Supernova shock breakout at high redshift and wide-field transient survey

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6th Feb 2014

IKI seminar

Outline

- Supernovae
- Transient surveys
- Ongoing/future supernova surveys
  - Kiso Supernova Survey (KISS)
  - Subaru/Hyper Suprime-Cam survey

Supernovae

Very bright

$L \sim 10^{42} erg/s \sim 10^{9} L_{\odot}$

Energy source

Shock heating

^{56}Ni-^{56}Co radioactive decay

Huge energy

$E_K \sim 10^{51} erg$

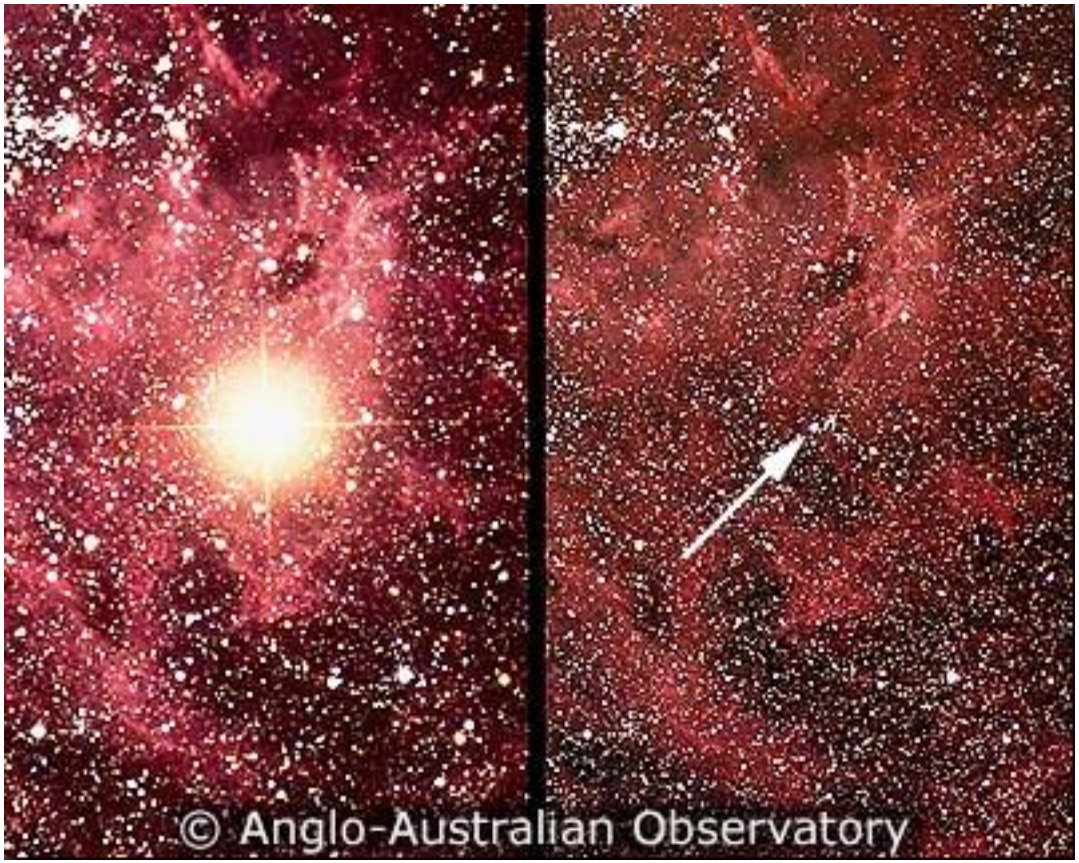
Gravitational energy

$GM^2_{\odot}/R_{NS} \sim 10^{53} erg$

Nuclear energy

$\Delta(^{12}C \rightarrow ^{56}Ni)M_{\odot} \sim 10^{51} erg$

SN1987A



Light curve of supernovae

~1month

(Optical) transient surveys

- We cannot predict where transients will appear, except for alerts by neutrino or GW signals.

Survey by telescopes with wide field of view

Survey	Diameter [m]	FoV [deg^2]	Depth [mag]	Area [deg^2/day]
ROTSE-III	0.45	3.42	18.5	450
MASTER-II	0.4	4(38)	19.5	2000
CRTS	0.7	8	19.5	1200
PTF	1.26	7.8	21	1000
Skymapper	1.33	5.7	19	1000
Pan-STARRS	1.8	7	21.5	6000
SDSS	2.5	1.5	22.6	150
SNLS	3.6	1	24.3	2
HST/GOODS	2.5	0.003	26	0.04

Rau+09

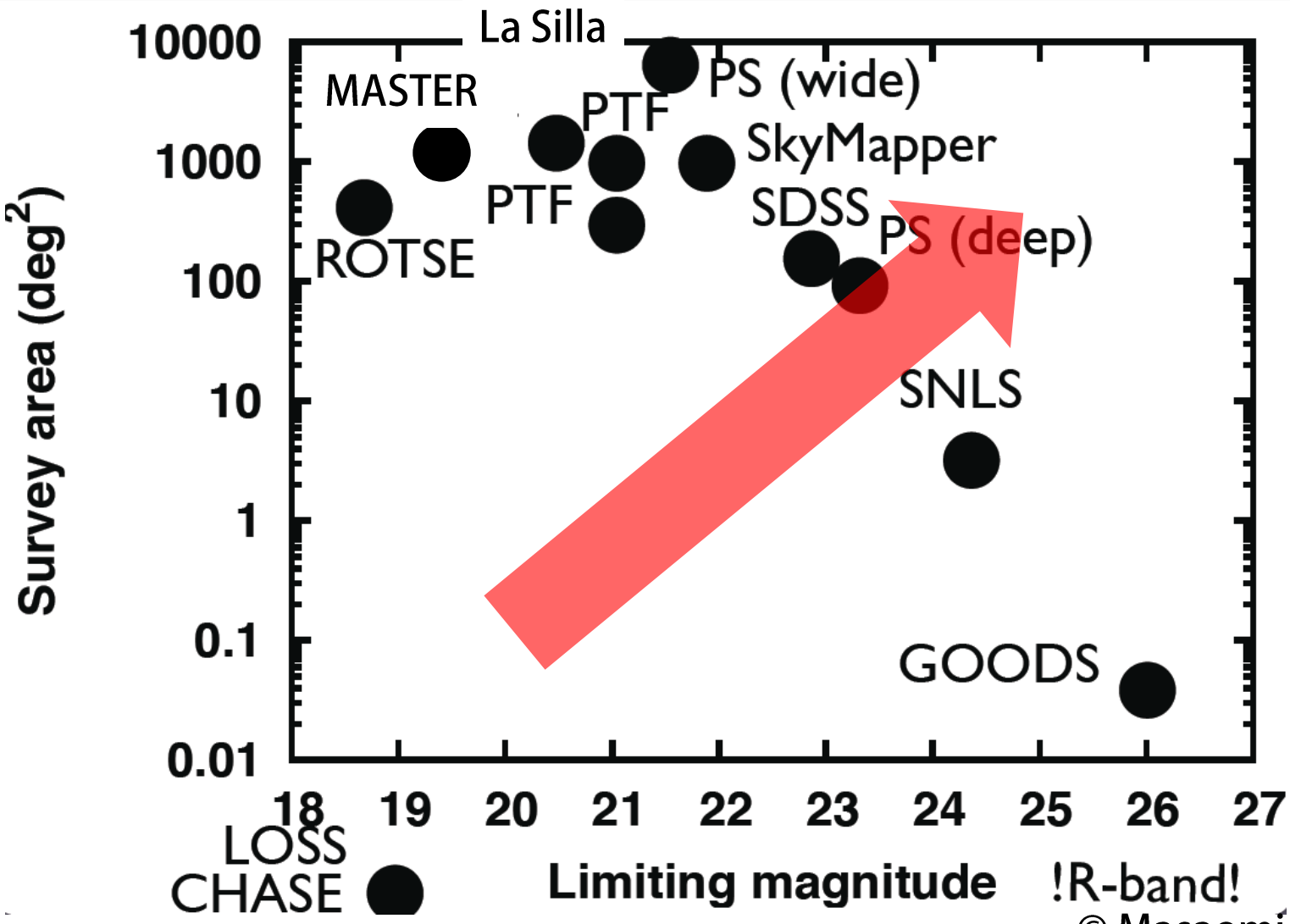
Transient search

- Aim: discovery of new transients
- Req.: large survey volume
- Method: wide and/or deep observations
- Wide survey for detailed study of transients

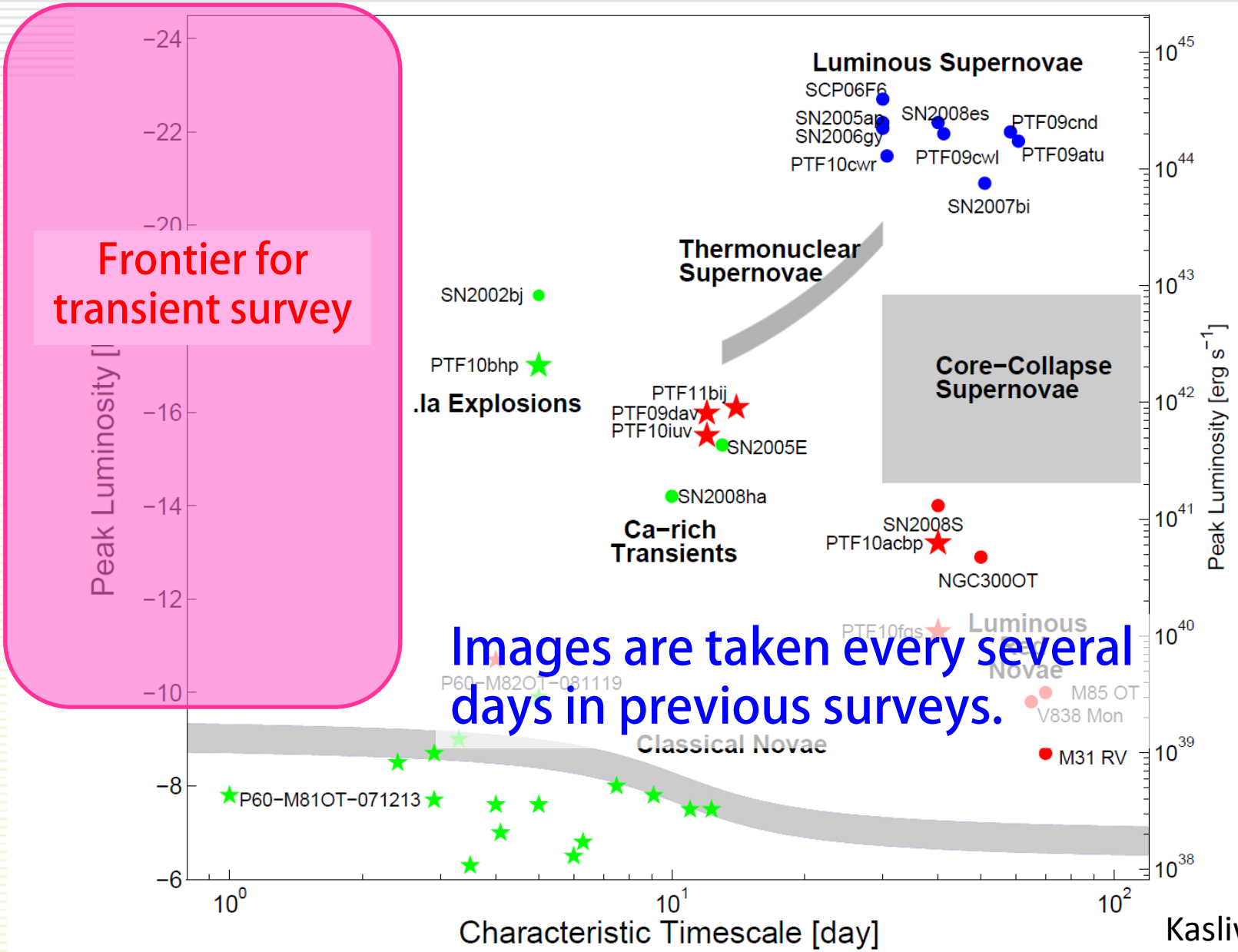
  It requires quick and continuous follow-up observations.
- Deep survey for detection of high-redshift transients

  It requires deeply investigated nearby similar transients.

