High-Redshift Supernova Survey with Shock Breakout

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Supernovae, Dark Energy and Cosmology

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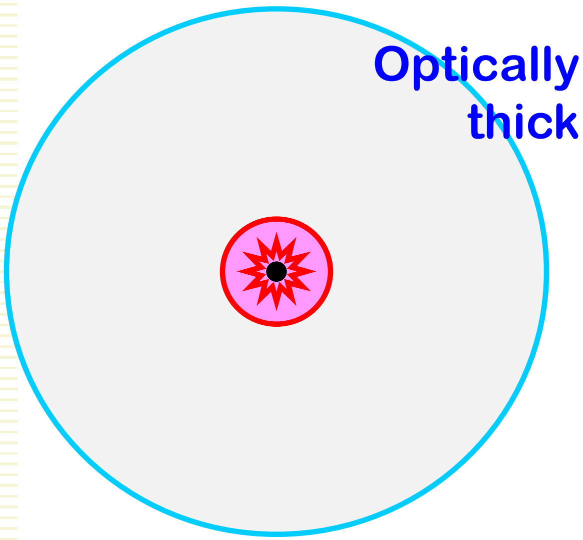
  - What is shock breakout?
  - Observation and theoretical model
  - Optical surveys
- HSC transient survey
  - Strategy
  - Science cases

Shock breakout

NT, Blinnikov, Baklanov, + 2009 ApJ 705 L10

NT, Morokuma, Blinnikov, + 2011 ApJS 193 20

What is shock breakout?



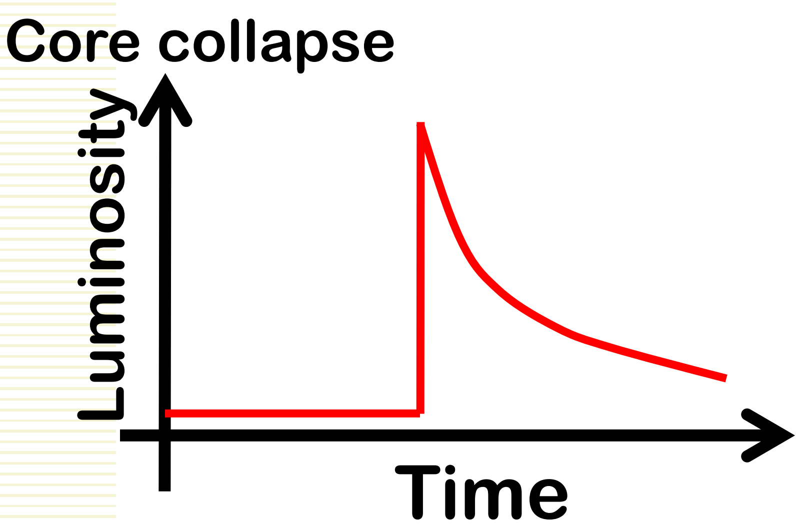
Massive Star (>10$M_\odot$)

e^--capture SNe (8-10$M_\odot$)

Core collapse

Shock formation

At the shock emergence,
a stored energy is released
as radiation.



Spectra are quasi-blackbody

$$T \sim R^{-3/4} E^{1/4}$$

<u>Typical properties</u>

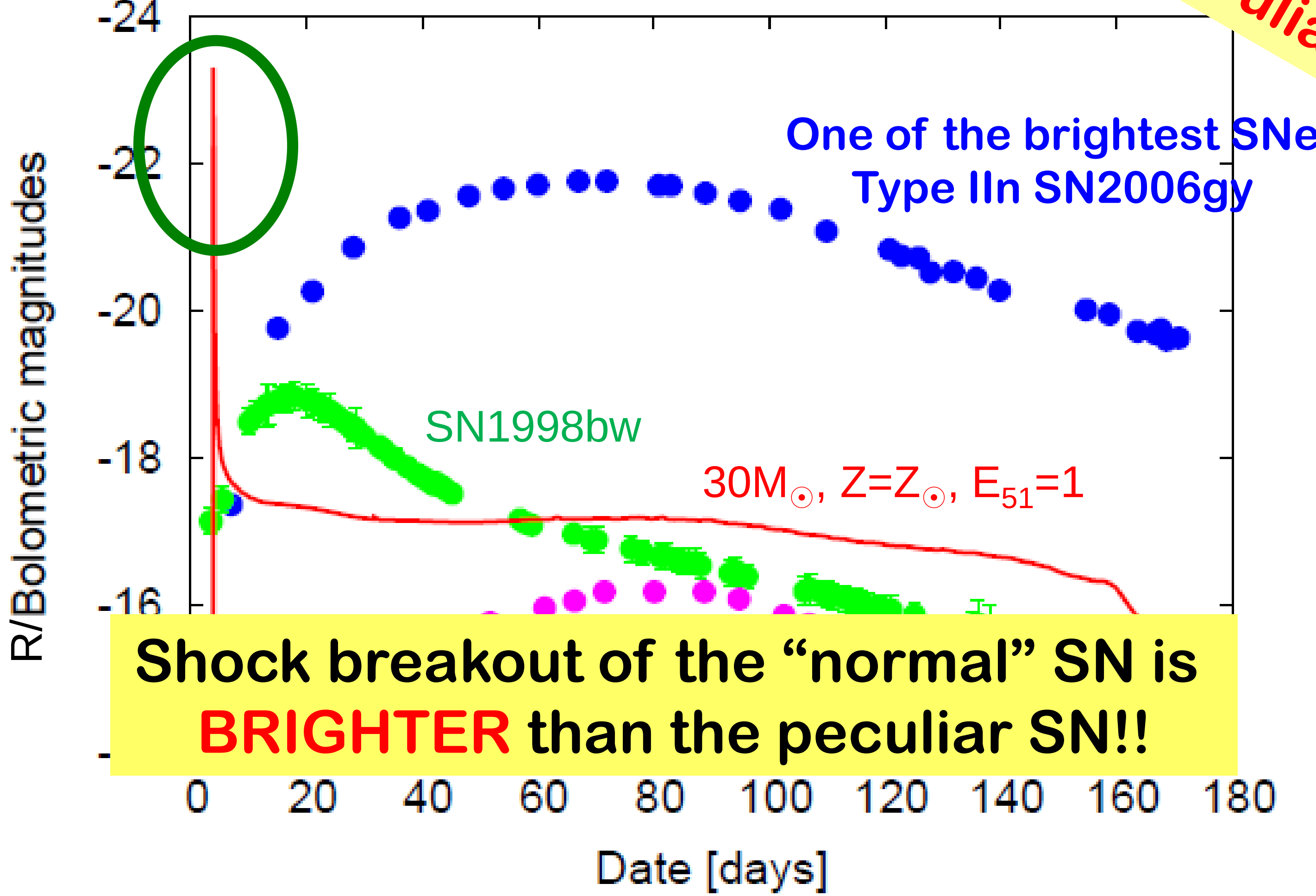
timescale: 100sec ~ 1day

peak wavelength: X-ray ~ UV

Shock breakout is **bright!**

- SN 2006gy (z=0.02: Smith + 08; Kawabata, ..., 09)
  - M_R~-22 (M(^{56}Ni)~15$M_\odot$ or CSM interaction)

This is a "peculiar" SN.

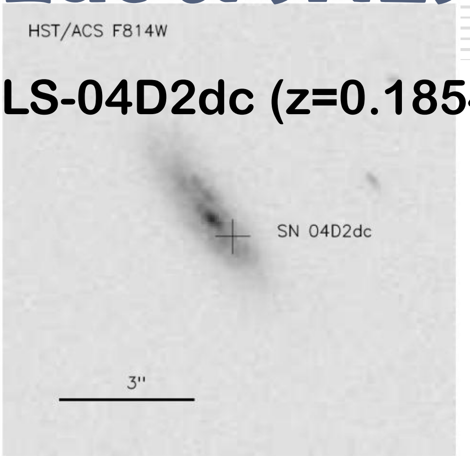


Shock breakout of the "normal" SN is **BRIGHTER** than the peculiar SN!!

