The star formation history of elliptical galaxies

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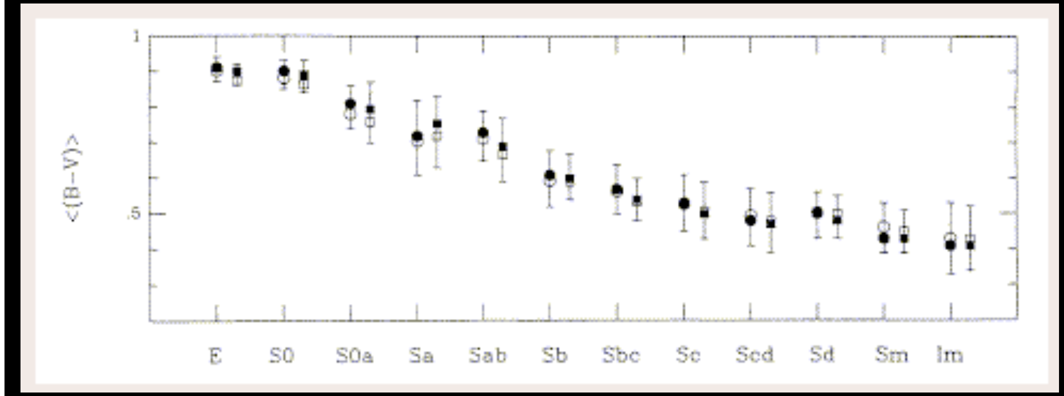
Eliptical galaxies

Represent ~ 10-20% of the galaxies but contain ~50% of the stellar mass of the Universe

M87 © Anglo-Australian Observatory
Photo by David Malin

- When did early type galaxies form their stars?
- What trigger the star formation
- What does stop the star formation
  - test models of galaxy formation and evolution

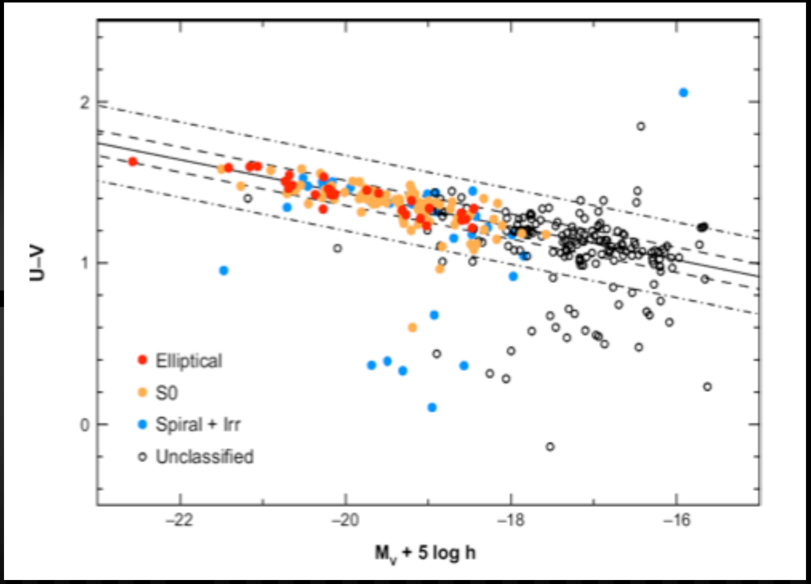
We want to derive ages, metallicities and chemical abundances ratios



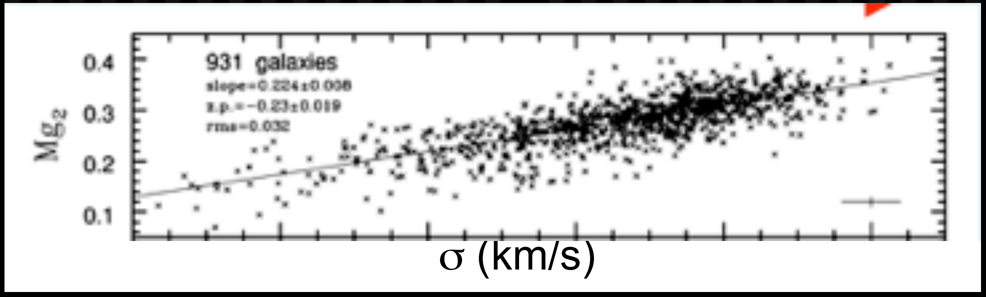
Red

Blue

They're the reddest galaxies of the Hubble sequence



Tight relations
CMR, Mg-s



Bernardi et al. (1998)

When did early-type galaxies formed their stars?

The classical two competing scenarios:

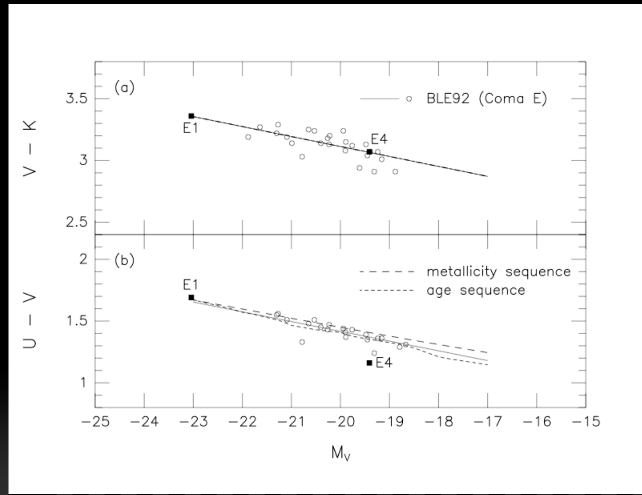
✓ They form all their stars at high redshift

- Tightness of the CMR, FP, Mg-σ
- Massive red galaxies observed already at z~1.5-2.5 (Franx et al. 2003, Daddi et al. 2004)

✓ They have suffered a more extended star formation history (Hierarchical scenarios)

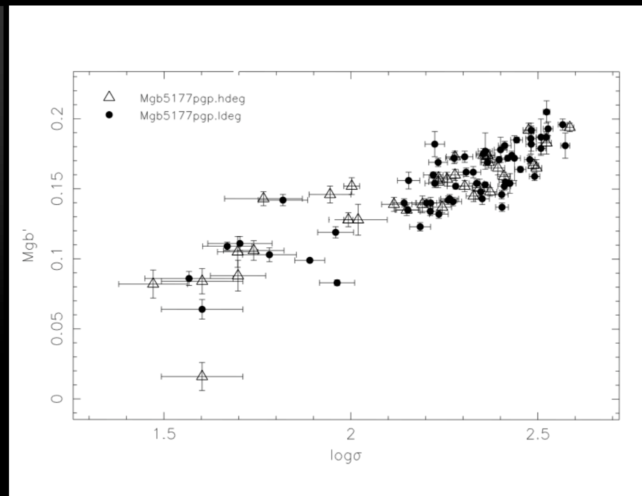
- Detection of fine structure (Schweizer et al. 1990)
- Central ages of nearby ellipticals (Gonzalez 1993).
- Mergers are observed at a rate compatible with hierarchical theories of galaxy formation (van Dokkum 1999).

Stellar populations are one of the observables that can be compared with the models of galaxy formation



Early-type galaxies follow very tight relations as CMR, FP, Mg-σ, but still we're debating

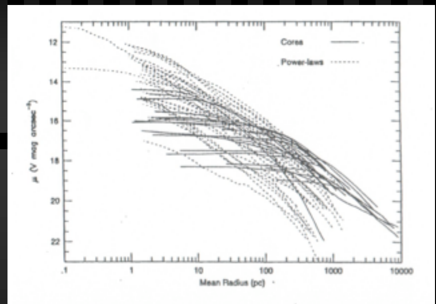
- Which parameters are changing with the mass/magnitude of the galaxies?
- Which parameters are responsible of the scatter among these relations?
- Is there any relation between the stellar populations and structural parameters which can give us information about the formation processes?
- Is there any difference between ET galaxies in different environments?, etc…

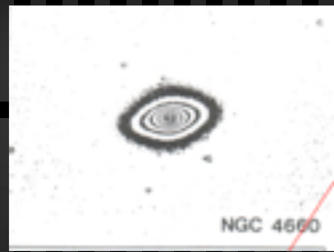


Structural properties of E galaxies are related to their Luminosity (Kormendy & Bender 1996) :

More Luminous (M_B< -20), slowly rotating , boxy isophotes, core inner profile, moderately triaxial, large amount minor axis rotation.

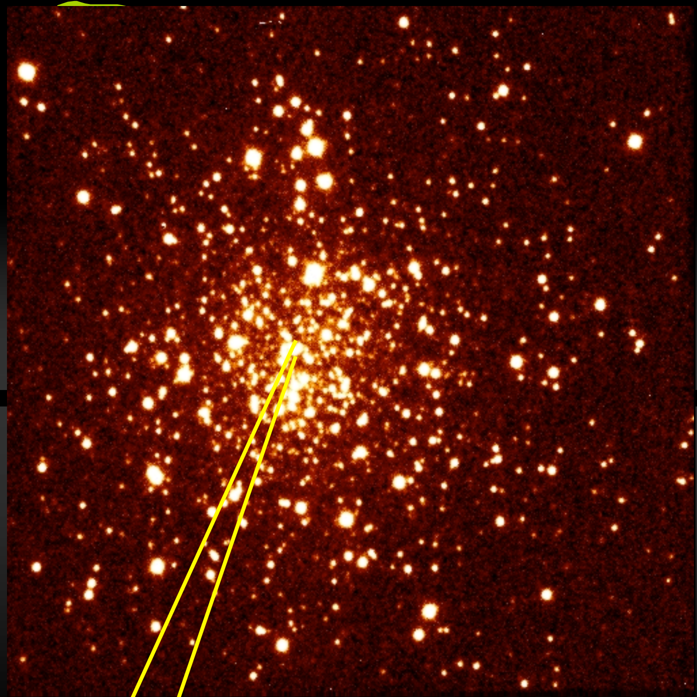
Less luminous (M_B>-20), rapid rotator , disky isophotes , power law inner profile, very little minor axis rotation.

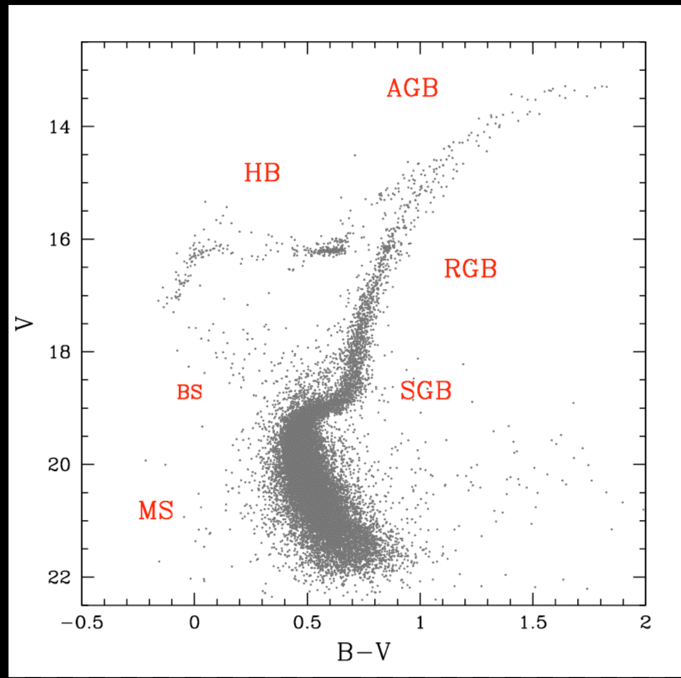


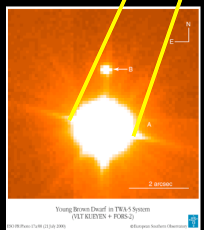


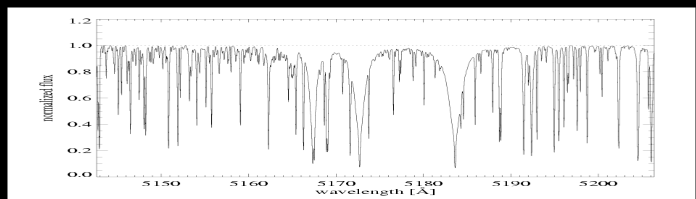
Mergers with and without dissipation can explain these properties (Barnes & Hernquist 1996, Faber et al. 1997, Khochfar & Burkert 2005, Naab et al. 2006b, Graham 2004) :
This could also explain the tilt of the FP (Oñorbe et al. 2005), and put into agreement the hierarchical scenarios with the derived SFH for galaxies (e.g. de Lucia et al 2004)...

Resolved Stellar Populations





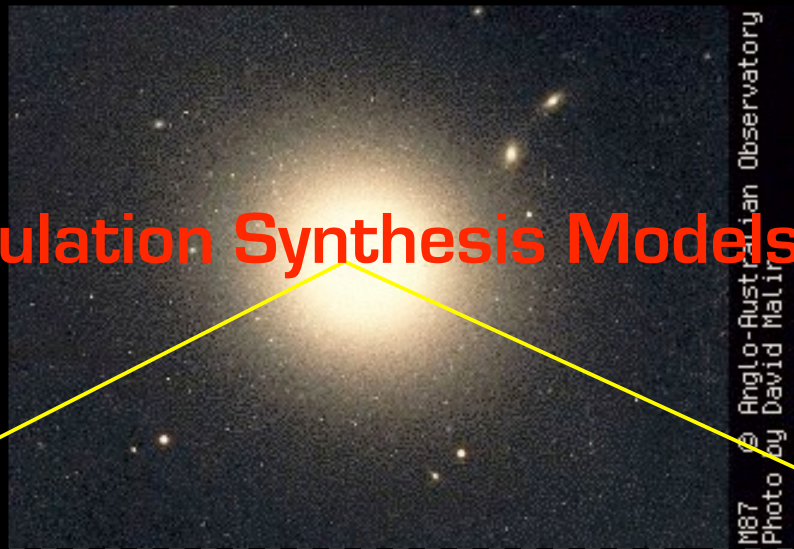




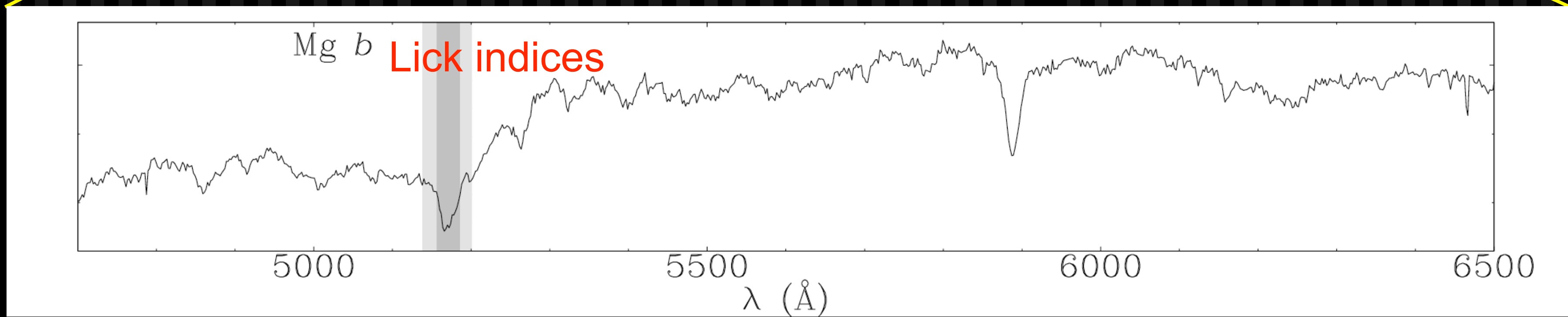
Age + Metallicity

Element ratios

Unresolved Stellar Populations



Population Synthesis Models

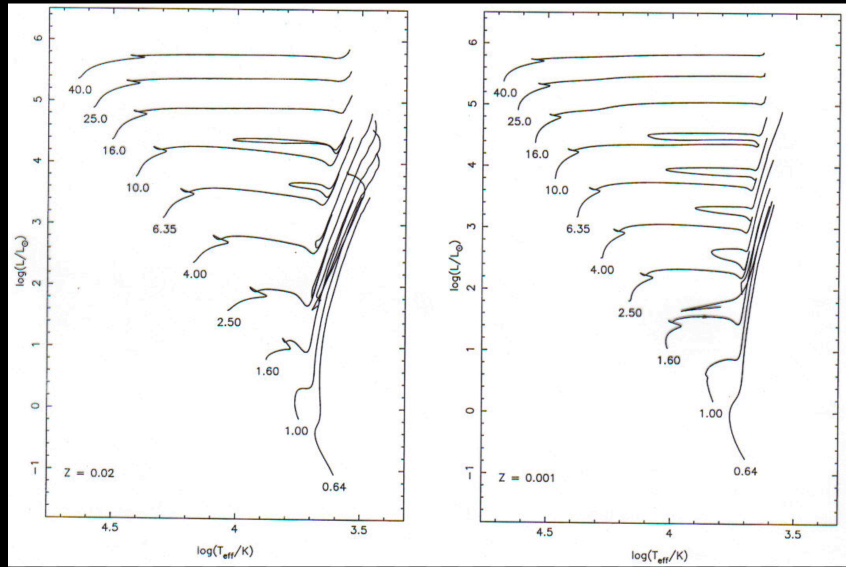


Ingredients:

Isocrones:

Uncertainties:

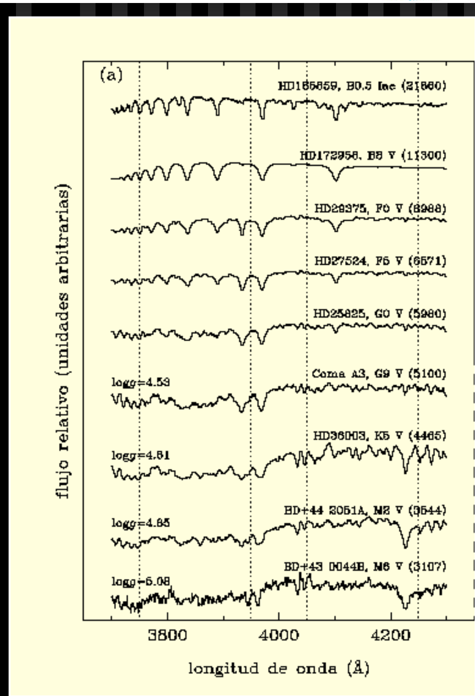
Overshooting, atomic difusion, opacities, loss of mass , rotation mixing, etc



Library of spectral energy distributions (or line-strength indices)

Uncertainties:

Lack of libraries covering a wide range in stellar parameters (cold stars and non-solar metallicities)



MILES:

Mid-resolution INT Library of Empirical Spectra

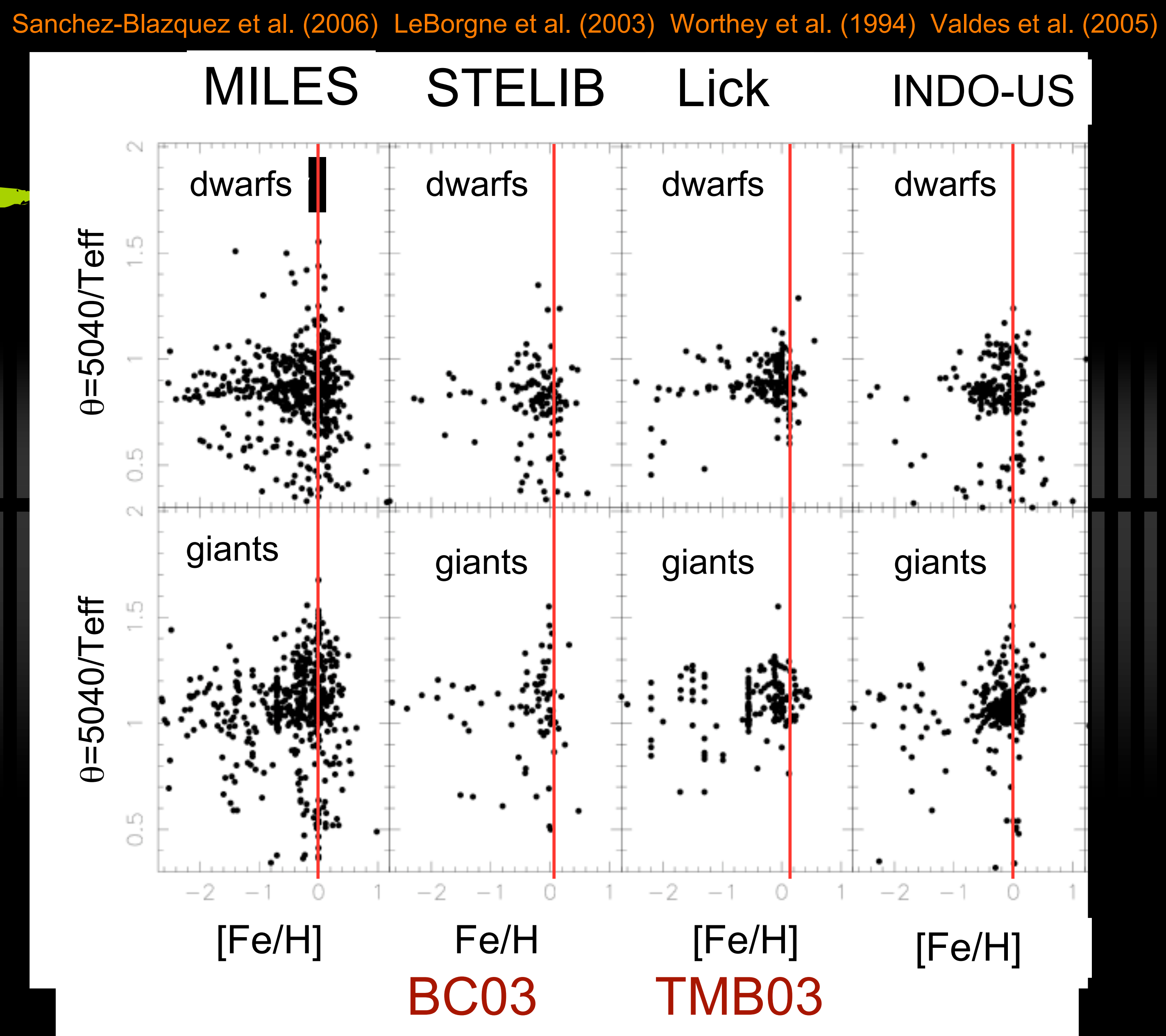
985 stars
FWHM =2.3 Å
3500-7500 Å

Sanchez-Blazquez et al. 2006

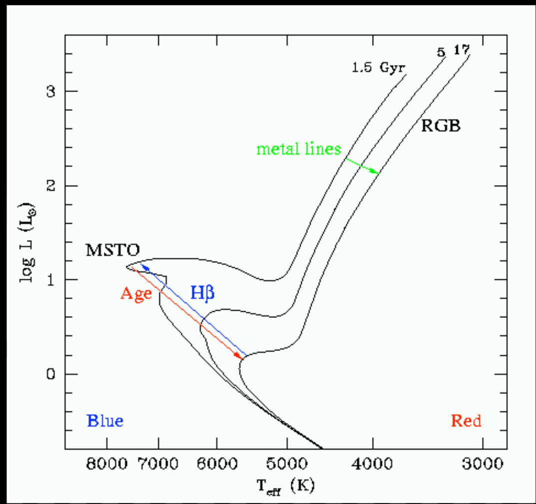
Sanchez-Blazquez, P., Peletier R., Vazdekis A., Jimenez-Vicente J., Cardiel N., Gorgas J., Cenarro J., Falcon-Barroso J., Selam S.

Available at: www.ucm.es/info/Astrof/miles/miles.html

Atmospheric parameter coverage



Be careful with SSP…

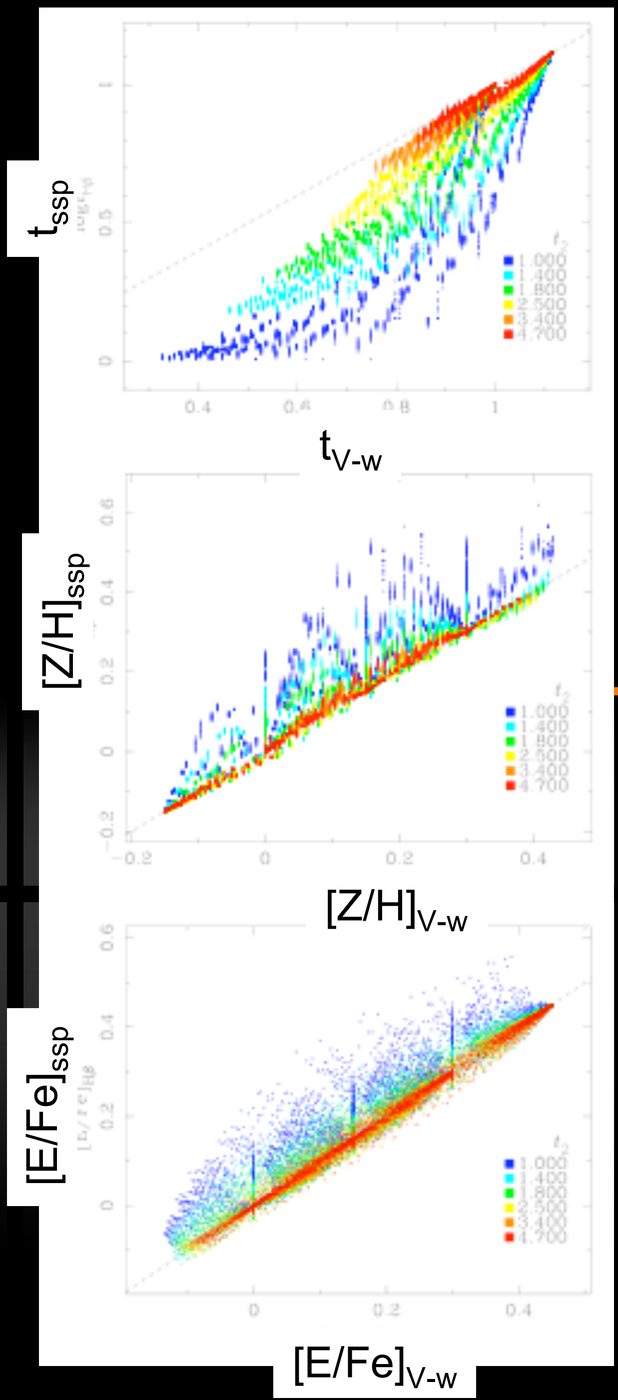


SSP-ages and metallicities not always can be approximated by ages and metallicities weighted in the V-band

Simplified 2 burst model:

age : extremely sensitive to the age of the young population

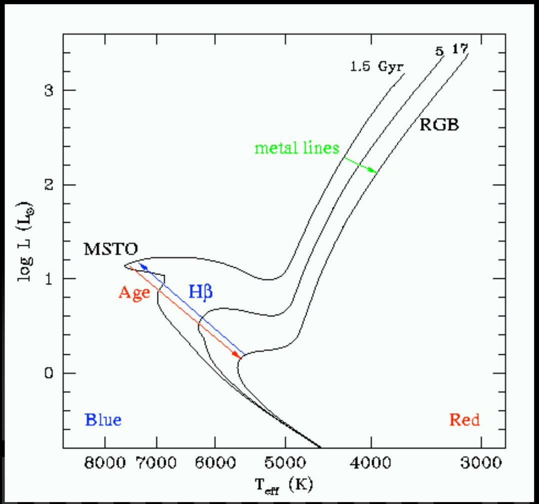
metallicity and [alpha/Fe] : bias toward the massive component

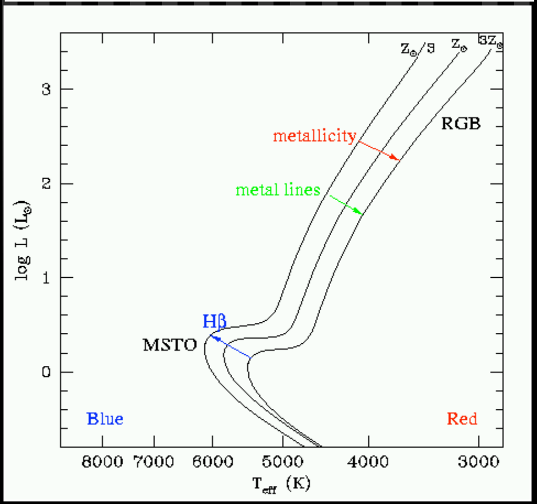


Serra & Trager (2006)

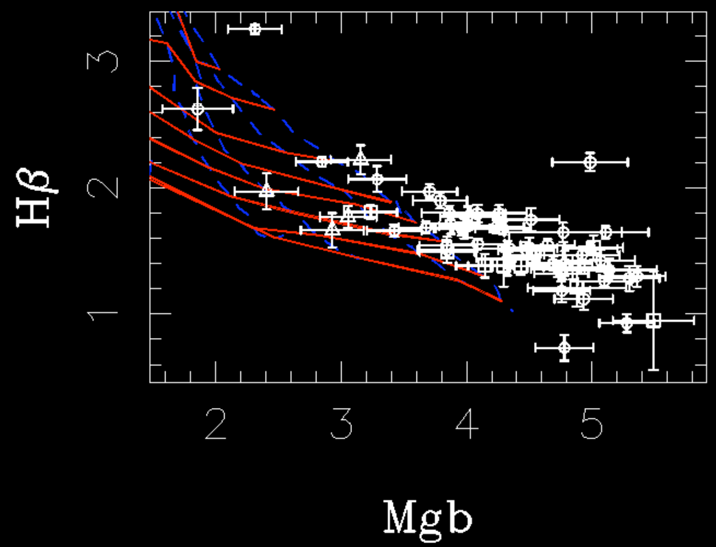
Problems

Age-metallicity degeneracy





Chemical abundances ratios



Elliptical galaxies show an overabundance in [Mg/Fe] as well as other elements with respect to the solar values.

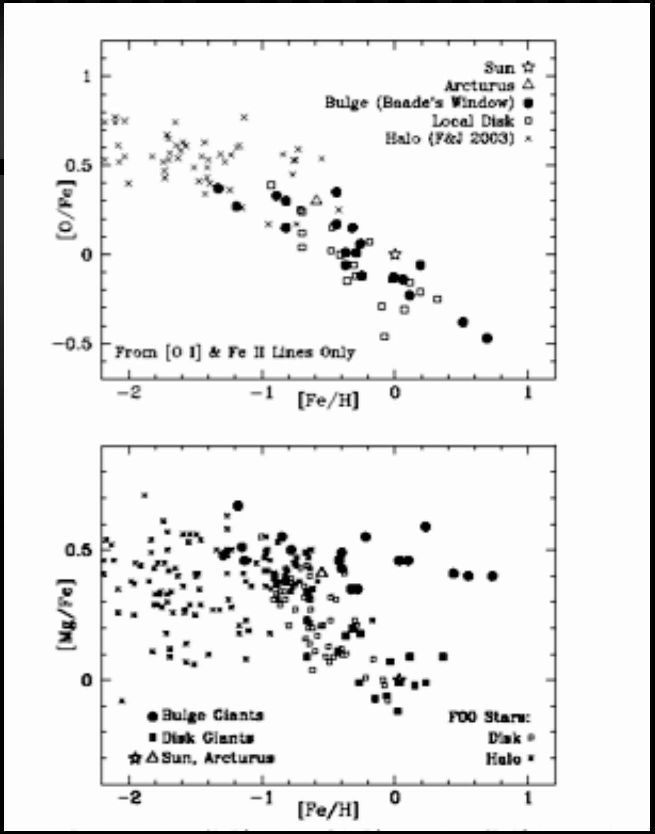
The stellar libraries have solar abundance ratios

In giant E galaxies:

[Mg/Fe], [N/Fe], [C/Fe] seem to be overabundant
(e.g. Worthey 1998, Vazdekis et al. 2001, etc)
[Ca/Fe] underabundant?
(e.g. Cenarro et al. 2001; Saglia et al. 2001)
We don't know the Oxigen abundance in E galaxies

Correction to the models:
- N, Ne, Na, Mg, Si, S, O, C (enhanced) : E
- – Cr, Fe, Co, Ni, Cu, Zn, Ca (depressed)

Important to keep this in mind when comparing with the models



Fulbright et al. 2005

Stellar populations of nearby early-type galaxies in different environments

Sample: 76 early-type (selected morphologically to cover a wide range in sigma)

40 in the field of loose groups (LDEG)

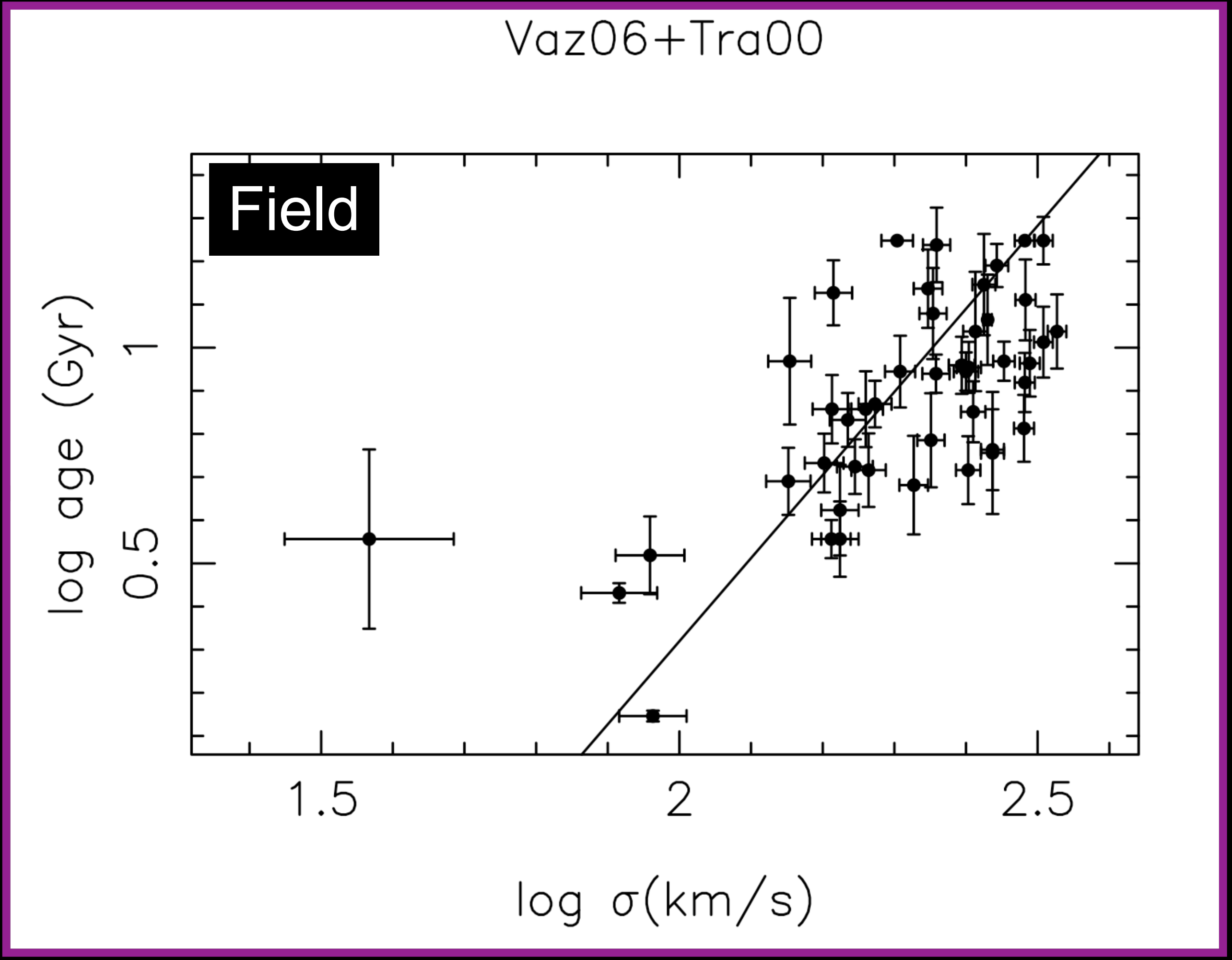
36 in the center of the Coma cluster (HDEG)