Survey parameters

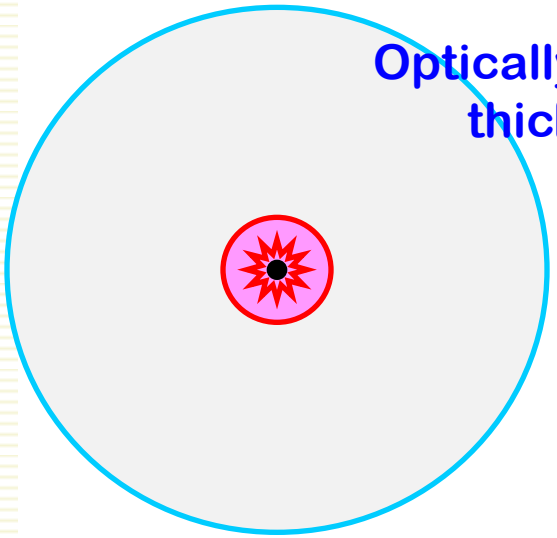


Transients

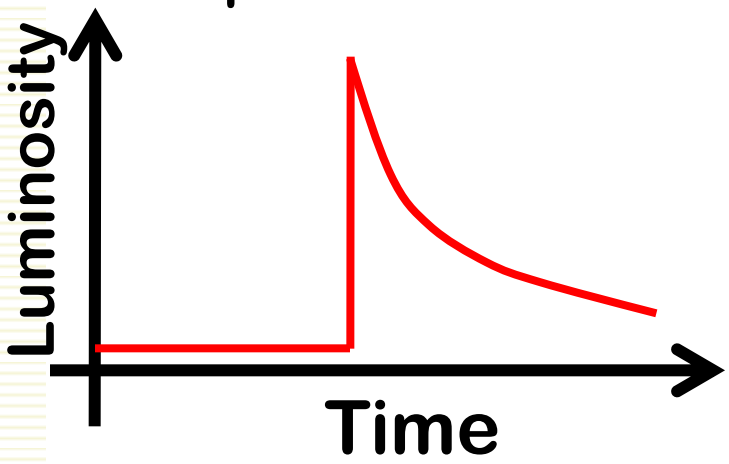


Kasliwal 11

Target of high-cadence survey -Shock breakout-



Core collapse



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

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

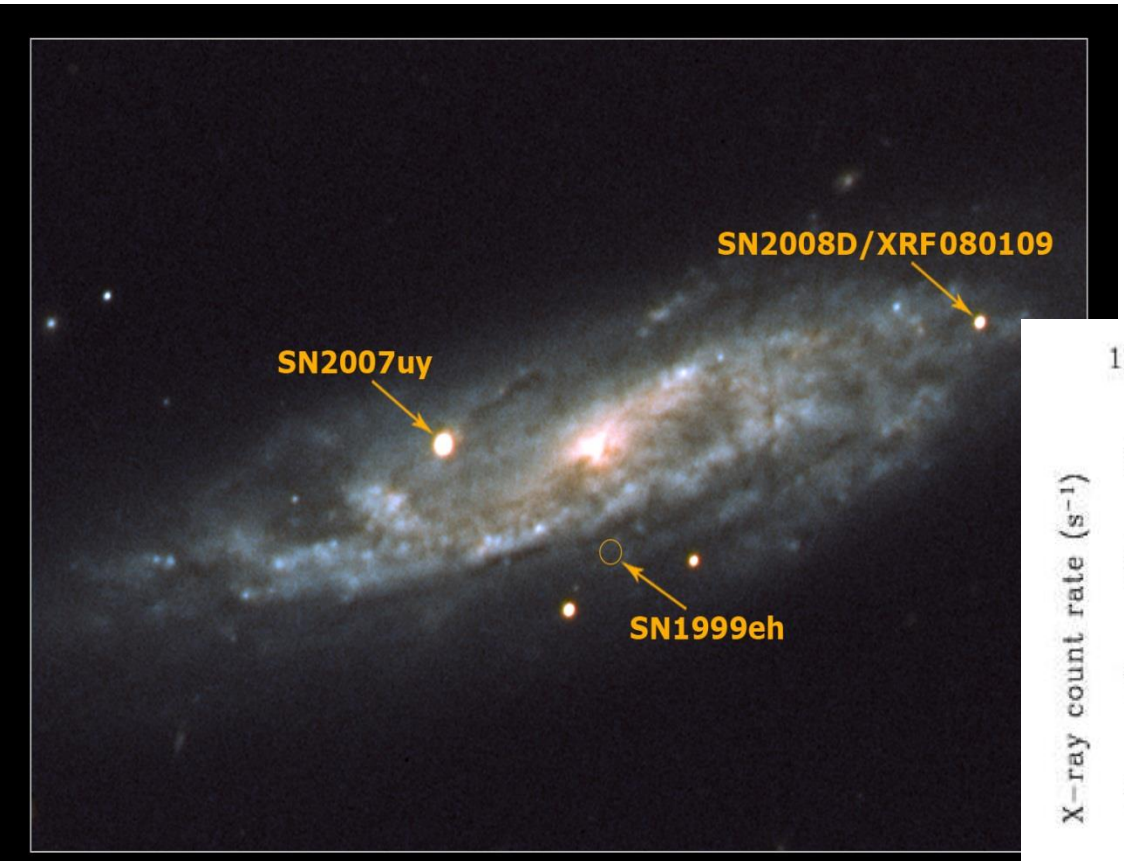
Typical properties

timescale: 100sec ~ 1day

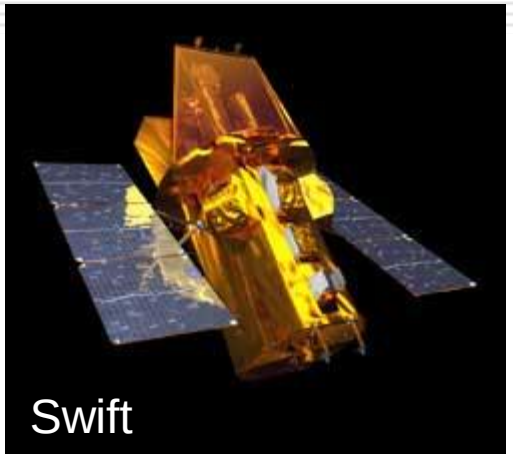
peak wavelength: X-ray ~ UV

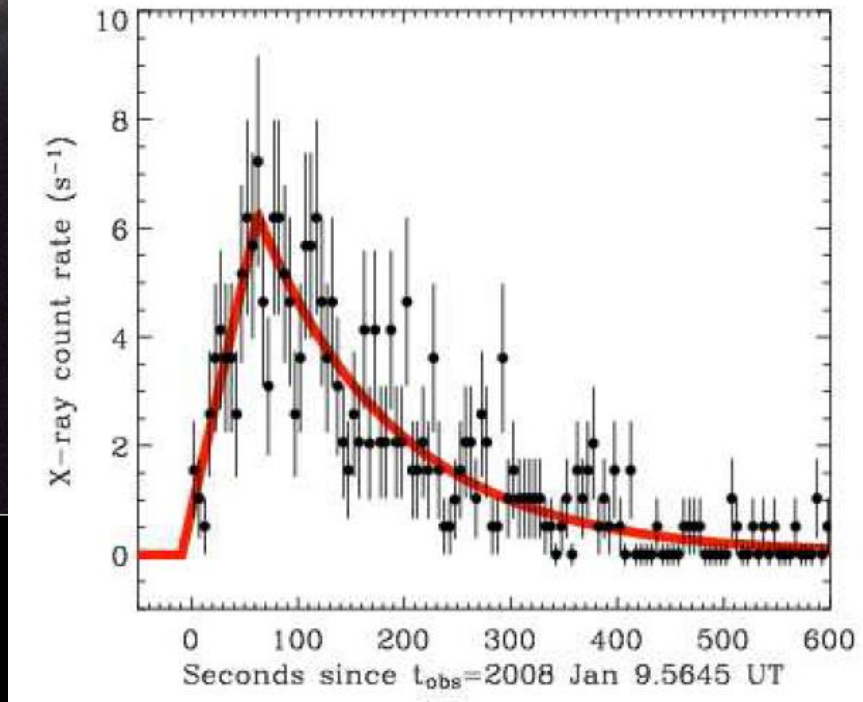
Most famous shock breakout -Type Ib SN2008D/XRO080109-

Soderberg + 08; Modjaz + 09



NGC 2770
Supernova factory



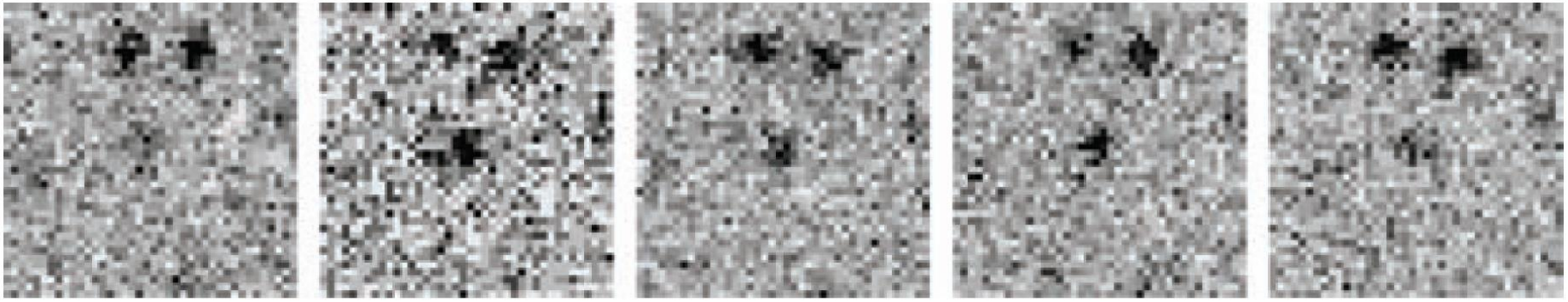


Shock breakout of Type IIP SNe
-SNLS-04D2dc & SNLS-06D1jd-

SNLS SuperNova Legacy Survey

SNLS-04D2dc (z=0.1854)

