The environmental fossil record of early-type galaxies

F. La Barbera[1]; A. Pasquali[2]; I. Ferreras[3]; A. Gallazzi[4,5]; R.R. de Carvalho[6]; I.G. de la Rosa[7]

[1]INAF-OAC, Naples, Italy; [2]ARI, Heidelberg, Germany;
[3]UCL-MSSL, London, UK; [4]INAF-OAA, Firenze, Italy; [5]DARK, Copenhagen, Denmark;
[6]INPE-DAS, Sao Paulo, Brazil; [7]IAC, Tenerife, Spain

Stellar populations of ETGs vs. environment

- The stellar population (SP) properties (e.g. Age, [Z/H], [α/Fe]) of early-type galaxies (ETGs) are expected to depend on the environment where they reside ⟷ Galaxy-galaxy interactions, Hydrodynamical/tidal effects

- Several studies have found that Age, [Z/H], and [α/Fe] all increase with galaxy mass (Thomas+'05; Nelan+'05; Gallazzi+'06; Smith+'07), σ being the main driver (Bernardi+03; Smith+'09)

- Environment, mostly characterized in terms of <u>"local density" Σ</u>, plays a secondary role

<u>contradictory results</u>

Age →
younger at low Σ (Thomas+'05; Bernardi+'06; Sanchéz-Blazquéz+'06; Cooper+'10; Zhu+'10);
younger at low Σ, but only for some fraction of ETGs (Thomas+'10);
no difference (Rettura+'11)

[Z/H] →
higher at low Σ (Thomas+'05; Sanchéz-Blazquéz+'06; de la Rosa+'07; Clemens+'09);
lower at low Σ (Gallazzi+'06);
no difference (Bernardi+'06; Zhu+'10)

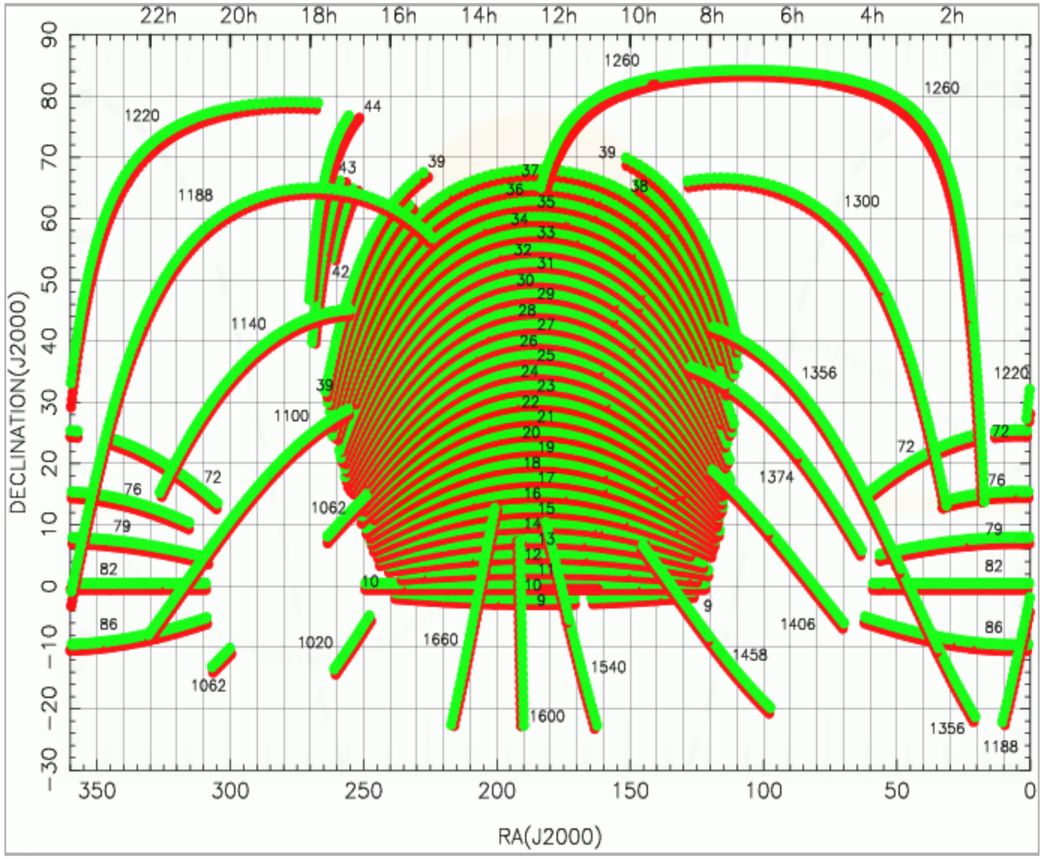
[α/Fe] →
lower at low Σ (Bernardi+'06; Zhu+'10);
no difference (Kuntschner'+02; Thomas+'05)

- Our work: we split ETGs into centrals and satellites (Pasquali+'10), and study, for the two classes separately, the dependence of SPs on the mass of the parent halo where ETGs reside

(La Barbera et al. 2014, MNRAS, in press, arXiv:1408:6816)

