MODULO:
models of proto galaxies

Chemical evolution with a multizone multiphase model

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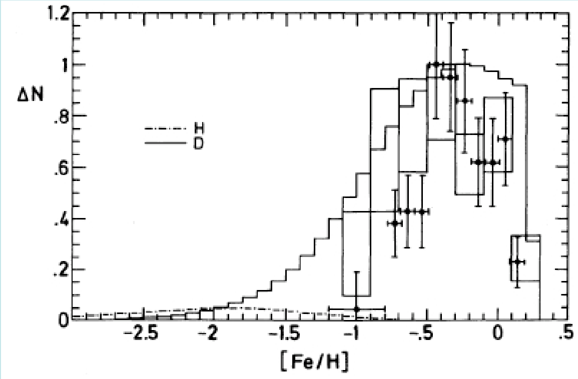
The model

Designed to study galaxies at present-time…and in their recent past:

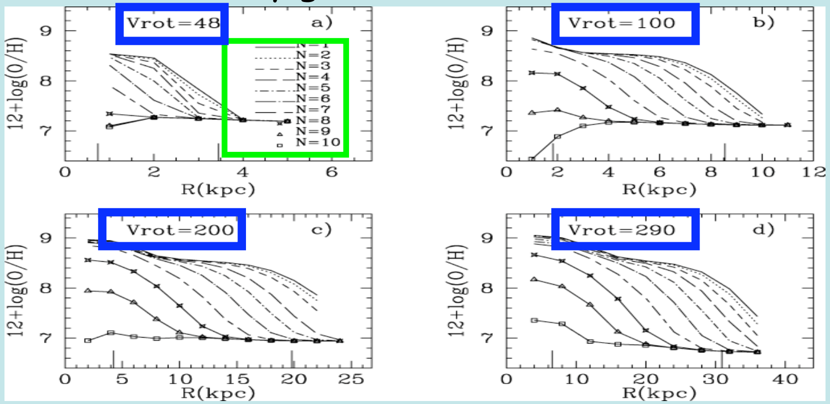
- Solar neighbourhood (e.g., Ferrini et al. 1992)
- Galactic halo, disk (thin and thick) and bulge (e.g., metallicity gradients, Ferrini et al. 1994, Magrini et al. 2009a)
- External galaxies (elliptical, spirals, irregulars, e.g. Molla' & Diaz 2005, Magrini et al. 2007)

Some results:

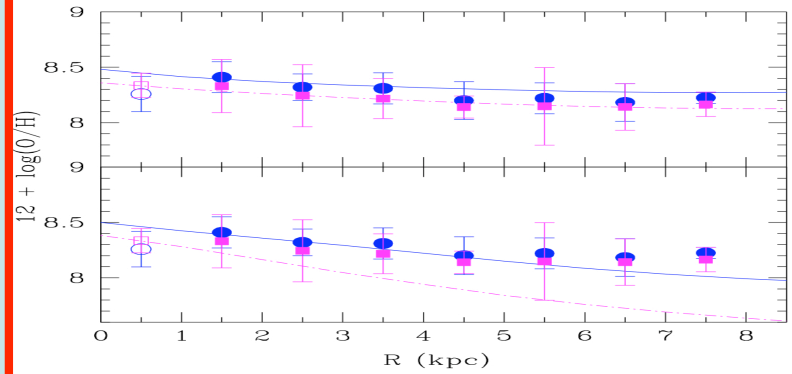
The solution of the G-dwarfs Problem (e.g. Ferrini et al. 1992)

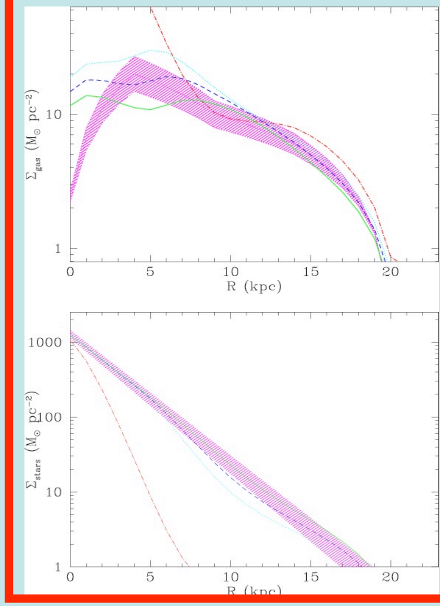


The link between mass, morphological Type and metallicity gradients (Molla' & Diaz 2005)



The time evolution of the metallicity gradient of M33 (Magrini et al. 2009b)

