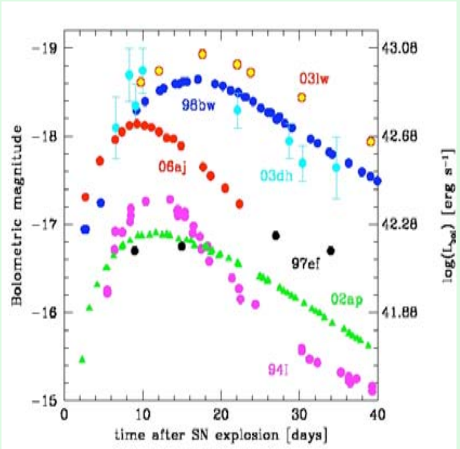
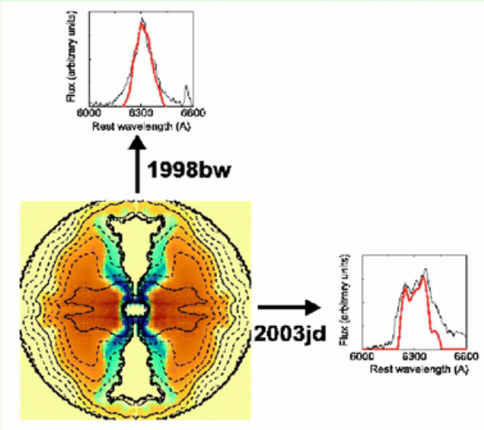
Hypernovae and GRBs





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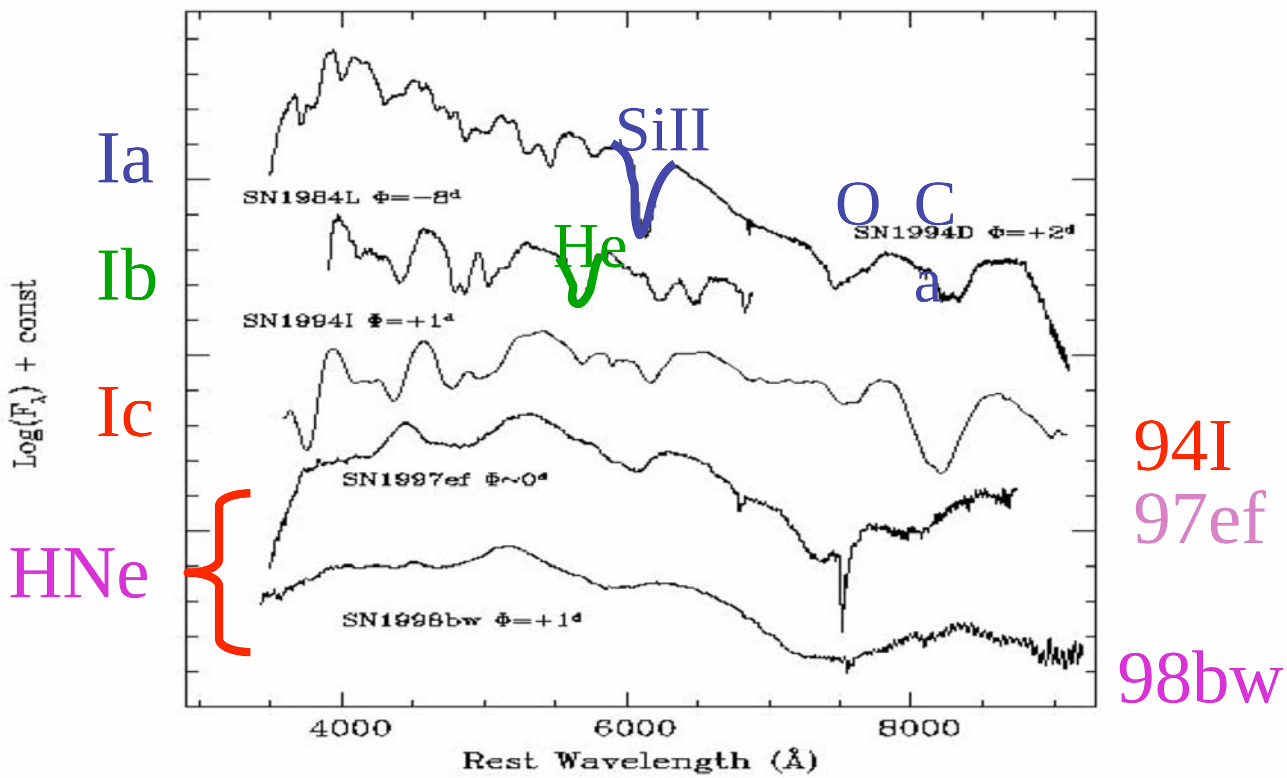
Istituto Naz. di Astrofisica, OATs

Type Iabc Spectra



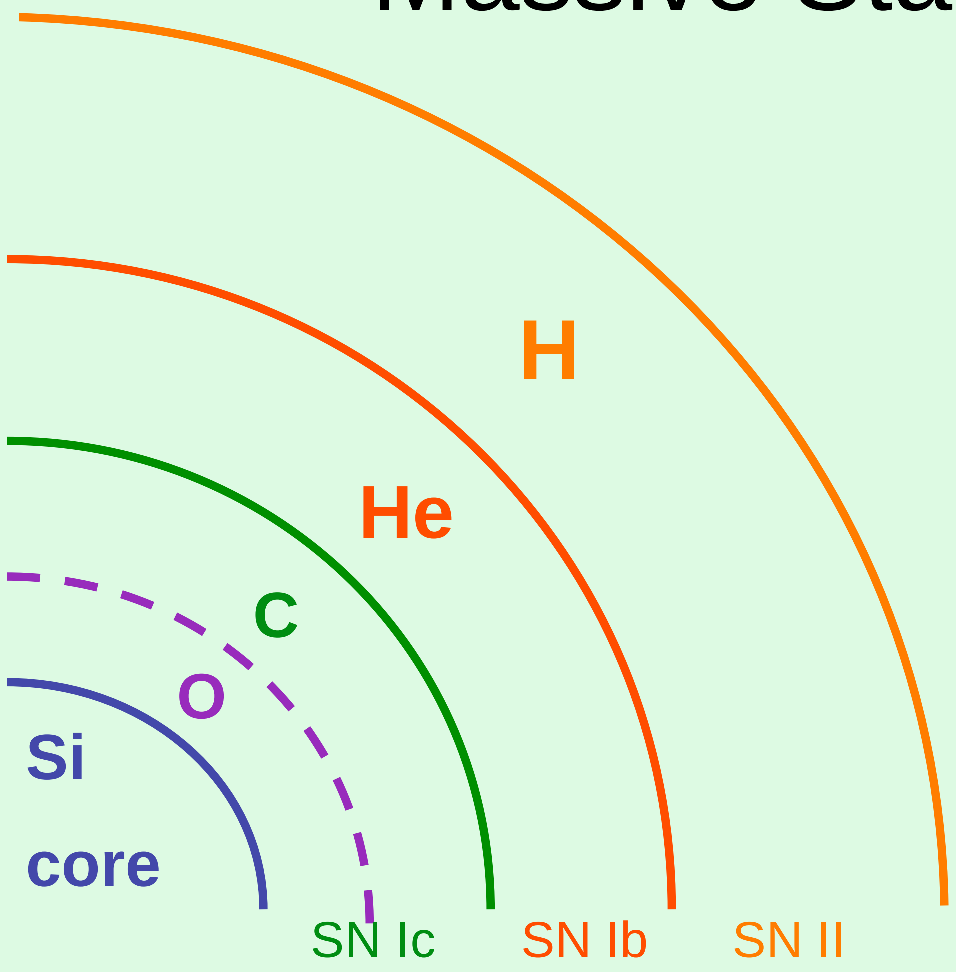
SN Ic: no H, no strong He, no strong Si

Hypernovae: broad features, blended lines

"Large mass at high velocities"

Core-Collapse SNe

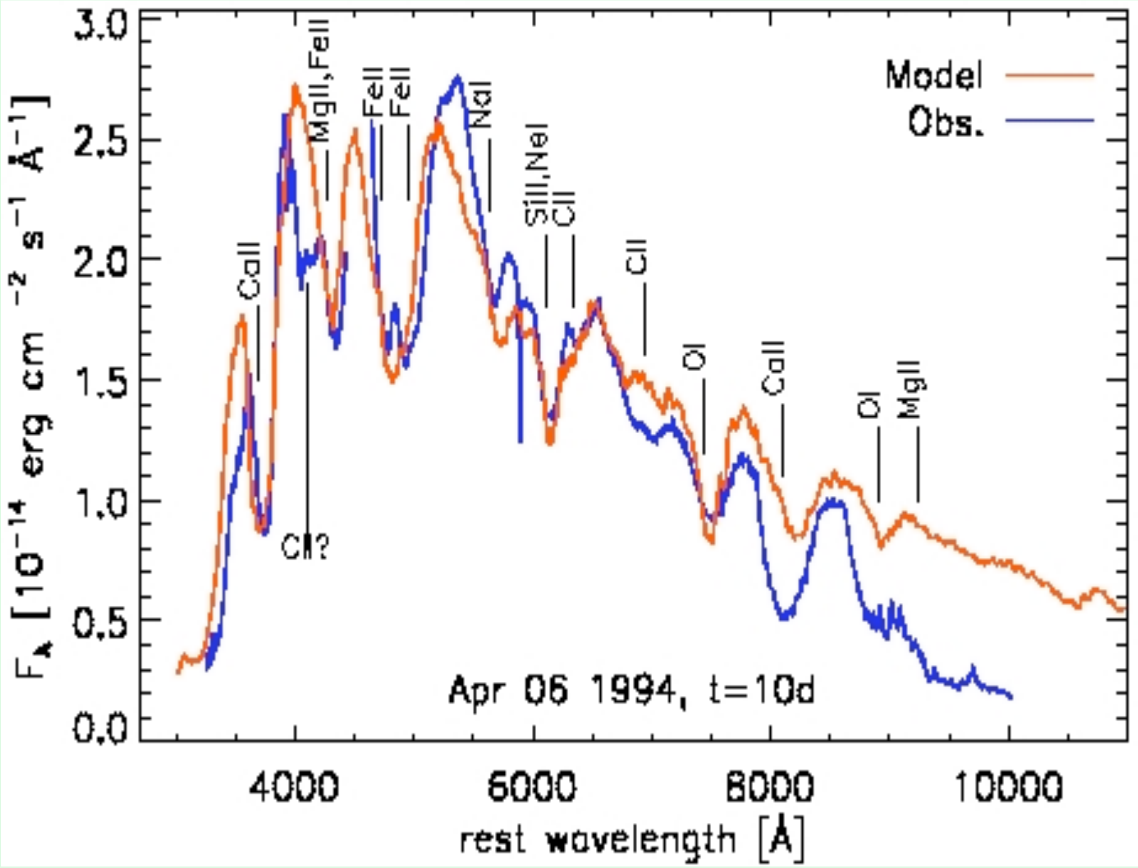
Massive Star (>8M$_\odot$)



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

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

Prelude: KITP, Nov. 1997

A broad-lined SN Ic:

SN1997ef

A classical model:

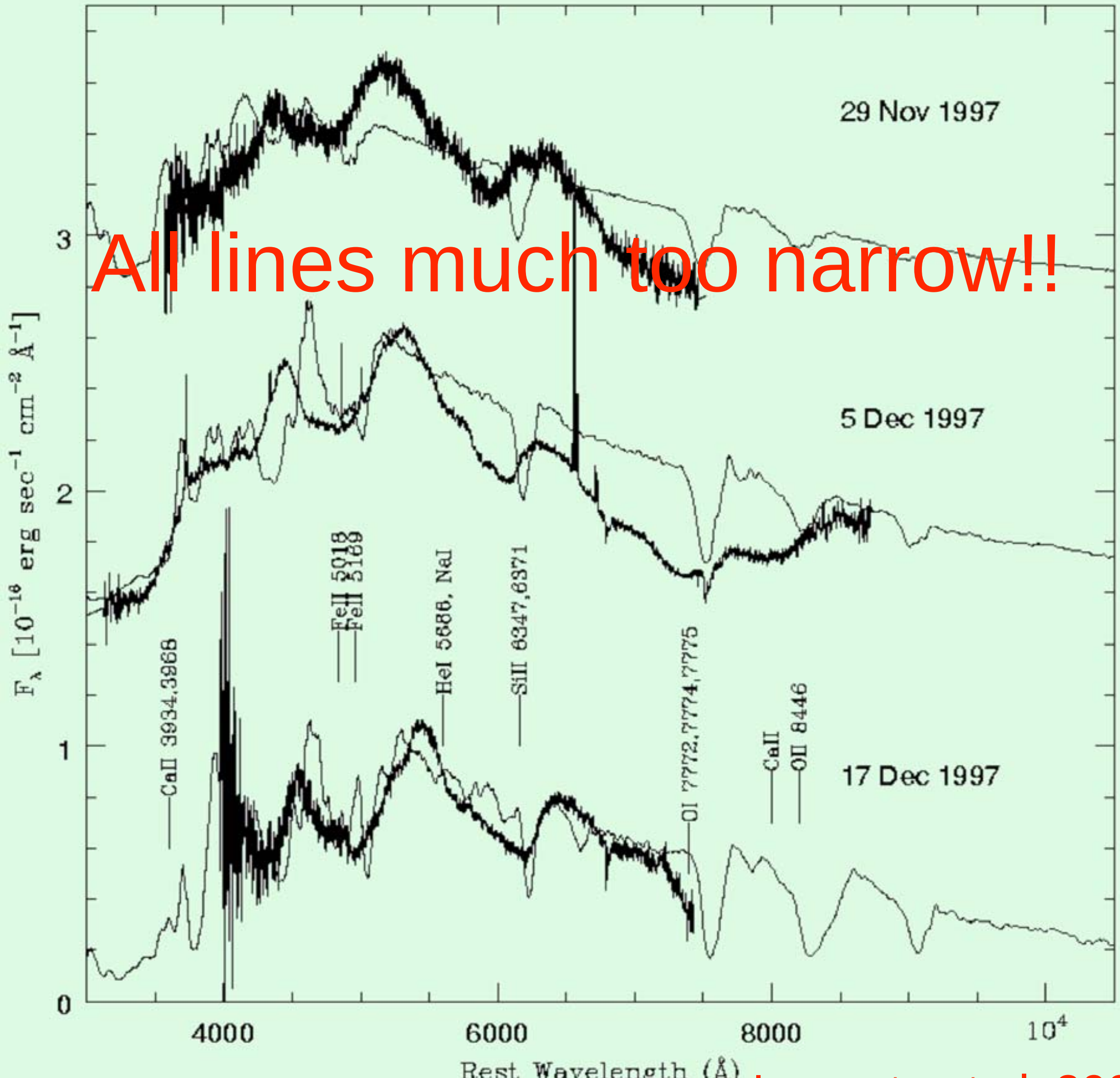
Model CO60

KE = 1 foe

$M_{ej} = 6\ M_\odot$

∴ Too little mass at high velocity

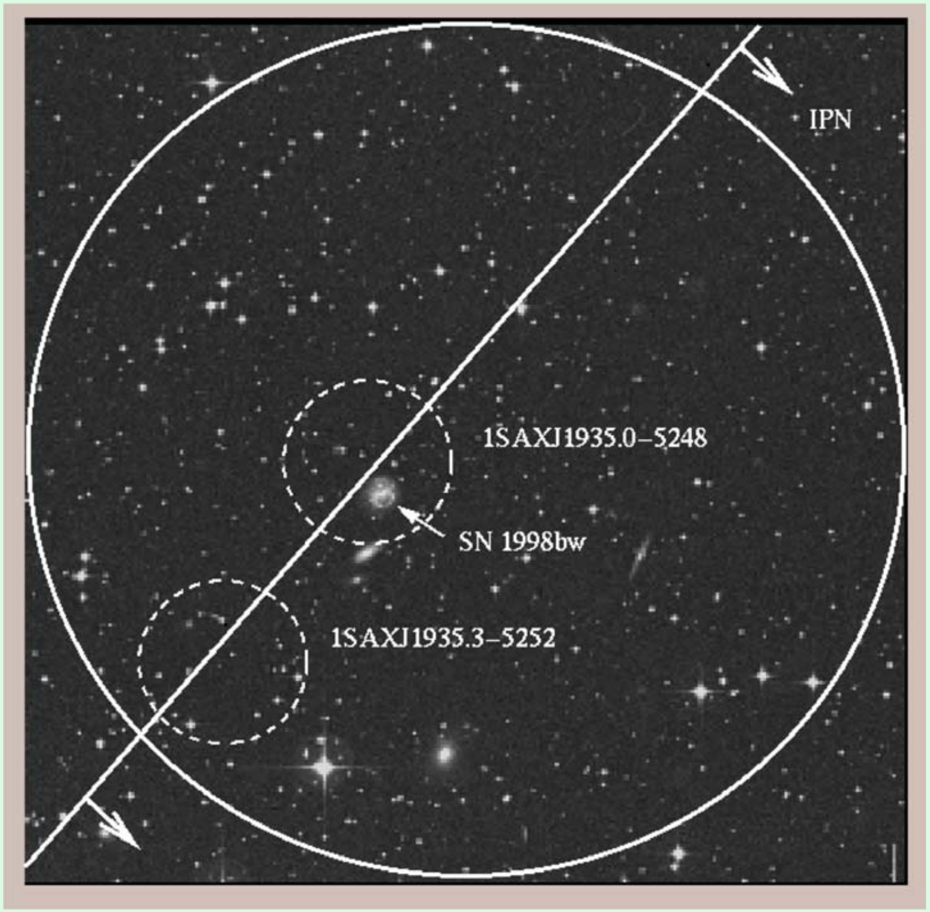
All lines much too narrow!!

