CHARACTERIZING THE STELLAR POPULATIONS OF SPIRAL GALAXIES

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Justification

- The stellar populations of spiral galaxies are a mixing of populations of variable age and metallicity.
- The present time data (abundances, gas densities) do not give information about the evolutionary track followed by the galaxy
- To determine only the mean age and metallicity does not allow to estimate how, when and where stars form.
- The spatial variations in spiral galaxies also need to be into account.
- Special phenomena as the formation of bars or outflows need dynamical information

The complexity of these galaxies needs other tools to estimate their evolution.

How to measure spectral indices in spiral galaxies

- Photometry;

  Filters in each spectral indices and in each continnum band

  (Beauchamp & Hardy 1997; Mollá, Hardy, Beauchamp 1999)

- Photometry with a Taurus Tunable Filter (etalon) –Fabry-Perot Interferometry

  (Ryder et al. 2005, MNRAS, acep.)

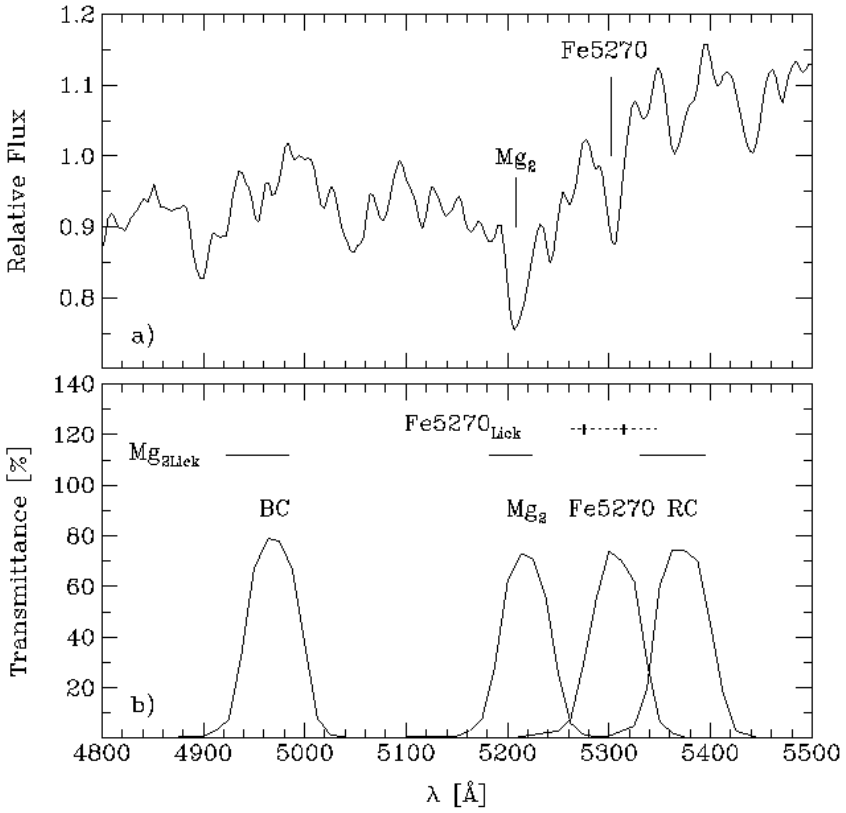
- OASIS:

  3D espectroscopy of high spatial resolution

  (Cantin et al. 2004, in prep.)

Beauchamp & Hardy 1997

•To obtain monochromatic images of galaxies in order to measure the Lick Mg and Fe52 indices

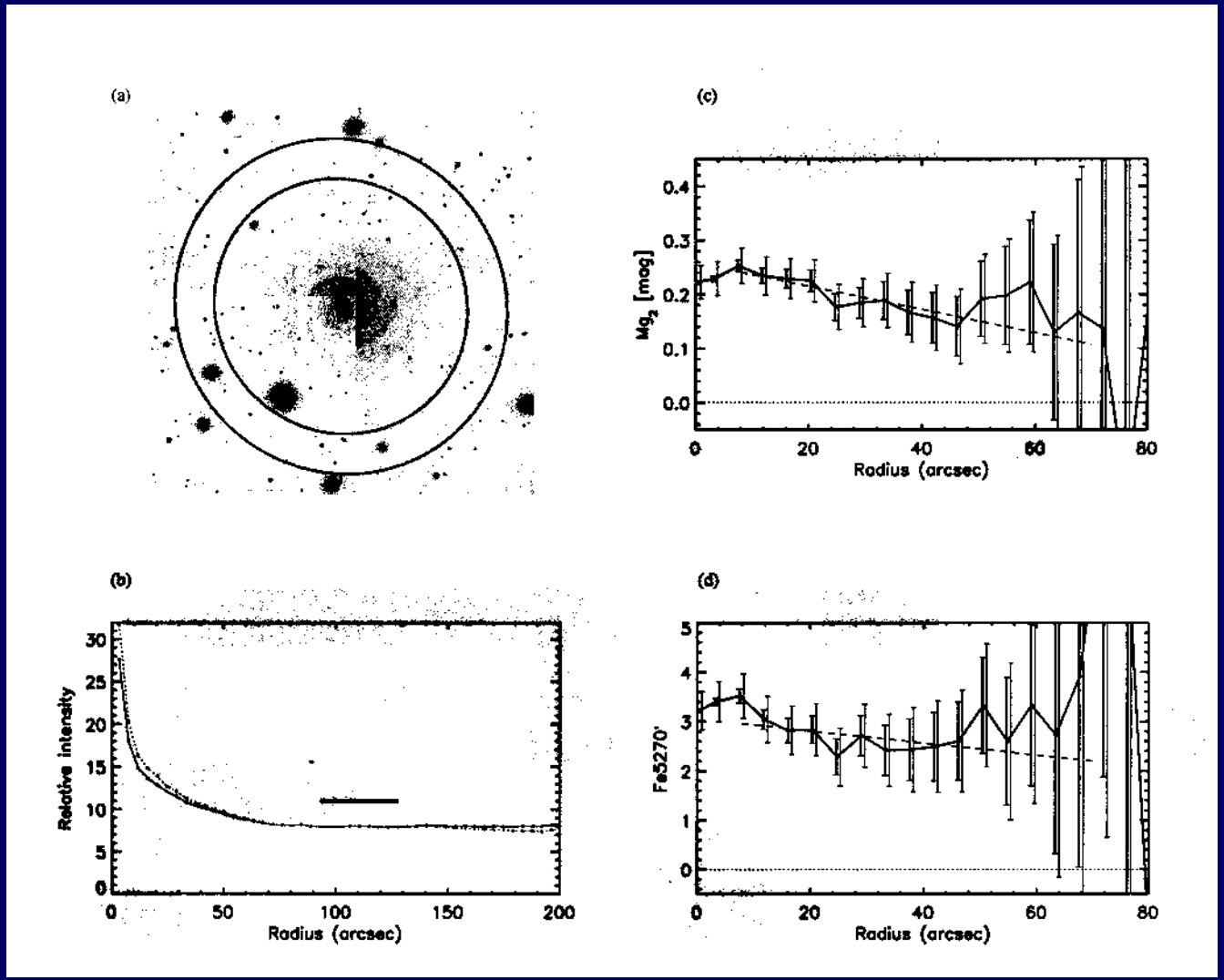


•Four intermediate-passband (60Å) filters, two of them centered on the magnesium and iron features and two on continuum regions, RC and BC for the red and blue continua, respectively.

• The use of spectral images increases the signal-to-noise ratio of the index measurement by azimuthally adding up all the information contained within a given radial interval.

•Azimuthal integration provides measurements of spectral indices useful to radial distances where the surface brightness of the galaxy reaches 24

Ryder, et al. 2004, MNRAS, accepted



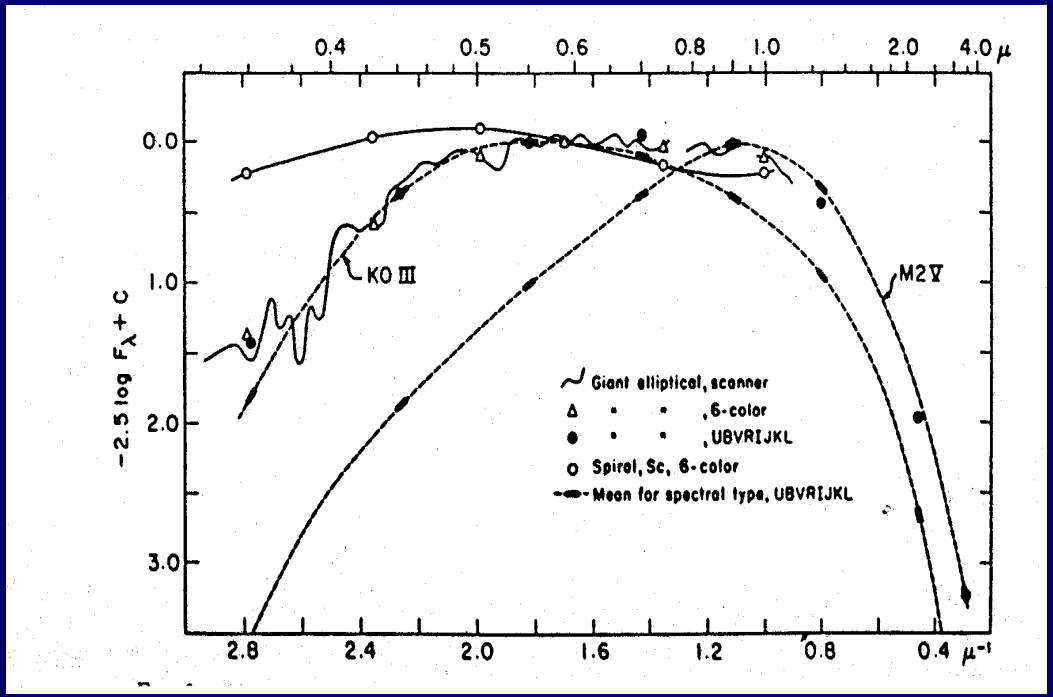
SYNTHESIS MODELS

- Origin: the study of globular clusters and elliptical galaxies
  - Colors or integrated spectral energy distributions for non-resolved objects
  - Stellar spectral lines, (metallic) Absorption indices: (Lick, Rose . . .)
- Data are analyzed using (evolutionary) synthesis models.
  - Stellar Libraries
  - Isochrones for SSP
  - Fitting Functions

The spectral distribution of energy is characteristic of each stellar spectral type. It changes depending on metallicity or (mass) age of the star.

