# The Rates of Type Ia Supernovae: a theoretical viewpoint

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# THE RATES OF SNIa's

- SNIa are important contributors of Fe

  → their rate is fundamental for the chemical evolution of stellar systems

  infer formation timescales from alpha overabundance

  their number is important for total Fe content of Galaxy Clusters and of the Universe

- SNIa provide a large energy input to the ISM

  → their rate is relevant for gas flows in Es and for feedback following SF episodes

- The scaling of the SNIa rate in different kinds of stellar populations provides clues on the progenitors

  → impact on the cosmological use of SNIa's

# THE SNIa RATES IN STELLAR SYSTEMS

$$\dot{n}_{Ia}(t_0) = k_{Ia} \int_0^{t_0} \psi(t - t_D) f_{Ia}(t_D) dt_D$$

$\psi$ is the SFR; $t_D$ is the delay time

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

$f_{Ia}$ is the distribution function of the delay times

For an instantaneous burst of Star Formation producing $M_{SF}$ mass of stars

$$\dot{n}_{Ia}(t_0) = k_{Ia} M_{SF} f_{Ia}(t_D = t_0)$$

Different channels for SNIa production correspond to different proportions of early/late epoch explosions, i.e. different DTDs

THE OBSERVED RATES IN SYSTEMS WITH DIFFERENT SF HISTORY MAP SUCH PROPORTIONS

# CLOSE BINARY EVOLUTION

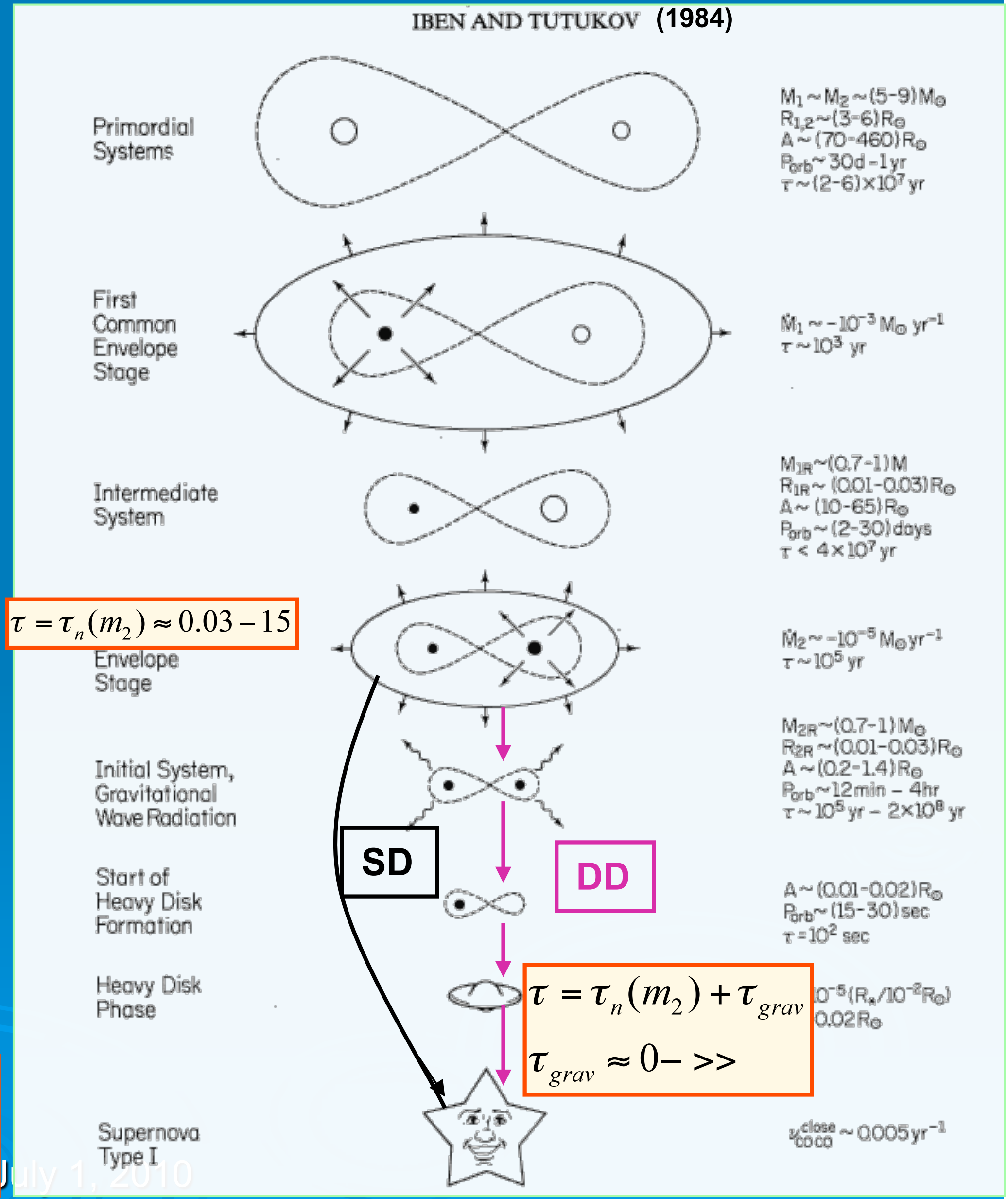
Provides two main cathegories of
SNIa progenitors:

- ➢ Single Degenerate Systems
  a CO WD accretes from a living companion
- ➢ Double Degenerate Systems
  the companion is another WD

explosion may occur when

- ➢ The WD Mass reaches the Chandrasekhar limit
  Chandra exploders
- ➢ A Helium layer of ≈0.1 $M_O$, accumulated on top of the WD, detonates
  Sub-Chandra exploders

A WIDE RANGE OF DELAY TIMES IN ALL CASES



# WEAKNESSES

H-rich SD CHANNEL : FINE TUNING OF THE ACCRETION RATE, but if consider wind from the WD this is less of a problem

Which fraction of the envelope (ε) of the secondary goes into CO WD growth?
At 13 Gyr, $M_{2,TO} = 0.9$, $M_{2,env} \sim 0.6$ if $\varepsilon = 0.5$, $\Delta M_{CO} \sim 0.3$ and the Ch mass is reached
$M_{WD}(SNIa) > 1.1$ imply $M_1 > 7$ $\longrightarrow$ FEW PROGENITORS

THIS CHANNEL HAS DIFFICULTY TO MAINTAIN A SUSTAINED RATE IN OLD PASSIVE GALAXIES

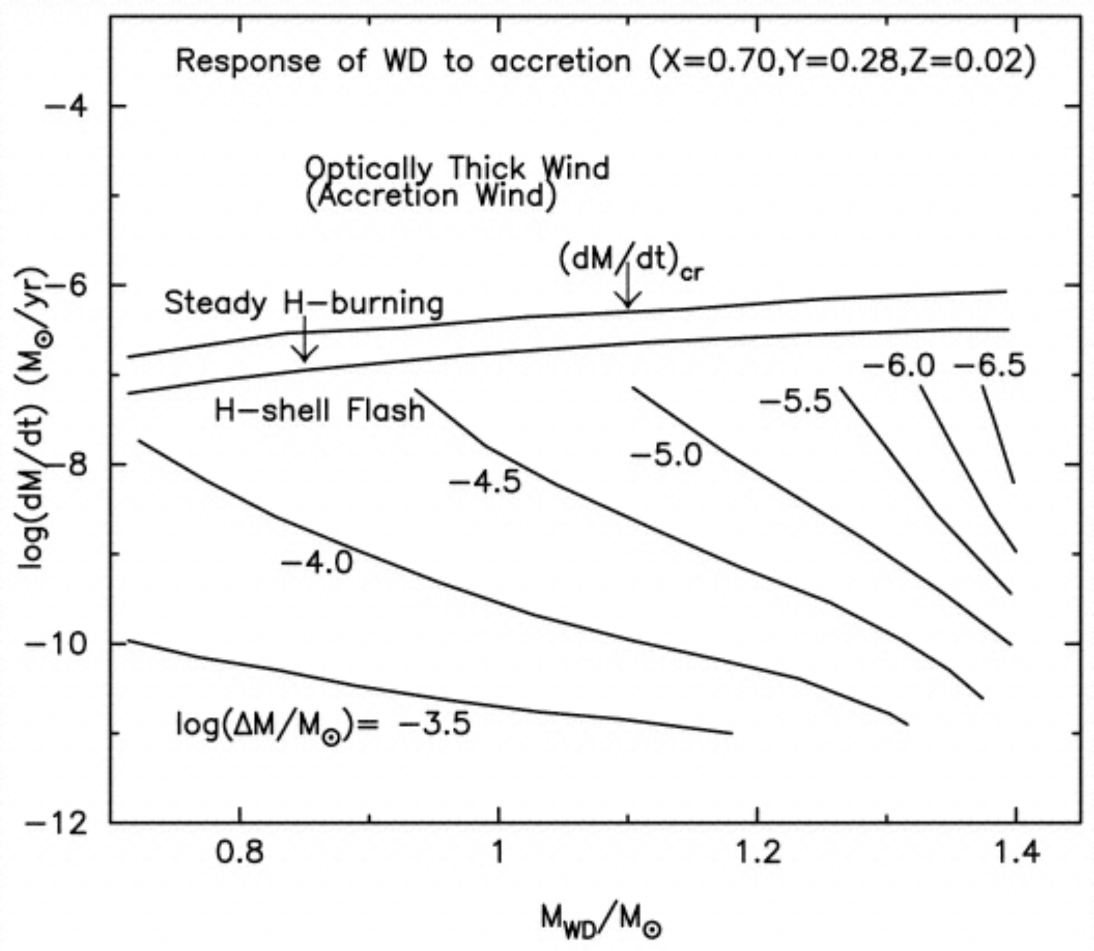
He-rich SD CHANNEL : NEED MASSIVE SECONDARY TO HAVE A LIVING HELIUM STAR

e.g. Wang et al. (2009) find $M_{2,min} \sim 5$ Mo with evolutionary lifetime of ~ 0.1 Gyr

THIS CHANNEL DOES NOT PROVIDE EVENTS LATER THAN A FEW 100 MYR

# FINE TUNING OF ACCRETION RATE

*From Hachisu & Kato 2001, Nomoto 1982*



If accretion rate is small Hydrogen accumulates on top of the WD, and ignites under degenerate conditions
→ NOVA EXPLOSION
and most of the accreted material gets lost

