The effects of different Type Ia SN progenitors in galactic chemical evolution

Francesca Matteucci

Department of Astronomy, Trieste

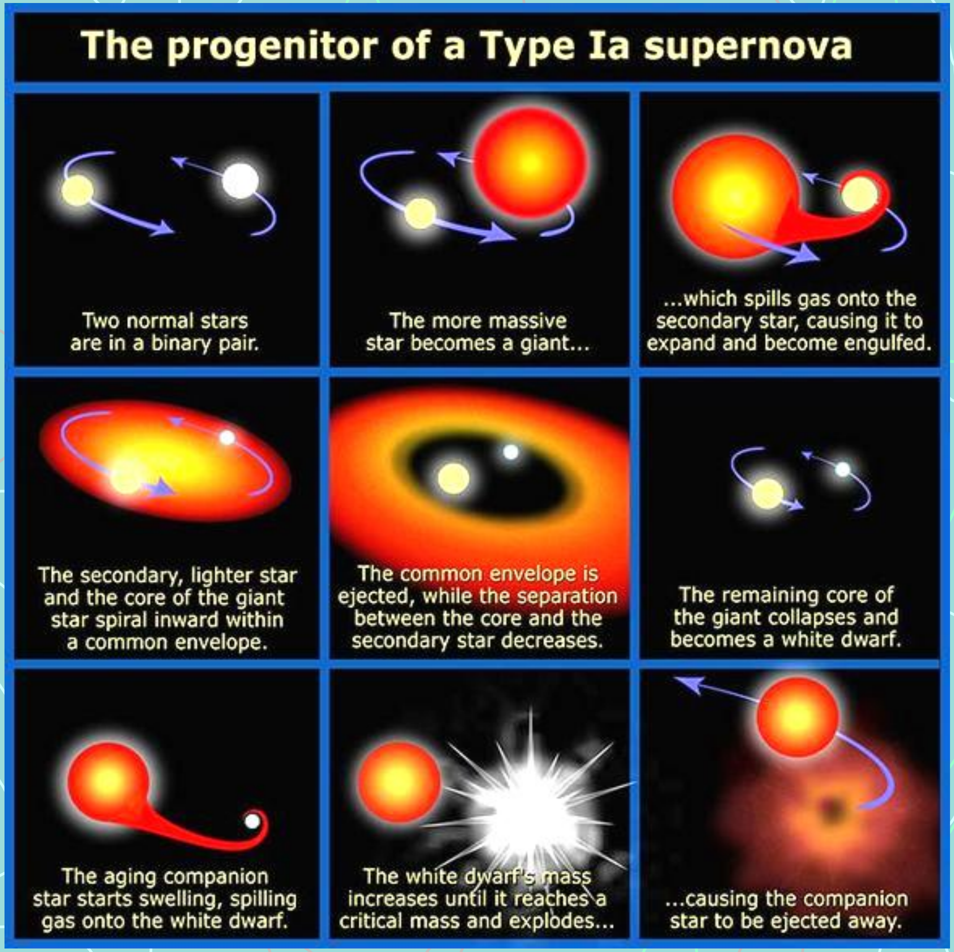
Paris, July 1, 2010

Summary of the talk

- Type Ia SN progenitors (different Delay Time Distributions, DTDs)
- Type Ia SN rates (DTD+SFR)
- Chemical evolution of the Milky Way: the effect of Type Ia SN rates on the [X/Fe] vs. [Fe/H] relations and G-dwarf metallicity distribution
- Constraints on the Type Ia SN progenitors

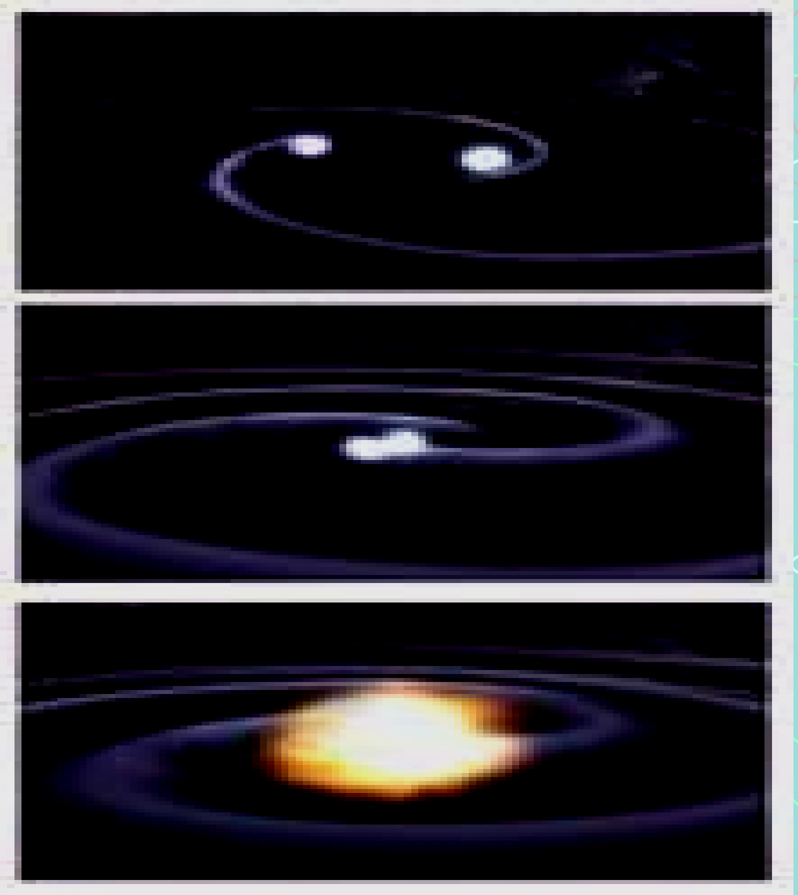
The SD model: typical timescales

- A binary system made of a C-OWD (M1) plus a MS or RG star (M2)
- The mass range for M2 (the clock for the explosion) is (0.8-8)Msun with timescales from 0.03 Gyr to 10 Gyr
- The mass range for M1 is (Mmin-8)Msun. (M1+M2)min=3Msun (Greggio & Renzini 1983)



The DD model: typical timescales

- Two C-OWDs merging after gravitational wave emission
- Range of masses (5-8)Msun (Iben & Tutukov 1984). M1>2Msun, M2>8Msun (Greggio 2005)
- Timescales from (0.03+Tgrav) Gyr to >10 Gyr
- Tgrav from 0.0014 Gyr to 18Gyr passing from 0.5 Rsun to 3Rsun in the separation (Greggio 2005)



