Observations of Type IIb Supernovae 2013df with Bright Shock Breakout

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Supernovae & Gamma-Ray Bursts 2014

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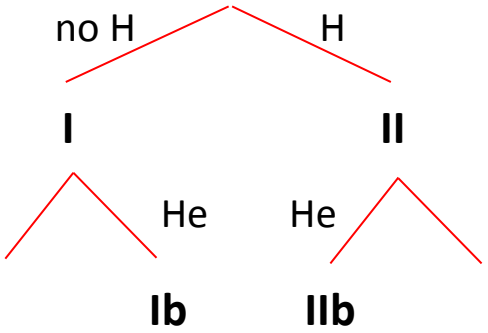
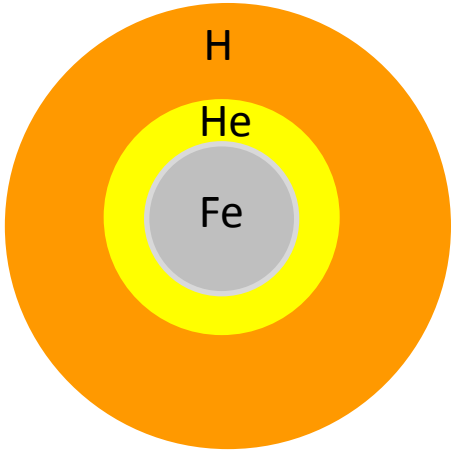
Type Ib and Type IIb SNe

Early time spectra
Type Ib … Hydrogen line ×
Type IIb … Hydrogen line ○

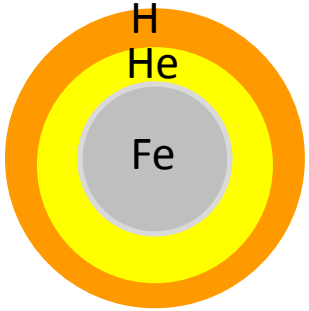




Type IIP

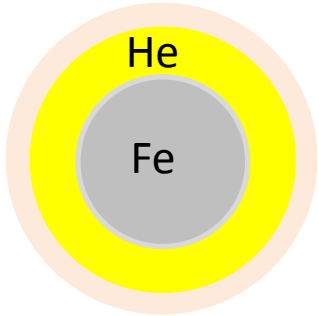
Type IIb SNe is mostly stripped the hydrogen envelope.

⇒Massive single star?
radiatively driven stellar wind



Type IIb

⇒Interaction in Binary system?
Roche-Lobe overflow or common-envelope evolution



Type Ib

Shock Cooling of Type IIb SNe and Diversity of Progenitor

In the LC at a few days after the explosion,
SN 1993J has the first peak due to cooling emission after shock breakout.

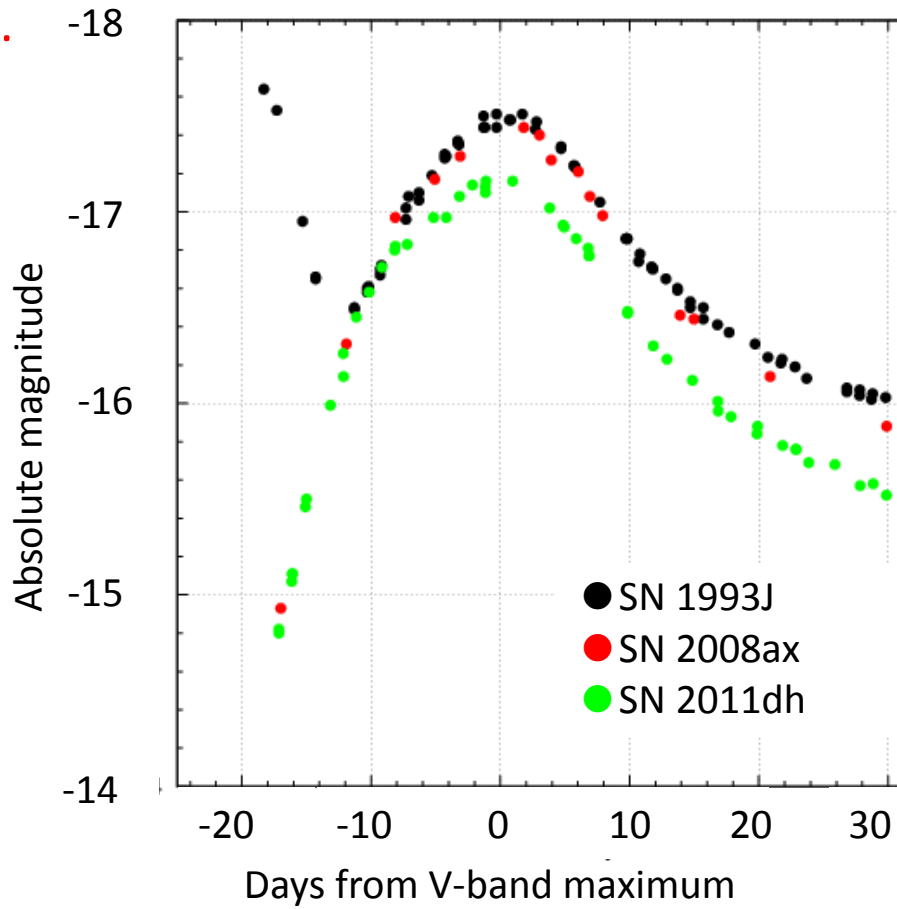
SN 2008ax and SN 2011dh don't show the first peak.