Schawinski et al. 08
Gezari et al. 08



Before shock breakout

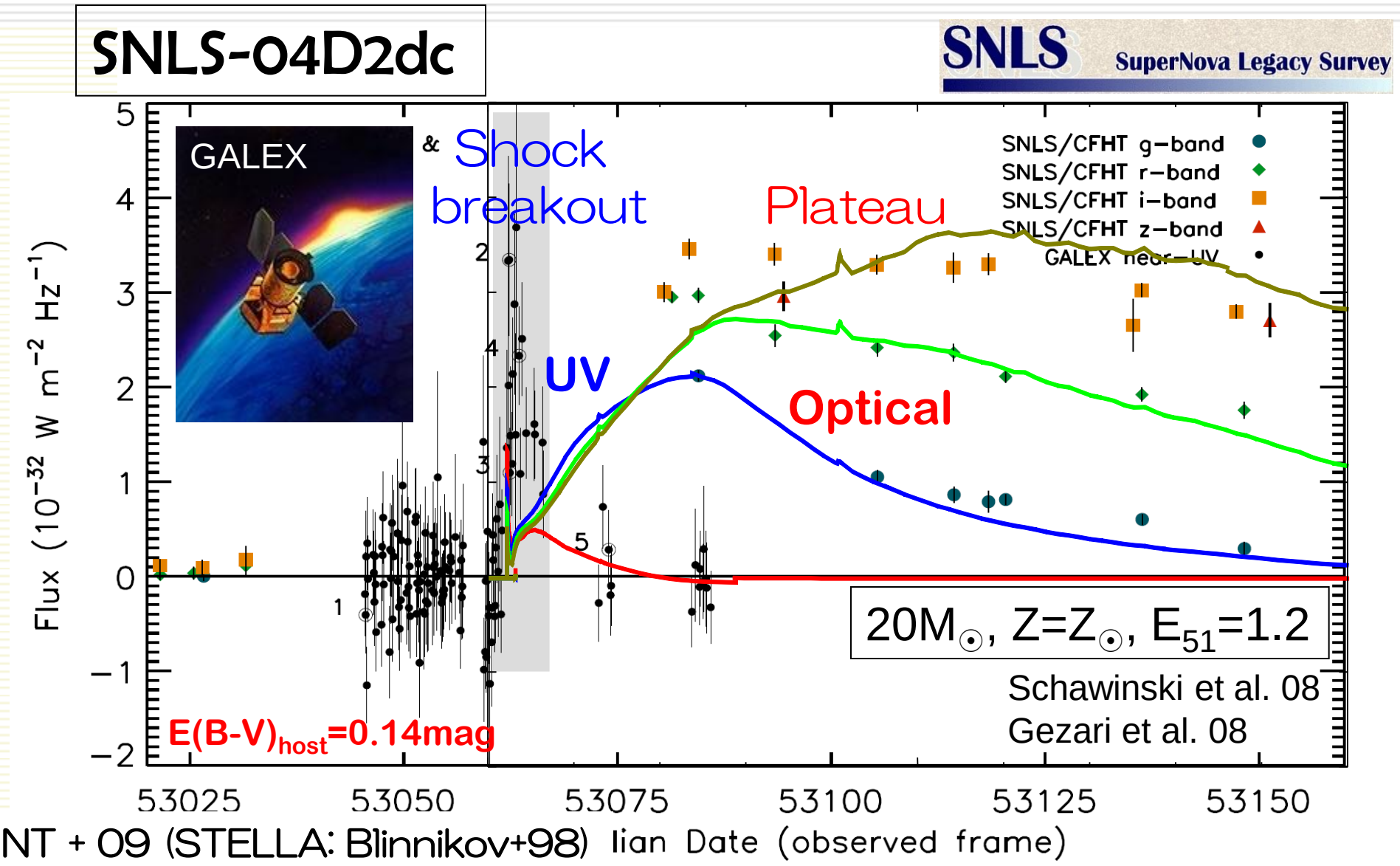
Peak of Radiative Precursor

Minimum between peaks

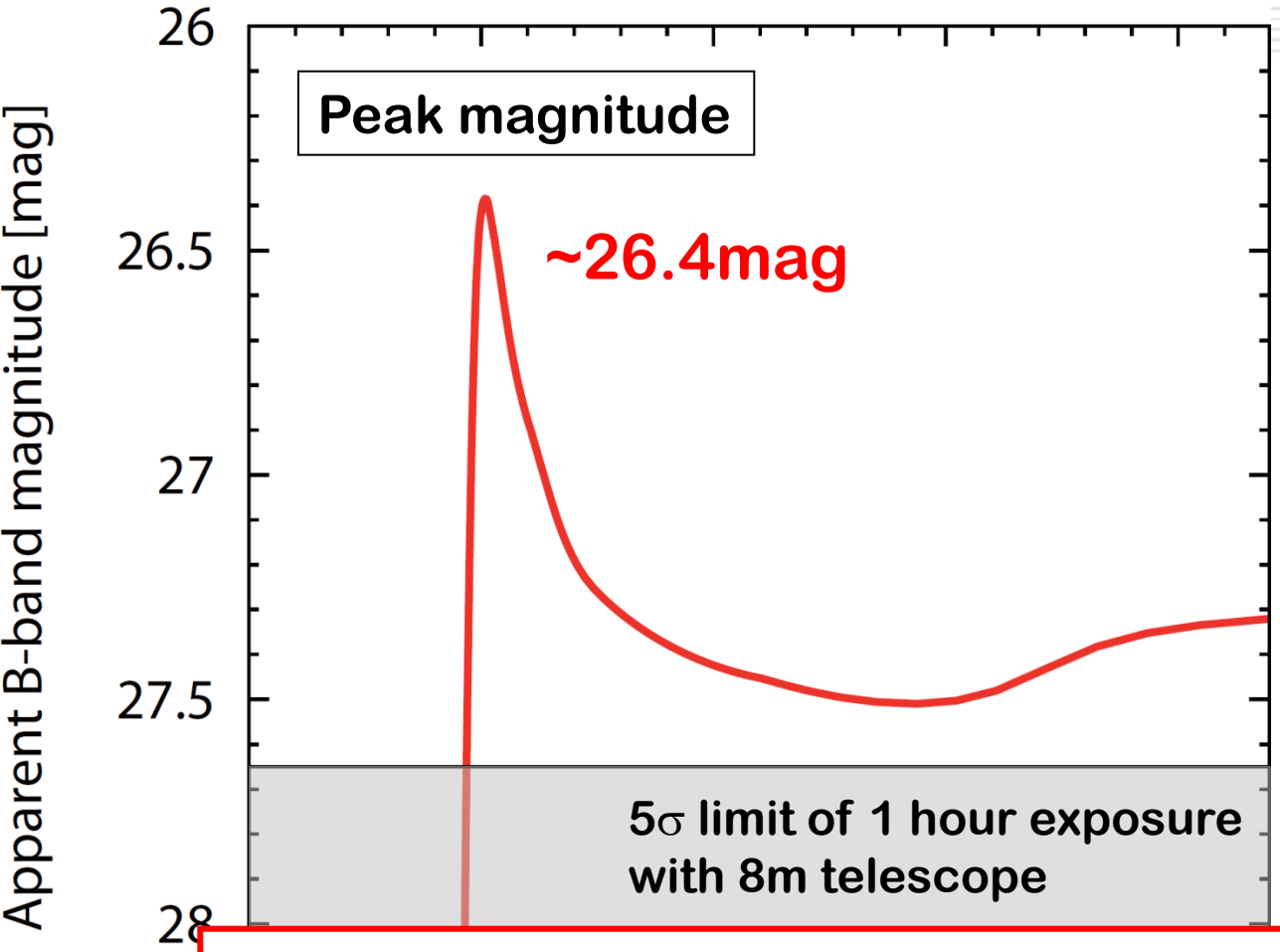
Post shock breakout peak

After near-UV peak

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

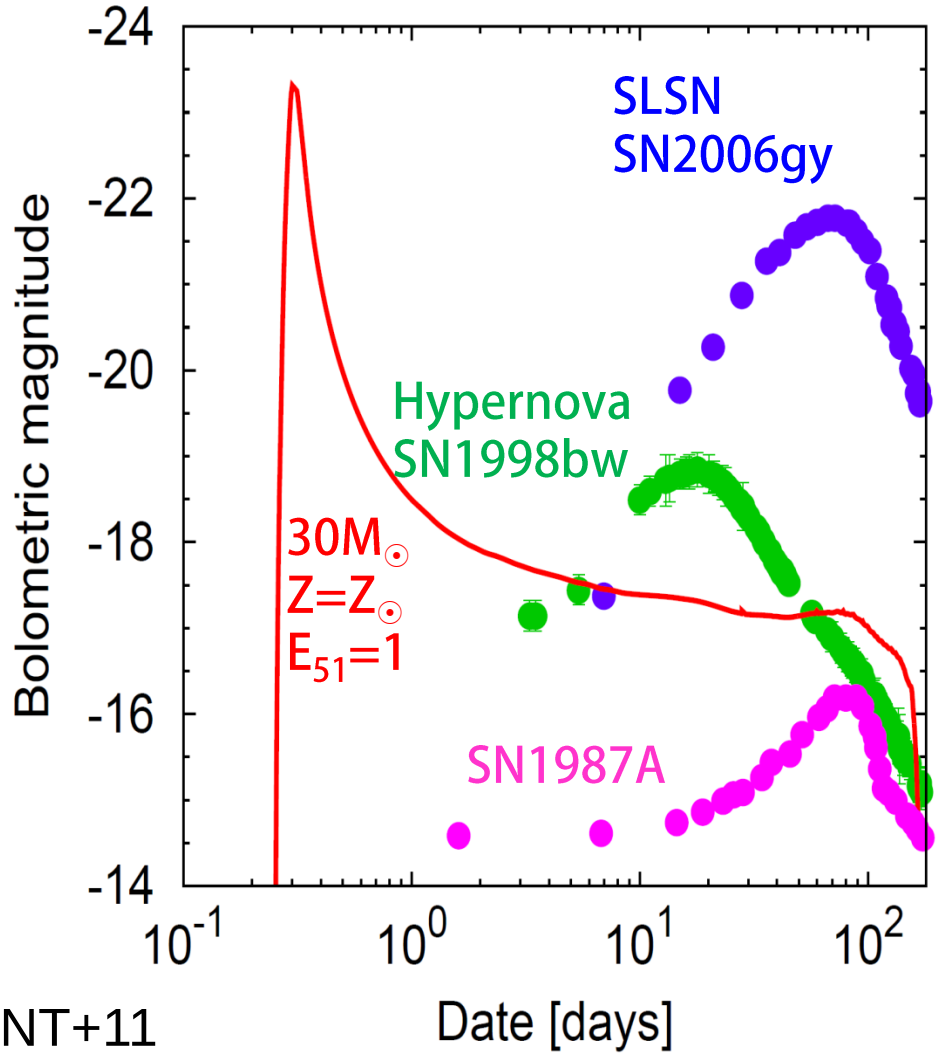
z=1: ~4600A (B or g)
(SNLS-04: ~3900A)

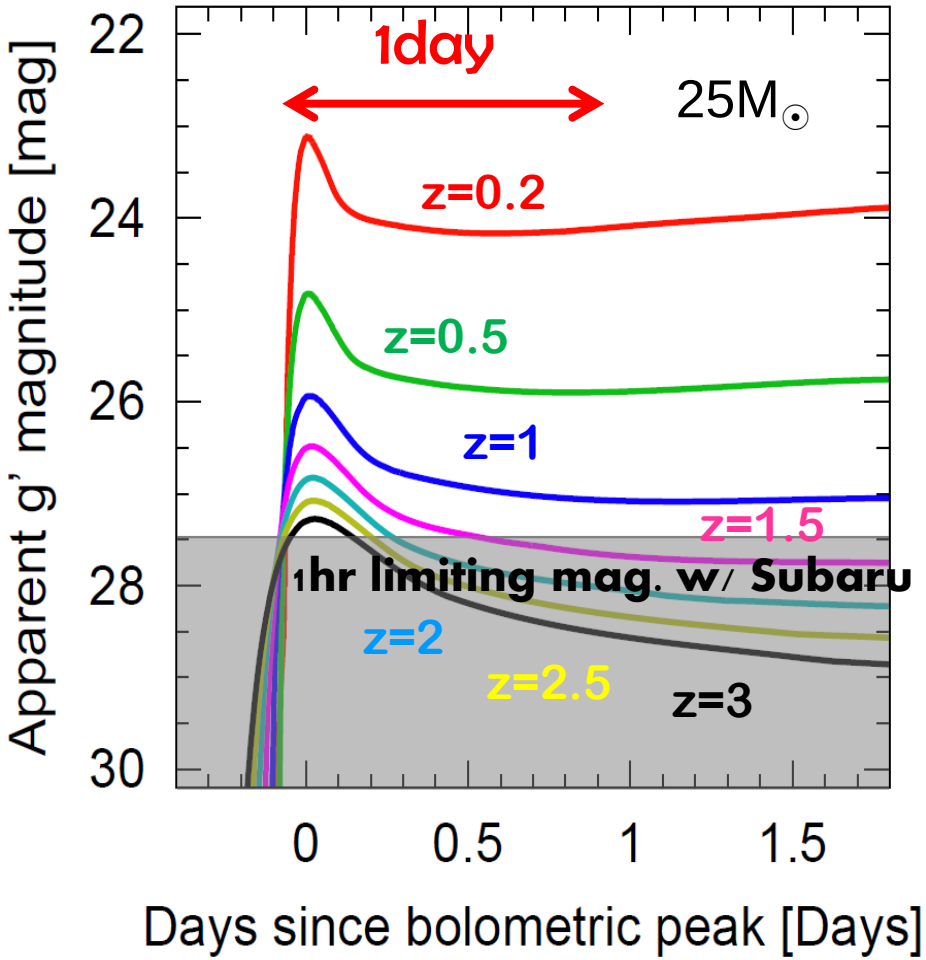
The normal core-collapse SN (CCSN) at z=1 can be detected.
Note: the current record of high-z normal CCSN is z~0.9.

Shock breakout is bright!