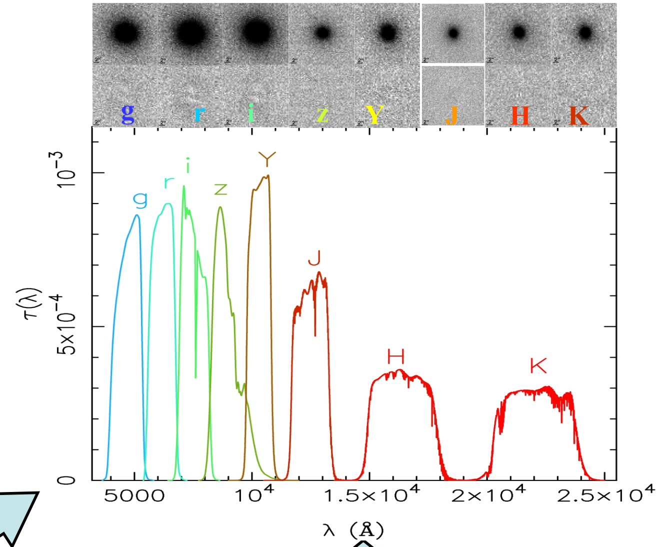
Spheroid's Panchromatic Investigation in Different Environmental Regions (SPIDER)

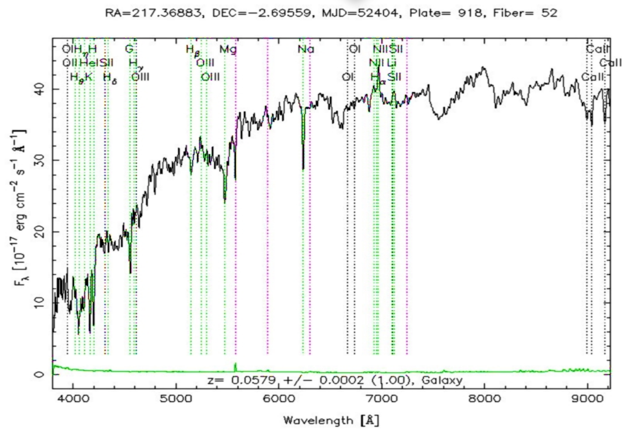
SDSS-DR7 (u=22.0,g=22.2, r=22.2, i=21.3, z=20.5)



UKIDSS-Large Area Survey (Y=20.5, J=20, H=18.8, K=18.4)

Total sky coverage ~1,200 sq. deg.





The sample

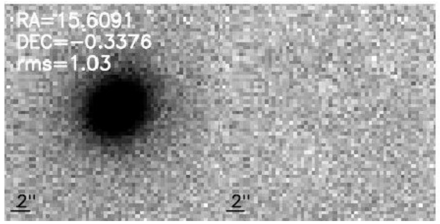
SPIDER volume-limited sample (Miller+'03)
ETGs: eclass<0, FracDev$_r$>0.8
$0.05 \leq z \leq 0.095$, $70 \leq \sigma \leq 420$ km s^{-1}
M_r<-20 (*bright* ETGs; Capaccioli+'92)

⟺ 39,993 ETGs from SDSS-DR6
(5,080 with griz+YJHK from UKIDSS)

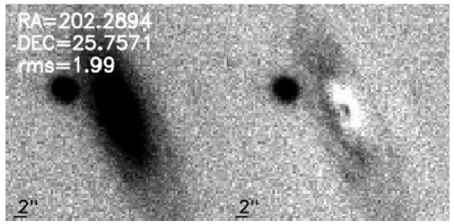
⇒ $\sigma \geq 100$km/s (>80% completeness for all σ bins)

⇒ low internal reddening, E(B-V)<0.1 (estimated from spectral fitting)

⇒ excluding spectra in the lowest quartile of the S/N distribution



"morphological" selection from
Galaxy Zoo (Lintott+2011)+χ^2 of Sersic fits

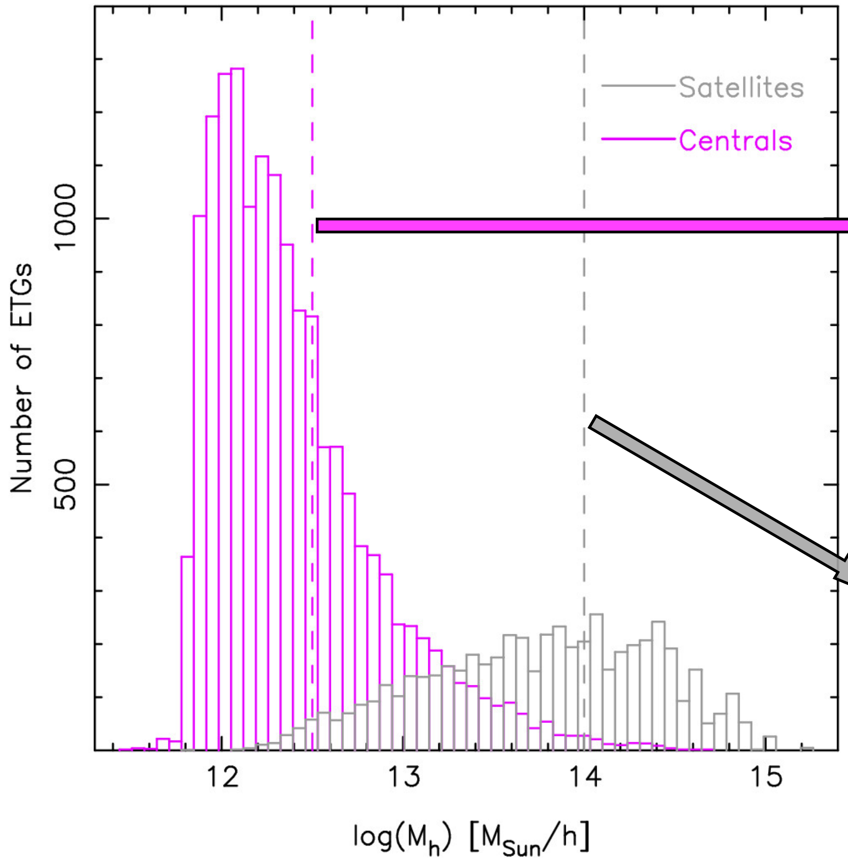


~15% of the entire sample

Final sample of 21,655 bona-fide ETGs

The environment

20,977 ETGs have environment defined from the updated (SDSS-DR7) group catalogue of Yang+2007. ETGs are split into centrals (most massive group members) and satellites (as in Pasquali+'10).



