Core-Collapse Supernovae and Gamma-Ray Bursts:

Type Ib SN2005bf and Type Ic SN2006aj/GRB060218

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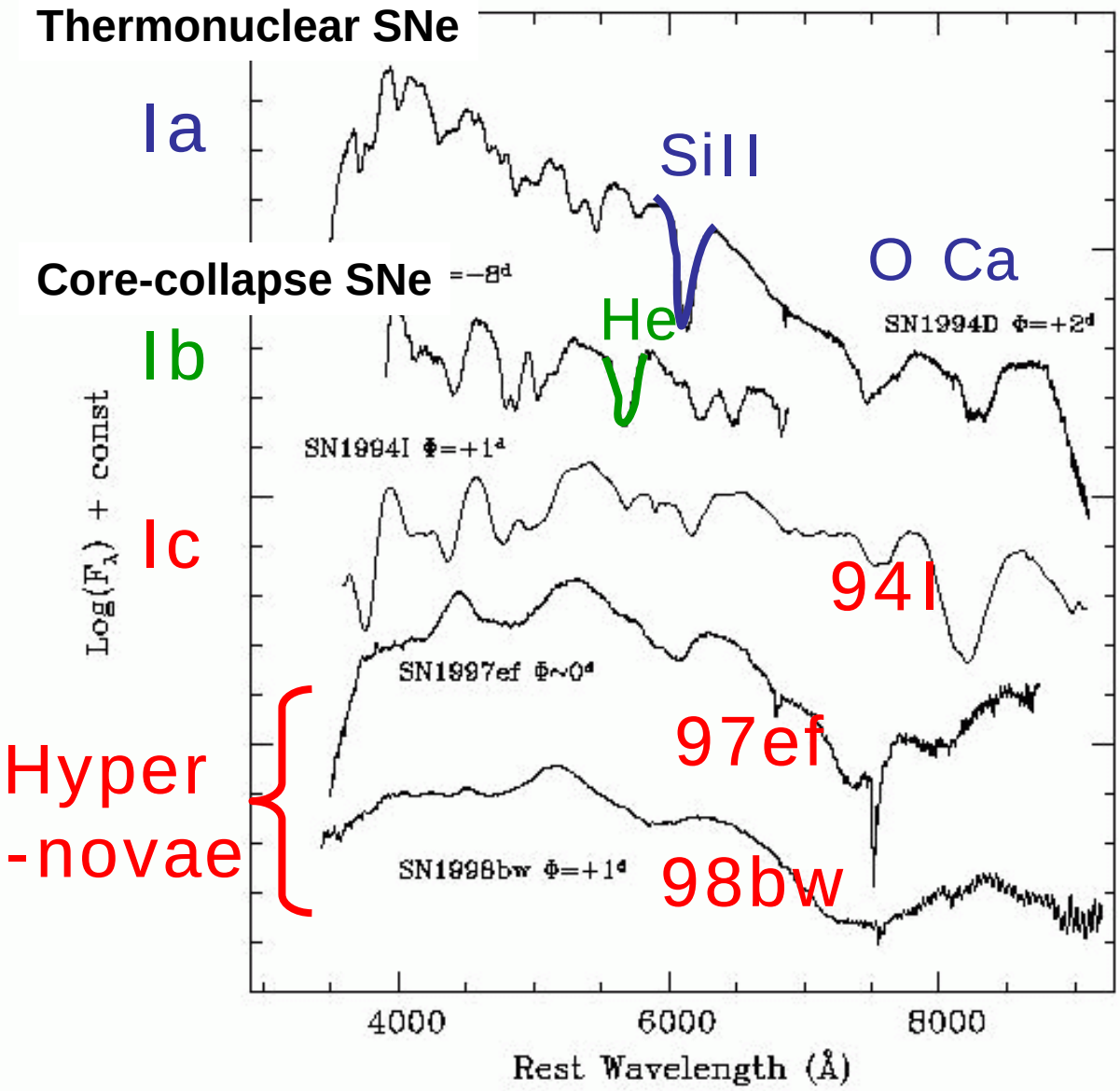
Spectra of Supernovae & Hypernovae



Ic: no H,

no strong He,

no strong Si

Hypernovae:

broad features

↑

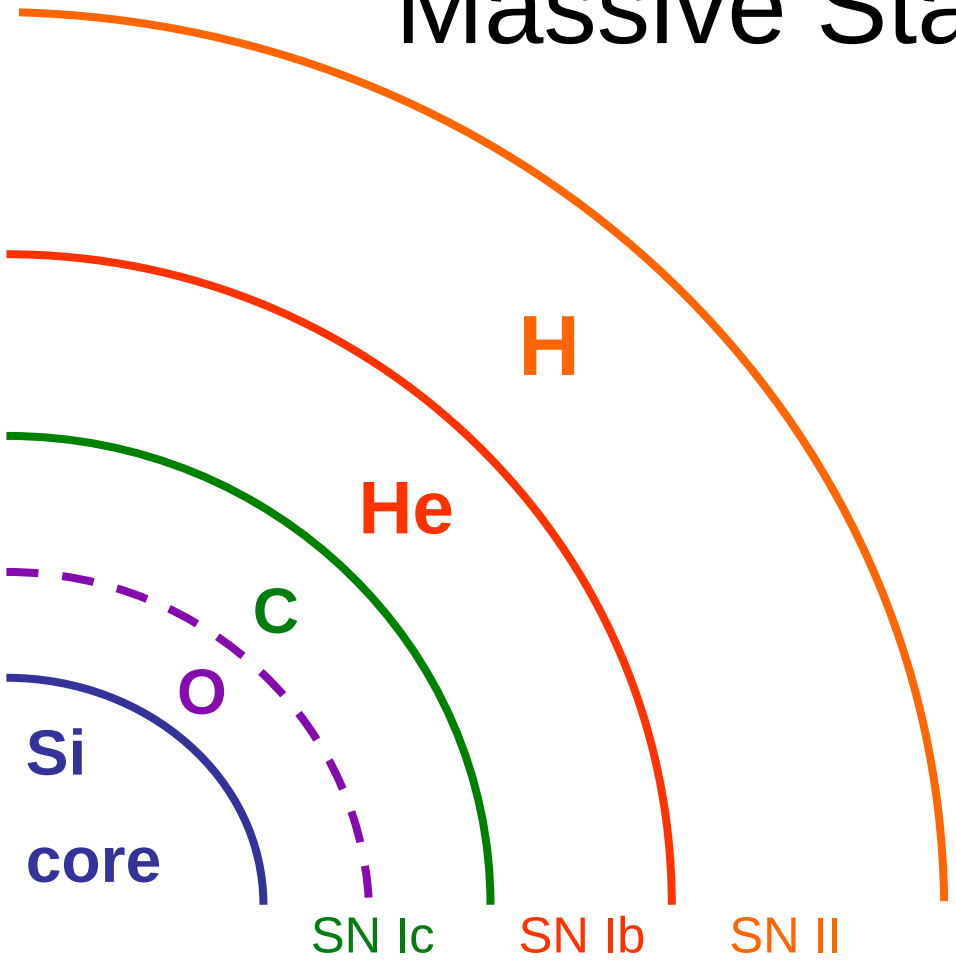
blended lines

↑

"Large mass at high velocities"

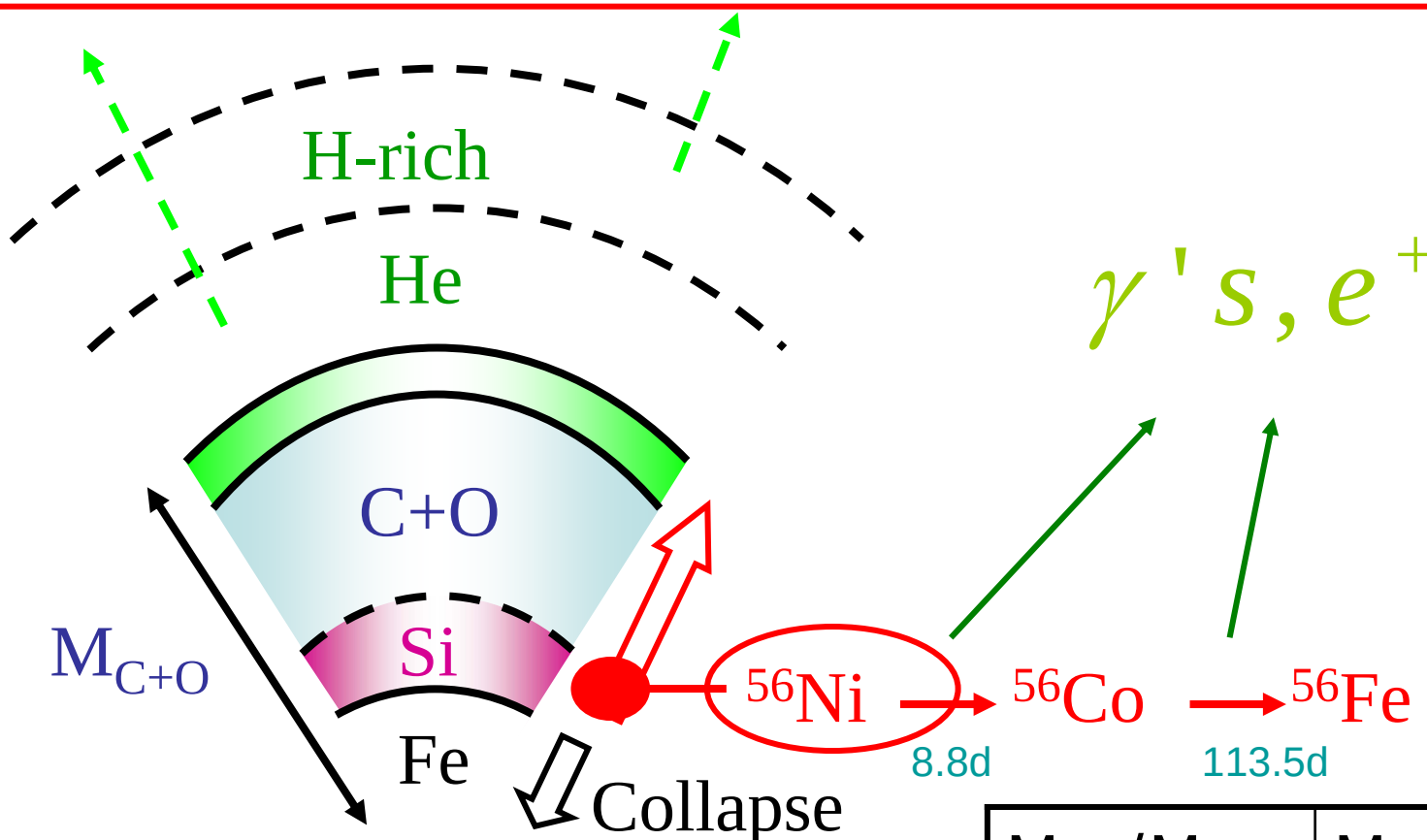
Core-Collapse SNe

Massive Star (>8$M_\odot$)



- Different mass loss
  → SN type
- Core collapse
- Compact object
  (NS/BH)
- Energy deposited
  → SN explosion

CO Star Models for SNe Ic

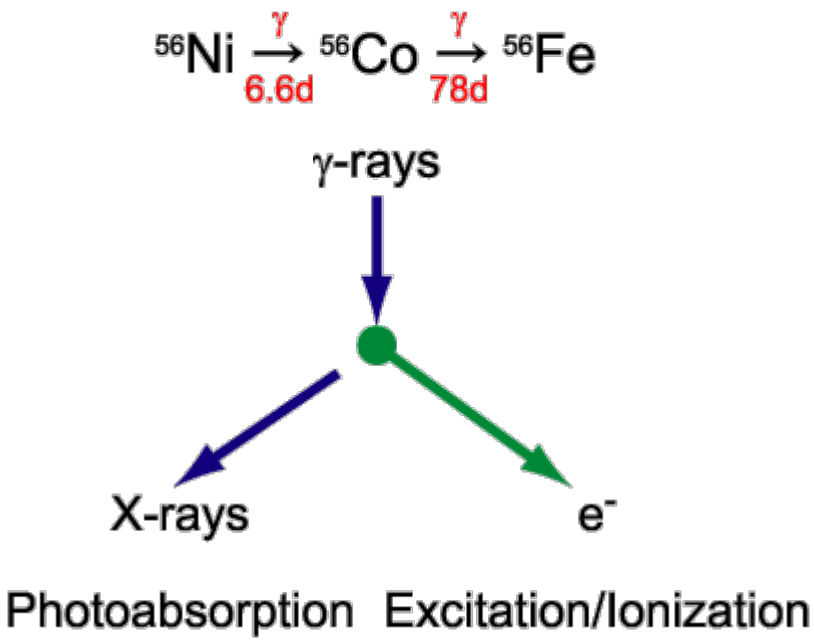


Parameters

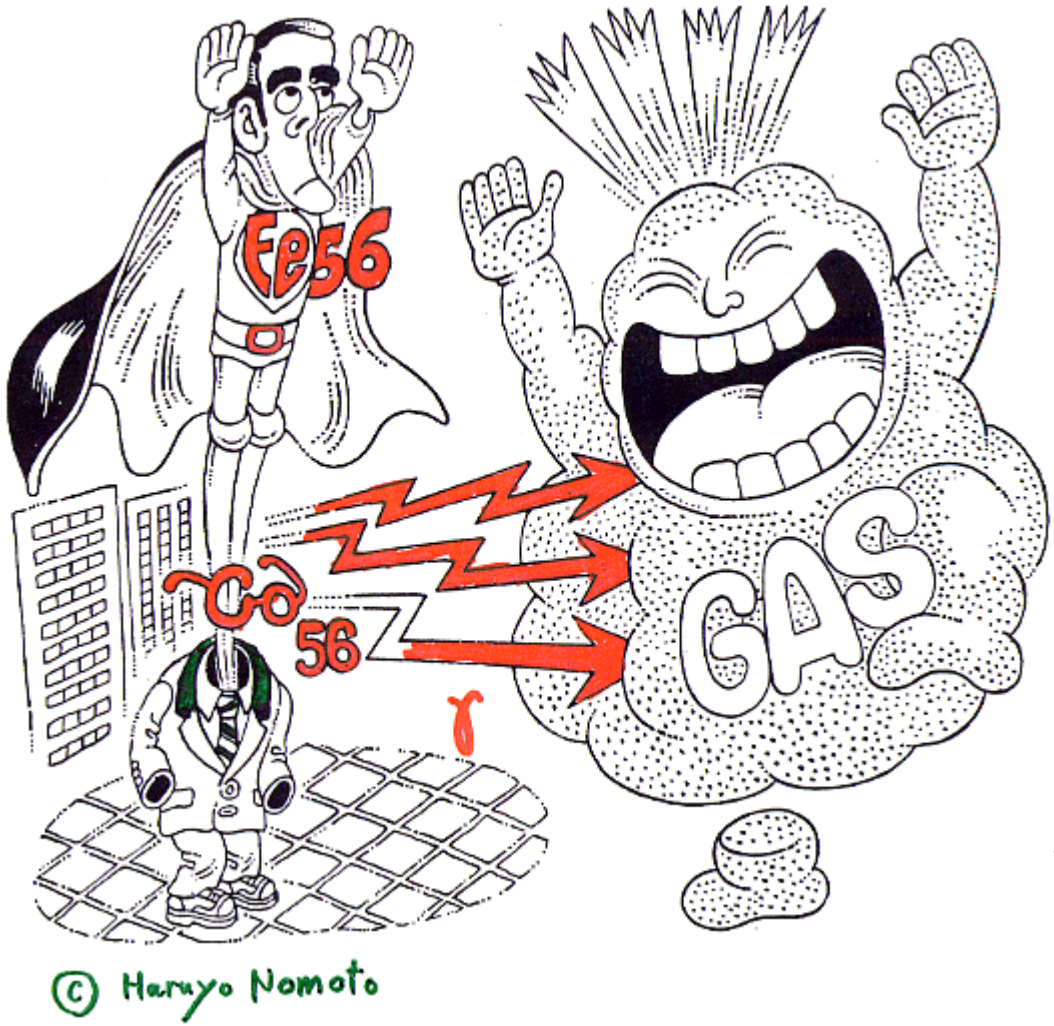
[M_{ej}, E, M(^{56}Ni)]