Typical S/N(Å) 3500-6500 are 110 (LDEG) and 50 (Coma)

[E/Fe] included in the models in a non-consistent way

- N, Ne, Na, Mg, Si, S, O, C (enhanced) : E
- Cr, Fe, Co, Ni, Cu, Zn, Ca (depressed)

Age with sigma

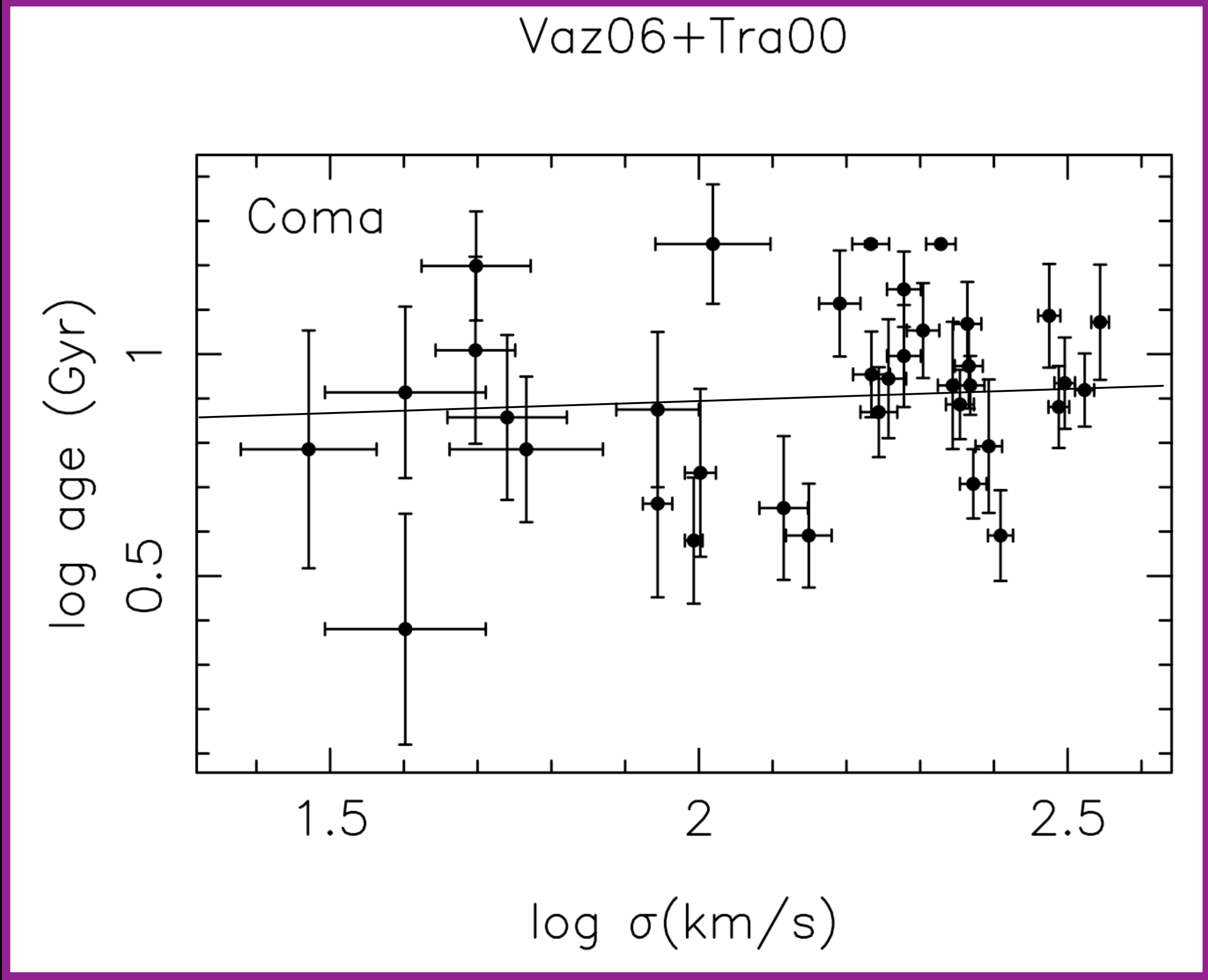


Caldwell et al 2003:

$age \propto \sigma^{0.95}$

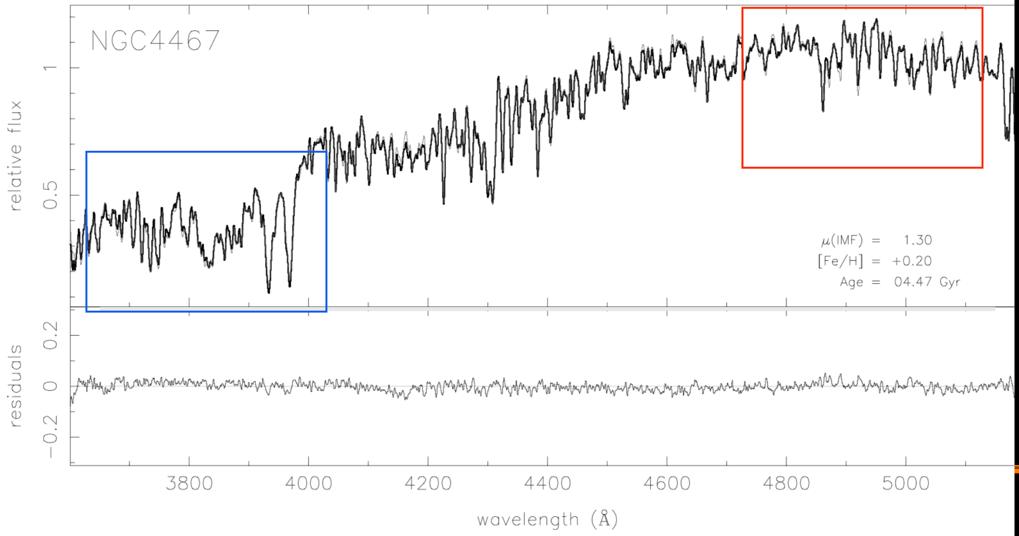
log age=(-1.40±0.62)+(0.97±0.26) log s rms(res)=0.24

Mean age vs. velocity dispersion.

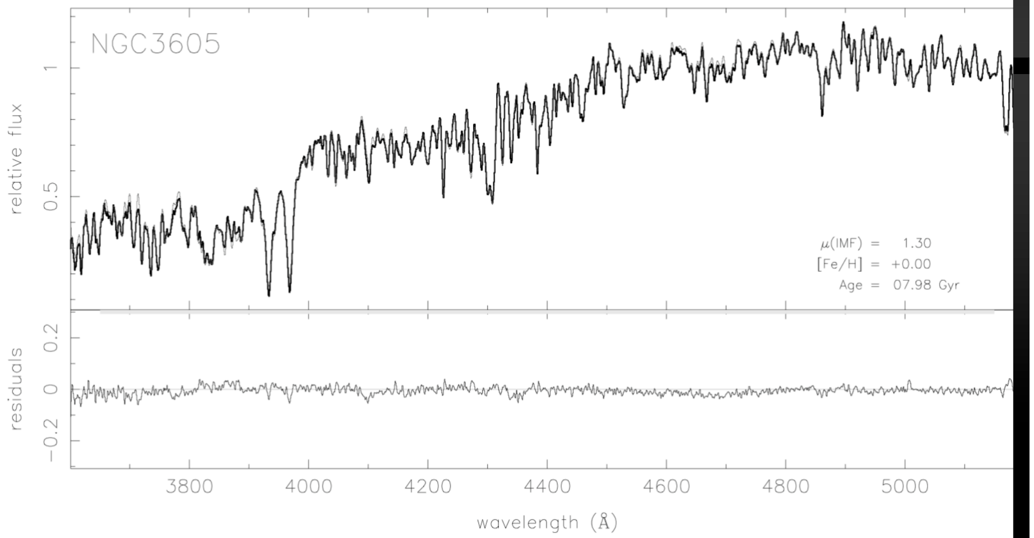


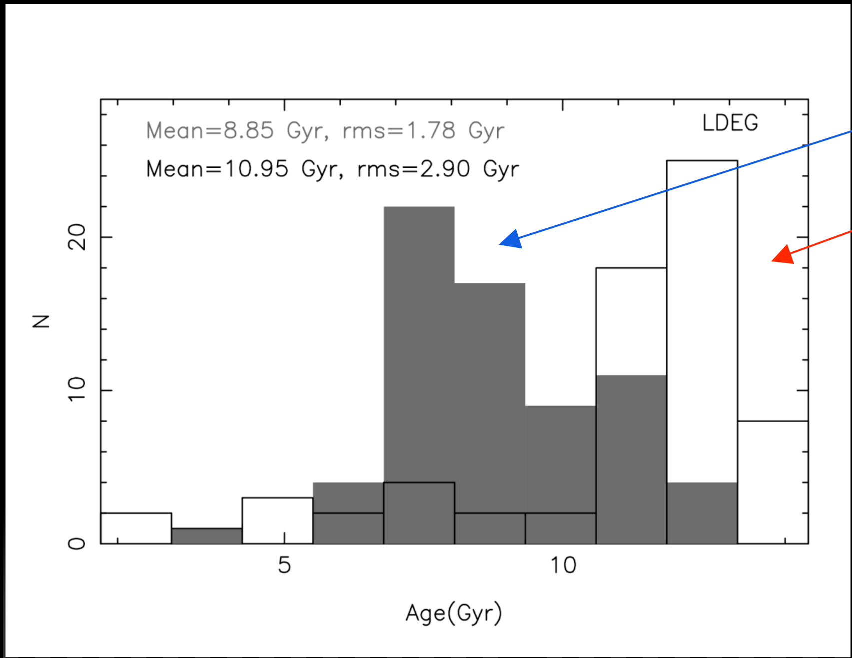
$\log \text{age}=(0.57\pm0.76)+(0.14\pm0.32)\log\sigma$ rms(res)=0.11

Comparison with the synthetic spectra



Synthetic spectra
by Vazdekis et al. (2007)
Using MILES
(Sanchez-Blazquez et al. 2006)





