Hierarchical growth and cosmic star formation:

enrichment, outflows and supernova rates.

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Daigne et al., ApJ, 617, 693 (2004)
Daigne et al. 2005, submitted to ApJ (astroph/0509183).

MLC Workshop : Probing early structure formation with Mass, Light, and Chemistry.
October 6 – 9, 2005, Univ. of Minnesota.

Understanding the cosmic history of star formation

We have developed a model which follows the cosmic evolution of baryons :

► the growth of the star-forming structures is computed in the framework of the hierarchical scenario (Press & Schechter).

For a given scenario of cosmic star formation (SFR and IMF), the model computes consistently :

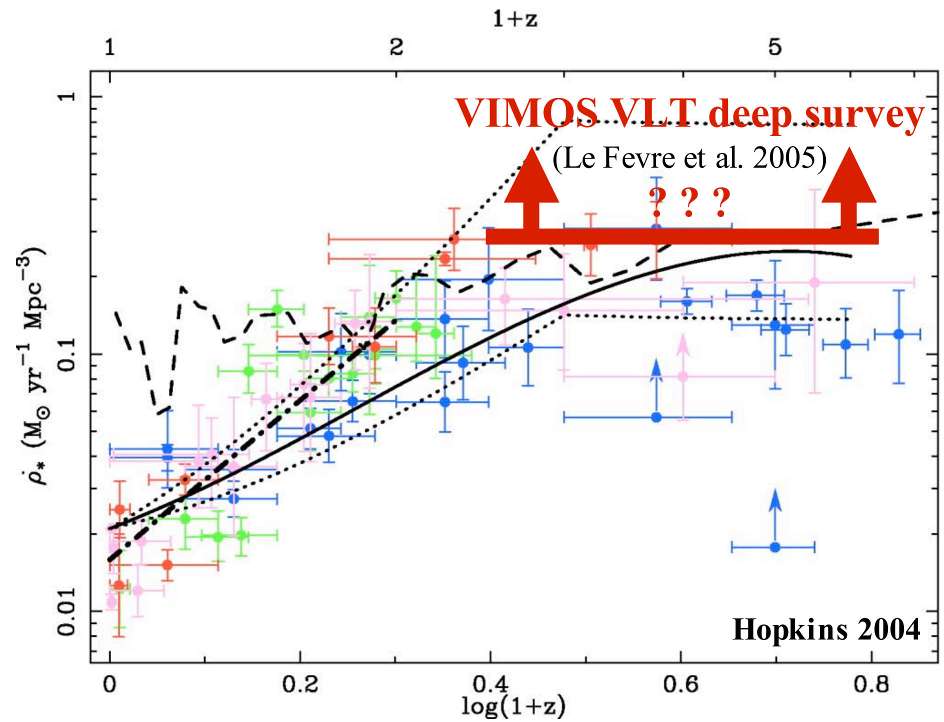
► the ionizing flux;
► the rate of explosive events (SNae ; in the future : GRBs);
► the metal enrichment of the structures (ISM) and the IGM (D, He, C, N, O, Si, S, Fe, Zn + global Z).

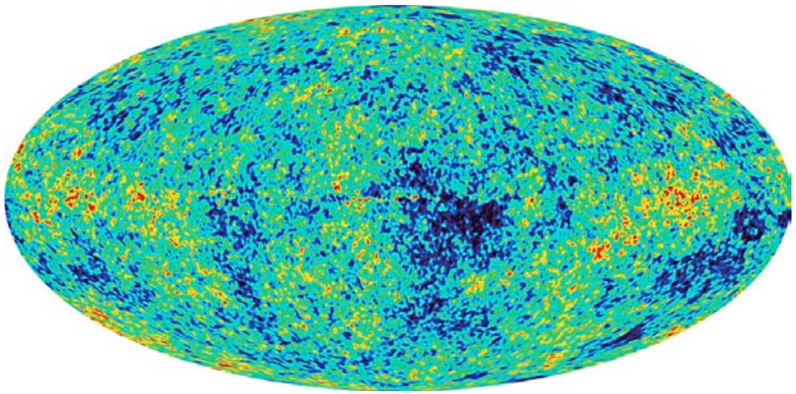
The evolution is followed from the first stars ($z>15$) up to now ($z=0$).

Introduction (1) : Cosmic SFR

The cosmic star formation rate can be measured up to z ~ 5.

(UV; [OII]; Hα,Hβ; X-rays; FIR; sub-mm; radio)



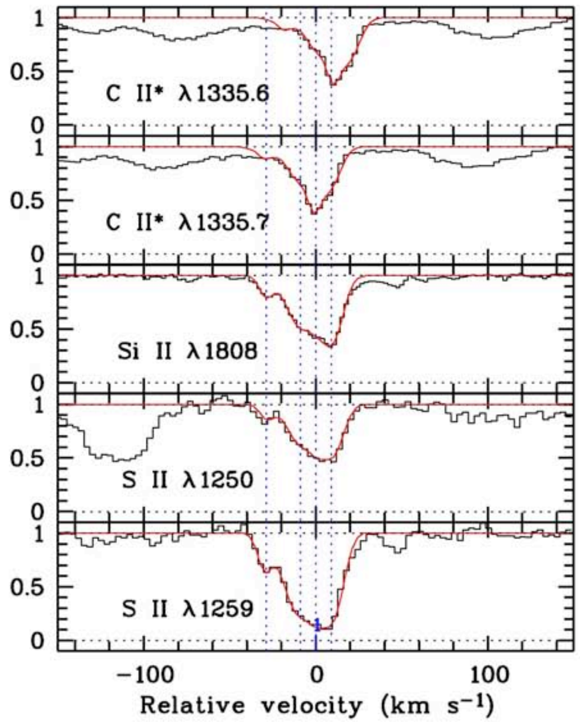


WMAP suggests a very early epoch (z ~ 10-30) of reionization in the IGM. (Kogut et al. 03)

Very massive pop. III stars ? (e.g. Oh et al. 01; Cen 03; Bromm 04).

The distribution of baryons in the Universe is measured :
Today 61 ± 18 % of all baryons are in star forming structures (Fukugita & Peebles 04).

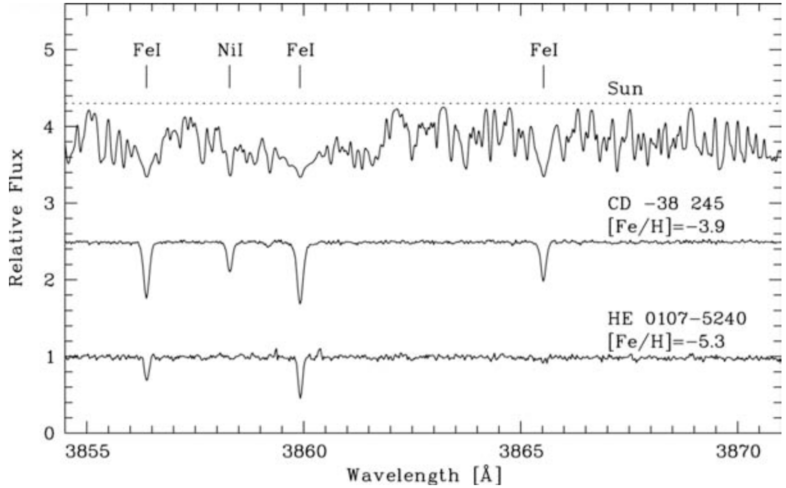
Introduction (2) : Cosmic Chemical Evolution



DLA in Q0405-43 at z=2.8
(Ledoux, Petitjean & Srianand 03)

Many measurements of metal abundances :

- Locally,
- **At high redshifts :**
  - In massive star forming galaxies (Shapley et al. 04),
  - In the Lyman α forest (Songaila 01; Simcoe et al. 04; Aguirre, Schaye et al. 04),
  - In DLA systems (Pettini et al. 02; Ledoux et al. 03; Prochaska et al. 03).



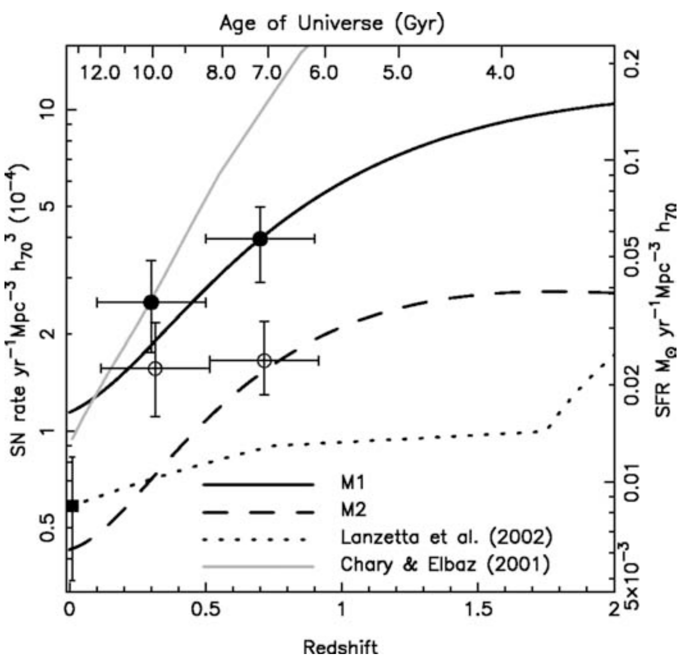
Christlieb et al. 2004

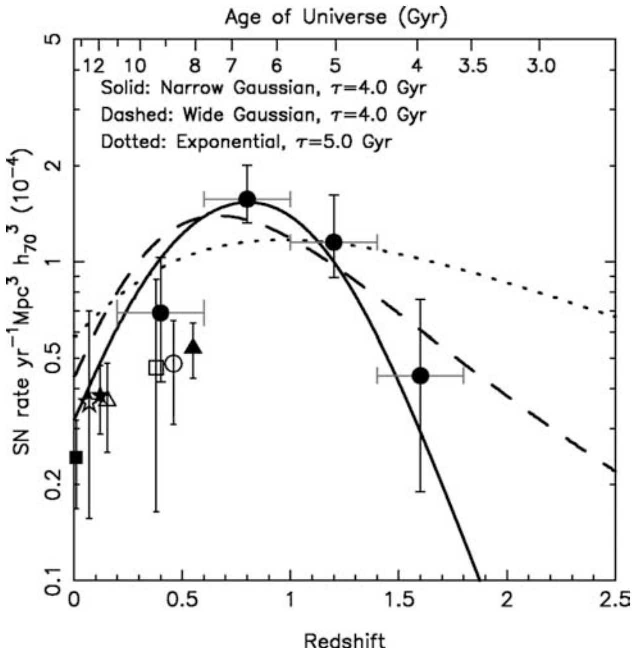
Extremely metal-poor stars may also probe the chemical composition at very high redshift.

e.g. HE 1327-2326 ([Fe/H]~ -5.4) (Frebel et al. 05, Aoki et al. 2005)
HE 0107-5240 ([Fe/H]~ -5.3) (Christlieb et al. 04)
CS 22949-037 ([Fe/H] ~ -4) (Depagne et al. 02)
G77-61 ([Fe/H]~-4) (Plez & Cohen 05)

Introduction (3) : SN/GRB rates

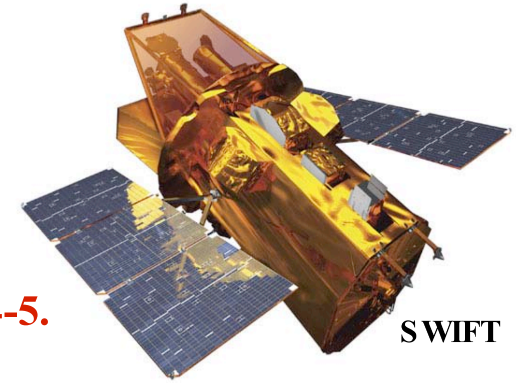
The type Ia supernova rate is measured up to z ~ 1.5
(GOODS data, Dahlen et al. 2004 + local measurements)





