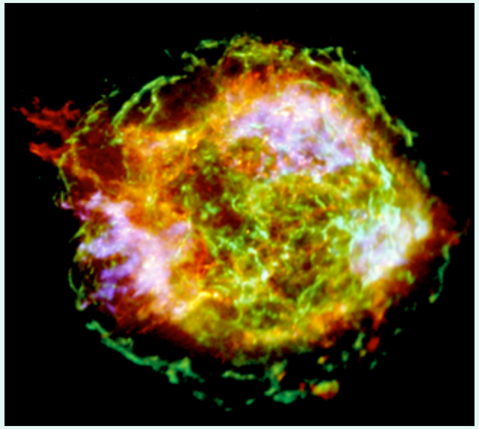
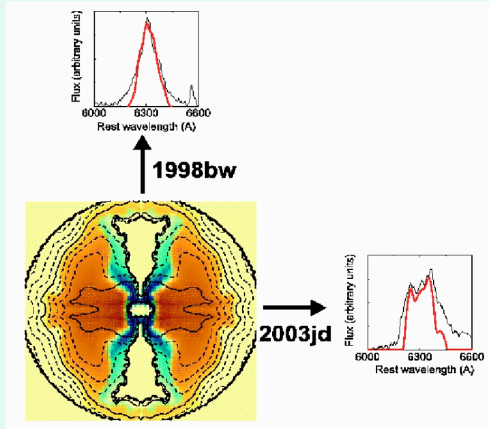
Type Ib/c Supernovae and GRBs



Paolo A. Mazzali



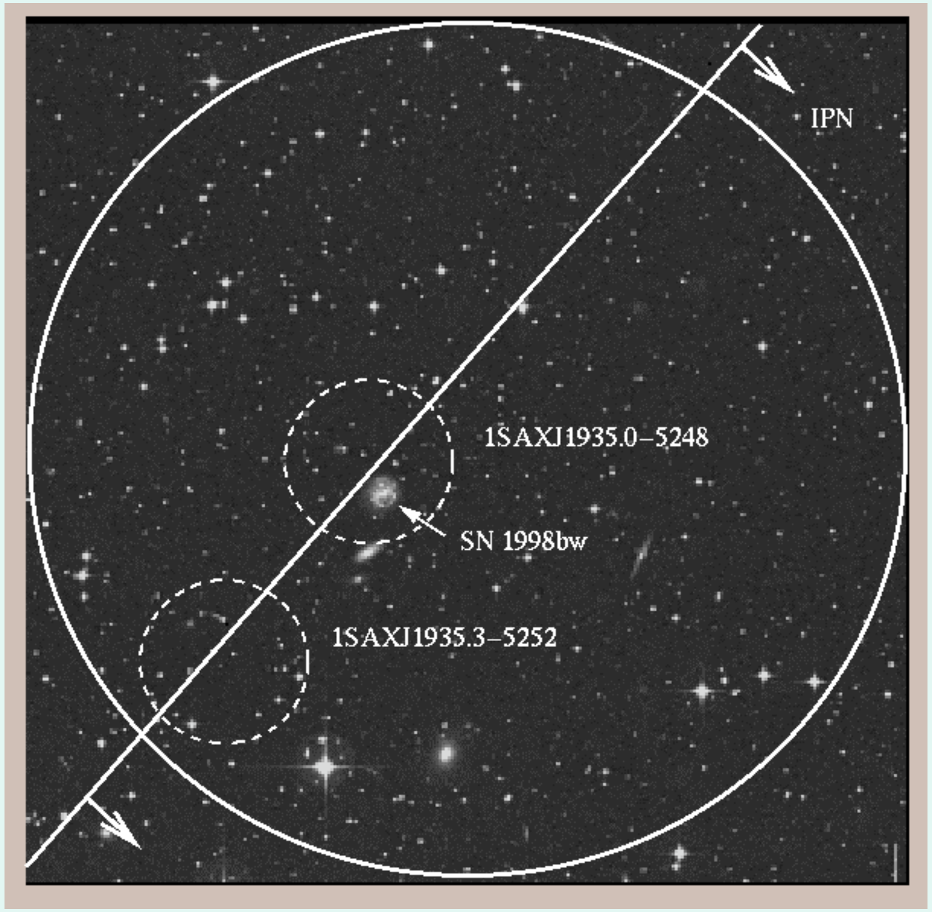
Max-Planck Institut für Astrophysik, Garching

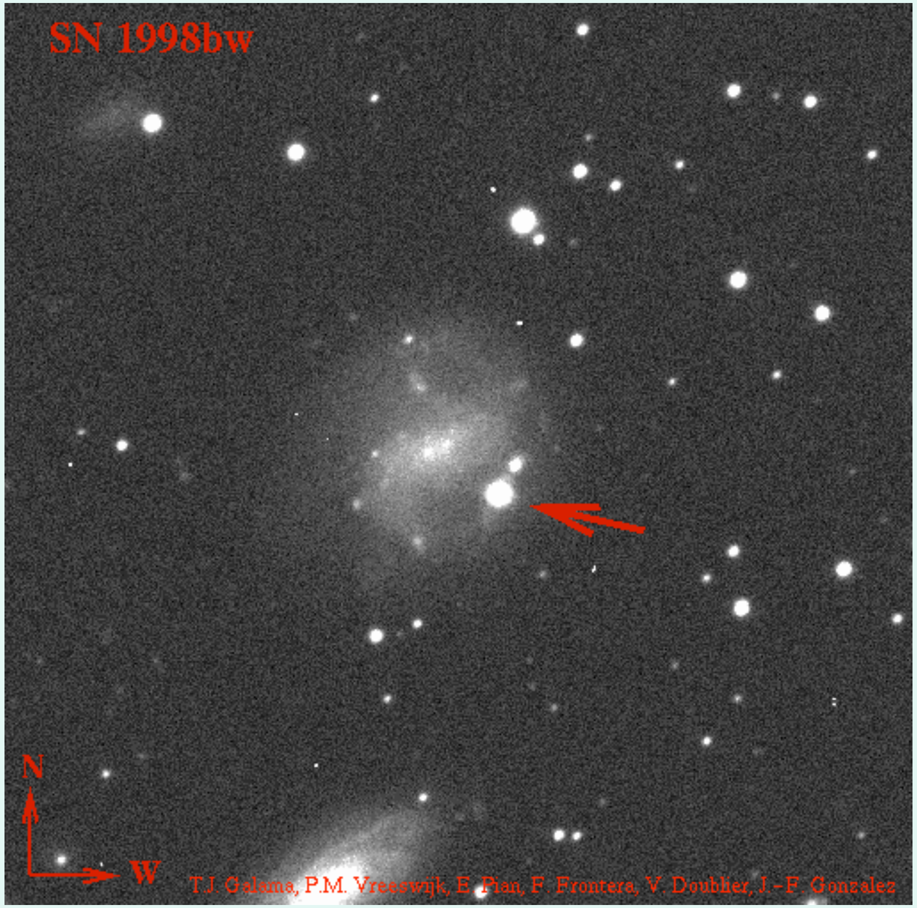
&

INAF, Padova Astron. Obs.

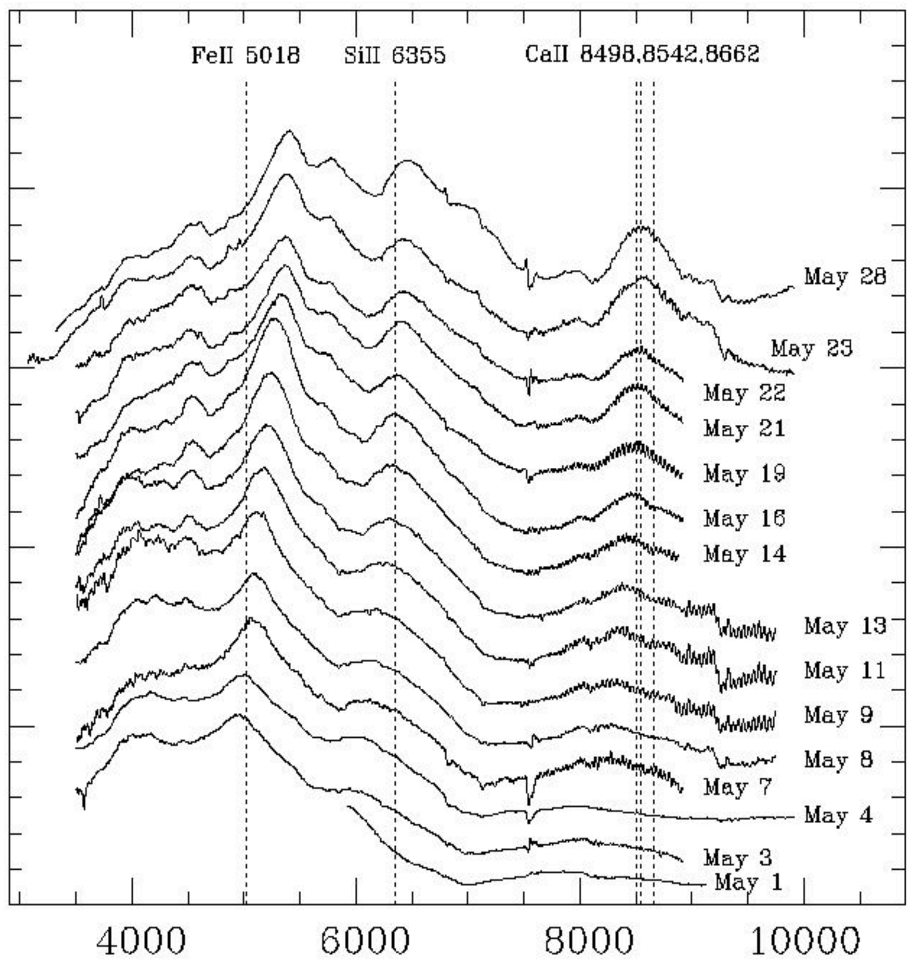
Most nearby long-soft GRBs come with a Supernova

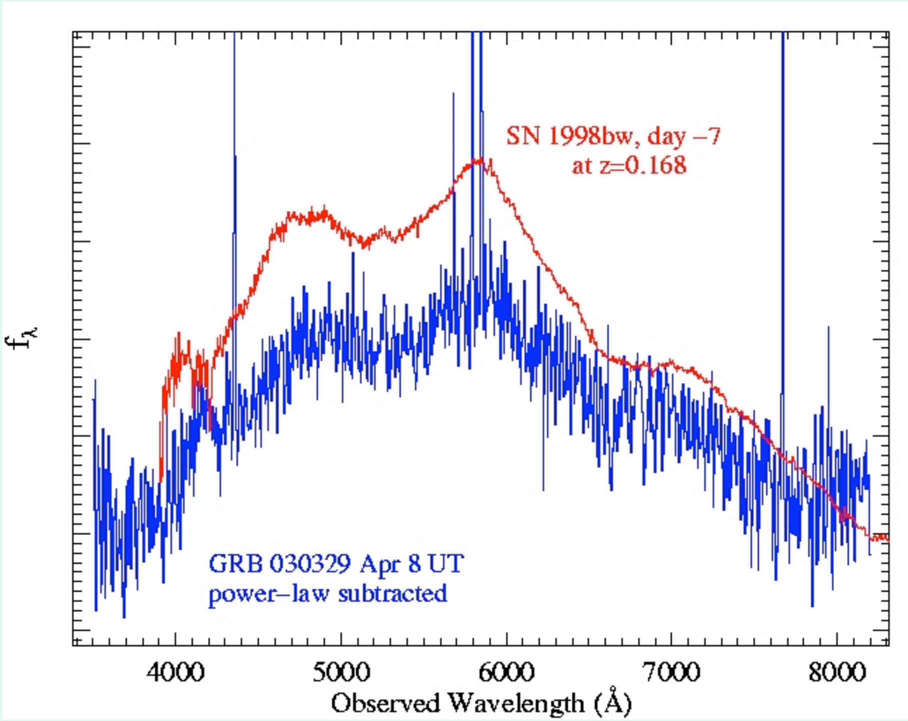
GRB980425: the optical counterpart





GRB/SNe are Broad-lined SNe Ic





SN2003dh / GRB030329

Matheson et al. 2003

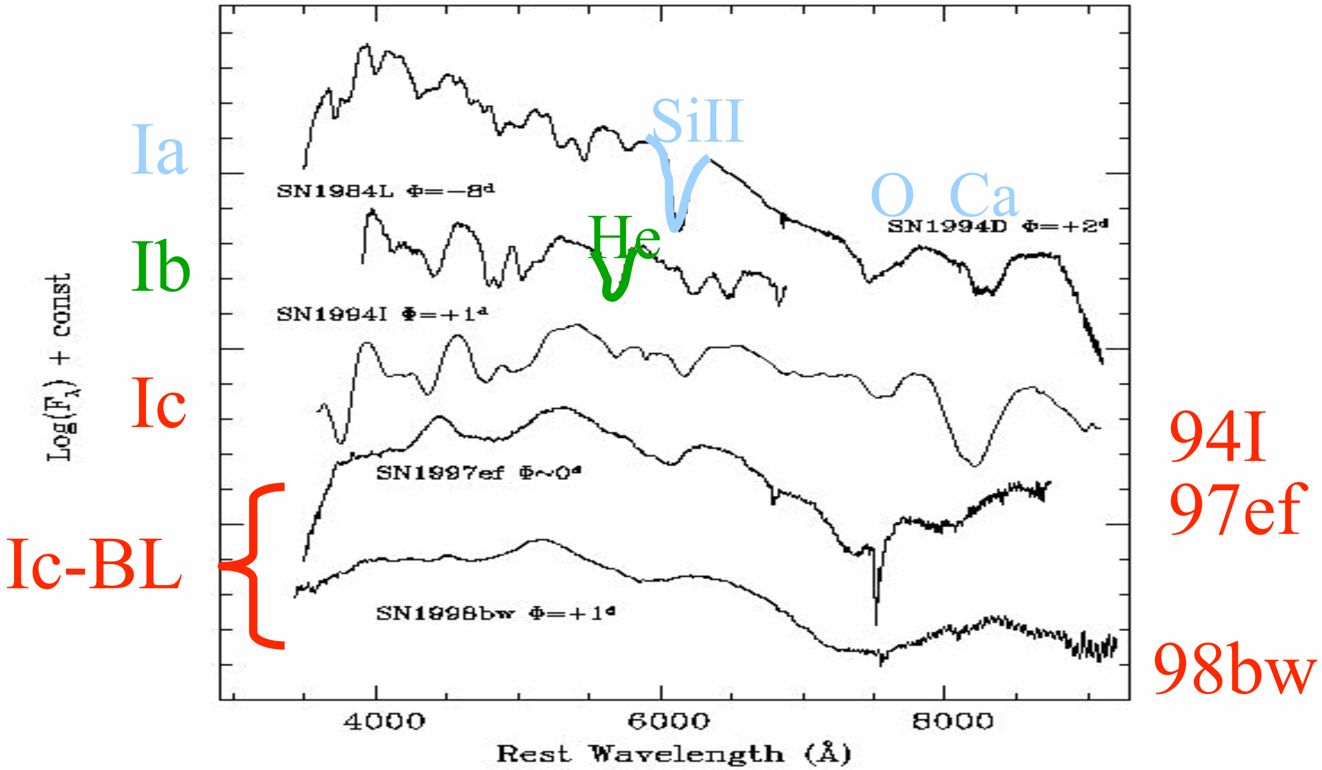
Patat et al. 2001

SN 1998bw / GRB980425

A spectral primer: SNe Ib/c and HNe

Ib: Helium lines visible

Ic: no Helium weak/no Si line



SNe Ic/BL:

Hypernovae:

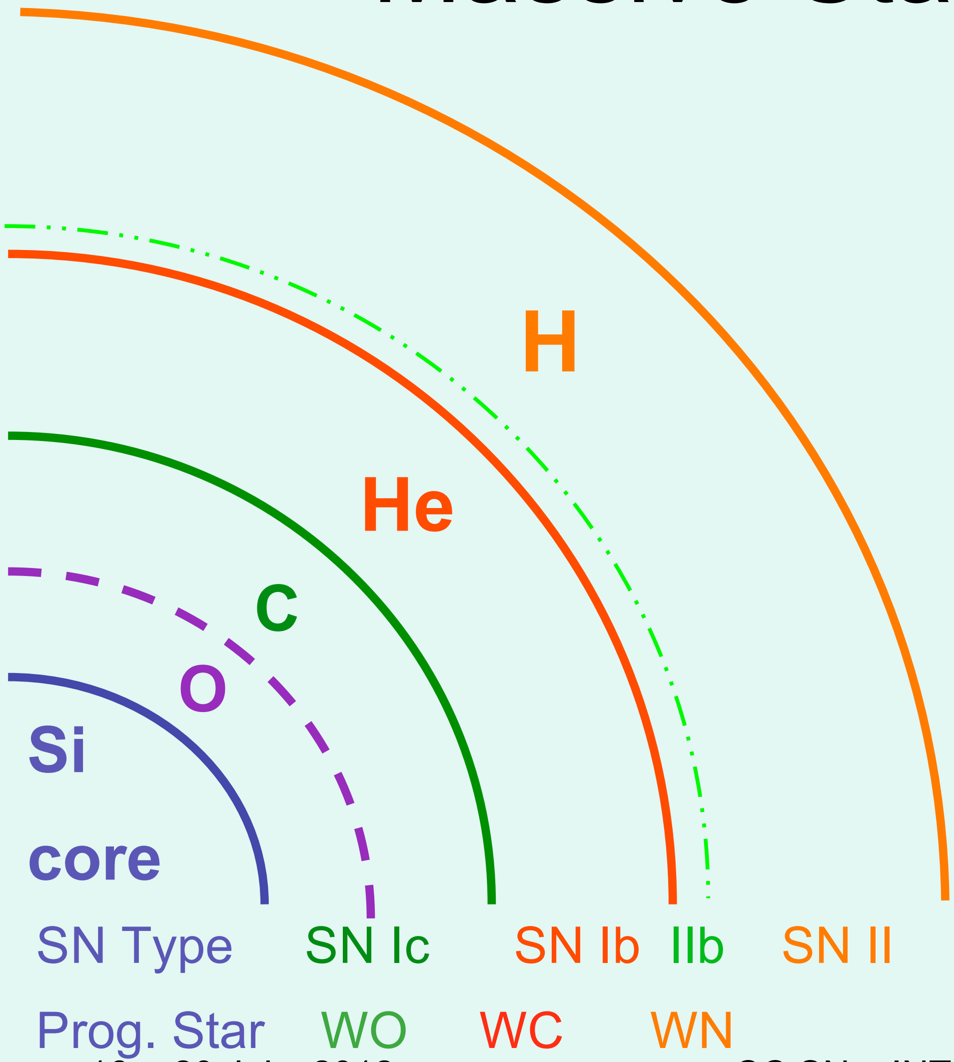
broad features,

blended lines

"Large mass at high velocities"

Core-Collapse SNe

Massive Star (>8$M_\odot$)



- Si burning → NSE
  → ^{56}Ni (~0.1-1$M_\odot$)
- Core collapse
- Compact object
  (NS/BH)
- **ν** emission
- KE deposited
- envelope ejection

