On the Radial Stellar Content of Early-Type Galaxies

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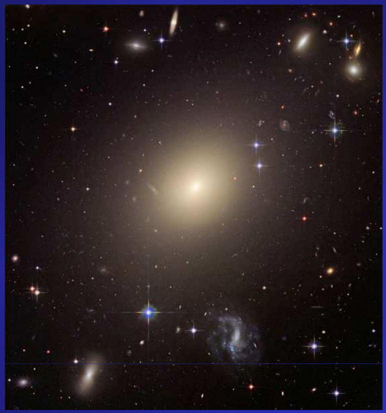
LAYOUT

- Introduction: ETGs formation + SPIDER
- Internal color gradients
- Results
  - SPIDER (SDSS+UKIDSS; z<0.1)
  - correlation with galaxy properties
  - environment
  - ……. beyond 1R_{eff} ……..

Early-type galaxies (ETGs)

ETGs (E+S0's) dominate



high mass end of the galaxy distribution

highest density regions (i.e. clusters)

<u>explaining their formation scenario is crucial for any theory of structure formation</u>

Competitive scenarios

"In-situ" (monolithic)

Merging

ETG formation - "Monolithic"

- Eggen+'62; Larson '75
  - gravitational collapse of gas proto-cloud
  - intense burst of star formation
  - supernovae-driven wind

→ old stellar populations + tight observed correlations (CM+FP)

→ hierarchical paradigm ?

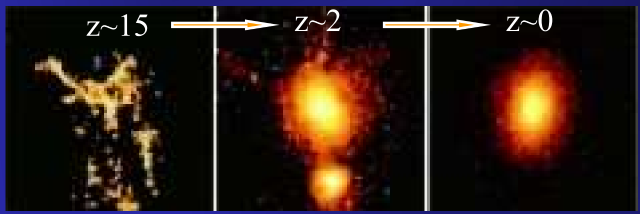
Revised "monolithic" collapse

- Kawata'01; Kobayashi'04; Merlin & Chiosi'06: in a CDM framework, ETGs can form "monolithically", through the assembly of many subgalaxies ($10^9 M_{Sun}$) at $z \geq 2$-3.

SPH simulation from Kobayashi'04

ETG formation - “Wet”/”Dry” mergers

- Toomre‘77, Kauffman+‘93: ellipticals form by “wet” merging of gaseous disc galaxies
  - arises naturally in a hierarchical framework
  - old stellar populations/scaling relations ?



SPH simulation of major merger at z~2 (Kobayashi ‘04)

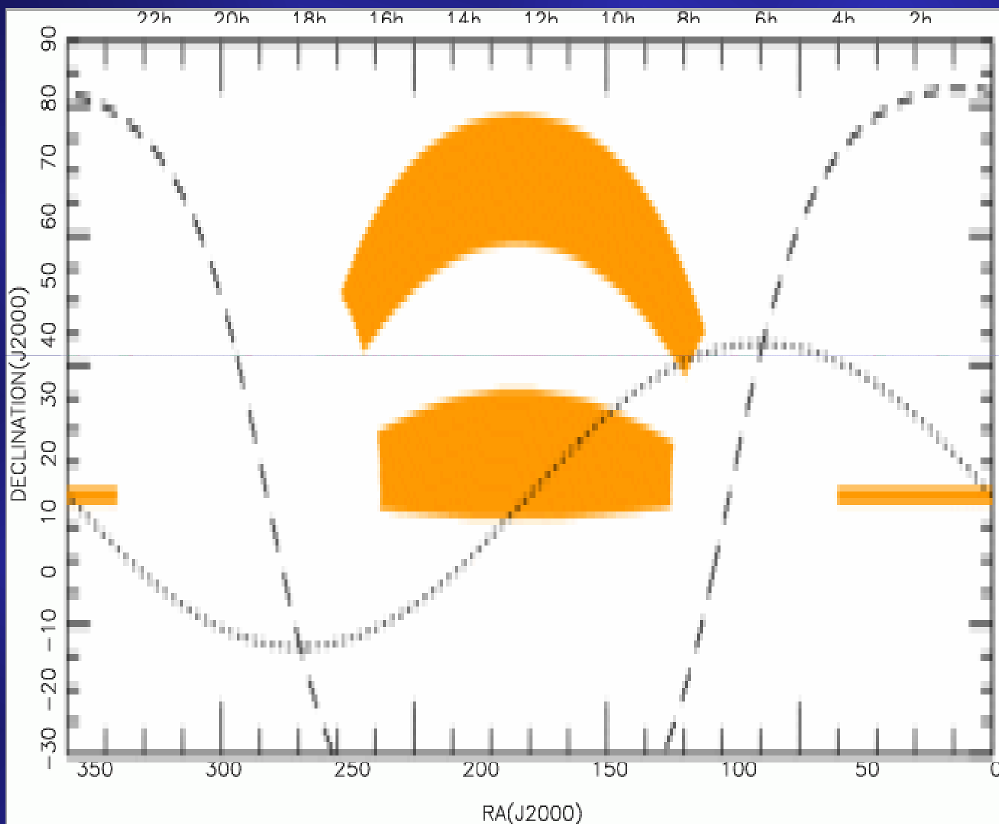
- Kauffmann & Haenelt‘00; Khochfar & Burkert‘03: the most recent mergers of bright E’s involved gas-poor galaxies
  - observed at both low- and high-z (van Dokkum+‘99; Van Dokkum‘05)
  - explaining both evolution in number density (Bell+‘04) and size growth (Daddi+‘05)

