On the timescales of Type Ia Supernovae and Kilonovae explosions

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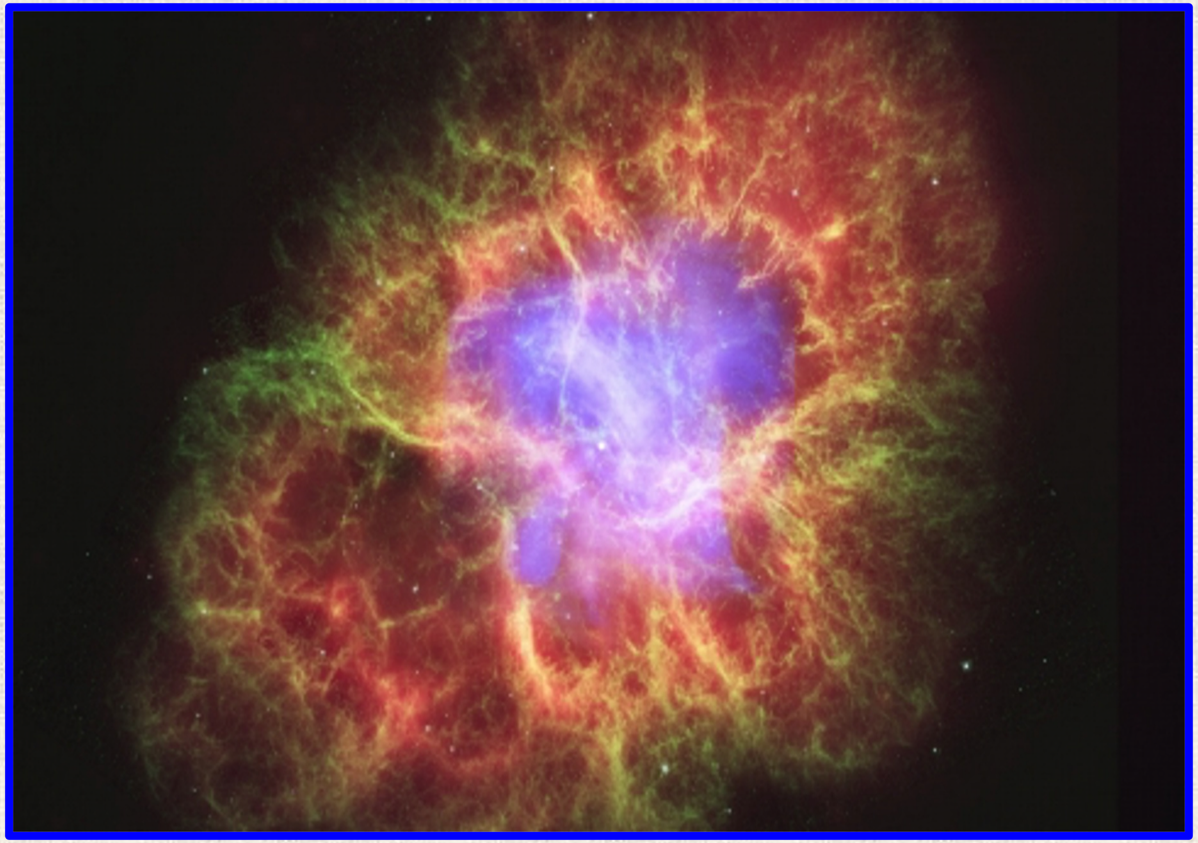
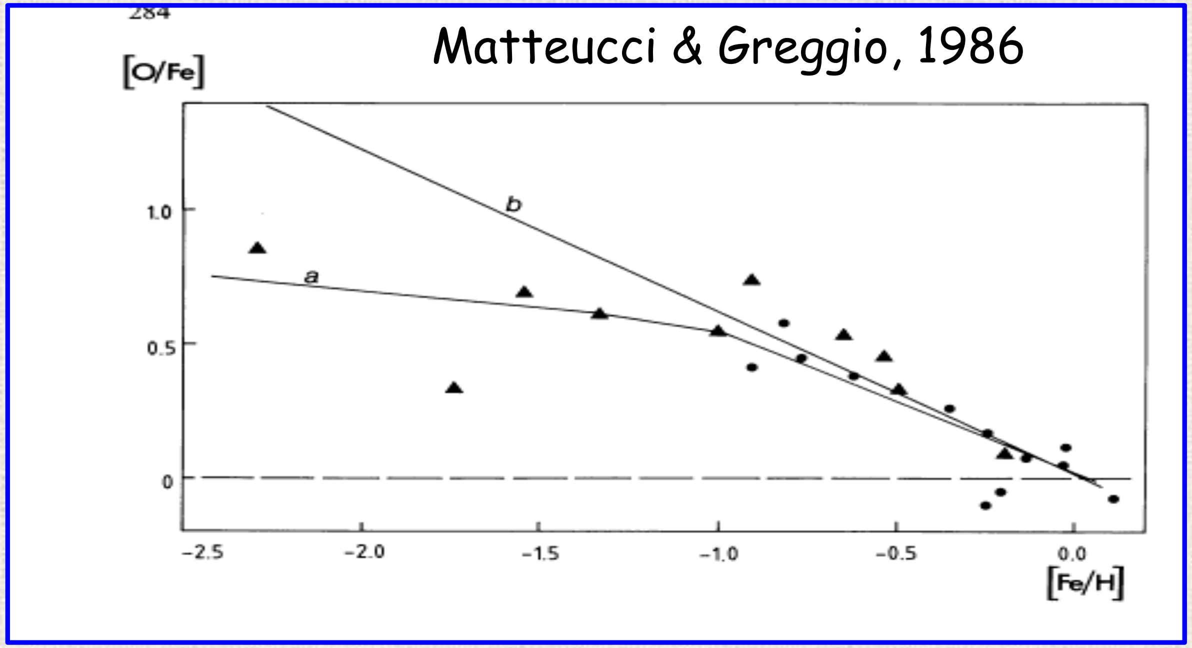
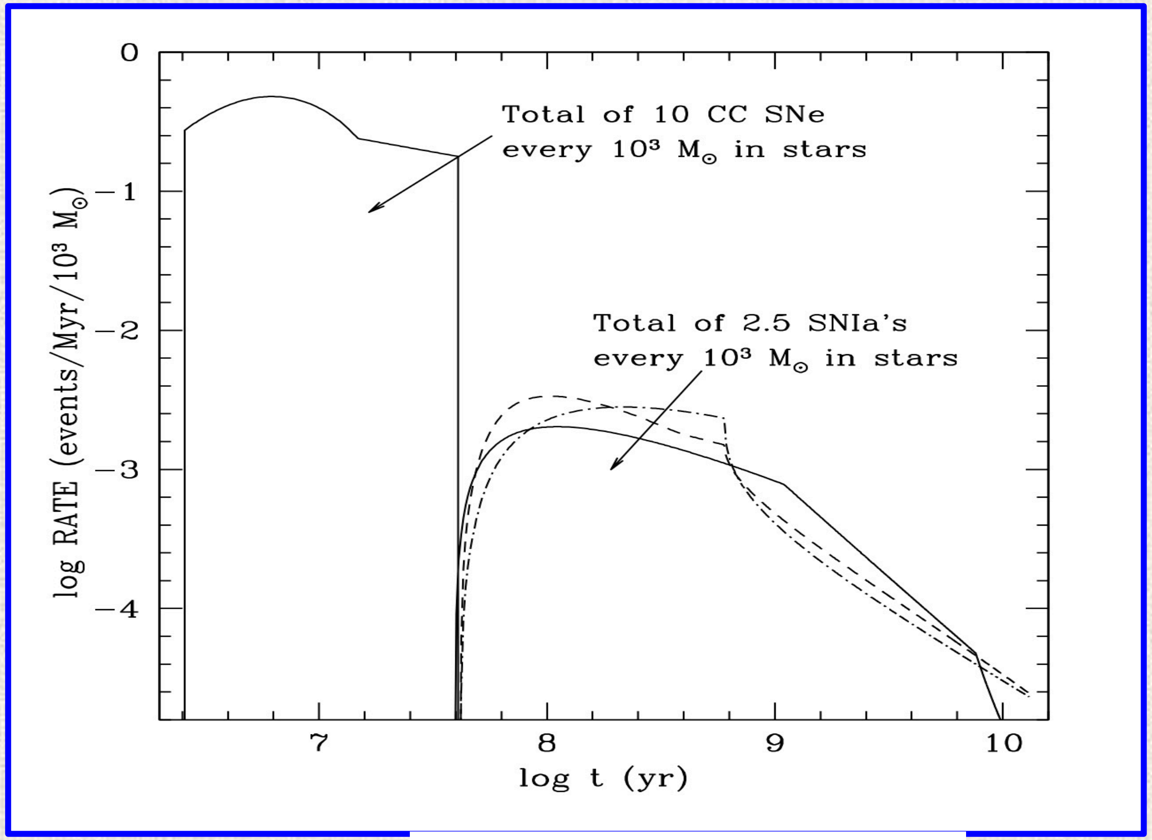


