Unresolved stellar populations in the E-ELT era

Patricia Sánchez-Blázquez (UAM)

Unresolved Stellar populations in the E-ELT era

The ELT will have to main advantages relative to today’s 10m-class telescopes:
-Much higher sensitivity
-Much higher spatial resolution

Studying unresolved stellar populations

The study of stellar populations is one of the most relevant diagnostic to constrain galaxy formation and evolution.

Quantitative analyses of the stellar content of galaxies pave the way to ‘convert’ starlight into physical quantities like stellar masses, chemical abundances and star formation histories, and to trace the evolution and chemical enrichment of galaxies.

The goal of stellar population studies is to extract these variables from the observed SED.

Archaeology

"The scientific study of past human cultures by analyzing the material remains (sites and artifacts) that people left behind"

Astro-Archaeology

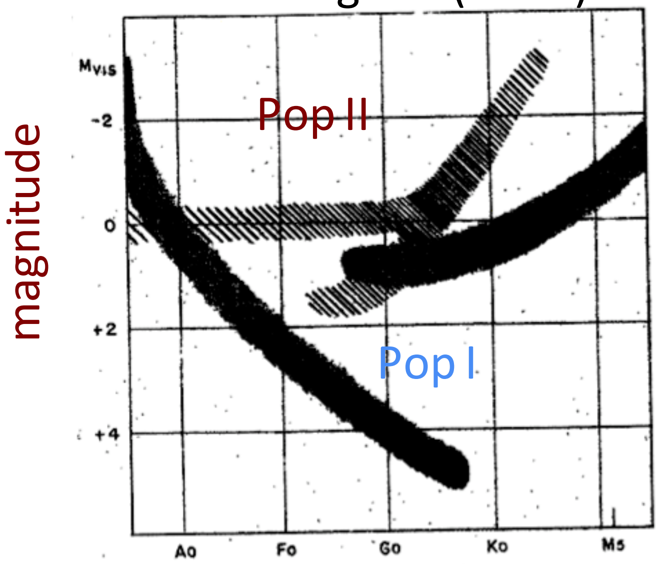
"The scientific study of past galaxies history by analyzing the material remains (old stars)"

The Concept of Stellar Populations

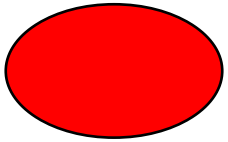
Population I (eg. Open clusters)

Population II (eg. Globular clusters of our galaxy)

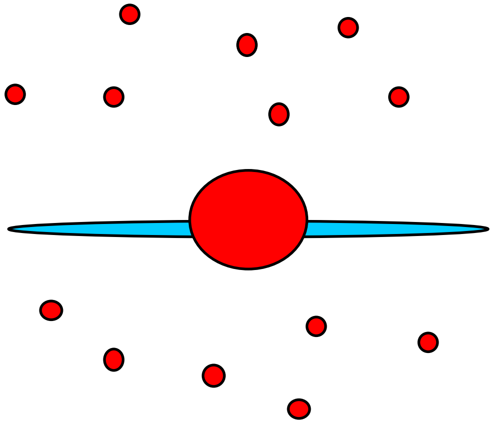
The HR diagram (1910)



spectral type



Early-types only have Pop II



Both populations coexist in spirals

Walter Baade 1944

- *Evolution of galaxies and its significance to cosmology* (Tinsley 1974)

(Tinsley 1968; Tinsley & Gunn 1976; Faber et al. 1972; Searle et al. 1974)

A quick Tour

Main Sequence (MS):

Core hydrogen burning phase. Longest phase of evolution

Turn-Off:

Hydrogen exhausted in core.

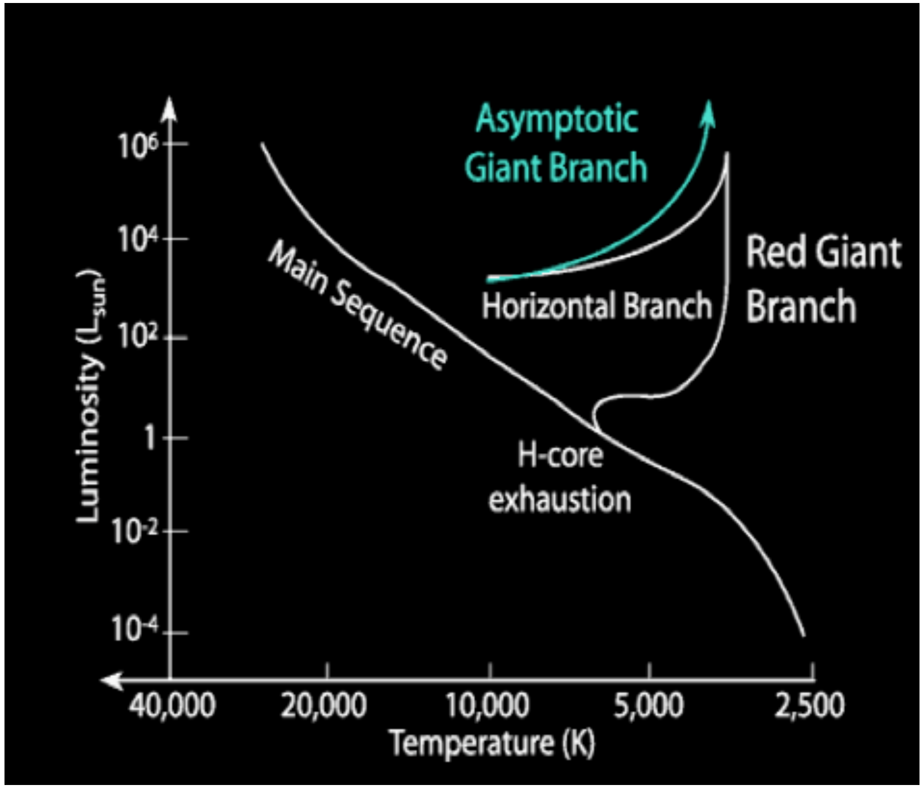
Red Giant Branch (RGB):

Hydrogen Burning in shell around inert helium core.

RGB tip: end of the RGB

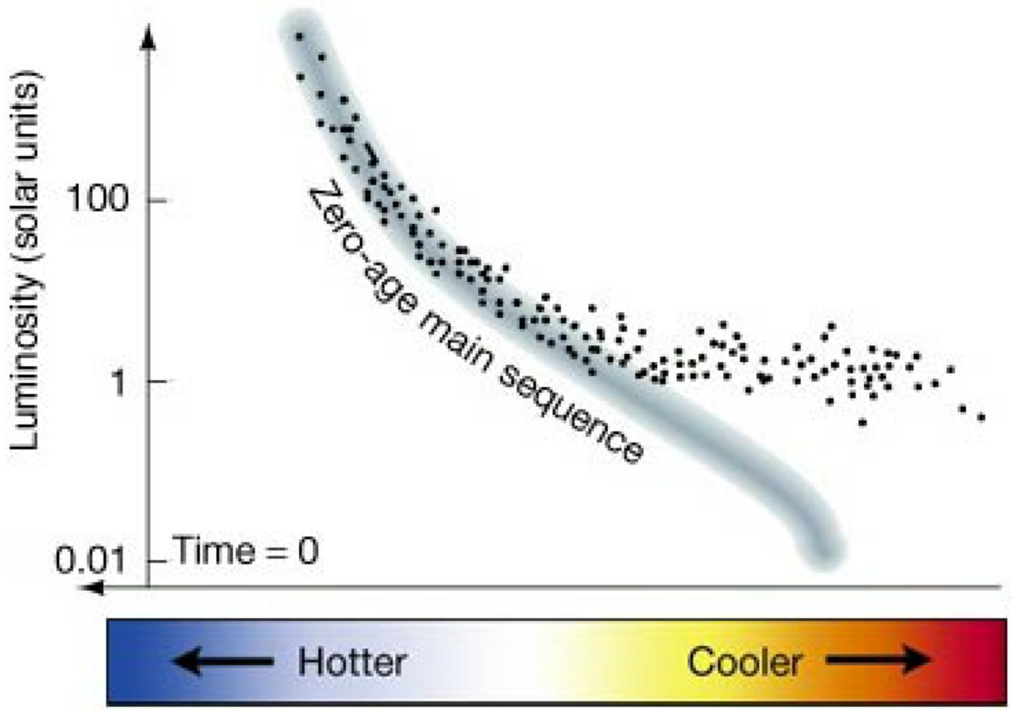
HB (RC): Helium burning in the core (details depends on the mass loss)

Asymptotic Giant Branch (AGB): He burning in shell around an inert C/O core. Complicated mass dependent evolution from now on.



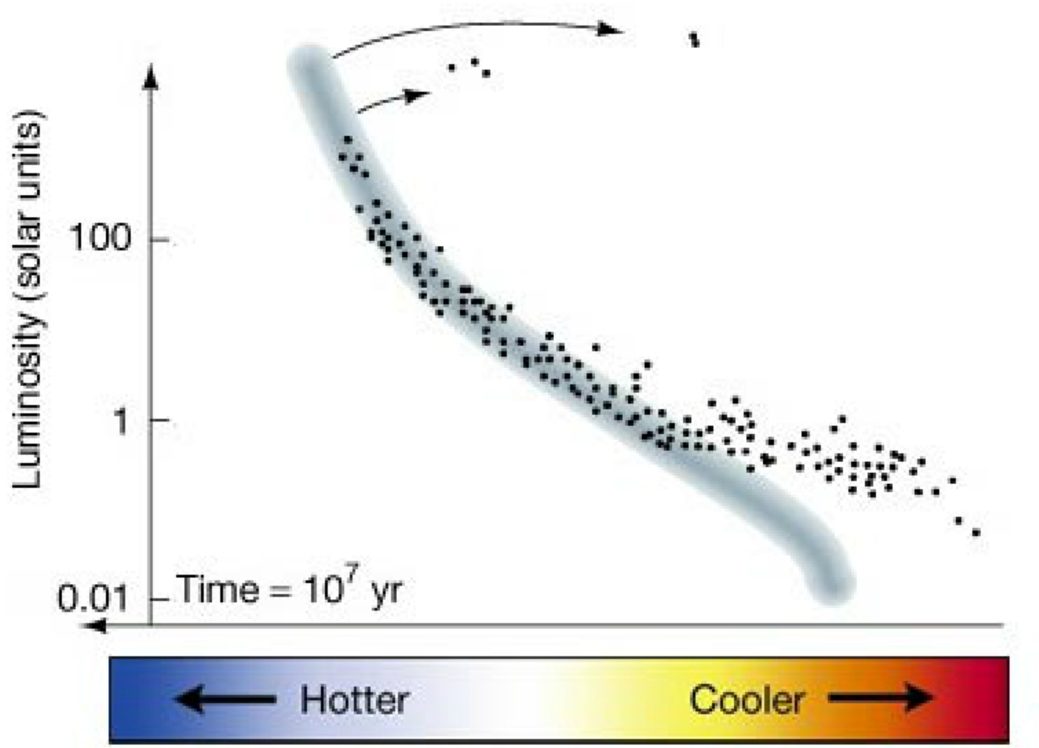
The evolution of the HR diagram

Most of the high mass stars have reached the Main Sequence, while some of the lower mass stars are still in the T Tauri phase



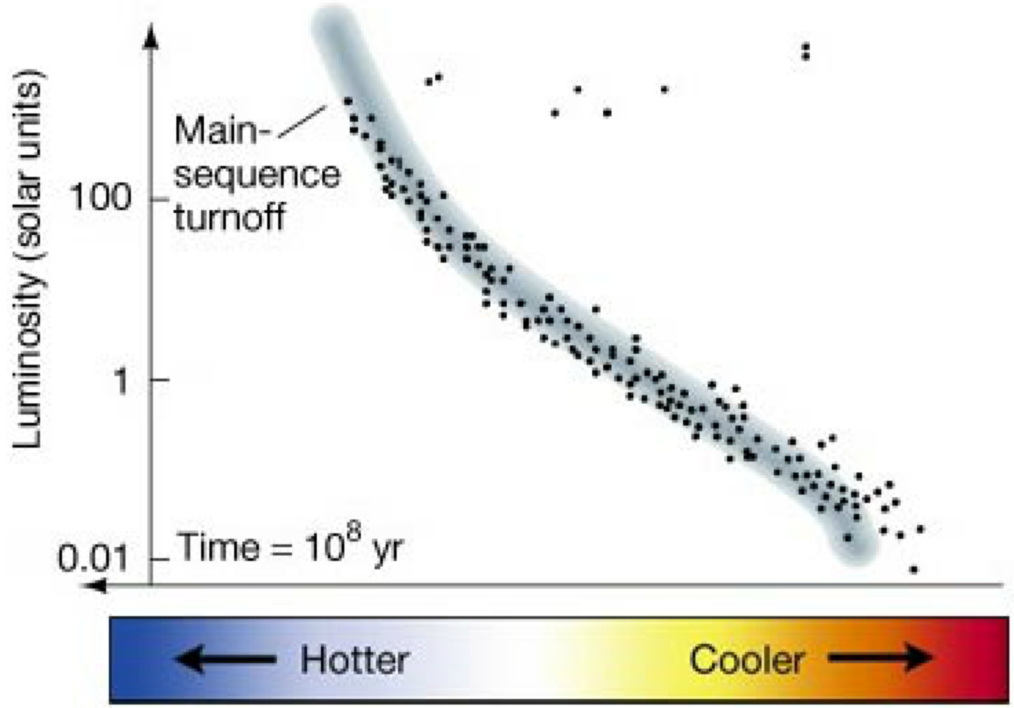
The evolution of the HR diagram

The highest mass O stars have used up all of their hydrogen and begin to evolve off the Main Sequence



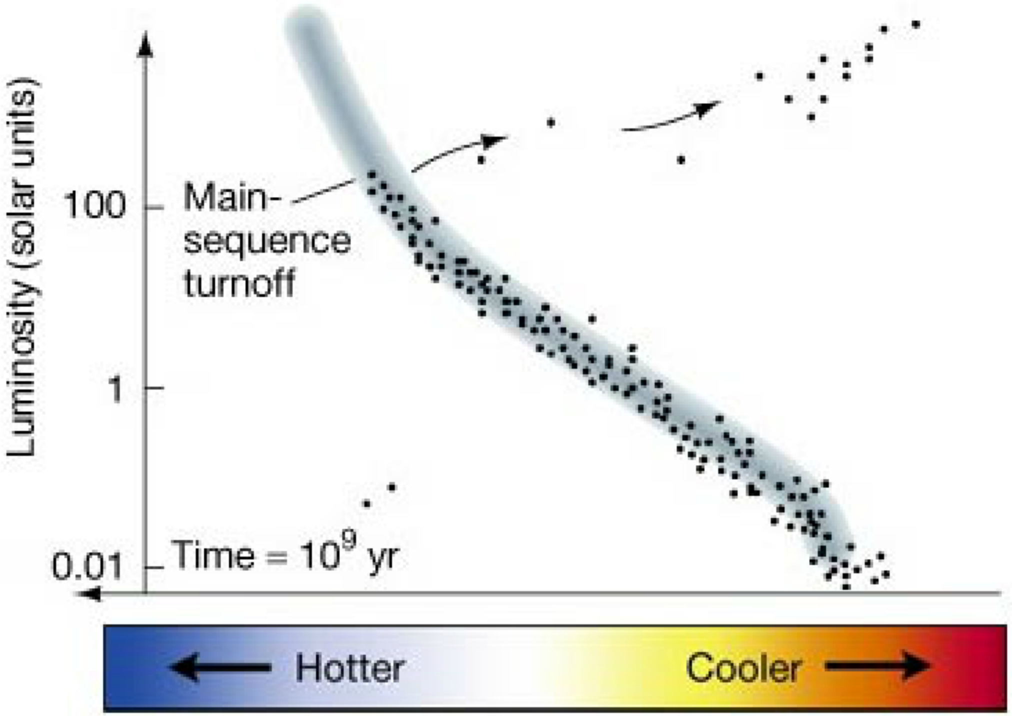
The evolution of the HR diagram

All of the O stars have gone supernova. The B stars begin to evolve off the Main Sequence



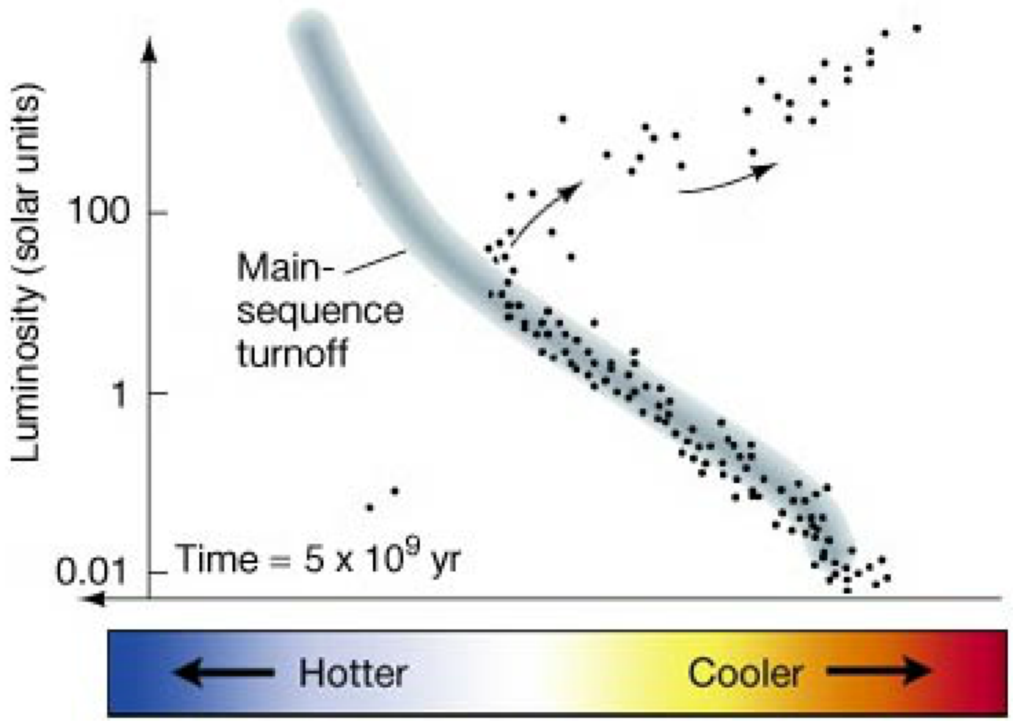
The evolution of the HR diagram

All of the B stars that are massive enough have gone supernova and the rest have evolved into red giants. The A stars begin to evolve off of the Main Sequence



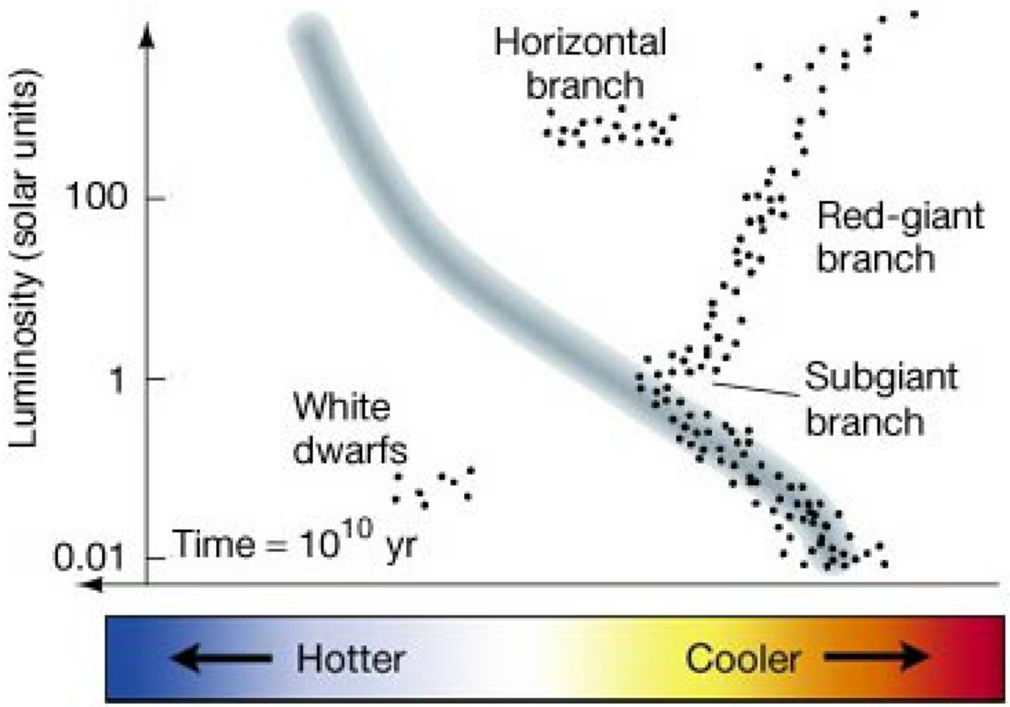
The evolution of the HR diagram

The G stars begin to evolve off of the Main Sequence. The red giant branch is populated with some of the originally more massive stars. Some of the first red giant stars that formed have already become white dwarfs.

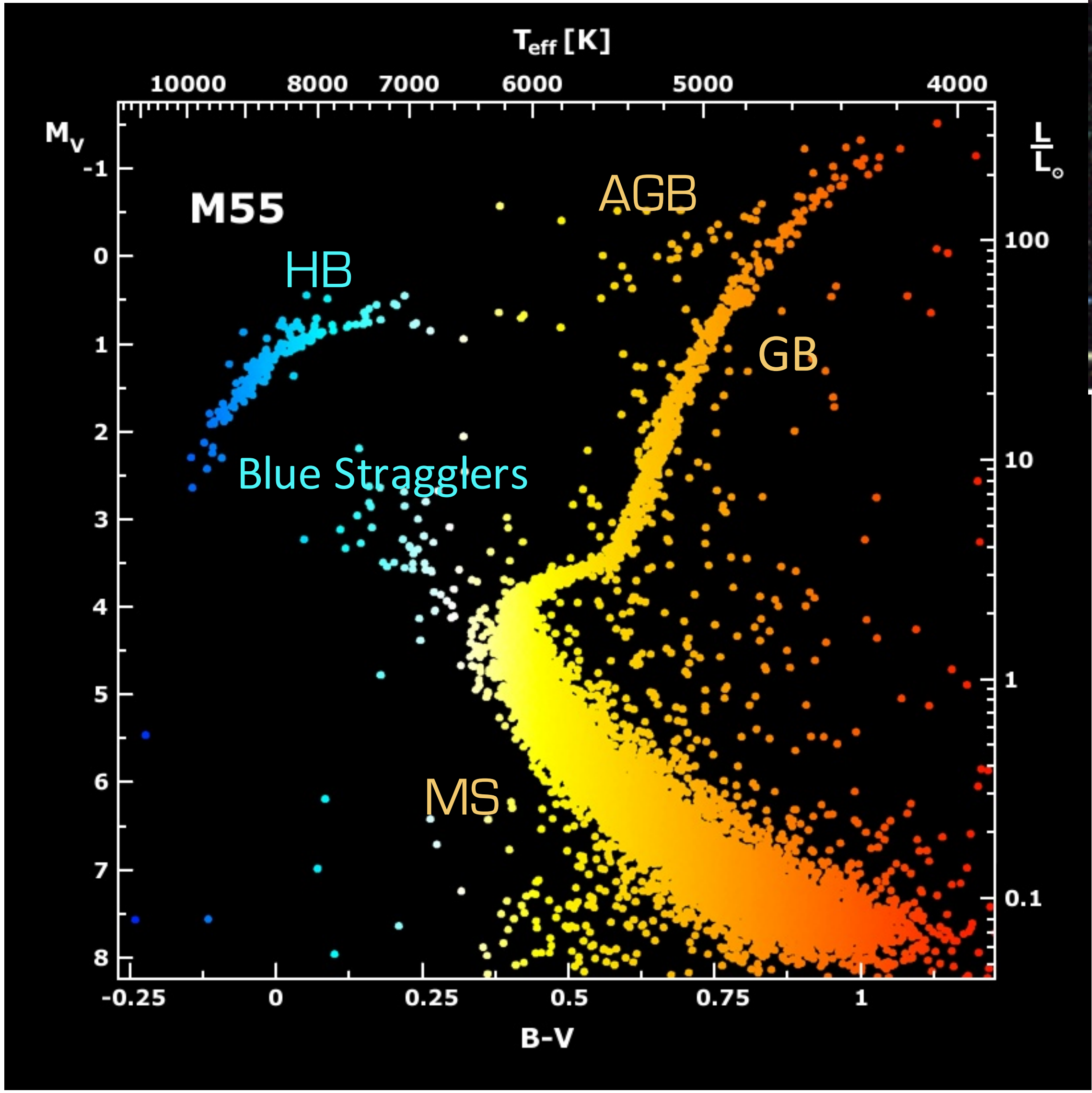


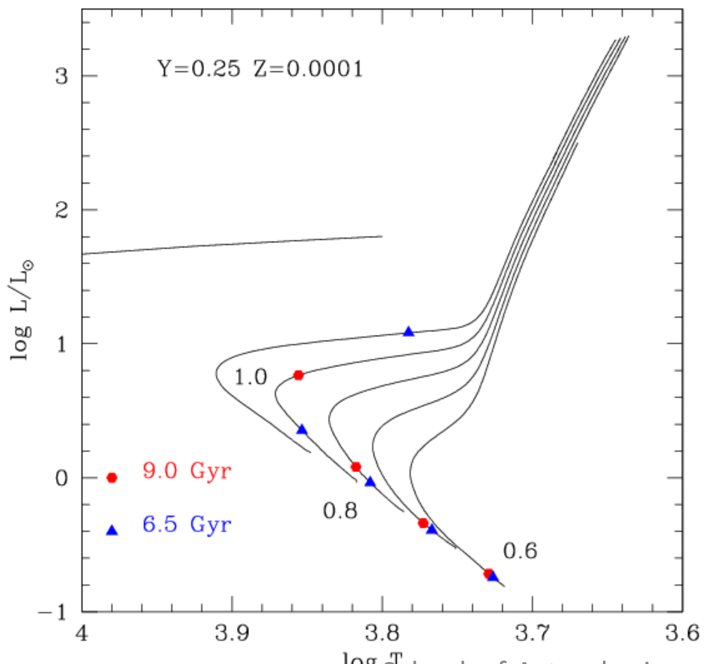
The evolution of the HR diagram

The OBAFG stars are all missing from the Main Sequence, the red giant branch is very well populated, and there are also many white dwarfs. Only K & M stars remain on the Main Sequence.

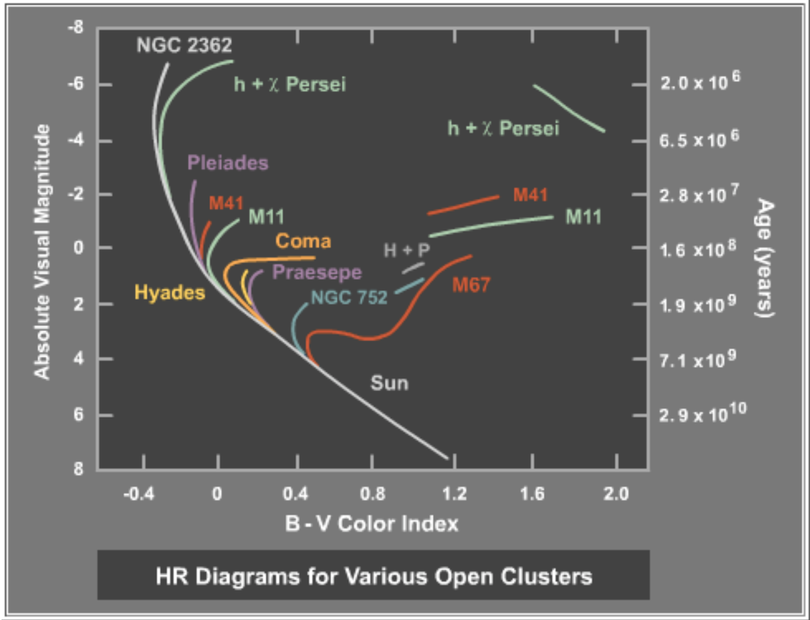


Old Stellar Populations



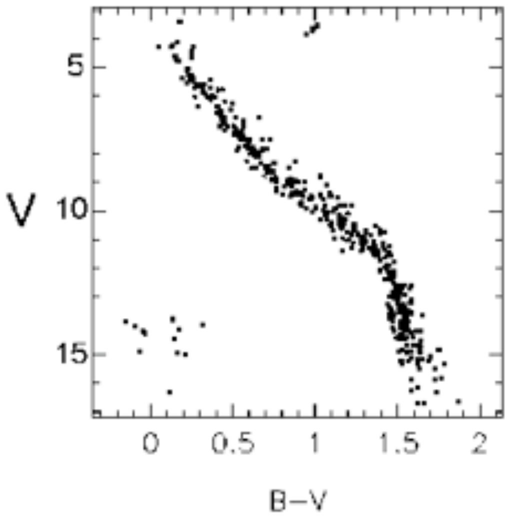


Open Clusters



A young cluster:

- The main sequence is the most prominent structure.
- There has not been enough time for stars to leave the main sequence



Simple stellar Populations (SSP)

Stars consists of objects born at the same time in a burst of star formation activity of negligible duration, with the same initial chemical composition.

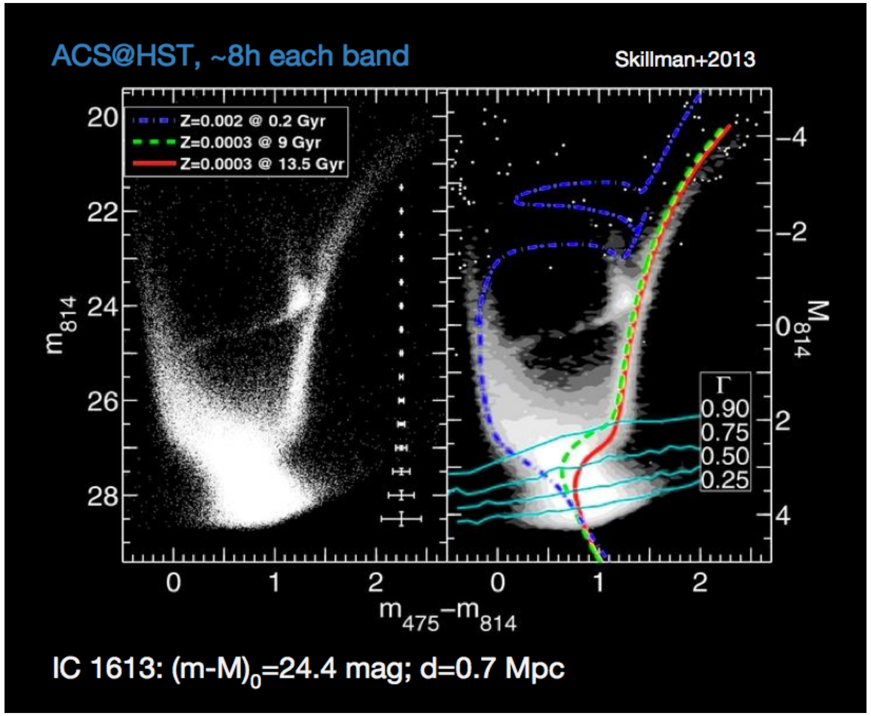
Open Cluster

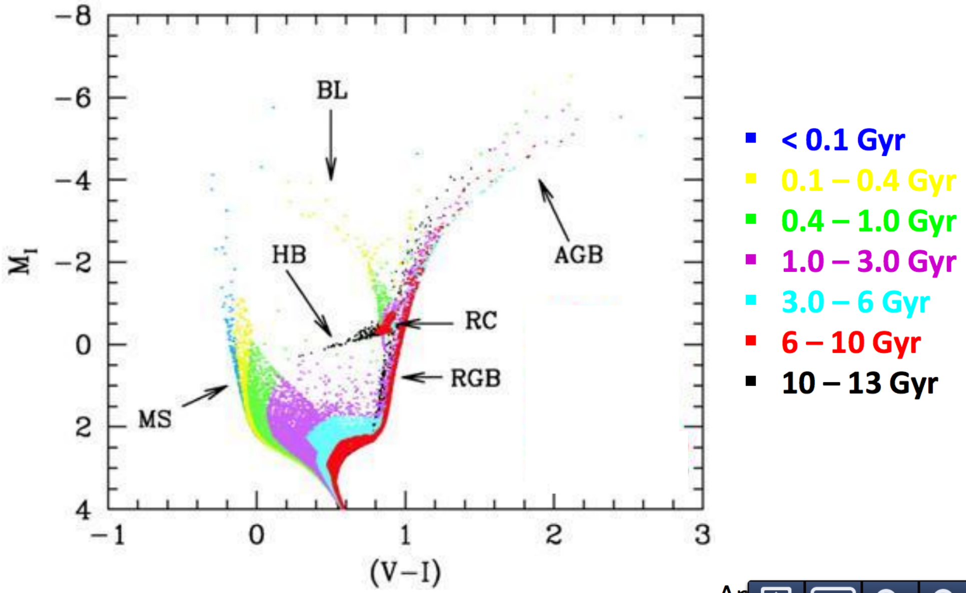
Globular Clusters

Composite stellar populations

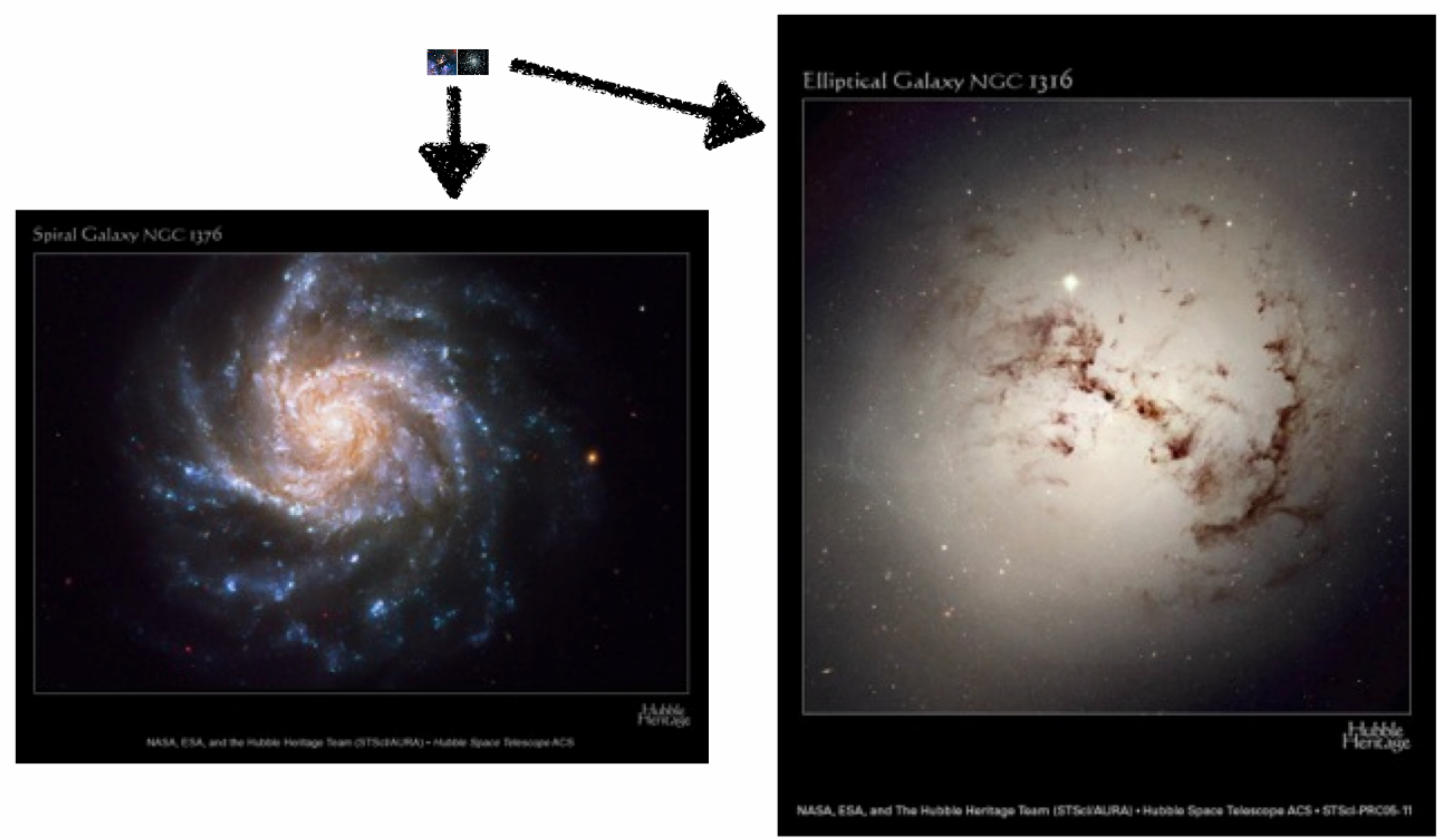
Composite systems

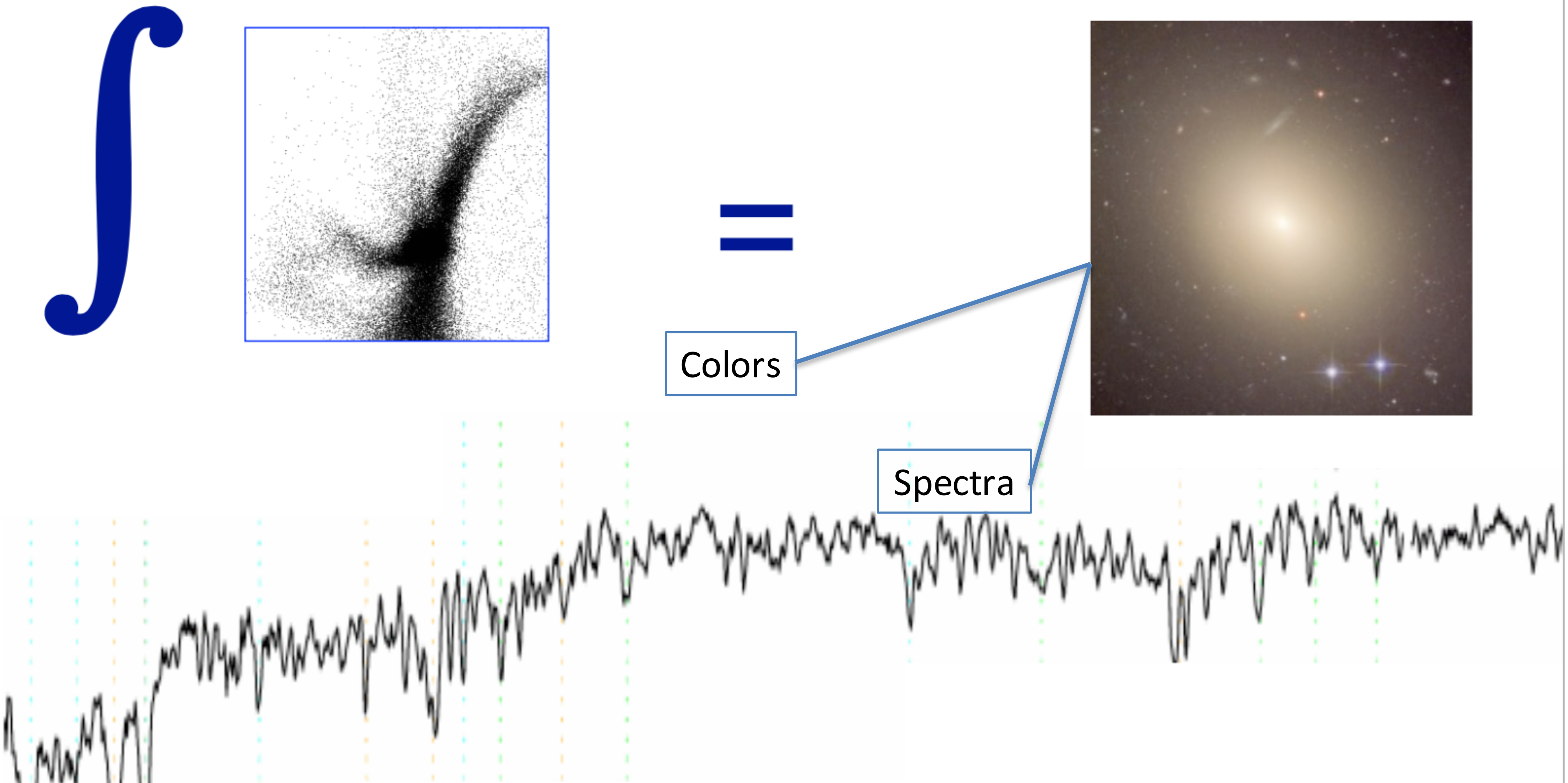
- Resolved stellar photometry of MSTO stars in NOW possible only in the local group (d< 1 Mpc)
  For more distant galaxies only evolved stellar populations can be detected.