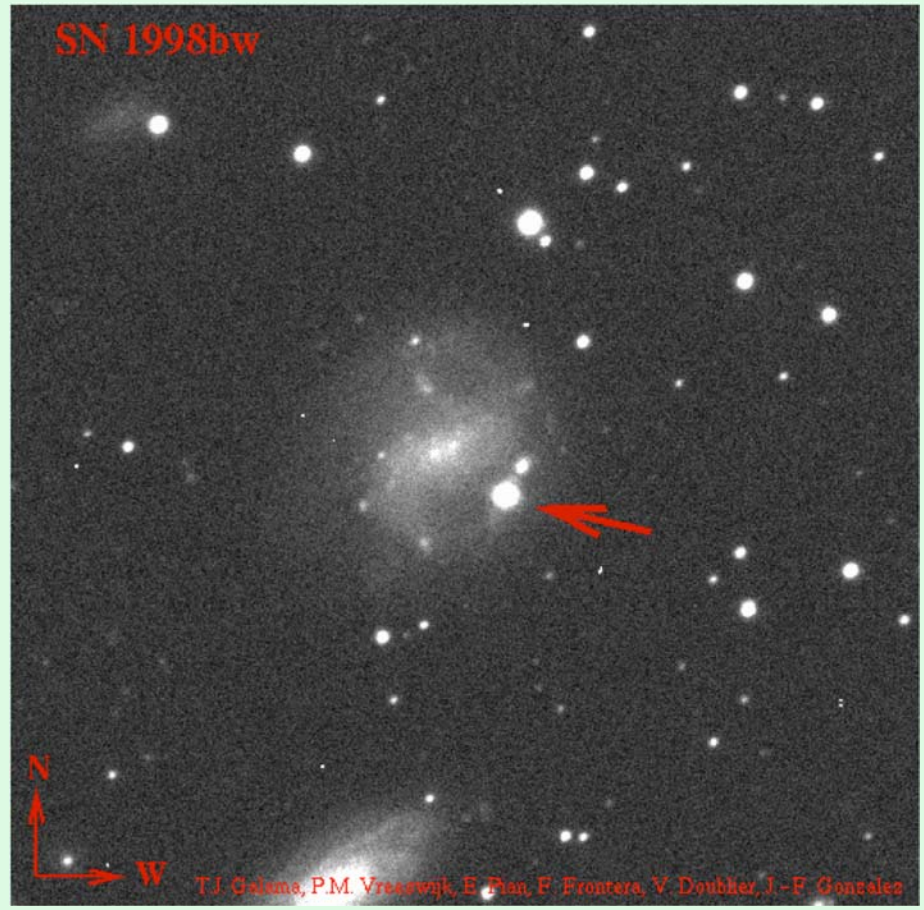


Iwamoto et al. 2000

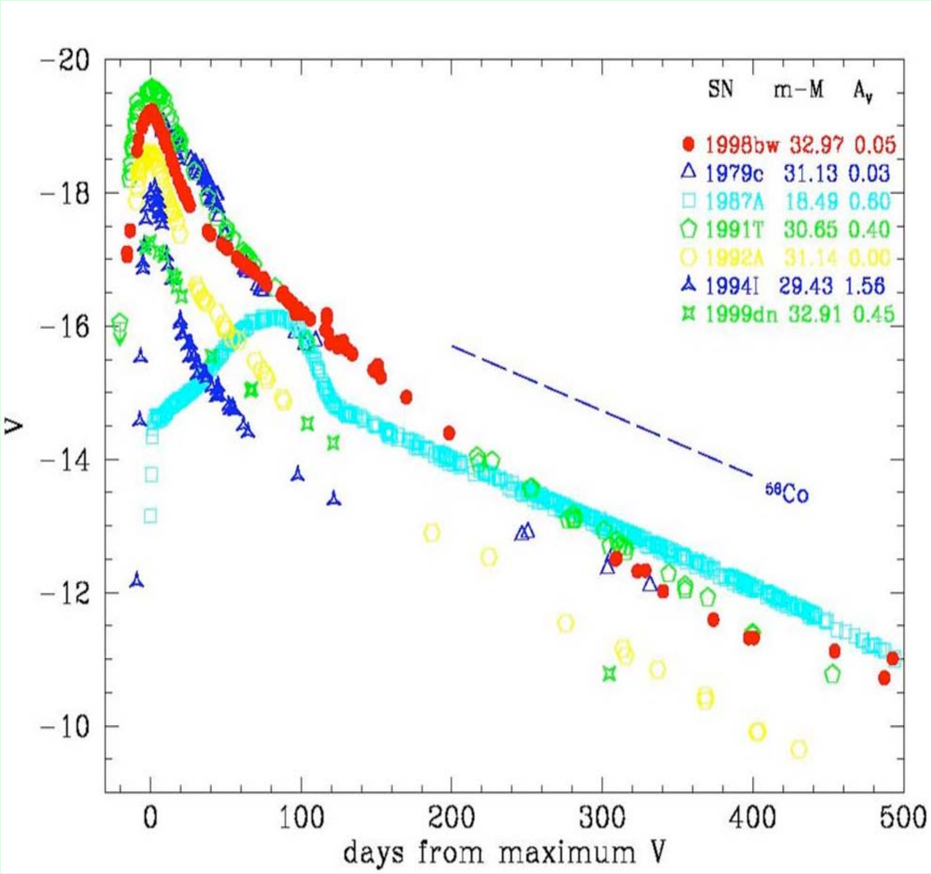
The smoking gun

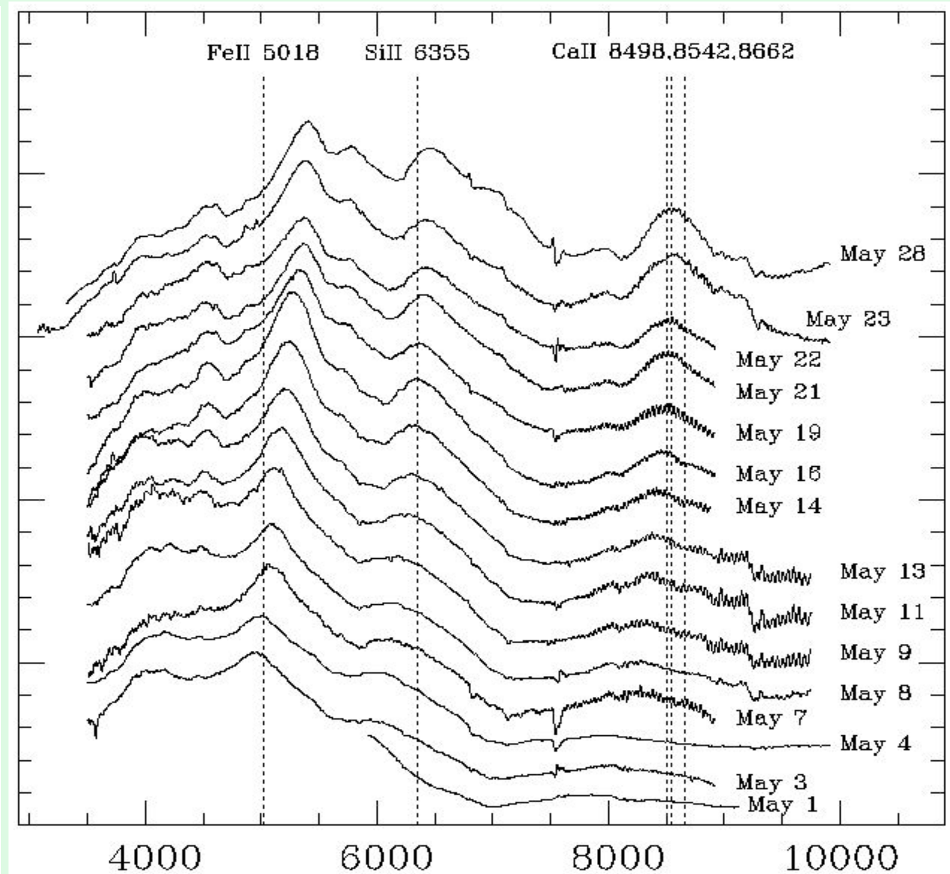
GRB980425: the optical counterpart





A Type Ic SN: 1998bw





SN1998bw was a very bright Type Ic SN,
with very broad absorption lines, indicative of
high-velocity ejecta (~0.1c), and of a very energetic explosion

Explosion Parameters

$$M_{ej}, M(^{56}Ni), KE$$

Light Curve

$$\tau_{LC} \sim (\tau_{dyn} \cdot \tau_{diff})^{1/2}$$

$$\sim \left(\frac{R}{V} \quad \frac{\kappa M_{ej}}{R\, c} \right)^{1/2}$$

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

Spectra

$$\nu_{ph} \propto (E/M_{ej})^{1/2}$$

`Classic' SN Ic vs. `Hypernova' model

E_k may not be unique

Model CO60 (1 foe):

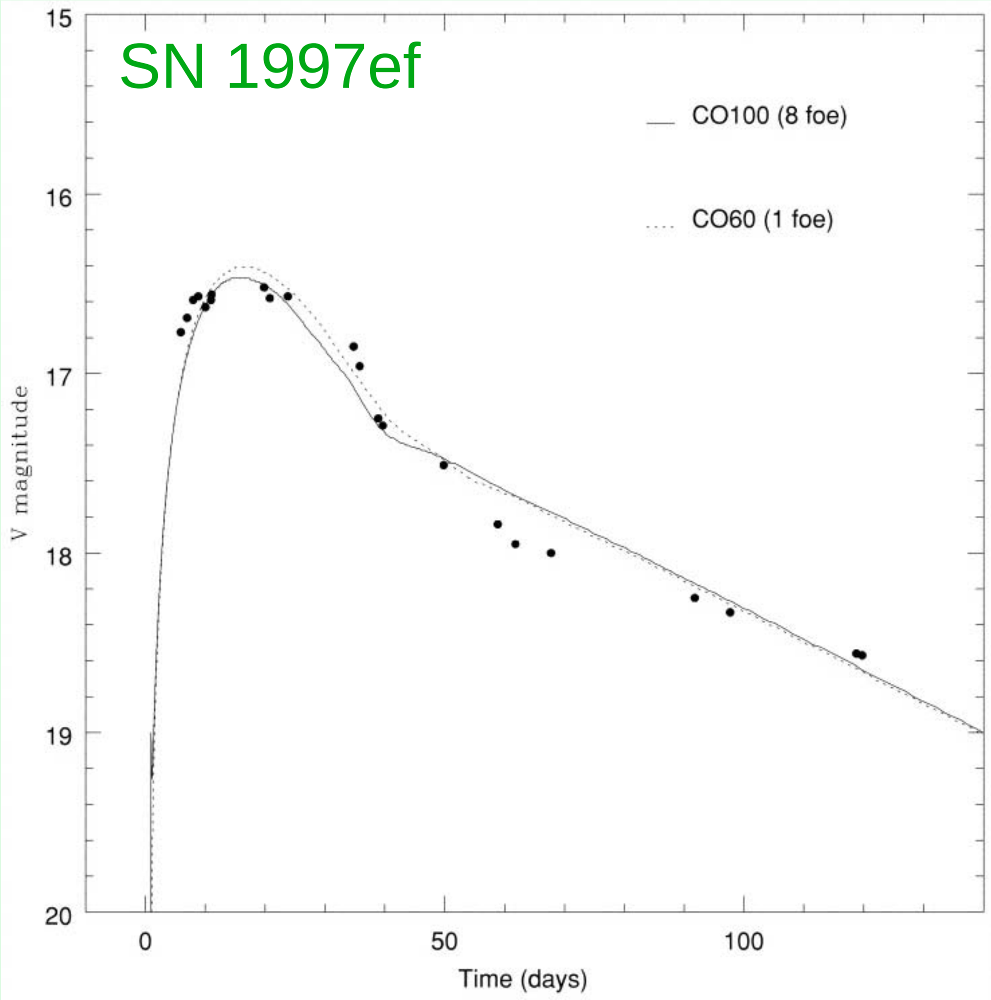
$$M(CO) = 6M_\odot$$

Model CO110 (8 foe):

$$M(CO) = 10M_\odot$$

both:

$$M(^{56}Ni) = 0.15M_\odot$$



Iwamoto et al. 2000

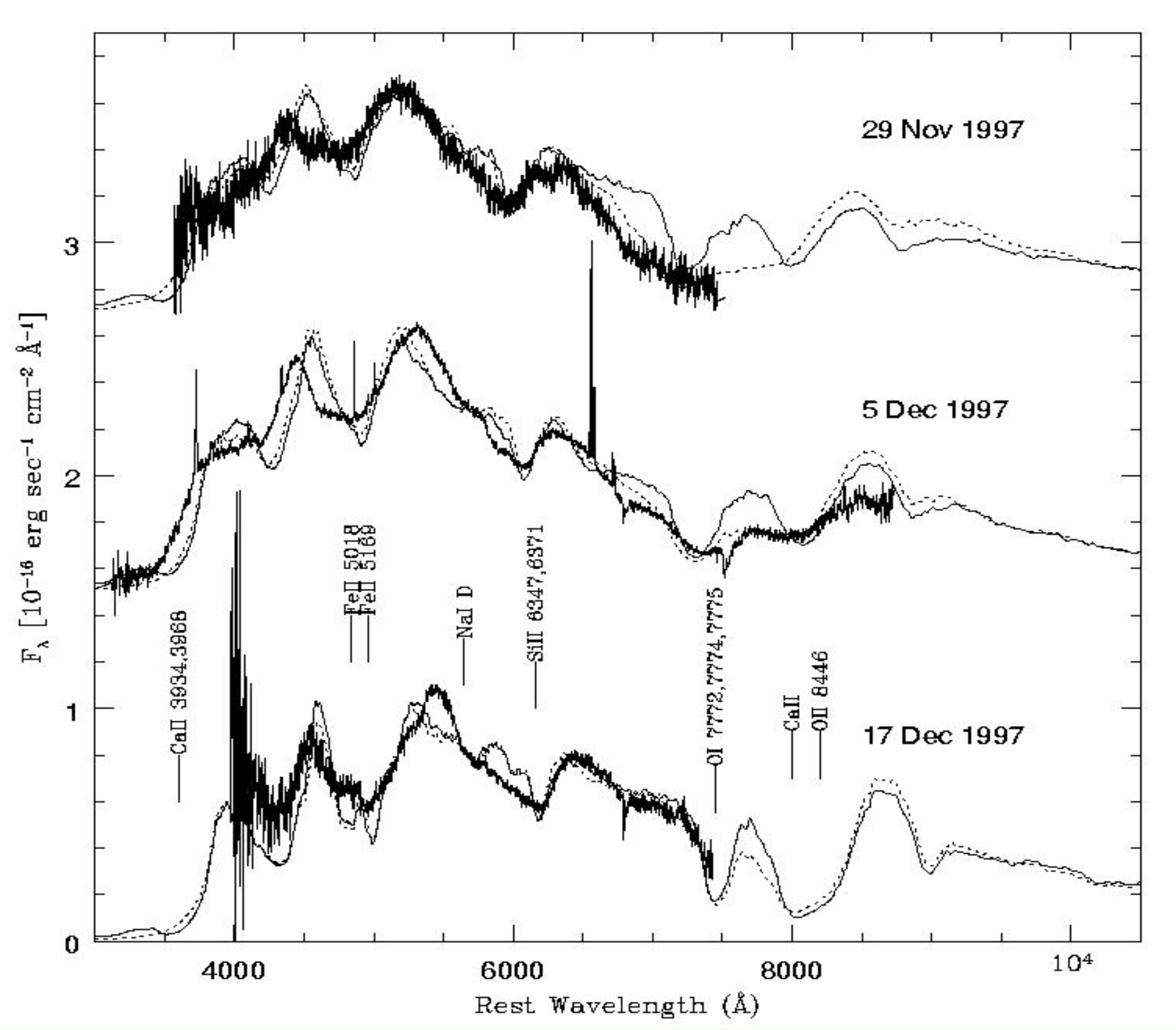
SN 1997ef

early-time spectra

A hypernova model: CO100

KE = 20 foe

Mej = 8 M⊙



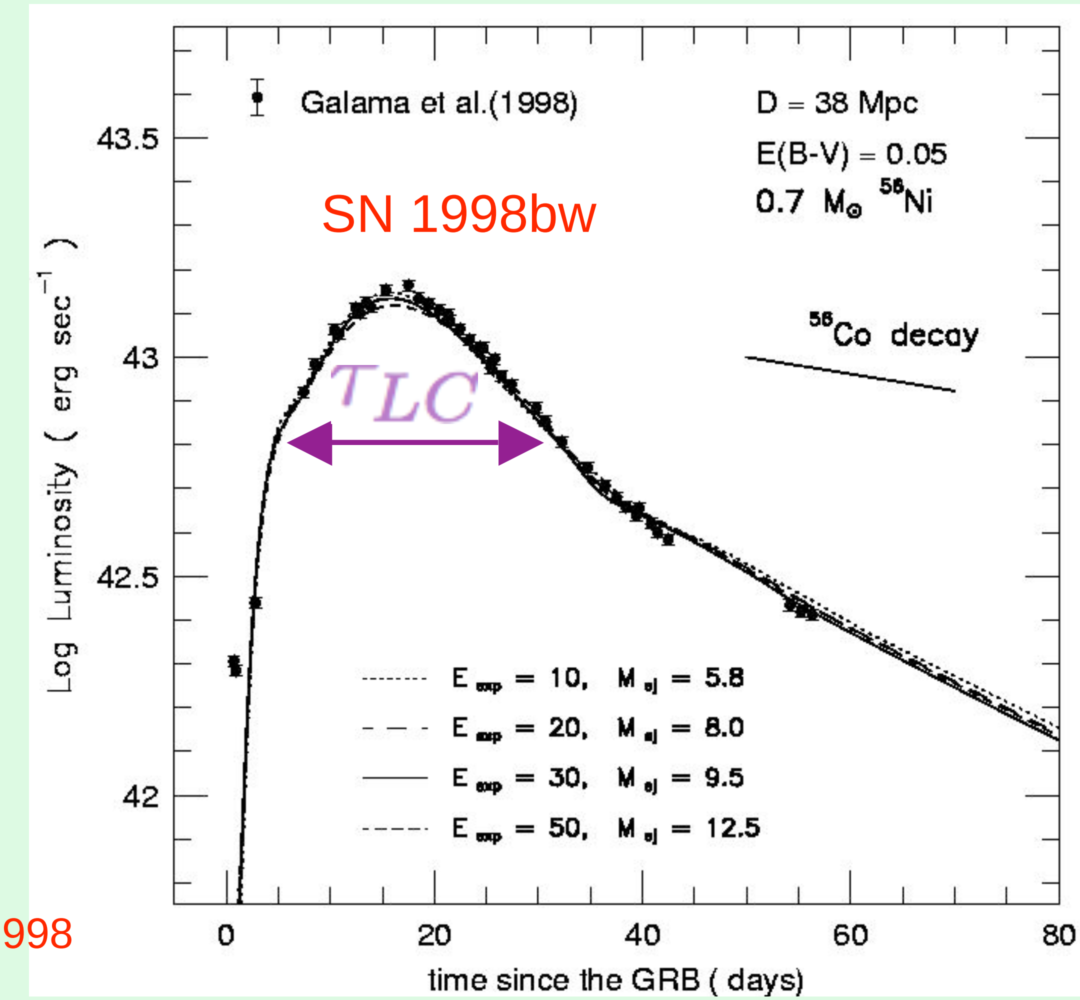
Mazzali et al. 2000

Determining the properties of SN 1998bw

Light curves can be degenerate

if both M and E are allowed to vary

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



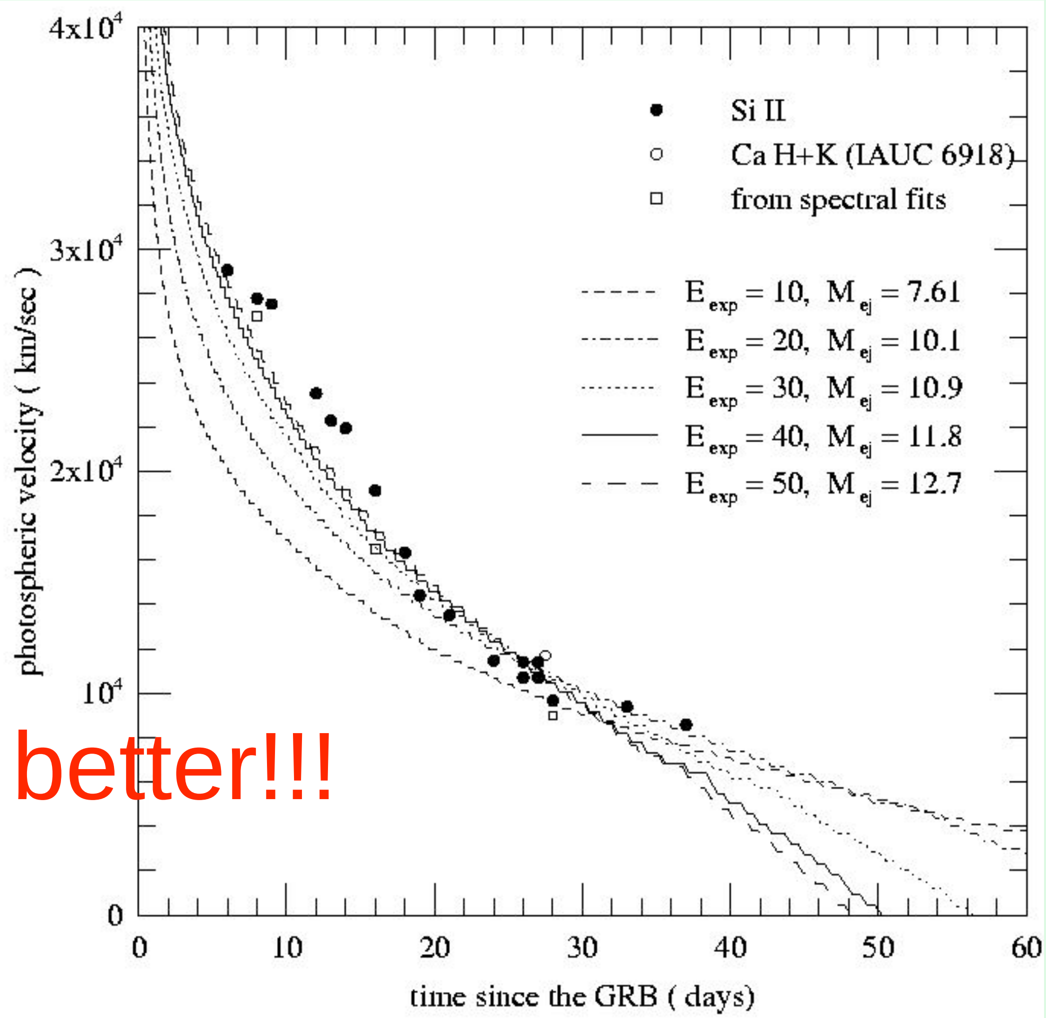
Iwamoto et al. 1998

Photospheric velocity useful to distinguish between models

$$\nu_{ph} \propto (E/M_{ej})^{1/2}$$

...but spectra are better!!!

SN 1998bw



Iwamoto et al. 1998

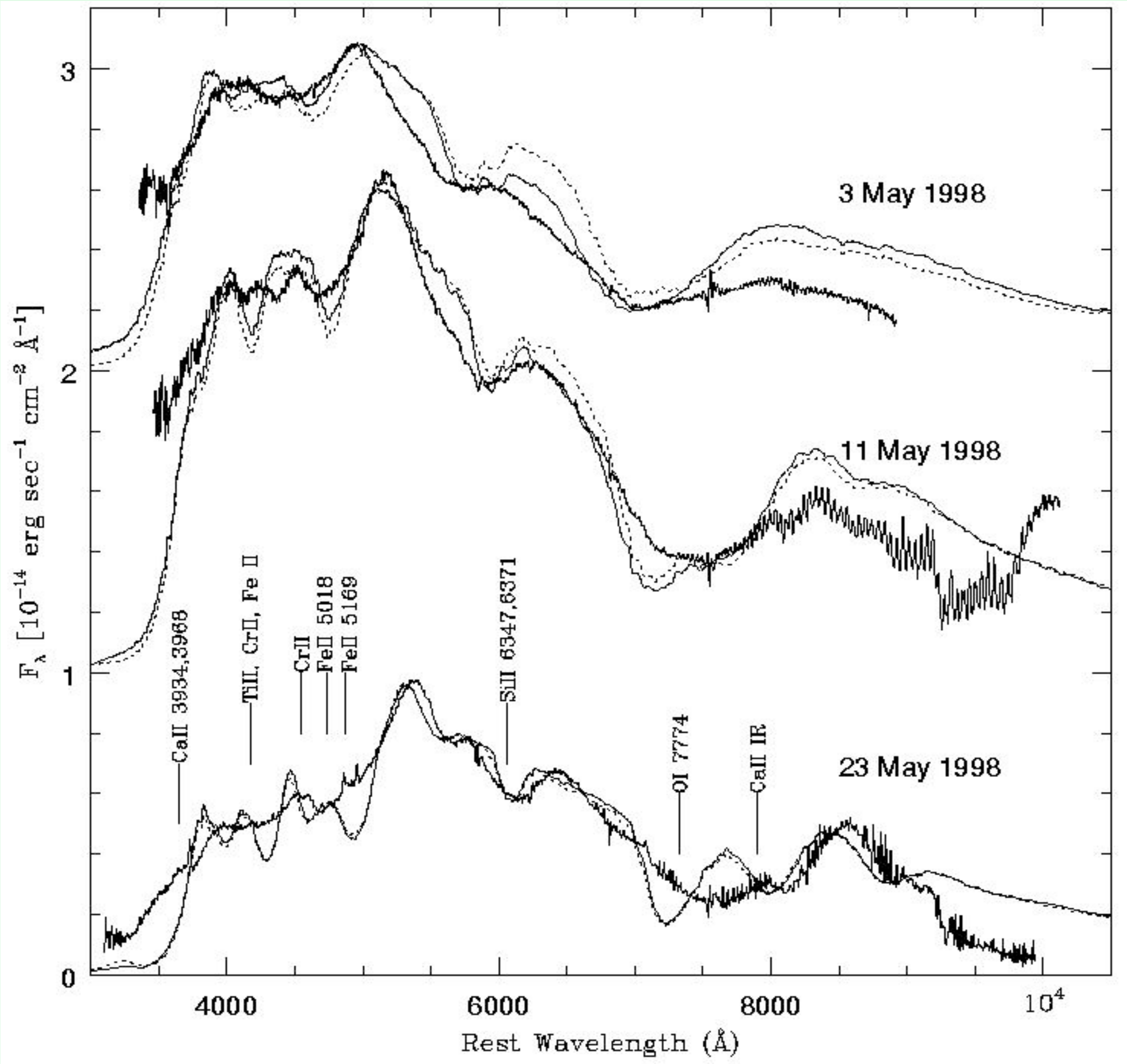
SN 1998bw

Early-time spectra

Model CO138

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

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



Iwamoto et al. 1998

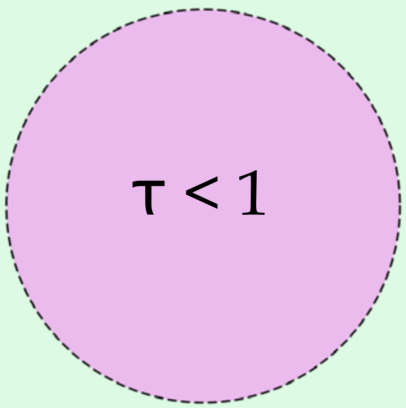
Late-time spectra of SNe

Ejecta are thin:

"Nebular Epoch"

Gas heated by deposition of e^+, γ's and

cooled by forbidden line emission



Spectrum: no continuum.

Emission line profiles depend on velocity, abundance distribution.

Homologous expansion, homogenous density and abundance: parabolic profiles

SN 1998bw

Late-time spectra

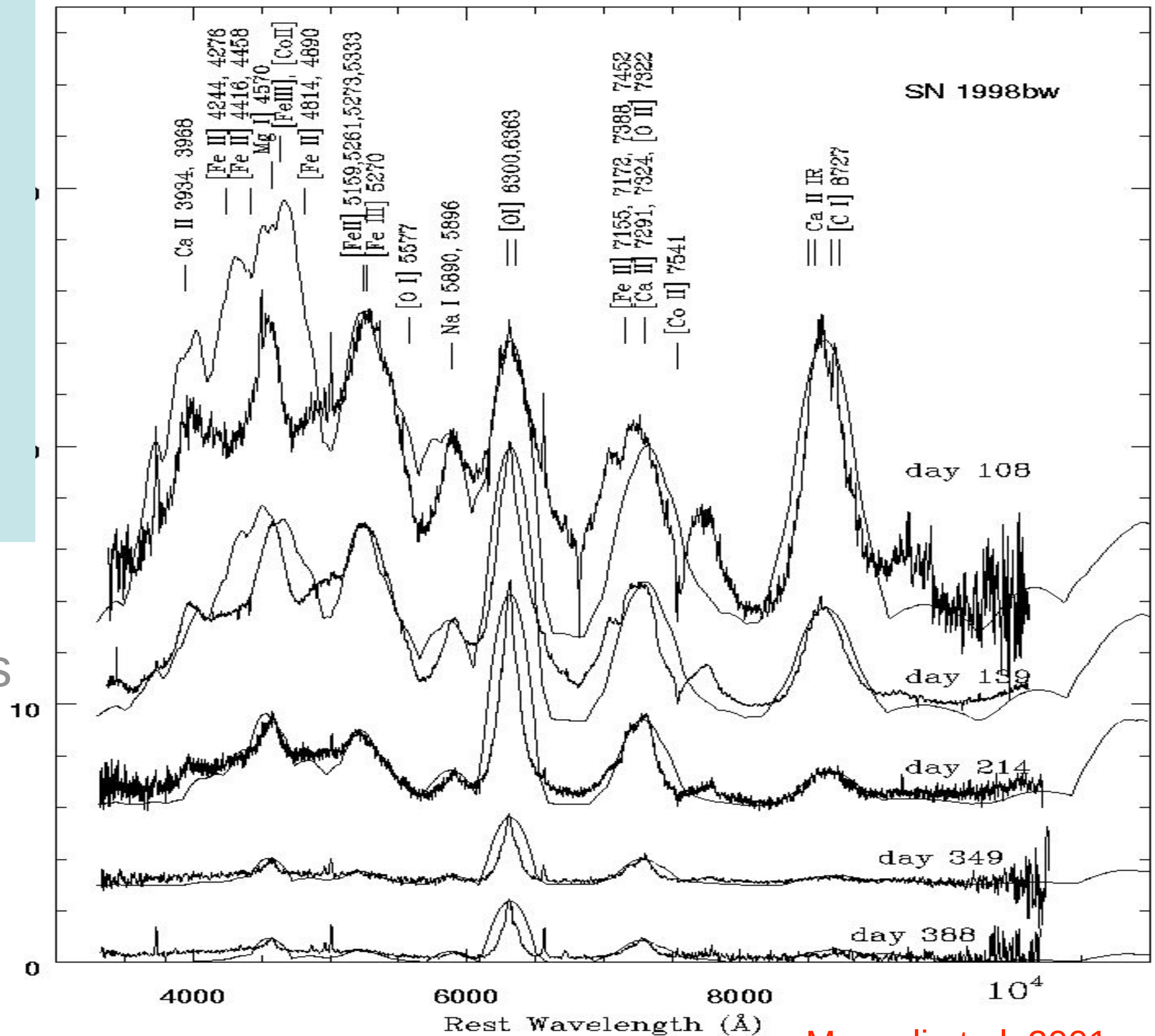
Line profiles not parabolic: v(Fe) > v(O)

