

# **Shock breakout survey with Hyper Suprime-Cam**

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24<sup>th</sup> Nov 2014  
Subaru seminar

# Outline

- Supernovae and shock breakouts
- Transient surveys
- Initial results of the HSC shock breakout survey

# **Supernovae and shock breakouts**

# Supernovae

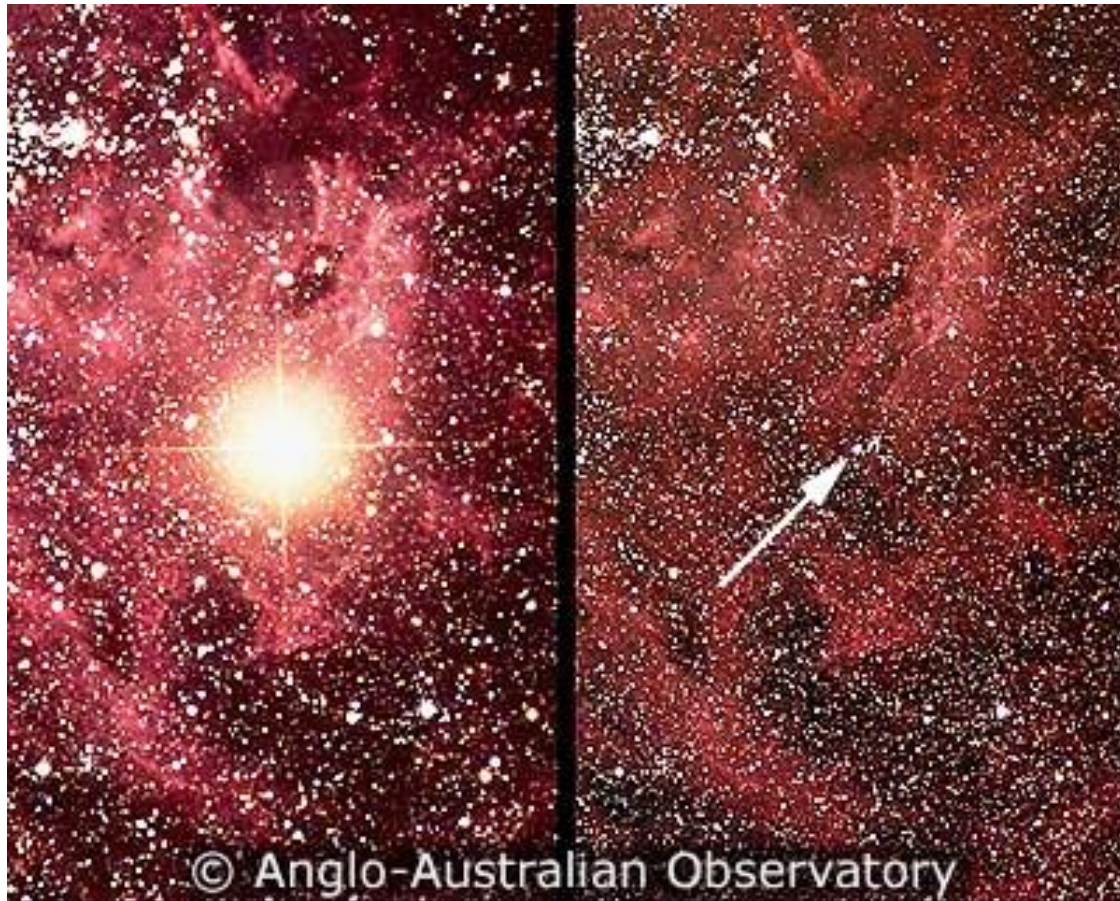
## -explosions of stars-

Very bright

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

Huge energy

$$E_K \sim 10^{51} \text{erg}$$



© Anglo-Australian Observatory

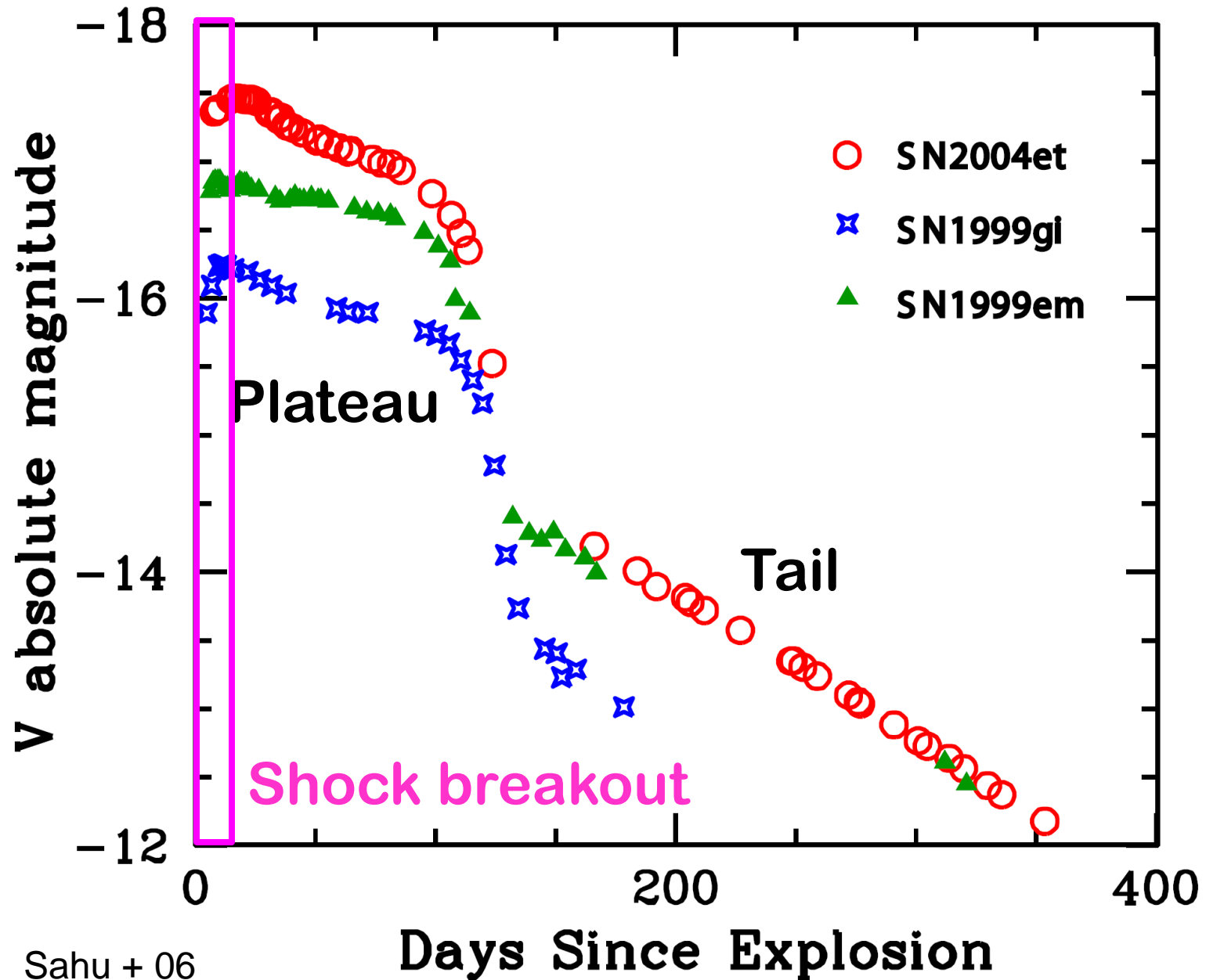
**SN1987A**

# Light curve of supernovae <sup>©SCP</sup>

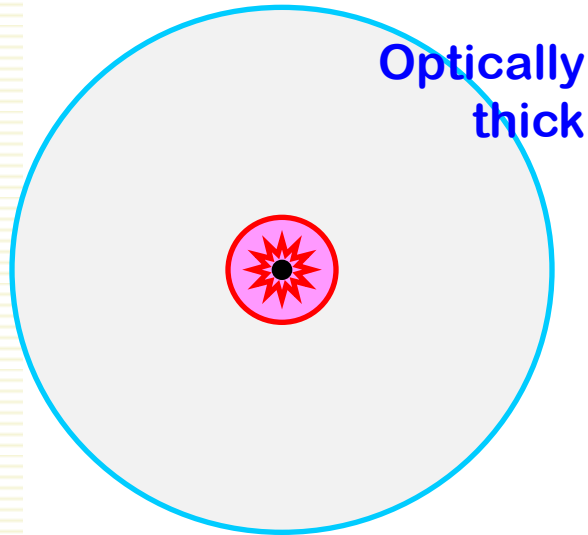
~1month  
↔



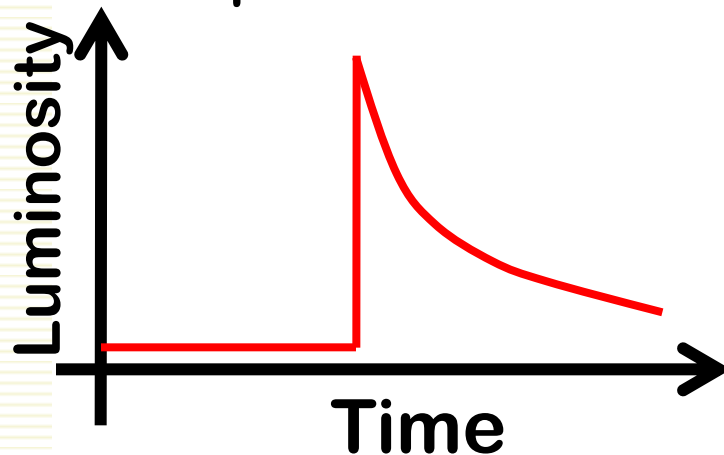
# V-band LCs of Type IIP SNe



# 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

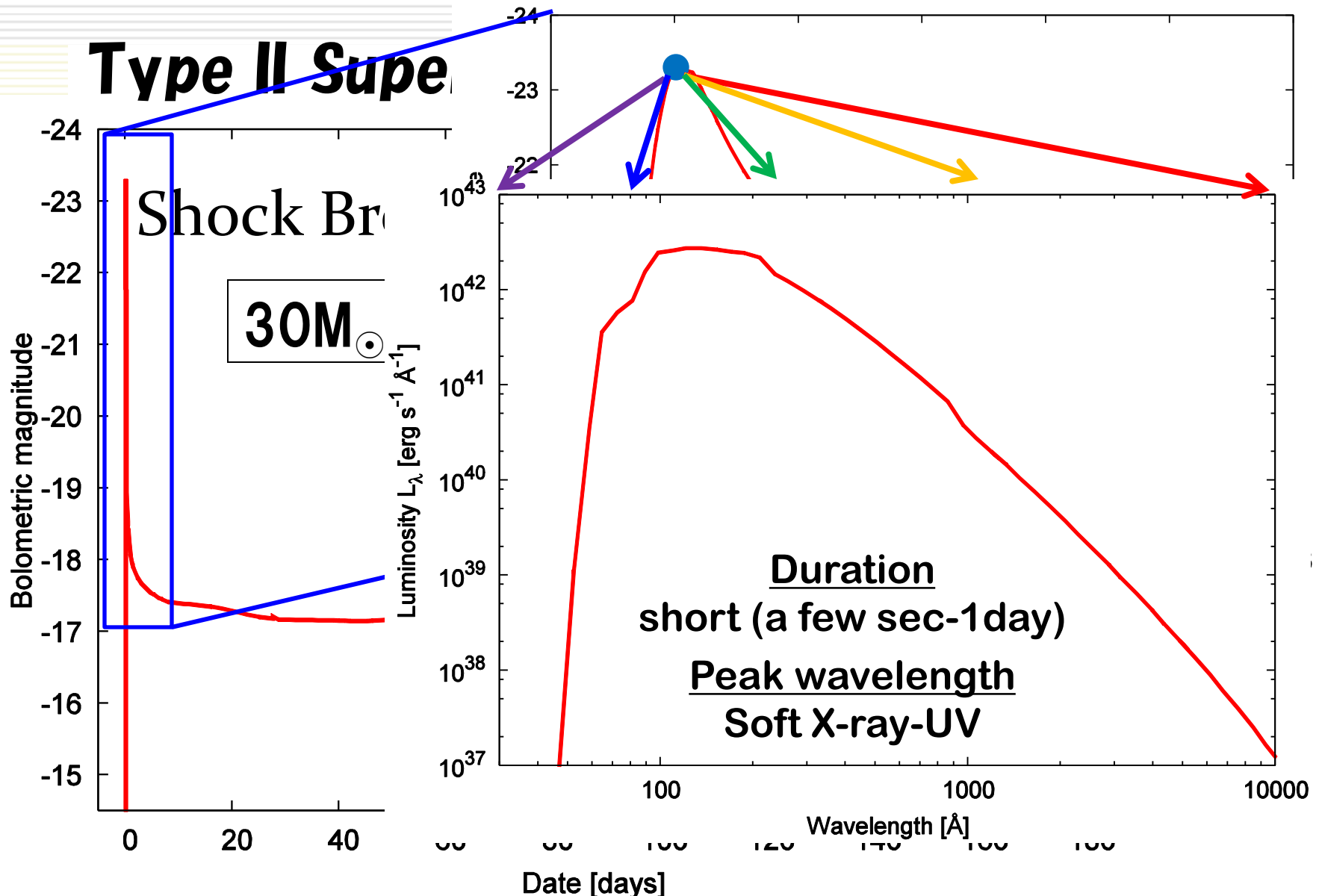
