The stellar population content of the outer halo of massive early-type galaxies

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ETGs: formation scenario(s)

gas-rich ("wet") major/minor mergers (Toomre'77, Kauffman+'93)

- arises naturally in a hierarchical framework
- old stellar populations/scaling relations ?

gas-poor ("dry") major/minor mergers (Kauffmann & Haenelt'00; Khochfar & Burkert'03)

- actually observed at both low- and high-z
- explaining size growth

"In-situ" formation, through the rapid assembly of subgalaxies ($10^9 M_{Sun}$) at $z \geq 2$-3 (Kawata'01; Kobayashi'04; Merlin& Chiosi'06; resembling "monolithic collapse" by Eggen+'62, Larson'75)

- explaining old stellar populations tight and observed (tight) correlations
- hierarchical paradigm ?
- size evolution ?

Two-phase formation: (compact) high-z cores + later accretion/minor-mergers (e.g. Naab+'09; Oser+'10).

- reconcile all observations (galaxy sizes, scaling relations, etc…)

Environmental effects (ram-pressure, starvation, etc…..)

ETGs: radial gradients

- Color and stellar population radial gradients, from the core to the outer halo, can be used to constrain the relative importance of these mechanisms.

- Most studies @$R \leq 1R_e$: ETGs become bluer/less metal-rich outwards (Peletier+'90)

  … but several contrasting results
  - Age, [α/Fe], etc..
  - dependence on mass
  - environment

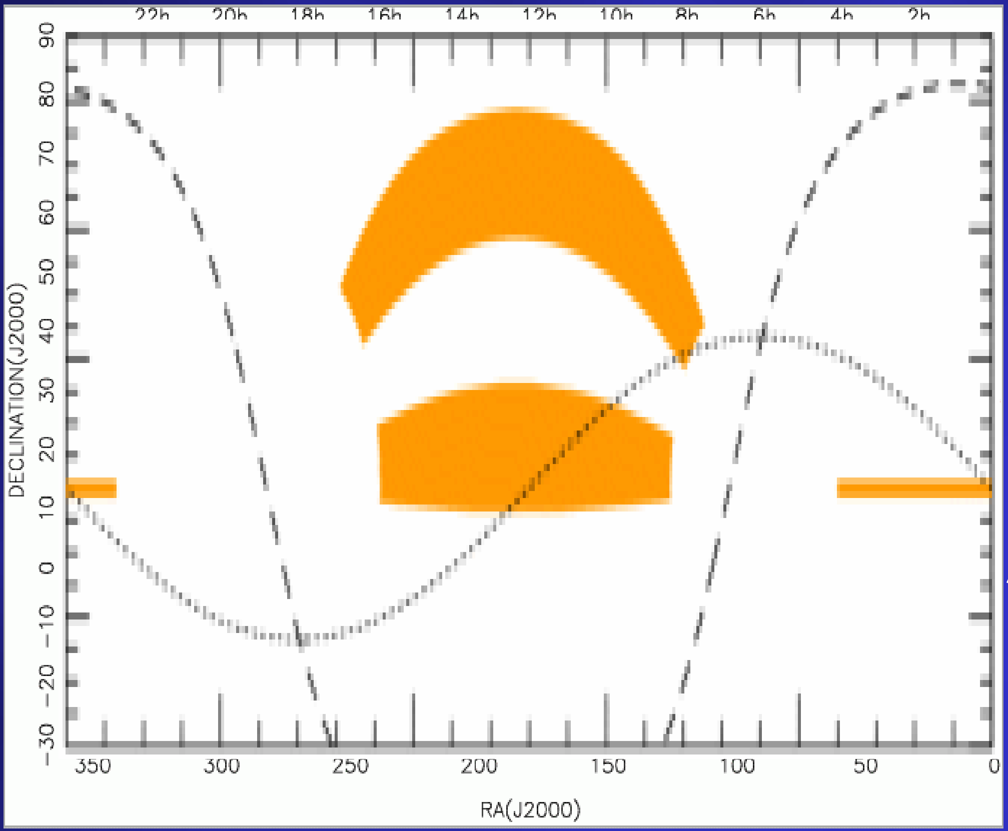
- Outer-halo stellar populations
  - spectroscopy: few galaxies, out to $\lesssim 3R_e$ (Coccato+'11; Greene+'12)
  - photometry: large samples, out to $\lesssim 10R_e$, optical colors only (e.g. Tal & Van Dokkum+'11)