v(Fe)~10,000 km/s

v(O)~6,000 km/s

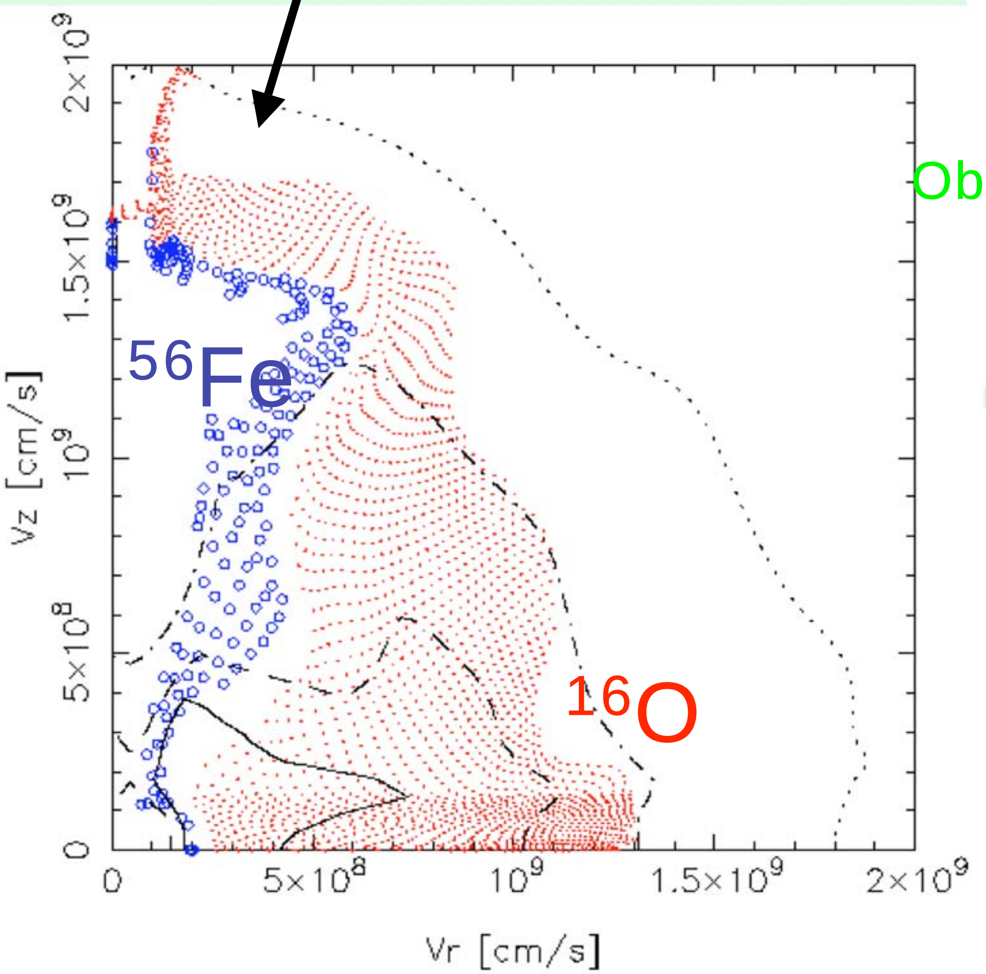
$M(^{56}Ni) \sim 0.6 M_\odot$

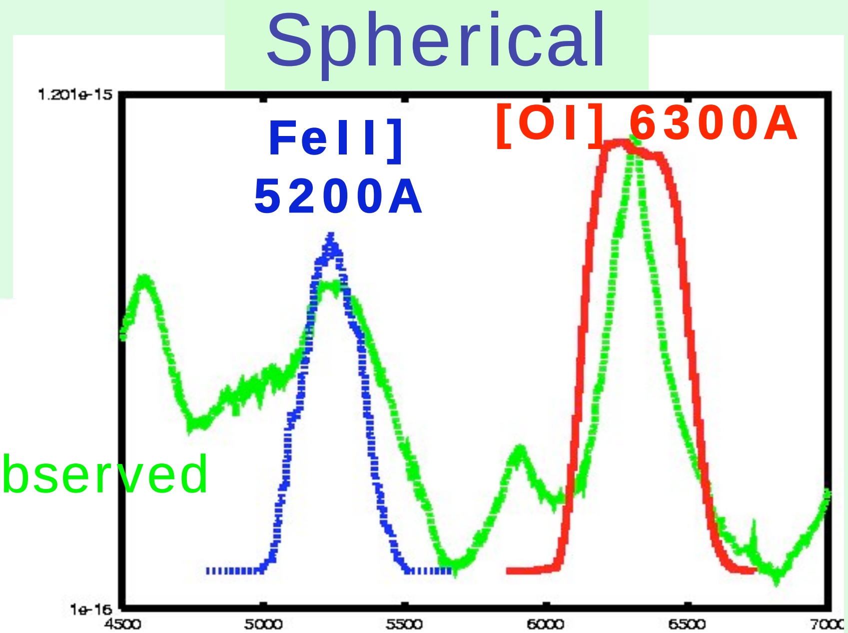
Mej ~ 8 MΘ

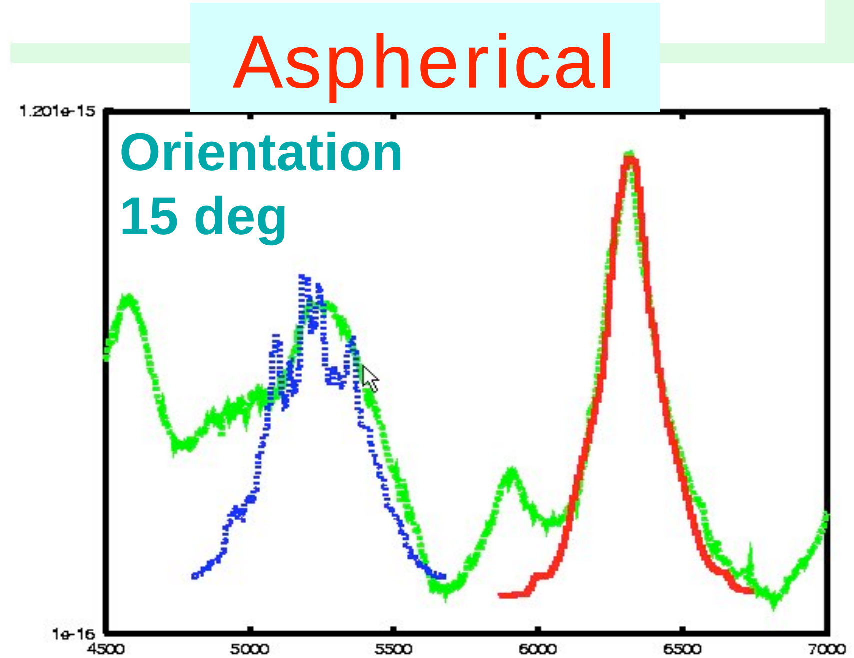


Mazzali et al. 2001

Interpretation as an **Aspherical explosion**

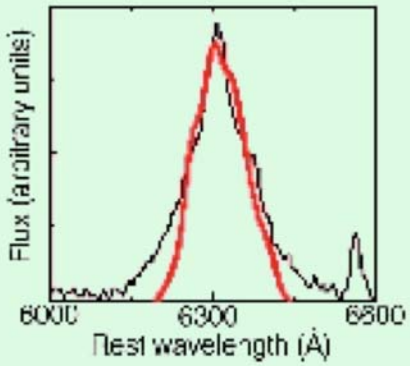




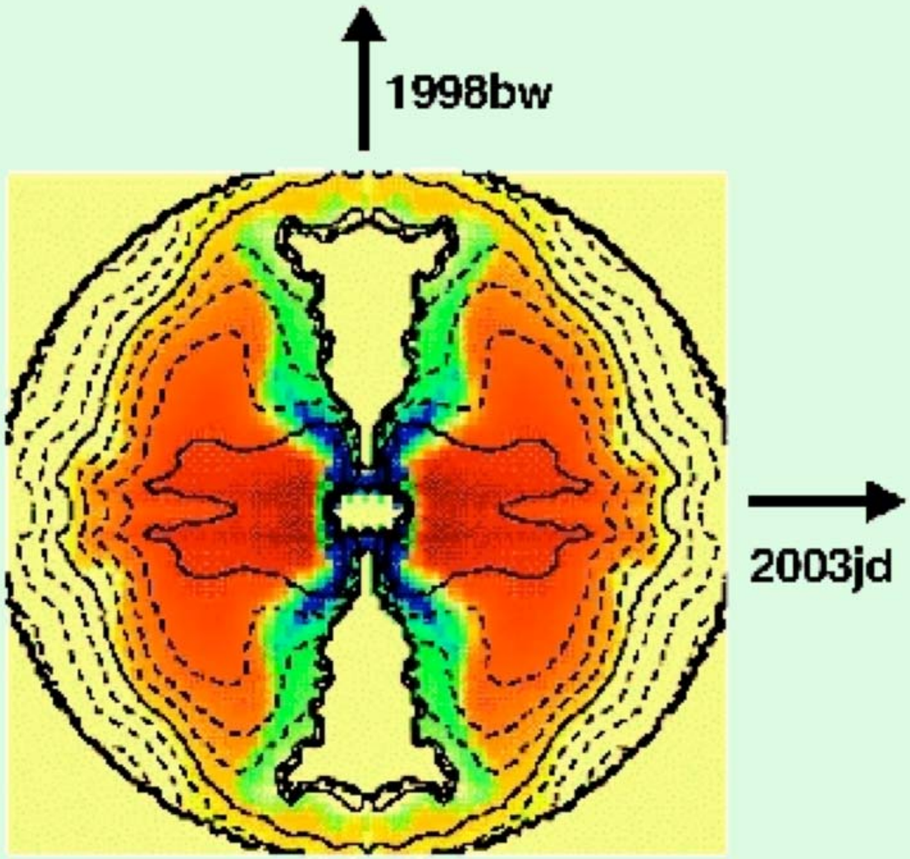


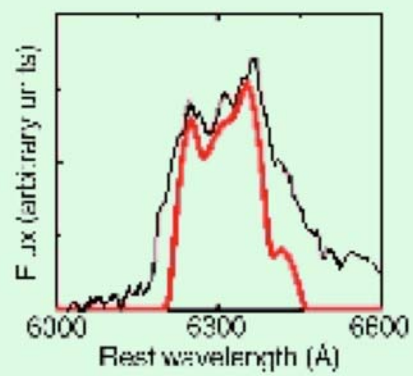
Maeda et al. 2002

What we see depends on where we look…



SN 2003jd: an aspherical SN viewed off-axis

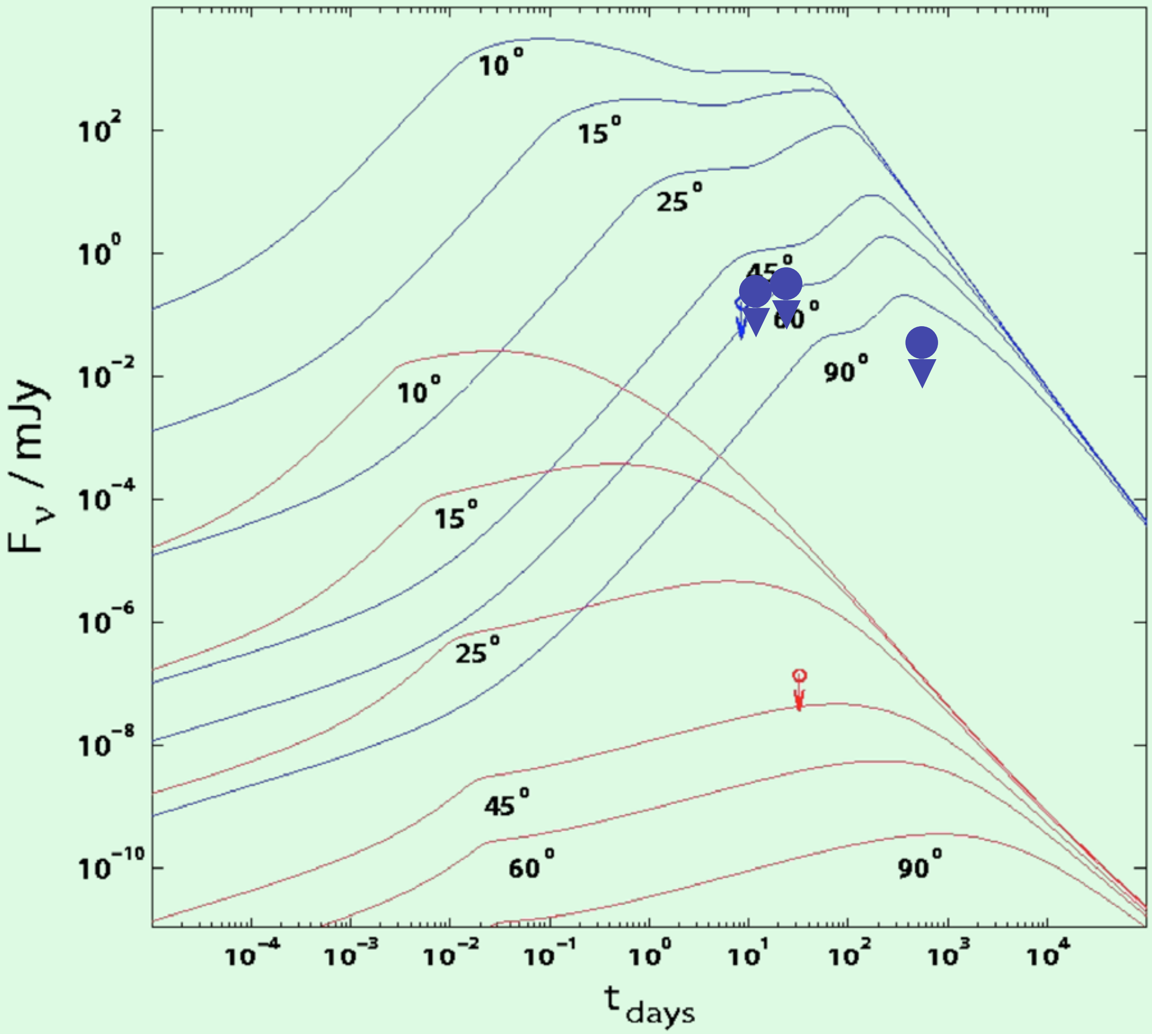




Mazzali et al. (2005), Science

Was SN 2003jd also a GRB/HN?

