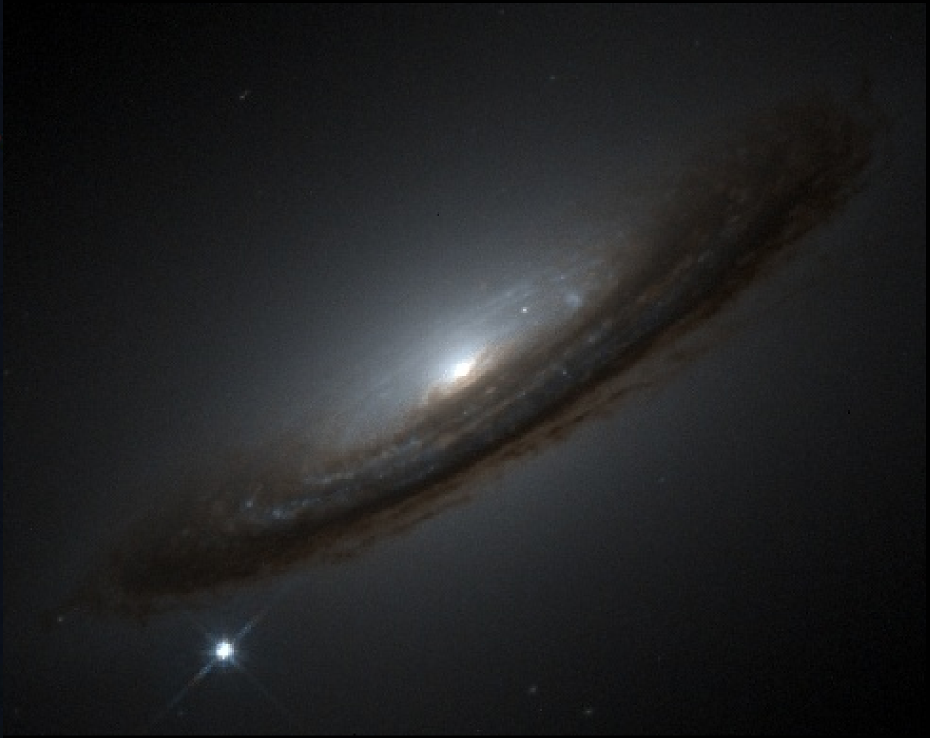
SN-Ia Rates in Different Environments



Massimo Della Valle

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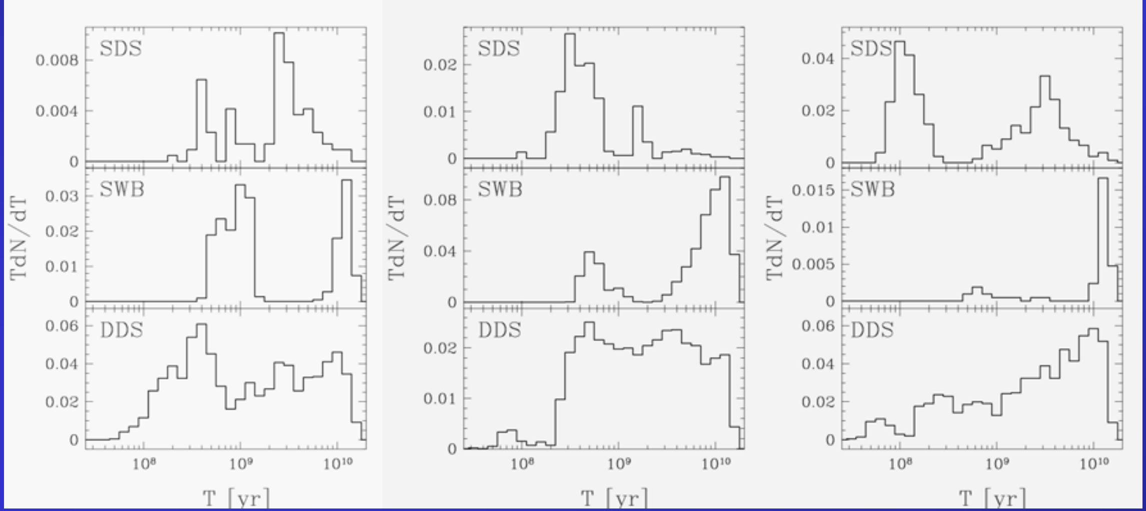
Outline

- SN-Ia rate vs. Hubble type (i.e. colors) of the p.g. (Mannucci & Panagia)
- SN-Ia rate vs. z (Cappellaro, Turatto…)
- SN-Ia rate vs. radio-power of the hosts (Mannucci & Panagia)
- SN-Ia rate: field vs. clusters (Mannucci, Gal-Yam, Maoz, Panagia, Sharon)

Goal: Delay Time Distribution→ Hints on SN-Ia progenitors

Many studies:
- Greggio & Renzini (1983)
- Yungelson & Livio (2000)
- Matteucci & Recchi (2001)
- Belczynski et al. (2005)
- Greggio (2005)



Belczynski et al. (2005)

Can we derive an empirical DTD from the existing observations of the SN rates?

Three different evidences:
1. SN-Ia rate dependence on galaxy color
2. SN-Ia rate evolution with redshift
3. SN-Ia rate dependence on galaxy radio power

The Data

1. SN from the well defined catalog by Cappellaro et al. (1999)

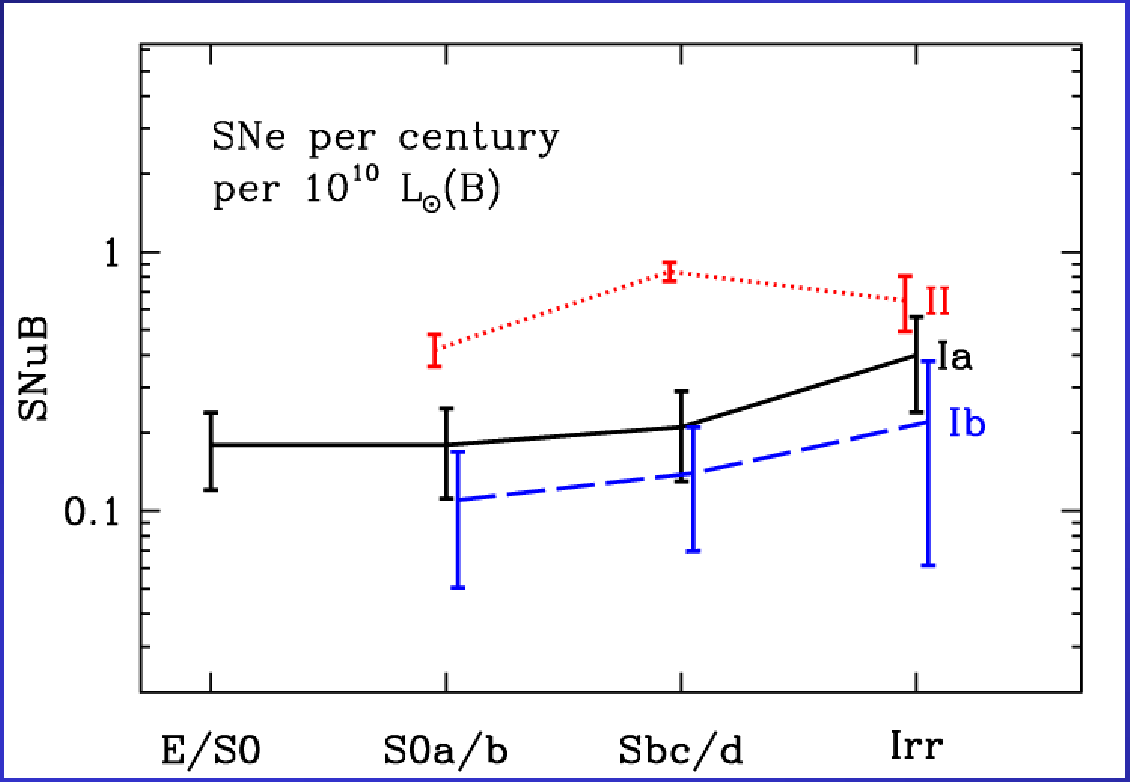
136 SNe, 5 optical surveys:

- Asiago
- Crimea
- Evans
- Cote d'Azur
- Cerro Tololo

Type	N Gal	Ia	Ib/c	II
E/S0	2048	21.0	0	0
S0a/b	2911	18.5	5.5	16.0
Sbc/d	2682	21.4	7.1	31.5
Irr	644	6.8	2.2	5.0

Rate in the Local Universe: SNe-Ia rates normalized to the B band

B: SNuB = SN/century/$10^{10}L_\odot(B)$



SNr(Ia):

- flat from E to Sd
- modest increase in Irr
- SN rate constant along the Hubble sequence??

B Lum is NOT a good tracer of stellar mass along the whole Hubble sequence

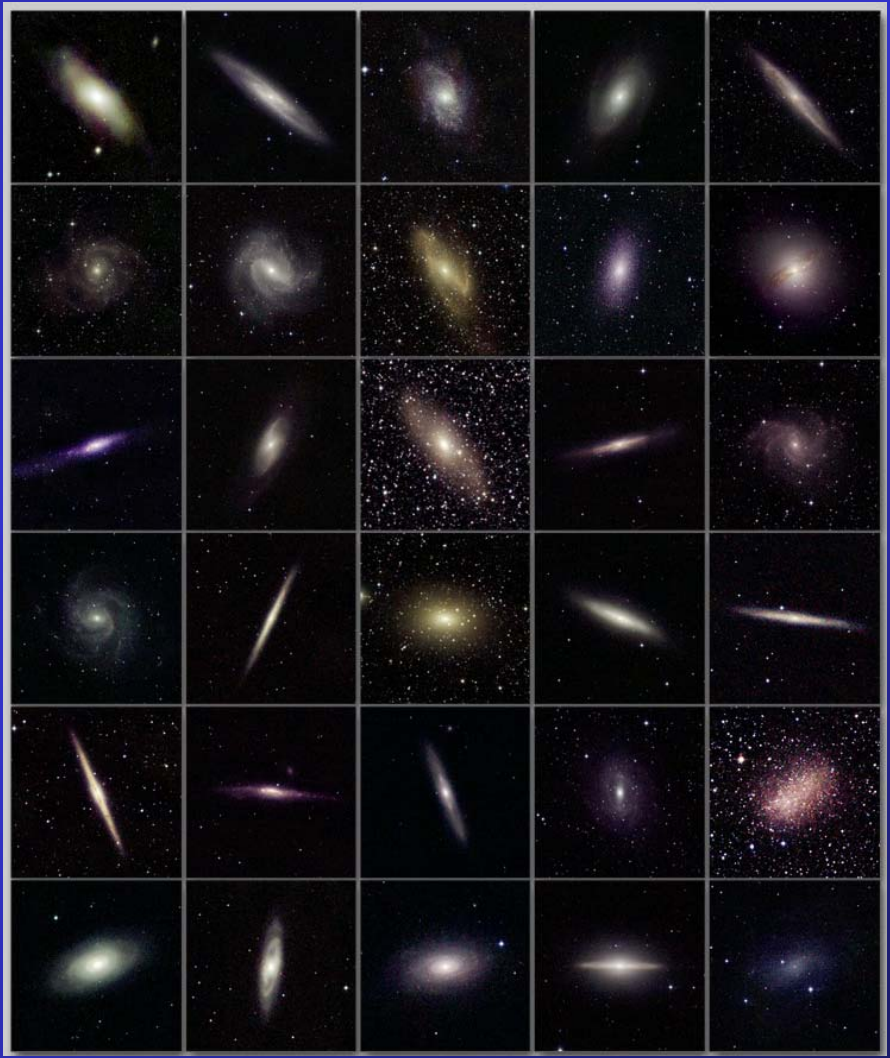
The SN rate per unit mass

B was the only available band for a large number of local galaxies until…

2MASS All-Sky

Data Release

Jarrett et al., (2003)

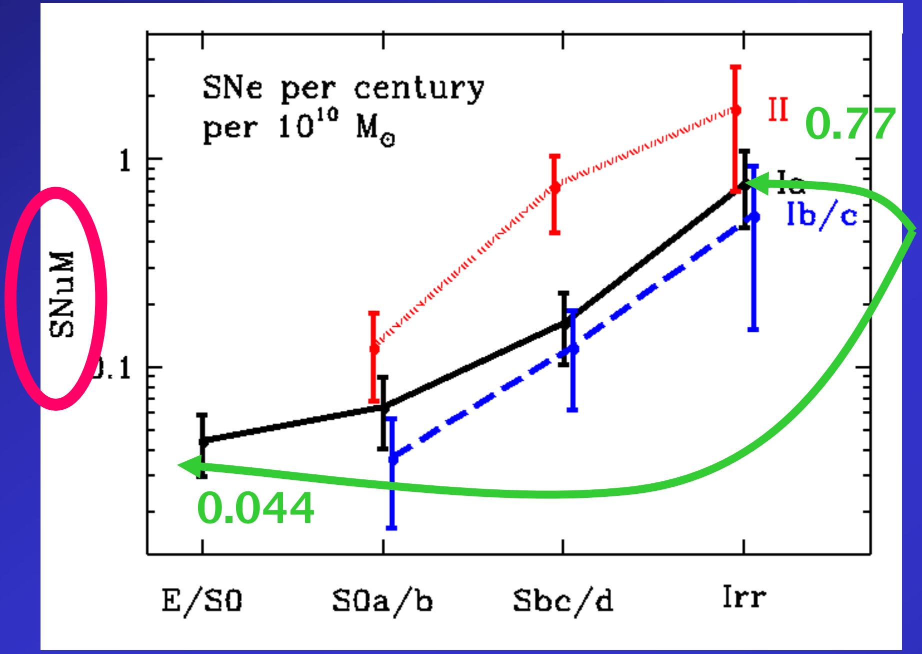


Mass from NIR data

$\mathrm{Log}(M/L_K) = 0.212(B-K) - 0.959$

Mannucci et al. (2005)

From SNuB to SNuM

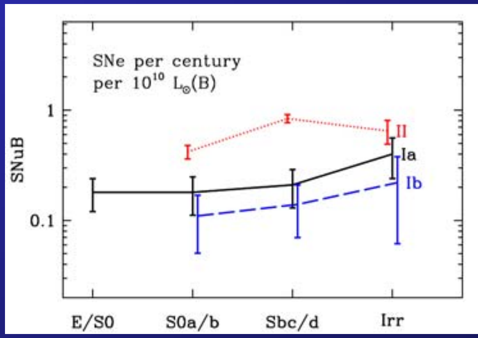


- Sharp dependence of the SN rates on morphology of the hosts for all SN types

For Ia:

