Supernova impostors

Erkki Kankare
(Queen's University Belfast)

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QUEEN'S UNIVERSITY BELFAST

Table 1
Volume-limited Sample of SNe Closer Than 15 Mpc Discovered in 2000–2011

SN	Host Galaxy	Velocity (km s^{-1})	Distance (Mpc)	Method	Type	A_V Host (Reference)	A_V MW	M_{peak}	Incl. (°)	Botticella	log L_{IR} ($L_\odot$)
2000db	NGC 3949	1020	14.6	Kinematic	IIP	...	0.07	...	57	No	9.93
2001ig	NGC 7424	754	10.8	Kinematic	IIb	<0.06[8] (Silverman et al. 2009)	0.03	−17.4[8]	59	No	...
2002ap	NGC 628	686	9.3[1]	Mean	Ic	0.04 (Takada-Hidai et al. 2002)	0.24	−17.7[2]	35	Yes	9.89
2002bu	NGC 4242	737	10.5	Kinematic	08S-like	...	0.04	...	52	Yes	...
2002hh	NGC 6946	318	5.7[2]	Mean	IIP	4.1 (Pozzo et al. 2006)	1.13	−18.4[2]	31	Yes	9.94
2003J	NGC 4157	1011	14.4	Kinematic	IIP	...	0.07	...	90	No	10.19
2003gd	NGC 628	686	9.3[1]	Mean	IIP	0.2 (Smartt et al. 2009)	0.23	−16.6[2]	35	Yes	9.89
2003ie	NGC 4051	917	13.1	Kinematic	IIP	...	0.04	...	30	No	9.90
2003jg	NGC 2997	914	13.1	Kinematic	Ib/c	3.7 N. Elias-Rosa et al. (in preparation)	0.36	−17.8[8]	32	No	...
2004am	M 82	487	3.3[3]	Cepheid	IIP	~5 (Mattila et al. 2012)	0.53	−15.4[12]	79	Yes	10.66
2004dj	NGC 2403	370	3.3[3]	Cepheid	IIP	0.4 (Smartt et al. 2009)	0.13	−16.6[2]	60	Yes	9.21
2004et	NGC 6946	318	5.7[2]	Mean	IIP	0.2 (Smartt et al. 2009)	1.13	−17.9[2]	31	Yes	9.94
2005ae	ESO 209-G009	862	12.3	Kinematic	IIb	...	0.86	...	90	No	9.85
2005af	NGC 4945	376	3.8[4]	TRGB	IIP	~0 (Pereyra et al. 2006)	0.61	−15.7[2]	90	Yes	10.45
2005at	NGC 6744	618	8.8	Kinematic	Ic	2.3 ± 0.3 (E. Kankare et al. in preparation)	0.14	−16.1[2]	54	Yes	9.89
2005ay	NGC 3938	1017	14.5	Kinematic	IIP	...	0.07	...	14	No	9.92
2005cs	M 51	702	10.0	Kinematic	IIP	0.3 (Smartt et al. 2009)	0.12	−15.9[2]	30	Yes	...
2006my	NGC 4651	912	13.0	Kinematic	II	...	0.09	...	50	No	9.58
2007gr	NGC 1058	634	9.3[5]	Cepheid	Ic	0.09 (Hunter et al. 2009)	0.21	−17.5[2]	20	Yes	...
2007it	NGC 5530	1046	14.9	Kinematic	II	...	0.39	...	67	No	...
2008S	NGC 6946	318	5.7[2]	Mean	08S-like	...	1.12	...	31	No	9.94
N300-OT	NGC 300	−38	1.9[6]	Cepheid	08S-like	...	0.04	...	40	No	8.35
2008ax	NGC 4490	797	11.4	Kinematic	IIb	1.5 (Chornock et al. 2011)	0.07	−18.5[2]	47	Yes	10.28
2008bk	NGC 7793	60	3.4[7]	Cepheid	IIP	~0 (Van Dyk et al. 2012)	0.07	−15.2[2]	53	Yes	8.92
2008iz	M 82	487	3.3[3]	Cepheid	RSN	$\lesssim$10 (Mattila et al. 2012)	0.53	...	79	No	10.66
2008jb	ESO 302-G014	636	9.1	Kinematic	IIP	0.19 (Prieto et al. 2012)	0.03	−15.3[9]	74	No	...
2009N	NGC 4487	1026	14.7	Kinematic	IIP	...	0.07	...	46	No	...
2009dd	NGC 4088	989	14.1	Kinematic	II	...	0.07	...	71	No	10.29
2009hd	NGC 3627	788	9.4[3]	Cepheid	II	3.7 (Elias-Rosa et al. 2011)	0.11	−17.7[2]	57	Yes	10.33
2009ib	NGC 1559	1004	14.3	Kinematic	IIP	...	0.10	...	60	No	10.31
2009ls	NGC 3423	1032	14.7	Kinematic	II	...	0.10	...	32	No	...
2010br	NGC 4051	917	13.1	Kinematic	Ib/c	...	0.04	...	30	No	9.90
2010dn	NGC 3184	766	10.9	Kinematic	08S-like	...	0.06	...	24	No	9.67
2011dh	M 51	702	10.0	Kinematic	IIb	<0.15 (Arcavi et al. 2011)	0.12	−17.0[10]	30	No	...
2011ja	NGC 4945	376	3.8[4]	TRGB	IIP	>3 (Monard et al. 2011)	0.59	−17.5[11]	90	No	10.45
2011jm	NGC 4809	979	14.0	Kinematic	Ic	...	0.11	...	90	No	...

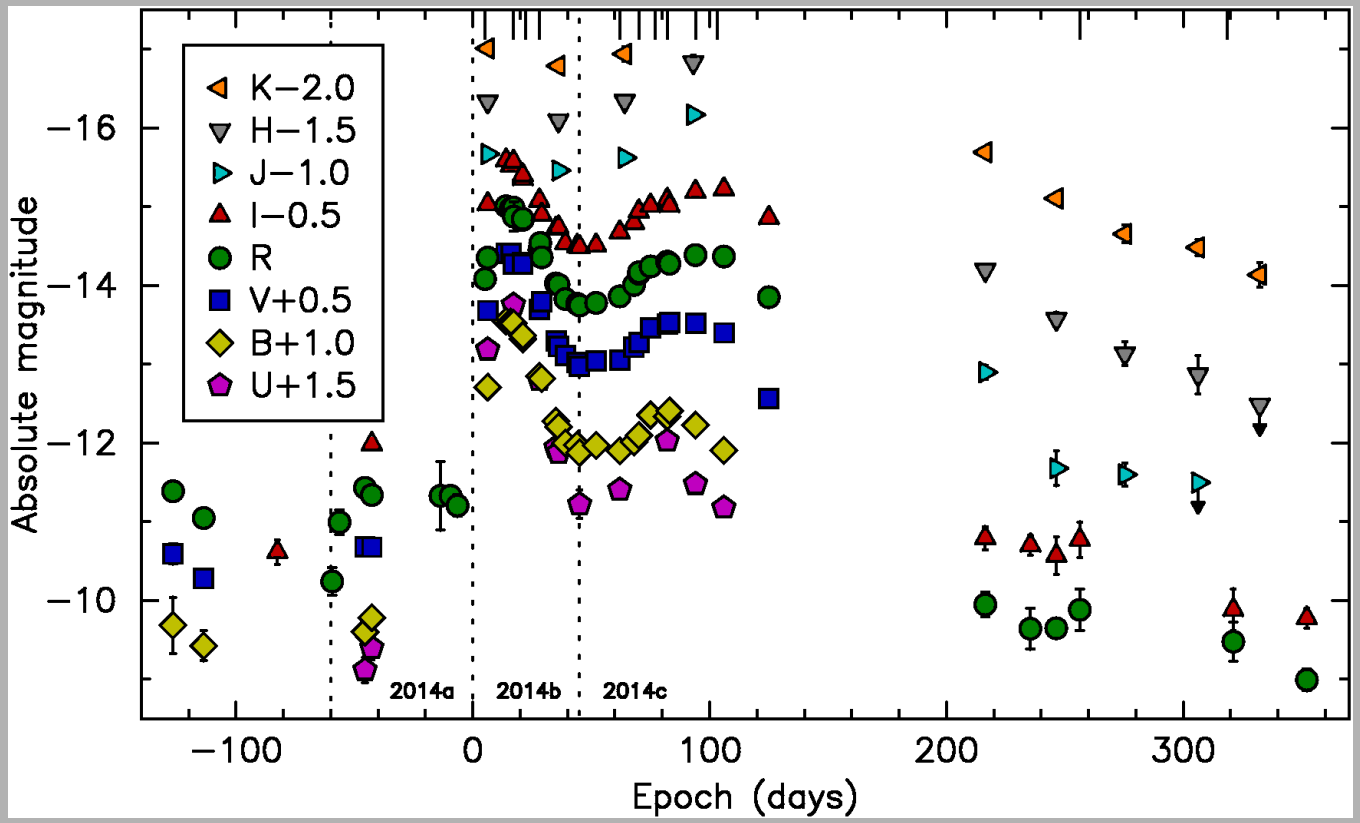
Notes. [1]Hendry et al. 2005; [2]Botticella et al. 2009; [3]Freedman et al. 2001; [4]Karachentsev et al. 2007; [5]NGC 1058, belongs to a group of nearby galaxies of which NGC 925 is also a member—Silbermann et al. 1996; [6]Gieren et al. 2005; [7]Pietrzyński et al. 2010; [8]Horiuchi et al. 2011; [9]Prieto et al. 2012; [10]Arcavi et al. 2011; [11]Monard et al. 2011; [12]Mattila et al. 2012.

- 36 CCSNe? within 15 Mpc – not complete
- 18 CCSNe + 4 08S-like within 12 Mpc
  - 18% 'SN impostors'

SNHunt248

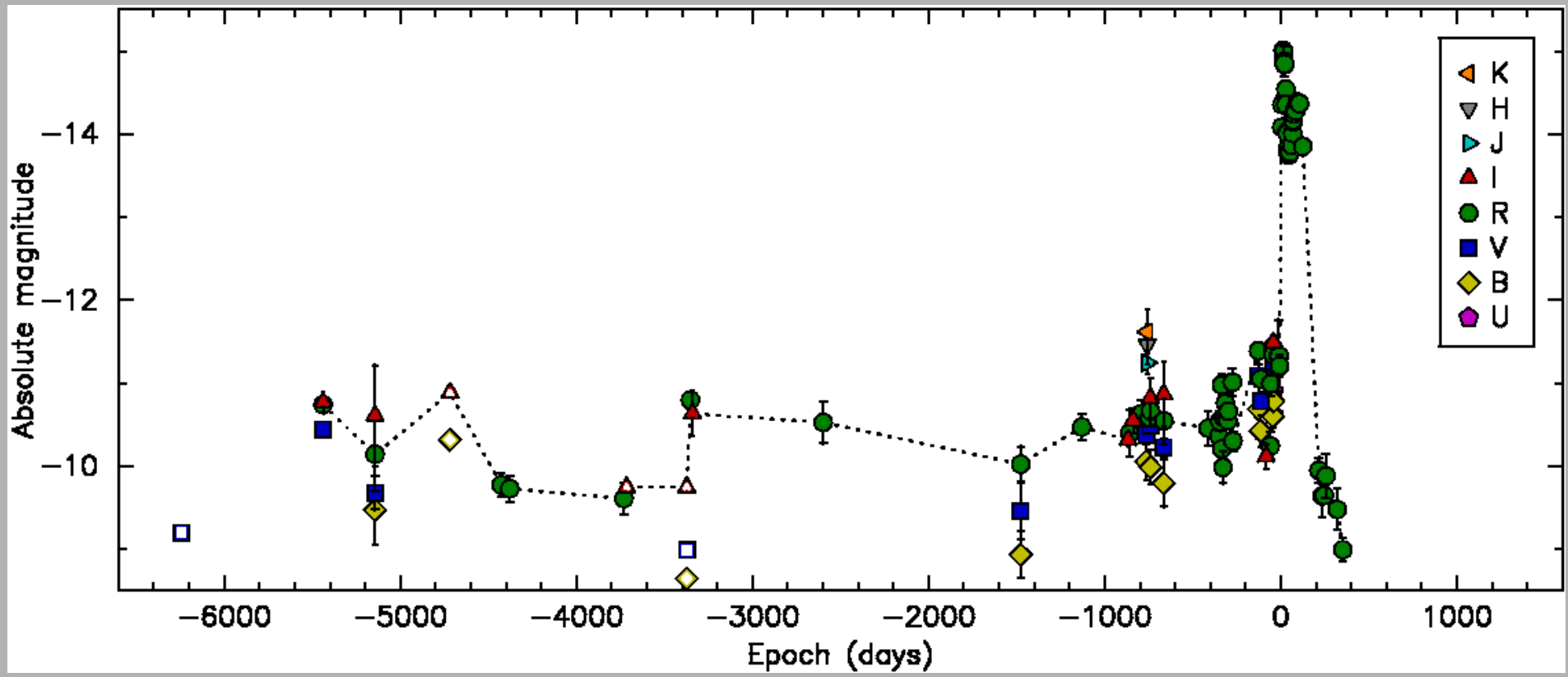
SNHunt248

- Kankare et al. (2015, A&A, 581, L4)
- Phase 2014b peak at $M_R \sim$ -15.0 mag
  - Comparable to brighter SN impostors and low-luminosity Type IIP SNe
- Phase 2014c peak at $M_R \sim$ -14.4 mag
  - CSM interaction?
- Phase 2014a peak at $M_R \sim$ -11.4 mag
  - 3 distinct peaks



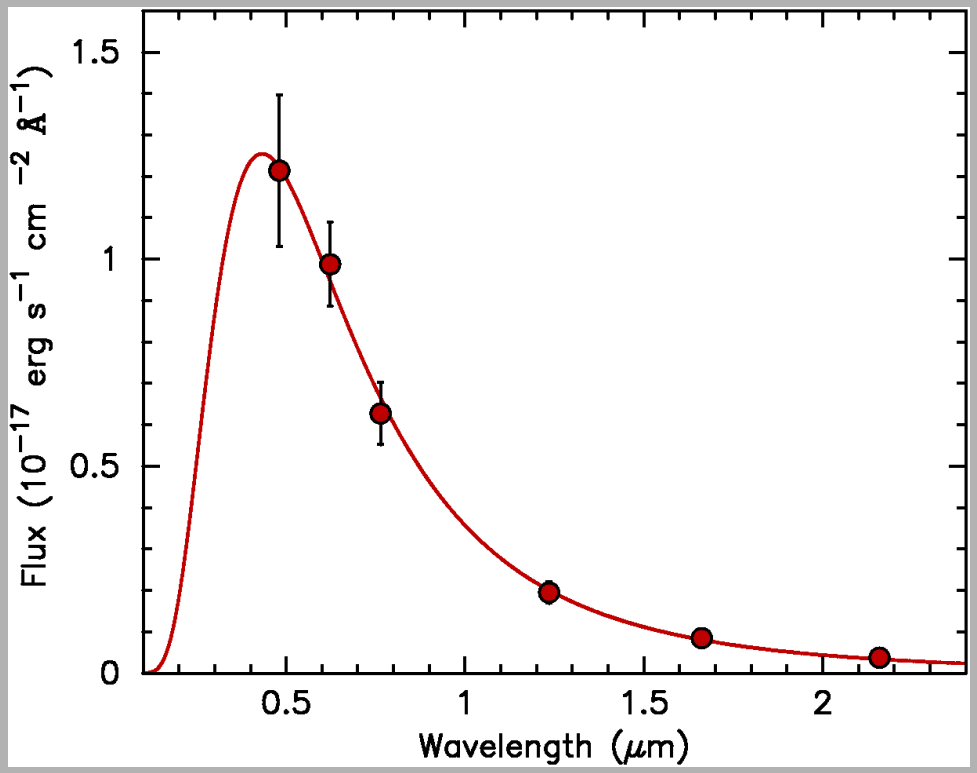
SNHunt248

- HST data reported by Mauerhan et al. (2015)
- Rapid variability episodes and smoother variations



SNHunt248

- HST data reported by Mauerhan et al. (2015)
- Rapid variability episodes and smoother variations
- *griJHK* SED on day -740
  - $T_{BB} \approx 6700$ K
  - $R_{BB} \approx 5.9 \times 10^{13}$ cm ($\sim 850\ R_\odot$)
  - $L_{BB} \approx 5 \times 10^{39}$ erg/s (log $L/L_\odot \sim 6.1$)



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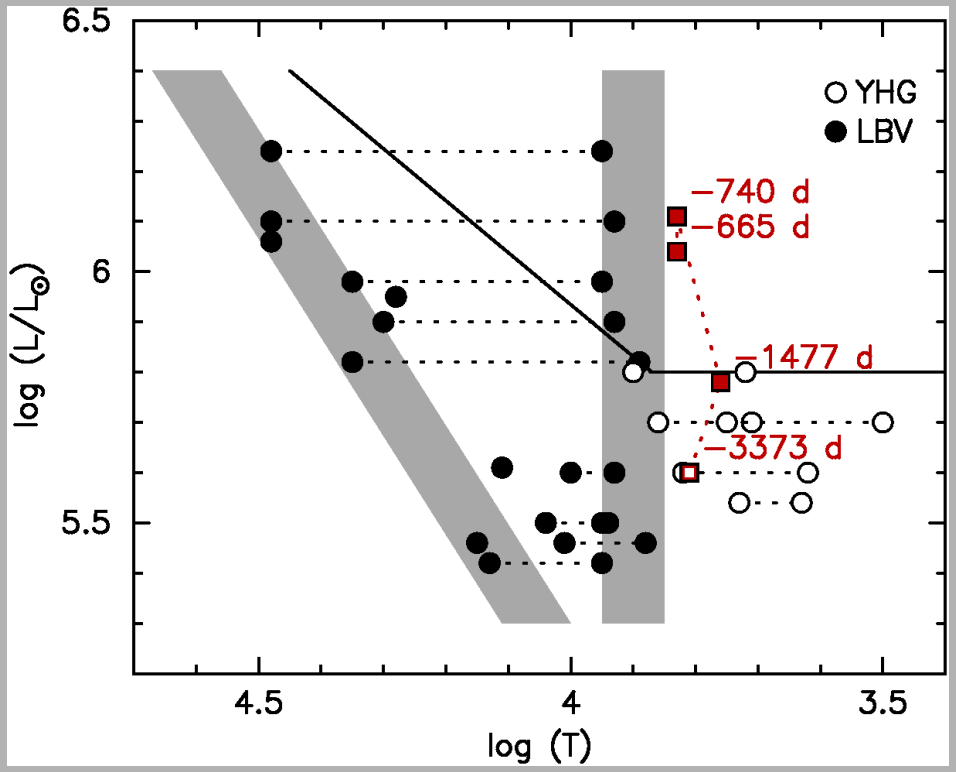
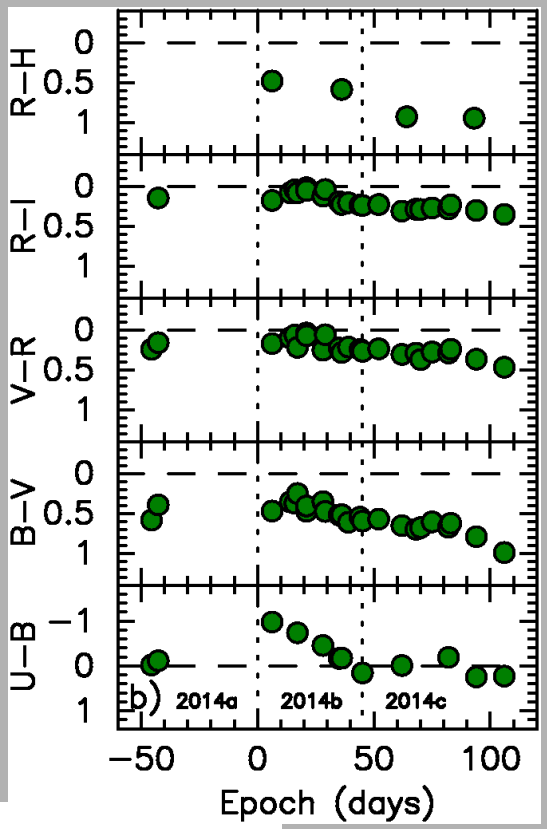
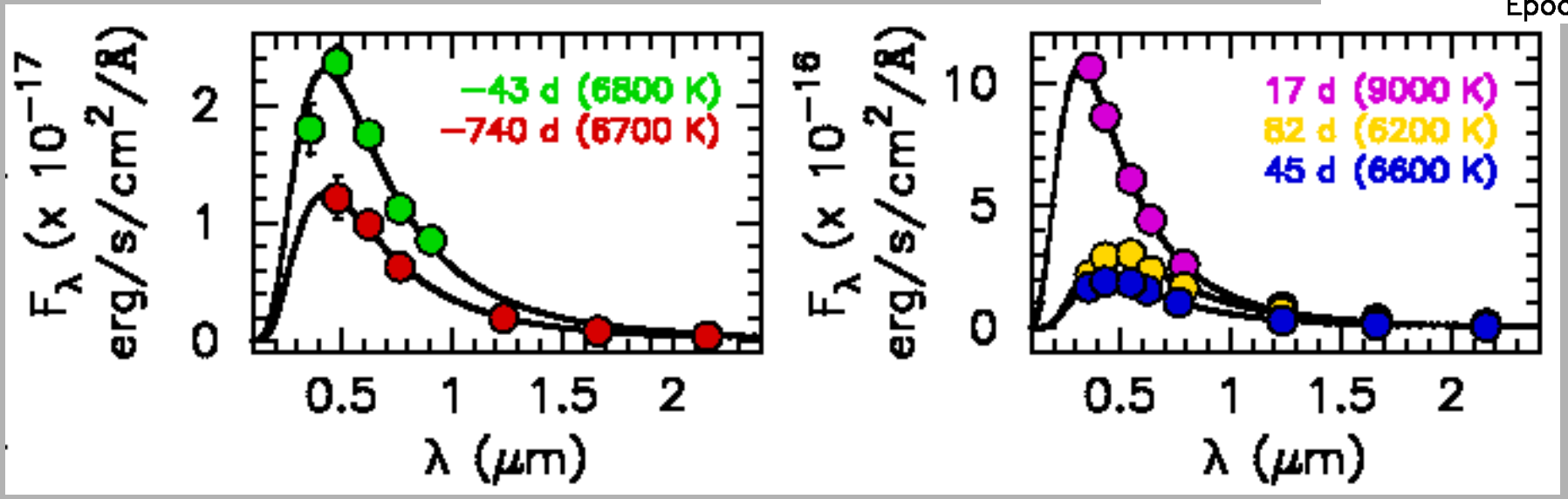
- Appearance of a yellow hypergiant (YHG)
  - No near-IR excess up to 2.2 μm
- Precursor variability in the luminosity



