Constraints on Galaxy Formation Timescales from observed alpha Overabundance

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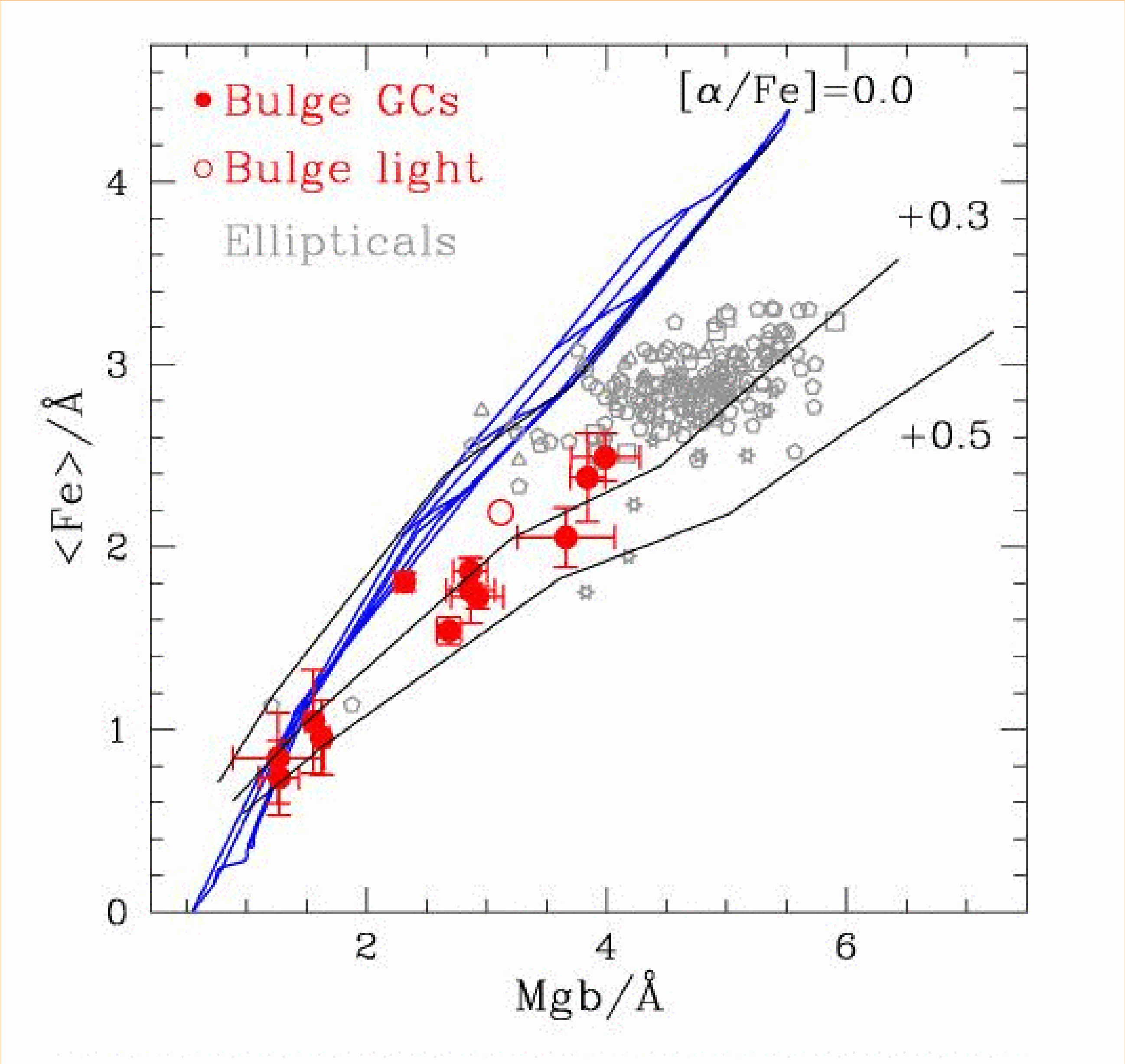
Maraston et al., 2003, A&A 400, 823



At given <Fe>, Mgb is strong relative to solar proportions

↓

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

- SNII provide the α's to the ISM
  $m \gtrsim 8\ m_\odot \Rightarrow \tau_{SNII} \lesssim 0.03$ Gyr