Shock cooling depend on the progenitor radius.
(Rabinak & Waxman 2011)

The progenitor is detected
in pre-explosion image (three examples).

93J … Red Super Giant in binary system
08ax … single WR star
a binary in a cluster
11dh … Yellow Super Giant in binary system

Origin of these diversity?



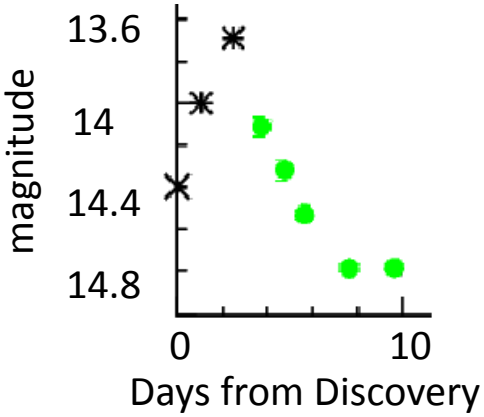
Observation & Data Reduction

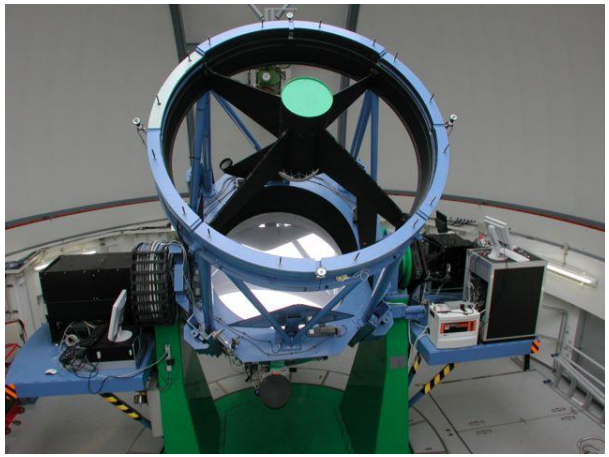
Supernovae 2013df in nearby galaxy NGC 4414

2013 June 7.8 Discovery at 14.4 mag

⇒rapid brightening and fading

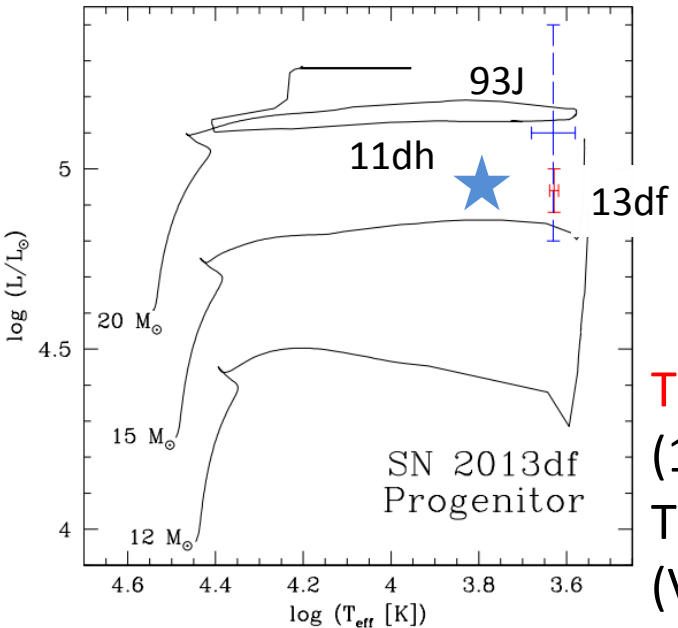
2013 June 11 Follow-up observation start