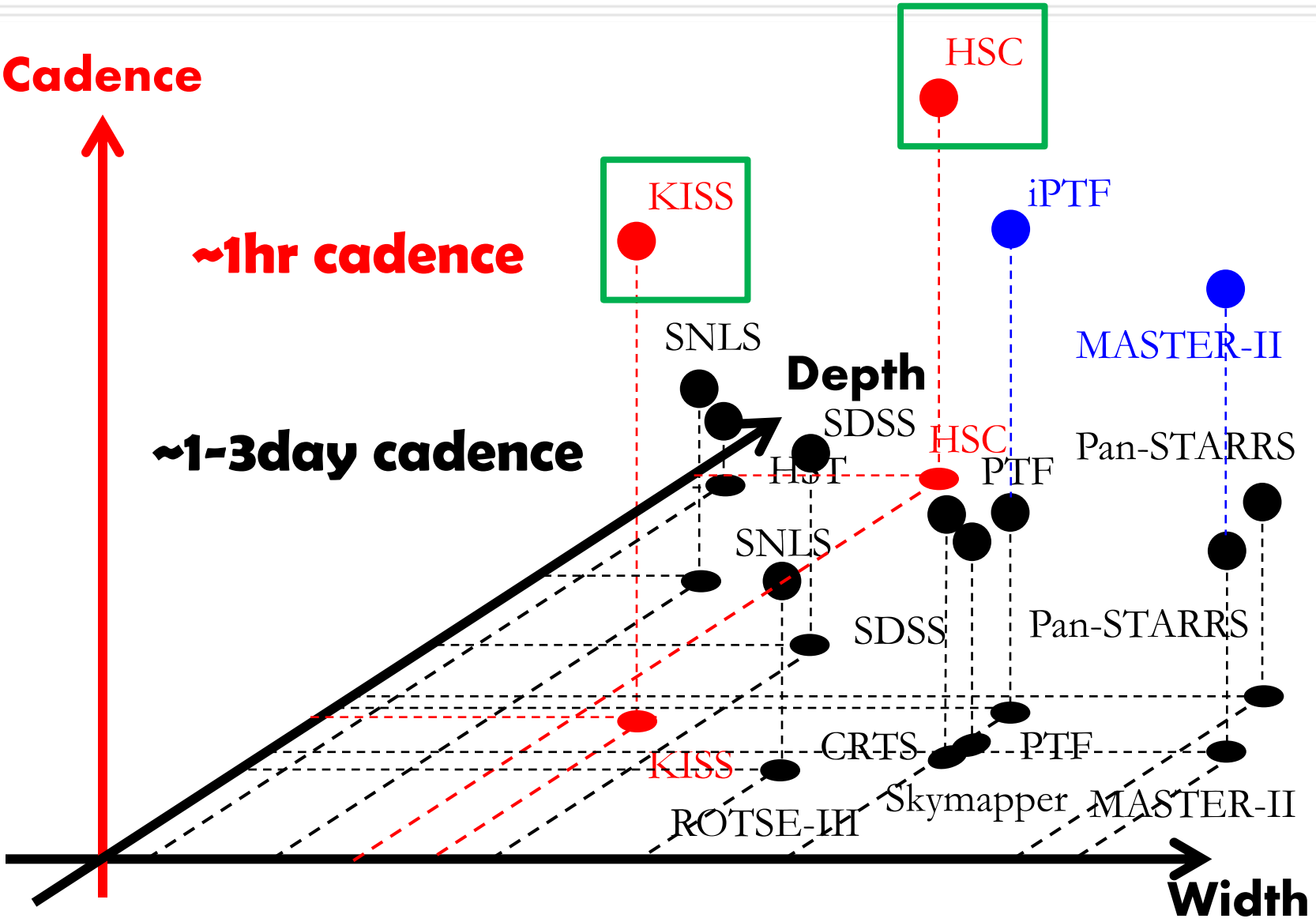
And common: ~70% of CCSNe are Type II

- Brighter than SLSNe
- Detectable up to z~3





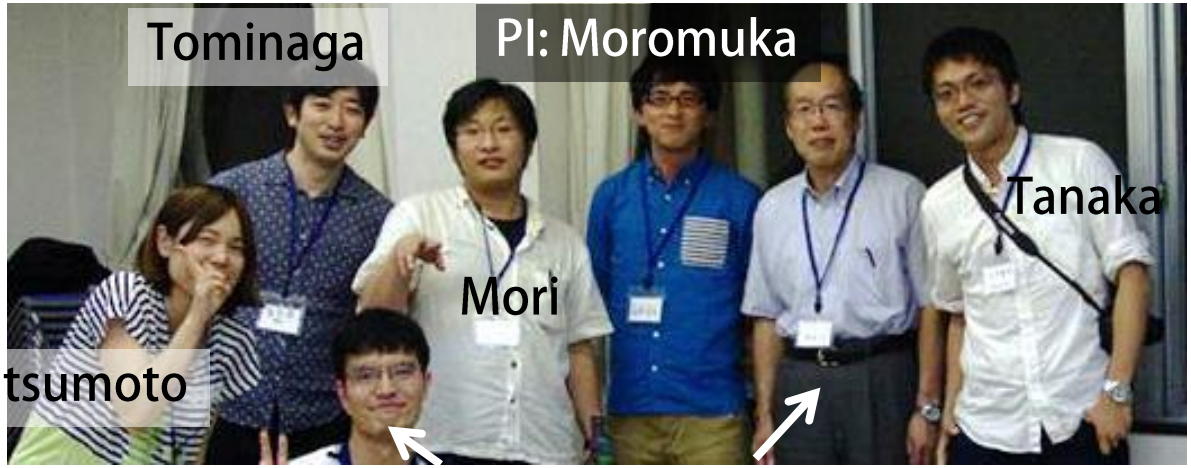
New dimension of survey



Two optical transient surveys

- Kiso Supernova Survey (KISS)
  - Nearby supernova survey
  - from Apr 2012
  - Characteristics: high cadence
  - Aim: detailed studies of nearby objects
- Subaru/Hyper Suprime-Cam survey
  - High-z supernova survey
  - from Feb 2014
  - Characteristics: the deepest survey with wide FoV
  - Aim: detection of various high-z objects

Nearby shock breakout survey
-Kiso Supernova Survey-



Tomoki Morokuma (Tokyo), Nozomu Tominaga (Konan),
Masaomi Tanaka (NAOJ), Emiko Matsumoto (Konan),
Kensho Mori (Hiroshima),
many other collaborators

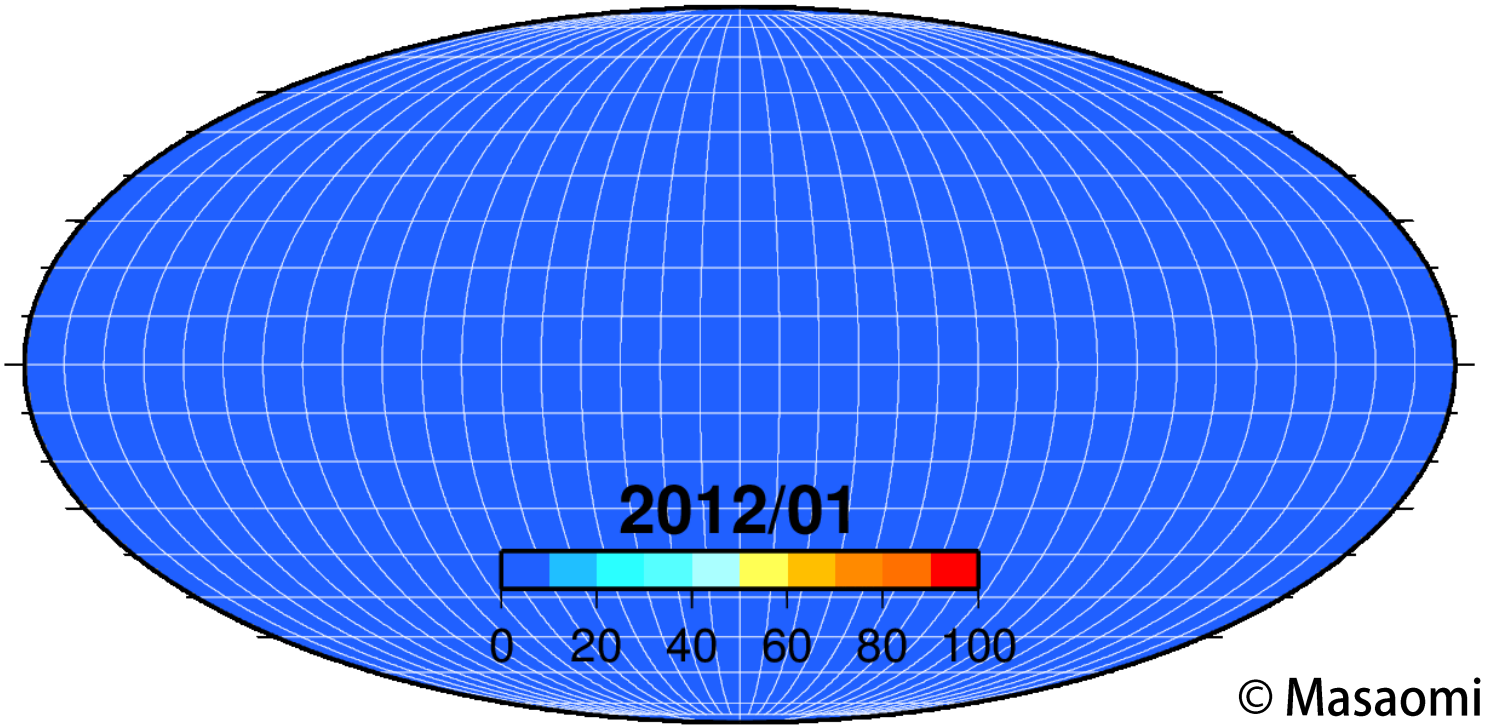
Kiso Supernova Survey (KISS)

from Apr 2012

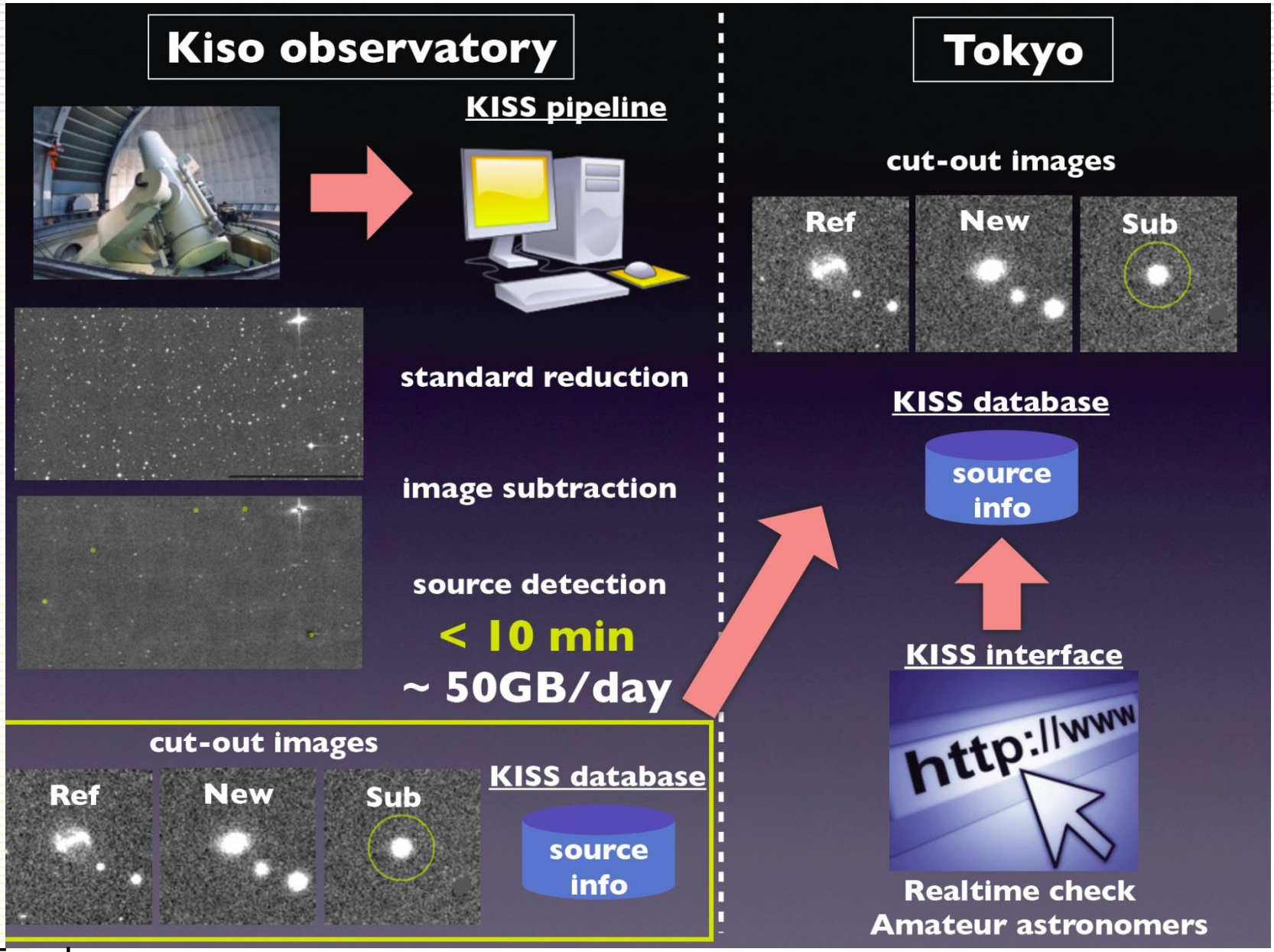
- Kiso Wide-Field Camera (KWFC)
  - Diameter: 1.05m FoV: 4deg^2
- 3min exposure ($m_{lim,g}$~21mag) with ~1hr interval