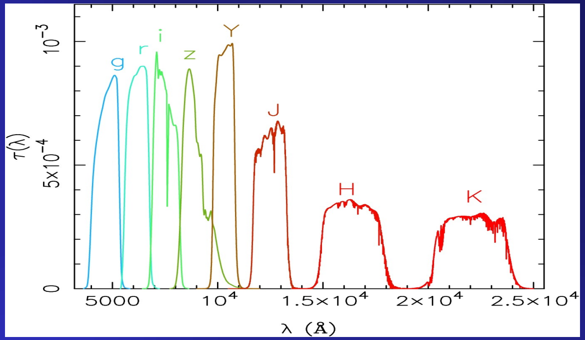
LAYOUT

- The sample
- Estimating color and Age+Z profiles
- Results: Age+Z vs. radius, mass, environment

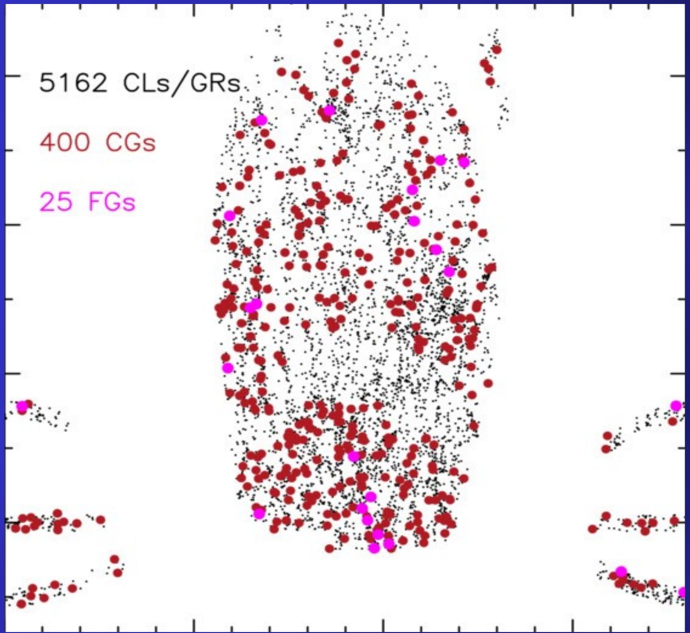
Spheroid's Panchromatic Investigation in Different Environmental Regions (SPIDER)

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





Updated catalog of galaxy groups (Berlind+'06)



→ virial analysis (Lopes+'09)

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

Total sky coverage ~1,000 sq. deg.

Selection criteria

SPIDER volume-limited sample (Miller+'03) of 39,993 ETGs from SDSS-DR6

M_r<-20 (*bright* ETGs; Capaccioli+'92)

spectroscopy available → $0.05 \leq z \leq 0.095$, $70 \leq \sigma_0 \leq 420$ km s^{-1}

ETGs → eclass<0, $FracDev_r$>0.8

match to UKIDSS-LAS DR4 → 5,080 ETGs with grizYJHK

→ Best (Sersic) fitting quality (χ^2<2 and σ_{logRe}<0.5dex in all bands)

→ **4,546 ETGs**: Color gradients vs. M_*, Age, [Z/H], [α/Fe], and environment (La Barbera+'10,'11)

→ Narrow redshift range (0.05–0.07) → homogeneous/best-quality sample; → minimize issues with k-/e-corrections

→ **1,255 ETGs**

→ Stellar mass complete sample (>$3 \cdot 10^{10} M_{Sun}$) → **1,043 ETGs**

→ Only "round" objects (b/a>0.65)

674 ETGs (La Barbera+'12)

First time stellar populations are investigated out to $8R_e$, by means of both optical and NIR data.

