Models for (spiral) galaxies

- Spectra
- Brightness Profiles
- Colors
- Spectral Indices

Stellar Populations Indicators: Synthesis Models

Averaged along the evolutionary history Properties

Constraints Chemical Evolution Models

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

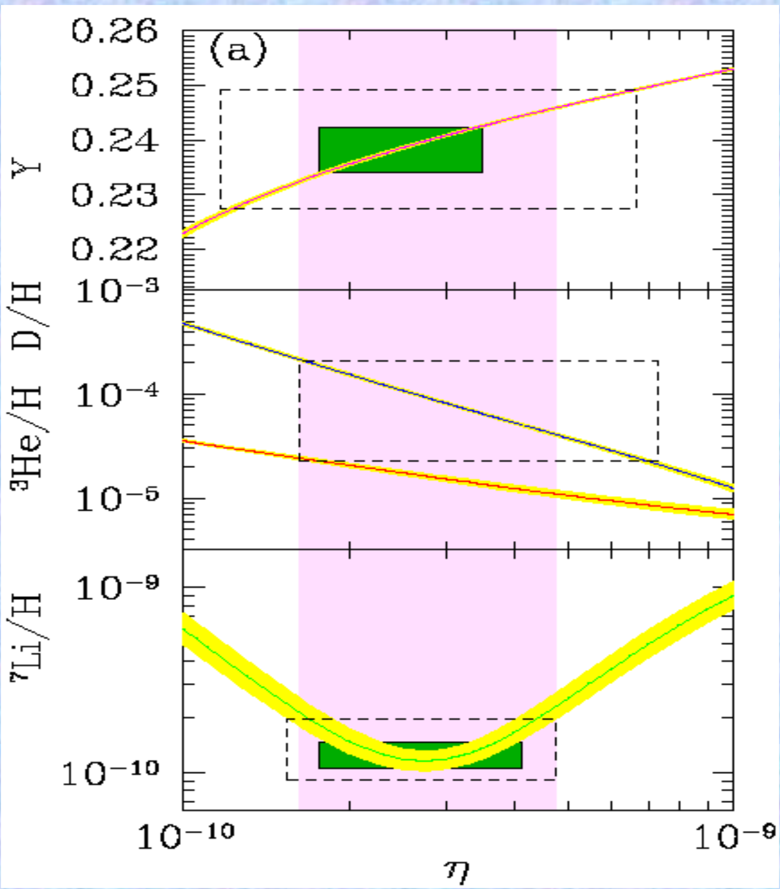
Present time

CHEMICAL EVOLUTION MODELS FOR SPIRAL AND IRREGULAR GALAXIES

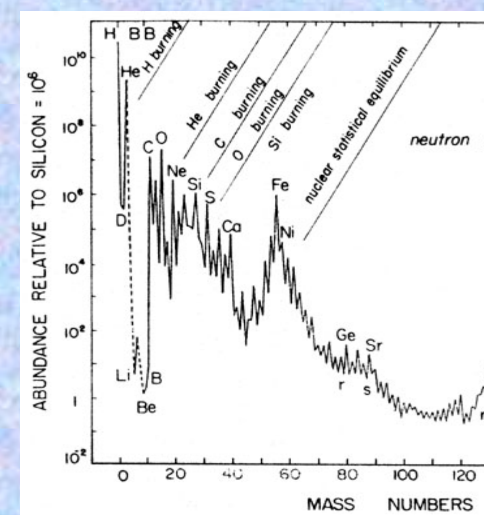
Mercedes Mollá
CIEMAT, Madrid (Spain)

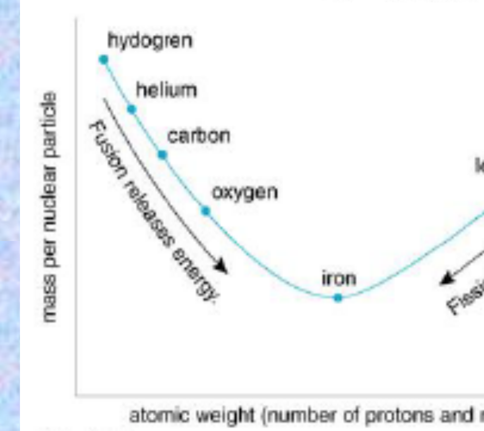
GH14-IFS techniques and analysis

Primordial & Solar abundances



Before the creation of stars. There are H, He and traces of Li or Be from Big Bang

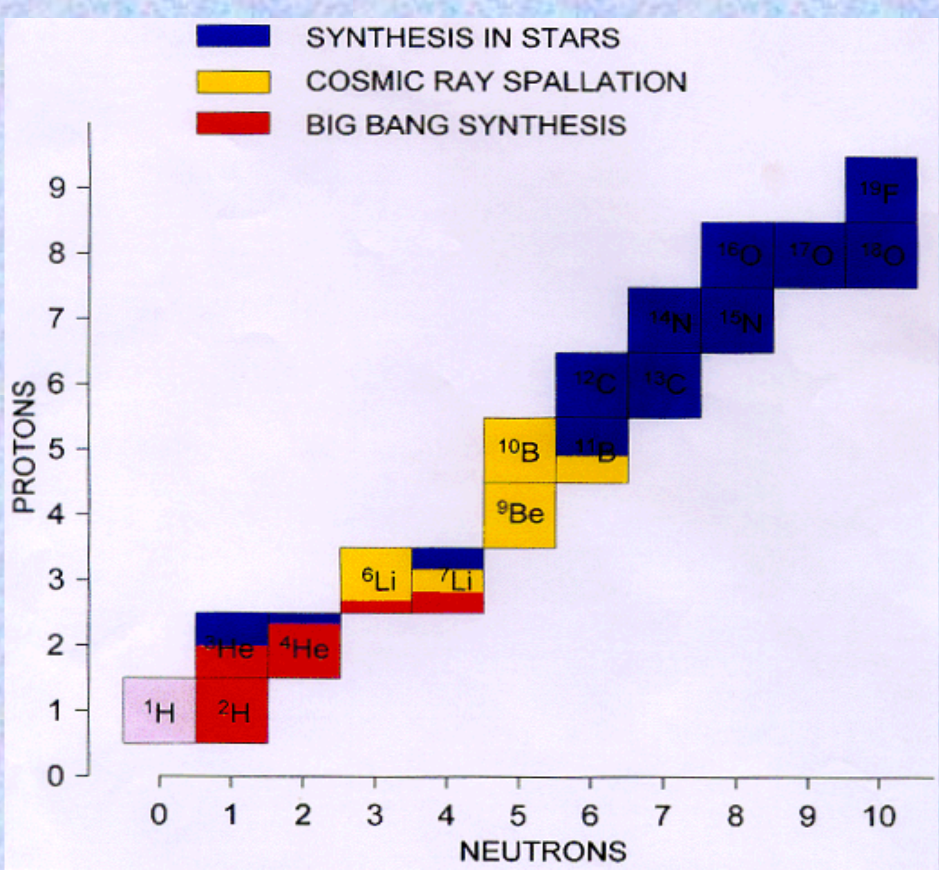




H	0.735
He	0.248
D	0.48e-4
He3	0.29e-4
C	0.292e-2
O	0.795e-2
N	0.856e-3
Ne	0.177e-2
Mg	0.671e-3
Si	0.730e-3
S	0.503e-3
Ca	0.674e-4
Fe	0.130e-2

- Associated with magic numbe
- Separation among pics: slow or rapide addition of n

- Chemical elements appear in the Universe as a consequence of three processes of elements production:
  - Big Bang Nucleosynthesis
  - Fragmentation processes (Cosmic Rays)
  - Stellar Nucleosynthesis
- H will dissapear at the same time that metals (elements weighther than He) increase their abundances.
- The gas composition is defined by: X+Y+Z=1, X=H Y=He, Z=metals
- Primordial abundances: X=0.76, Y=0.24, Z=0,
- Solar abundances: X=0.70, Y=0.28, Z=0.02.



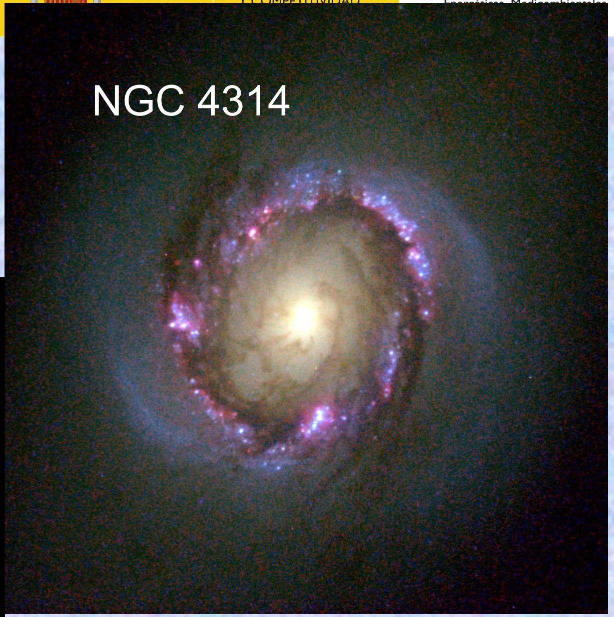
Burbidge, Burbidge & Hoyle 1957

Overview of nucleosynthesis mechanisms

- H-burning
- He-burning
- C-burning
- O-burning
- Ne-burning
- Si-burning
- NSE

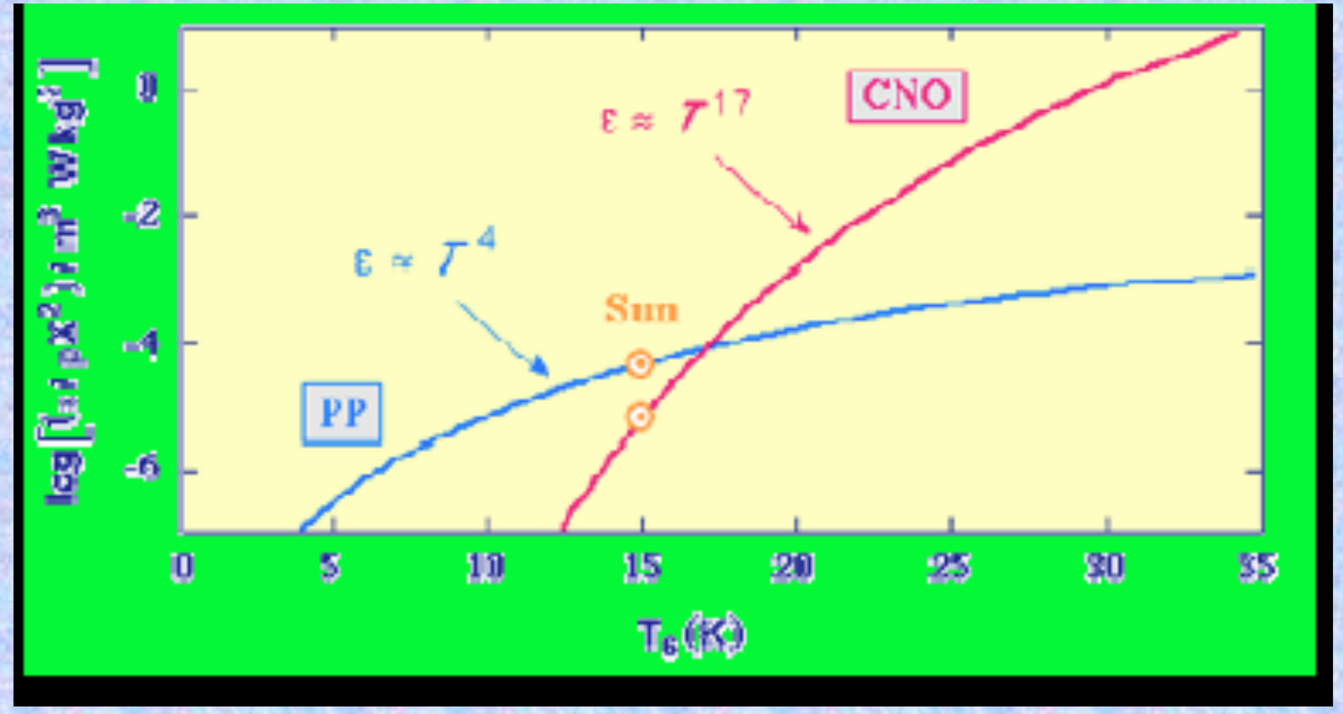
- s-process
- r-process
- p-process
- γ-process
- ν-process
- spallation reactions

Some of these mechanisms can work in hydrostatic or hydrodynamic regimes



New stars forming: HII regions

Production of nuclei in stars: Stellar yields



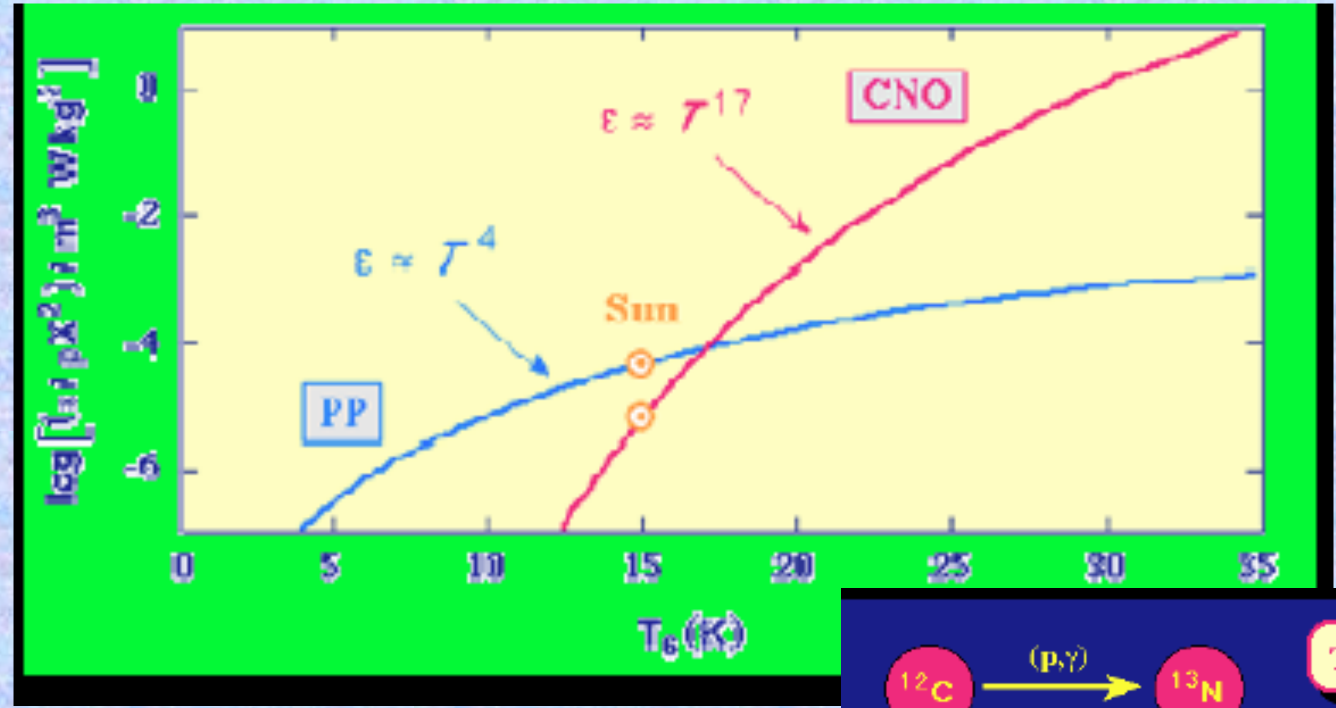
Low mass stars: m < 4Msun

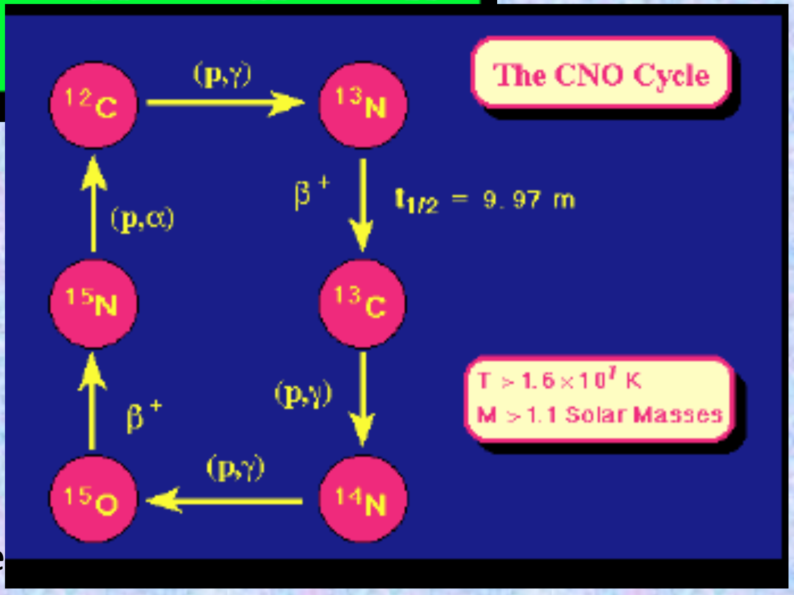
Burning of H

Burning of 4He

$$^{4}He + ^{4}He \leftrightarrow *^{8}Be$$
$$^{4}He + *^{8}Be \leftrightarrow *^{12}C$$

Production of nuclei in stars: Stellar yields





Intermediate mass stars:

4 Msun< m < 8 Msun

Burning of 12C

CNO cycle

Production of N (primary)

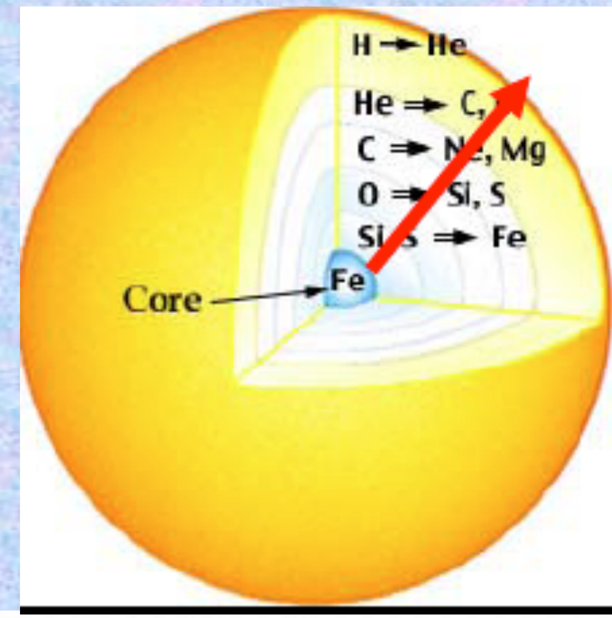
GH14-IFS technique

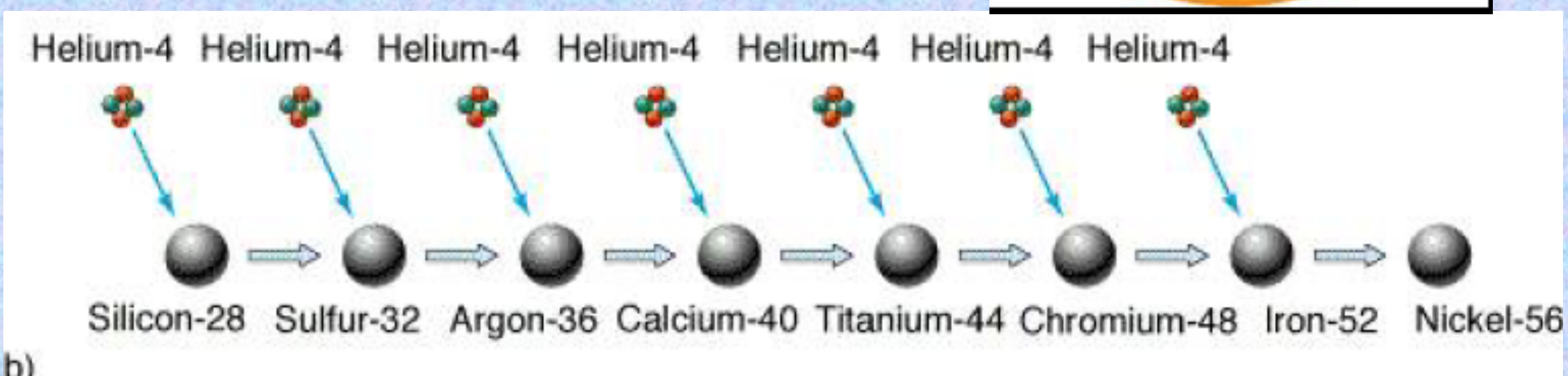
Production of nuclei in stars: Stellar yields

Massive stars: m > 8Msun

Production of elements by α-process

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



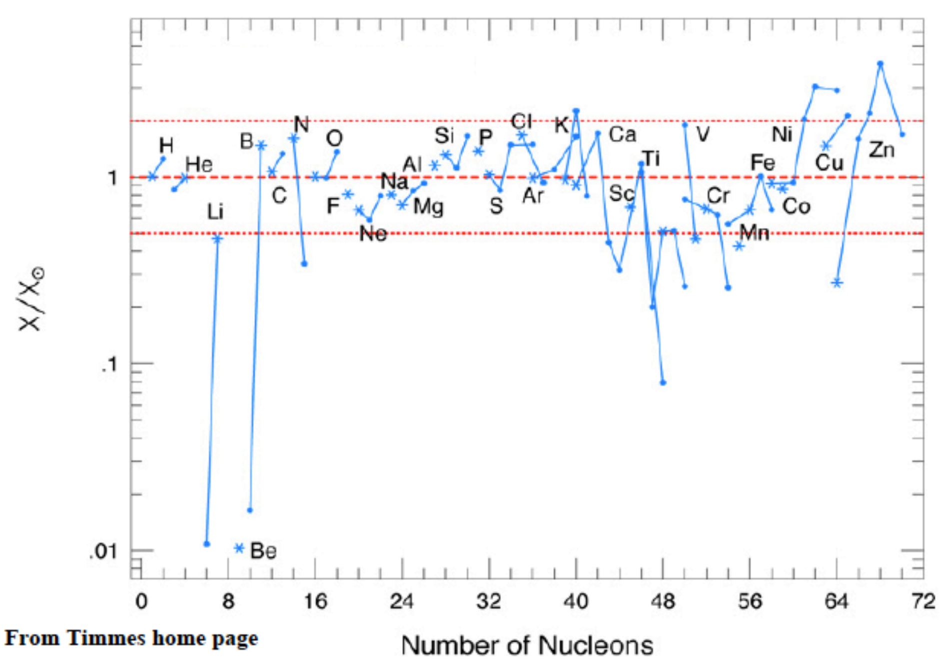


Several elements until Fe form in a onion-skin structure with the Fe in the center

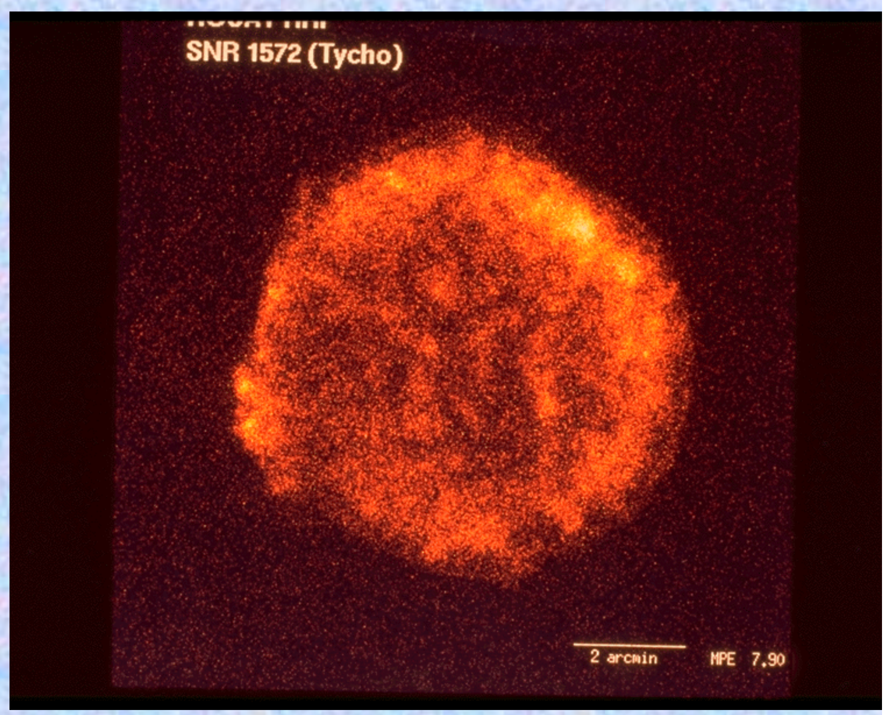
Nucleosynthesis in gravitational SN

It is determined by:

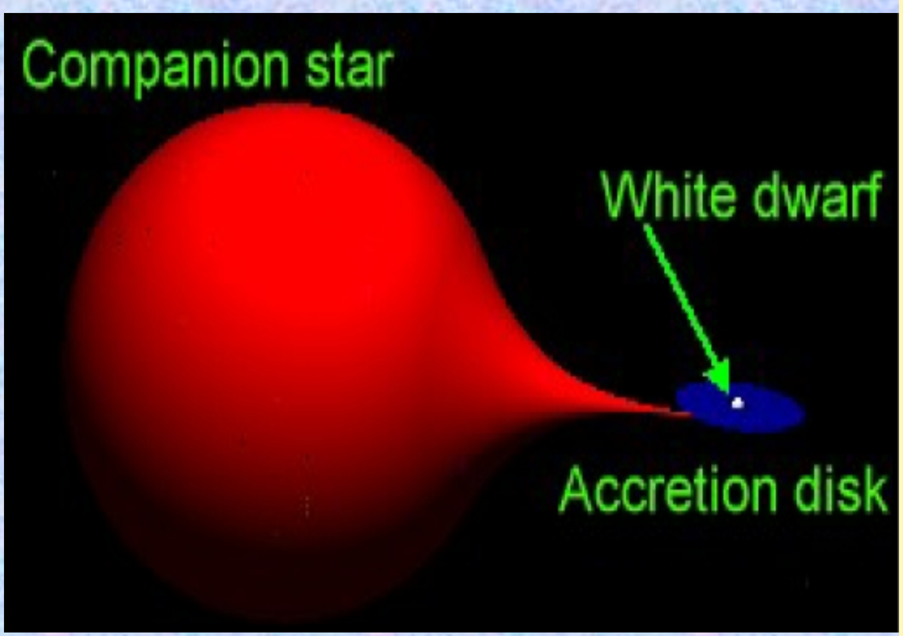
- Nucleosynthesis during the presupernova evolution
- Explosive burning induced by the shock wave



From Timmes home page



Supernovae type Ia: binary systems



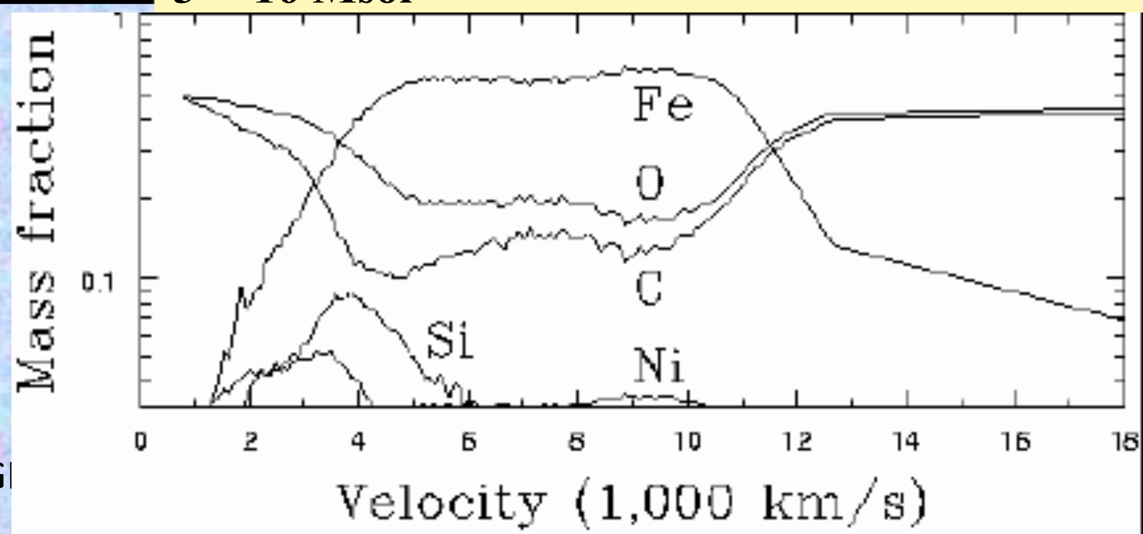
•The SNIa form in a binary system in which the evolved component is a CO-WD acreting the companion star mass. This way a nuclear deflagration is produced.

•The deflagration front propagates by electrons moving at subsonic velocities. The wave preceding the wave front eject the star without any rest

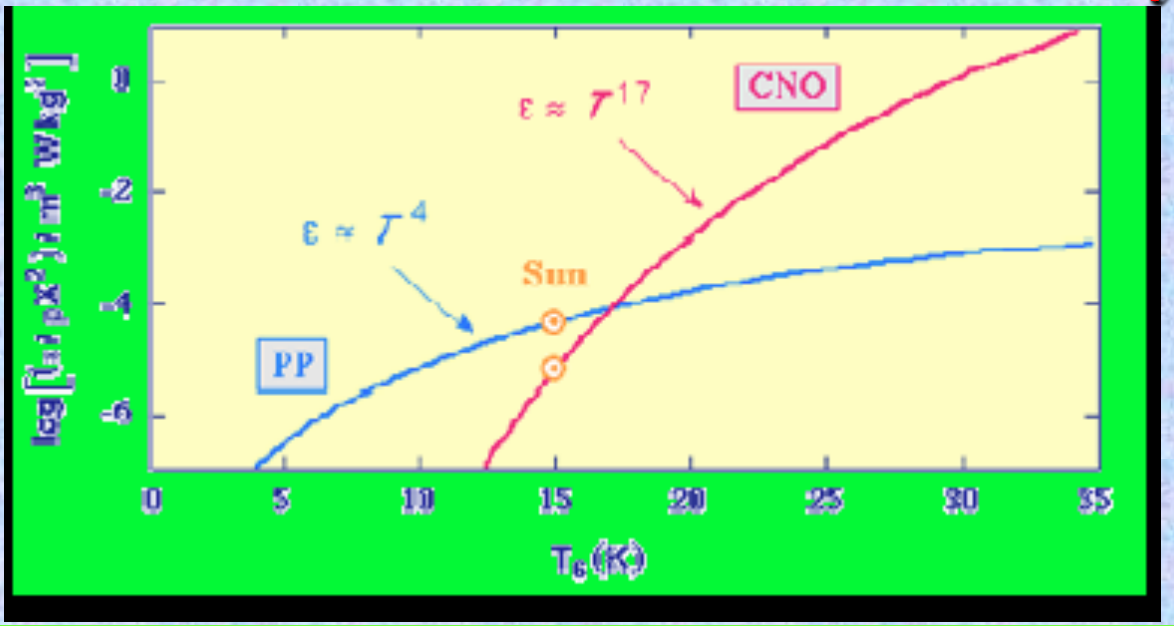
•The masses of the binary system are between 3 -- 16 Msol

- Merging of two CO WD
- He star accreting WD
- H (Red giant) acreting WD

■The most important of these SNIa is the large quantity of Fe produced, they eject 0.6 Mo



Production of nuclei in stars: Stellar yields



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

- **Low mass stars produce He and C12**
- **Intermediate mass stars produce C,N and O**
- **Massive stars produce O,Ne,Mg,S..,N, and Fe**
- **Binary Systems, SNIa Fe**

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- **Binary Systems, SNIa Fe**

The meanlifetimes of different stars explain the relative abundances of elements

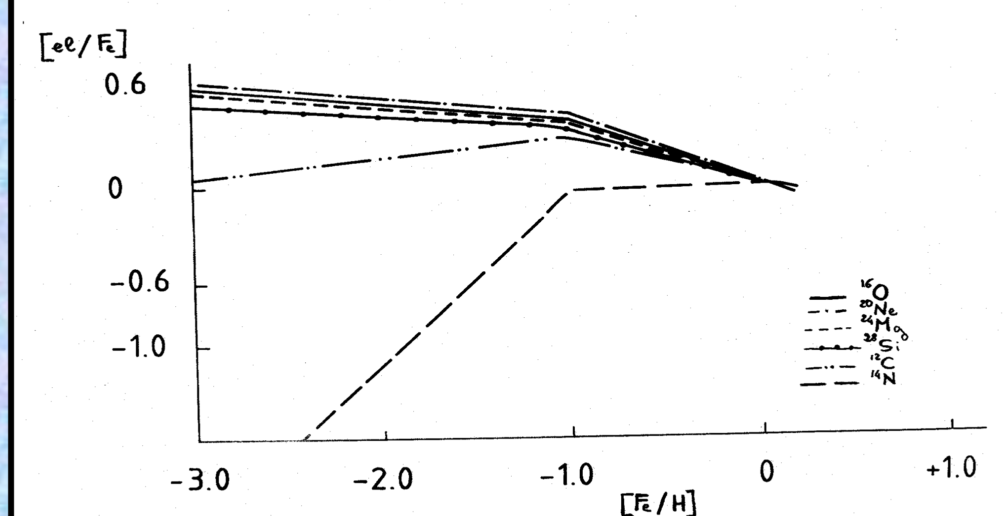

Fig. 3

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Cycle pp: low mass stars *m<4Mo*
Cycle pp+CNO: intermediate mass stars *4Mo< m < 8Mo*
Cyc

- **Low**
- **Inte**
- **Ma**
- **Bin**

The me
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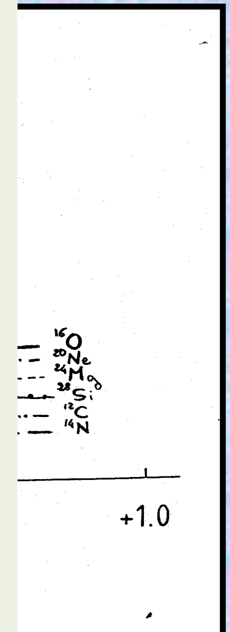
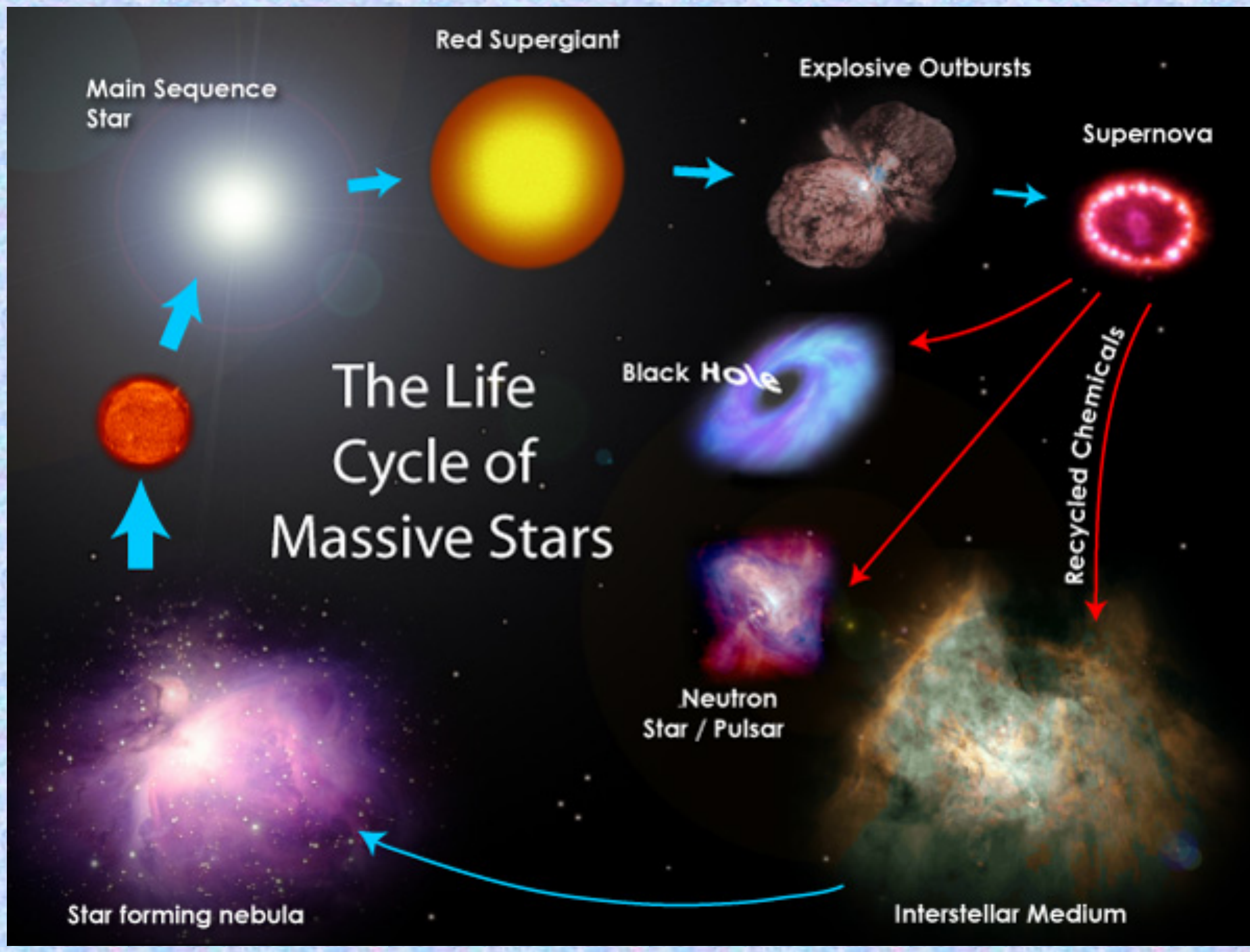
EACH ELEMENT APPEARS AT ADIFFERENT TIME FOLLOWING THE MASS OF THE STAR WHICH PRODUCES IT

RELATIVE ABUNDANCES GIVE INFORMATION ABOUT DIFFERENT STELLAR MASS RANGE CREATING ELEMENTS



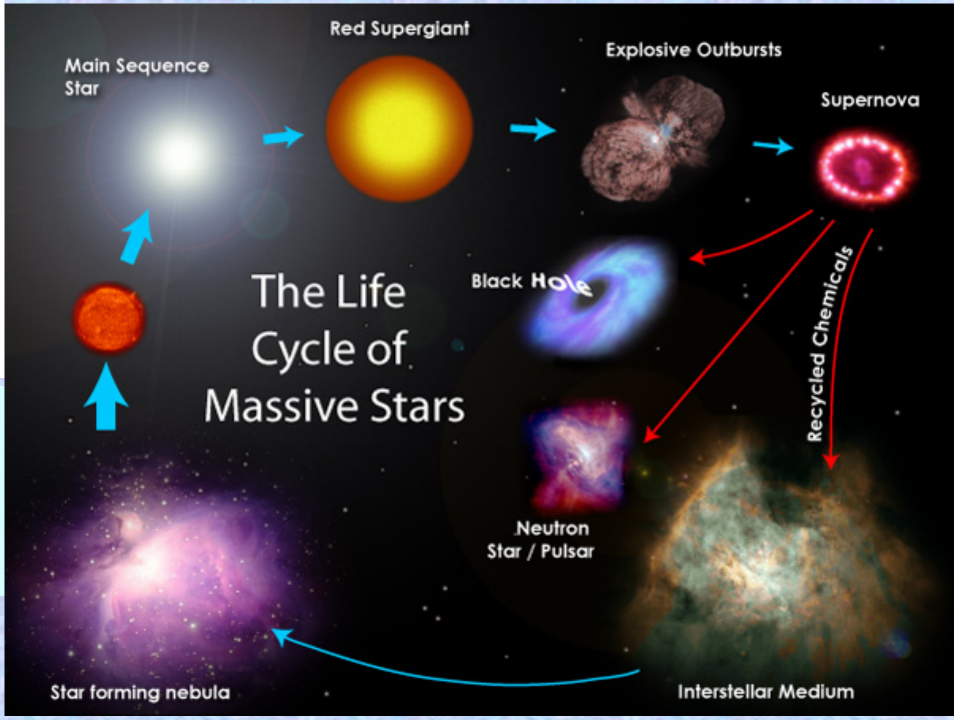


Main Sequence Star
Red Supergiant
Explosive Outbursts
Supernova
The Life Cycle of Massive Stars
Black Hole
Recycled Chemicals
Neutron Star / Pulsar
Star forming nebula
Interstellar Medium

Galaxies Chemical Evolution Aim

Chemical elements are created and then:

- Ejected and diluted in the interstellar medium
- Incorporated to the sucessive generations of stars



Elemental abundances give clues about star formation: when, how, with which rate stars form

•Phases:

–to understand processes,

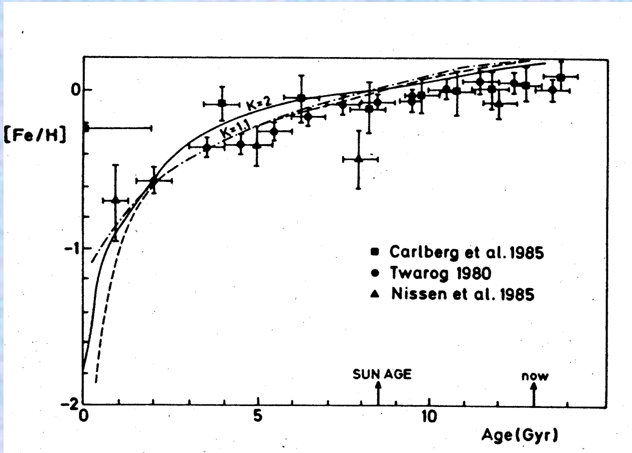
–to predict elemental abundances,

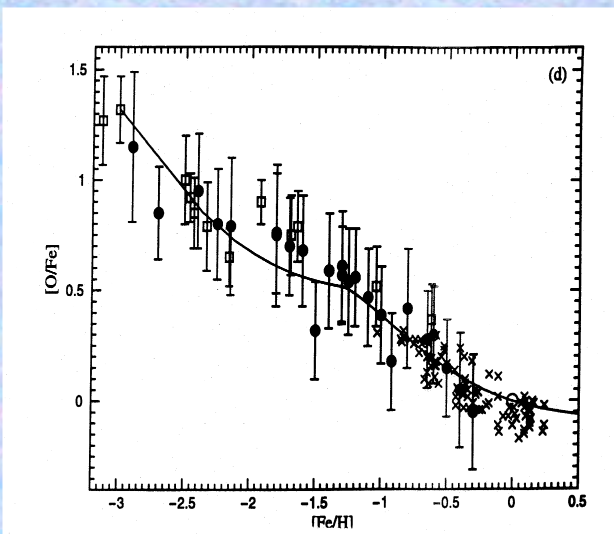
–to compare with data

GCE tries to explain how and when the elements appear

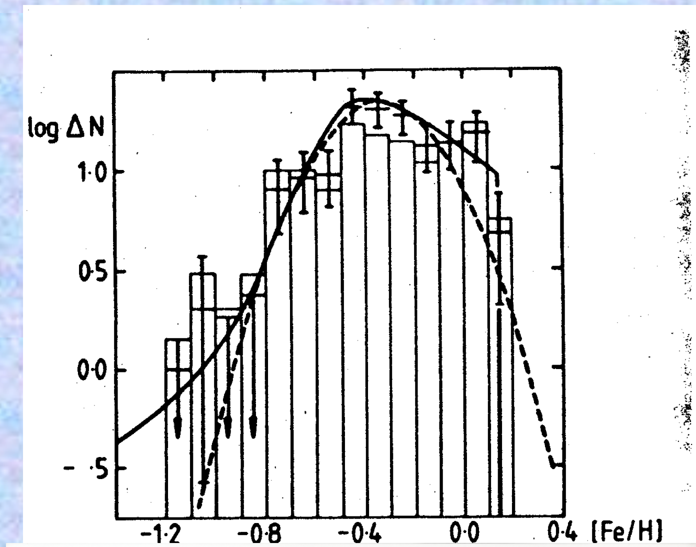
From elemental abundances we may deduce the evolutionary histories of galaxies

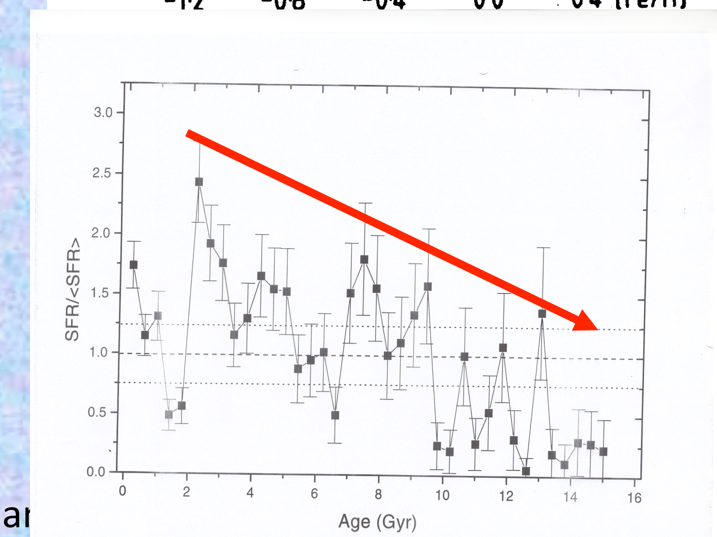
Some MWG early observational data



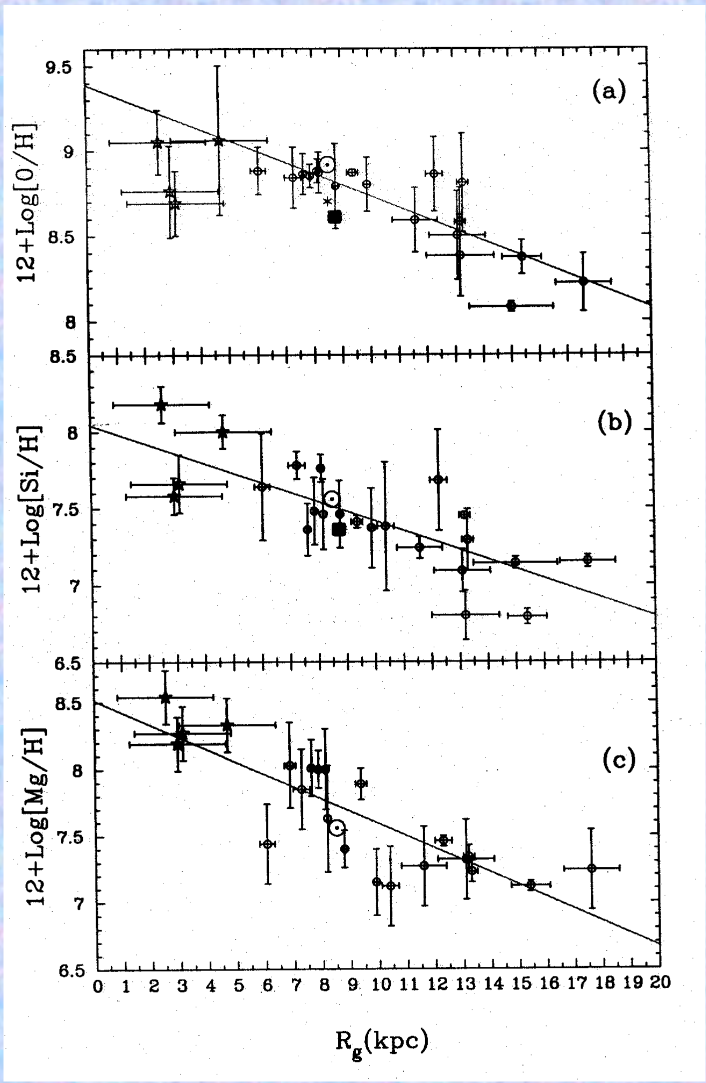


- The age-metallicity relation
- The G-dwarf metallicity distribution
- The star formation history in the SN
- The relative abundance of elements



