Type IIn supernovae

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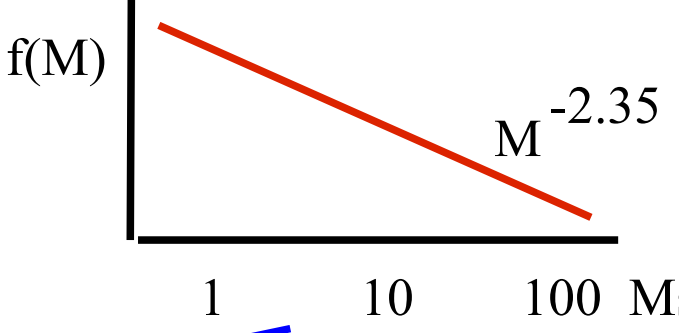
- Introduction
- SN IIn : CS interaction
- X-rays : highly dense CSM
- Light curves and spectra
- GRB connection ?



WD

99.5%

0.5%

RIP

WD + MS/RG/WD

TNSN

SN Ia (Tycho, SN 1006)

CCSN, …?

pre-SN

SN IIP (SN 1999em, Crab)	RSG
SN IIL	RSG
SN Ibc	WR
SN IIb (SN 1993J, Cas A)	RSG
SN II	YSG/RSG/LBV?
SN Ibn	WR? RSG?

TNSN : CCSN ~ 1 : 7

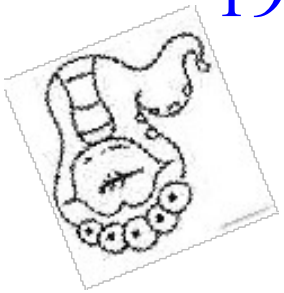
SN IIn : distressing diversity

(LC, spectra., line profiles)

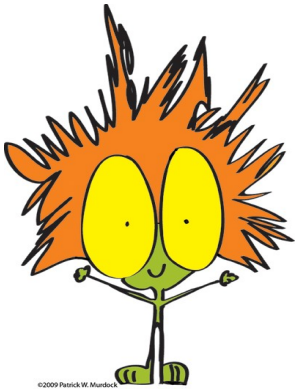
2006jc

1994W

1988Z



2005ip



2006gy

2011hw

1995G

2008iy

Type IIn (Schlegel 1990)

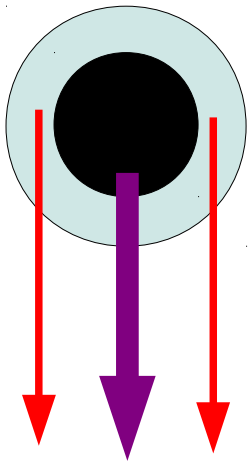
- **narrow** (<1000 km/s) Hα (He I) ontop broad (>3000 km/s)

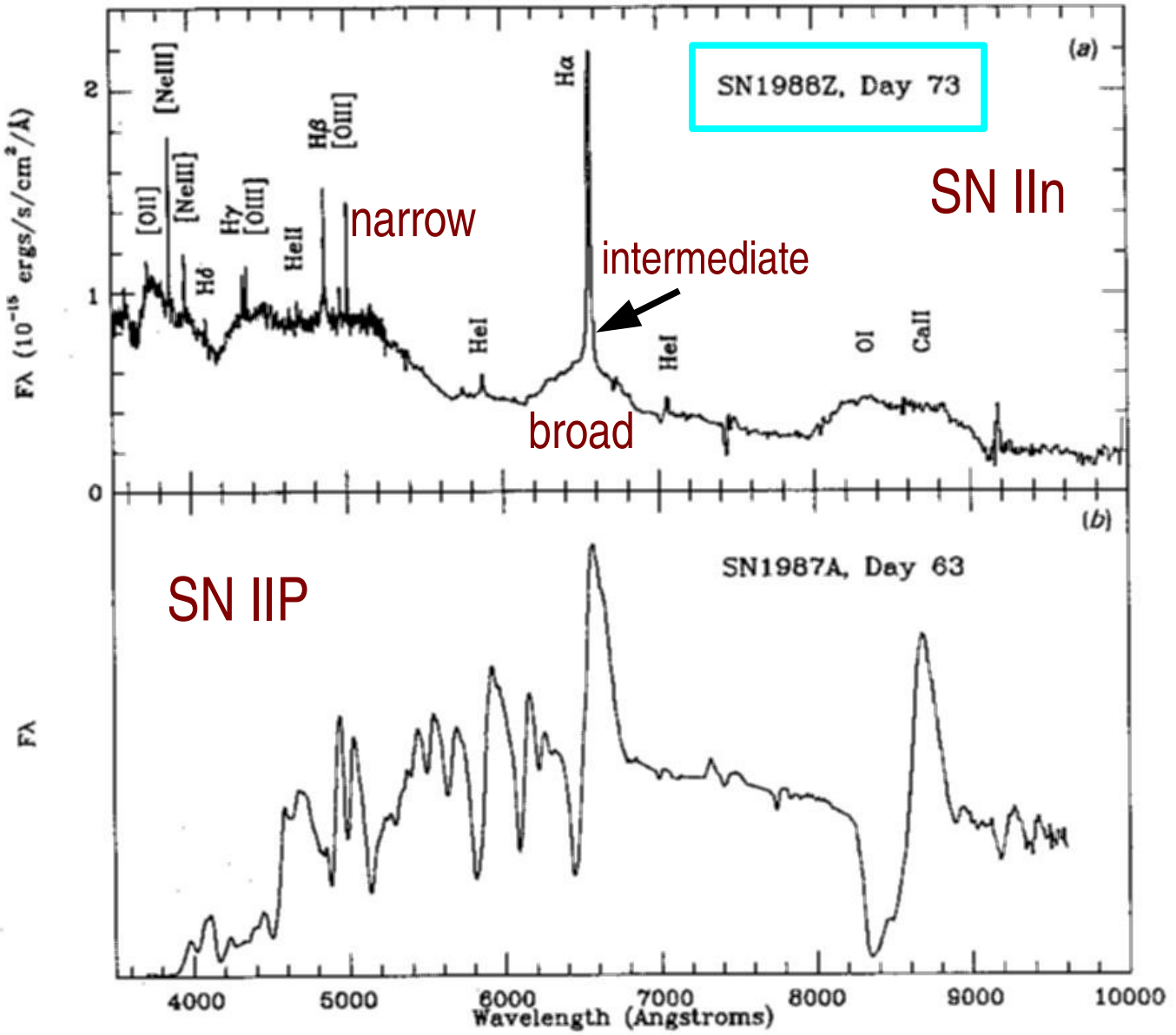
- blue continuum

- slow evolution (in most cases)

- weak/no broad absorptions

SN 1988Z (Stathakis & Sadler 1991)





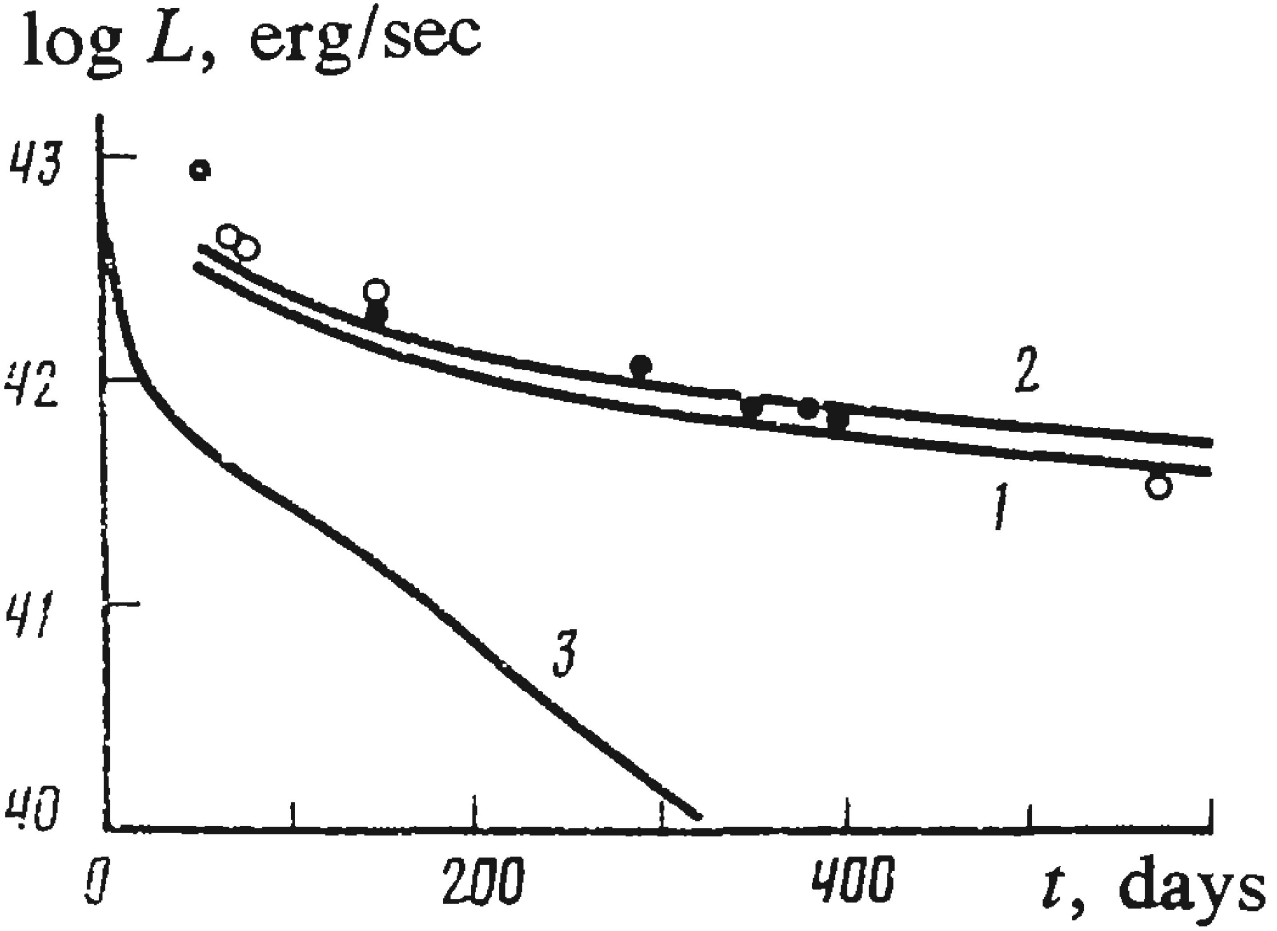
⇒ **the light is powered by interaction with a dense CSM ejected 100-1000 yr before explosion**

(1990)

