

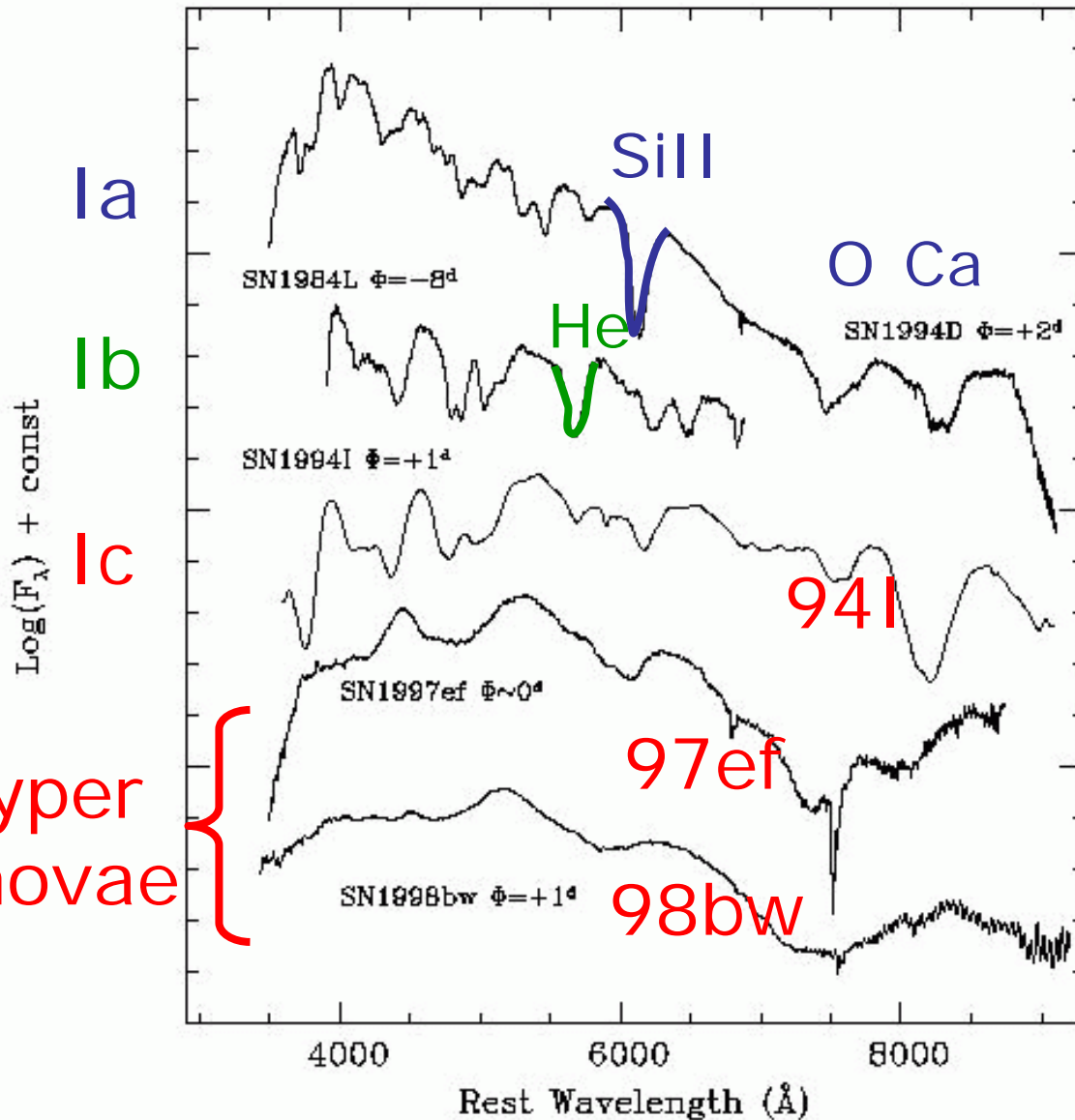
Unique Type Ib Supernova 2005bf and Aspherical Explosions



MAGNUM (U. Tokyo)

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P.A. Mazzali, J. Deng
M. Modjaz, R.P. Kirshner

Spectra of Supernovae & Hypernovae

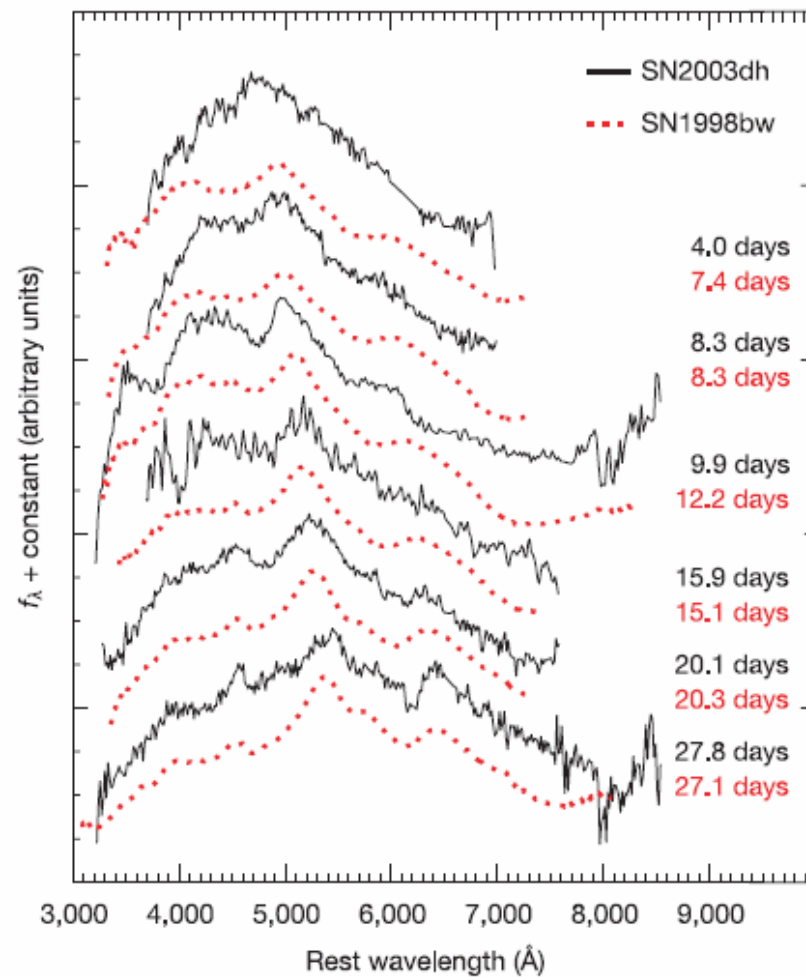
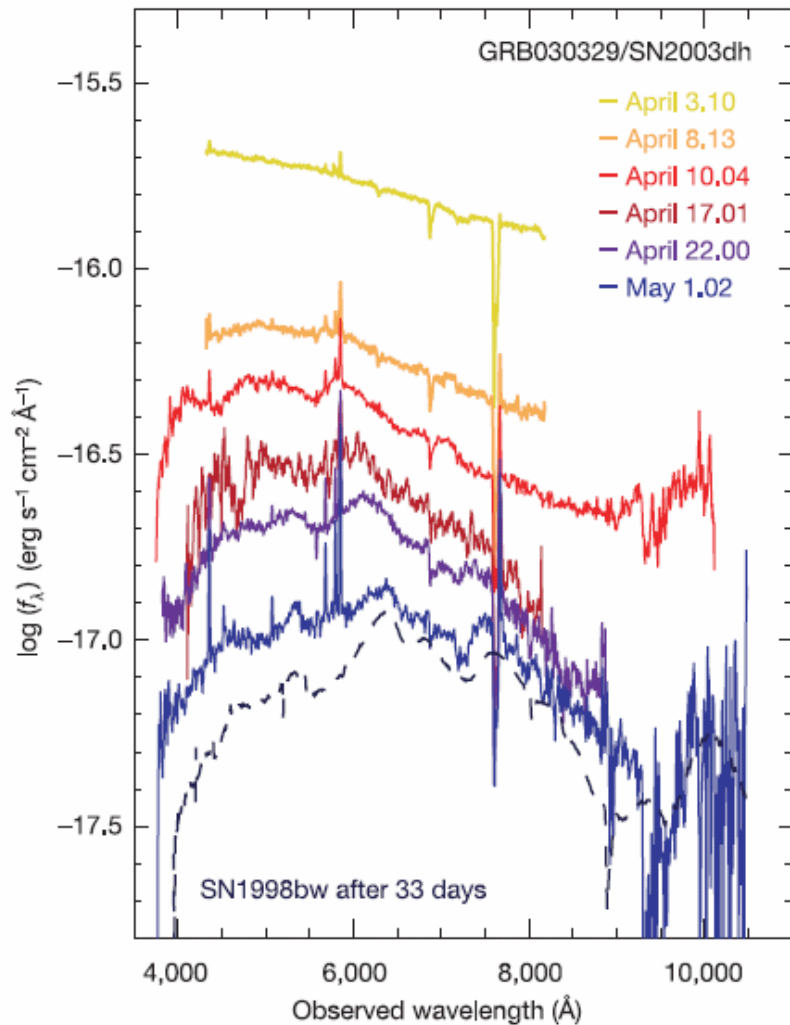


Ic: no H,
no strong He,
no strong Si

Hypernovae:
broad features
↑
blended lines
↑
"Large mass at high velocities"

