

# **Supernova shock breakout and high-redshift supernova surveys**

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**(Konan University)**



12<sup>th</sup> Dec 2012

Kavli IPMU focus week for supernovae near and far

# Contents

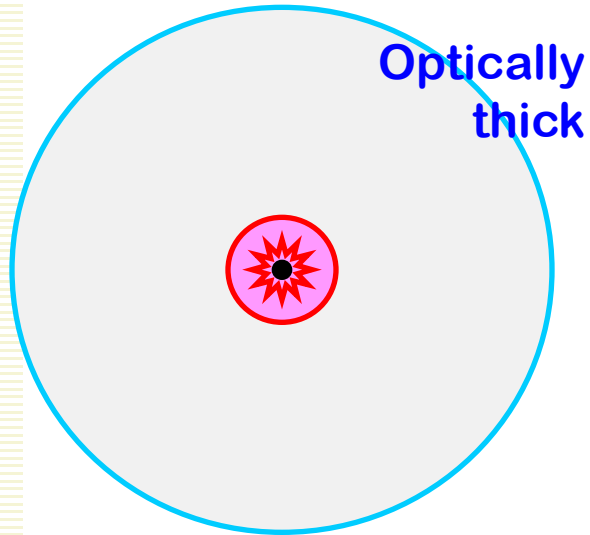
- **Shock breakout**
  - What is shock breakout?
  - Observation and theoretical model
  - Optical surveys
- **HSC transient survey**
  - Strategy
  - Science cases

# Shock breakout

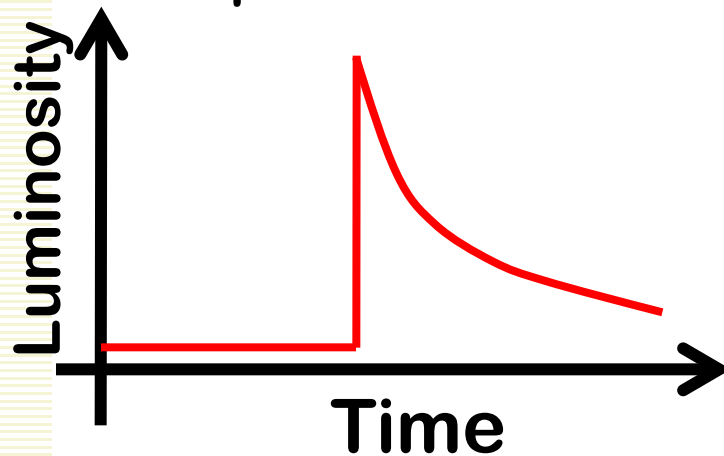
NT, Blinnikov, Baklanov, + 2009 ApJ 705 L10

NT, Morokuma, Blinnikov, + 2011 ApJS 193 20

# What is shock breakout?



Core collapse



Massive Star ( $>10M_{\odot}$ )

e<sup>-</sup>-capture SNe ( $8-10M_{\odot}$ )

Core collapse

Shock formation



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

Spectra are quasi-blackbody

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

Typical properties

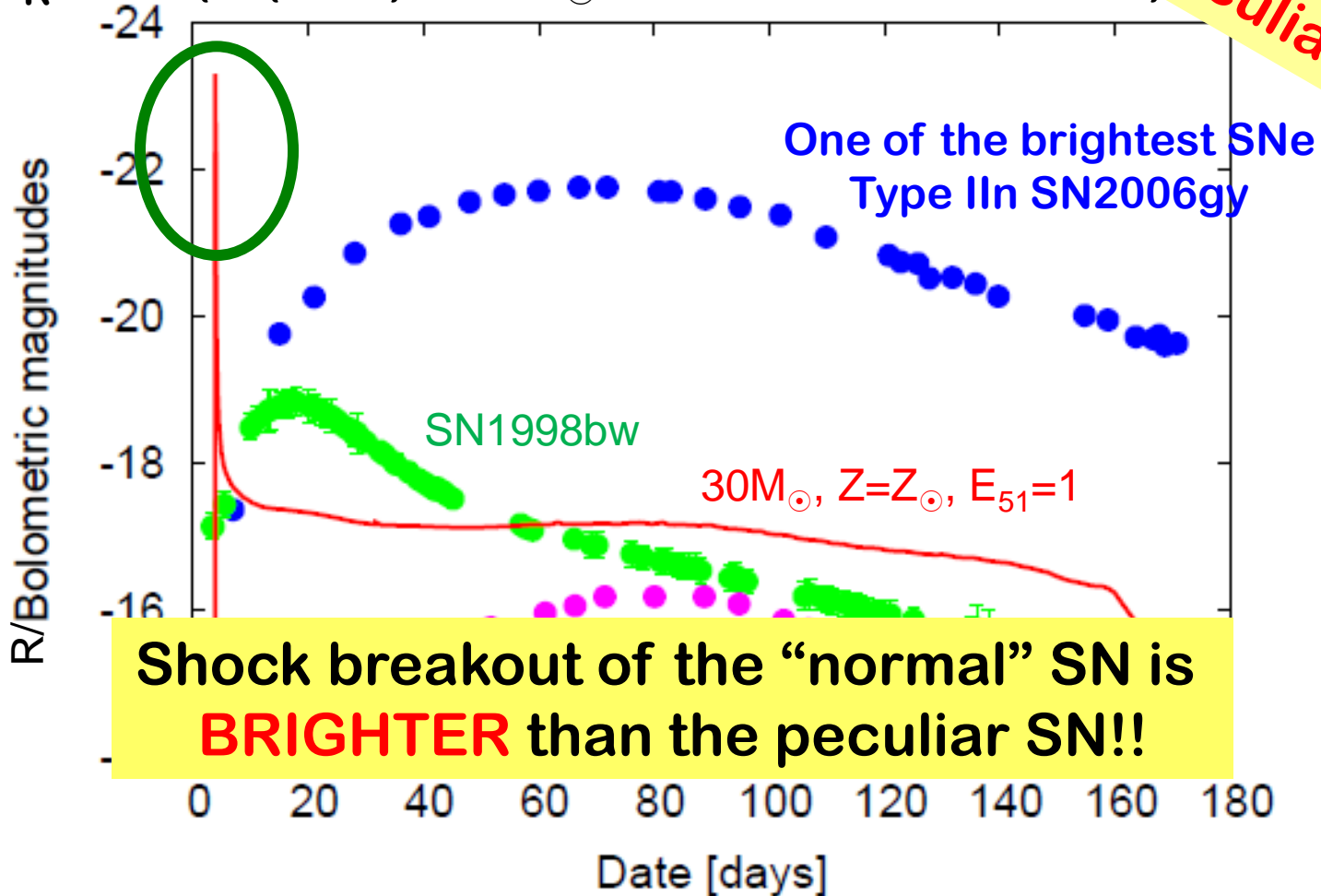
timescale: 100sec ~ 1day

peak wavelength: X-ray ~ UV

# Shock breakout is **bright!**

- SN 2006gy (z=0.02: Smith + 08; Kawabata, ..., 2009)
  - $M_R \sim -22$  ( $M(^{56}\text{Ni}) \sim 15M_\odot$  or CSM interaction)

This is a "peculiar" SN.



# Shock breakout of Type IIP SNe

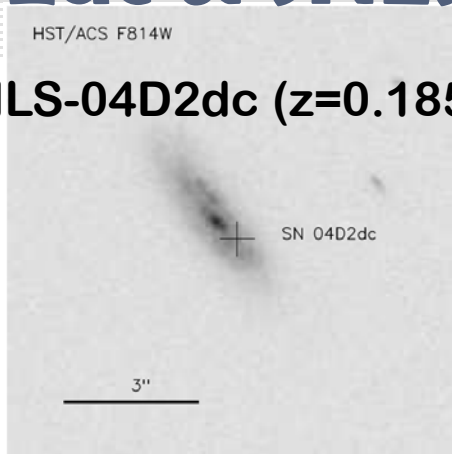
## -SNLS-04D2dc & SNLS-06D1jd-

**SNLS** SuperNova Legacy Survey

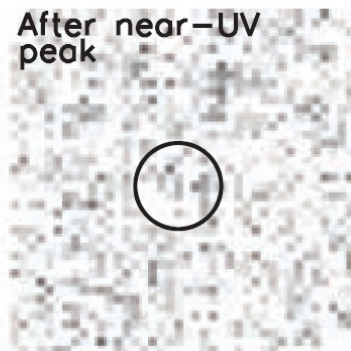
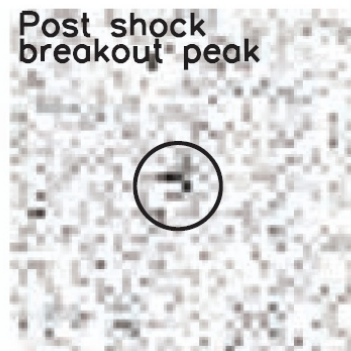
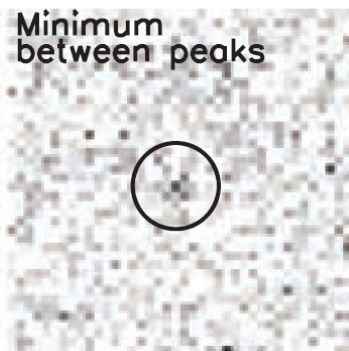
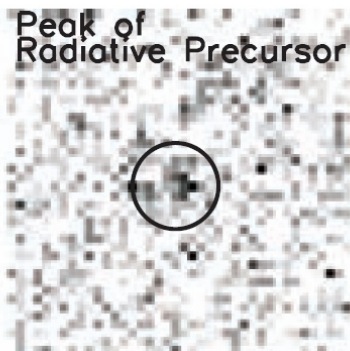
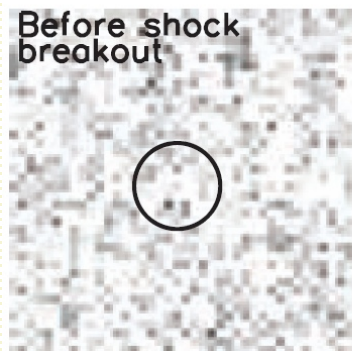
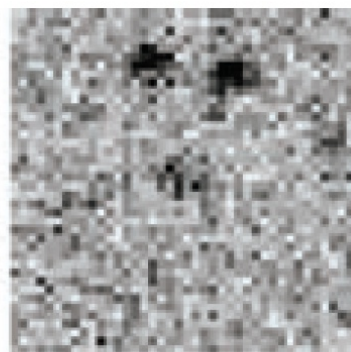
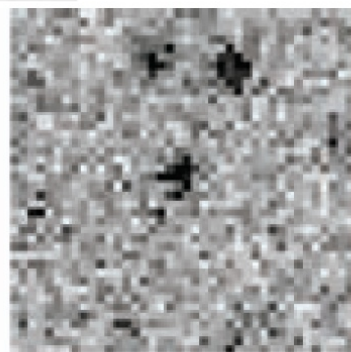
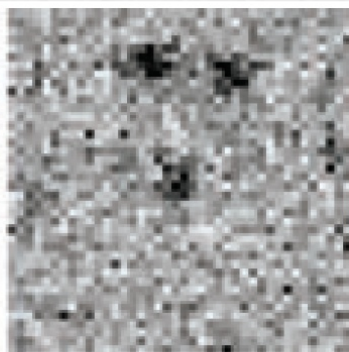
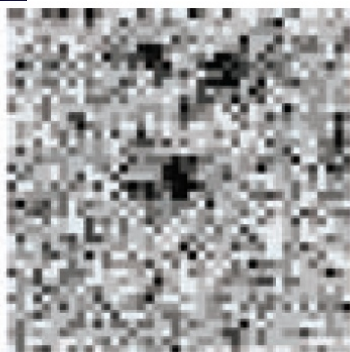
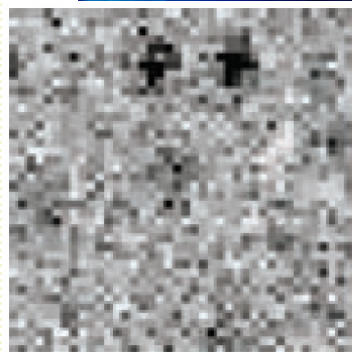