If accretion rate is high, H (and its He ashes) burn steadily in shell,
→ the star becomes a Red Giant and a Common Envelope forms around the two components, to be eventually dispersed

Only within a narrow range of accretion rates (~$10^{-7}$ Mo/yr) H is burnt 'in pace' with accretion, the WD remains compact and grows in mass

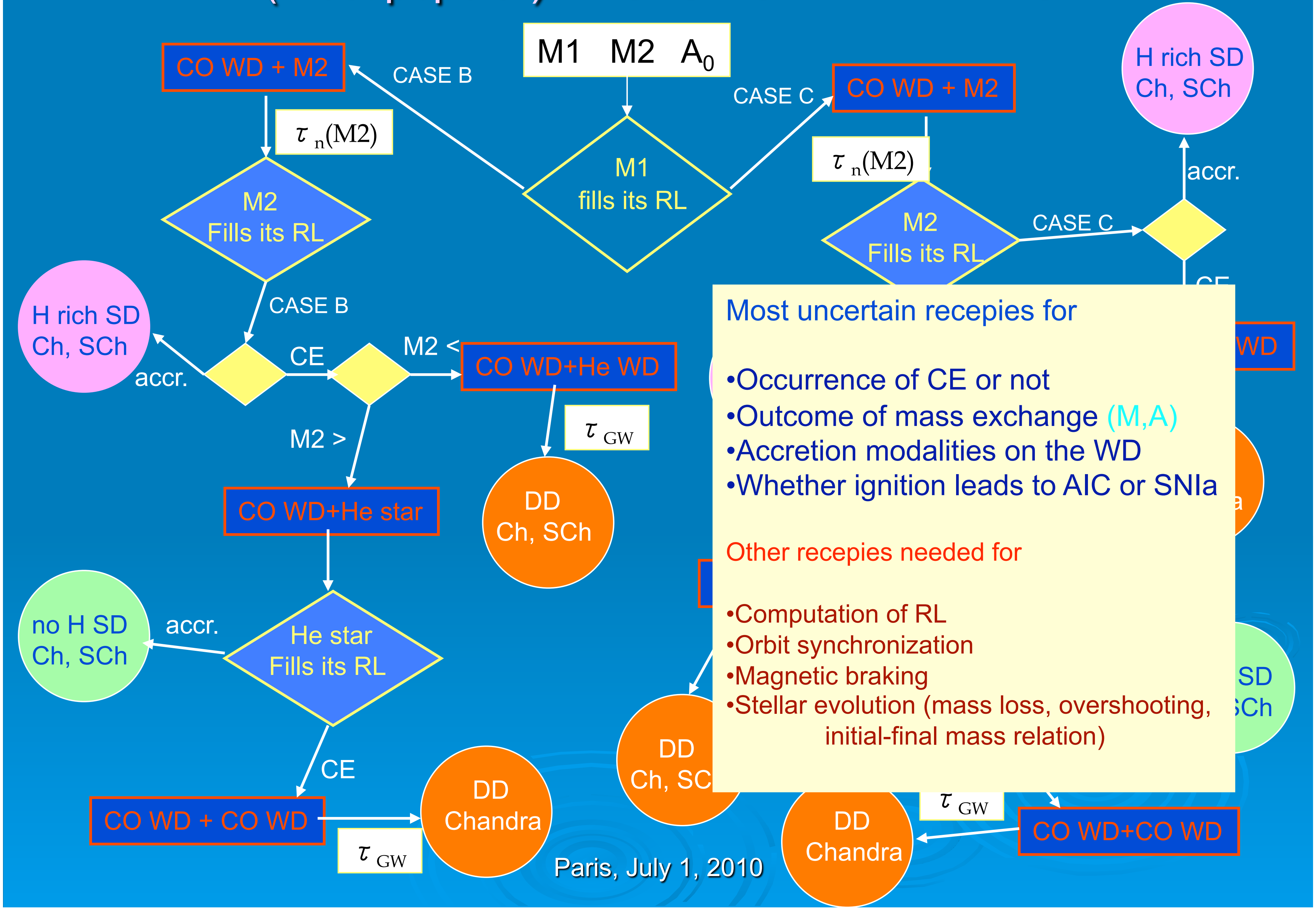
# WEAKNESSES

CO+CO DD CHANNEL : C IGNITES OFF CENTER ⟶ $e^-$ CAPTURE SN
FORMATION OF A n STAR, WITH ~ NO DISPLAY (Saio & Nomoto 1985)
but if rotation is considered C may ignite at the center and lead to explosion
(Piersanti et al. 2003)

THIS CHANNEL MAY PROVIDE NO SNIa AT ALL

SUB-CHANDRA EXPLODERS : IRON GROUP ELEMENTS AT
HIGH VELOCITY, WIDE RANGE OF M(NI)
THIS CHANNEL MAY EXPLAIN SOME SNIa

# (most popular) EVOLUTIONARY PATHS



Most uncertain recepies for

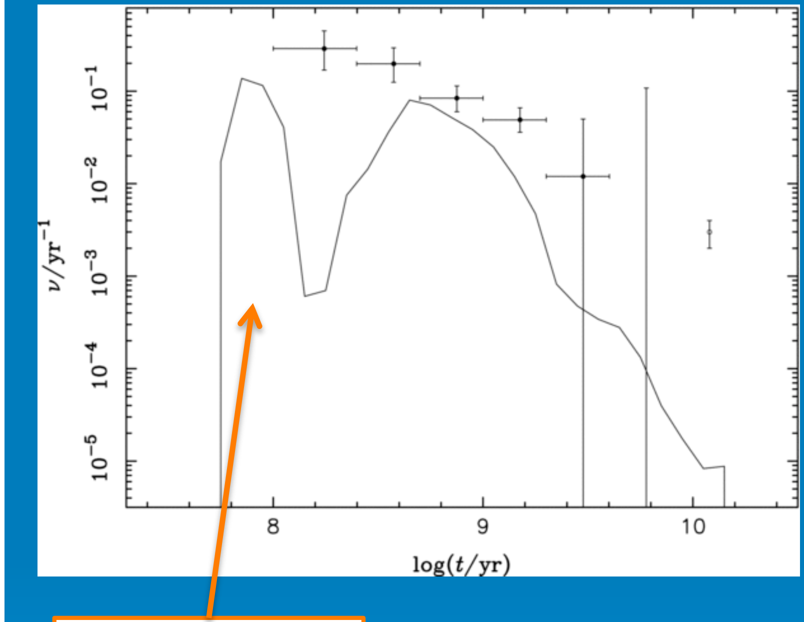
- Occurrence of CE or not
- Outcome of mass exchange (M,A)
- Accretion modalities on the WD
- Whether ignition leads to AIC or SNIa

Other recepies needed for

- Computation of RL
- Orbit synchronization
- Magnetic braking
- Stellar evolution (mass loss, overshooting, initial-final mass relation)

# DTDs FROM BPS codes:
# SD progenitors

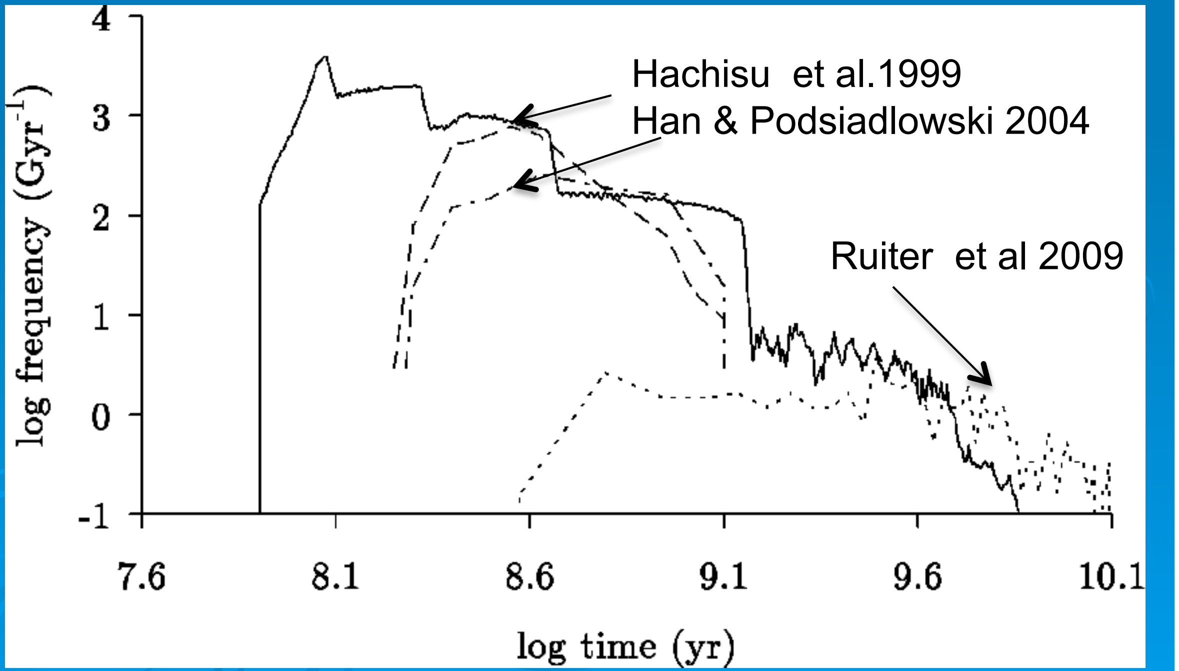
*From Meng & Yang 2010*



He star + WD

The agreement between the results of different BPS codes for the SD channel looks rather poor