- **rate(Irr) ~ 17 rate(E)**

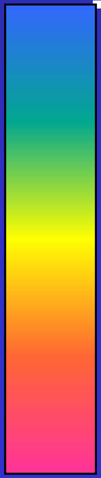
- **Level of significance >99%**



X 5-10 → van den Bergh 1990, Della Valle & Livio 1994
(Dallaporta 1973; Oemler & Tinsley 1979 → Ibc)

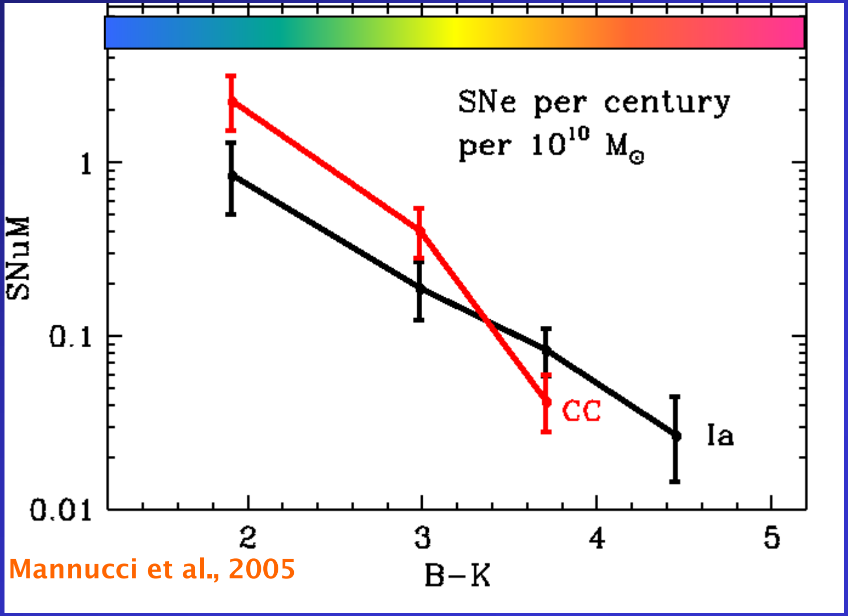
SN rate vs. galaxy color

B-K is a better tracer of stellar population than morphology → is related to the mean age of the stellar population → tracer of SFR



B-K color	N gal	Ia	CC
<2.6	1499	9.0	20.0
2.6 - 3.3	2178	15.4	29.6
3.3 – 4.1	3396	37.4	17.7
> 4.1	1276	6.0	0

SN rate vs. galaxy color



Mannucci et al., 2005

CC and Ia have similar behaviour for blue galaxies: strong correlaton with (B-K): Ia: rate(blue) = 30 rate(red)

SN Ia in red galaxies are related to the **old stellar pop** with rates proportional to the total mass in star (long delay times ~ a few Gyr)

SNe Ia in blue galaxies are related to the **young stellar pop** with rates proportional to the SFR (→ DT as short as the timescale of the color evolution of the hosts, ~ 0.5 Gyr)

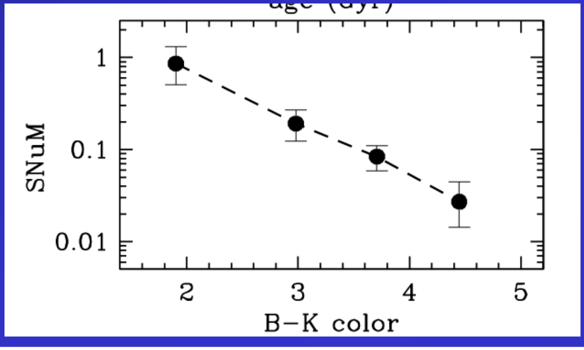
See Sullivan et al. (2006)→ different SN sample

Scannapieco & Bildsten (2005); Matteucci et al. (2006); Lowenstein 2006; Calura et al. 2007;

→ chemical evolution of galaxies and clusters

Deriving the DTD

- dependence of the rate on the colors (Mannucci et al., 2005)



Timescale

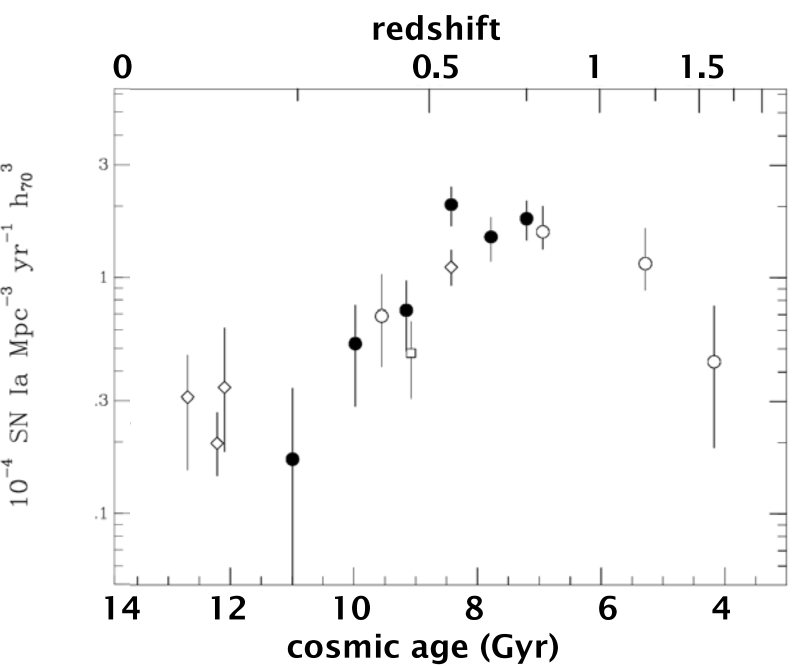
0.5-1 Gyr

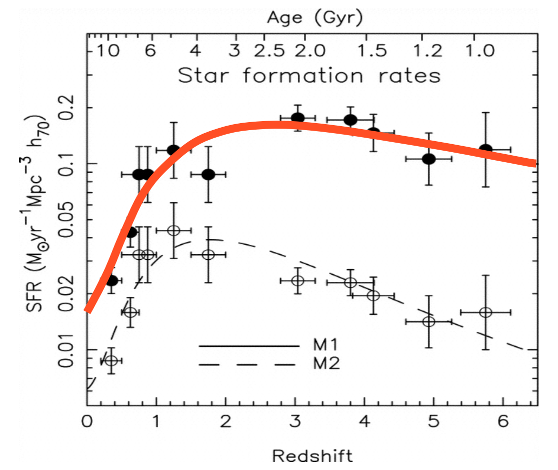
evolution of the colors

High-redshift observations

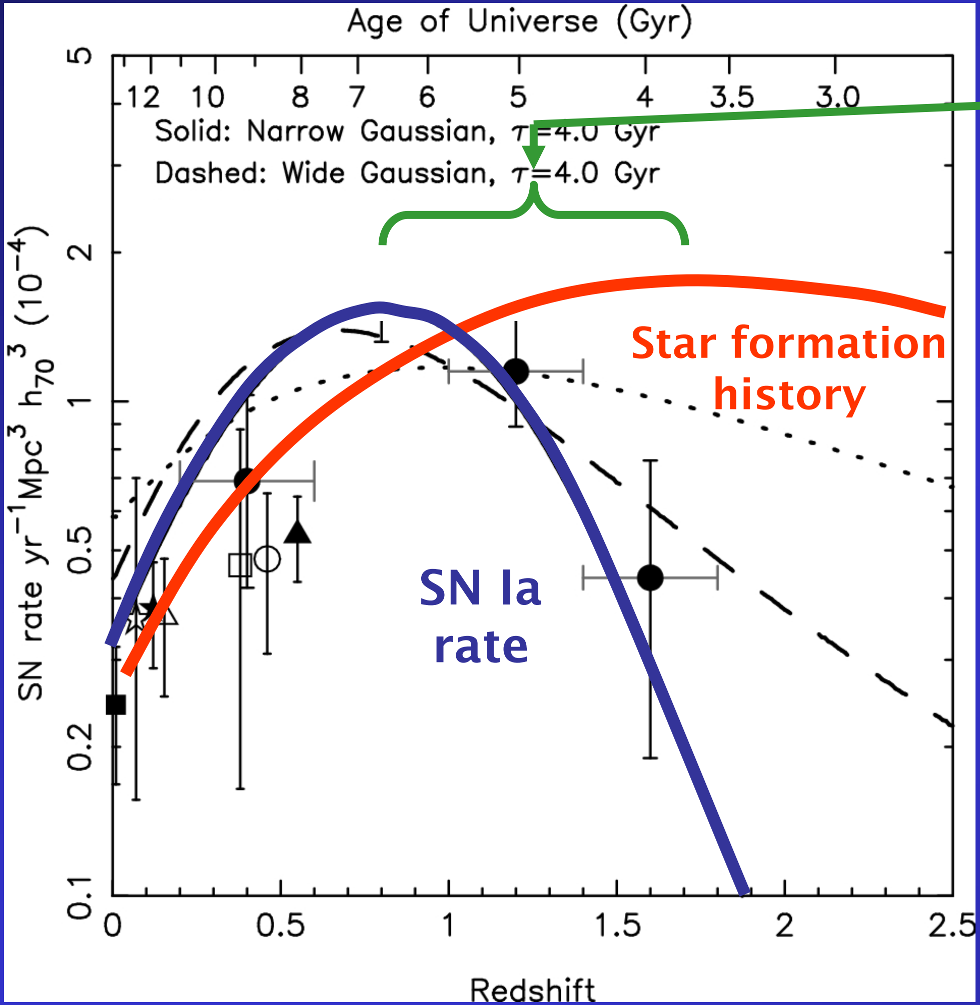
1. Several measurements of Ia SN rate up to z=1.6:
   - Hardin et al. 2000
   - Pain et al., 2002
   - Madgwick et al. 2003
   - Cappellaro et al., 2004
   - Botticella et al. 2006
   - Gal-Yam & Maoz, 2004
   - Dahlen et al., 2004 (GOODS)
   - Strolger et al., 2004 (GOODS)
   - Tonry et al., 2003
   - Pain et al., 2006
   - Barris & Tonry (2006)
   - Neill et al. 2006
2. Comparison with the cosmic Star formation

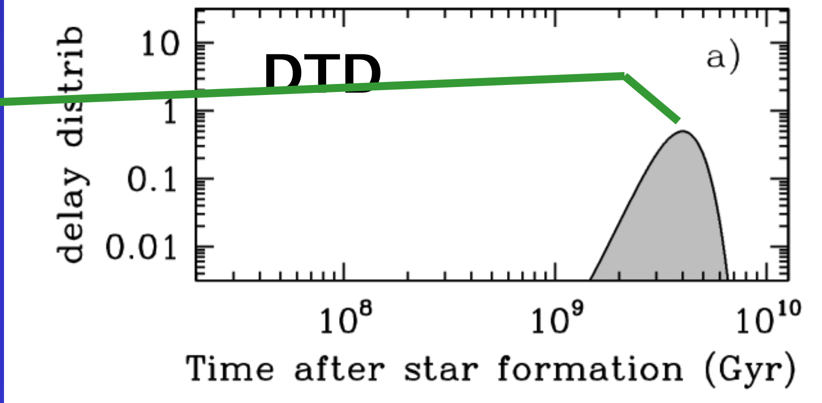
   History (e.g. Madau et al. 1998; Giavalisco et al. 2004)





High-redshift observations



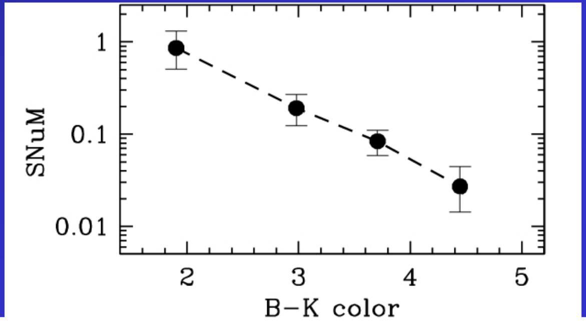


The evolution of the type Ia SN rate follows the SFR, but shifted at lower redshifts due to the lag between the time when the progenitor is formed and the time of the explosion as SN. **These results have been interpreted by Dahlen et al. 2004, Strolger et al. 2004 as evidence for a very long delay time, about 3-4 Gyr between the formation of the stars in the binary systems and the explosion as SN-Ia.**

Deriving the DTD

Timescale

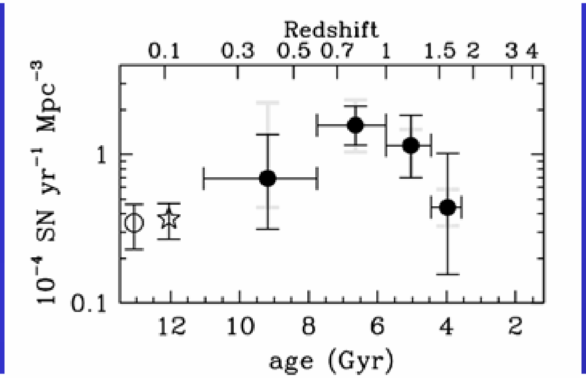
- dependence of the rate on the colors (Mannucci et al., 2005)



0.5-1 Gyr

evolution of the colors

- evolution of the rate with redshift (Dahlen et al., 2004)