HST/ACS F814W

SNLS-04D2dc ( $z=0.1854$ )



Schawinski et al. 08  
Gezari et al. 08

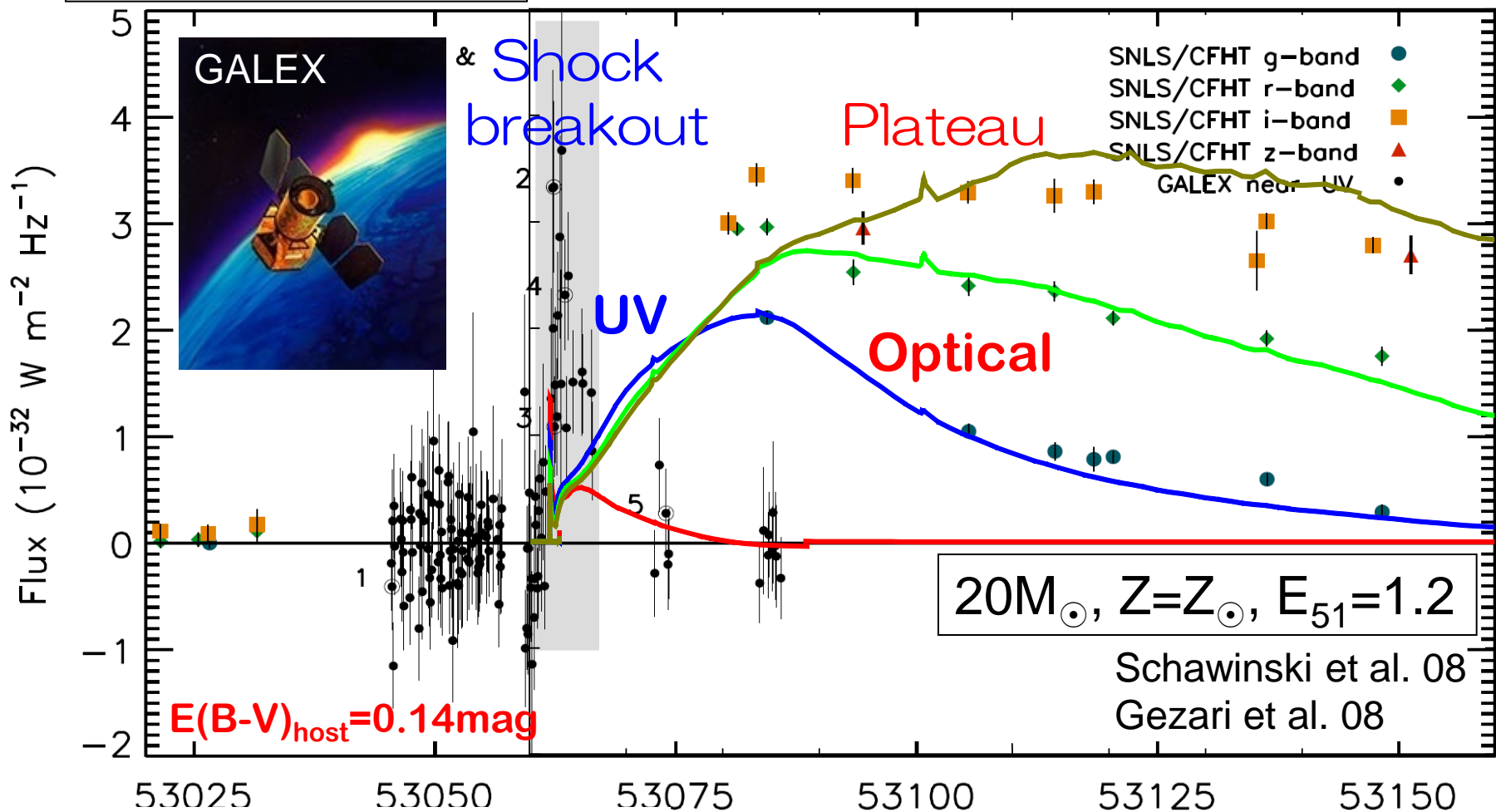


# Shock breakout of Type IIP SN

## — Observations and model —

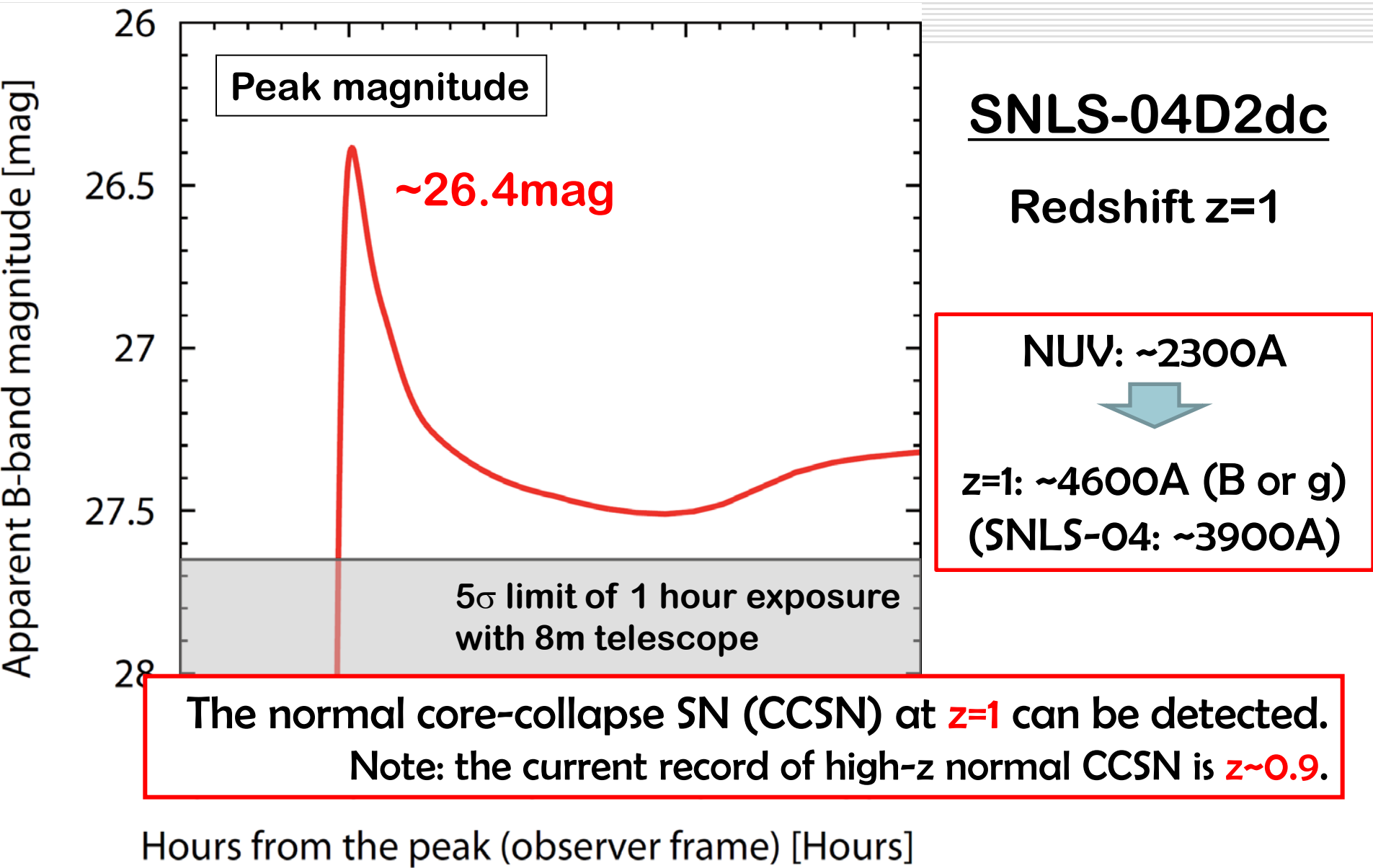
SNLS-04D2dc

SNLS SuperNova Legacy Survey



NT + 09 (STELLA: Blinnikov+98) Iian Date (observed frame)

# When the same SN takes place at $z=1$ ,





# Two optical surveys of shock breakout

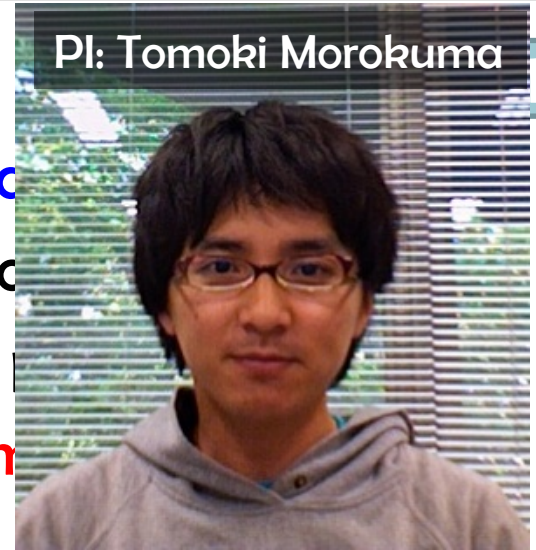
- Nearby shock breakout survey

- Aim: detailed investigation of shock breakout  
follow-up spectroscopy, multicolor observations of plateau and tail
- Kiso Supernova Survey (KISS) from

- 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

PI: Tomoki Morokuma

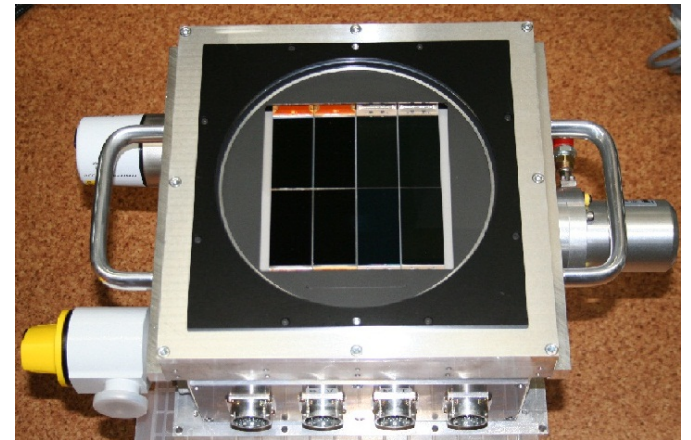
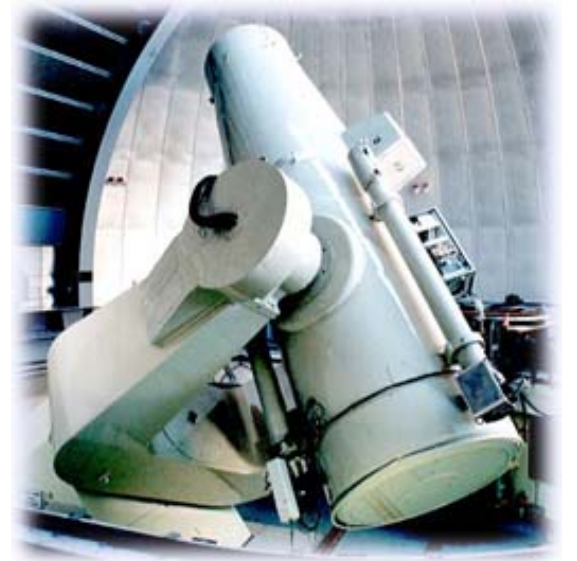