*From Mennekens et al 2010*



Hachisu et al.1999

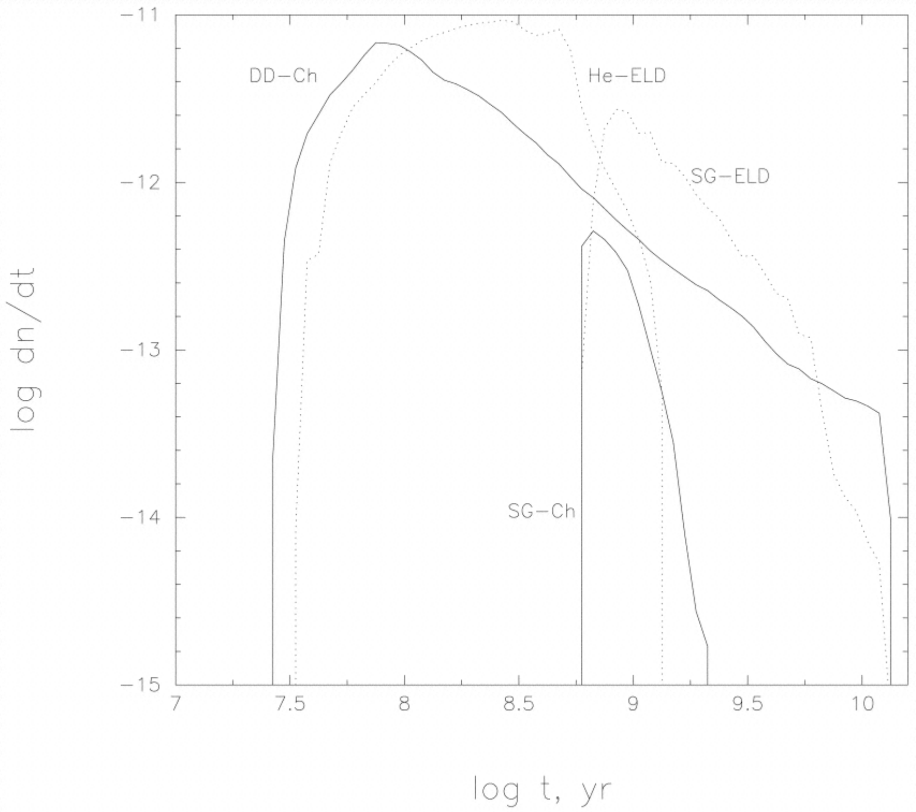
Han & Podsiadlowski 2004

Ruiter et al 2009

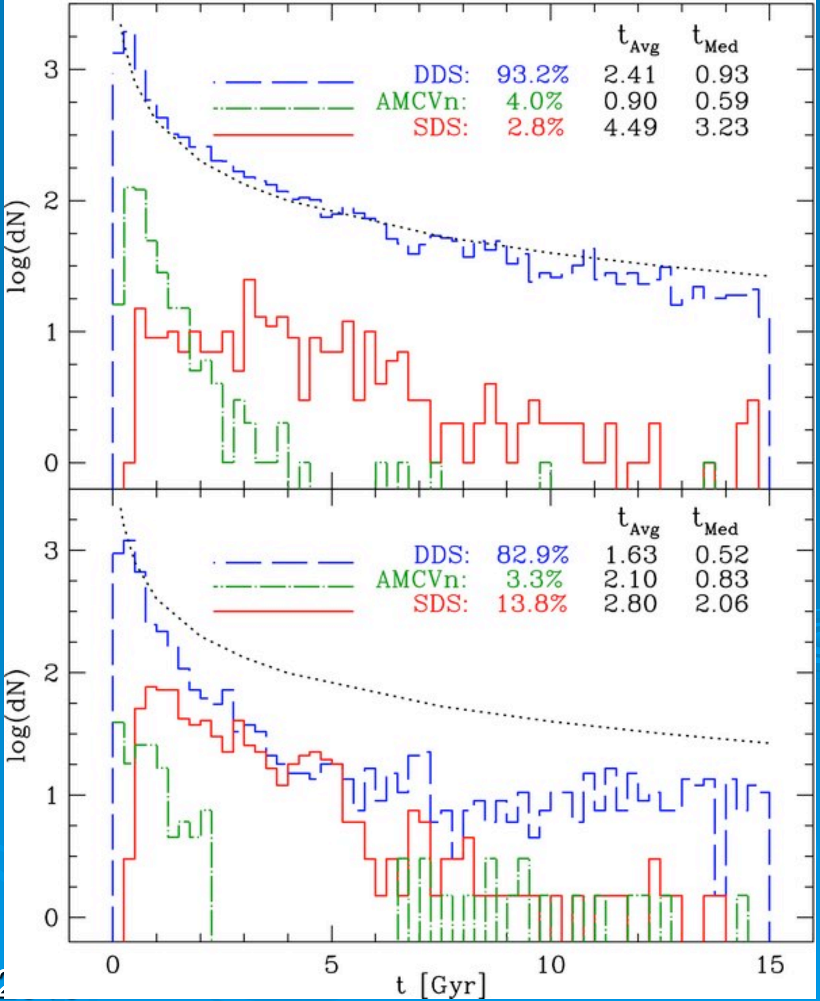
# DTDs FROM BPS CODEs:
# DD progenitors

For DDs the BPS realizations agree in giving ~ 2 orders of mag decline over ~ 1 Hubble time