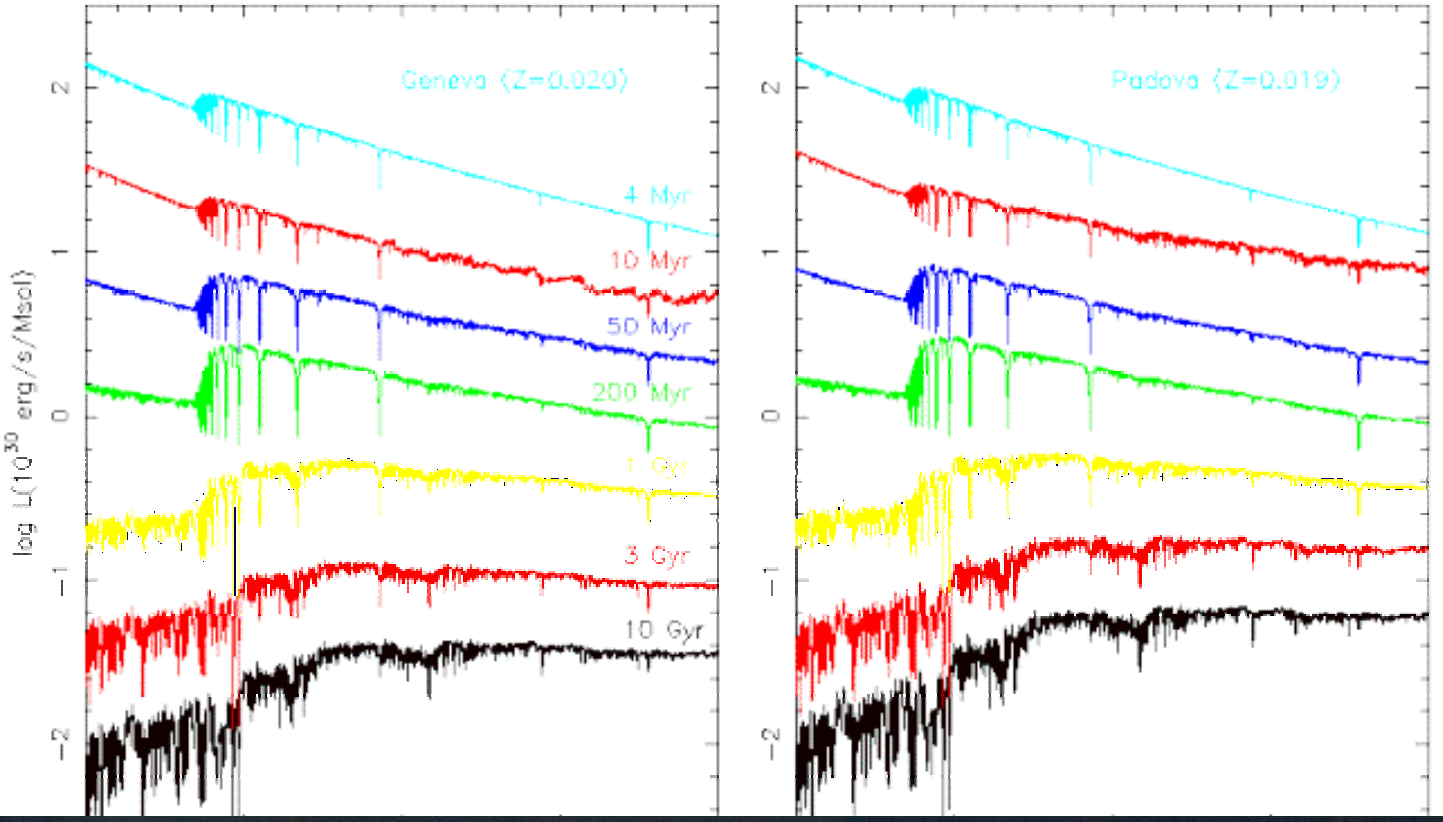
The fit of models with data gives the proportion of each type of star contributing to the observed spectral distribution

$$F_\lambda = \sum_{j=1}^{N} C_j f_{\lambda,j}$$



Spectral energy distributions for SSP

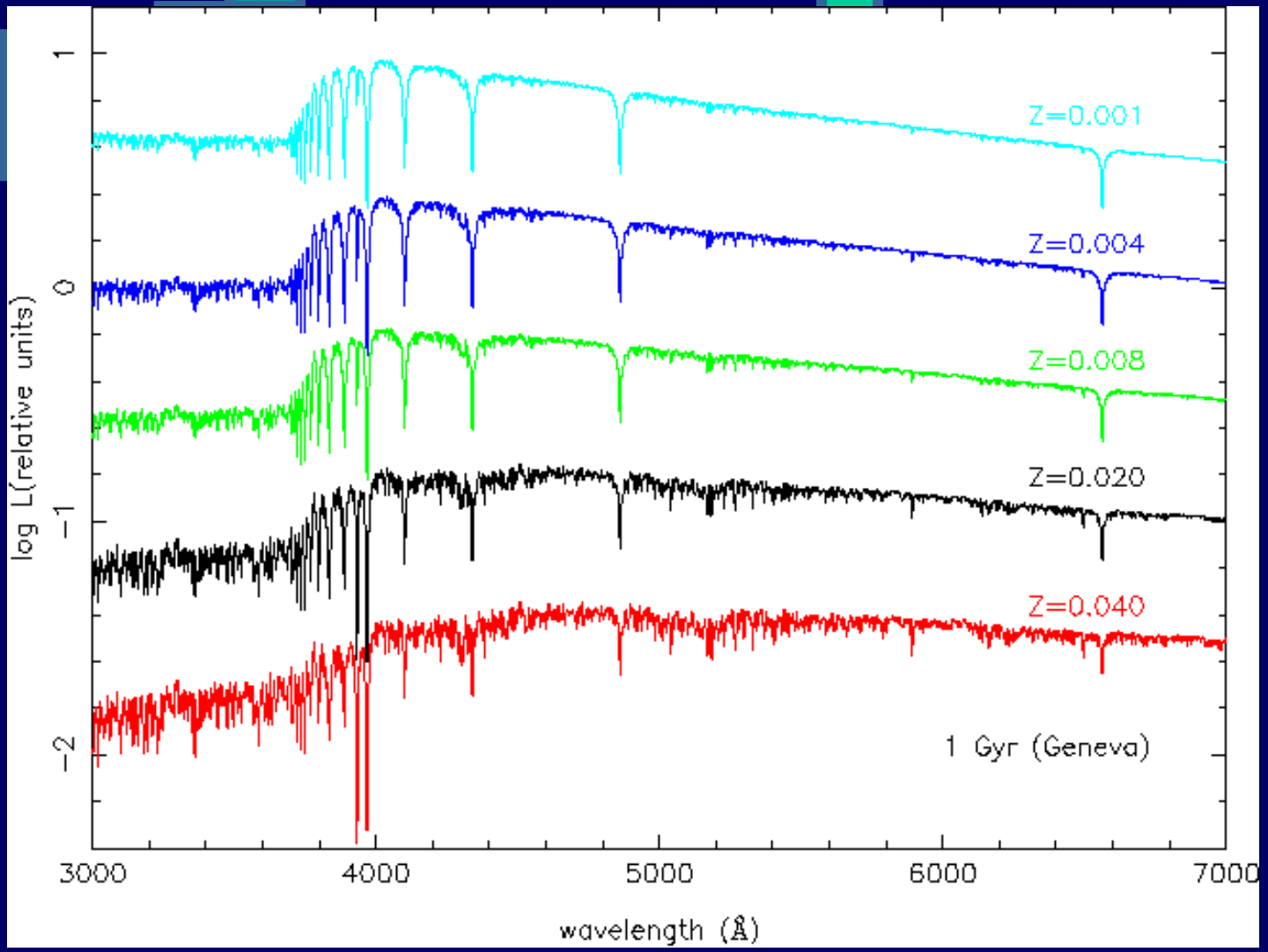
Martins al 2004, MNRAS



SSP = population of stars formed in a istantaneous burst of SF

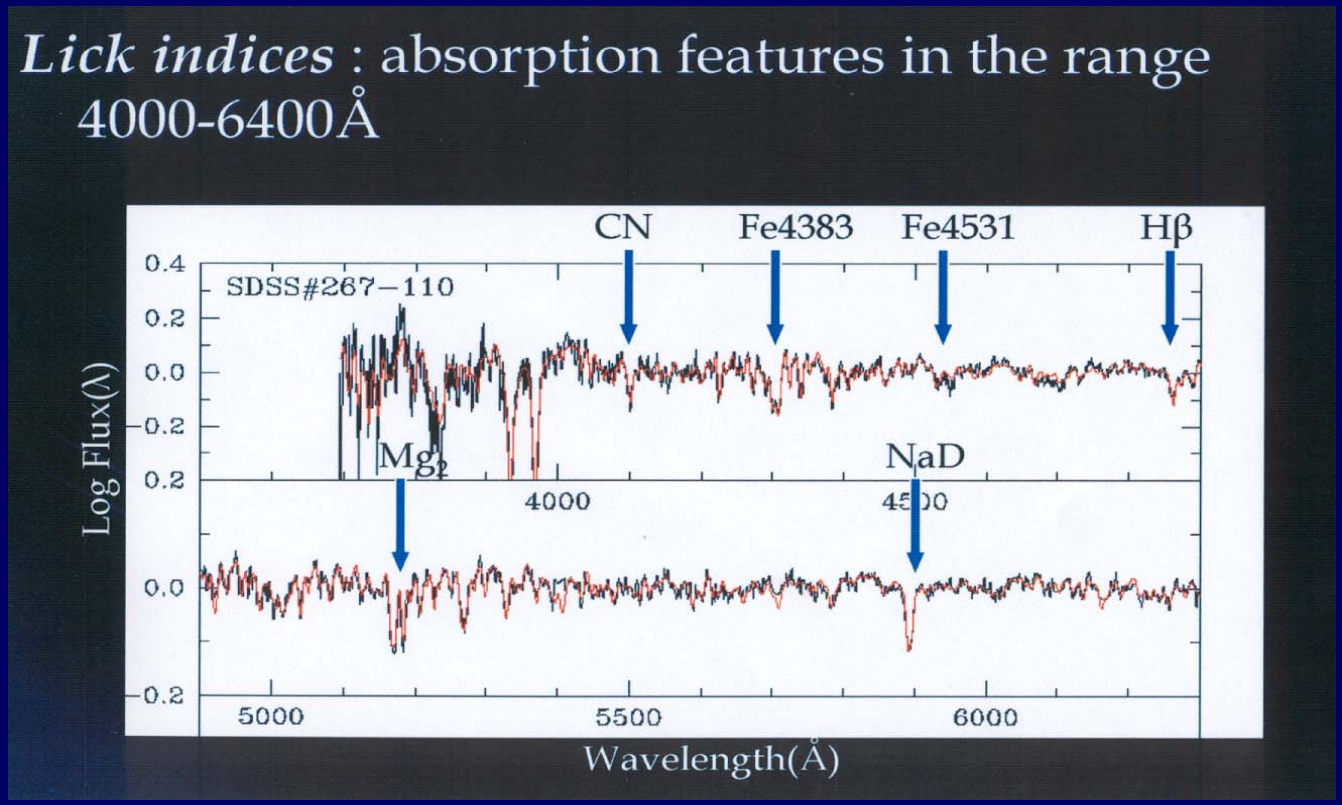
$$S_\lambda(t,Z) = \int f_\lambda(t,Z,m)\phi(m)dm$$

Convolution with IMF
↓
SSP spectrum


Z=0.001
Z=0.004
Z=0.008
Z=0.020
Z=0.040
1 Gyr (Geneva)
log L(relative units)
1
0
−1
−2
3000
4000
5000
6000
7000
wavelength (Å)

Spectral absorption indices

Synthesis models also produce colors and spectral indices.



