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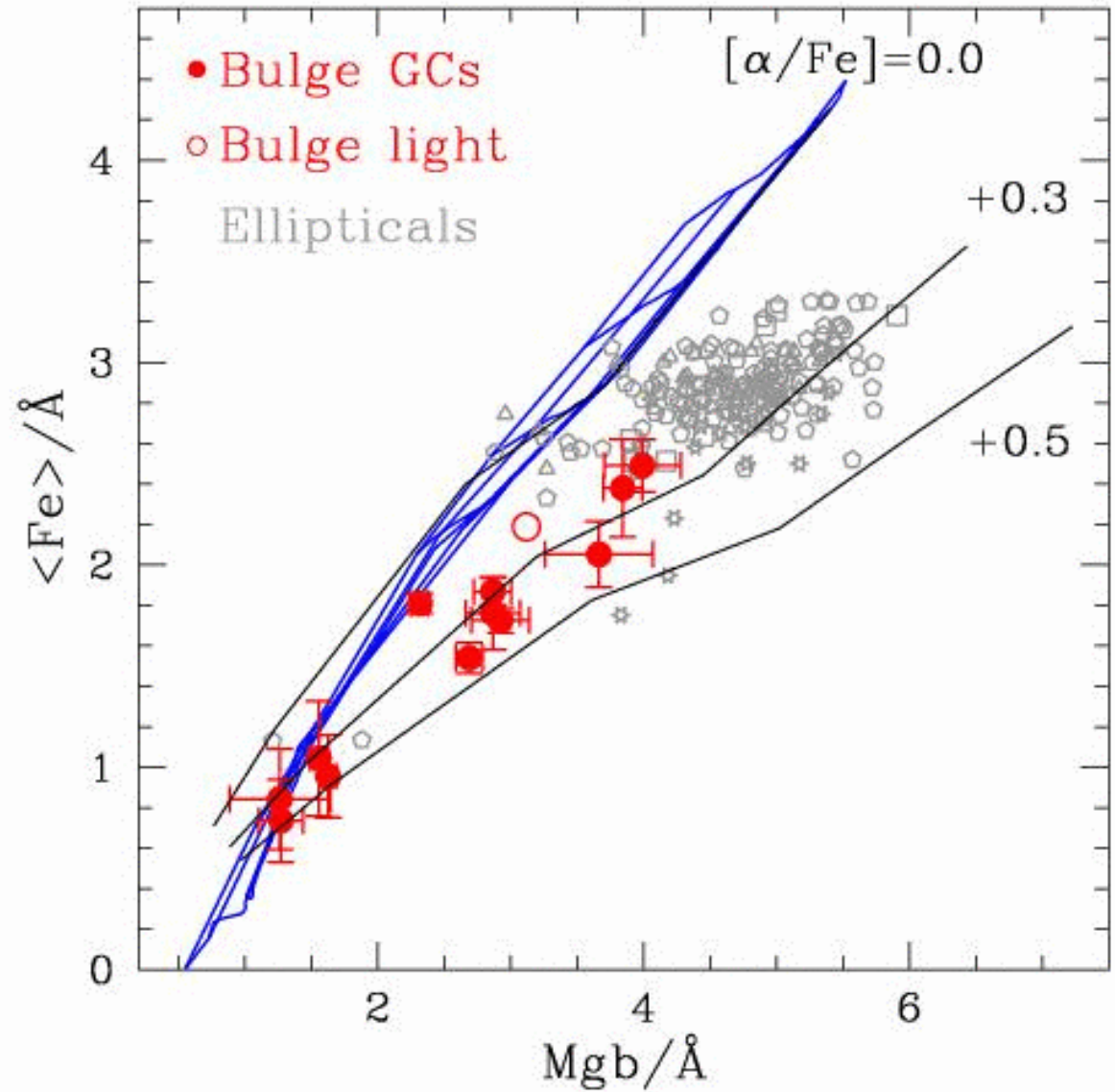
# Constraints on Galaxy Formation Timescales from observed alpha Overabundance

