Workshop "Simulations numériques de la formation des galaxies dans le contexte des grands relevés"
Lyon, 2011, October 17-19

A Glimpse in the Arcanes of Chemodynamical Simulations

Stéphanie Courty[1],

C. Gareth Few[2], *Brad K. Gibson*[2],

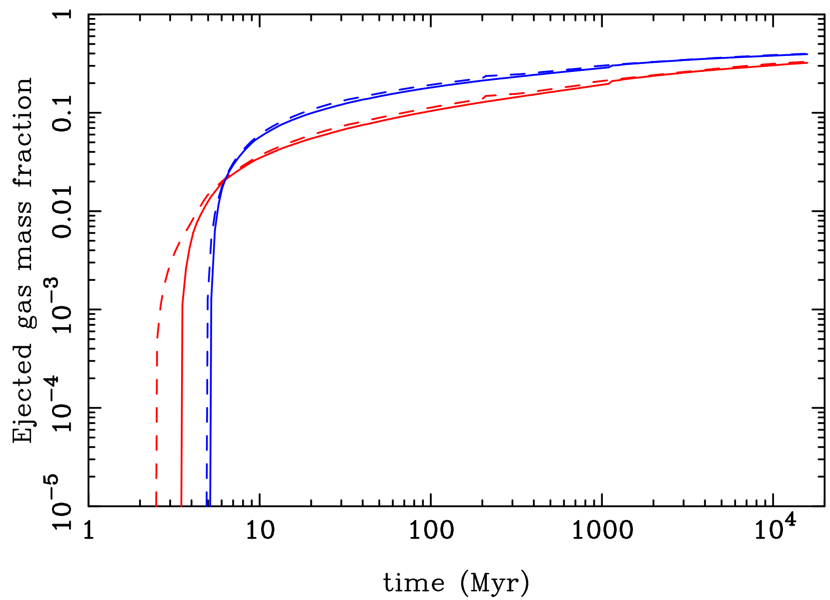
Léo Michel-Dansac[1], *Jérémy Blaizot*[1]

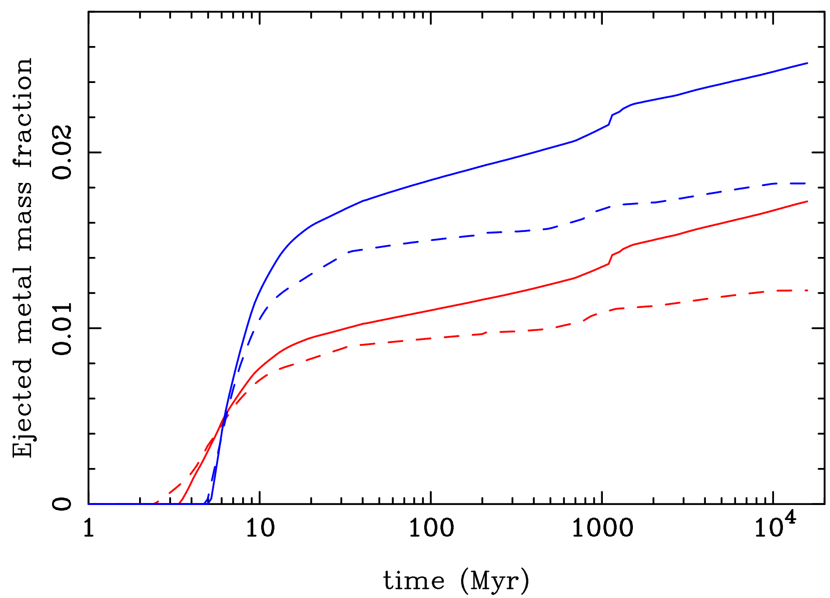
[1]*Center for Astrophysical Research of Lyon (France)*
[2]*Jeremiah Horrocks Institute for Astrophysics & Supercomputing (UK)*

- Enrichment of the inter-stellar (and inter-galactic) medium from the nucleosynthetic activity of stars

- Successive generations of stars will form in gas with different relative chemical abundances (clues on star formation history of galaxies)

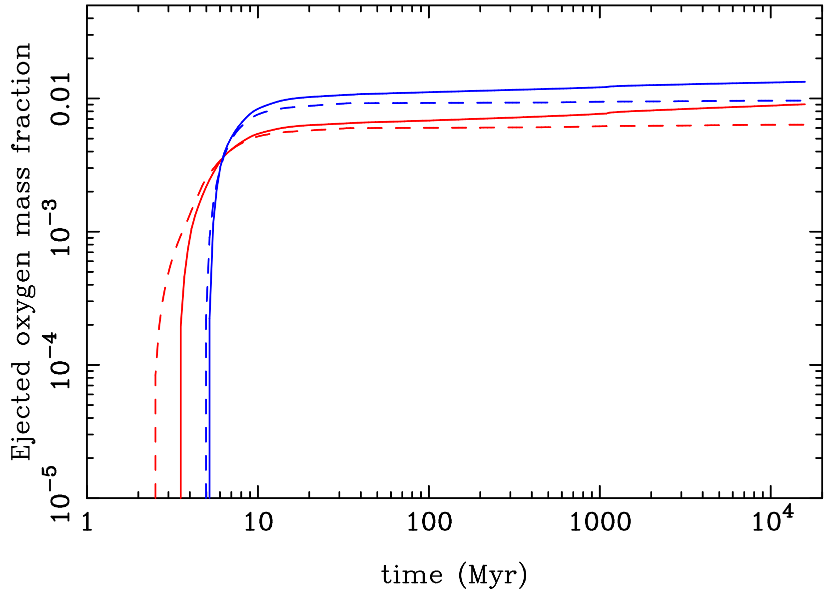
Chemodynamical codes:
Chemical evolution models convolved self-consistently with the dynamical history of galaxies





Different sites of element production:

- α-elements (O, Mg, Si,...) primarily produced by massive stars with short lifetimes (end their lives as SN_{II})
- Iron originate in carbon-oxygen white dwarfs systems that accrete mass from binary companions until they reach the Chandrasekhar mass and explode as SN_{Ia}
- Low and intermediate mass stars end their life after an AGB phase by the loss of their envelop (produce elements such as carbon and nitrogen)



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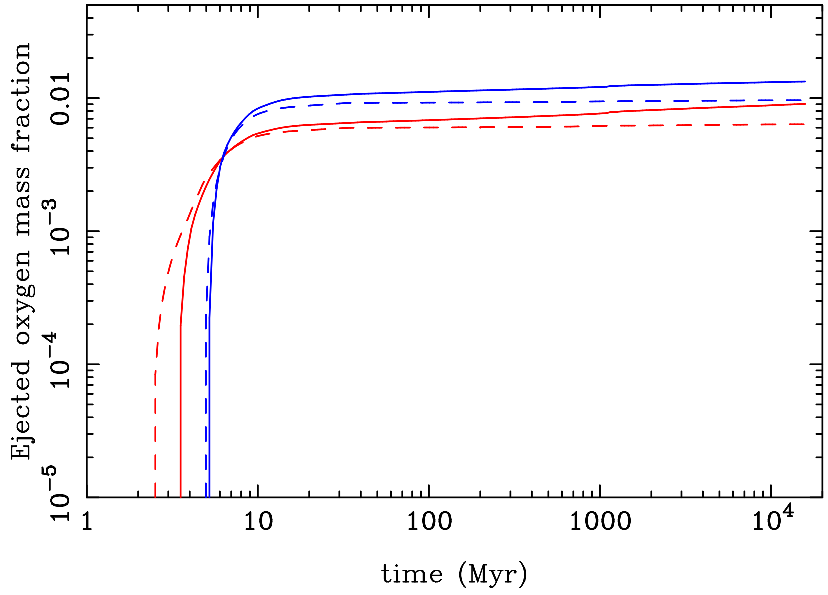