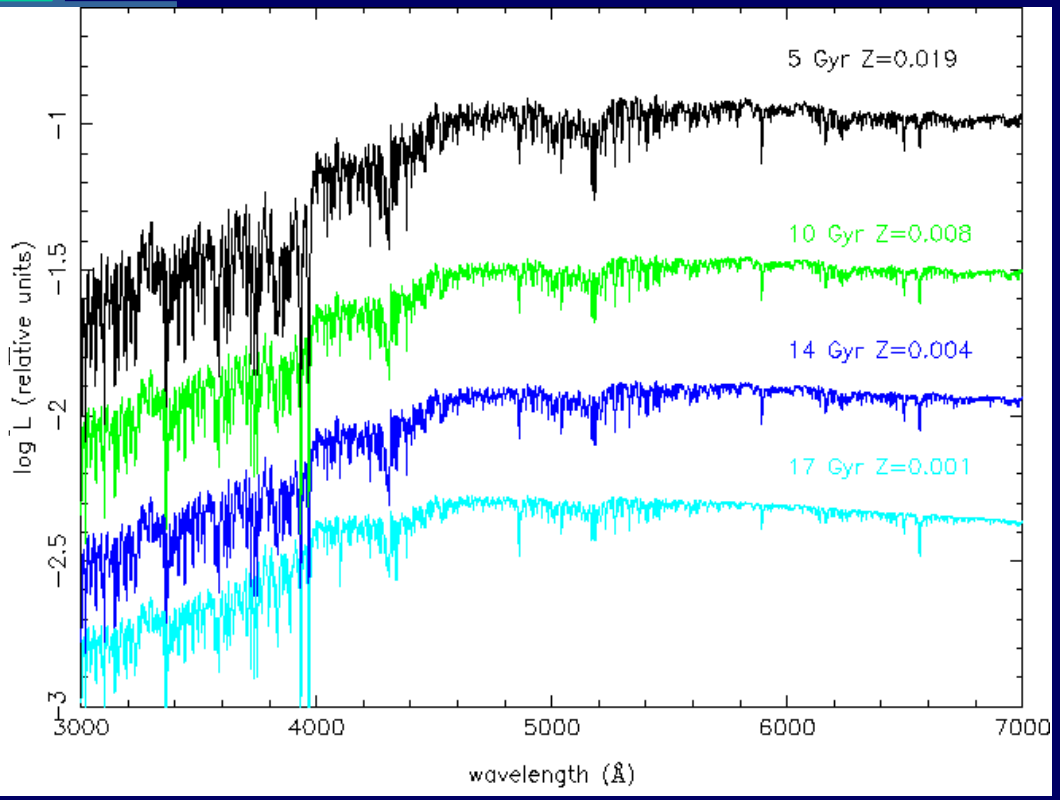
The absorpcion lines or indices of Lick' system are very used.

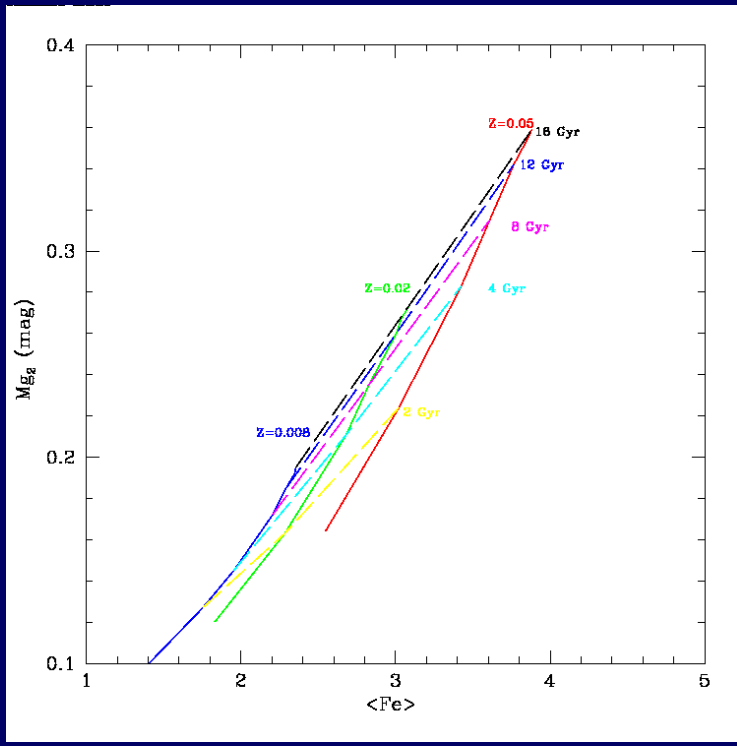
Fitting functions: the value of the index for each stars (Teff, log g, Z)

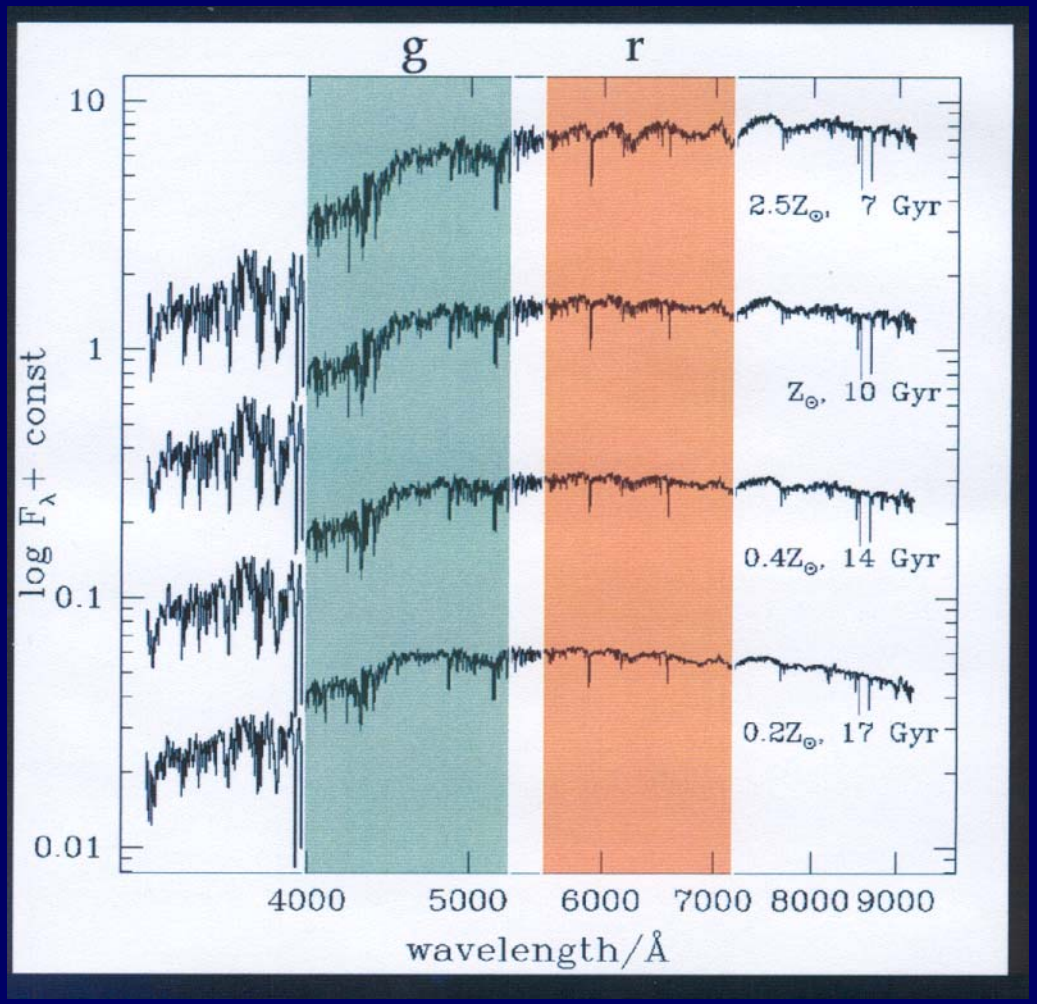
Restrictions of Models

The age-metallicity degeneracy:

old and metal-poor stellar populations show similar SED and spectral indices than the young and metal-rich ones



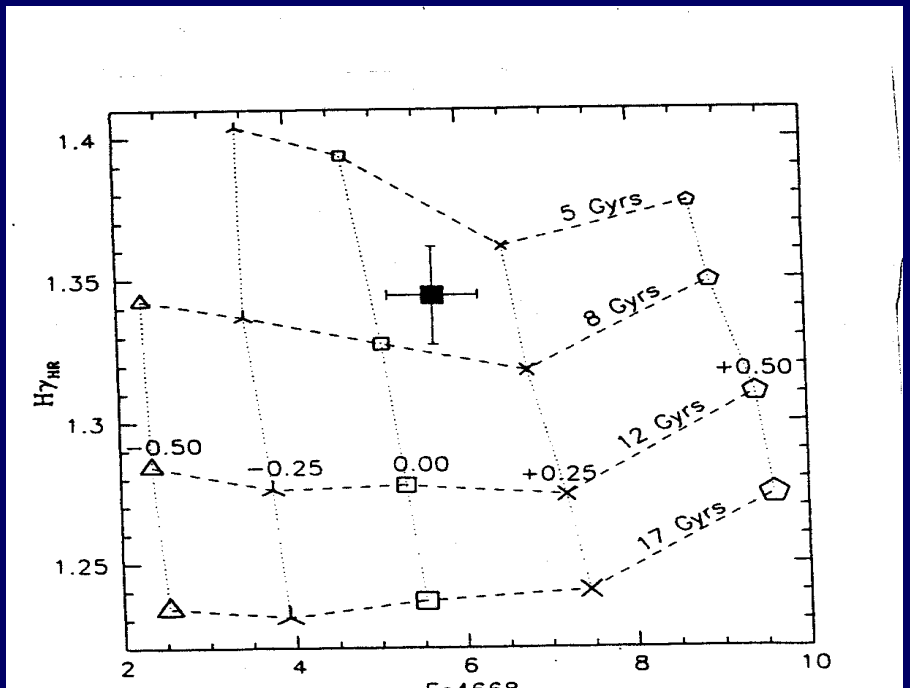



g
r
10
1
0.1
0.01
log F_λ + const
2.5$Z_\odot$, 7 Gyr
$Z_\odot$, 10 Gyr
0.4$Z_\odot$, 14 Gyr
0.2$Z_\odot$, 17 Gyr
4000
5000
6000
7000
8000
9000
wavelength/Å

The observed data are overploted on a graph with 2 indices: a mean metallicity and age are obtained

The method to face the age-metallicity degeneracy is to use two orthogonal indices