KISS strategy

- g-band observation of SDSS fields
- ~3min exposure with ~hour interval
- observe fields over 5 epochs every night



Realtime analysis

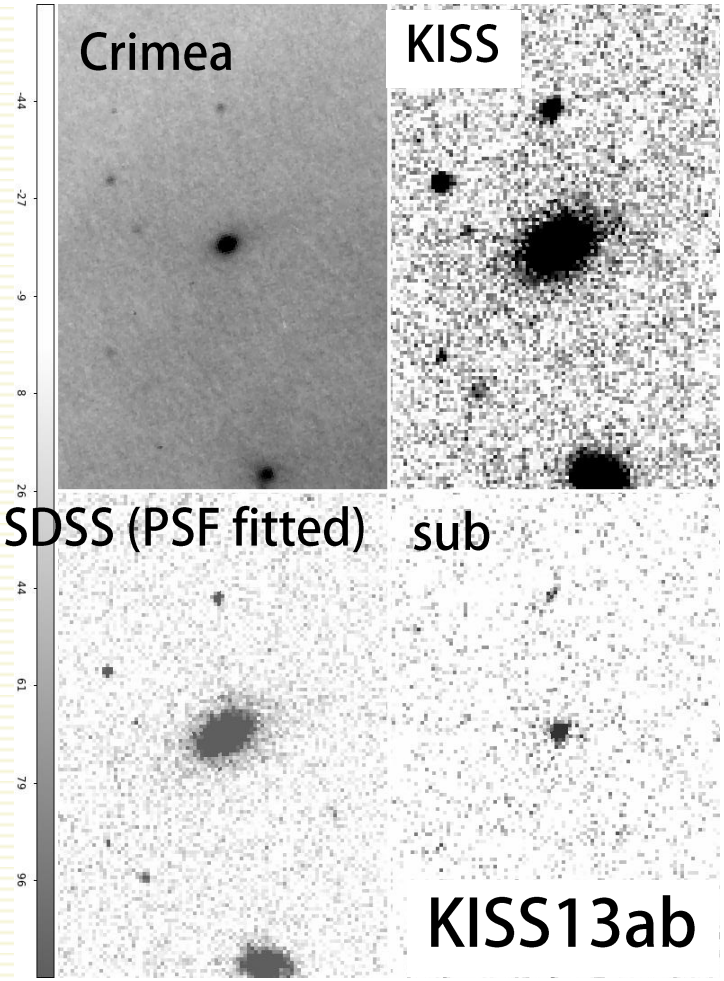


KISS collaboration

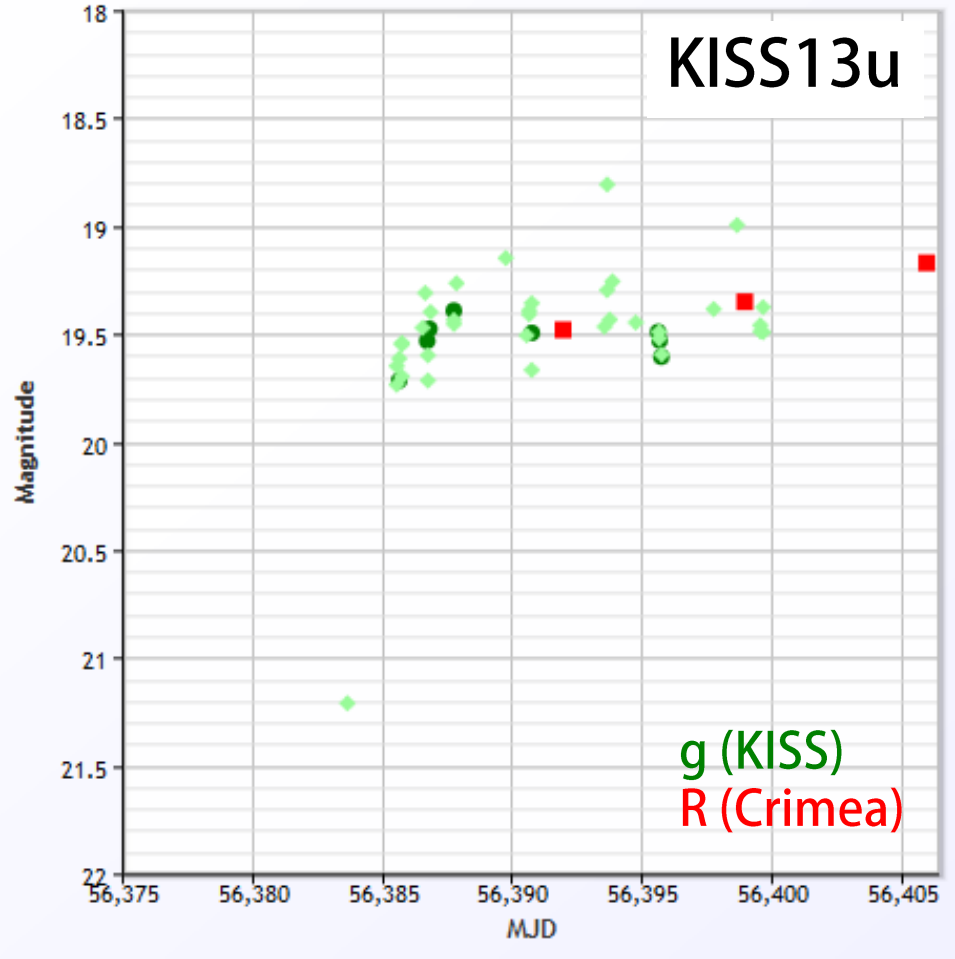
- Japan/Taiwan team
  - Kanata(1.5m)/HOWPol, MITSuME(0.5m), Lulin(1m)
- Rochester Institute of Technology (KPNO 0.9-m)
  - Michael W. Richmond
- Indian Institute of Astrophysics (HCT)
  - Devendra Sahu
- Carnegie Supernova Project (CSP; NOT)
  - Eric Hsiao, Maximilian Stritzinger, Mark Phillips, Nidia Contreras, Francesco Taddia Morrell, Carlos Contreras
- Telescopio Nazionale Galileo (TNG/DOLORES; 3.5m)
  - Paolo Mazzali, Emma Walker, Elena Pian
- SNFactory (UH88/SNIFT)
  - Greg Aldering
- Sternberg Astronomical Institute (Crimea, Moscow)
  - Dmitry Tsvetkov, Nikolay Pavlyuk

KISS-SAI collaborated obs.

- Good seeing



- Multiband obs.



HSC transient survey

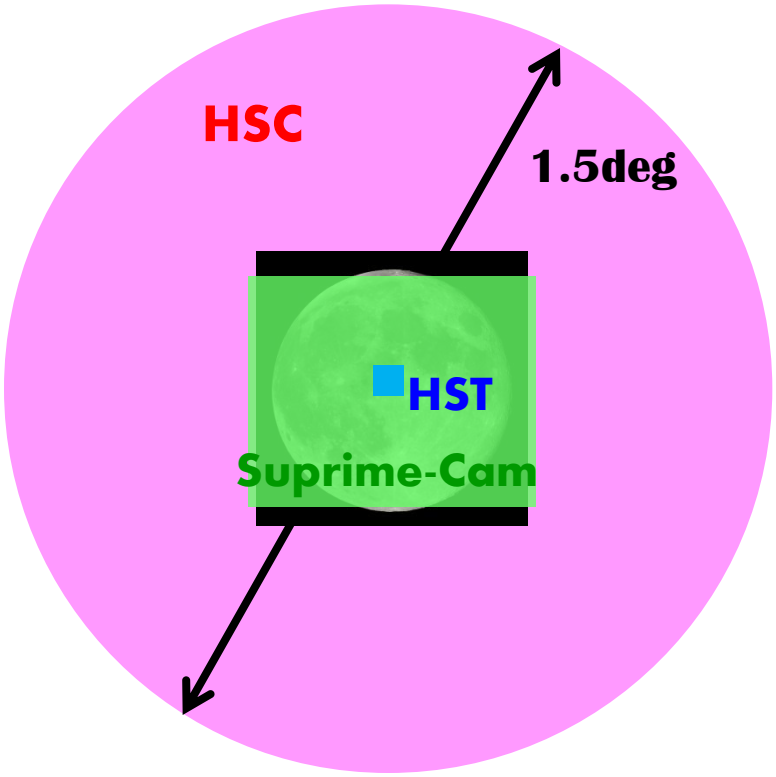
HSC-transient group

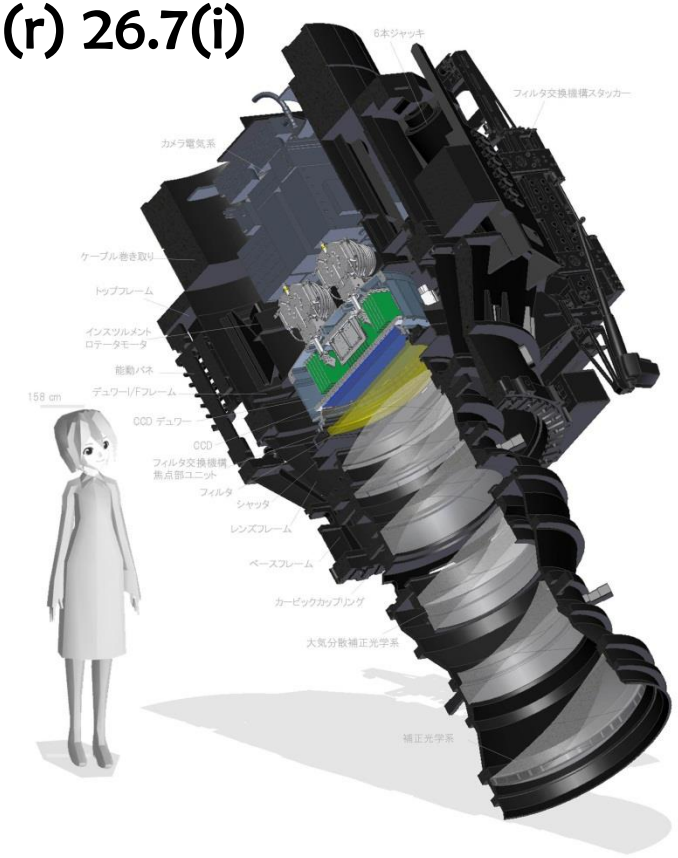
Tomoki Morokuma (Tokyo), Naoki Yasuda (Kavli IPMU), Yuji Urata (NCU, Taiwan), Kuiyun Huang (ASIAA), Masaomi Tanaka (NAOJ), Jun E. Okumura (Kyoto), Tomonori Totani (Kyoto), Nozomu Tominaga (Konan), Takashi J. Moriya (Bonn Univ.), Robert Quimby (Tokyo/Kavli IPMU), Keiichi Maeda (Kavli IPMU), Shigehiro 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)