$$T \sim R^{-3/4} E^{1/4}$$

Typical properties

**timescale:** 1sec ~ 1day

**peak wavelength:** X-ray ~ UV

# Theoretical light curve of a Type II SN

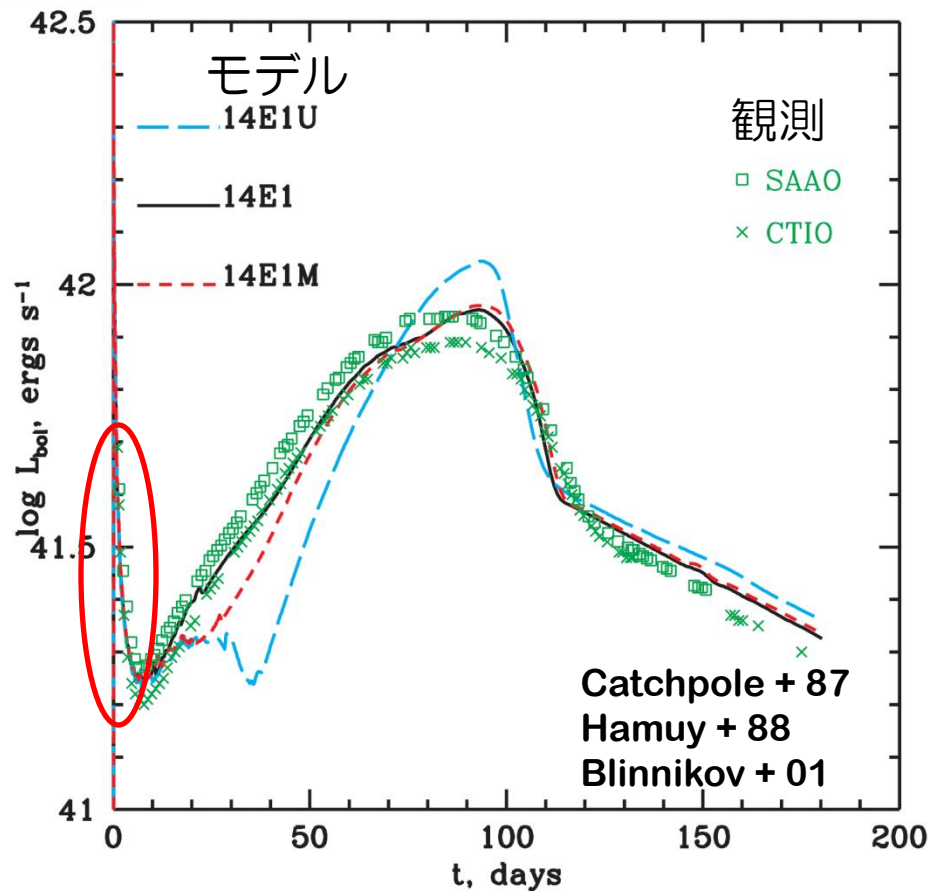




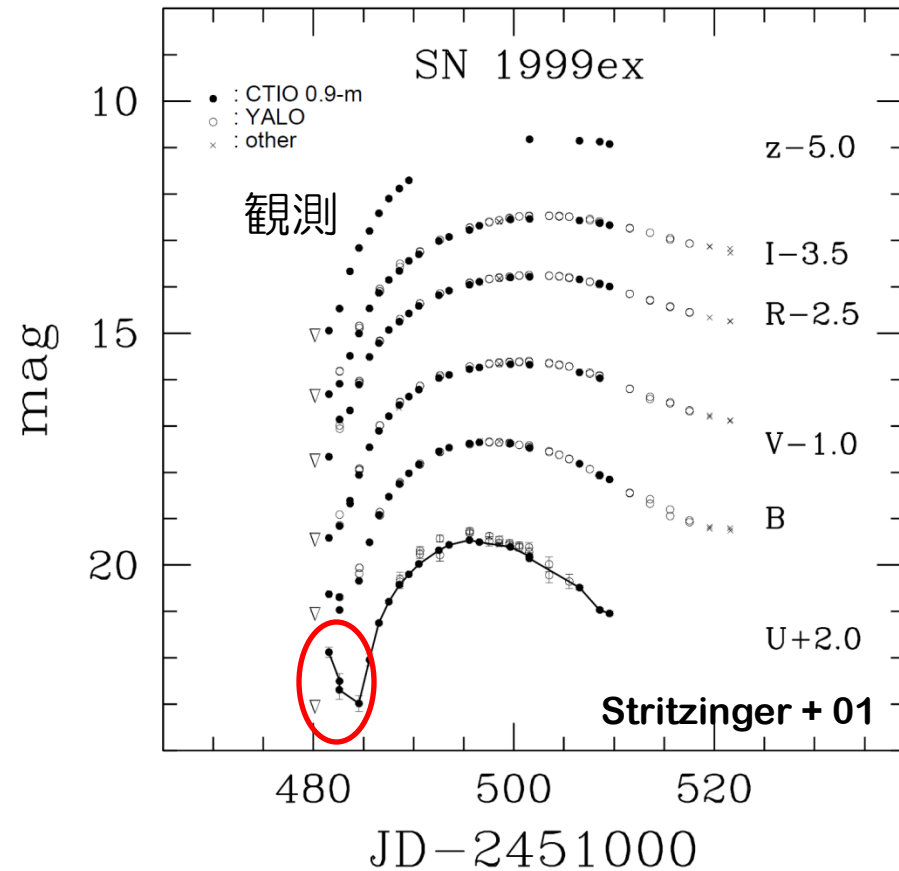
# Observations before 2008

## -Tail of shock breakout-

### Type II-peculiar SN1987A

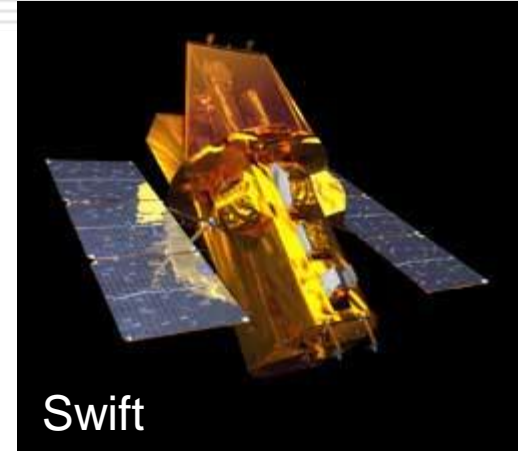


### Type Ib SN1999ex

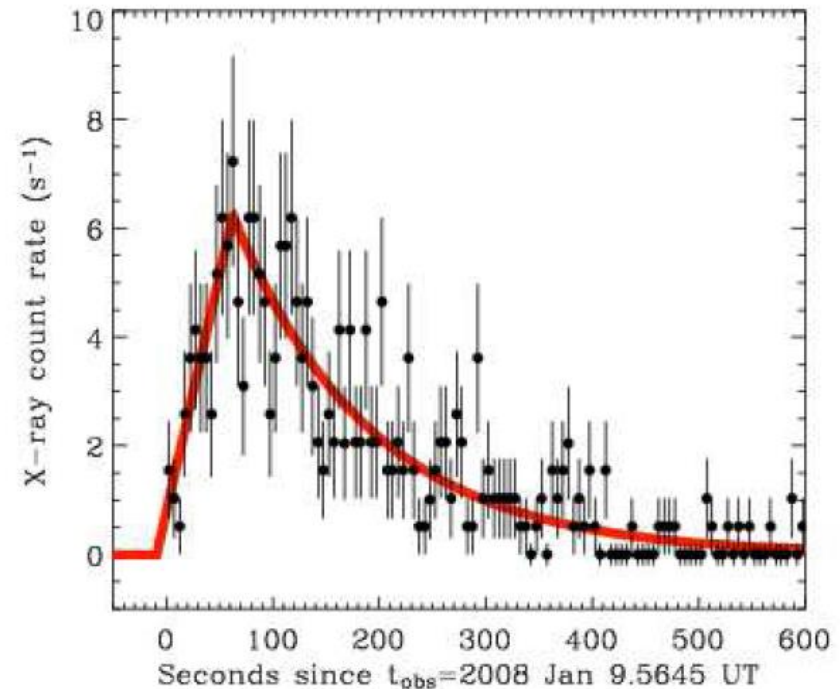


# Serendipitous detection of shock breakout -Type Ib SN2008D/XRO080109-

Soderberg + 08; Modjaz + 09



NGC 2770  
Supernova factory



# Shock breakouts of Type IIP SNe

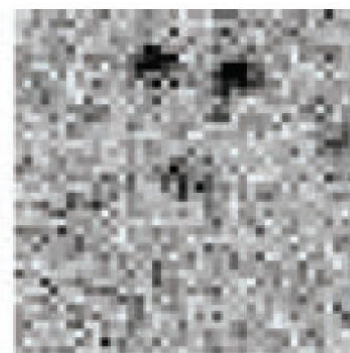
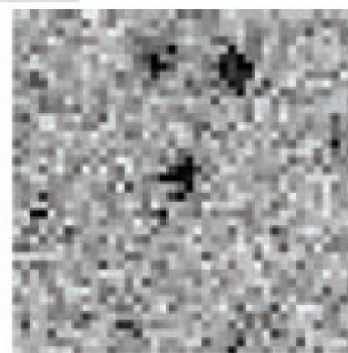
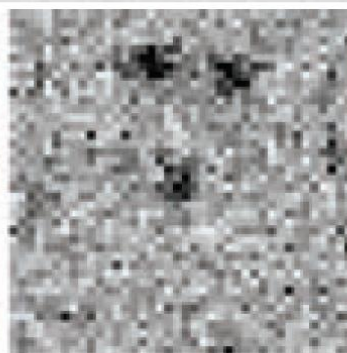
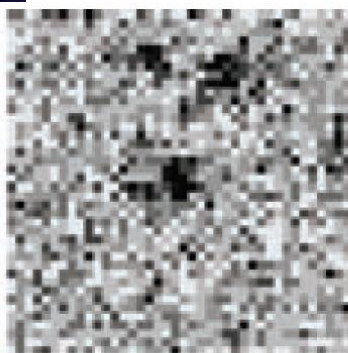
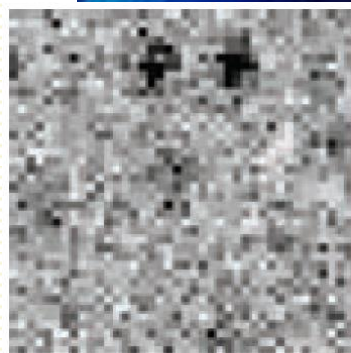
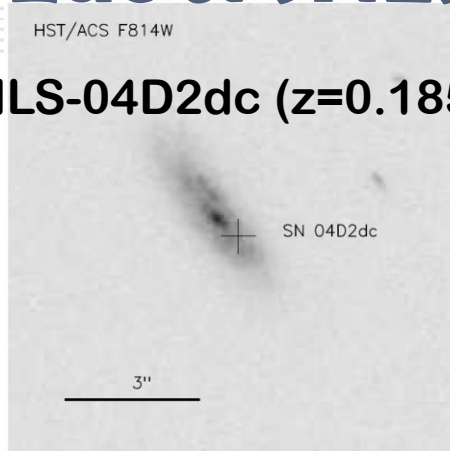
## -SNLS-04D2dc & SNLS-06D1jd-