3-4 Gyrs

evolution of the cosmic SFR

SN rate vs. radio power of the host

Asiago Survey $T<-1.5$

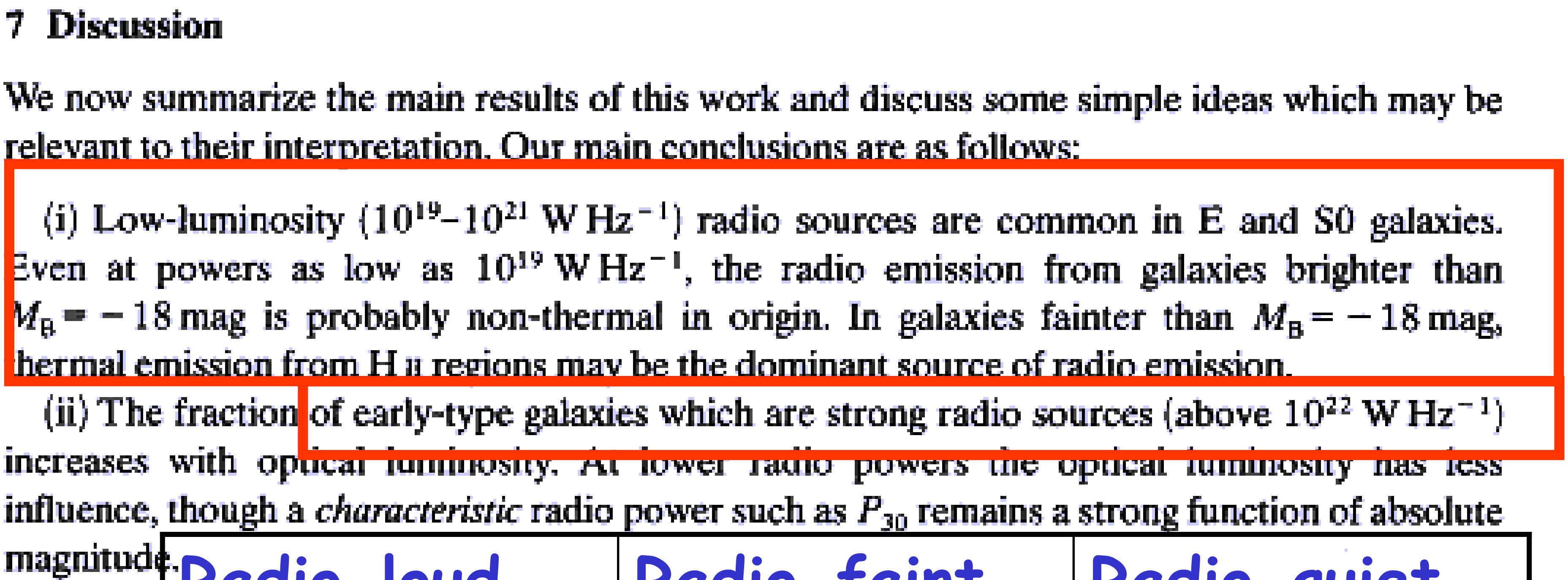
X

NRAO VLA SKY SURVEY

It is a Survey at 1.4 GHz covering the whole sky north of -40°

Parkes MIT NRAO Survey at 4.85 GHz $f_{1.4}=f_5 \times (5/1.4)^{-0.75}$

Sadler, Jenkins & Kotanyi 1989



7 Discussion

We now summarize the main results of this work and discuss some simple ideas which may be relevant to their interpretation. Our main conclusions are as follows:

(i) Low-luminosity (10^{19}–10^{21} W Hz^{-1}) radio sources are common in E and S0 galaxies. Even at powers as low as 10^{19} W Hz^{-1}, the radio emission from galaxies brighter than $M_B = -18$ mag is probably non-thermal in origin. In galaxies fainter than $M_B = -18$ mag, thermal emission from H II regions may be the dominant source of radio emission.

(ii) The fraction of early-type galaxies which are strong radio sources (above 10^{22} W Hz^{-1}) increases with optical luminosity. At lower radio powers the optical luminosity has less influence, though a *characteristic* radio power such as P_{30} remains a strong function of absolute magnitude.

Radio-loud	Radio-faint	Radio-quiet
10^{29}	$>10^{27}$ & $<10^{29}$	$< 10^{27}$
erg s^{-1} Hz^{-1}	erg s^{-1} Hz^{-1}	erg s^{-1} Hz^{-1}

SNe-Ia in Radio-Galaxies

Della Valle & Panagia 2003;

Della Valle et al. 2005

Galaxies	C.T. (yr) x 10^{10} $L_{B\odot}$	SNe	Rate SNu(M)
Radio-Quiet 1729	7127		$0.11^{+0.06}_{-0.03}$
Radio-Faint 212	1770		$0.23^{+0.18}_{-0.11}$
Radio-Loud 267	2199		$0.43^{+0.19}_{-0.14}$

SNe-Ia in Radio-Galaxies

Della Valle & Panagia 2003;

Della Valle et al. 2005

Galaxies	C.T. (yr) x 10^{10} $L_{B\odot}$	SNe	Rate SNu(M)
Radio-Quiet 1729	7127	7.5	$0.11^{+0.06}_{-0.03}$
Radio-Faint 212	1770	4	$0.23^{+0.18}_{-0.11}$
Radio-Loud 267	2199	9.5	$0.43^{+0.19}_{-0.14}$

We concluded that the rate of SNeI-a in radio-loud galaxies is definitely higher than it is in radio-quiet by a factor ~ 4 (2 up to 7) @ significance level 99.96%

Della Valle et al. 2005

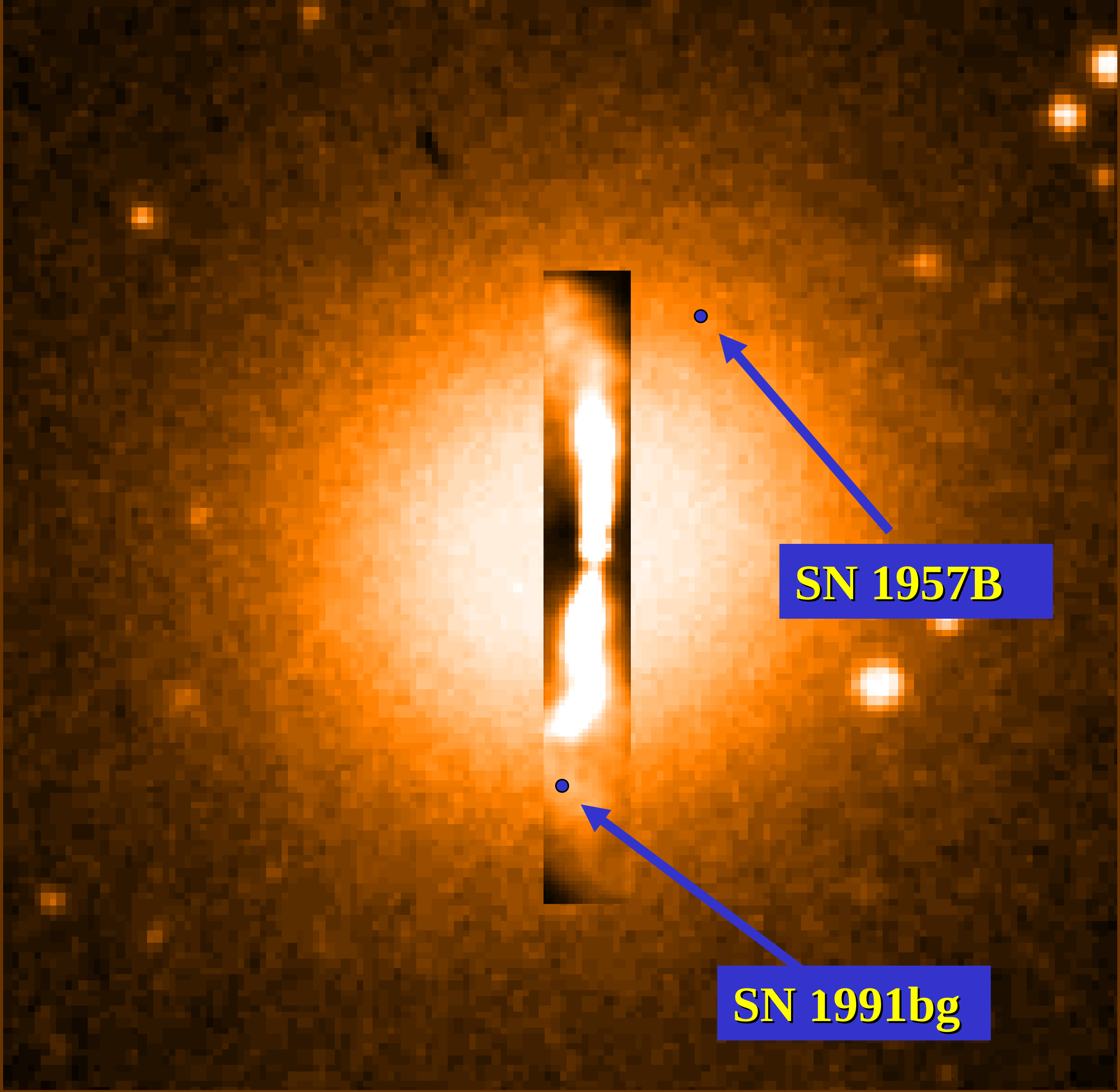
Galaxies	C.T. (yr) x 10^{10} $L_{B\odot}$	SNe	Rate SNu(M)
Radio-Quiet 1729	7127	7.5	$0.023^{+0.012}_{-0.008}$
Radio-Faint 212	1770	4	$0.052^{+0.041}_{-0.025}$
Radio-Loud 267	2199	9.5	$0.100^{+0.044}_{-0.032}$

The 'jet-induced' accretion scenario

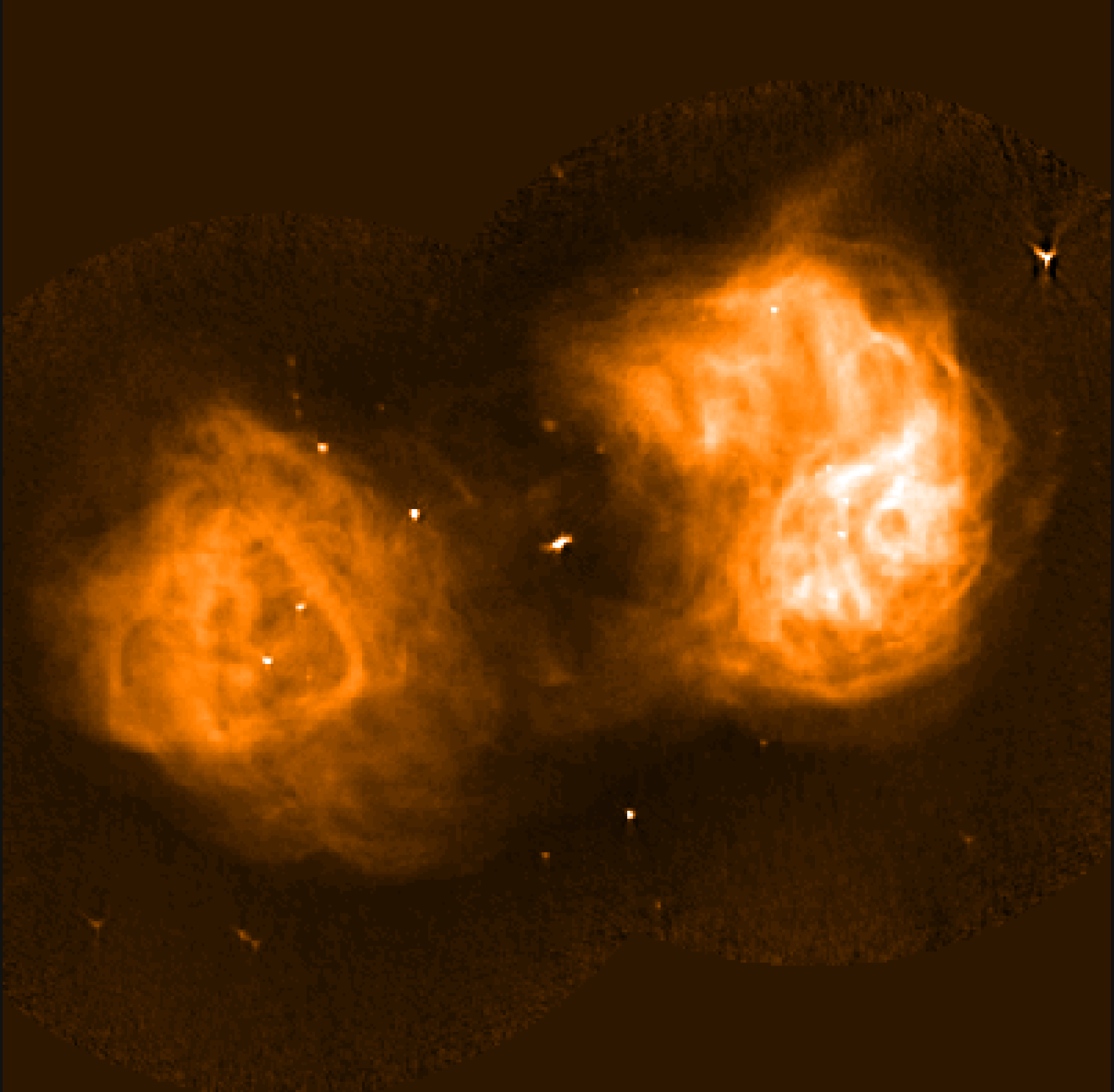
Capetti (2002) and Livio et al. (2002) suggest that jets may lead to an increase of the accretion onto the WDs from either ISM or the companion. In the 'jet-induced' accretion scenario the enhancement of the rate of SNeI-a (and Novae)

