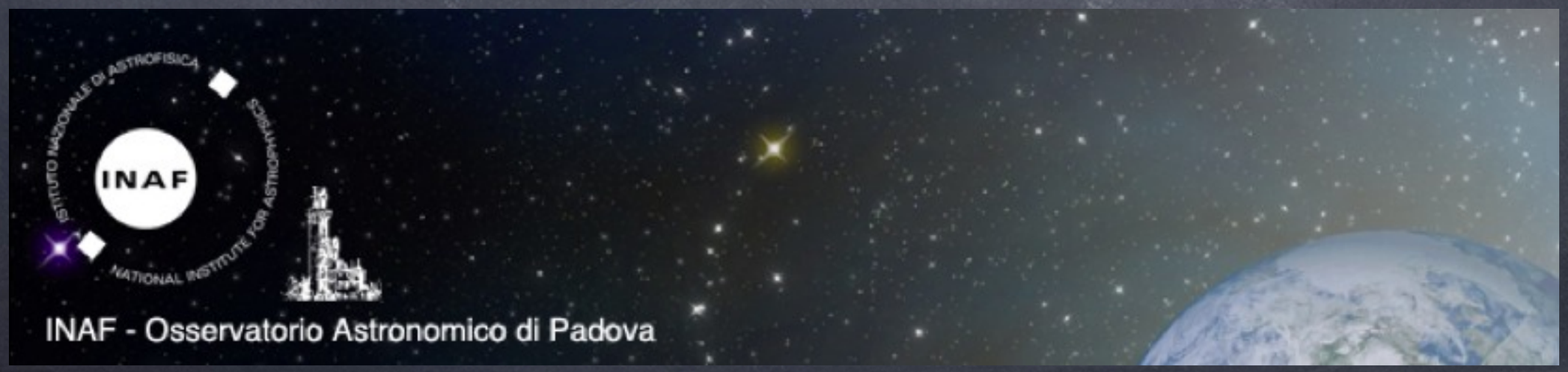
Early Interaction in CC-SNe

Massimo Turatto

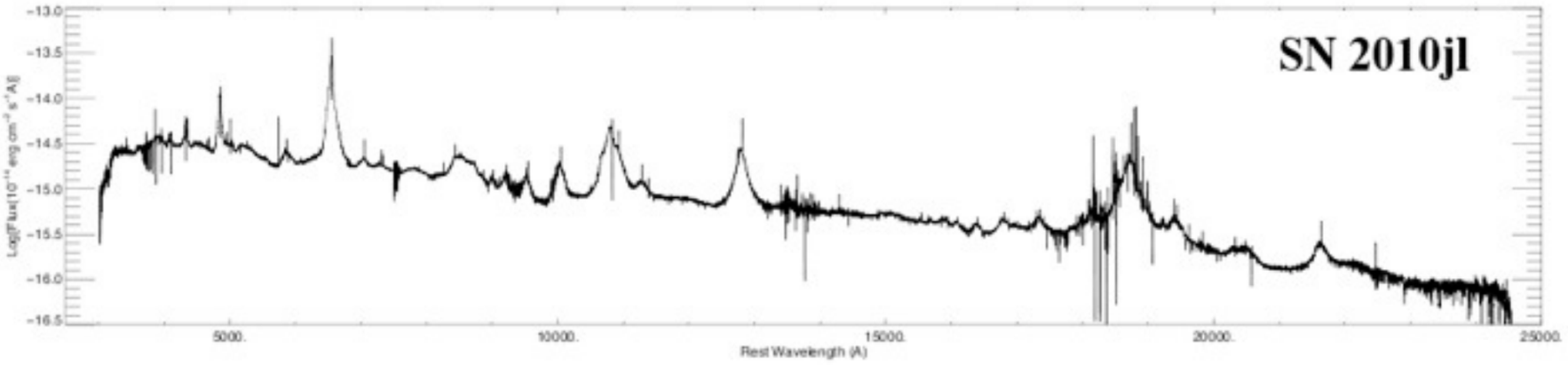


outline

- IIn & super-luminous
- new Ibn. Scenario
- early interaction in IIP
- conclusions

strong interaction

- classical SNIIn, e.g. 1988Z (MT+ 1991), 1995N, 1995G, ...



Pastorello et al. 2005

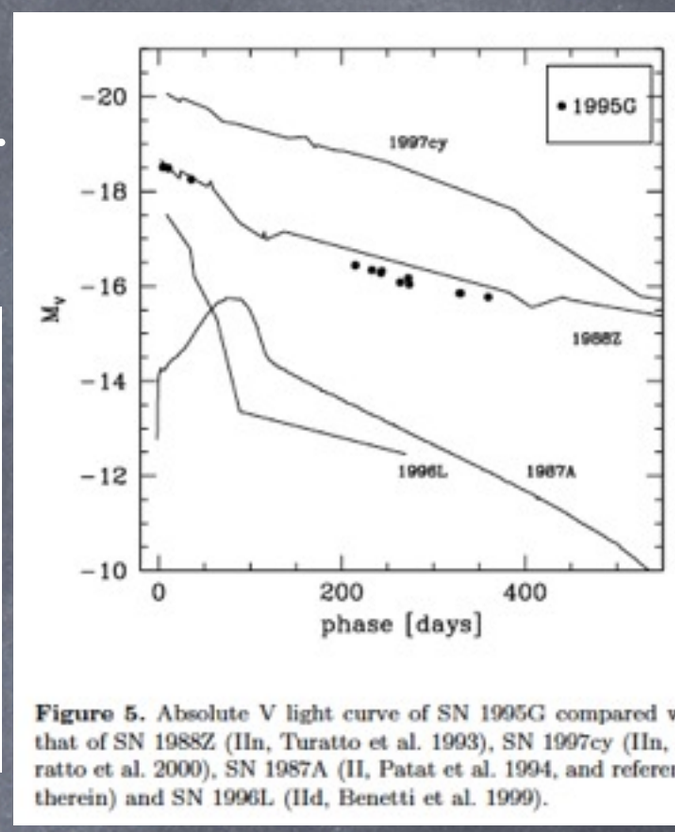


Figure 5. Absolute V light curve of SN 1995G compared with that of SN 1988Z (IIn, Turatto et al. 1993), SN 1997cy (IIn, Turatto et al. 2000), SN 1987A (II, Patat et al. 1994, and references therein) and SN 1996L (IId, Benetti et al. 1999).

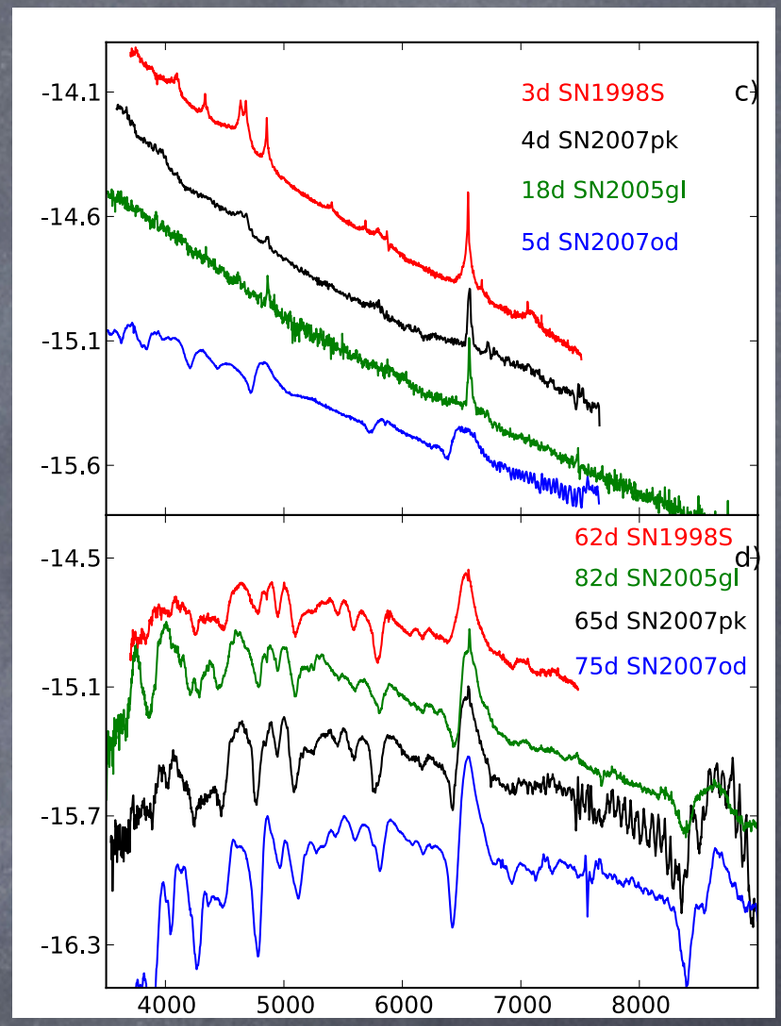
associated to explosion of massive stars (LBV??, timing??)
suggestive but indirect proofs:

- transitional 2001ig and 2003bg (radio l.c. modulation => recent LBV S Dor variations; Kotak & Vink 2006)
- 2007rt (Trudle 2009)
- 2006tf (Smith 2008)
- 2010jl (massive progenitor, Smith 2011, Zhang et al. 2012)
- 2010mc (Ofek et al. 2013, outburst 40d before; probably 2009ip-like !)

- SNIIn: phenomenological not physical class

  -impostors
  - M<-16 (Smith+ 2011, Pastorello, 2011)
  - LBV eruption
  - 2009ip re-emerging from behind the Sun

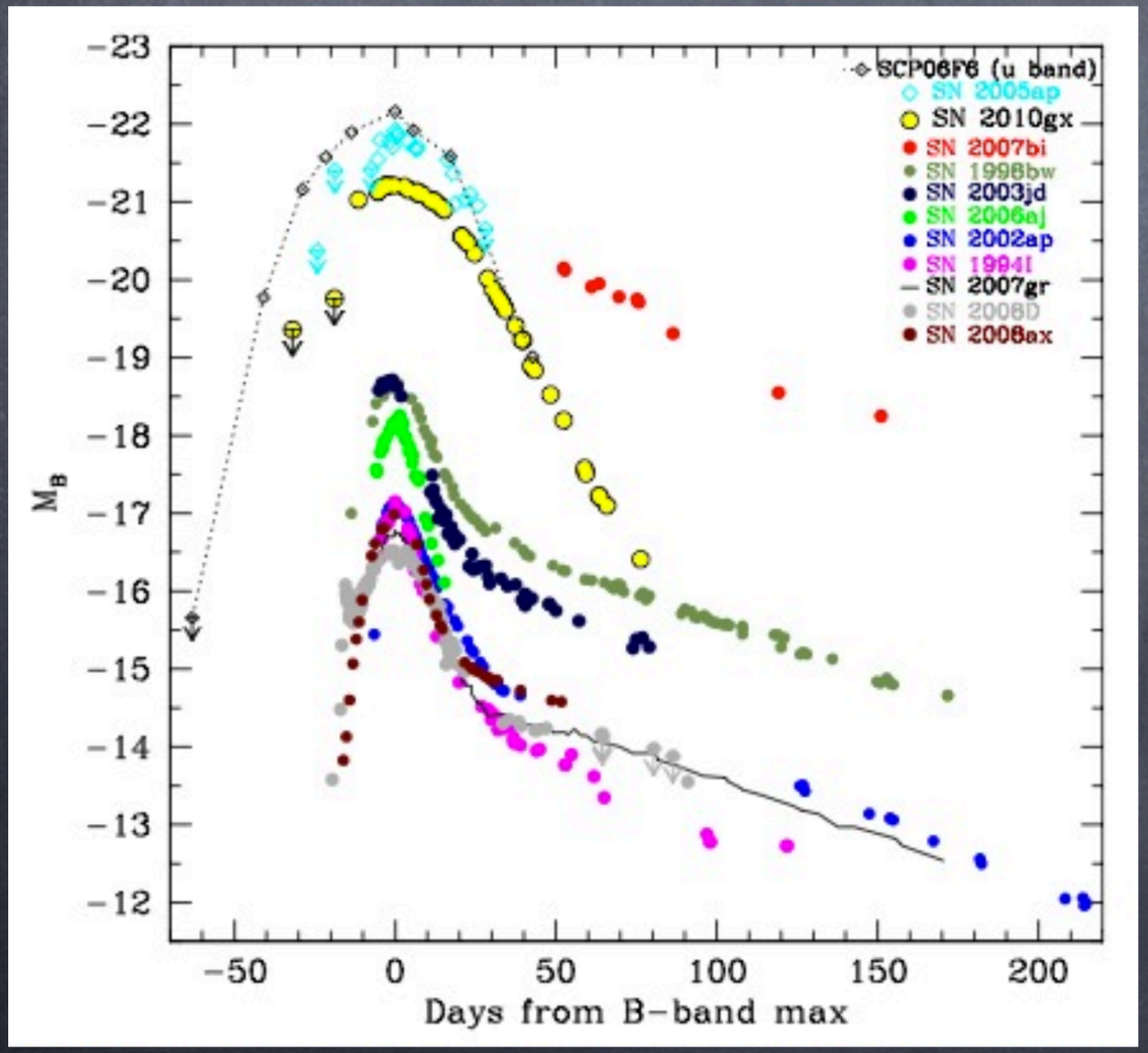
  -mixed objects
  - 2005gl (LBV progenitor, Gal Yam & Leonard 2009)
    IIn ➠ IIP
  - 2007pk (Inserra+ 2013)

