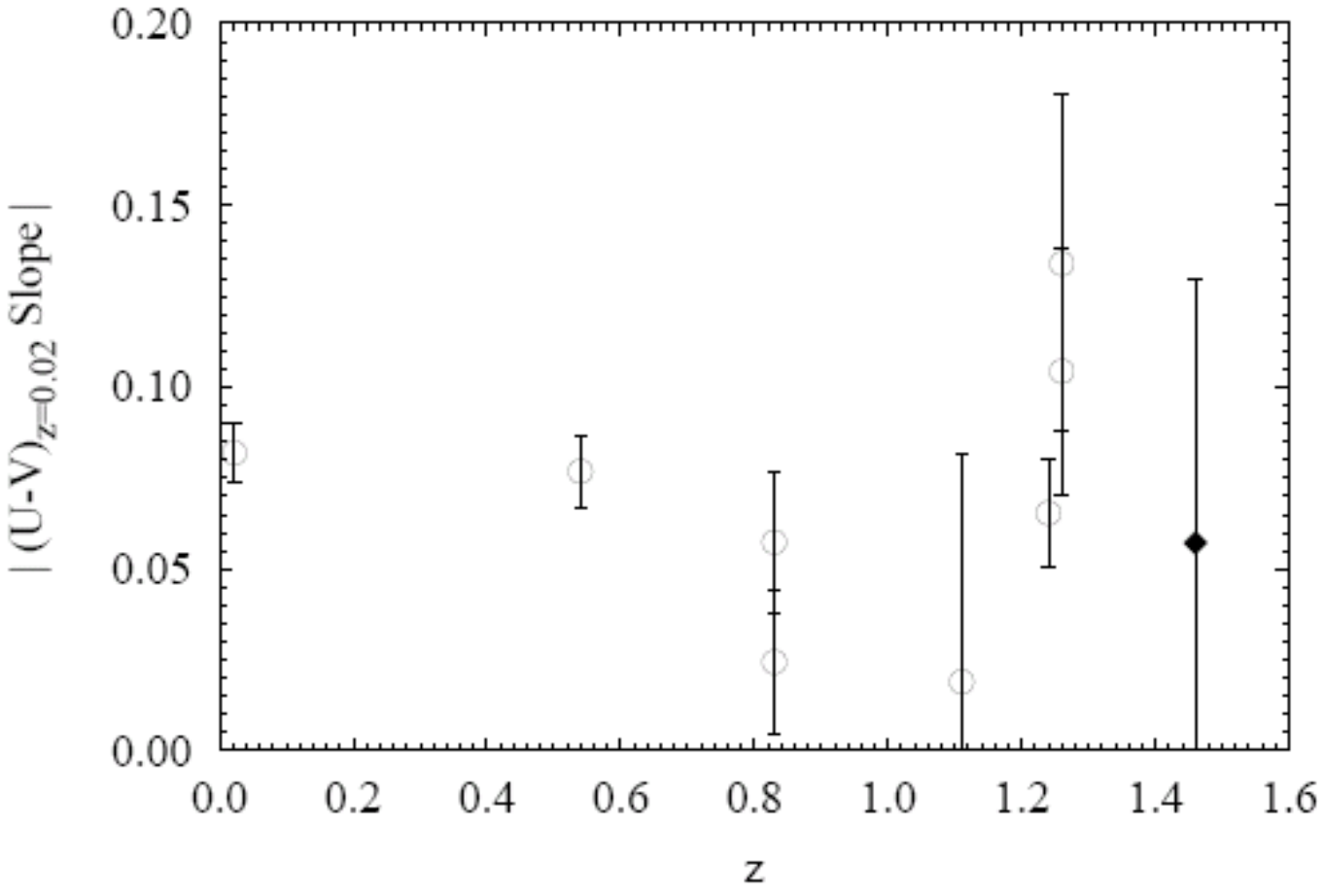
XMMUJ2235, z=1.39 Lidman 08 NIR CMR, Hawk-I@VLT



Build-up of RS:
inside -> outside

State-of-the-art: high-z cluster studies

XMMXCS2215, z=1.45 Hilton 09



No evolution of the CMR slope

XMMUJ1229, z=0.975

(J.S. Santos et al 2009 A&A)

- XMM-Newton serendipitous discovery:
  XDCP survey Boehringer et al. 2005
- HST/ACS i_{775}, z_{850} + VLT/FORS2 spectra
  Supernova Cosmology Project Dawson et al. 2009
- NTT/SOFI NIR J (40 min), Ks (1 hr)

Analysis

Investigate the properties of the cluster galaxy population

- Intracluster medium: T, Z_{Fe}, L_X

- Galaxy structural analysis: SB profile fitting
  visual classification

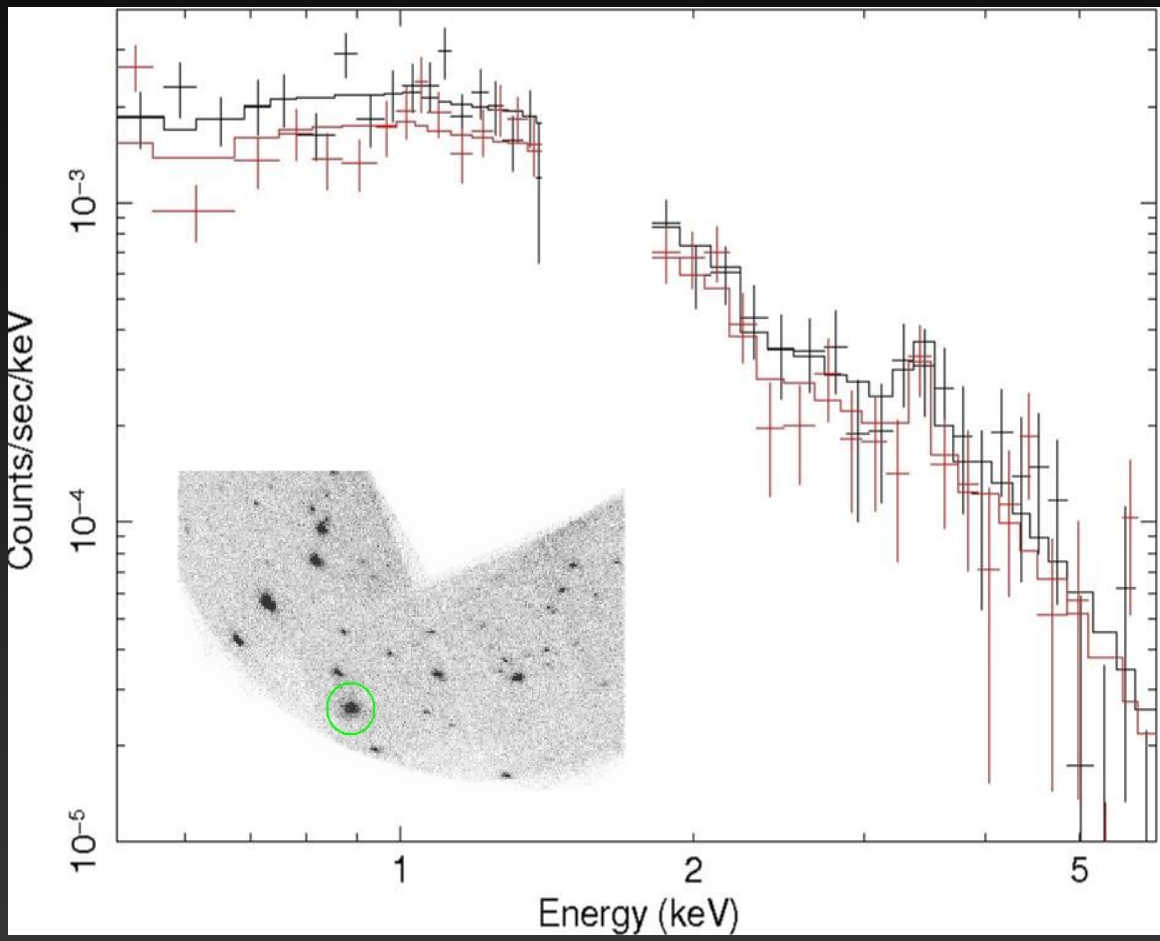
- Colour-Magnitude Relation: slope, zp, scatter
- SED analysis: stellar ages, masses, SFH
- BCG(s) properties

