The evolution of the rate of type Ia Supernovae

….. during the last 30 years

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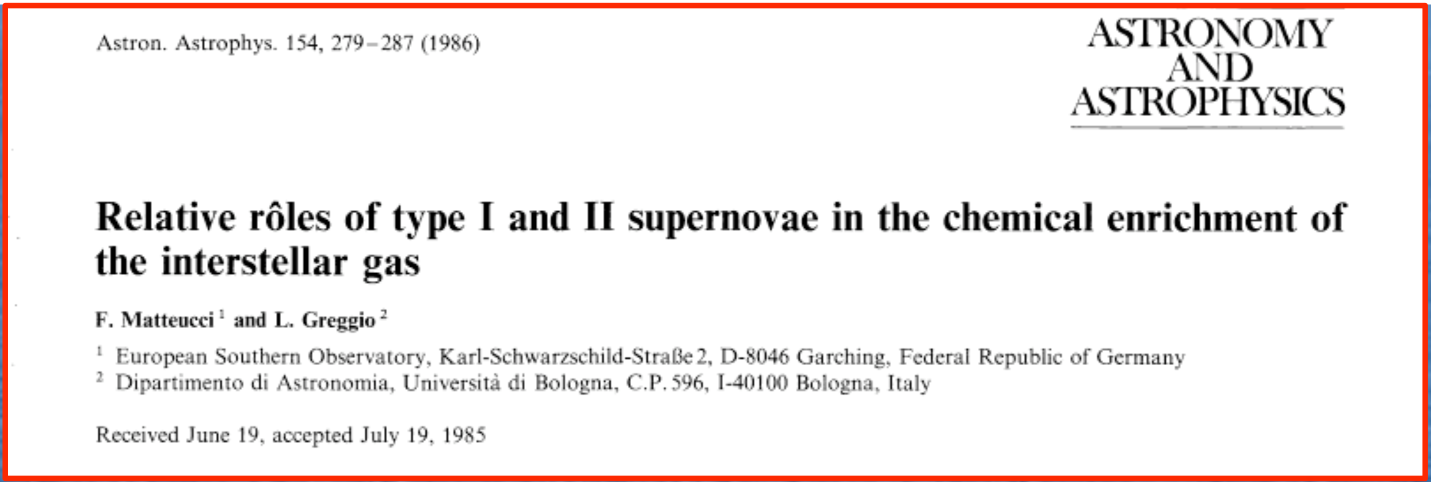
@ Francesca-Fest; Settembre 2013



Astron. Astrophys. 154, 279–287 (1986)

ASTRONOMY
AND
ASTROPHYSICS

Relative rôles of type I and II supernovae in the chemical enrichment of the interstellar gas

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Received June 19, accepted July 19, 1985

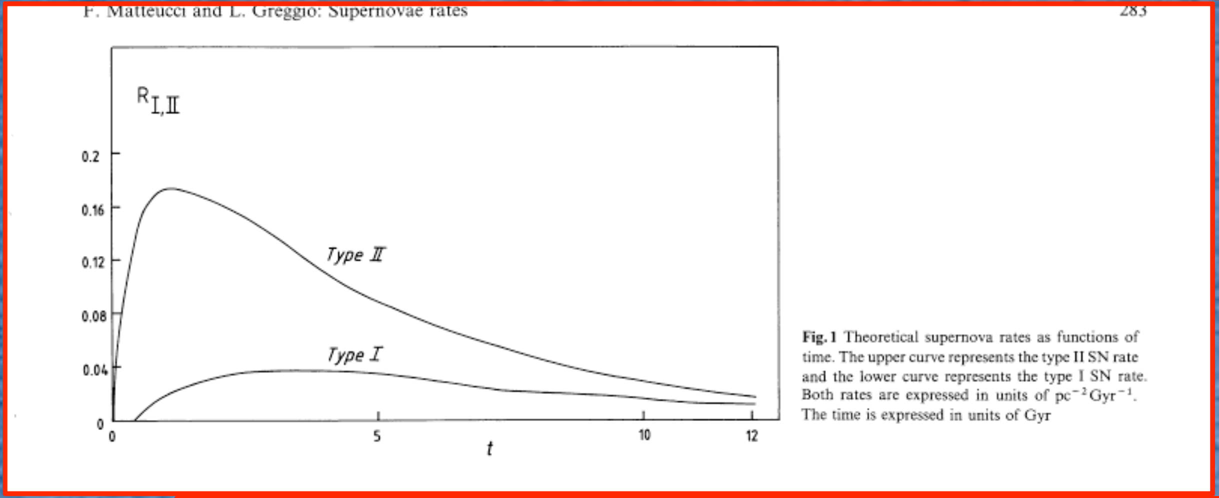


Fig. 1 Theoretical supernova rates as functions of time. The upper curve represents the type II SN rate and the lower curve represents the type I SN rate. Both rates are expressed in units of $pc^{-2}\,Gyr^{-1}$. The time is expressed in units of Gyr

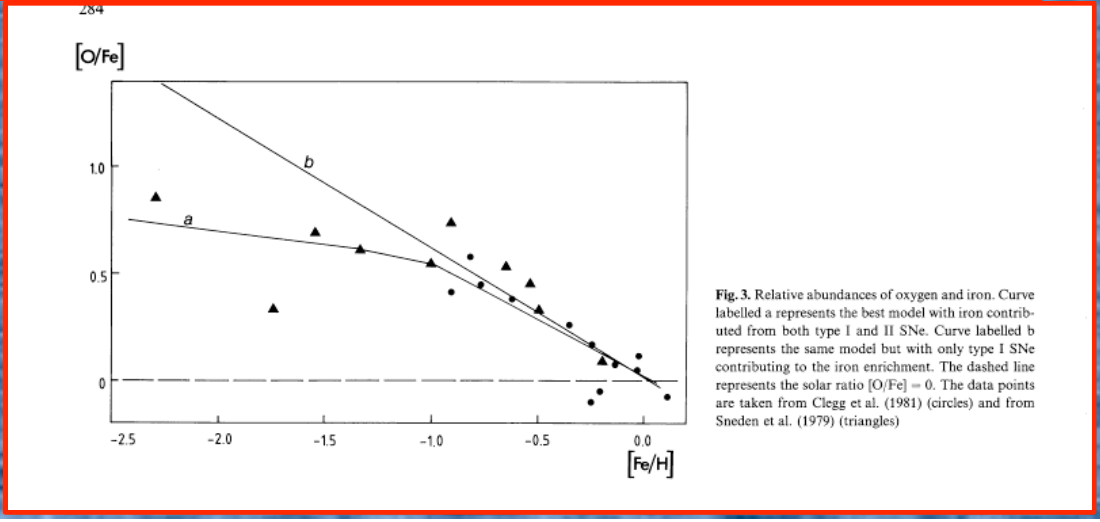
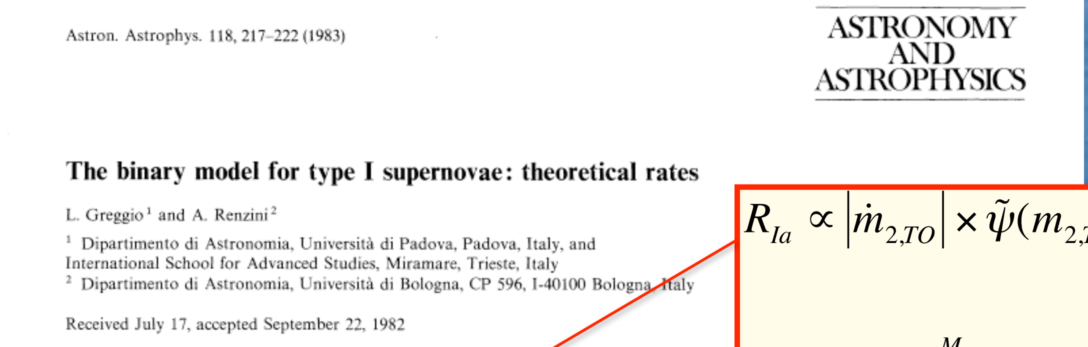


Fig. 3. Relative abundances of oxygen and iron. Curve labelled a represents the best model with iron contributed from both type I and II SNe. Curve labelled b represents the same model but with only type I SNe contributing to the iron enrichment. The dashed line represents the solar ratio [O/Fe] = 0. The data points are taken from Clegg et al. (1981) (circles) and from Sneden et al. (1979) (triangles)

The Fe release to the ISM is delayed with respect to O enrichment.
Thus, the low metallicy stars have supersolar O/Fe ratios

The Single Degenerate channel



Astron. Astrophys. 118, 217–222 (1983)

ASTRONOMY
AND
ASTROPHYSICS

The binary model for type I supernovae: theoretical rates

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Received July 17, accepted September 22, 1982

The clock is the evolutionary lifetime of the secondary

$$R_{Ia} \propto \left|\dot{m}_{2,TO}\right| \times \tilde{\psi}(m_{2,TO})$$

$$\tilde{\psi}(m_{2,TO}) \propto \int_{M_{B,m}}^{M_{B,M}} \psi(M_B) f(\mu) \frac{dM_B}{M_B}$$