*Laura Greggio, Osservatorio Astronomico di Padova, Italia*

At given  $\langle \text{Fe} \rangle$ , Mgb is strong relative to solar proportions



$$(Z_a/Z_{\text{Fe}}) > (Z_a/Z_{\text{Fe}})_{\text{SUN}}$$



- SNIi provide the  $\alpha$ 's to the ISM  
 $m \gtrsim 8 m_{\odot} \Rightarrow \tau_{SNIi} \lesssim 0.03 \text{ Gyr}$
- SNIa provide a substantial part of the Fe to the ISM  
 $m \lesssim 8 m_{\odot} \Rightarrow t_H \gtrsim \tau_{SNIa} \gtrsim 0.03 \text{ Gyr}$

If SF ends before a large fraction of SNIa has exploded, the stars could not incorporate the Fe from Ias, and their metallicity distribution will be overabundant in  $\alpha$ 's (underabundant in Fe)



$$Z_{\alpha}/Z_{\text{Fe}} \Rightarrow t_{\text{SF}}$$

Matteucci (1994) :

Salpeter IMF + model for Ia progenitors  $\longrightarrow t_{\text{SF,E}} < 0.3 \text{ Gyr}$

The constraint depends on the model for the Ia progenitors  
 (Matteucci and Recchi 2001)

Define:

$A_{\text{Ia}}(t)$  as the fraction of stars of an SSP which end up as a SNIa realization probability of the Ia event

$f_{\text{Ia}}(\tau)$  as the distribution function of the delay times normalized to 1 over the whole  $\tau$  range ( $\tau_n \leq \tau \leq \tau_x$ )

⇒ The Ia rate at time  $t$  is:

$$\dot{n}_{\text{Ia}}(t) = k_{\alpha} \times \int_{\tau_n}^{\min(t, \tau_x)} d\tau \cdot \psi(t - \tau) \cdot A_{\text{Ia}}(t - \tau) \cdot f_{\text{Ia}}(\tau)$$

where

$\psi$  is the SFR in  $m_{\odot}/\text{yr}$

$k_{\alpha}$  accounts for the dependence on the IMF:

$$k_{\alpha} = \frac{\int_{m_1}^{m_2} dm \cdot \phi(m)}{\int_{m_1}^{m_2} dm \cdot m \cdot \phi(m)}$$

$k_{\alpha} = 2.8, 1.5$  for  $\alpha = 2.35$ , Kroupa IMF, within  $0.1 \leq m/m_{\odot} \leq 120$

For a burst of SF:  $\psi = \psi_0$  in  $0 \leq t \leq t_B$   
 $\psi = 0$  in  $t > t_B$

$$\dot{n}_{Ia}(t) = k_\alpha \times \psi_0 \times \int_{t-t_B}^t d\tau \cdot A_{Ia}(t-\tau) \cdot f_{Ia}(\tau)$$

- SSP :  $t_B \ll$

$$\dot{n}_{Ia}(t) = k_\alpha \psi_0 A_{Ia,0} f_{Ia}(\tau = t) t_B = k_\alpha \mathcal{M}_B A_{Ia,0} f_{Ia}(\tau)$$

For galaxies: assume  $A_{Ia}(t) = \text{const} = A_{Ia}$

- Late Type:

$$\begin{aligned} \dot{n}_{Ia}^{LT} &= k_\alpha \times A_{Ia} \times \langle \psi \rangle \times \int_{\tau_a}^{\min(t, \tau_z)} d\tau \cdot f_{Ia}(\tau) \\ &\simeq k_\alpha \times A_{Ia} \times \mathcal{M}_{LT} \times \langle f_{Ia} \rangle_{\tau_a, t} \end{aligned}$$

- Early Type:

$$\begin{aligned} \dot{n}_{Ia}^{ET} &= k_\alpha \times A_{Ia} \times \psi_B \times \int_{t-t_B}^t d\tau \cdot f_{Ia}(\tau) \\ &\simeq k_\alpha \times A_{Ia} \times \mathcal{M}_{ET} \times \langle f_{Ia} \rangle_{t-\Delta t, t} \end{aligned}$$

## OBSERVED RATES (Cappellaro, Evans & Turatto 1999)

$$\star \quad \dot{n}_{Ia}^{LT} \simeq 0.2 \text{ SNU} = \frac{0.2}{100} \times \frac{L_B}{10^{10} L_{B,0}} = 0.2 \cdot 10^{-12} L_B \text{ events/yr}$$

$$\dot{n}_{Ia}^{LT} = k_\alpha \times A_{Ia} \times \langle \psi \rangle \times \int_{\tau_a}^{\min(t, \tau_x)} d\tau \cdot f_{Ia}(\tau) \quad t \rightarrow \tau_x \quad \mathfrak{J}_{Ia} \rightarrow 1$$

$$\rightarrow A_{Ia} \simeq \frac{0.2}{k_\alpha} \times \frac{1}{(M_*/L_B)_{LT}} \times \frac{t_{Gyr}}{\mathfrak{J}_{Ia}(t)} \times 10^{-3} \approx 10^{-3}$$

