Supernova Classification

Focus on new SN types

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Queen's University Belfast

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Overview

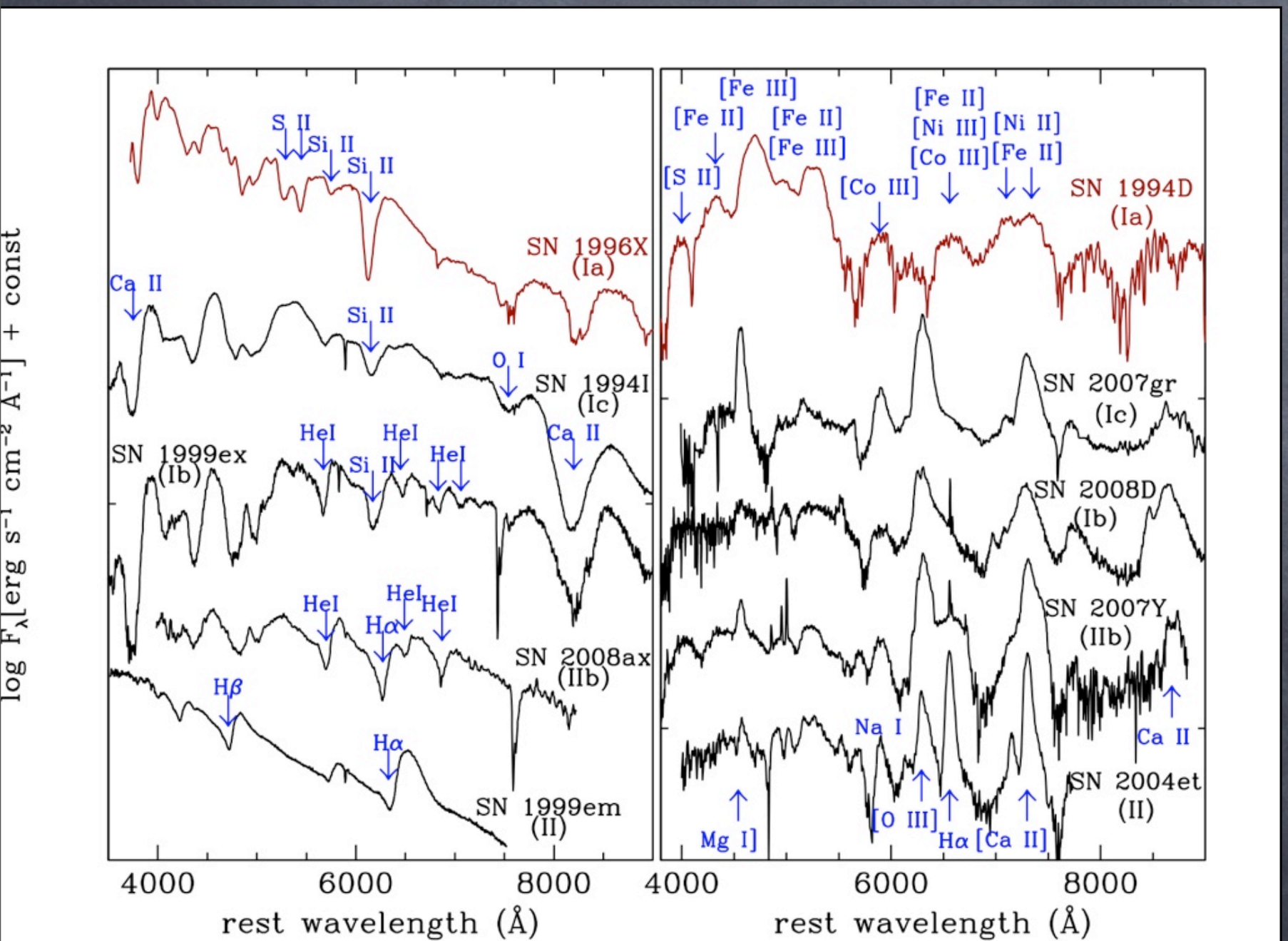
- Introduction: traditional supernova classification scheme

- Transients in the luminosity gap novae-supernovae:
  - Faint, H-rich core-collapse supernovae
  - Faint supernovae IIn or supernova impostors?
  - Sub-luminous stripped-envelope supernovae

- Hyper-luminous supernovae:
  - Super-Chandrasekhar mass supernovae Ia
  - Ejecta-CSM interacting supernovae (IIn & Ibn)
  - Hyperluminous SN Ic & Quimby's family: a link to pair-instability events?

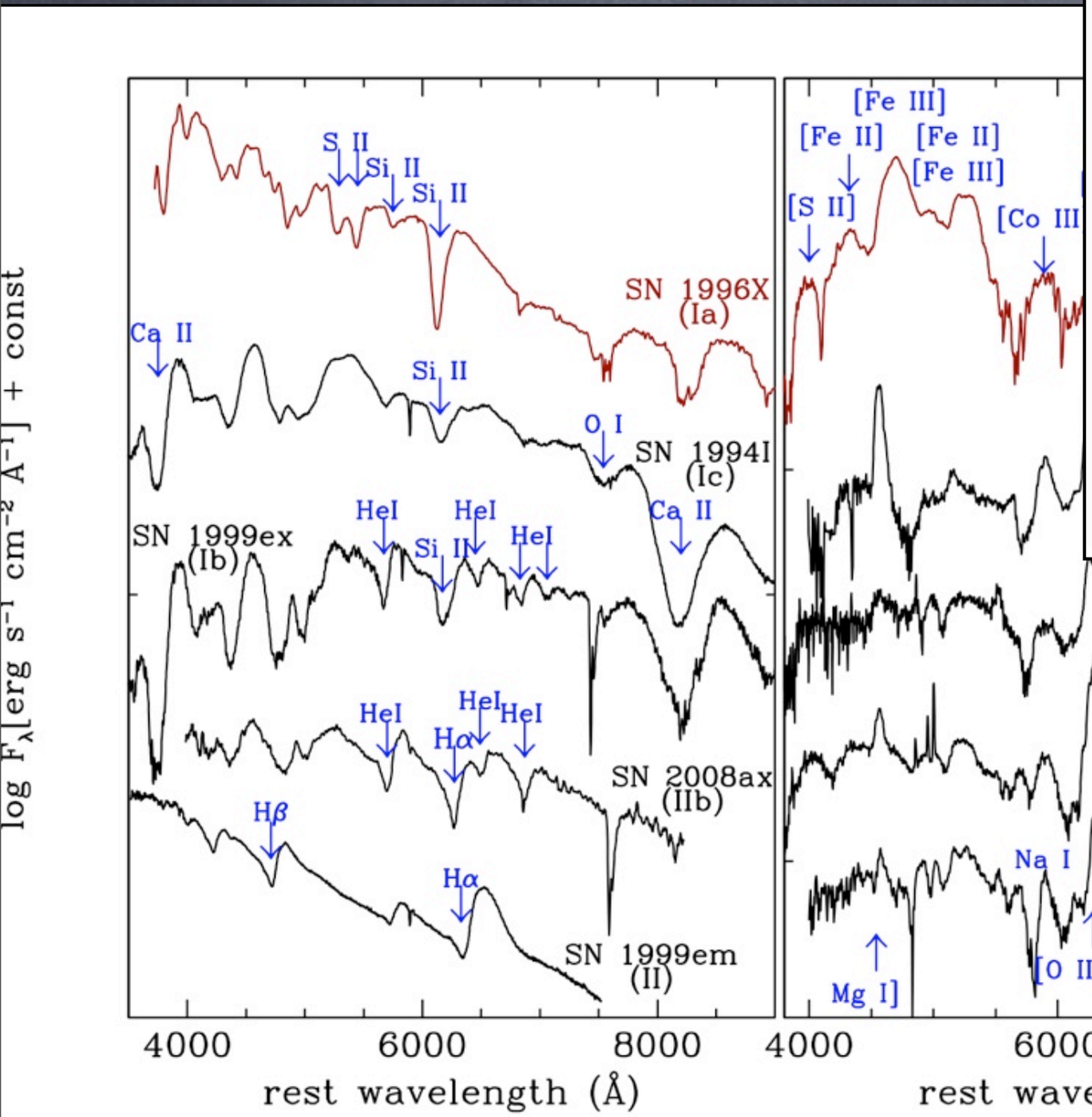
- Summary

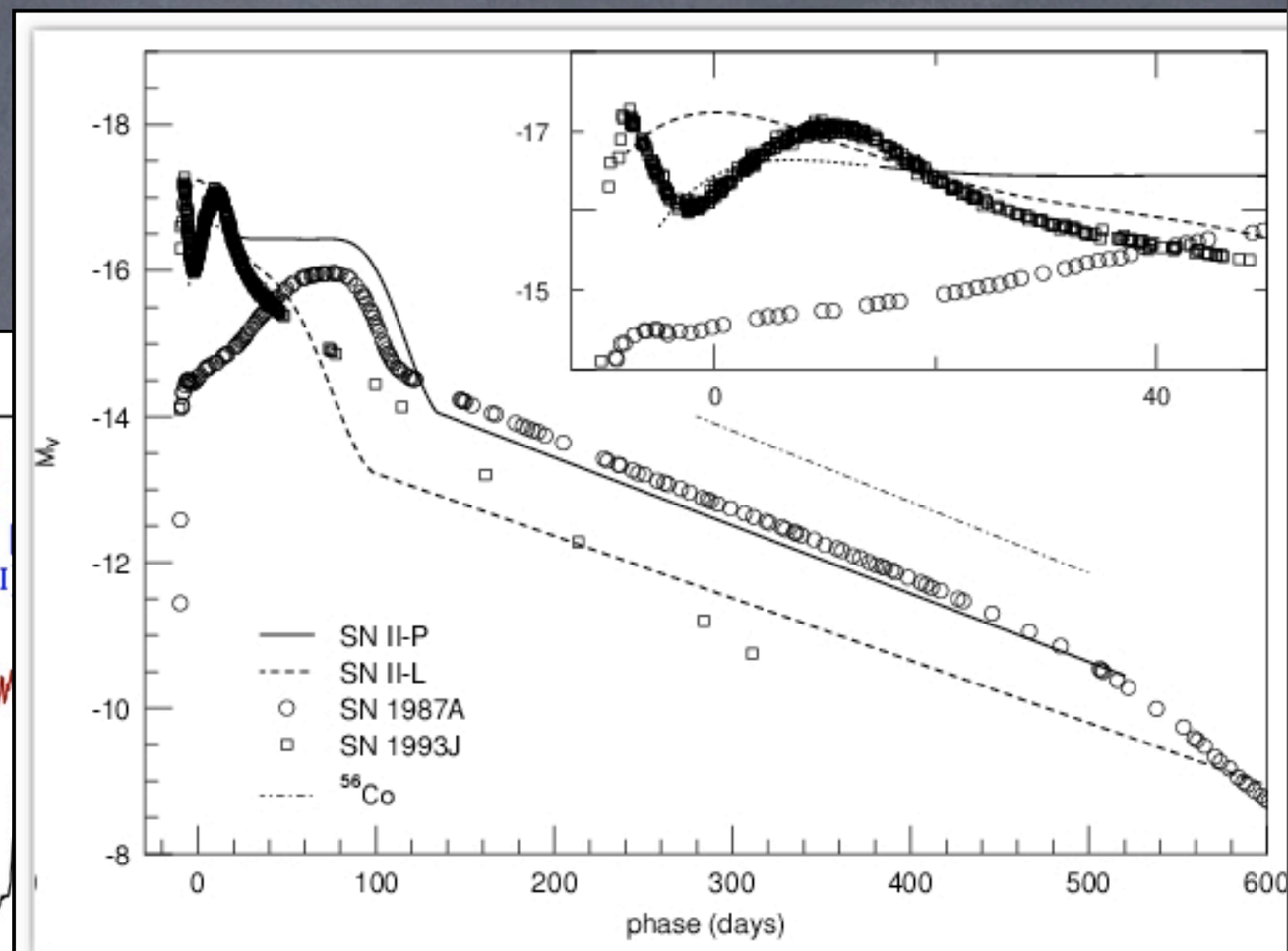
Traditional SN classification



Traditional SN classification

Wheeler & Benetti 2000





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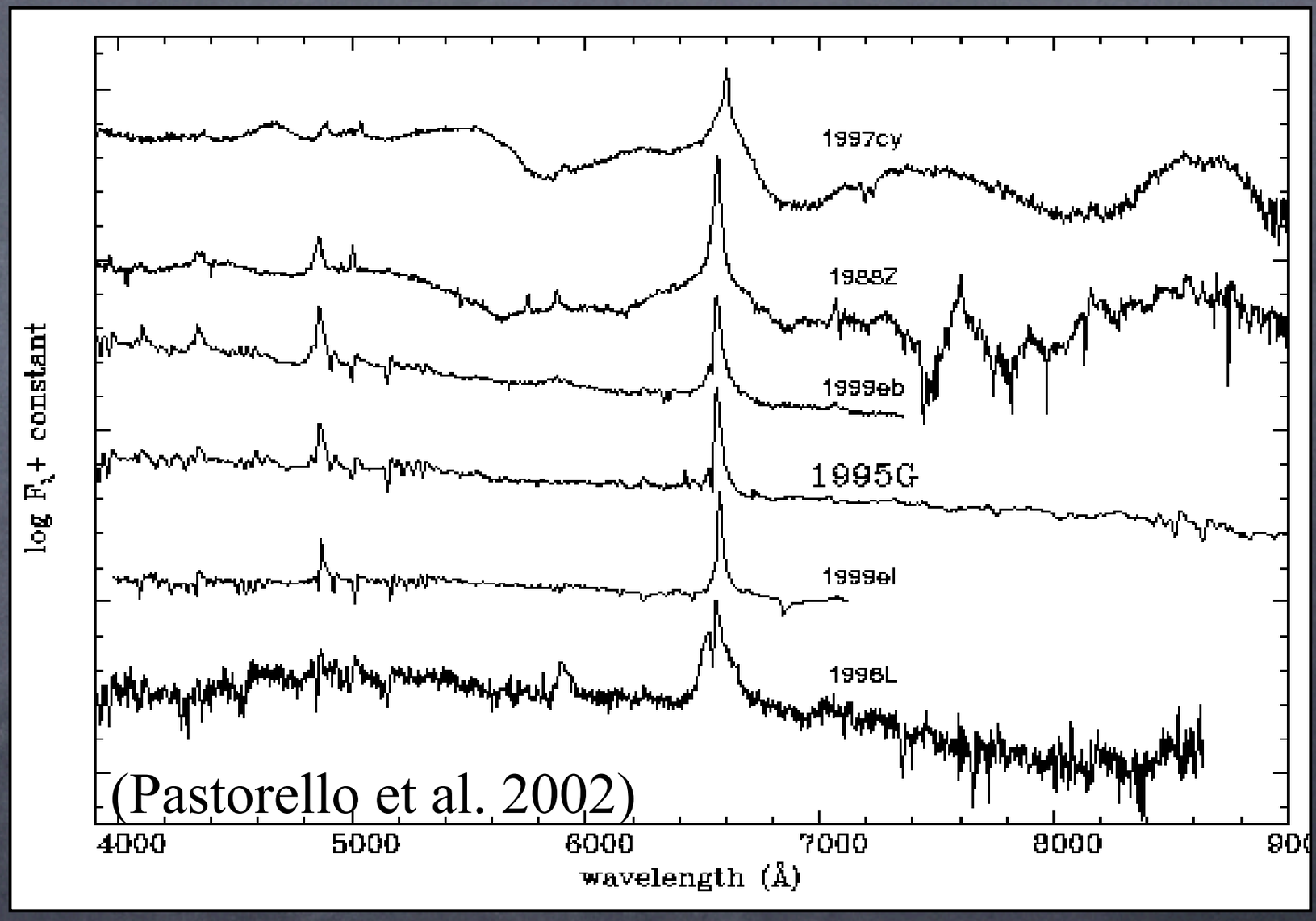