# Nearby shock breakout survey with Kiso Schmidt telescope

- Kiso Wide-Field Camera (KWFC)

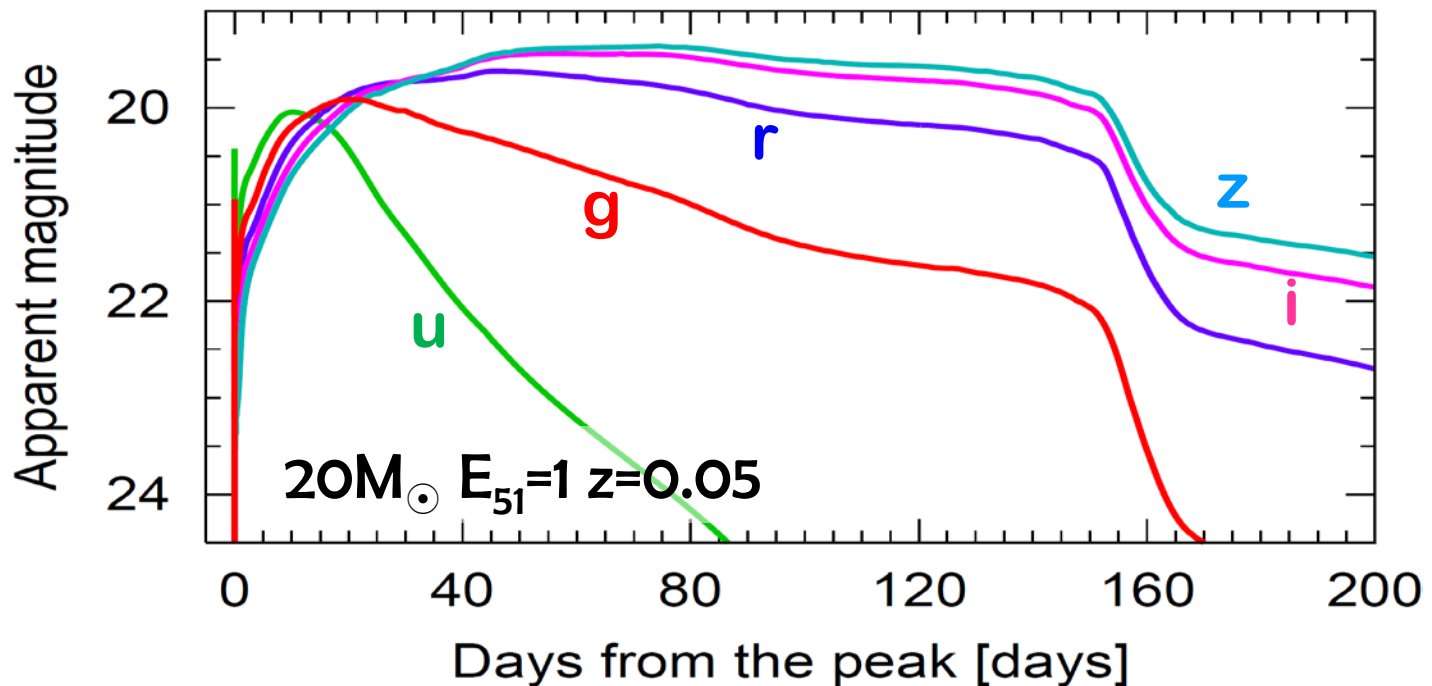
from Apr 2012

- Diameter: 1.05m FoV: **4deg<sup>2</sup>**
- $m_{\text{lim}} (10\sigma)$  w/ 15min: 22.1(g)



# Kiso Supernova Survey (KISS)

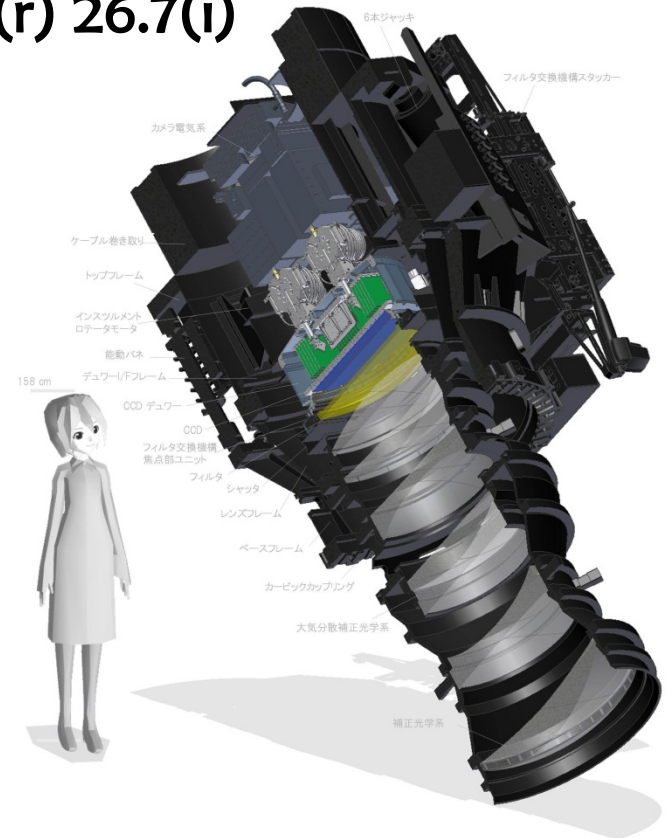
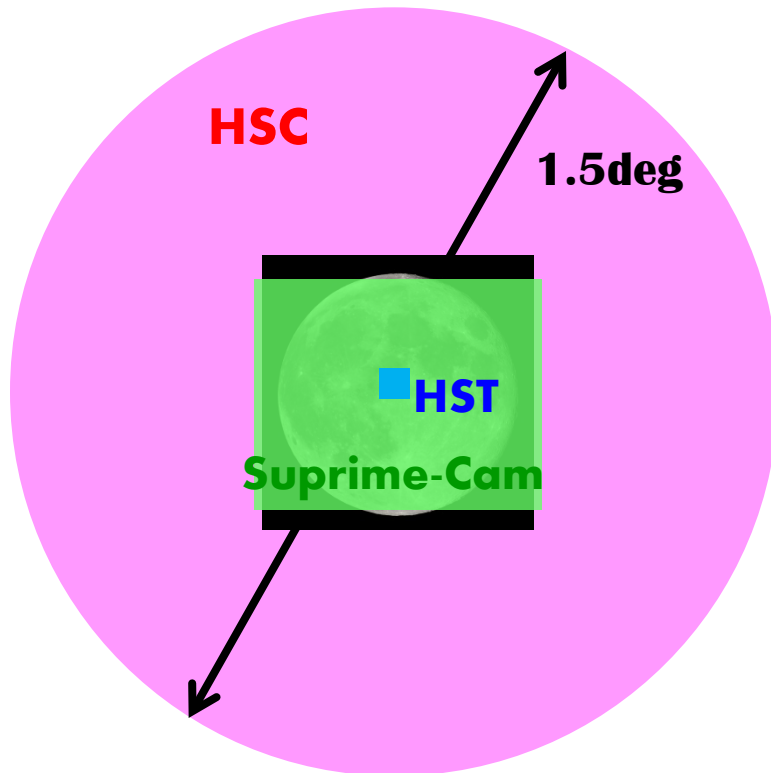
- observes SDSS fields in g band
- 3min exposure ( $m_{\text{lim}} \sim 21\text{mag}$ ) with  $\sim 1\text{hr}$  interval
- $\sim 3$  shock breakout in the 3 year project
- $m_{\text{plateau}} \sim 20\text{mag}$ ,  $m_{\text{tail}} \sim 22\text{mag}$   $\rightarrow$  follow-up obs.



# High-*z* shock breakout survey with Subaru telescope

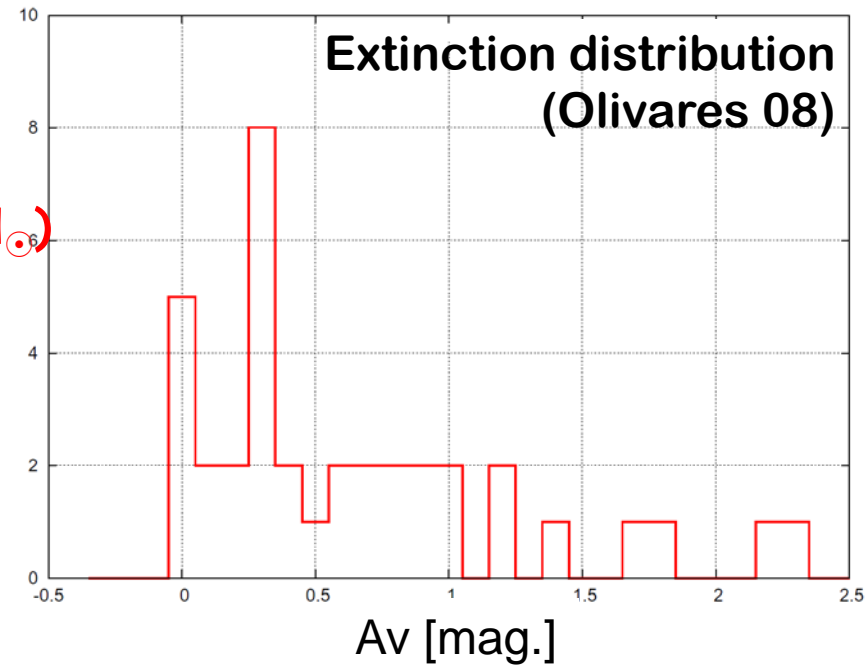
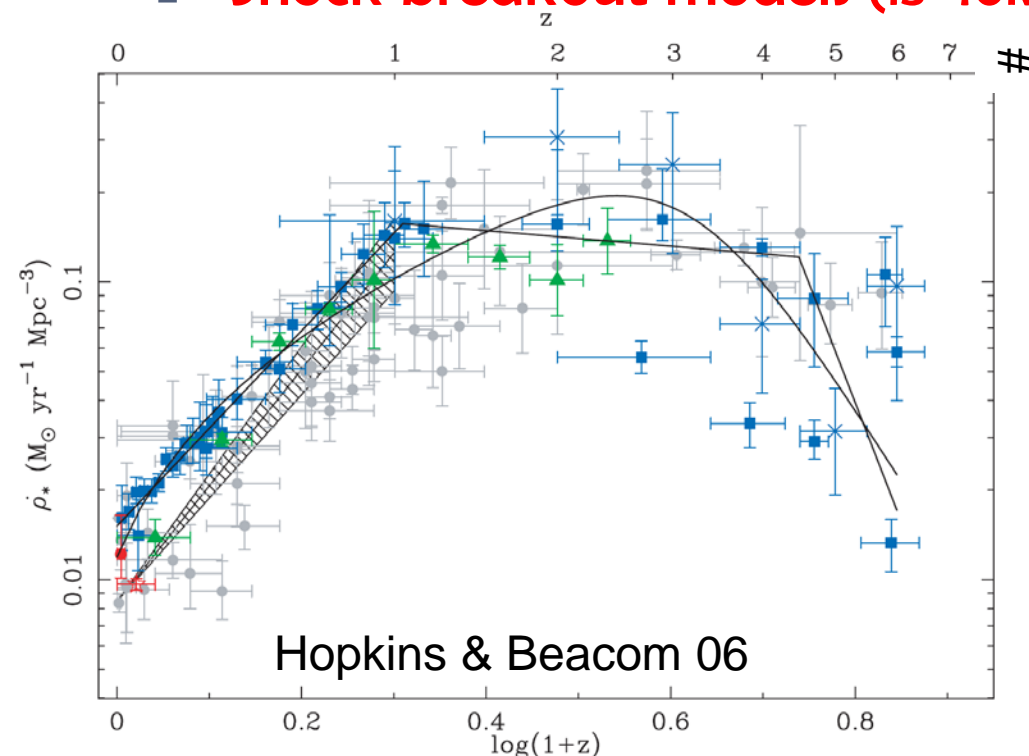
- Hyper Suprime-Cam (HSC)
  - Diameter: 8.2m, FoV: **1.77deg<sup>2</sup>**
  - $m_{\text{lim}} (5\sigma)$  w/ 1hr: 27.5(g) 27.2(r) 26.7(i)