Delay time distribution

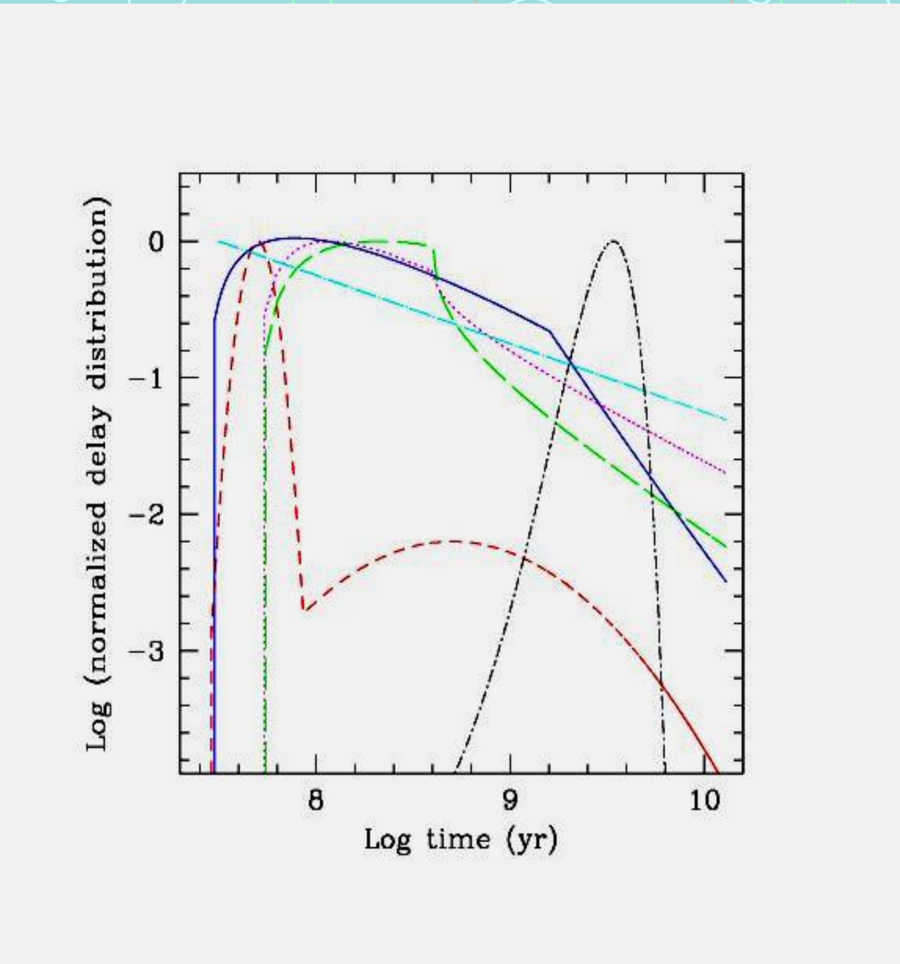
- SNe Ia are producing the bulk of Fe in the universe
- The delay time distribution (DTD) of SNe Ia is therefore very important to compute galactic chemical evolution
- Each SN Ia progenitor model in characterized by a specific DTD
- We refer to prompt Type I a SNe if they explode in the first 100Myr since star formation starts

Various Delay Time Distributions

- Single degenerate model (SD) with minimum time delay of 35 Myr (Greggio & Renzini 1983)
- Double degenerate model (DD) close and wide channel, with minimum time delay of 35Myr + grav. time delay (Greggio 2005)
- Bimodal empirical DTD by Mannucci& al. (2006)
- Empirical DTD by Strolger & al. (2006) where the minimum explosion time is 250 Myr, derived from cosmic Type Ia SN rate
- Empirical DTD by Pritchet &al.08 going t^(-0.5)

Various Delay Time Distributions

- Blue line: DTD from SD model (FM&Recchi2001)
- Dashed red line: bimodal DTD Mannucci +(2005)
- Green line: DTD from DD model (wide channel)
- Black dashed-dotted line:DTD Strolger +04
- Cyan: DTD Pritchet+08



The Type Ia SN rates

- The Type Ia SN rate can be expressed as the product of DTDxSFR (Greggio 2005):

$$R_{Ia}(t) = k_\alpha \int_{\tau_i}^{min(t,\tau_x)} A(t-\tau)\psi(t-\tau)DTD(\tau)d\tau$$

- Where, psi(t) is the SFRand A is the fraction of Type Ia SN progenitors in the whole range of masses and kalpha:

$$k_\alpha = \int_{m_L}^{m_U} \phi(m)dm$$

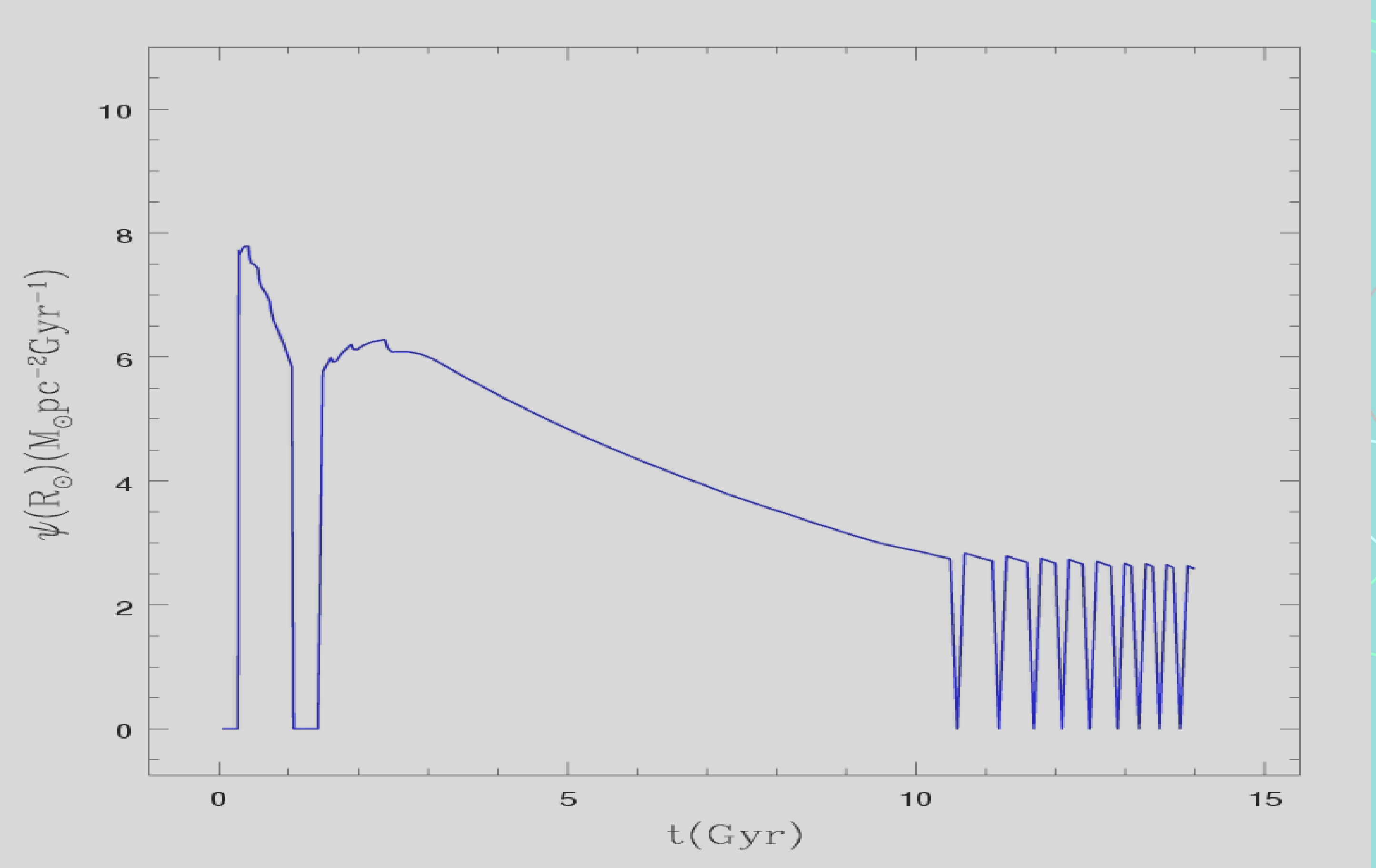
Galactic Chemical Evolution:the MW

- The DTD of the SD and DD scenarios are not very different, whereas the Mannucci et al. (05,06) DTD is quite different
- It predicts that prompt Type Ia SNe (exploding before 0.1 Gyr) are 50% of the total
- The DTDs of the SD and DD scenarios predict roughly 7-13% of prompt Type Ia SNe
- The different fractions of prompt SNe can produce differences in the [O/Fe] vs. [Fe/H] relation in the MW

The two-infall model for the MW

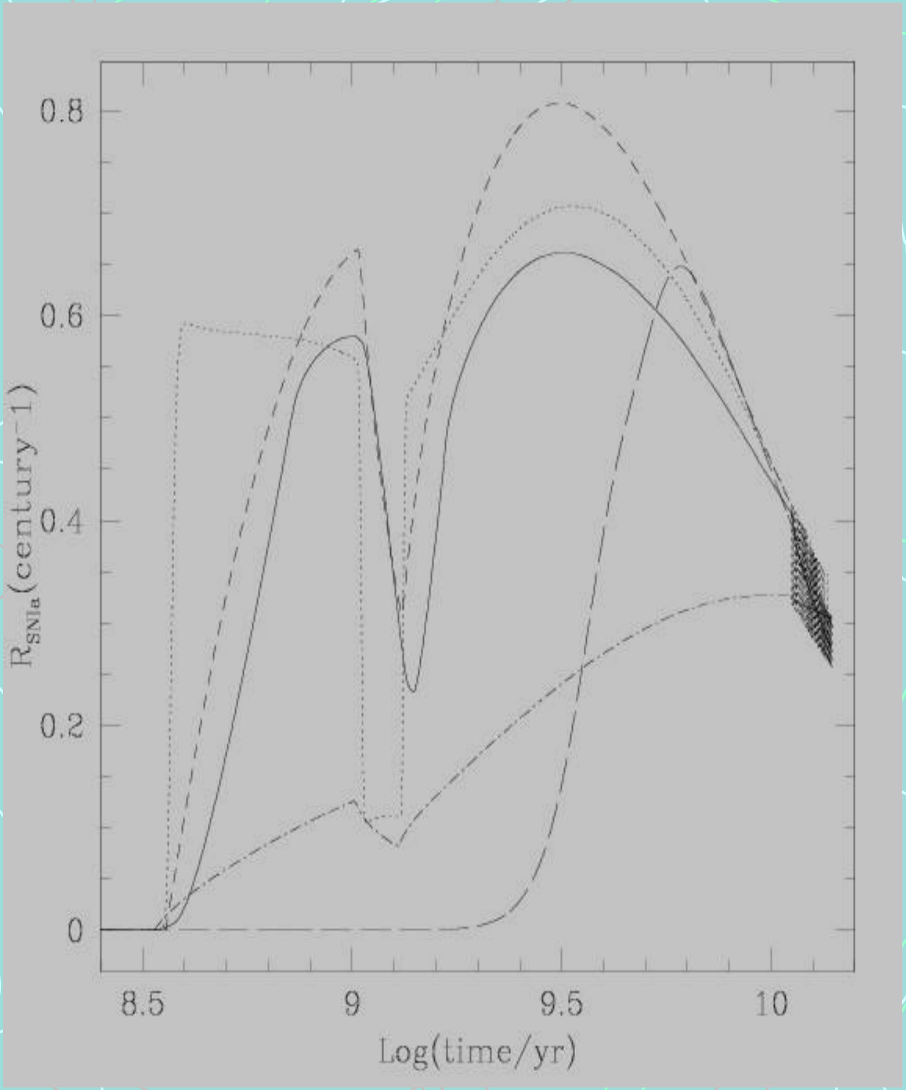
- Chiappini, FM & Gratton (1997) suggested that the halo and part of thick disk formed out of a first gas infall episode on a timescale of 1-2 Gyr
- The thin disk formed inside-out and on much longer timescales (7-8 Gyr at the solar circle)