The age is weighted by the luminosity

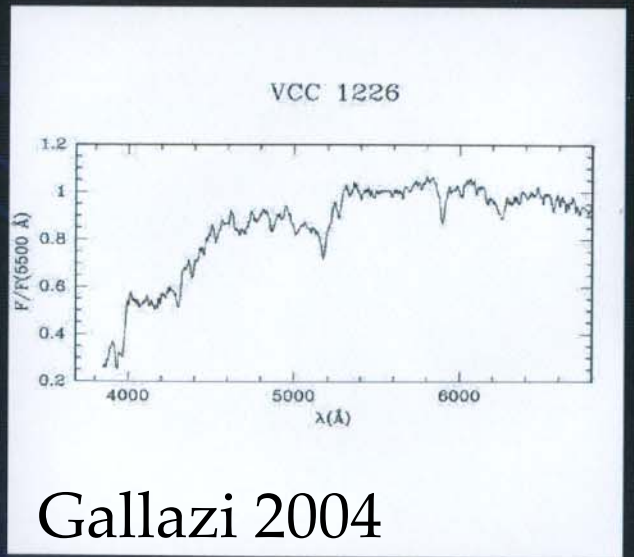


Different SFH → different **photometric** and **spectral** properties

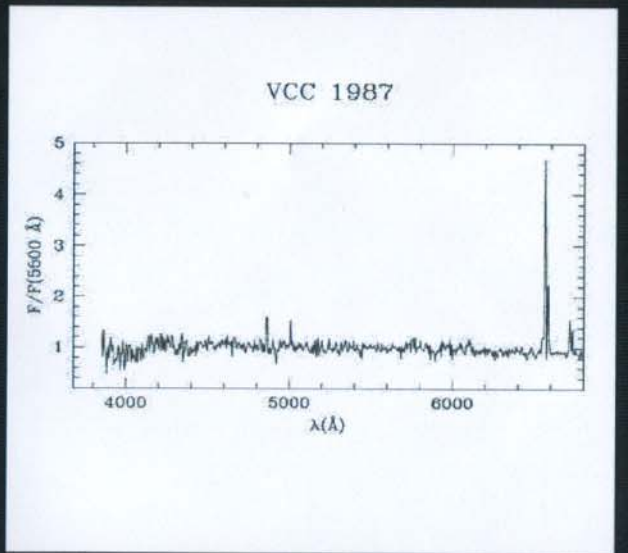
E/S0

Sc

The mixing of stellar populations is evident in spiral galaxies, (disks and bulges)



Gallazi 2004

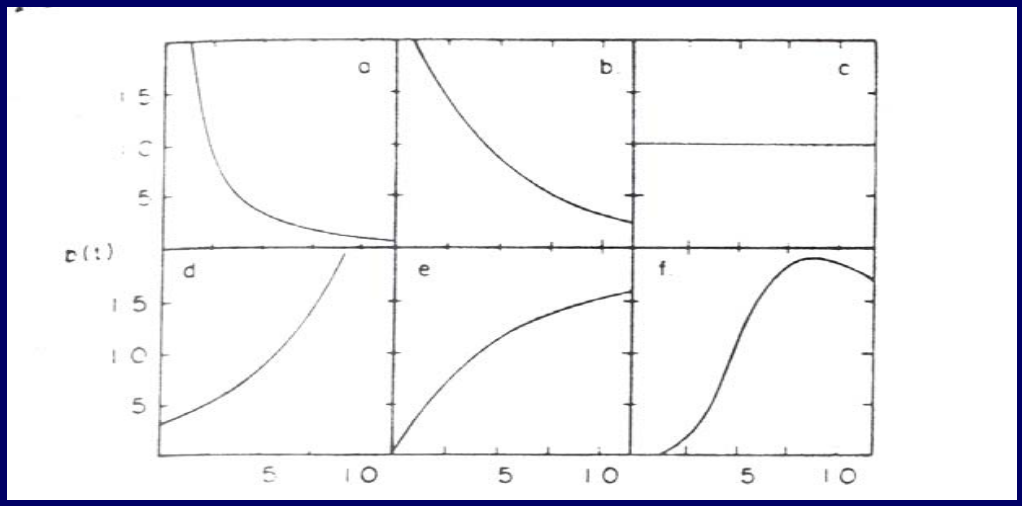


- The star formation history must be assumed

$$F_\lambda(t) = \int_0^t S_\lambda(t', Z)\psi(t - t')dt'$$

Convolution with SFH
↓
Galaxy spectrum

The star formation history can not be obtained from these SSP. When the technique is used in galaxies where a mixing stellar populations is aparent, some hypothesis about the possible star formation history are assumed



OUR APPROACH FOR SPIRAL GALAXIES

- The evolutionary synthesis models in spirals are computed from the SFR(t) obtained through a chemical evolution

$$F_\lambda(t) = \int_t dt' \Psi(t') F_\lambda^{SSP}(t - t')$$

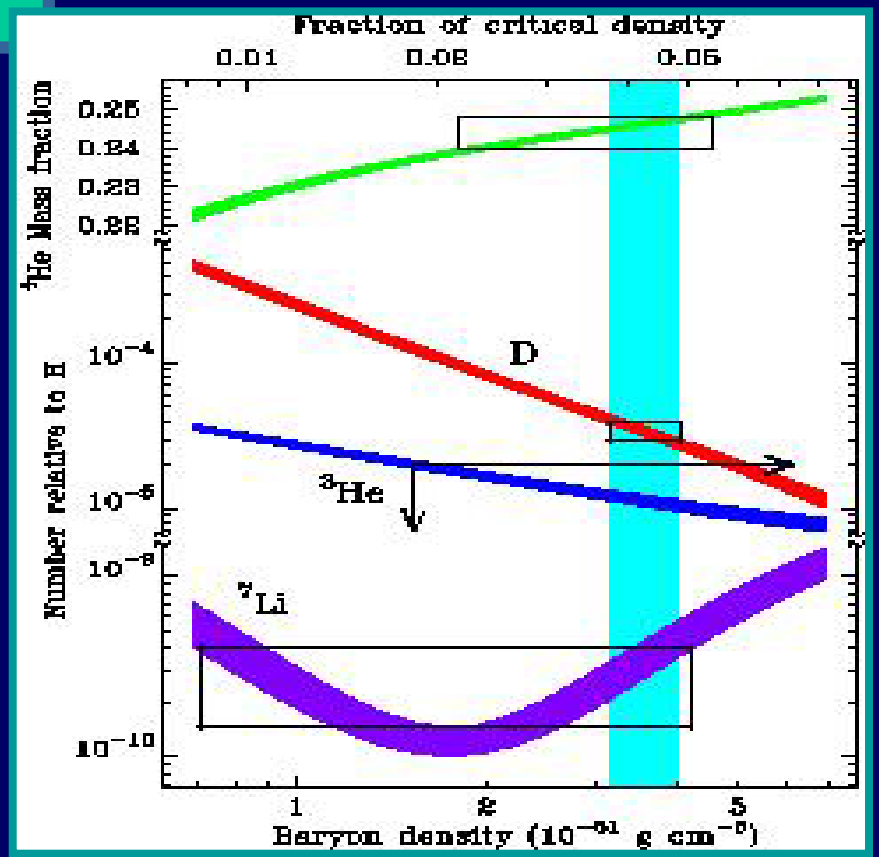
- We use the observed spectral indices in bulges
- We have also data of Mg2 y Fe52 obtained for three Virgo galaxias Virgo (Beauchamp 1997; Beauchamp & Hardy 1997)

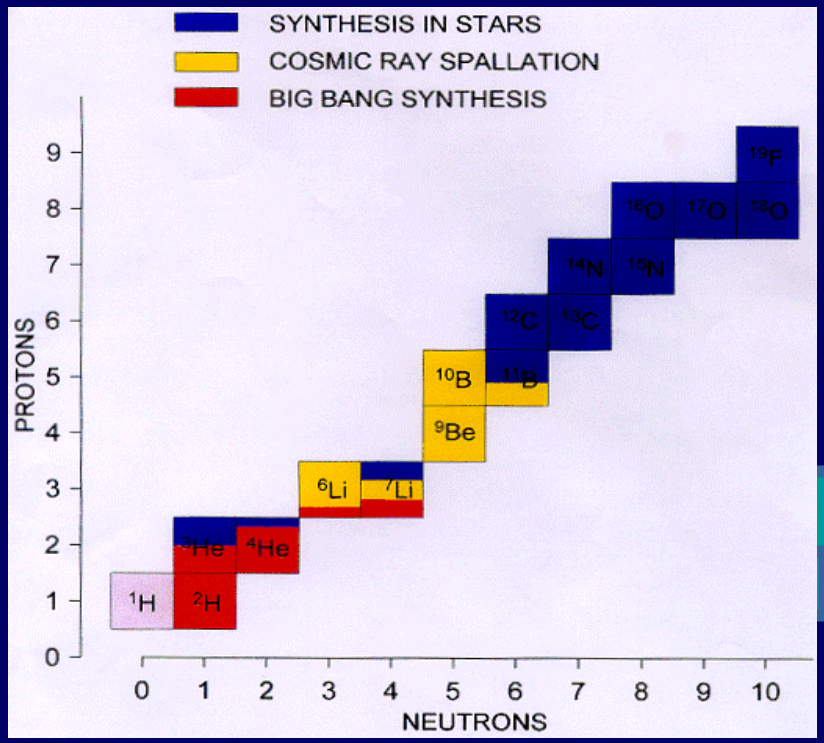
  A dependence on the galactocentric radius there appears.
- There is a diiferent behavior of Fe5270 compared with Mg2. As in elliptical galaxies this may be related on the disk and star formation processes.

CHEMICAL EVOLUTION

Chemical evolution describes the increase of elements in the Universe

Primordial abundances given by modern comological models compared with data





The proportion of metal increase when they create in stars and dlilute in the ISM. The final effect is shown in absorption lines and in emission lines

Basic equations

$$\frac{dM}{dt} = f$$

$$\frac{dMs}{dt} = \Psi - E$$

$$\frac{dMg}{dt} = -\Psi + E + f$$

$$M = Ms + Mg$$

- f= gaz flux (closed box =0)
- M= total mass of the system
- Y=SFR (star formation rate)
- E= mass ejection of stars when they die
- Ms= stellar mass
- Mg= gaz mass

Each star loss mass after its mean life-time, τm. Remaining a remnant wm.