Enrichment timescale: SF burst



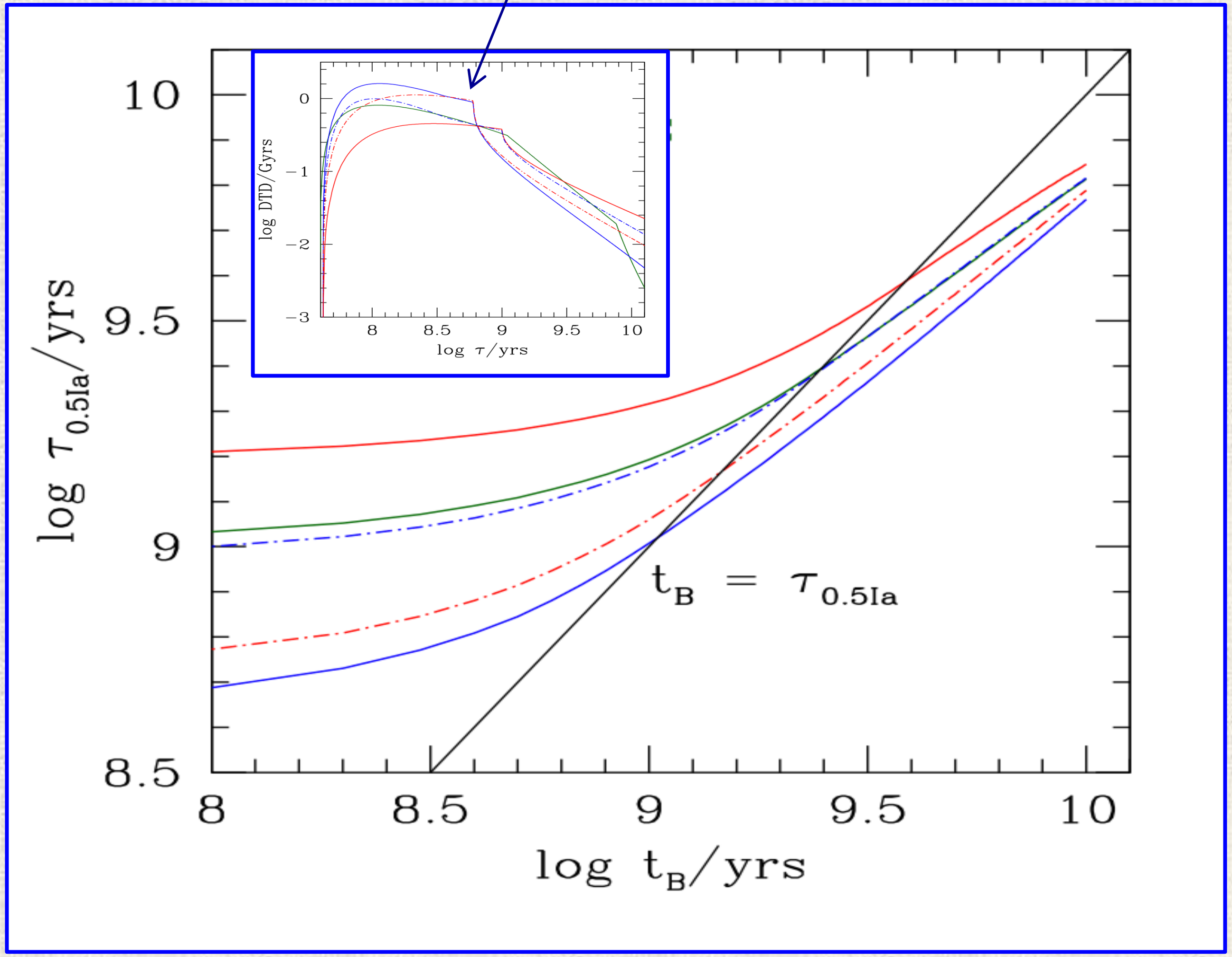


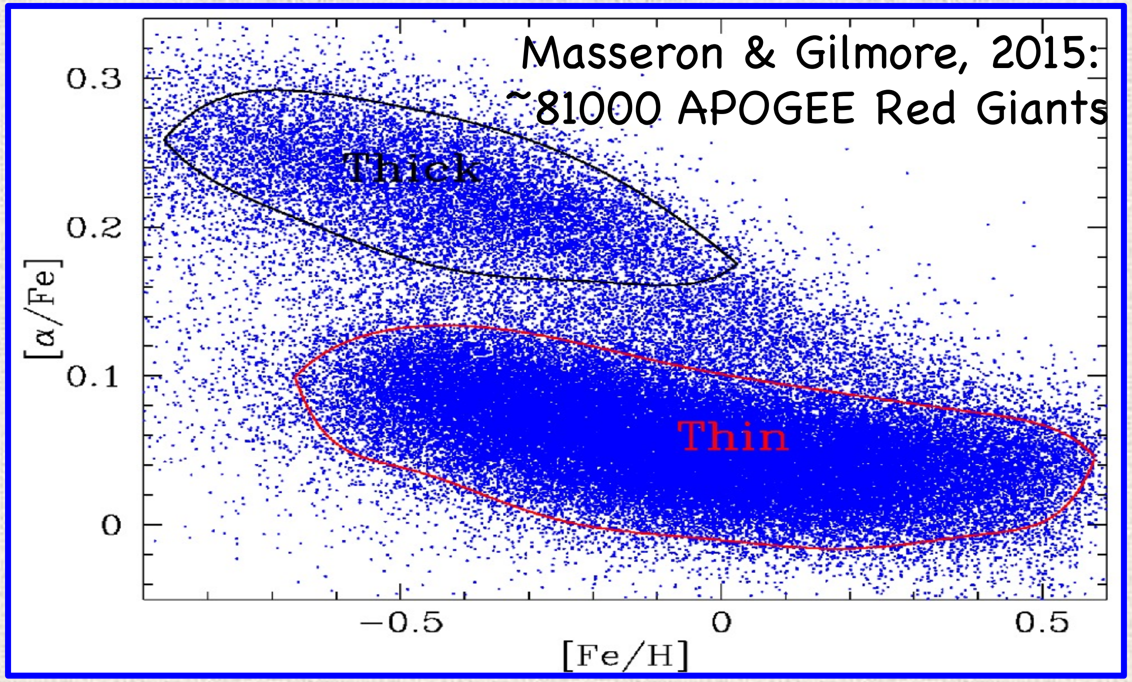
Greggio & Renzini, 2011

Enrichment timescale: extended SF

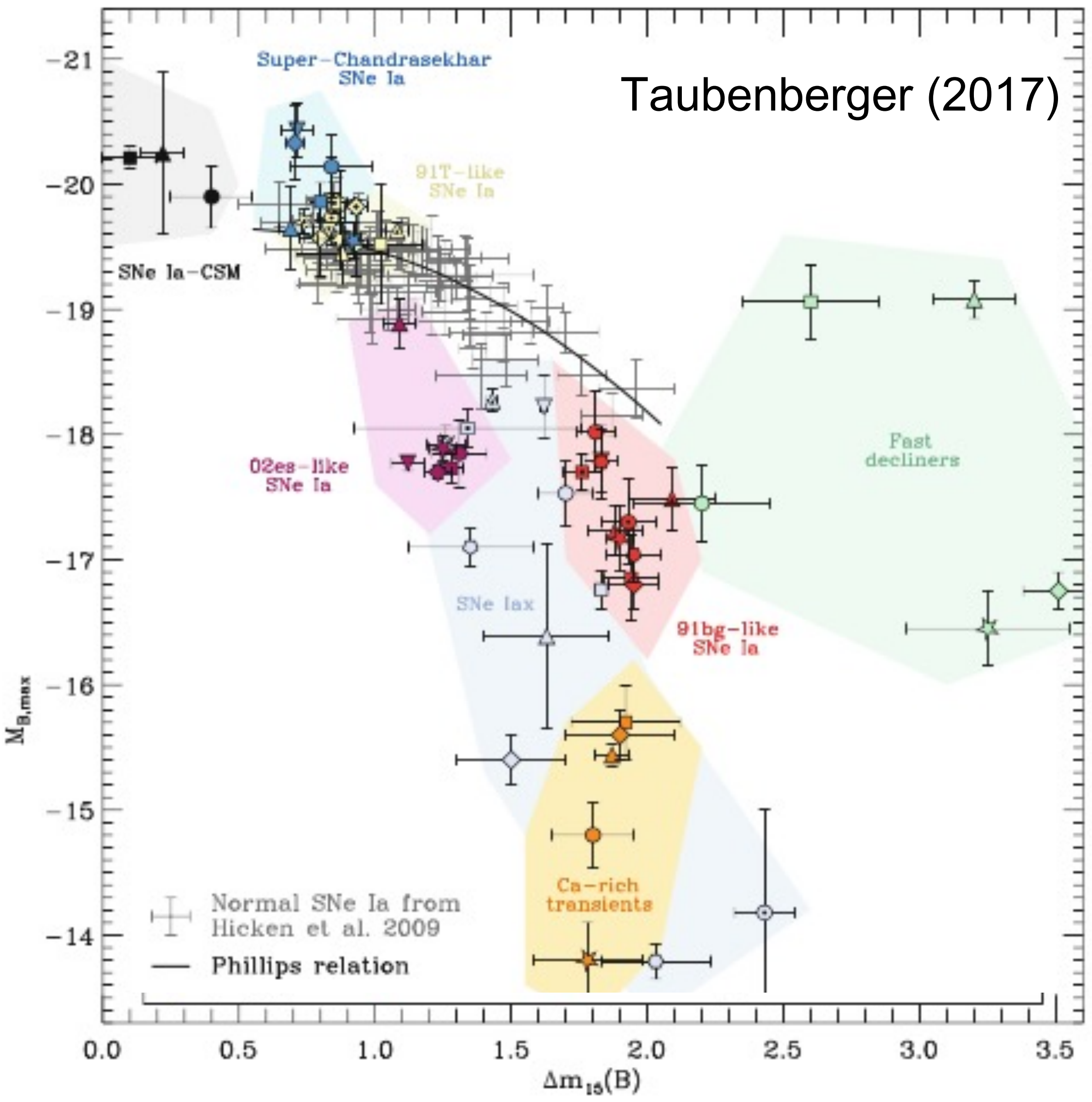
SNIa DTDs for a selection of progenitor's models

$\tau_{0.5Ia}$ =Time span in which ½ of the SNIa explosions have occurred





Light Curve properties : a large diversity



A variety of explosion mechanisms:

- Pure Deflagration Chandra models
- Delayed Detonation Chandra models
- Double Detonation Sub-Chandra models
- Detonation of Helium accreted layer on a sub-Chandra WD

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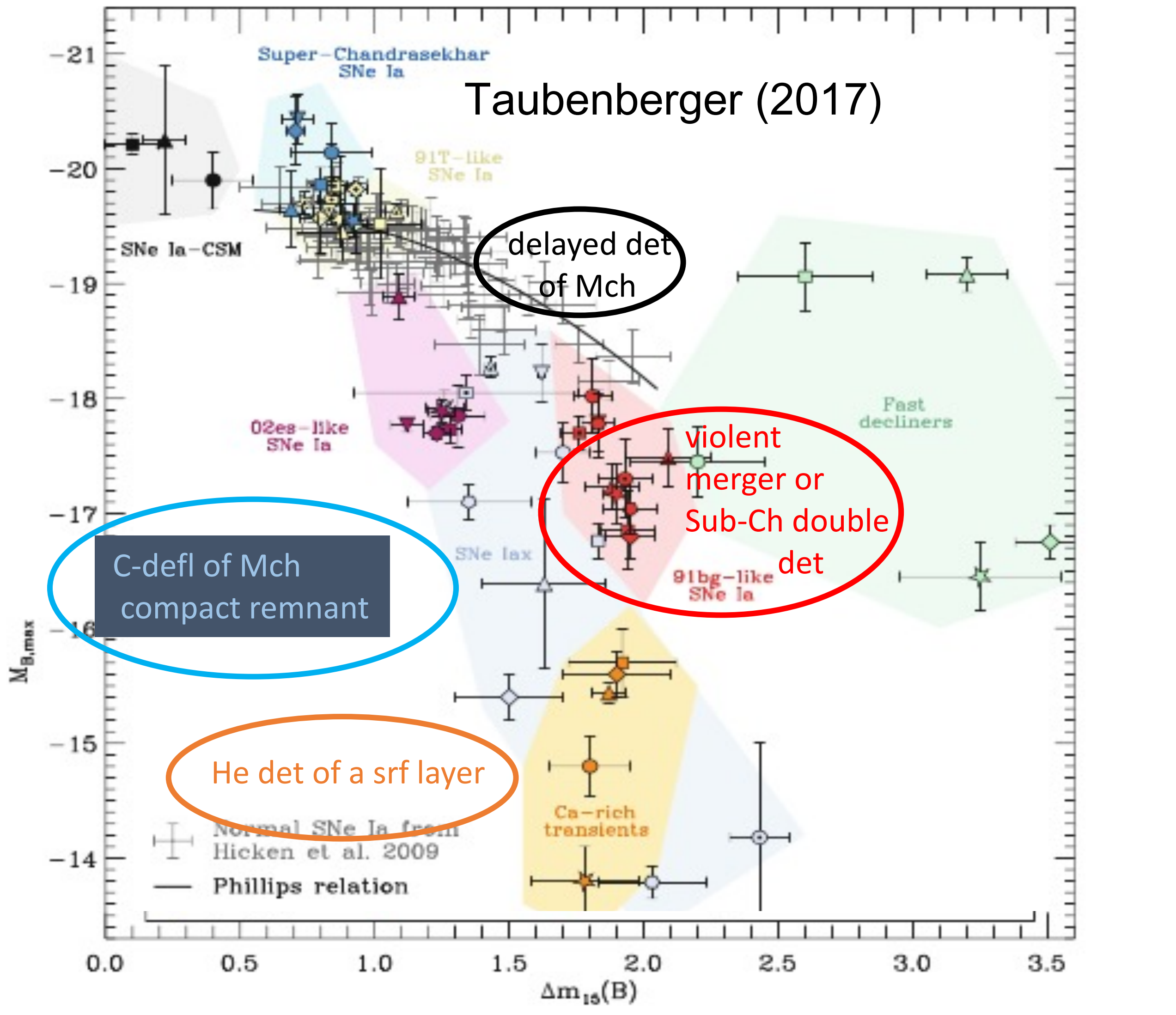
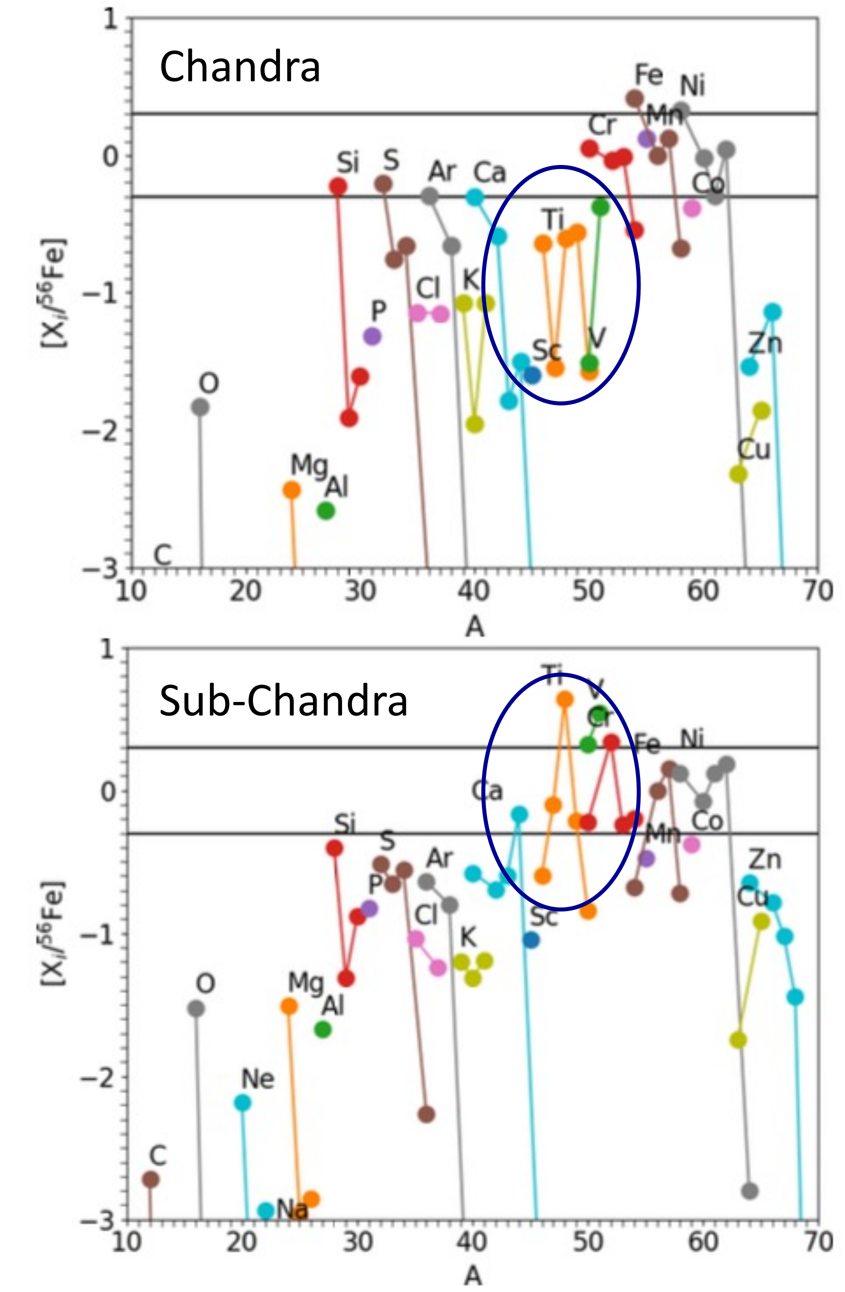
Explosion mechanisms