C1: low-M_h (<12.5) centrals

C2: high-M_h (>12.5) centrals

S1: low-M_h (<14) satellites, ($R<0.5R_{200}$)

S2: high-M_h (>14) satellites ($R<0.5R_{200}$)

S3: all-M_h satellites at outer $R(>0.5R_{200})$

For each environment:

- we median-combine spectra in bins of galaxy velocity dispersion (σ);
- stacked spectra have <u>high S/N</u> (from 100 to 2000, depending on σ and λ).

Stellar population properties from stacked spectra

Age, metallicity ([Z/H]), and A_v are estimated with the spectral fitting code STARLIGHT (Cid-Fernandes+‘05)

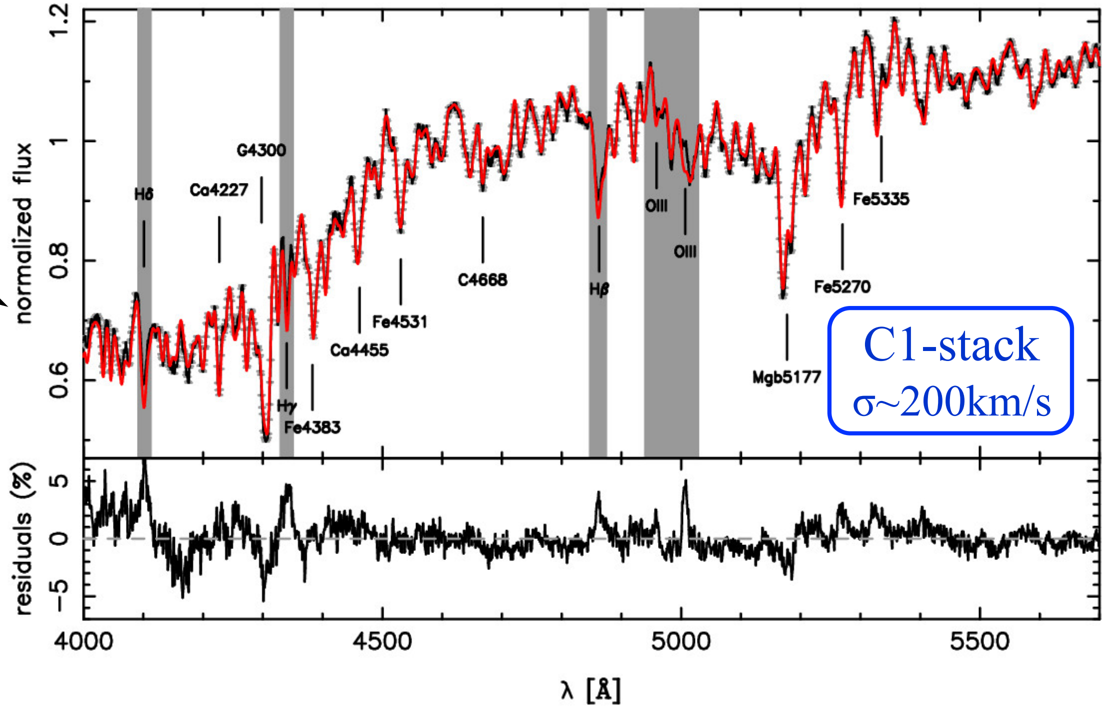
linear combination of 108 MILES SSPs:

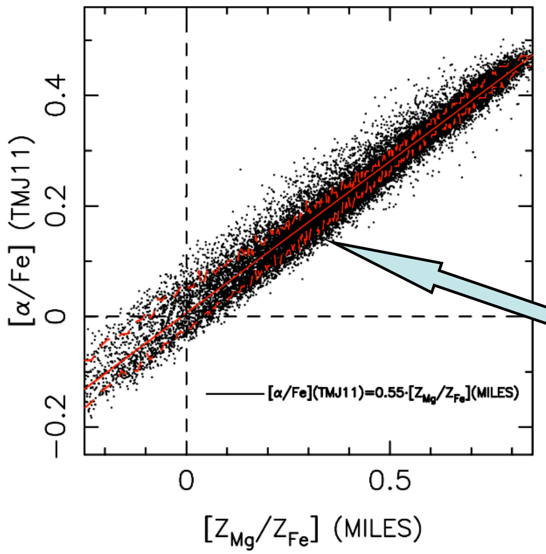
1<Age<14Gyr

-0.7<[Z/H]<0.22

CCM (Cardelli+’89) extinction law

Kroupa IMF (but see Ferreras+’13; La Barbera+’13)





