

A rate study of Type Ia supernovae with Subaru/XMM-Newton Deep Survey



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Abstract

★ Our goal

Type Ia supernova rate at high redshift ($z > 1.0$)

★ Method

Classification of SNe → SNe Ia or CC SNe (Ib/c or II)

→ Using light curves

★ SXDS Observations (Morokuma+2008a)

~1000 variable objects in SXDF (Subaru/XMM-Newton Deep Field)
(They include all of SXDF variable objects in 2002,03 and 05.)

→ ~200 are SN-like objects (found in 2002)

→ 50 SNe Ia (SXDF = 5 fields of view of Subaru/S-Cam)

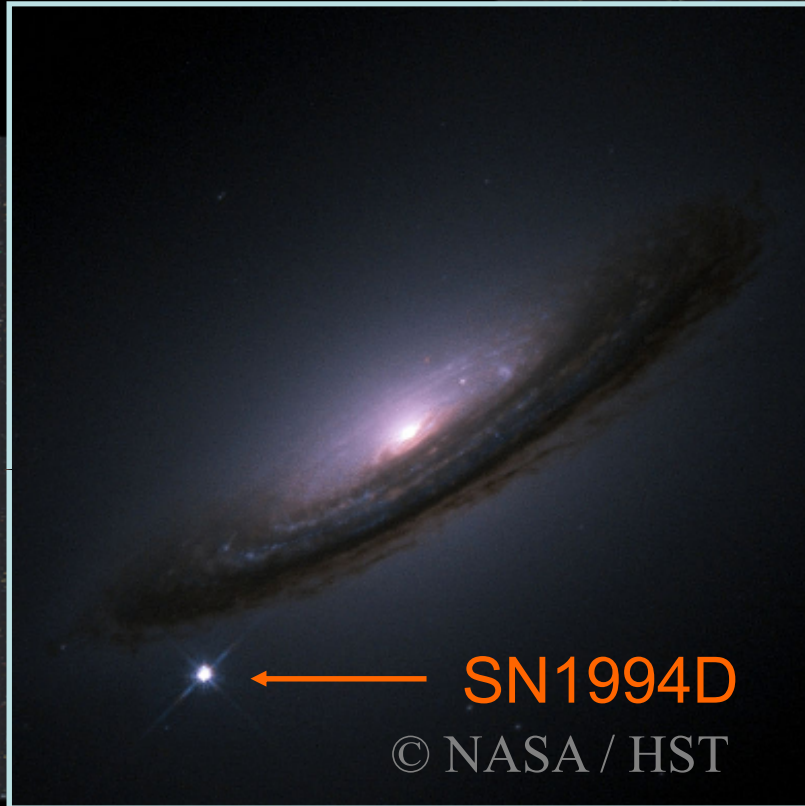
★ Rates

Obtained SN Ia rates gradually increasing in higher redshift

A deep space photograph of a starry night sky, featuring numerous stars of varying colors (white, blue, yellow) and magnitudes. The word "Introduction" is centered in a bright yellow, sans-serif font. The background is a dark, grainy field of stars, with some brighter stars appearing as distinct points of light. The overall composition is centered and balanced.

Introduction

Type Ia supernovae



★ Unique properties

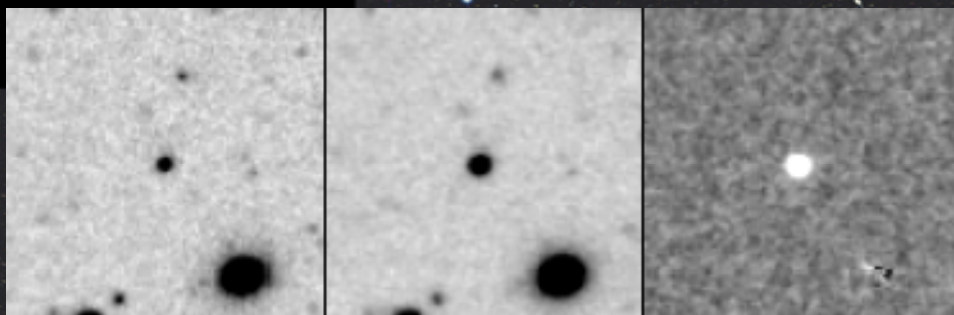
- **Very bright** ($M_B \sim -19$ mag)
→ Observe SNe Ia at high- z ($z \sim 1$)
- **Very similar**
→ Every SN Ia has a similar light curve and a spectrum.

Type Ia supernovae are standard candles in the universe.
→ SNe Ia are useful to measure cosmological parameters !!

How to detect SNe ?

(1) Detect variable objects with repeat imaging observations

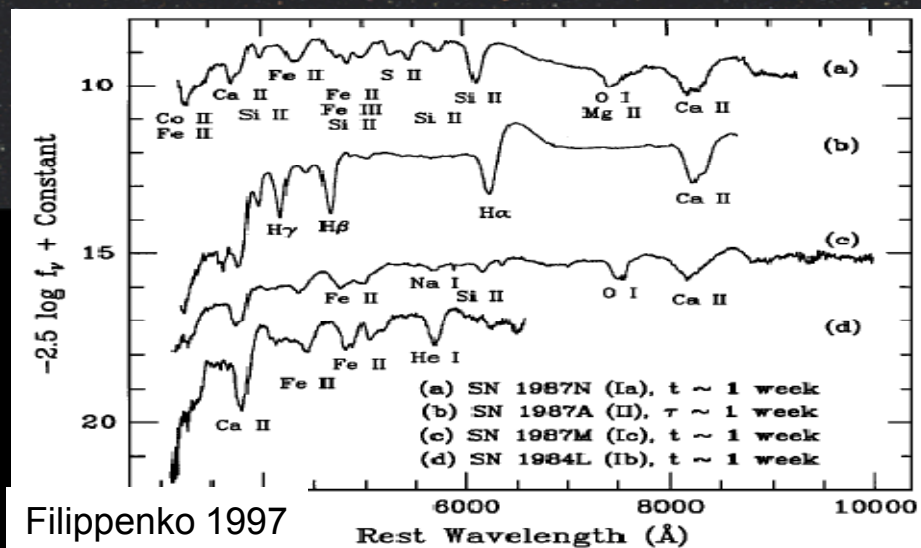
Example of a SN Ia at $z=0.606$ (Morokuma+2008)