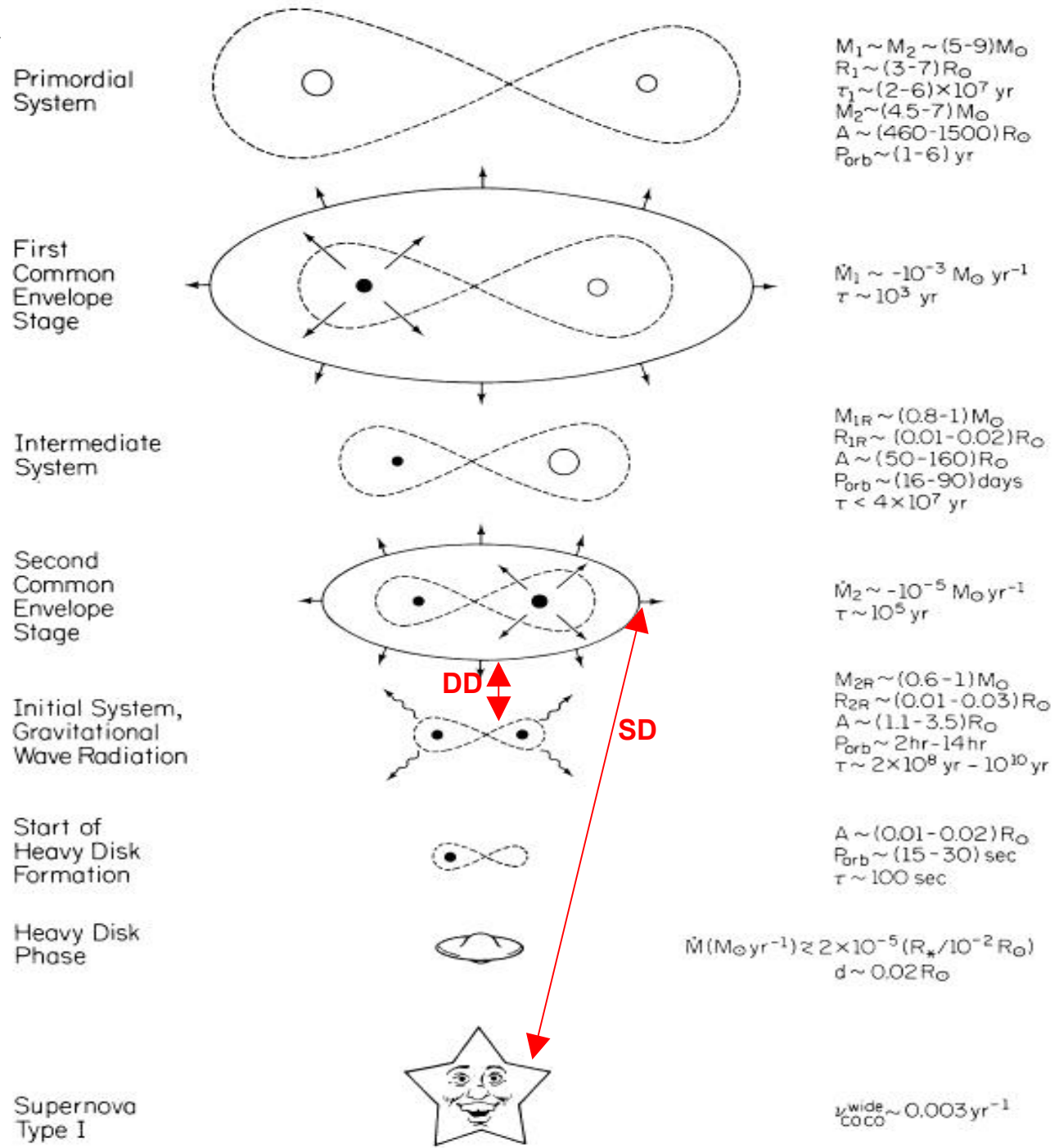
$$\star \quad \dot{n}_{Ia}^{ET} \simeq 0.2 \text{ SNU}$$