1.5m Kanata telescope + HOWPol
BVRI photometry
Spectroscopy

Osaka-kyoiku Univ.
51cm telescope
BVRI photometry

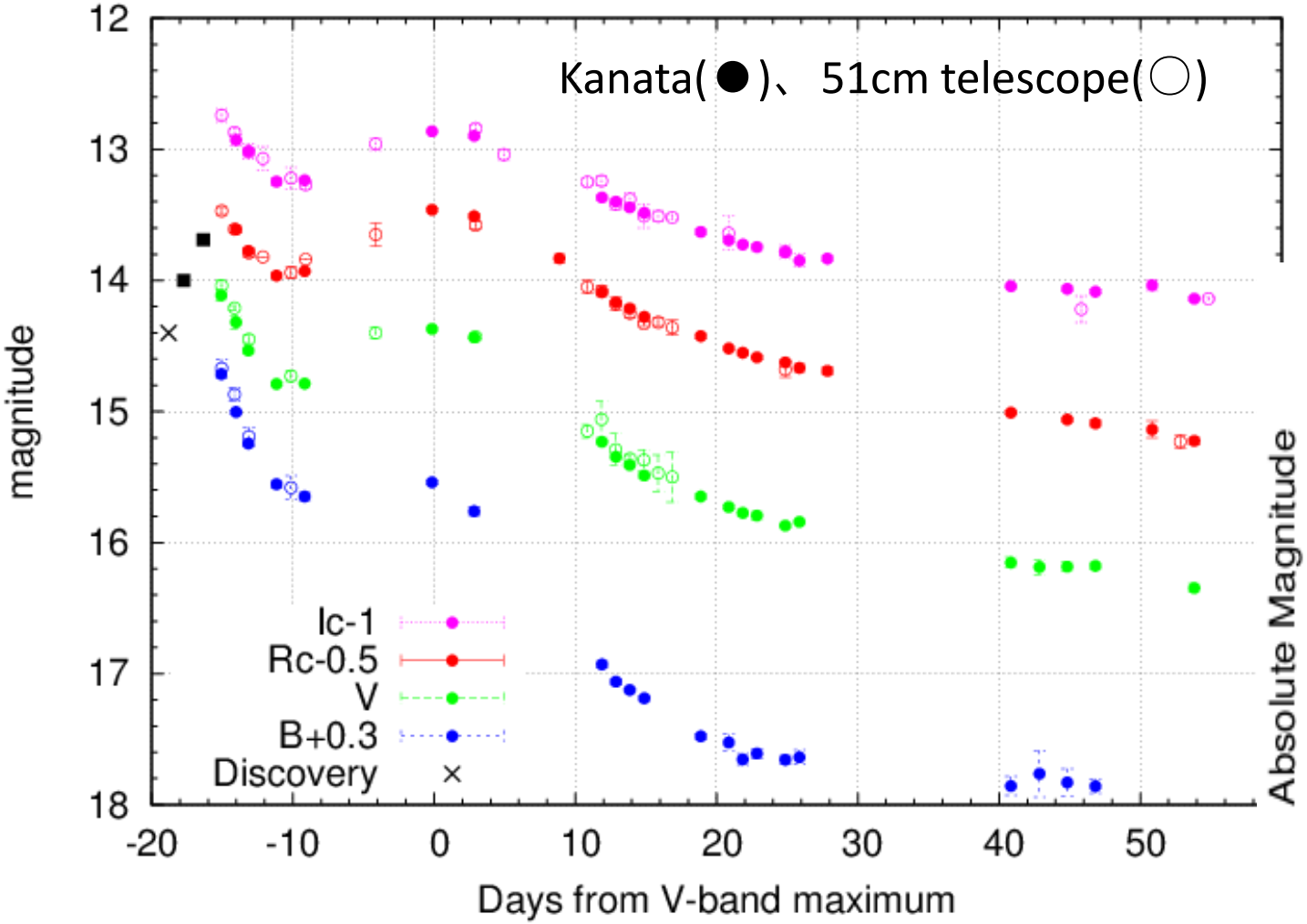


2013 Dec. 21 Subaru telescope (Spectroscopy)

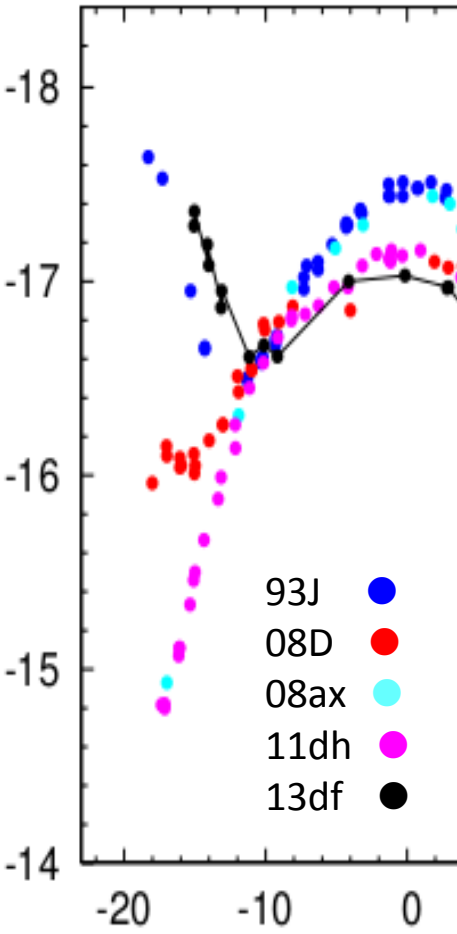
The progenitor of 13df was detected in archive HST image.
(1999 April 29 UT) ⇒$545 \pm 65\ R_{\odot}$
The explosion date of SN 2013df is about June 4.3.
(Van Dyk et al. 2014)

Results

Light Curve



absolute V-band LC



SN 2013df shows rapidly decline from -15 day to -11day.

The secondary maximum at V-band is 14.29 mag @June 26.6 UT.

The shock cooling is brighter.