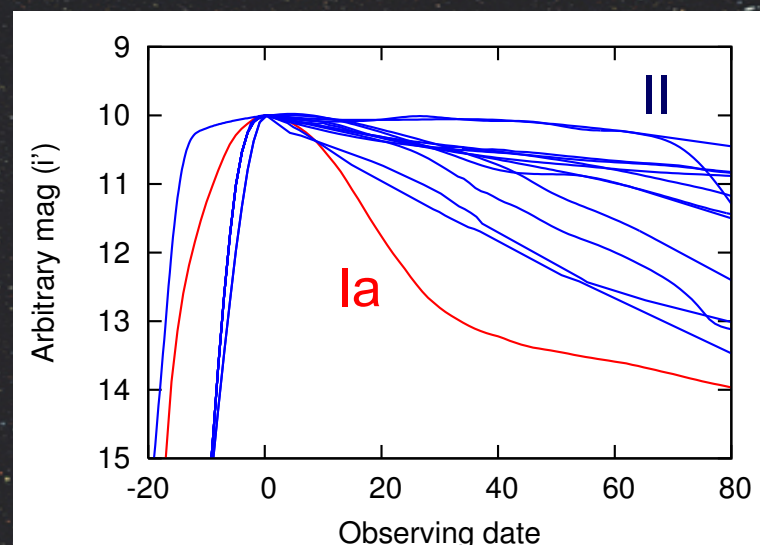
Reference Another Image Subtracted Image

(2) Classify SNe

① From Spectra (Confirmed method)



② From Light-Curves (Our Method)



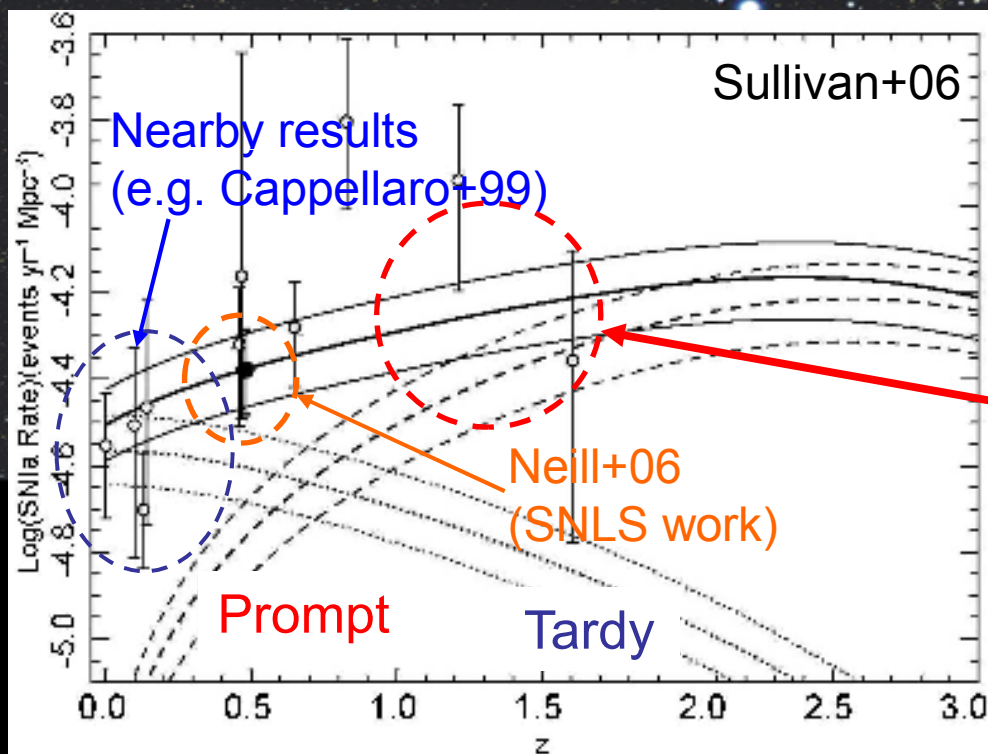
SN Ia rate study

Motivation

SN Ia rate is the clue of **progenitors of SNe Ia**

Recently, **wide delay time distribution of SNe Ia** are shown by rate studies.

(“Delay time” → time interval between star formation and SN explosion)



★ Two populations of SNe Ia ?
(Mannucci+2005, 2006)

“Prompt” : Short delay time ($\sim 0.1-1$ Gyr)

“Tardy” : Long delay time ($\sim 1-10$ Gyr)

High-z rate is important!!

It is difficult to measure that
from current SN surveys

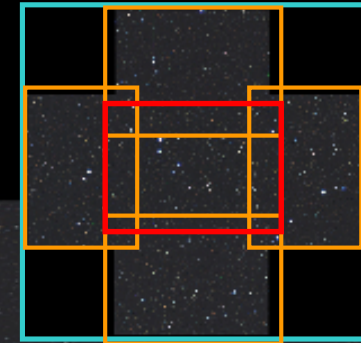
→ **SXDS data set is useful**

A dark, starry night sky with numerous stars of varying colors (white, blue, yellow, orange) and sizes. A large, white, semi-transparent cross shape is overlaid on the center of the image. The text "Our work" is written in a bright yellow, sans-serif font in the center of the cross.