$M_{ms}/M_\odot$	$M_{C+O}/M_\odot$
~ 40	13.8
~ 35	11.0
~ 22	5.0

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



$L_{SN} \propto M(^{56}Ni)$



Explosion Parameters

M_{ej}, E

Light Curve

Spectra

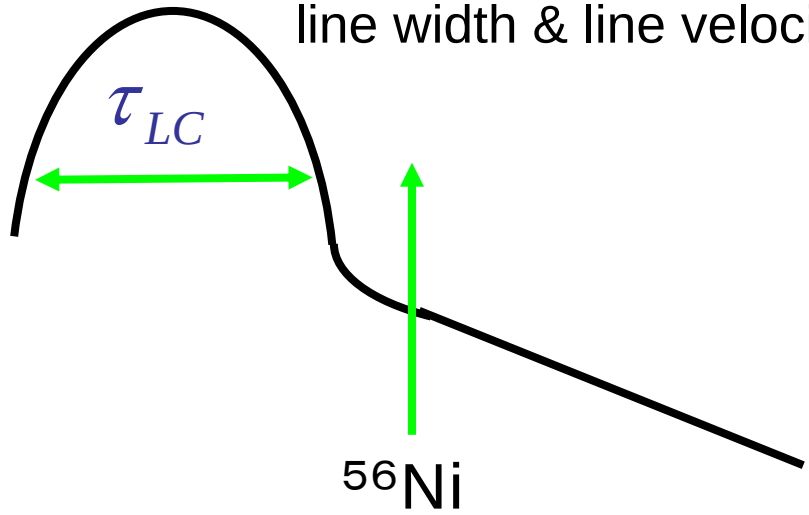
$$\tau_{LC} \sim (\tau_{dyn} \cdot \tau_{diff})^{1/2}$$

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

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

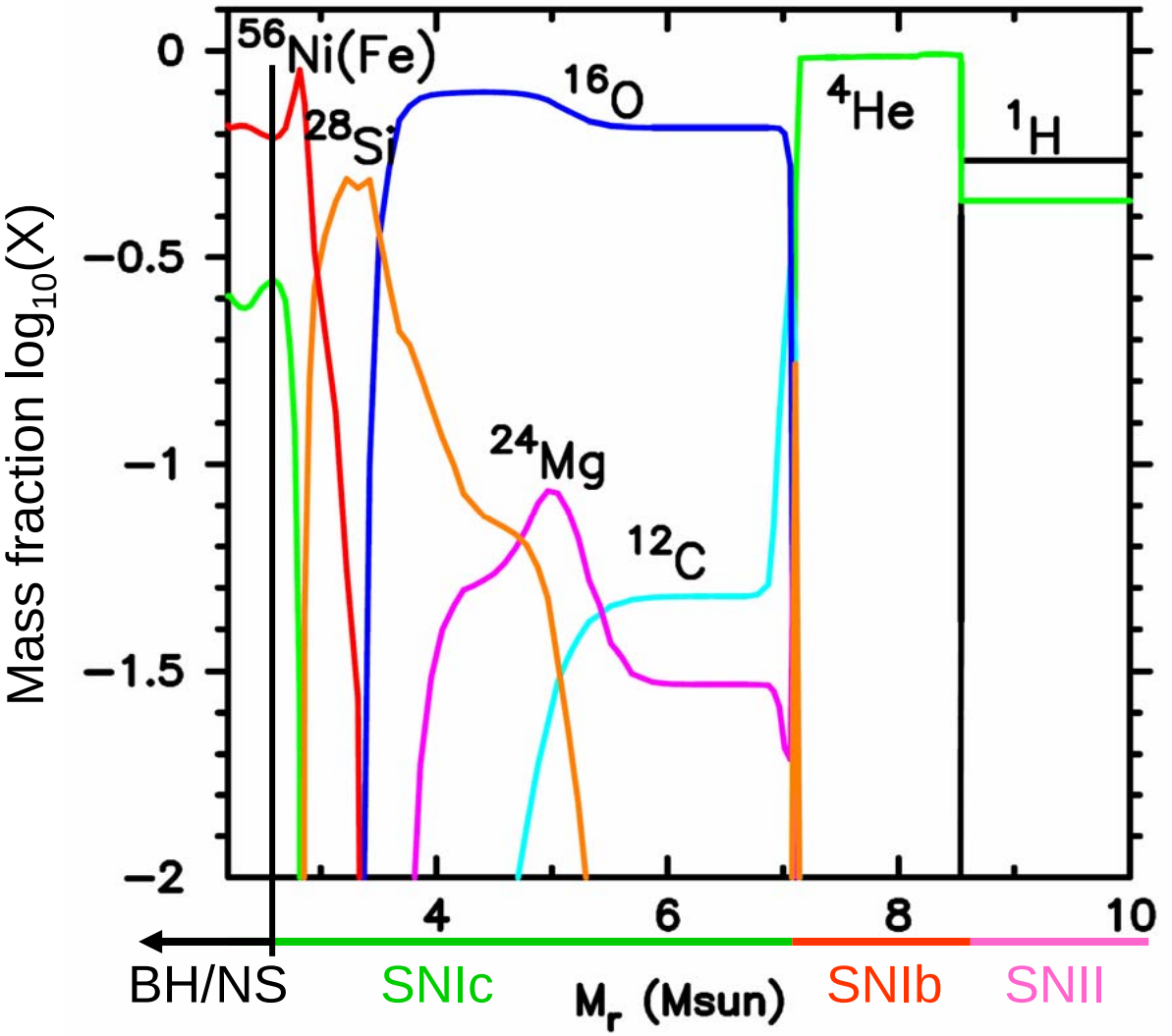
$$v_{ph} \propto (E / M_{ej})^{1/2}$$

line width & line velocity



Progenitors of SNe Ib/c

The abundance distribution after a SN explosion



M_{ej}, E, & M(^{56}Ni)

(Light curve & spectra)

↓ SN nucleosynthesis

M_{rem}

(E & M(^{56}Ni))

↓

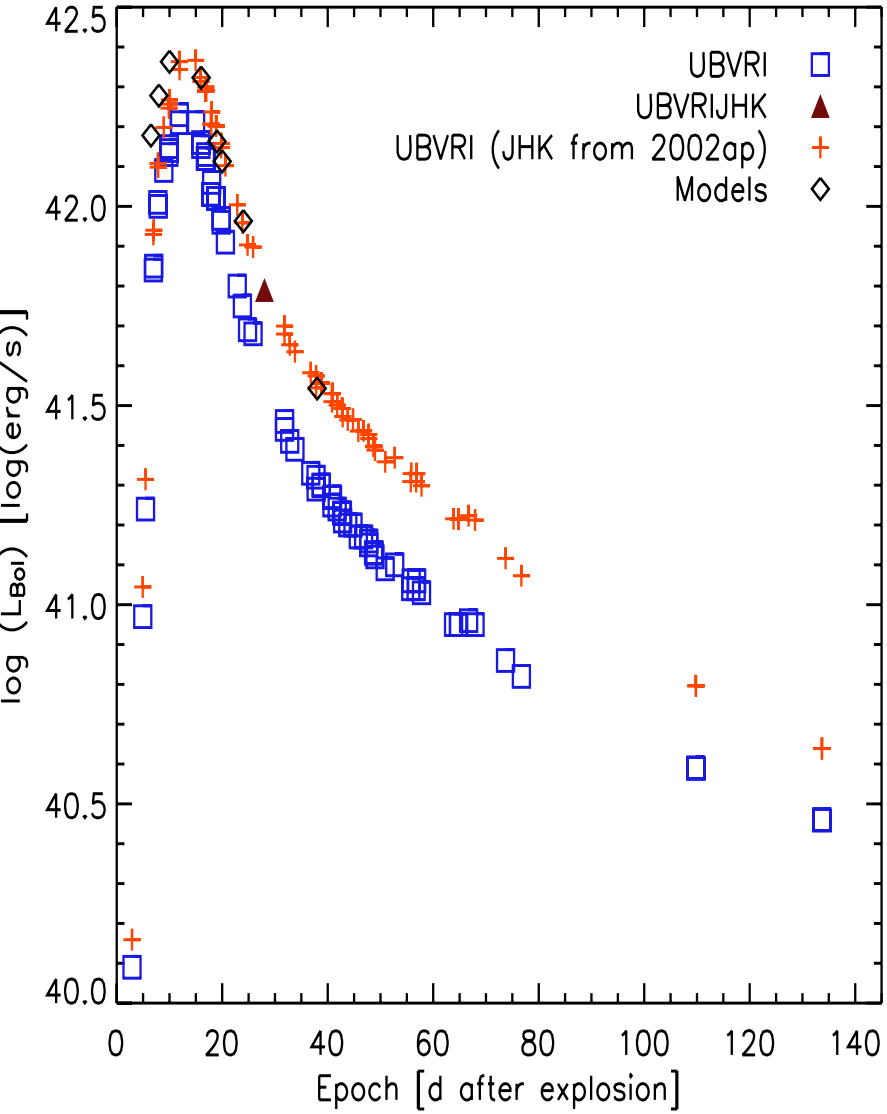
M_{C+O} or **M_{He}**

(= M_{ej} + M_{rem})