X-ray analysis

- XMM-Newton Exp ~ 400 ksec ~ 1300 counts

- Spectral fit
  z=0.975

Z_{Fe}/Z_{sun} 0.34 ± 0.14
T 6.5 ± 0.7 keV
$L_{X[0.5-2.0]}$ 3.3 10^{44} erg/s



Redshift distribution

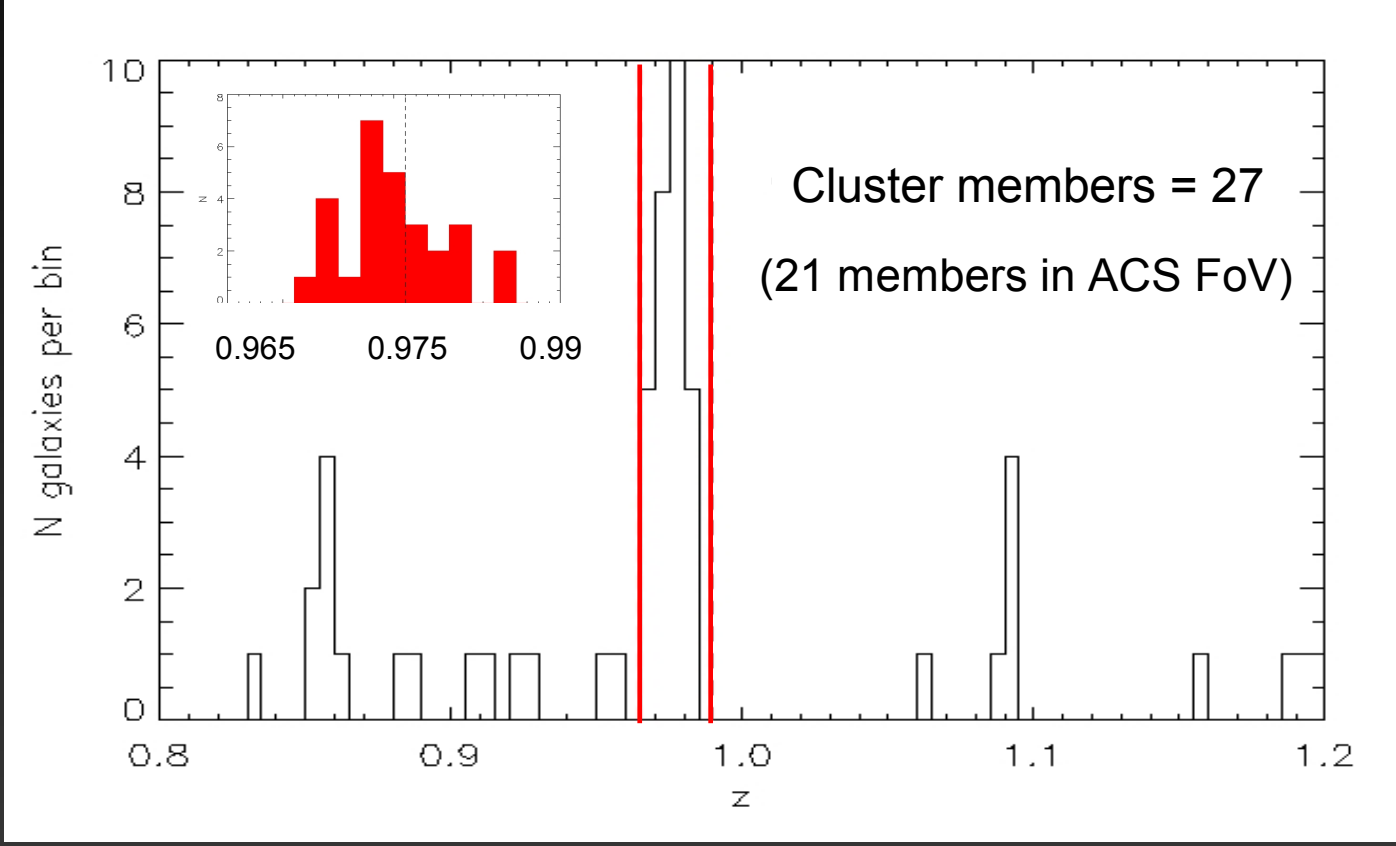
Target selection: R-Z colour

Priority 1: (R-Z) > 1.8 and z < 23

Priority 2: 1.6 < (R-Z) < 1.8 and z < 23

→ 64 redshifts

median z=0.975



Velocity dispersion

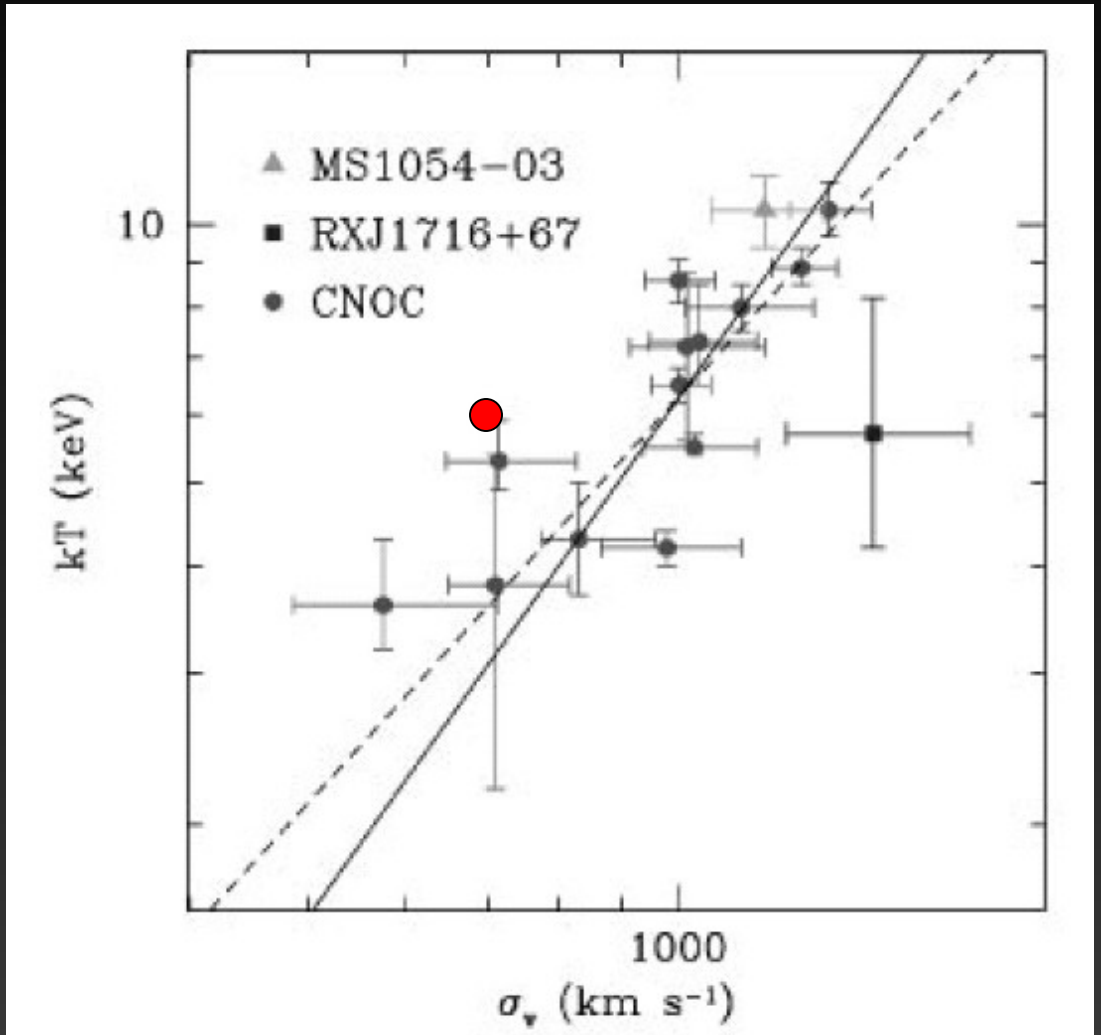
Tx – σ relation Wu 1999,
Tx – σ High-z clusters Rosati 2002

σ = 683 km/s

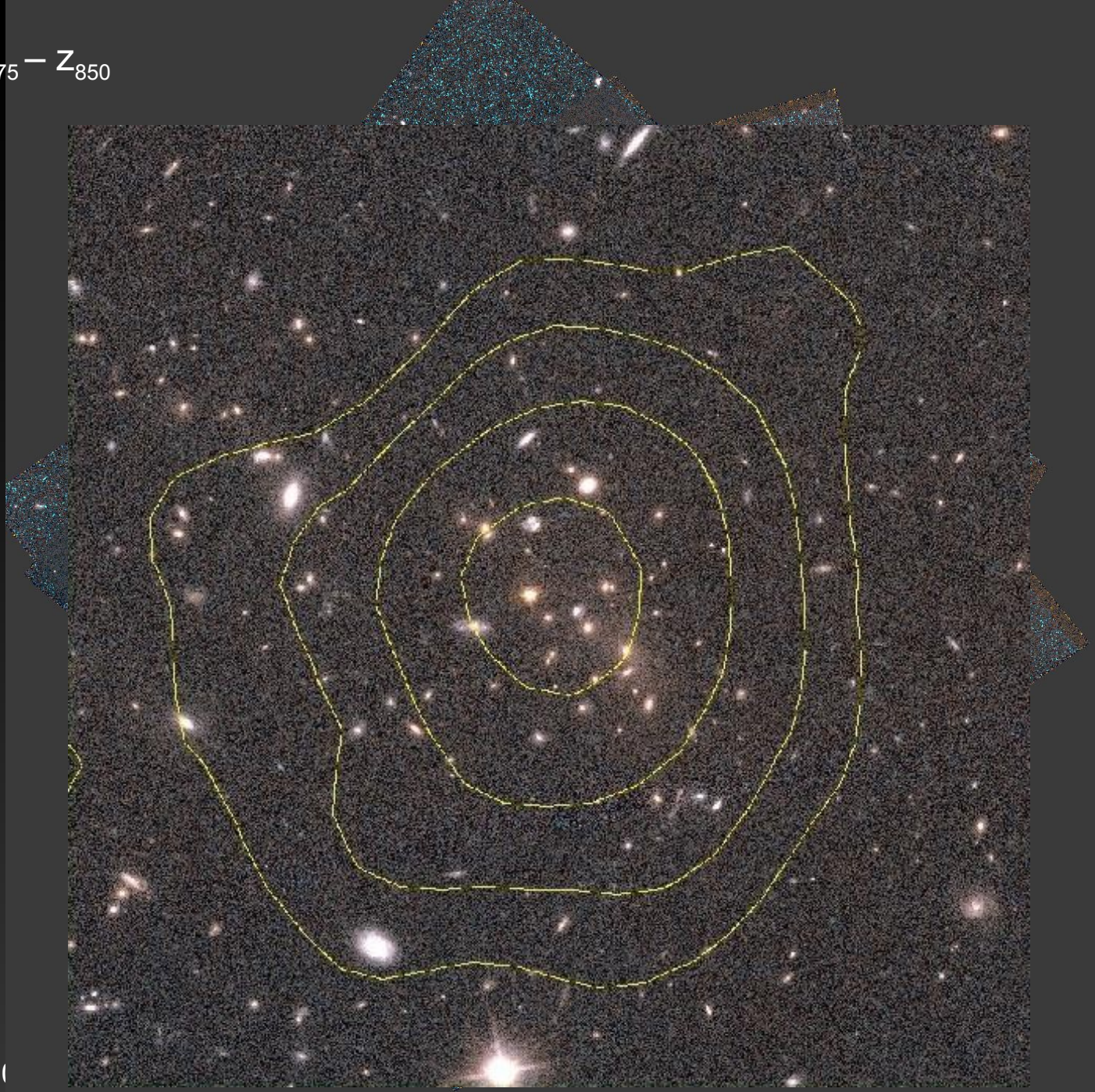
Beers 1990 estimator

($\Delta z=10^{-3}$)