- SNIa provide a substantial part of the Fe to the ISM
  $m \lesssim 8\ m_\odot \Rightarrow t_H \gtrsim \tau_{SNIa} \gtrsim 0.03$ 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 α's (underabundant in Fe)

$$\Downarrow$$

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

Matteucci (1994) :
Salpeter IMF + model for Ia progenitors $\longrightarrow t_{SF,E} < 0.3$ Gyr

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

Define:

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

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

$\Rightarrow$ The Ia rate at time t is:

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

where

ψ is the SFR in $m_\odot$/yr

k_α accounts for the dependence on the IMF:

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

$k_\alpha = 2.8, 1.5$ 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:

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

- Early Type:

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

OBSERVED RATES (Cappellaro, Evans & Turatto 1999)

★ $\dot{n}_{Ia}^{\rm LT} \simeq 0.2$ SNu $= \frac{0.2}{100} \times \frac{L_{\rm B}}{10^{10} L_{\rm B\odot}} = 0.2 \cdot 10^{-12}\, L_{\rm B}$ events/yr

$$\dot{n}_{Ia}^{\rm LT} = k_\alpha \times A_{\rm Ia} \times \langle\psi\rangle \times \int_{\tau_n}^{min(t,\tau_x)} d\tau \cdot f_{\rm Ia}(\tau) \qquad t \to \tau_x \quad \Im_{Ia} \to 1$$

$$\longrightarrow A_{\rm Ia} \simeq \frac{0.2}{k_\alpha} \times \frac{1}{(M_*/L_{\rm B})_{\rm LT}} \times \frac{t_{Gyr}}{\Im_{Ia}(t)} \times 10^{-3} \approx 10^{-3}$$

★ $\dot{n}_{Ia}^{\rm ET} \simeq 0.2$ SNu

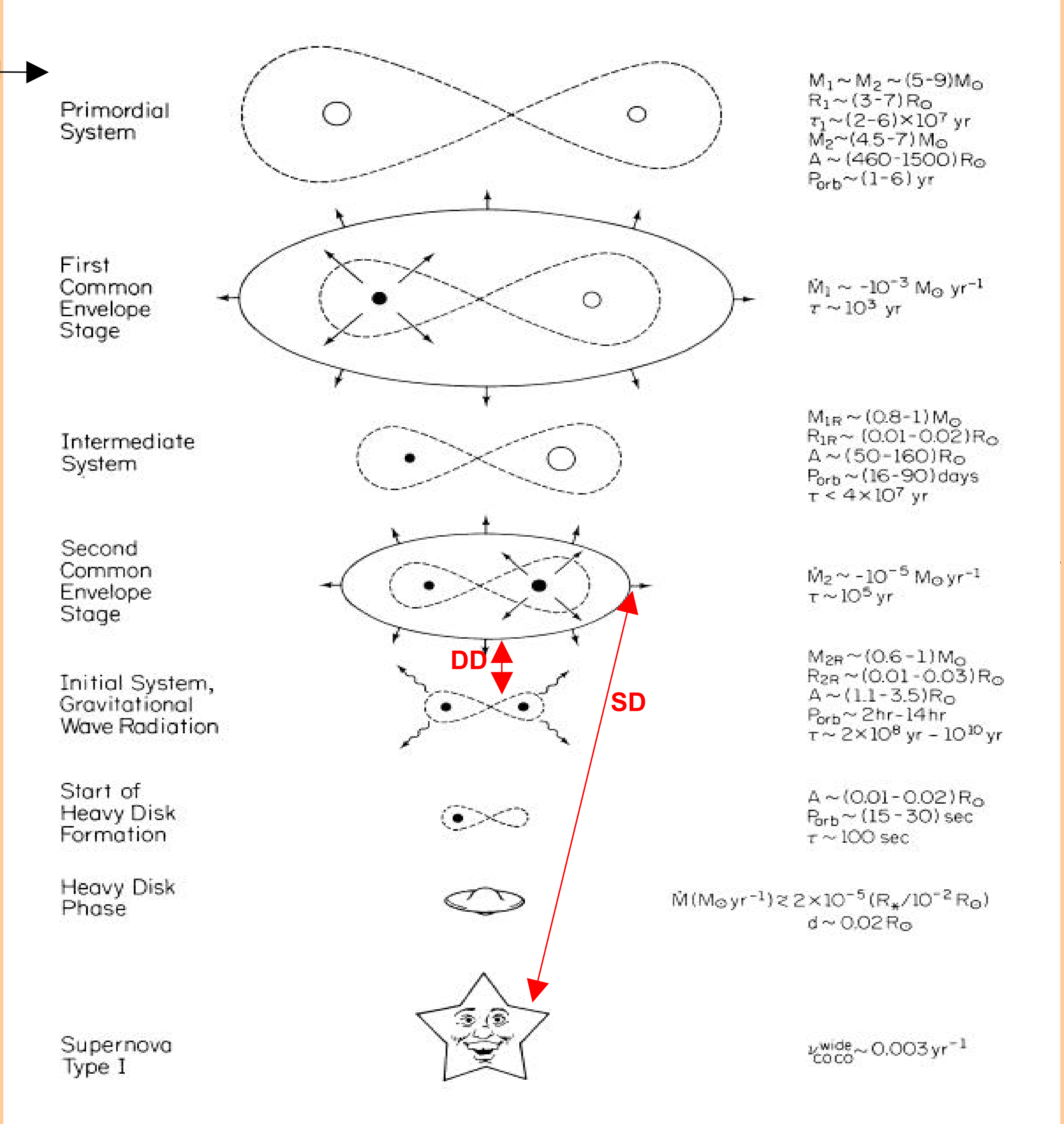
$$\frac{\dot{n}^{E}_{Ia,SNU}}{\dot{n}^{L}_{Ia,SNU}} \simeq \frac{(\mathcal{M}/L_{\rm B})_{ET}}{(\mathcal{M}/L_{\rm B})_{LT}} \times \frac{\langle f_{\rm Ia}\rangle_{t-\Delta t,t}}{\langle f_{\rm Ia}\rangle_{\tau_n,t}}$$