*Yungelson & Livio 2000*



*Ruiter et al. 2009*



# THEORETICAL DTD

## analytical relations based on stellar evolution

*(Greggio 2005)*

Characterize the model DTD by the clock of the explosions

Parametrise key astrophysical variables

SINGLE DEGENERATES:
DELAY TIME=NUCLEAR LIFETIME

DOUBLE DEGENERATES:
DELAY TIME=NUC.LIFETIME + GWR DELAY

$$\tau_{nuc} \propto m^{-2.5}$$

$$\tau_{GWR} \propto \frac{A^4}{M_{DD}^3}$$

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

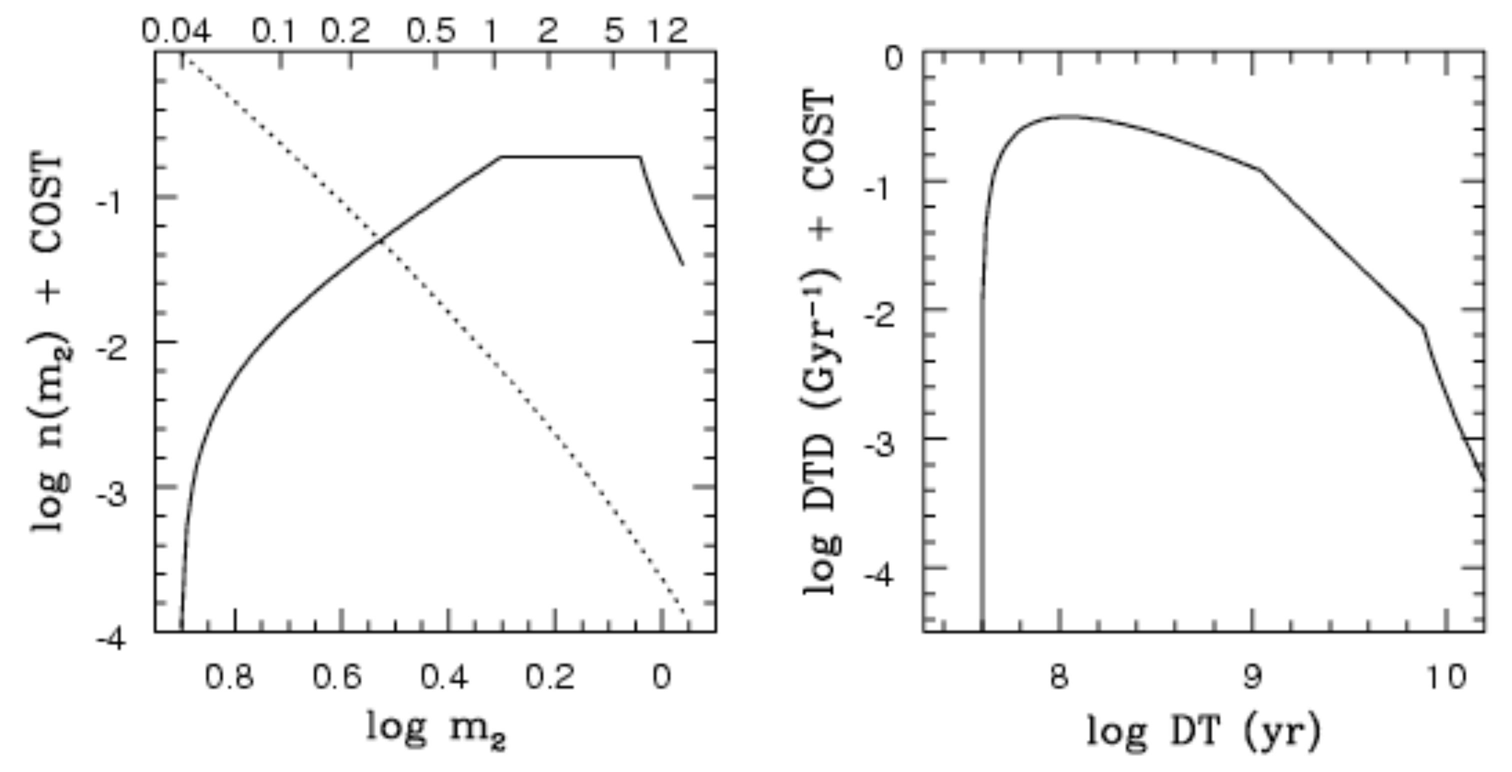
# SINGLE DEGENERATES

$t_D = t_{MS}(M_2)$ $t_D \longleftrightarrow M_2$

$$\dot{n}(t_D)dt_D \propto \varphi(M_2)dM_2$$

$$DTD \propto \varphi(M_2)\left|\dot{M}_2\right|$$

$2 \leq M_1 \leq 8$ $M_2 \leq M_1$ $\varepsilon = 1$



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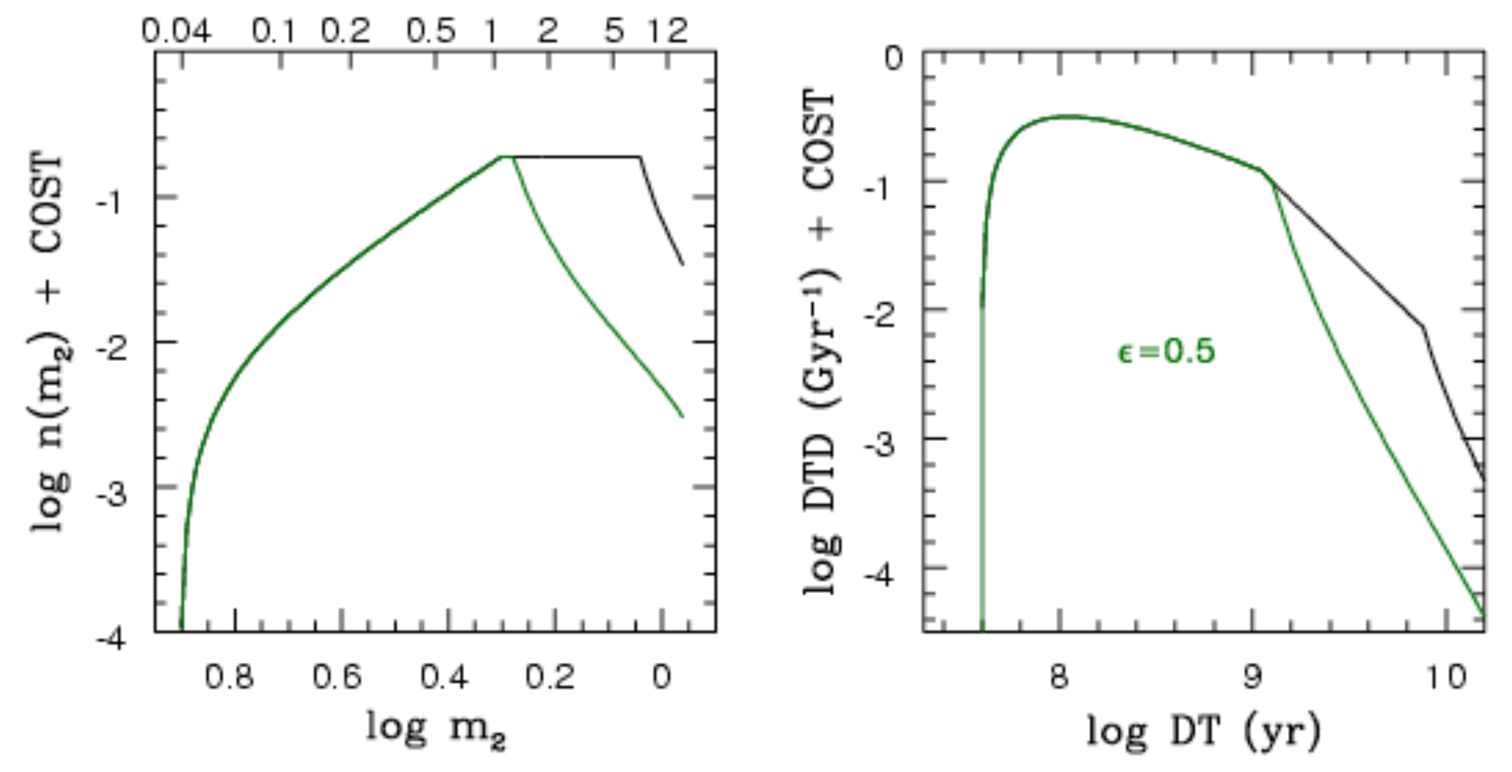

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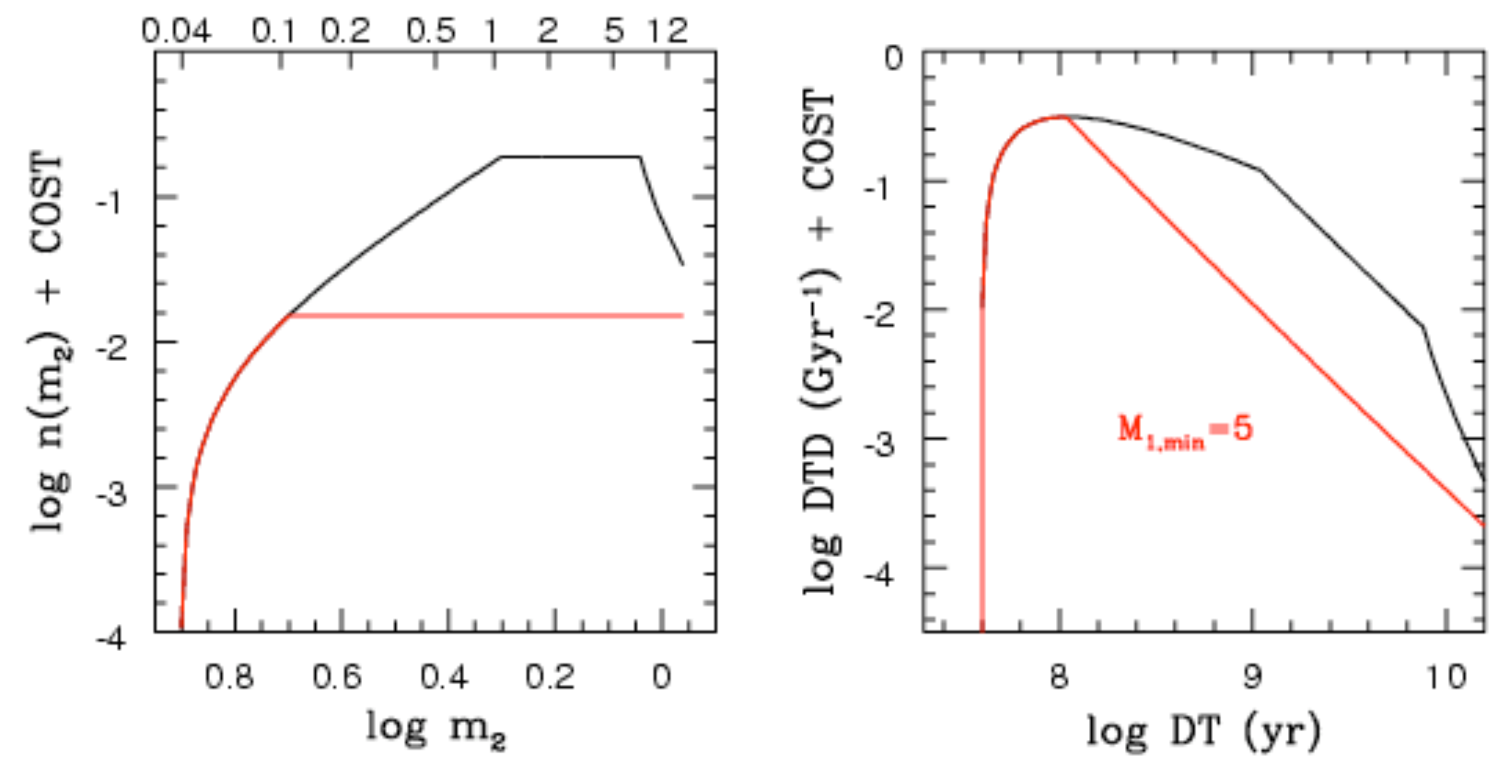

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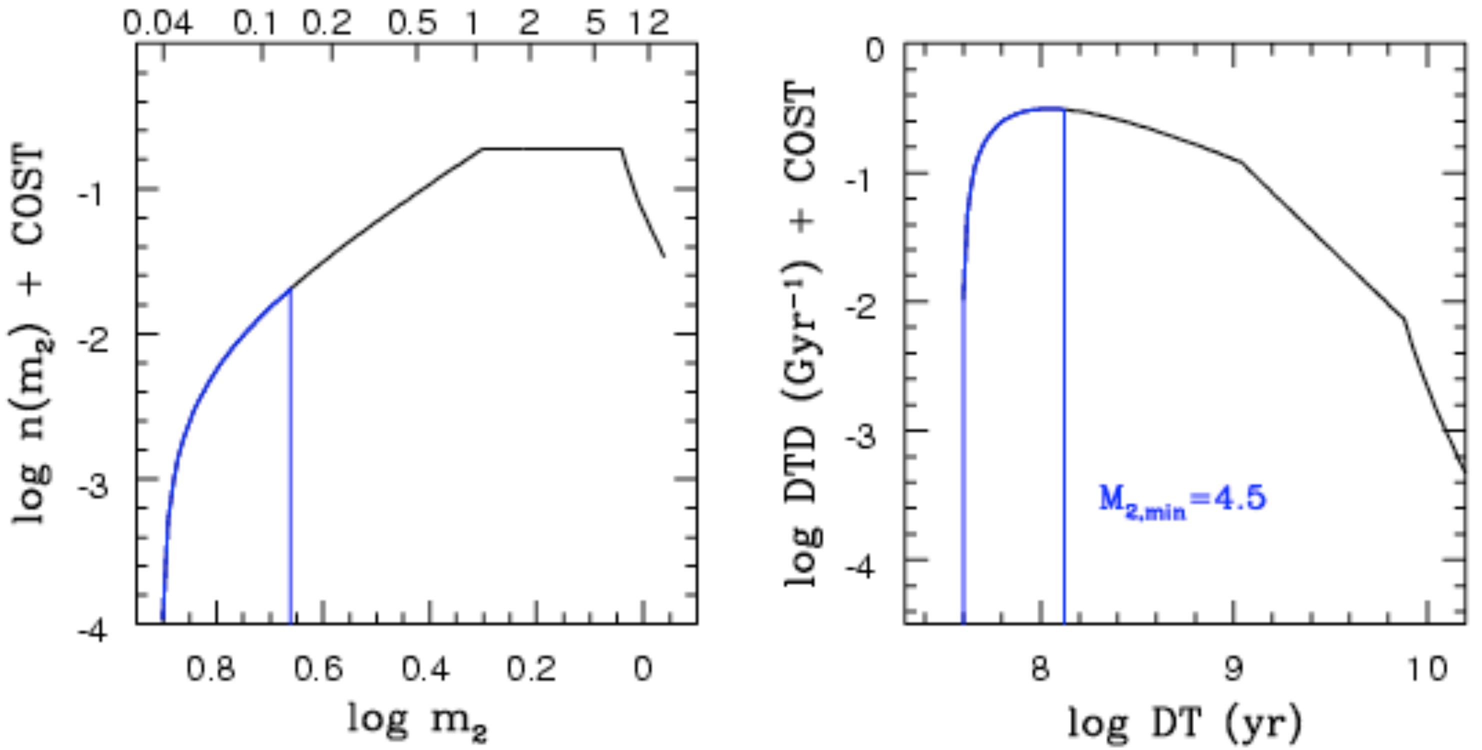
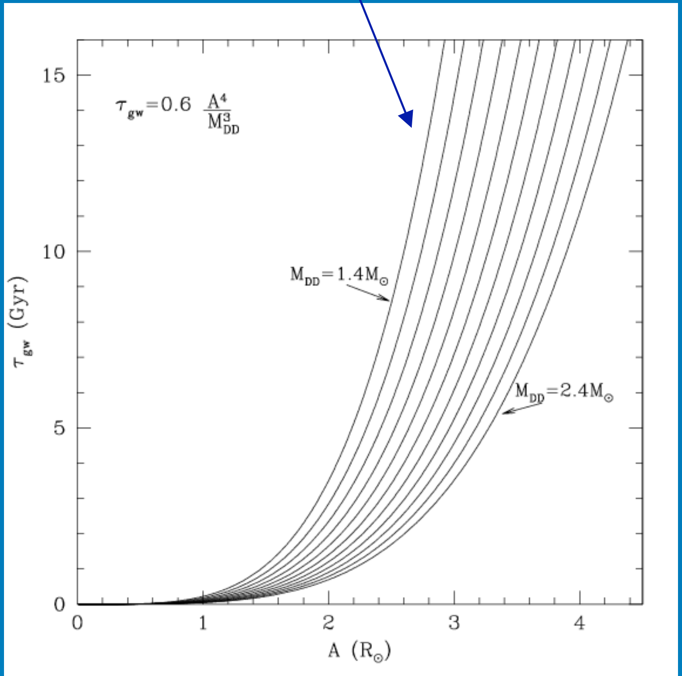