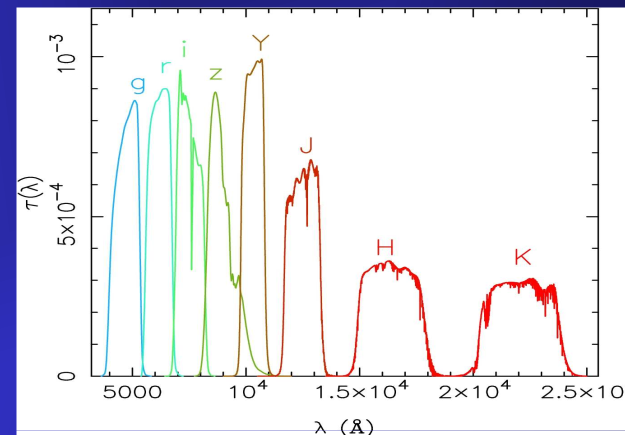
Example of “dry”/”red” merger at z~0
(van Dokkum‘05)

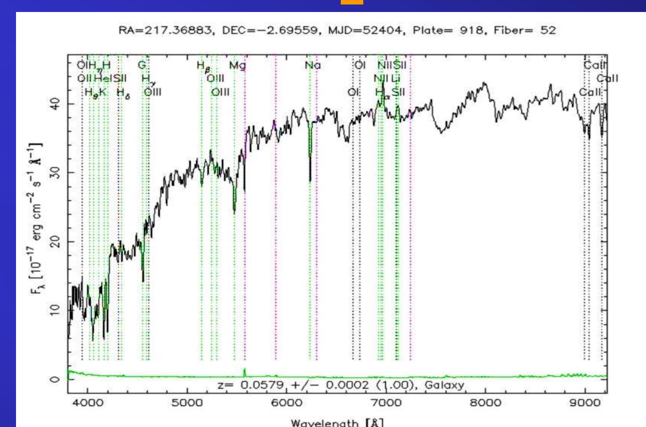
- THESE and OTHER processes (e.g. tidal interactions) depend on the ENVIRONMENT where galaxies reside

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)

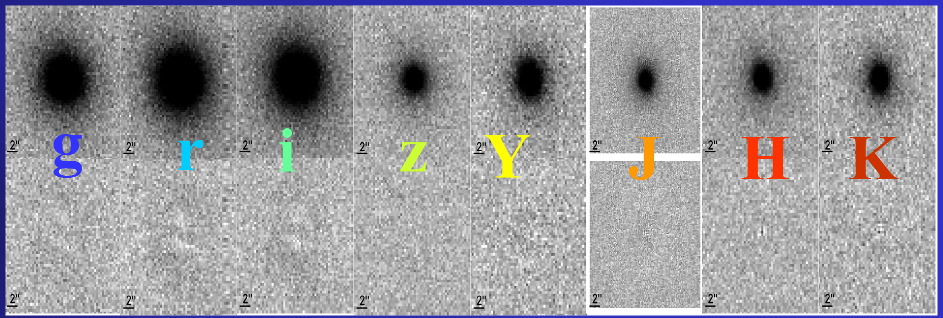
Total sky coverage ~1,200 sq. deg.

SPIDER: sample and galaxy parameters

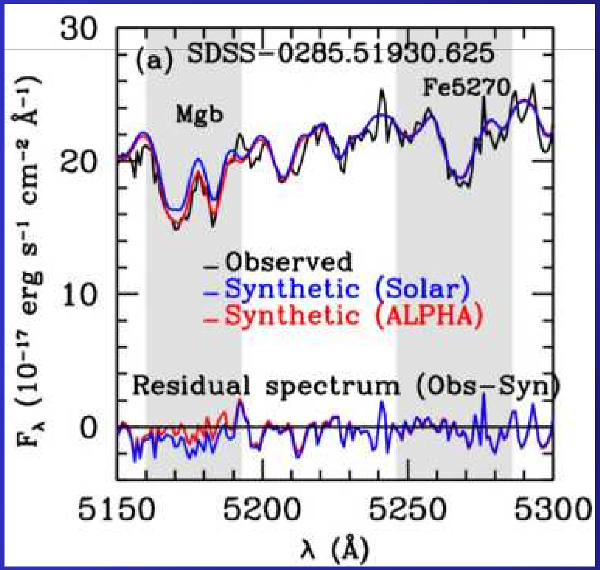
Volume-limited sample (Miller+'03) of 39,993 ETGs from SDSS-DR6

- 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}
- early-type galaxies → eclass<0, $FracDev_r$>0.8
- matching to UKIDSS-LAS DR4 → 5,080 ETGs with grizYJHK