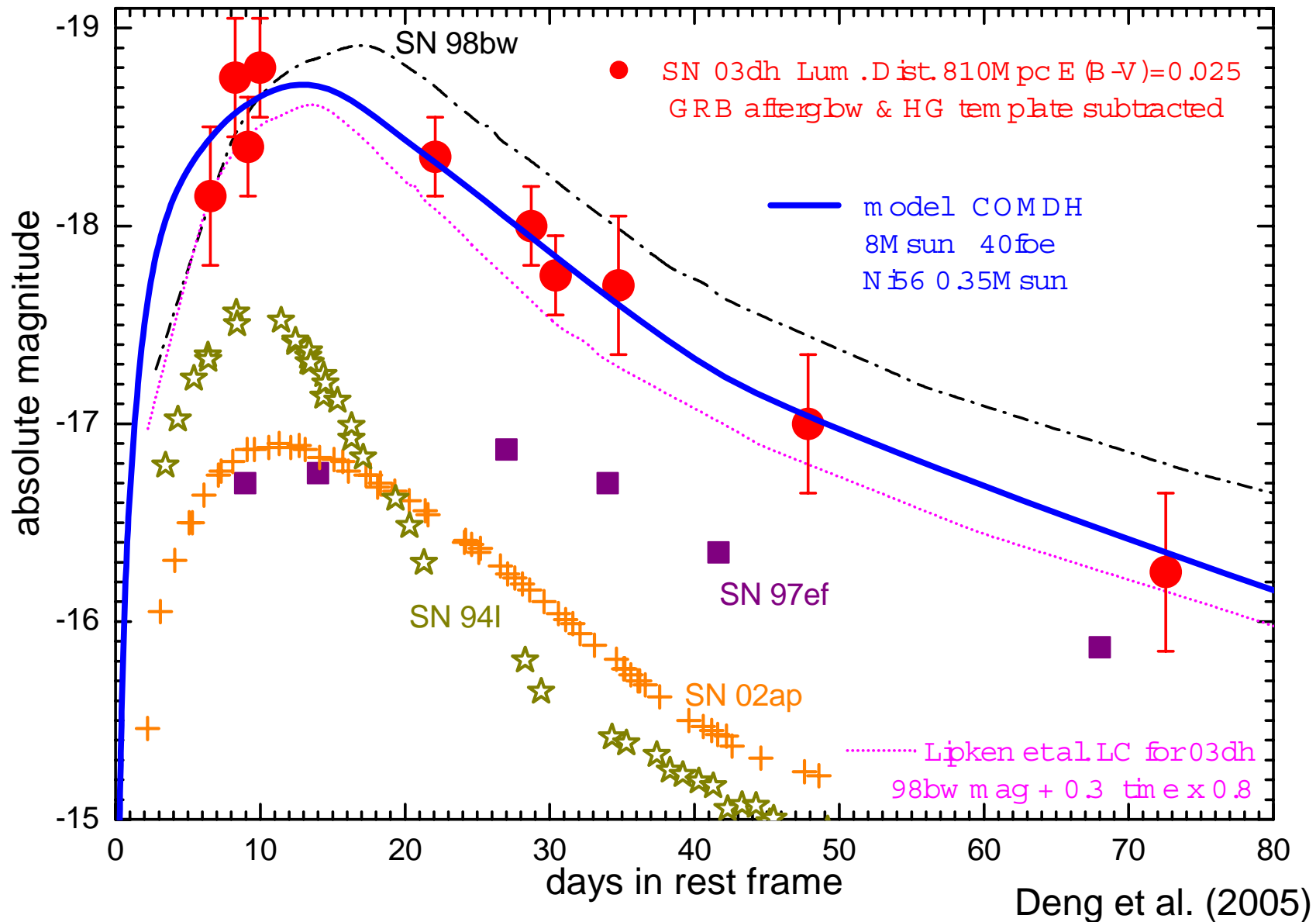
Hyper-novae

GRB 030329 / SN 2003dh

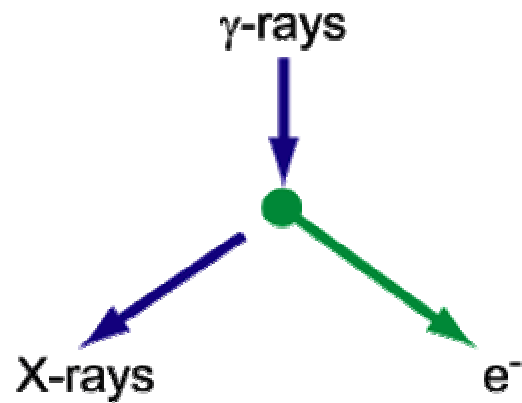


Hjorth et al (2003)

SN2003dh / GRB030329

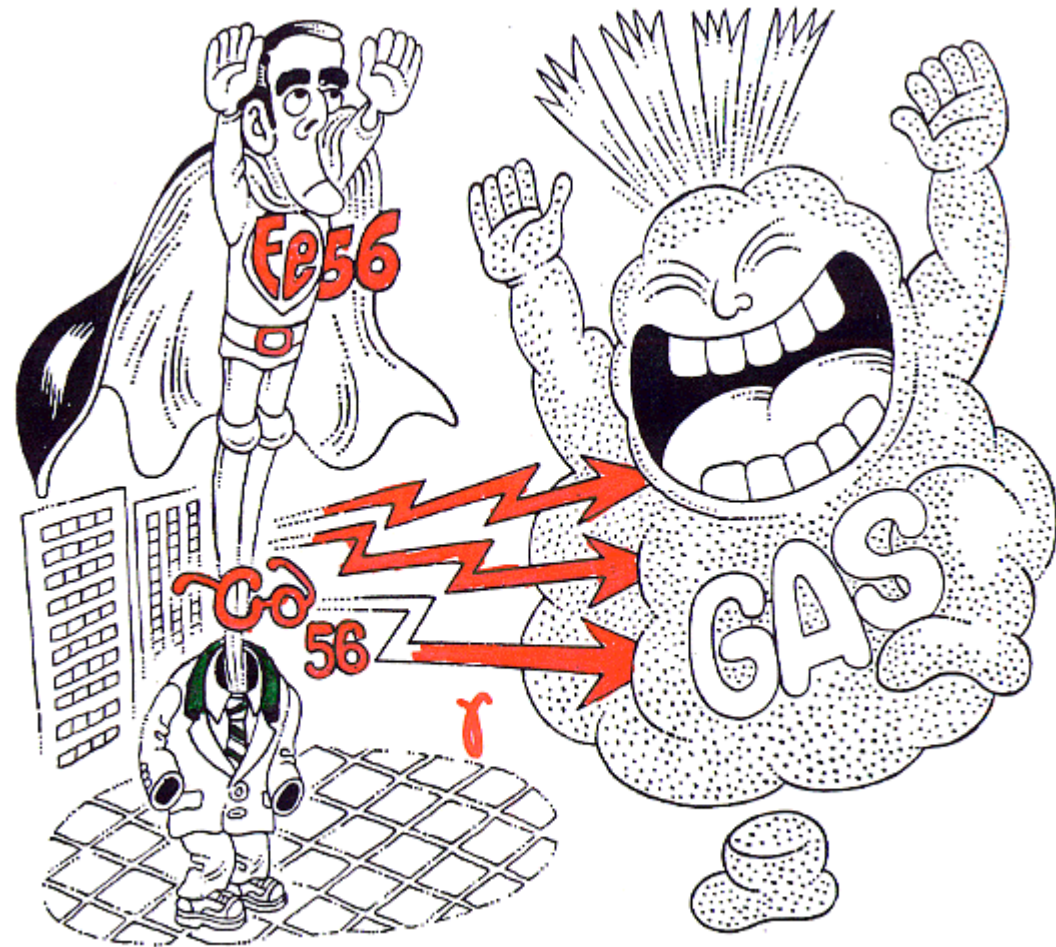


^{56}Co -decay



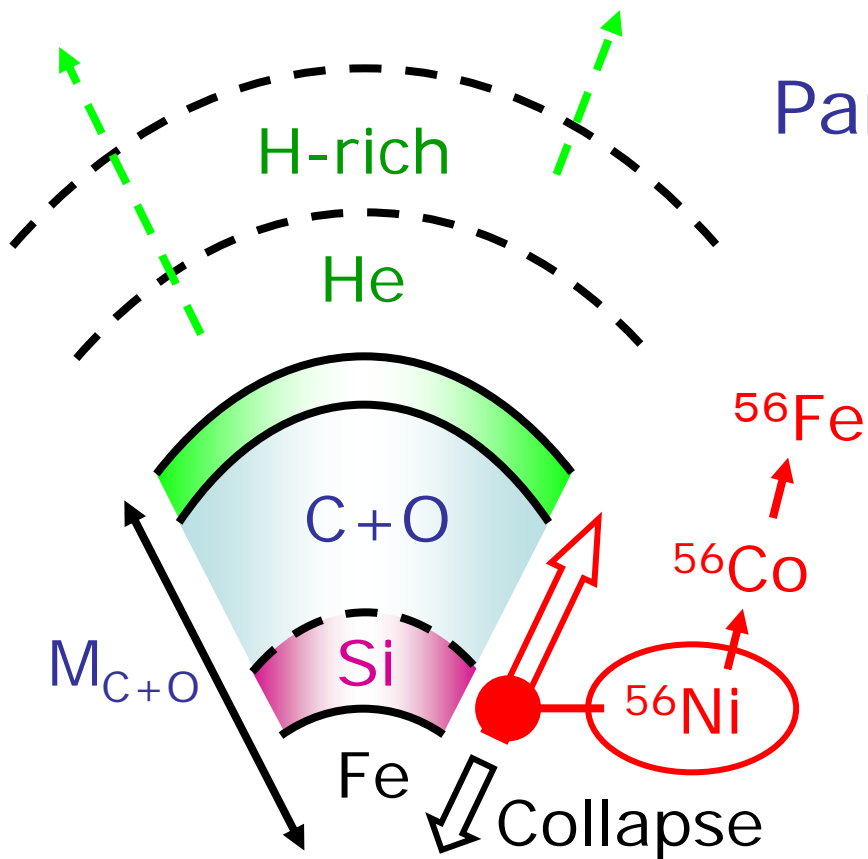
Photoabsorption Excitation/Ionization

$L \propto M(^{56}\text{Ni})$
Shape: M_{ej}



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CO Star Models for SNeIc



Parameters [M_{ej} , E , $M(^{56}\text{Ni})$]