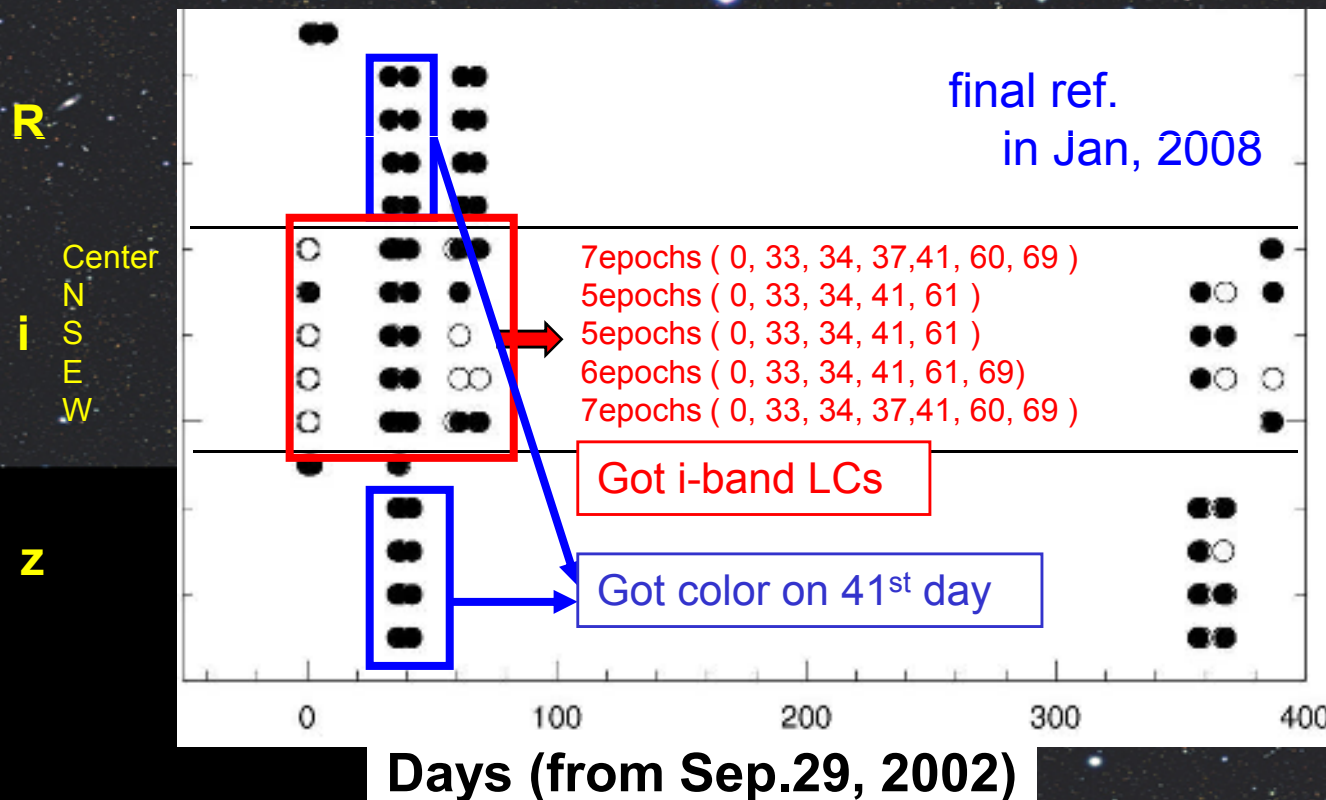
Our work

SXDS Subaru/Suprime-Cam observations

SXDF consists of 5 fields of view of Suprime-Cam
= 0.918 deg²



Observing Date 2002.9.30.~12.10. = about 70days
(**i obs.**) 5~7 epochs → Light curves
(**R and z obs.**) 2~4 epochs → Color



- Exp.time>30min
- Exp.time<=30min

Method

$$N_{exp}(z) = \int \frac{r_V(z)}{1+z} CT(z)V(z)dz,$$

① Select SN-like light curves → Remove AGN, variable stars

Criteria

- ① Bright in 2002 and under detection limit in 2003 and 2005
- ② More than 3 points of light curves are $>5\sigma$ limit