SN1987F

Curve #3

M=8 Msun E=1 B
M(Ni56)=0.07 Msun



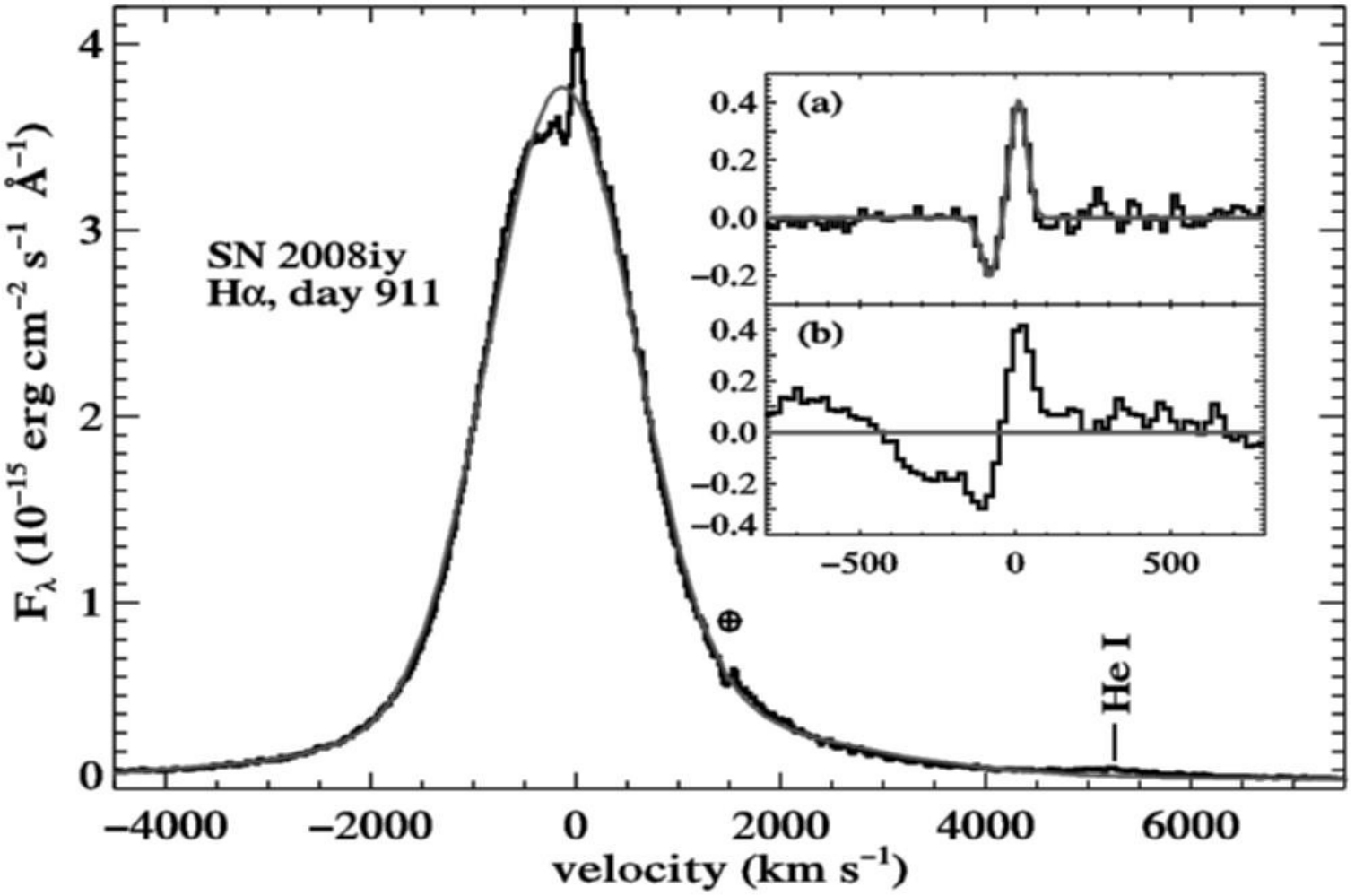
(1990, 1992)

$w=(dM/dt)/u_w \sim (1.5\text{-}2)\cdot 10^{17}$ g/cm

dM/dt=?

Wind velocity ? In most SN IIn ~ 100 km/s

SN 2008iy (Miller et al 2010)



$$dM/dt = 4\pi r^2 \rho u = wu$$

$$dM/dt = 0.015 w_{17} (u/100 \text{ km/s}) \quad (\text{Msun/yr})$$

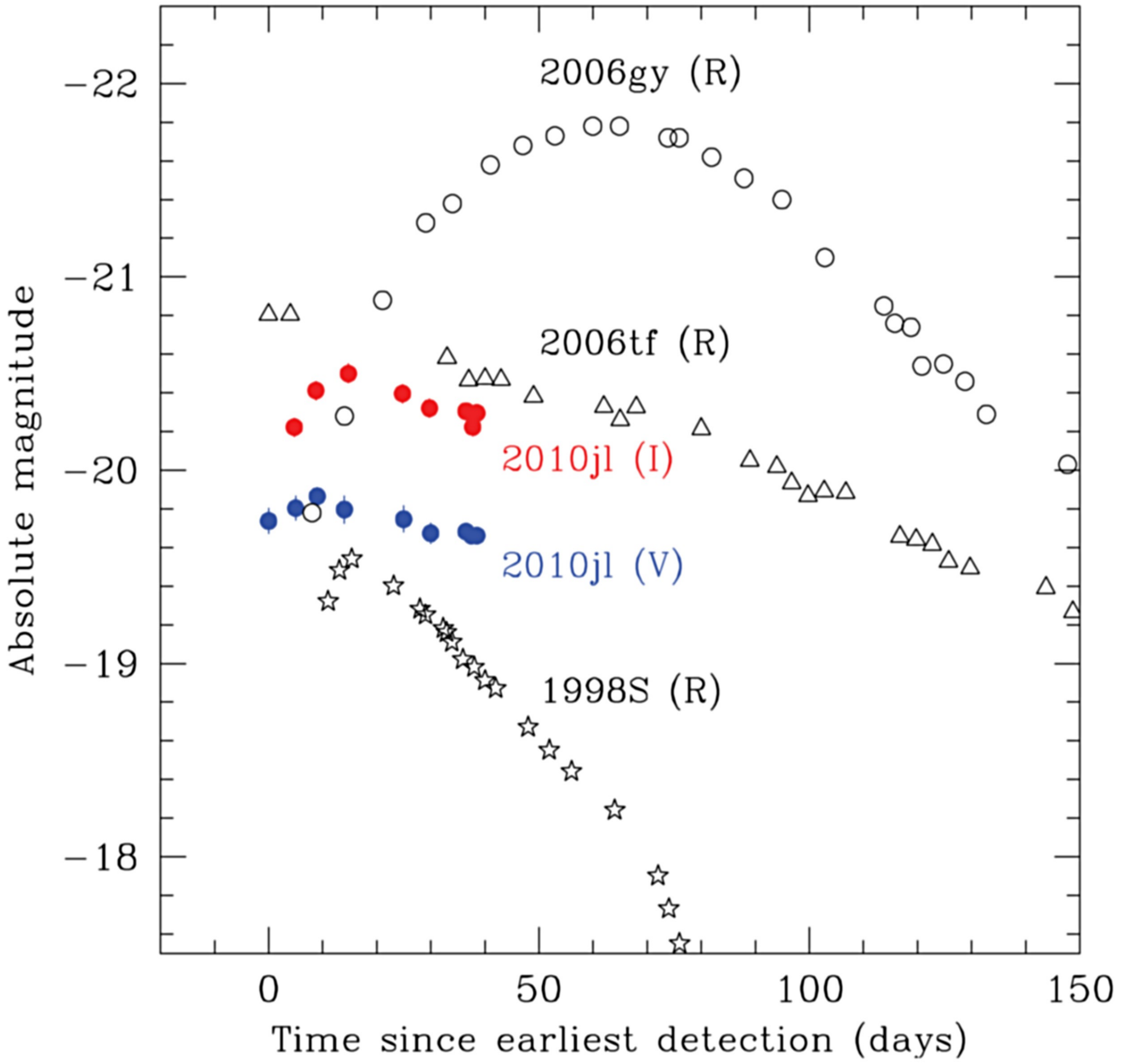
enormous mass-loss rate !

SN 2010jl: dM/dt via X-rays

SN 2010jl

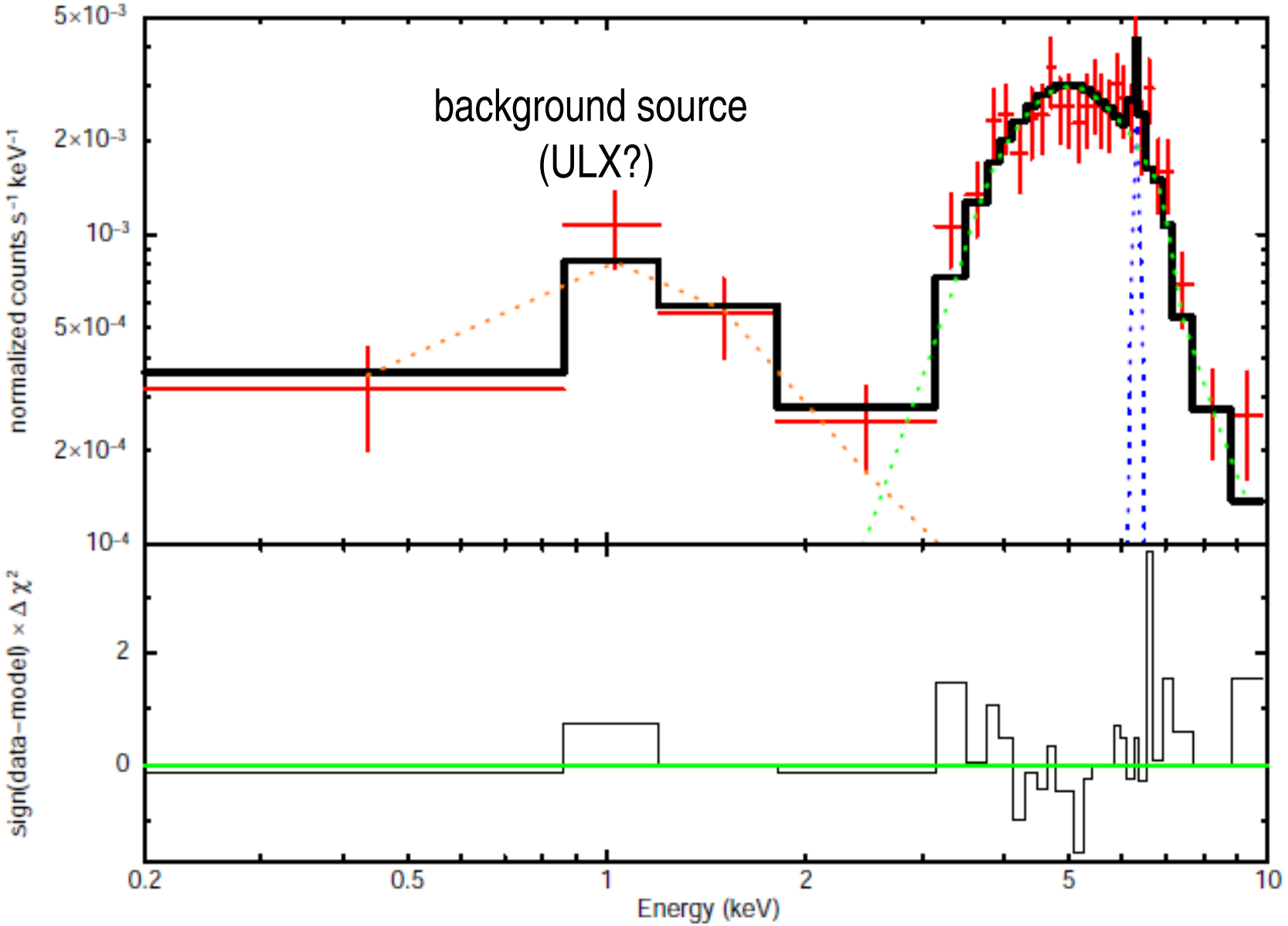
(Stoll et al 2011)

LogL = 44 (erg/s)