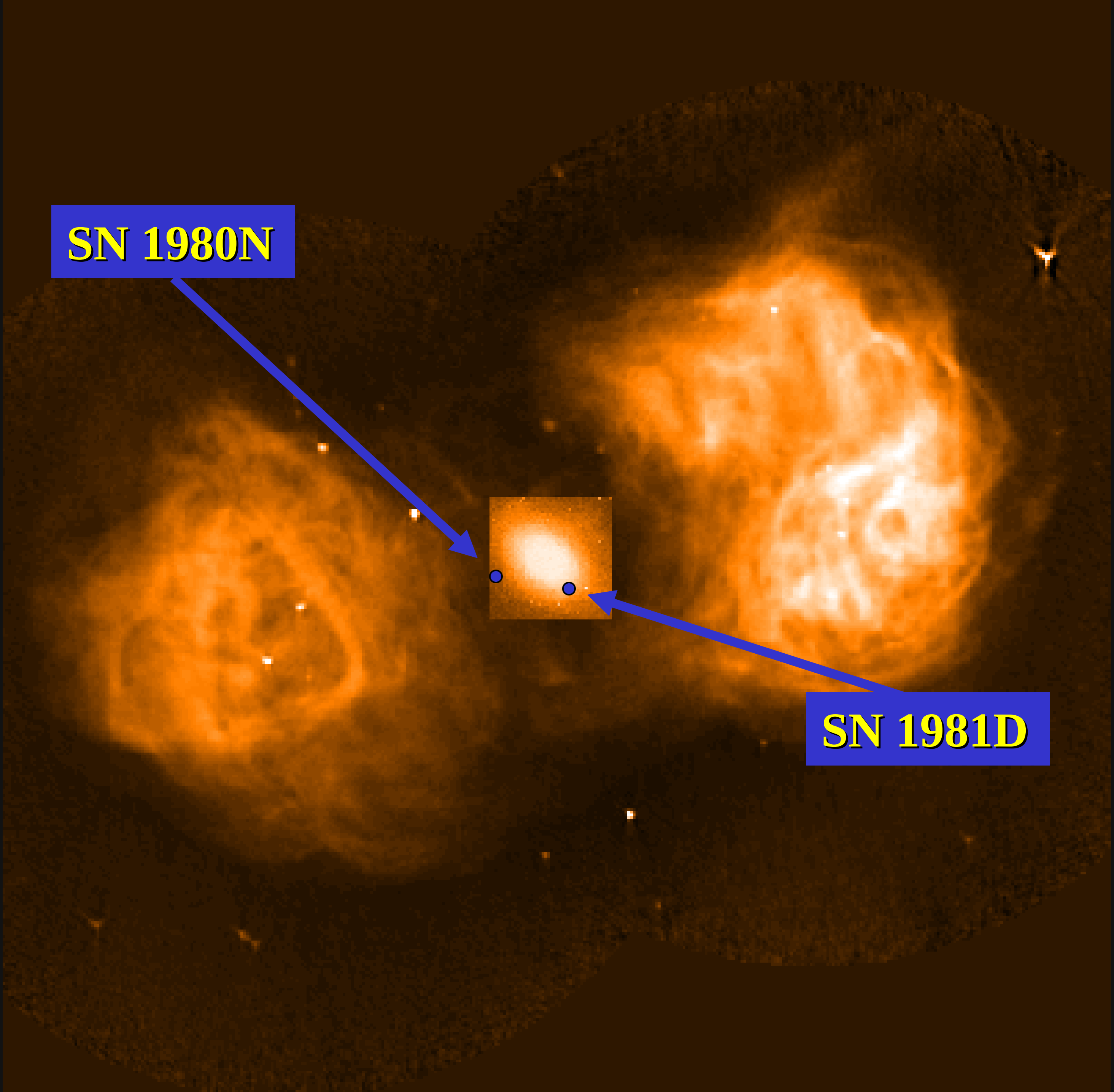
↓

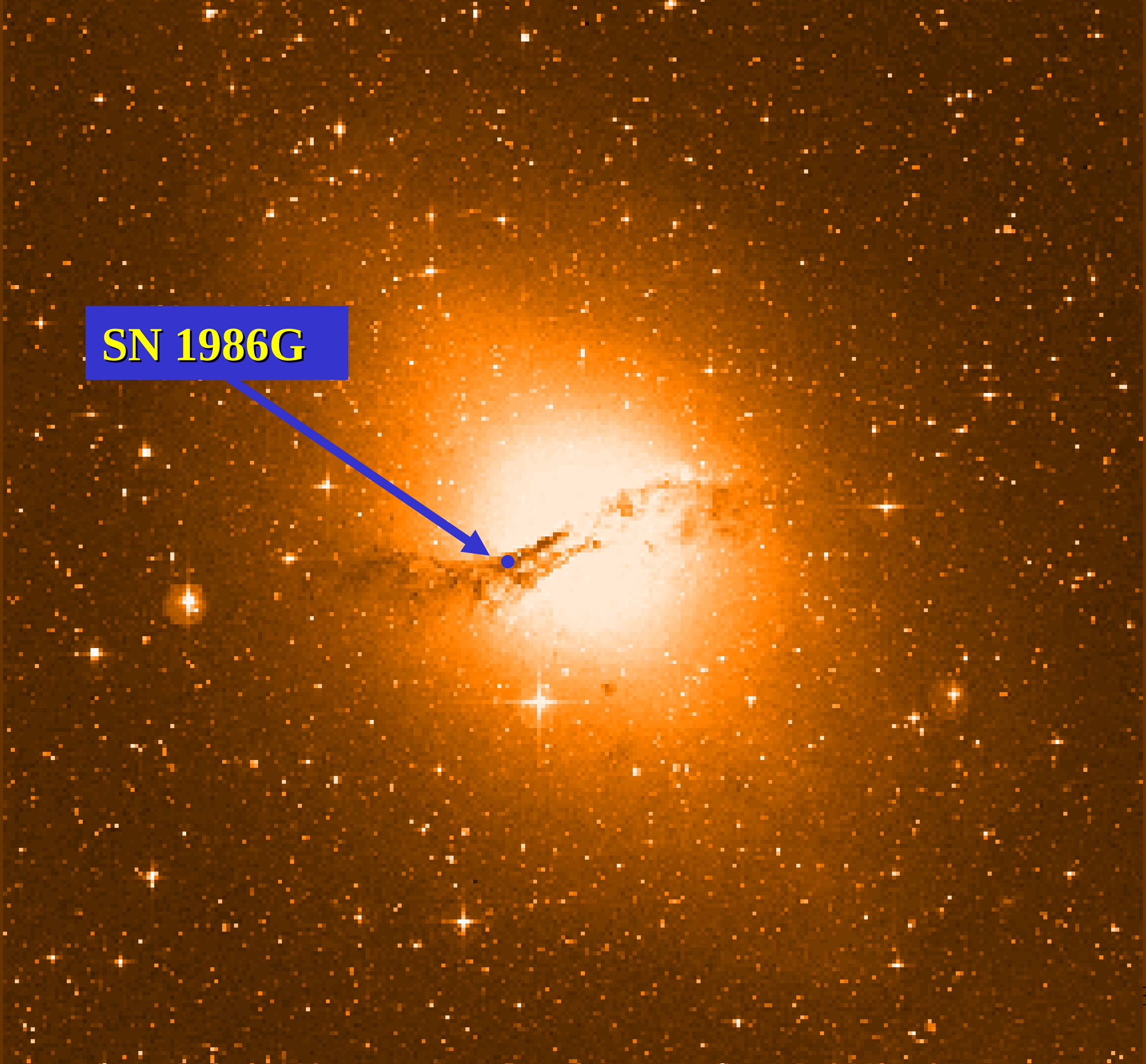
… is expected to be spatially confined to the regions close to jets and/or the bulk of radio activity

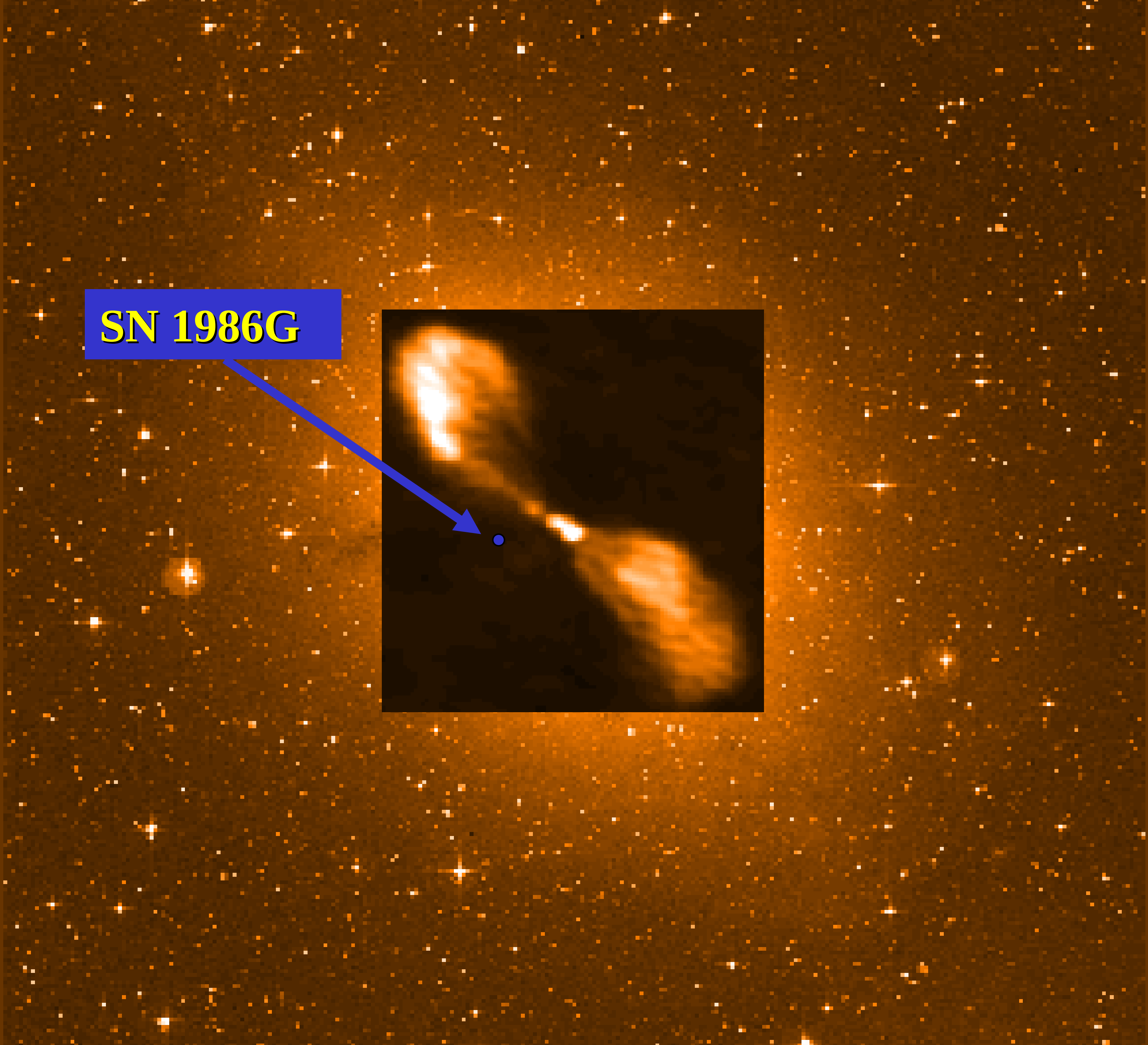


SN 1957B
SN 1991bg



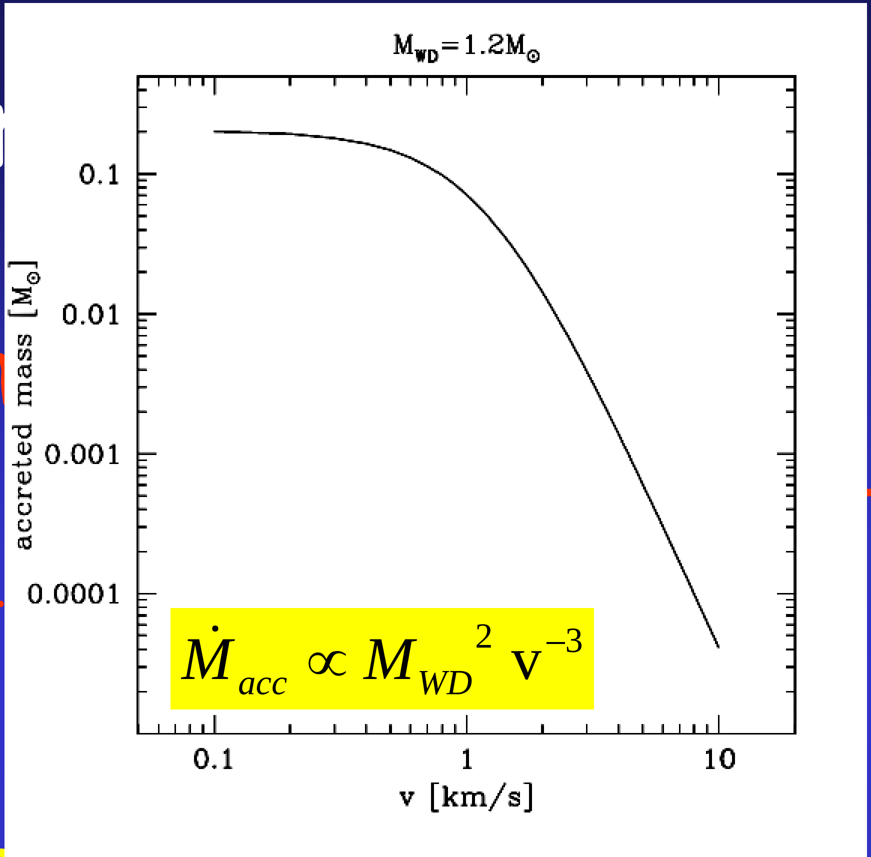

SN 1980N
SN 1981D


SN 1986G


SN 1986G

Therefor

There is no convincin
correlation between
jets (no statistically support



The Bondi accretion be
v<<1 km/s. For typical star velocities of ~ 100km/s, the amount of accreted material onto the WD (for a crossing-time of 100Myr) is ~ $10^{-5}/^{-6}$ $M_\odot$

The common origin of SNeI- and radio-jets

Repeated episodes of interactions or mergers with dwarf companions provide the fresh supply of relatively young stellar population in which SNeI-a are best produced

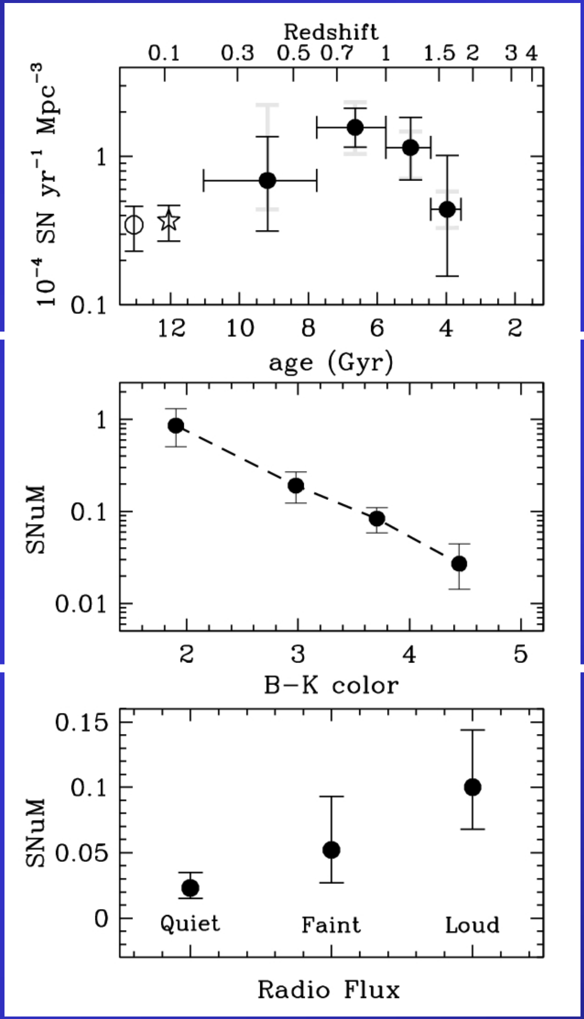
Strong radio activity in early-types galaxies is mostly triggered by interaction or/and mergers (Baade & Minkowski 1954, Heckman et al. 1986).