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

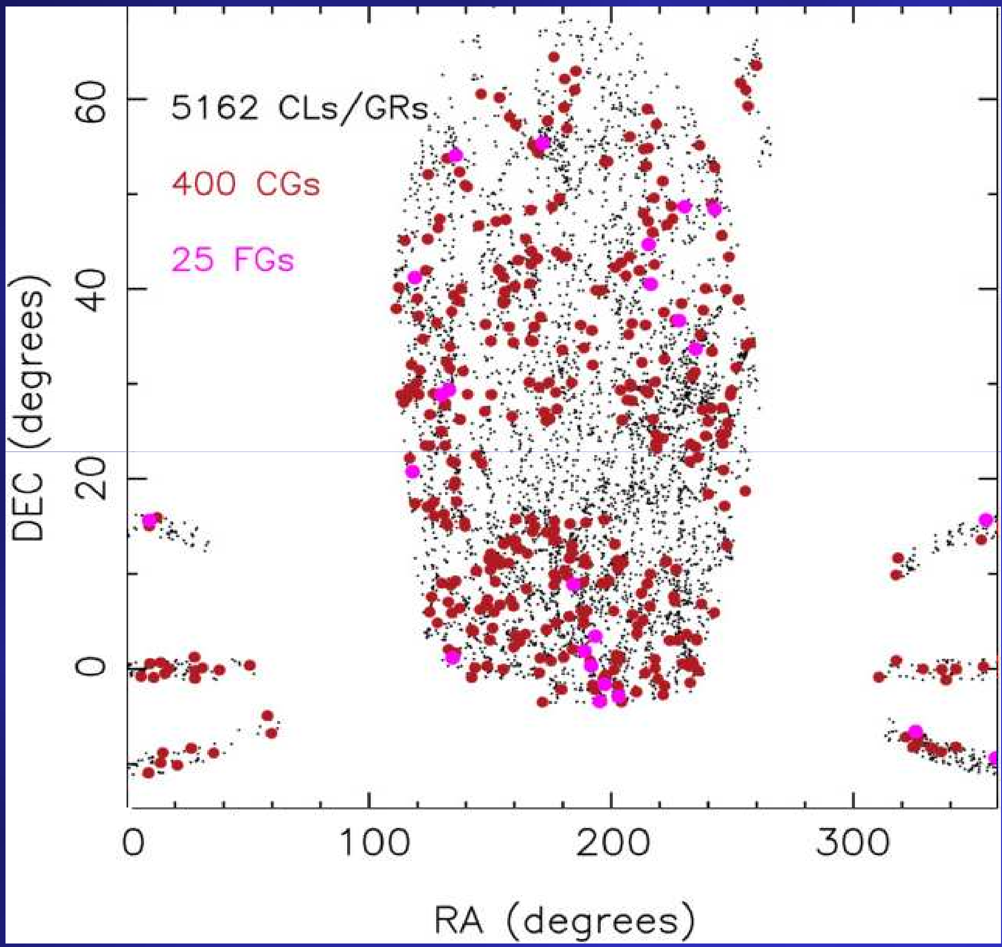


- 62 days of CPU time
- INPE-LAC cluster + INAF-OAC beowulf (65 CPUs)



SDSS spectra: STARLIGHT (Cid Fernandes+'05) with α-enhanced MILES models (Cervantes+'07)

The environment of the SPIDER



Largest SDSS group catalog @ low-z (<0.1)
10124 groups-3D FoF (Berlind+'06, ApJSS)

400 Compact Group Candidates
(McConnachie+'09)

25 Fossil Group Candidates (La Barbera+ '09)

Virial analysis (Lopes+'09)
group members + σ_{cl} + R_{200} + M_{200}

local density $\Sigma_N = N/(\pi d_N^2)$, $N = (N_{group})^{1/2}$,
d_N=distance to the N-th nearest member

Field Galaxies:
- non-group members
- radial offset>$5R_{200}$
- velocity offset>$5\sigma_{cl}$

Three decades in local galaxy density AND two decades in parent halo mass

…… SPIDER papers ……

- Sample + data analysis
  (La Barbera et al. '10a)
- Scaling relations from g through K vs. environment
  (La Barbera+ '10b, c)
- Star formation histories+stellar masses
  (de la Rosa+ '11; Swindle+ 11)
- Characterization of the evolutionary state of galaxy groups
  (Ribeiro+ '11, submitted)
- **Optical+NIR internal color gradients vs. environment**
  (La Barbera+ '10d; La Barbera+ '11)

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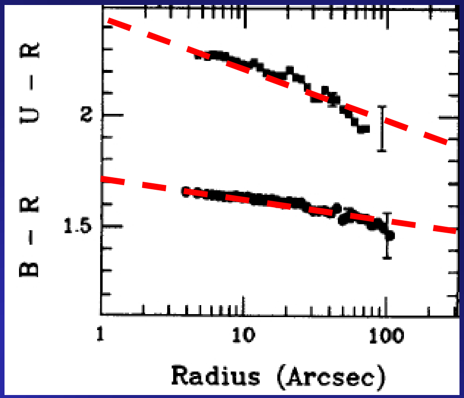
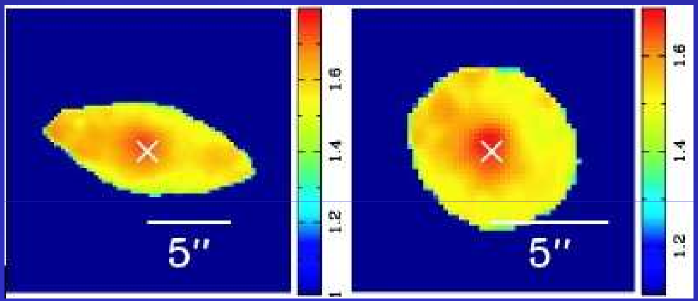
Internal color gradients (CGs) in ETGs

- defined as the slope of the radial color profile. → negative CGs



CGs of NGC4261 (Peletier+'90)

- redder in the galaxy center



(Tamura & Ohta'00)

- Metallicity is the main driver (Peletier+'90) as confirmed by absorption-line gradients (Gonzalez'93)

- Age plays a secondary role, <u>still debatable</u> (e.g. Wu+'05)

- The effect of internal dust <u>seems</u> to be negligible (Michard '05; Savoy+'09; but see Wise & Silva'96)

CGs of massive galaxies

Observations	Formation scenarios
Metallicity/age gradients	
➢ Age gradients $\nabla_t < 20\text{-}30\%$ (Saglia+'00; Wu+'05)	"In-situ" formation - gas-rich merging
➢ Metallicity gradient $-0.4 < \nabla_Z < -0.2$ (Tamura+'00; La Barbera+'03; Ferreras+'05)	ALL
Dependence on luminosity/mass	
➢ No dependence (Peletier+'90; Michard'05; Park+'07; Ferreras+'09)	Mergers
➢ Flattening at both low and high mass (Roche+'10; Tortora+'10)	Mergers
➢ Steepening (Tamura & Ohta'03; den Brok'11)	"In-situ" formation
The environment	
➢ Shallower CGs at high density (La Barbera+'05; Ko & Im'05; den Brok+'11)	Mergers
➢ No dependence (Park+'07; Roediger+'11)	"In-situ" formation