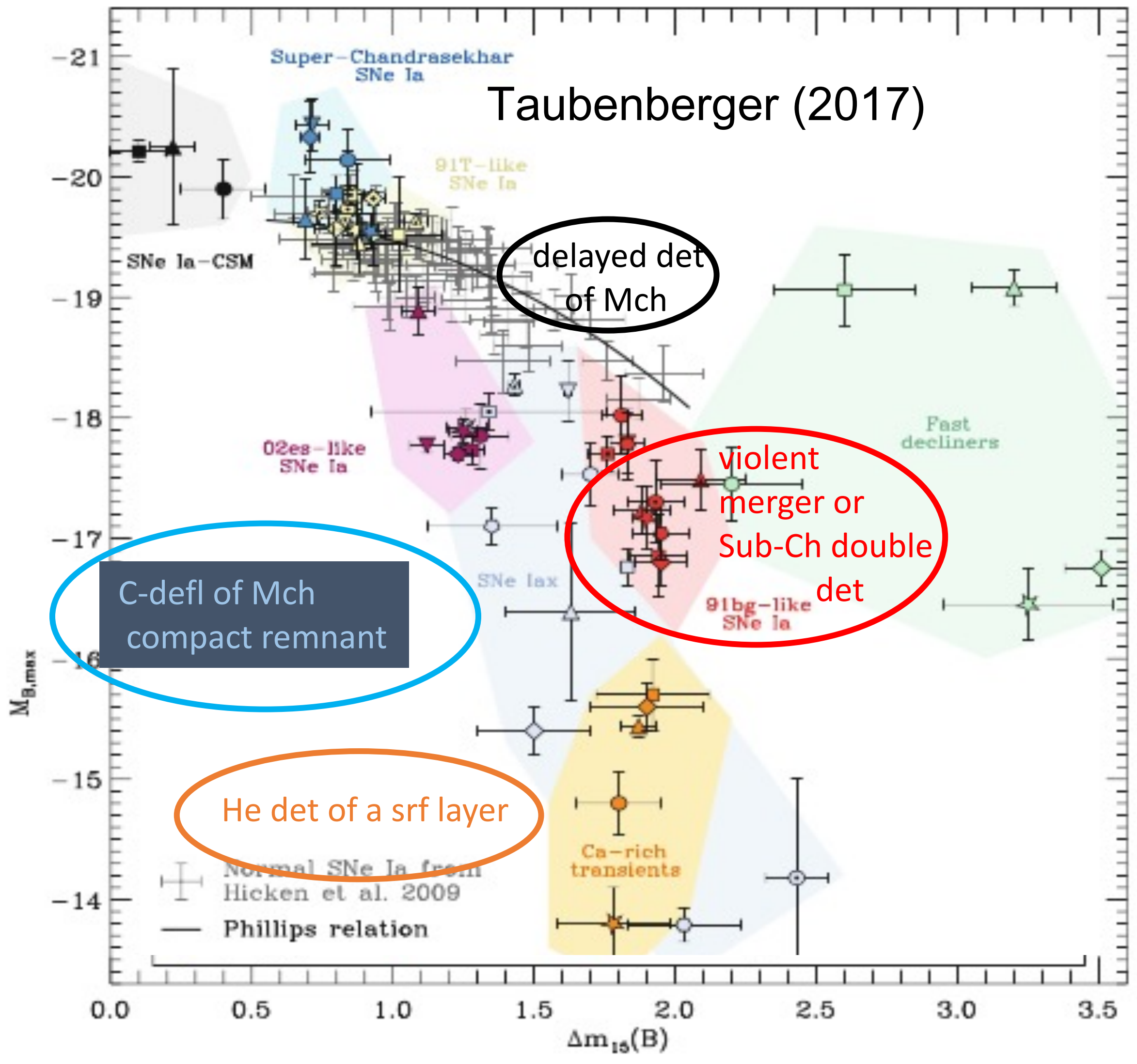


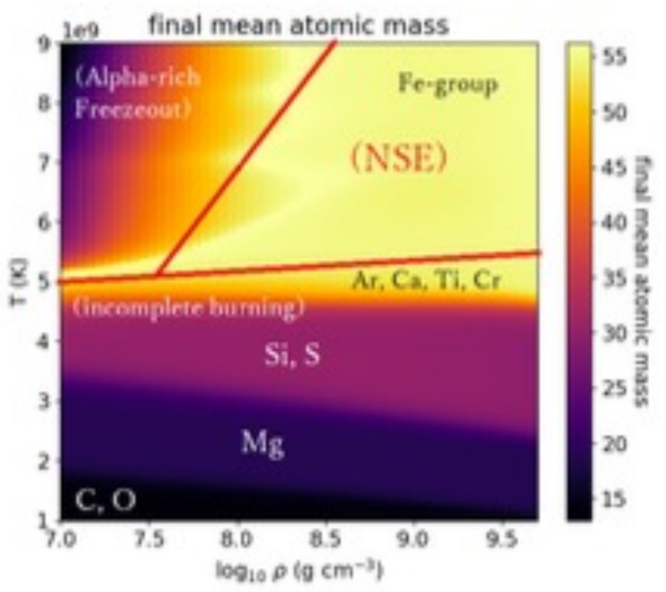
Leung & Nomoto, 2023

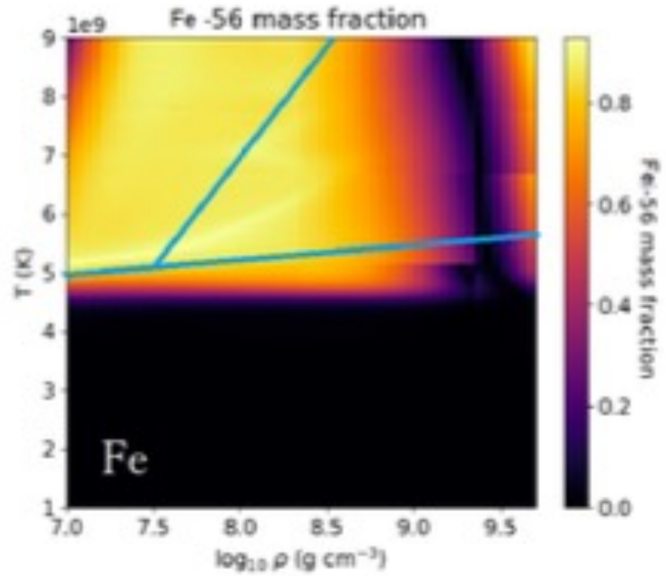


Explosion mechanisms

Leung & Nomoto, 2023

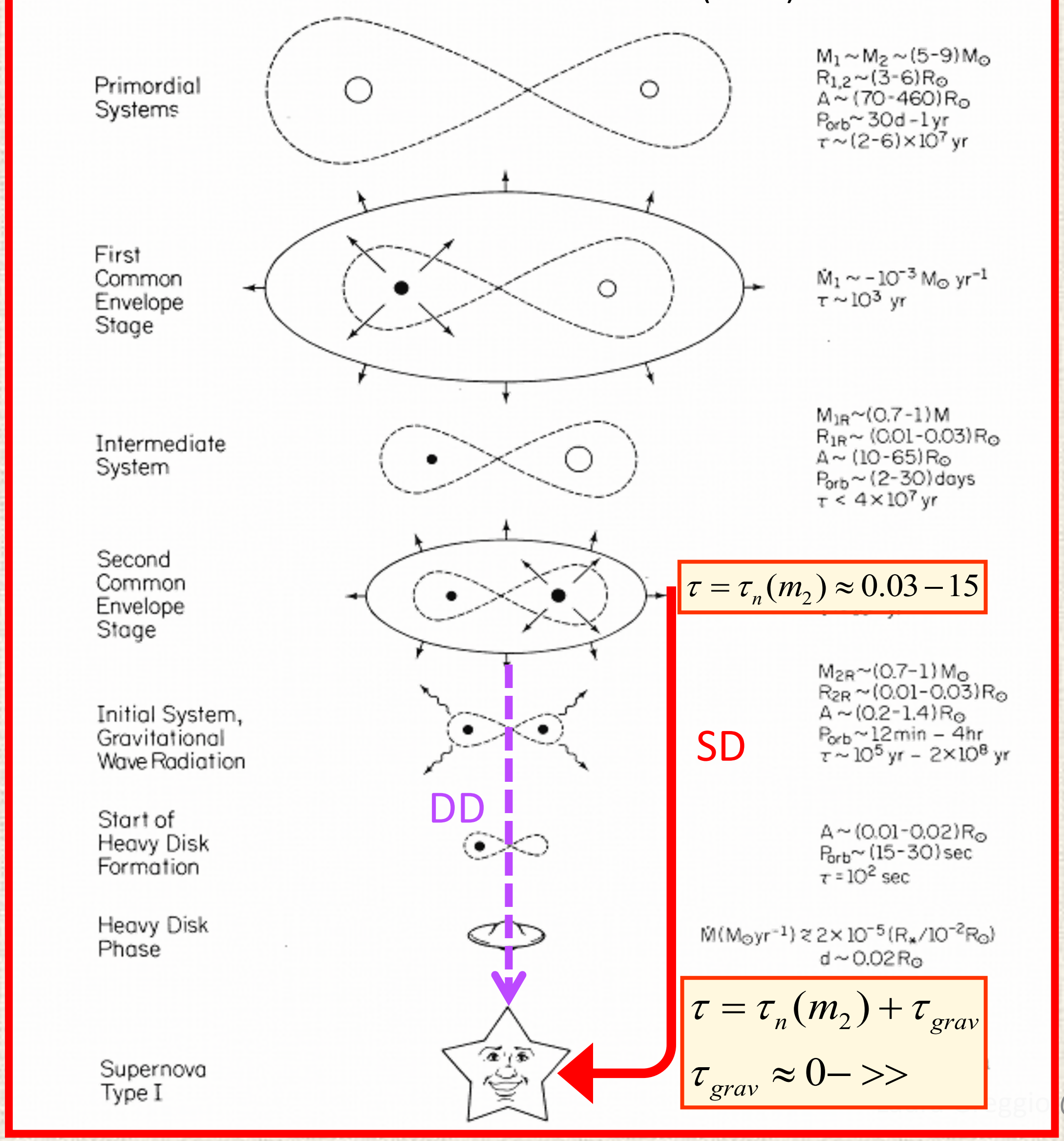




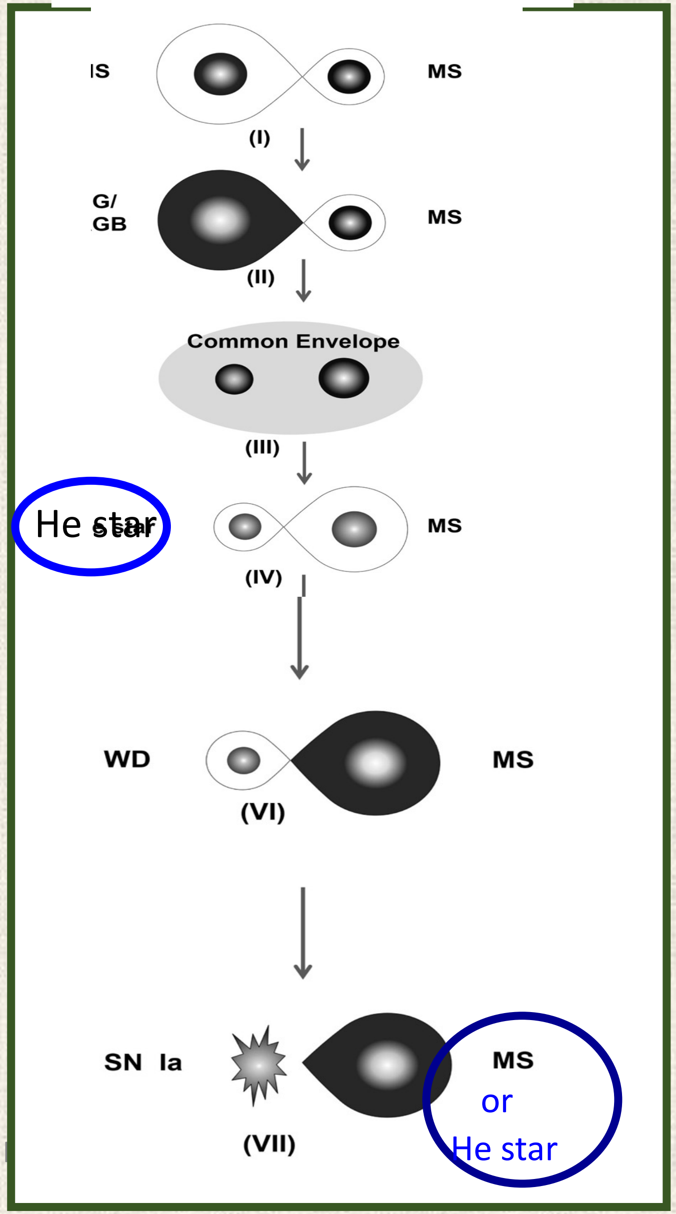


Progenitor systems

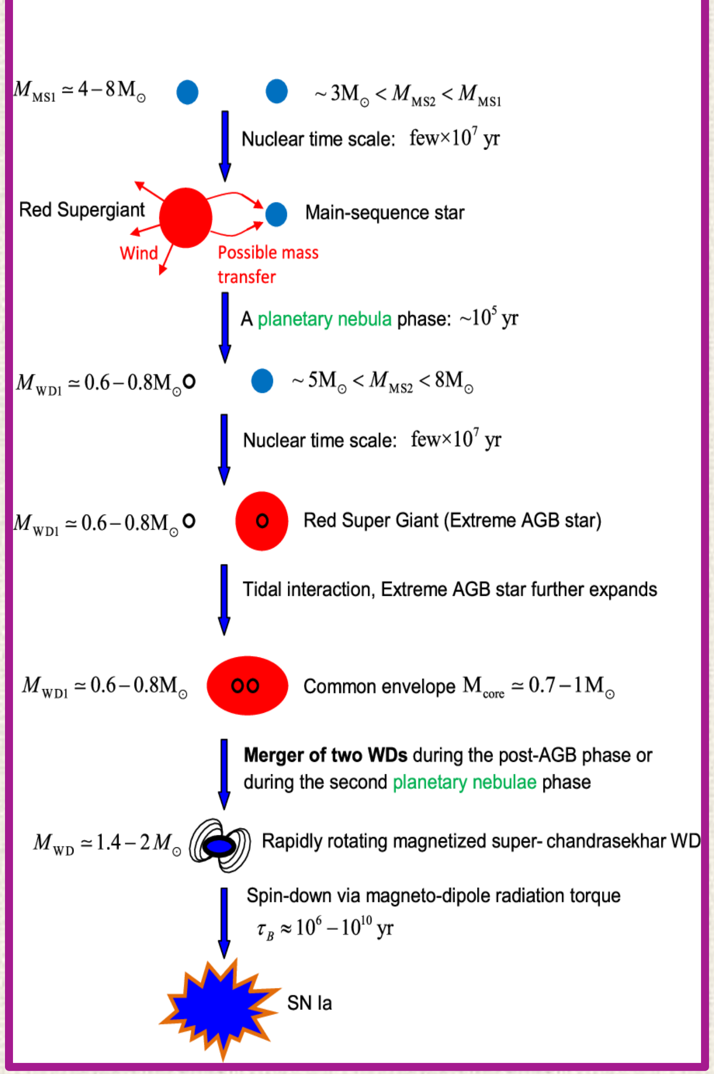
IBEN AND TUTUKOV (1984)