SNHunt248 colour evolution

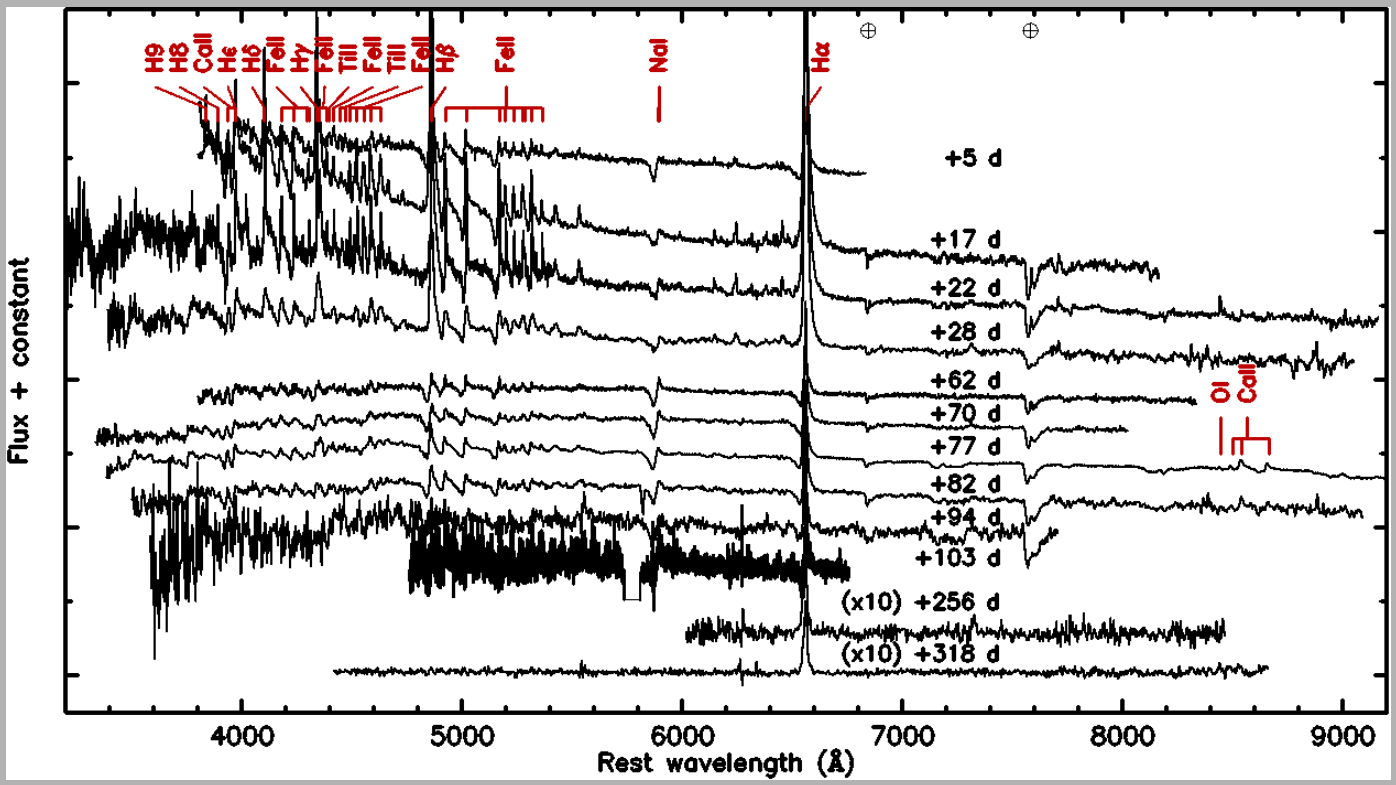
- Flat colour evolution, *U–B* main exception
- T_{BB} at phase 2014a (-43 d) similar to that at -740 d
- T_{BB} maximum (~9000 K) at the phase 2014b peak (17 d)
- Onset to phase 2014c (45 d) and the phase 2014c peak (82 d) at a similar T_{BB}





SNHunt248 spectral sequence

- Narrow P Cygni lines, absorption minimum at ~1000 km/s
  - Supernova impostor (M_R ~ -15.0 mag at maximum)
- Strong Balmer lines, a forest of FeII and other metal lines



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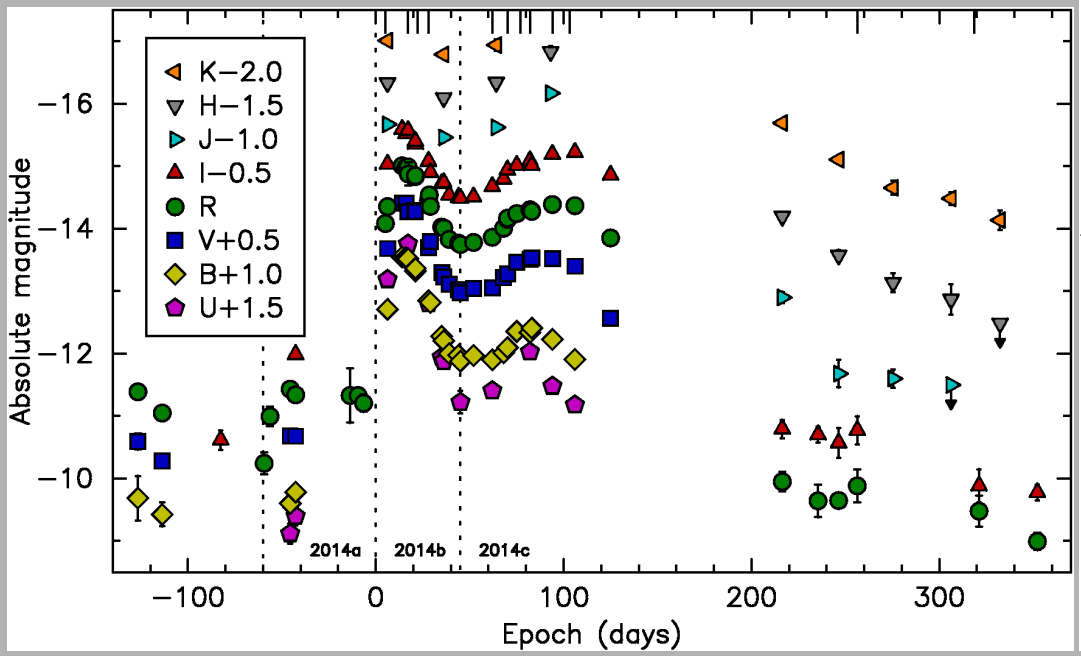
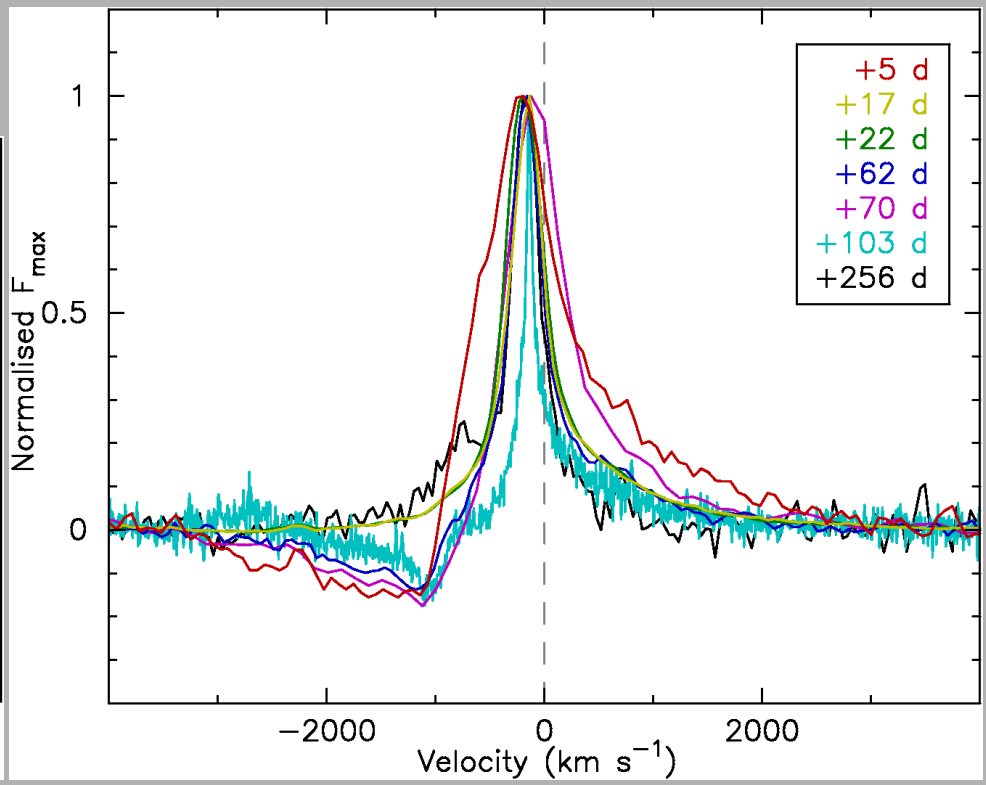
  - Balmer line absorption component absent in the +17 and +22 d spectra
  - Re-appears on day +62 (phase 2014c) with an identical profile compared to +5d (phase 2014b)





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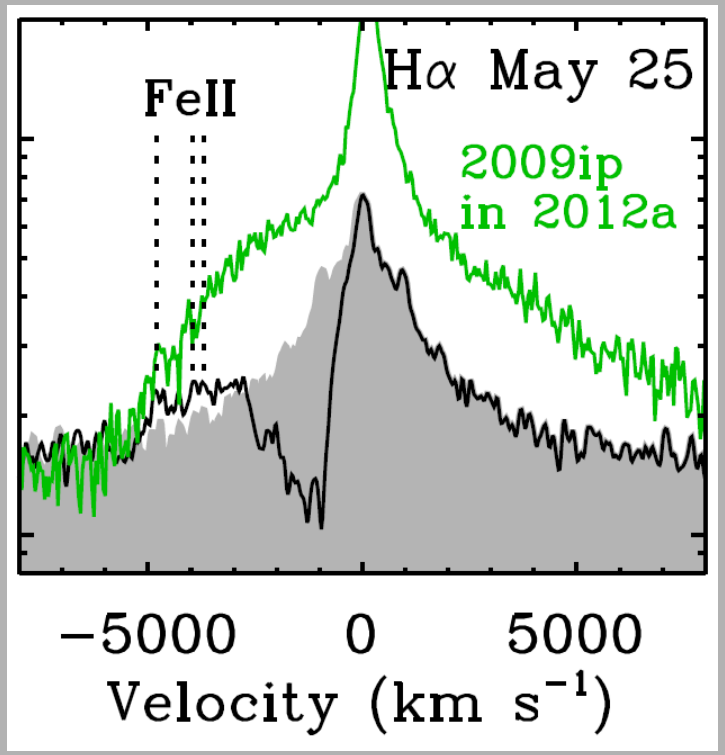
- Early spectrum by Mauerhan et al. (2015) displays a similar P Cygni profile before phase 2014b at day -9 (phase 2014a).
  - The 2014a event outburst interacts with 2 shell-like regions of CSM



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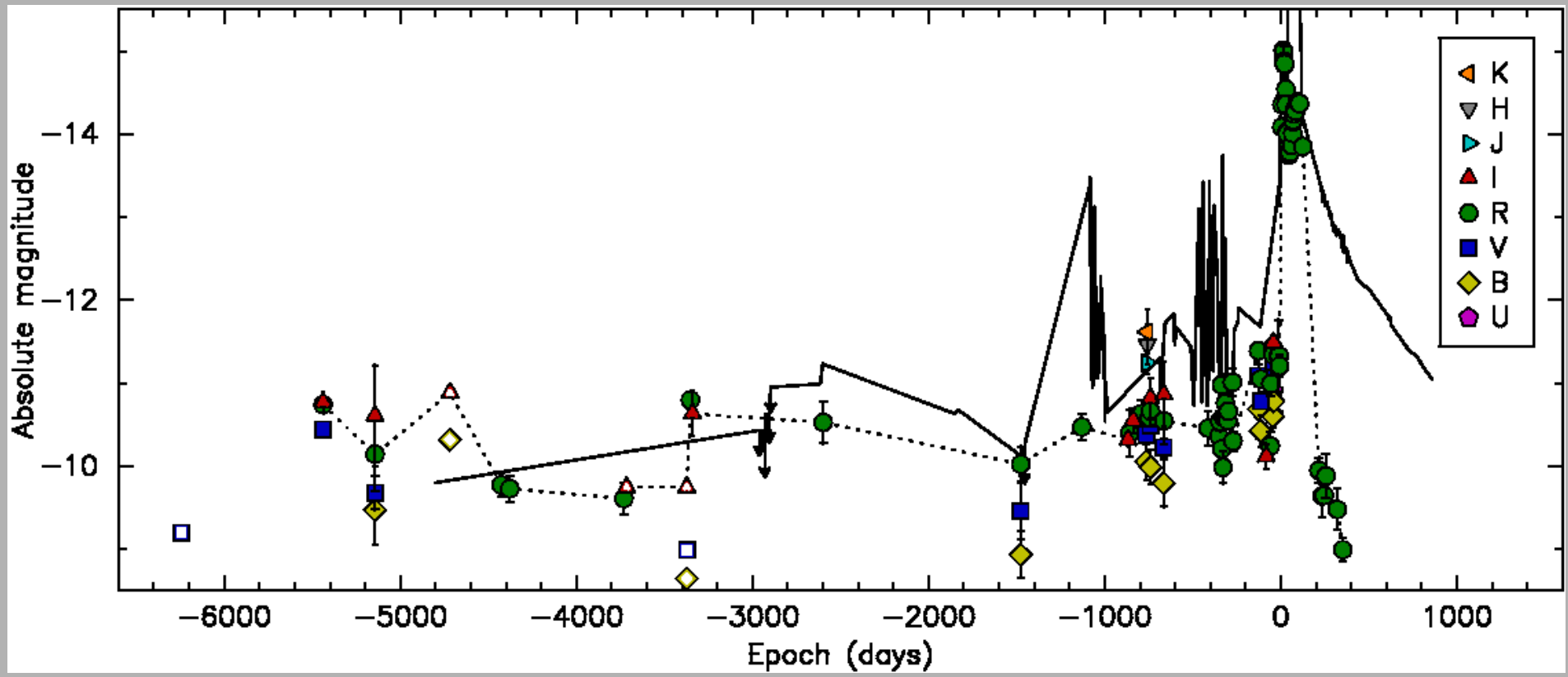
  - The 2014a event outburst interacts with 2 shell-like regions of CSM
- A possible Galactic YHG analogue: IRAS 17163-3907 (Lagadec et al. 2011)

ESO/E. Lagadec

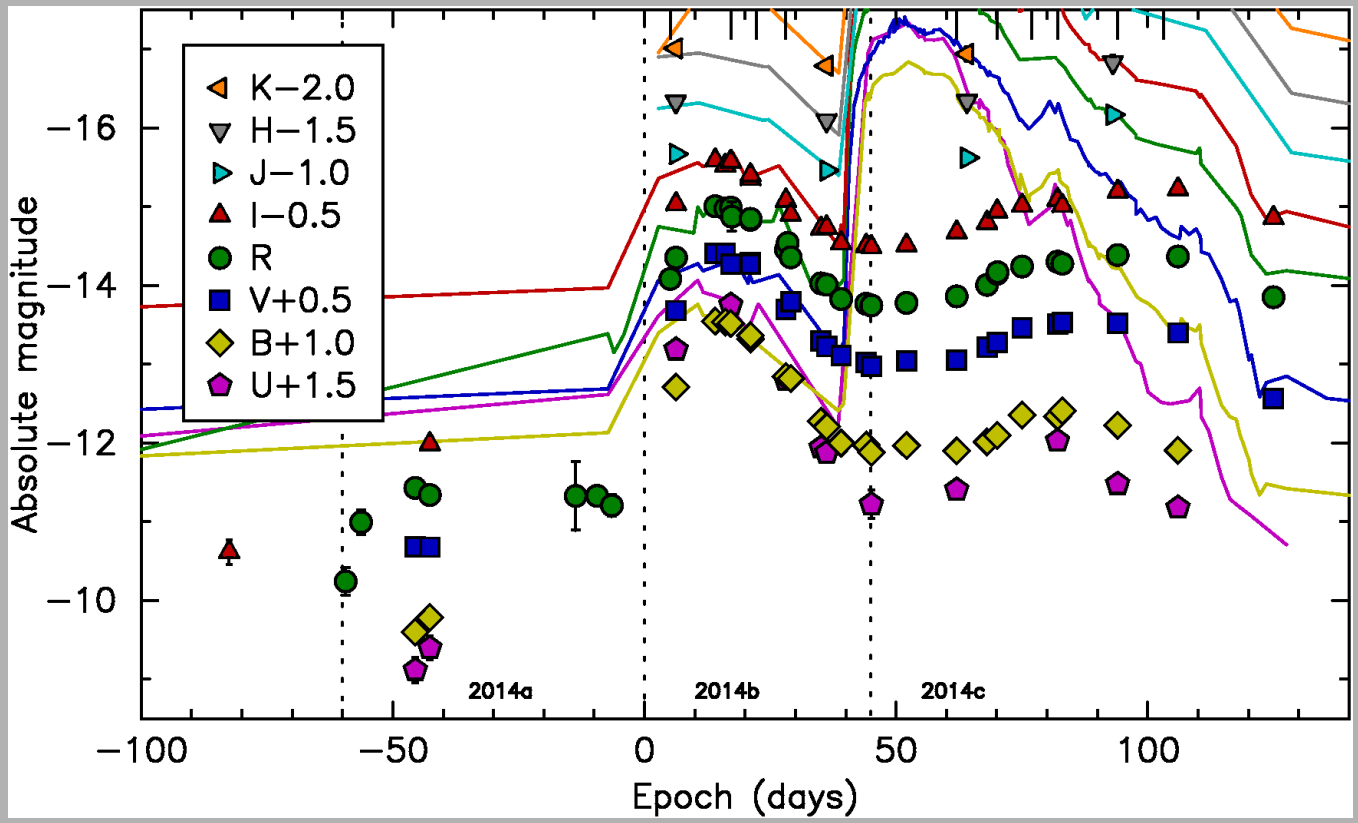
SNHunt248 and SN 2009ip

- HST data reported by Mauerhan et al. (2015)
- Rapid variability episodes and smoother variations
- Historical light curve of SN 2009ip ~1 mag brighter



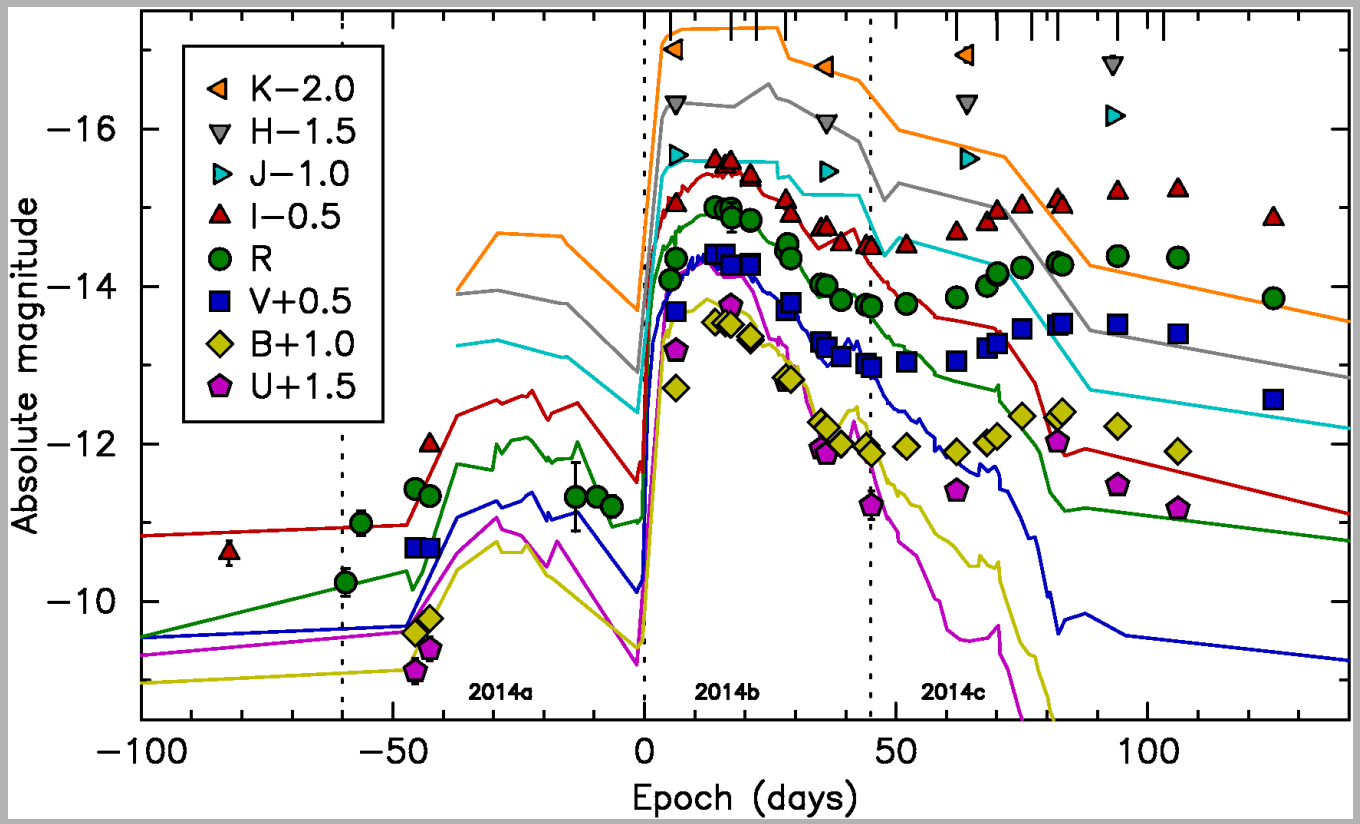
SNHunt248 and SN 2009ip

- Phase 2014b of SNHunt248 comparable to the '2012a' phase of SN 2009ip without a shift in magnitude, in all bands from optical to near-IR



SNHunt248 and SN 2009ip

- Phase 2014b of SNHunt248 comparable to the '2012a' phase of SN 2009ip without a shift in magnitude, in all bands from optical to near-IR
- With a +3 mag (and -40 d) shift the '2012a' phase of SN 2009ip is comparable to the 2014a phase of SNHunt248
- AND the '2012b' phase of SN 2009ip comparable to the 2014b phase of SNHunt248, in all bands