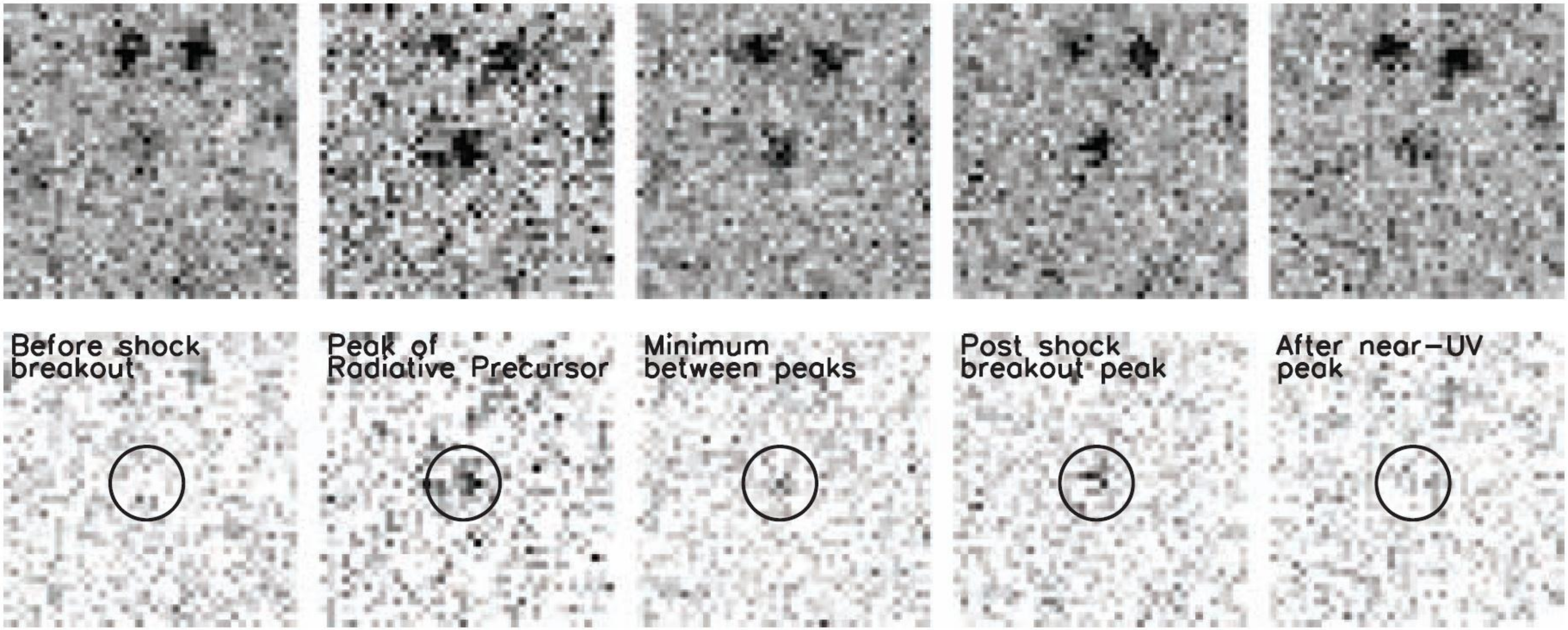
Shock breakout of Type IIP SNe

-SNLS-04D2dc & SNLS-06D1jd-

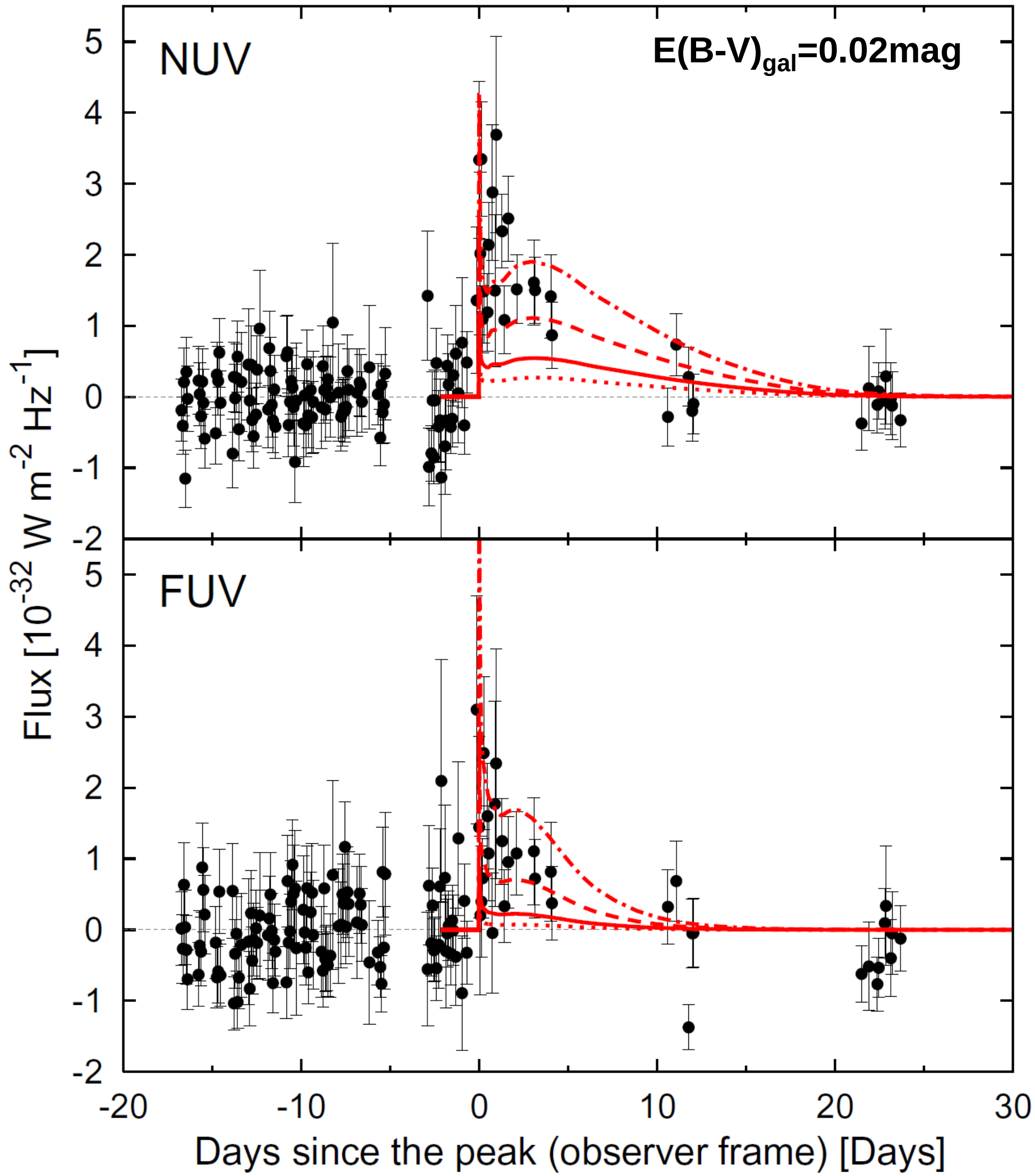
SNLS-04D2dc (z=0.1854)

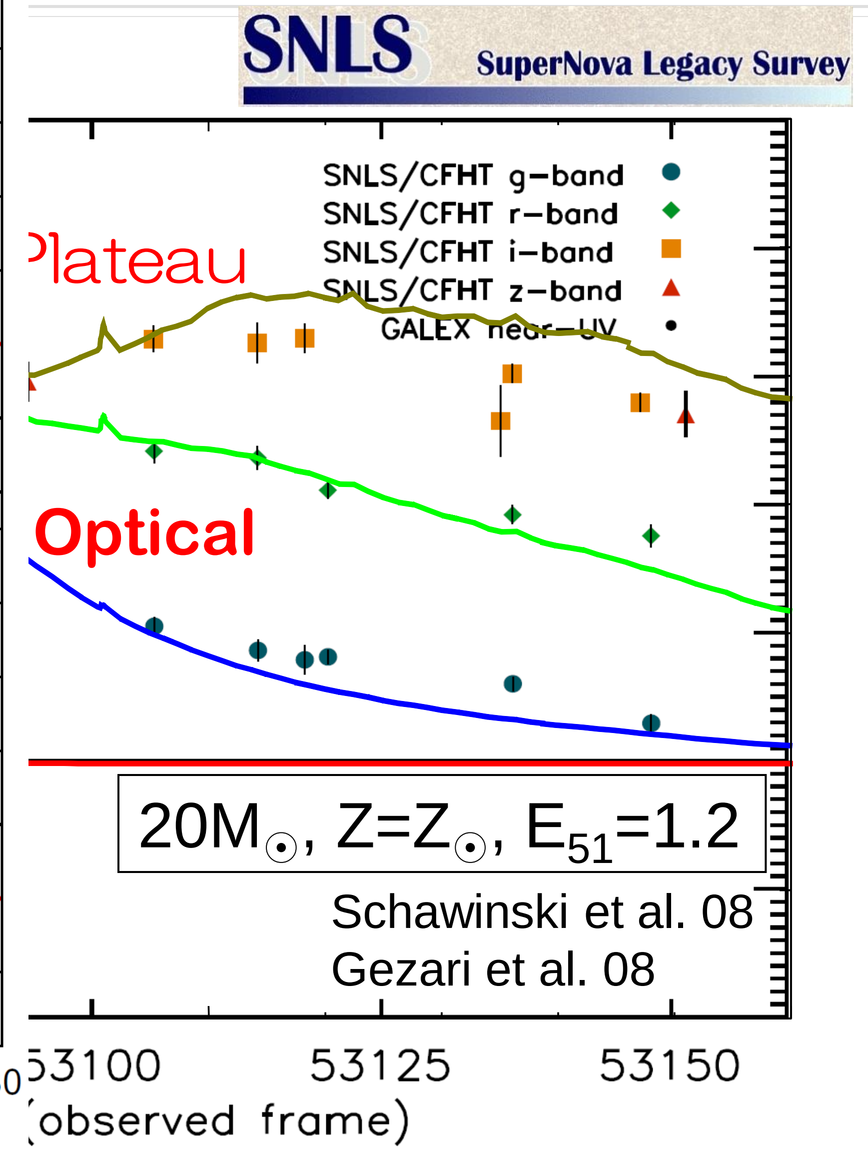


Schawinski et al. 08
Gezari et al. 08

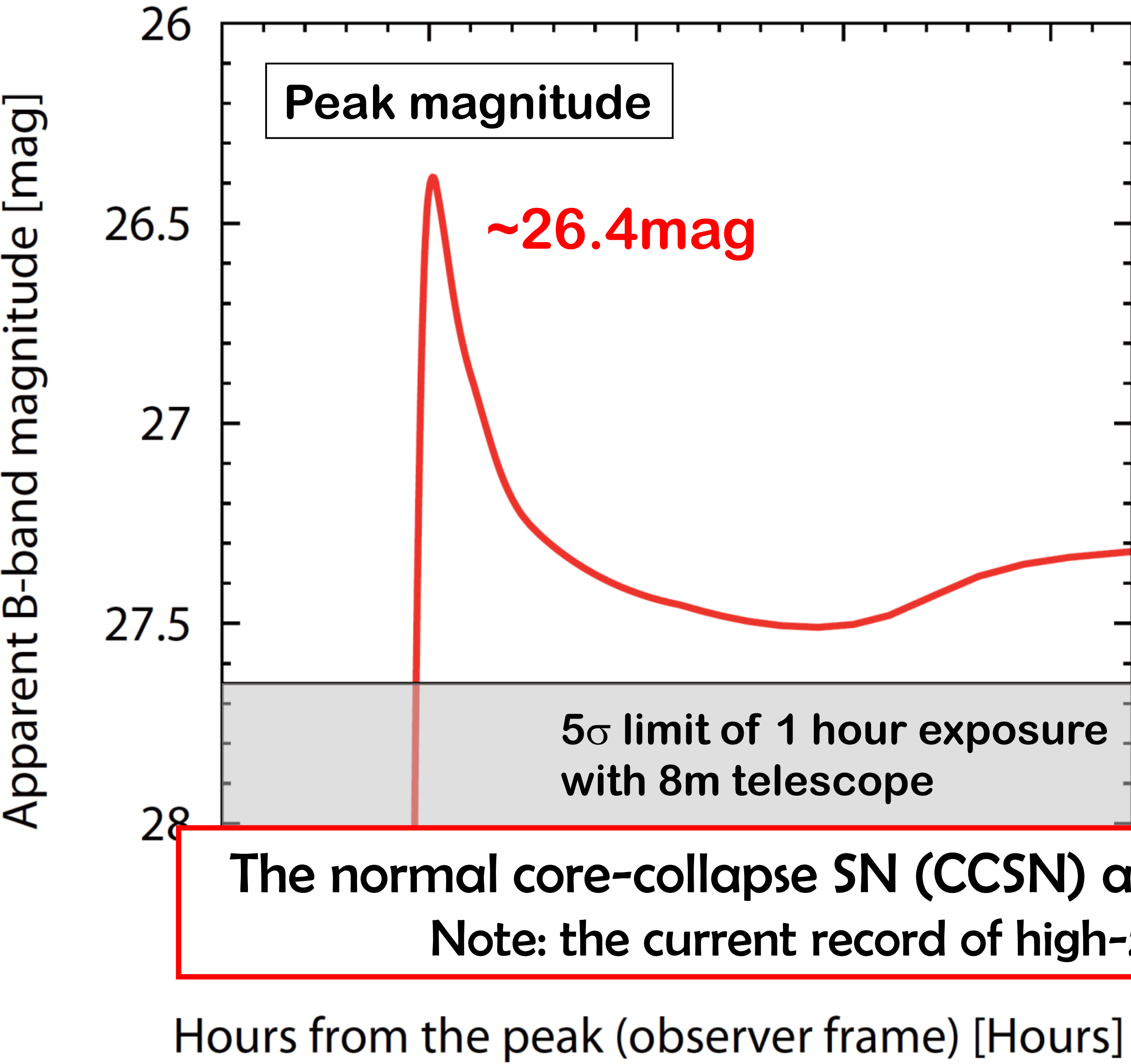


Shock breakout of Type IIP SN
—Observations and model—





When the same SN takes place at z=1,



SNLS-04D2dc

Redshift z=1

NUV: ~2300A

z=1: ~4600A (B or g)
(SNLS-04: ~3900A)

The normal core-collapse SN (CCSN) at z=1 can be detected.
Note: the current record of high-z normal CCSN is z~0.9.