Results

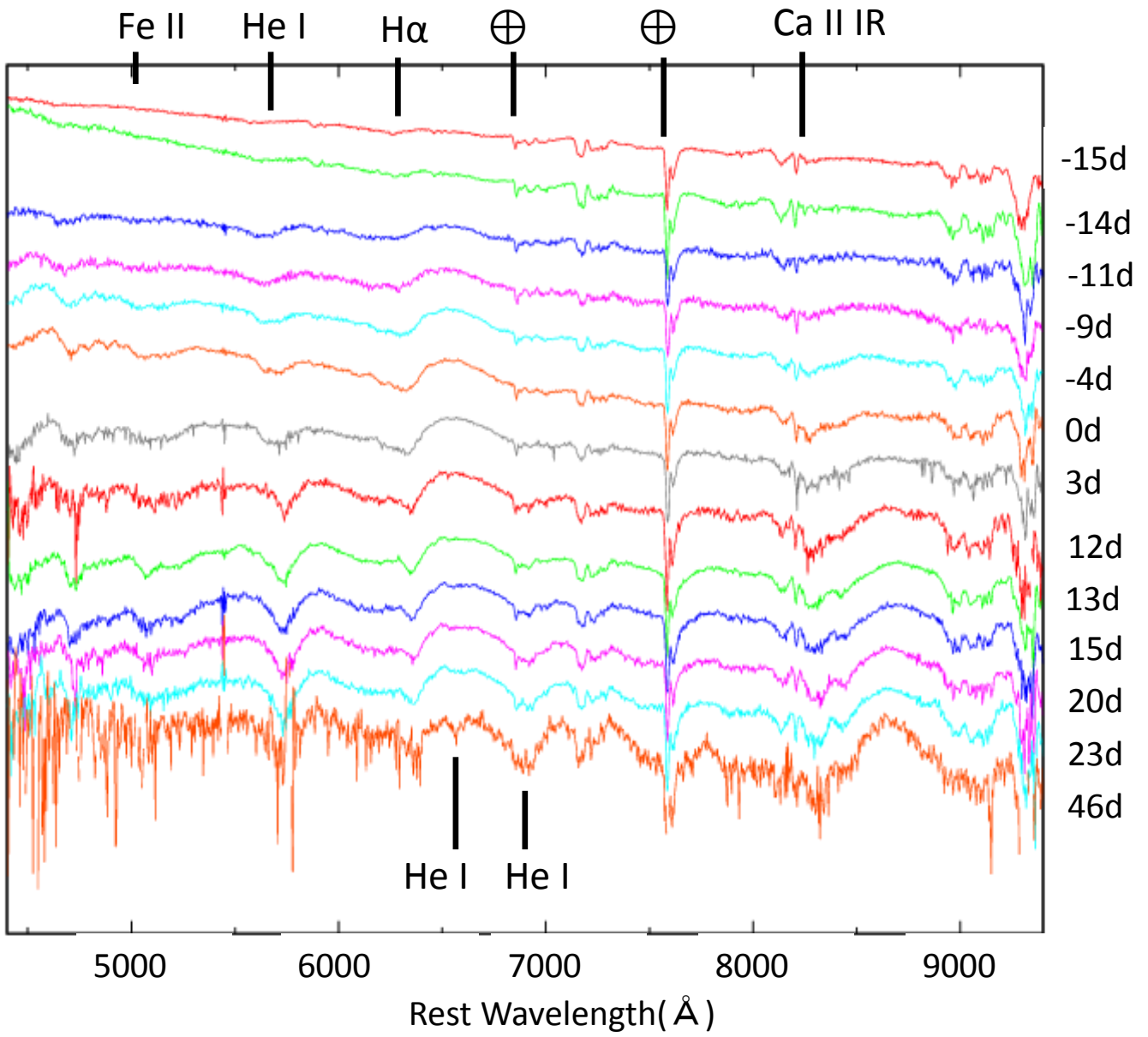
Early Spectral Properties

Hydrgen and helium line at -15 day are seen.
⇒a similarity to 93J

08ax and 11dh dominated hydrogen at early phase.
⇒diversity of progenitor

At 12 day,
He I 5876 becomes narrow.

At 46 day,
He I 6678 is seen clearly.



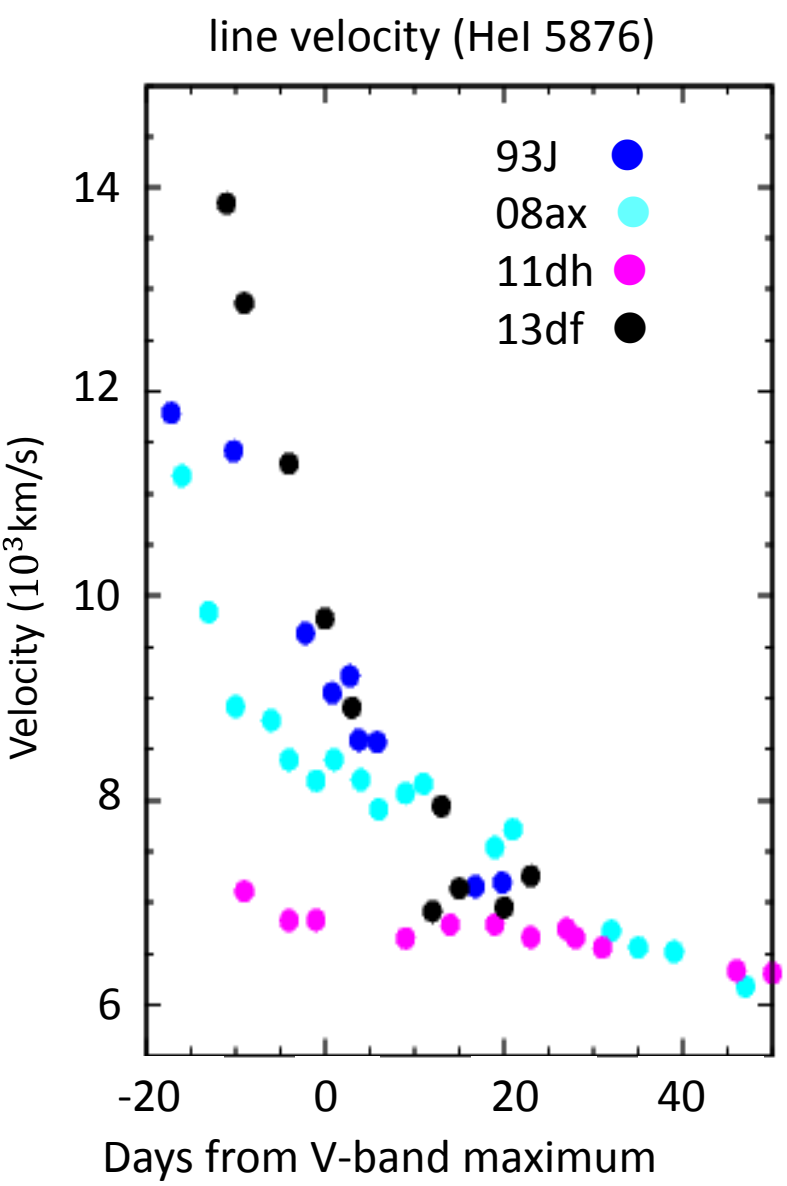
The Comparison of Other Type IIb SNe Spectrum