$$\frac{\dot{n}_{Ia, SNU}^E}{\dot{n}_{Ia, SNU}^L} \simeq \frac{(M/L_B)_{ET}}{(M/L_B)_{LT}} \times \frac{\langle f_{Ia} \rangle_{t-\Delta t, t}}{\langle f_{Ia} \rangle_{\tau_a, t}}$$

$$\rightarrow \frac{\langle f_{Ia} \rangle_{t-\Delta t, t}}{\langle f_{Ia} \rangle_{\tau_a, t}} \simeq \frac{(M/L_B)_{LT}}{(M/L_B)_{ET}} \approx 0.1$$

- SNIa rates in Late Type Galaxies can be used to constrain  $A_{Ia}$
  - SNIa rates in Early Type Galaxies can be used to constrain  $f_{Ia}$
- The dependence of  $\dot{n}_{Ia}^{ET}$  with redshift reflects  $f_{Ia}(\tau)$

From  
Iben and Tutukov, 1984  
ApJS 54, 335





# SINGLE DEGENERATE

CLOCK IS  $\tau_{\text{env}}(M_2)$

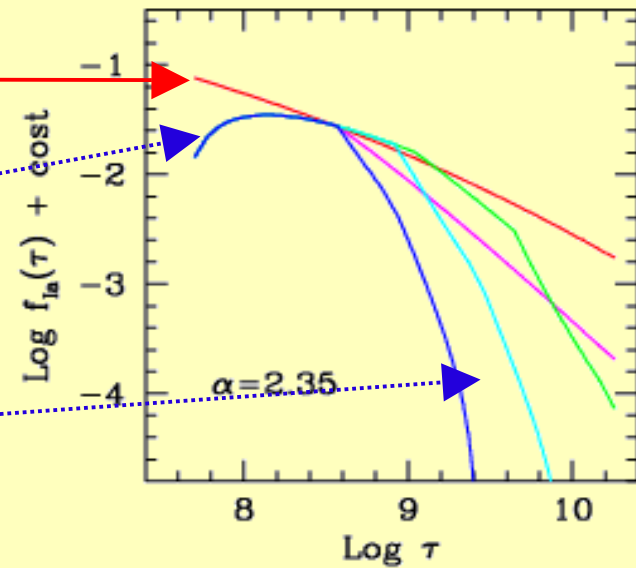
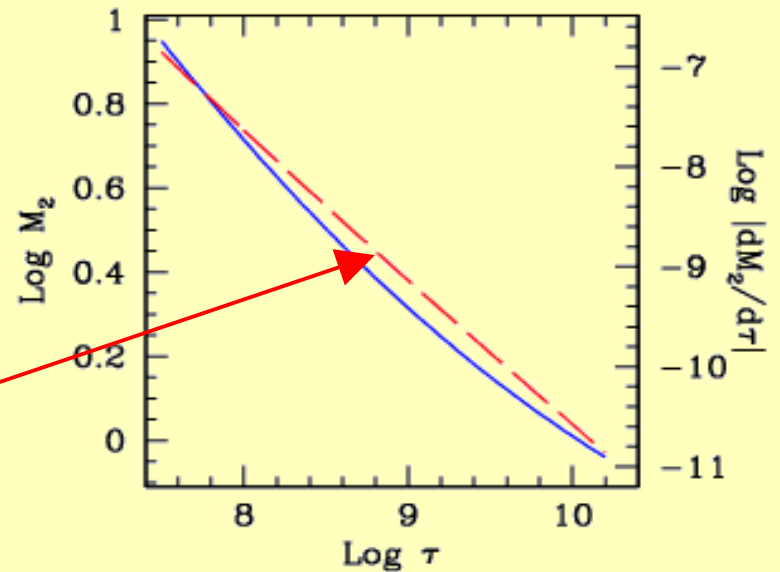
$$|f_{\text{Ia}}(\tau) \cdot d\tau| \propto |n(M_2) \cdot dM_2|$$

