# SN Ia Rate Dependence on Host Galaxy Properties in Subaru SXDS and Implications for Delay Time Distribution

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# Type Ia Supernova

- thermonuclear explosions of carbon-oxgen white dwarf (WD) in binary systems
- The progenitor binary system leading to SNe Ia is still unknown
  - single degenerate scenario (SD)

    the accretion is from a non-degenerate companion star
  - double degenerate scenario (DD)

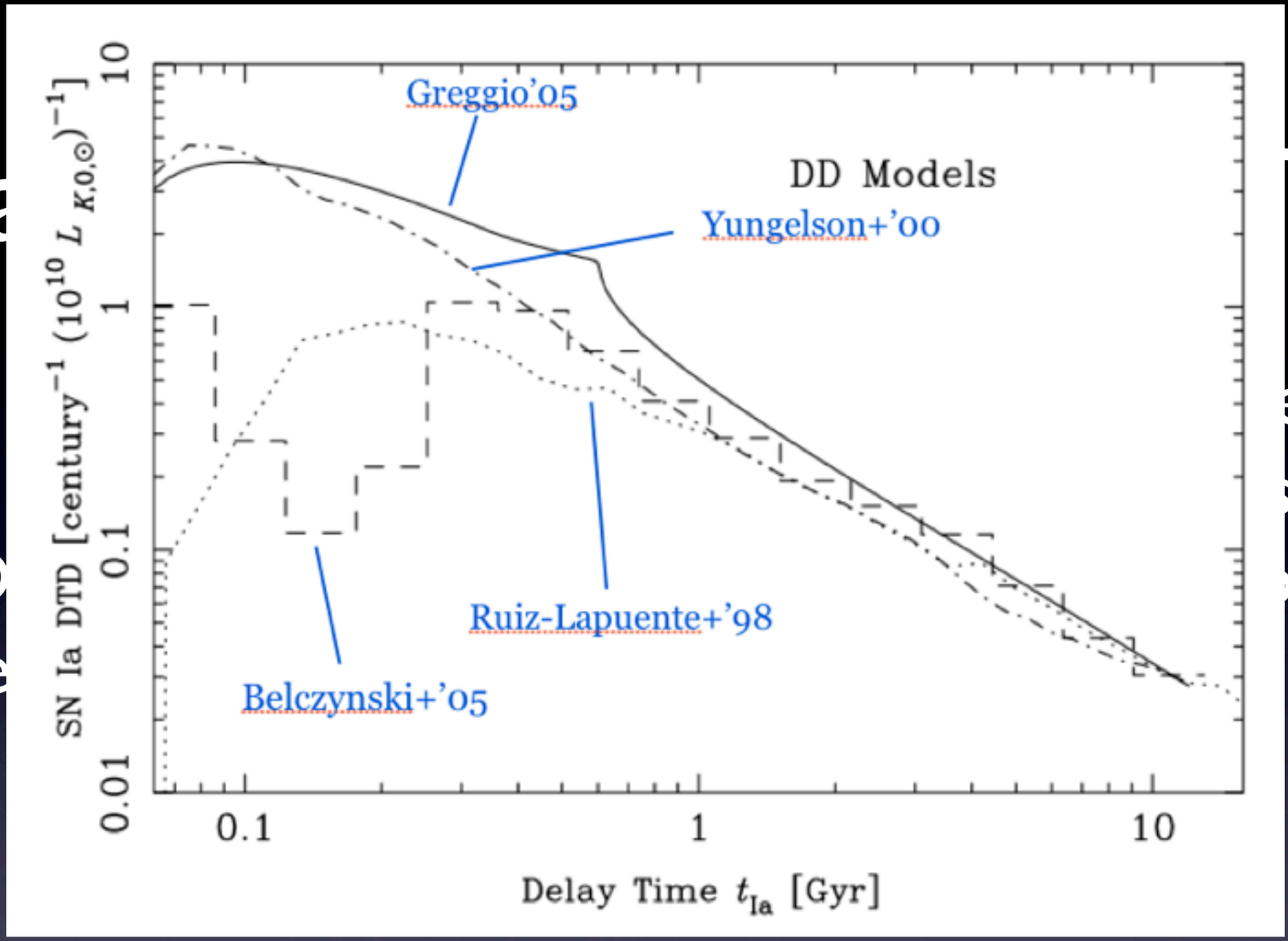
    a merger of two WDs results in a SNe Ia

# Delay Time Distribution (DTD)

- SNe Ia are expected to have a wide range of delay times form star formation to supernova explosions, and the DTD can be used to discriminate the the proposed progenitor models

# Dela TD)

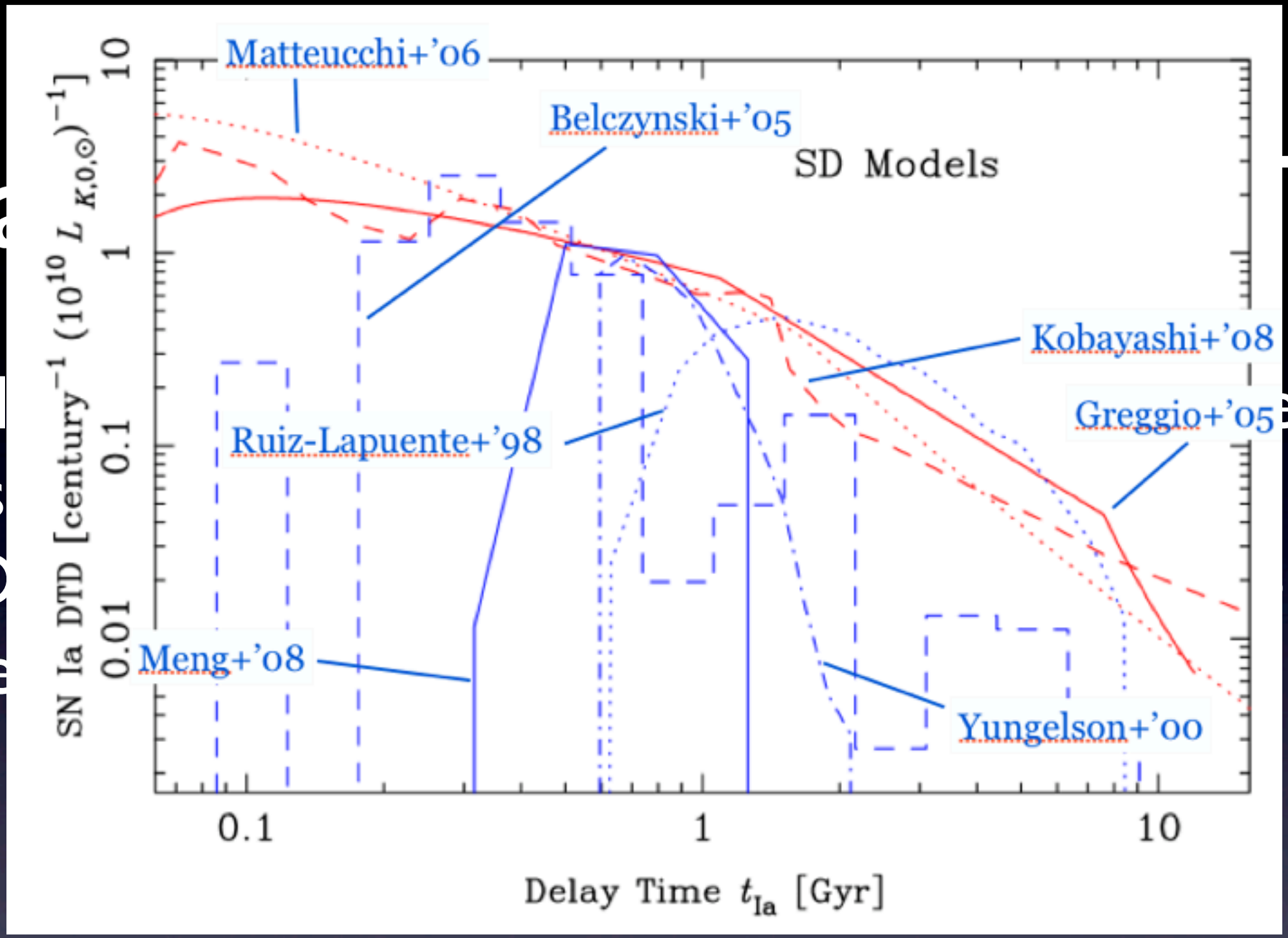
- SNe I elay times sions, and the D roposed proge




- DD : the delay times is mainly determined by the $t_{GW}$ from the formation of a DD binary to a merger after angular momentum loss by gravitational wave radiation
- power-law like DTD

# Dela TD)

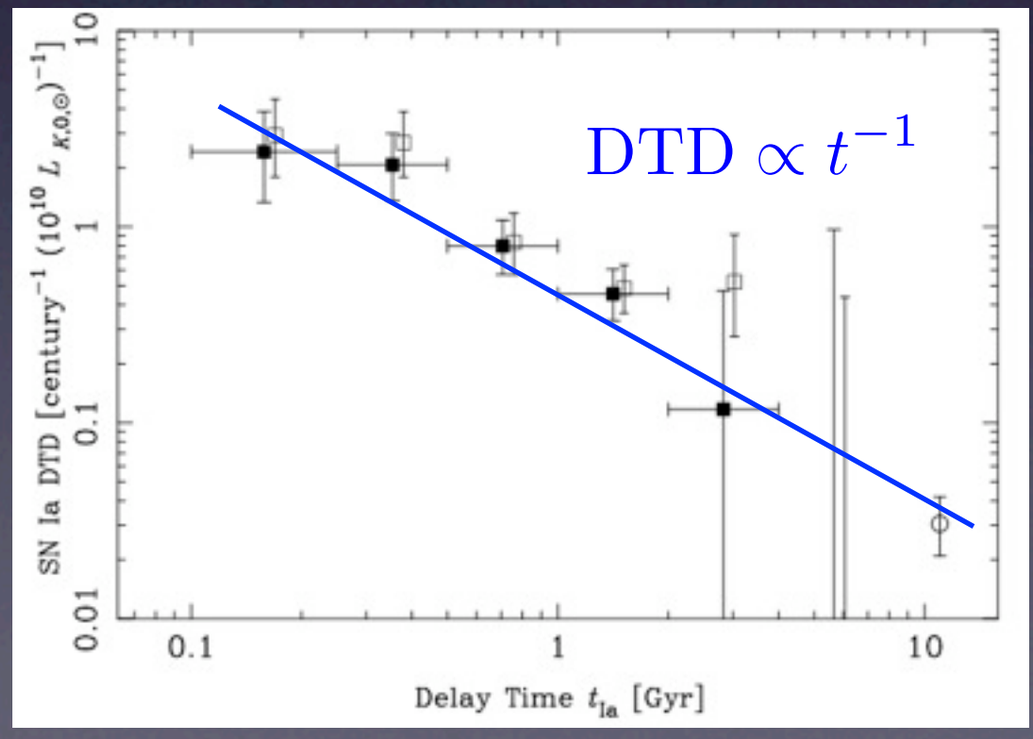
- SNe I elay times ions, and the D roposed proge



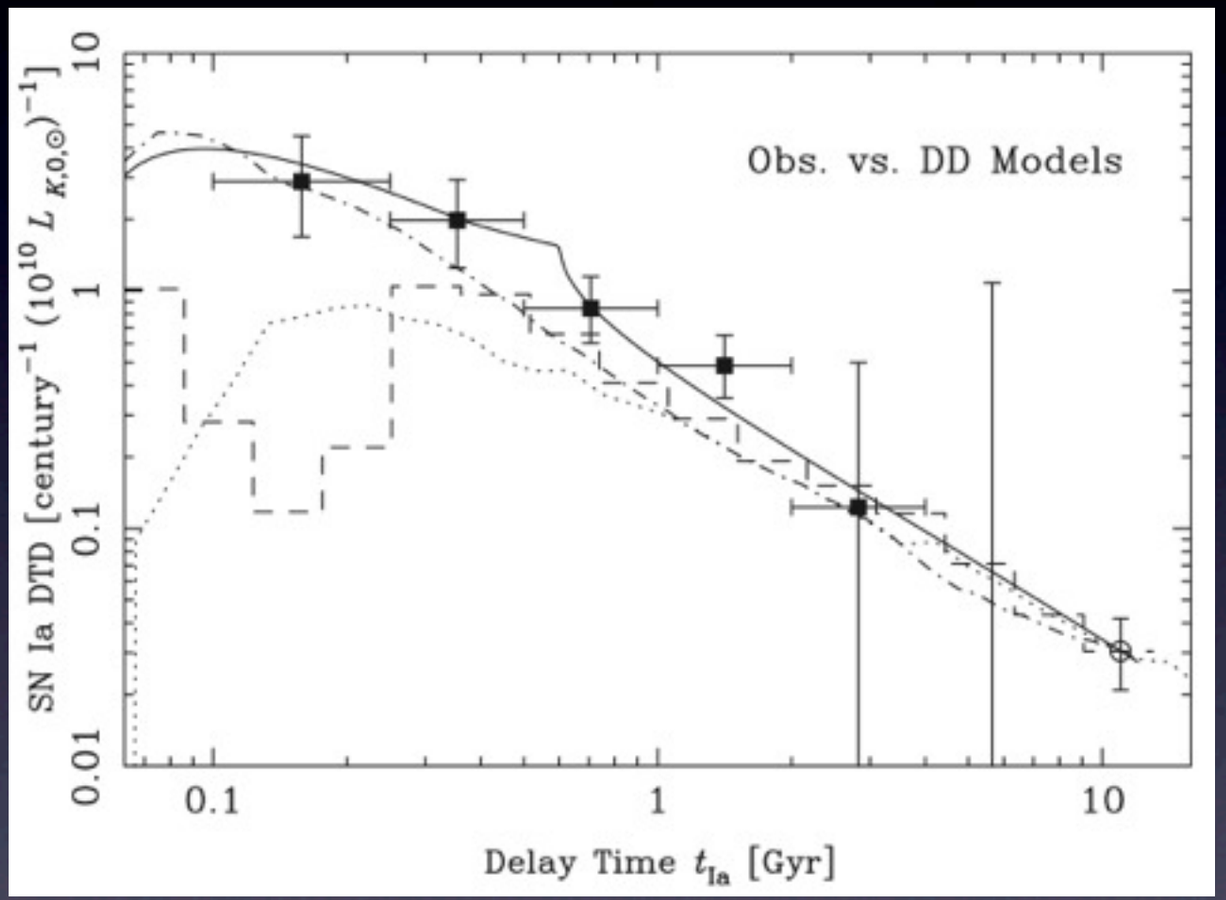

- SD : the delay time is essentially determined by the main-sequence lifetime of the secondary star in a binary
- some characteristic secondary mass scales preferred for successful SN Ia events

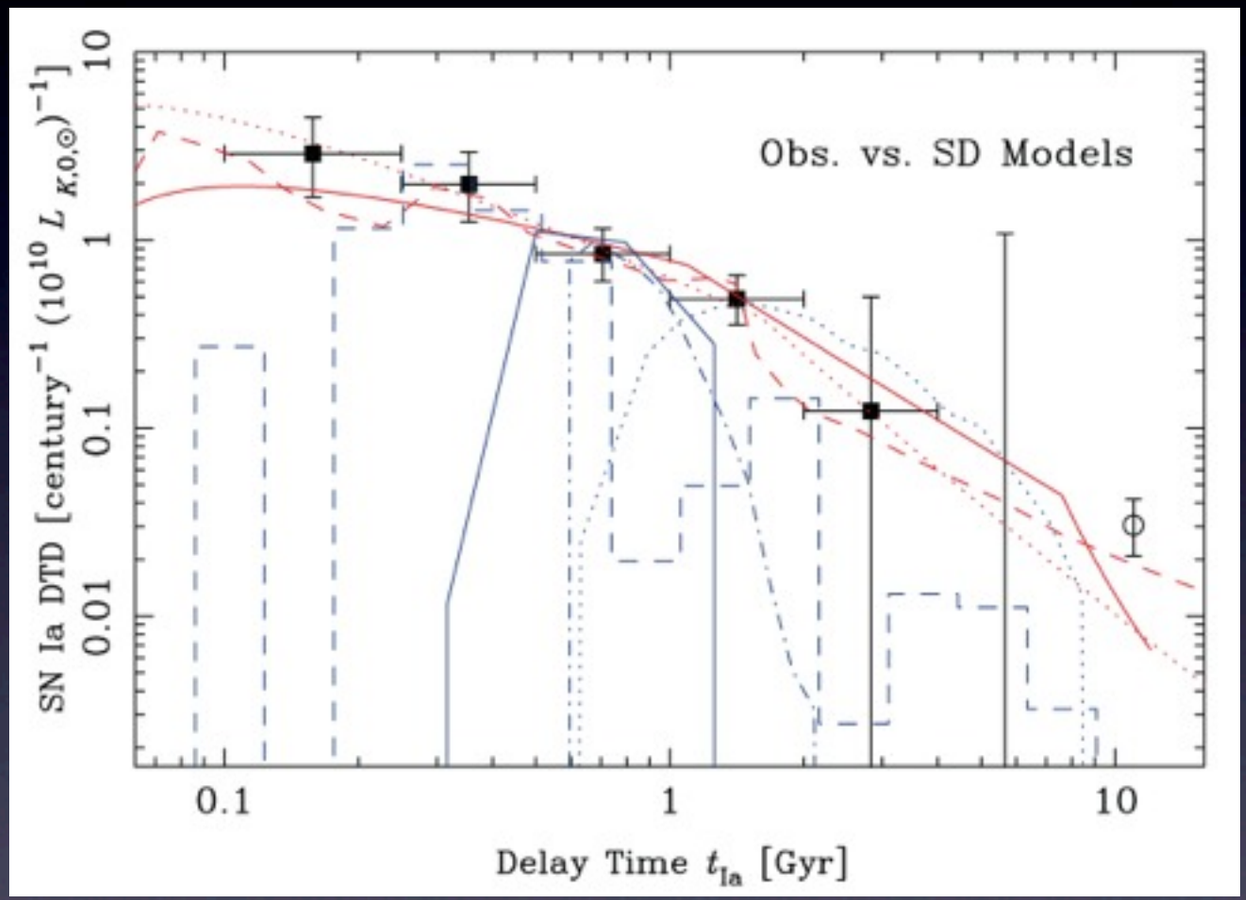
# Totani+08

- measured the SN Ia DTD in a delay time range of 0.1-8.0 Gyr by using faint variable objects detected in Subaru/XMM-Newton Deep Survey (SXDS)
- passive galaxy sample (already formed 90% of stars)
  > delay time can be approximated by stellar age
- 65 SN candidates showing significant spatial offset from the nuclei of the host galaxies
- Power-law DTD at ~0.1-10Gyr



# DTD and la progenitor




- consistent with generic DTD features of DD models
- in SD case, observed DTD strongly constrain the parameter space of SD models

# This Work

- In Totani+08, only passive galaxies were selected and SN Ia candidate were picked up as transient having significant offset so that DTD can be measured safely