**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



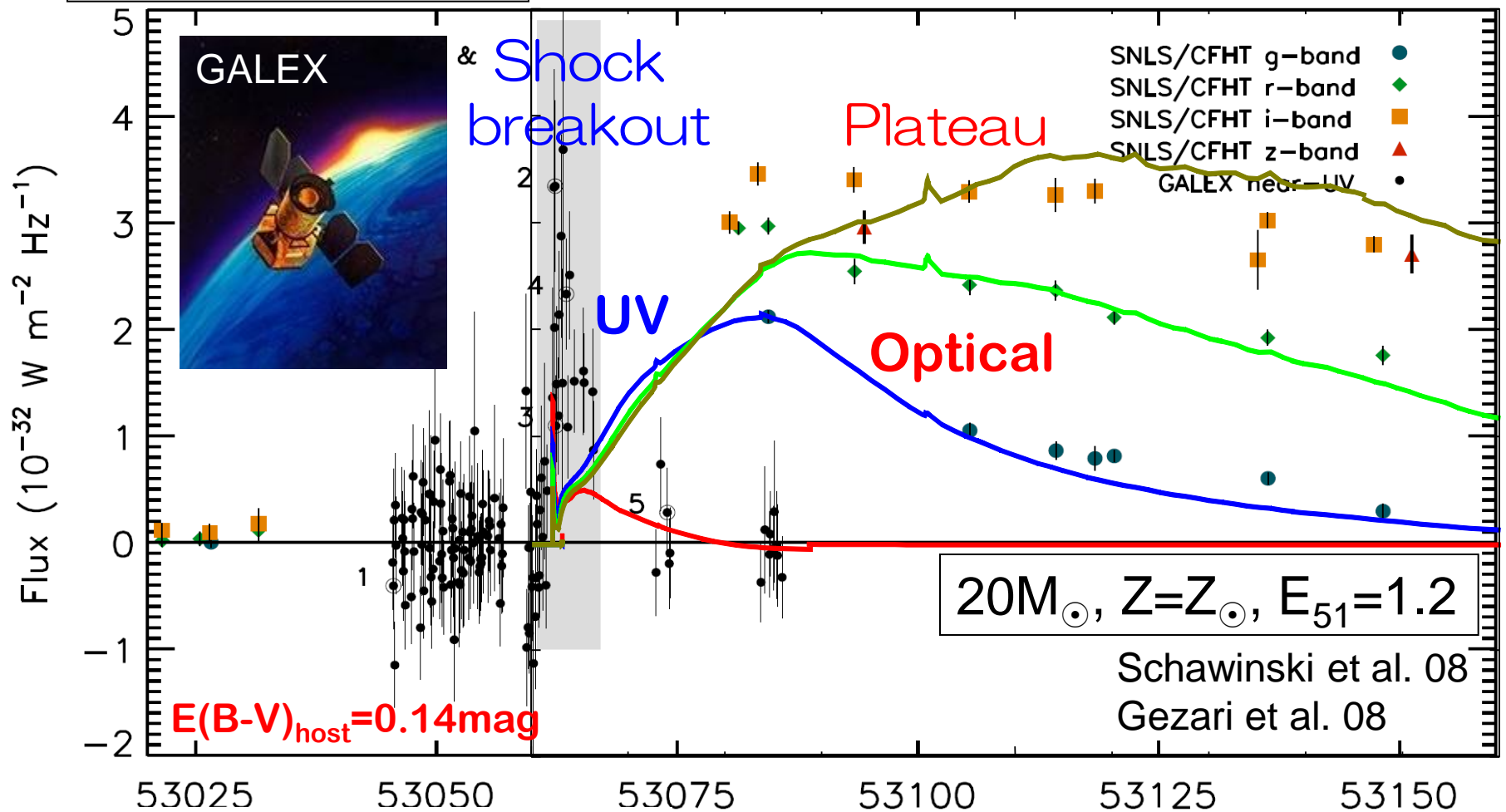
# Shock breakouts of Type IIP SN

## -Observations and model-

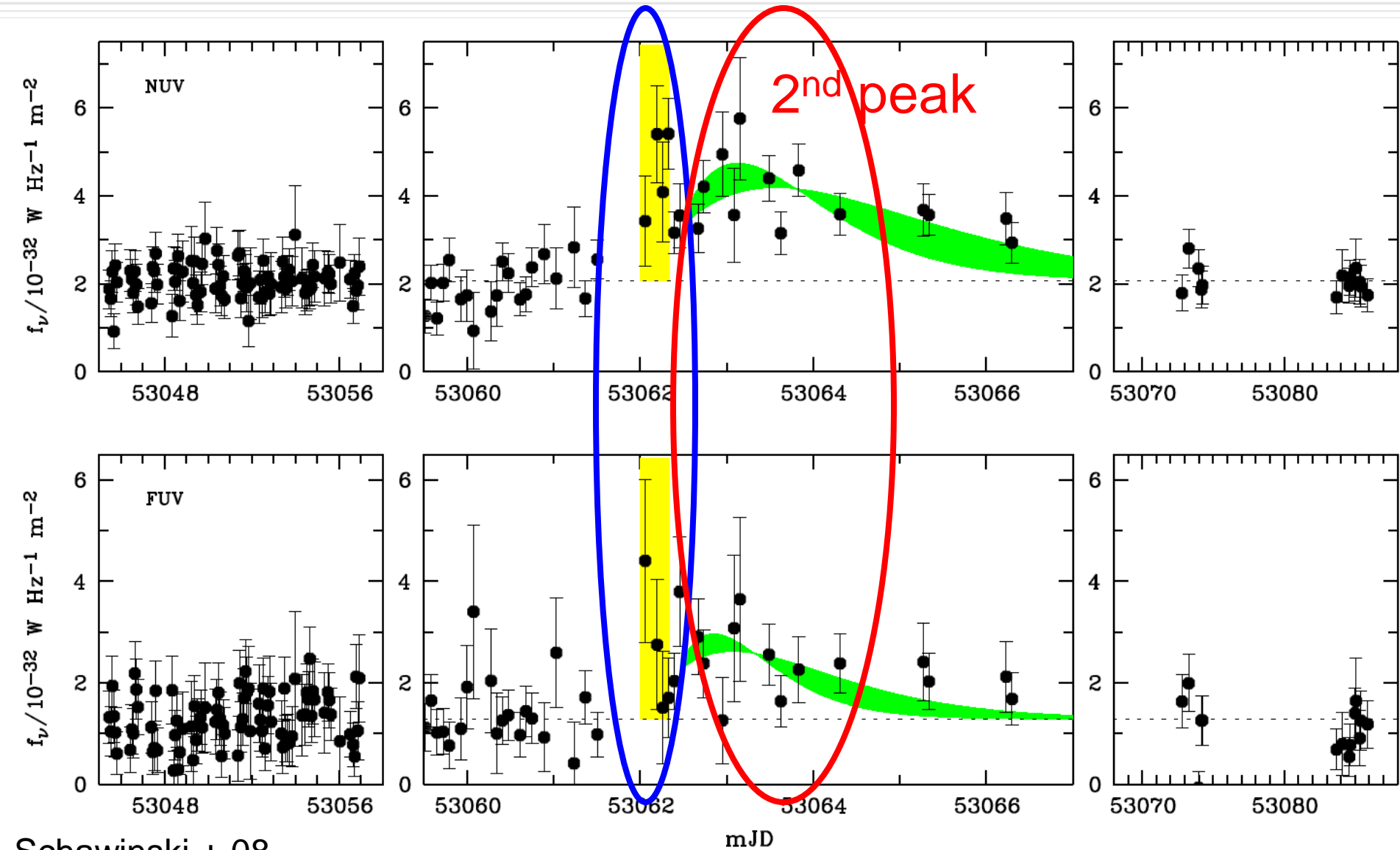
SNLS-04D2dc

SNLS

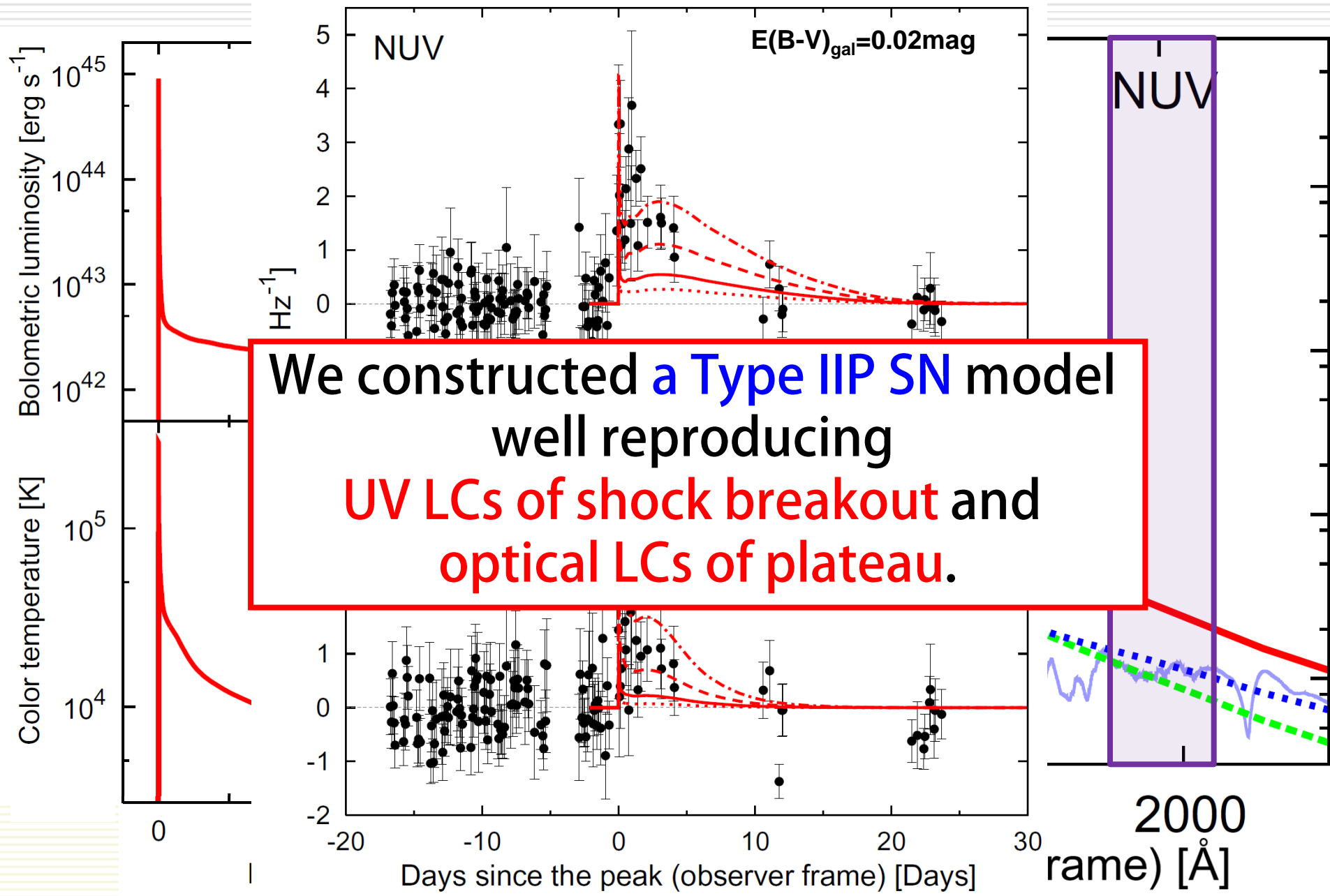