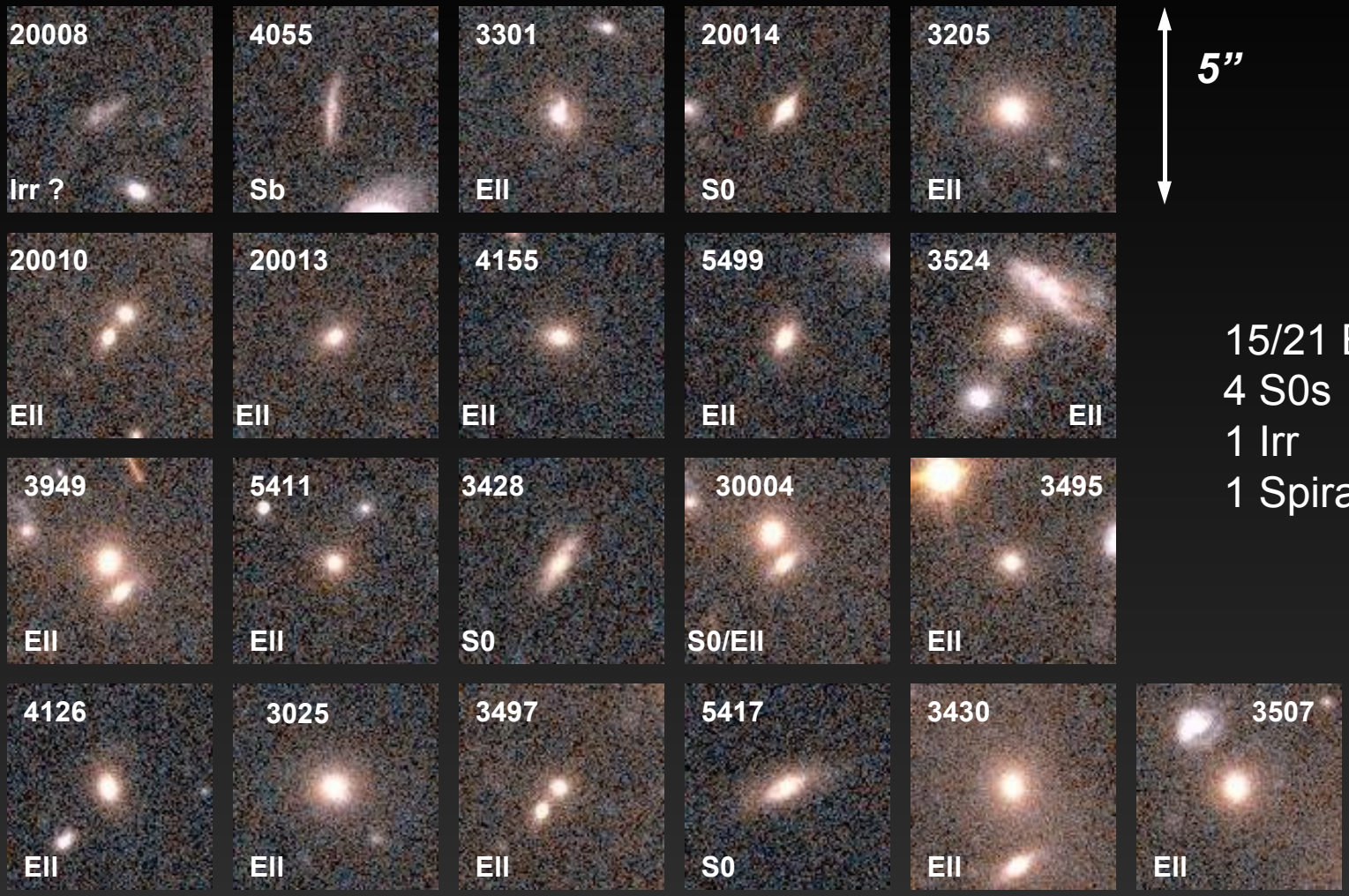
Within the large scatter of Tx – σ relation