$$f_{\text{Ia}}(\tau) \propto n(M_2) \times |\dot{M}_2|$$

$$n(M_2) \propto (M_2)^{-2.35}$$

$$M_1, M_2 \leq 8M_{\odot}$$

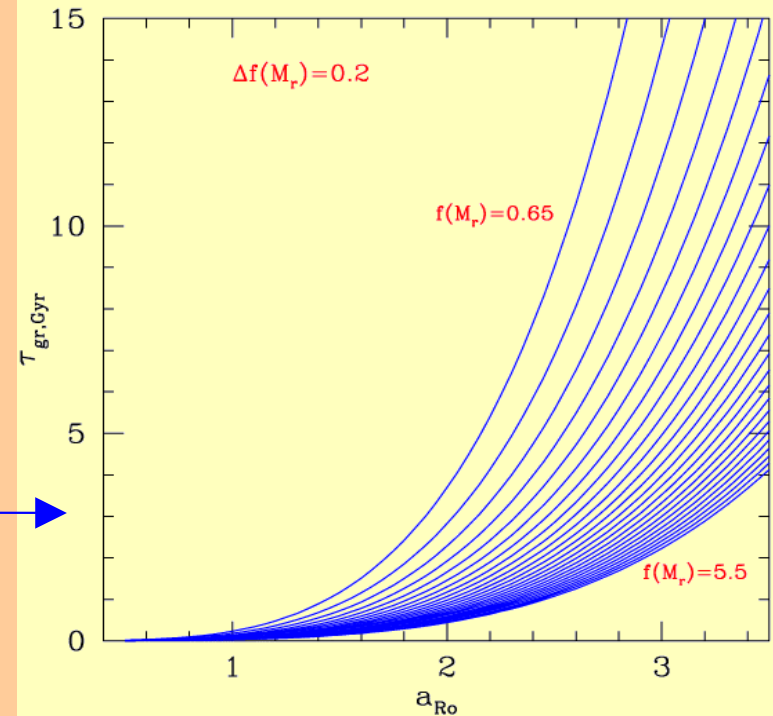
$$M_{\text{WD}} + \epsilon \cdot M_{2,\text{env}} \geq 1.4M_{\odot}$$



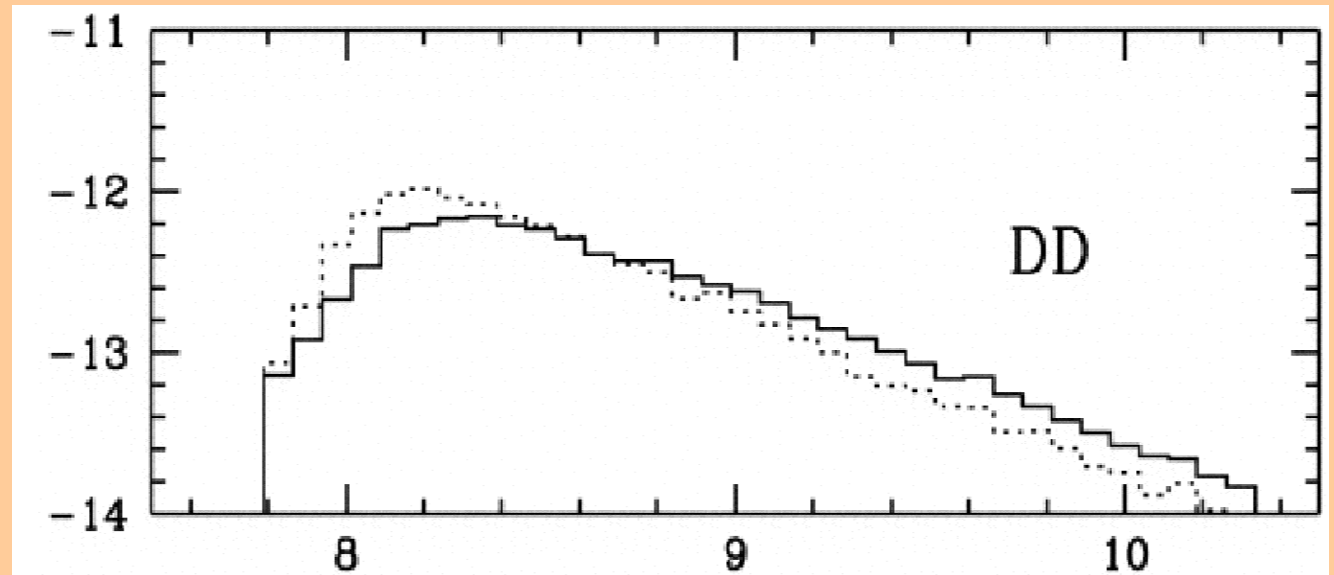
# DOUBLE DEGENERATE

CLOCK IS  $\tau_{EV}(M_2) + \tau_{gr}$

$$\tau_{gr} = \frac{0.15 \times (a_{ff}/R_{\odot})^4}{M_{1r} M_{2r} (M_{1r} + M_{2r})} \text{ Gyr}$$