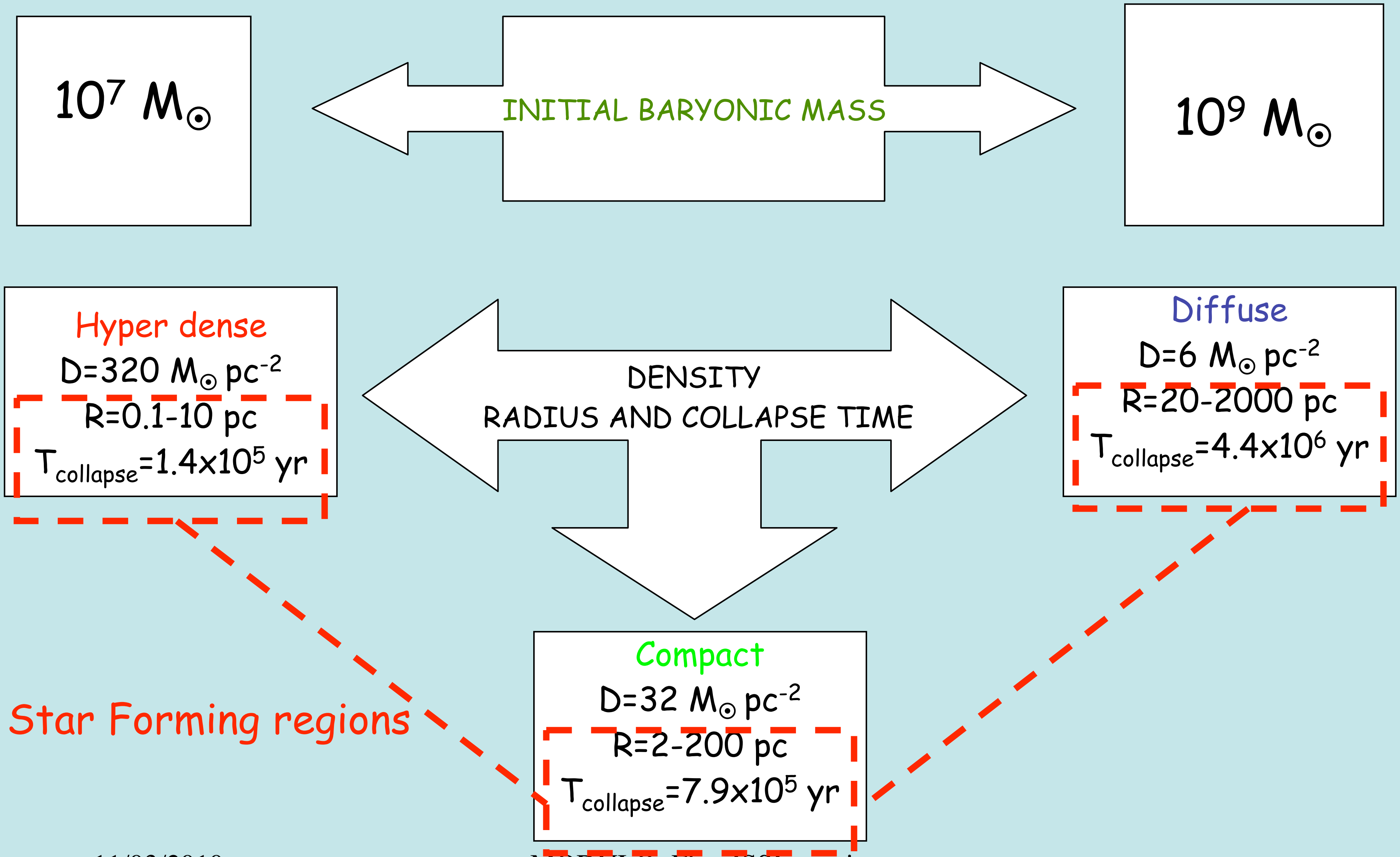




The radial distribution of the different baryonic components in the MW (e.g. Magrini et al. 2009a)

Characteristics of proto-galaxies

(Hunt & Hirashita):



From HII regions to galaxies

- Given the characteristic of the star formation regions (radius and collapse time), we consider larger regions containing the initially available mass of gas (10^7 and 10^9 $M_\odot$) and the given surface densities, Σ= 320, 32, 6 $M_\odot pc^{-2}$

$$R = \sqrt{(M/\pi \Sigma)}$$

and a collapse time corresponding to the free fall time of the host galaxy

$$\tau = \sqrt{(3\pi/32\, G\, \rho)} \text{ where } \rho = M/(4/3\, \pi\, R^3)$$

Size of the regions/galaxies

Hyper dense	Compact	Diffuse
$R=\sqrt{(10^7/\pi 320)}=$ 100 pc $T=5.2\ 10^6$ yr	$R=\sqrt{(10^7/\pi 32)}=$ 320 pc $T=3\ 10^7$ yr	$R=\sqrt{(10^7/\pi 6)}=$ 730 pc $T=\ 10^8$ yr
$R=\sqrt{(10^9/\pi 320)}=$ 1 kpc $T=1.5\ 10^7$ yr	$R=\sqrt{(10^9/\pi 32)}=$ 3.2 kpc $T=9.\ 10^7$ yr	$R=\sqrt{(10^9/\pi 6)}=$ 7.3 kpc $T=8\ 10^8$ yr

Initial conditions: SF efficiency

- We consider a star formation efficiency of 0.1 meaning that after ≈ a dynamical time 10% of the total mass is converted into stars
- Thus the SFR is inversely proportional to the collapse time, being higher in the more compact objects
- The initial gas mass infall onto an inner disk where clouds and stars are formed

The equations of the model:

Star formation

$$\frac{ds_{1,D}}{dt} = H_{1,D}c_D^2 + a_{1,D}c_D s_{2,D} - D_{1,D}\,,$$

$$\frac{ds_{2,D}}{dt} = H_{2,D}c_D^2 + a_{2,D}c_D s_{2,D} - D_{2,D}\,,$$

$$\frac{dg_D}{dt} = -\mu_D g_D^n + a'_D c_D s_{2,D} + H'_D c_D^2 + W_D + f g_H\,,$$

Infall

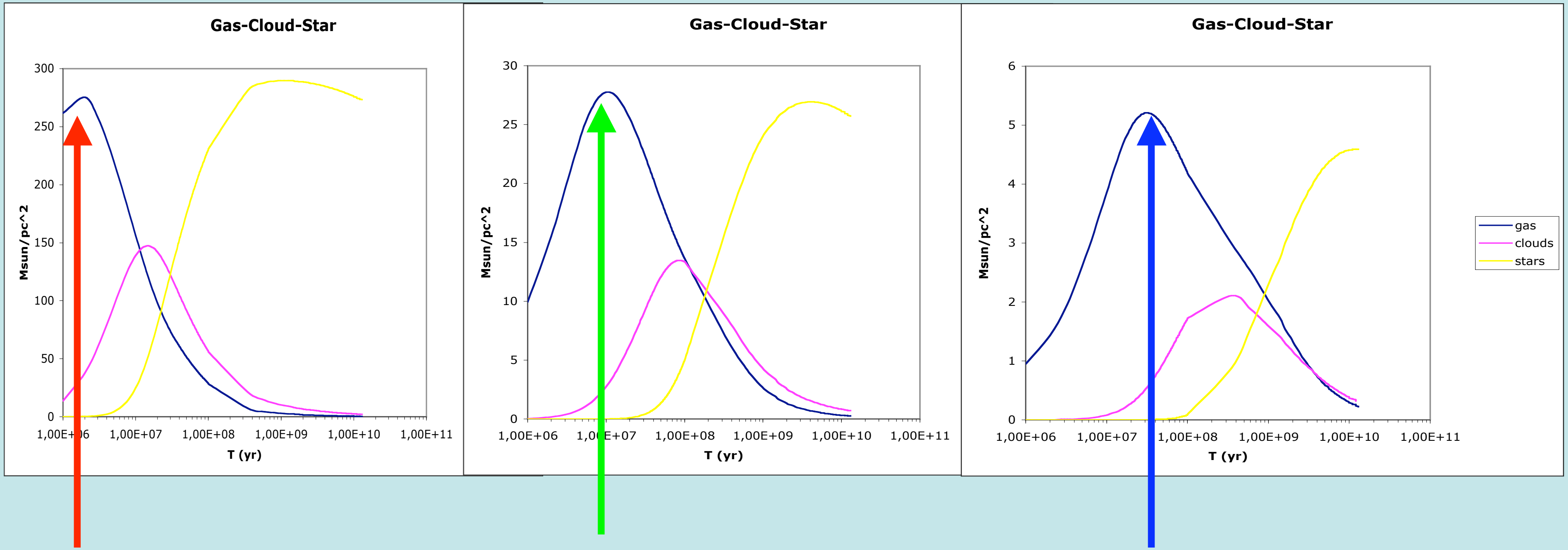
Cloud formation

$$\frac{dc_D}{dt} = \mu_D g_D^n - (a_{1,D} + a_{2,D} + a'_D)c_D s_{2,D} - (H_{1,D} + H_{2,D} + H'_D)c_D^2$$

$$\frac{dr_D}{dt} = D_{1,D} + D_{2,D} - W_D$$

Atomic gas, molecular clouds and stars:

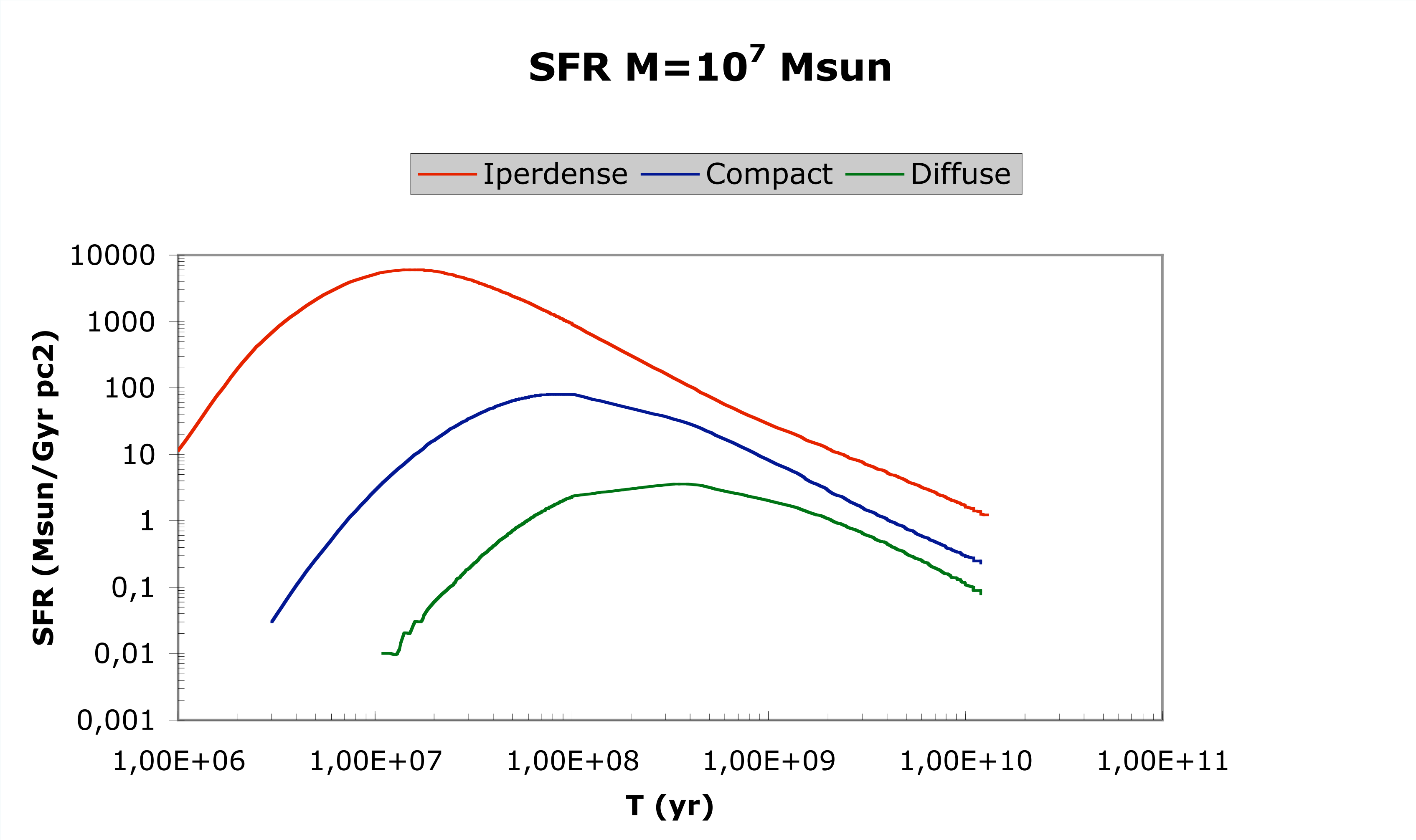
Hyper dense --> compact --> diffuse



Peak of the gas falling from the 'halo': $2x10^6$, $1x10^7$, $3x10^7$ yr

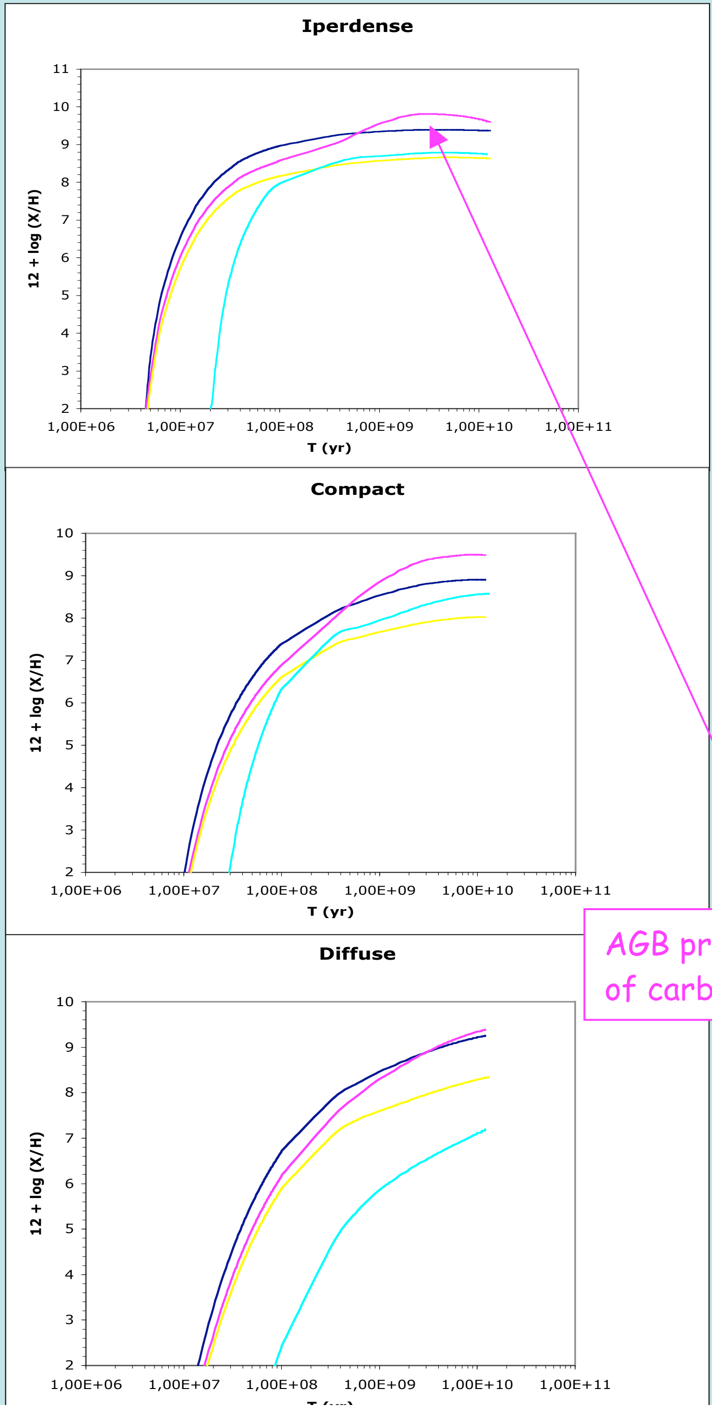
- Infall time ($\propto$ collapse free fall time)
- Star and cloud formation efficiencies