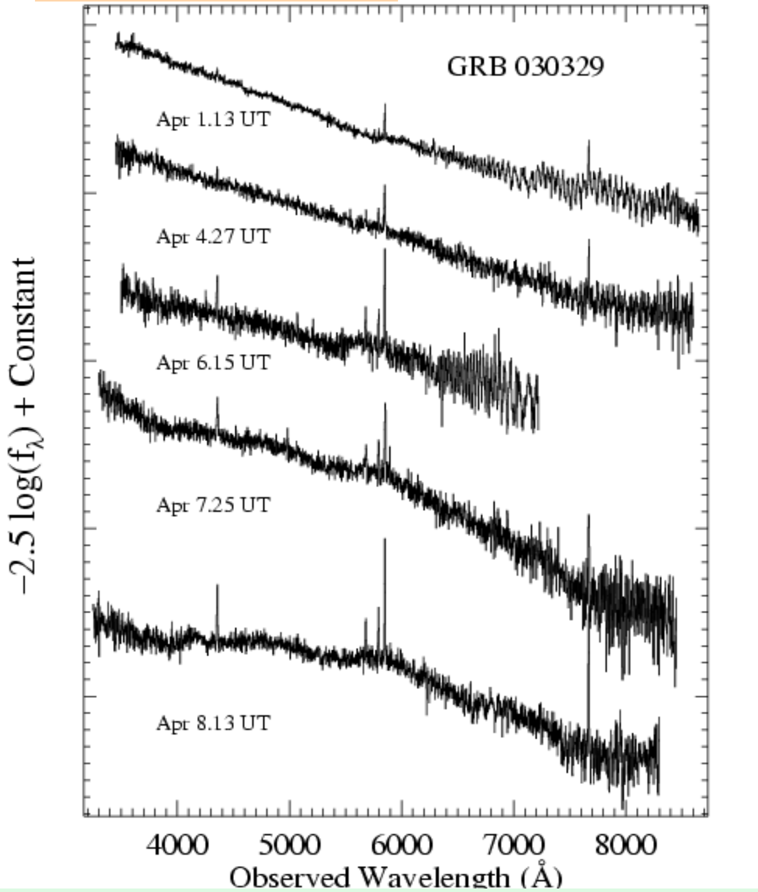
- X-ray and Early Radio upper limits are not in contradiction with a GRB viewed off-axis
- Later Radio upper limits (Soderberg et al 2005) indicate no jet

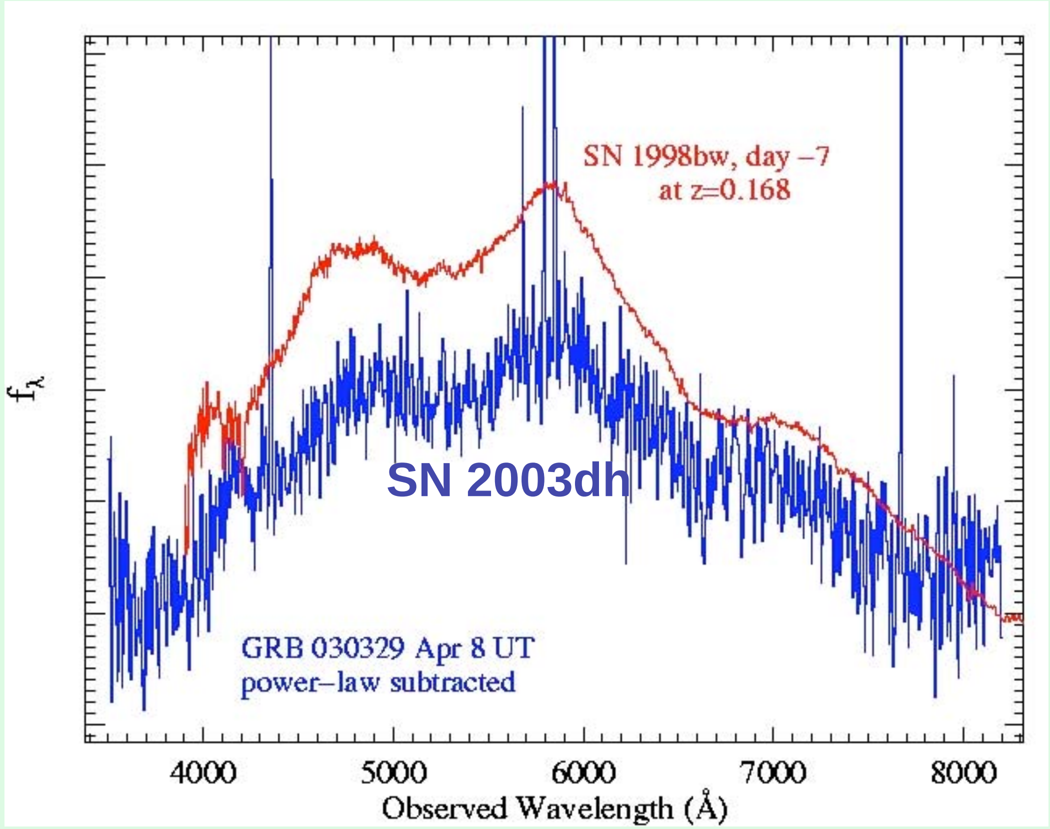


Mazzali et al. 2005

The Confirmation:
GRB030329 / SN2003dh (HN)

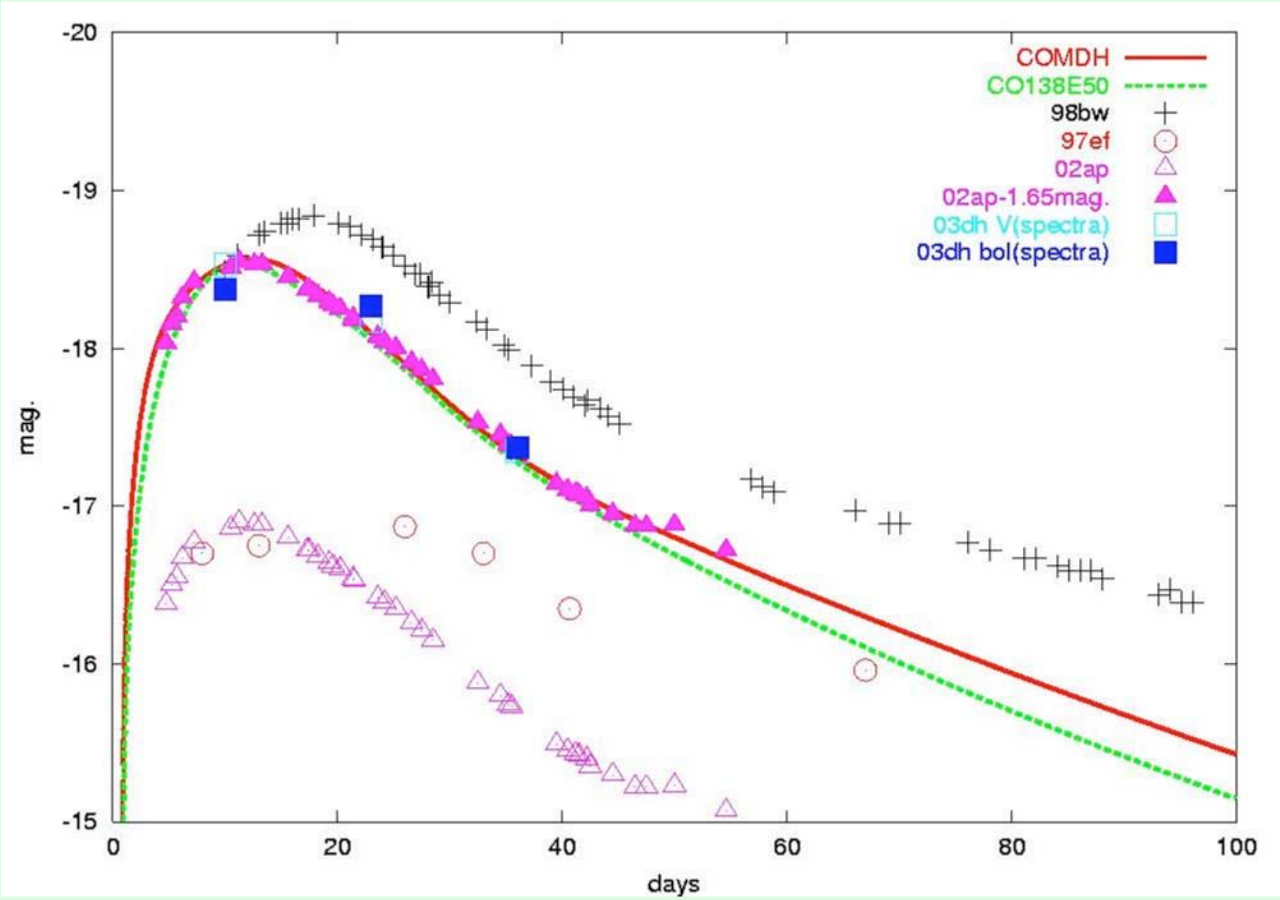
Z = 0.167





Stanek et al. 2003

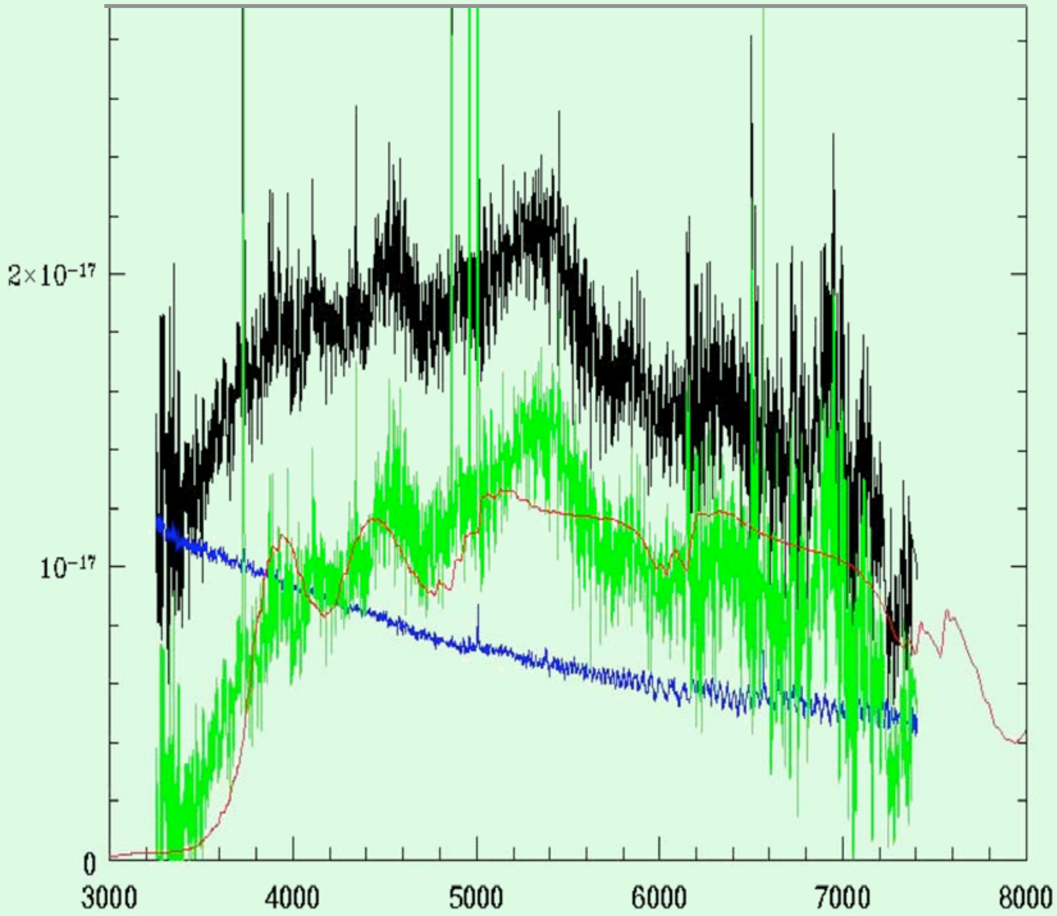
SN 2003dh: the light curve



SN 2003dh is somewhat dimmer than SN 1988bw, but much brighter than both SNe 1997ef and 2002ap

Mazzali et al. 2003

SN 2003dh: another Hypernova



SN 2003dh is almost as bright and powerful as SN 1998bw:

KE = 3.8 10^{52} erg

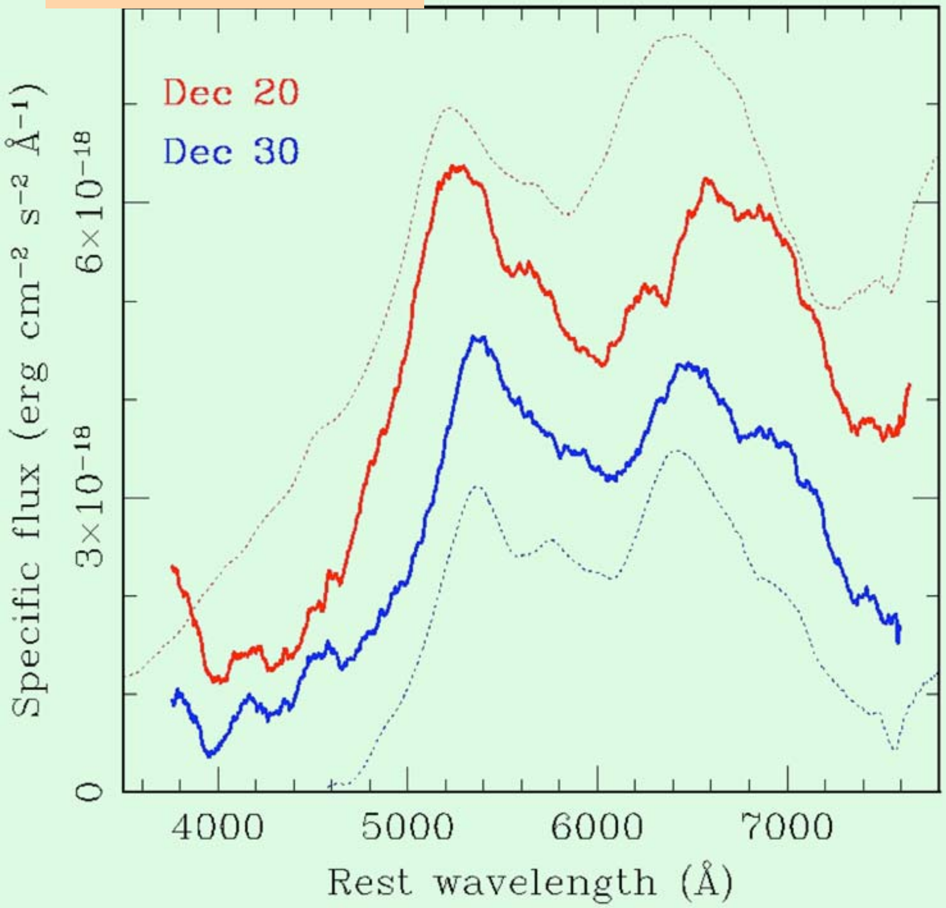
$$M(^{56}Ni) \sim 0.35 M_\odot$$

$$M_{ej} \sim 8 M_\odot$$

Mazzali et al. 2003

GRB031202 / SN2003lw (HN)