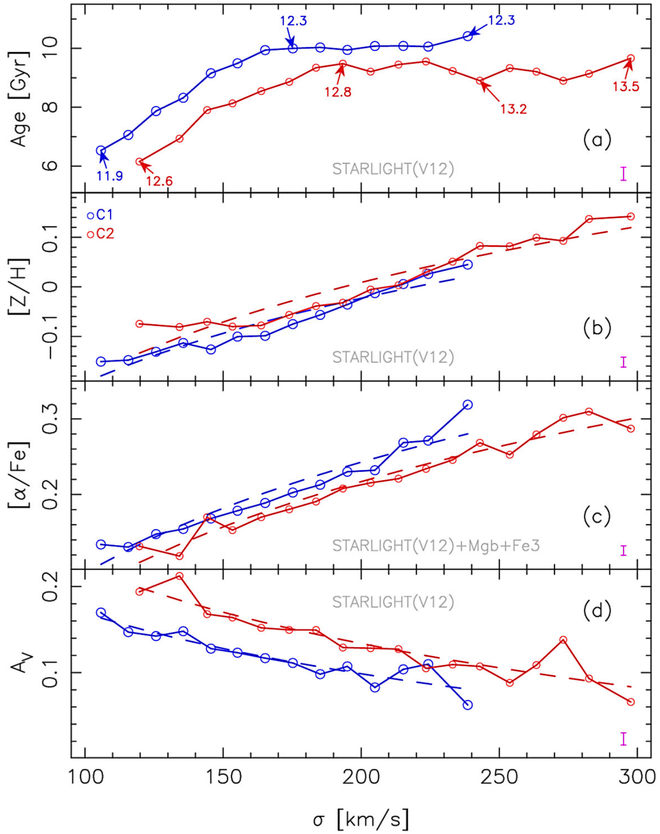
We use MILES SSP models (Vazdekis+’10) to measure a proxy for [α/Fe] (see La Barbera+’13):

$$[Z_{Mg}/Z_{Fe}] = [Z/H]_{Mgb5177} - [Z/H]_{Fe3} \quad \text{(at fixed age)}$$

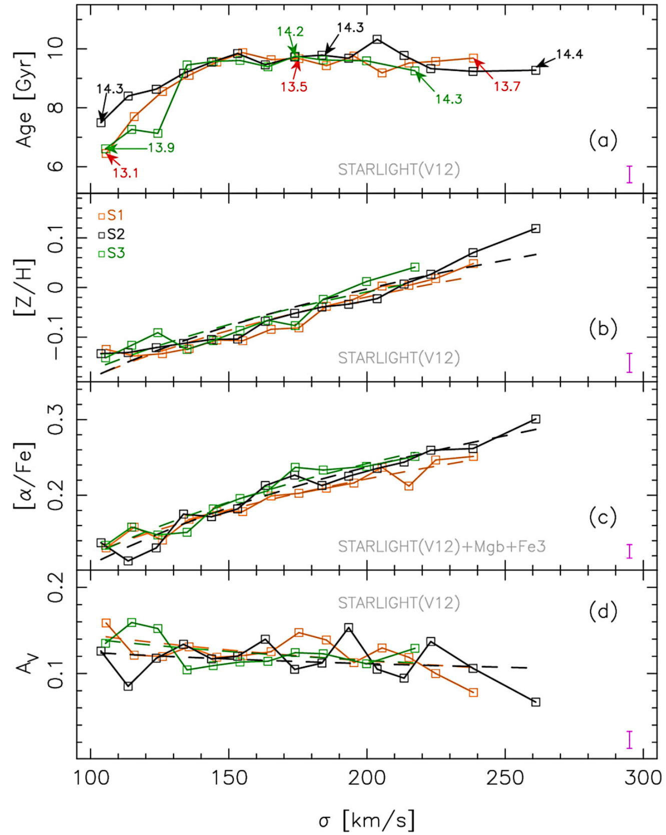
A remarkably tight correlation exists with estimates from α-enhanced models (Thomas+’11).