$M_{B,M} = 8 + m_{2,TO}$
$M_{B,m} = \max\{2m_{2,TO}, M_{Bmin}\}$

220

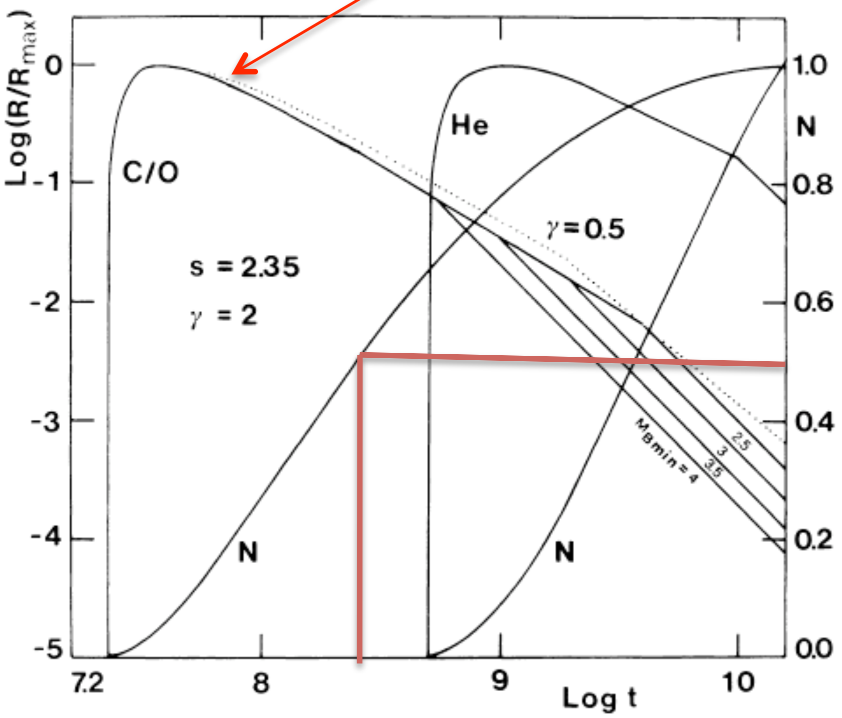


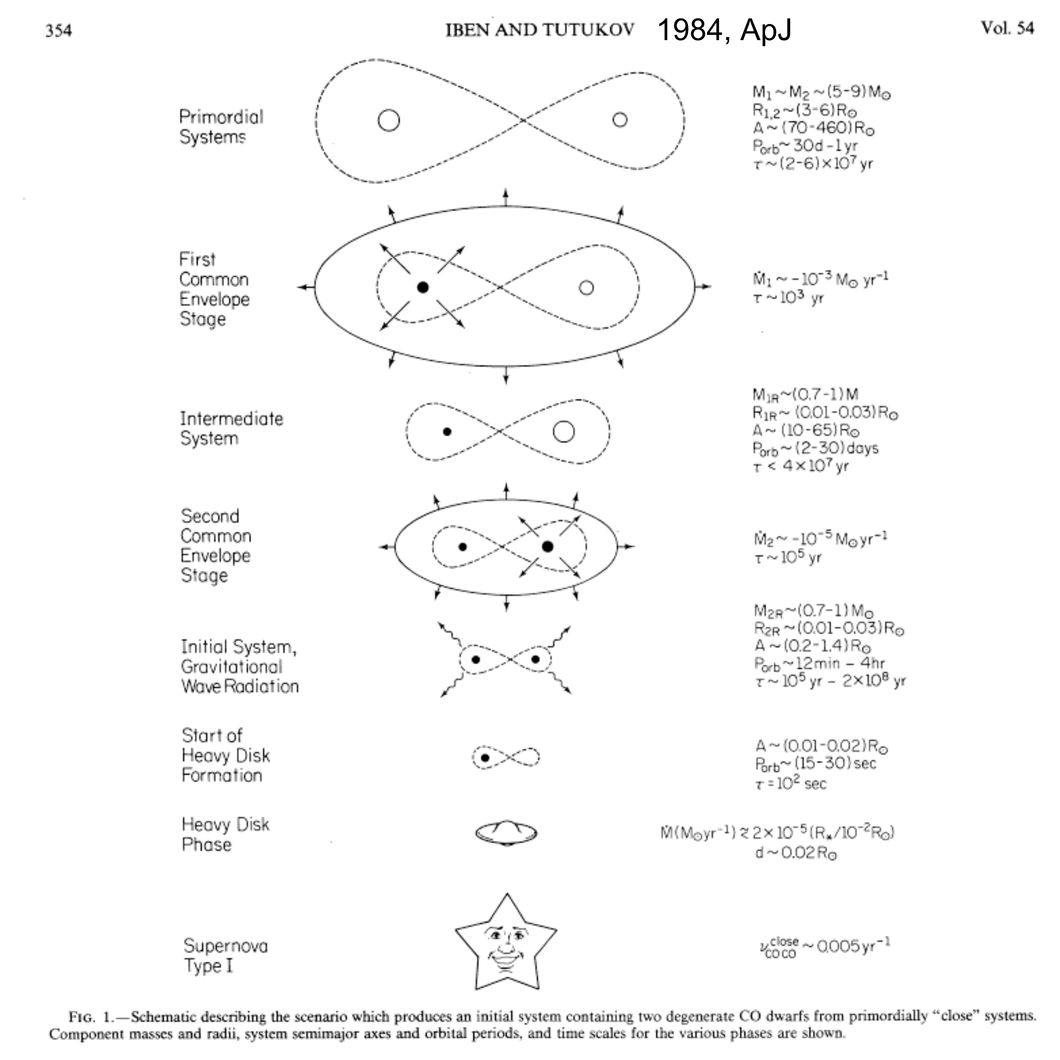
Fig. 1. The SNI rate following a burst of star formation *vs* the time (in yr) elapsed since the burst. The rates refer to both C/O and He white dwarf precursors, and are normalized to their respective maximum values. The values of the parameters s, γ, and $M_{B,\min}$ are reported. The dotted line refers to $\gamma = 0.5$ and $M_{B,\min} = 3$. The number of SNe exploded until the time t is also drawn for both kinds of precursors

As a stellar population ages, the evolutionary clock slows down

The SN rate decreases in spite of the increasing IMF factor

Steeper drop at late ages due to requirement on total mass of the system

The Double Degenerate channel



354 IBEN AND TUTUKOV 1984, ApJ Vol. 54

FIG. 1.—Schematic describing the scenario which produces an initial system containing two degenerate CO dwarfs from primordially "close" systems. Component masses and radii, system semimajor axes and orbital periods, and time scales for the various phases are shown.

$$t_D = t_{MS}(m_{2,TO}) + t_{GWR}(m_1, m_2, A....)$$

$$t_{GWR} \propto \frac{A^4}{m_{WD1} m_{WD2} m_{DD}}$$

The Double Degenerate channel

354 IBEN AND TUTUKOV 1984, ApJ Vol. 54

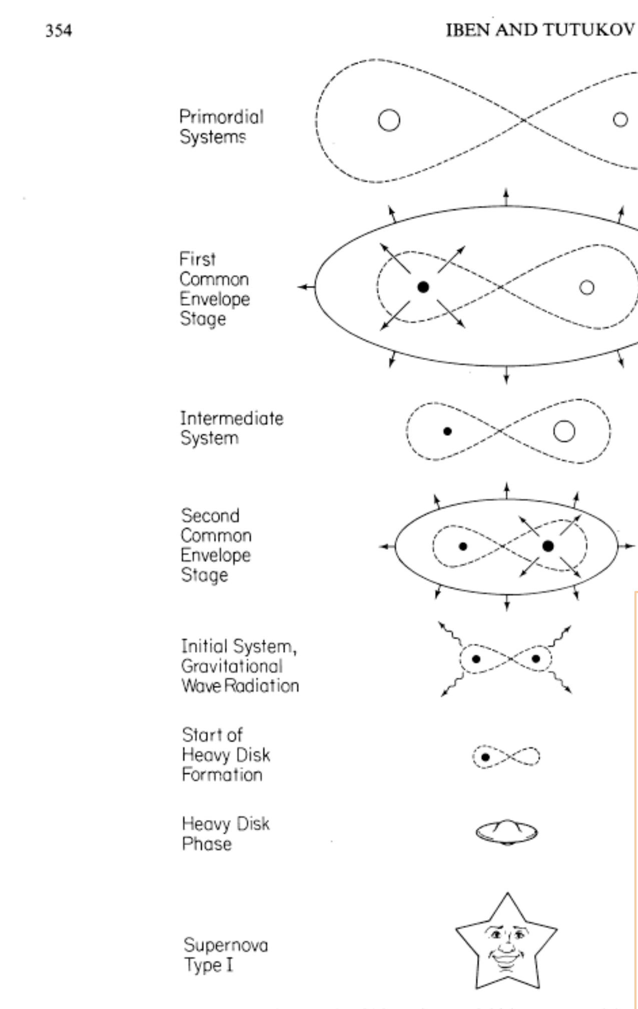
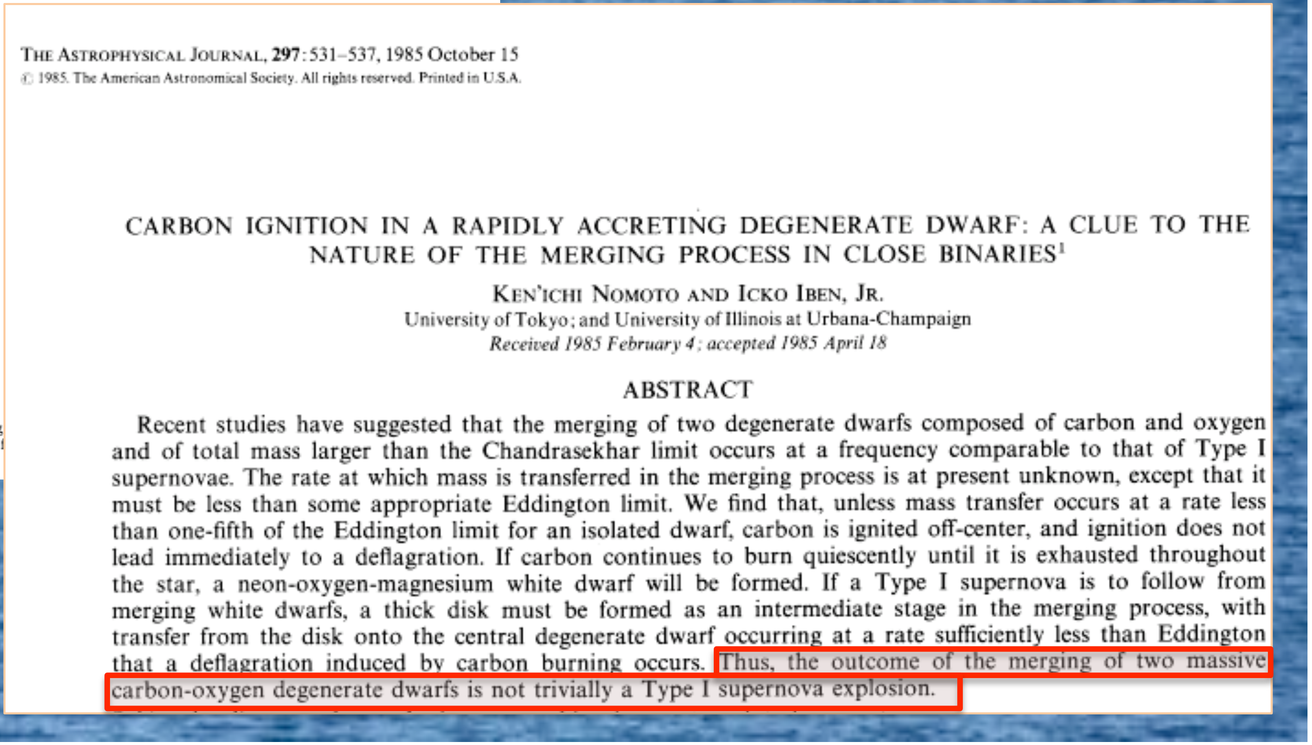