The total ejection for the whole stars is:

$$E(t) = \int_{m_l}^{\infty} (m - \omega_m)\Psi(t - \tau_m)\Phi(m)dm$$

Initial mass function

Ejected Mass for stars of mass M

The mass transformed in stars in a time (t-τm) which are now ejecting mass and dying

A chemical evolution model

The existence of infall gas

Initial Conditions

Evolutionary Scenario

Hypotheses about SFR y (t) y FIM F(m)

Mtot of gas for t=0

EQUATIONS SYSTEM

stellar evolution
mean lifetimes of stars
yields p_{zm}

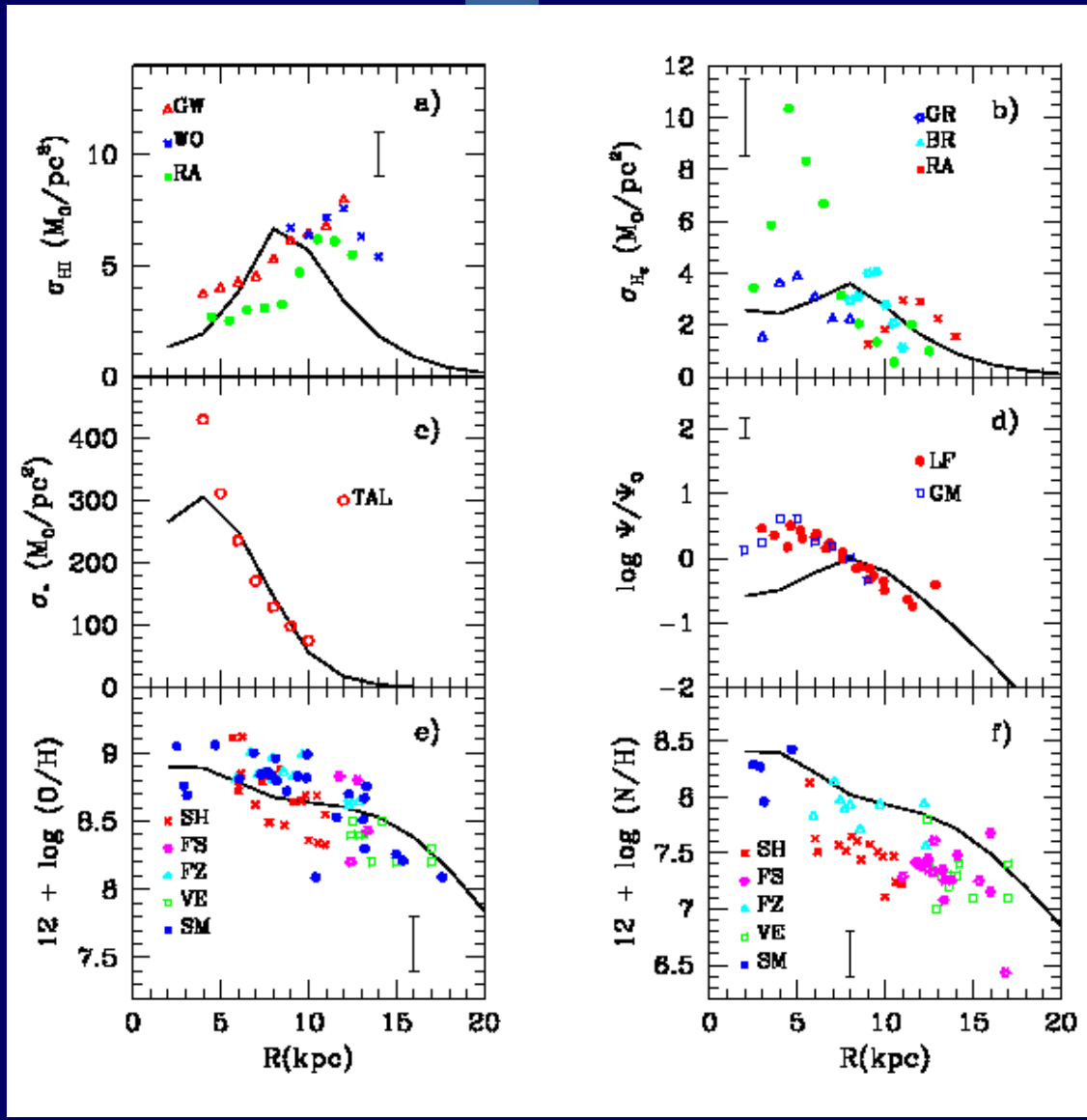
comparison with observed data

RESULTS:

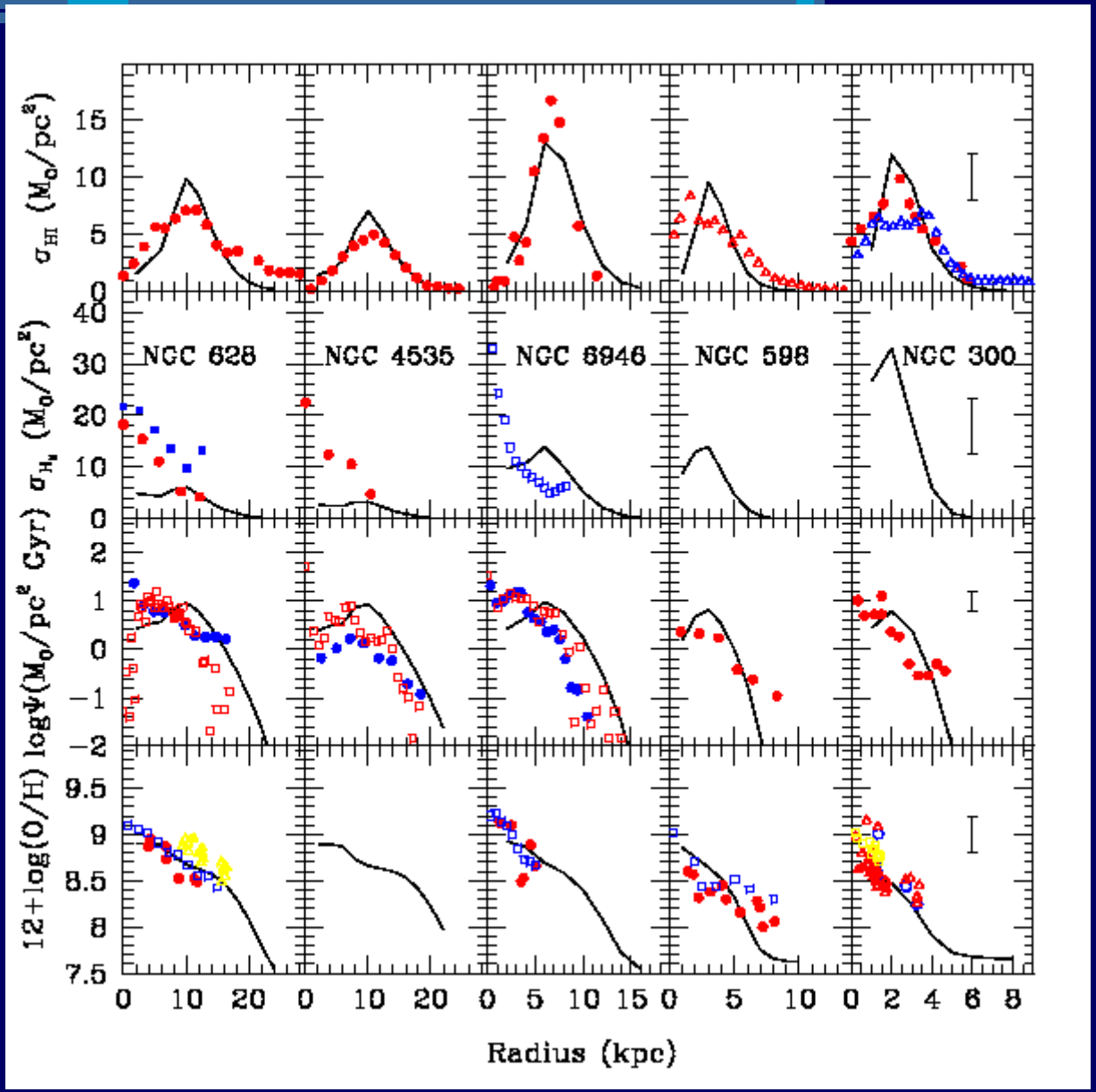
- Gas, stars and total (g,s,m)(t,r)
- Abundances for 15 elements Xi, and total abundance Z
- Relative Abundances [X/Y]
- Star formation histories y (t,r)
- Age-metallicity relations Z(t,r)

Results: The model for the Milky Way Galaxy

- We can obtain separetely the radial distributions of diffuse and molecular gas
- The radial gradients flattens in the inner disk in agreement with recent data (Smartt et al. 2001)
- The star formation rate surface density is underestimated in the inner radii