Unresolved stellar populations

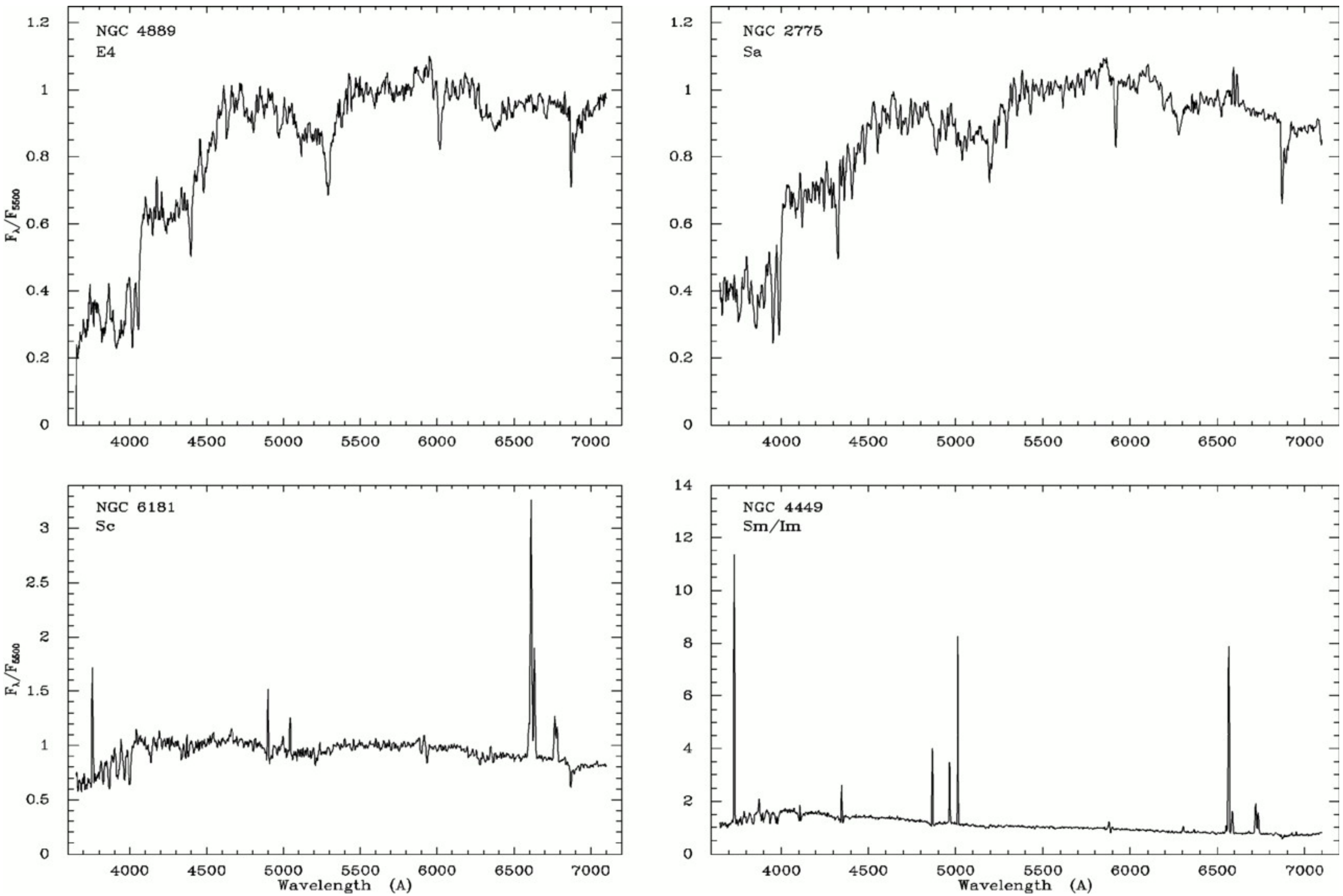


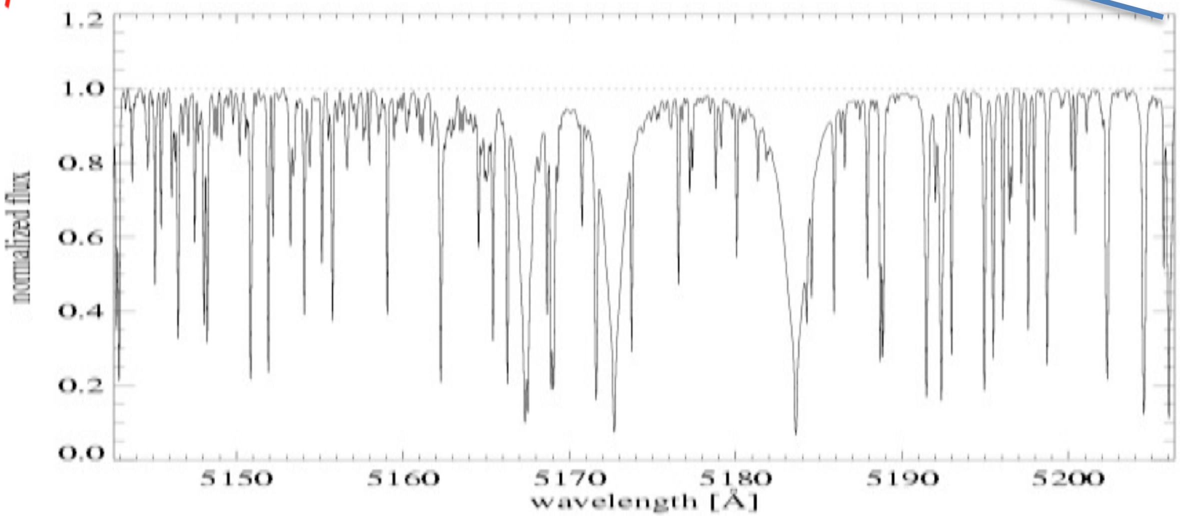


How much information remains?

To extract information we need to compare with stellar population models

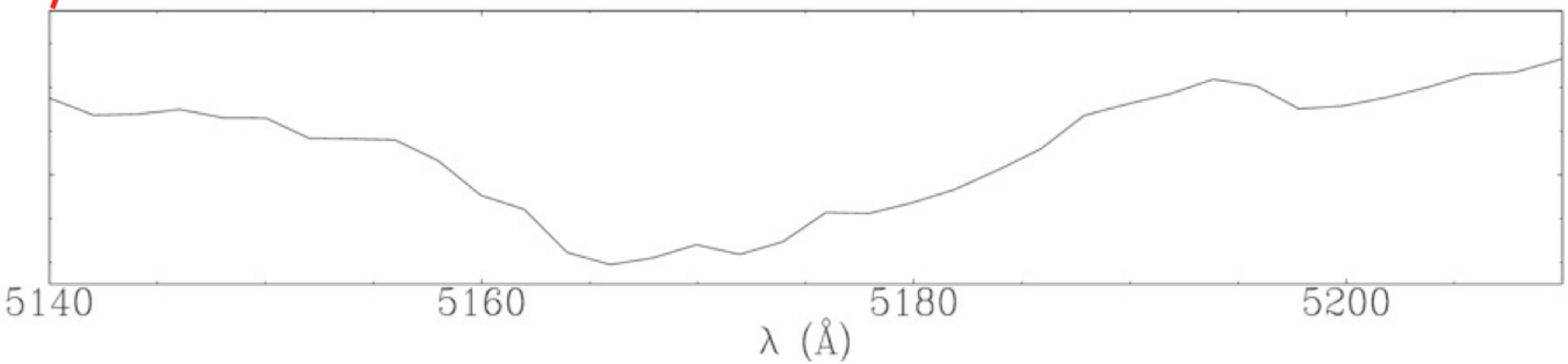
Spectra of galaxies with different ages



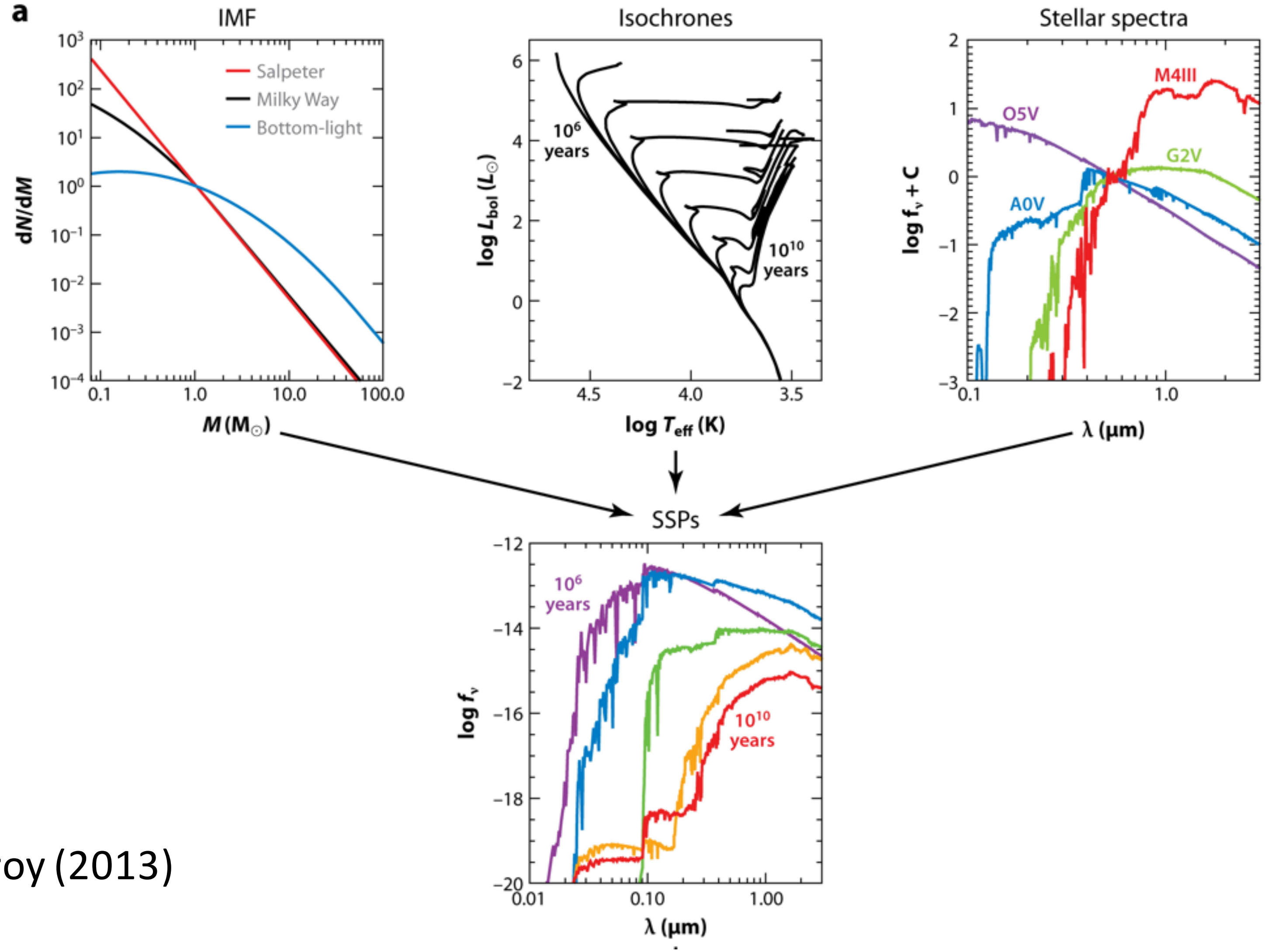


normalized flux
1.2
1.0
0.8
0.6
0.4
0.2
0.0
5150
5160
5170
5180
5190
5200
wavelength [Å]

Spectral resolution reduced by stellar velocities in bright galaxies



Stellar population models



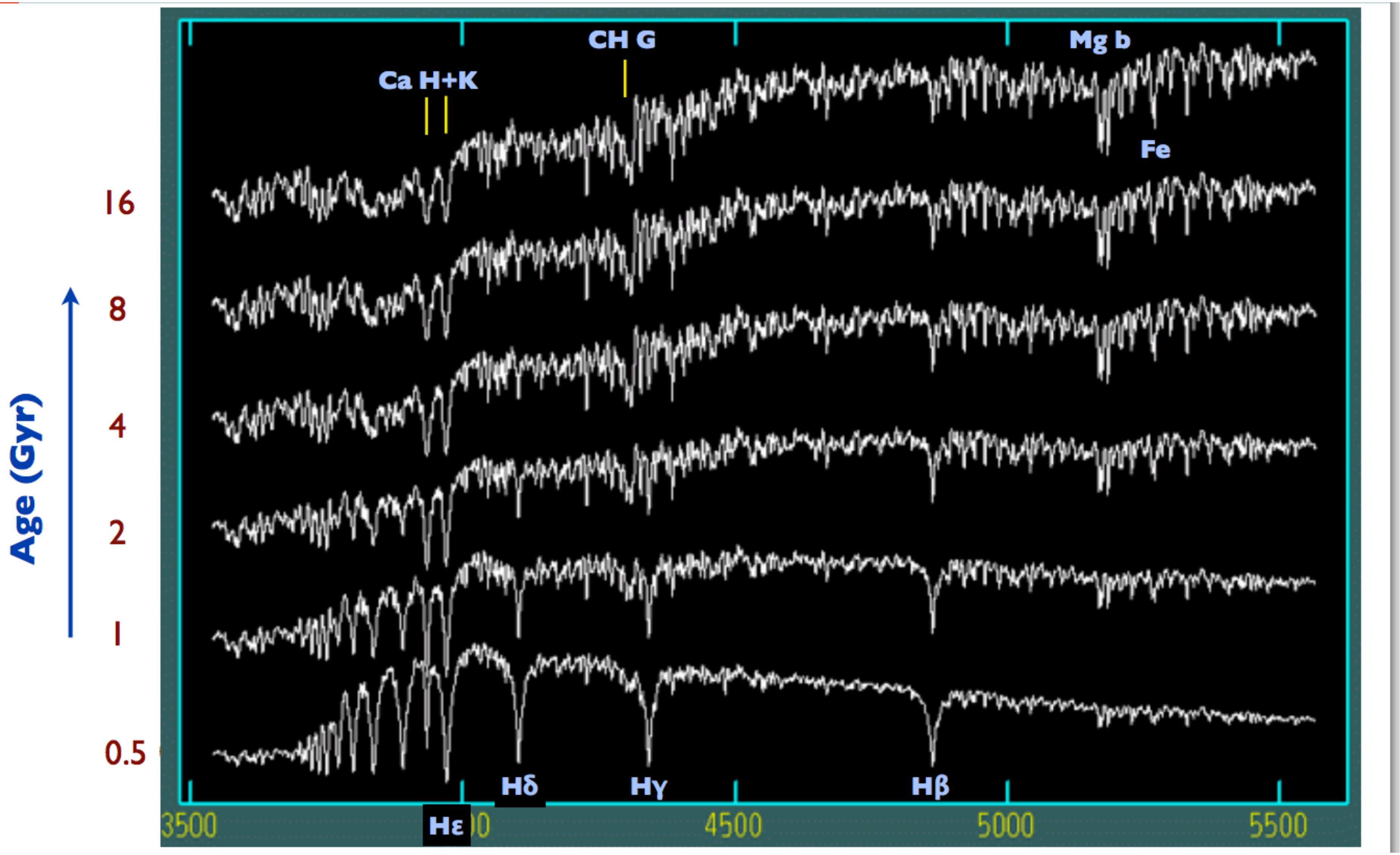
Conroy (2013)

The simple stellar population (SSP)

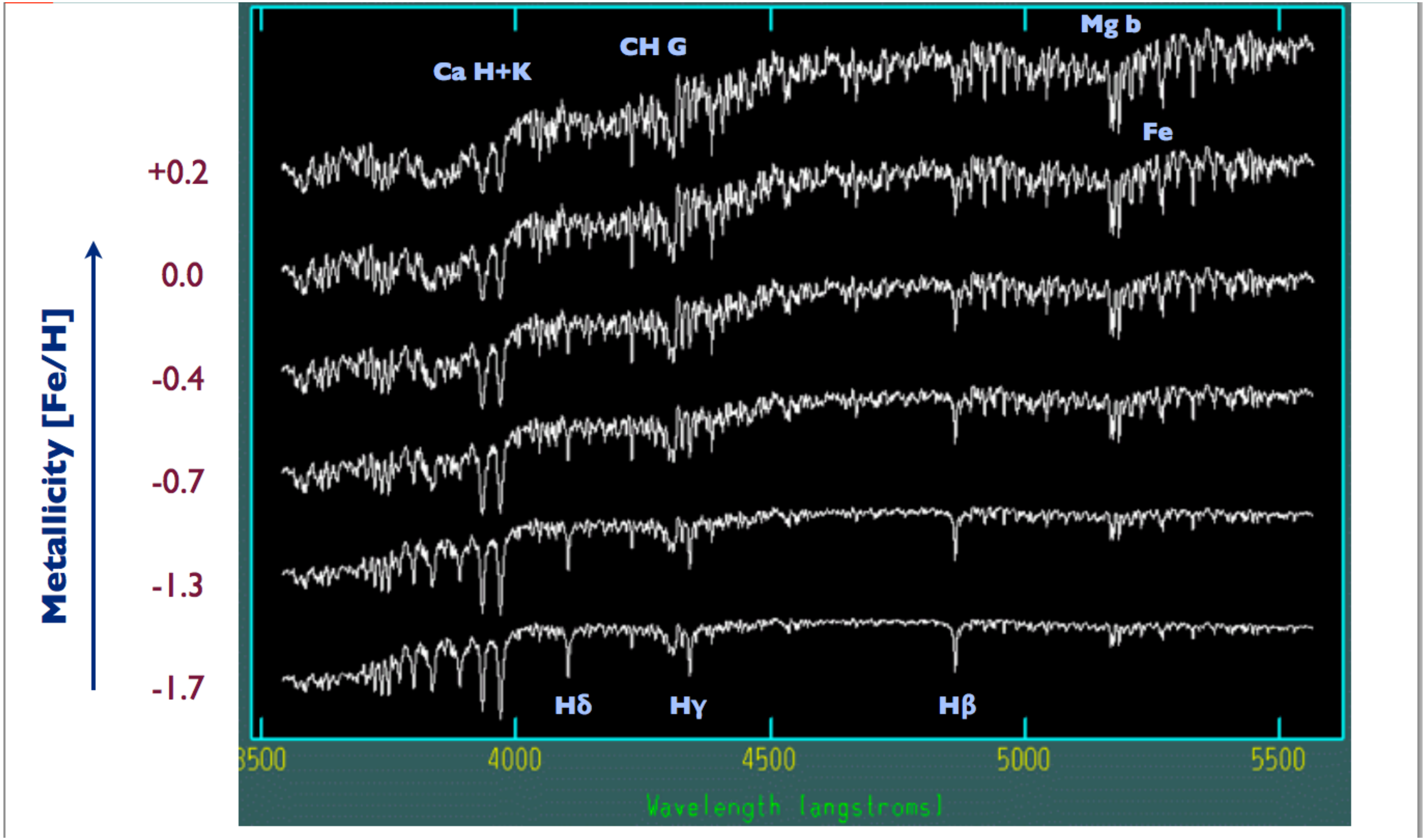
$$f_{SSP}(t, Z) = \int_{m_{lo}}^{m_{up}(t)} f_{star}[T_{\rm eff}(M), \log g(M)|t, Z]\Phi(M)dM$$

- $\phi(M)$ is the initial mass function
- f_{rmstar} is a stellar spectrum
- f_{SSP} is the resulting time and metallicity dependent SSP spectrum
- m_{lo}: typically hydrogen burning limit (0.08 or 0.1 $M_{\odot}$)
- $m_{up}(t)$: dictated by stellar evolution

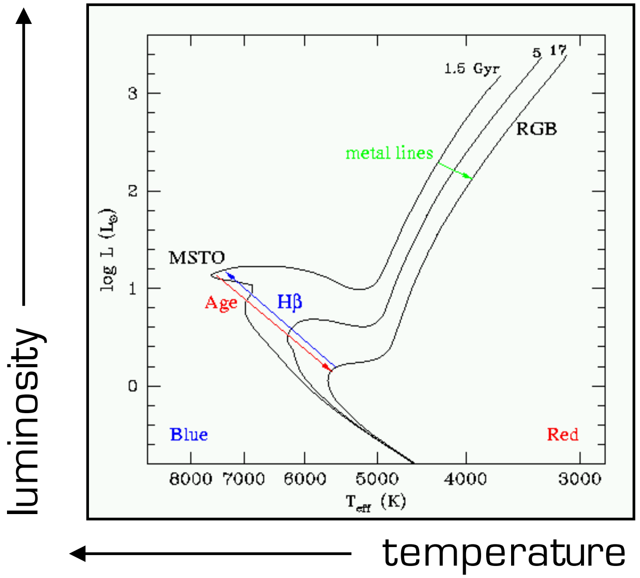
Solar metallicity SSP with different ages



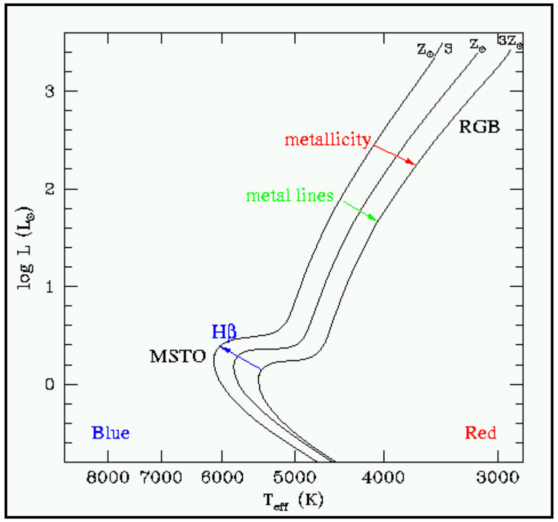
12 Gyr old SSP with different metallicities



The Age-metallicity degeneracy



Different age isochrones



Different metallicity isochrones

The population of stars gets redder when the age increases
and also when the metallicity increases → Age-Metallicity degeneracy

MSTO is the clock to age-date galaxies

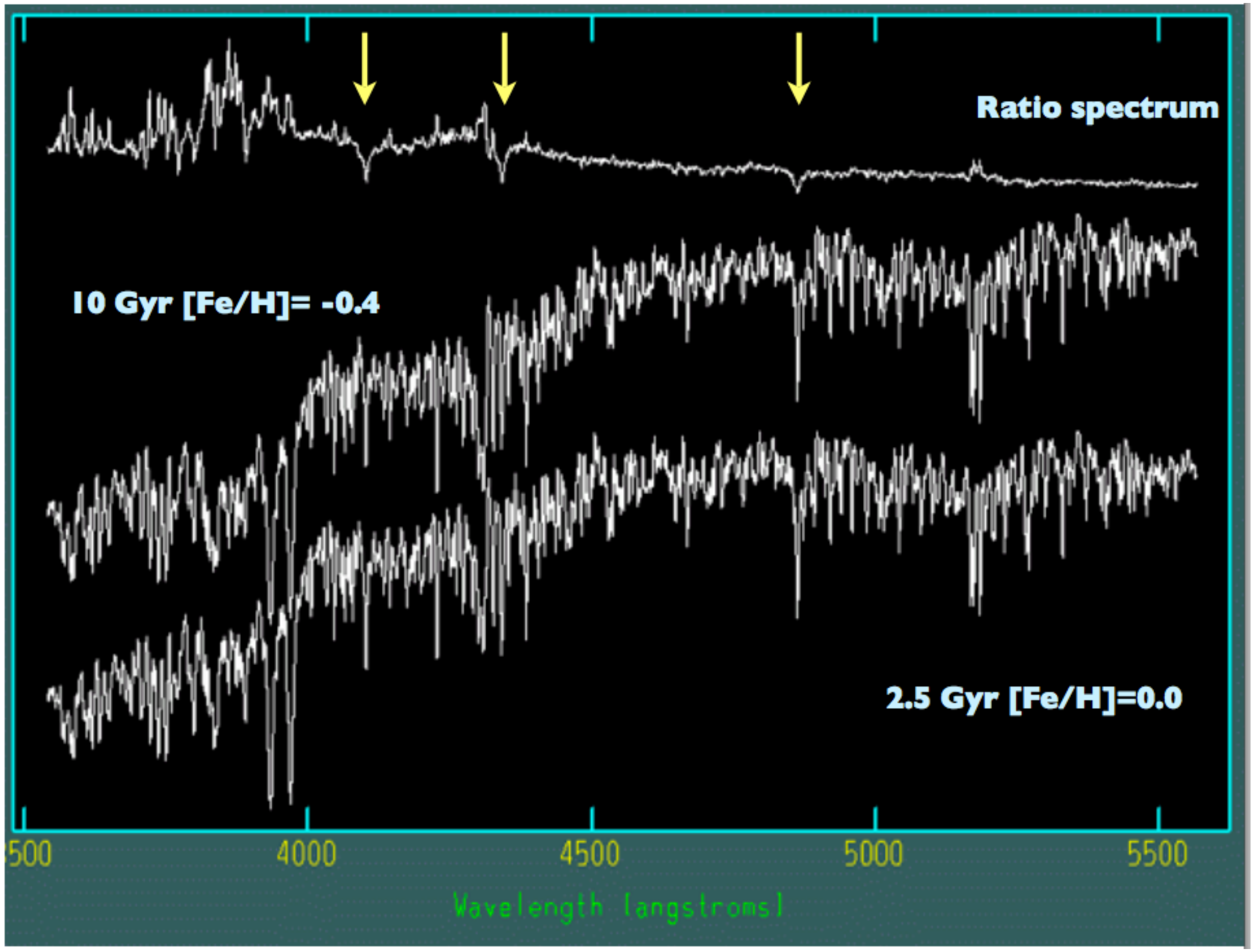
Disentanglying age and metallicity

Two spectra with age and metallicity chosen to produce same broad-band colours.

Similar spectra, but differences in detail at the Balmer lines.
Also at λ< 4000 Å

We can exploit this localized spectral information to beat the age-metallicity degeneracy

But how?
Indices vs full spectral fitting



Fitting models to data

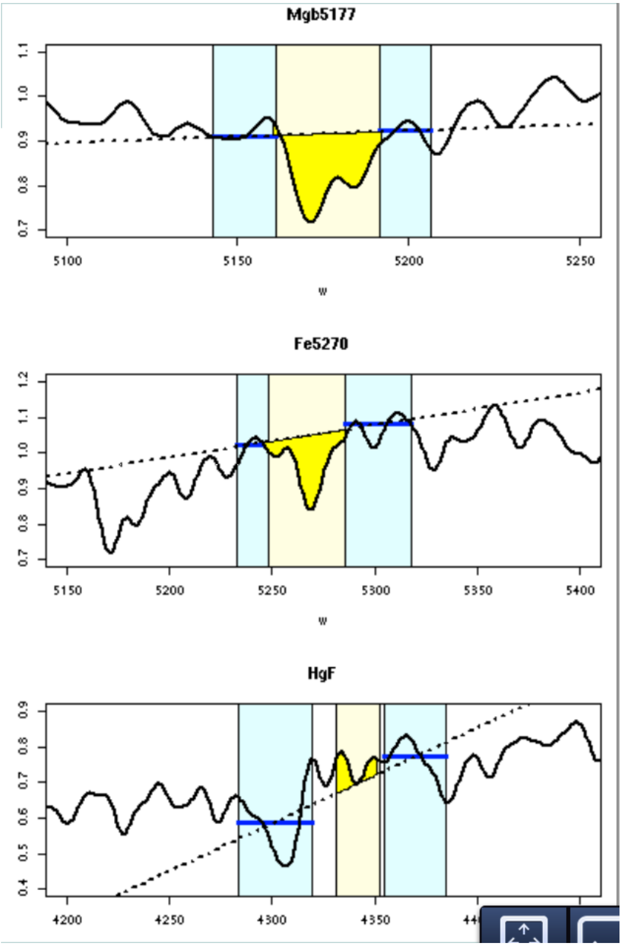
- The fitting can be done:
- (a) Using a set of given absorption lines (indices)
- (b) Using the whole available spectrum

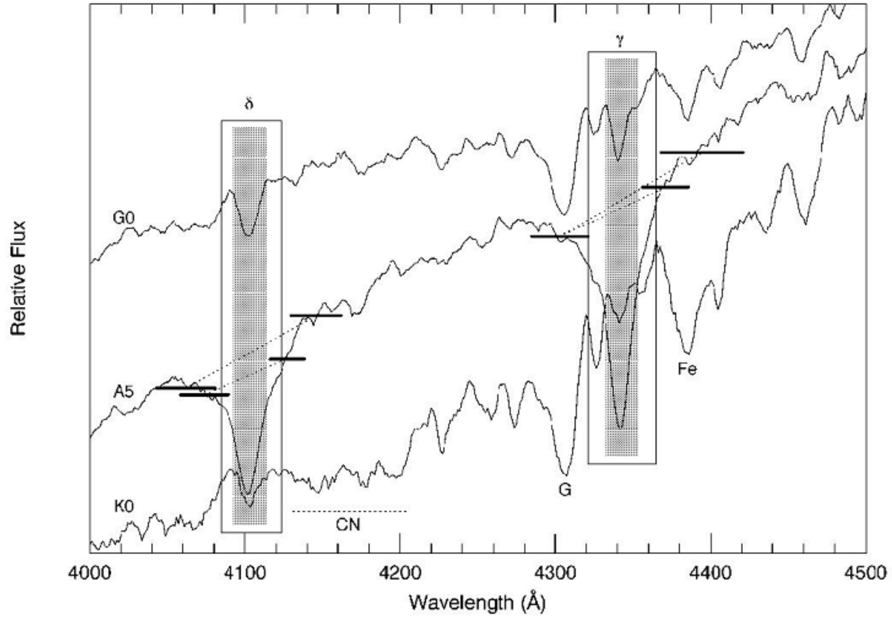
- 3 basic methods to compare models with data

(1) Fitting data to SSP models (usually with a)
(2) Fitting data to parametric SFH (with both a and b)
(3) Fitting data to non-parametric SFH (usually with b)

Stellar populations in early-type galaxies

Lick Indices

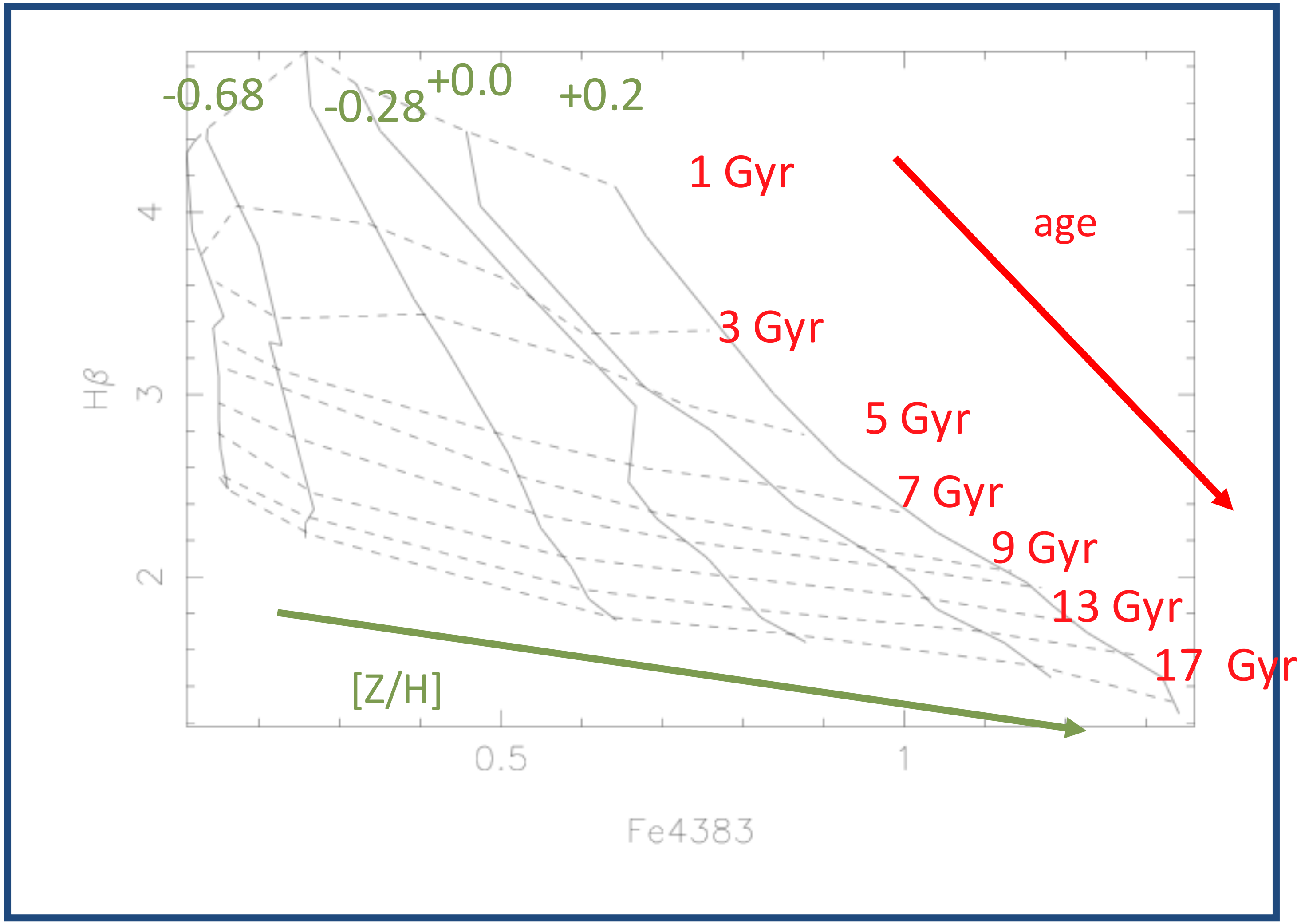




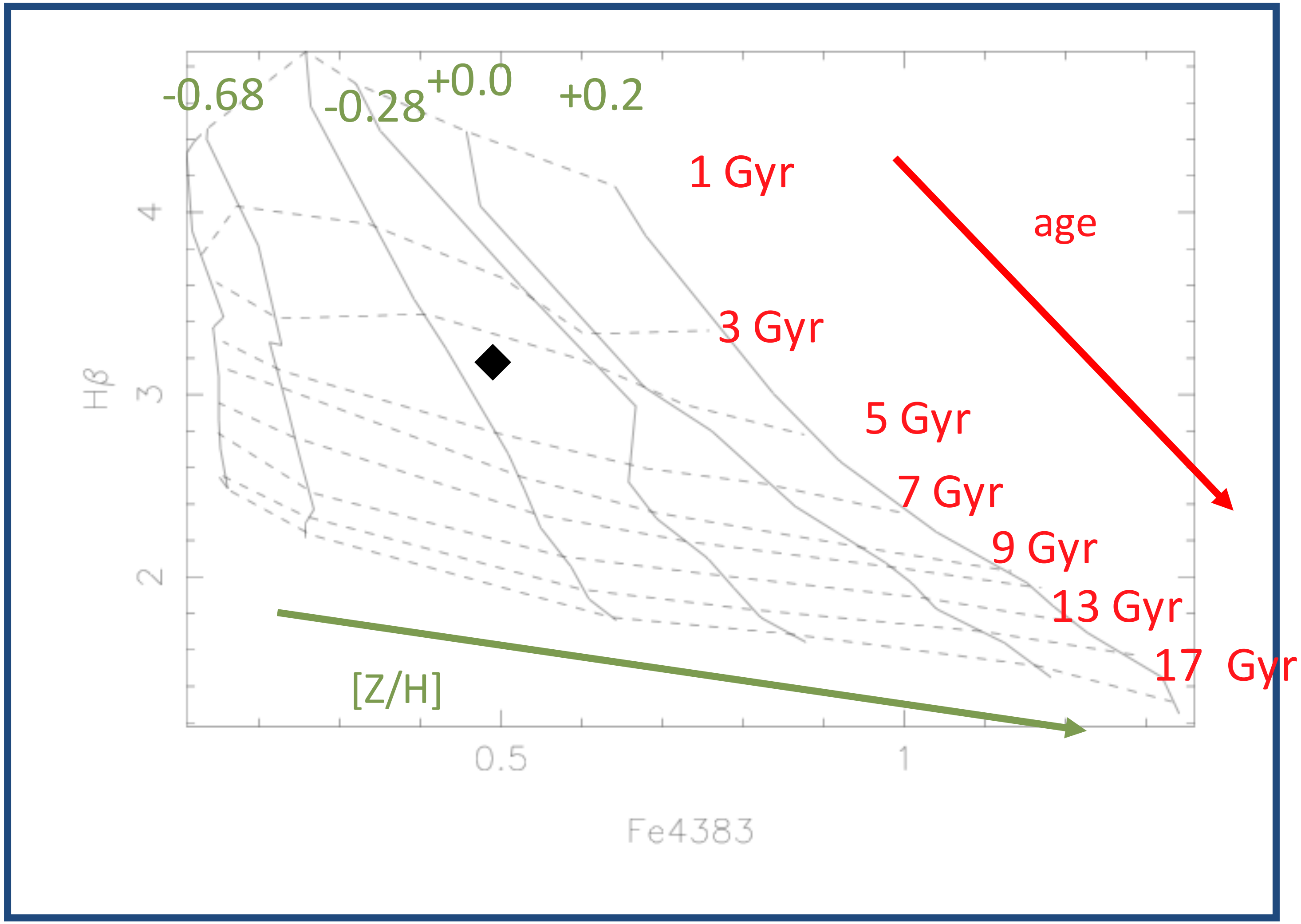
Definition in Burstein et al. (1993); Gorgas et al. (1993) ; Worthey et al. (1994); Trager (1998)

Other indices: Rose (1994); Fannelli et al. (1998); Diaz, Terlevich & Terlevich (1989); Cenarro et al. (2001); Frogel et al. (2001)

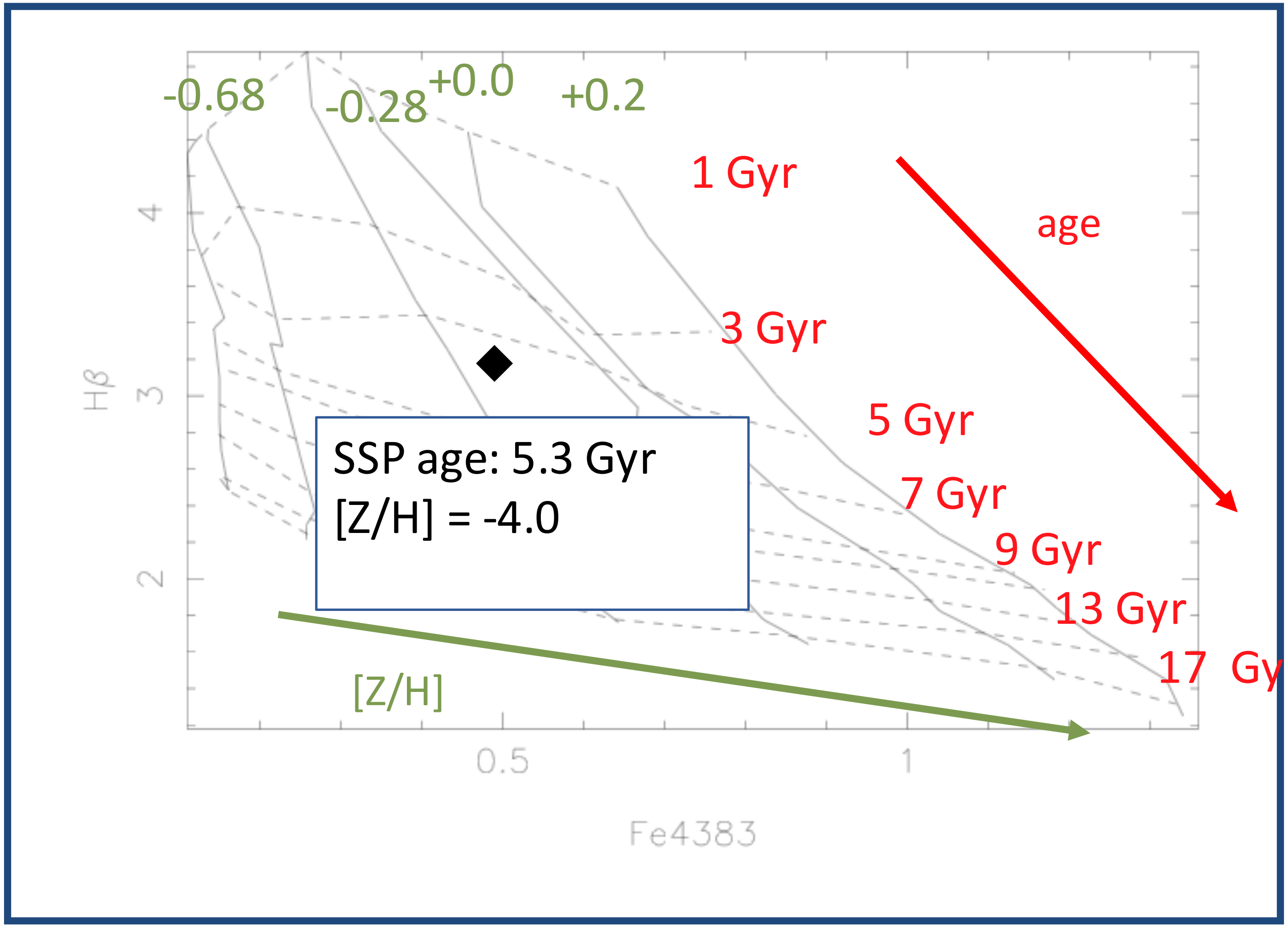
Obtaining SSP-equivalent parameters



Obtaining SSP-equivalent parameters

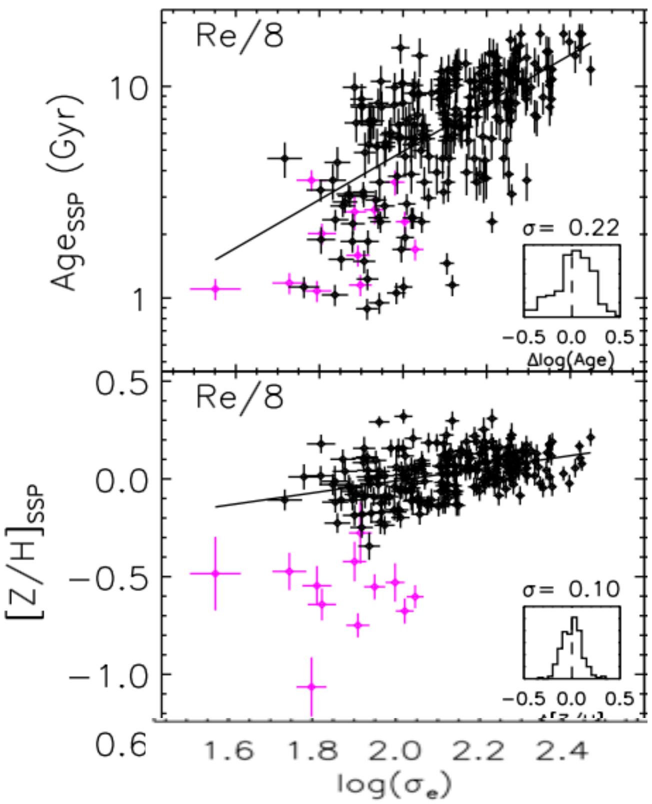


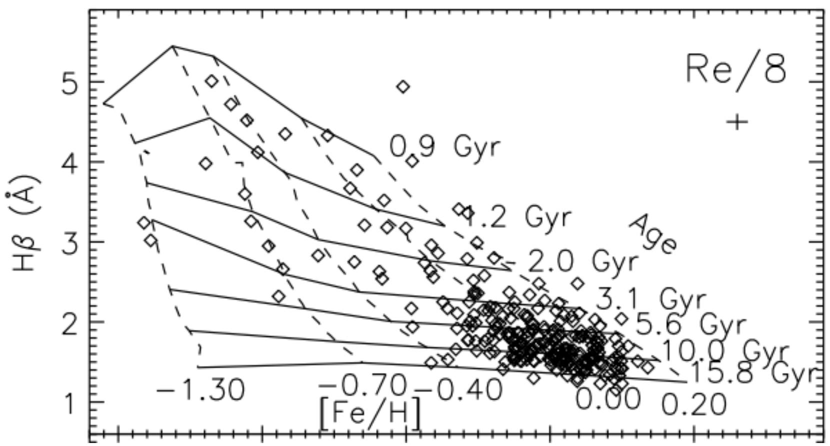
Obtaining SSP-equivalent parameters



Stellar populations in the centers of early-type galaxies

McDermid et al. (2015)