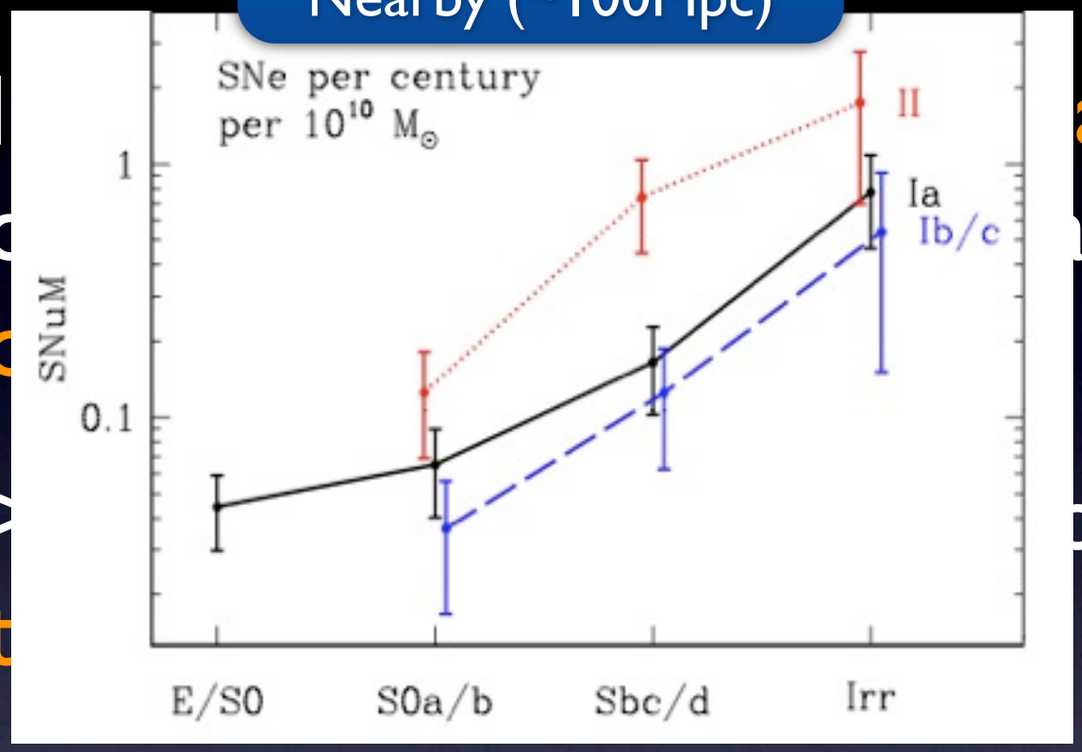
  > Motivation: would like to examine the DTD including all types of galaxies using SN Ia sample identified by LC fitting

- the correlation between SN Ia rate and host properties (stellar mass, SFR, SSFR)

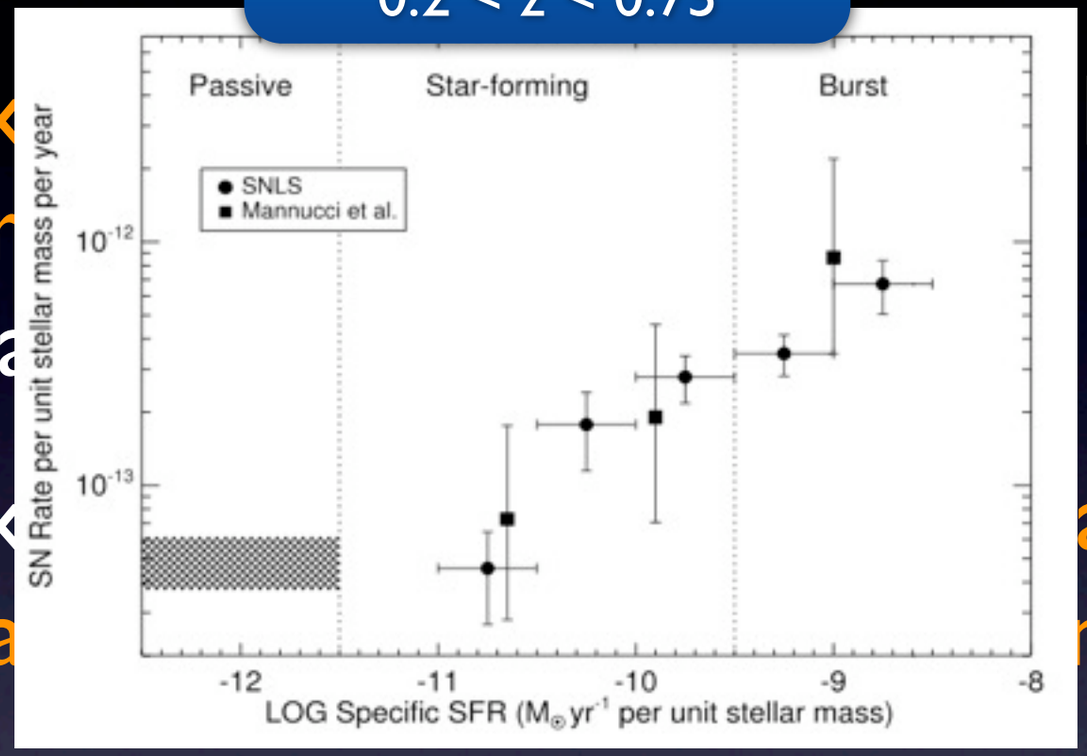
- Investigate the correlation between SN Ia rate and host galaxy properties (SSFR, stellar mass, SFR) and check whether Totani+08 DTD reproduce the observation

# This Work

Mannucci+05
Nearby (~100Mpc)




Sullivan+06
0.2 < z < 0.75




- the correlation between SN Ia rate and host properties (stellar mass, SFR, SSFR)

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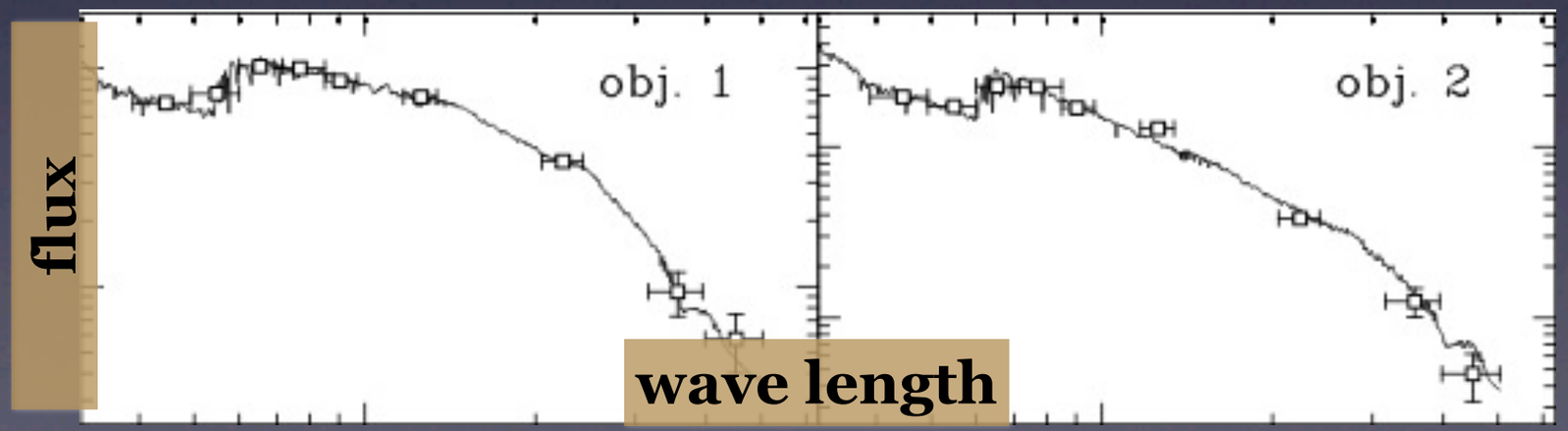
# SXDS Data - Galaxy

- wide (~1deg^2)
- multi-wavelength survey

optical: B, V, Rc, i', z (Subaru/Suprime-Cam)
NIR: J, K (UKIDSS survey)
IR: 3.6μm, 4.5μm (Spitzer/IRAC)
X-ray: 0.5-2.0, 2.0-100keV (XMM-Newton)

- ~10 epochs during 2002/09-2005/09
- hyperz code

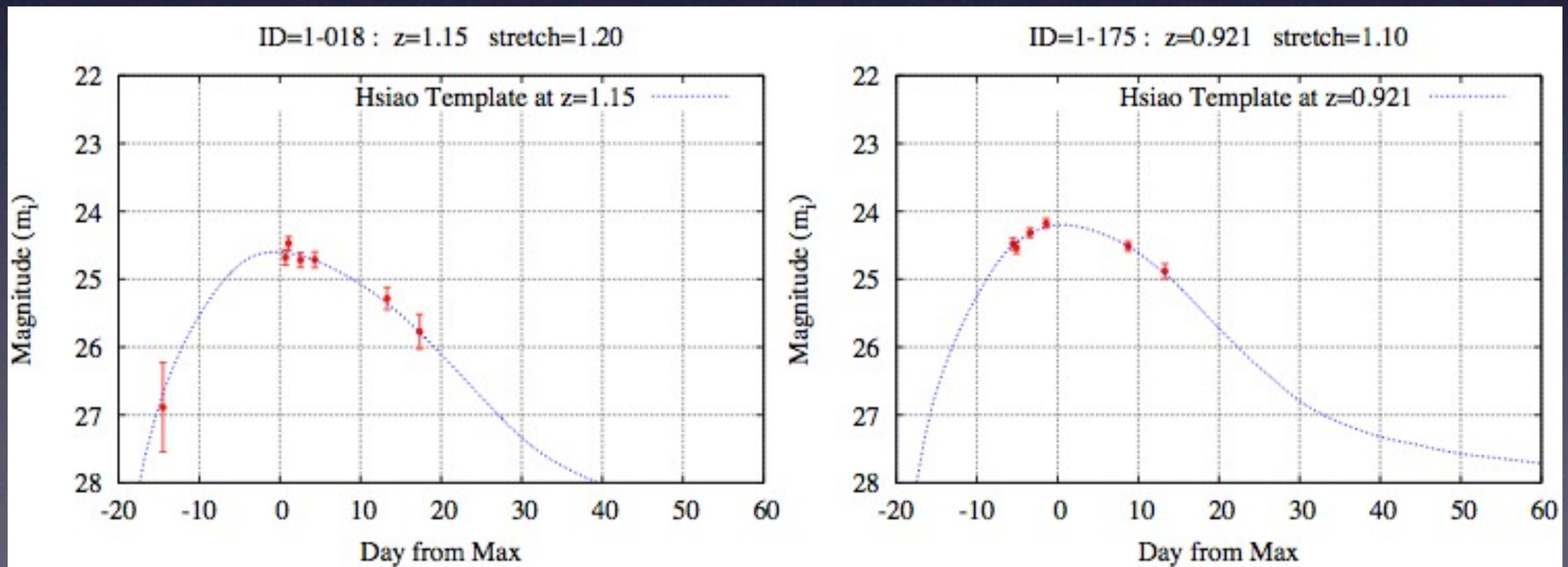
> SFH, stellar mass, Av




- $\mathrm{Rc}, i', 3.6\mu\mathrm{m}$ detection $(m_{\mathrm{lim}} = 27.7, 27.7, 23.1)$ > 69159 galaxies

# SNe sample (Ihara+10, in prep)

- photometrically confirmed 46 SNe Ia ($0.2 < z < 1.3$)
- Light curve fitting with Hsiao+08 template
- in our galaxy sample > 39 SNe Ia



# testing DTD models

- Power-law DTD
  - Totani+08 DTD

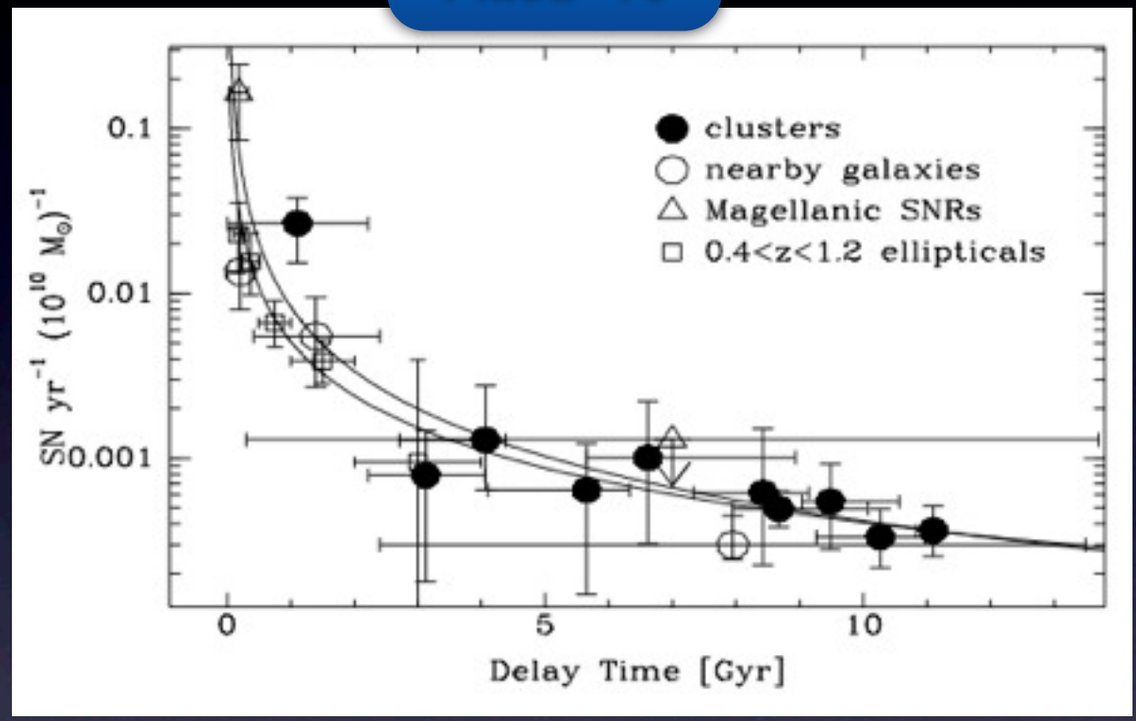
$$\mathrm{DTD} \propto t^{-1.08} (\mathrm{Totani} + 08)$$

  - Pritchet+08 DTD

$$\mathrm{DTD} \propto t^{-0.5} (\mathrm{Pritchet} + 08)$$

  - index -1.5 DTD

Maoz+10




$$\mathrm{SNR} = \int_0^t \psi(t') \mathrm{DTD}(t - t')\, dt'$$

- A+B model (Scannapieco & Bildsten 05)

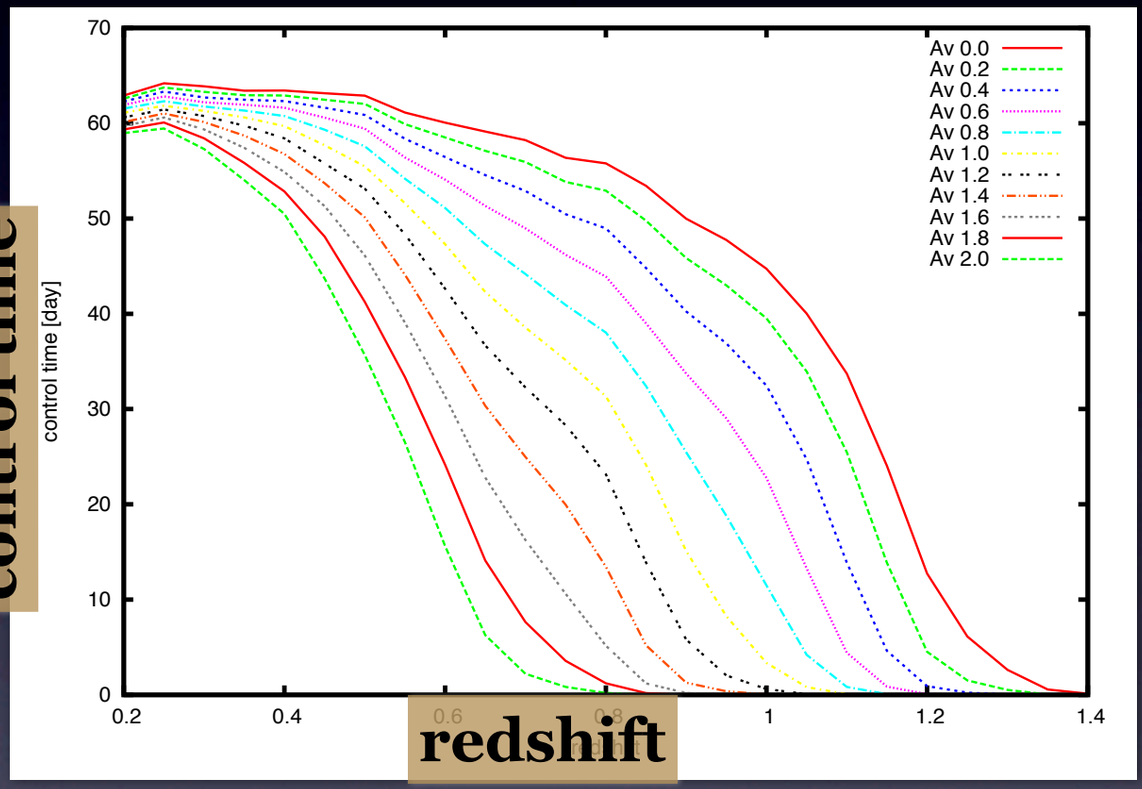
$$\mathrm{SNR} = \underbrace{AM_{tot}(t)}_{\text{delayed}} + \underbrace{B\psi(t)}_{\text{prompt}}$$