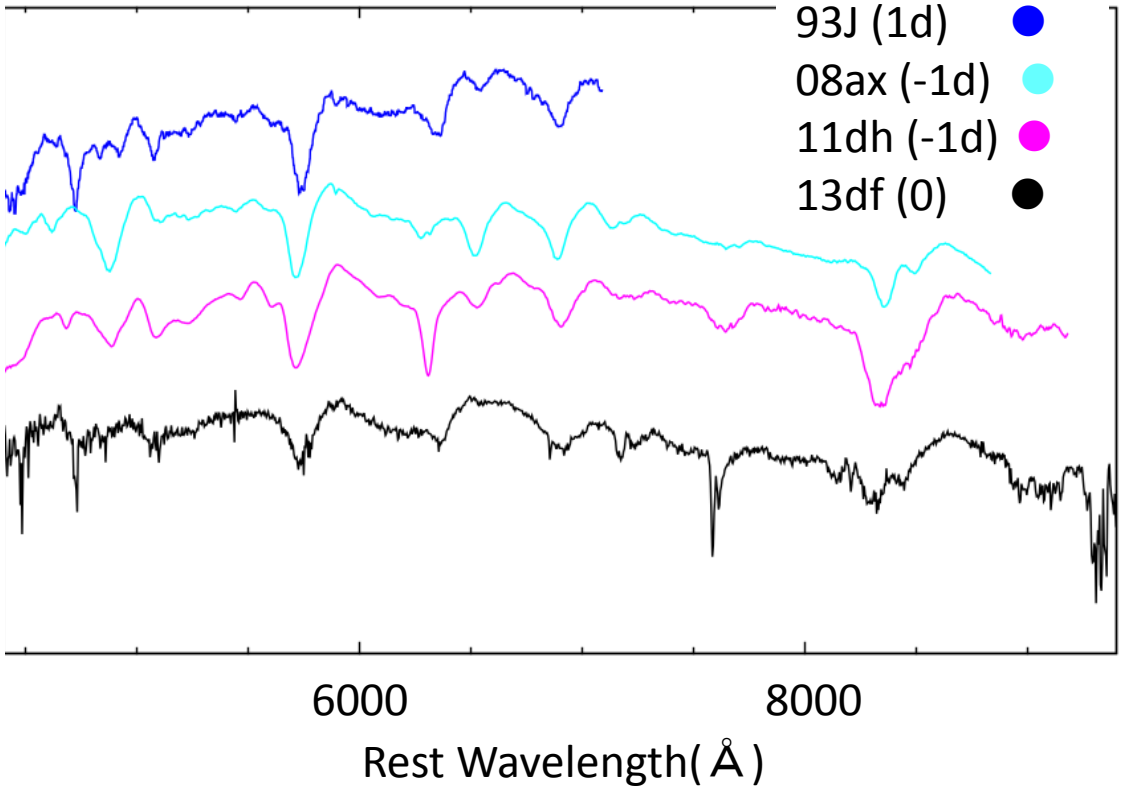
After V-band maximum, the line velocity of 13df is similar to that of 93J.

The FWHM of 13df is larger than that of 93J.

⇒The explosion energy of 13df is similar to that of 93J.

The difference of FWHM reflect the difference of outerlayer.