Therefore….

The strong enhancement of SNI-a rate in radiogalaxies has the same common origine as the radio activity but **there is not** causality link between the two phenomena.

radio activity and episodes of star formation are coeval the observed excess of type Ia SNe in radio-loud galaxies implies evolutionary times (main sequence+time to accrete up to explosion) of the same order of magnitude than the duration of radio-activity, i.e. ~ 100 Myr **(Srinand & Gopal-Krishna; Wan et al. 2000)**

Deriving the DTD



1. evolution of the rate with redshift (Dahlen et al., 2004)
2. dependence of the rate on the colors (Mannucci et al., 2005)
3. dependence of the rate with radio-power (Della Valle et al., 2005)

Timescale

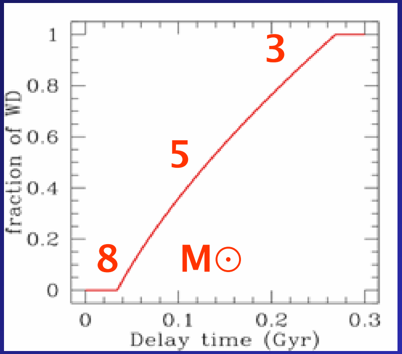
3-4 Gyrs
evolution of the cosmic SFR

0.5-1 Gyr
evolution of the colors

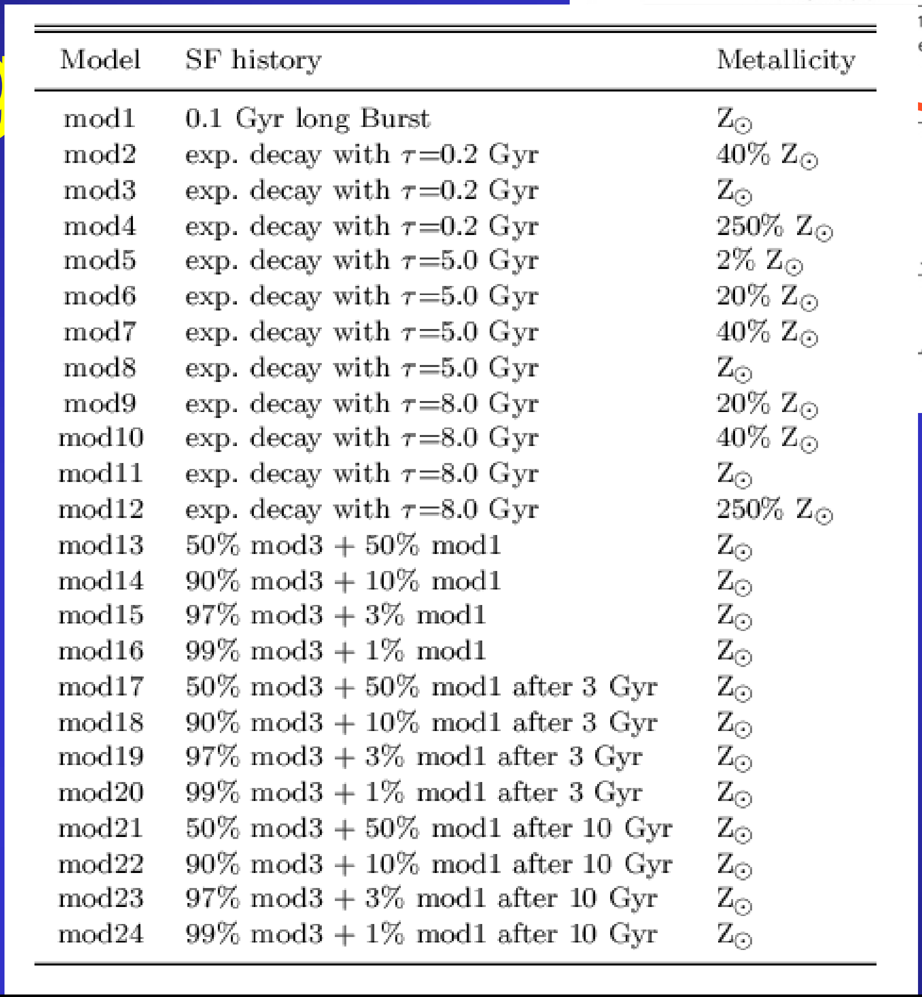
0.1 Gyr
lifetime of radio activity

Is there a DTD satisfying all these?

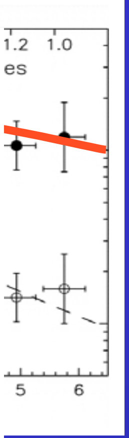
Ing

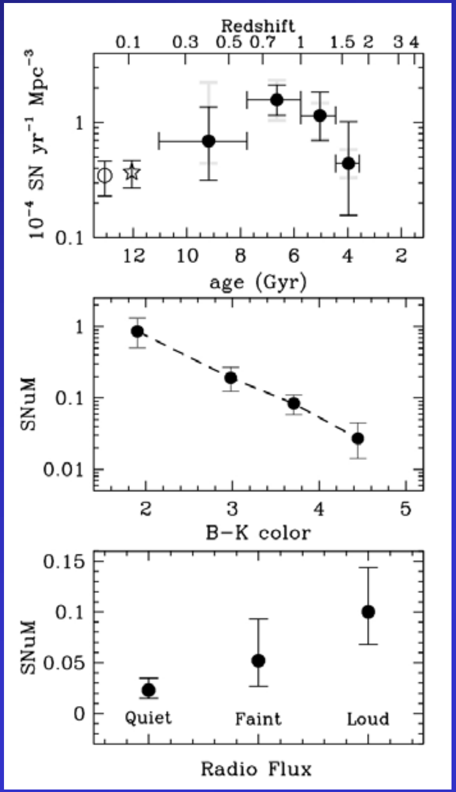


Salpeter IM



Model	SF history	Metallicity
mod1	0.1 Gyr long Burst	$Z_\odot$
mod2	exp. decay with τ=0.2 Gyr	40% $Z_\odot$
mod3	exp. decay with τ=0.2 Gyr	$Z_\odot$
mod4	exp. decay with τ=0.2 Gyr	250% $Z_\odot$
mod5	exp. decay with τ=5.0 Gyr	2% $Z_\odot$
mod6	exp. decay with τ=5.0 Gyr	20% $Z_\odot$
mod7	exp. decay with τ=5.0 Gyr	40% $Z_\odot$
mod8	exp. decay with τ=5.0 Gyr	$Z_\odot$
mod9	exp. decay with τ=8.0 Gyr	20% $Z_\odot$
mod10	exp. decay with τ=8.0 Gyr	40% $Z_\odot$
mod11	exp. decay with τ=8.0 Gyr	$Z_\odot$
mod12	exp. decay with τ=8.0 Gyr	250% $Z_\odot$
mod13	50% mod3 + 50% mod1	$Z_\odot$
mod14	90% mod3 + 10% mod1	$Z_\odot$
mod15	97% mod3 + 3% mod1	$Z_\odot$
mod16	99% mod3 + 1% mod1	$Z_\odot$
mod17	50% mod3 + 50% mod1 after 3 Gyr	$Z_\odot$
mod18	90% mod3 + 10% mod1 after 3 Gyr	$Z_\odot$
mod19	97% mod3 + 3% mod1 after 3 Gyr	$Z_\odot$
mod20	99% mod3 + 1% mod1 after 3 Gyr	$Z_\odot$
mod21	50% mod3 + 50% mod1 after 10 Gyr	$Z_\odot$
mod22	90% mod3 + 10% mod1 after 10 Gyr	$Z_\odot$
mod23	97% mod3 + 3% mod1 after 10 Gyr	$Z_\odot$
mod24	99% mod3 + 1% mod1 after 10 Gyr	$Z_\odot$





Collection of galaxy models from Bruzual & Charlot (2003),
different SF histories (single burst to a rate extended over a Hubble time) metallicities from 2%--250% solar…..
For each model: present day (B-K) colour and SN-Ia rate, obtained by convolving the SFH of each galaxy

Time(loud) = 0.5 ÷ 1.5
yr
Time(faint) = 2 ÷ 10 · 10^8 yr

Assumed DTDs

Single population analytic models

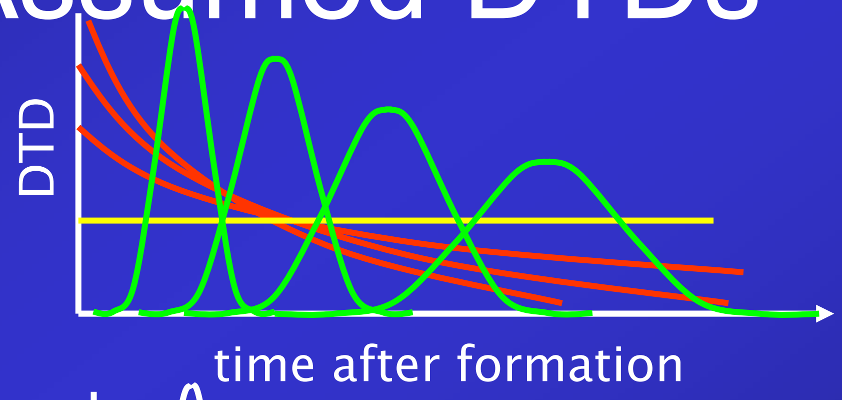
- Exponen. decay, τ=1 Gyr
- Exponen. decay, τ=2 Gyr
- Exponen. decay, τ=3 Gyr
- Exponen. decay, τ=6 Gyr
- Constant
- Gauss at 0.05 Gyr, σ =0.01 Gyr
- Gauss at 0.5 Gyr, σ =0.1 Gyr
- Gauss at 1.0 Gyr, σ =0.2 Gyr
- Gauss at 1.0 Gyr, σ =1.0 Gyr
- Gauss at 2.0 Gyr, σ =2.0 Gyr
- Gauss at 2.0 Gyr, σ =0.4 Gyr
- Gauss at 3.4 Gyr, σ=0.7 Gyr
- Gauss at 4.0 Gyr, σ=2.0 Gyr

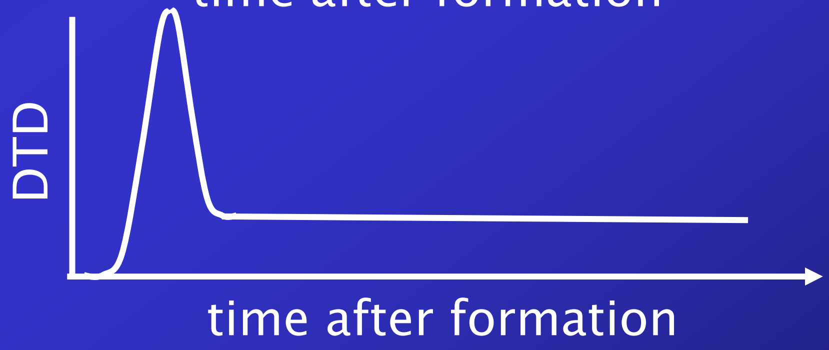
Two-populations analytic models

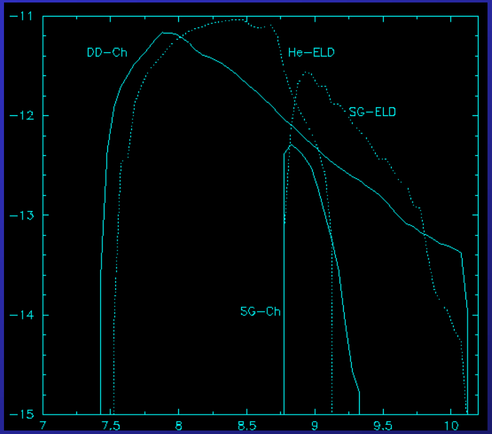
- 50% prompt + 50% gauss. 4 Gyr
- 50% prompt + 50% expon. 3 Gyr
- 50% prompt + 50% const.