from Aug 2013



# Theoretical expectation

- Cosmic star formation history (Hopkins & Beacom 2006)
- Distribution of host galaxy extinction (Olivares 08)
- IGM absorption (Madau 95)
- Salpeter's IMF
- Shock breakout models (13-40M<sub>⊙</sub>)

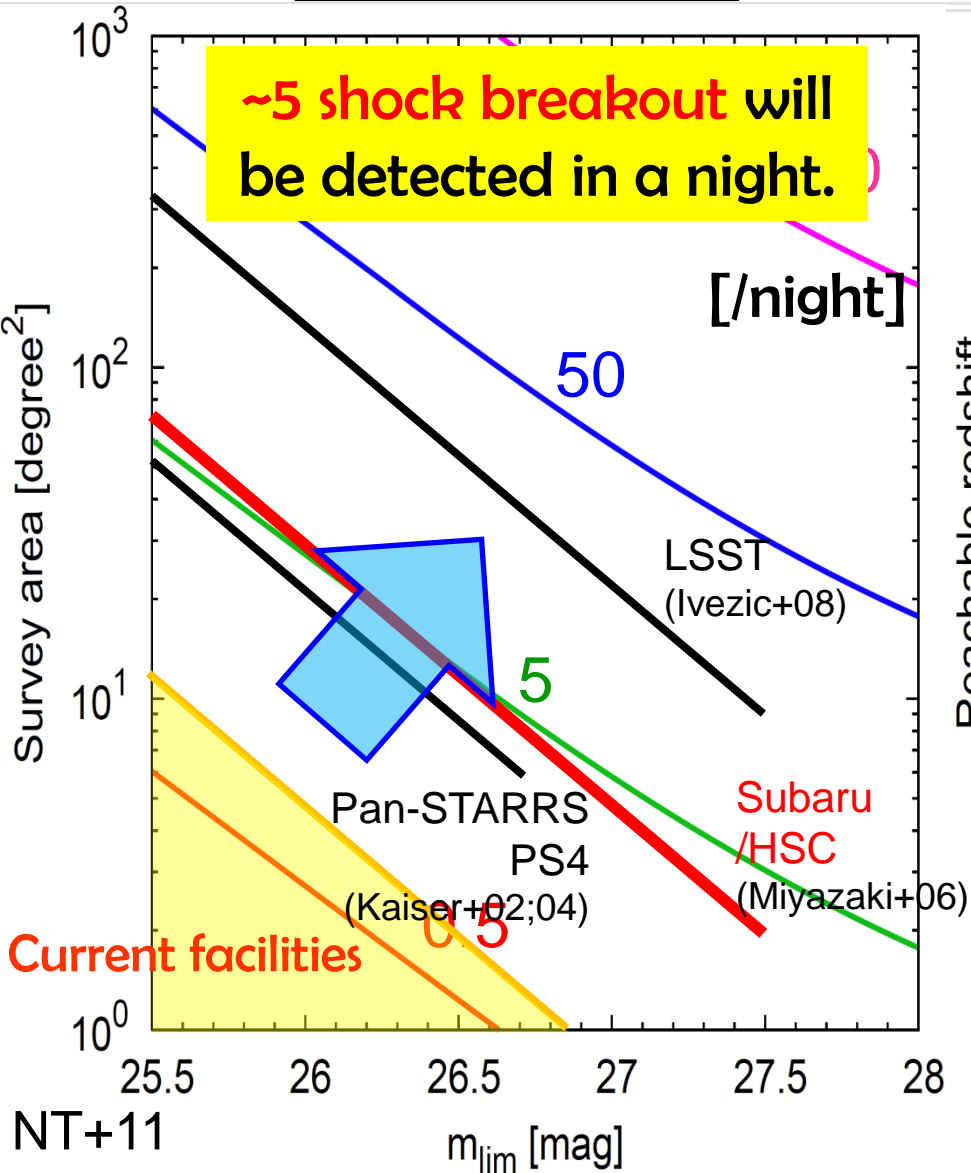


gray: Hopkins (2004)  
Hatched region & green: FIR (24 mm)  
red: radio (1.4 GHz) & H estimate  
blue: UV & UDF