$$\longrightarrow \frac{\langle f_{\rm Ia}\rangle_{t-\Delta t,t}}{\langle f_{\rm Ia}\rangle_{\tau_n,t}} \simeq \frac{(\mathcal{M}/L_{\rm B})_{LT}}{(\mathcal{M}/L_{\rm B})_{ET}} \approx 0.1$$

- SNIa rates in Late Type Galaxies can be used to constrain $A_{\rm Ia}$
- SNIa rates in Early Type Galaxies can be used to constrain $f_{\rm Ia}$

  The dependence of $\dot{n}_{Ia}^{\rm ET}$ with redshift reflects $f_{\rm Ia}(\tau)$

From
Iben and Tutukov, 1984
ApJS 54, 335



SINGLE DEGENERATE

CLOCK IS $\tau_{ev}(M_2)$

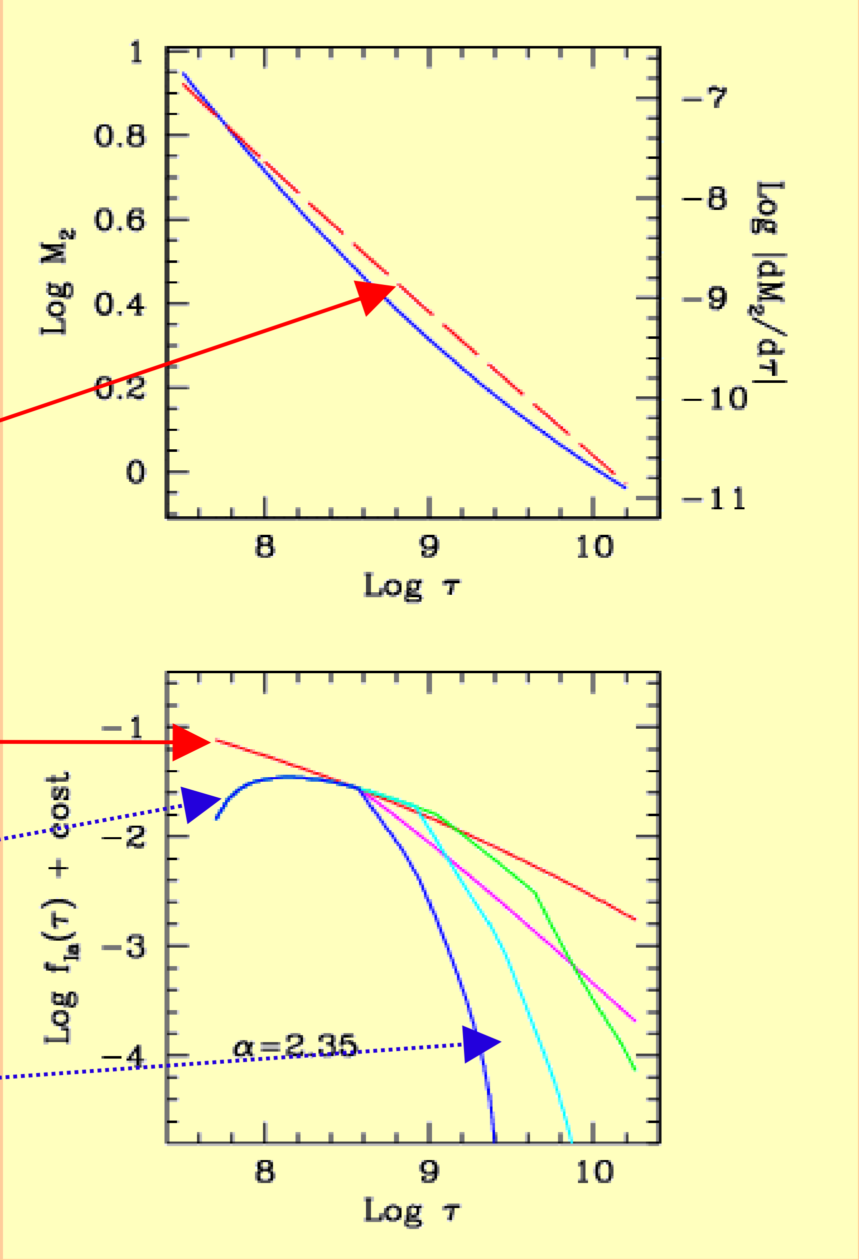
$$|\, f_{Ia}(\tau)\cdot d\tau \,| \;\propto\; |\, n(M_2)\cdot dM_2 \,|$$

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

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

$$M_1, M_2 \le 8 M_\odot$$

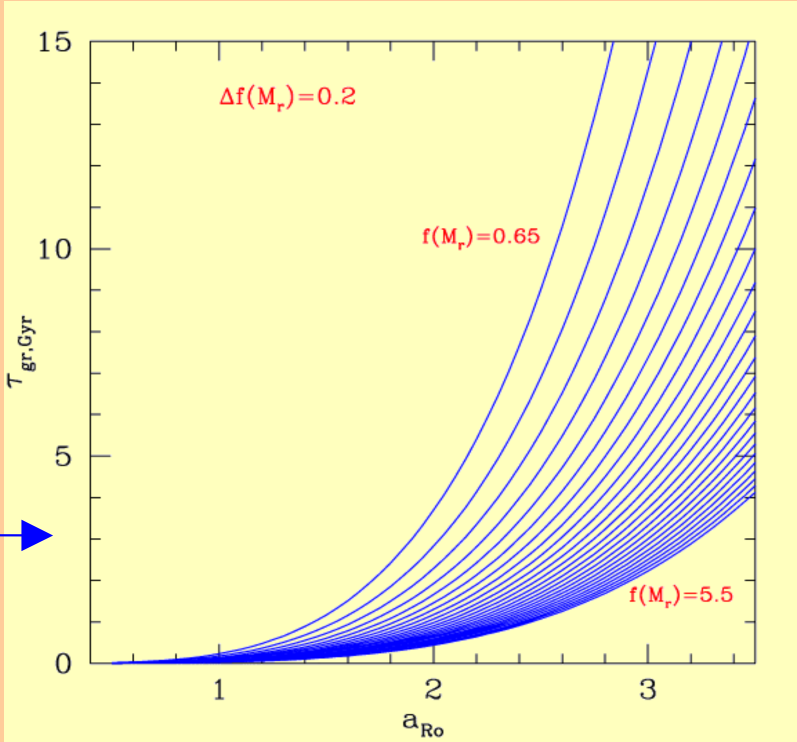
$$M_{WD} + \epsilon \cdot M_{2,env} \ge 1.4 M_\odot$$