Color gradients (CGs) from 2D Sersic fitting

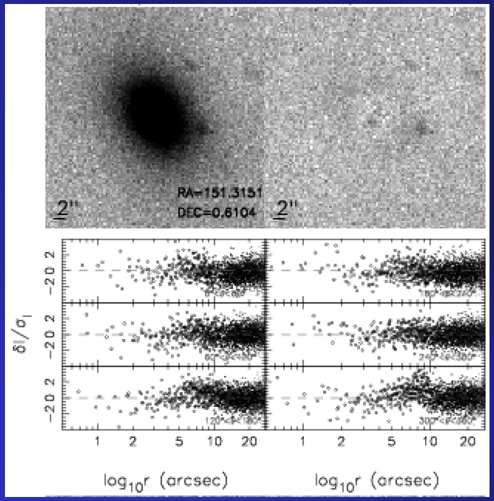
The galaxy image, in a given band W, is modeled as

$$I_W(x,y) = S(x,y;\mu_{o,W}, r_{e,W}, n_W) * P(x,y)$$

S → 2D Sersic law

P → PSF model

$\mu_{o,W}, r_{e,W}, n_W$ → structural parameters

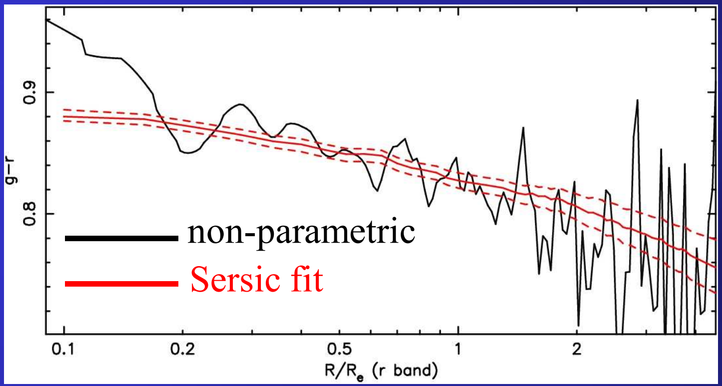


ETG Sersic fitting in r band (2DPHOT)

The CG is defined as the slope of the linear fit to the parametric color profile:

$$\nabla_{W_1-W_2}(r_{eW_1}, n_{W_1}, r_{e,W_2}, n_{W_2}) = -2.5\times\log(I_{W_1} / I_{W_2})$$

in the radial range of 0.1 to 1 R_e.



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

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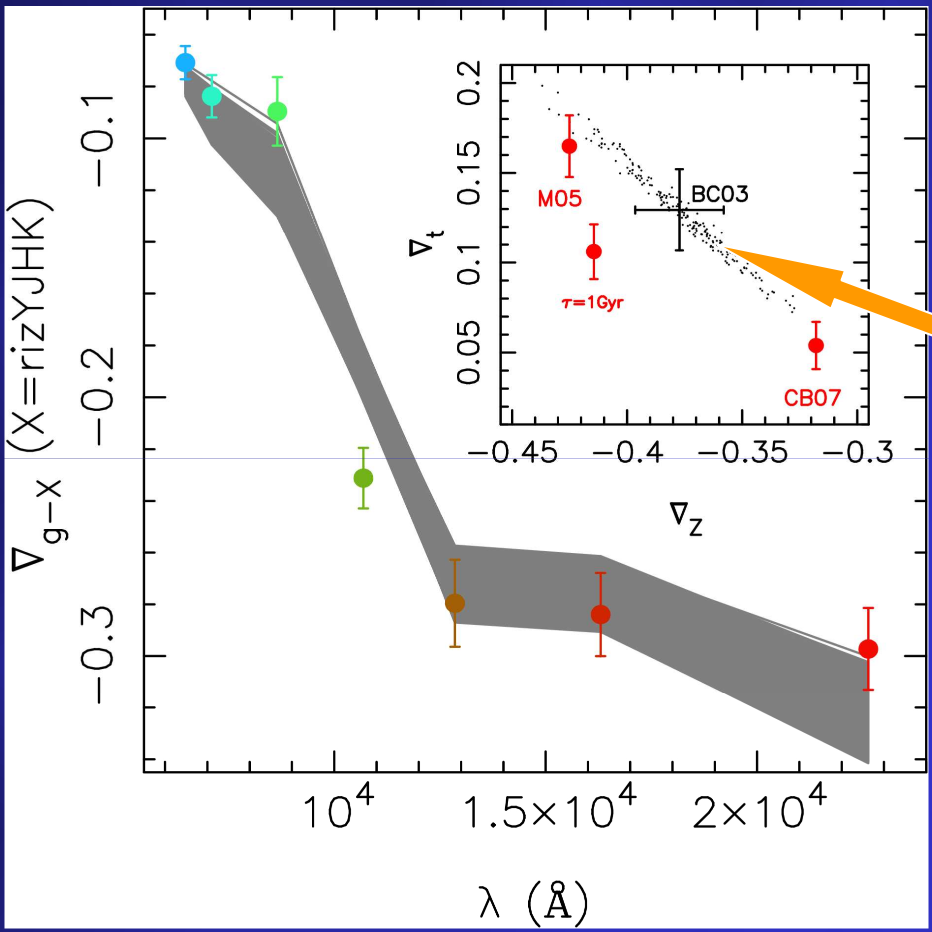
Color and stellar population gradients