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Color profiles from 2D Sersic fitting

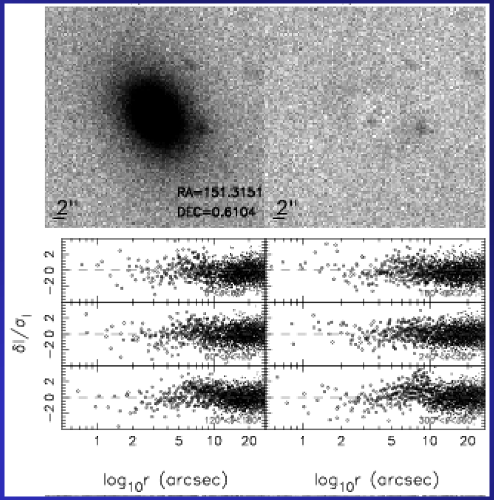
The galaxy image, in a given band X, is modeled as

$$I_X(x,y) = S(x,y;\mu_{o,X}, r_{e,X}, n_X) * P(x,y)$$

S → 2D Sersic law

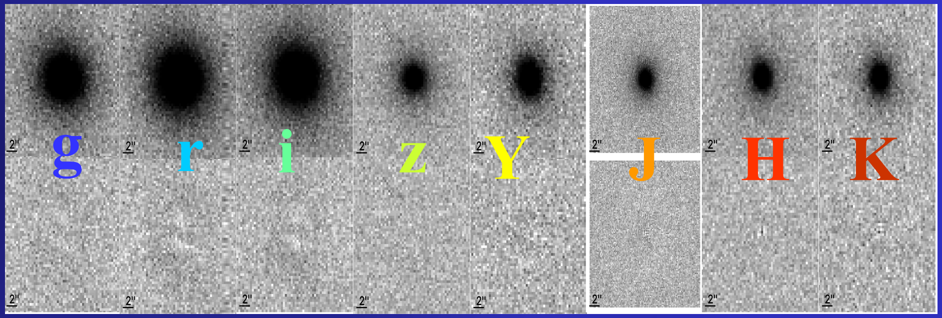
P → PSF model

$\mu_{o,X}, R_{e,X}, n_X$ → structural parameters



ETG Sersic fitting in r band (2DPHOT)

Sersic structural parameters are homogeneously derived in grizYJHK with 2DPHOT (La Barbera+'08)



→ INPE-LAC cluster + INAF-OAC beowulf (65 CPUs)

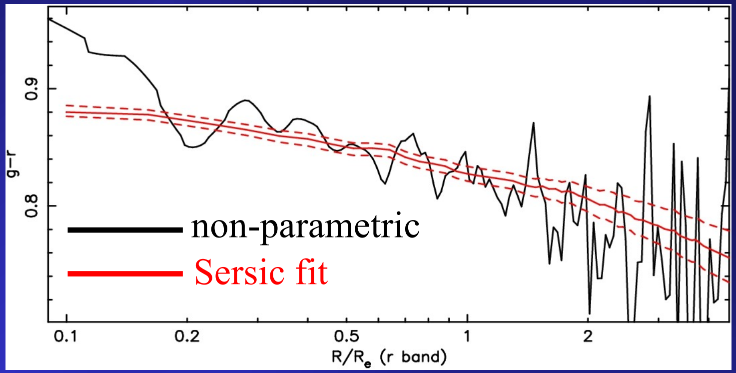
Colors, in the form g-X (X=rizYJHK), are computed from the median ratio of (parametric) surface brightness profiles:

$$g - X = -2.5 \times \log(< I_g / I_X >) + const$$

as a function of galacto-centric distance, i.e. **R/R$_e$** (in r band).