Dahlen et al. 2004

The type II supernova rate is measured up to z ~ 0.8

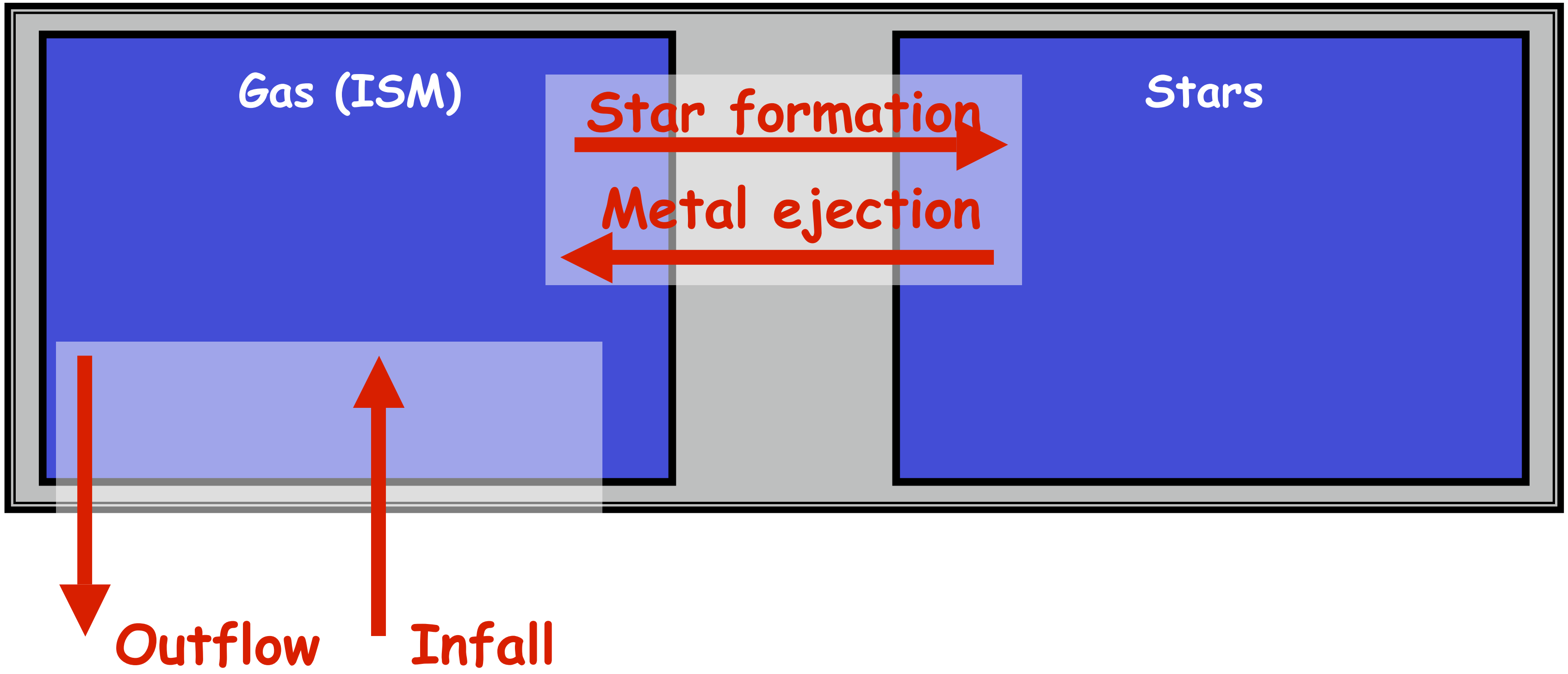


SWIFT

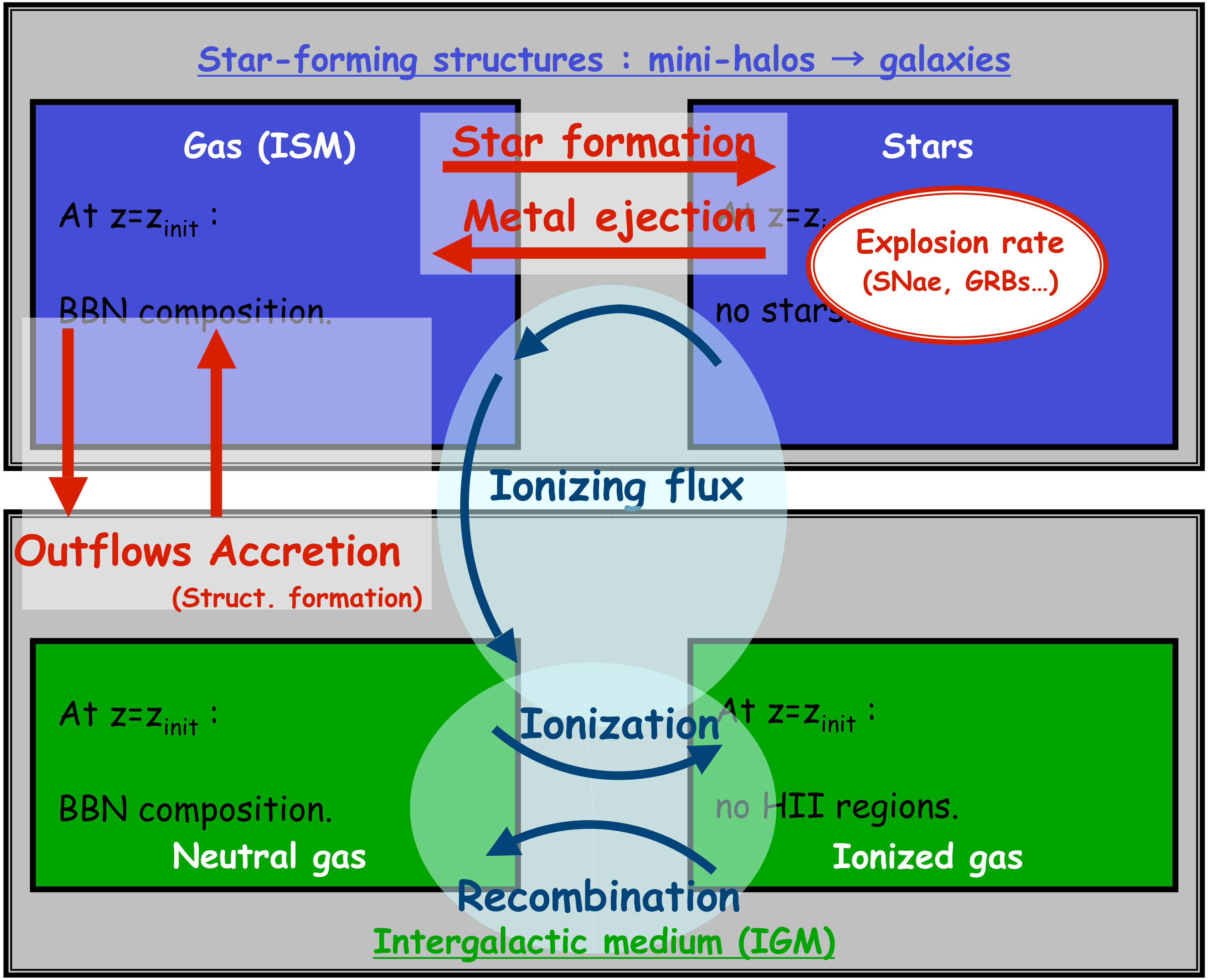
In the near future, the GRB rate will hopefully be measured up to z > 4-5.
See the recent detection of GRB050904 at z=6.29 !

Modeling the Cosmic Chemical Evolution

Standard formalism (see e.g. Tinsley 1980) :



This work : extended version to model the **chemical evolution of the gas in the ISM of star-forming structures and in the IGM in the framework of the hierarchical scenario of structure formation.**


Star-forming structures : mini-halos → galaxies
Gas (ISM)
At z=zinit :
BBN composition.
Star formation
Metal ejection
Stars
At z=zinit
no stars.
Explosion rate
(SNae, GRBs...)
Ionizing flux
Outflows Accretion
(Struct. formation)
At z=zinit :
BBN composition.
Neutral gas
Ionization
At z=zinit :
no HII regions.
Ionized gas
Recombination
Intergalactic medium (IGM)

Model parameters

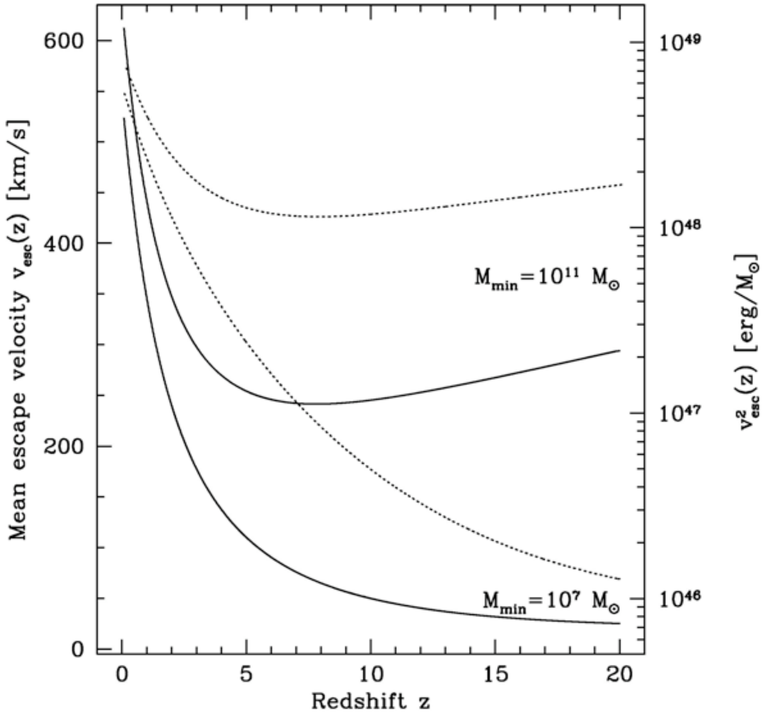
Main parameters :

► **Minimum mass of the DM halos of star forming structures. We test $10^6 \rightarrow 10^{11}$ $M_\odot$.**

► **SFR and IMF : Normal mode : SFR $\propto$ exp(-t/τ) / IMF 0.1 – 100 $M_\odot$**
Pop III. : SFR $\propto$ exp(-Z/Z_c) / IMF 40 – 100; 140 – 260; 270-500 $M_\odot$

► **Efficiency of the outflow :** $\frac{1}{2}\dot{M}\,V_{esc}^2 = \varepsilon \dot{E}_{kin}^{SN}$

Computed at each z from the distribution of the DM halo mass (PS formalism).