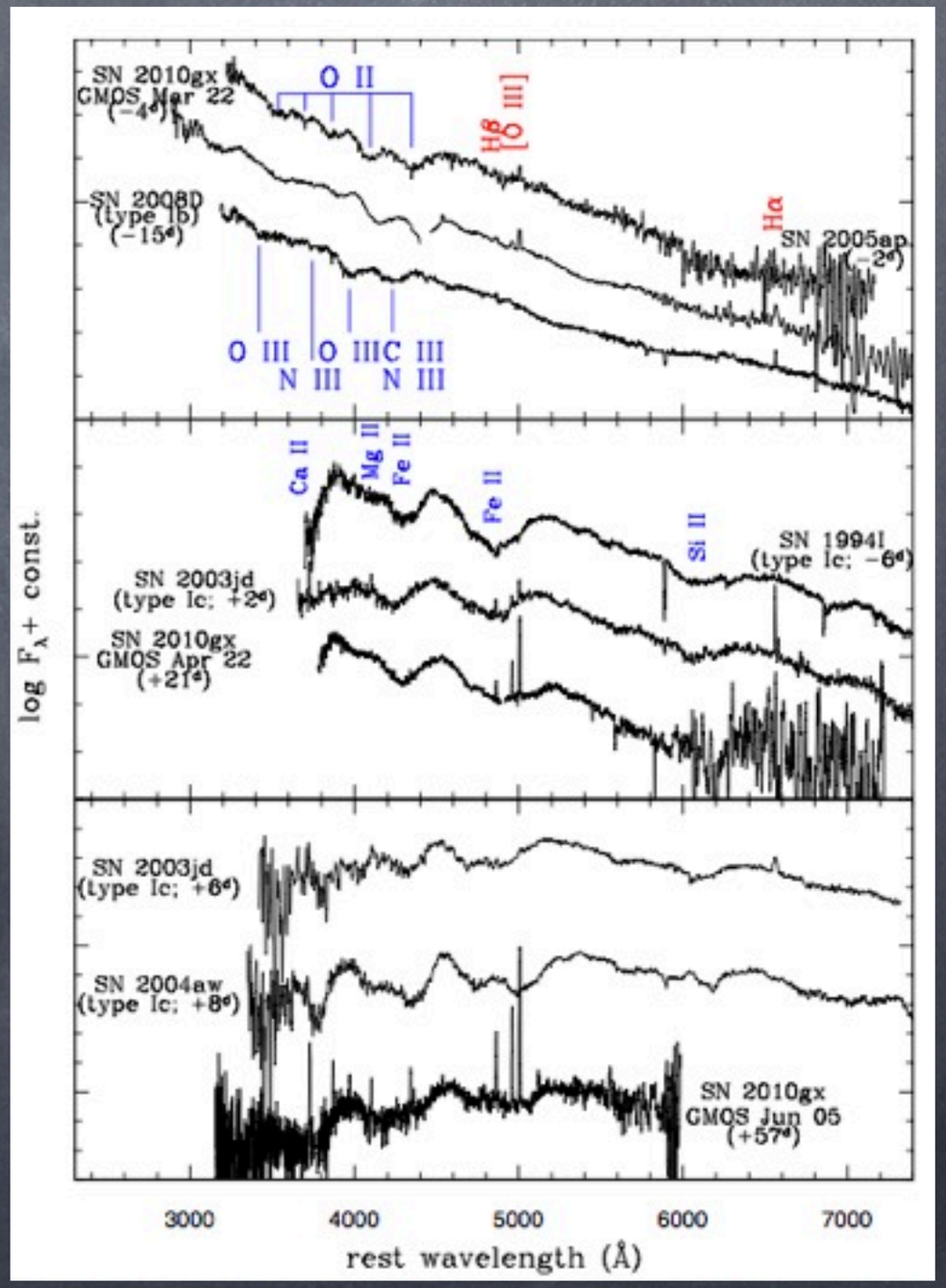


  -SNIa-CSM
  - homogeneous sample of 15 (Silverman+ 2013)
  - -21 < M < -19, lack He, dust forming, young stellar pop.
  - spectrum: 1999aa + BB cont + narrow lines from CSM
  - Ia with a symbiotic nova progenitor (SD scenario)
  - no proof !!

strong interaction of SN ejecta + dense, H-rich CSM

- Superluminous SNe
  - 2006gy (Smith+ 2007, Agnoletto+ 2009; ηCar-like eruption prior to explosion ~10$M_\odot$)
  - 2010gx (Pastorello+ 2010, **featureless then SN Ic emerging**; M(^{56}NI)<0.4$M_\odot$, Chen+ 2013)
  - 2008es Gezari, Aldering
  -





CSM-Interacting SE-SNe (Ibn)

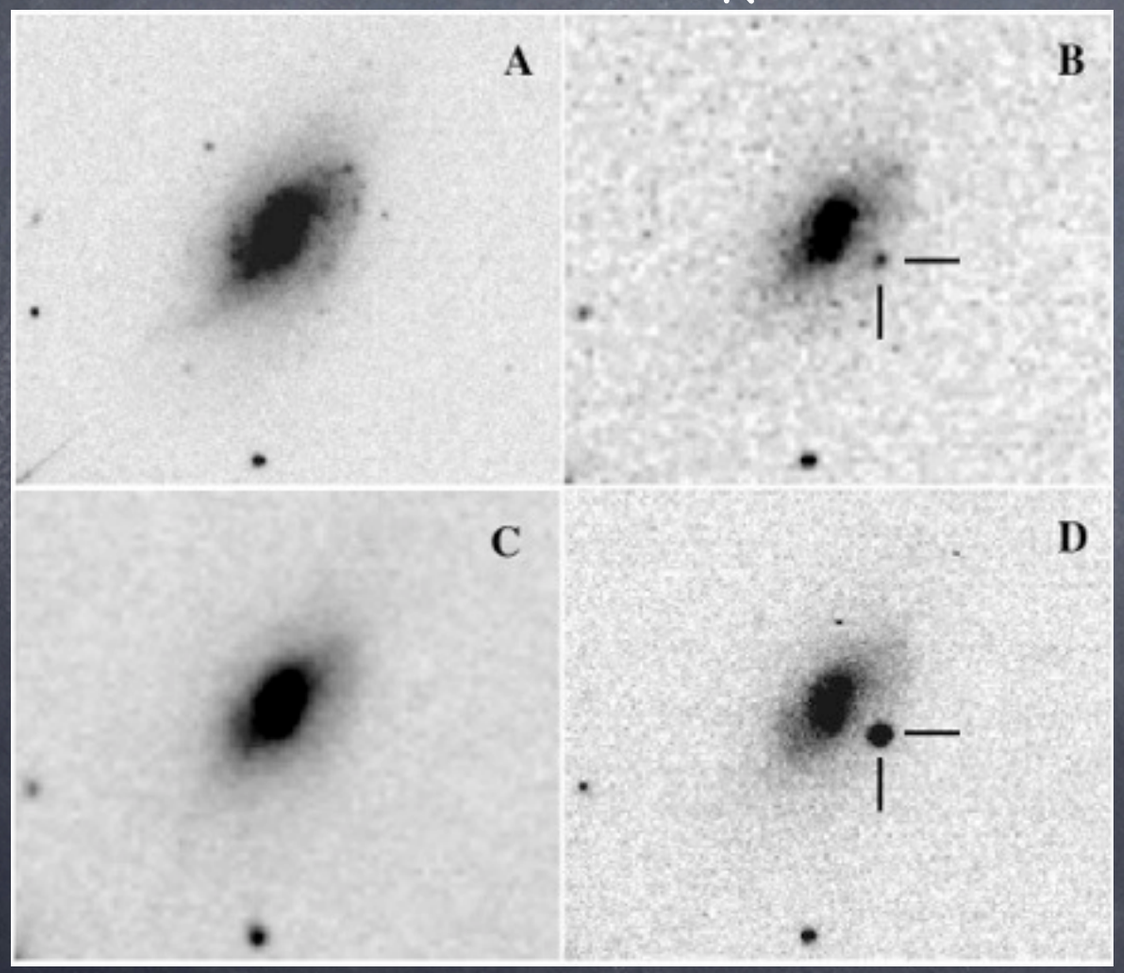
- narrow HeI emissions (analogy to IIn)
- interacting with He-rich, H-deprived CSM
- first example: SN1999cq (Matheson+ 2000)
- key object: SN2006jc, pre-SN burst
- systematic analysis by Pastorello+ 2008

SN2006jc

Pastorello+ 2007

transient (10/2004)
M_R=-14.1, 5 epochs

r' SDSS



Itagaki (09/2006) SN 2006jc (10/2006)

Δd=0.1±0.3arcs

full evolution

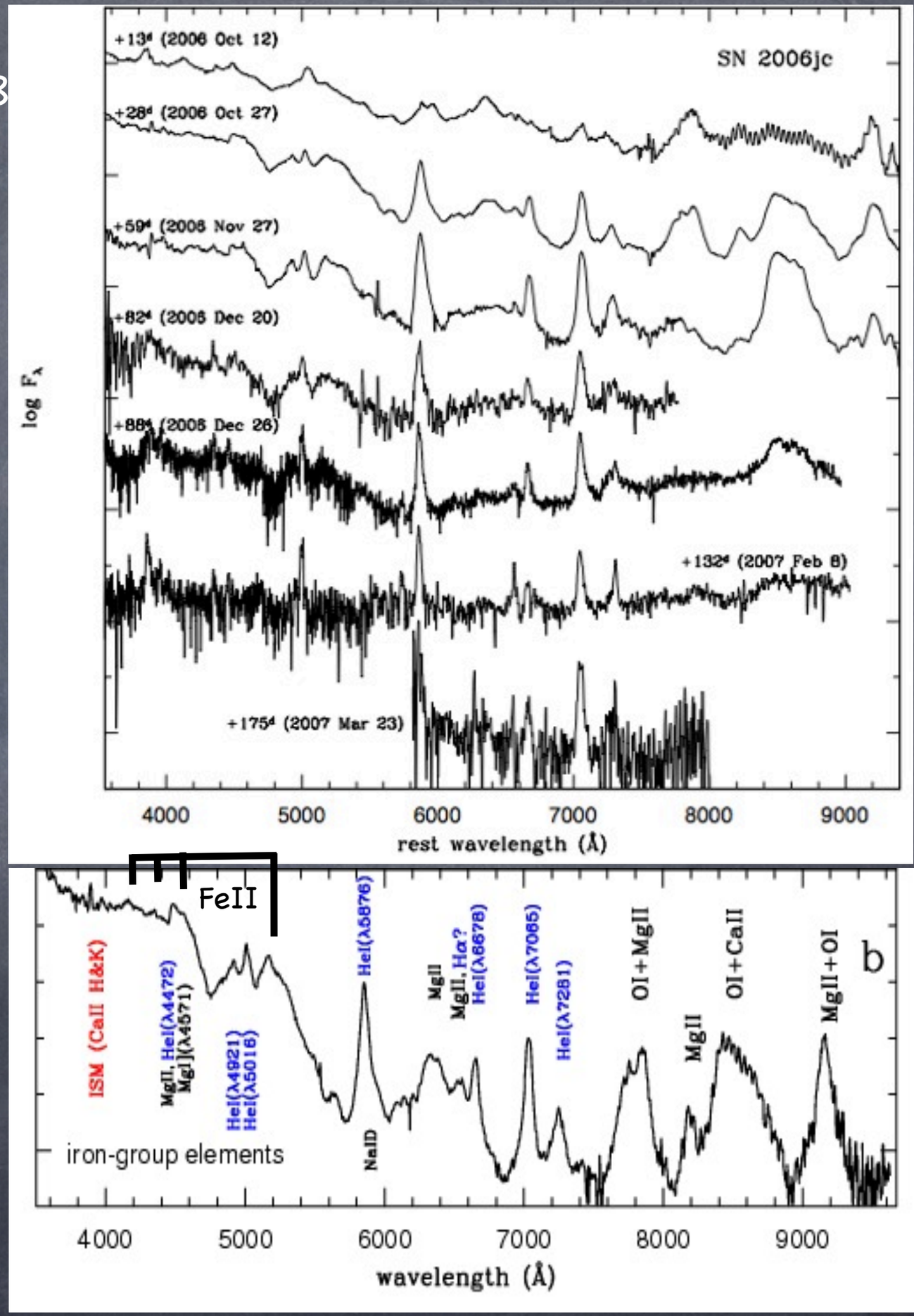
Pastorello+ 2007, 2008

<u>early (t<130d)</u>:

- blue pseudo-continuum (blend of FeII as in IIn, Foley+ 2007)
- X-ray and UV emission (Immler+ 2008, Bufano+ 2009)
- broad (5-9000 km/s) lines of IME
- moderately narrow (2-3000km/s) HeI consistent with ejection in 2004 (M_{CSM}~0.1$M_\odot$ Smith+ 2008, Anupama 2009)
- HeI (blue P-Cyg) v~1000km/s
- residual narrow Hα

<u>late (t>130d)</u> (Pastro+ 2008):

- no blue ps-continuum
- narrow (2200km/s) HeI
- stronger narrow(!) Hα



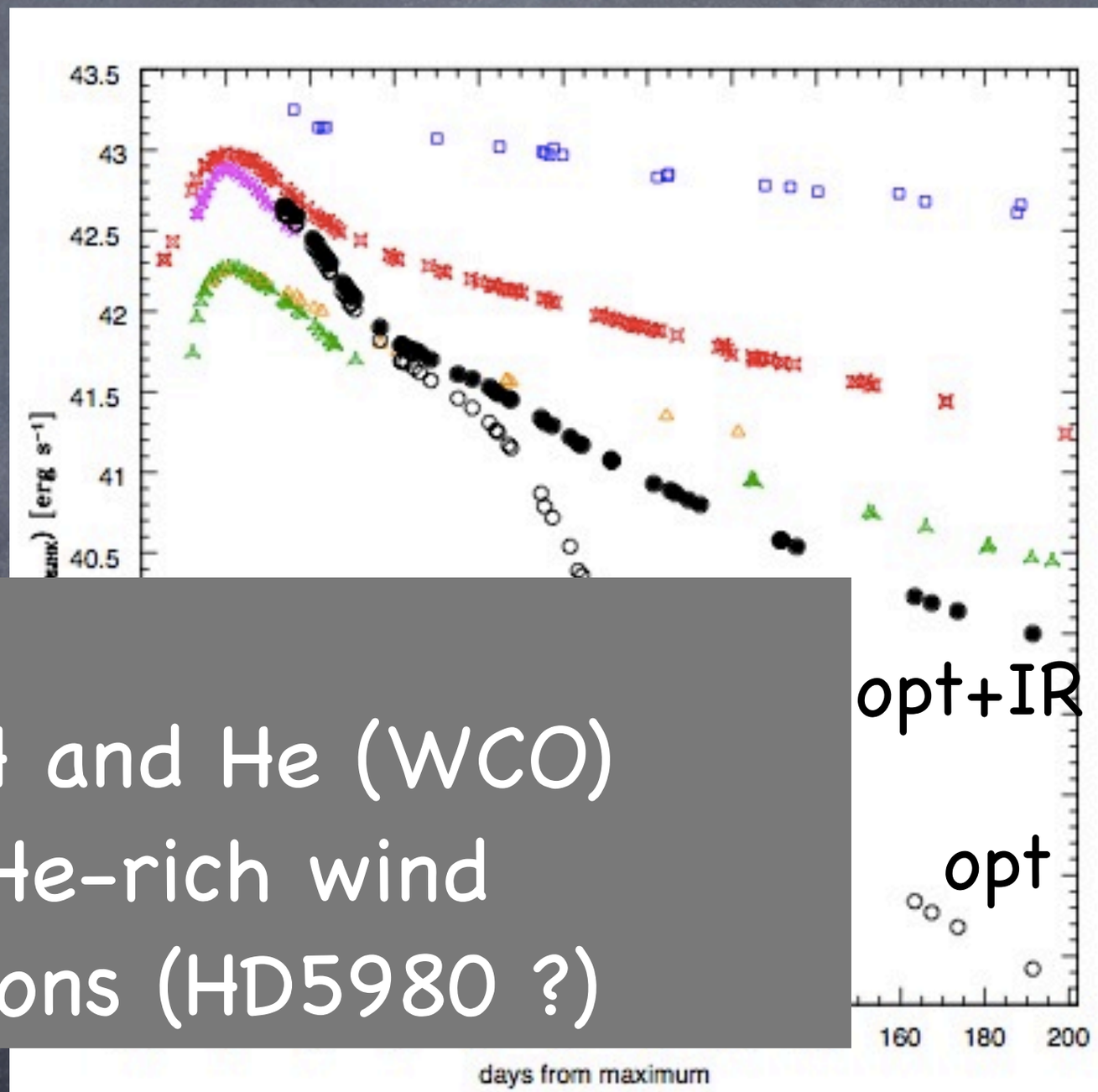
light curve:

- as fast as normal Ib/c
- moderate ^{56}Ni

very early dust (Di Carlo+ 2008, Mattila 2008, Smith+ 2008..):

- asymmetric line profiles
- IR excess
- 2 components (CDS & pre-existing)

Pastorello et al. 2008

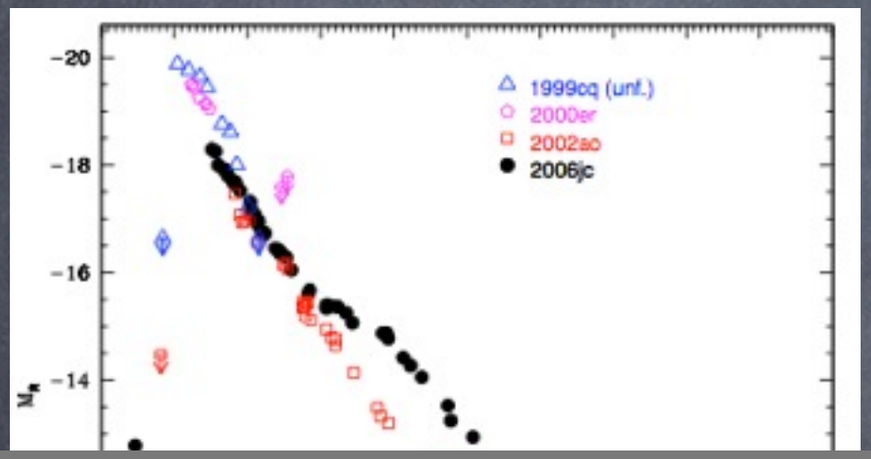


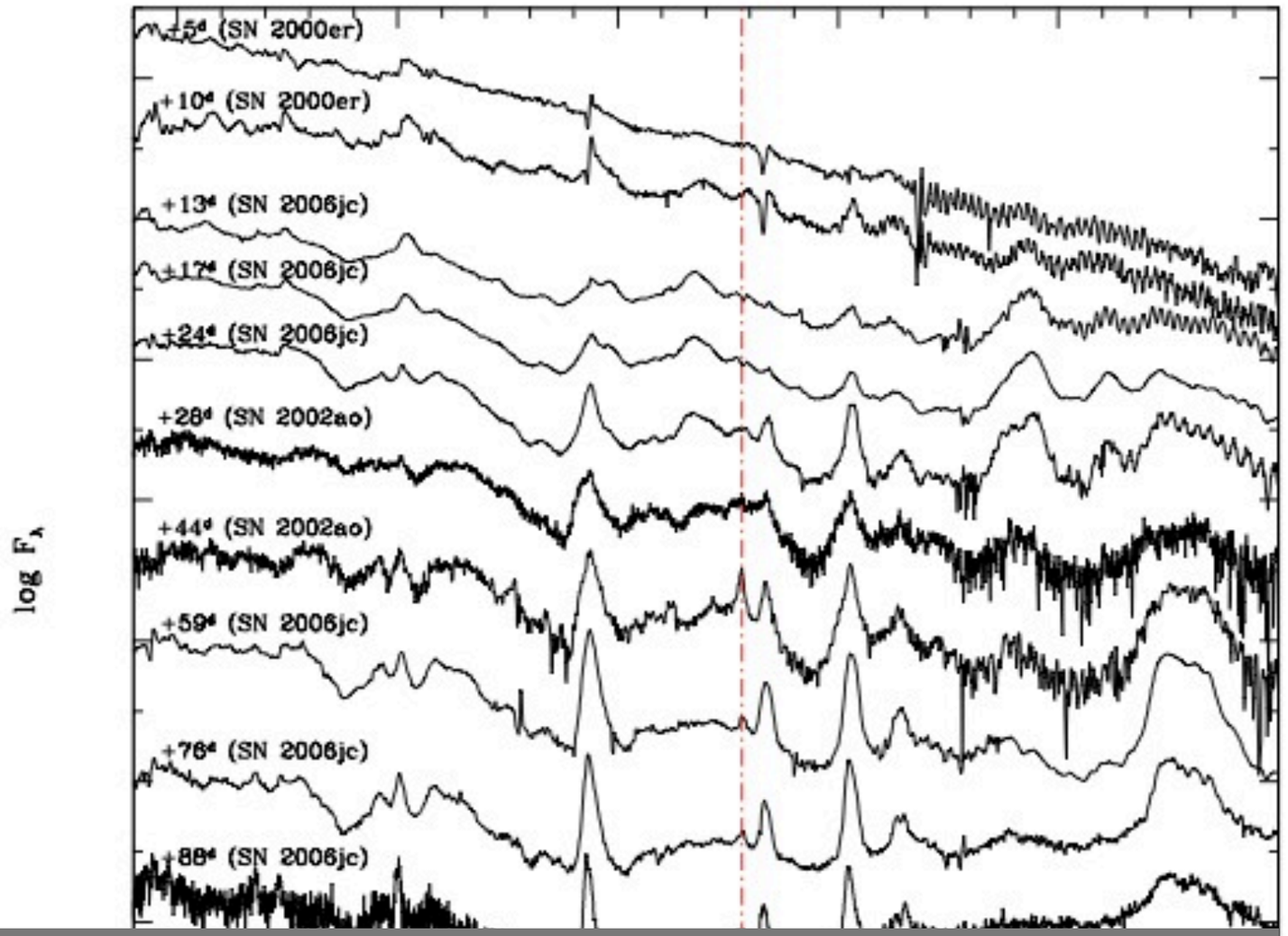
scenario:

- progenitor stripped by H and He (WCO)
- interacting with a fast, He-rich wind
- experiencing LBV eruptions (HD5980 ?)

common evolution (Pasto+ 2008)