(Pastorello et al. 2002)

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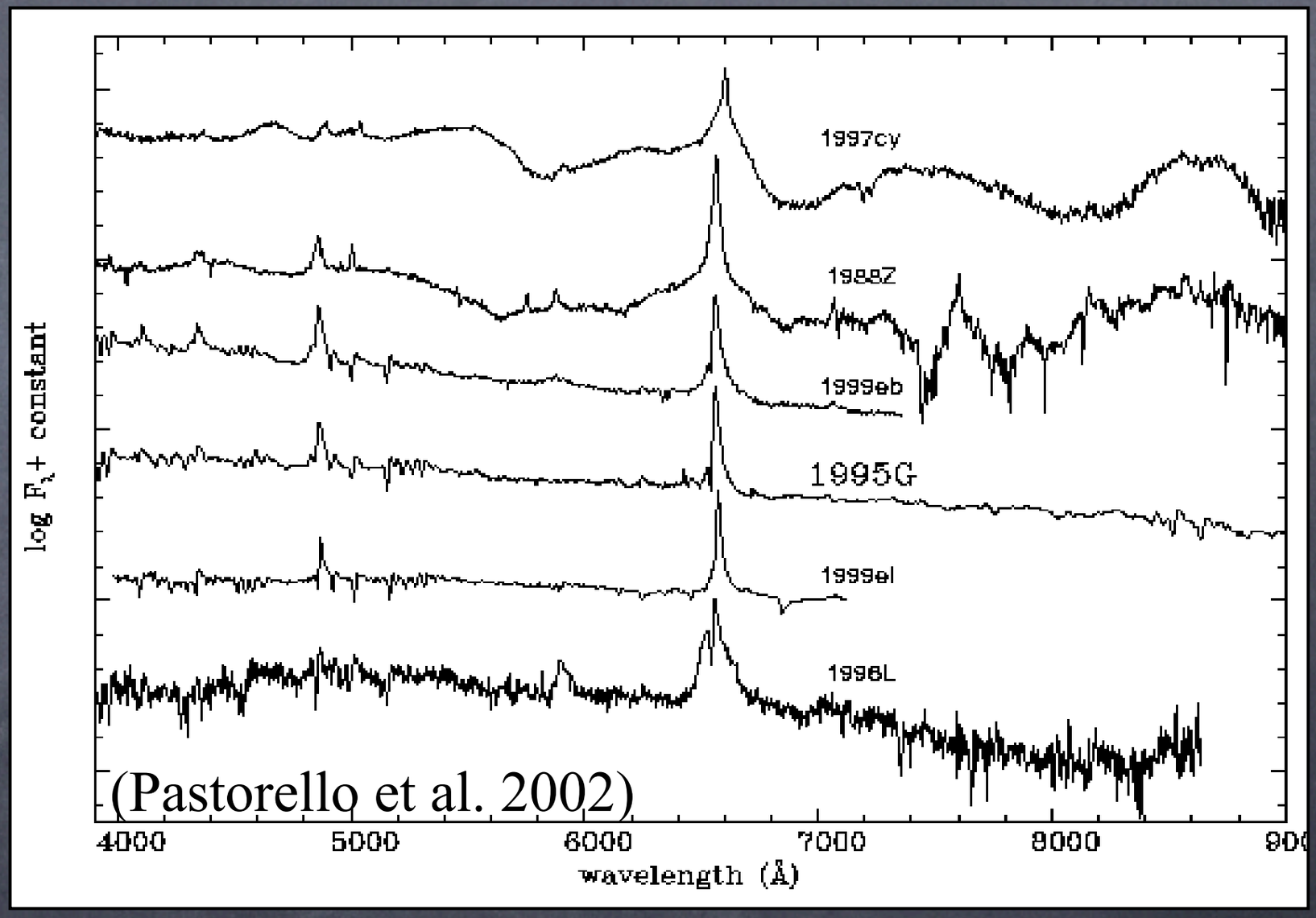

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SNe type IIn - interaction between SN ejecta and H-rich CSM

(Schlegel, 1990; MNRAS, 244, 269)

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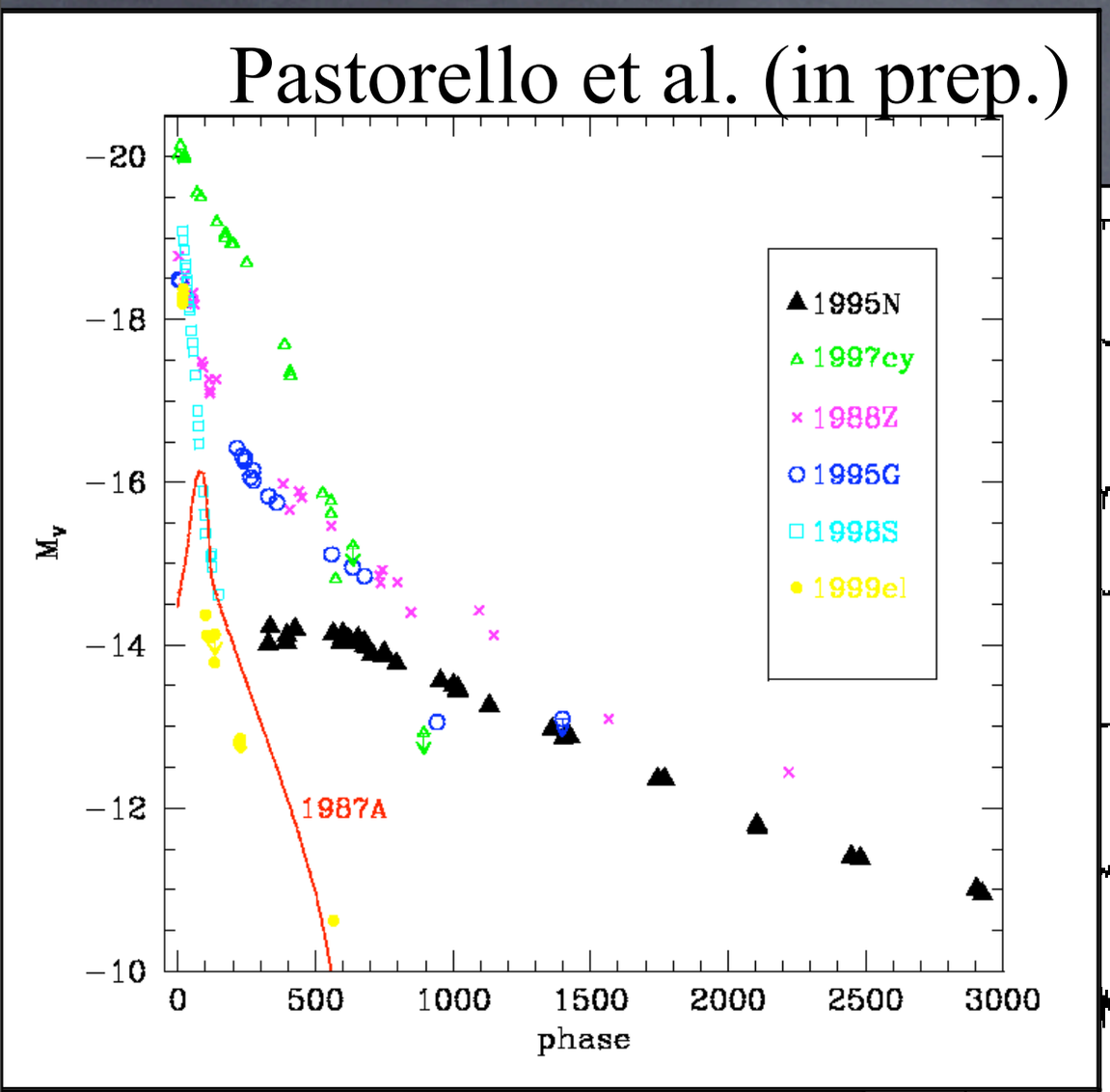

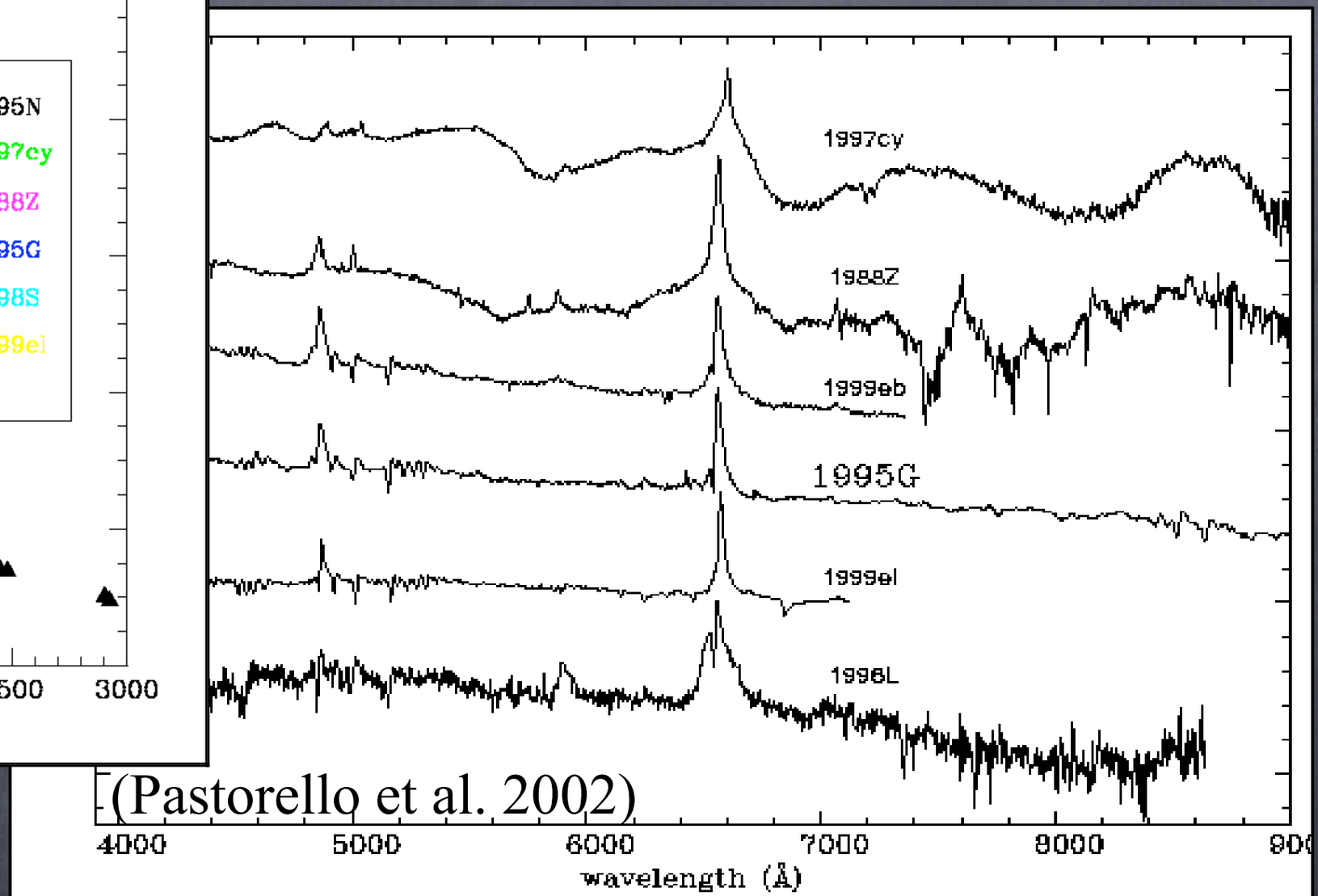

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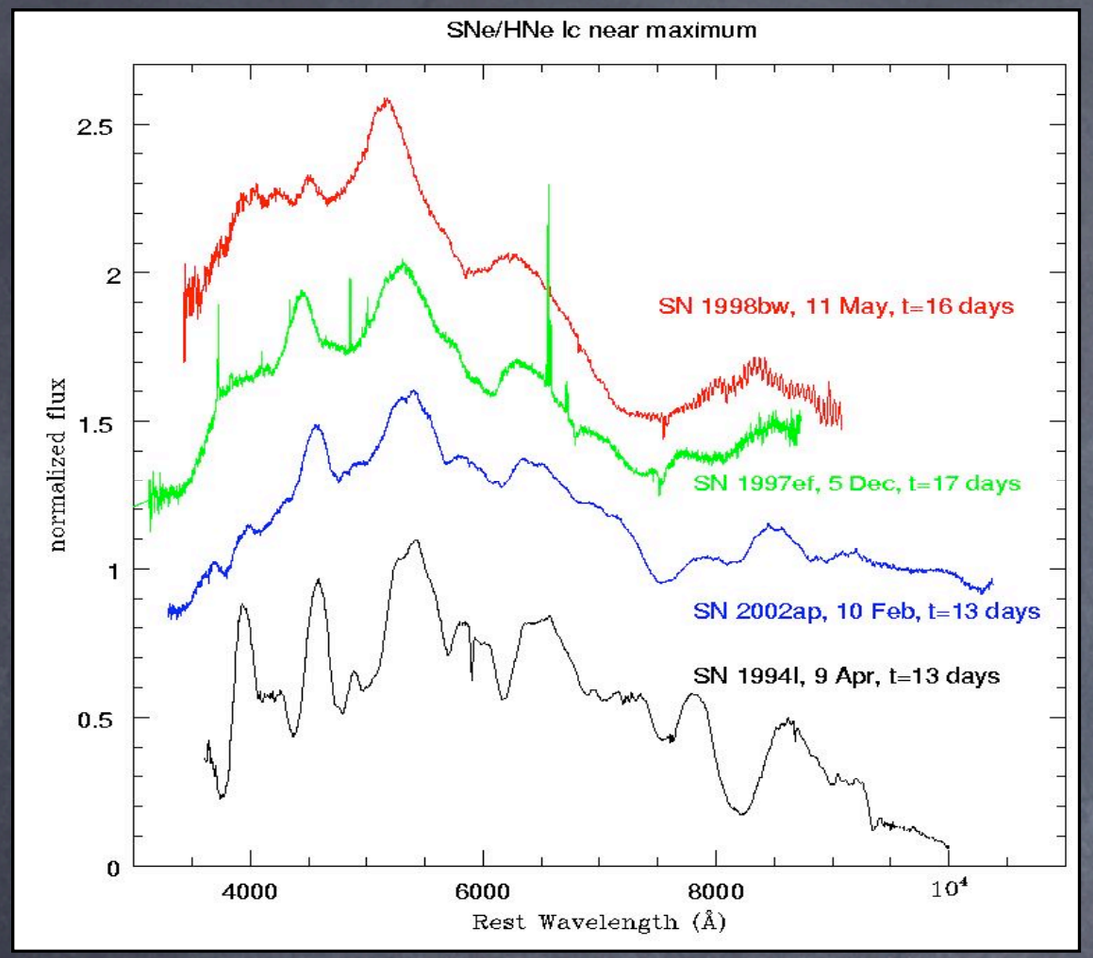