Two optical surveys of shock breakout

- Nearby shock breakout survey

  Tanaka-san's talk

  - Aim: detailed investigation of shock breakout

    follow-up spectroscopy, multicolor light curves

    observations of plateau and tail phases
  - Kiso Supernova Survey (KISS) from Apr 2012
- High-z shock breakout survey
  - Aim: detection of the highest-z normal CCSNe

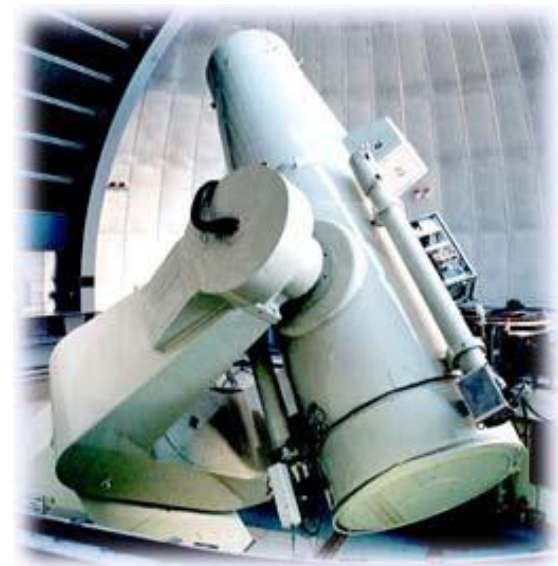
    investigation of cosmic evolution

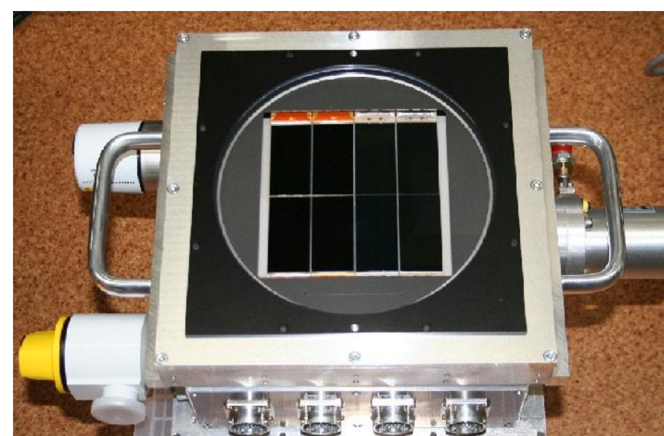
    multicolor light curves of shock breakout
  - Subaru/Hyper Suprime-Cam survey from Aug 2013

Nearby shock breakout survey with Kiso Schmidt telescope

from Apr 2012

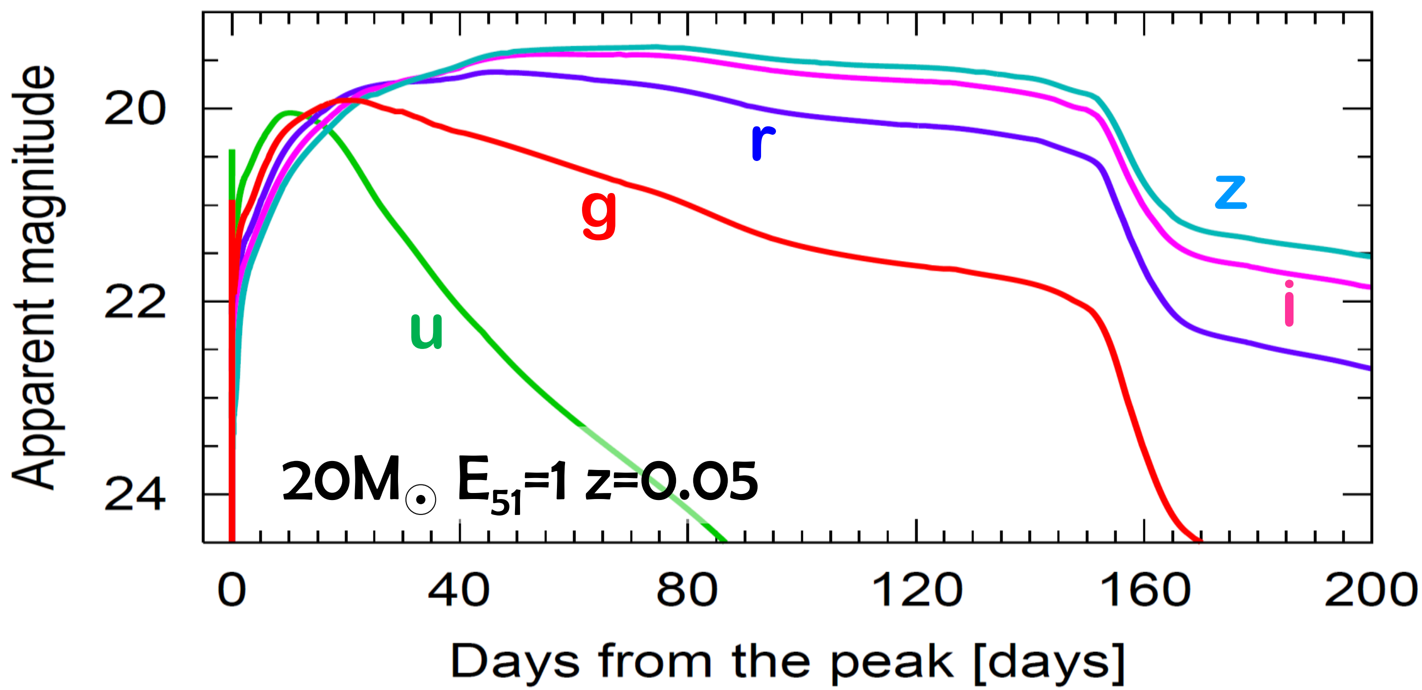
- Kiso Wide-Field Camera (KWFC)
  - Diameter: 1.05m FoV: 4deg^2
  - m_{lim} (10σ) w/ 15min: 22.1(g)





Kiso Supernova Survey (KISS)

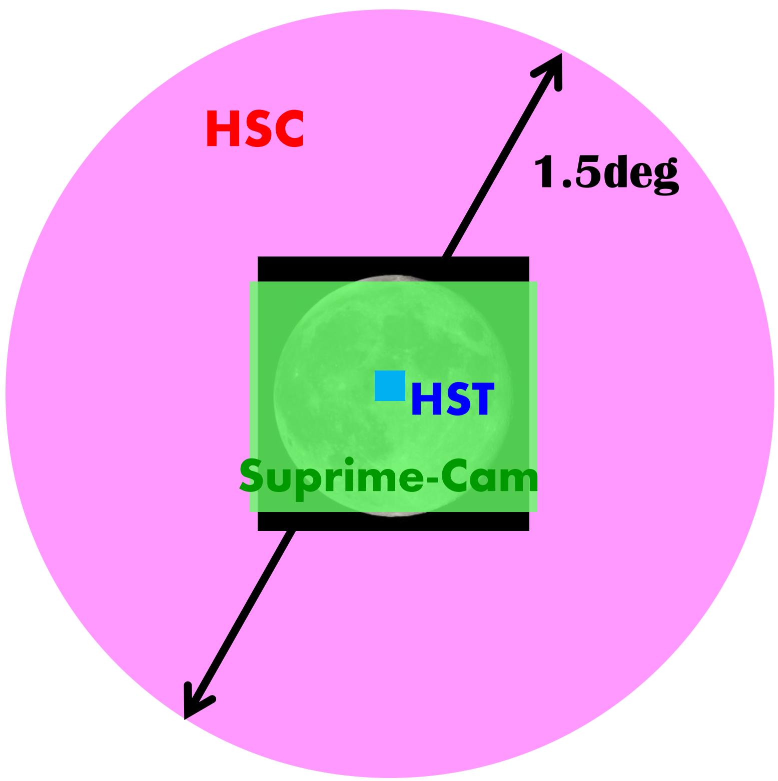
- observes SDSS fields in g band
- 3min exposure (m_{lim}~21mag) with ~1hr interval
- ~3 shock breakout in the 3 year project
- $m_{plateau}$~20mag, m_{tail}~22mag → follow-up obs.