3650-4050 Å shaded

4750-5150 Å white

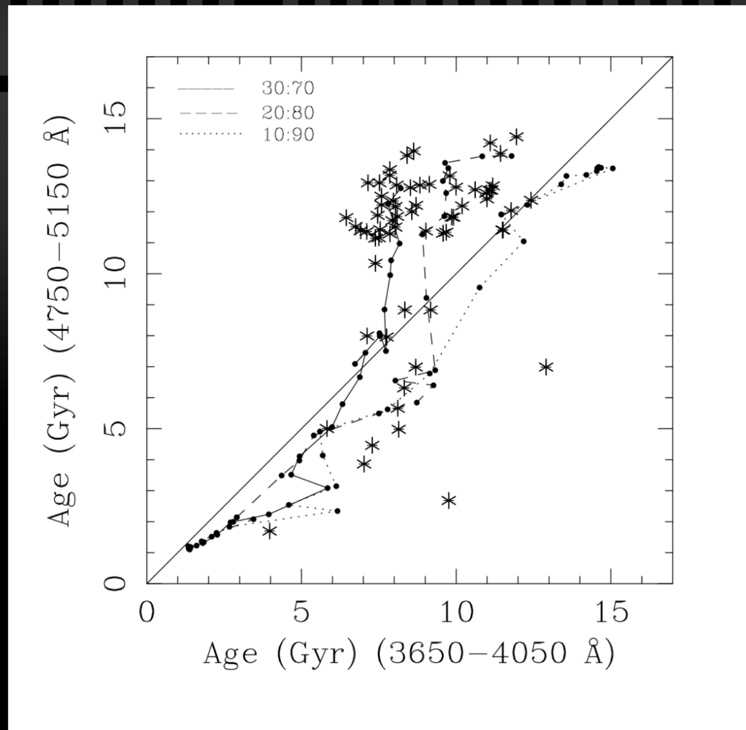
Field galaxies

15.5 Gyr [Z/H]=-0.38:[Z/H]=+0.2

70:30% solid

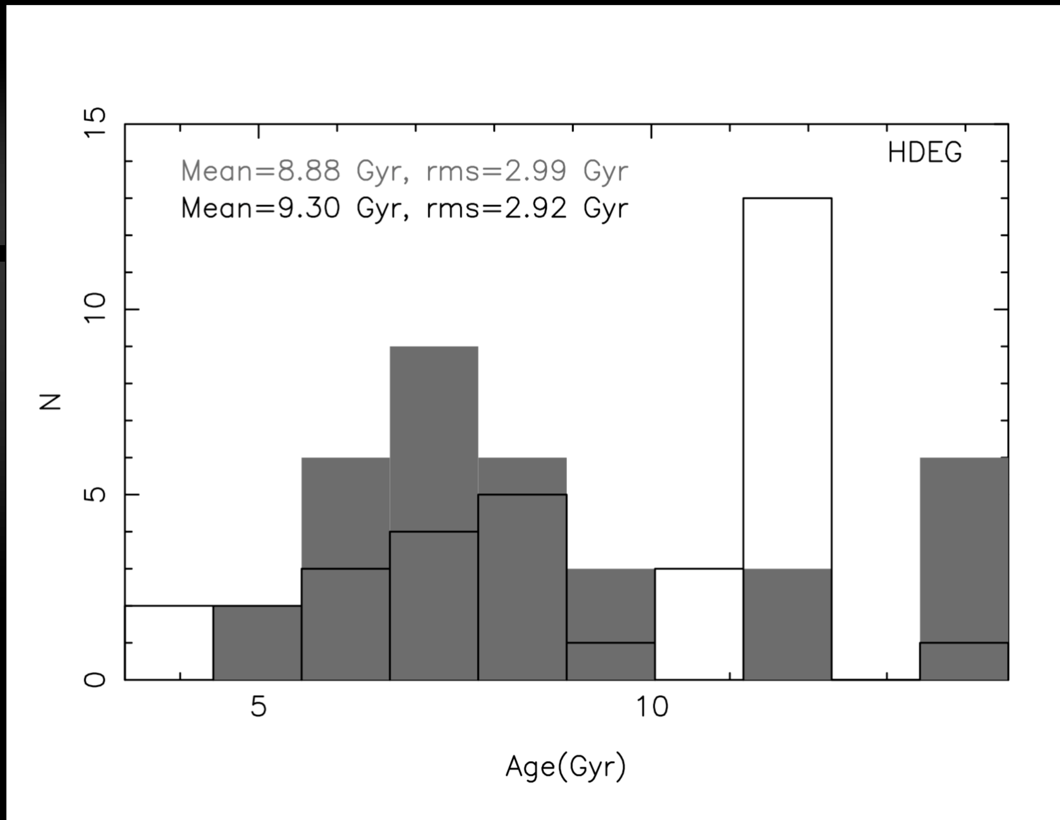
80:20% dashed

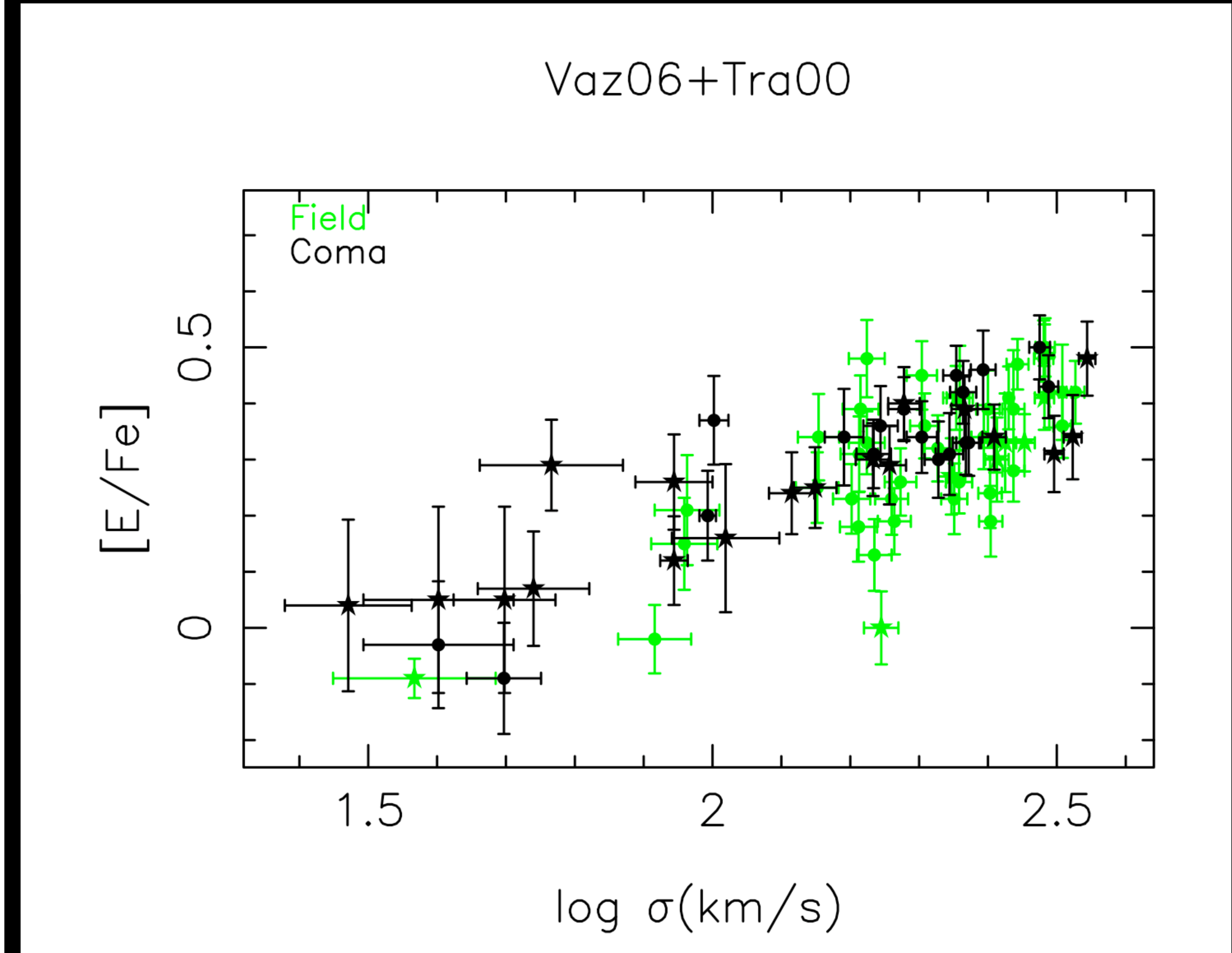
90:10% dotted



Comparison of ages in two spectral ranges

Coma galaxies

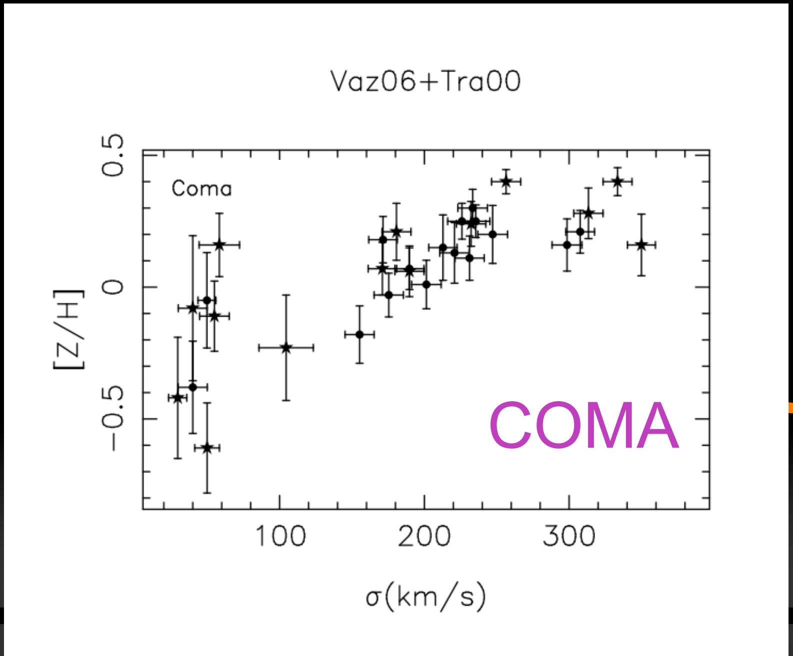


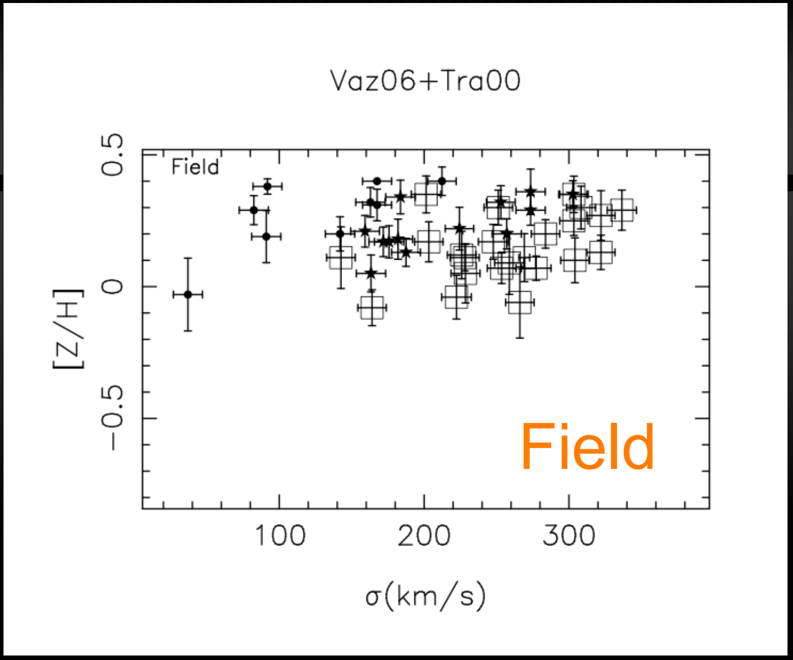


On average,
at a given mass,
Coma galaxies
show higher
[E/Fe] than field
Galaxies:

-shorter
timescales of star
formation
-flatter IMF
-selective mass
loss

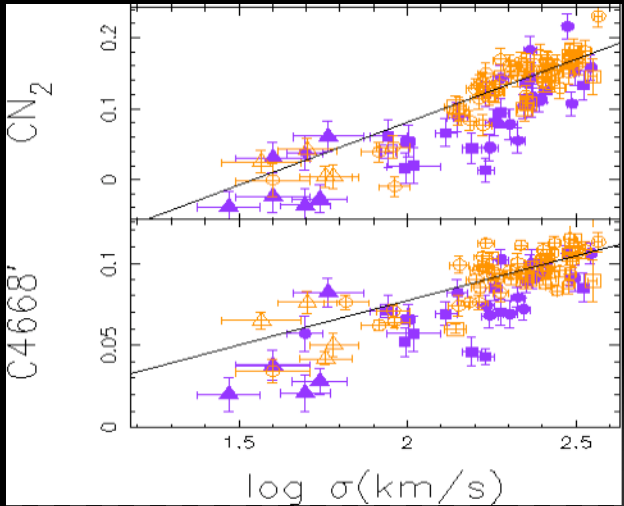
[Z/H] vs σ



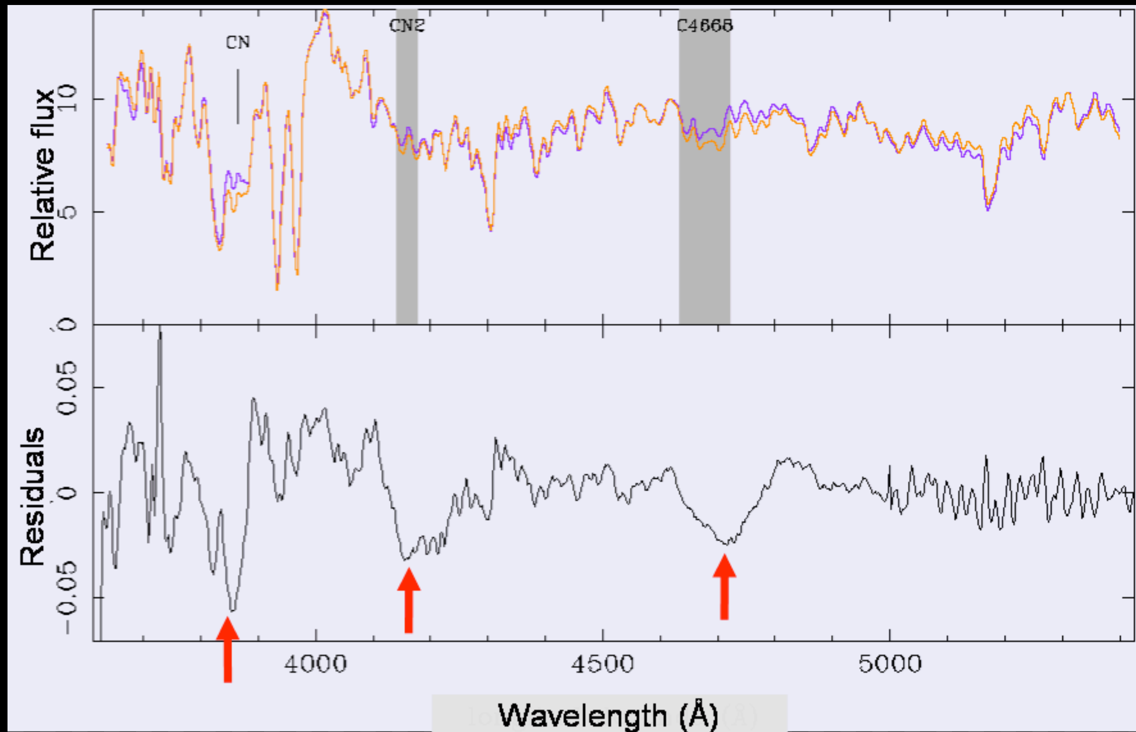


In agreement with Trager et al. 2000, Collobert et al. 2006

C and N



Coma
Field



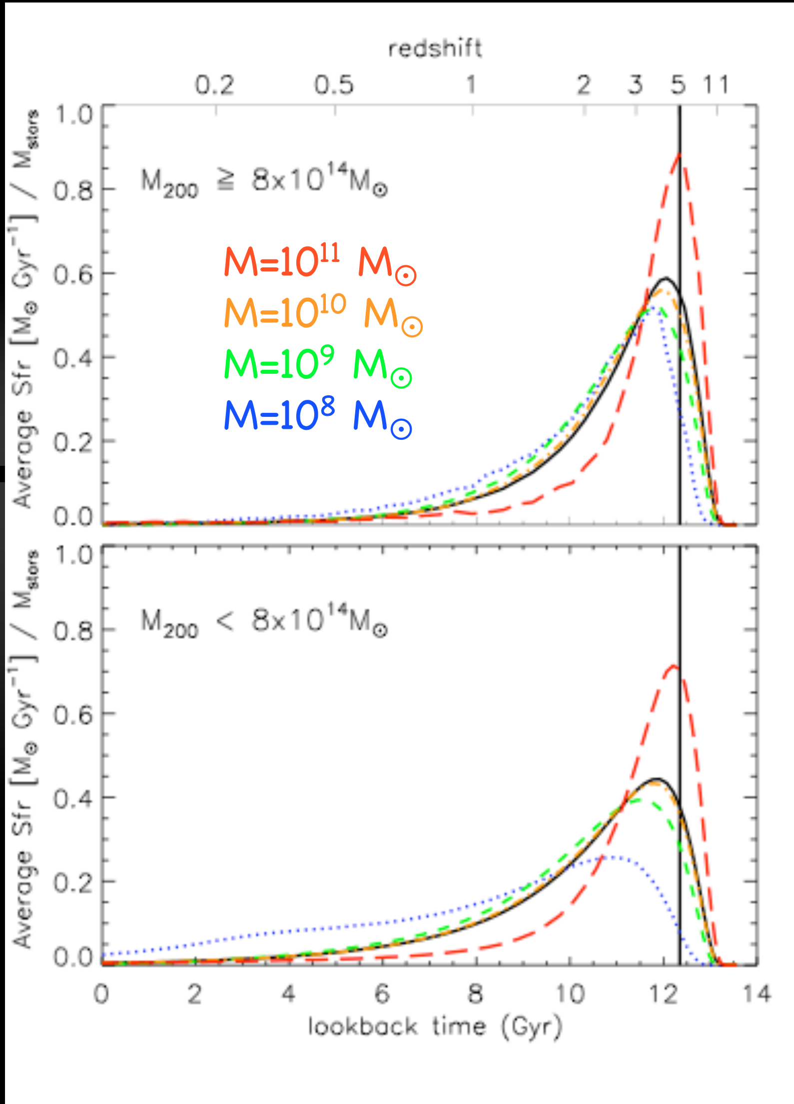
Mg C,N Fe

time

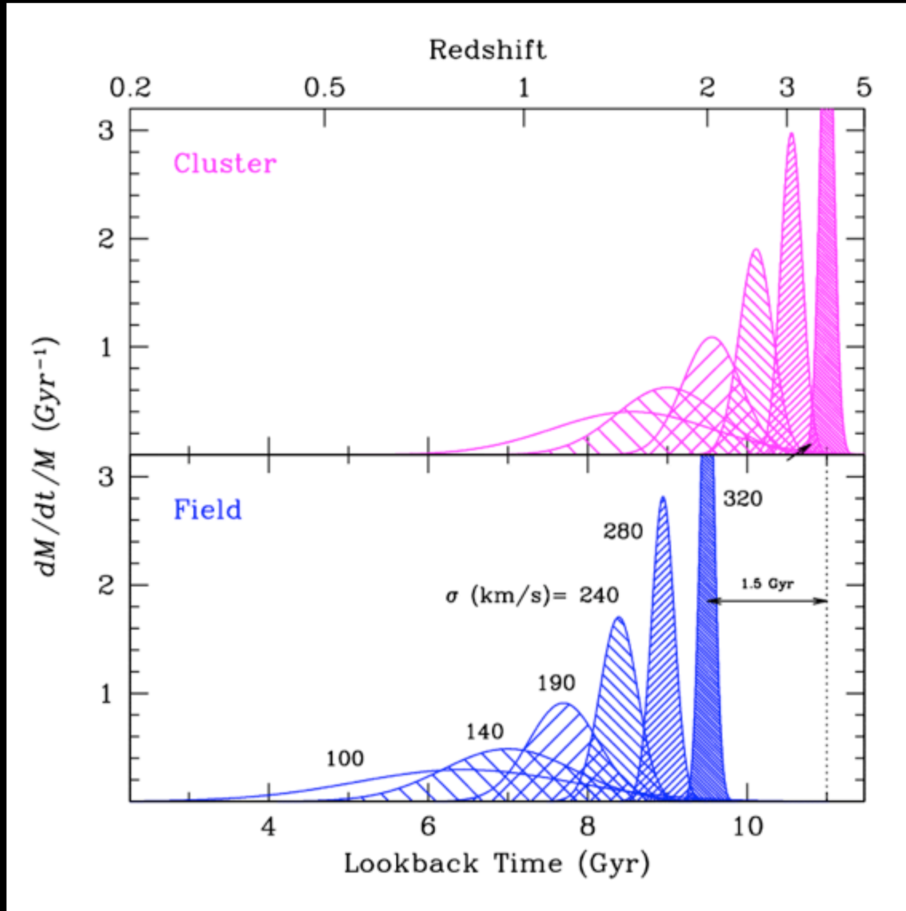
Sanchez-Blazquez et al. 2003

Star formation histories as a function of environment

De Lucia et al. 2006



Thomas et al. 2005



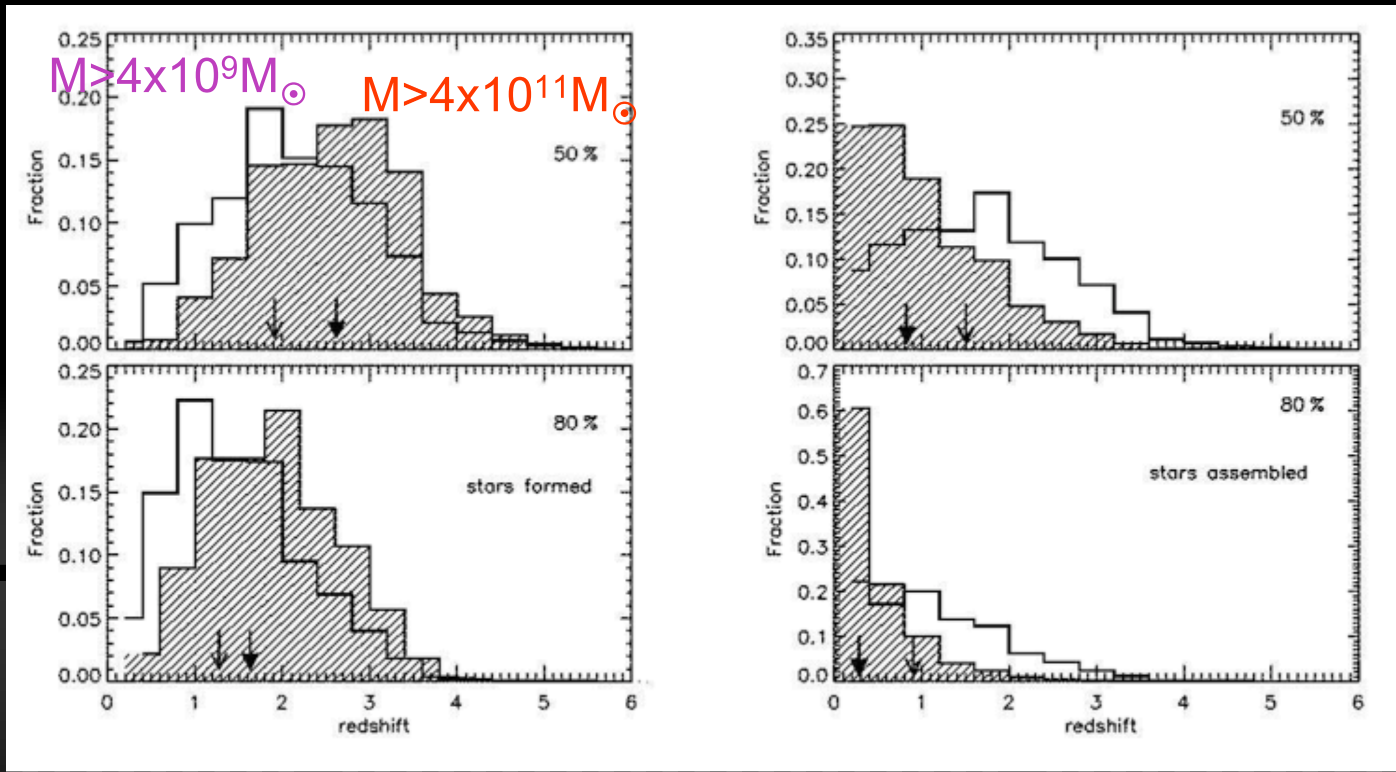
General Conclusion

- ✓ We find differences between galaxies in the field and in the Coma cluster. Galaxies in the Field are more compatible with having suffered a more extended star formation history than galaxies in the Coma cluster

-Coma galaxies are more “coeval”. The SFH is less dependent on mass.
-Low mass LDEG have suffered a more extended SFH than more massive galaxies.

stars formed

stars assembled



SMA by De Lucia et al. 2006

Interaction with and without dissipation leads to different stellar population gradients:

* Dissipation: stronger metallicity gradients a correlation between [Z/H] gradient and mass (Bekki & Shioya 1999).