Star formation histories:



The peak of the SF depends essentially on the collapse time

ISM chemical abundances



- Chemical abundances of major constituents of molecules

  → α-elements (produced mainly by massive stars through SNII) oxygen, carbon, silicon

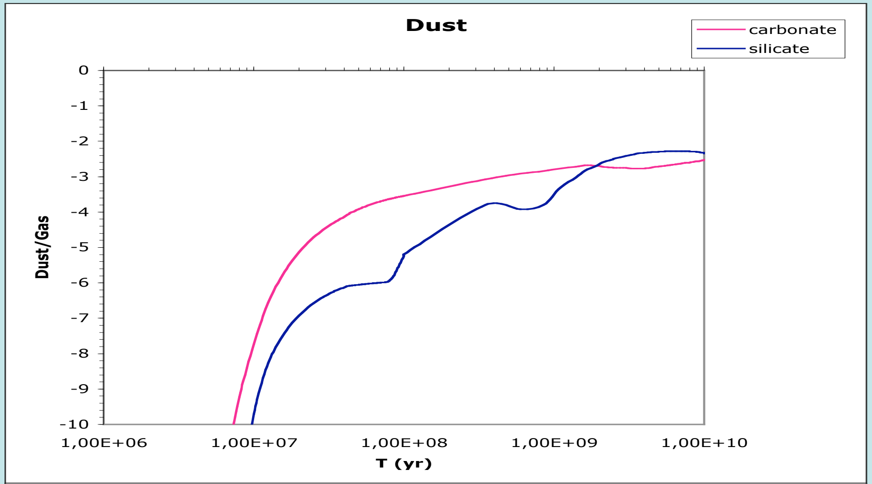
  → elements produced by intermediate mass stars through AGB phase: nitrogen (but also carbon)

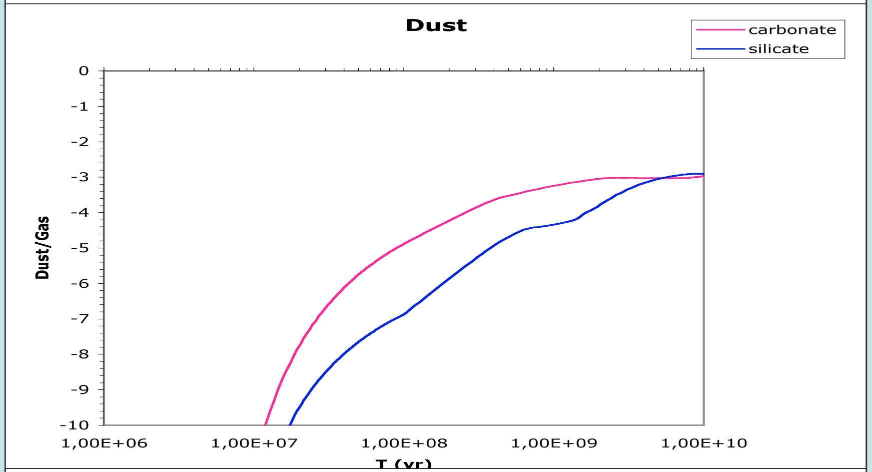
The evolution of dust

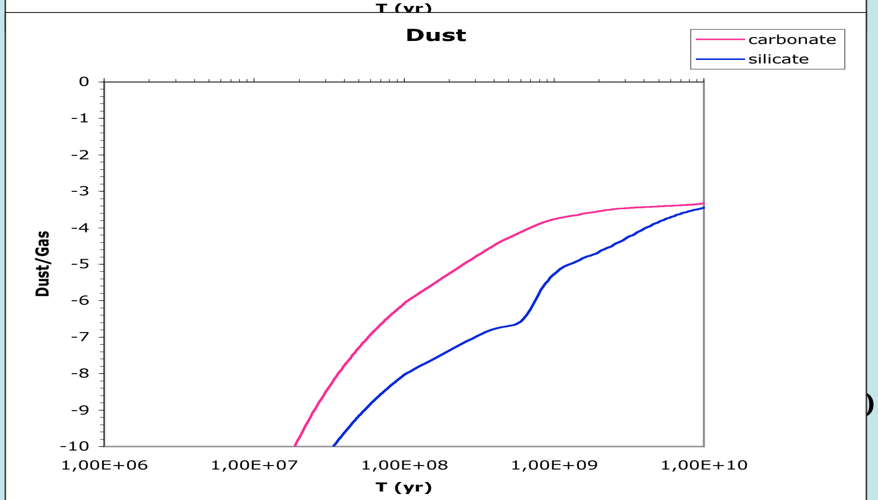
Dust (carbonate and silicate)
produced by

→ AGB stars (Zhukobska 2008)
→ Supernovae (Bianchi & Schneider 2007)

but also destroyed by SNe







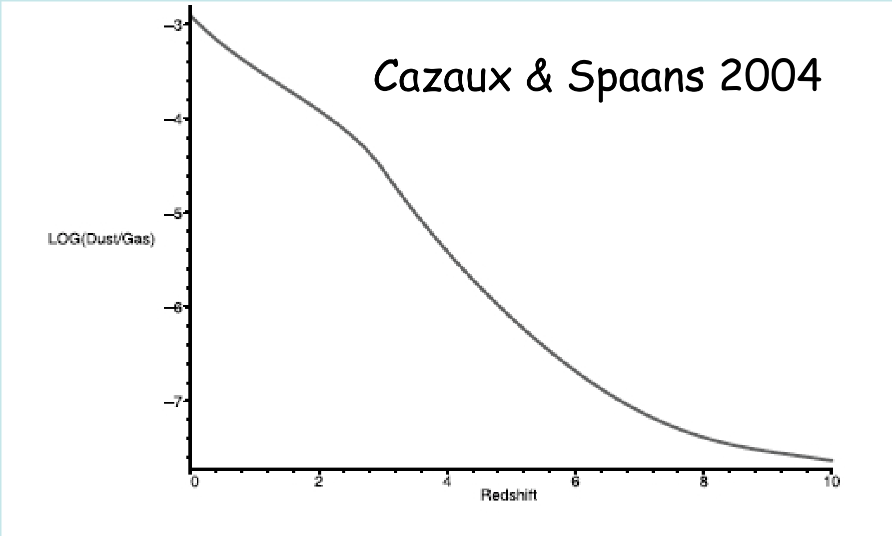


FIG. 16.—Dust-to-gas mass ratio as a function of the redshift for our model disk galaxy; see the text for parameter values.