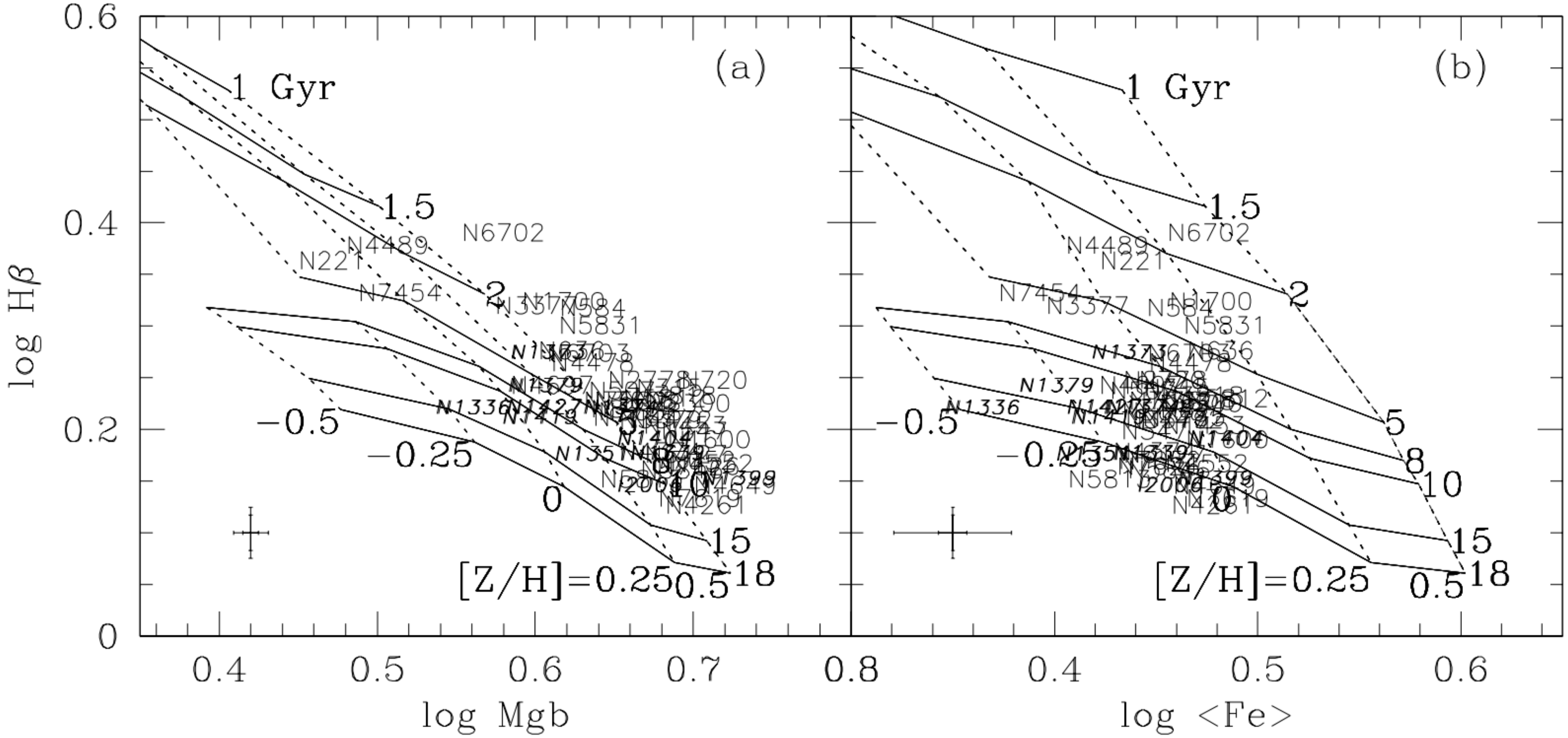


[MgFe50]

See also Trager et al. (2000); Sanchez-Blazquez et al. 2006, 2009; Gavazzi et al. 2008; Kuntschner et al. (2000); Kelson et al. 2005

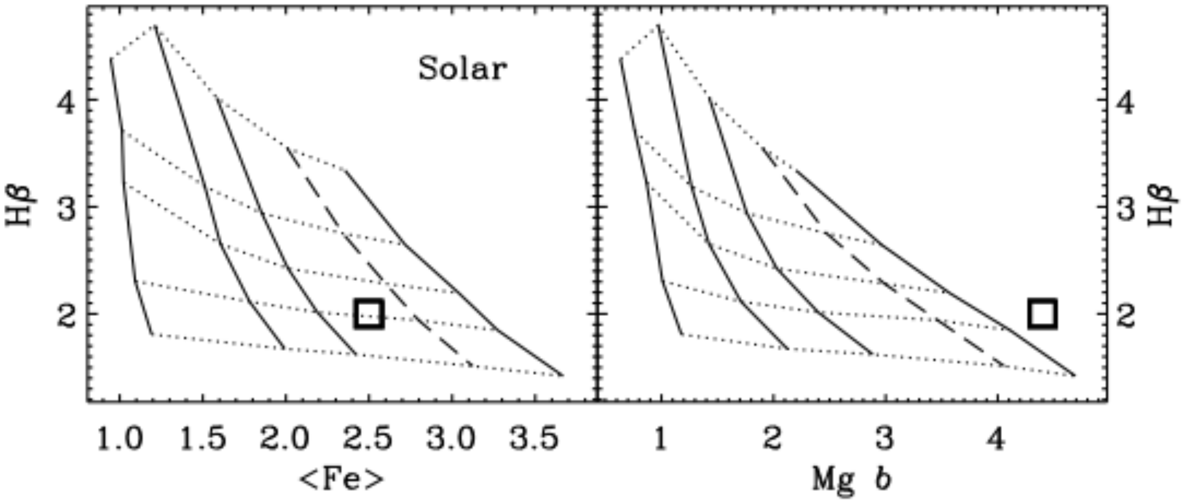
Chemical abundance ratios in early-type galaxies

Trager et al. (2000)

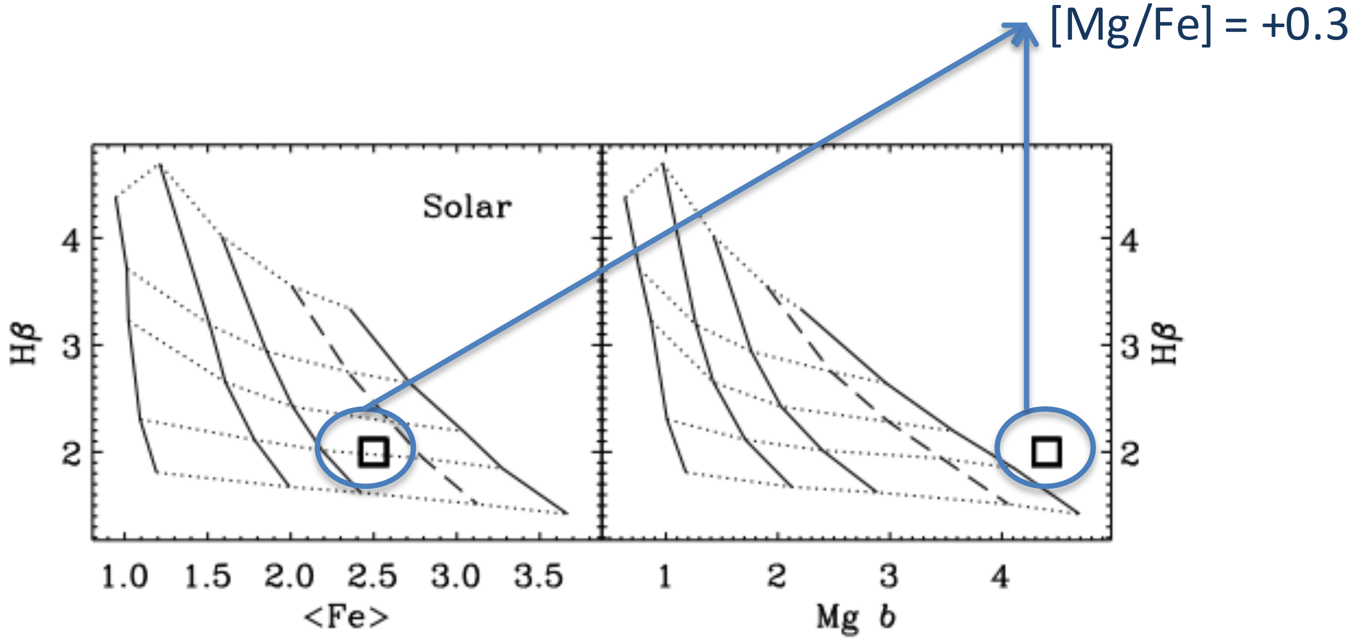


Models are built assuming the same chemical composition of the Sun (same ratio of different chemical species)

Obtaining chemical abundance ratios



Obtaining chemical abundance ratios



Abundance ratios

Basically we can think of nucleosynthesis occuring in three primary environments:

1) Type II SN: produce **alpha-elements***, r- (rapid Neutron capture) process elements, and some s-(slow neutron capture) process elements (short timescales).
2) Type Ia SN: Produce Fe-peak elements (longer timescales).
3) AGB: produce some light elements (N) and some s-process elements.

*Note: alpha-elements: Those synthetized by alpha-capture (O, Ne, Mg, Si, Ar, Ca)

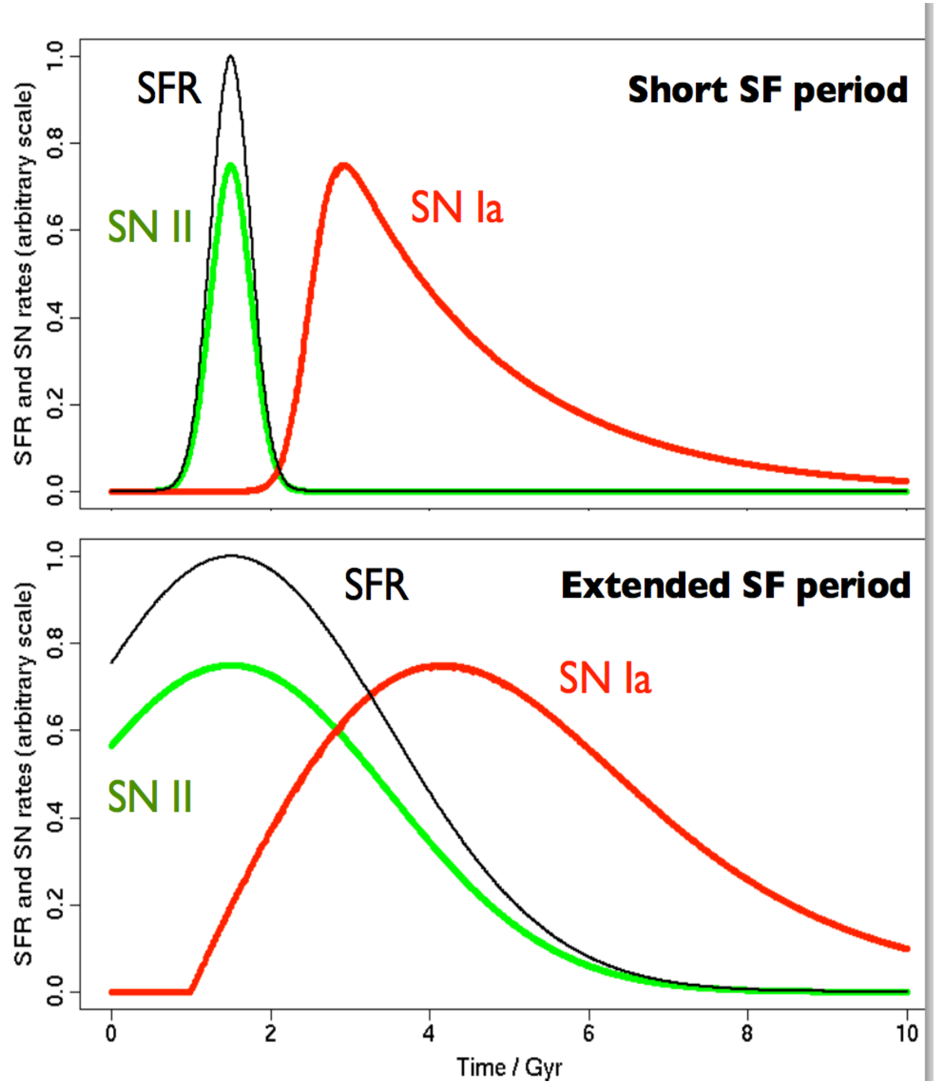
Consider SN rates from short duration burst of SF:

SNII rate is proportional to the star formation rate

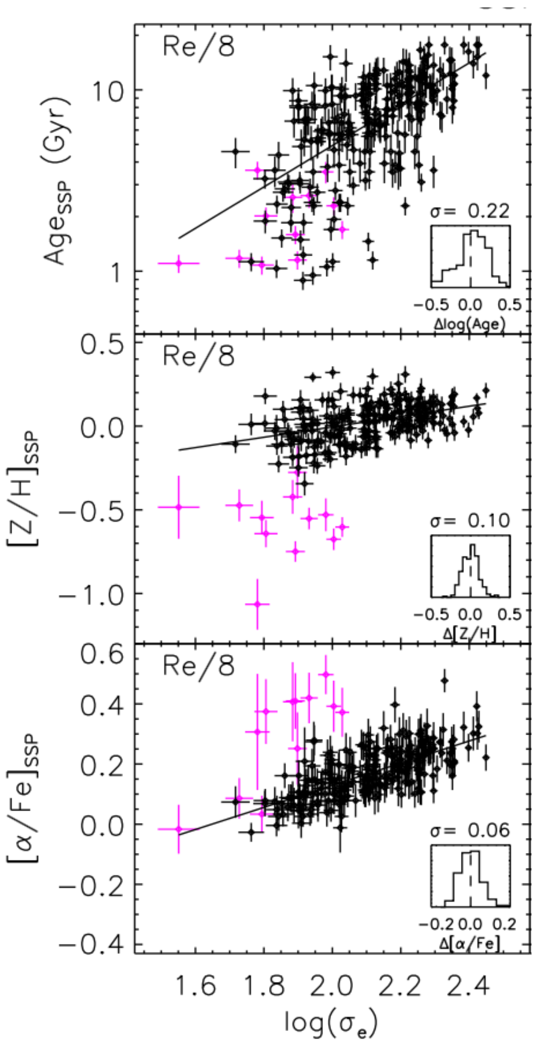
SNeIa follow after delay ~$10^{8\text{-}9}$ yr (broad distribution of precuror lifetimes)

If burst is short, only Mg-rich SNII products incorporated into stars (SNIa ejecta just escape from galaxy) → **High [Mg/Fe]**

Longer burst allow incorporation of some of the Fe rich SNIa ejecta: **Lower Mg/Fe**

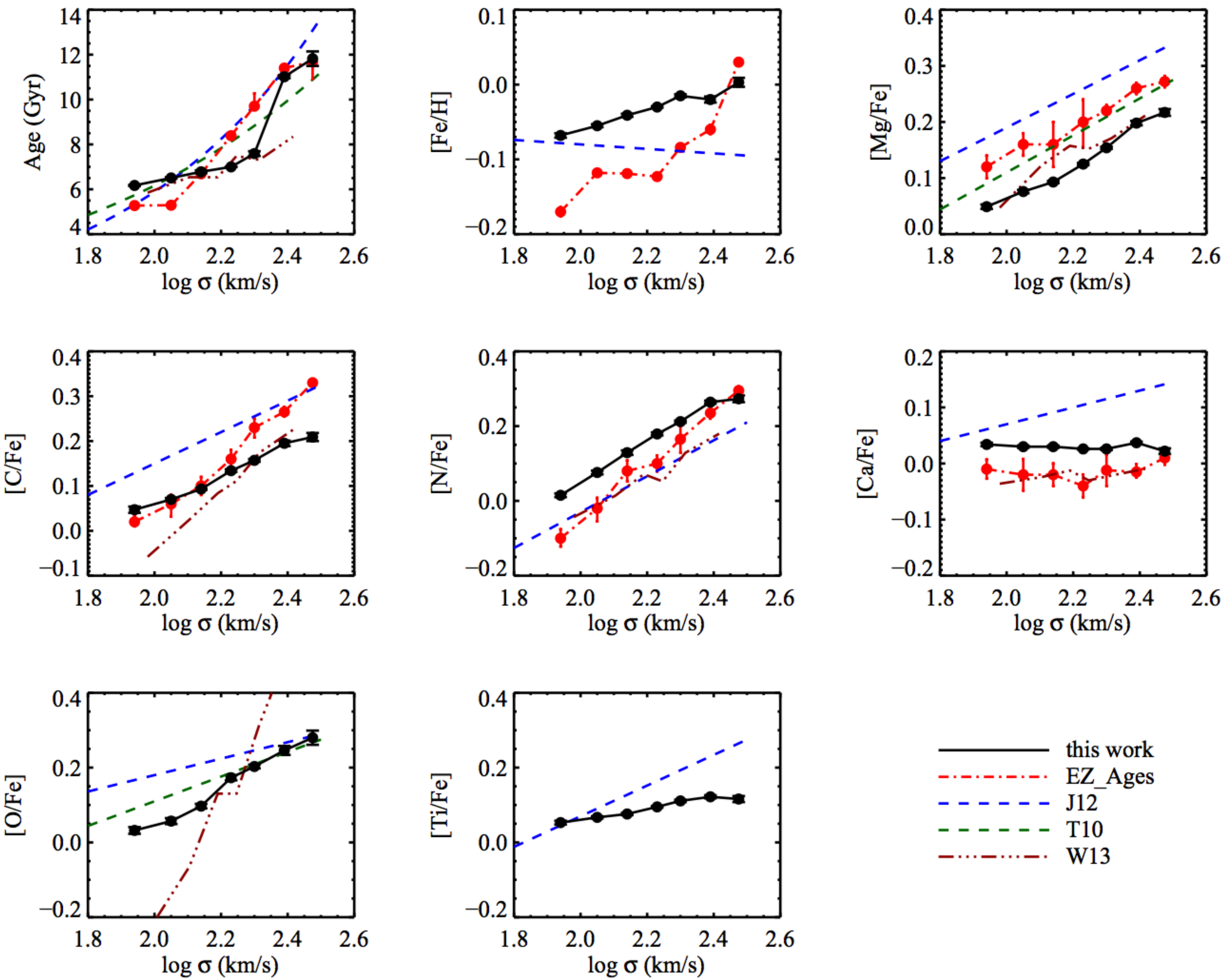


Stellar populations in the centers of early-type galaxies

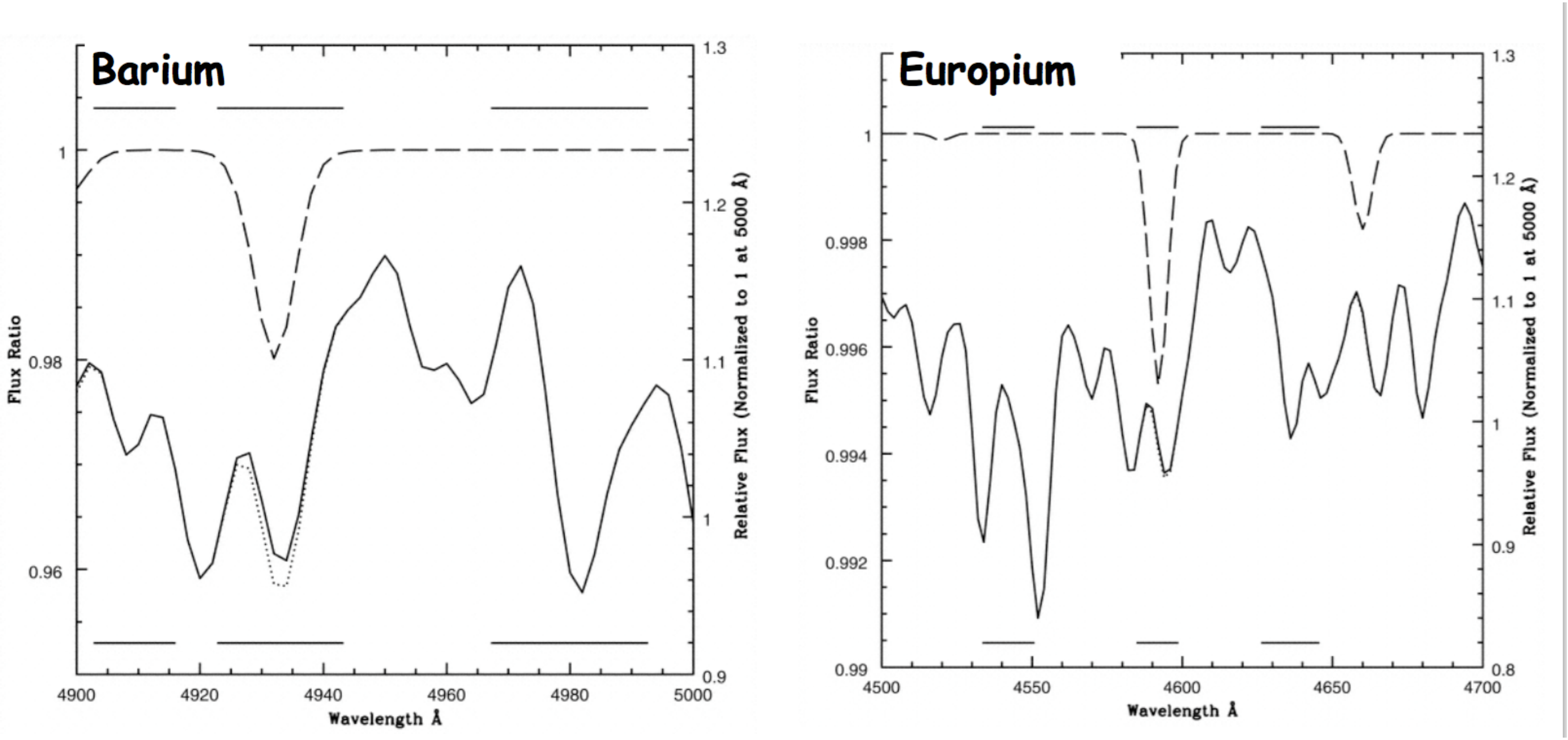


More massive galaxies are older, have higher global metallicity and higher [alpha/Fe] → they formed their stars at higher redshift and in shorter timescales

McDermid et al. (2015)


Age (Gyr)
[Fe/H]
[Mg/Fe]
[C/Fe]
[N/Fe]
[Ca/Fe]
[O/Fe]
[Ti/Fe]
log σ (km/s)
this work
EZ_Ages
J12
T10
W13

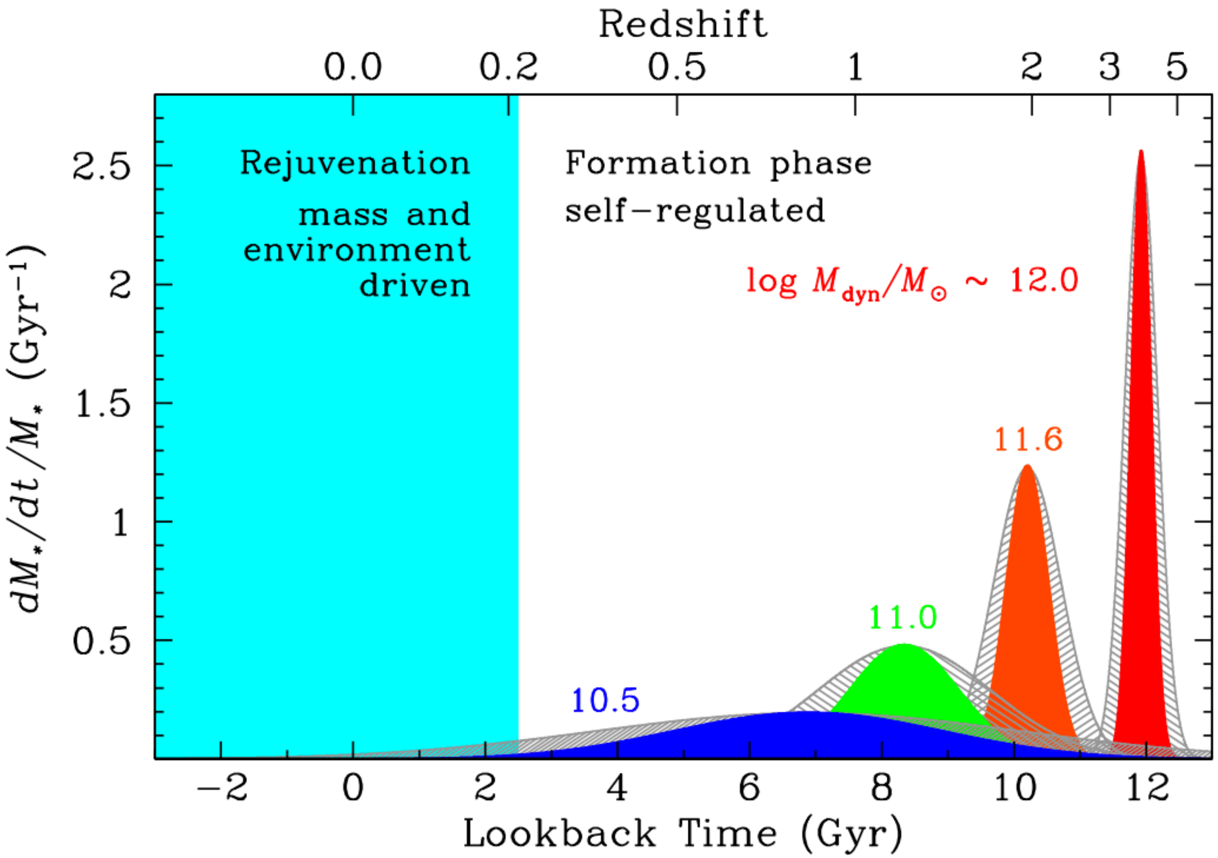
Abundance ratios at the E-ELT era



C, N, O, Na, Mg, Al, Si, S, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni Cu, Zn, Sr, Ba and Eu

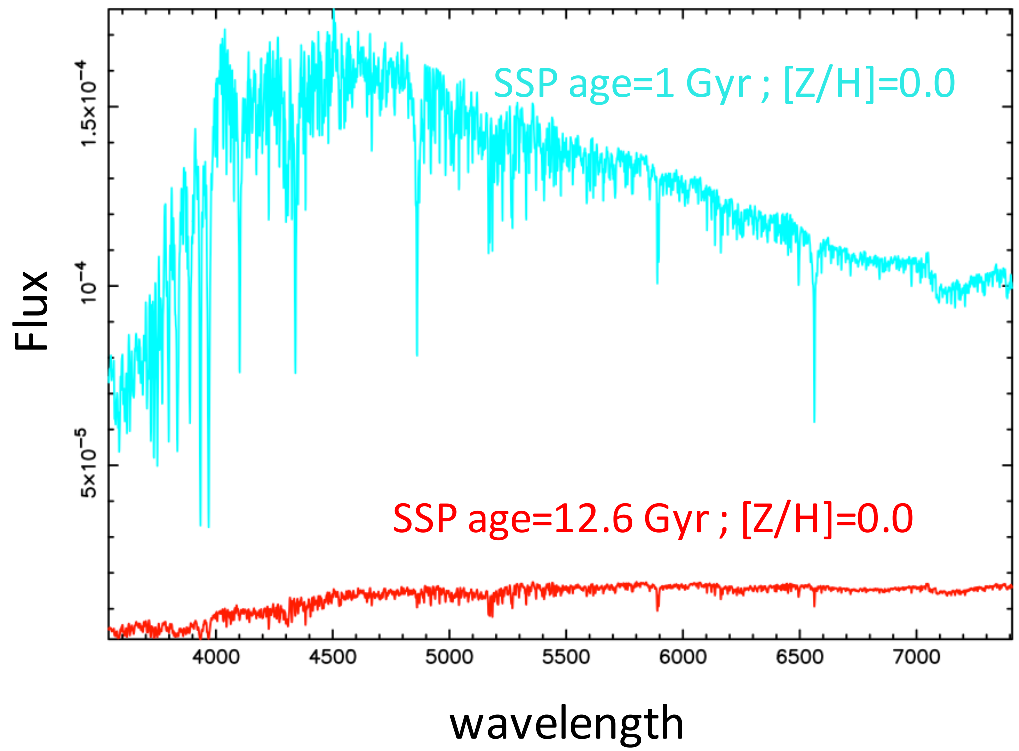
Serven, Worthey & Briley (2005)

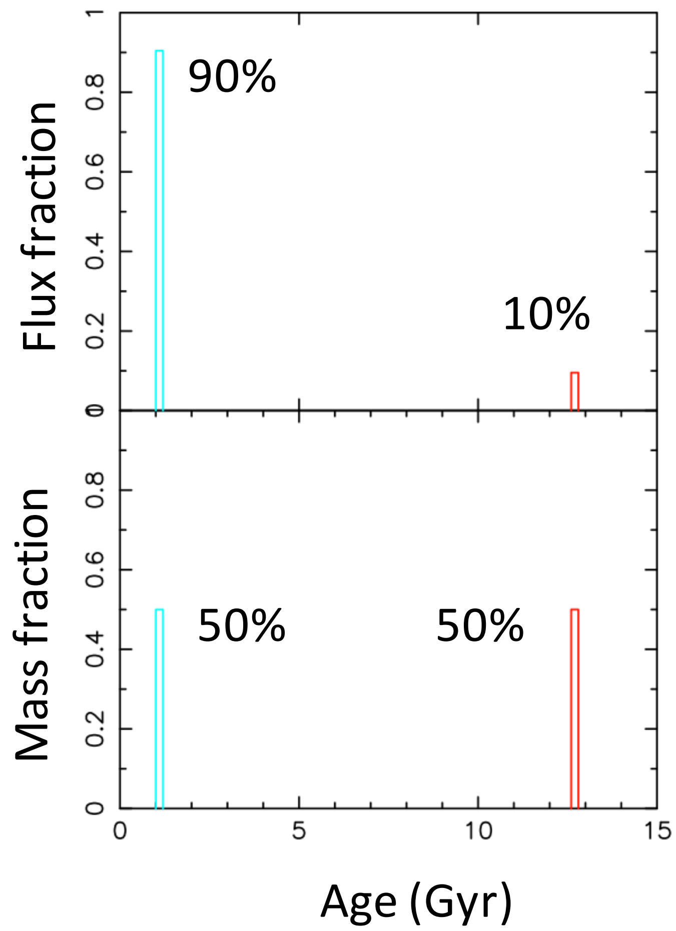
SFH as derived from chemical abundances



Thomas et al. (2010)

What do we get with SSP when the SFH is more complicated?

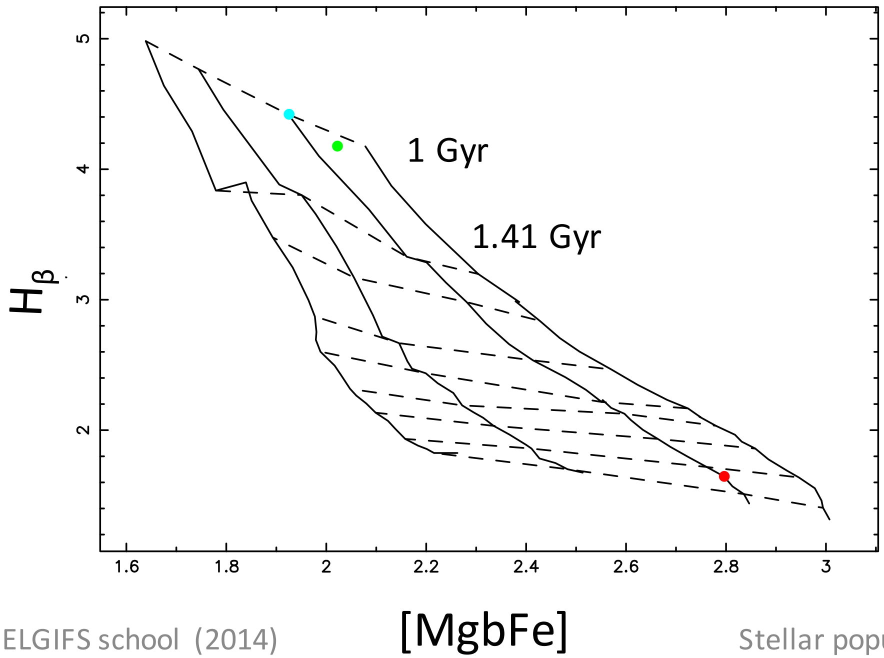


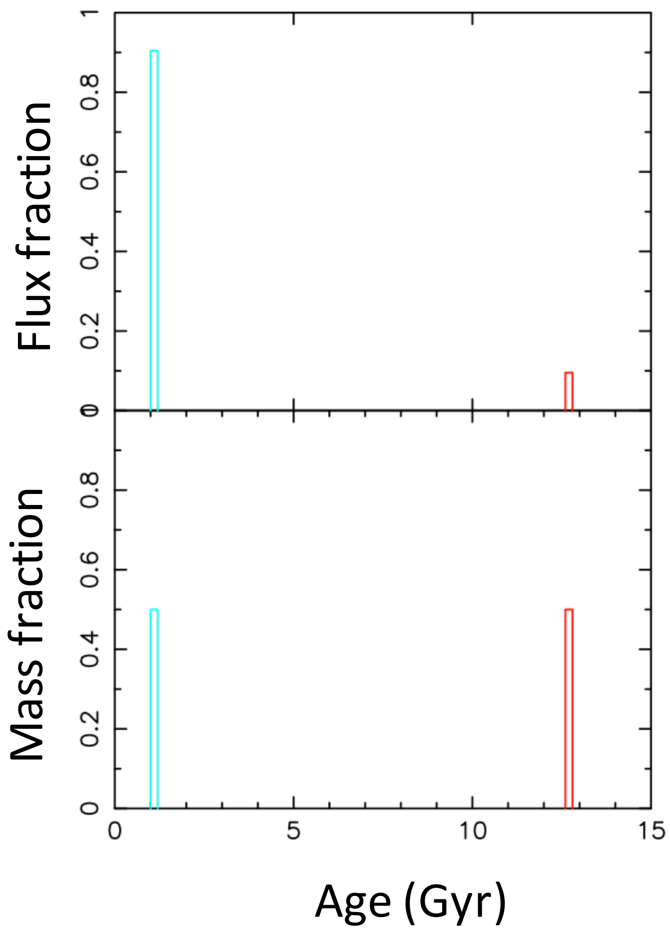


What do we get with SSP when the SFH is more complicated?

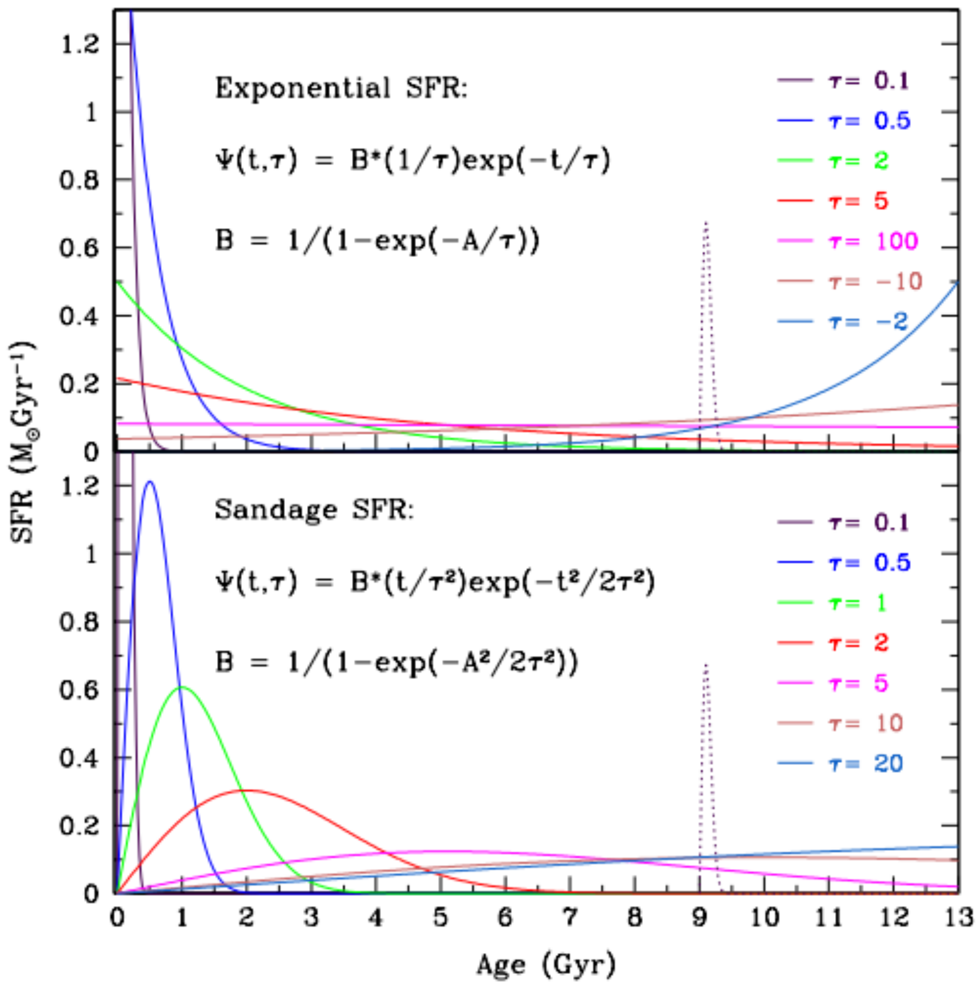
50% 1 Gyr + 50% 12.6 Gyr

SSP age = 1.02 Gyr





Second method: Parametric SFH



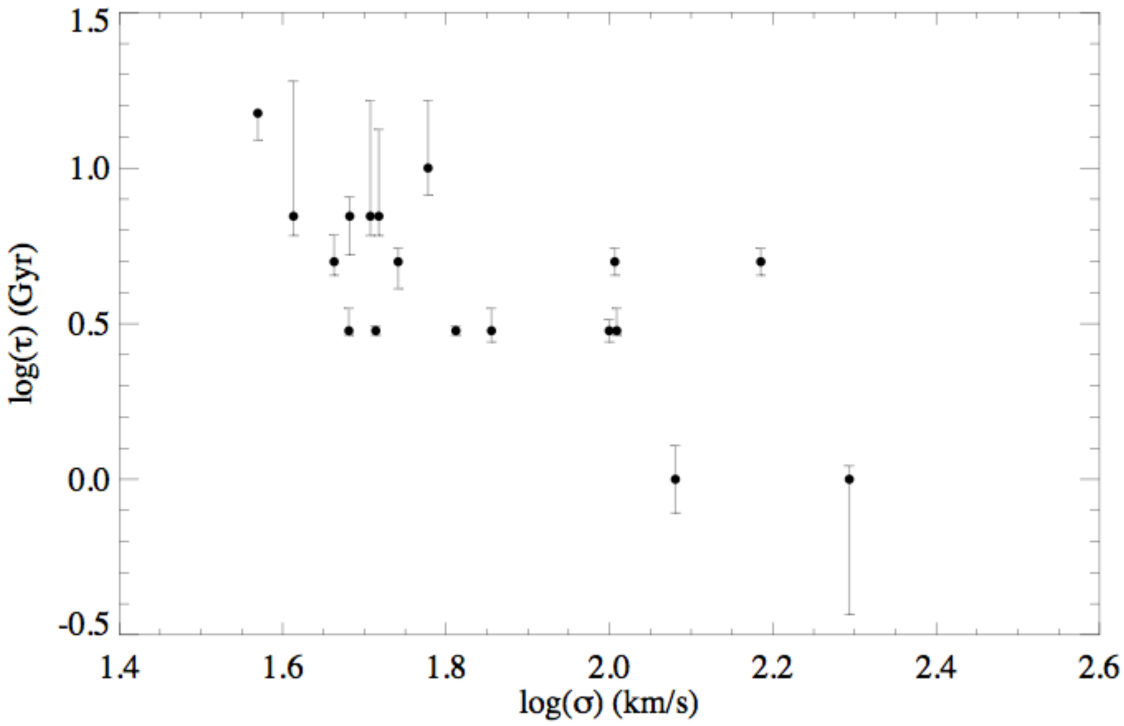
Bayesian method

- Construct a library of stochastic star formation histories and derive median-likelihood estimates of ages and metallicities (Kauffmann et al. 2003; Gallazzi et al. 2005).