Hyper Suprime Cam on Subaru telescope

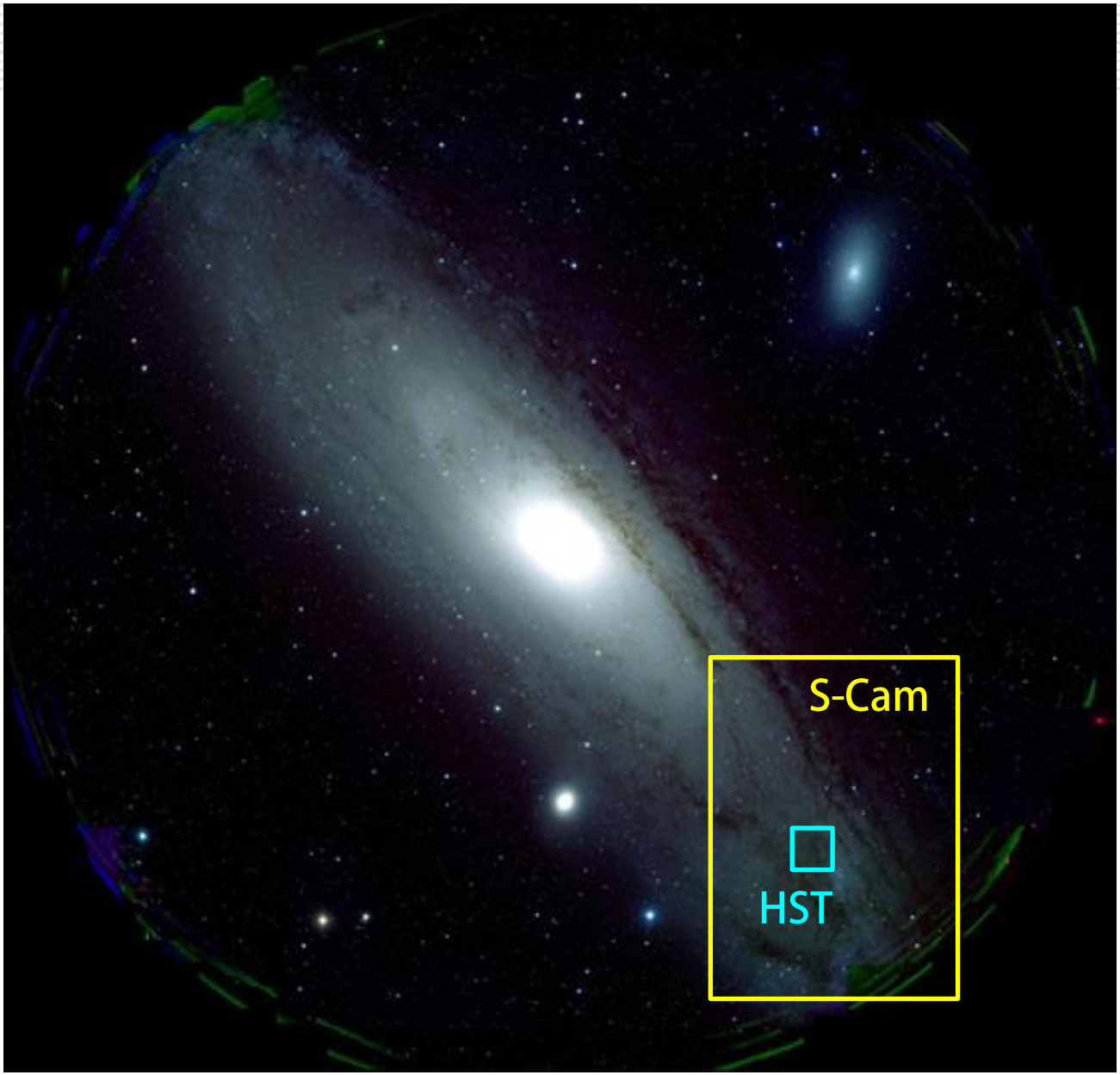
- Hyper Suprime-Cam (HSC)
  - Diameter: 8.2m, FoV: 1.77deg^2
  - m_{lim} (5σ) w/ 1hr: 27.5(g) 27.2(r) 26.7(i)

from Feb 2014





First image (M31) -Feb 2013-



HSC strategic program

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

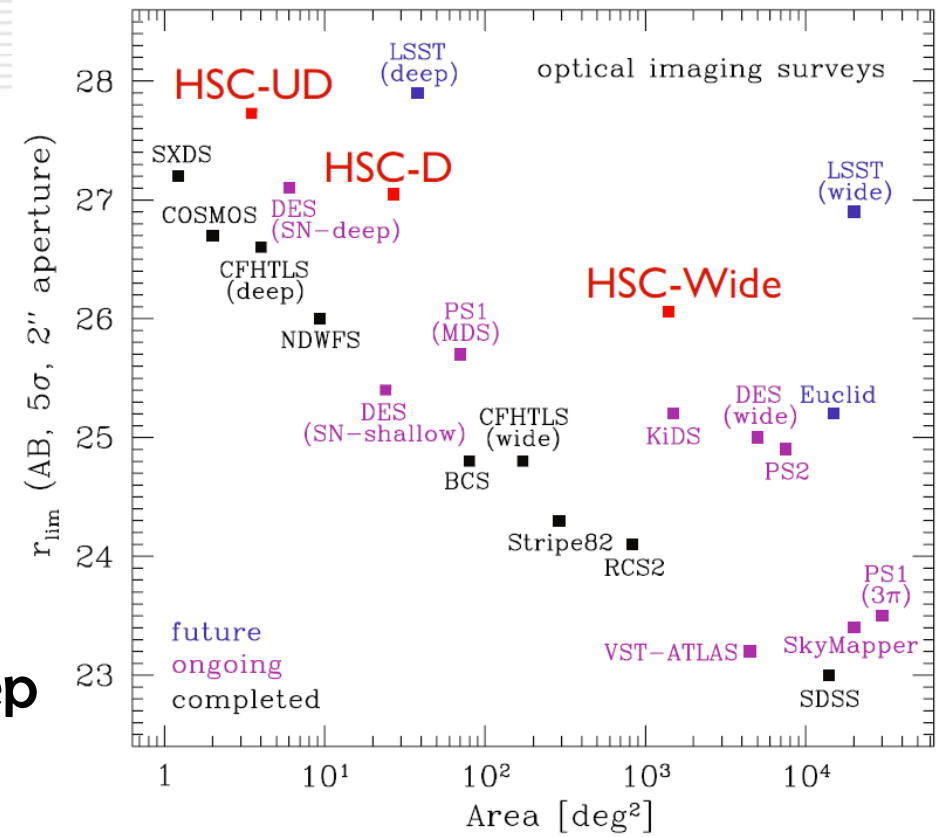
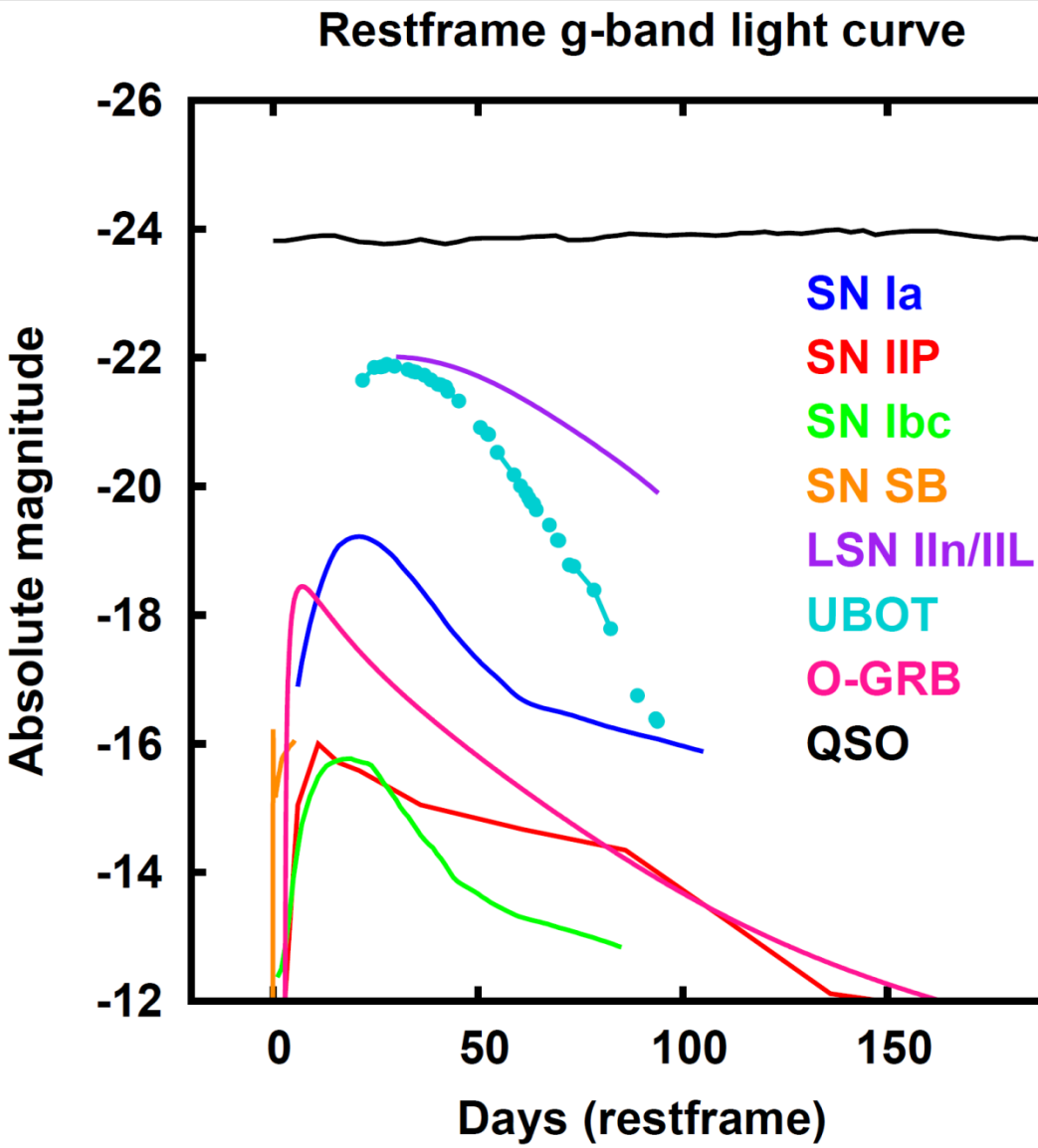


Table 1: **Summary of HSC-Wide, Deep and Ultradeep layers**

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

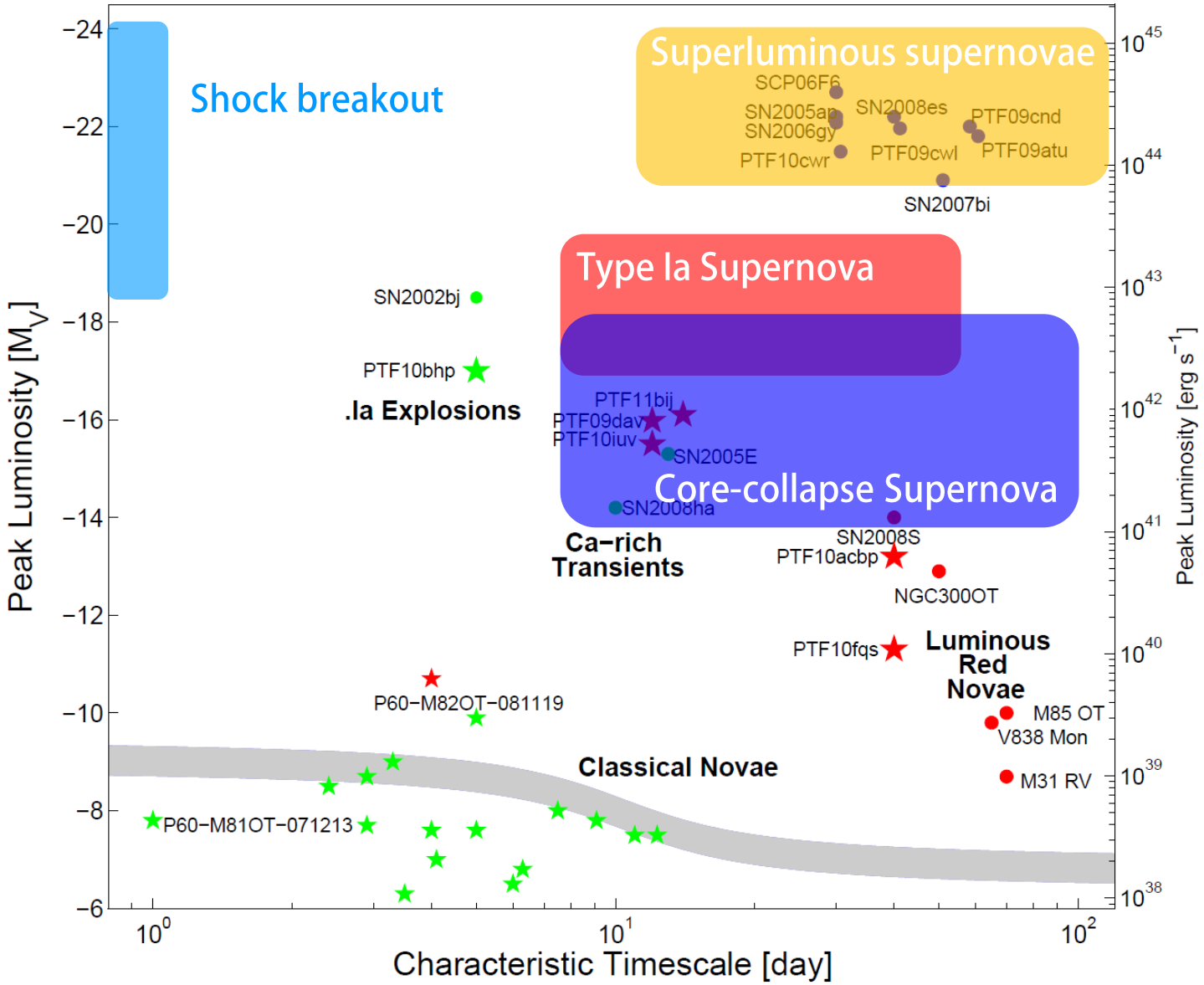
Objectives

- Type Ia SN
- Core-Collapse SN
- Shock Breakout
- Superluminous SN
- GRB Orphan Afterglow
- QSO