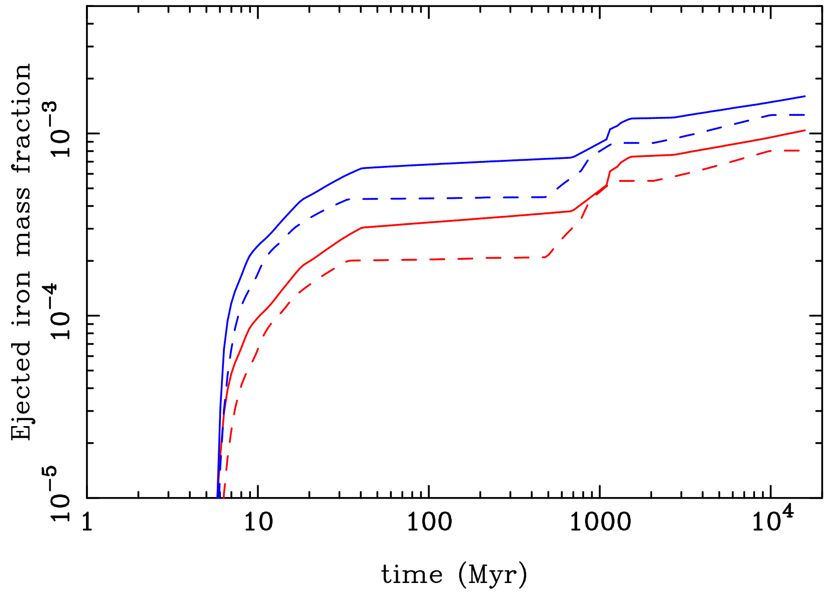

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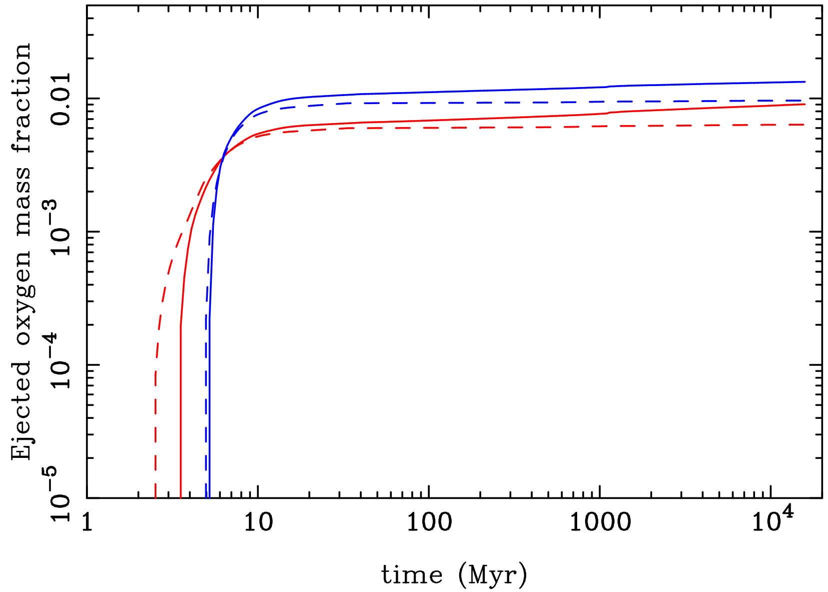

