Chemical evolution models for spiral and irregular galaxies

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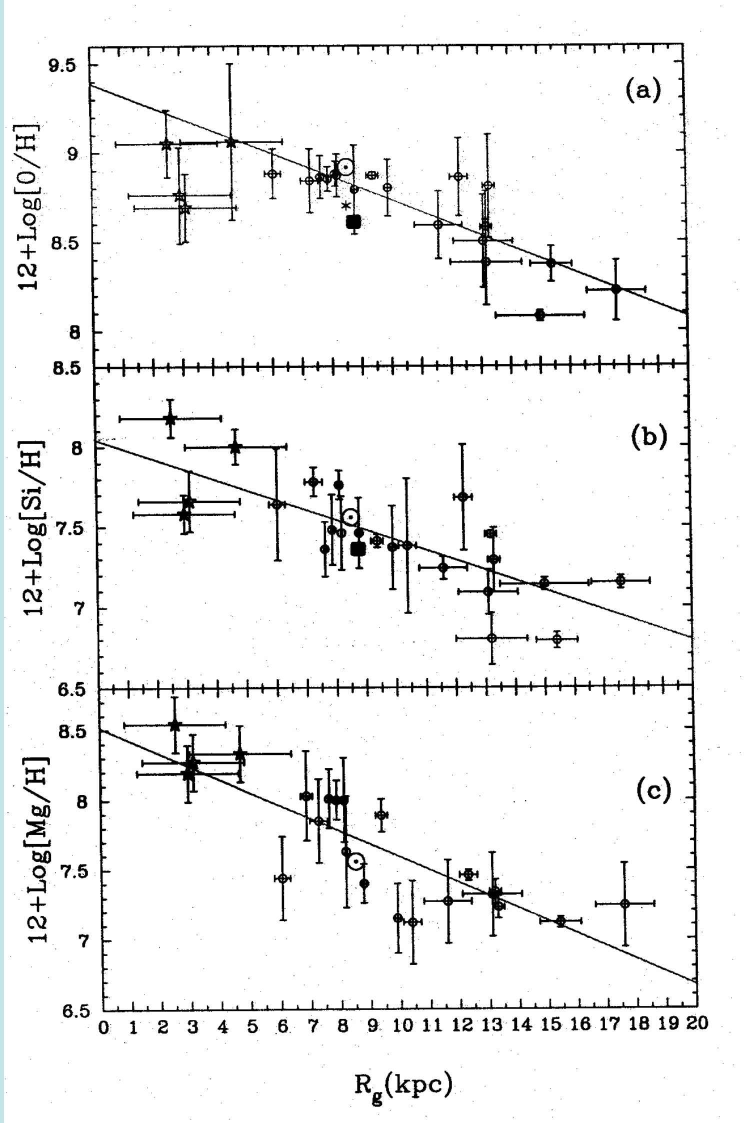
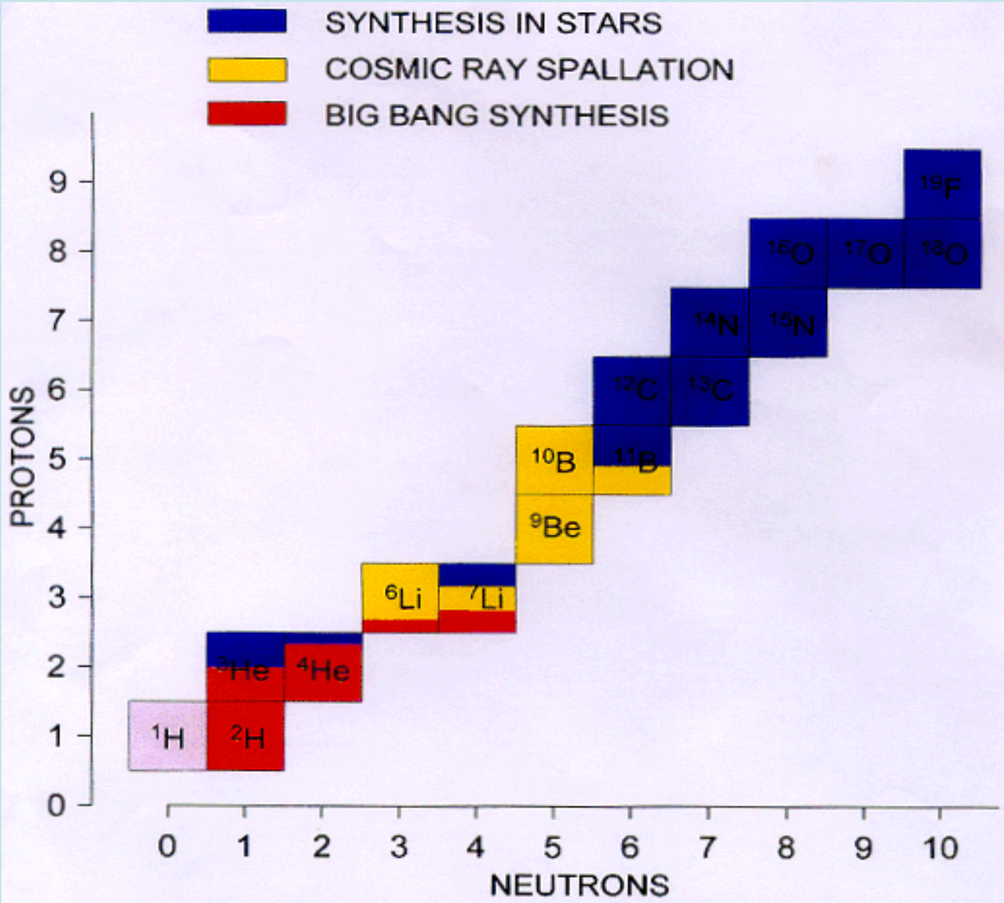
Cabo de Gata, 2013

CHEMICAL EVOLUTION MODELS: OBJETIVES

- Chemical evolution models try to explain the chemical elements abundances and distributions within galaxies:
  - Radial Variations of abundances
  - Metallicity Distribucions
  - Relative abundances of elements
- Ingredients which governs the chemical evolution
  - Star Formation
  - Nucleosynthesis in the interior of stars
  - Initial Mass Function (IMF)
  - Mass loss of stars during their evolution
  - Exchange of matter or gas with external regions



- Chemical elements appear in galaxies as consequence of three processes:
  - the Big Bang nucleosynthesis,
  - the stellar nucleosynthesis or
  - the fragmentation processes by cosmic rays
- In the centers of stars the nuclear fision reactions create different elements
- H will dissapear at the same time that metals (elements weighther than He) increase their abundances.
- Primordial abundances: X=0.76, Y=0.24, Z=0,
- Solar abundances: X=0.70, Y=0.28, Z=0.02.

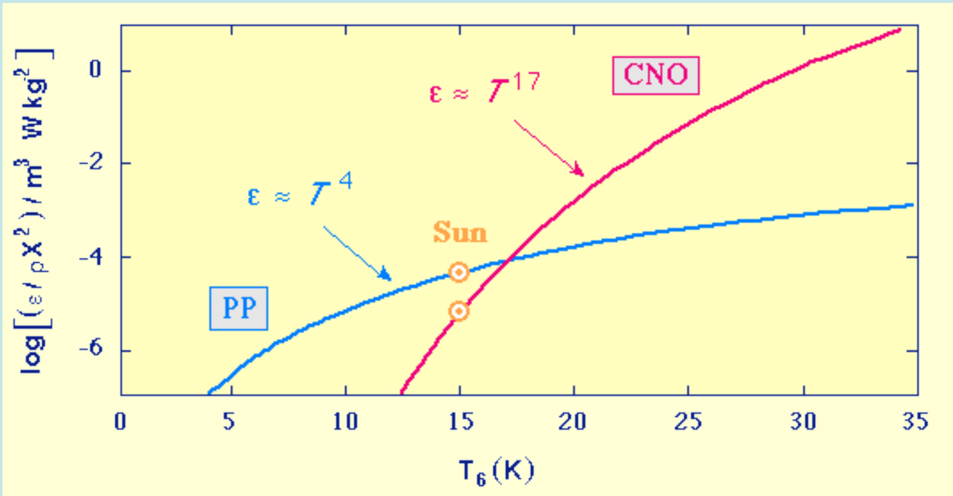


IMF + stellar yields

- Αβσολυτε αβυνδανχεσ depend on the yield of a generation of stars single stellar generation: p_z + IMF

$$y = \frac{1}{1-R}\int_m^\infty m p_{z,m}\Phi(m)dm$$

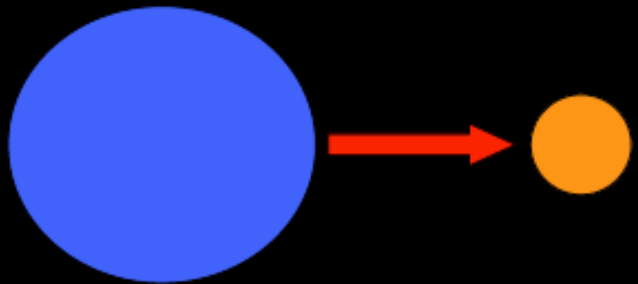
- Differences in SFR, infall… produce differences in abundance among regions or radial gradients



- **Cycle pp: low mass stars *m<4Mo***
- **Cycle pp+CNO: intermediate mass stars *4Mo< m < 8Mo***
- **Cycle CNO+ capture α: massive stars *m > 8Mo***

Explosive sources of energy

Gravitational collapse



Electron degenerate core

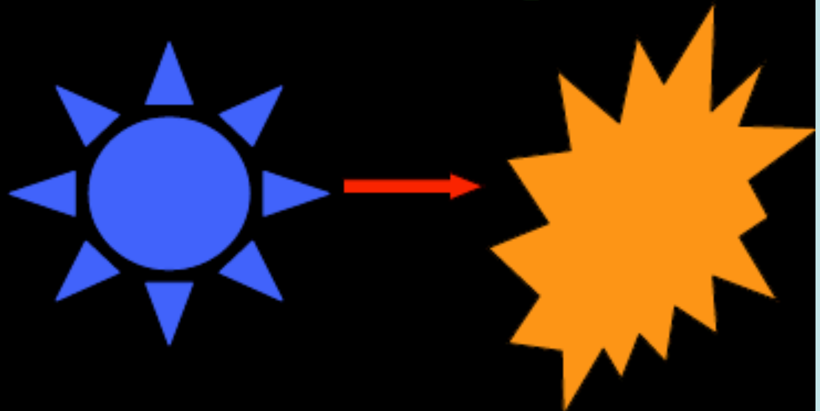
M ~ 1.4 Mo
R ~ 10^8-10^9 cm

$\Delta E_G \sim 10^{53}$ erg

Neutron star

M ~ 1.4 Mo
R ~ 10^6 cm

Thermonuclear explosion



$\{^{12}C, ^{16}O\} \rightarrow \{^{56}Ni\}$

q ~ 7×10^{17} erg/g

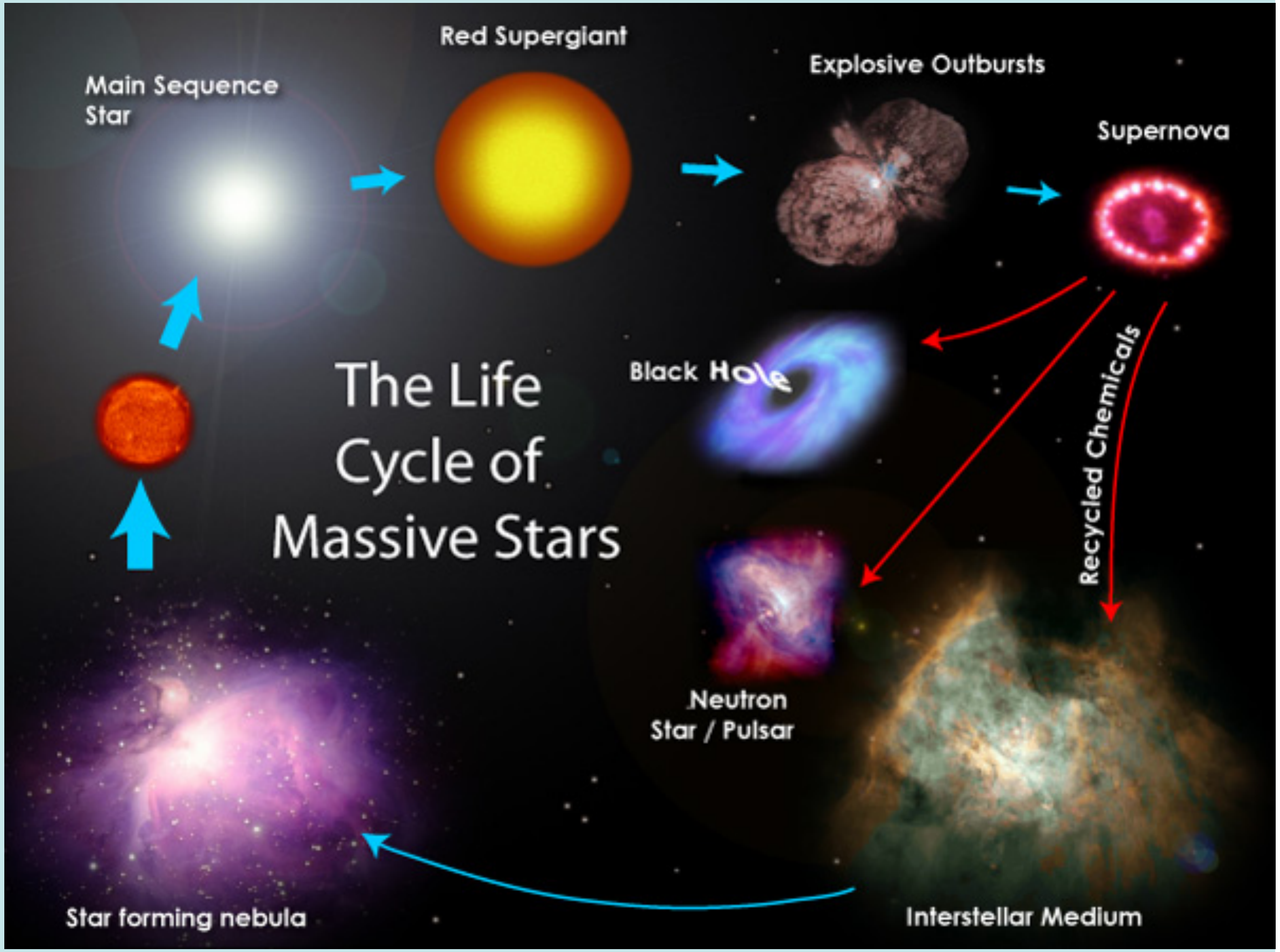
1 Mo x q ~ 10^{51} erg

❖ **Chemical elements are then:**

- Ejected and diluted in the interstellar medium
- Incorporated to the sucesive generations of stars which
- The gas composition is defined by: X+Y +Z=1, X=H Y=He, Z=metals

❖ **Abundances provide information about the stellar formation**

❖ **Different elements proceed from different mass range of stars**



Chemical Evolution Models

- These models calculate the chemical evolution of a galaxy: stars form, die and eject the elements created by stellar nucleosynthesis.
- They are the tool to interpret the elemental abundances in terms of star formation rate and/or of the gas dilution/enrichment processes in each region
- The evolutionary history gives the final state of the gas and stars, and the intermediate steps, too. The successive stellar generations are well defined in terms of age, metallicity (abundances) and stars and gas masses.
- The classical numerical chemical evolution models do not require as long computation time as cosmological simulations, they are better to test new assumptions or new inputs

The basic equations

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

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

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

$$M = Ms + Mg$$

- f= flux of inflow gas (iy may be 0)
- M= total mass of the system
- Ψ=SFR (star formation rate
- E= mass ejection rate by the stars
- Ms=stellar mass
- Mg= gas mass

Each star loss mass after its stellar lifetime τm, after this there is a remnant ωm, and tehrefore the total ejection by all stars created in a region is:

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

Initial mass function or number of stars in the range dm

Mass of stars created in the time (t-τm) which are now dying and ejecting mass after a time τm

Ejected mass by a star of mass m

The total yield of a stellar generation

$$y = \frac{1}{1-R}\int_{m}^{\infty} m p_{z,m}\Phi(m)dm$$

$p_{z,m}$ is the metal fraction ejected by a star of mass m

The abundance of metals may be obtained fron this equation, which implies:

$$\frac{d(ZMg)}{dt} = -Z\Psi + Z_f f - Z_w w + E_z$$

1) Z metals which dissapear from the gas when stars form

2) Zf f mass of metals which going in to the region when the gas infall

3) Zw w is the mass of metals which dissapears with the outflow of gas

4) Ez quantity of metals ejected by stars

$$E_Z = \int_{m_t}^{\infty} m p_{z,m}\Psi(t-\tau_m)\Phi(m)dm +$$

$$\int_{m_t}^{\infty}(m-\omega_m - m p_{z,m})Z(t-\tau_m)\Psi(t-\tau_m)\Phi(m)dm$$

The first part is the yield or metals newly created

The second one correspond to the metals which were before, in the original gas with which the star form

THE SIMPLE MODEL: THE CLOSED BOX MODEL

1)The system will have 2 types of stars

- those with mass $m > m_1$ with t= dying when form
- those with $m < m_1$ and $t = \infty$

2) The system is closed f=0

3) Metals are instantaneously mixed with the ISM

$$Z = y \ln \frac{M}{Mg} = y \ln \mu^{-1}$$

If

Model predictions:

1. **Abundance proportional to the total yield of one stellar generation**
2. **This relation abundance-yield is independent of the star formation history or the star formation rate**

Model problems:

1. **The G-dwarf metallicity distribution is not reproduced**
2. **The relation not sufficient to obtain the observed radial gradient of abundances**

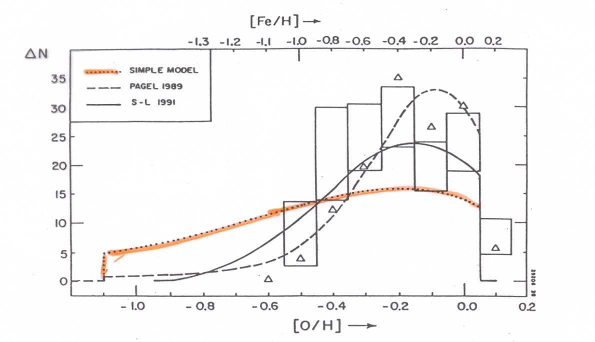


Figure 23: *Distribution function of oxygen abundances of 132 G-dwarfs in the solar cylinder, binned in intervals of 0.1 in [O/H]. Triangles show the data points after Pagel (1989ab), based on a reanalysis of those discussed by Pagel & Patchett (1975), and boxes show lower and upper limits based on a new discussion of the dependence of the scale height on age and metallicity by Sommer-Larsen (1991a).*

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Posible solutions:

1. **Infall of enriched (or not) gas**
2. **Metallicity dependent yields**
3. **Radial flows which dilute or enrich the gas of the region**
4. **Star formation law which varies with the radial disc**

Model predi

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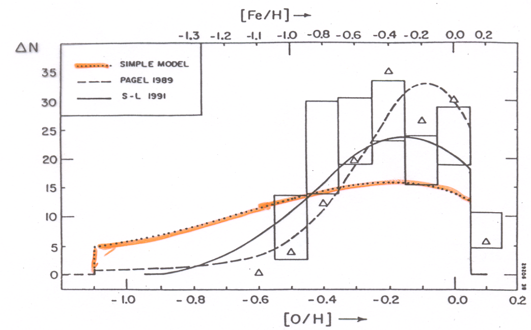

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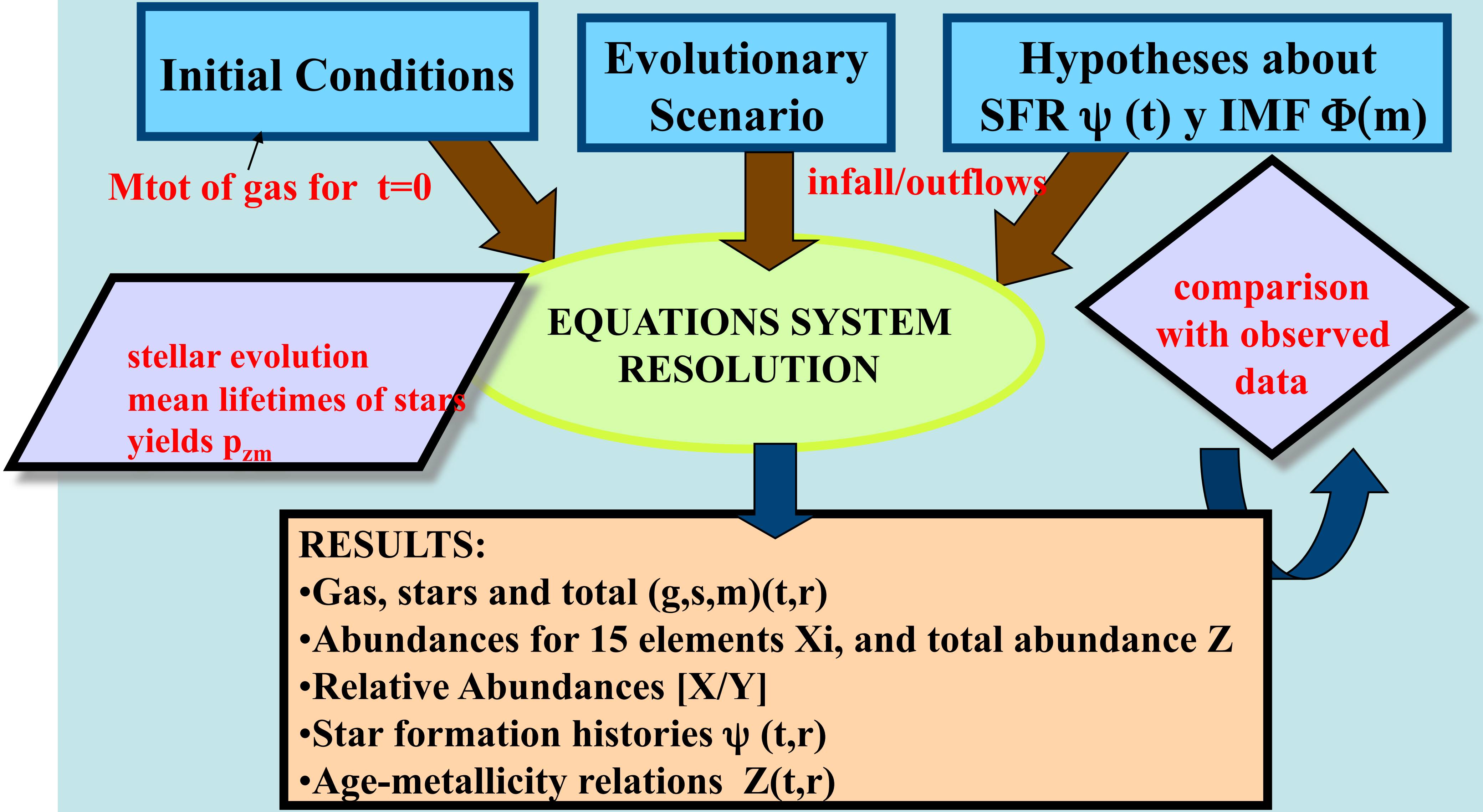
A chemical evolution model



infall/outflows

Initial Conditions

Evolutionary Scenario

Hypotheses about SFR ψ (t) y IMF Φ(m)

Mtot

- **Initial Conditions:**
  - **total mass**
  - **Gas mass**
  - **Primordial abundances**
- **Initial mass function (IMF):**
  - **Variations with time**
  - **Variations in the space**
- **Star formation laws: different possibilities**
- **The metallicity dependent yields**
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- **The galactic scenario: the formation and evolution of the galaxy**

•Age-metallicity relations Z(t,r)

Clayton (1987)

- Simple models; Ψ(t)=ωMg(t), linear with gas
- The disc increases when the mass falls
- The total mass increase several times from Mo
- The infall rate decreases with time
- The metallicity of the infall gas is constant
- The instantaneous recycing approximation is assumed
- The maximum of the gas delayed over the infall
- Gradients of abundances not suficiently steeper

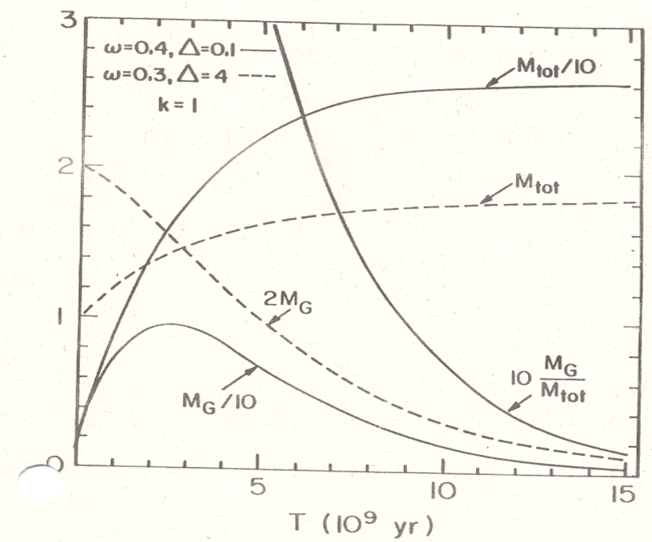


Fig. 1. Two contrasting examples of the behavior of the gas mass $M_G(t)$ for models having k = 1 are displayed (with scale changes as noted) as multiples of the initial mass M_{G0}. Models with small Δ (solid lines) have a maximum before declining because the early infall is large, whereas those having large Δ (dashed lines) decrease monotonically owing to the small early infall. The infall itself (not shown) is exponential for k = 1 models. Also shown are the total disk masses in units of M_{G0}, showing that the small Δ cases have a greater growth factor. Models having k > 1 are qualitatively similar.

Pagel & Tautvasiene (1998)

- Delayed ejection of some elements
- Reproduces the G-dwarf MDF
- Reproduces the [α/Fe] vs [Fe/H] data

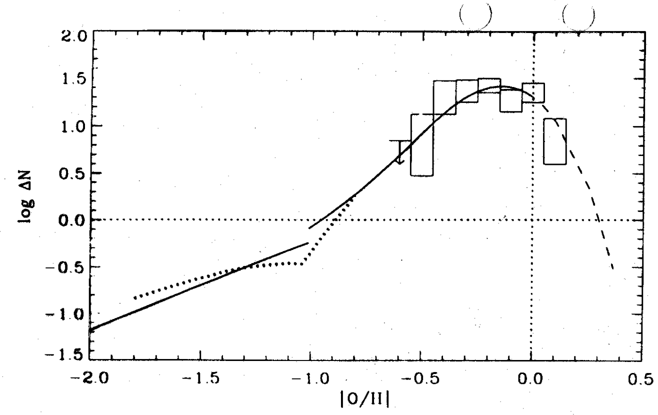


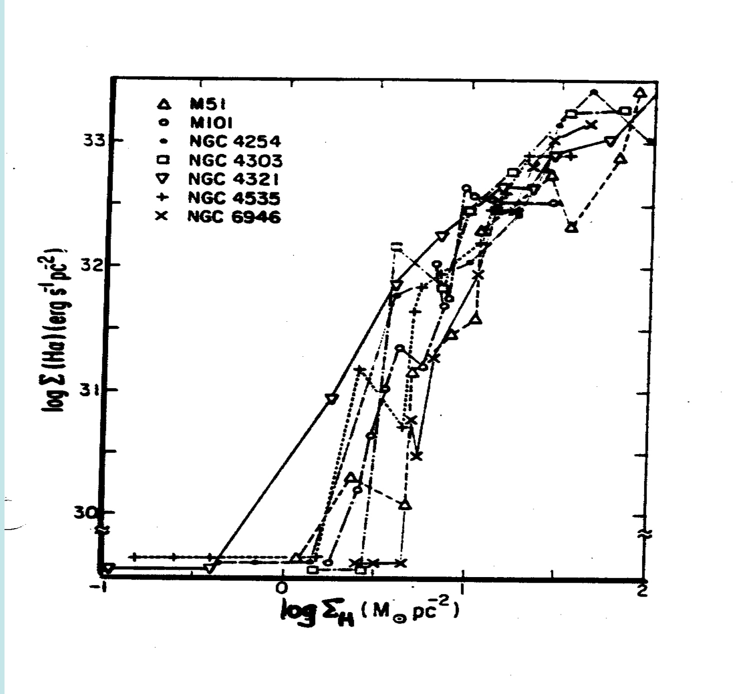
Fig. 8.22. Oxygen abundance distribution function for disk stars. Data deduced from observation are shown by the boxes (same as in Fig. 8.19, after Sommer-Larsen 1991a) and by the dotted line and curve at lower left (after Beers & Sommer-Larsen 1995). The solid curve shows the distribution given by the model of Pagel & Tautvaišienė (1995), *MNRAS*, **276**, 505. observat the dot shows

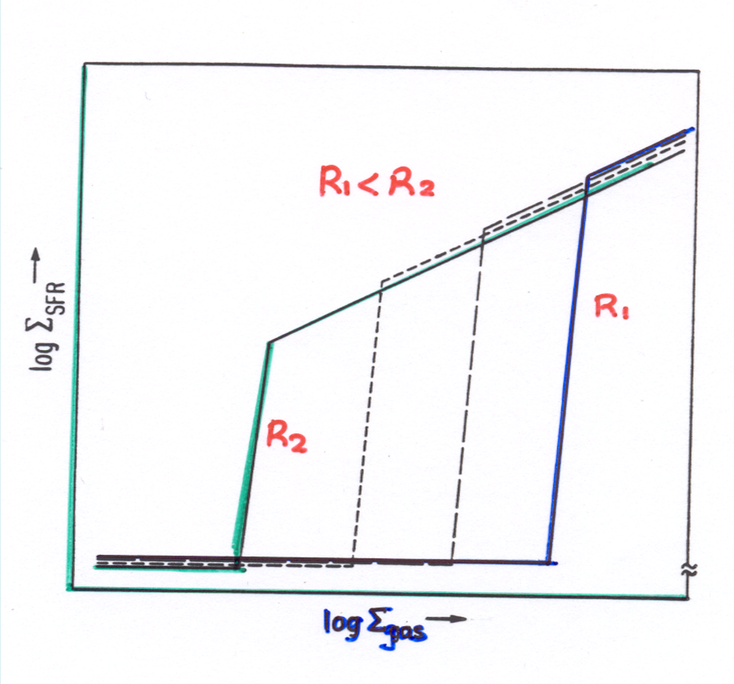
Numerical Models

- The numerical models solve directly the equations systems: all useful inputs may be included
- There is a large number of models with different hypotheses about the ingredients, IMF, SFR, stellar yields, or scenario
- Some of these models are
  - Lacey & Fall (1983, 1985:
    - Disc-halo conexion
    - Infall variable with the galactocentric radius
  - Wyse & Silk (1989)
    - Dependence of the SFR on the total mass of the galaxy
    - SFR dependent on R
  - Matteucci & Francois (1989)
    - Halo-disc conexion
    - Infall variable with raidus and time
    - Dependence of the SFR with the radius and with the total mass
  - Díaz & Tosi (1994,1995)
    - Other external galaxies

Star formation Models

- Franco & Shore : interaction of OB asociations with the interstellar medium
- Parravano (1989): mechanims of auto-regulation for the star formation, if there are many massive stars the star formation inhibitates
- Vázquez & Scalo (1989): when the gas acretes there is a burst of star formation
- Kennicutt (1989): the SFR depends on the gas density (with a threshold)





❖Lacey & Fall (1983,1985)

- ➢Conection halo-disc with   independent of R
- ➢SFR =K g^n n=1 (f=5.5 Gyr) or n=1.5 (f=3.5 Gyr)
- ➢Infall variable f(R)

❖Matteucci & Francois (1989)

- ➢Dos componentes, halo y disco
- ➢ c(R)g^n n=1, 2 y cte en el halo

$$\Psi(r,t) = \upsilon\left(\frac{\sigma_g(r,t)}{\sigma_t(Rsol,t)}\right)^{2(k-1)}\left(\frac{\sigma_g(r,t_G)}{\sigma_g(r,t)}\right)^{k} G^K(r,t)$$

$$\frac{dG_{\inf}}{dt} = A(r)\exp(-t/\tau(r))$$

$$\tau(r) = 0.5r - 1$$

$$A(r) = \frac{\sigma(r,t_G)}{\tau(r)(1-e^{-t_G/\tau(r)})}$$

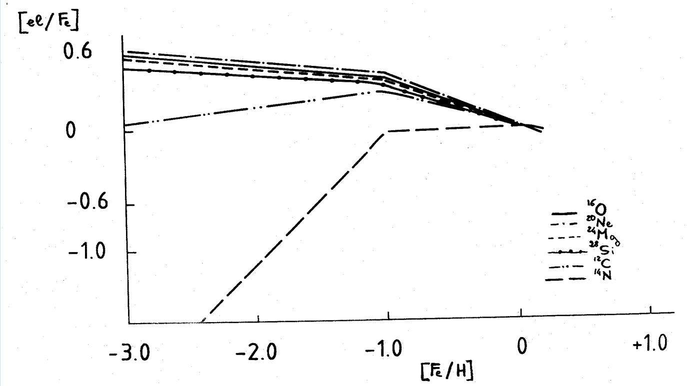


Fig. 3

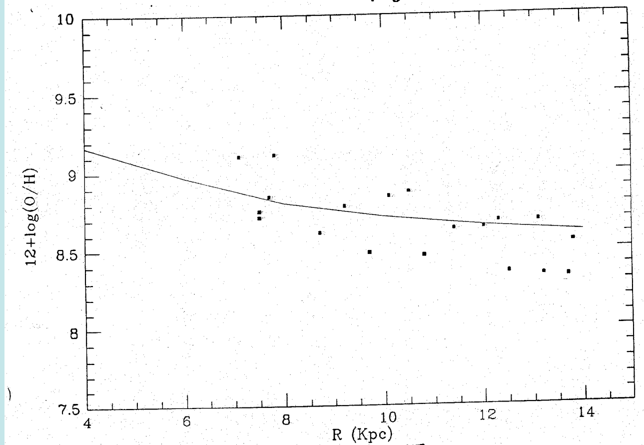


Fig 5

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Two infalls model

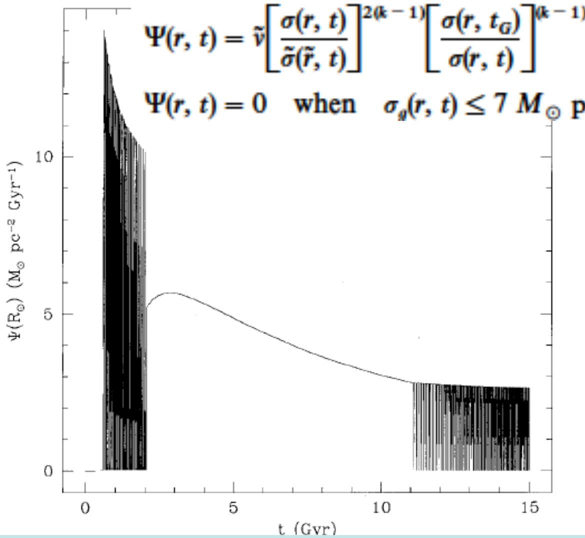
$$\frac{dG_i(r,t)_{inf}}{dt} = \frac{A(r)}{\sigma(r,t_G)}(X_i)_{inf}\, e^{-t/\tau_T} + \frac{B(r)}{\sigma(r,t_G)}(X_i)_{inf}\, e^{-(t-t_{max})/\tau_D},$$