Significance of spectrum

Broad lines

→ Large Kinetic Energy

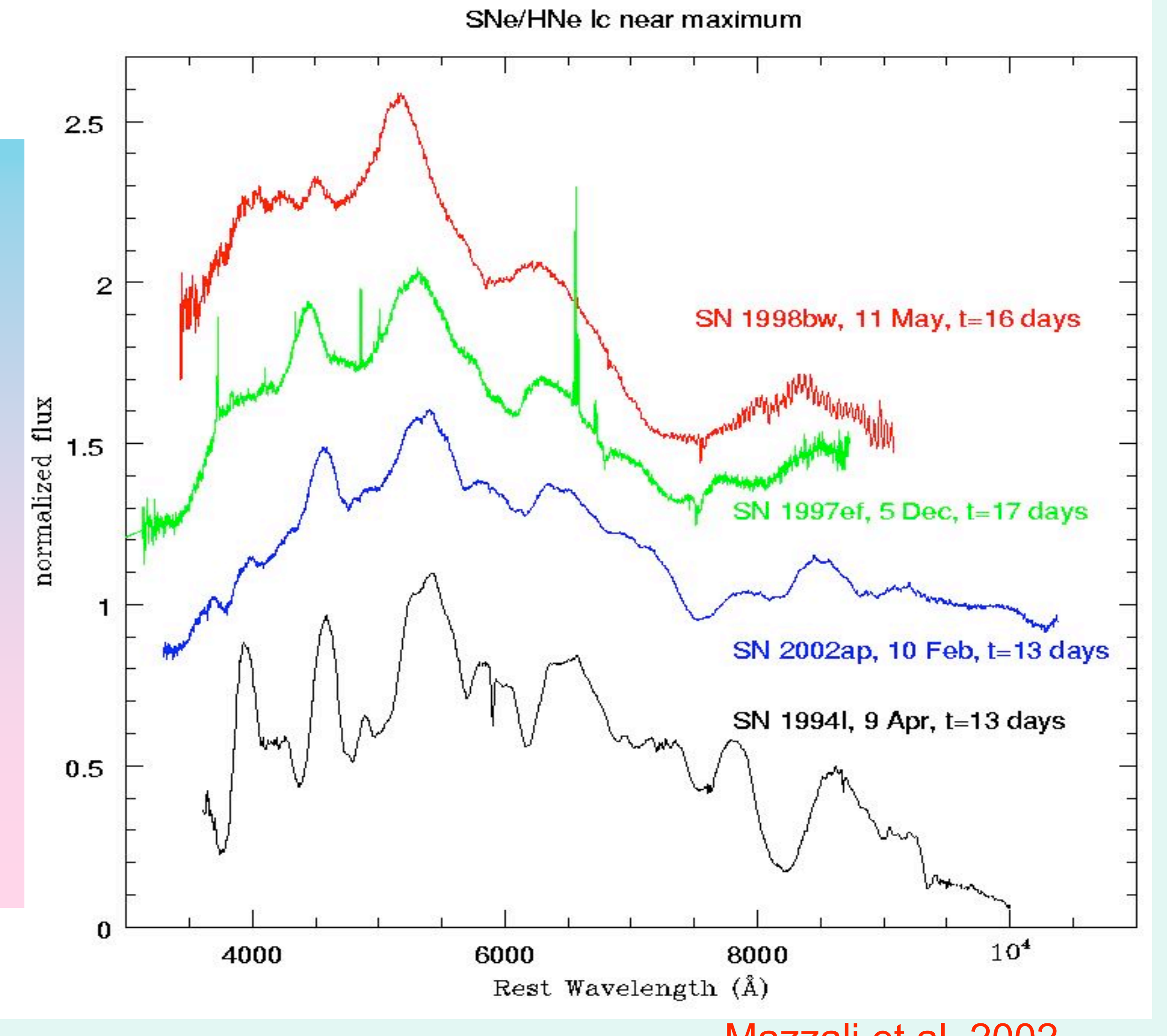
→ "Hypernovae"

(only SN1998bw was associated with a GRB)

Narrow lines

→ "normal" KE (1 foe)

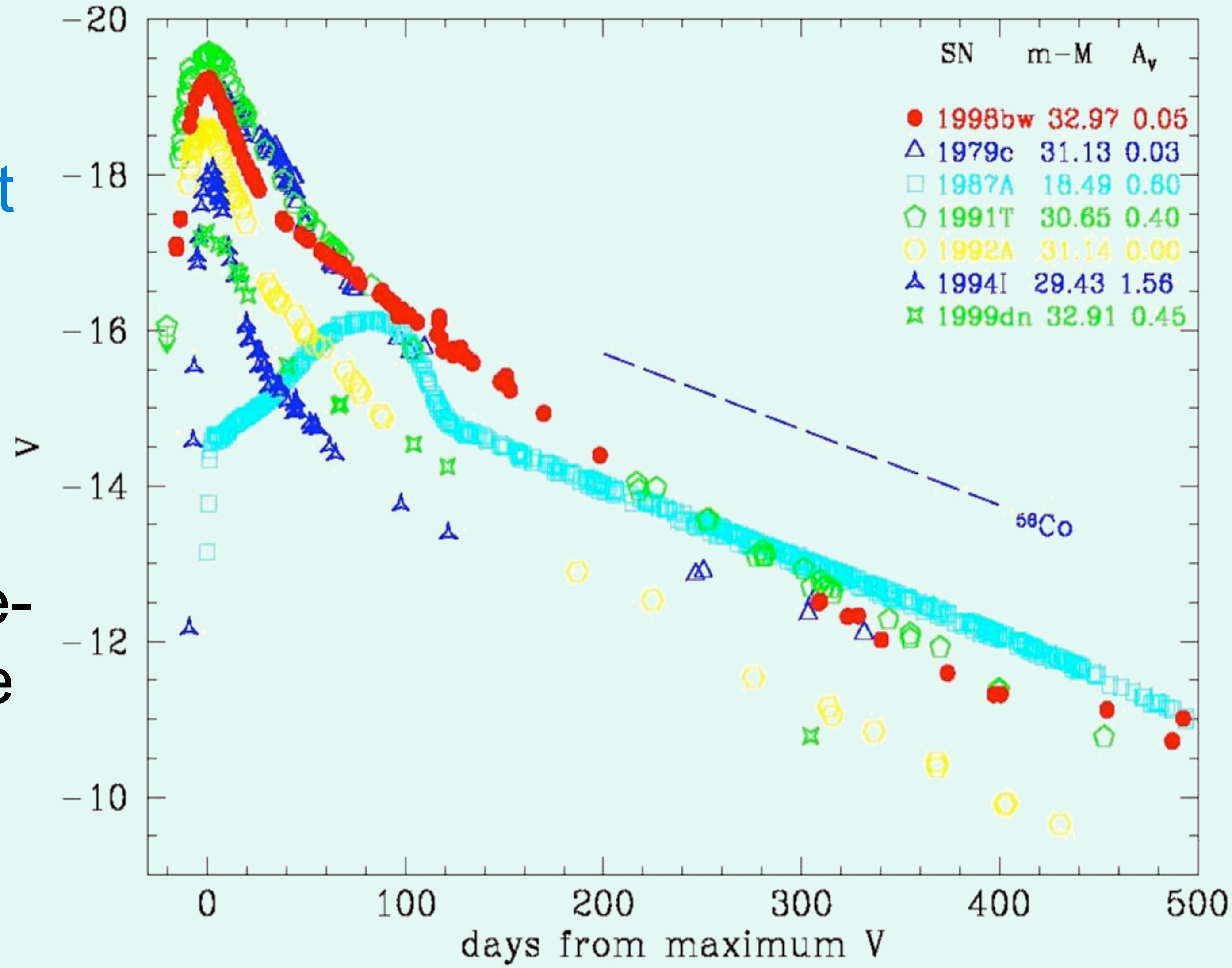
→ Normal SN Ic



Mazzali et al. 2002

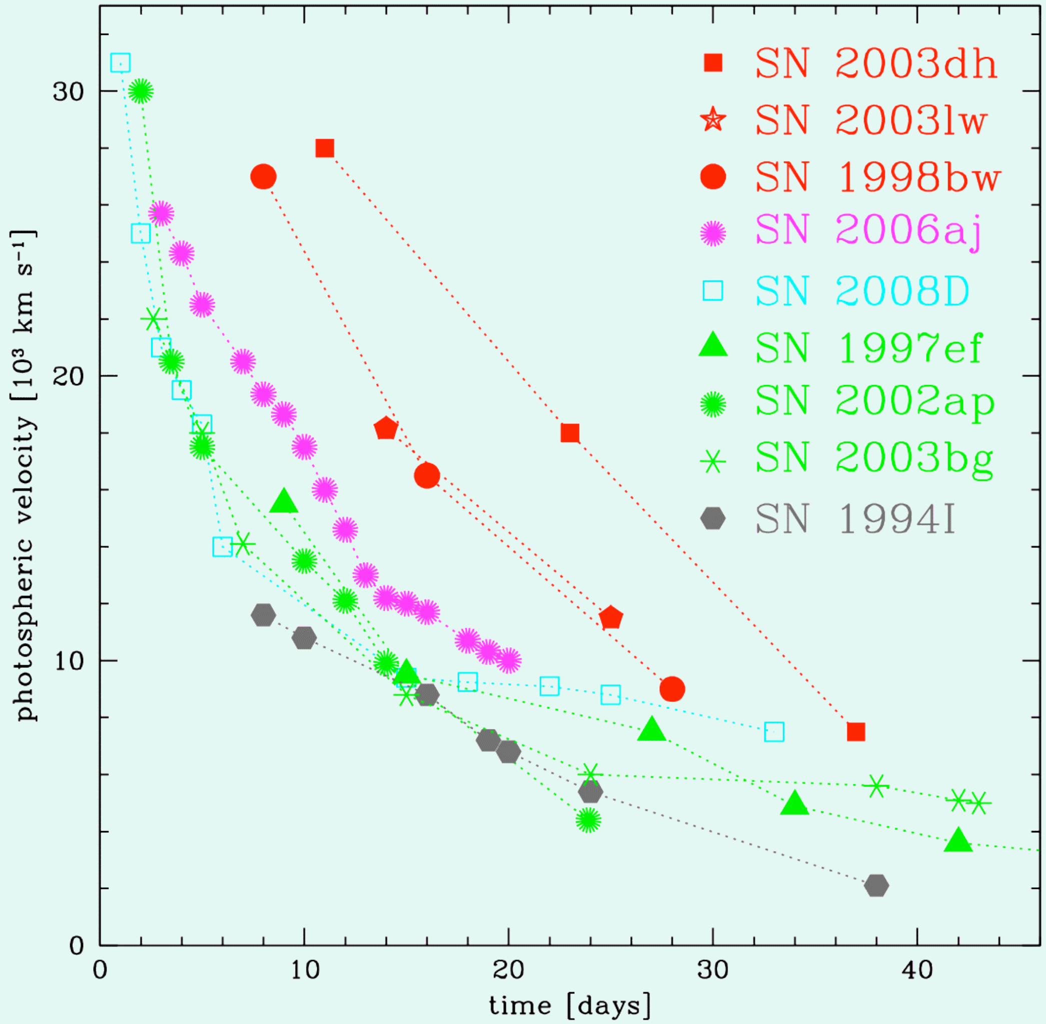
GRB/SNe are luminous

- SN1998bw was as bright as a SN Ia
- It produced much more 56Ni than `normal' core-collapse SNe (~ 0.5 M⊙)



GRB/SNe are highly energetic

- GRB/SNe have very high expansion velocities (optical velocities up to 0.1c track relativistic properties)
- XRF/SNe have lower velocities

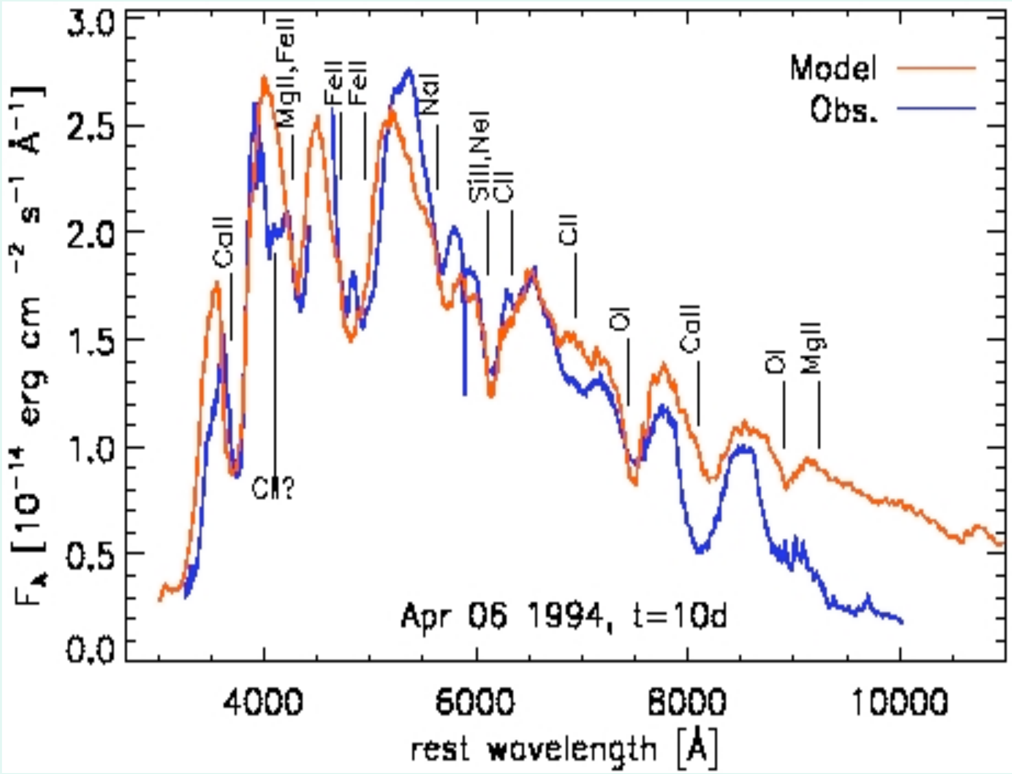


after Pian et al. 2006, Nature

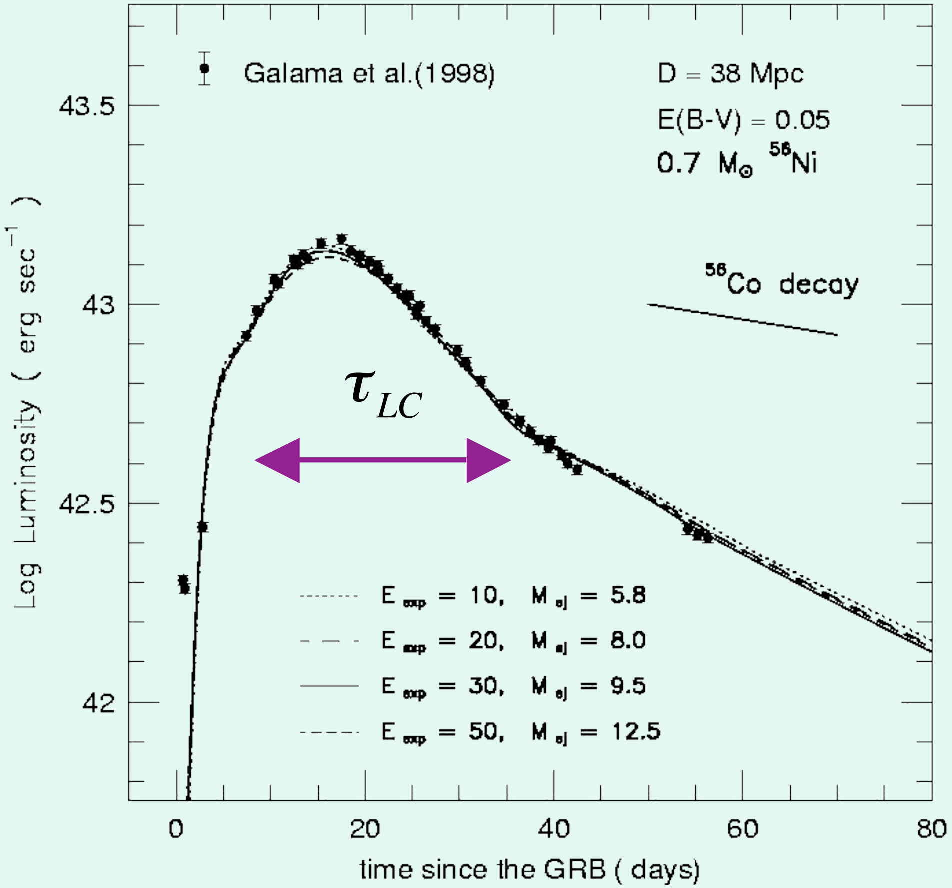
A “typical” (?) SN Ic: SN1994I

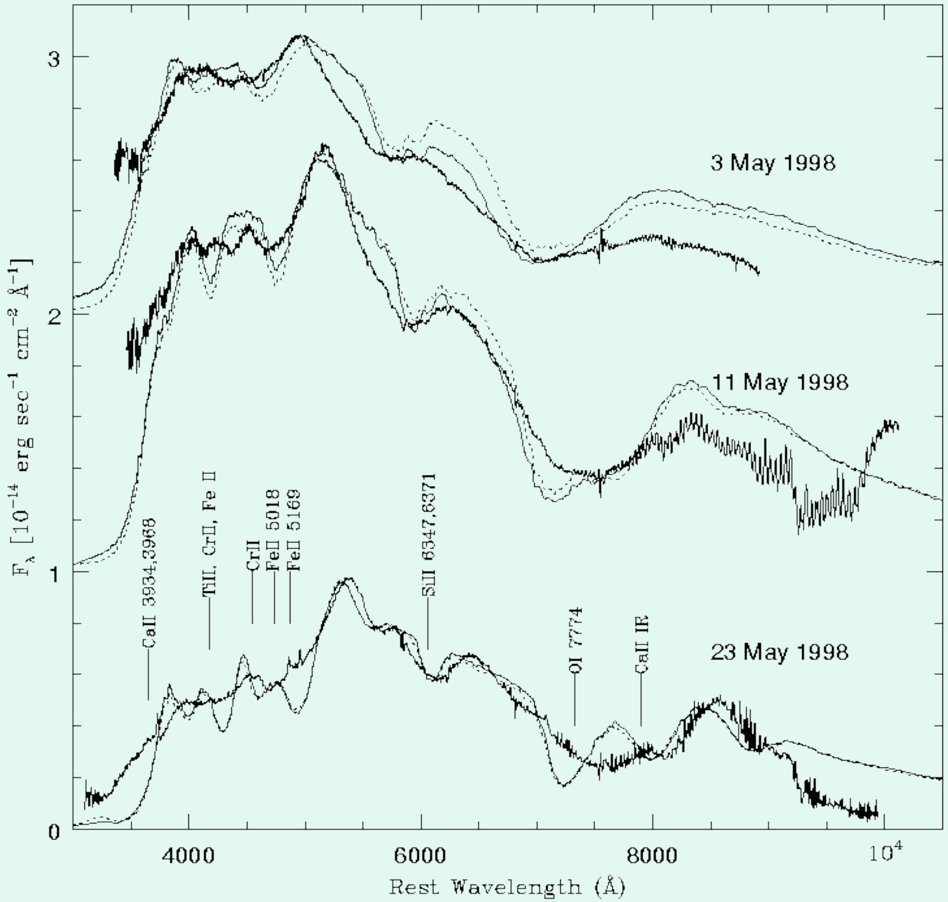
- Fit spectrum with a classical model:
- Mej ~ 1 M⊙, KE~10^{51} erg (1 foe)
- Abundances dominated by O, Si
- M(^{56}Ni) ~ 0.1 M⊙