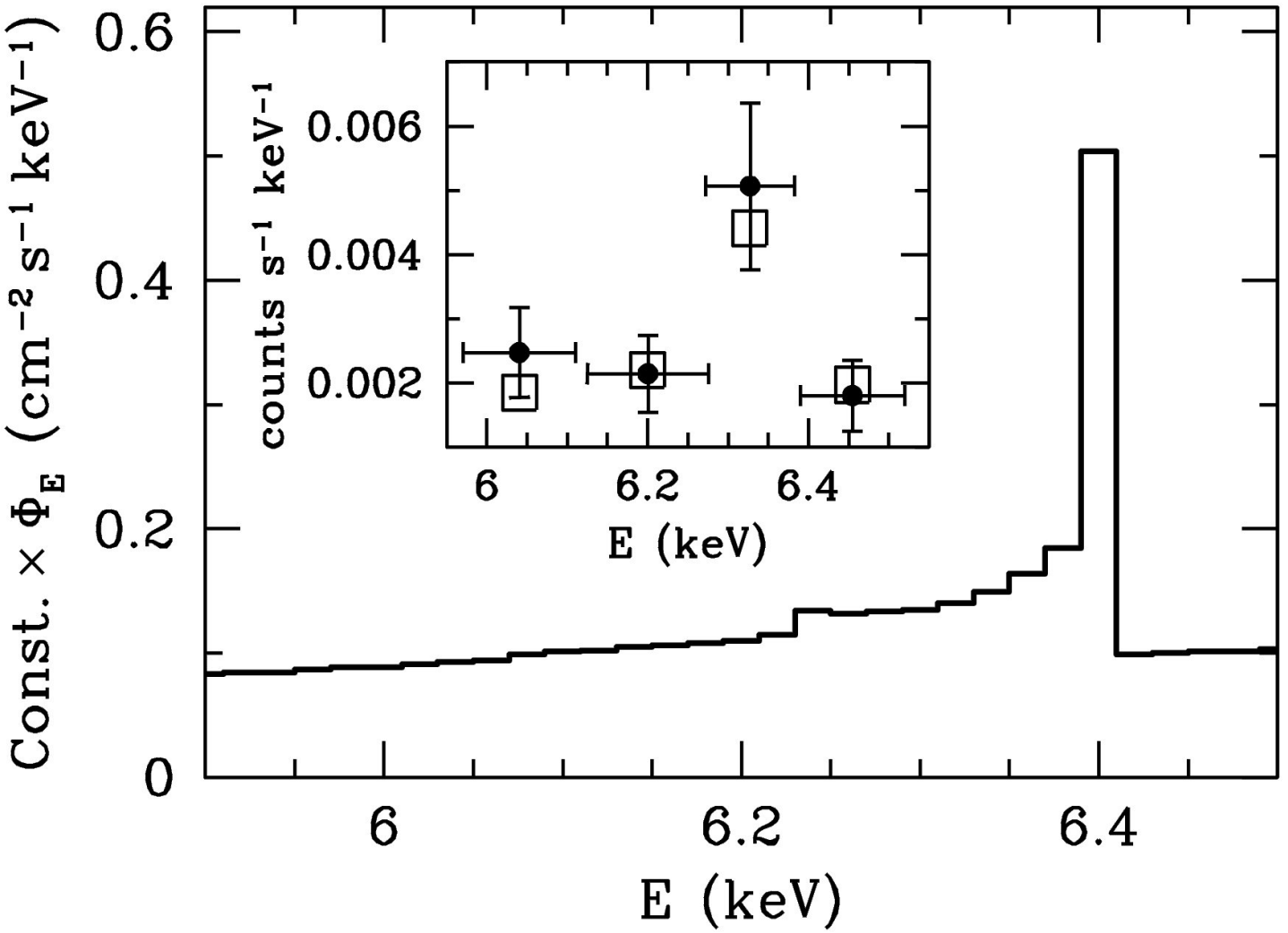


SN 2010jl : Heavily absorbed X-rays (Chandra et al 2012)

59 day since 2010 Oct 10



SN 2010jl: fluorescent Kα from cool gas



X-ray view on CSM around SN 2010jl

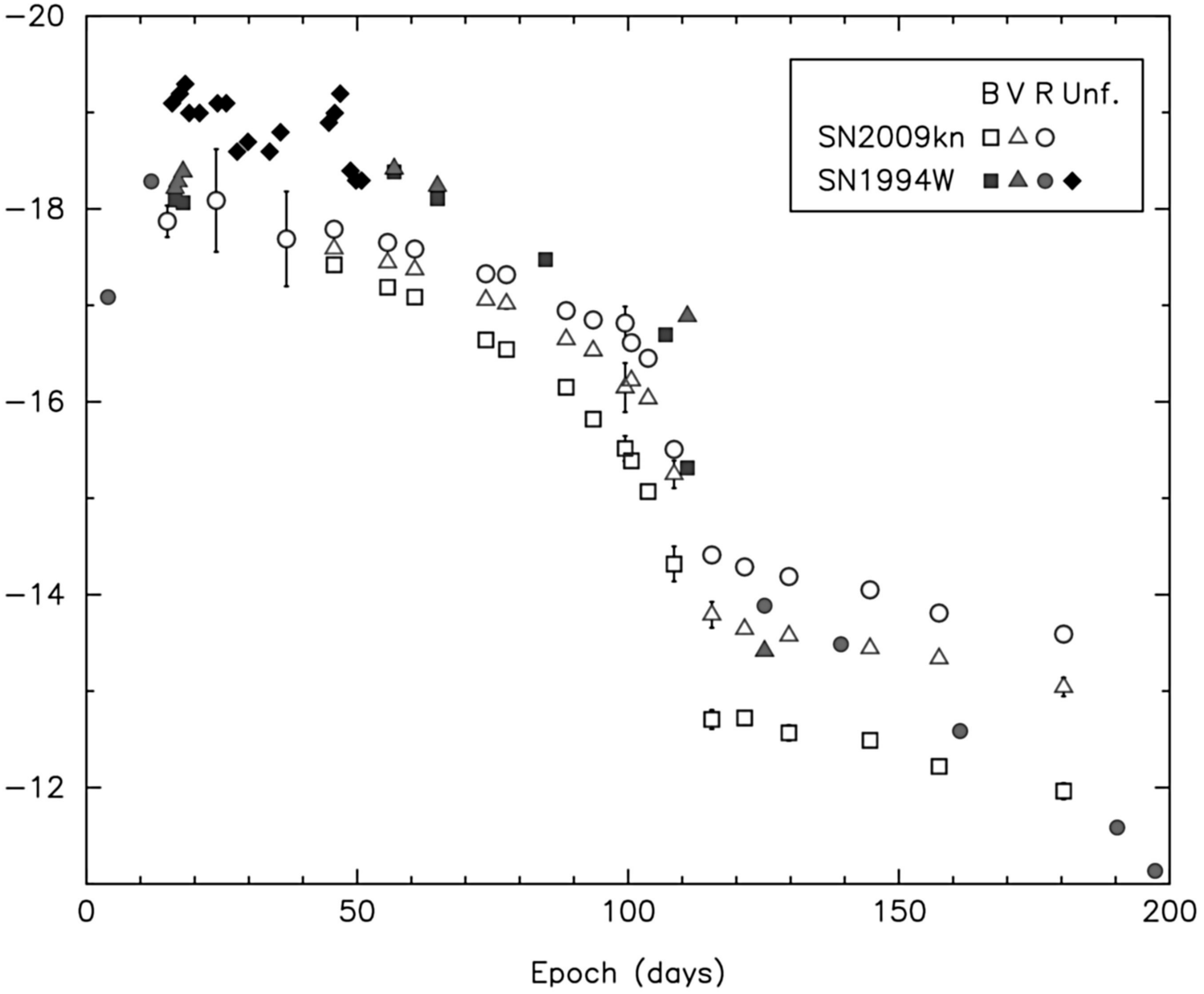
$N(H) \sim 10^{24}\ cm^{-2}$

$L_X \sim 10^{42}\ erg/s$

$dM/dt \sim 0.01\ Msun/yr$

Diversity of light curves

SN 1994W and SN 2009kn: SN IIP-like light curve



Plateau indicates radiation trapping

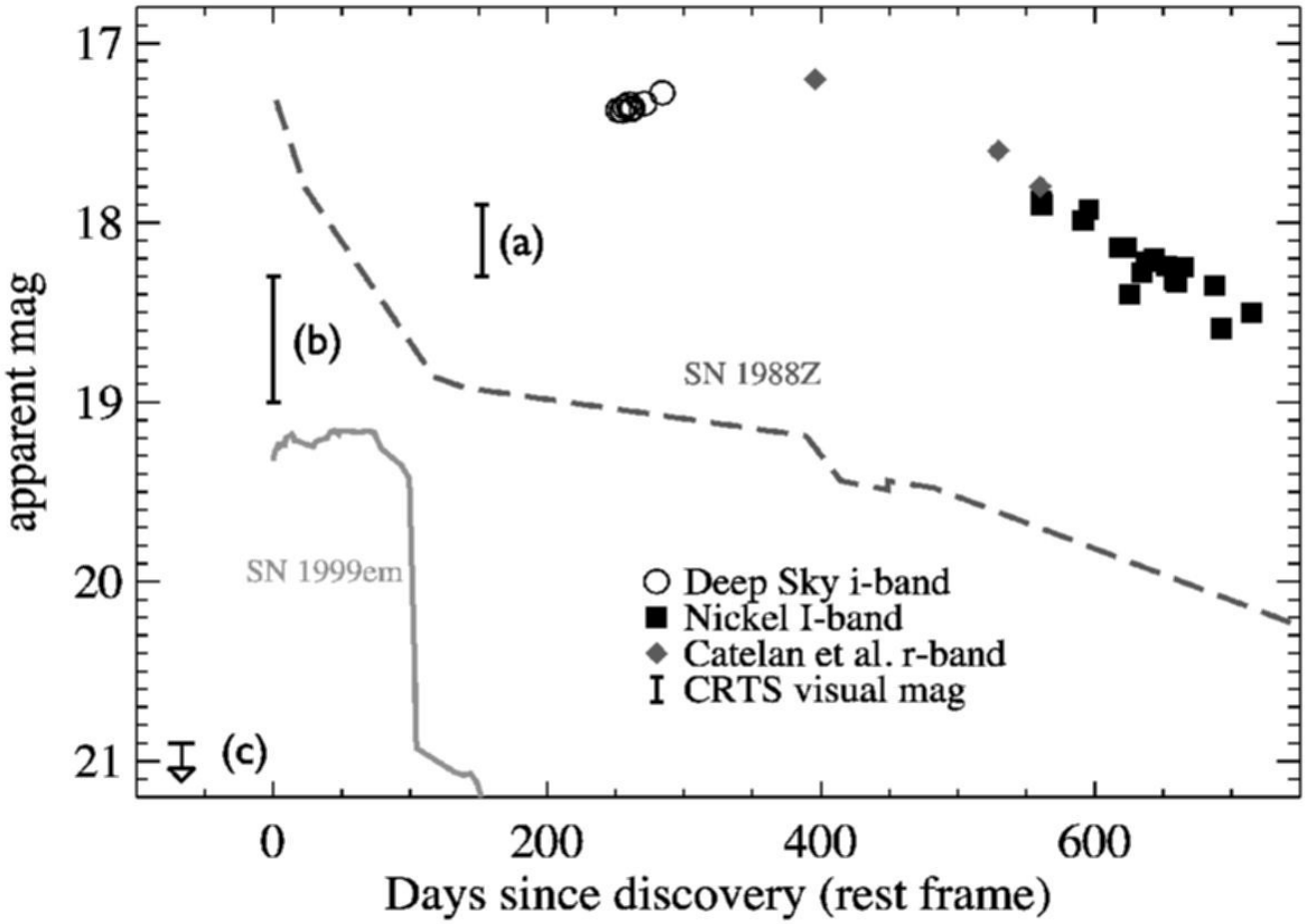
$$t_{dif} > t \Rightarrow M_{shell} \sim 2M_{sun}$$