Theoretical models

- Yungelson & Livio (2000), DD-Ch,
- Yungelson & Livio (2000) He-ELD,
- Yungelson & Livio (2000) SG-Ch,
- Yungelson & Livio (2000) SG-ELD,
- Belczynski et al (2005) SDS, $\alpha\lambda$=0.3
- Belczynski et al (2005) SWB, $\alpha\lambda$ =1.0
- Greggio (2005) wide DD τ=0.4 β =-0.9
- Greggio (2005) close DD τ=0.5 β=-0.75
- Greggio (2005) SD chandra
- Greggio (2005) SD sub-chandra
- Matteucci & Recchi (2001)

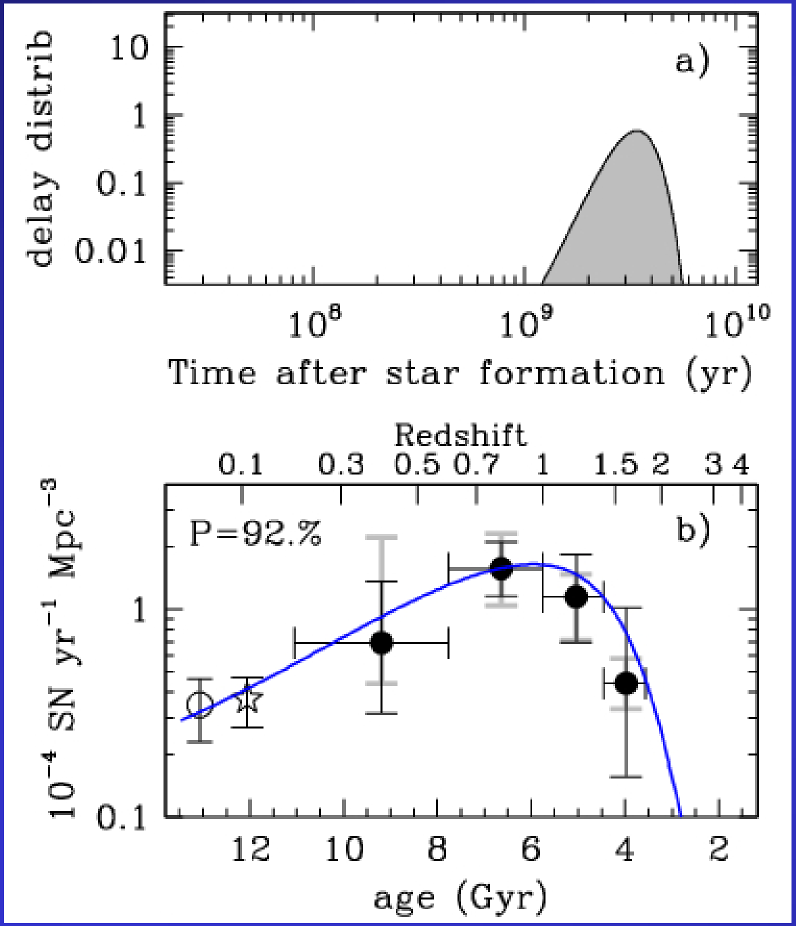


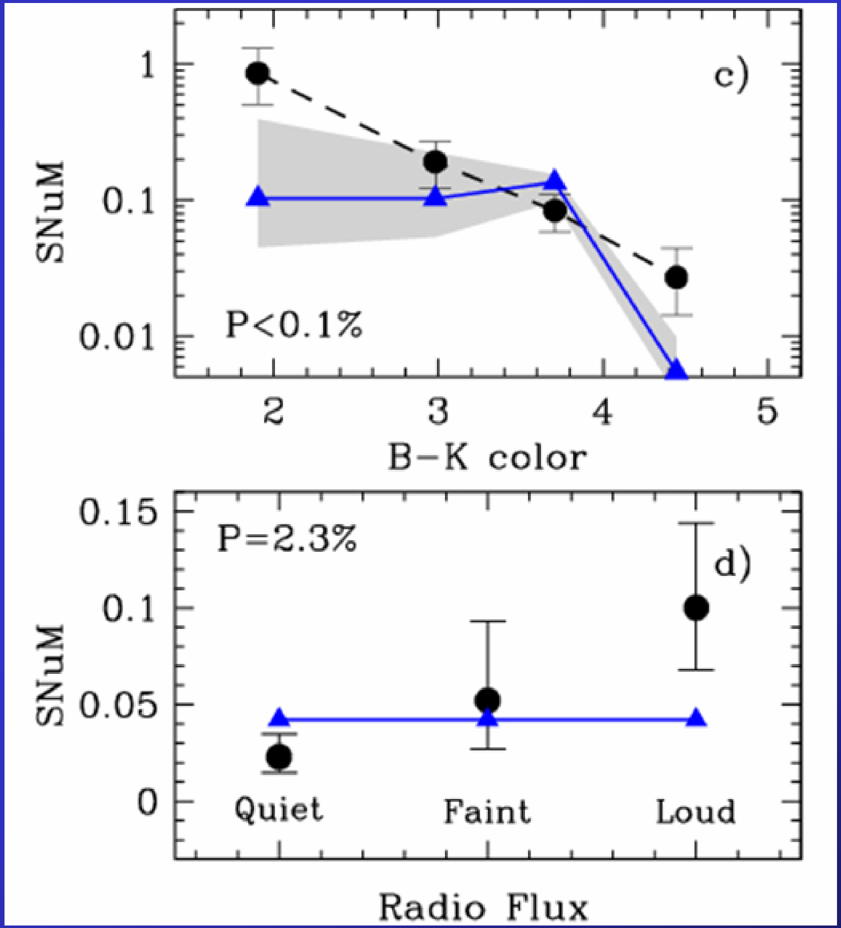




Deriving the DTD

single population: gaussian, 3.4 Gyr

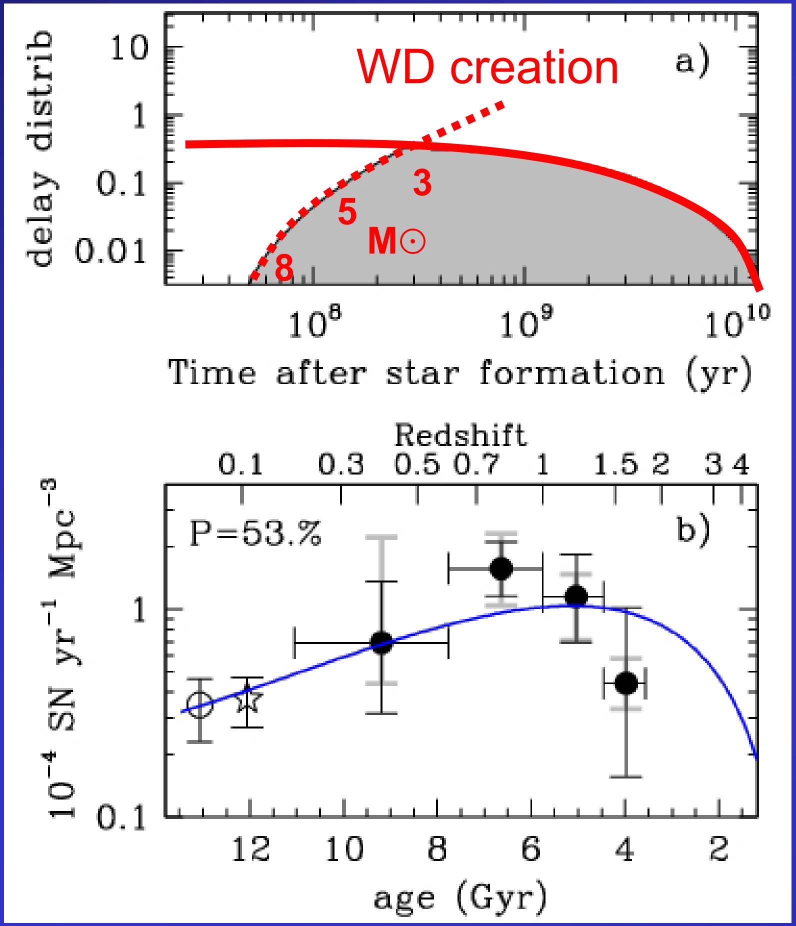


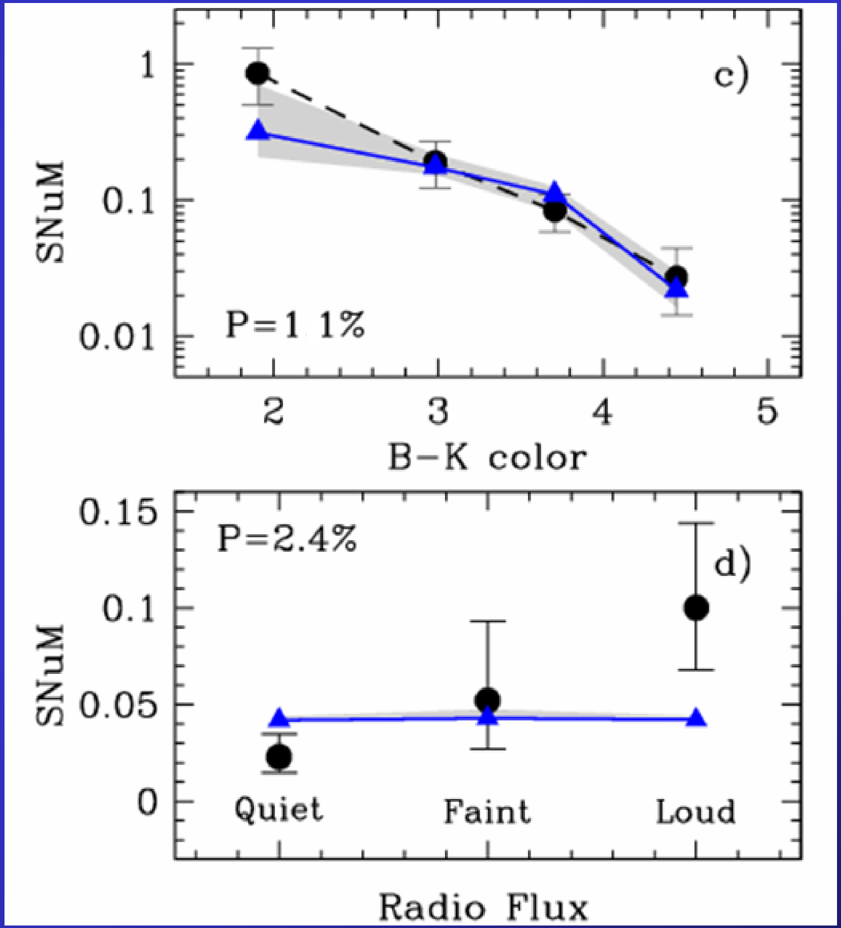


Mannucci, DV & Panagia 2006

Deriving the DTD

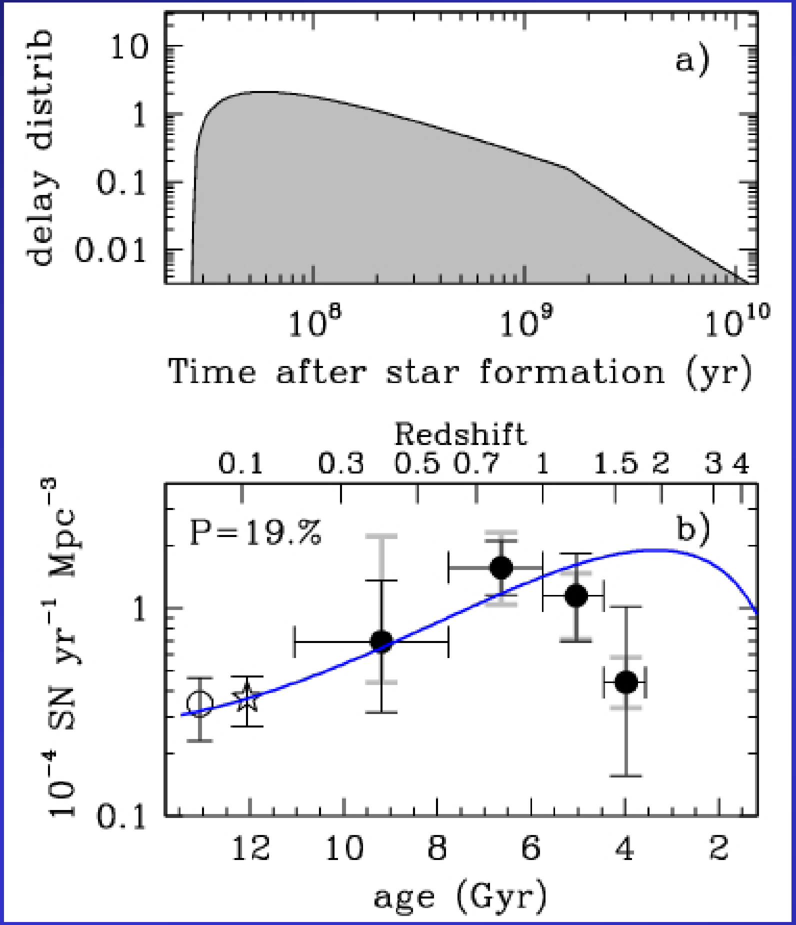
single population: exponential decay, 3 Gyr