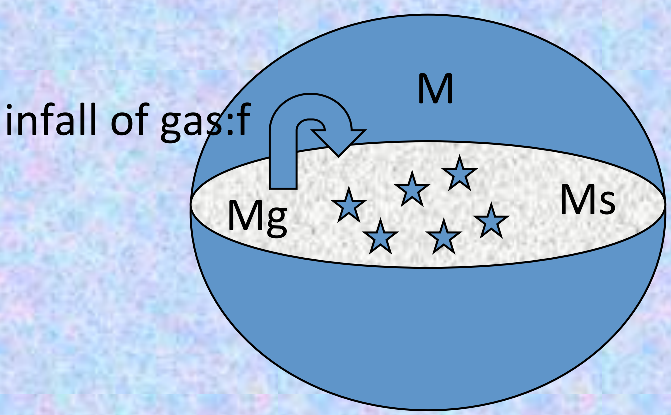


CHEMICAL EVOLUTION MODELS: OBJETIVES



- 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

The basic system of CEM



- f= flux of inflow gas (it 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

Ejected mass by a star of mass m

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

The basic equations of a CEM

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

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

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

$$M = Ms + Mg$$

- f= flux of inflow gas (it may be 0)
- M= total mass of the system
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Initial mass function or number of stars in the range dm

Ejected mass by a star of mass m

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

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)ZΨ, 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

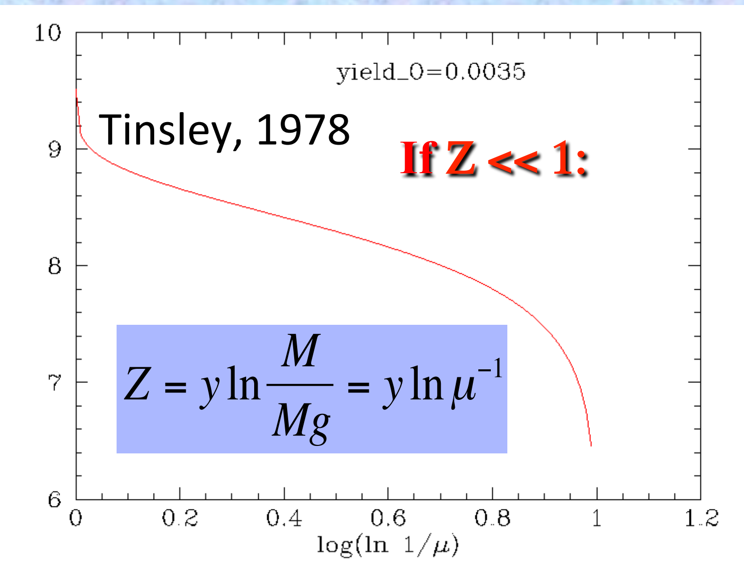
THE SIMPLE MODEL: THE CLOSED BOX MODEL

1)The system will have 2 types of stars

- ❑ those with mass $m>m_1$ with $t=0$
- ❑ those with $m<m_1$ and $t=\infty$

2) The system is closed f=0

3) Metals are instantaneously mixed with the ISM



Model predictions:

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

Problems:

1. **The G-dwarf metallicity distribution is not reproduced**
2. **The relation not sufficient to obtain the observed radial gradient of abundances**
3. **The delay due to the mean-lifetimes of stars is necessary to each element appears in a different time**

Chemical Evolution Models

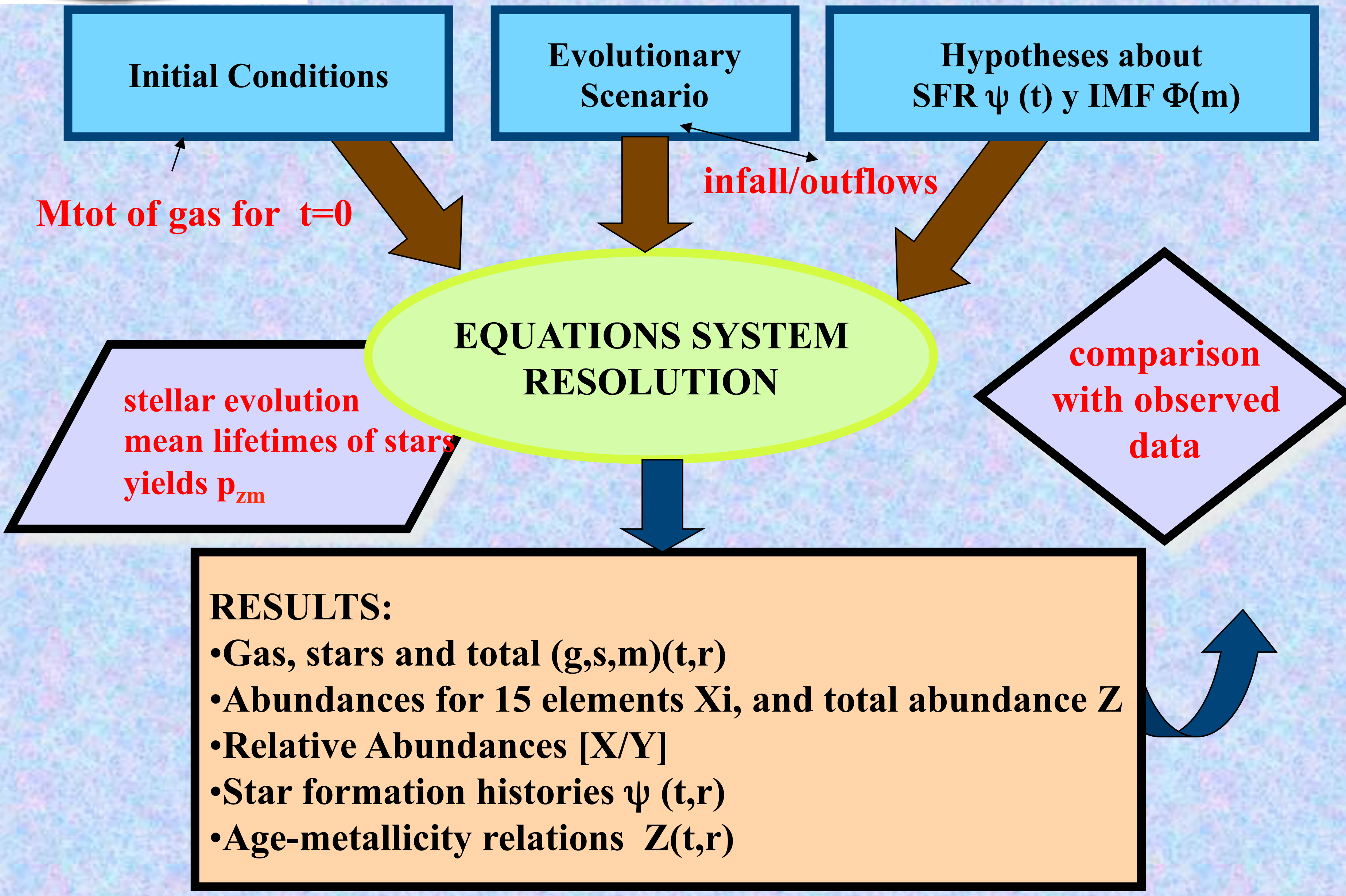
•These models calculate the chemical evolution of a galaxy: stars form, die and eject the elements created by stellar nucleosynthesis.

•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

A chemical evolution model



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infall/outflows

Initial Conditions

Evolutionary Scenario

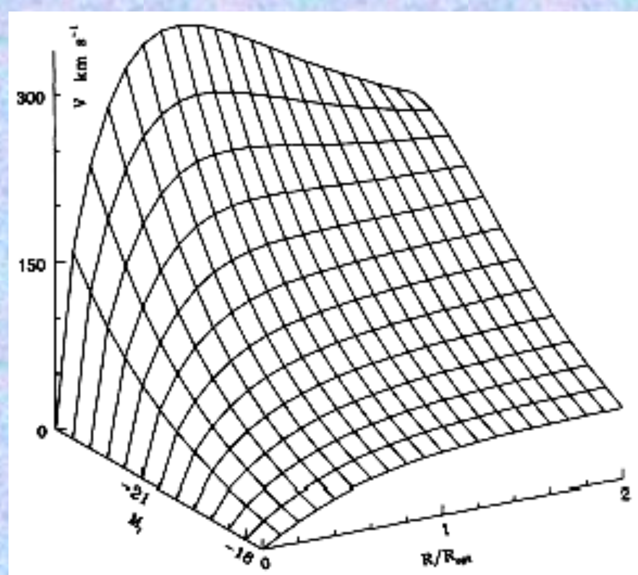
Hypotheses about SFR ψ (t) y IMF Φ(m)

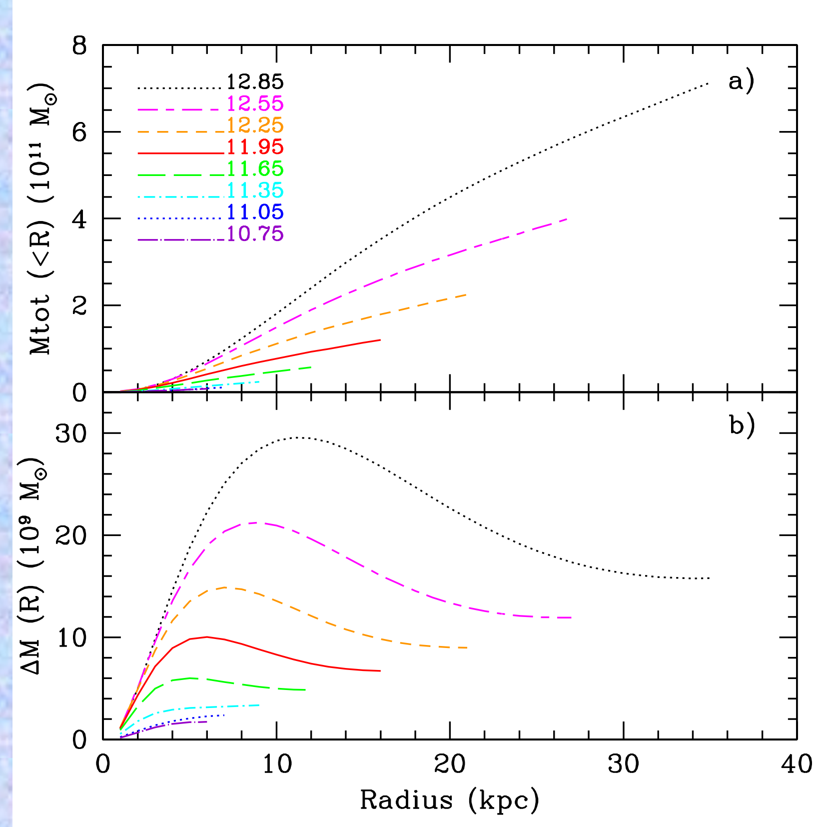
Mtot

- Initial Conditions:
  - total mass
  - Gas mass
  - Primordials abundances
- Initial mass function (IMF):
  - Variations with time
  - Variations in the space
- Star formation laws: different possibilities
- The metallicity dependent yields
- The existence of possible inflows or outflows of gas
- The galactic scenario: the formation and evolution of the galaxy

•Age-metallicity relations Z(t,r)

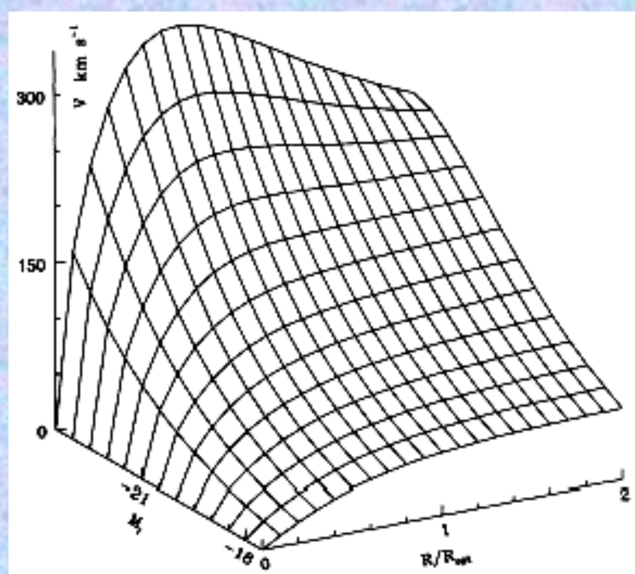
Ingredients of the multiphase chemical evolution model: the scenario

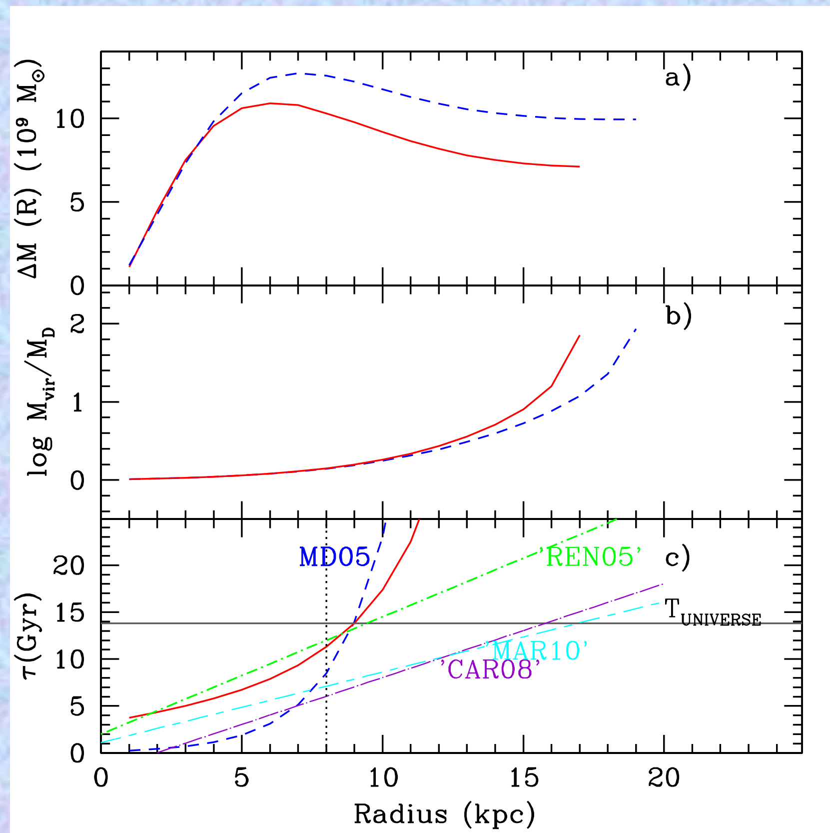




The total mass M of each modeled galaxy and its radial distribution M(R) have been computed from the universal rotation curve V(R) from Salucci (2007)

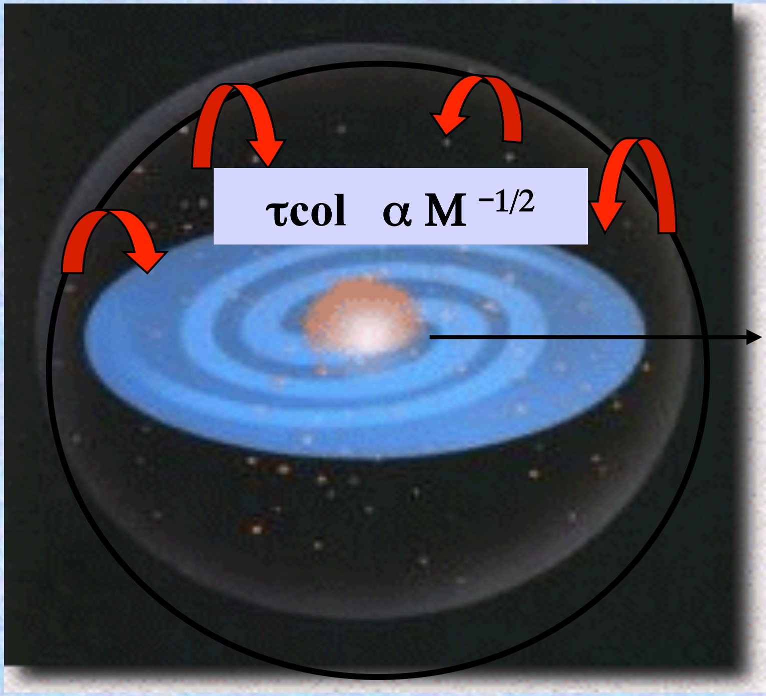
Ingredients of the multiphase chemical evolution model: the scenario

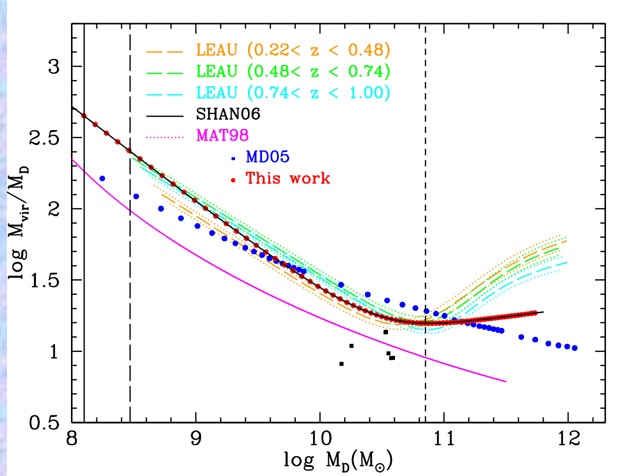


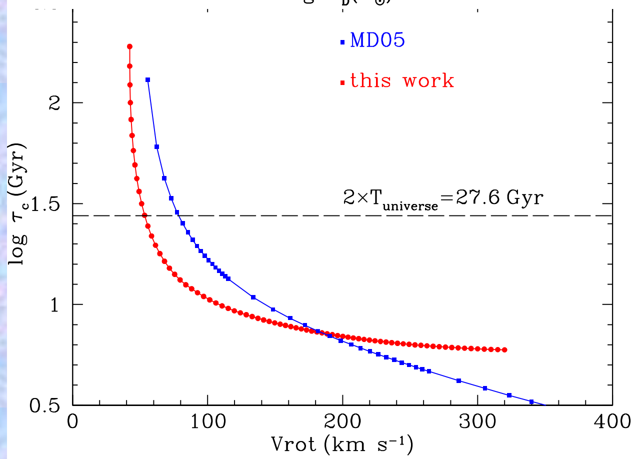


The total mass M of each modeled galaxy and its radial distribution M(R) have been computed from the universal rotation curve V(R) from Salucci (2007)

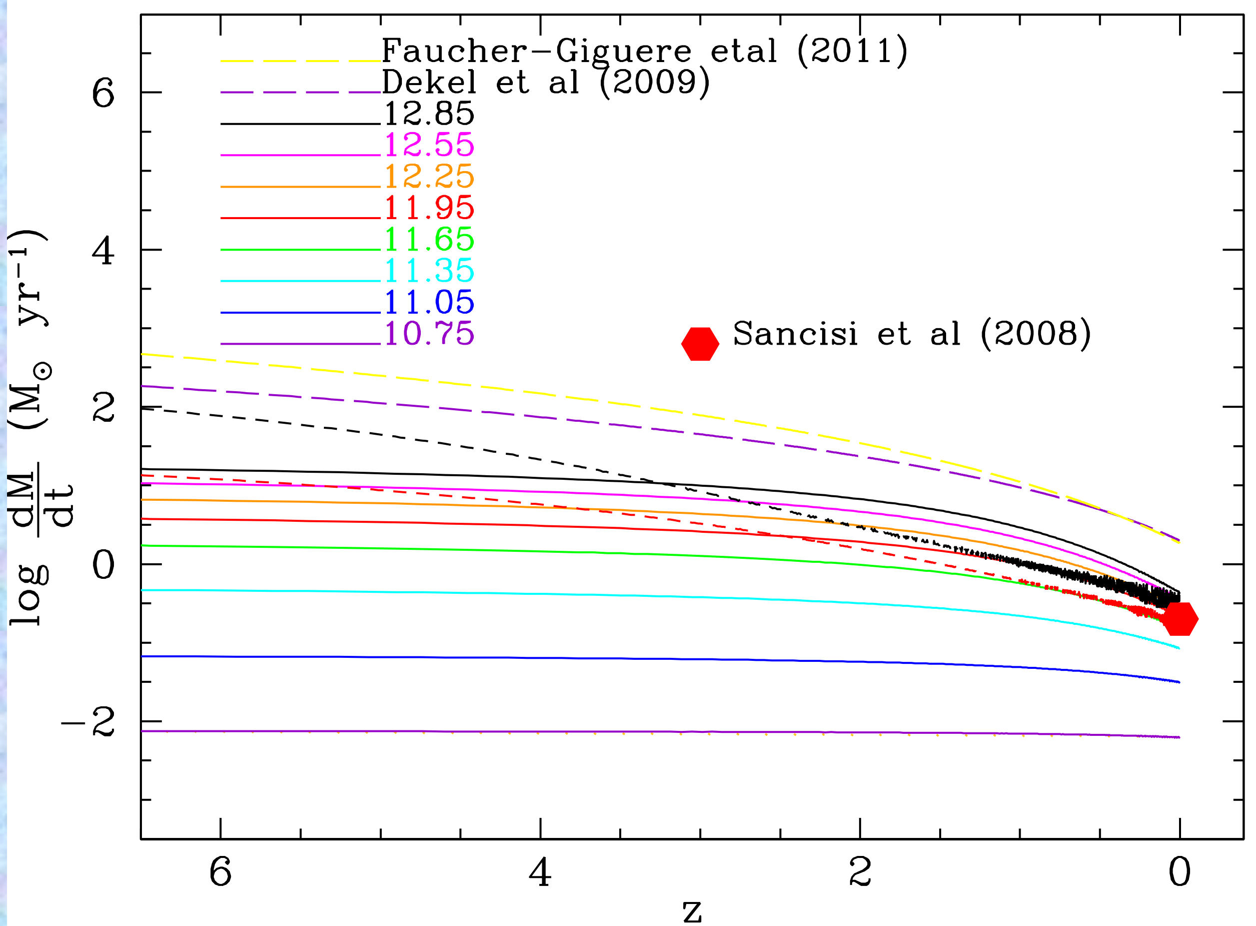
Ingredients : The infall rate







- The gas collapses onto the equatorial plane and forms out the disc
- Infall rate α $1/\tau_{col}$
- τ_{col} = f(Mgal) …calibration with the MWG
- Since σmass =f(R), τ=τ(R), following Shankar et al.