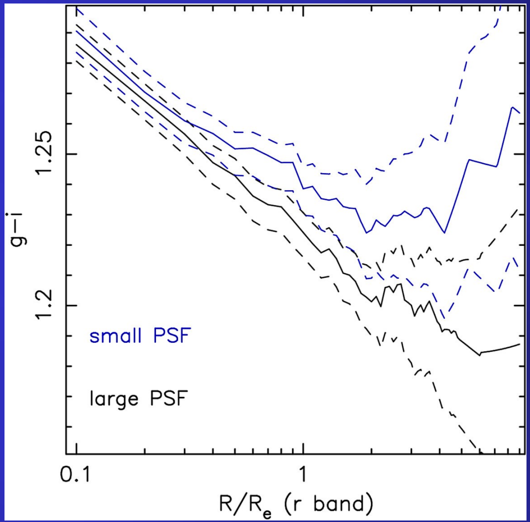
Color profiles: systematics

- Parametric color profiles agree well with non-parametric ones (consistent with, e.g., Kormendy'09; Tal&vanDokkum'11).



Parametric vs. non-parametric (median-stacked) g-r color profile for 100 ETGs ($10^{11}M_{Sun}$).

- SDSS red-halo issue (e.g. de Jong'08; Bergval+'10; Tal&van Dokkum'11)



Stacked g-i color profiles when using small (15x15) and large (121x121) PSFs (for $10^{11}M_{Sun}$ ETGs).

- Color profiles with fixed and free-fitting background agree remarkably well (<0.02mag/arcsec^2 at the largest radii probed).

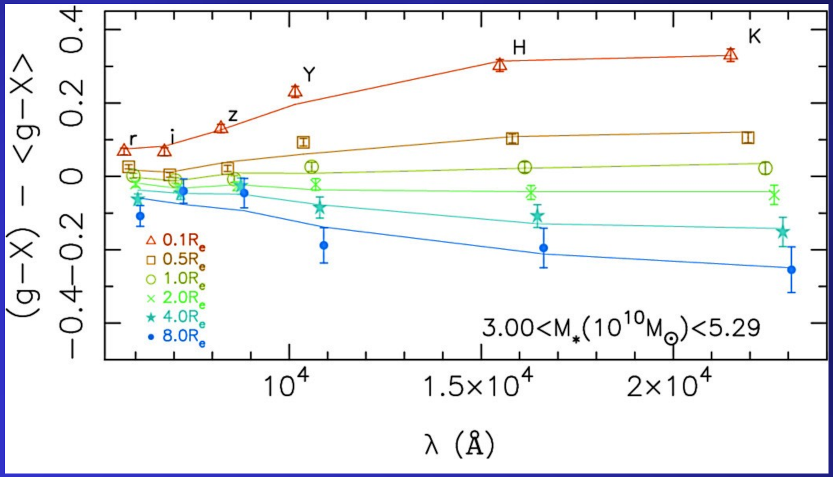
From color to stellar population profiles

six fiducial radii: R/R_e=0.1, 0.5, 1, 2, 4, 8

For each mass bin and R/R_e, colors are fitted by minimizing the expression:

$$\chi^2(Age, Z) = \sum_{X=rizYHK} \frac{\left[(g-X)_{obs} - (g-X)_{\text{mod}} + const_X\right]^2}{\sigma^2_{g-X}}$$

$const_X$: small(~0.02mag) offsets to improve overall matching of models and colors (independent of R/Re).



1SSP fitting example: typical rms~0.01–0.02mag

models

Bruzual&Charlot'03 + Charlot&Bruzual'07(unpublished)
IMF: Chabrier+Scalo
Stellar library: STELIB

Charlot&Bruzual*(unpublished)
IMF: Chabrier+Salpeter
Stellar libraries: INDOUS, MILES, STELIB, BaSel3.1