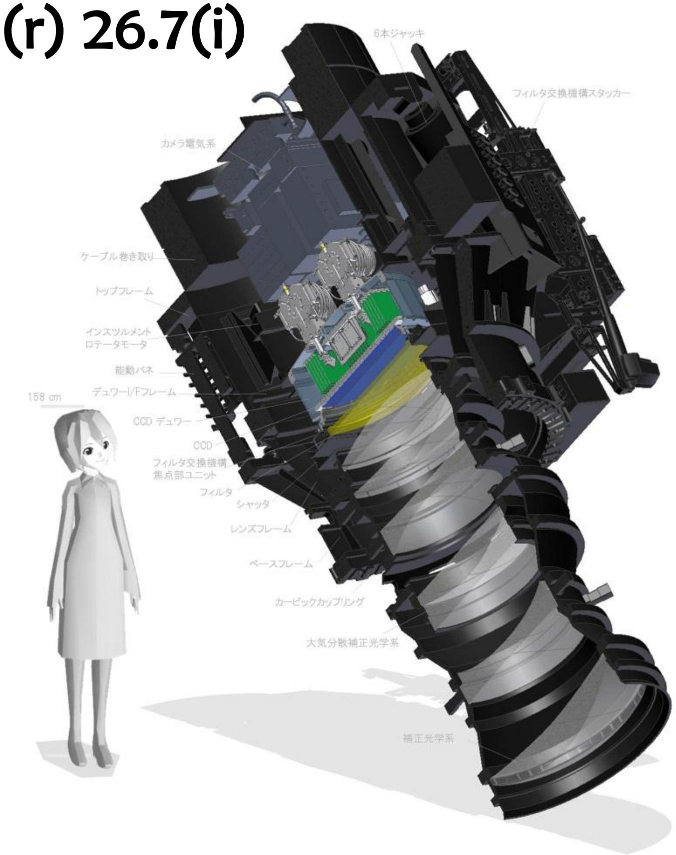


High-z shock breakout survey with Subaru telescope

from Aug 2013

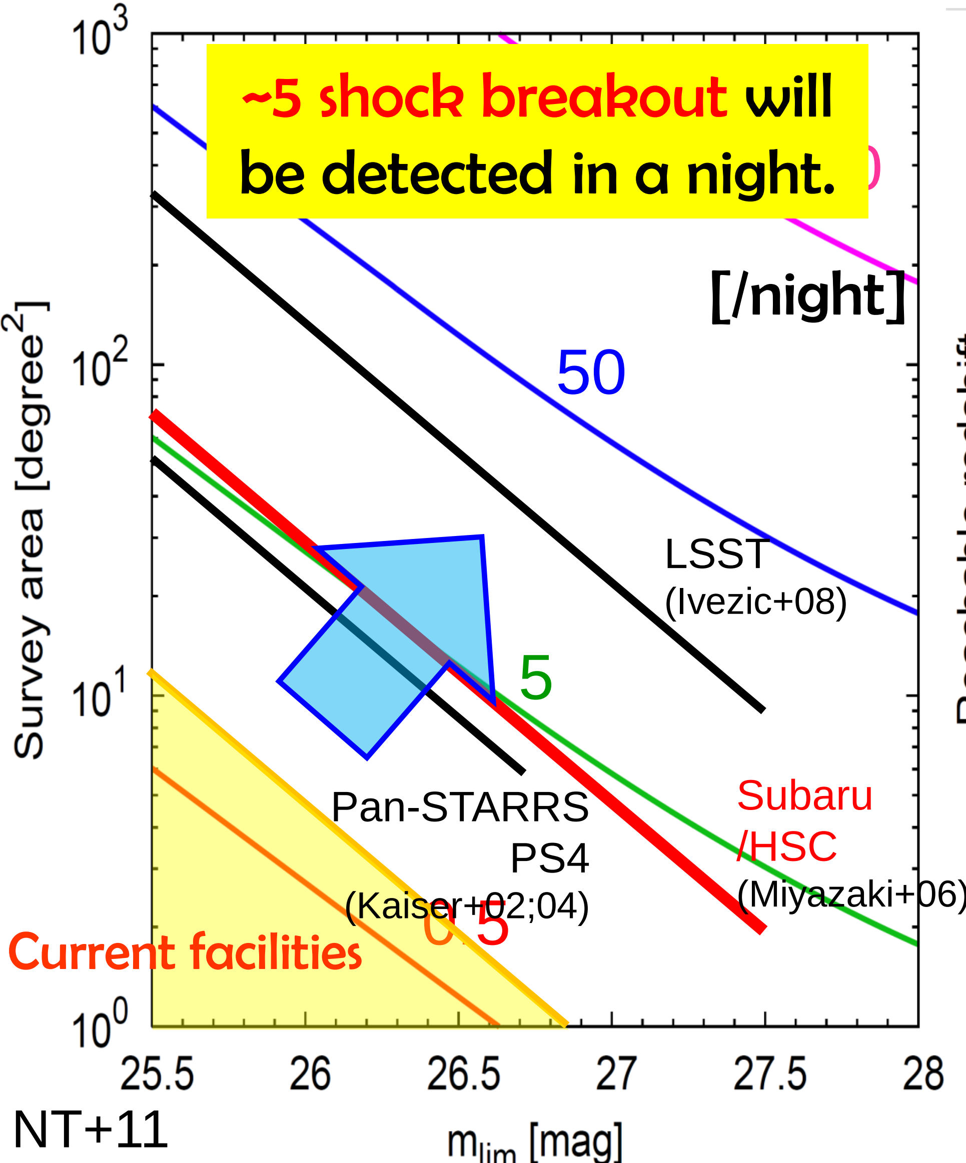
- Hyper Suprime-Cam (HSC)
  - Diameter: 8.2m, FoV: 1.77deg^2
  - m_{lim} (5σ) w/ 1hr: 27.5(g) 27.2(r) 26.7(i)