Mean internal color gradient, $\nabla_{g\text{-}X}$ (X=rizYJHK)



La Barbera & de Carvalho'09

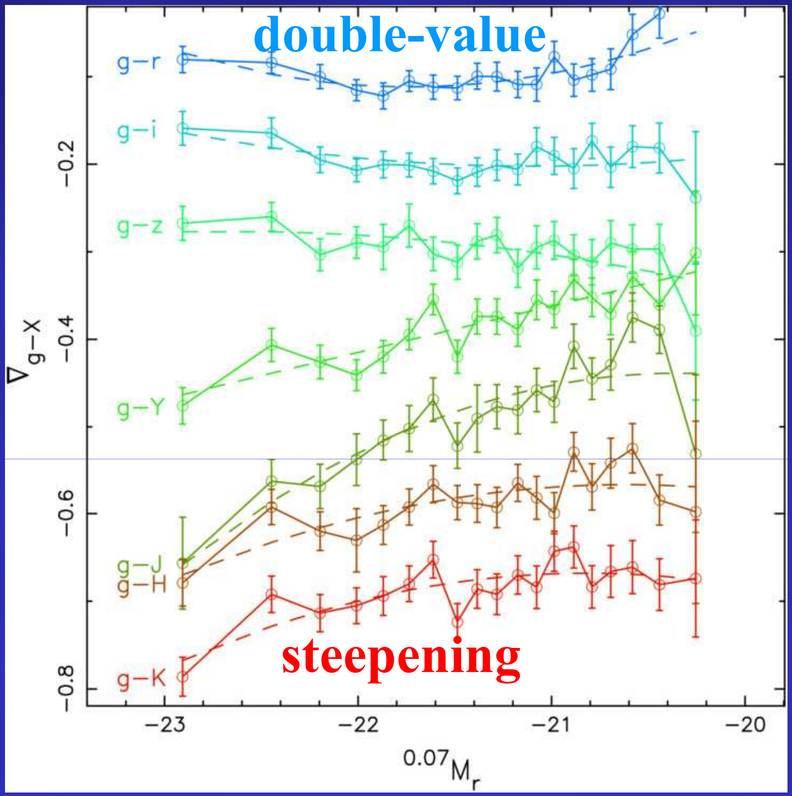
Fitting $\nabla_{g\text{-}X}$ with a free combination of age/metallicity gradients (∇_t/∇_Z)

negative ∇_Z
"inner=more metal-rich"
+
small, but significantly positive, ∇_t
"inner=younger"

Other studies have then found evidence for positive age gradients in massive galaxies
(e.g. Clemens+'09, using SDSS spectra; Tortora+'10; Roediger+'11)

Correlation with mass/luminosity

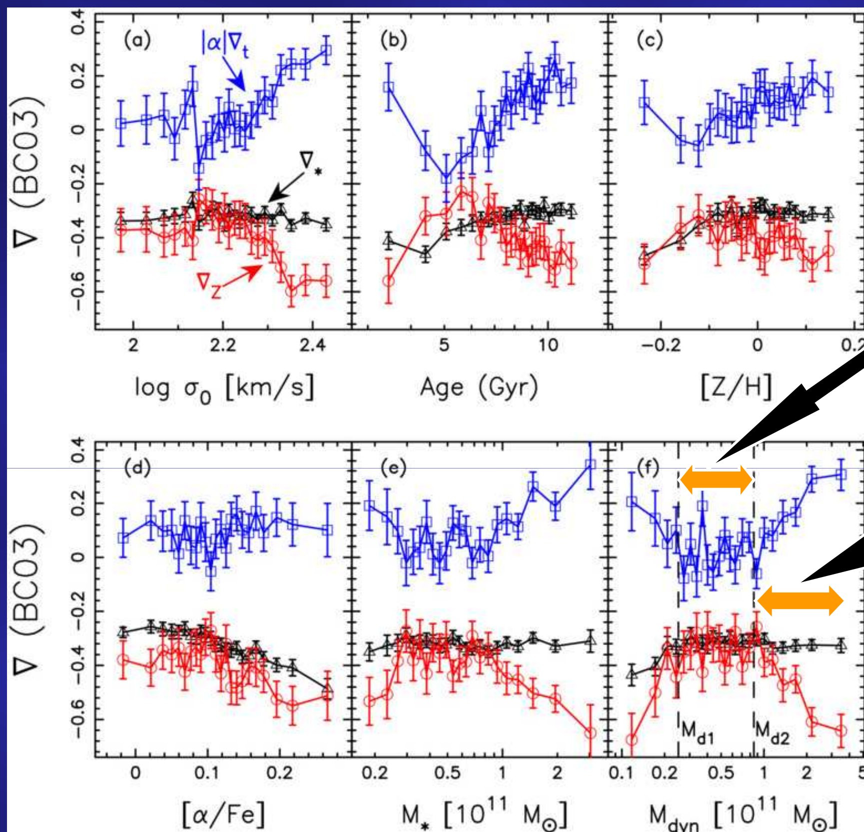
..... one of the most debatable issues ....



Do the ∇'s correlate with mass ?

There is NO unique answer.