Fig. 1.—Schematic describing the scenario which produces an initial system containing
Component masses and radii, system semimajor axes and orbital periods, and time scales f

$$t_D = t_{MS}(m_{2,TO}) + t_{GWR}(m_{1,} m_{2,} A....)$$

$$t_{GWR} \propto \frac{A^4}{m_{WD1} m_{WD2} m_{DD}}$$



The Astrophysical Journal, **297**: 531–537, 1985 October 15

CARBON IGNITION IN A RAPIDLY ACCRETING DEGENERATE DWARF: A CLUE TO THE NATURE OF THE MERGING PROCESS IN CLOSE BINARIES[1]

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Received 1985 February 4; accepted 1985 April 18

ABSTRACT

Recent studies have suggested that the merging of two degenerate dwarfs composed of carbon and oxygen and of total mass larger than the Chandrasekhar limit occurs at a frequency comparable to that of Type I supernovae. The rate at which mass is transferred in the merging process is at present unknown, except that it must be less than some appropriate Eddington limit. We find that, unless mass transfer occurs at a rate less than one-fifth of the Eddington limit for an isolated dwarf, carbon is ignited off-center, and ignition does not lead immediately to a deflagration. If carbon continues to burn quiescently until it is exhausted throughout the star, a neon-oxygen-magnesium white dwarf will be formed. If a Type I supernova is to follow from merging white dwarfs, a thick disk must be formed as an intermediate stage in the merging process, with transfer from the disk onto the central degenerate dwarf occurring at a rate sufficiently less than Eddington that a deflagration induced by carbon burning occurs. Thus, the outcome of the merging of two massive carbon-oxygen degenerate dwarfs is not trivially a Type I supernova explosion.

Mon. Not. R. astr. Soc. (1986) **223,** 69–77

Type I SNe from double degenerate CO dwarfs and their rate in the solar neighbourhood

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Accepted 1986 May 22. Received 1986 May 1

Summary. An updated set of stellar models for various metallicities (from 10^{-6} to 10^{-2}) has been used to compute rates of Type I supernovae in the framework of the double degenerate CO dwarf model, which has been suggested to be a good candidate for explaining the origin of such supernovae. In particular, we have computed the Type I SN rate for several chemical compositions of the progenitor stars by means of a chemical-evolution model for the solar neighbourhood.

The main results can be summarized as follows:

(i) The relative number of binary systems giving rise to Type I SNe is a decreasing function of their metal content. However, this effect is not noticeable when the Type I SN rate is computed by means of a star-formation rate which is proportional to some power of the gas density, since the Type I SN rate mainly follows the same trend. The main difference between the rate computed by taking into account the various chemical compositions of the progenitors and the one computed for a unique chemical composition (solar), is the time at which Type I SNe begin to appear, which is shorter in the first case.

(ii) In both cases, the predicted Type I SN rate at the present time in the solar neighbourhood is lower by a factor of 10 with respect to the observed one. It is worth noting that the model of chemical evolution we used, reproduces all the main features of the solar neighbourhood as well as the observed Type II SN rate.

Therefore, although the many uncertainties present in the derivation of the Type I SN rate and in the observational estimate of SN rates do not allow firm conclusions, we suggest that Type I SNe are likely to come not only from the double degenerate CO dwarf model.

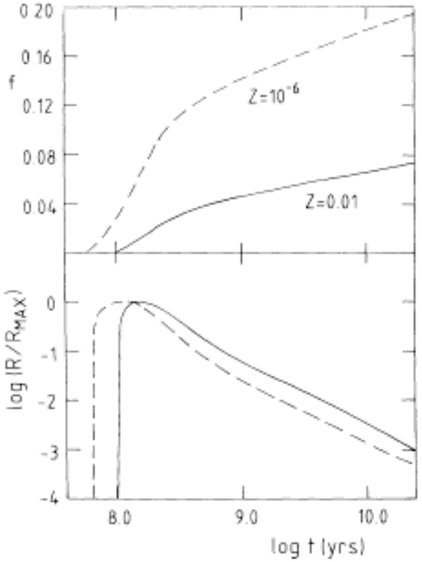


Figure 2. Upper panel: The cumulative fractionary number of merging events of double degenerate dwarfs as a function of time. The fraction is computed with respect to all binary systems with total mass between 6 and 18 $M_\odot$. The continuous line refers to a stellar generation with $Z=0.01$ and $Y=0.25$, whereas the broken line refers to a stellar generation with $Z=10^{-6}$ and $Y=0.20$. Lower panel: The logarithm of the rate of merging events, normalized to the maximum computed rate, as a function of time for the two stellar generations discussed above.

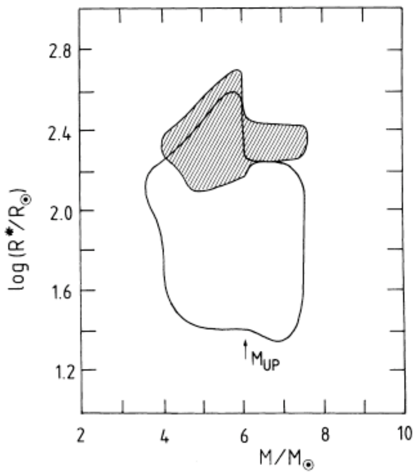
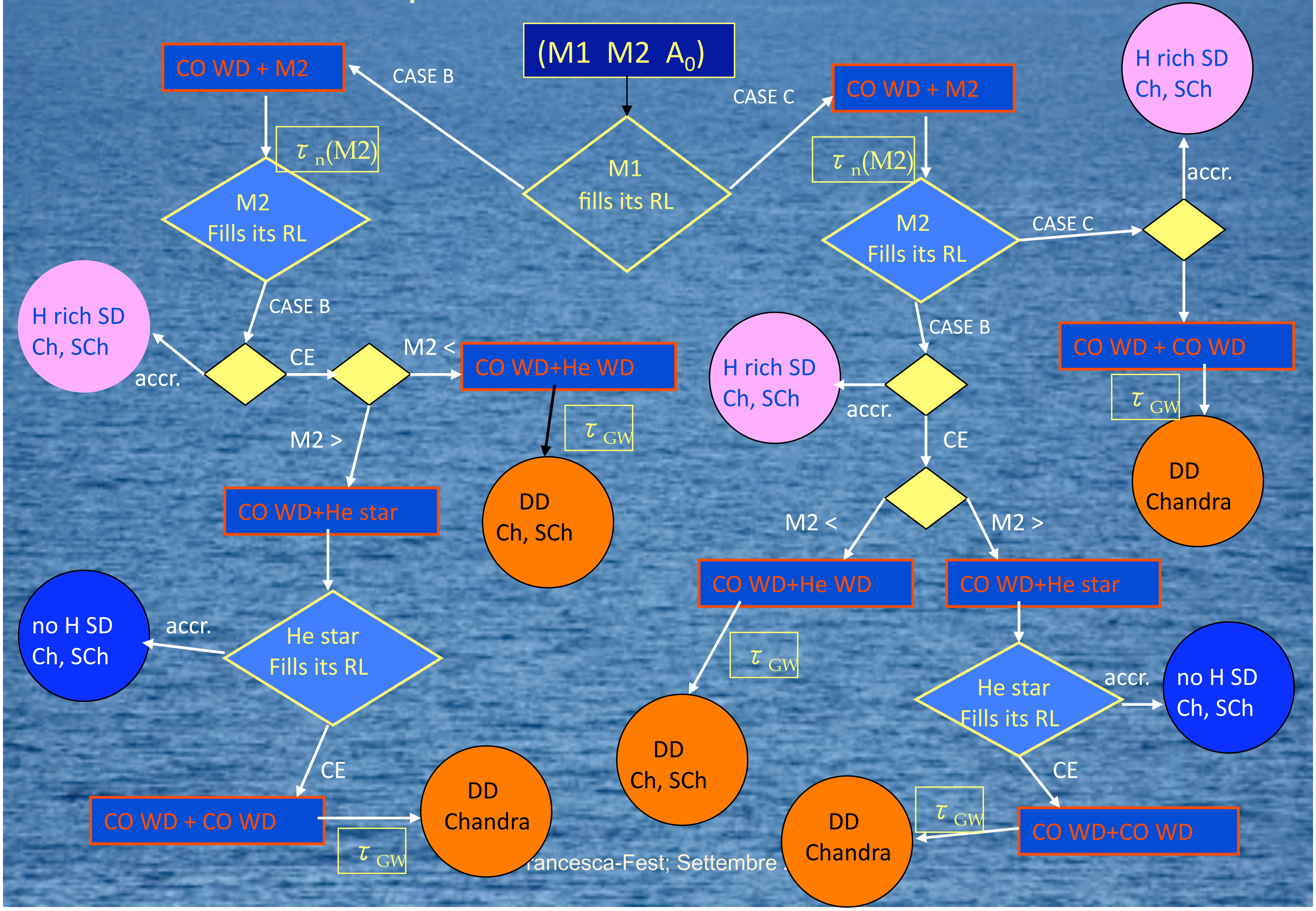