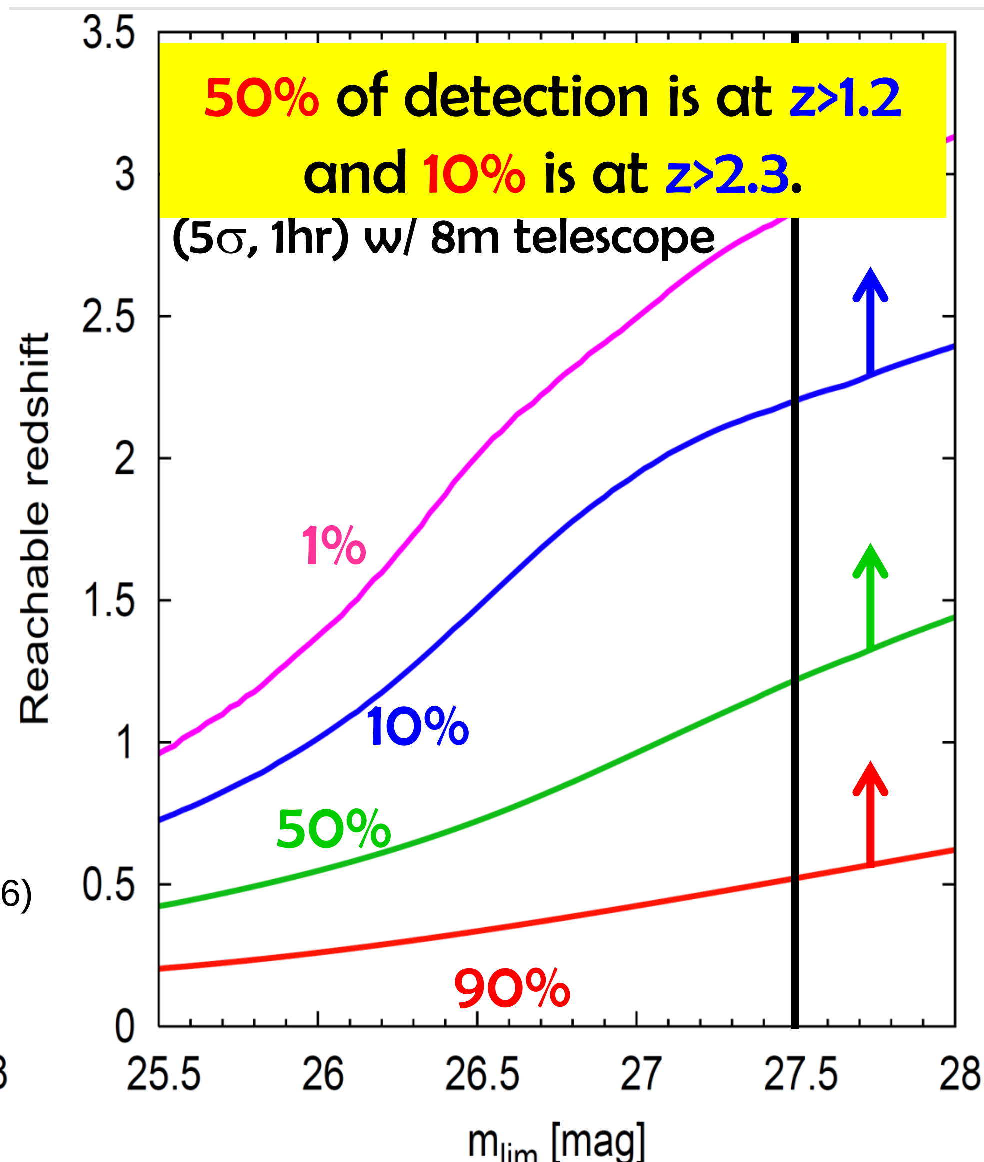
Theoretical expectation

Detection rate

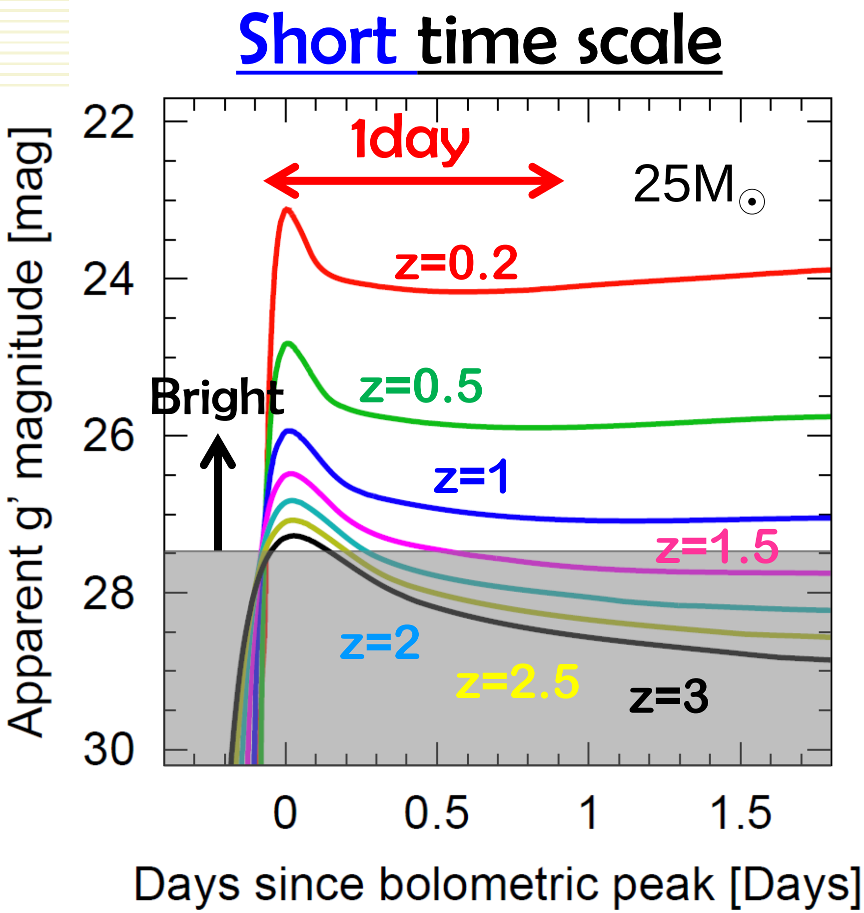


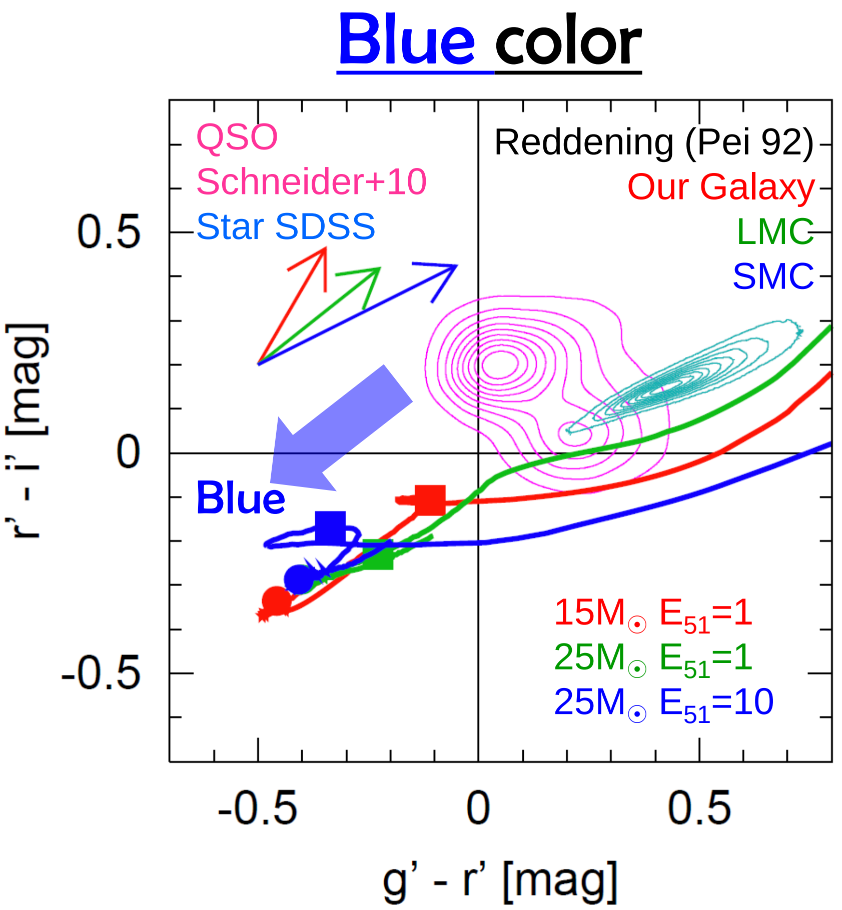
NT+11

Redshift distribution



How to identify them from LCs?





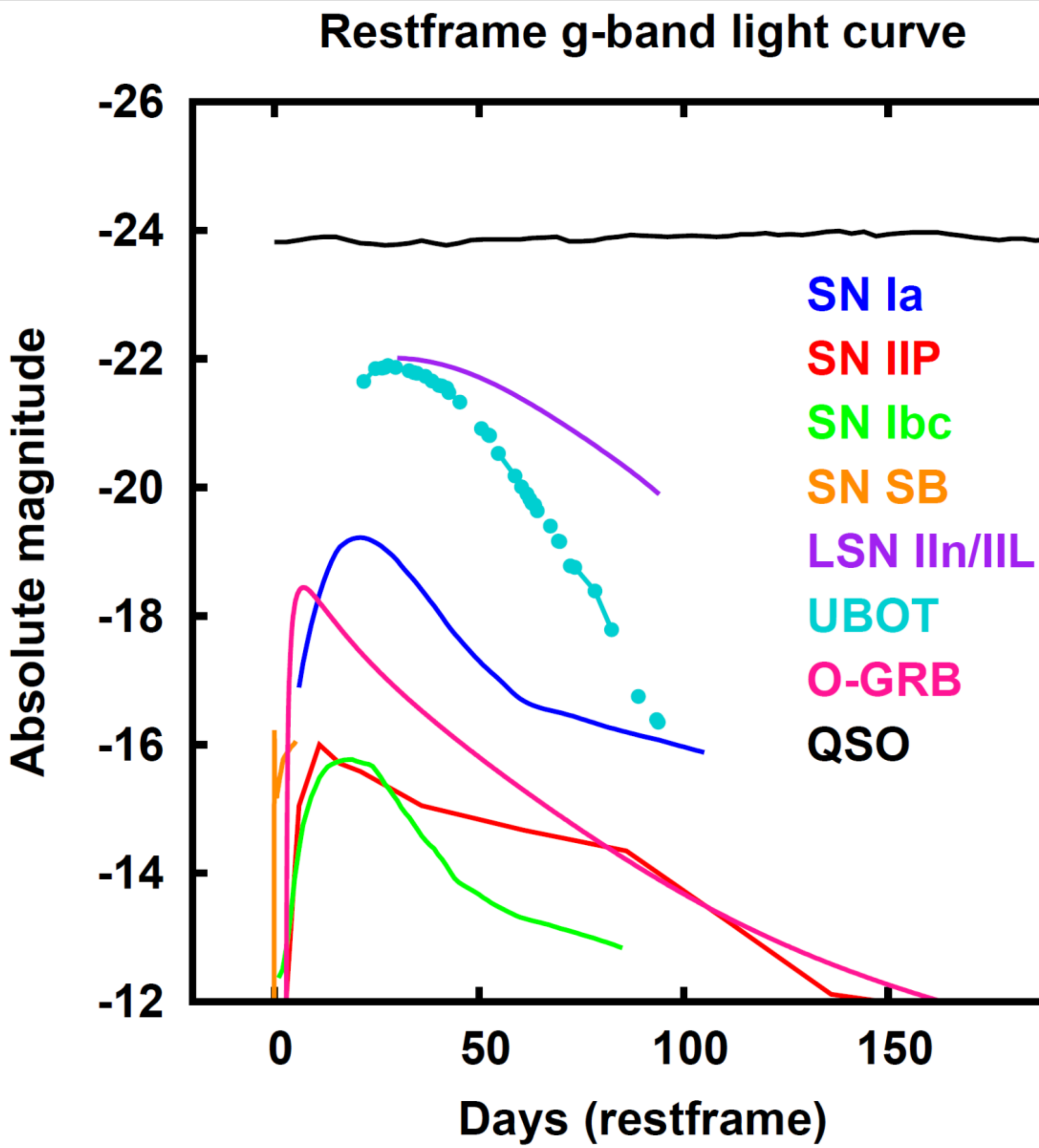
Multicolor observations in blue bands with ~hour intervals are essential to detect and identify shock breakout.

HSC transient survey

Tomoki Morokuma (Tokyo), Naoki Yasuda (Kavli IPMU), Yuji Urata (NCU, Taiwan), Kuiyun Huang (ASIAA), Masaomi Tanaka (NAOJ), Jun E. Okumura (Kyoto), Tomonori Totani (Kyoto), Nozomu Tominaga (Konan), Takashi J. Moriya (Kavli IPMU), Robert Quimby (Tokyo/Kavli IPMU), Keiichi Maeda (Kavli IPMU), Shigehiro Nagataki (Kyoto), Ching-Hsuan Shen (NCU, Taiwan), Cheng-Hsien Tang (NCU, Taiwan), Meng-Feng Tsai (NCU, Taiwan), Min-Feng Wang (NCU, Taiwan), Naoki Yoshida (Tokyo)

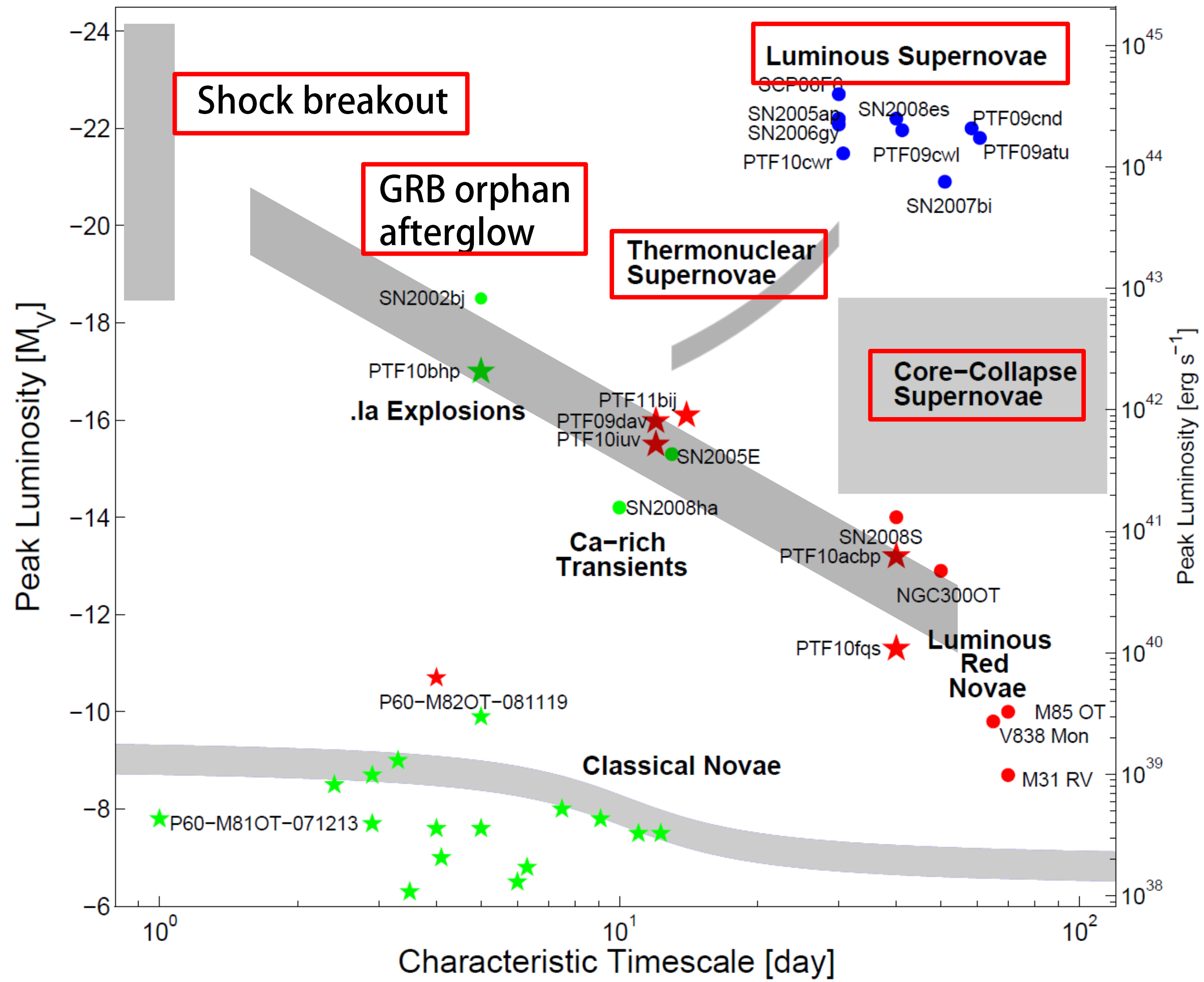
Objectives

- Type Ia SN
- Core-Collapse SN
- Shock Breakout
- Type IIn/IIL LSN
- Type Ic LSN
- GRB Orphan Afterglow
- QSO