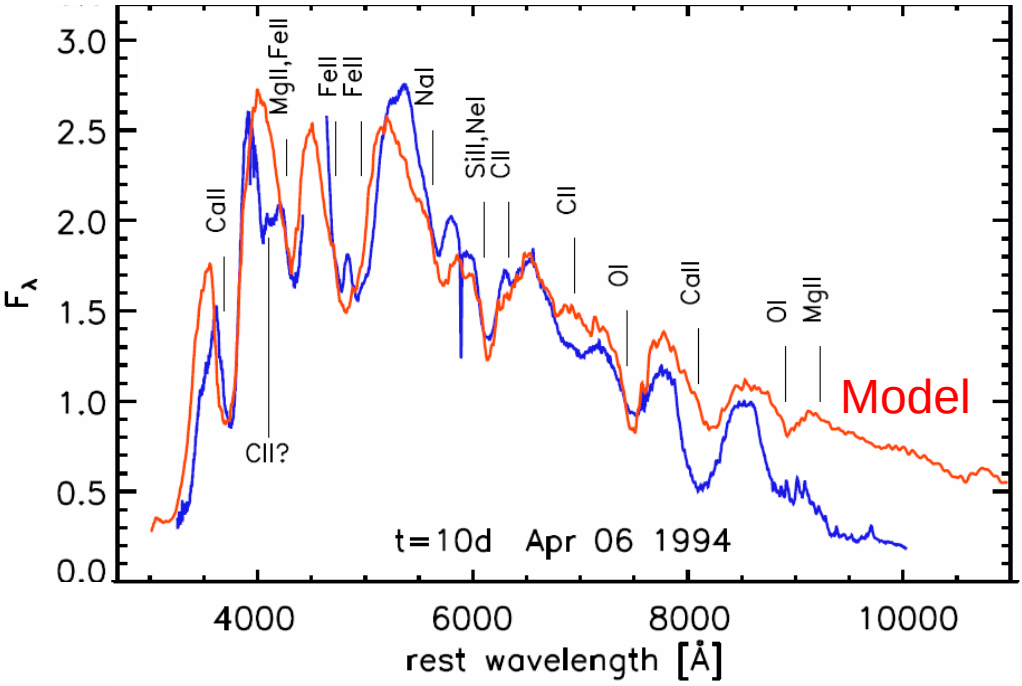
↓ Pre-SN evolution

M_{ms}

Normal Type Ic SN: SN 1994I

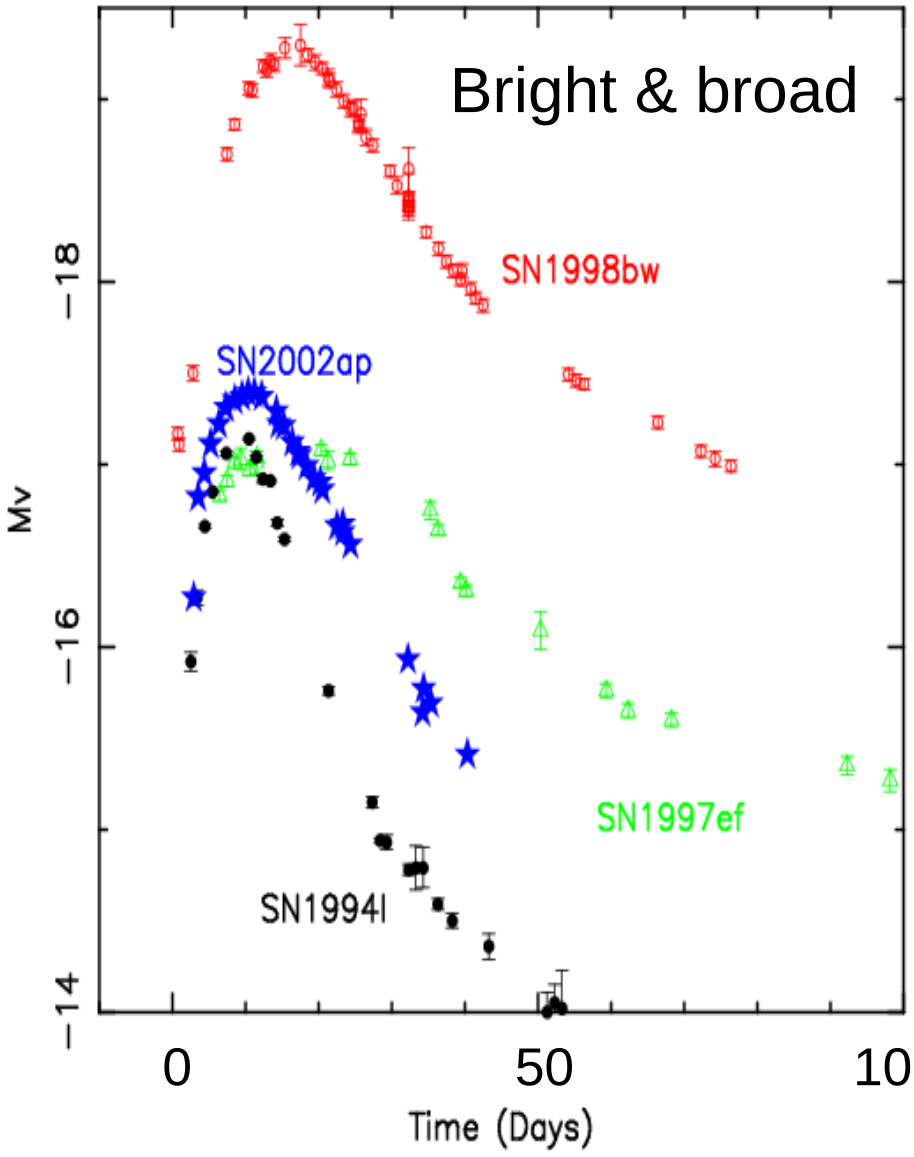


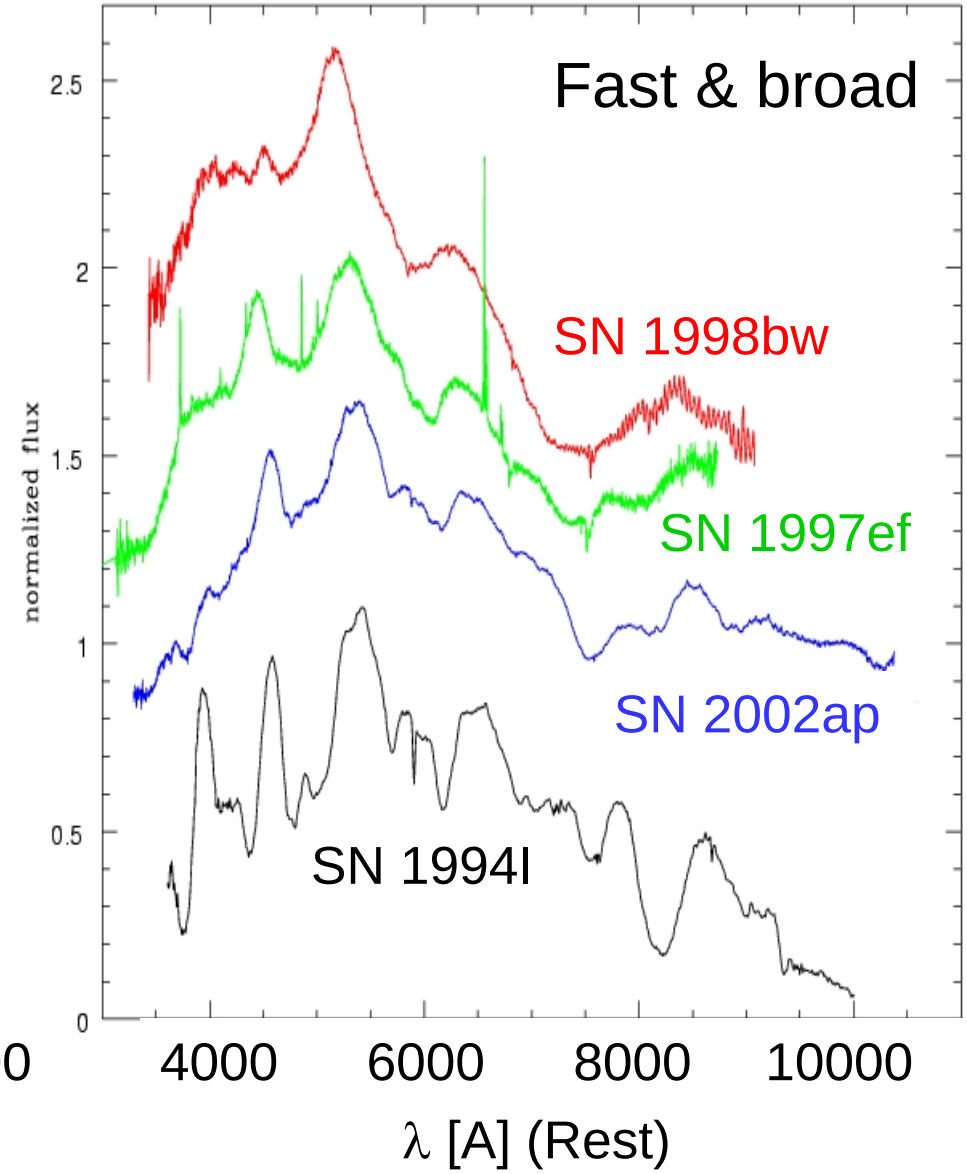
Sauer et al. 2006



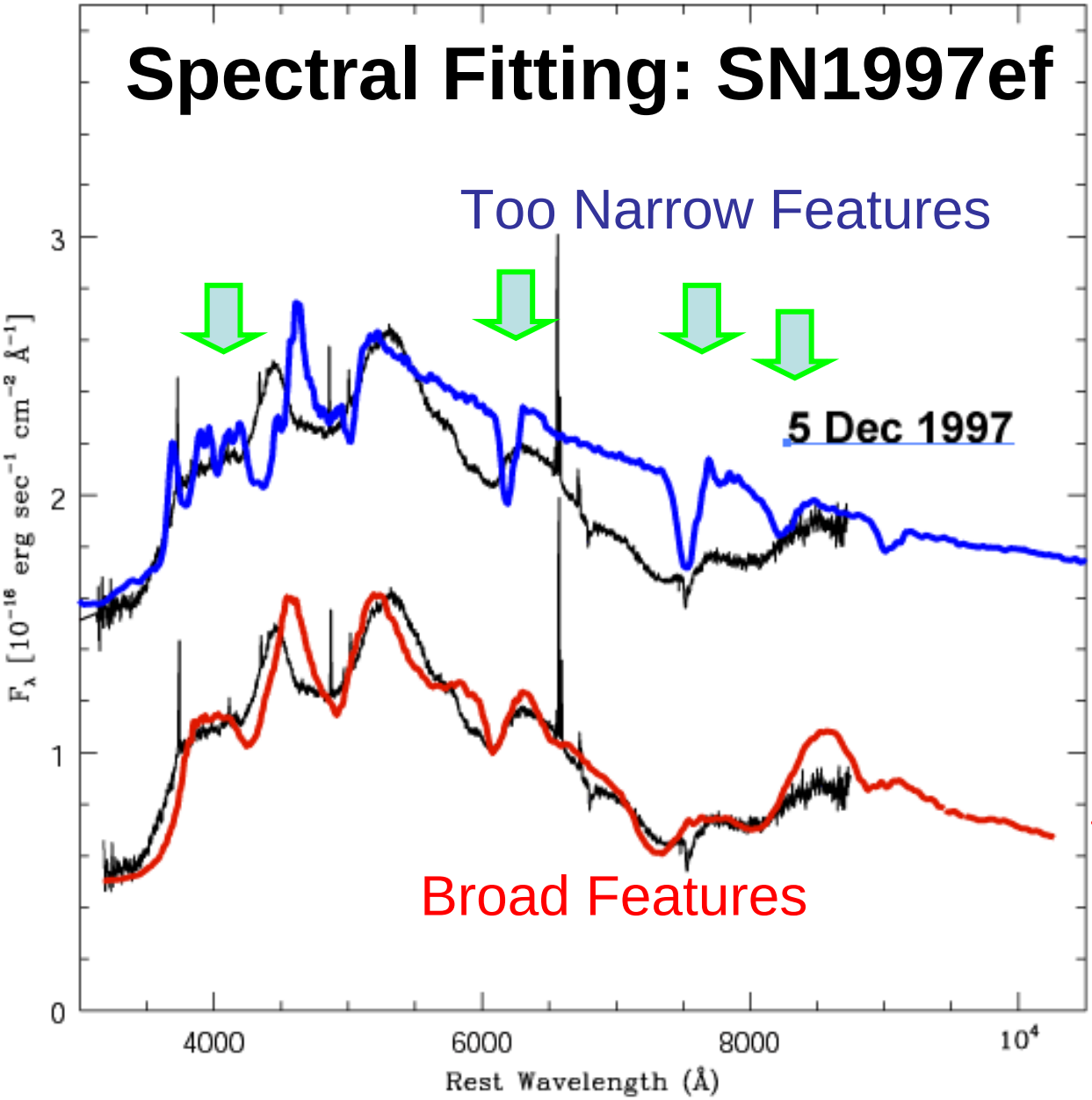
$M_{ej} \sim 1\ M_\odot$ (C+O star)
($M_{ms} \sim 14 \pm 1\ M_\odot$)
$E \sim 1 \times 10^{51}$erg
$M(^{56}Ni) \sim 0.07 M_\odot$

Hypernovae


Bright & broad
SN1998bw
SN2002ap
SN1997ef
SN1994I
Mv
−18
−16
−14
0
50
100
Time (Days)


Fast & broad
SN 1998bw
SN 1997ef
SN 2002ap
SN 1994I
normalized flux
2.5
2
1.5
1
0.5
0
4000
6000
8000
10000
λ [A] (Rest)

Spectral Fitting: SN1997ef



Iwamoto et al. (2000)

$E_{51}=E/10^{51}$ erg

Normal SN
(**$E_{51}=1$**)

Small M_{ej}

Hypernova
(**$E_{51}=20$**)

Large M_{ej}
at High Vel.

HN explosions

Hypernovae: $E>10^{52}$erg

	Name	$M_{ej}/M_\odot$	$M_{ms}/M_\odot$	$E/10^{51}$erg	$M(^{56}Ni)/M_\odot$
HN	1998bw	10	40	50	0.4
	1997ef	8	30-35	15	0.15
	2002ap	4	20-25	4	0.08
SN	1994I	1	13-15	1	0.07

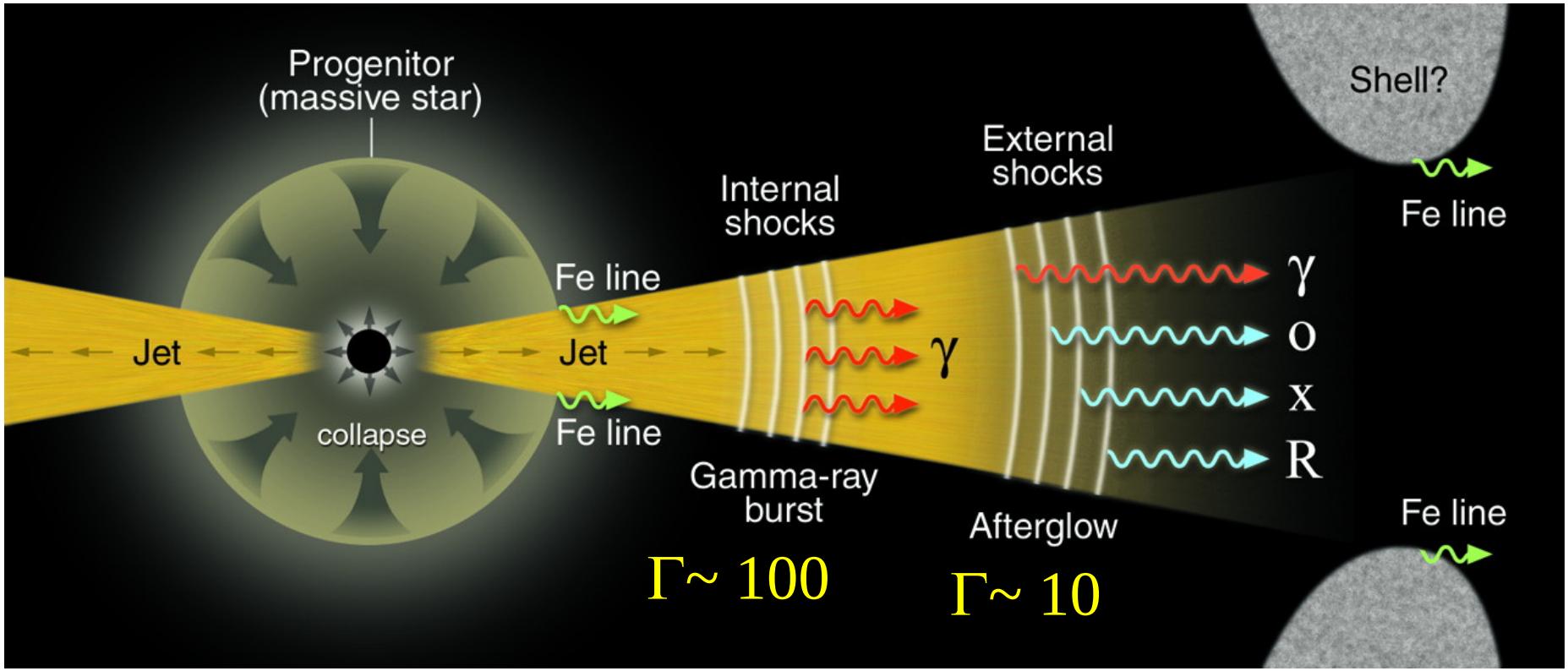
Massive & **energetic** explosions!!
Some of **HNe** are associated with **gamma-ray bursts (GRBs)**.

Gamma-Ray Bursts

Synchrotron emission

from relativistic shocks in jets.