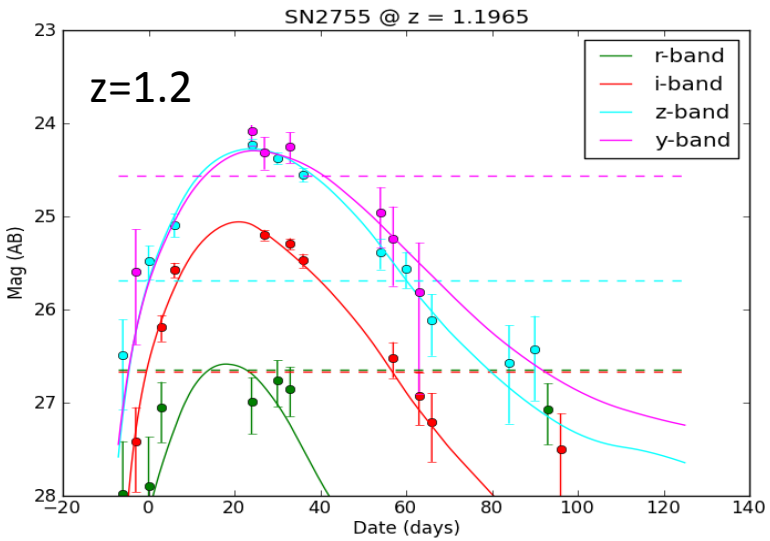
Time scales

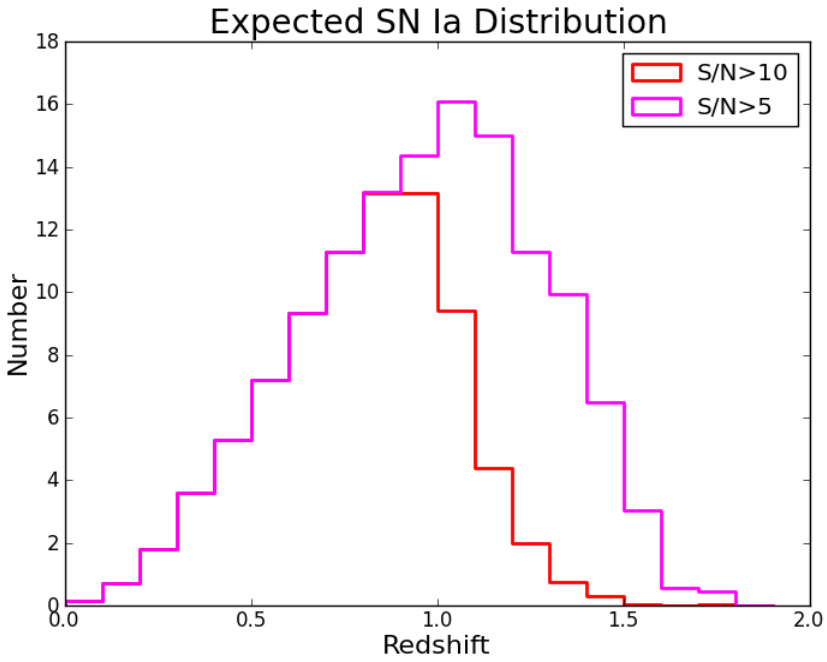
day ⟷ year



Type Ia SNe

(deep)/UD





- 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 at z > 1 is still small number.

HSC-UD survey

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

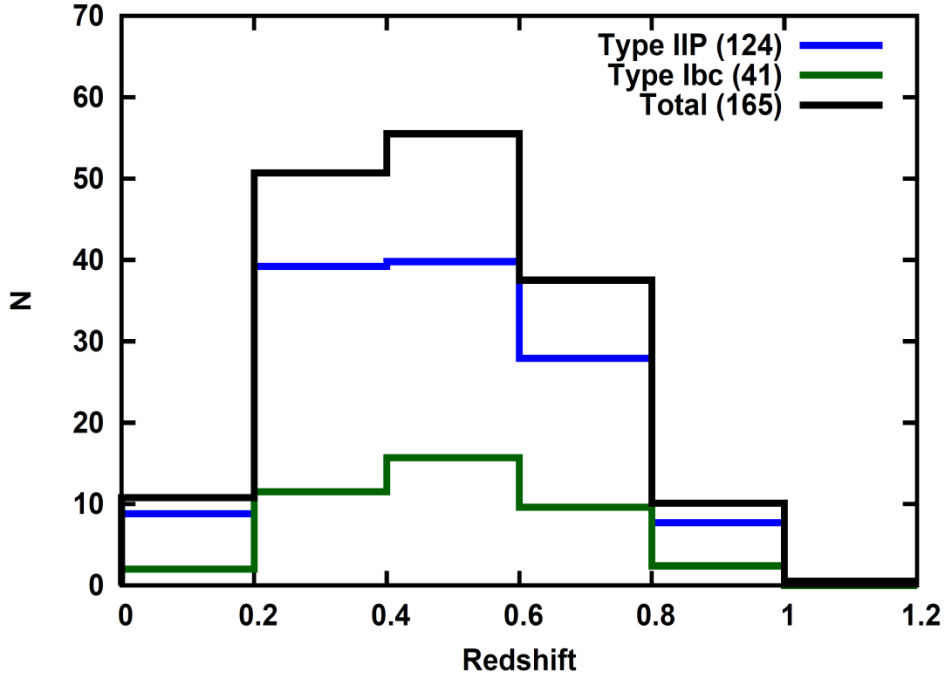
~80 SN (~20 at z > 1) for S/N>10

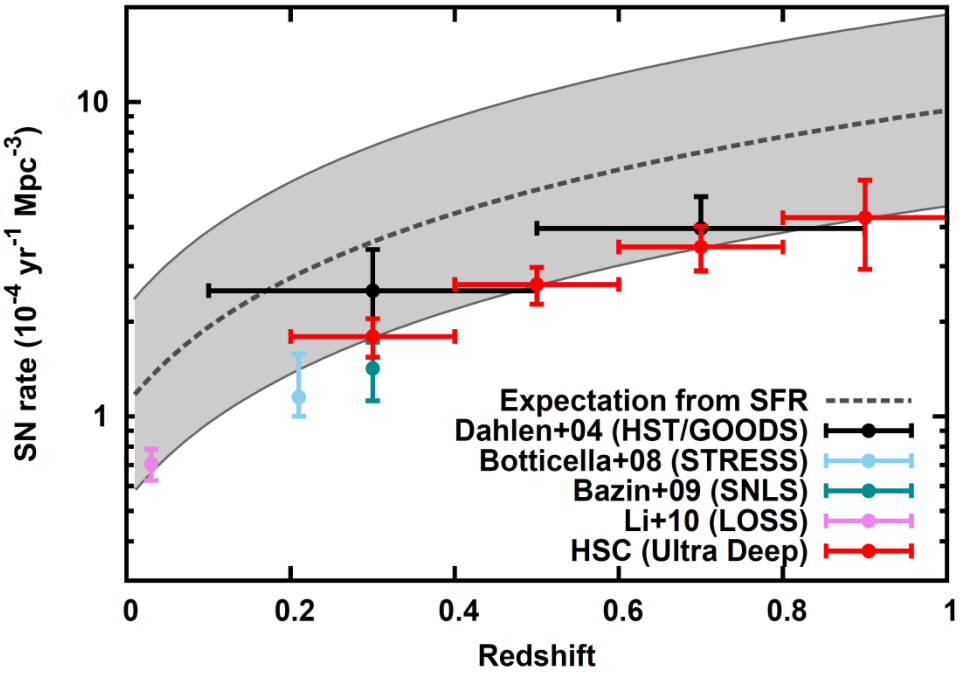
(3 bands detection)

(deep)/UD

Core-collapse SNe

- Available for free with SNe Ia cadence





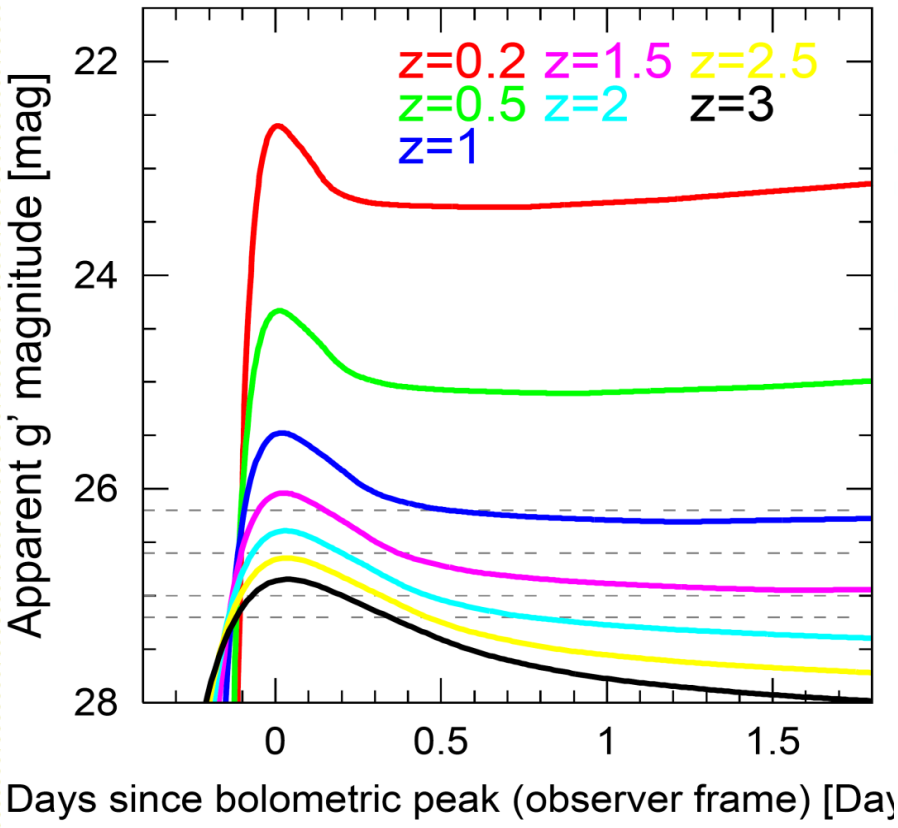
Survey	Tel.	Redshift	# of SNe
SNLS	CFHT	~0.3	120
GOODS	HST	0.1–1.3	45
HSC-UD	Subaru	0.2–1.0	~165