Time scales

day ⟷ year



Kasliwal 11

Cadence requirements

- τ~day → in a night and/or in a month
  - SN shock breakout
  - solar system, [weak lensing (i): >10-30min]
- τ~month → in a month and in 2-4 months
  - SN Ia, core-collapse SN, GRB orphan afterglow
  - AGN
- τ~1-several year(s) → in 5 years
  - Super Luminous SN
  - AGN

Survey strategy

led by Nishizawa-san, Yasuda-san, Tominaga

- Dynamic scheduling is compatible with transient studies to balance completeness and maintain cadence in the multi bands.
- Satisfactions of cadence requirements have small disadvantage in completeness and dead time. (preliminary)
  - Wide: daily/monthly schedule for WL, shock breakout, solar system, AGN
  - Deep/UD: 1 intensive year for SNe Ia, CCSNe & continuous obs. over 5 years for SLSNe

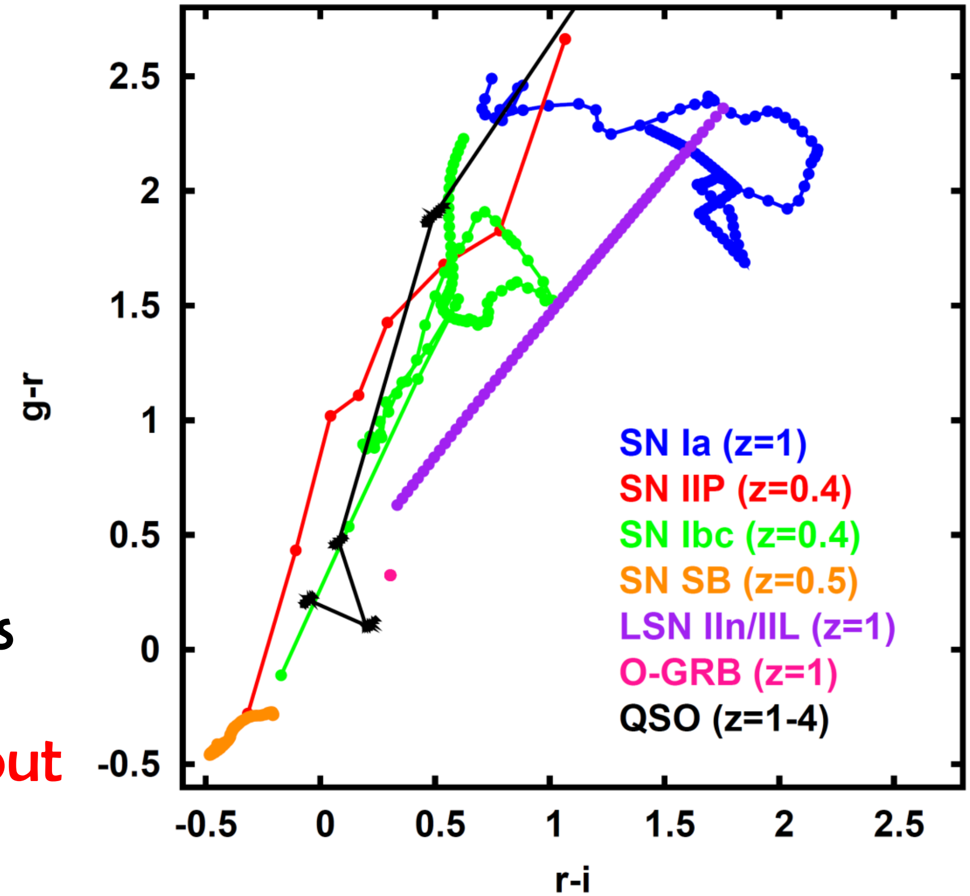
Transient finding & classification

led by Tanaka-san, Urata-san

- **Finding methods**
  - Catalog finding
  - Image subtraction
- **Classification**
  - Color (evolution) & multicolor light curves
  - Photometric/ spectroscopic redshift

⇨ Follow-up observations

Challenging for shock breakout

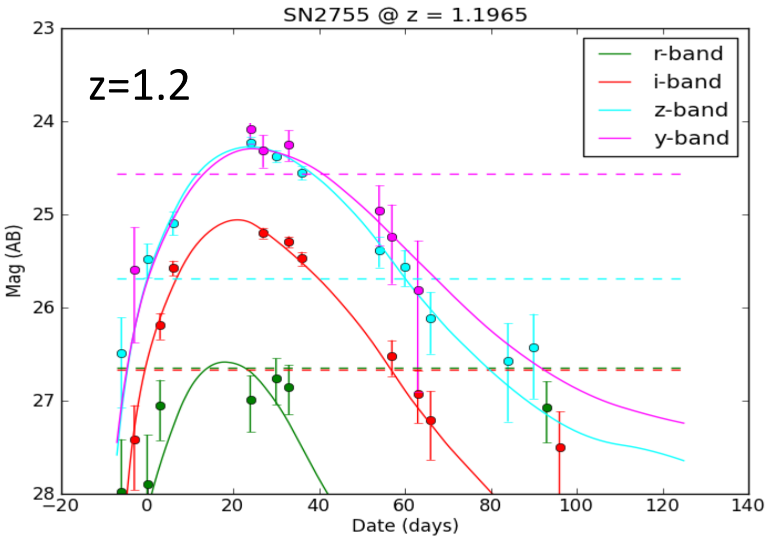


Science cases
with HSC-transient survey

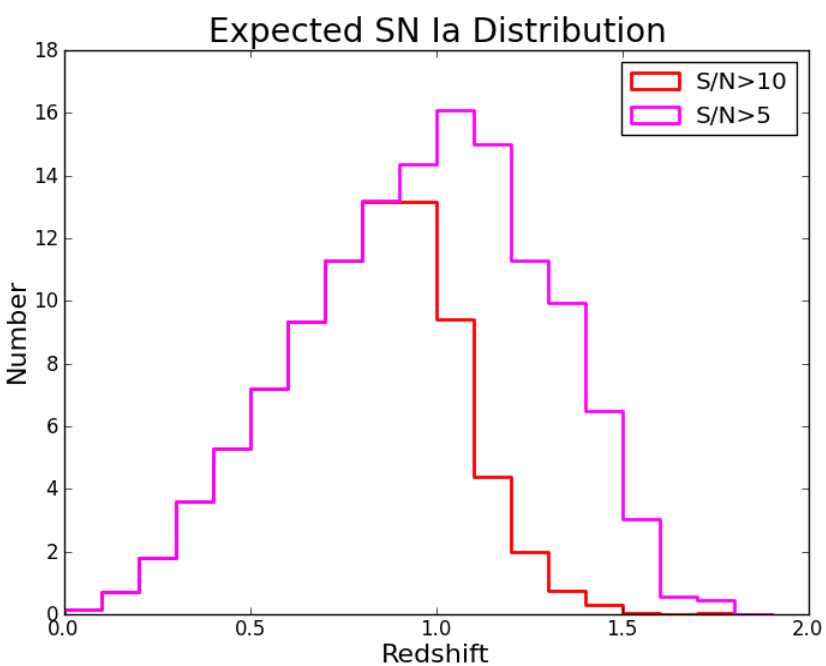
Type Ia SNe

(deep)/UD

led by Yasuda-san, Okumura-san



- SDSS: 0.05 < z < 0.4
- SNLS: 0.3 < z < 1.0
- HST: z > 1.0
- DES: 0.3 < z < 1.0
  - ~5000 SN Ia



SN Ia @ z > 1 is still small number.

HSC-UD survey

~130 SN (~60 at z > 1) for S/N>5

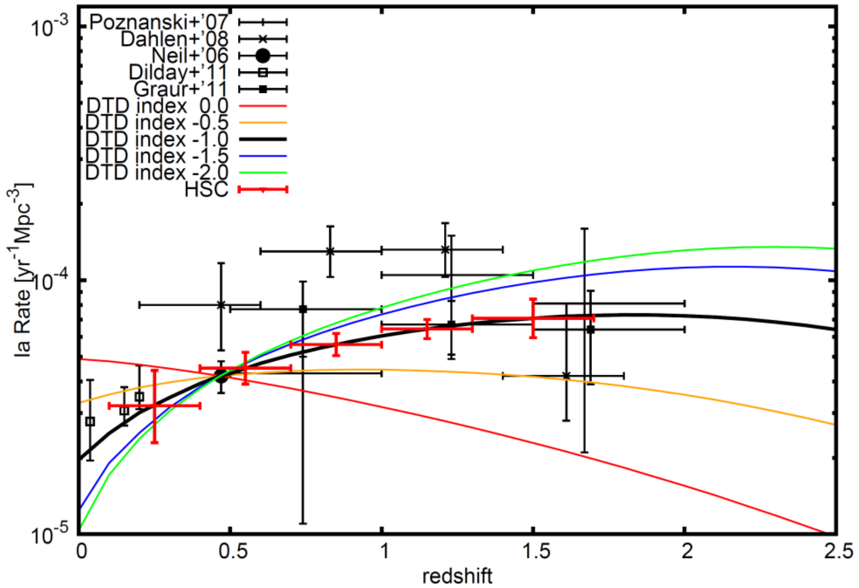
~80 SN (~20 at z > 1) for S/N>10

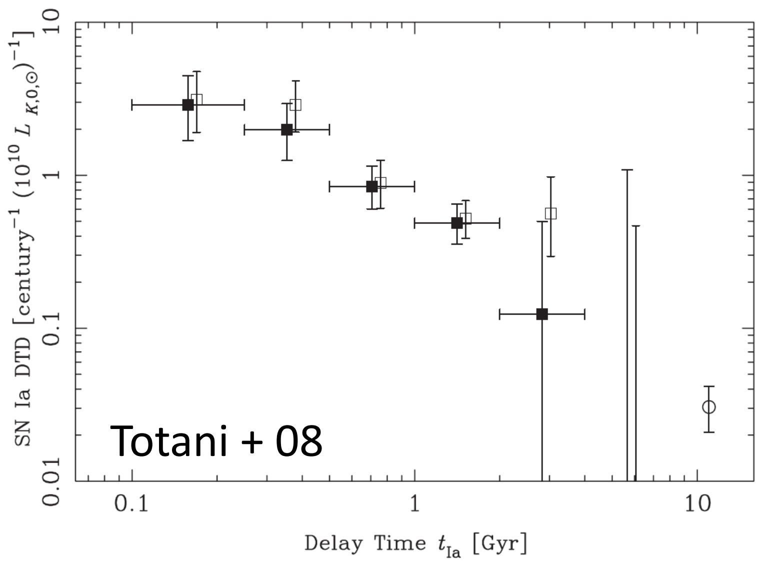
(3 bands detection)