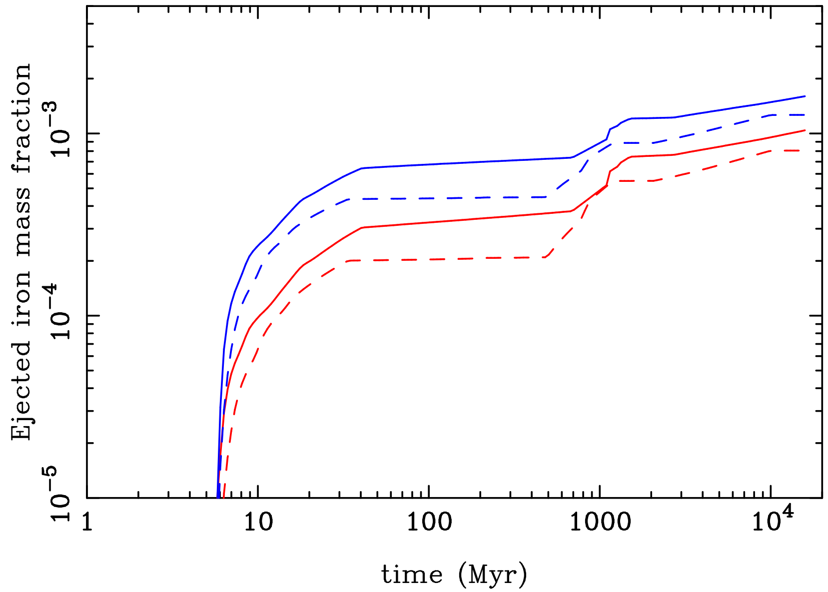

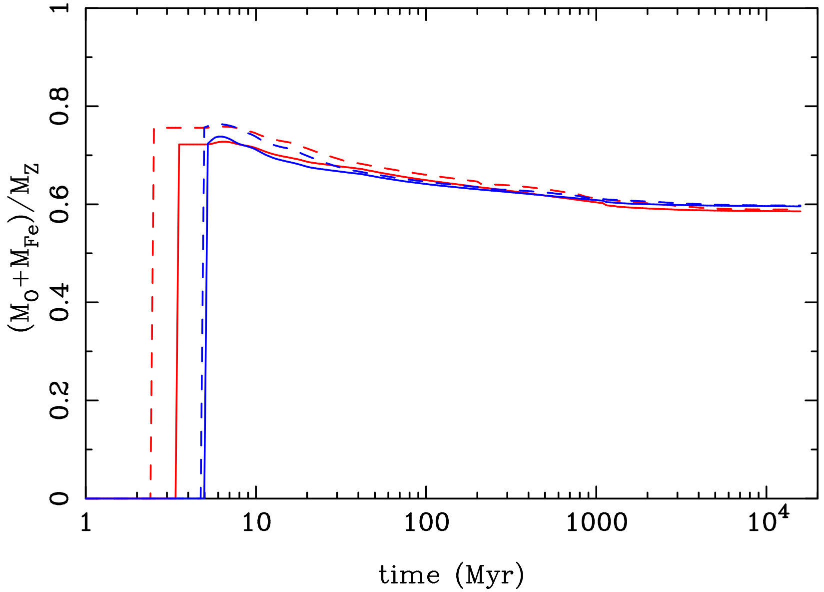

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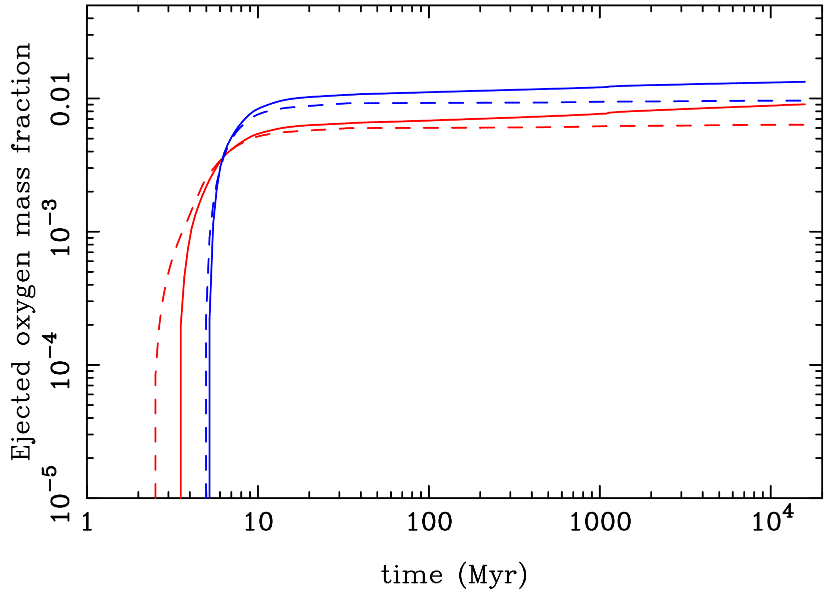
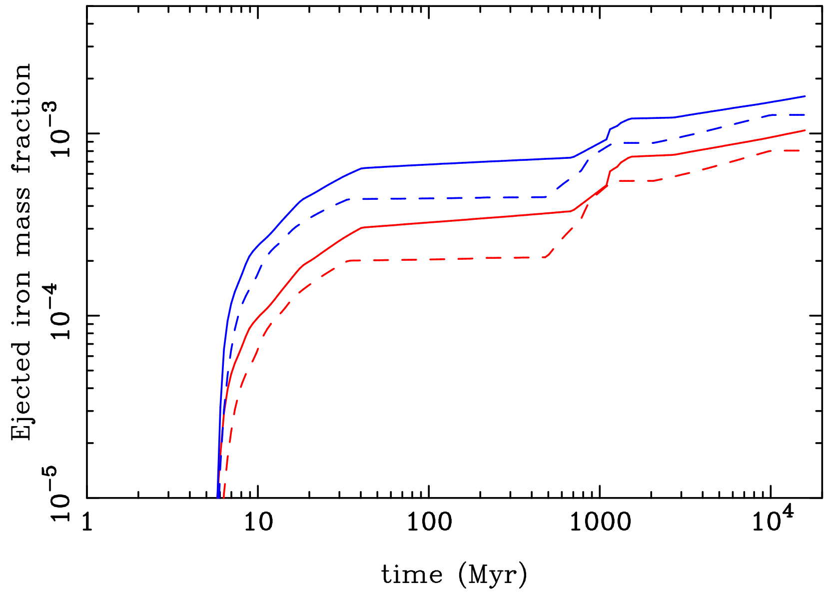
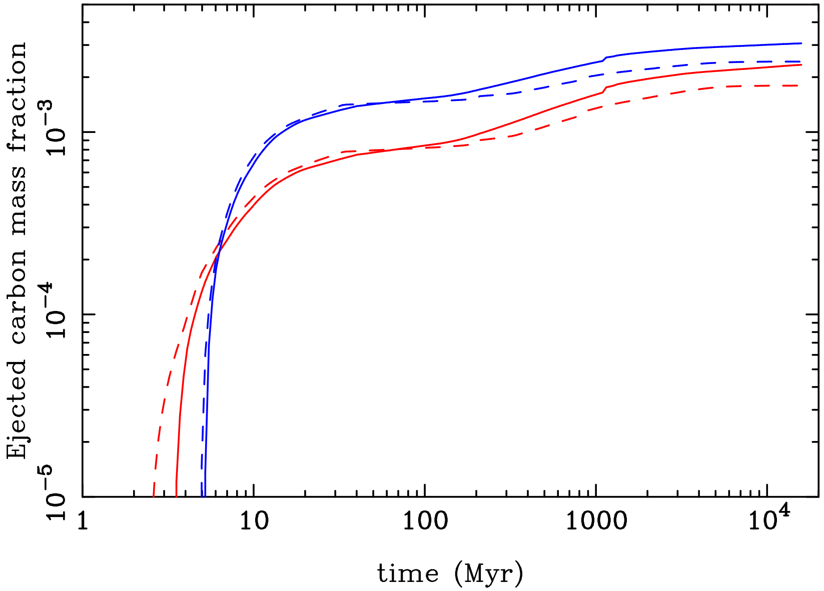






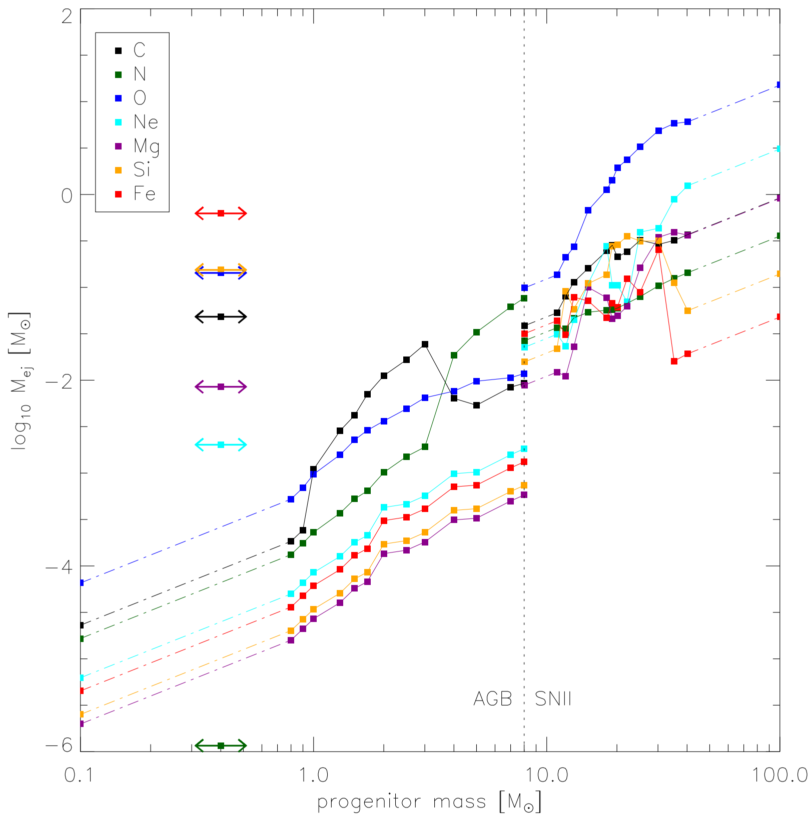
Chemical evolution models compile data from stellar evolution and stellar nucleosynthesis

- **The stellar lifetimes** (time at which a star leaves the main sequence phase, increase with decreasing initial stellar mass), *Kodama&Arimoto (1997)*

- **The stellar yields** (masses of fresh elements produced and ejected by a star of initial mass and metallicity)

for high-mass stars, from *Woosley&Weaver (1995)* ;
$M=[11,40]\ M_\odot$, $Z=[0.,Z_\odot]$

for low and intermediate mass stars ($M=[0.8,8]\ M_\odot$),
from *van den Hoek&Groenewegen (1997)* for AGBs ;
from *Iwamoto et al. (1999)* for SN_{Ia}

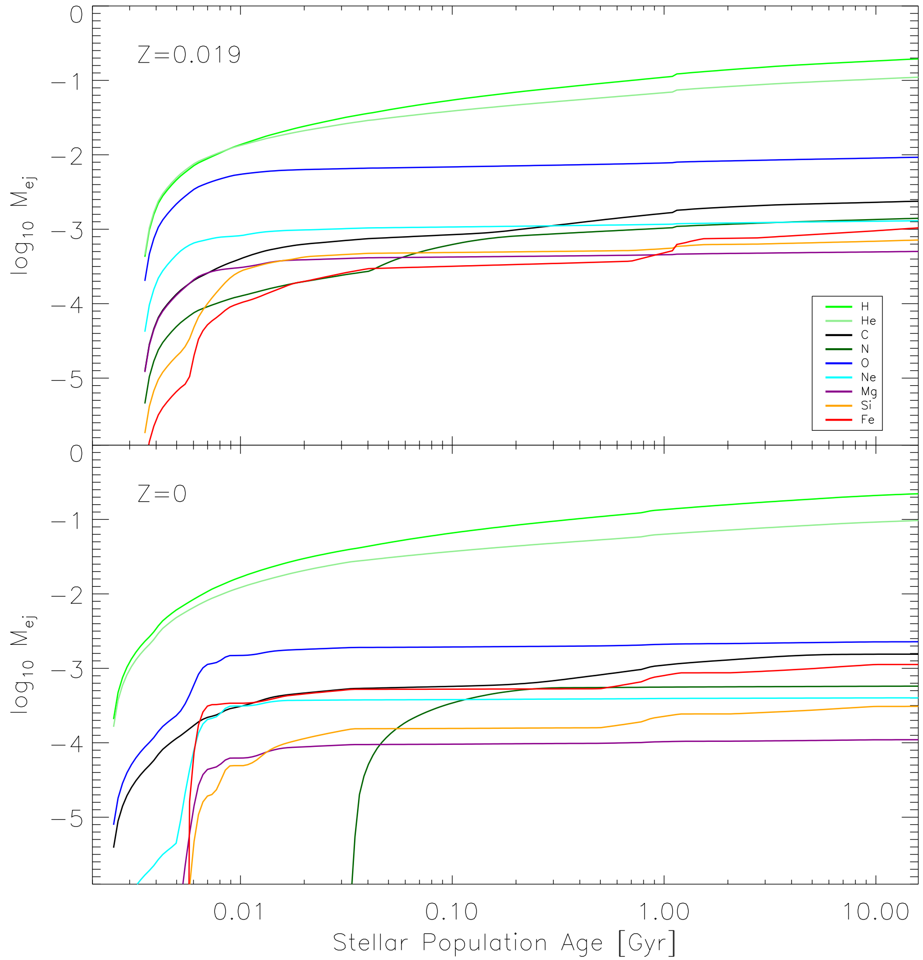


- **The time evolution of the SN_{Ia} rate** (depends on the mass range for the primaries and the secondaries (main sequence or red giants stars) *Greggio&Renzini (1983), Mannucci et al. (2006), Kobayashi et al. (2000)*