"Firecone" model



Supernova – GRB Connection

Three GRB－SNe = all Type Ic Hypernovae

$E > 10^{52}$ erg (～10×normal SN)

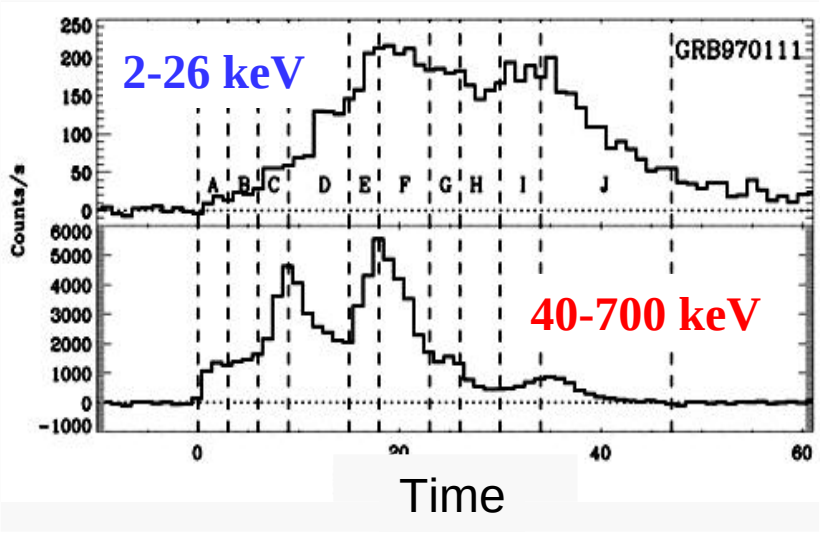
Large M_{ms} →Black Hole Forming SNe

Aspherical

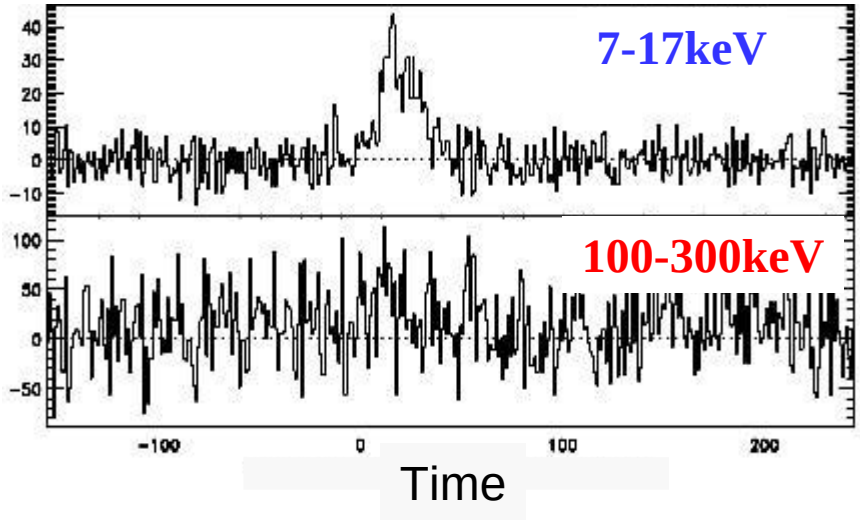
GRB	SN	$M_{ej}/M_\odot$	$M_{ms}/M_\odot$	$E/10^{51}$erg	$M(^{56}Ni)/M_\odot$
980425	1998bw	10	40	50	0.4
030329	2003dh	7	35	40	0.35
031203	2003lw	13	45	60	0.55

X-Ray Flashes

Gamma-ray burst



X-ray flash



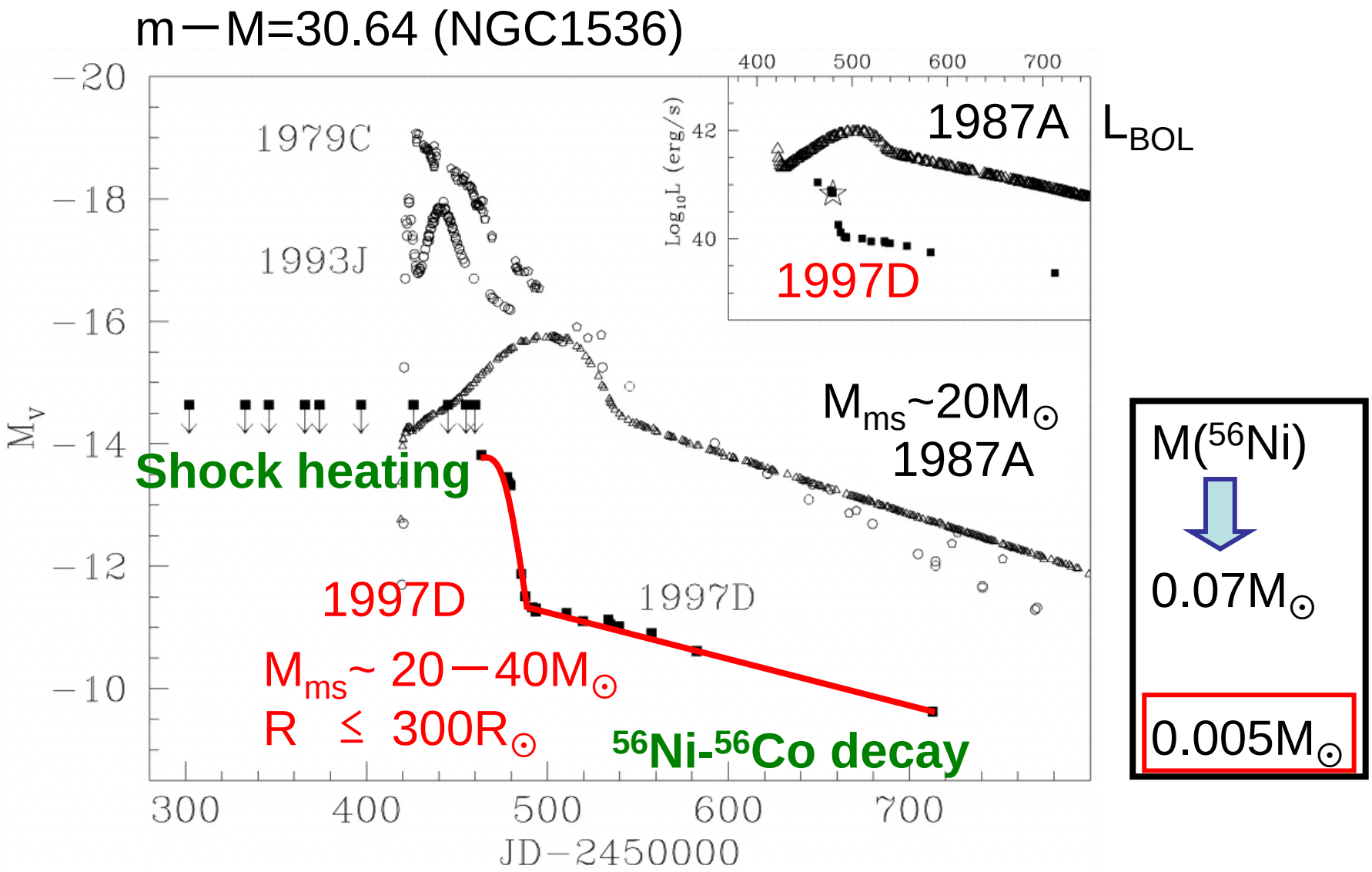
GRBs and **XRFs** are similar events,
but **gamma-ray** fluences are different.

What causes the difference?

- Viewing angles? (Yamazaki et al. 2003)
- Lorentz factors of relativistic jets? (Dermer et al. 2000)

SNⅡ 1997D: Faint SN

Turatto, Mazzali, Young,
Nomoto, Iwamoto et al. (1998)



M(^{56}Ni)

0.07$M_\odot$

0.005$M_\odot$

Type II-P
SN 1997D

Very narrow lines.

V < 1000 km s^{-1}.

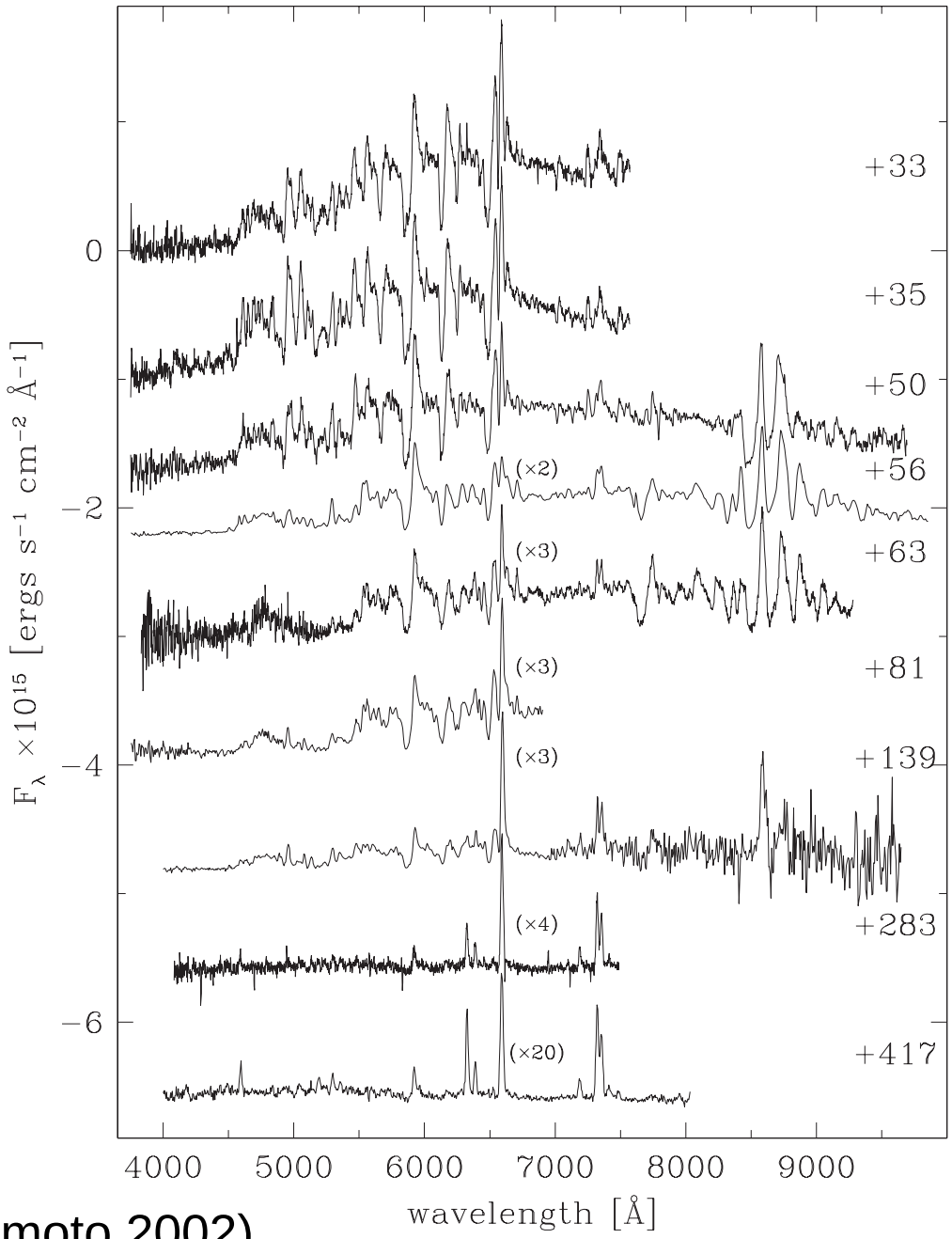
E=1-4×10^{50} ergs.