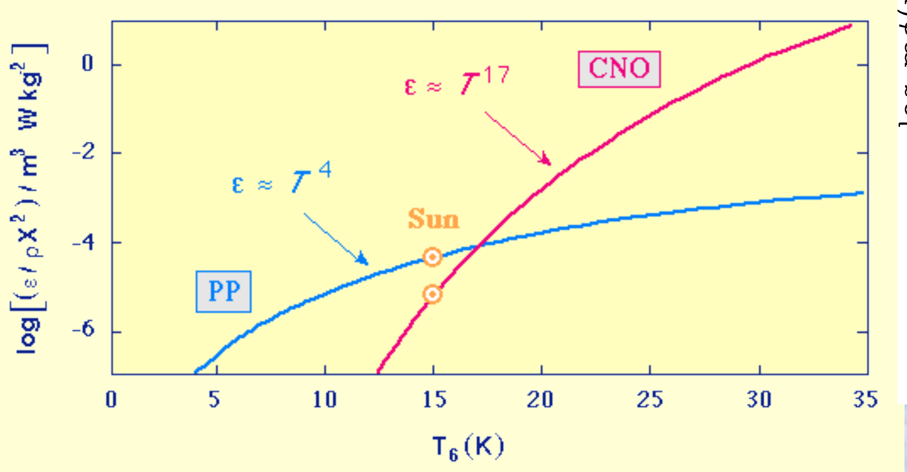


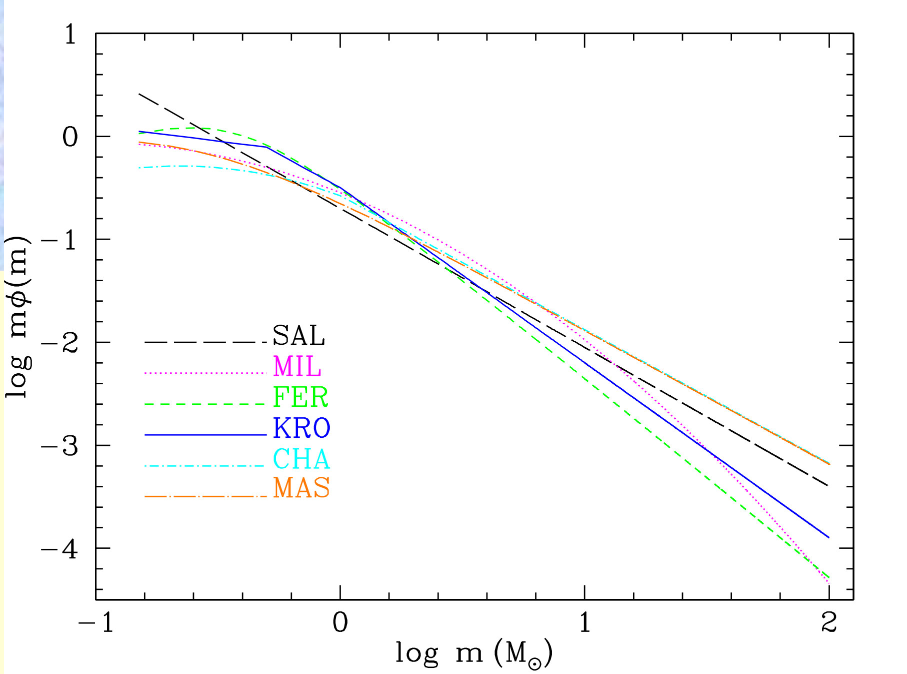
GH14-IFS techniques and analysis

IMF + stellar yields

- Absolute aundances depend on **the yield of a generation of stars** (single stellar population): p_z + IMF

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





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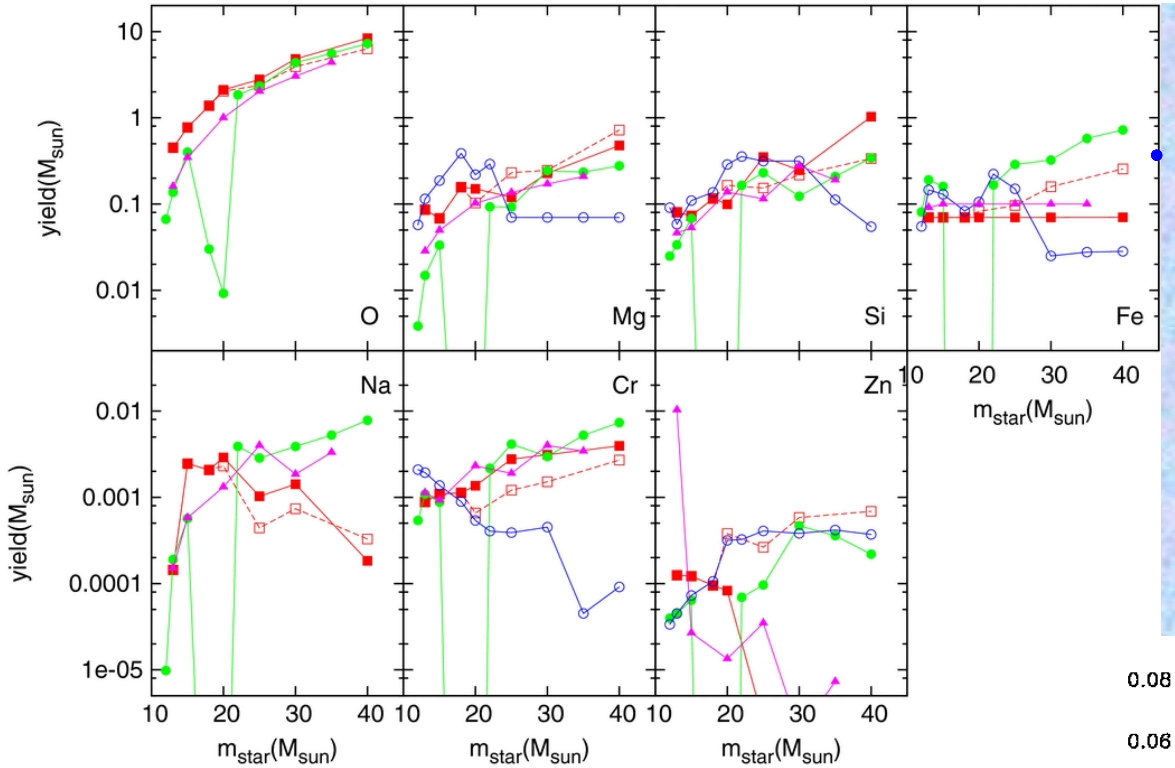
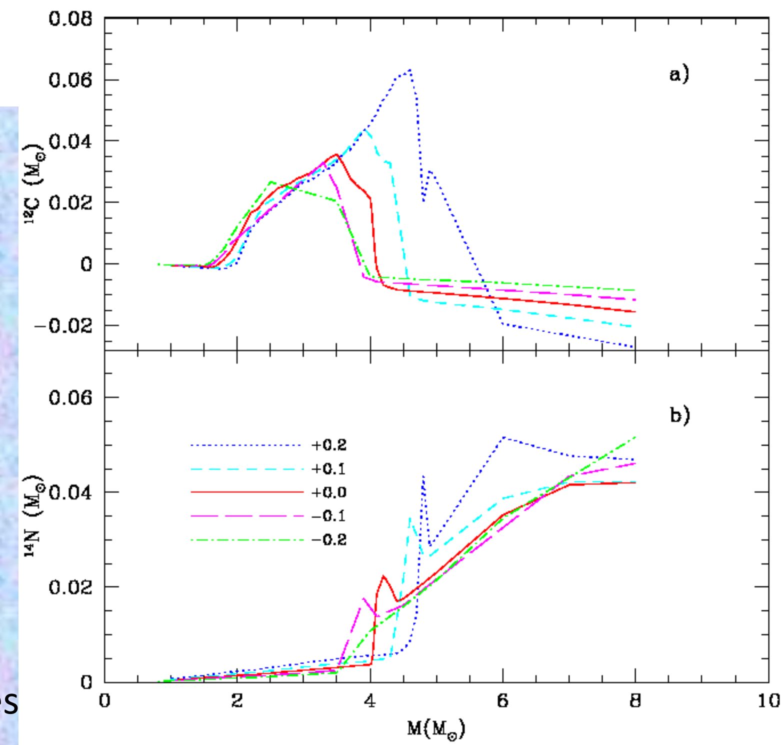


- Massive star yields
  - Woosley & Weaver (1995)
  - Frohlich et al. (2008)
  - Chieffi & Limongi (2004)
  - Kobayashi et al.
  - Maeder & Meynet (1992)
  - Maeder, Meynet & Hischi (2005)
  - Portinari et al. (1998)



- LIM yields
  - Renzini & Voli (1991)
  - Van der Hoek & Groenewegen (1997)
  - Marigo (2001)
  - Gavilán et al. (2005)
  - Ventura et al. (2002)
  - Dray et al (2003)
  - Karakas & Lattanzio (2010)

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Inputs of the multiphase 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 μg $^{1.5}$

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:
  - $K = \varepsilon_K (G/V)^{1/2}$
  - $\mu = \varepsilon_\mu (G/Vd)^{1/2}$
  - $H = \varepsilon_H$ cte /Vd
  - $a = \varepsilon_a (G\,\rho_c)^{1/2} / <m_{s2}>$
- The efficiency ε_a is a local parameter
- The efficiency ε_K is assumed as constant for all halos
- Efficiencies ε_μ y ε_H are variable for each galaxy

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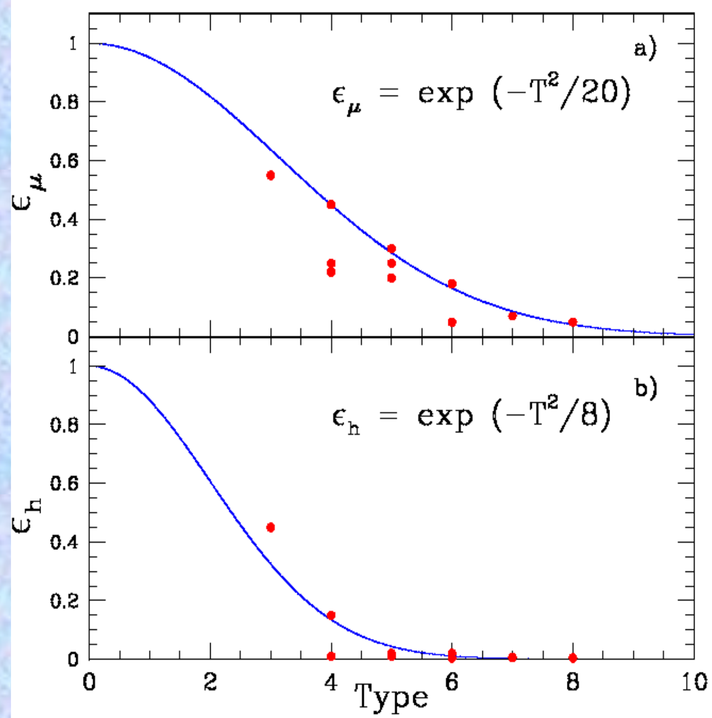
- Every parameter changes along the galactocentric radius:
  - $K = \varepsilon_K (G/V)^{1/2}$
  - $\mu = \varepsilon_\mu (G/Vd)^{1/2}$
  - $H = \varepsilon_H \, cte / Vd$
  - $a = \varepsilon_a (G \rho_c)^{1/2} / \langle m_{s2} \rangle$
  - $\tau_{col} = \tau_{col,0} \exp(R/\lambda)$
- The efficiency 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_μ y ε_H are variable for each galaxy
- The collapse time scale depends on the total mass of the gaaxy



From data of molecular and diffuse gas masses in galaxies (Young et al. 1996), we found that efficiencies to form molecular clouds and stars depend on morphological type of galaxies.

We vary only 2 "parameters", total mass and T

		1	2	3	4	5	6	7	8	9	10		
	Vrot	0.95	0.8	0.75									
1	30												
2	40												
3	48												
…													
10	71												
…													
18	99						M33						
…													

28	200				MWG								
…													
39	291			M31									
…													
43													
44	387												

BCD & HII Gal.

Low mass galaxies

Normal spirals

Starbursts

Low surface brightness Galaxies

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		1	2	3	4	5	6	7	8	9	10		
	Vrot	0.95											
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…													
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…													
18	99												
…													

28	200												
…													
39	291			M31									
…													
43													
44	387												

BCD &

Table 1. Theoretical galaxy models selected to represent a simulated Hubble sequence

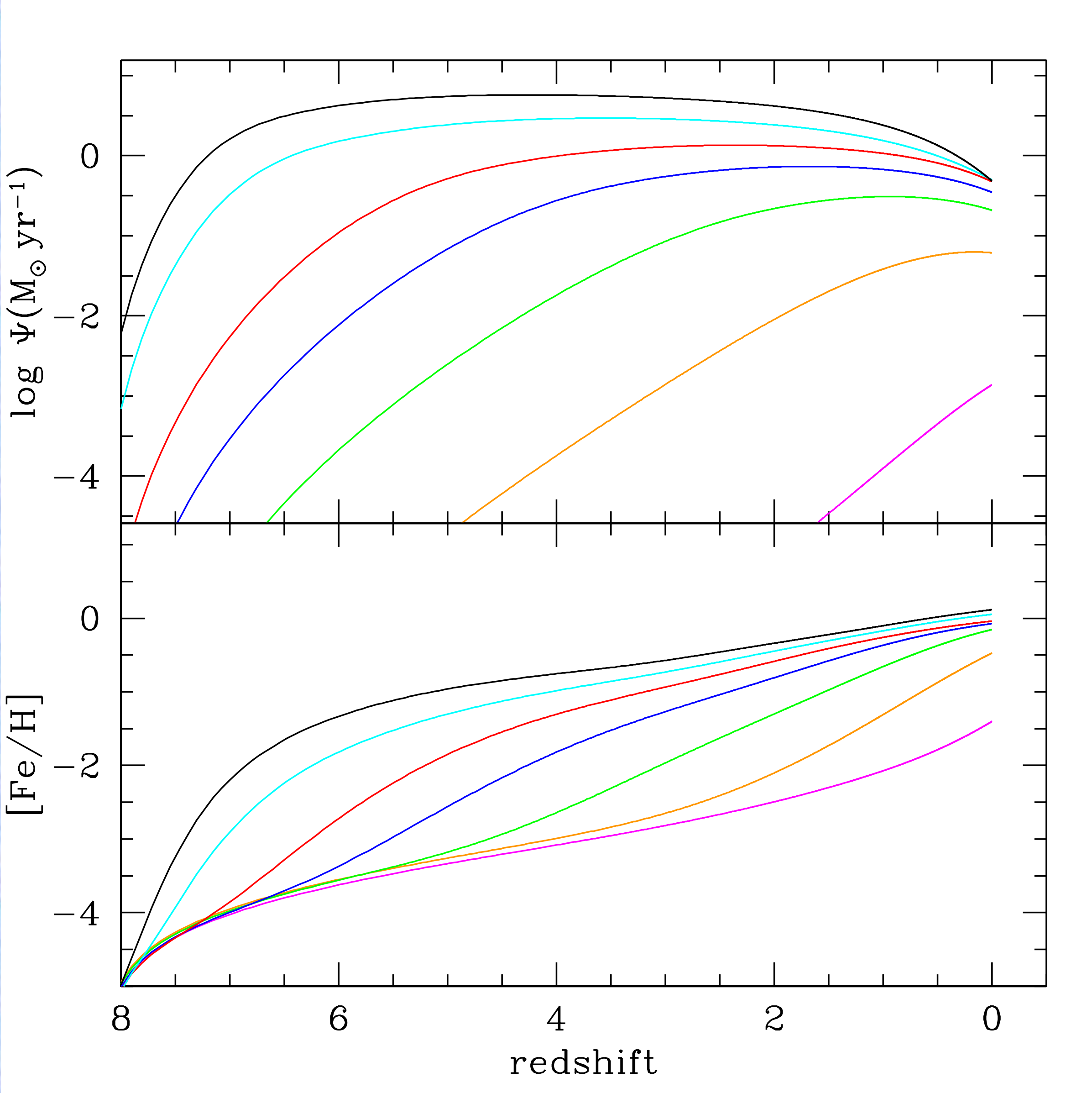
dis	*Vmax* km s^{-1}	*Mgal* 10^{11} M$_{\odot}$	*Ropt* kpc	τ_c Gyr	*nt*	ϵ_ν	ϵ_δ
3	48	0.3	2.3	31.6	8	0.037	$2.6\ 10^{-4}$
10	78	1.3	4.1	15.5	7	0.075	$1.5\ 10^{-3}$
21	122	4.3	7.1	8.1	6	0.15	$1.0\ 10^{-2}$
24	163	9.8	10.1	5.4	5	0.30	$5.0\ 10^{-2}$
28	200	17.9	13.0	4.0	4	0.45	$1.4\ 10^{-1}$
35	250	33.5	16.9	2.9	3	0.65	$3.4\ 10^{-1}$
39	290	52.7	20.6	2.3	1	0.95	$8.8\ 10^{-1}$

Starbursts

Low surface brightness Galaxies

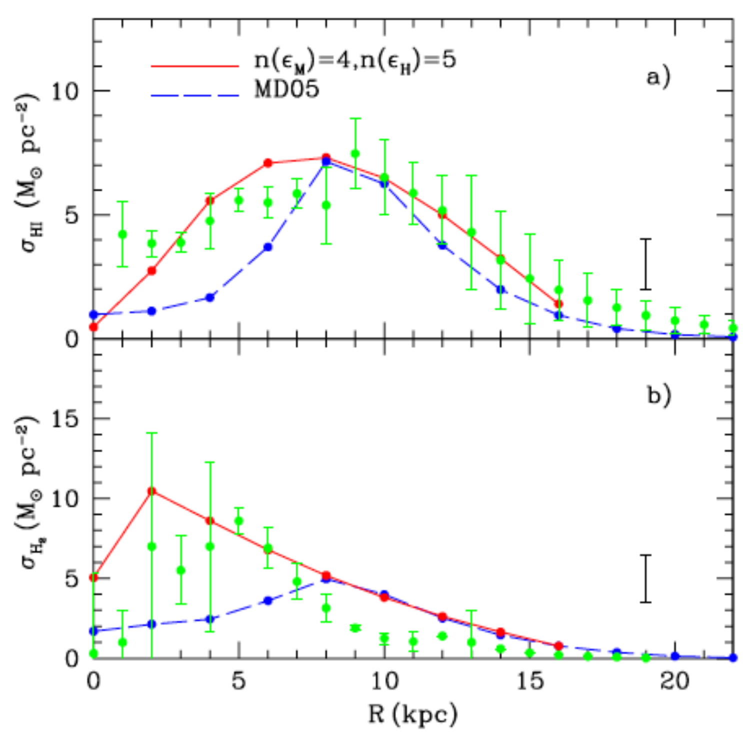
New grid of models: updating the inputs and assumptions

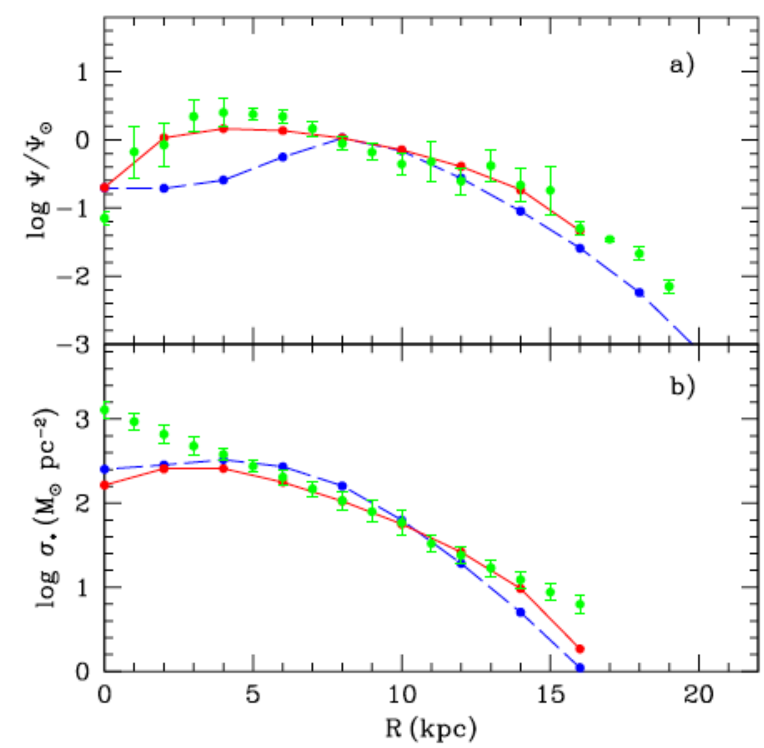
- Radial distributions computed following equations from Salucci et al. (2007) defined in terms of Mvir and arriving to longer distances along the galactocentric radius
- Collapse time-scale τ modified to follow the prescriptions from Shankar et al. (2006) about the observed ratio Mdisk/Mhalo
- New grid 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
- Radial dependence $\tau(R)$ smoother than the old one
- Efficiencies ε_M and ε_H selected independently: 10 values in the range [0--1]
- Revision of new set of stellar yields and different IMFs

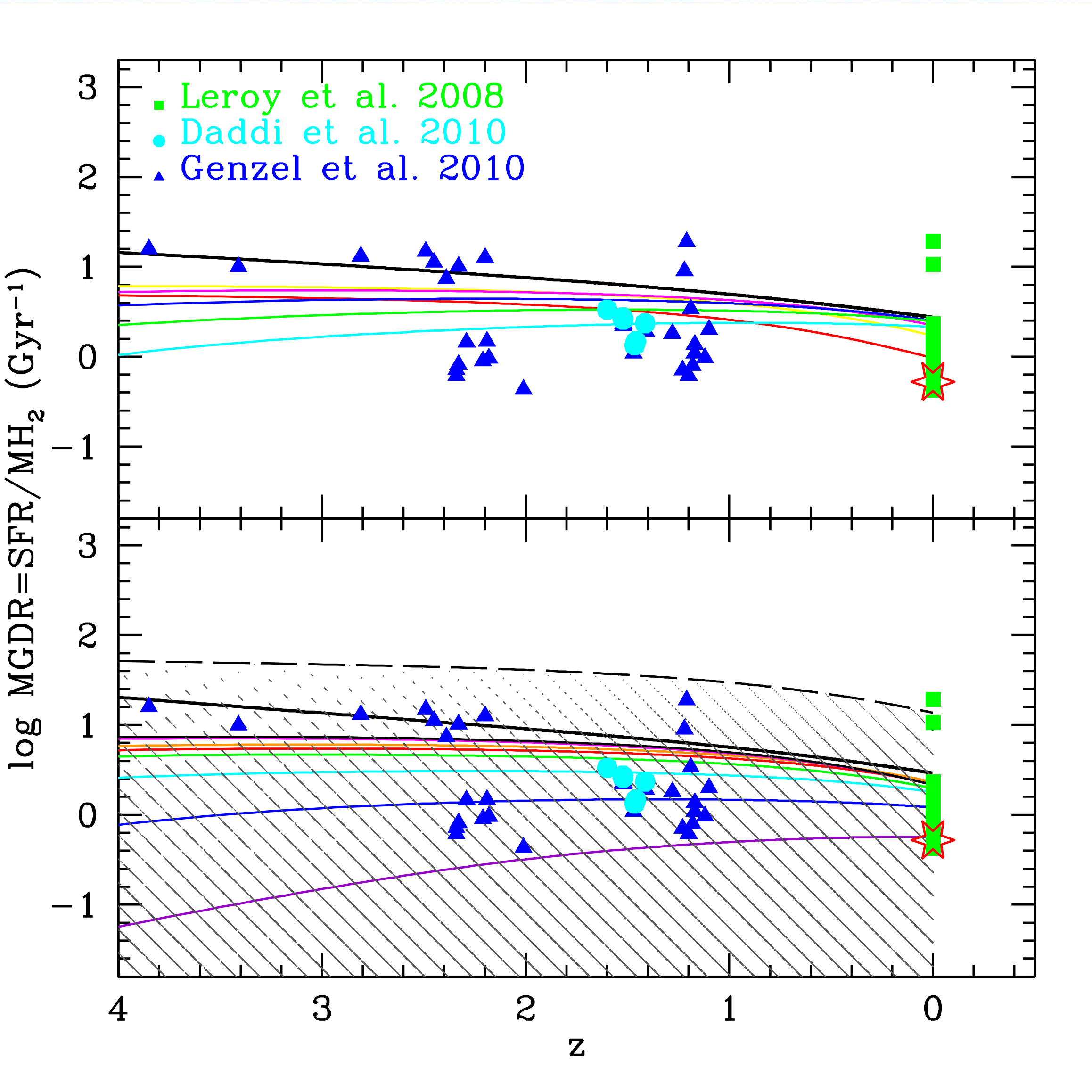


GH14-IFS techniques and analysis

Calibration of the MWG disk: radial distributions of surface density of gas, stellar mass and SFR