Figure 1. The areas in the $M-\log R^*$ (R^*=semi-major axis) diagram for which a double degenerate merging event is possible for the same chemical compositions as in Fig. 2. The smaller shaded area refers to $Z=0.01$, $Y=0.25$, whereas the larger one refers to $Z=10^{-6}$, $Y=0.20$.

A simplified Scenario Code flow chart



(M1 M2 A_0)

M1
fills its RL

CASE B

CO WD + M2

τ_n(M2)

M2
Fills its RL

CASE B

accr.

H rich SD
Ch, SCh

CE

M2 <

CO WD+He WD

τ_{GW}

DD
Ch, SCh

M2 >

CO WD+He star

He star
Fills its RL

accr.

no H SD
Ch, SCh

CE

CO WD + CO WD

τ_{GW}

DD
Chandra

CASE C

CO WD + M2

τ_n(M2)

M2
Fills its RL

CASE C

accr.

H rich SD
Ch, SCh

CO WD + CO WD

τ_{GW}

DD
Chandra

CASE B

accr.

H rich SD
Ch, SCh

CE

M2 <

CO WD+He WD

τ_{GW}

DD
Ch, SCh

M2 >

CO WD+He star

He star
Fills its RL

accr.

no H SD
Ch, SCh

CE

CO WD+CO WD

τ_{GW}

DD
Chandra

Output SNIa rates

Tutukov & Yungelson 1994

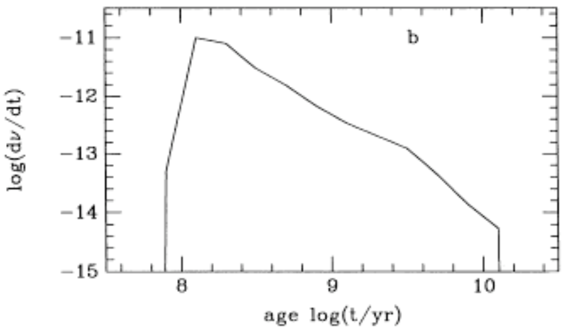
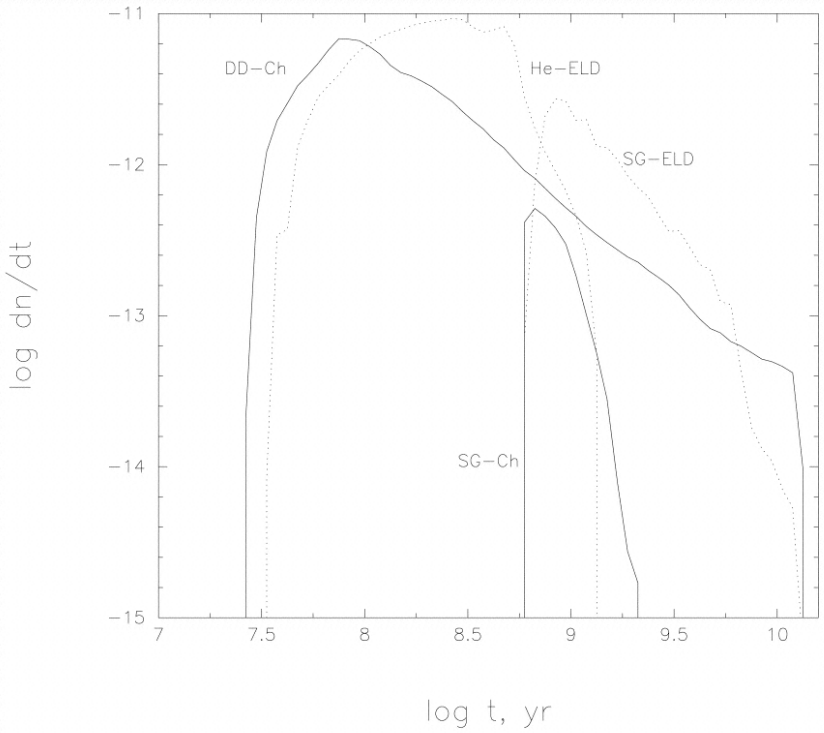


Figure 1. (a) The contribution to the present annual rate of occurrence of SNeIa as a function of the age of the precursor system for the case of continuous star formation. The rate is scaled to the formation of one binary star with the mass of the primary between 0.8 and 100 M$_{\odot}$. (b) The dependence of the rate of occurrence of SNeIa on age for the case of an instantaneous star formation burst. The rate is scaled to the instantaneous transformation of 1 M$_{\odot}$ of matter into binary stars with $0.8 \leq M_1 \leq 100$ M$_{\odot}$ and a Salpeter mass function of primaries.

Yungelson & Livio 2000



Ruiz-Lapuente, Burkert & Canal 1996

Vol. 447

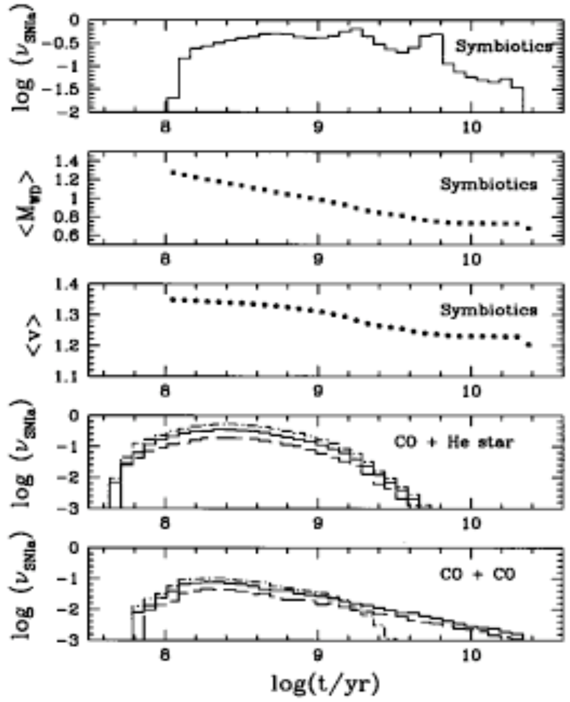


FIG. 1.—*Top to bottom:* Evolution of the SN Ia rate, after an outburst of star

These results are difficult to include in a chemical evolution code, so most models were then constructed using the GR83 formula or equivalent

2013

Greggio 2005: analytical rates

An instantaneous burst of star formation producing M_{SF} mass of stars delivers SNIa at a rate of:

$$\dot{n}_{Ia}(t) = k_{Ia} M_{SF} f_{Ia}(t_D = t)$$

t_D is the delay time; f_{Ia} its distribution function

k_{Ia} is the number of events per unit mass of the parent Stellar Population

In a system with a SFR ψ, at epoch t the SNIa rate is:

$$\dot{n}_{Ia}(t) = k_{Ia} \int_0^t \psi(t - t_D) f_{Ia}(t_D) dt_D$$

If ψ ≈ constant and t >>

$$\dot{n}_{Ia} \cong k_{Ia}\psi \int_0^t f_{Ia}(t_D) dt_D = k_{Ia}\psi$$

In the MW: SNIa rate ~ 1 every 100 yrs
SFR ~ few Mo/yr

$k_{Ia} \sim$ few 10^{-3} M_o^{-1}

A 1000 M_o stellar population should include a few SNIa progenitors to account for the observed rate