② Classify by LC fittings → Remove Type II supernovae

Type Ia supernovae are identified

③ Correct the number of Type Ia supernovae

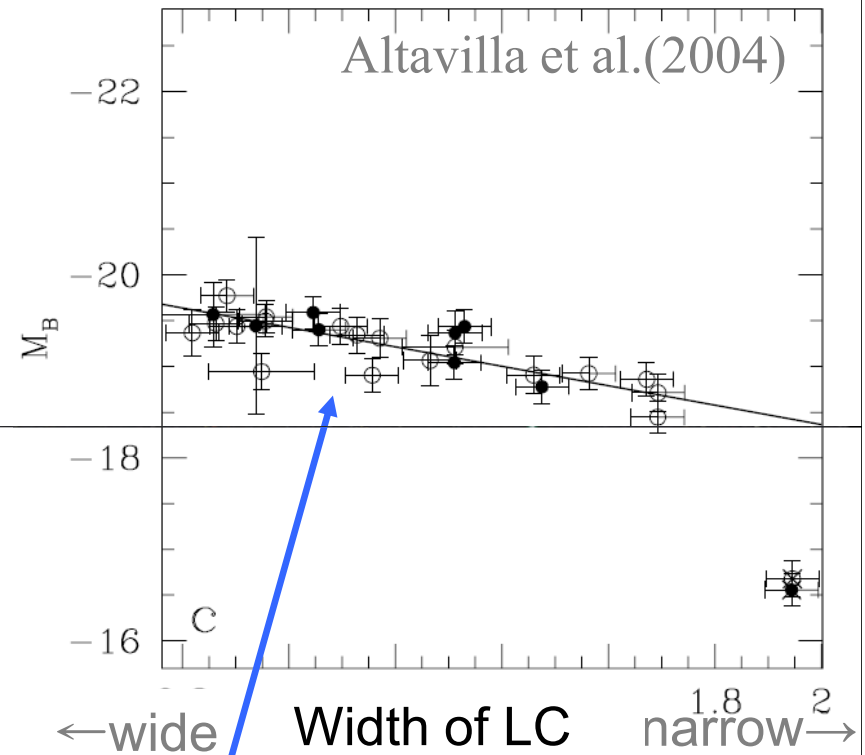
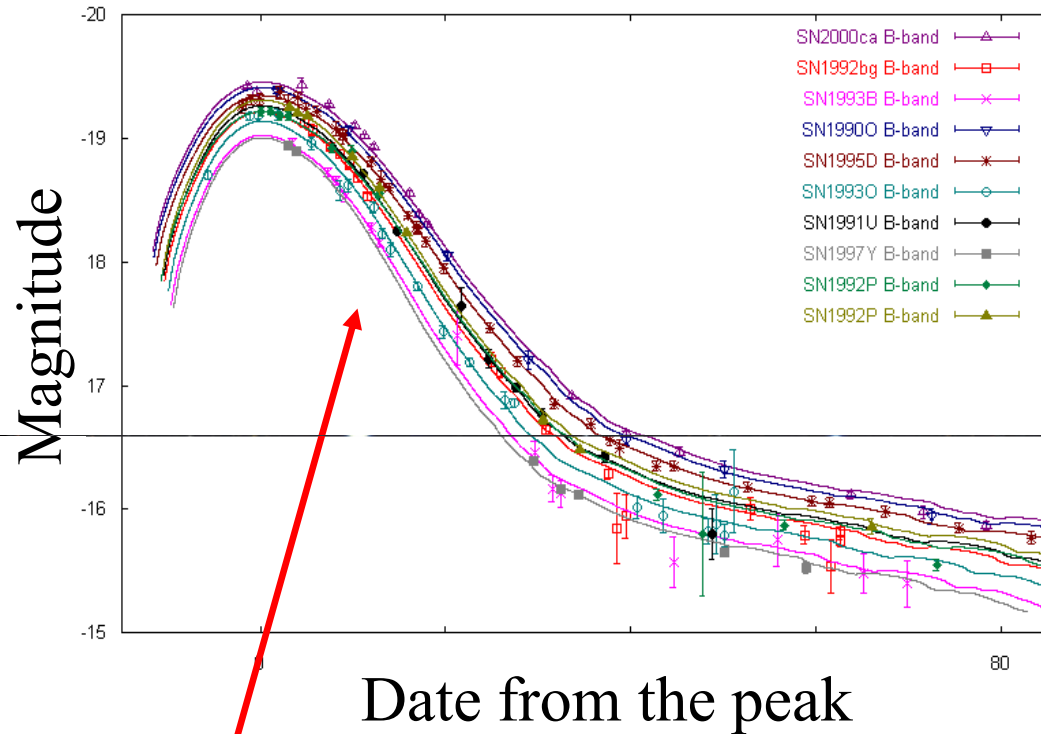
④ Time & Volume calculation

SN Ia rate

A dark, star-filled field with a large white cross overlaid on it. The cross is centered and extends to the edges of the image. The stars are of various colors, including white, blue, and orange. The text "Results of LC fittings" is written in yellow in the center of the cross.