Trends with σ and environment

Central ETGs



Satellite ETGs

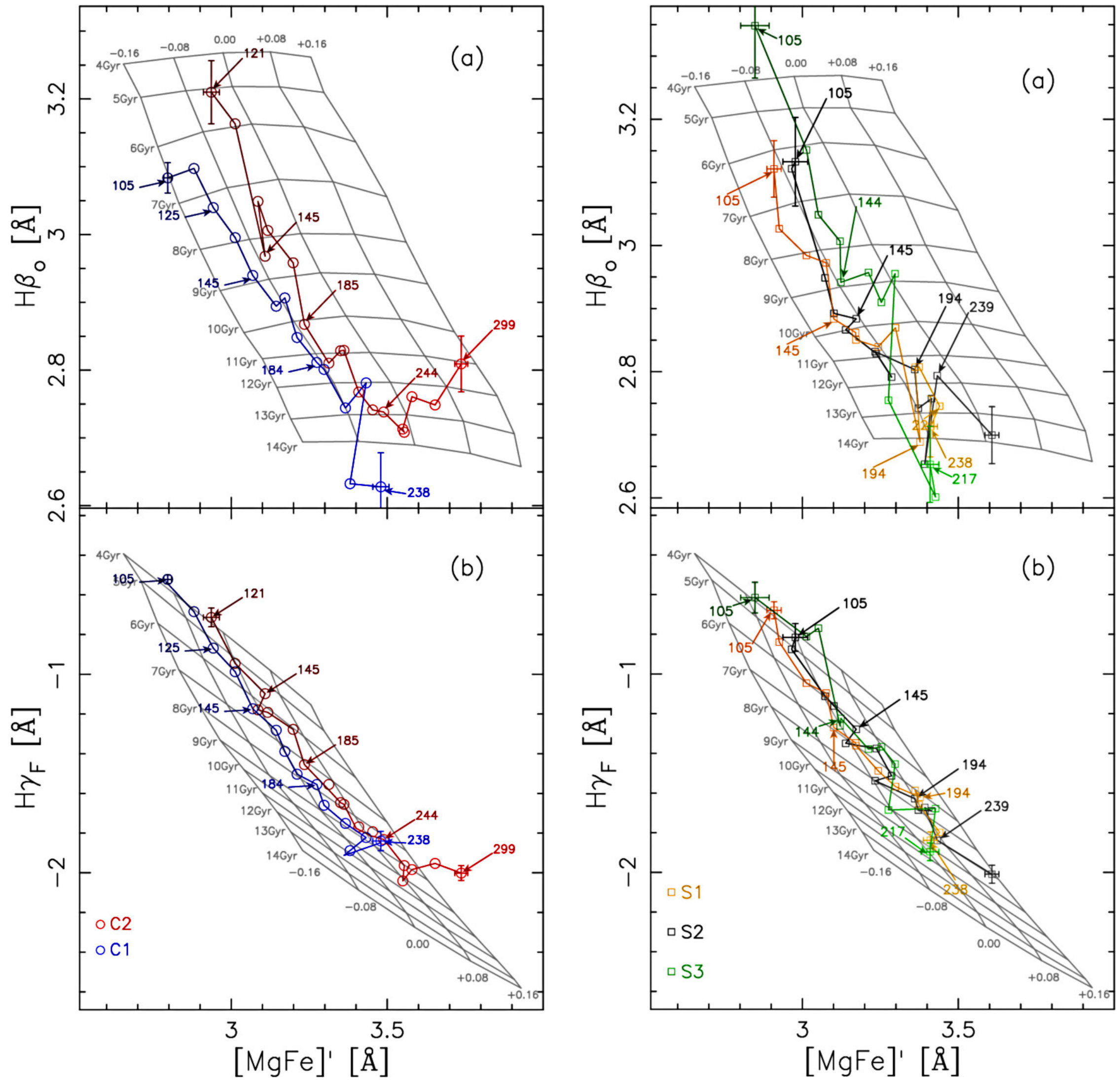


Age, metallicity, and [α/Fe] increase with σ, in agreement with previous works (e.g. Trager+'00; Bernardi+'03; Thomas +'05; Smith+'07; Zhu+'10; Thomas+'10; Harrison+'11)

- Centrals in "groups", i.e. with "high"-M_h (sample C2), have younger ages, higher [Z/H], lower [α/Fe], and higher A_V than those with low M_h (sample C1).

- Satellite ETGs in the outskirts (sample S3) have younger ages (and to less extent higher [α/Fe] and higher AV) than those in "clusters" (i.e. with high-M_h; sample S1).

Trends with σ and environment (line strengths)



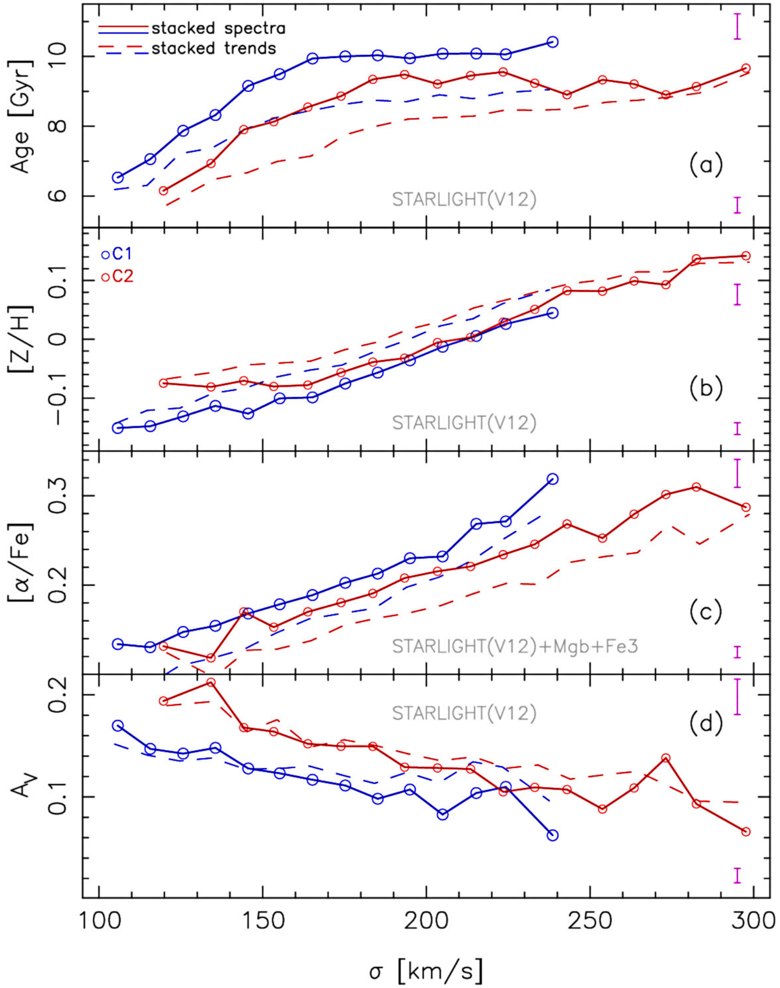
Age-sensitive indicators (Hβ and Hγ, nearly independent of [α/Fe]; see Thomas, Maraston, Korn'04) are plotted as a function of the total metallicity indicator [MgFe]' ([α/Fe]-independent; see Thomas, Maraston, Bender'03).

Differences *wrt* environment are confirmed from the analysis of line strengths:

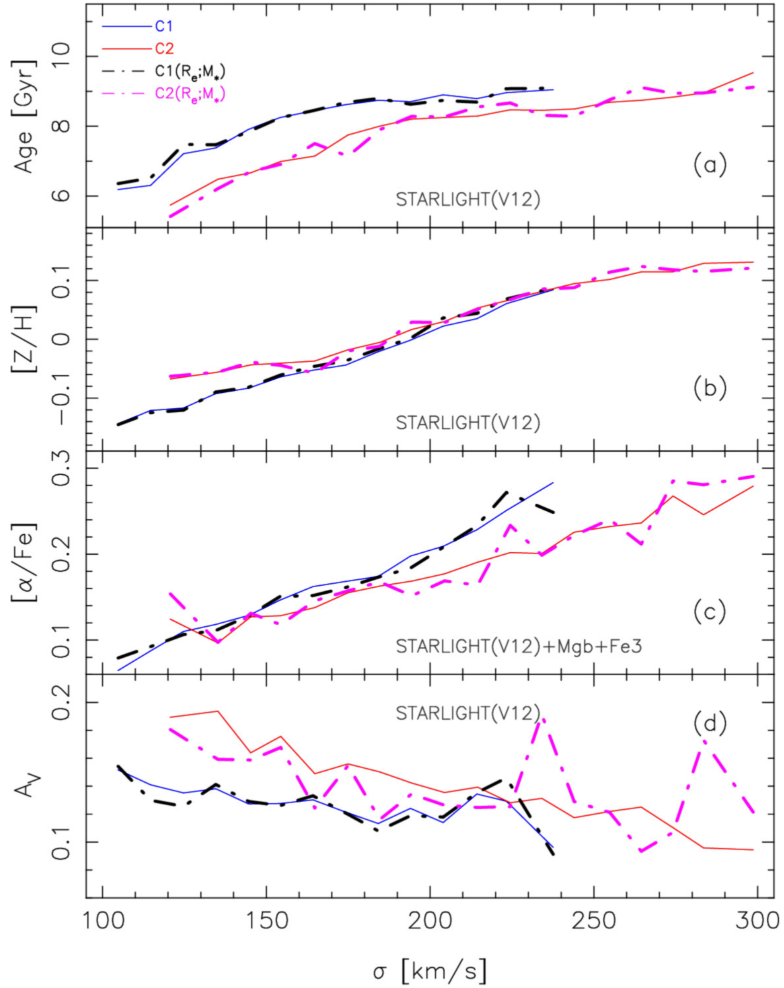
Centrals with "high"-M_h (sample C2), are younger and more metal-rich than those with low M_h (sample C1).

Satellite ETGs in the outskirts (sample S3) are younger than those in groups' central regions (samples S1 and S2).

Possible “systematics”



Comparison of results from stacked and individual spectra.



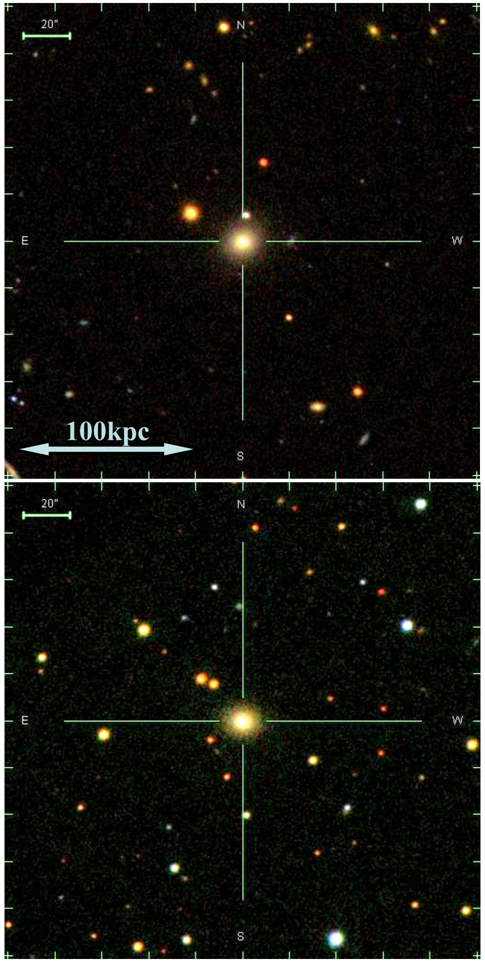
Comparison of trends for C1 and C2, with those of two subsamples selected to have the same range of Re and M_* at fixed σ.

Stellar-mass formation histories

only 9% (1%) of systems with M_h<12.5 have (>1) satellites

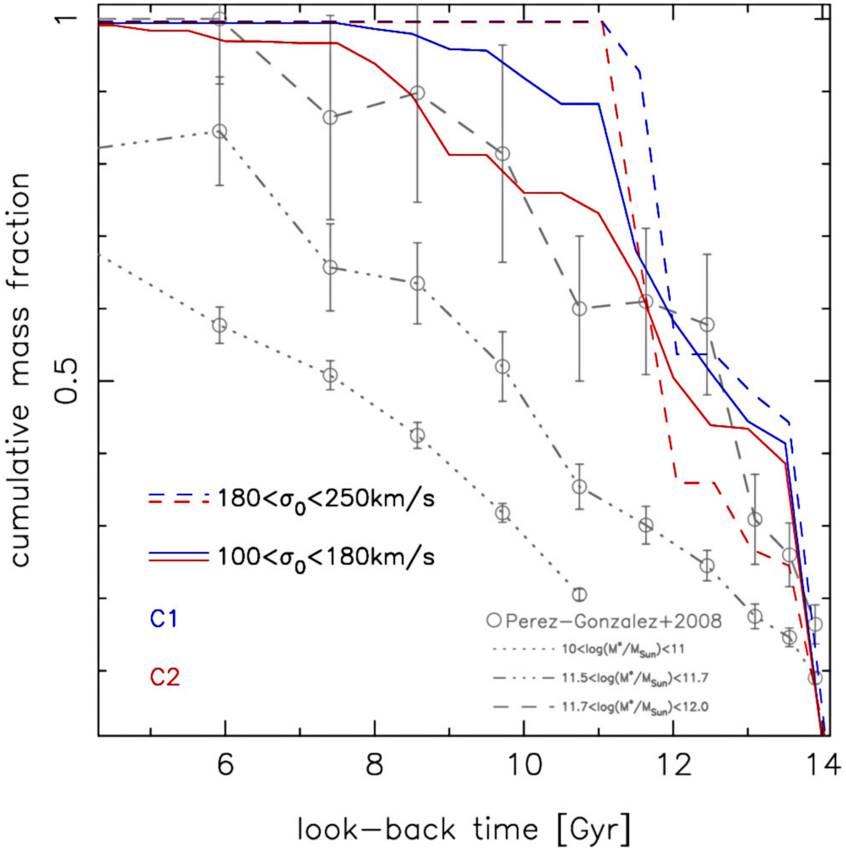
C1

C2



z ~0.065
σ ~200km/s
R_e~6kpc
$M_* \sim 10^{11} M_{Sun}$

most systems are low-multiplicity groups



Comparison of stellar-mass formation histories between C1 and C2.