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Secondary parameters :

► **z_{init} where the first stars form (equivalent : initial fraction of baryons in the star forming regions).**
Time is related to redshift by :

$$\frac{dt}{dz} = \frac{9.78\ h^{-1}\ \mathrm{Gyr}}{(1+z)\sqrt{\Omega_\Lambda + \Omega_m (1+z)^3}}$$

$\Omega_\Lambda = 0.73$, $\Omega_m = 0.27$ and $h = 0.71$ (Spergel et al. 2003)

► **Mass range, fraction of white dwarfs, and time delay for SNIa.**

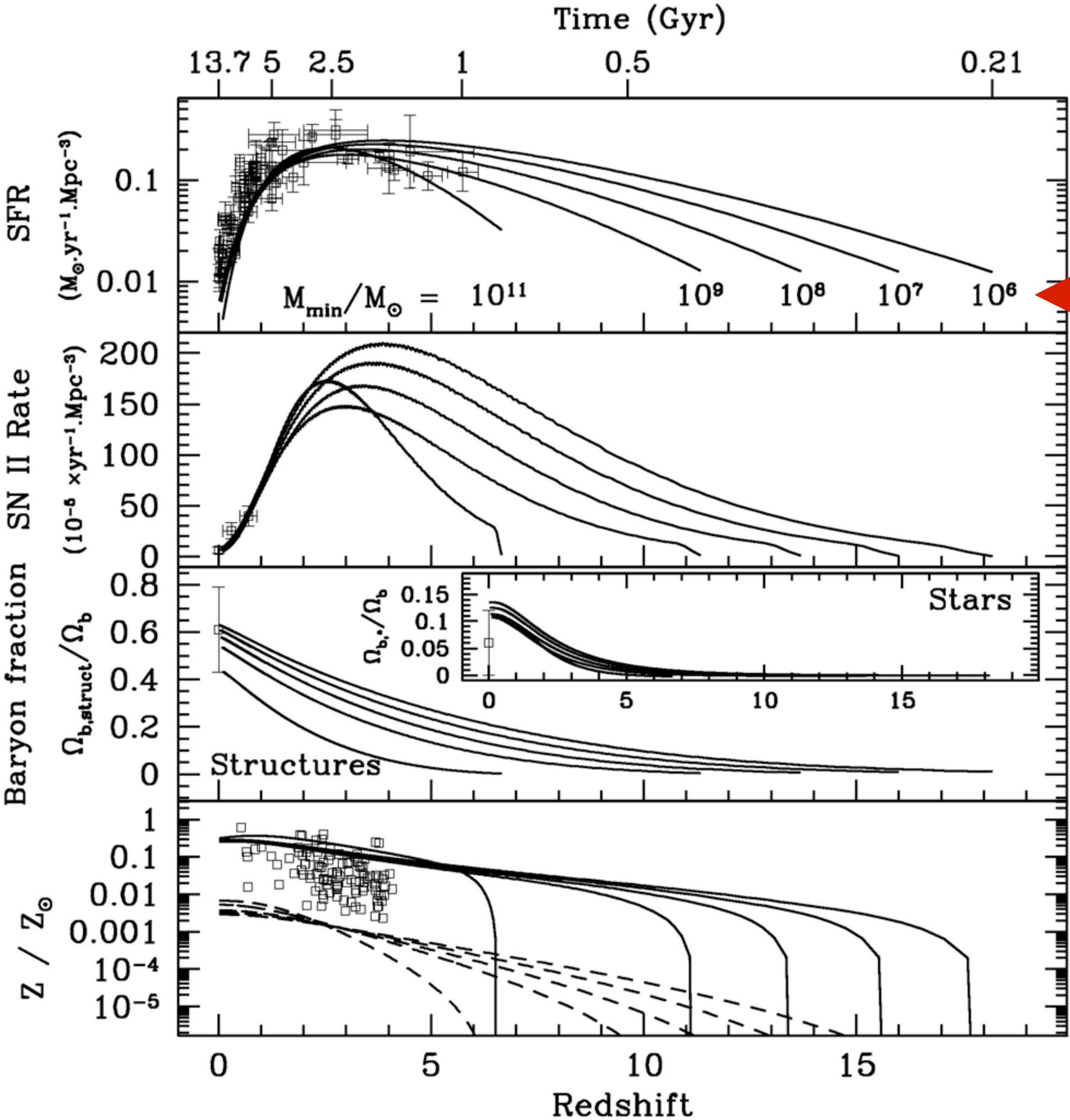
Other input :

► **Distribution n(M,z) of structures and corresponding mass flux onto the star forming structures.**
Computed in the hierarchical scenario using a code initially developed by A. Jenkins.
(Parameters : Γ= 0.21 ; σ_8 = 0.9 ; R_{sphere} = 8 kpc ; PS + Sheth-Tormen.)

► **Mass and metal dependant stellar yields. (van den Hoek et al. 97, Woosley & Weaver 95 and Heger & Woosley 02)**

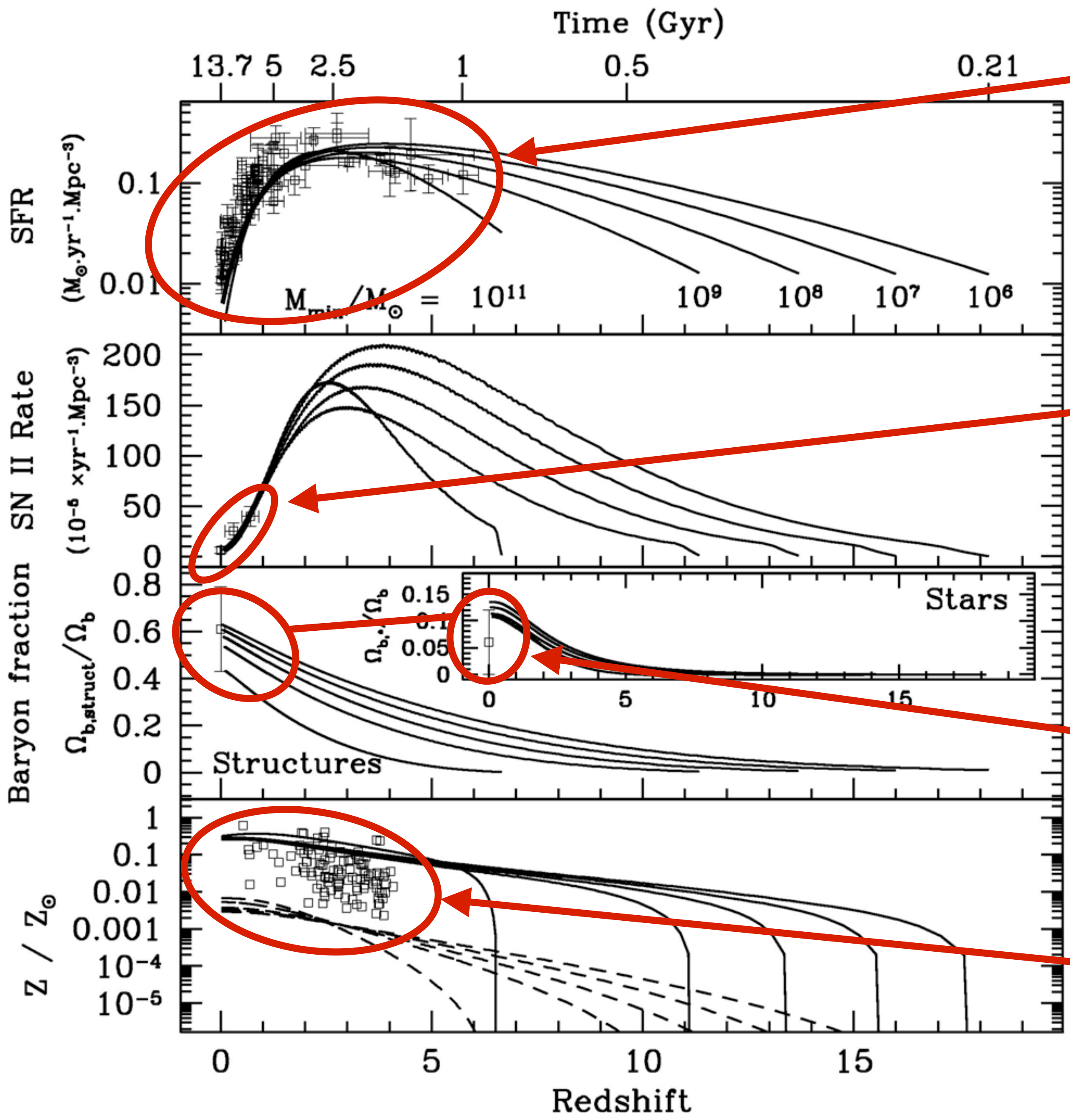
► **Stellar ionizing fluxes (Schaerer 02).**

Model 0 : no early massive mode



Minimum DM halo mass of star forming structures

Model 0 : no early massive mode



The observed SFR is well fit.

The SN II rates are reproduced.

Local :

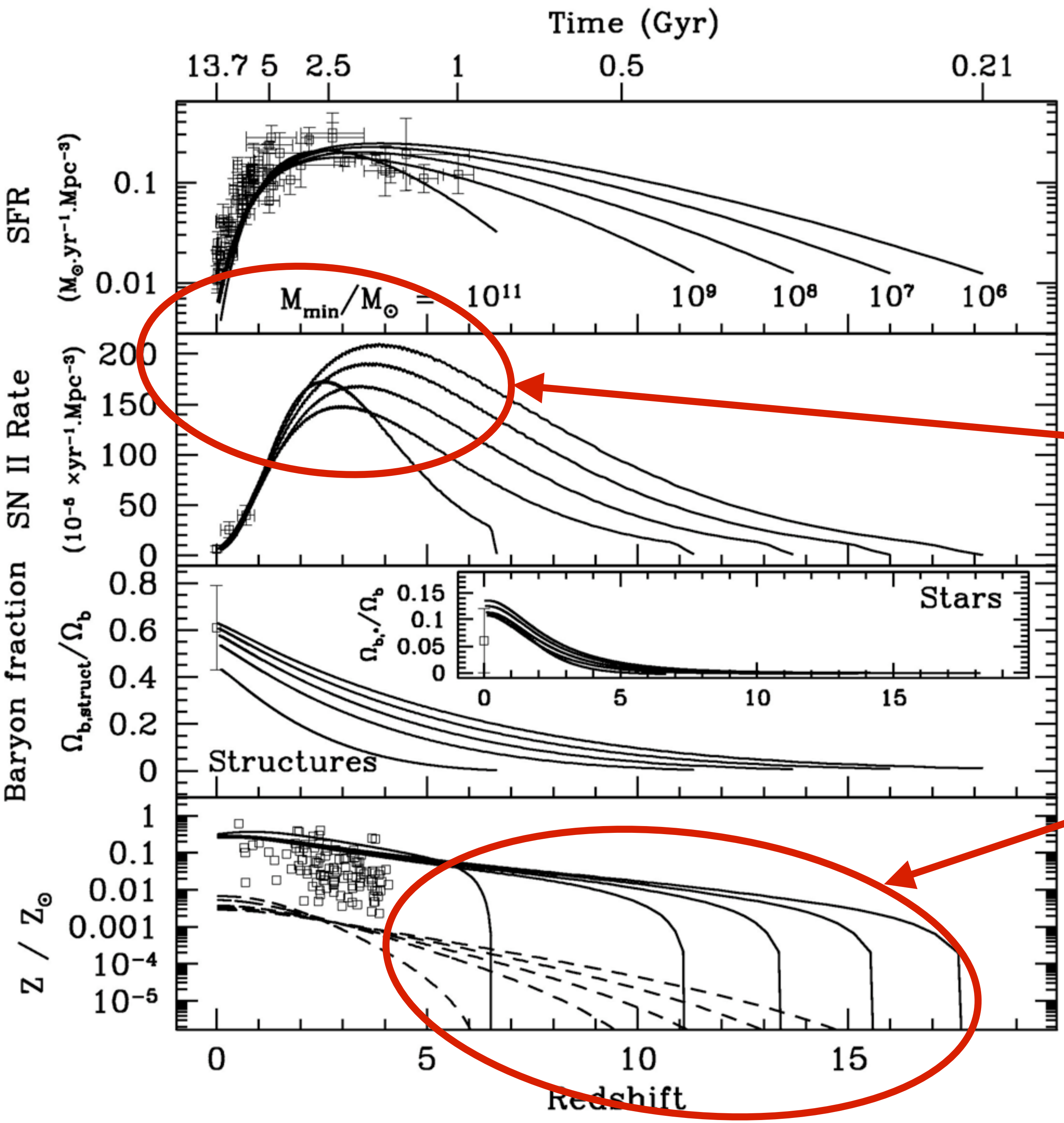
Fraction of baryons in the structures : OK.