SFR in the Milky Way with gas threshold



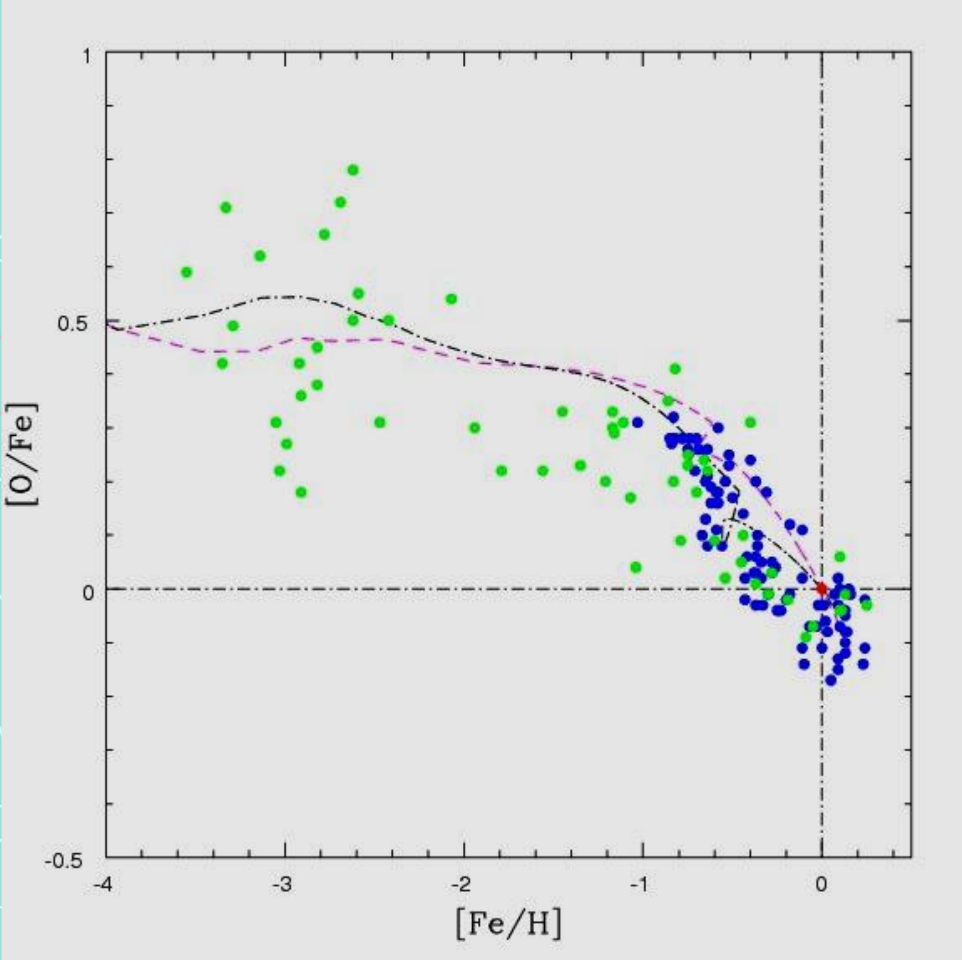
Type Ia SN rates

- Type Ia SN rates as predicted by the SFR in the MW a different DTDs
- Continuous line: DD model (wide) of Greggio(05); short dashed line:SD model (GR83,MR01)
- Dotted line: DTD of Mannucci et al. (06)
- Long dashed: DTD Strolger+ dashed dotted DTD Pritchet+



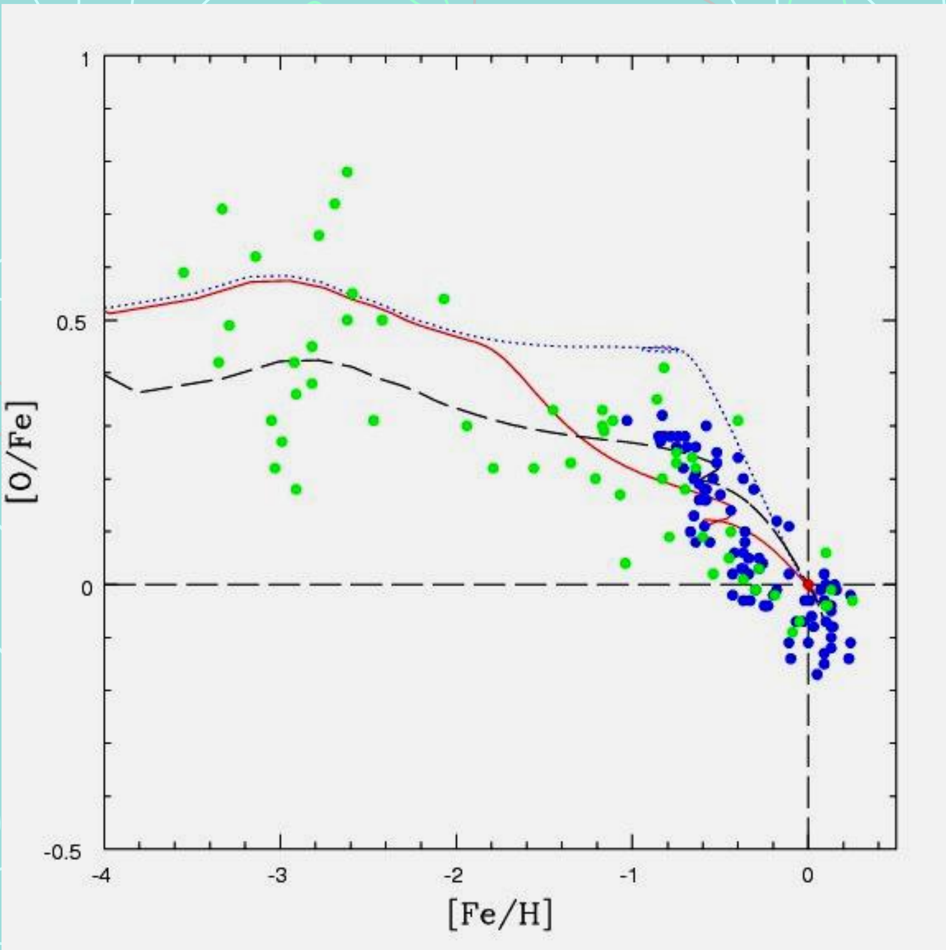
The [O/Fe] vs. [Fe/H] in the MW (SD and DD)

- Data from Francois et al. (2004). Halo stars from Cayrel et al. (2004)
- Dashed line: best model predictions with the SD DTD
- Dashed-dotted line: predictions with the DD DTD (wide channel)