1SSP, 2SSP, exp(-t/τ), burst

L-weighted *Age* and *Z*

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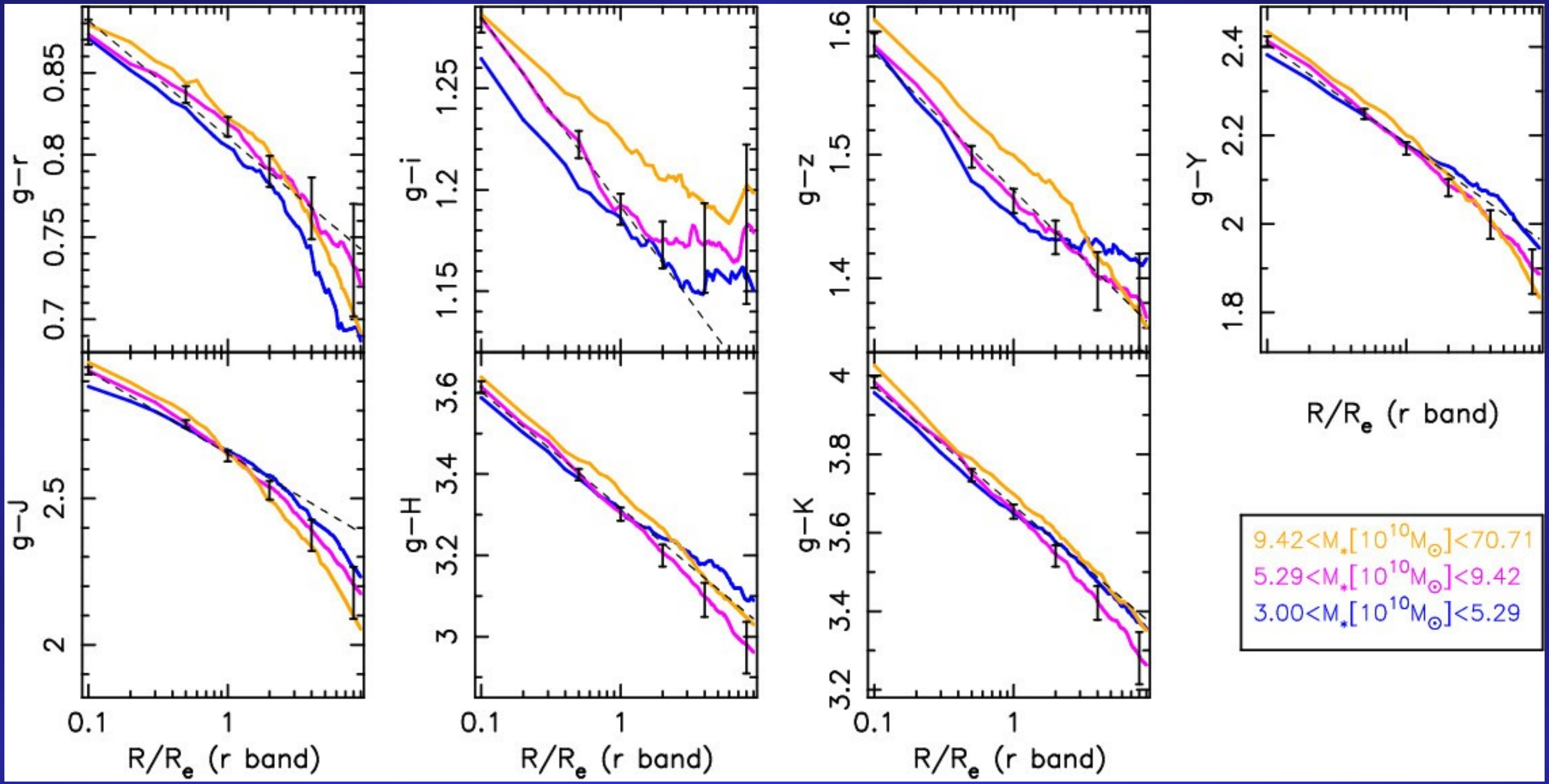