z = 0.105



Highly reddened, but a close analogue of SN1998bw

With GRB031202/SN2003lw,

ALL 3 nearest GRBs are Hypernovae

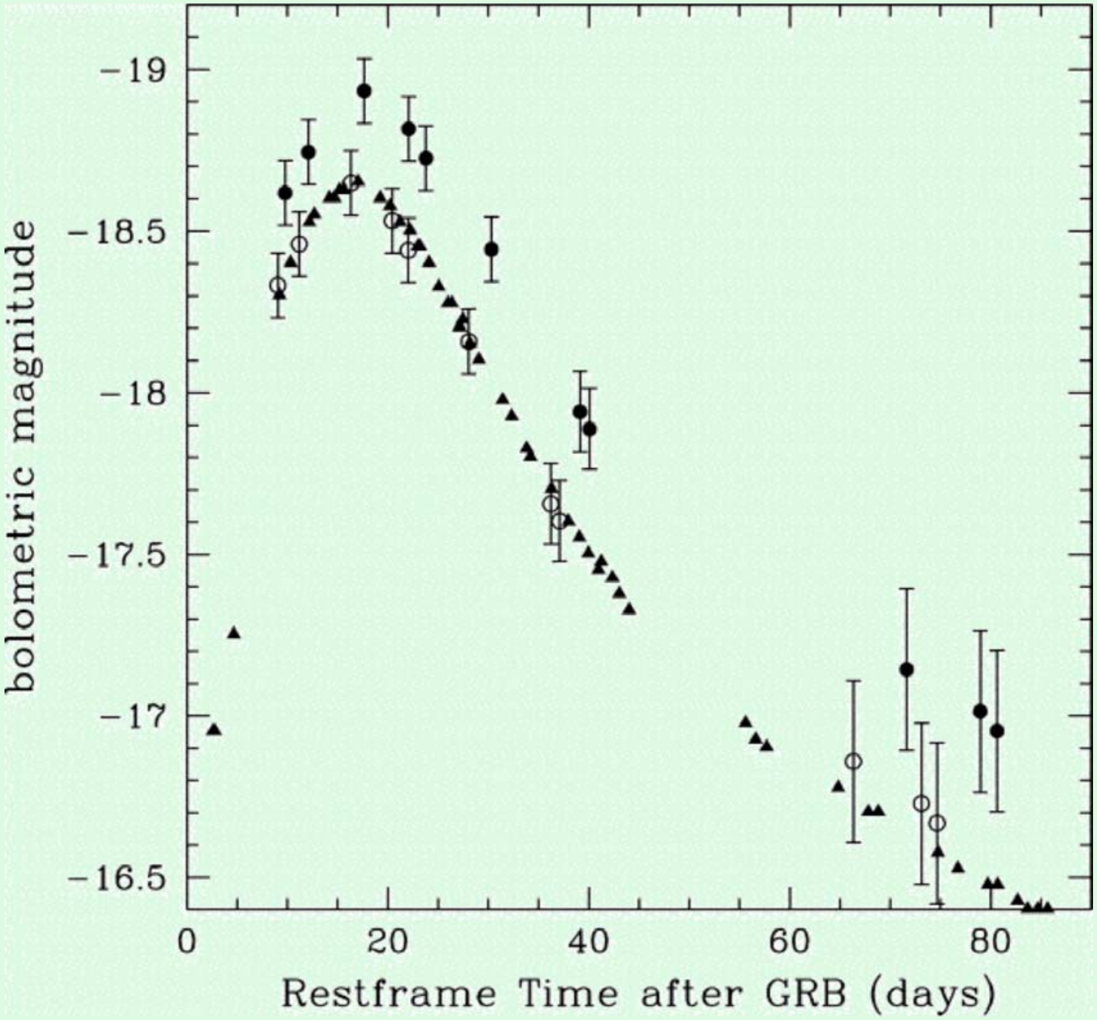
Malesani et al. 2004

SN2003lw: the Light Curve

The most
powerful HN

E_K~ 60 foe

Mej ~ $13M_\odot$
$M(^{56}Ni)$~$0.6M_\odot$



(Mazzali et al. 2006)

Type Ic SNe / Hypernovae

Broad lines

→ Large Kinetic Energy

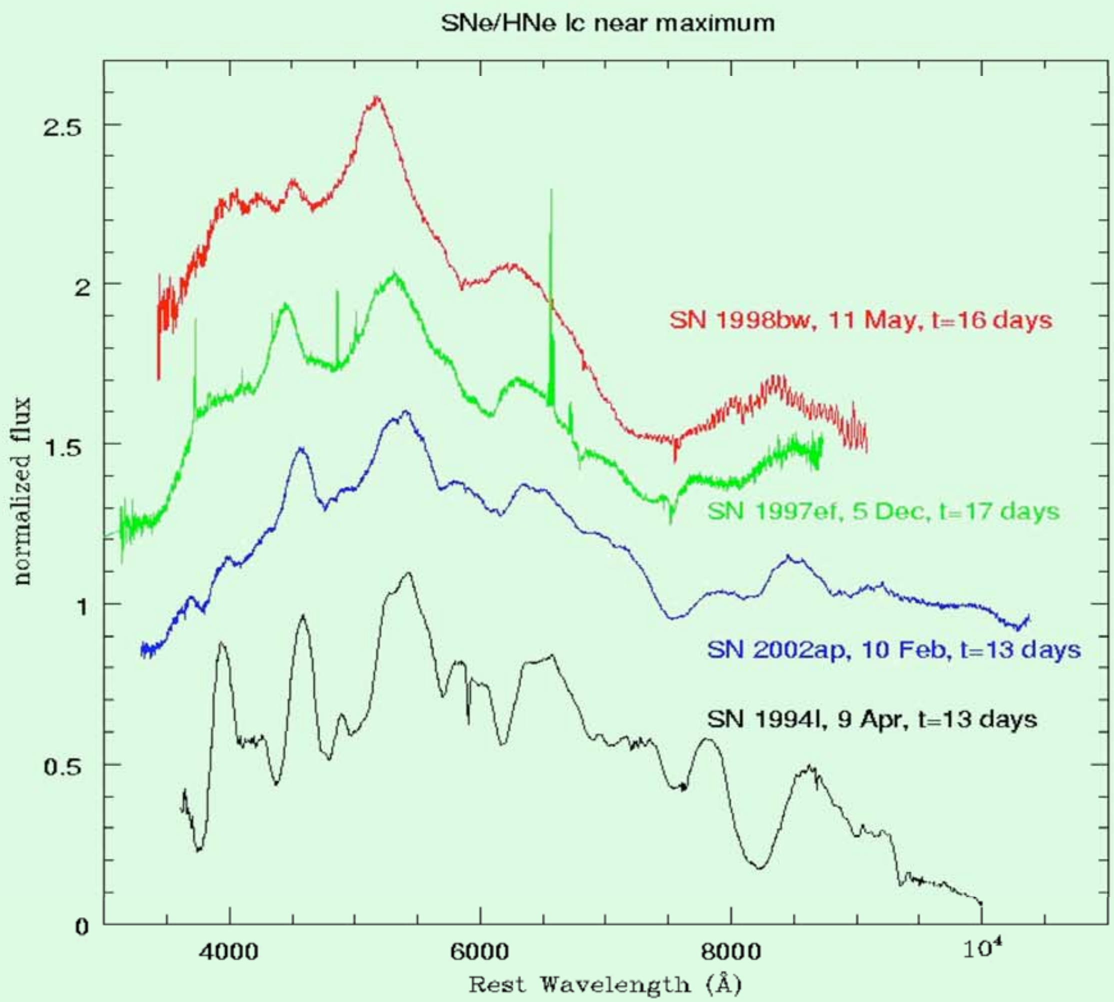
→ "Hypernovae"

(only SN1998bw was associated with a GRB)

Narrow lines

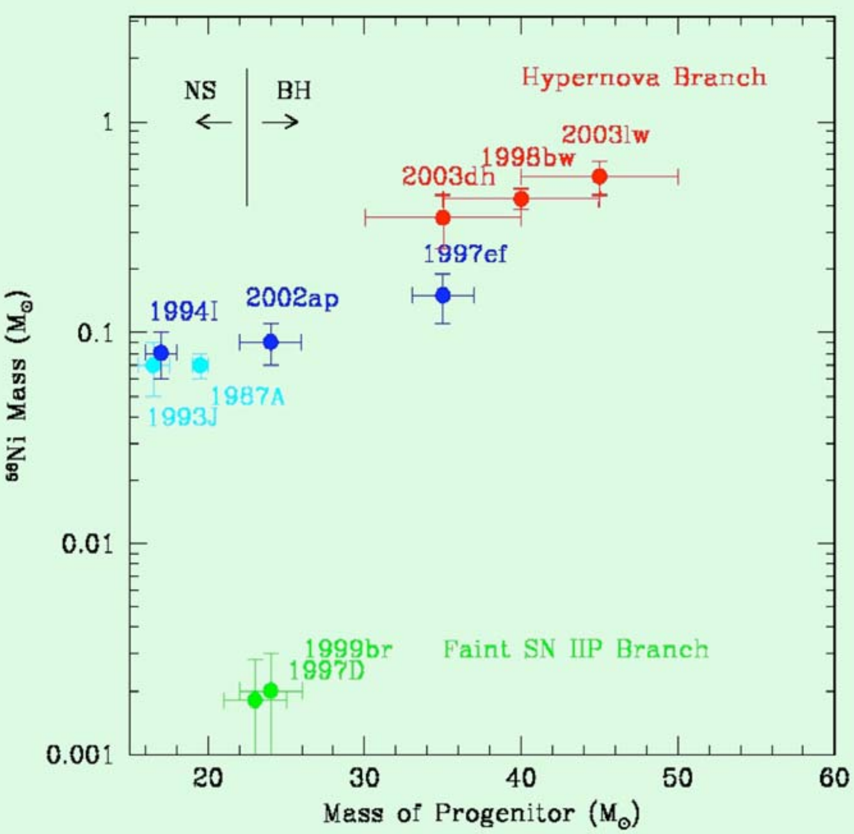
→ "normal" KE (1 foe)