V~1000km s^{-1}

2002gd, 1999br

Faint

M(^{56}Ni)~0.005$M_{\odot}$

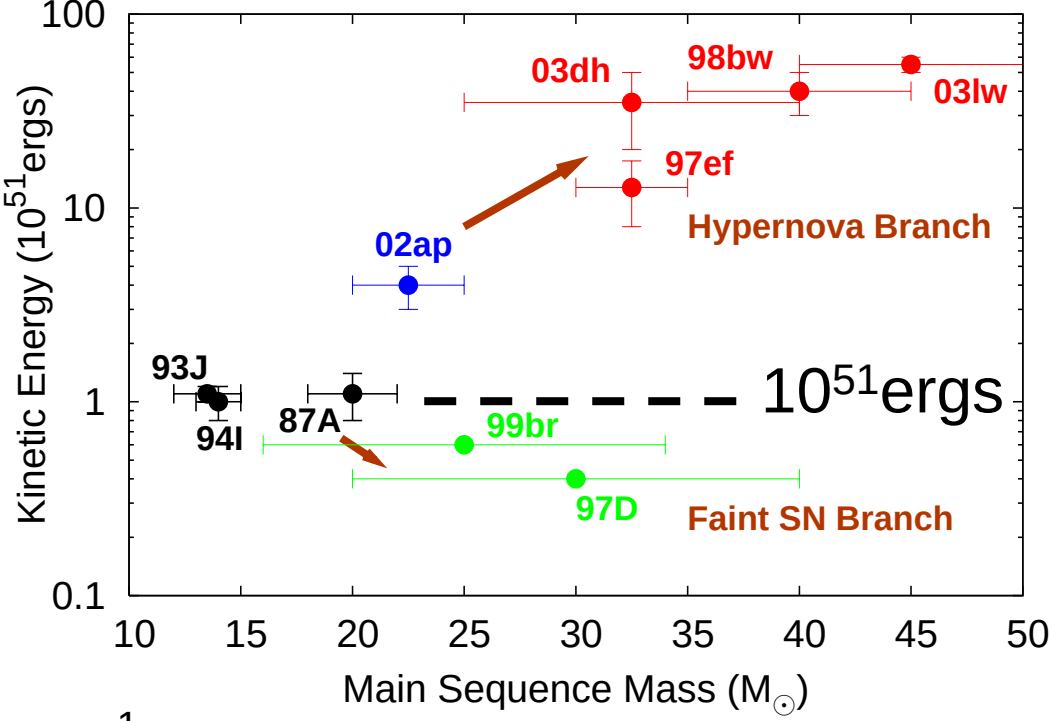


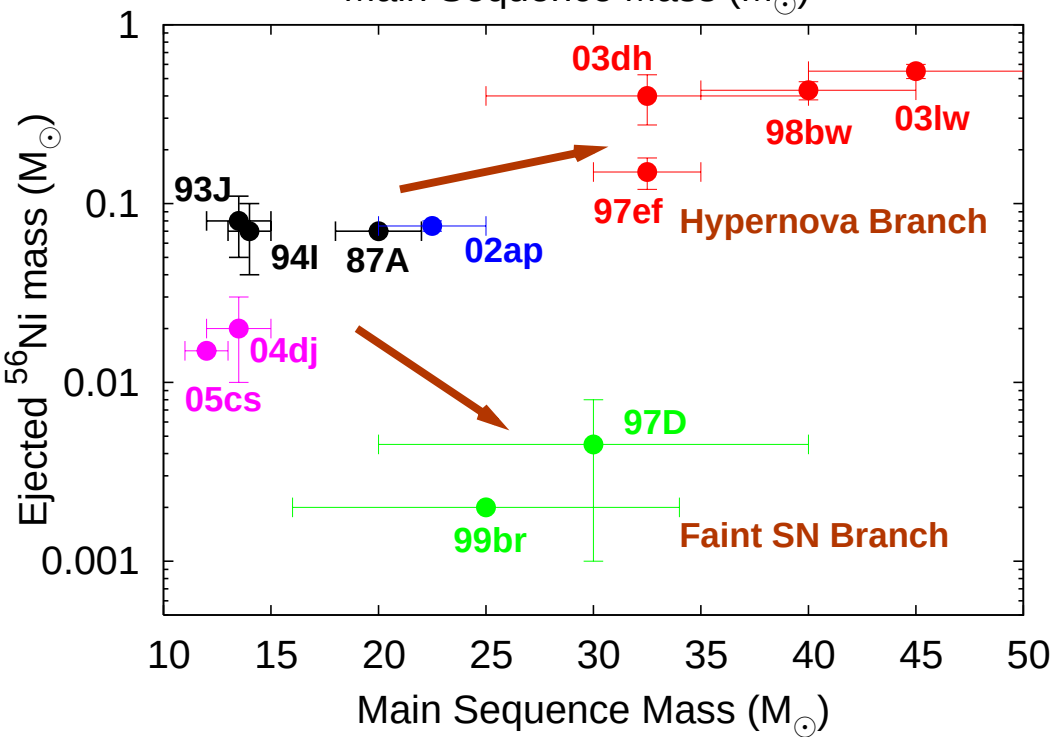
(Turatto, Mazzali, Young, Nomoto 2002)

Core-Collapse Supernovae

Maeda & Nomoto 2003
Nomoto et al. 2006

- Massive (>20$M_\odot$) SNe are divided into 2 branches.
  - Hypernovae
  - Faint Supernovae





Type Ib SN2005bf
and
Type Ic SN2006aj/GRB060218

Peculiar Type Ib SN: SN 2005bf

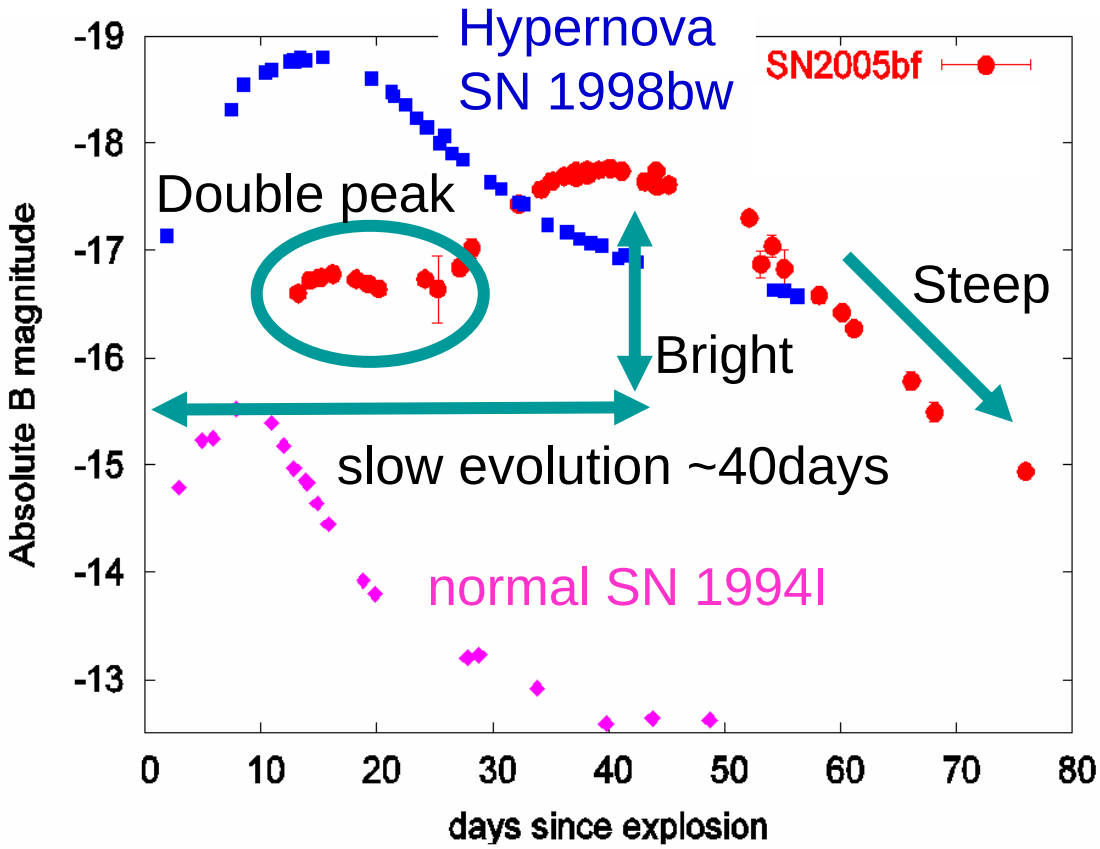
SN2005bf was reported as SNIc
- Moore & Li IAUC. 8507
- Modjaz et al. IAUC. 8509

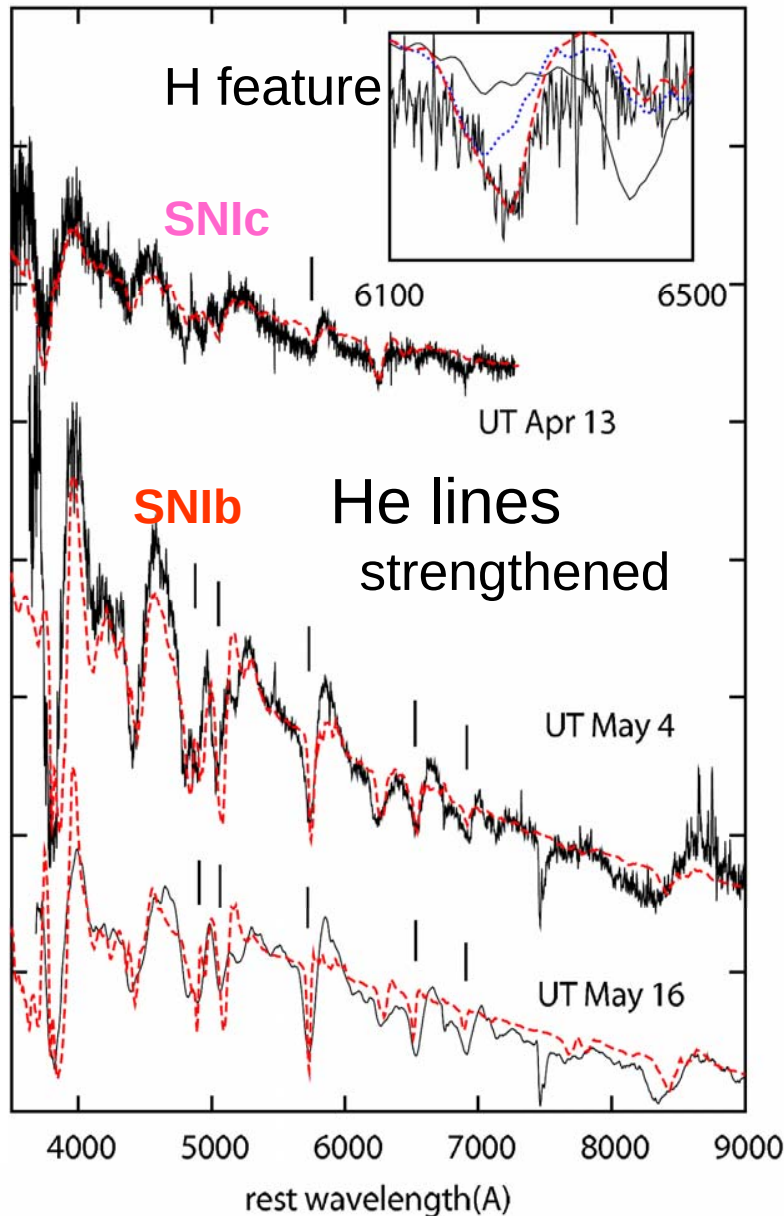
He lines were gradually strengthened
- Wang & Baade IAUC. 8521
- Modjaz et al. IAUC. 8522

The classification is changed from SNIc to SNIb.

Anupama et al. 2005
Folatelli et al. 2005
Tominaga et al. 2005
Maeda et al. 2006 submitted
Tanaka et al. 2006 in prep.
Modjaz et al. 2006 in prep.

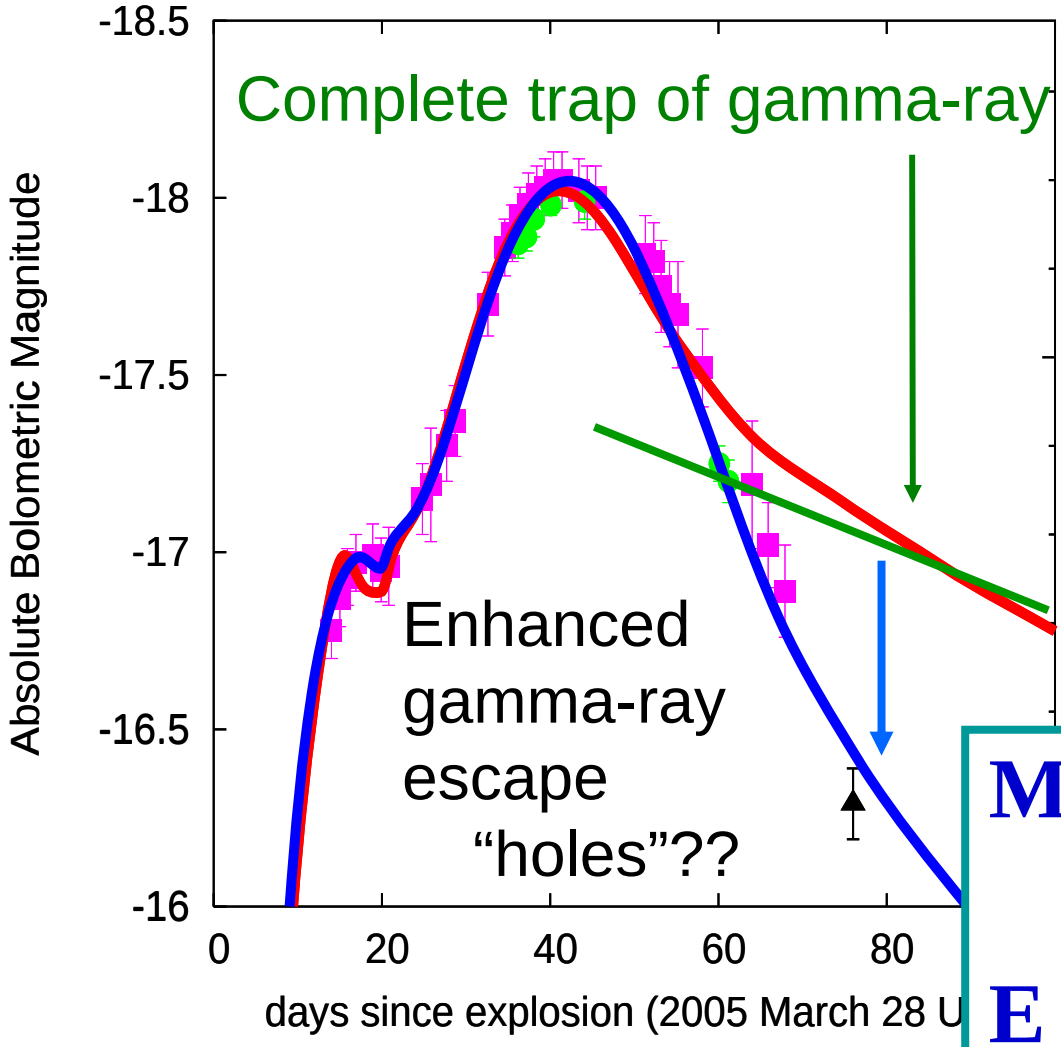
Peculiar LC and spectra: SN2005bf





Anupama et al. 2005
Tominaga et al. 2005
Maeda et al. 2006 submitted
Tanaka et al. 2006 in prep.

Explosion model: SN2005bf



Spectra:
narrow feature
Light curve:
broad & bright

Massive & less energetic

$M_{ej} \sim 6 - 7\ M_\odot$ **(He star)**
$(M_{ms} \sim 25 \pm 2\ M_\odot)$
$E \sim 1.3 \times 10^{51}$ **erg**
$M(^{56}Ni) \sim 0.3\ M_\odot$ **(NS)**

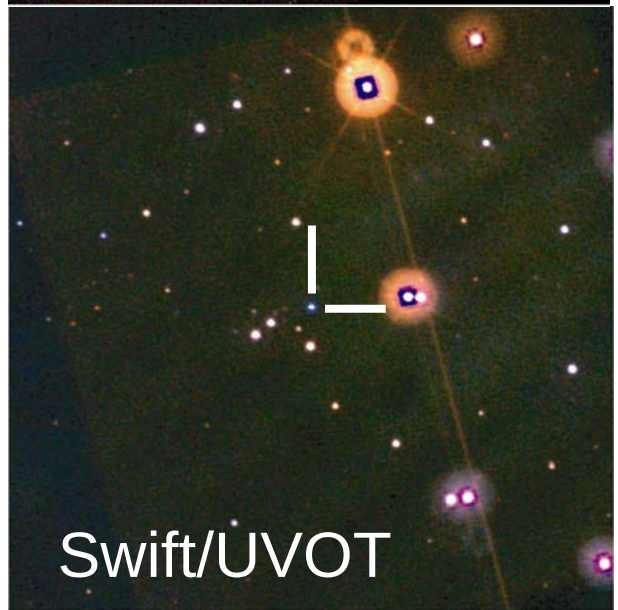
Tominaga et al. 2005

GRB/XRF 060218/SN 2006aj

- Detected on 18th Feb. 2006 by Swift
- **Long Duration: t~2000sec**
- Peak energy: E_{peak}~10keV

Campana et al. 2006

It is not **a Gamma-Ray Burst (GRB)**, but a **X-Ray Flash(XRF)**.