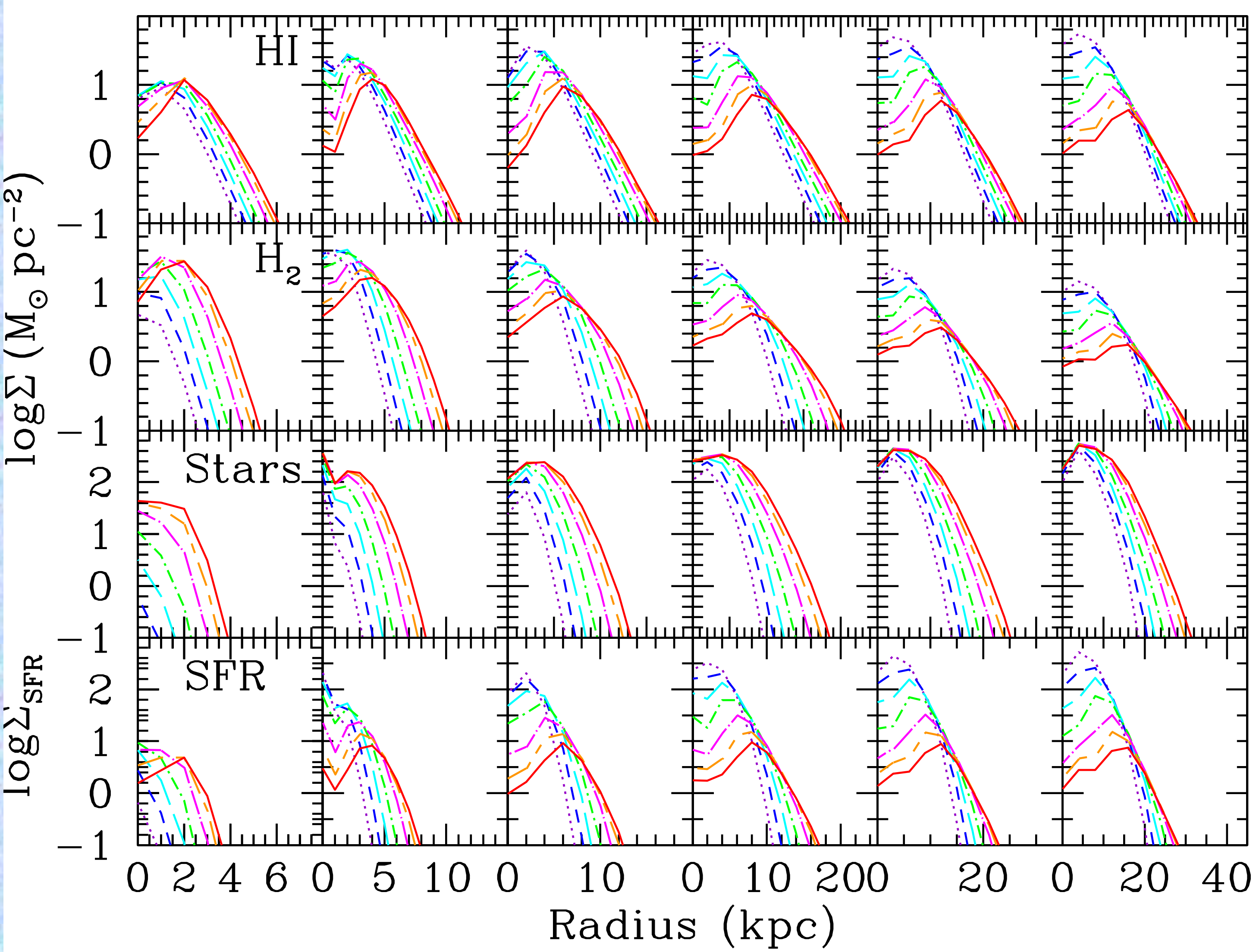




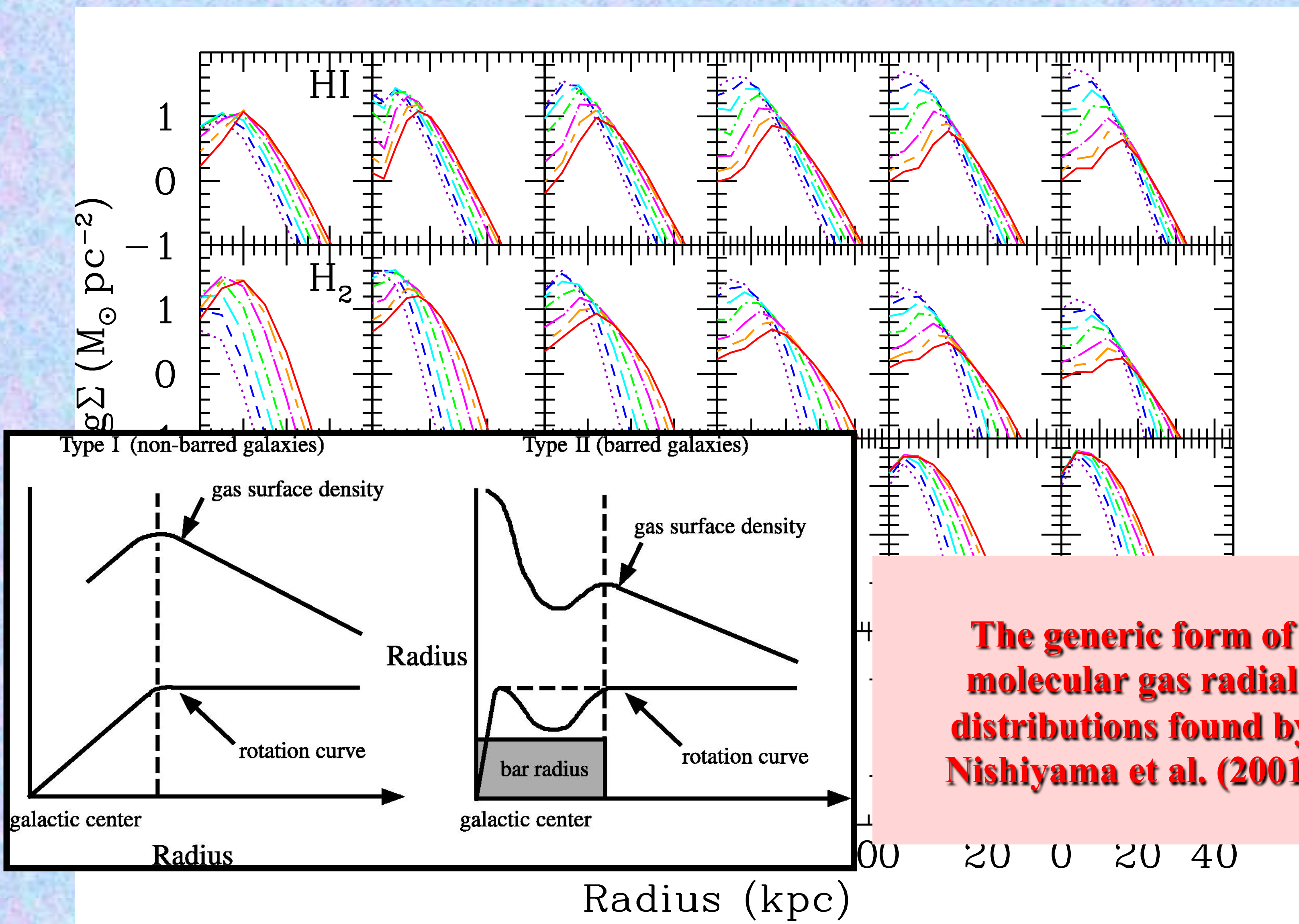


The evolution of the SF efficiency measured as SFR/MH2 along the redshift

Evolution of disks along redshift



Evolution of disks along redshift



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

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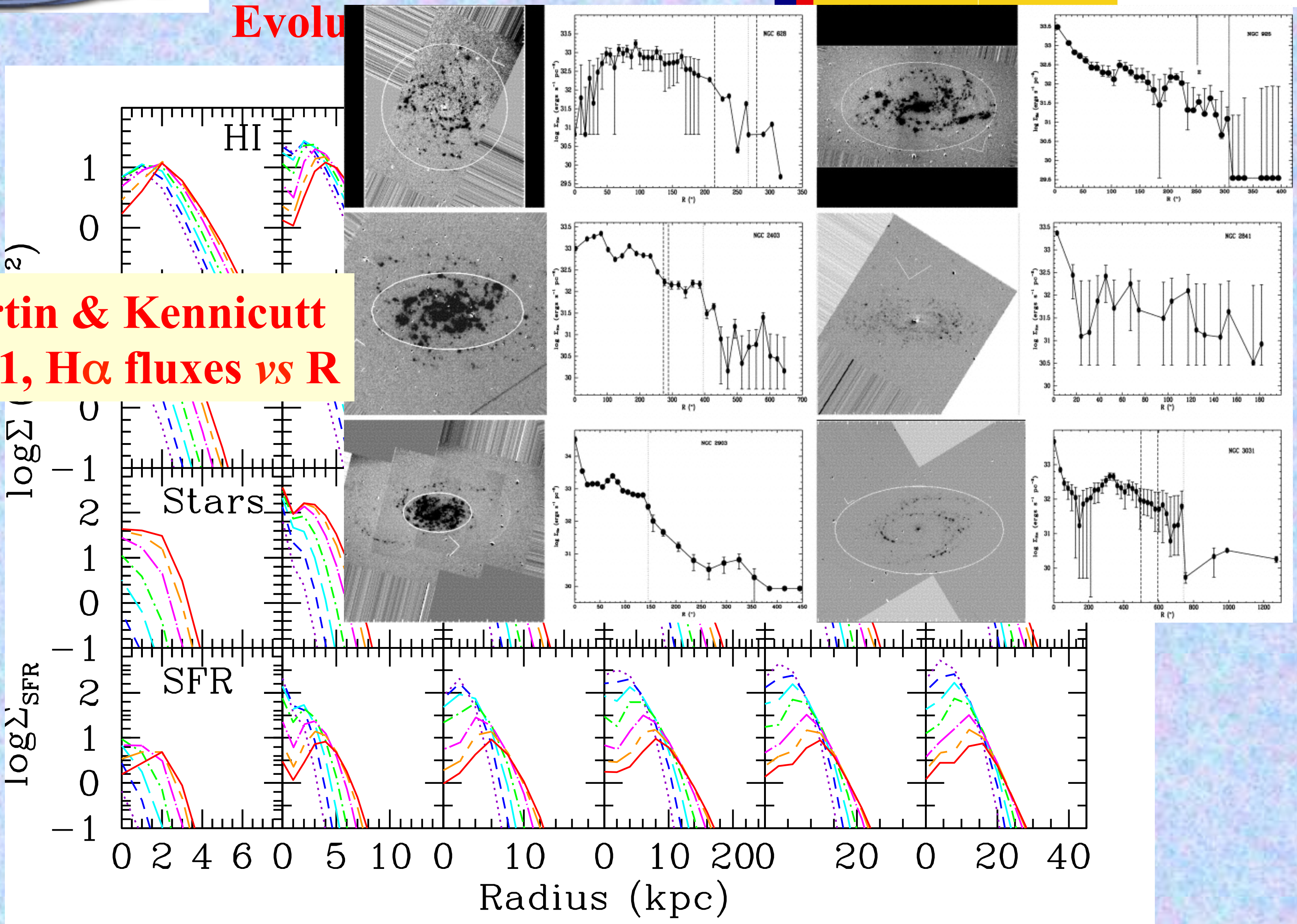
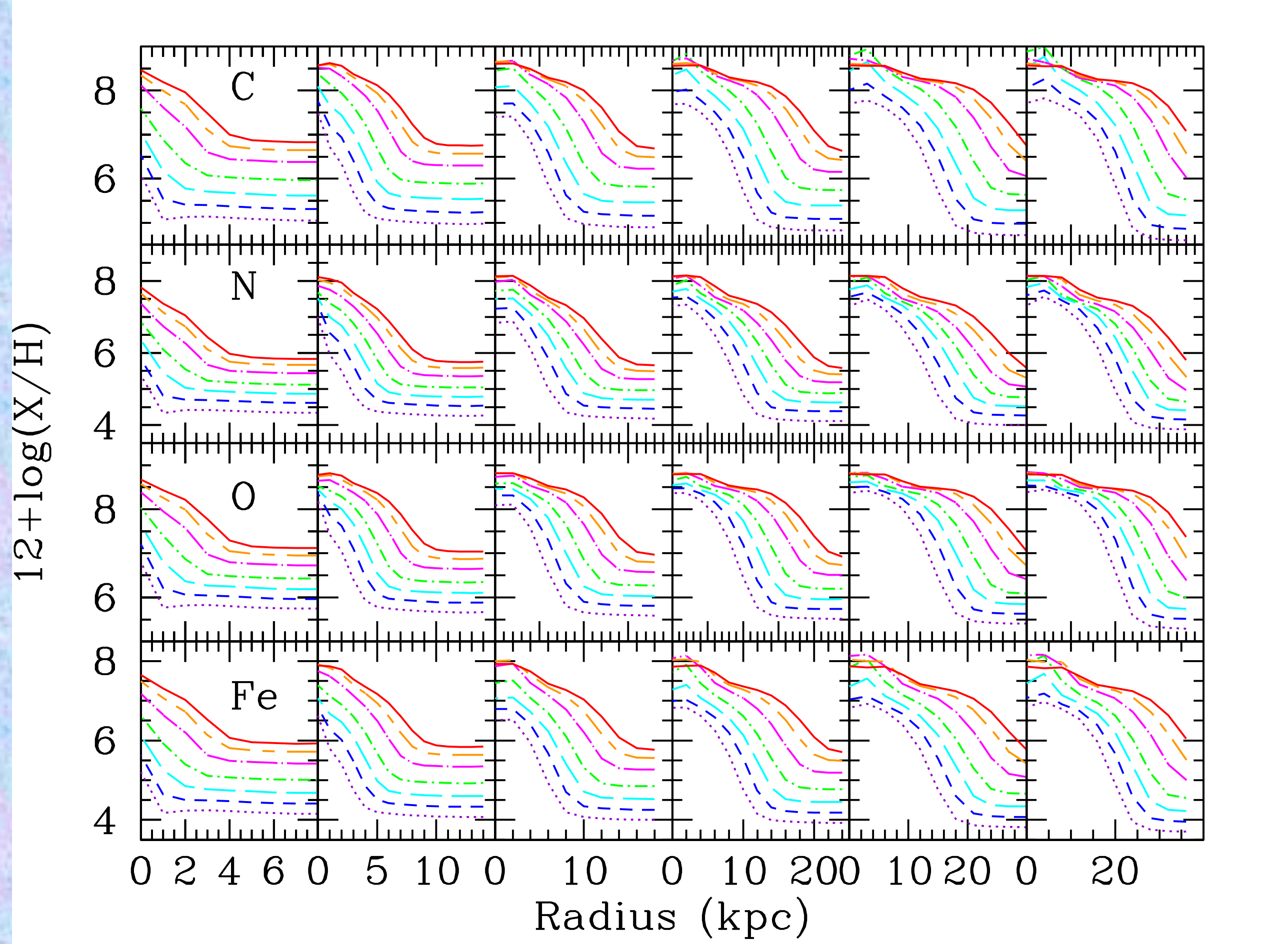
Evolu



Martin & Kennicutt 2001, Hα fluxes *vs* R

The evolution of the abundance radial distributions along z



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

The inner radial distributions flatten compared with the discs

Our models show a maximum oxygen abundance 12+log(O/H)~8.9- 9.0 (Pilyugin et al)

There is also a minimum abundance

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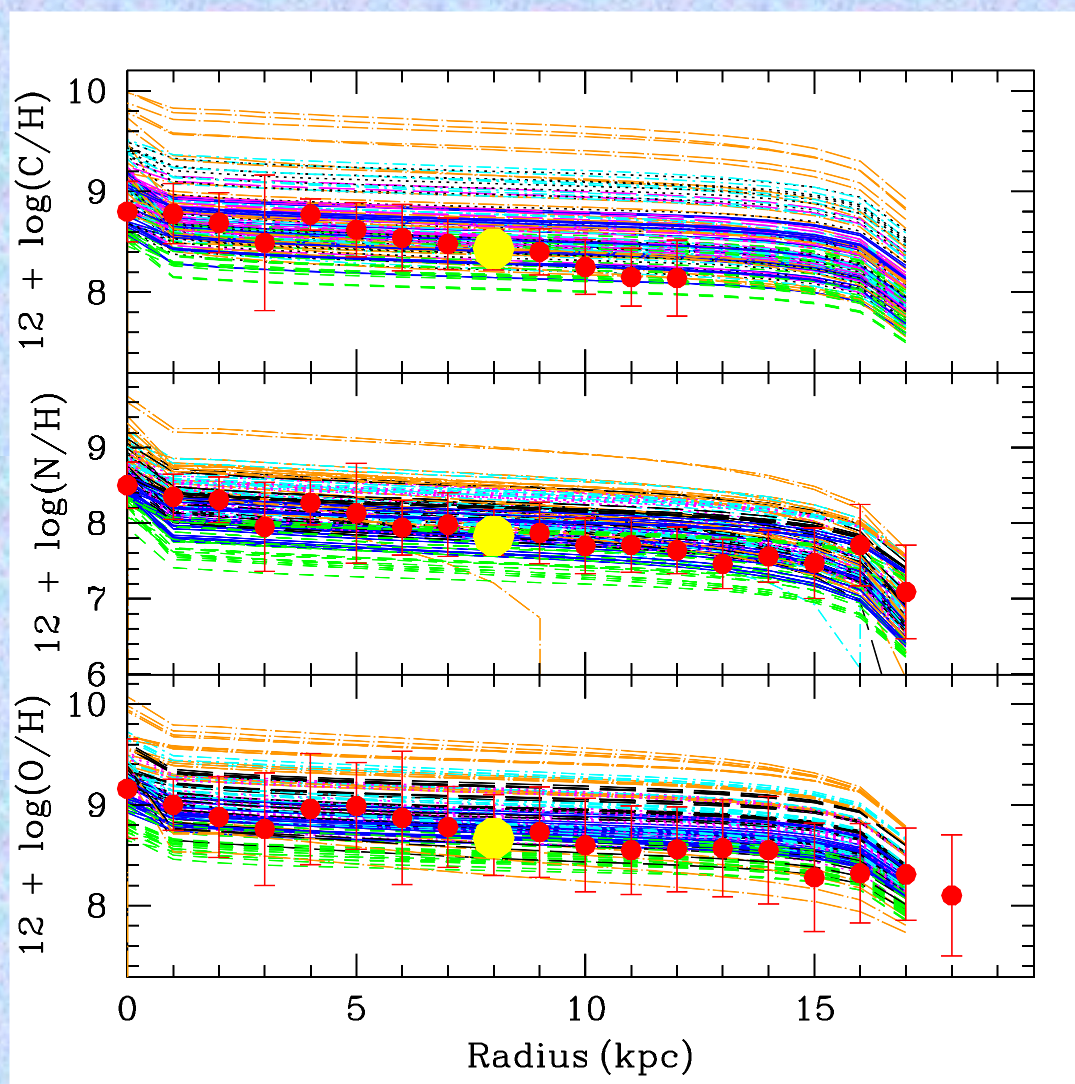
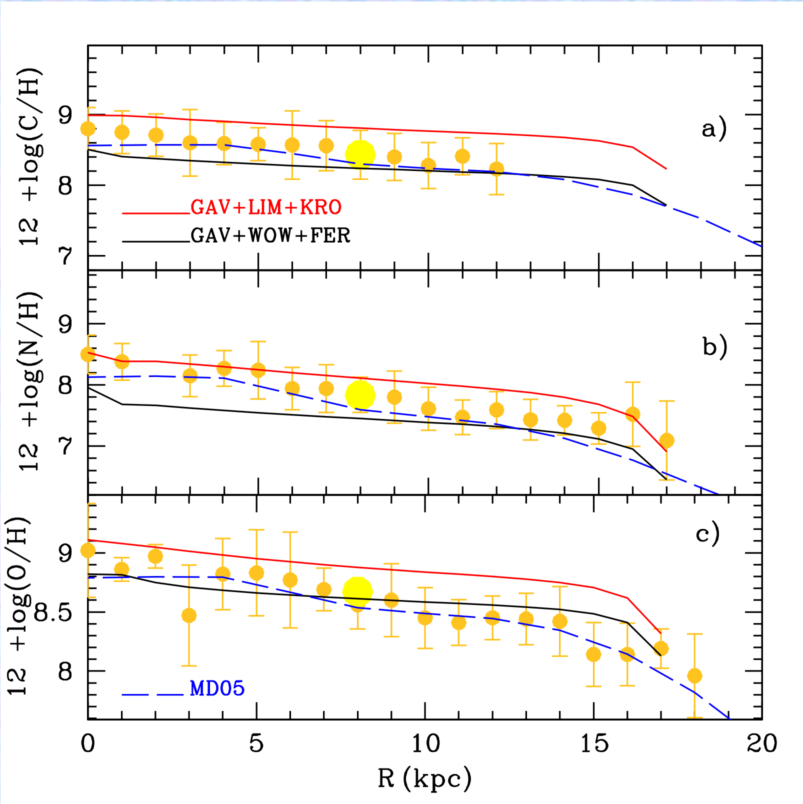
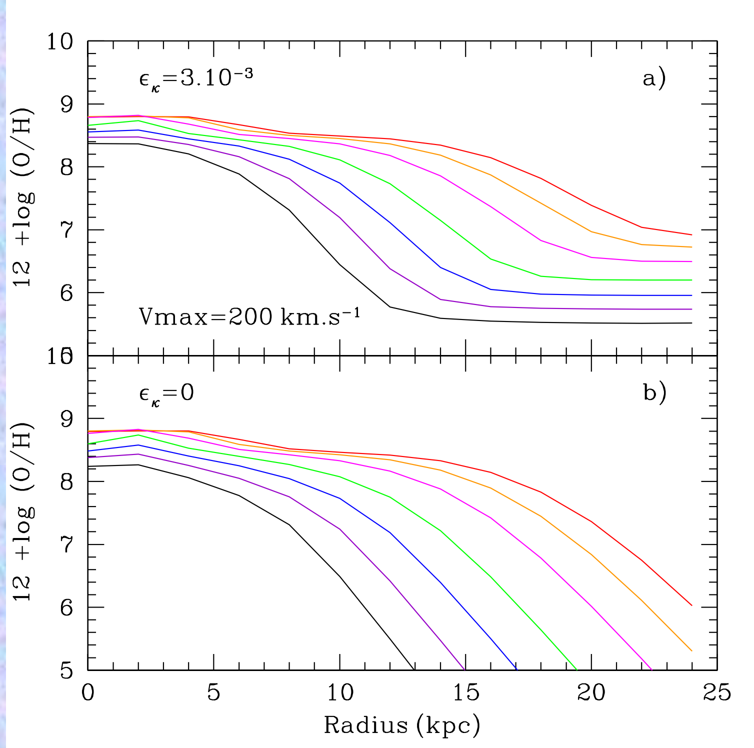
IMF & stellar yields: no effect on the radial gradient of abundances, only variations on the absolute values of abundances