# Rate Calculation

**Observation**

$$\mathrm{SNR} = \frac{N_{obs}}{\Sigma\ \mathrm{CT}_i(z, A_V)}$$

- control time (CT) : detectable time of SN Ia
- SNR: Suprenova rate



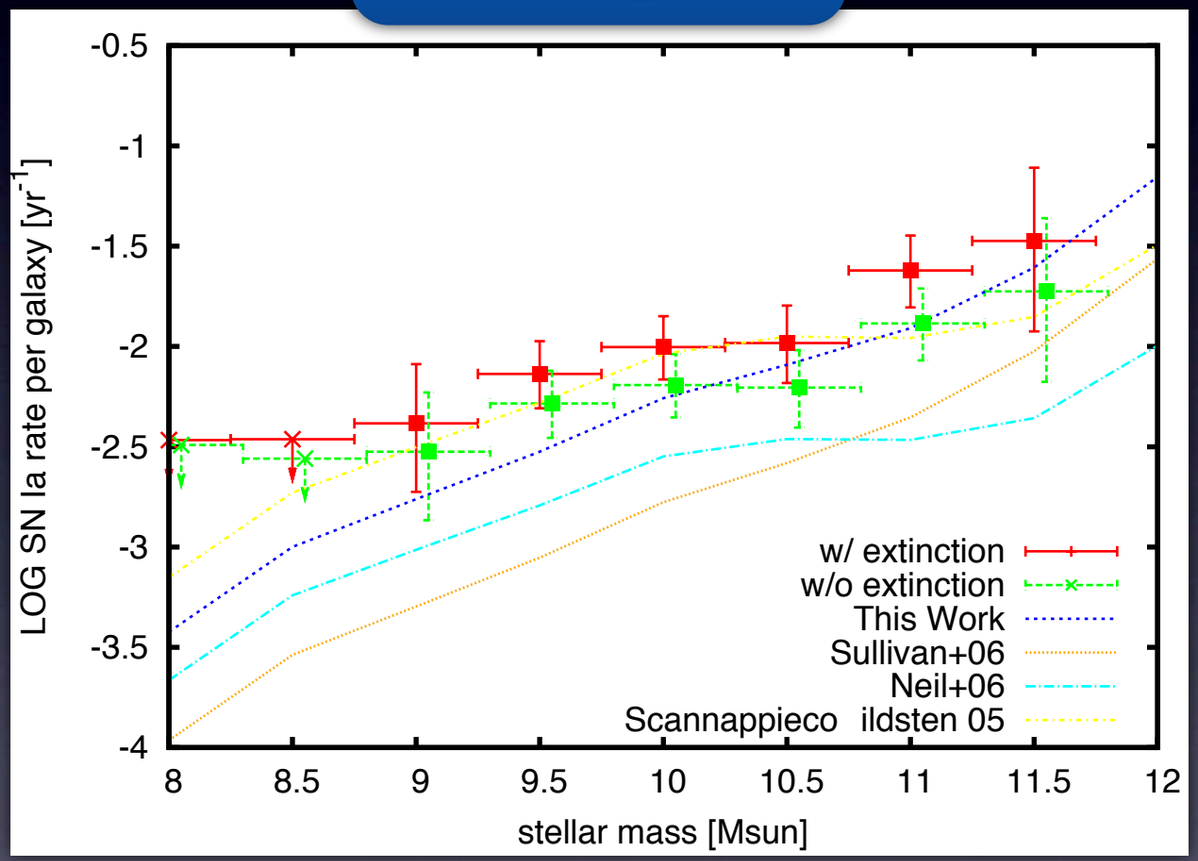

**Why extinction ?**

- SN rate can be affected by dust extinction
- photo-z Av (might be a overcorrection)
- tried to see how extinction can affect the SN rate for two extreme case (w/o extinction, photo-z Av)