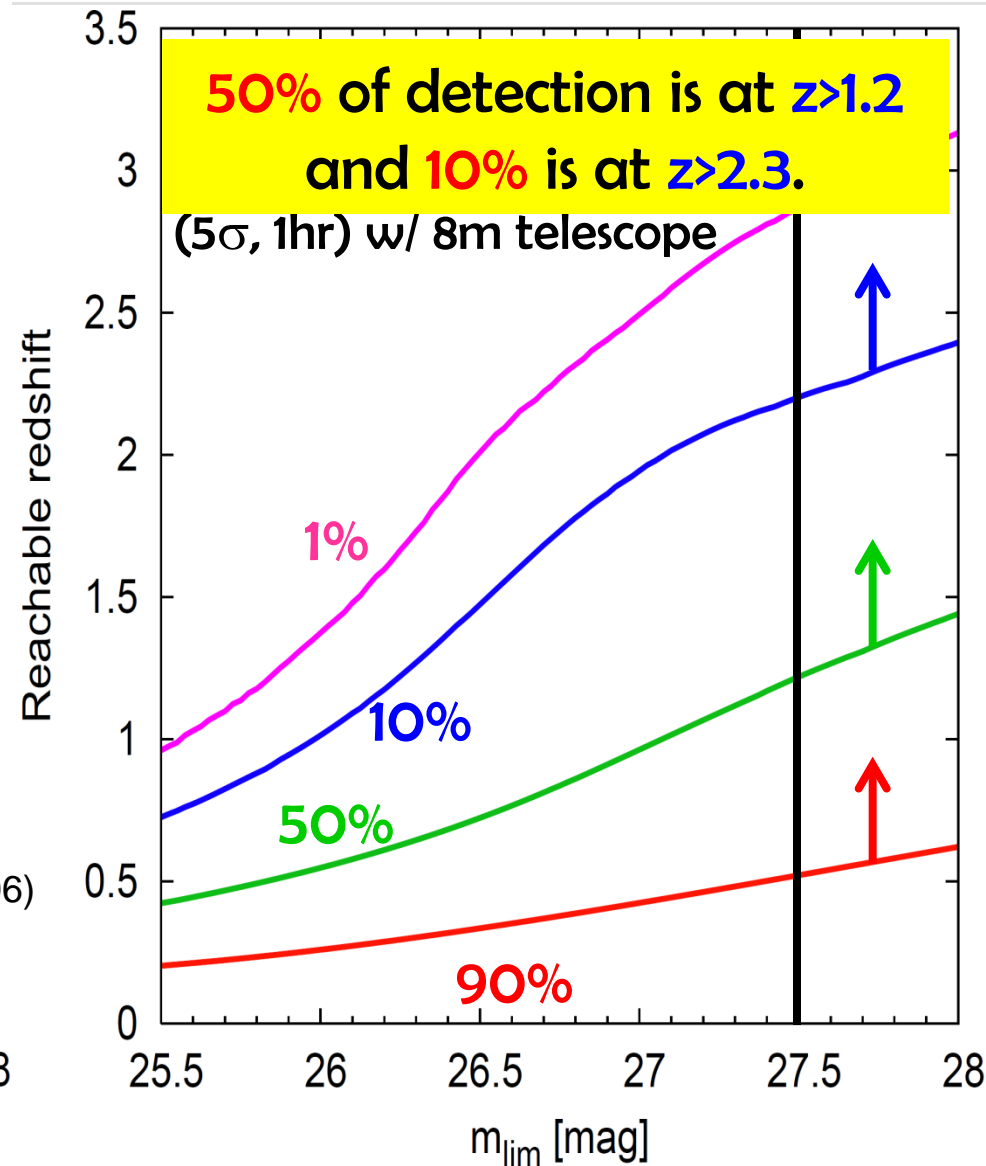


# Theoretical expectation

## Detection rate

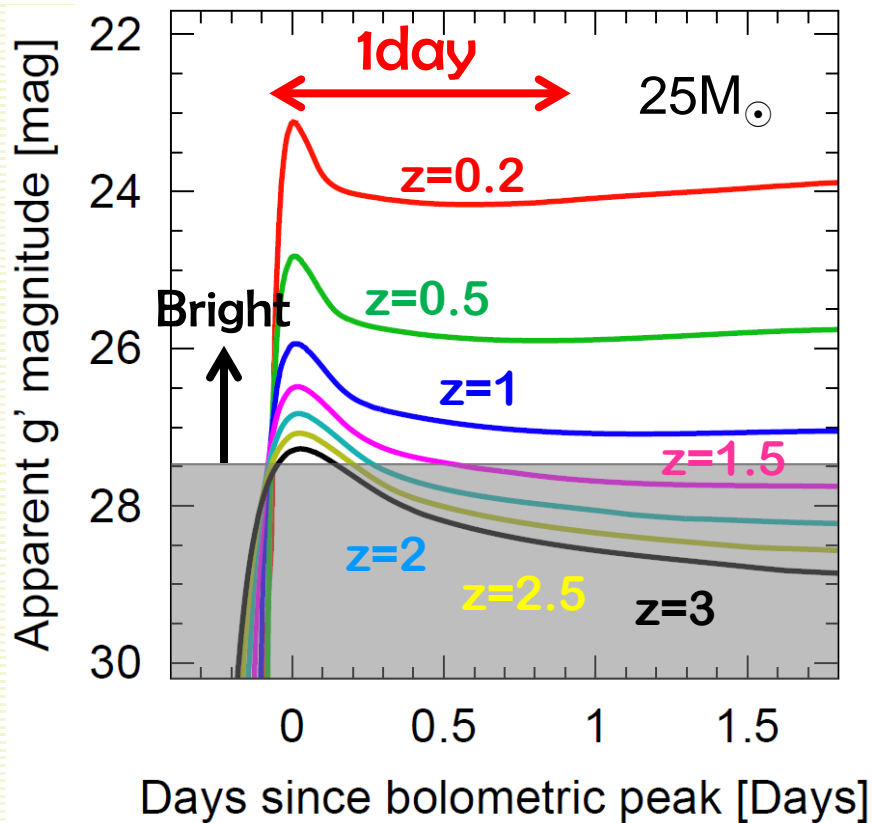


## Redshift distribution

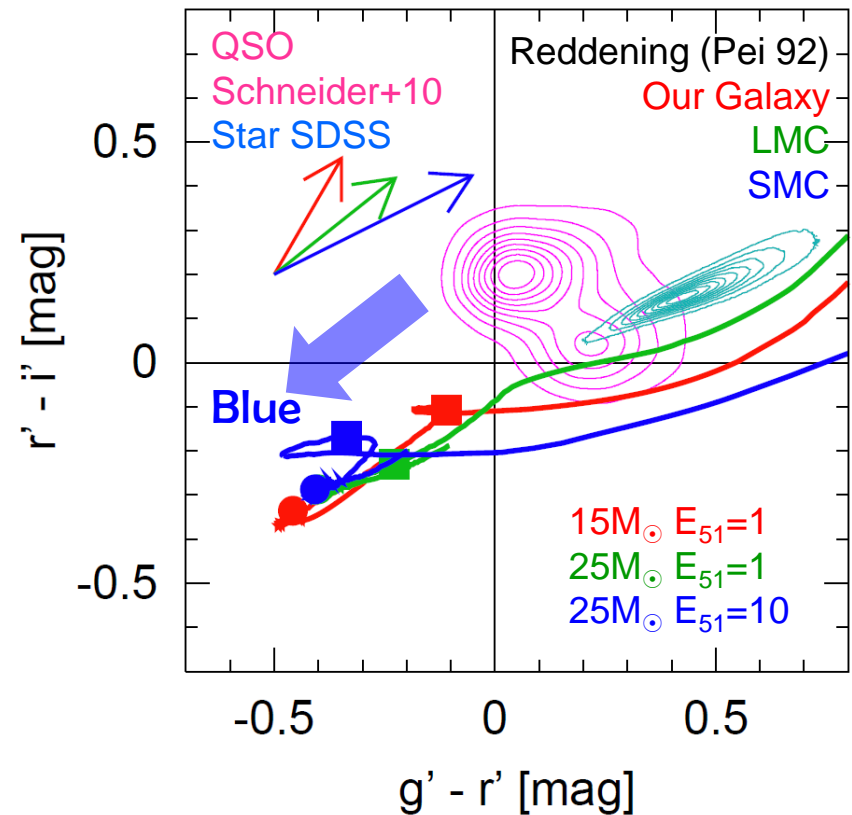


# How to identify them from LCs?

## Short time scale



## Blue color



**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)



# HSC survey

- **Primary science**
  - Weak lensing
  - Galaxy evolution
- **300nights/5yrs**
- **3 layers**
  - Wide, Deep, Ultradeep

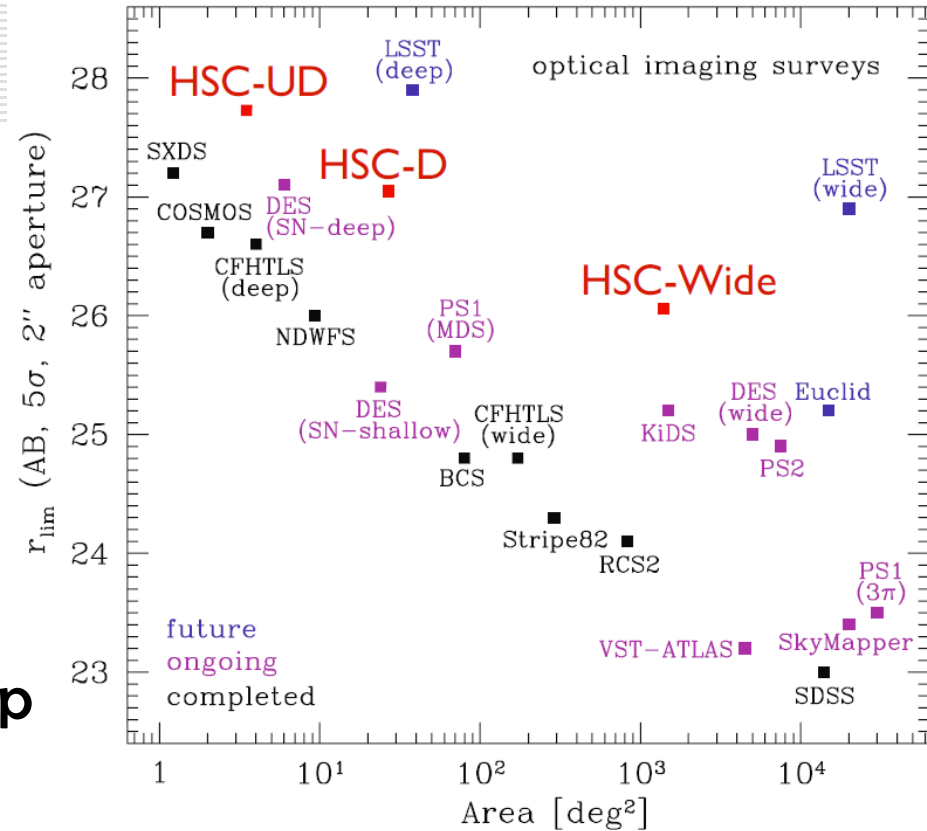
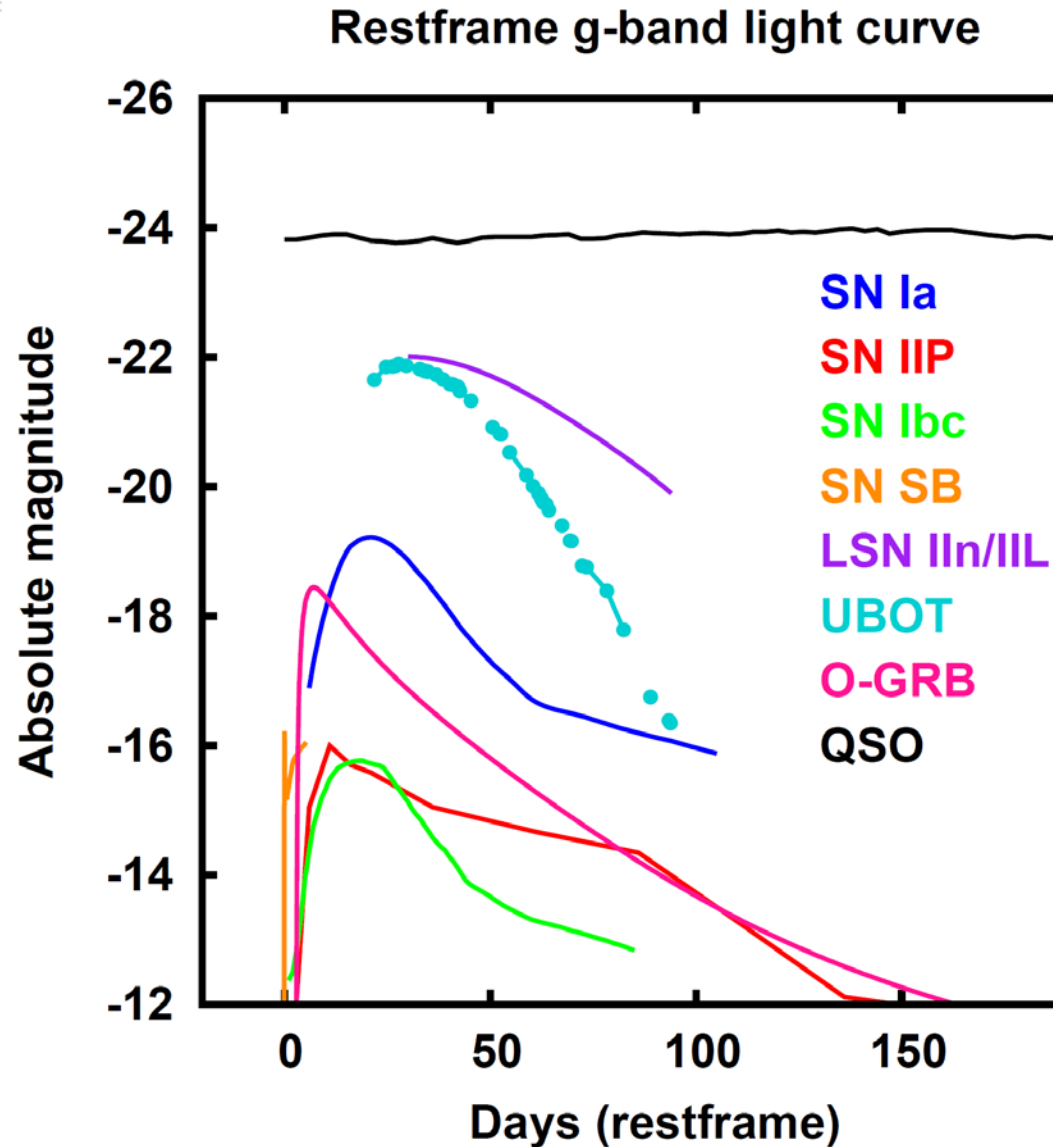


Table 1: Summary of HSC-Wide, Deep and Ultradeep layers

Layer	Area [ $\text{deg}^2$ ]	# of HSC fields	Filters & Depth	Comoving volume [ $h^{-3}\text{Gpc}^3$ ]	Key Science
Wide	1400	916	<i>grizy</i> ( $r \simeq 26$ )	$\sim 4.4$ ( $z < 2$ )	WL cosmology, $z \sim 1$ gals, clusters
Deep	27	15	<i>grizy</i> +3NBs ( $r \simeq 27$ )	$\sim 0.5$ ( $1 < z < 5$ )	$z \lesssim 2$ gals, reionization, WL calib.
Ultradeep	3.5	2	<i>grizy</i> +3NBs ( $r \simeq 28$ )	$\sim 0.07$ ( $2 < z < 7$ )	$z \gtrsim 2$ gals, reionization, SNeIa