SuperNova Legacy Survey



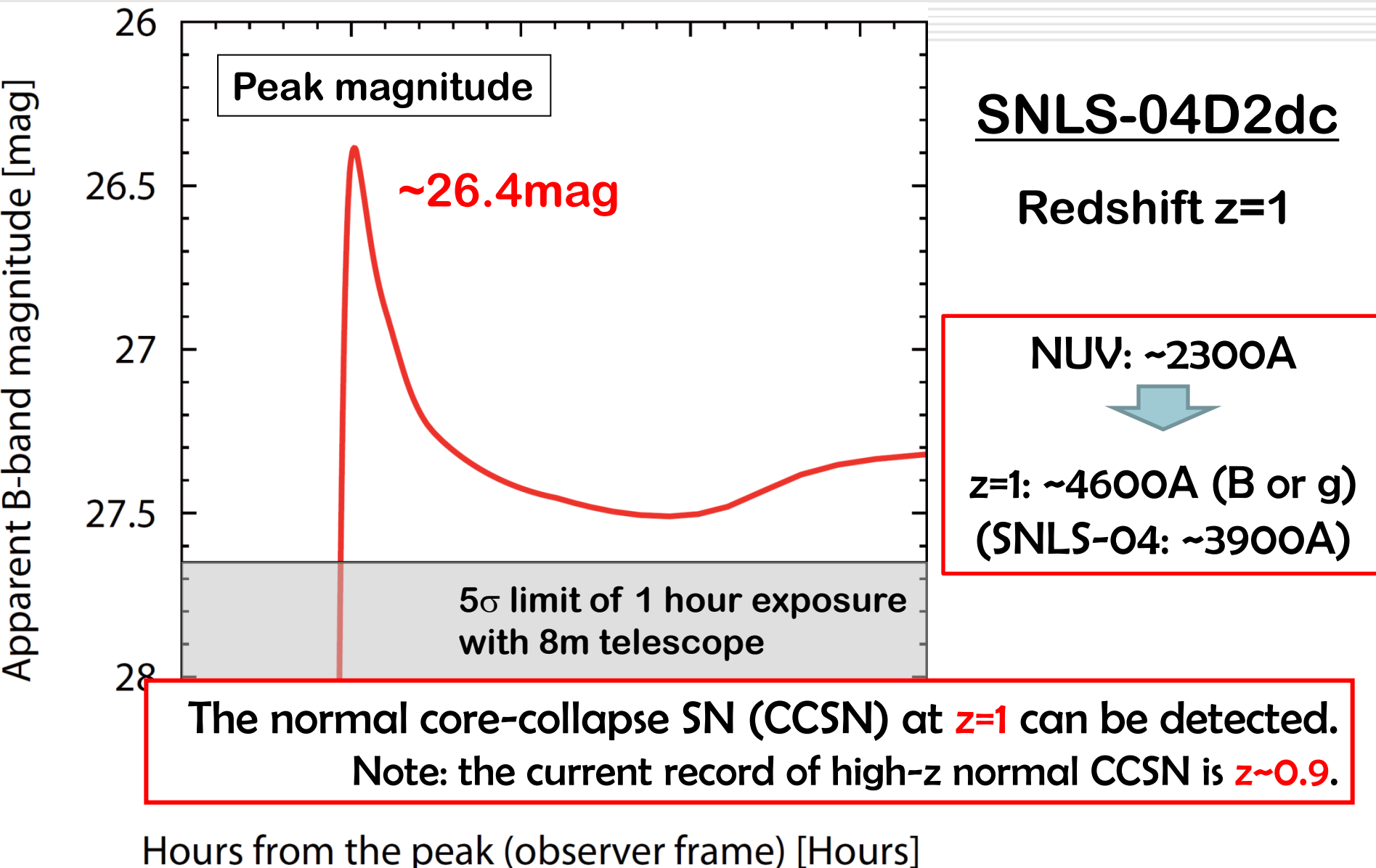
# UV LCs of Shock breakouts



# Model: light curve & color evolution



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

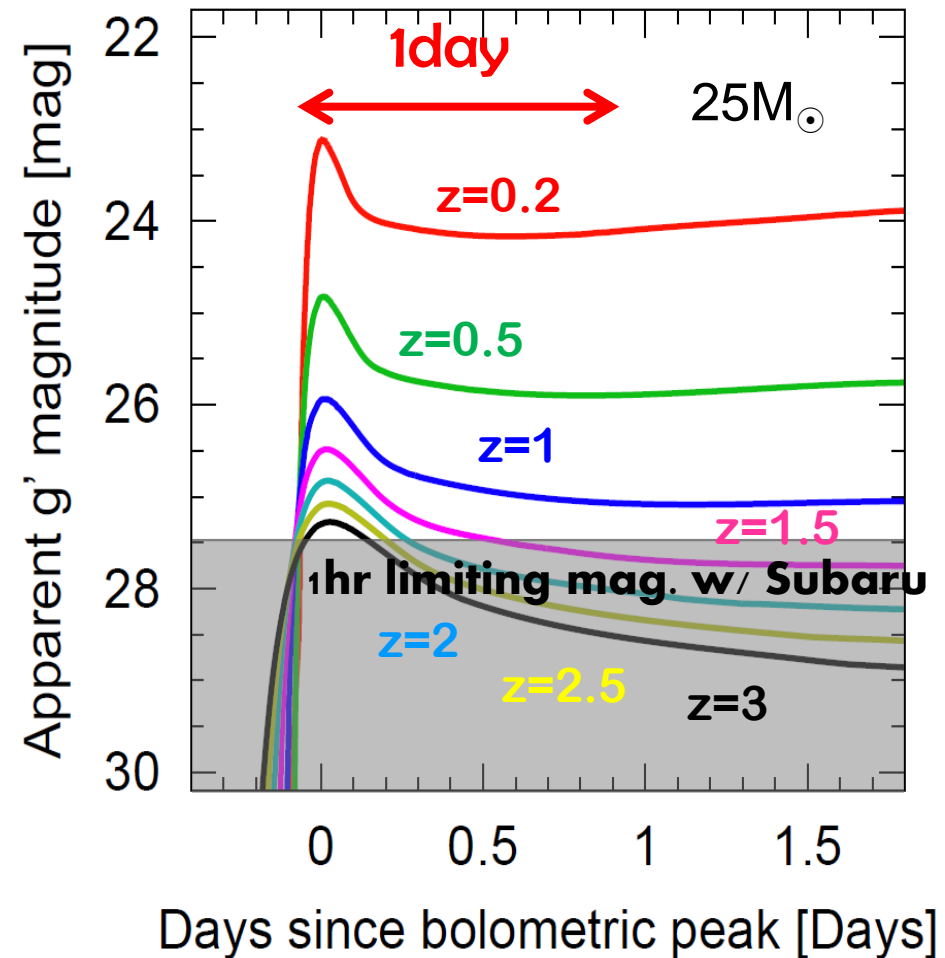
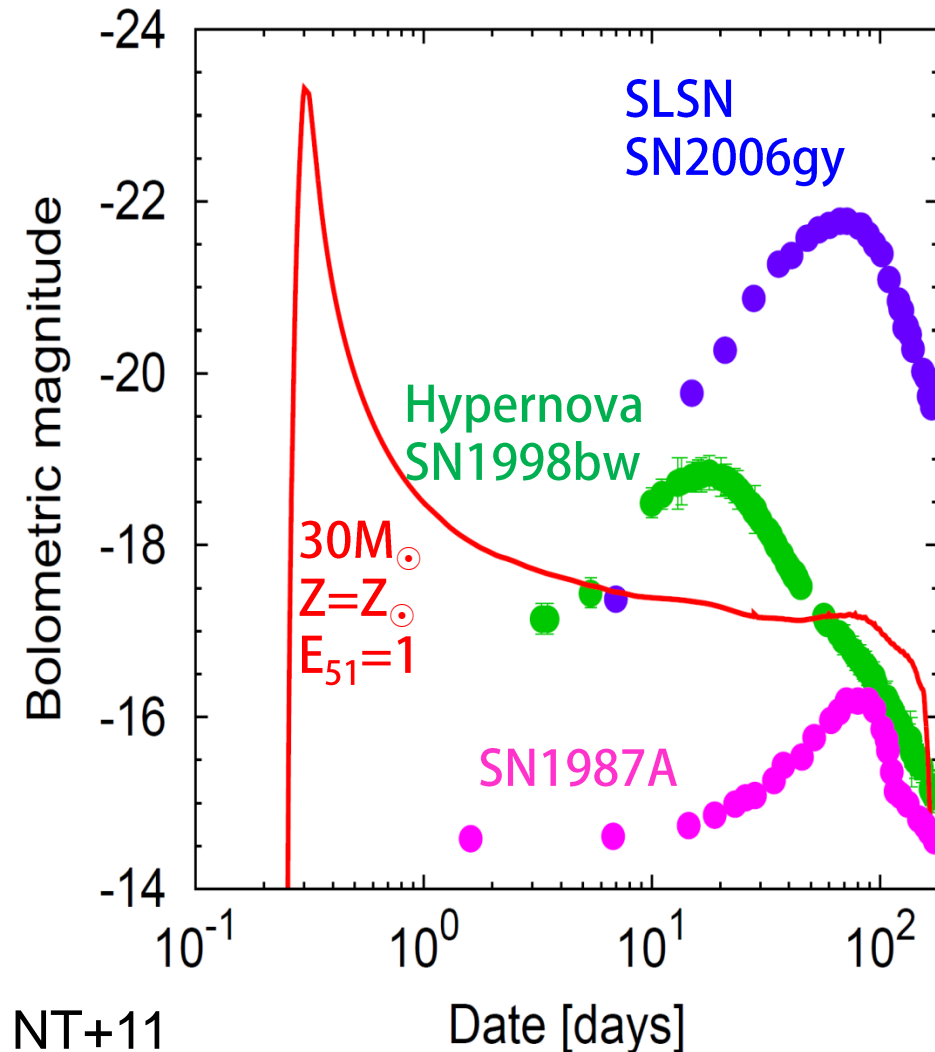