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Detected ISM molecules

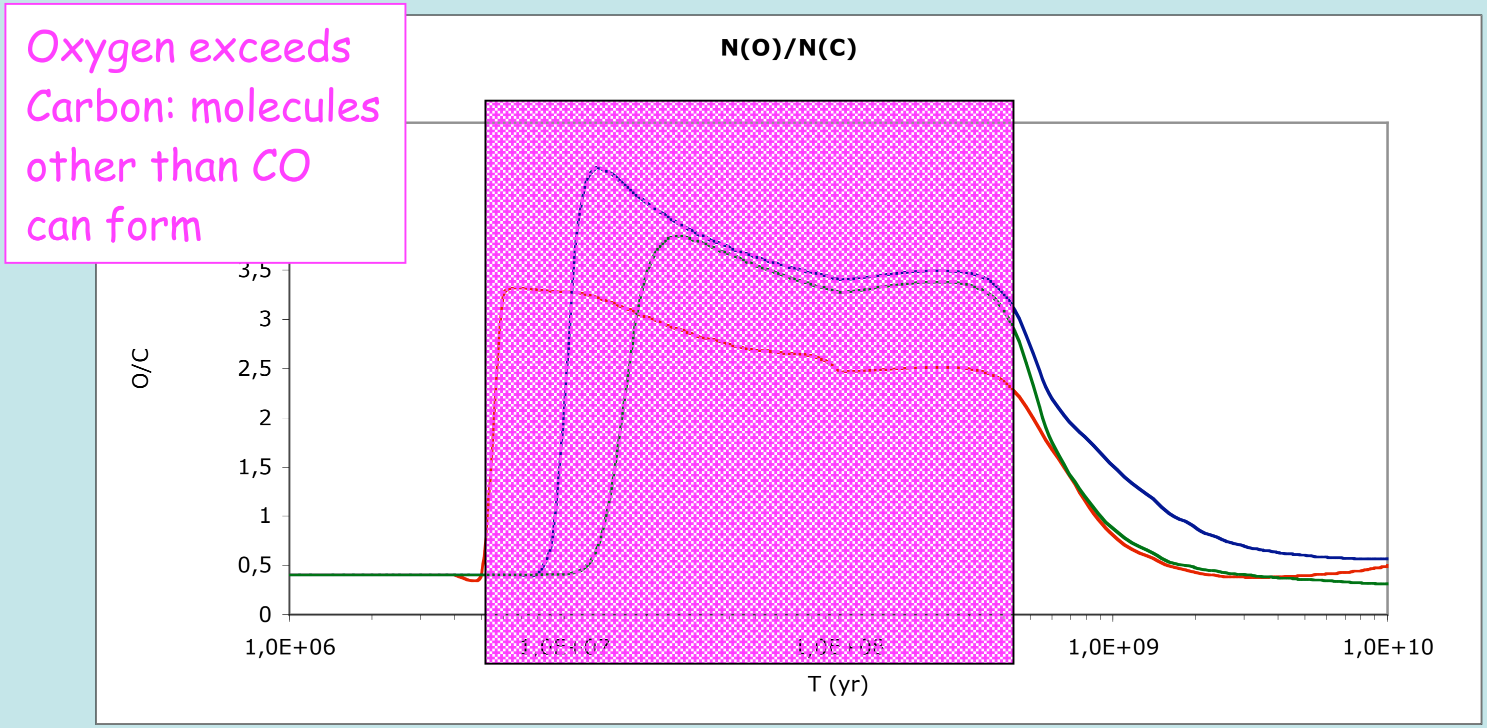
The most abundant molecules

H_2	HD	[illegible]	[illegible]	[illegible]			
CH	CH[illegible]	[illegible]	[illegible]	C_2H	$*C_3$		
CH_3	C_2H[illegible]	[illegible]	[illegible]	CH_4	C_4		
$c\text{-}C_3H_2$	H_2C[illegible]	[illegible]	[illegible]	C_5	$*C_2H_4$	C_5H	
H_2C_4(lin)	$*HC_4H$	CH_3C_2H	C_6H	$*HC_6H$	H_2C_6		
$*C_7H$	CH_3C_4H	C_8H	$*C_6H_6$				
OH	CO	CO+	H_2O	HCO	HCO+		
HOC+	C_2O	CO_2	H_3O+	HOCO+	H_2CO		
C_3O	CH_2CO	HCOOH	H_2COH+	CH_3OH	CH_2CHO		
CH_2CHOH	CH_2CHCHO		HC_2CHO	C_5O	CH_3CHO	$c\text{-}C_2H_4O$	
CH_3OCHO	CH_2OHCHO		CH_3COOH	CH_3OCH_3	CH_3CH_2OH	CH_3CH_2CHO	
$(CH_3)_2CO$	$HOCH_2CH_2OH$		$C_2H_5OCH_3$	$(CH_2OH)_2CO$			
NH	CN	N_2	NH_2	HCN	HNC		
N_2H^+	NH_3	$HCNH^+$	H_2CN	HCCN	C_3N		
CH_2CN	CH_2NH	HC_2CN	HC_2NC	NH_2CN	C_3NH		
CH_3CN	CH_3NC	HC_3NH^+	$*HC_4N$	C_5N	CH_3NH_2		
CH_2CHCN	HC_5N	CH_3C_3N	CH_3CH_2CN	HC_7N	CH_3C_5N?	HC_9N	$HC_{11}N$
NO	HNO	N2O	HNCO	NH2CHO			
SH	CS	SO	SO+	NS	SiH		
*SiC	SiN	SiO	SiS	HCl	*NaCl		
*AlCl	*KCl	HF	*AlF	*CP	PN		
H_2S	C_2S	SO_2	OCS	HCS+	$c\text{-}SiC_2$		
*SiCN	*SiNC	*NaCN	*MgCN	*MgNC	*AlNC		
H_2CS	HNCS	C_3S	$c\text{-}SiC_3$	$*SiH_4$	$*SiC_4$		
CH_3SH	C_5S	FeO					

Courtesy of V. Casasola

The formation of molecules

- We consider a very simple chemistry to form molecules: CO, H_2O, SiO, HCN
- We consider CO as the most probable molecule to form, thus only the excess oxygen, (O-C), can form the other molecules, e.g., H_2O and SiO.