Correlation with stellar populations and mass: the role of age/metallicity gradients



BC03 SSP models

"low" mass ETGs

$2.5 \cdot 10^{10} < M_{dyn} < 8.5 \cdot 10^{10}$

"high" mass ETGs

$M_{dyn} > 8.5 \cdot 10^{10}$

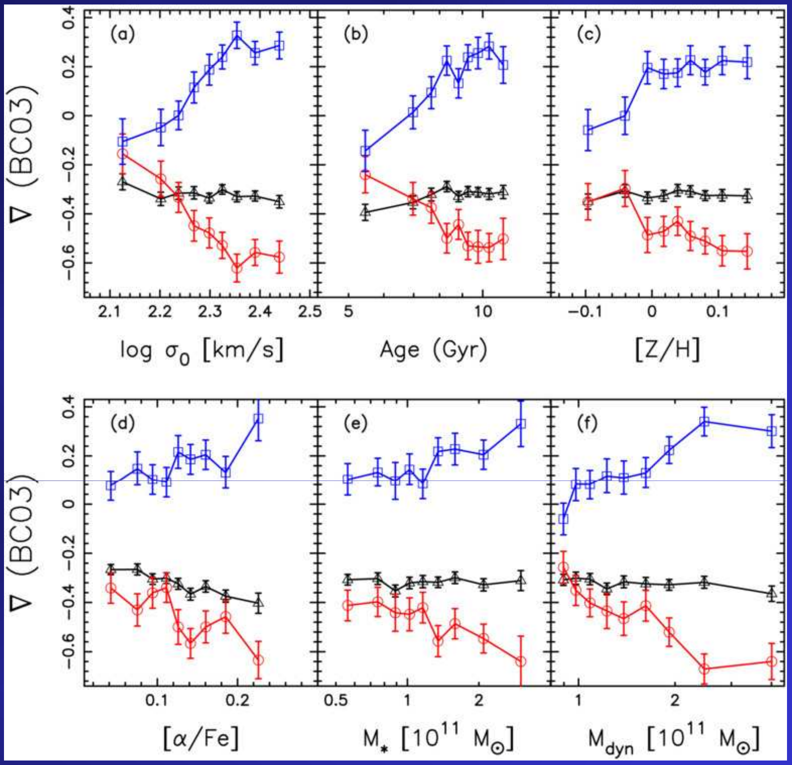
Different behavior of "low" and "high" mass ETGs

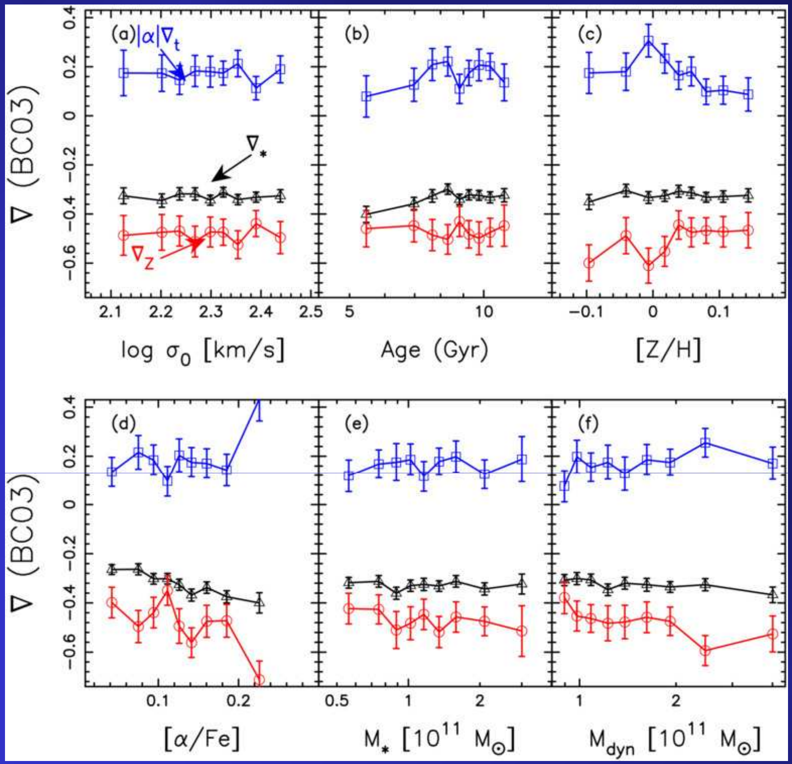
At high-mass, the lack of correlation between ∇_* and mass is because of an anti-correlated variation of age and metallicity gradients

Notice the trend with [α/Fe] (significant at 7σ's!!), which is due to ∇_Z.

What is driving what ?

"high" mass ETGs





Correcting for the correlation of ∇'s with σ_0, we find that all correlations are removed but the ones with [α/Fe].

→ σ_0, [α/Fe]