- Assign to each model a probability distribution in each parameter $P=\exp(-\chi^2/2)$, where χ^2 is calculated by comparing the line-strenght indices (or the whole SED) with the models

Parametric techniques

$$\psi(t) = [1M_\odot + \epsilon M_{PG}(t)]\tau^{-1}exp(-t/\tau)$$



Ganda et al. (2007)

Non-parametric SFH

- In the simplest implementation one specifies a fixed set of age bins and fits for the fraction of mass formed within each bin.

- MOPED (Heavens et al. 2000)
- STARLIGHT (Cid Fernandes et al. 2005)
- STECKMAP (Ocvirk et al. 2006)
- VESPA (Tojeiro et al. 2007)
- ULySS (Koleva et al. 2009)
- MacArthur et al. (2009)

Method

$$M_\lambda = \left[\sum_{j=1}^{N} x_j b_{j,\lambda} r_\lambda \right] \otimes G(v_*, \sigma_*)$$

where $b_{j,\lambda}$ is the spectrum of the j^{th} SSP

$r_\lambda = 10^{-0.4(A_\lambda - A_{\lambda_0})}$ is the reddening term

M_{λ_0} is the synthetic flux

$\vec{x}$ is the population vector and $\otimes$ denotes the convolution operator

Each component x_j (j=1,..., N_*) represents the fractional contribution of the SSP with age t_j and metallicity Z_j to the model flux at λ_0.

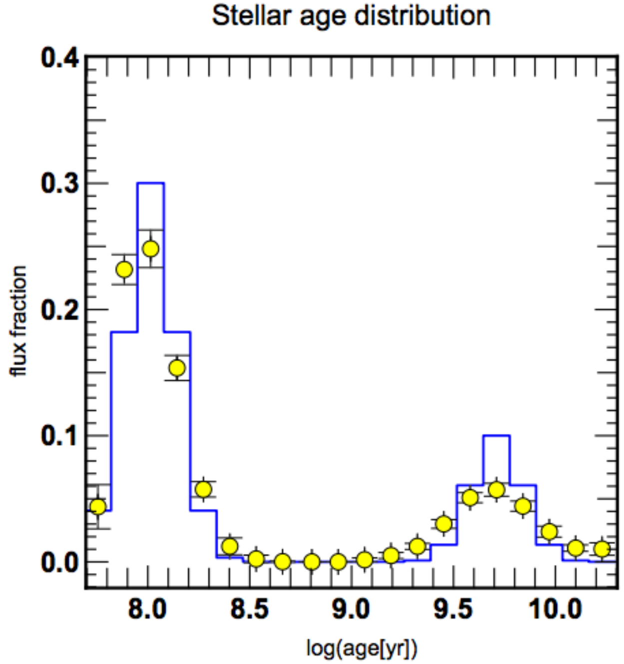
Deriving SFH

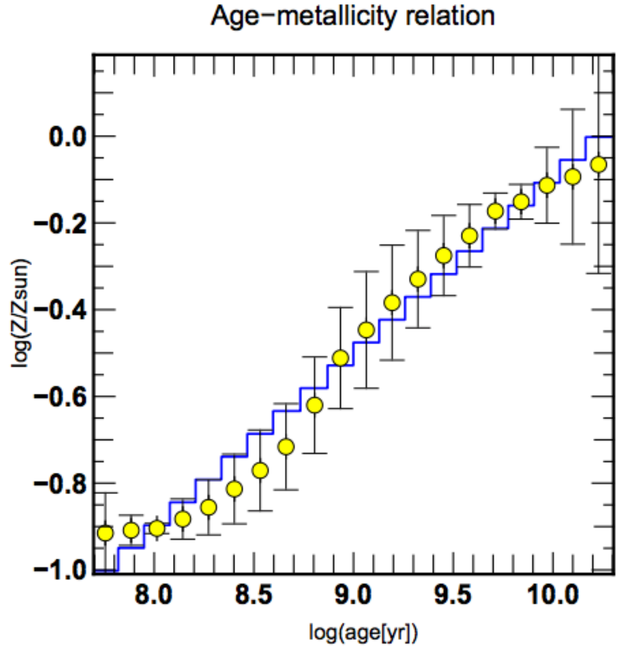
$$\chi^2 = \sum_\lambda [(O_\lambda - M_\lambda) w_\lambda]^2$$

where w_λ^{-1} is the error in O_λ

This **problem is non-linear and ill conditioned** -- small fluctuations in the data lead to large variations in the solution
This is due to the noise of the data and the presence of degeneracies

Full spectral fitting

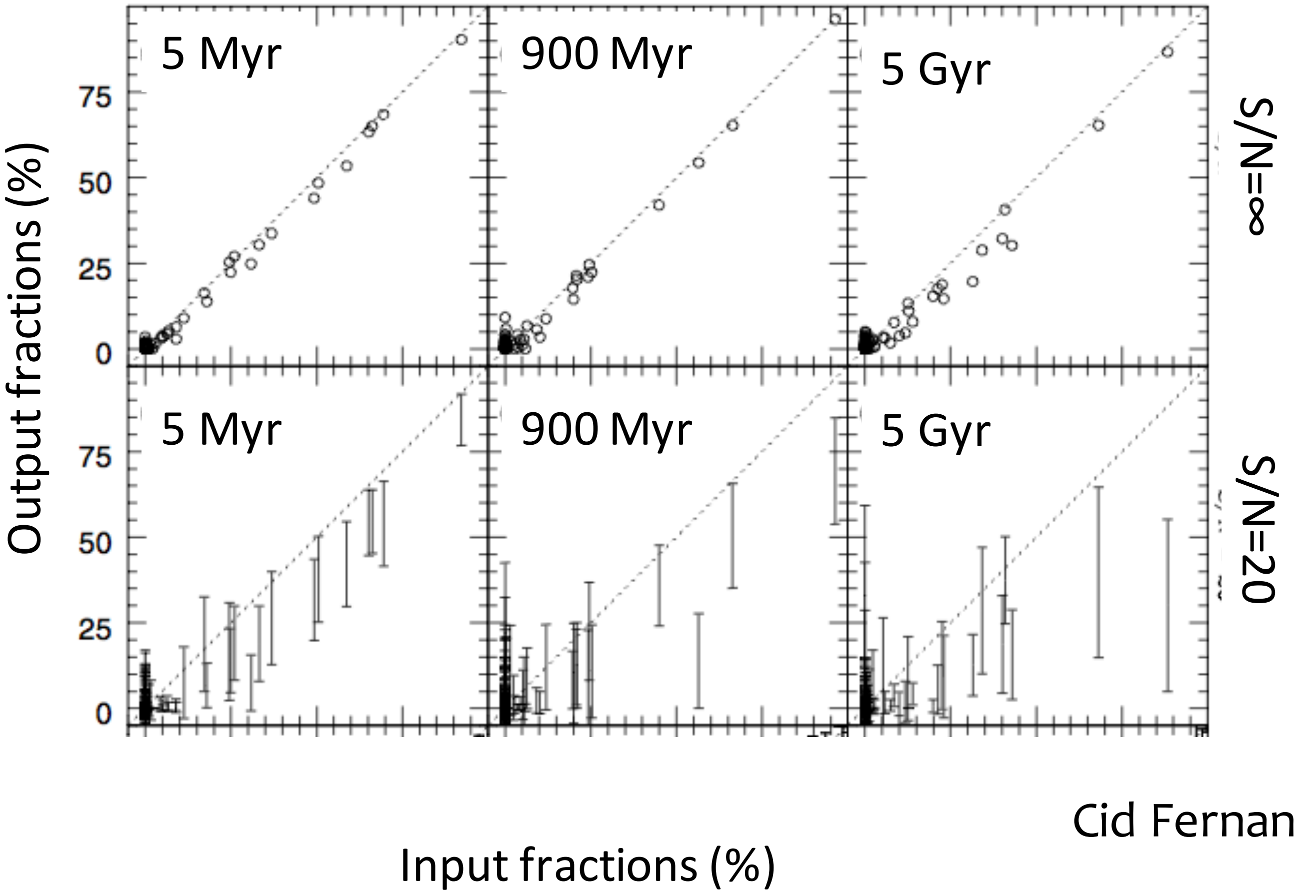




This **problem is non-linear and ill conditioned** -- small fluctuations in the data lead to large variations in the solution.
This is due to the noise of the data and the presence of degeneracies.

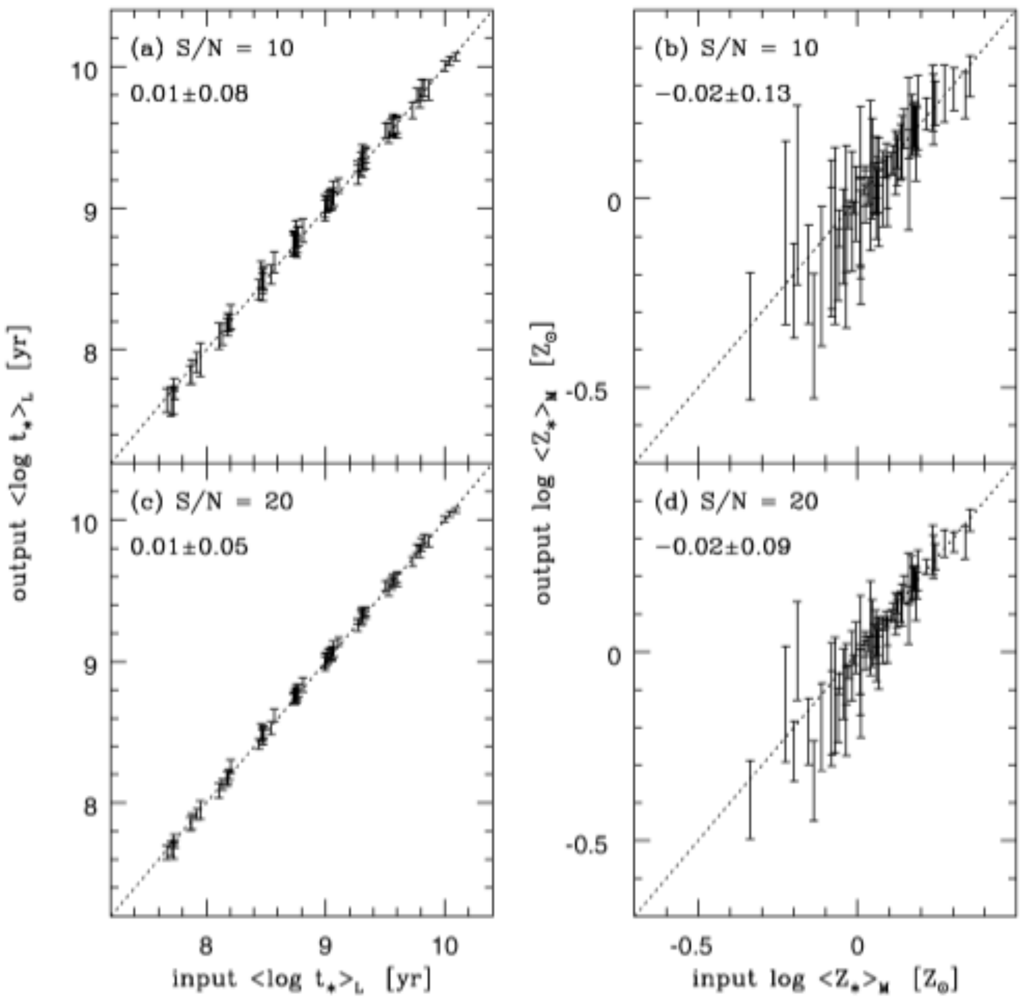
Effect of the S/N

The accuracy of the method depends strongly on the S/N of the observed spectra



Cid Fernandes et al. (2004)

Full spectral fitting

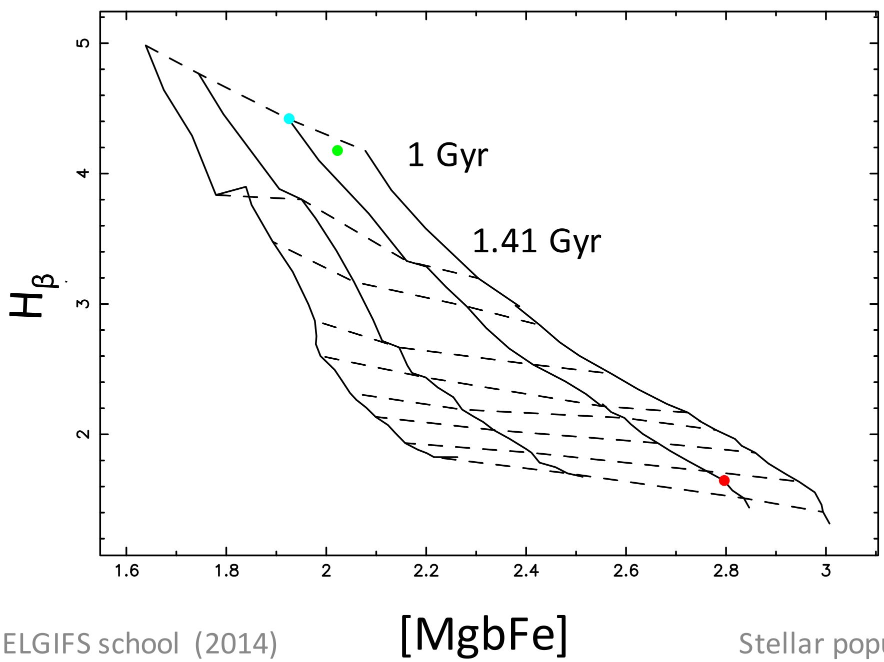


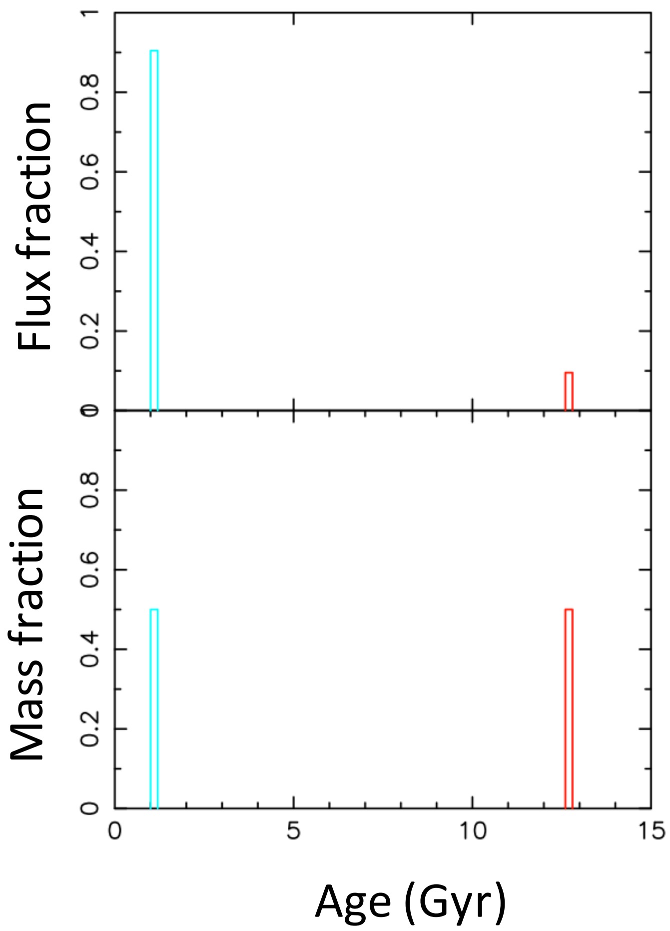
$$< Age >_{LW} = \frac{\sum_{i=1}^{nbins} flux_i age_i}{\sum_{i=1}^{nbins} flux_i}$$

$$< Age >_{MW} = \frac{\sum_{i=1}^{nbins} mass_i age_i}{\sum_{i=1}^{nbins} mass_i}$$

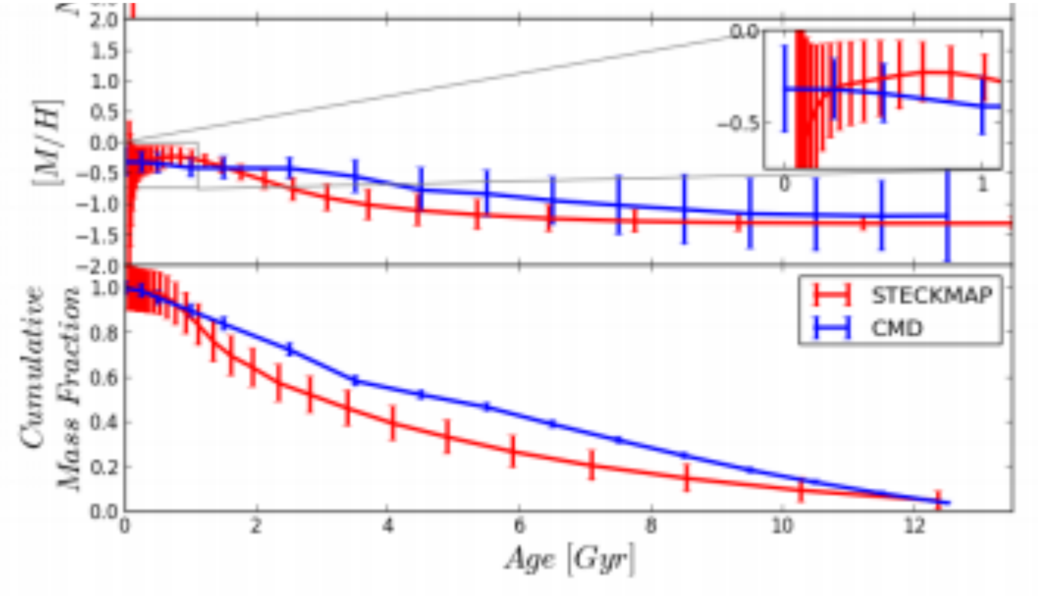
What do we get with mean values when the SFH is more complicated?

MW age = 1 Gyr x 0.5 + 12.6 Gyr x 0.5 = 6.8 Gyr
LW age = 1 Gyr x 0.9 + 12.6 Gyr x 0.1 = 2.16 Gyr
SSP age = 1.02 Gyr

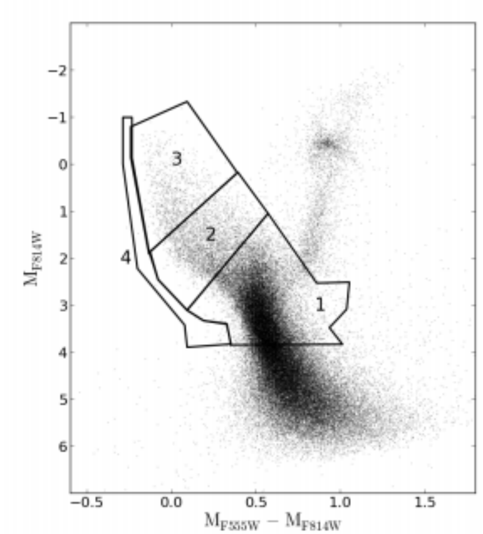




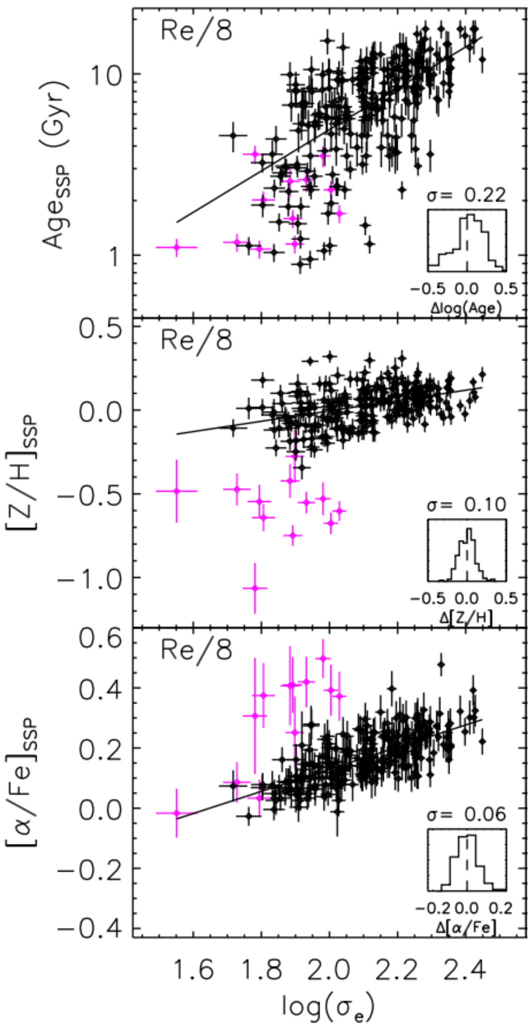
Comparison of resolved and unresolved SP
Test case: LMC

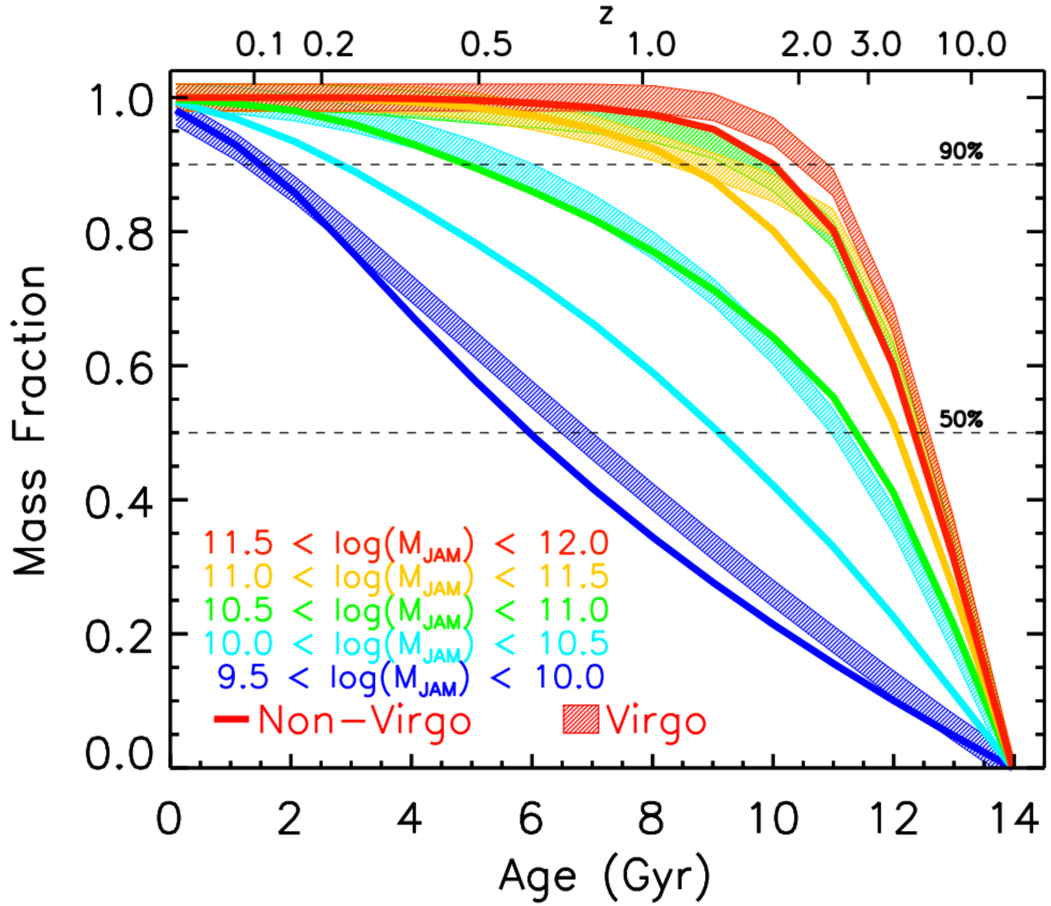


Ruiz-Lara et al. (2015)



Cumulative SFH





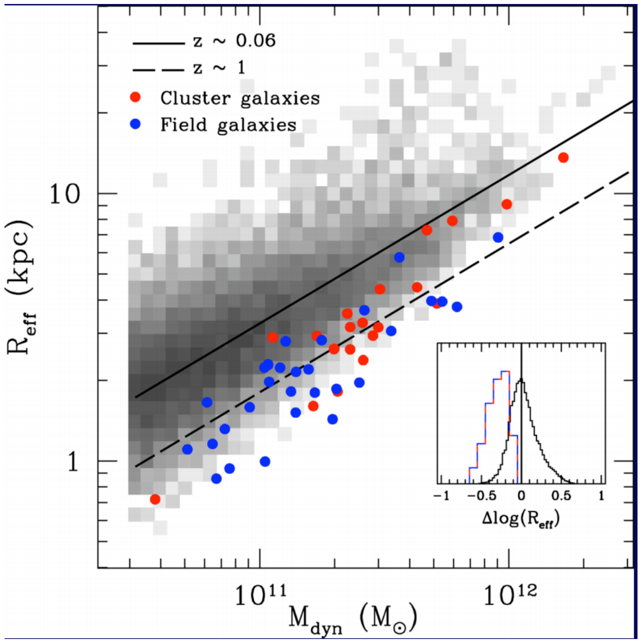
McDermid et al. (2015)

Summary of first lecture

- We revised the methods to derive stellar population properties in galaxies where we cannot resolve individual stars.
- Different techniques give consistent results in the overall picture of the formation of elliptical galaxies, which are the most studied systems:

Massive elliptical galaxies form their stars earlier and in shorter timescales than less massive ones.

Size-mass relation of passive (and masive) galaxies

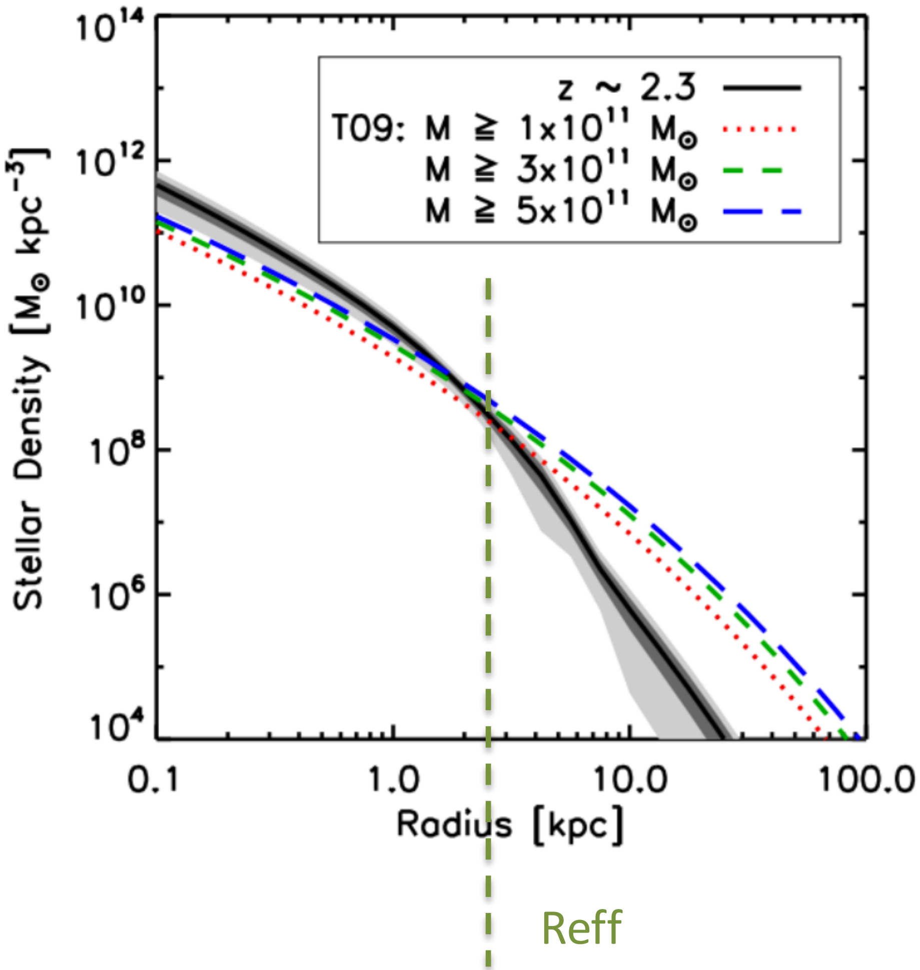


Early-type galaxies with M*> 10^{11} Msol

Size evolution:
~2 times smaller at z~1
~3 times smaller at z~2

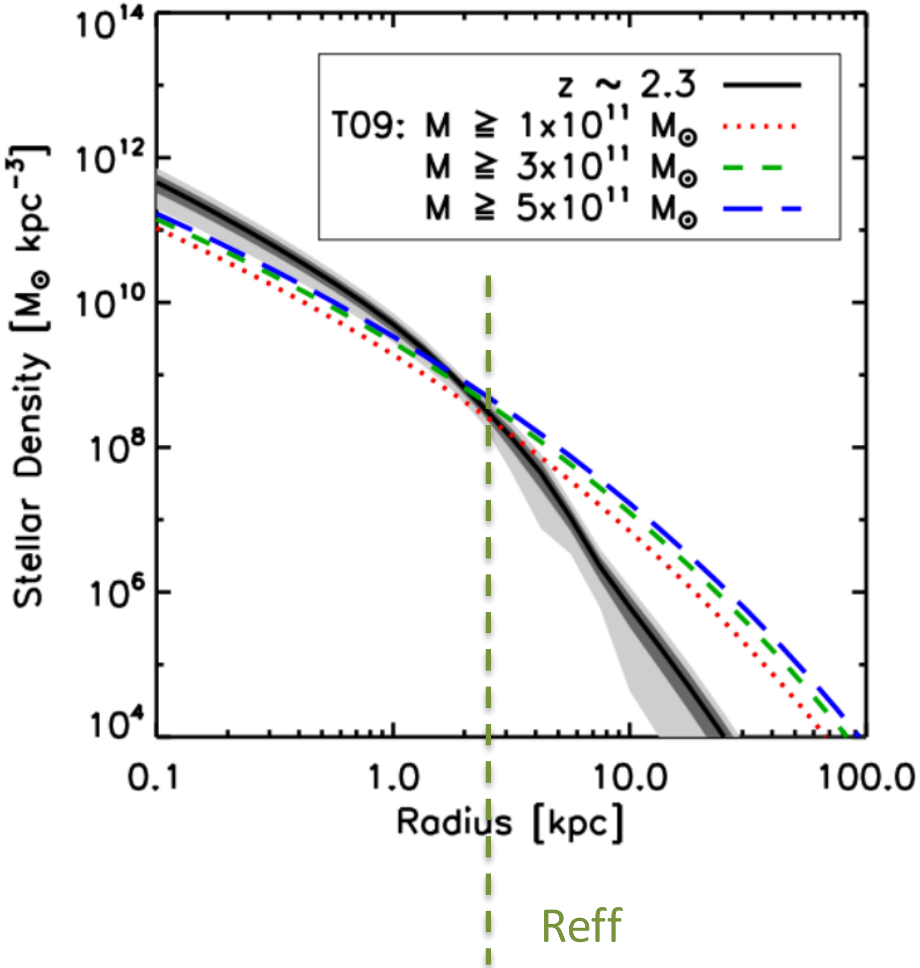
(also they have disk like morphologies)
(van der Wel et al. 2011; Buitrago et al. 2011)

Size evolution of ETG



Benzanson et al. (2009)

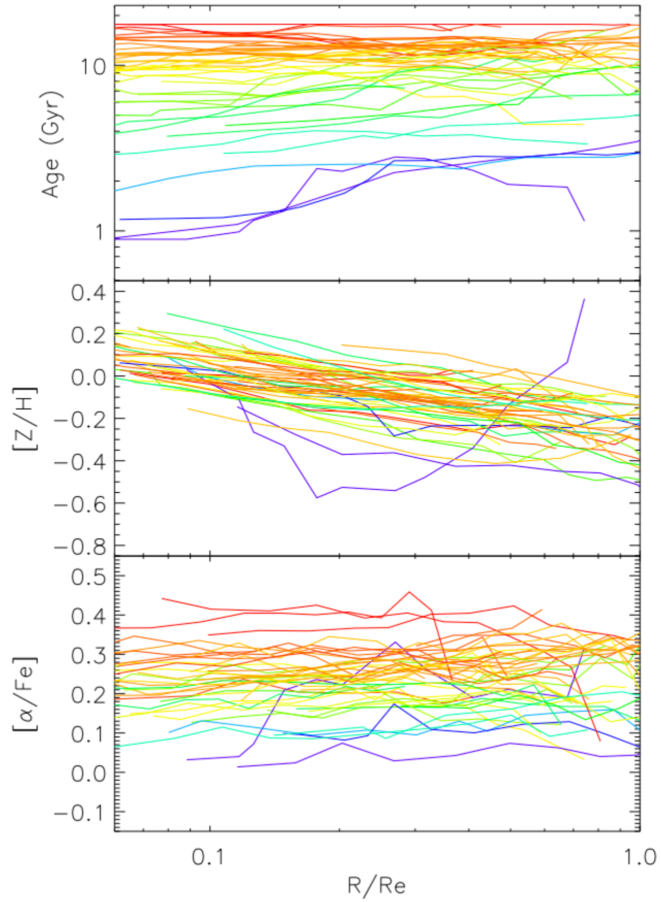
Size evolution of ETG

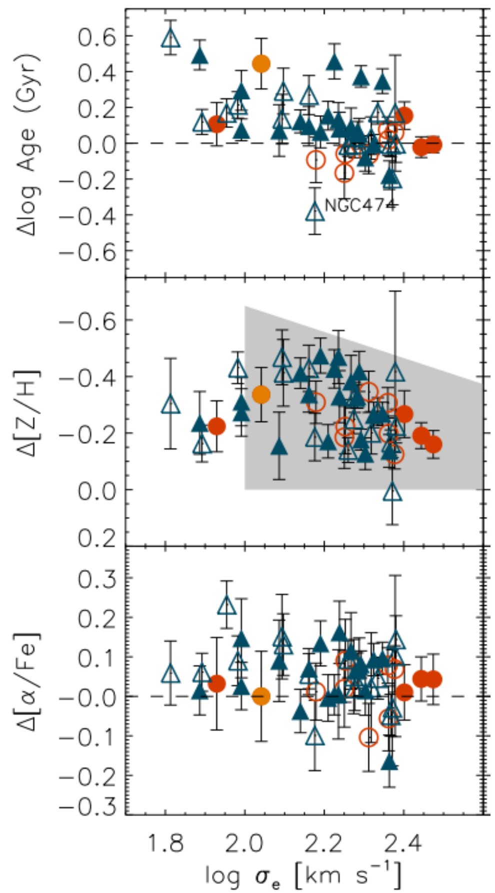


The most accepted scenario is that massive ETG grow by minor mergers

Benzanson et al. (2009)

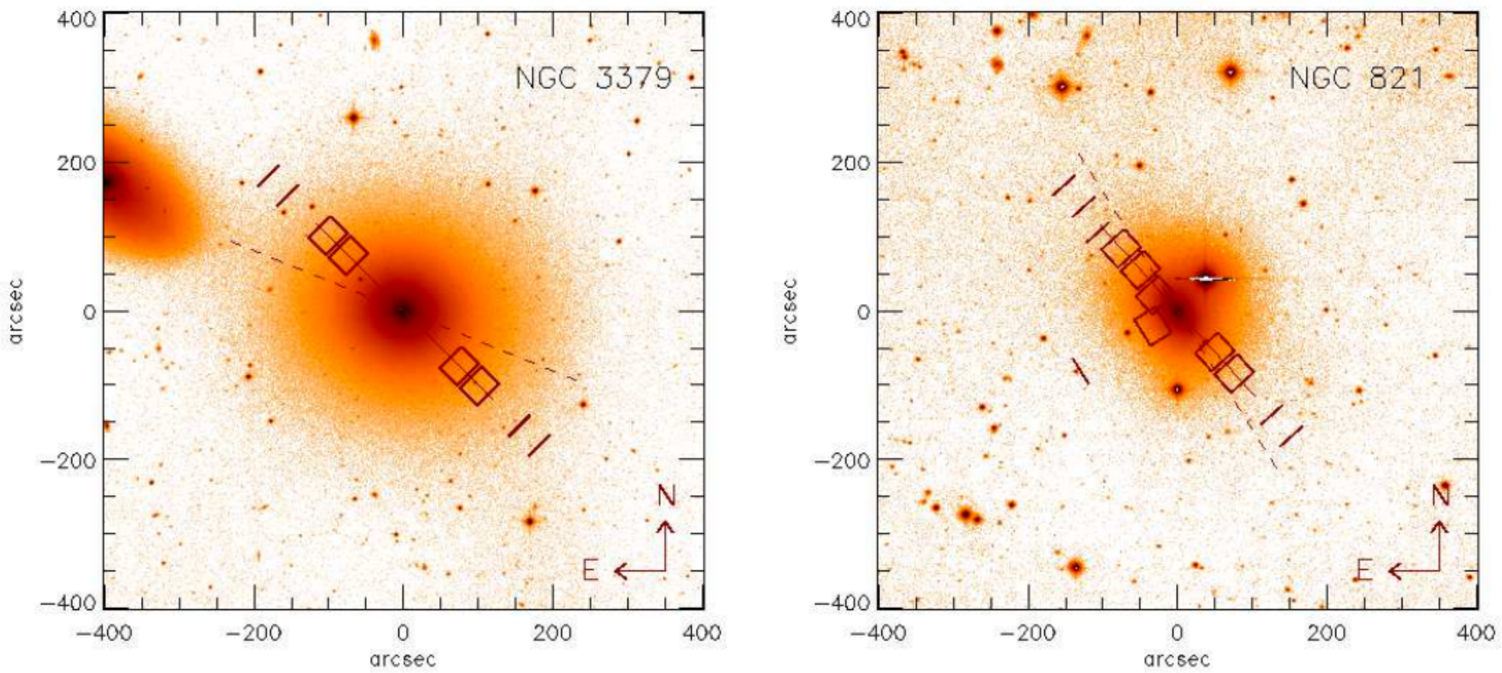
Stellar population gradients in early-type galaxies





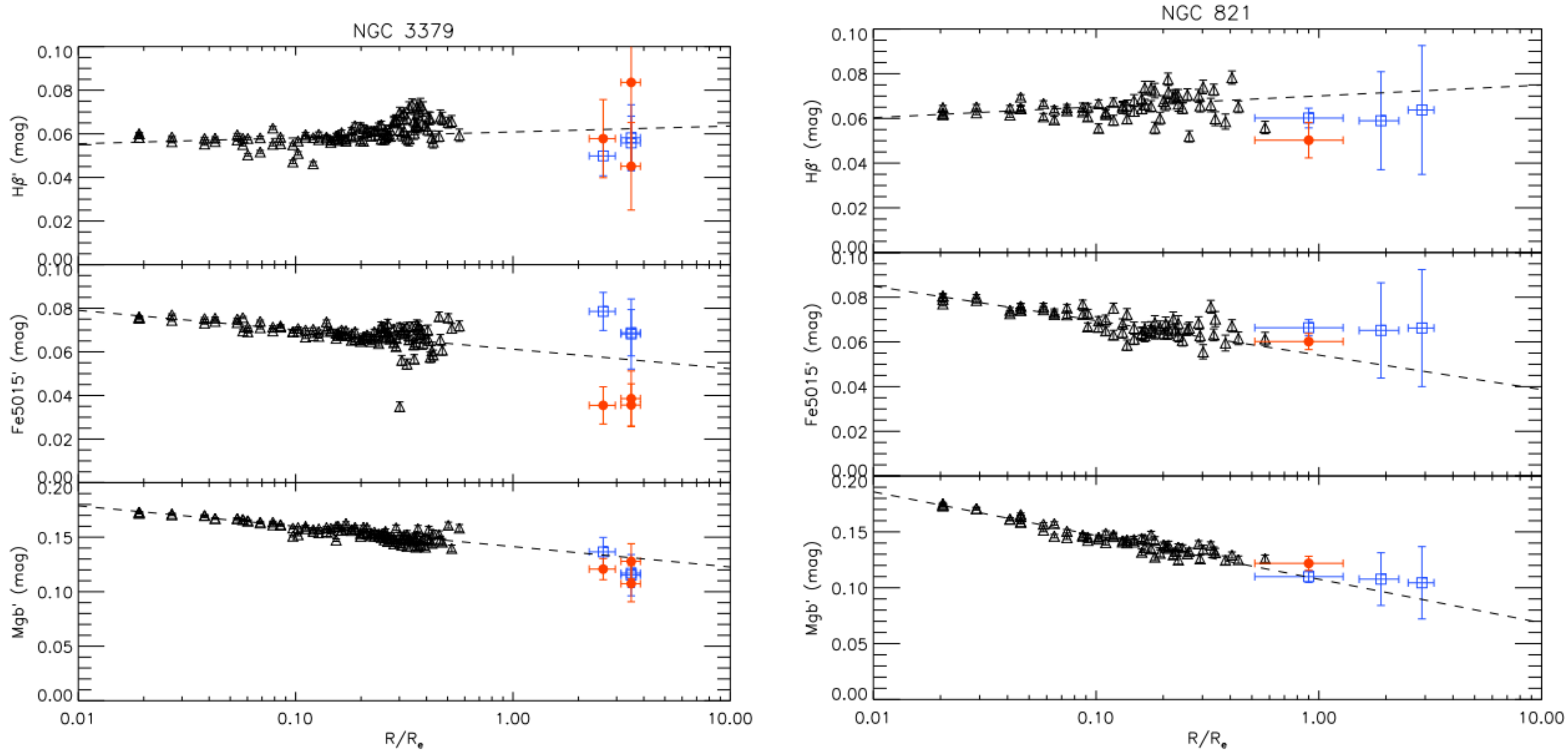
Kuntschner et al. (2010)

Early-type galaxy gradients out to 4Reff



Weijmans et al. 2009

Radial gradient out to 4 Reff



Weijmans et al. 2009

Other possible techniques with the E-ELT: obtaining metallicities with PNe

- All populations older than ~10^8 yr make PN and in a large galaxy, hundreds are available for study

- We can observe them up to very large radii and avoid the age-metallicity degeneracy.
- O and Ne are not expected to change from AGB nucleosynthesis
- **Problem: [OIII]4363 or [SII]6717, 6731 are very faint.**

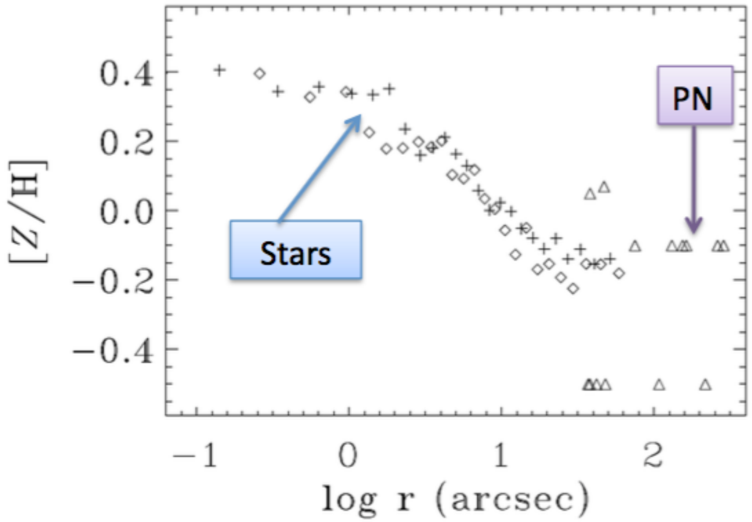
- If one can measure [OIII]4363, [SII]6716,6731 and [NII]6548,6584, then one can directly measure a population's abundance distribution function and constrain its history of chemical enrichment.