Light Curve

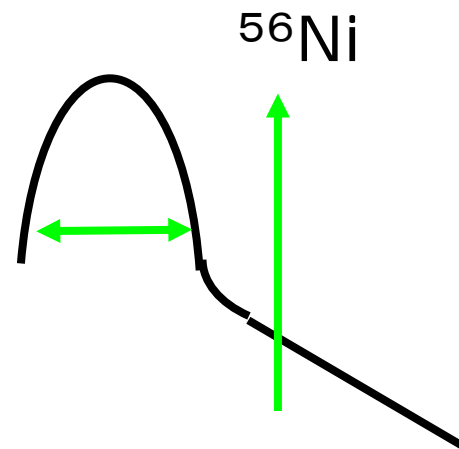
Spectra

$$\tau \sim [\tau_{\text{dyn}} \cdot \tau_{\text{diffusion}}]^{1/2} \quad E \propto M_{\text{ej}}$$

$$\sim \left[\frac{R}{V} \cdot \frac{\kappa M_{\text{ej}}}{R c} \right]^{1/2}$$

$$\propto \kappa^{1/2} M_{\text{ej}}^{3/4} E^{-1/4}$$

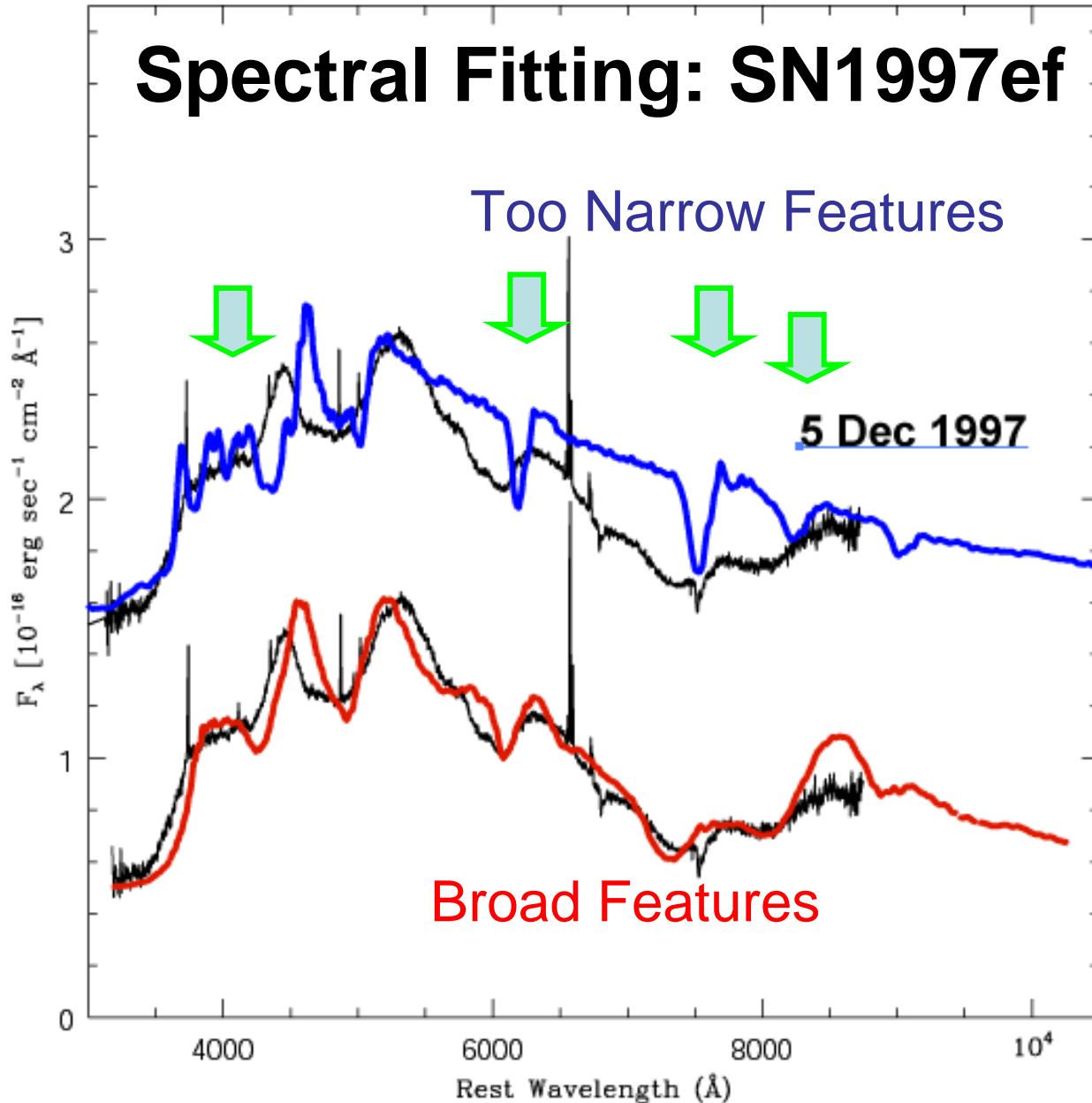
$$E \propto M_{\text{ej}}^3$$



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

Spectral Fitting: SN1997ef

Iwamoto et al.
(2000)



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

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

Small M_{ej}

Hypernova
($E_{51} = 20$)

Large M_{ej}
at High Vel.

Supernova – GRB Connection

Three GRB – SNe = all Type Ic **Hypernovae**

$E > 10^{52}$ erg ($\sim 10 \times$ normal SN)

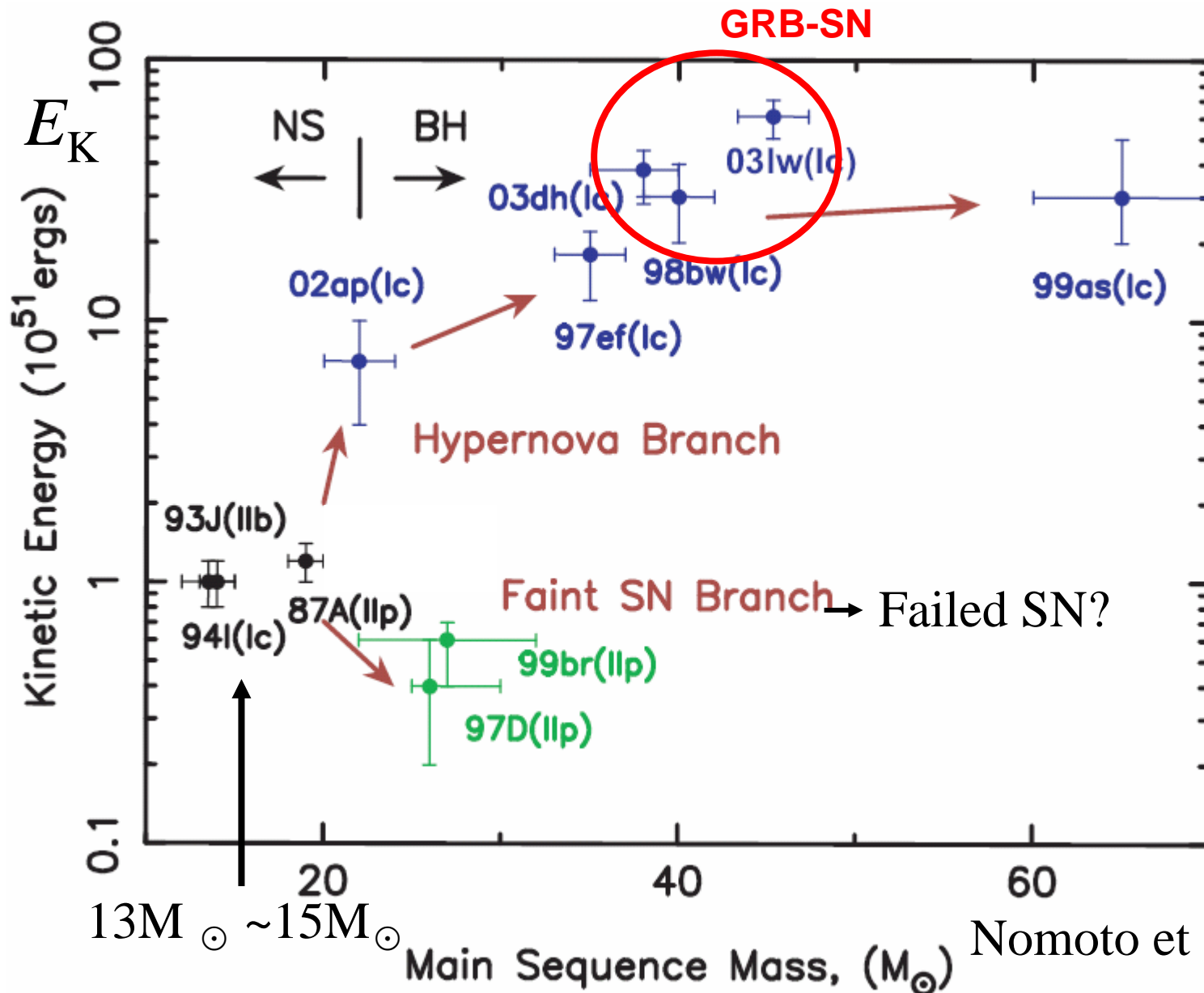
Large $M_{\text{ms}} \rightarrow$ **Black Hole Forming SNe**