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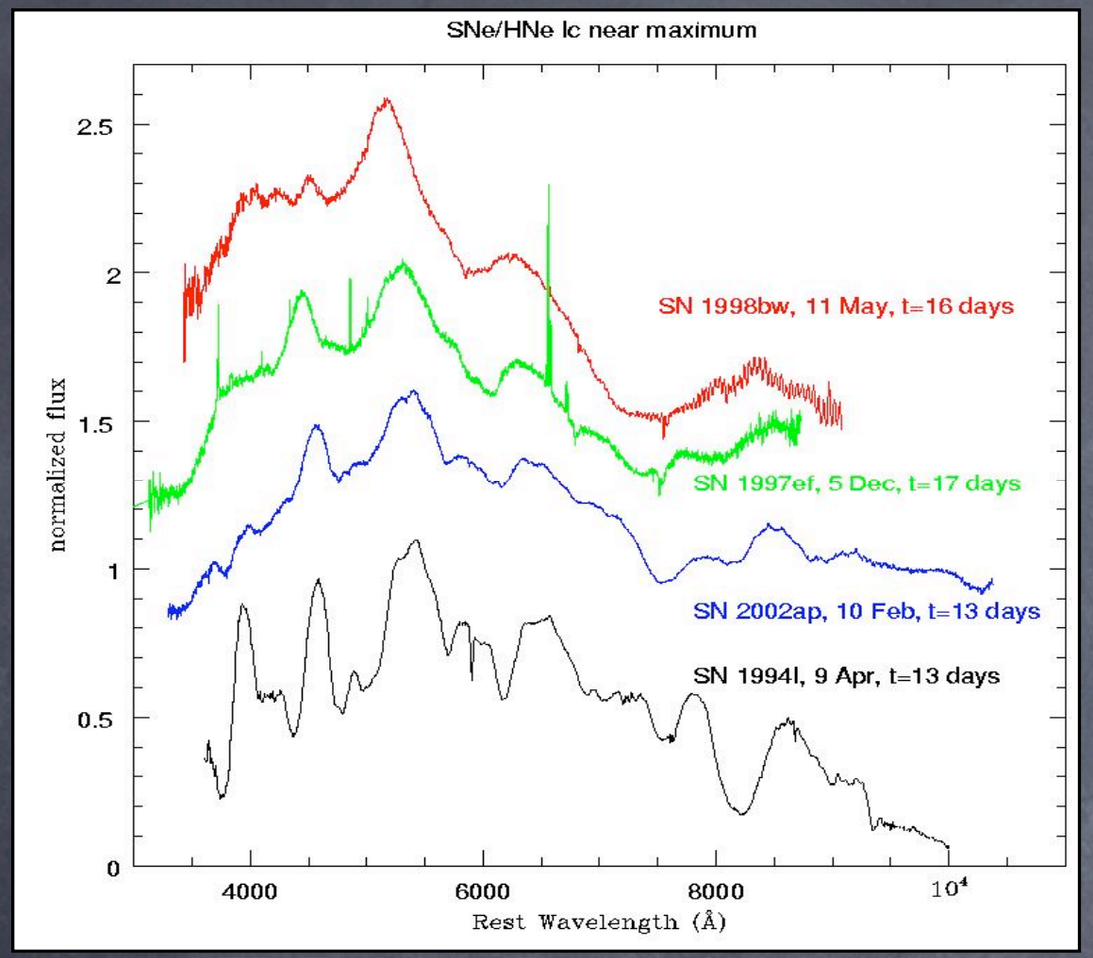

Broad lined type Ib/c SNe / Hypernovae => connection with GRBs

(credits for figures: Nomoto/Mazzali & collaborators - see also: Galama et al. 1998, Iwamoto et al. 2000; Mazzali et al. 2000, 2002, 2003, 2006, 2007; Sollerman et al. 2000, 2002, 2006; Patat et al. 2001;Bloom et al. 2002;Yoshiii et al. 2002;Kawabata et al. 2003; Matheson et al. 2003; Stanek et al. 2003, 2005; Malesani et al. 2004; Della Valle et et al. 2003, 2006; Pian et al. 2006; Soderberg et al. 2006; Tomita et al. 2006;Modjaz et al. 2006, Chornock et al. 2010...)

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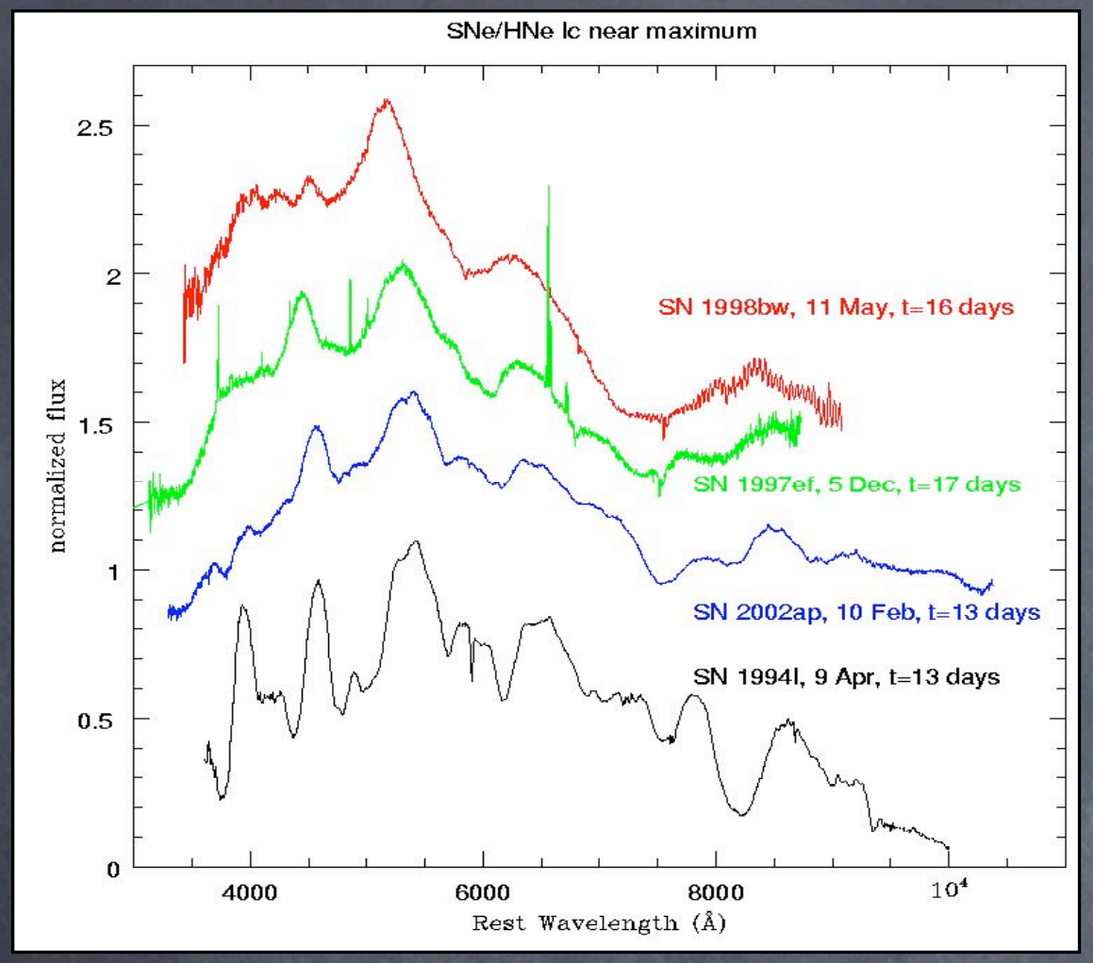