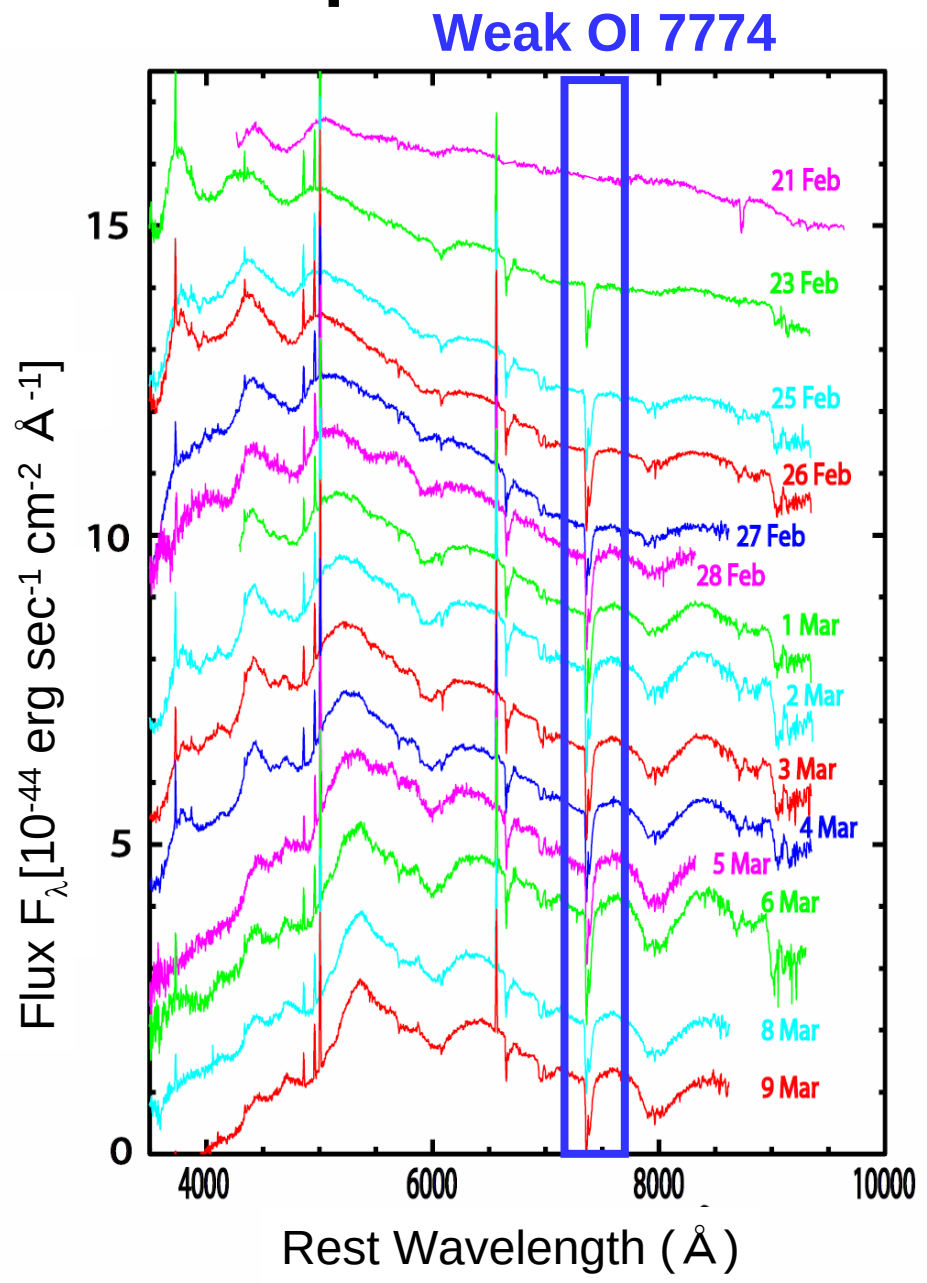


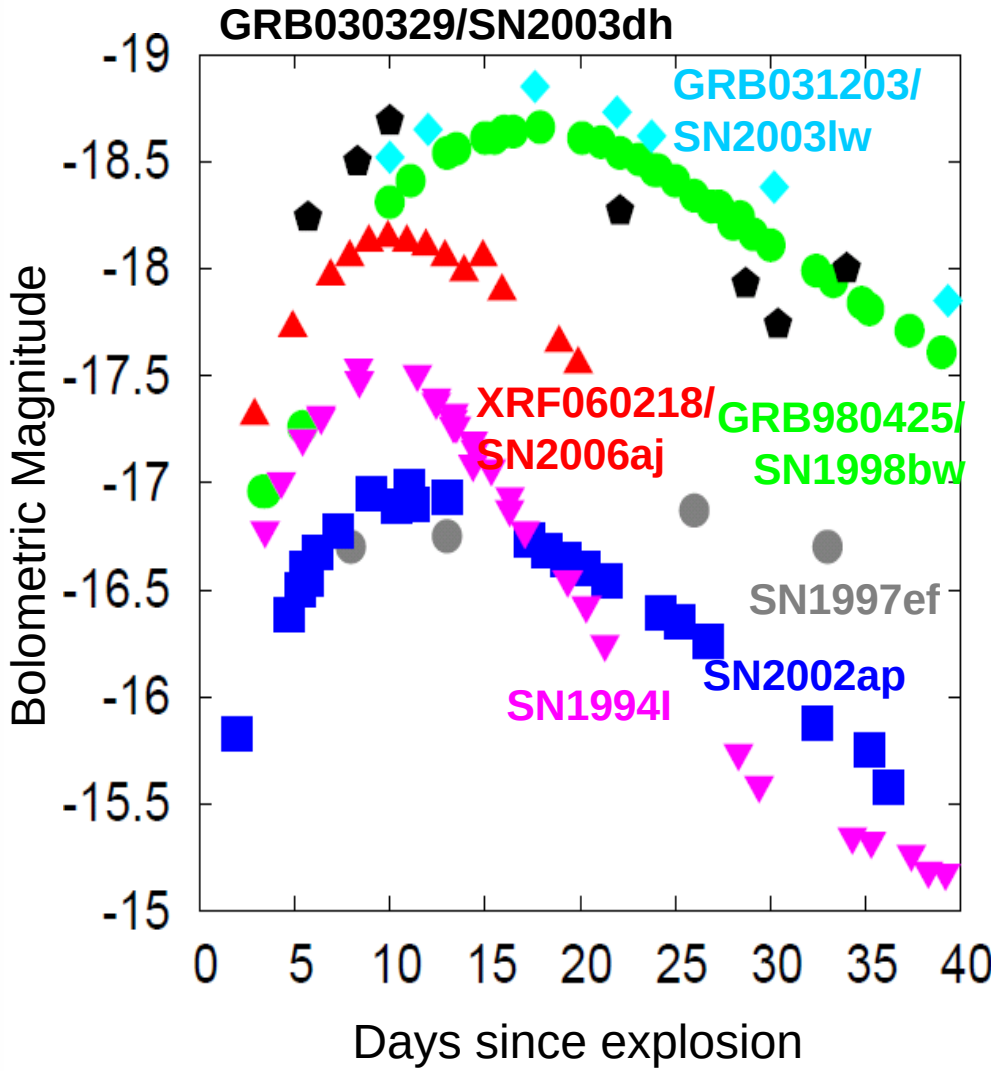
Redshift: **z=0.0335** (~140Mpc)

SN2006aj

SN 2006aj is a first case to observe spectra of a SN associated with a XRF.