Aspherical



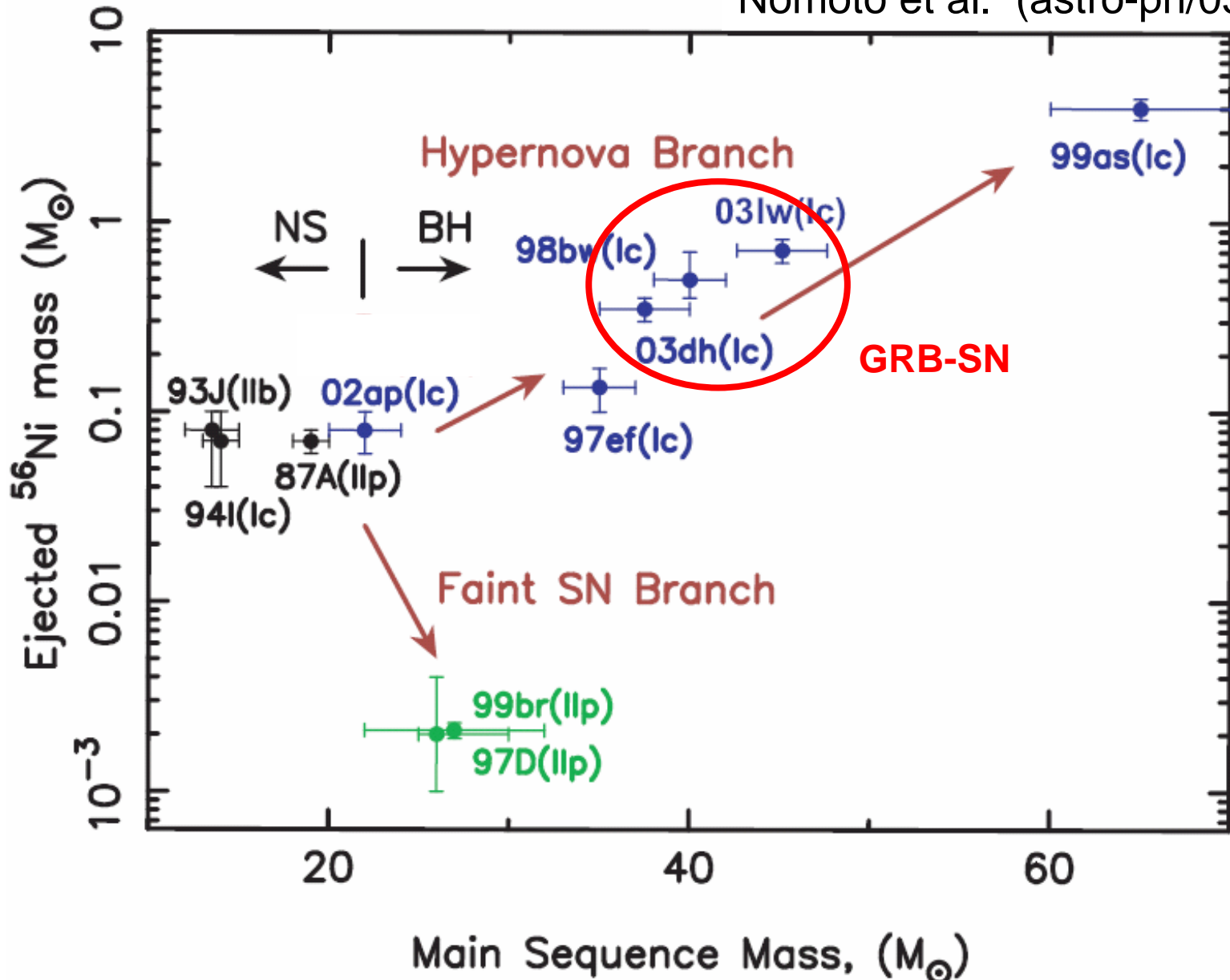
GRB	SN	M_{CO}/M_{\odot}	M_{ms}/M_{\odot}	$E/10^{51}$ erg	$M(^{56}\text{Ni})/M_{\odot}$
980425	1998bw	14	40	30	0.4
030329	2003dh	11	35	40	0.35
031203	2003lw	16	45	60	0.55

Hypernovae/Faint SNe

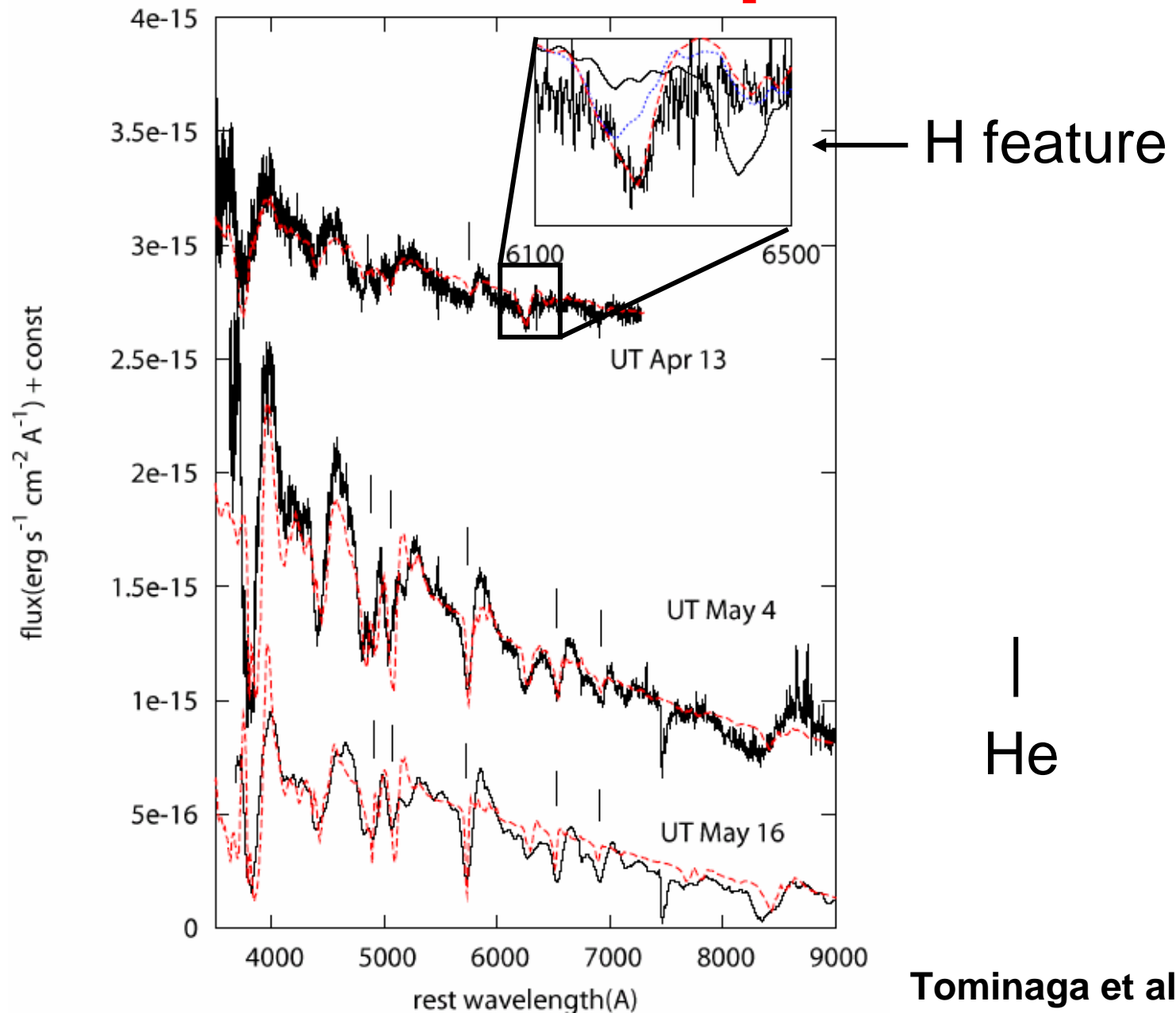


Hypernovae/Faint SNe (^{56}Ni mass)