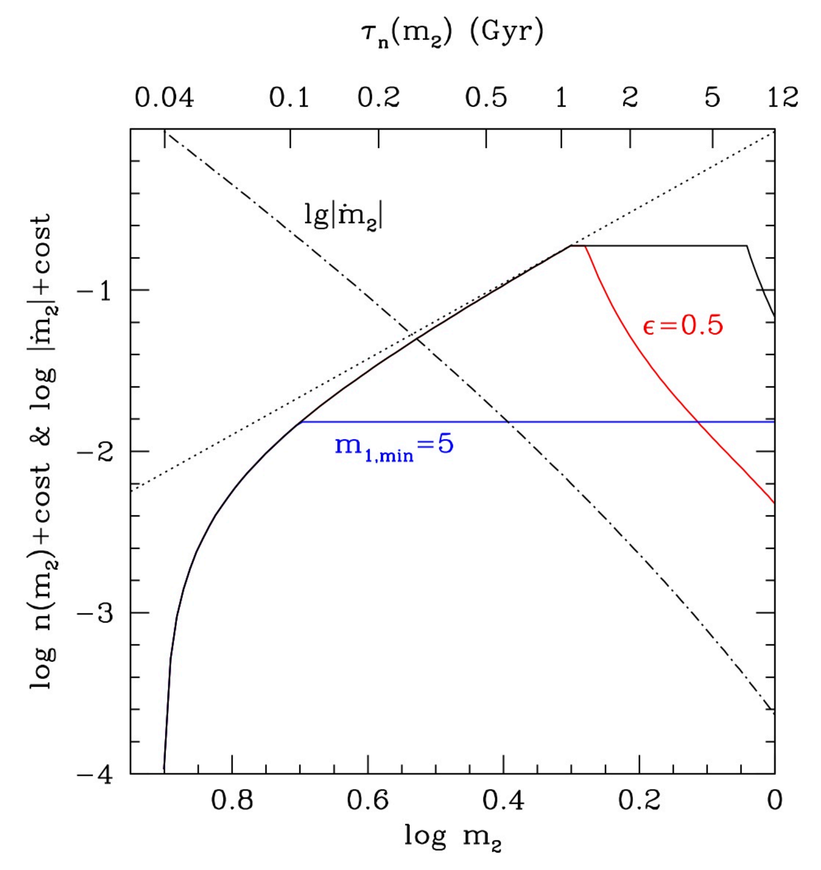
Single Degenerates

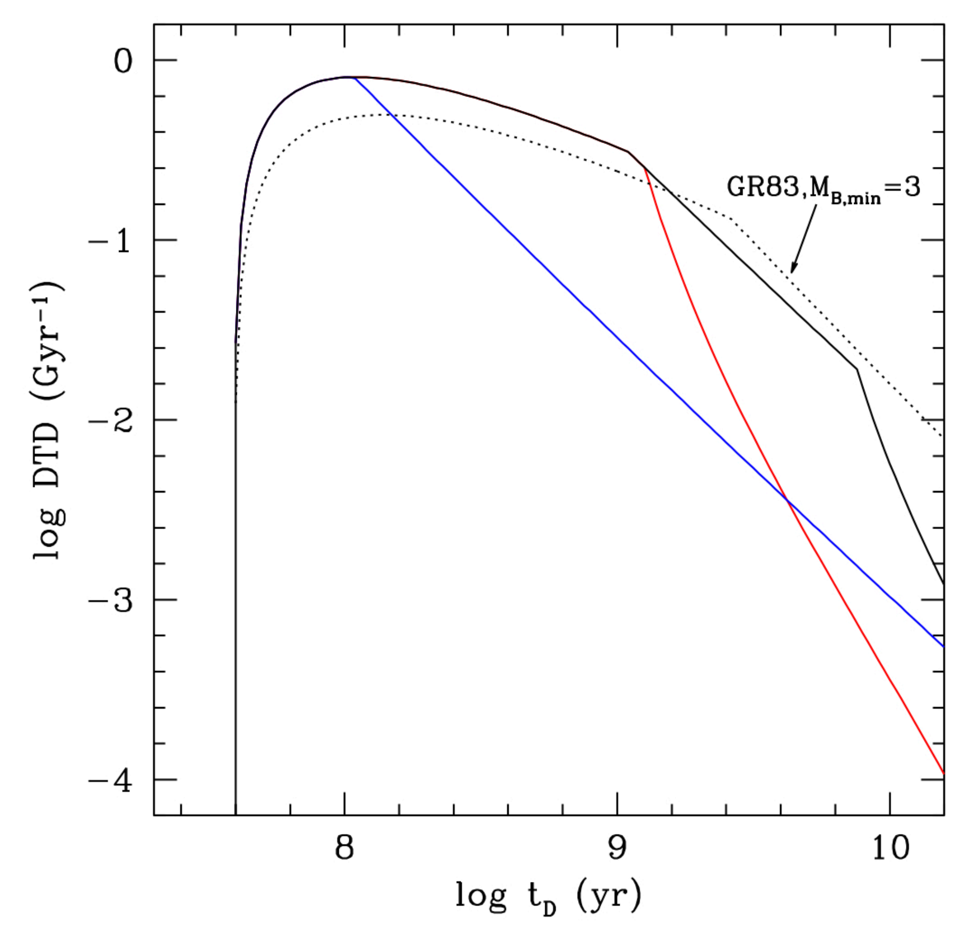
$$R_{Ia} \propto \left|\dot{m}_{2,TO}\right| \times \tilde{\psi}(m_{2,TO})$$

$$\tilde{\psi}(m_{2,TO}) \propto \int_{m_{1,\min}}^{m_{1,\max}=8} \psi(m_1) f(m_{2,TO}/m_1)\, dm_1$$

$m_{1,\min} = \max\{m_{2,TO}; 2; f(m_{2,env})\}$

The SNIa rate following a burst of SF

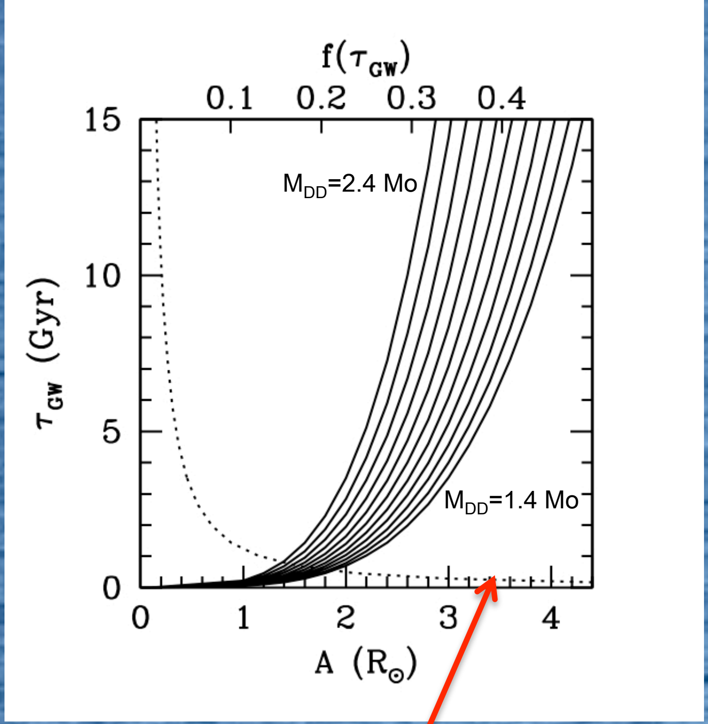




Double Degenerates : the clock

$$t_D = \tau_{MS}(m_2) + \tau_{GW}$$

$$\tau_{GW} = \frac{0.15A^4}{m_{WD1}m_{WD2}(m_{WD1}+m_{WD2})} \cong 0.6\frac{A^4}{M_{DD}}$$



A flat distribution of A maps into a distr. of t_{GW} skewed at the short end

CO WDs in close binaries mostly come from Stars with M > 2Mo
→ evolutionary lifetimes t_{MS} < 1Gyr

The gravitational wave radiation delay t_{GW} spans the whole Hubble time with A ranging in a small interval (< 4 Ro)