- **The initial mass function** *(Salpeter (1955), Kroupa (1993), Kroupa (2001), Chabrier (2003), etc...)*

- Compute for coeval stellar populations of different initial metallicities the time evolution of their abundances

- Look-up table *(indexed by age and initial metallicity and normalized on the initial stellar mass)* records the ejected mass and mass of metals, the ejecta abundances and the number of SN_{II} and SN_{Ia}



The Chemodynamical Version of RAMSES

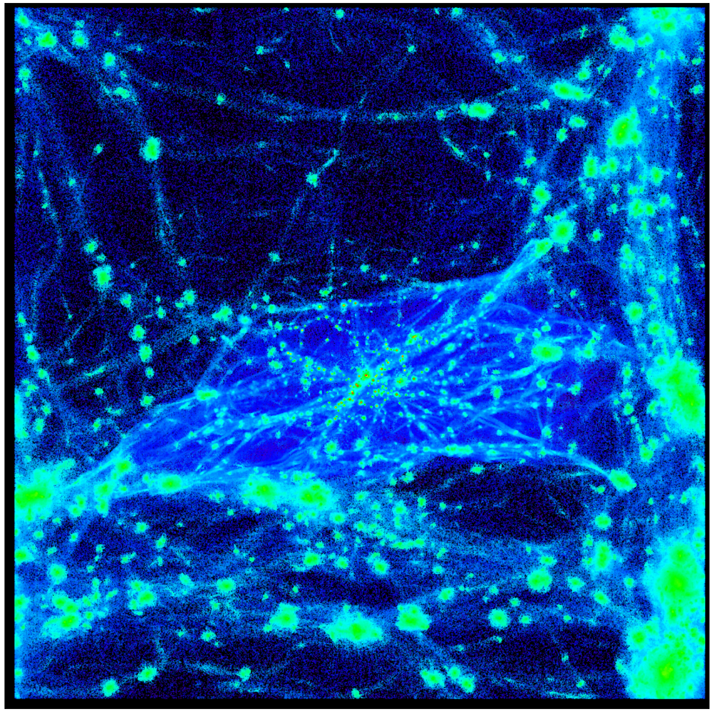
- *For each stellar population and at each time-step, look-up "yield" table provides data for chemical enrichment and feedback processes*
  - Kinetic feedback in the SN_{II} phase: gas density, metal density, momentum and energy ($\epsilon_{sn_{II}} 10^{51}$ erg per SN event with ϵ_{sn} a radiative efficiency) dumped in a feedback-sphere of a given radius
  - Local thermal feedback in the AGB and/or SN_{Ia} phase: gas density, metal density, momentum and energy ($\epsilon_{sn_{Ia}} 10^{51}$ erg per SN event) dumped in the gas cell the stellar population sits in
- Chemical elements are new passive scalars advected by the hydro solver (currently, H, C, N, O, Mg, Si, Fe, and Z)

Standard version of RAMSES (*R. Teyssier et al.)*
based on the instantaneous recycling approximation ;
follows the global metallicity Z ;
enrichment and feedback from short-lived, massive stars

Different Hydro Codes, Different "Yield" Tabulations

- Theis et al., 1992
- Berczik et al., 1999
- Lia et al., 2002
- Kawata&Gibson, 2003
- Valdarnini et al., 2003
- Kobayashi et al., 2004
- Tornatore et al., 2007
- Oppenheimer&Dave, 2008
- Martinez-Serrano et al., 2008
- Wiersma et al., 2009
- Shen et al., 2010

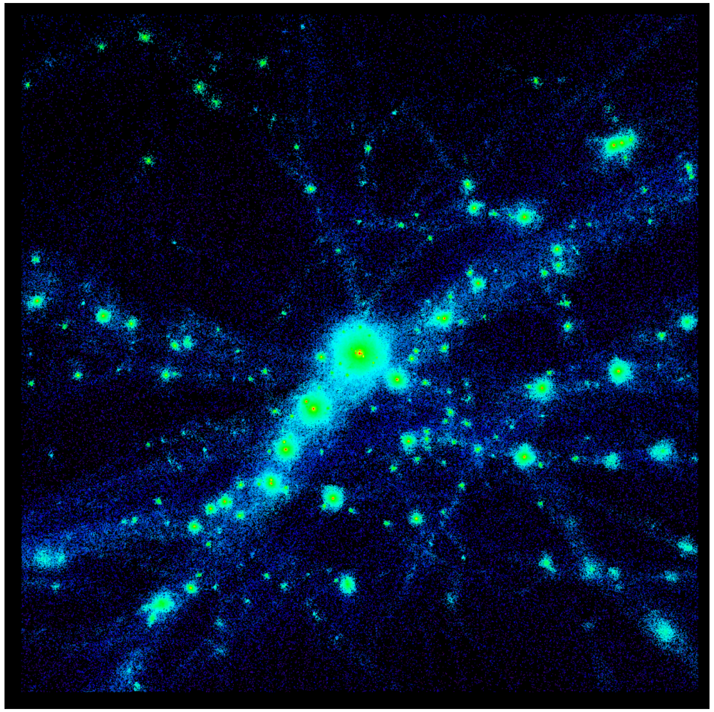
Cosmological Simulation of MW-Size Galactic Disks



$\longleftarrow$ $20\, h^{-1}\ Mpc$ $\longrightarrow$

Cosmological Simulation of MW-Size Galactic Disks

5.3 Mpc



Host halo:

R_{vir}=210 kpc

$M_{tot}=7\times10^{11}\ M_{\odot}$

Spatial resolution (physical), 435 pc

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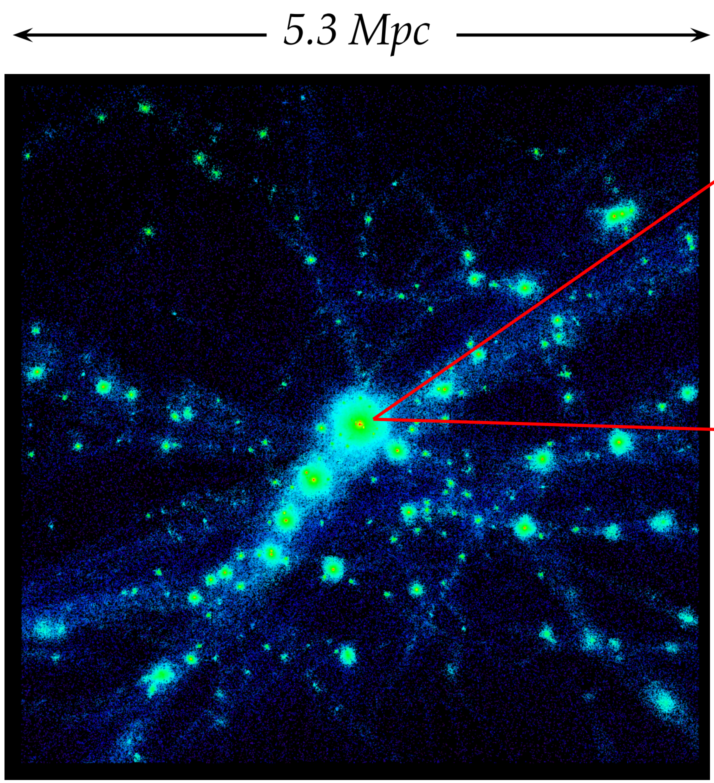