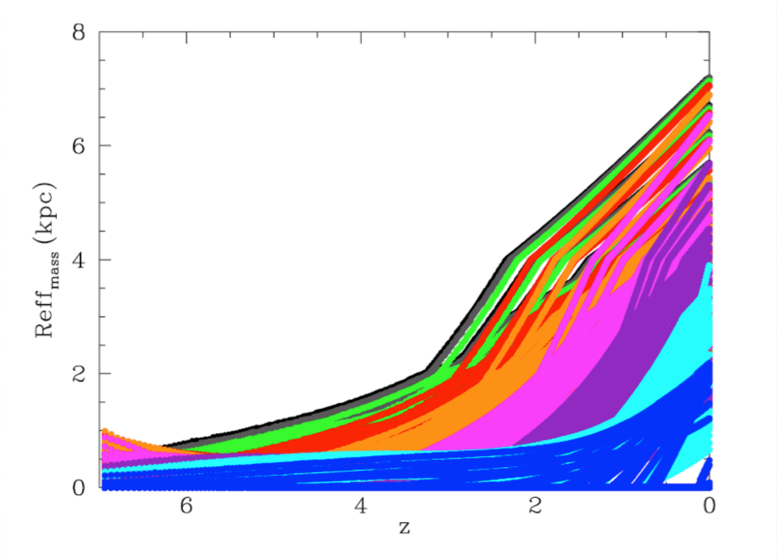






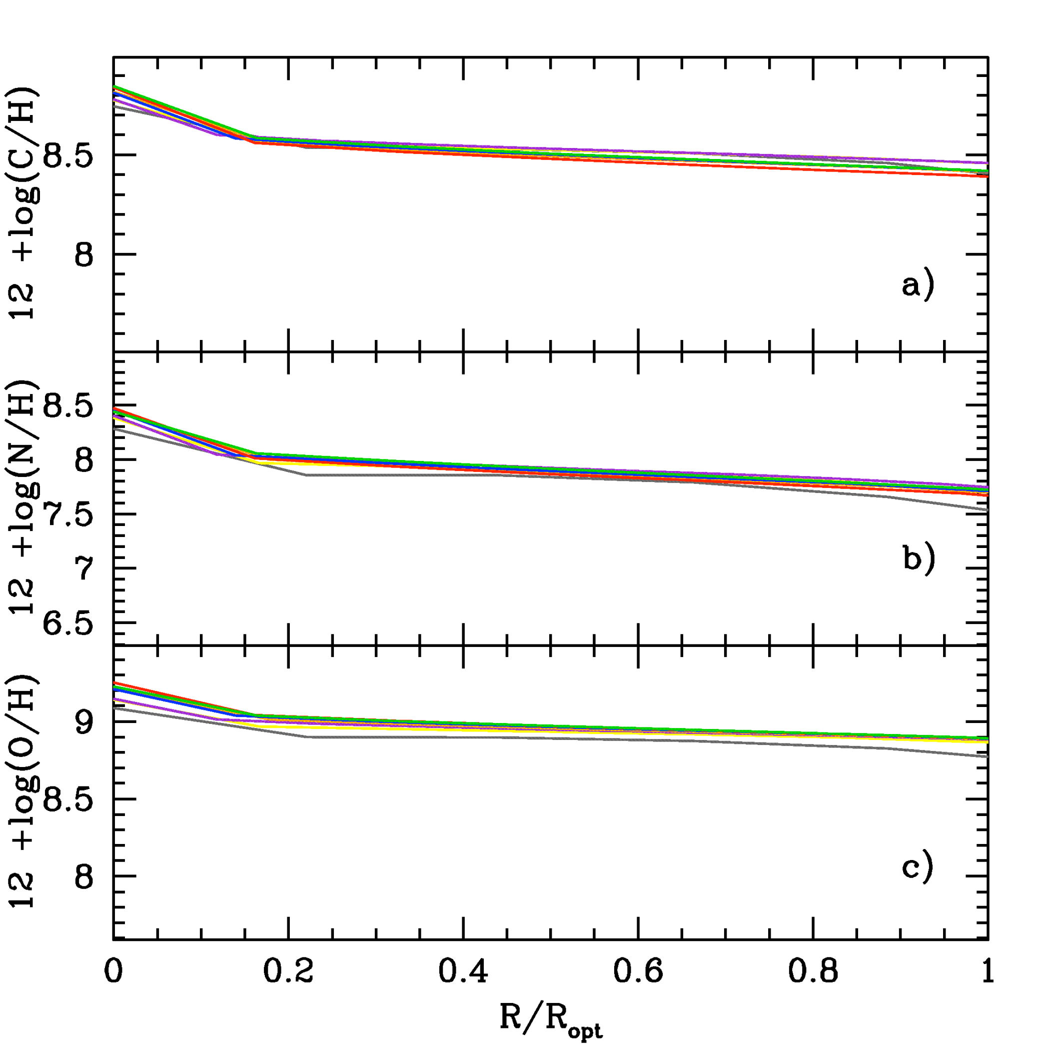
A variation of the infall rate, now smoother than in our old models, changes the radial gradient which is flatter now

A fllatening of the radial gradient appears in the O distributions: It seems due to the infall rate of enriched gas from the halo

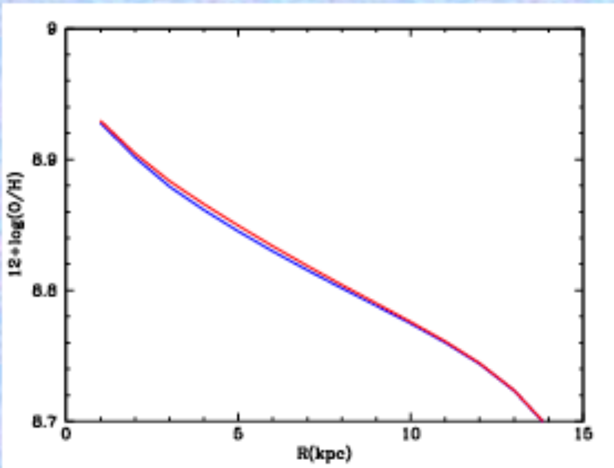


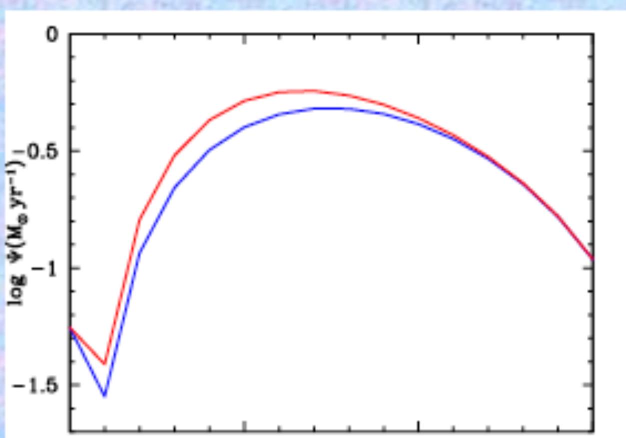
The radial gradients for the same ε_M and ε_H and different Mvir models, when measured with normalized distances, are equivalent

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



Next step: 2D Chemical evolution models





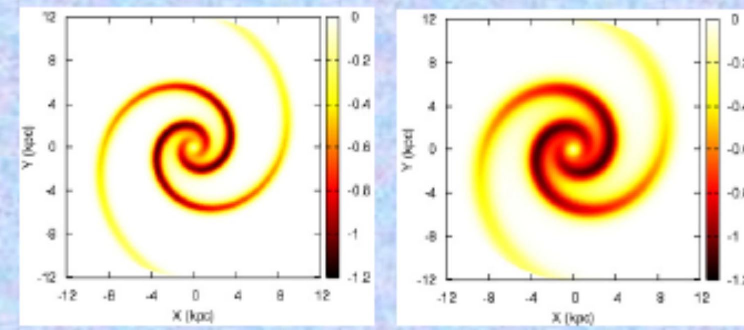


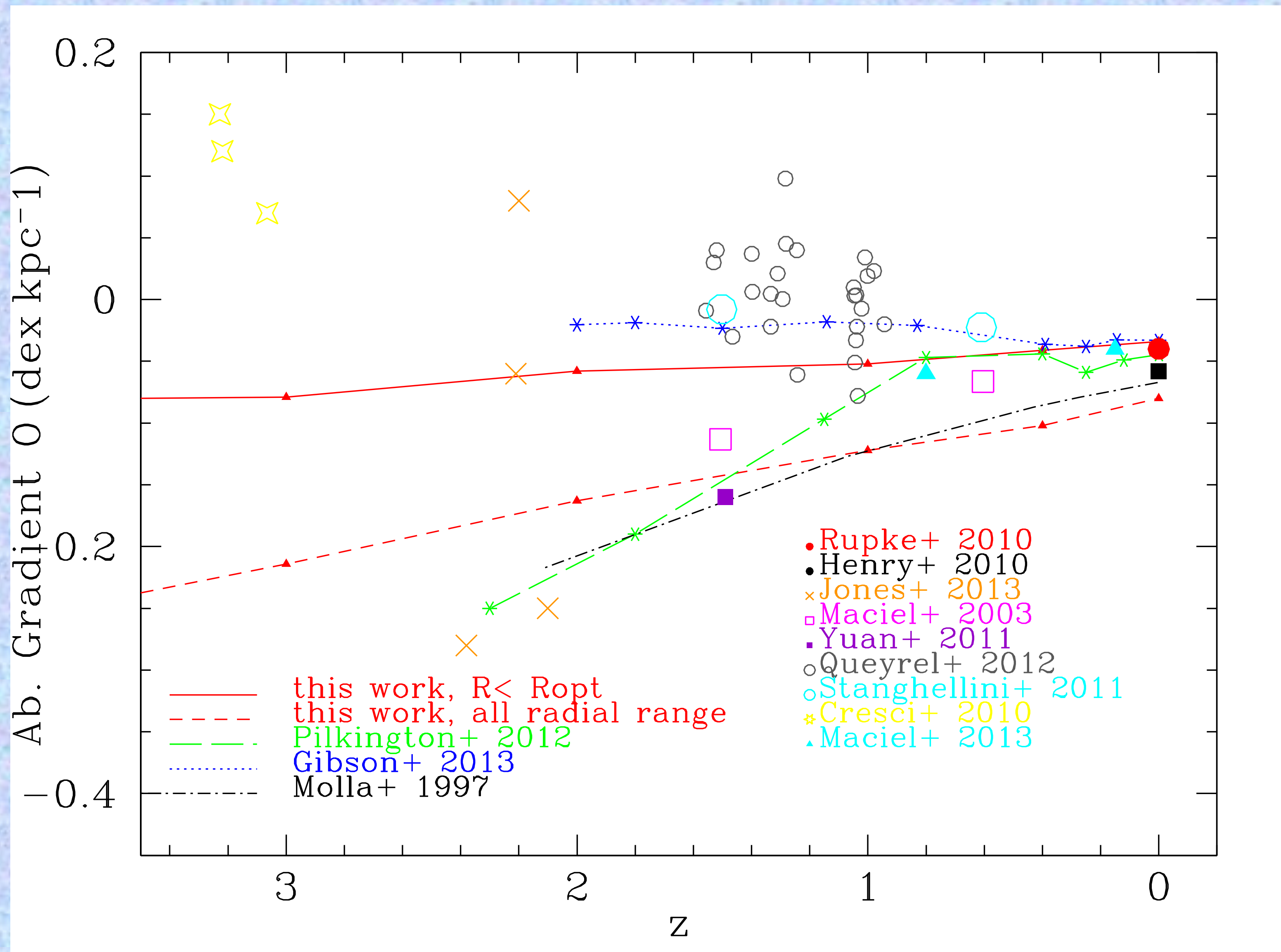
Fig. 2. Map of the perturbing potential in the plane of the galaxy. The colors represent the values of $\Phi_1(R,\varphi)$ in arbitrary units. The picture on the *left* is the potential with $\sigma = 2.5$ kpc and on the *right* $\sigma = 4.7$ kpc. For $i = 14°$ we have on the left $\sigma_\perp = 0.6$ kpc and on the right $\sigma_\perp = 1.1$ kpc.

"The surface density of a zero-thickness disk can be represented mathematically as the sum of an axisymmetric or unperturbed surface density $\Sigma_0(R)$, and a perturbed surface density $\Sigma_1(R,\phi)$, which represents the spiral pattern in a frame that rotates at angular speed Ω_p. The azimuthal coordinate at the rotating frame of reference is $\phi = \theta - \Omega_p t$, where θ is the angle at the inertial frame" (Junqueira et al. 2013)

$$\Sigma_1(R, \theta - \Omega_p t) = \Sigma_s e^{i[m(\theta-\Omega_p t)+f_m(R)]},$$

SUMMARY

1. We are computing models for a wide range of total masses and efficiencies.
2. 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"
3. Different IMFs or stellar yield sets only change the absolute values of abundances but not the shape of the radial gradients.
4. A realistic infall rate of gas to form disks is essential to reproduce the observed radial distributions: the infall rate determines the radial gradients of abundances
5. Similar efficiencies produce similar radial gradients of elemental abundances when measured in normalized radius: the mass of each galaxy does not determine the radial gradient
6. Abundances are local: caution is necessary when global quantities are compared with some other local
7. The radial gradient changes following the spatial range and also with time
8. The evolution with redshift and the comparison with new data will allow to discriminate between galaxy formation scenarios.
9. To be calculated: the spectral energy distributions and the corresponding magnitudes, colors, brightness profiles and spectral absorption stellar indices



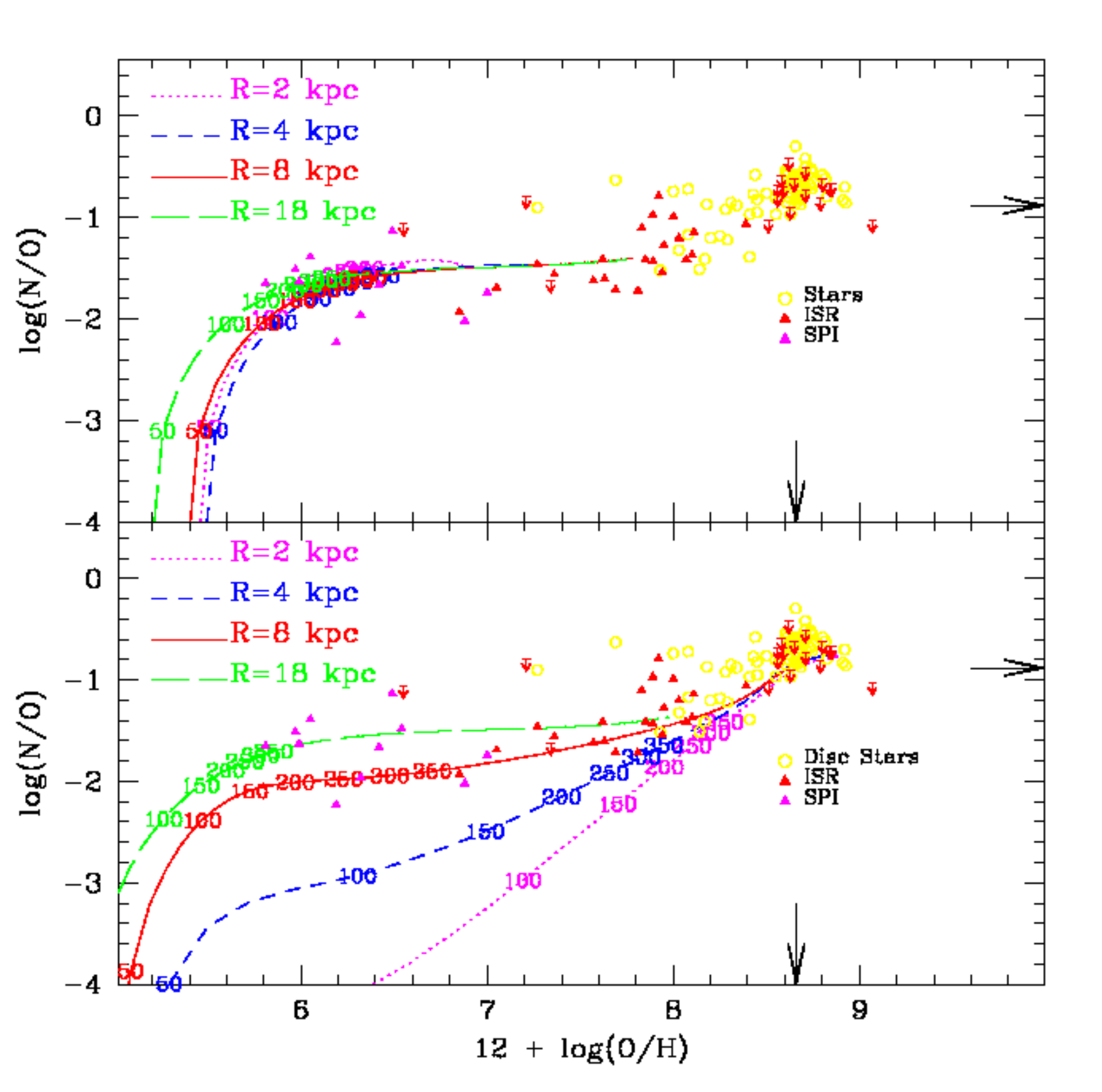
0.2
0
0.2
−0.4
Ab. Gradient O (dex kpc−1)
3
2
1
0
z
Rupke+ 2010
Henry+ 2010
Jones+ 2013
Maciel+ 2003
Yuan+ 2011
Queyrel+ 2012
Stanghellini+ 2011
Cresci+ 2010
Maciel+ 2013
this work, R< Ropt
this work, all radial range
Pilkington+ 2012
Gibson+ 2013
Molla+ 1997

The N/O vs O/H

In the disk, the most evolved region (magenta line) has an evolutionary track which is different than the one from the outer less evolved disk regions (green line)

A dispersion will appears with different SFR efficiencies

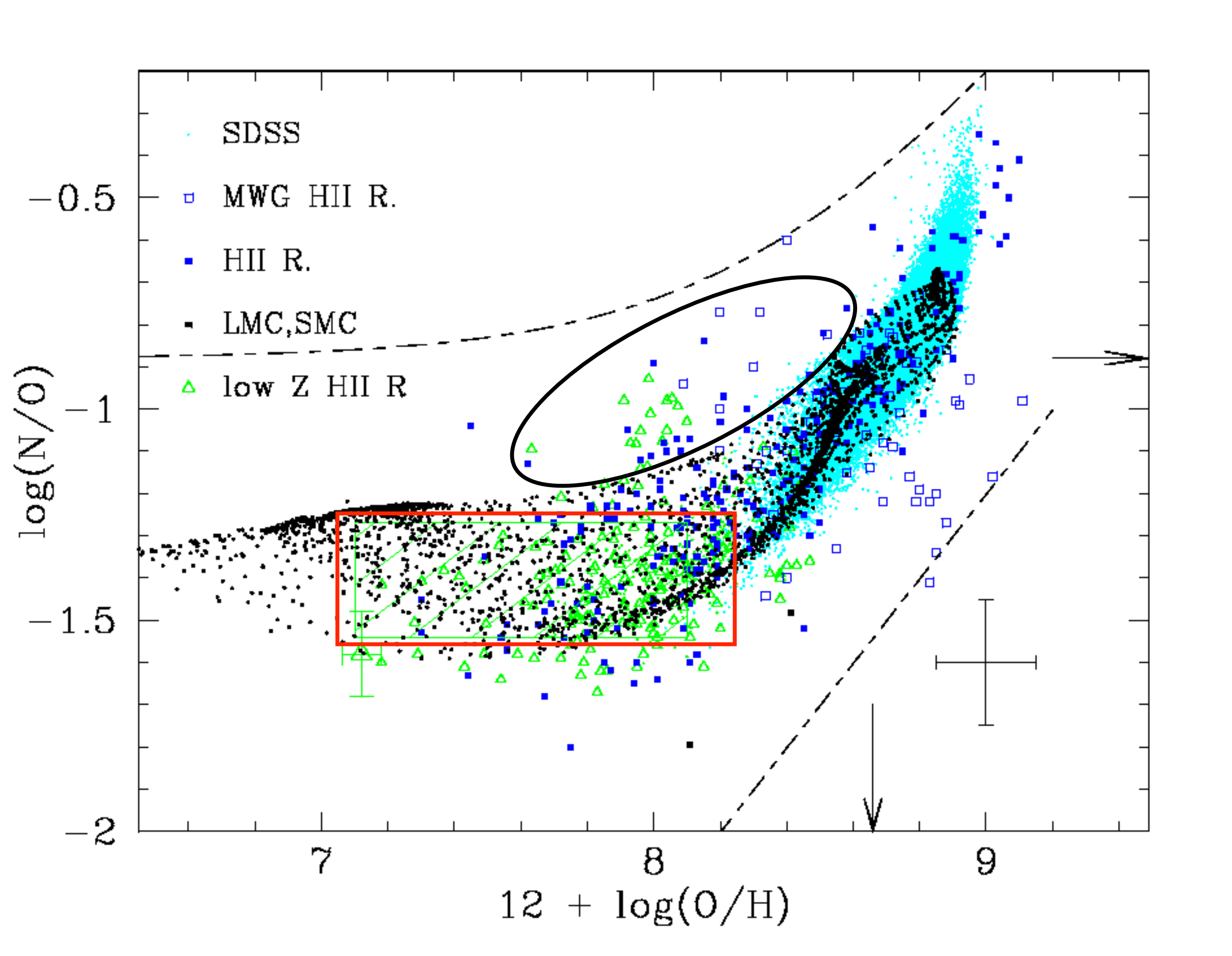
In the halo all tracks are similar with a flat behaviour, falling over data



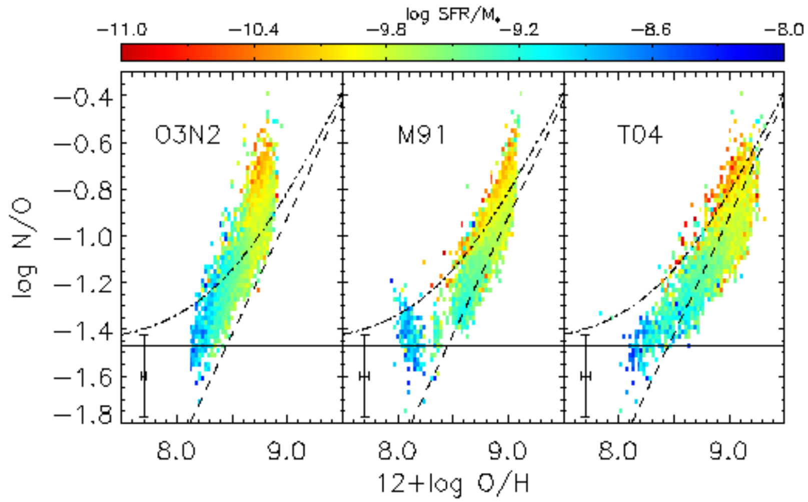
Nitrogen over Oxygen

Using this grid of models, we have obtained these results in the plane N/O vs O/H for the whole set of models and all computed time steps (Mollá et al. 2006).