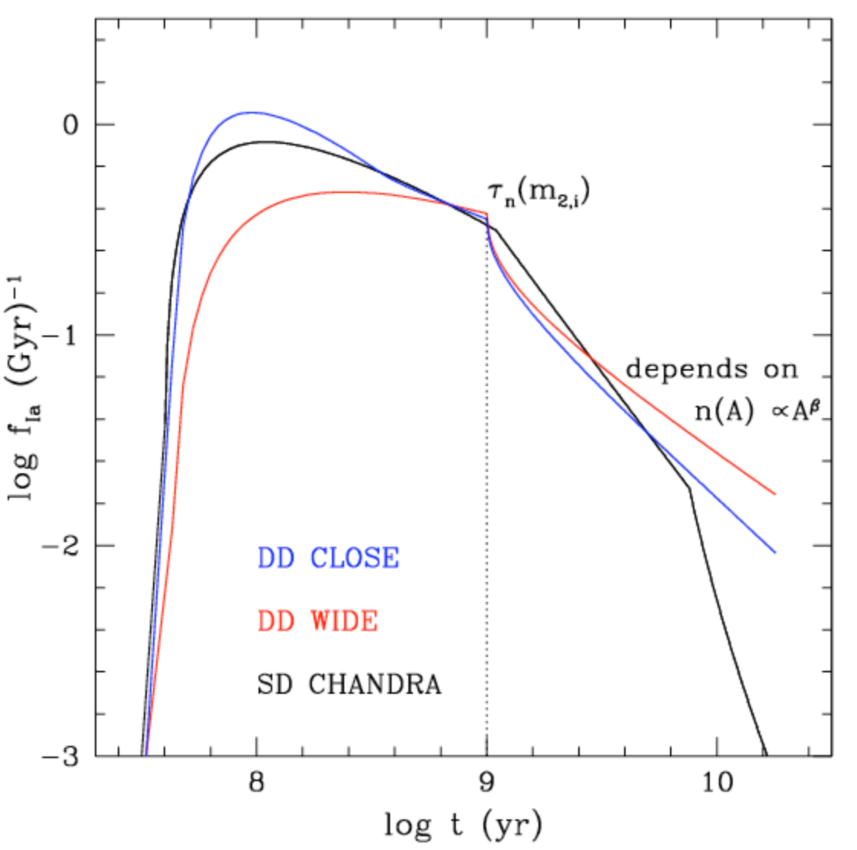
The separation A is attained after 2 or more CE phases: we need to characterize its distribution over a range of 4 Ro from an initial distribution over few Ro – few 100 Ro

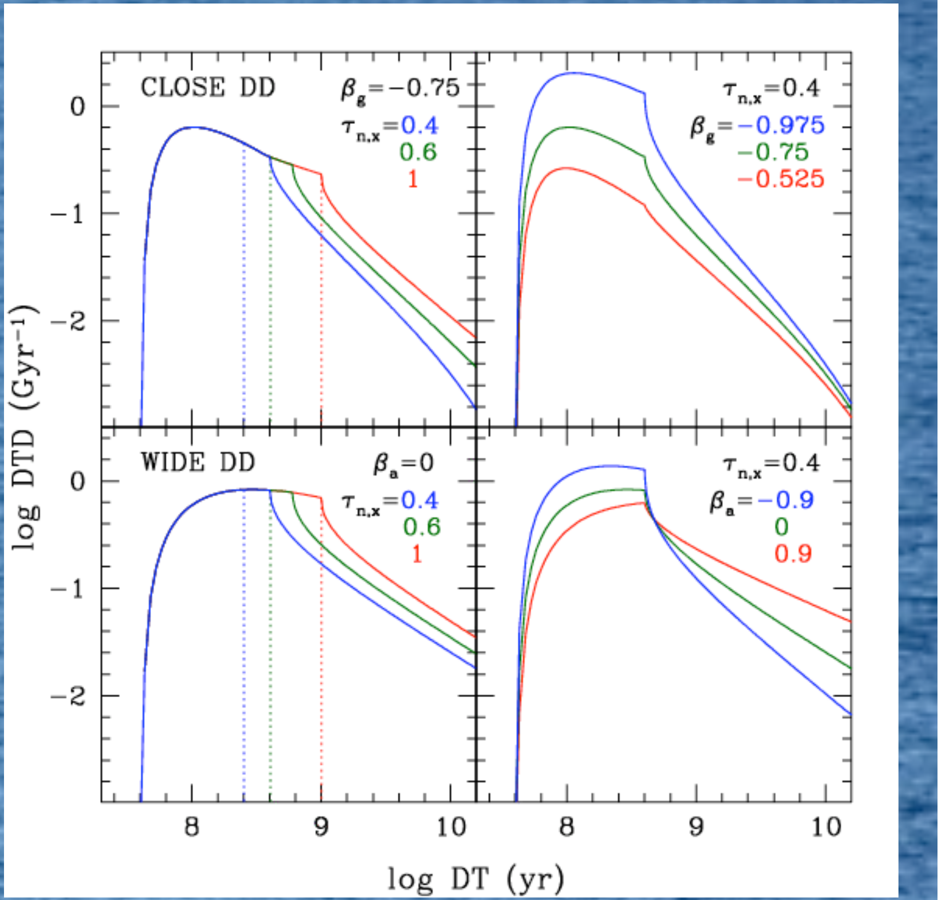
DD CLOSE: CE shrinks more the more massive systems
(t_{MS} short -> t_{GW} short)

DD WIDE: M_{DD} and A (almost) decoupled

Double Degenerates : the rate

The DTD is a modification of that of the SD case

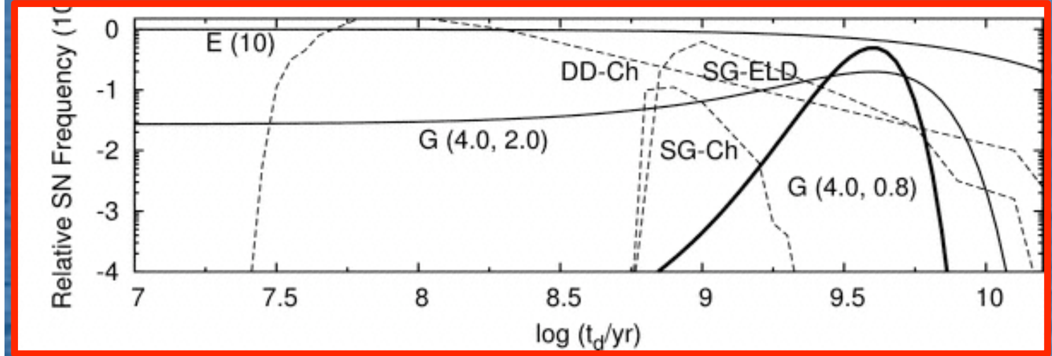




DTD shape controlled by
the mass range of the primary and secondary, and their distribution
the distribution of the separations, the degree of shrinkage during the CE phases

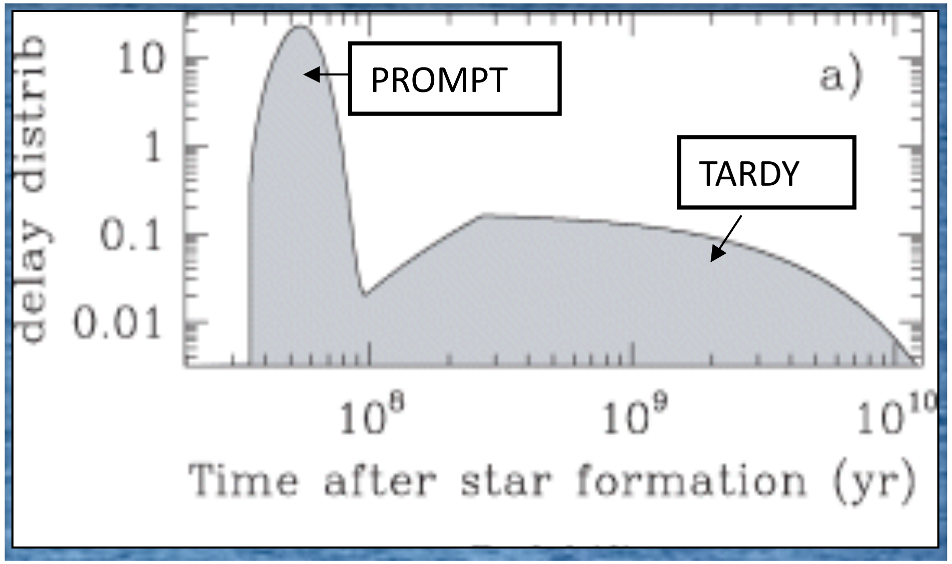
Empirically derived DTDs:

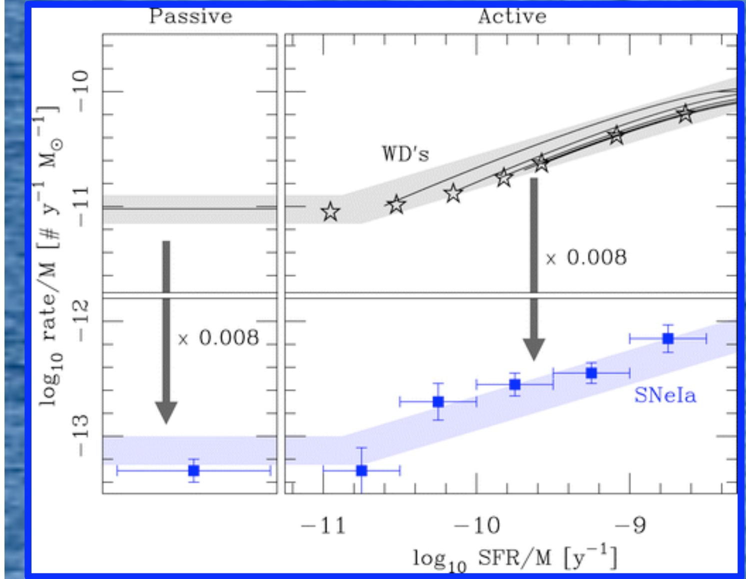
$$\dot{n}_{Ia} = k_{Ia} M_{SF} \langle f_{Ia} \rangle_{\psi}$$



Strolger et al. (2004):
best fit of cosmic SNIa rate as function of z requires a Gaussian DTD centered at 4 Gyr
Problems with high SNIa rate in young (blue) galaxies

Mannucci, Della Valle & Panagia (2006):
to explain rate in radio loud and radio quiet Es
Problem with CC SNe production