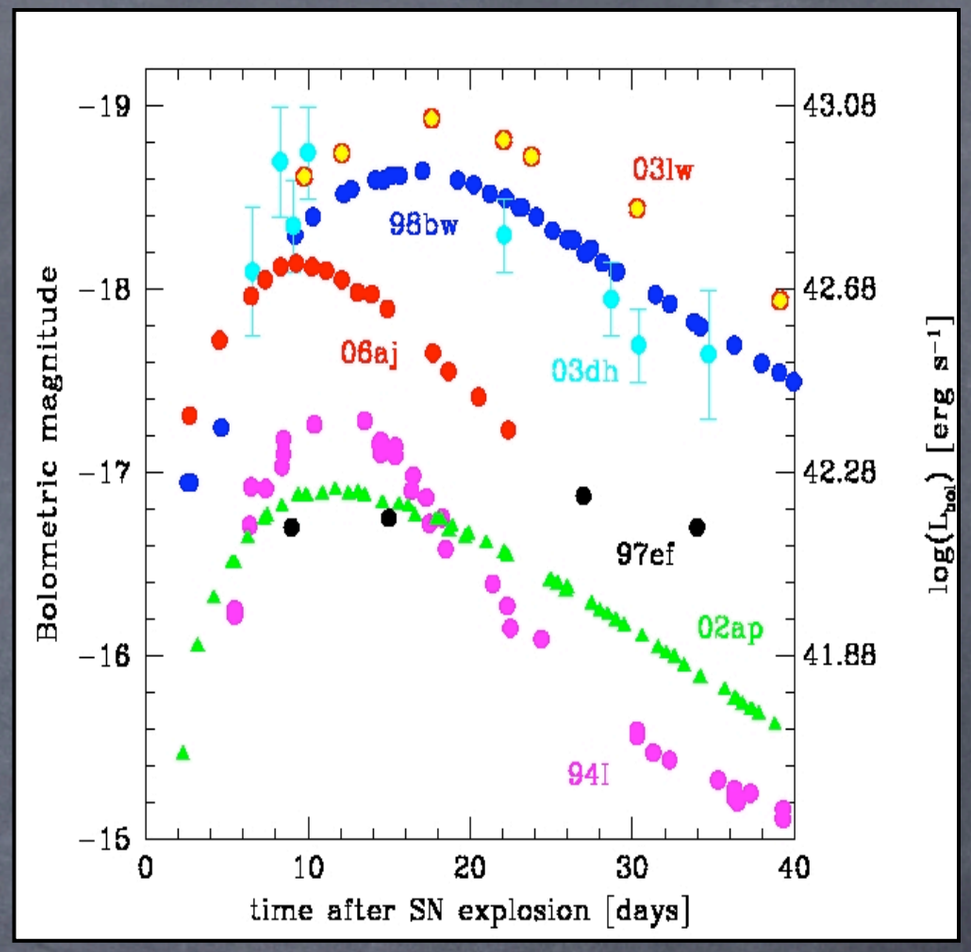

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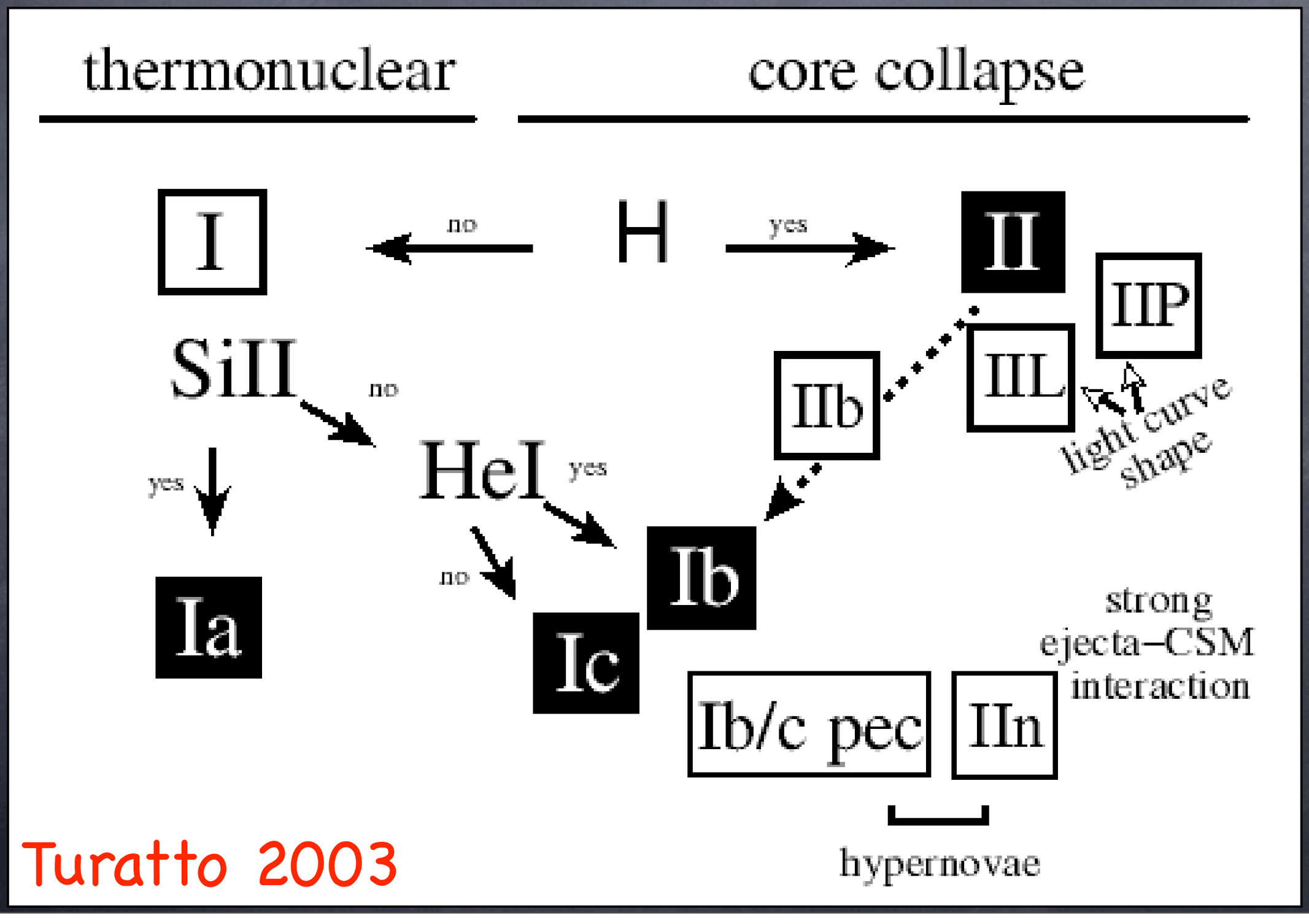
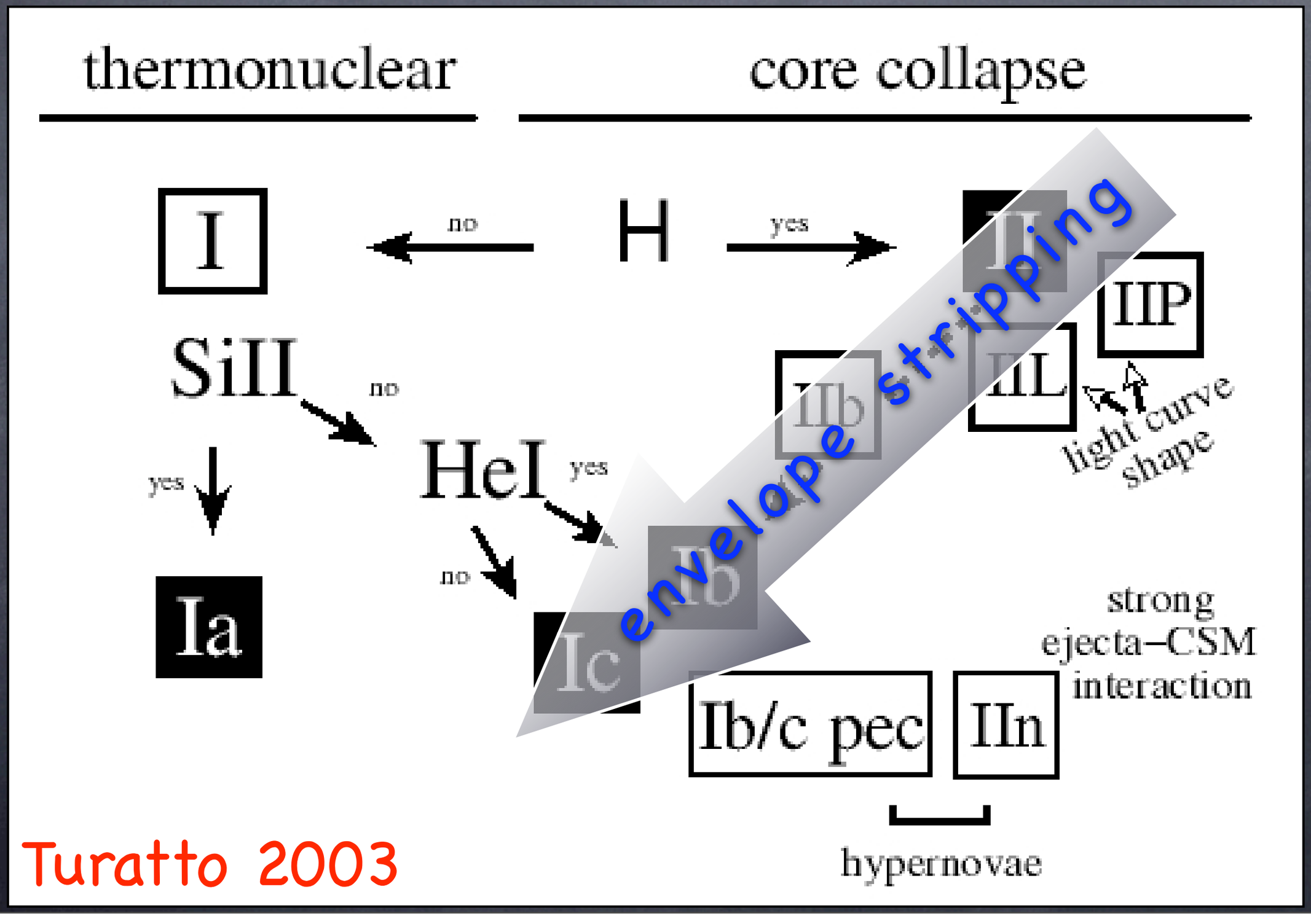


Turatto 2003

Traditional SN classification



Turatto 2003

New SN Types

- Targets of traditional SN searches were luminous galaxies or nearby galaxy clusters.
- Searches focused on detection of type Ia SNe, mild interest toward other SN types
- Modern surveys are ultra-deep, focused on "empty" fields (e.g. looking for transients in faint, metal-poor galaxies) or "all-sky": ROTSE, Catalina Sky Survey (CSS), Palomar Transient Factory (PTF), SkyMapper, PanSTARRS => discovery of new SN types!

Faint SNe or SN impostors?

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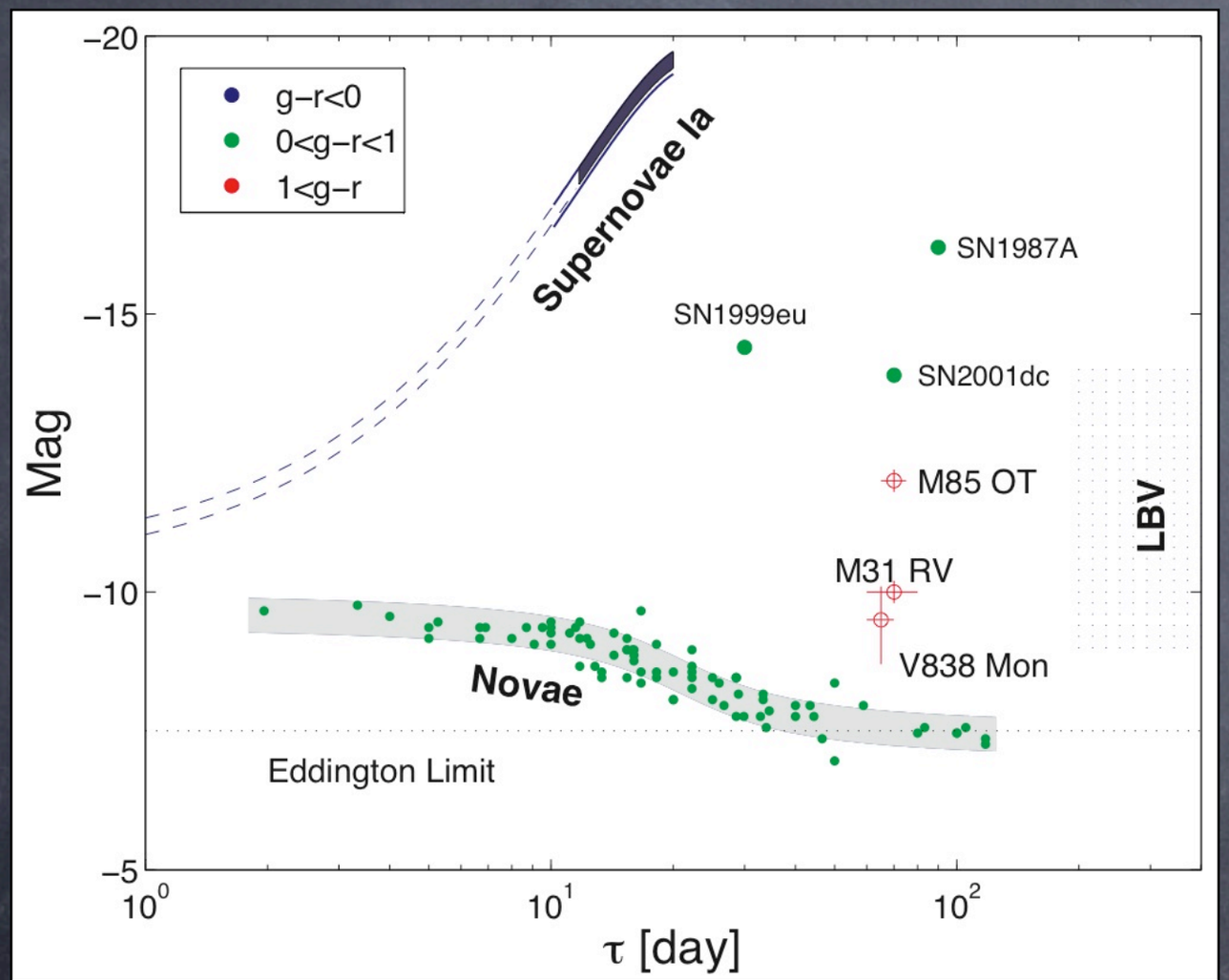

- CC-SNe: M<-14
- Luminous Novae: M>-10

Kulkarni et al. 2007, Nature, 447, 458

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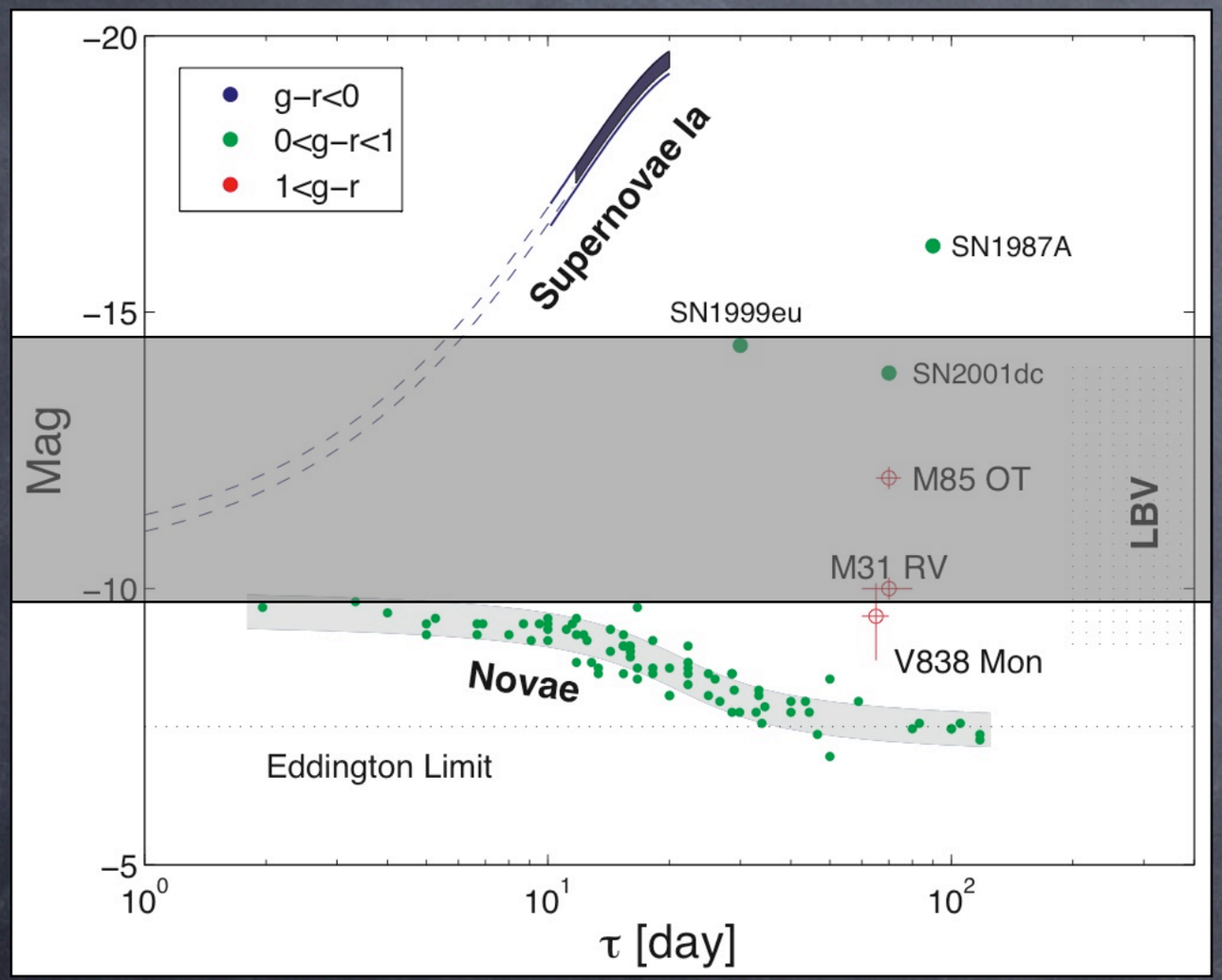

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- CC-SNe: M<-14
- Luminous Novae: M>-10
- Grey zone: -10>M>-14