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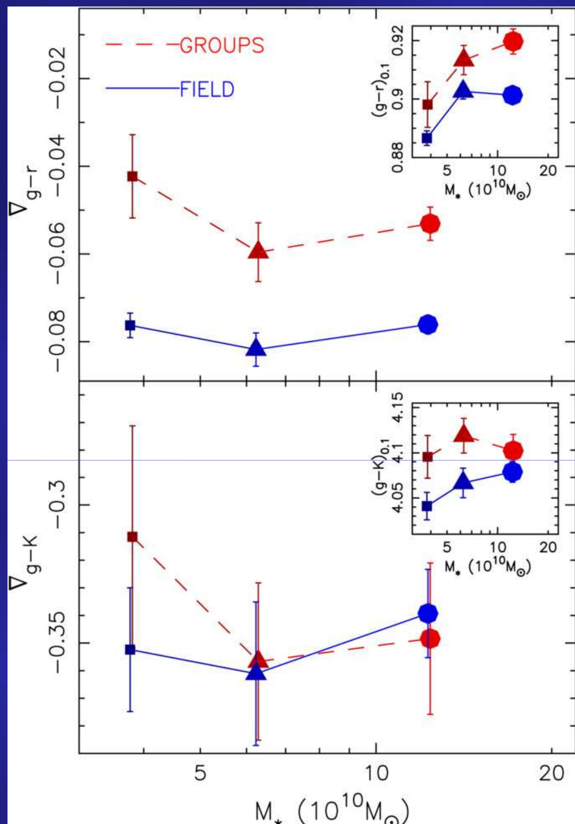
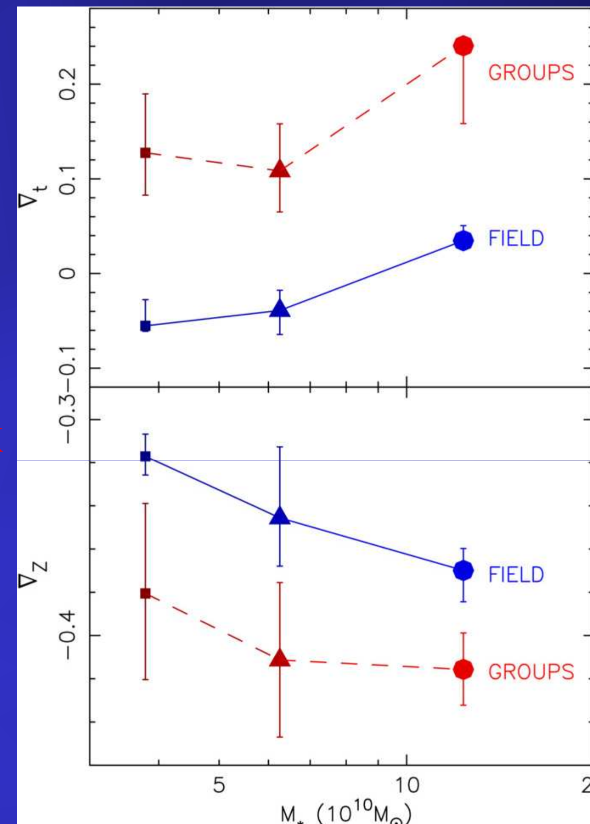
Age and metallicity gradients vs. environment

Color gradients of field vs. high-Σ_N ETGs.



SSP models of ∇_{g-X} (CB07)

Stellar population gradients



- In the optical, high-Σ_N ETGs have shallower gradients, at all M_*'s.
- NO difference in the optical-NIR

- **∇_t>0 and stronger for group (wrt field) ETGs**
- **Field ETGs: ∇_t<0 (low-M), ∇_t>0 (high-M)**
- **∇_Z's of group ETGs are more negative**

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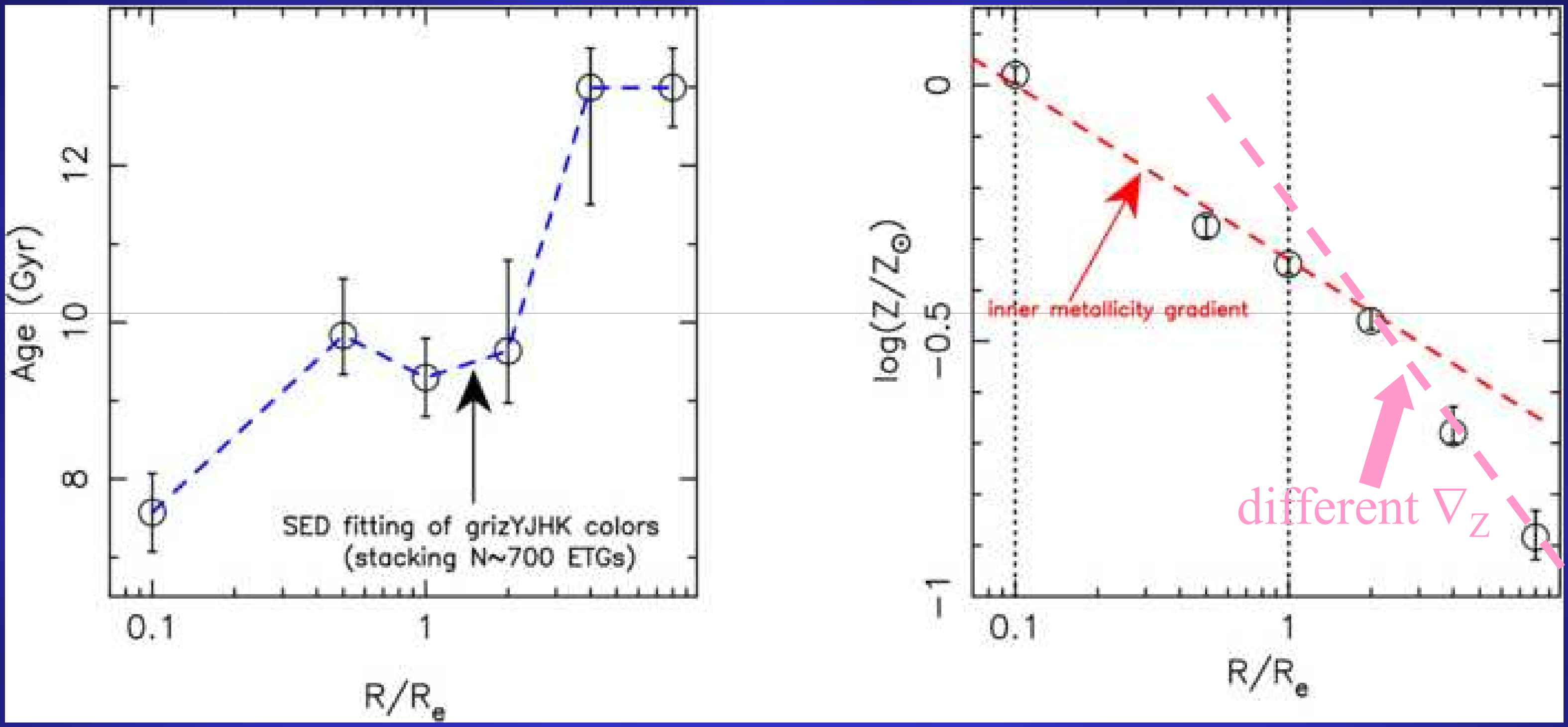
Outer stellar populations