The fraction in stars is only marginaly fit.

Global evolution of the metallic content in the structures and in the IGM : OK

$Z_{ISM} > Z_{DLAs} > Z_{IGM}$

Model 0 : no early massive mode

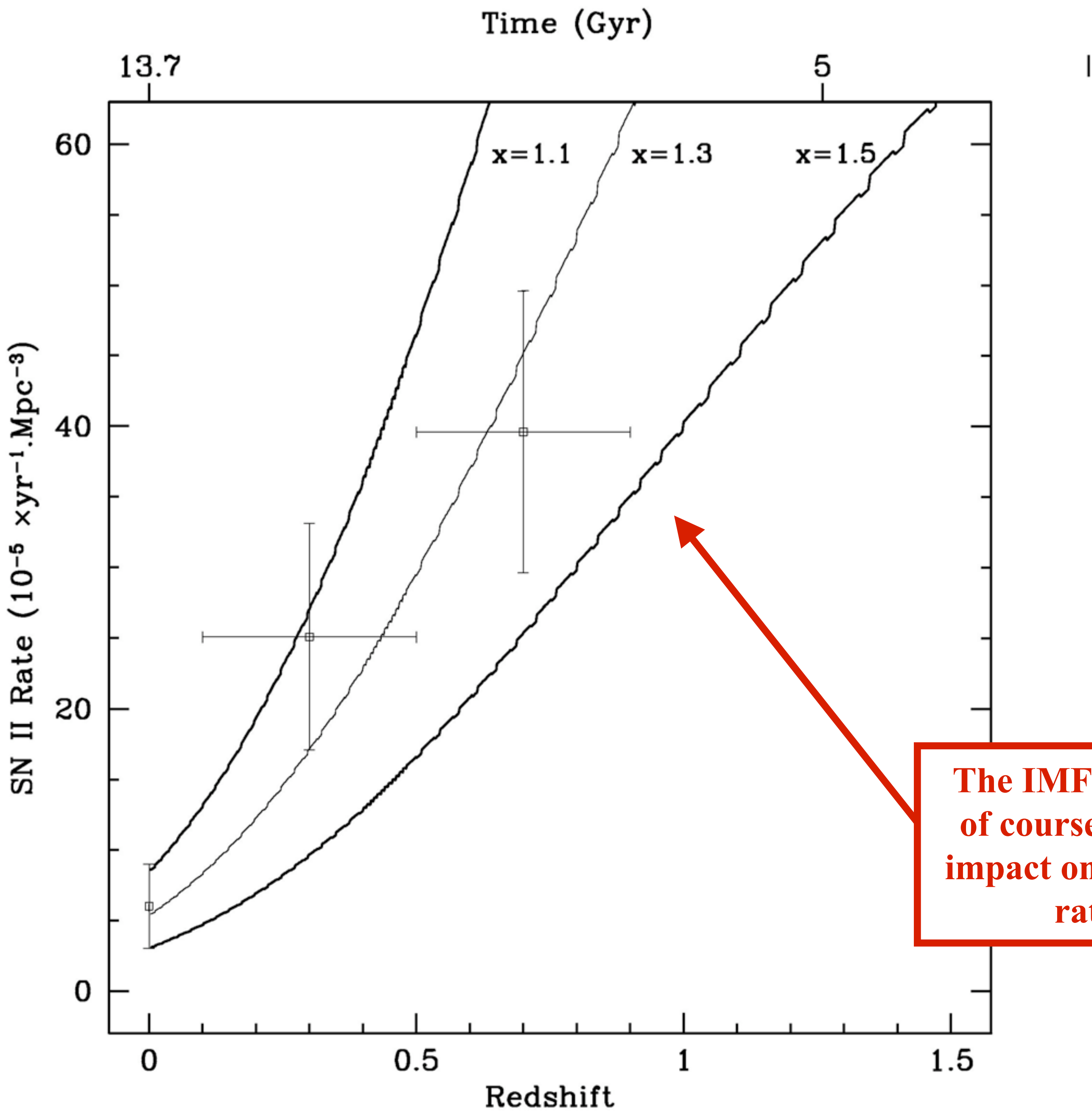


High SNII rates are predicted at z~3-5.

The metallicity in the structures increases rapidly.

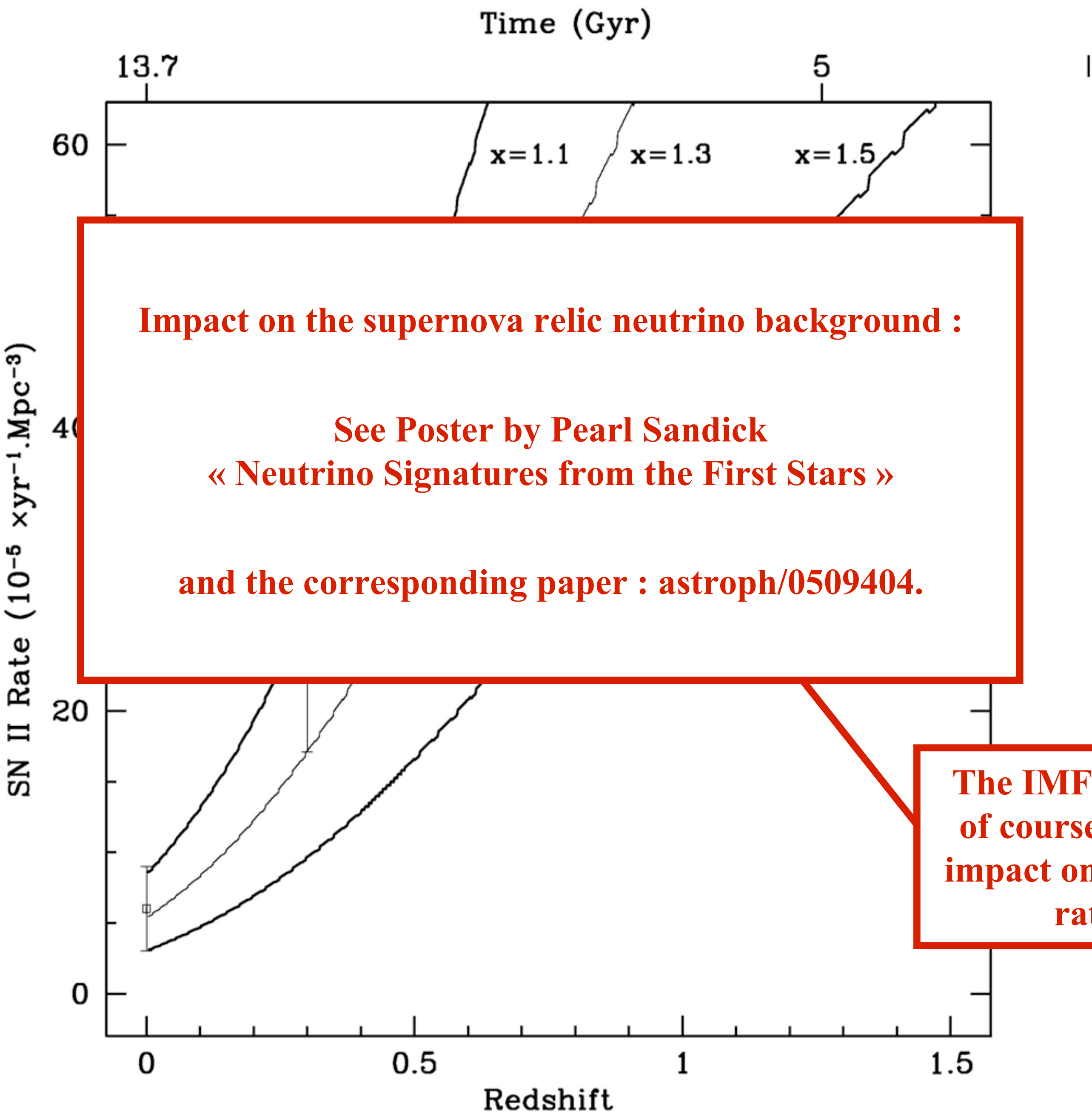
The evolution is much slower in the IGM.

Type II Supernova Rate



The IMF slope has of course a strong impact on the SN II rates.

Type II Supernova Rate



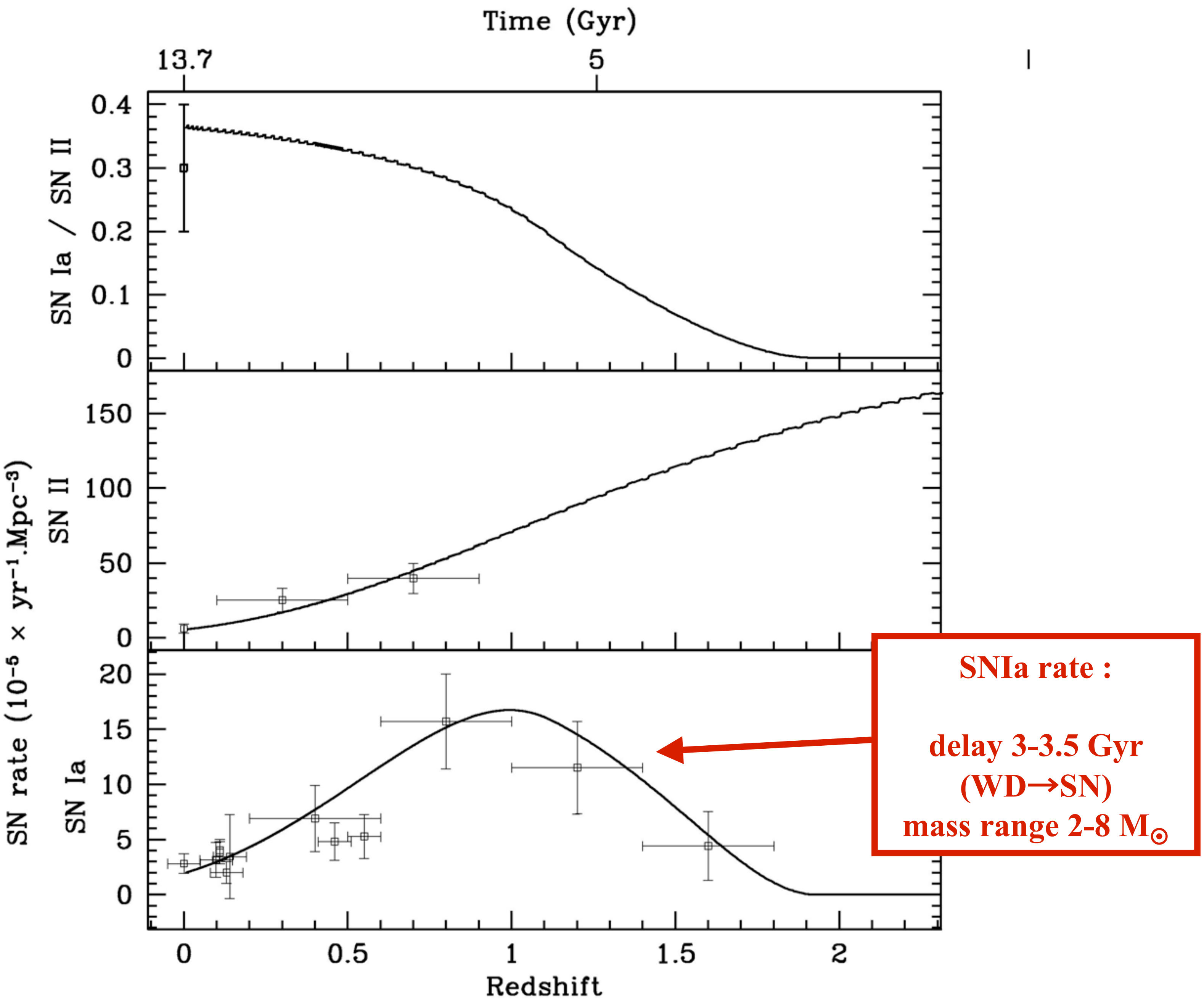
Impact on the supernova relic neutrino background :