Type Ia SNe -rate-

led by Okumura-san

- SN Ia rate density
  - Most accurate SN Ia rate upto z~1.5
  - constrain delay time distribution
- Delay time distribution
  - delay time between star formation and SNe Ia
  - constrain progenitor system



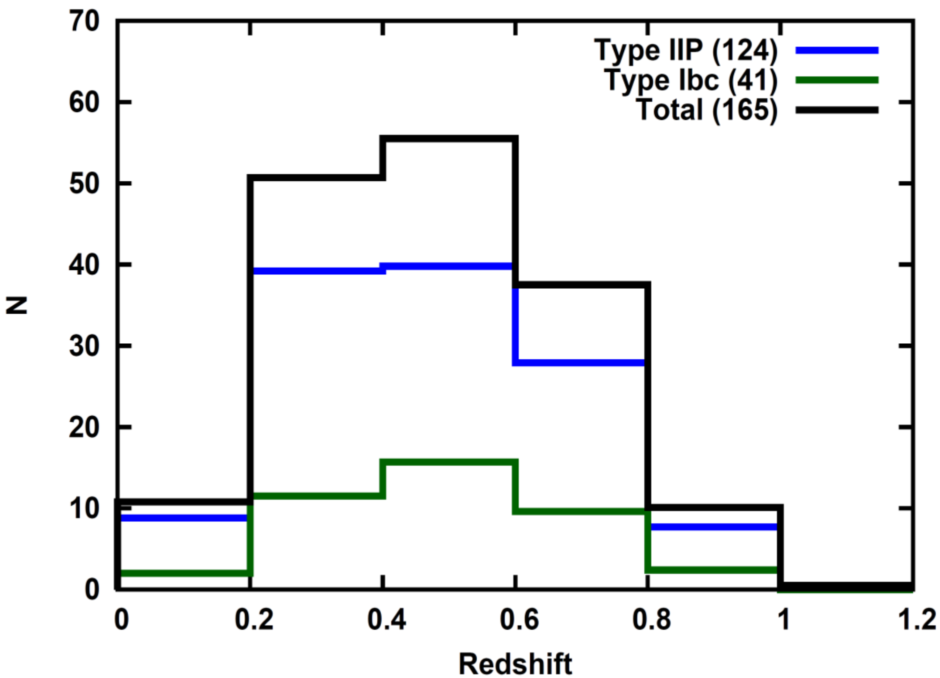


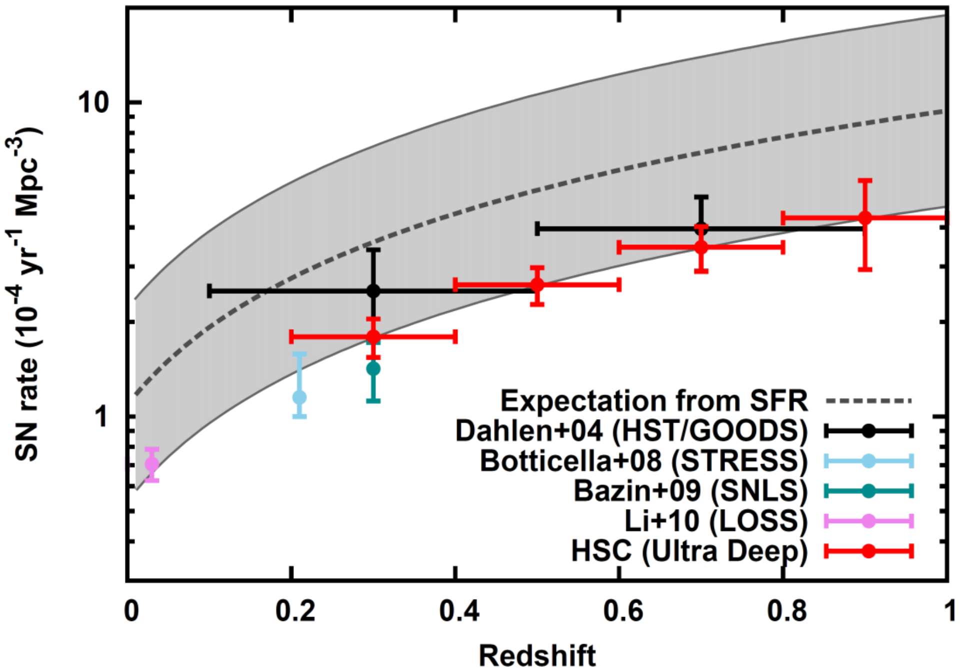
Core-collapse SNe

(deep)/UD

led by Tanaka-san

- Available for free with SNe Ia cadence





Survey	Tel.	Redshift	# of SNe
SNLS	CFHT	~0.3	120
GOODS	HST	0.1−1.3	45
HSC-UD	Subaru	0.2−1.0	~165

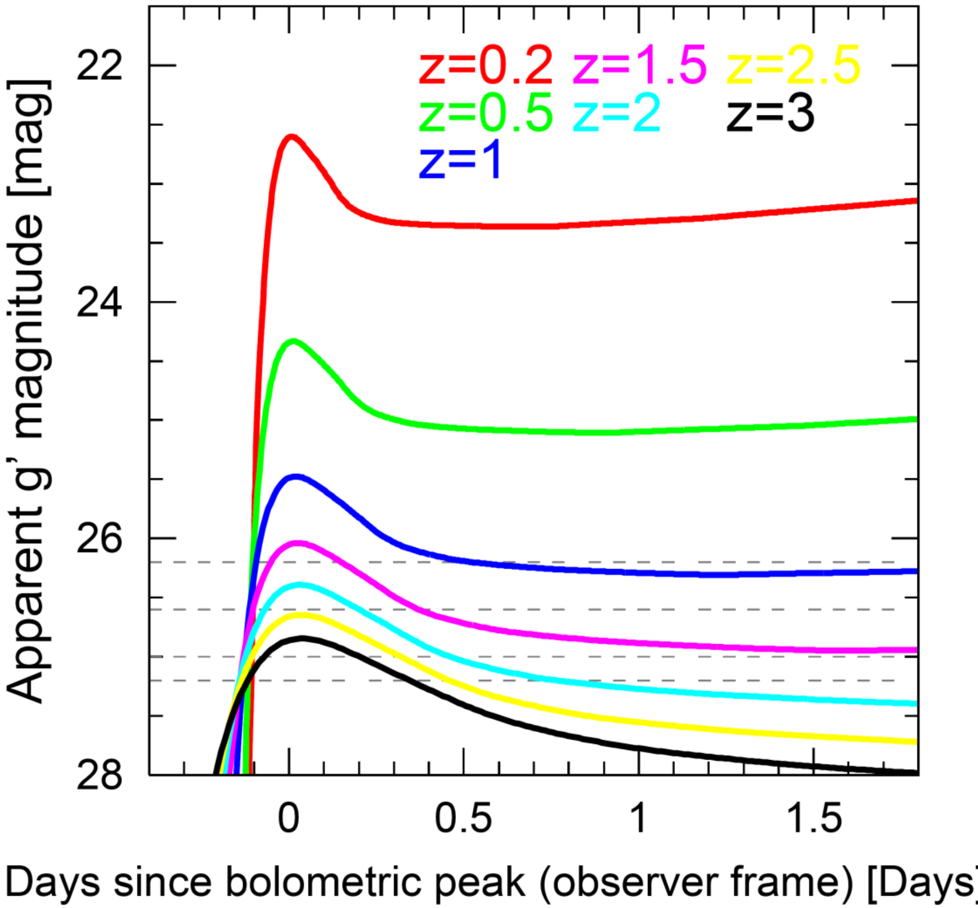
wide/deep/UD

Shock breakout

led by Tominaga, Morokuma-san

- Brightest phenomenon (normal SNe @z~3)
- >3 g- and >1 r-bands obs. in 1 night
- Discovery channel
  - only 3 events
  - no opt. obs.

	Num.SNe (1st year)	Num. SNe	Redshift 50%	Redshift 10%
Wide	19	96	$\gtrsim$0.5	$\gtrsim$0.9
Deep	9	52	$\gtrsim$0.6	$\gtrsim$1.4
UD	2	14	$\gtrsim$0.8	$\gtrsim$1.7