and relatively compact CS envelope

$$R_{CS} \sim 10^{15}\,\mathrm{cm}$$

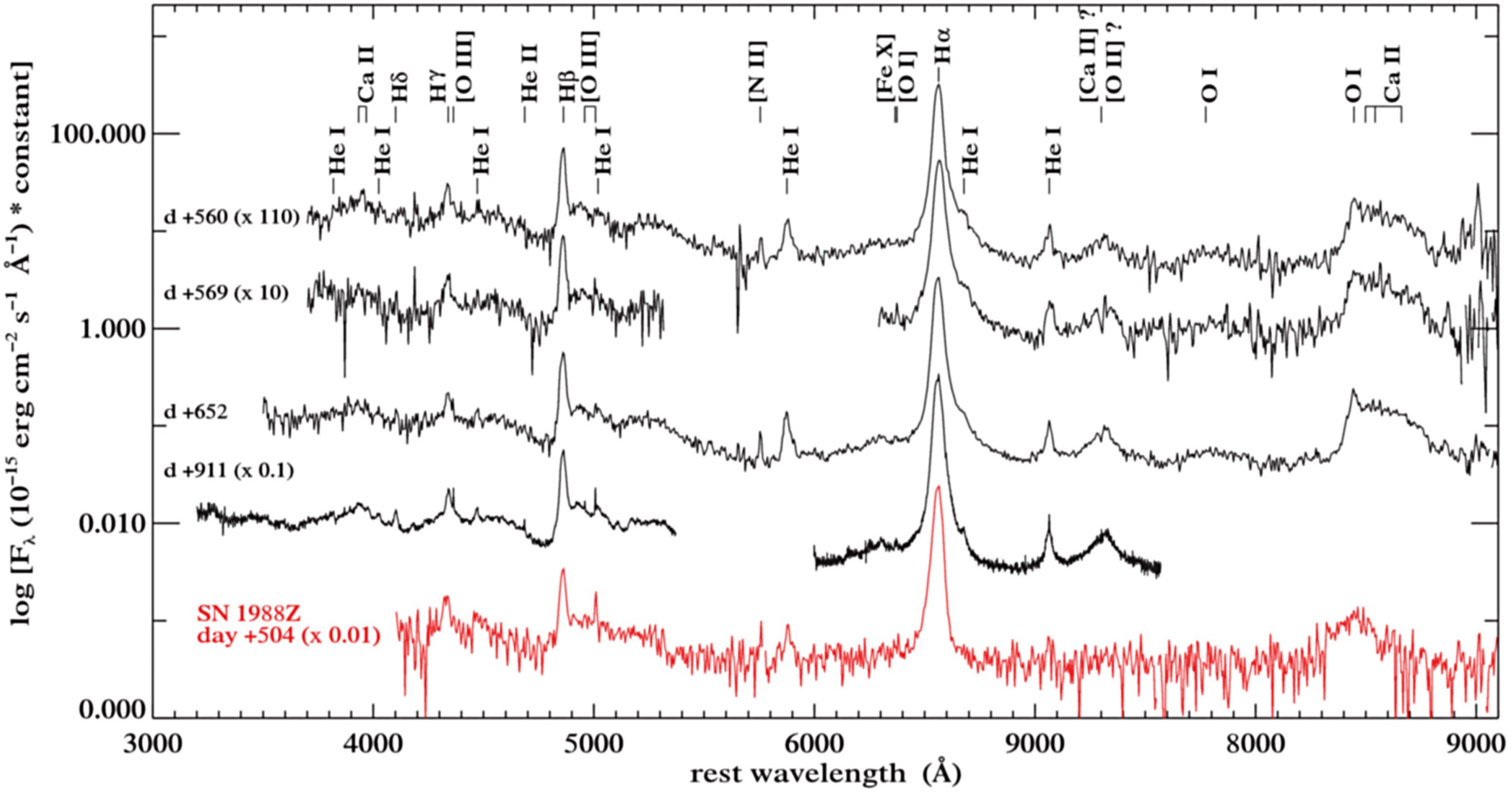
SN 2008iy : interaction with an extended CS shell

(Miller et al. 2010)



SN 2008iy

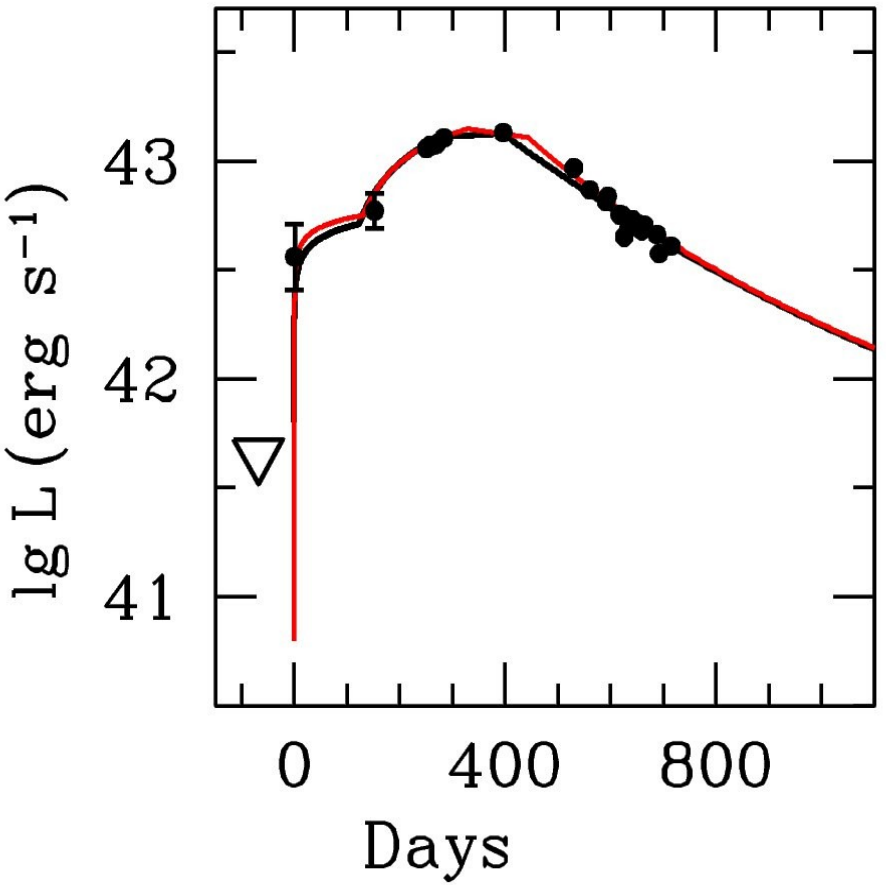
Miller et(al 2010)

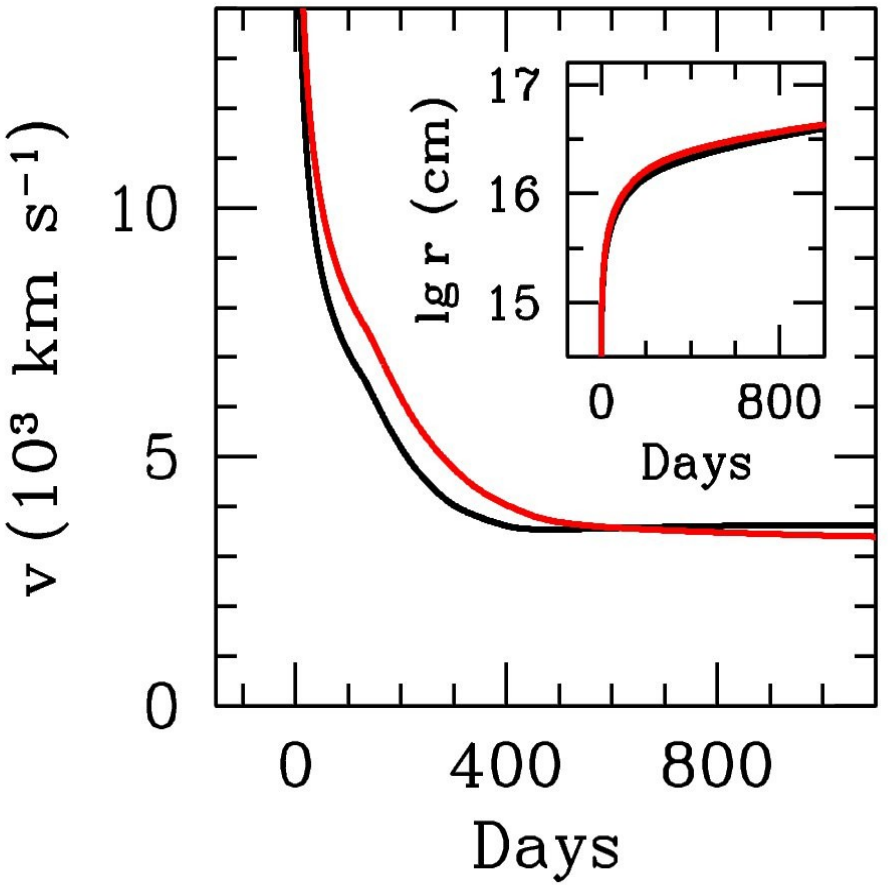


SN 2008iy :