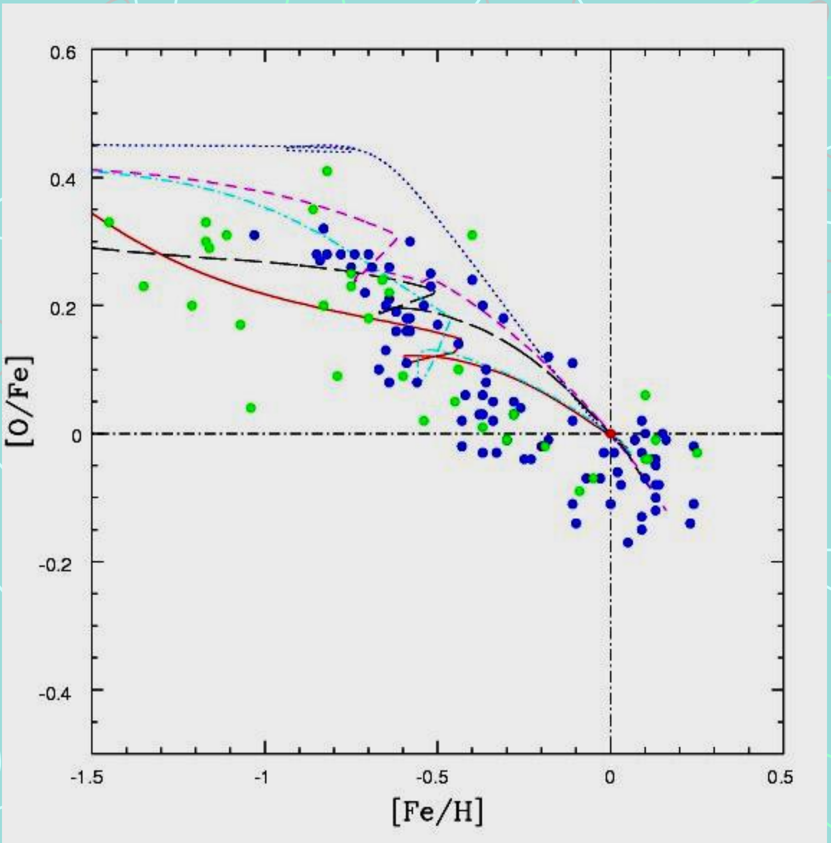
The [O/Fe] vs. [Fe/H] in the MW

- Dotted line: DTD of Strolger + . Produce a very long [O/Fe] plateau
- Long dashed: DTD Pritchet 08
- Red continuous line: DTD of Mannucci+ (bimodal). Too many prompt Type Ia SNe



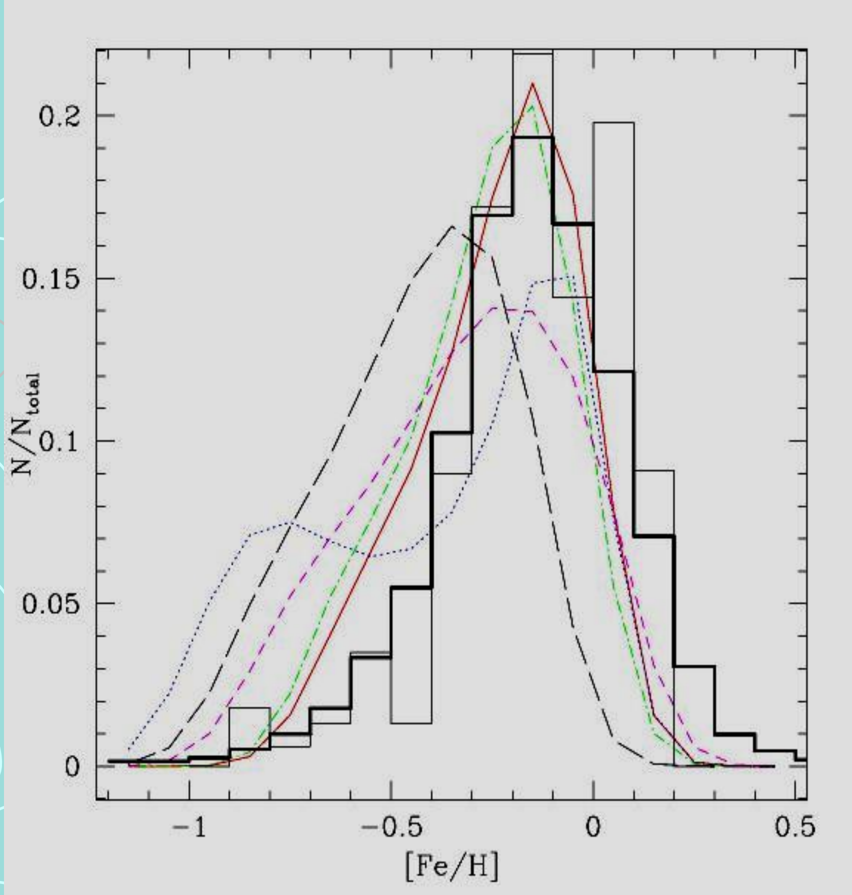
The [O/Fe] vs. [Fe/H] in the MW: a zoom

- Here we show a zoom of the knee area to highlight the effect of different DTDs
- The SD and DD models produce similar results
- The DTD with no prompt SNe Ia and that with too many prompt produce a worse fit



The G-dwarf metallicity distribution

- Data from the Geneva-Copenhagen Survey (Nordstrom et al. 04, thich histogram; Jorgensen 00, thin)
- Best models are from SD and DD DTDs and Mannucci+ DTD
- Long dashed:Strolger+, dotted Pritchet+