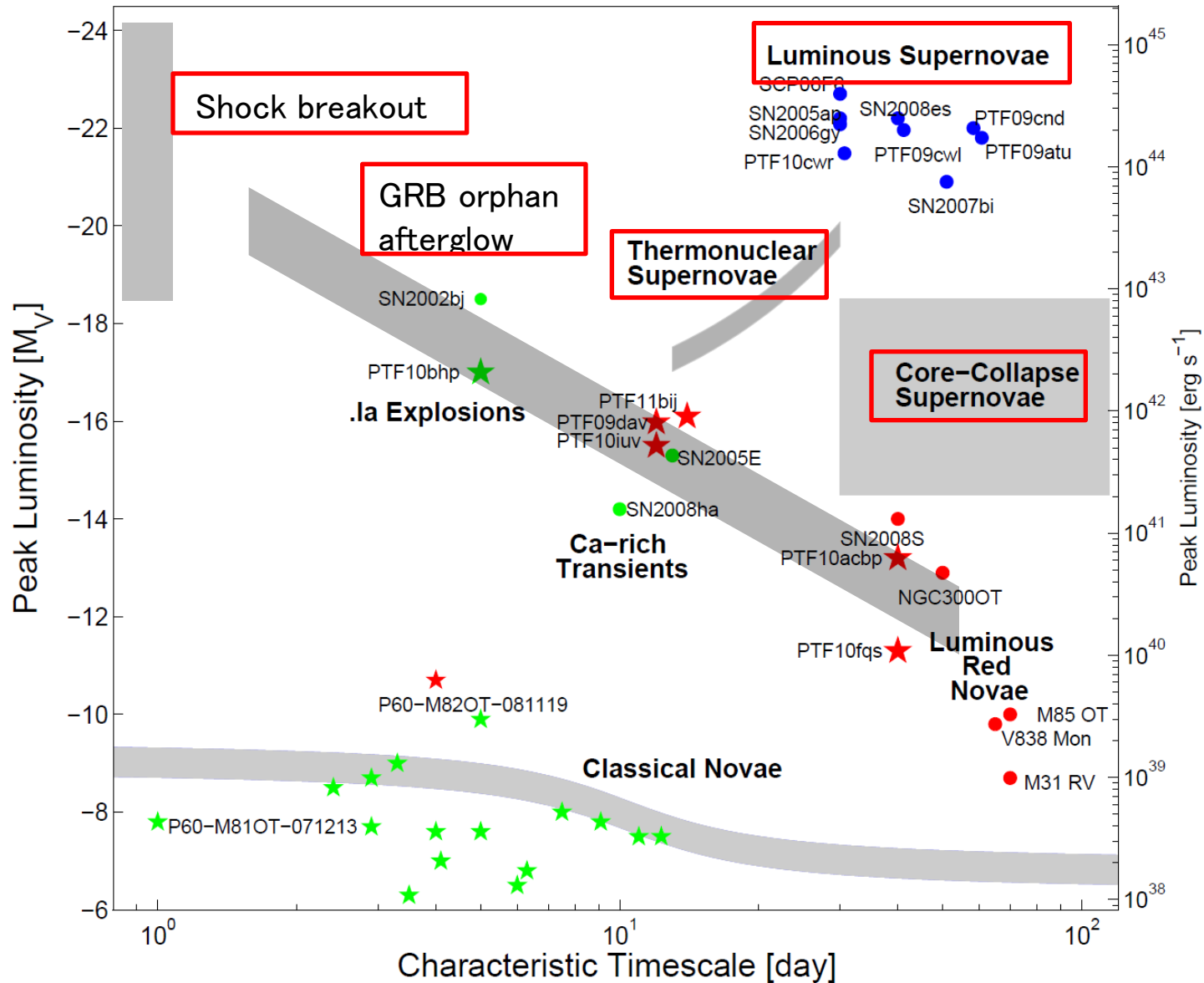
# Objectives

- Type Ia SN
- Core-Collapse SN
- Shock Breakout
- Type II<sub>n</sub>/II<sub>L</sub> LSN
- Type Ic LSN
- GRB Orphan  
Afterglow
- QSO



# Time scales

day ← → year



# Cadence requirements

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

**Dynamic scheduling** will be performed.

# Transient finding & classification

led by Tanaka-san, Urata-san

## ■ Finding methods

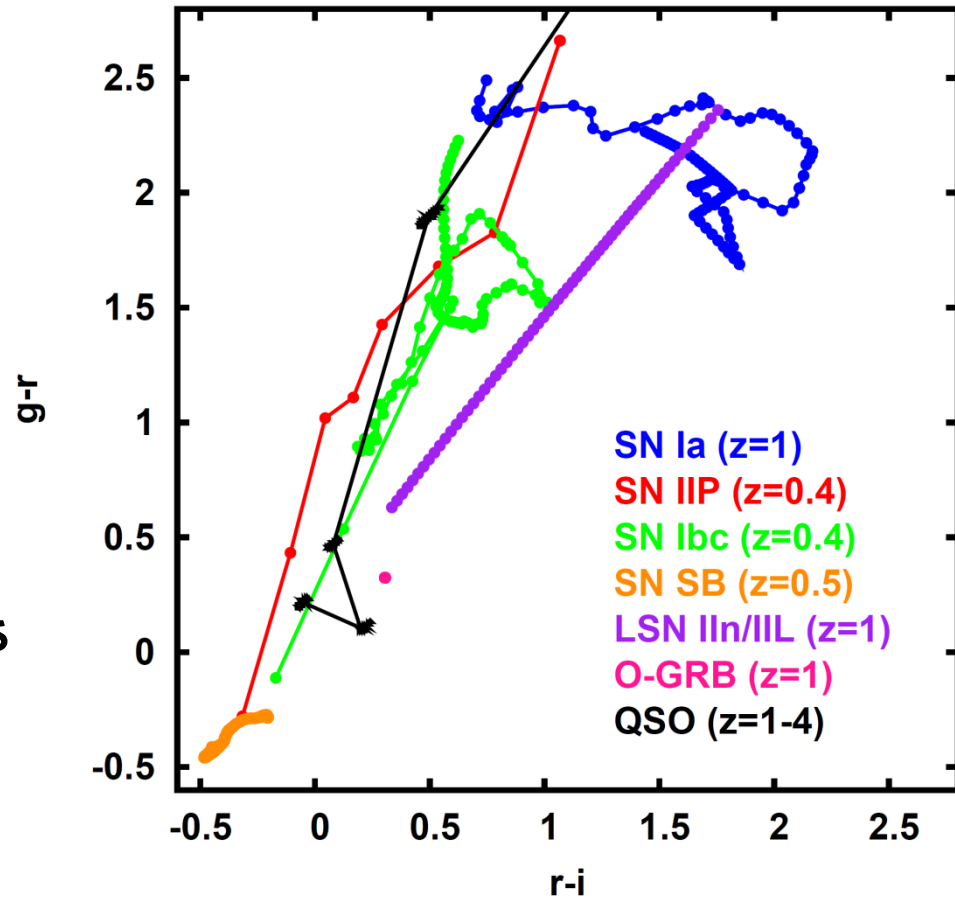
- Catalog finding
- Image subtraction

## ■ Classification

- Color (evolution) & multicolor light curves
- Photometric/  
spectroscopic redshift



Follow-up observations



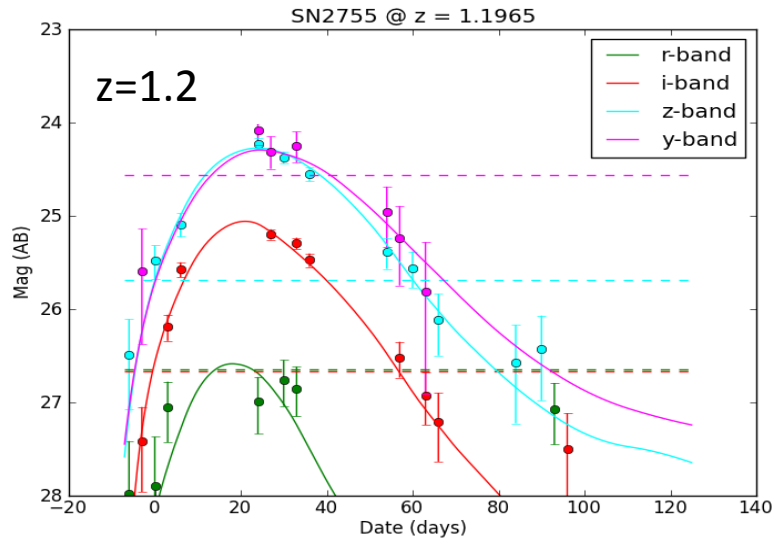
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# **Supernovae with HSC-transient survey**

# Type Ia SNe

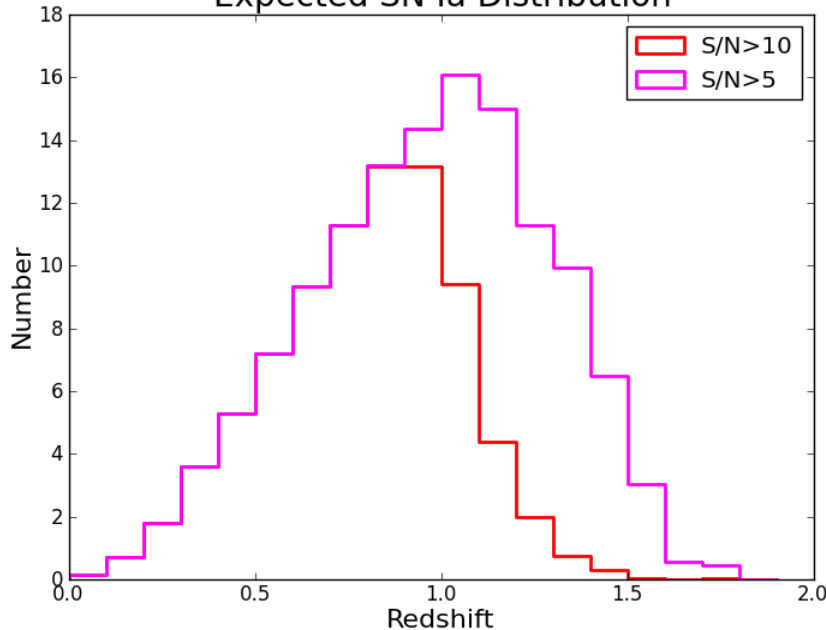
(deep)/UD

led by Yasuda-san, Okumura-san



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

Expected SN Ia Distribution



SN Ia @  $z > 1$  is still small number.