ACS $i_{775} - z_{850}$



Visual classification of cluster members



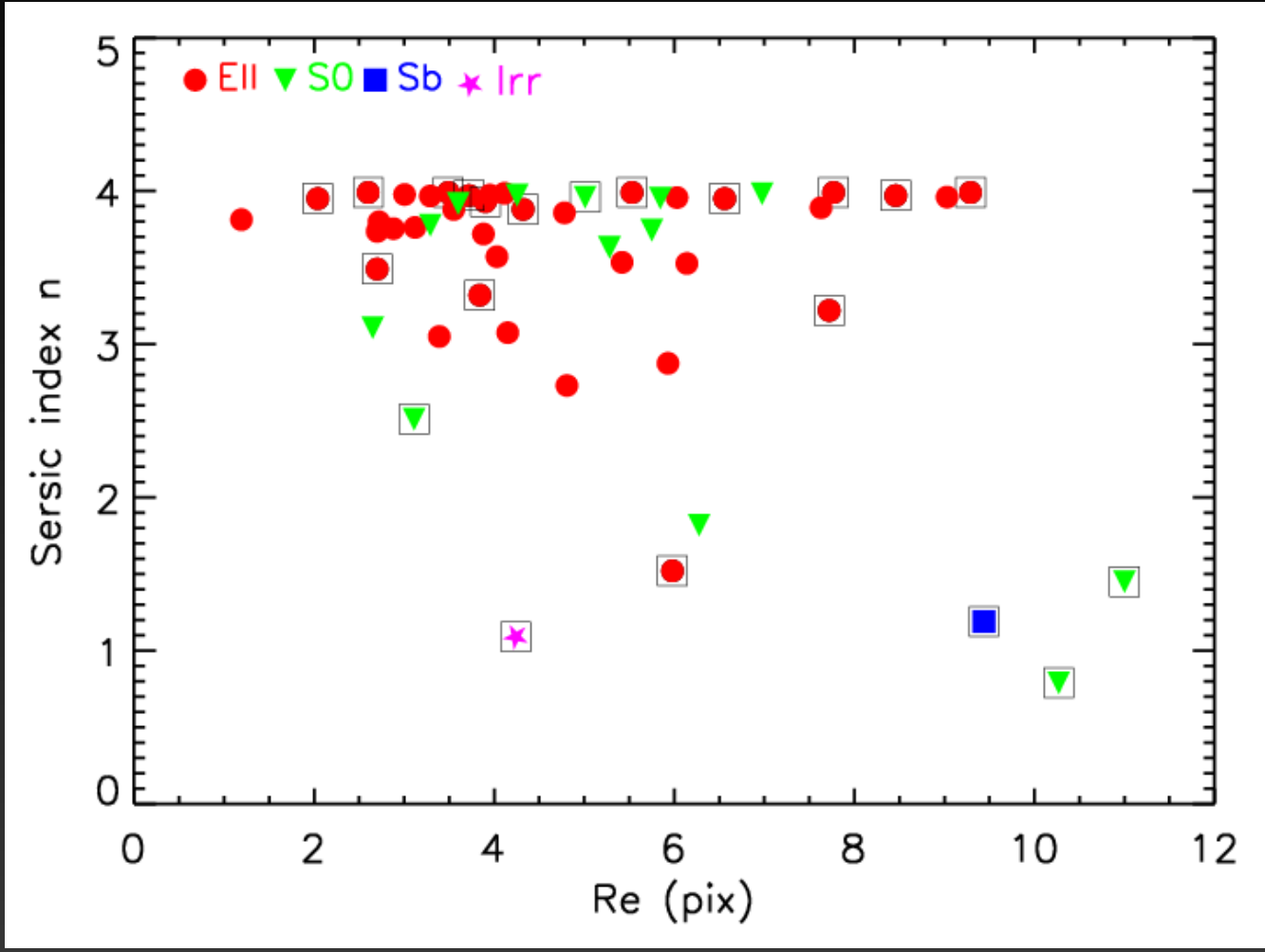
15/21 Ell
4 S0s
1 Irr
1 Spiral

ACS galaxy templates: Postman 2005

Structural analysis

Sersic model fitting with GIM2D Simard 2002

Spec gals □
median Re = 5.5 pix
median n = 3.9