Results of LC fittings

Light curve



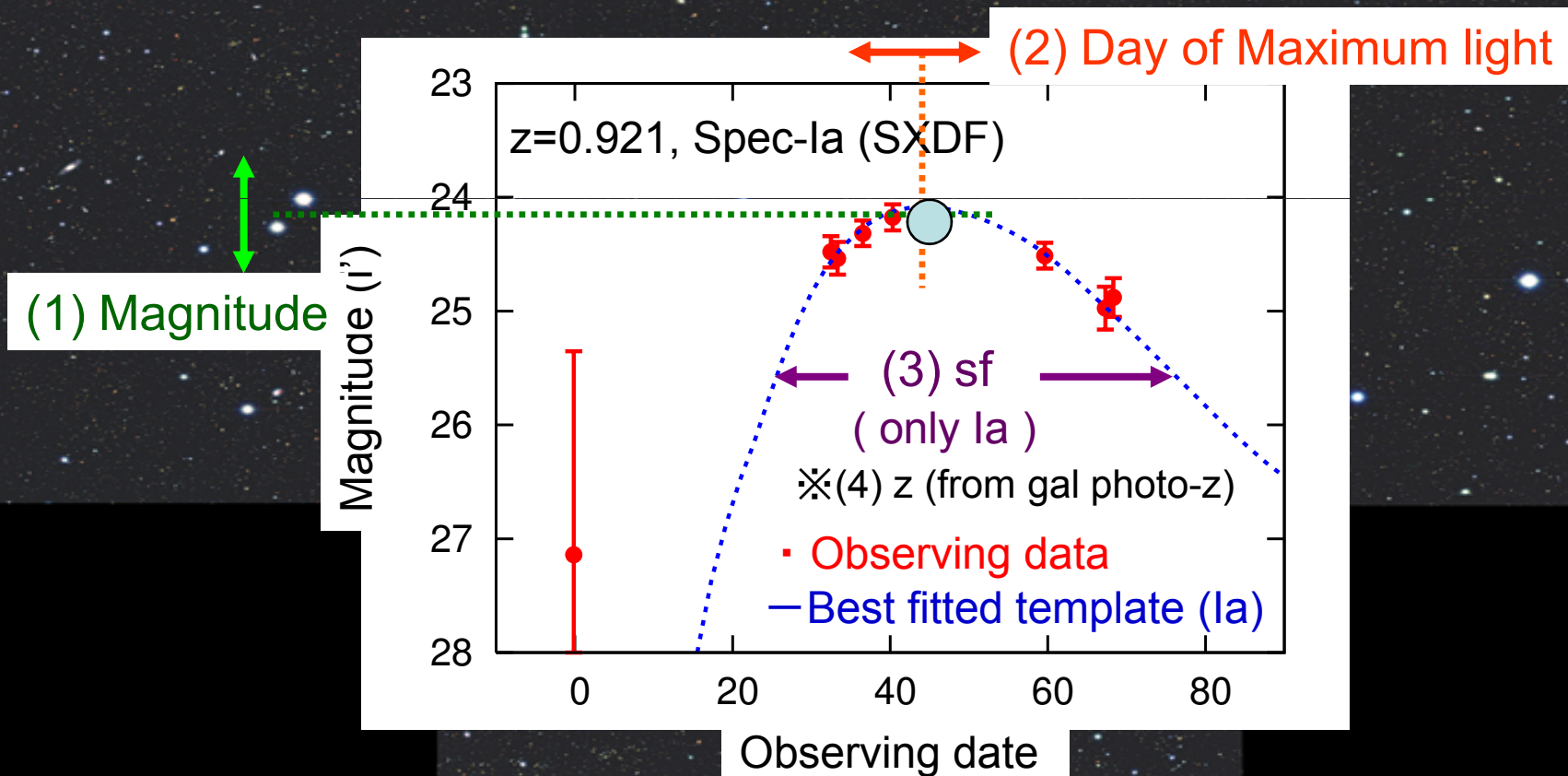
Every SN Ia has a similar LC

The relation of peak magnitude and width of LC
Width of LC = Stretch Factor

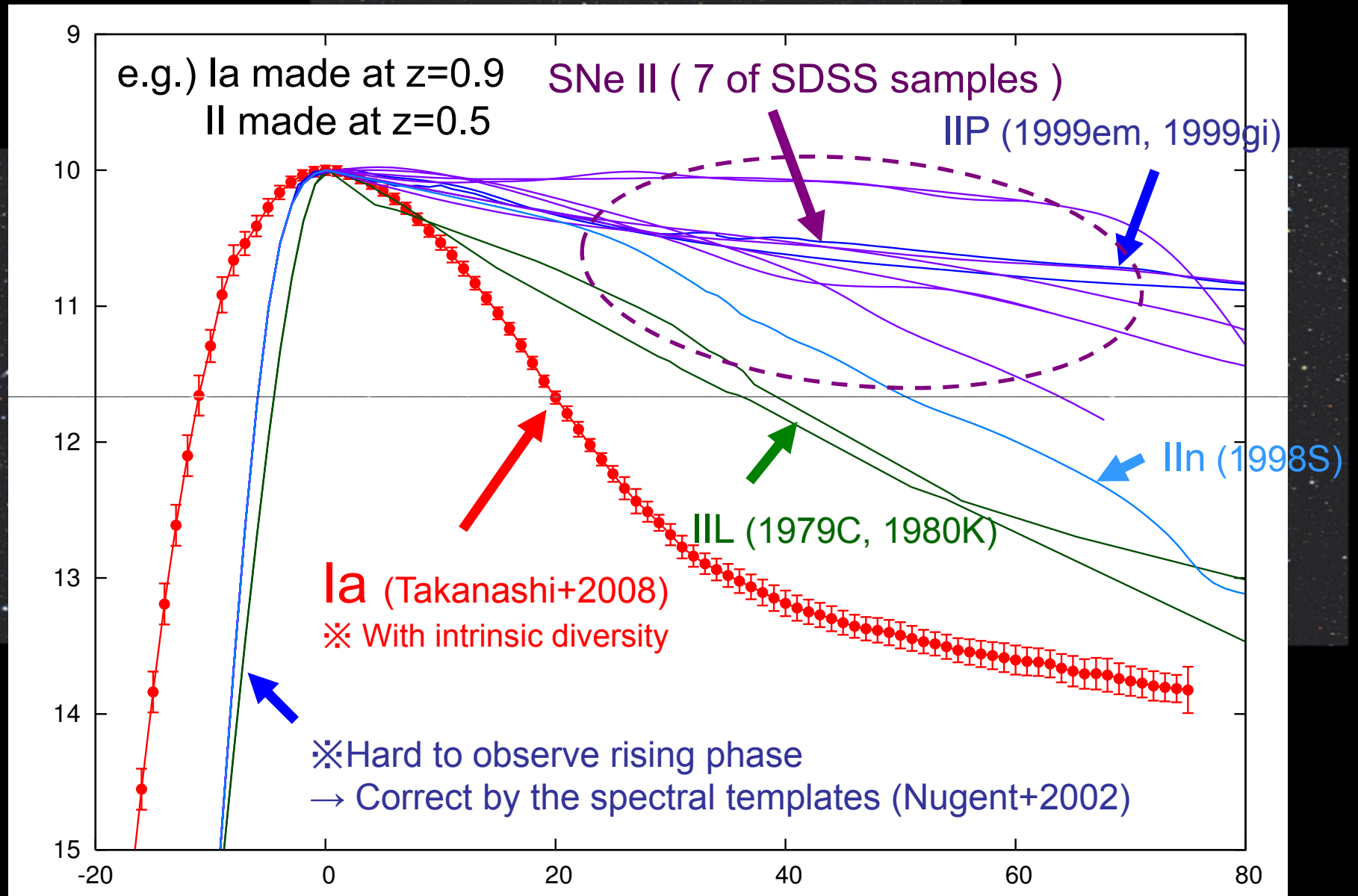
LC fitting Method

★ We classify SNe into type Ia and type II by fitting observed LCs with template LCs.