<u>Stars in central ETGs today formed on a longer time-scale than those of central ETGs in "isolation"</u> (consistent with differences detected in age and [α/Fe]), perhaps because of <u>gas-rich interactions with their companion galaxies</u>.

Summary

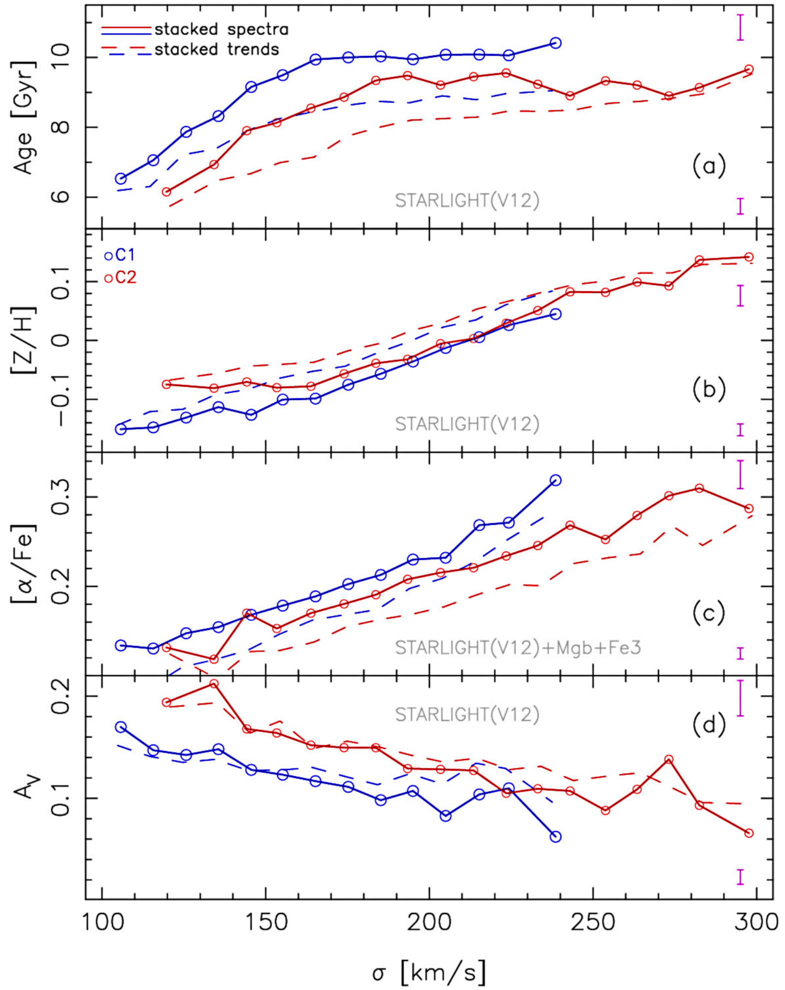
How central and satellite ETGs see their parent groups/clusters:

Satellite ETGs in the outskirts (sample S3) have younger ages (and to less extent higher [α/Fe] and higher AV) than those in "clusters" (i.e. with high-M_h; sample S1), e.g. because they were accreted later into the group/cluster, having their star-formation quenched by environmental processes (e.g. "strangulation").

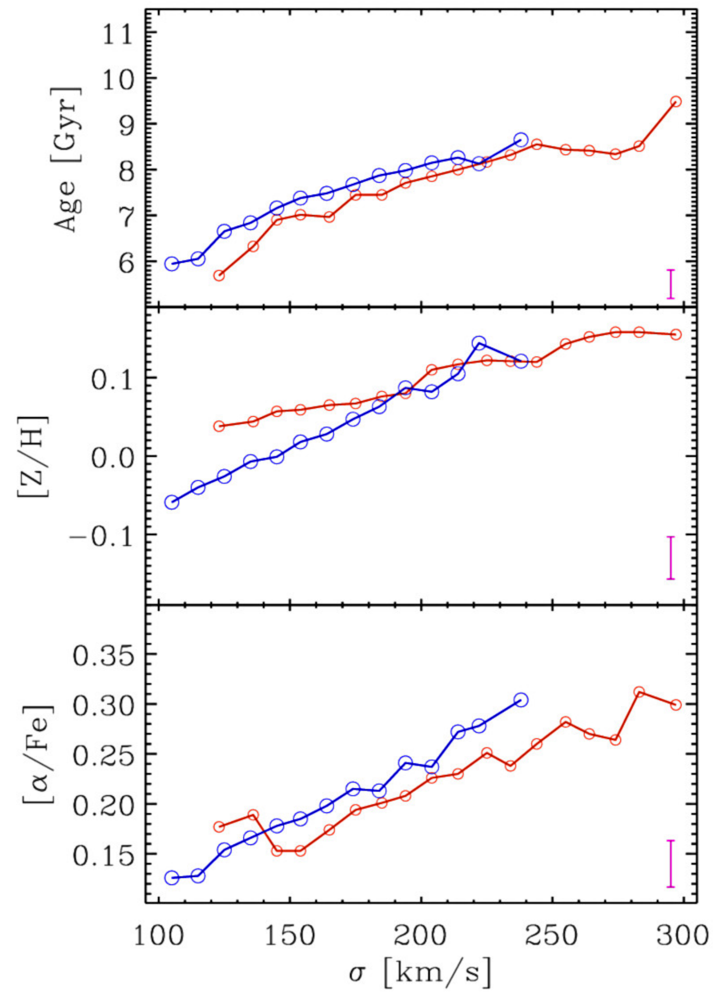
Central ETGs in "groups", i.e. with "high"-M_h (sample C2), have younger ages, higher [Z/H], lower [α/Fe], and higher A_V than those with low M_h (sample C1). We argue that this is because ETGs in C2 underwent gas-rich interactions more than those in C1.