1. Ultra-faint supernovae
2. Luminous Red Novae
3. LBV outbursts
4. Other exotic eruptions

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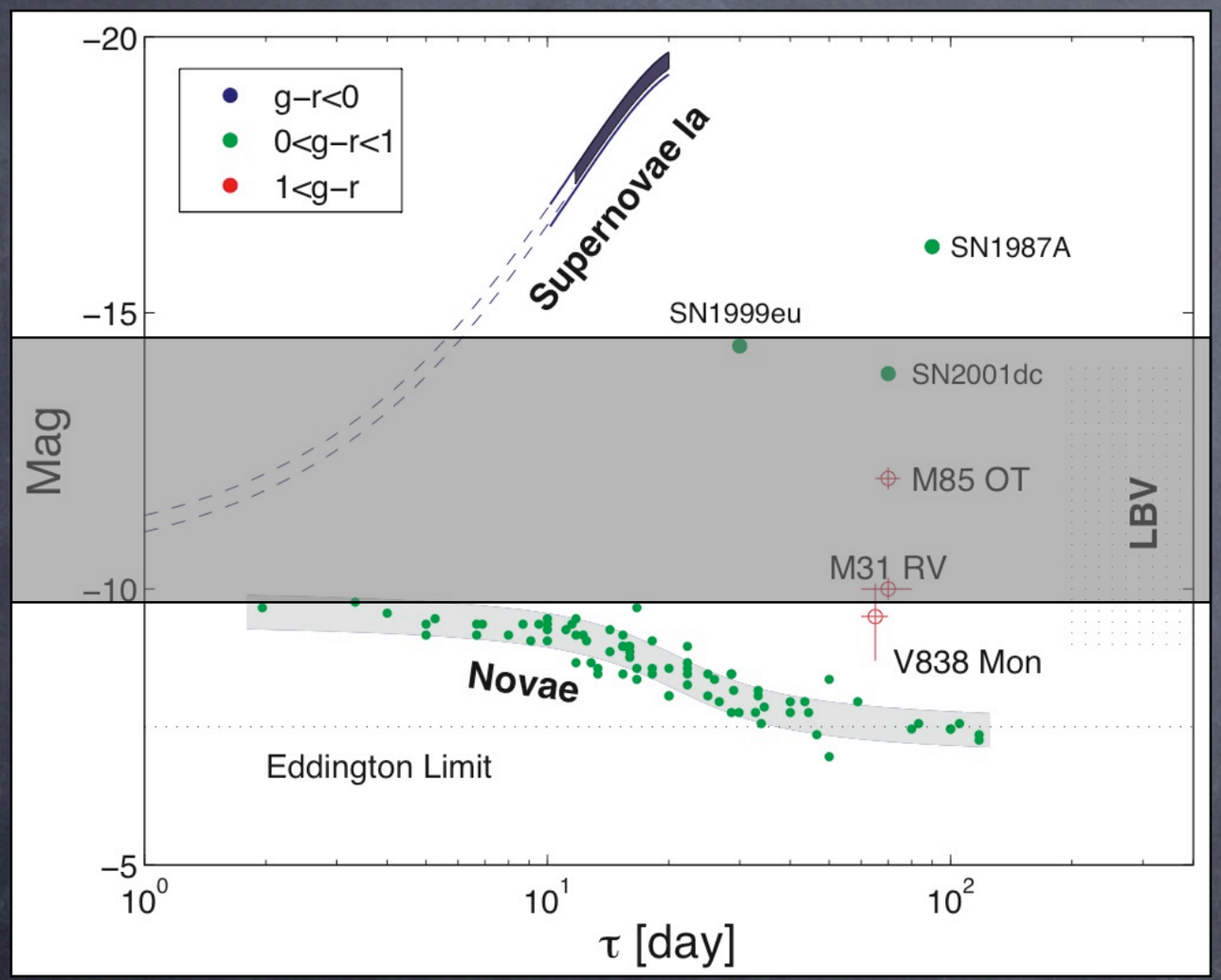

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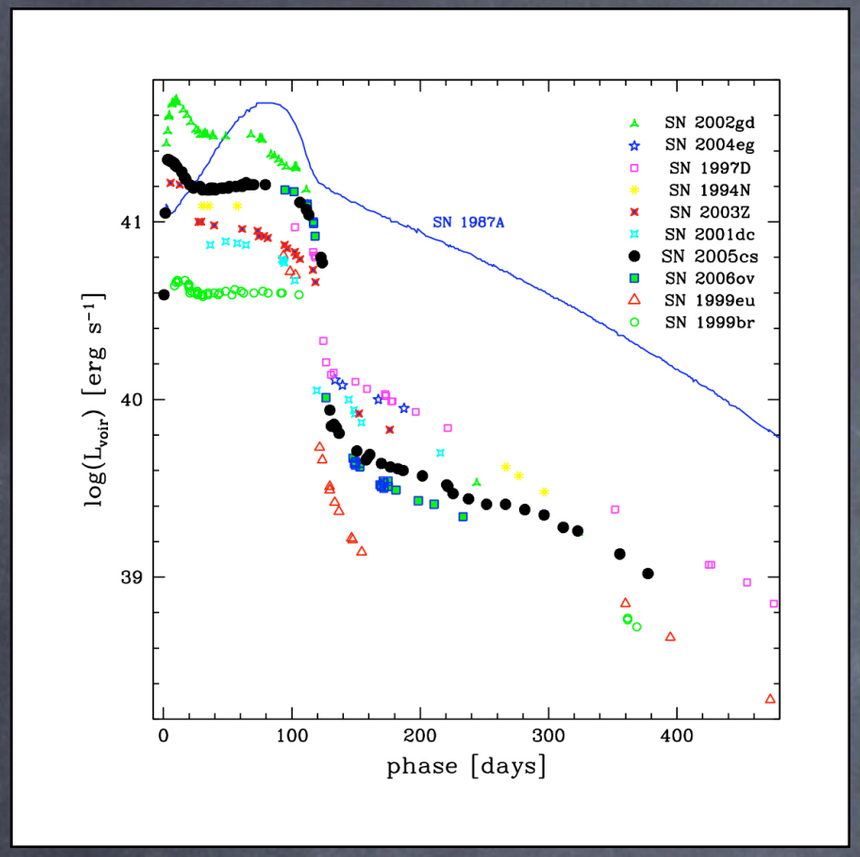
1. Ultra-faint supernovae

SN impostors

Kulkarni et al. 2007, Nature, 447, 458

Ultra-faint Supernovae

Sub-luminous type IIP SNe



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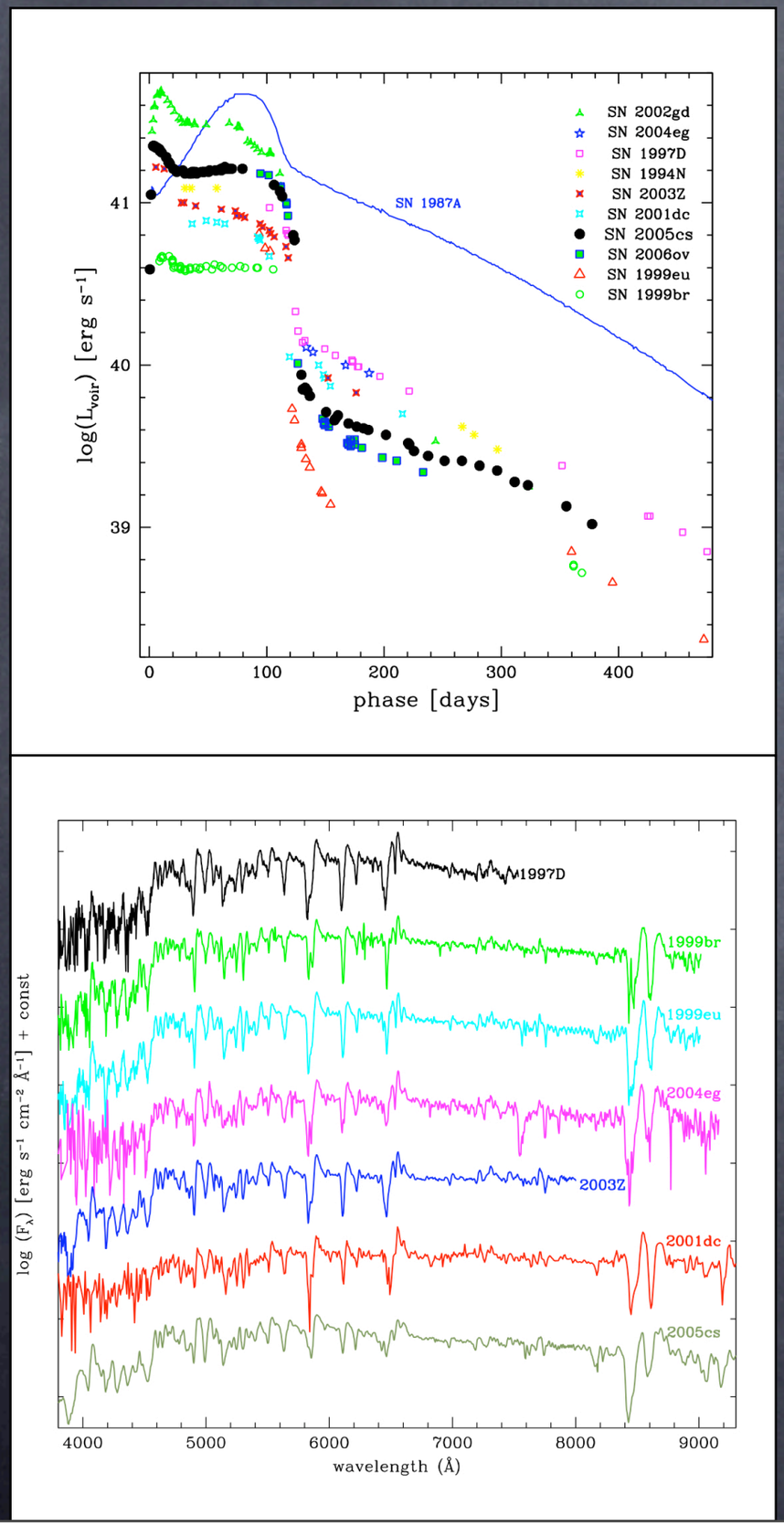

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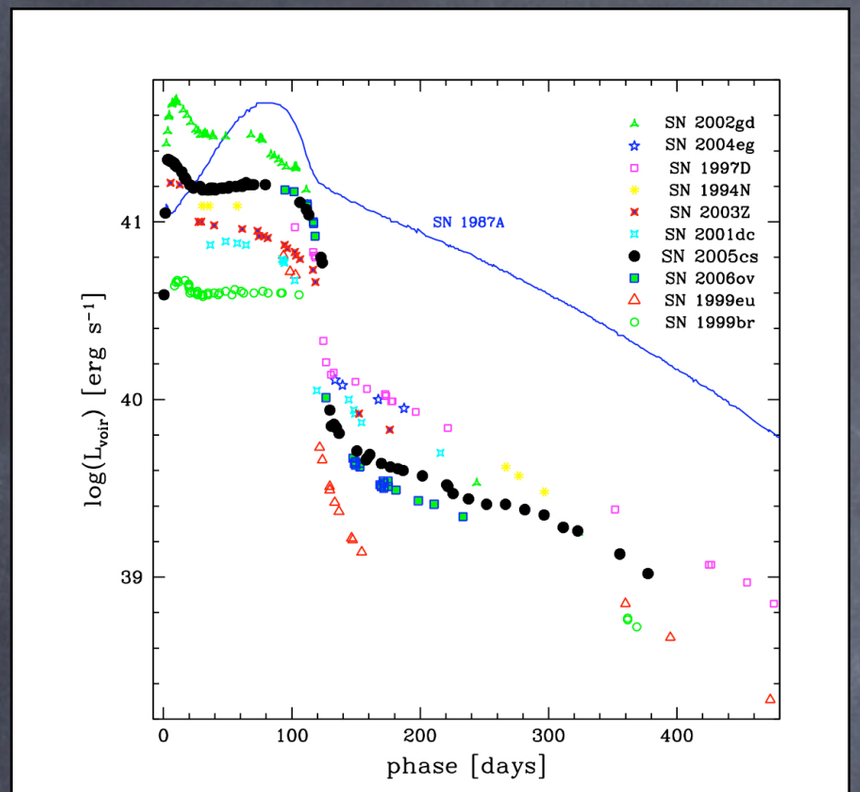
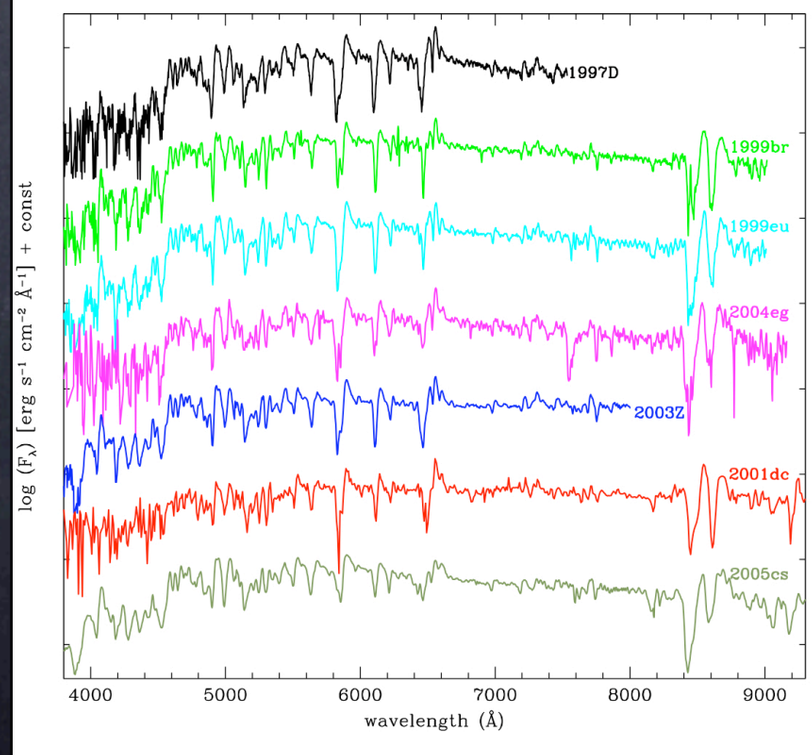
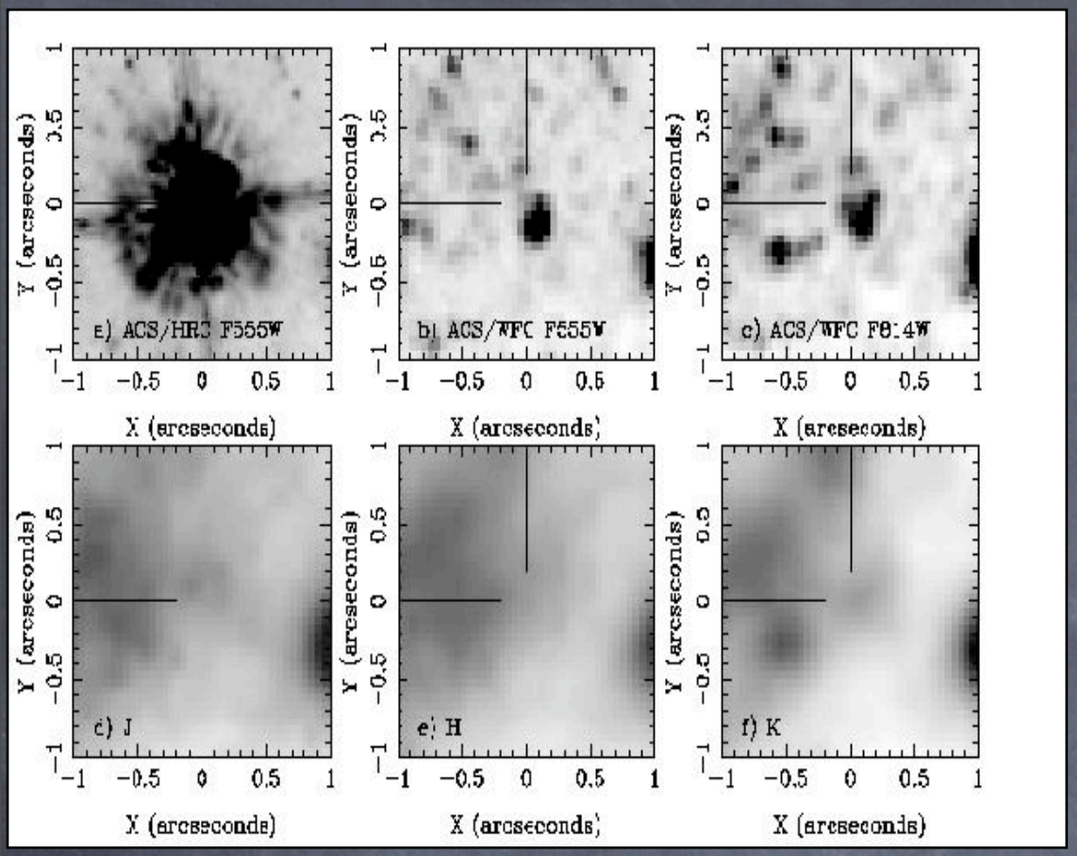