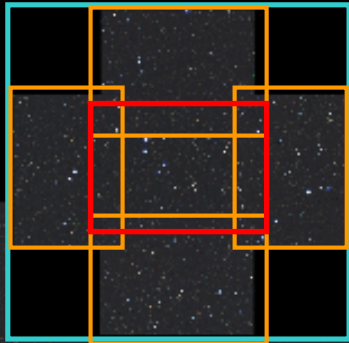
【 χ^2 fitting 】 Reduced $\chi^2 = \sum_n \left(\frac{\text{Obs.} - \text{Temp.}}{\text{error}} \right)^2 / \text{f.o.d.}$



Template(1 of Ia and 12 of II)



SNe in SXDF



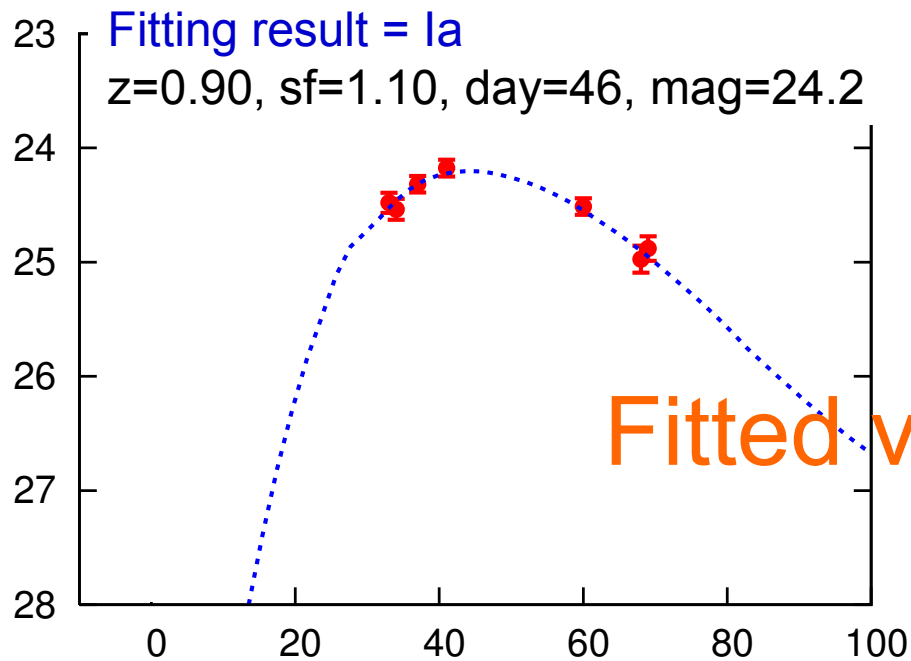
~200 SN-like objects were discovered in 2002.
→ 50 are SNe Ia. The others are SNe II or AGN
(not yet classified)

All of 9 confirmed spec-Ia samples are identified as Type Ia by the LC fitting.

○ Type Ia

Ex.1 1-175 (spec-Ia)

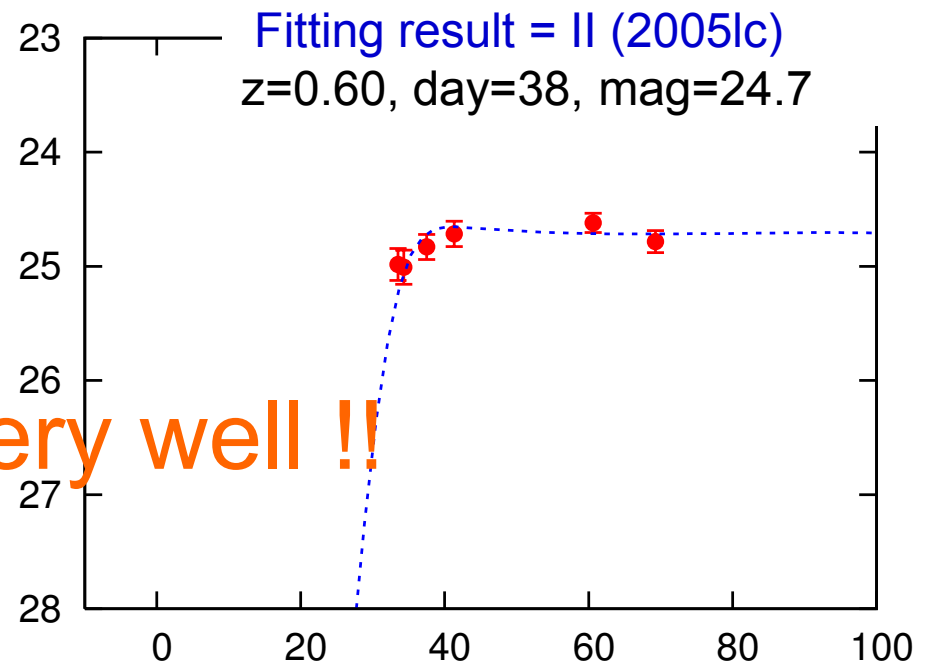
$z=0.921$ i' max = 24.16



○ Type II

Ex.2 1-045 (?)

$z=0.625$ i' max = ?



Fitted very well !!

Raw number of SNe Ia in SXDF

	0.2-0.6	0.6-1.0	1.0-1.4	1.4-1.8
SXDF(50)	6	25	19	—
Poznanski+07(22) (SDF)	0 (<0.5)	9 (0.5-1.0)	10 (1.0-1.5)	3 (1.5-2.0)
Dahlen+08(56) (GOODS)	8	25	20	3

A dark, star-filled sky with a large white cross overlaid on it. The cross is centered and extends across most of the image. The stars are of various colors, including white, blue, and orange. The text "Completeness and Contamination" is written in yellow across the center of the cross.