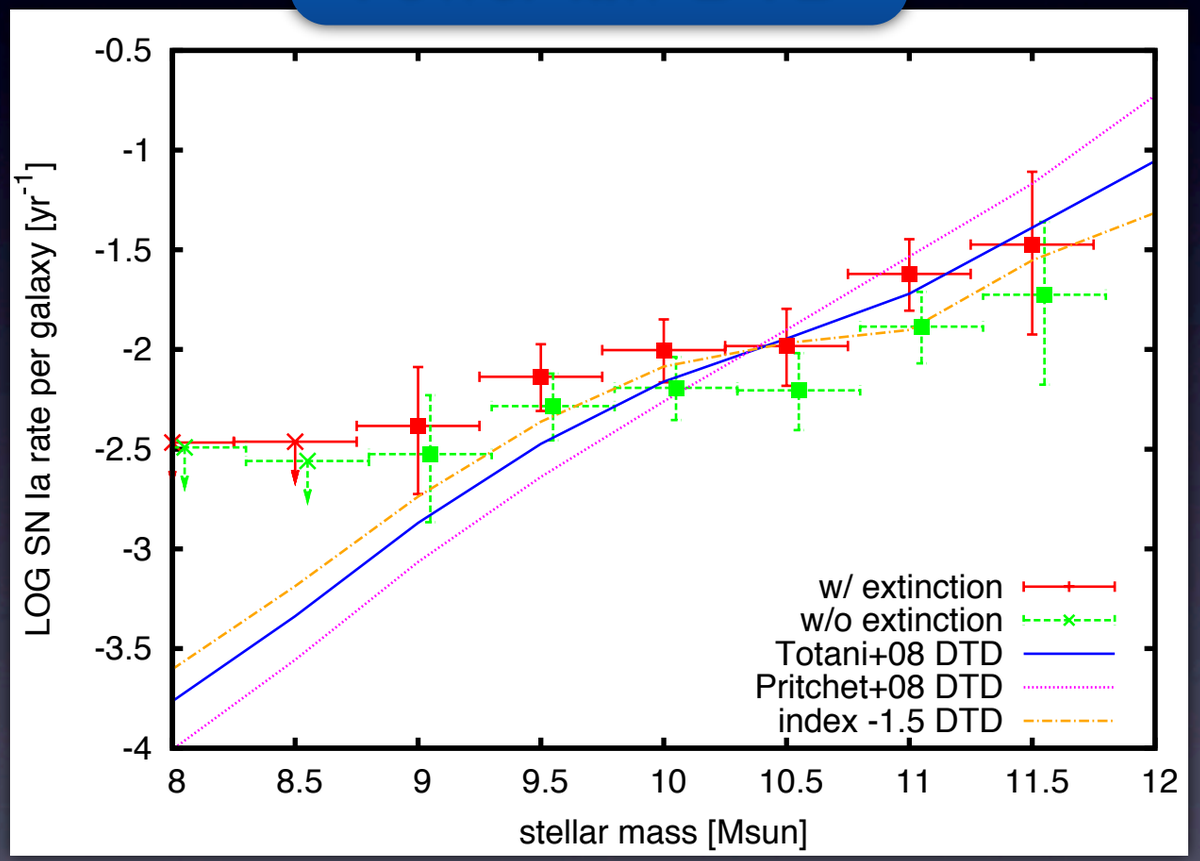
# result - stellar mass

SN Ia Rate

A+B




Power-law DTD

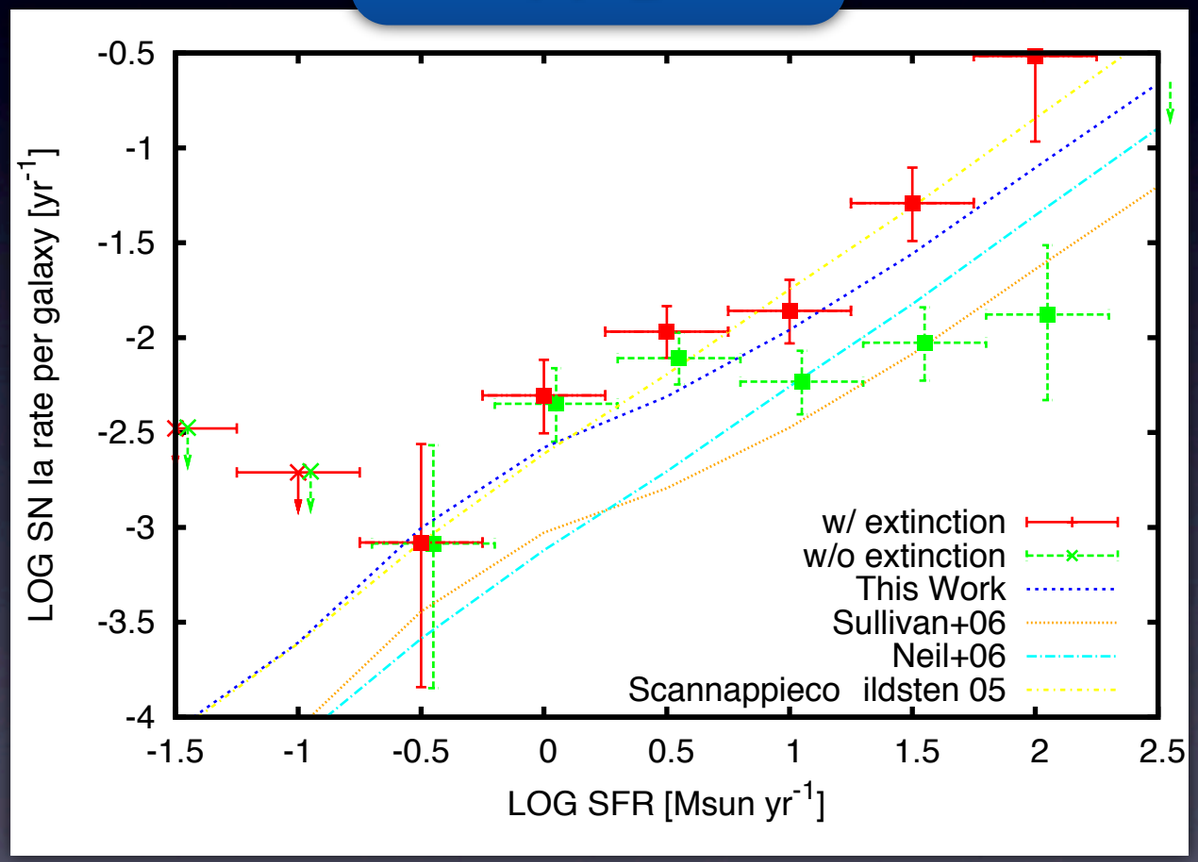



stellar mass

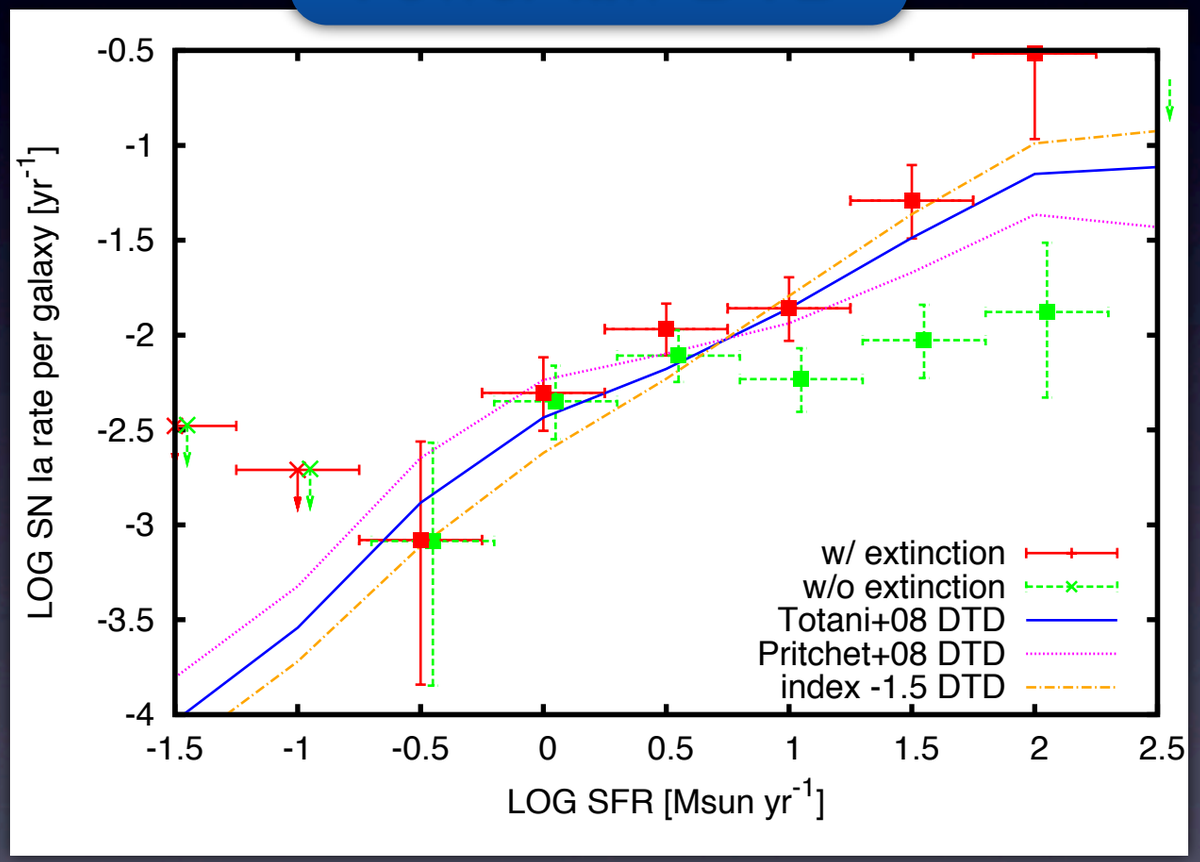
# result - SFR

SN Ia Rate

A+B




Power-law DTD



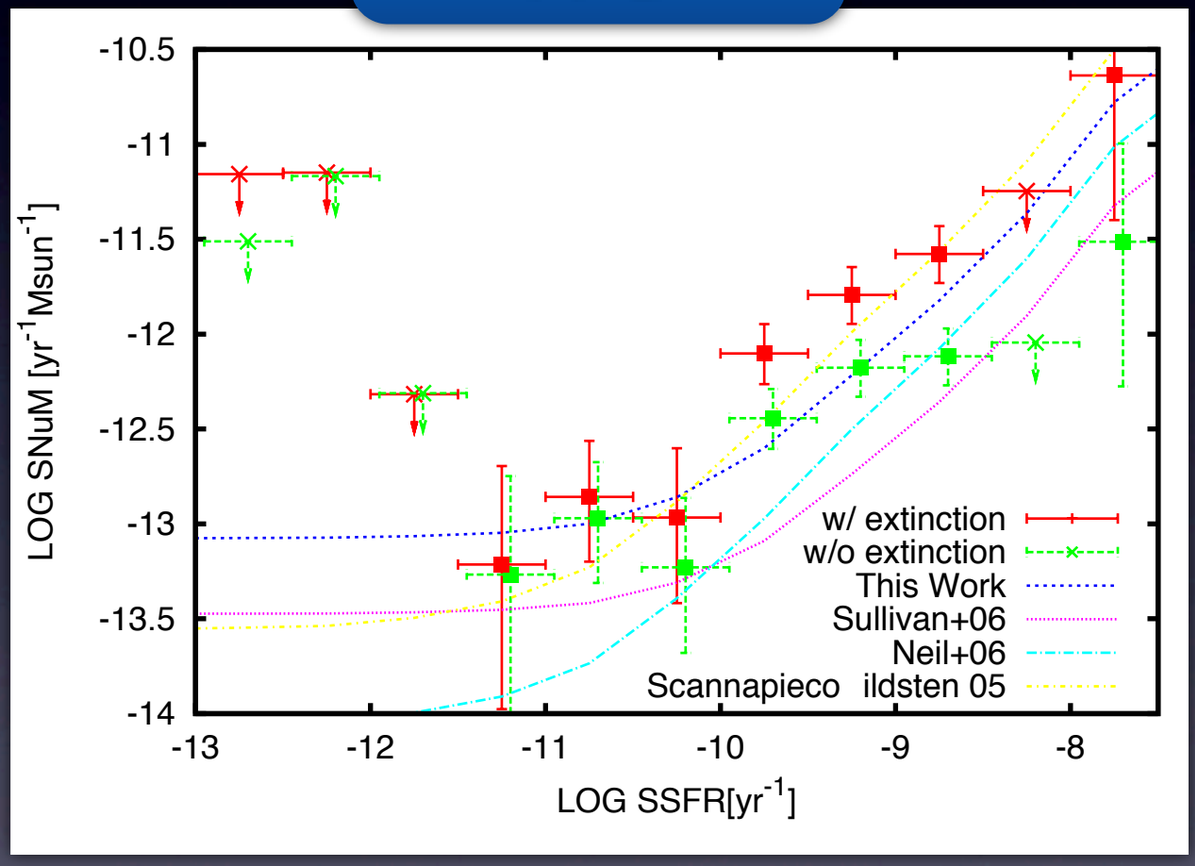

SFR

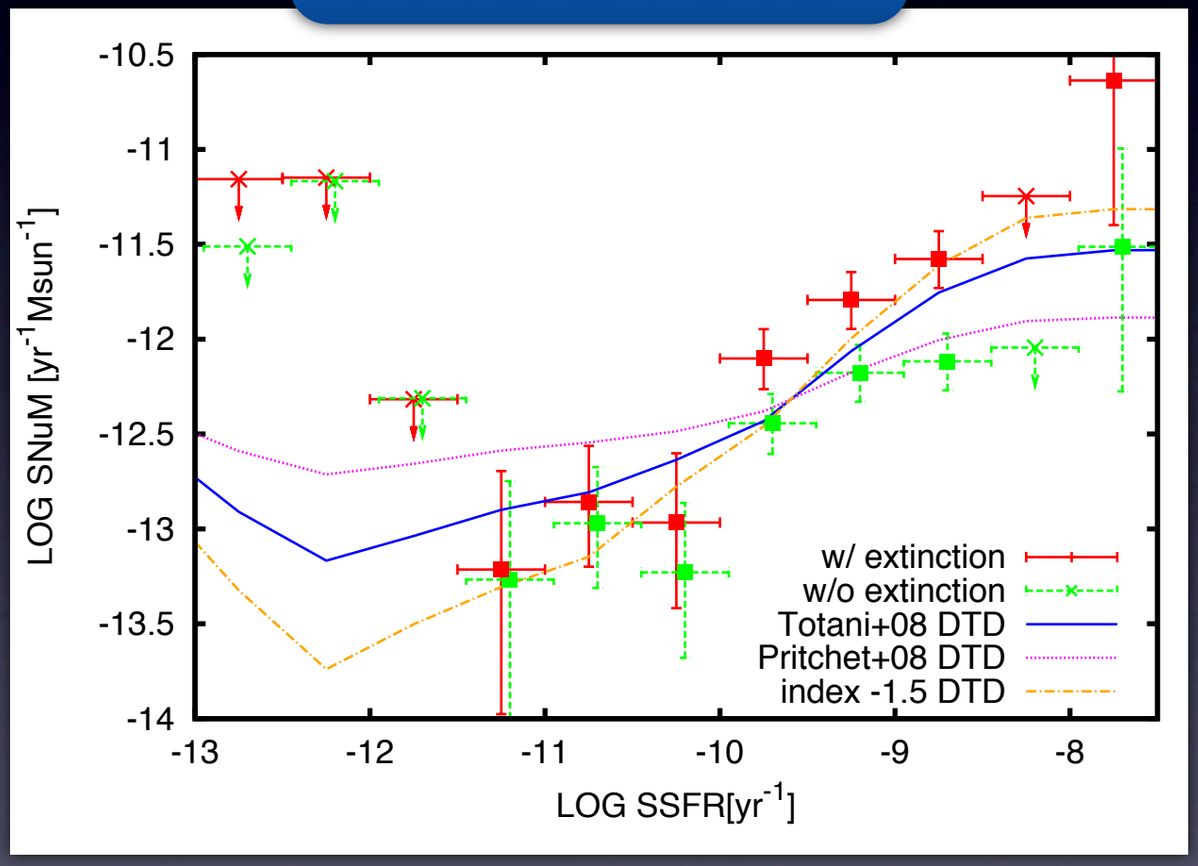
# result - SSFR

A+B

Power-law DTD

SNuM



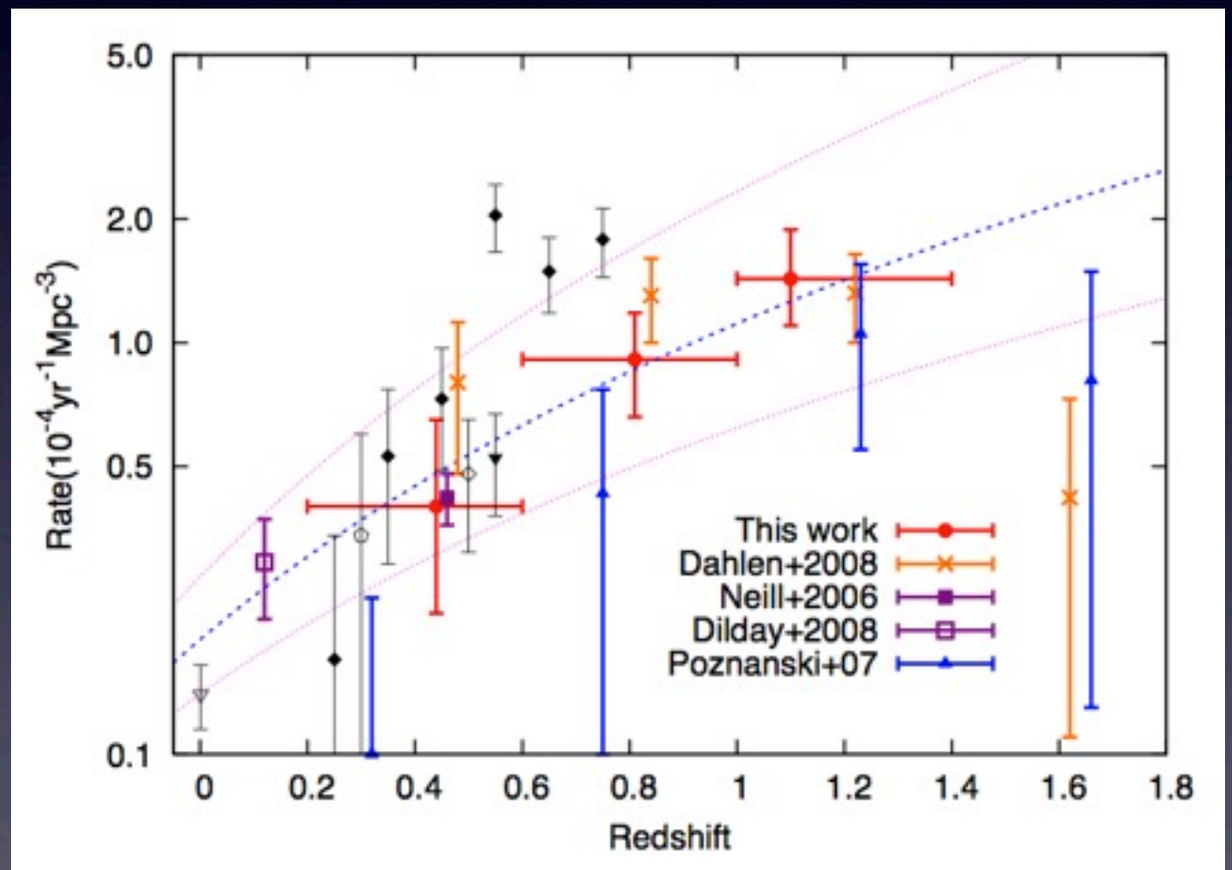

SSFR

# result

- the correlation between SN Ia rate and host galaxy properties could be confirmed at z=0.2-1.3
- extinction correction of the SN rate will be crucial problem when SN rate plotted against SFR / SSFR
- Totani+08 DTD seems to reproduce the correlation well, in contrast, Pritchet DTD appears shallower
- A+B model also explain the feature as well, but the coefficients can be varied with survey

# SN Ia rate study in SXDS

- Ihara+10, in prep
  - SN Ia rates at $0.2 < z < 1.3$
  - Ia rate increases up to $z \sim 1.2$




$$r_V(z) = r_0(1+z)^{\alpha}$$

$$\alpha = 2.55^{+0.56}_{-0.40}(\mathrm{stat.})^{+0.22}_{-0.32}(\mathrm{syst.})$$

$$r_0 = 0.20^{+0.08}_{-0.05}(\mathrm{stat.})^{+0.03}_{-0.04}(\mathrm{syst.}) \times 10^{-4}\mathrm{yr}^{-1}\mathrm{Mpc}^{-3}$$

# A+B model

- the values of A and B

$$A = 8.7\,[10^{-14} yr^{-1}\ M_{\odot}^{-1}]$$
$$B = 8.9\,[10^{-4} M_{\odot}^{-1}]$$

Sullivan+06

$$A = 5.3^{+1.2}_{-1.2}$$
$$B = 3.9^{+0.7}_{-0.7}$$

Neil+06

$$A = 1.4^{+1.0}_{-1.0}$$
$$B = 8.0^{+2.6}_{-2.6}$$

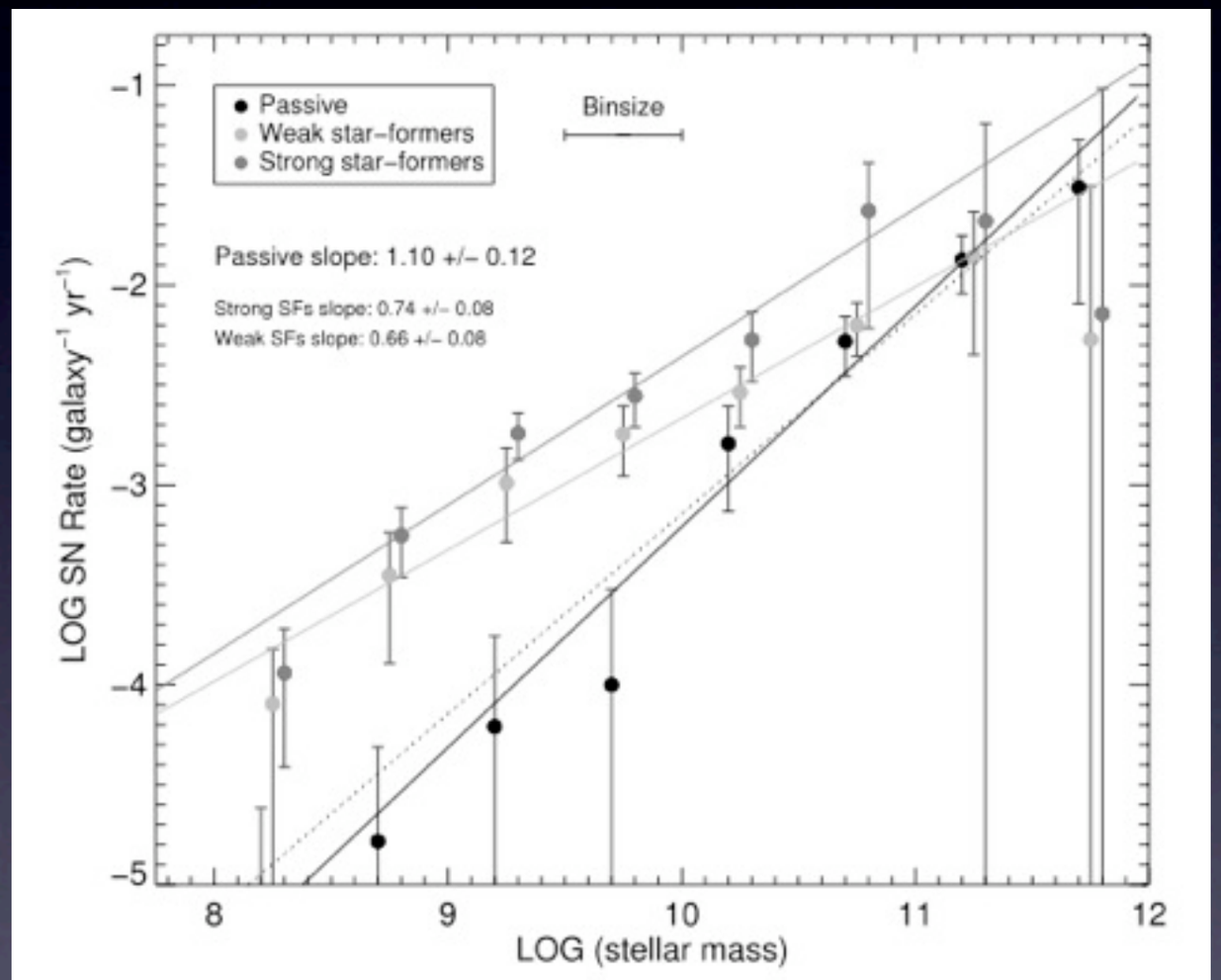
Scannapieco&Bildsten05

$$A = 4.4^{+1.6}_{-1.4}$$
$$B = 26^{+11}_{-11}$$

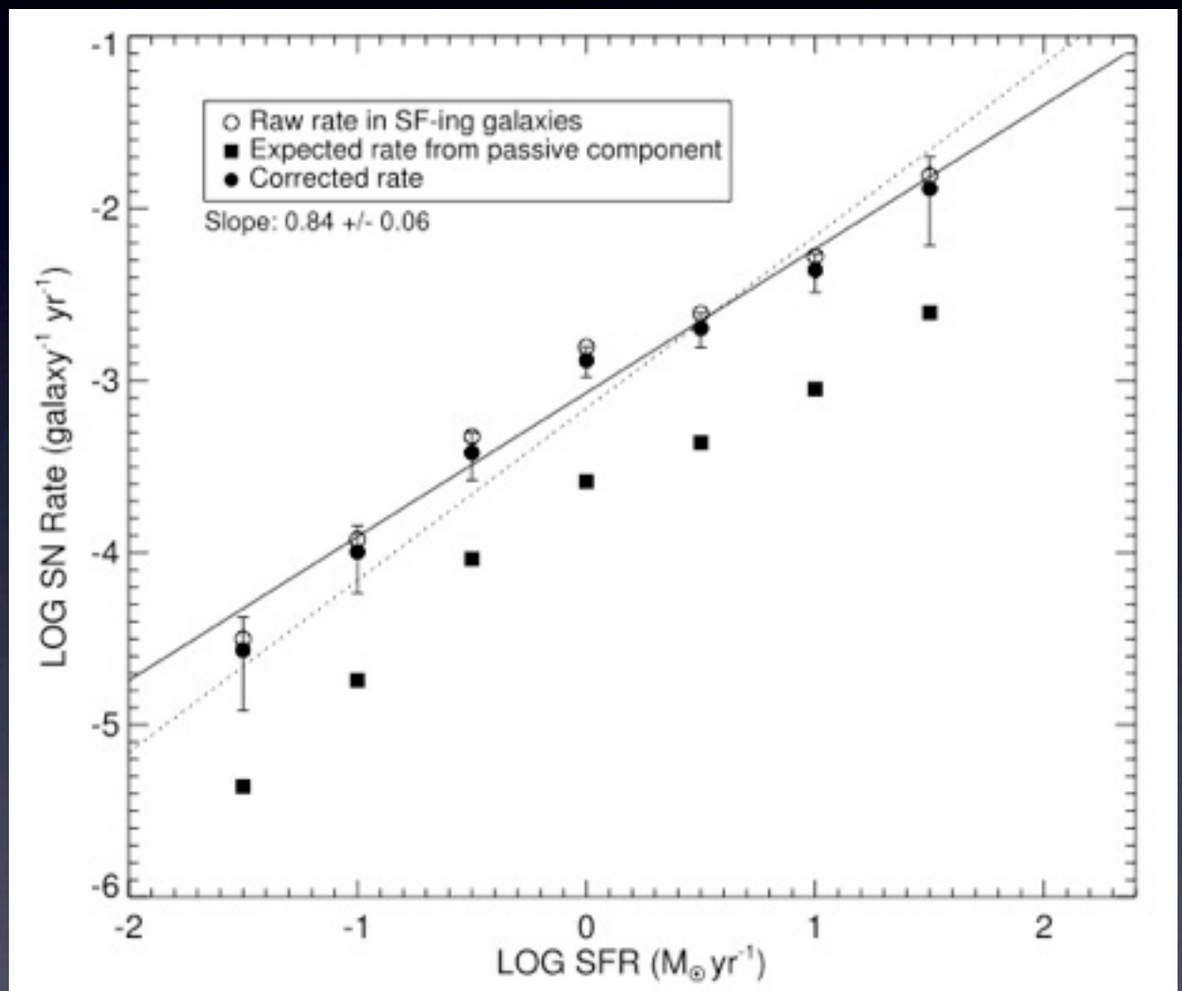
- A+B model can reproduce the observation well, however, these value can be changed which field or populations we are looking on
- need a careful treatment when applied as universal DTD