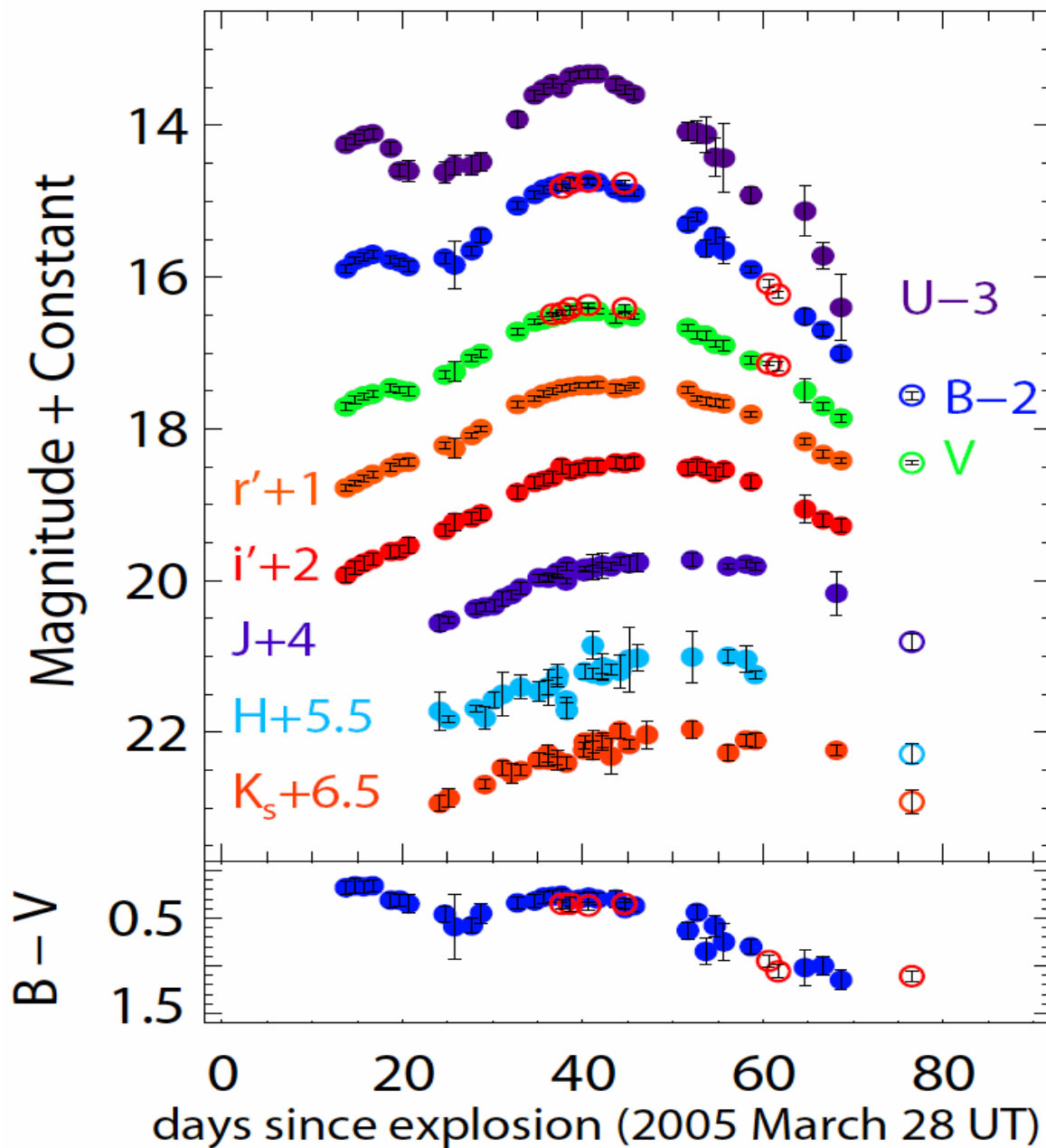
Nomoto et al. (astro-ph/0308136)