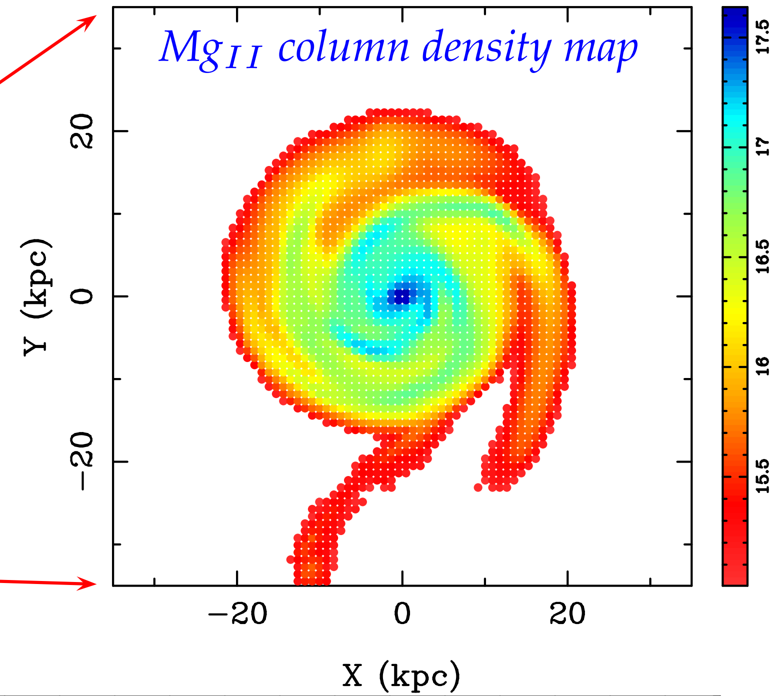

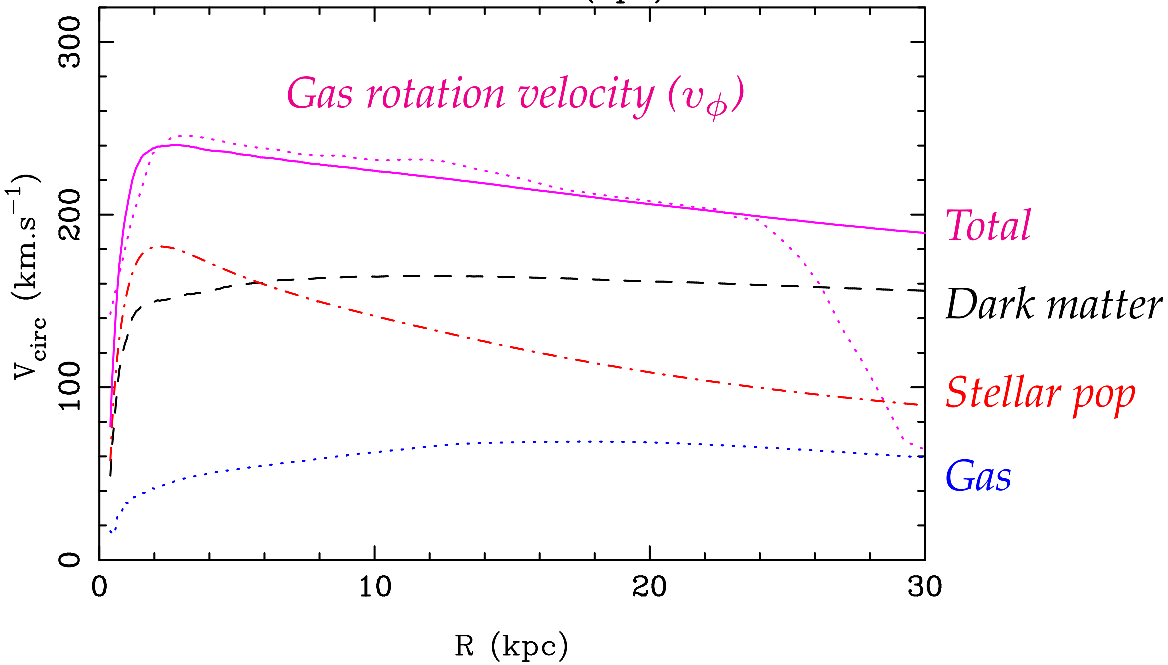

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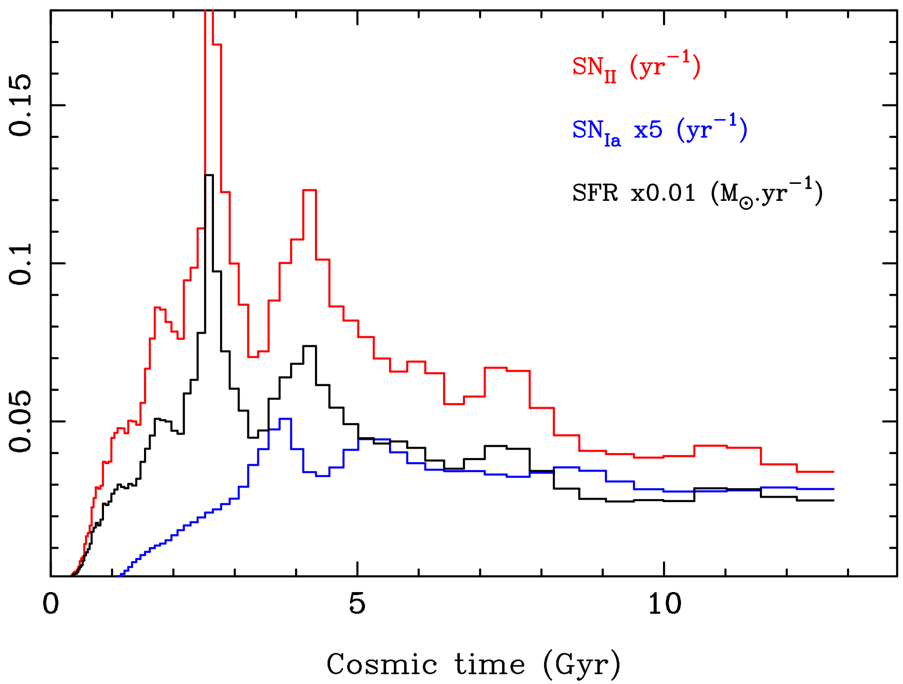
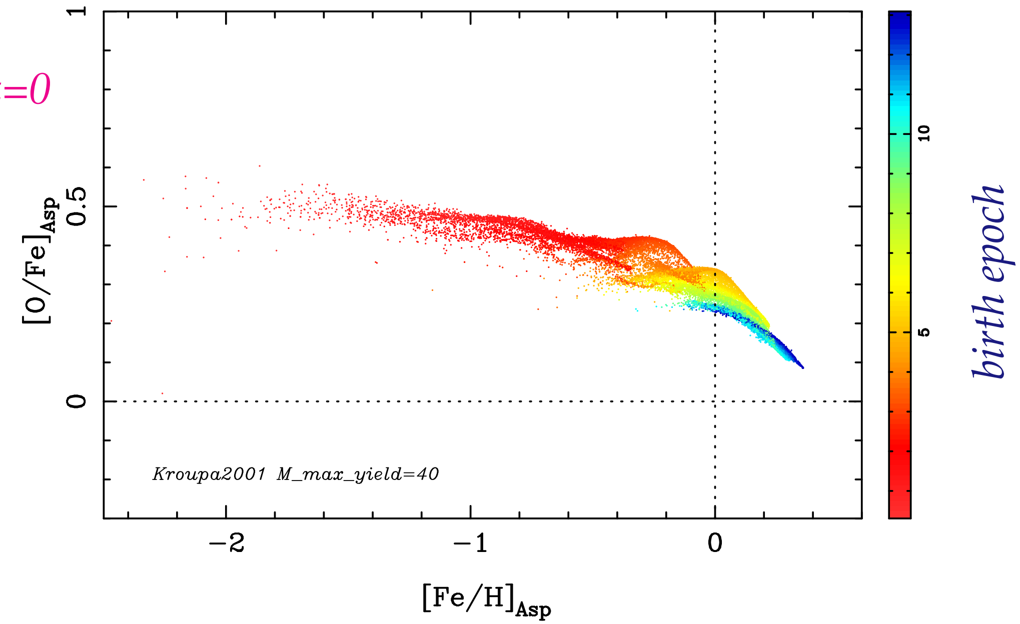
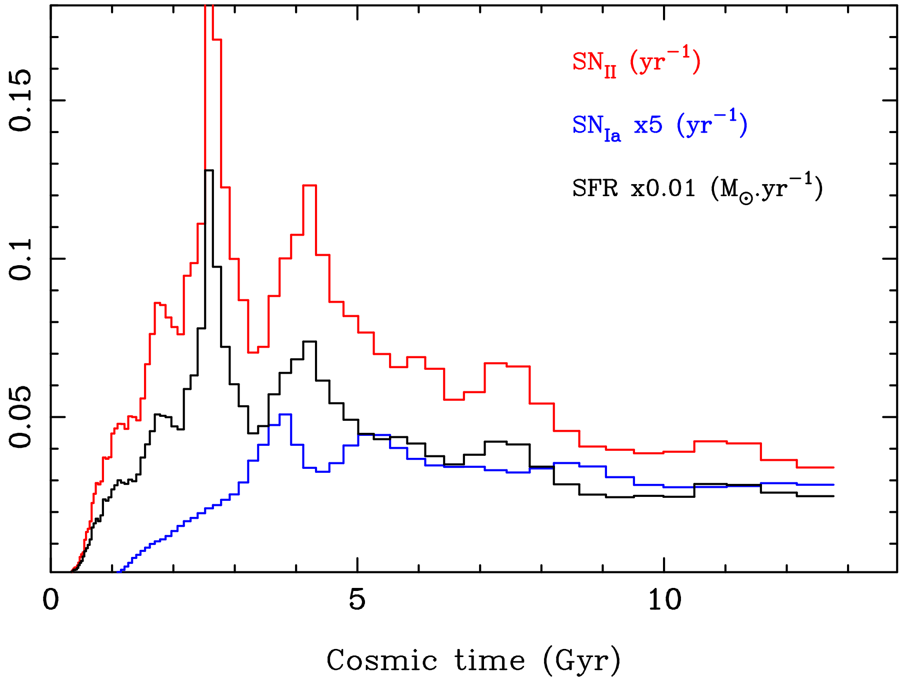