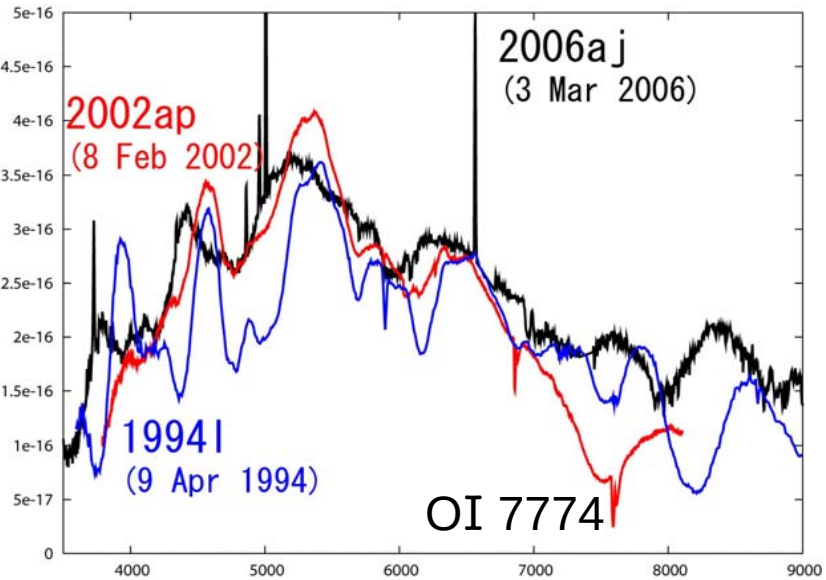
Spectra and LC: SN 2006aj

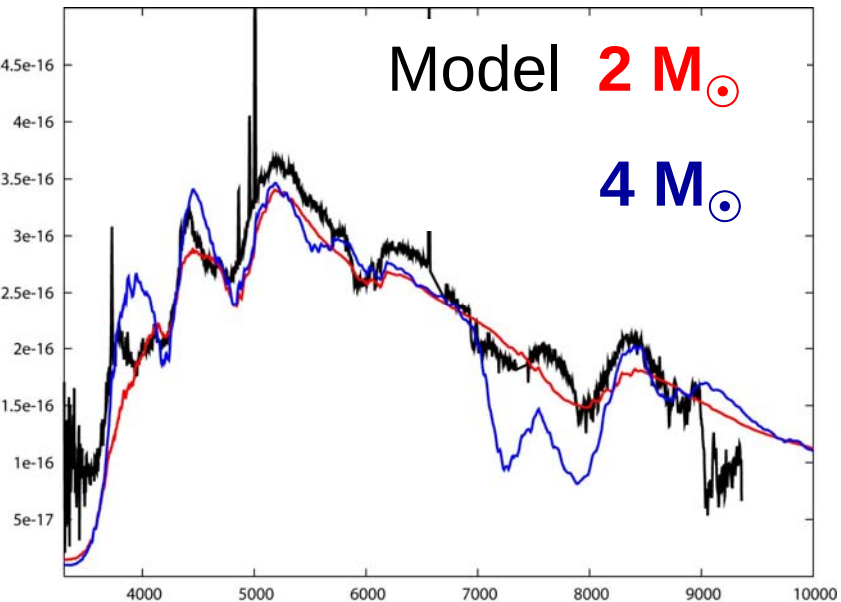


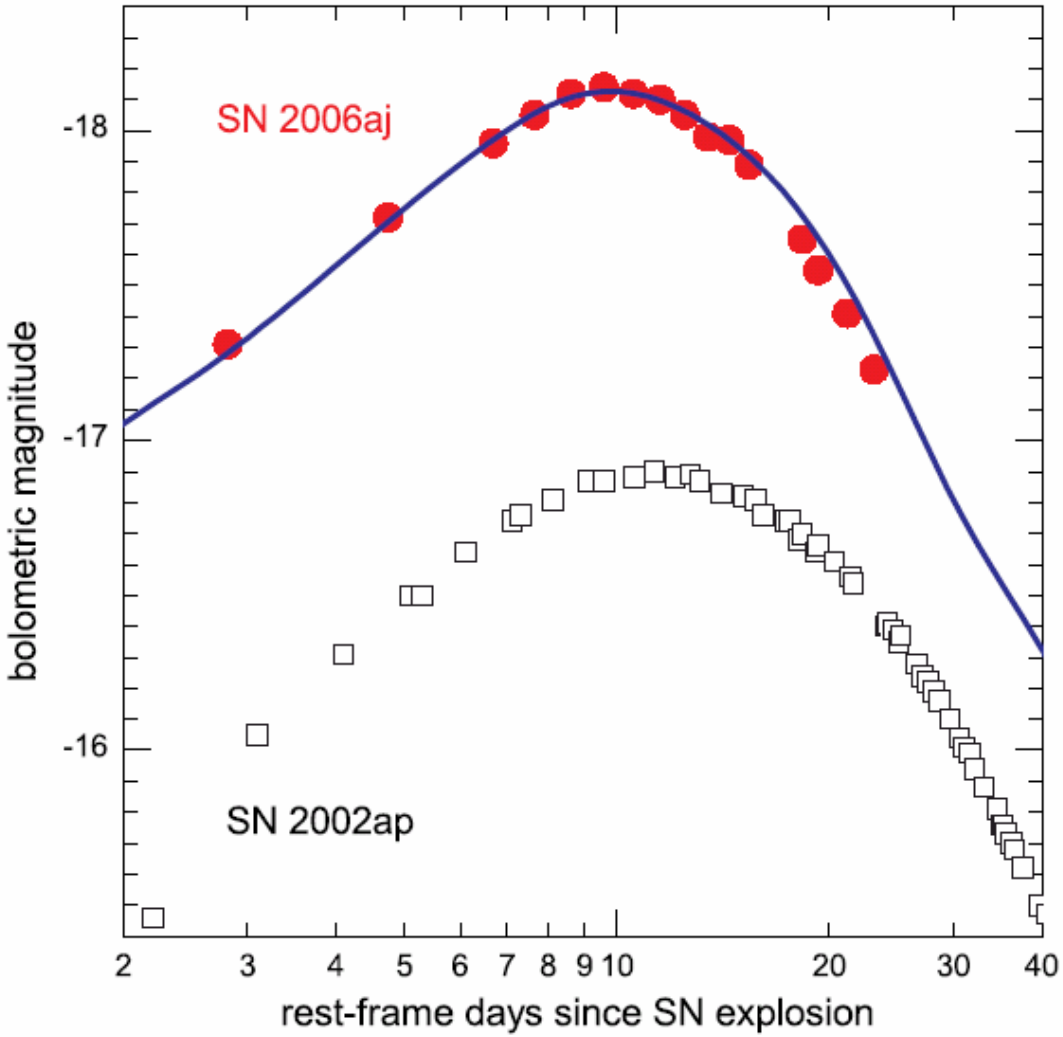


Pian et al. 2006

XRF 060218/ SN 2006aj

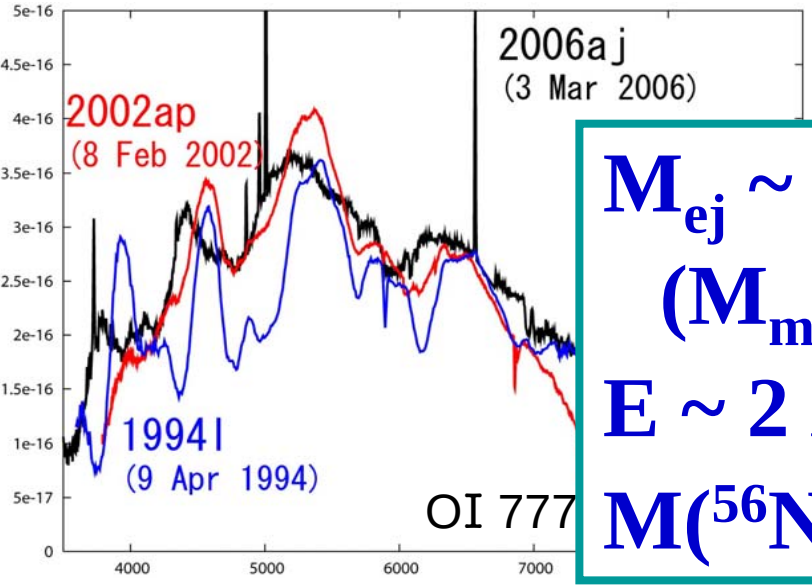


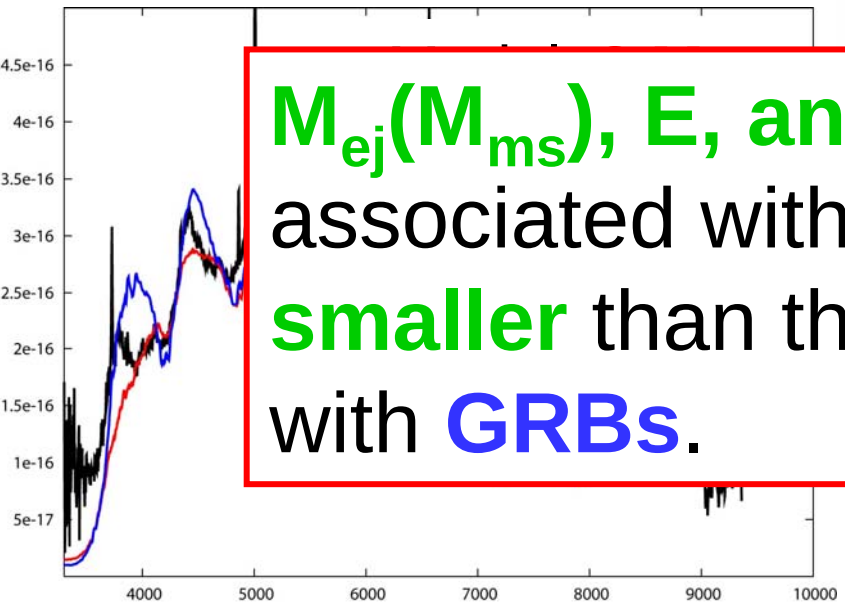


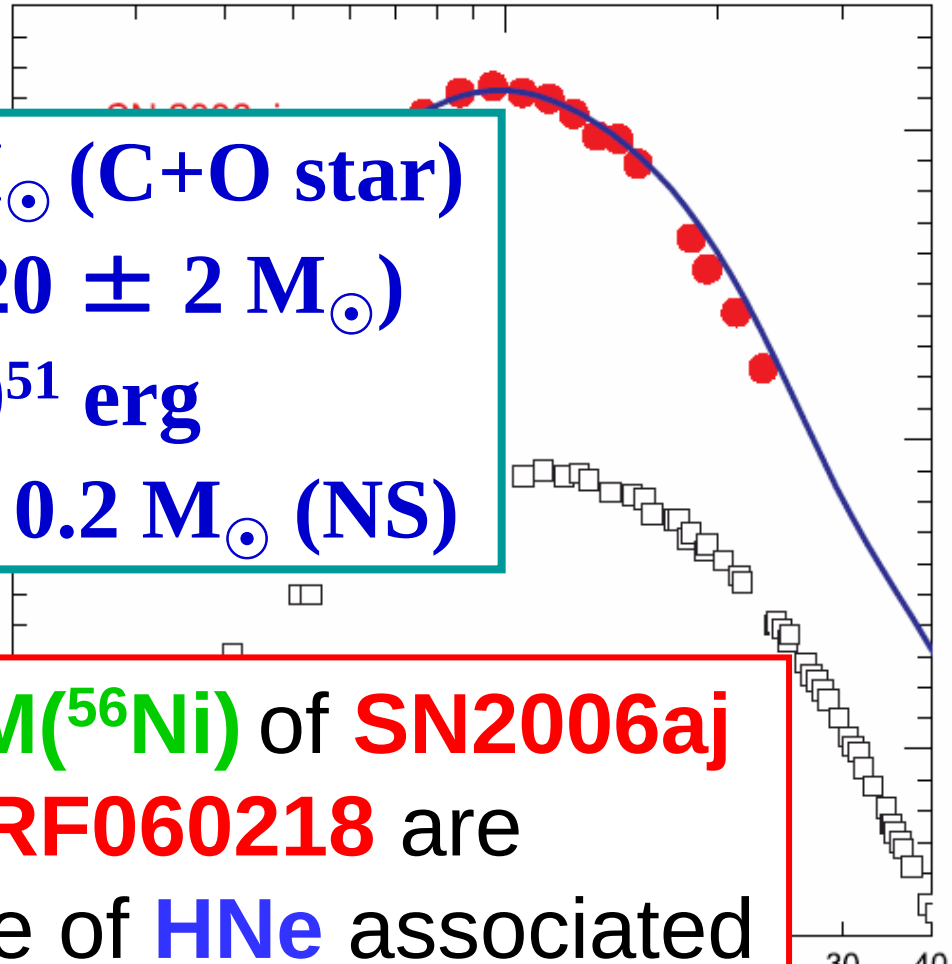


Mazzali et al. 2006
Tanaka et al. 2006 in prep.

XRF 060218/ SN 2006aj







$M_{ej} \sim 2\ M_\odot$ (C+O star)

($M_{ms} \sim 20 \pm 2\ M_\odot$)

$E \sim 2 \times 10^{51}$ erg

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

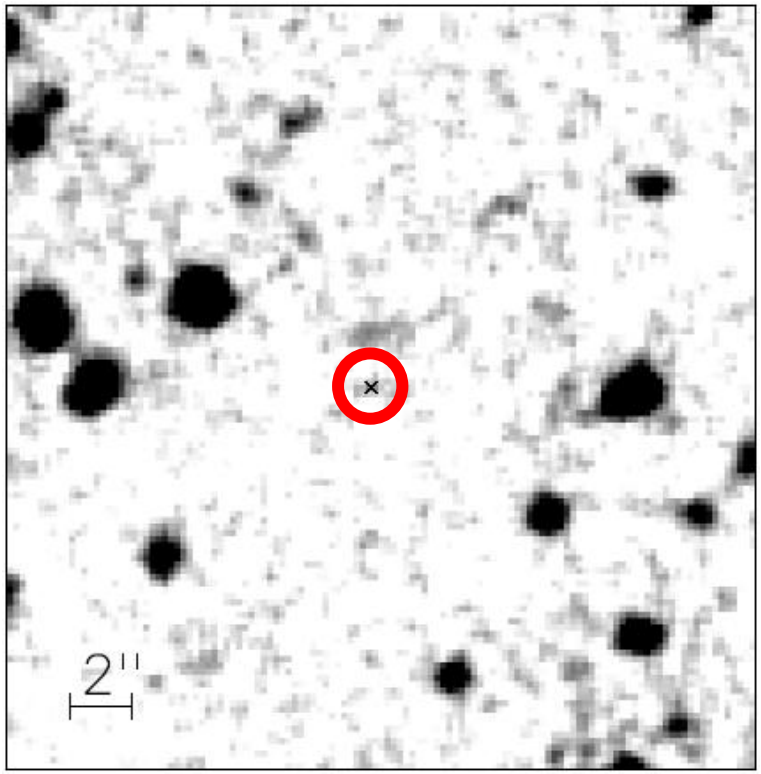
$M_{ej}(M_{ms})$, E, and $M(^{56}Ni)$ of **SN2006aj** associated with **XRF060218** are **smaller** than those of **HNe** associated with **GRBs**.

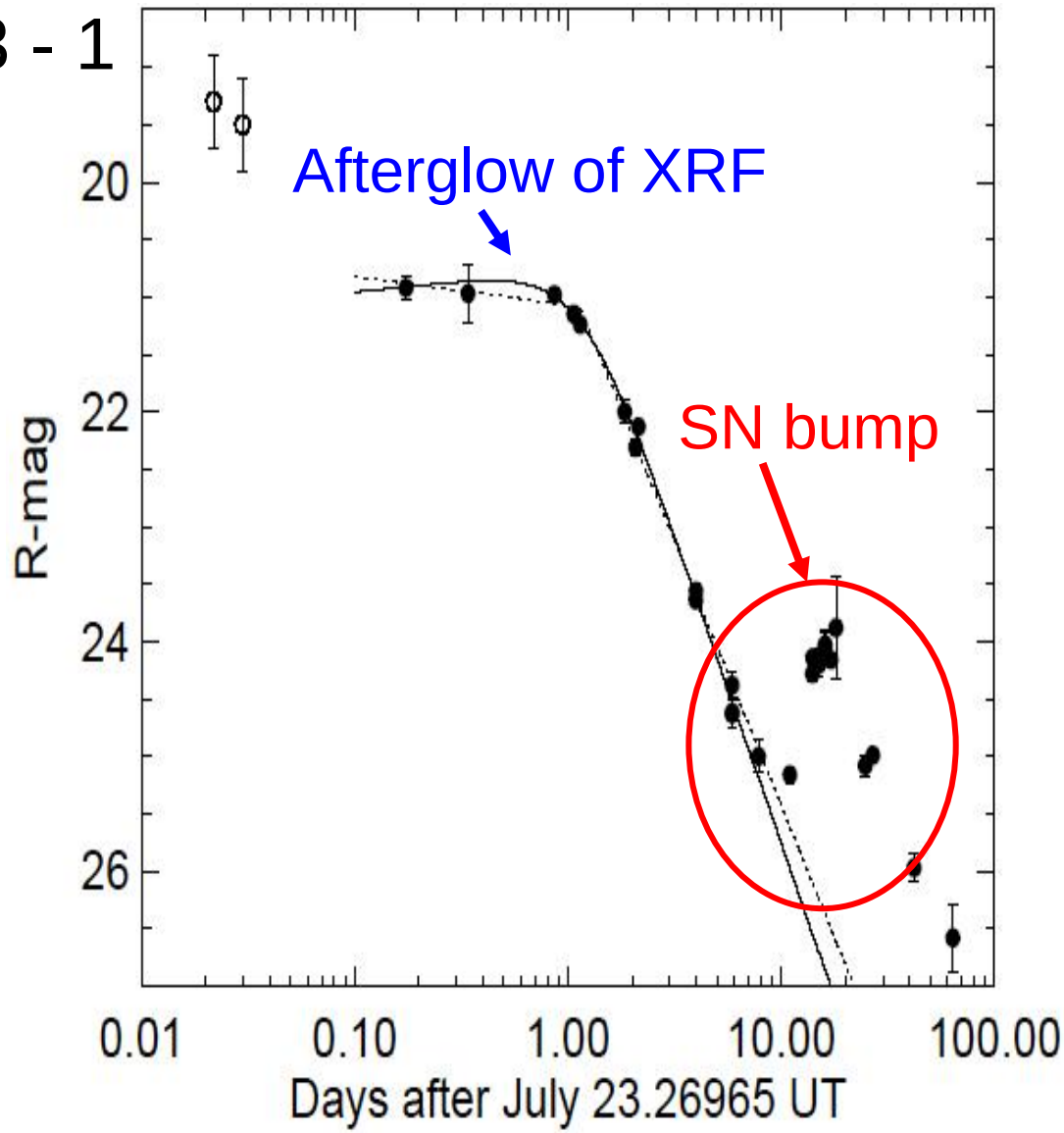
Tanaka et al. 2006 in prep.