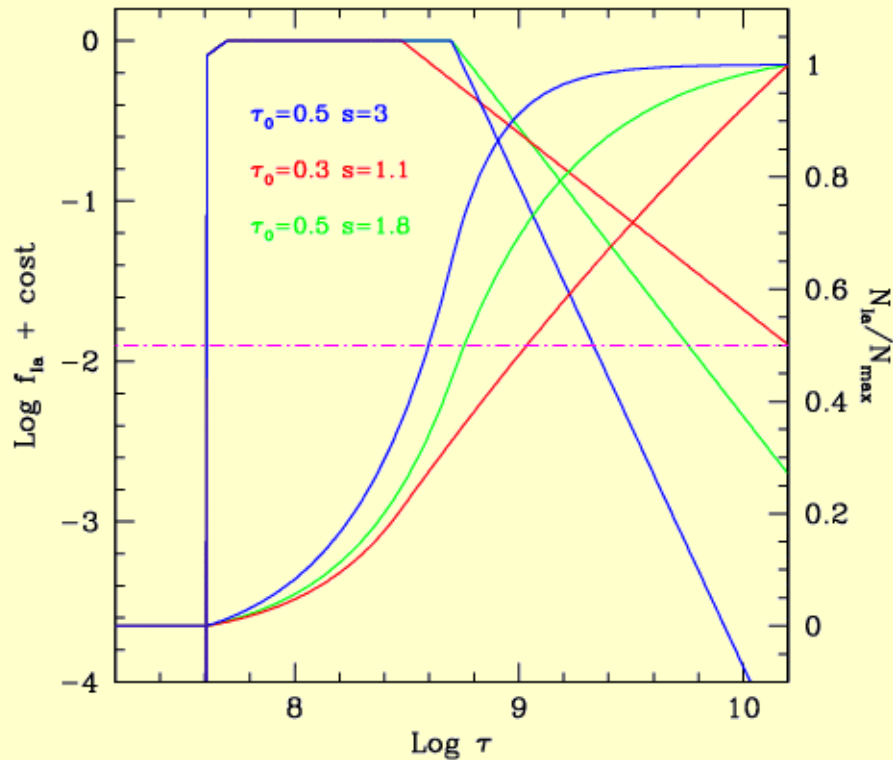


Ruiz Lapuente & Canal  
1998, ApJ 497, L57



A useful parametrization:

$$f_{Ia}(\tau) \propto \begin{cases} (\tau/\tau_1)^m & \text{if } \tau_n \leq \tau \leq \tau_1 \\ 1 & \text{if } \tau_1 \leq \tau \leq \tau_0 \\ (\tau/\tau_0)^{-s} & \text{if } \tau_0 \leq \tau \leq \tau_x \end{cases}$$