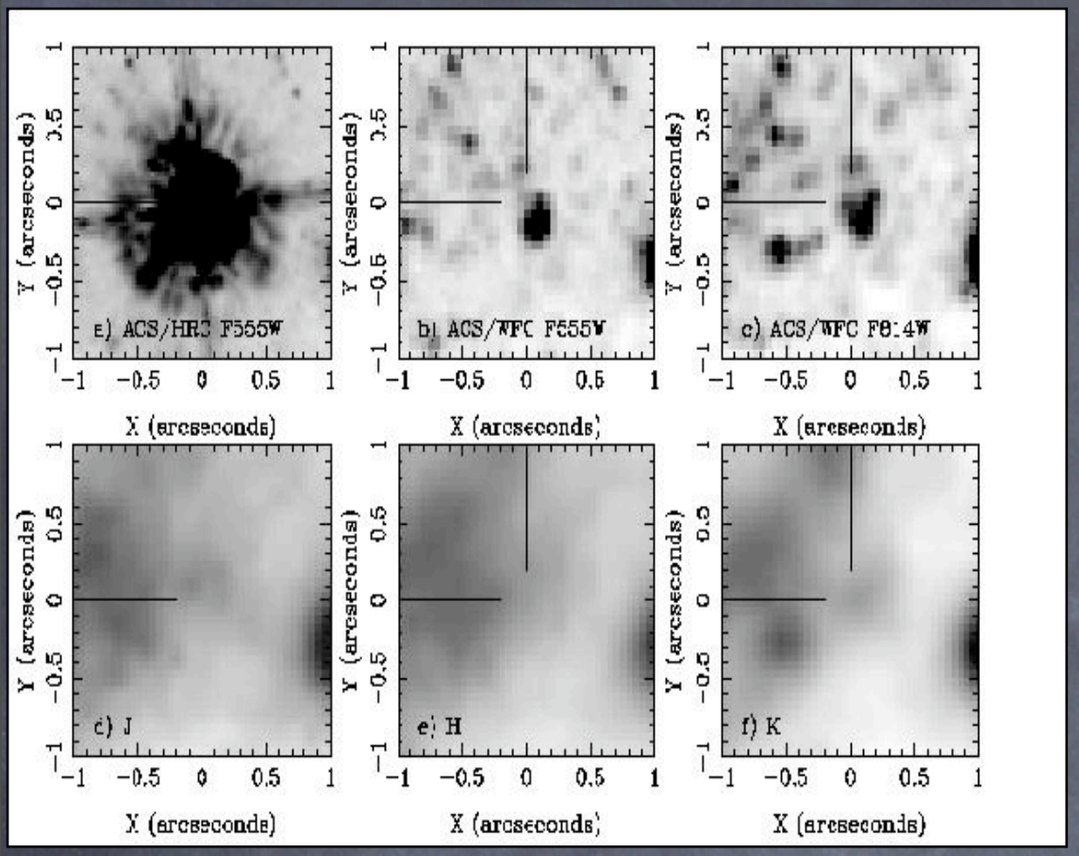
- Faint plateau (mag > -16)
- Long-duration plateau (100-120d)
- Steep post-plateau mag decline
- Red colours
- Faint LC radioactive tail (^{56}Ni mass << 10^{-2} Mo)
- Narrow spectral lines (v_{ph}=700-1200 km s^{-1})
- Prominent Ba II lines
- Fe- and O-poor nebular spectra

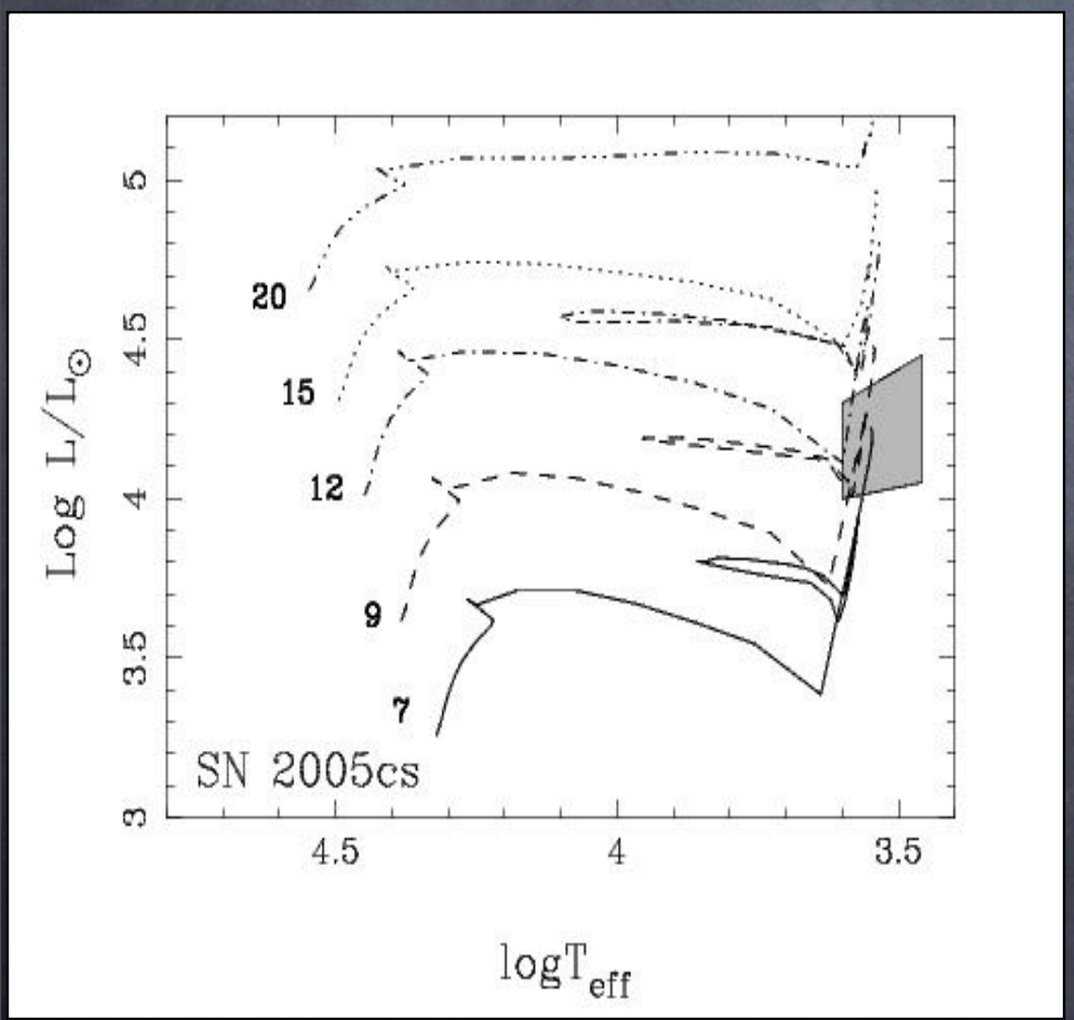
Turatto et al. 1998; Benetti et al. 2001; Zampieri et al. 2003;Pastorello et al. 2004, 2006, 2009



The progenitors:

the case of SN 2005cs





The progenitors:

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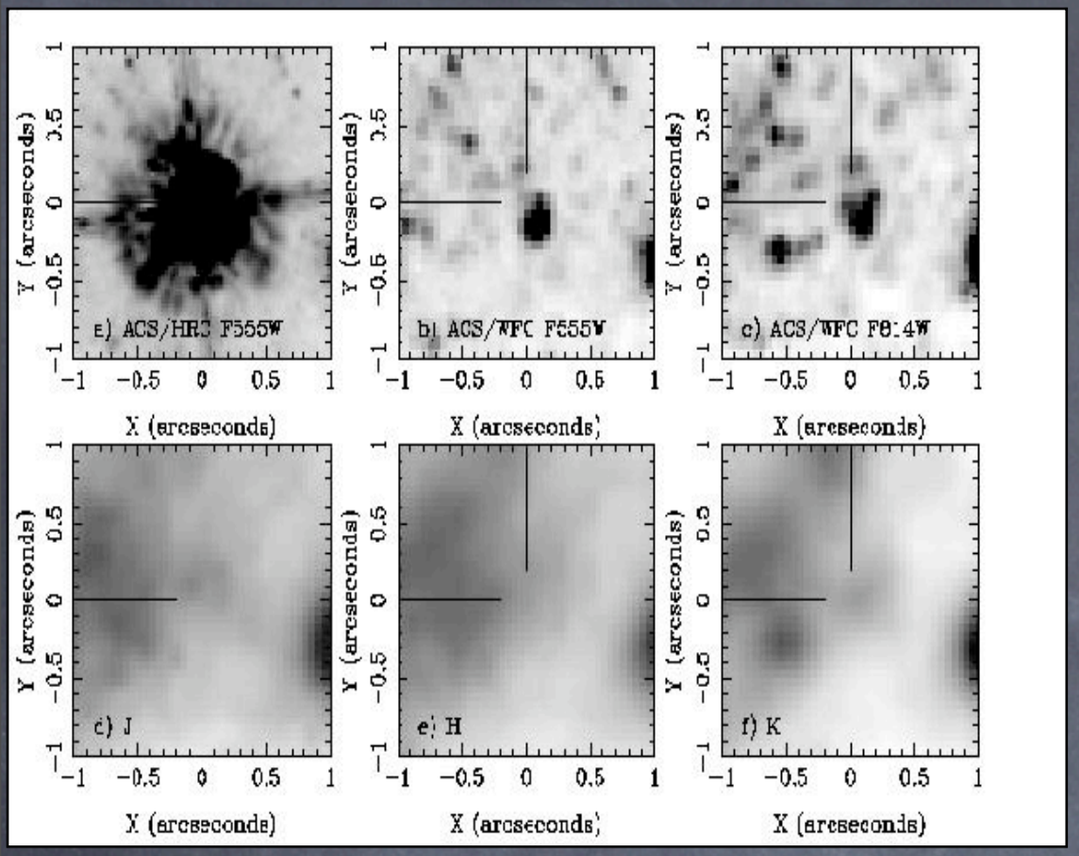
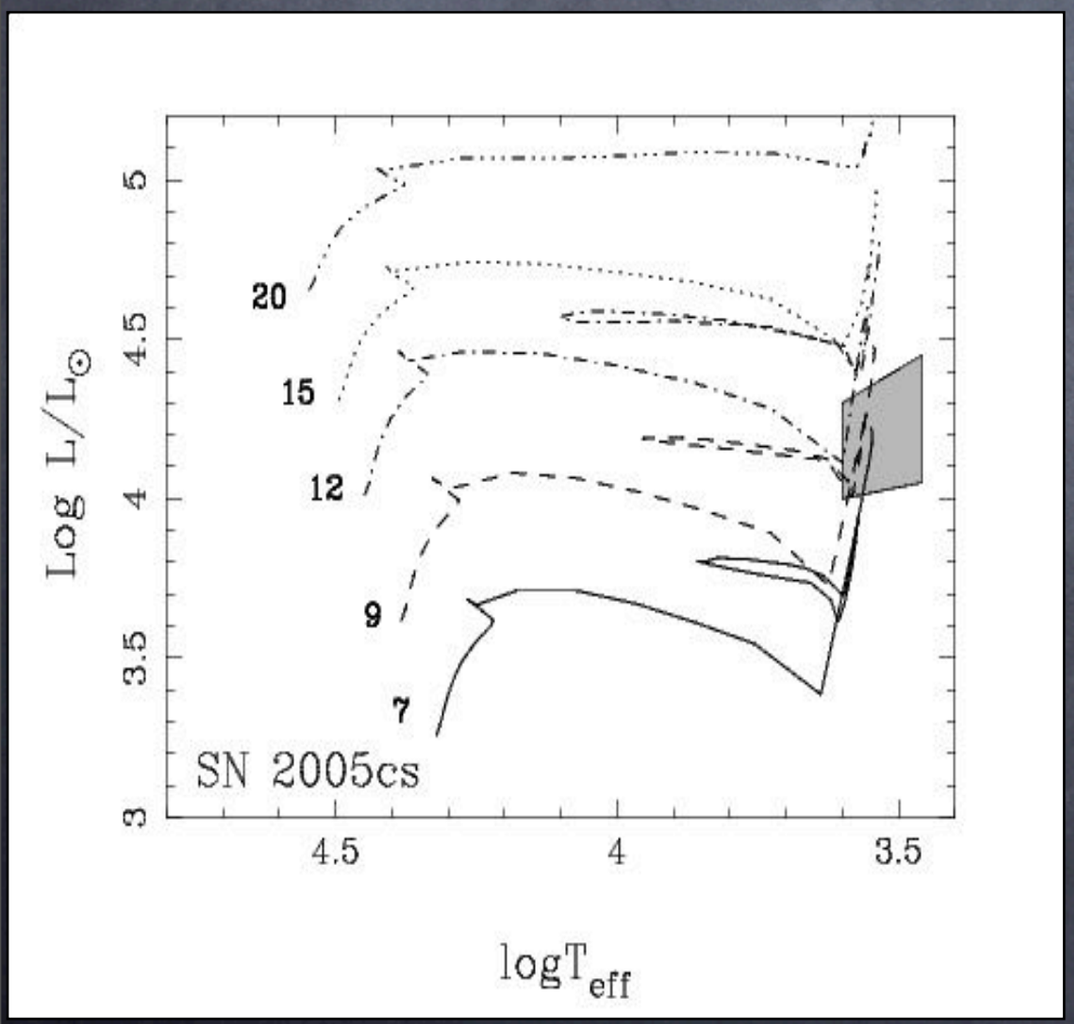
- DIRECT DETECTION