Sauer et al. 2006



SN 1998bw: modelling





$$\tau_{LC} \propto \frac{\kappa^{1/2} M^{3/4}}{E^{1/4}}$$

$$M_{ej} = 10.9 M_\odot$$

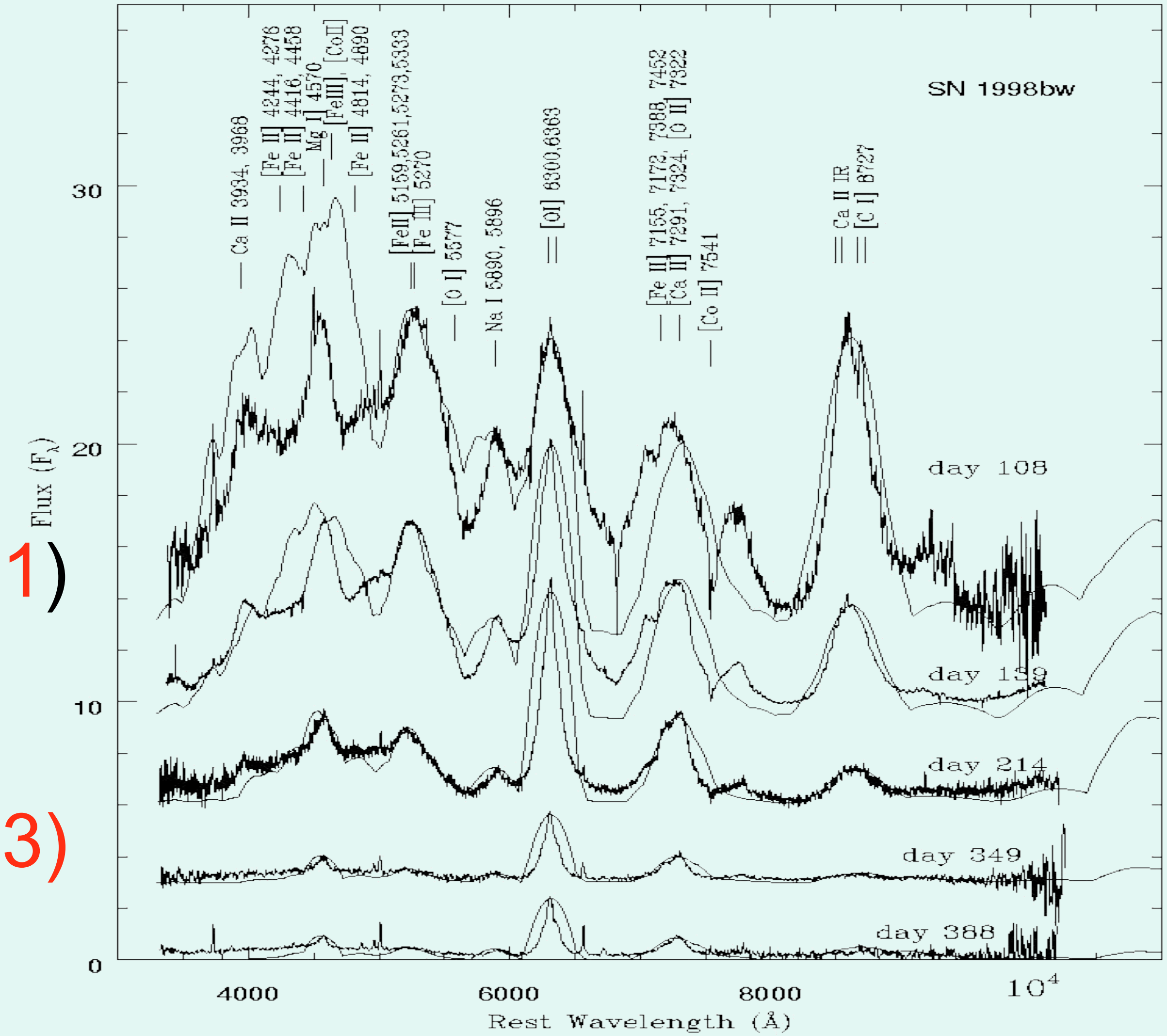
$$M(^{56}\mathrm{Ni}) = 0.5 M_\odot$$

$$KE = 5\times 10^{52}\, erg$$

Iwamoto et al. 1998

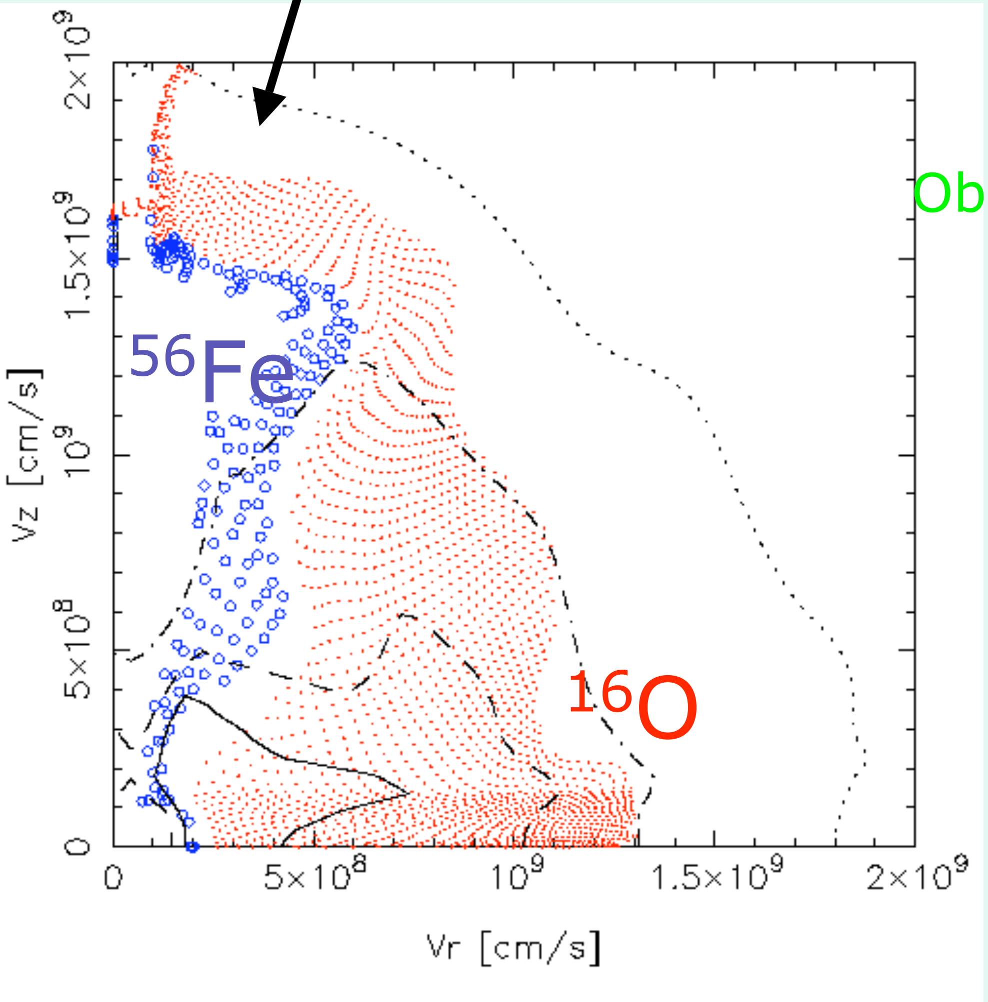
GRB/SNe are highly aspherical

- Evidence in nebular spectrum (Oxygen line broader than Fe lines, Mazzali et al. 2001) but also in light curve (Maeda et al. 2003)

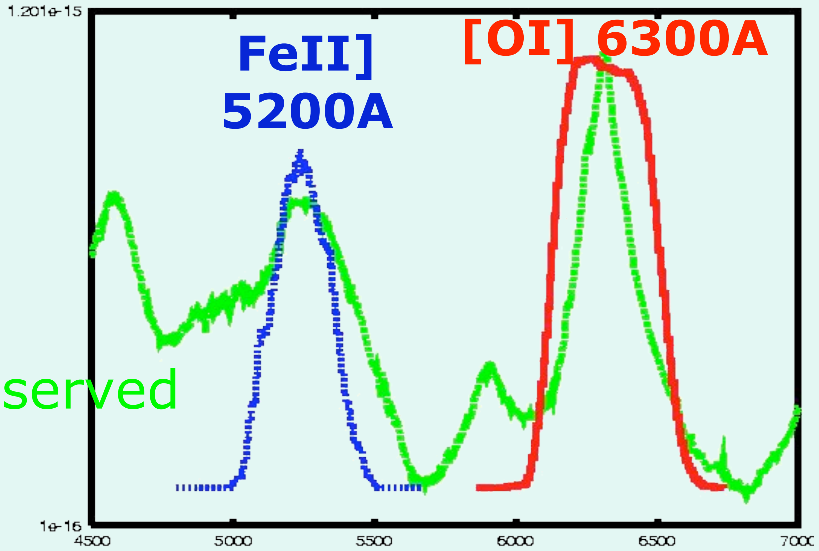


Aspherical explosion:

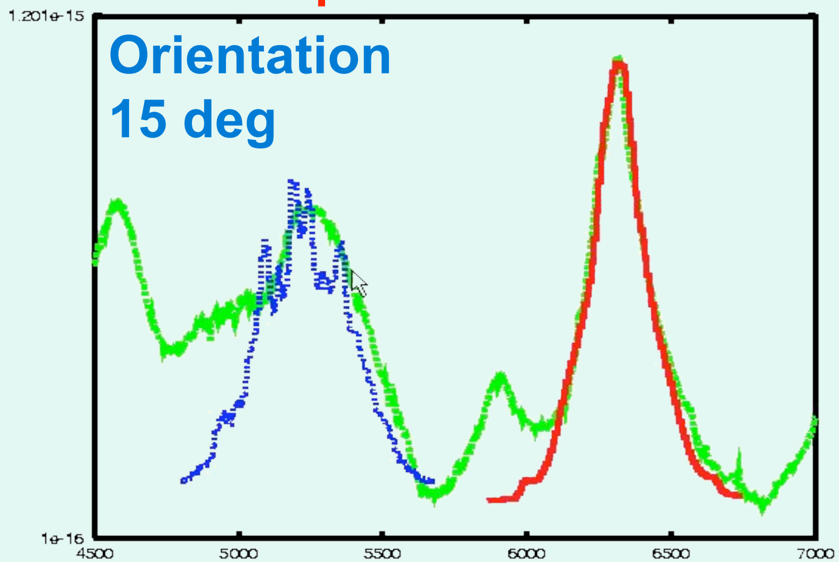
aspect-dep line shape



Spherical



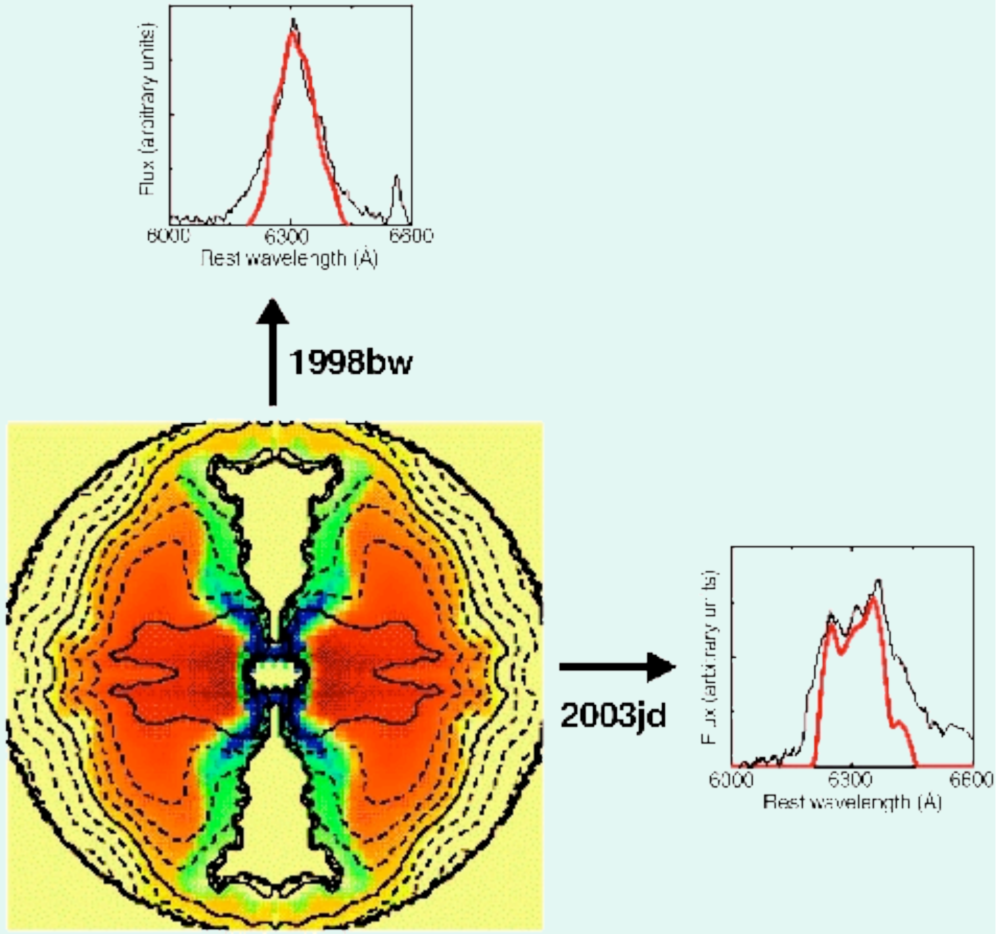
Aspherical



Maeda et al. 2002

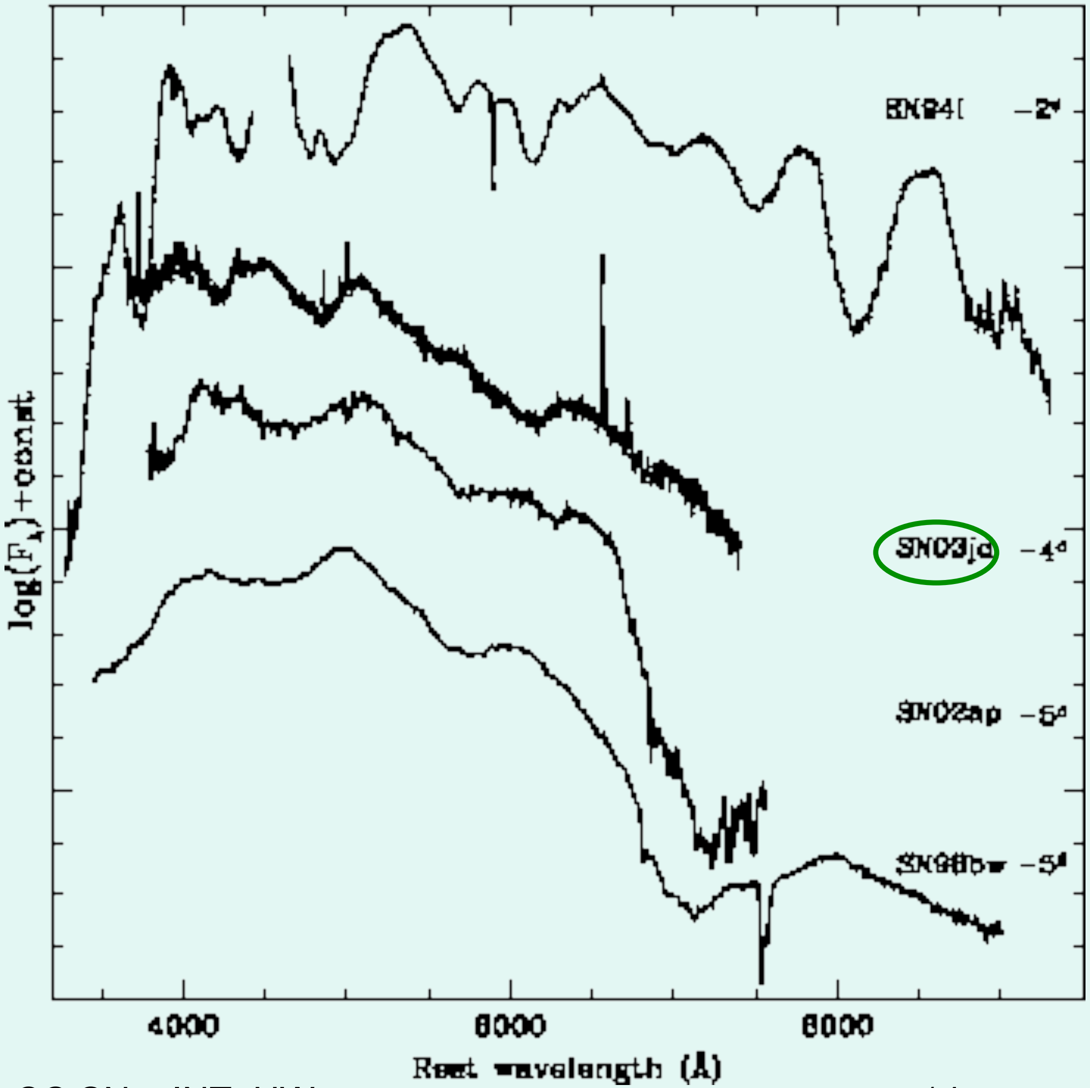
Prediction from asphericity: off-axis GRB/SNe

- Double-peaked [O I] line indicates edge-on SN
- SN Ic 2003jd had broad lines was luminous, and showed a double-peaked [O I] line
- but the presence of an off-axis GRB seems to be ruled out by radio limits (Soderberg)
- So, something's missing



Was SN 2003jd = SN1998bw?