He star channel
Liu & Stancliffe (2020)



Core-degenerate scenario
Ilkov & Soker (2012)



The distribution of the delay times and the SNIa rate

For an instantaneous burst of SF mass M the number of SNIa exploding within *(t,t+dt)* is:

$$dn_{Ia}(t) = M \times k_{Ia} \times f_{Ia}(t_d = t)dt$$

k_{Ia} = realization probability of the Ia scenario (#/Mo)
f_{Ia} is the fraction of systems with delay time t_d equal to t

The distribution of the delay times is proportional to the SNIa rate following a burst of SF

$$\dot{n}_{Ia}(t) = M \times k_{Ia} \times f_{Ia}(t_d = t)$$

$$\int_0^{t_H} f_{Ia}(t)dt = 1$$

Analytical DTDs: Single Degenerates

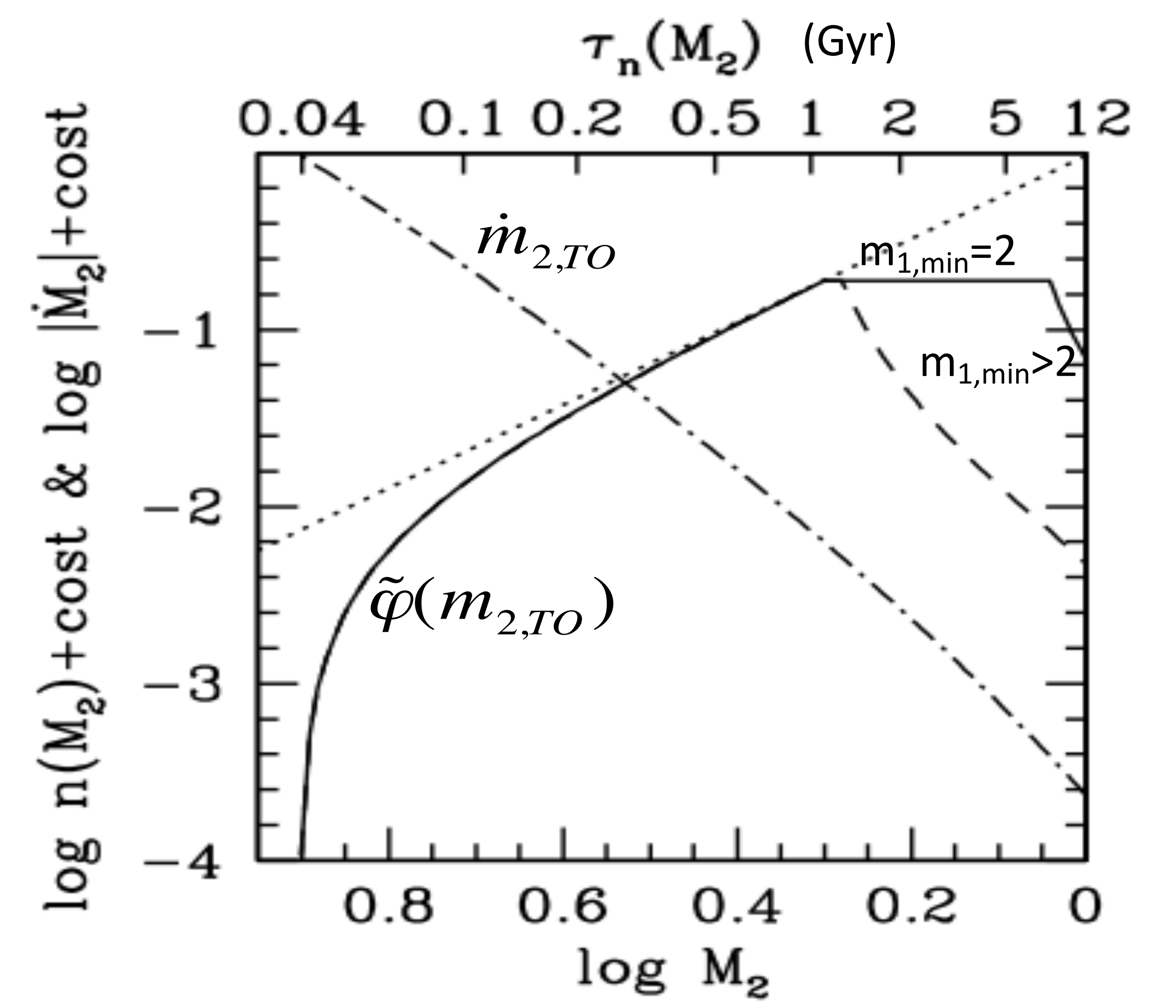
The clock is the evolutionary lifetime of the secondary

$$f_{Ia}(t)dt \propto n(m_2)dm_2$$

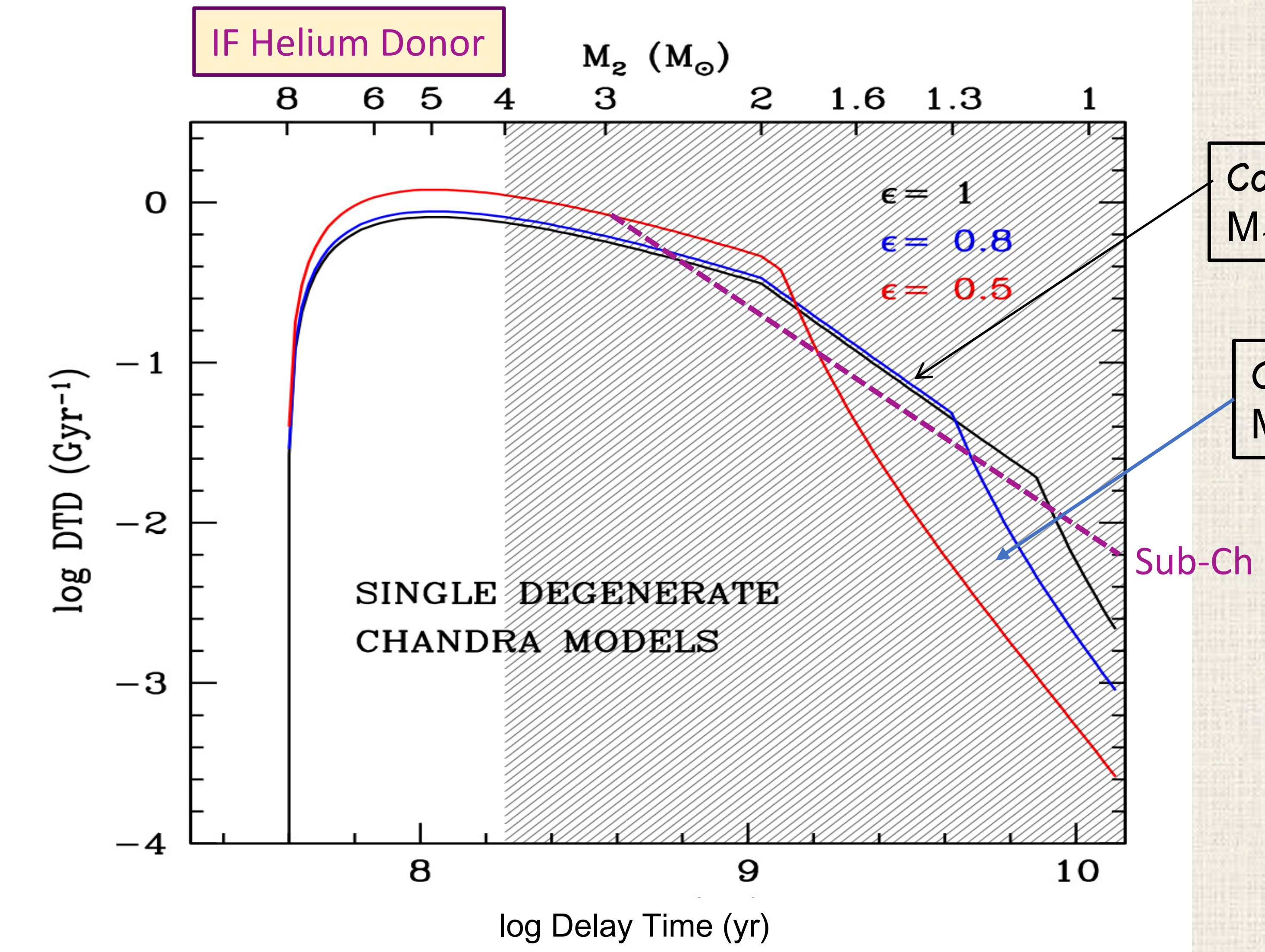
$$f_{Ia}(t) \propto \left|\dot{m}_{2,TO}(t)\right| \times \tilde{\varphi}(m_{2,TO})$$

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

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



Analytical DTDs: Single Degenerates

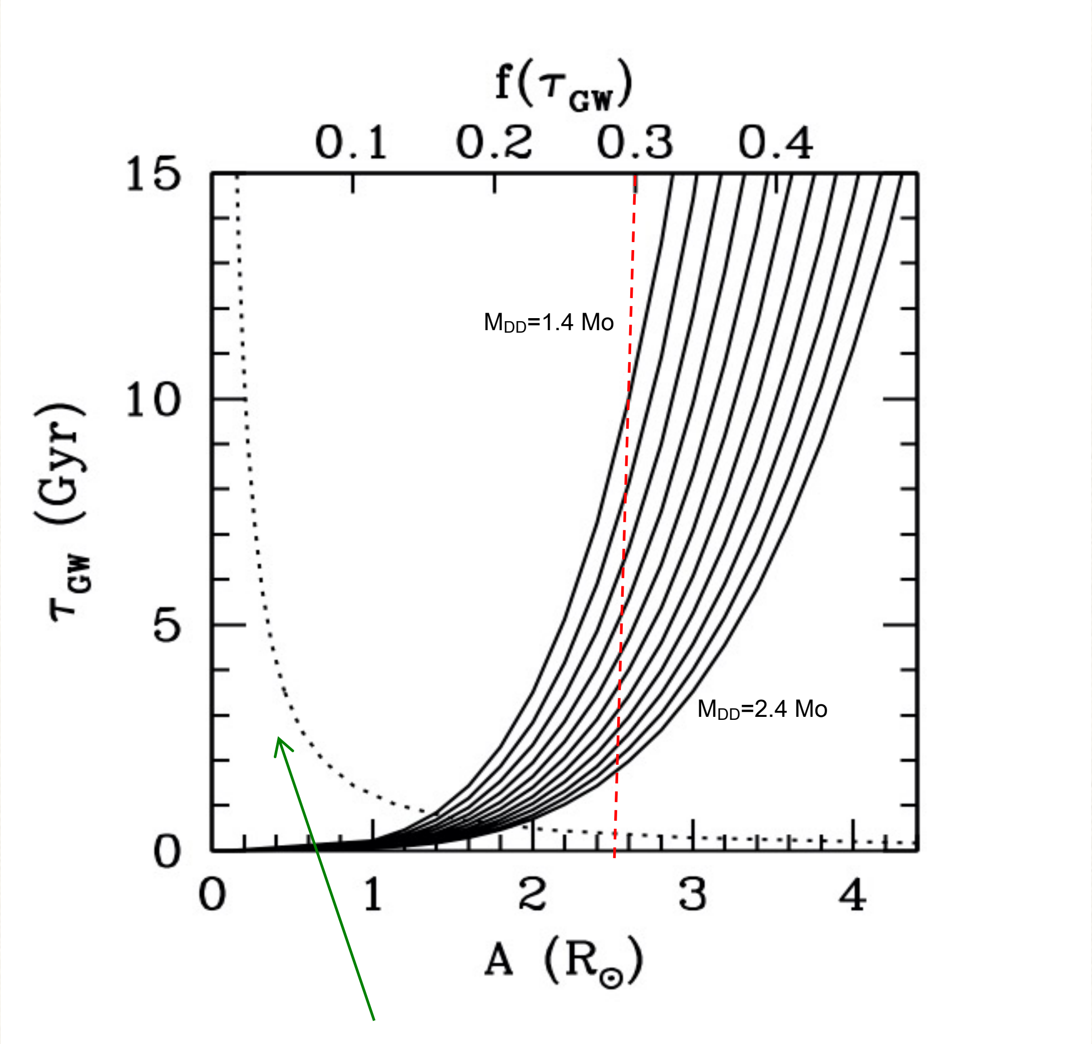


Condition:
$M_{1,min} = 2\ M_\odot$

Condition:
$M_{WD} + \varepsilon\ M_{2,env} \geq 1.4\ M_\odot$

At 10 Gyr:
$M_2=1$, $M_{2,env} \approx 0.7$
If $\varepsilon=1$ $M_{WD,min}=0.7$
$M_{1,min} = 3$
If $\varepsilon=0.5$ $M_{WD,min}=1.1$
$M_{1,min}= 6.5$