1999cq: poor
2000er: only early
2002ao: only mid-age
2006jc: missing max

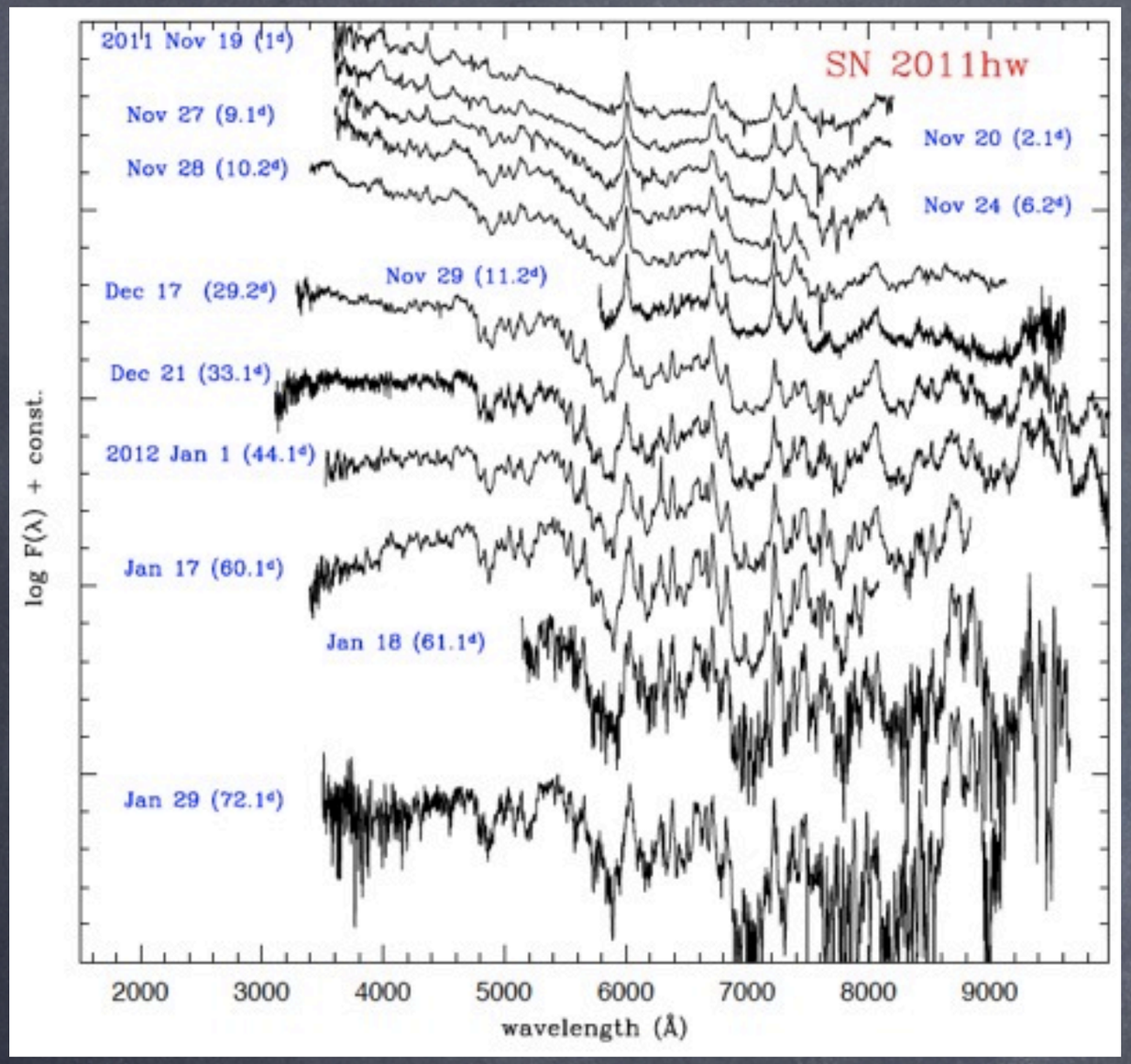




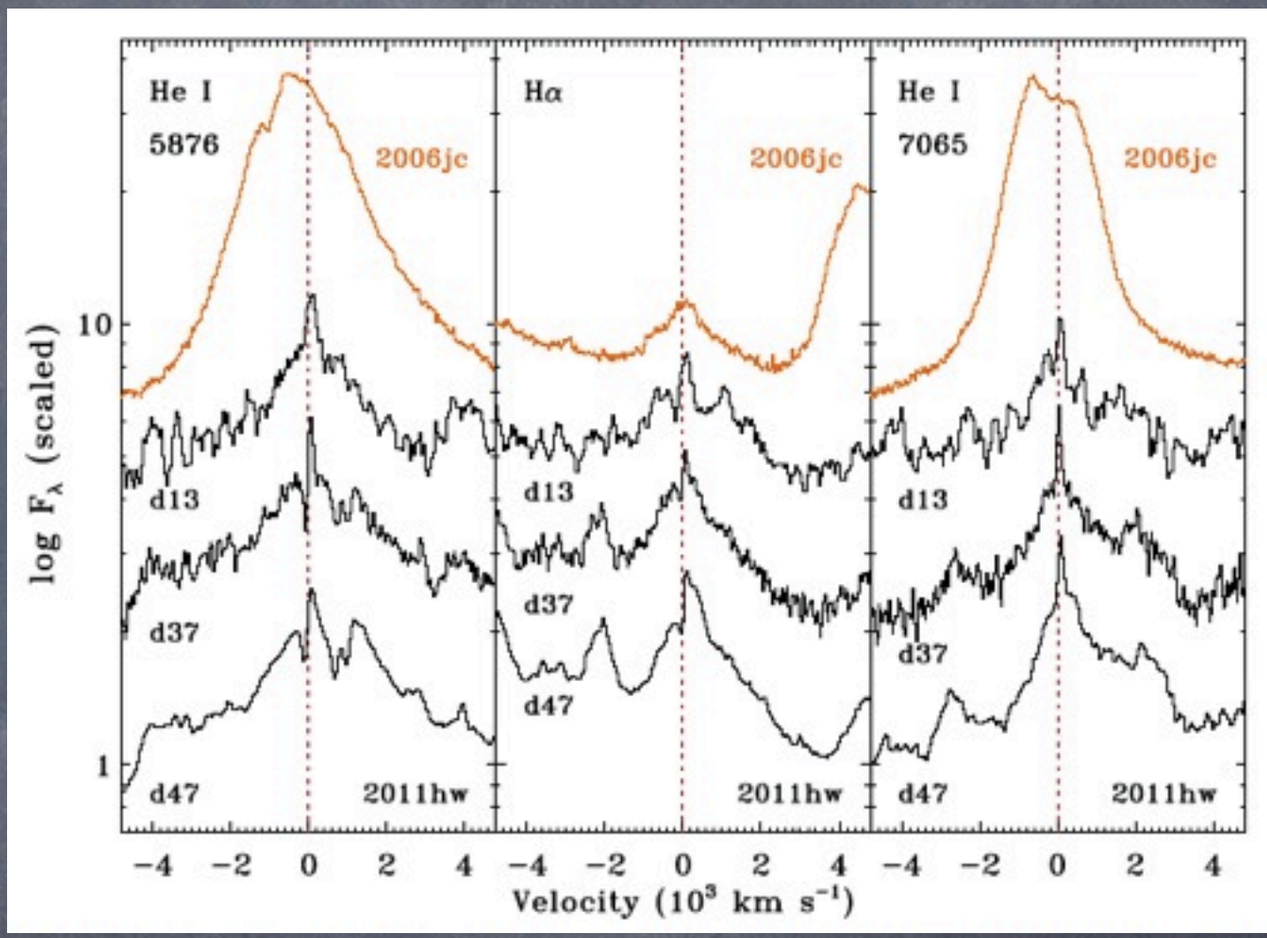
- diffences (e.g. He left in the envelope of 2000er)
- overall similarity, unexpected if interaction

==> all SNIbc interacting with He-rich CSM (WR w. major ejections)

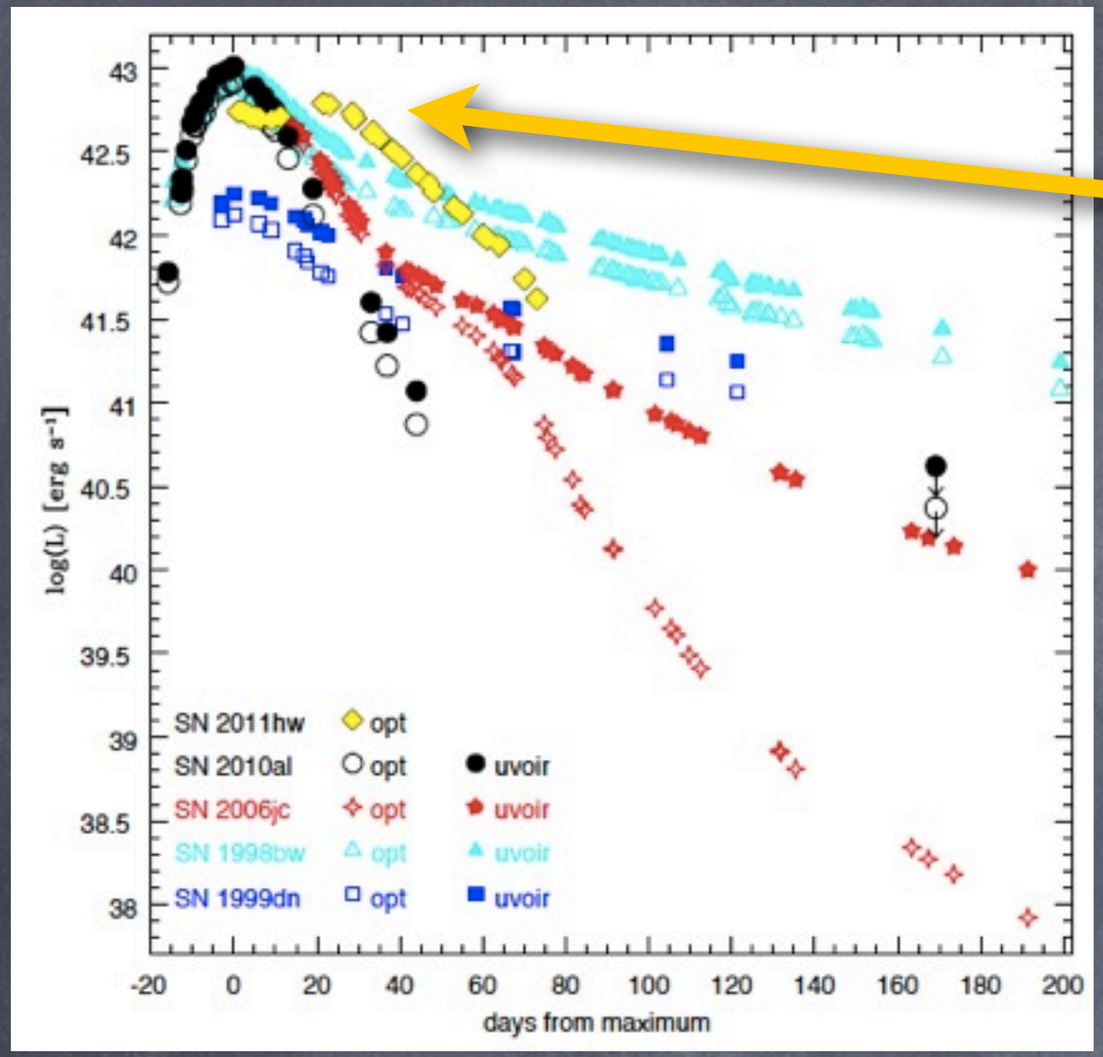
SN 2011hw (Smith+ 2012, Pasto+ 2013)



H !!



- HeI and Hα (FWHM~1900km/s) + unresolved components (v~250km/s)
- narrow (v<250km/s)coronal lines ([ArX], [FeV], [FeVII]..)
- pseudo-continuum
- lower contast (+ 6000°K BB due to H ??)