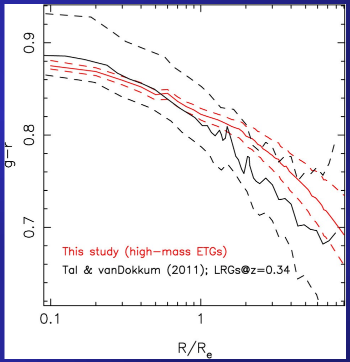
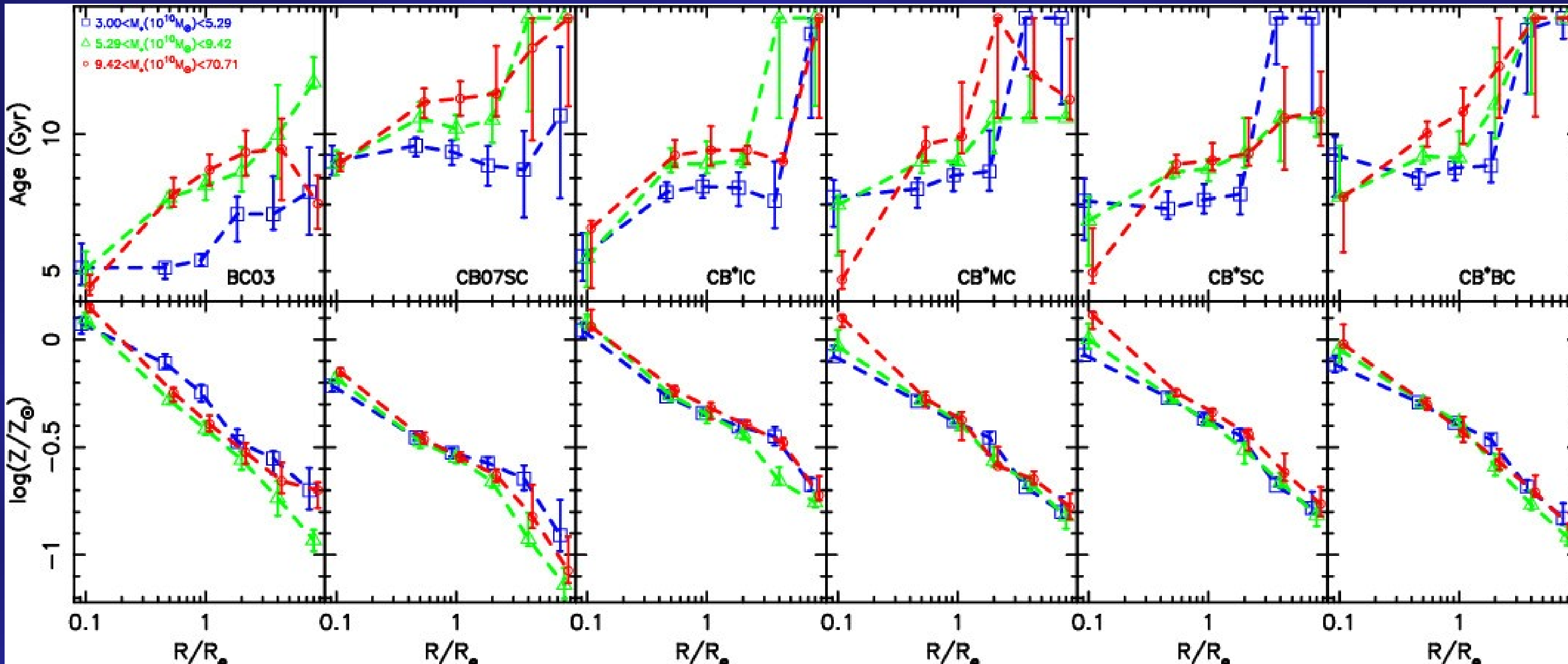
Color profiles out to 8R_e