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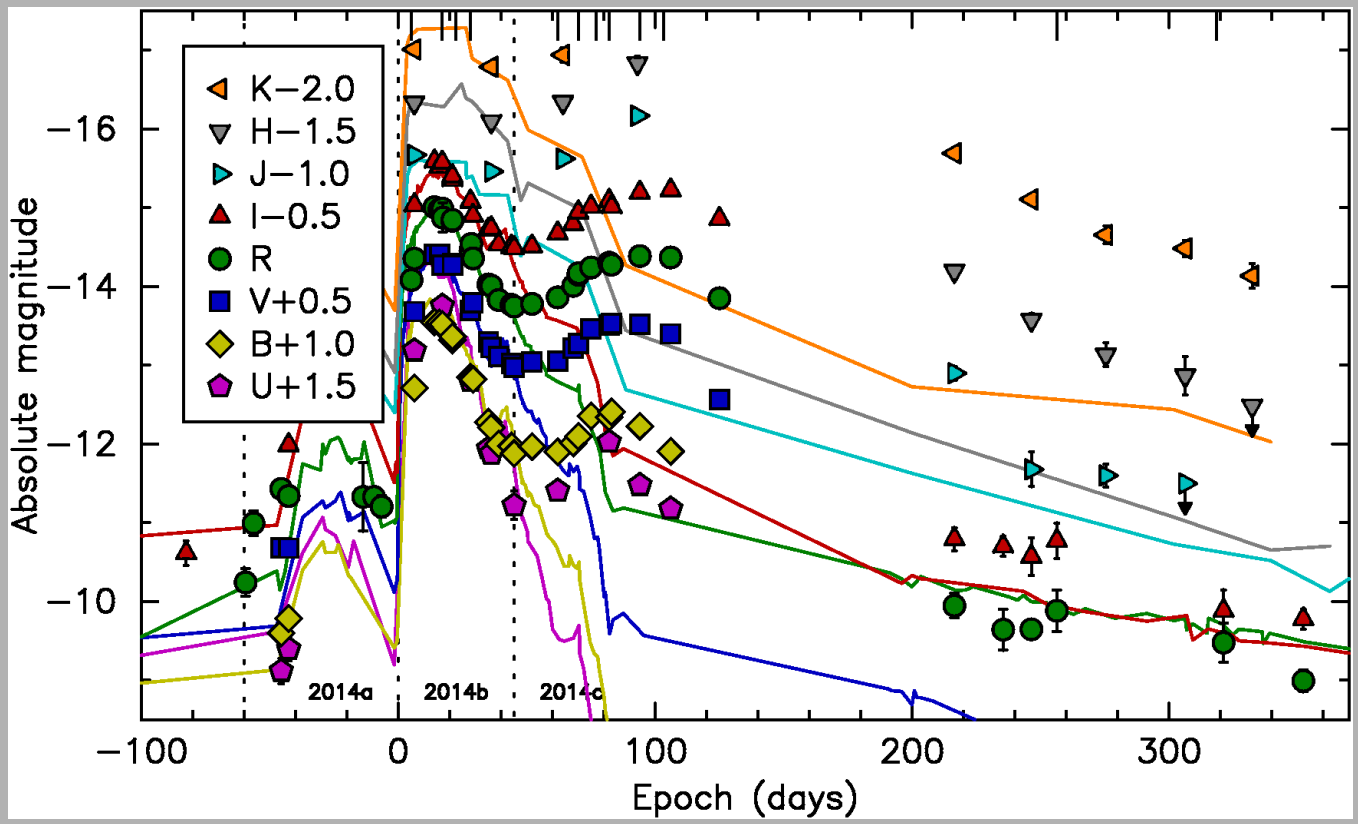
- Similar up to +350 d in *R*
  - But not in near-IR



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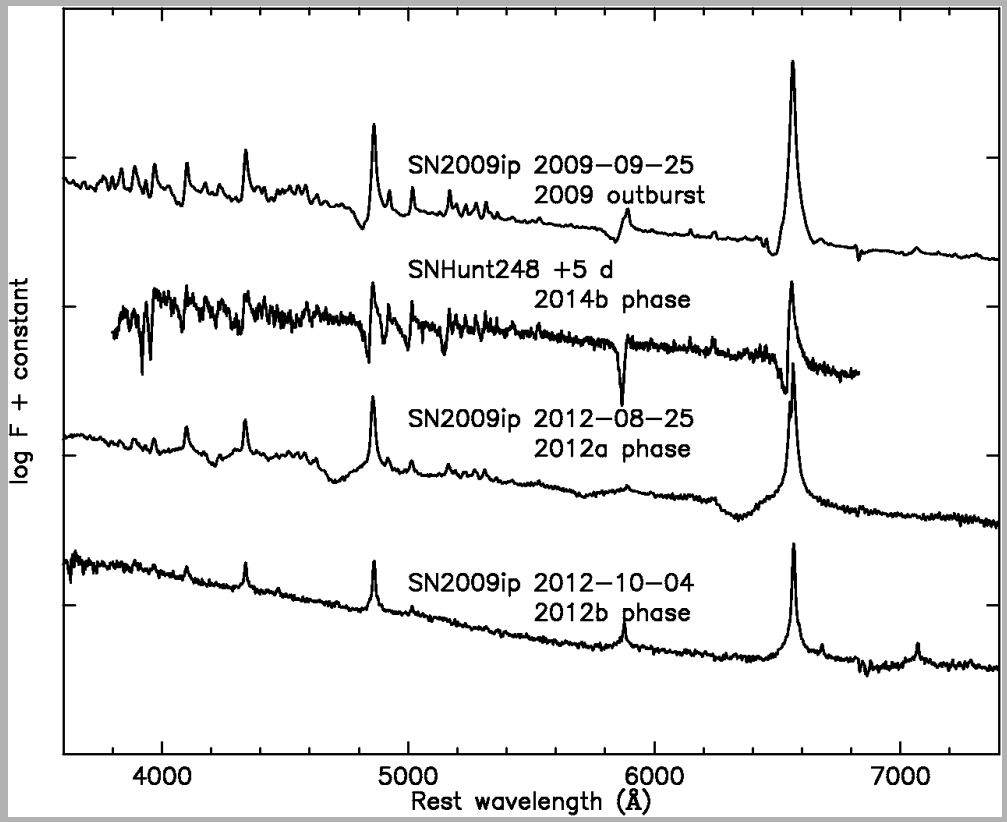
- AND the '2012b' phase of SN 2009ip comparable to the 2014b phase of SNHunt248, in all bands
- Similar up to +350 d in *R*
  - But not in near-IR
- Spectroscopically not similar objects
  - Rising 2014b/2014c phases of SNHunt248 different compared to phases '2012a' and '2012b' of SN 2009ip
  - Most similarities with the 2009 discovery outburst

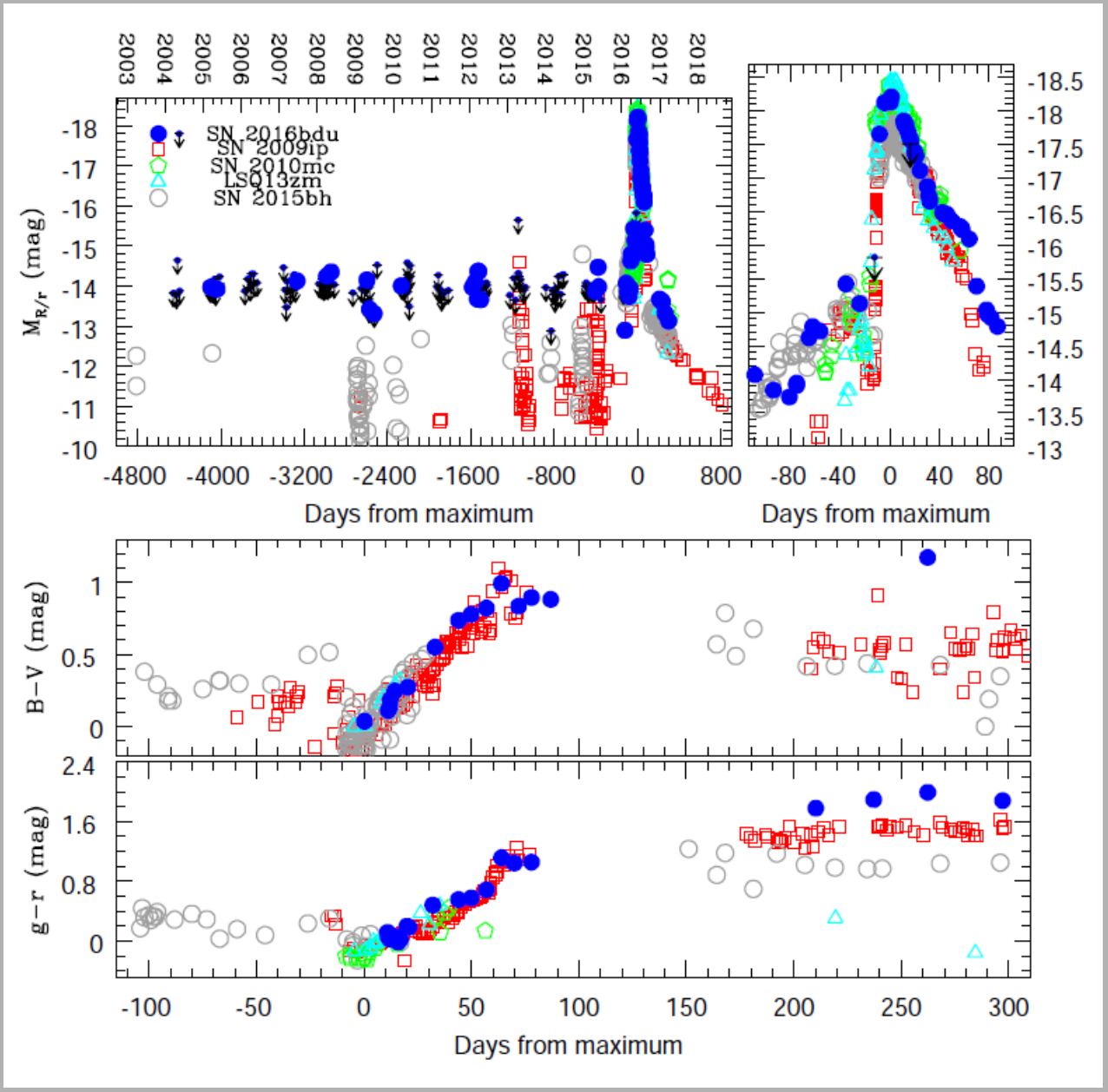


SNHunt248 summary

- Three distinct peaks in the light curve of SNHunt248
  - Outburst in the 2014a event
  - Interaction with 2 CSM shells in phases 2014b and 2014c
  - Now below observed historical minimum
- Historical light curve data spanning over ~15 yrs
  - Rapid variability and smooth evolution episodes
  - Precursor with an appearance of a yellow hypergiant
- Evolution unlike that observed in Galactic yellow hypergiants
- Some similarities in the light curve evolution compared to SN 2009ip
- Most likely a genuine SN impostor, not a terminal explosion
- Merger event?

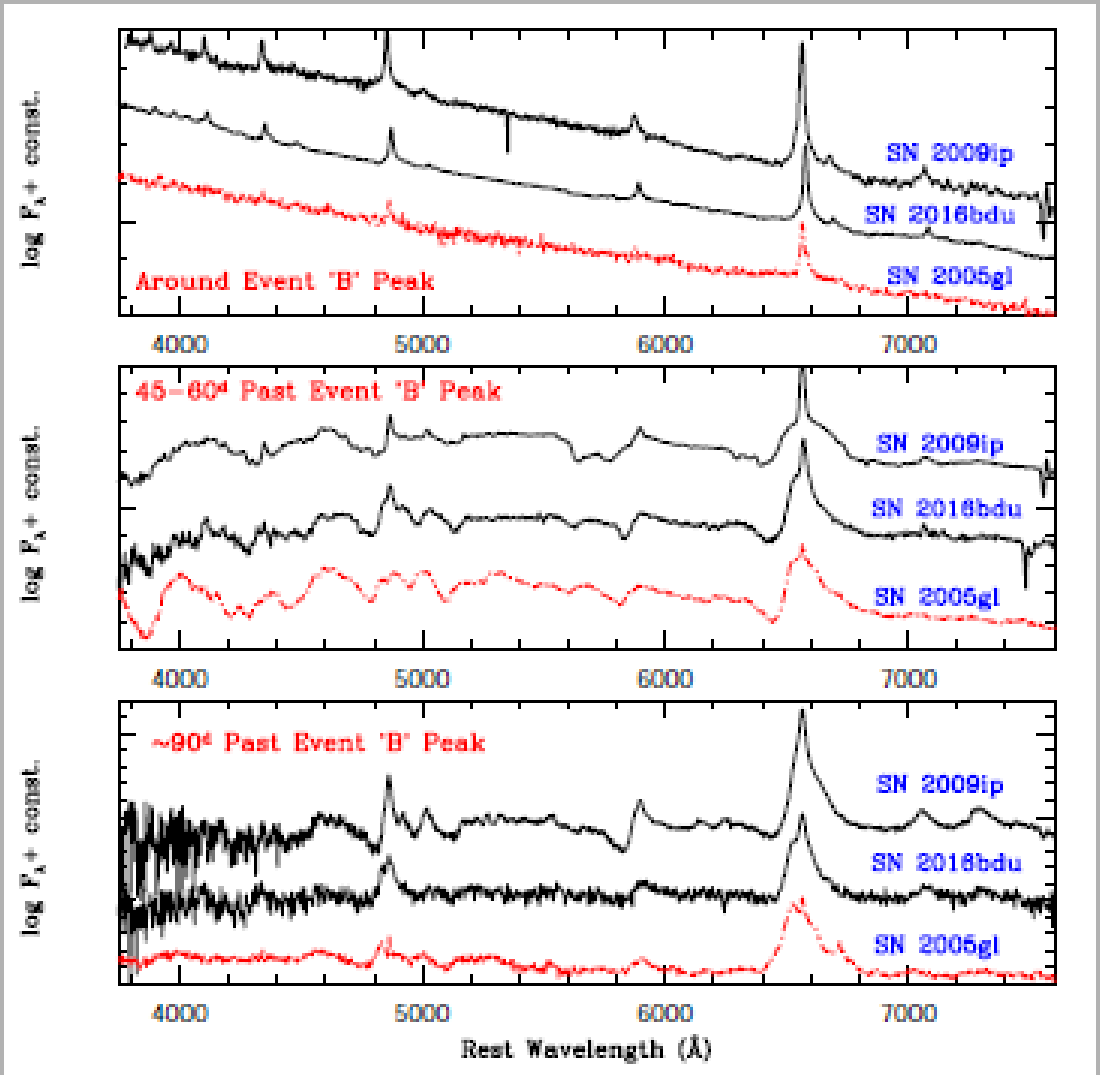
SN2009ip-like events

SN2009ip-like events



- Pastorello et al. 2017, MNRAS, accepted, arXiv:1707.00611
- SN2009ip-like object SN2016bdu
- Surprising photometric similarity during the 'b'-phase of the events

SN2009ip-like events



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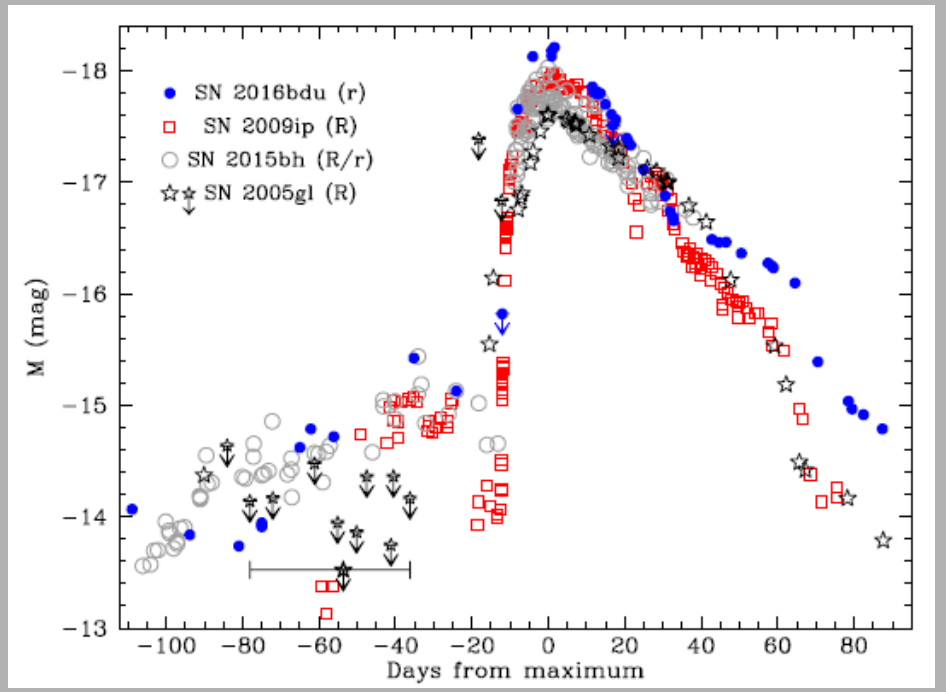
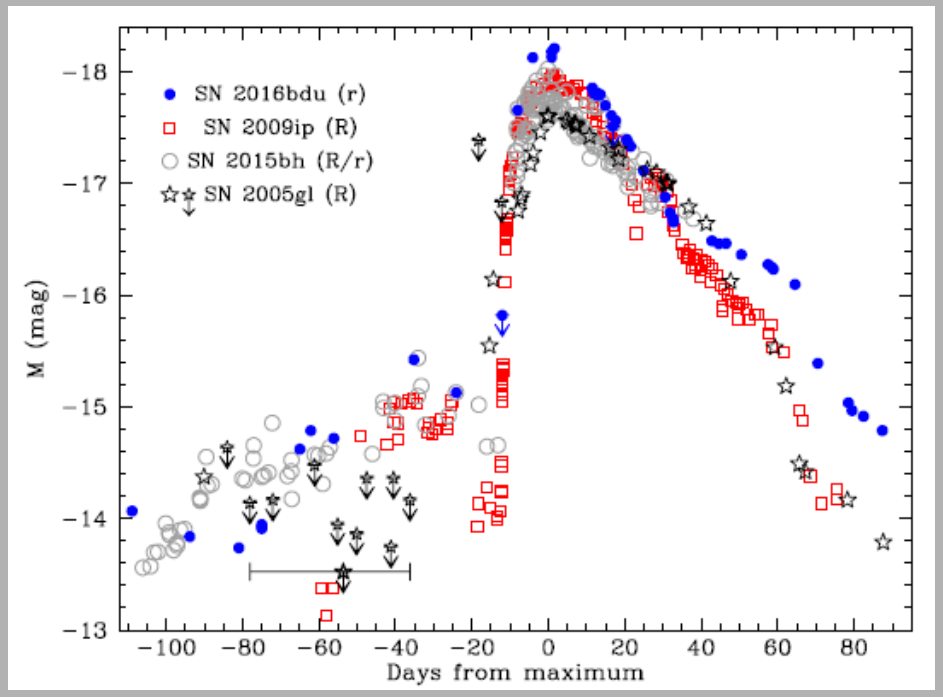
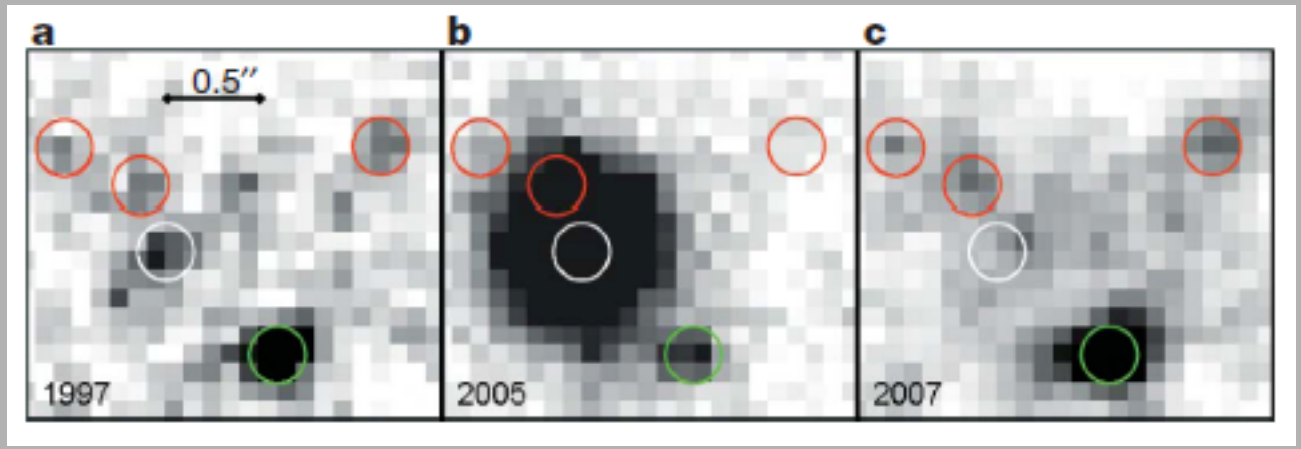
- SN2005gl similar to SN2009ip?