SN Ib 2005bf: Spectra

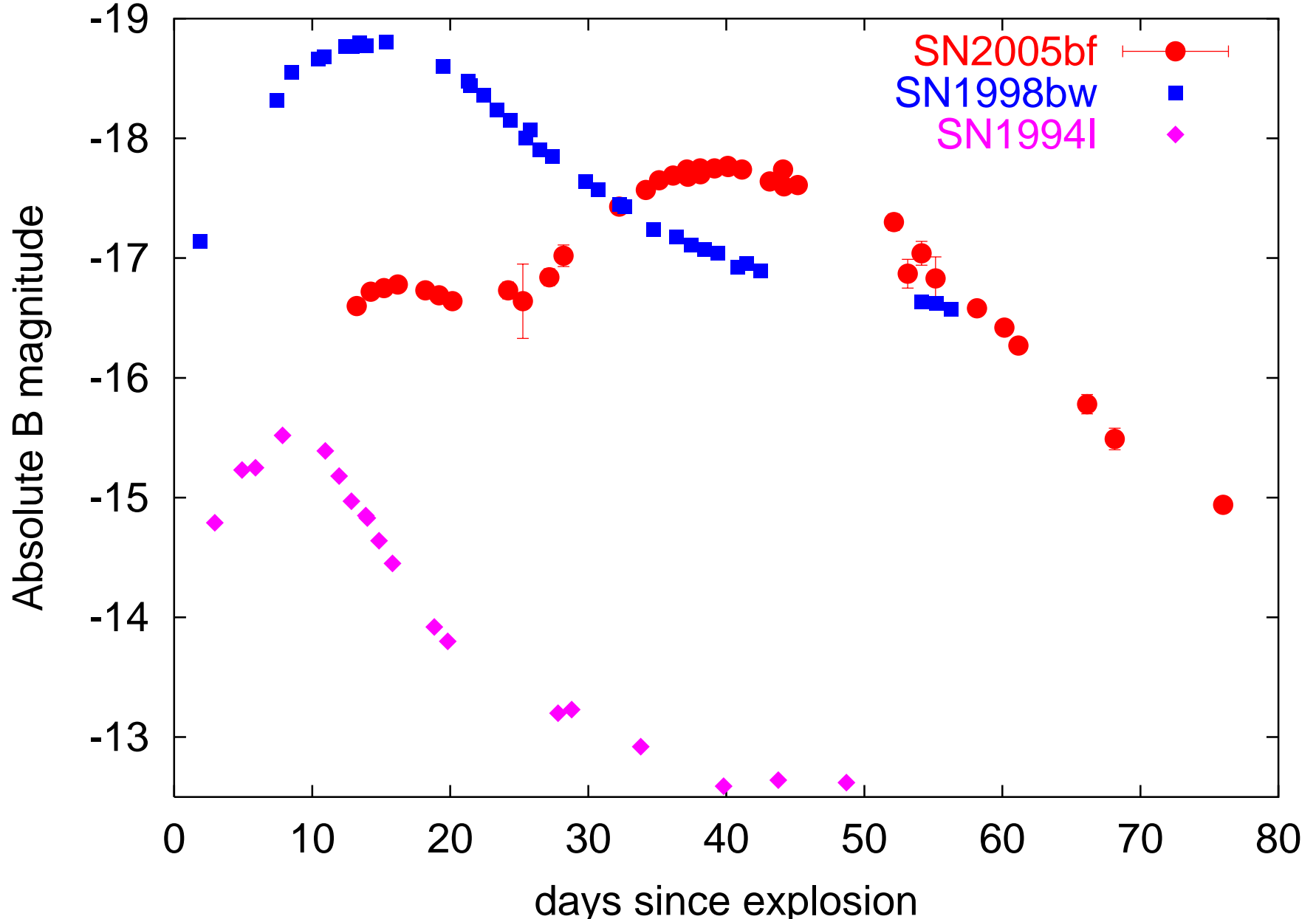


SN 2005bf: Observed Light Curves

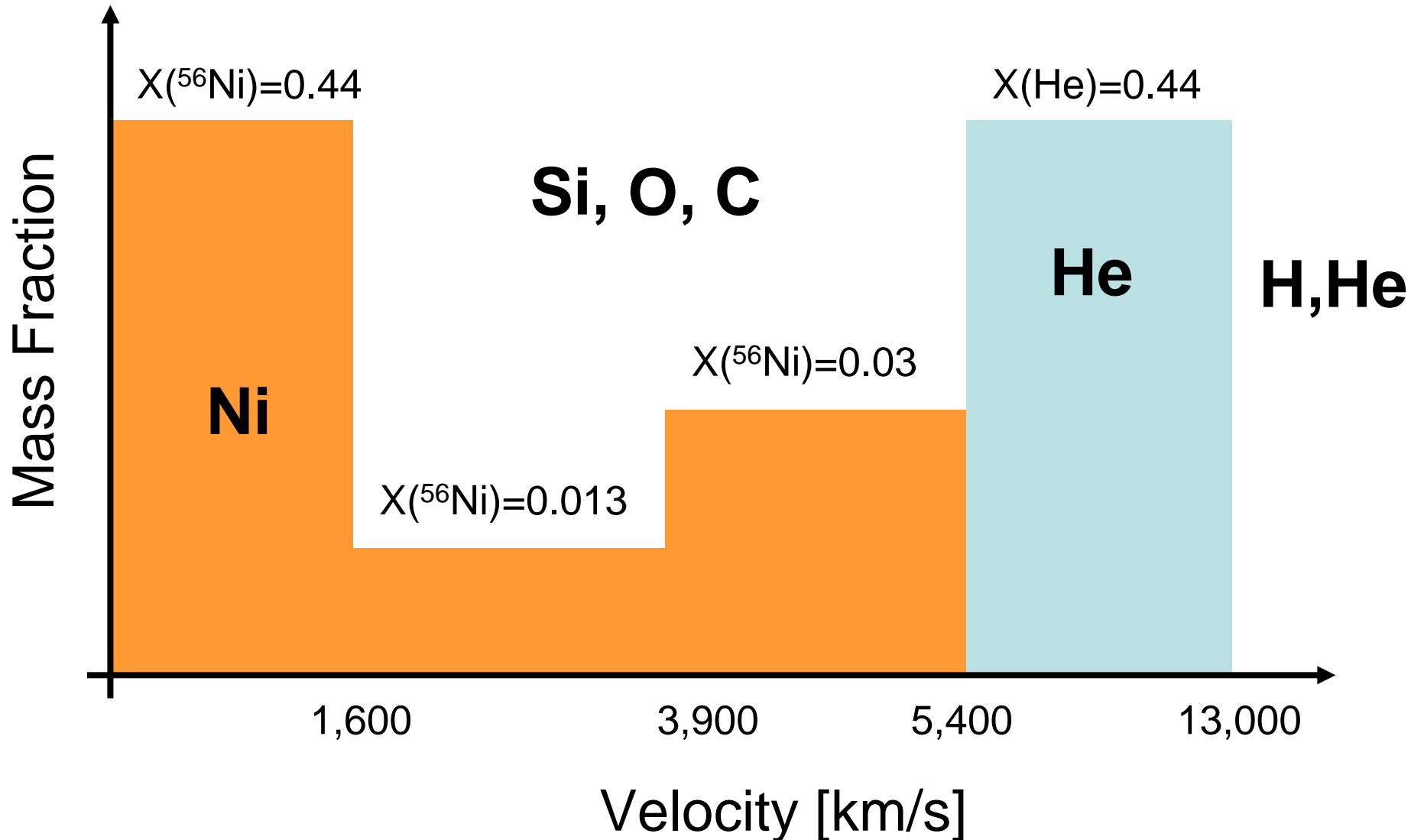


Tominaga et al. 2005
Folatelli et al. 2006
Modjaz et al. : poster

Comparison with other SN Ib/c



SN 2005bf: Abundance Distribution



Type Ib SN 2005bf

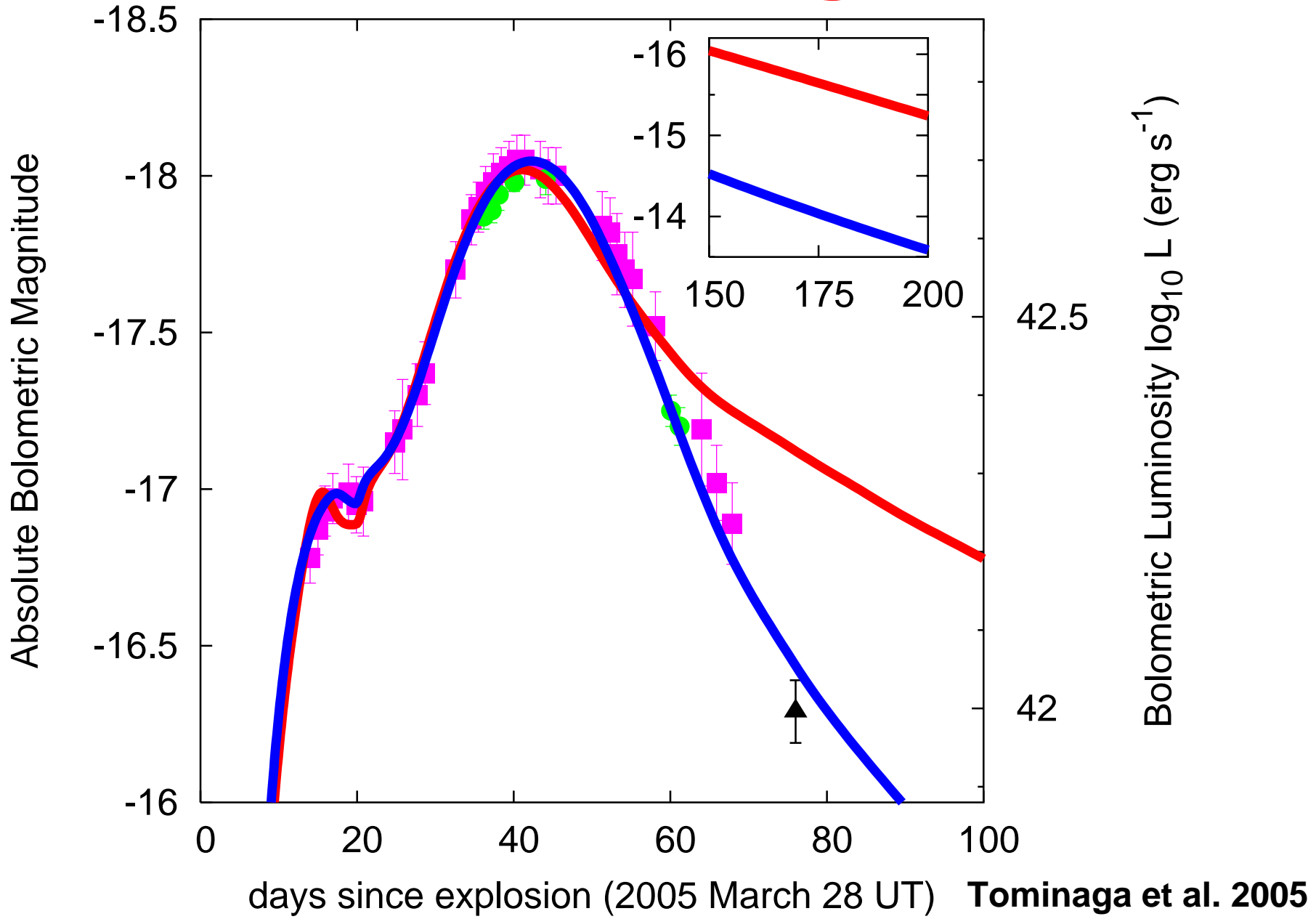
- **Peculiar Light Curve**

- Double peaks
- Slow rise to the 2nd peak (~40 days)

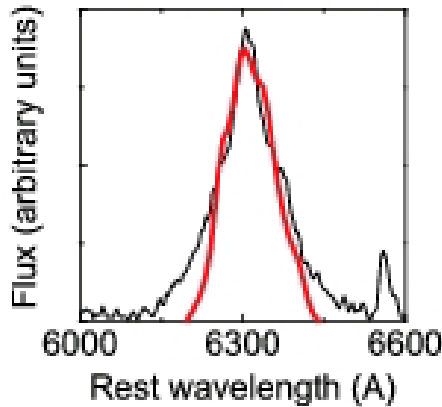


- Double peaked ^{56}Ni distribution \rightarrow **Jets?**
- $M_{\text{ej}} \sim 6 - 7 M_{\odot}$ ($M_{\text{ms}} \sim 25 - 30 M_{\odot}$)
- $E \sim 1.3 \times 10^{51}$ erg $\leftarrow M(^{56}\text{Ni}) \sim 0.3 M_{\odot}$
- Explosion of a WN star He, H features