Putative SN associated with XRF

XRF 030723 z ~ 0.3 - 1

Fynbo et al. 2004

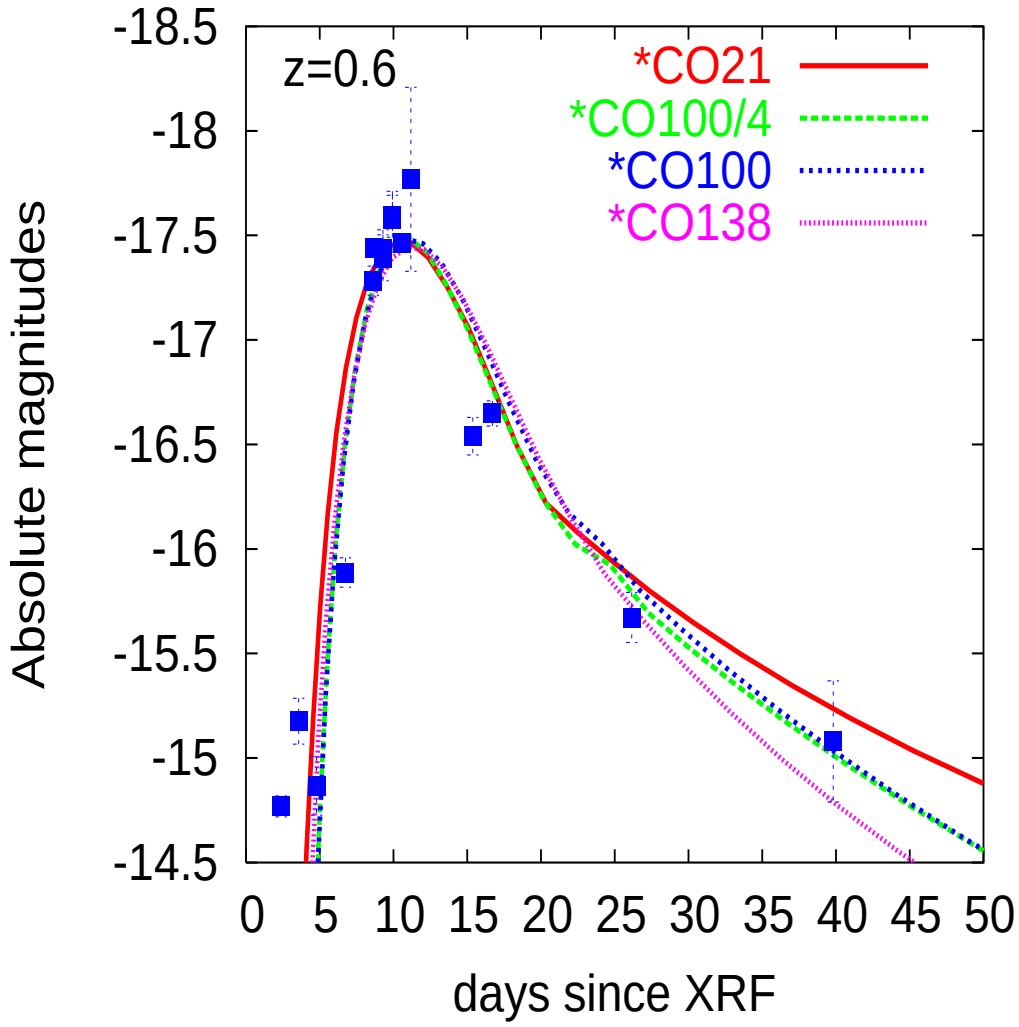




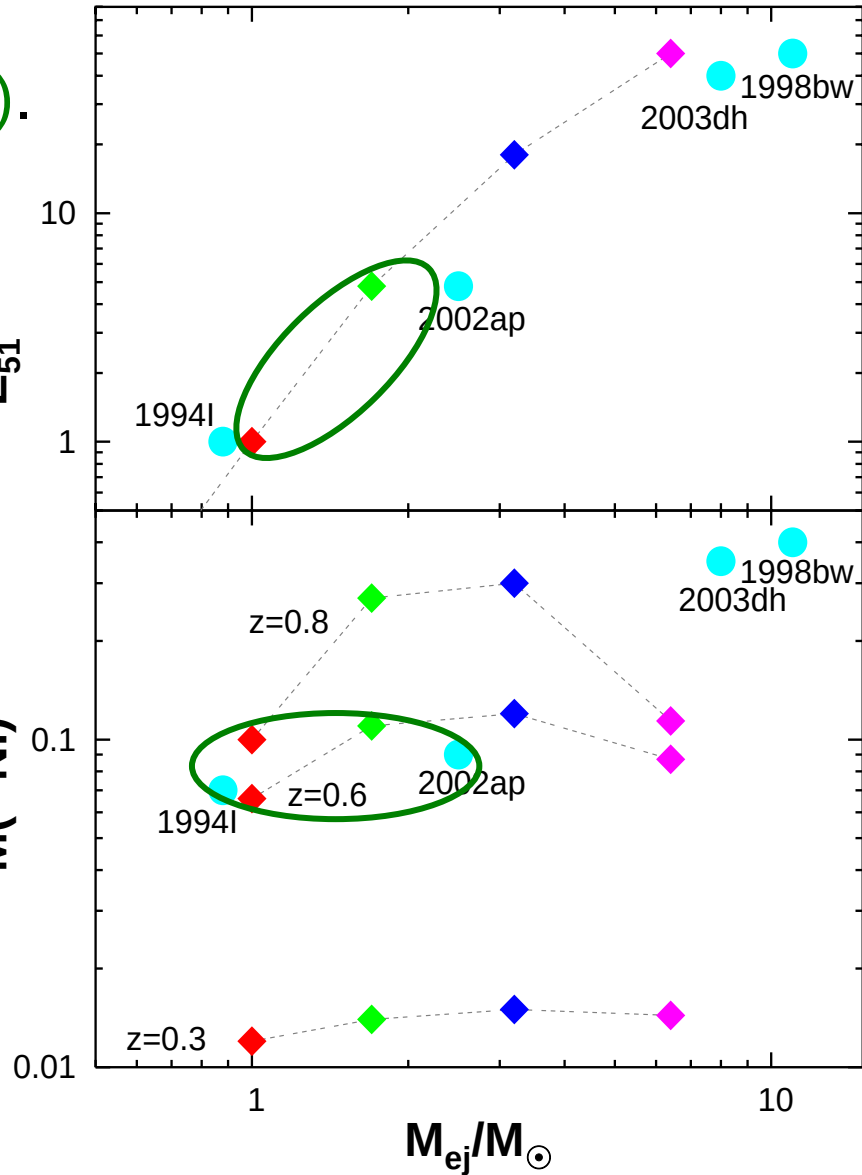
SN model for XRF 030723

Redshift: z=0.3, 0.6, and 0.8

To derive sets of (M_{ej}, E, M(^{56}Ni)).



Tominaga et al. 2004



SN model for XRF 030723

Tominaga et al. 2004

Redshift: z=0.3, 0.6, and 0.8

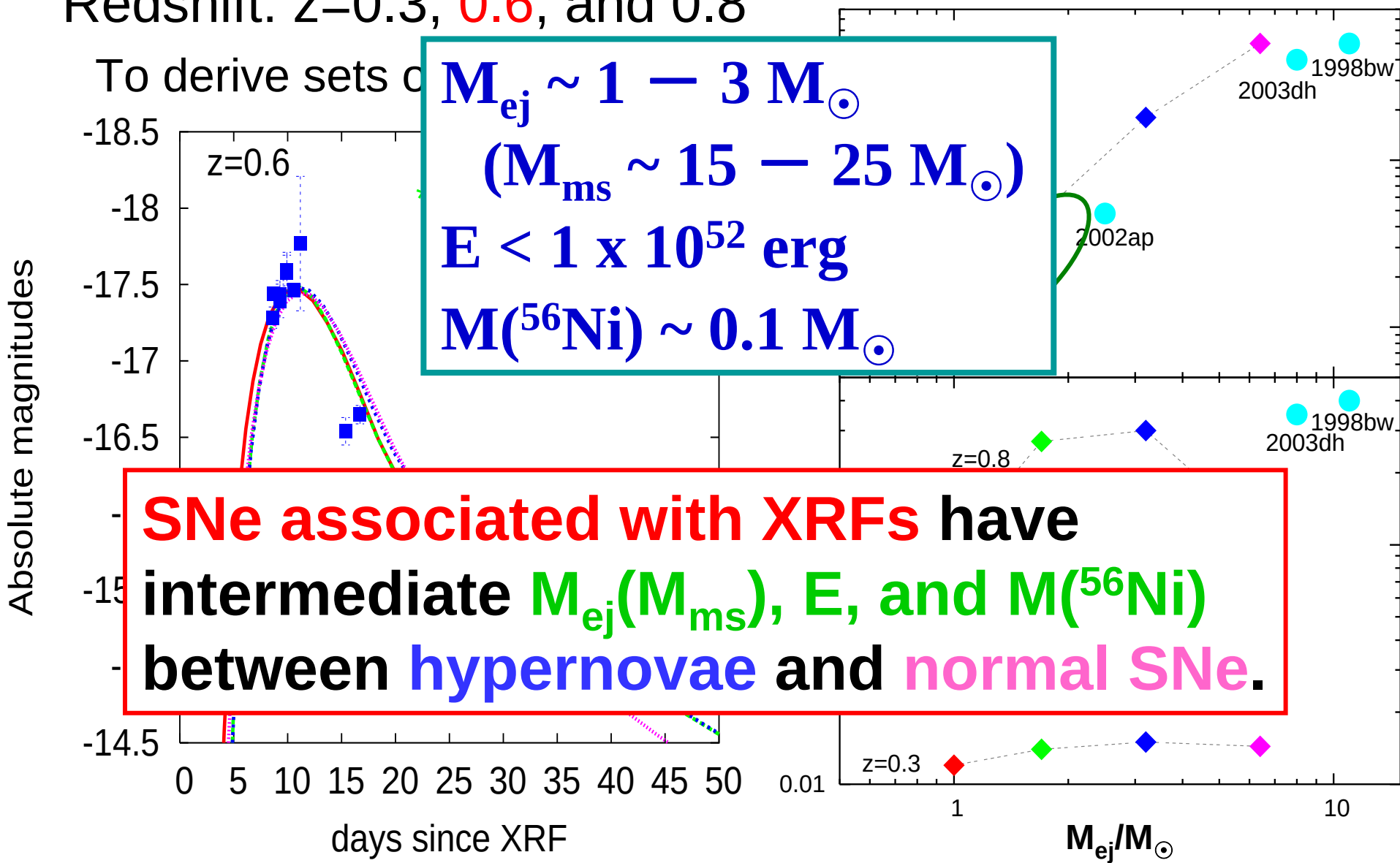
To derive sets o

$M_{ej} \sim 1 - 3\ M_\odot$

$(M_{ms} \sim 15 - 25\ M_\odot)$

$E < 1 \times 10^{52}$ erg

$M(^{56}Ni) \sim 0.1\ M_\odot$



SNe associated with XRFs have intermediate $M_{ej}(M_{ms})$, E, and $M(^{56}Ni)$ between hypernovae and normal SNe.

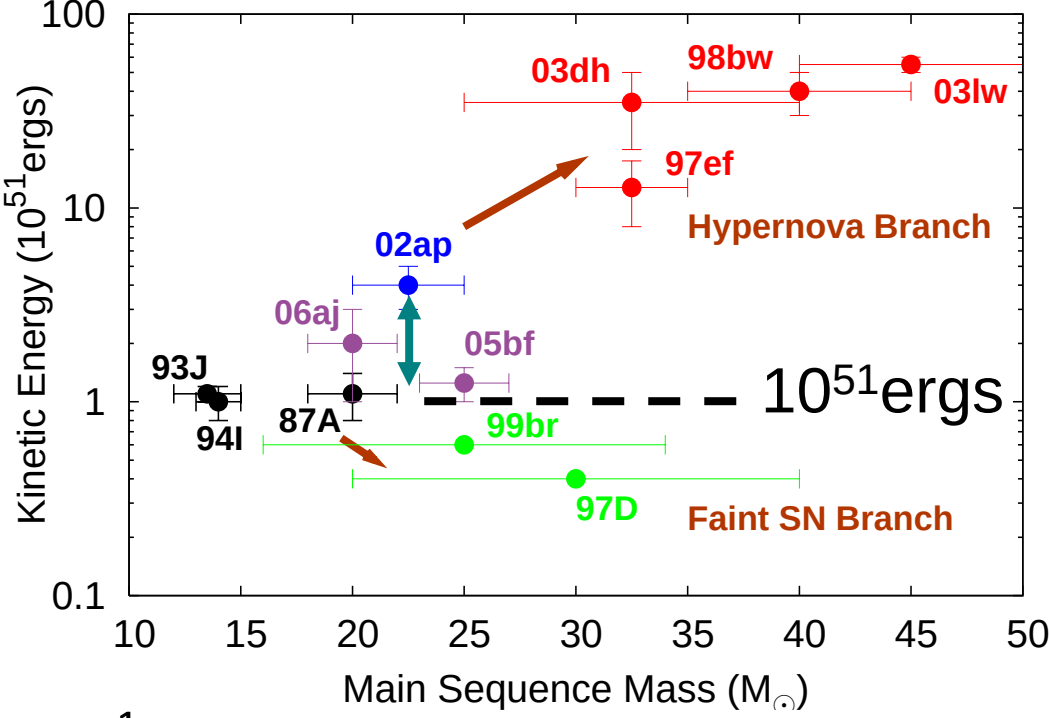
Core-Collapse Supernovae

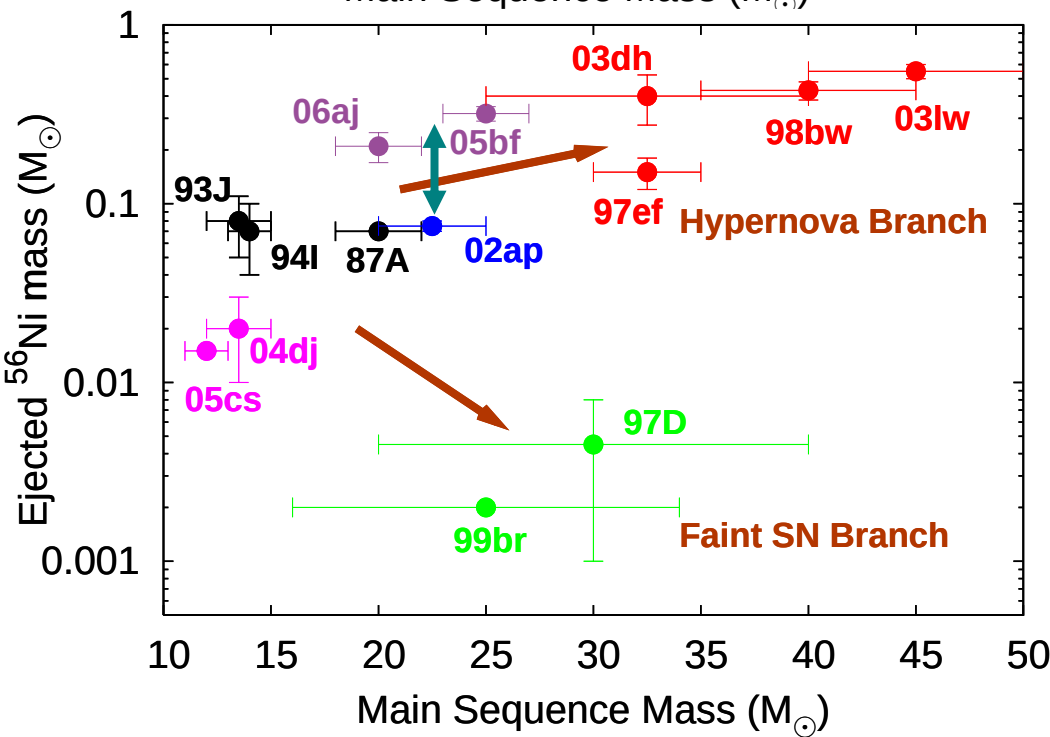
Maeda & Nomoto 2003
Nomoto et al. 2006

M_{ms}~ 20 – 25 $M_{\odot}$

Core-Collapse SNe (XRFs)

Neutron star
or
black hole





Core-Collapse Supernovae

Maeda & Nomoto 2003
Nomoto et al. 2006

M_{ms}~ 20 – 25 $M_\odot$

Core-C

(

Neutron star
or
black hole

The number of minutely observed type Ib/c SNe is still small.

Instant and consecutive observations are needed!!