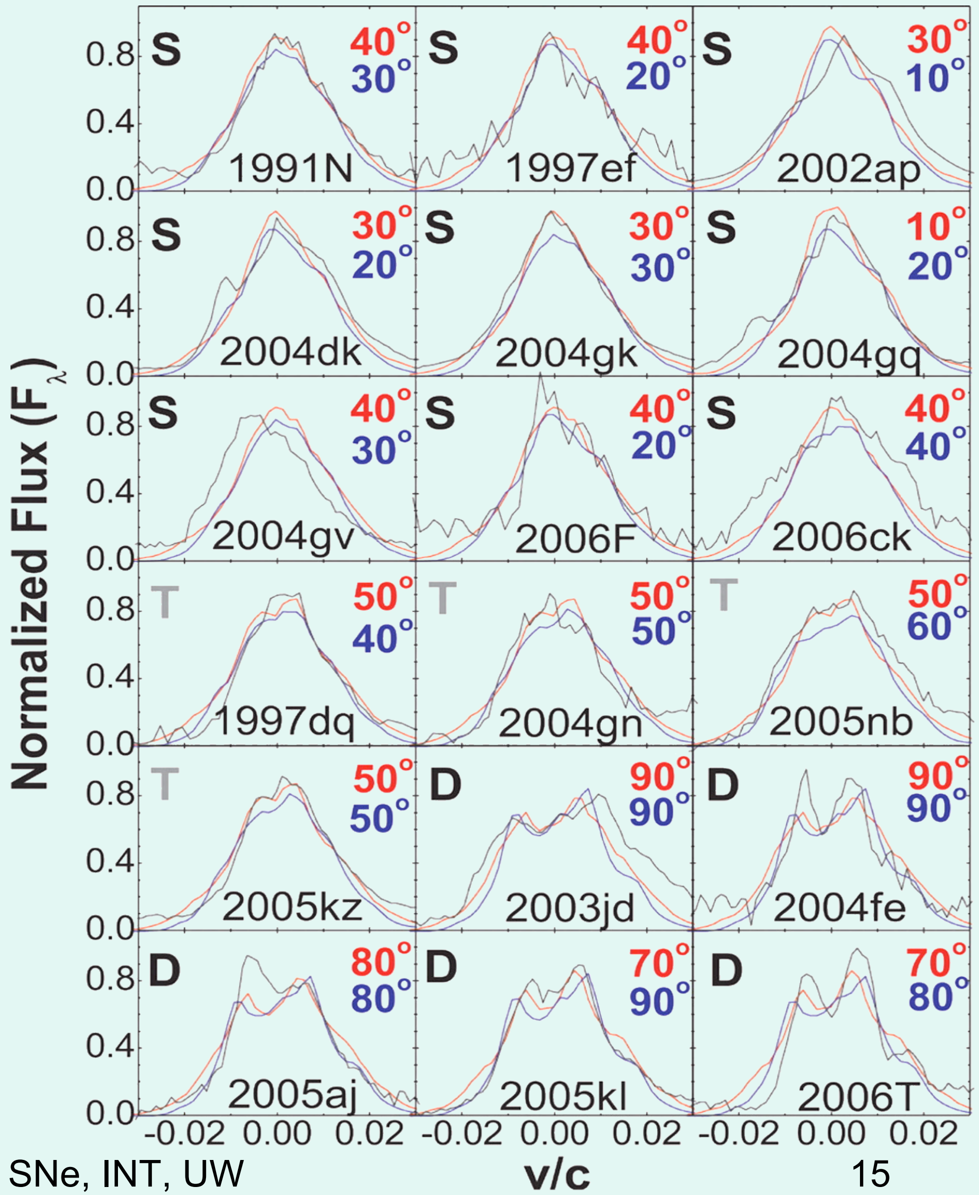
- It was almost as bright at peak as SN1998bw (Mv = -18.7)
- Early-time spectra had broad lines, but closer to SN2002ap



Mazzali et al. (2005)

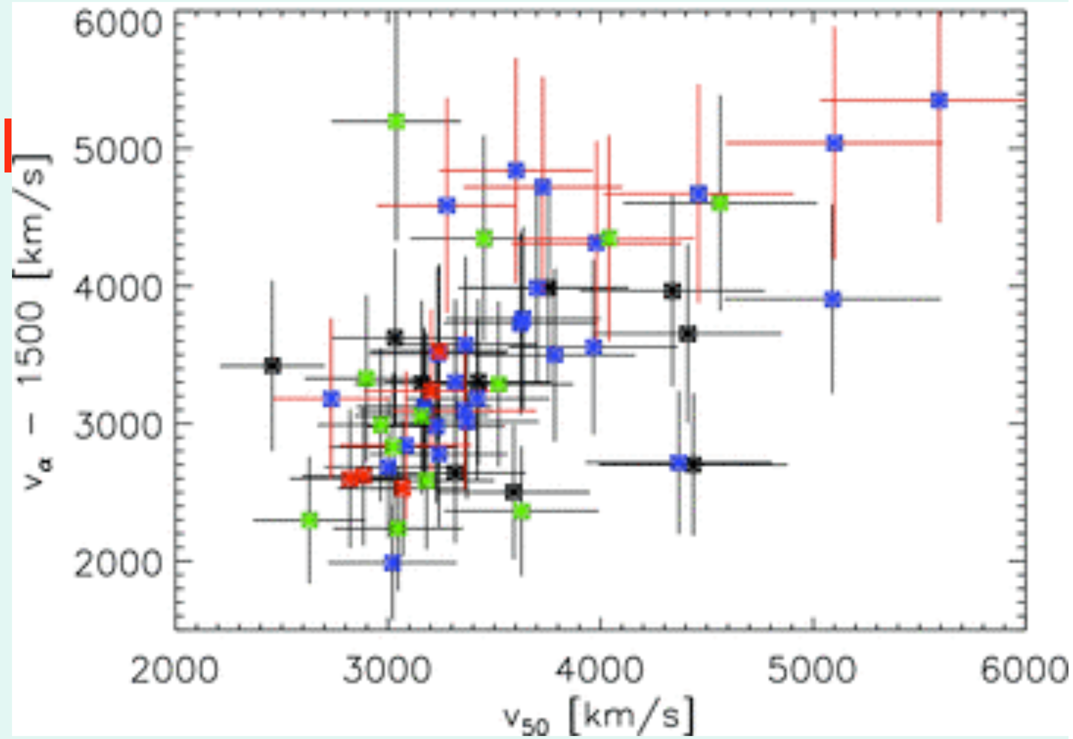
How common is asphericity?

- SNe Ib/c are consistent with being aspherical
- BL-SNe are the most aspherical
- They have the widest range of nebular properties (Maeda et al. 2008, Tanaka et al. 2009): even double peaks have wider separation



Asphericity?

- BL-SNe (red crosses) are the most aspherical
- They have the widest range of nebular properties (Tanaka et al. 2009)
- No relation between core velocity and mass, 56Ni mass or KE (Maurer et al. 2010)



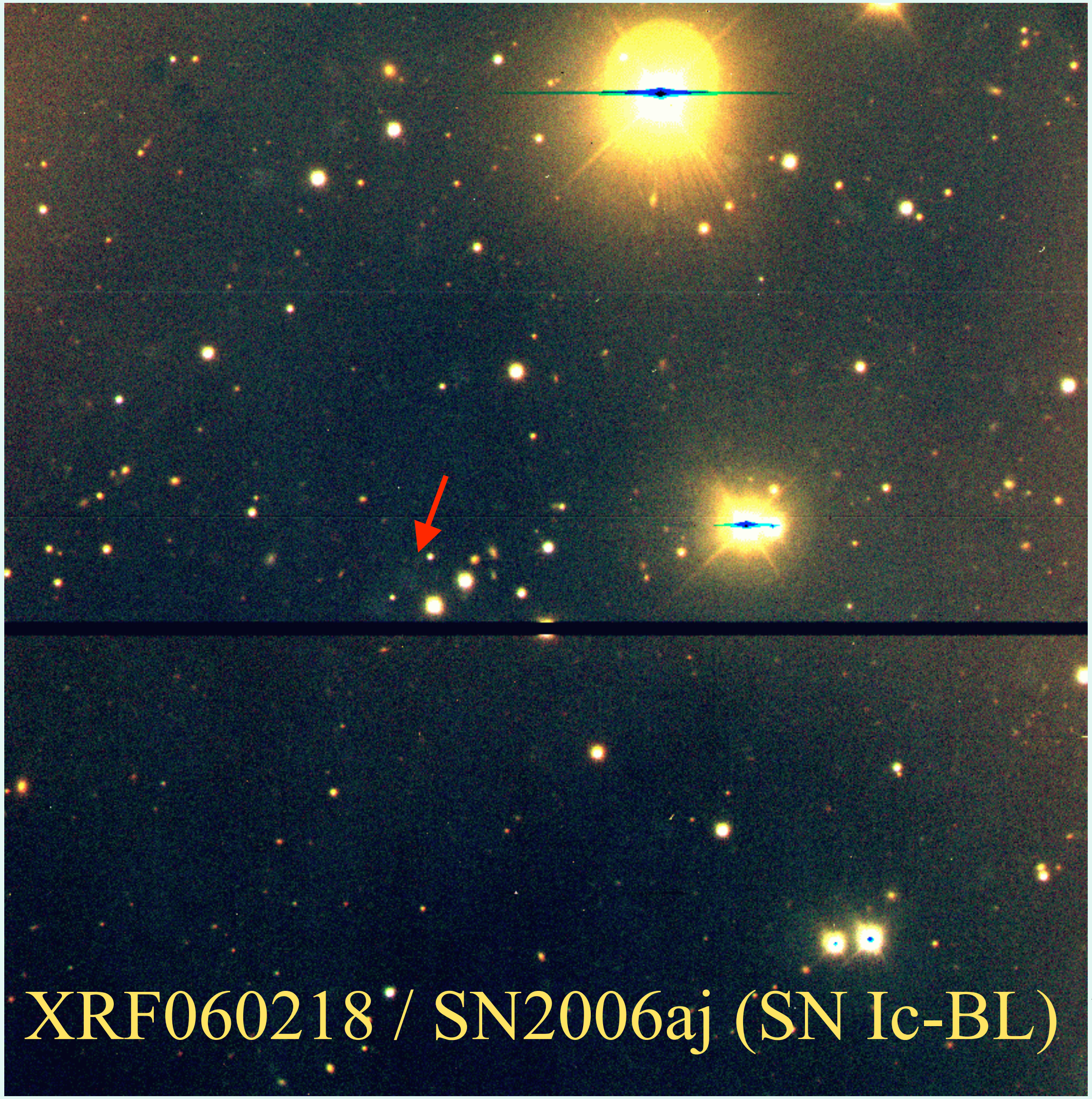
v_{50}: measured [O I] vel.

$v\alpha = (E/M)^{1/2}$

Going down in energy…….

X-ray Flashes (XRF):

weak, soft equivalent of long GRBs



VLT

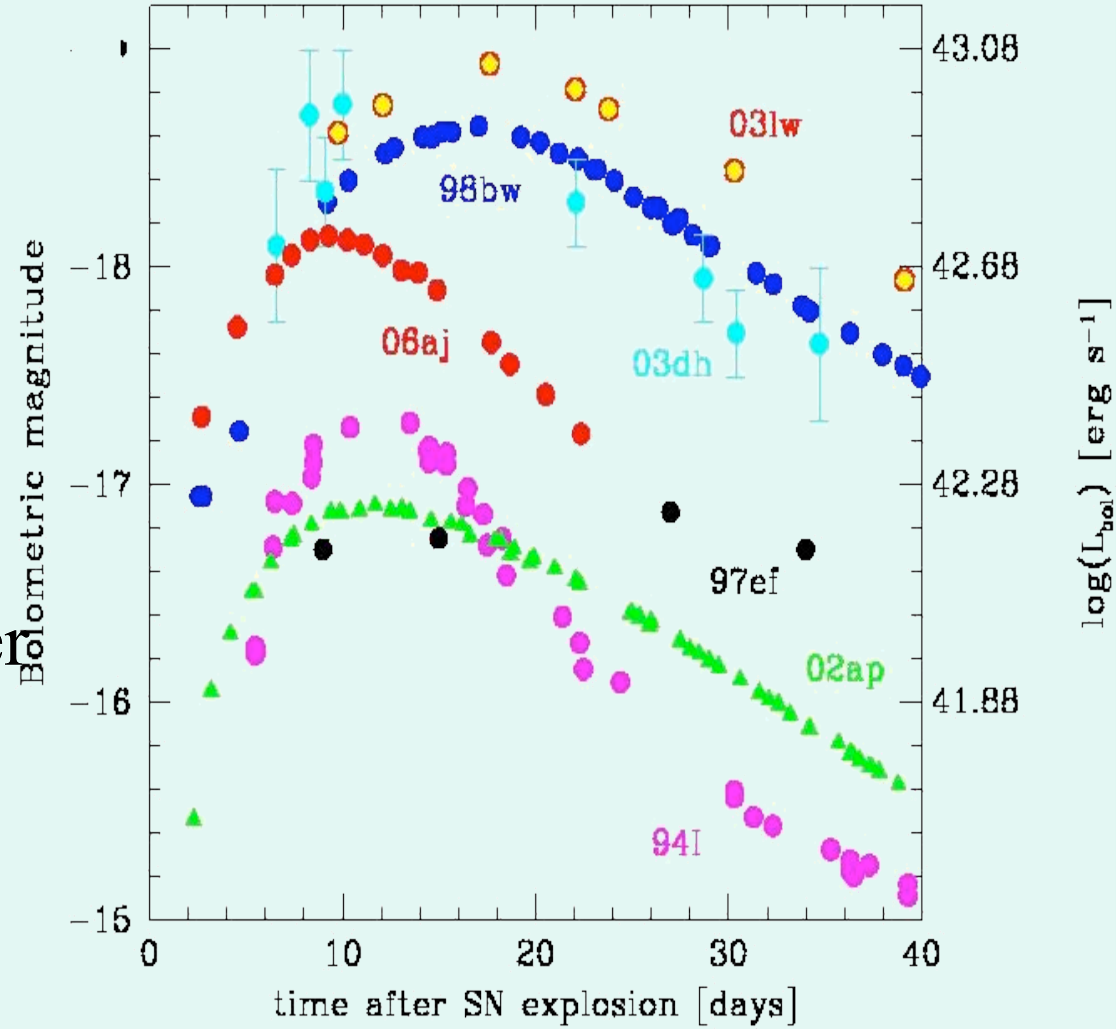
SN Ic 2006aj: Bolometric Light Curve

SN2006aj, a BL-SN Ic, was dimmer than GRB/SNe (98bw, 03dh, 03lw)

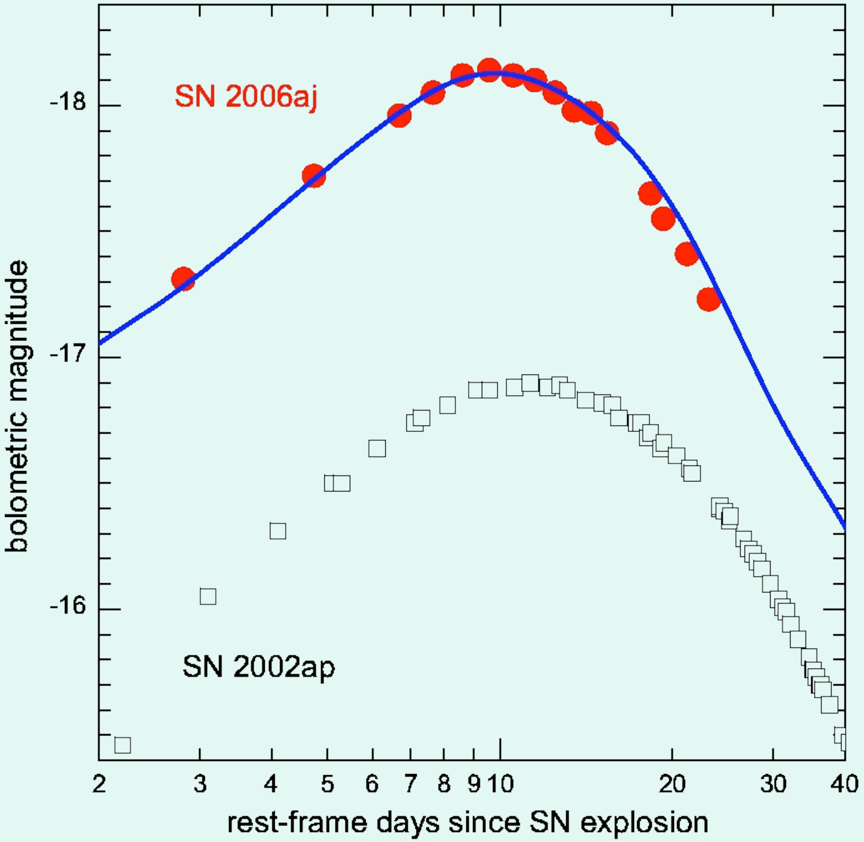
Light curve similar to non-GRB broad-lined SN Ic 2002ap, but brighter