# sullivan+06

stellar mass




SFR

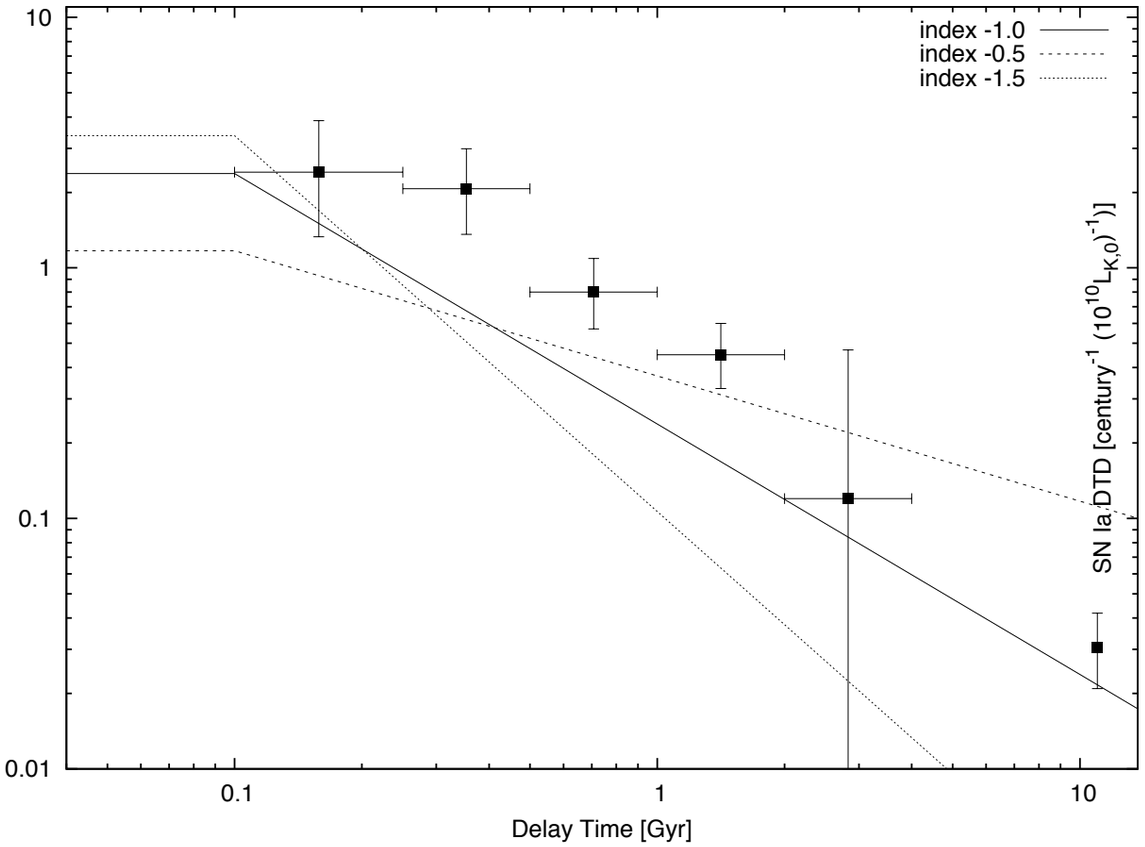


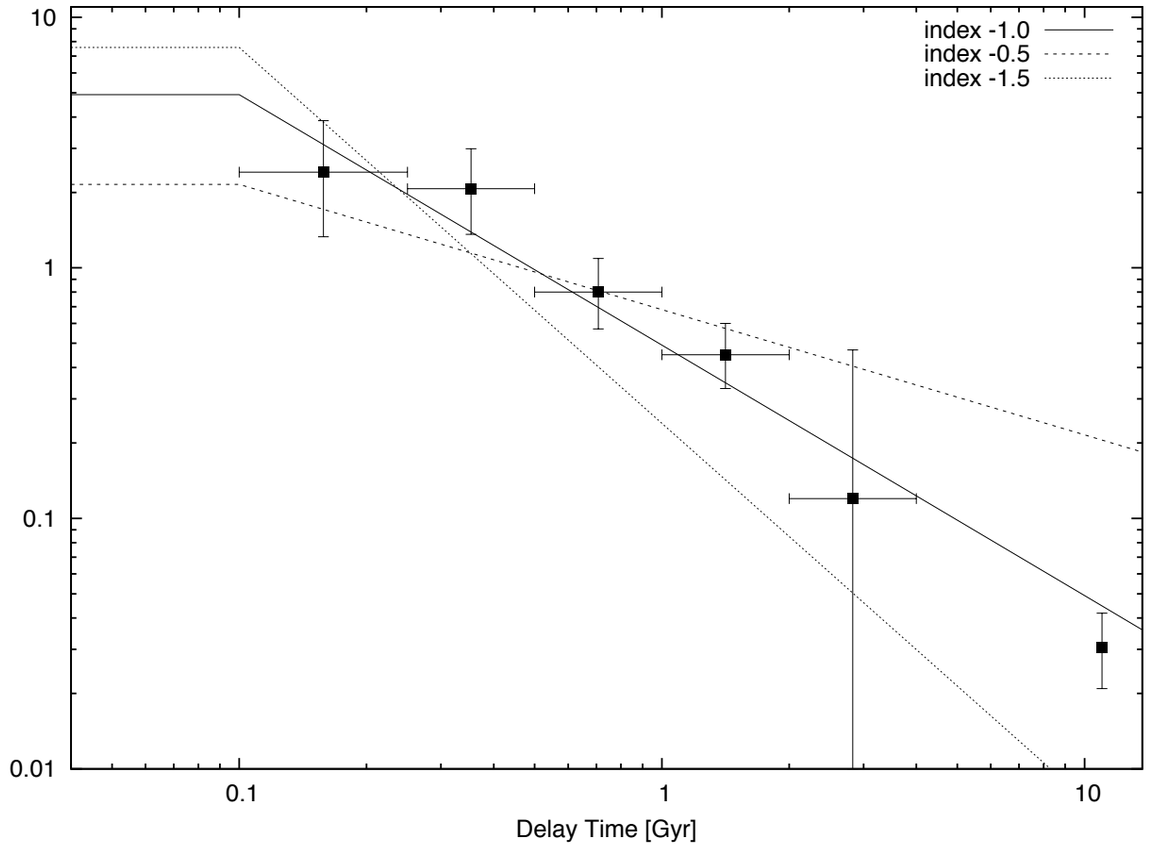
# DTD

w/o extinction

w/extinction

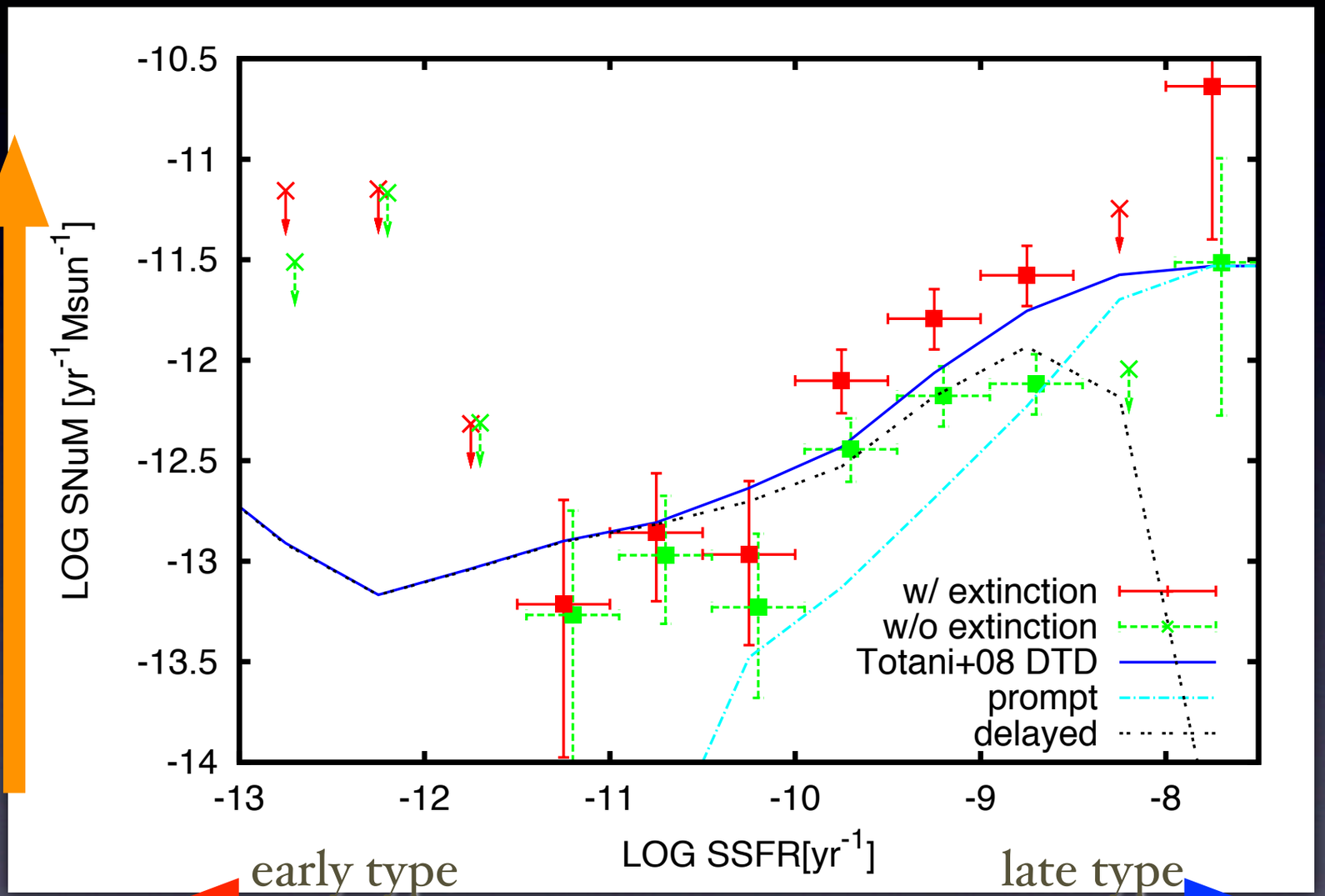
Delay Time Distribution



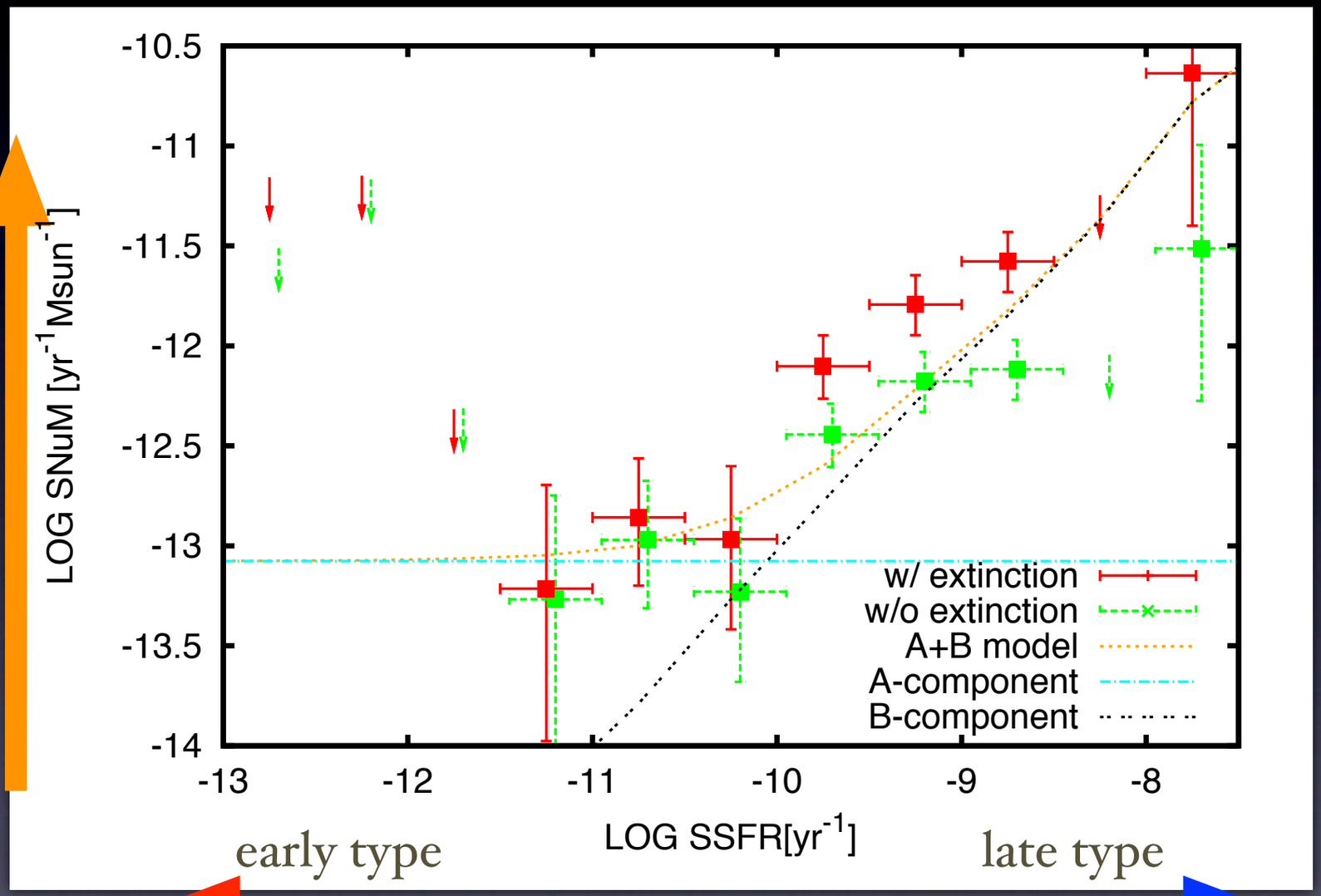

DTD models

# SSFR



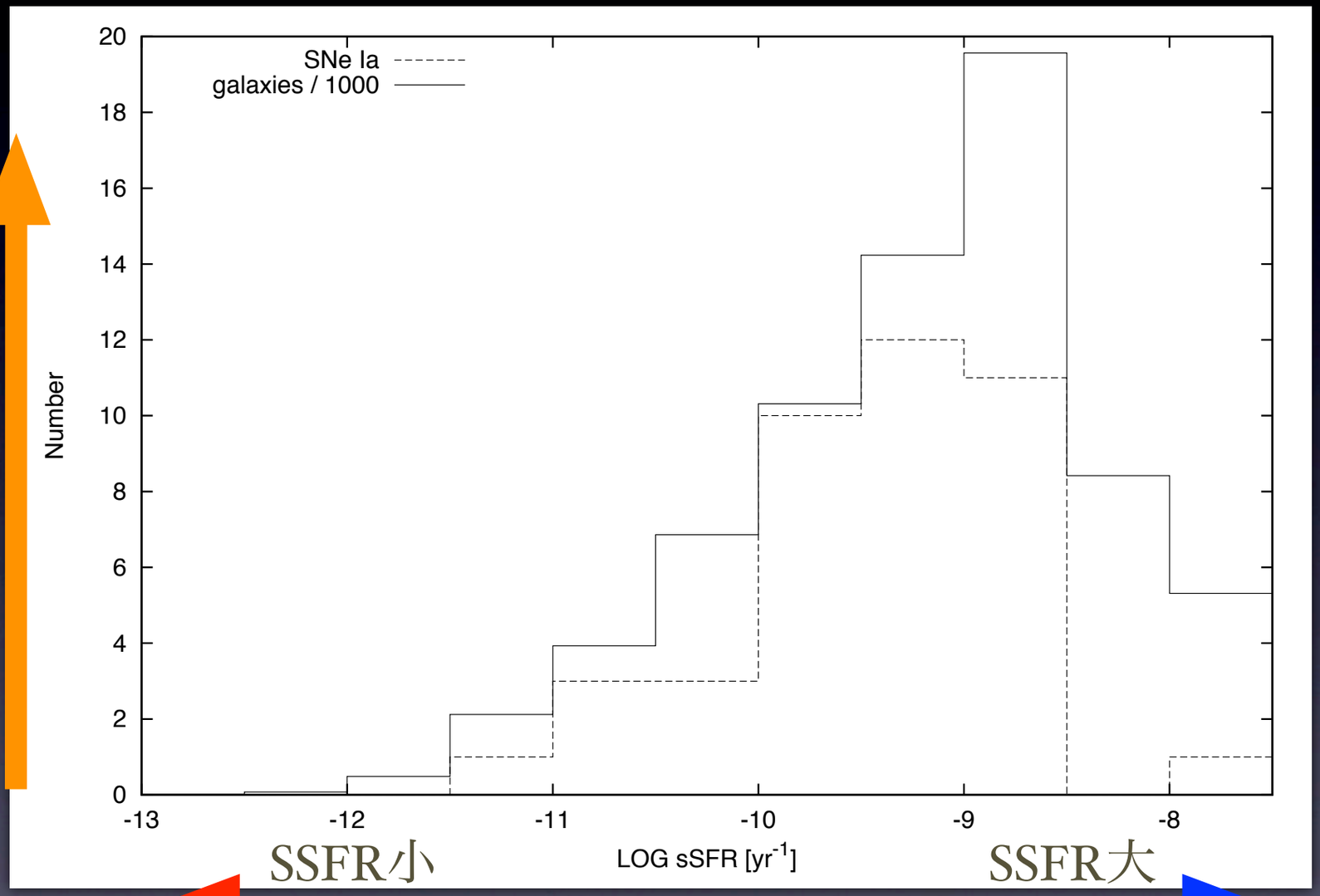

prompt & delayed components

# SSFR




A & B components

# 結果 - SSFR




SNuM

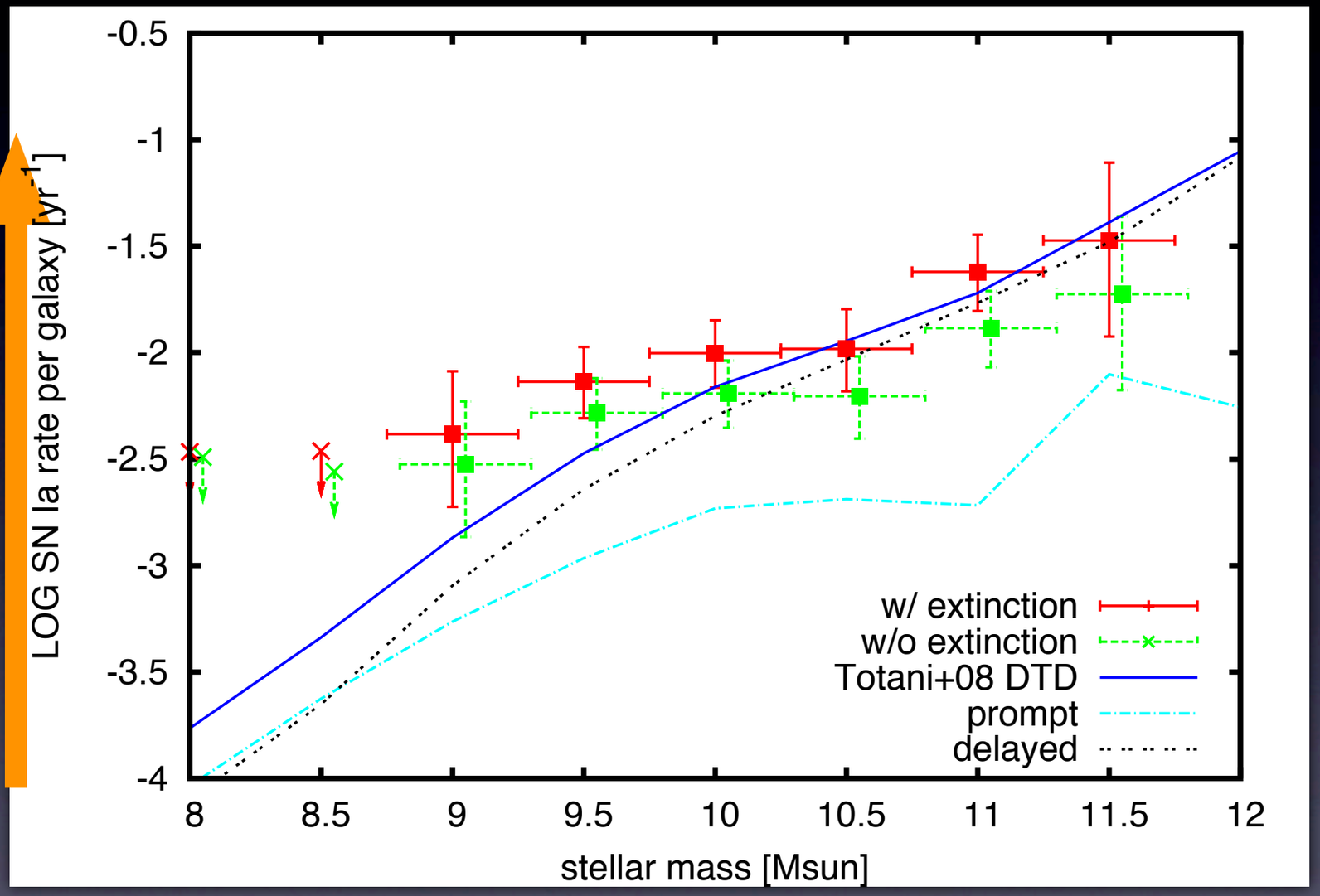
early type

late type

SSFR histogram

# stellar mass

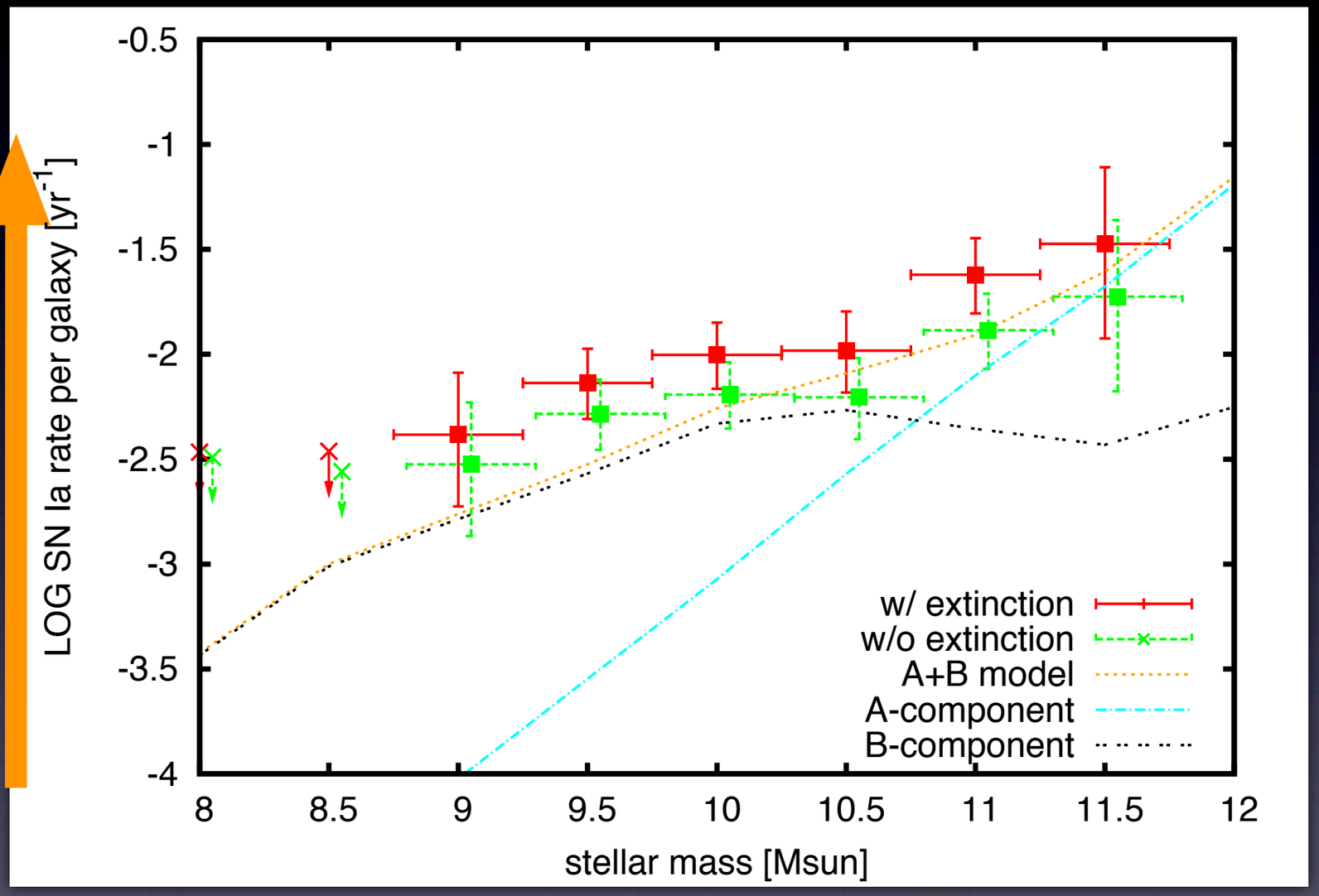
SN Ia Rate