Chiappini et al. (1997, 2003)

- A first collapse forms out the halo (time scale < 1 Gyr), a second one forms out the disc in a time scale ~8Gyr
- A radial gradient of abundances stepper in the inner disc and flatter in the outer one
- A radial gradient of abundances that grows with time
- There is no need to invoke stellar winds of massive stars to reproduce C
- There is no need to invoke a large contribution to primary N by massive stars
- C and N are mostly created by low and intermediate mass stars

$$\Psi(r,t) = \tilde{\nu}\left[\frac{\sigma(r,t)}{\tilde{\sigma}(\tilde{r},t)}\right]^{2(k-1)}\left[\frac{\sigma(r,t_G)}{\sigma(r,t)}\right]^{(k-1)} G^k(r,t),$$

$$\Psi(r,t) = 0 \quad \text{when} \quad \sigma_g(r,t) \le 7\, M_\odot\, pc^{-2},$$



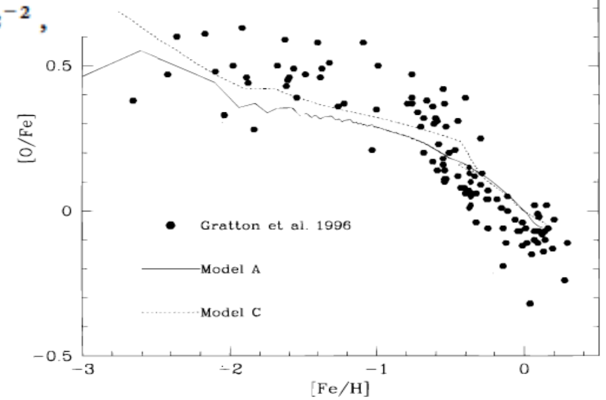
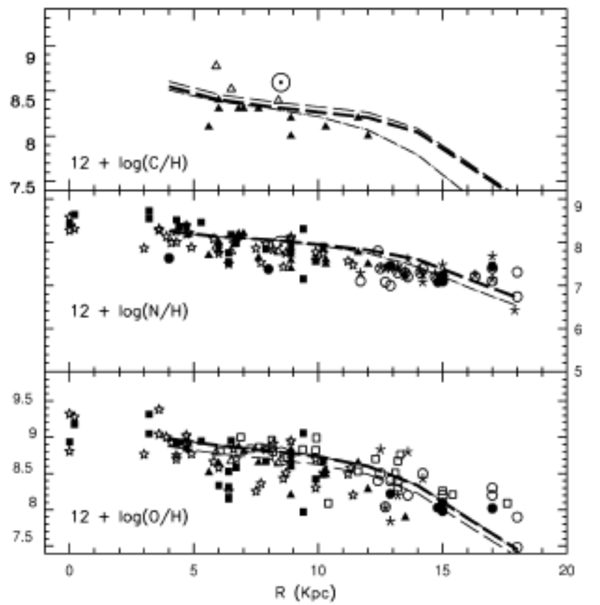
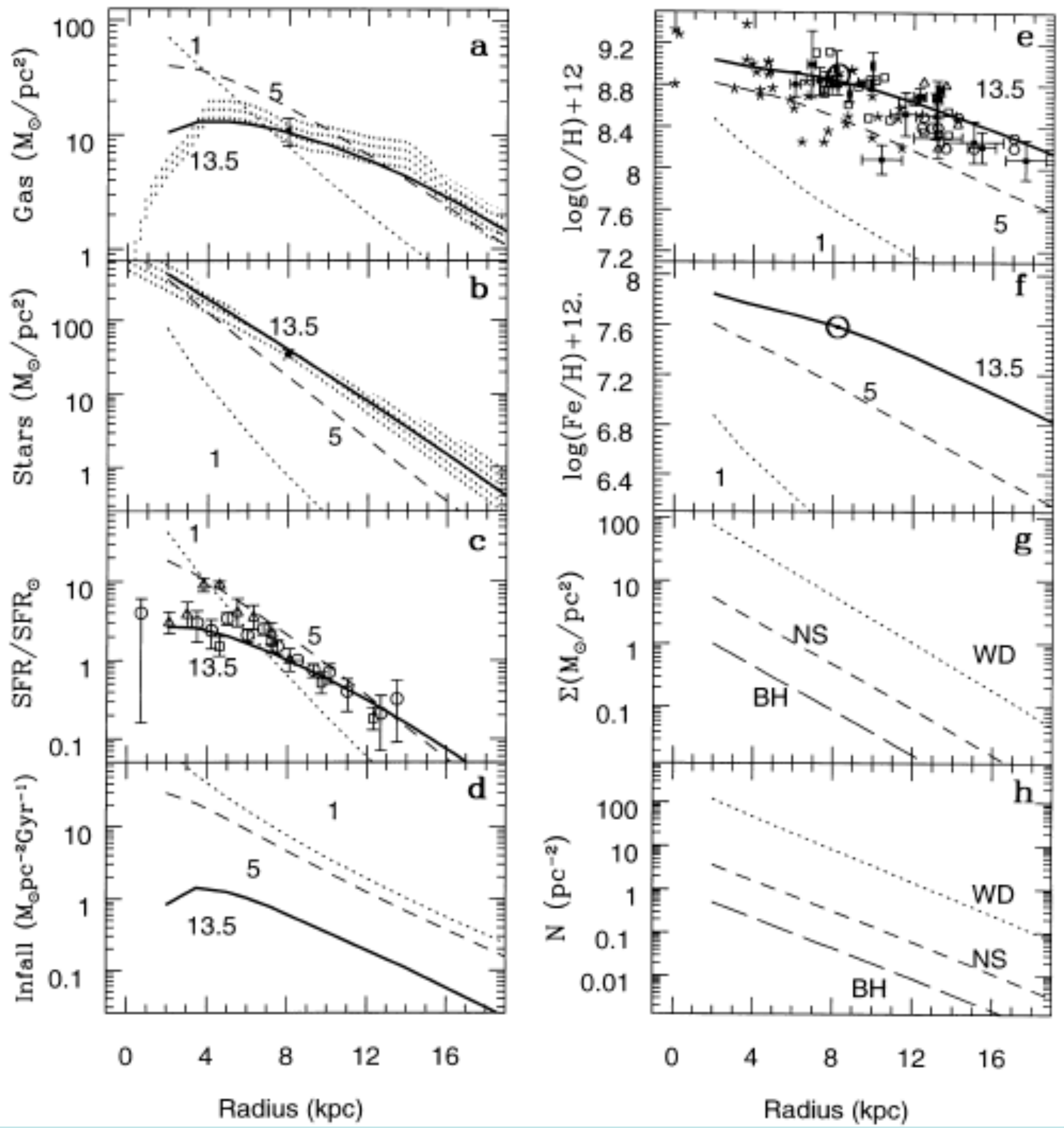


FIG. 3.—[O/Fe] vs. [Fe/H] behavior for model A (*solid line*) and model C (*dotted line*).



Boissier & Prantzos (1999)

- Stellar yields: WW95 + RV81
- IMF: Kroupa et al 1993
- SNIa: Thielemann et al. 1986
- SFR: $0.1 g^{1.5} (R/R_s)^{-1}$
- Infall: f α exp(-t/τ), dep. R
- Spectrophotometric evolution
- (Geneve stellar tracks)
- dust



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infall/outflows

Initial Conditions | **Evolutionary Scenario** | **Hypotheses about SFR ψ (t) y IMF Φ(m)**

Mtot

- **Initial Conditions:**
  - **total mass**
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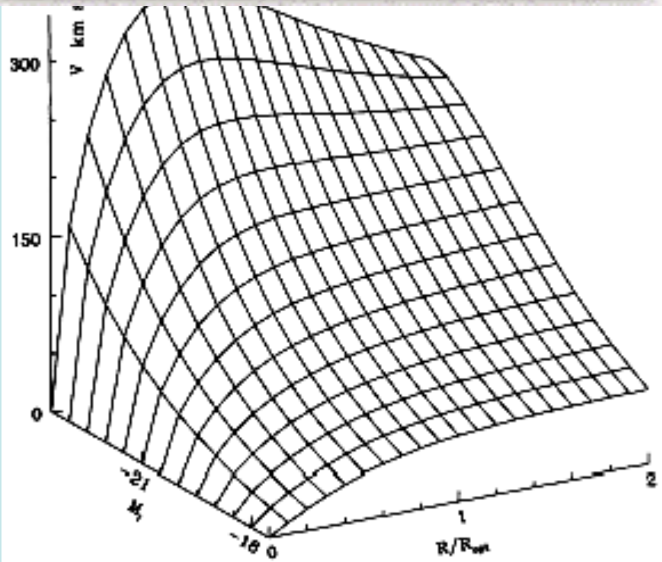
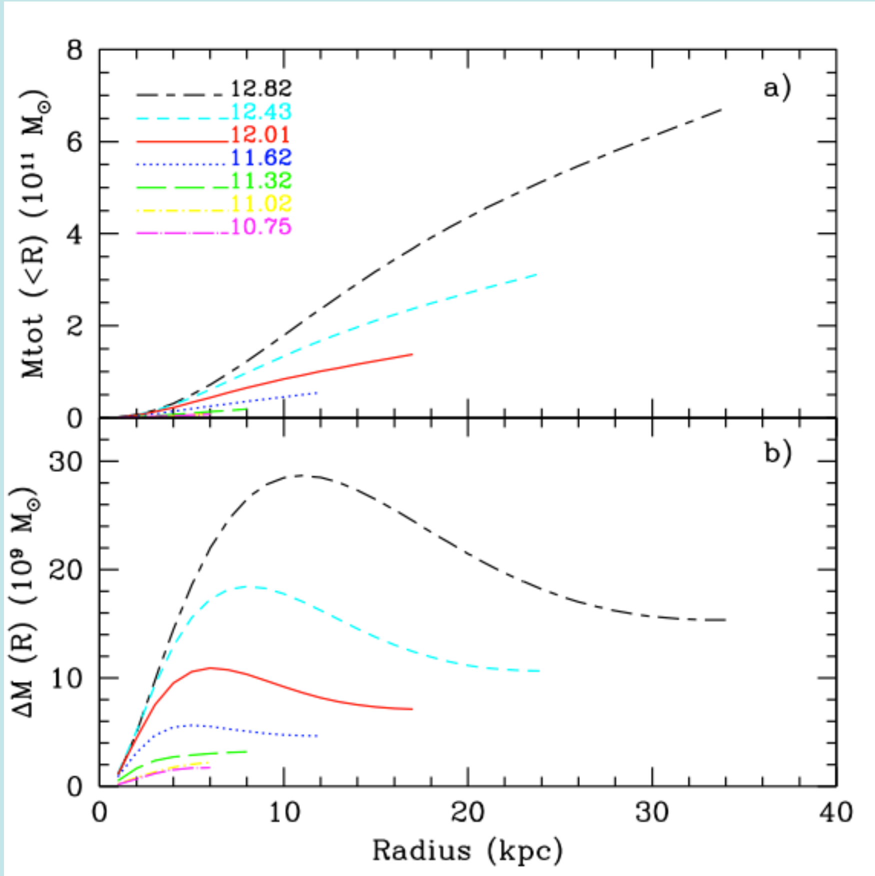
•Age-metallicity relations Z(t,r)

- The radial gradient of abundances in a disk is related with differences in the ratio SFR/infall
- IMF and stellar yields change the relative abundances and the absolute values of abundances but the radial gradient doesnt´t show large variations with these parameters
- The star formation may change with R due to the gas density profile, and to variations in the efficiencies to form stars (thermodynamical conditions)
- The infall rate may dilute (or enrich) the ISM Zf><Zdisk

The multiphase chemical evolution model: the scenario





The total mass M of each modeled galaxy and its radial distribution M(R) have been computed from the universal rotation curve V(R) from Salucci et al. (2007)

New grid of models: updating the inputs and assumptions

- **Radial distributions computed following equations from Salucci et al. (2007) defined in terms of Mvir and arriving to longer distances along the galactocentric radius**
- Collapse time-scale τ modified to follow the prescriptions from Shankar et al. (2006) about the observed ratio Mdisk/Mhalo
- Radial dependence $\tau(R)$ smoother compared with the old one.
- Both efficiencies to form molecular clouds, ϵ_M and stars, ϵ_H , are selected independently
- Revision of new set of stellar yields and different IMFs
- New grid of models: 75 radial mass distributions,
  - Mvir $\in [5\ 10^{10} - 10^{13}]$ Msun
  - Mdisk $\in [1.25\ 10^{8} - 5.3\ 10^{11}]$ Msun
  - Vrot $\in$ [42-320] km/s

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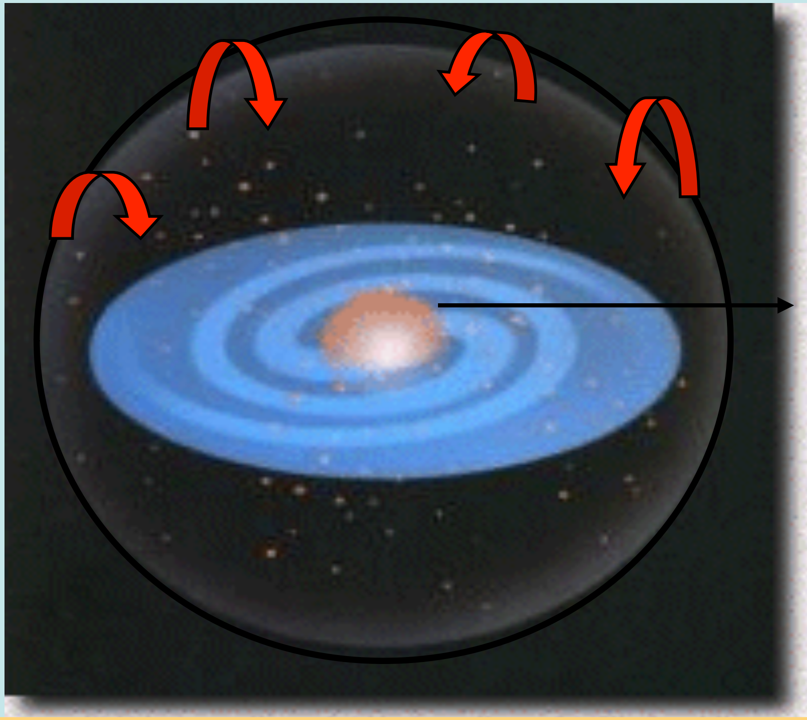
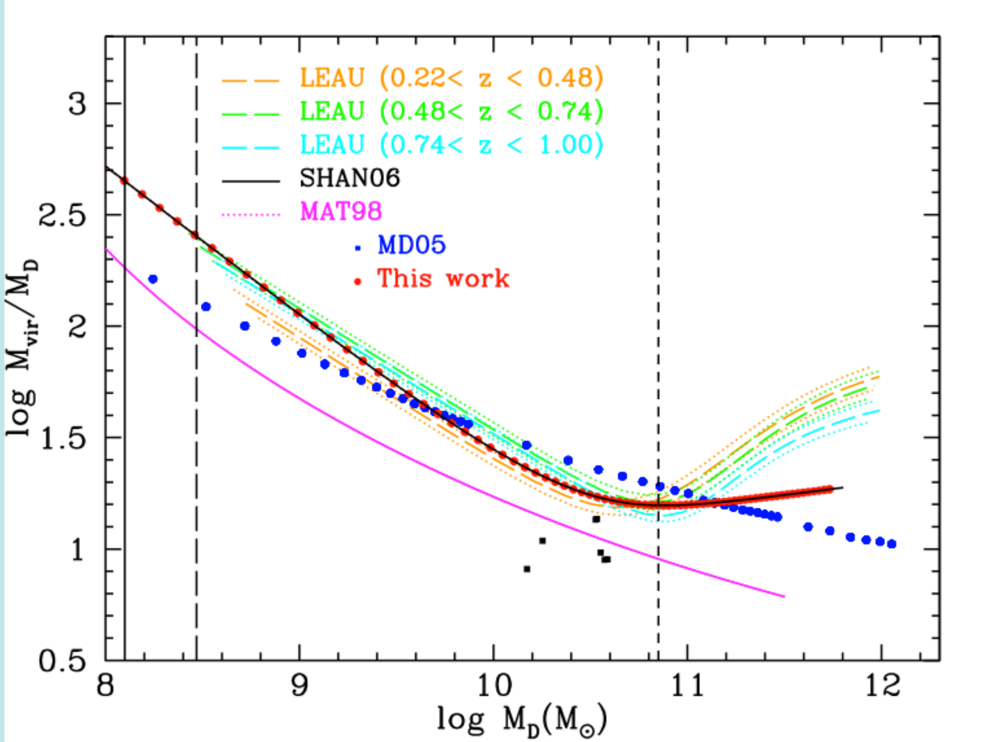
The multiphase chemical evolution model: The infall rate





- The gas collapses onto the equatorial plane and forms out the disc
- The infall rate is inversely proportional to a characteristic collapse time scale $_{col}$
- This collapse time scale $_{col}$ is computed depending on total mass through the Shankar et al (2006) prescriptions, which give Mvir/Mdisk, and after calibrated with the MWG

New grid of models: updating the inputs and assumptions

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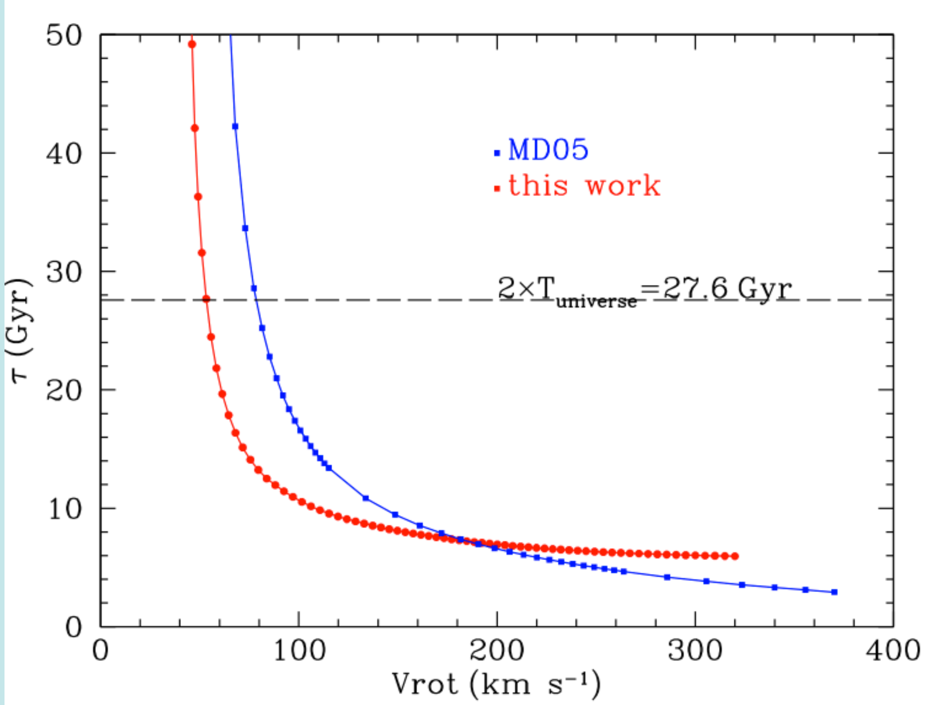
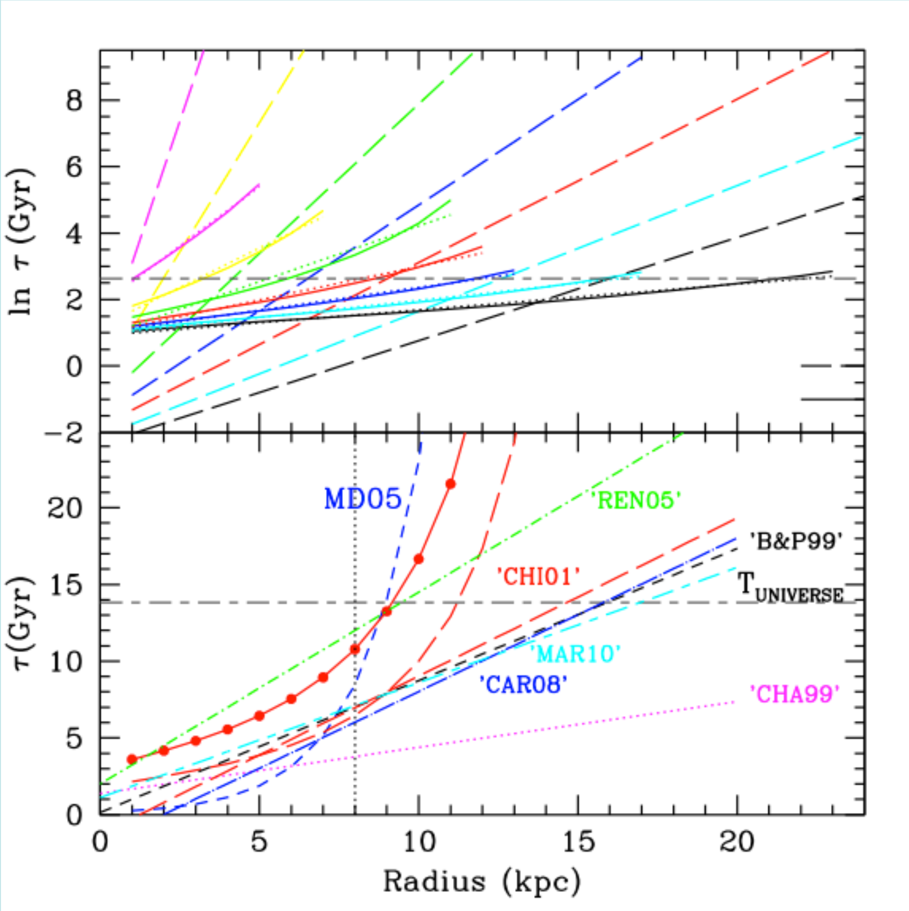
The collapse time-scale or infall rate





- Grid: 75 values Vrot-Mdyn-Mdisk−τcoll
- A different function τ(Vrot) than MD05
- Different dependence on galactocentric radius
- Comparison with other works for MWG

The chemical evolution model: The star formation law

$$\Psi_D(t) = (H_1 + H_2)c_D^2(t) + (a_1 + a_2)S_{2,D}(t)c_D(t)$$

Star formation in the halo: SFR α K g $^{1.5}$

Stars form through cloud-cloud collisions: s α Hc ^{2}

In the disc molecular clouds form from the diffuse gas c α Mg $^{1.5}$

Stars also form from the interaction between massive stars and molecular clouds: s α *a* c s $_2$

- Every parameter changes along the galactocentric radius:
  - $K = \varepsilon_K (G/V)^{1/2}$
  - $M = \varepsilon_M (G/Vd)^{1/2}$
  - $H = \varepsilon_H$ cte /Vd
  - $a = \varepsilon_a (G \rho_c)^{1/2} / \langle m_{s2} \rangle$
  - $\tau_{col} = \tau_{col,0} \exp(R/\lambda)$
- The efficiency ε_a does not change with R since it is a local process
- The efficiency ε_K is assumed as constant for all halos
- Efficiencies ε_M y ε_H are variable for each galaxy
- The collapse time scale τ_{col} changes according to the total mass of the galaxy

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New grid of models: updating the inputs and assumptions

- Radial distributions computed following equations from Salucci et al. (2007) defined in terms of Mvir and arriving to longer distances along the galactocentric radius
- Collapse time-scale τ modified to follow the prescriptions from Shankar et al. (2006) about the observed ratio Mdisk/Mhalo
- Radial dependence τ(R) smoother compared with the old one.
- Both efficiencies to form molecular clouds, ϵ_M and stars, ϵ_H , are selected independently
- Revision of new set of stellar yields and different IMFs
- New grid of models: 75 radial mass distributions,
  - Mvir $\in$ [5 10^{10} -10^{13}] Msun
  - Mdisk $\in$ [1.25 10^{8} -5.3 10^{11}] Msun
  - Vrot $\in$ [42-320] km/s

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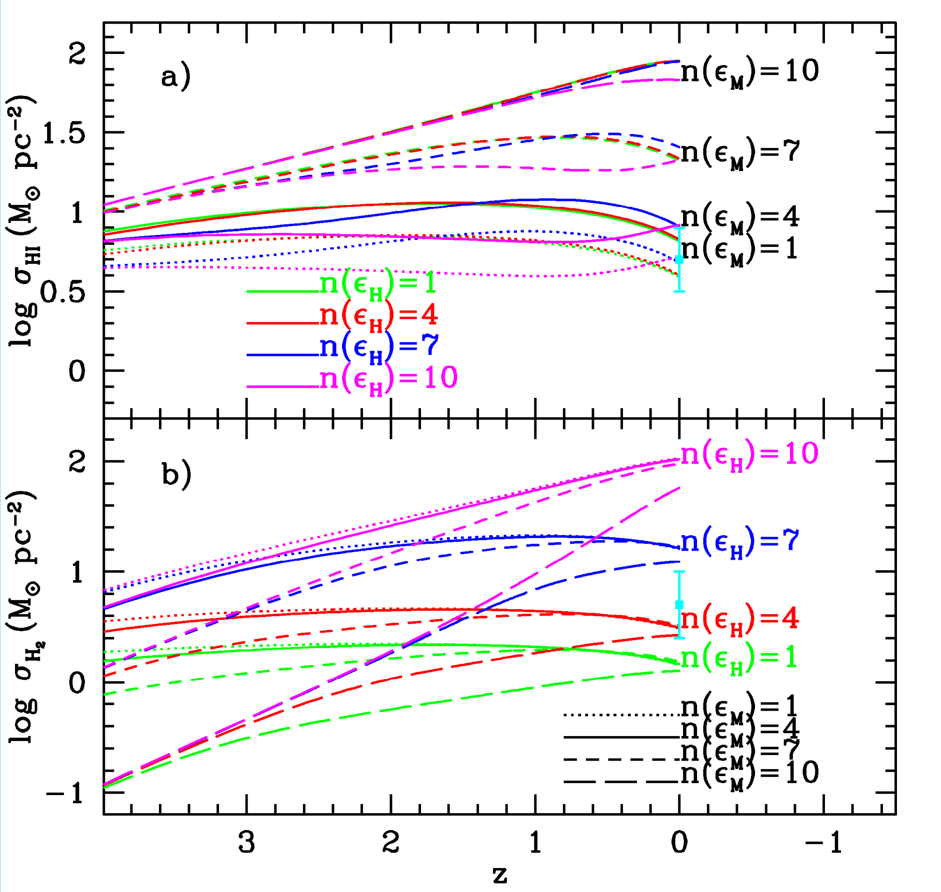
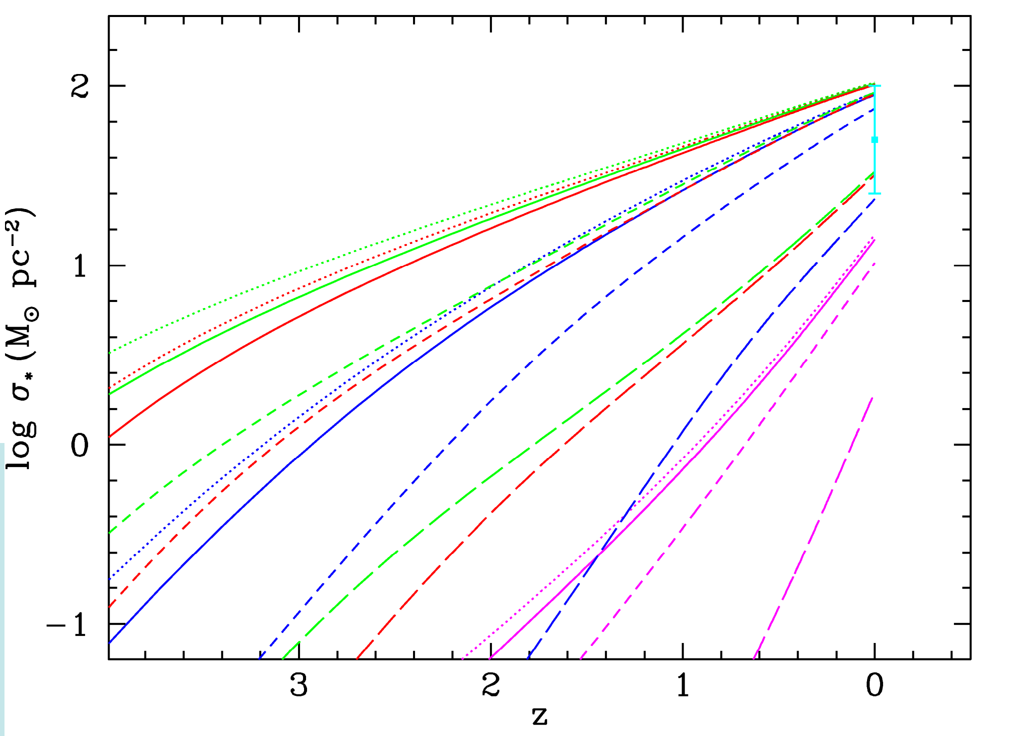
Different values for ε_M and ε_H



The Solar Region model:

- Ndis=68, Mdyn=10^{12} M_0
- Mdisk=6.5$10^{10}$ M_0
- Ropt=12 kpc



Cabo de Gata, 2013

The MWG model:

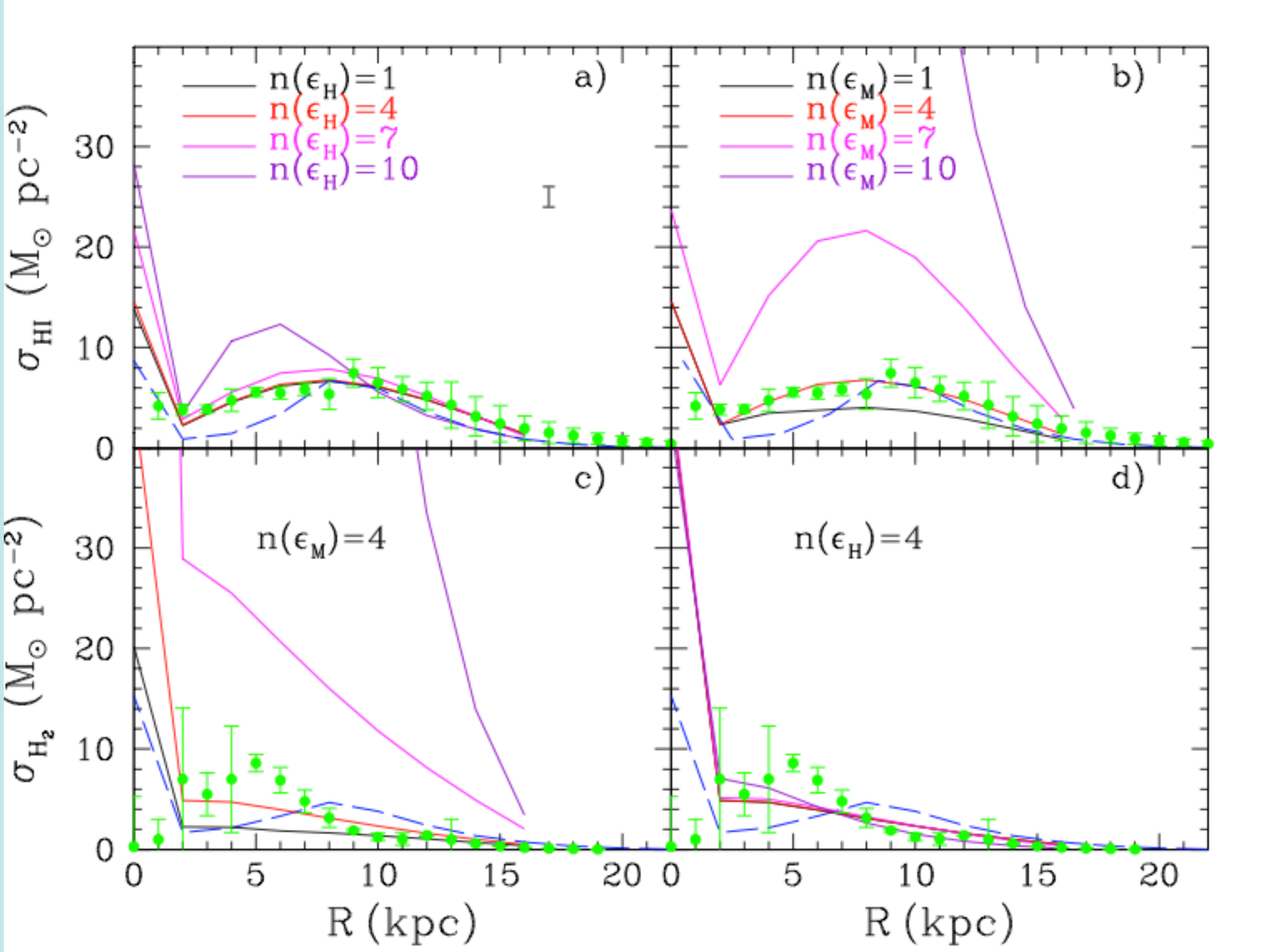
•Ndis=68,

•Mdyn=10^{12} M_0

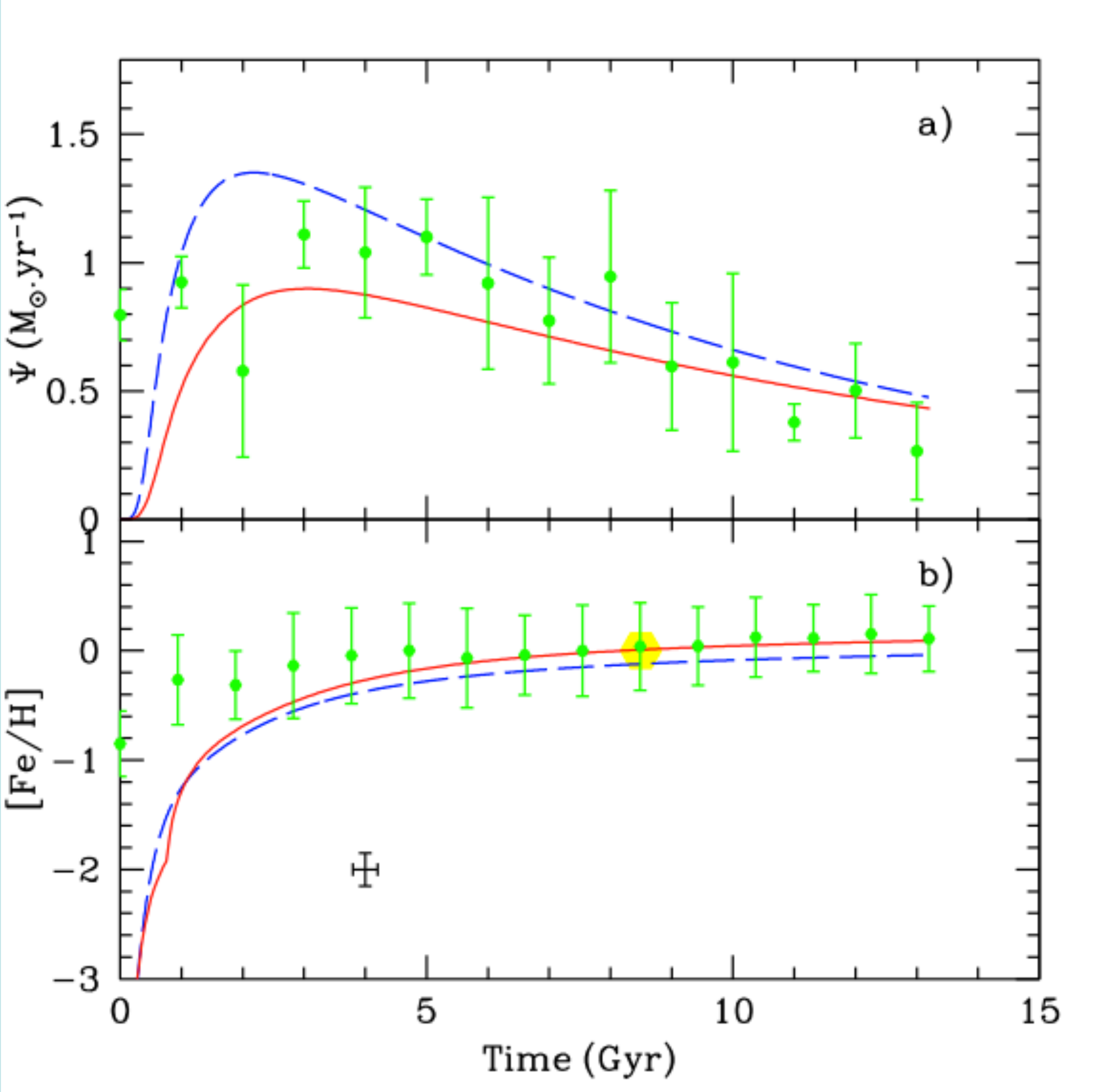
•Mdisk=6.510^{10} M_0

•Ropt=12 kpc

•Different efficiencies

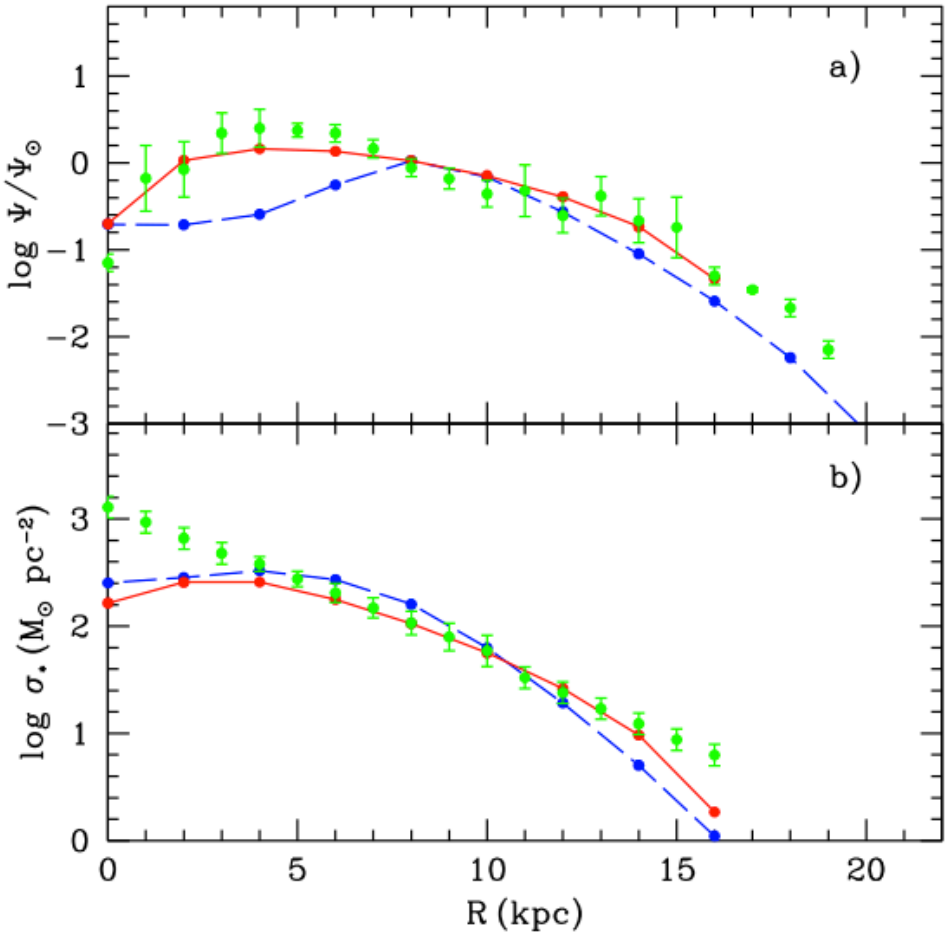


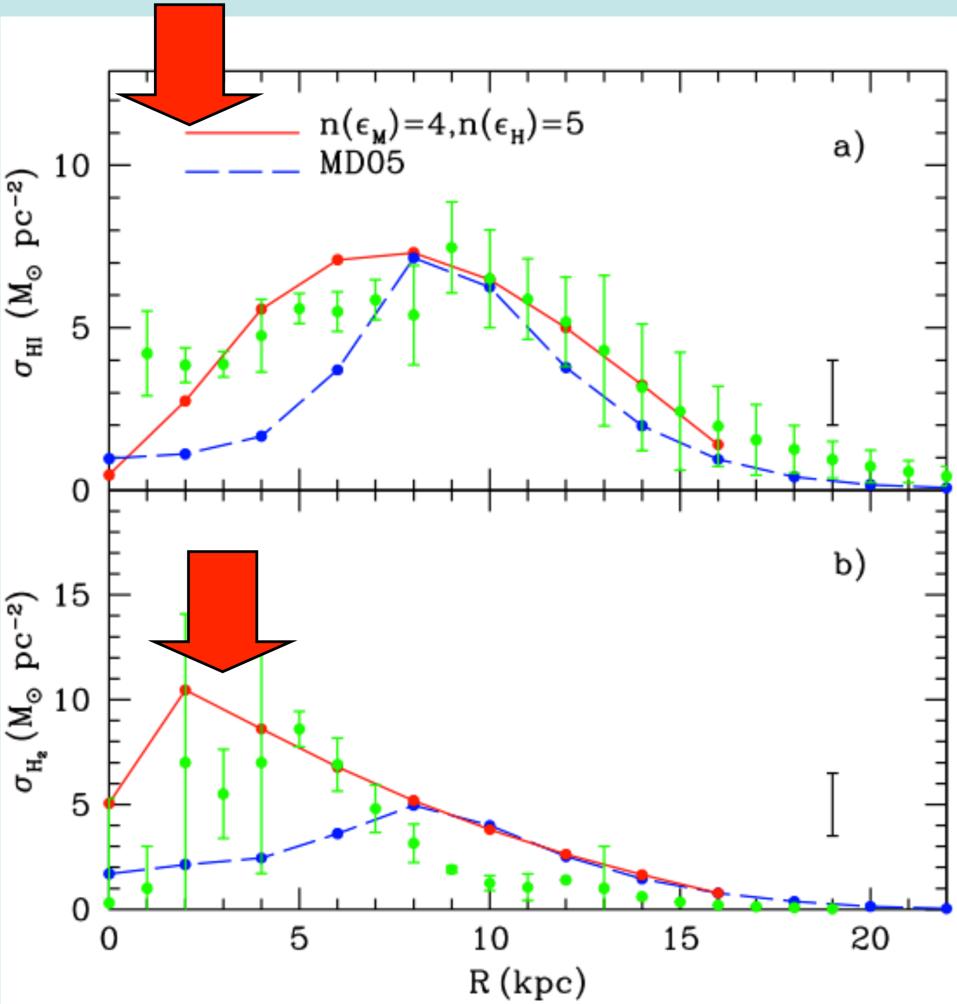
The Solar Vicinity: SFR and enrichment histories



The MWG model:

- Ndis=68, Mdyn=10^{12} M_0
- Mdisk=6.5$10^{10}$ M_0
- Ropt=12 kpc
- Radial Region 8 kpc
- N(ε_M)=4, N(ε_H)=5





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- Revision of new set of stellar yields and different IMFs

- New grid of models: 75 radial mass distributions,
  - Mvir $\in [5\ 10^{10} - 10^{13}]$ Msun
  - Mdisk $\in [1.25\ 10^{8} - 5.3\ 10^{11}]$ Msun
  - Vrot $\in [42-320]$ km/s

IMF + stellar yields

Integrated true stellar yields

$$y_i = \frac{1}{1-R}\int_{m_1}^{m_{up}} p_i(m)\Phi(m)dm$$

$p_i(m)$, fraction of the star of mass m ejected as element i newly formed

R return fraction, ejected mass by died stars

1-R locked stellar mass (low mass stars and remnants)

Five different IMFs

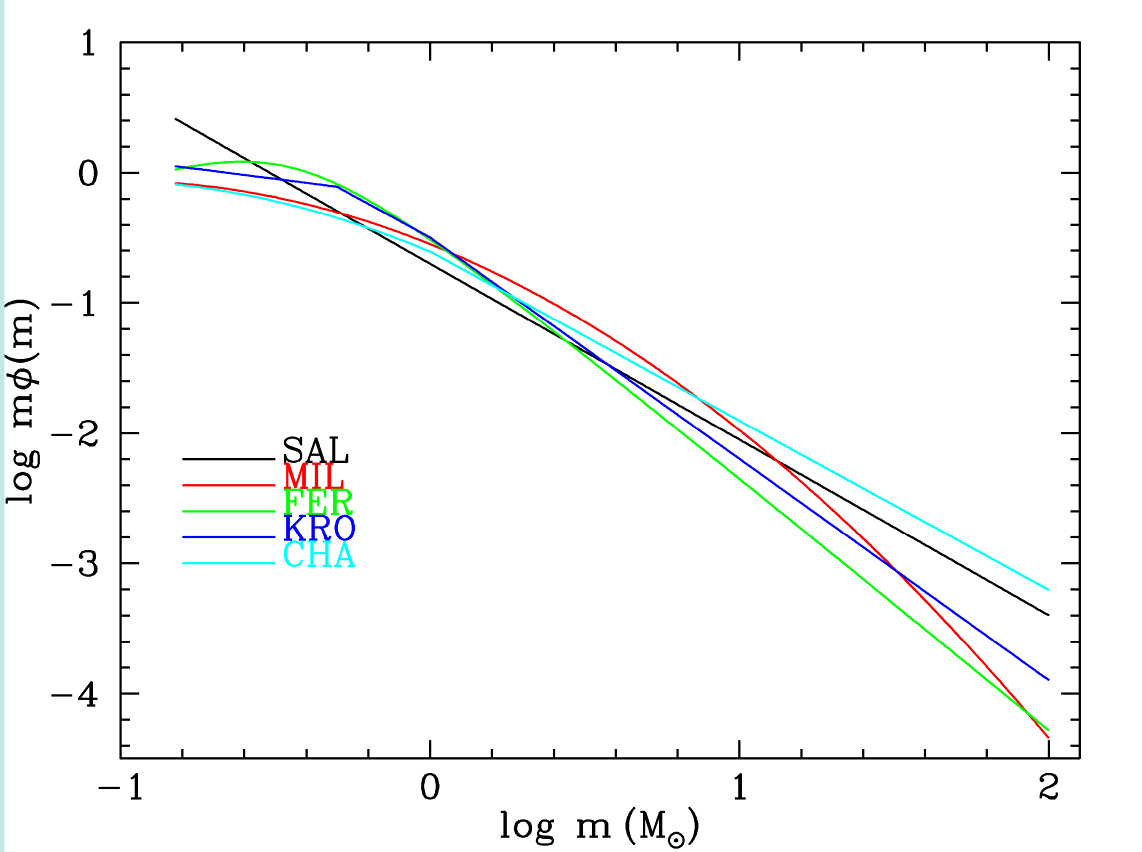
Salpeter (1955)

Miller & Scalo (1979)

Ferrini et al (1998)

Kroupa (2002)

Chabrier (2003)



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Integrated true stellar yields

Combination of stellar yields + IMF

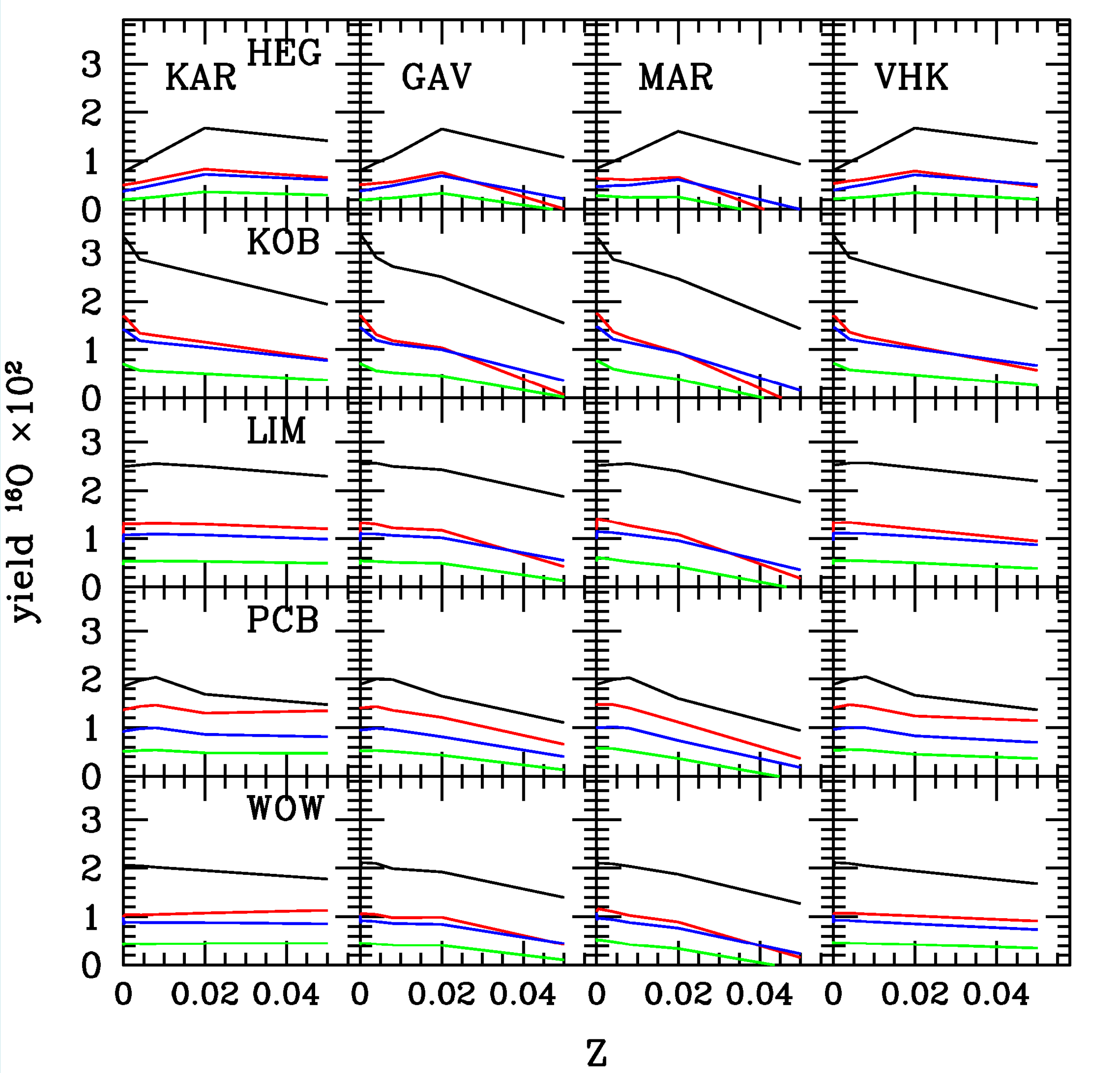
Dependence on Z

Salpeter (1955)

Miller & Scalo (1979)

Ferrini et al (1998)

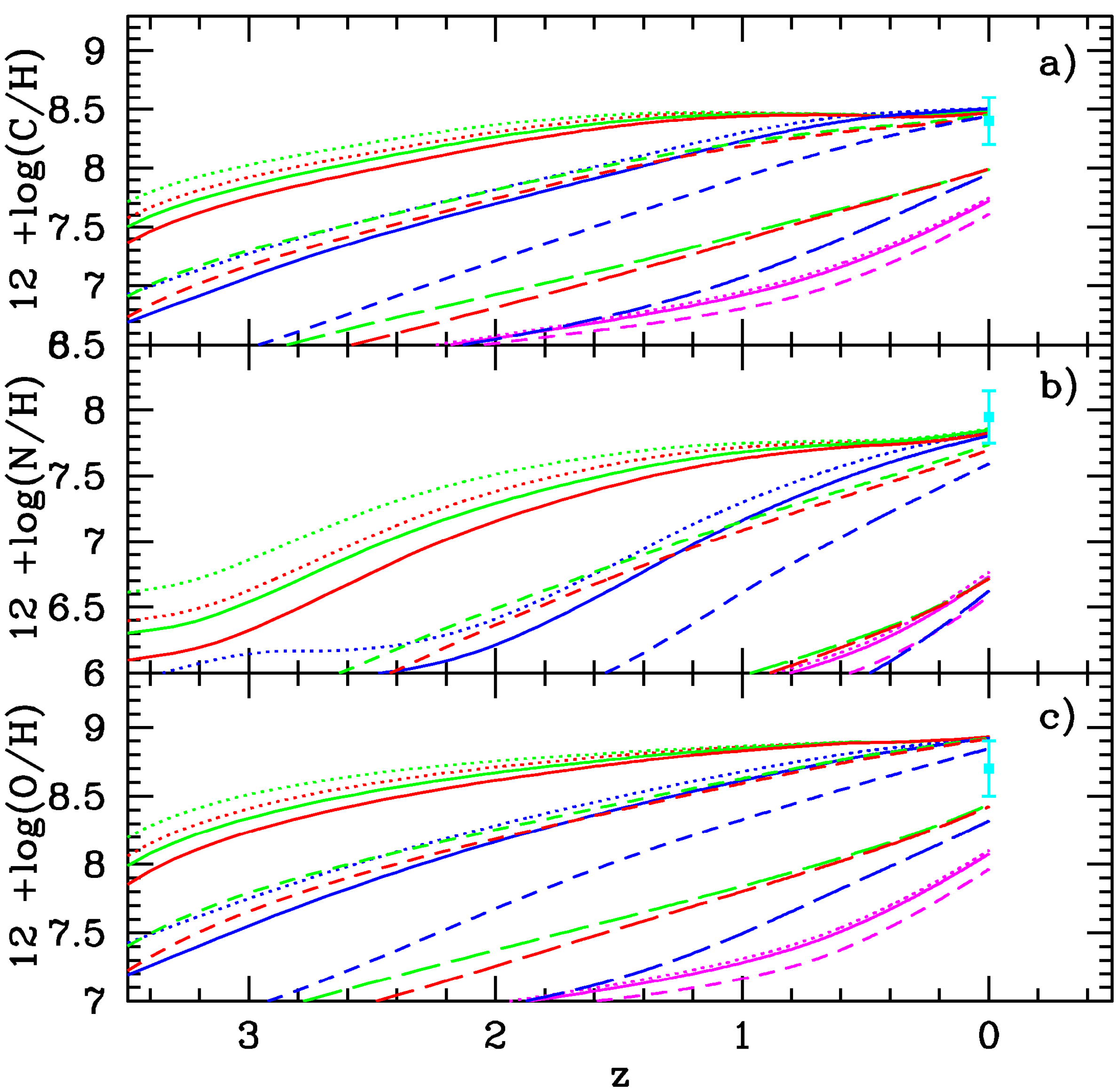
Kroupa (2002)



Evolution of abundances for a Solar Region for different efficiencies

The MWG model:

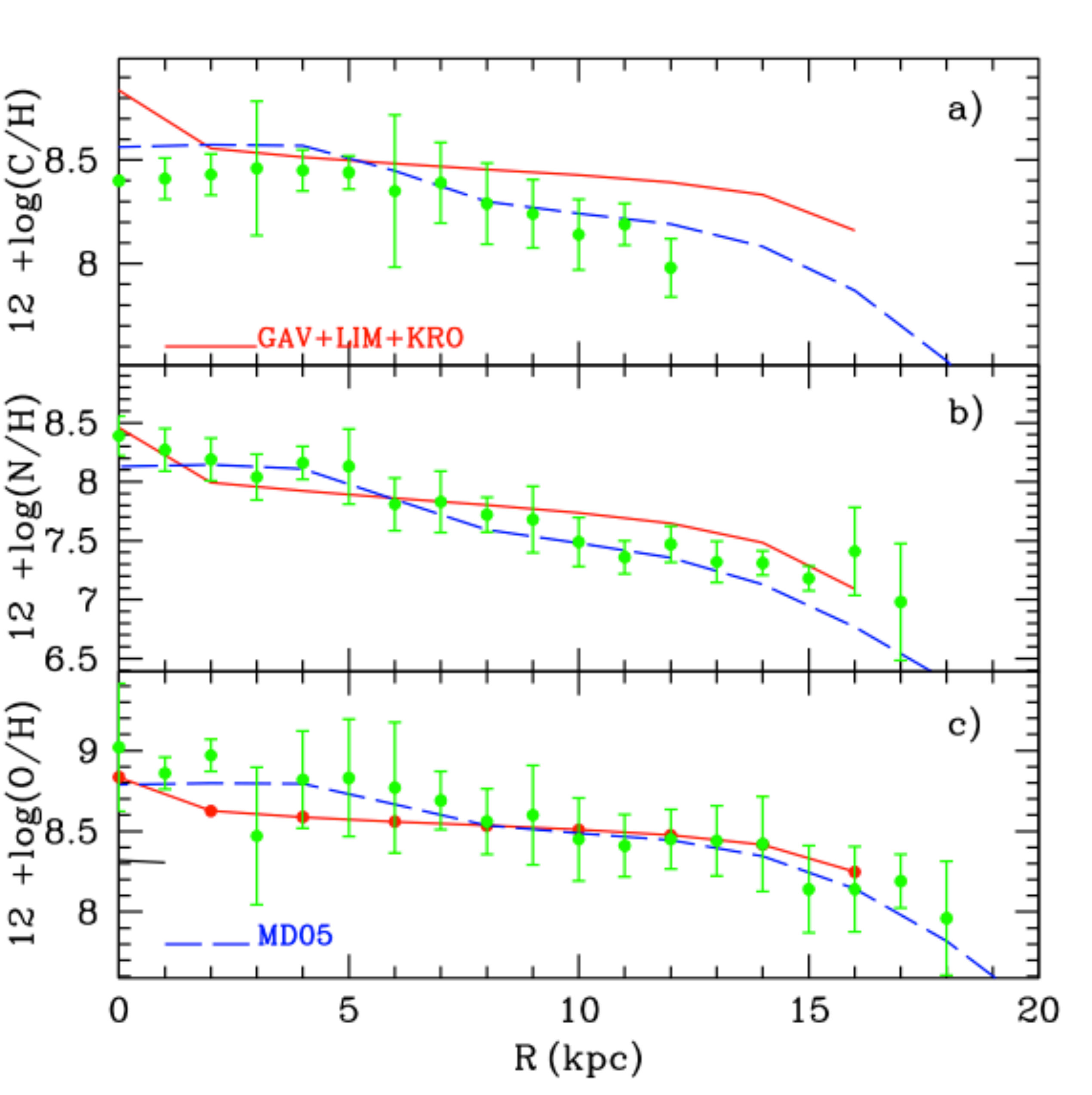
- Ndis=68, Mdyn=10^{12} M_0
- Mdisk=6.5$10^{10}$ M_0
- Ropt=12 kpc
- Different efficiencies



Cabo de Gata, 2013

The MWG model:

- Ndis=68, Mdyn=10^{12} M_0
- Mdisk=6.5$10^{10}$ M_0
- Ropt=12 kpc
- $N(\varepsilon_M)$=4, $N(\varepsilon_H)$=5



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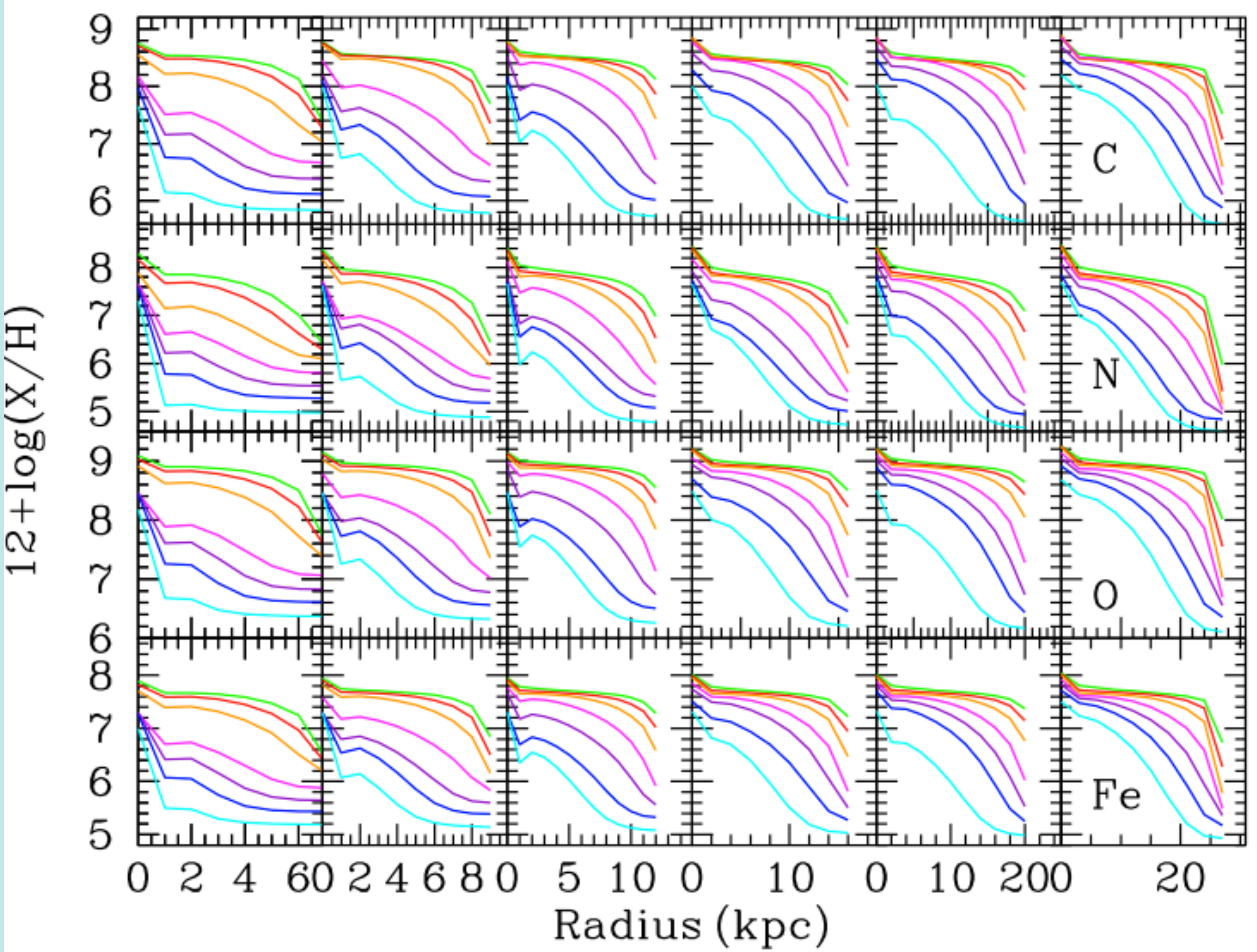
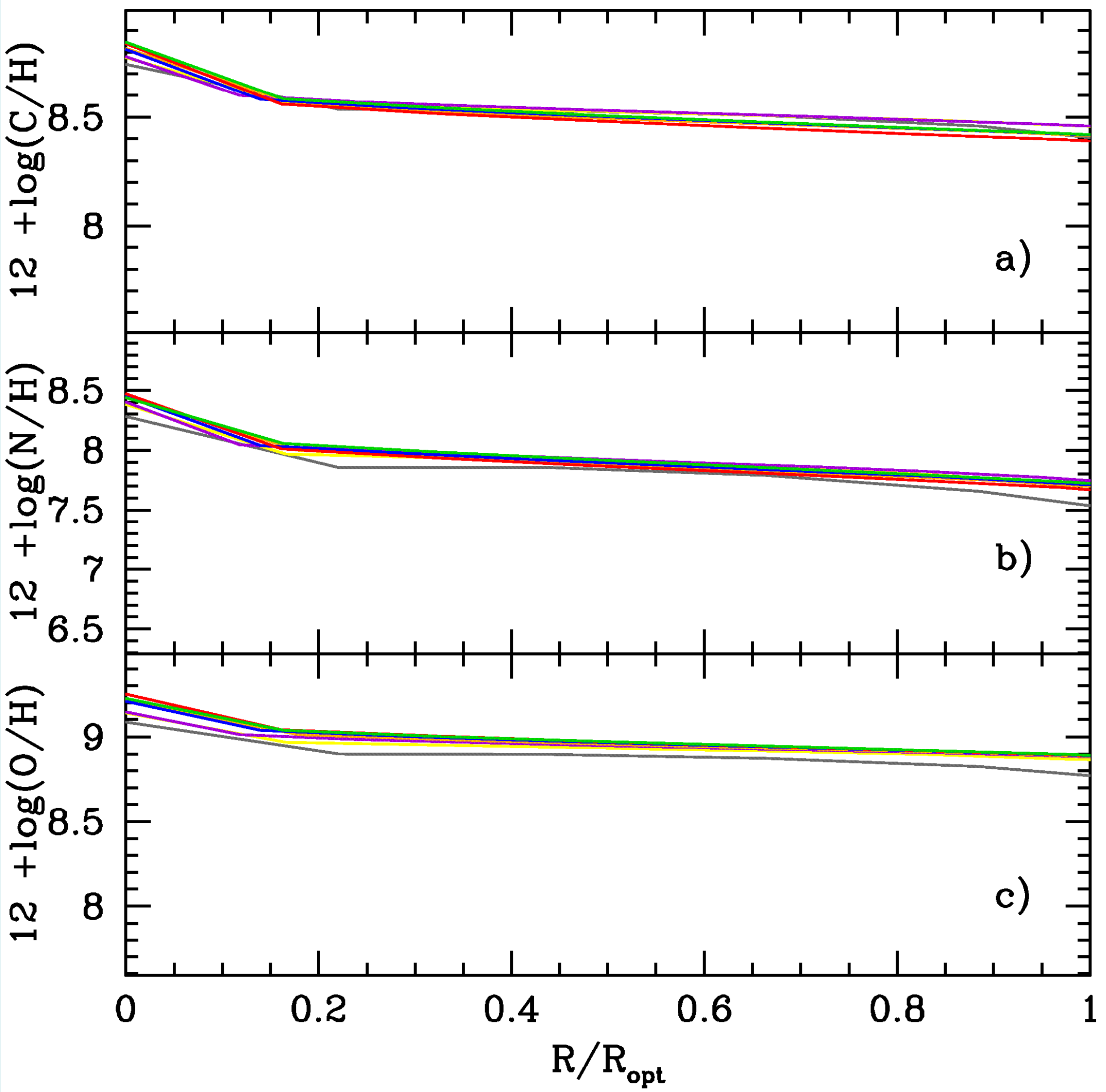