Analytical DTDs: Double Degenerates



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

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

$$\tau_{GW} = \frac{0.15A^4}{m_{WD1}m_{WD2}(m_{WD1}+m_{WD2})} \cong 0.6\frac{A^4}{M_{DD}^3}$$

$\tau_{MS}(m_2) < 1$ Gyr

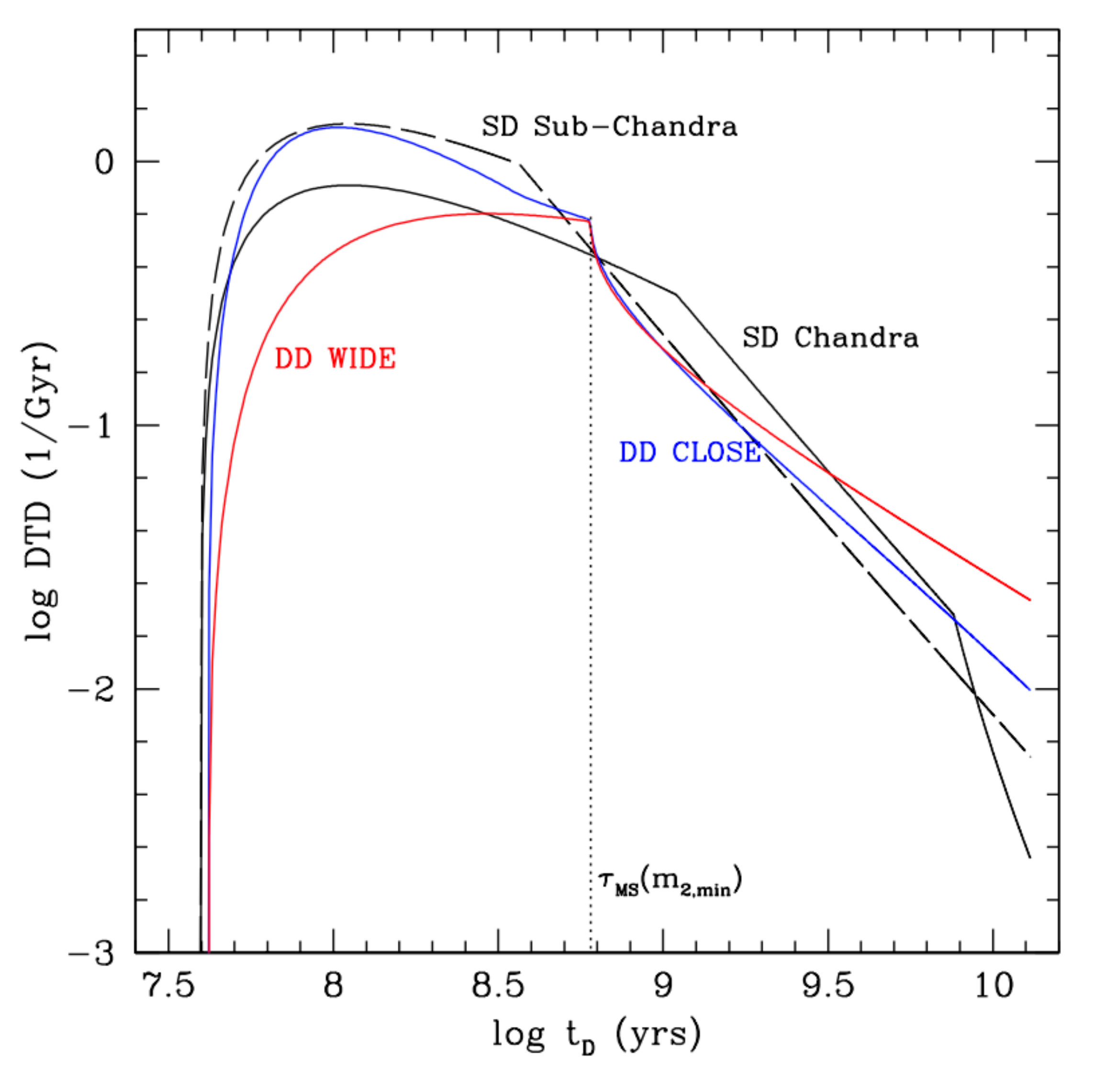
DD CLOSE: CE shrinks more the more massive the systems

t_{MS} short -> t_{GW} short: DTD more populated at short delays

DD WIDE: M_{DD} and A decoupled

DTD is flatter than for the DD CLOSE

Analytical DTDs: Double Degenerates



The DTD is a modified SD curve

Width of the peak controlled by the least massive secondary in successful systems

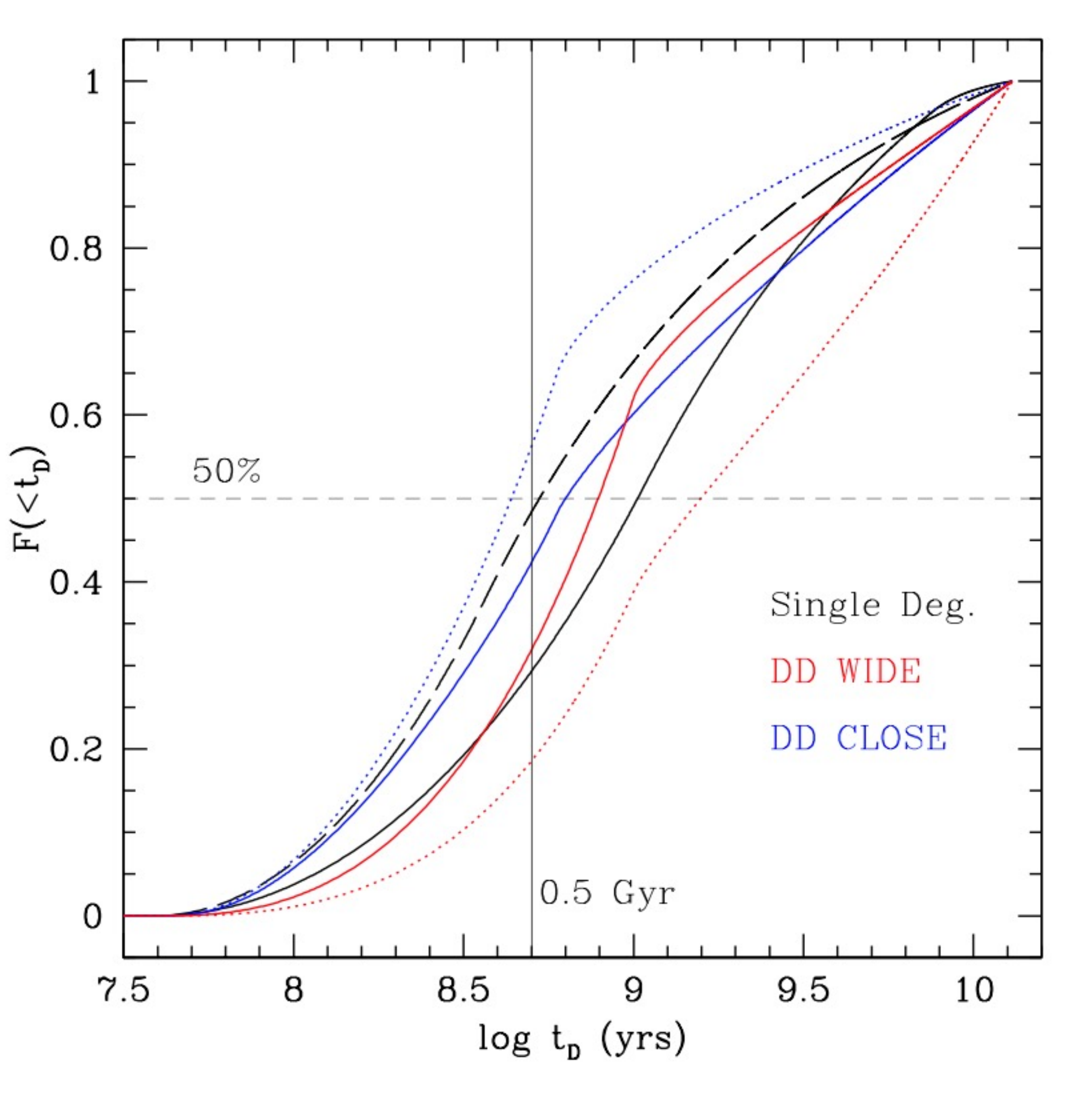
Late epoch decline controlled by distribution of separations A

at late delay times: $t_d \sim \tau_{GW}$ $\tau_{GW} \propto A^4$

$n(t_d)dt_d \propto n(A)dA$ $\frac{dA}{dt_d} \propto 0.25 t_d^{-0.75}$

$n(A) \propto A^\beta$ $n(\tau)d\tau \propto \tau^{0.25\beta - 0.75}$

Cumulative fraction of explosions



Different DTDs imply

- different timescales for the release of SNIa products to the ISM
  50% of events within the first

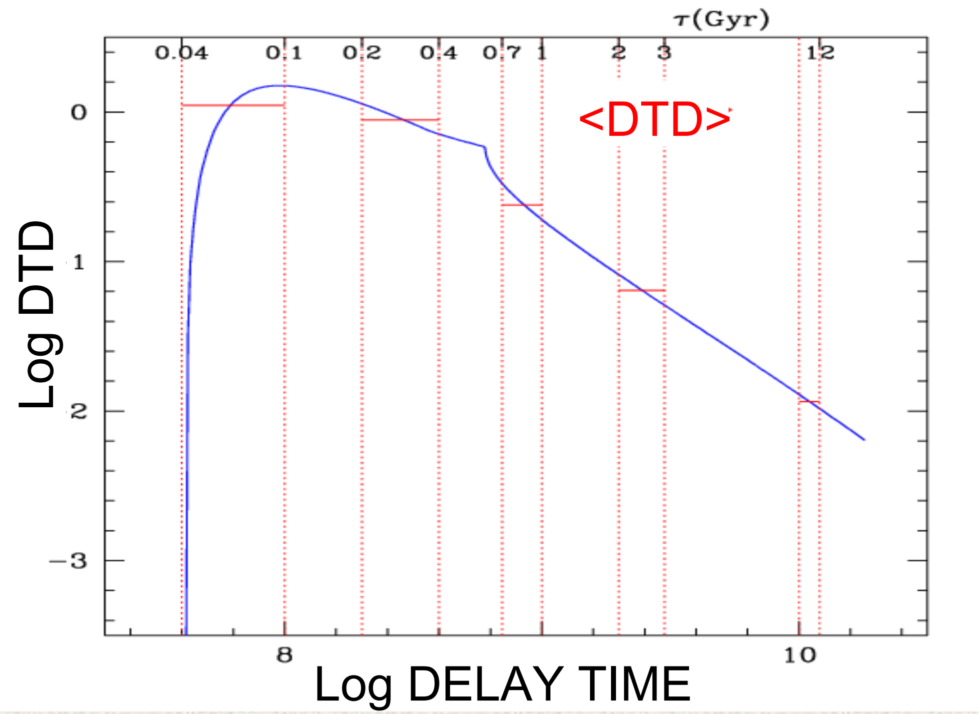
	0.5	0.65	0.8	1	Gyr
for	s-Ch	DDC	DDW	SDCh	

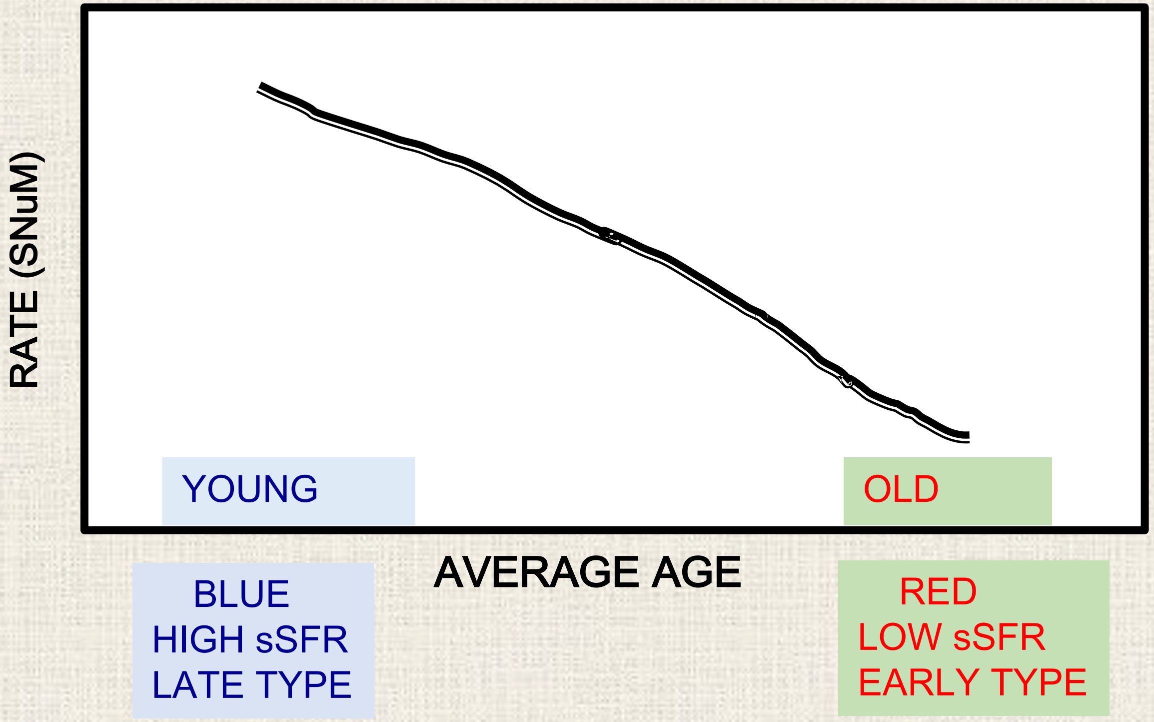
- different fractions of prompt events (e.g. events within the first 0.5 Gyr)