# A probe of a **high-*z*** CCSN

**Common:**  $\sim 70\%$  of CCSNe are Type II

■ Brighter than SLSNe

■ Detectable up to  $z \sim 3$





# **Transient surveys**

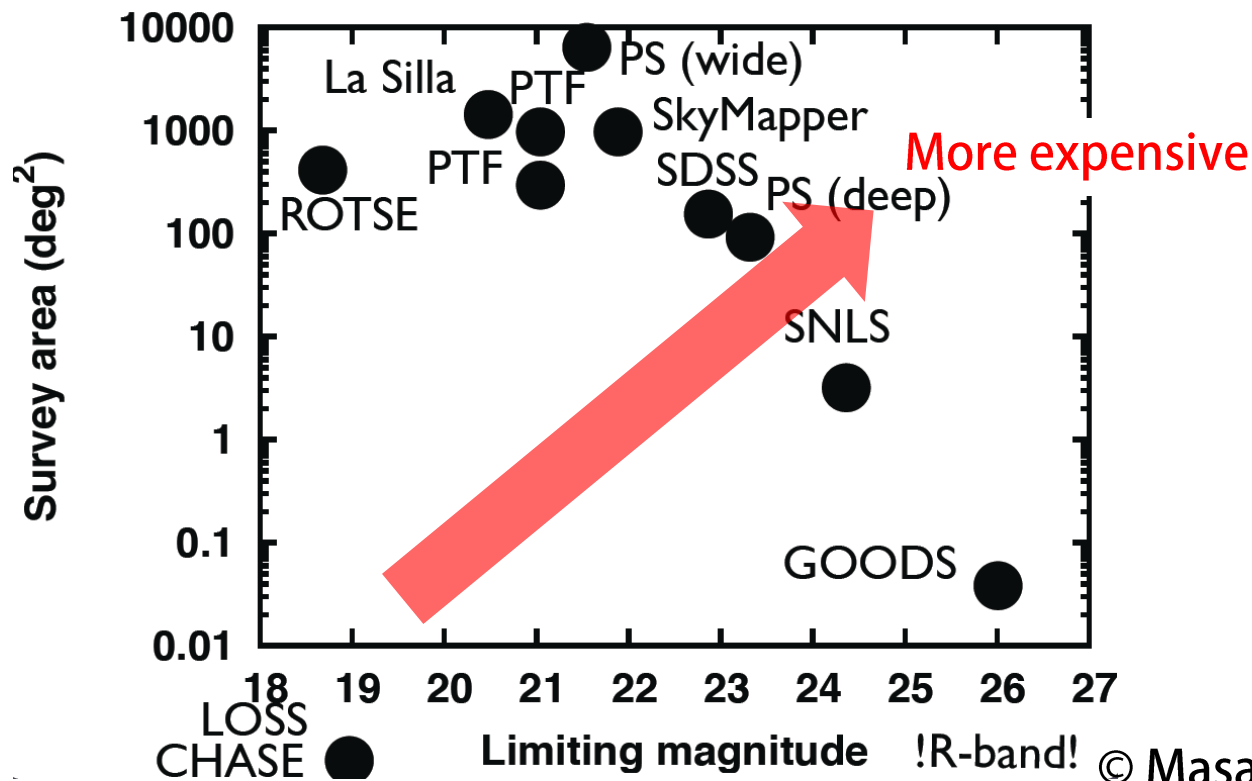
# **Supernovae take place without precursors**