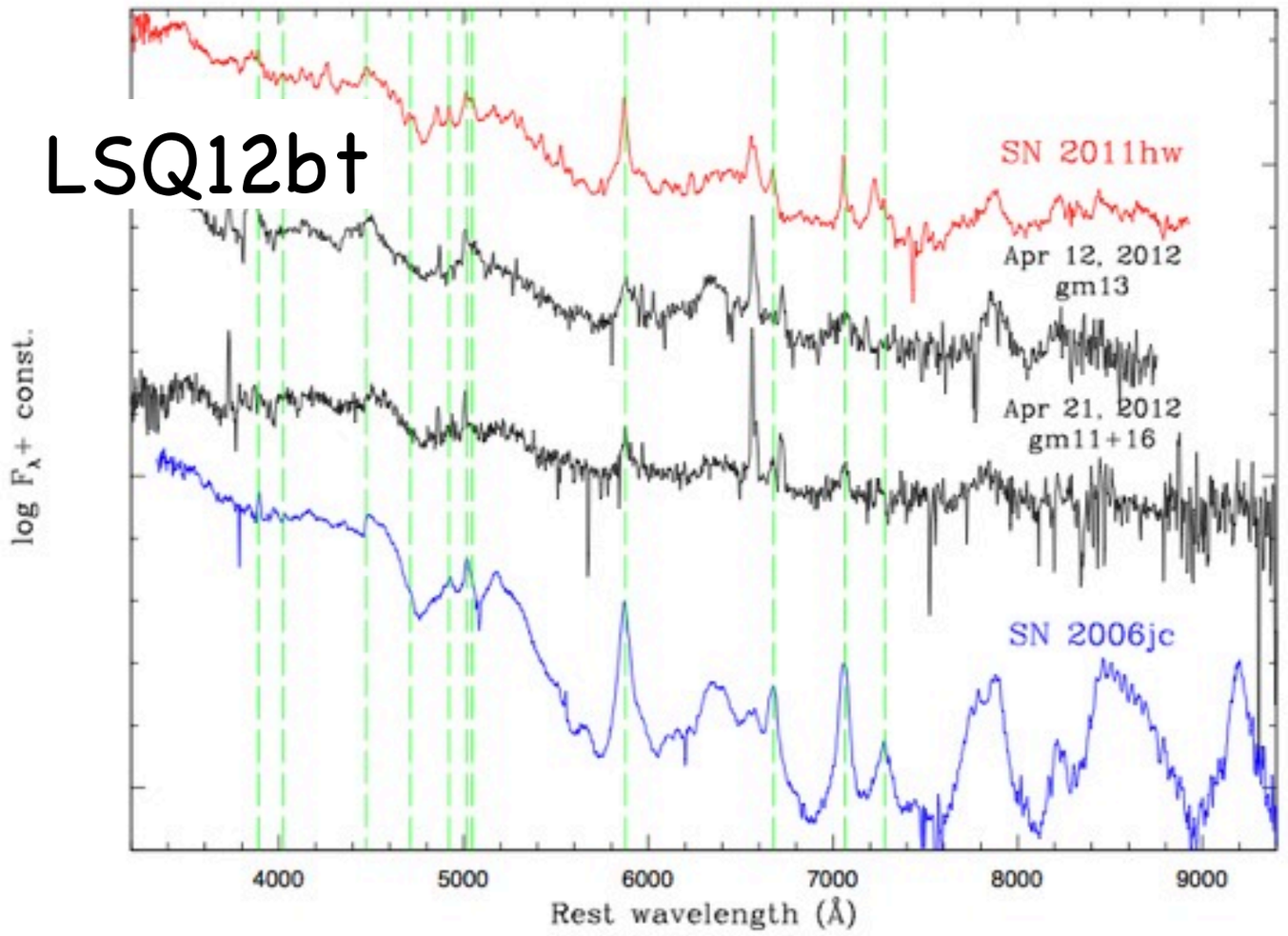


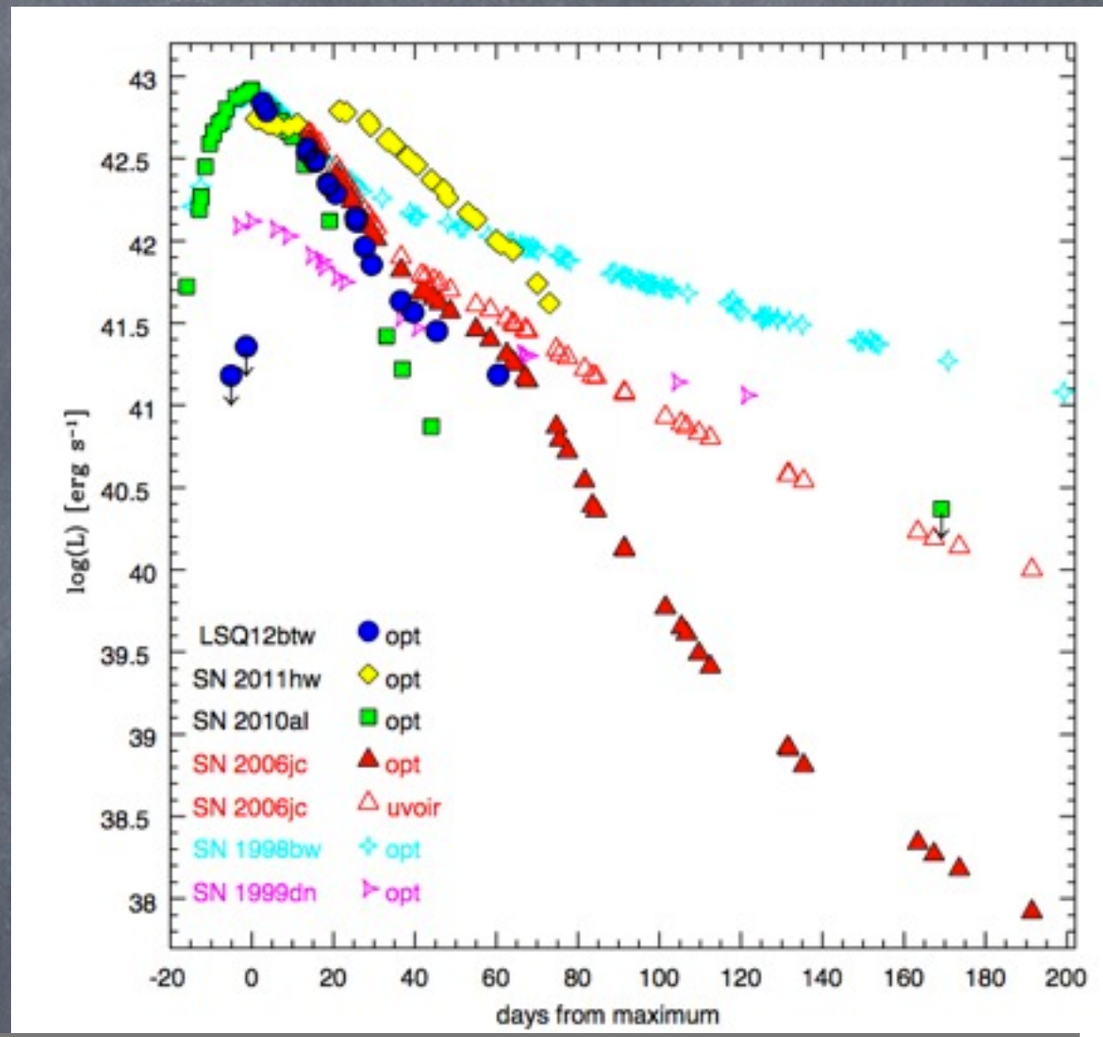
light curve:
bright
flat (supported by H)

- fast and slow CSM components, not typical WR
- He- and H-rich CSM
- stronger CSM interaction

-Ofpe/WN, LBV ➠ WR

the last born: LSQ12btw





similar to 2011hw

- fast and slow CSM components, not typical WR
- He- and H-rich CSM

-Ofpe/WN bridging LBV to WR (AG Car & R127)

Environment

SN	Host		μ (H73)	M_{btc}	R_{oSN}/R_{25}	12+log(O/H) Tremonti 04	12+log(O/H) @R_{SN}
1999cq	UGC11268	Sbc	35.23	-21.48	0.129	9.23	9.18
2000er	PGC9132	Sab	35.47	-21.63	#N/A	9.26	#N/A
2002ao	UGC 9299	SAB	31.73	-18.07	0.604	8.60	8.36
2006jc	UGC 4904	SBbc	32.00	-17.28	0.703	8.45	8.17
2005la	KUG1249+278	Sc	34.46	-18.29	0.938	8.64	8.26
2010al	UGC4286	Sab	34.25	-20.42	0.371	9.03	8.88
2011hw	Anon	S	34.88	#N/A	#N/A	#N/A	#N/A
LSQ12btw	SDSS J101028+05	S	36.87	-19.17	0.239	8.80	8.71
PTF11qcj	PGC2295826	?	35.37	-18.10	0.157	8.60	8.54
PS1-12sk	CGCG208-042	E	36.75	-21.62	0.826	#N/A	#N/A
OGLE	Anon	S?	36.96	#N/A	#N/A	#N/A	#N/A

- spirals (PS1-12sk E with SF)
- all with μ>μ(Virgo) [1% CCSNe Pasto 2008)]
- broad range in M_{host} & Z

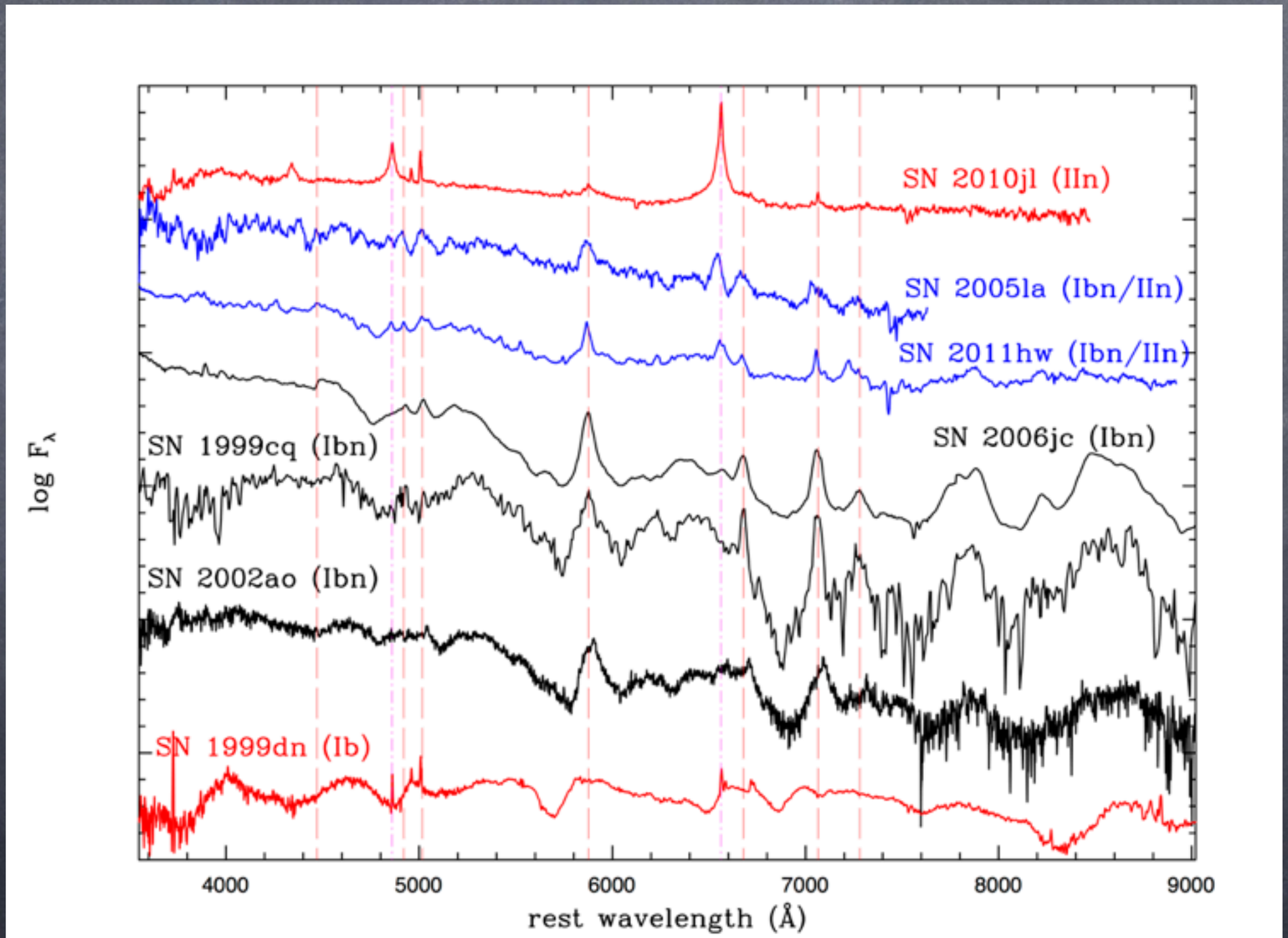
scenario

➡ with slow, dense H-rich CSM (IIn)
0- CCSNe with CSM, 1- final LBV explosions, 2- SNIa, 3- other

➡ with (H+He)-rich CSM (IIn/Ibn)
LBV-to-WN
2005la, 2011hw: slow (<200 km/s) wind (He+H)-rich; stronger interaction modifying l.c.

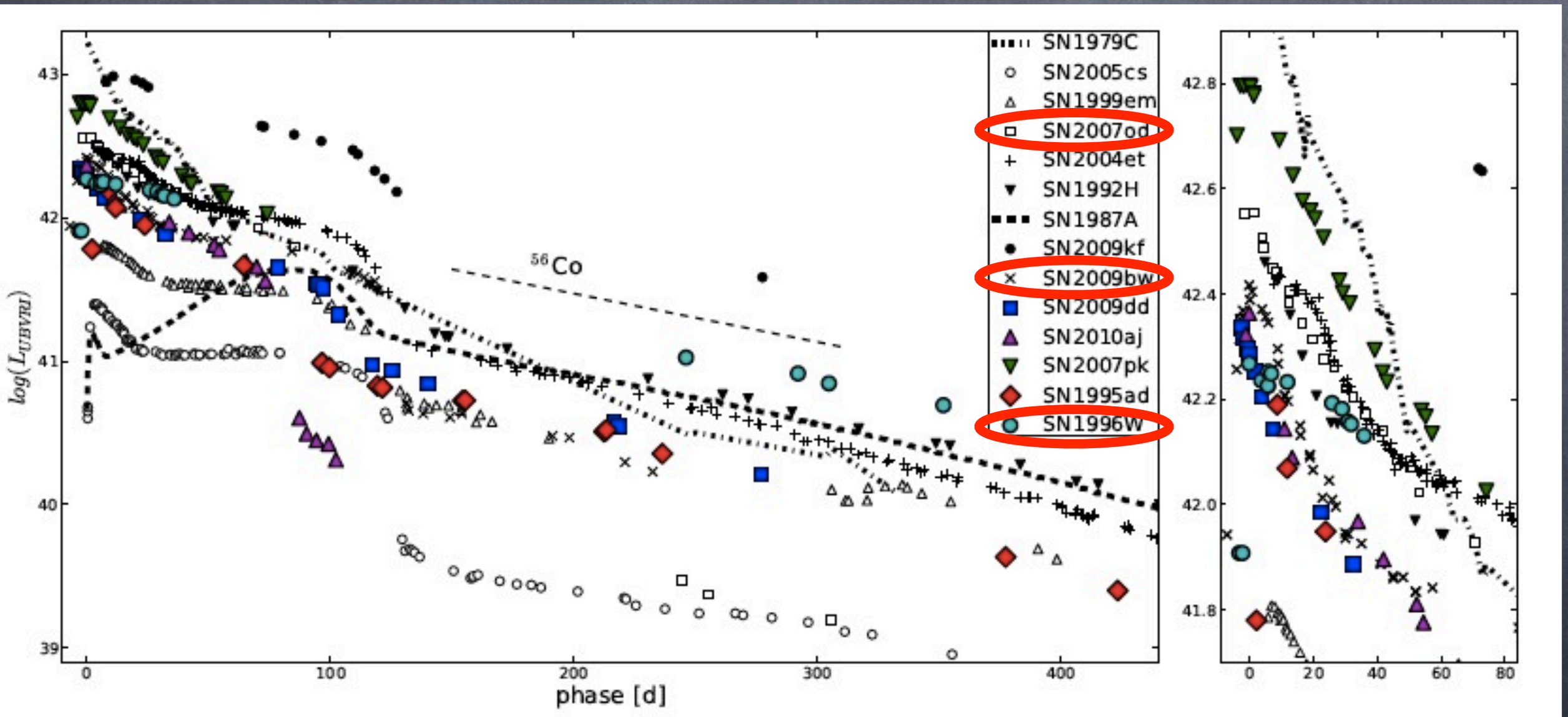
➡ with He-rich, H-depleted CSM (Ibn)
WCO progenitor (SNIc):
2006jc-like, fast wind (~1000km/s) He-rich CSM, late H (far away)
...
WCO/WN progenitor (SNIb): H-stripped, He in CSM & envelope
2010al, 2000er, fast (1000 km/s) wind He-rich, weak/broad H from early phases