SN 2005bf: Model Light Curves



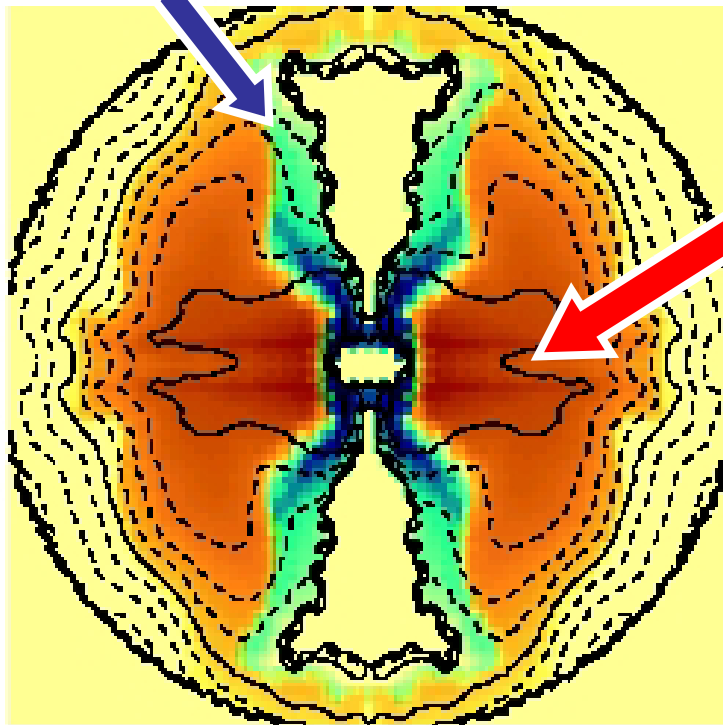
Hypernova: Bipolar Explosion



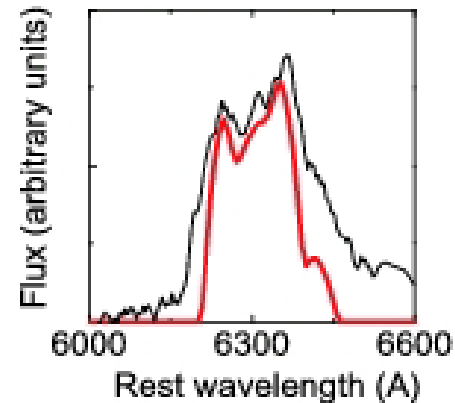
^{56}Fe

↑

1998bw

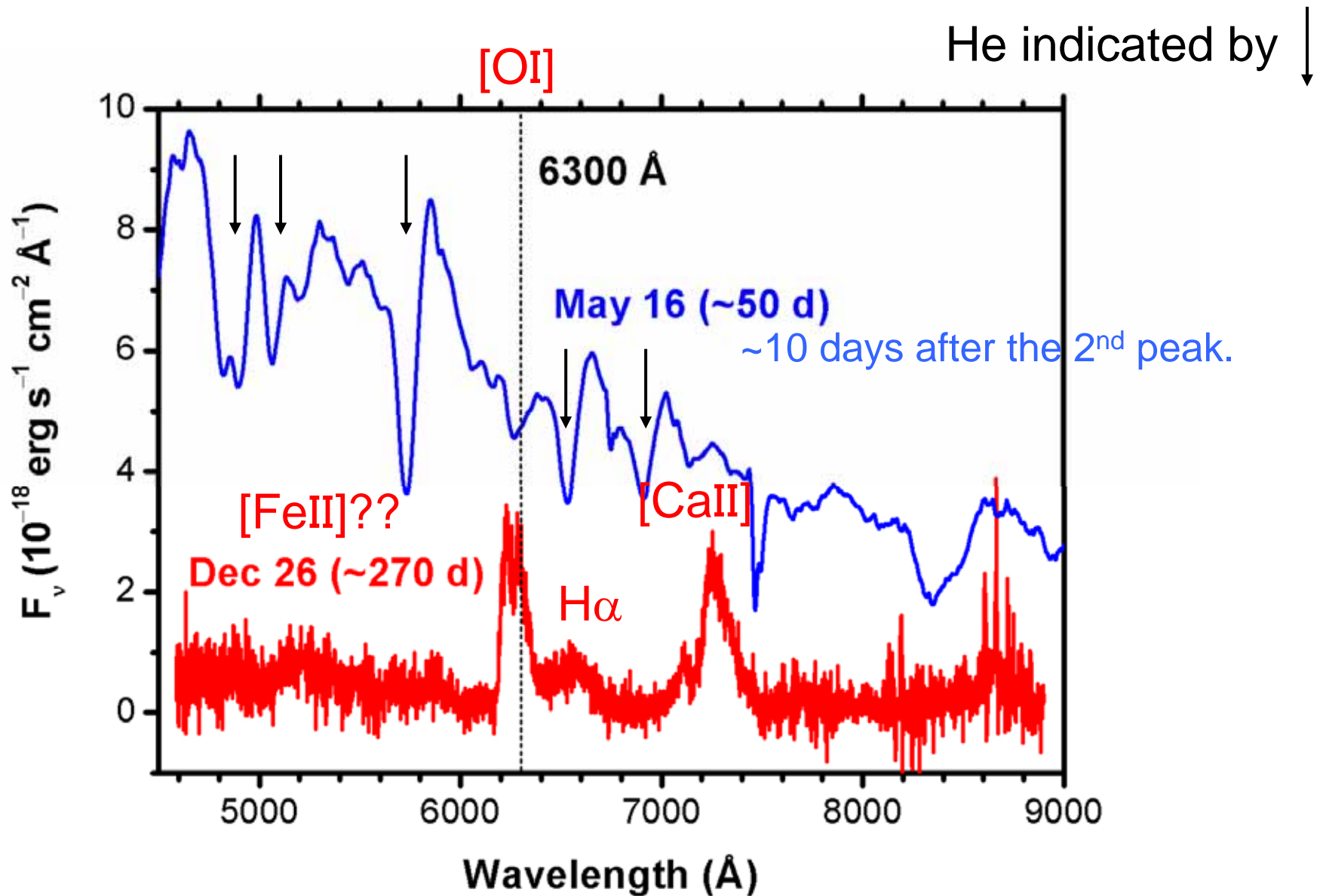


[OI] 6300Å (SUBARU)

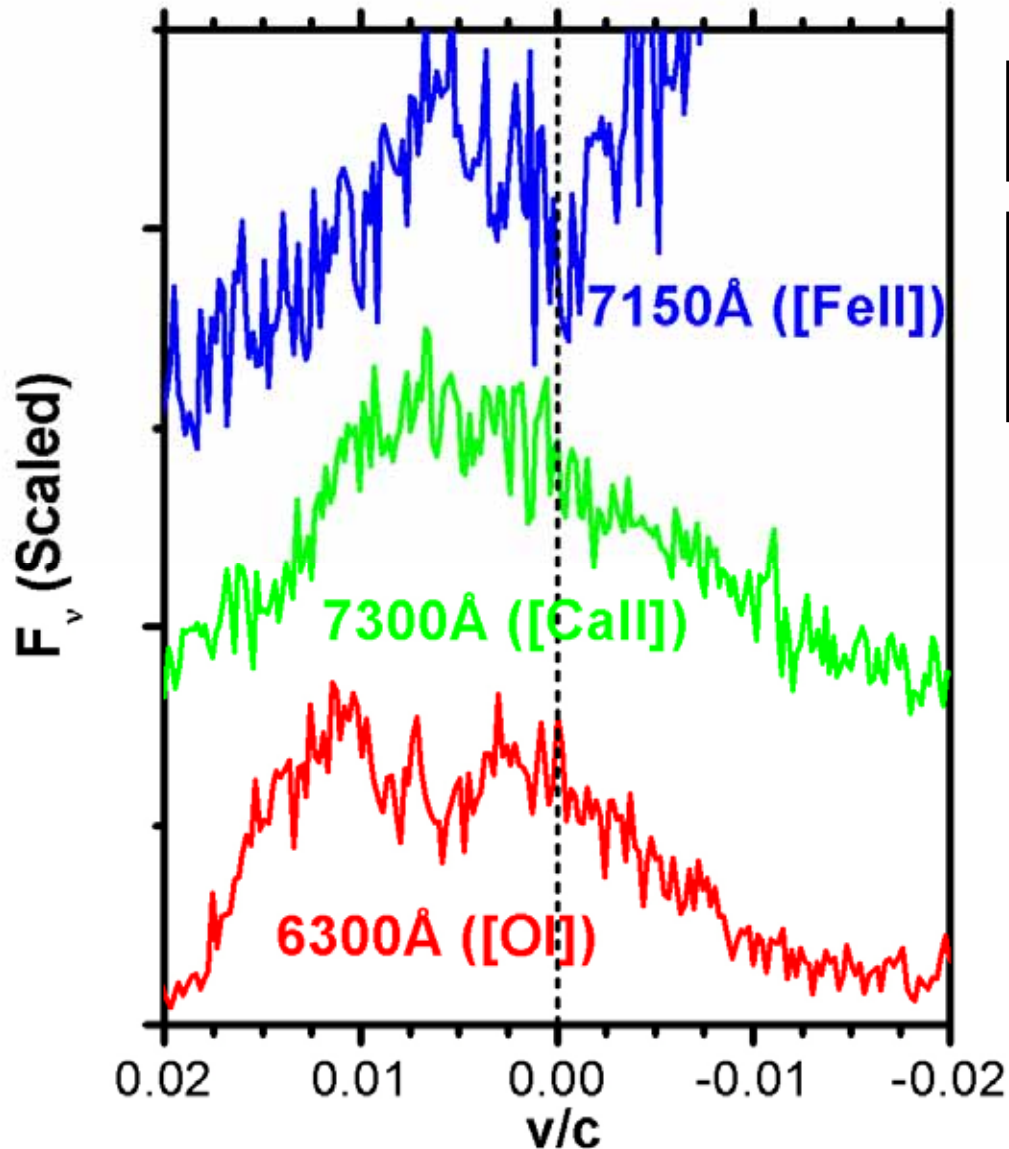


Maeda et al. (2002, 2005)
Mazzali et al. (Science 2005)

Subaru FOCAS Obs. of SN 2005bf

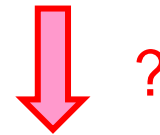


Peculiar Line Profiles: Blueshift and ...