See Poster by Pearl Sandick
« Neutrino Signatures from the First Stars »

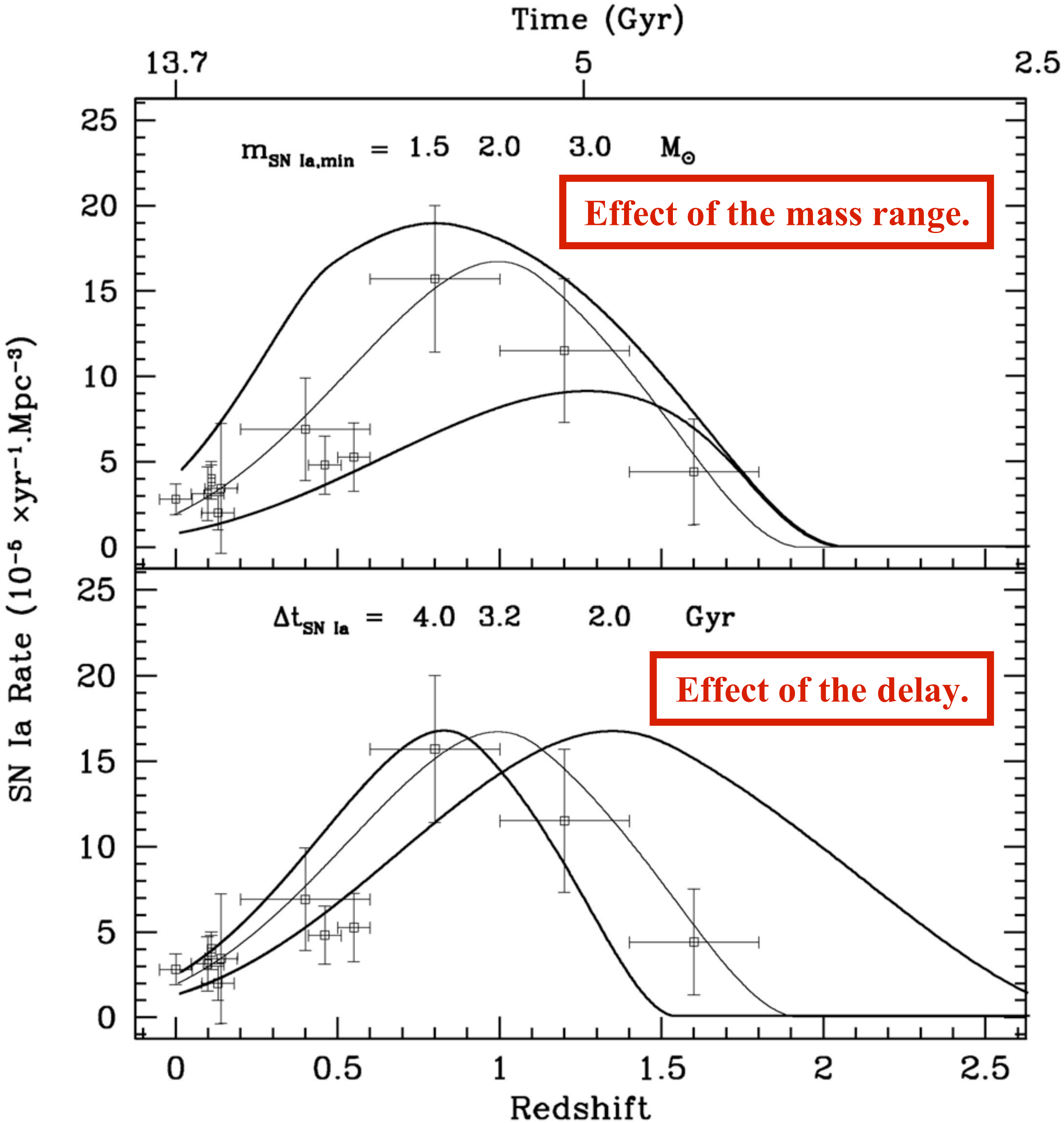
and the corresponding paper : astroph/0509404.

The IMF slope has of course a strong impact on the SN II rates.

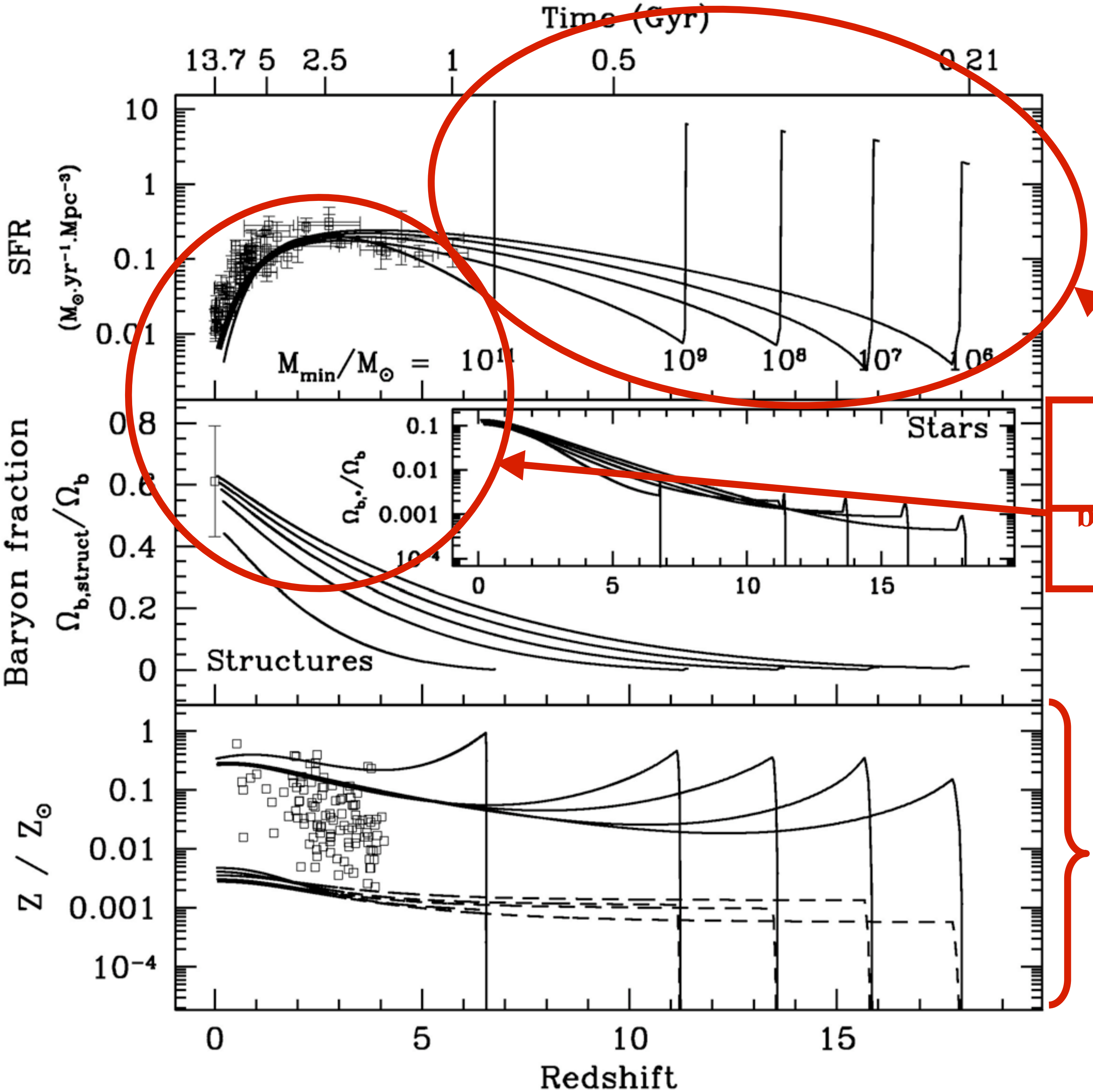
Supernova Rate



Type Ia Supernova Rate



Model 1 : Model 0 + massive mode (40-100 $M_\odot$)

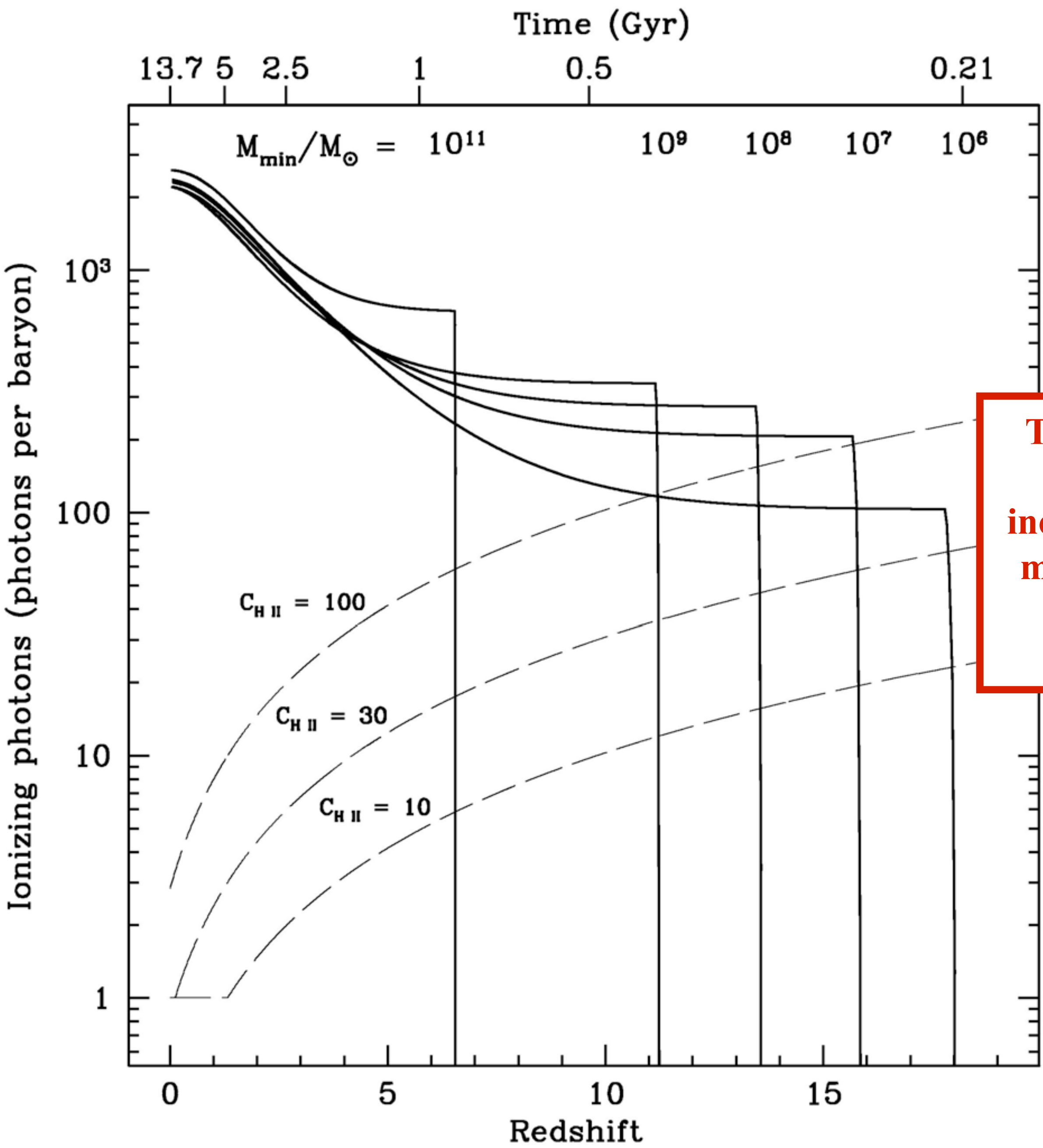


Initial massive starburst

baryon fractions : unchanged.