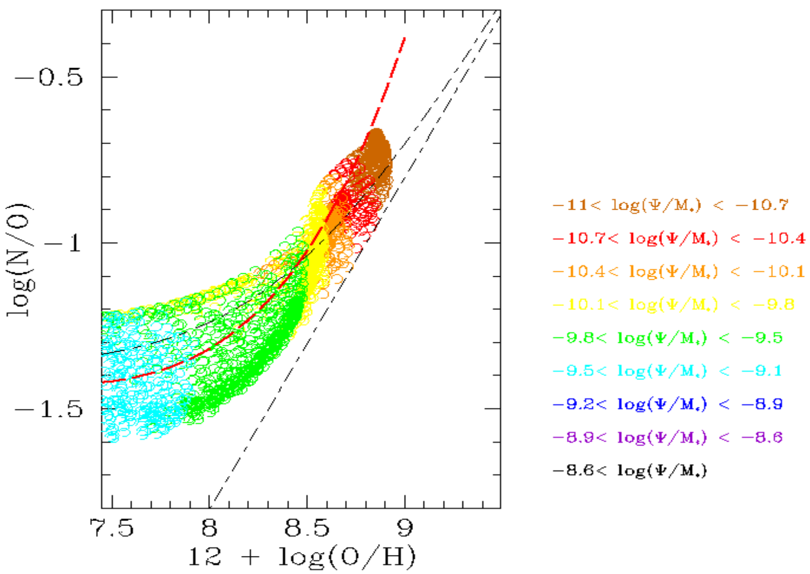
The present day abundances distribution in the plane N/O vs O/H compared with data from Galactic and extragalactic HII regions

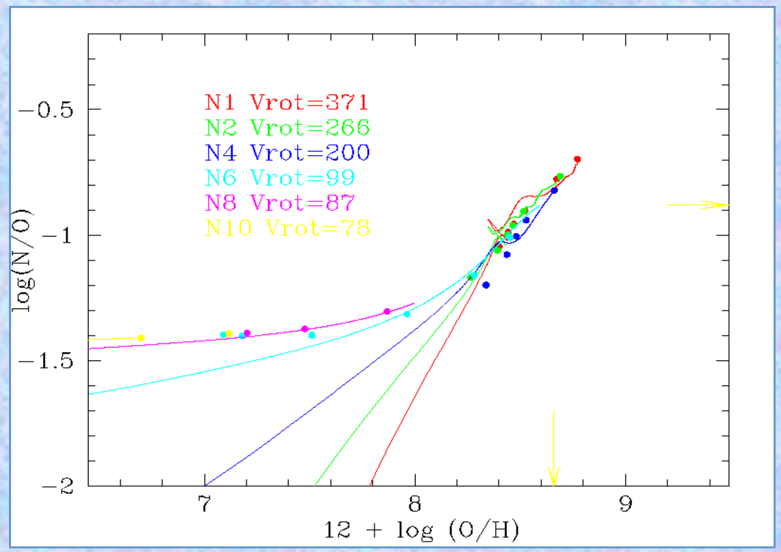


THE RELATION N/O-SFR-SFH

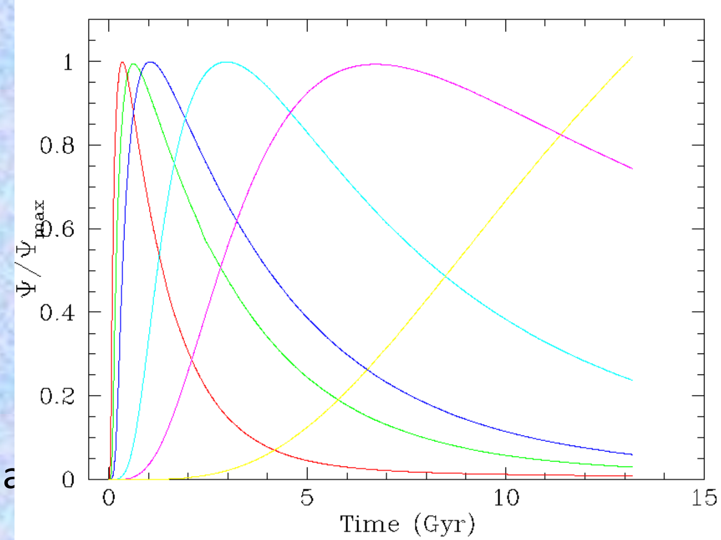


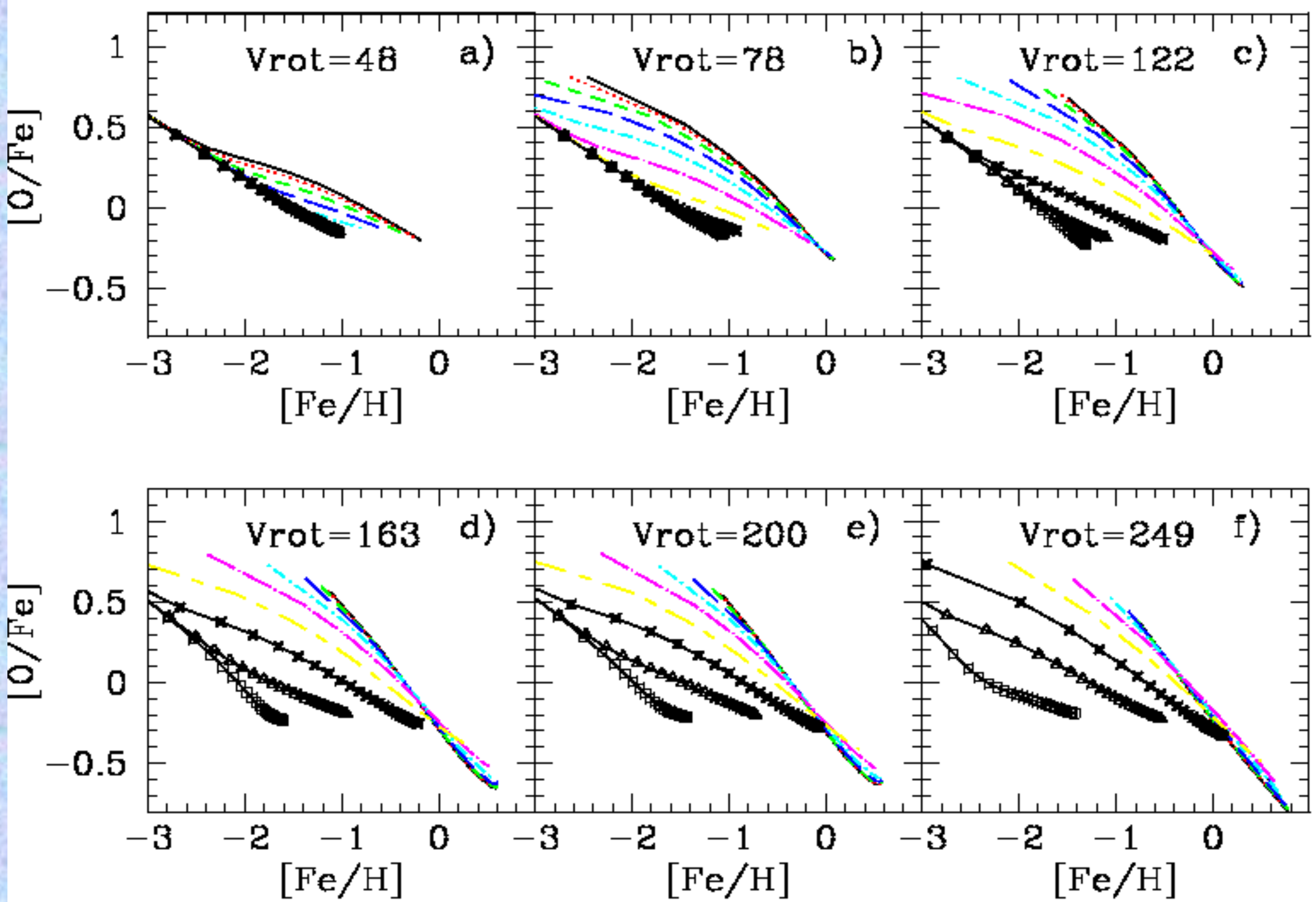
Galex data (Mallery et al. 2007)





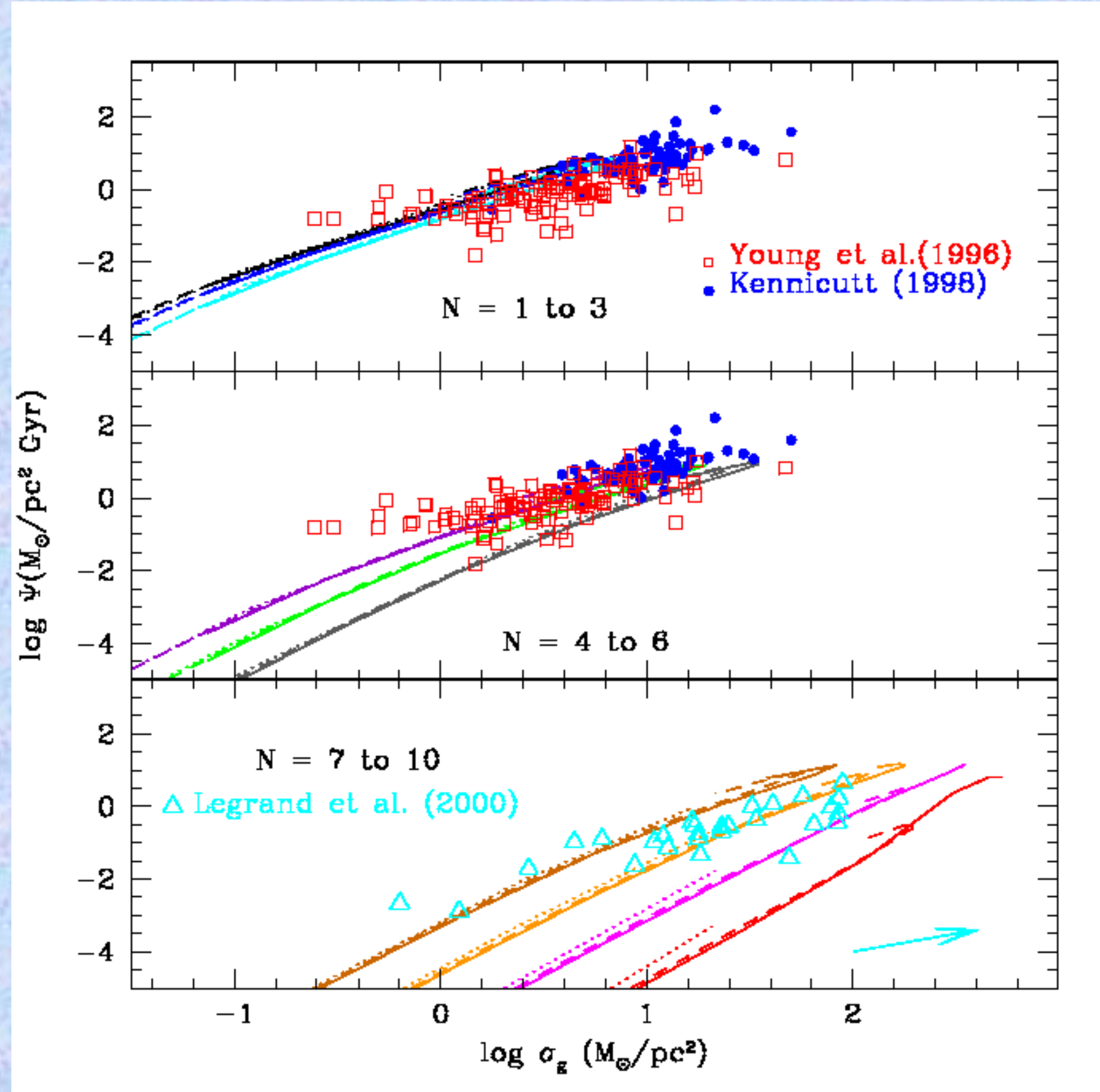
a) Tracks of the lowest mass galaxy with the smallest star formation efficiency.
b)Tracks of the most massive galaxy and the highest star formation efficiency.




Vrot=48 a)
Vrot=78 b)
Vrot=122 c)
Vrot=163 d)
Vrot=200 e)
Vrot=249 f)
[O/Fe]
[Fe/H]
1
0.5
0
−0.5
−3
−2
−1
0

The star formation rate *vs* the gas density

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



HOWEVER

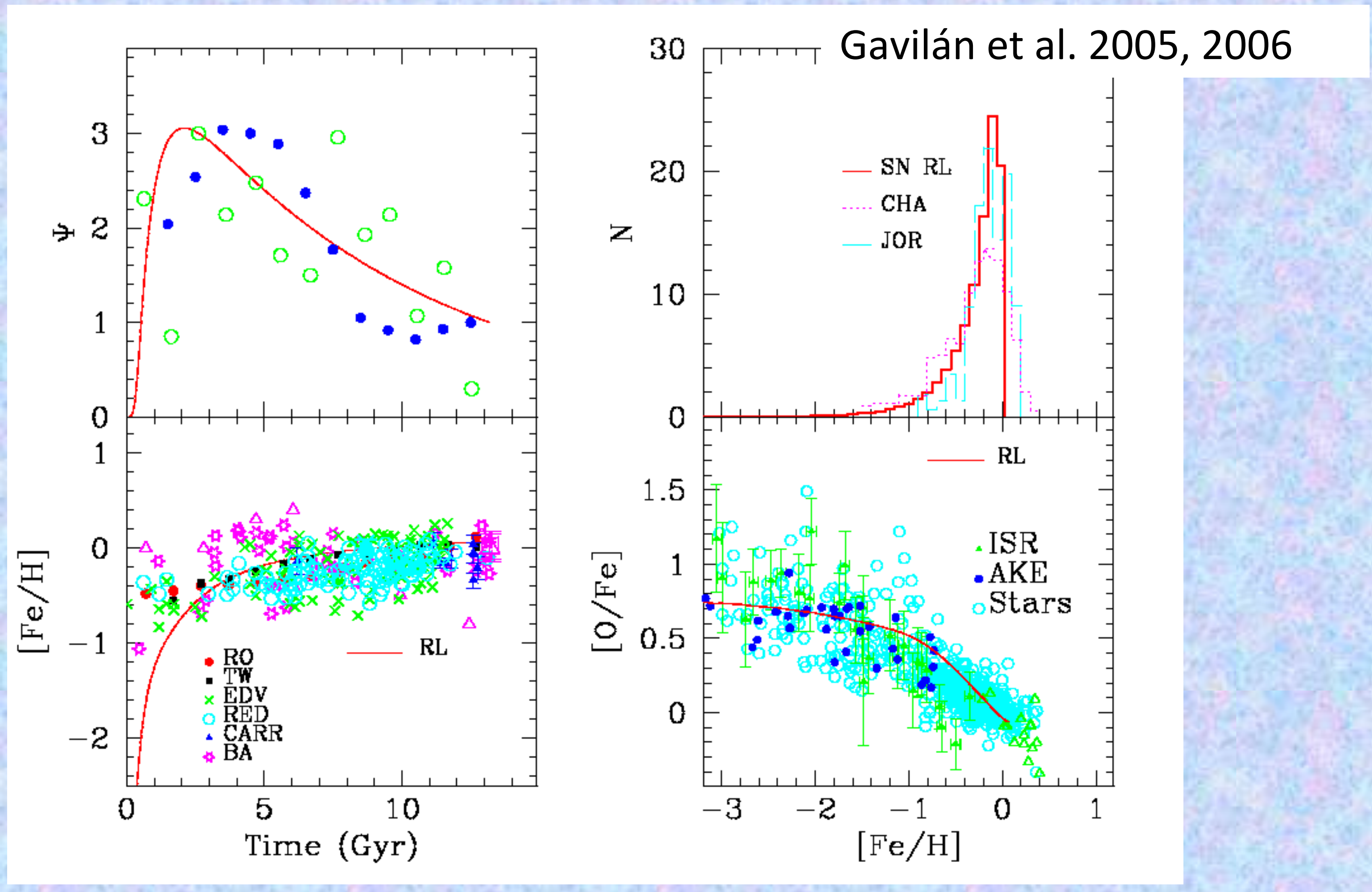
•Although the radial gradient of abundances is well reproduced in the models, our results depend on the fitting of gas stars and star formation profiles…

•..and the molecular gas and the star formation rate show radial distributions decreasing in the inner disk, at variance of observed. They are not well tuned compared with observations

•It seems that we need a slower evolution…

WE NEED BETTER MODELS

Calibration: the model against the Solar Vicinity data



- **The age-metallicity relation and the star formation history for the solar region**
- **The metallicity distribution does not show the G-dwarf problem**

Our MD05 grid of models

- Mollá & Díaz (2005): 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)
- Efficiencies to form molecular gas and stars 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

SUMMARY OF MODELS GRID

- We have used the universal rotation curve from Persic, Salucci & Steel (1996) to calculate radial mass distribucions M (R)
- We have computed the collapse time scale for each distribution from the relation $\tau_{col,gal} / \tau_{col,MWG} = (M_{MWG}/M_{gal})^{0.5}$
- We have found analytical expressions for ε_{μ} (T) y ε_{h} (T)
- We compute models for 44 radial mass distributions, and 10 different values of eficiencies (ε_{μ} , ε_{H}) between 0 and 1, as it corresponds to their probability meaning, for each one = 440 different models
- The results of this bi-parametric grid can be applied to any spiral or irregular galaxy of given rotation velocity or total mass in order to estimate its evolution

Big Bang nucleosynthesis

Time 0: singularity.

Enormeus Pressure and Temp: quarks & gluons plasma

Large density: the radiation can not travel

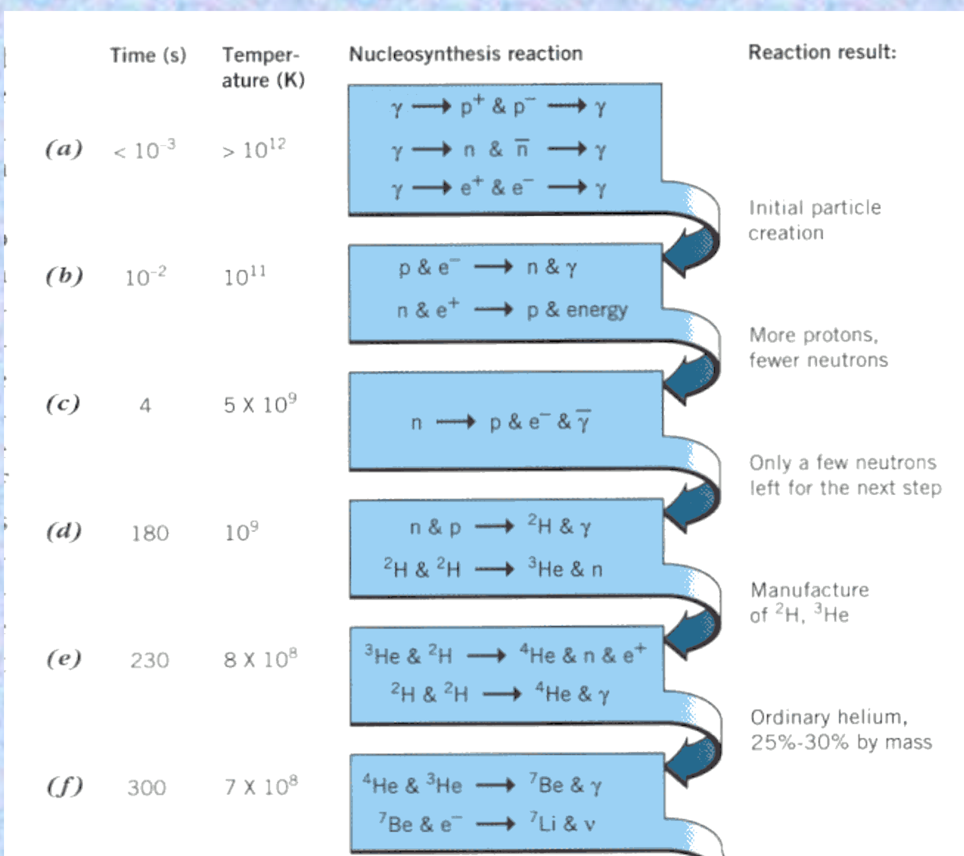


FIGURE 21.10 One possible sequence for nu-cleosynthesis at specific times in the Big Bang

1. Ionized Plasma **Exponential expansion. Loss of pressure and temp.**

Big Bang nucleosynthesis

Time 0: singularity.

Enormeus Pressure and Temp: quarks & gluons plasma

Large density: the radiation can not travel

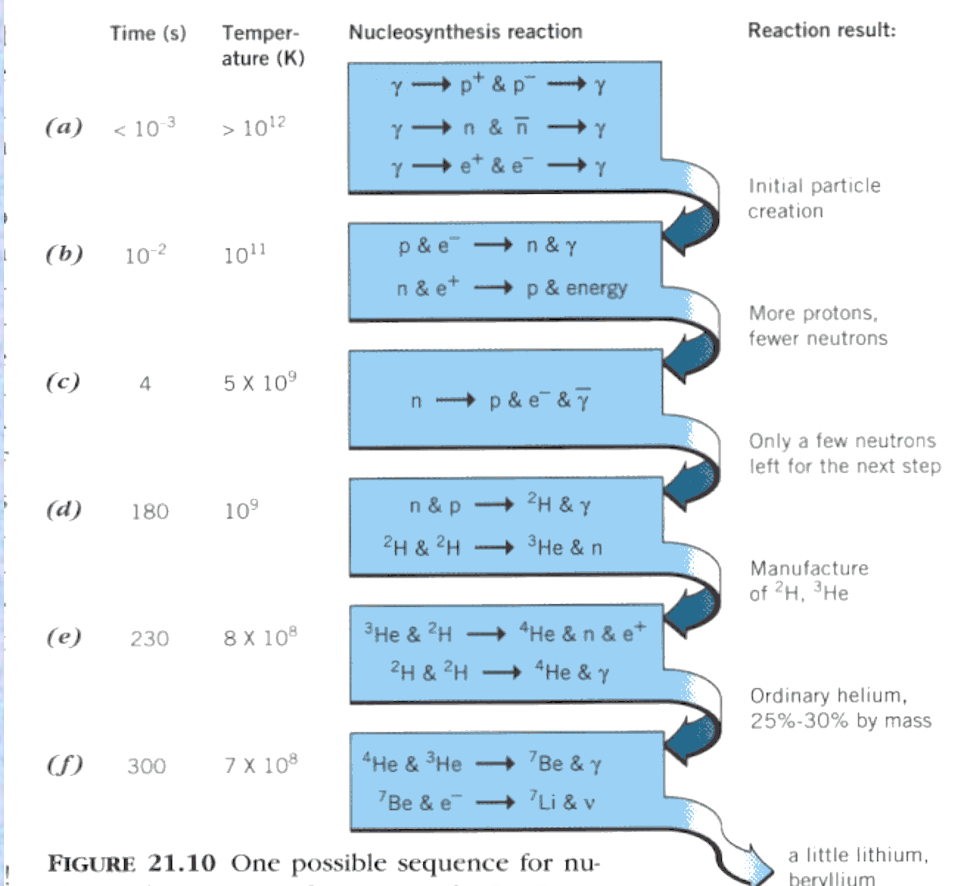


FIGURE 21.10 One possible sequence for nucleosynthesis at specific times in the Big Bang

1. **Ionized Plasma Exponential**
2. **Massive particles Barionic matter**
3. **Light particles: neutrones creation**
4. **Radiation Era: Photons unable to create more matter.** Ratio nucleons
5. **Formation of light nuclei (H y D):**
6. **Nuclear Reaccions: ^{3}He y ^{4}He, He abundance fixed**

Big Bang nucleosynthesis

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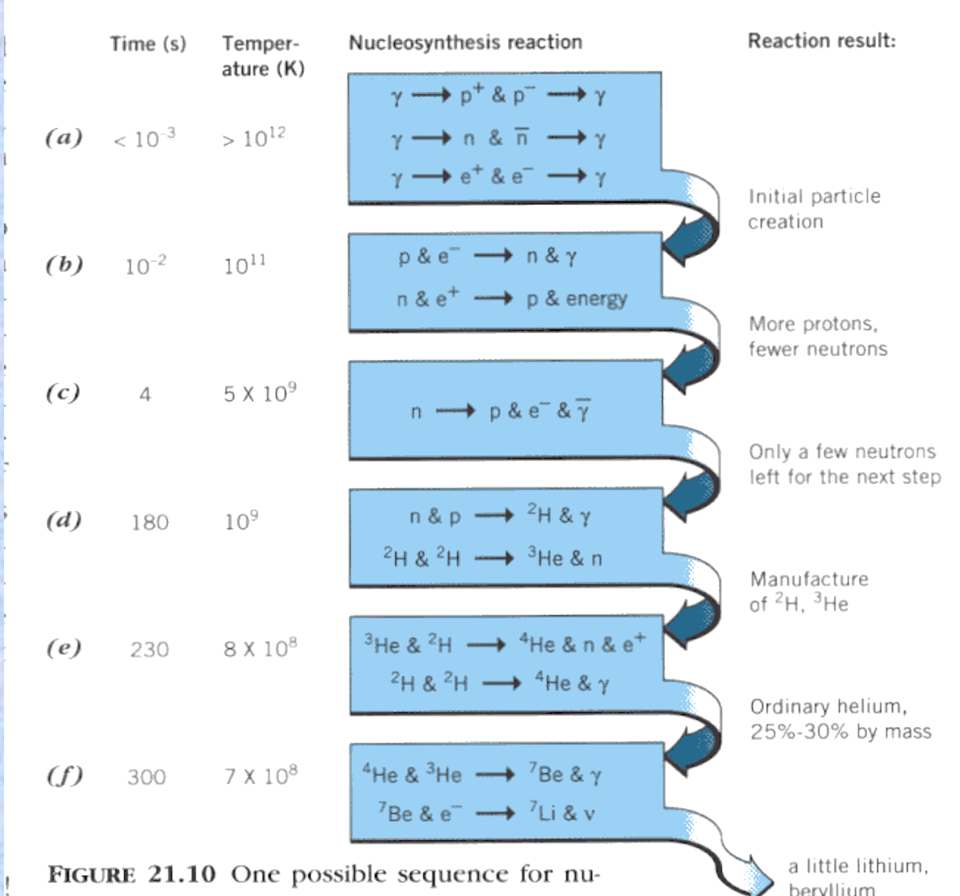
Enormeus Pressure and Temp: quarks & gluons plasma