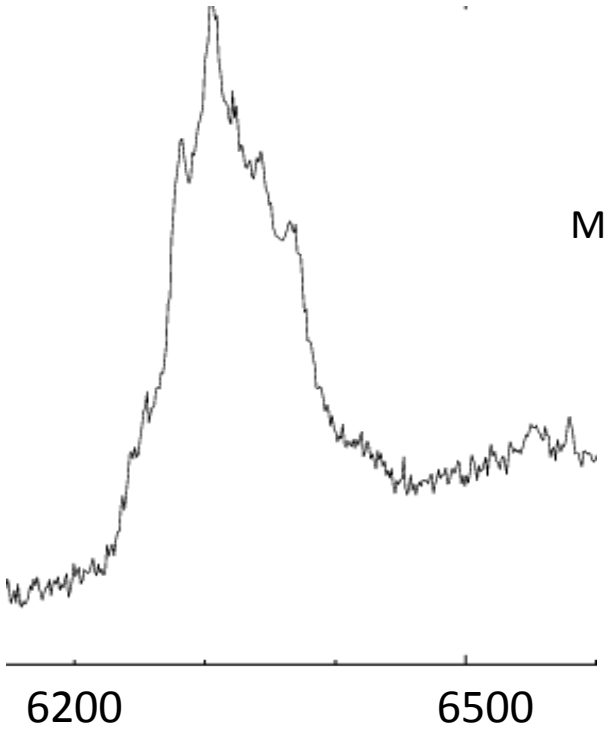
Nebular Spectral Properties

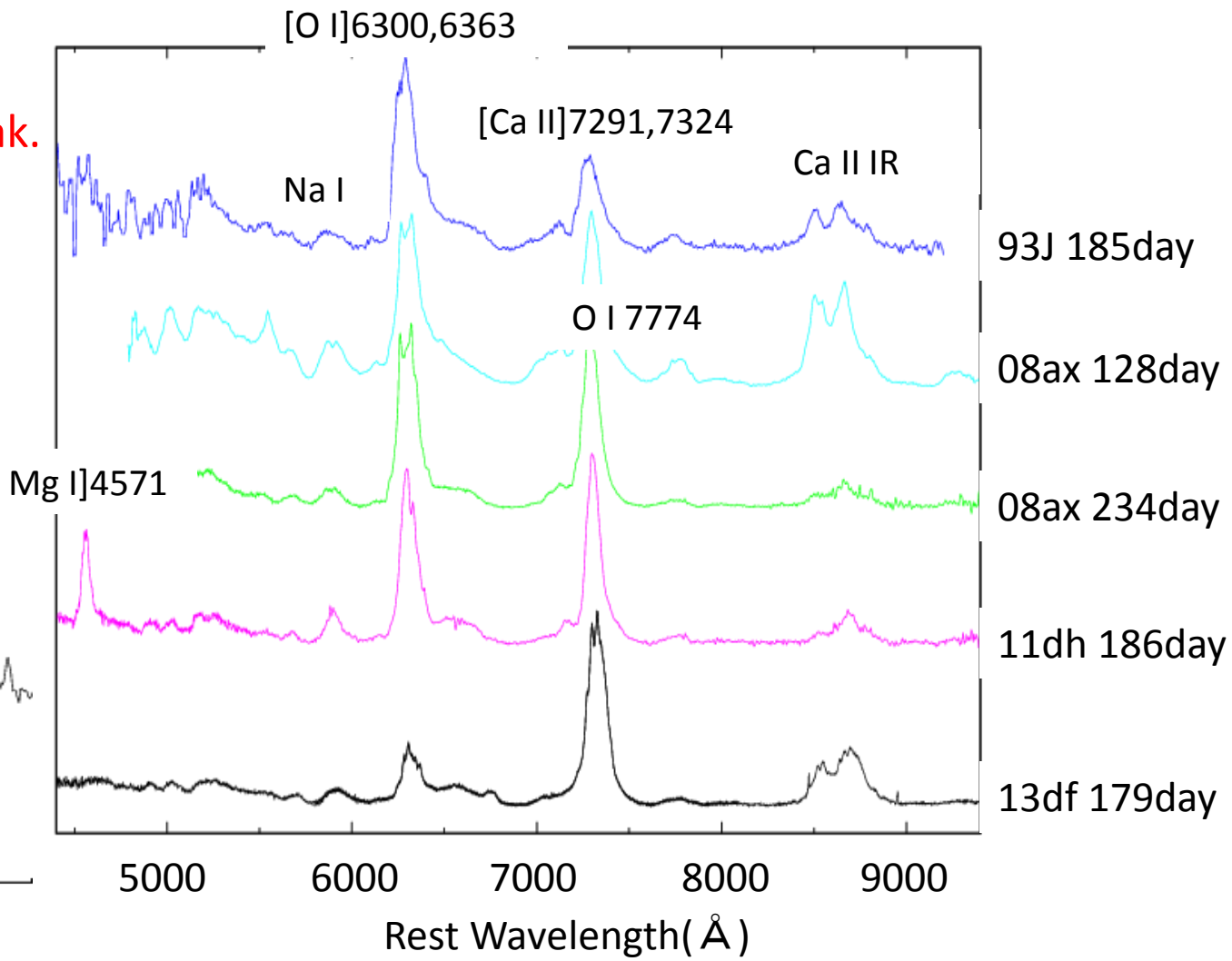
The emission lines dominate in contrast to early spectrum.

The [O I] line profile of SN 2013df show single-peak. It has some narrow peak.

⇒SN 2013df have clumpy gas or a torus structure?

The [O I] 6300, 6363 line of SN 2013df is very weak.