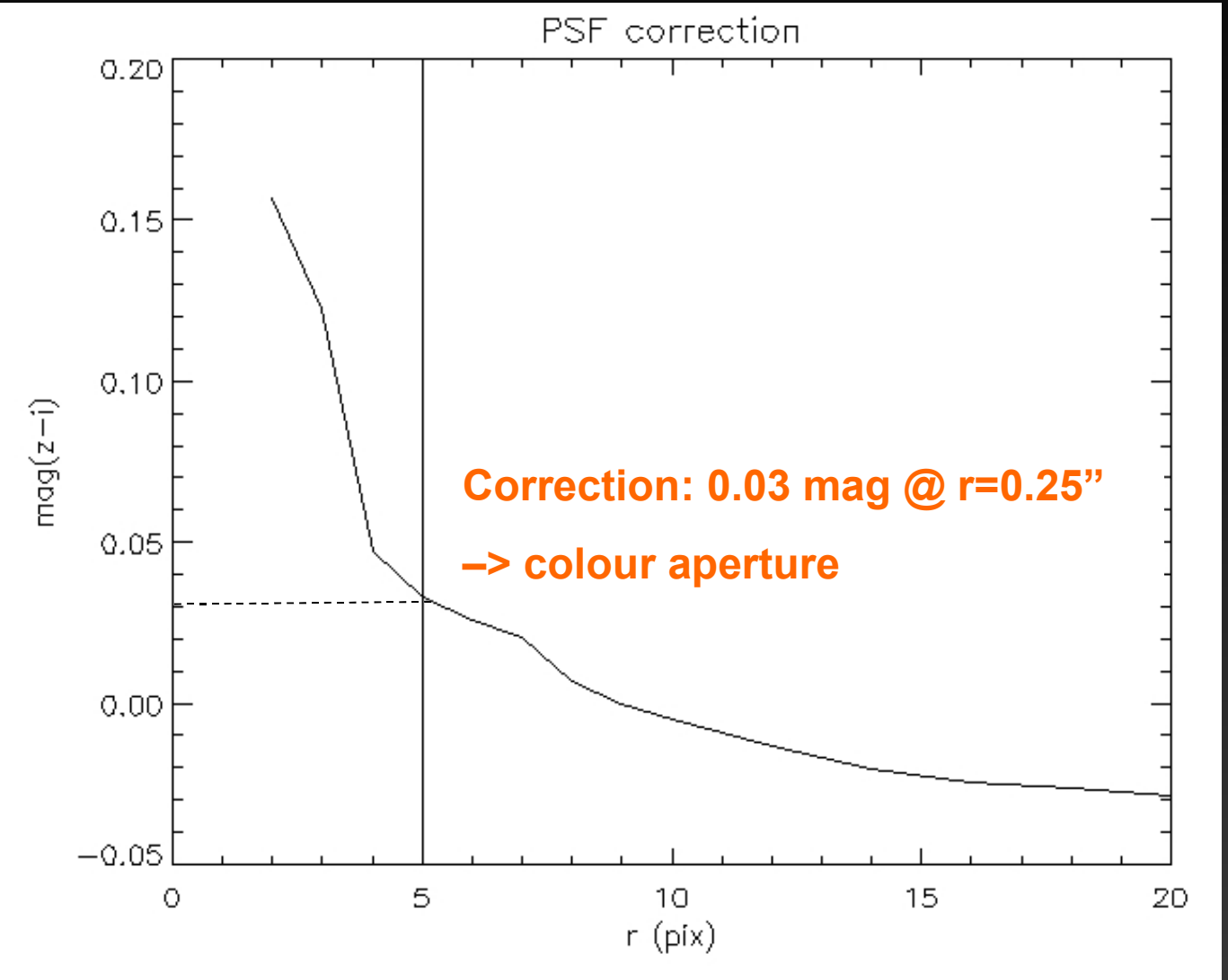
Colour-Magnitude Relation I

Standard method: PSF aperture correction from data

PSFs

i_{775} = 0.085”

z_{850} = 0.095”



Colour-Magnitude Relation I

Standard method: PSF deconvolved from data

Colour r = 0.25”

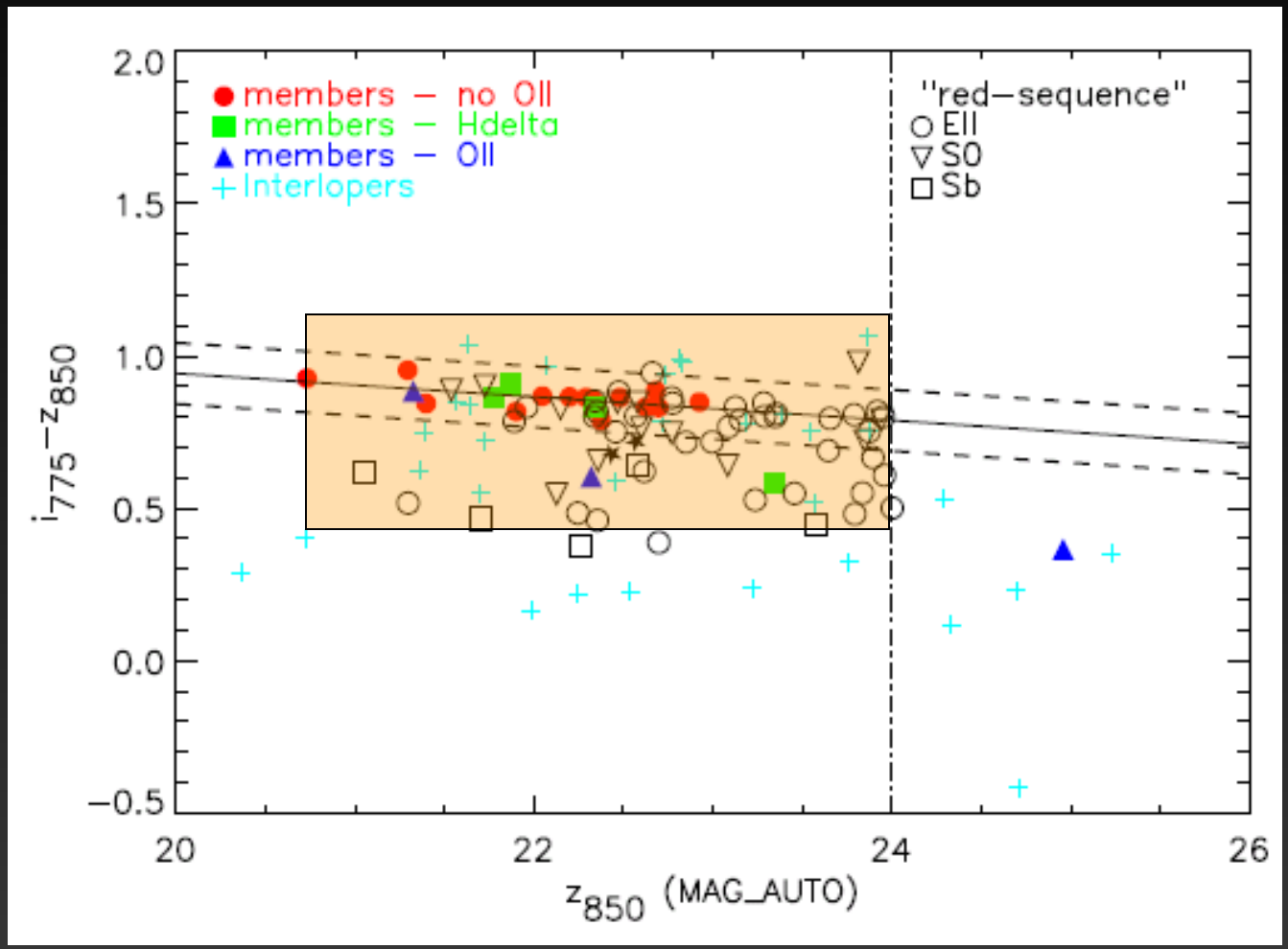
spec members only:

- Robust linear fit
- CMD σ = 0.04 mag

photometric sample

31 galaxies in 3 σ region

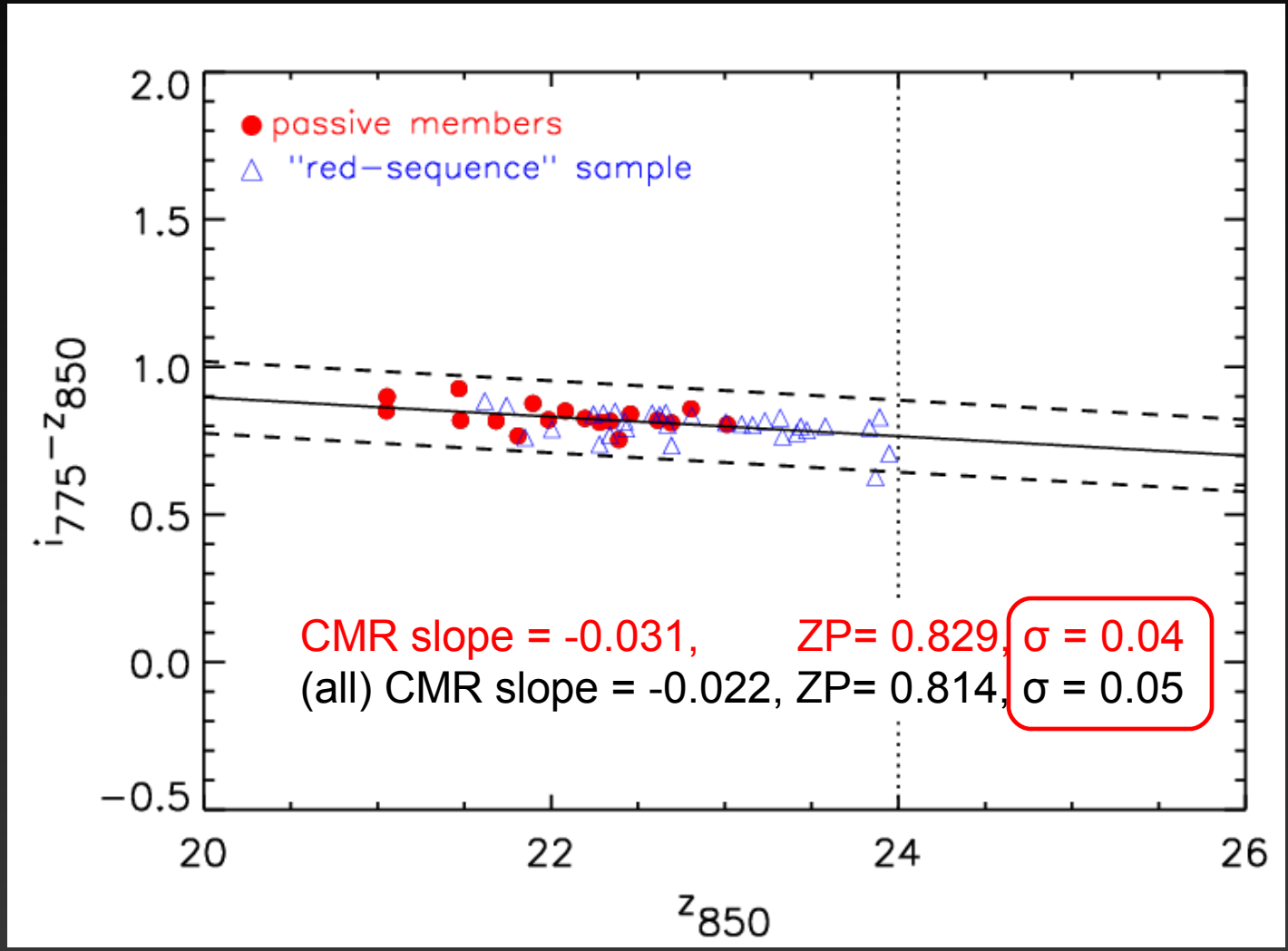
CMD σ = 0.05 mag



Colour-Magnitude Relation II

Different approach: use galaxy models GIM2D, PSF convolved with models

Colour r = 0.25”



SED fitting

Stellar masses & ages of 16 spec members + 18 “red-sequence” gals

1) PSF matching

- Growth curves of stars in the science images
- Match i_{775}, z_{850}, Ks data to J-band seeing
- Aperture photometry in fixed aperture r=0.5”/1.2”
- Extrapolate to 3” radius -> bulk of the flux

Image quality

i_{775} = 0.085”

z_{850} = 0.095”

Ks = 0.69”

J = 0.98”

2) Fitting:

- 3-parameter fit (age T, τ, mass)

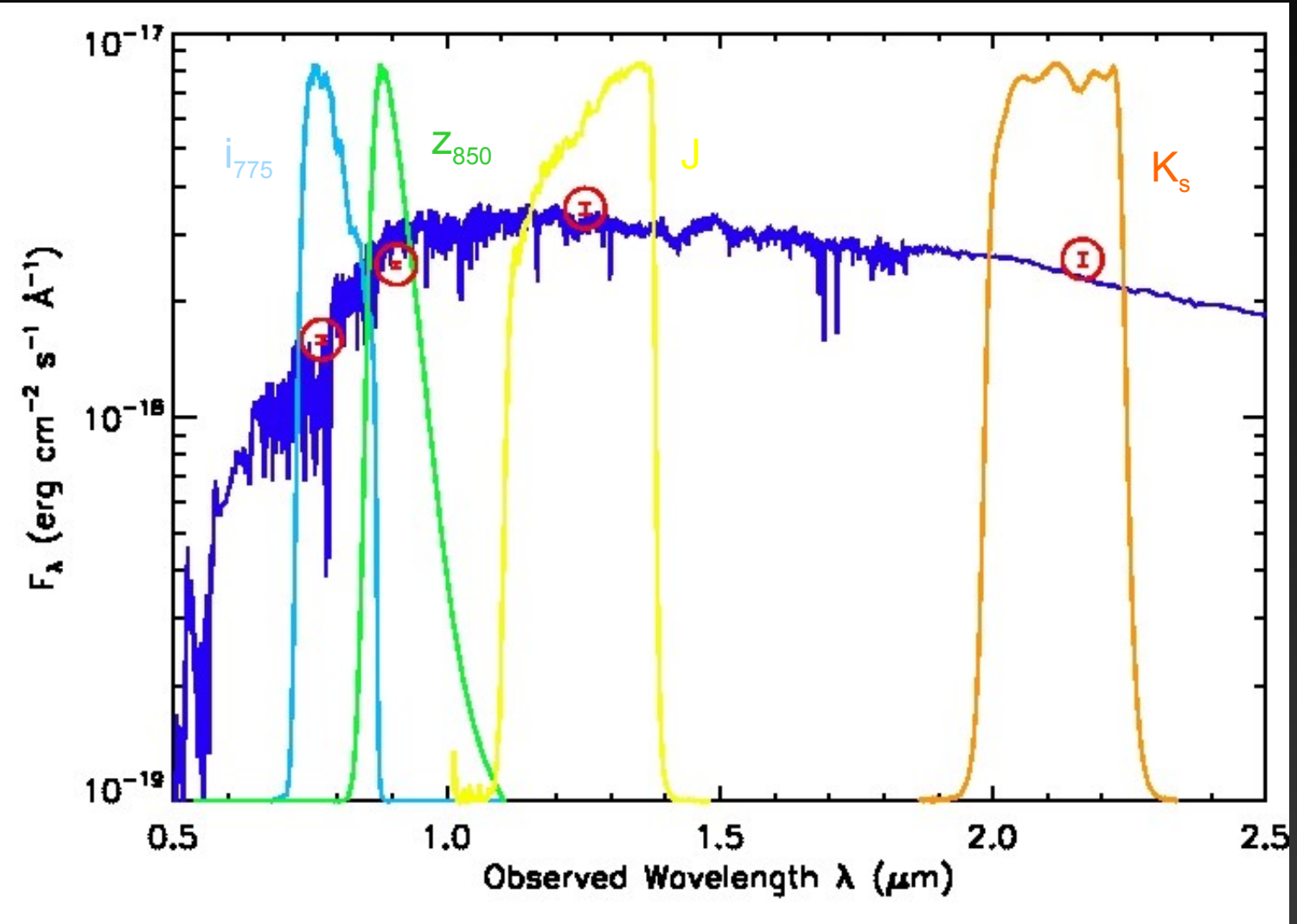
Bruzual & Charlot 2003 models, delayed exponential SFR,