spectroscopic sequence



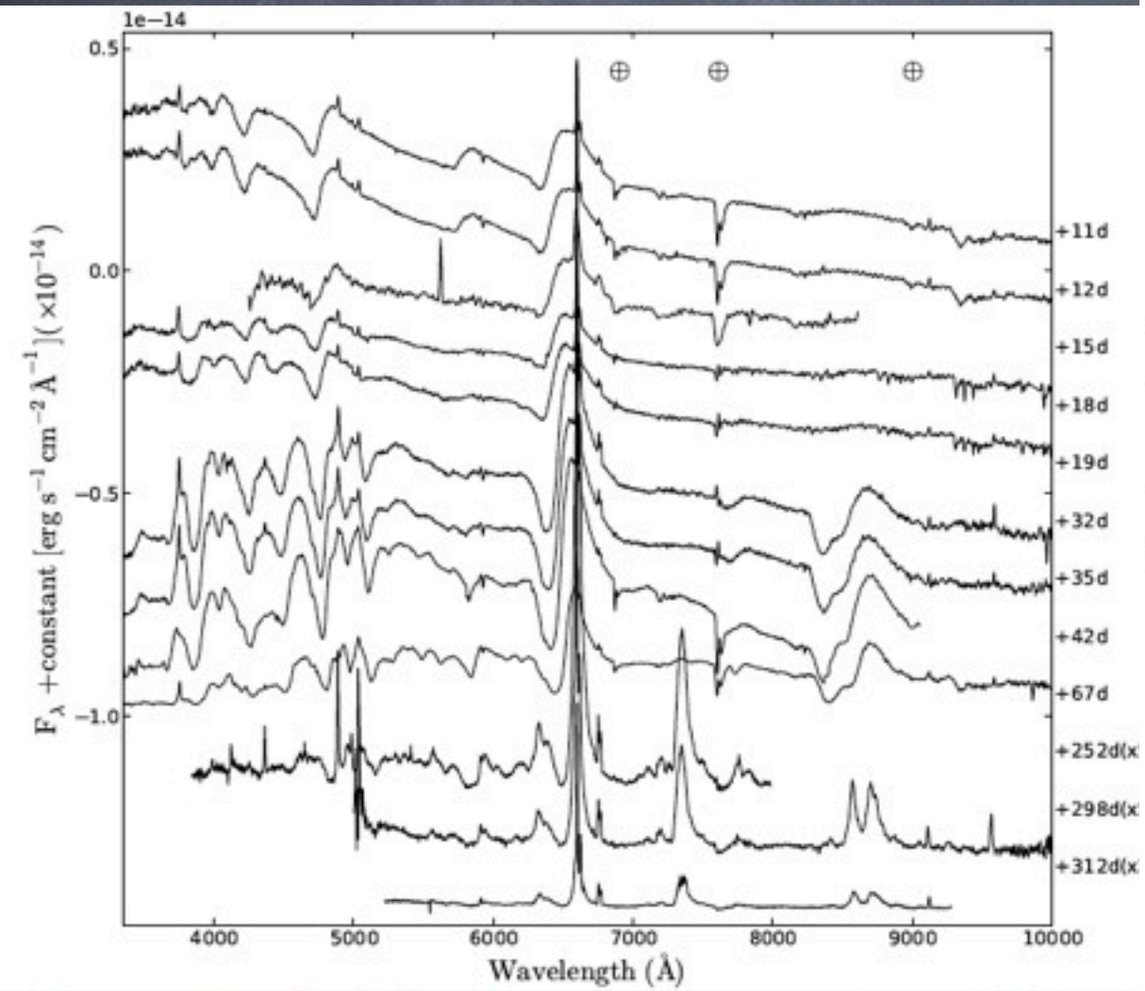
moderately bright SNIIP

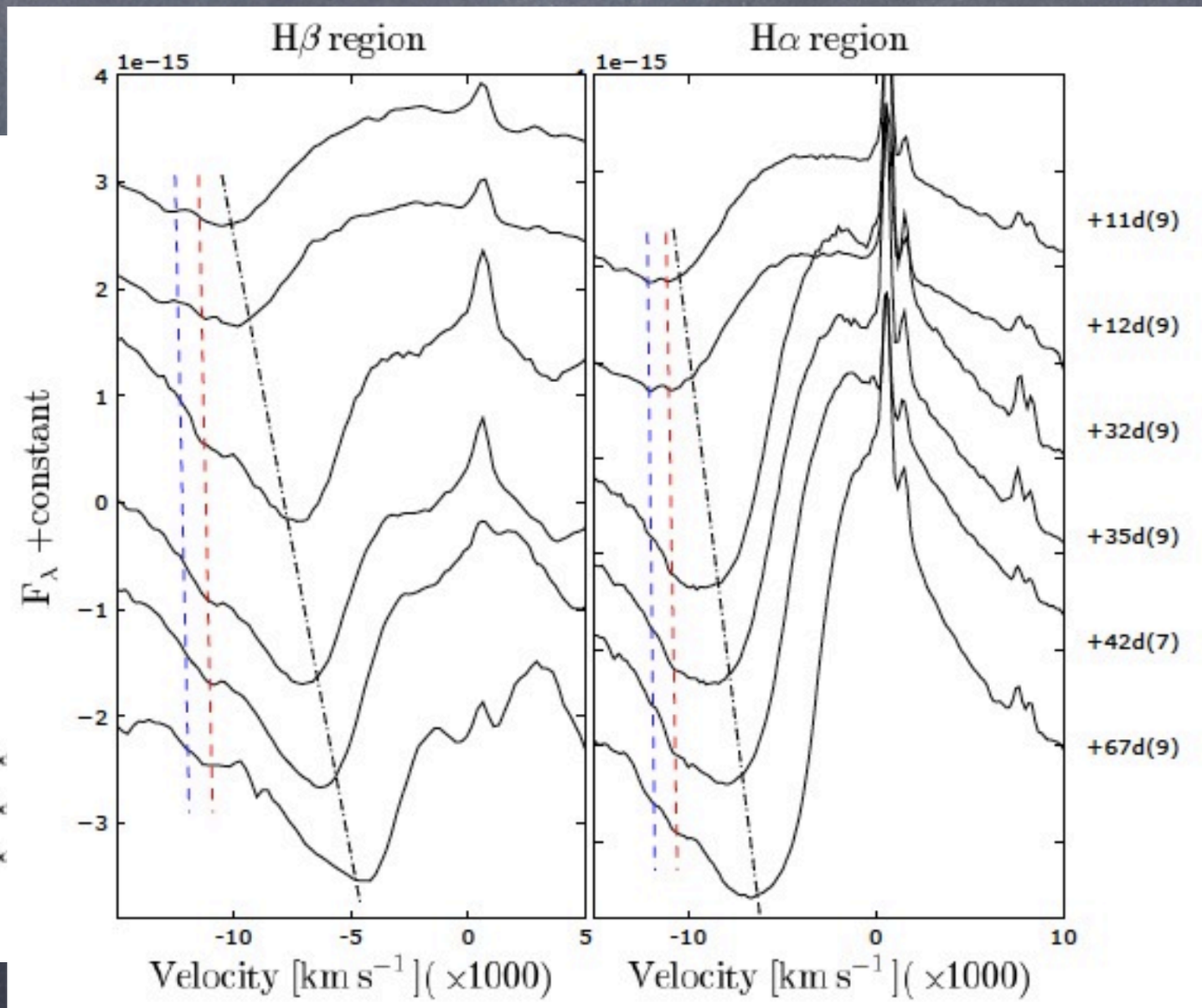
Inserra+ 2010-1013



1996W

- typical IIP
- well designed P-Cyg
- M_B^{max}=-17.59
- M(Ni)=0.14M$_\odot$



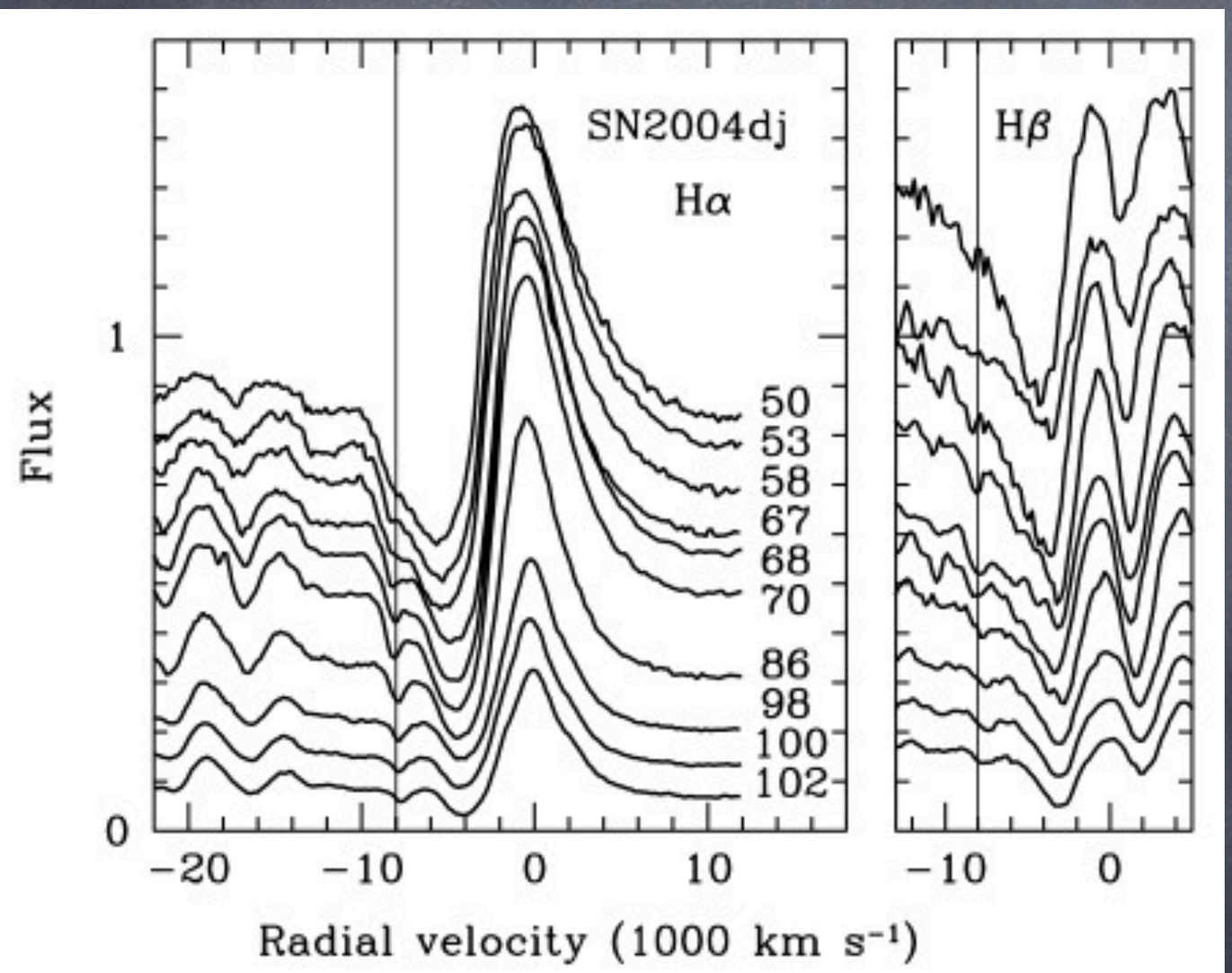


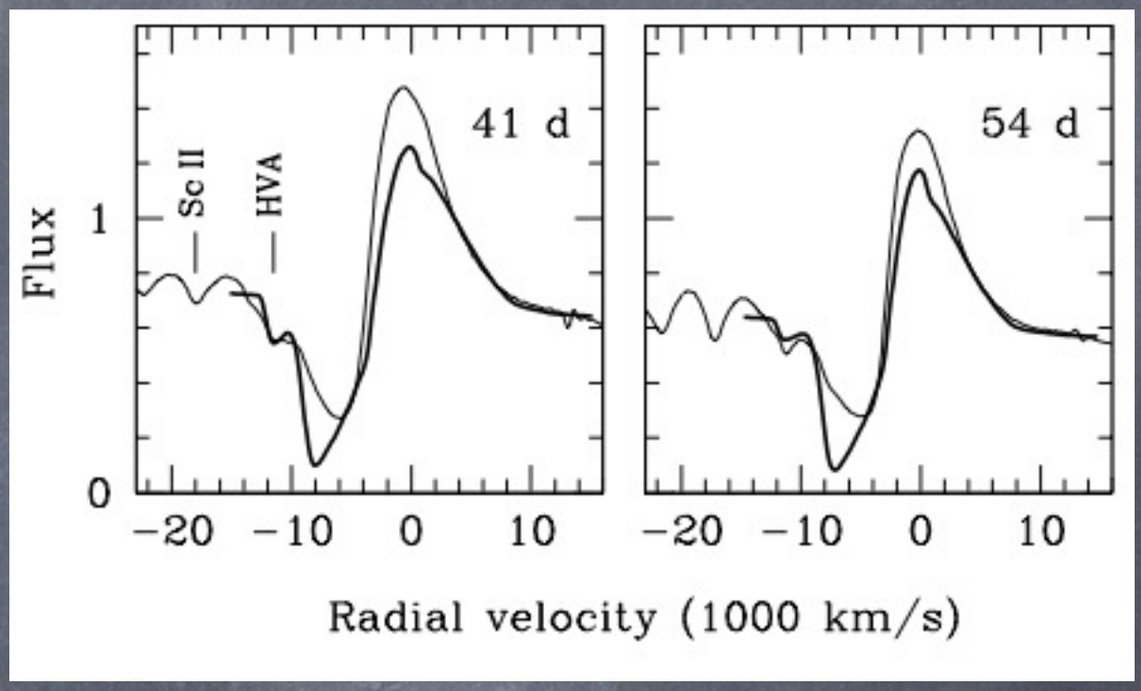
HV features of Hα, Hβ and HeI

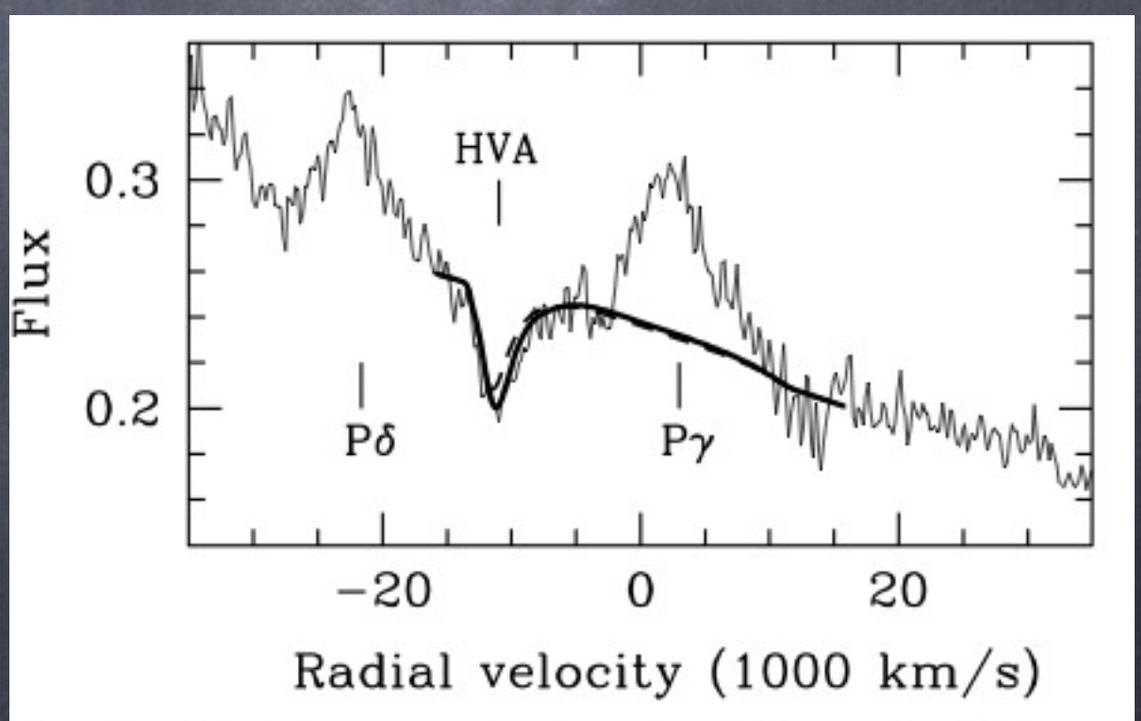
N.Chugai, RC, VU 2007

1999em

2004dj

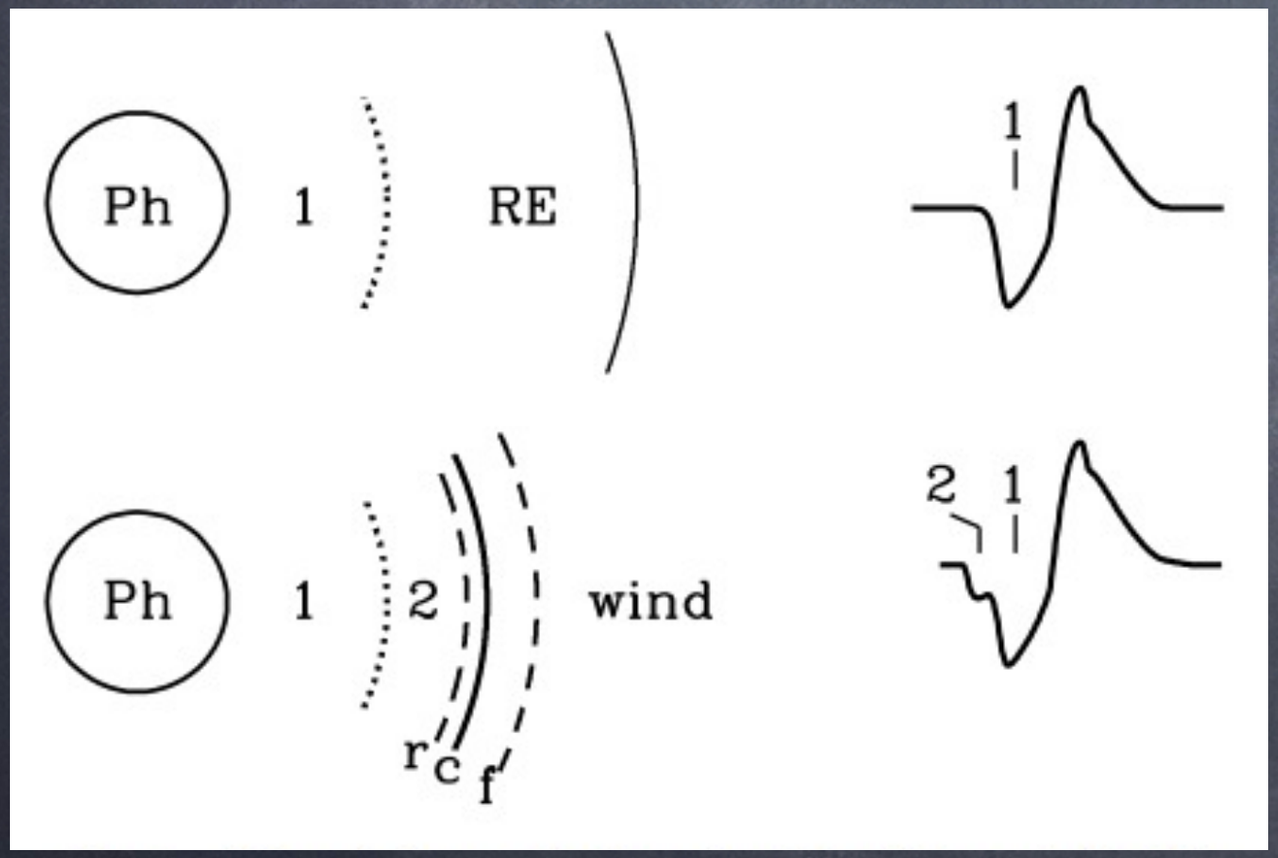


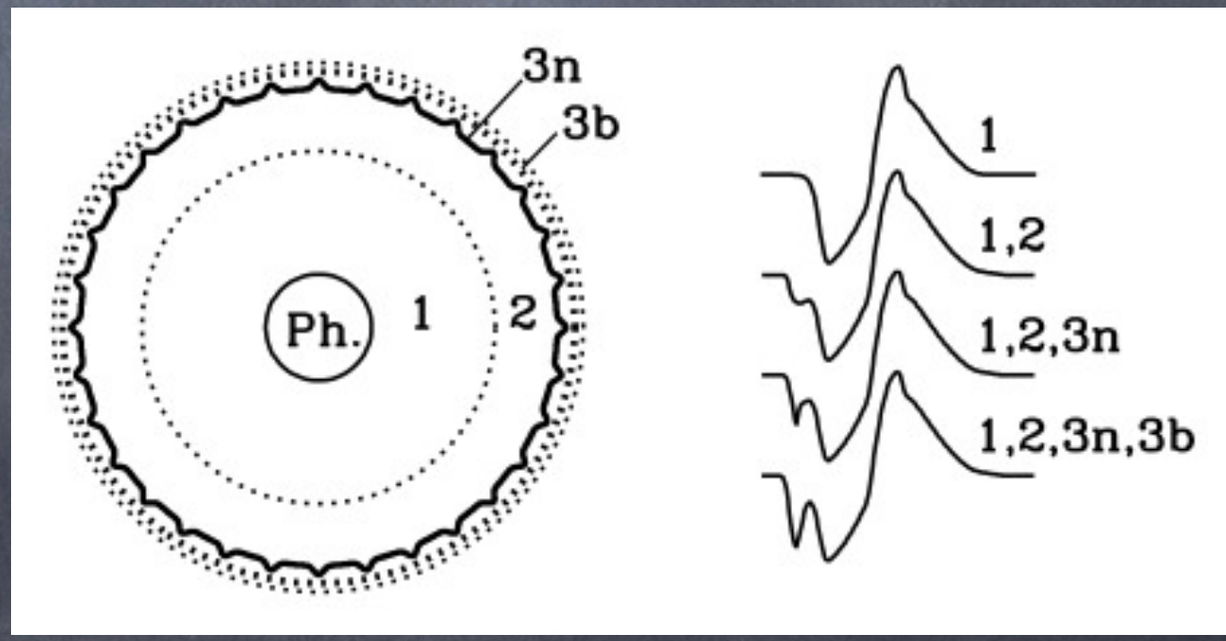




interaction with a RSG wind

10^{-6} M yr^{-1}
10 km/s