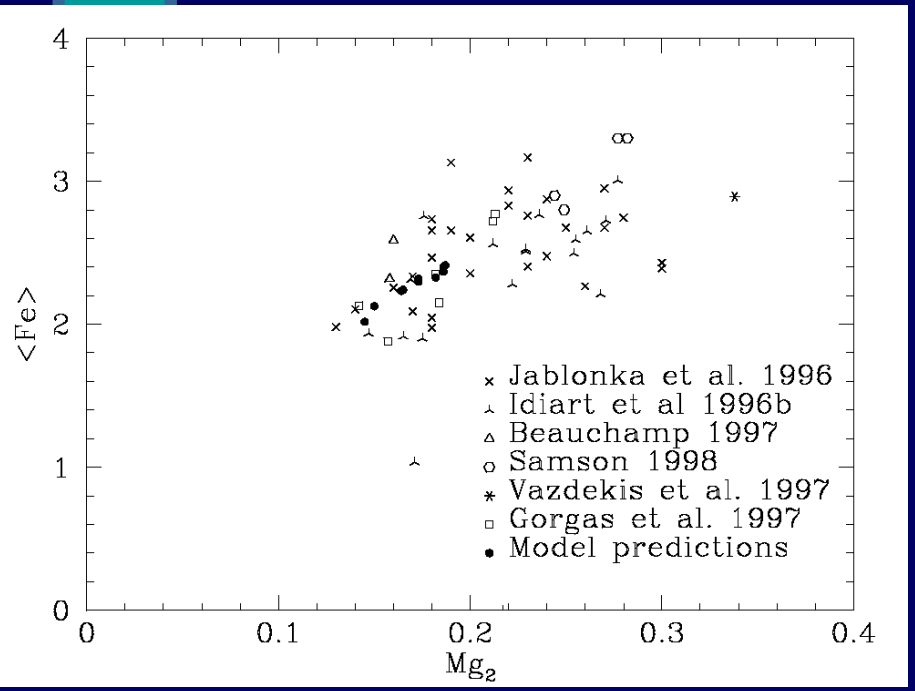


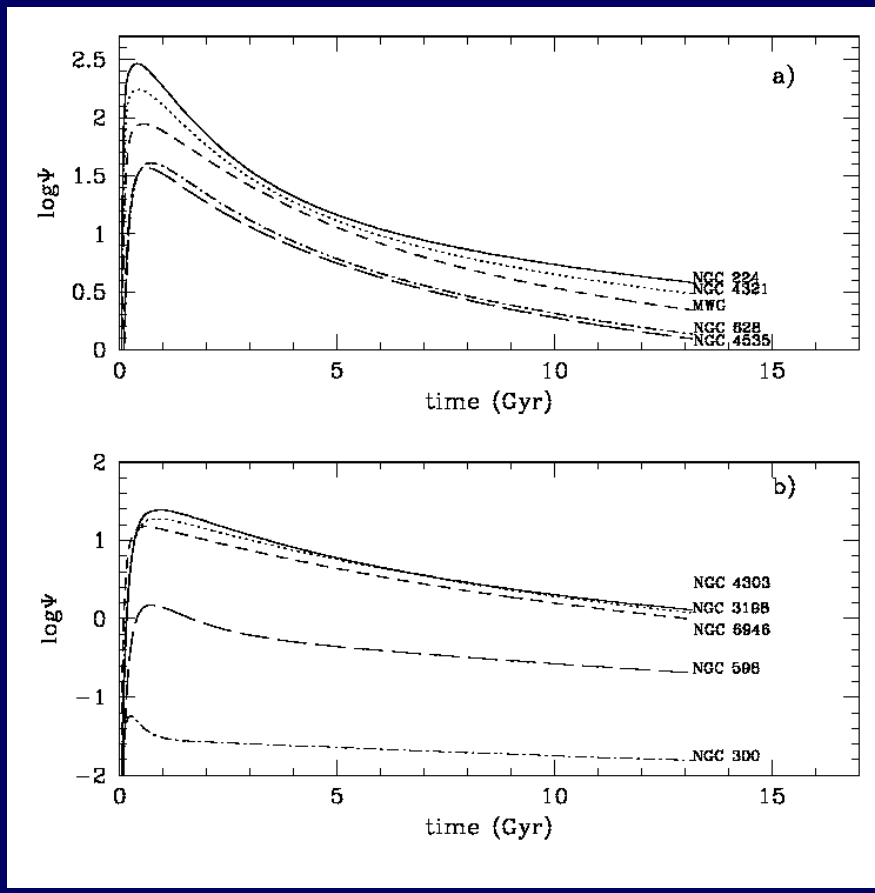
Results: Other spiral galaxies



The spectral indices in bulges

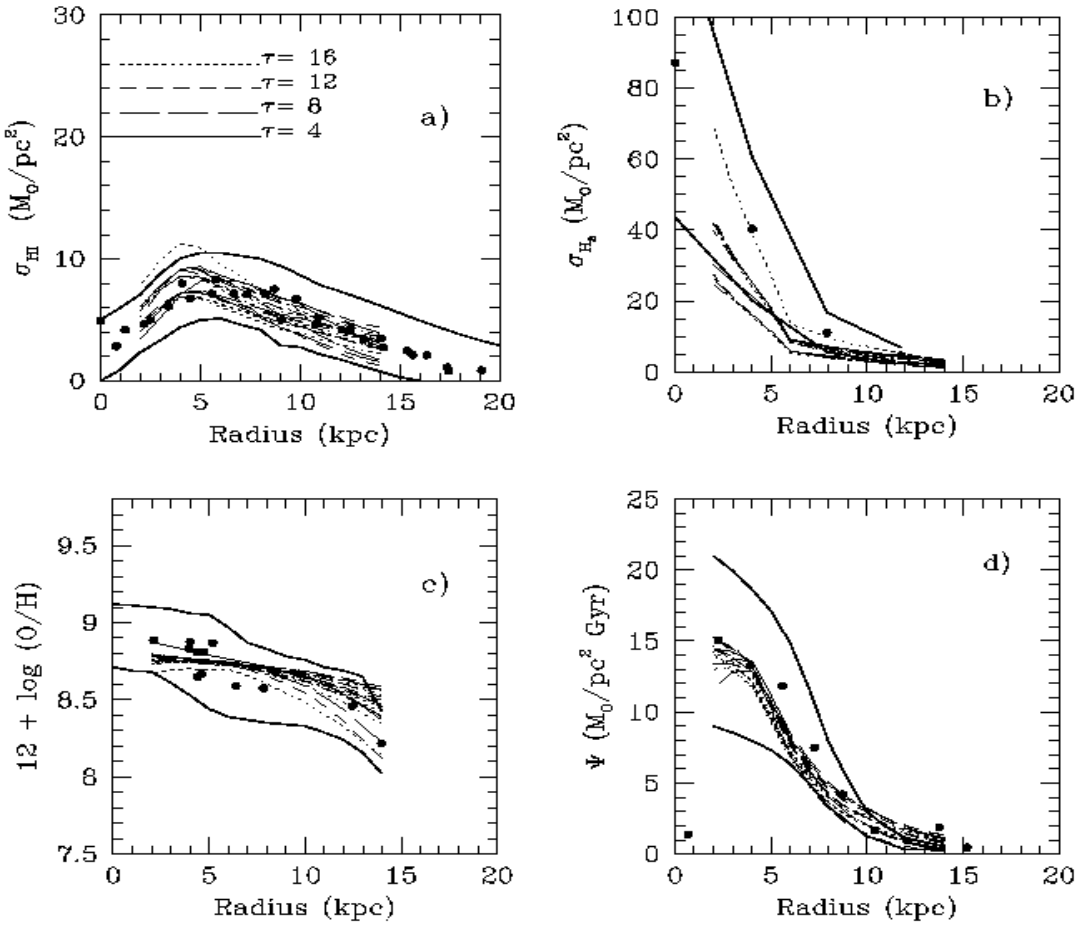
We checked our technique using chemical evolution results for some spiral bulges to compute the absorption indices Mg2, <Fe>...





Our results are useful to estimate the star formation history of these bulges.

We have computed 500 chemical evolution models with variable inputs (20 ε's, 5 τ, 5 λ):



Posible chemical evolution models that reproduce the gas data at the present time:

Only 19 are valid

Infall colapse time τ_0

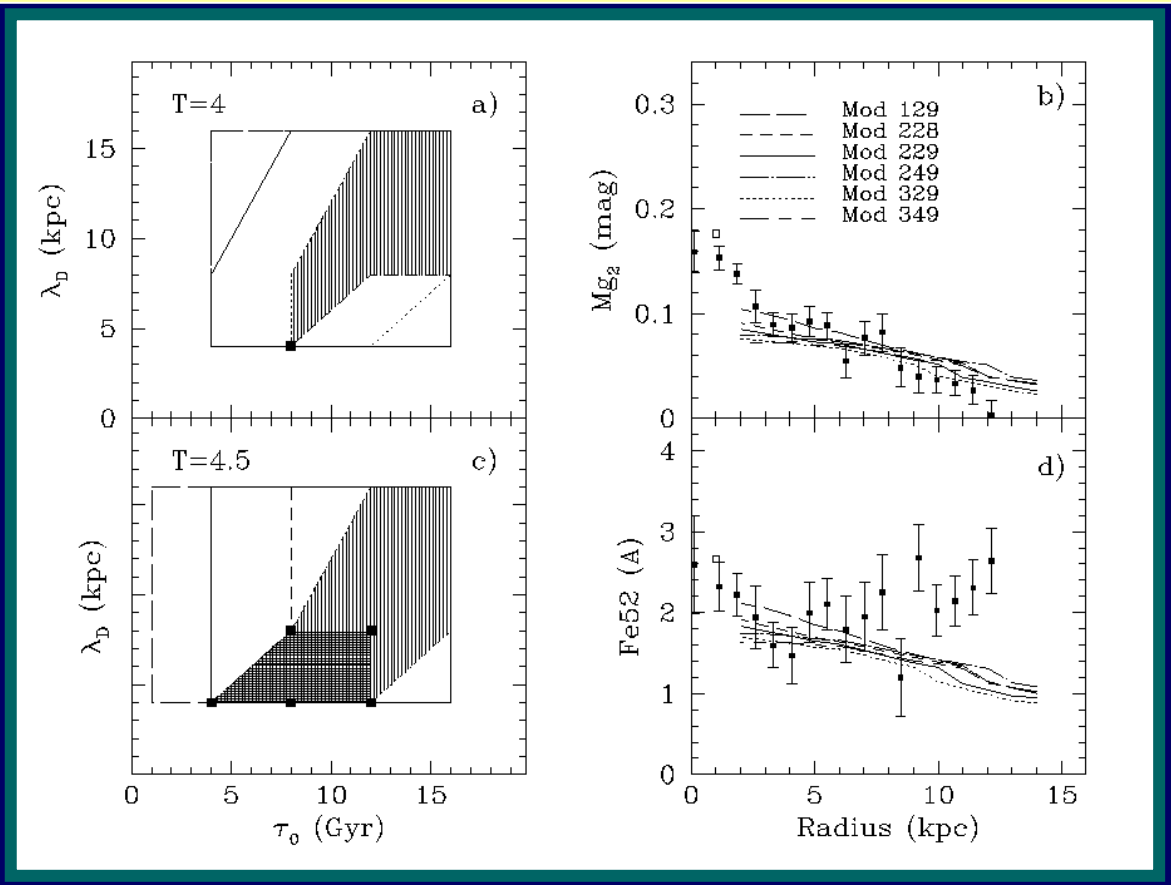
Scale length for the function $\tau=\tau_0 \exp -(R-R_0/\lambda)$

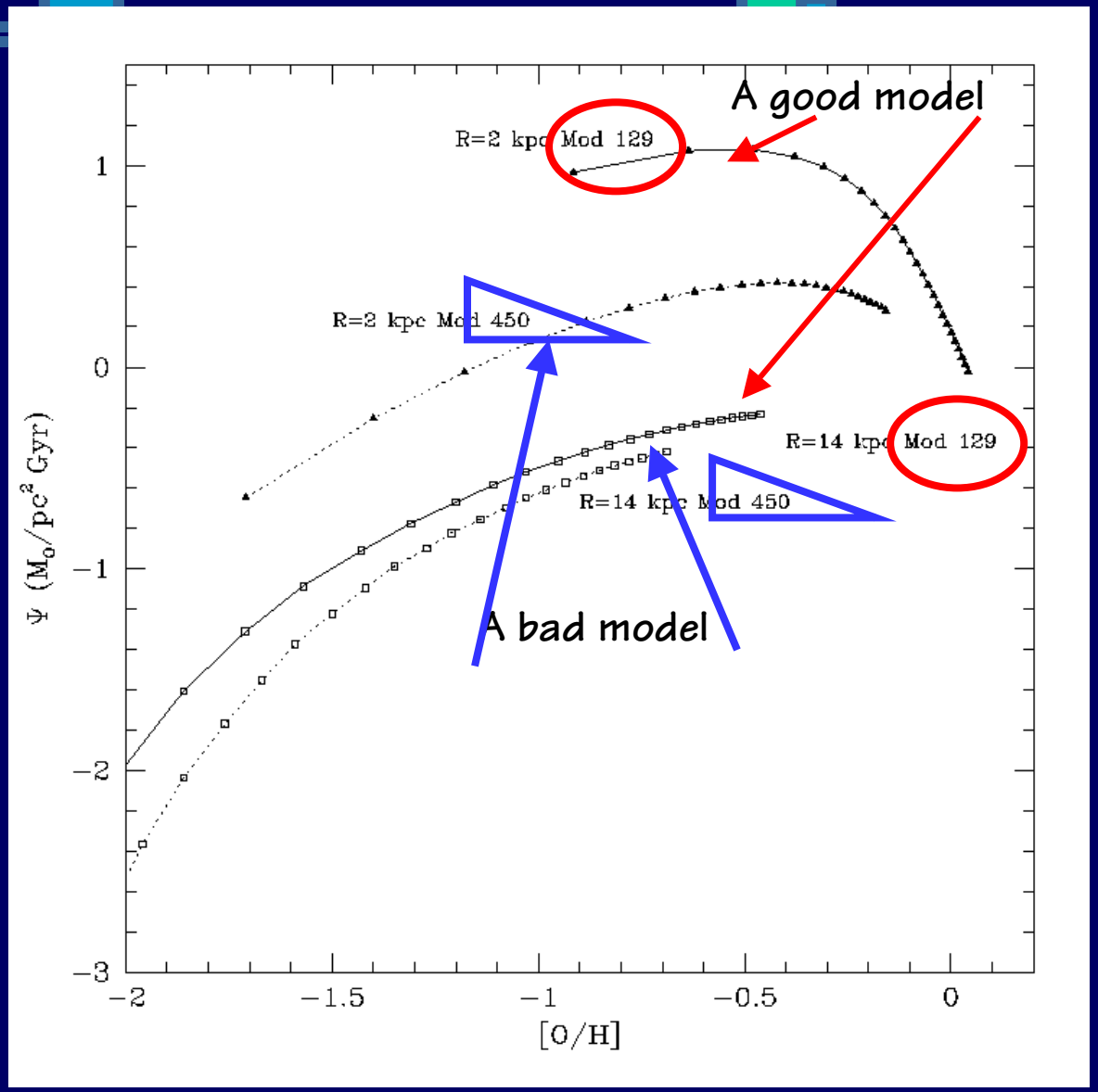
Efficiencies to form stars and molecular clouds