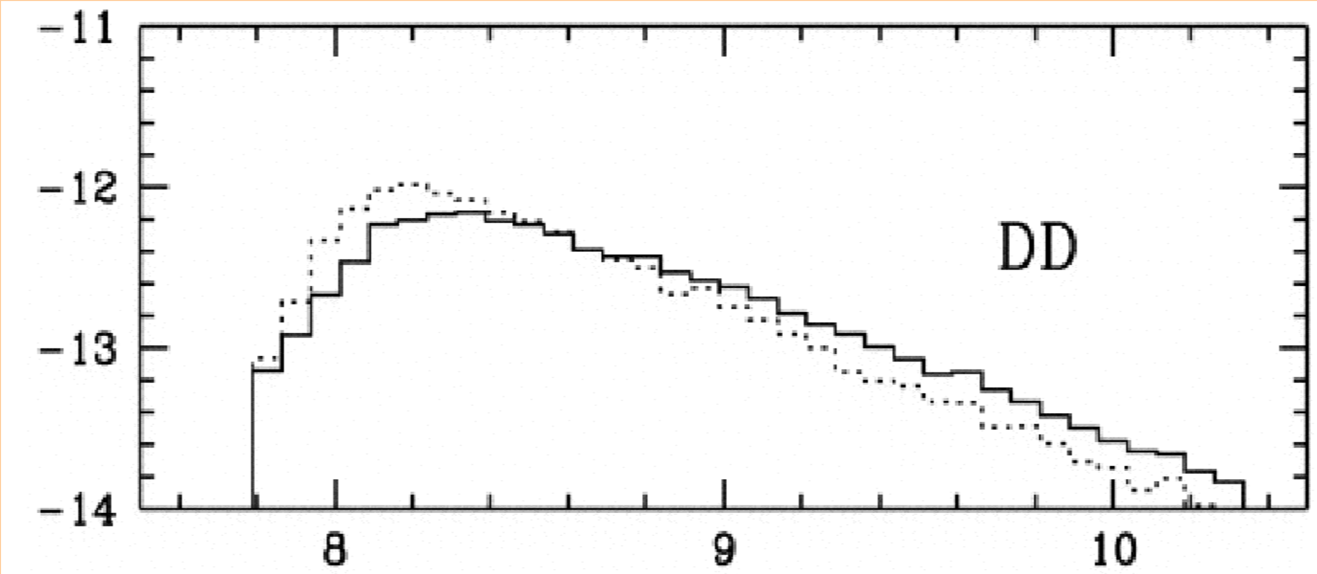
DOUBLE DEGENERATE

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

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

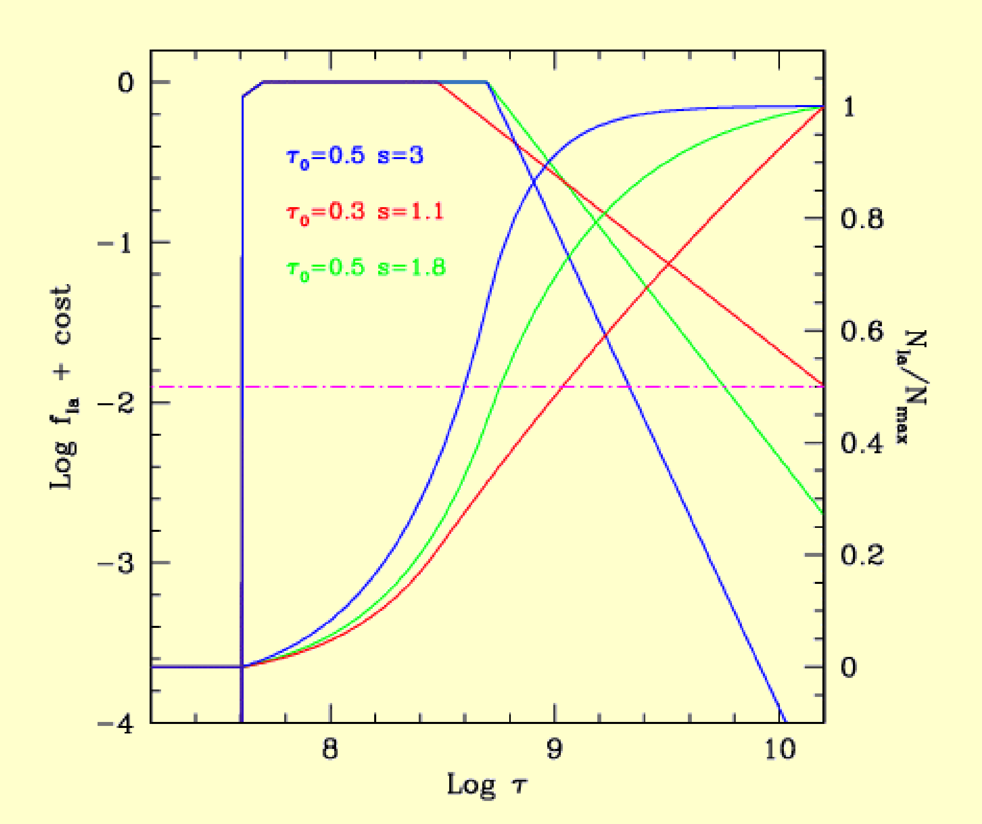


Ruiz Lapuente & Canal 1998, ApJ 497, L57