Conclusions

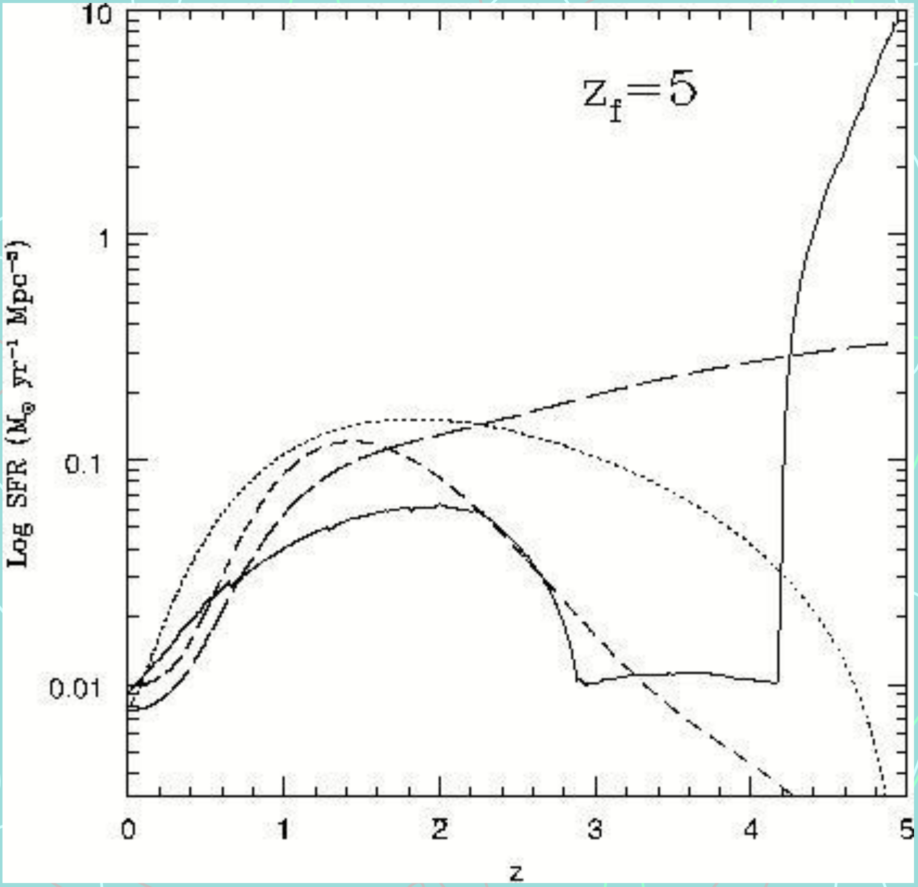
- The SD and DD delay time distributions (DTDs) are similar and produce negligible differences in the [O/Fe] vs. [Fe/H] relation
- Prompt Type Ia SNe are necessary to reproduce the observations, but their fraction should be no more than 10-20%
- The DTDs without or with less than 10% prompt Type Ia SNe do not reproduce the [O/Fe] vs. [Fe/H] nor the G-dwarf metallicity distribution
- May be a mixed scenario SD+DD is the most likely one (Greggio & al. 2008)

Cosmic Type Ia SN rates

- The cosmic Type Ia SN rate is defined as the rate observed in an unitary volume of the universe, where different types of galaxies are present
- It is defined in SNe per year per Mpc^(-3)
- Different cosmic star formation rates predict different cosmic Type Ia rates, for a fixed DTD
- SFR histories depends on assumptions on galaxy formation (monolithic/hierarchical)

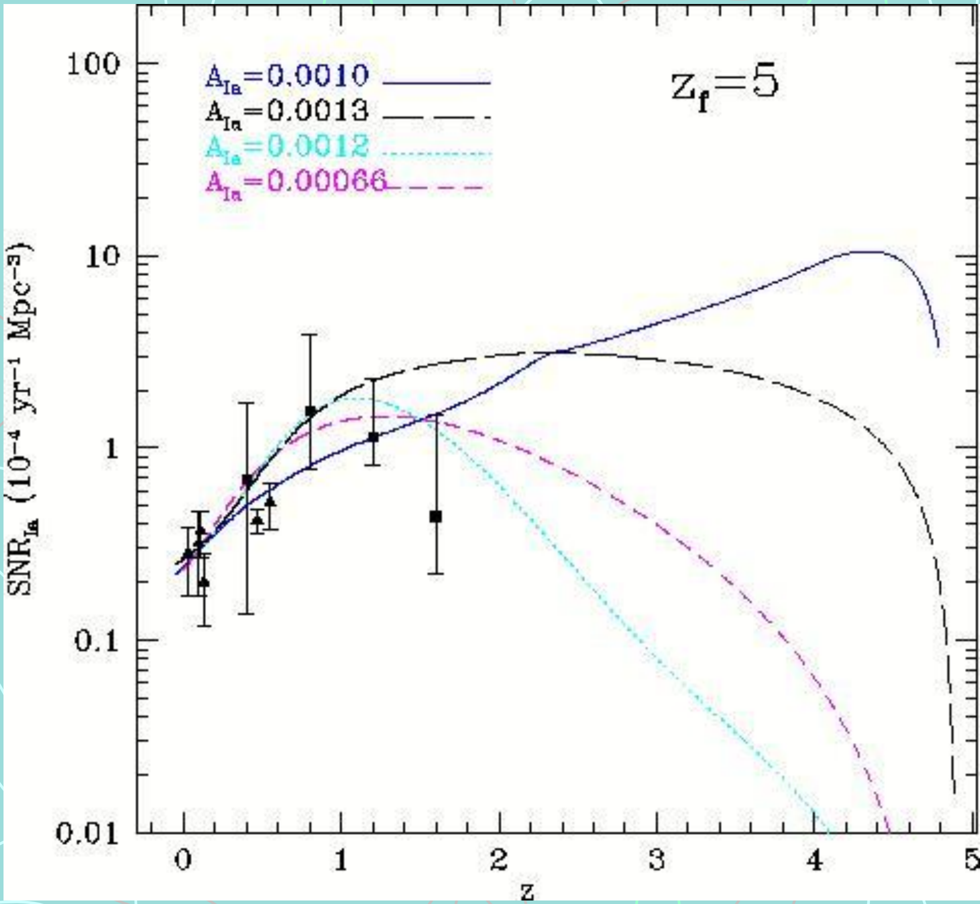
Cosmic Star Formation Rates

- Different cosmic SFRs: continuous line is the cosmic SFR in the monolithic scenario of Calura & FM(04)
- Short-dashed (Madau et al. 98) and dotted (Strolger et al. 04) are SFRs similar to those predicted in the hierarchical scenario
- Long-dashed is a monolithic model from Madau et al. (98)