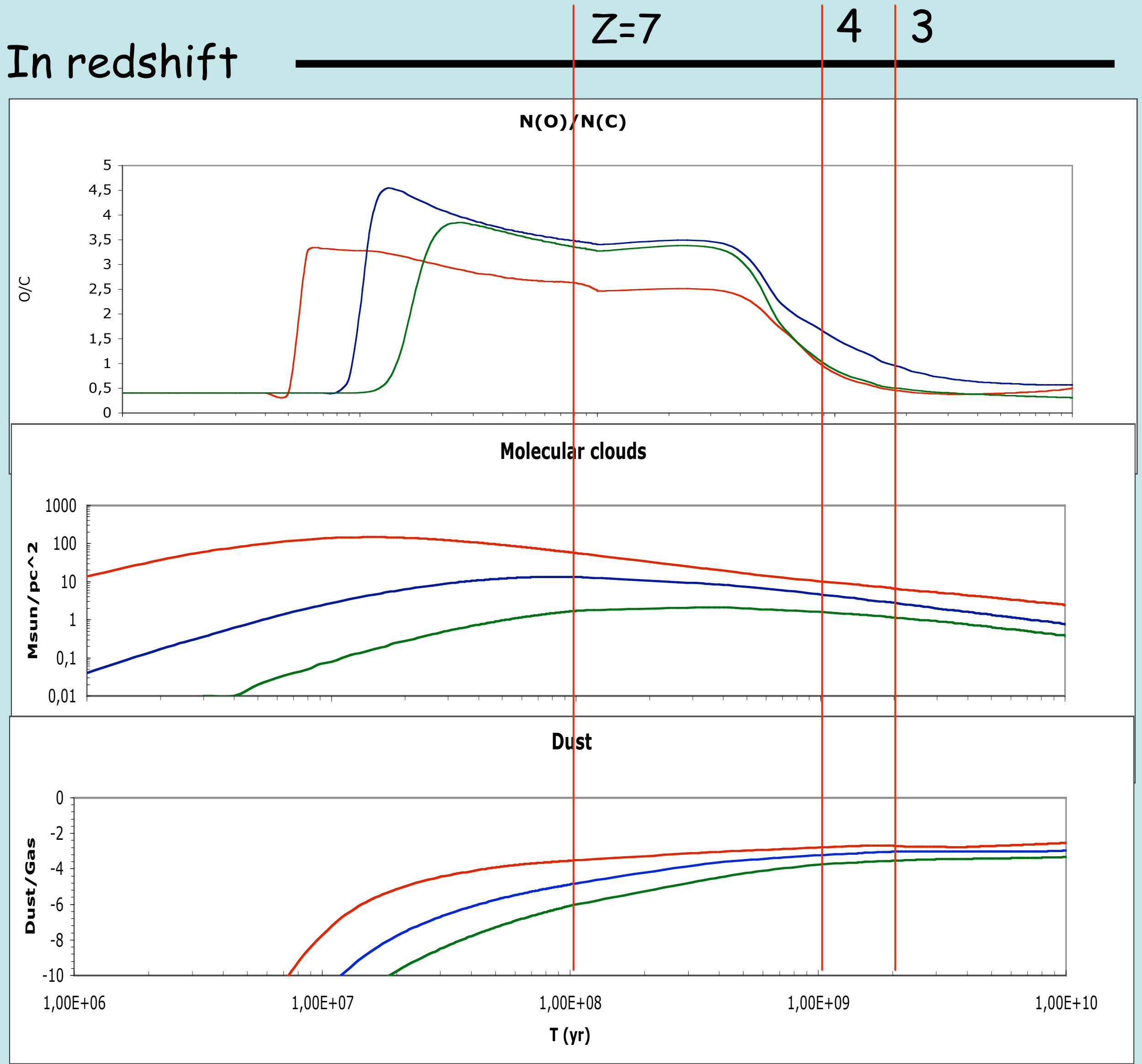


What we need to form a molecule different than CO:

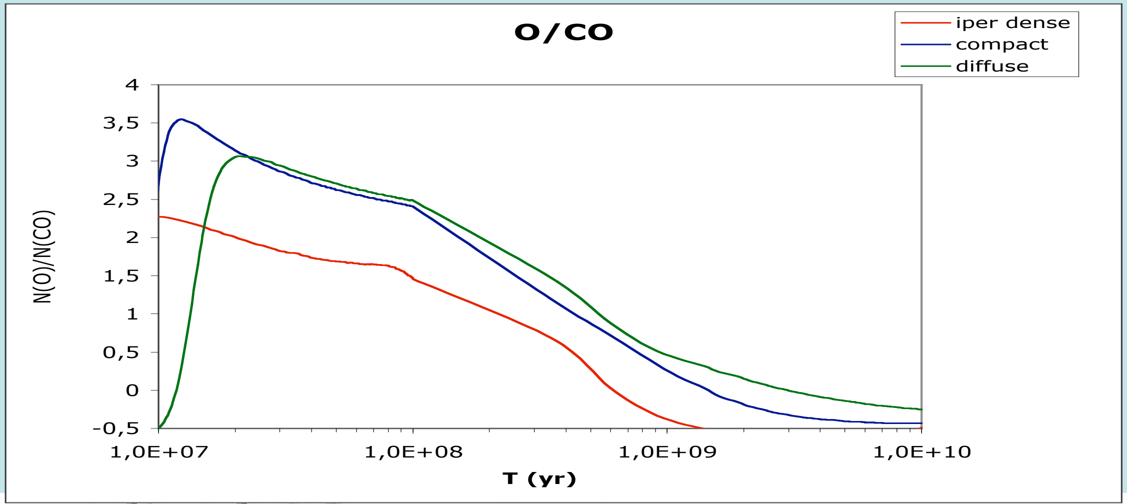
1. N.(O) > N. (C)

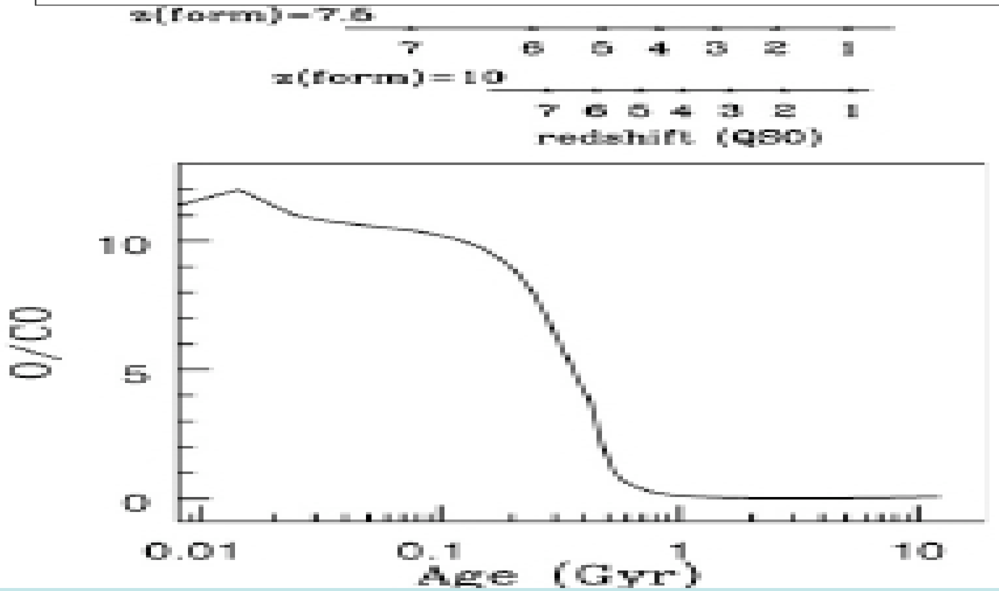
2. Presence of Molecular clouds

3. Dust to allow the formation of molecules on their surface



Comparison with a model of an elliptical galaxy:

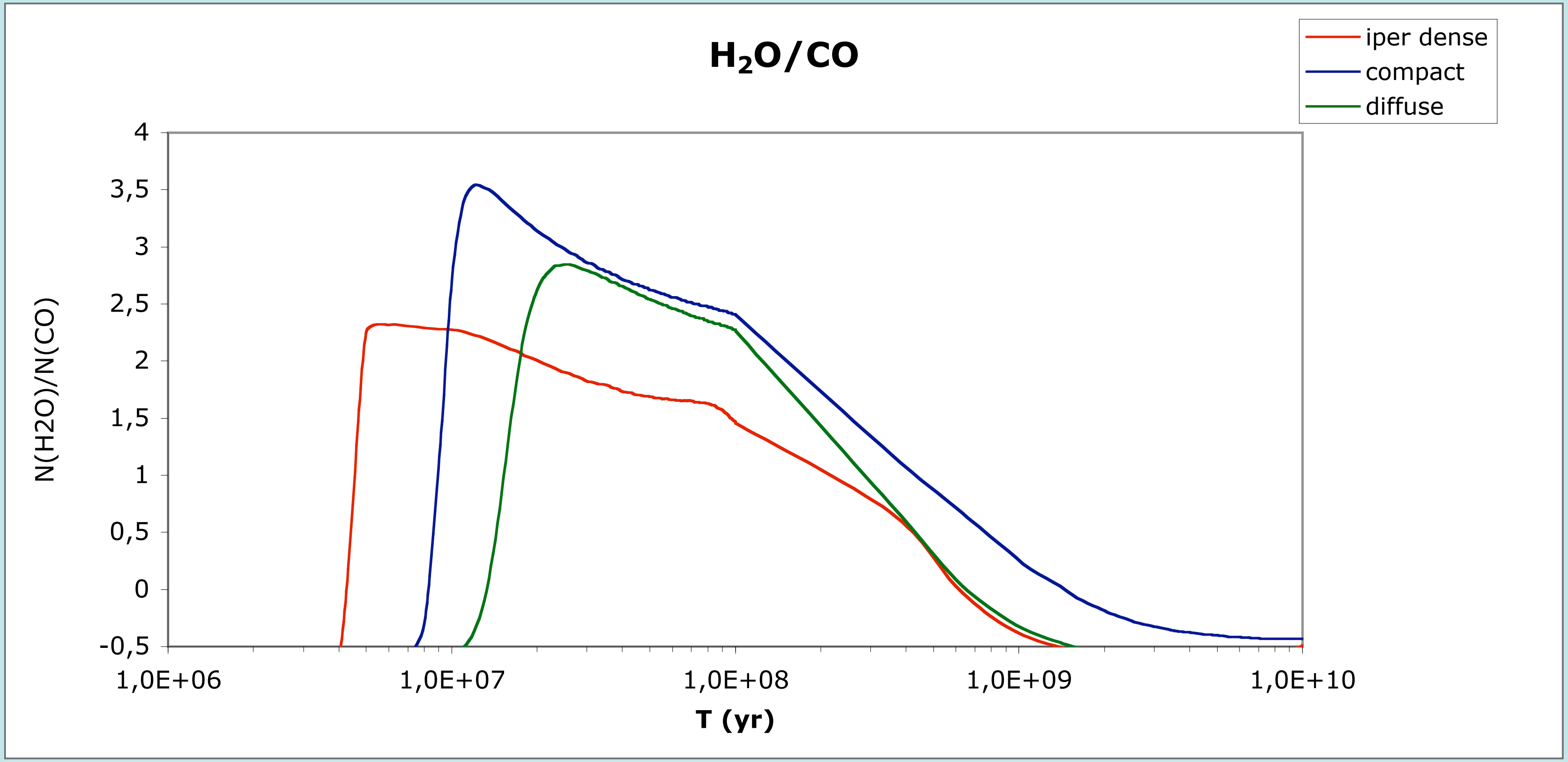




Matteucci & Pipino

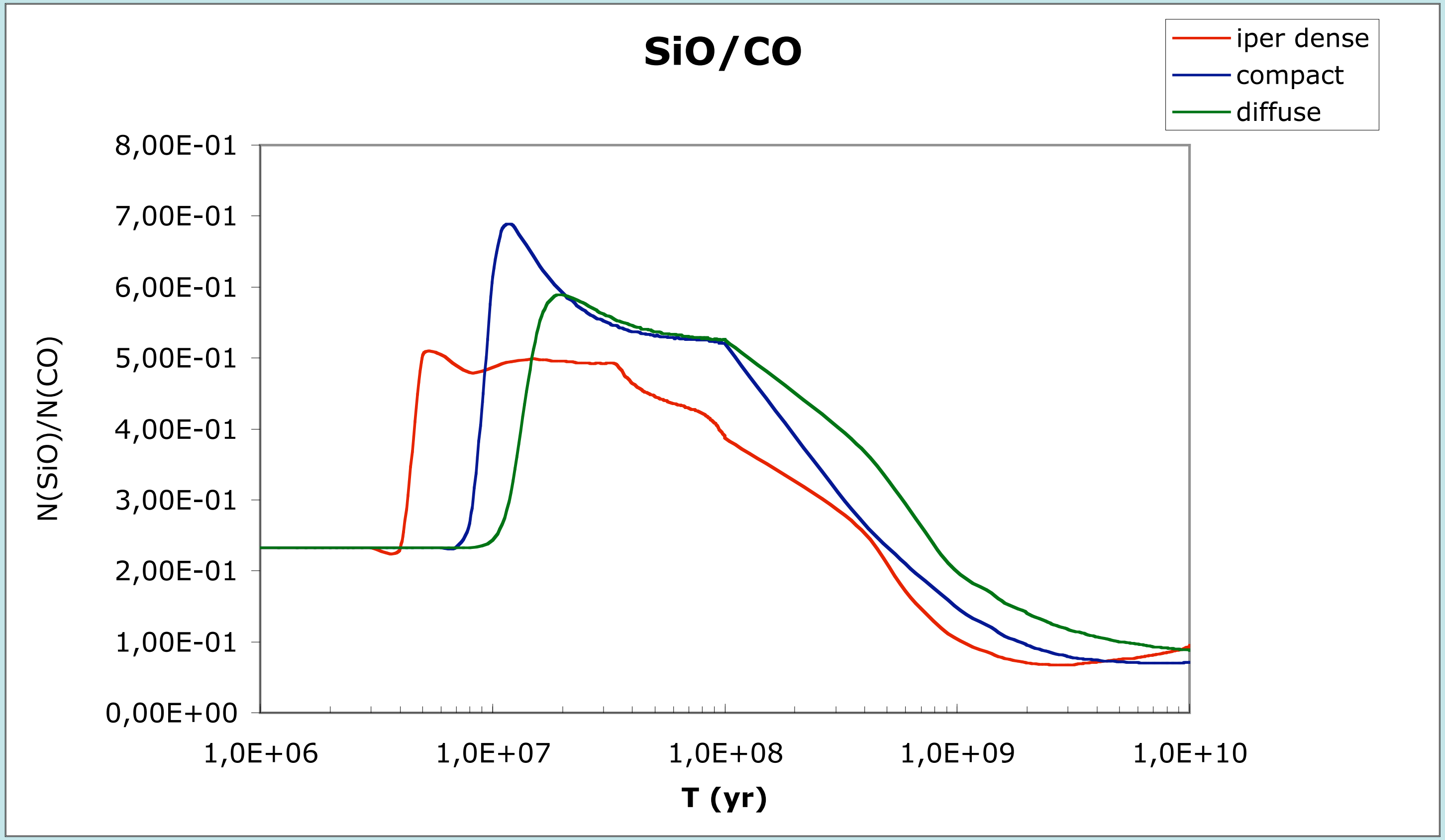
The formation of water:

Assuming that all remaining oxygen after the formation of CO molecules would form H_2O--> $n(H_2O)>n(CO)$ at ~0.01-0.1 Gyr



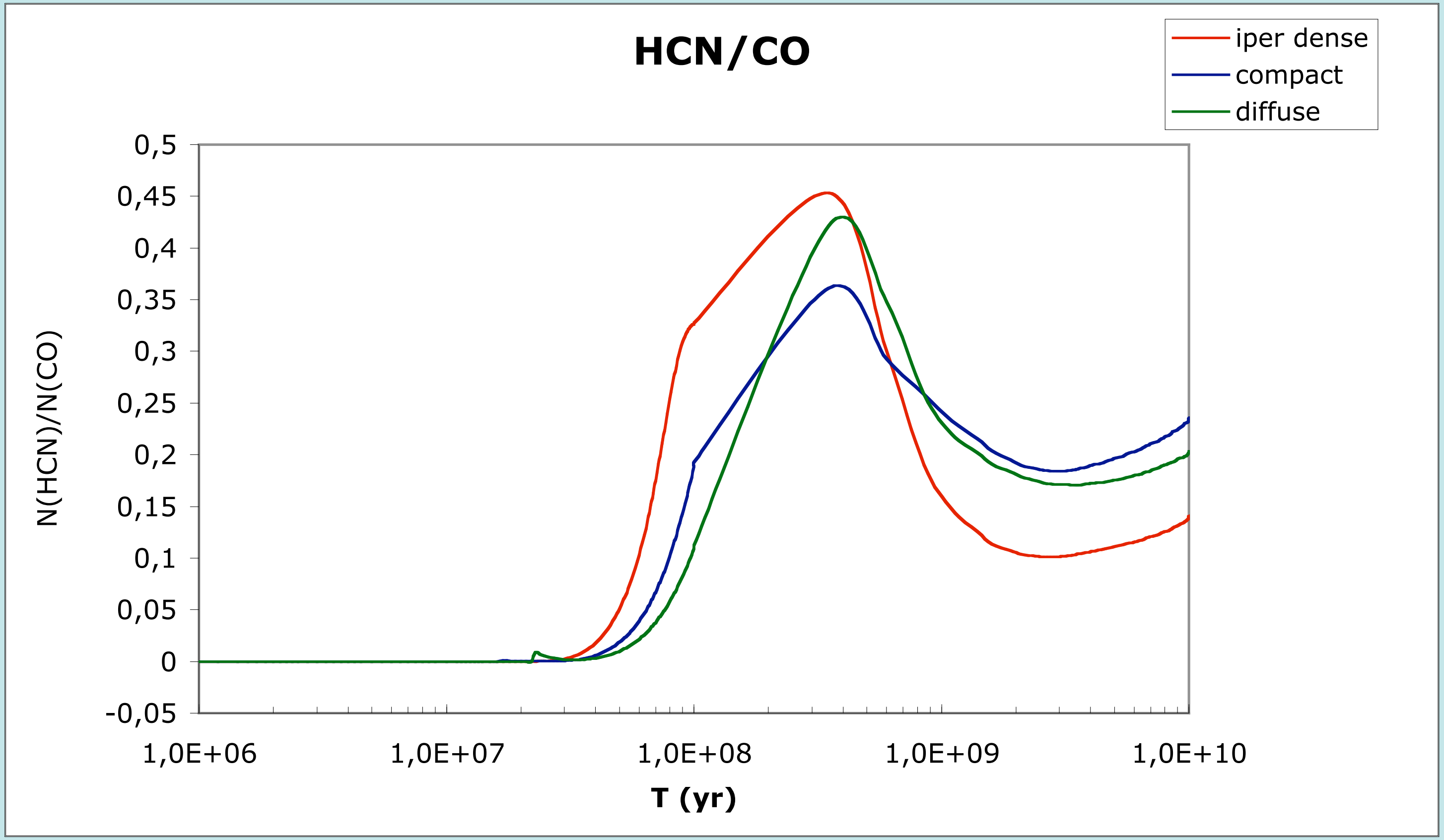
The formation of SiO molecule:

Considering the minimum between N(O-C) and N(Si) respect to N(C) we compute the time evolution of the ratio N(SiO)/N(CO) --> due to the lower abundance of Si respect to C, N(SiO) << N(CO), and having a maximum after 0.01-0.1 Gyr



The formation of the HCN molecule:

When the production of N starts, we consider that all nitrogen is used to form HCN molecules, and thus CO is made with the remaining carbon.



Conclusions:

Our chemical evolution model is able to follow the time evolution of:

A. atomic, molecular gas and stars surface densities

B. the ISM abundances of different chemical elements

C. the dust-to-gas ratio (total, carbonate, silicate)

We need a link to the processes of molecule formation

Questions:

1. Is there a threshold in Dust-to-gas ratio and in molecular cloud density to form molecules?

1. What about the other molecules containing carbon like HCN? We would need something like PROBABILITY of molecule formation…..