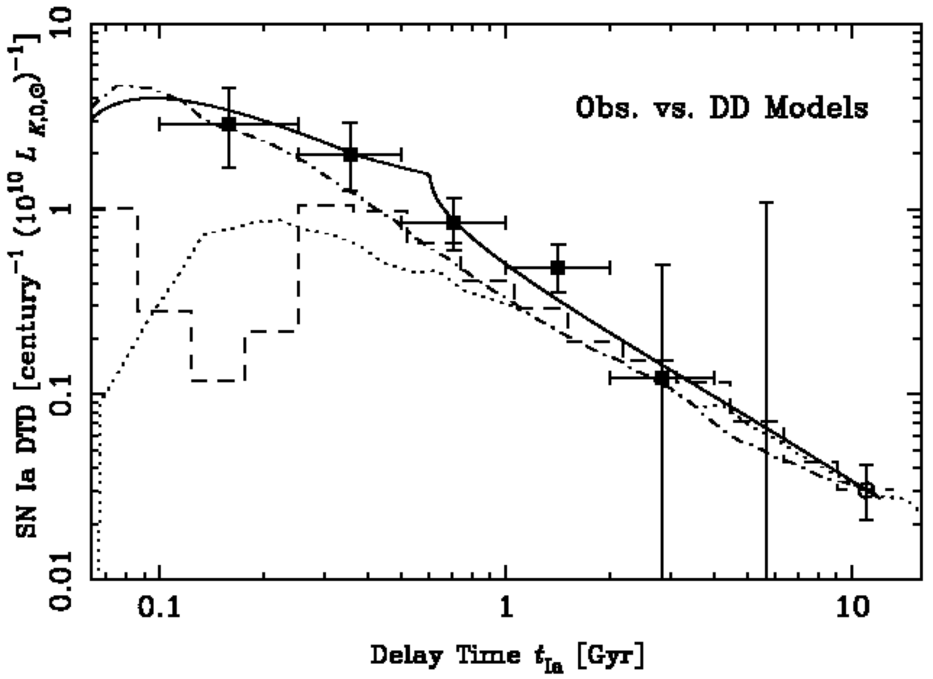
Pritchet et al. (2008): the SN rate scales as the WD formation rate

$$\longrightarrow \quad f_{Ia} \propto \varphi(m_{TO})|\dot{m}_{TO}| \approx t^{-0.5}$$

Problem: too efficient at late delays

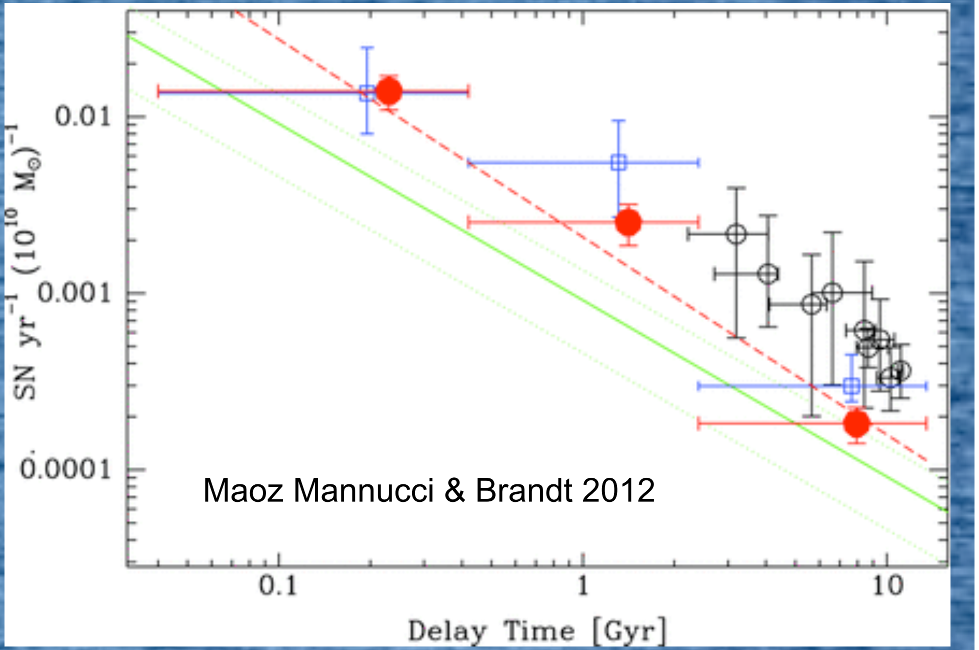
Totani et al. 2008:
SNIa rate in old passive galaxies at z = 0.4 – 1.2
Probe delay times 0.1—8 Gyr
Point at 10 Gyr from Mannucci et al. (2005)
Curves: solid G2005 close DD
dash-dotted Yungelson & Livio (2000)
dotted Ruiz-Lapuente & Canal (1998)
dashed Belczynski et al. (2005)

$$\dot{n}_{Ia} = k_{Ia} M_{SF} \left\langle f_{Ia} \right\rangle_{\psi}$$



Maoz … 2011-2013:
derive DTD from elaborated analysis of rates in large samples of galaxies with various SFH
Red : from SDSS2 (132 SNIa in 66000 galaxies)
Blue : same analysis on LOSS sample
Black : rate in clusters as function of redshift

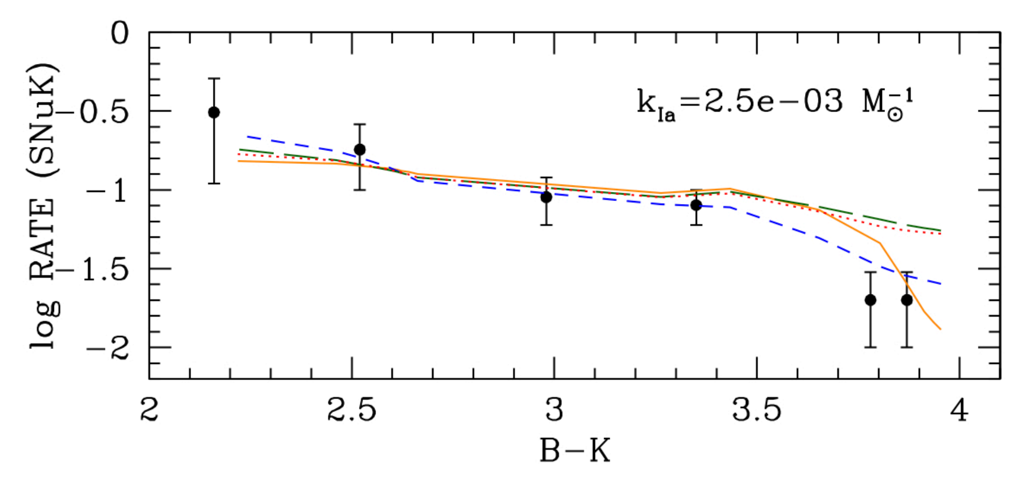
Red line: DTD = K $t_D^{-1.12}$
Green line: DRD = K t_D^{-1}



Maoz Mannucci & Brandt 2012

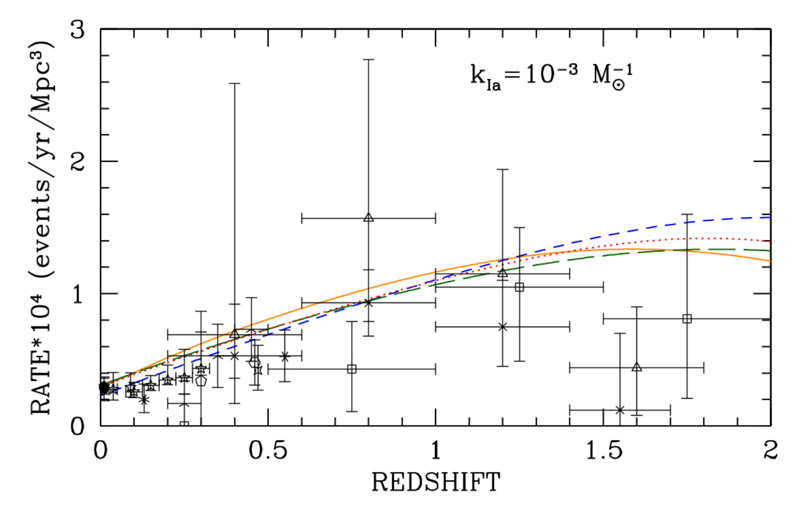
The SNIa productivity

(number of events you get from 1 Mo of parent SP ever)



$$\frac{\dot{n}_{Ia}(t)}{L_K(t)} = k_{Ia} \frac{\langle f_{Ia} \rangle_{\psi}}{\langle (L_K / M)_{SSP} \rangle_{\psi}}$$