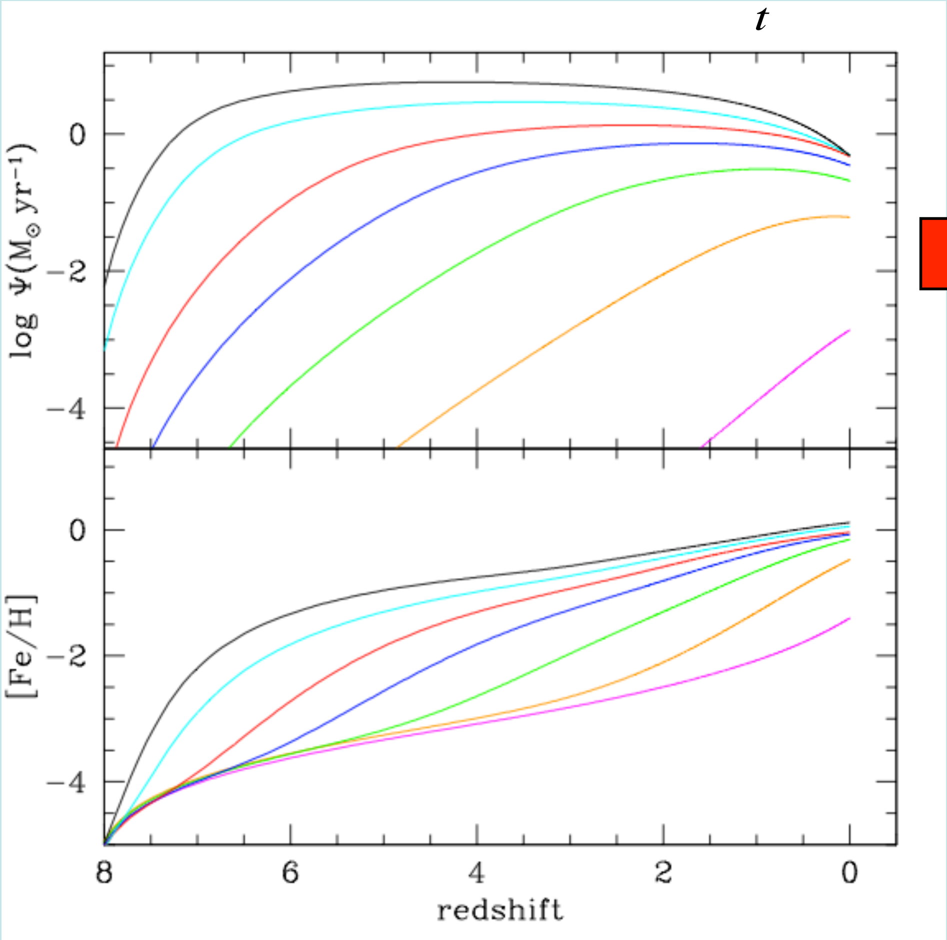
The radial gradients for the same ε_M and ε_H and different Mvir models, when measured with normalized distances, are equivalent

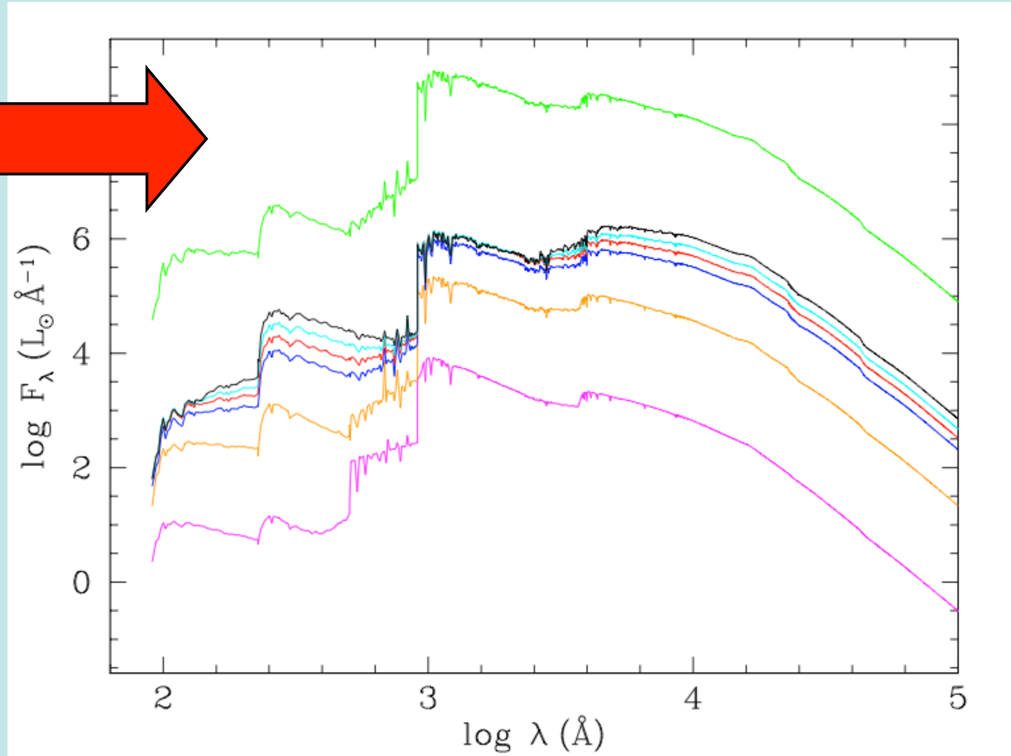
By observing different radial gradients with a normalized radial scale we may distinguish different efficiencies to form molecular clouds or stars in galaxies



From the evolutionary histories and using evolutionary synthesis models, we obtained the spectral energy distributions, magnitudes and colors, brightness profiles and spectral absorption lines along the galactocentric radius for every galaxy model.

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





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CONSOLIDER - INGENIO GTC

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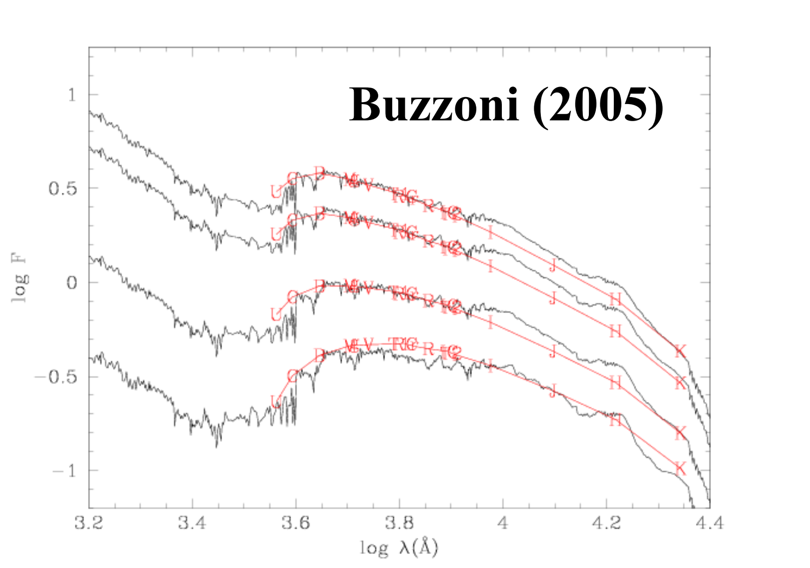
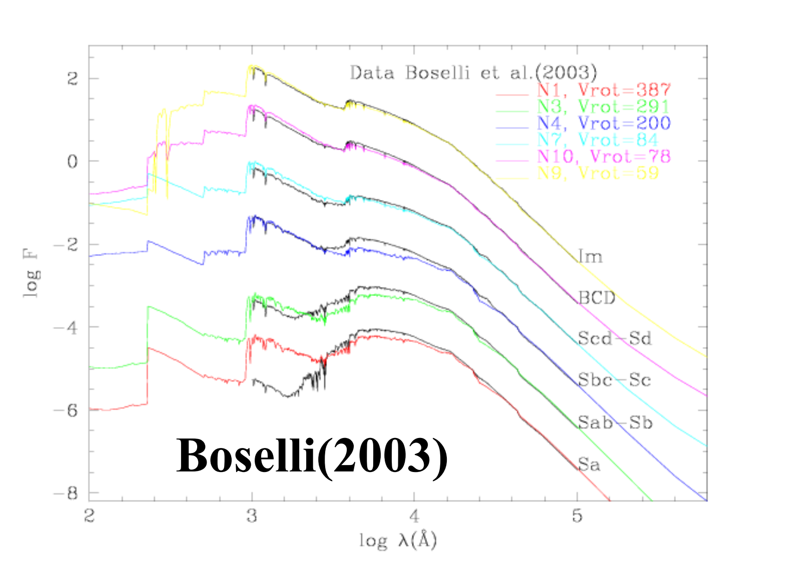
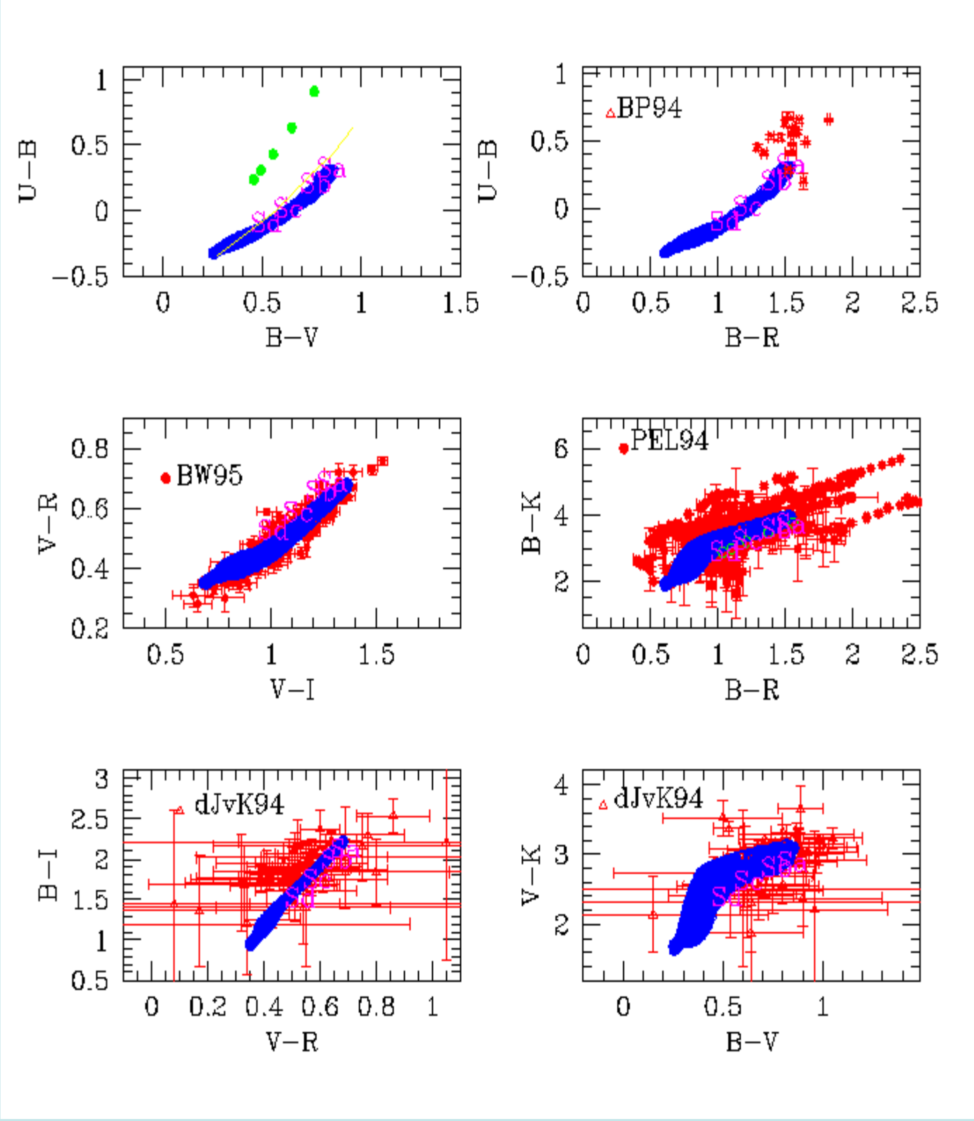
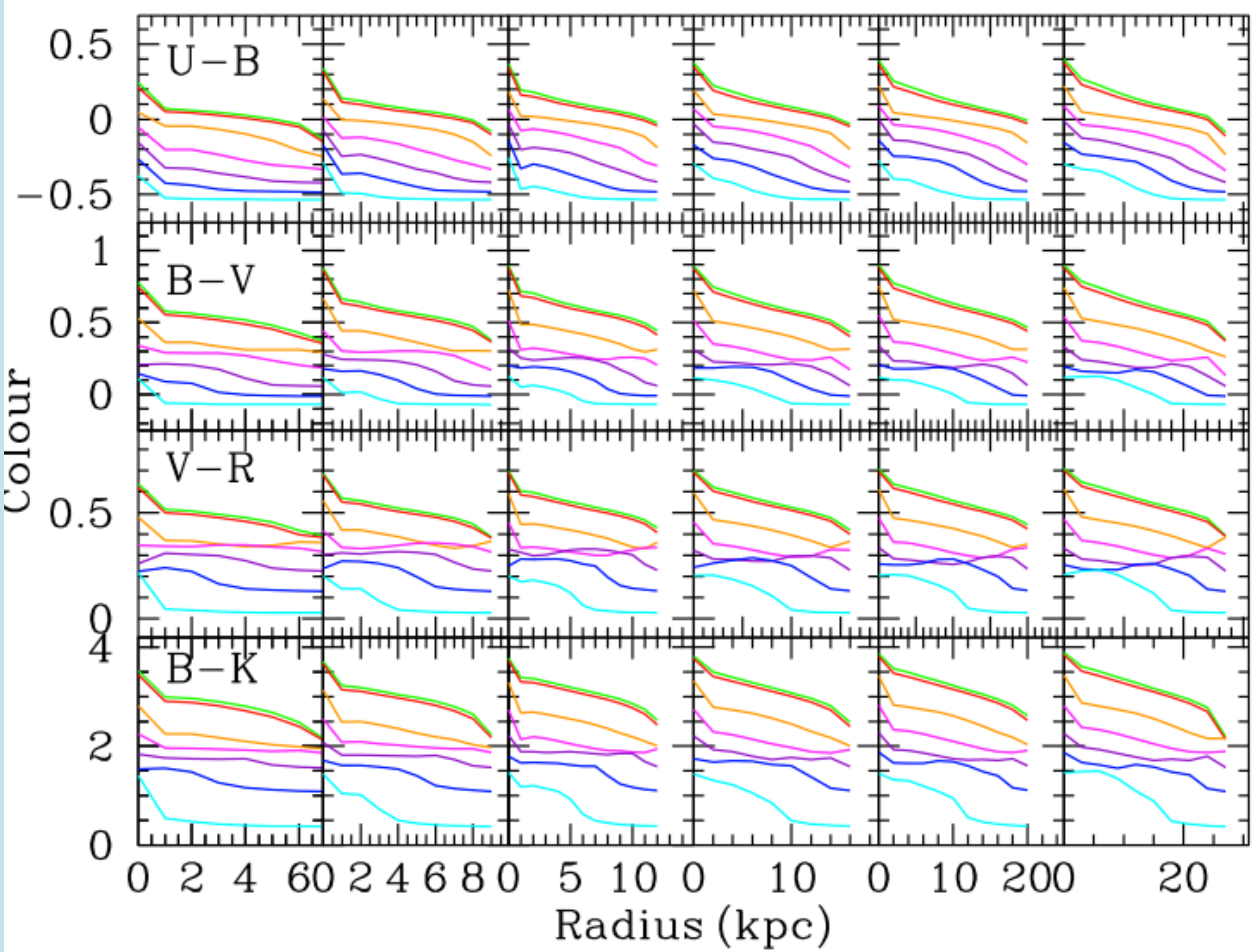
SEDs and colors for our galaxy models:







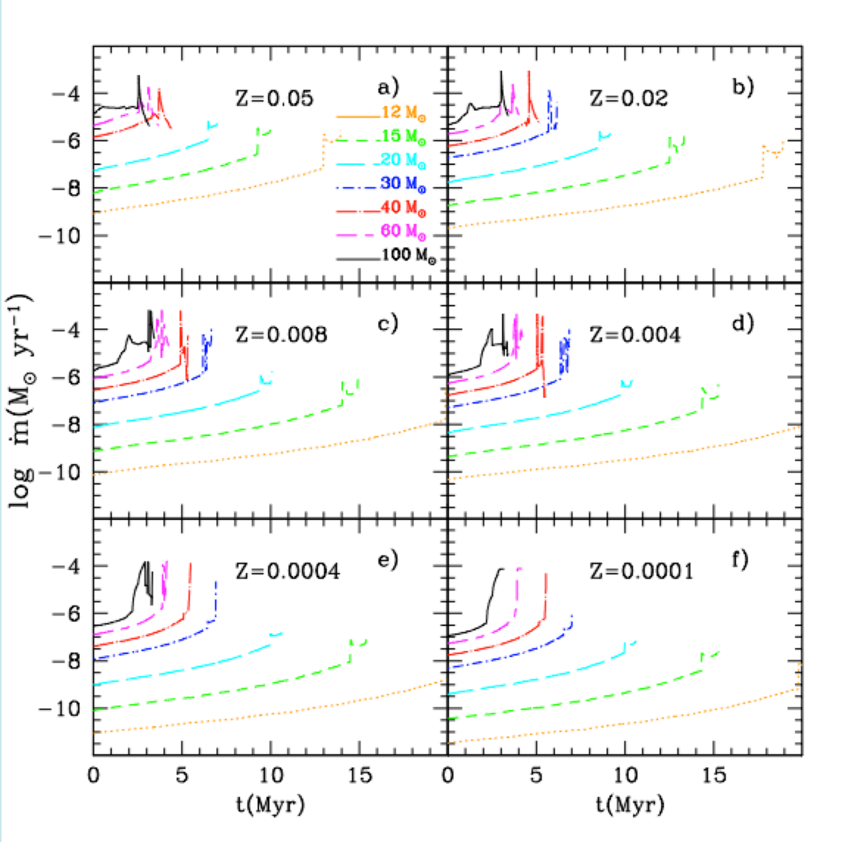

U−B
B−V
V−R
B−K
Colour
Radius (kpc)
0.5
0
−0.5
1
0.5
0
0.5
0
4
2
0
0 2 4 6
0 2 4 6 8
0 5 10
0 10
0 10 20
0 20

VERY YOUNG STELLAR POPULATIONS: MASSIVE STARS

- Very luminous stars, small number:
  - Nebular Continuum
  - Emission lines contribution to broad band magnitudes
  - Color-color diagrams

•M> 30 Msun: massive stars, lost mass by stellar winds, Wolf-Rayet stars

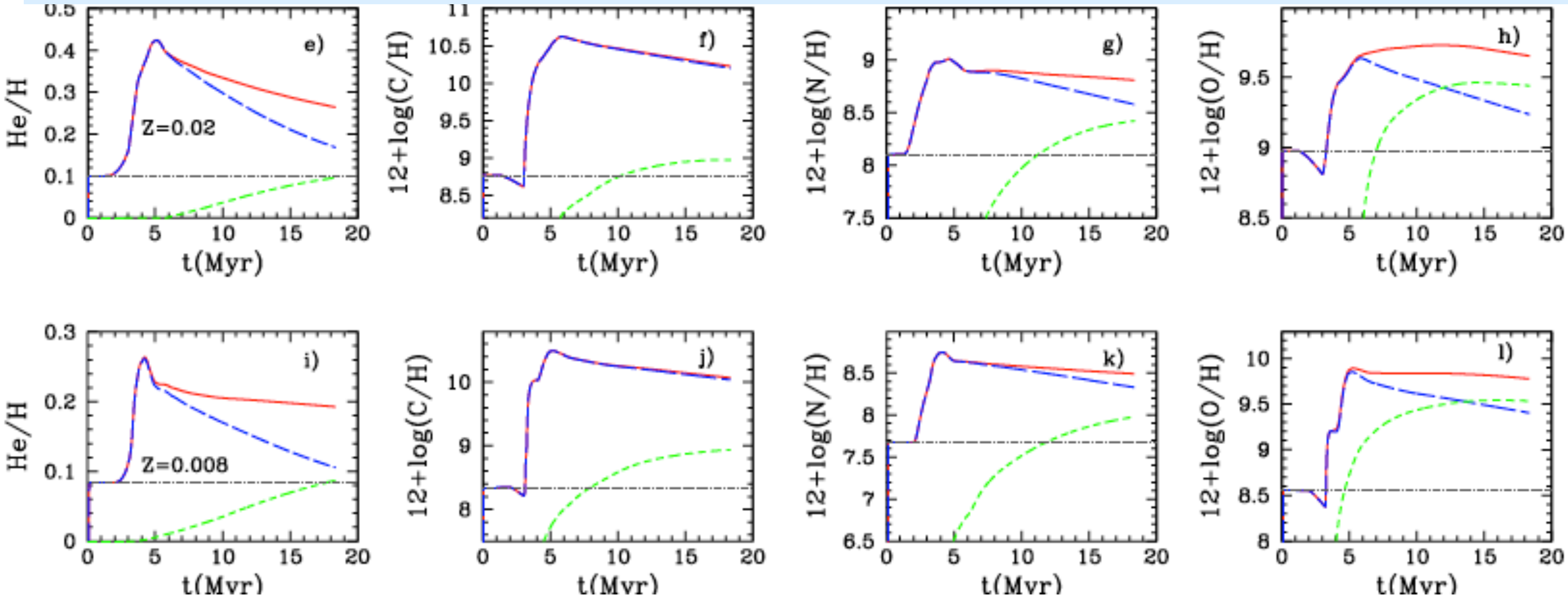
-Ejected elements He, C, N and O, ISM abundances change



Time evolution of abundances in SSPs

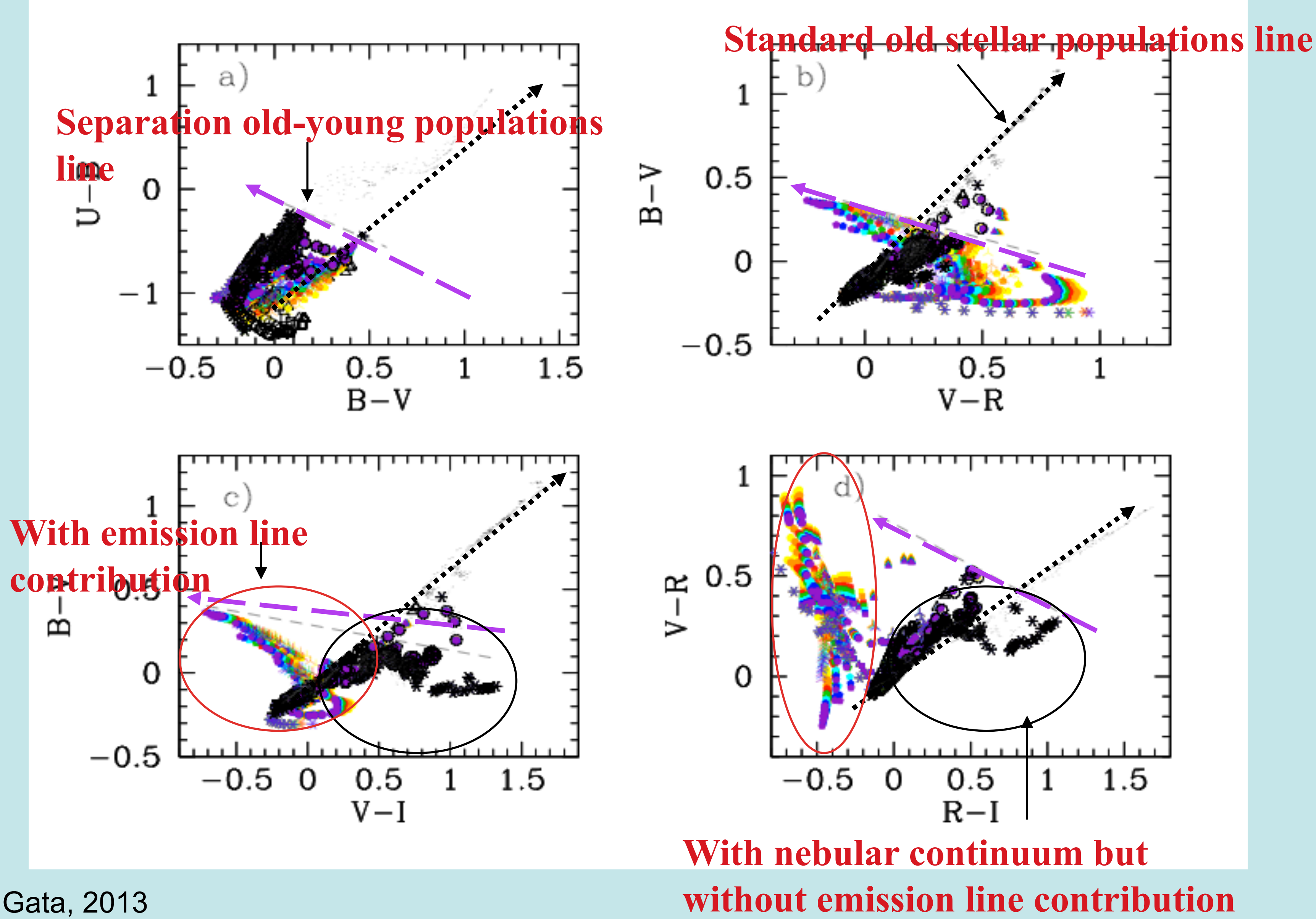
--contribution of winds - long dashed (blue) lines,
--contribution from SN-- short-dashed (green) lines
--total abundances with solid (red) lines.

- For He both contributions are more or less similar at the end of 20 Myr if Z>0.004.
- Stellar winds produce high abundances of C and O for Z > 0.004.
- 12+log(O/H) reaches almost 11, almost two orders of magnitude larger than expected with SN.
- N shows higher abundances than expected for all metallicities, even for the two lowest ones.



PHOTOMETRIC PROPERTIES: THE YOUNGEST STELLAR POPULATIONS EFFECT

- **Colors in Johnson and SDSS systems, Hα and Hβ luminosities and equivalent widths, and ionizing region size, have been computed for a wide range of metallicities Z = 0.0001, 0.0004, 0.004,0.008,0.02 and 0.05, and ages, from 0.1 Myr to 20 Gyr in Mollá et al. (2009, Paper I).**
- **Emission lines are shown in Martín-Manjón et al. (2010, Paper II).**
- **Colors calculated with the contribution of emission lines to the broad-band filter magnitudes (García-Vargas, Mollá & Martín-Manjón, 2013, Paper III)**



Cabo de Gata, 2013

SUMMARY

We are computing models for the complete grid of total masses and efficiencies.

We calculate the spectral energy distributions and the corresponding magnitudes, colors, brightness profiles and spectral absorption stellar indices

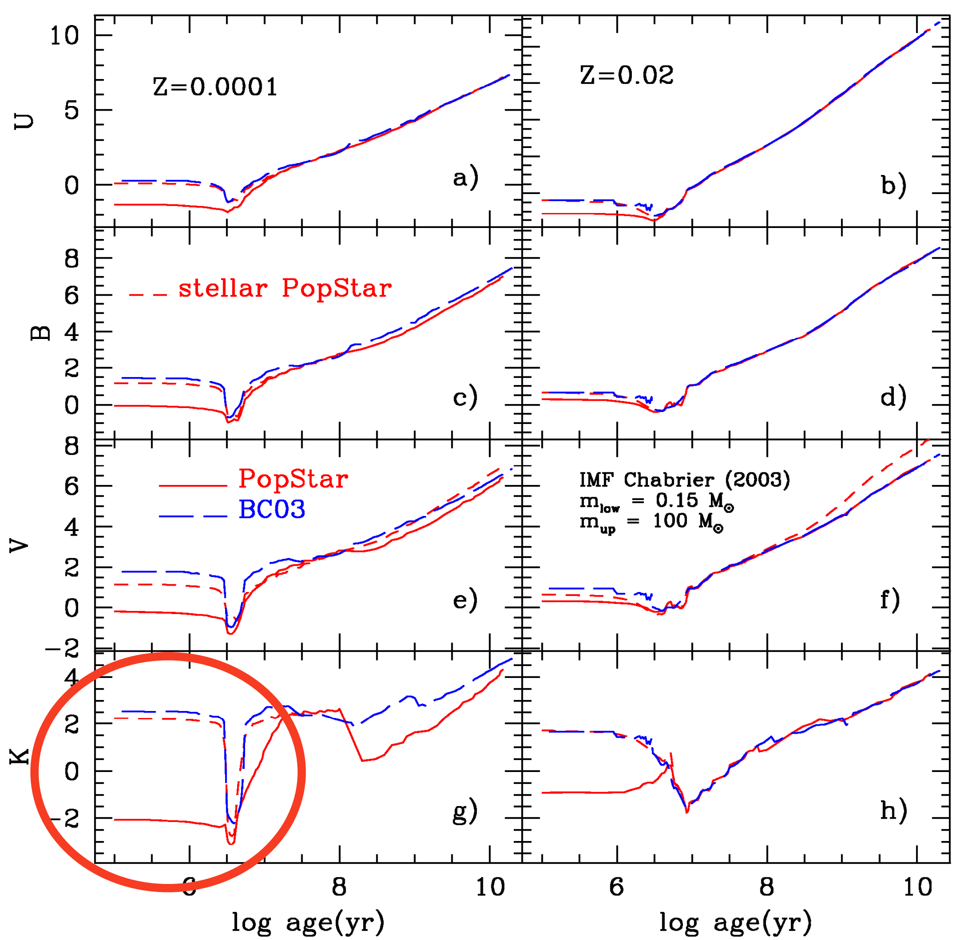
New models seem being in better agreement with observations of molecular clouds and star formation rate radial distributions, therefore they will be better estimates of the "expected values"

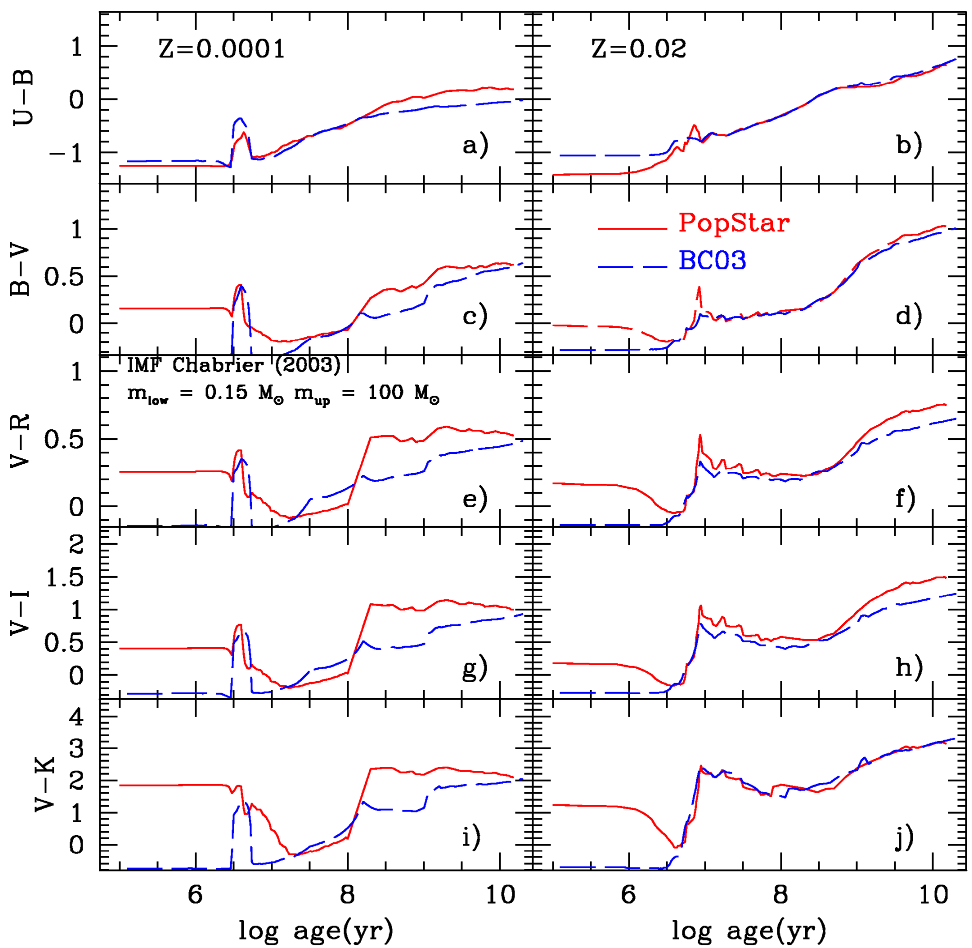
A realistic infall rate of gas to form disks is essential to reproduce the observed radial distributions

The evolution with redshift and the comparison with new data will allow to discriminate between galaxy formation scenarios.