prompt & delayed components

# stellar mass

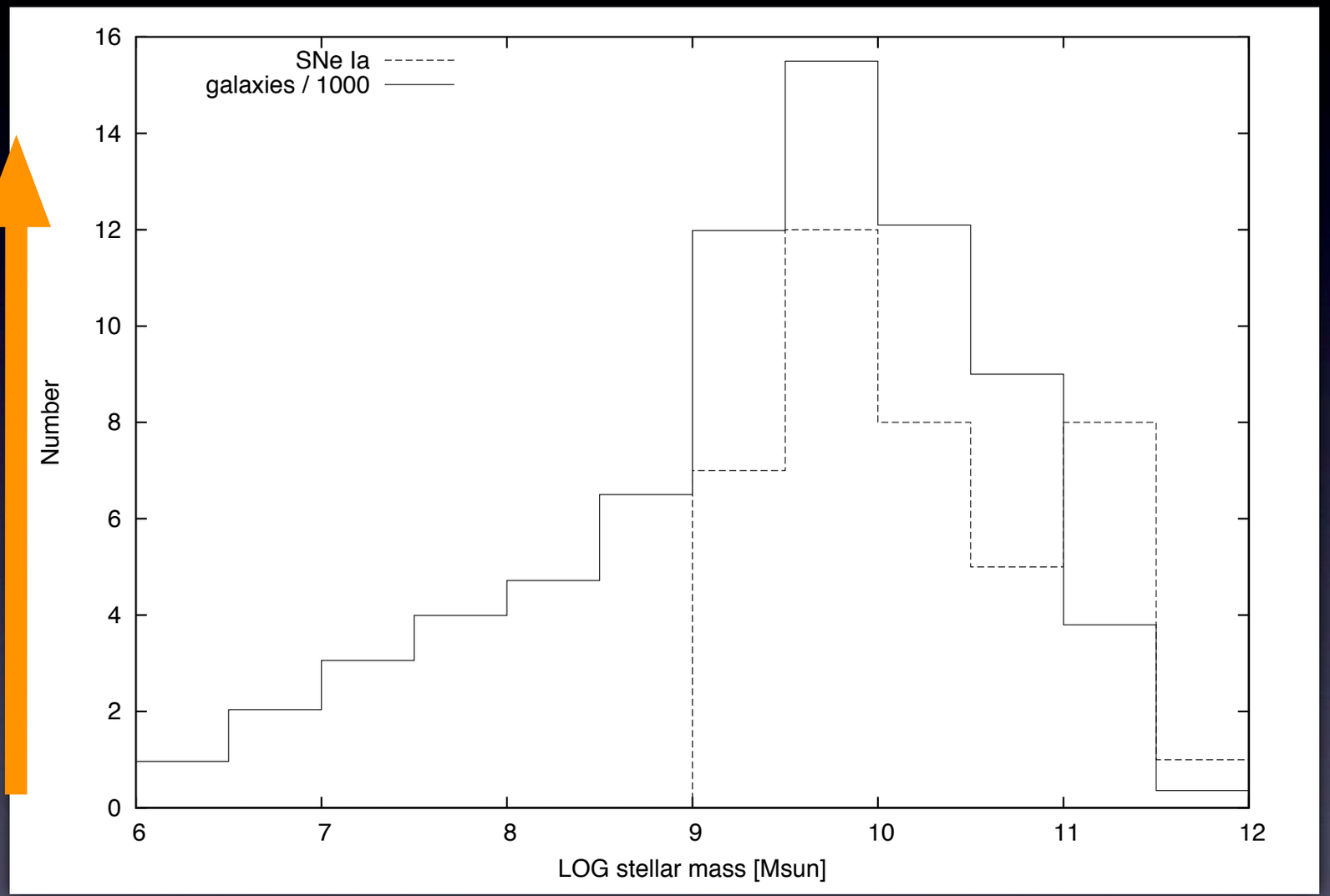
SN Ia Rate




A & B components

# stellar mass

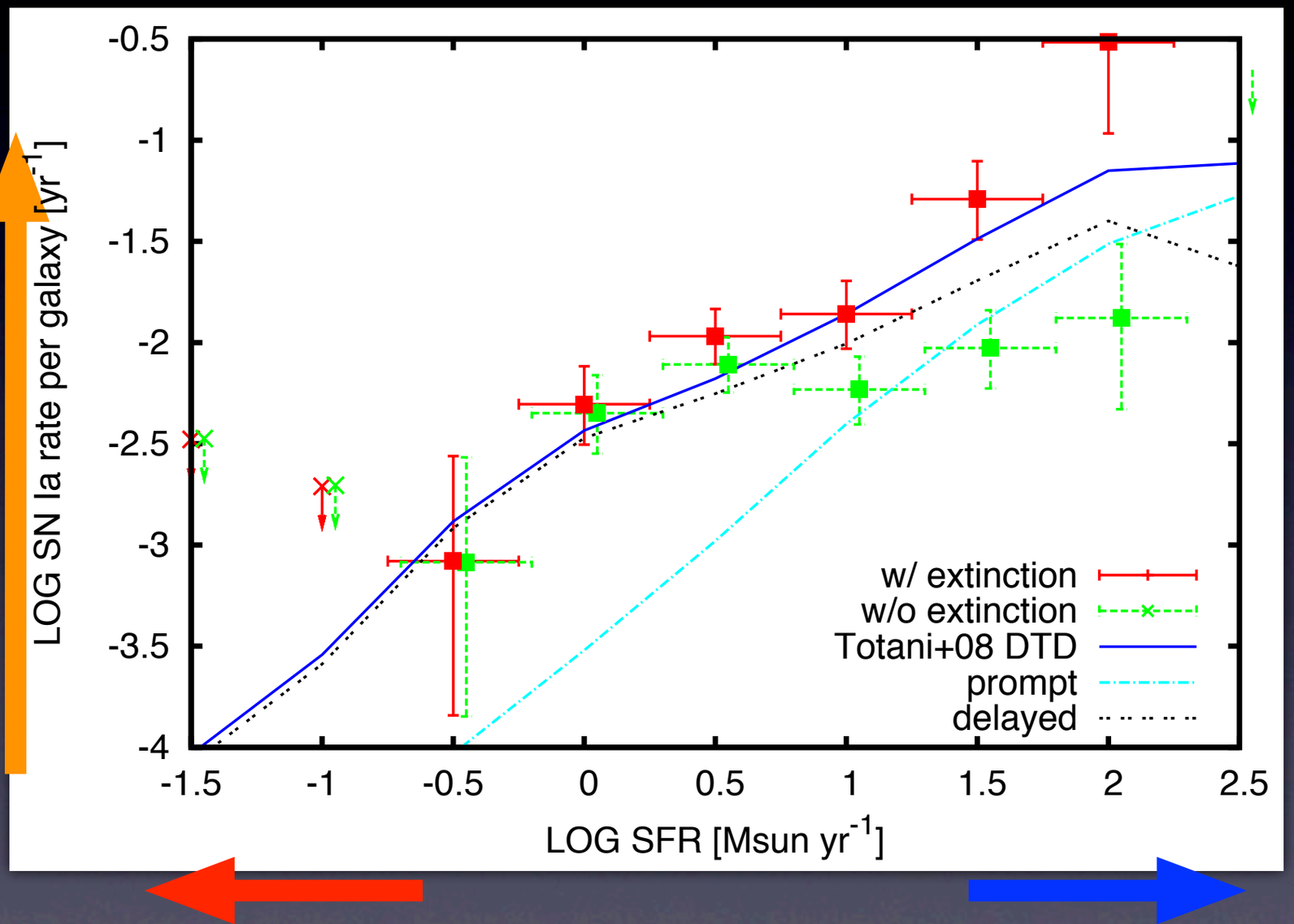
SN Ia Rate




stellar mass histogram

# SFR

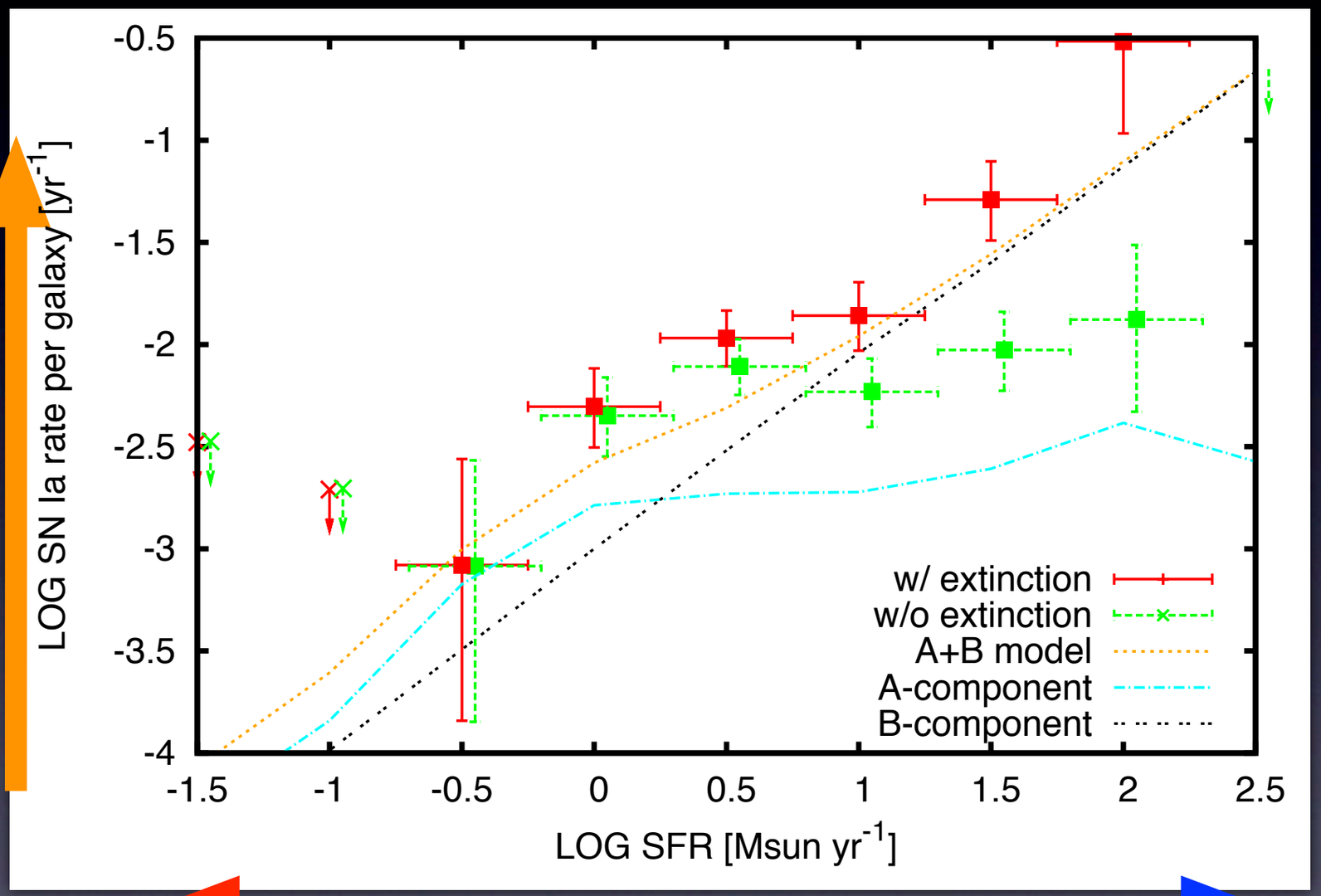
SN Ia Rate




prompt & delayed components

# SFR

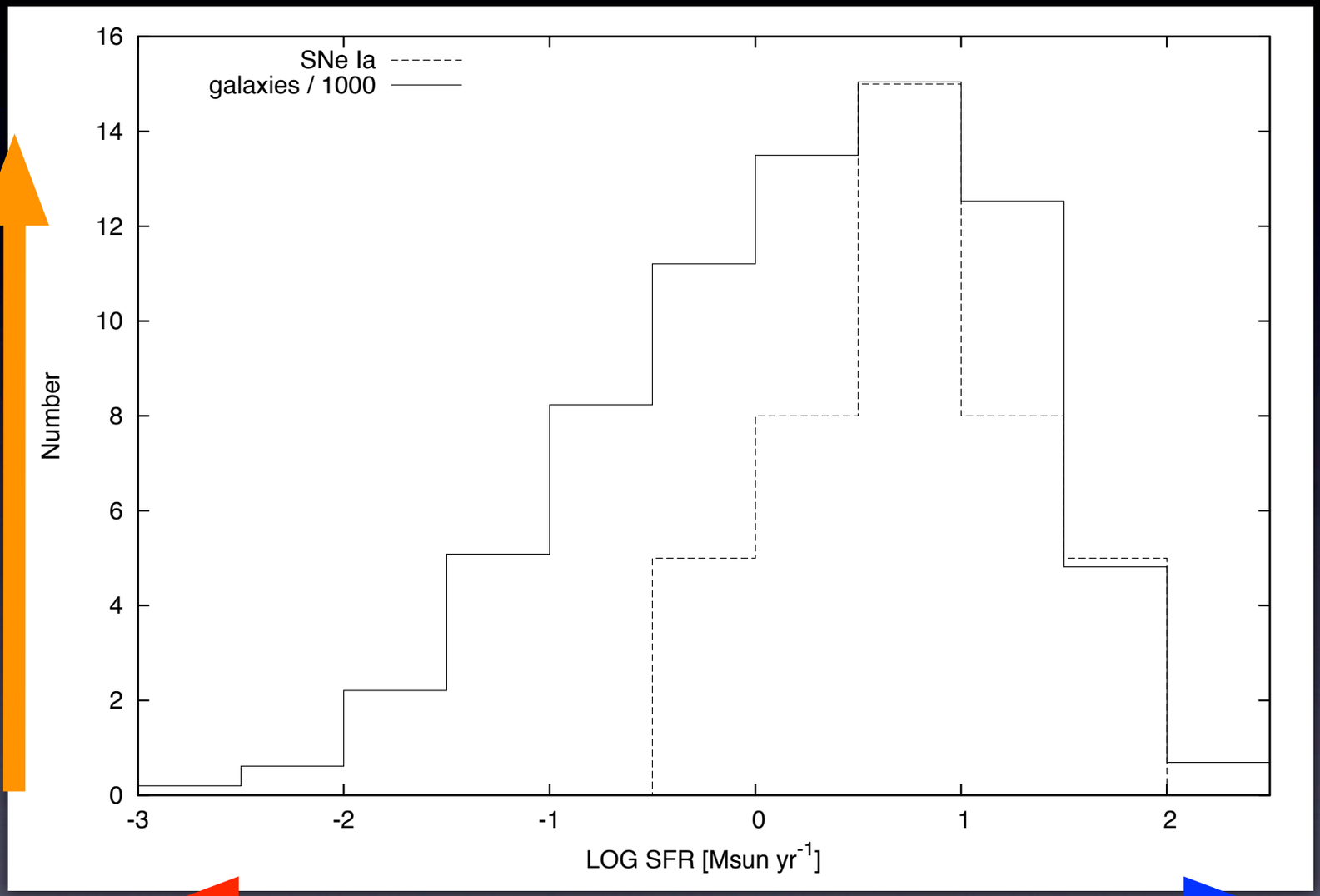
SN Ia Rate




A & B components

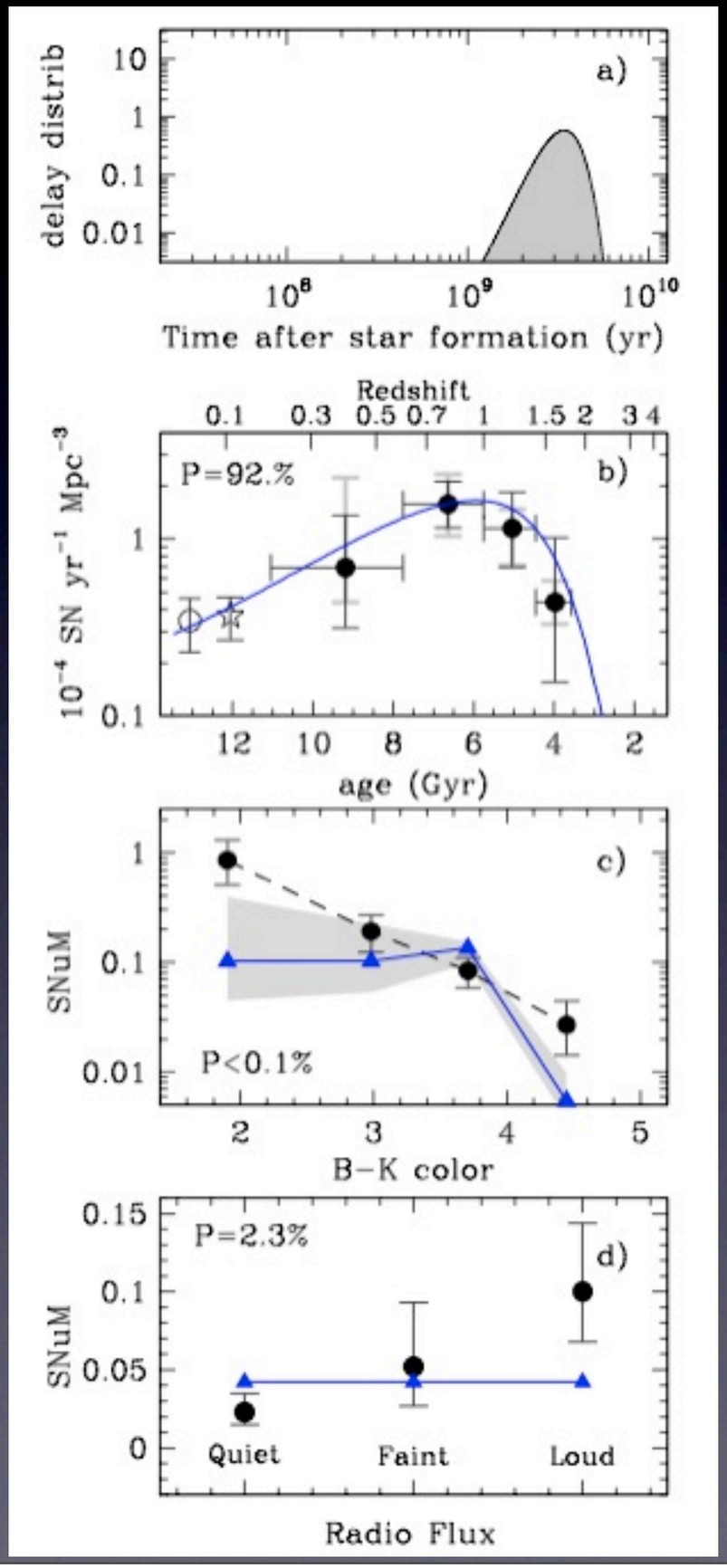
# SFR

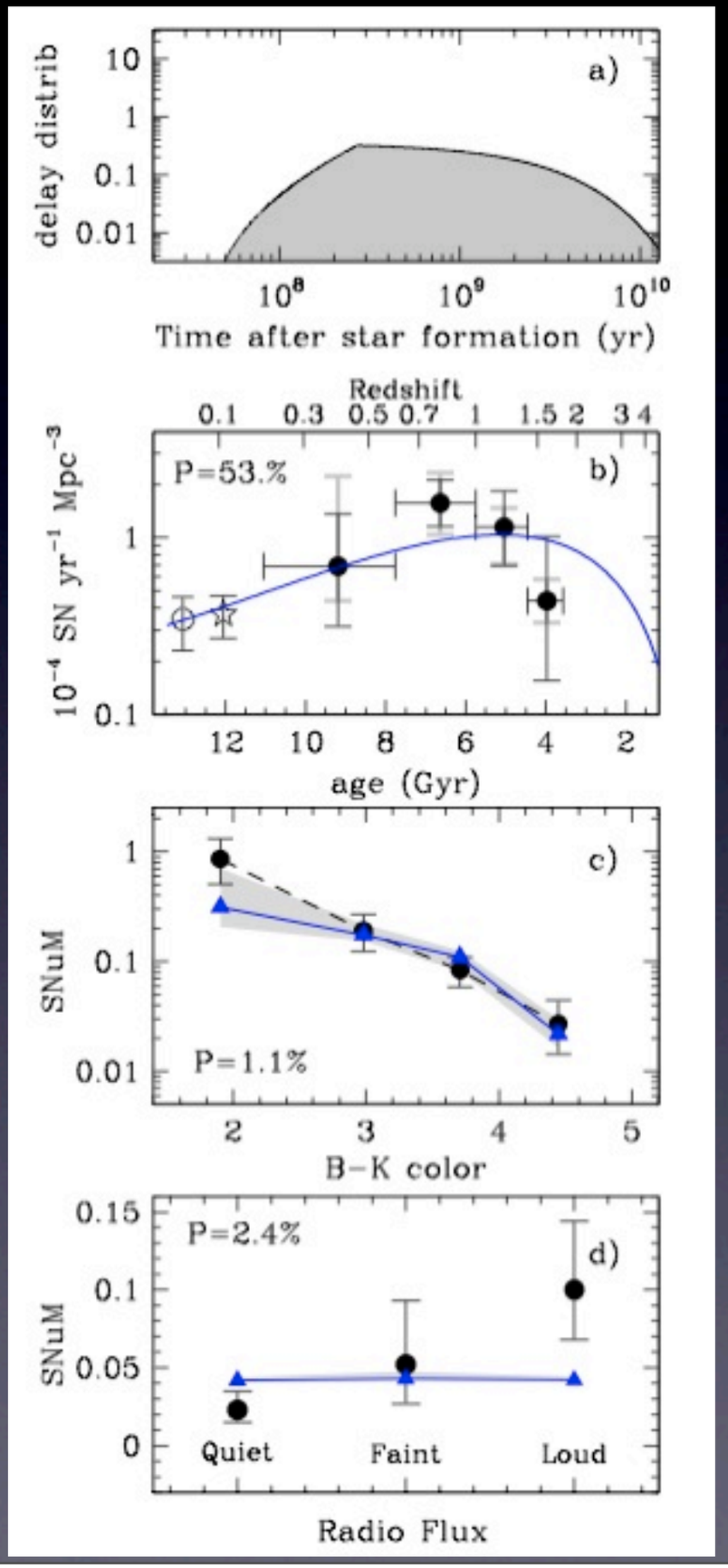
SN Ia Rate

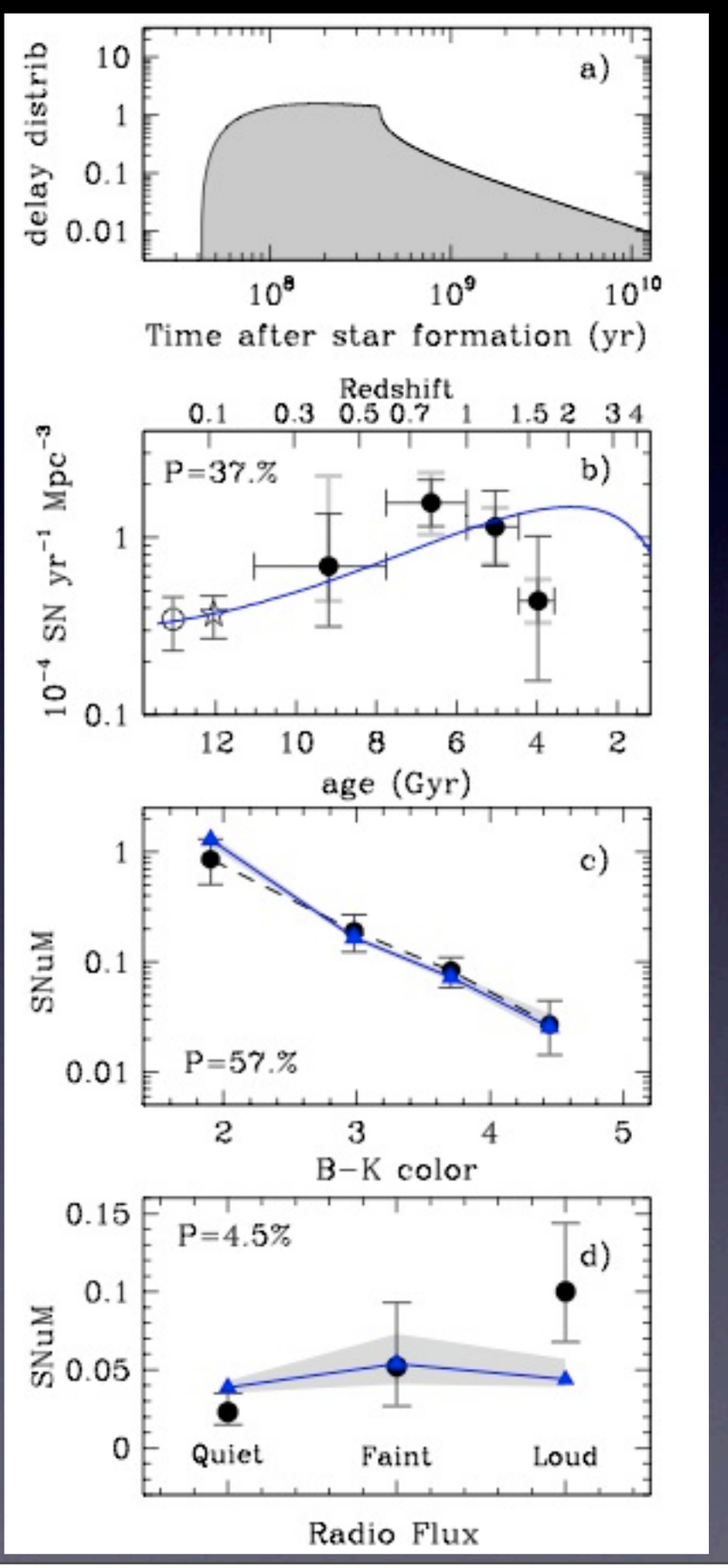



SFR histogram