Completeness and Contamination

Simulation

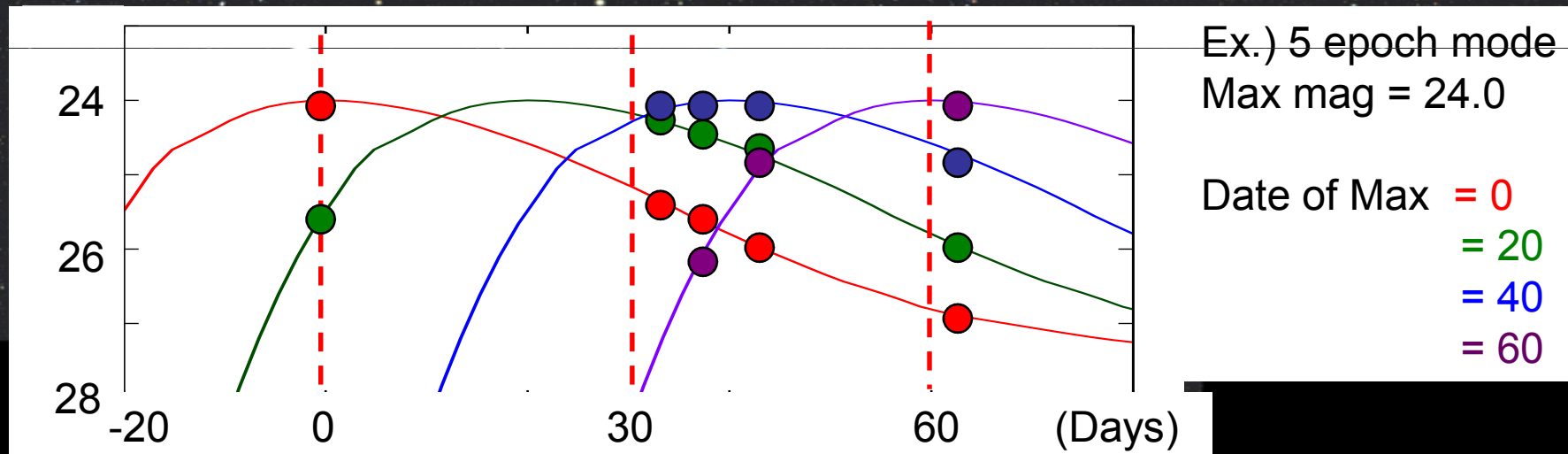
★ Make light curves in the observed i' -band using templates

- High- z SNe Ia ($z \sim 1$): \rightarrow observed i' = rest U - B
- Limiting magnitudes ~ 26 mag (5σ , 3600 sec exposure)
- Maximum magnitudes of SNe $\sim 22.0 \sim 25.5$ mag. $\rightarrow z = 0.3 \sim 1.4$

★ Input four parameters

Redshift, Maximum Magnitude, Date of Maximum, Stretch Factor

★ Example of artificial lightcurves



Make $\sim 100,000$ light curves of SNe Ia and II

\rightarrow Check “Completeness” (ID confidence) and “Contamination”

Correct SN number from Contamination

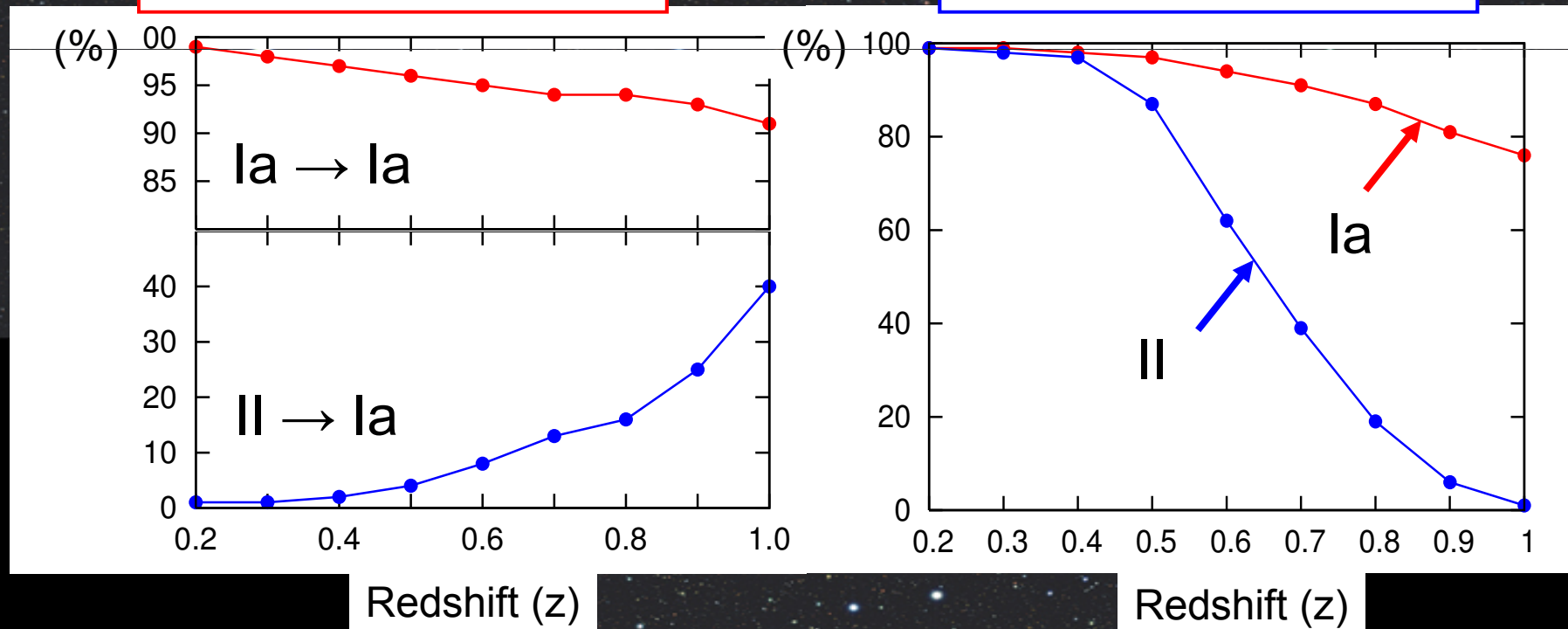
Type II rate (\propto SFR) (Botticella+07)

$$f(z) = \frac{0.55 \times 10^{-4} (1+z)^{3.9}}{r_0 (1+z)^\alpha} \times \frac{LC_{II}}{LC_{Ia}} \times \frac{\epsilon_{II}}{\epsilon_{Ia}}$$