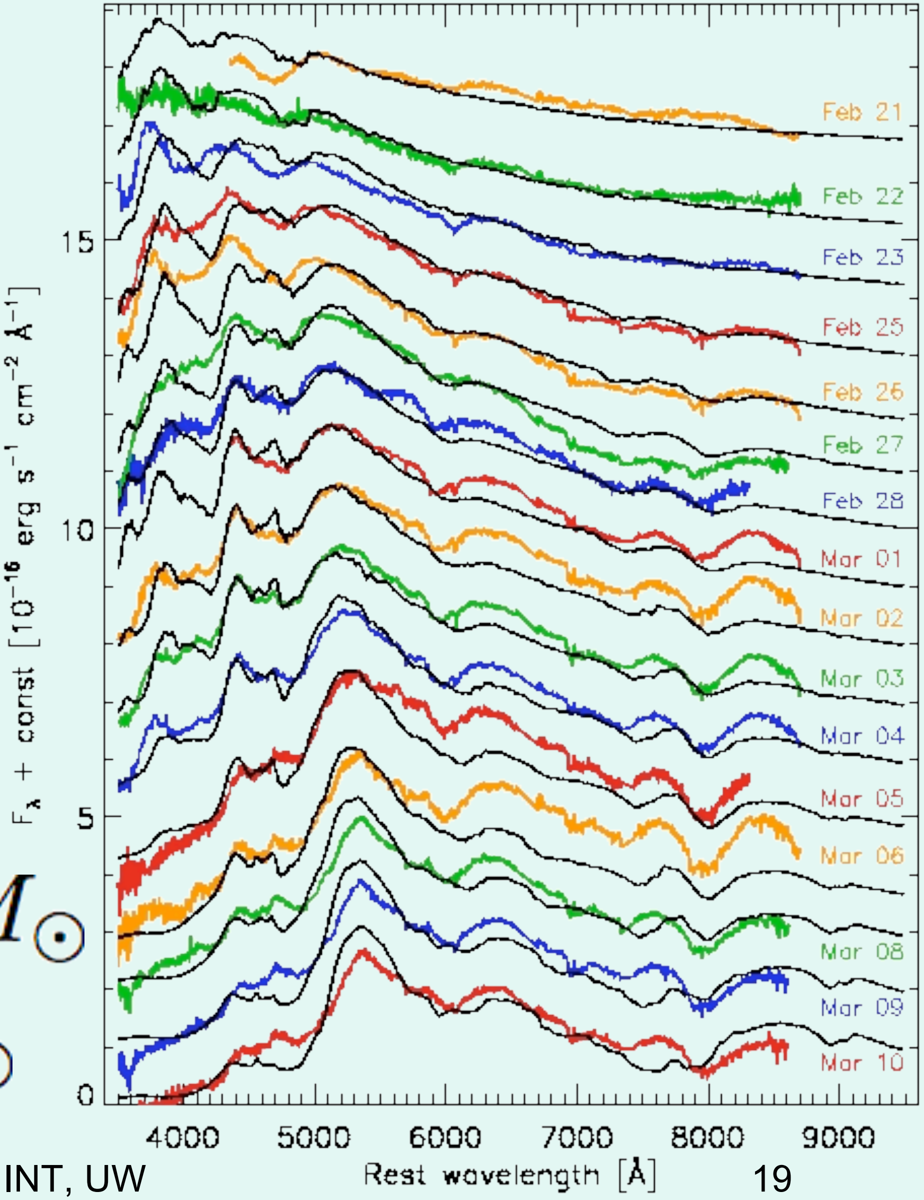
Estimate ~ 0.2M$_\odot$ of ^{56}Ni

Rapid LC evolution:
➔ M_{ej}^3/E is small



SN2006aj: intermediate M, KE





$KE = 2 \times 10^{51} erg$ $M_{ej} = 2M_\odot$

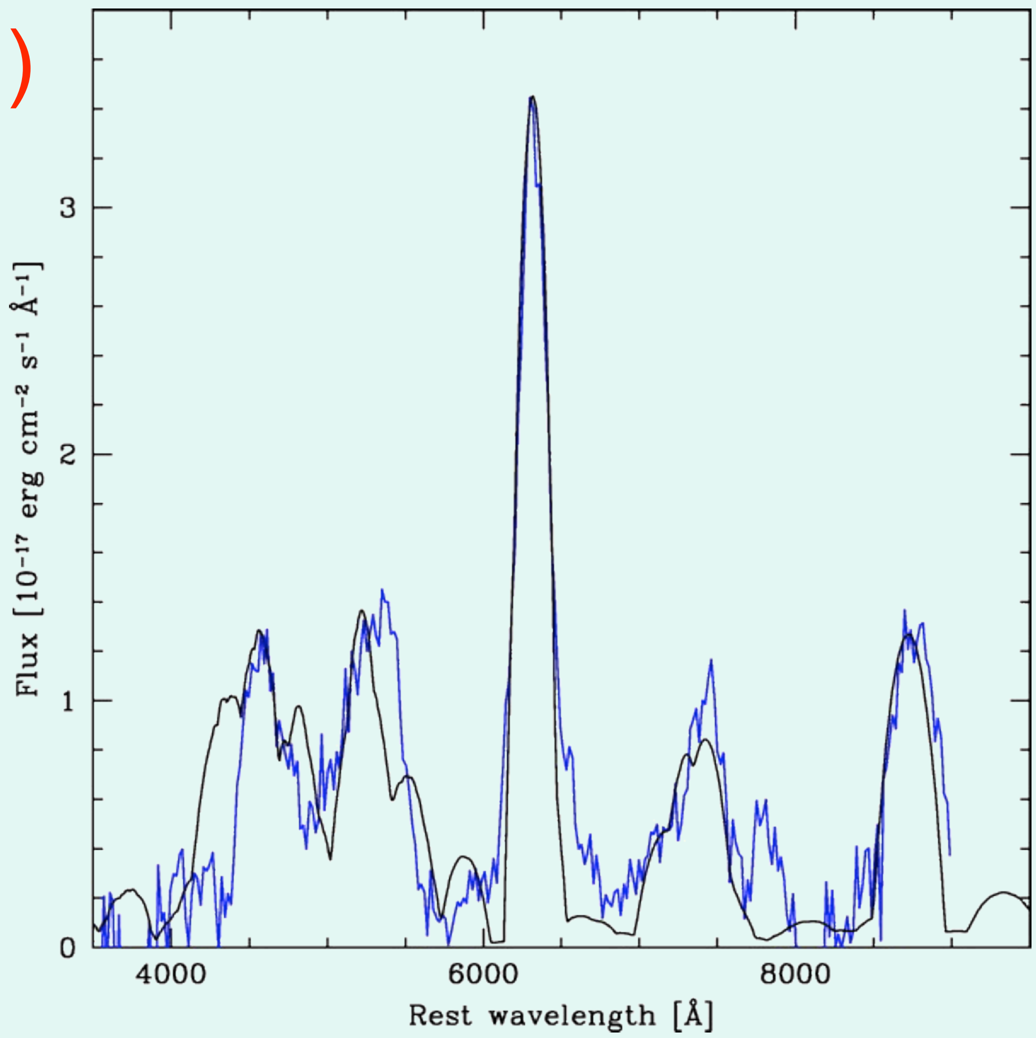
$$M(^{56}\mathrm{Ni}) = 0.21M_\odot$$

Mazzali et al. 2006

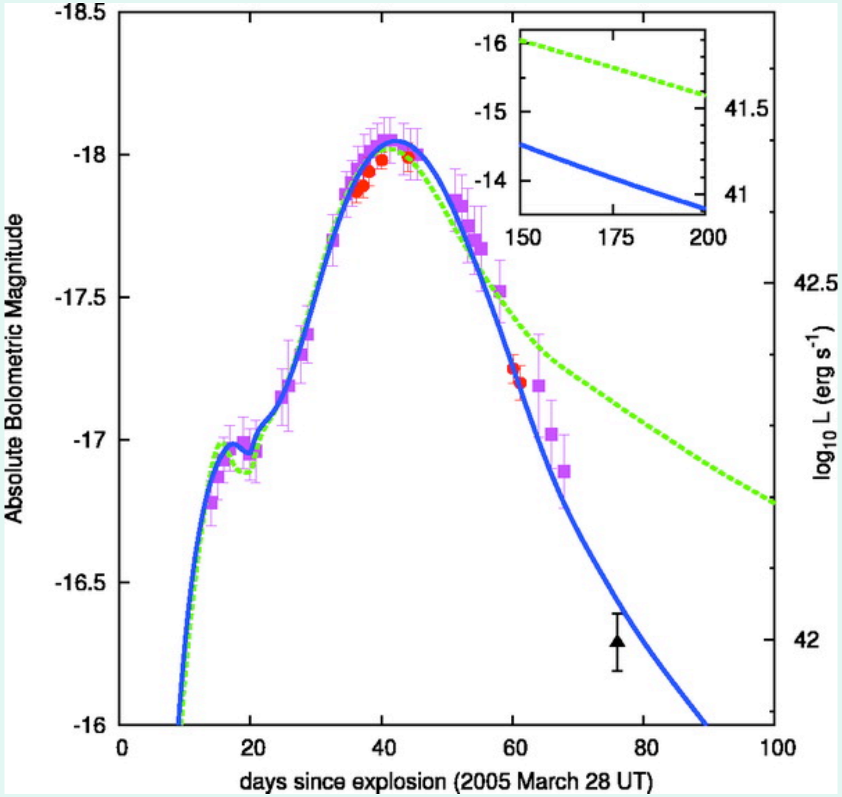
SN 2006aj/XRF060218, nebular phase

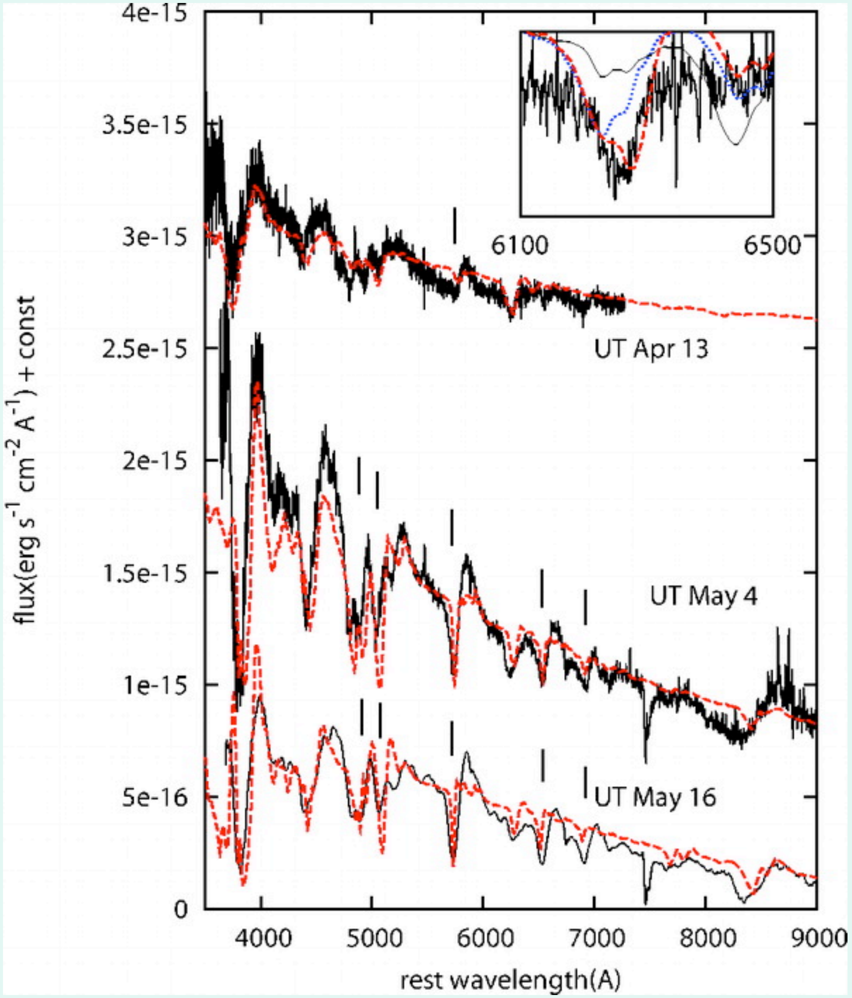
- CO core mass (2 M☉) small for BH remnant
- NS more likely: did a Magnetar power the explosion?
- Nebular analysis confirms values, finds little asphericity, as in SN2002ap

(Mazzali et al. 2008)



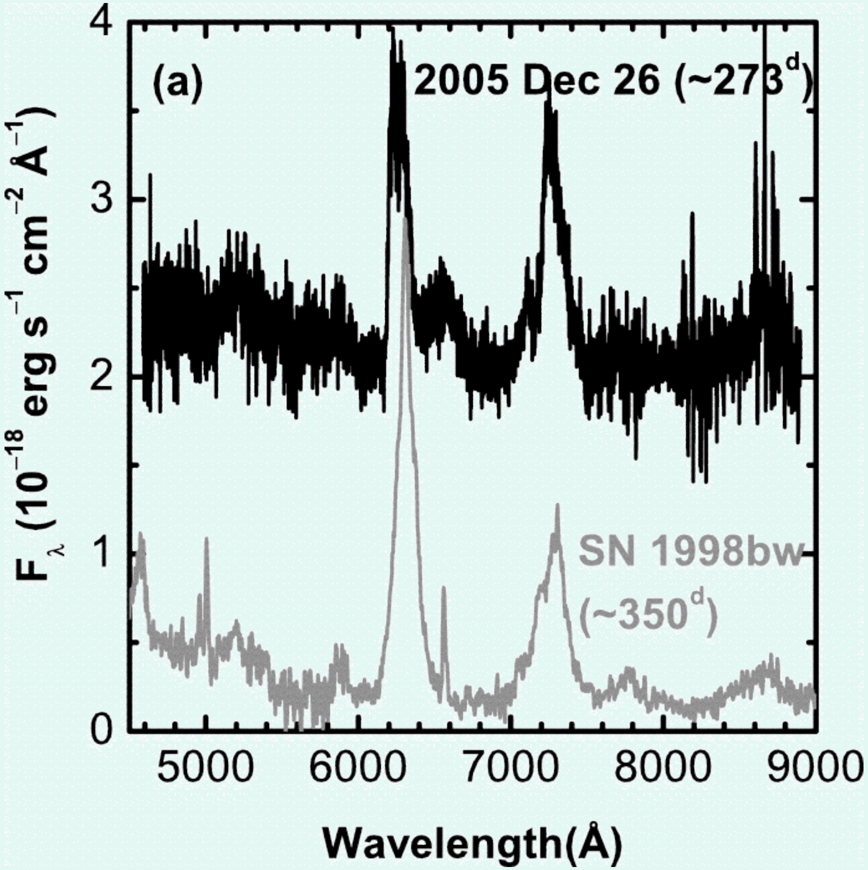
A Magnetar in SN Ib 2005bf

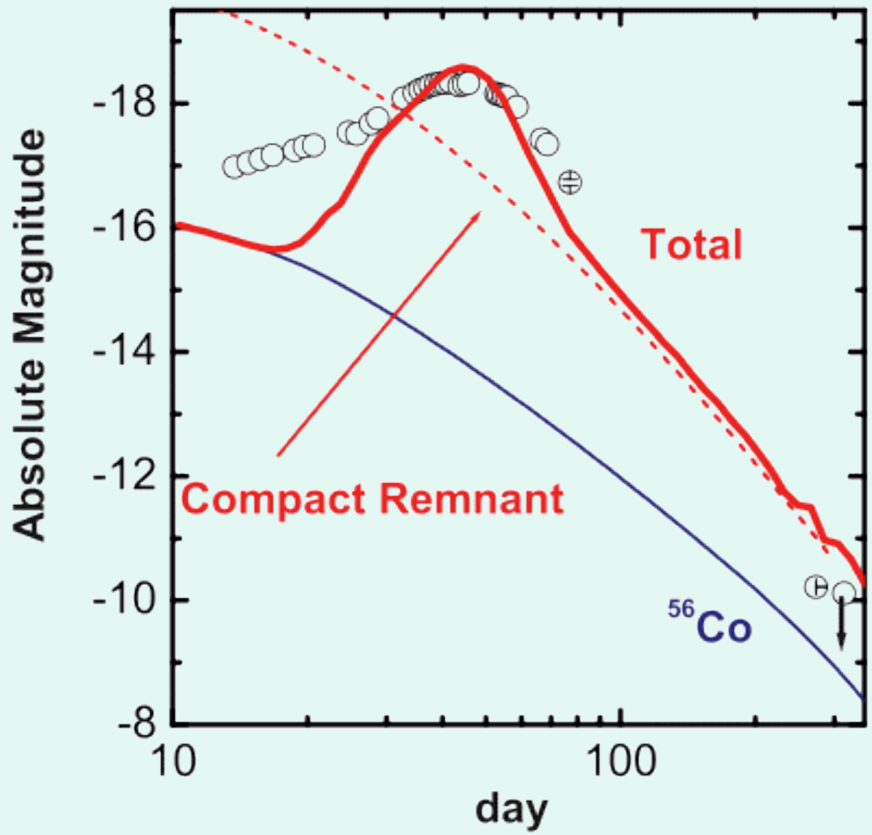




The type Ib SN 2005bf
(Tominaga et al. 2007)
showed a bright, late 2nd LC peak

Role of Magnetar



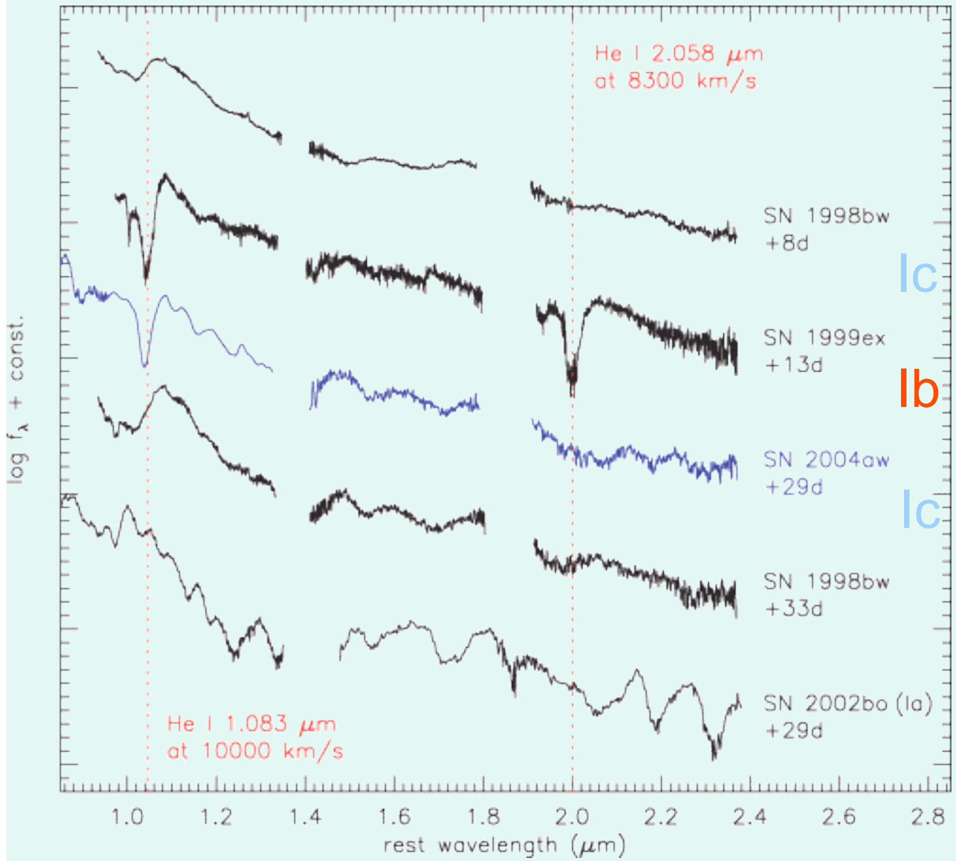


- Nebular lines offset by a few 1000 km/s
- Magnetar activity may have been responsible for the rebrightening

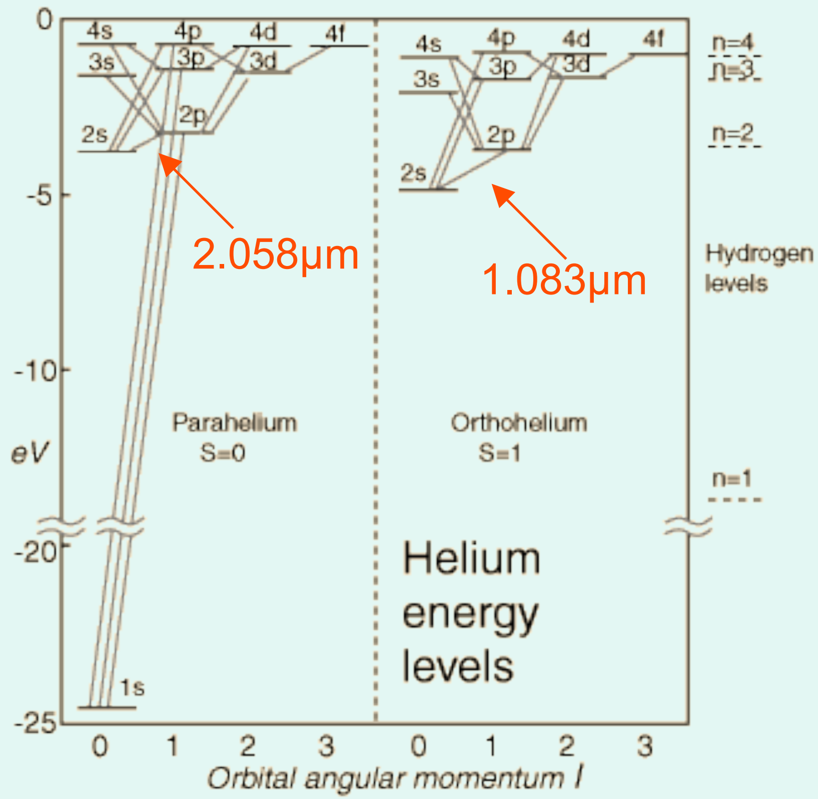
(Maeda et al. 2007)