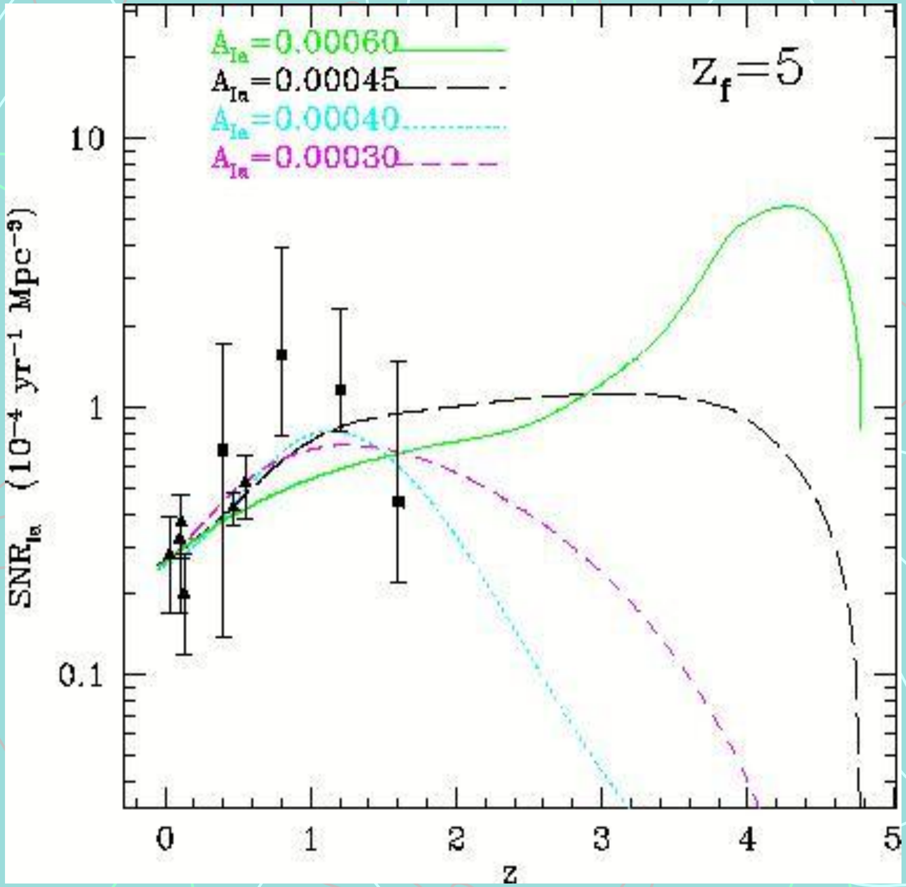


Cosmic Type Ia SN Rates

- Predicted cosmic Type Ia SN rates by adopting the different cosmic SFRs and the DTD for the SD model (Valiante et al.08)
- Data from Mannucci et al. (05), Strolger et al. (04), Blanc et al. (04), Pain et al. (02), Dahlen et al. (04), Neill et al. (06), Madgwick et al. (03)



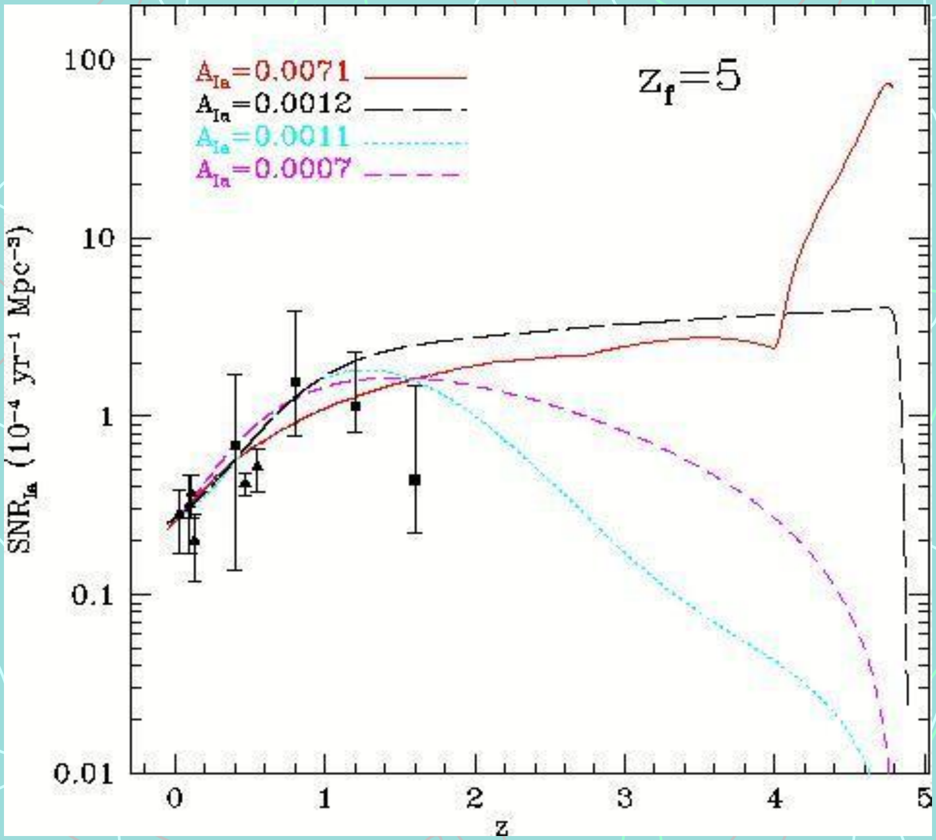
Cosmic Type Ia Rates for different DTDs



- Same data as before
- Different cosmic SF histories convolved with the DTD for DD model, as suggested by Greggio (2005) for the wide channel (Valiante et al. 2008)

Cosmic Type Ia SN Rates for the DTD of Mannucci et al. (05,06)

- Different cosmic histories of SF convolved with the DTD of Mannucci et al. (05,06)
- The data are the same as in the previous figures
- The DTD of Mannucci et al. predicts many more Type Ia SNe at high z than the other two DTDs



Conclusions

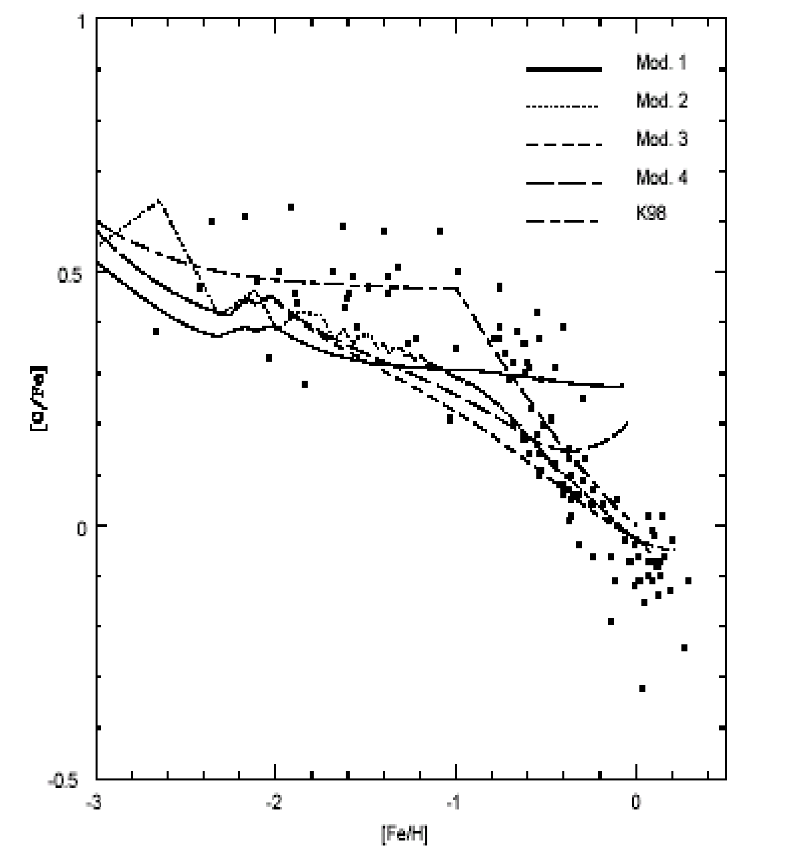
- The SD and DD delay time distributions (DTDs) are similar and produce negligible differences in the [O/Fe] vs. [Fe/H] relation
- Different SF histories in galaxies of different morphological type determine different timescales for SNIa enrichment, once a DTD is assumed. The shortest in E, the largest in Irr (Matteucci & Recchi 2001)
- Prompt Type Ia SNe (present also in the SD and DD scenarios) are necessary to reproduce most of observational data but they are perhaps less than 50% of the total