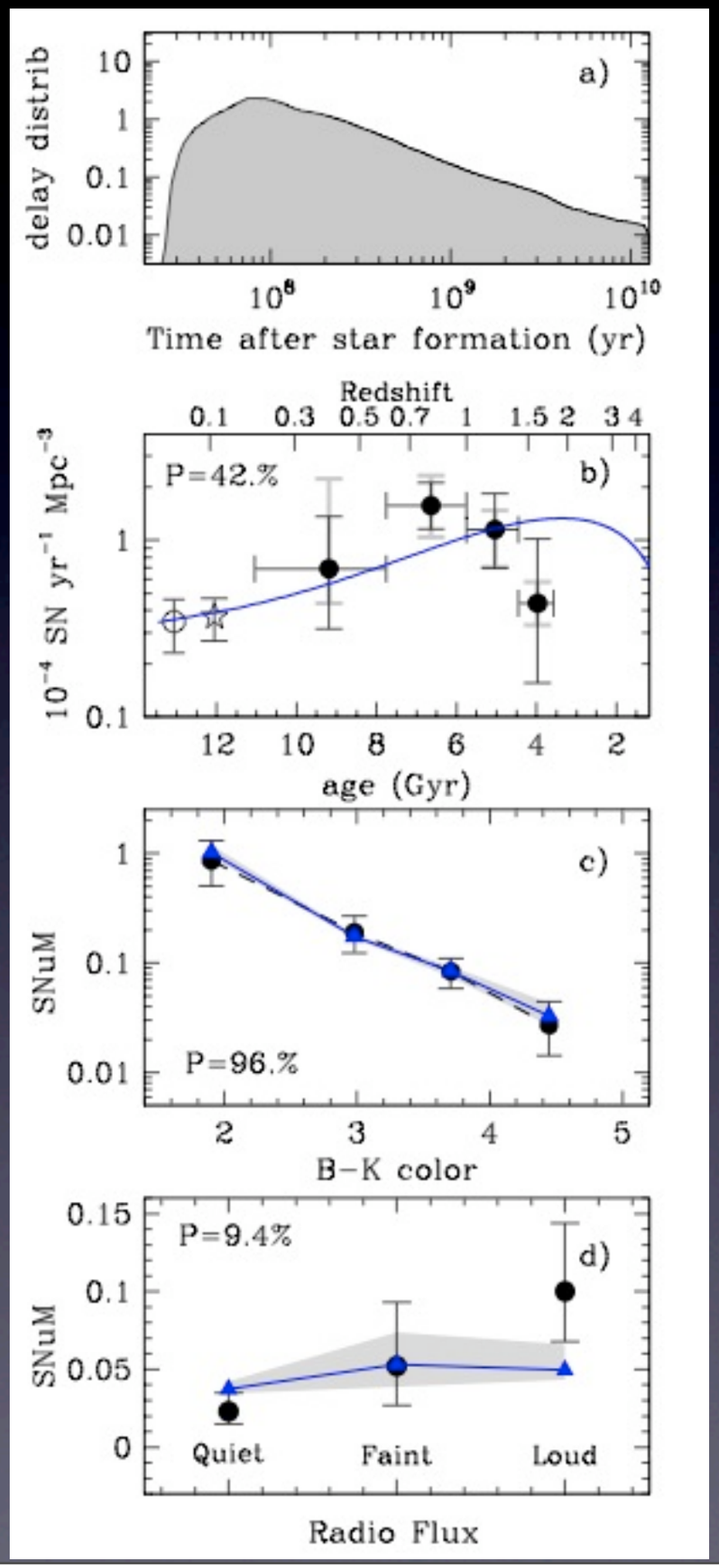
# Mannucci+06

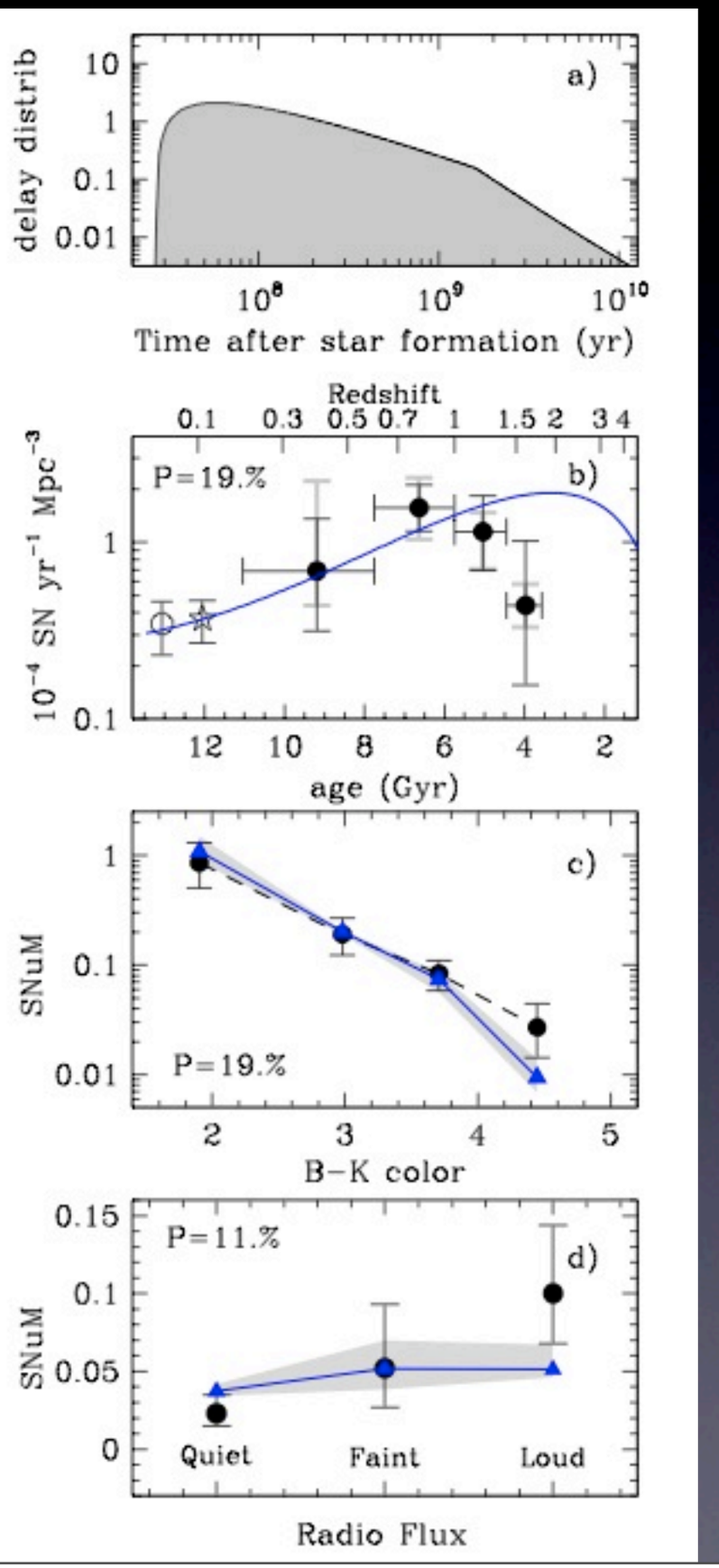

a)
delay distrib
Time after star formation (yr)
b)
P=92.%
Redshift
age (Gyr)
c)
P<0.1%
SNuM
B−K color
d)
P=2.3%
Quiet
Faint
Loud
Radio Flux

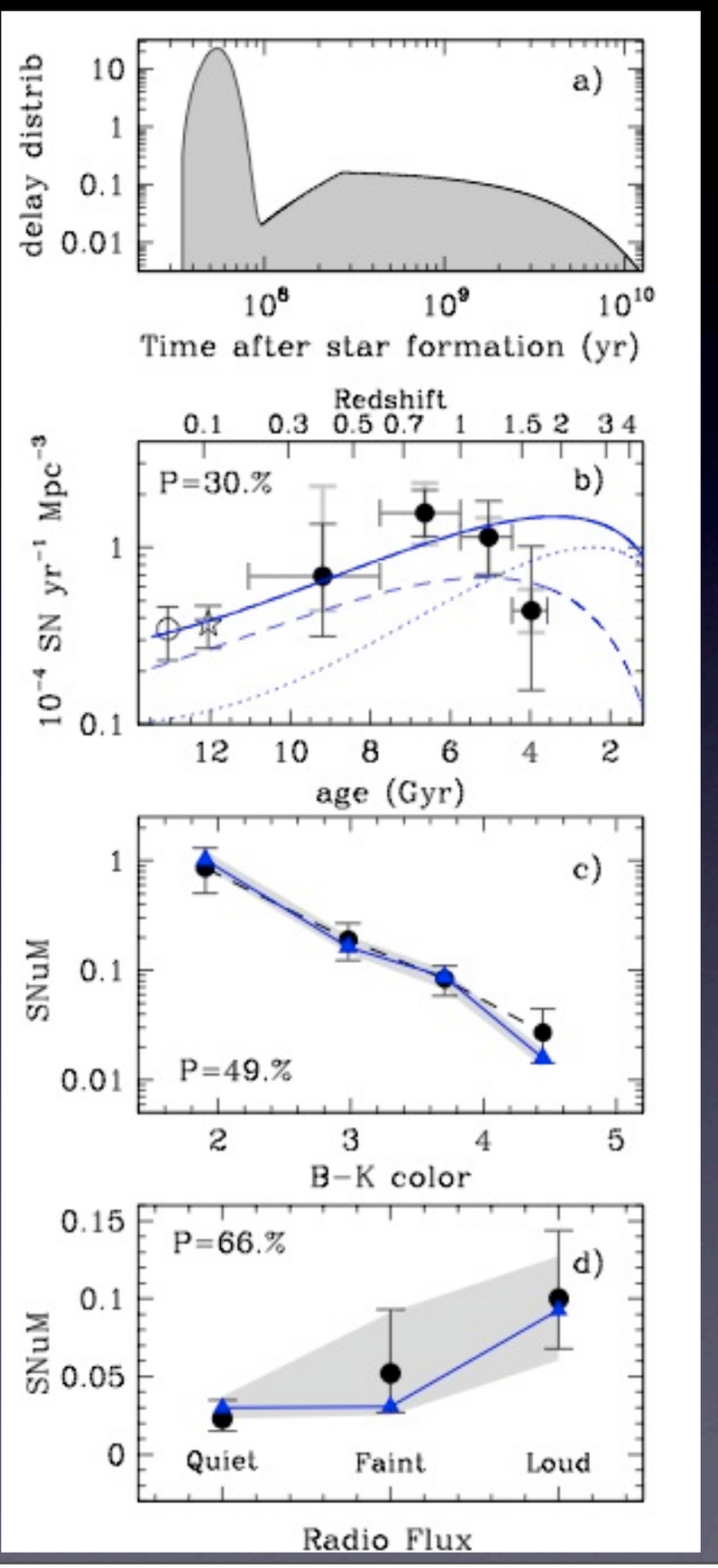

a)
delay distrib
Time after star formation (yr)
b)
P=53.%
Redshift
age (Gyr)
c)
P=1.1%
SNuM
B−K color
d)
P=2.4%
Quiet
Faint
Loud
Radio Flux


a)
delay distrib
Time after star formation (yr)
b)
P=37.%
Redshift
age (Gyr)
c)
P=57.%
SNuM
B−K color
d)
P=4.5%
Quiet
Faint
Loud
Radio Flux