## HSC-UD survey

$\sim 130$  SN ( $\sim 60$  at  $z > 1$ ) for  $S/N > 5$   
 $\sim 80$  SN ( $\sim 20$  at  $z > 1$ ) for  $S/N > 10$  (3 bands detection)

Yasuda-san's talk

# Type Ia SNe -rate-

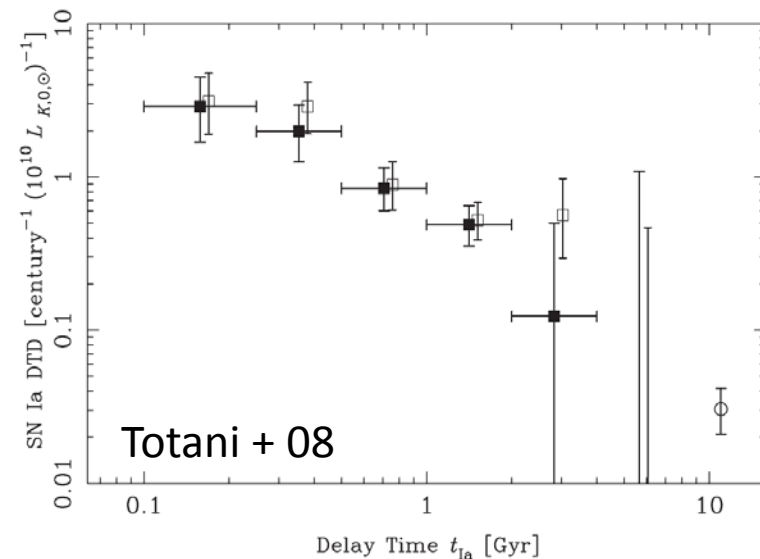
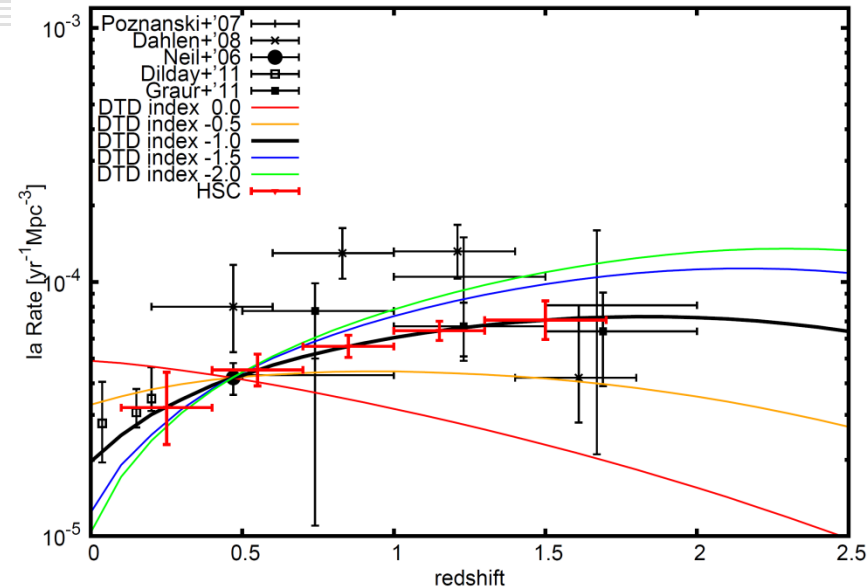
led by Okumura-san

## ■ SN Ia rate density

- Most accurate SN Ia rate upto  $z \sim 1.5$
- constrain **delay time distribution**

## ■ Delay time distribution

- delay time between star formation and SNe Ia
- constrain **progenitor system**



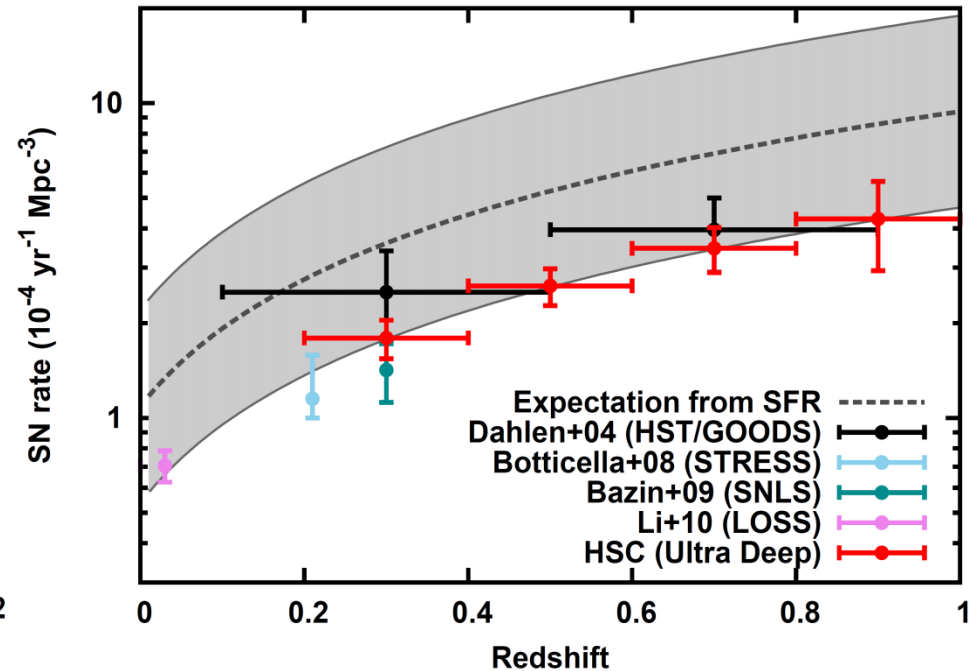
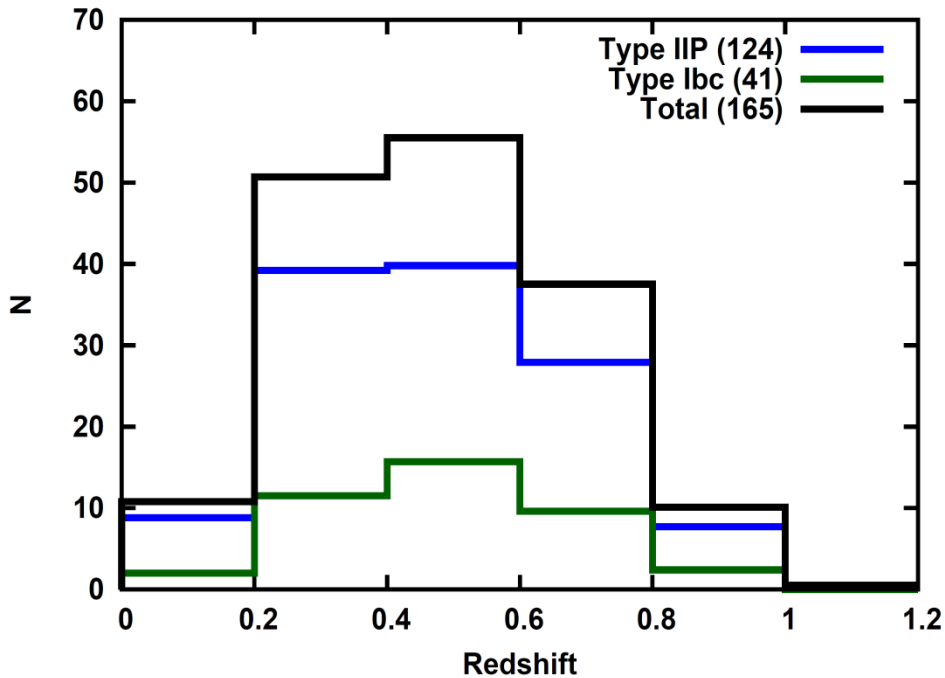


# Core-collapse SNe

(deep)/UD

led by Tanaka-san

- Available **for free** with SNe Ia cadence

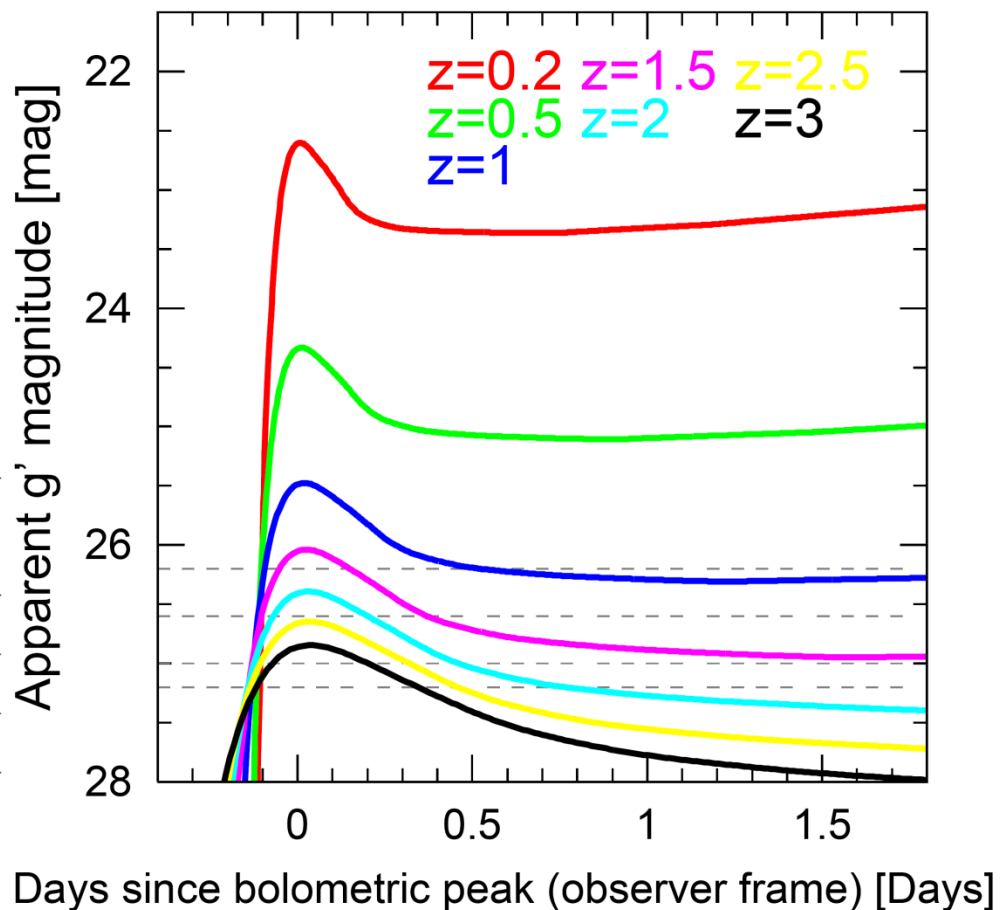


Survey	Tel.	Redshift	# of SNe
SNLS	CFHT	~0.3	120
GOODS	HST	0.1-1.3	45
<b>HSC-UD</b>	<b>Subaru</b>	<b>0.2-1.0</b>	<b>~165</b>