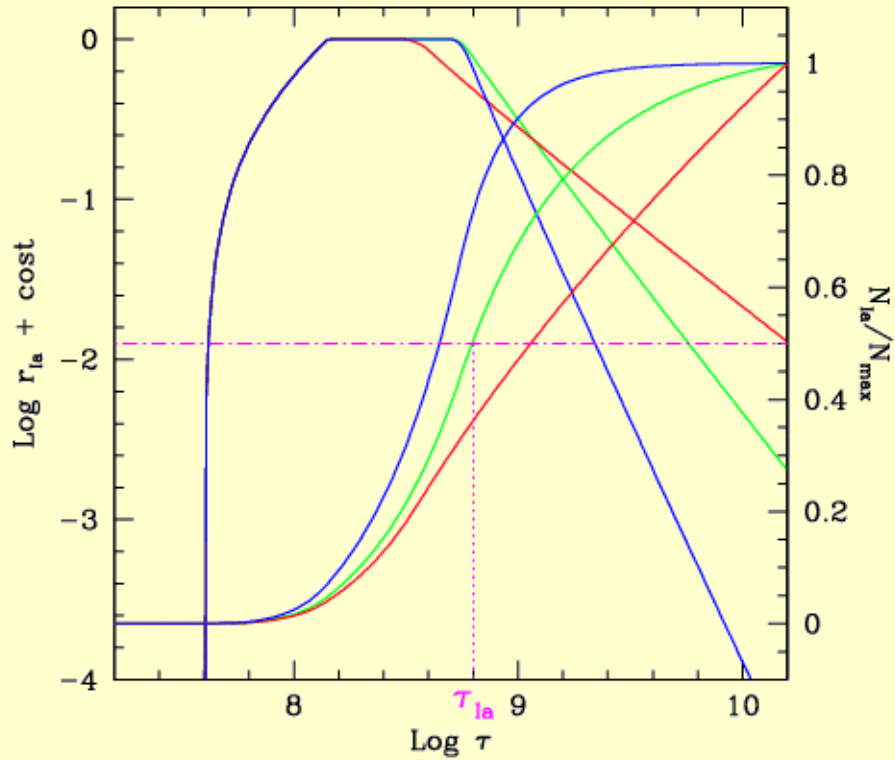


model	$\tau_1$ (Gyr)	$\tau_0$ (Gyr)	$s$
SD (GR83)	0.05	0.5	1.8
SD (G96)	0.05	0.8	3
DD (TM86)	0.1	0.25	1.5
DD (RC98)	0.1	0.3	1.1
SD (RBC95)	0.1	1.5	1.6

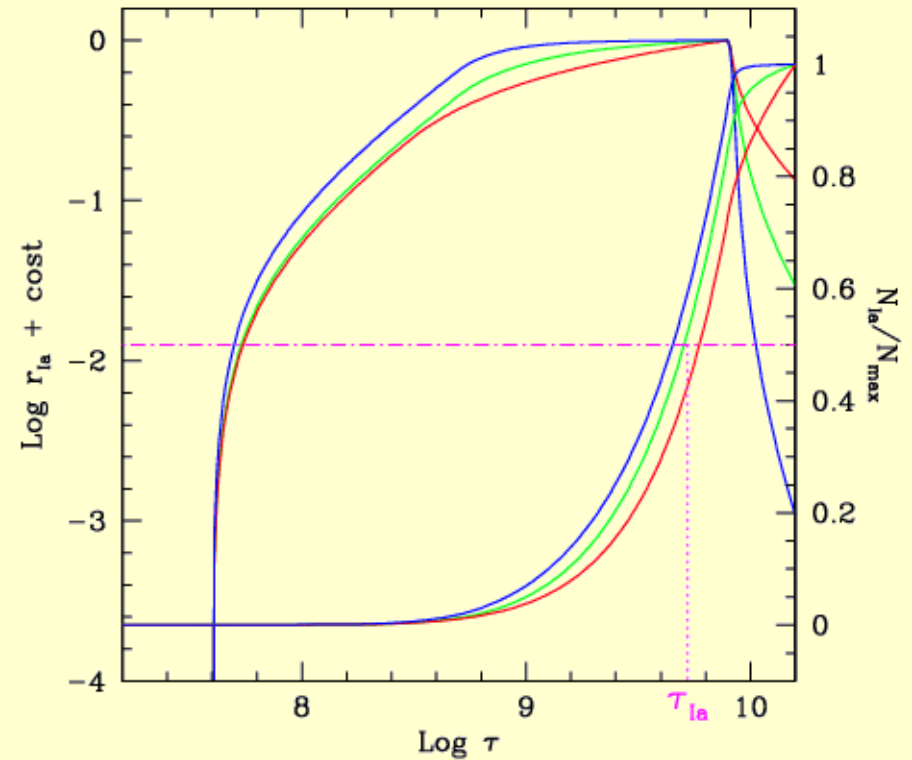
For a burst of SF:

$$\dot{n}_{Ia}(t) = k_{\alpha} \times A_{Ia} \times \psi_0 \times \int_{t-t_B}^t d\tau \cdot f_{Ia}(\tau)$$