A useful parametrization:

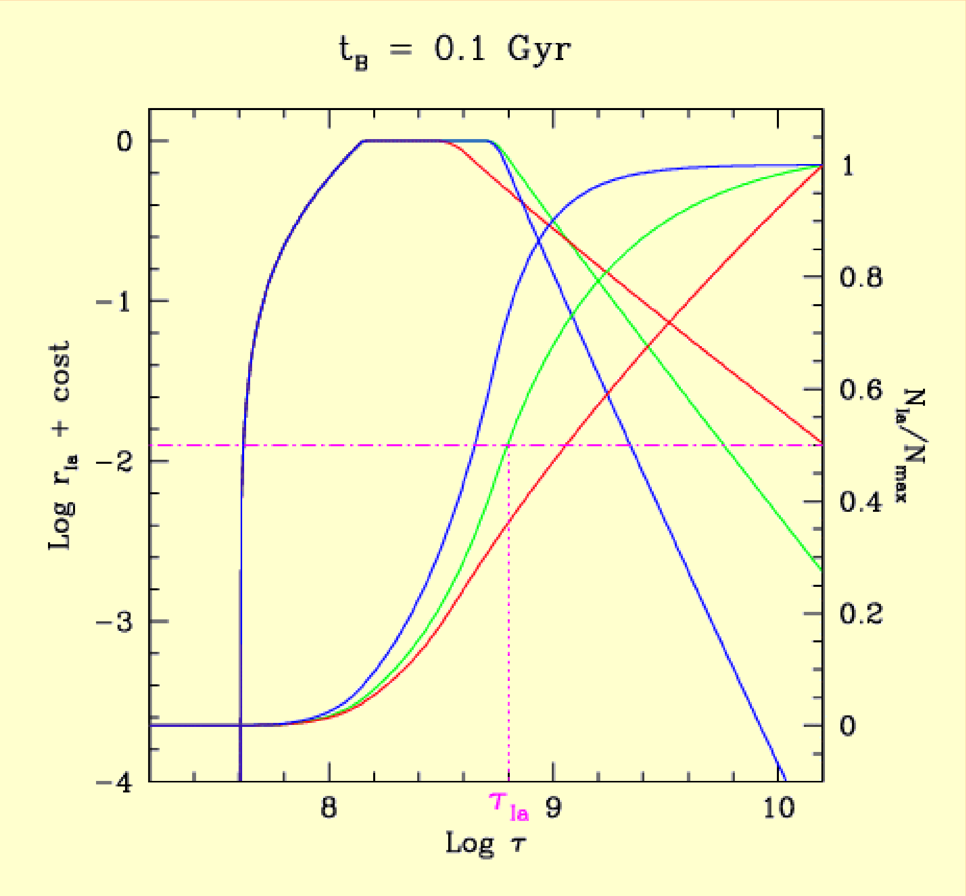
$$f_{Ia}(\tau) \propto (\tau/\tau_1)^m \quad in \quad \tau_n \leq \tau \leq \tau_1$$
$$1 \quad in \quad \tau_1 \leq \tau \leq \tau_0$$
$$(\tau/\tau_0)^{-s} \quad in \quad \tau_0 \leq \tau \leq \tau_x$$