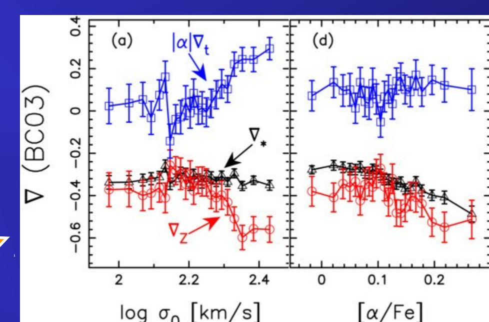
- ETGs redden outwards, out to the largest radii probed, from g-r thorugh g-K, and for all three mass bins.
- The g-r trend is consistent (at ~1σ) with that of Tal & van Dokkum'11 (optical data only for LRGs).



Age+Z profiles out to $8R_e$

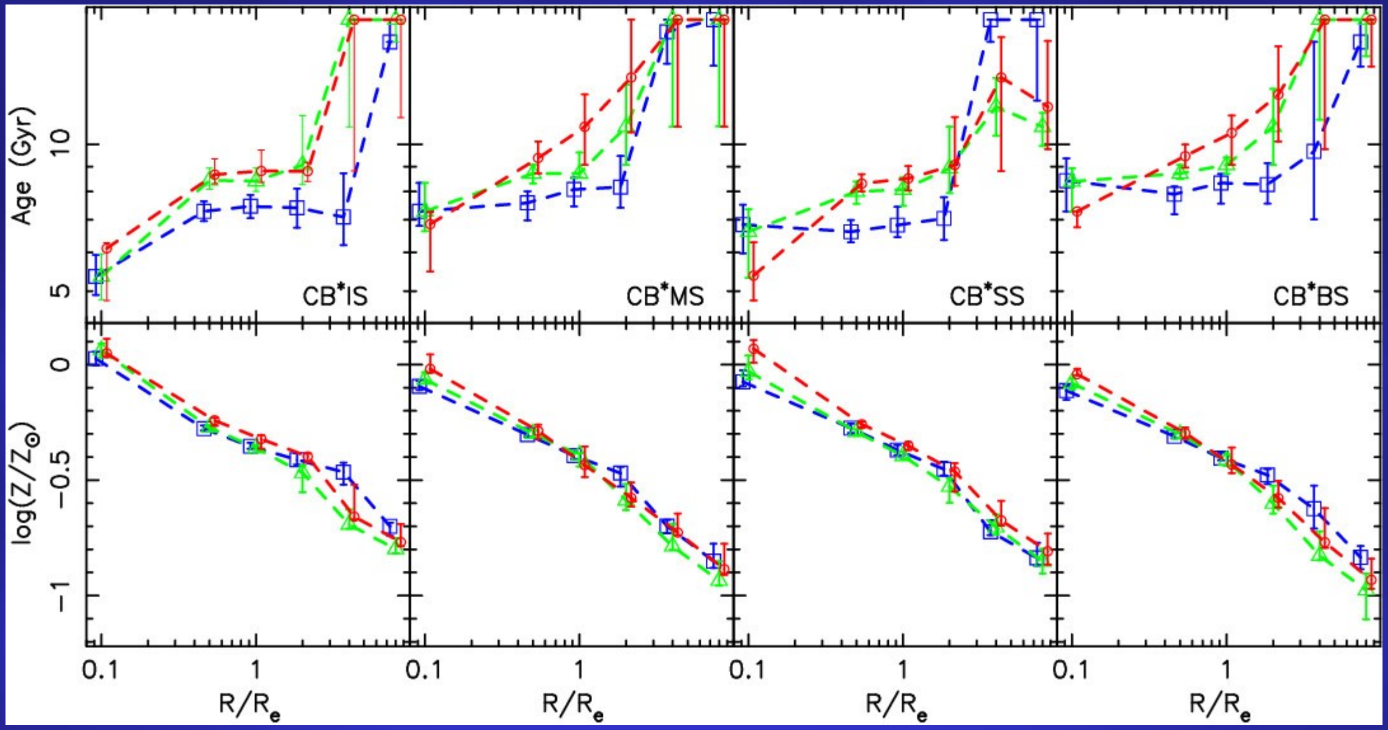


- Metallicity decreases outwards, out to the largest radii probed, and tends to steepen in the outskirts (>1–$2R_e$) .
- At second order, age gets older outwards.
- Inner (≤$1R_e$) Z gradients steepen at high mass.