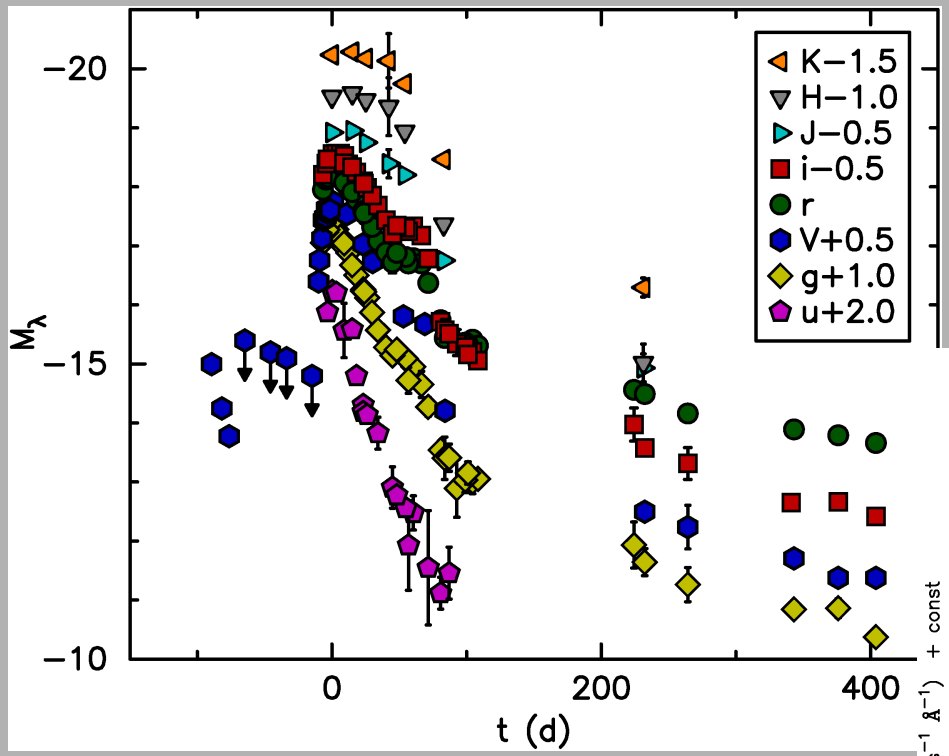
SN2009ip-like events



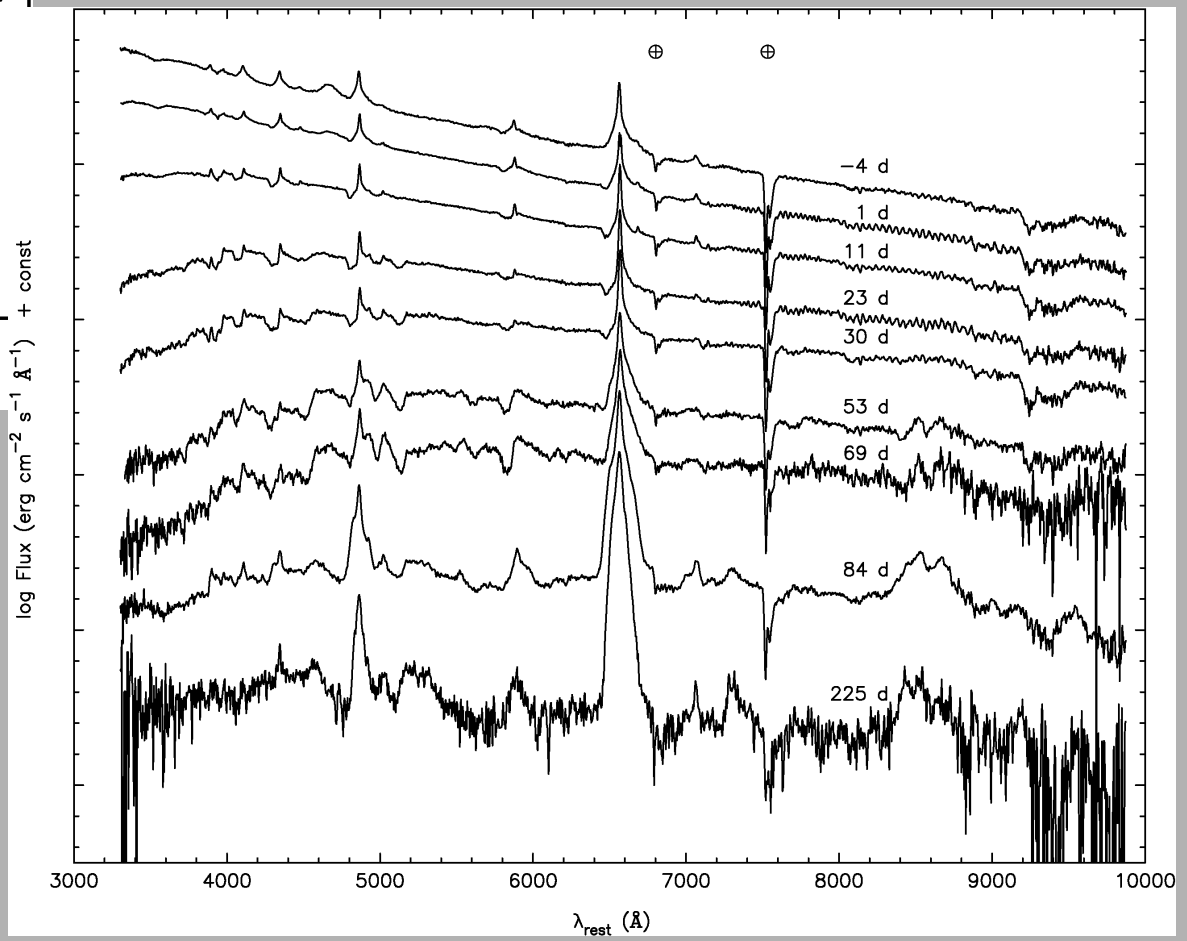
- Pastorello et al. 2017, MNRAS, accepted, arXiv:1707.00611
- SN2005gl similar to SN2009ip?
- What fraction of Type IIn are in fact SN2009ip-like?
- Are SN2009ip-like transients terminal events?
- Disappearance of the LBV-like progenitor star of SN2005gl (Gal-Yam & Leonard, 2009, Nature, 458, 865)



SN2009ip-like SN2016cvk



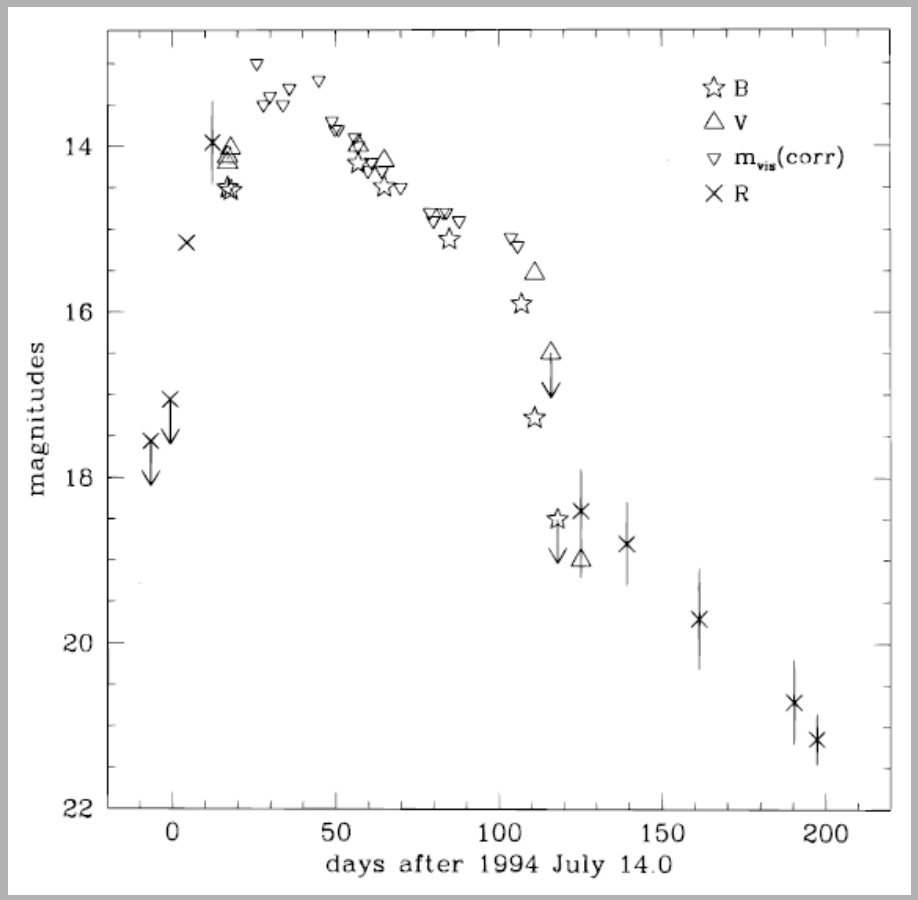
- Kankare et al. 2018, in prep.

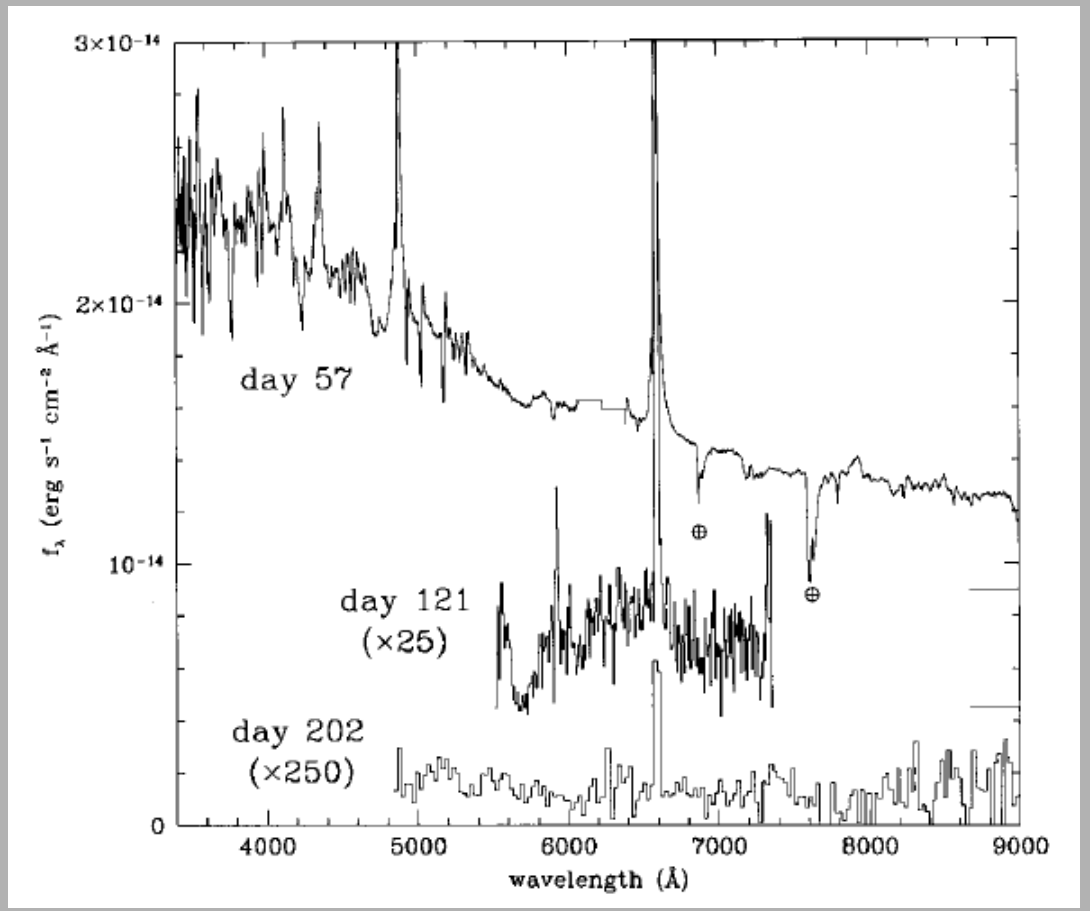


SN1994W and SN2009kn-like events

SN 1994W

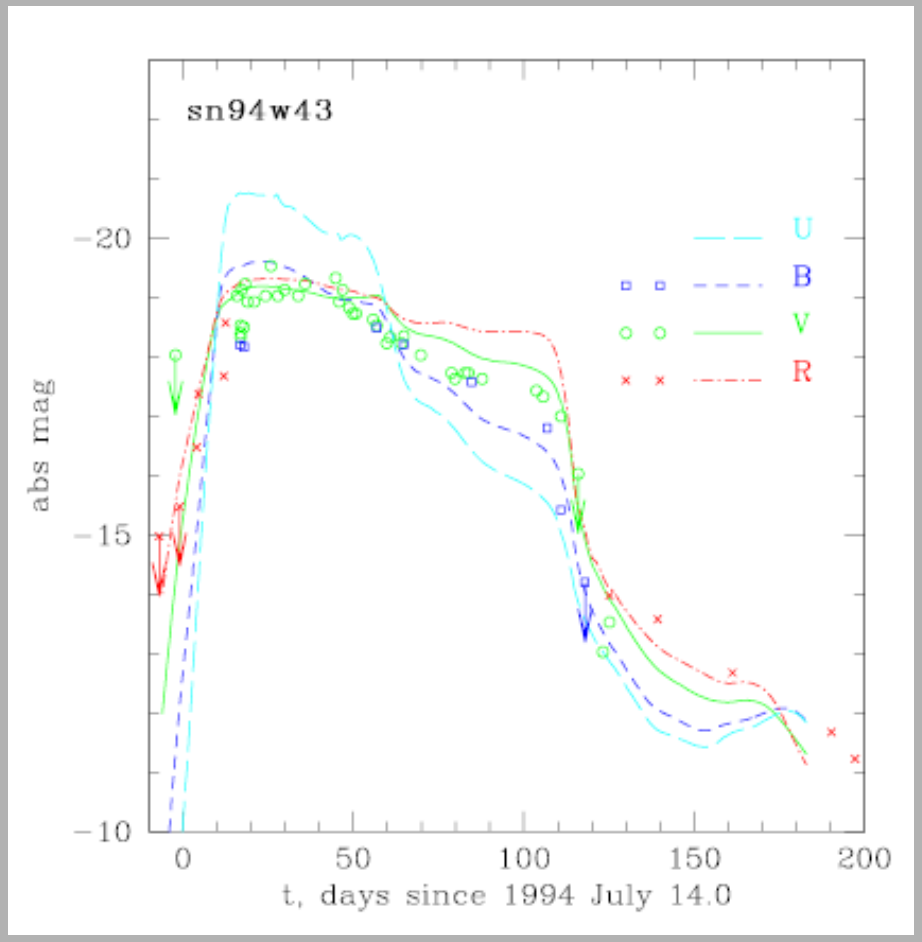
- Sollerman et al. (1998, ApJ, 493, 933) favours a fallback SN interpretation

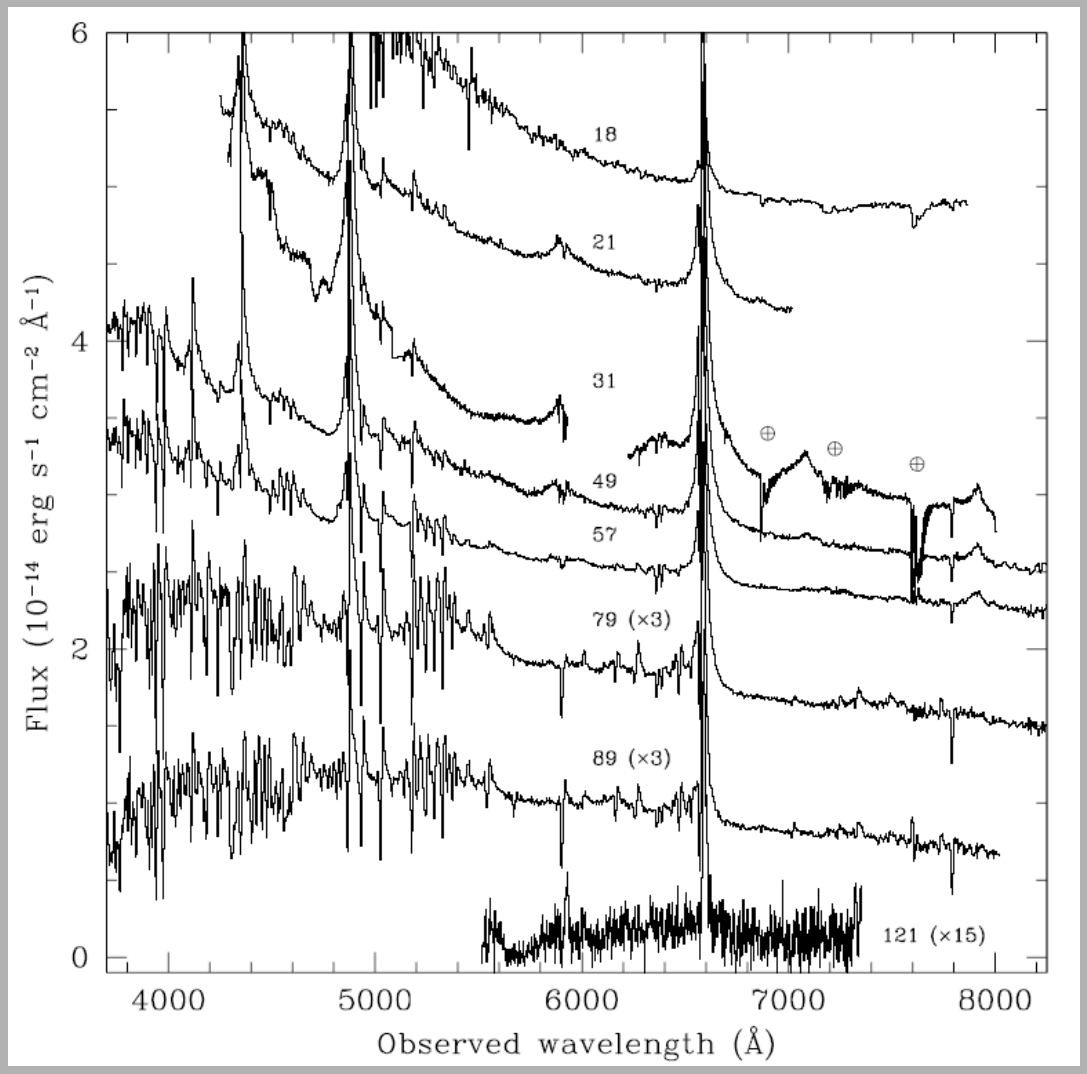




SN 1994W

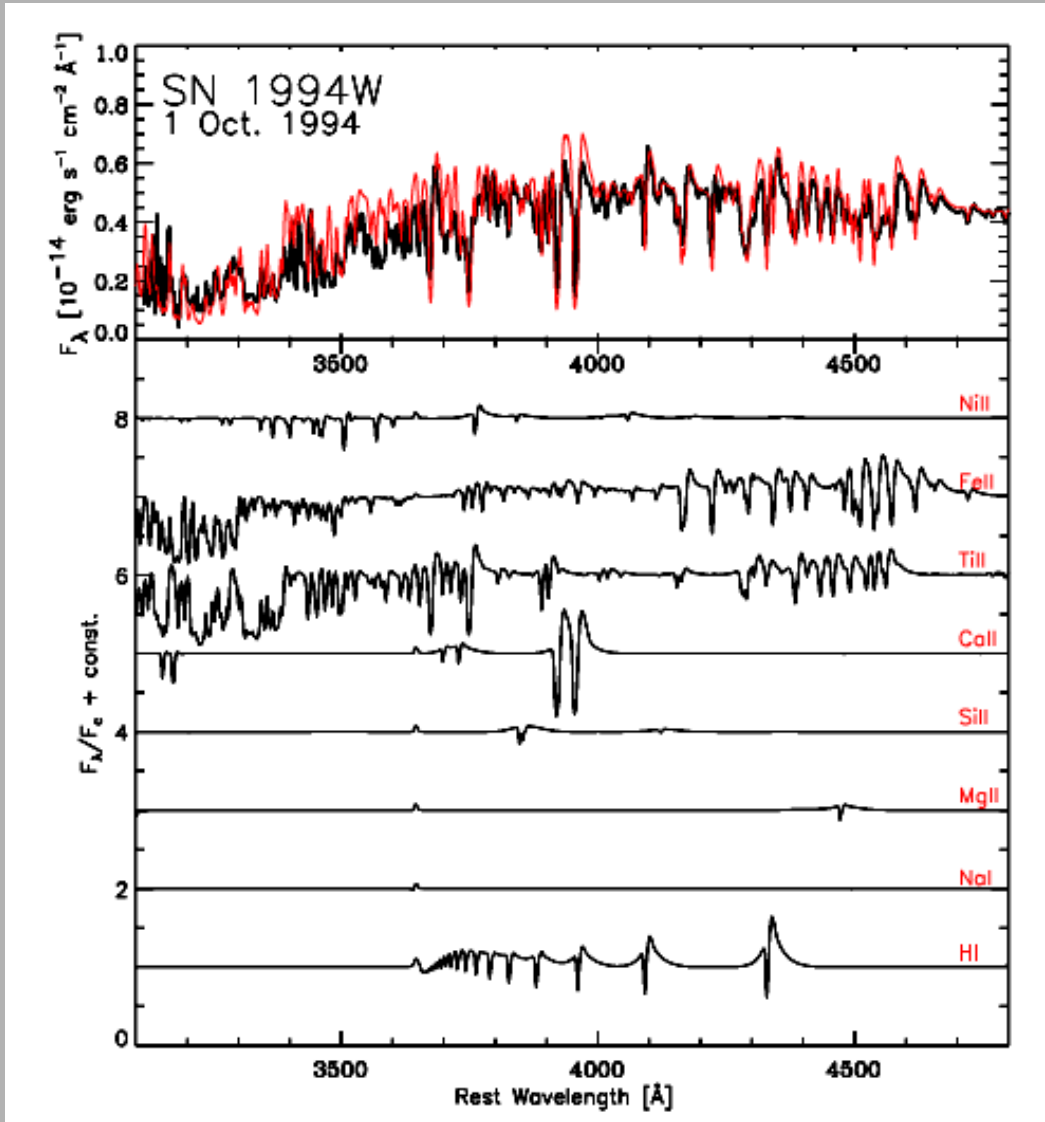
- Chugai et al. (2004, MNRAS, 352, 1213) favours a electron-capture SN interpretation

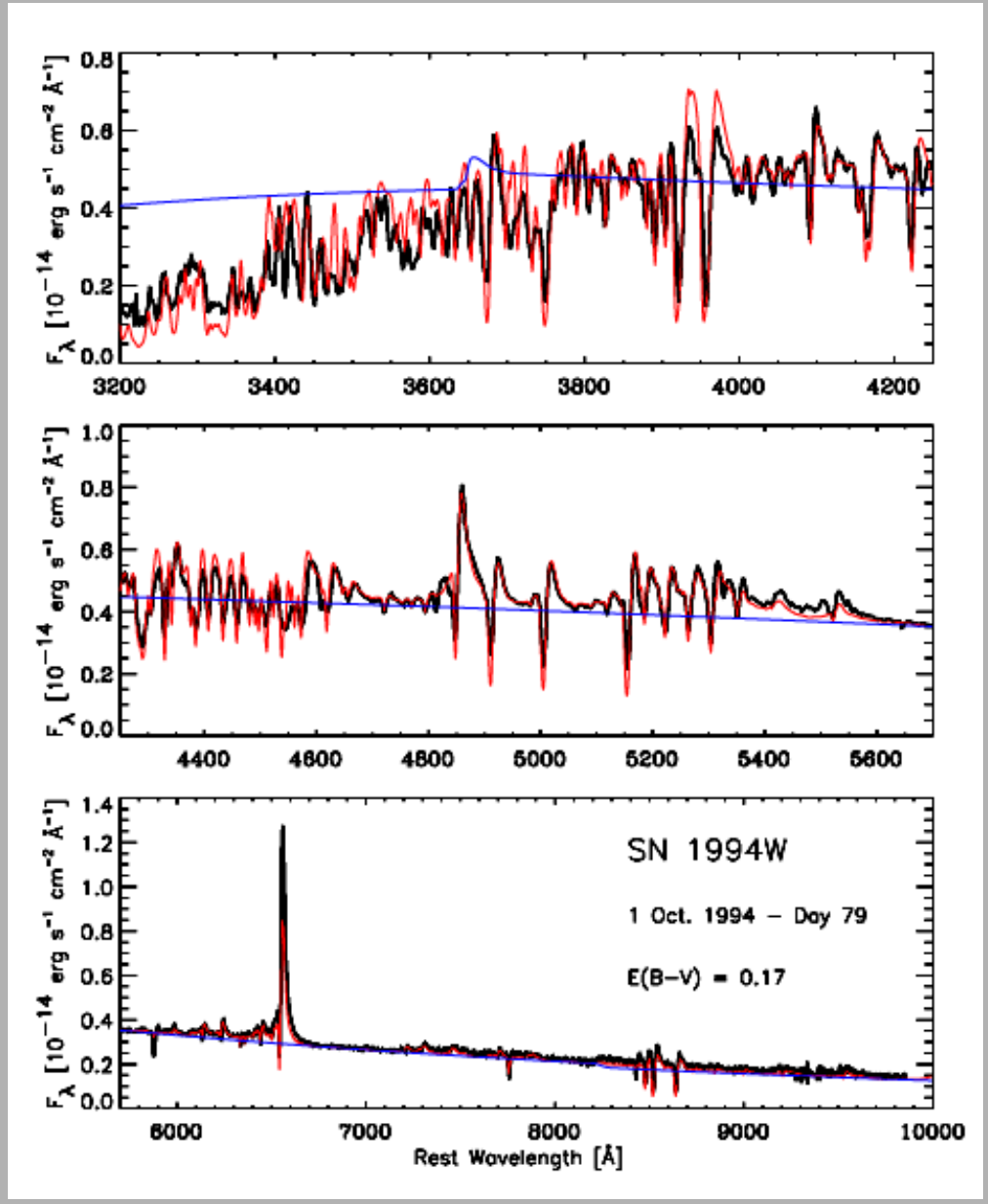




SN 1994W

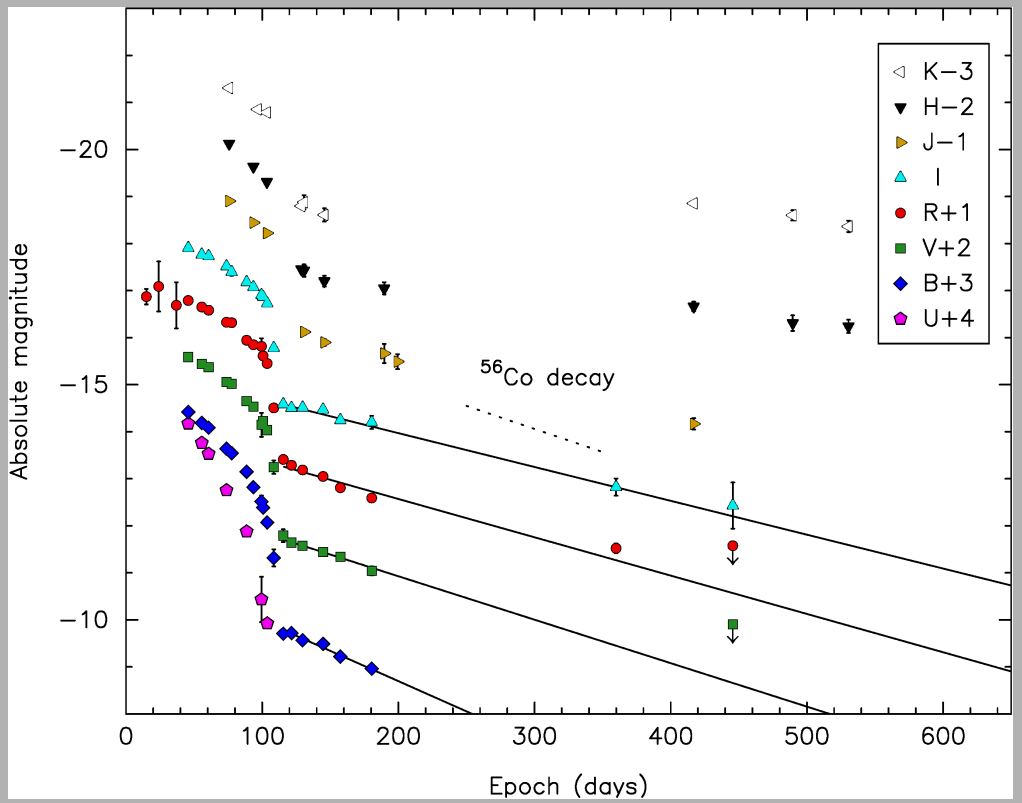
- Dessart et al. (2009, MNRAS, 394, 21) favours a pair of interacting shells interpretation