$t_B = 0.1$  Gyr

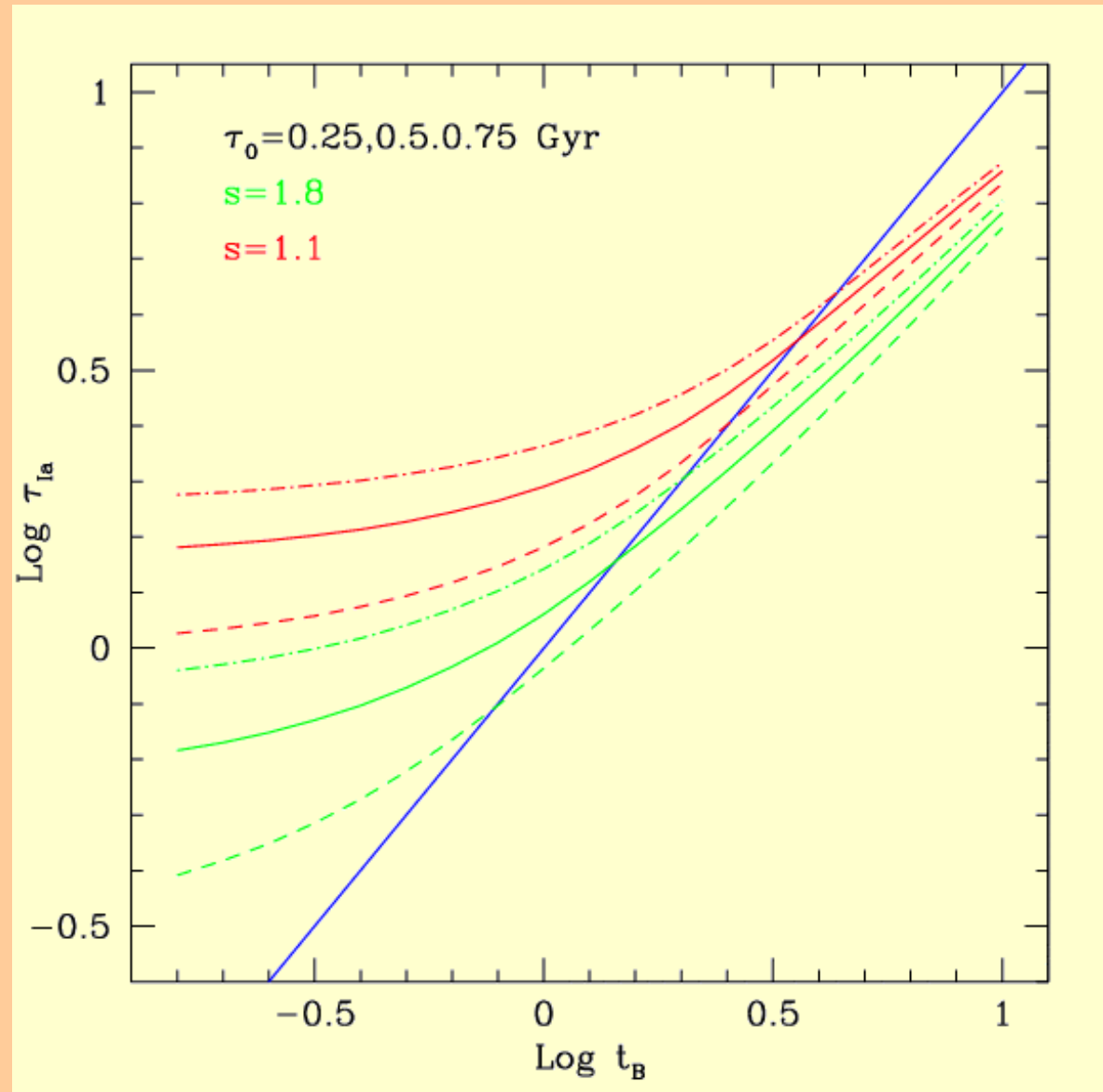


$t_B = 8$  Gyr



ISM pollution occurs on longer timescales for longer Burst duration

A Salomonic Criterion:  
The overabundance is realized when about 1/2 of SNIa explode after the burst ends



*Greggio, Recchi, Matteucci,  
in preparation*

## CONCLUSIONS

- $\tau_{\text{Ia}}$  is sensitive to both  $\tau_0$  and the late epochs decline slope  $s$
- $\tau_{\text{Ia}}$  is longer for longer durations of the SF episode  
but for sufficiently large  $t_{\text{B}}$  the condition  $\tau_{\text{Ia}} < t_{\text{B}}$  becomes verified  
→ abundance ratios **DO** yield info on  $t_{\text{B}}$
- the constraint on  $t_{\text{B}}$  depends on the SNIa model

Models in the literature correspond to  $t_{\text{B}}$  in the range  $1 \div 4$  (Gyr) to accomodate an  $\alpha$  overabundance