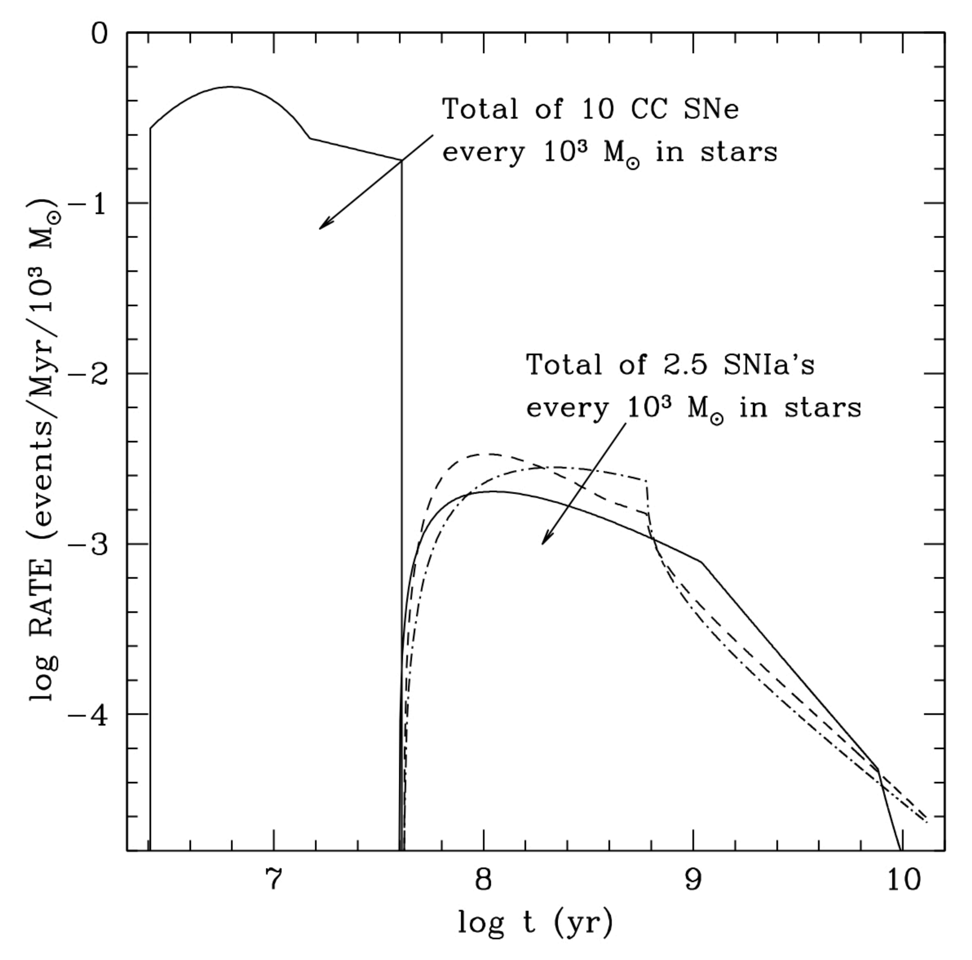
on CET99 (SNuK)	$k_{Ia} = 2.5\ 10^{-3}$
on SNLS RATE (SNuM)	$k_{Ia} = 1.6\ 10^{-3}$
on cosmic RATE	$k_{Ia} = 1\ 10^{-3}$
Maoz et al. 2013	$k_{Ia} = 1.3\ 10^{-3}$

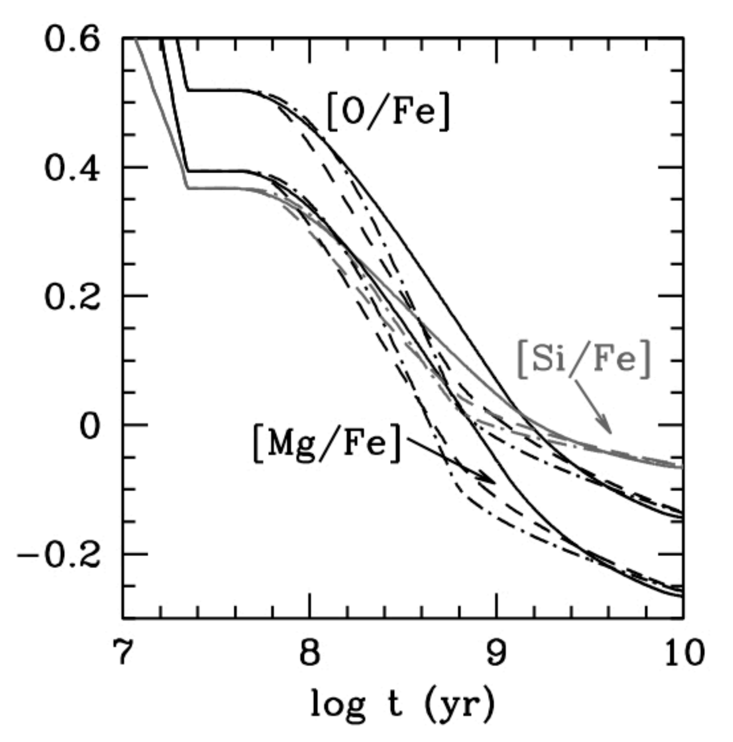


$k_{Ia} \approx 2\ 10^{-3}$ (Mo)$^{-1}$
for a flattened Salpeter
which has 0.04 (Mo)$^{-1}$ stars with
mass between 2.5 and 8 Mo

The observed rates require that ~ 5 % of them are in close binaries of the right kind to produce a SNIa – QUITE MANY

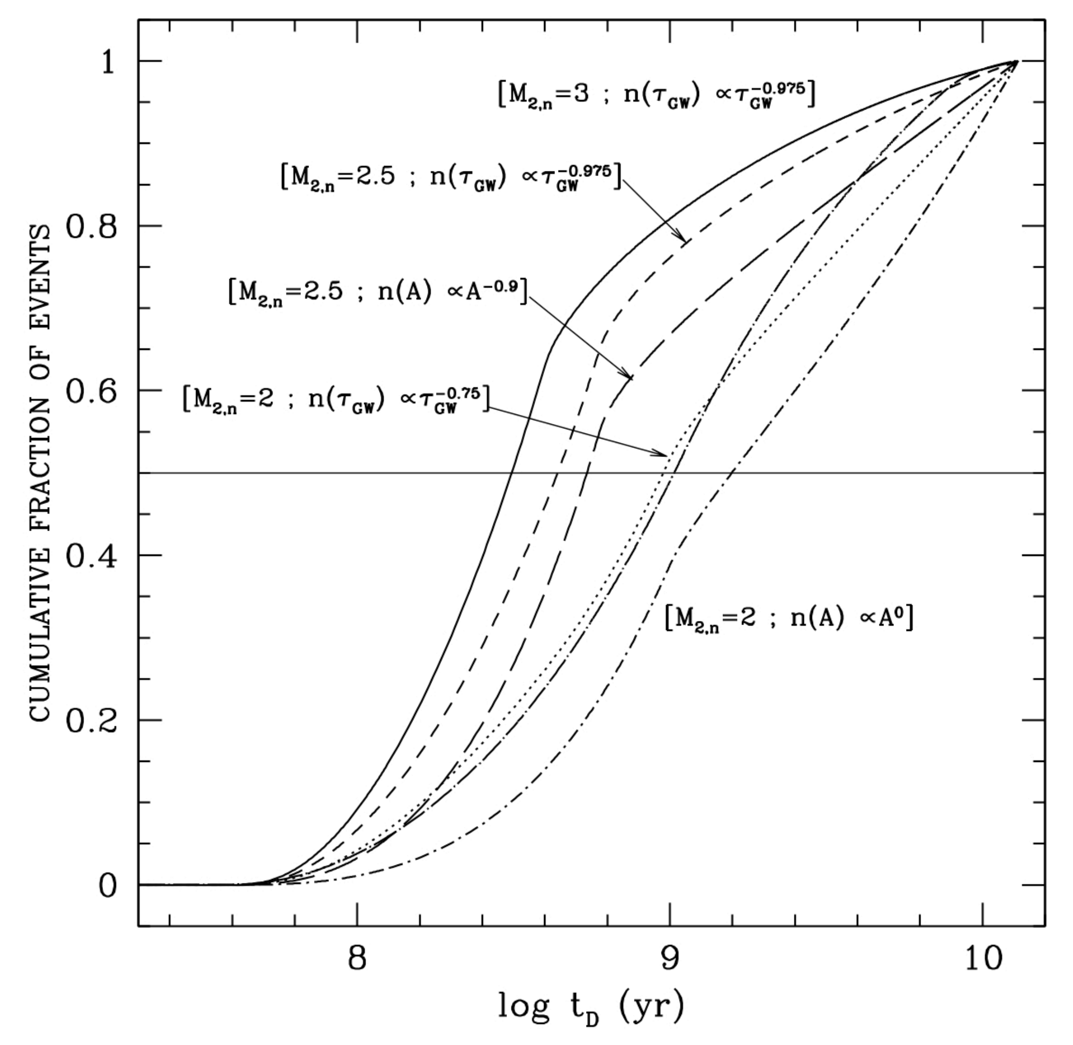
The SN rate from a Burst of SF





from Greggio & Renzini (2011). Stellar Populations. A user guide from low to high redshift. Wiley-VCH.

The timescale for Fe release from SNIa's



For a wide variety of models the timescale for 50% of explosions varies between 0.3 and 1 Gyr

In the next 30 years

- ✓ Refine the measurement of k_{Ia} as larger samples of galaxies are monitored for SNIa’s and determinations of their SFH improve
- ✓ Same set of data will allow us to retrieve info on the shape of the DTD … BUT … it will remain hard
- ✓ The SNIa progenitor systems will be better constrained by detailed observations (spectra at different phases) of events
- ✓ SNIa explosion models will be further developed and new channels/ configurations may come up (Sub-Chandra ?!)

However my bet is that the time scale for the Fe release to the ISM from a star burst will not change much and

Francesca’s results will remain valid