# DOUBLE DEGENERATES

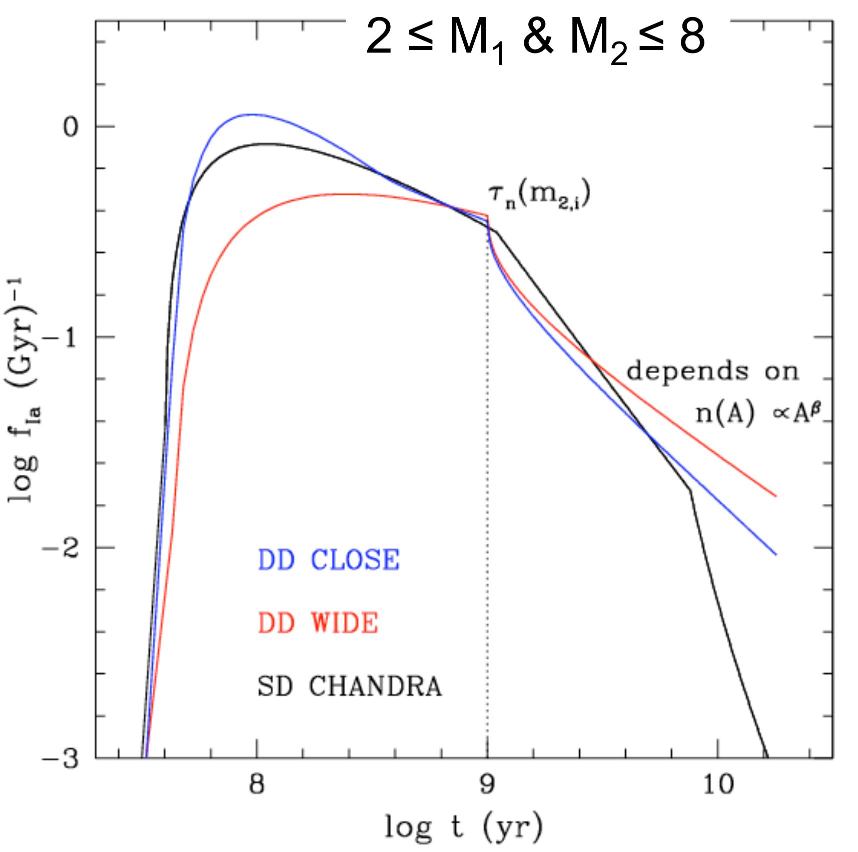
$t_D = t_{MS}(M_2) + t_{GW}(M_{DD},A)$



What matters are the distributions of the params in a narrow range

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

$2 \leq M_1$ & $M_2 \leq 8$



The DTD is a modification of that of the SD case

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

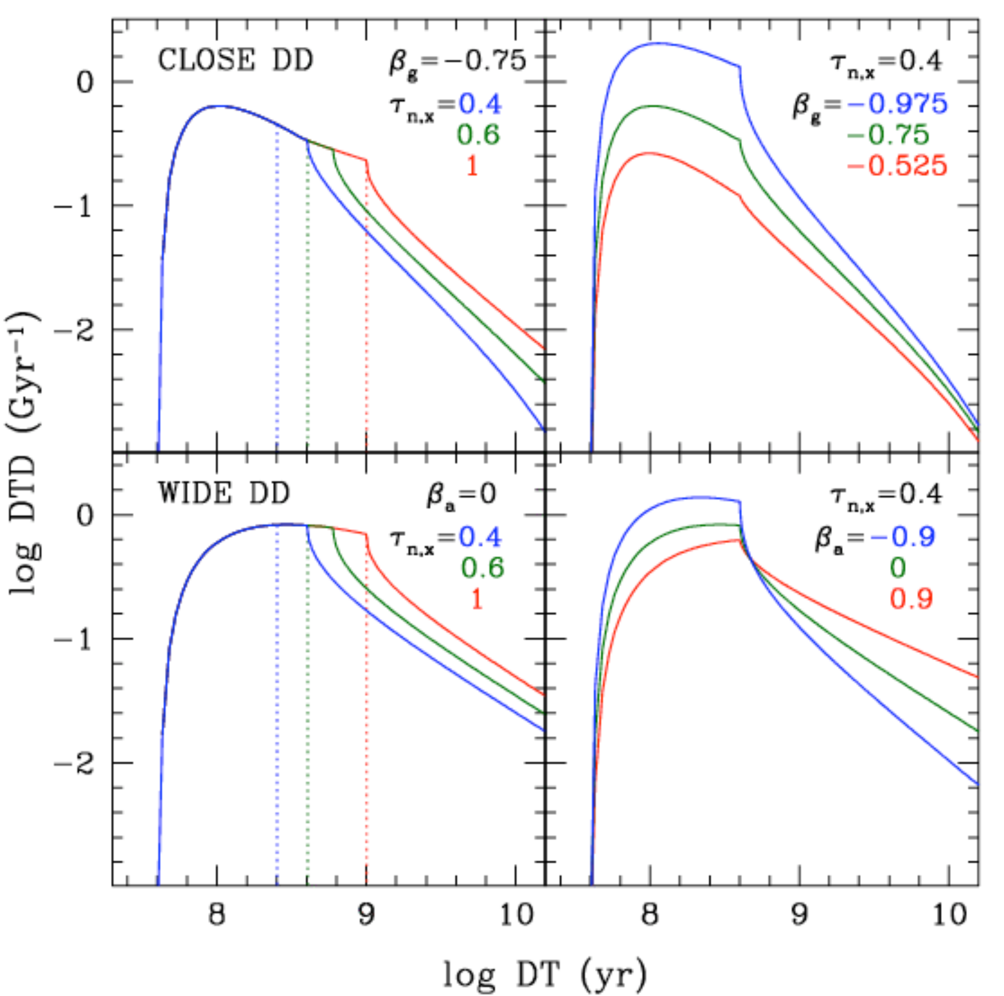
DD WIDE: $M_{DD}$ and A (almost) decoupled

# DTD FOR DDS
## effect of main parameters

There are 2 main parameters considered:

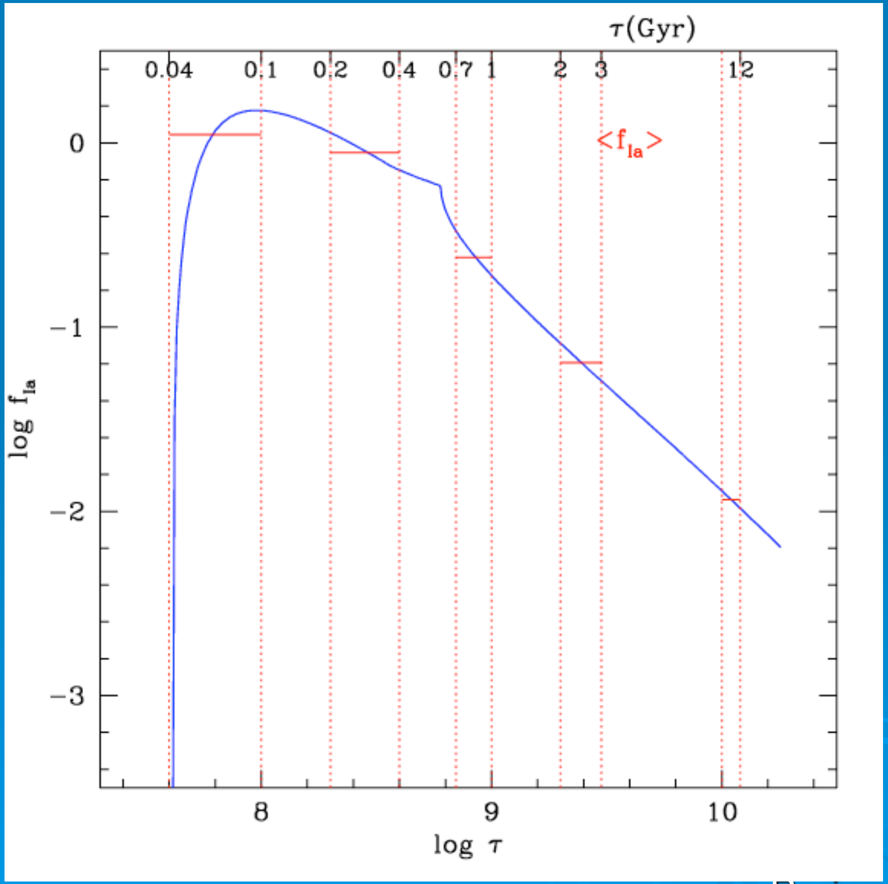
$\tau_{n,x}$ :MS lifetime of the least massive (primordial) secondary