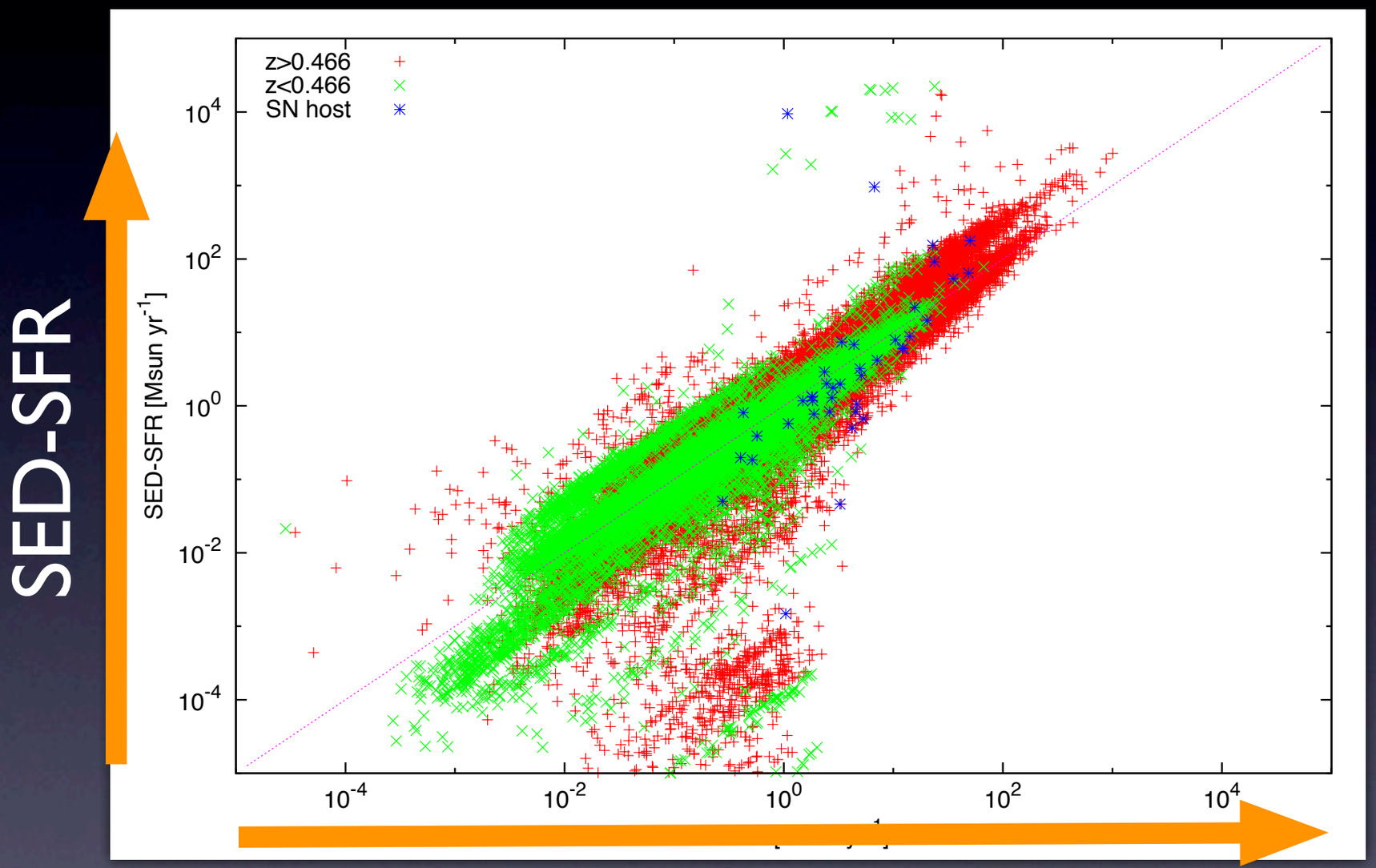
# Mannucci+06


a)
delay distrib
Time after star formation (yr)
b)
P=42.%
Redshift
age (Gyr)
c)
P=96.%
SNuM
B−K color
d)
P=9.4%
Quiet
Faint
Loud
Radio Flux

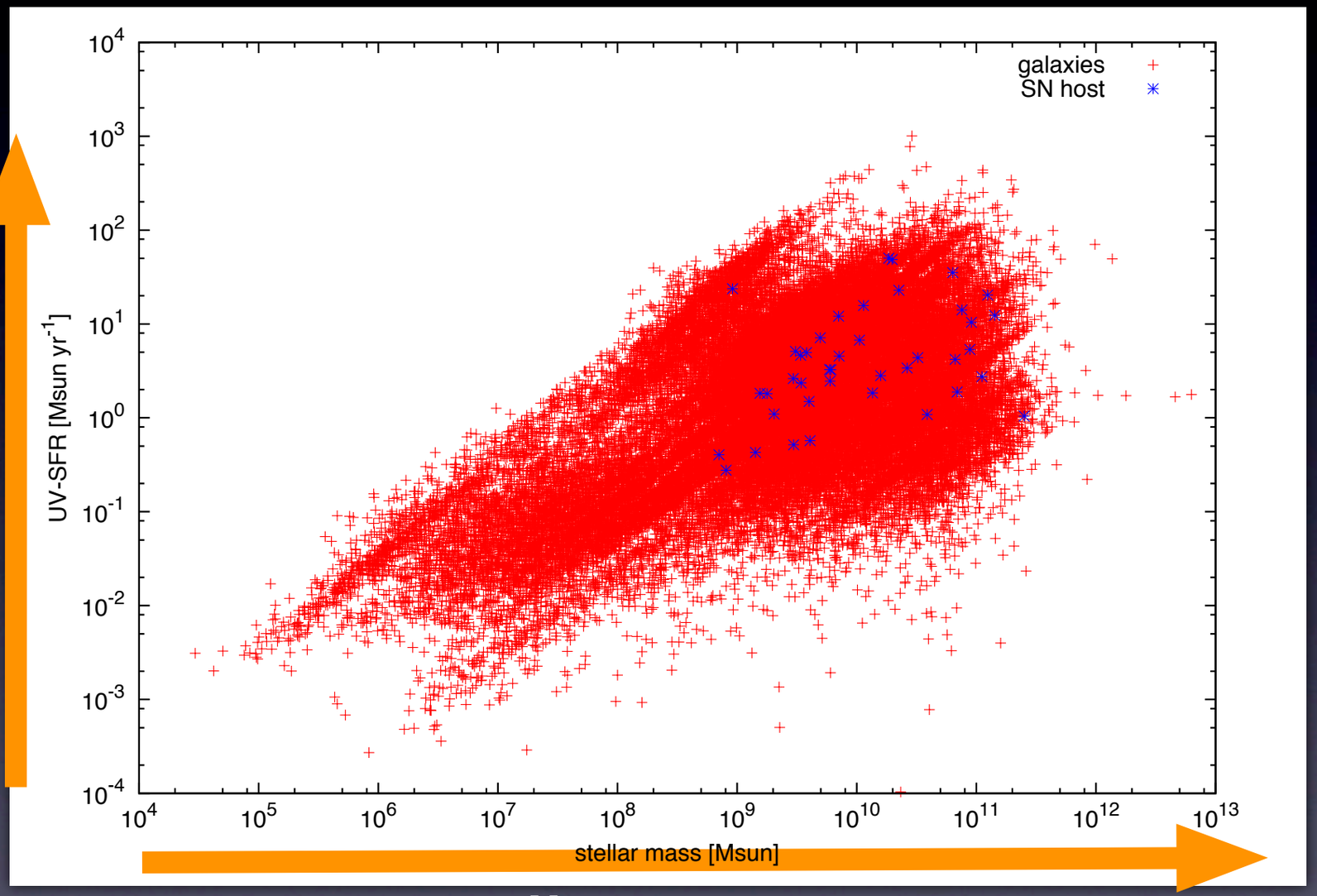

a)
delay distrib
Time after star formation (yr)
b)
P=19.%
Redshift
age (Gyr)
c)
P=19.%
SNuM
B−K color
d)
P=11.%
Quiet
Faint
Loud
Radio Flux


a)
delay distrib
Time after star formation (yr)
b)
P=30.%
Redshift
age (Gyr)
c)
P=49.%
SNuM
B−K color
d)
P=66.%
Quiet
Faint
Loud
Radio Flux

# sed-sfr vs uv-sfr



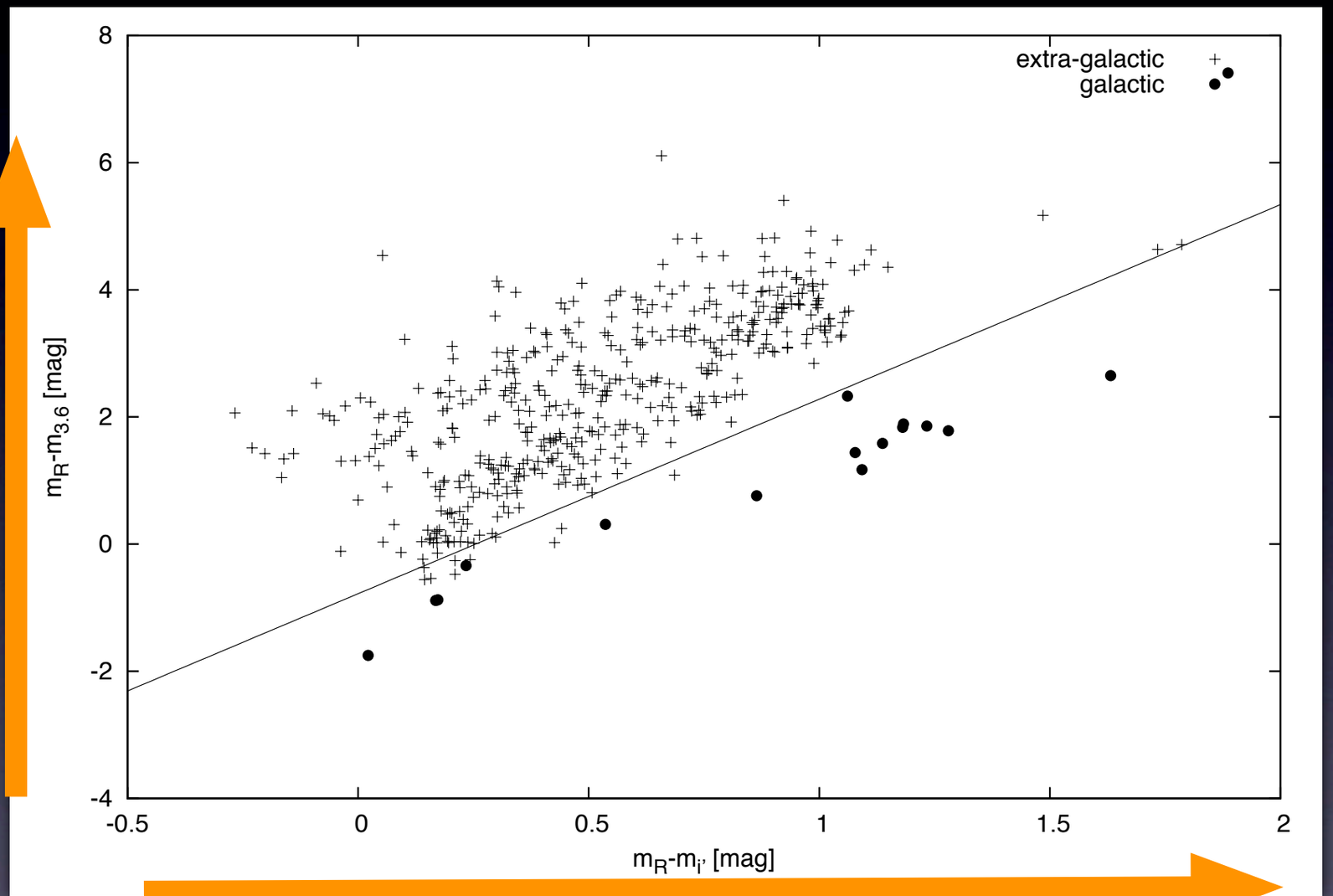
# SFR vs stellar mass




SFR

stellar mass

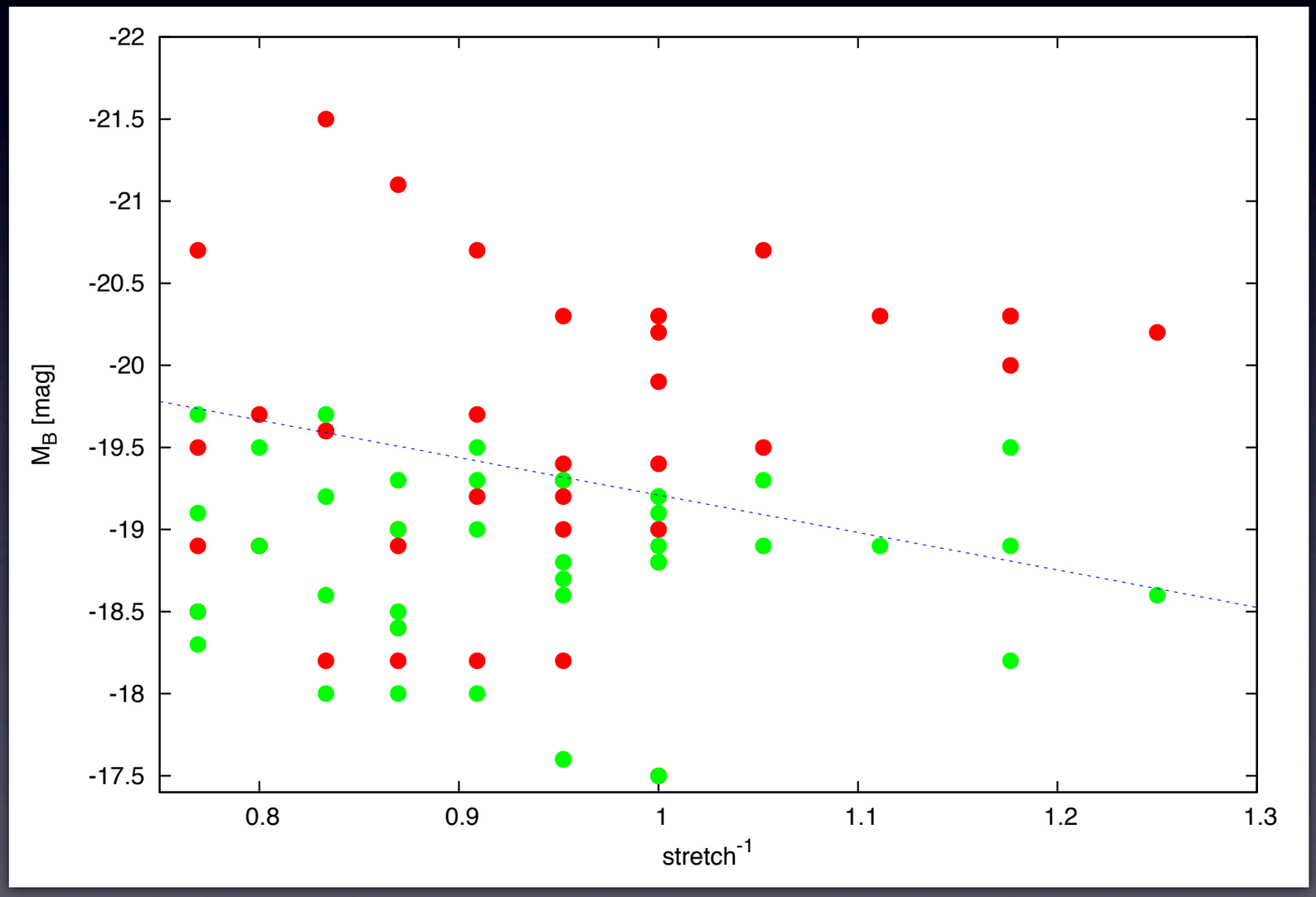
# star extraction




R - 3.6μm

R - i’

# $M_B$ vs stretch$^{-1}$

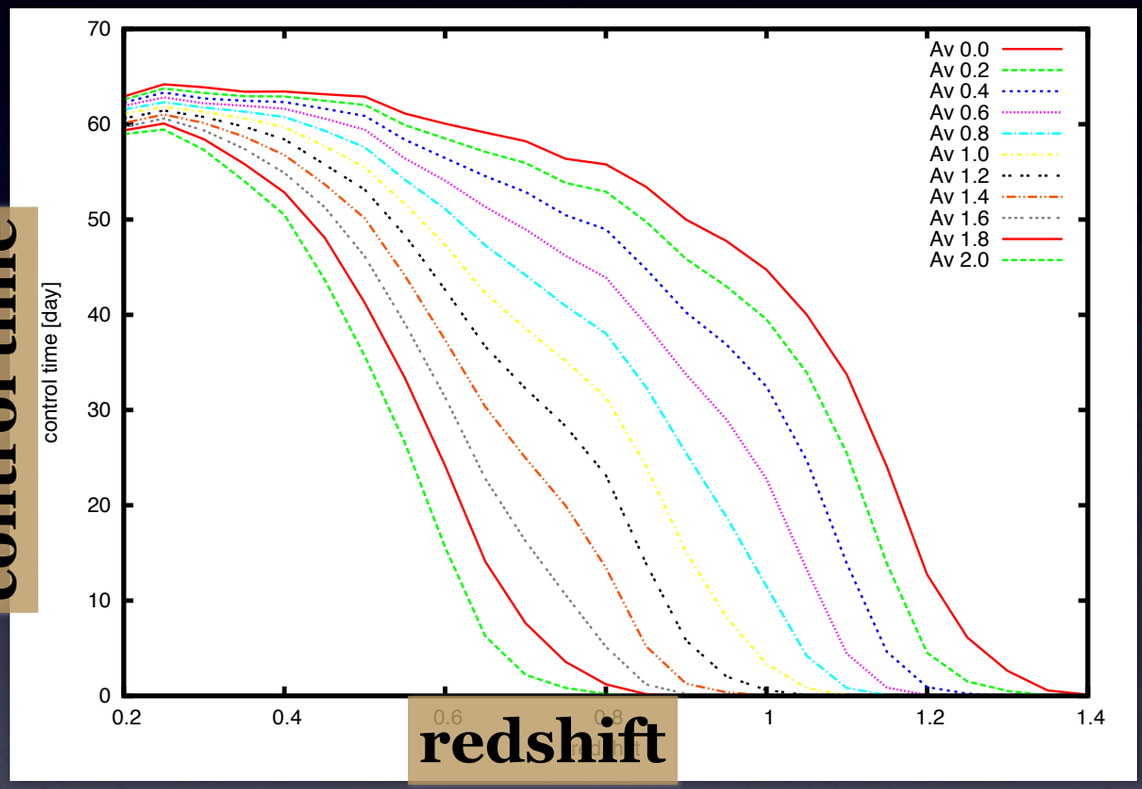


# Rate Calculation

**Observation**

$$\mathrm{SNR} = \frac{N_{obs}}{\Sigma\ \mathrm{CT}_i(z, A_V)}$$

- control time (CT) : detectable time of SN Ia
- SNR: Suprenova rate




**Model**

$$\mathrm{SNR} = \int_0^t \psi(t')\mathrm{DTD}(t - t')\ dt'$$

$$N_{\mathrm{exp}} = \Sigma\ \mathrm{SNR}_i \cdot \mathrm{CT}_i$$

- Nexp = 37.61 (Nobs = 39)
- w/o extinction : Nexp = 71.87