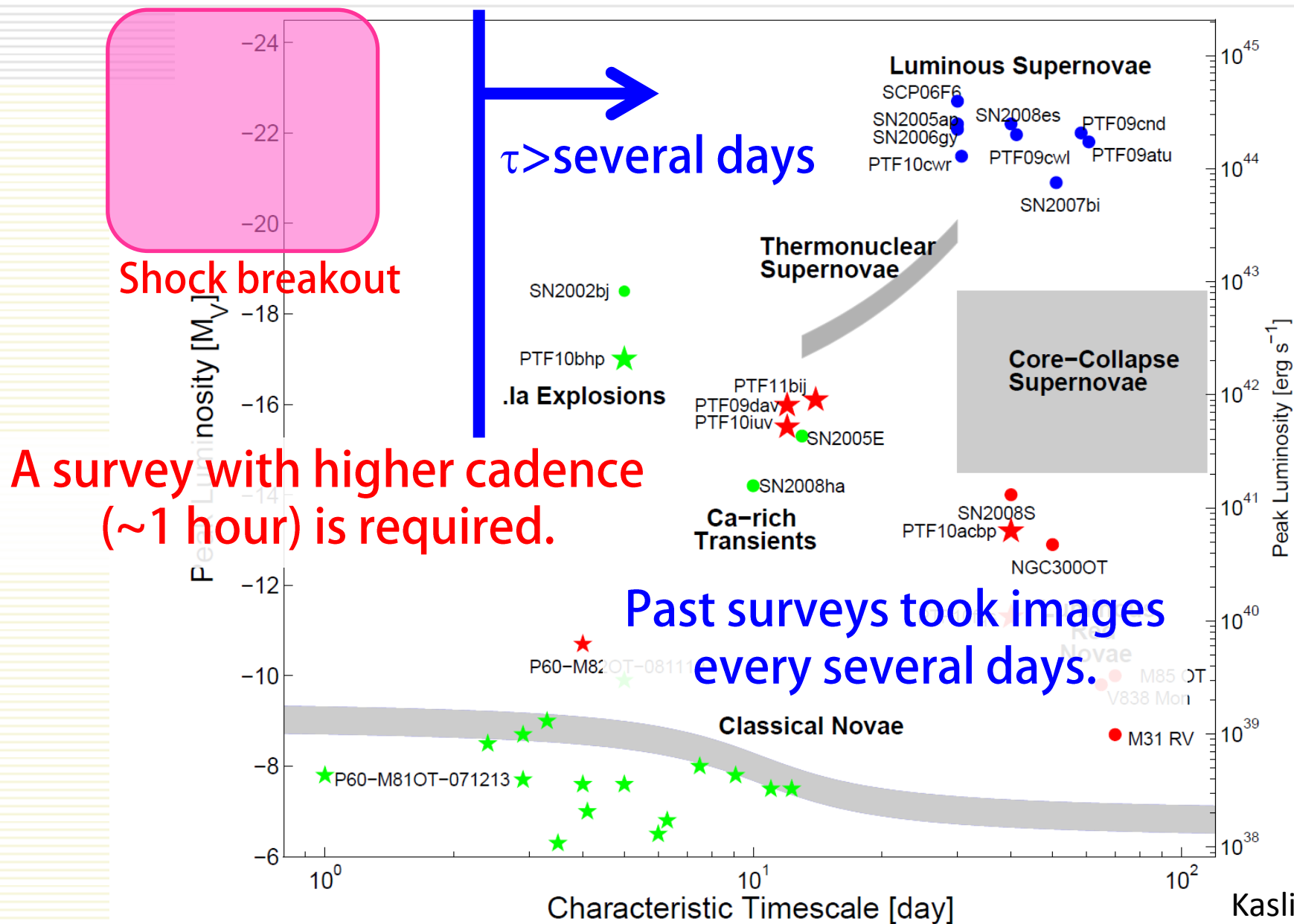
© Anglo-Australian Observatory

# Transient surveys

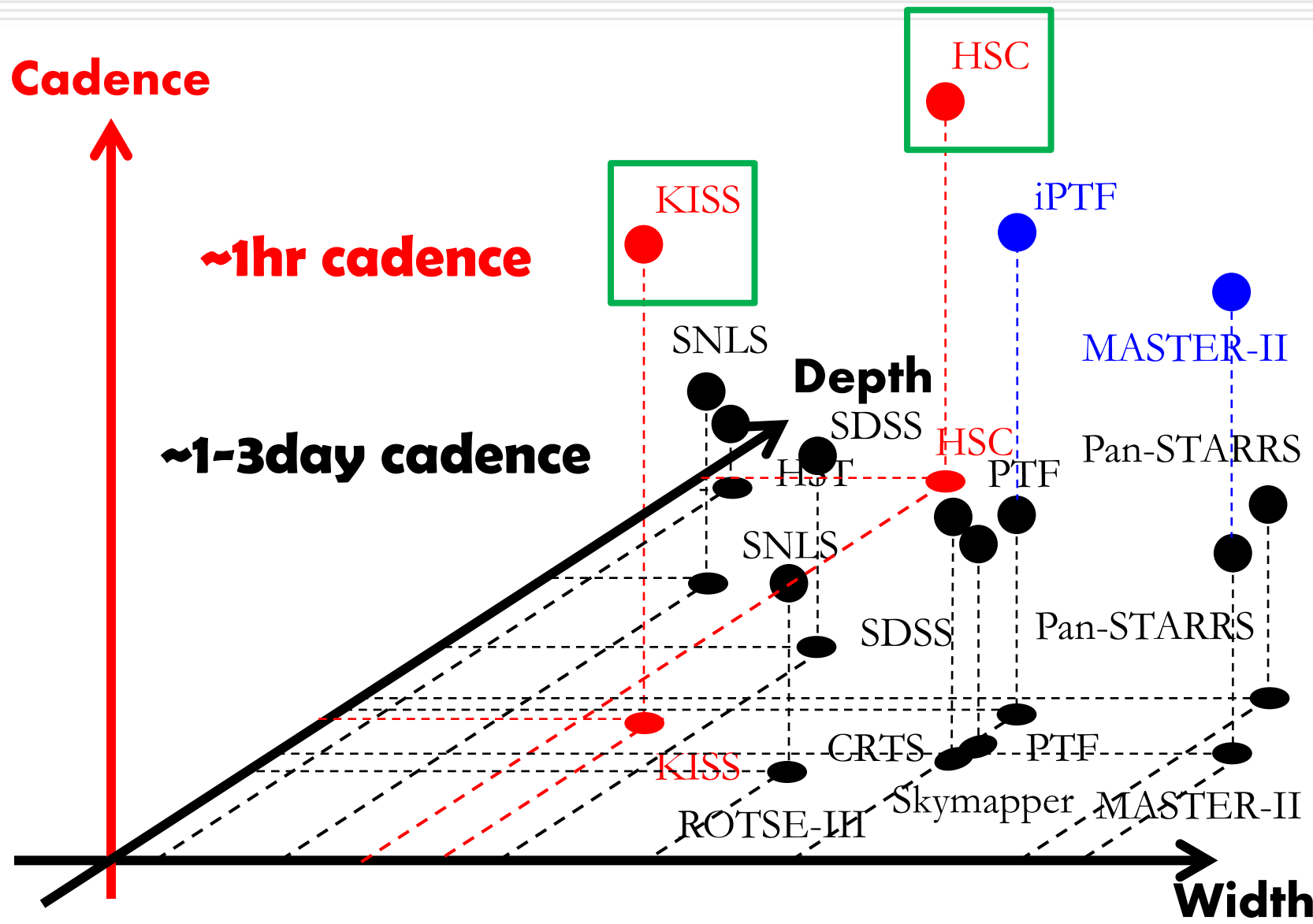
- **Aim:** discovery of **new** transients
- **Req.:** **large** survey volume
- **Method:** **wide** and/or **deep** observations



# Time scale and brightness of transients



# New dimension of survey



# Two high-cadence optical transient surveys

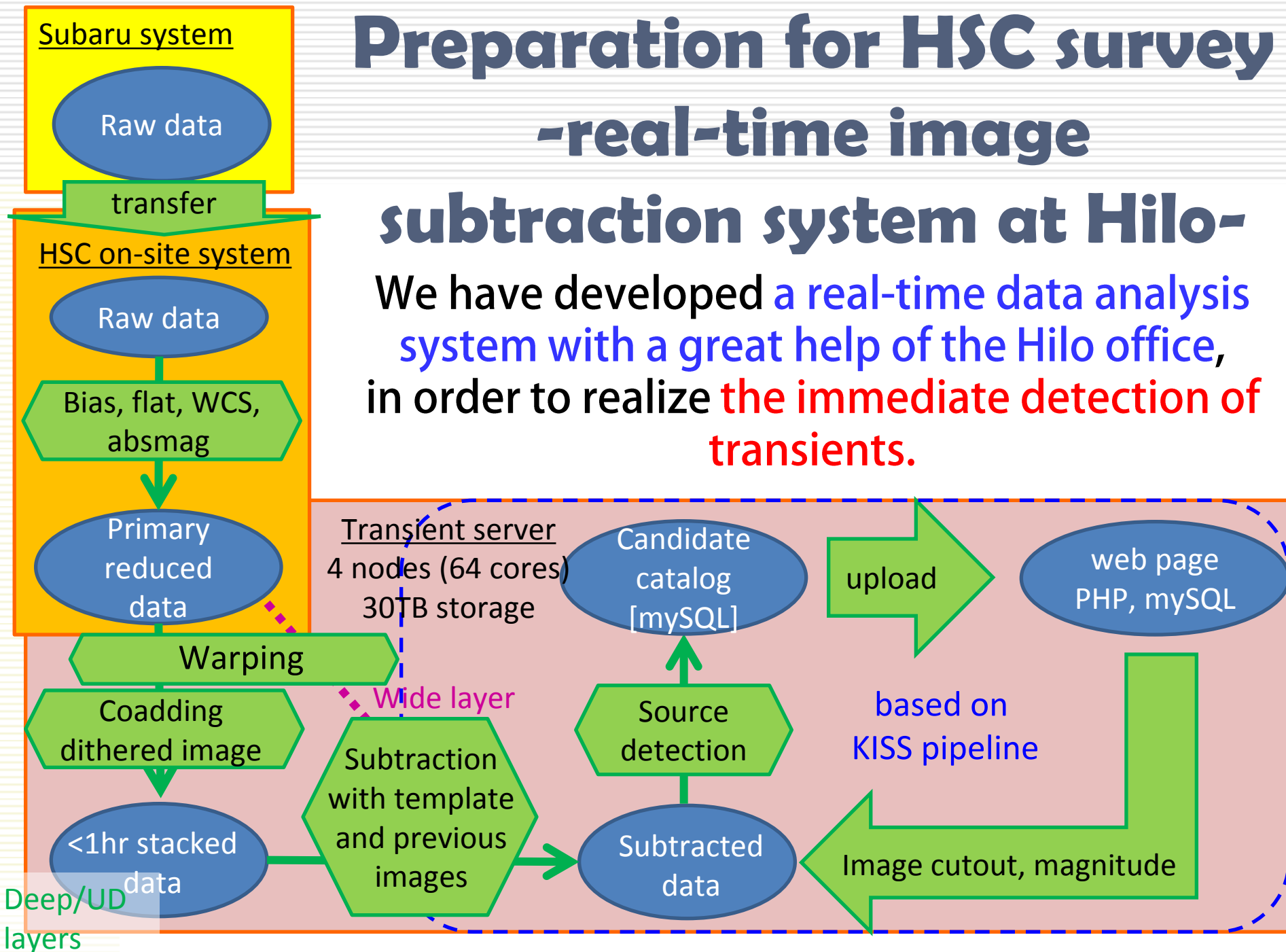
- **Subaru/Hyper Suprime-Cam survey**
  - High- $z$  supernova survey
  - from Jul 2014
  - Aim: detection of high- $z$  shock breakouts
- **Kiso Supernova Survey (KISS)**
  - Nearby supernova survey
  - from Apr 2012
  - Aim: detailed studies of nearby shock breakouts