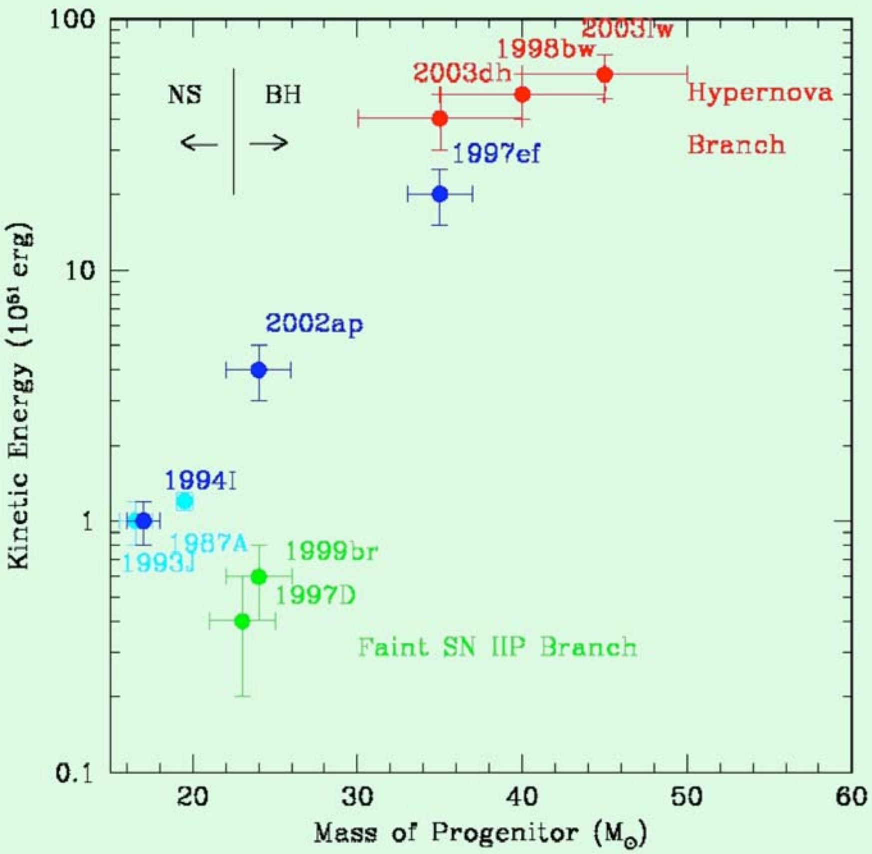
→ Normal SN Ic



Mazzali et al. 2002

$$M(^{56}Ni) \propto M_{MS} \qquad KE \propto M_{MS}$$

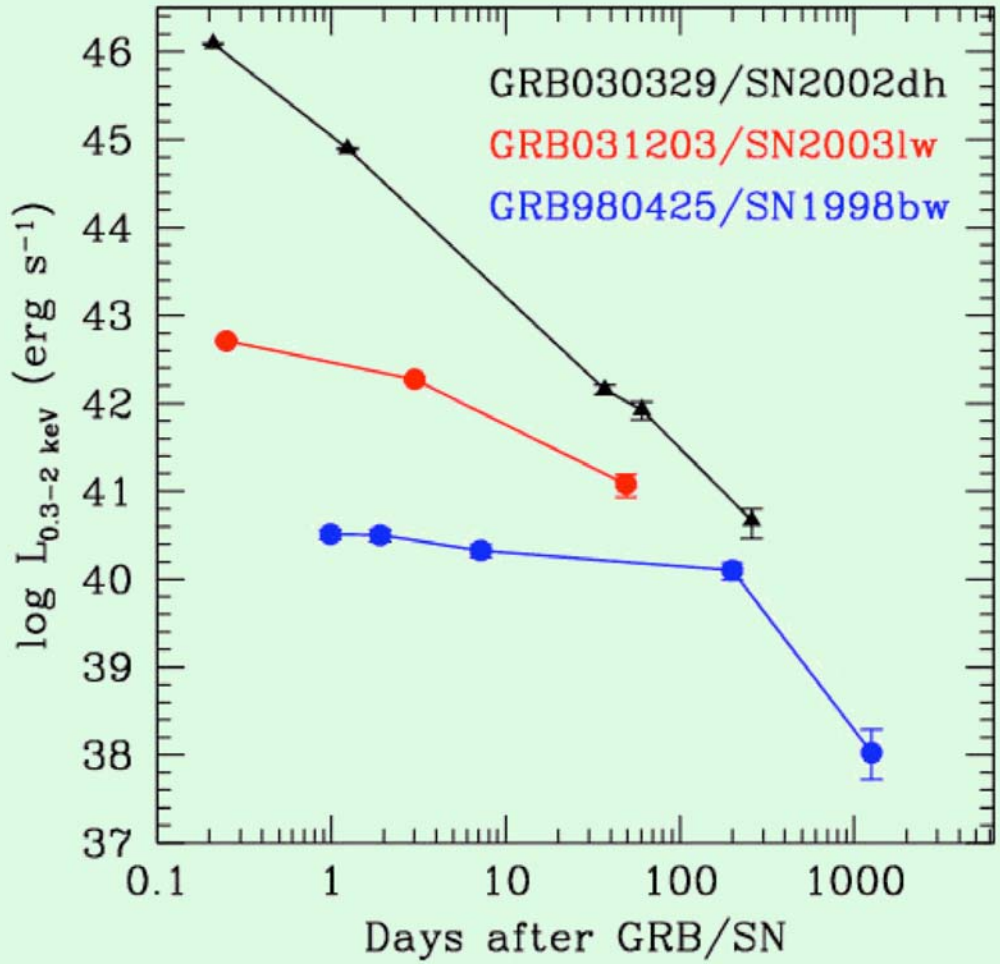




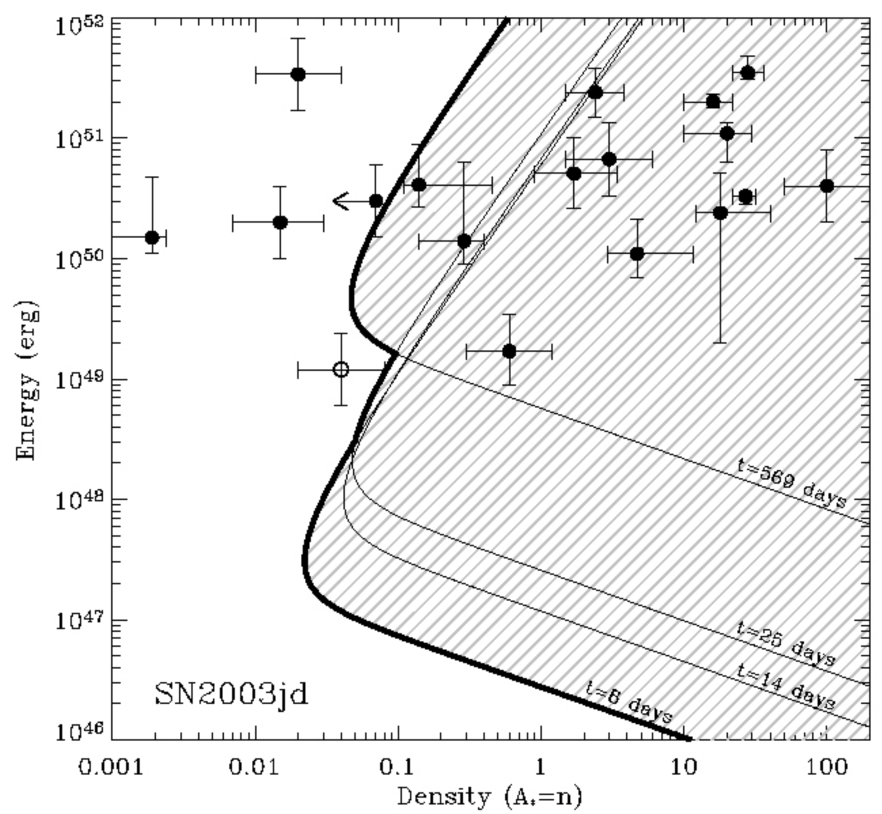
3 HNe/GRB

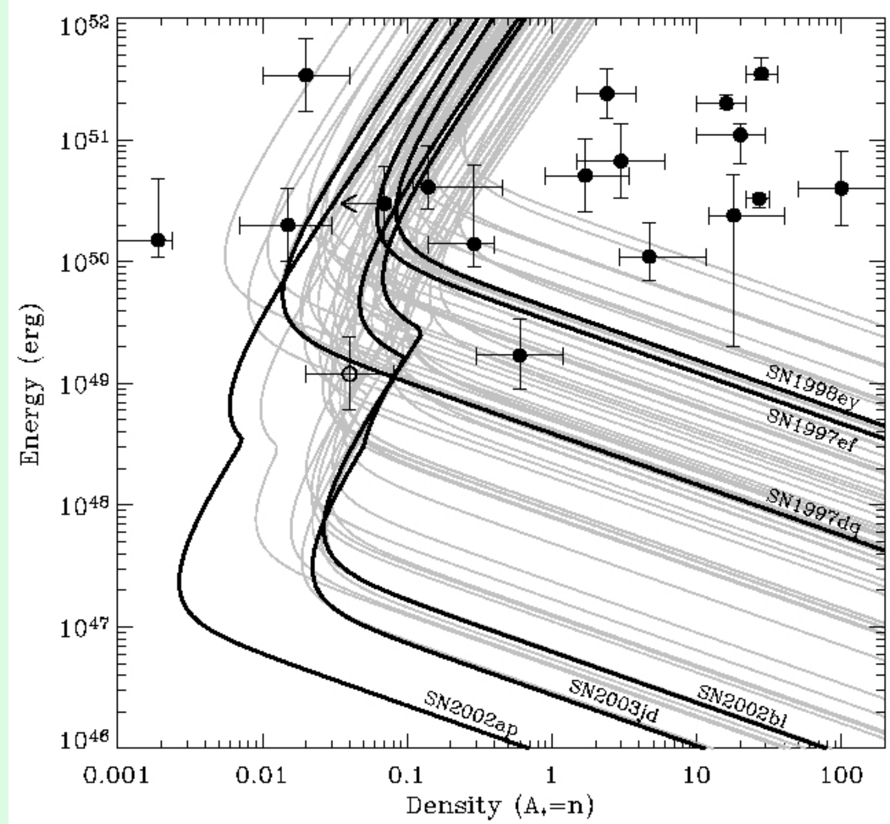
Same SN properties, but very different X-ray light curves (and radio properties)

→ What is the diagnostic value?



Radio Properties of SNe Ibc





Most HNe show no radio (Soderberg et al 2005)

Either no jet, or a low-density environment (wind)

Another KITP hit

XRF060218/SN2006aj

z=0.033

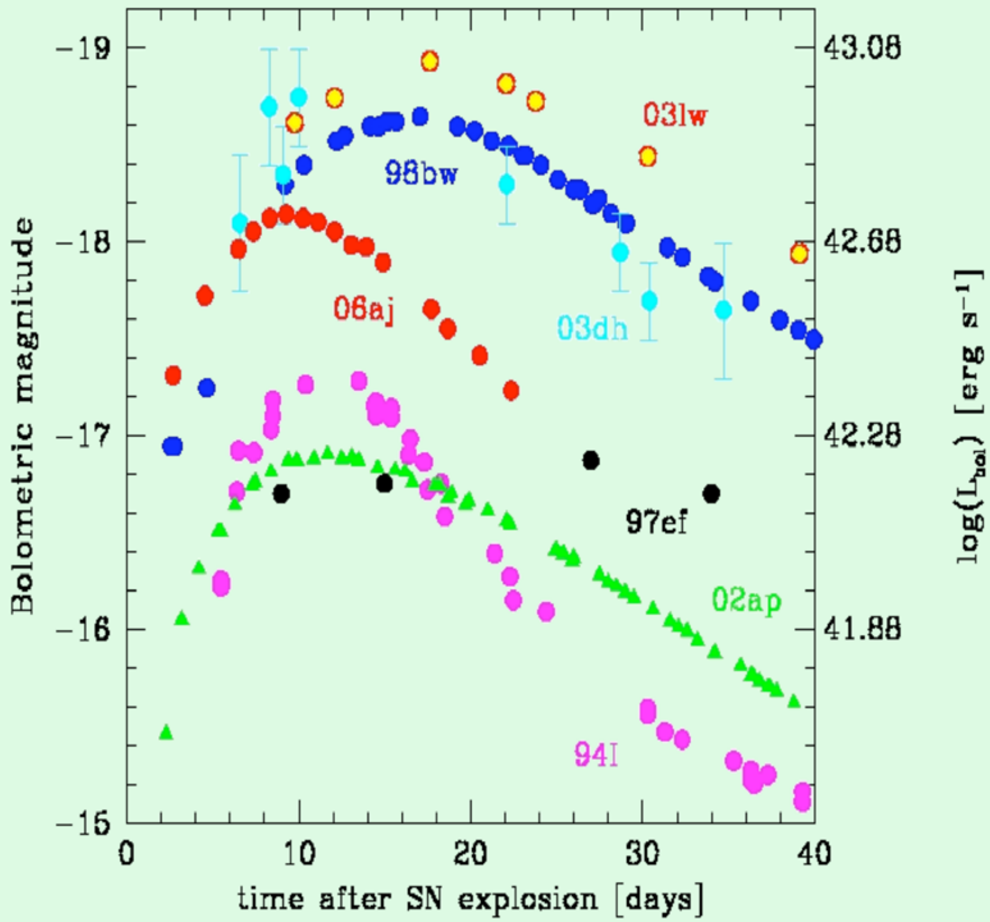
SN2006aj was dimmer than other GRB/SNe (98bw, 03dh, 03lw)

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

$M(^{56}Ni) \sim 0.2 M_{\odot}$

Rapid LC evolution:

➔ M_{ej}^3/E is small

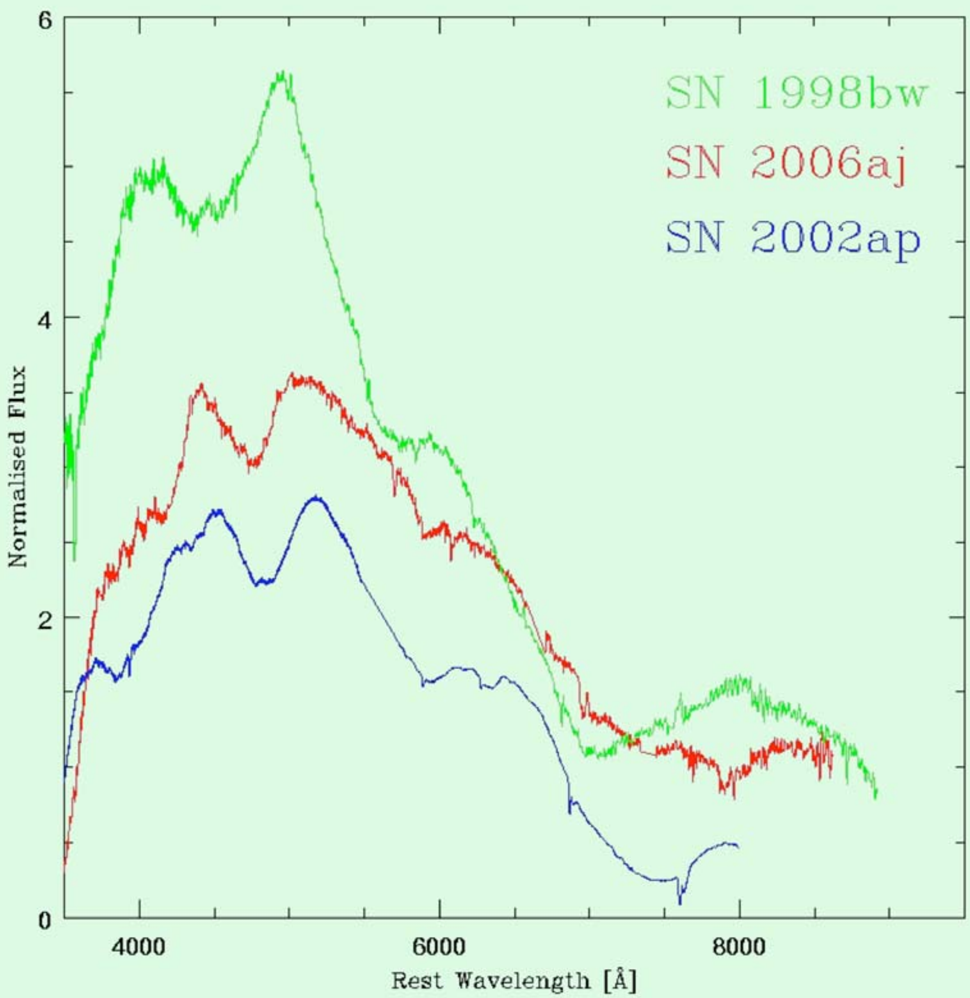


Pian et al. (2006), Nature

An Oxygen-poor SNIc (Ic/d?)

Closest match is the broad-lined, non-GRB SN2002ap, more than the "traditional" HN SN1998bw

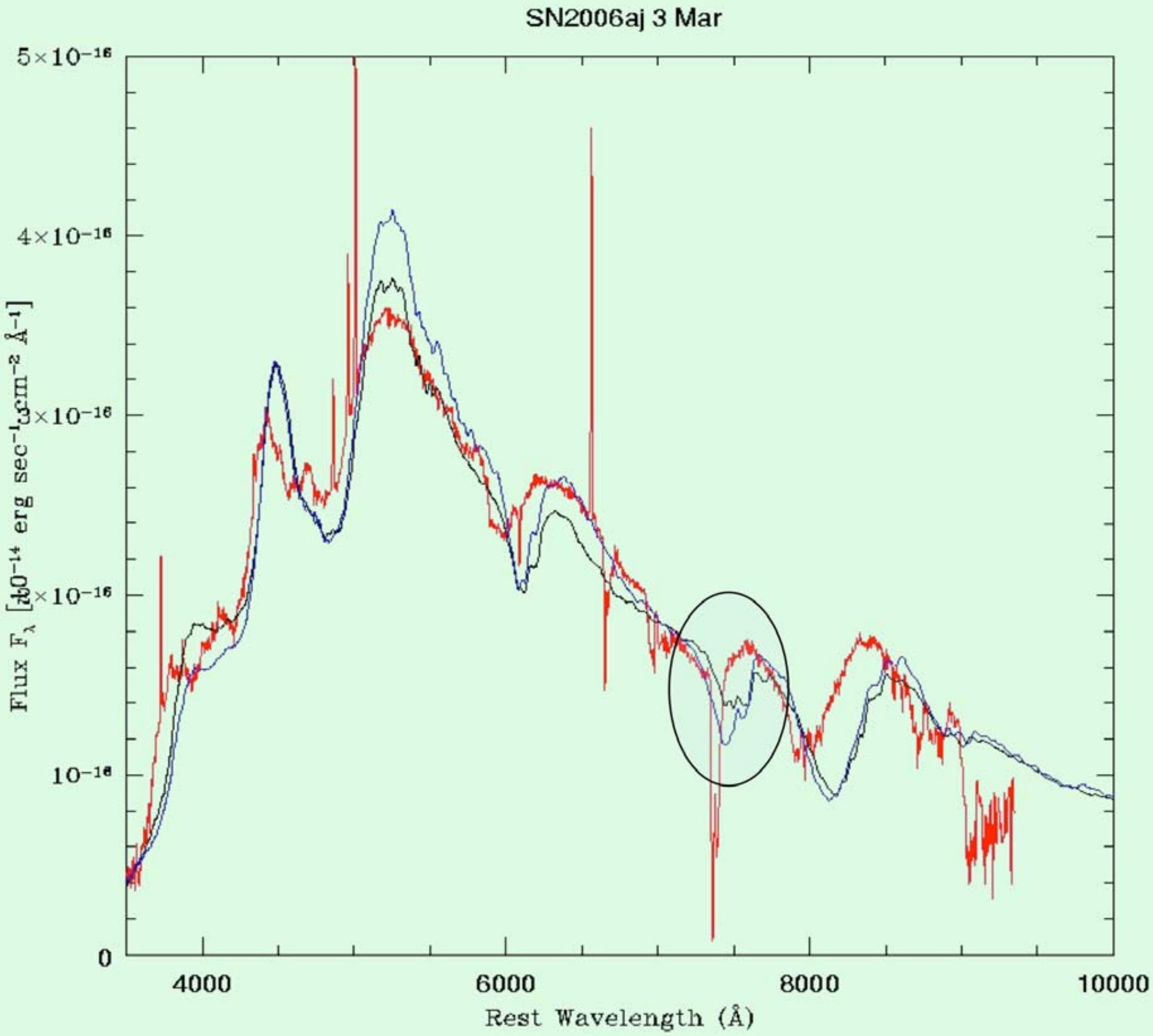
OI line (7300Å) weak or absent



Testing for Oxygen

A Model with similar O content as SNe 1998bw and SN 2002ap has strong OI 7774Å line.

A model with ½ the mass of SN 2002ap (and less O) is a better fit.



SN2006aj: Spectral modelling

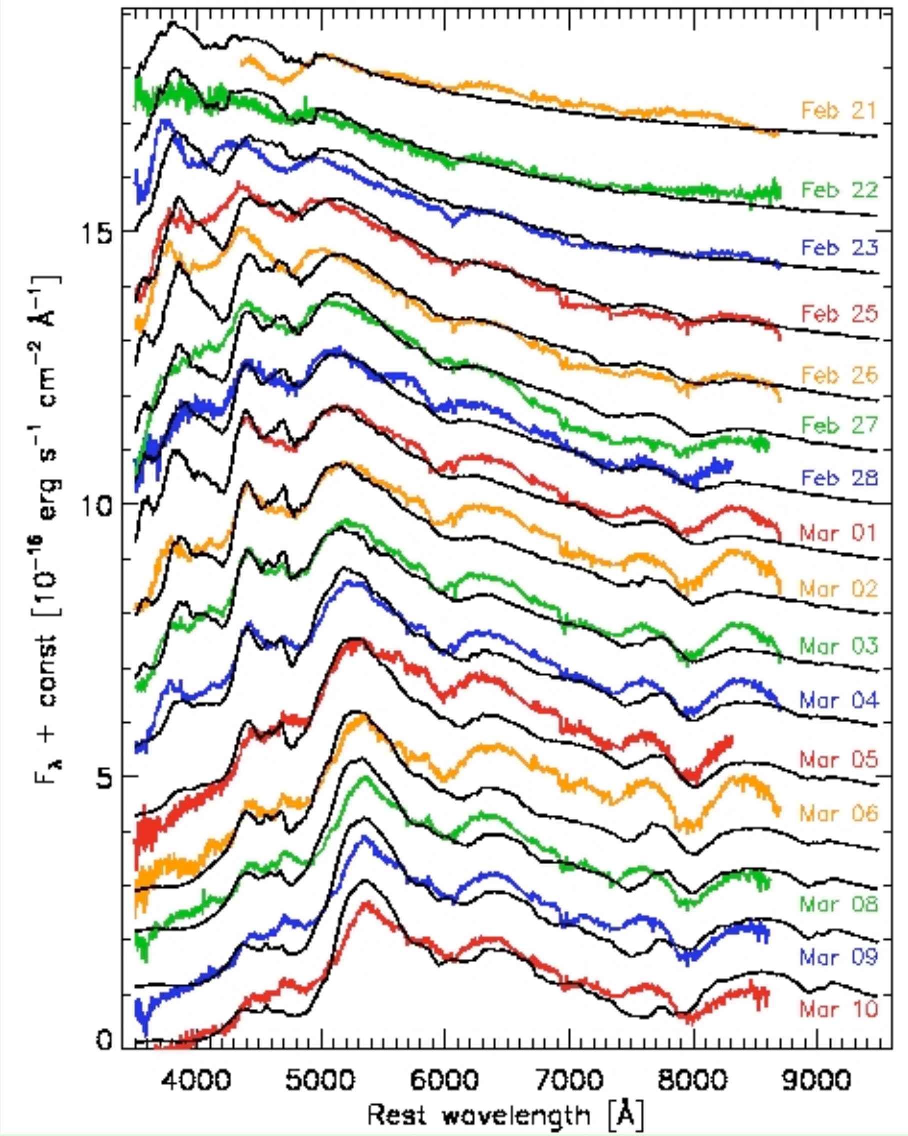
Model similar to that used for SN2002ap, but with smaller M*ej*, KE, more ^{56}Ni, less O.