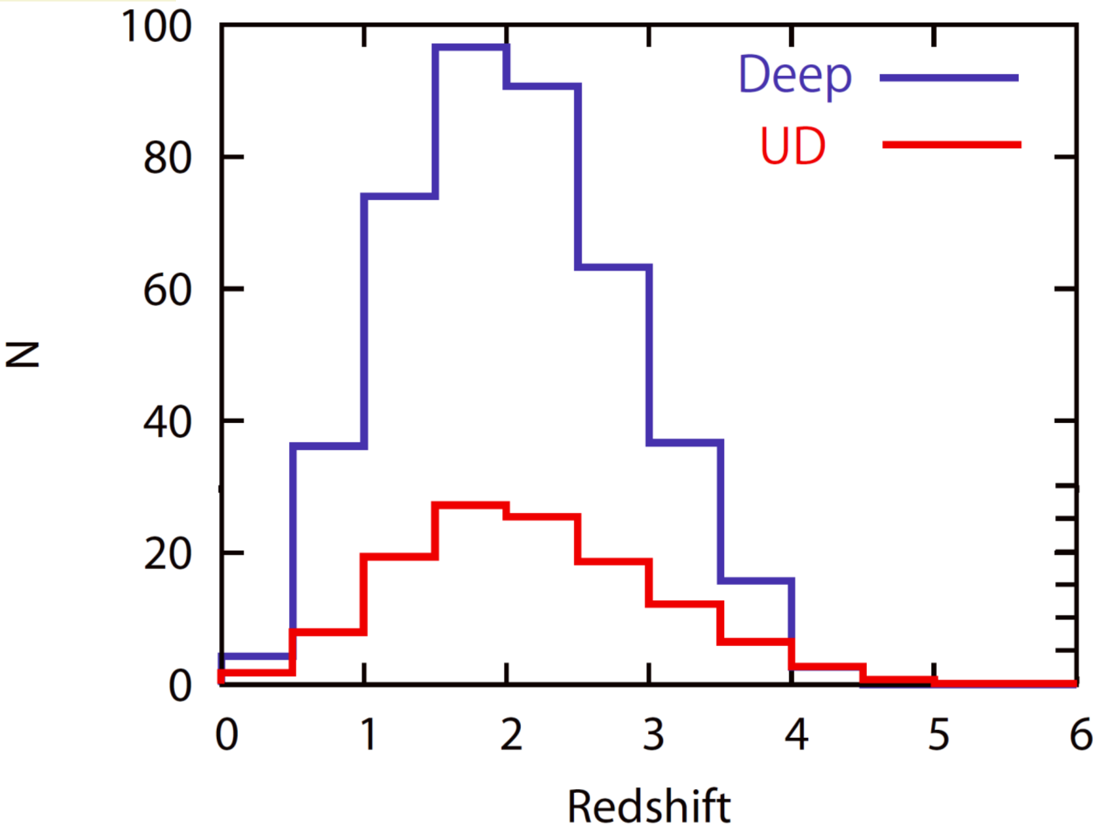


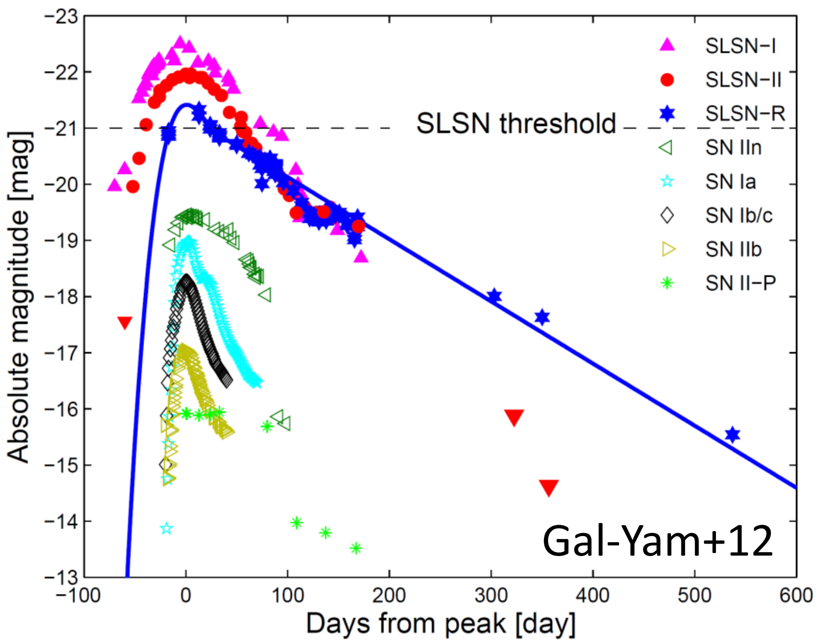
deep/UD

Super Luminous Supernova

led by Moriya-san, Urata-san, Quimby-san

- Rare extremely bright SNe
- CCSN detection @ z~4

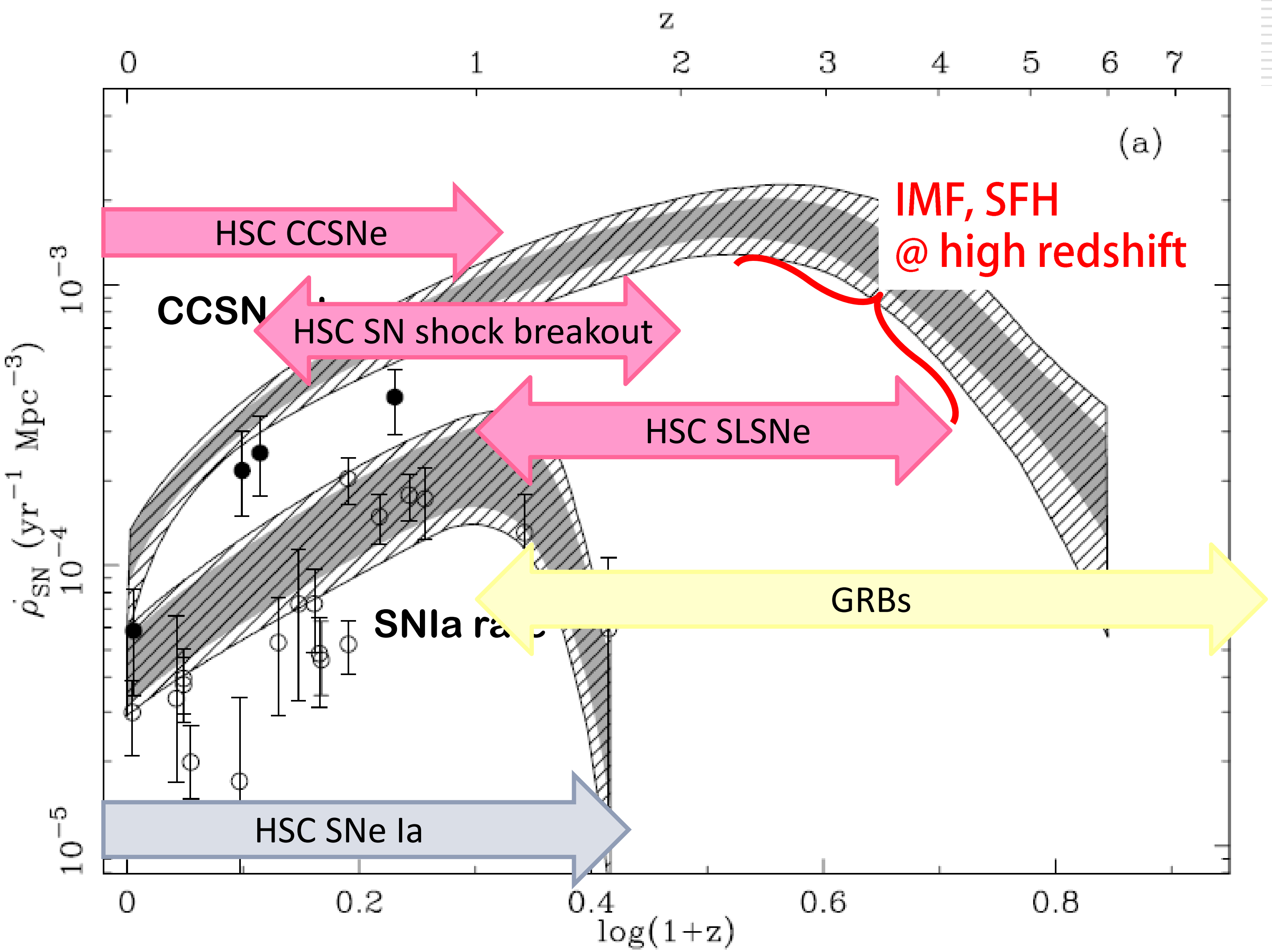




<u>Slow follow-up obs.</u>

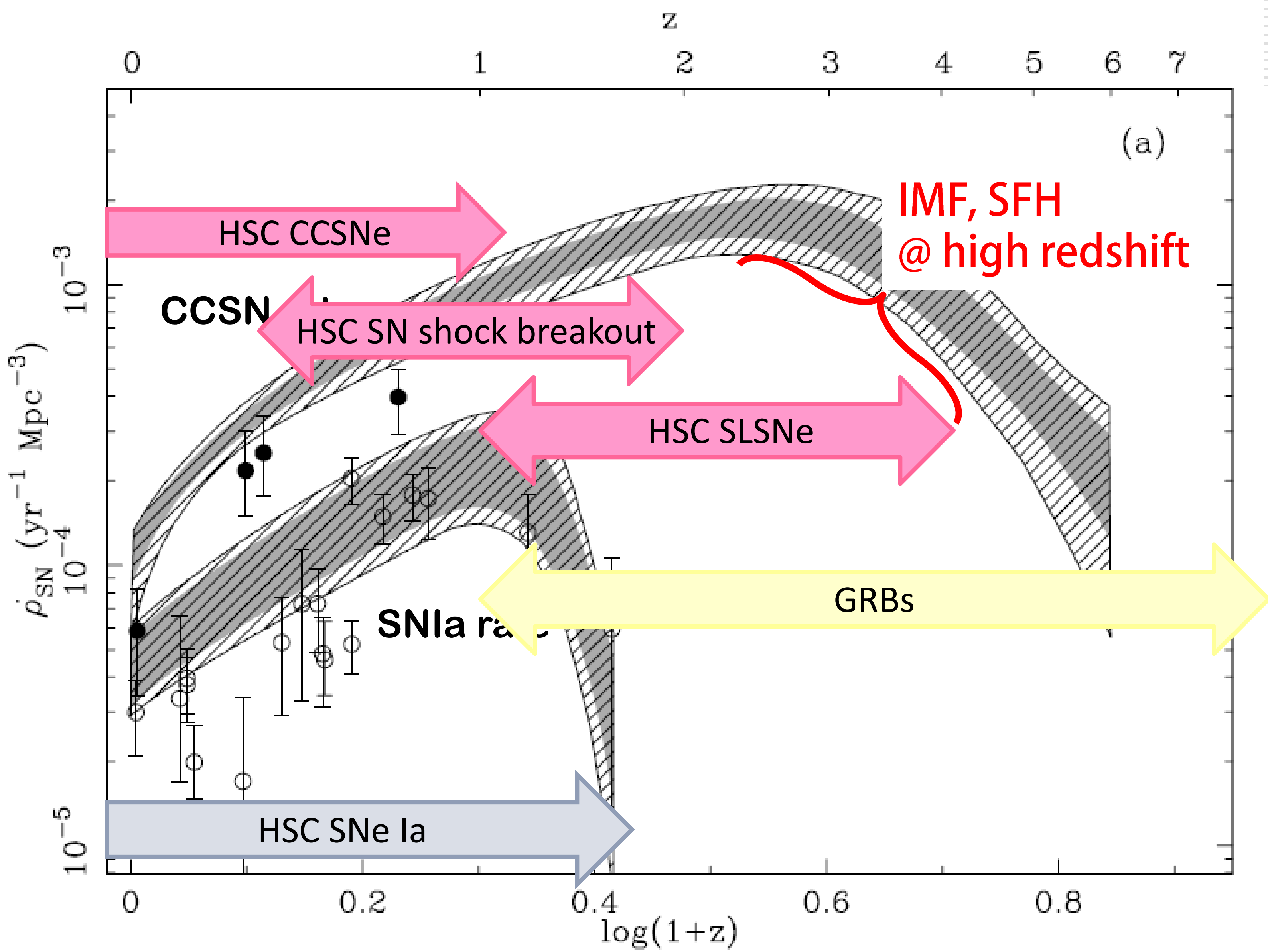
1-month stacked data

SN rate history



Hopkins & Beacom 06 and references therein

Distance ladder in SNe



Hopkins & Beacom 06 and references therein

Summary

- Shock breakout is the most promising phenomenon to detect high-z normal CCSNe.
- Nearby optical survey (KISS) started.
  - detailed study (spectroscopy, long-term evolution)
- High-z optical survey w/ Subaru will start.
  - ~5 shock breakout/night (10% at $z>2.3$)
  - identified by short timescale and blue color
- Many SN science cases are available with HSC-wide/deep/UD.
  - Distance ladder in SNe upto $z\sim4$ connecting to GRBs