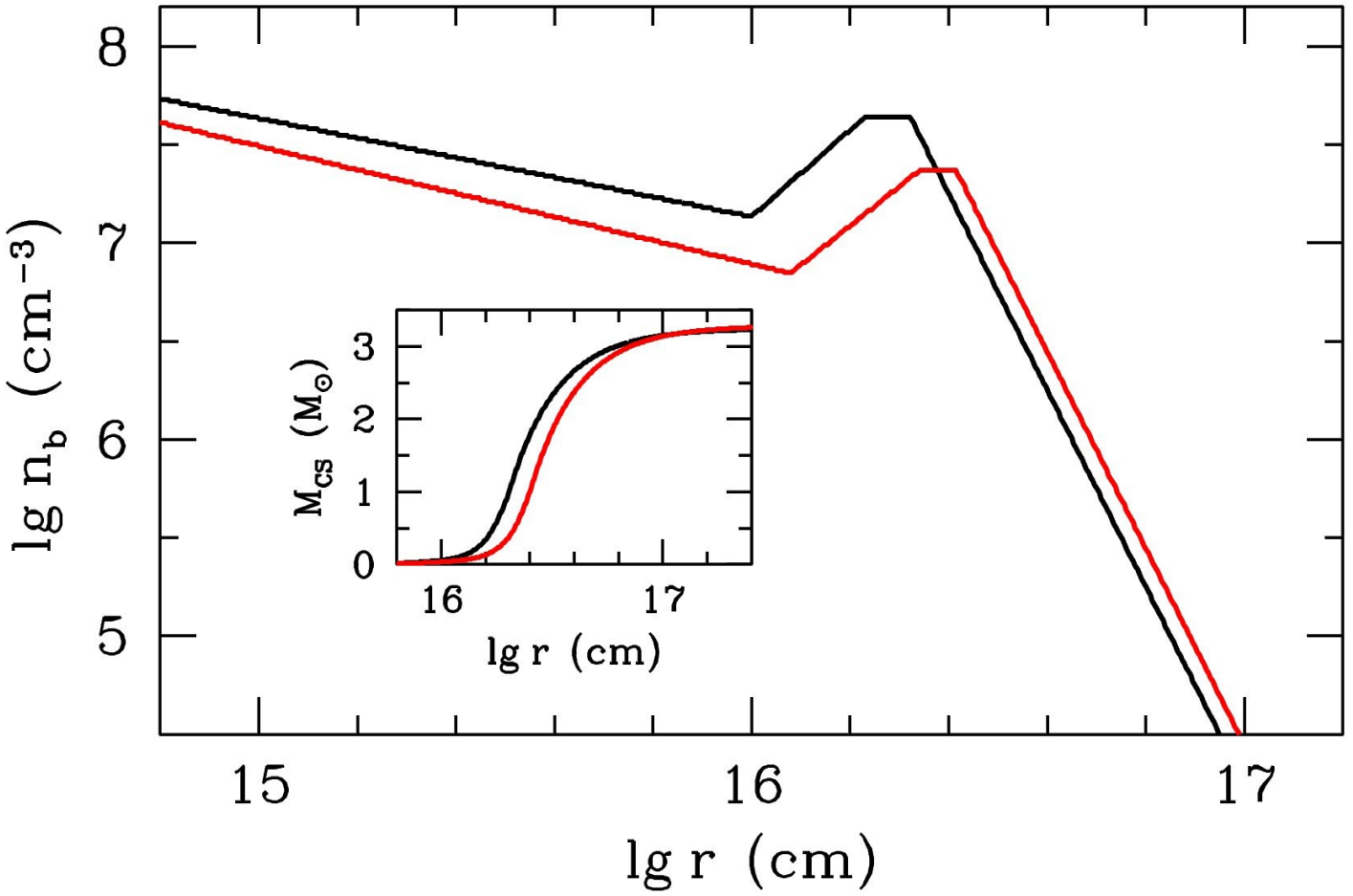
degeneracy of SN parameters:

1. $M=5M_{sun}$ $E=1.5\ 10^{51}$ erg
2. $M=20M_{sun}$ $E=3\ 10^{51}$ erg



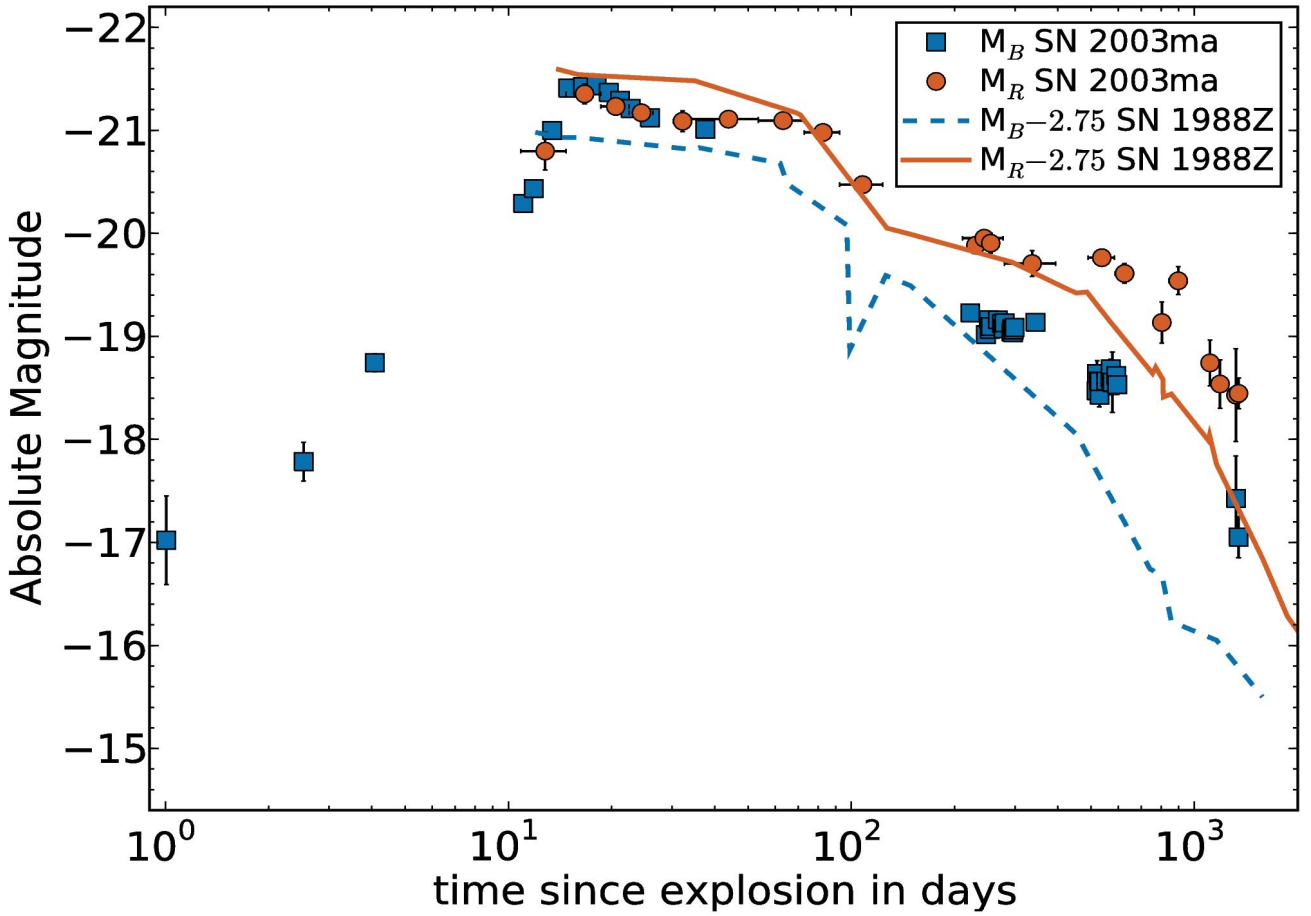


$M_{CS} \sim 3M_{sun}$ $R \sim 2\ 10^{16}$ cm $t_{loss} \sim -70$ yr



SN 2003ma (z=0.289): $E_{rad} \sim 4\ 10^{51}$ erg (Rest et al 2011)

→ $E \geq 8\ 10^{51}$ erg > typical E of CCSN



SN IIn light curves suggests diversity of:

→ **CSM density and structure**

→ **pre-SN mass-loss process**

→ **pre-SNn and explosion mechanisms ?**

Optical spectra :

1. Composition of CSM

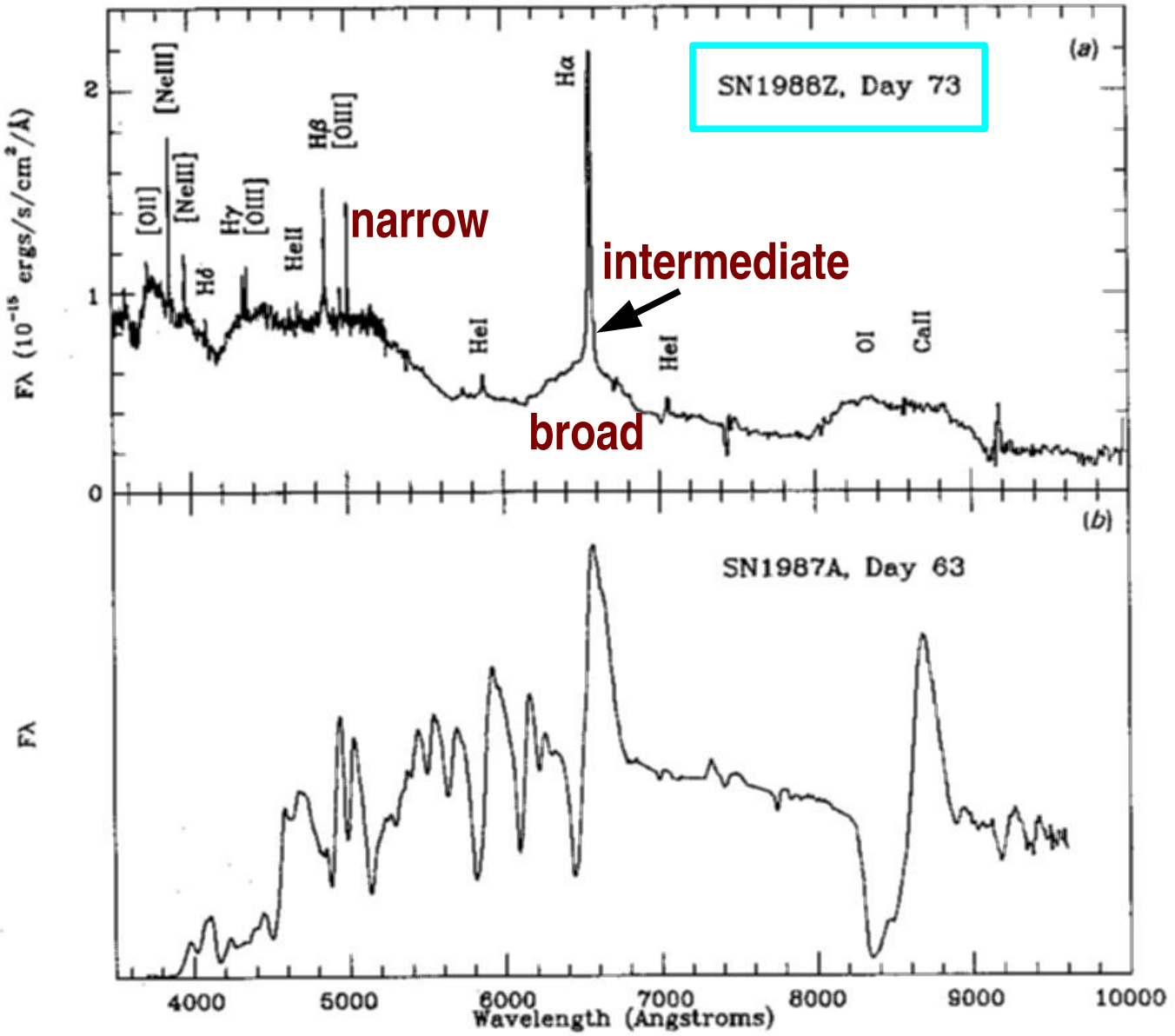
> He-rich SN IIn (SN 2006jc-like)

> H-poor (SN 2011hw)