- We median-stack the color profiles of ~700 (best-quality data) ETGs
- SED fitting of g-X (X=rizYJHK) up to 8·R/R_e



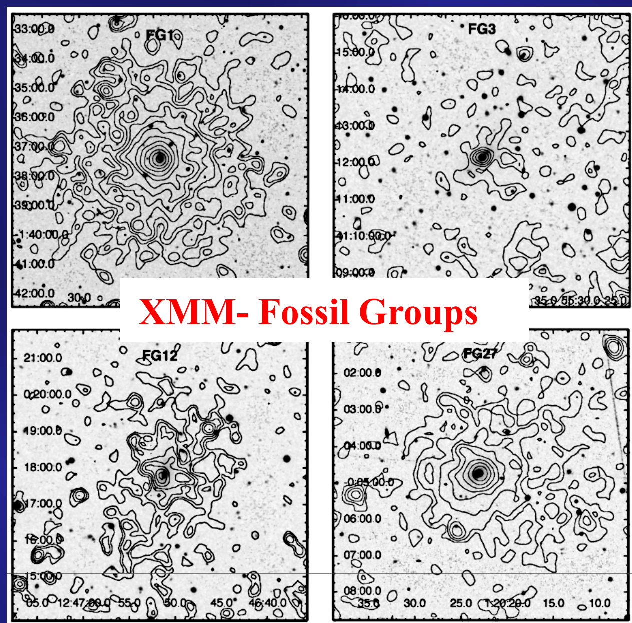
- The change of ∇_Z suggests that the outer (old and metal-poor) stellar population has a different origin than the inner one.

Summary

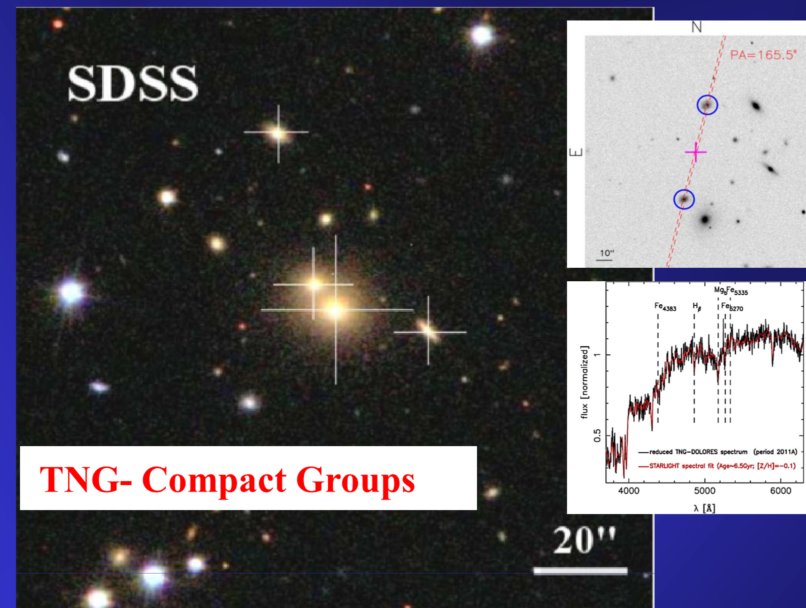
- Positive age gradients (~5-20% per radial decade) in ETGs
- For $M^*>10^{11}\cdot M_{Sun}$, we find a strong correlation of age/metallicity gradients with mass ⇒ expected by "in-situ" formation (for $R\leq 1Re$)
- At given mass, a strong correlation between metallicity gradient and [α/Fe] exists ⇒ gas-rich mergers dilute the ∇_Z, and decrease the [α/Fe]
- Group ETGs have stronger (age) gradients than their field counterparts
  ⇒ later gas-cooling in field ETGs, producing a younger, more metal-rich population in the galaxy outskirts
- The metallicity gradient changes beyond $\sim 2\cdot R_e$
  ⇒ minor mergers "depositing" metal-poor/old stars in the galaxy outskirts

A variety of processes contribute to the formation of bright ETGs, their efficiency depending on environment/mass/radius

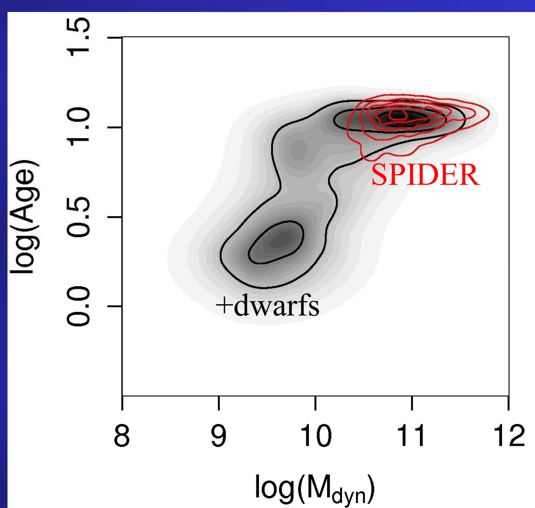
…. IN PROGRESS ….



+ M. Paolillo; B. De Filippis



+A. Mercurio; M. Paolillo; E. Pompei



+M. Trevisan