SN_{II}/SN_{Ia} rates in the disk of the MW, ∼4.6 (Mannucci et al. 2008)

Stellar populations in the disk at z=0





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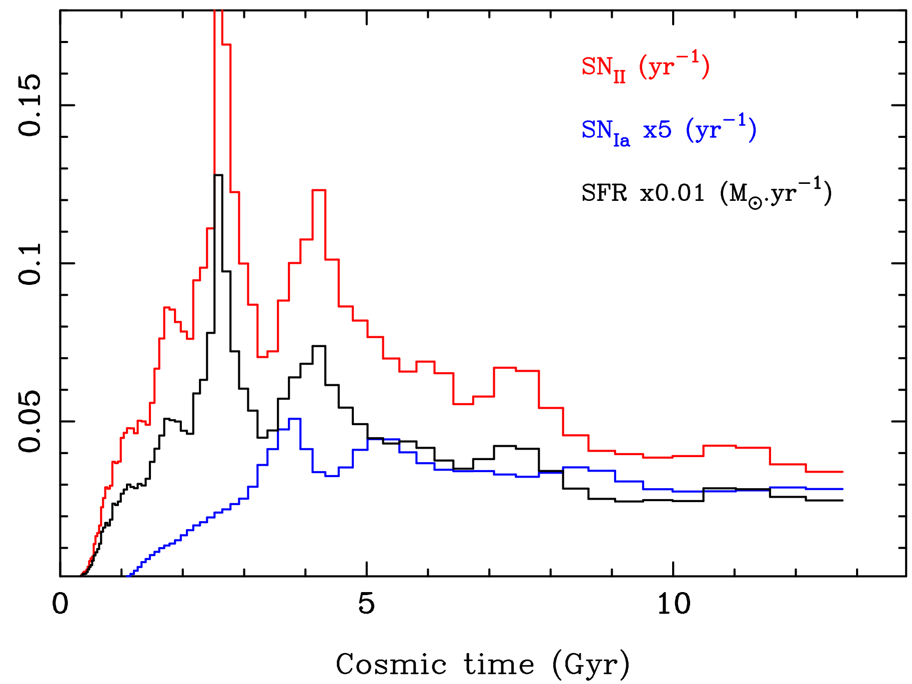

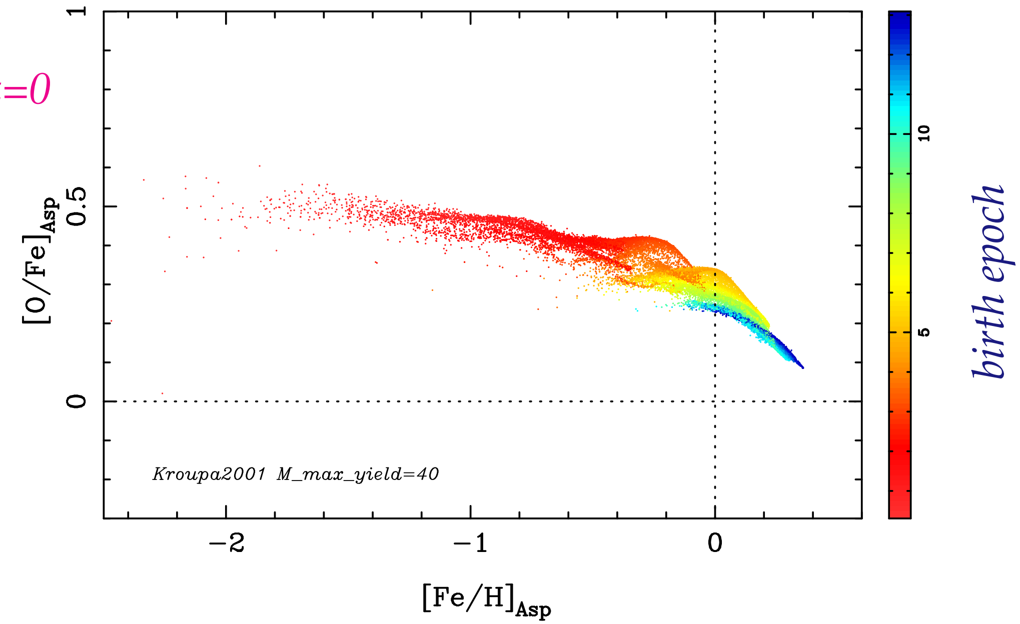

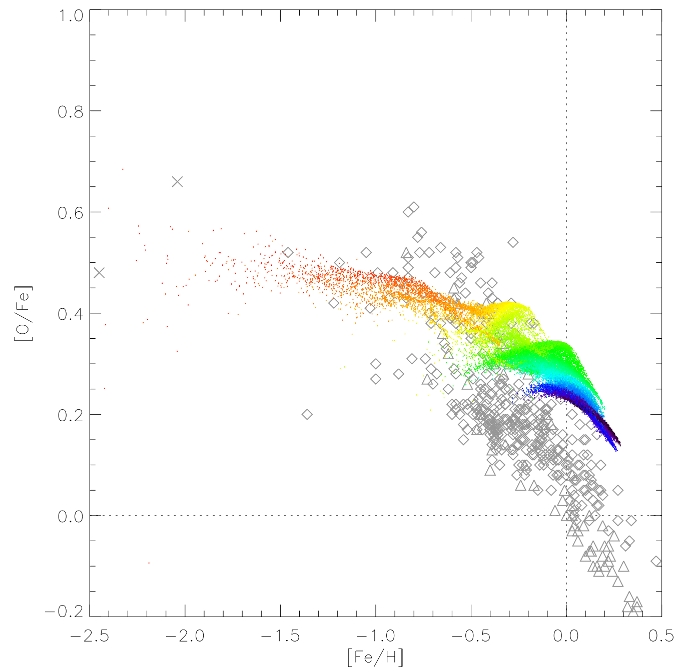

SN_{II}/SN_{Ia} rates in the disk of the MW, ∼4.6 (Mannucci et al. 2008)