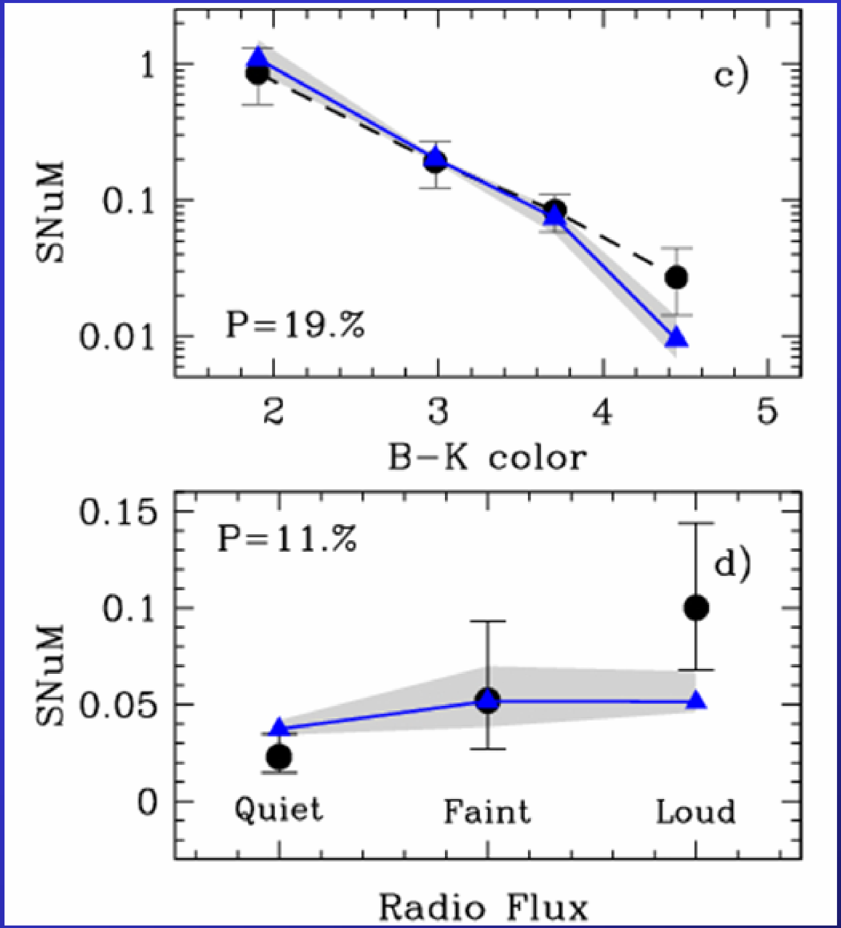




Deriving the DTD

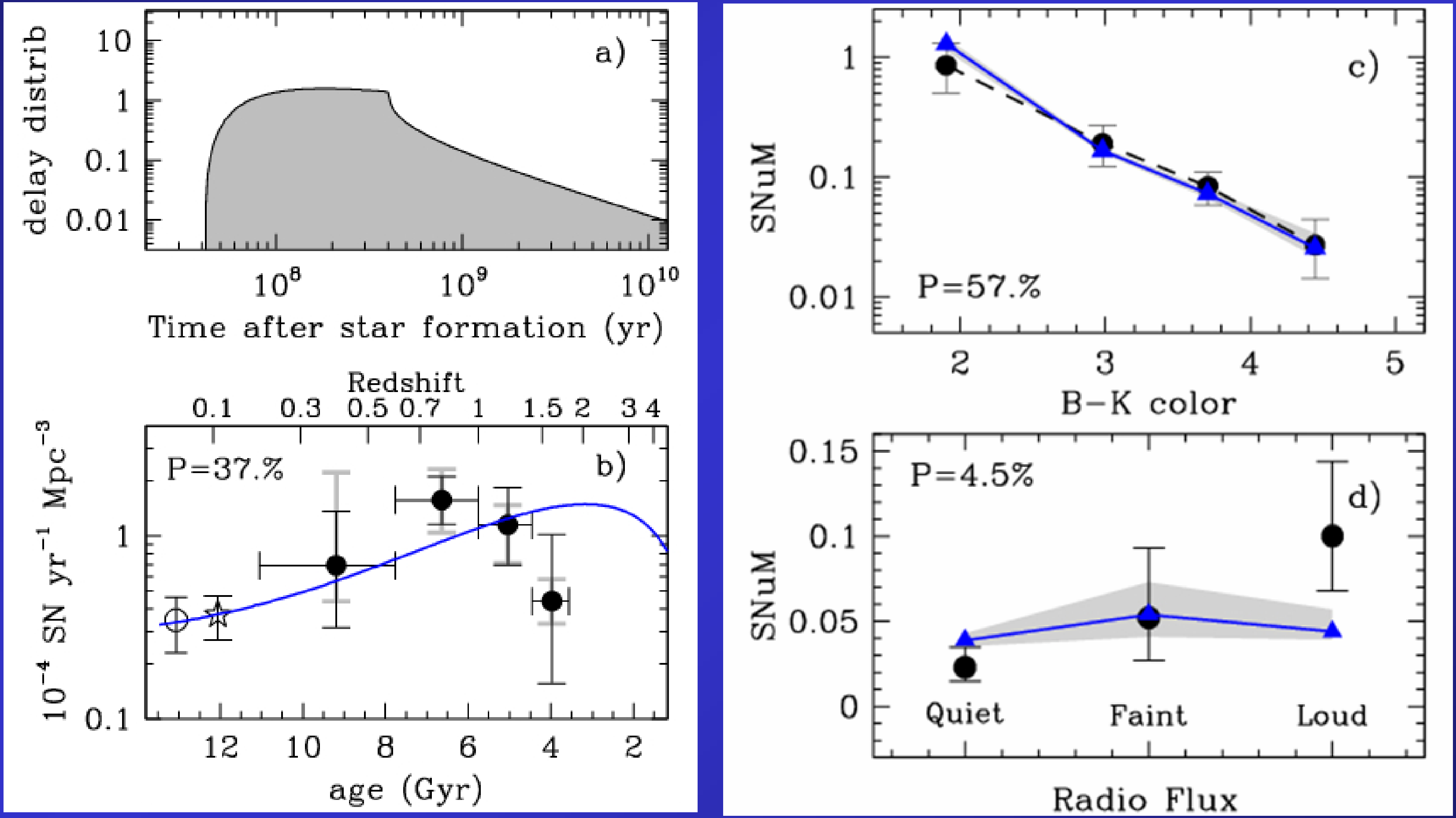
Theoretical model: Matteucci & Recchi (2001) - SD





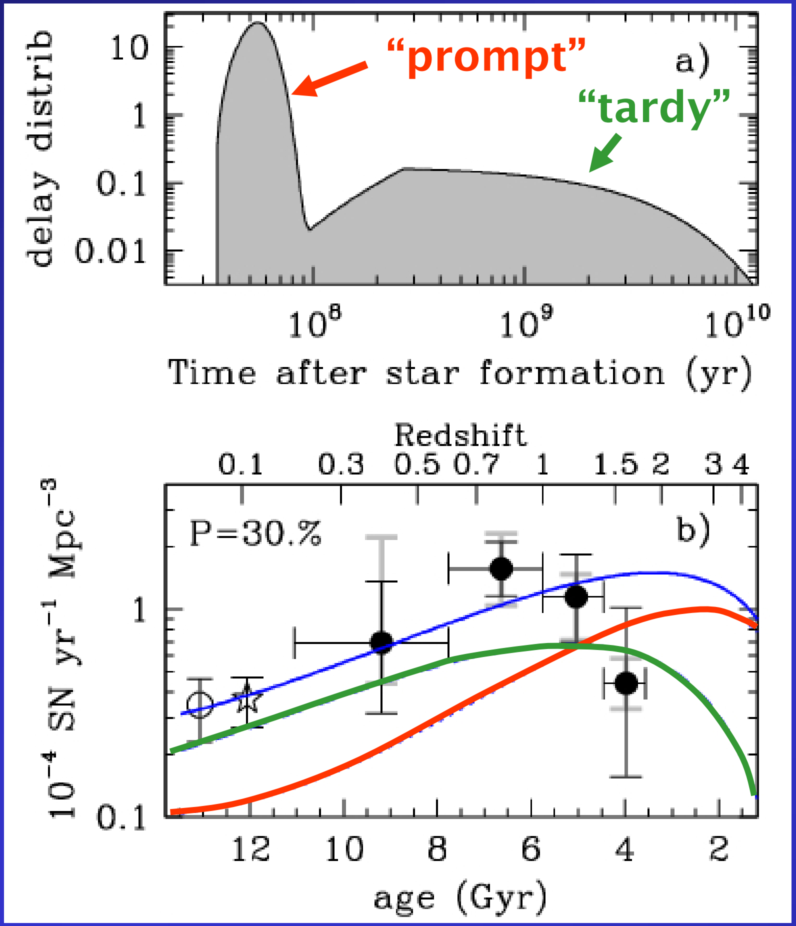
Deriving the DTD

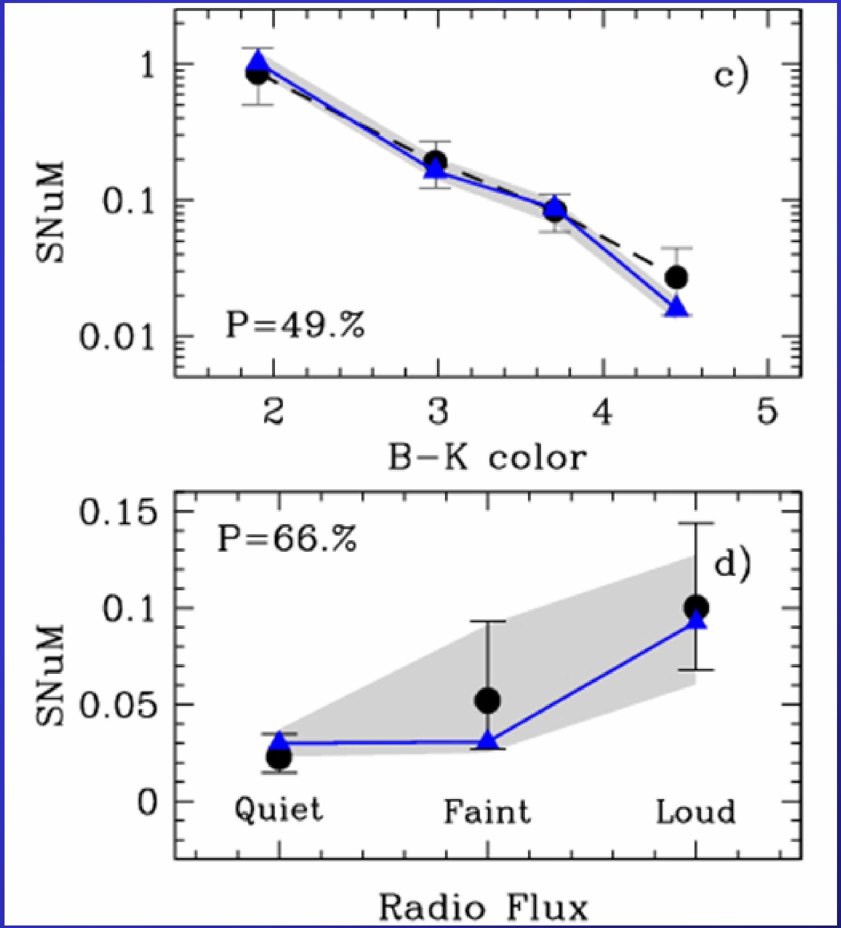
Theoretical model: Greggio (2005) - DD



Deriving the DTD

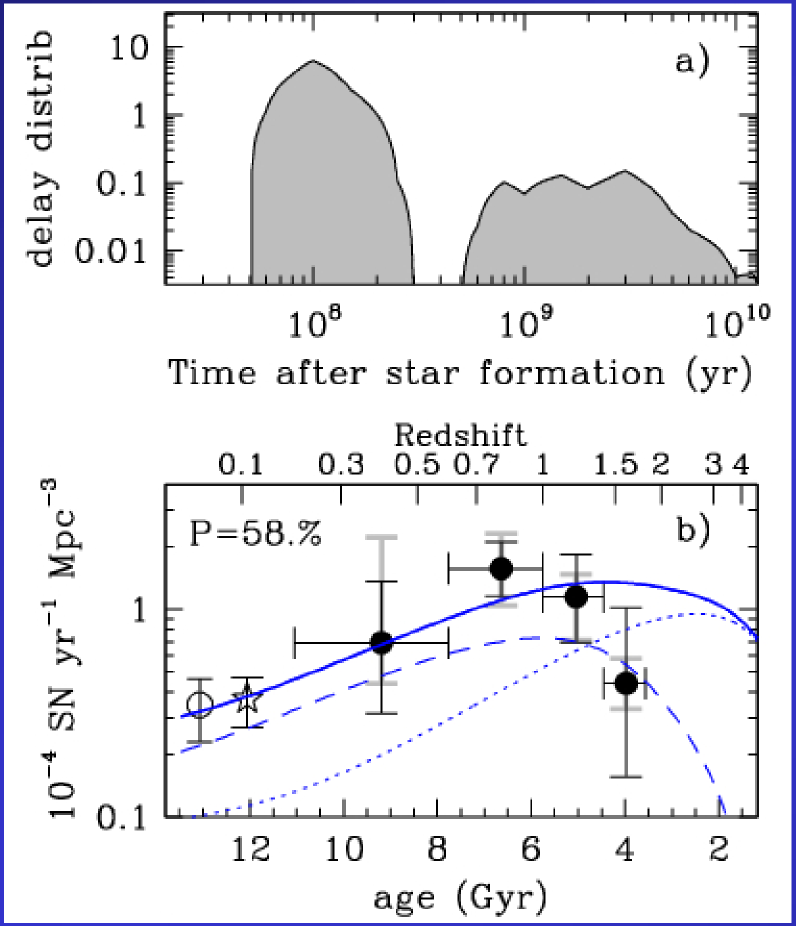
Two populations: 50% prompt + 50% exp

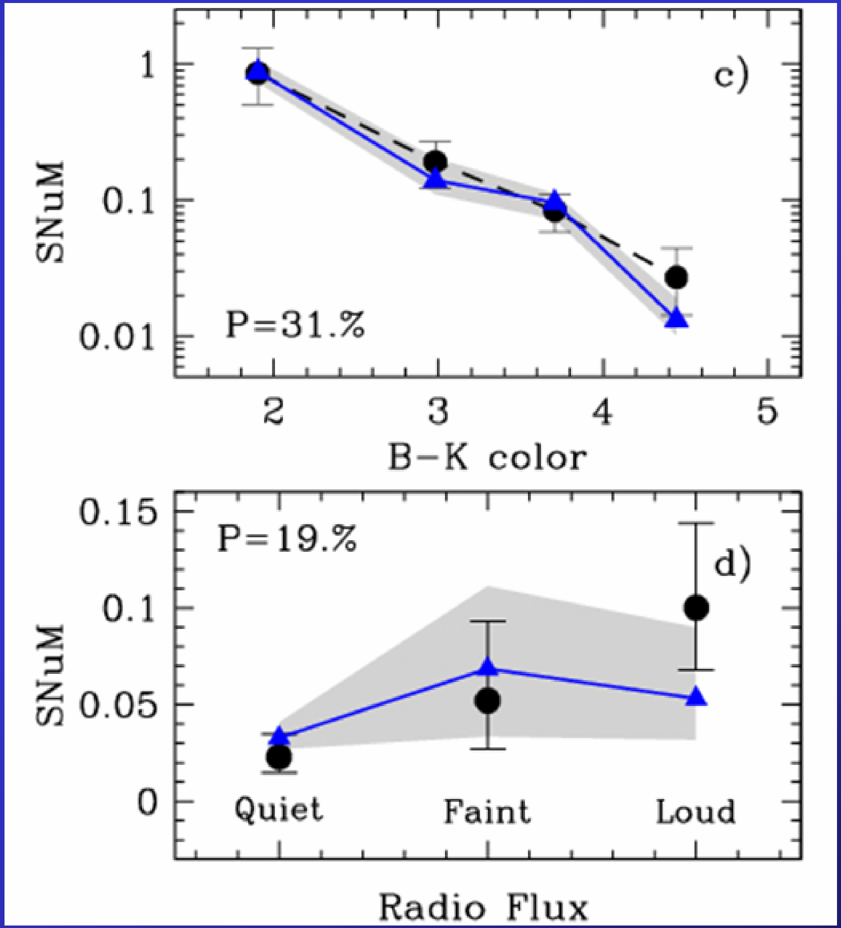




Deriving the DTD

Theoretical model: Belczinsky et al. (2004) - SD





Model	η (%)	X^2(z)	X^2(color)	X^2(radio)
Single population analytic models				
Exponen. decay τ=1 Gyr	4.5	2.1	26	3.9

Summarizing:

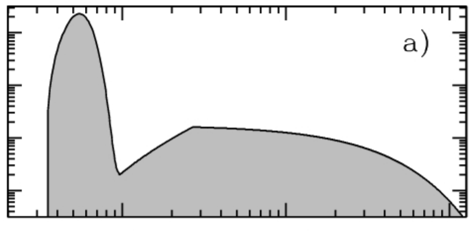
1. About 50% of the SNe must explode within 10^8 yr
2. About 25% must explode after $2\cdot10^9$ yr
3. Best with two distinct populations of progenitors:
   1. "prompt", young stars, dominating in S/Irr
   2. "tardy", all populations, more important in E/S0
4. For the first time, theoretical models have something to reproduce
5. No existing theoretical model provides a perfect fit