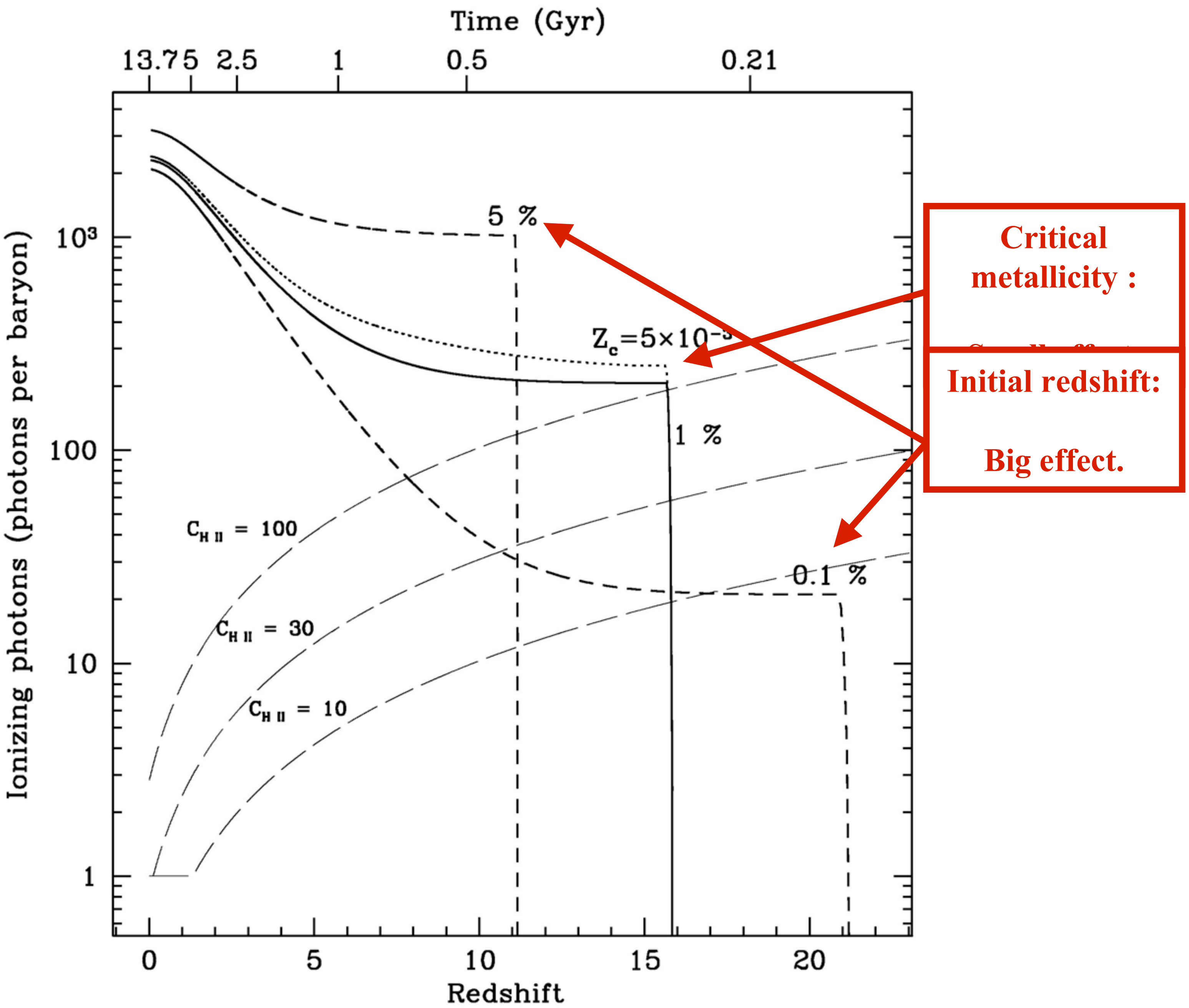
The metallicity now shows an early sharp rise both in the structures and in the IGM.

Model 1 : Ionizing flux (40-100 $M_\odot$)

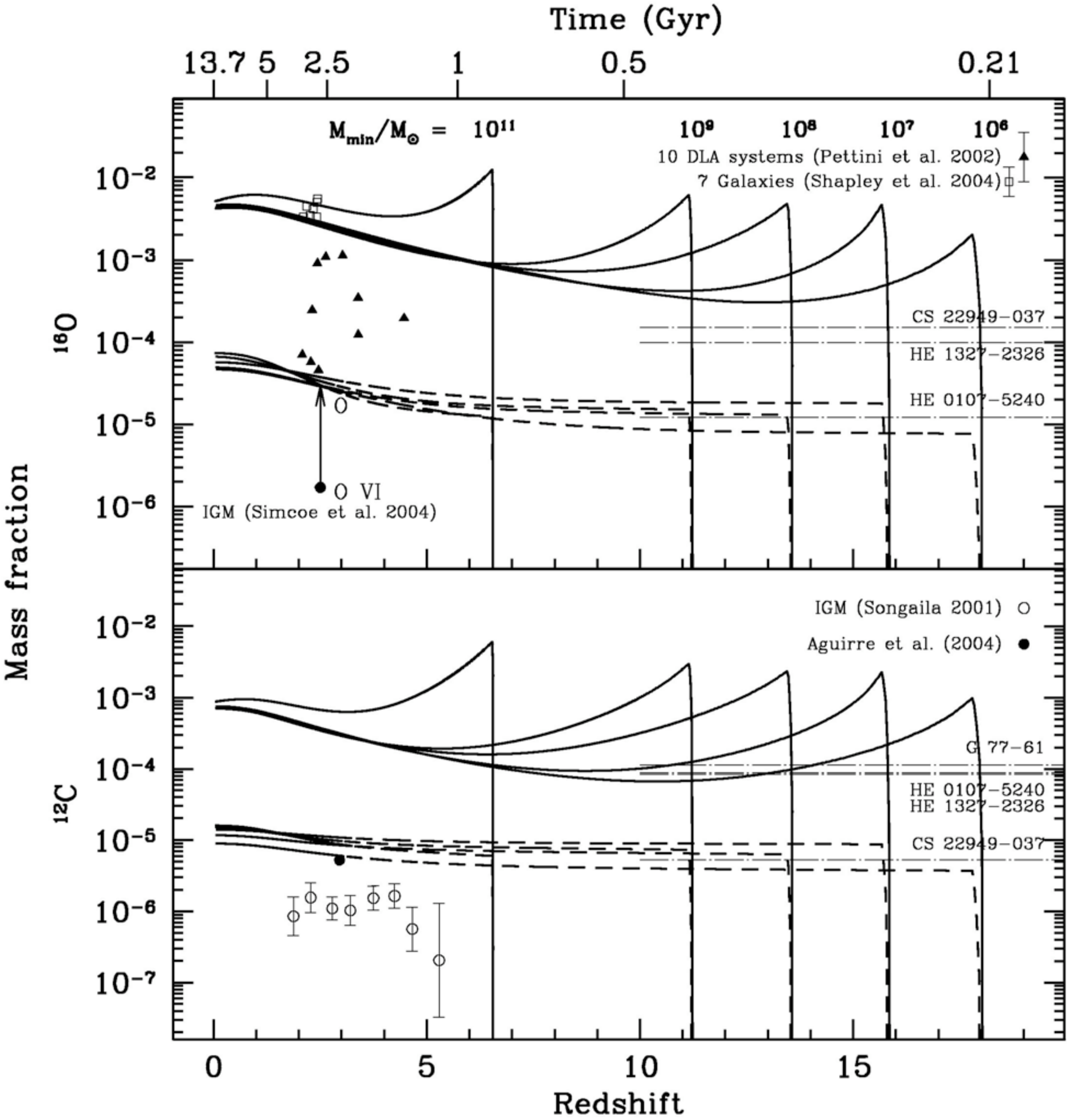


The capacity of stars to reionize the IGM is increased when the initial massive starburst peaks at lower redshift, i.e. M_{min} is larger.

Model 1 : Ionizing flux (40-100 $M_\odot$)



Model 1 : Carbon and Oxygen (40-100 $M_\odot$)



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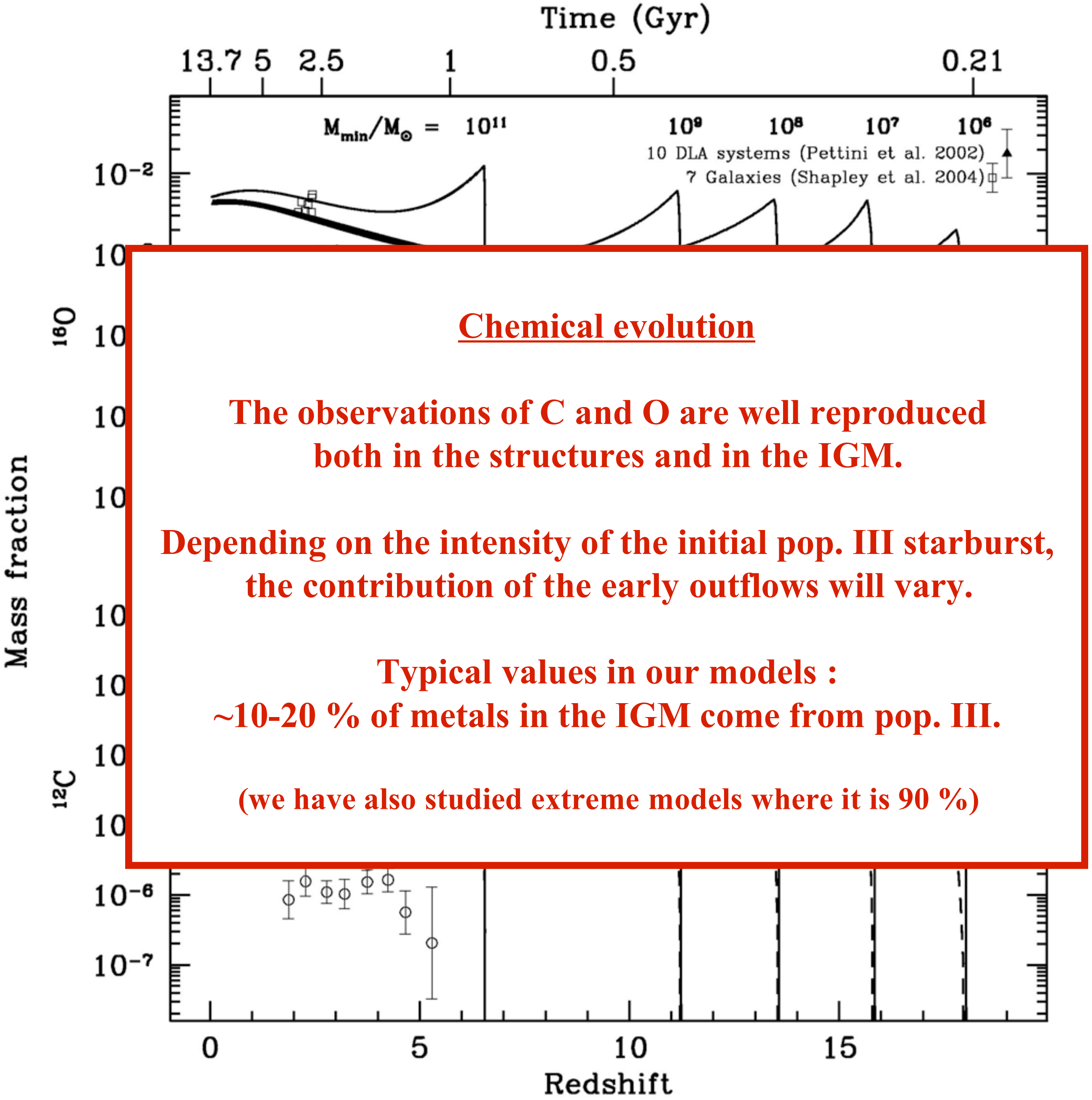