Conclusions

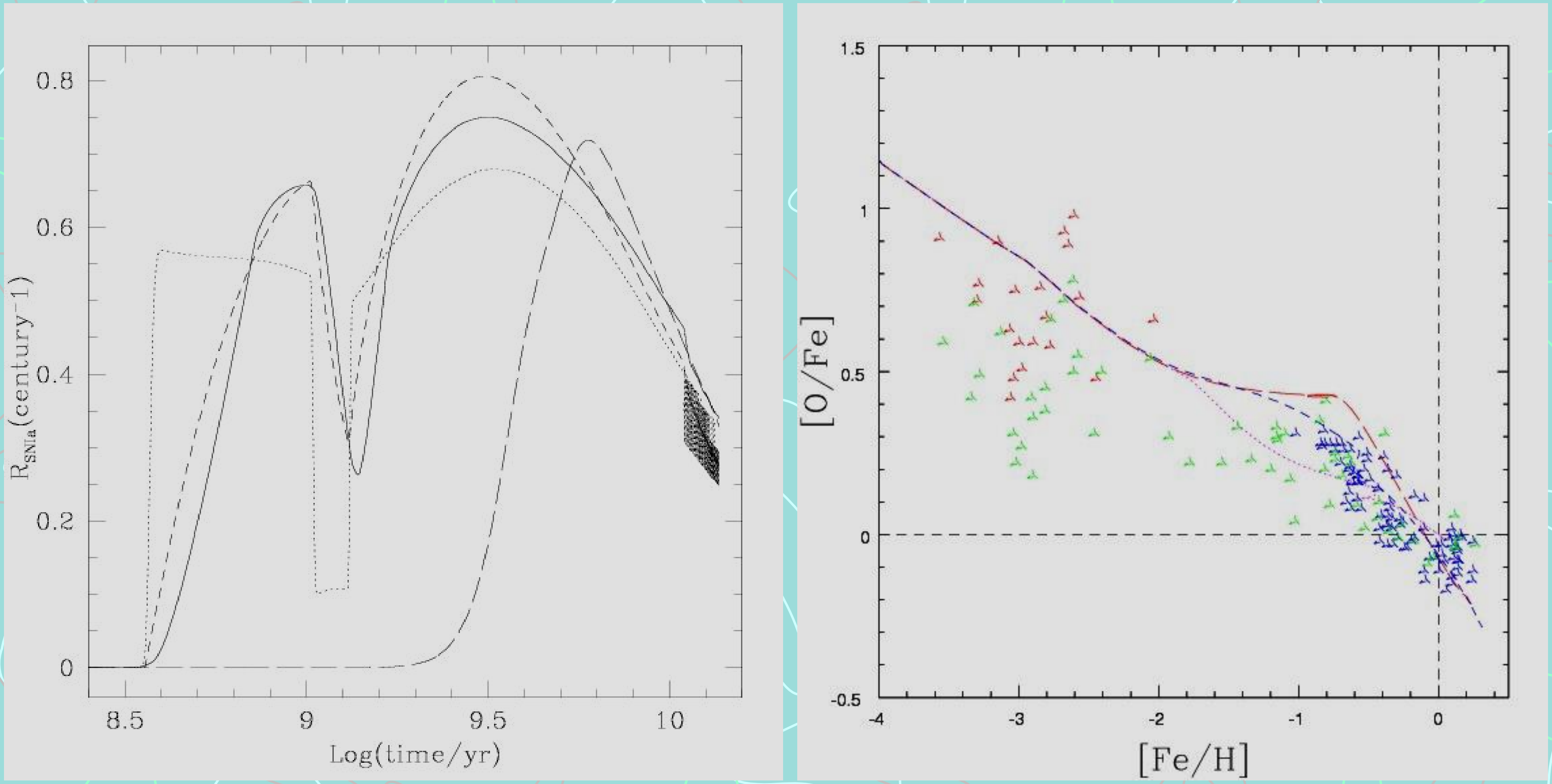
- High-redshift data on SN Ia do not yet allow us to draw firm conclusion on the SN Ia progenitors
- The cosmic Type Ia SN rate depends not only on the DTD (i.e. progenitors) but mainly on the assumed cosmic star formation rate
- Hierarchical cosmic SFRs predict a decreasing Type Ia SN rate at high redshift with any DTD!
- The contrary occurs for monolithic cosmic SFRs!
- High-z SNIa rates can impose constraints on galaxy formation models

Kobayashi model with metallicity dependence of the Type Ia SN rate

- Kobayashi et al. (1998) predicted a Type Ia SN rate with a minimum delay time of 330 million years plus the time to reach [Fe/H]=-1.0 in the gas
- We recomputed the [O/Fe] with this rate and found a flat behaviour (Model1)



The [O/Fe] vs. [Fe/H] in the MW: DTD of Strolger et al.2005



Cosmic Star Formation Rate (Calura & FM 2006)

- Comparison between theoretical monolithic cosmic SFR (Calura & Matteucci 2006) with data
- Data from Sawicki & Thomson (2006) and Schiminovic et al. (2005) and Lanzetta et al. (2002), not corrected for exinction
- Data for z>2 are still uncertain (Hopkins 2004)