Correlation of the SNIa rate with the properties of the host

$$\dot{n}_{Ia}(t) = k_{Ia}\int_0^t \psi(t-t_d) f_{Ia}(t_d)\,dt_d$$

$$R_{Ia}(t) = \frac{\dot{n}_{Ia}(t)}{\int_0^t \psi(t)} = k_{Ia}\langle f_{Ia}\rangle$$



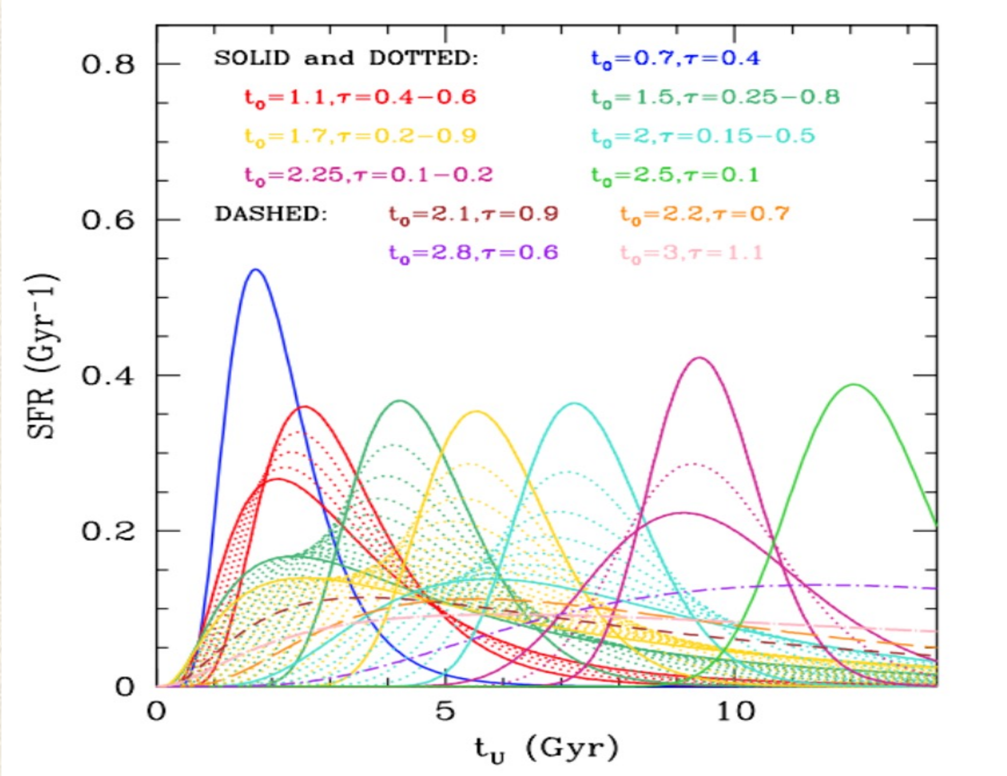


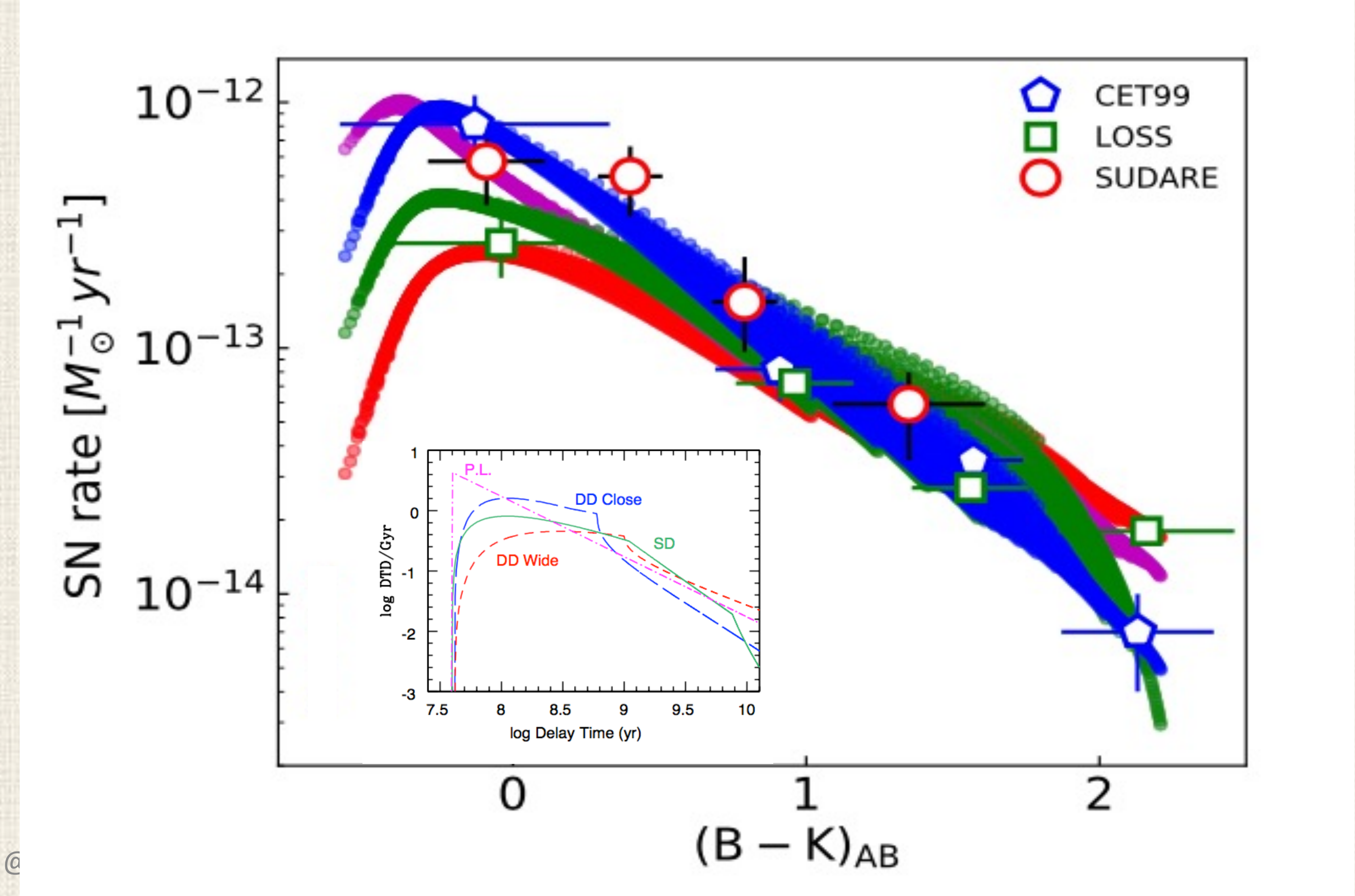
Younger galaxies have higher rates per unit mass than *older* galaxies

Constraining the DTD with the SNIa rates

(Greggio & Cappellaro,2019, AA625, A113)

Comparison between models and observed rates
for a family of Log-Normal SFH (Abramson et al. 2016)

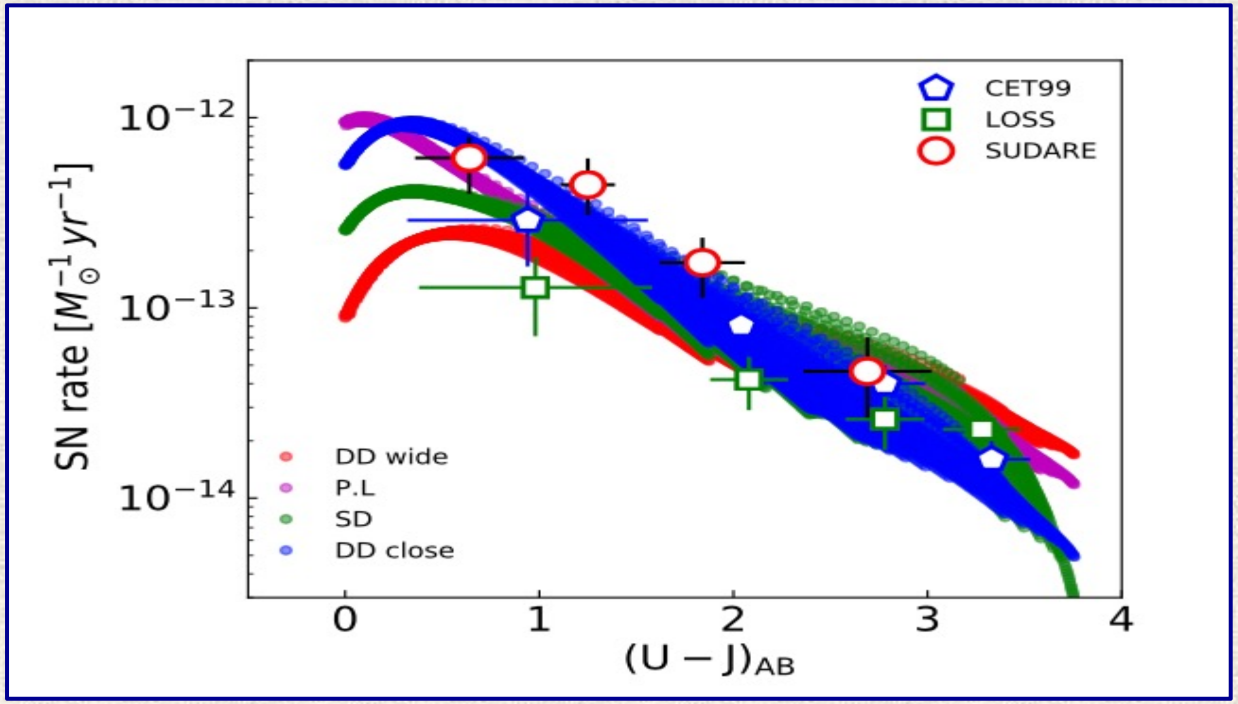


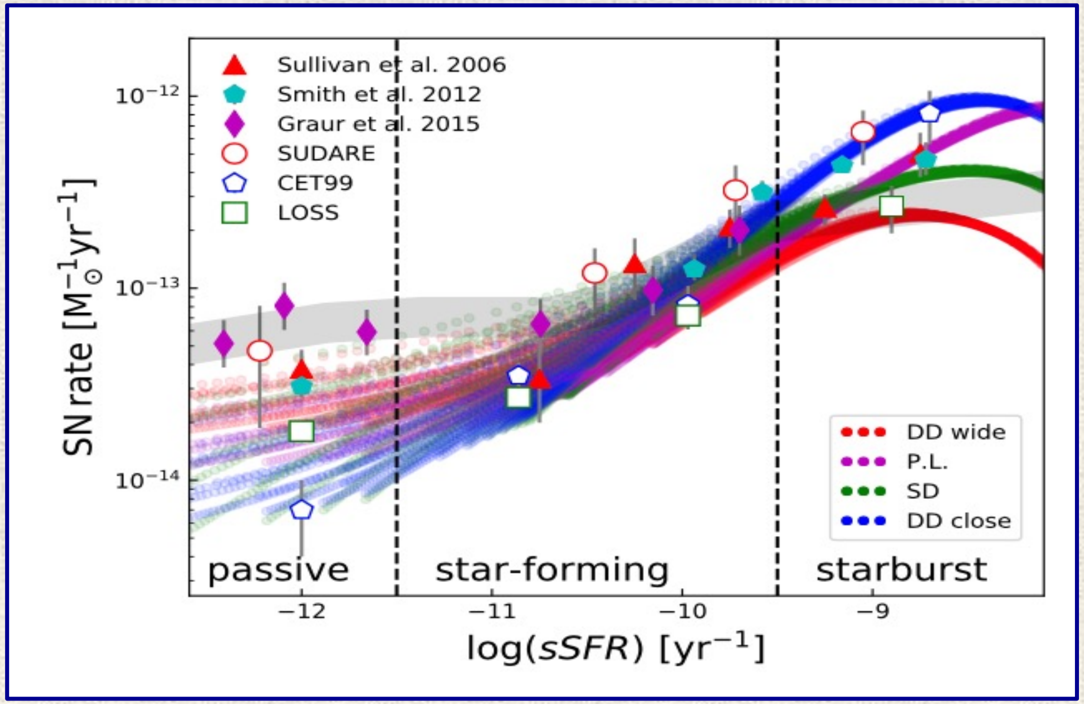


Constraining the DTD with the SNIa rates

(Greggio & Cappellaro,2019, AA625, A113)