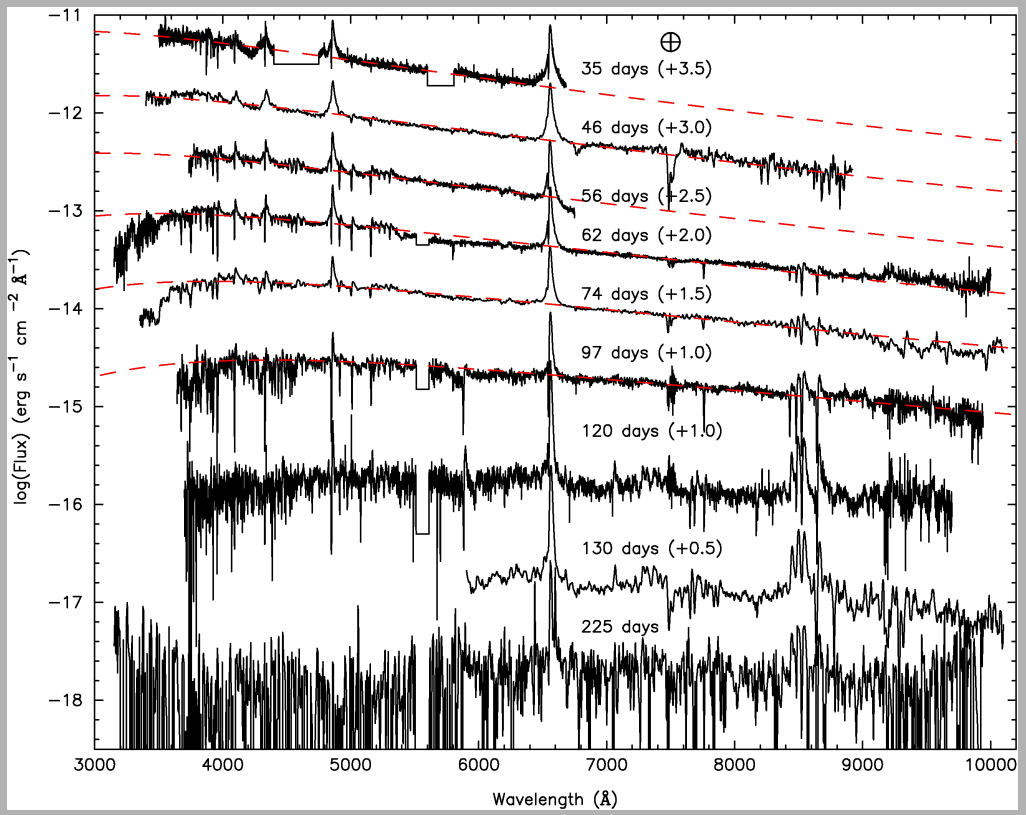




SN 2009kn

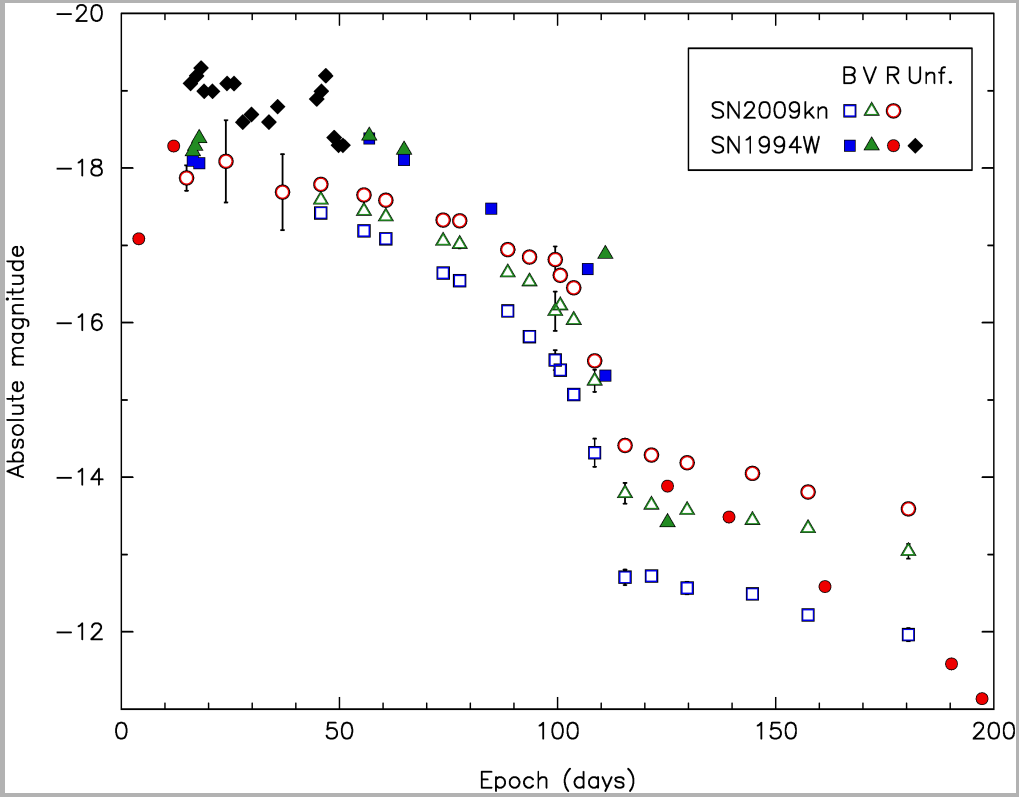
- Kankare et al. (2012, MNRAS, 424, 855) favours an electron-capture SN interpretation, but does not exclude colliding shells

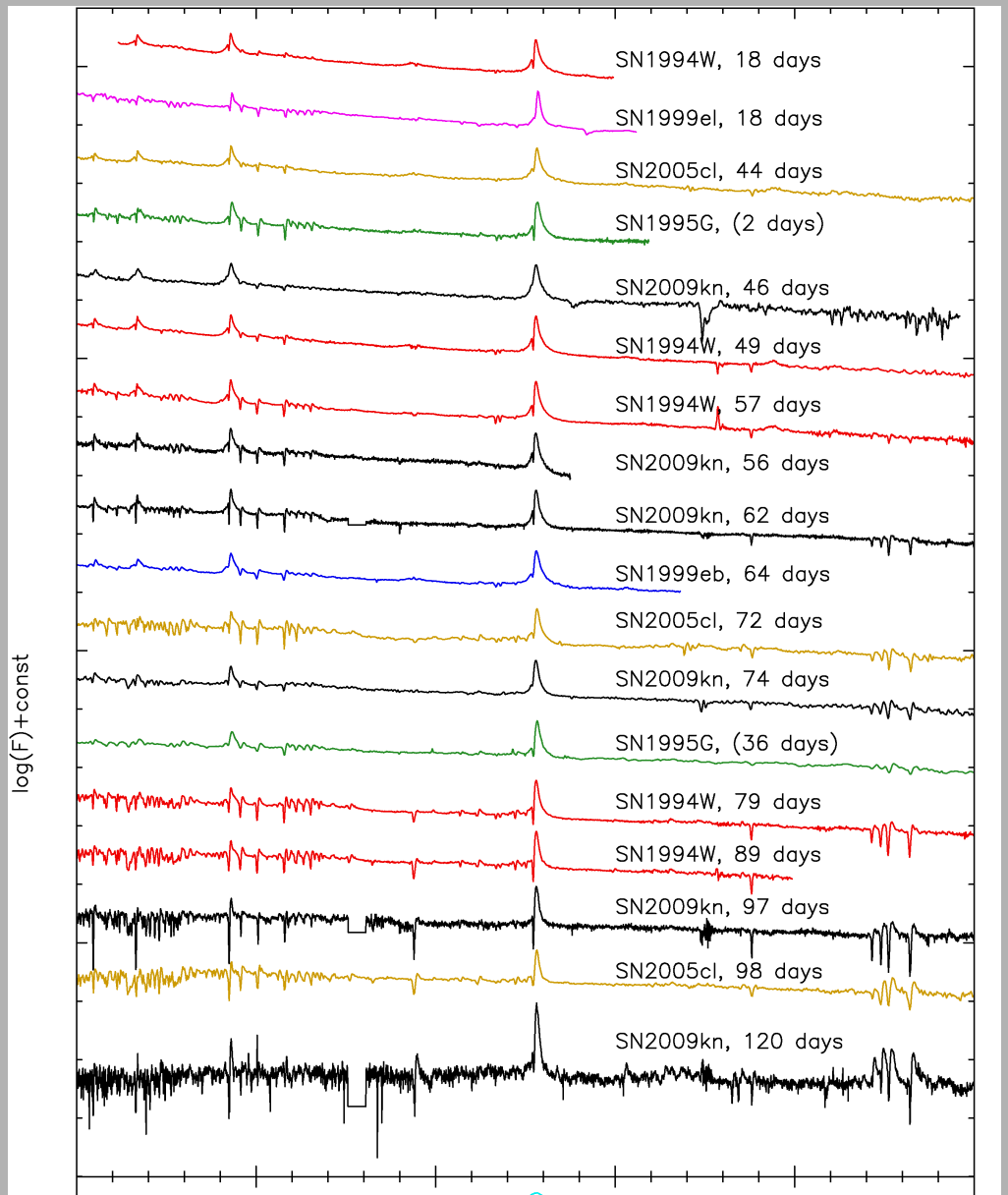




SN 2009kn

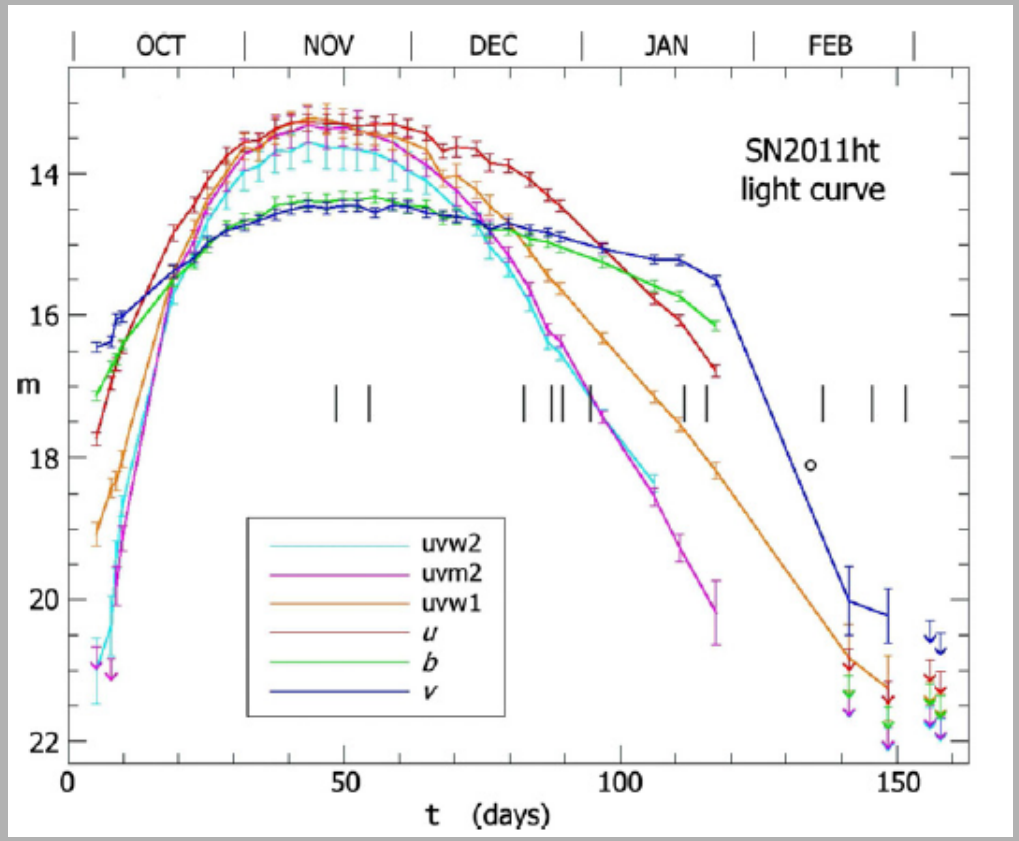
- Kankare et al. (2012, MNRAS, 424, 855) favours an electron-capture SN interpretation, but does not exclude colliding shells
- Twin of SN 1994W
- Suggesting a larger sample of events

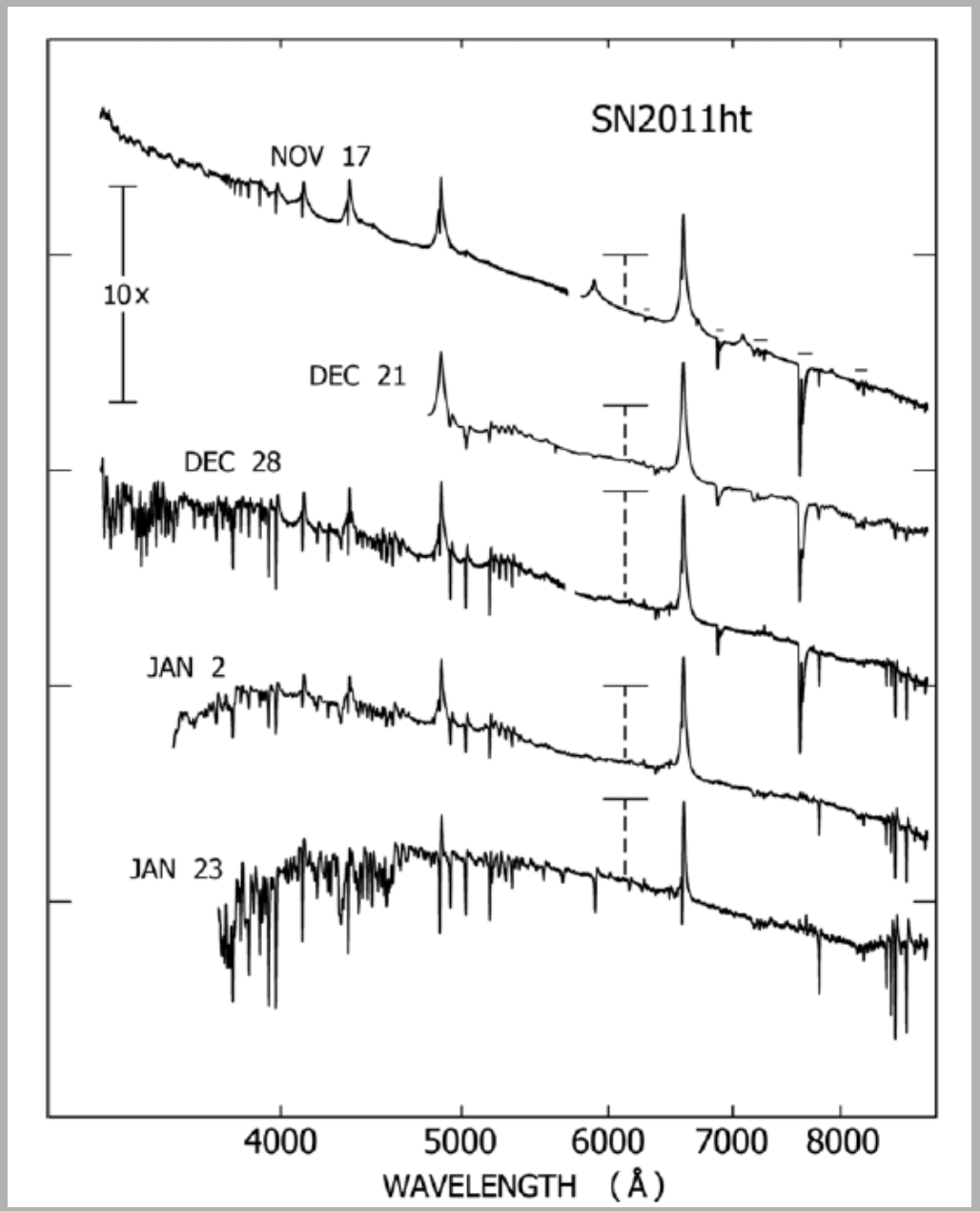




SN 2011ht

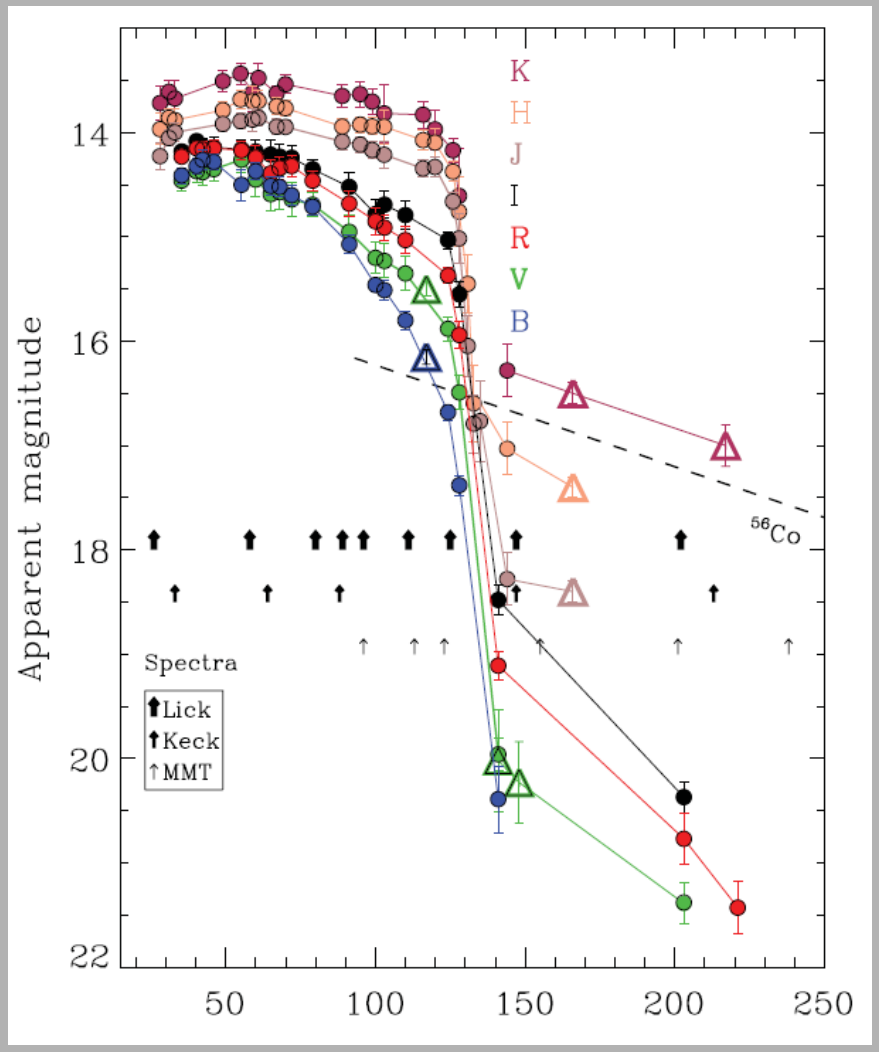
- Humphreys et al. (2012, ApJ, 760, 93 – Paper II) favours a SN impostor interpretation
- See also Roming et al. (2012, ApJ, 751, 92 – Paper I)