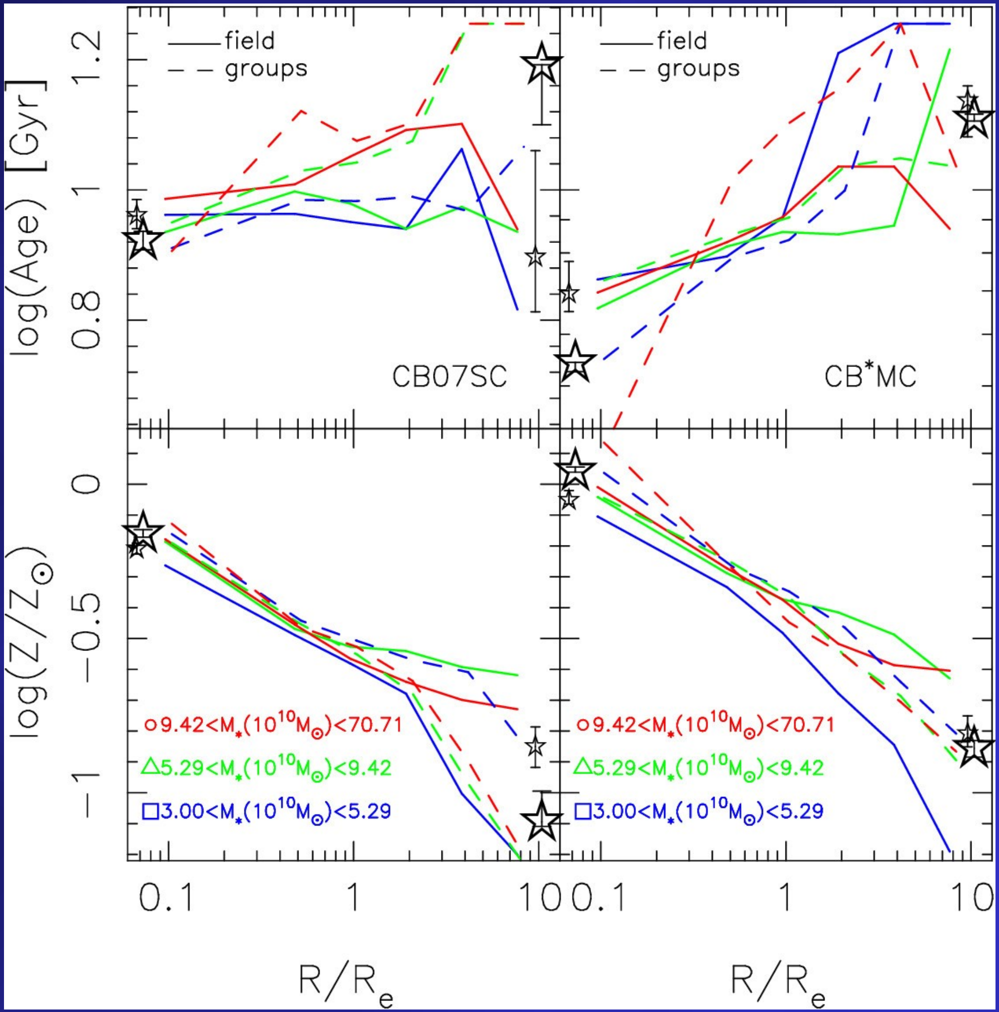
Significant correlations with σ_0 and [α/Fe] (Paper IV)

Age+Z profiles out to $8R_e$



The steepening of the metallicity gradient is significant for all mass bins/models for a Salpeter (wrt Chabrier) IMF.

Age+[Z/H] profiles out to $8R_e$: environment



ETGs are split according to the environment:

- 336 in groups
- 205 in the field

(out of 674 in total)

- Steepening of Z gradient at low mass, detected for all models and environments.
- At intermediate-/high- mass, the result is more uncertain (unless one assumes a Salpeter IMF).
- Field ETGs do not show significant age gradients.

Summary

- Massive ETGs ($>3 \cdot 10^{10} M_{Sun}$) redden outwards, out to $8R_e$, from g-r through g-K.
- Negative metallicity gradients in both core and halo regions.
- Metallicity gradients steepen with galacto-centric distance (and mass/[α/Fe]).
- Positive age gradients, with old stellar populations in the outer halo (mostly for group, wrt field, ETGs).

These findings support a two-phase formation process whereby the inner region forms by dissipative "in-situ" collapse, while the outer envelope is made up of accreted small satellites with stars born during the first stages of galaxy formation.