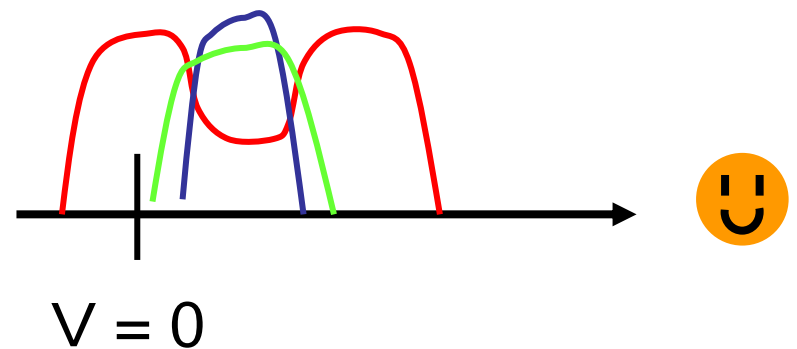


Blueshift

Double peak in O,
Single peak in Fe, Ca



Dist. Along the Line-Of-Sight

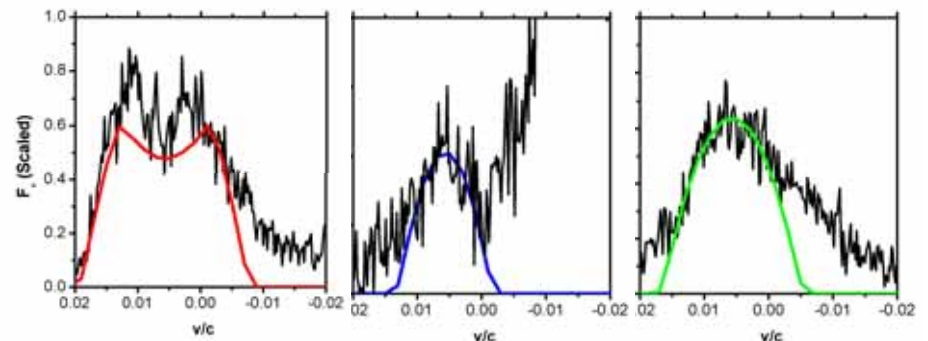
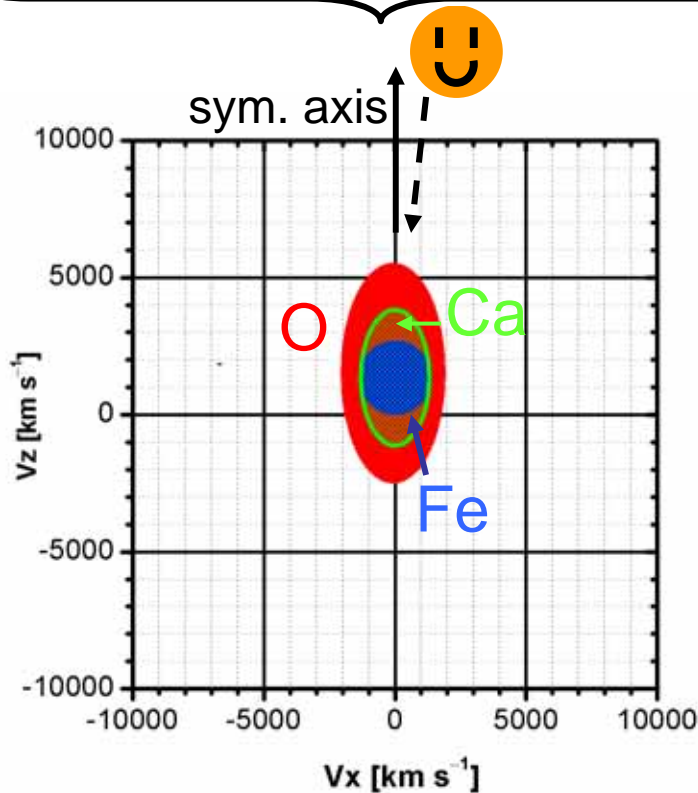
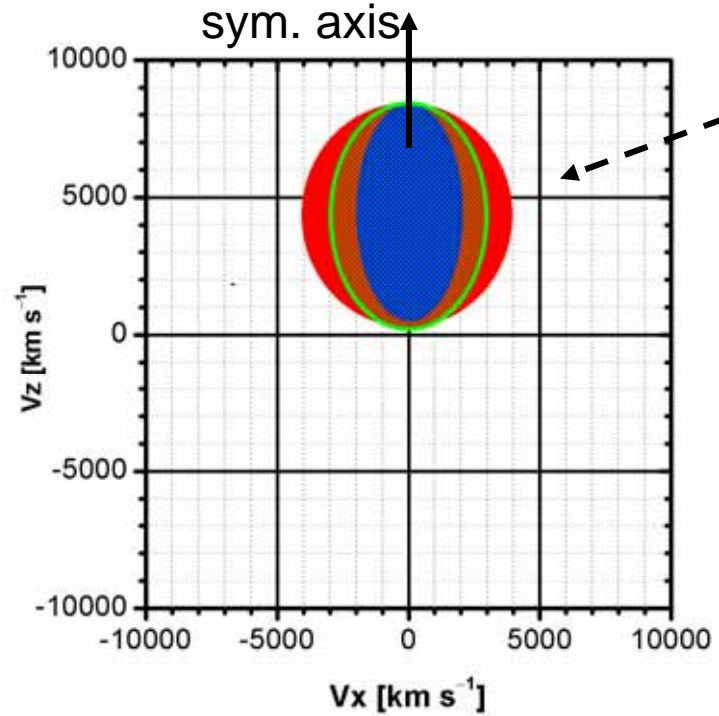
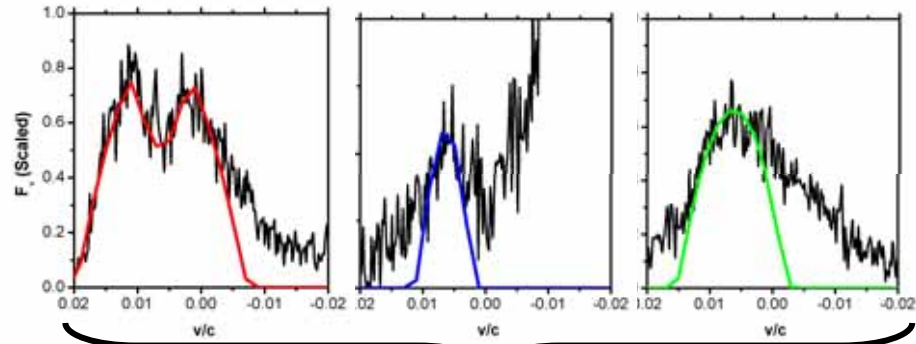


One-Sided Ejection of $^{56}\text{Ni}(\text{Fe})$?

[OI]
6300

[FeII]
7150

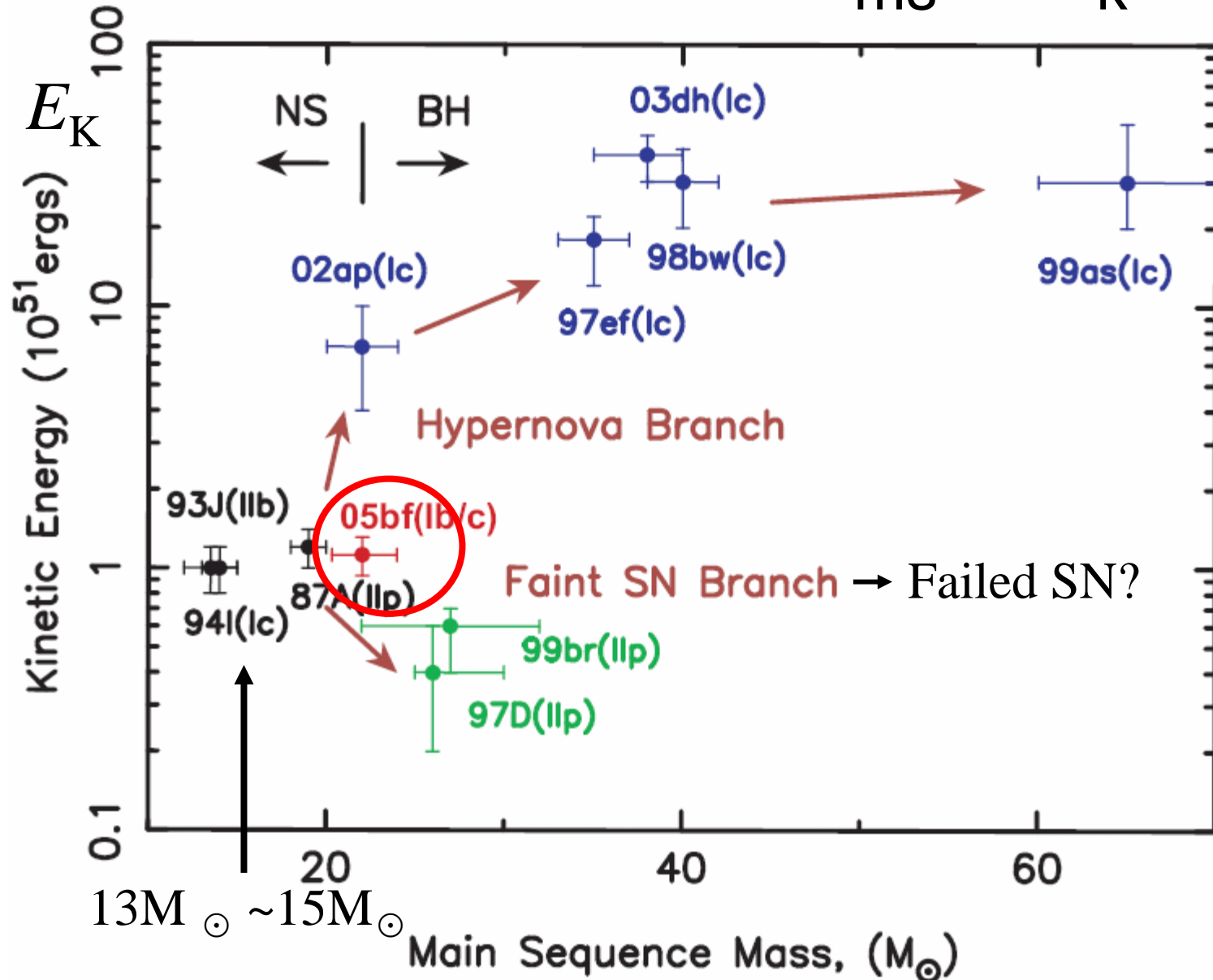
[CaII]
7300



Type Ib SN 2005bf

- Nebula Spectrum
 - [FeII], [CaII],[OI] : Blue shifted by ~ 1500 km/s
 - [OI] : Double peaks
 - Unipolar Jet ?
 - Kick ? ($v \sim 200 - 600$ km/s ?)
- Neutron Star Forming SN ??
 - normal E, small M(compact star)
 - large ^{56}Ni mass
 - Magnetar?

SN 2005bf in $M_{\text{ms}} - E_{\text{k}}$



SN 2005bf in $M_{\text{ms}} - M(^{56}\text{Ni})$