Discussion

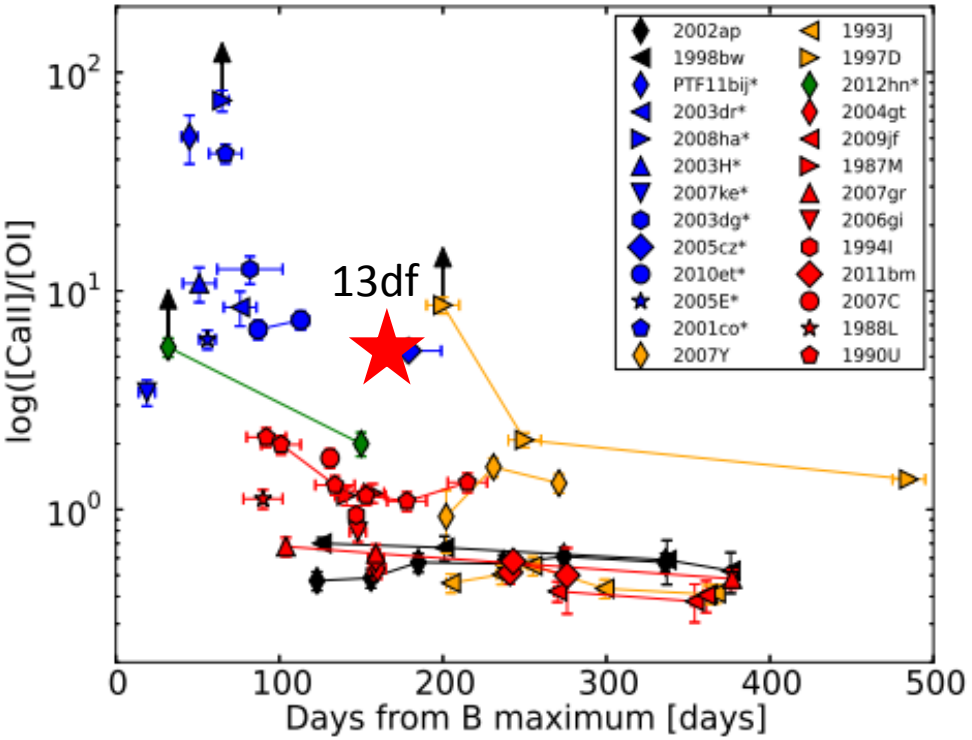
Progenitor Mass

Oxygen mass in a CC SN strongly depends on progenitor's mass.
On the other hand, calcium mass does not depend on very much.
⇒The progenitor mass can estimate from the flux ratio [Ca II]/[O I].
(Fransson & Chevalier 1989)

The flux ratio of [Ca II]/[O I] is ~ 0.48 at 179 day.
The main sequence mass of SN 2005cz have $10 \sim 12 M_{\odot}$.
⇒The main sequence mass of SN 2013df have $10 \sim 12 M_{\odot}$.

The WR star have $\geq 12 M_{\odot}$ initially.
⇒SN 2013df is too small to strip the hydrogen envelope.

The progenitor of SN 2013df must be in binary system.



Valenti et al. 2013

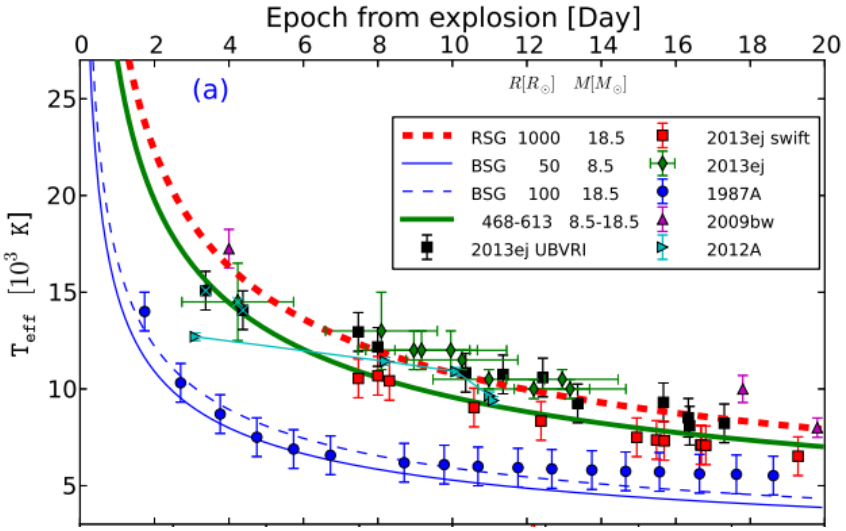
Discussion

Progenitor Radius

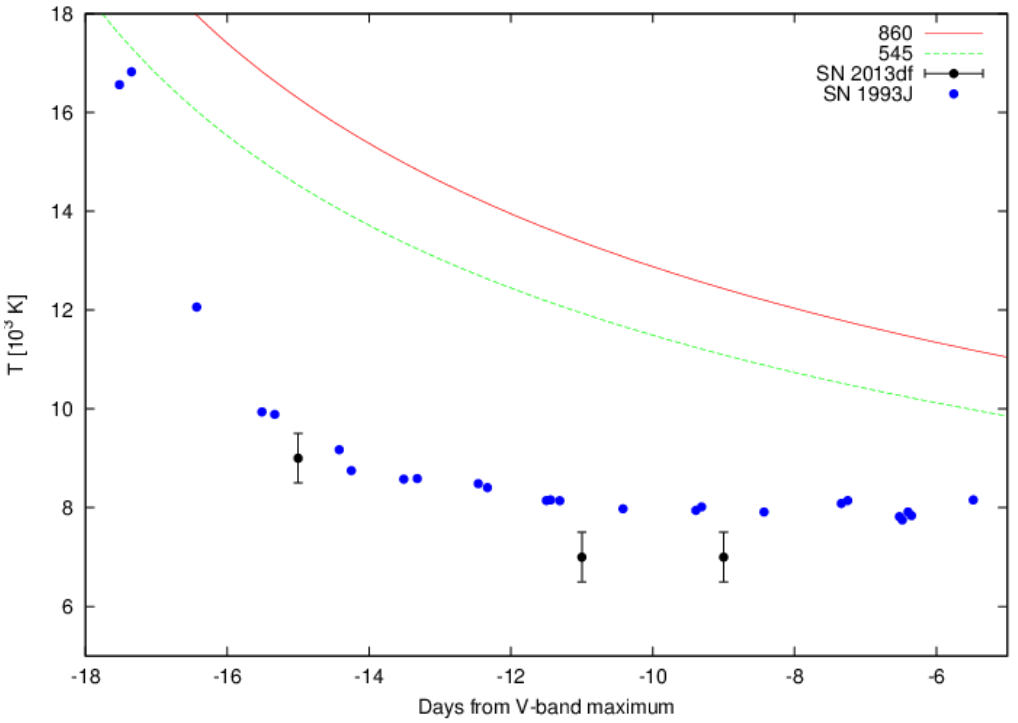
The shock cooling luminosity and temperature depend on the progenitor radius.
(Rabinak & Waxman 2011)