* No dissipation: shallower metallicity gradients, pure stellar mergers tend to wipe out the original gradient in the galaxy, but not completely

(White 1980). If the growing of structure is hierarchical it could be an anti-correlation between [Z/H] gradients and mass.

Relation between SP gradients and other structural properties of galaxies

*Galactic winds: negative [Z/H] gradient, positive [E/Fe] local [Z/H] correlated with the local potential

(Franx & Illingworth 1990; Martinelli et al. 1998, Pipino & Matteucci 2006)

Gradients of SP: the sample

- ✓ 11 early-type galaxies (10 E 1 S0) covering a wide range in luminosity
- ✓ Observed with Keck (S/N in the external bins (at ≈ 2 r_{eff}) of 55 per Å)

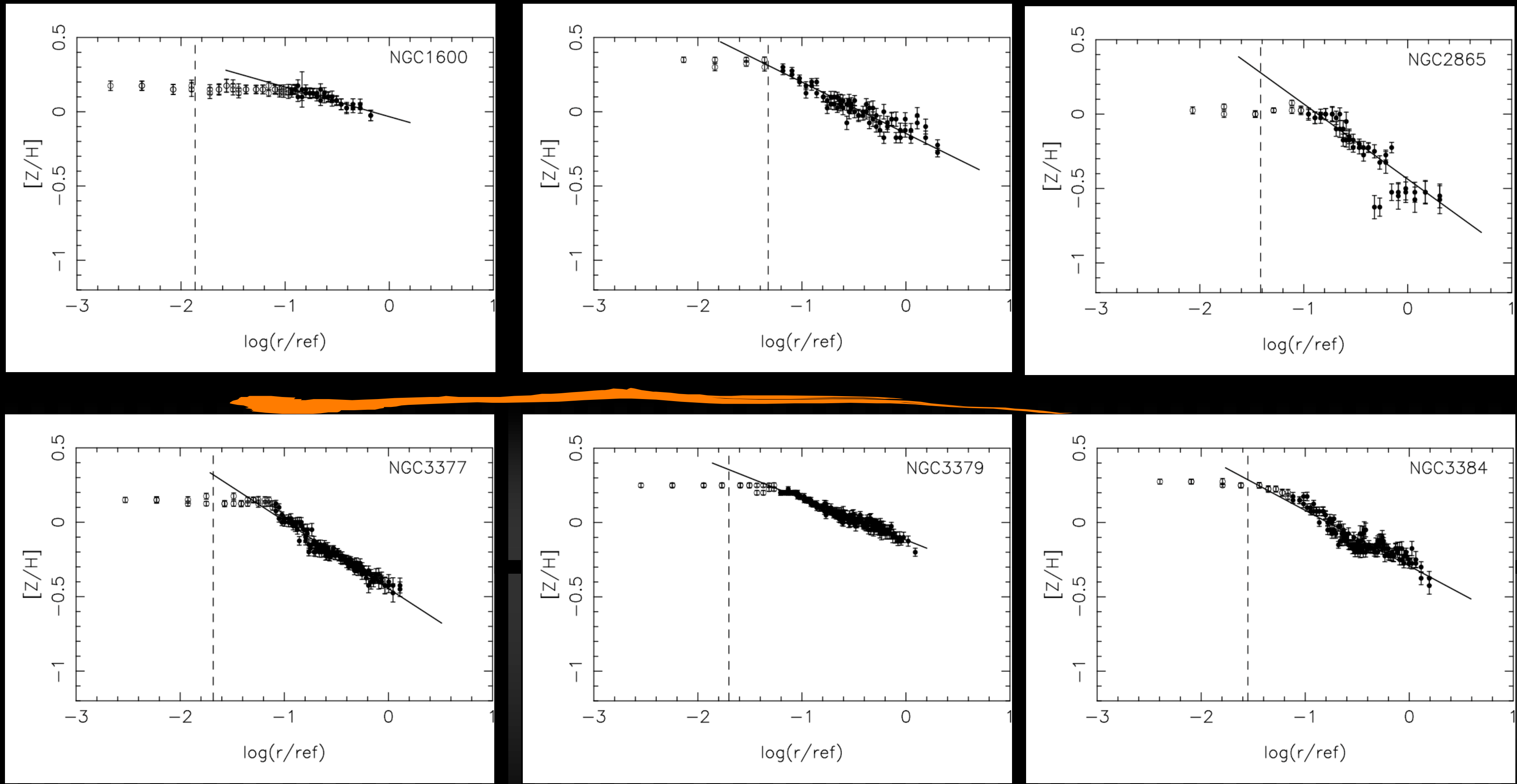
Derivation of Stellar population parameters

χ^2-minimization with 11 Lick/IDS indices using TMB03.

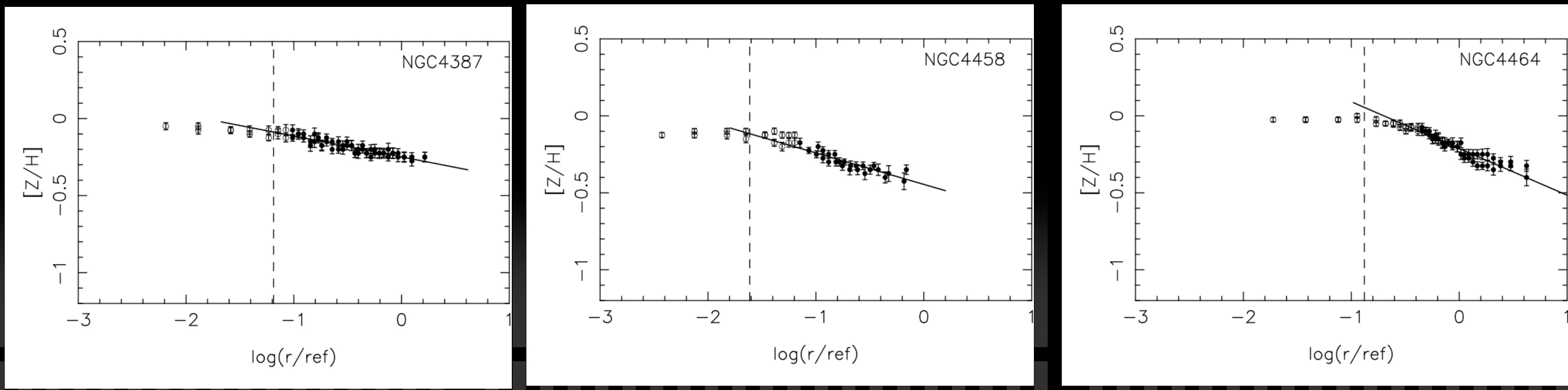
Comparison with other techniques and models

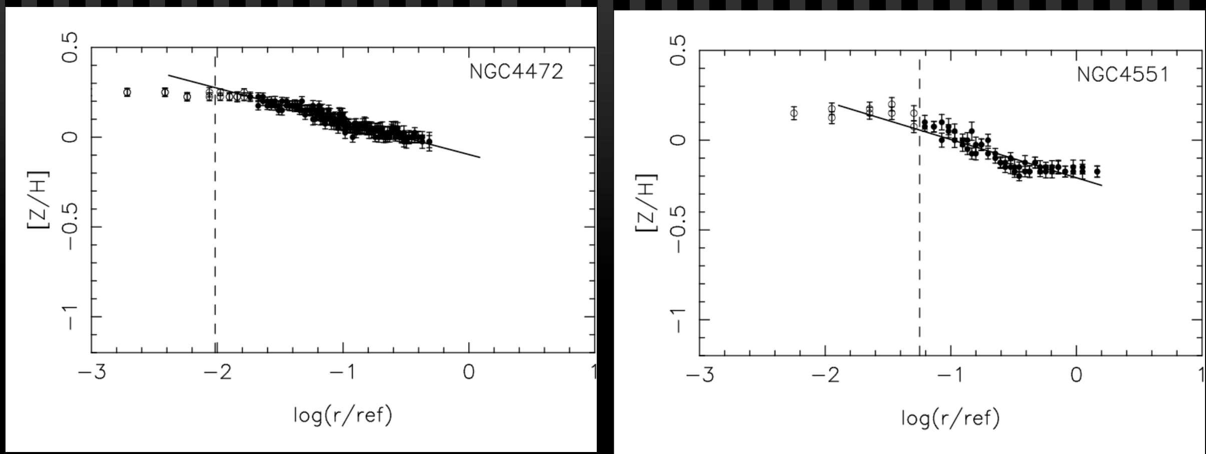
Fit 3 indices, different partitions of [E/Fe], Vazdekis et al. 2007 and BC03 with Trager et al. (2000) method ...

[Z/H] gradients



[Z/H] gradients

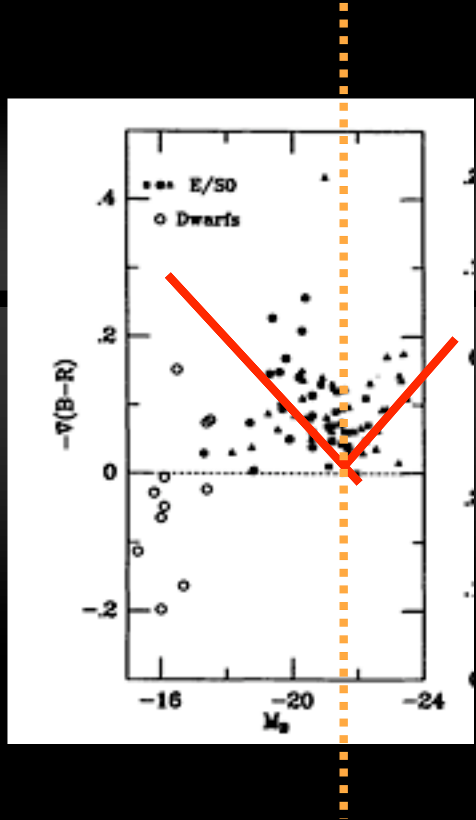




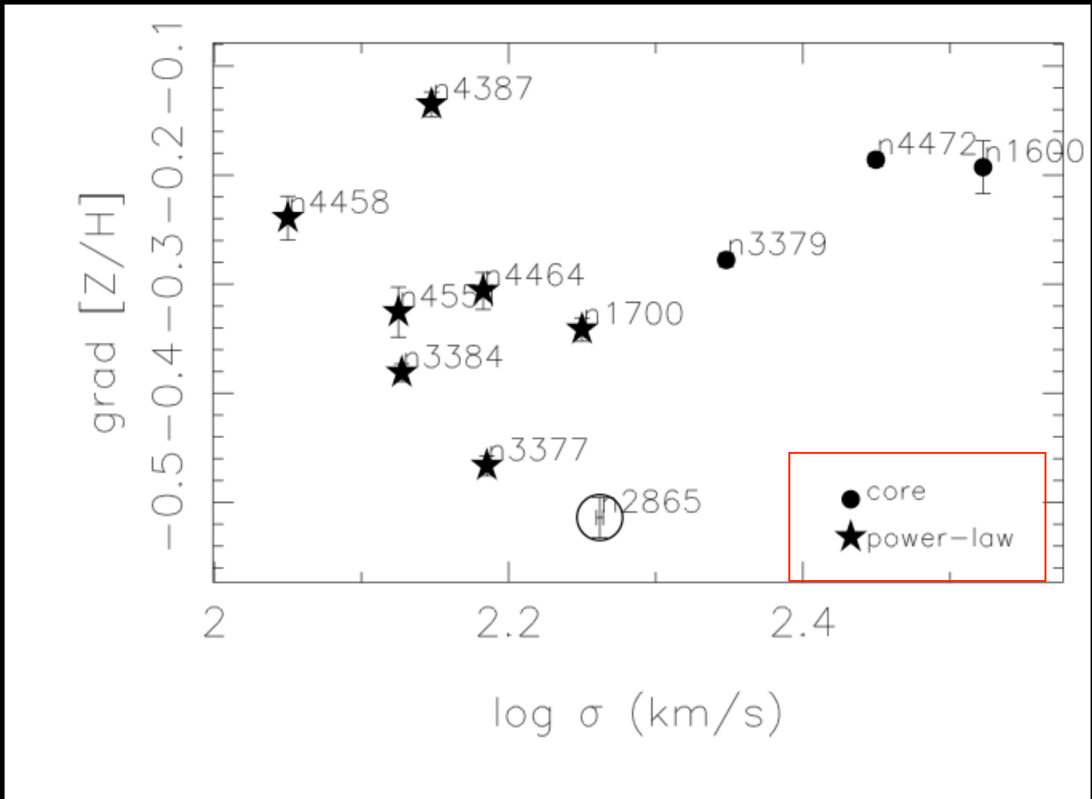
Mean: 40% variation
In metallicity

Color gradients vs. M_B

Kormendy & Djorgovski 1989



Grad [Z/H] vs. central σ



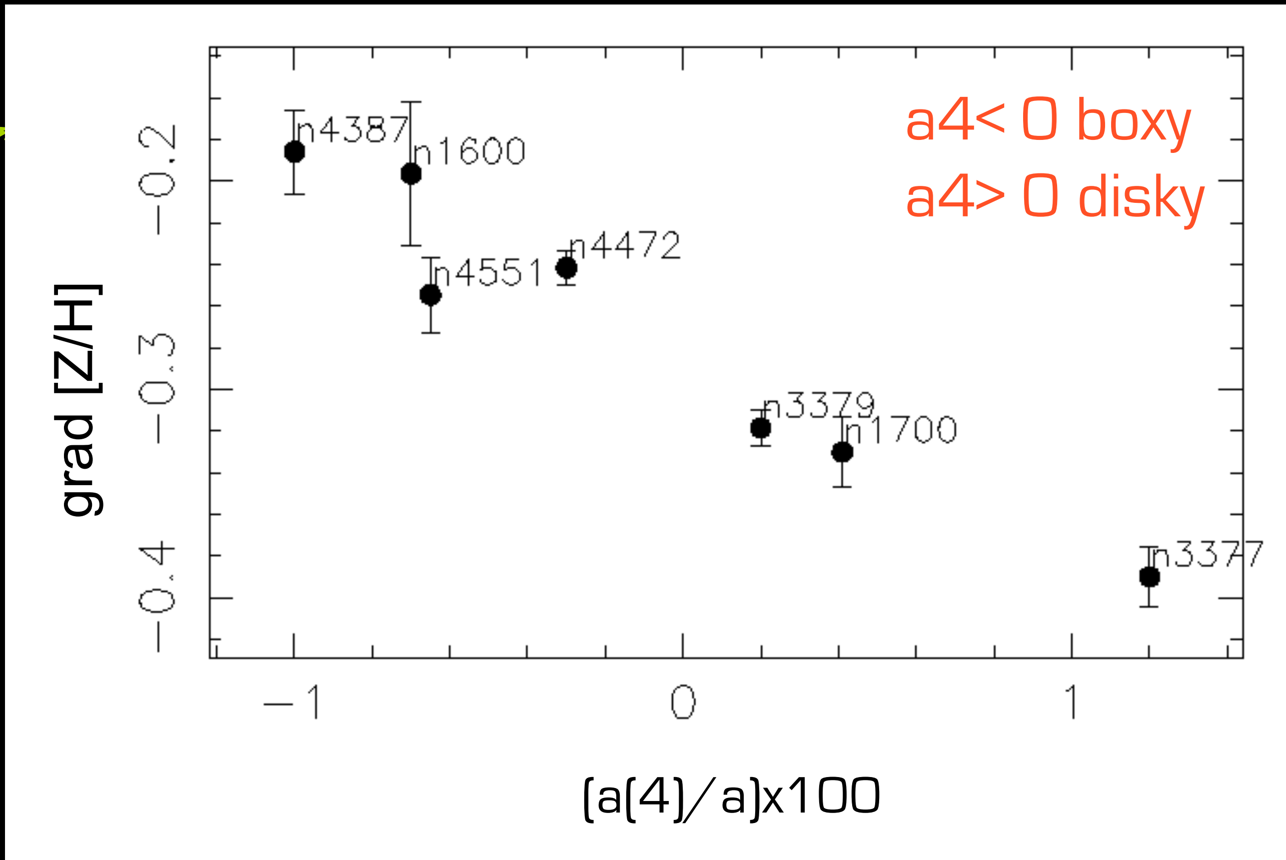
Colors gradients and line-strength gradients are steeper in ETG with:

$M \approx 10^{11} M_{\odot}$
$\sigma \approx 200$ km/s
$M_B \approx -20.5 - 21.5$

(Vader 1988; Carollo et al. 1993; Kormendy & Djorgovski 1989)

- Transition between dry/and wet mergers? (Faber et al. 2005) Schawinski et al. 2006

Metallicity gradient vs. isophote shape

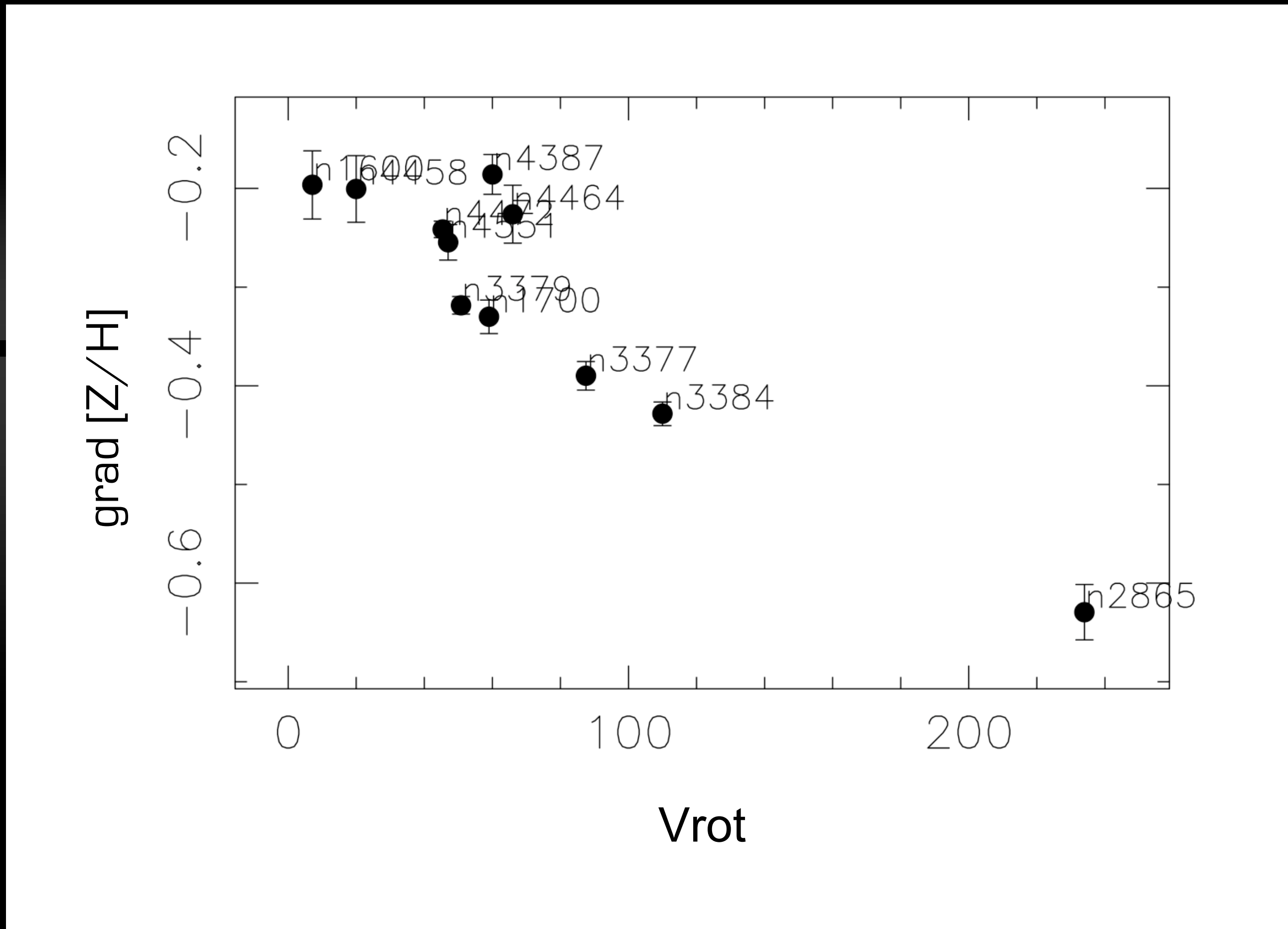


a4

Dissipation during the interaction (Bekki & Shioya 1999)

See Vader et al. (1998)

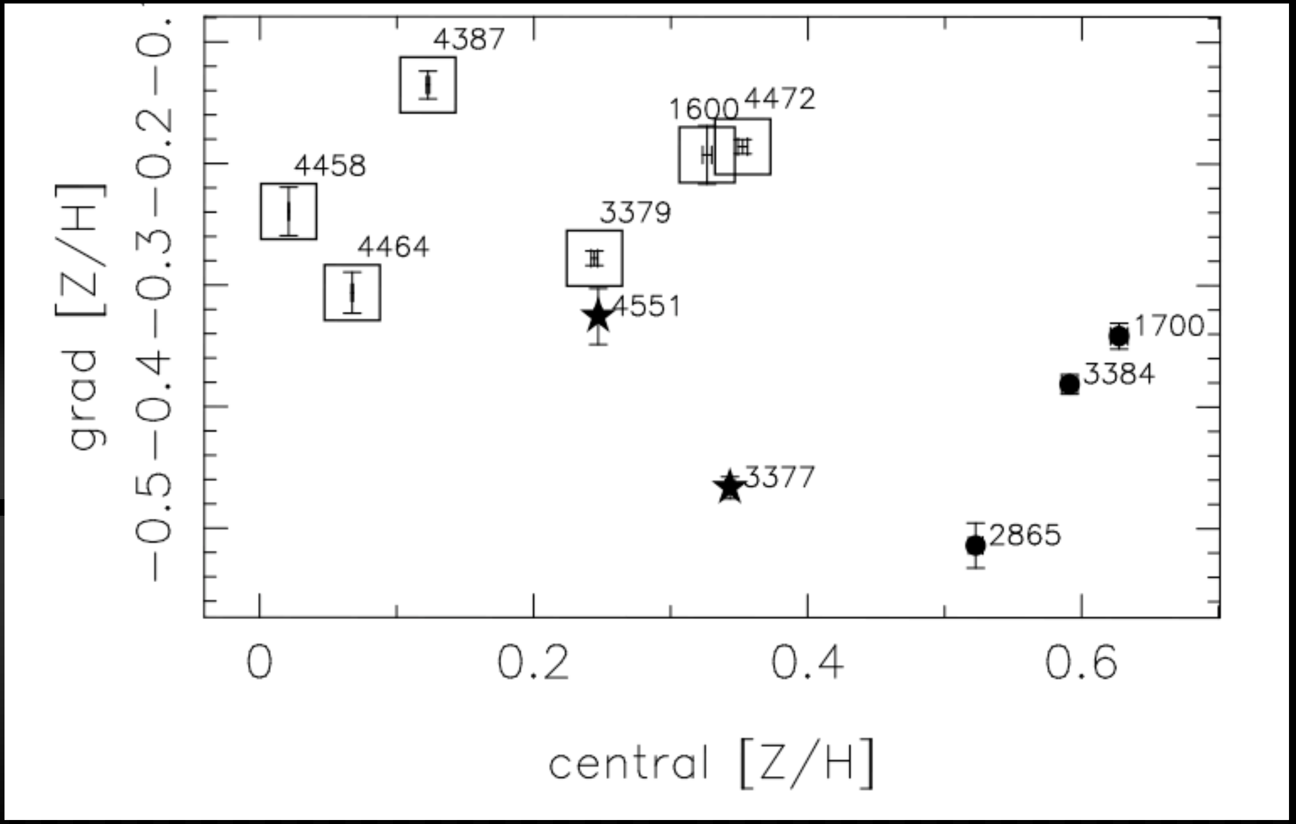
Metallicity gradient vs Vrot



Relation between gradients and central values

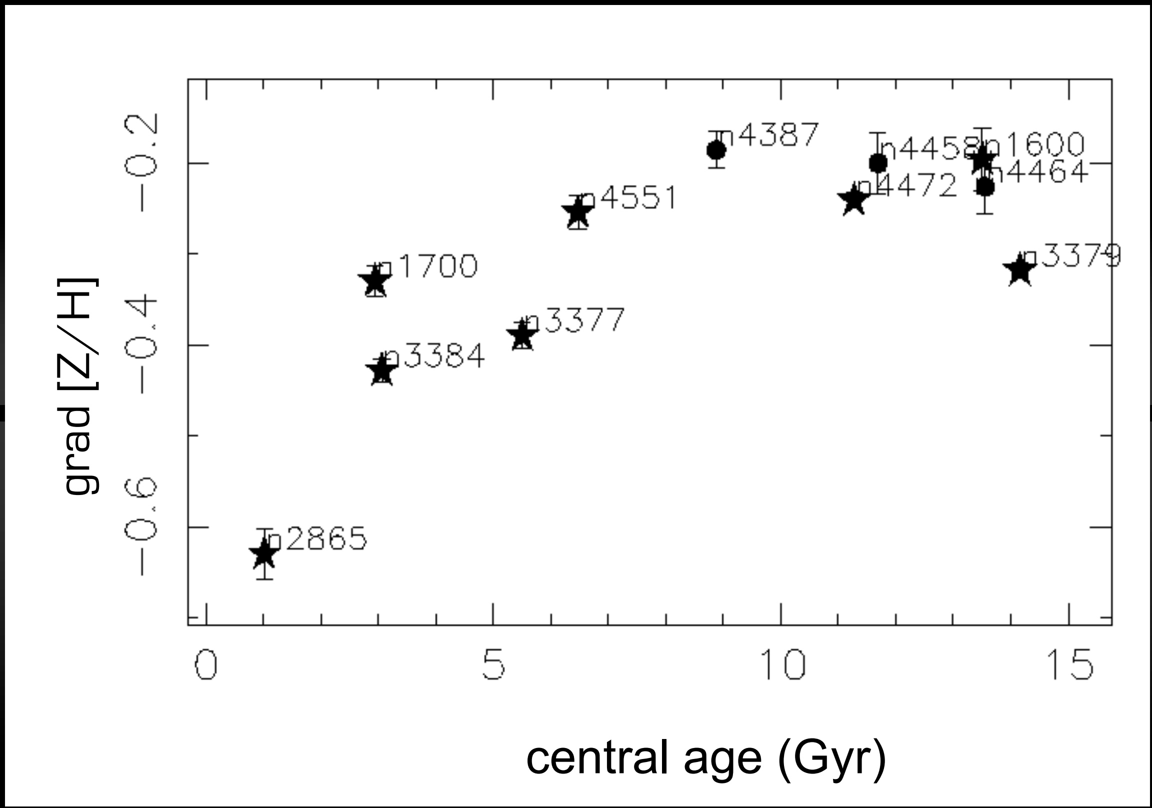
yes:
Gonzalez & Gorgas (1995)
Kuntschner et al. (2006)

No: Kobayashi & Arimoto (1999)
Mehlert et al. (2003)

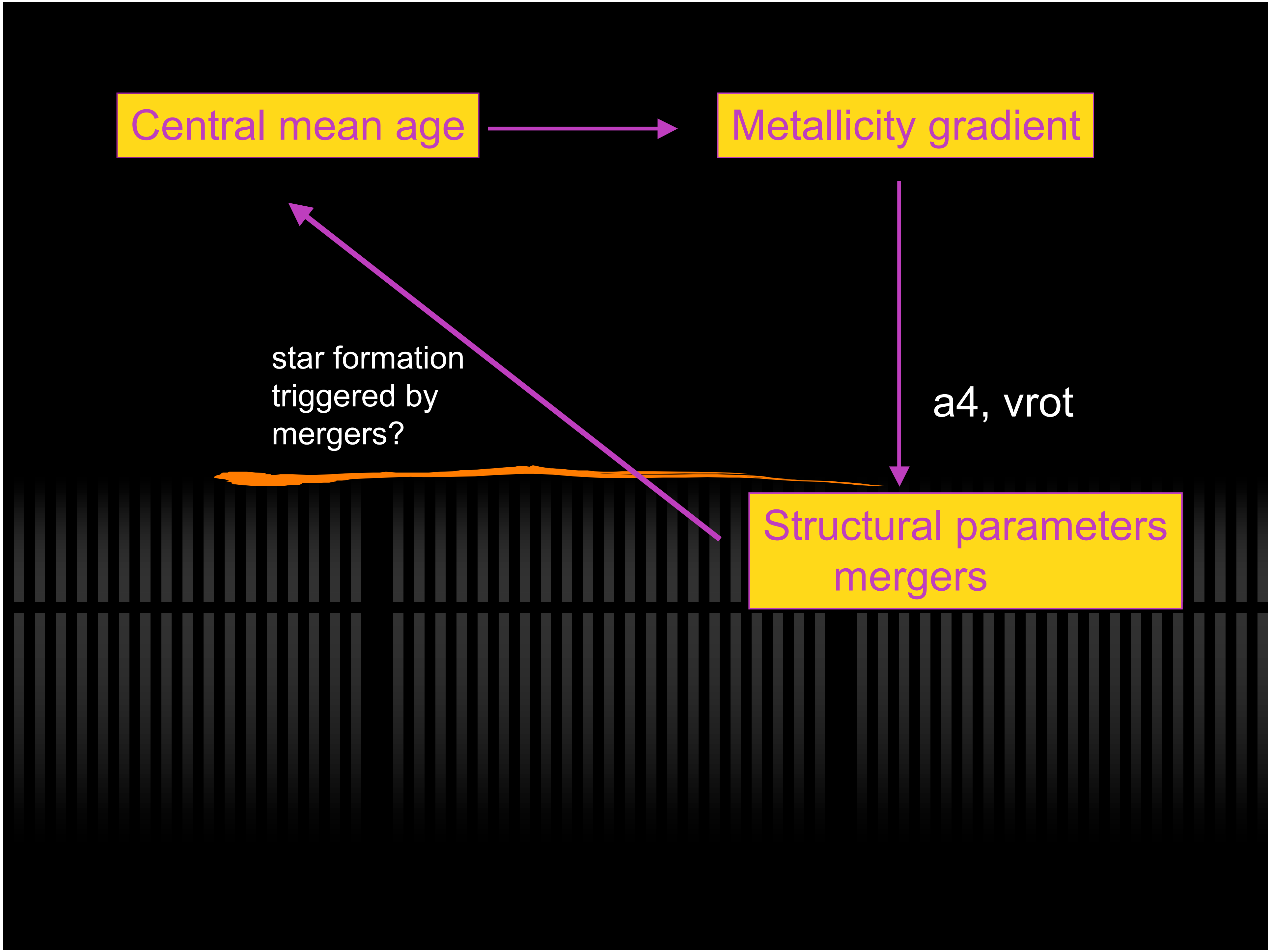


The relation have implications for the interpretation of, e.g., the Color-magnitude diagram

Relation between [Z/H] gradients and central values



Circles: [Fe/H] > +0.2
Stars: [Fe/H] < +0.2


Central mean age
Metallicity gradient
a4, vrot
star formation
triggered by
mergers?
Structural parameters
mergers

[E/Fe] gradients: Predictions

*Martinelli et al . 1998; Tantalo et al. 1998; Pipino et al. 2006: Collapse with dissipation or merger of gaseous clumps :

Positive and rather steep [E/Fe] gradients (outside-in formation).

* Fully cosmological E with SN and AGN feedback of a single galaxy with σ=250 km/s (Gibson et al. 2006)

Positive, although shallower than in the above predictions, [O/Fe] gradient d[O/Fe]/dlog r=+0.1.

*Chemodynamical evolution of 124 ellipticals (SN and AGN feedback) with merging histories from major mergers to monolithic collapse.