- Possibility of getting, not only the mean values but also the dispersion.

Previous attempts with 8m class telescopes

Mendez et al. (2005) (20h using FORS1 at the VLT); Walsh et al. (1999) (only lower limits)

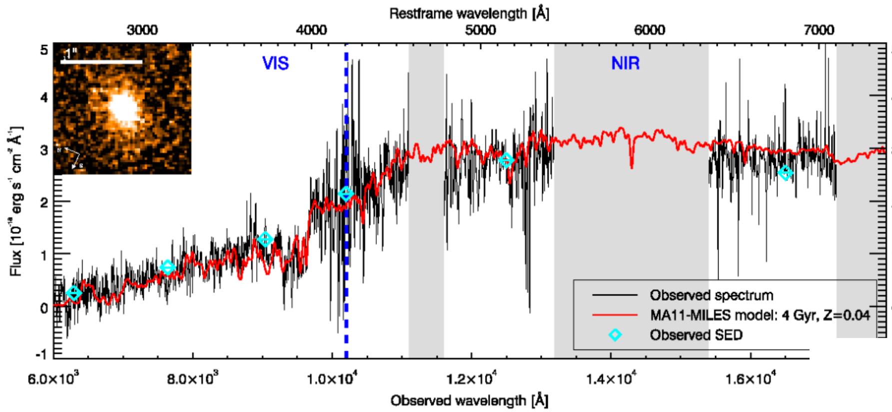
NGC 4697
d=11 Mpc



42 PNe in M31 bulge (Richer+1999; Jacoby & Ciardullo 1999), Also in M32 (Stasinka et al. 1998; Richer et al. 2008) and NGC5128 (Walsh et al 1999)

ETG at high redshift

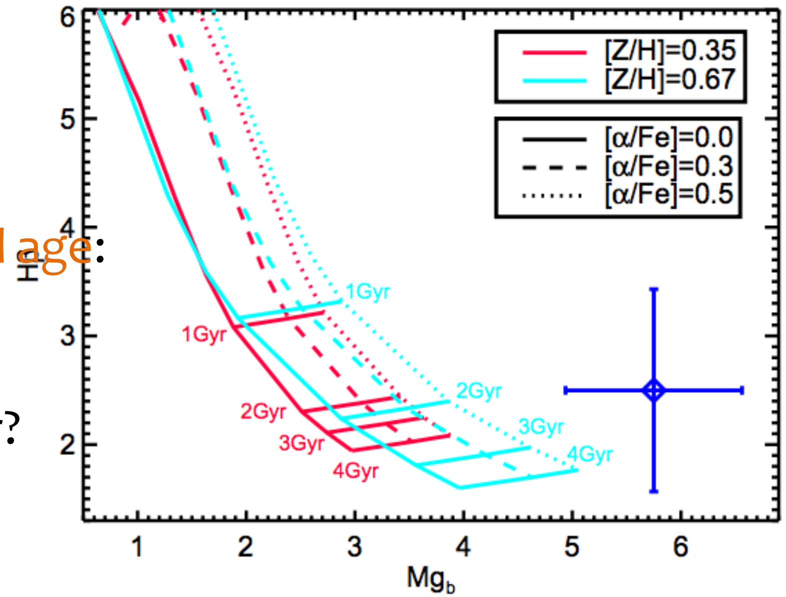
9 nights at the VLT/UT2 (Xshooter)



Early-type galaxy at z~1.4 with σ~385 km/s

Age=4.1 Gyr
[Z/H]= 0.5
[α/Fe]=0.4

Results imply stars formed at z>5 in a Δt=0.1 Gyr

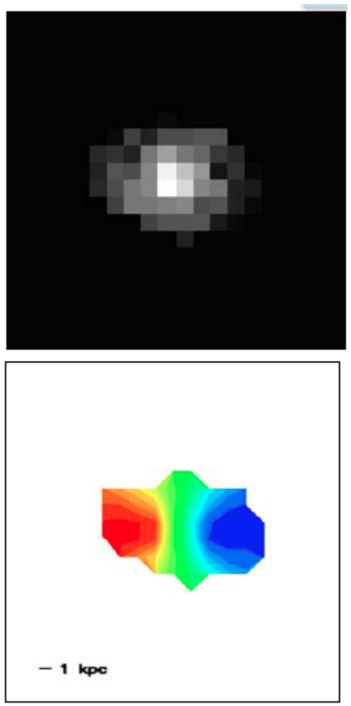


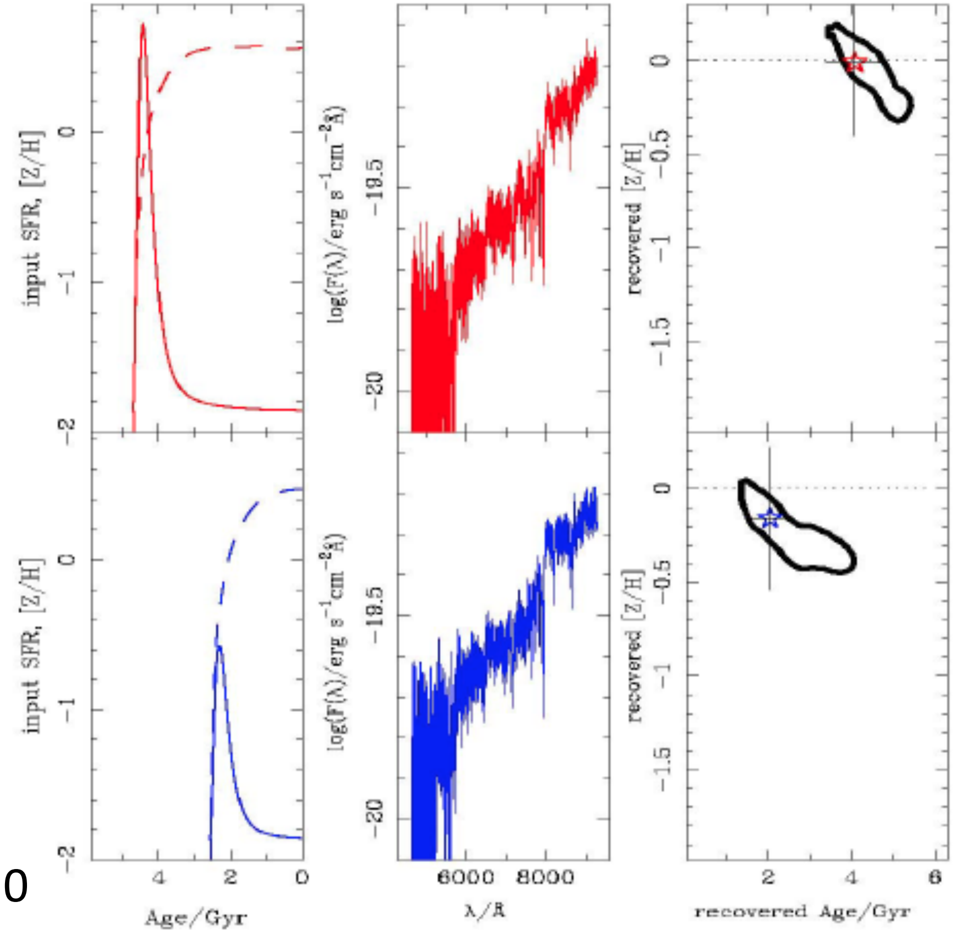
Very high metallicity, high [α/Fe] and an old age:

-rejuvenation?
-accretion of metal poor stars in the center?
Still many uncertainties

Lonoce et al. (2015)

What can we get with current facilities





Simulations of a disk galaxy at z=1.0
With a disk scale-length of 0.4”.
80h with MUSE

Difficult to obtain a statistical sample of galaxies

Stellar populations in early-type galaxies in the E-ELT era

Some ideas:

- E-ELT will allow us to explore the detailed chemical abundance ratios in ETG (fine tune SFH and constraints nucleosynthesis.

- E-ELT will allow us measure SP gradients up to very large radii to test theories of mass assembly.

- E-ELT will allow us to observe large samples of galaxies at high redshift and study their properties individually

Outline

- The big assumption: the IMF
- Unresolved stellar populations in disk galaxies (both at low and high redshift): where do we stand, we are we going
- Spectroscopic surface brightness fluctuations (a new technique to constrain stellar pop models)

The big assumption: the IMF

- Dynamical studies provide an accurate measure of the M/L, but can't discern who contributes to M.
- Integrated light studies address that problem and can constrain the shape of the IMF
- But that is a **difficult** problem

Measuring the IMF in the integrated spectra

Very challenging

The faint low mass stars ($M<0.5$ Msun) which dominate the total stellar mass budget in galaxies (60-80%), contribute only of order 1% in the integrated light.

In early-type galaxies, the stars that dominate the light (K and M giants) have a similar spectra as the stars that dominate the mass budget (K and M dwarfs)

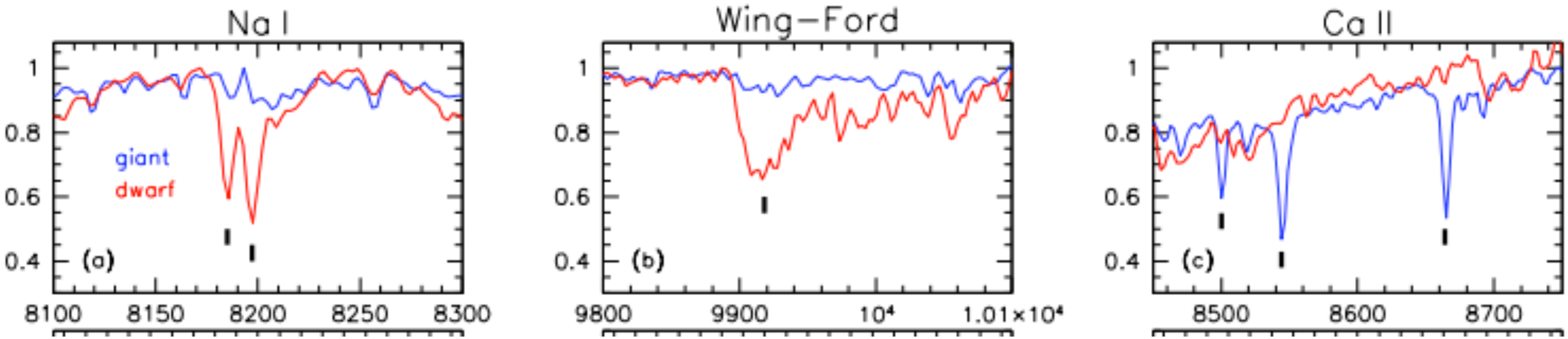
Detecting IMF variations using line-strength indices requires measurements with very high accuracy.

Counting dwarf stars

It can be done quantifying the amount of dwarf stars using gravity-sensitive absorption features. The strongest dwarf-sensitive features are:

NaIλ8183,8195 doublet
FeHλ9916 wing Ford band

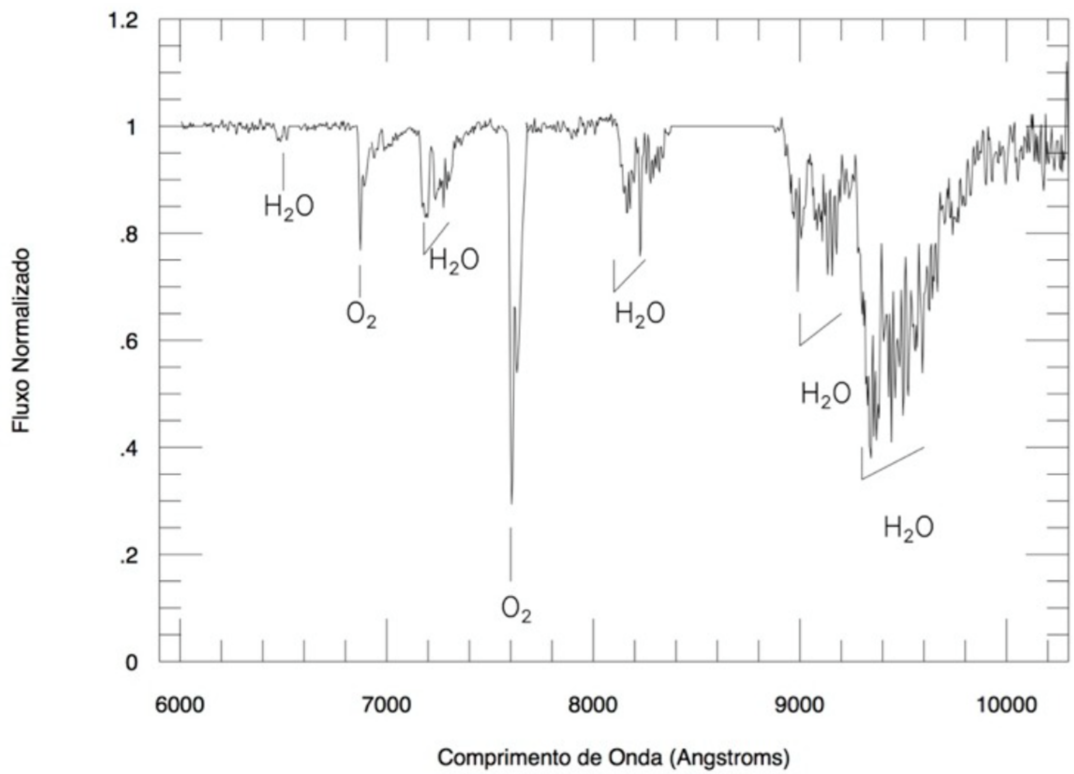
The strongest giant-sensitive features is the CaIIλ8498,8542,8662 triplet.



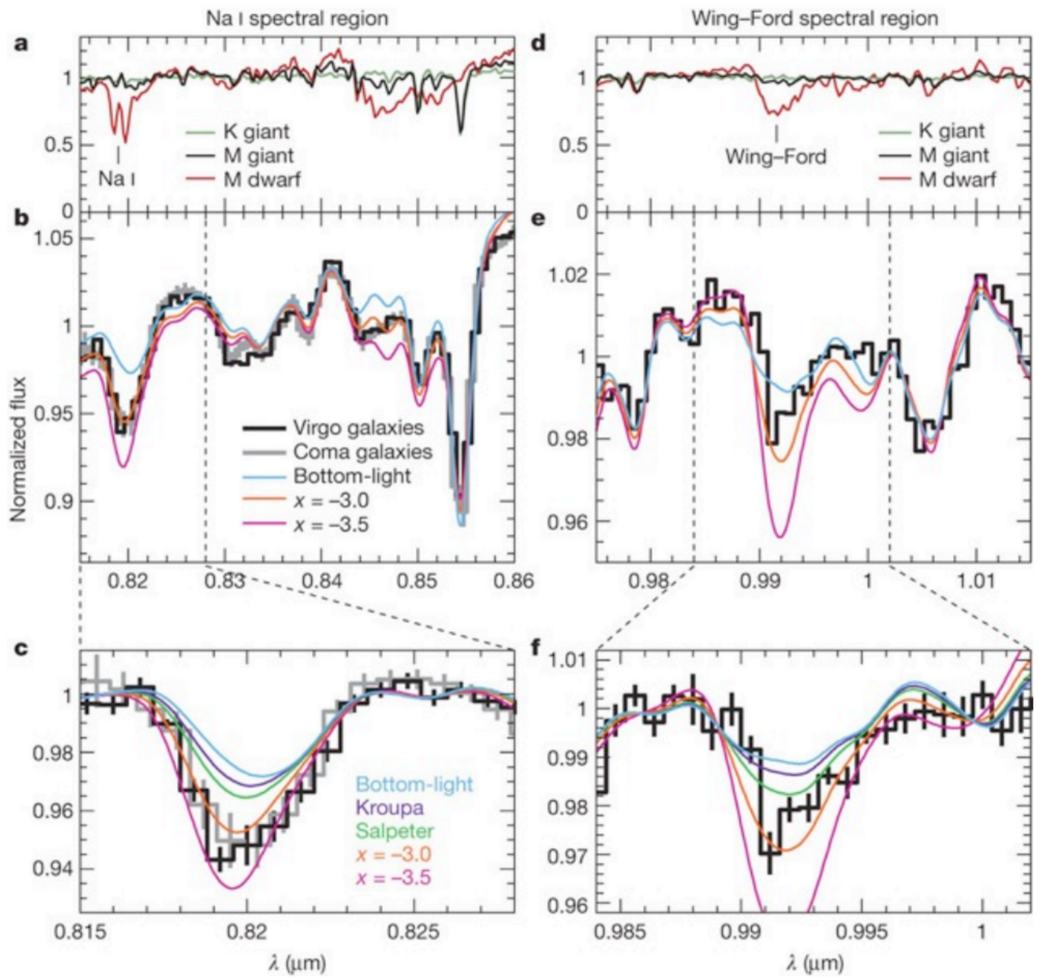
Difficulties: abundance ratios

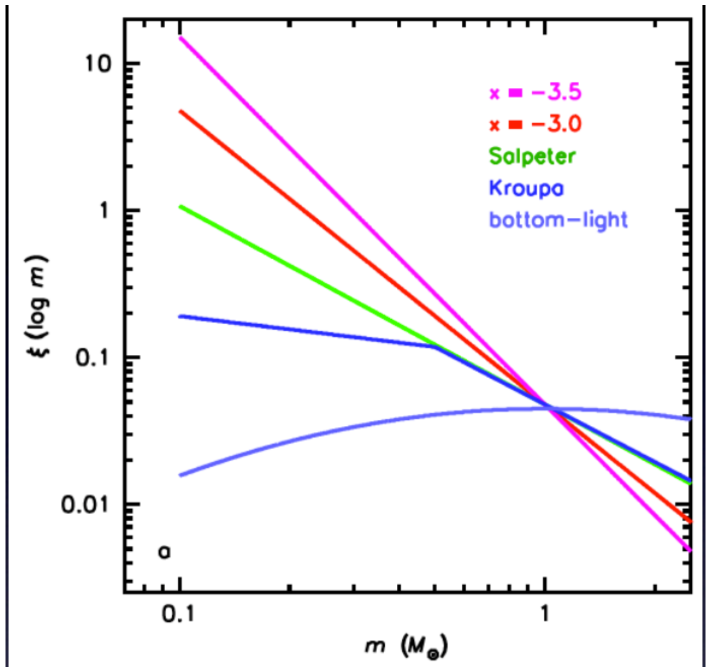
- The IMF-sensitive features also vary with elemental abundance pattern and some vary with stellar age.

Difficulties: telluric absorption



Counting dwarf galaxies

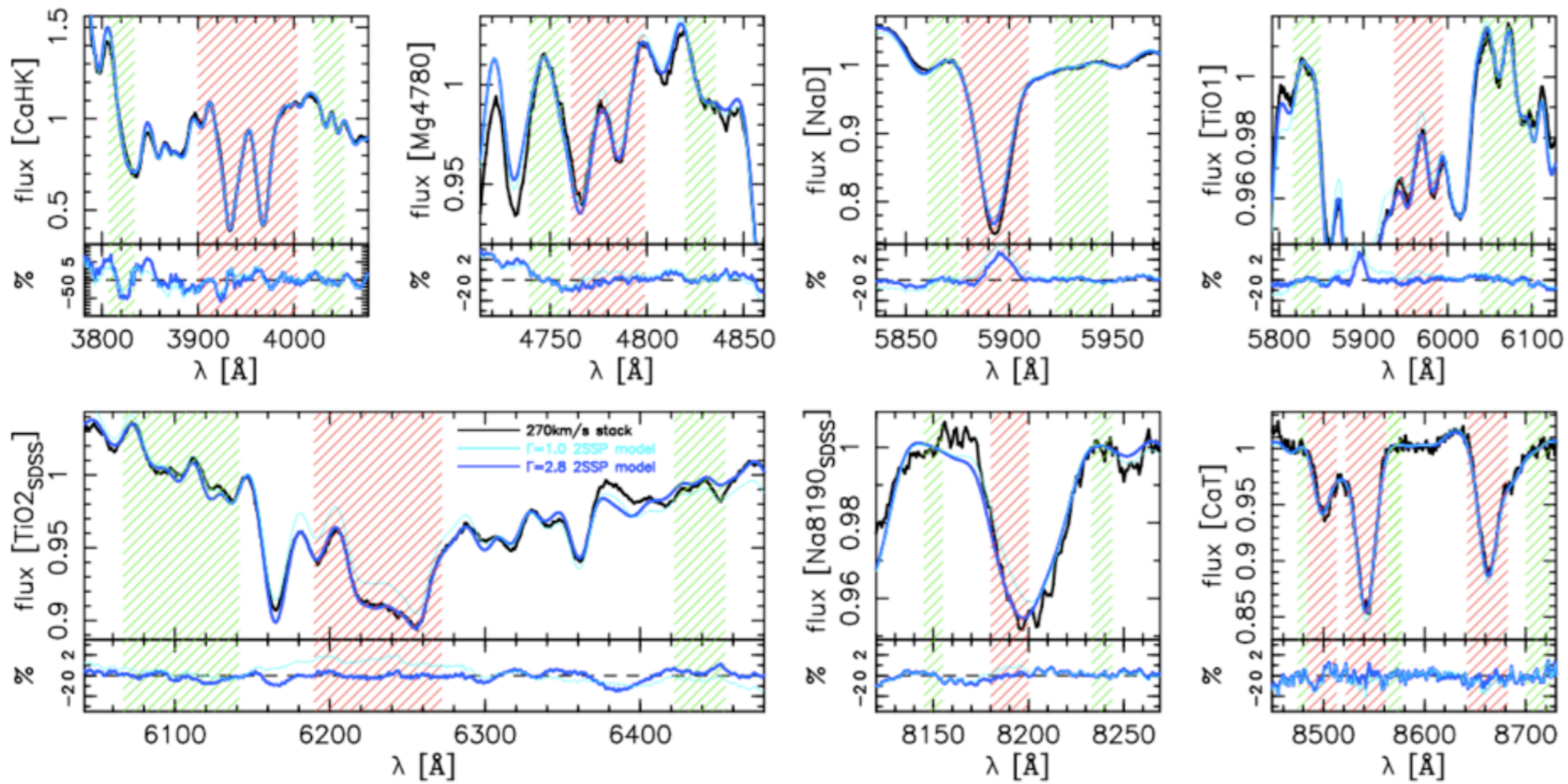




A substantial population of M dwarfs in ETG

Van Dokkum & Conroy (2010)

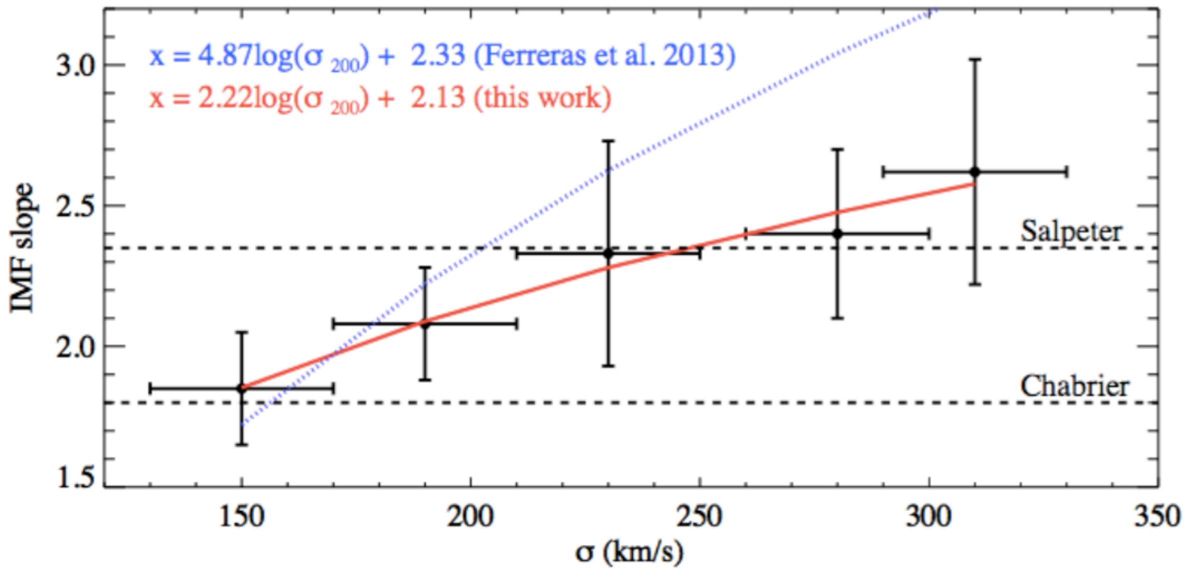
Confirmation from other groups/methods



La Barbera et al. (2013); Ferreras et al. (2012)
Stacked spectra of +25.000 SDSS galaxies
Analysis of several indices

See also van Dokkum & Conroy (2012)
Martinez-Serrano et al. (2014)

There is a correlation with the mass of the galaxy

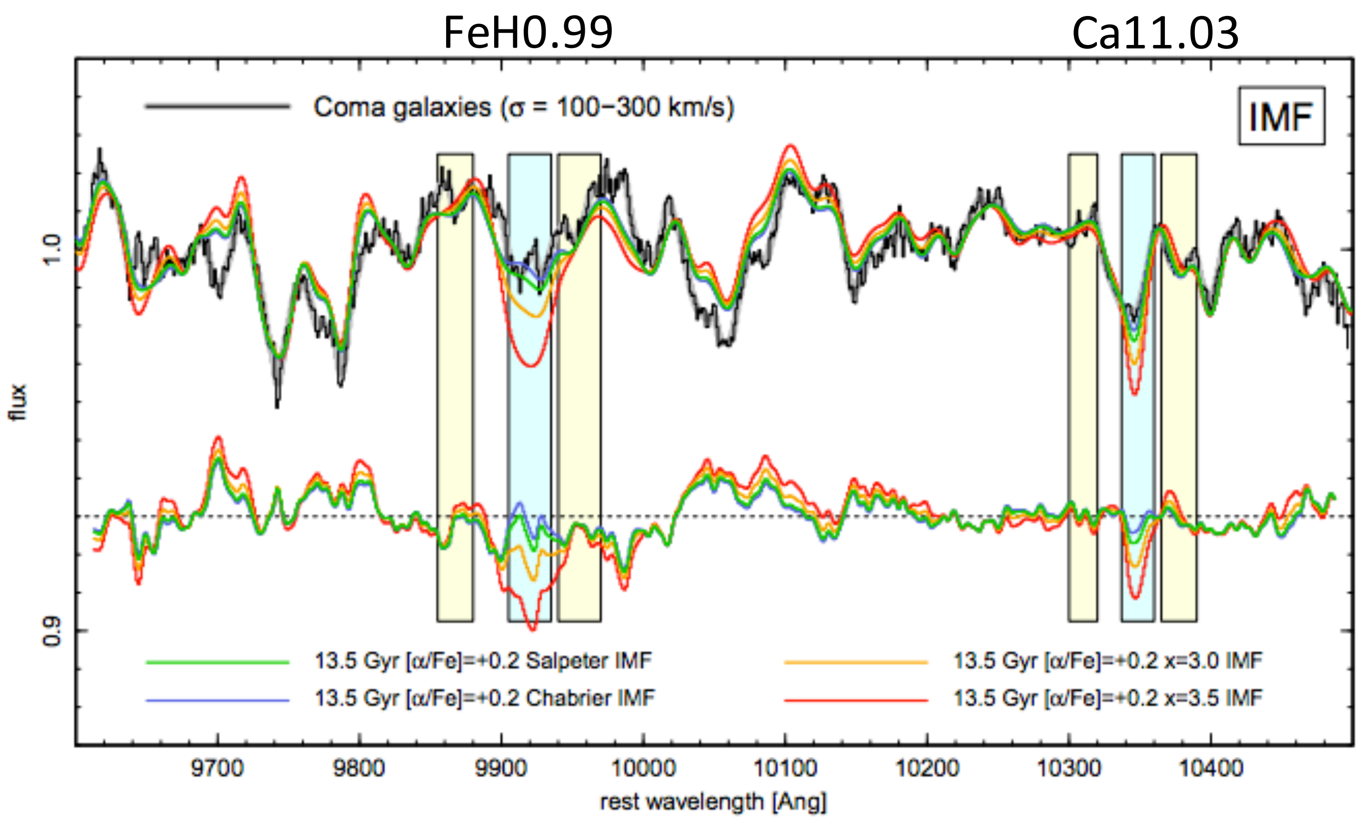


More massive galaxies have a higher content of dwarfs/giant stars

Conroy & Van Dokkum 2012; Spiniello et al. (2012, 2013); Ferreras et al. 2013; Tortora et al. 2013; La Barbera et al. 2013; among many others…

Contradictory results

Smith found, on the contrary, that the Wind Ford band of massive ETG in Coma is reproducible with a Salpeter IMF

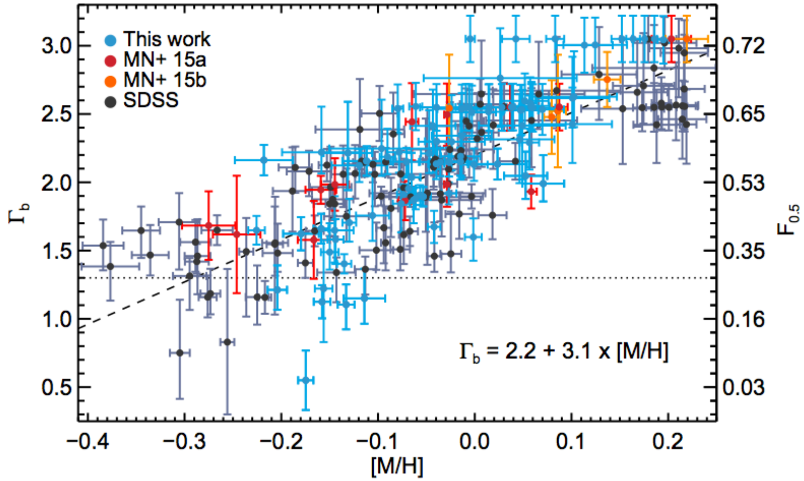


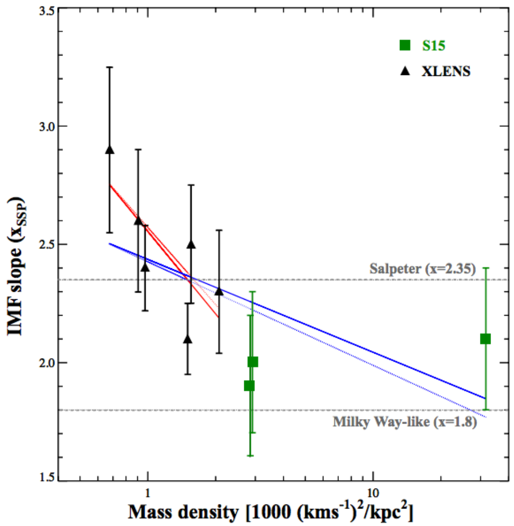
Stacked J-band spectra from SUBARU

Smith et al. (2012)

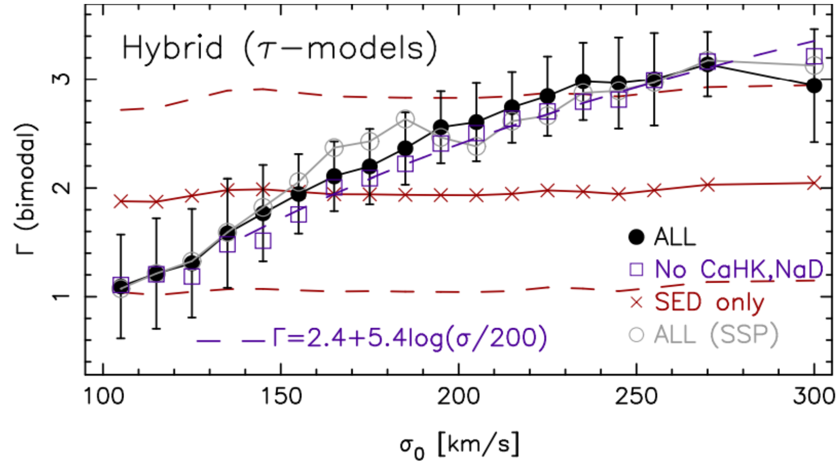
What is the IMF driver?