Comparison between models and Observed rates for Log-Normal SFH



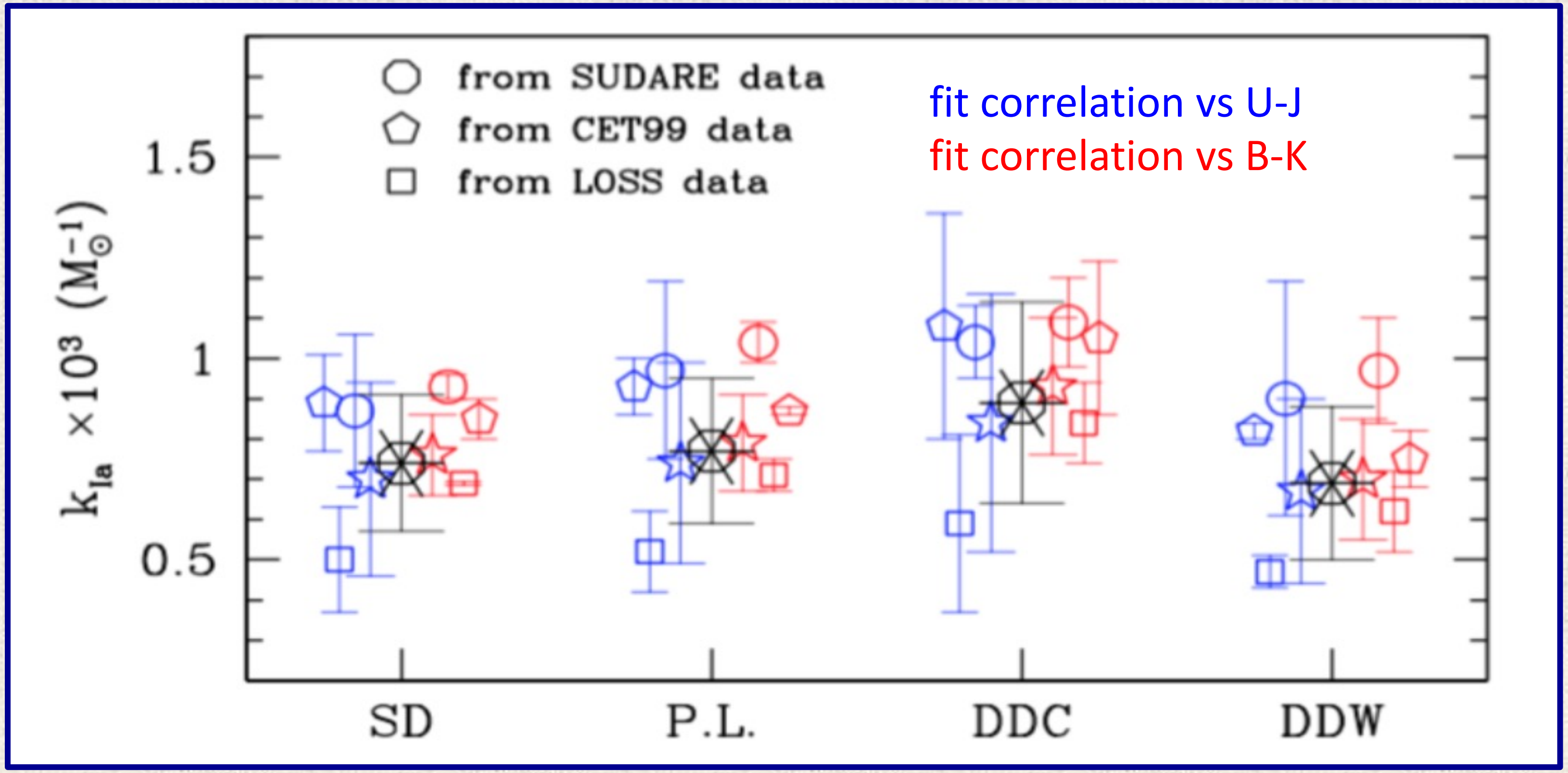


The differences of the observed rates at the color/sSFR extremes will yield a robust constraint on the DTD model

k_{Ia} : the realization probability of the SNIa channel

the number of SNIa's from one solar mass stellar population exploding within a t_H

$$R_{Ia}(t) = \frac{\dot{n}_{Ia}(t)}{\int_0^t \psi(t)} = k_{Ia}\langle f_{Ia}\rangle$$



At intermediate color the rates are similar: $k_{Ia} = 0.8 \times 10^{-3}\ (1/M_o)$

compare with $N(m=2.5-8)/M = 4 \times 10^{-2}\ (1/M_o)$

Kilonovae

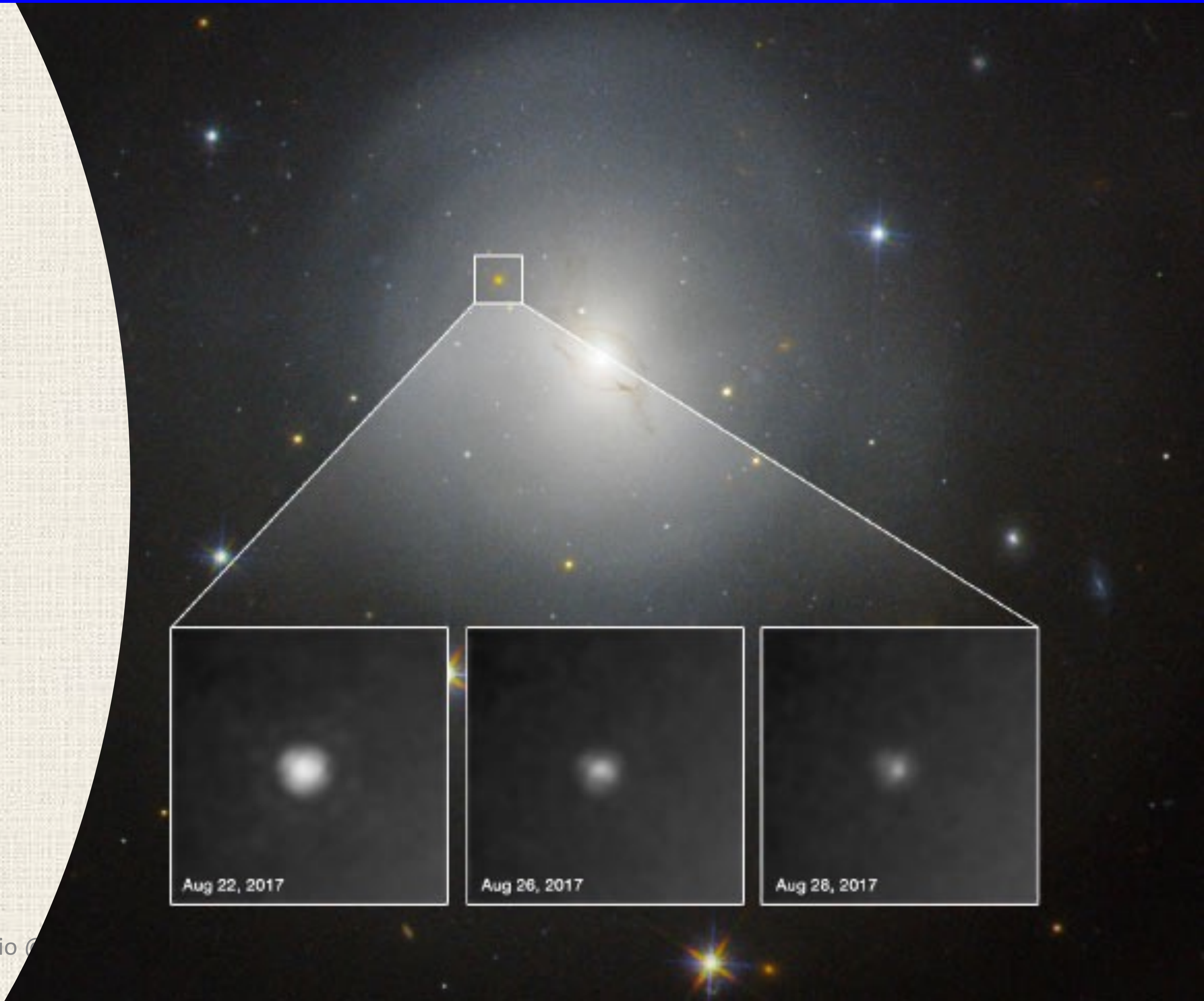
On Aug 17, 2017 a GW signal from a NSM was detected by LIGO/VIRGO (GW170817)

11 hr later Las Campanas detects one optical transient in the same region of the sky (AT2017gfo)

FERMI and INTEGRAL register a sGRB (GRB170817A) occurred shortly after GW170817 in the same sky region

9 days later CHANDRA detects it in x-rays
16 days later VLA detects it in the radio

NSM ---- sGRB ---- KNe



The Delay Time of Kilonovae

(Greggio, Simonetti & Matteucci, 2021, MNRAS 500, 1755)