Chemical evolution

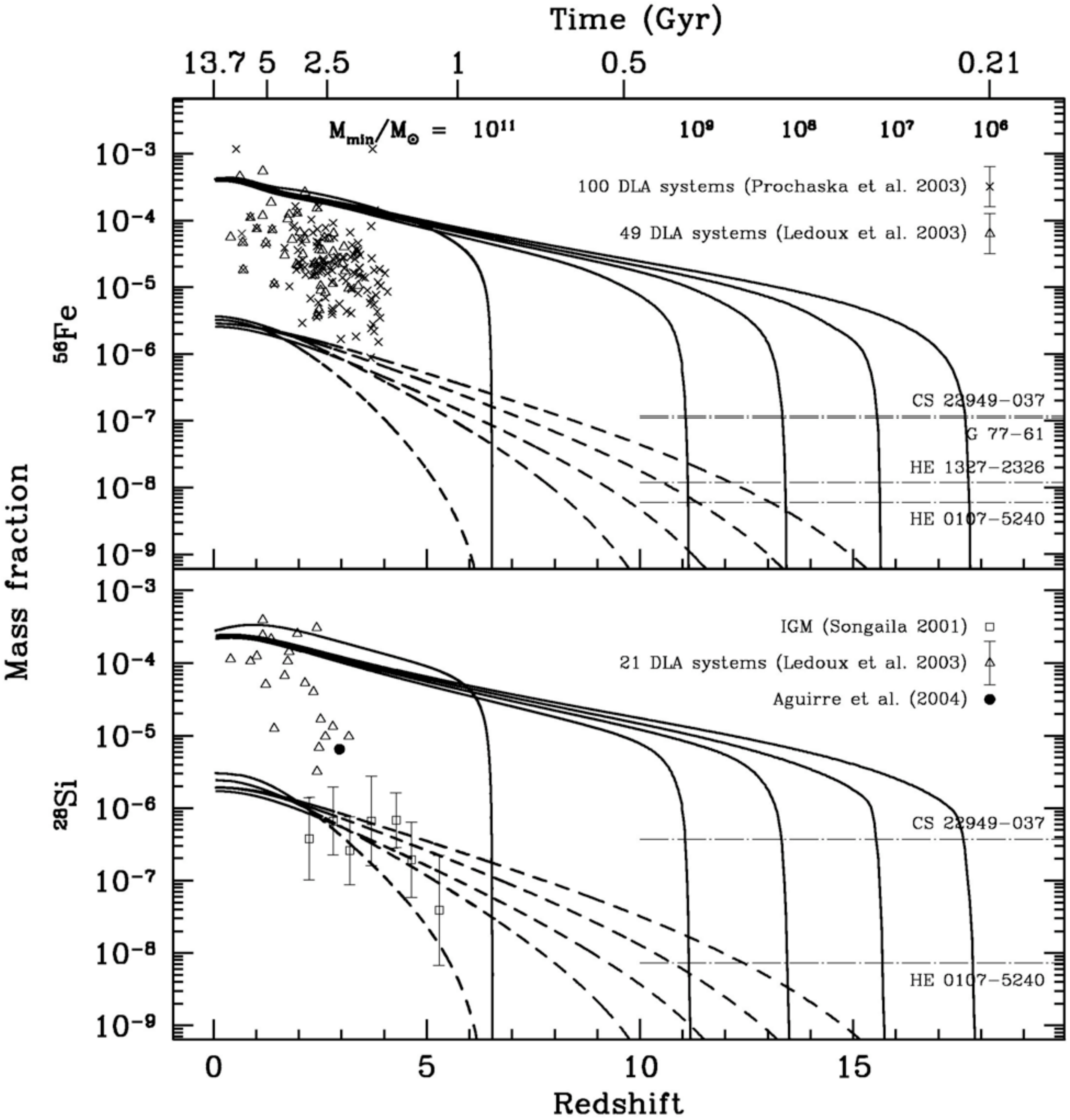
The observations of C and O are well reproduced both in the structures and in the IGM.

Depending on the intensity of the initial pop. III starburst, the contribution of the early outflows will vary.

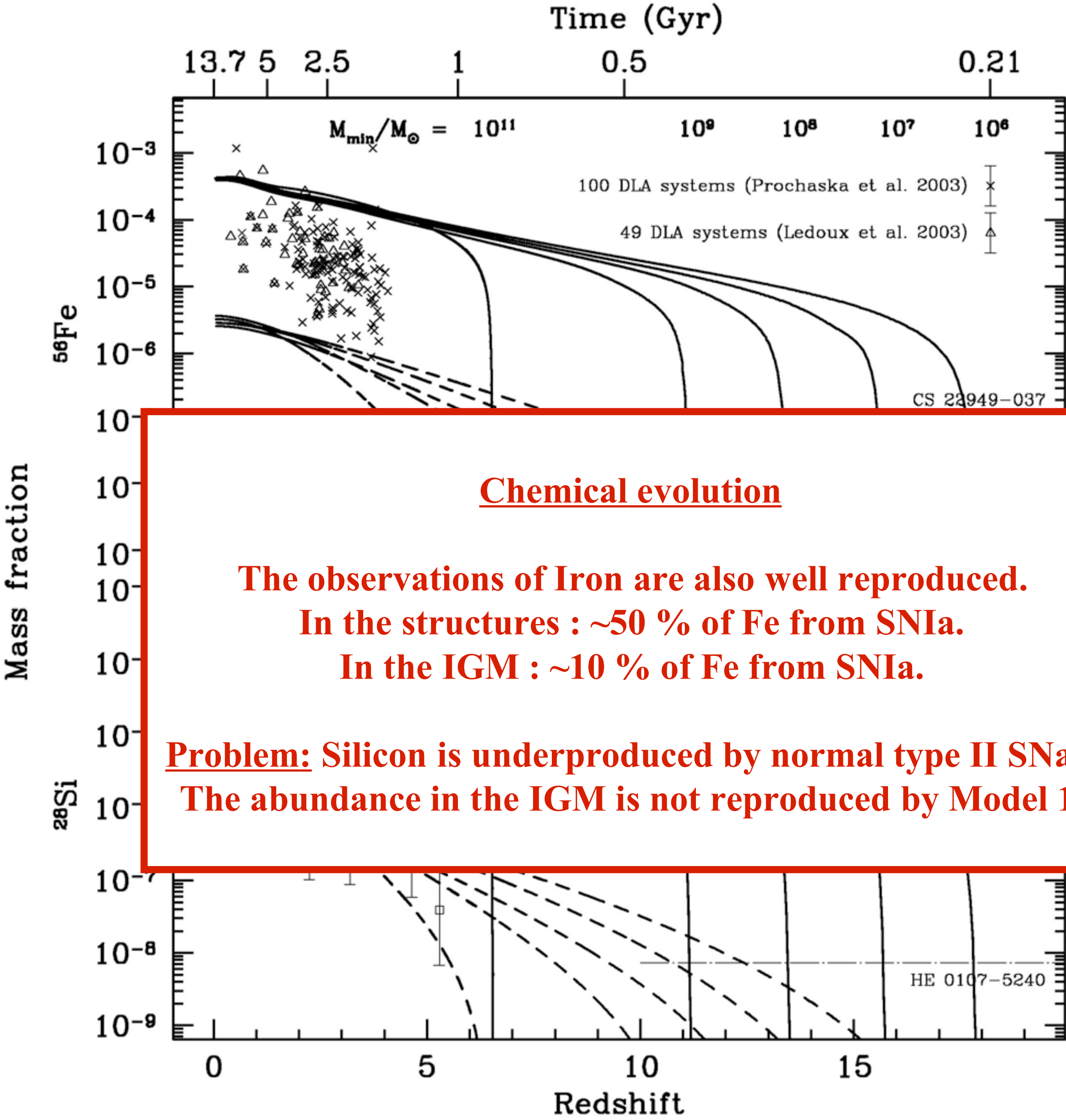
Typical values in our models :
~10-20 % of metals in the IGM come from pop. III.

(we have also studied extreme models where it is 90 %)

Model 1 : Silicon and Iron (40-100 $M_\odot$)



Model 1 : Silicon and Iron (40-100 $M_\odot$)