Comparison with models focused on old stellar populations

- GALAXEV models (Bruzual & Charlot, 2003), Maraston (2005)
- Nebular continuum: Not included in BC03, MAR05





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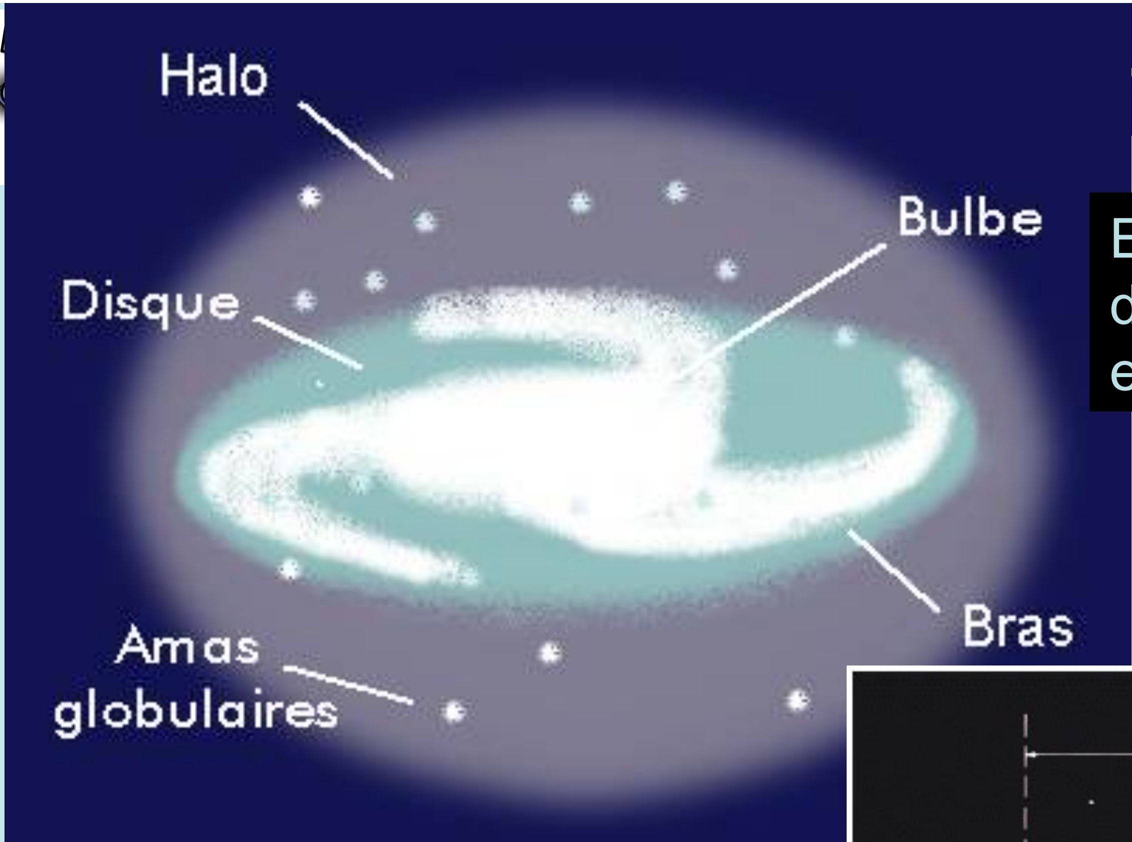
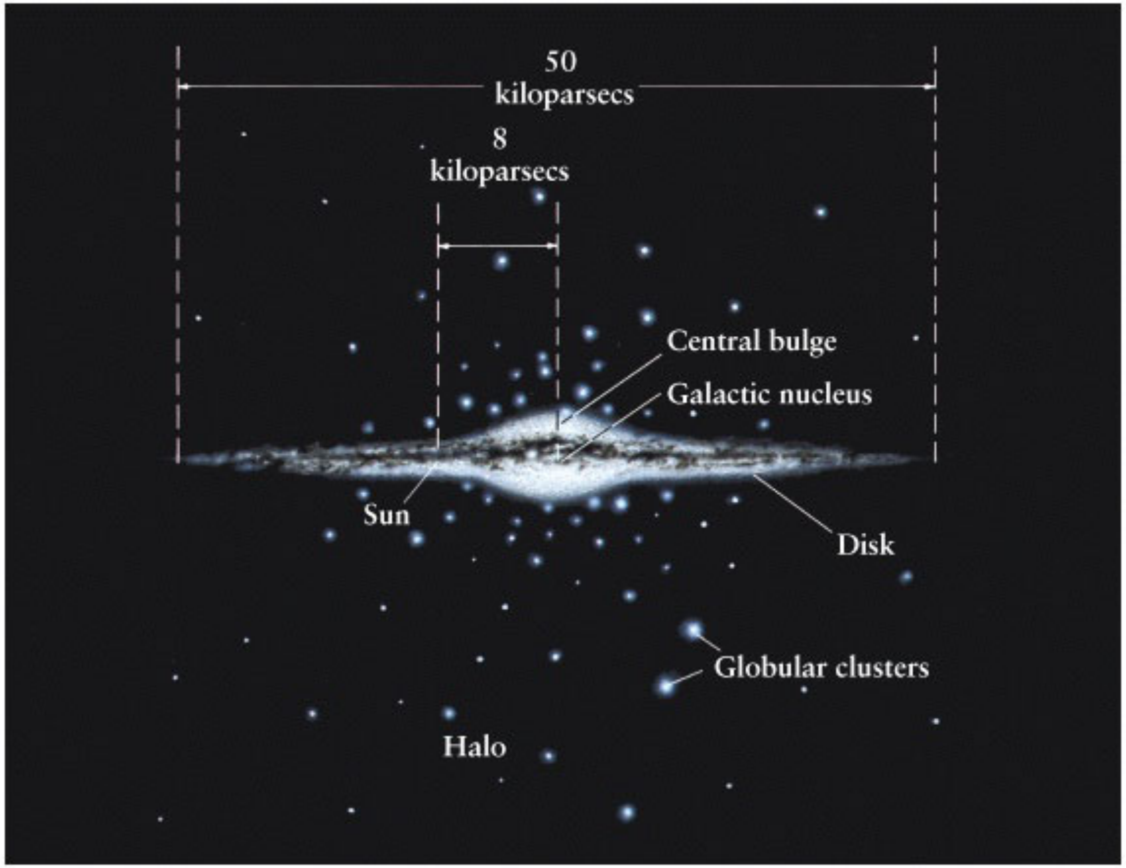
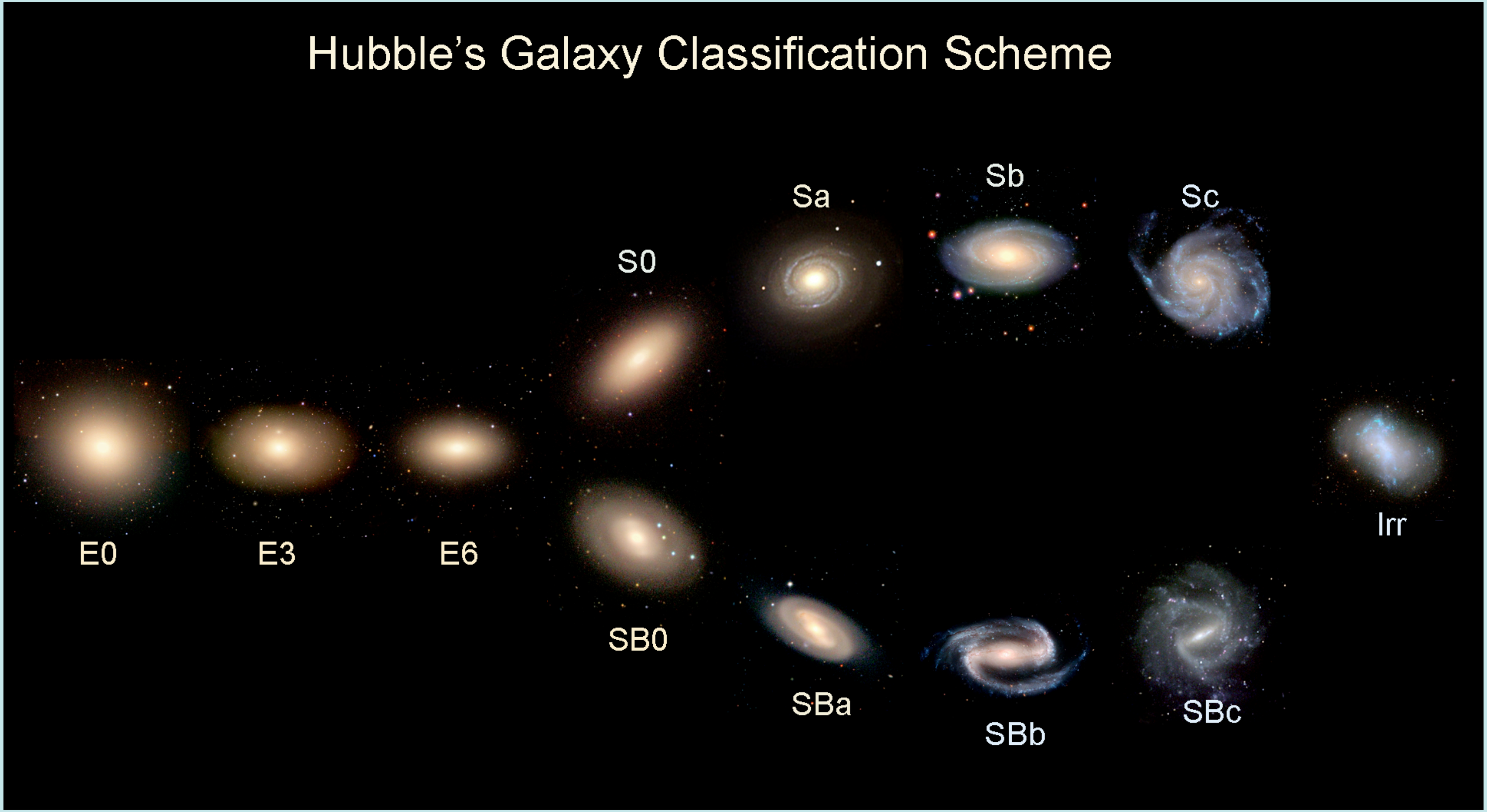
Each spiral galaxy forms within a dark halo with a bright disk in the equatorial plane





Cabo de Gata, 2013


Hubble's Galaxy Classification Scheme
Sa
Sb
Sc
S0
E0
E3
E6
Irr
SB0
SBa
SBb
SBc

		1	2	3	4	5	6	7	8	9	10		
	Vrot	0.95	0.8	0.75									
11	50												
12	53												
13	56												
…													
18	71												
…													
25	100						M33						
…													

43	190				MWG								
…													
60	250			M31									
…													
70													
75	400												

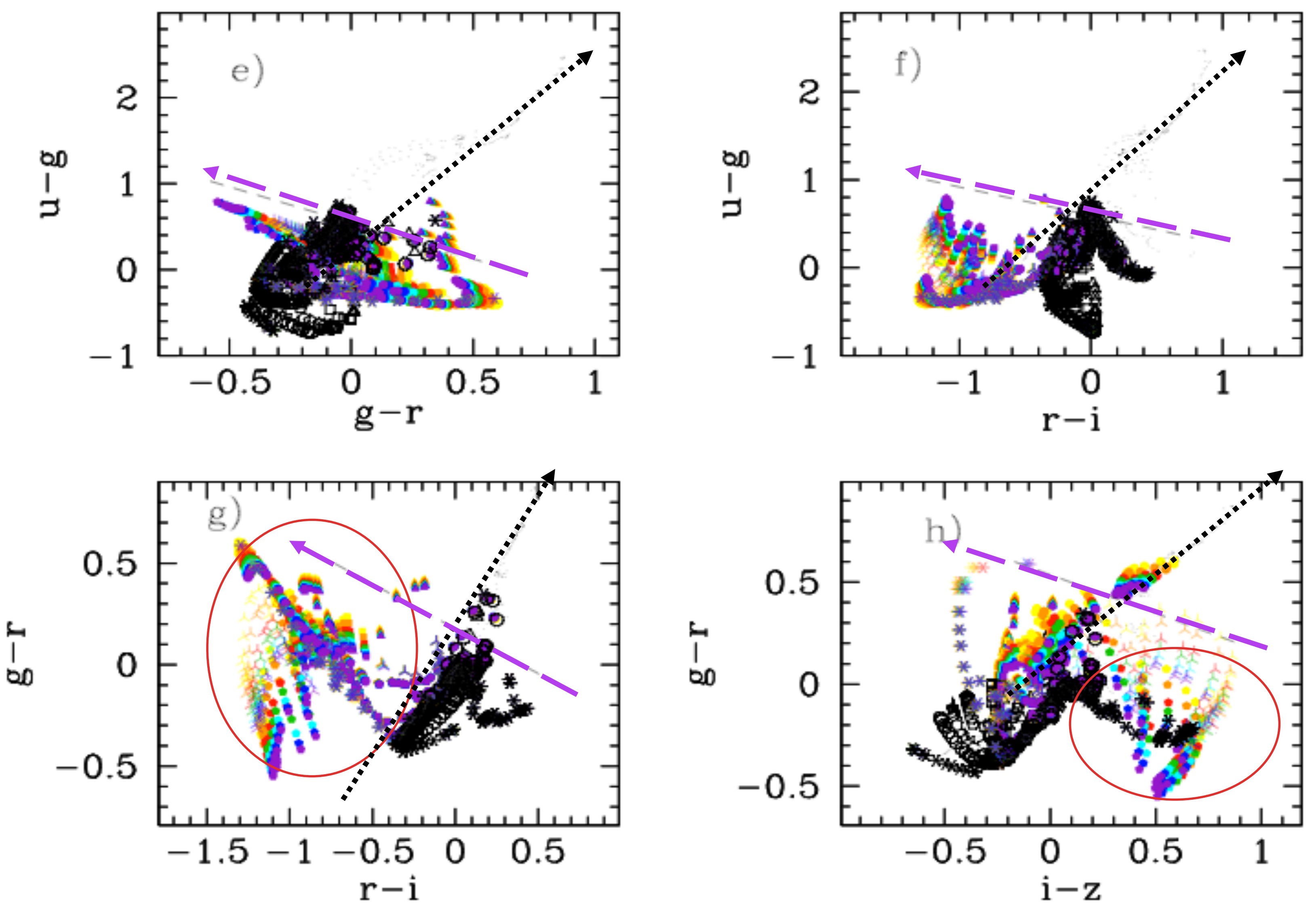
BCD & HII Gal.

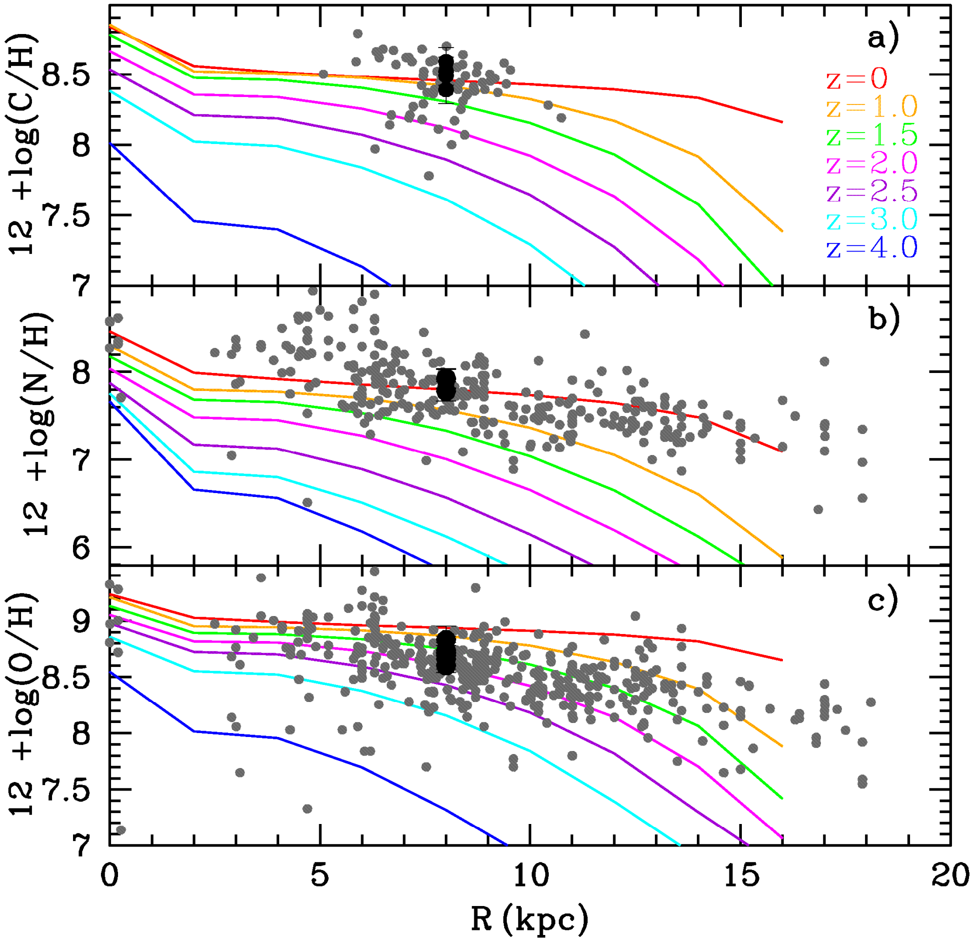
Low mass galaxies

Normal spirals

Starbursts

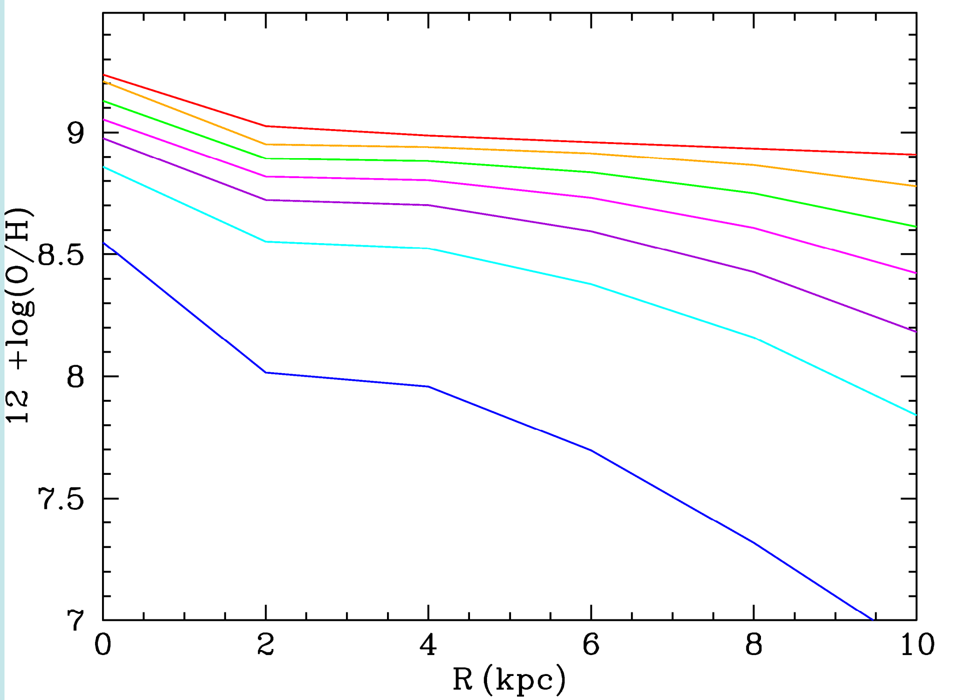
Low surface brightness Galaxies

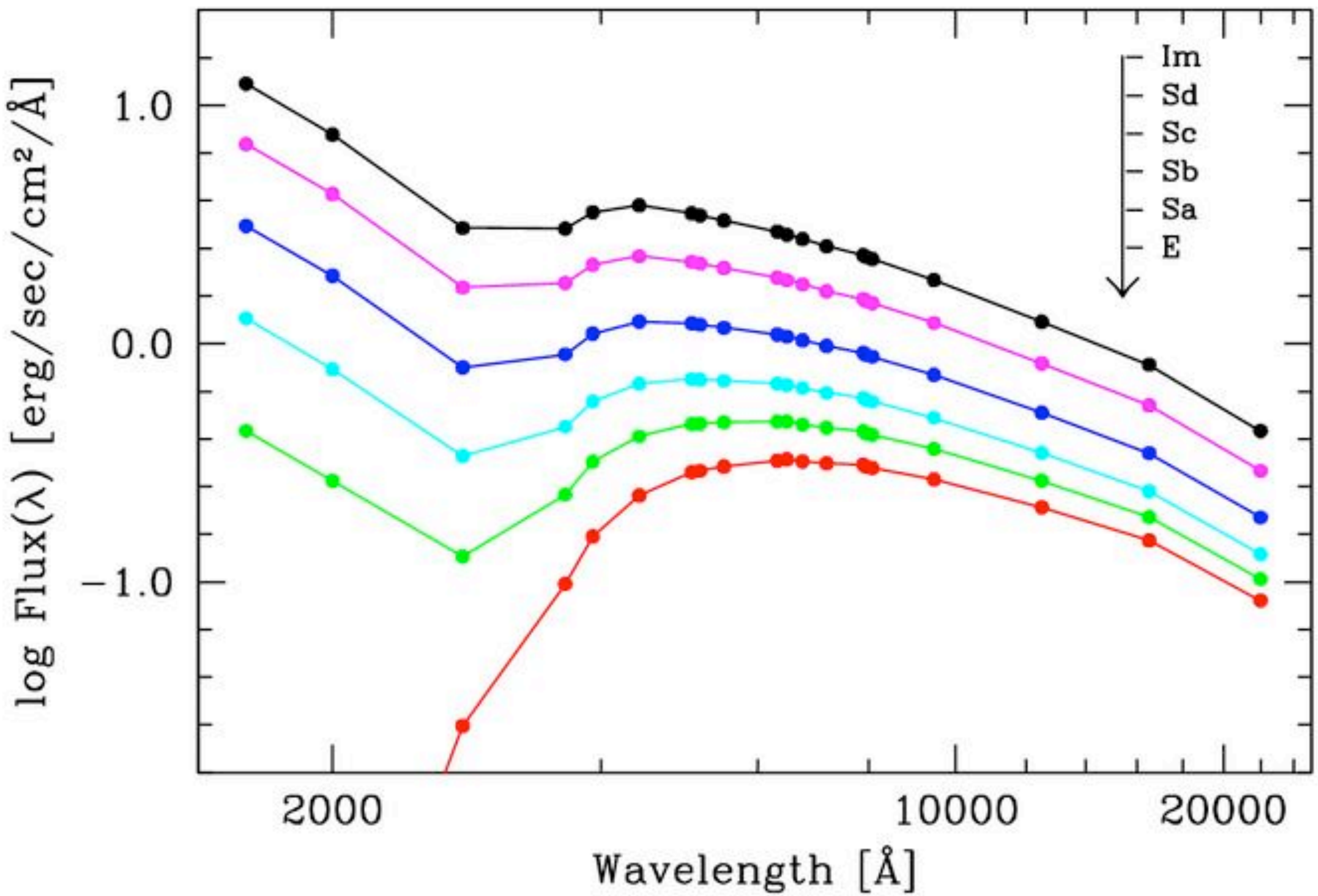

e)
u−g
g−r
f)
r−i
g)
g−r
r−i
h)
i−z



The evolution of radial gradients of oxygen for a MWG model: it flattens with time, the variation is smoother than before

Without the outer regions





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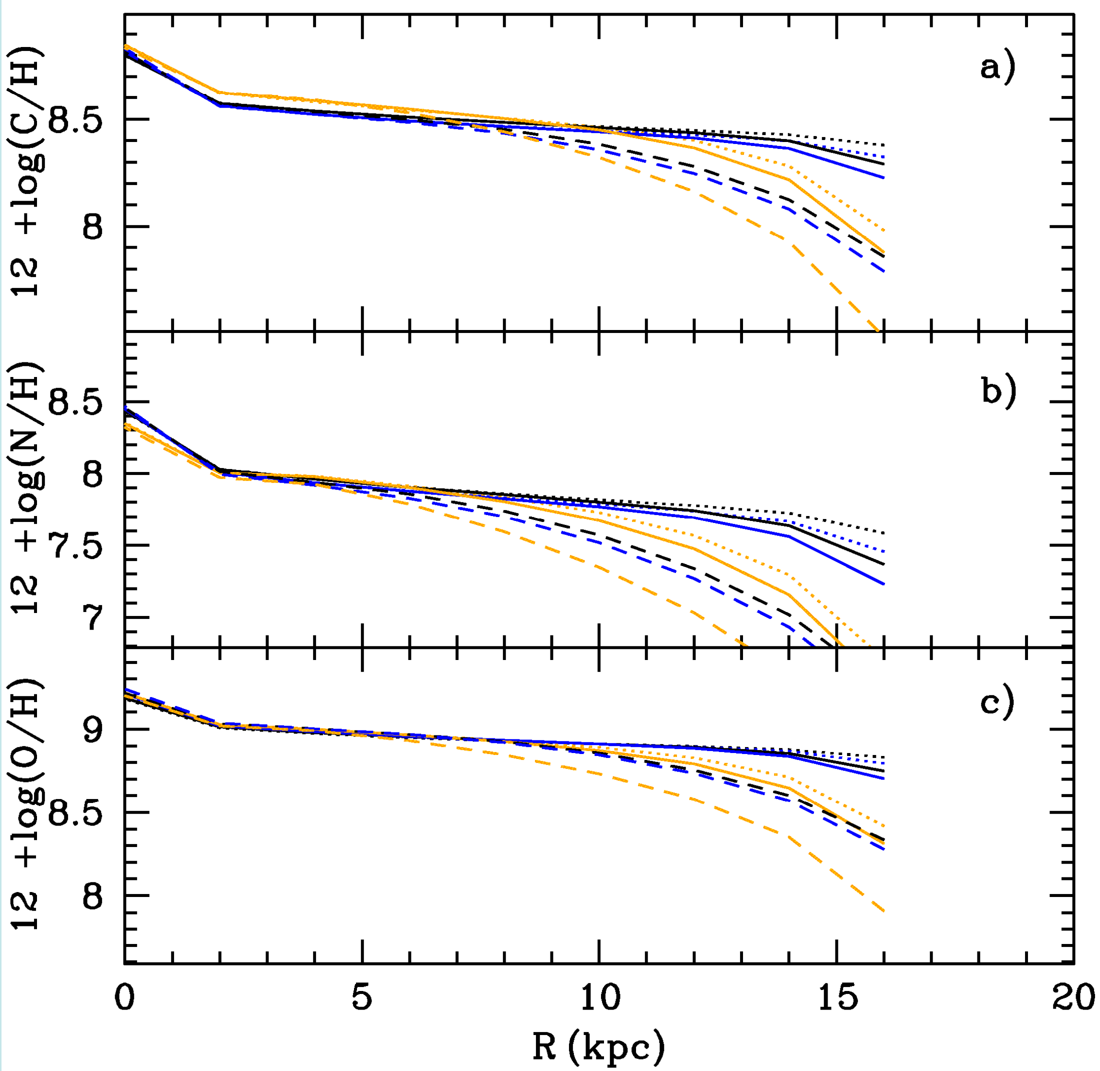
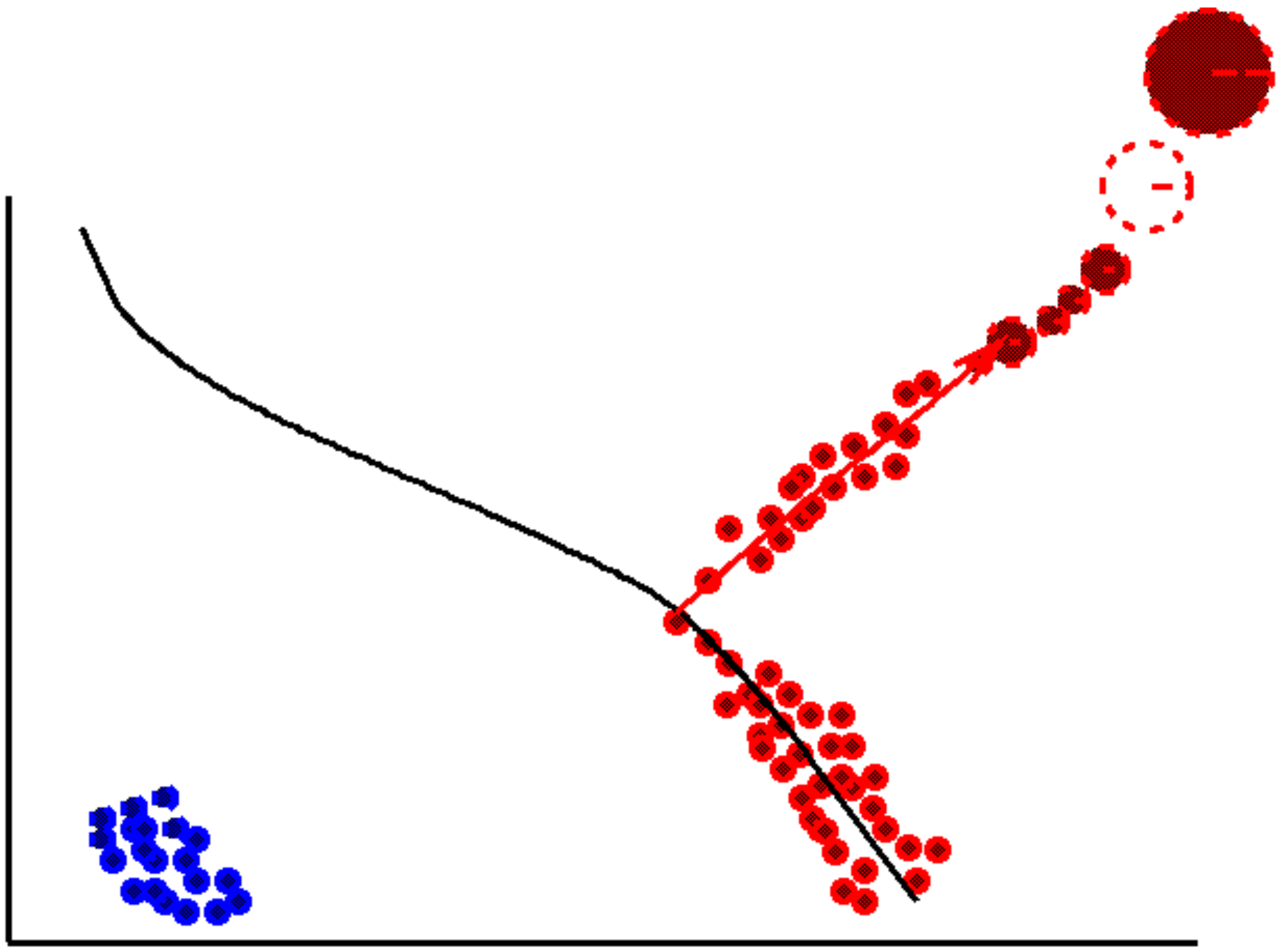
Radial gradients of abundances for different efficiencies

The MWG model:

- Ndis=68, Mdyn=10^{12} M_0
- Mdisk=6.5$10^{10}$ M_0
- Ropt=12 kpc
- Different efficiencies

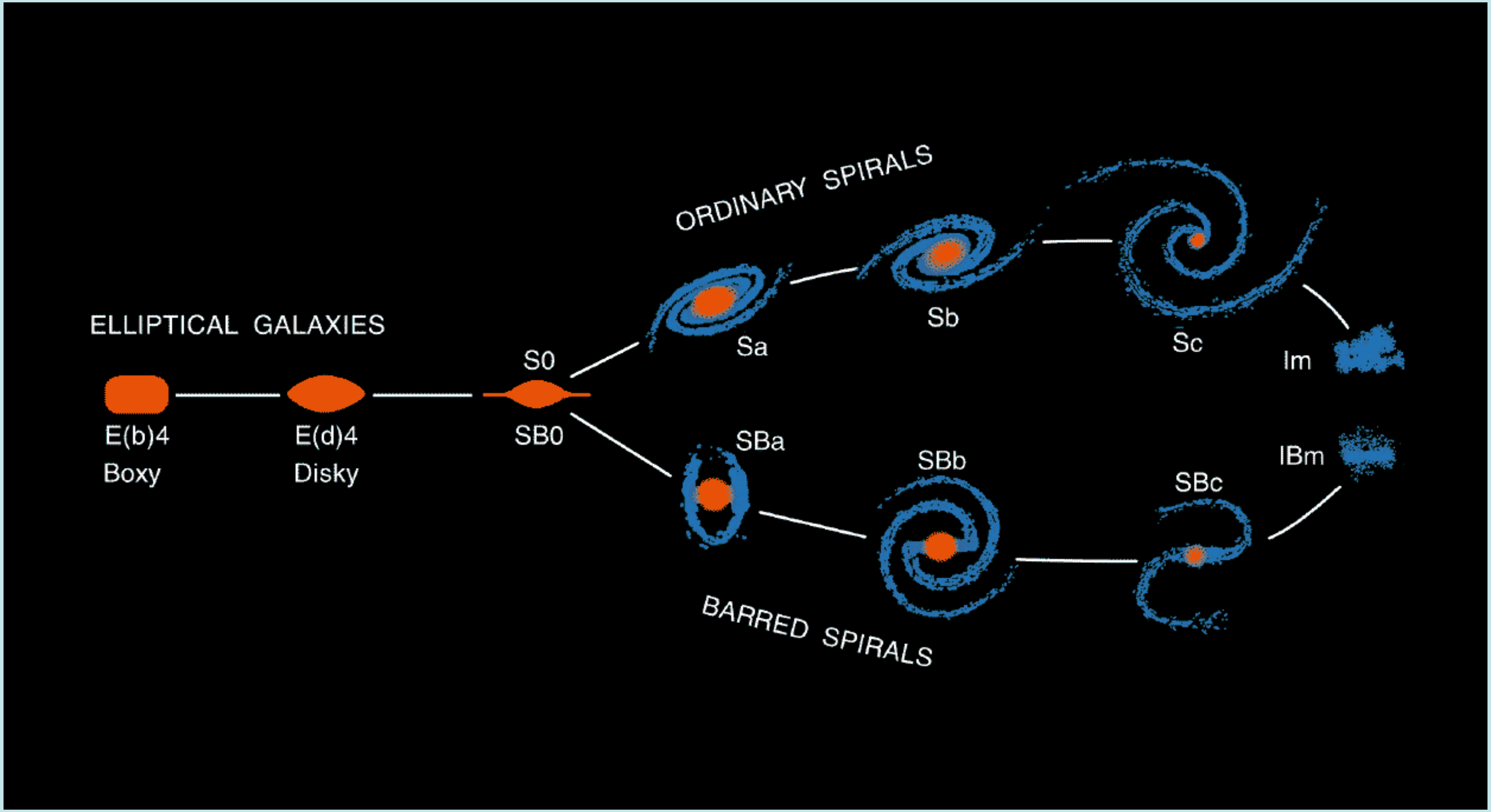




T = 10 billion years old --> just red stars left;
lots of white dwarfs; no stars more massive than
one solar mass left on the main sequence