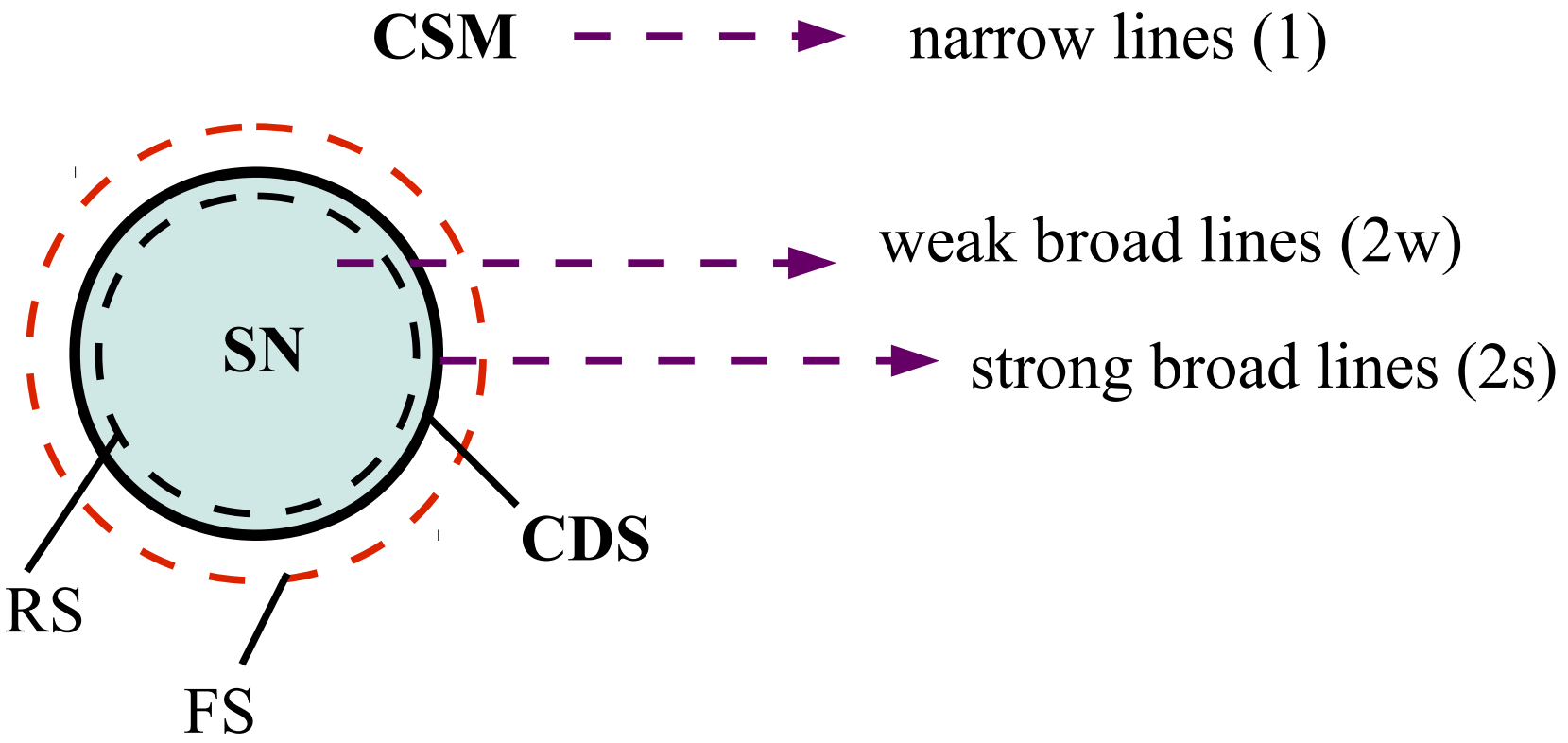
> SN Ibc colliding with H-rich CSM ?
(SN 1997cy, 1999E, 2001ic, 2001em)

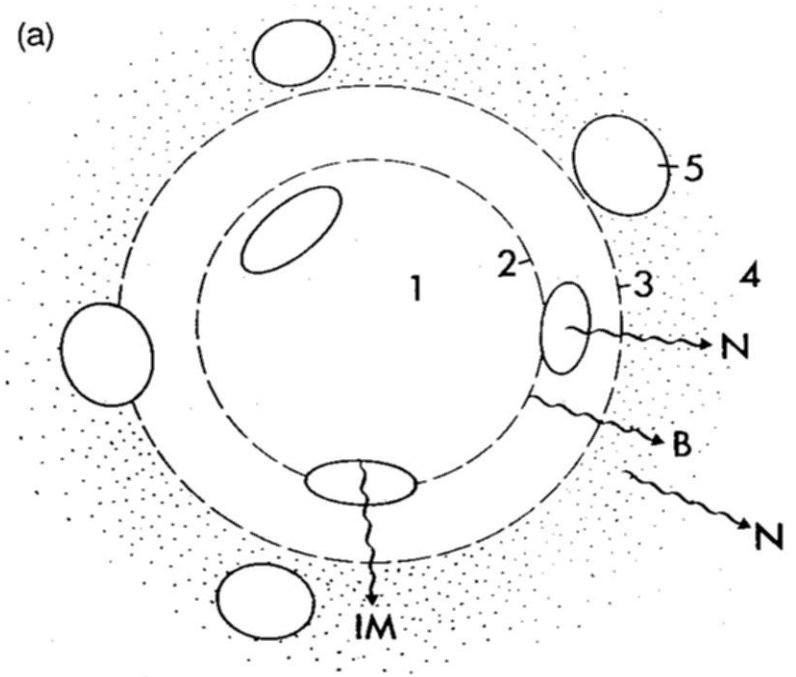
2. Line-emitting region ?

SN 1988Z (Stathakis & Sadler 1991)

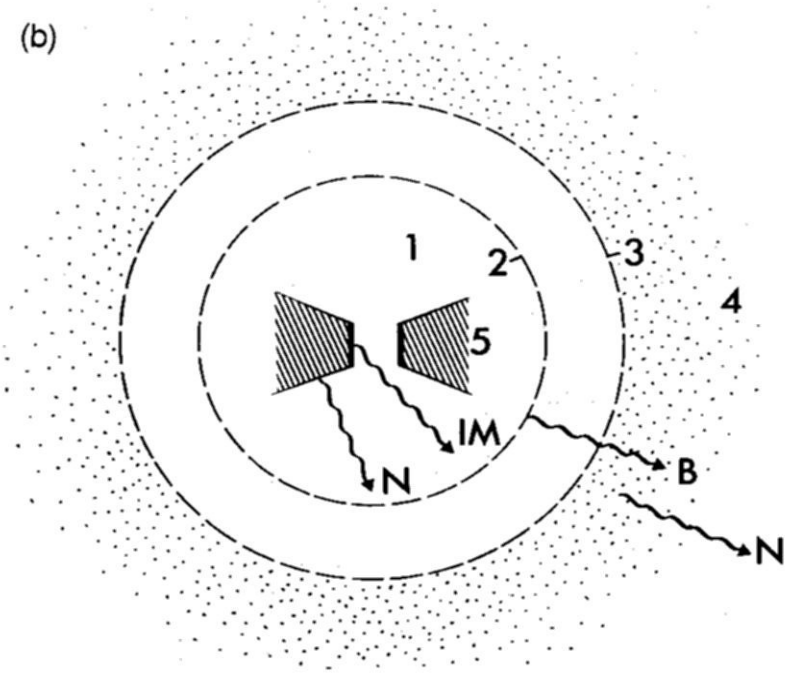


«standard» model: no place for intermediate component





shocked CS clouds

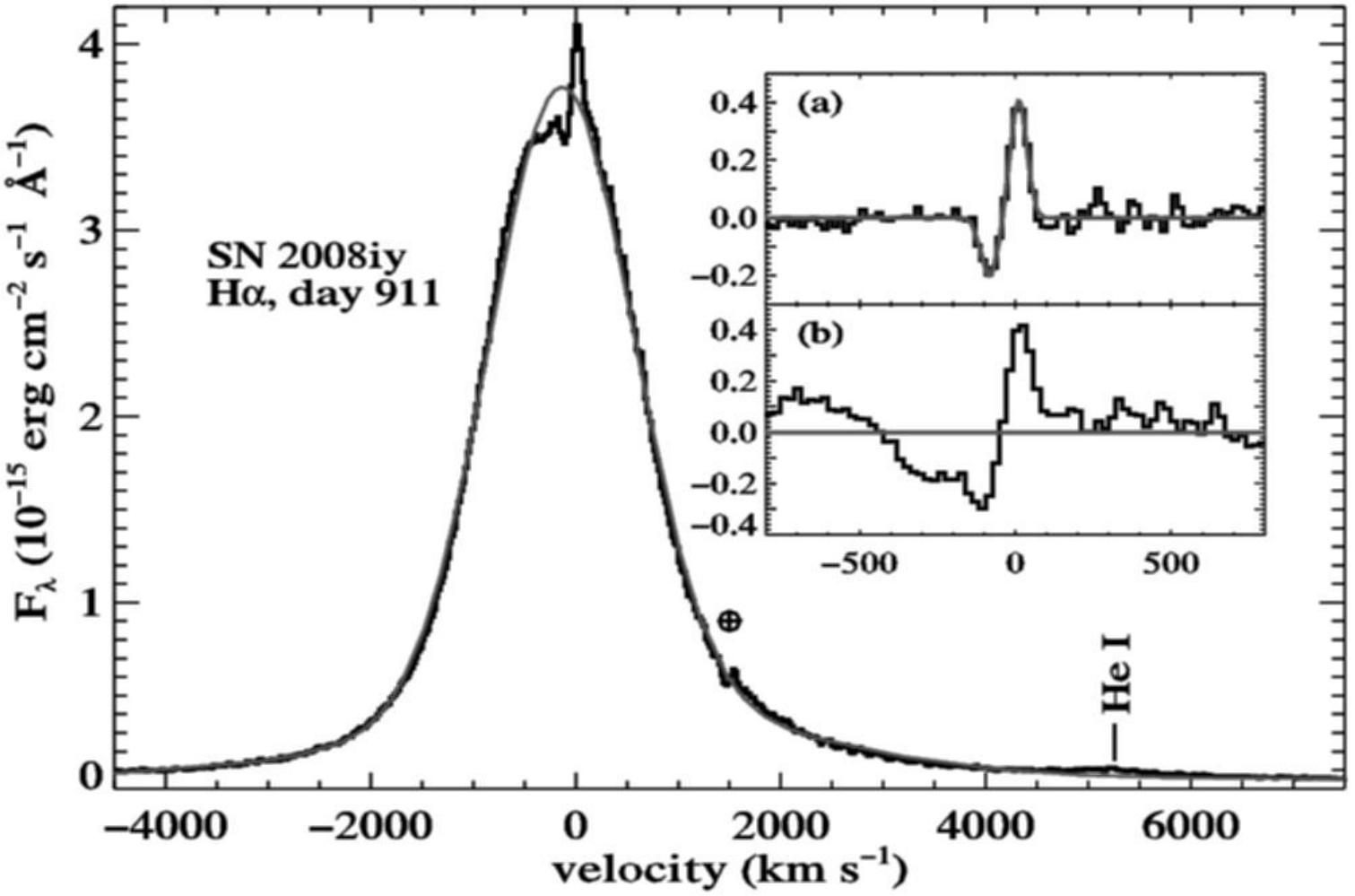


shocked equatorial CSM

(Chugai&Danziger 1994)

Graceful broad wings?

SN 2008iy (Miller et al 2010)



Broad wings ?