# Preparation for HSC survey -real-time image

## subtraction system at Hilo-

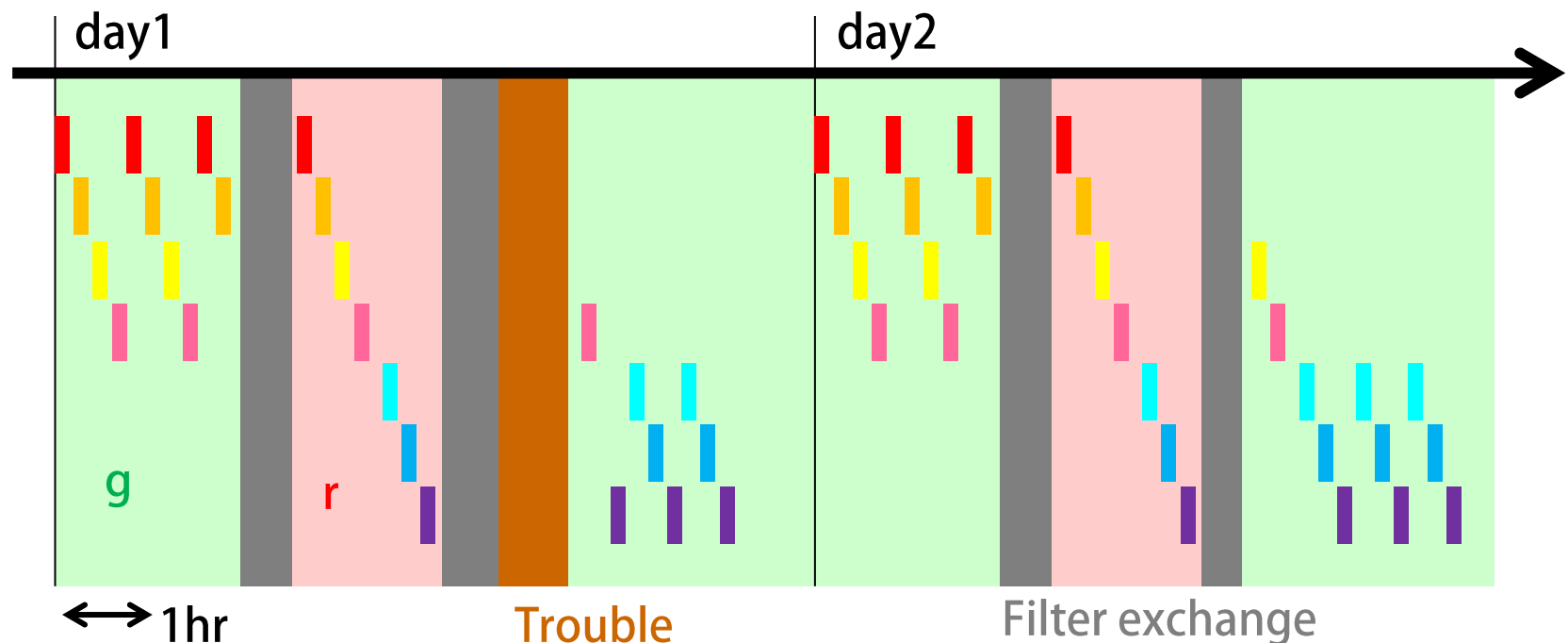
We have developed a real-time data analysis system with a great help of the Hilo office, in order to realize the immediate detection of transients.



# HSC openuse observation

## -2 and 3 July 2014 (UT)-

- 7 fields ( $\sim 12\text{deg}^2$ )
- 2 continuous nights
- 3 **g** and 1 **r** 10min exposures with  $\sim 1$  hr interval



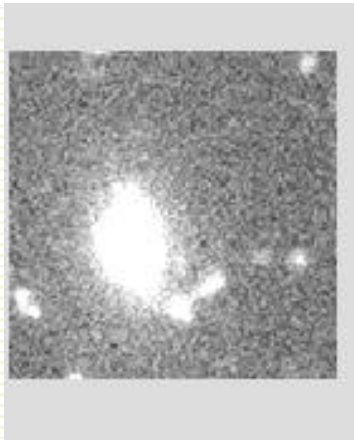


# HSC openuse observation

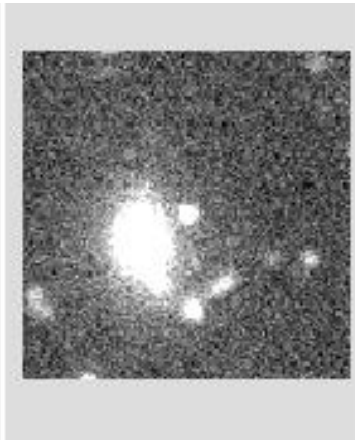
## -2 and 3 July 2014 (UT)-

- The quick image subtraction system lists candidates at **~30min** after exposures.
- We can find SNe via web pages.

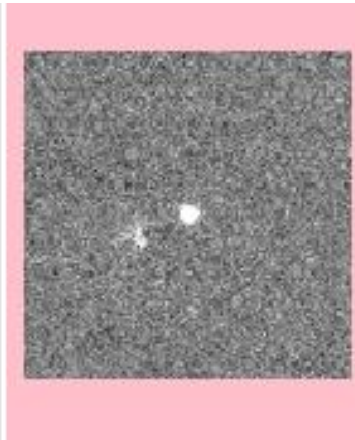
Reference



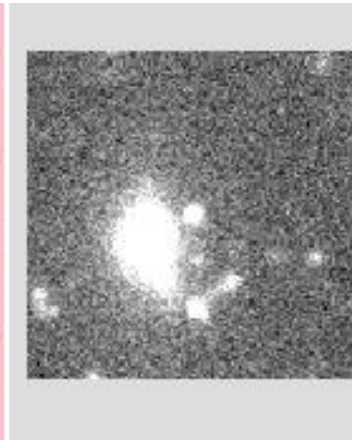
New



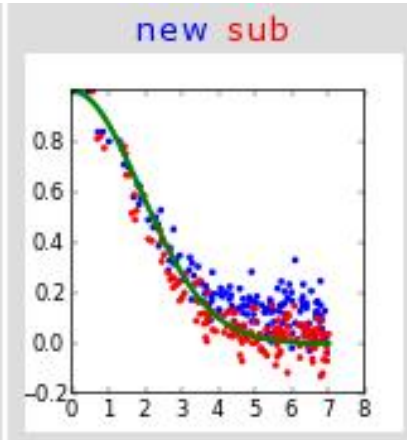
Subtracted



Previous



Profile



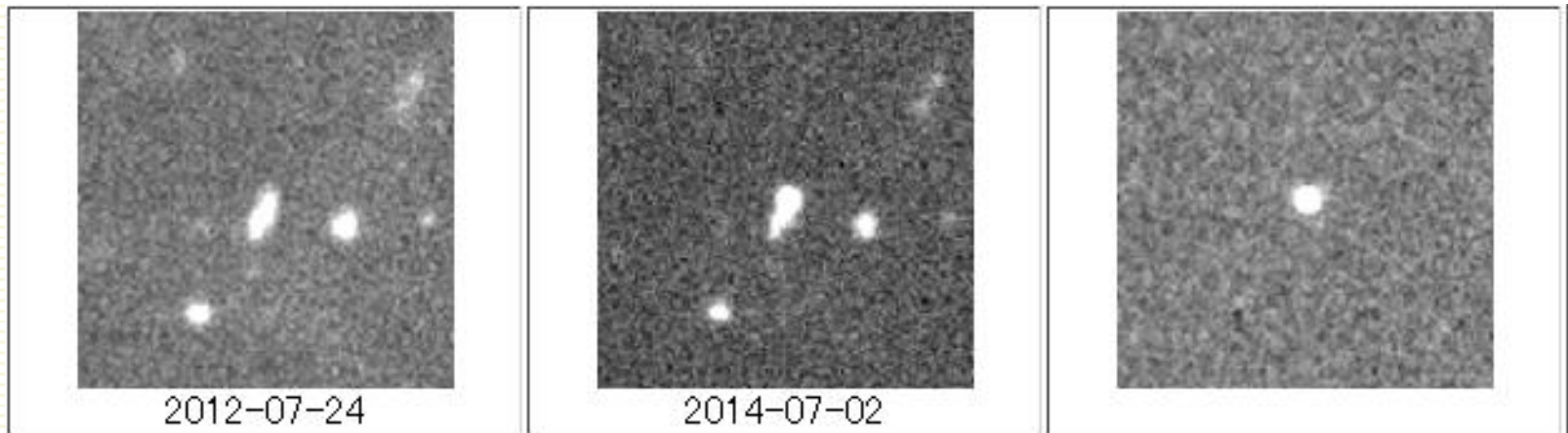
# Quick alert of candidates within 1 day after the observation