$\psi(t) = t/\tau \, e^{(-t/\tau)}$, τ = [0.2-5.8] Gyr

- Solar metallicity
- Salpeter IMF, cut off [0.1-100] Msun

SED fitting

SED of one of the brightest galaxies



SED fitting: masses, ages

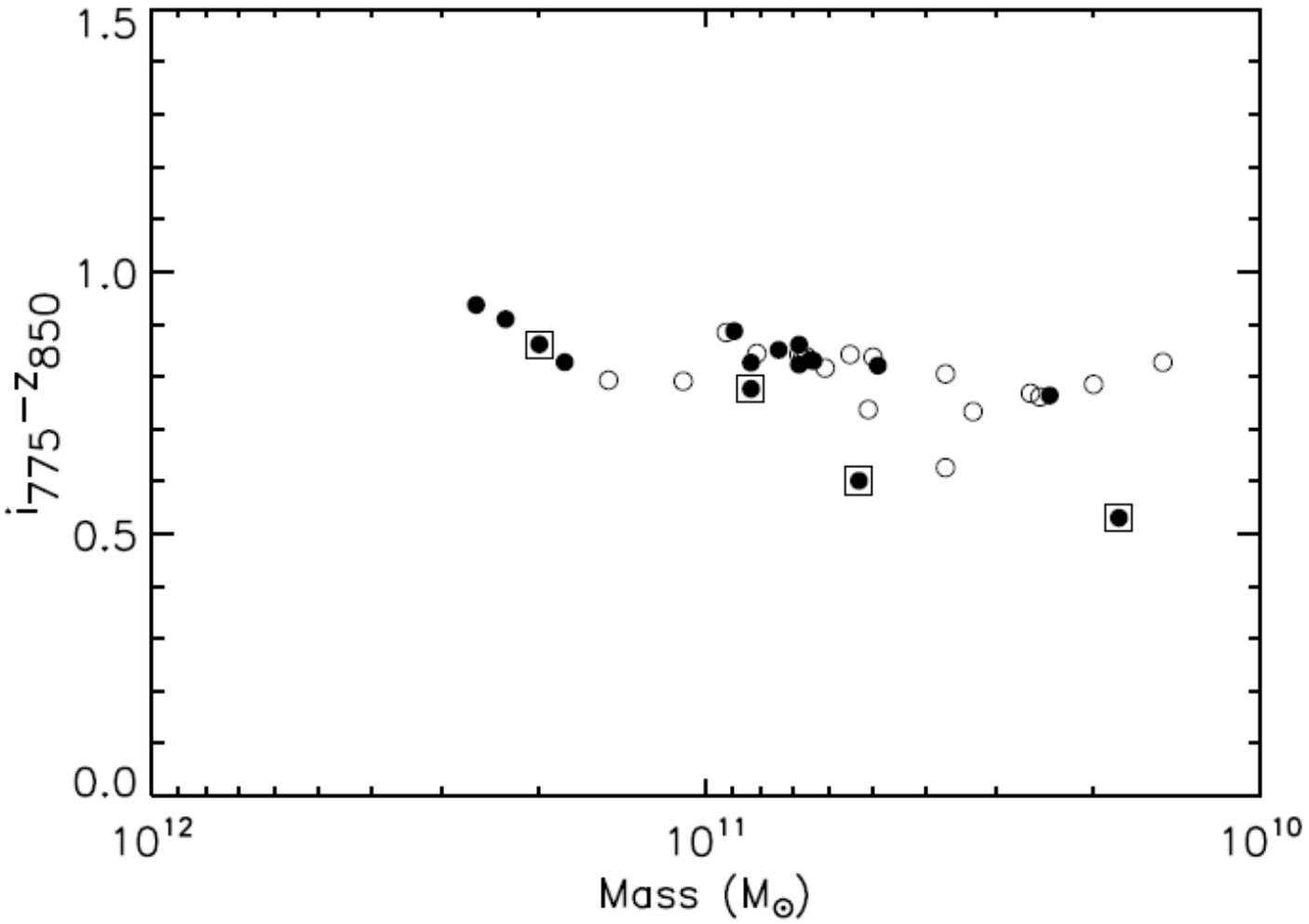
- Spec members
- Red-sequence sample
- OII / late-types

ETGs:

M=7x10^{10} sun

SF weighted age = 4.3 Gyrs

(median values)