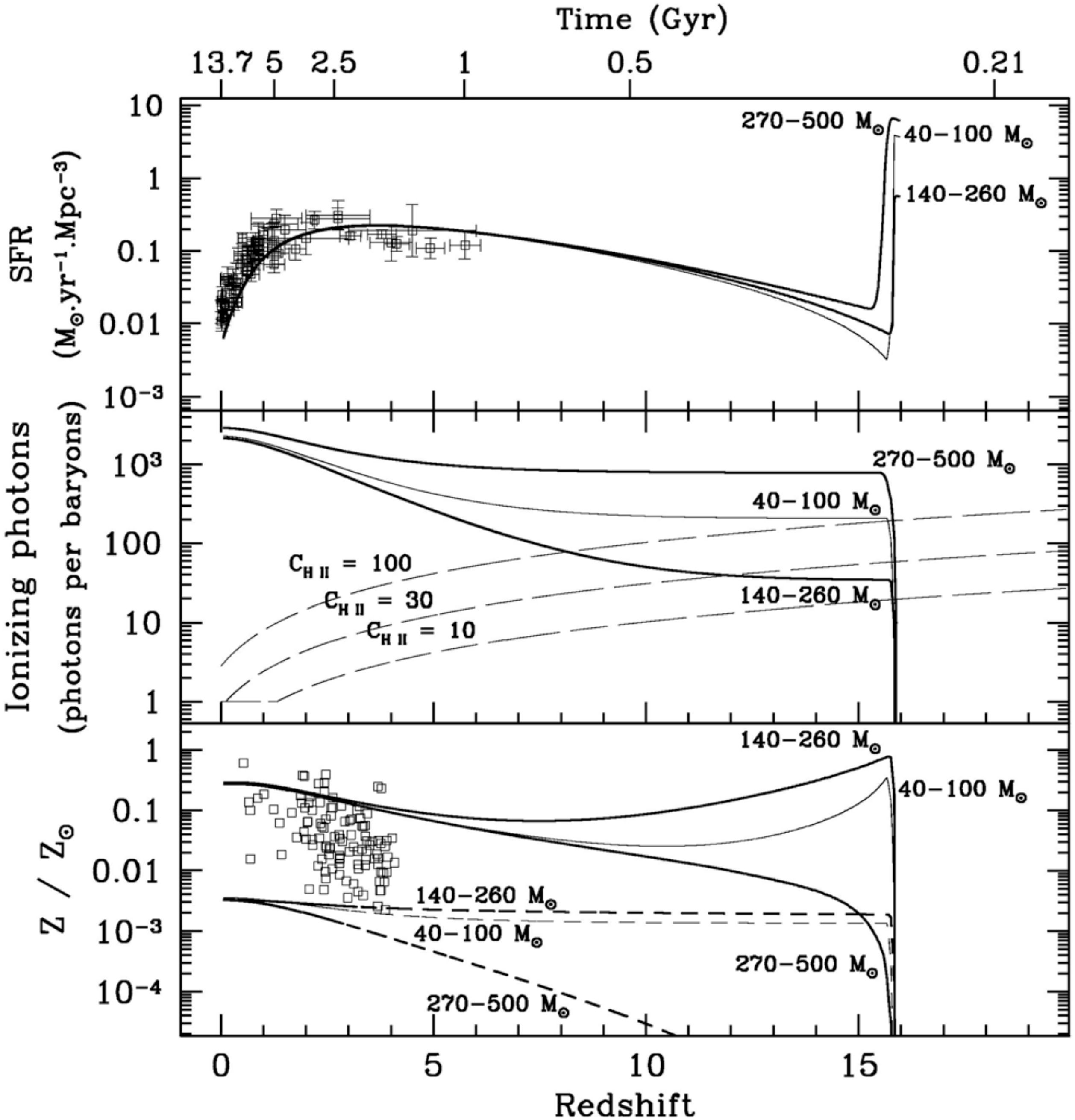


Chemical evolution

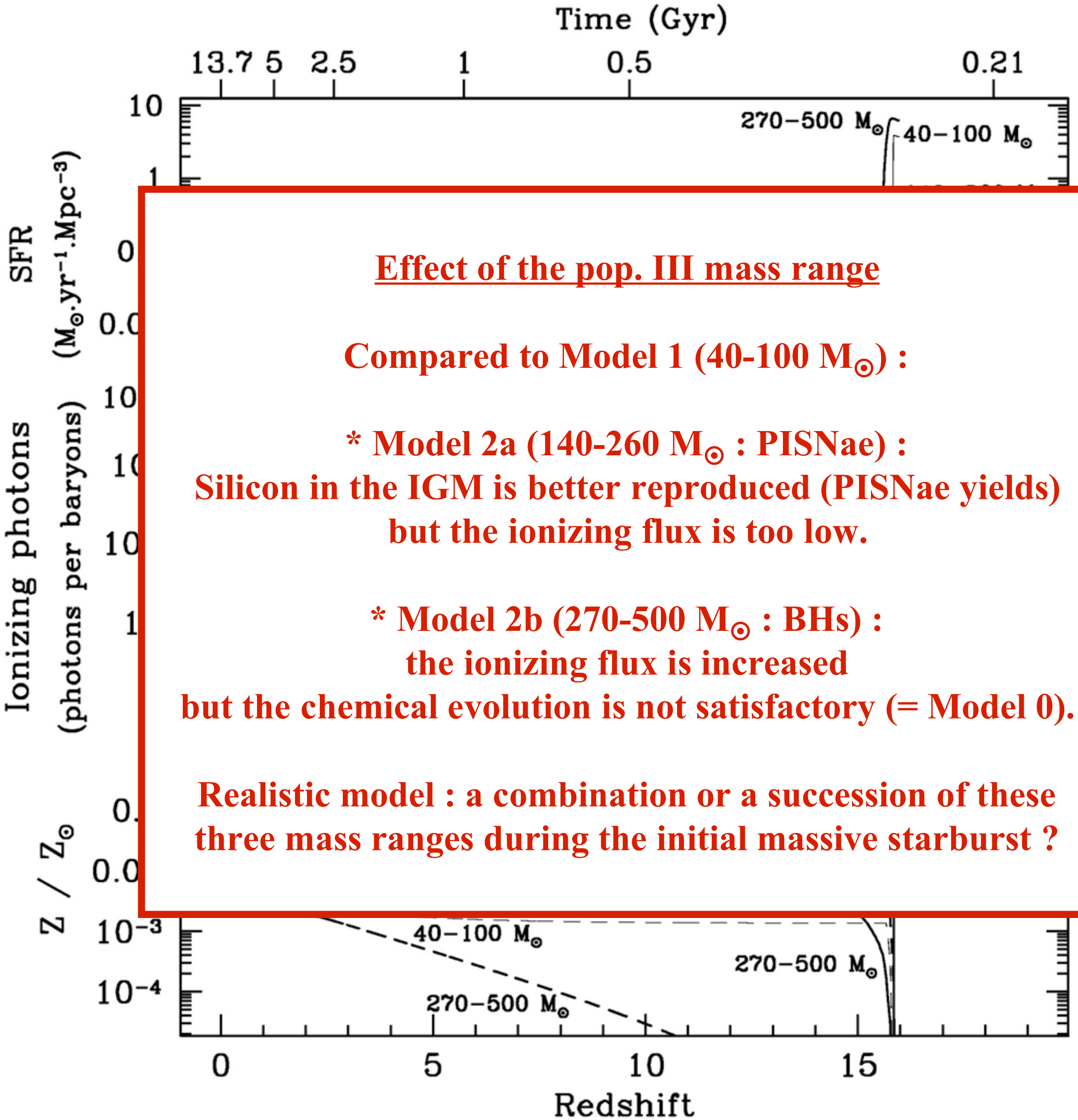
The observations of Iron are also well reproduced.
In the structures : ~50 % of Fe from SNIa.
In the IGM : ~10 % of Fe from SNIa.

Problem: Silicon is underproduced by normal type II SNae.
The abundance in the IGM is not reproduced by Model 1.

Mass range of the pop. III stars



Mass range of the pop. III stars



Effect of the pop. III mass range

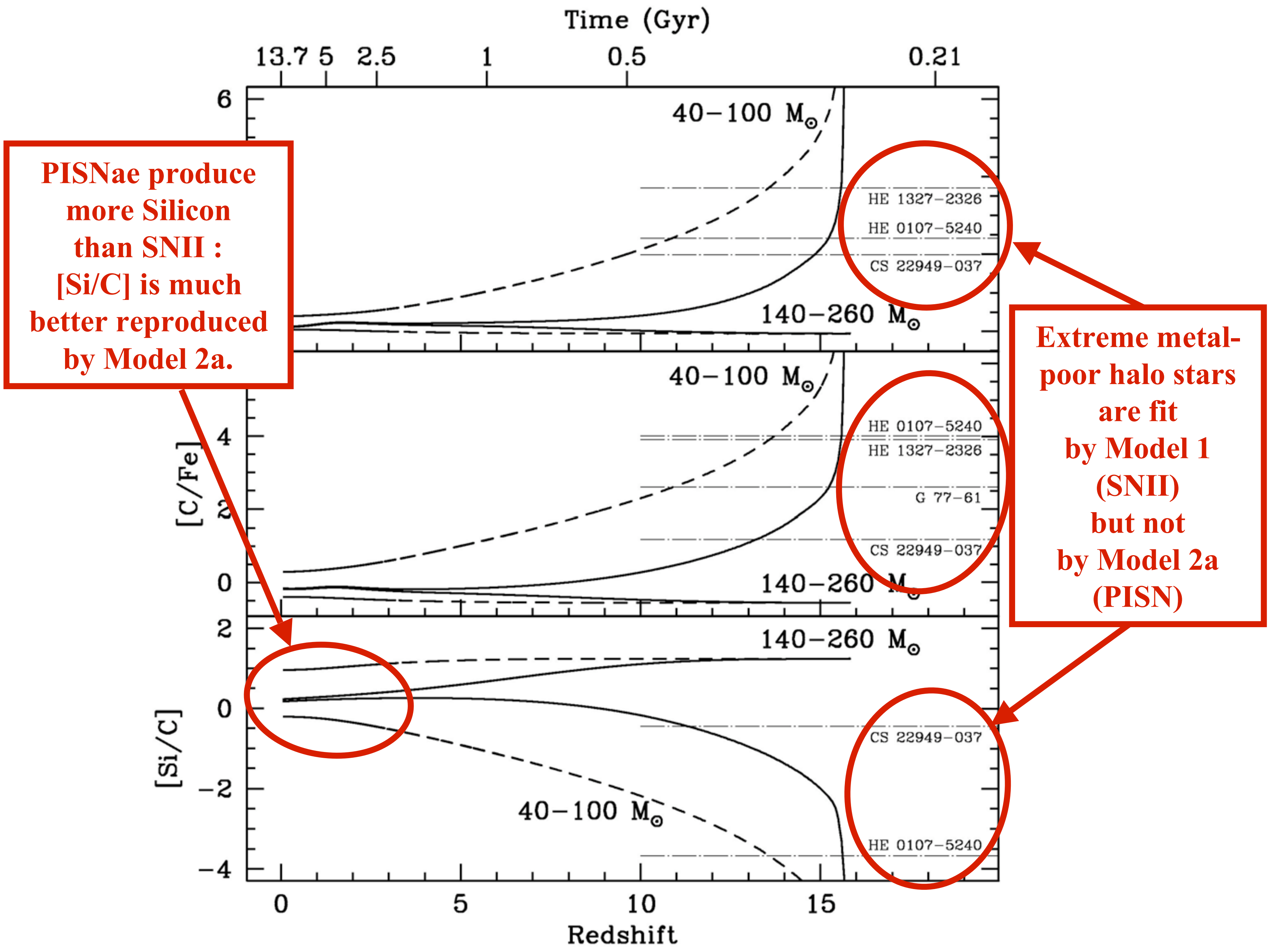
Compared to Model 1 (40-100 $M_\odot$) :

*** Model 2a (140-260 $M_\odot$: PISNae) :**
Silicon in the IGM is better reproduced (PISNae yields)
but the ionizing flux is too low.

*** Model 2b (270-500 $M_\odot$: BHs) :**
the ionizing flux is increased
but the chemical evolution is not satisfactory (= Model 0).

Realistic model : a combination or a succession of these three mass ranges during the initial massive starburst ?

Abundance ratios



Summary

In the framework of the hierarchical scenario for structure formation :

► **The physical parameters of the normal mode of star formation are strongly constrained :**

→ **mass of the DM halos of star forming structures (M_{min}~10^6-10^8 $M_\odot$, z_{init} ~ 10-15).**

→ **intensity of the SFR (observed SFR at z > 3 : OK but VIMOS ???).**

→ **efficiency of the outflow (peaks at 5-20 %).**

Then :

► **The present fraction of baryons in the star forming structures $\Omega_{b,struct}/\Omega_b(z=0)$ is reproduced, as well as the fraction of baryons in stars $\Omega_{b,*}/\Omega_b(z=0)$.**

► **The type II supernova rate is reproduced (IMF slope x = 1.3) :**
Consequences on the supernova relic neutrino background :
see Poster « Neutrino signatures from the First Stars » by Pearl sandick.

► **The type Ia supernova rate is reproduced :** **Δt ~ 3-3.5 Gyr (total delay : 4-4.5 Gyr) and 1-2 % of WDs (2-8 $M_\odot$).**

Summary

First stars :

► **Massive Pop. III stars are needed for the early reionization of the IGM.**
The mass range and the intensity of this mode are constrained by the chemical evolution.
Favored case : 40 – 100 $M_{\odot}$ but Silicon is under-abundant in IGM.
Mixing model with three components ???
- **140-260 $M_{\odot}$: good progenitors for Si**
- **270-500 $M_{\odot}$: improves the UV flux**

► **The global chemical evolution in the ISM and the IGM is reproduced.**
(Pop. III stars produce ~ 10 % of the metals in the IGM).

► **Very metal-poor halo stars can probe the chemical composition of the very early ISM.**
Their very peculiar abundances seem to suggest a component of < 100 $M_{\odot}$ pop. III stars.

► **Extension of the model :**
- **Mixing model for pop. III (three mass ranges),**
- **Impact of different stellar yields (Nomoto et al., Maeder & Meynet…)**
- **Multi-components model (clusters / galaxies in the field).**

► **Byproducts :**
- **Supernova relic neutrino background : astroph/0509404,**
- **Predictions for the evolution of the stellar explosion rates (SNae, GRBs) with redshift : in progress,**
- **Other backgrounds…**