Data from Ramirez et al. (2002), Bensby et al. (2004), Cayrel et al. (2004)

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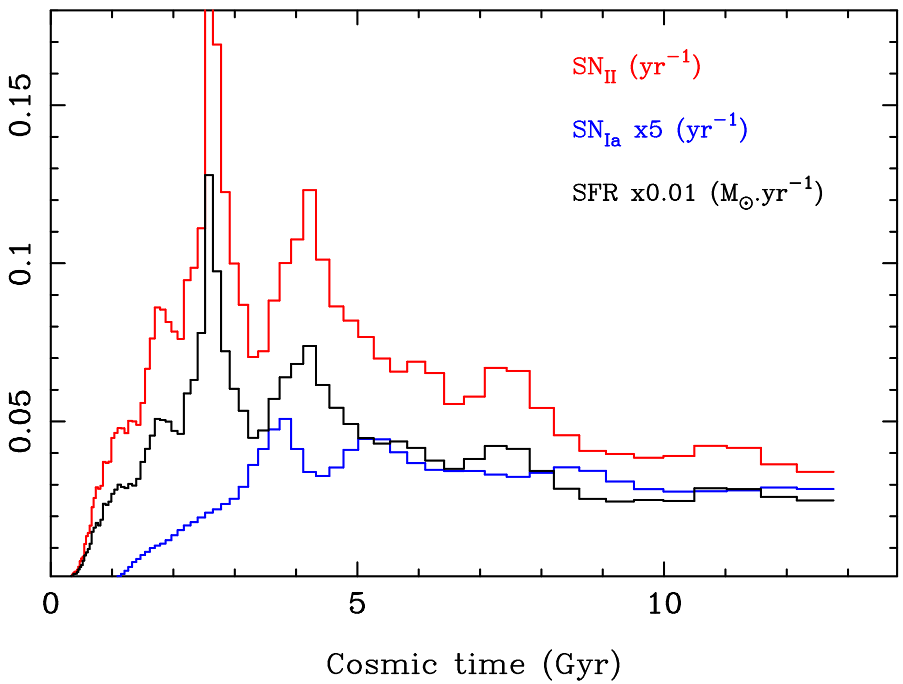

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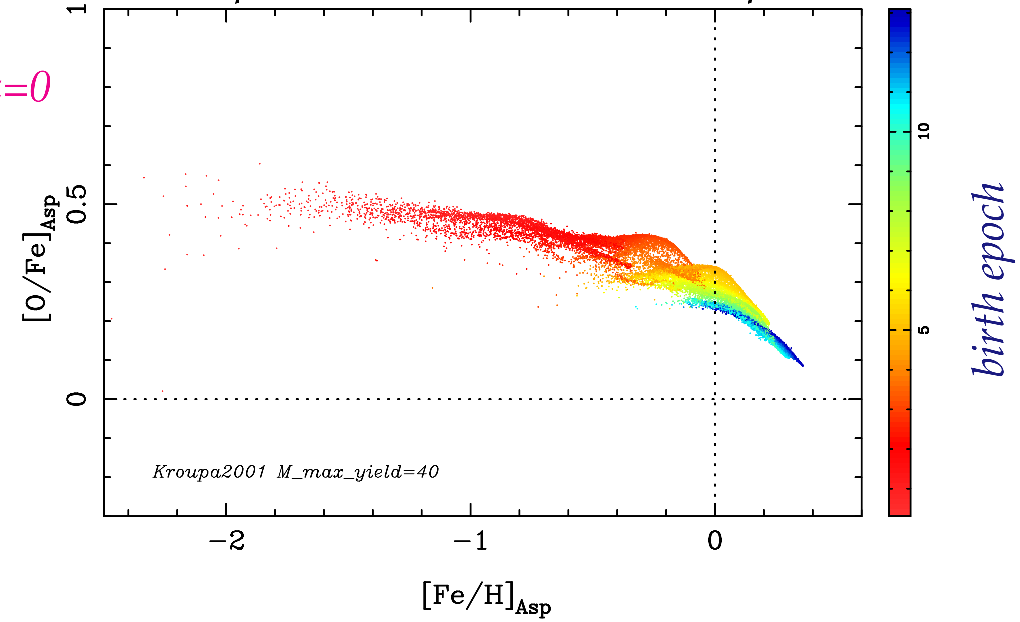
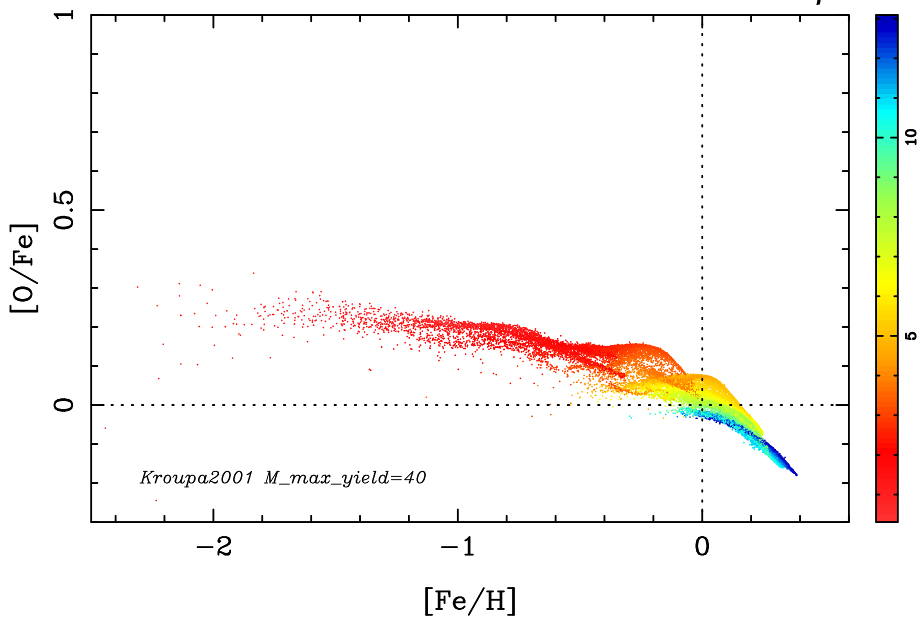
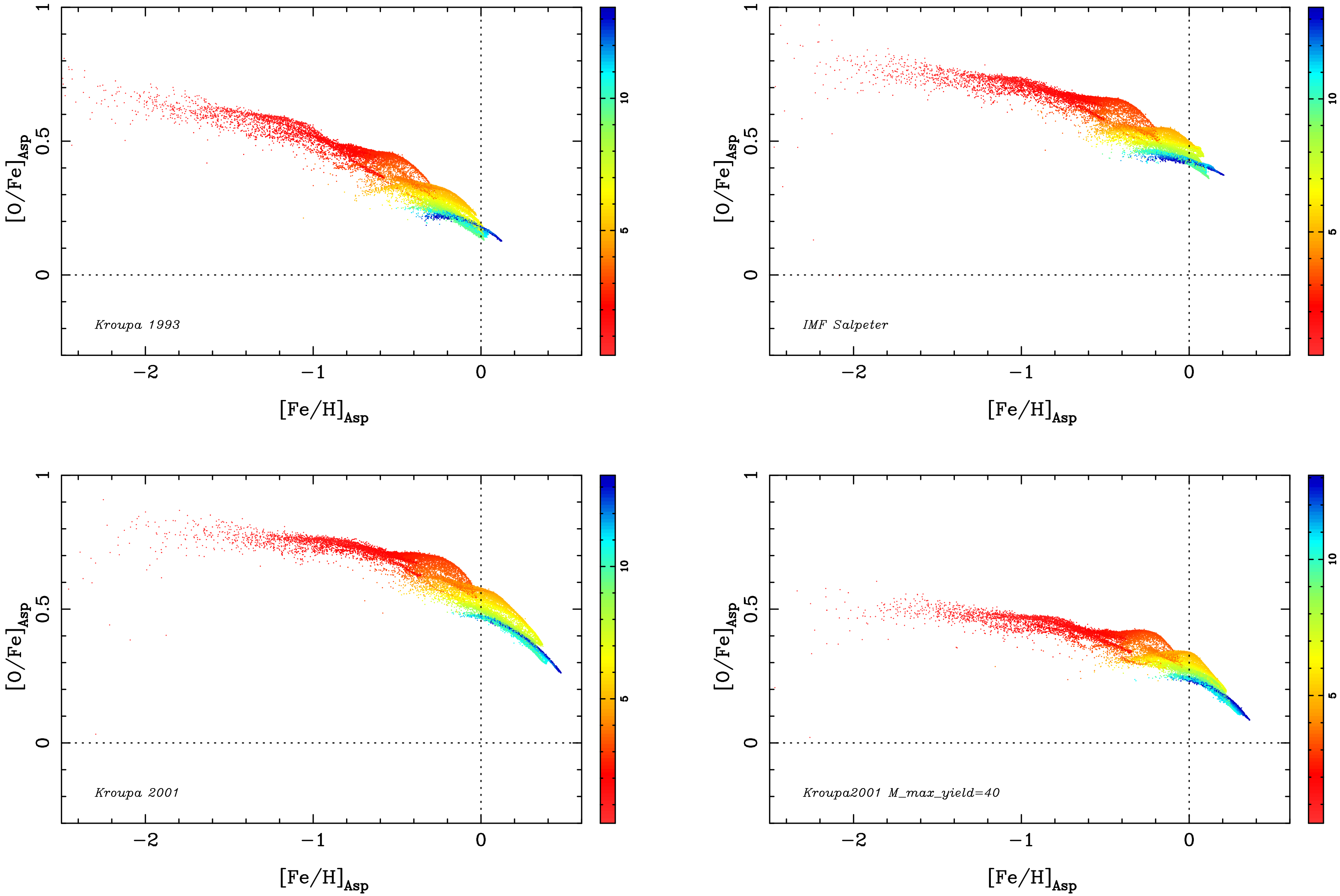
Asplund et al. (2004) solar composition