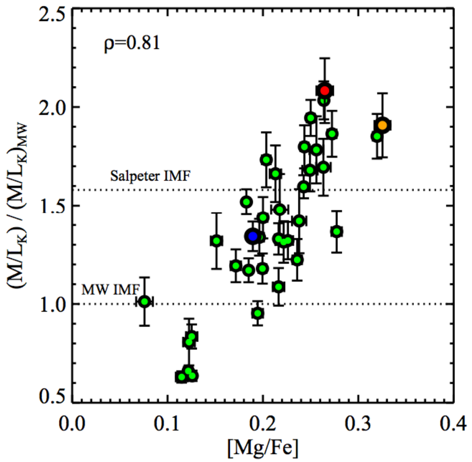
Martin-Navarro et al. (2015)





Spiniello et al. (2015)





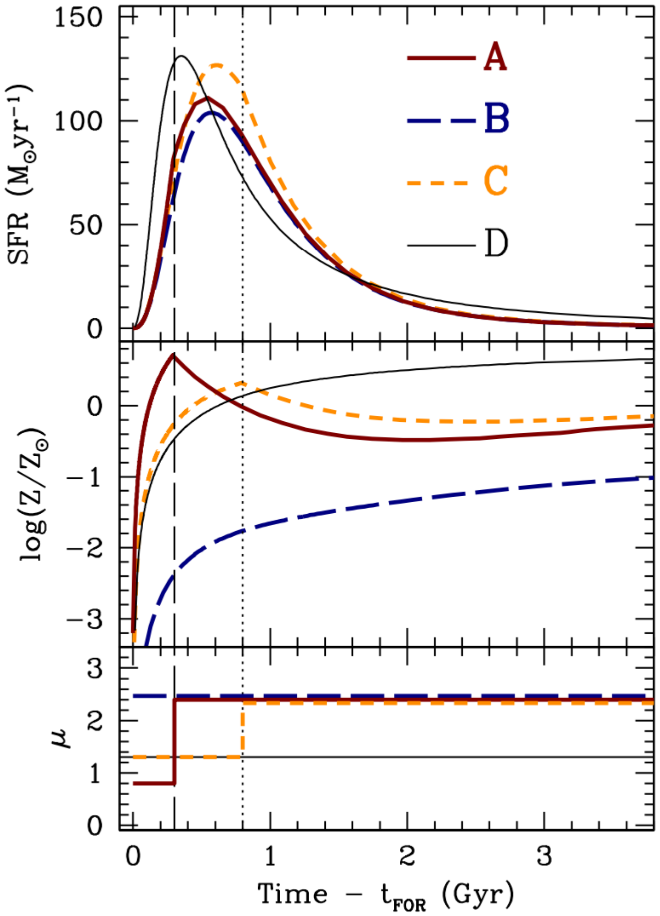
La Barbera et al. (2013)

Van Dokkum et al. (2012)

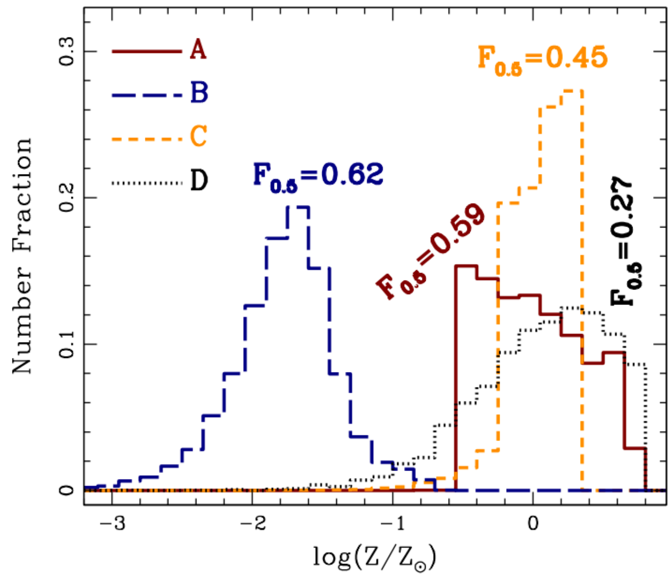
IMF

- It is possible to constrain the low mass end of the IMF on the basis of integrated spectra of galaxies
- These analyses indicate the presence of a trend between the IMF and galaxy mass (in agreement with dynamical studies)
- No clear whether trends is due to a correlation with mass, metallicity, [Mg/Fe] or [Z/H]

Bottom heavy IMF cannot explain metallicities. IMF evolving with time

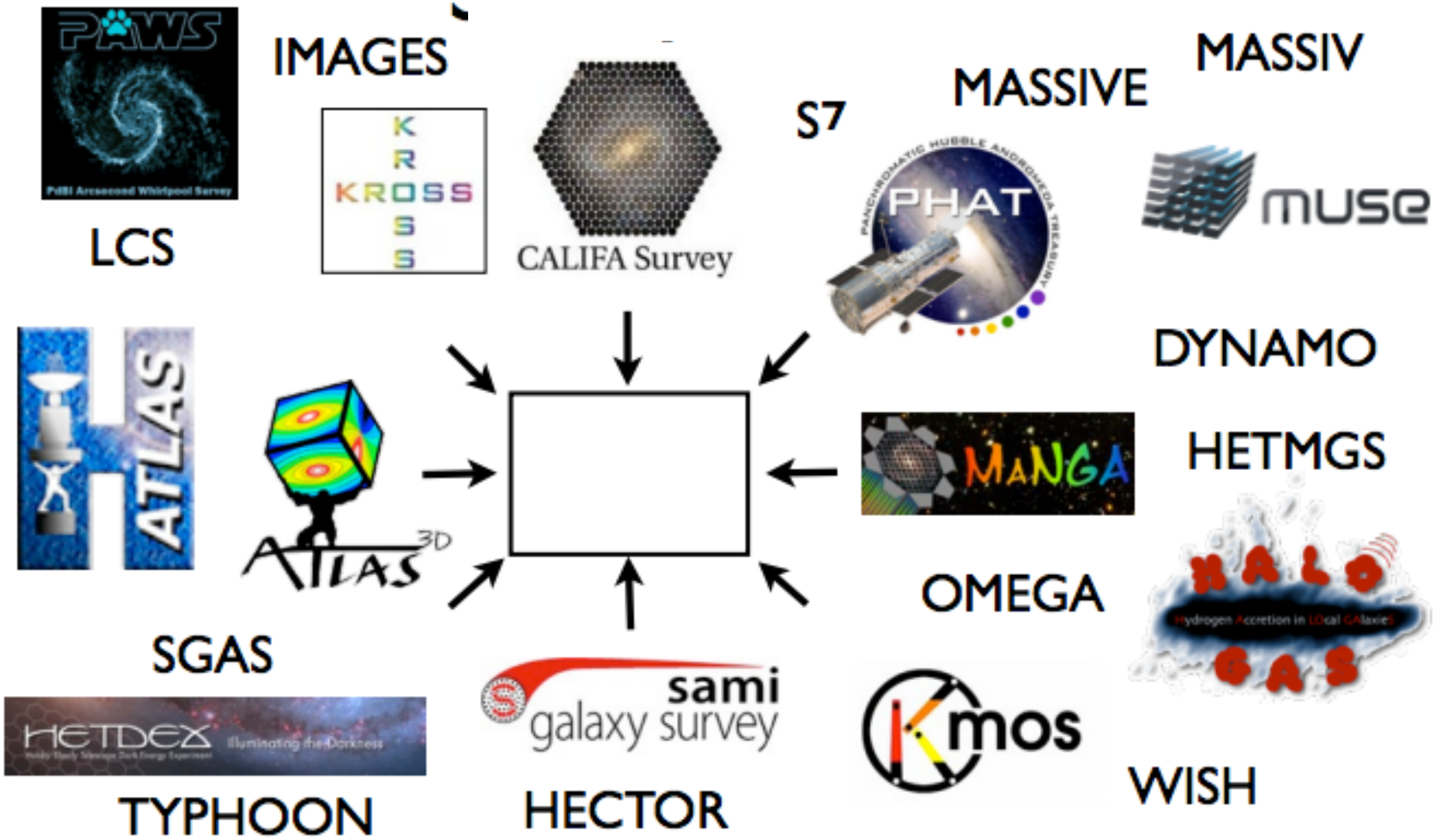


Weidner et al. (2013)



Disk galaxies

Surveys with IFS



Unresolved stellar populations with IFS

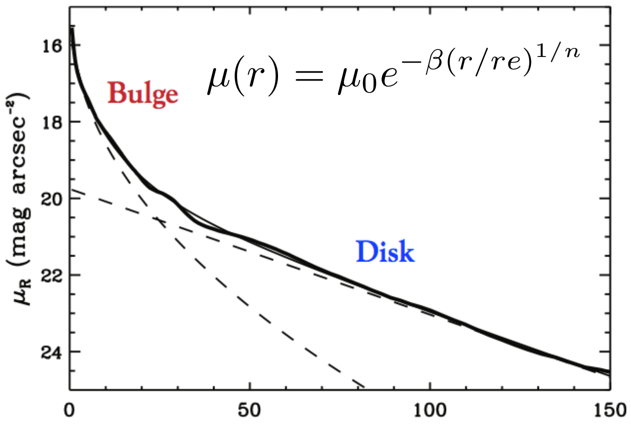
Other individual efforts: Rawle et al. 2008, 2010; Pracy et al. 2009; Sil'chenko et al 2009,2011, 2013.; PSB et al. 2013; Chillingarian (2009); Coccatto et al. (2011), etc…

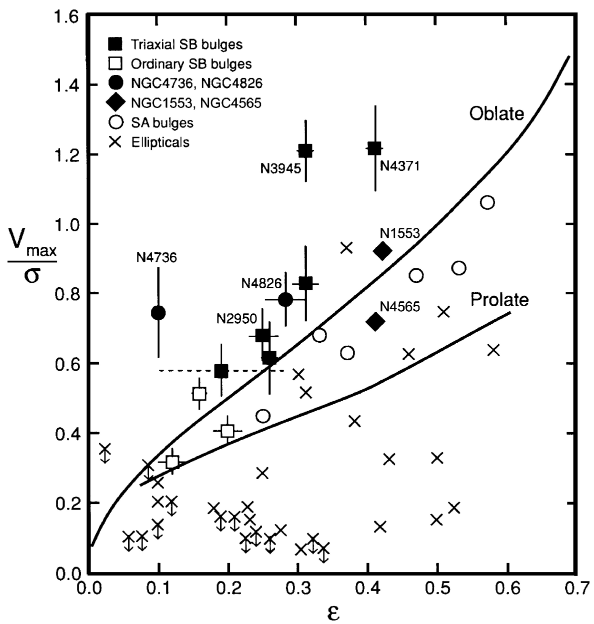
Disk galaxies

- Bulges of disk galaxies (the importance of different types of bulges)

- Disk of galaxies (stellar migration, inside out formation)

Different types of bulges





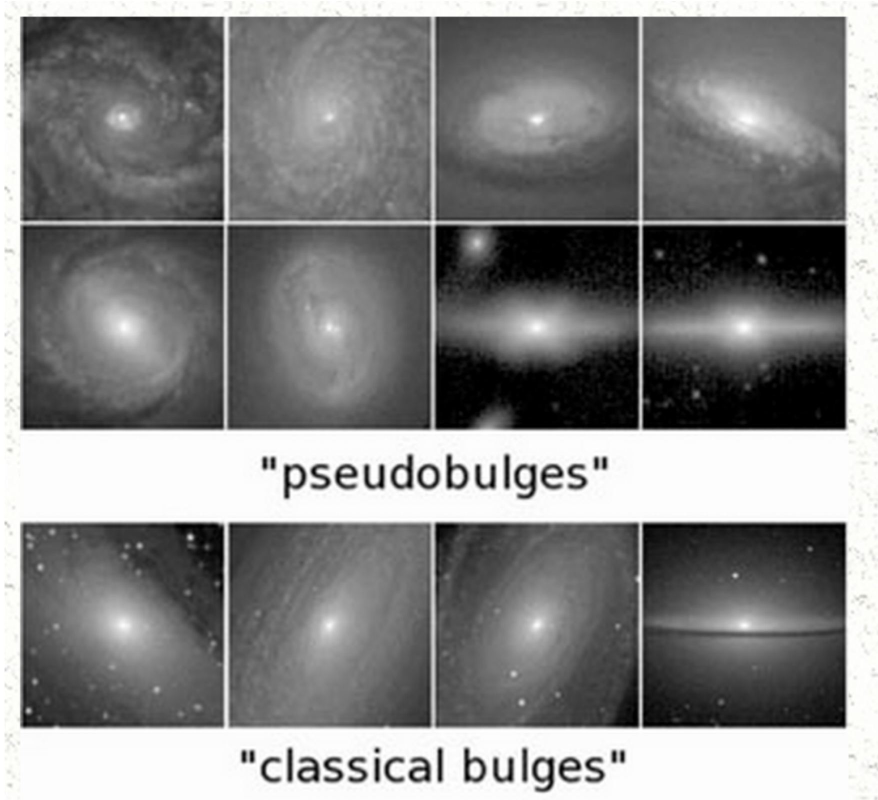
Classical:

- Sersic n~4 in the SB profile
- dynamically hot [low (v/σ)]

Disky bulge: (*pseudobulges*)

- Sersic n~1 (exponential) SB profile
- Disk like kinematics [high (v/σ)]

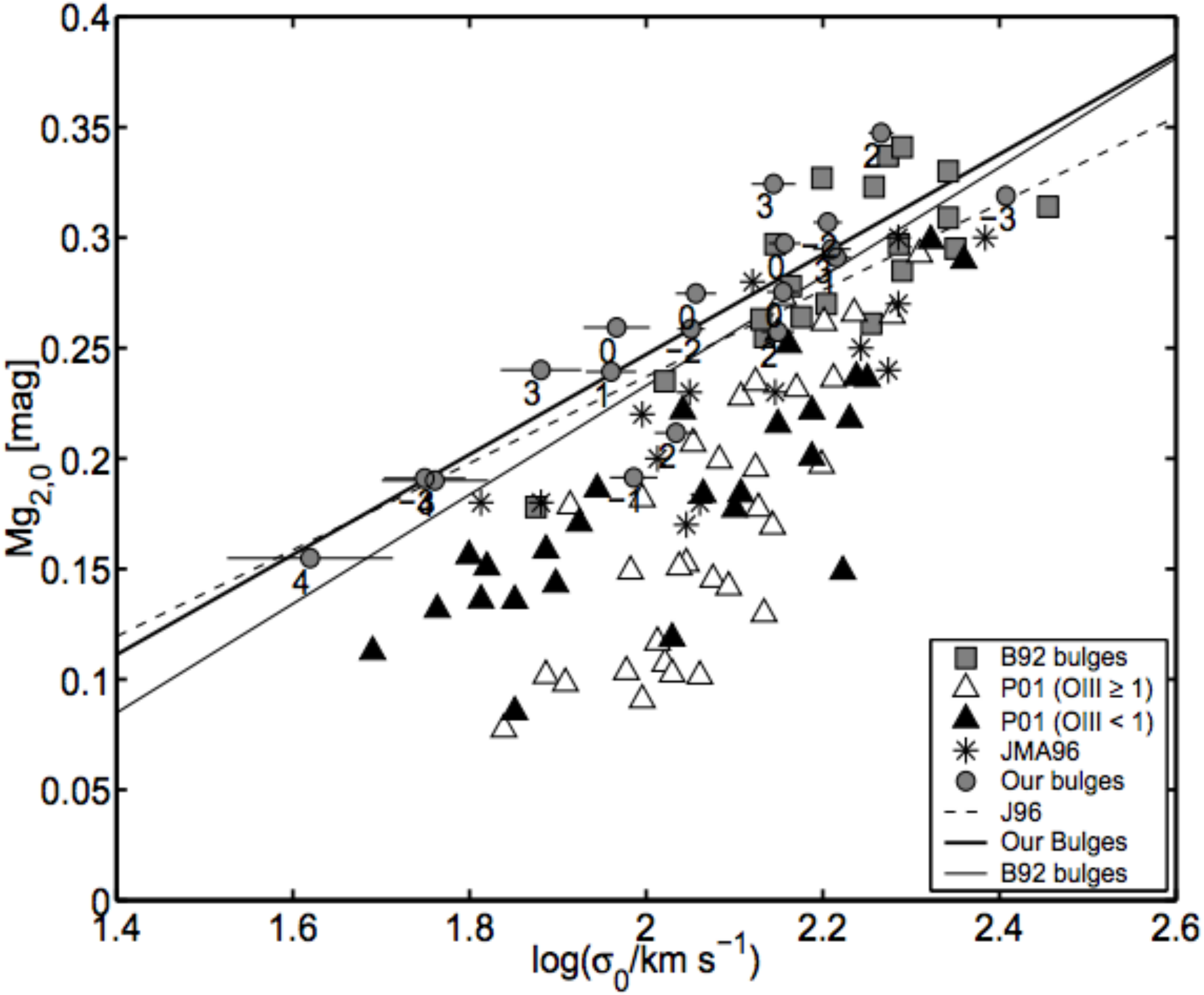
Different types of bulges



Classical: Believed to be formed through merger or clump instabilities.
Expected: old, α-enhanced (high [Mg/Fe]) stellar populations.
Pseudobulges: (associated to internal processes, related to bars). Formed in longer timescales.
Expected: young, not- α -enhanced
Boxy/peanut: believed to be the inner parts of bars

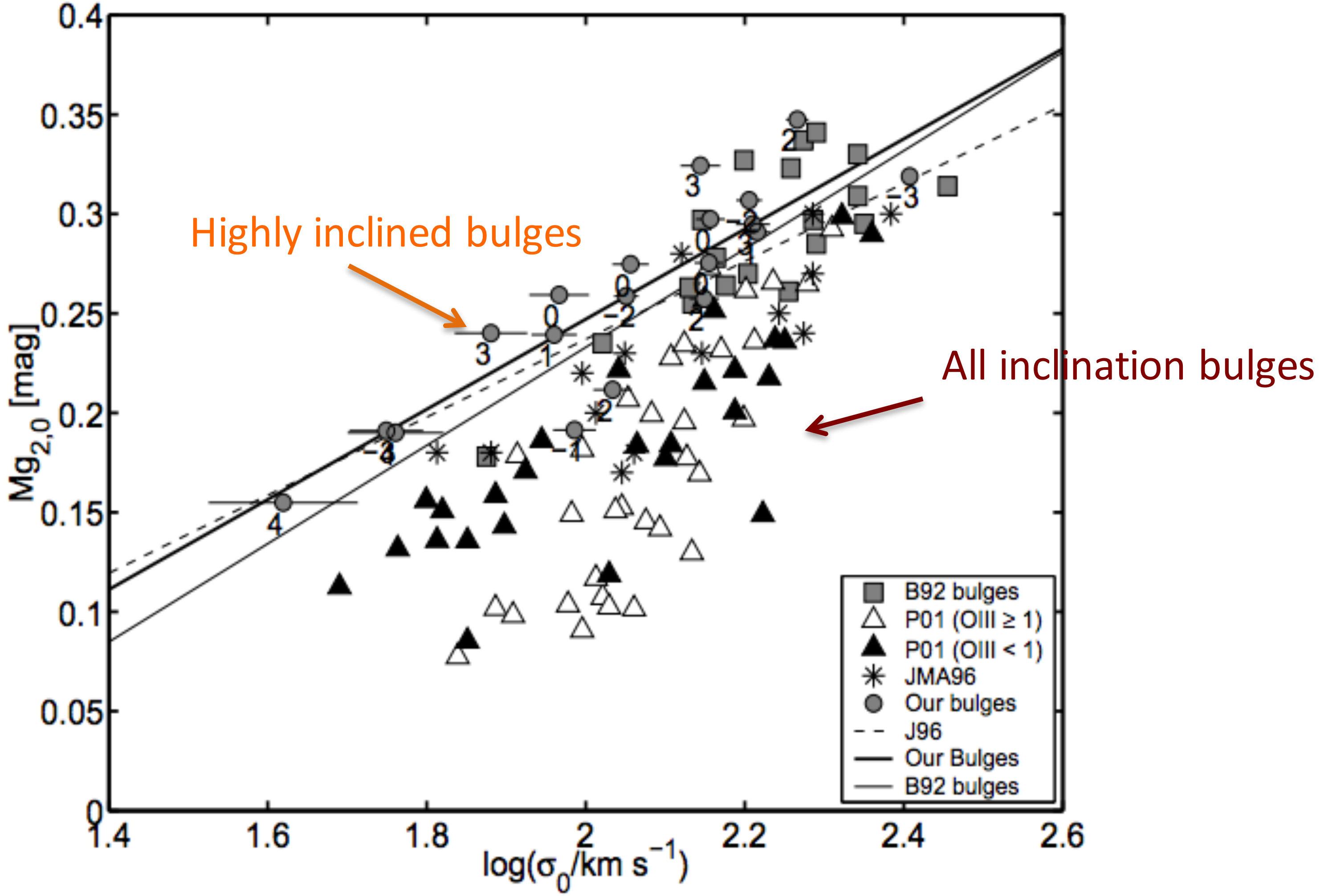
We still do not know the importance of each processes in making up bulges! We can do this studying their stellar populations.

Bulges as composite systems



Falcon-Barroso et al. (2002)

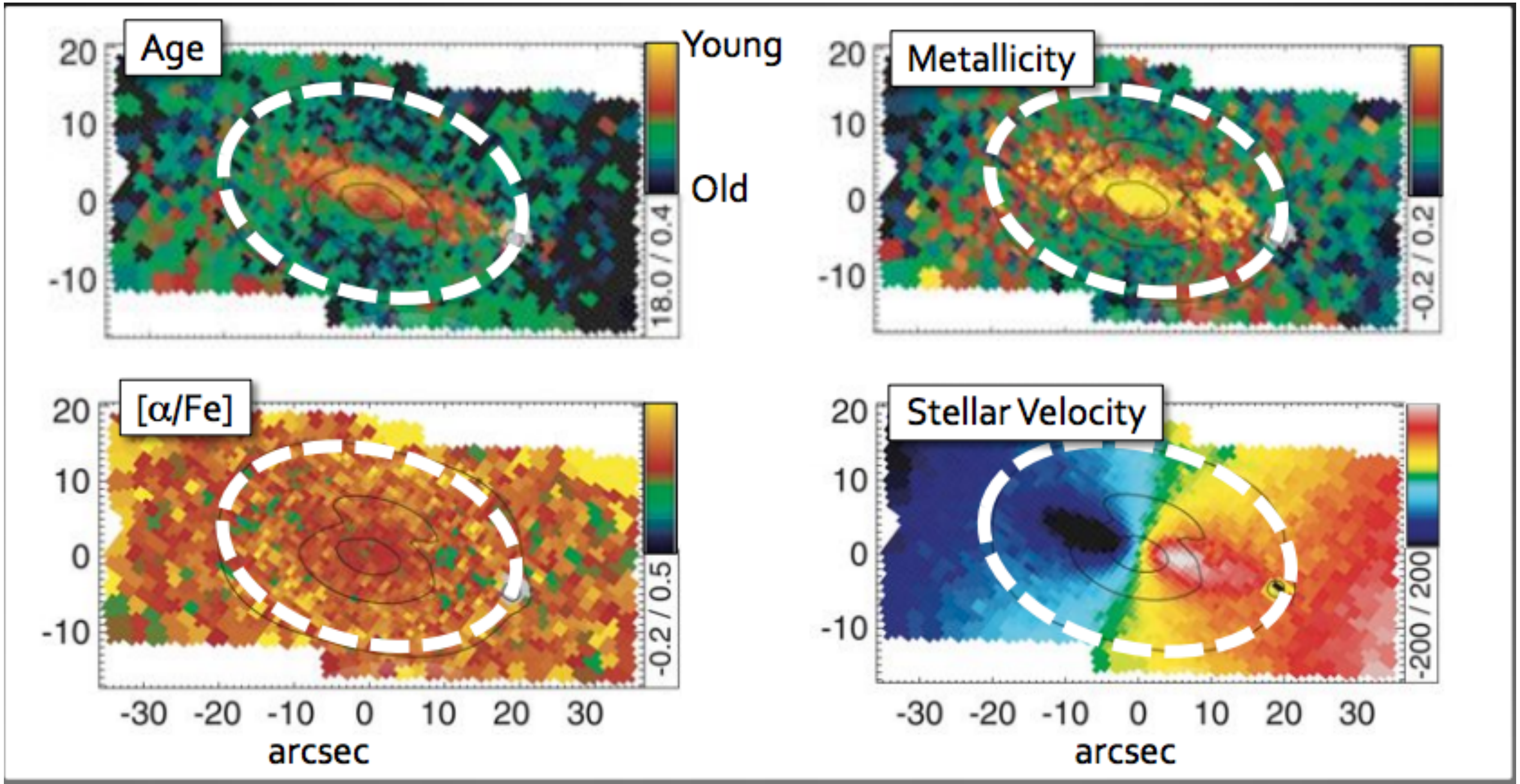
Bulges as composite systems



Falcon-Barroso et al. (2002)

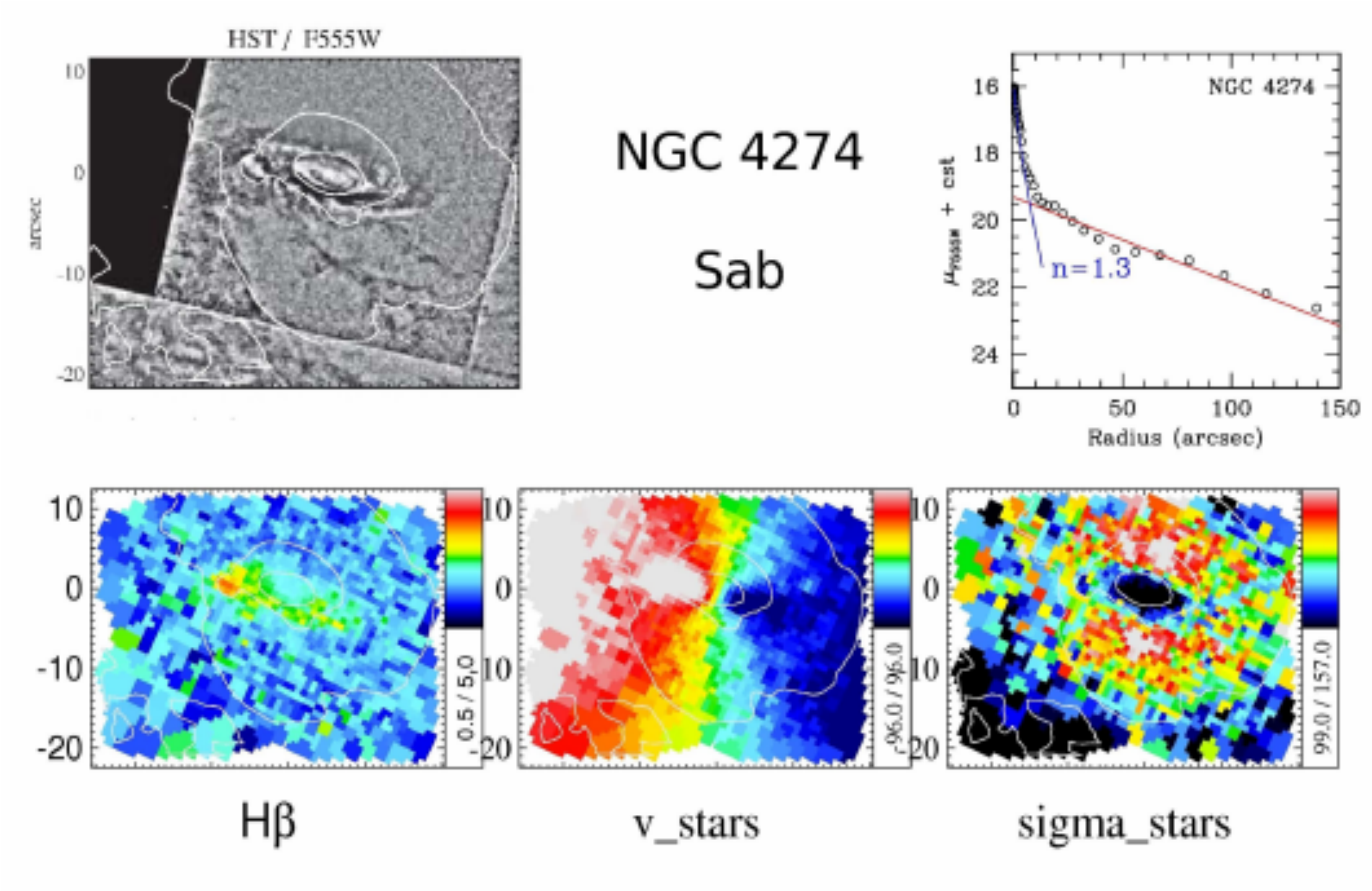
Stellar Populations with IFS: examples

40% of the galaxies show signs of contributions from young stellar populations
Many early-type galaxies contain kinematically defined central disks.



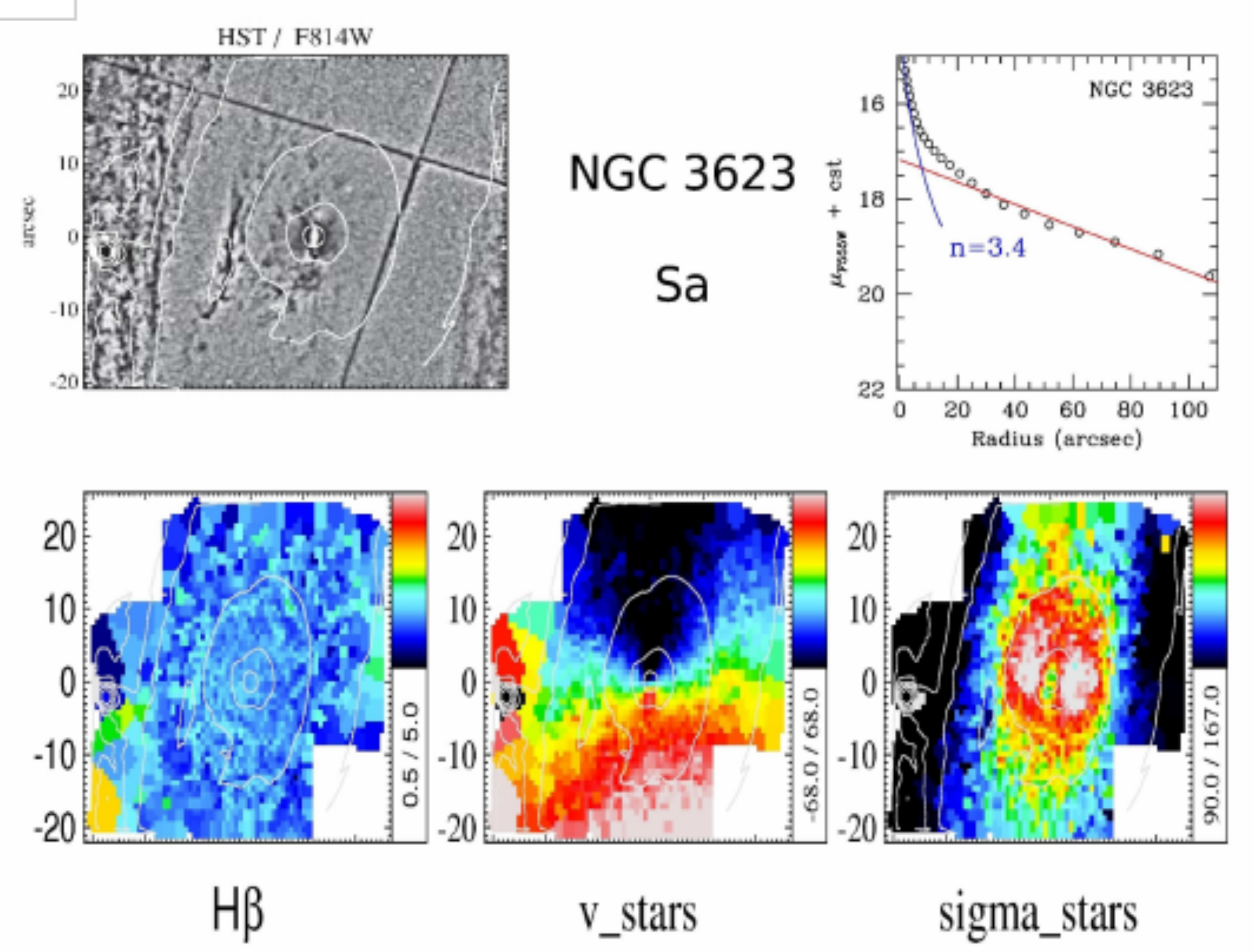
Kuntschner et al. 2010 (SAURON)

Bulges of Sa



Falcon-Barroso et al. (2006)
Peletier et al. (2007)

Bulges of Sa



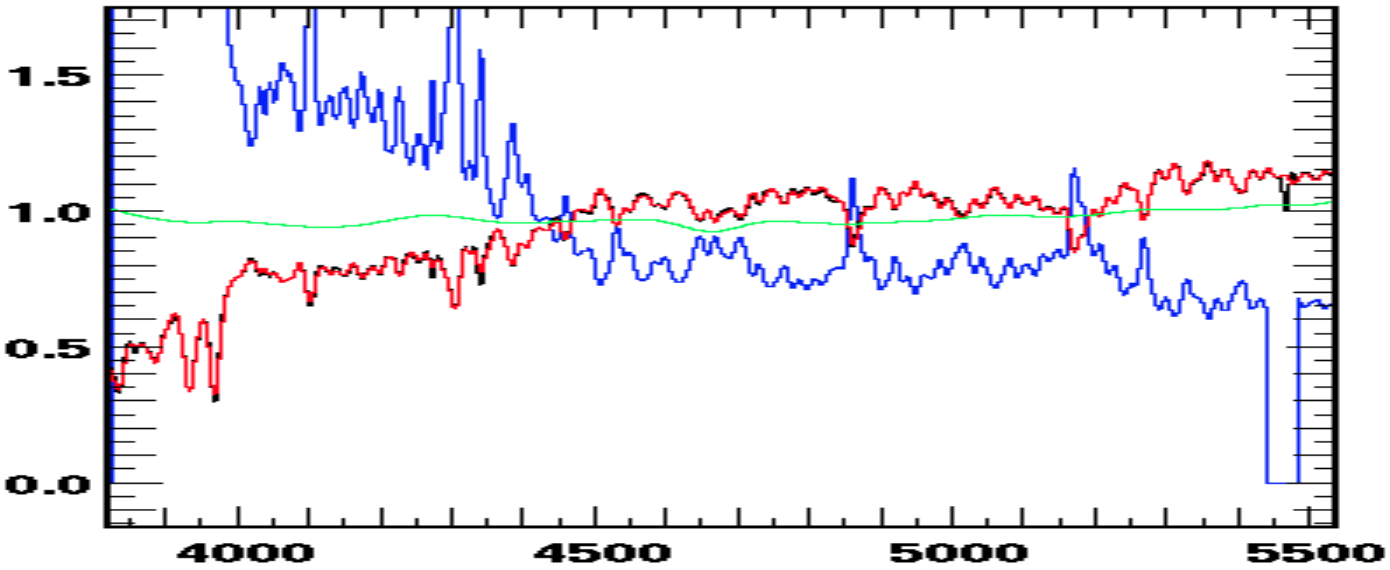
Falcon-Barroso et al. (2006)
Peletier et al. (2007)

50% of spiral galaxies contain inner, fast rotating disks… Still we do not know…

- The detailed stellar population properties of those disks and the relation with other properties of the galaxies (some disks are old)
- This will be related with the formation mechanism (did they really formed through internal or external processes are important?)
- We have not quantified the importance (in terms of mass fraction of central disks)
- Contamination from the disk is still an issue.

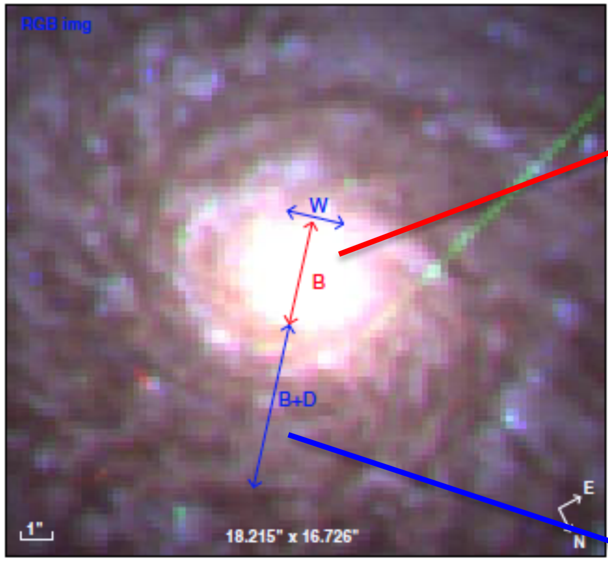
Disentangling different populations

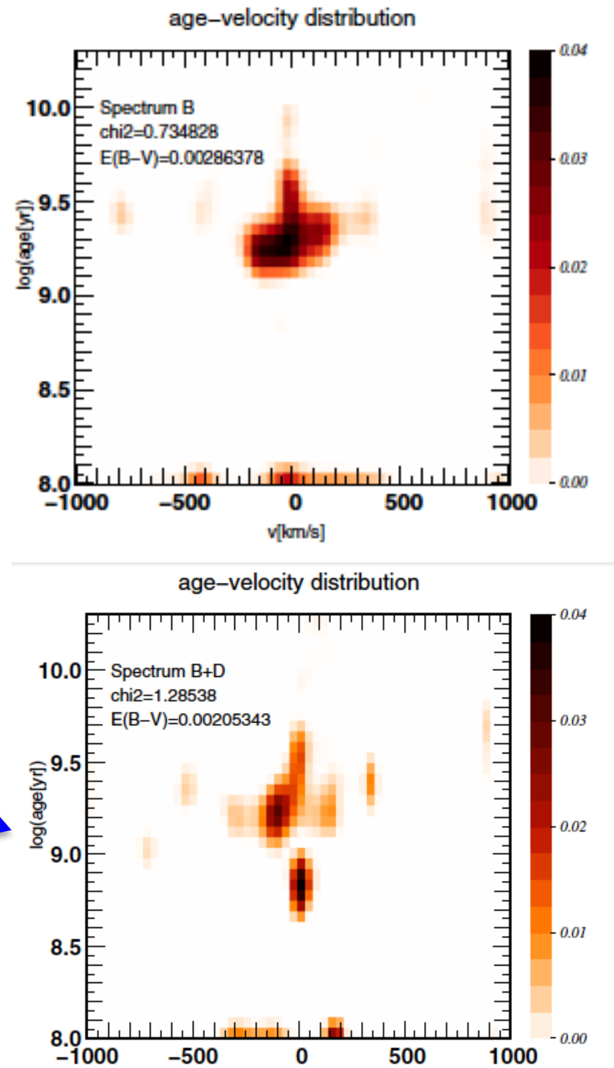
$$M_\lambda = \left[\sum_{j=1}^{N} x_j b_{j,\lambda} r_\lambda \right] \otimes G(v_*, \sigma_*)$$



New challenges with the E-ELT: New techniques

- Separation of kinematically distinct components in bulges of nearby galaxies
- Need high S/N and spectral resolution





Ocvirk et al. (2008)

Separating different components

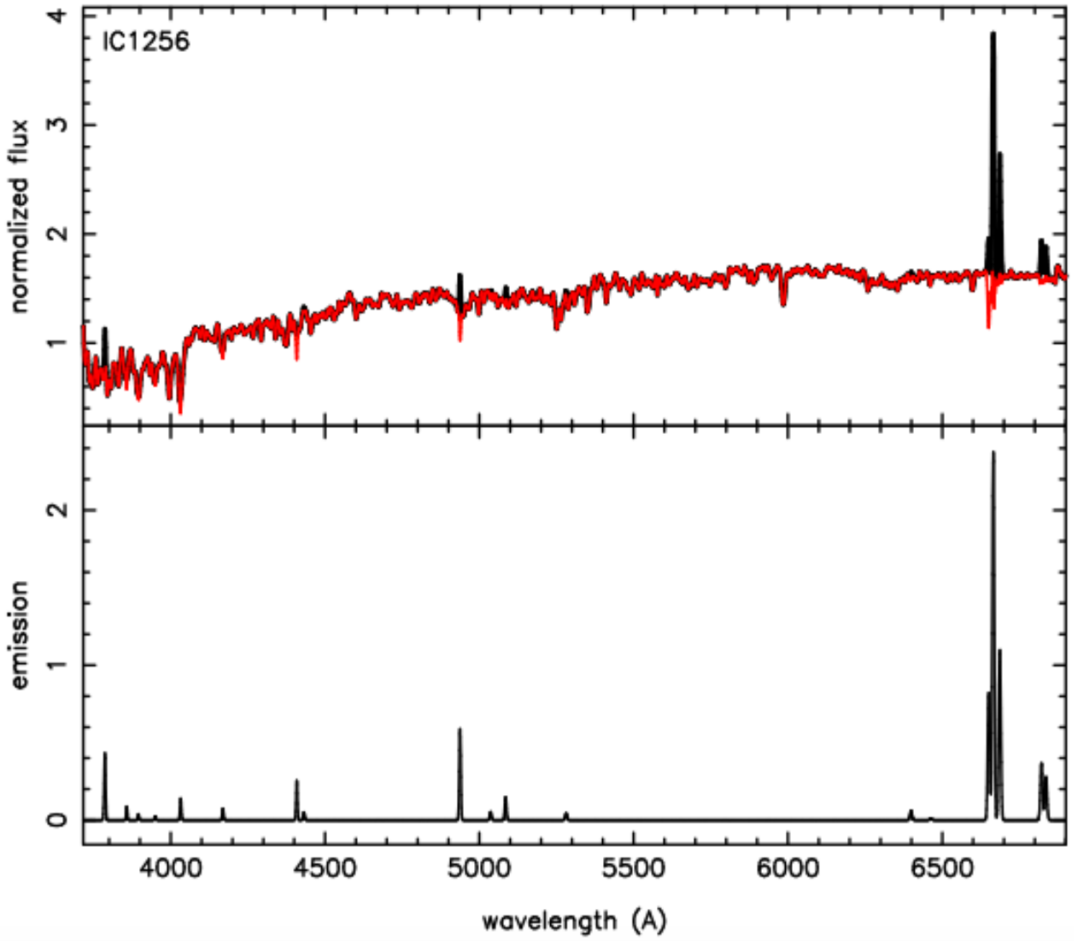
- Constrain the light fraction originating form bulges and *pseudobulges* and constrain their ages.
- Constrain the light fraction originating from the disk and correct the age of the bulge for this contamination.
- Compare the photometric bulge/disc decomposition with the spectroscopic separation.