Num	τ (Gyr)	λ_D	T	ε_μ	ε_H	χ^2_{OH}	χ^2_{SFR}	χ^2_{Hi}	χ^2_{H2}	P_{OH}	P_{SFR}	P_{HI}	P_{H2}	P_{Mg2}	P_{Fe52}
129	4.	4.	4.5	.259	.017	0.957	6.040	0.378	2.318	1.000	0.983	1.000	1.000	1.00	1.00
228	8.	4.	4.0	.344	.041	1.201	2.114	1.401	6.413	1.000	1.000	1.000	0.983	1.00	1.00
229	8.	4.	4.5	.259	.017	0.361	1.716	1.670	1.672	1.000	1.000	1.000	1.000	1.00	1.00
248	8.	8.	4.0	.344	.041	3.416	5.335	0.265	4.814	0.999	0.992	1.000	0.998	0.97	1.00
249	8.	8.	4.5	.259	.017	1.922	5.119	1.681	3.177	1.000	0.993	1.000	1.000	0.98	1.00
329	12.	4.	4.5	.259	.017	0.714	4.887	2.690	2.806	1.000	0.995	1.000	1.000	1.00	1.00
348	12.	8.	4.0	.344	.041	2.647	2.896	0.689	5.276	1.000	1.000	1.000	0.995	0.95	1.00
349	12.	8.	4.5	.259	.017	1.223	2.533	1.352	2.101	1.000	1.000	1.000	1.000	0.98	1.00
368	12.	12.	4.0	.344	.041	3.398	4.783	0.435	4.985	0.999	0.996	1.000	0.997	0.91	1.00
369	12.	12.	4.5	.259	.017	1.937	4.505	1.562	3.238	1.000	0.997	1.000	1.000	0.88	1.00
388	12.	16.	4.0	.344	.041	3.773	6.222	0.402	4.947	0.998	0.980	1.000	0.997	0.88	1.00
389	12.	16.	4.5	.259	.017	2.336	6.089	1.799	4.032	1.000	0.982	1.000	0.999	0.90	1.00
448	16.	8.	4.0	.344	.041	2.095	3.567	1.337	6.075	1.000	0.999	1.000	0.988	0.94	1.00
449	16.	8.	4.5	.259	.017	0.858	3.219	1.130	2.056	1.000	1.000	1.000	1.000	0.83	0.90
450	16.	8.	5.0	.189	.007	1.506	2.976	5.057	3.874	1.000	1.000	0.989	1.000	0.83	0.90
468	16.	12.	4.0	.344	.041	2.841	3.930	0.804	5.543	1.000	0.999	1.000	0.993	0.90	1.00
469	16.	12.	4.5	.259	.017	1.440	3.480	0.918	2.611	1.000	1.000	1.000	1.000	0.93	0.99
488	16.	16.	4.0	.344	.041	3.215	4.675	0.634	5.387	0.999	0.996	1.000	0.994	0.87	1.00
489	16.	16.	4.5	.259	.017	1.795	4.237	0.965	3.167	1.000	0.998	1.000	1.000	0.92	0.99

Then we calculate the radial distributions of spectral indices Mg2 and Fe5270.

Only 6 models may fit simultaneusly these constraints and those from the gas.




A good model
R=2 kpc Mod 129
R=2 kpc Mod 450
R=14 kpc Mod 129
R=14 kpc Mod 450
A bad model
Ψ (M⊙/pc² Gyr)
[O/H]
1
0
−1
−2
−3
−2
−1.5
−1
−0.5
0

OASIS: An optical integral-field spectrograph

Cantin et al. (in preparation)

- Observations for two barred galaxies:
  NGC4900 & NGC5430
- Central regions with spatial and spectral resolution:

Gas information through emission lines:

Age

Metallicity

the recent stellar populations Present time

Integrated

Stars information through absorption lines:

Age

Metallicity

Averaged

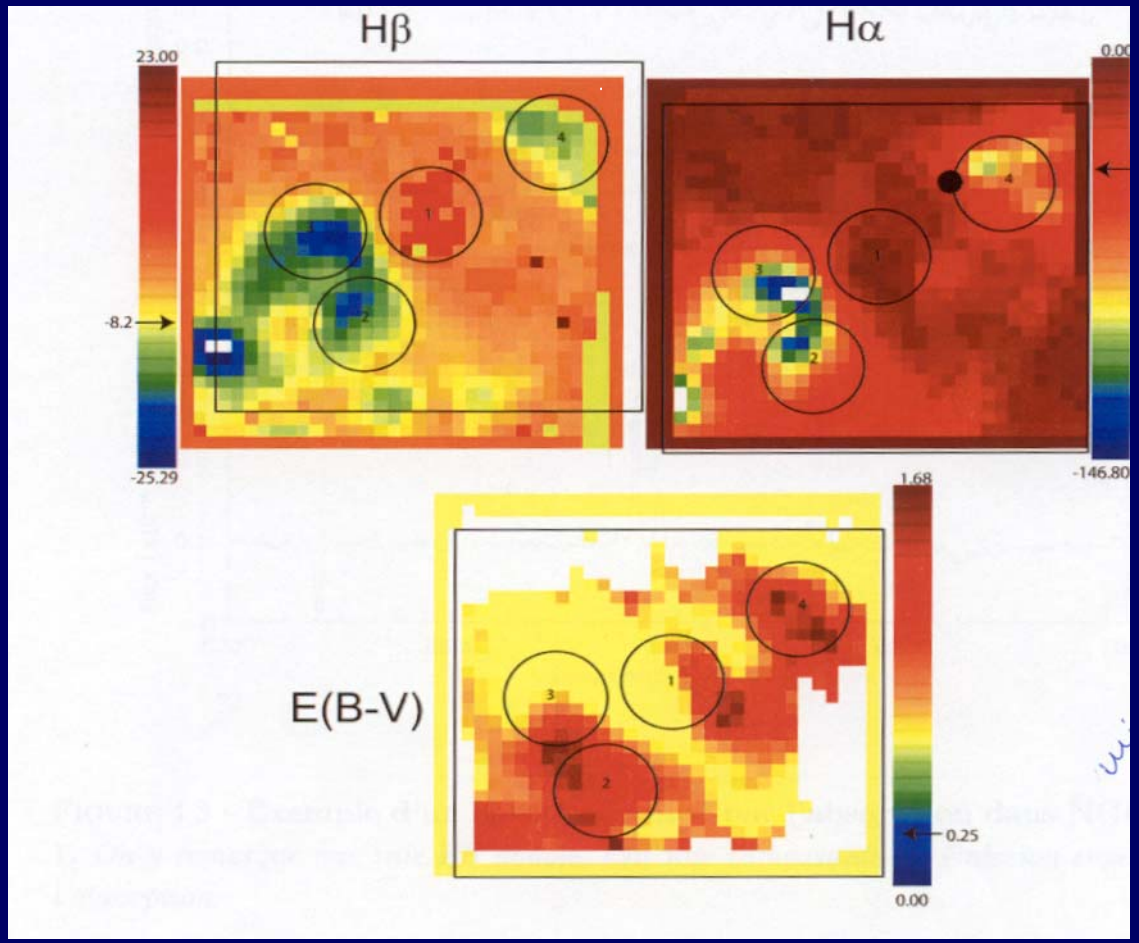
Barred Galaxies

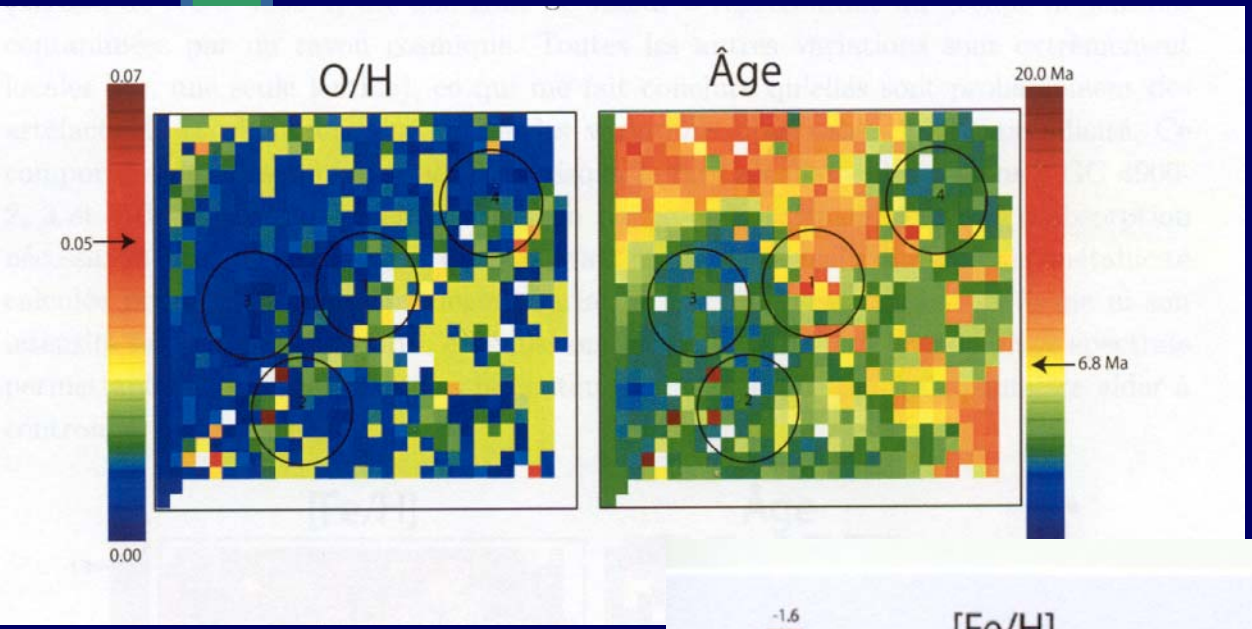
- The importance of the stellar bars in the central regions of galaxies is due to they may apport fresh gas proceeding of the disk to this region.

- This new gas increases the star formation rate thus producing a mix of young and old stellar populations in the same region: Emission lines and absorption indices may give information about the two populations.