:e

Hubble Sequence



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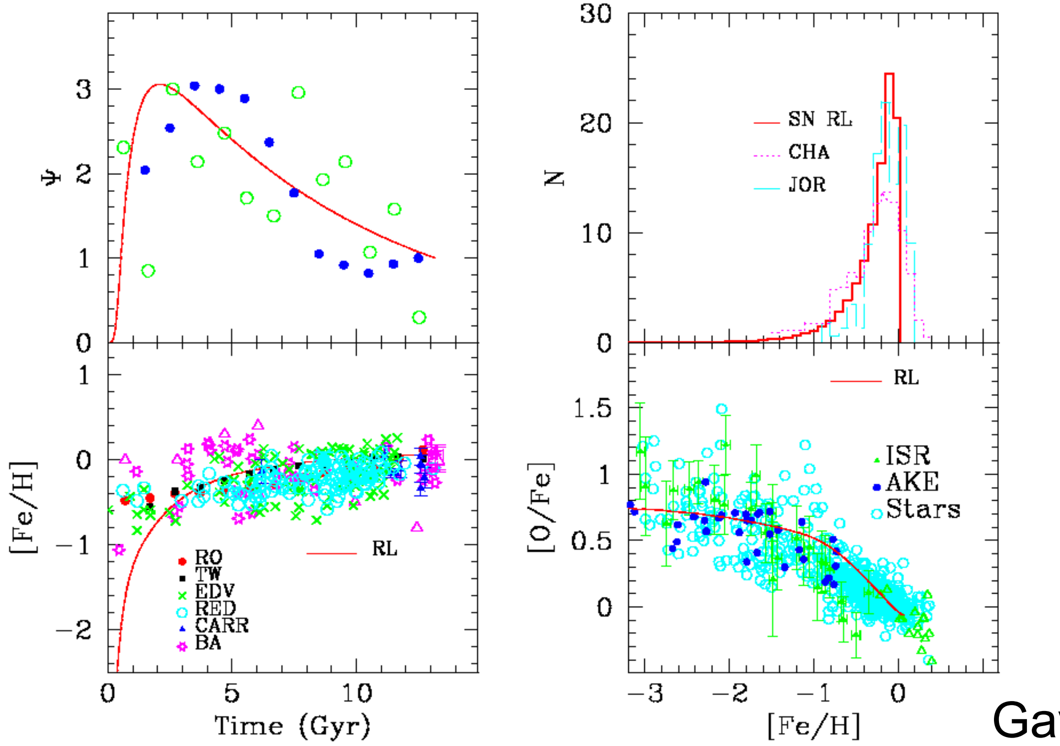
Calibration: the model Vrot=200 km/s and N=4 against the Solar Vicinity data

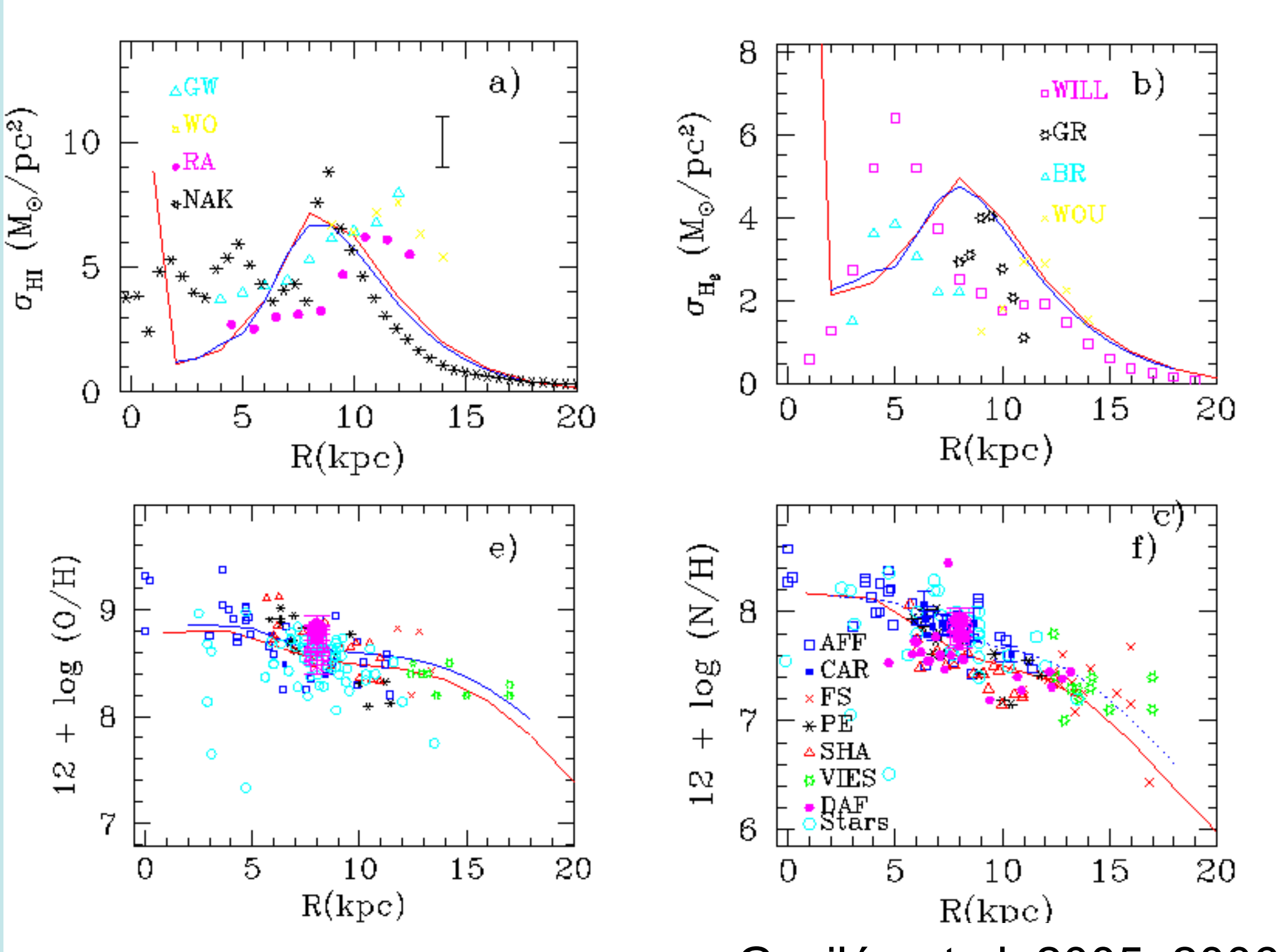


Gavilán et al. 2005, 2006

- The age-metallicity relation and the star formation history for the region at R= 8 kpc are well fitted
- The metallicity distribution does not show the G-dwarf problem

II. Calibration: the model: Vrot=200 km/s and N=4 against the Galactic disk data

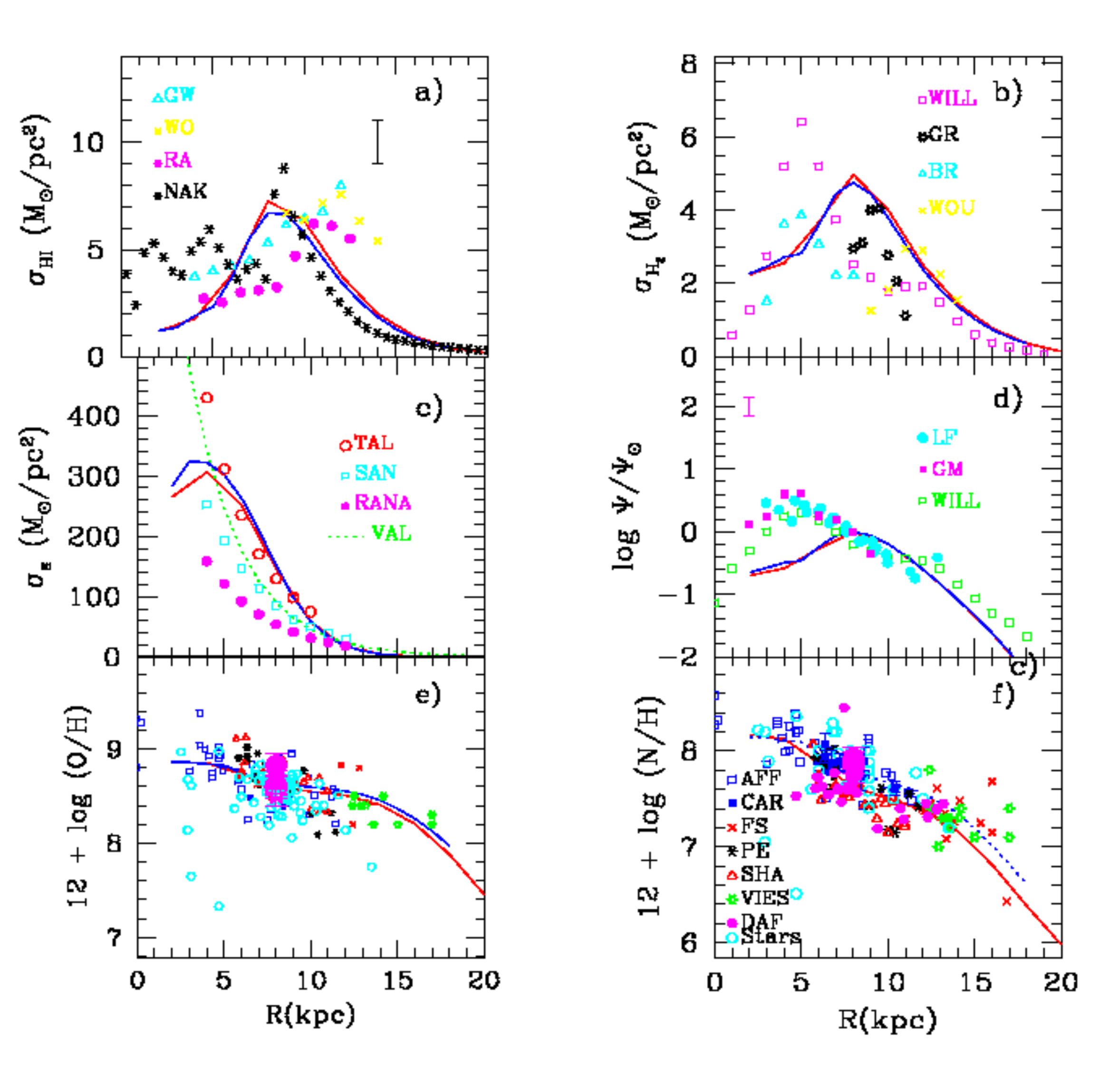
- We can obtain separately the radial distributions of diffuse and molecular gas
- The radial gradients flattens in the inner disk in agreement with data (Smartt et al. 2001)



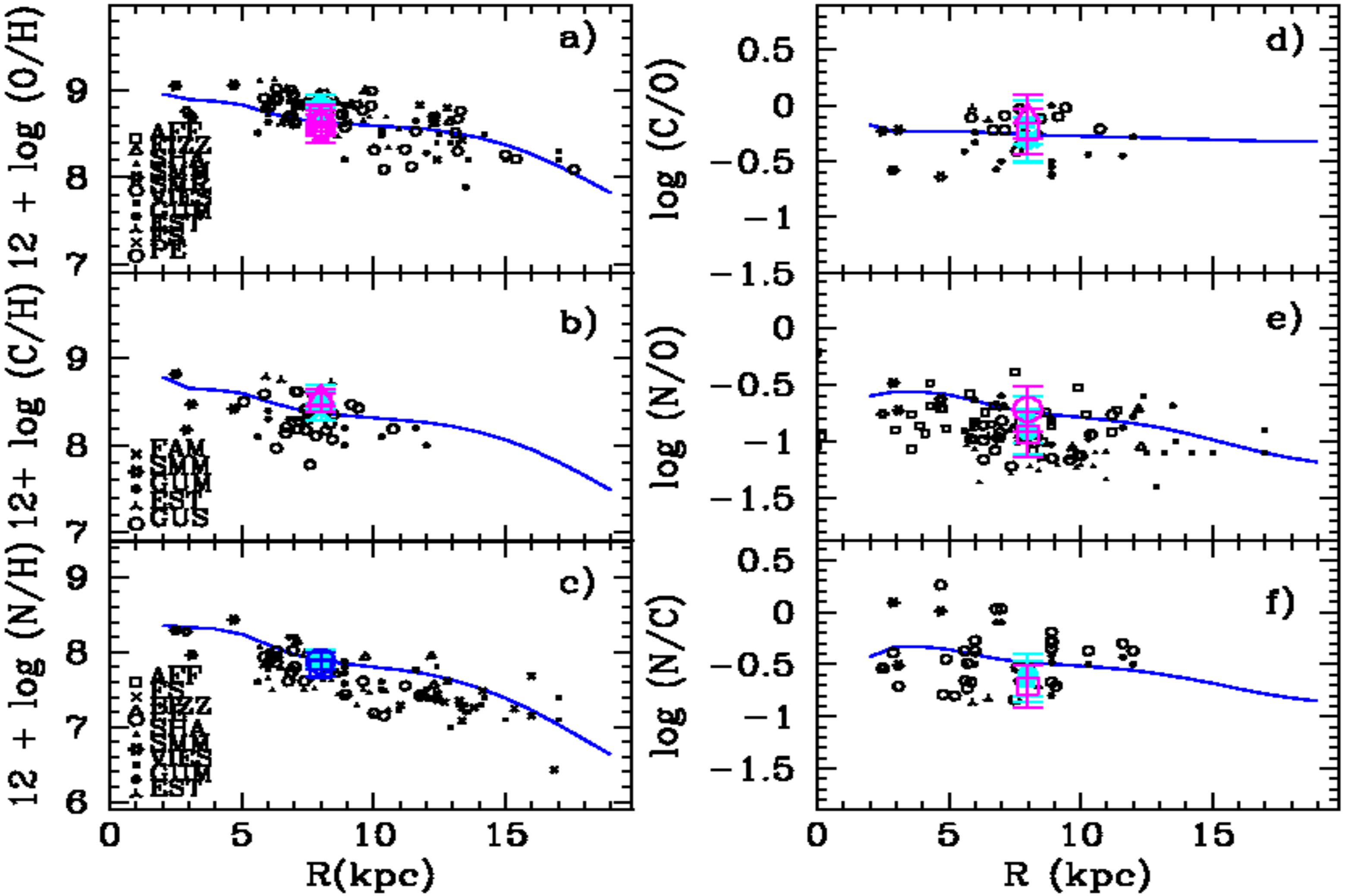
Gavilán et al. 2005, 2006

Calibration: the model for MWG (Gavilán et al. 2005, 2006)

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



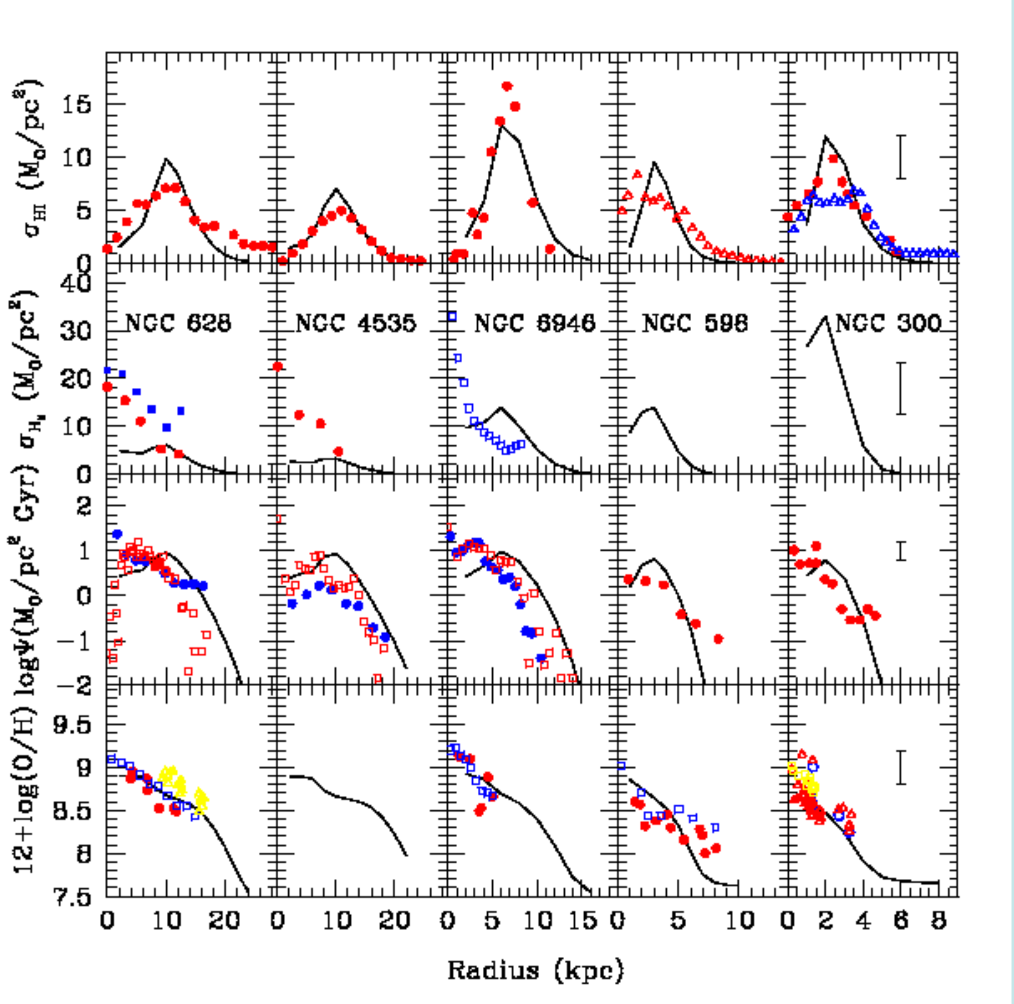
THE RADIAL GRADIENTS OF CNO ABUNDANCES



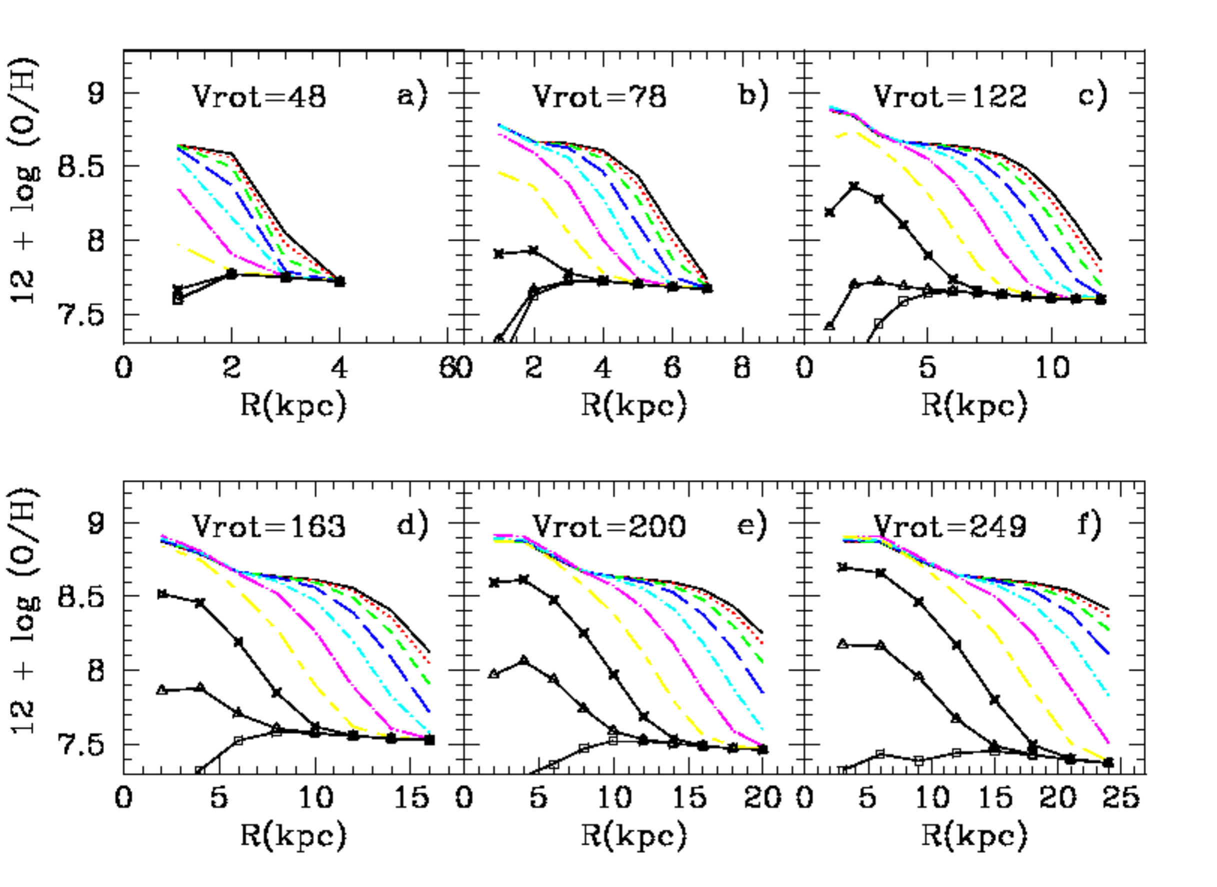
Results for particular galaxies:

1. Radial distributions for every galaxy in each time step
2. **Time evolution for the calculated quantities in each radial region of the galaxies**
   a) Star formation history
   b) Age-metallicity relation

Mollá & Díaz (2005)



Present time Oxygen radial distributions



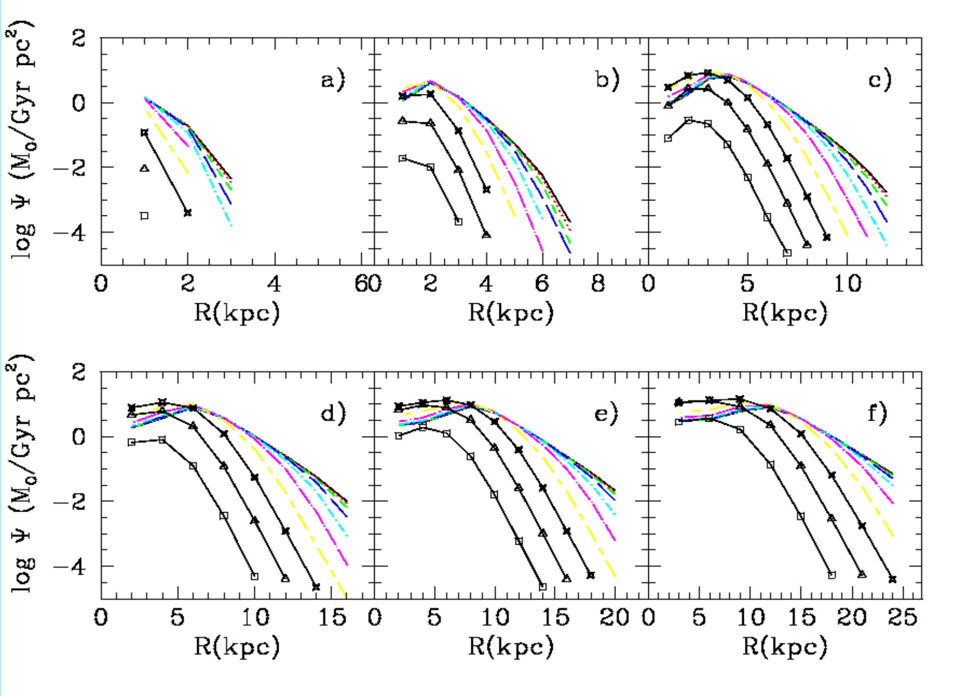
Flat radial gradients for low evolved galaxies and for the most evolved ones

A minimum level of O abundances at 7.5 dex

A saturation level around 9.0

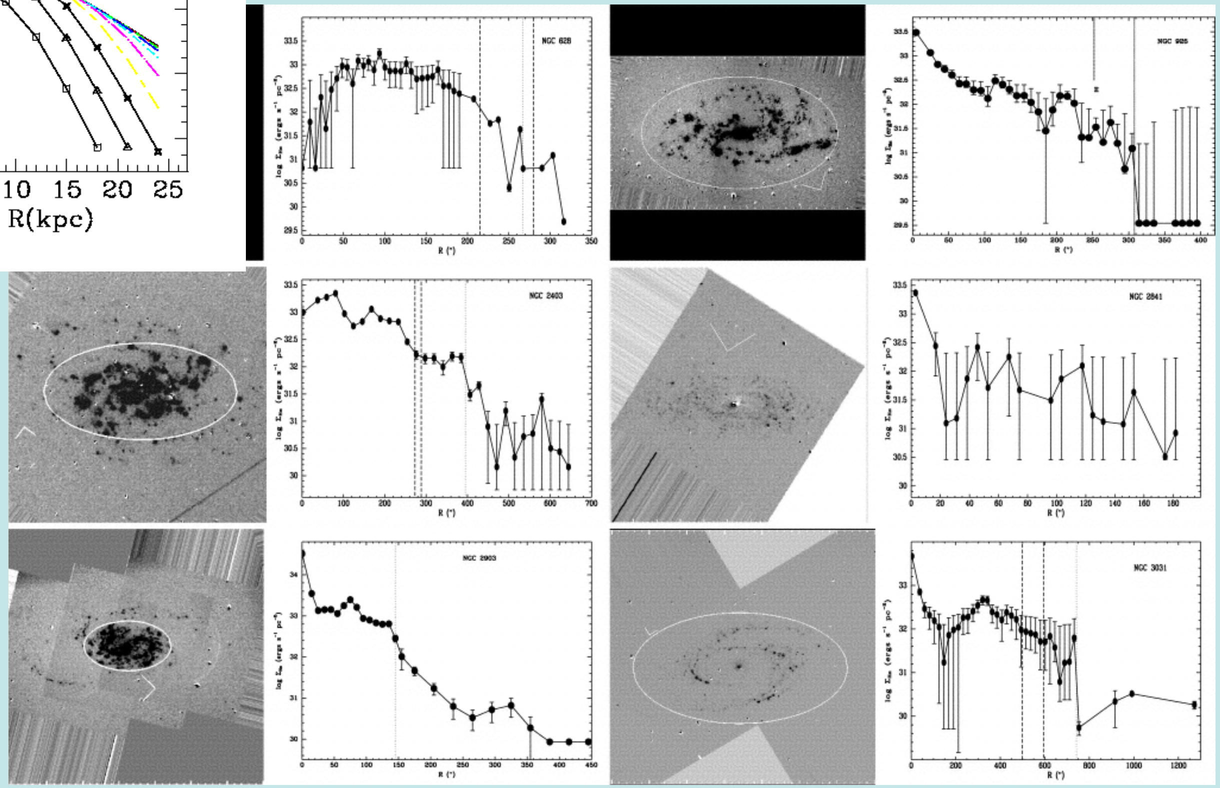
ESTALLIDOS collaboration

Star formation rate radial distributions



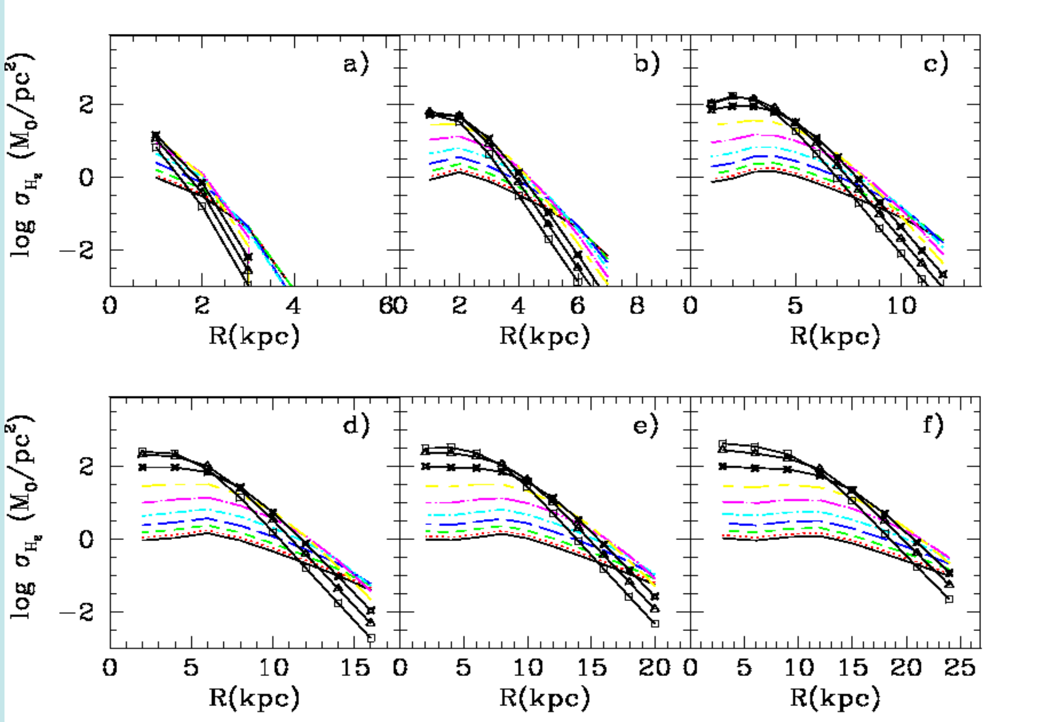
These distributions flattens at the inner disks

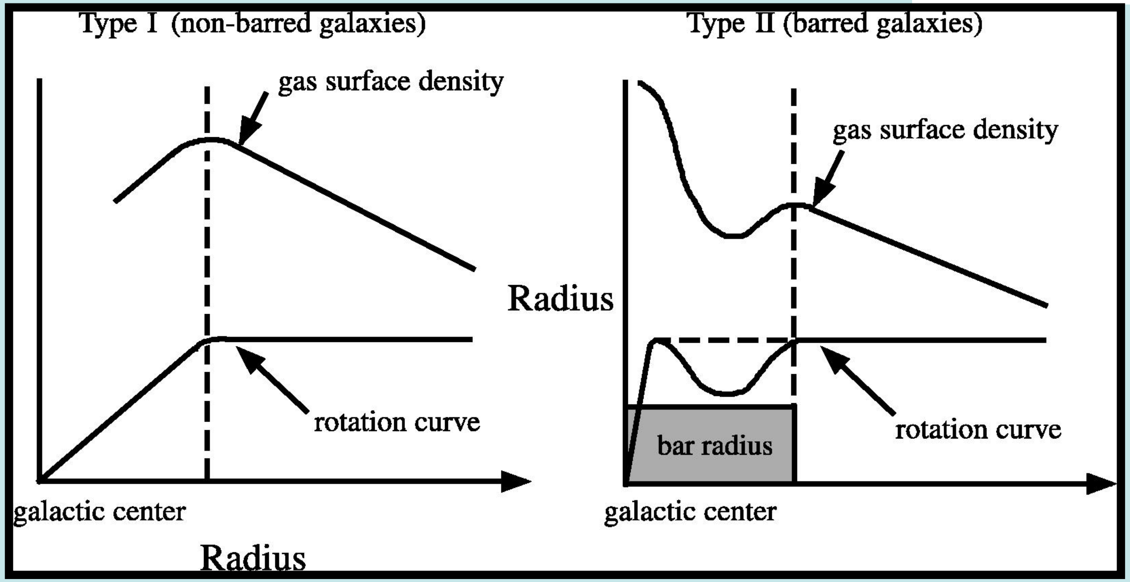
Martin & Kennicutt 2001, Hα fluxes *vs* R



Molecular gas surface density radial distributions

The distributions may be fitted to exponential but they are flatter at the inner radial regions, as observed