Can galaxy formation/evolution models (e.g. SAMs) explain the observed trends with σ and environment ?

Comparison to "median" trends

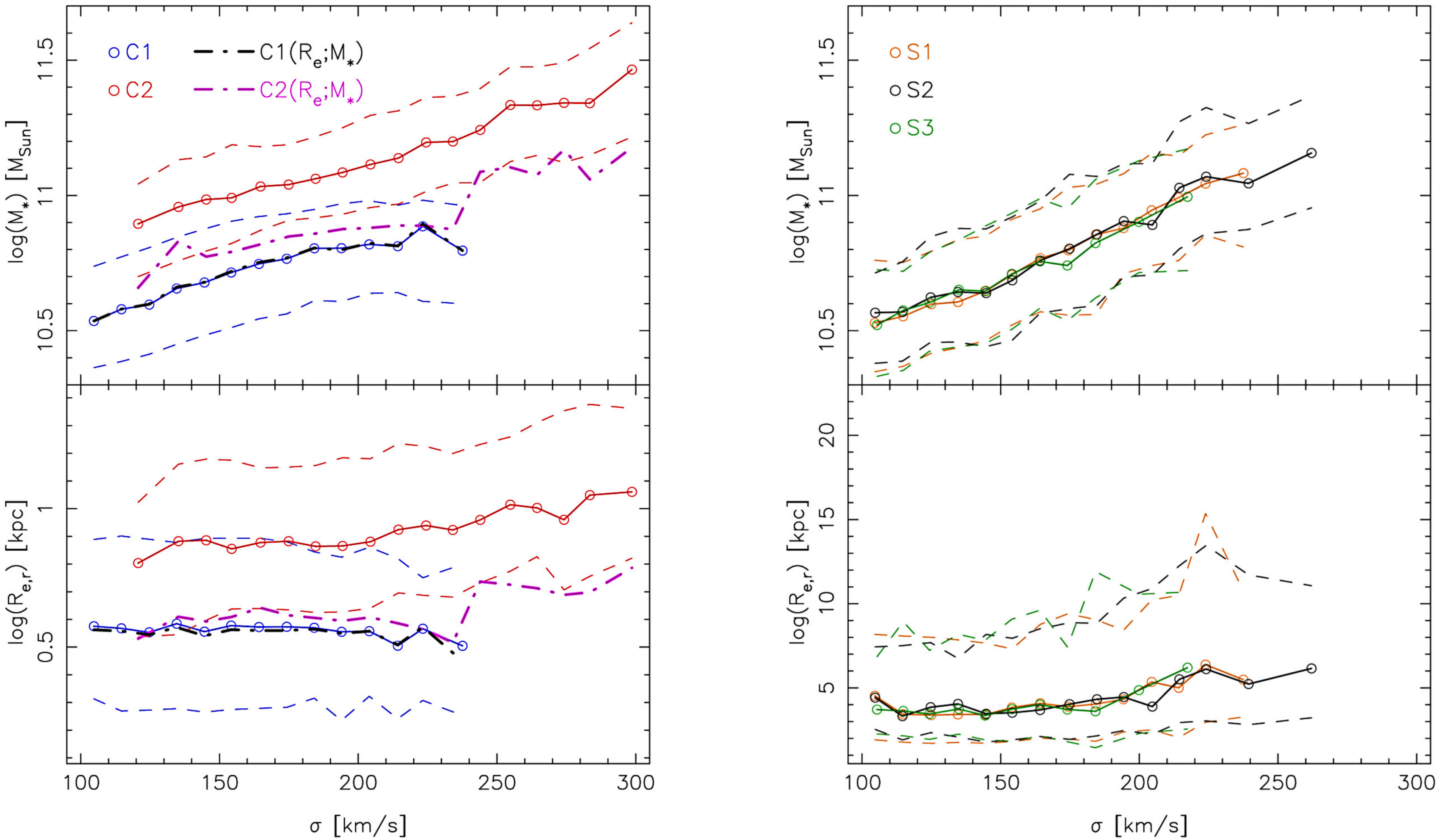


Comparison of trends obtained from stacked spectra, with those obtained by median-combining the (STARLIGHT) estimates for individual spectra.



Median trends, obtained from individual spectra by fitting line-strengths with BC03 SSP models, by Gallazzi+'06.

Trends of stellar mass and galaxy size vs. σ



Because of the correlation between stellar-mass and halo-mass, ETGs in C2 have higher stellar masses (larger size) than those in C1, while for satellites no environmental dependence is found.

Comparison to other definitions of environment

sample (1)	field (2)	group (3)	un-classified (4)
C1	42%	27%	31%
C2	32%	47%	21%
S1	12%	62%	26%
S2	0%	84%	16%
S3	3%	78%	19%

Percentage of galaxies in each sample of ETGs, classified as field and group systems, as well as un-classified objects, according to Berlind+ (see Paper II)