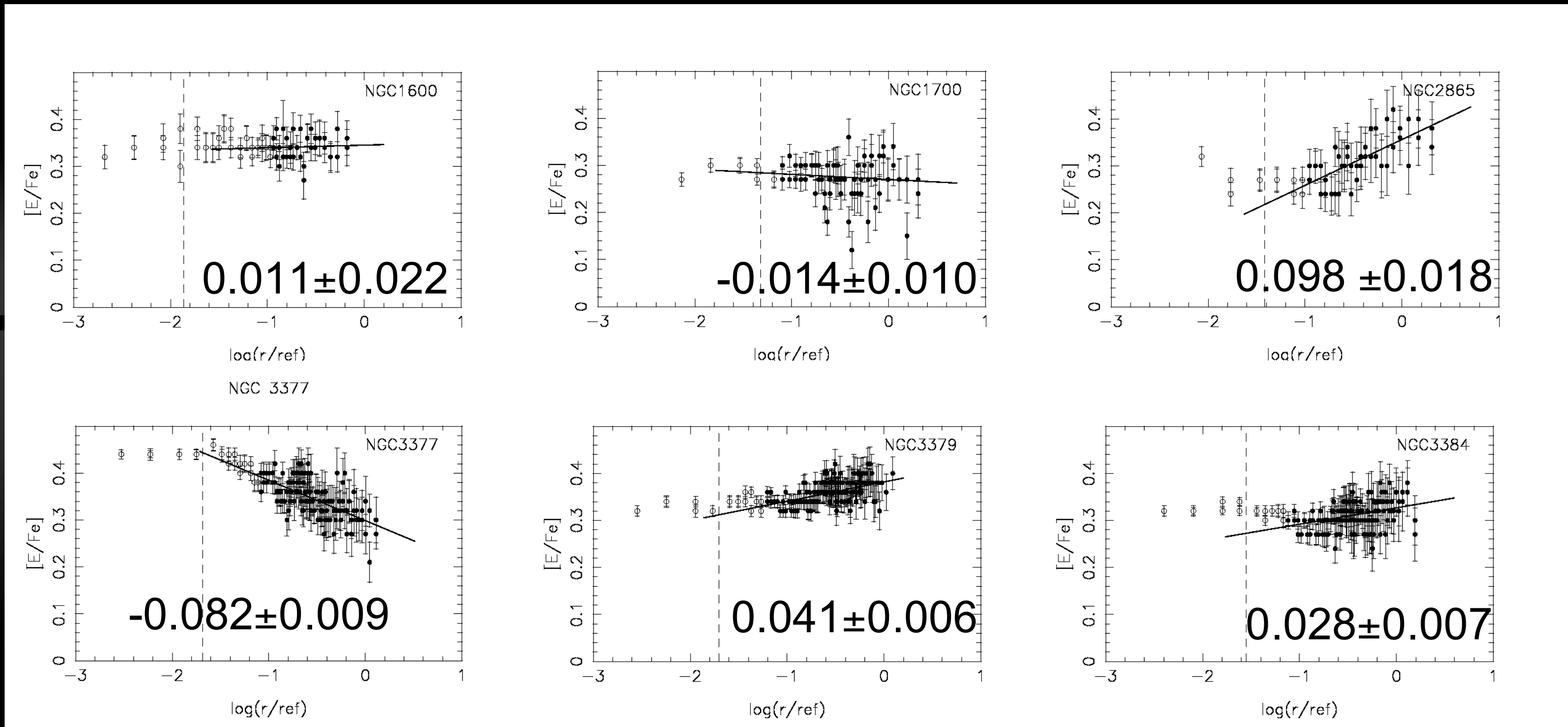
(Kobayashi 2004); Positive [O/Fe] gradients.

(not much difference between the [O/Fe] of galaxies which have and have not suffered major mergers)

All of them obtain the mean [E/Fe] weighting the [E/Fe] of the individual stars with the V luminosity .

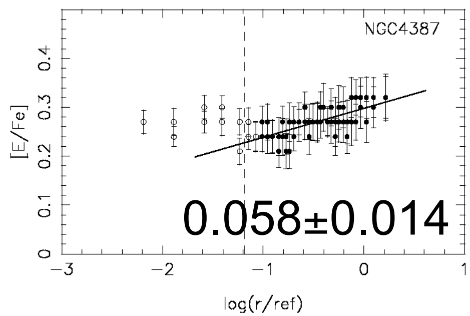
Where E means Enhanced: O, Ne, Mg, Si, S, Ar, Ca, Ti, N, Na

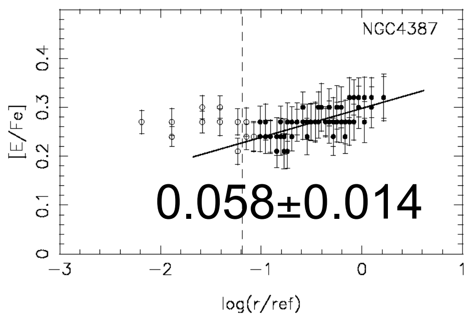
[E/Fe] gradients

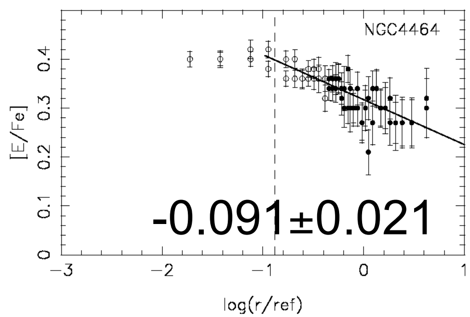


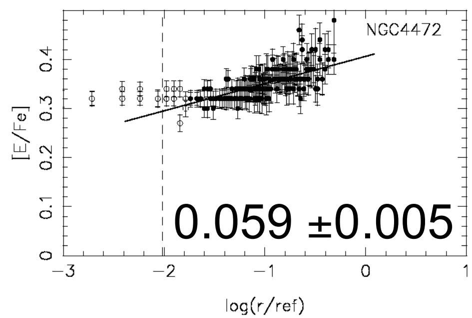
Enhanced: O, Ne, Mg, Si, S, Ar, Ca, Ti, N, Na

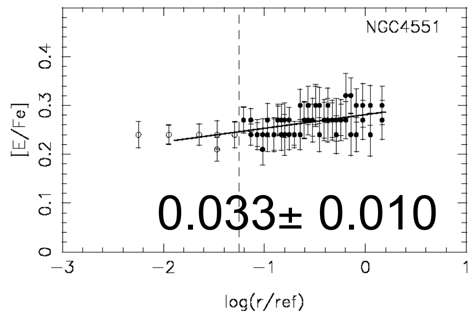
[E/Fe] gradients



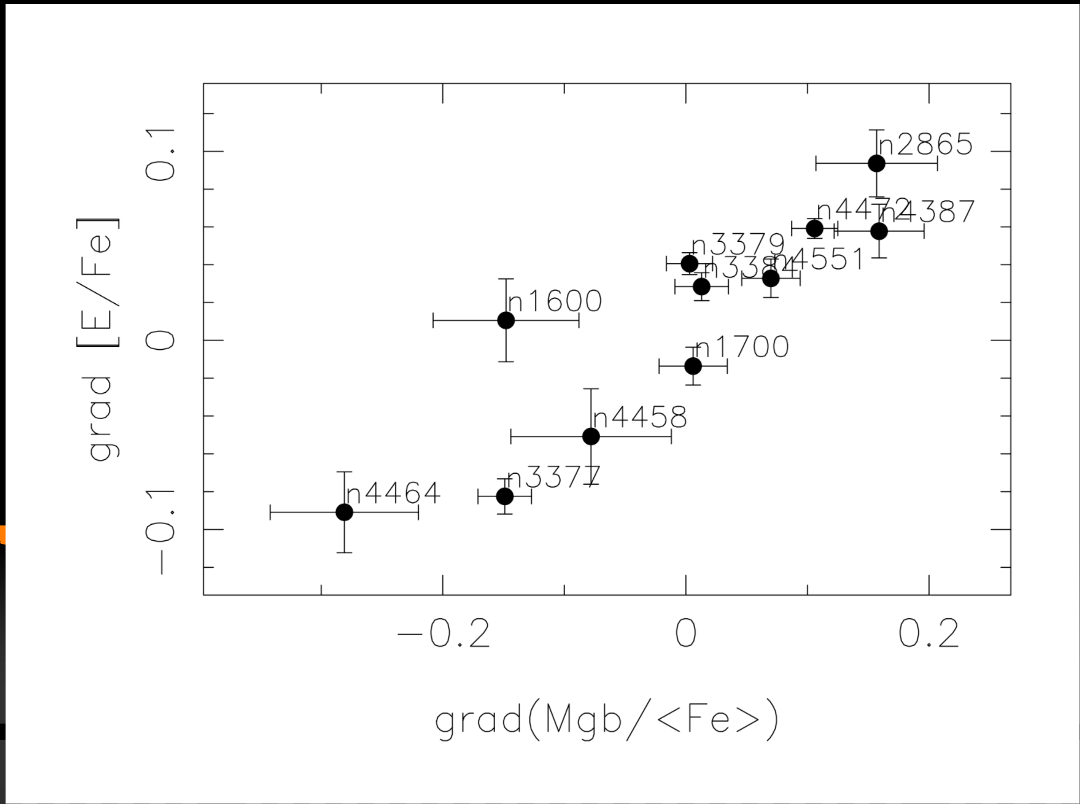






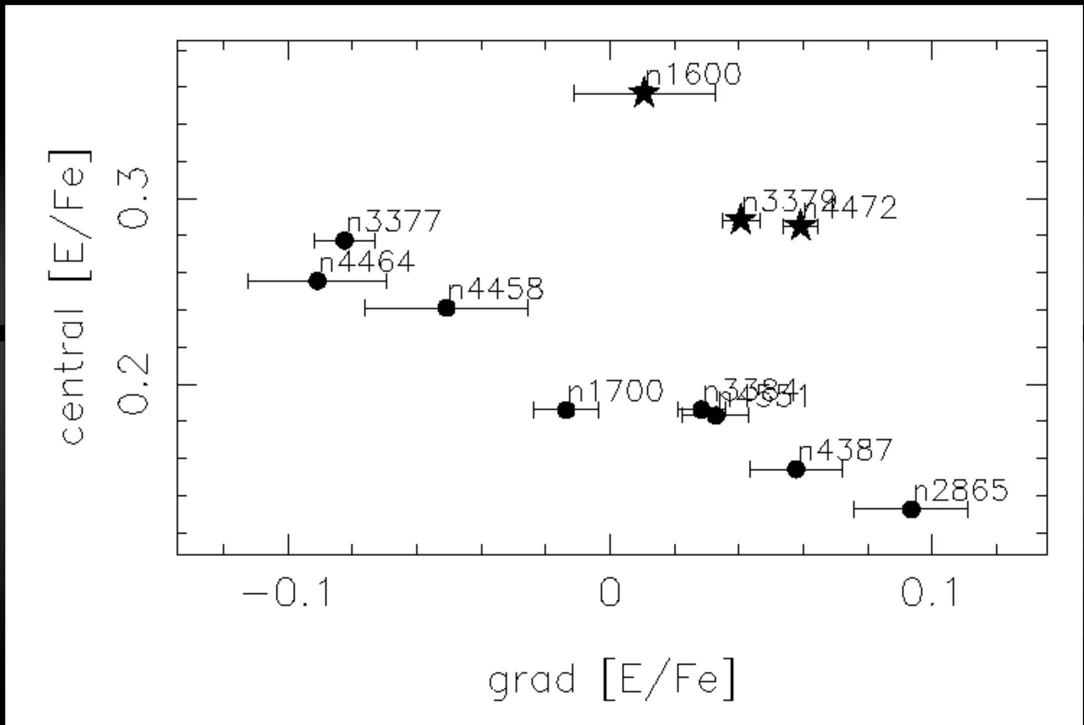


- Simple outside-in scenarios are not valid for all our galaxies
- Duration of SF is not the only parameter controlling gradients.



n2865
n4472
n4387
n3379
n3384
n4551
n1600
n1700
n4458
n3377
n4464
0.1
0
−0.1
−0.2
0
0.2
grad [E/Fe]
grad(Mgb/<Fe>)

Correlation of [E/Fe] gradient with the central value



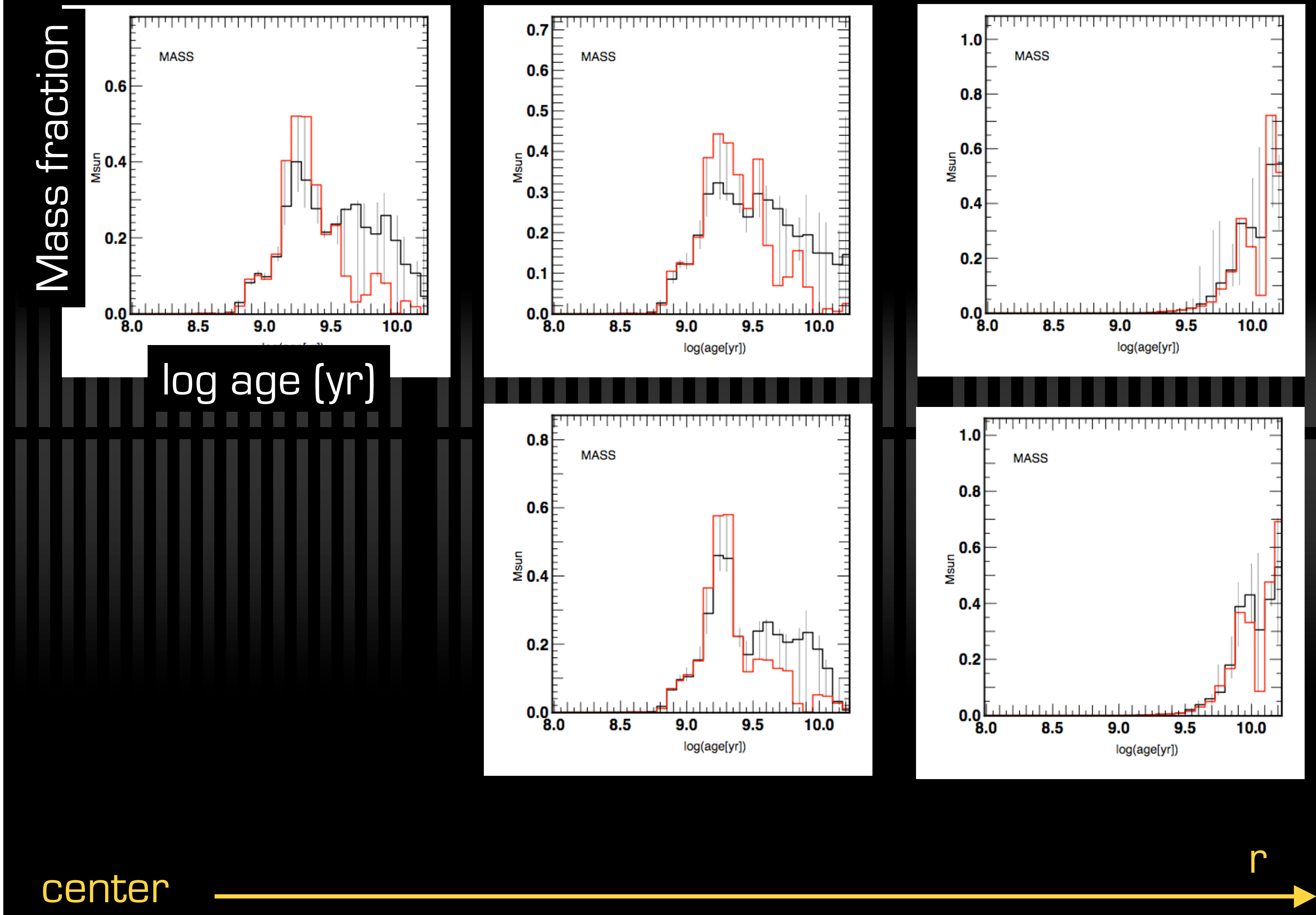
Stars: core galaxies (σ> 200 km/s)
Circles: power-law galaxies (σ< 200 km/s)

STECMAP (Ocvirk et al. 2006a,b)
(STEllar Content via Maximum A Posteriori)
-non-parametric method
http://astro.u-strasbg.fr/obs/GALAXIES/stecmap_eng.html

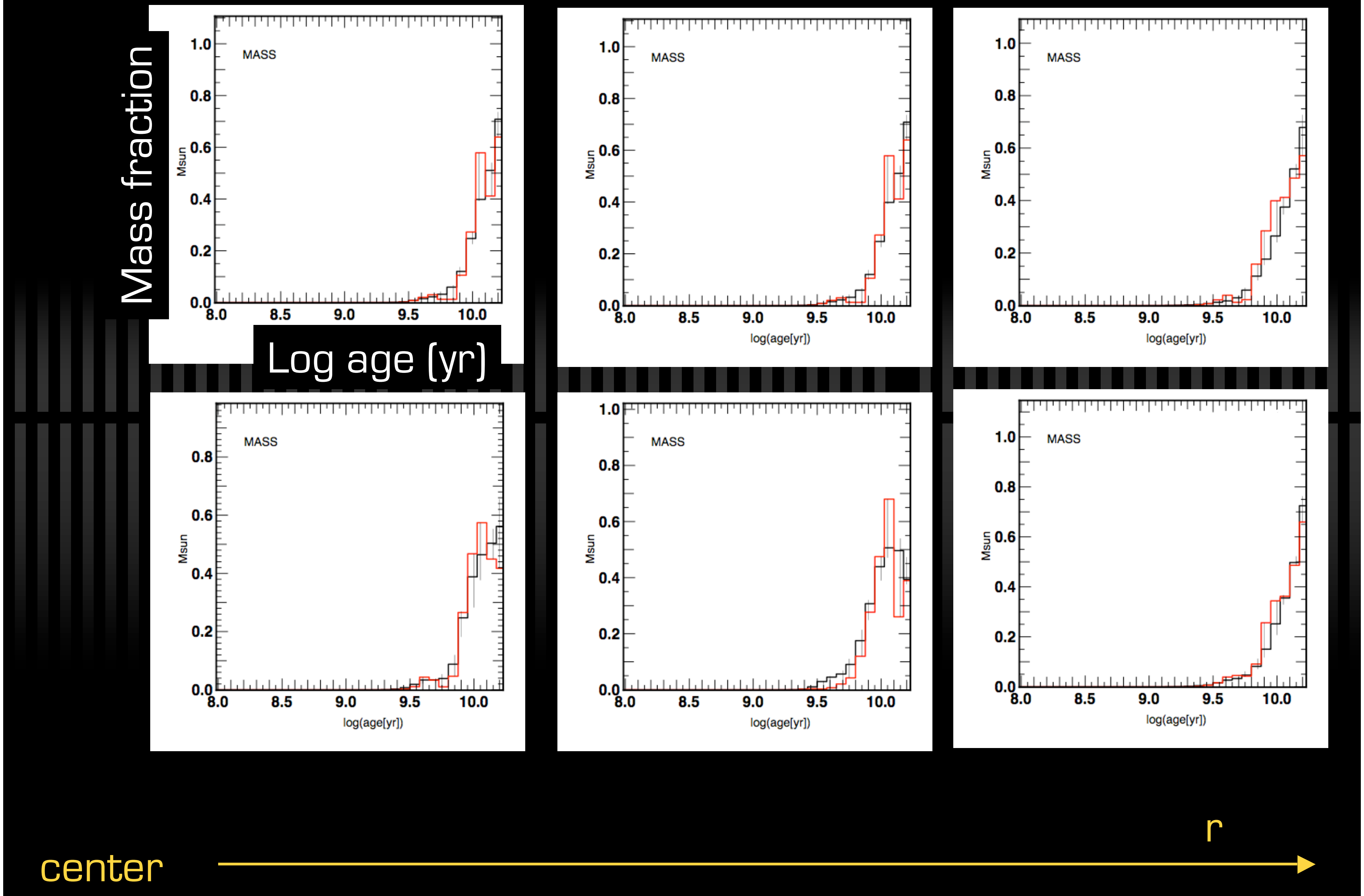
Vazdekis et al. (2007) (MILES) (3500-5100 Å)

SFH along the radius

NGC 2665



NGC 1600



General conclusions

(1) The negative [E/Fe] gradients and the lack of correlation between grad[E/Fe] and grad[Z/H] discard galactic winds as the only mechanism to produce gradients for all the galaxies.