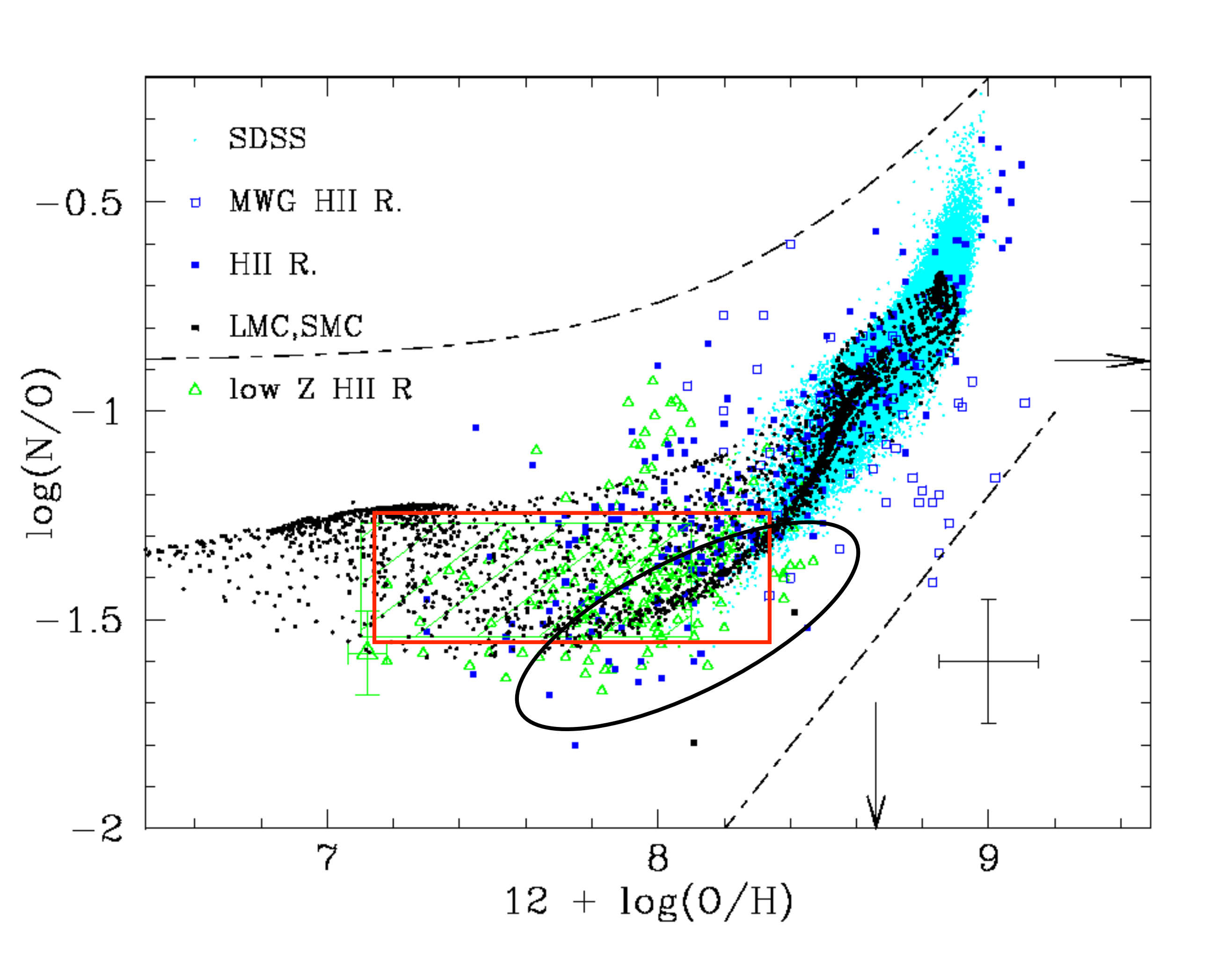




The generic form of the molecular gas radial distributions found by Nishiyama et al. (2001)

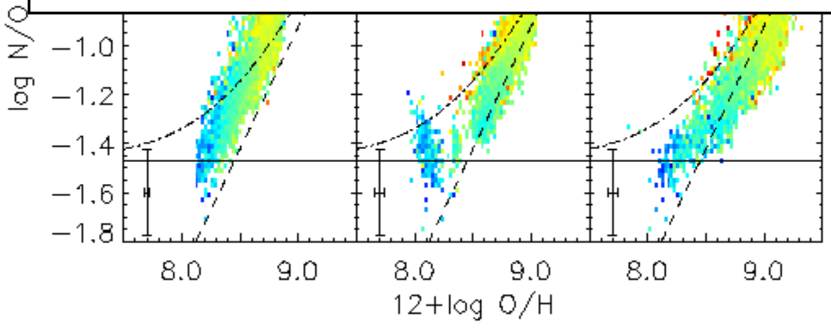
Nitrogeno vs Oxigeno

Los puntos negros representan modelos teóricos en el plano N/O vs O/H comparados con datos (puntos azules y verdes)

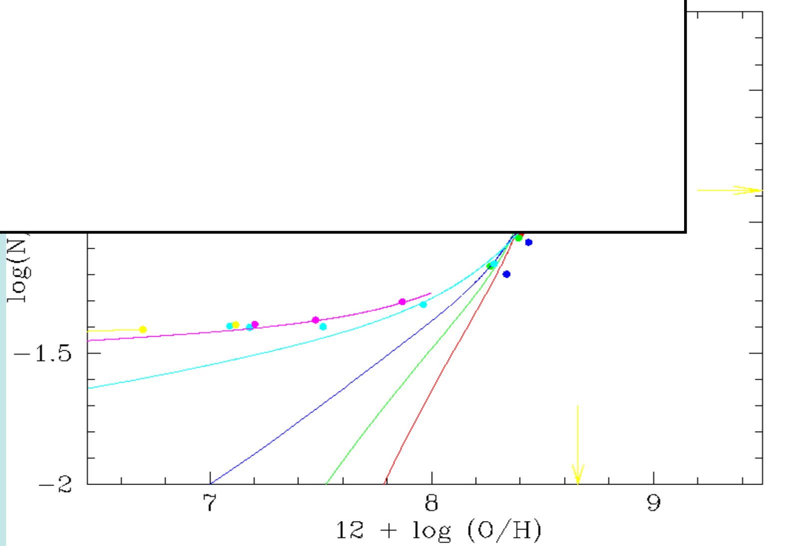


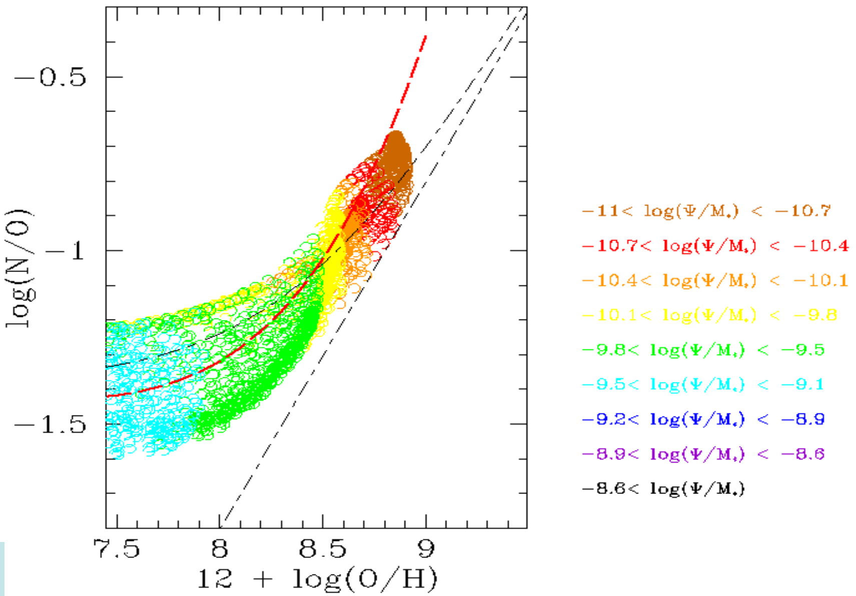
Cabo de Gata, 2013

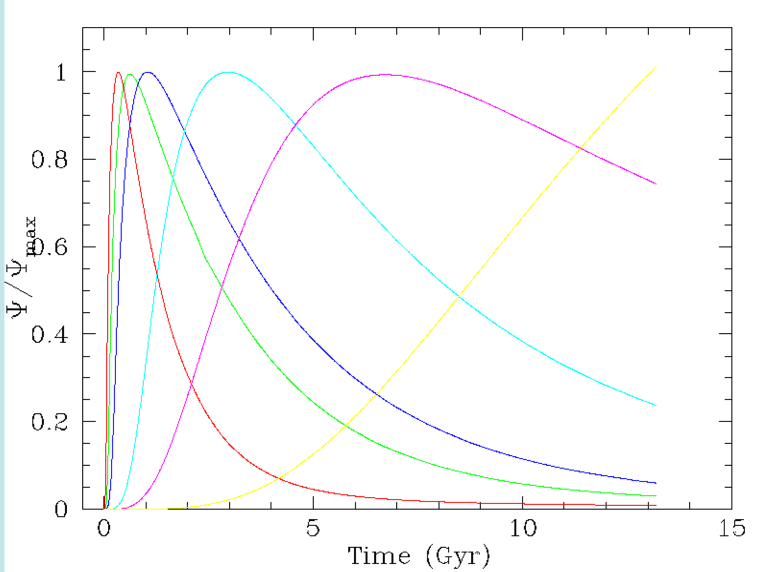
THE RELATION N/O-SFR-SFH



Galex data (Mallery et al. 2007)

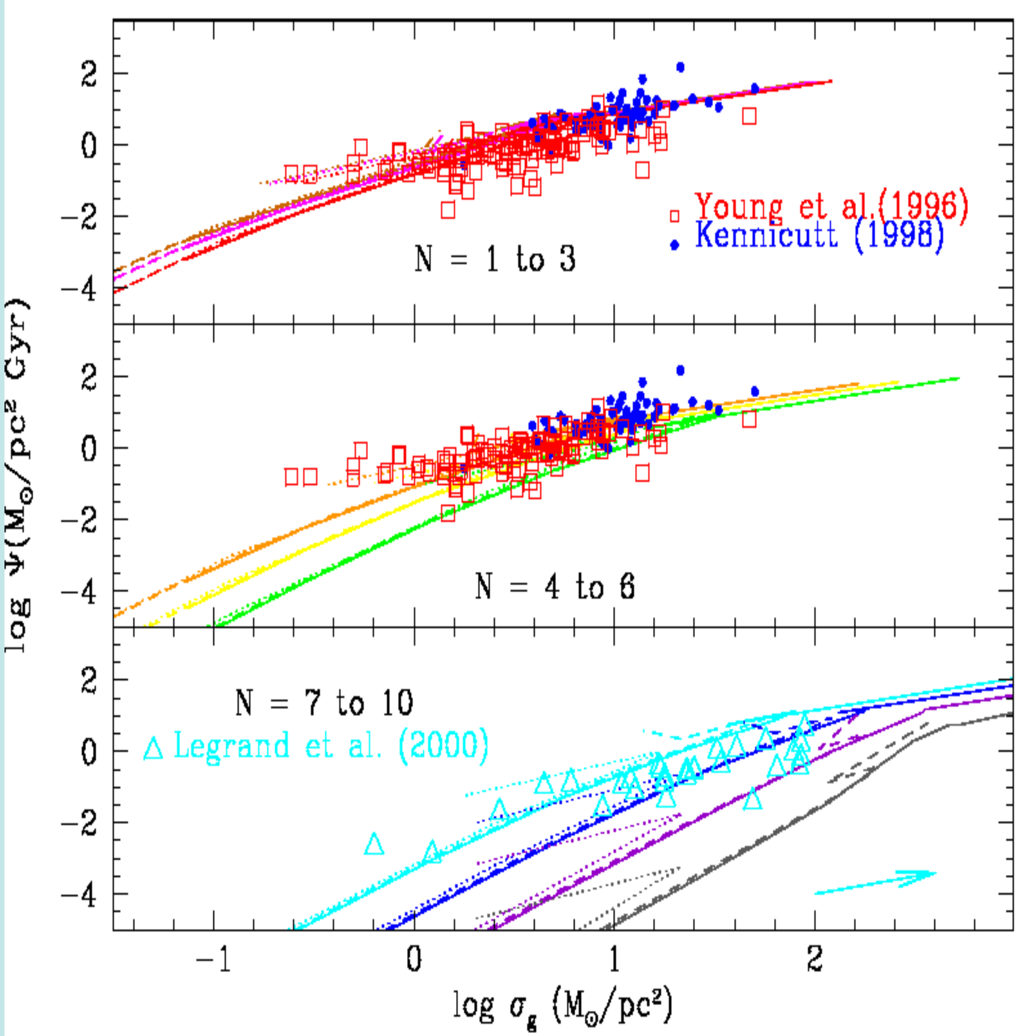






The star formation rate *vs* the gas density

The relation simulates a Kennicutt law, with different threshold density for every morphological type galaxy.



Observing Galaxies

Constraints Chemical Evolution Models

- **HII regions, emission lines Abundances**
- **Hα fluxes : (recent) Star formation rate**
- **Atomic and molecular gas densities**

Present time

- **Brightness Profiles**
- **Colors**
- **Spectral Indices**

Stellar Populations Indicators: Synthesis Models

Averaged along the evolutionary history Properties

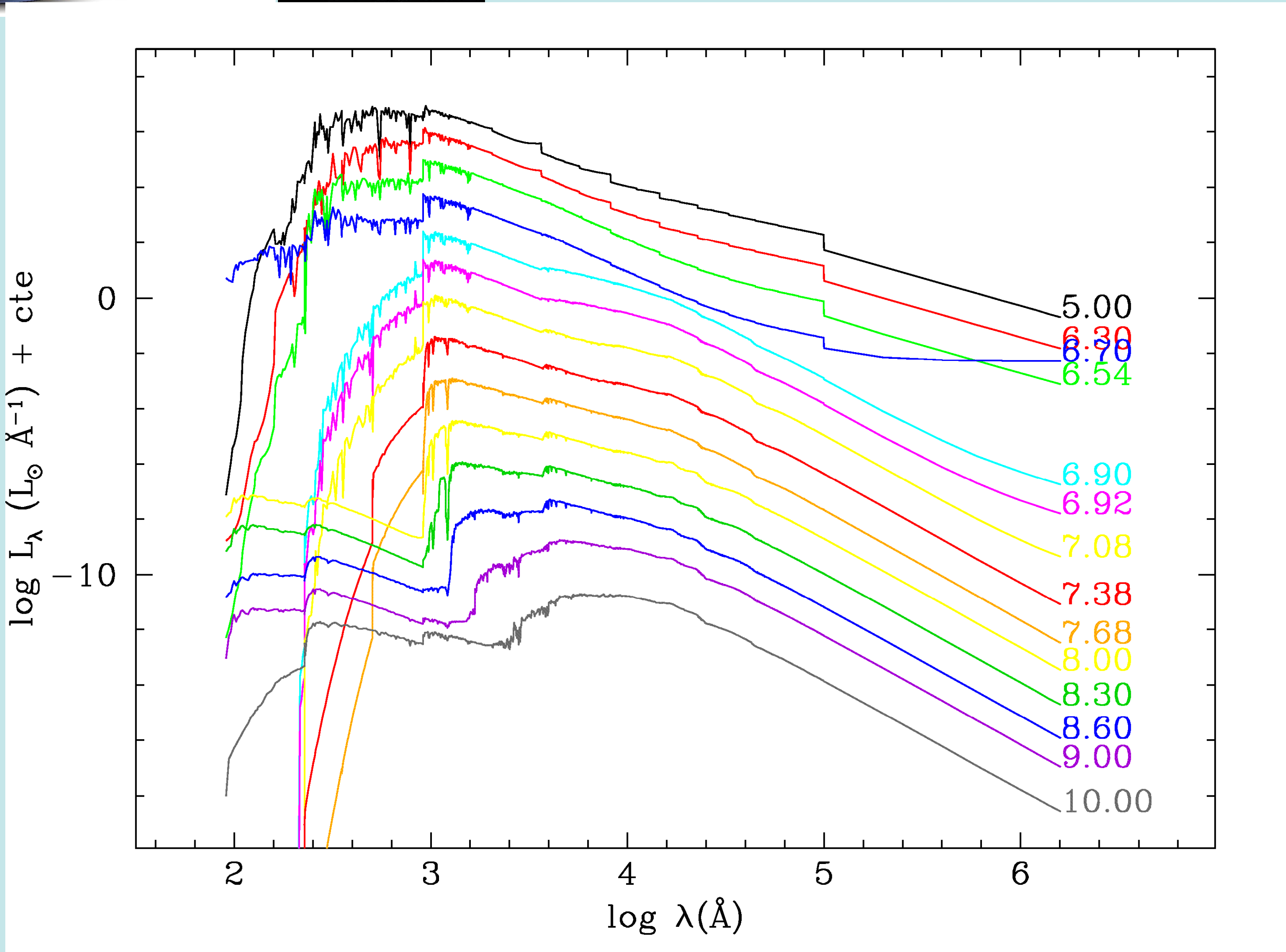
Chemical Evolution Models

- These models calculate the chemical evolution of a galaxy: stars form, die and eject the elements created by stellar nucleosynthesis.
- They are the tool to interpret the elemental abundances in terms of star formation rate and/or of the gas dilution/enrichment processes in each region
- The evolutionary history gives the final state of the gas and stars, and the intermediate steps, too. The successive stellar generations are well defined in terms of age, metallicity (abundances) and stars and gas masses.
- The classical numerical chemical evolution models do not require as long computation time as cosmological simulations, they are better to test new assumptions or new inputs

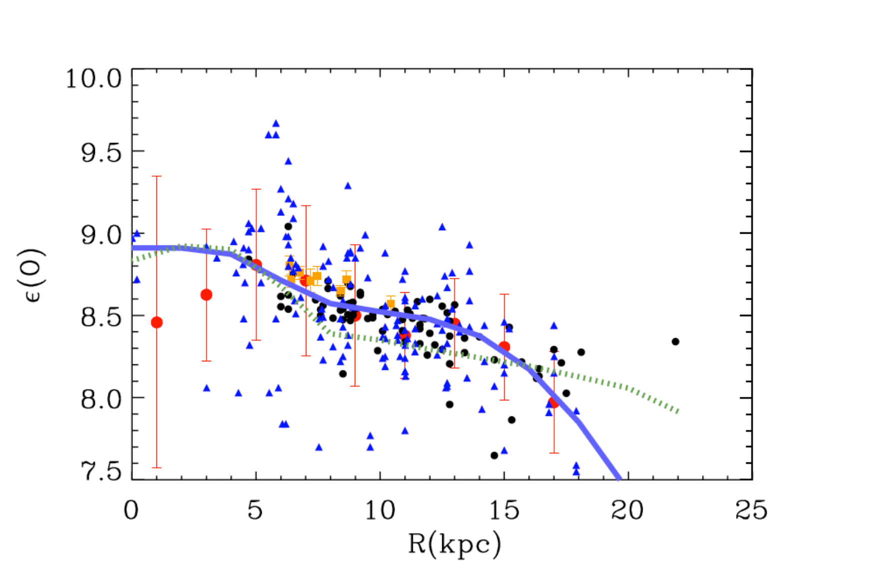
Our MD05 grid of models

- In Mollá & Díaz (2005) we presented a grid of chemical evolution models depending on the galaxy total mass and on the efficiency of star formation rate
- Radial distributions of mass calculated from the Universal Rotation Curve from Persic, Salucci & Steel (1996), defined by the ratio $\lambda(L_{gal}/L_{MWG})$
- Efficiencies to form molecular gas and stars were changed simultaneously: each N defined a set (ε_M, ε_H)
- A by-parametric grid of 44 radial mass distributions, defined by the rotation velocity, (vrot 30 to 300 km/s) and 10 values of N (ε_M, ε_H in the range [0,1]), were calculated, with the corresponding radial distributions of abundances, stars and gas densities and star formation rates.
- Results (radial distributions of gas, abundances, star formation...), and the time evolution of each radial region, were given as a function of the total mass of the galaxy for different values of efficiencies to form molecular cloud and stars

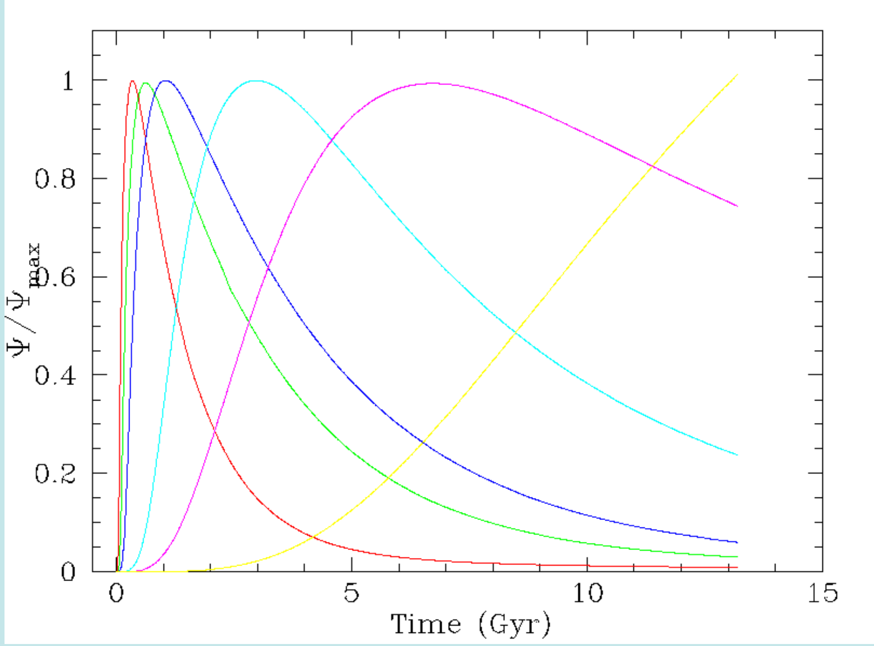
Espectros de poblaciones estelares

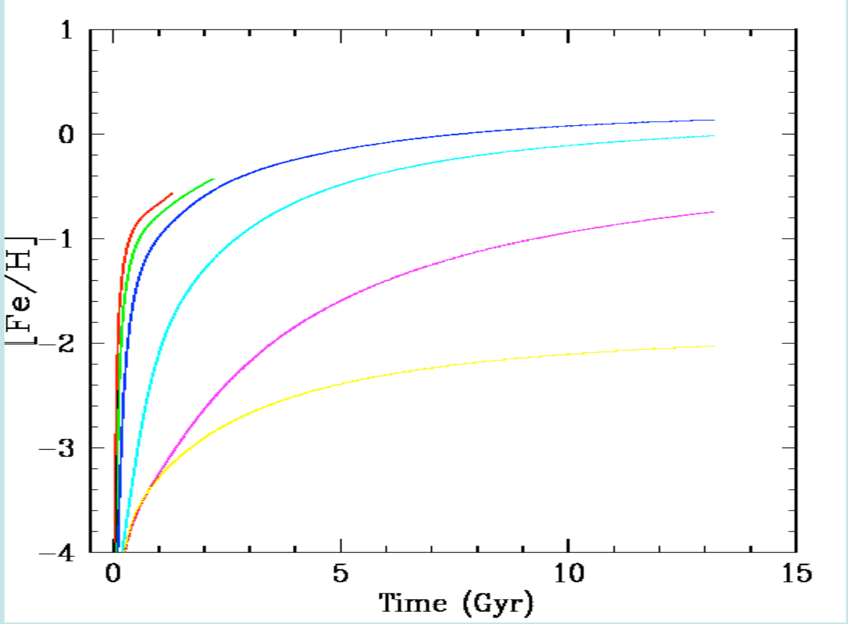


Gradientes de abundancia en discos



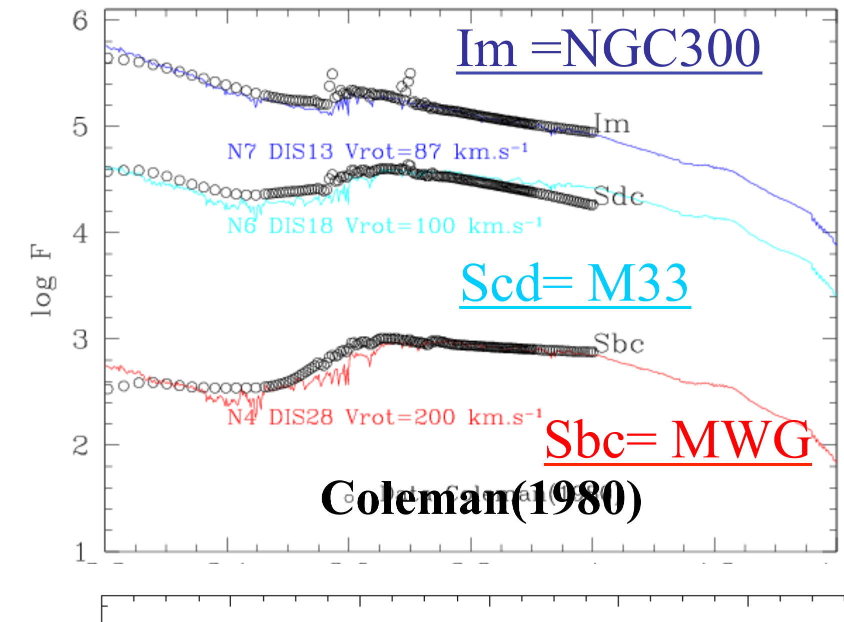
Relación de gradientes con la formación de estrellas en distintas regiones de los discos

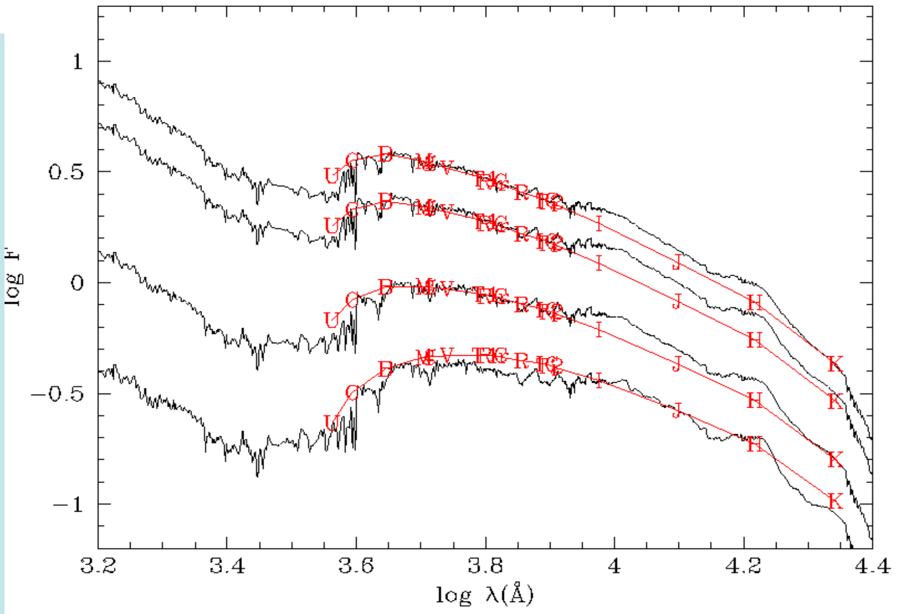


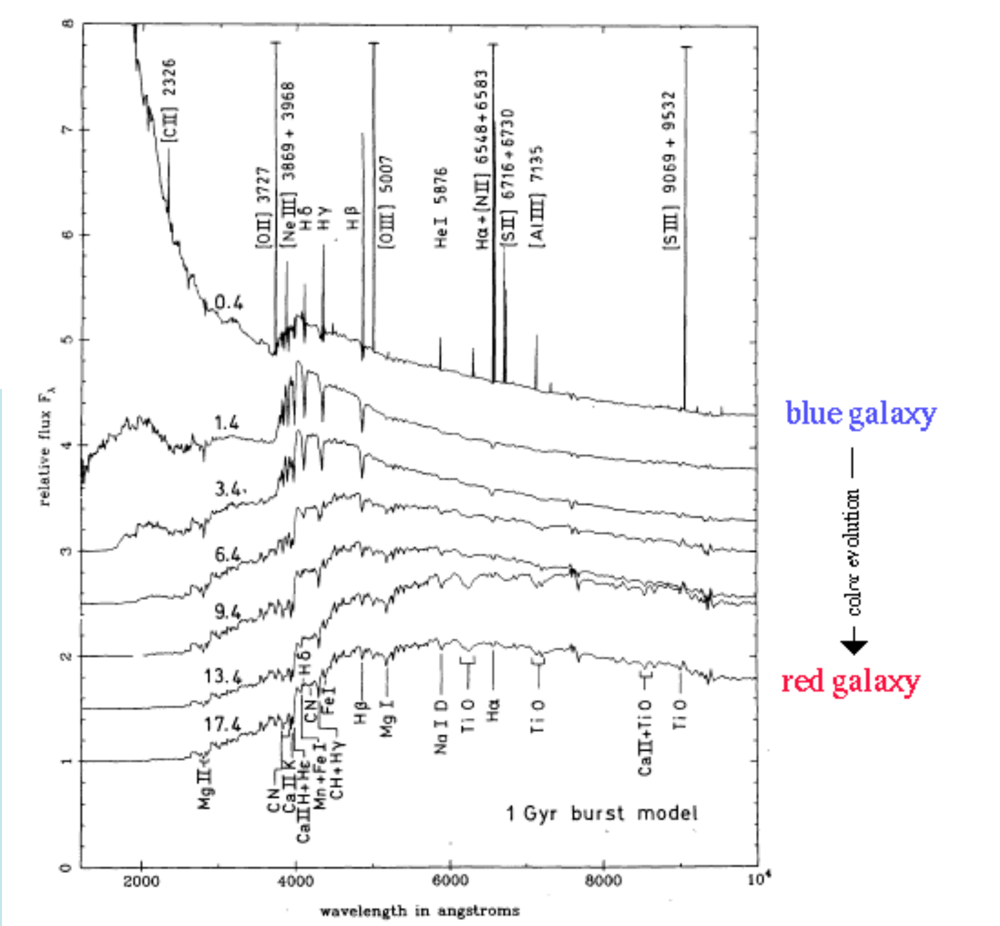


Cabo de Gata, 2013

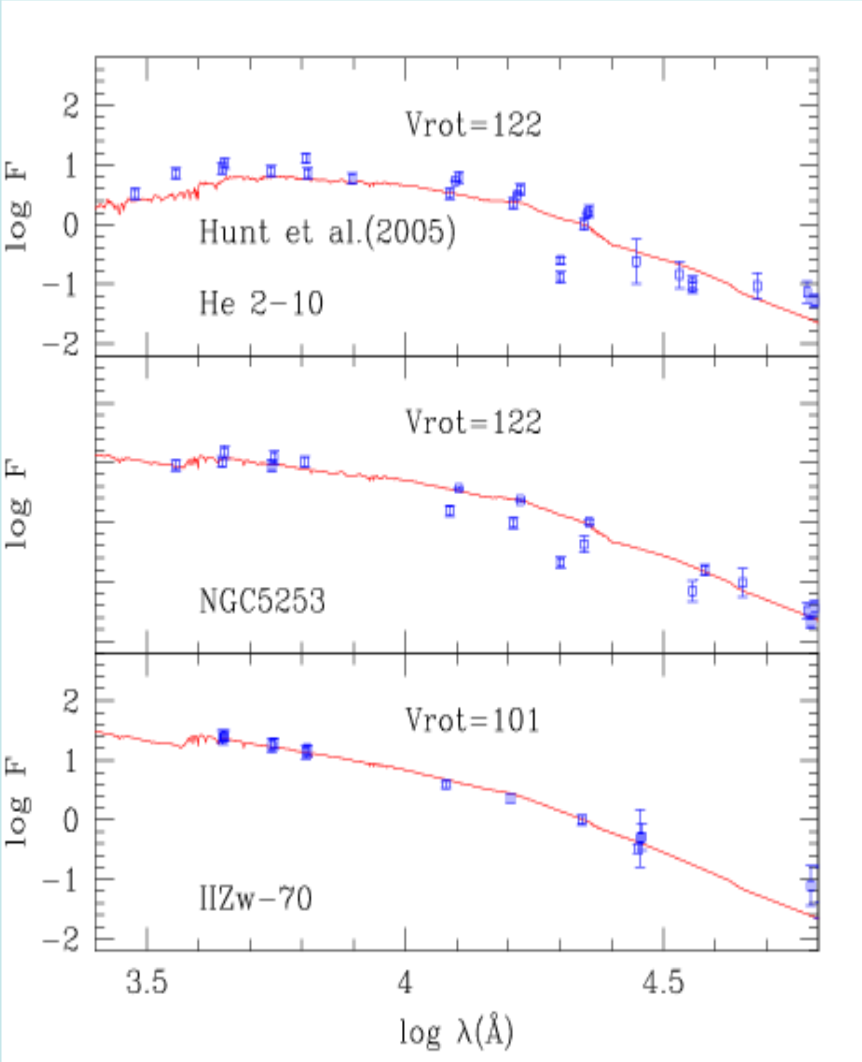
POBLACIONES ESTELARES INTEGRADAS

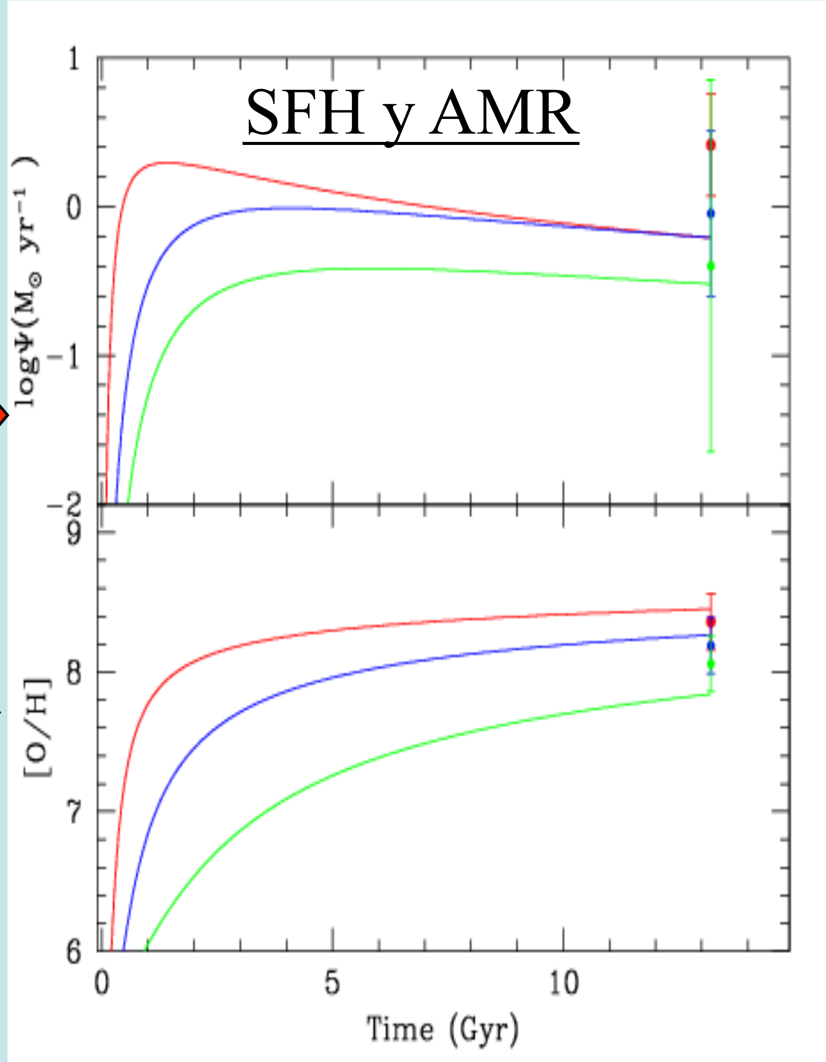






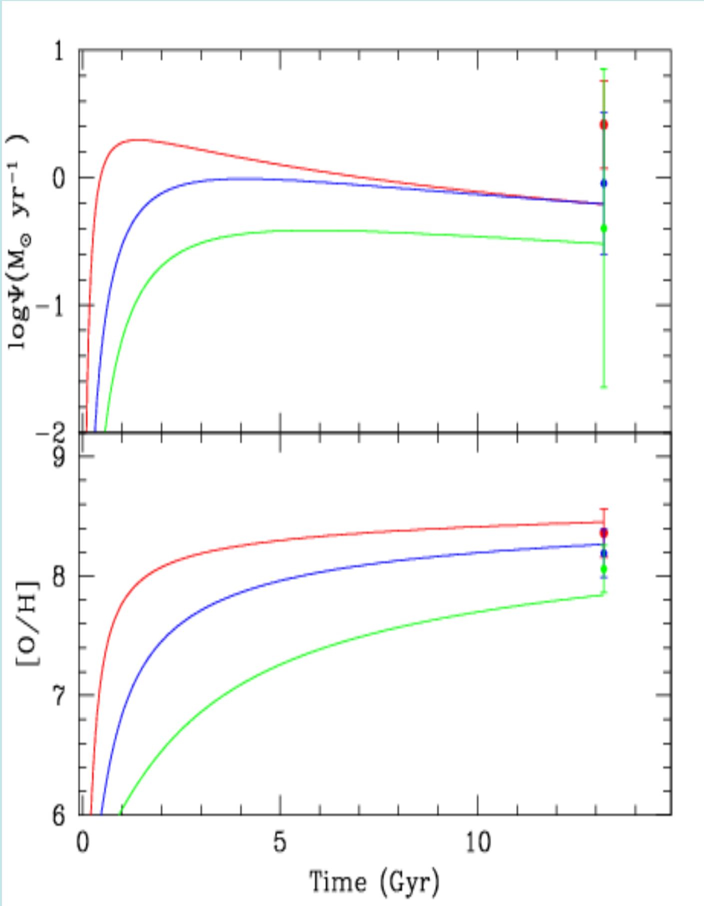
La relación de las distribuciones espectrales de energía con las historias de formación estelar y enriquecimiento químico