led by Masaomi

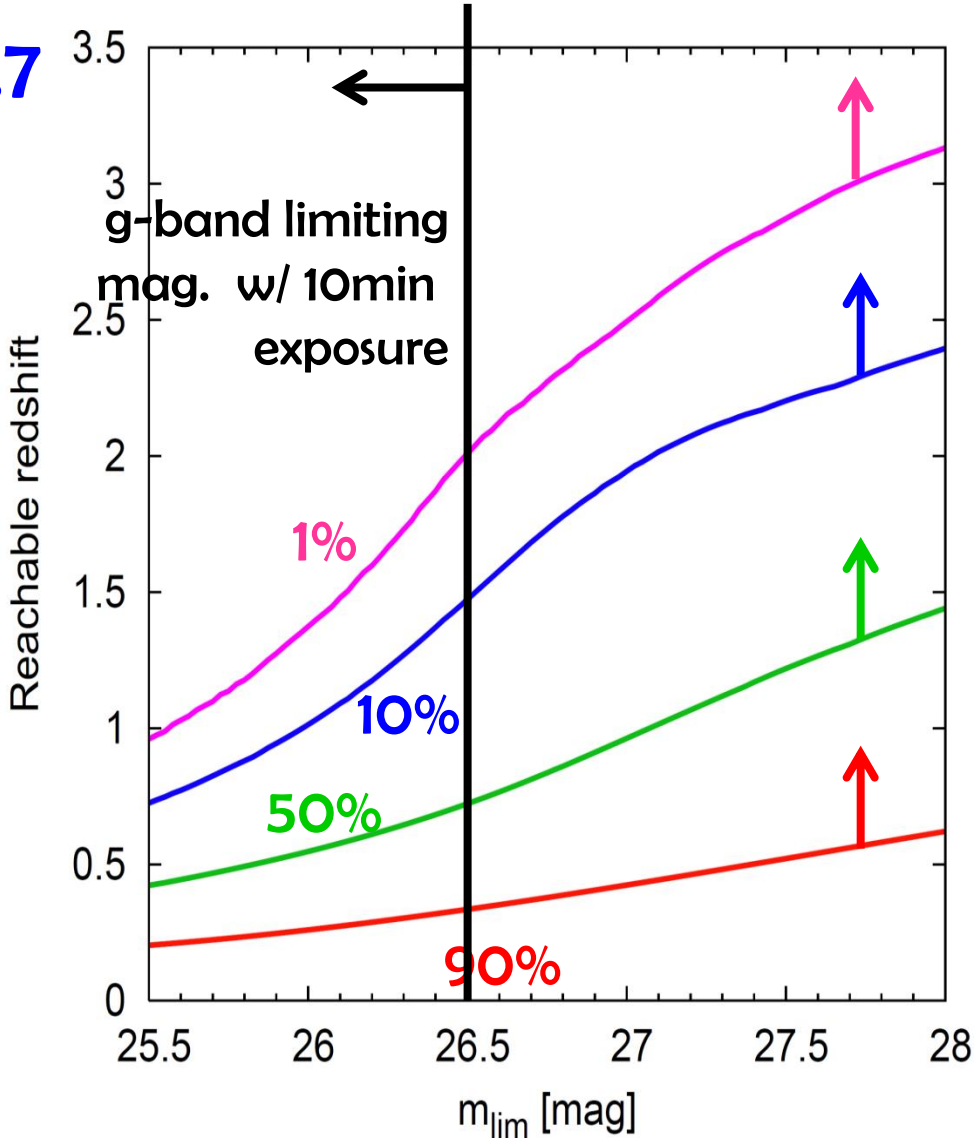
Wide/Deep/UD

Shock breakout

50% of detection is at **z>0.7** and **10%** is at **z>1.4**.



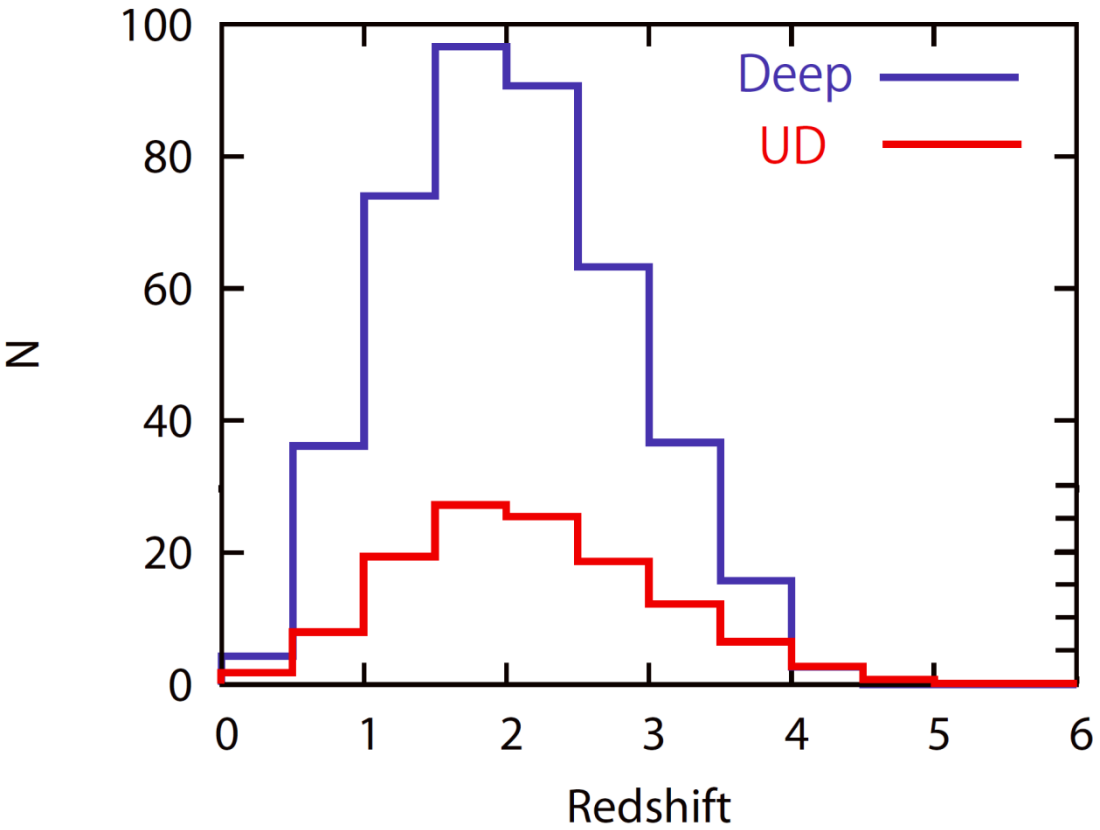
NT+11

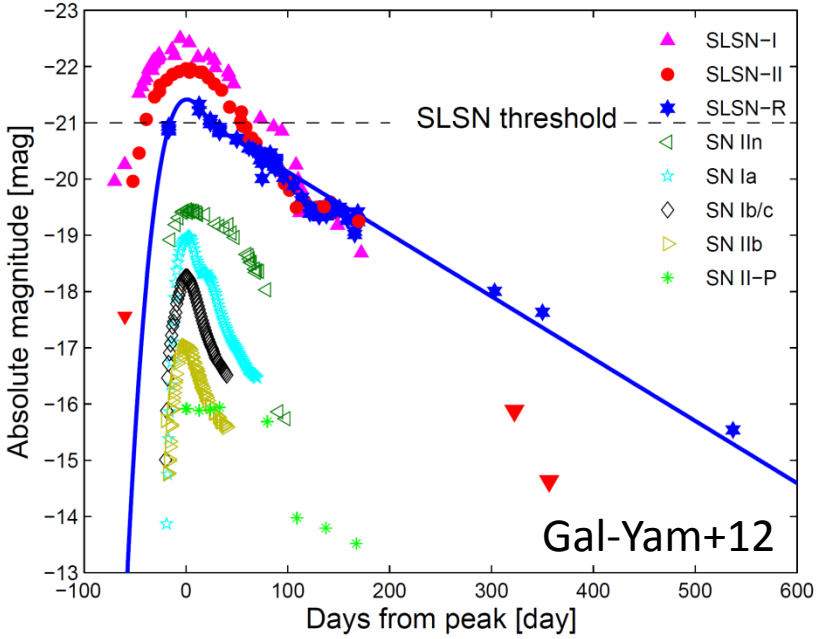


deep/UD

Super Luminous Supernova

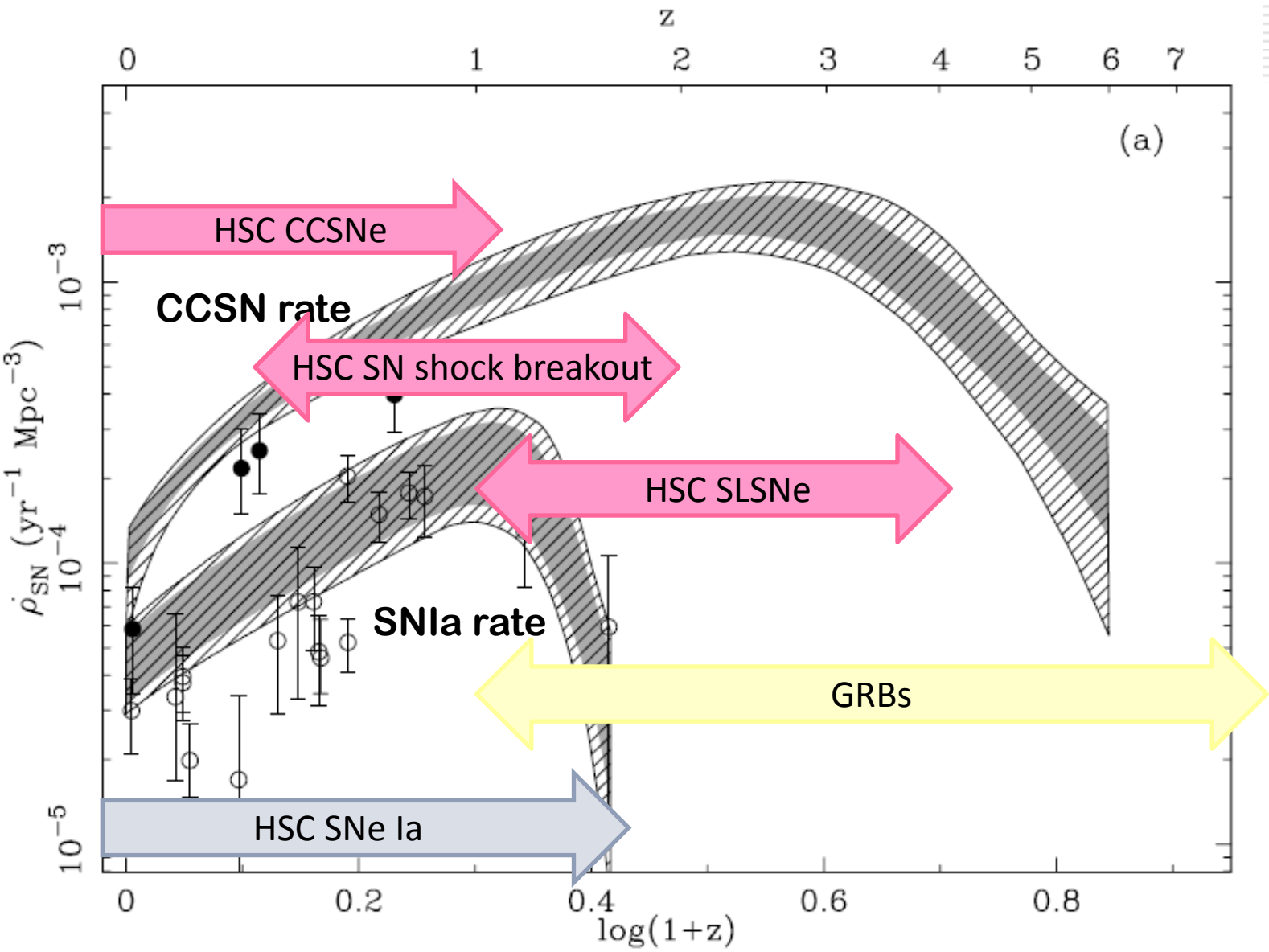
- Rare extremely bright SNe
- CCSN detection @ z~4





led by Takashi

SN rate history with HSC



Hopkins & Beacom 06 and references therein

Summary

- Wide-field transient survey is important for supernova/transient studies.
- We started/are starting two transient surveys.
  - High-cadence nearby optical survey (KISS)
  - High-z optical survey with Subaru/HSC
- Many SN science cases are available with HSC-wide/deep/UD.
  - We will detect SNeIa, CCSNe, Shock breakouts, SLSNe.
  - A ladder of SNe upto z~4 constrains star formation history and connects nearby SNe to GRBs