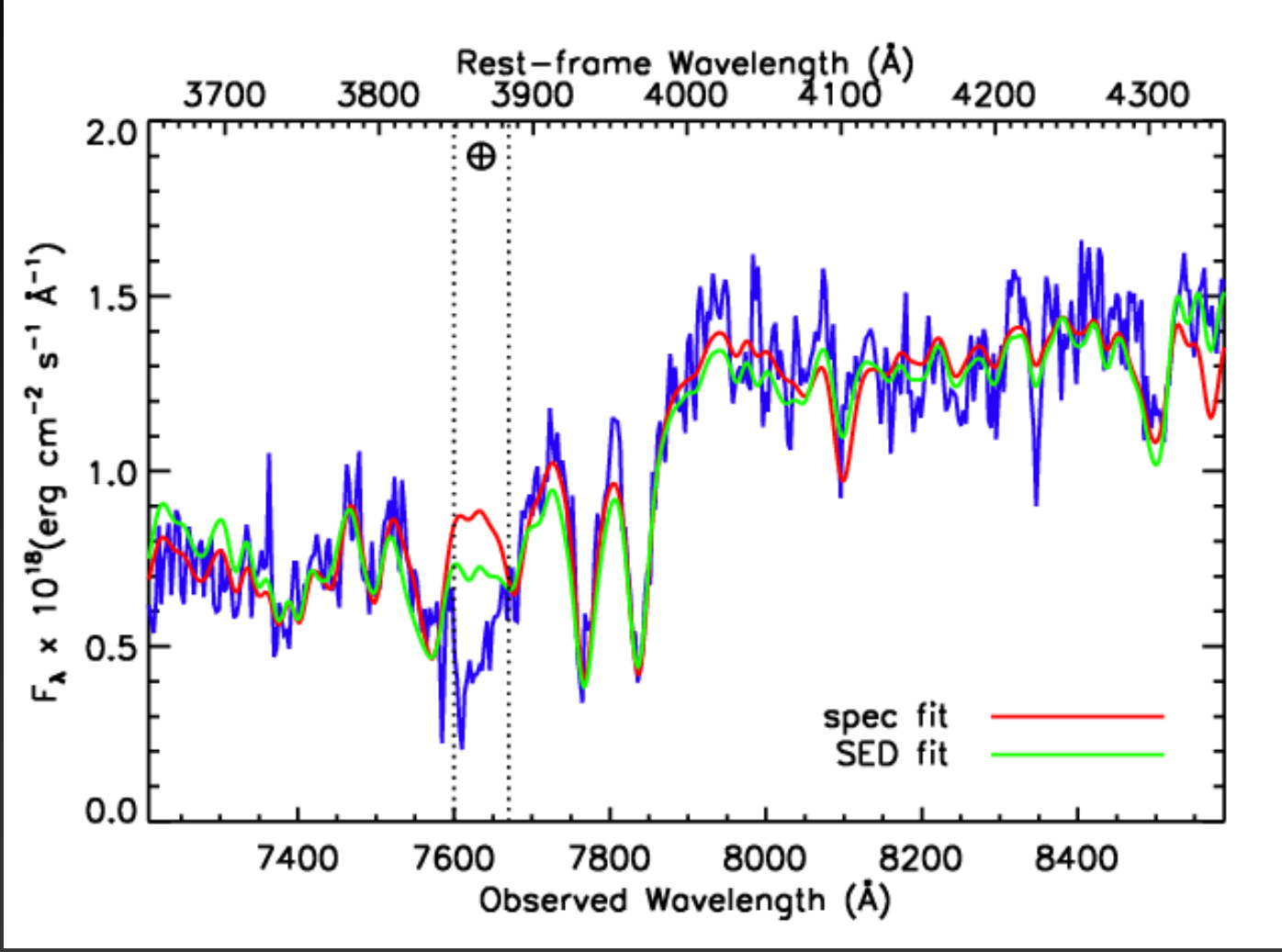


Star formation history

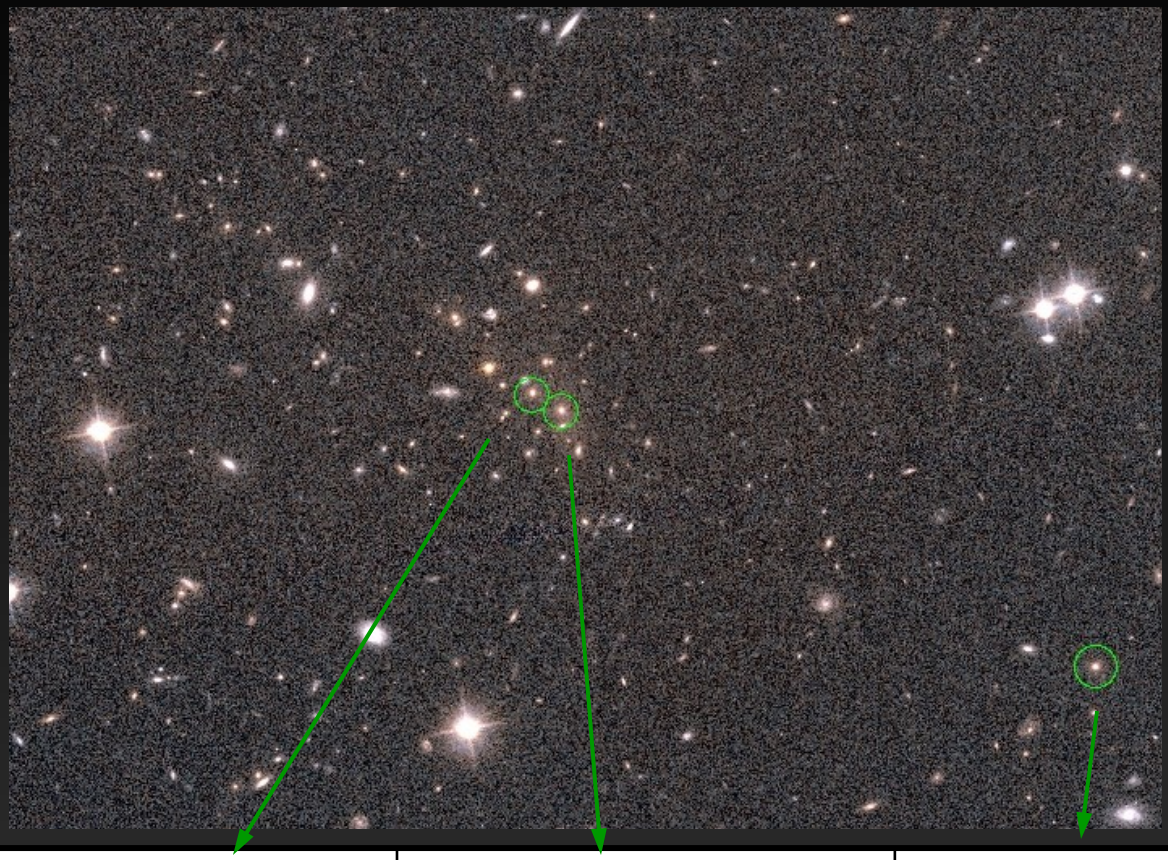
Stacked spectrum of 8 passive galaxies with no H_δ absorption

$z_{form} = 3.0 \pm 0.5$

Age = $3.7^{+0.4}_{-0.5}$ Gyr



Brightest Cluster Galaxy(ies)



ID	*3507*	*3430*	*3025*
Z_{850}(AB)	21.47	21.06	21.05
Dist X-ctr (’’)	1	5	78
M (10^{10} M_{sun})	26	23	20
Age (Gyr)	5.74	5.74	4.83

Conclusions

- X-ray properties show that XMM1229 is a massive cluster (> L*)
  T= 6.5 keV, Z_{Fe}/Z_{sun} =0.34

- i_{775} - z_{850} CMD:
  1) Standard method, scatter = 0.04 mag -> construct “red-sequence” sample
  2) Model CMD, scatter = 0.04 (0.05) mag
  CMD parameters consistent with other works at high-z

- Velocity dispersion: σ = 683 km/s

- Galaxy morphology: deficit of S0s?
  - Spec gals: high Sersic index *n* (~ 3.9) 15/21 Ell, 4/21 S0s
  - “Red-sequence” gals: high Sersic index *n* (~ 3.7) 22/31 Ell, 9/31 S0s

- Old & massive galaxy population mass: 7.4 10^{10} M_{sun} SFR age: 4.3 Gyr
- 3 bright galaxies instead of one prominent BCG

ICM-galaxy population: high Z_{Fe}/Z_{sun} + old gals -> chemical enrichment ended