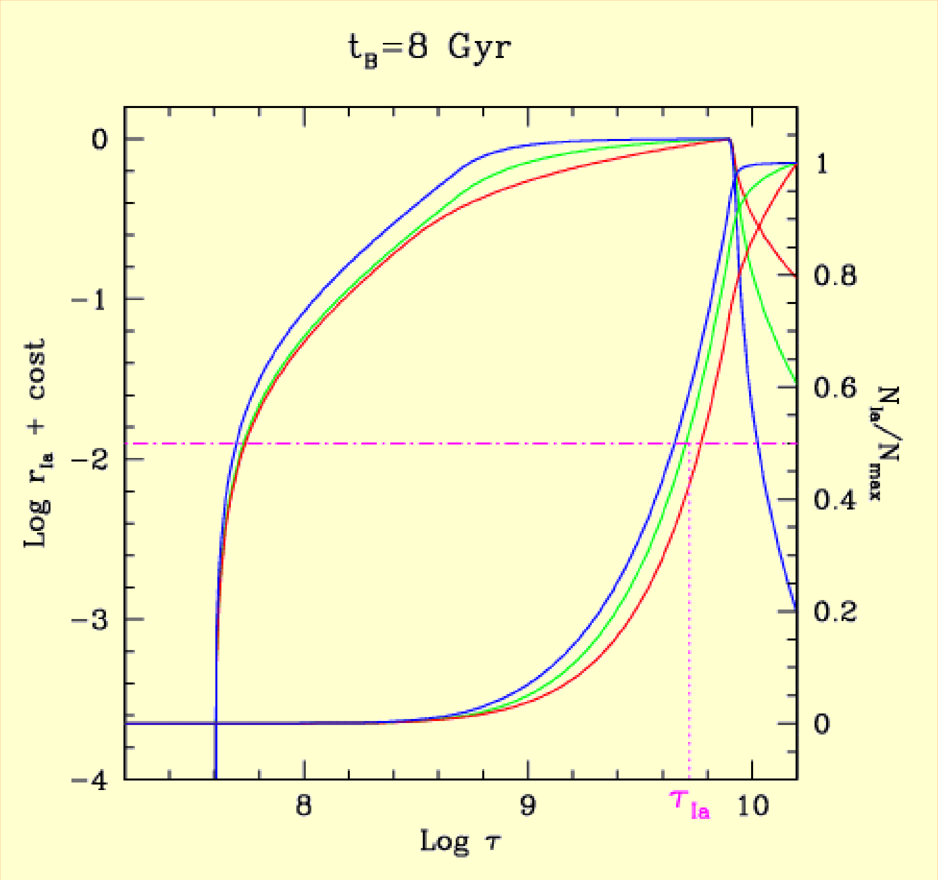


model	τ_1(Gyr)	τ_0(Gyr)	s
SD (GR83)	0.05	0.5	1.8
SD (G96)	0.05	0.8	3
DD (TM86)	0.1	0.25	1.5
DD (RC98)	0.1	0.3	1.1
SD (RBC95)	0.1	1.5	1.6

For a burst of SF:

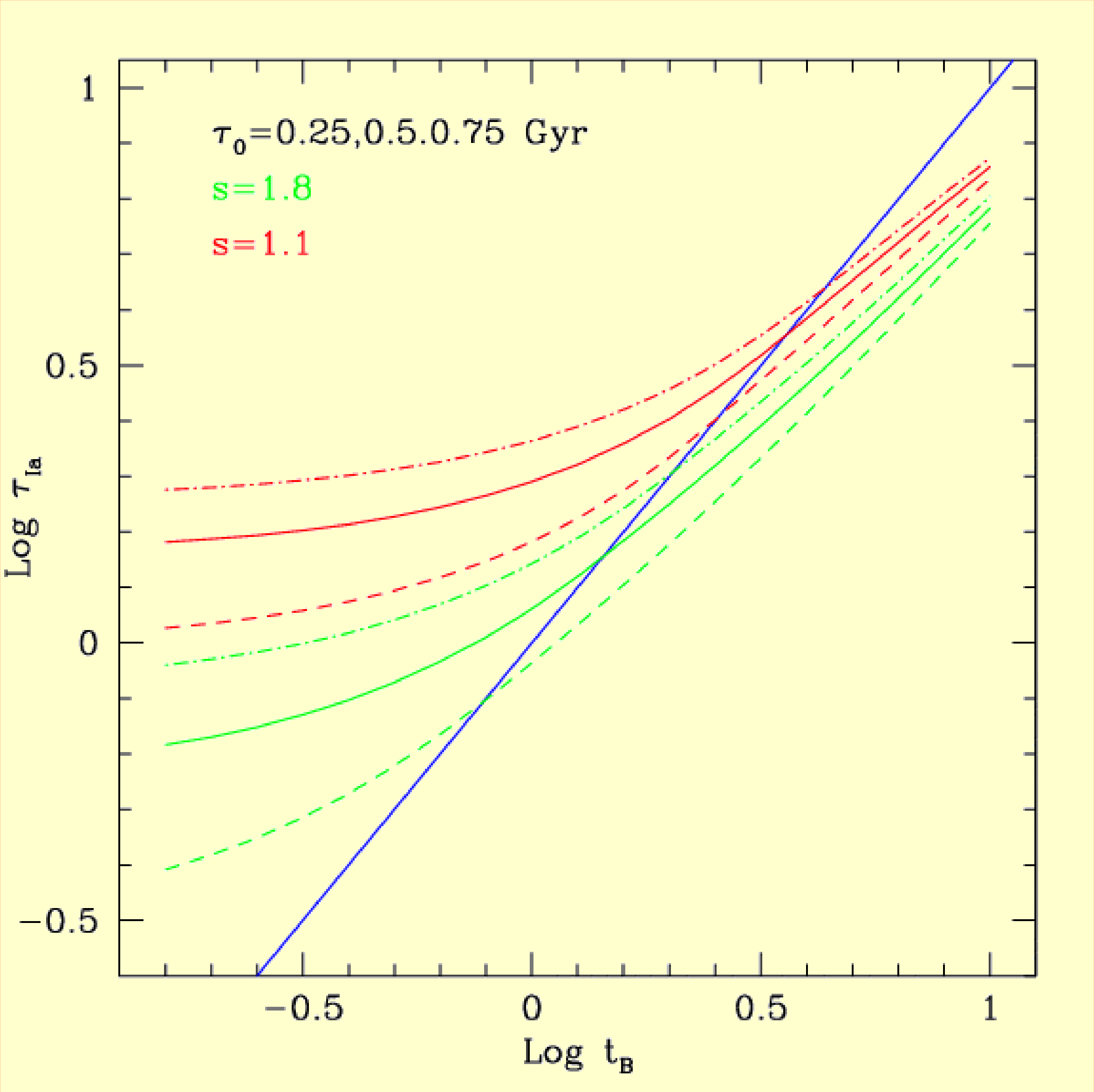
$$\dot{n}_{Ia}(t) = k_\alpha \times A_{Ia} \times \psi_0 \times \int_{t-t_B}^{t} d\tau \cdot f_{Ia}(\tau)$$





ISM pollution occurs on longer timescales for longer Burst duration

A Salomonic Criterion:
The overabundance is realized when about ½ of SNIa explode after the burst ends



Greggio, Recchi, Matteucci, in preparation

CONCLUSIONS

- τ_{Ia} is sensitive to both τ_0 and the late epochs decline slope s

- τ_{Ia} is longer for longer durations of the SF episode

  but for sufficiently large t_B the condition $\tau_{Ia} < t_B$ becomes verified

$\rightarrow$ abundance ratios DO yield info on t_B

- the constraint on t_B depends on the SNIa model

Models in the literature correspond to t_B in the range $1 \div 4$ (Gyr) to accomodate an α overabundance