- This mixed stellar populations are observed in an integrated spetrum but their spatial distributions is limited: the use of OASIS

Preliminary Results NGC 4900





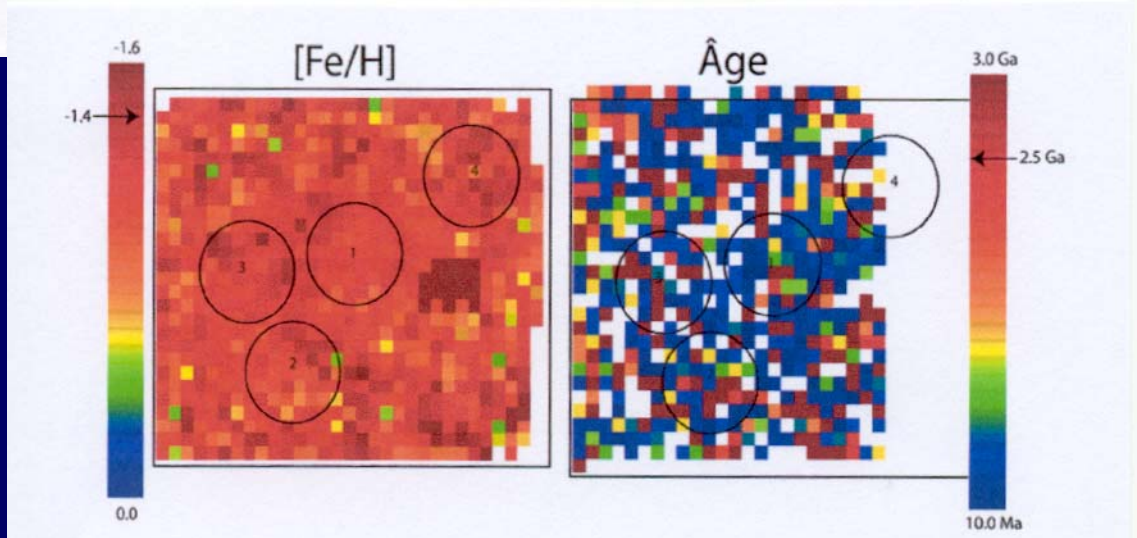
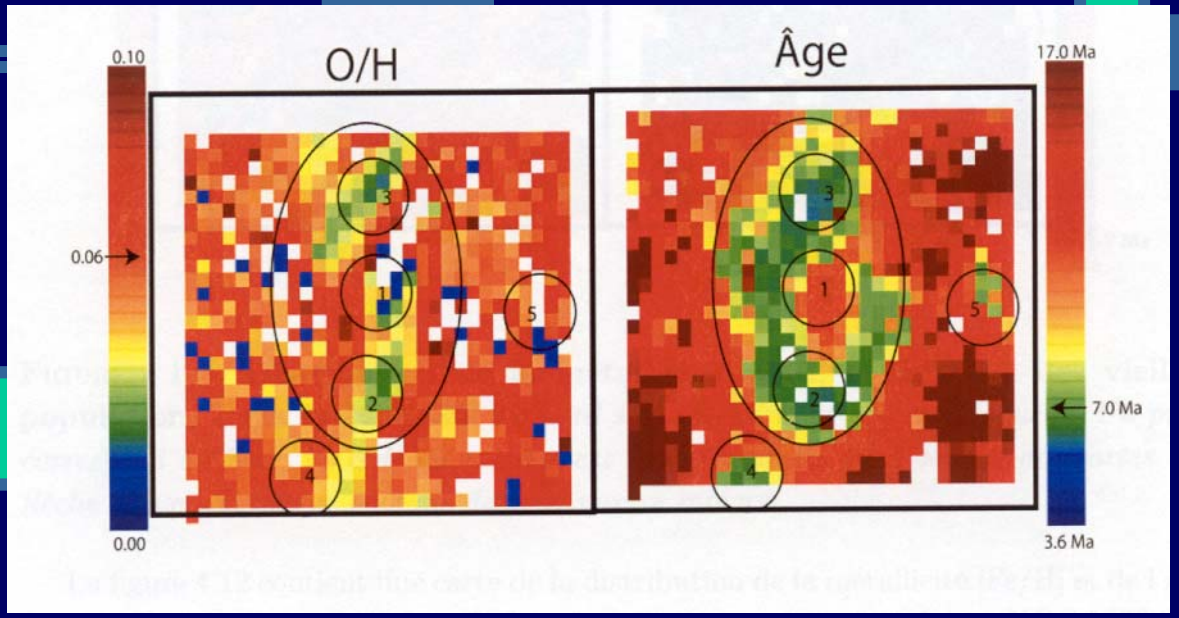
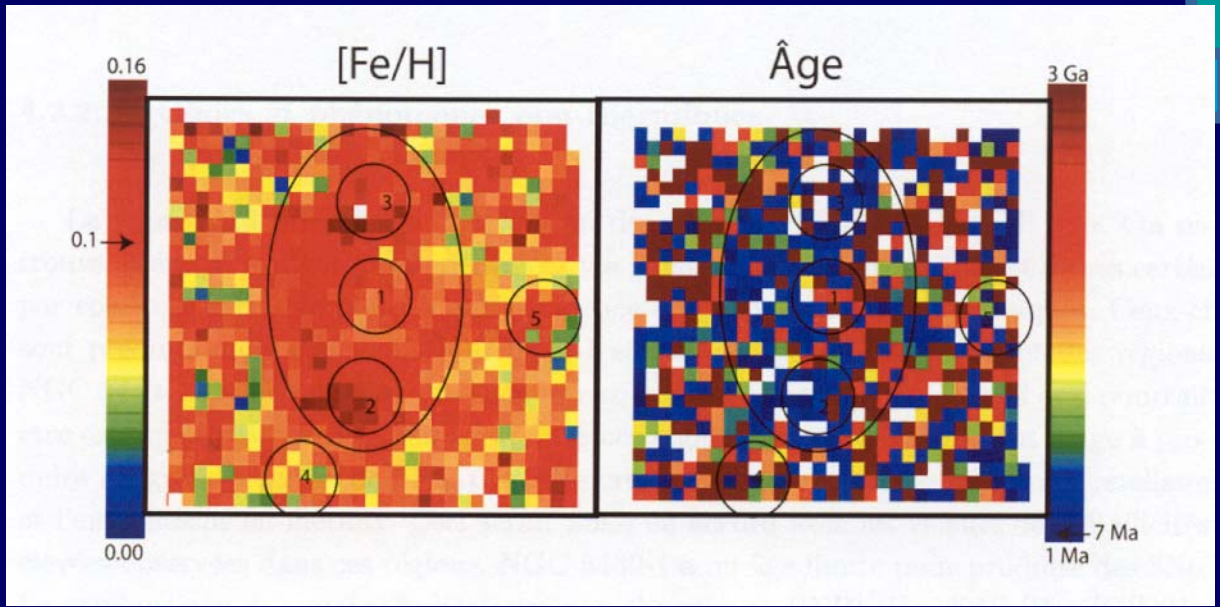


FIGURE 4.5 – **Distribution de la métallicité [Fe/H] et de l'âge des vieilles po-**



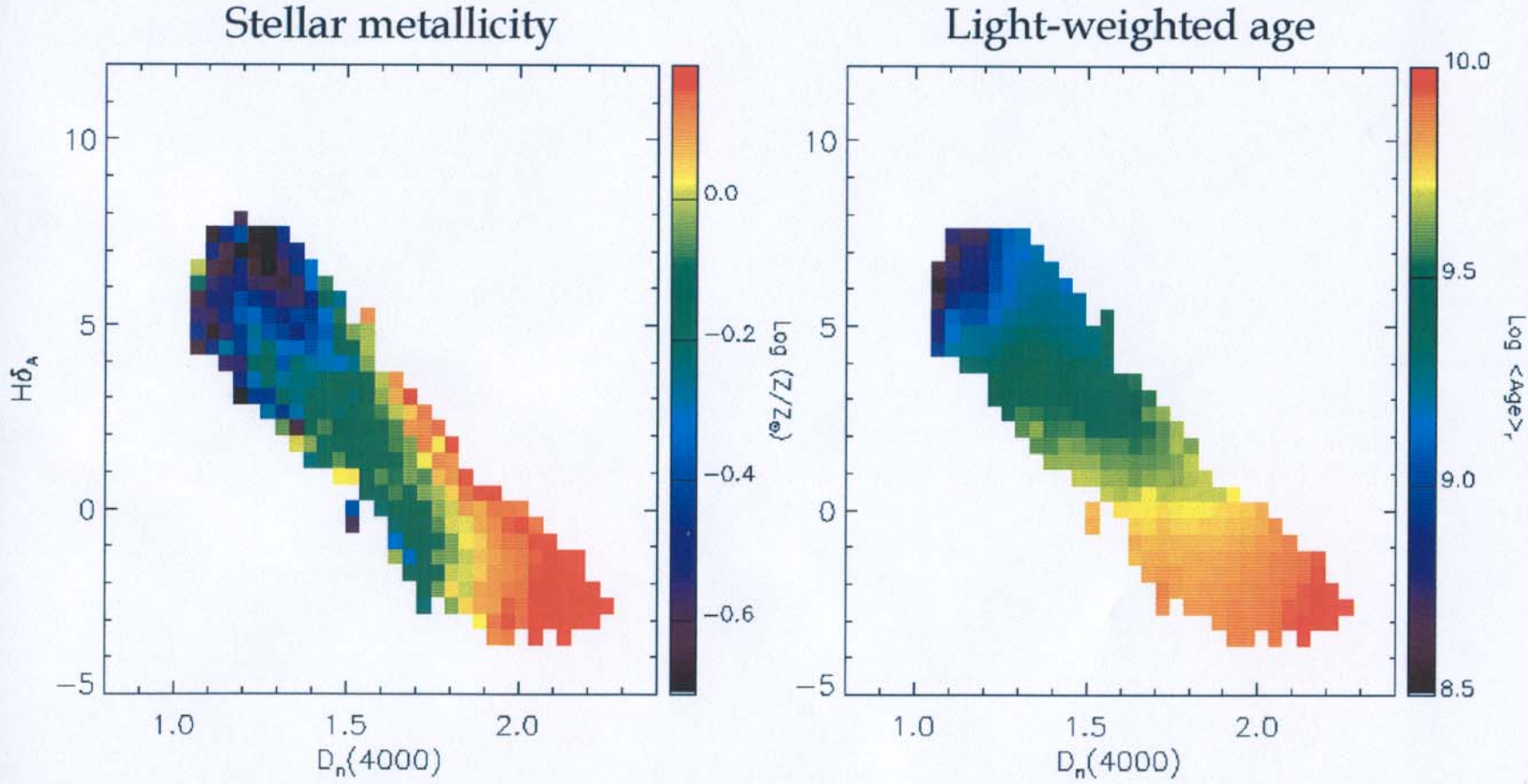
Preliminary Results NGC 5430



Age and metallicity along Hδ-D4 plane

Gradients of the *average* properties along the plane

A. Gallazi



Summary: Characterizing stellar populations in spiral galaxies

- Measured spectral indices in spiral bulges and disks:
  - Beauchamp & Hardy(1997)
  - Mollá, Hardy & Beauchamp (1999)
  - Jablonka et al. (1999)
  - Proctor and (2002)
  - Ryder et al. (2005, MNRAS, accepted)
  - Cantin et al. (2005, in preparation)
- We may use chemical evolution models to estimate the possible star formation histories.

  Then we apply the evolutionary synthesis models to each one of the SSP or *stellar generations*.
- We have used this technique for spiral bulges and three spiral galaxies for which data were available

  (Mollá et al. 1999; Mollá et al. 2000; Mollá & Hardy 2002)
- A powerful tool to discriminate among these histories, solving the usual uniqueness problem of chemical evolution models and the degeneracy problem of the spectral synthesis