(Belczinsky et al. 2004 ; Kobayashi et al. 1998)

Model	η (%)	X^2(z)	X^2(color)	X^2(radio)
Belczynski et al (2005) SWD, $\alpha\lambda$=1.0	4.5	16	18	3.9
Greggio (2005) wide DD τ=0.4 β =-0.9	4.0	1.1	0.8	2.7
Greggio (2005) close DD τ=0.5 β=-0.75	4.0	1.0	0.6	2.7
Greggio (2005) SD chandra	4.0	0.9	1.4	3.3
Greggio (2005) SD sub-chandra	4.0	1.2	2.2	2.6
Matteucci & Recchi (2001)	4.4	1.4	2.0	1.9

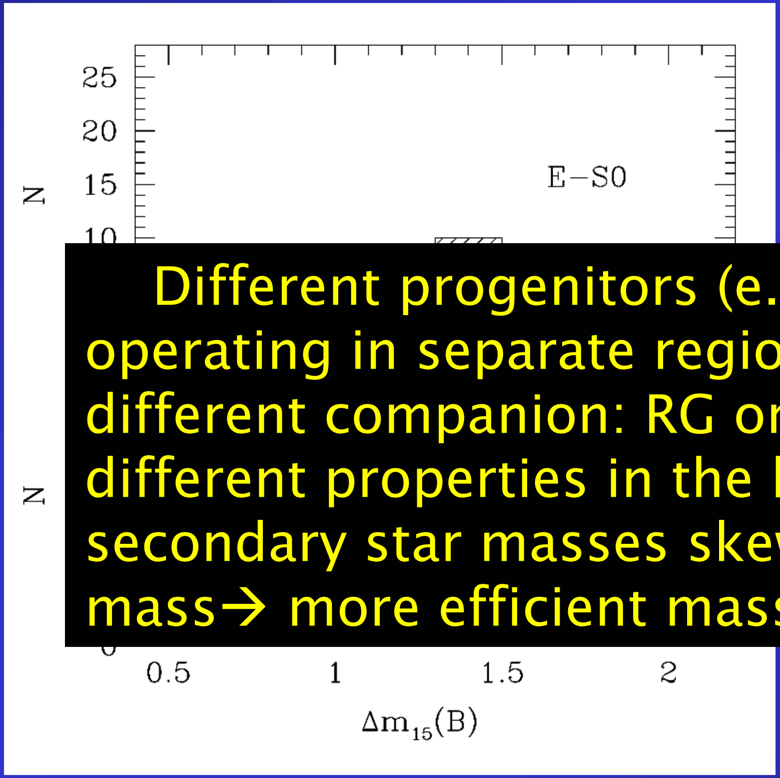
Bimodality = Different progenitors ?

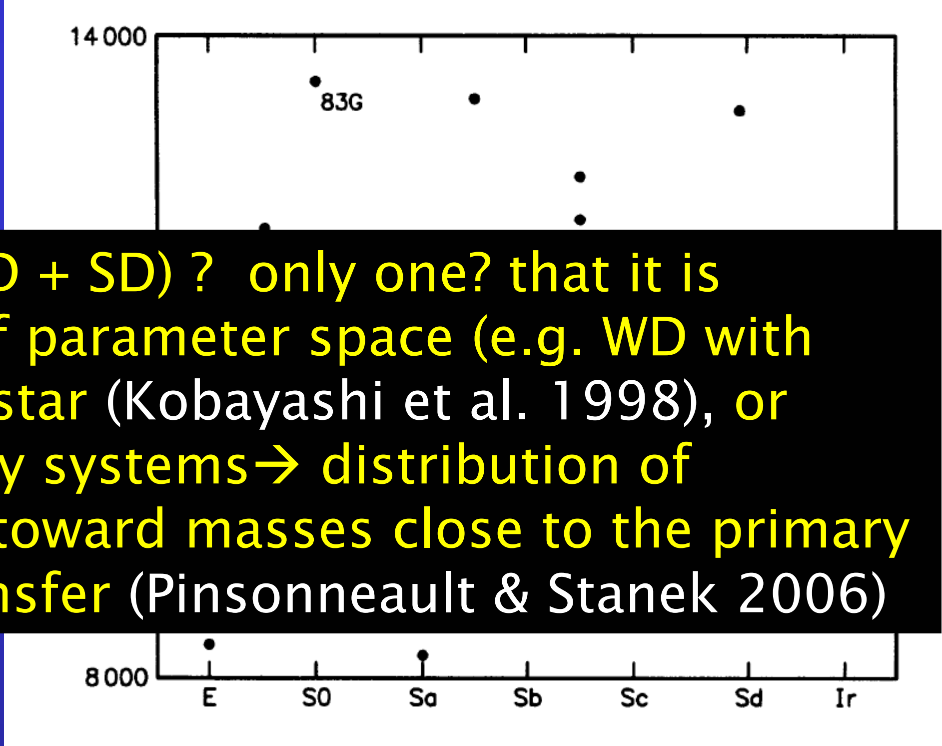
Other bimodality in SN properties



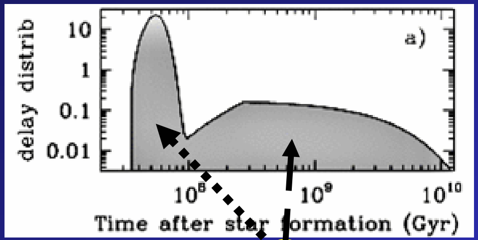
1. Peak brightness and

2. Expansion velocities



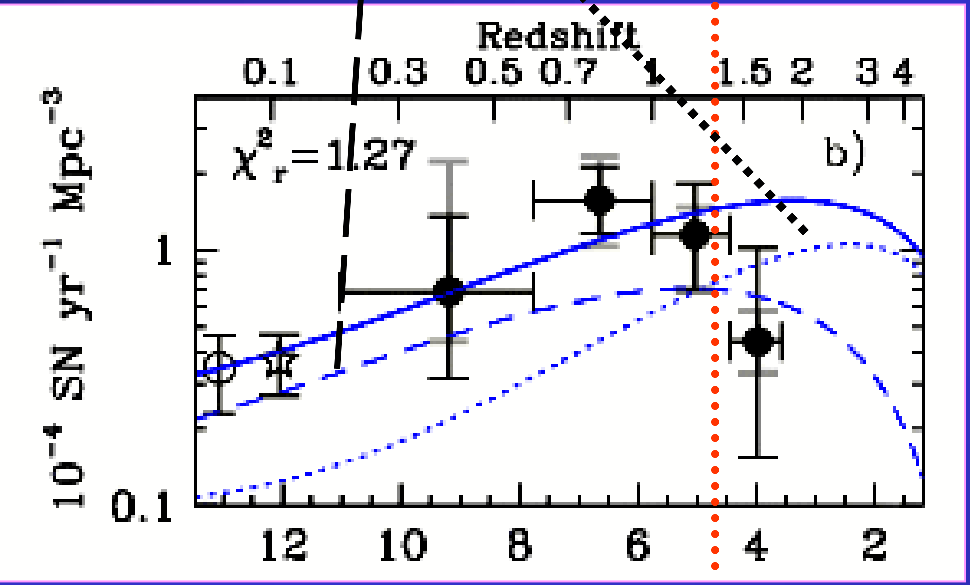


Different progenitors (e.g. DD + SD) ? only one? that it is operating in separate regions of parameter space (e.g. WD with different companion: RG or MS star (Kobayashi et al. 1998), or different properties in the binary systems→ distribution of secondary star masses skewed toward masses close to the primary mass→ more efficient mass transfer (Pinsonneault & Stanek 2006)



logical Consequences

- The fraction of SNe coming from the two populations changes with time



At z=0 the “tardy” component is predominant (2/3 vs 1/3). At z=1.3 the two contributes are equivalent at z=2 the contribute of the “prompt” component is about twice as large the “tardy” one. → Phillips’s relationship is calibrated on the “tardy” component→ luminosity-decline rate relation might change with redshift??? Metallicity? (Nomoto et al. 2003)

Chemical Evolution of the Universe

Intracluster medium:

- Fe/H ~ -0.5 solar
- no strong evolution with z

(Tozzi et al. 2003)

Present observed SN Ia rate ➔ 1/10 of the observed Fe mass

(Renzini et al. 2004)

CC SNe: similar contribution (1/6)

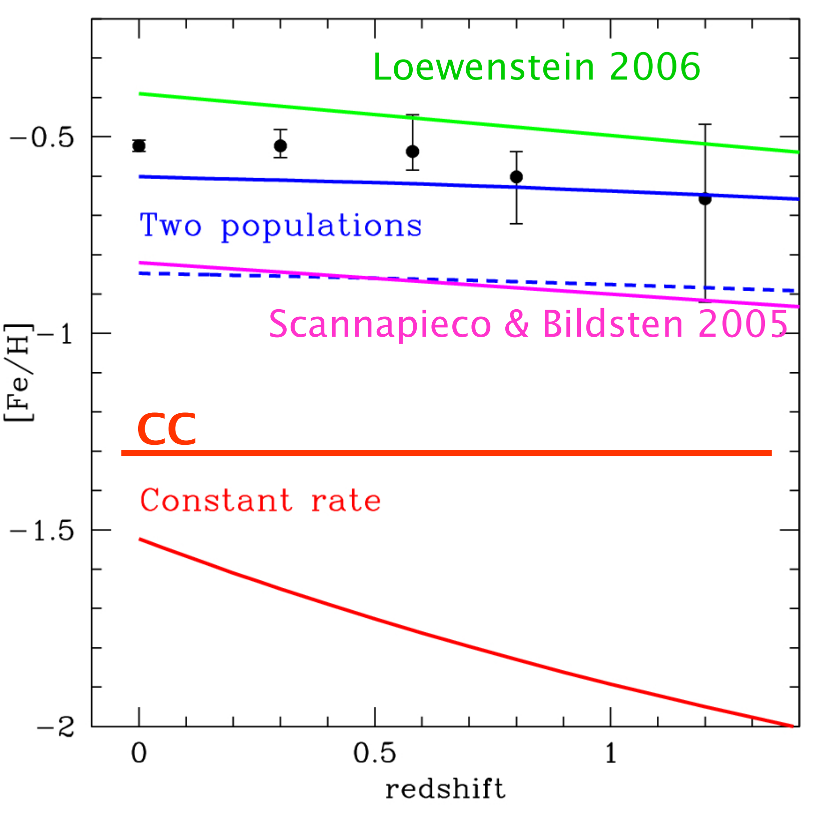
Maoz & Gal-Yam (2004)

"top-heavy IMF the only viable option"

Another possibility:

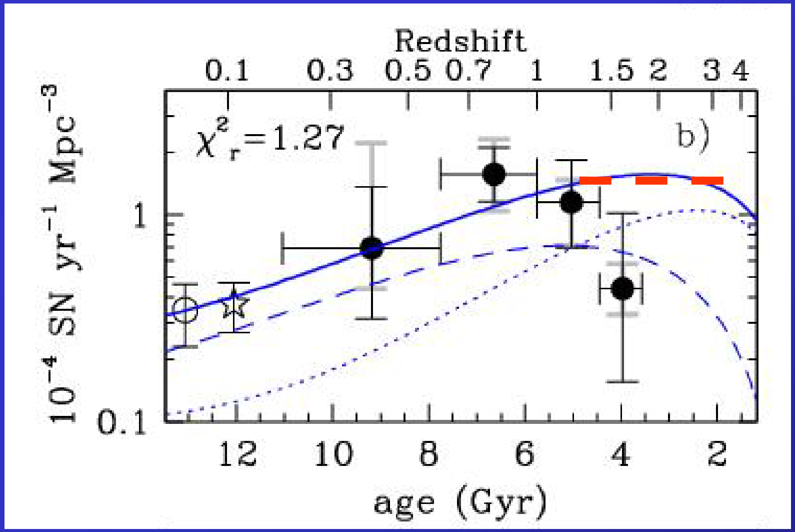
Two populations hypothesis

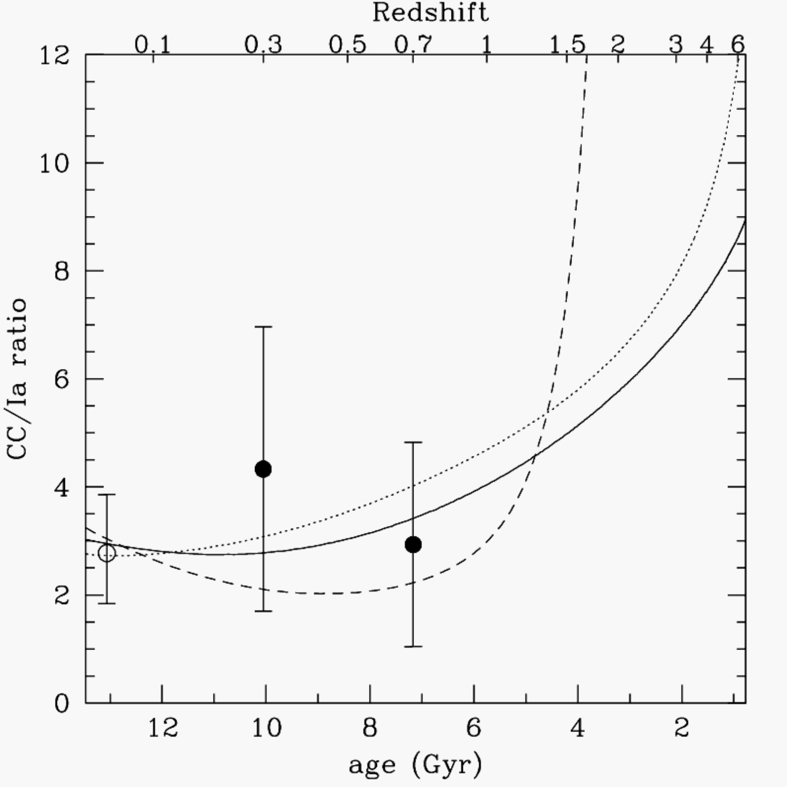
(Scannapieco & Bildsten 2005; Matteucci et al. 2006; Lowenstein 2006, Calura et al. 2007)



Testing the prompt and tardy populations: Predictions (JWST/ELT)

1. Roughly constant rate at $1<z<4$, rate$\sim 1\cdot 10^{-4}$ SN yr^{-1} Mpc^{-3}





2. CC/Ia rate ratio rising from 3 to 9 at $z\sim 6$. Rate ratios are easier to observe, lower selection effects

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