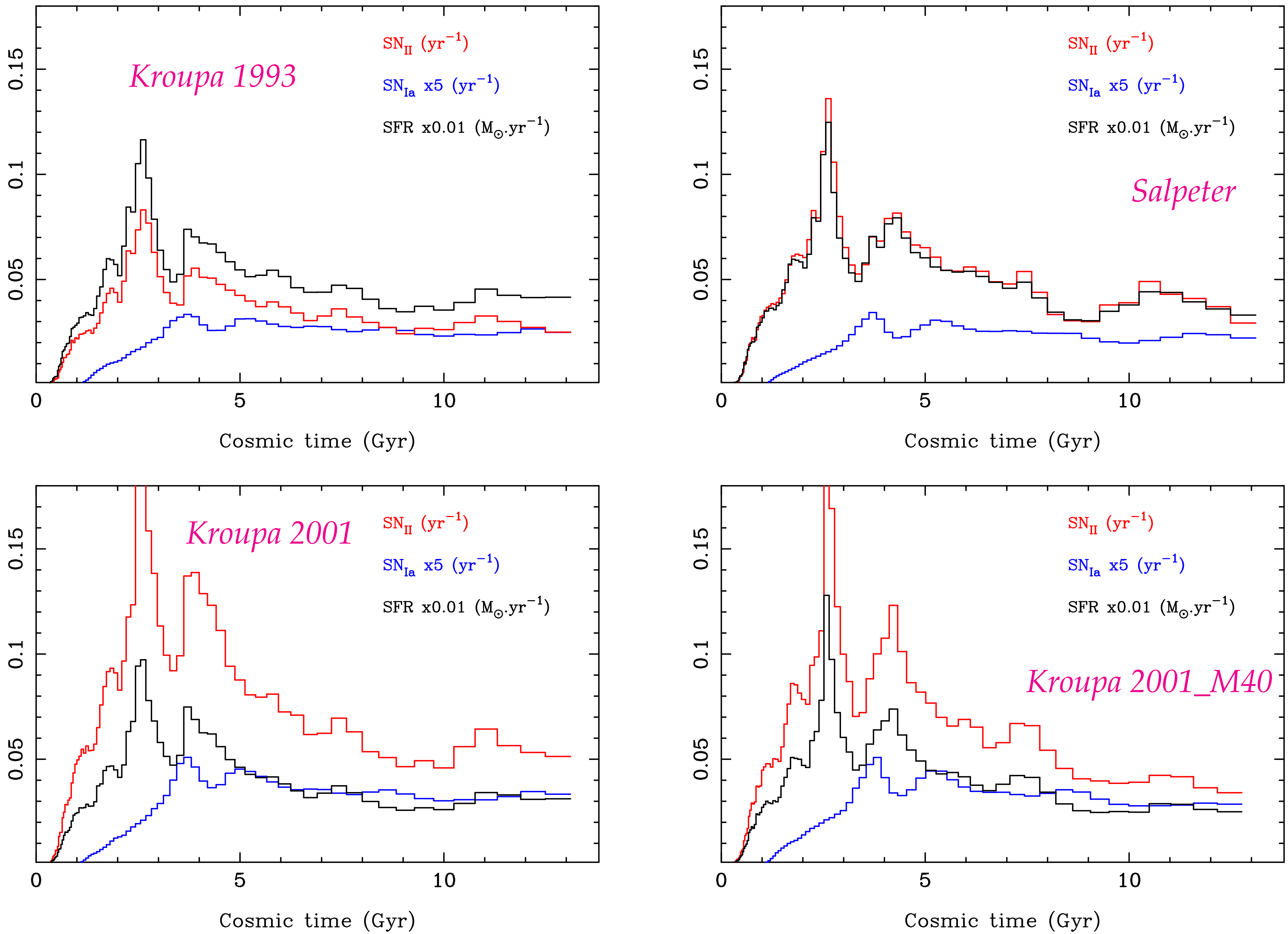


Anders&Grevesse (1989) solar composition

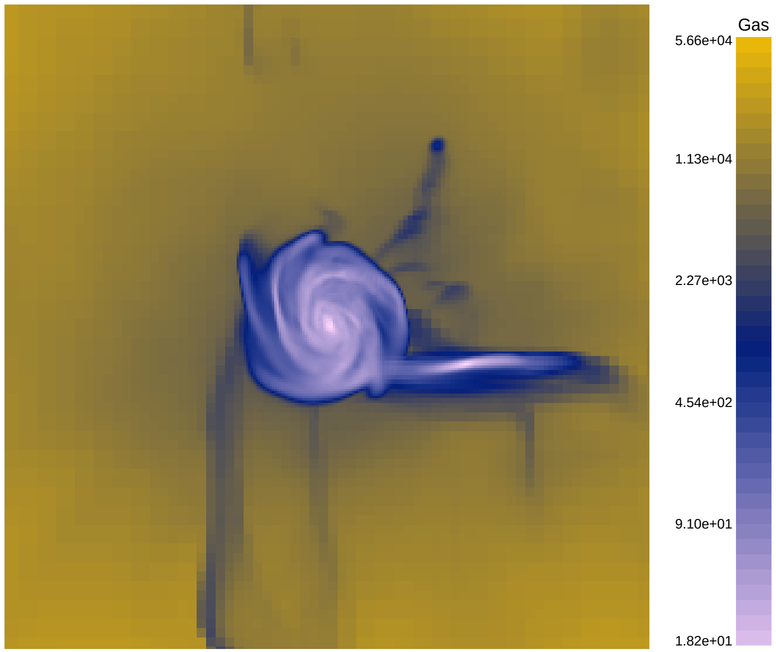




Kroupa 1993
IMF Salpeter
Kroupa 2001
Kroupa2001 M_max_yield=40
$[O/Fe]_{Asp}$
$[Fe/H]_{Asp}$
1
0.5
0
−2
−1
0
5
10



Kroupa 1993
Salpeter
Kroupa 2001
Kroupa 2001_M40
SN$_{II}$ (yr^{-1})
SN$_{Ia}$ x5 (yr^{-1})
SFR x0.01 (M$_\odot$.yr^{-1})
0.05
0.1
0.15
0
5
10
Cosmic time (Gyr)



- Next sets of comparison will involve the SN_{Ia} rate distribution
- Higher resolution galactic disks
- Analysis of the gas in absorption at different redshifts (in the halo with highly-ionized species, CIV, OVI)