β : describes how the final separations (A) are distributed



# CONSTRAINING THE DTD WITH SNIa RATE

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



THE RATE PER UNIT MASS IN LATE TYPE GALAXIES WILL BE LARGER THAN IN EARLY TYPE GALAXIES

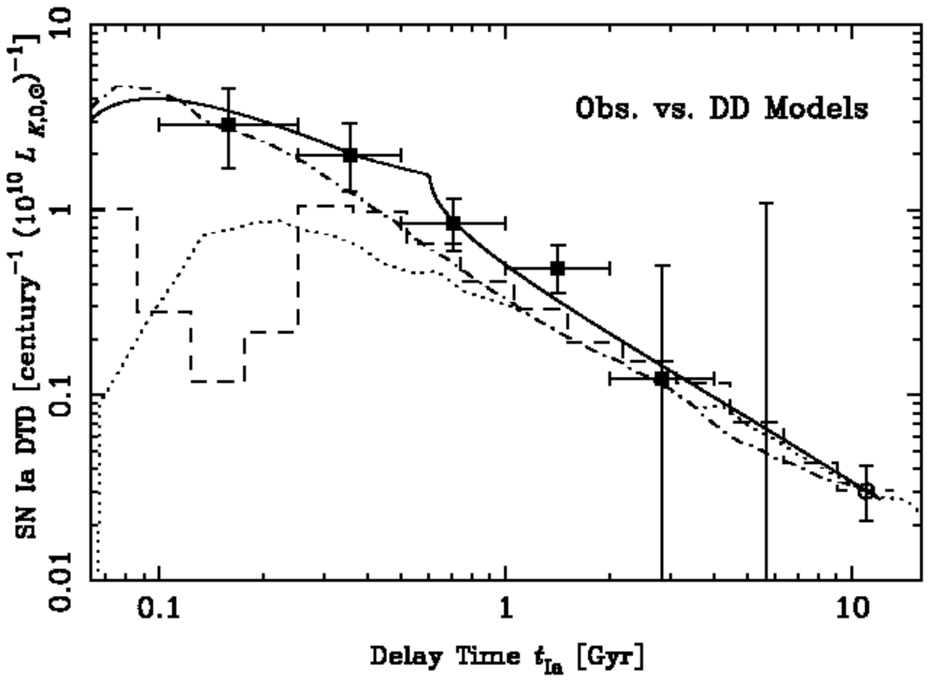
(e.g. *Greggio and Renzini 1983)*

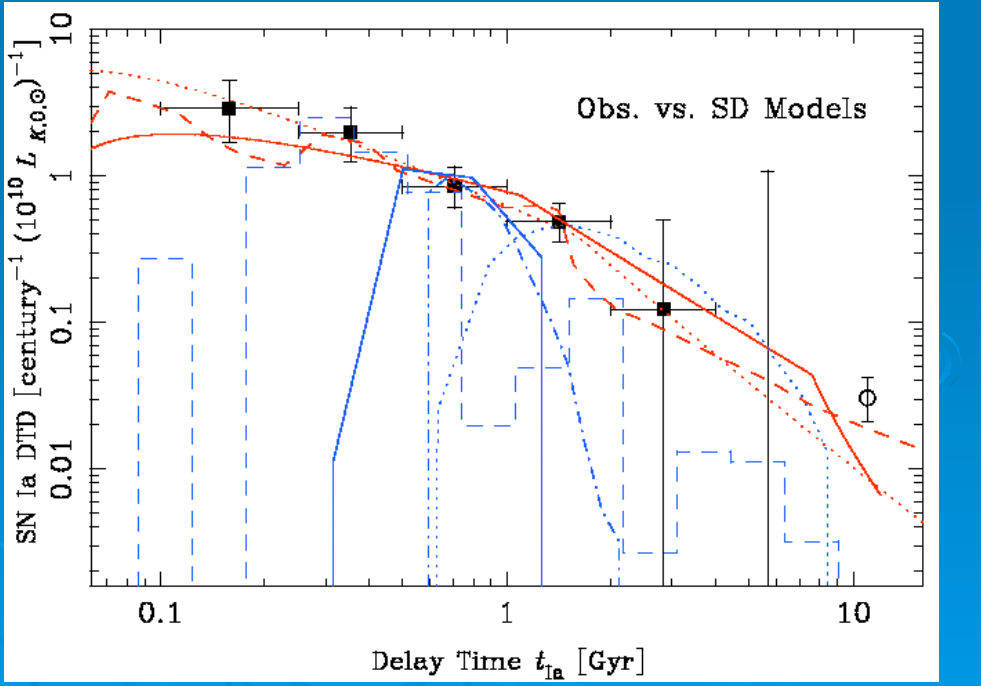
Bluer galaxies are ‘younger’, then they have larger specific SNIa rates

THE SCALING OF THE RATE PER UNIT MASS WITH THE *‘AGE’* OF THE PARENT GALAXY DEPENDS ON THE DTD

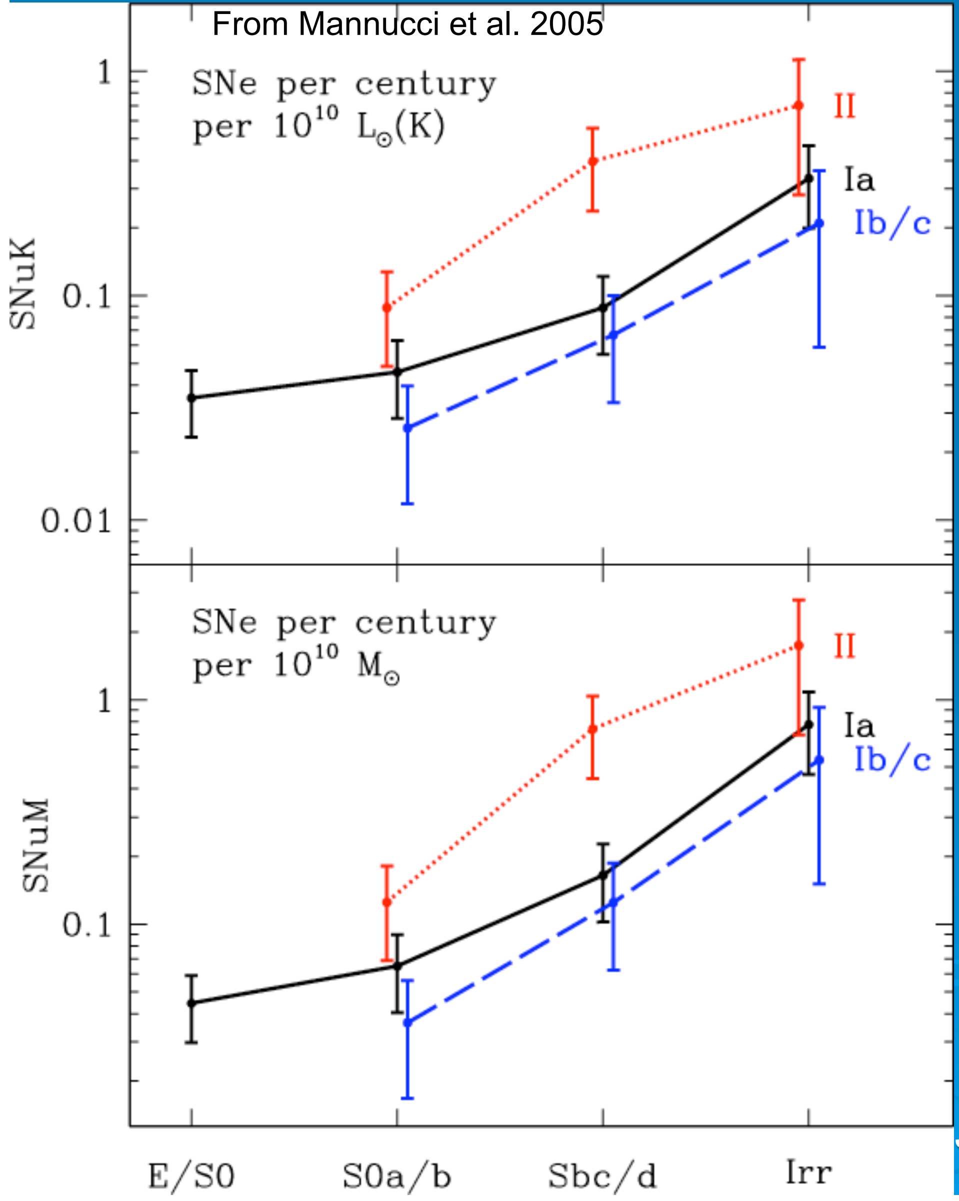
# THE RATE IN PASSIVE GALAXIES

From Totani et al. 2008





# THE RATE versus THE PARENT GALAXY MORPHOLOGICAL TYPE


From Mannucci et al. 2005

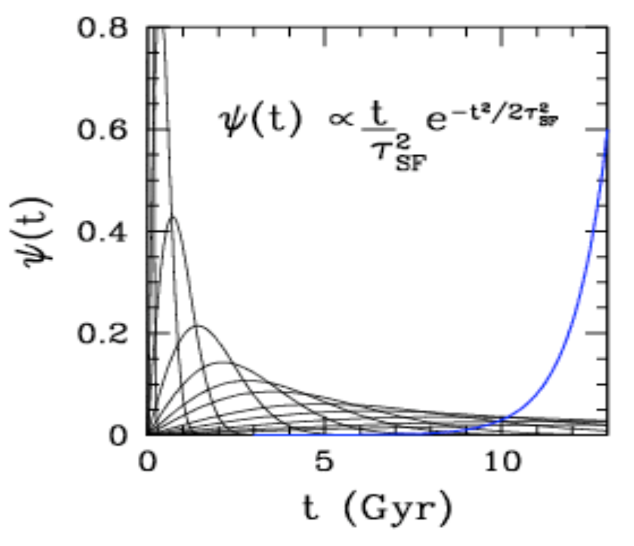
$$\frac{\dot{n}_{Ia}(t)}{L_K(t)} = k_{Ia} \frac{\langle f_{Ia} \rangle_\psi}{\langle L_K \rangle_\psi}$$

Theoretical rates from convolving DTDs with SFHs for the different morphological types.