*The Astronomer's Telegram*

## First supernova candidates discovered with Subaru/Hyper Suprime-Cam

ATel #6291; *Nozomu Tominaga (Konan U./Kavli IPMU, U. Tokyo), Tomoki Morokuma (U. Tokyo), Masaomi Tanaka (NAOJ), Naoki Yasuda (Kavli IPMU, U. Tokyo), Hisanori Furusawa (NAOJ), Jian Jiang (U. Tokyo), Satoshi Miyazaki (NAOJ), Takashi J. Moriya (U. Bonn), Junichi Noumaru (NAOJ), Kiaina Schubert (NAOJ), and Tadafumi Takata (NAOJ)*

*on 4 Jul 2014; 15:51 UT*

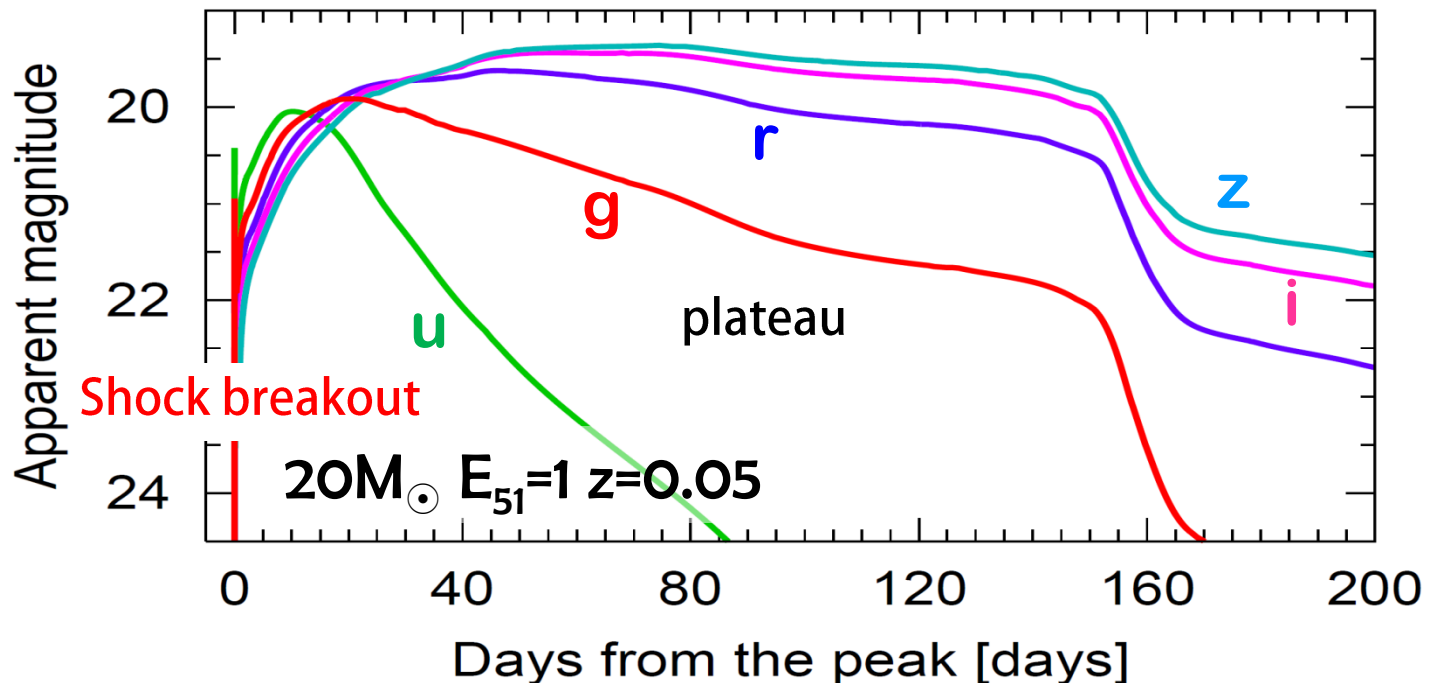


<http://tpweb2.phys.konan-u.ac.jp/~tominaga/HSC-SN/>

# Nearby shock breakout survey

## -Kiso Supernova Survey (KISS)-

- Complementary to the HSC high- $z$  survey
- $m_{\text{plateau}} \sim 20\text{mag}$ ,  $m_{\text{tail}} \sim 22\text{mag}$ 
  - Plateau and spectra are easily followed up.
- Kiso Wide Field Camera (FoV:  $4\text{deg}^2$ )

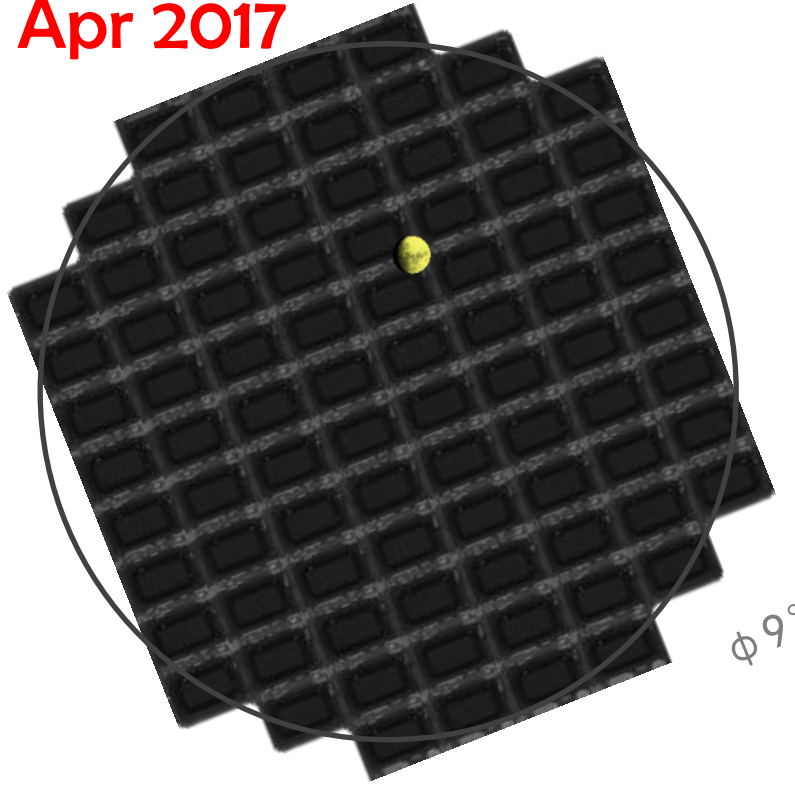




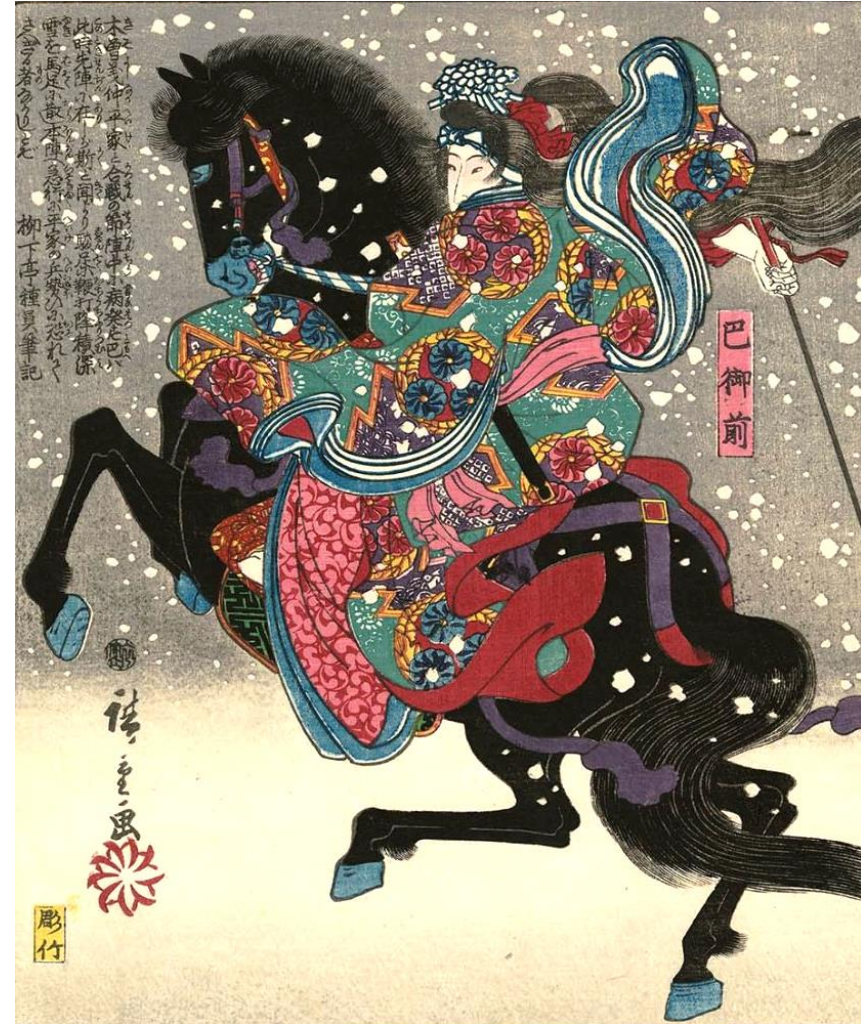
# Tomo-e Gozen Project

## Next nearby high-cadence (**2Hz**) survey

From Apr 2017



- $20\text{deg}^2$  in  $\phi 9\text{deg}$
- 84 CMOS chips
- **2Hz** readout



# Summary

- High- $z$  shock breakout survey with HSC is starting.
- The real-time transient detection system installed at the Hilo office works well. We have successfully announced the discovery immediately after the run.
- We found shock breakout candidates with the HSC and FOCAS runs. This demonstrates that the shock breakouts are the good probes of the high- $z$  supernovae.
- Nearby shock breakout surveys are complementarily important.