  - 8-10 Mo (Maund et al. 2005, MNRAS, 364, L33; Li et al. 2006, ApJ, 641, 1060)

  - 6-8 Mo (Eldridge et al. 2007, MNRAS, 376, L52)

  - 6-10 Mo (Smartt et al. 2009, MNRAS, 395, 1409)





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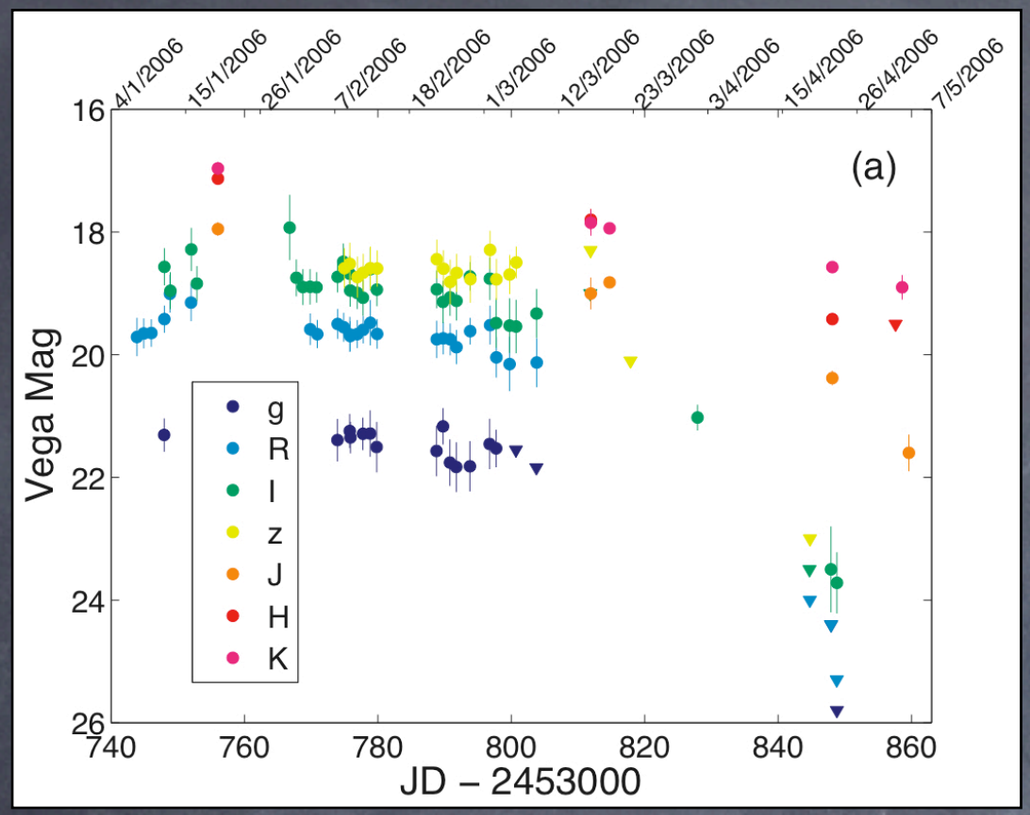
- HYDRODYNAMIC MODELLING

  - 17.3±1.0 Mo (Utrobin & Chugai 2008, A&A, 491, 507)

  - 10-15Mo (Pastorello et al. 2009, MNRAS, 376, L52)

M85-2006OT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12/3/2006
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15/4/2006
26/4/2006
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(a)
Vega Mag
16
18
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740
760
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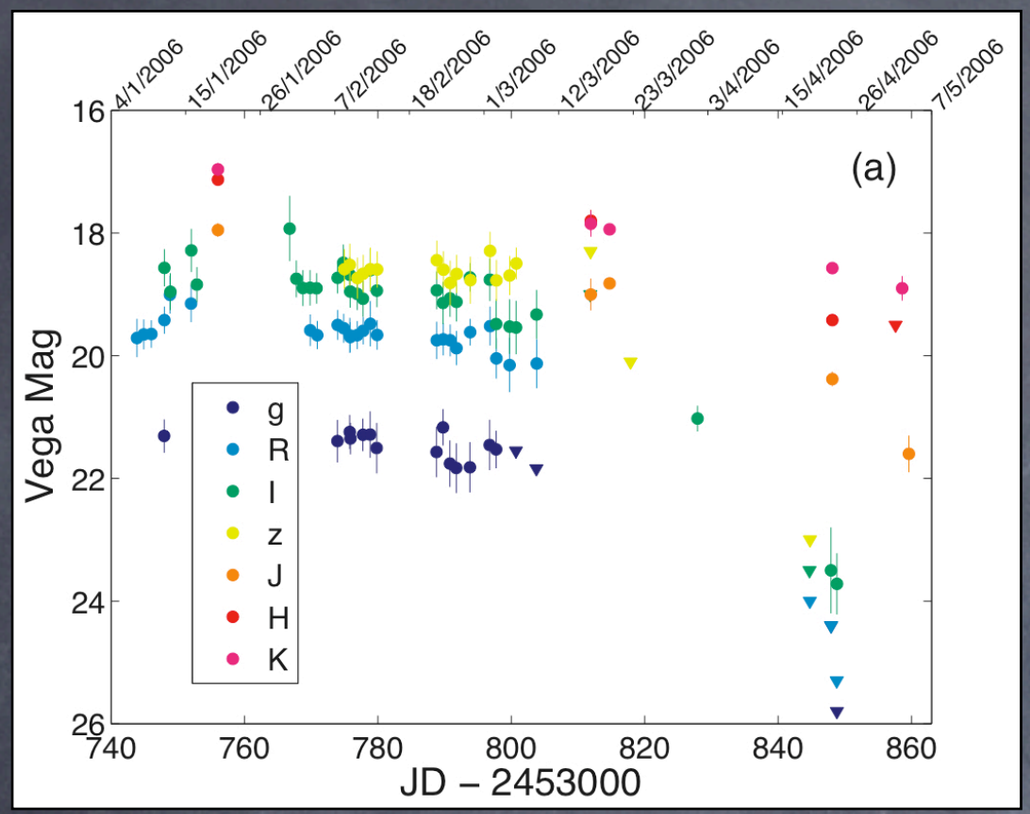
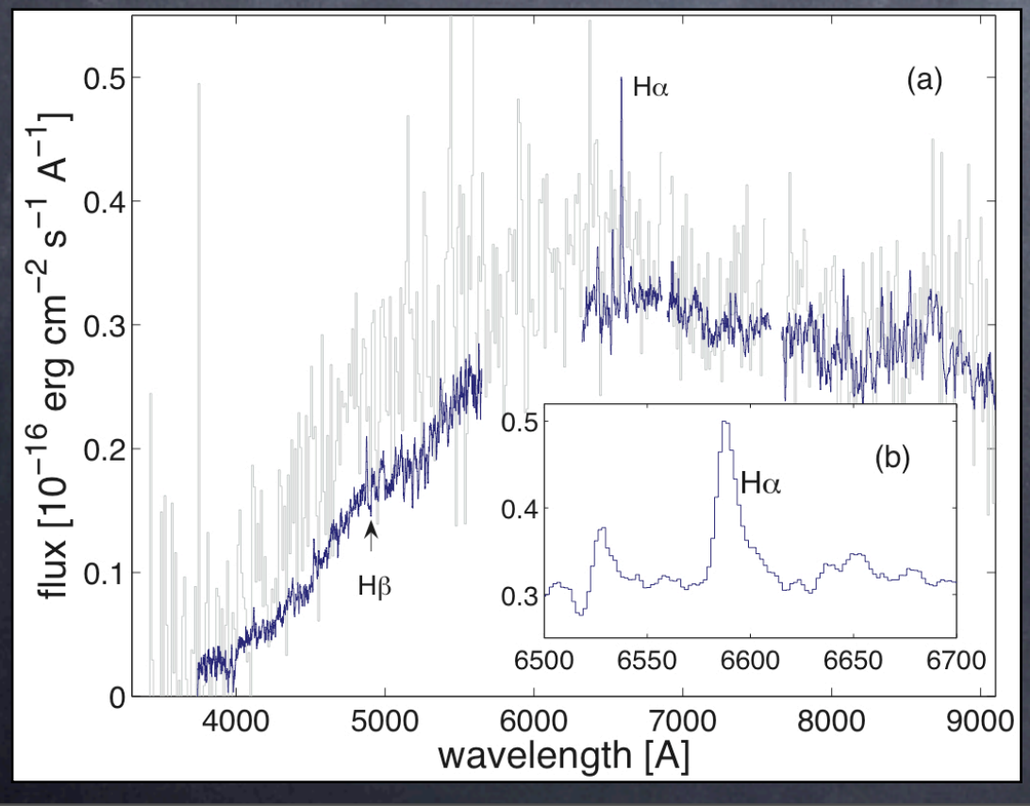
JD – 2453000

M85-2006OT





- Modest peak luminosity (M_I~ -13)
- Red colour
- Featureless spectrum (only weak, narrow lines of H, CaII, KI, FeII)
- Analogies with V838 Mon, M31 RV, V4332 Sgr ("Luminous Red Novae")
- Old stellar population
- Low mass progenitor

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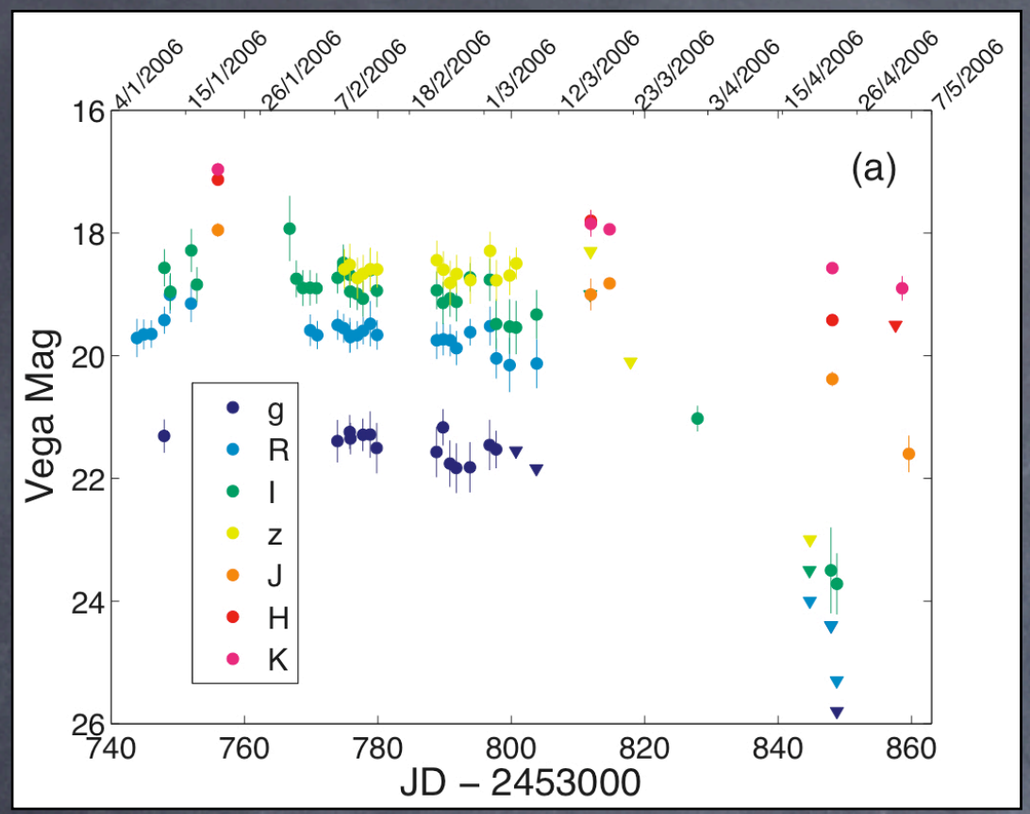