First constrain the SFHs: use U-V and B-K colors of the galaxy sample

# MORPHOLOGICAL TYPE AND SFH

Take model SFH
*(Gavazzi et al. 02)*

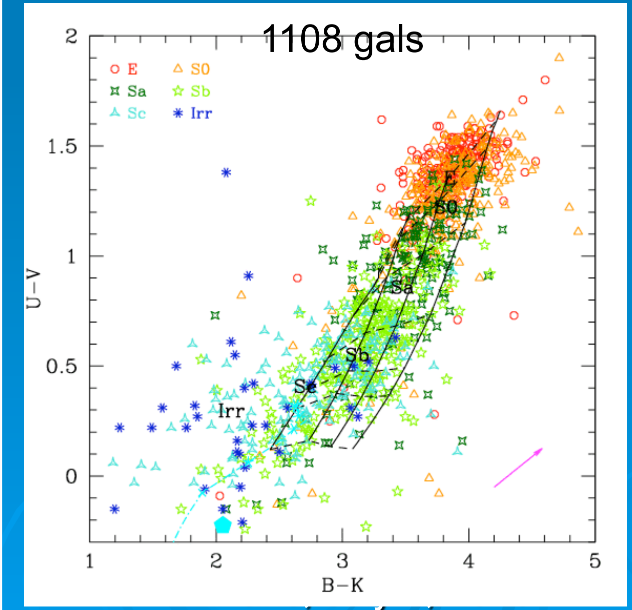


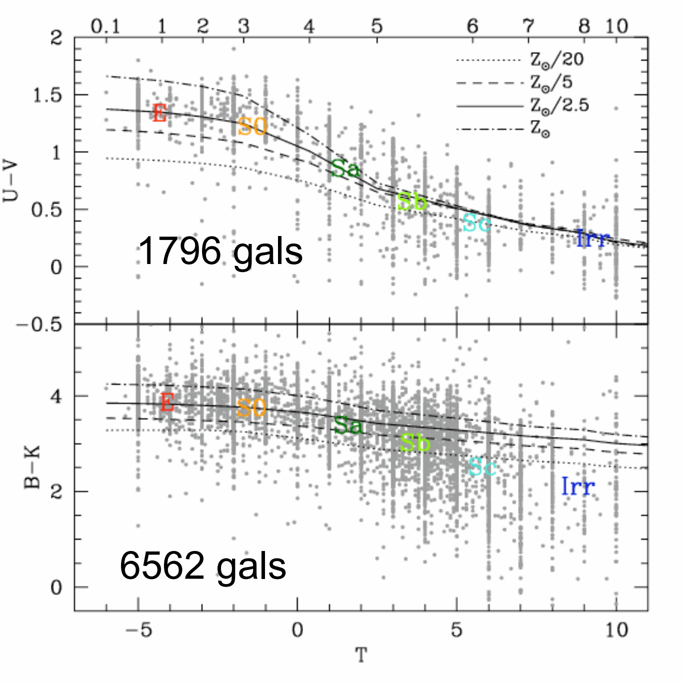
Check the correlation
With all galaxies in the sample

Get integrated colors
(SFH + SSP models
from Padova database)

Compare to galaxies
of Cappellaro Evans
and Turatto 99 sample

Get relation between
Morph. Type T and τ(SF)





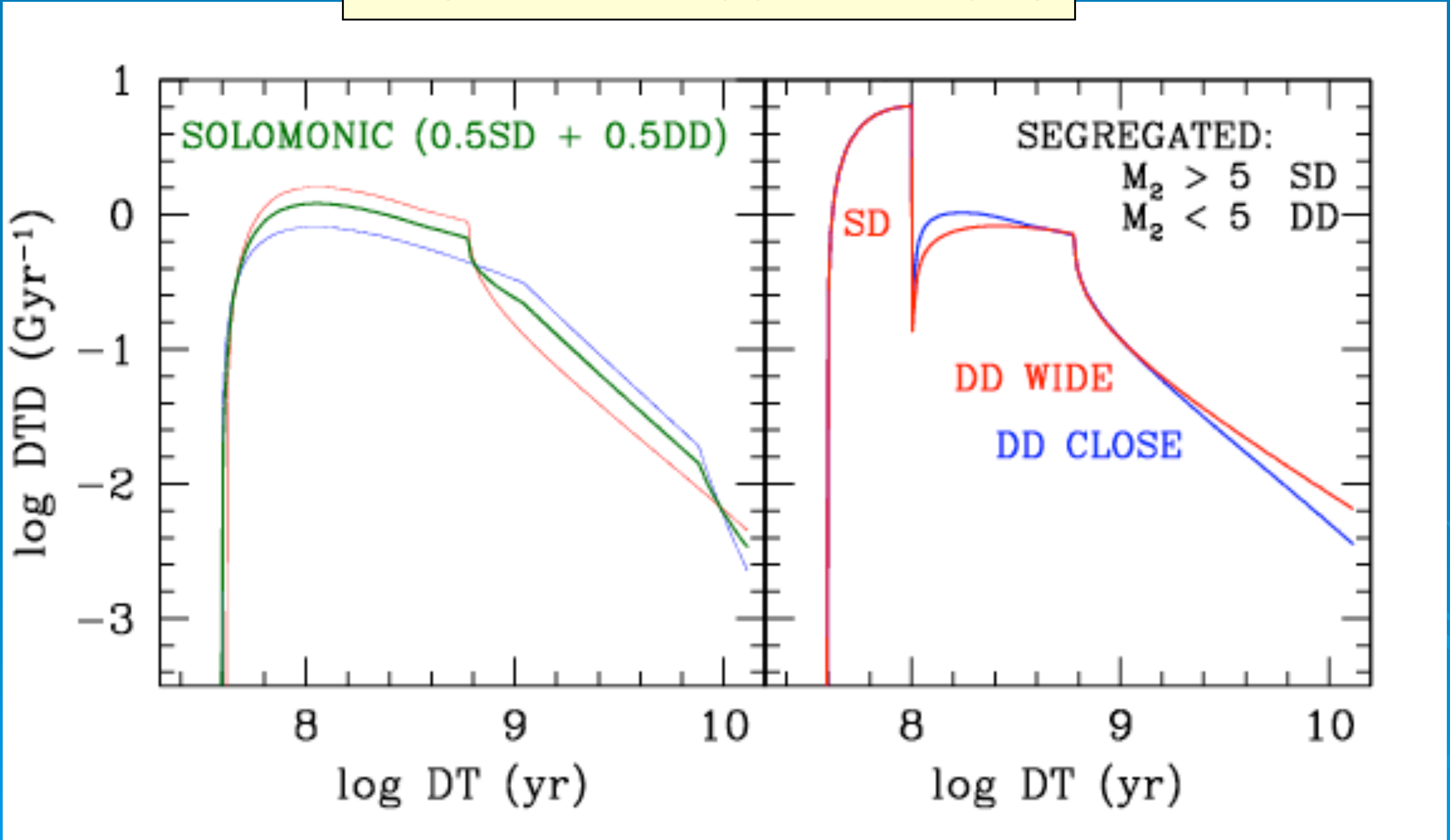
MORPHOLOGICAL TYPE

# MIXED DTDS

- Direct observations favour SD (e.g. Patat et al. 2007)
- DDs lack H and provide events at very late epochs

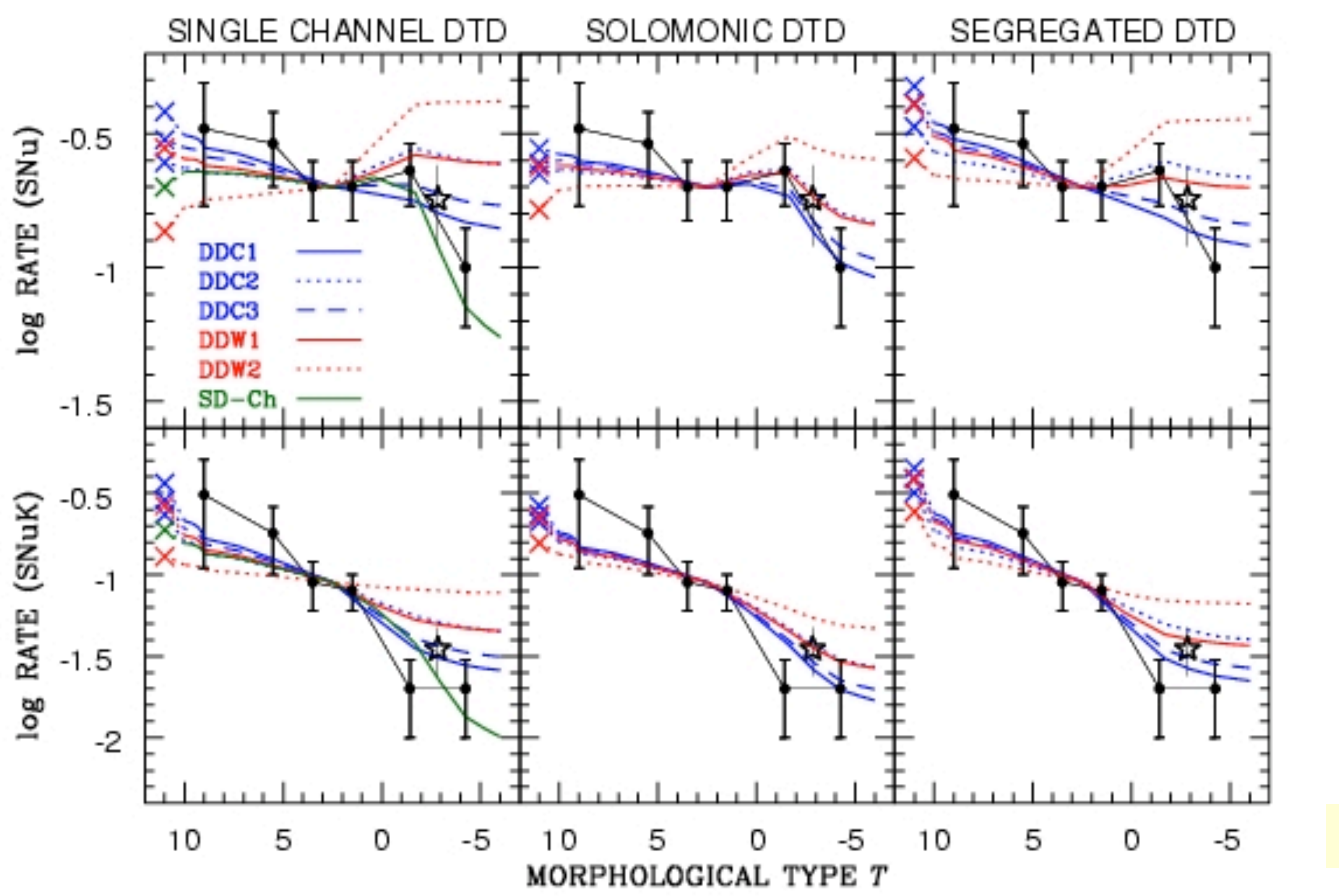
LIKELY BOTH CHANNELS ARE AT WORK

TWO EXTREME COMBINATIONS



# CORRELATION OF THE RATE WITH THE PARENT GALAXY MORPHOLOGY

Theoretical rates from convolving DTDs with model SFHs
→ RATES AS FUNCTION OF τ(SF)
+ calibration of τ(SF) versus T
→ RATES AS FUNCTION OF T