All GRB/XRF SNe are Ic

SNe Ib v. Ic: Helium



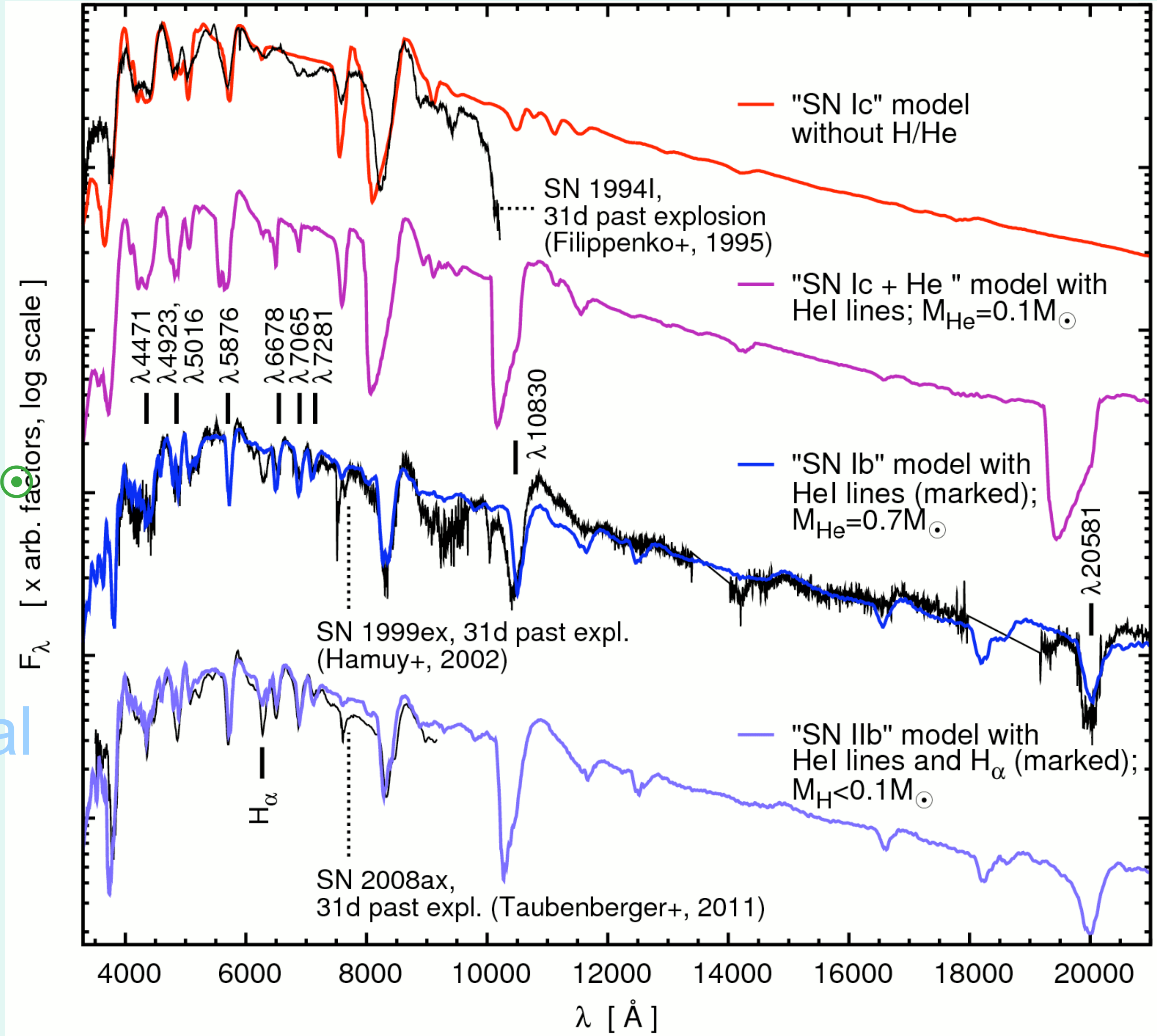
Taubenberger et al. 2006



Strongest HeI lines in IR. 1μ can cause confusion, 2μ line unique

It takes little He to make a SN Ib

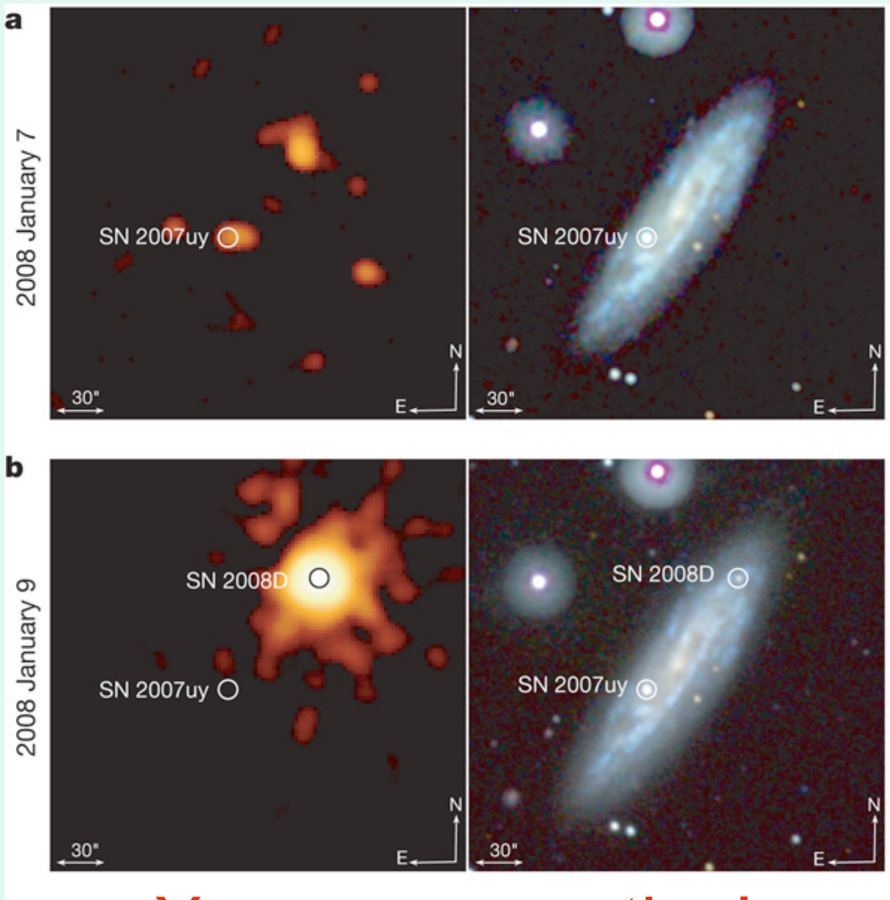
- HeI requires non-thermal processes
- SNe Ib: M(He) >~ 0.1 $M_\odot$
- SNe IIb: M(H)~0.02$M_\odot$
- Different spectral subclasses are sharply separated

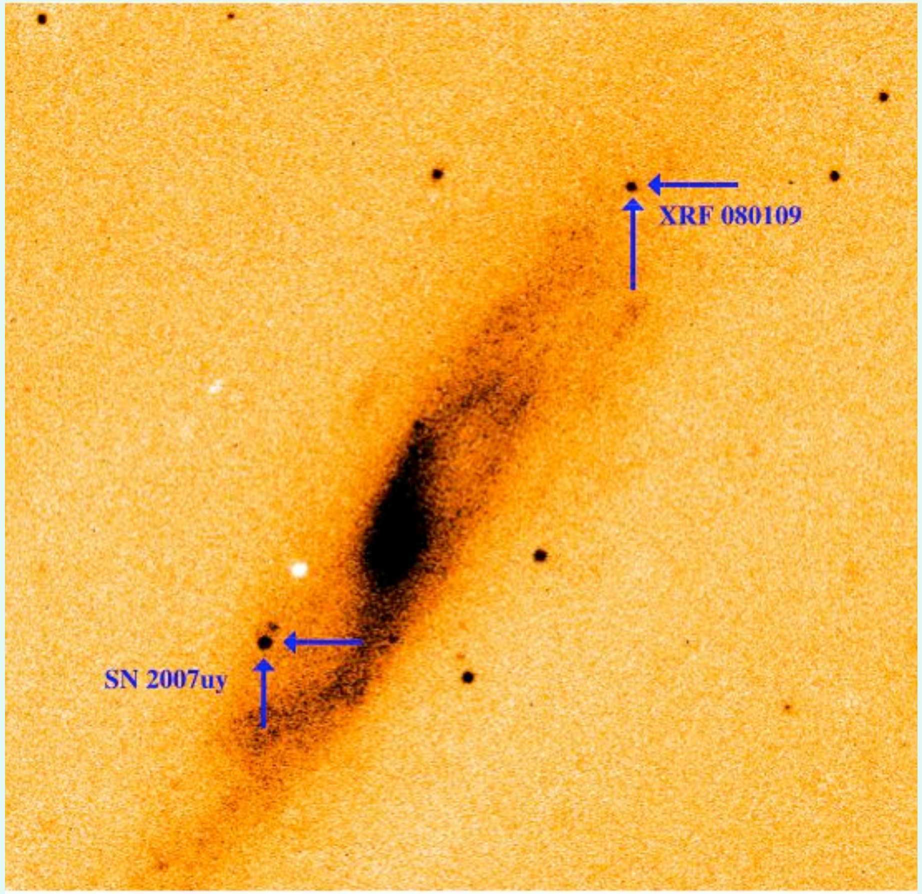


(Hachinger et al., 2012)

What happens in SNe Ib?

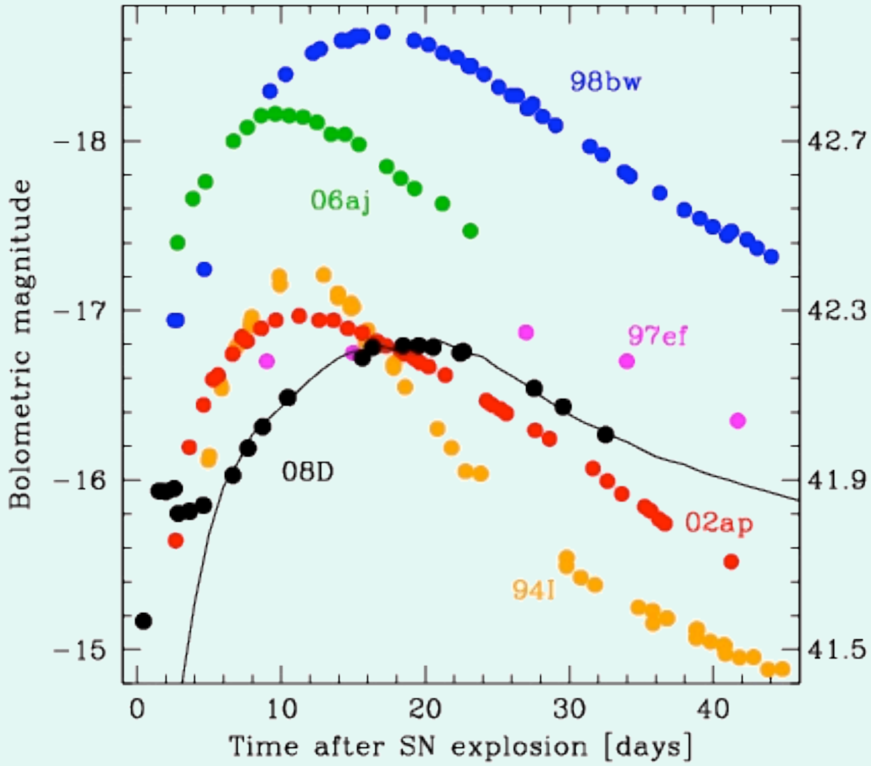
SN2008D: breakout?

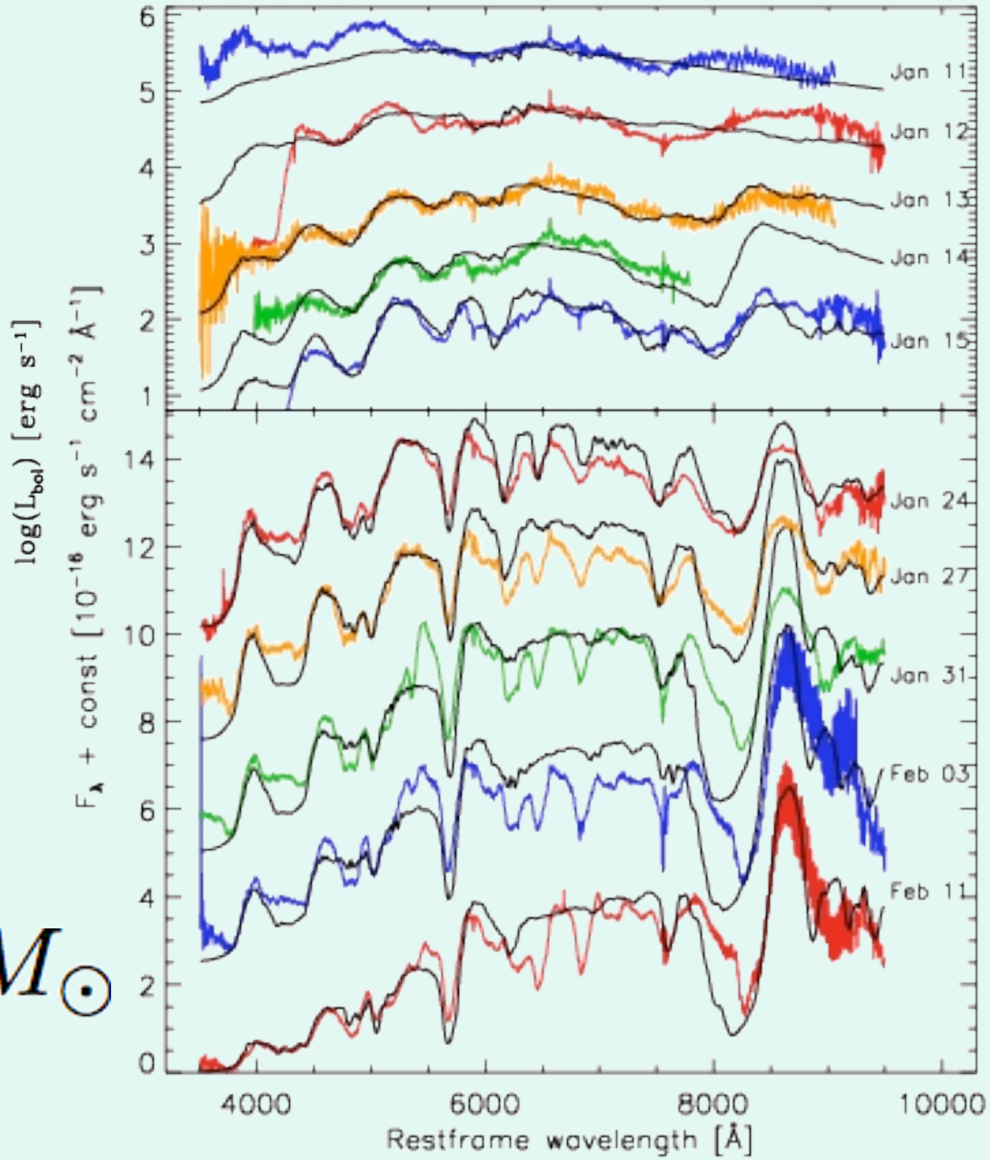




X-rays optical IR

HN SN Ib 2008D / XRF080109: again intermediate values





$KE = 7 \times 10^{51} erg$ $M_{ej} \approx 6 M_\odot$

$M(^{56}\mathrm{Ni}) = 0.09 M_\odot$

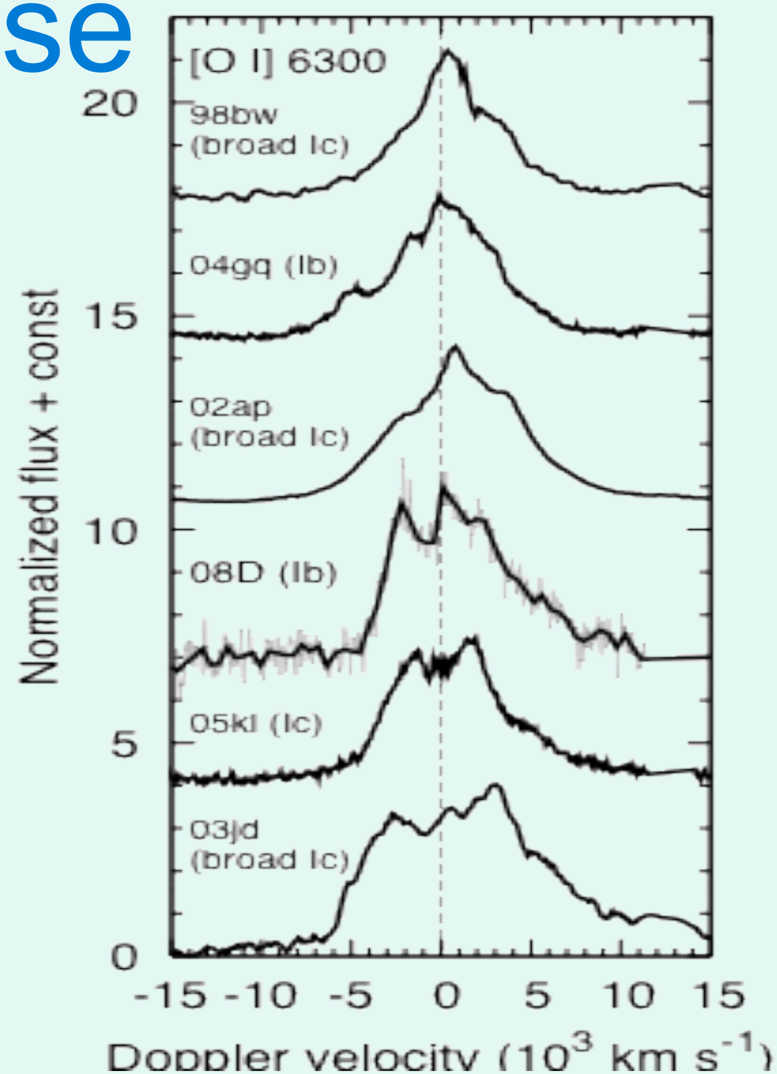
Mazzali et al. 2008, Tanaka et al. 2009

SN2008D / XRF080109: the nebular phase

- [O I] line has double-peaked profile, like SN2003jd
- An energetic, highly aspherical explosion, viewed far from the polar axis
- He shell blocked any jet

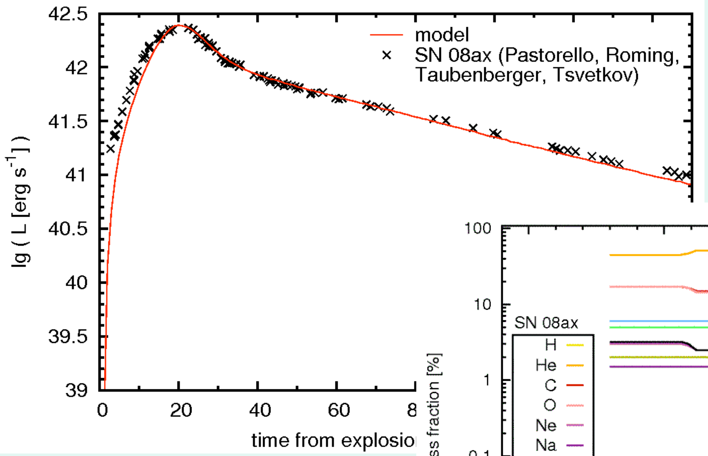
$KE = 7 \times 10^{51} erg$ $M_{ej} \approx 6 M_\odot$