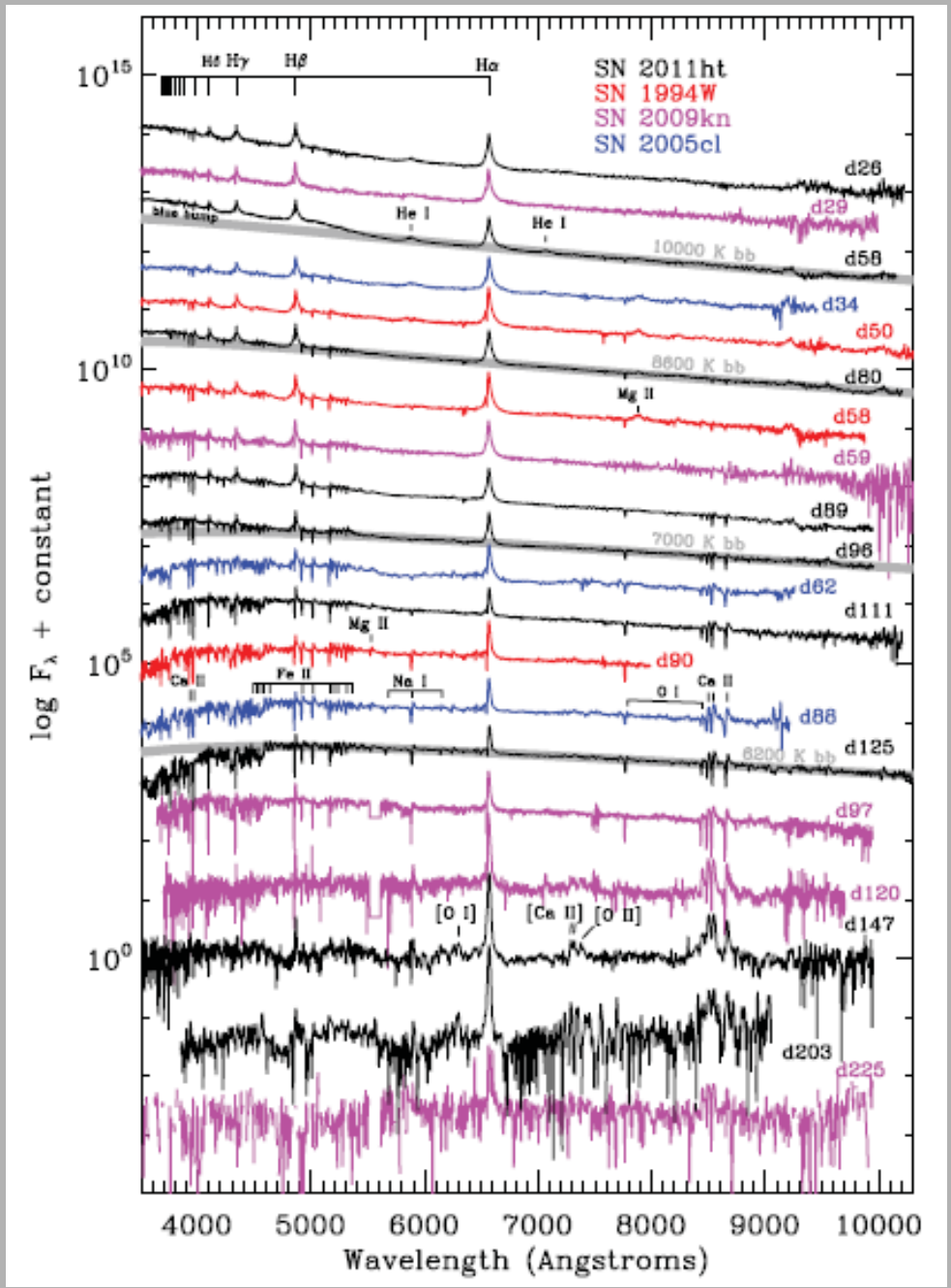




SN 2011ht

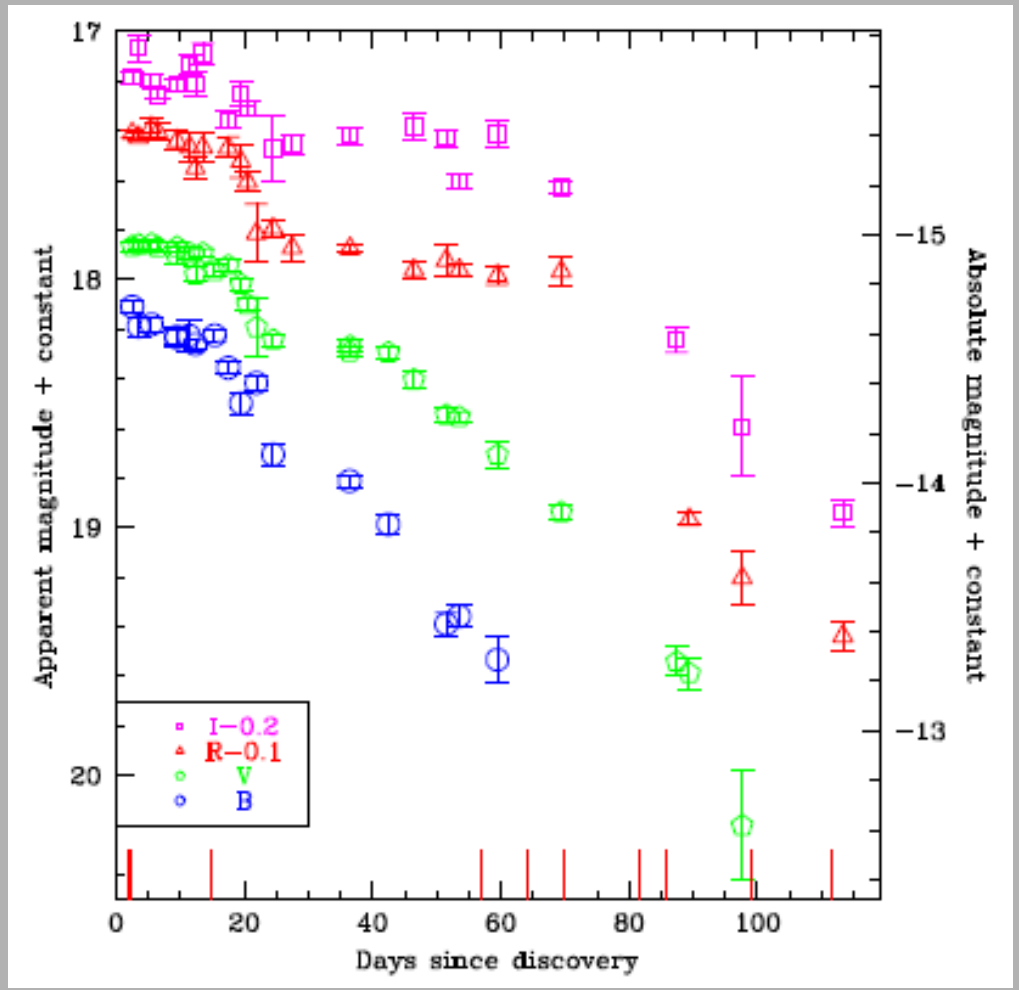
- Mauerhan et al. (2013, MNRAS, 431, 2599) favours an electron-capture SN or fallback SN interpretation

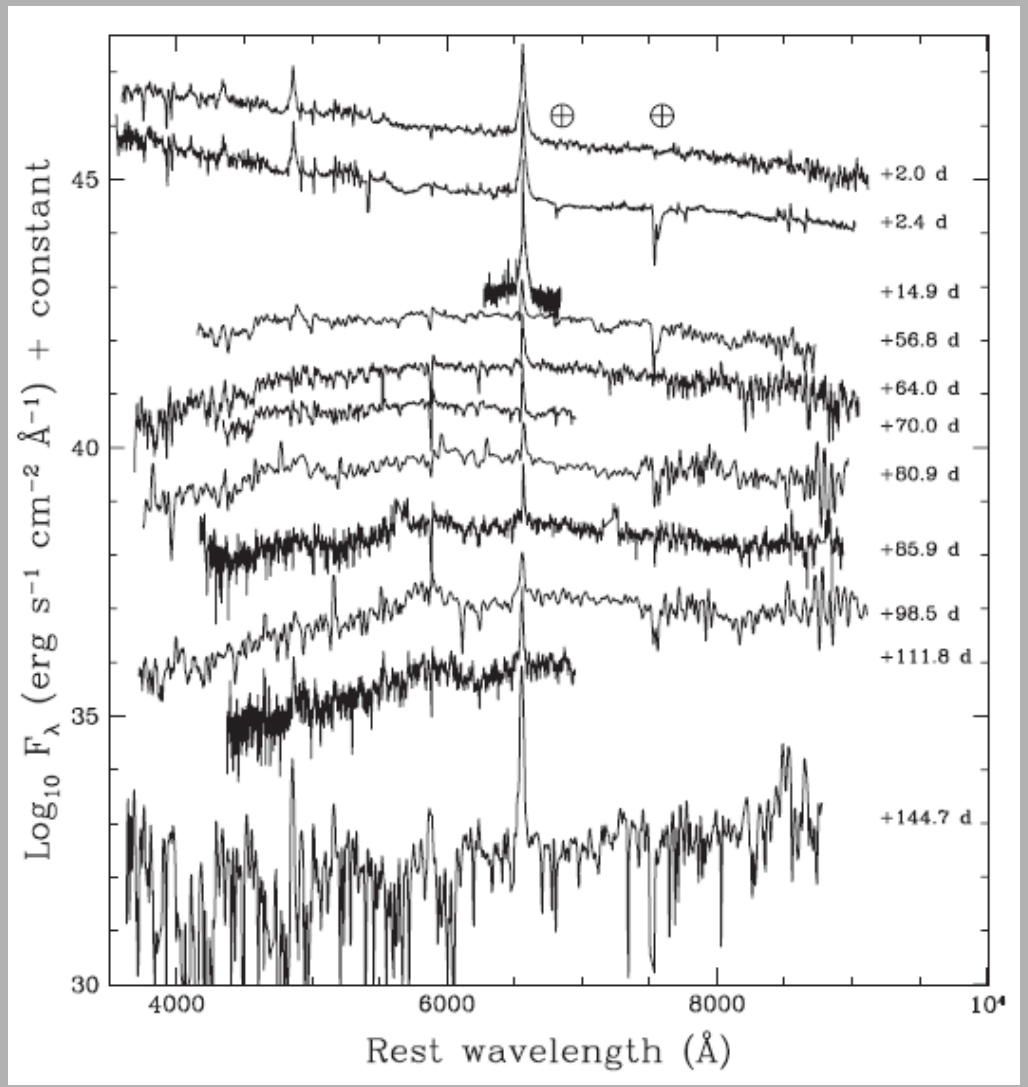




SN 2011A

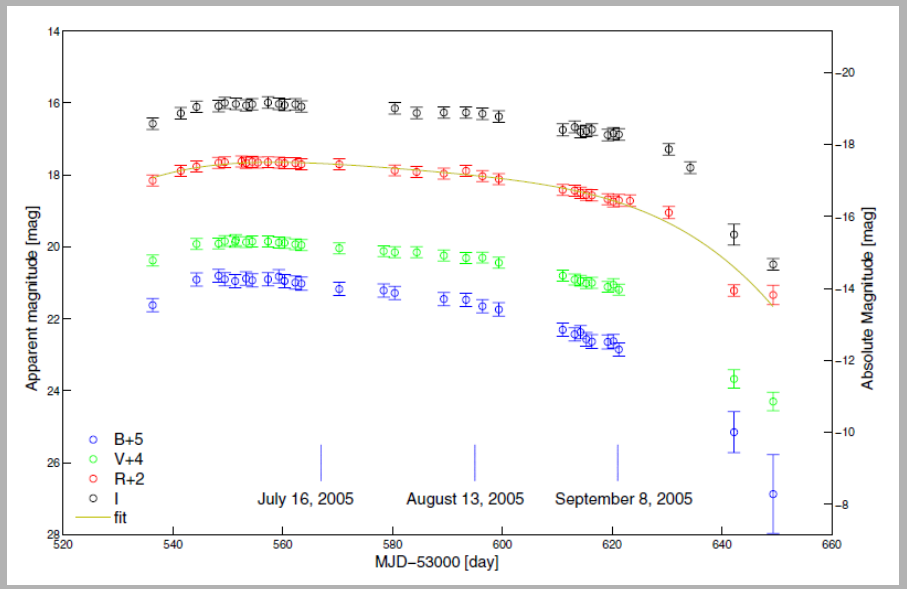
- de Jaeger et al. (2015, ApJ, 807, 63) favours a SN impostor interpretation

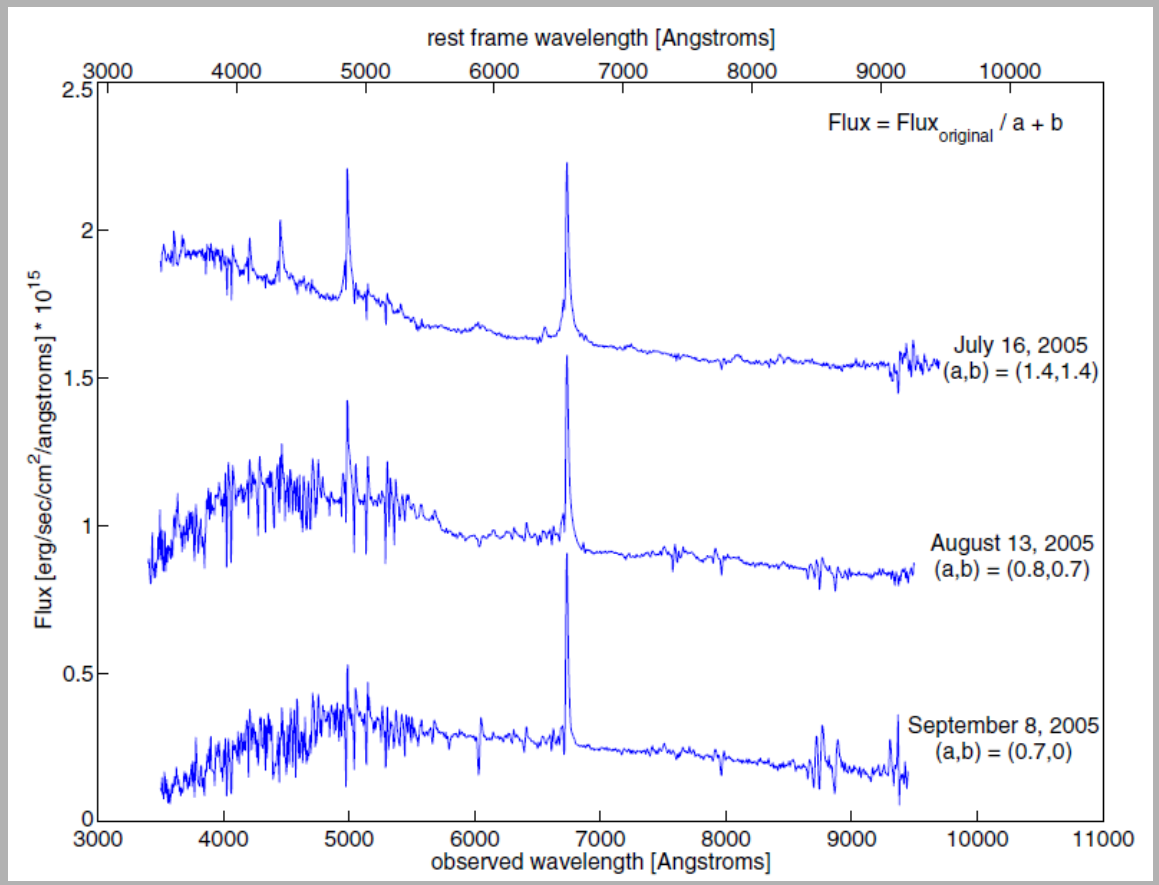




SN 2005cl

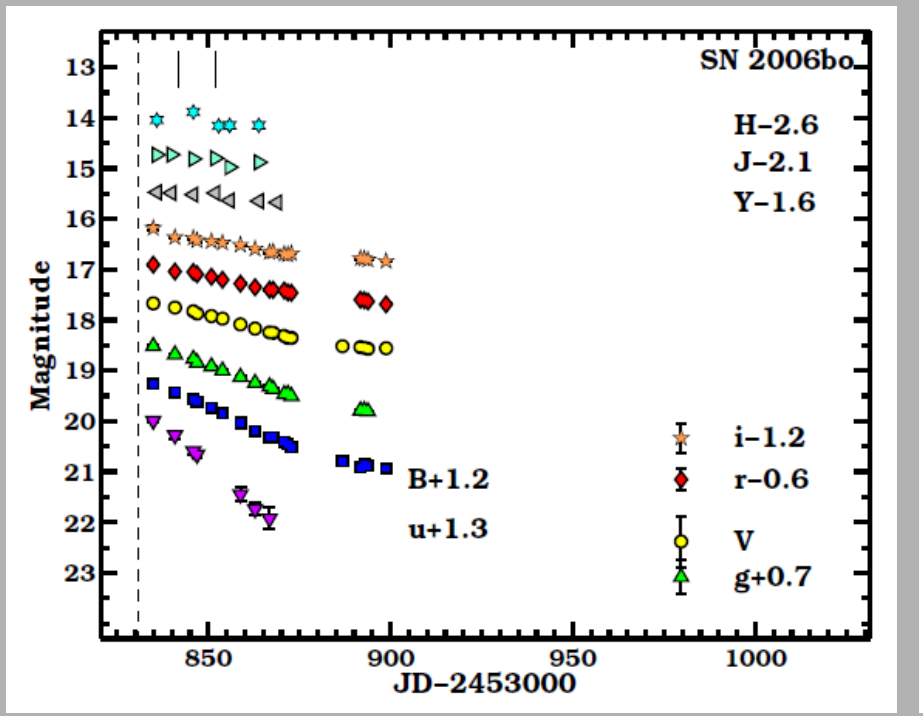
- Kiewe et al. (2012, ApJ, 744, 10) presented a sample of 4 Type IIn SNe (2005bx, 2005cl, 2005cp, 2005db) from the Caltech Core-Collapse Project (CCCP)

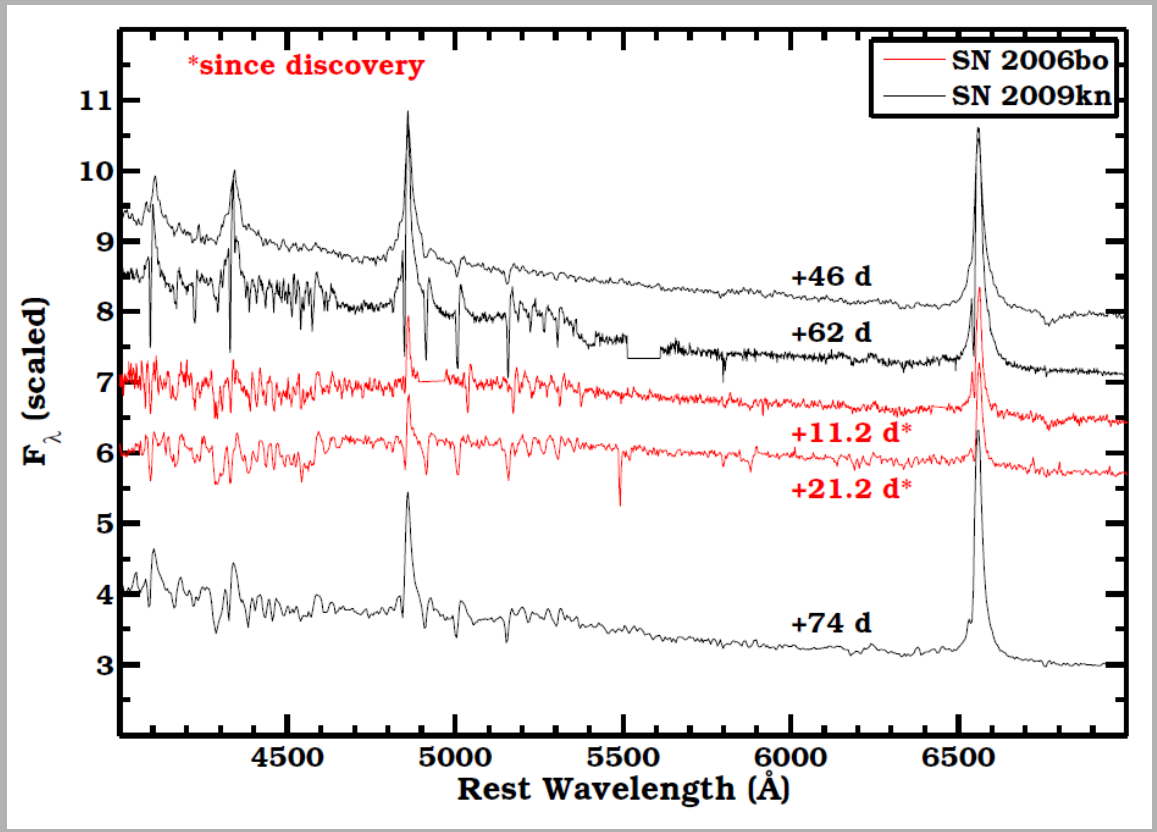




SN 2006bo

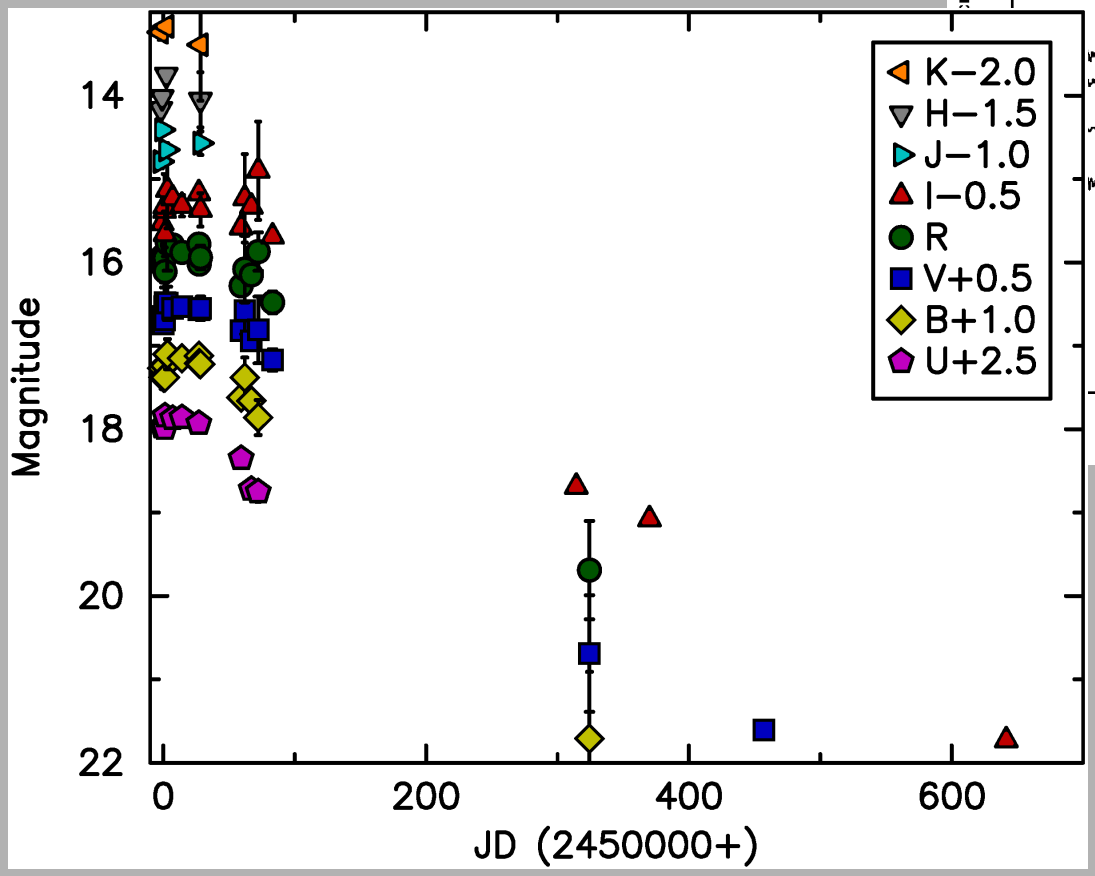
- Taddia et al. (2013, A&A, 555, A10) presented a sample of 5 Type IIn SNe (2005kj, 2006aa, 2006bo, 2006qq, 2008fq) from the Carnegie Supernova Project (CSP)