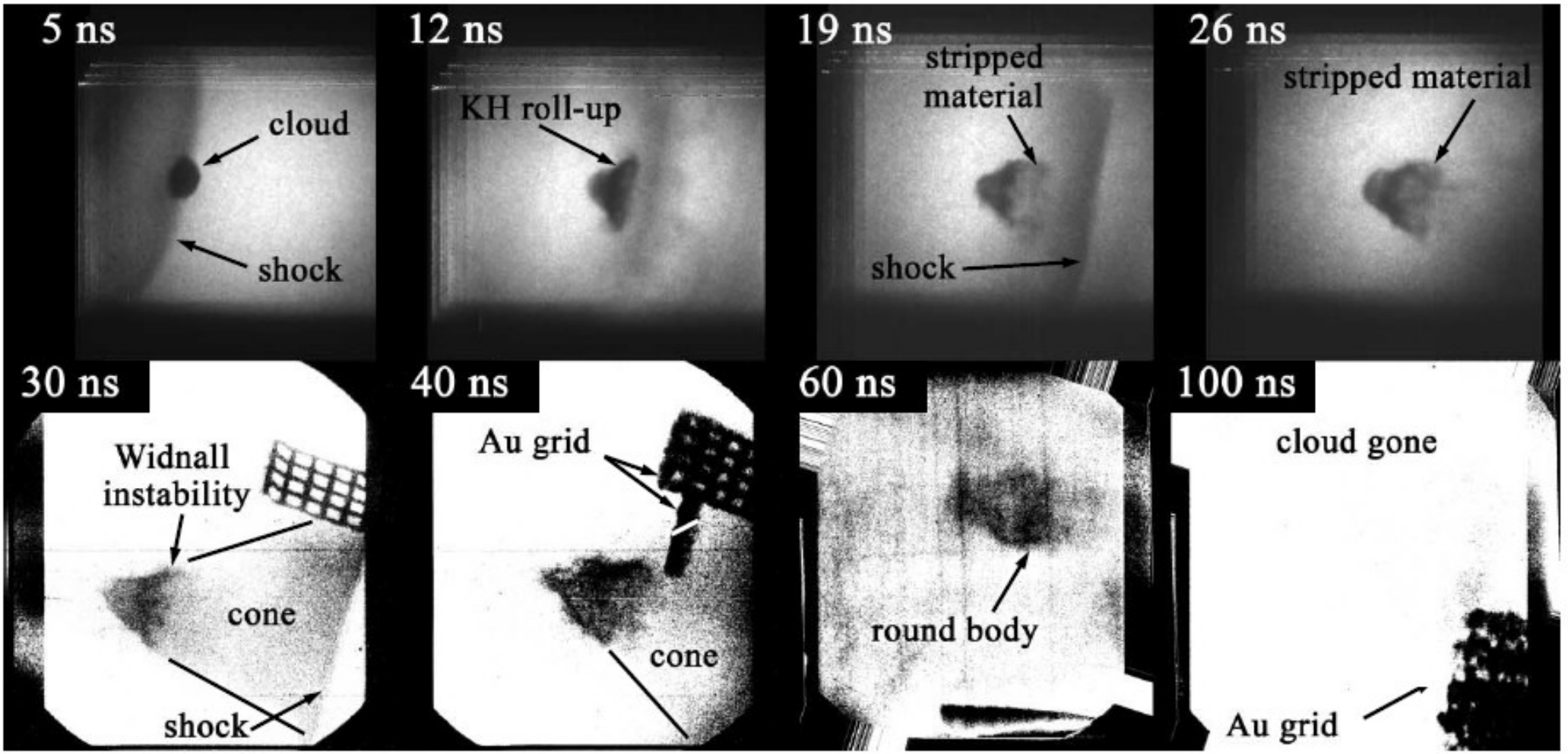
* multiple Thomson scattering on thermal electrons (t<<100d)

* shocked clouds stripping → high V fragments → wings

* charge transfer between hot protons of forward shock and neutral cool H atoms of CS clouds (unlikely)

Cloud stripping

Omega Laser facility (Hansen et al 2007)



Pre-SN mass loss mechanisms?

1. Dense wind (LBV/RSG/YSG)
2. Common envelope ejection
3. Violent outburst (LBV, eta Car-like)

Summary

> SN IIn light is from SN/CSM collision

> Diversity of LC → different mass loss pattern

> Some SNe IIn: $E \sim 10^{52}$ erg

Q1 : Optical spectra formation?

Q2 : Heavy mass loss by pre-SNe ?

Q3 : Pre-SN and explosion mechanism ?

SN IIn/GRB connection ?

(1) Binary : → CE ejection → SN IIn (CD 1994)

(2) Binary : NS + RSG → inspiral → SN II

(Barkov&Komissarov 2011)

(3) Binary NS + RSG → inspiral → SN IIn

(Chevalier 2012)

→ **whether GRB occasionally accompany SN IIn ?**

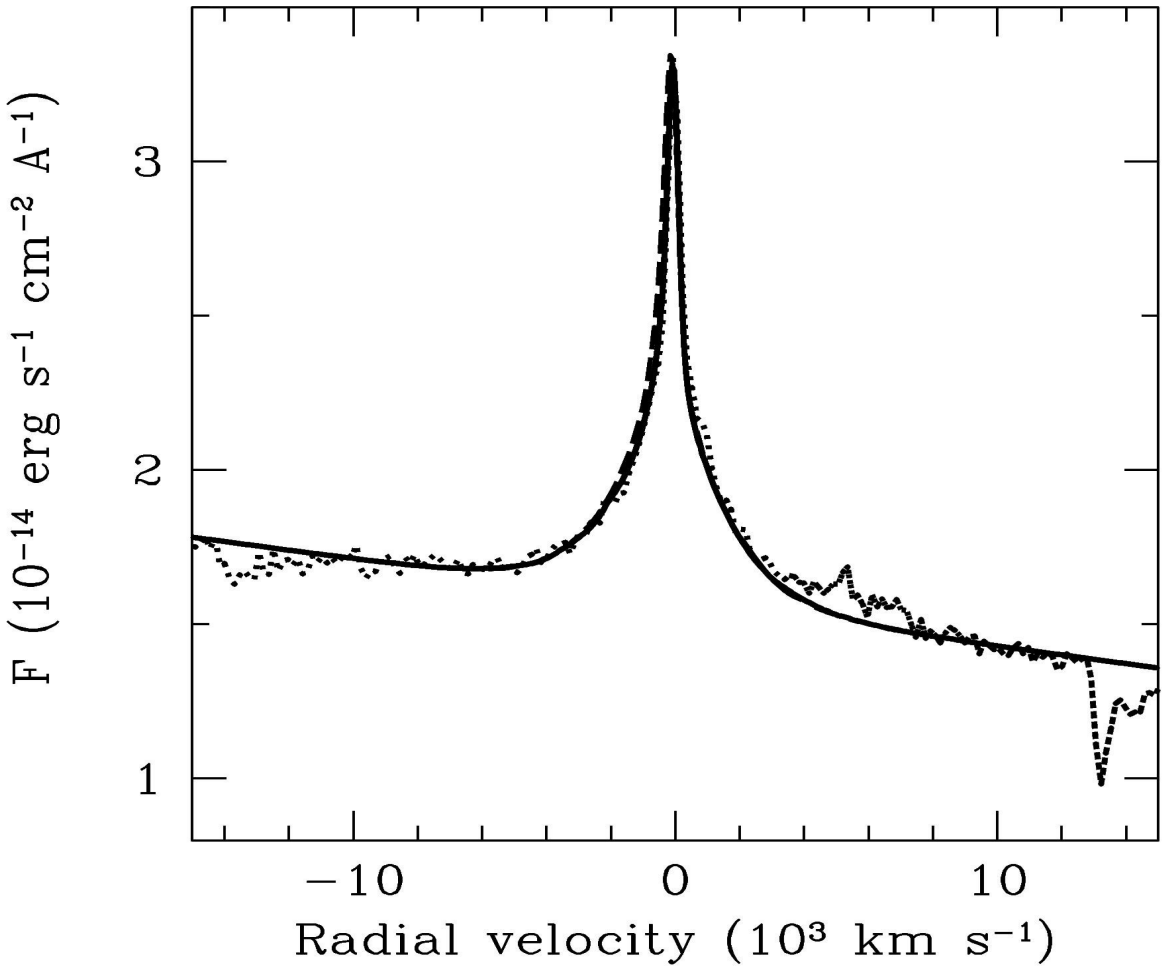
Data are inconclusive:

SN 1997cy/GRB970514 (Germany et al. 2000)
SN 1999E/GRB980910 (Rigon et al. 2003)

THANKS

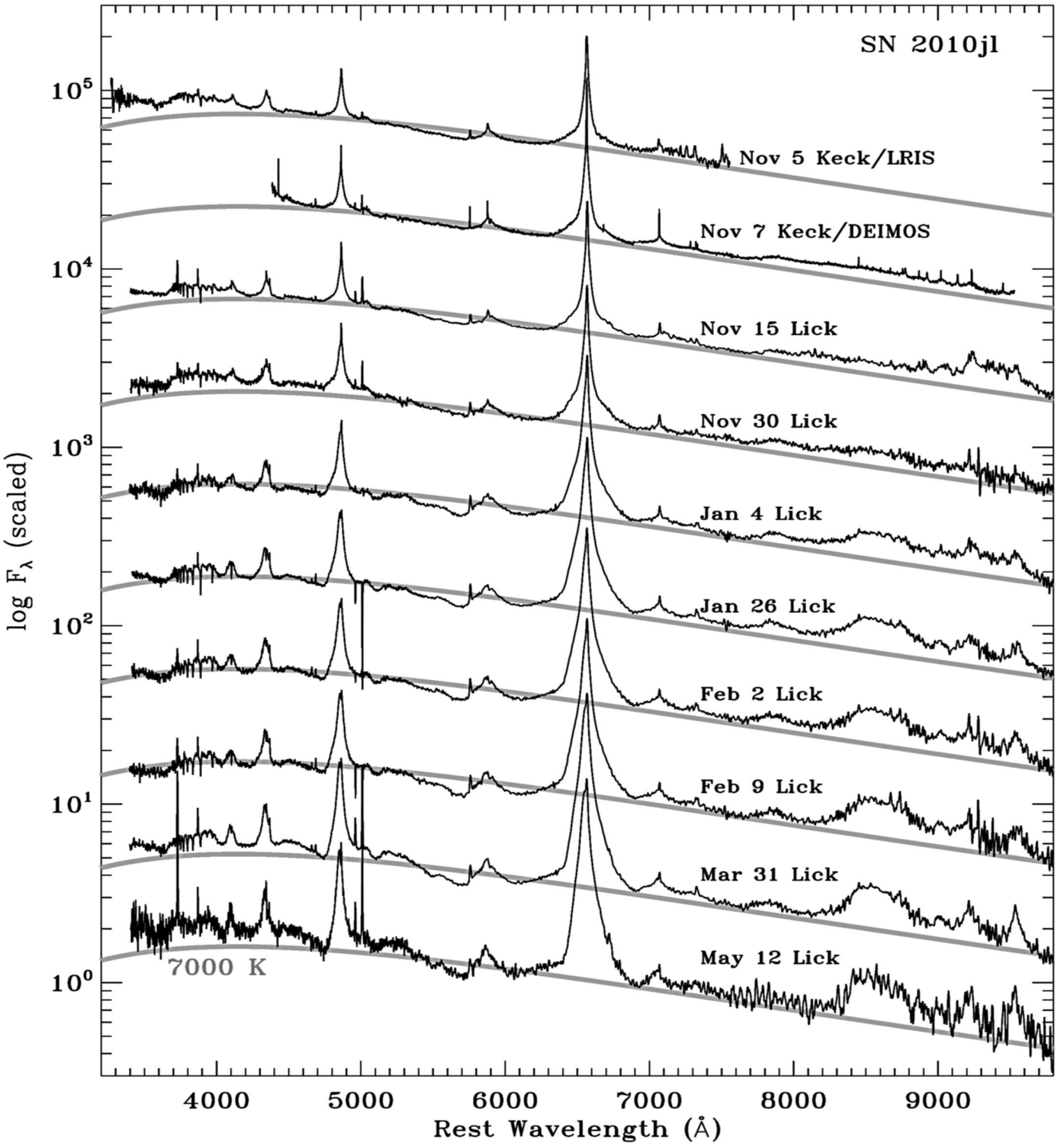
SN 1998S: thermal Thomson broadening in opaque cocoon