Stellar populations in the disk of disk galaxies

- With long slit: McArthur et al. (2009); Sanchez-Blazquez et al (2011)

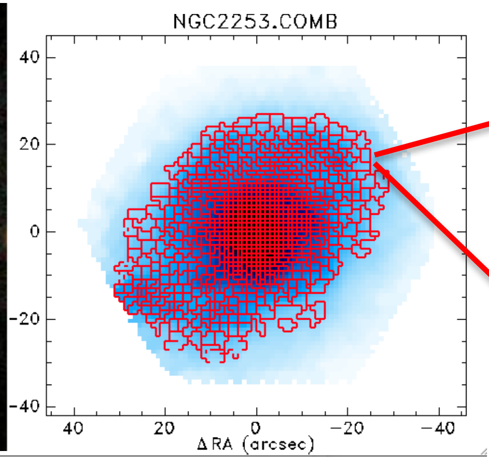
- With IFU: Yoachim et al. (2012); Sanchez-Blazquez et al. (2014); Gonzalez-Delgado (2015)

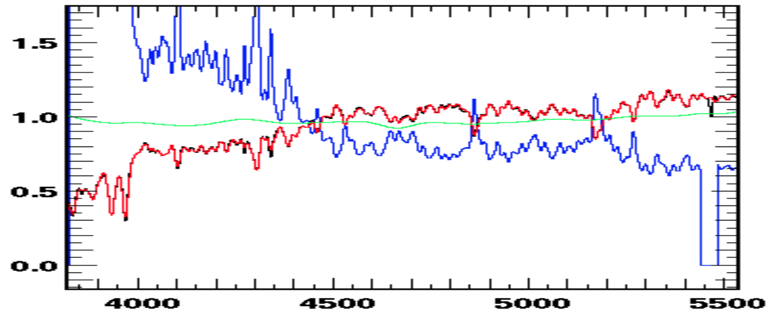
Emission line correction

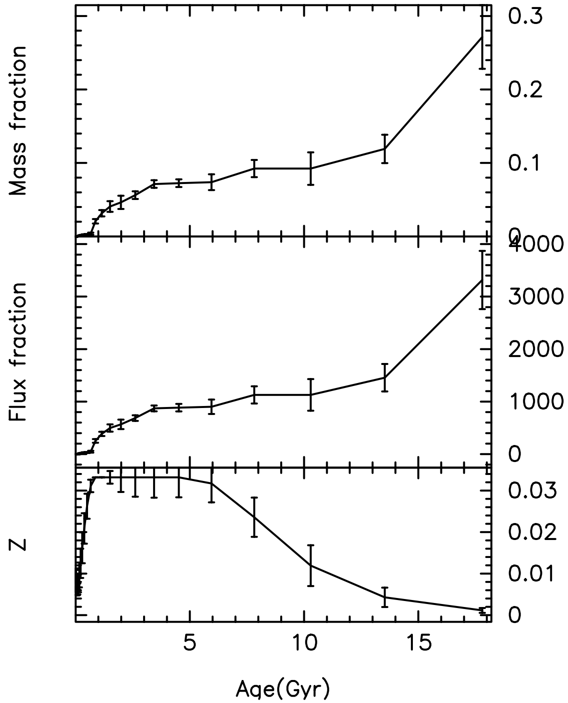


CALIFA Survey

S/N~40 per Å (@ 5800Å)





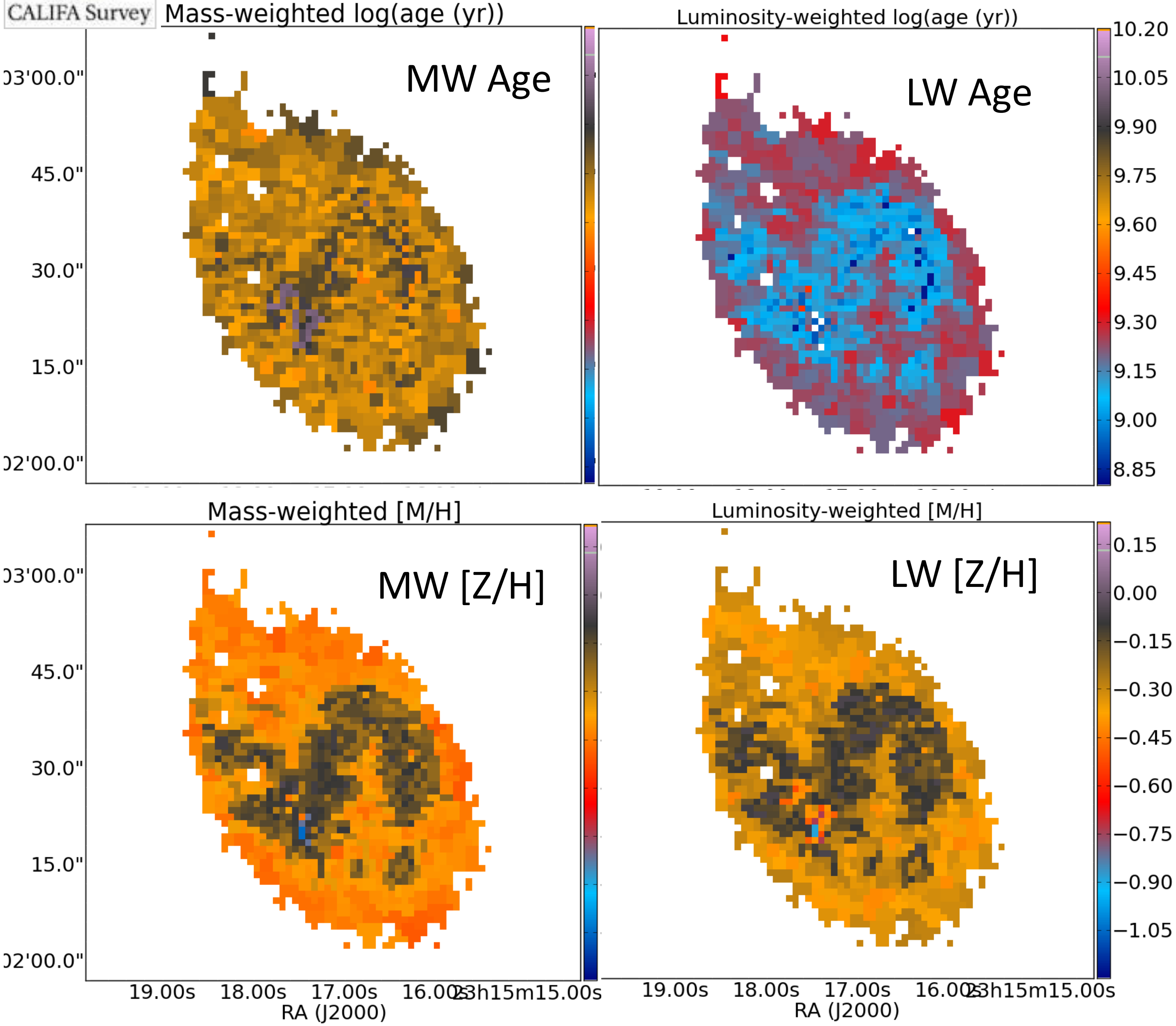


Mean values

$$< \log age >_{MW} = \frac{\sum_i mass(i) \log age_i}{\sum_i mass(i)}$$

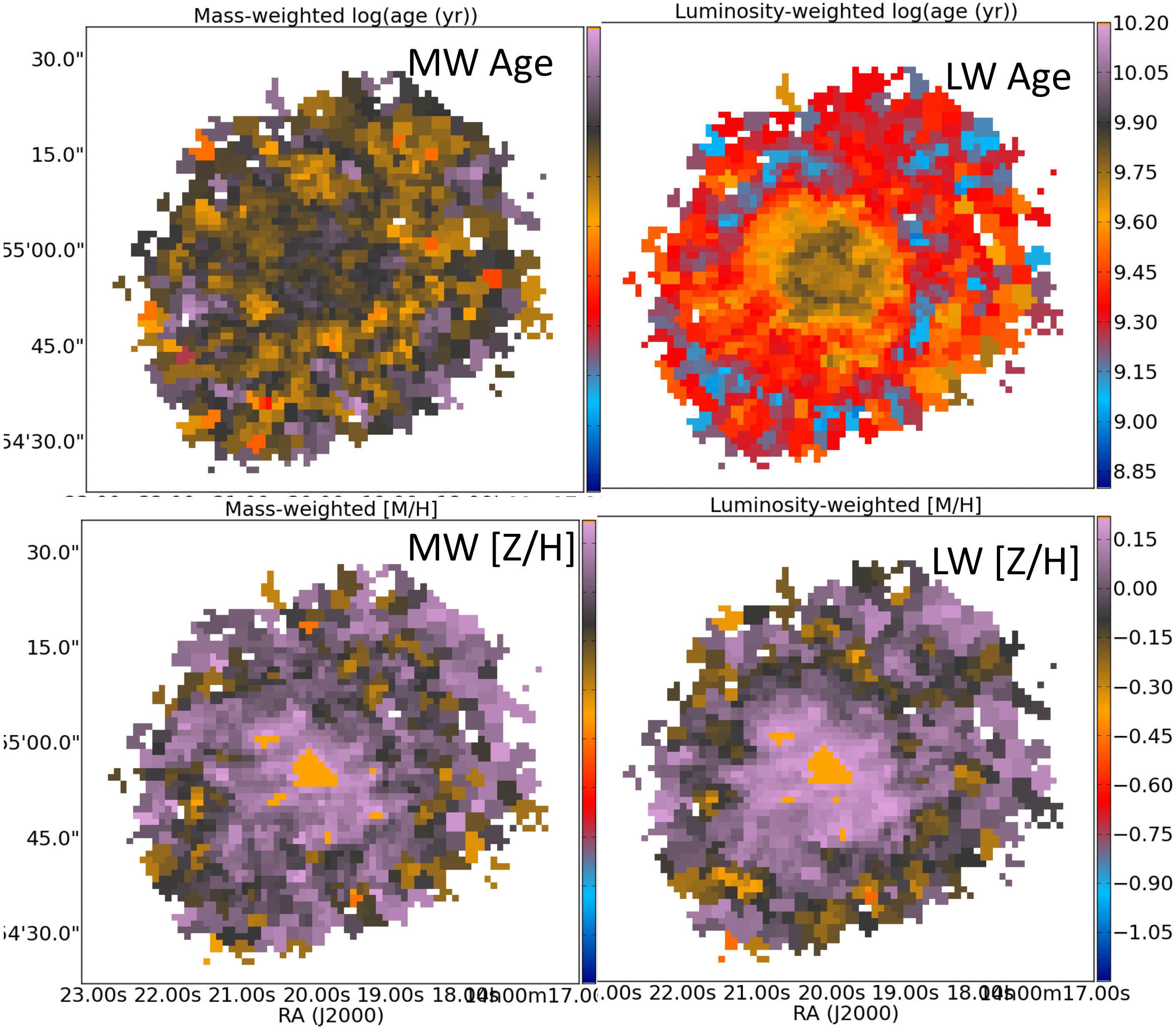
$$< \log age >_{LW} = \frac{\sum_i flux(i) \log age_i}{\sum_i flux(i)}$$

The Stellar populations in disk galaxies



Sánchez-Blázquez et al. (2014)

The Stellar populations in disk galaxies

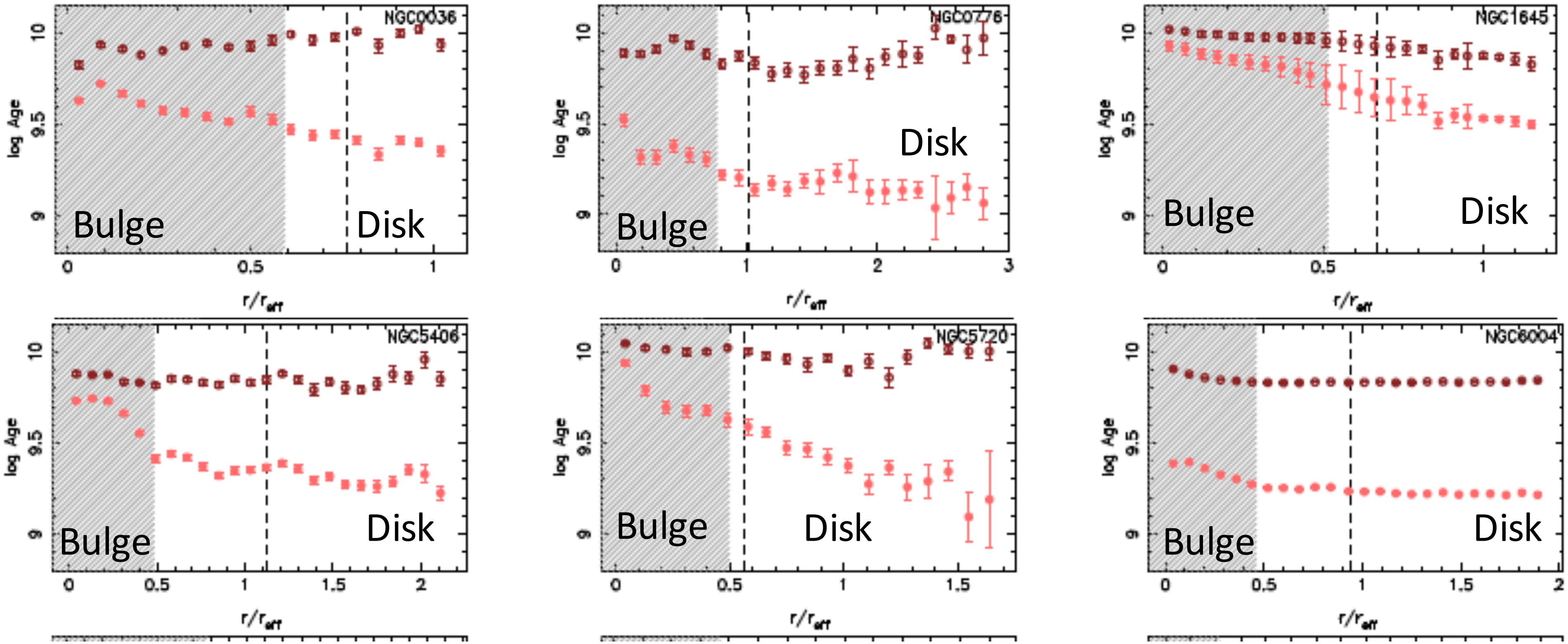


Luminosity weighted values

Mass weighted values

Age gradients

reff = 1.67835rd

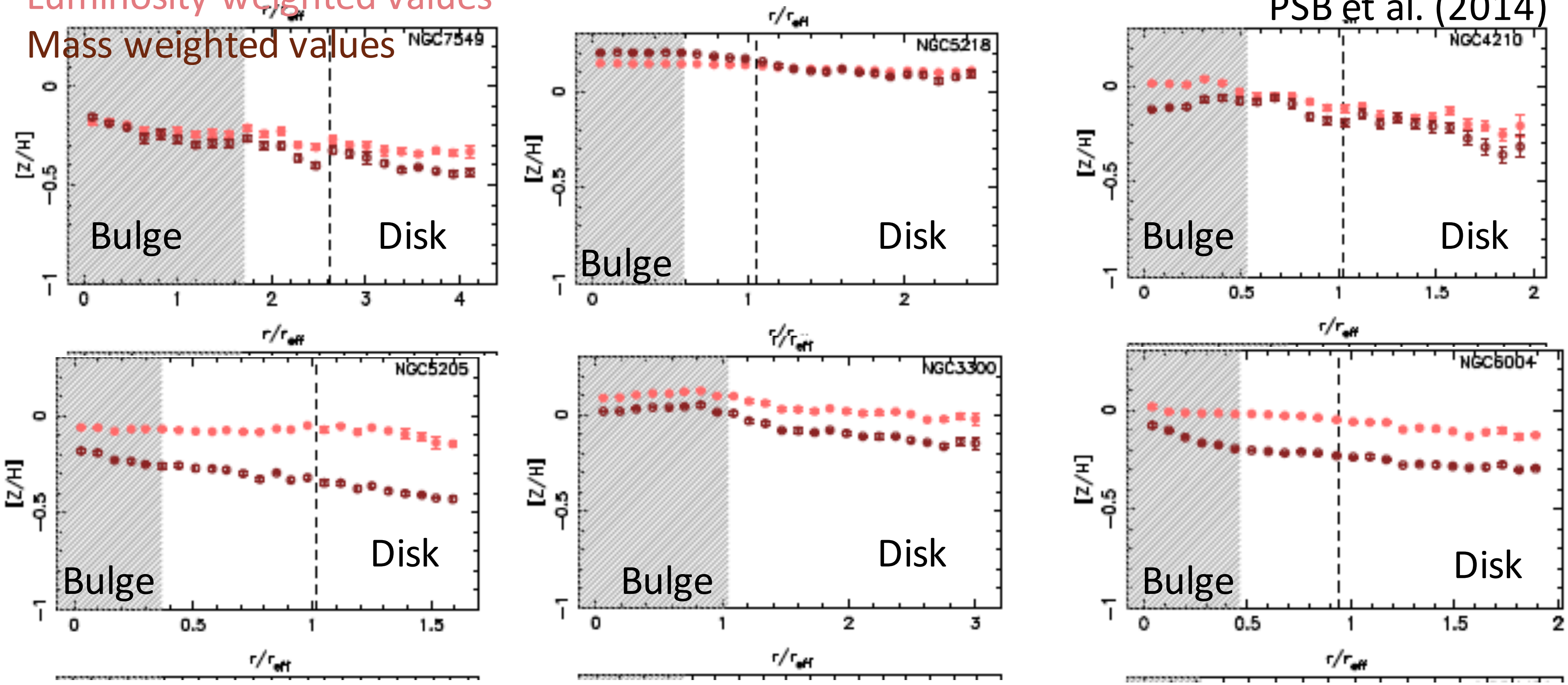


- Results:
- Mass-weighted age gradient reflect **old stellar populations** at all sampled radii
- Lum-weighted age gradient is always negative in the disk region (although very mild)

Metallicity gradients

Luminosity weighted values
Mass weighted values

PSB et al. (2014)



Results:
- In general, metallicities are very high in the disk region
- The slopes of the MW and LW metallicities are very similar

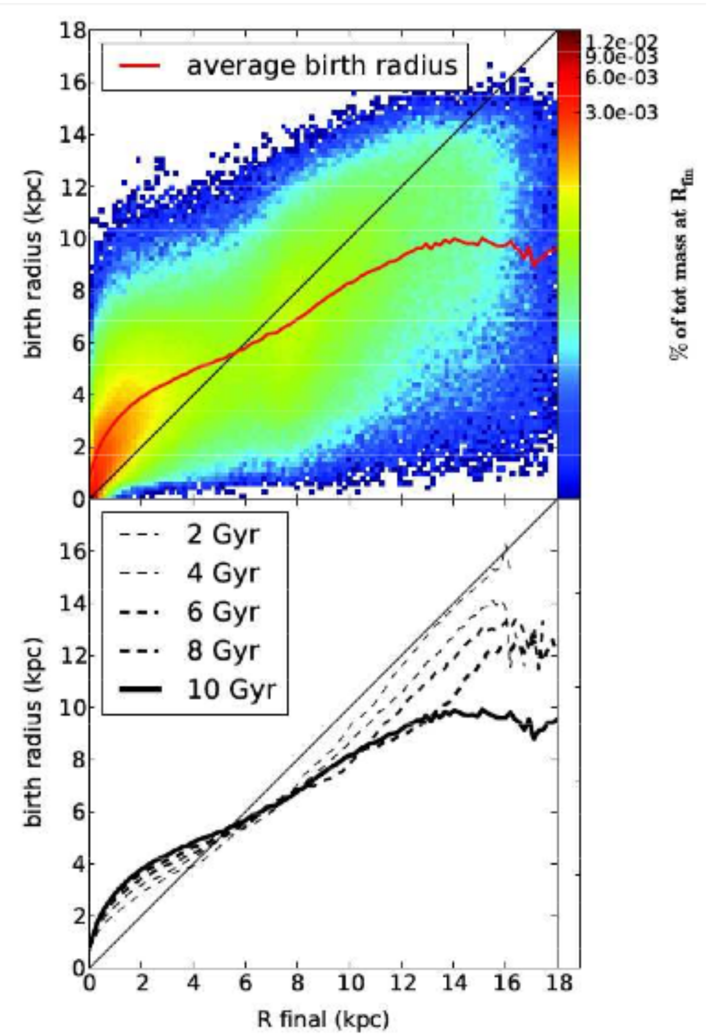
Unresolved stellar populations in disk galaxies

→The flat mass-weighted age gradient and the high metallicity values suggest an early and rapid formation of the disk (similarly to what is seen in resolved stellar population studies (e.g., Gorgarten 2010; William et al. 2009).

→Alternatively, radial migration can bring old and metal rich stars from the internal parts.

Radial migration in disks

Kubryk et al. (2013)



•In numerical simulations, stars do not remain where they were born (e.g., Roskar et al. 2008; PSB et al. 2009)

See Friedli et al. (1998), Minchev & Famey (2010), Minchev et al. (2011, 2012); Shevchenko et al. (2011), Brunetti et al. 2011, Grand et al. (2012)

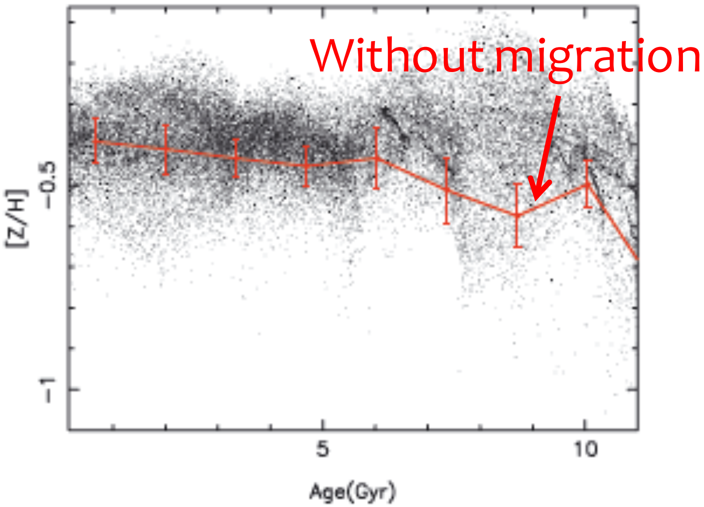
Importance of studying radial migration

→ Ongoing and upcoming surveys (SEGUE, RAVE, HERMES, APOGEE, 4MOST) designed to study the structure of the MW structure require the understanding of the dynamical processes affecting the stellar distribution

Flatten the age-metallicity relation and increase the scatter

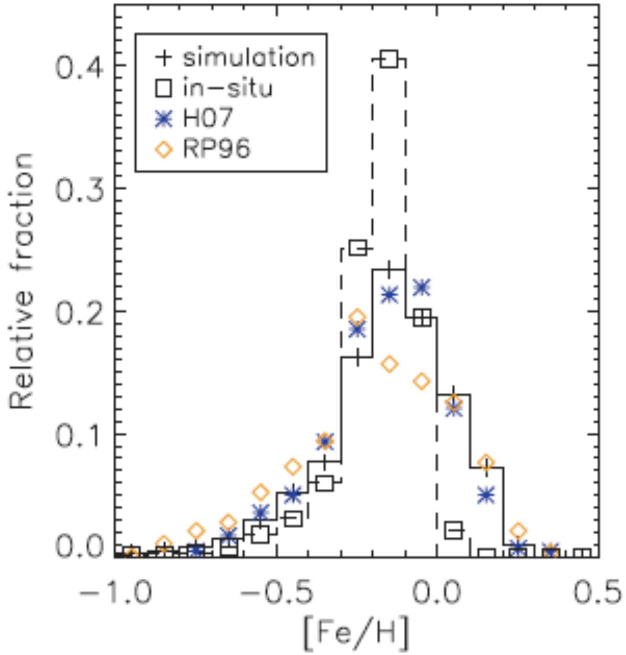
Widen the metallicity distribution funcion

PSB et al. 2009



Flattening of the AMR

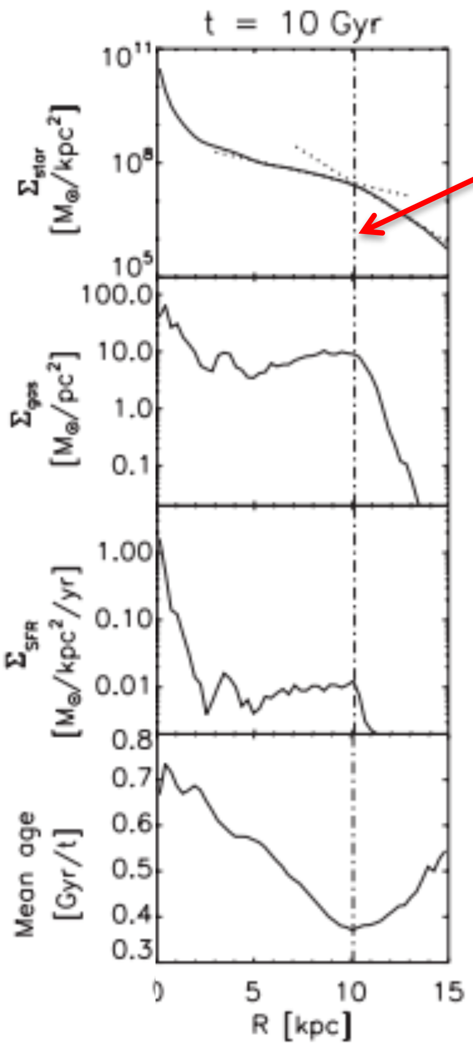
Roškar et al. 2008b



Widening of the MDF

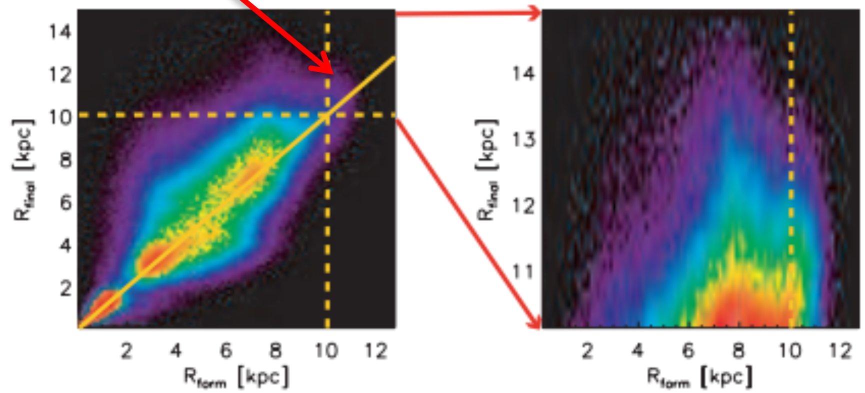
Stellar migrations in disk galaxies

- 60% spiral galaxies have truncated profiles



truncation radius

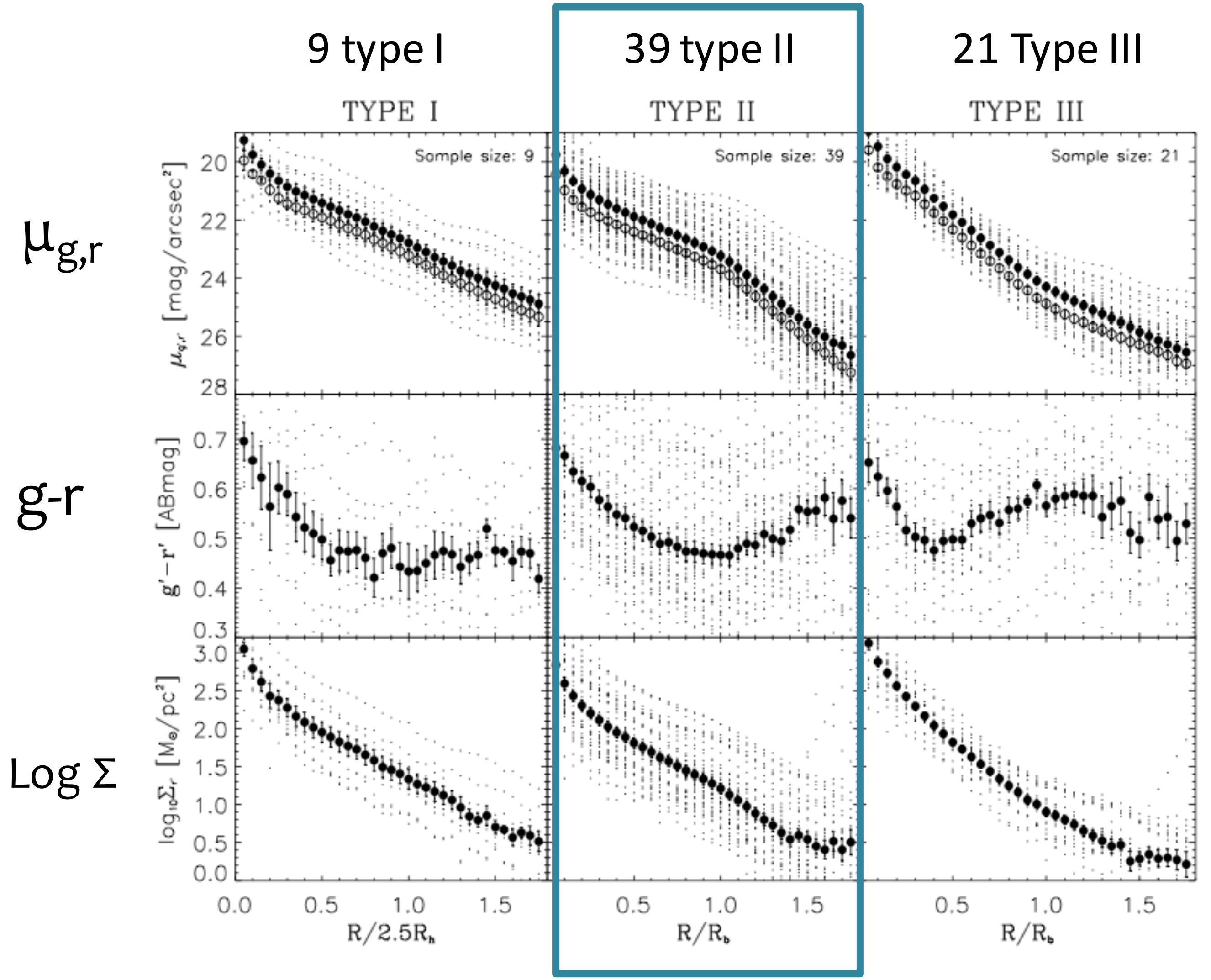
Roskar et al. (2008)



Understand the stellar migration is very important for:
- Stellar archaeology
- Chemical evolution models (age-metallicity relation, MDF)

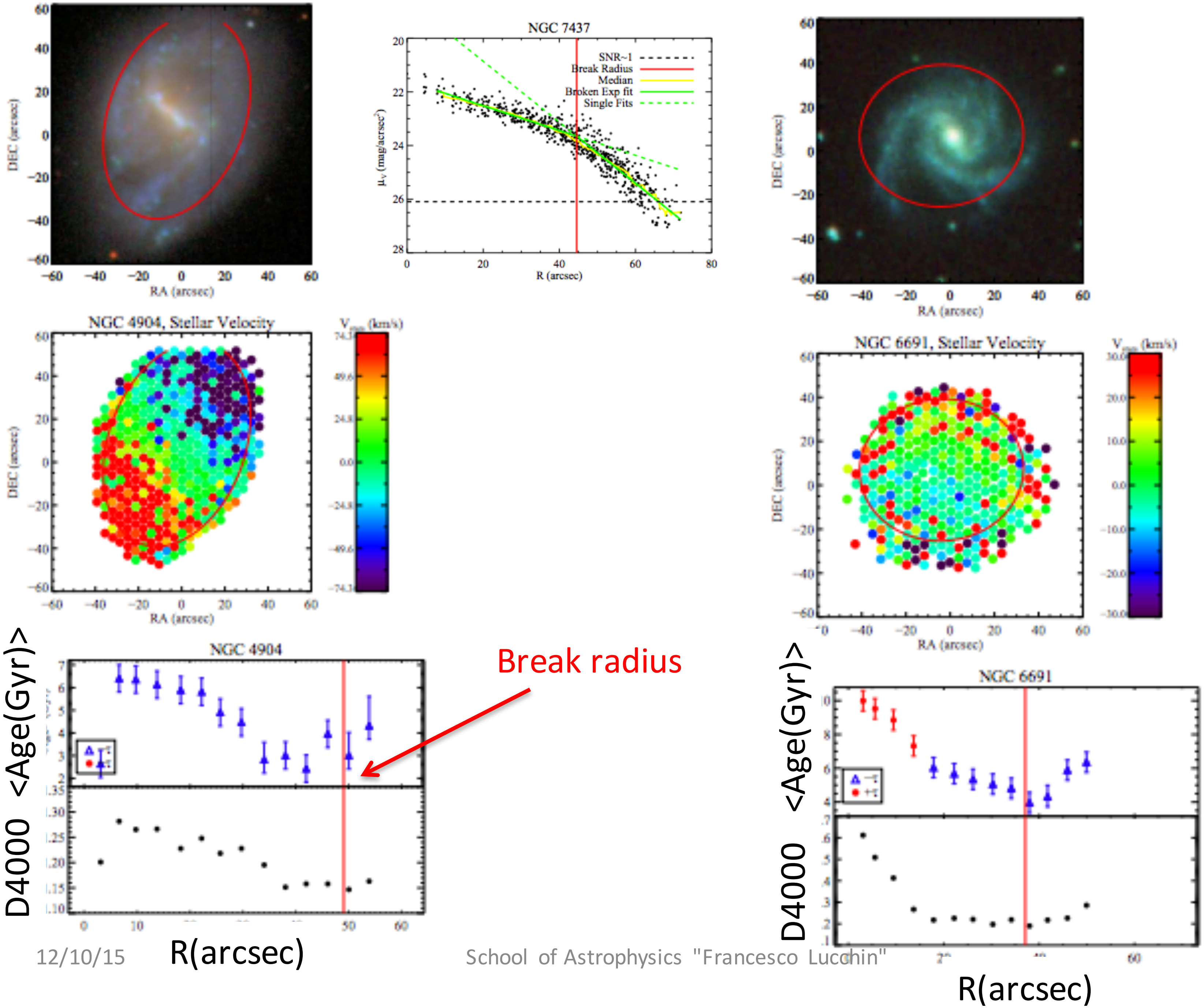
Stellar Migration in disk galaxies

Bakos et al. 2008



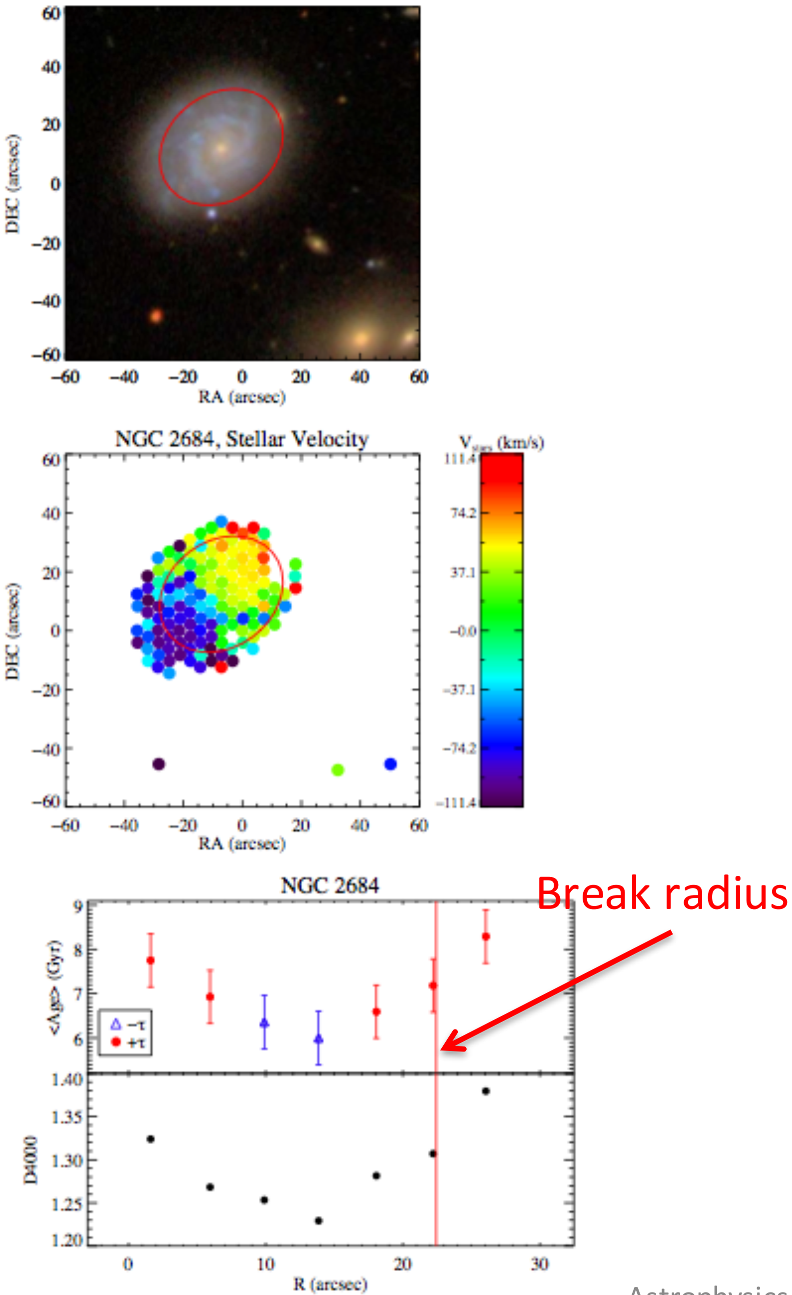
Stellar Populations in the outer disks

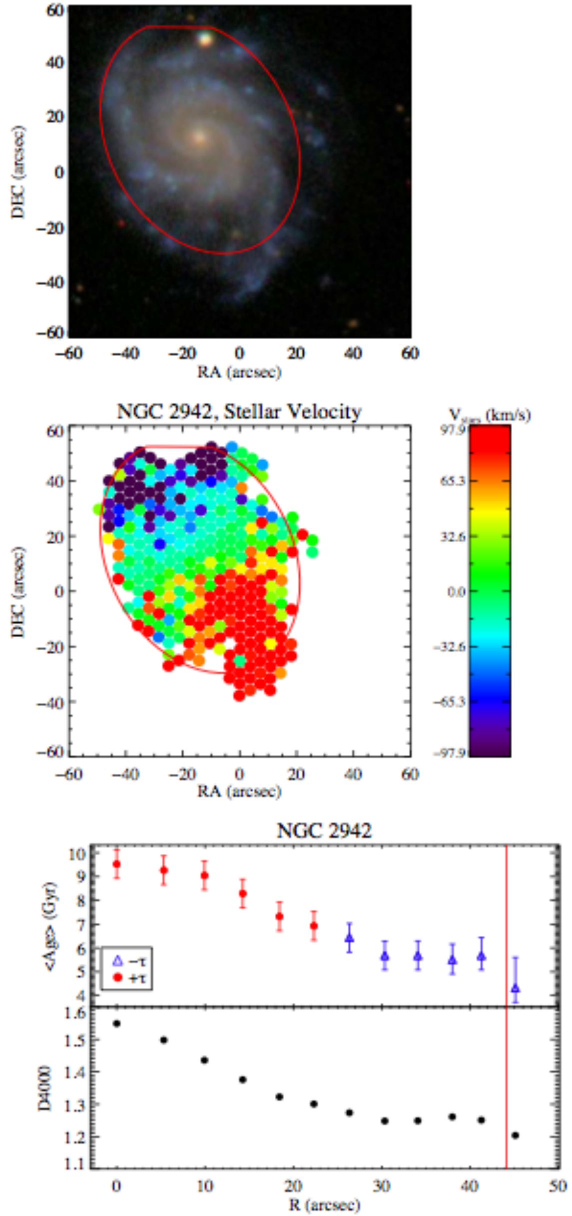
Yoachim et al. (2012)



Stellar Populations in the outer disks

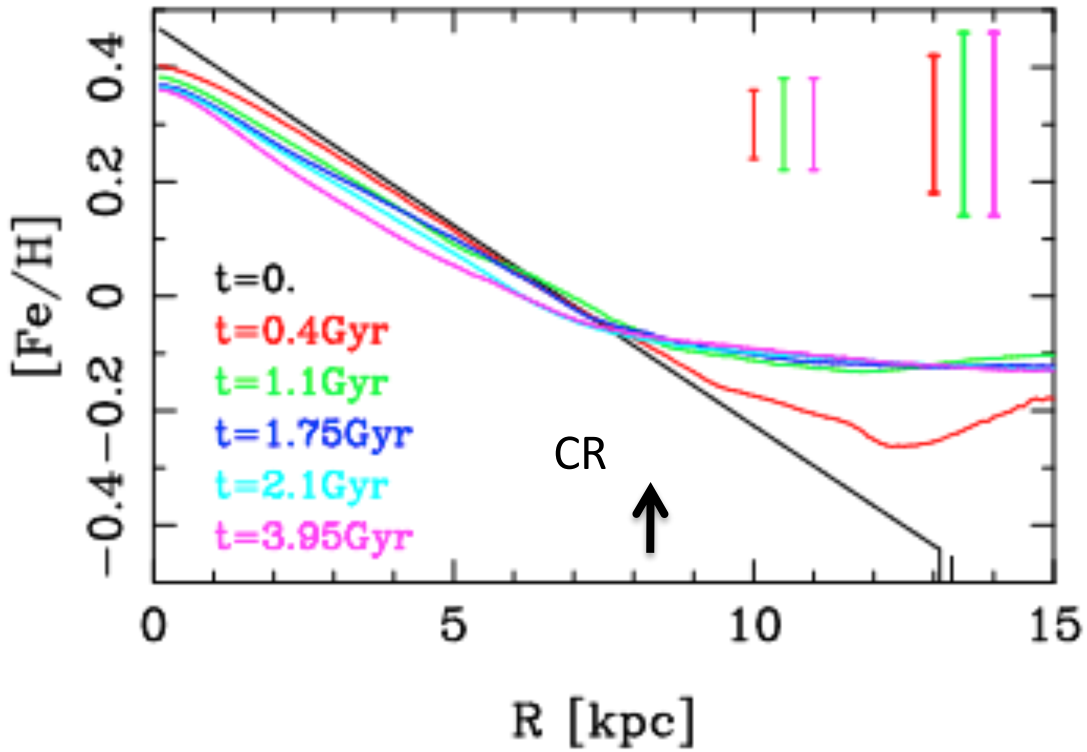
Yoachim et al. (2012)