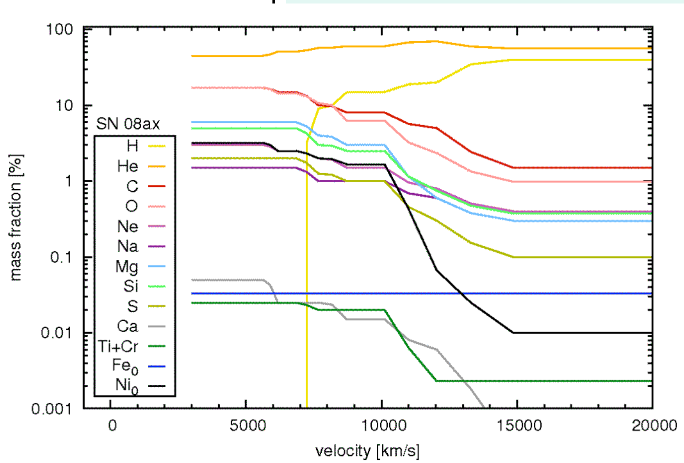
$M_{ZAMS} \sim 30 M_\odot$

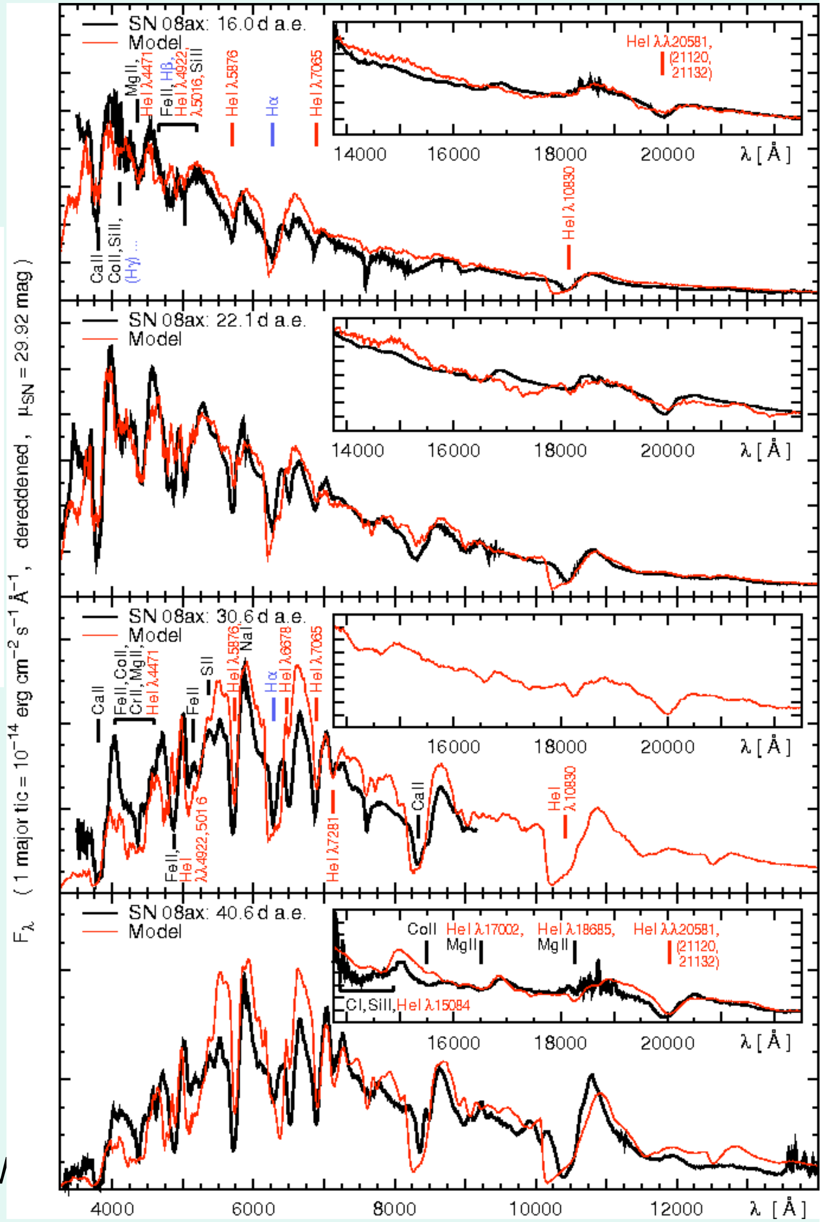


Mazzali et al. 2008, Tanaka et al. 2009

A normal SN IIb: 2008ax







$$KE = 10^{51} erg$$

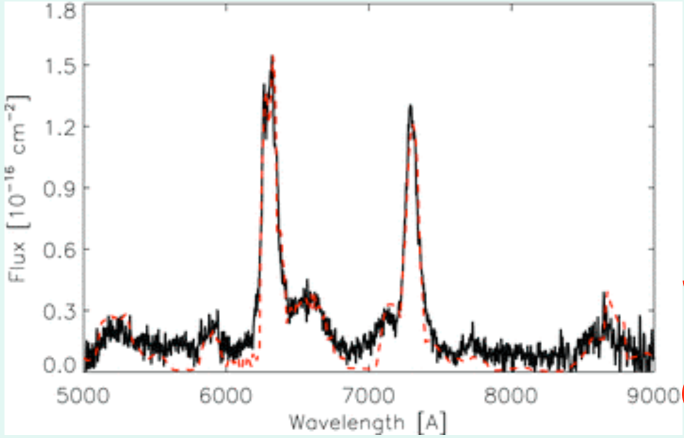
$$M_{ej} \approx 2.5 M_{\odot}$$

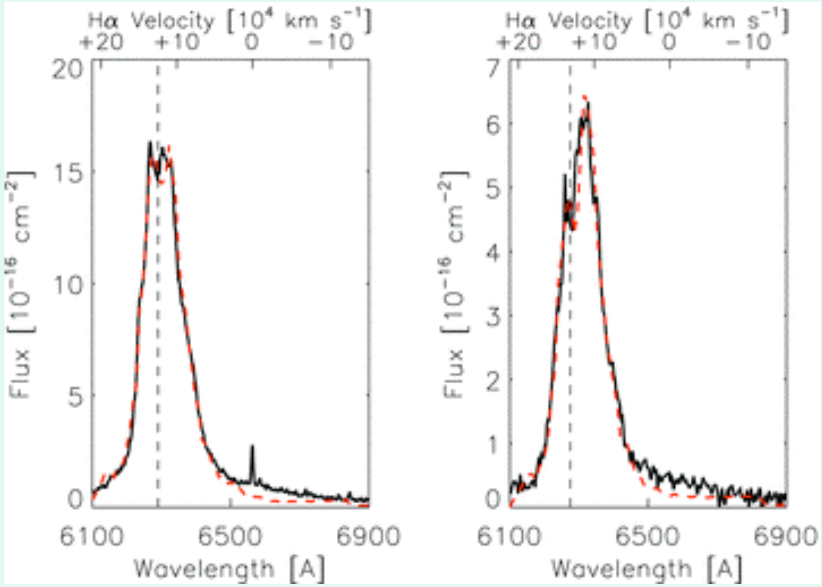
$$M(H) \approx 0.05 M_{\odot}$$

$$M(He) \approx 1.2 M_{\odot}$$

$$M(^{56}Ni) \approx 0.09 M_{\odot}$$

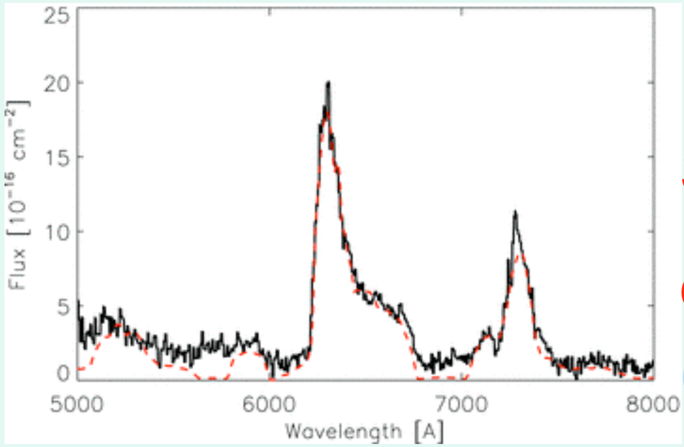
Aside: H emission in SNe IIb





SN2008ax

d 358



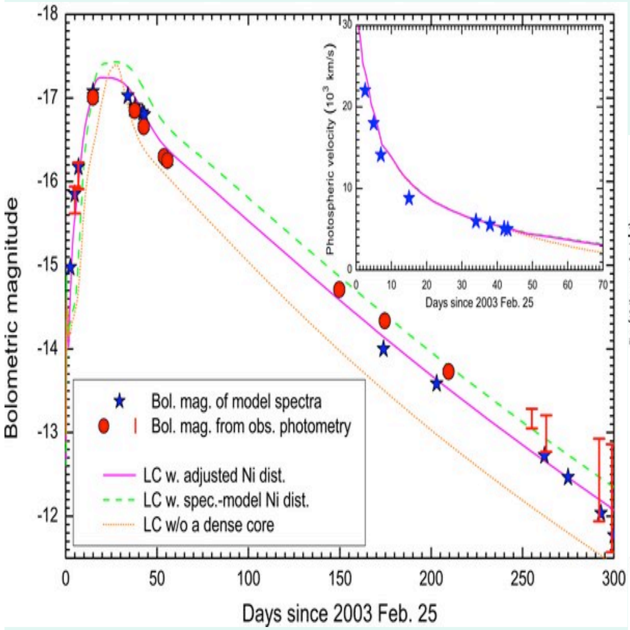
SN1993J SN2001ig SN2003bg

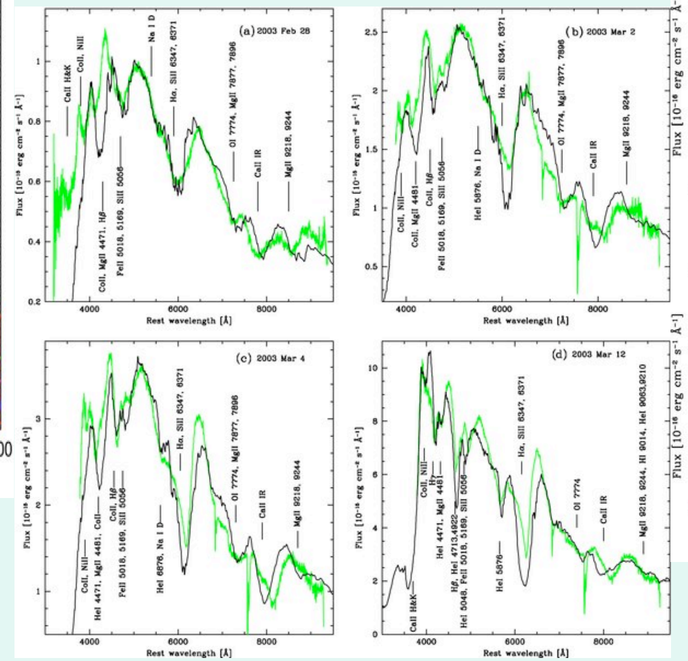
d 363 d359 d301

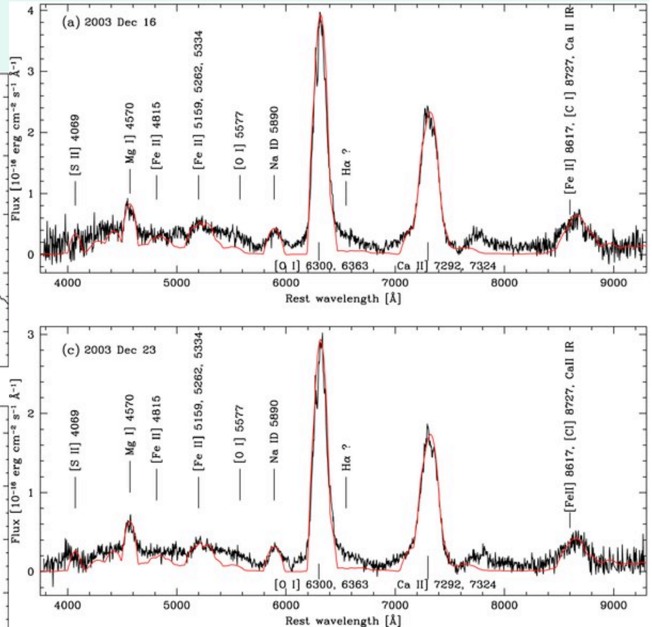
(all have ~0.1-0.3$M_\odot$ of H)

- depending on mixing of H into He, Hα emission may be seen (H is ionised by UV photons emitted by non-thermally ionised He and by non-thermal electrons)

SN IIb HNe: 2003bg







$$KE = 5\times10^{51}erg$$

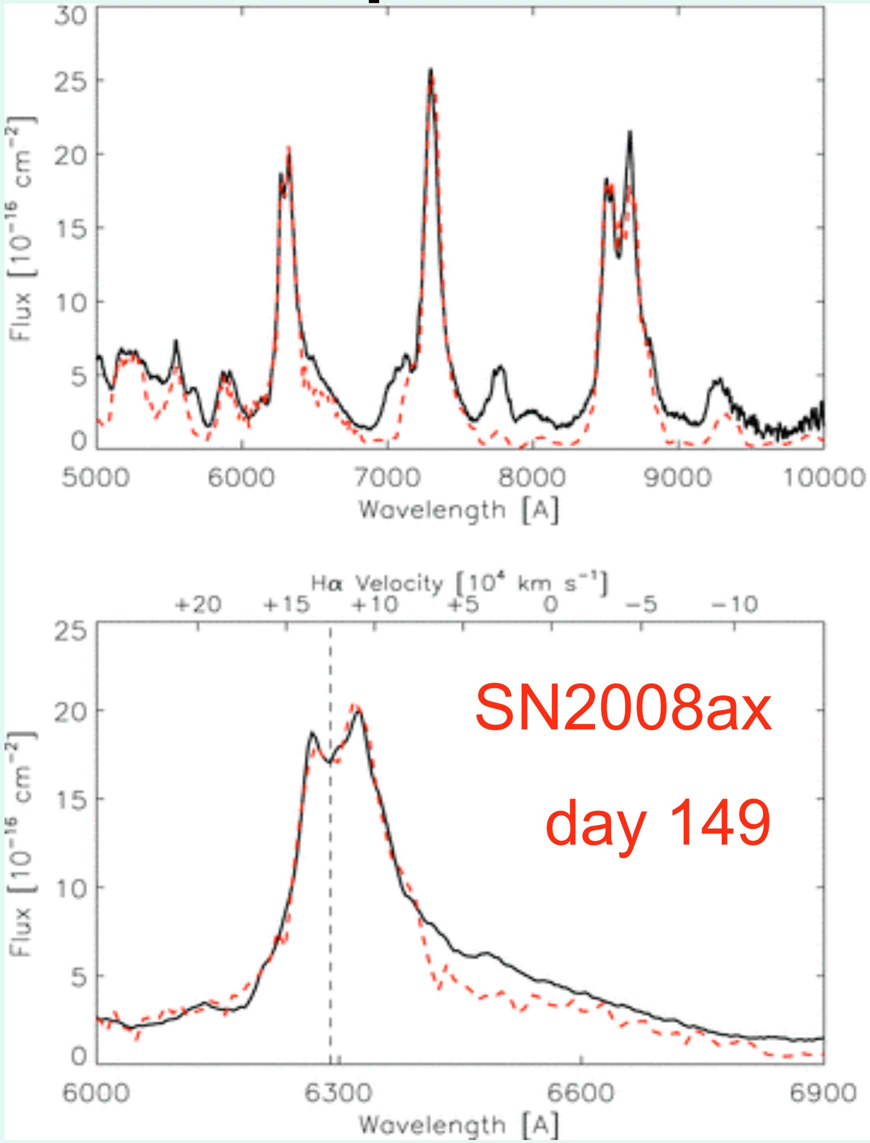
$$M_{ej} \approx 4M_{\odot}$$

$$M(^{56}\mathrm{Ni}) = 0.20M_{\odot}$$

Again, nebular analysis finds little asphericity (Mazzali et al. 2009)

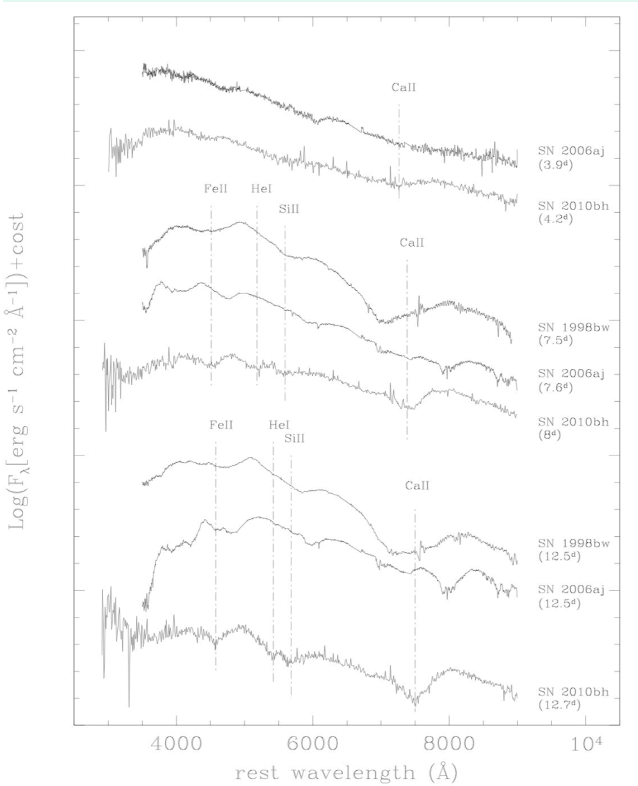
Aside: "narrow" double peaks

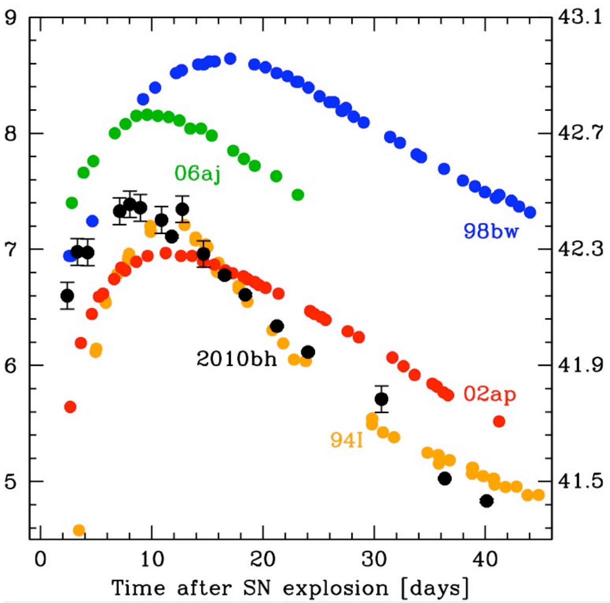
- Several SNe Ib/c show a split in the [O I] line, but the wavelength separation of the peaks is almost always quite small
- One possibility is
  asphericity in the inner ejecta
- Another is the effect of
  Ha absorption
  (Maurer et al. 2010): this is often seen in SNe IIb and occurs for
  v(H) ~ 12000km/s:
  $\lambda(H\alpha) \rightarrow \lambda(O\ I)$
  This is more likely in SNe IIb

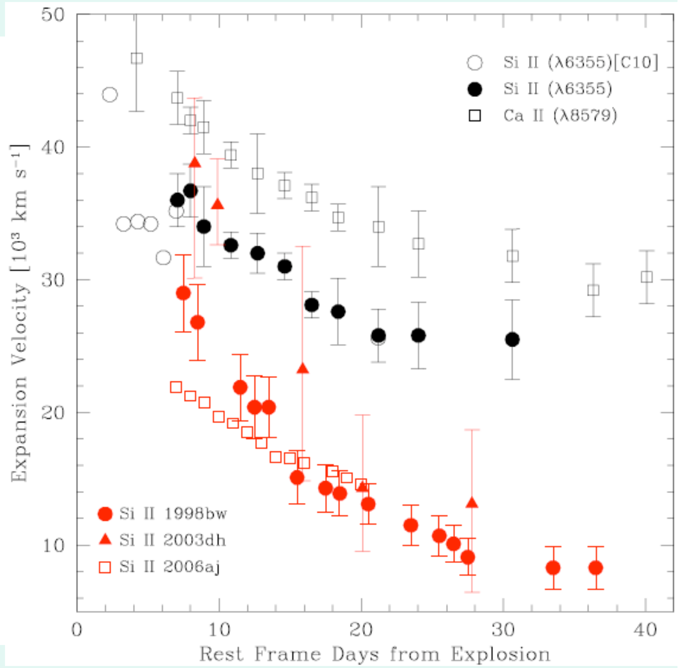


Recent events:

SN2010bh/XRF100316D



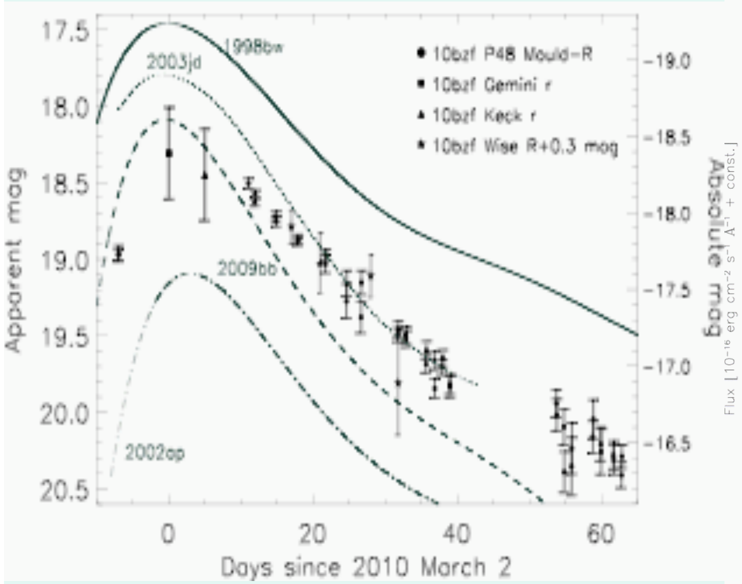


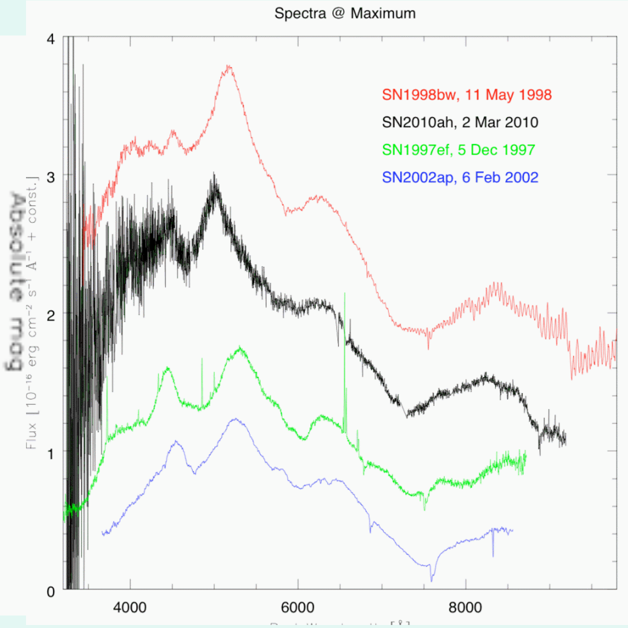


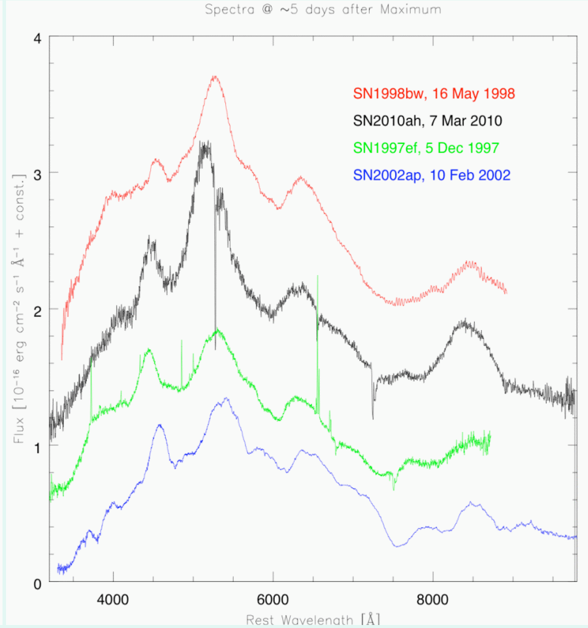
Bufano et al. 2012

- A Type Ic SN, not very bright, but with very high velocities
- Estimate M(56Ni) ~0.1 M⊙, Mej~3 M⊙, KE~10^{52}erg
- So KE is high, but mass is not

SN2010ah/PTF10bzf



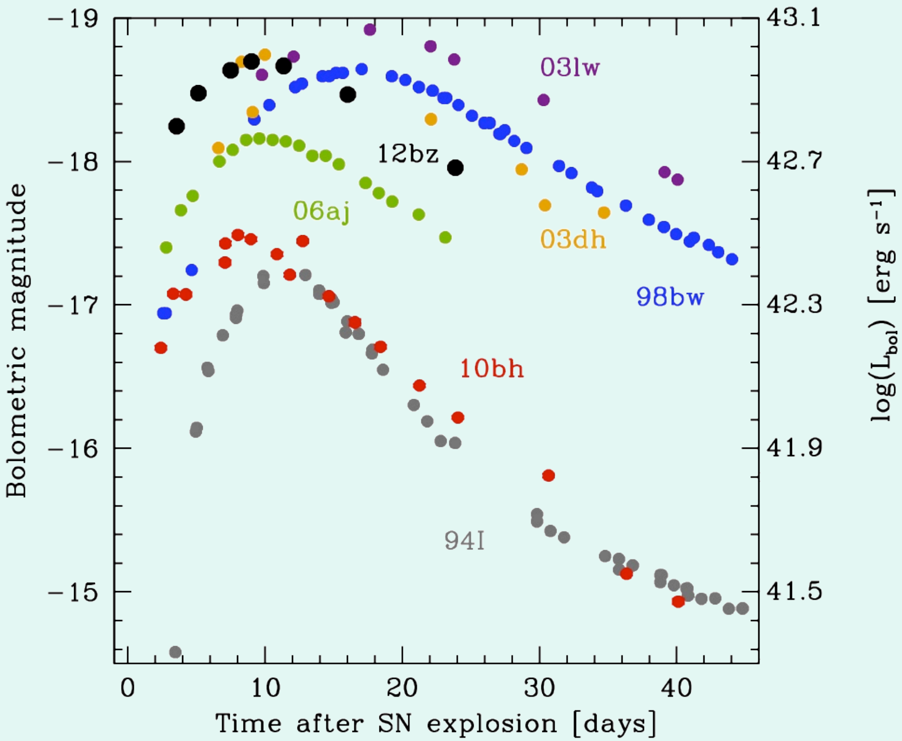


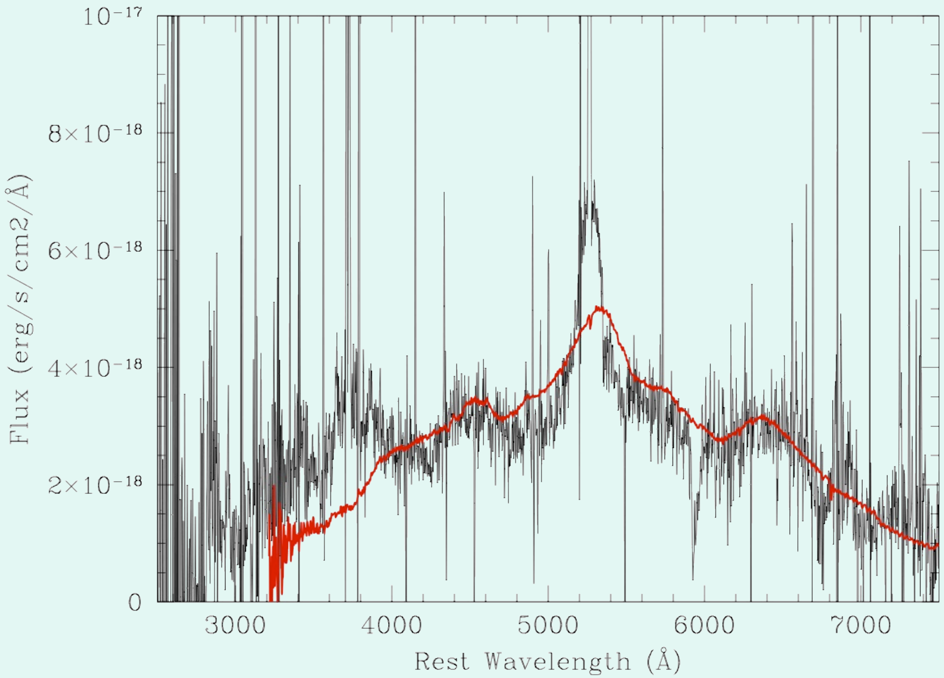


Corsi et al. 2011

- A rather bright SN Ic. No GRB/XRF.
- Luminosity, velocities, line broadening intermediate between SNe 1997ef and 1998bw
- Estimate M(56Ni) ~0.2 M☉, Mej~3-5 M☉, KE~1-1.5 10^{52}erg
- So KE is high, Mej not small: not large enough for a GRB?

SN2012bz/GRB120422A



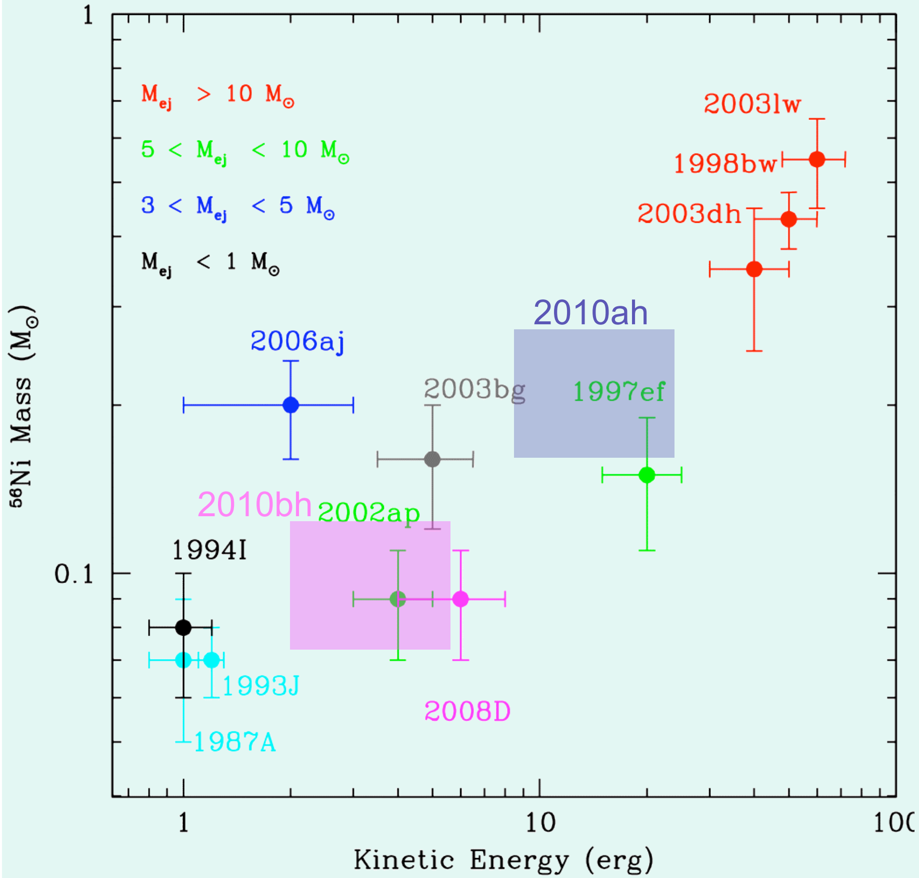


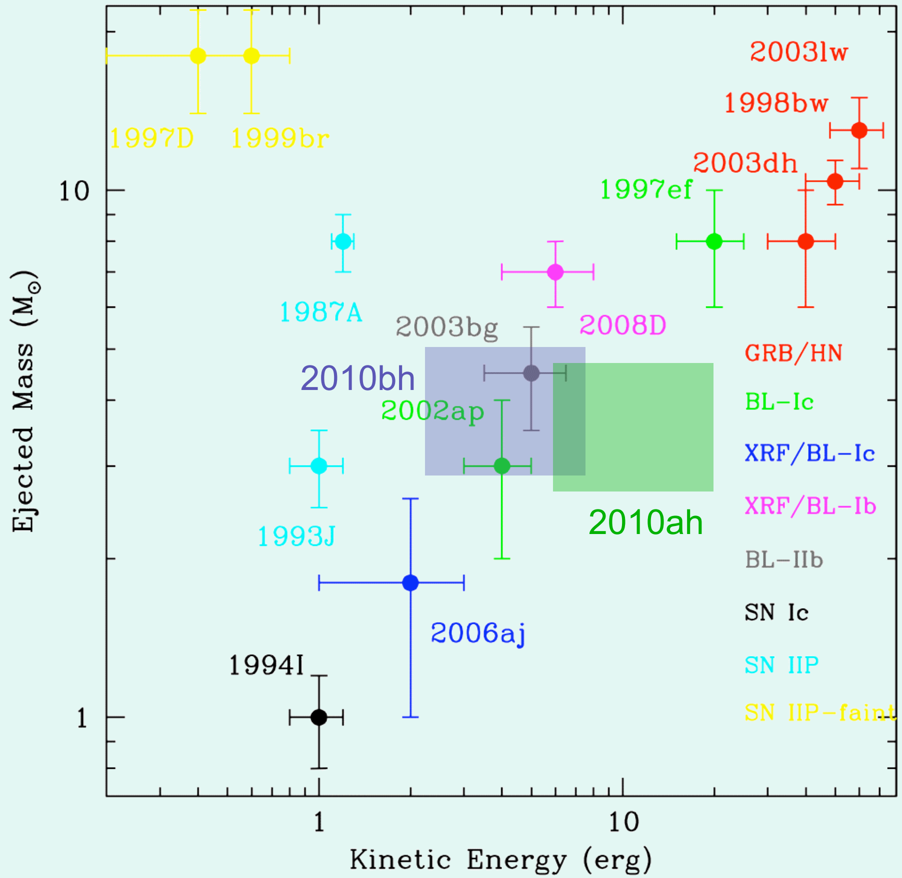
10bz: 22 May 12, t_rest=23d

98bw: 19 May 98, t_rest=24d

- Redshift z=0.28
- Similar in LC and spectra to SN1998bw, SN2003dh, confiming trend

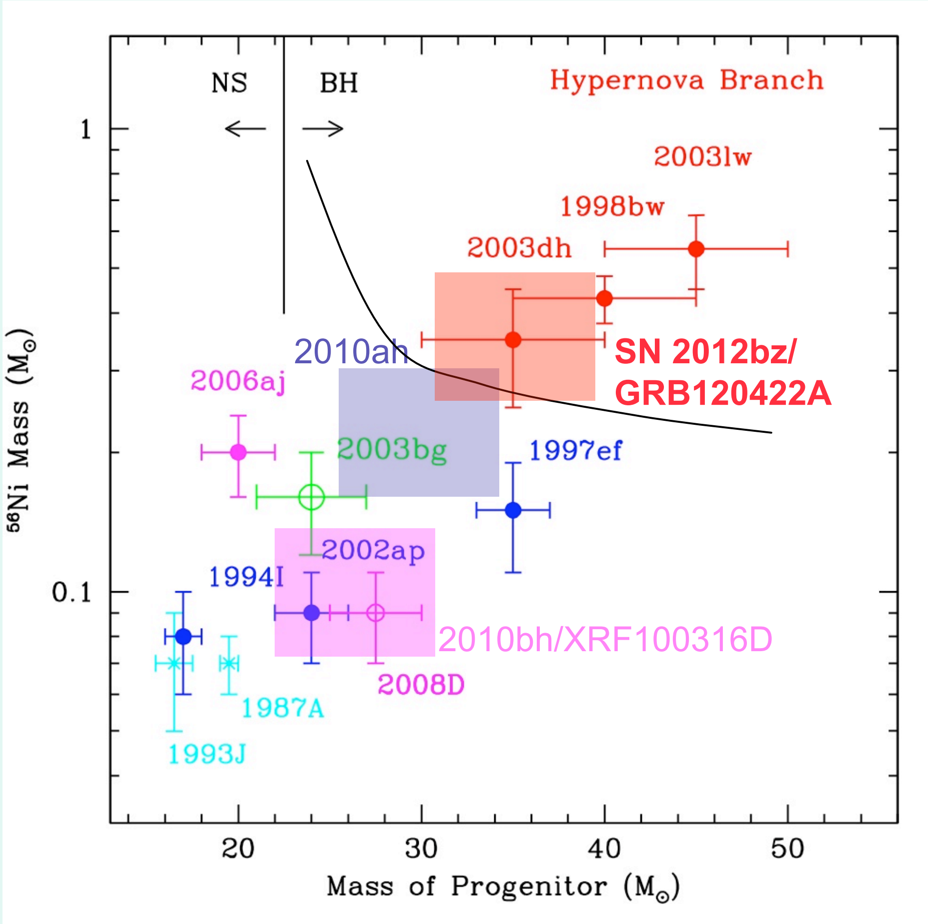
Modelling results

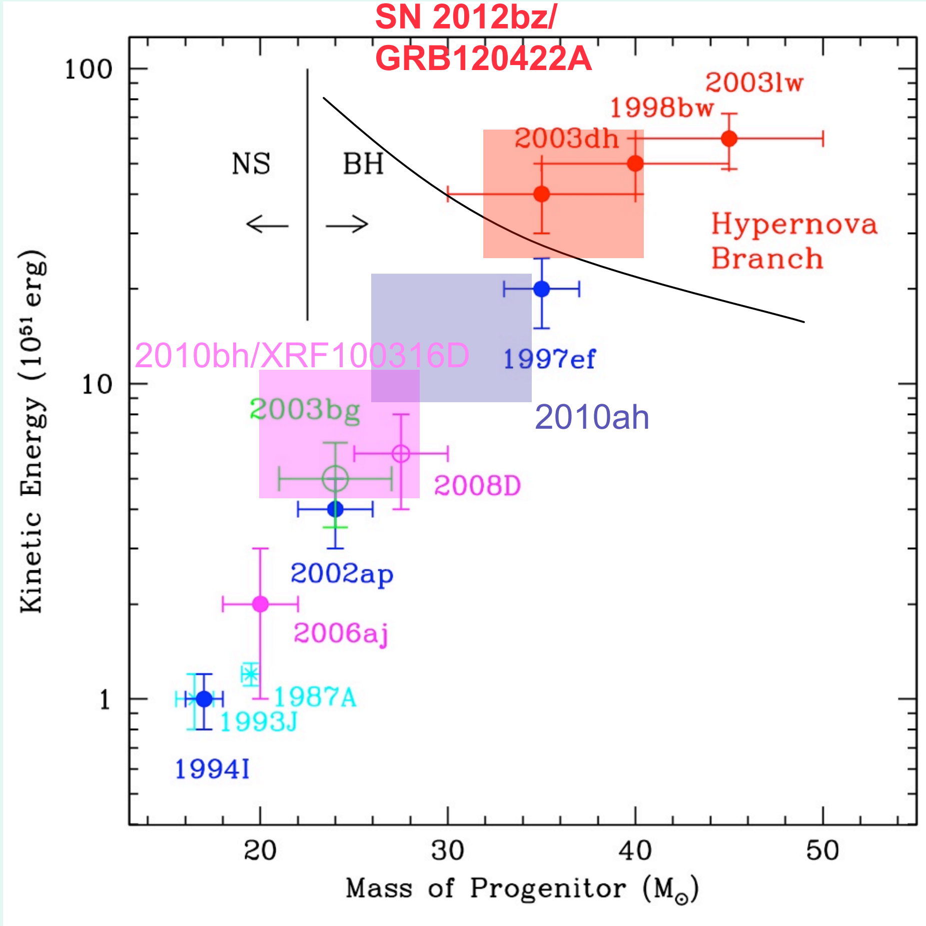




Kin En and ejected mass seem to be correlated, ^{56}Ni less so

Props of SNe Ibc as f(prog. mass)





A minimum mass and energy seem to be required for GRBs

The Grand Scheme

- Collapse of very massive (~35-50 $M_\odot$), stripped stars to BHs makes aspherical GRB-HN (GRB can be very different, HN much less).
- Collapse of less massive star (~ 20 $M_\odot$) to NS can cause a less energetic, less aspherical SN and an XRF (via magnetic activity ?).
- Presence of too much He prevents GRB, still allows XRF (fast/aspherical breakout)
- ブラディ　ヘル !!!