# Shock breakout

led by NT, Morokuma-san

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

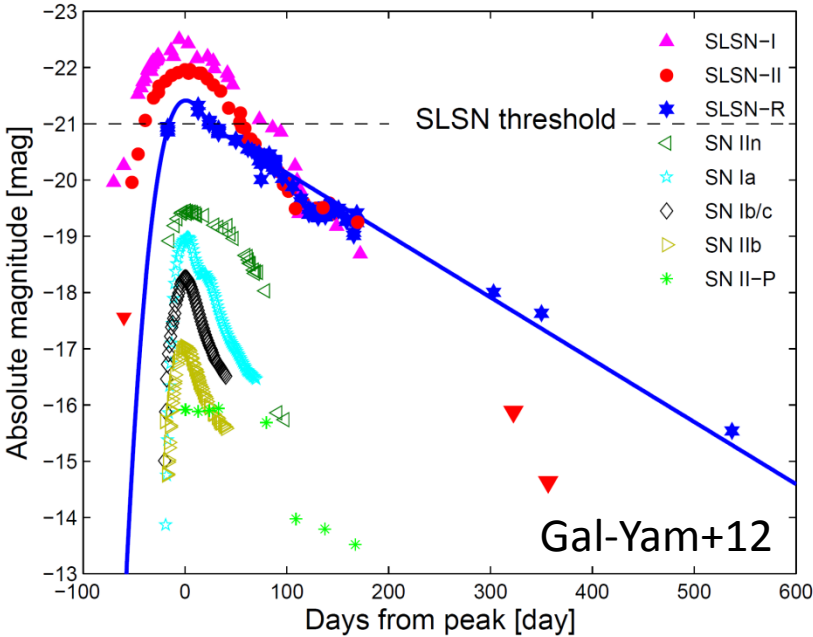
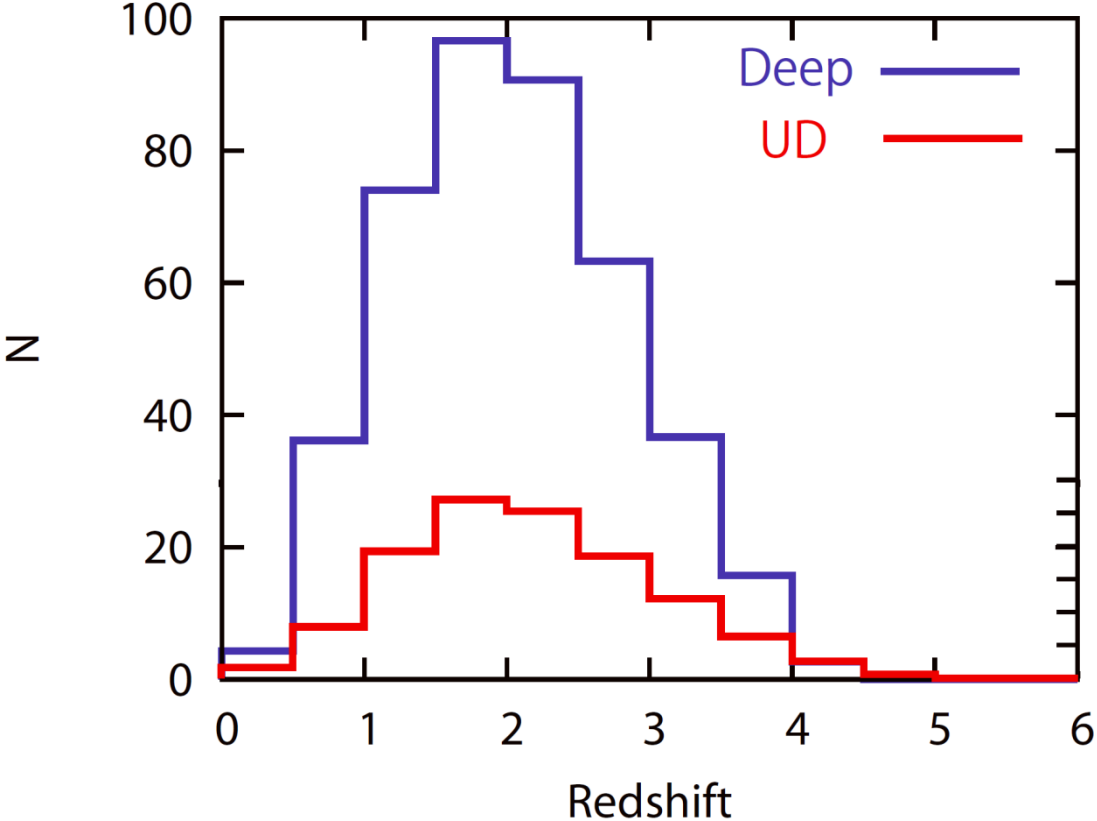


	Num.SNe (1st year)	Num. SNe	Redshift	
			50%	10%
Wide	19	96	$\gtrsim 0.5$	$\gtrsim 0.9$
Deep	9	52	$\gtrsim 0.6$	$\gtrsim 1.4$
UD	2	14	$\gtrsim 0.8$	$\gtrsim 1.7$

# Super Luminous Supernova

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

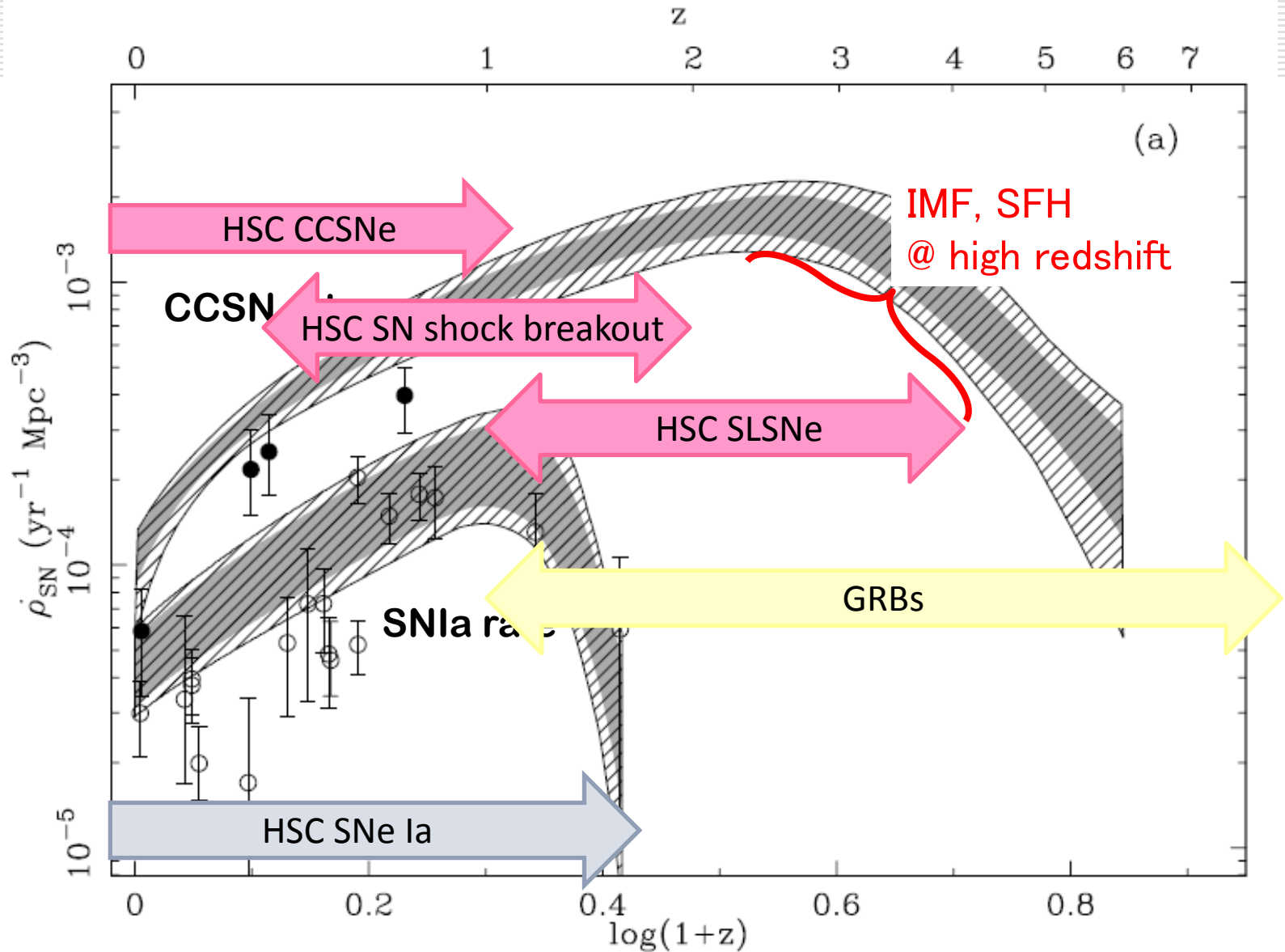
- Rare extremely bright SNe
- CCSN detection @  $z \sim 4$



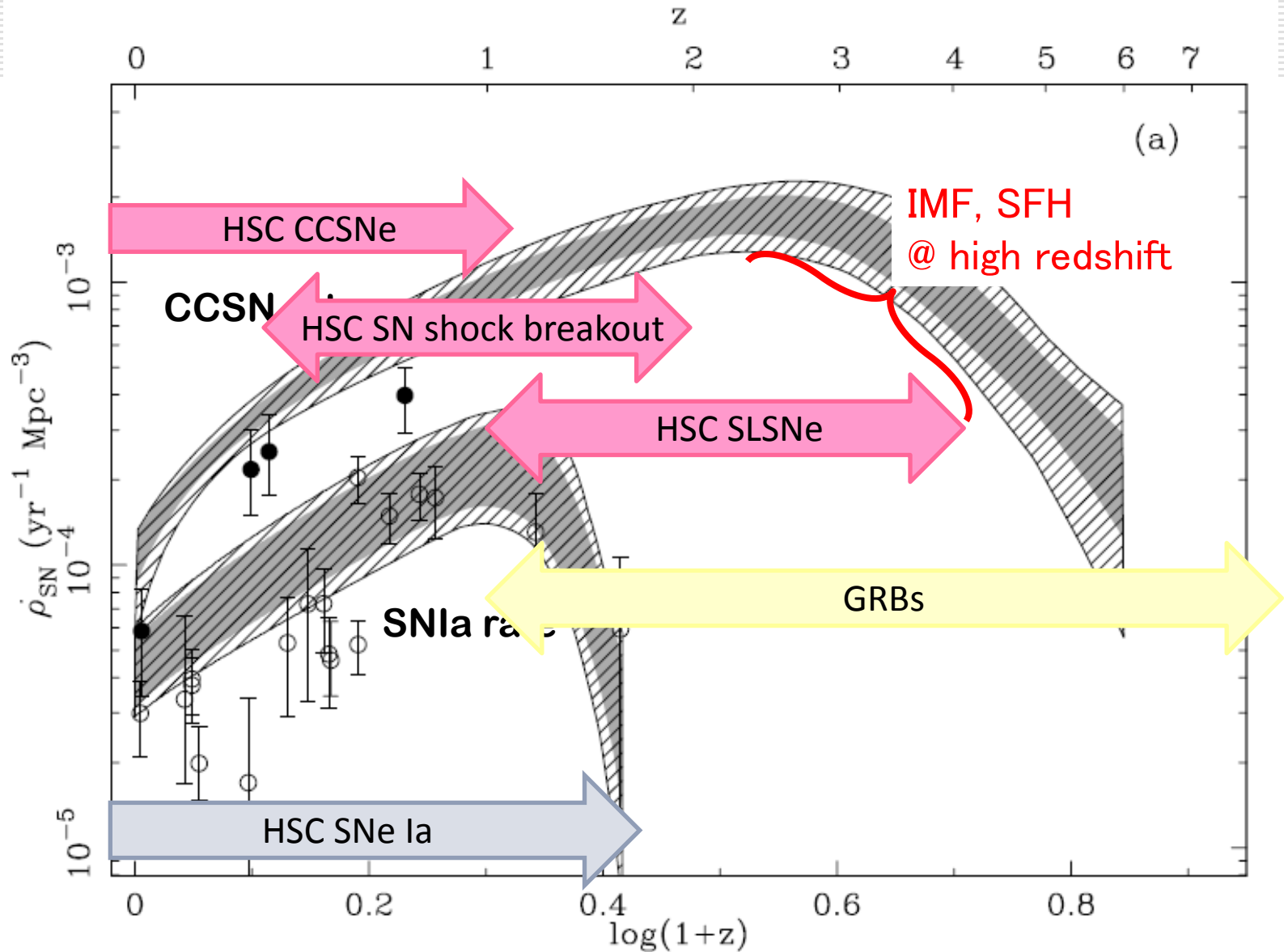
Slow follow-up obs.  
1-month stacked data

Quimby-san's and Moriya-san's talk

# SN rate history



# Distance ladder in SNe



# 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 survey**.
  - **Distance ladder in SNe upto  $z \sim 4$  connecting to GRBs**