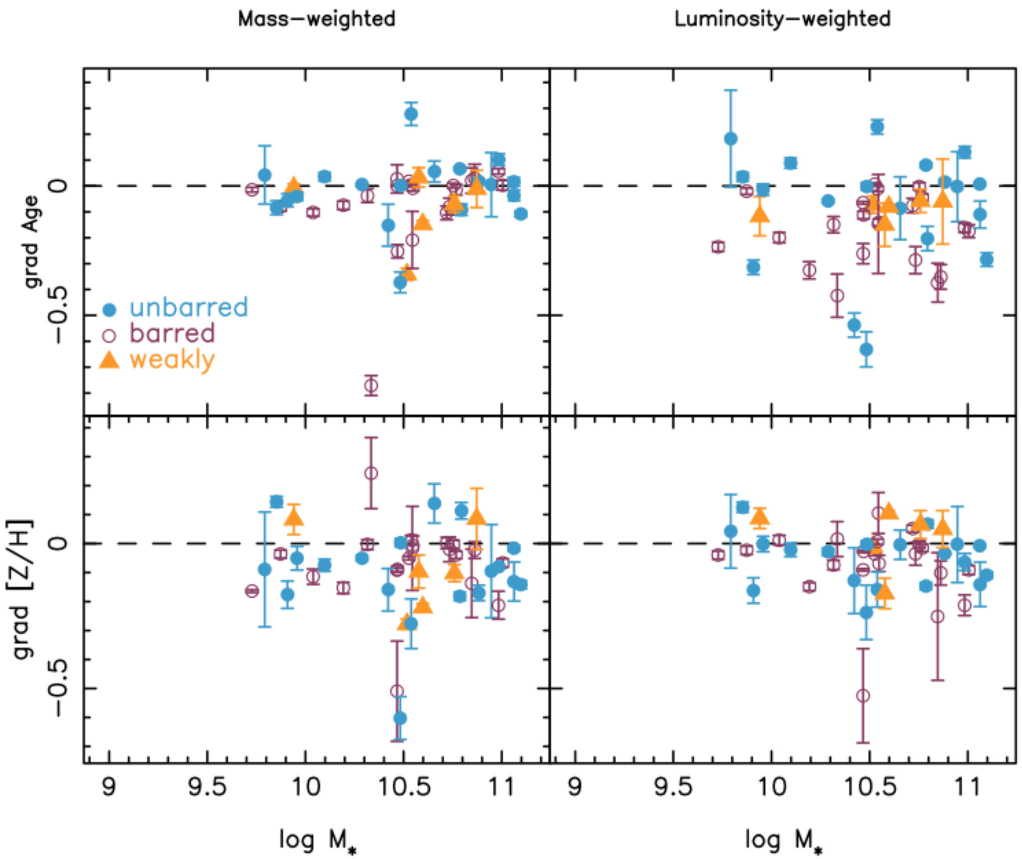
Evolution of the stellar metallicity gradient due to radial migration(predictions)

Di Matteo et al. (2013)



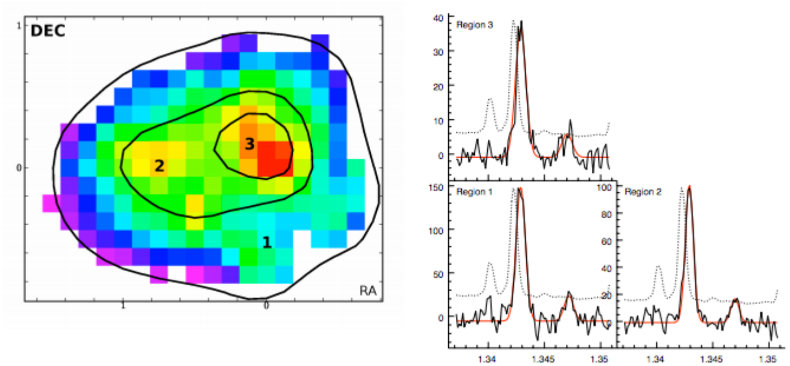
Minchev , Chiappini & Martig (2012)
(see also Friedli 1998; Minchev & Famaey (2010); Brunetti et al. (2011); Di Matteo et al. 2013)

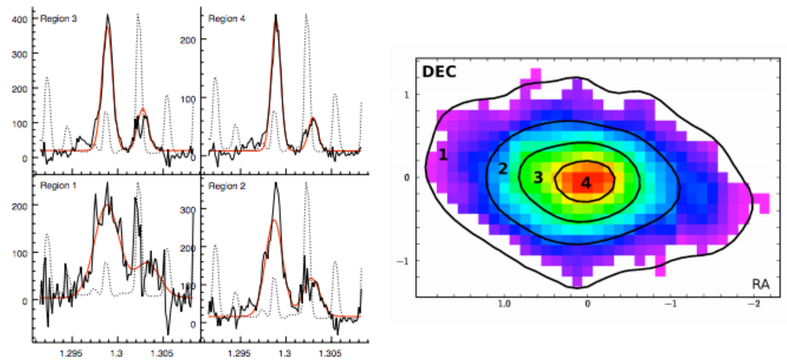
Influence of bars in producing radial migration



Sanchez-Blazquez et al. (2014)

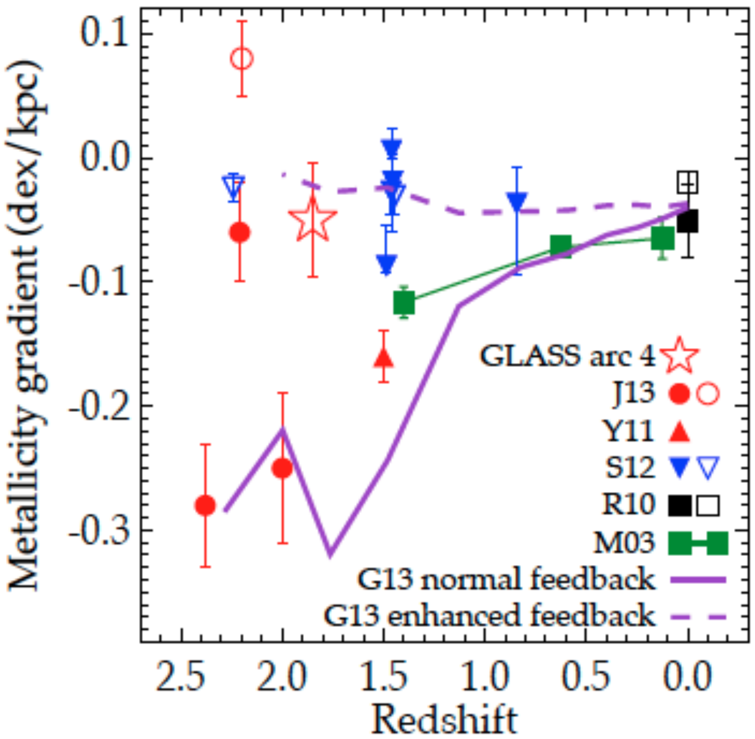
Intermediate-redshift disk galaxies





From Queyrel et al. (2012)

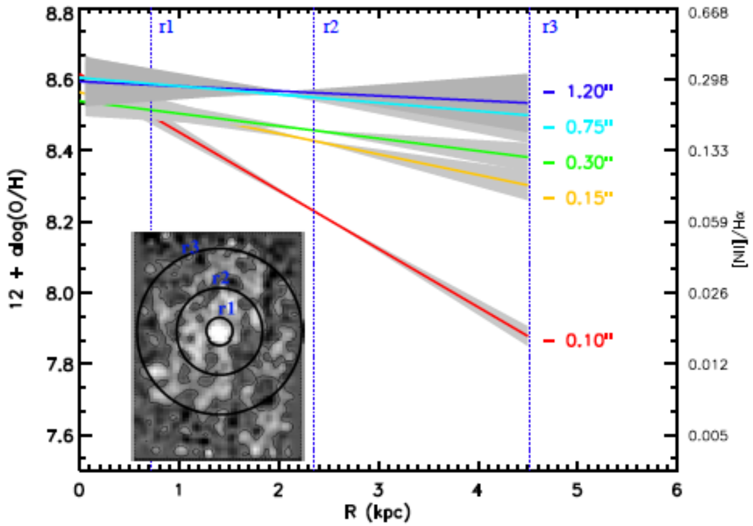
Feedback processes: Temporal evolution of the metallicity gradient



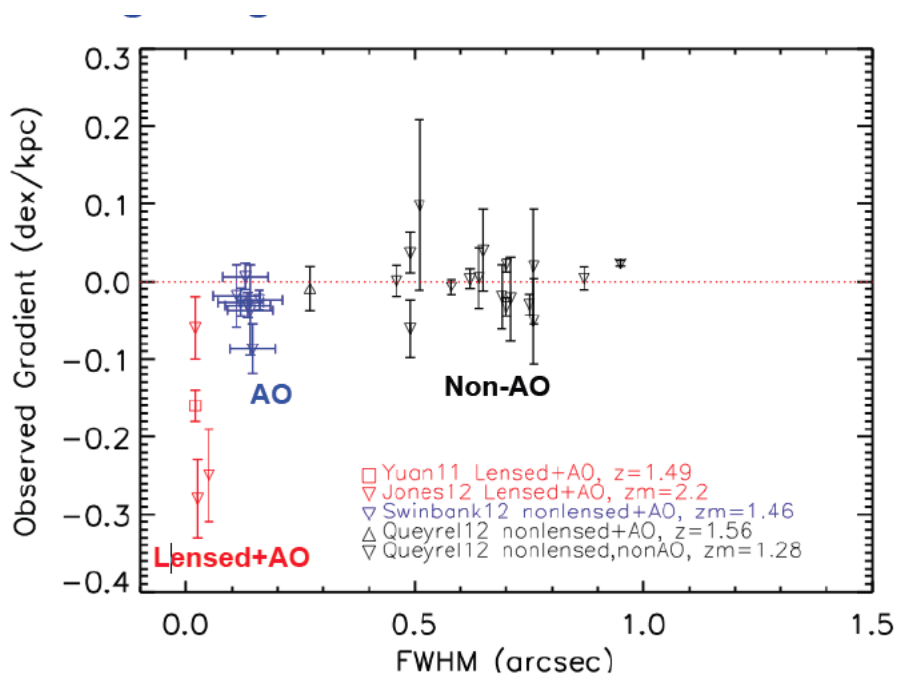
- Evolution of the metallicity gradient with time give us information about the feedback processes
- Empirical evidence remains highly contradictory.

Jones et al. (2014)

High-angular resolution is essential for high-z gradient gradients



Resolution better than 1 kpc is needed
With MUSE, 0.2”→ 1.6 kpc at 0.5 < z < 1 (in concordance cosmology
→ Difficult to obtain representative samples



Yuan, Kewley, & Rich 2013

Stellar populations in disk galaxies with the ELT

- Quantify the importance of secular processes in shaping disk galaxies.
- Quantify the amount of radial migration.
- Evolution of the metallicity gradients with time (feedback constraints).
- Survability of bars, spiral arms nature, feedback (with higher spatial resolution).

Some uncertainties in theoretical modelling of stellar populations

1. Stellar evolution

(TP)AGB, HB, BS, post-AGB, WR, convection, rotation, binary evolution, etc

2. Dust

Extinction law, molecular cloud vs. cirrus, geometry of dust, etc..

3. Metallicity evolution and distribution

Rarely discussed, but metallicity distributions are observed

4. IMF

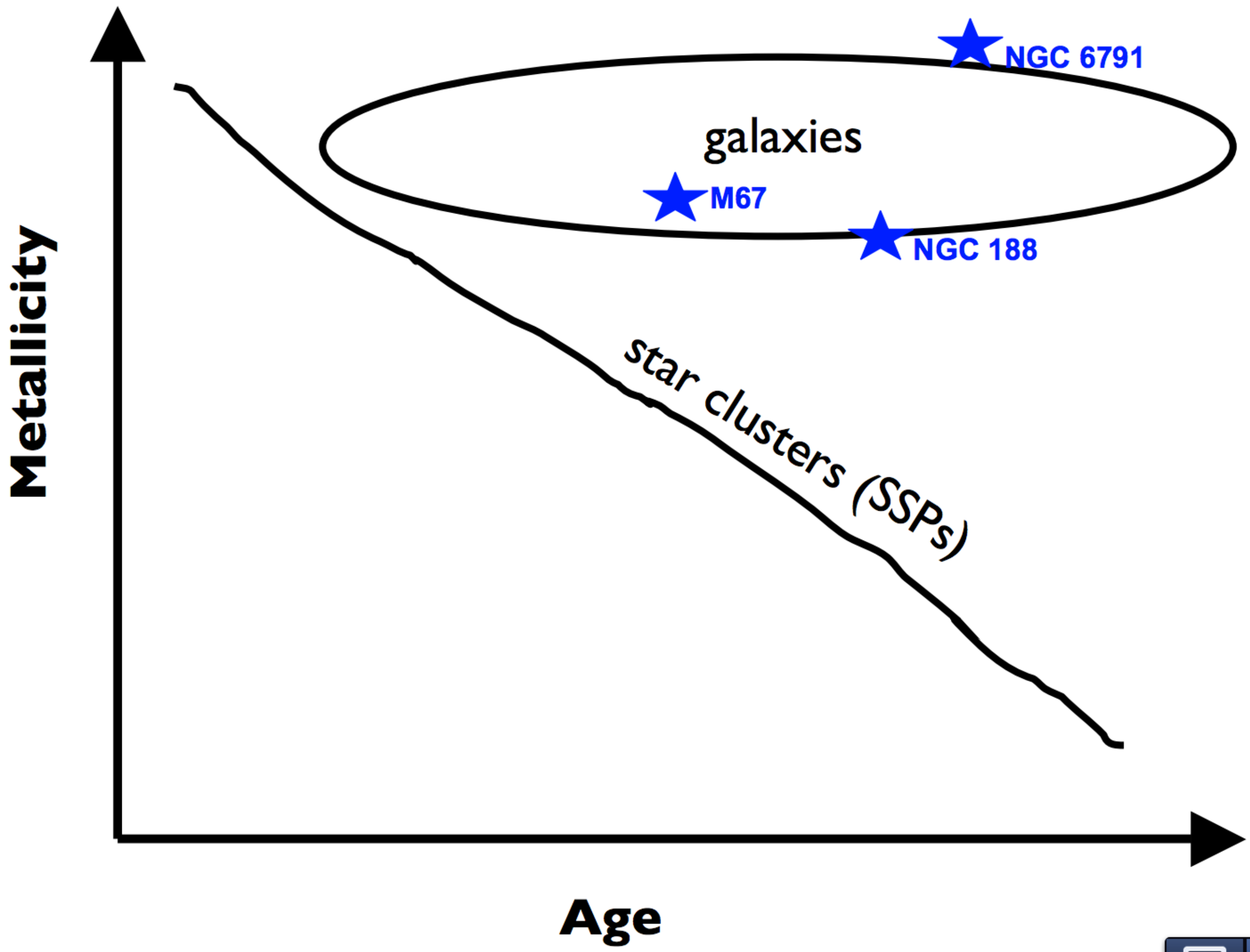
Effects normalization, and SED shape- degerate with SFH

5. Stellar spectral libraries

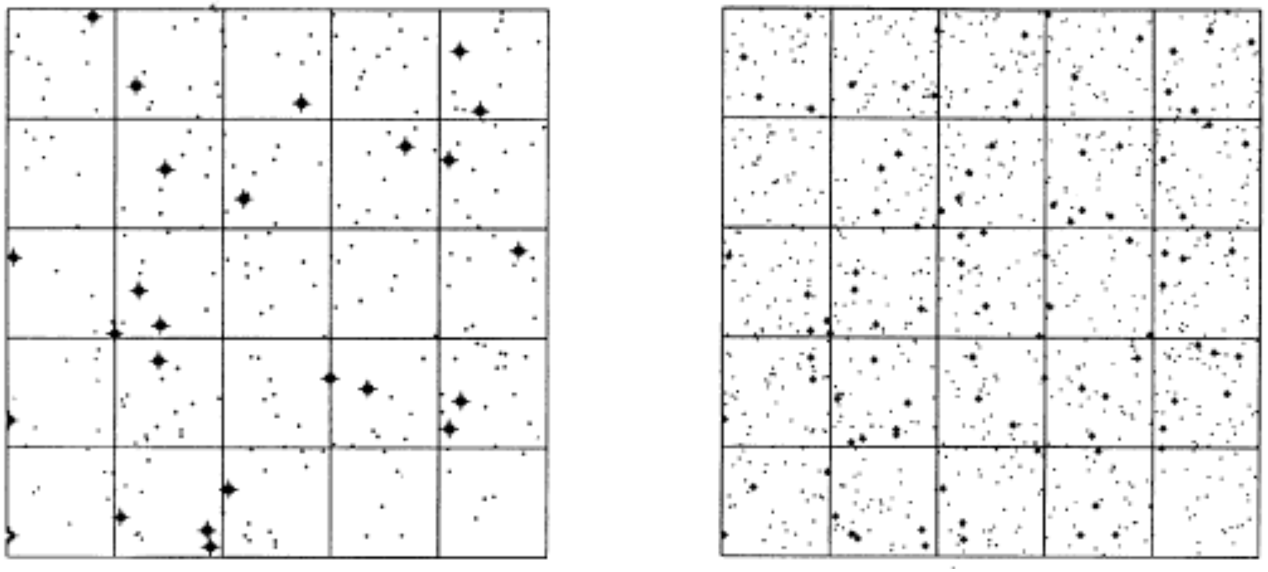
Theoretical and empirical libraries have known flaws

6. Non solar abundance patterns (α-ehancement)

Impact both stellar evolution and the spectral libraries

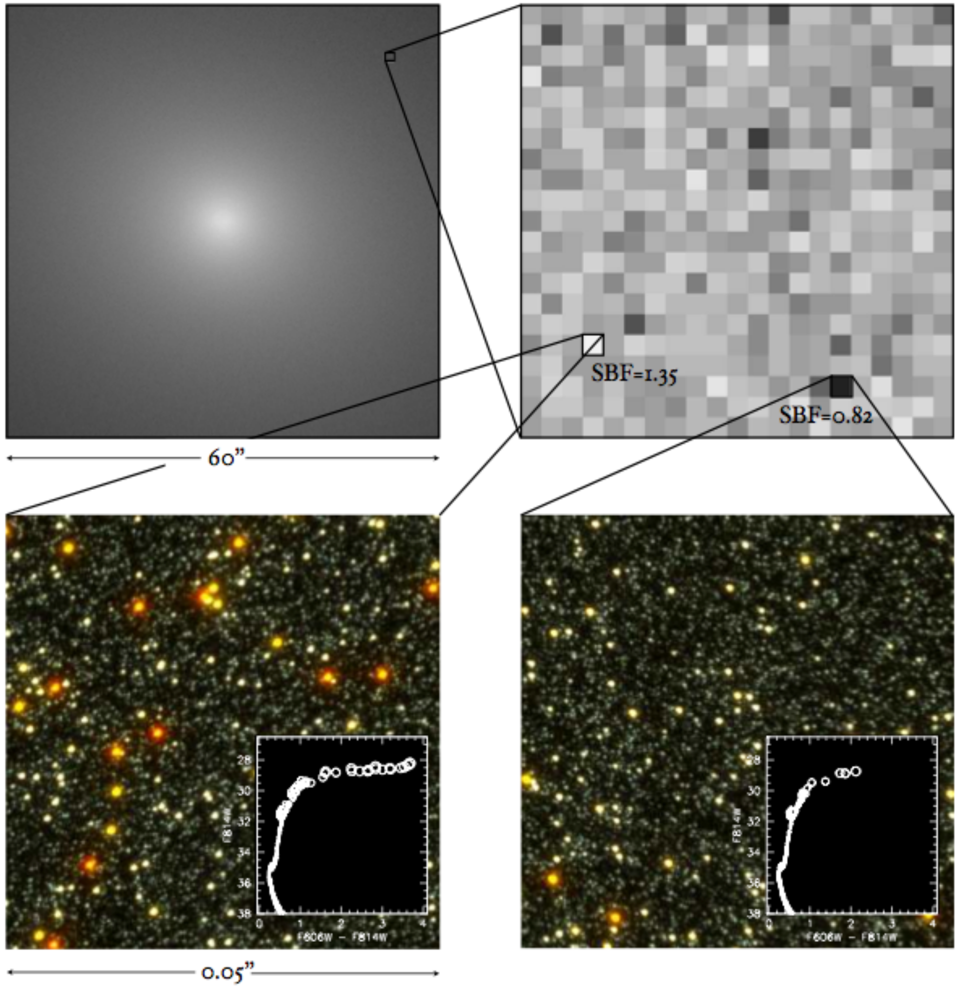

NGC 6791
galaxies
M67
NGC 188
star clusters (SSPs)
Metallicity
Age

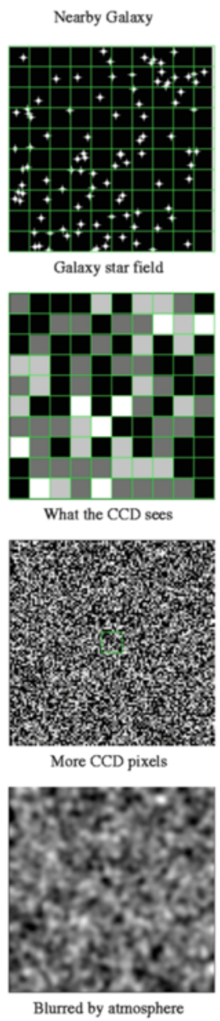
Surface brightness fluctuations



Tonry & Schneider (1998)

Surface brightness fluctuations





If we take an image of the target population at distance D with angular resolution $\delta\phi$, each resolution element will contain an average number of unresolved stars $<N>$

$$<N> = n(D\,\delta\phi)^2$$

n is the number of star per unit area across the observed face of the target population

The average flux from the stars in each resolution element (SB):

$$<F> = <N>\, f = <N>\, L/4\pi D^2 = nL(\delta\phi)^2/4\pi$$

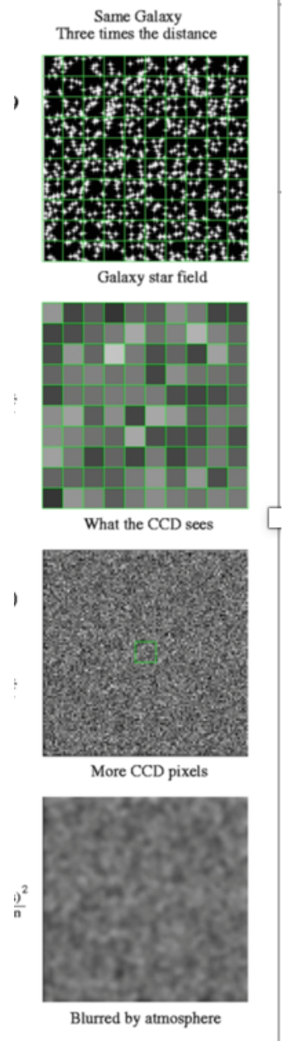
f is the flux of a single star (we assume all stars have the same intrinsic luminosity)

Due to Poisson fluctuations in the number of star populating each resolution element, $<F>$ is NOT constant and its variance will be:

$$\sigma_{<F>} = <N>^{1/2} f = n^{1/2} L\,\delta\phi/4\pi D \propto 1/D$$

Therefore:

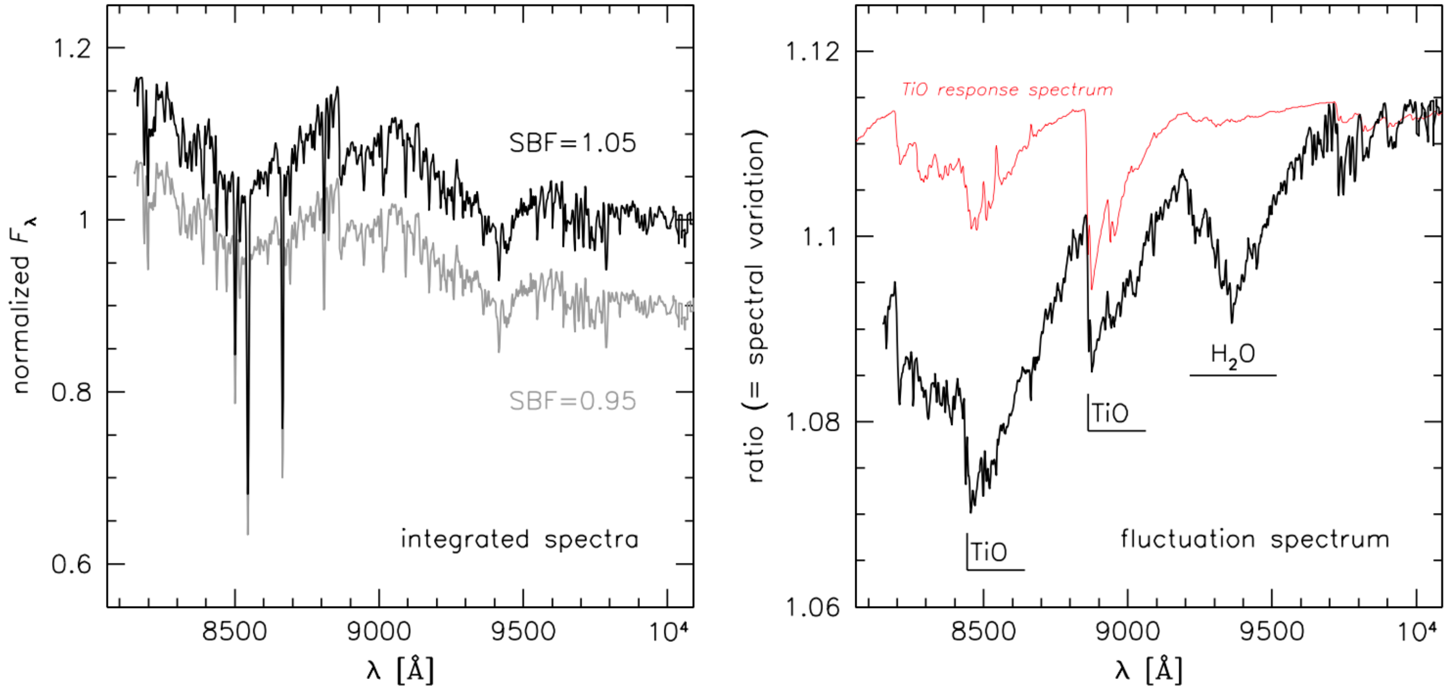
$$\frac{\sigma^2_{<F>}}{<F>} = \frac{\bar{L}}{4\pi D^2} \rightarrow D \qquad \bar{L} = \frac{\sum_i \overline{N}_i L_i^2}{\sum_i \overline{N}_i L_i}$$



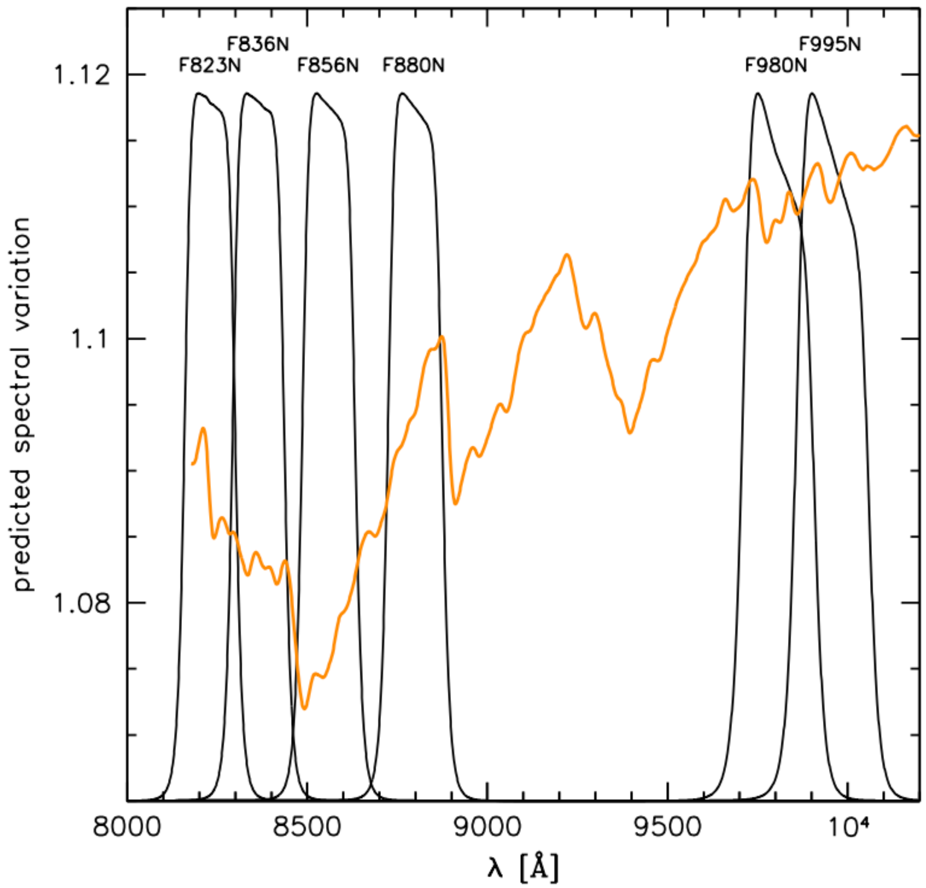
Measurements accurate to 1% are needed to detect fluctuations in galaxies at a distance of about 20 Mpc

SBF spectral characteristics

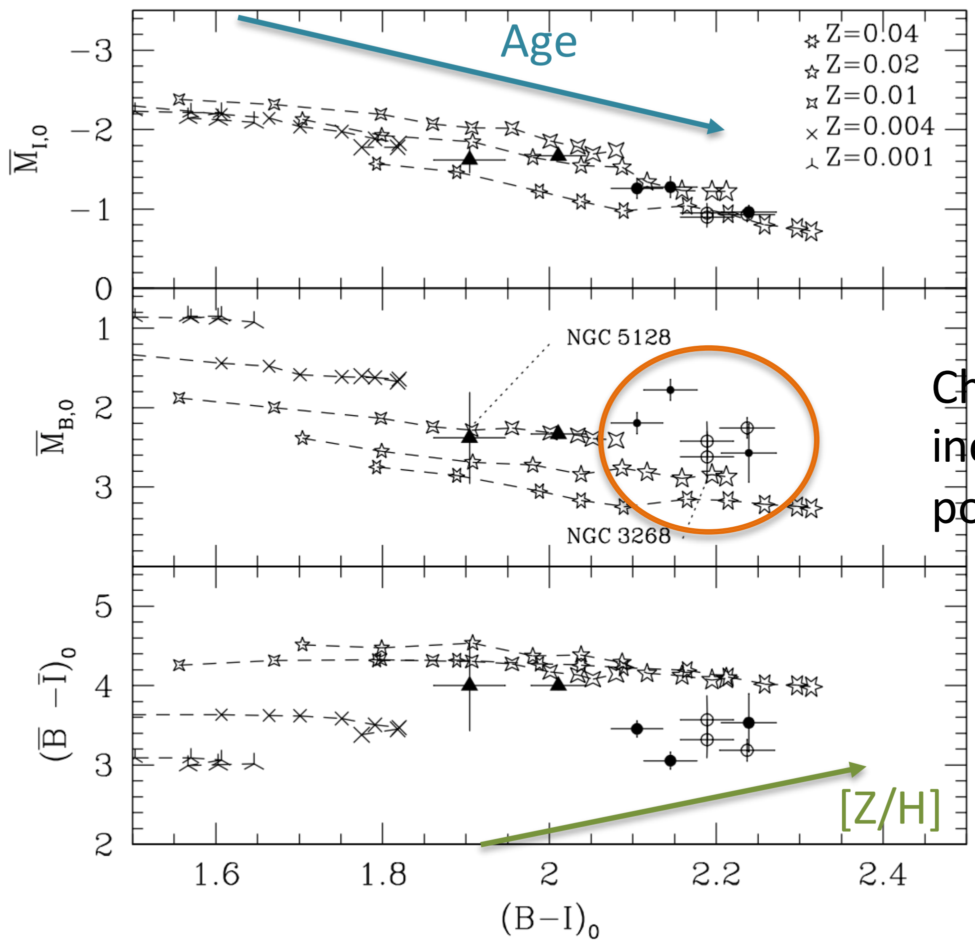
<N>= 2×10^7 stars per resolution element (simulating NGC4472)



Measuring colors in the fluctuations spectra



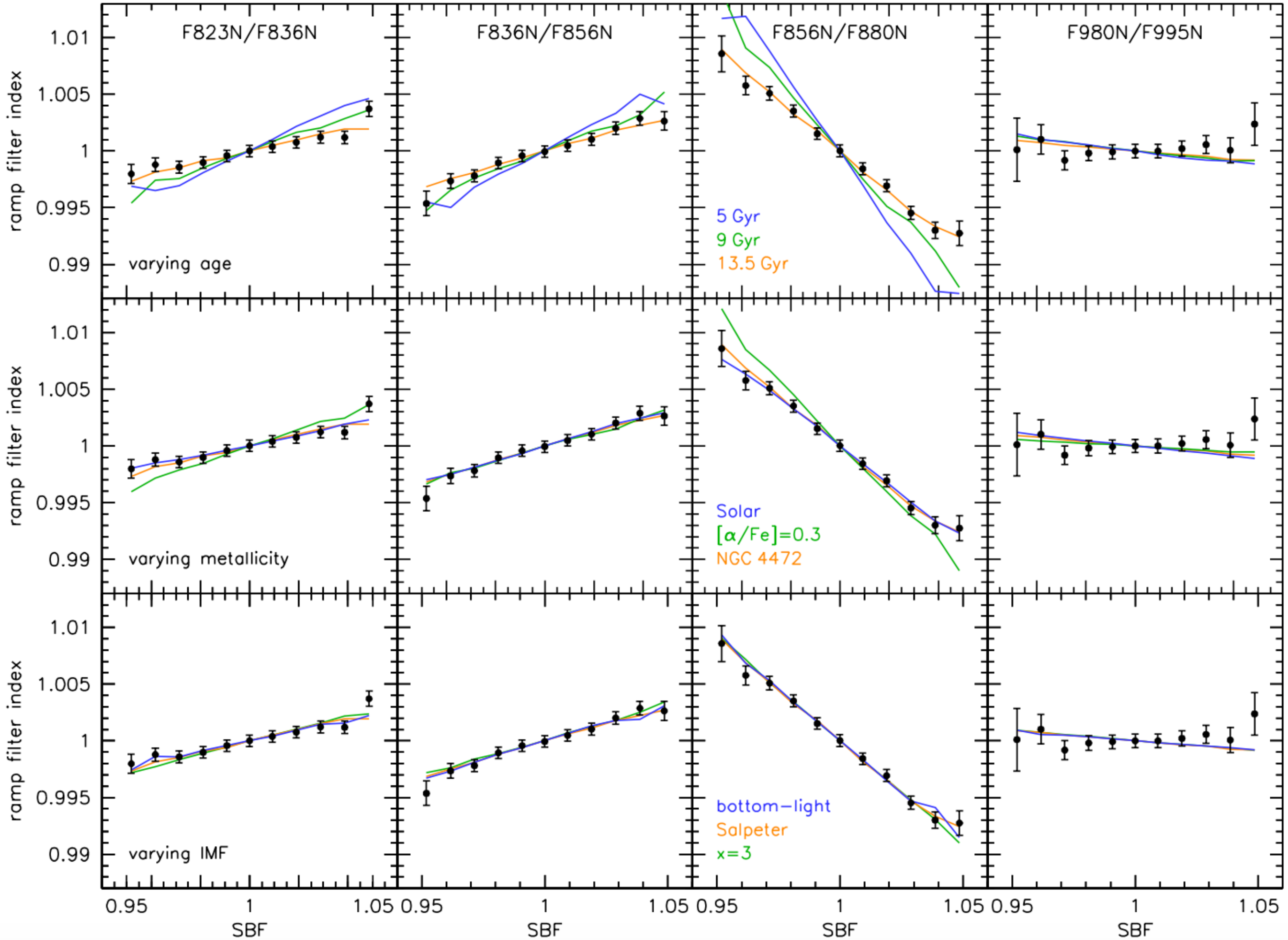
Testing the models with SBF in different bands



Change N_{post}/N_{HB} or include a metal poor population

Cantielo et al. (2007)

In the near-IR

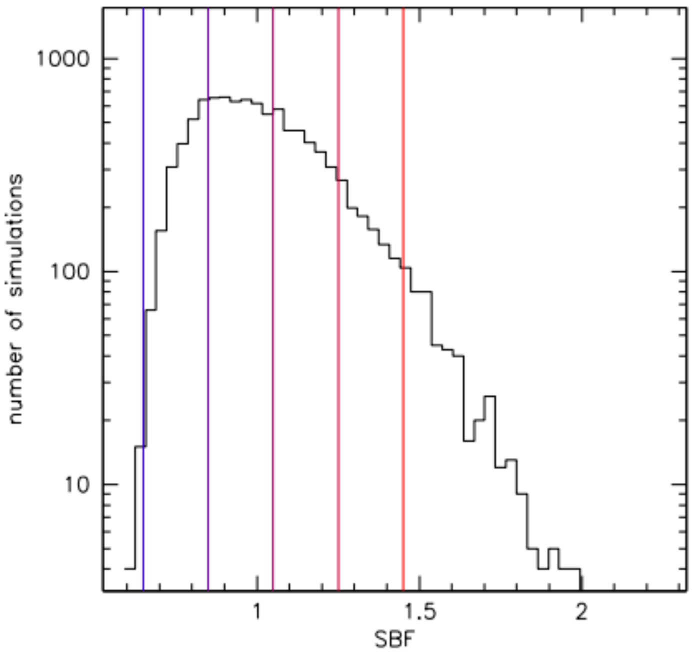


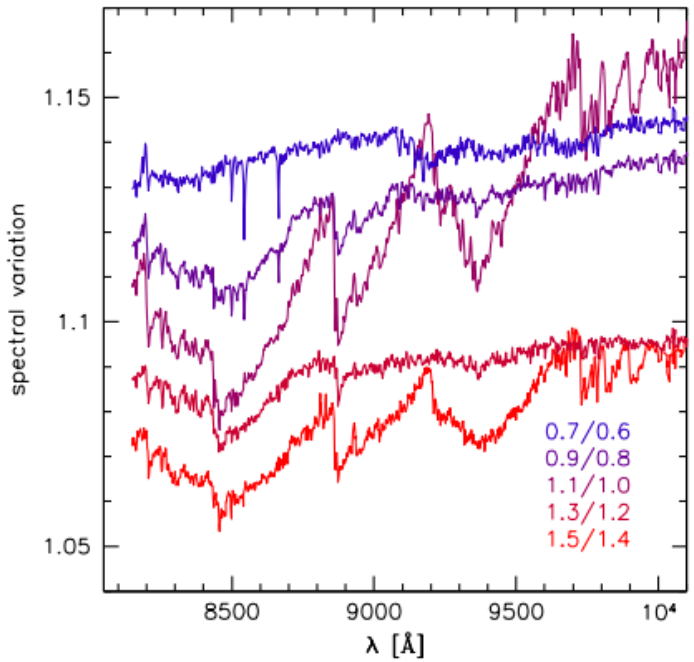
If we are in a regime with far less stars per pixel..

- For $<N_{stars}> = 10^5$
- Sightlines free of luminous giants→ providing a window to the low RGB and MS

Spectroscopic SBF in the near-IR

Assuming <Nstars>=10^5 per pixel



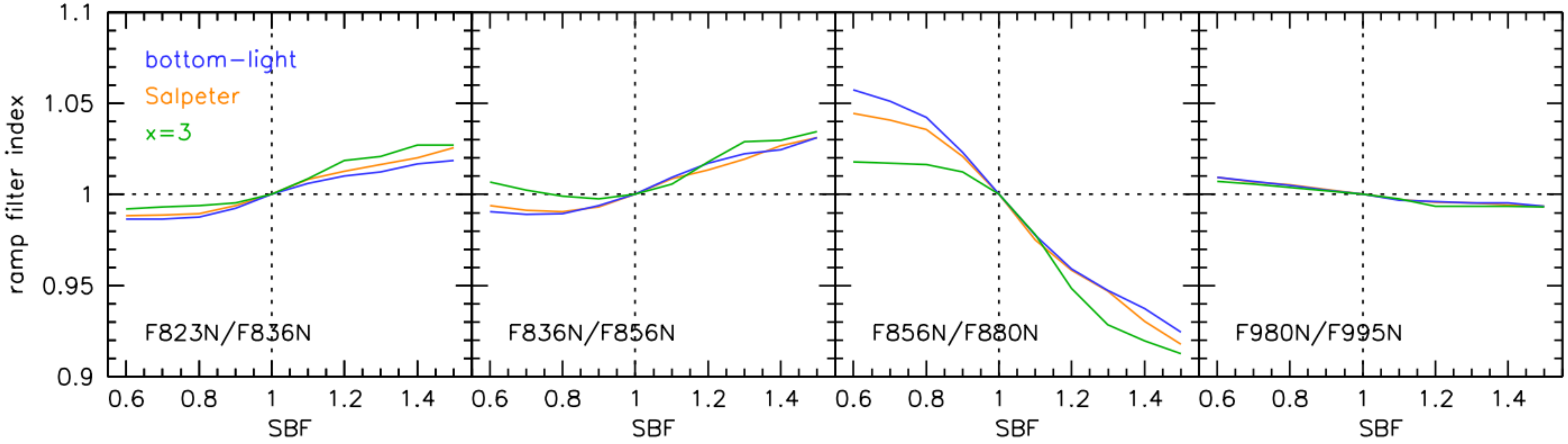


Variation of low luminosity giants and subgiants with temperature

Variation of the spectra of very luminous giants with temperature

Van Dokkum & Conroy (2014)

Constrains on the IMF



Van Dokkum & Conroy (2014)

Summary: unresolved stellar populations with the ELT

- Detailed chemical abundances (Eu, Ba, Ca, Ni, O, K, Si, Sc, Ti, V, Cr, Sr..) to fine tune the SFH of galaxies and also to constrain nucleosynthesis.
- The study of stellar population gradients up to several reff (testing growing mechanims)
- High redshift galaxies (representative samples up to z~1.5)
- Separating kinematically different components of galaxies (very important in the centers of spiral galaxies)
- Stellar populations in galaxy disks (many things remain to be done)
- High redshift galaxies (also for disk galaxies). Representative samples up to z=1.5
- Evolution of gradients with time (feedback constrain and quantification of migration)

→ We should develop **of other techniques** to make the best use of the data (e.g., spectroscopic SBF)