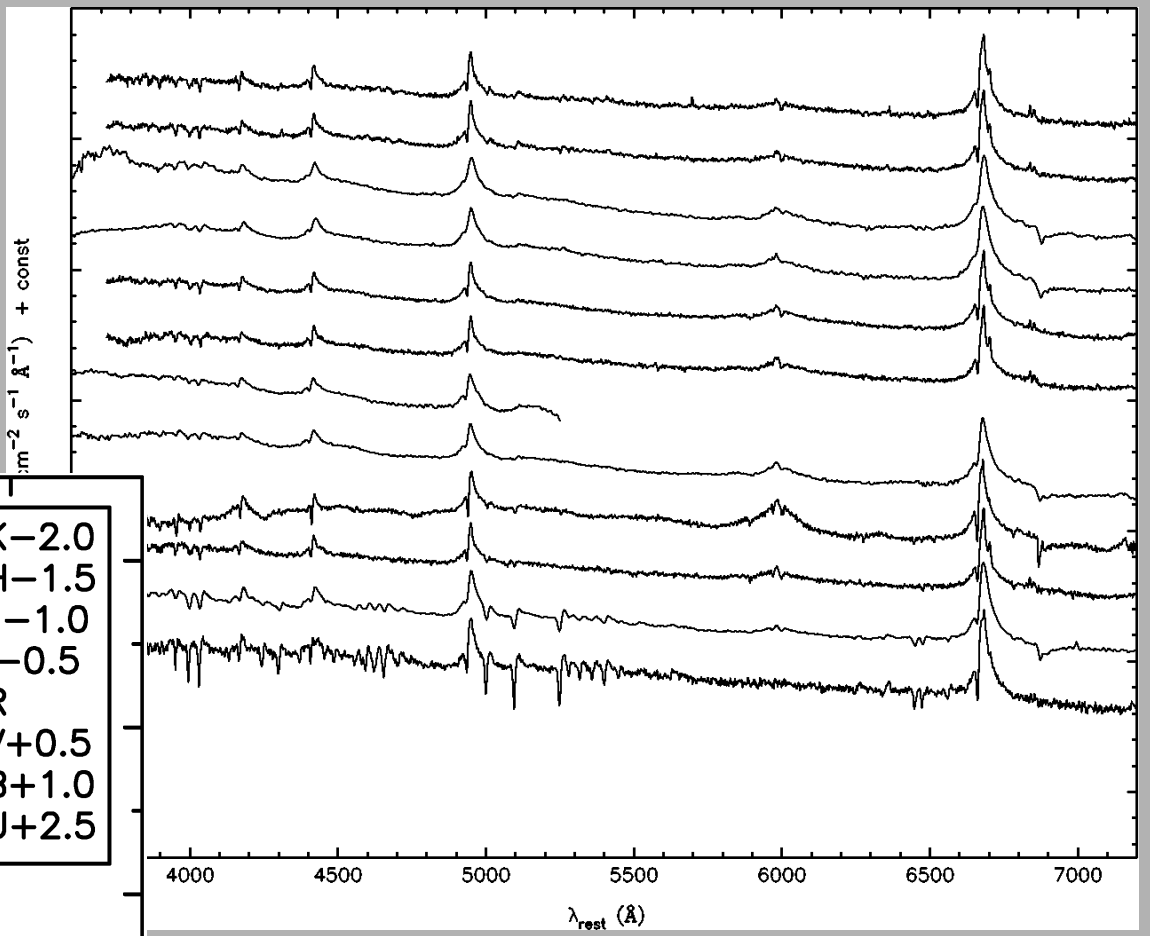




SN 1999eb

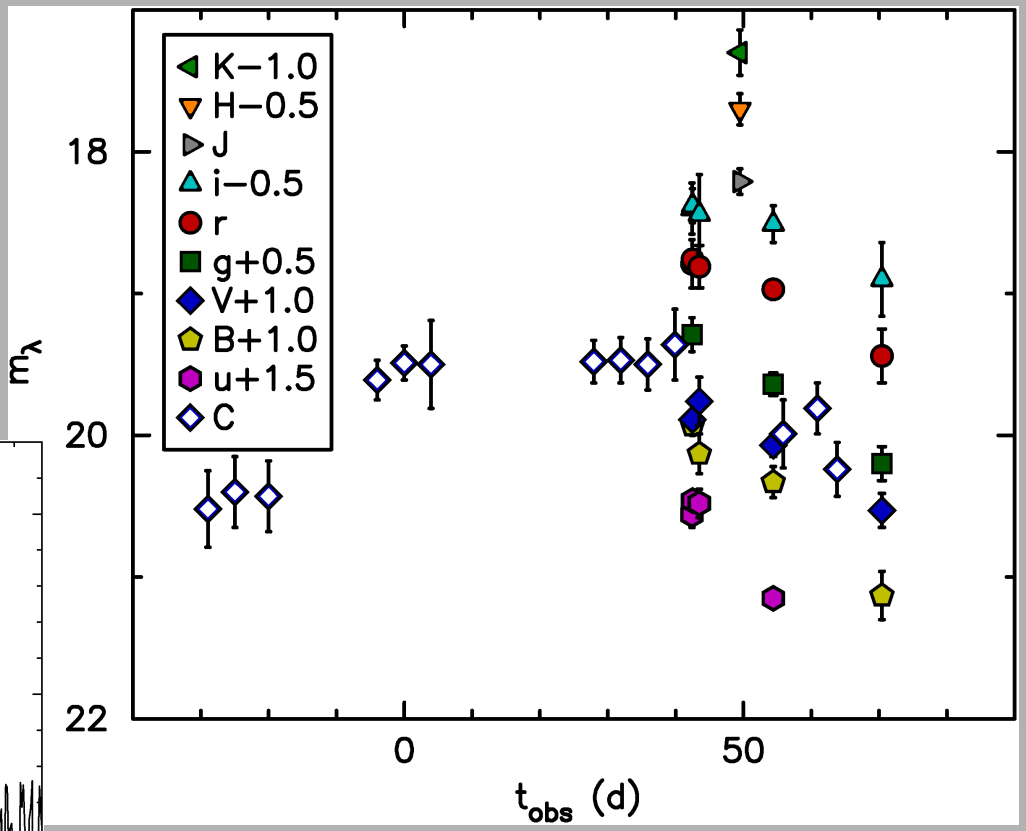
- Unpublished data set
- Late-time *HST* points (Li et al. 2002, PASP, 114, 403)

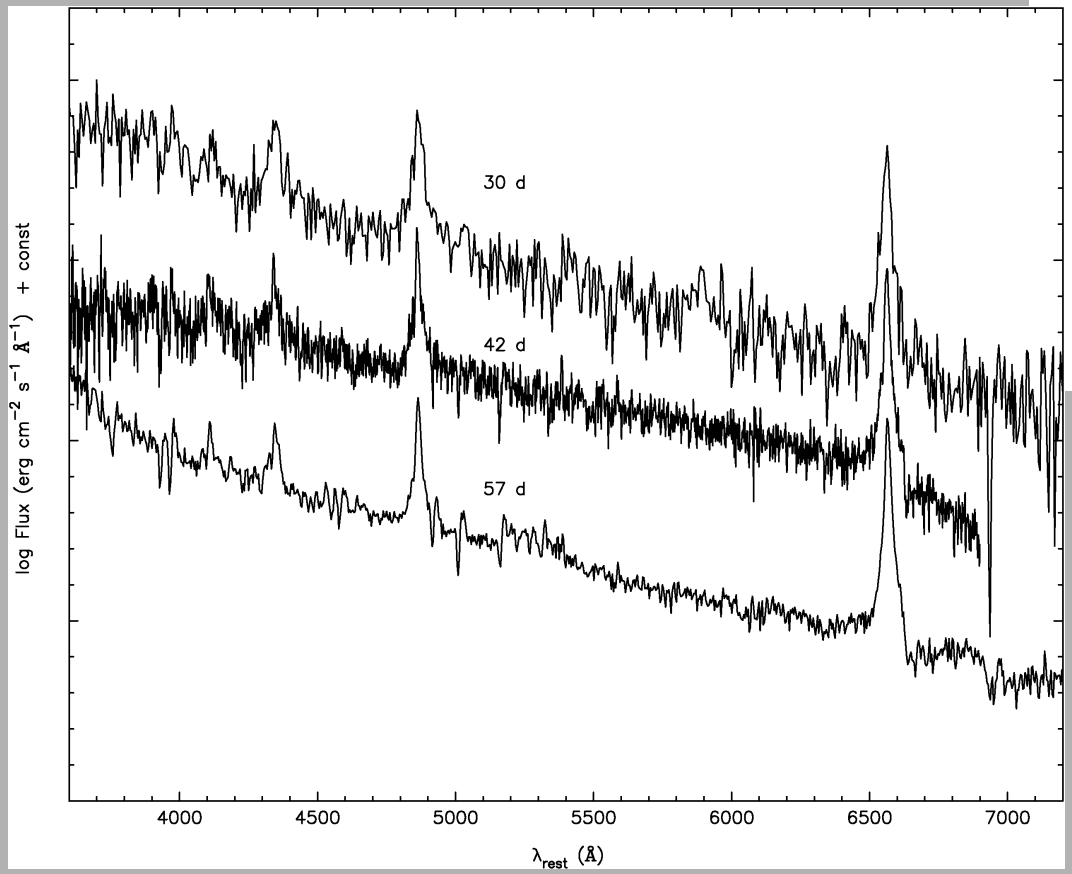




SN 2017ben

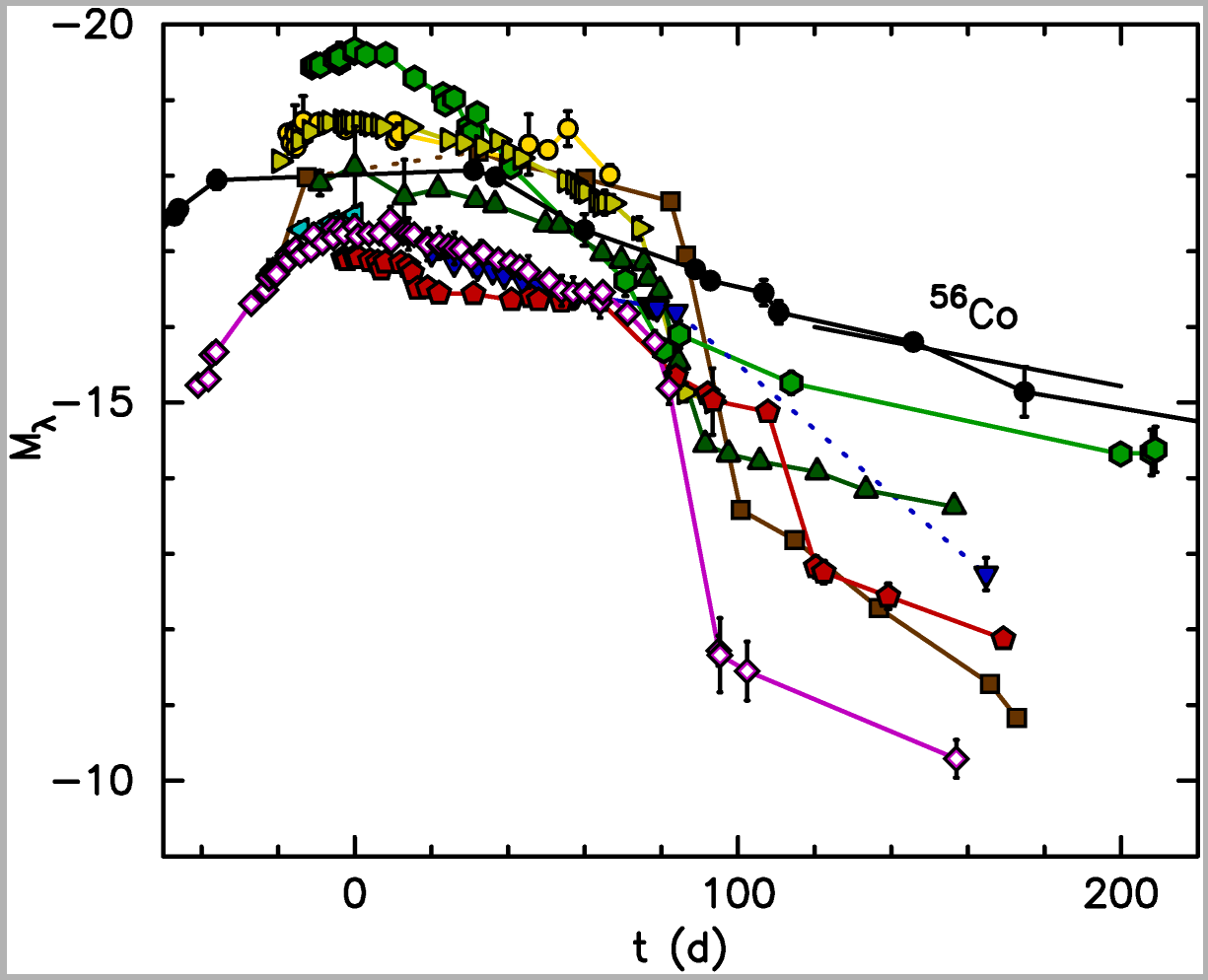
- ATLAS17bdx
- Long light curve rise (cf. SN 2011ht)





A class of SN 1994W-like events

- ~700 km/s P Cygni lines of H I, Fe II, Ti II, Ca II
- Typically a ~100 d light curve plateau
- Distinctive tail phase
- Kankare et al. (in prep.)



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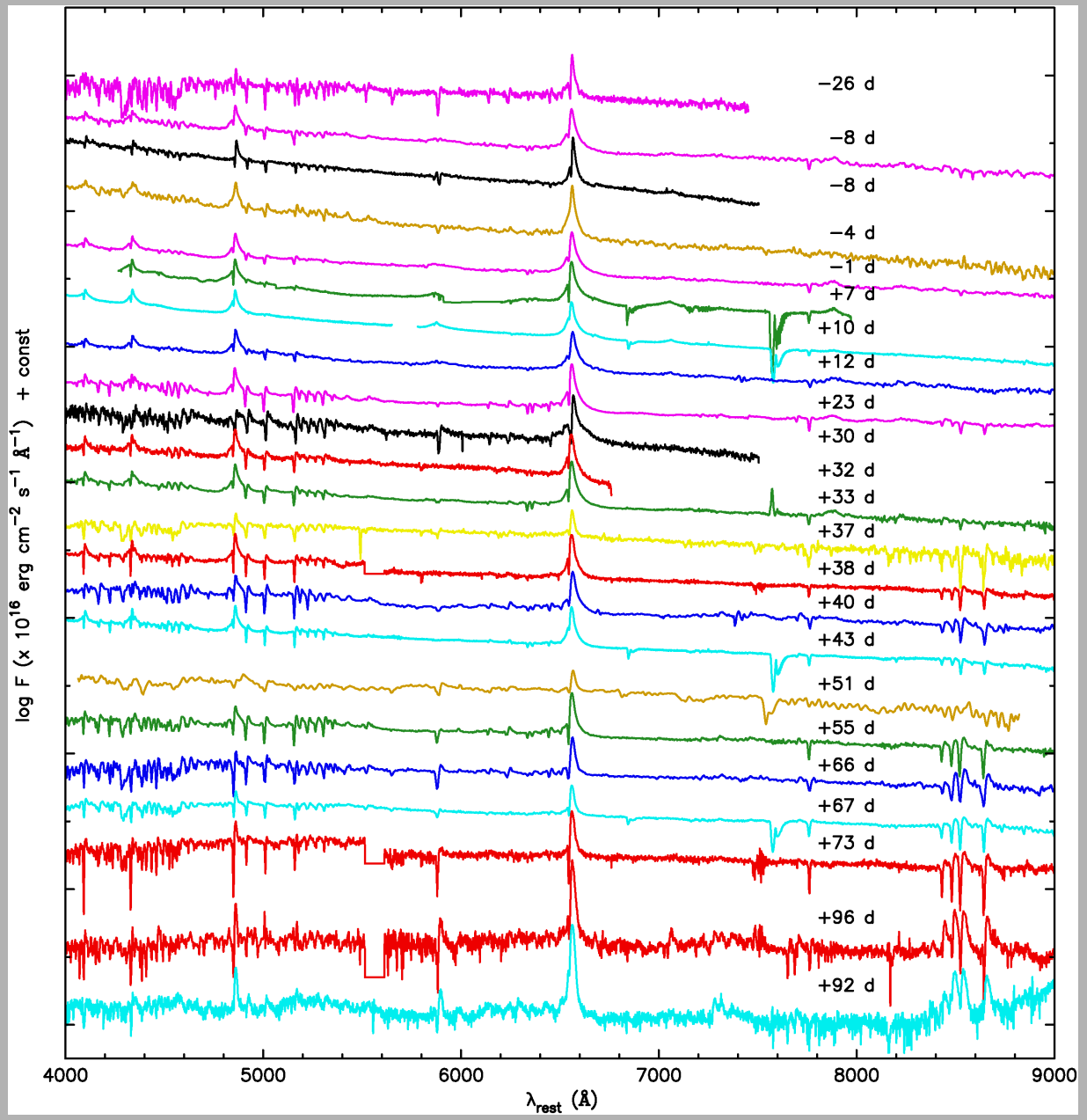
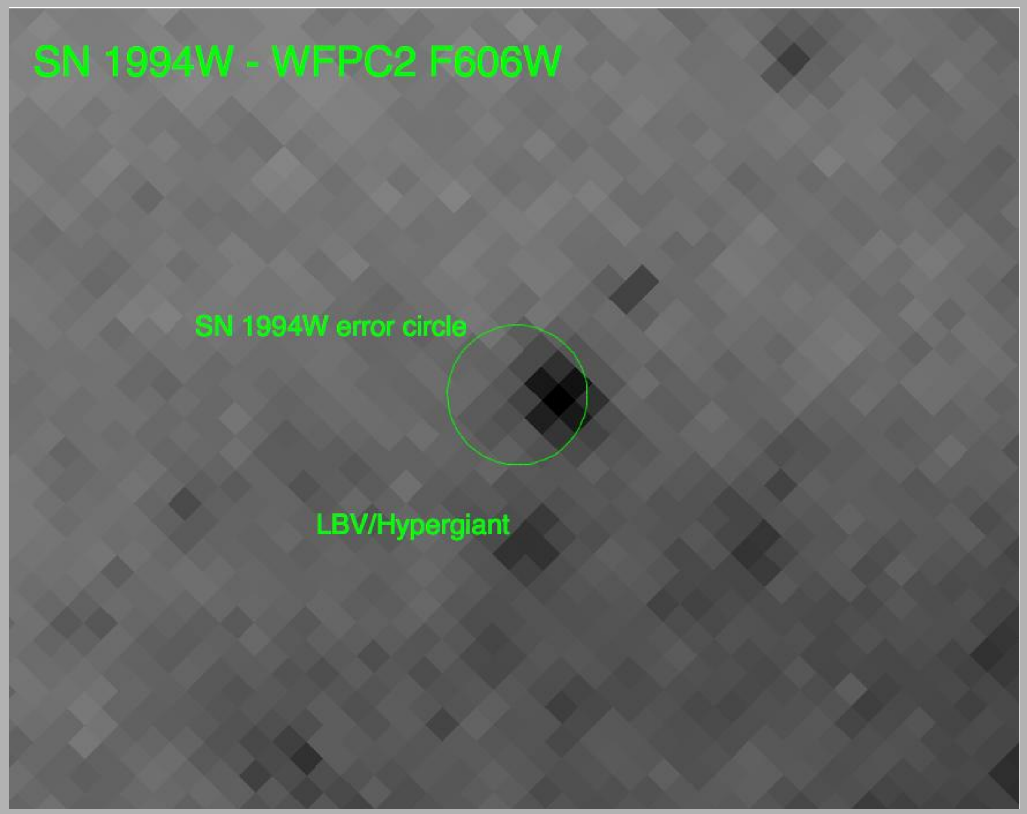


Late-time imaging of SN 1994W explosion site

- *HST* imaging
  - WFPC2 (F450W, F606W, F814W) 2001-07-04
  - ACS (F814W) 2004-05-29
  - WFC3 (F336W) 2011-01-30
- Co-incident source:
  - M_V = –8.60 mag
  - $B - V$ and $V - I$ colours are not self-consistent for a single temperature
  - Most likely a blended cluster
- Nearby source:
  - M_V = –7.83 mag
  - Mid-A to early-F super/hyper-giant (log L ~ 6.2 dex) with a temperature of 7500 − 8500 K



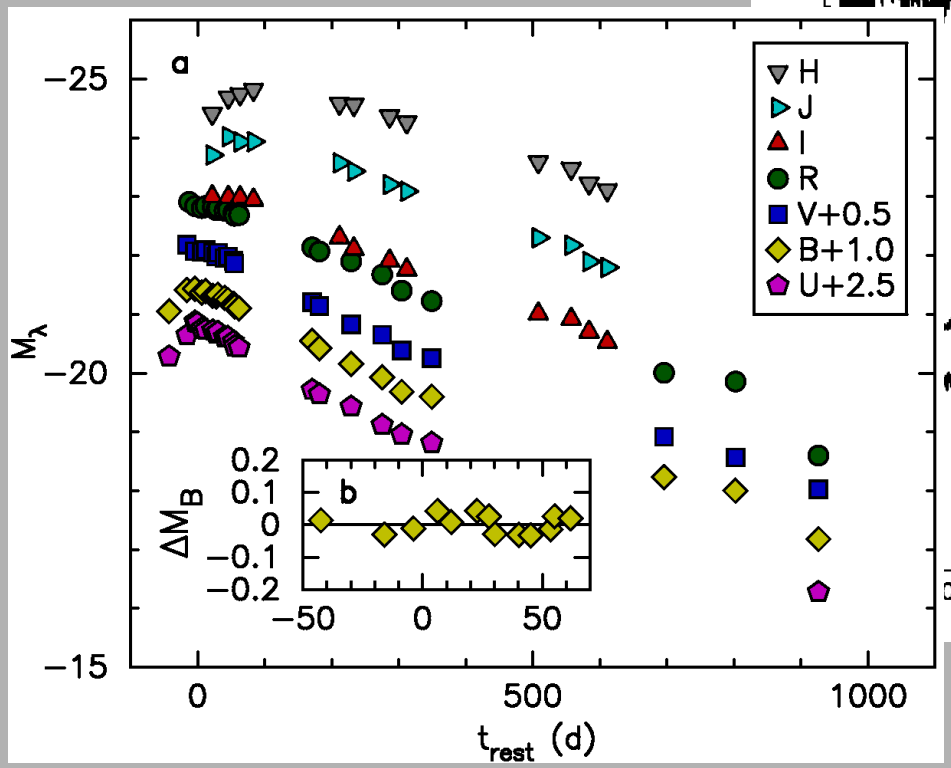
SN1994W and SN2009kn-like events summary