Sample: 9279 gals

Sample: 6562 gals

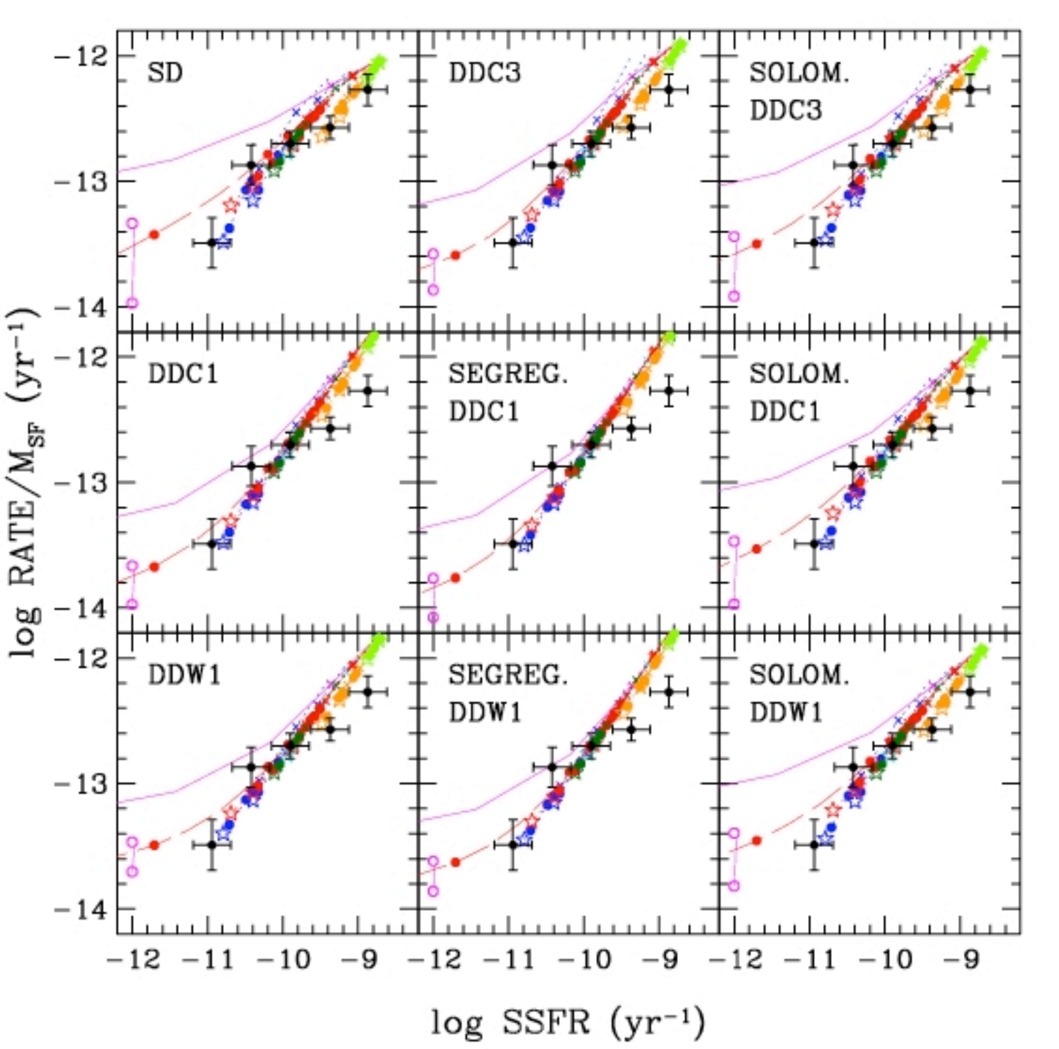
One channel and Mixed models fit similarly

WIDE DDs produce too many late events

Notice the difference btw S0 and E in the upper panels

# THE SNIa RATE versus THE SPECIFIC STAR FORMATION RATE

Data from Pritchet, Howell & Sullivan 08

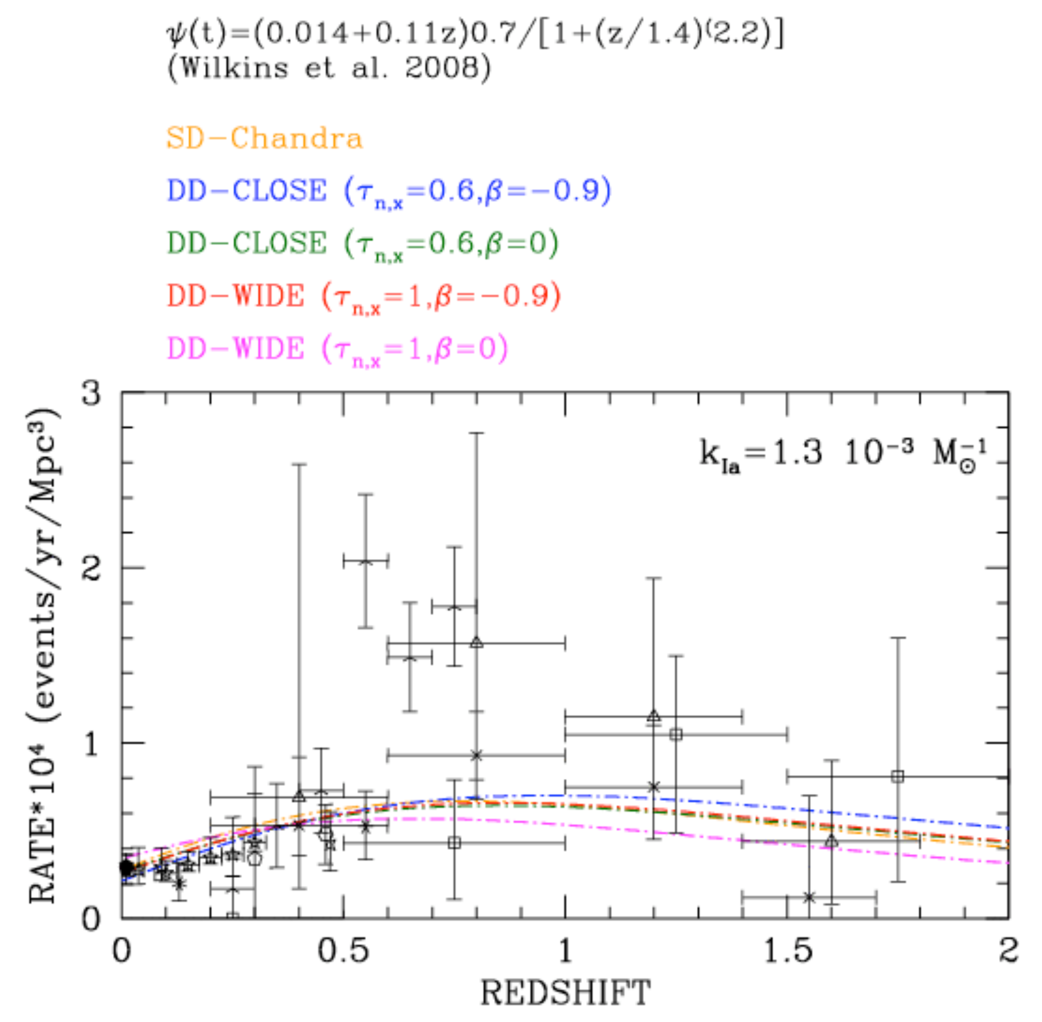


Models: convolution of DTDs with
'Sandage' SFHs
Power laws SFHs
Constant SFR
Current burst
Current strong burst
Dots at ages between 7 and 11 G

No clear preference for the best DTD
Some models seem to have too much power at short delays, but …

'Sandage' SFH with most SF in the past have very low SSF but appreaciable SNIa rate
How passive are the passive Galaxies in SNLS?

# COSMIC SNIa RATE



# THE SNIa PRODUCTIVITY

$k_{Ia}$ = number of events from a SP which formed 1 Mo of stars

if $\psi = \text{const} = \psi_0$

$$\dot{n}_{Ia}(13G) = k_{Ia}\int_{0}^{13}\psi(t-t_D)f_{Ia}(t_D)dt_D = k_{Ia}\psi_0$$

$k_{Ia}$ can be evaluated observationally in sistems with const. SFR as

$$k_{Ia} = \frac{\text{RATE(@ late epochs)}}{\text{SFR}}$$

| | |
|---|---|
| on CET99 (SNuK) | $k_{Ia} = 2.8\ 10^{-3}$ |
| on SNLS RATE (SNuM) | $k_{Ia} = 1.6\ 10^{-3}$ |
| on cosmic RATE | $k_{Ia} = 1.3\ 10^{-3}$ |
| from M(Fe) in ICM<br>(Maoz et al. 2010) | $k_{Ia} = (1.5 \div 3.4)\ 10^{-3}$ |

$k_{Ia} \approx 2\ 10^{-3}\ (\text{Mo})^{-1}$
for a flattened Salpeter

This same IMF has 0.04 stars with 2.5<M<8

The observed rates require that ~ 5 % of them are in close binaries of the right kind

# Conclusions

- Stellar evolution naturally produces a DTD over a wide range of Delay Times : accomodates PROMPT and TARDY SNIa events

- Difficult to produce strong discontinuities within one SNIa channel

  PROMPT and TARDY could be generated by two different channels e.g. SD for early and DD for intermediate and late events

- The trend of the SNIa rate with the parent galaxy type or SSFR does not help discriminating btw single channel and mixed models

  (likely mixed models are more realistic )

- Current rates indicate that the SNIa productivity is

  $k_{Ia} \sim 2\ 10^{-3}\ (1/Mo)$ within a factor of 2

  ( this is about 1/5 of the CC productivity)