(2) The relation of the gradients with mass, a4, Vmax and the shape of the LOSVD seems to indicate that elliptical galaxies formed through mergers with a systematic decrease, with mass, of the degree of dissipation during these interactions.

(3) The relation between the stellar population parameters in the center and along the radius suggests that the relative recent episodes of star formation that have been observed in the center of a large fraction of E galaxies (Gonzalez 1993; Caldwell et al. 2003, Trager et al. 2000, Sanchez-Blazquez et al. 2006) have been triggered by mergers.

(4) More data of high quality needed!!

Stellar populations od red galaxies in clusters since z~0.7 EDisCS

- ✓ Las Campanas Survey

  18.6 < I < 22 at z~0.5

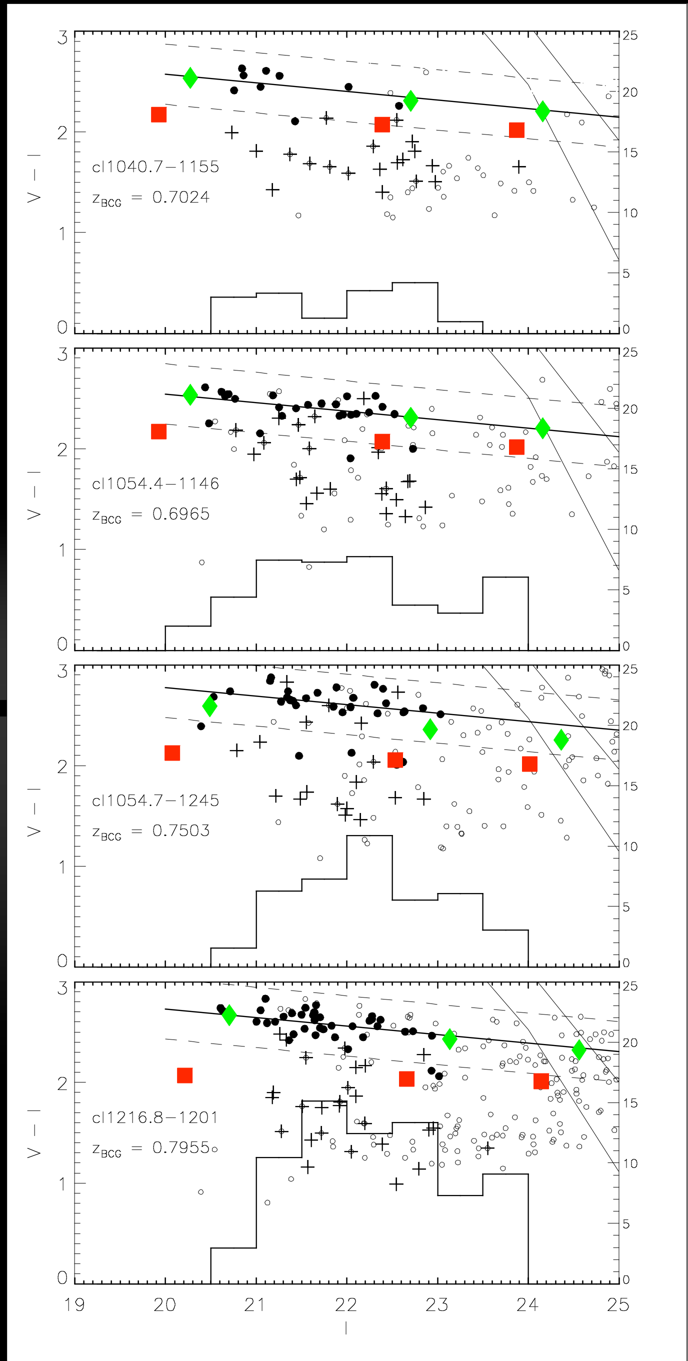
  19.5< I < 23 at z~0.8

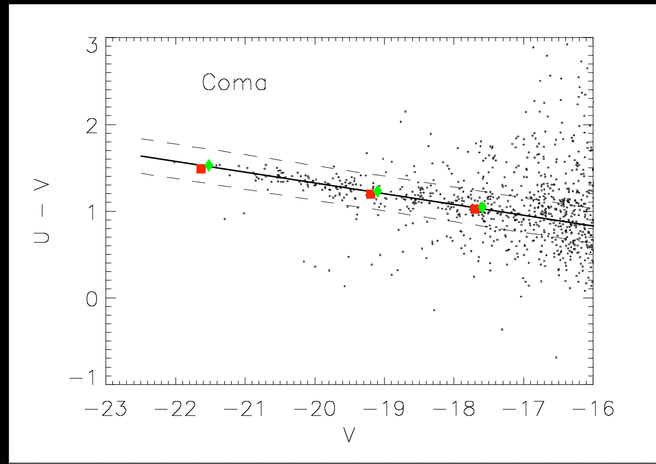
excluding:

- zclus – 0.2 < zphot < zclus + 0.2
- objects with a photometric sed with very high probability of being a star.

uclan

Single burst at z=3
Exponentially declining
SF starting at z=0.3 with t=1

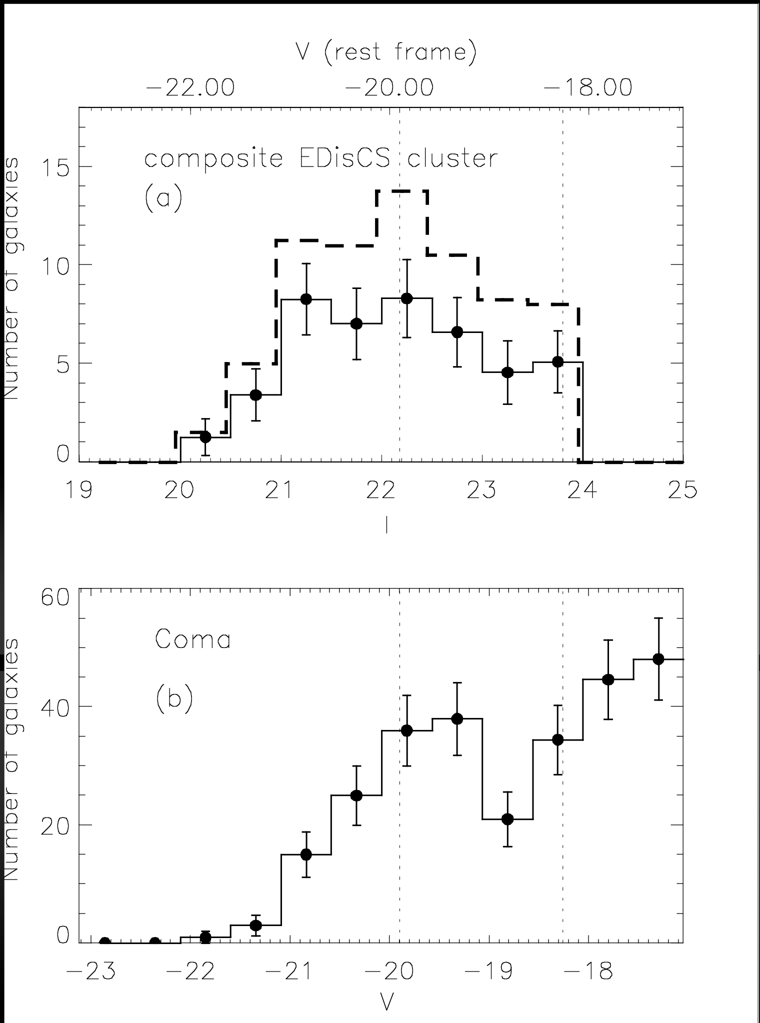




De Lucia et al.
2004 ApJ Letter

Data from Terlevich et al. (2001)

Smail et al. 1998; Kajisawa et al. 2000, Nakata et al. 2001, Kodama et al. 2004



De Lucia et al. 2004 ApJL

-- Defining as "faint" galaxies 0.4 < L/L* < 0.1 (5σ detection limit), the luminous-to-faint ratio on the red sequence is 0.34±0.06 in Coma and 0.81±0.18 in EDisCS

-- The effect is seen also in the single-cluster distributions, despite of the variety of cluster properties: such a deficit may be a universal phenomenon in clusters at these redshifts

A deficiency of red galaxies at faint magnitudes compared to Coma

-- A synchronous formation of stars in all red sequence galaxies is ruled out, **and** the comparison with Coma quantifies the effect as a function of galaxy magnitude

-- A large fraction of the red faint galaxies has moved onto the red sequence relatively recently, having their SF presumably ended at z<0.8

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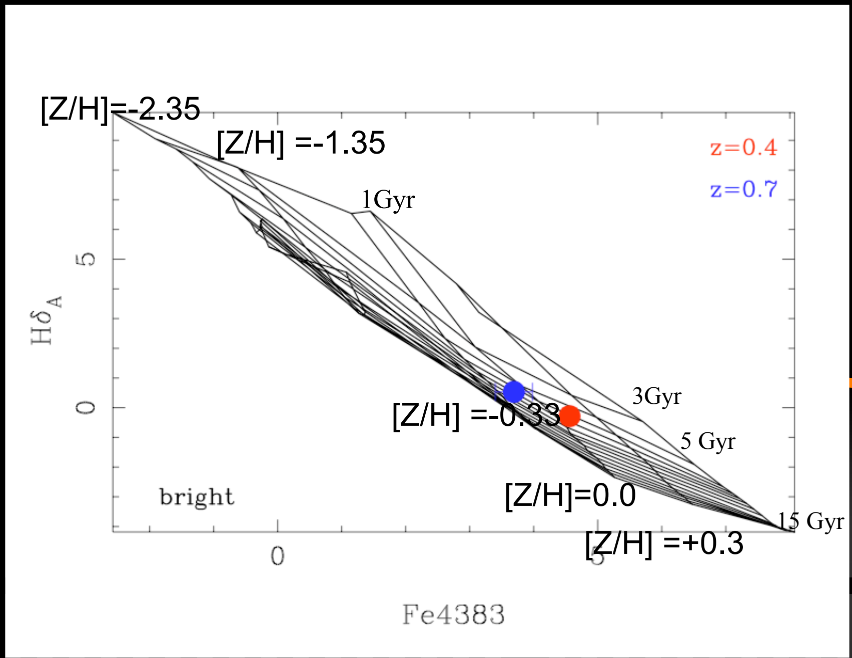
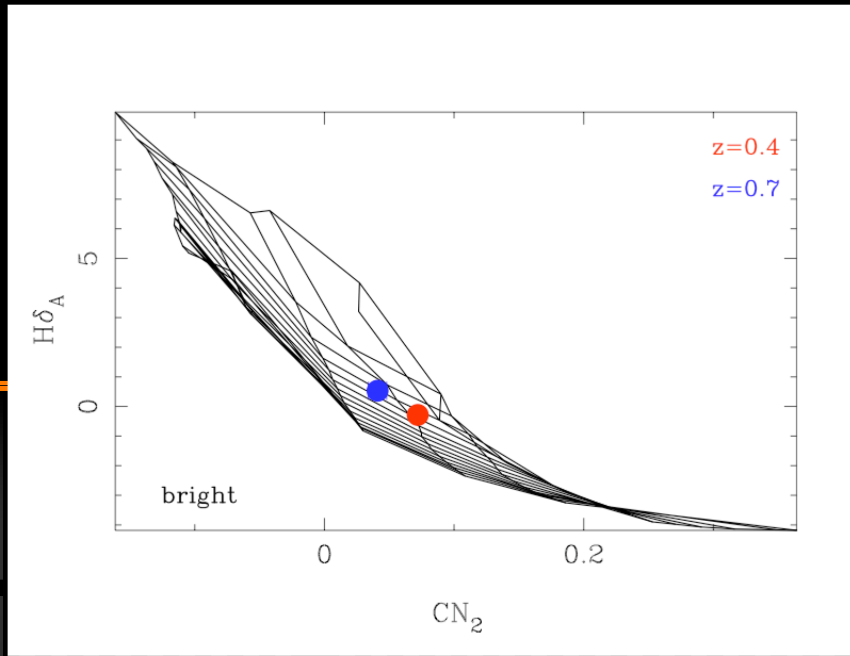
Is the bright end of the red sequence completely formed at z~0.7?

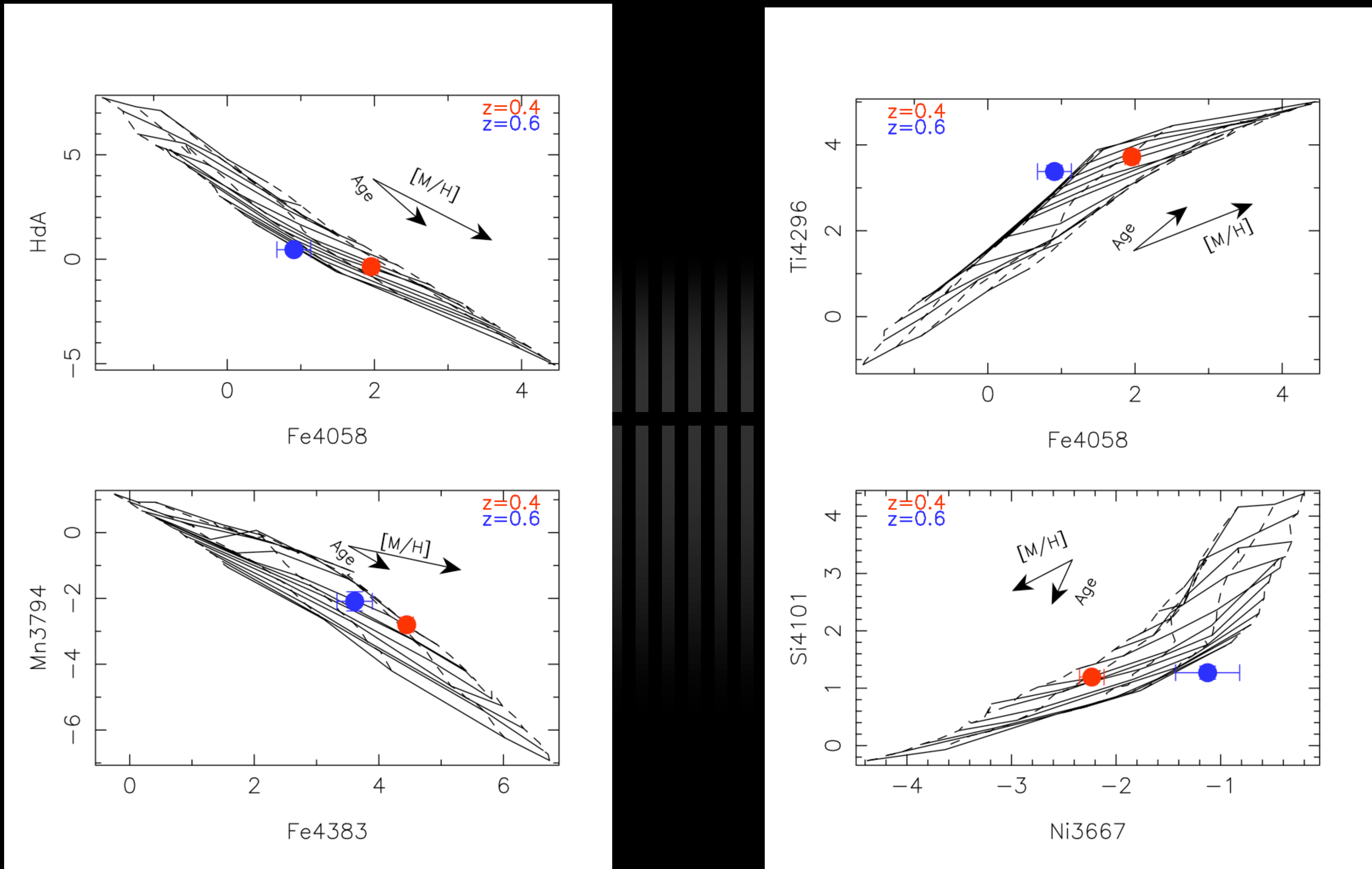
Index-index diagrams





Thomas et al. (2003) models

Other indices



Models by Vazdekis et al. (2006)

Indice definition by Serven et al. (2005)

Still work in progess…

- ✓ Not all the bright galaxies were already in the red sequence at z~0.7

- ✓ Keep tuned..