Large density: the radiation can not travel



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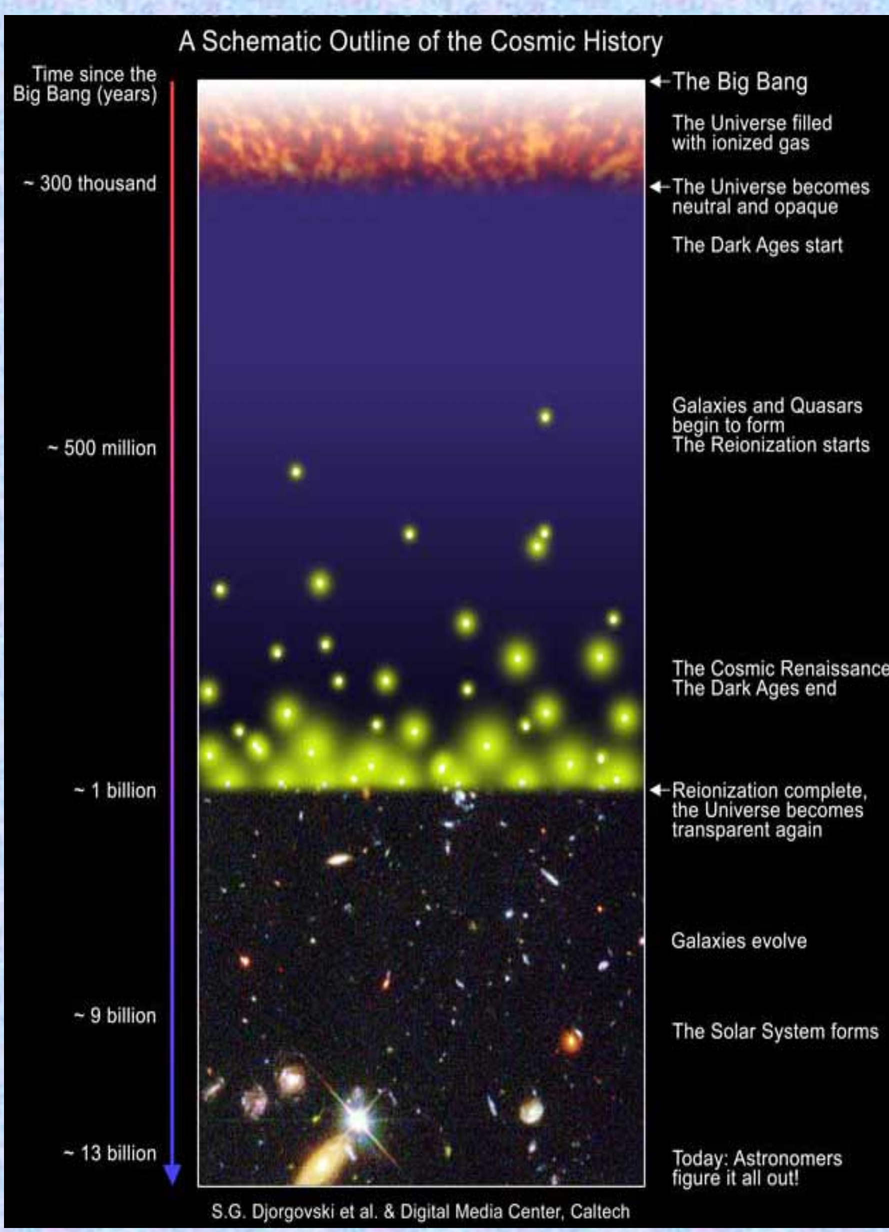
7. **Recombination Era: When T< 3000 K, the process of atoms formation starts**

Evolution of Universe



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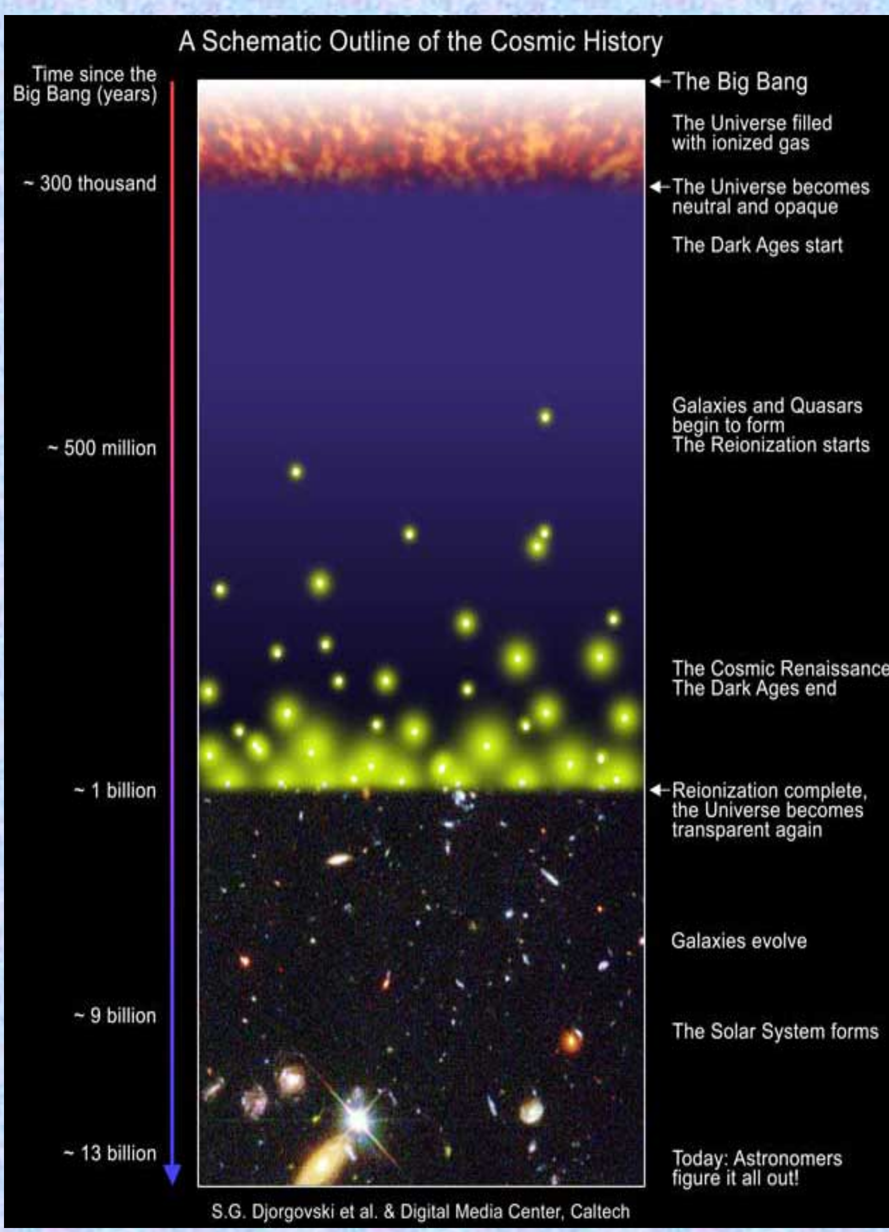
7. **Recombination Era: When T< 3000 K, the process of atoms formation**
8. **Radiation and matter Microwave cosmic radiation(2.7 K)**

Evolution of Universe



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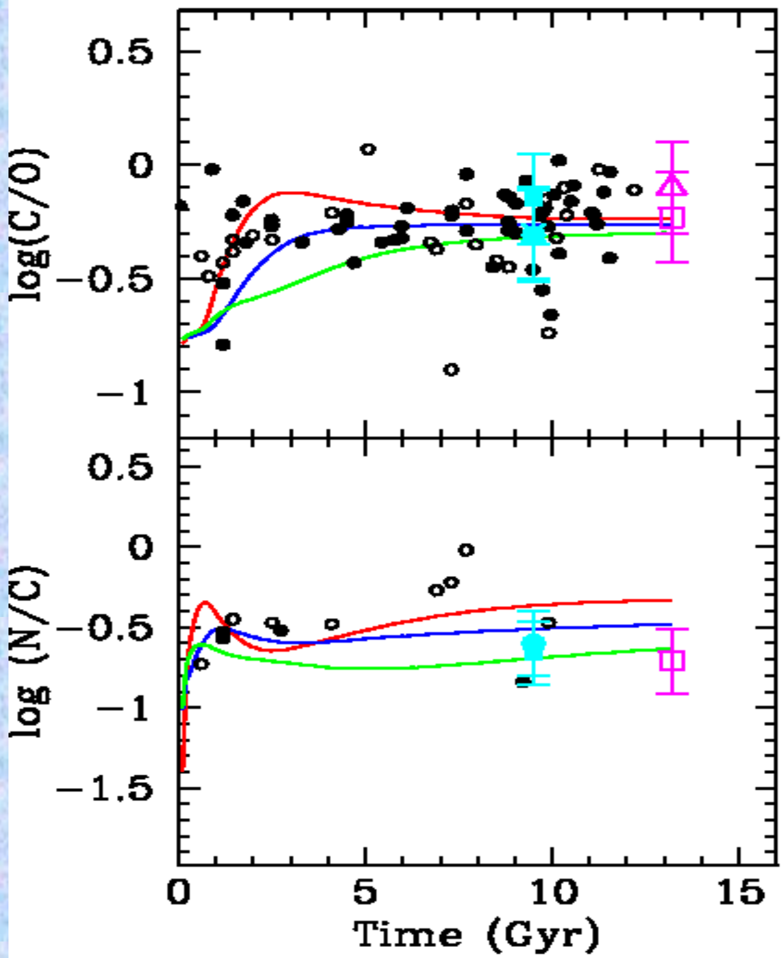
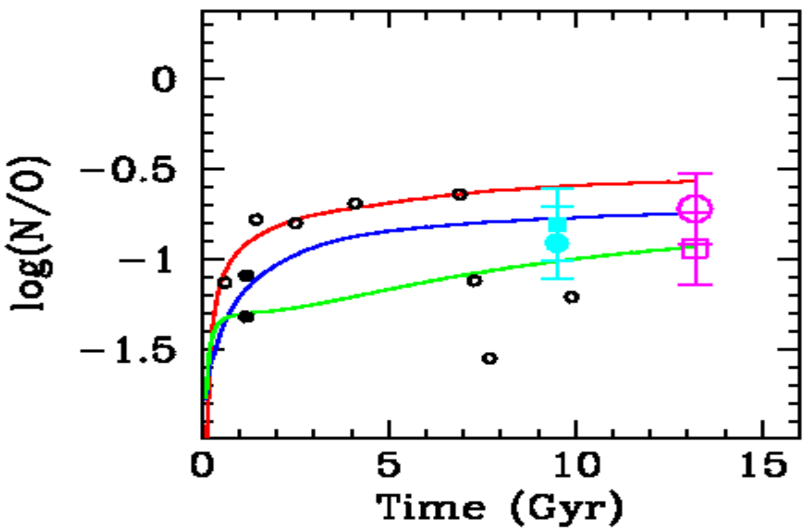
7. Recombination Era: When T< 3000 K, the process of atoms formation
8. Radiation and matter Microwave
9. Gravitation, Mass accumulation, galaxy formation and star formation

THE TIME EVOLUTION OF CNO ABUNDANCES





- **The elemental abundances reproduce well the observed data for the SN and also for other radial regions.**
- **The relative CNO abundances also are well fitted**

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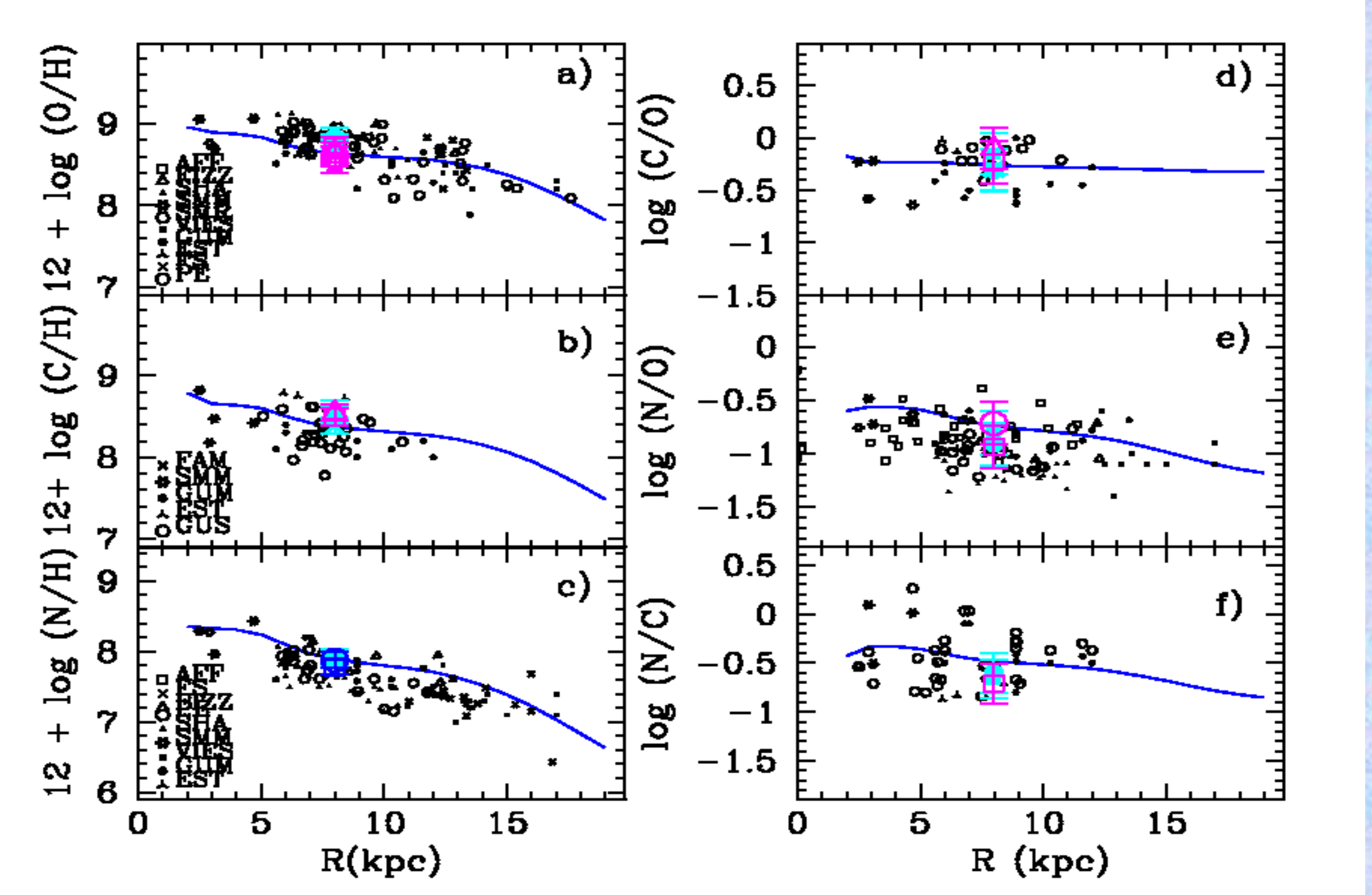
THE RADIAL GRADIENTS OF CNO ABUNDANCES



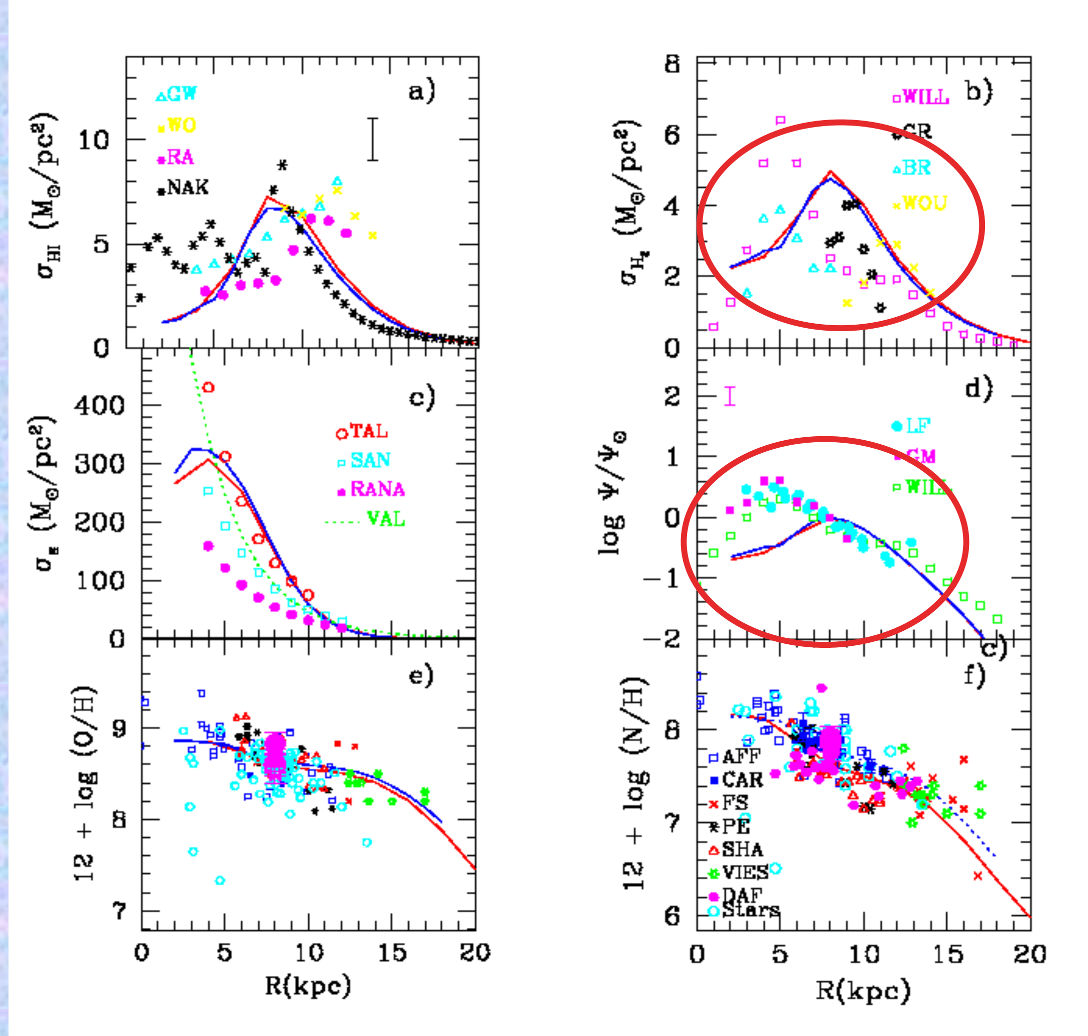
Pc

February

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

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

- 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



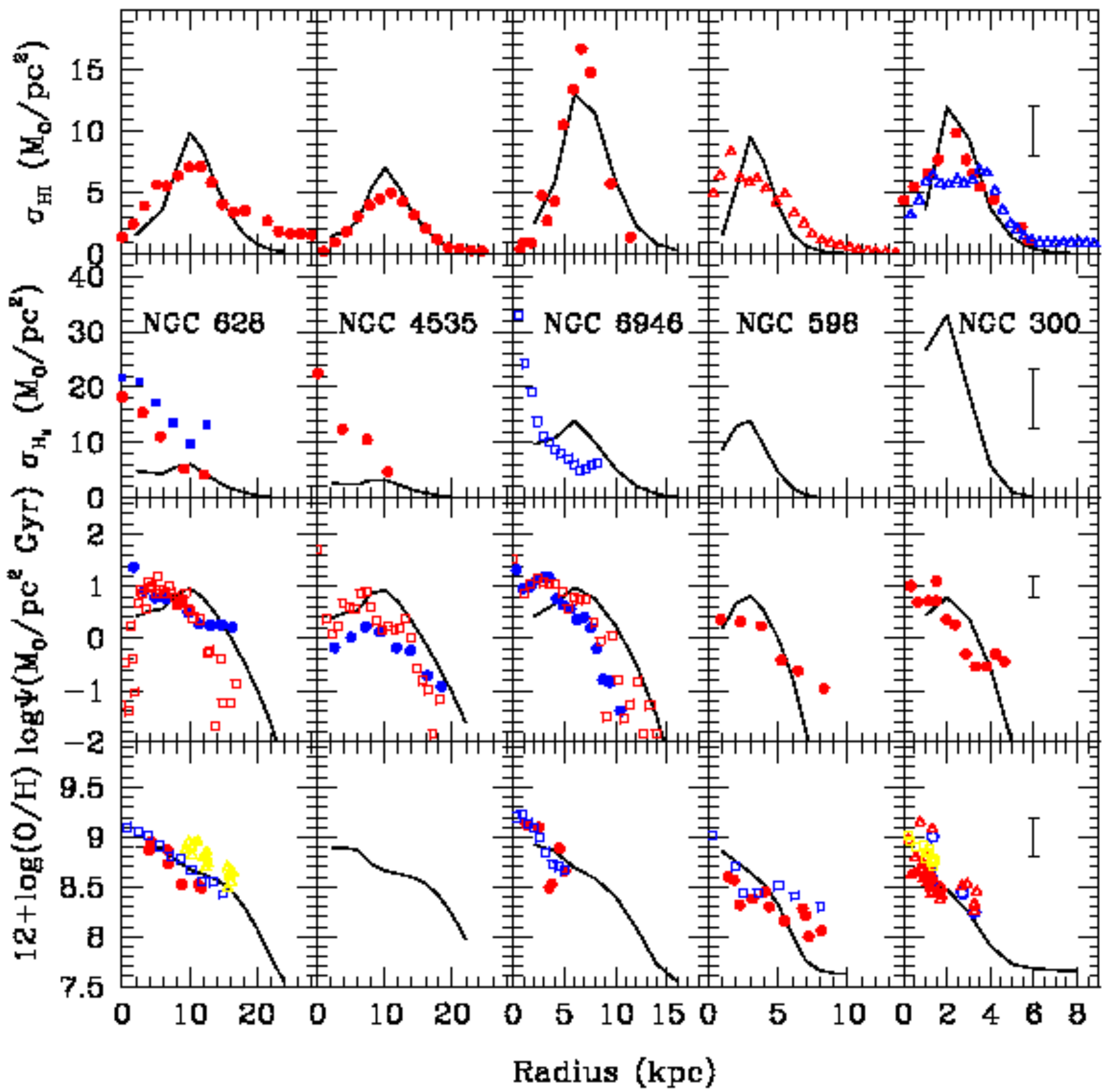
III. Calibration.

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**

- **Star formation history**
- **Age-metallicity relation**

Mollá & Díaz (2005)



Porto, 2013 February