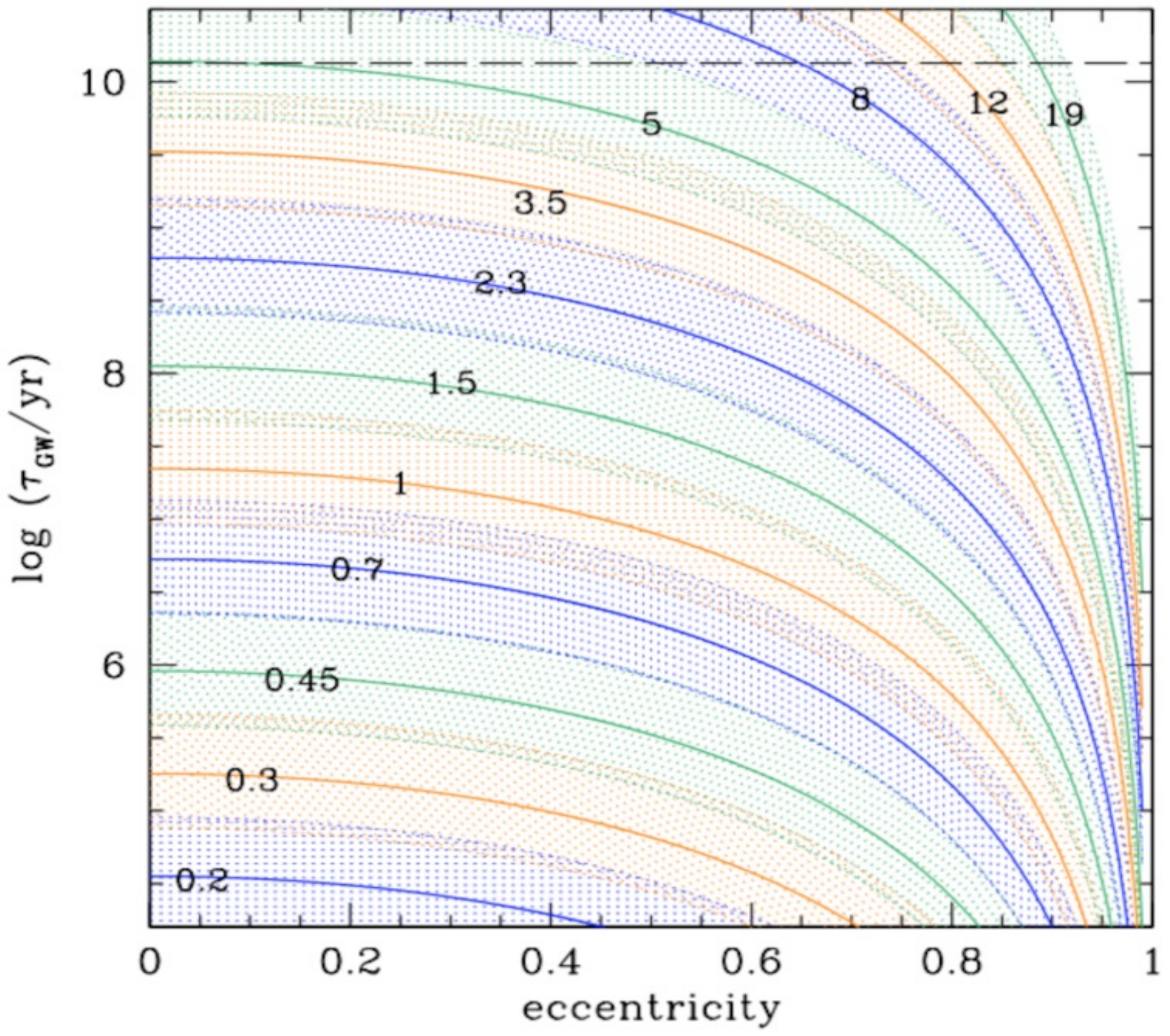
$$t_d = \tau_{MS}(m_2) + \tau_{GW}$$

$$\tau_{MS}(m_2) = 5 - 30\ Myr \ll \tau_{GW}$$

$$\tau_{GW} = \frac{0.6A^4}{M_{DN}^3} \times (1 - e^2)^{7/2}\ \mathrm{Gyr}$$

Shaded regions show range for $2.2 < M_{DN} / Mo < 4$

Labels show A in Ro



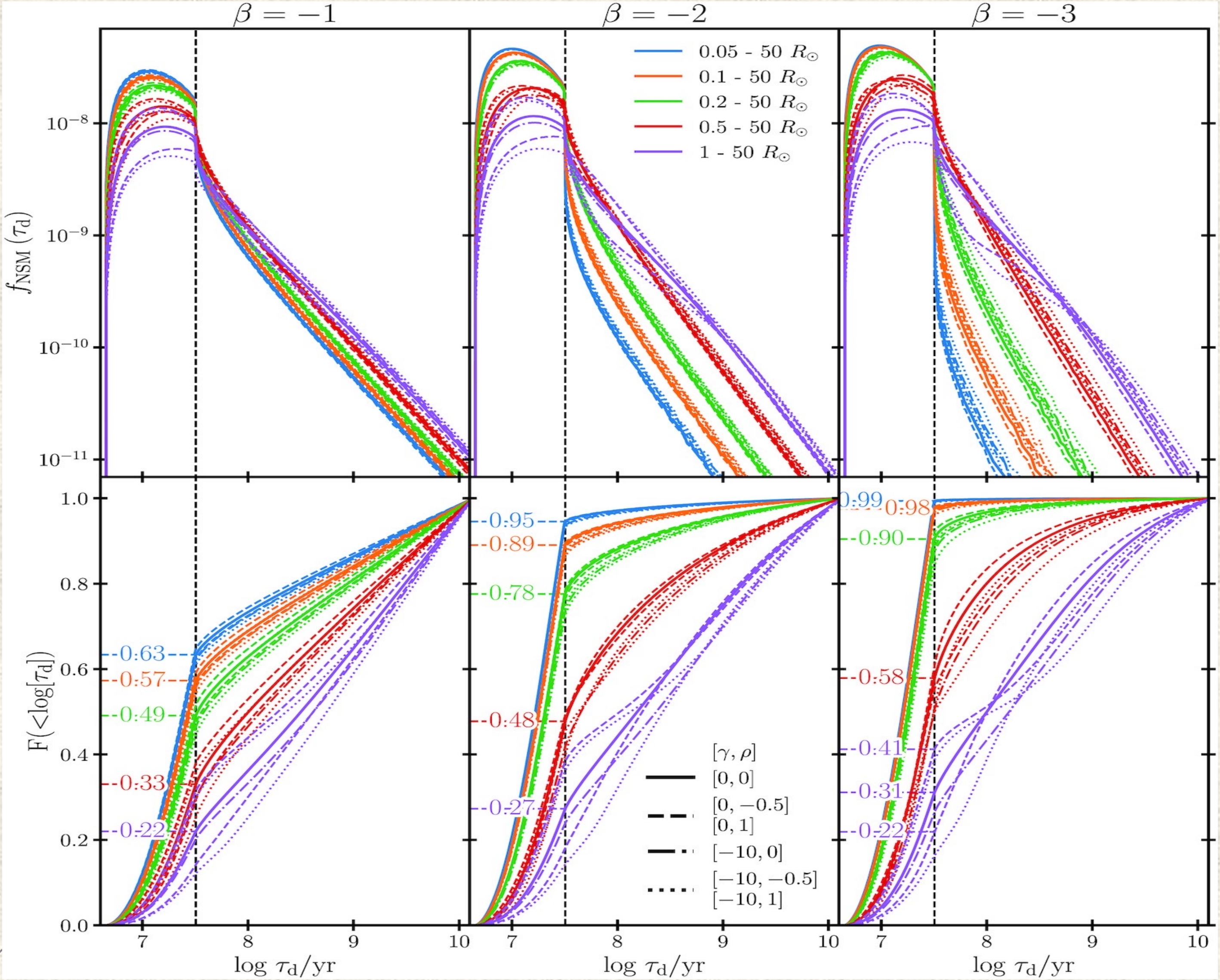
The DTD of Kilonovae

(Cavallo & Greggio 2023, MNRAS 522, 3529)

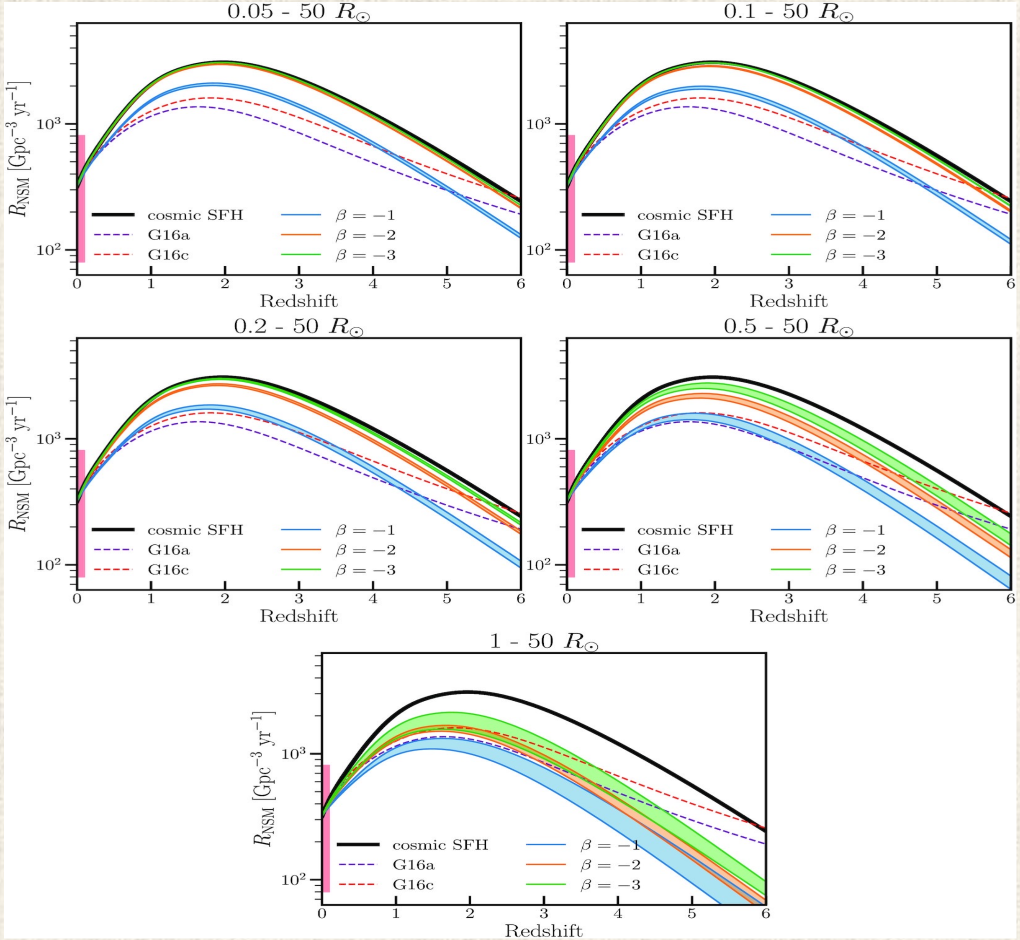
$$\tau_{GW} = \frac{0.6A^4}{M_{DN}^3} \times (1-e^2)^{7/2}\ \mathrm{Gyr}$$

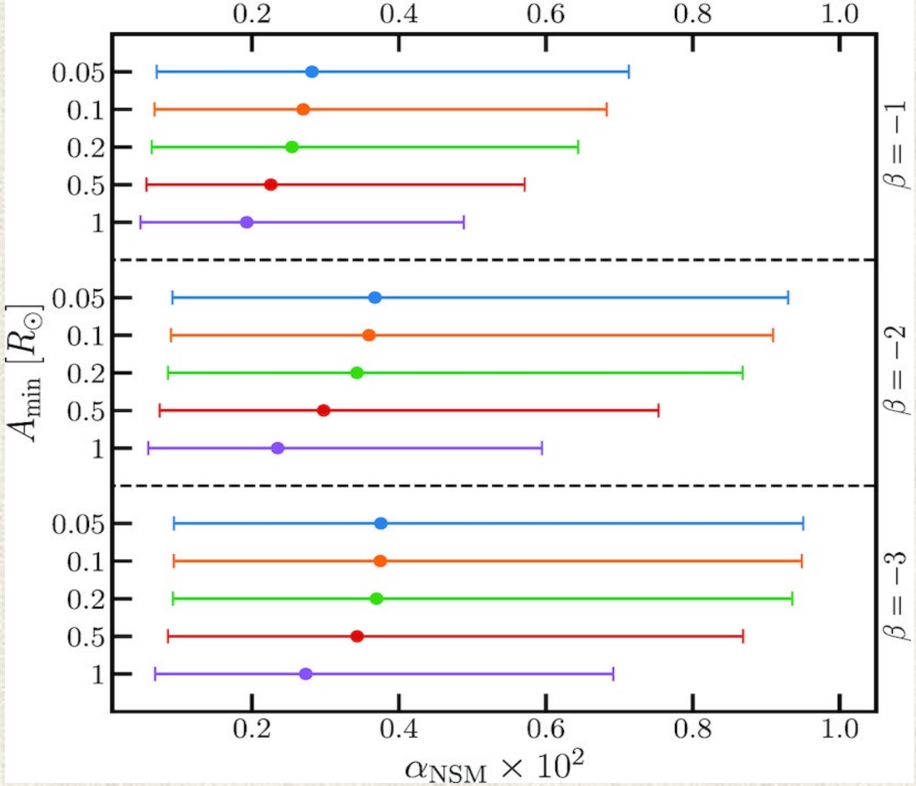
$$\begin{cases} f(A) \propto A^{\beta} & A > A_{min} \\ f(M_{DN}) \propto M_{DN}^{\gamma} \\ f(e) \propto e^{\rho}. \end{cases}$$

β=-1,-2,-3 A_{min}/R_o = 0.05,0.1,0.2,0.5,1
γ = -10 , 0
ρ = -0.5, 0, 1

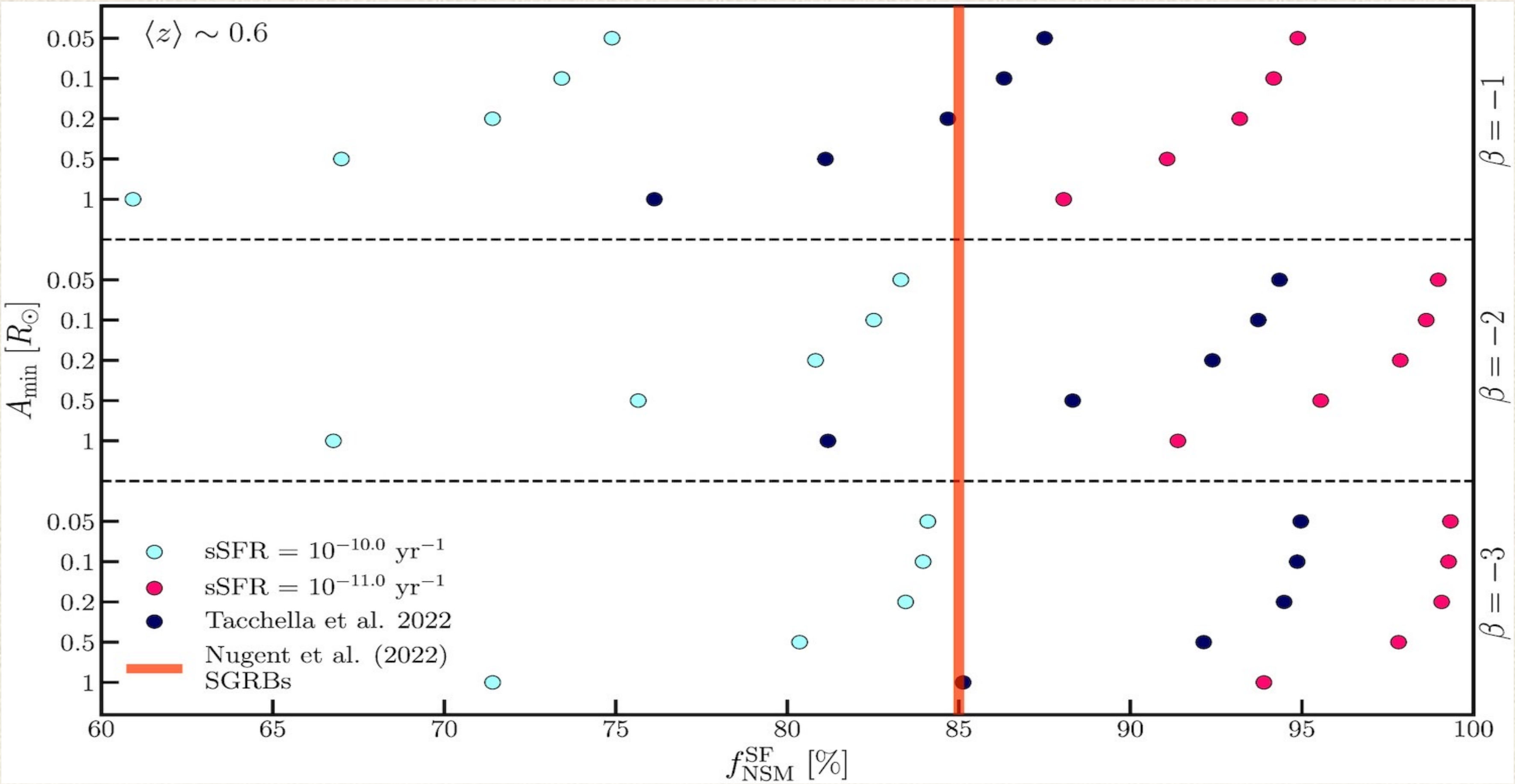


Constraining the DTD of Kilonovae: cosmic rate





Constraining the DTD of Kilonovae: properties of host galaxies



WRAPPING UP

Progenitors: likely both SDs and DDs

Explosion mechanisms: both Chandra and Sub-Chandra

The large diversity suggests that more mechanisms are at work, though the Delayed Detonations may be the typical mechanism of the 'normal' SNIa

The DTD : wide, more populated at short delay times

To constrain its shape we need a detailed understanding of the galaxies' SFH

The realization probability is about 1 event per 1000 Mo of parent population

To improve our understanding: thorough mapping of the diversity of the SNIa events with the properties of the host, both global and local