($\tau_T \sim 3 \ldots 4$, $R \sim 10^{15}$ cm)

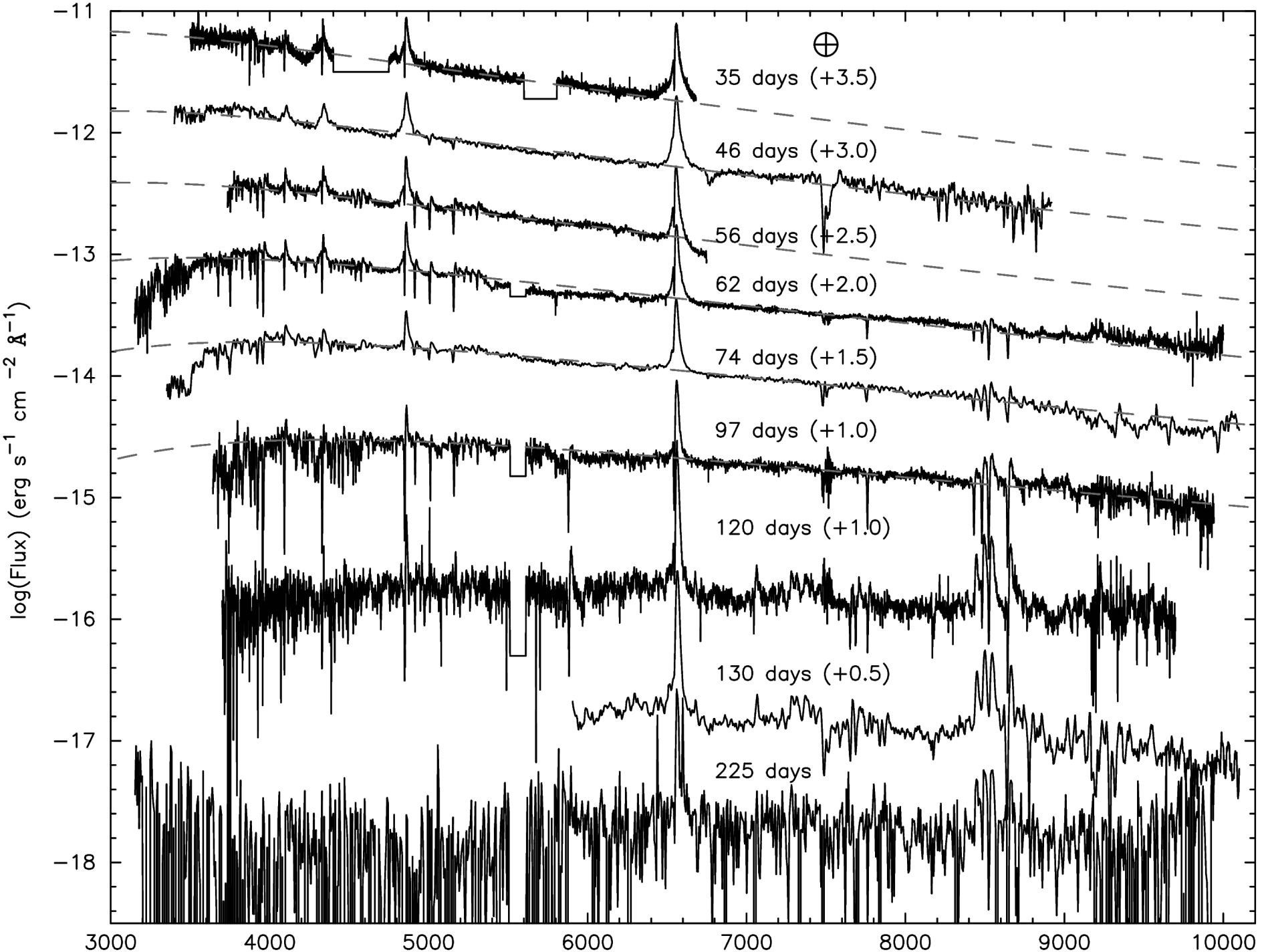


… but not in late SN IIn

SN 2010jl

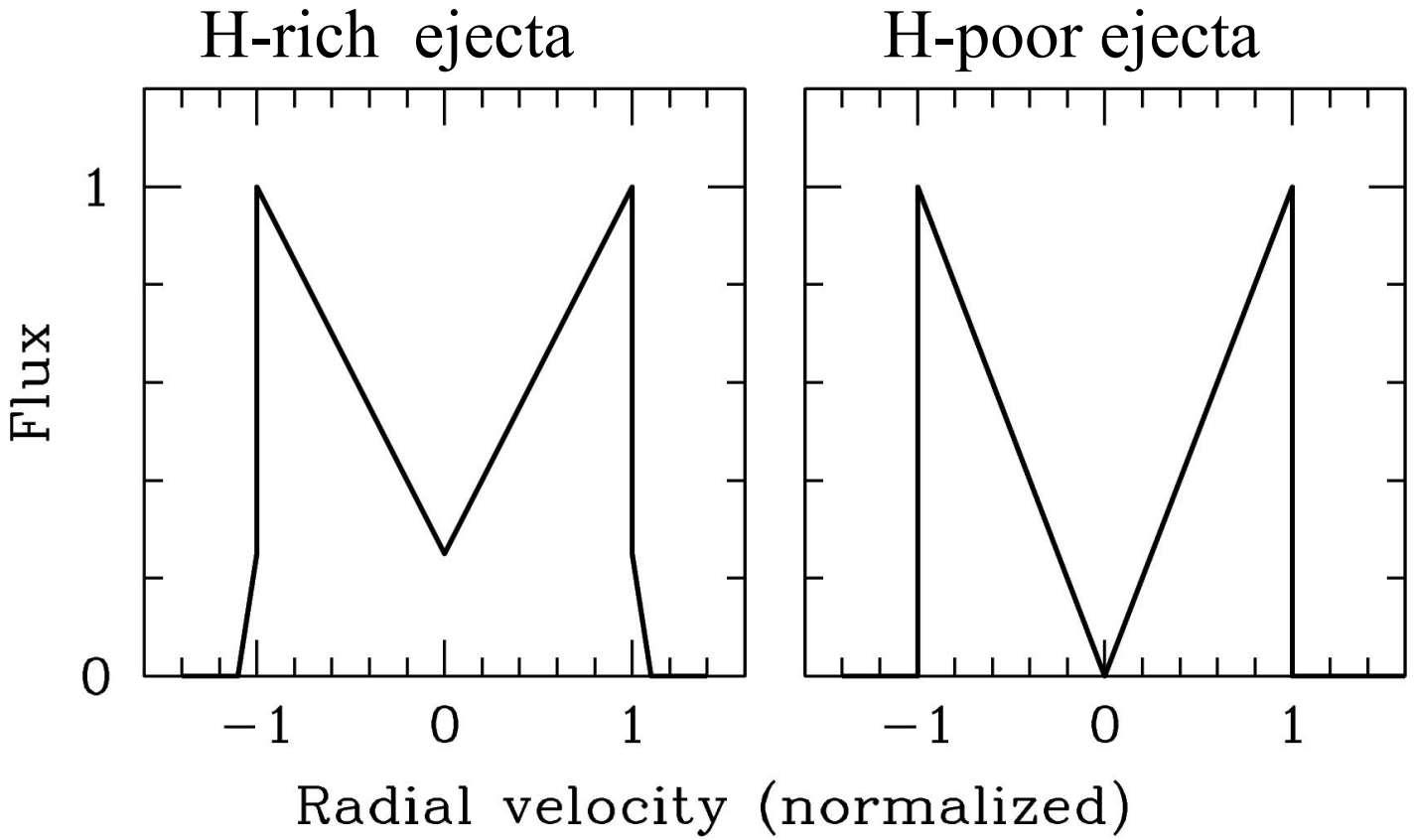

SN 2010jl
Nov 5 Keck/LRIS
Nov 7 Keck/DEIMOS
Nov 15 Lick
Nov 30 Lick
Jan 4 Lick
Jan 26 Lick
Feb 2 Lick
Feb 9 Lick
Mar 31 Lick
May 12 Lick
7000 K
log F$_\lambda$ (scaled)
Rest Wavelength (Å)
4000
5000
6000
7000
8000
9000
10^5
10^4
10^3
10^2
10^1
10^0

SN 2009kn : twin of SN 1994W



thin CDS

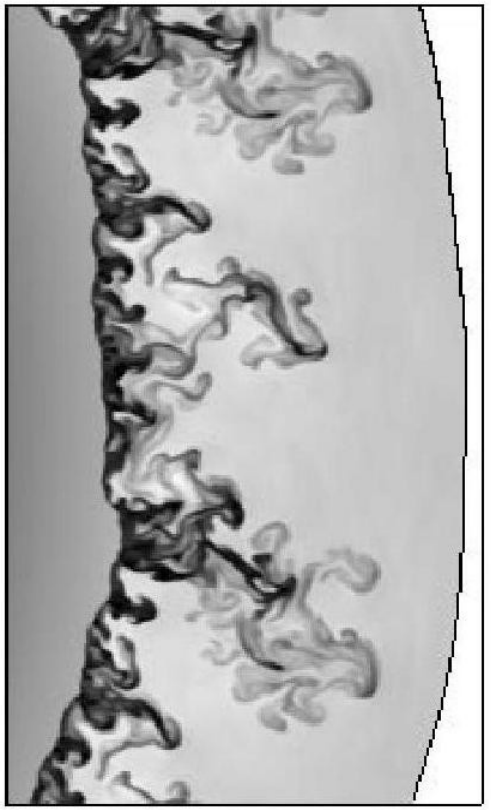
1. optically thin line => boxy)
2. optically thick ...



Never observed !

RT instability (Chevalier 1982; Chevalier & Blondin 1995)

fragmented CDS

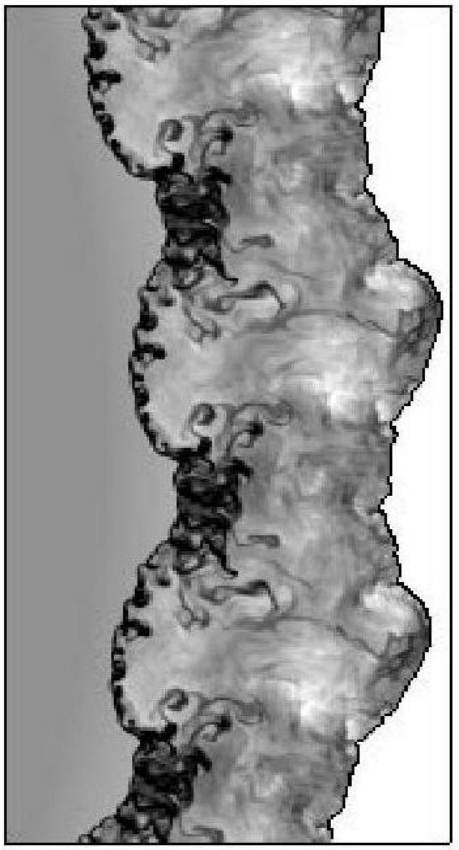


(Blondin & Ellison 2001)

boxy

Never observed in SNIIn !

well mixed fragmented CDS



(Blondin & Ellison 2001)

«parabolic»

(Chugai et al 2004)