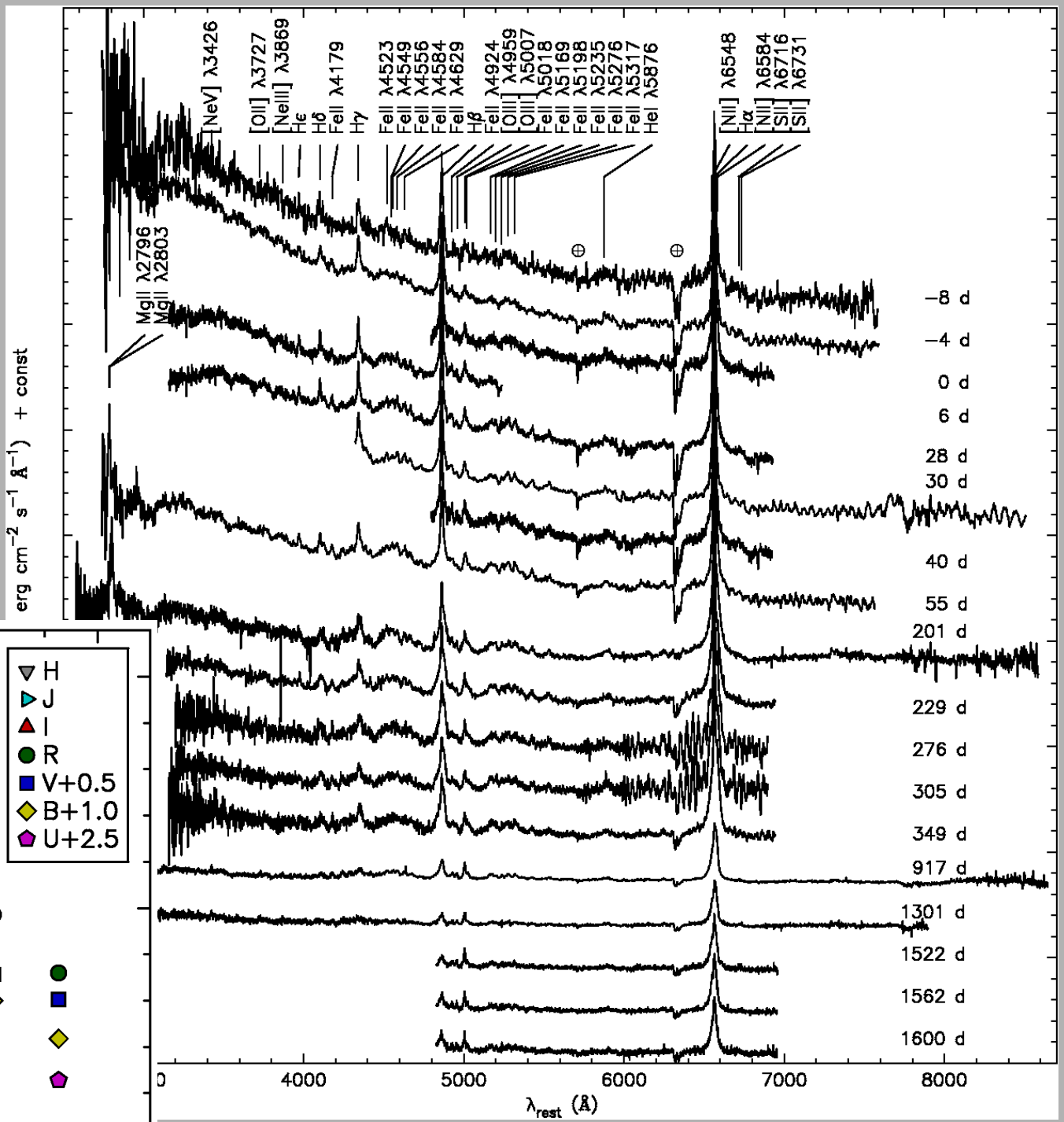
- There is a class of SN 1994W-like events
  - Similar characteristics:
    - Narrow ~700 km/s P Cygni lines of H I, Fe II, Ti II, Ca II
    - Typically a ~100 d light curve plateau
    - Distinctive tail phase
- No surviving luminous progenitor in the late-time *HST* imaging of SN 1994W
  - Suggests: Not collisions of non-terminal outburst shells from LBV-like stars

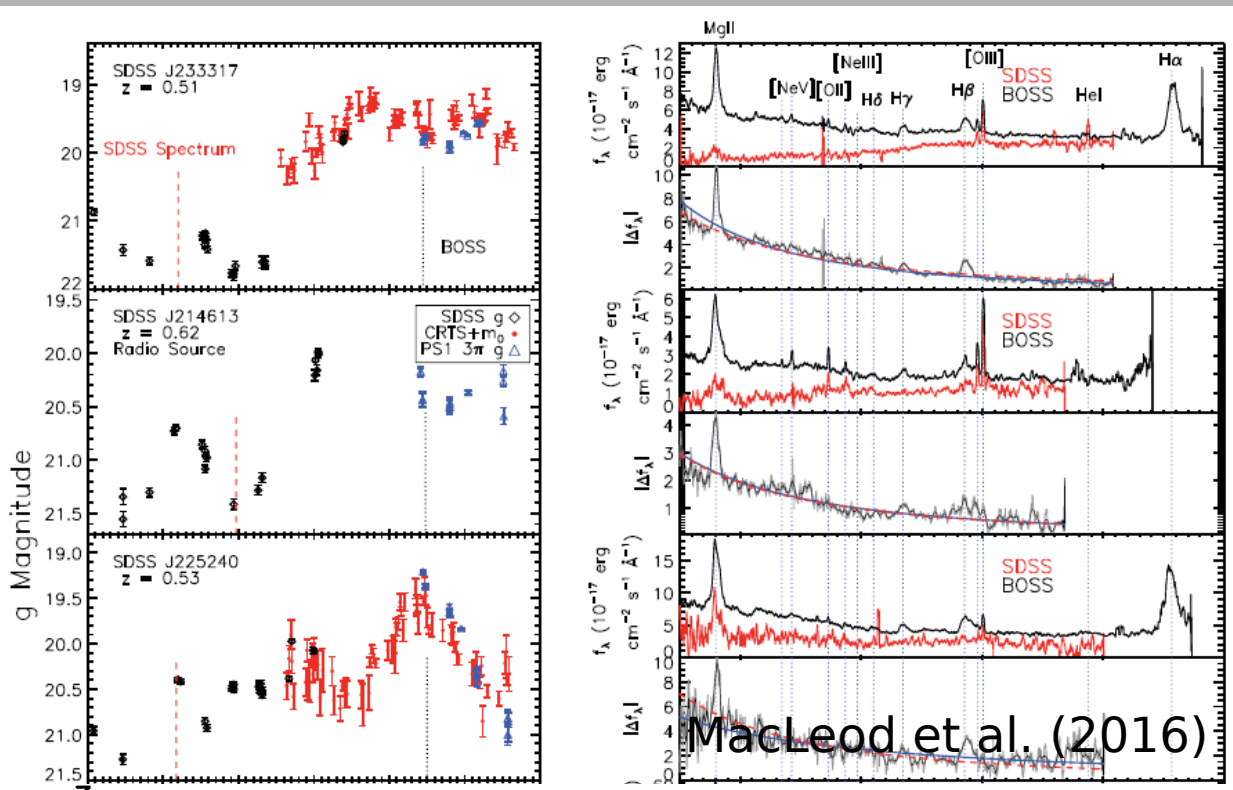
PS1-10adi-like events

PS1-10adi

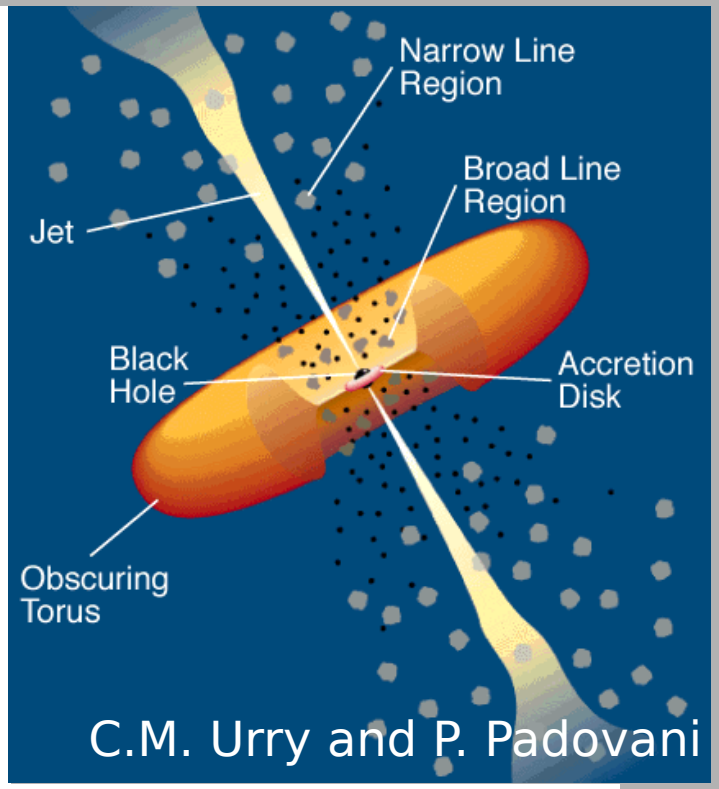
- Kankare et al. (2017, Nature Astronomy)
- Smooth evolving
- Narrow spectral lines (~1000 km/s)
- Extremely energetic (~10^{52} erg)
- Seyfert hosts



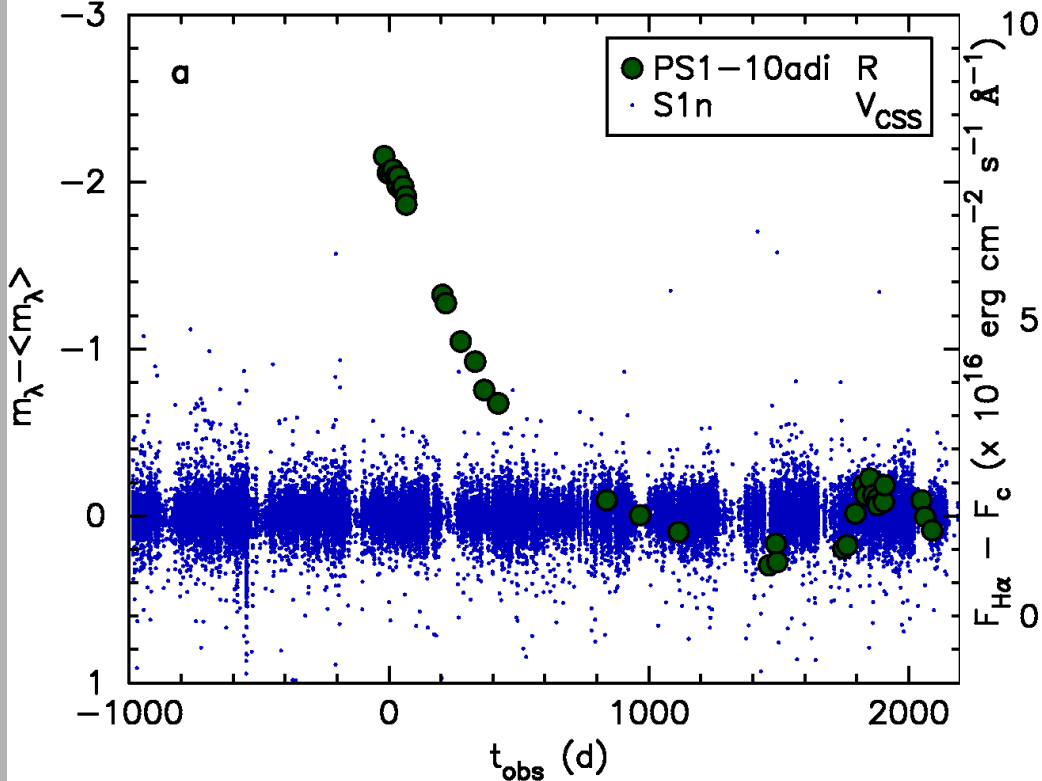


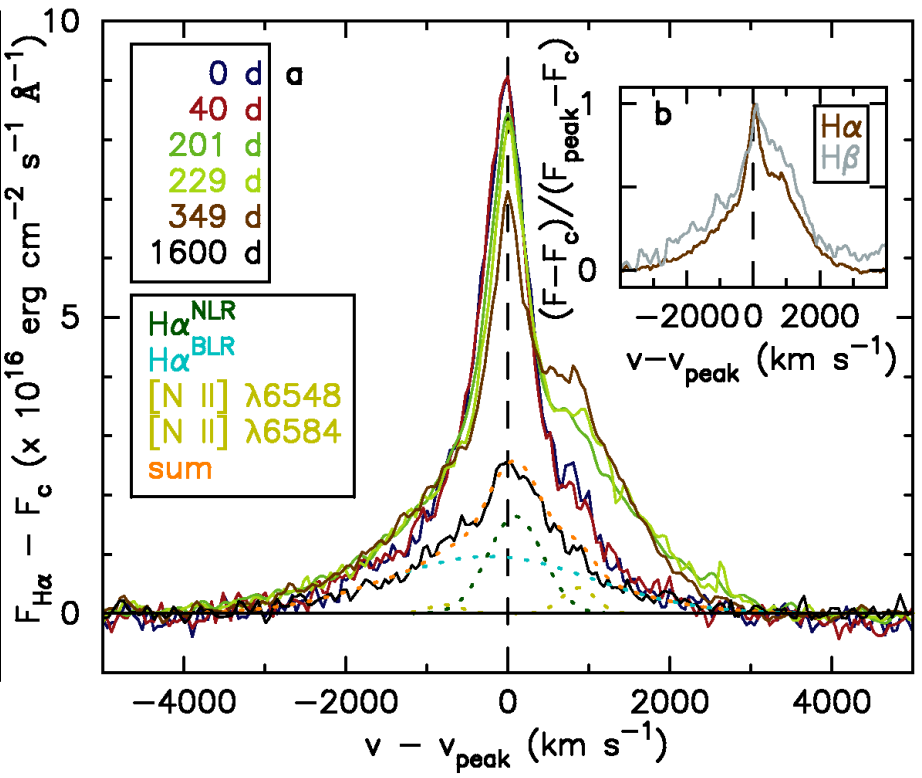


MacLeod et al. (2016)

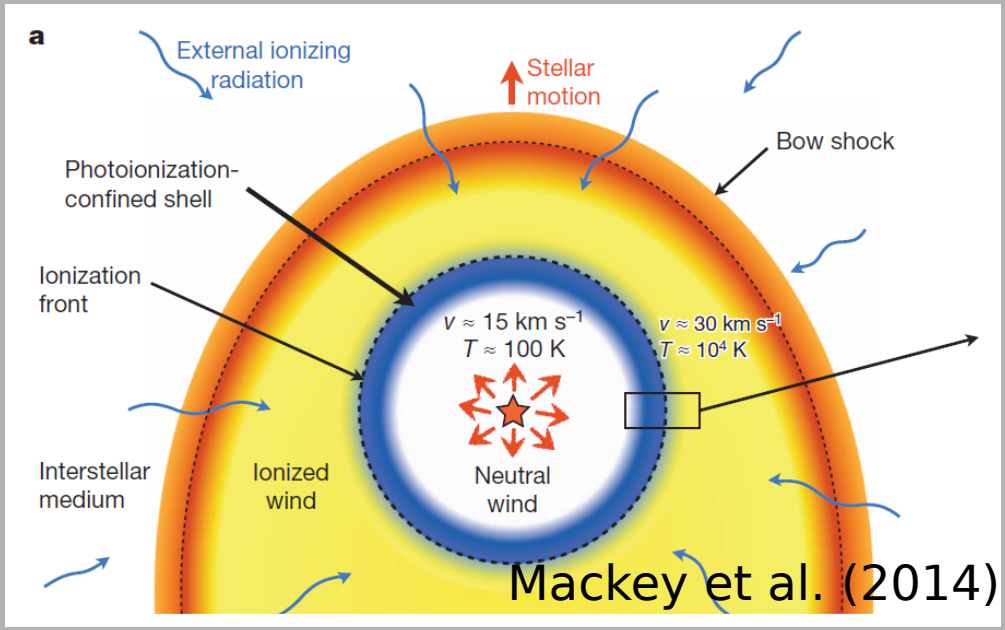


C.M. Urry and P. Padovani

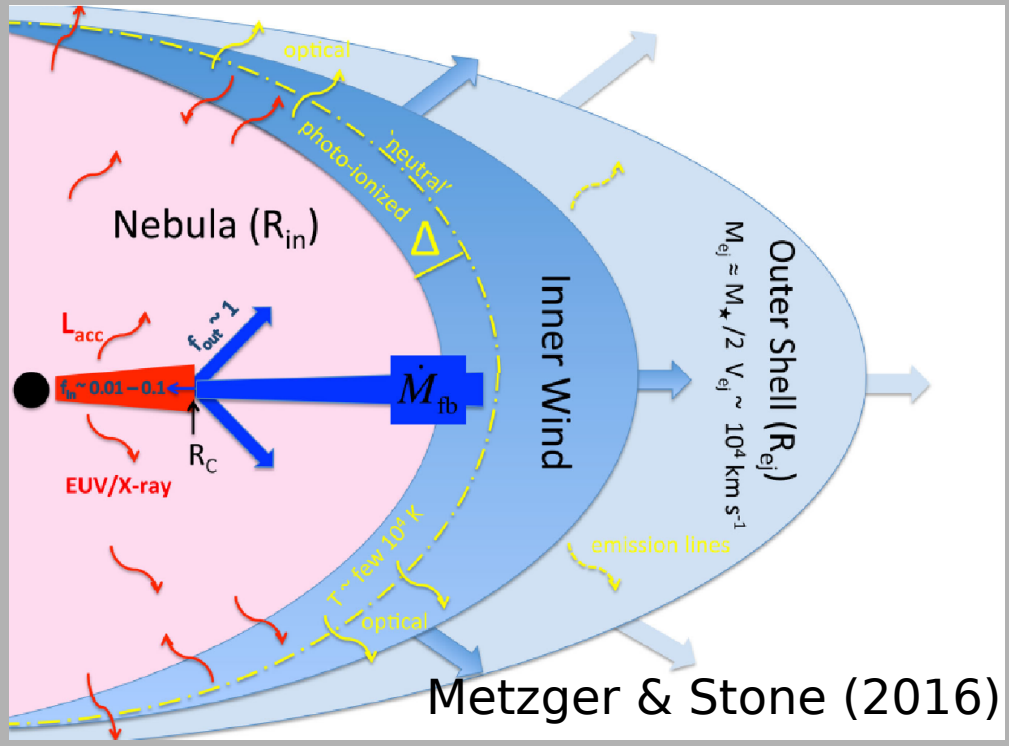




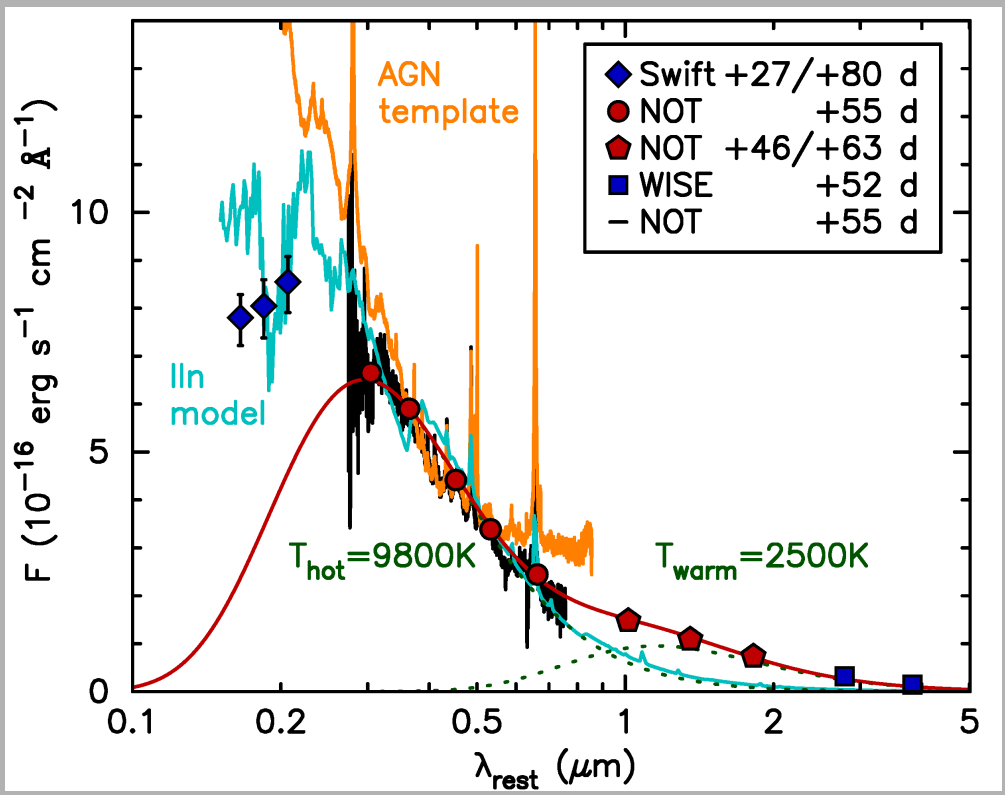
NLR SN or TDE-ISM?

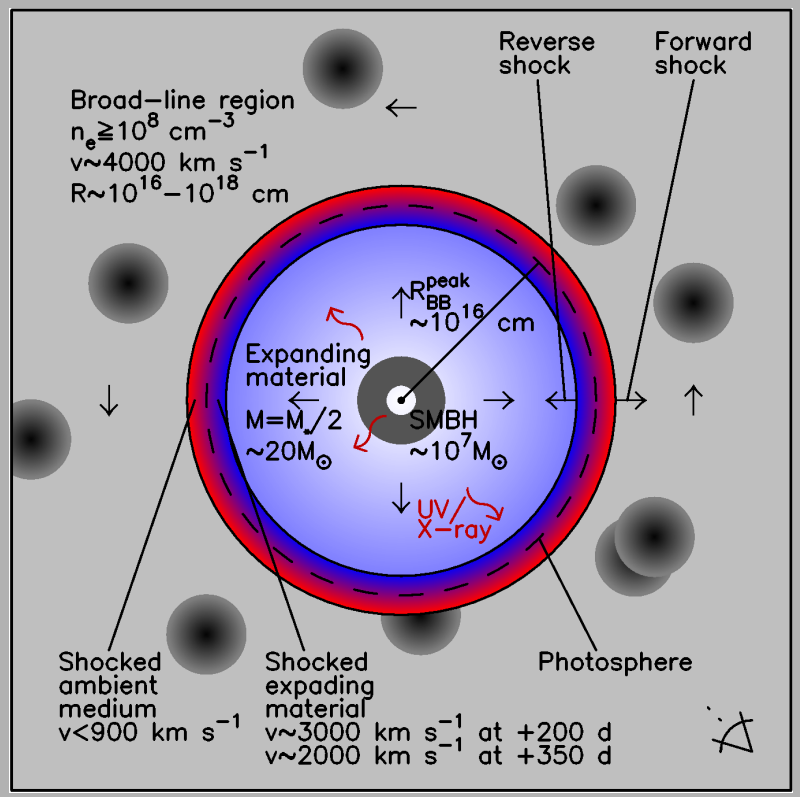


Mackey et al. (2014)



Metzger & Stone (2016)





Summary

- Large variety of objects with an uncertain terminal supernova nature
- Not only non-terminal outbursts of luminous blue variables
- Faint objects most relevant for supernova rates