Type Ia rate (Fit later)

LC fitting accuracy

Detection efficiency

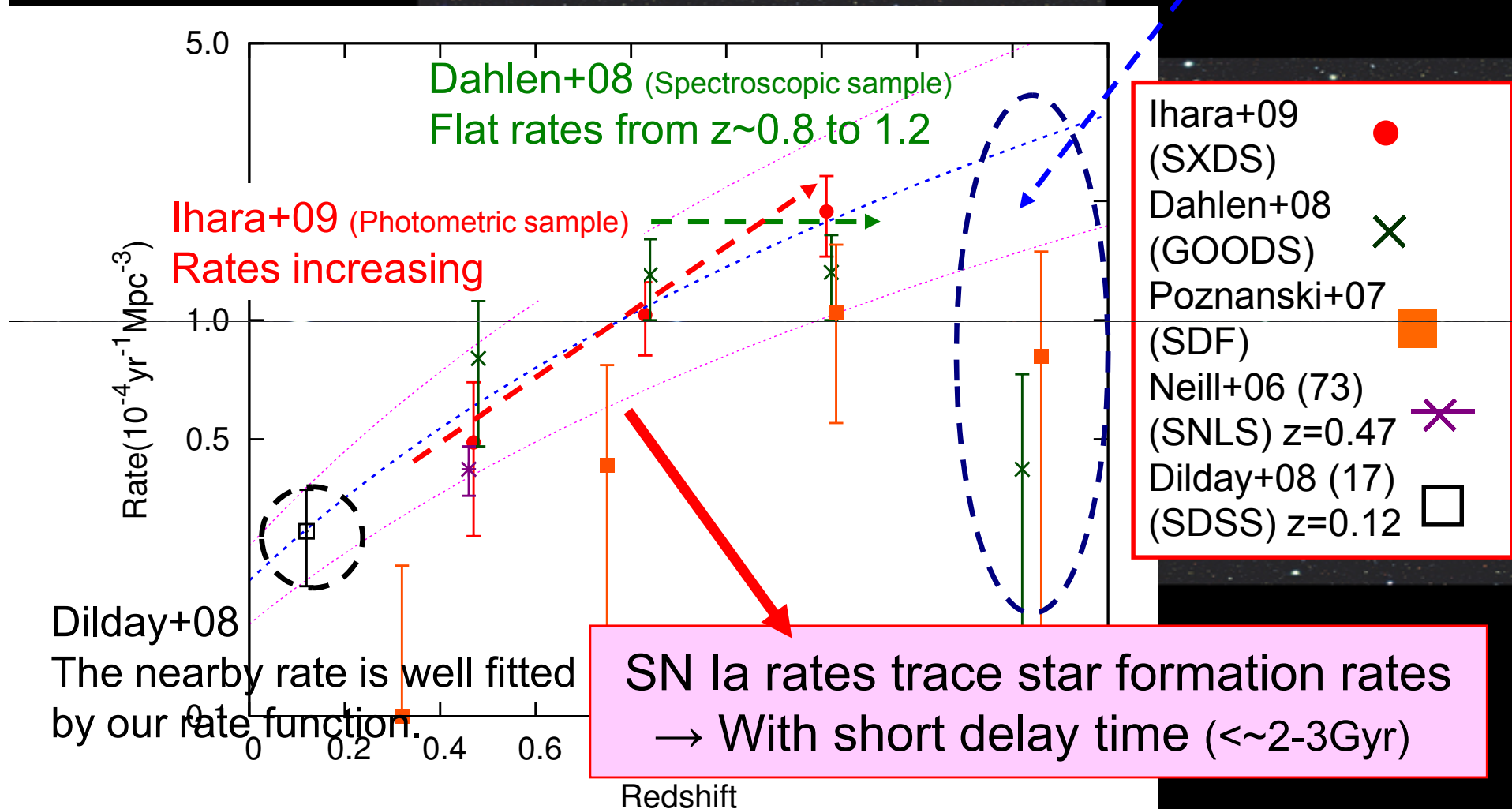


A dark, star-filled field with the text "Rate results" overlaid in yellow. The stars are of various colors, including white, blue, and orange, and are scattered across the field. The text is centered and has a slight shadow effect.

Rate results

Compared with the other results

At the highest redshift,
Not obtained by our results



Summary & Future Work

★ SNe Ia in SXDF

- We classified SNe Ia in SXDF by light curve fitting.
- Out of 50 SNe Ia, 19 SNe Ia are high- z samples ($z > 1$).
- We can get high- z SNe Ia with a ground telescope (SUBARU) comparable by the search by HST (Dahlen+2008)

★ Rates

- We obtained the rates similar to Dahlen+08, but the rates in SXDF are increasing to higher redshift.
- Existence of SNe Ia with short delay time ($< \sim 2-3$ Gyr)

(Future Work)

- Suprime-Cam z' -band survey is on-going (P.I.:Furusawa). (But the weather condition was very bad until now...)
- We expect to obtain highest- z SNe Ia at $z > 1.4$.

A wide-field photograph of a starry night sky, likely a star cluster or galaxy core, featuring numerous bright and faint stars of various colors (white, blue, yellow, orange). The word "Fin" is overlaid in the center in a red, sans-serif font. The image is framed by a black border.

Fin