O-dominated shell (~0.1M⊙) at 20-25,000 km/s: shell ejection from progenitor?

$$M_{ej} \sim 2M_{\odot}$$

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

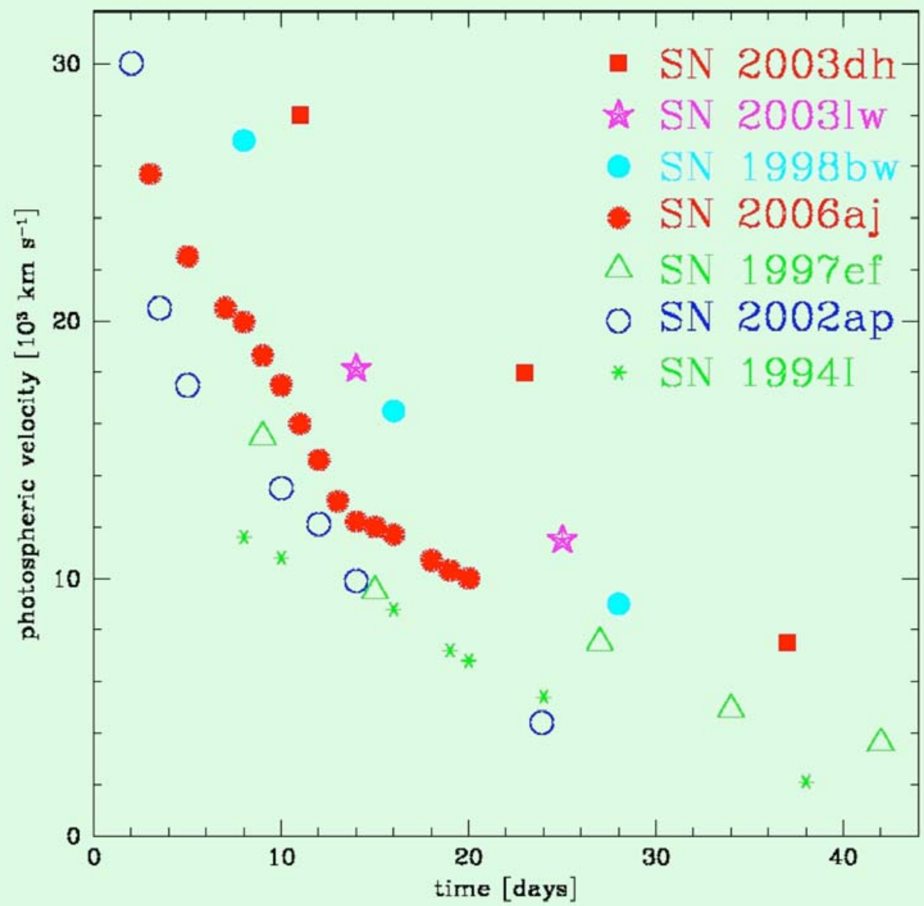
$$E_K \sim 2 \times 10^{51}\,\mathrm{erg}$$



Mazzali et al. (2006), Nature

Evolution of photospheric velocity from spectral modelling

- SN2006aj never reached velocities as high as the GRB/SNe
- It is intermediate between non-GRB, broad-lined SNe Ic such as SN2002ap and SN1997ef, and GRB/SNe

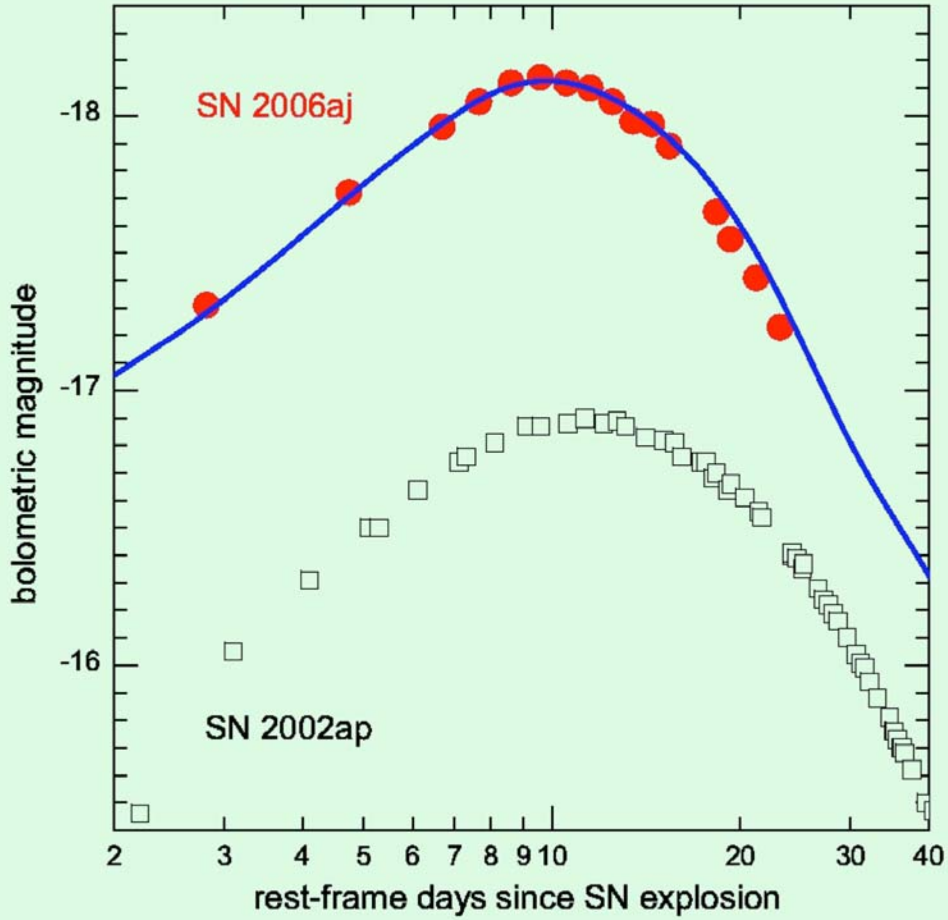


Pian et al. (2006), Nature

SN 2006aj: a Light Curve model

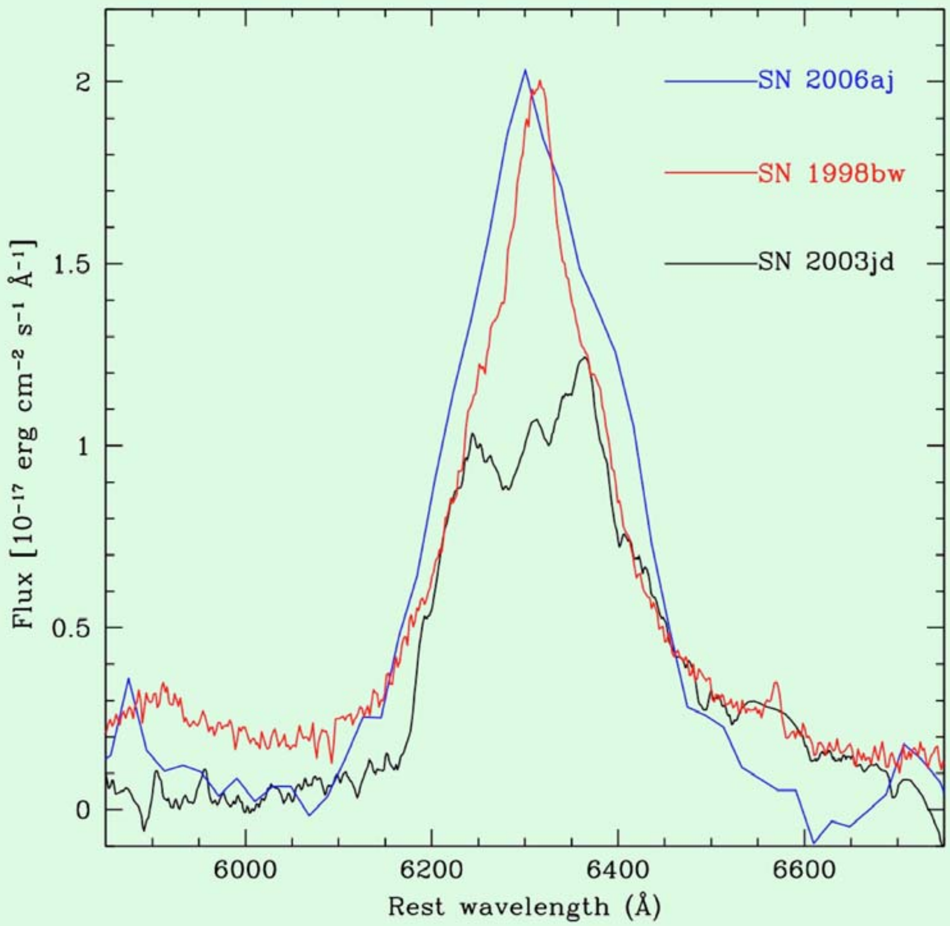
Explosion model gives a LC consistent with results of spectral fitting

Mazzali et al. (2006), Nature



SN2006aj: nebular spectra

- Strong [OI] line
- Low O mass (1.3M⊙)
- Small M_{ej} (2M⊙)
- No sign of major asphericity



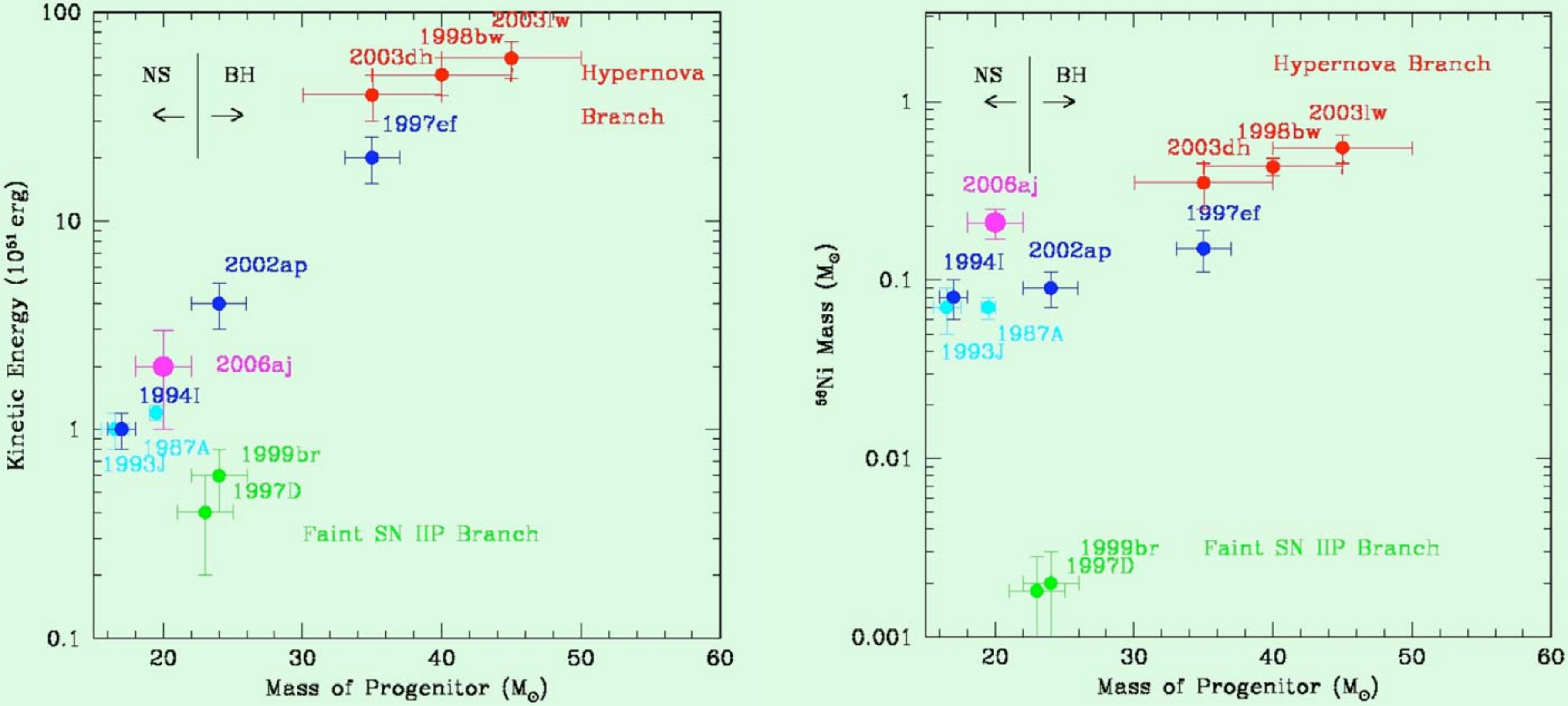
Properties of SN2006aj

- SN 2006aj exploded as a CO core (a WR star) of ~3.3 $M_\odot$.
- The ejecta (~2$M_\odot$) consisted of O (~1.3$M_\odot$), and heavier elements (~ 0.5$M_\odot$), incl. ~ 0.2$M_\odot$ of ^{56}Ni.

→The progenitor of SN 2006aj was a small mass star (M_{ZAMS} ~ 20 $M_\odot$).

- Remnant was a NS (M ~ 1.4 $M_\odot$).
- Magnetic activity induced the XRF (Magnetar)

Placing SN2006aj in context



A neutron star-making SN

Properties of Type Ib/c Super/Hypernovae

SN	83N	94I	06aj	02ap	97ef/dq	98bw
type	Ib	Ic	Ic-en	Ic (Hypernovae)		
M_{ZAMS}	15	15	20	21	34	40
M_{He}	4	4	5.5	6.6	13	16
M_{CO}	2	2	3.3	4.5	11	14
M_{Expl}	4	2.1	3.3	4.6	11.1	13.8
M_{Rem}	1.25	1.2	1.4 NS	2.1	1.6	2.9
M_{Ej}	2.75	0.9	2.0	2.5	9.5	10.9
M_{He}	2.0	---	---	0.1	---	---
M_{CO}	0.5	0.6	1.4	1.8	5.3	8
$M_{IME(Si,S)}$	0.1	0.2	0.4	0.5	4	2
M_{Ni}	0.15	0.07	0.2	0.1	0.13	0.7
E_{51}	1	1	2	5	19	50
GRB	X	X	√ (XRF)	X	X	√

Hypotheses, future checks

- Magnetar activity may have been responsible for the high energy transient

→ possible rebrightenings

- Asymmetries, orientation TBD when nebular spectra available
  – expect [O I] 6300,6363Å emission to be weak w/r to Fe and broad

The Grand Scheme

- Collapse of very massive (~35-50 $M_\odot$), stripped stars to Black hole makes GRB-HN (GRB can be very different, HN much less).
- Collapse of less massive star (~ 20 $M_\odot$) to NS can cause an XRF (via magnetic activity ?).
- Some of these NS may later (when spin is lower) harbour some short-hard GRBs (SGRs).
- If system is a close binary (possibly necessary for mass loss) it may end as a NS-NS merger and again produce a short-hard GRB.

Debates

- Are ALL long GRB SNe?
- Are all GRBs similar (viewing angle effect) or are they really very different?
- How do GRBs and XRF relate?
- What are the progenitors?
-
- ….. Cosmological use….???

誕生日おめでとう、憲一　！