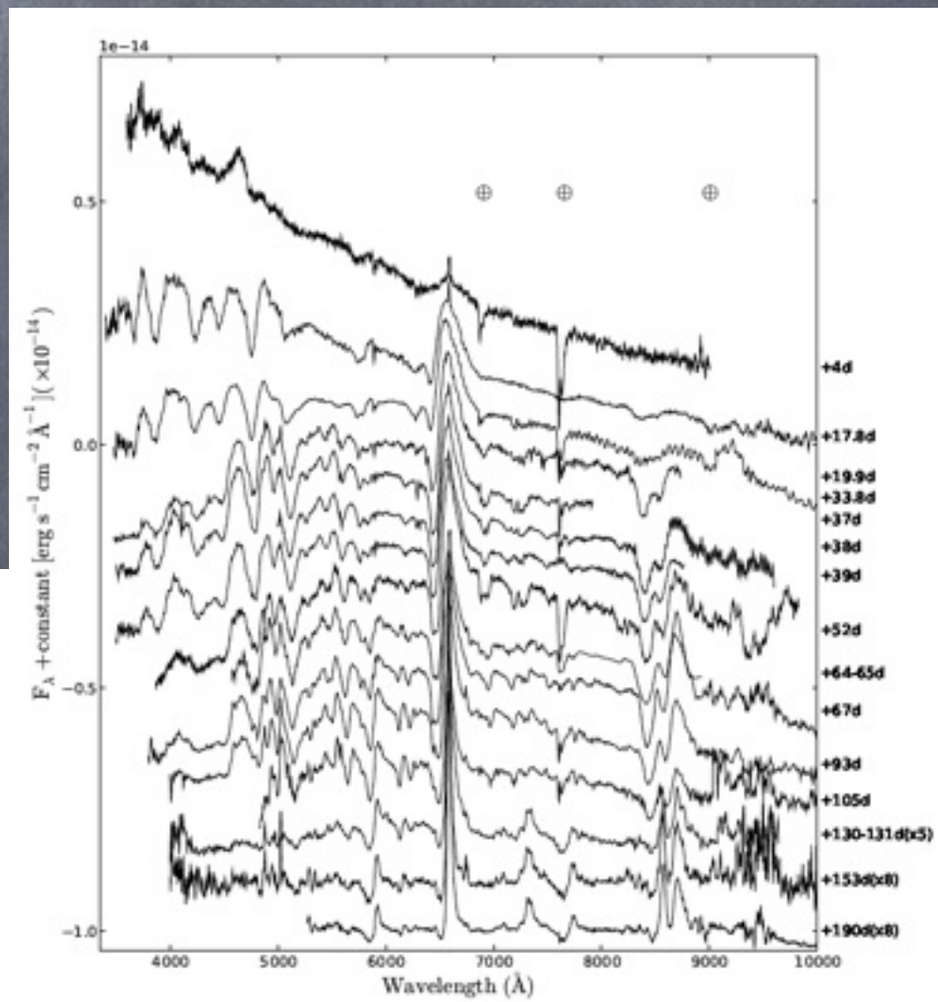




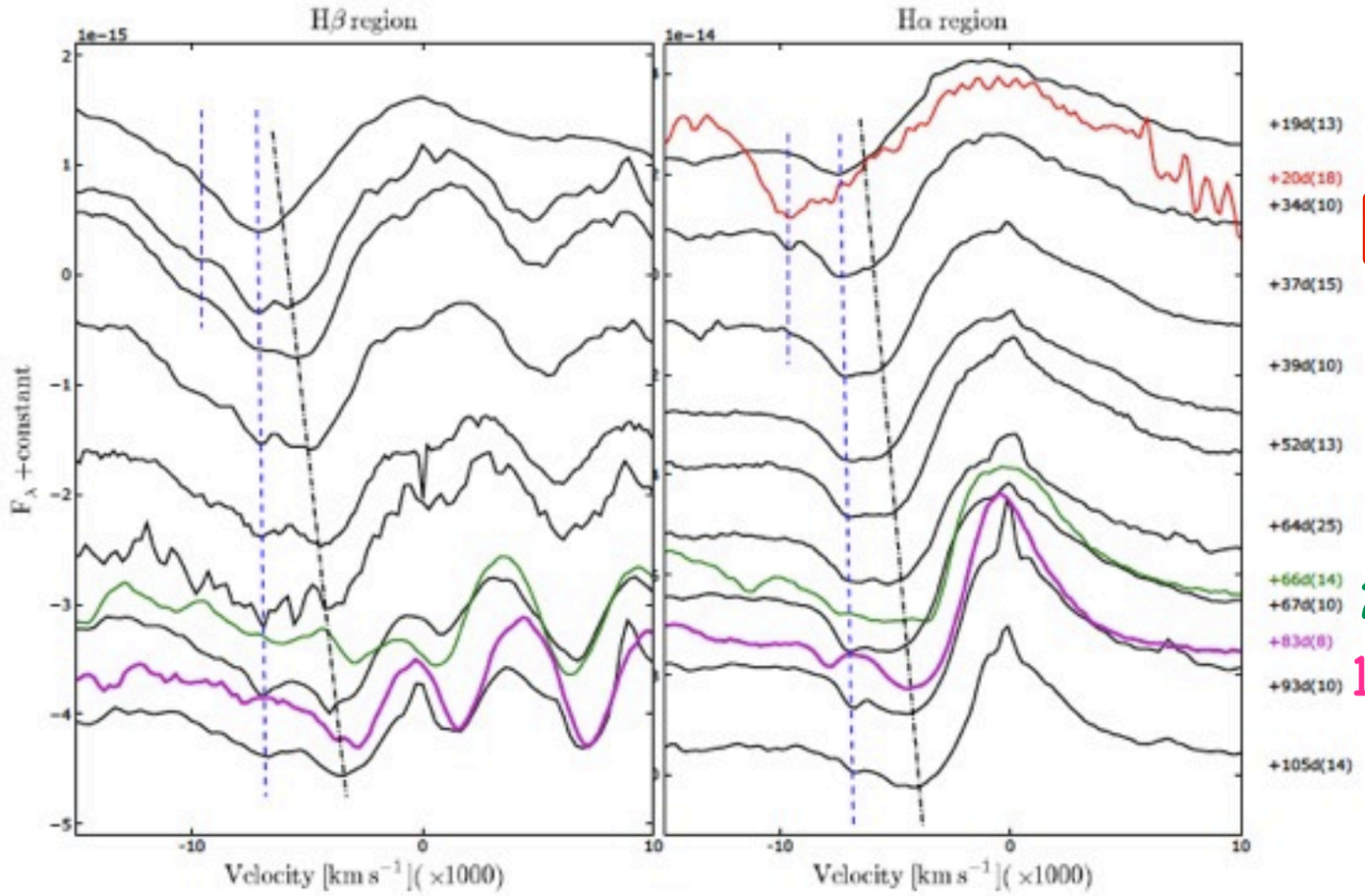
2009bw

Inserra+ 2012

- normal IIP
- M_R^{max}=-17.82
- M(Ni)=0.02M$_\odot$
- R_i = 3.6-7 x 10^{13}cm
- modelling: 11-15 M$_\odot$



HeI



2004dj

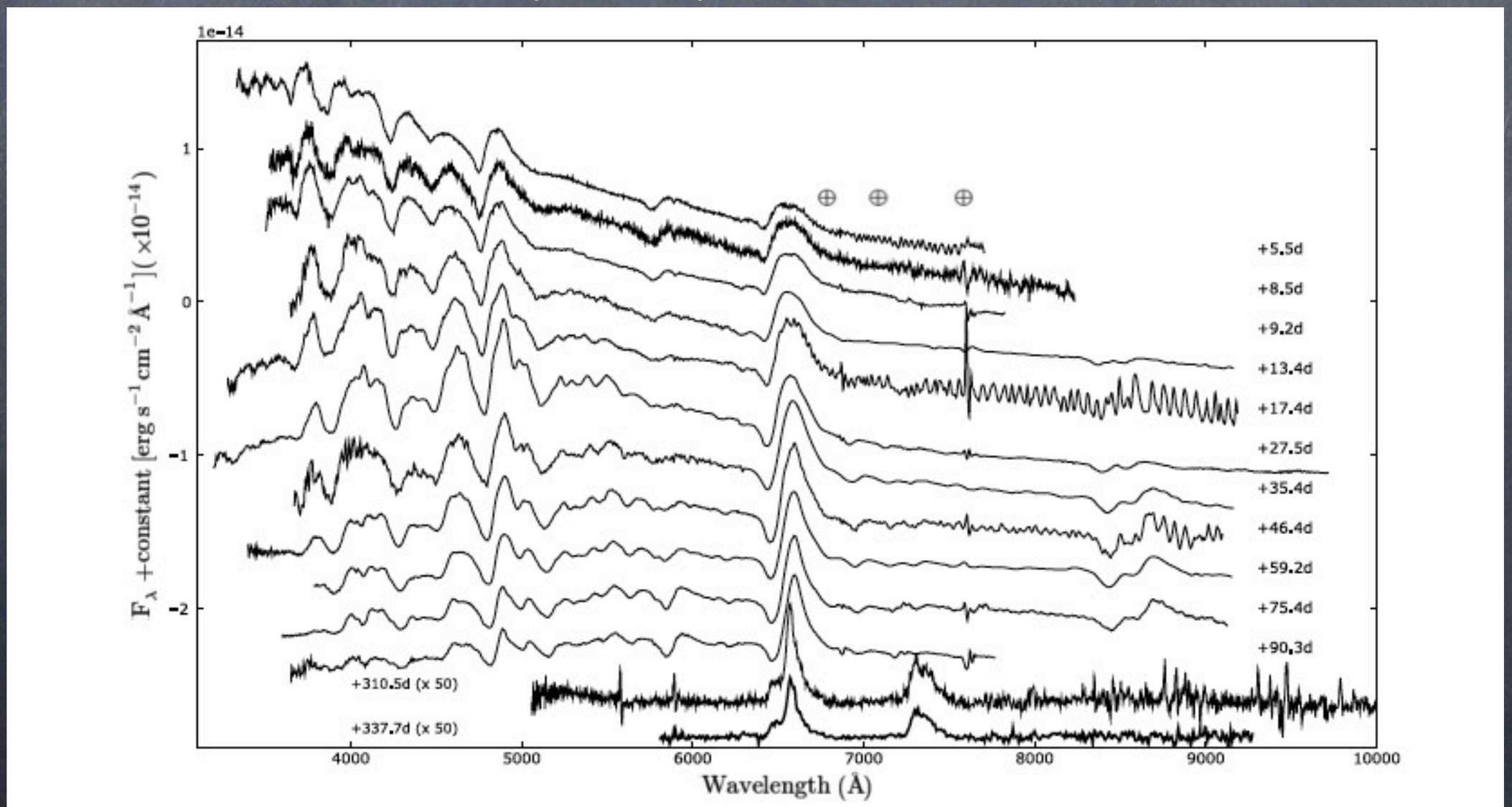
1999em

2007od

Inserra+ 2011a-2011b

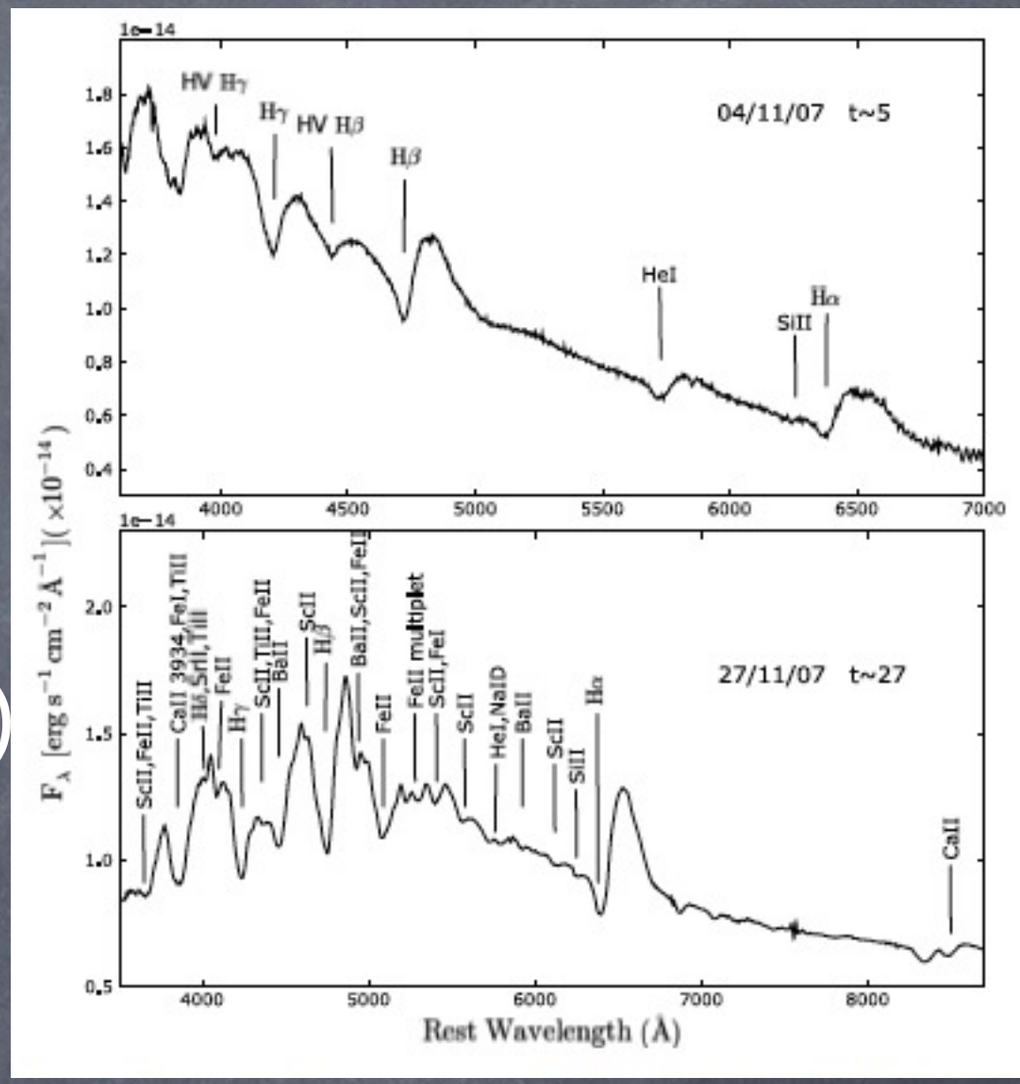
- overall normal IIP
- model: 9.7-11 $M_\odot$

  but:
- early dust fomation $\simeq$200d
- late CSM interaction (IIP !!)



early CSM ?

- boxy early $H\alpha$ emission
- 4400 A & 6250 A features.
  H? different velocities.



- Synow: BaII (λ4524), SiII (λ6350)
- Phoenix:
  - 6250 is SiII
  - T too high for BaII
  - FeII poor fit of v
  - probably FeII + HV($H\beta$)
  - $H\alpha$ collisionally pop. (79C & 93J)
  - complex density profile

wide
fast (v(H)≃25000 km/s)
≃ HV(SNIa)

summary

- interaction with dense CSM powers a wide variety of bright objets grouped into IIn

- increasing number of SE SNe in He-rich CSM (Ibn)
    1. fitting in the scenario
    2. some with increased H (LBV ➠ WR)

- evidence of early CSM interaction in (moderately bright) IIP, consistent with RSG wind

- need for models of CSM interaction for various configurations