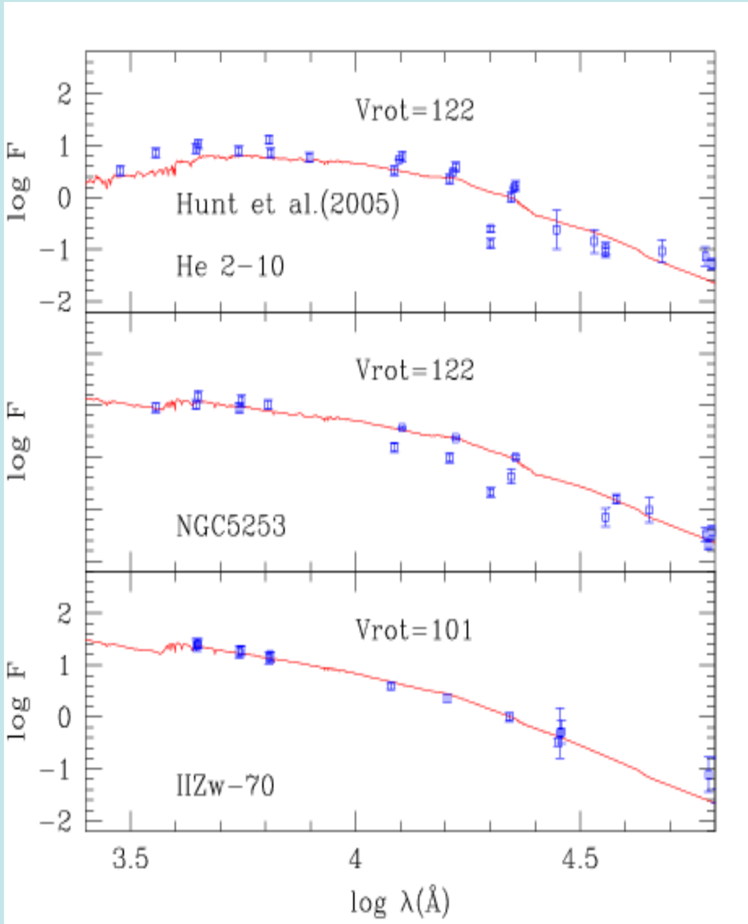




From the evolutionary histories and using evolutionary synthesis models, we obtained the spectral energy distributions, magnitudes and colors, brightness profiles and spectral absorption lines along the galactocentric radius for every galaxy model.

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



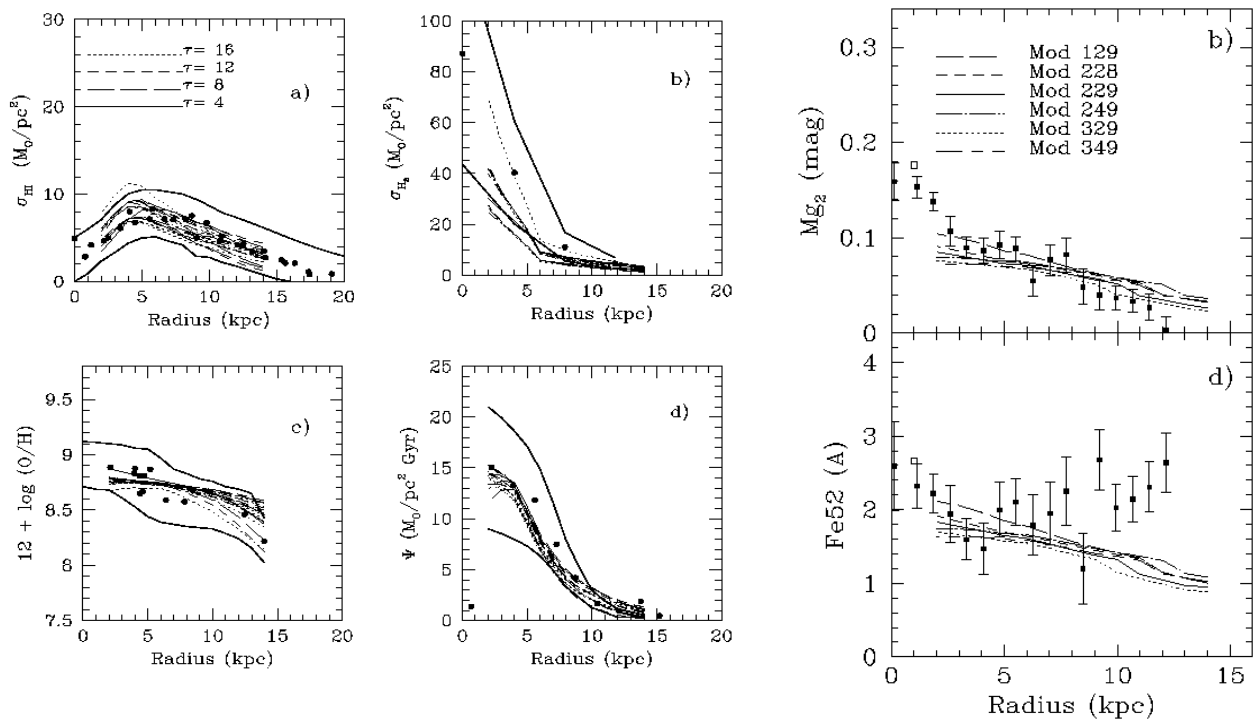


Spectral absorption stellar indices: the stellar abundances

We computed 500 chemical evolution models with variable inputs (ε´s, τ) for 3 galaxies from the Virgo cluster (Mollá et al. 1999)

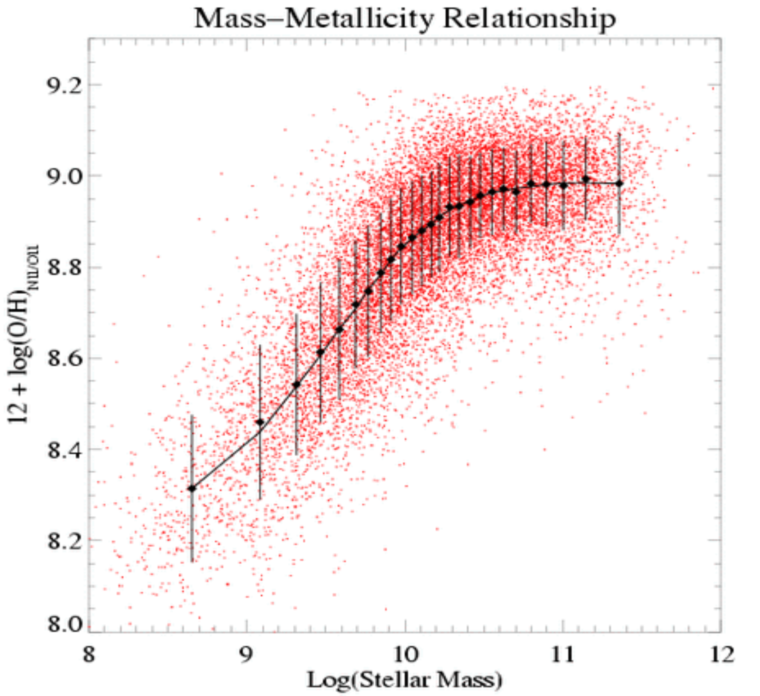
Posible chemical evolution models that reproduce the gas data at the present time:

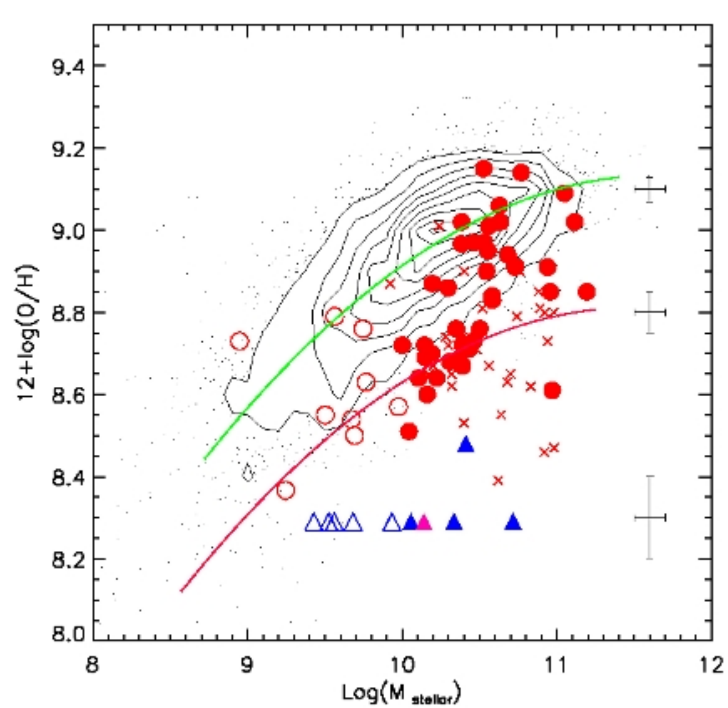
Only 19 from 500 are valid



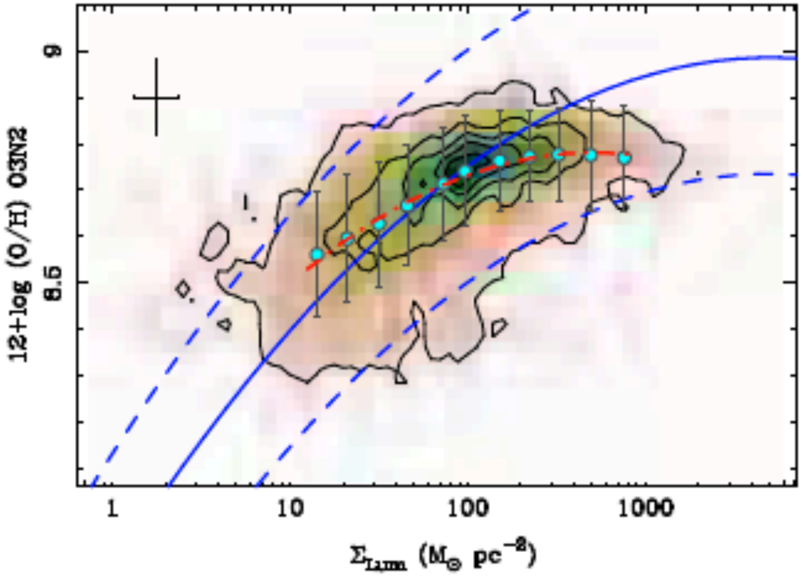
Only 6 models from 500 may fit simultaneusly these stellar constraints and those from the gas.

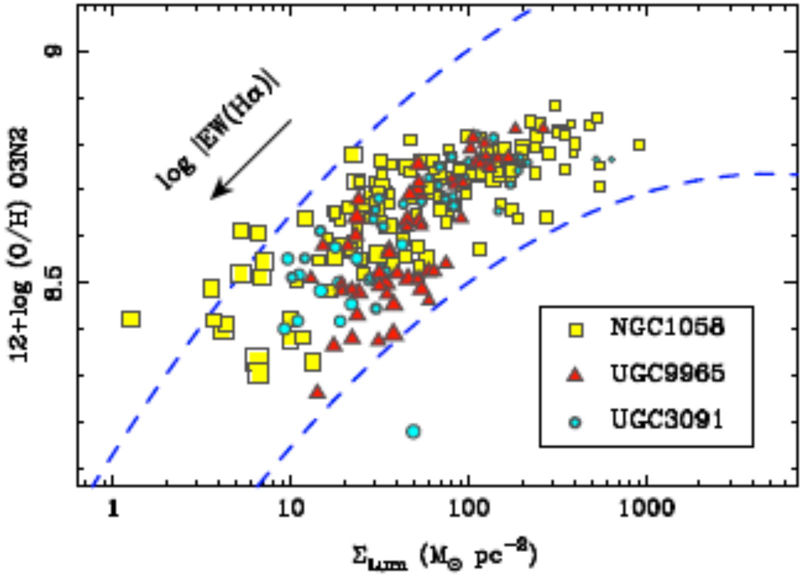
Relación masa-metalicidad





F. Rosales, 2012, astroph





C.

Comparison with the closed box model

- Usually the *closed box model* is used:
  - It assumes that the whole stars of a generation have died and ejected their products.
  - It is an approximation which only gives the upper limit of abundances.
  - Its predictions are not valid when the gas fraction decreases.

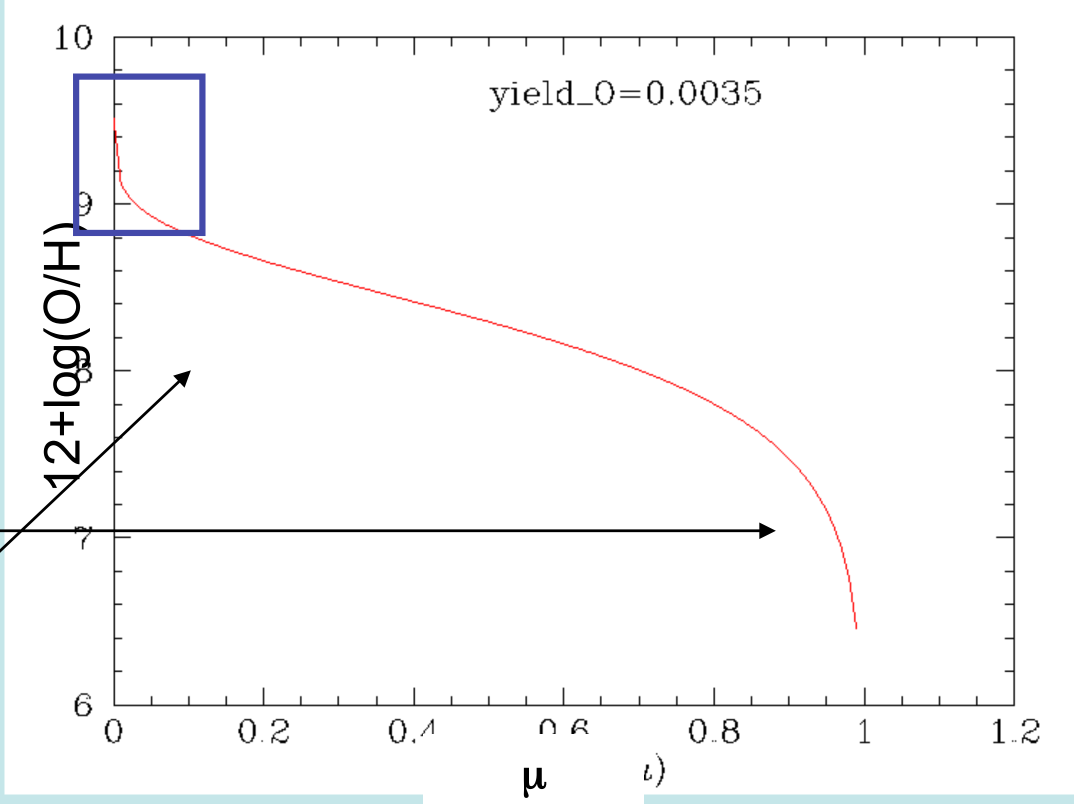
$$E_Z = \int_{m_t}^{\infty} m p_{z,m} \Psi(t-\tau_m)\Phi(m)dm +$$

$$\int_{m_t}^{\infty} (m - \omega_m - m p_{z,m}) Z(t-\tau_m)\Psi(t-\tau_m)\Phi(m)dm$$

If: a) the system is **closed** and

b) the products are instantaneous ejected and diluted E(t)= (t)R

c) Z=y ln ^-1 only if Z << 1



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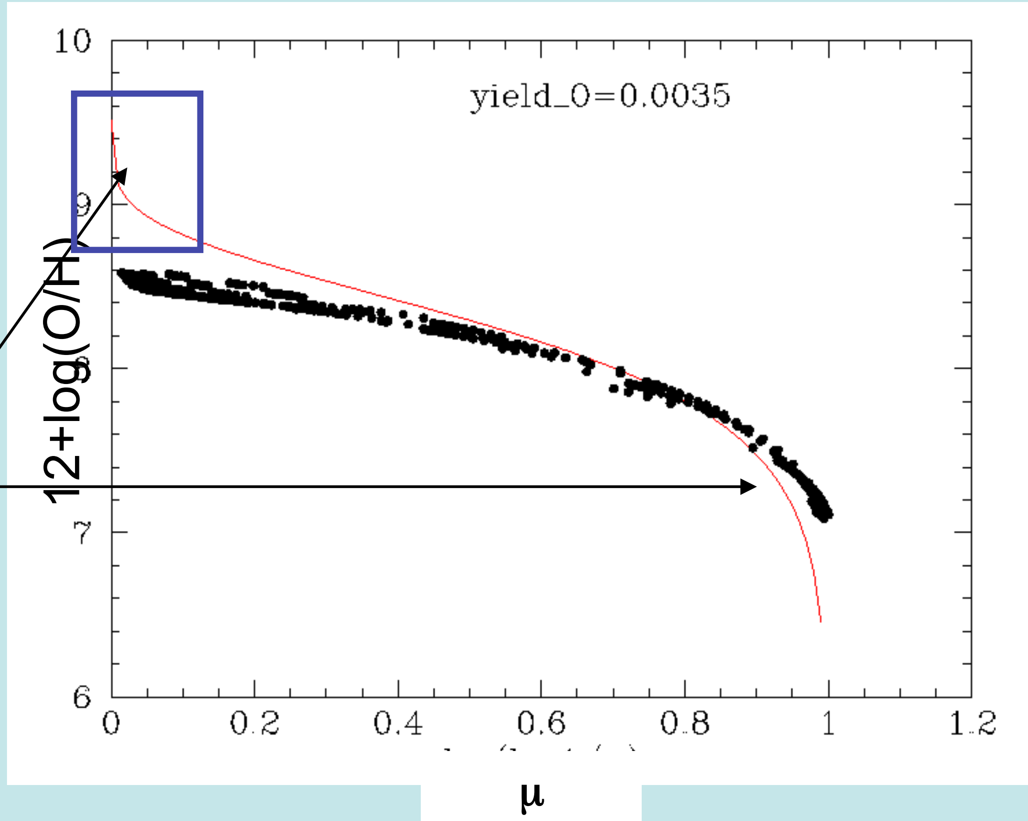


Production of nuclei in stars: Stellar yields

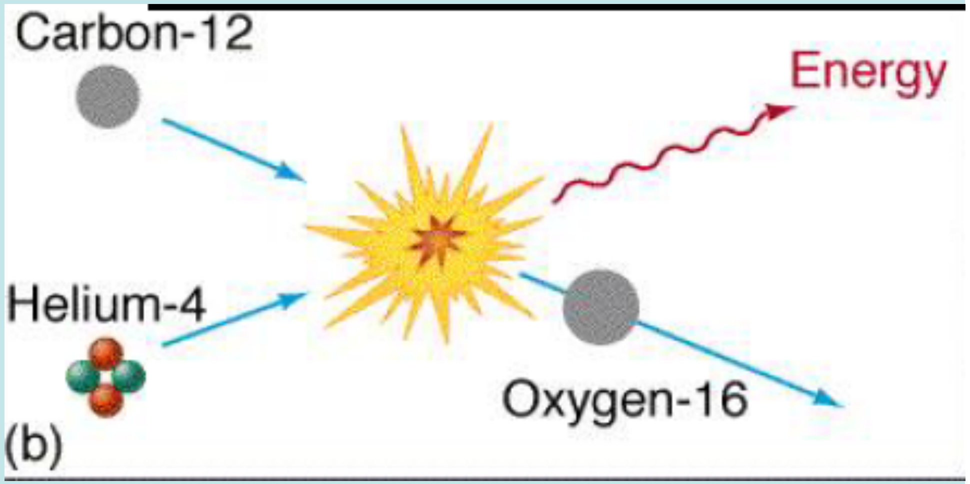
Intermediate mass stars:

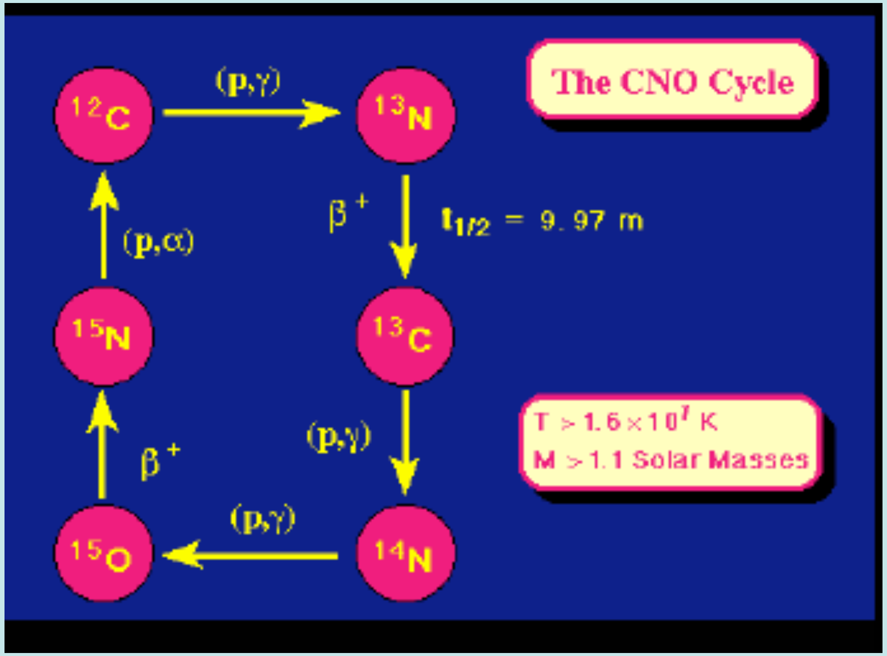
4 Msun< m < 8 Msun

Burning of 12C

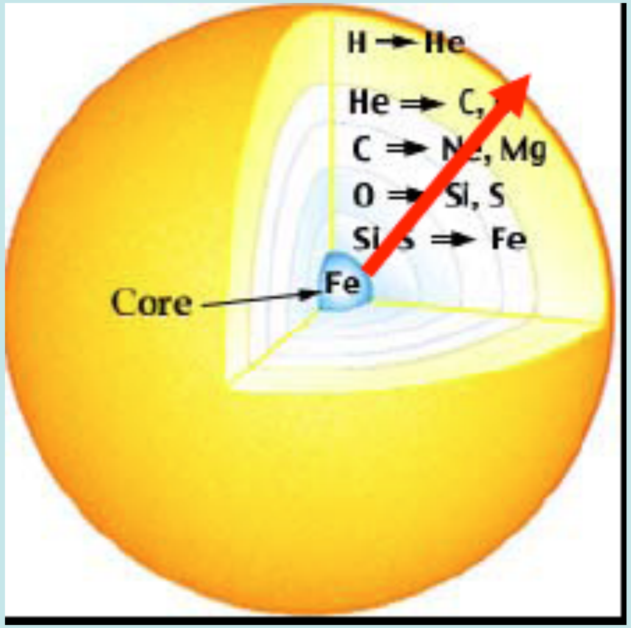
CNO cycle

Production of N (primary)



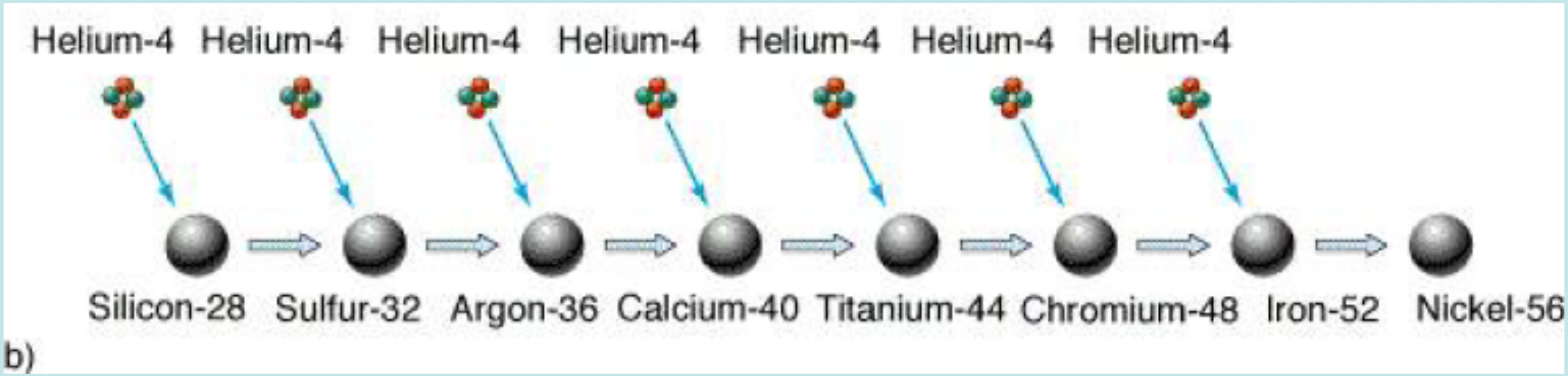


Massive stars: m > 8Msun



Process alpha

$${}^{4}He \overset{\alpha}{\leftrightarrow} {}^{8}Be \overset{\alpha}{\leftrightarrow} {}^{12}C \overset{\alpha}{\leftrightarrow} {}^{16}O \overset{\alpha}{\leftrightarrow} {}^{20}Ne$$



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GOBIERNO DE ESPAÑA — MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Ciemat — Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Universo Composition:
5% barionic matter

25% dark matter

70% dark energy

Formation of structures:

Cosmological simulations of galaxy formation

Types of galaxies

Morphological Evolution of galaxies

GALAXIES: STARS and CHEMICAL ENRICHMENT

Star formation

Life and death of stars

Stellar evolution: mean lifetimes and production of elements

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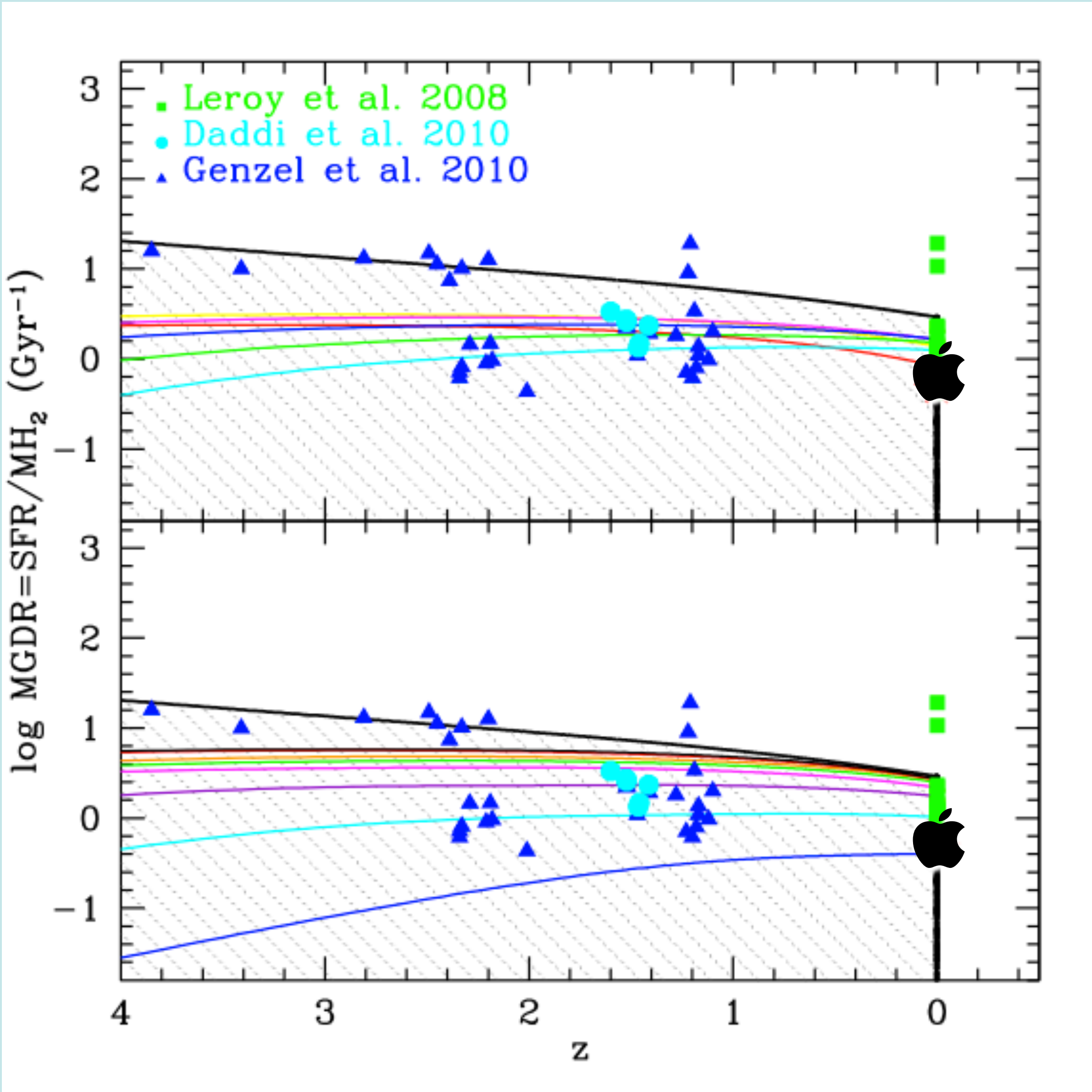
Abstract

We will summarize our grid of chemical and spectro-photometrical models applied to spiral and irregular galaxies. They have been calculated consistently by applying to the chemical evolution models from Mollá & Díaz (2005), updated with the most recent inputs (Mollá et al 2013 in preparation).

We will analyze the impact of the new assumptions related with the infall rate law, the IMF and stellar yields, and new prescriptions to form molecular clouds.

Furthermore we will show the spectro-photometric information obtained when the evolutionary synthesis models from POPSTAR (Mollá et al 2009, Martín-Manjón 2010, García-Vargas et al. 2013) are applied to the resulting star formation and enrichment histories of this type of galaxies.


Leroy et al. 2008
Daddi et al. 2010
Genzel et al. 2010
log MGDR=SFR/MH$_2$ (Gyr^{-1})
z

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