Some SNe is consistent with this model.

However, the temperature evolution of SN 1993J (Lewis et al. 1994) and SN 2013df is not consistent.



SNe 2013ej, 1987A, 2009bw, 2012A
Valenti et al. 2014



Discussion

Progenitor Radius

The shock cooling luminosity of SN 2013df scaled to that of SN 1993J to clear to the uncertainty about the some parameter.

$$L = 8.5 \times 10^{42} \frac{E_{51}^{0.92} R_{*,13}}{f_\rho^{0.27} (M/M_\odot)^{0.84} \kappa_{0.34}^{0.92}} t_5^{-0.16} \ \mathrm{erg\,s^{-1}}$$

$$L_{13df} = L_{93J} \frac{R_{13df}}{R_{93J}} \left(\frac{t_{13df}}{t_{93J}} \right)^{-0.16}$$

$$\Rightarrow 530 \sim 1200\, R_\odot$$

This uncertainty include the systematics differences and the error of explosion date.

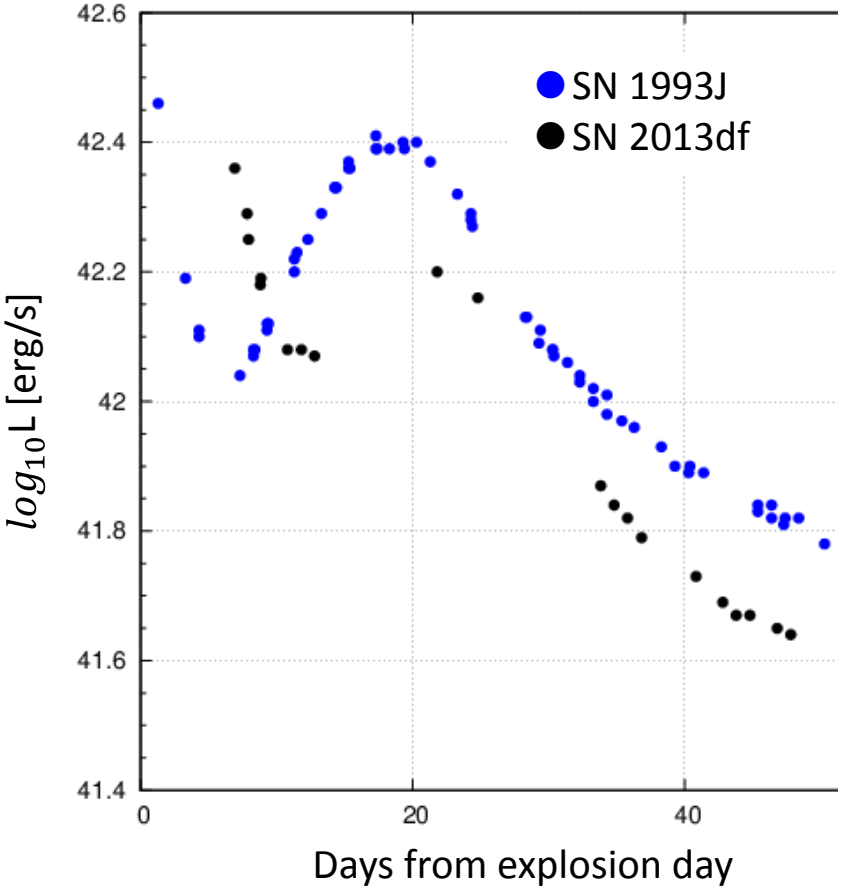
The median value ($860 R_\odot$) is larger than the radius obtained HST image.

The difference of the progenitor's density structure?

Mass loss in a short period before explosion?

quasi-bolometric LC

BVRI-bands occupy about 60% of the bolometric luminosity



Summary

We present optical photometry and spectroscopy of Type IIb supernovae 2013df.
SN 2013df shows bright shock cooling at few days after explosion.

The progenitor radius of SN 2013df estimate from the shock cooling luminosity.
The median value ($860R_{\odot}$) is larger than the radius obtained HST image.
⇒The difference of the progenitor's density structure?
⇒Mass loss in a short period before explosion?

The spectrum of SN 2013df at early phase and the helium line velocity after V-band maximum is similar to those of SN 1993J.
The explosion energy of 13df is similar to that of 93J.

The nebular spectra of SN 2013df show [O I] 6300, 6363 line is very weak.
The main sequence mass of SN 2013df have $10 \sim 12M_{\odot}$
estimated from the flux ratio of [Ca II]/[O I].
⇒SN 2013df is too small to strip the hydrogen envelope.
The progenitor of SN 2013df must be in binary system.