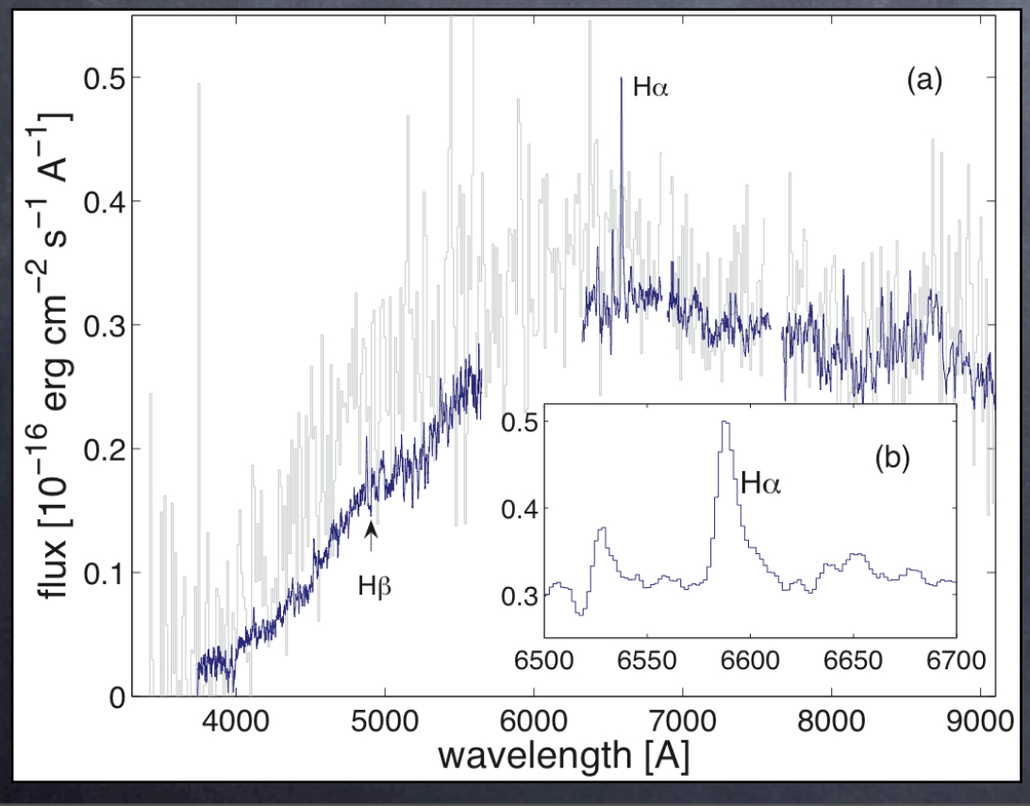

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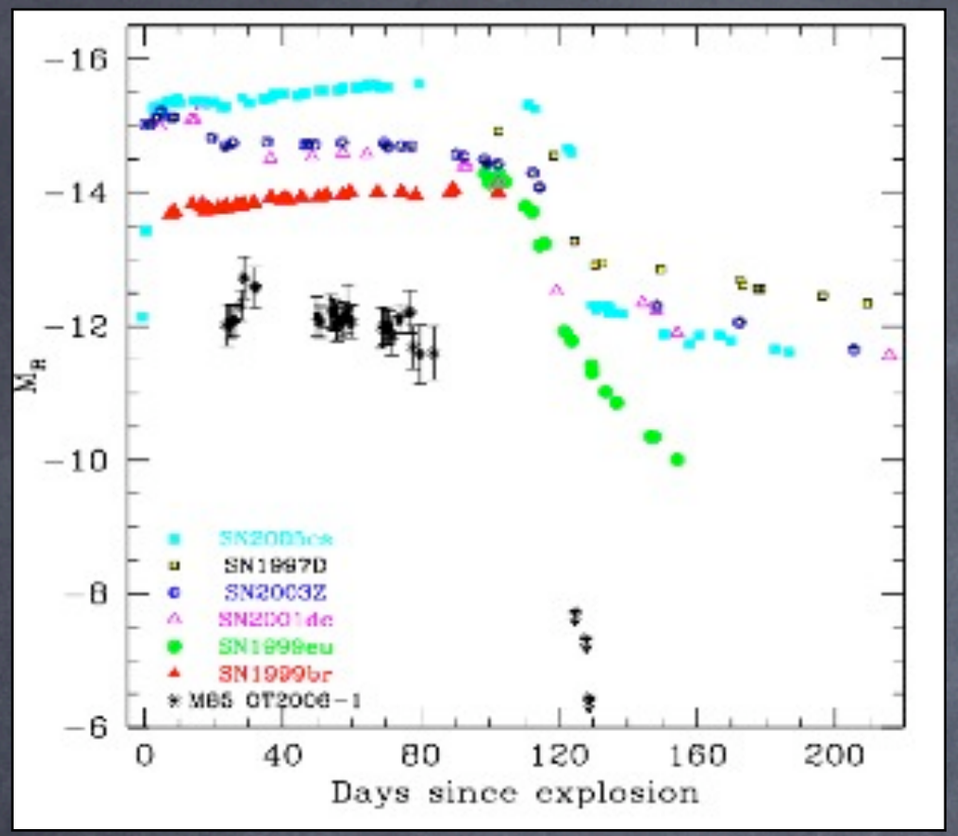
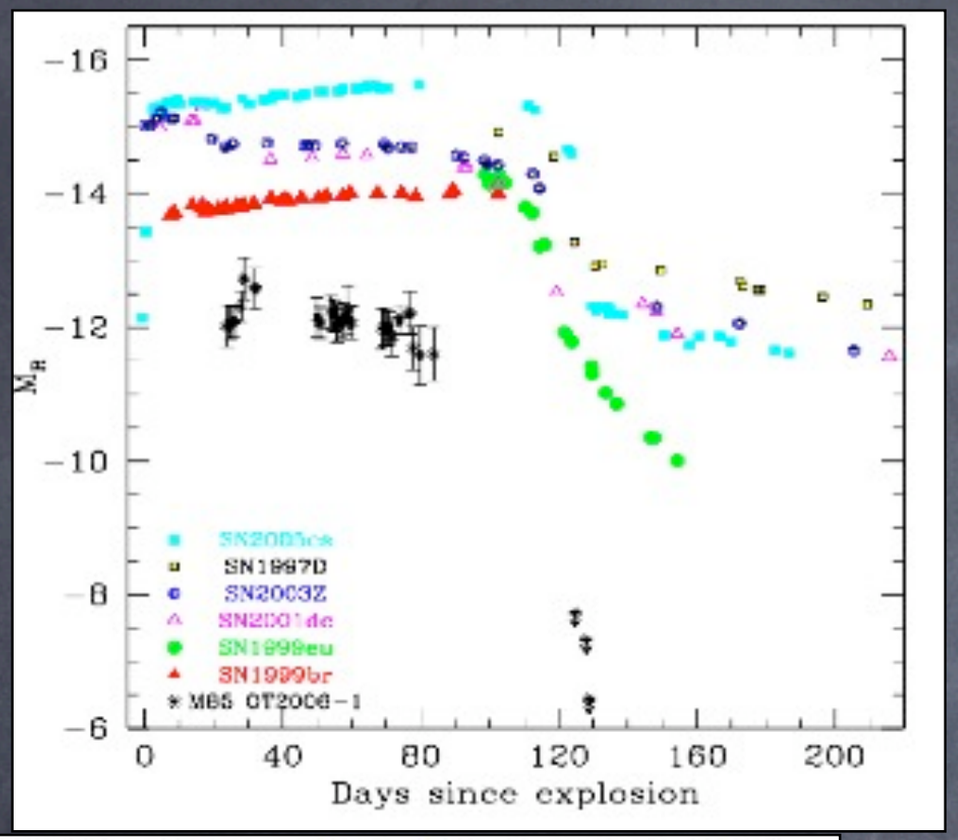
⇒ Exotic outburst from a low-mass (<2Mo) star (stellar merger?)

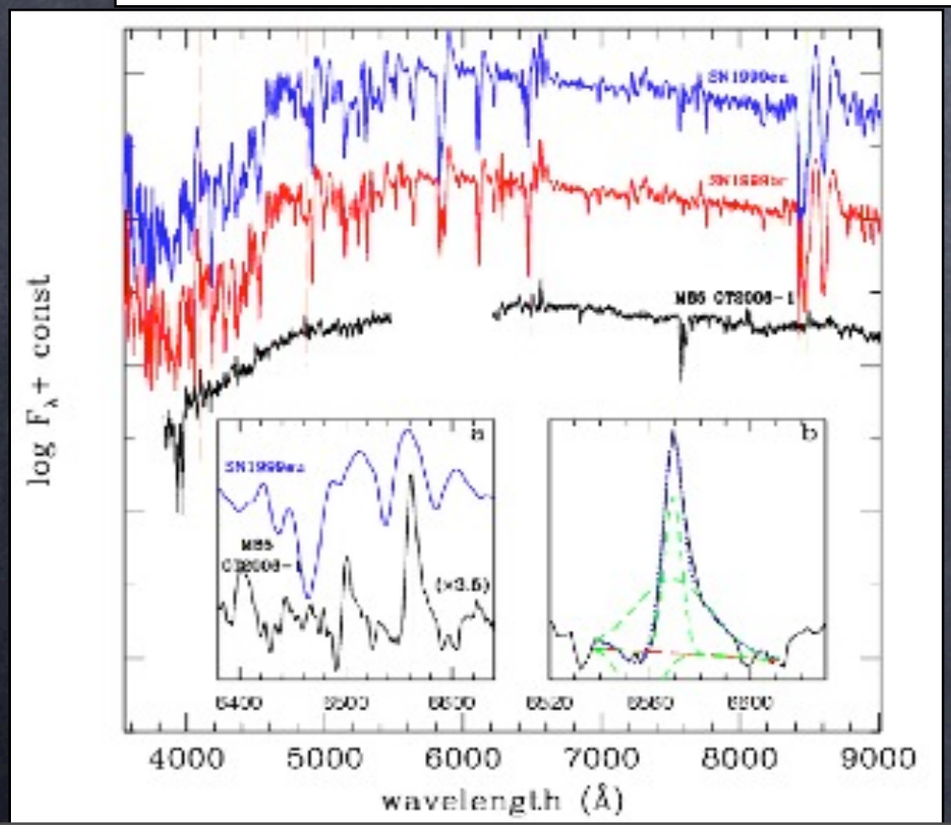
(Kulkarni et al. 2007, Nature, 447, 458)

M85-2006OT


−16
−14
−12
−10
−8
−6
M_R
SN2005cs
SN1997D
SN2003Z
SN2001dc
SN1999eu
SN1999br
M85 OT2006-1
0
40
80
120
160
200
Days since explosion

M85-2006OT





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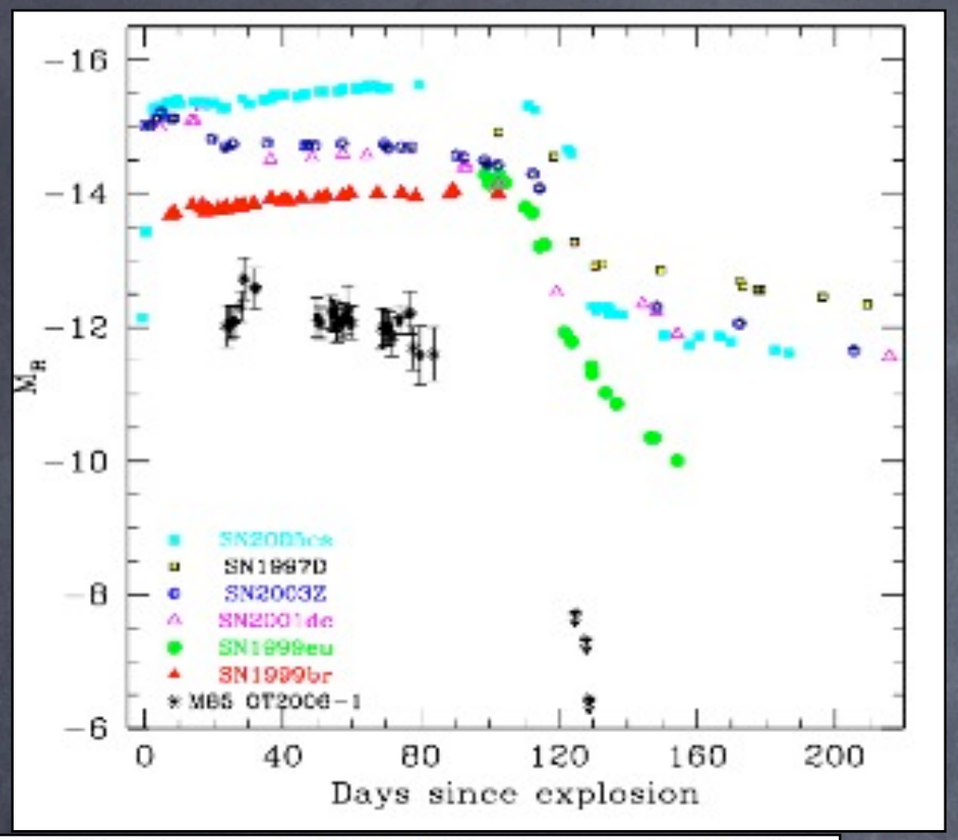

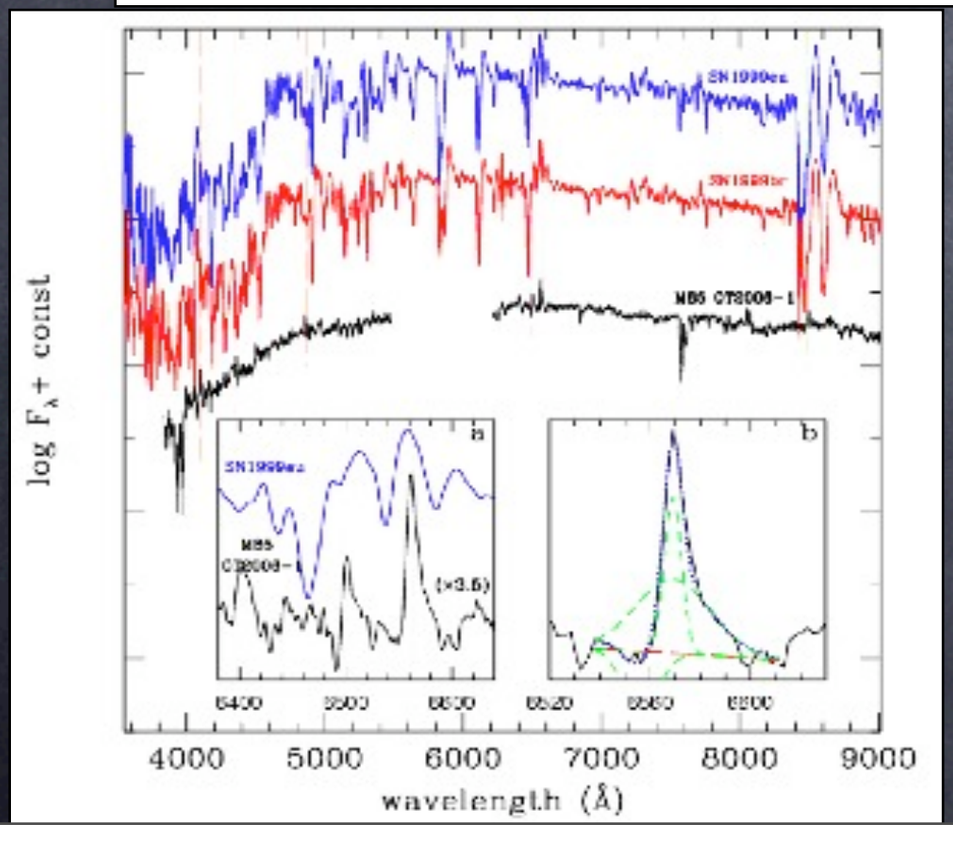

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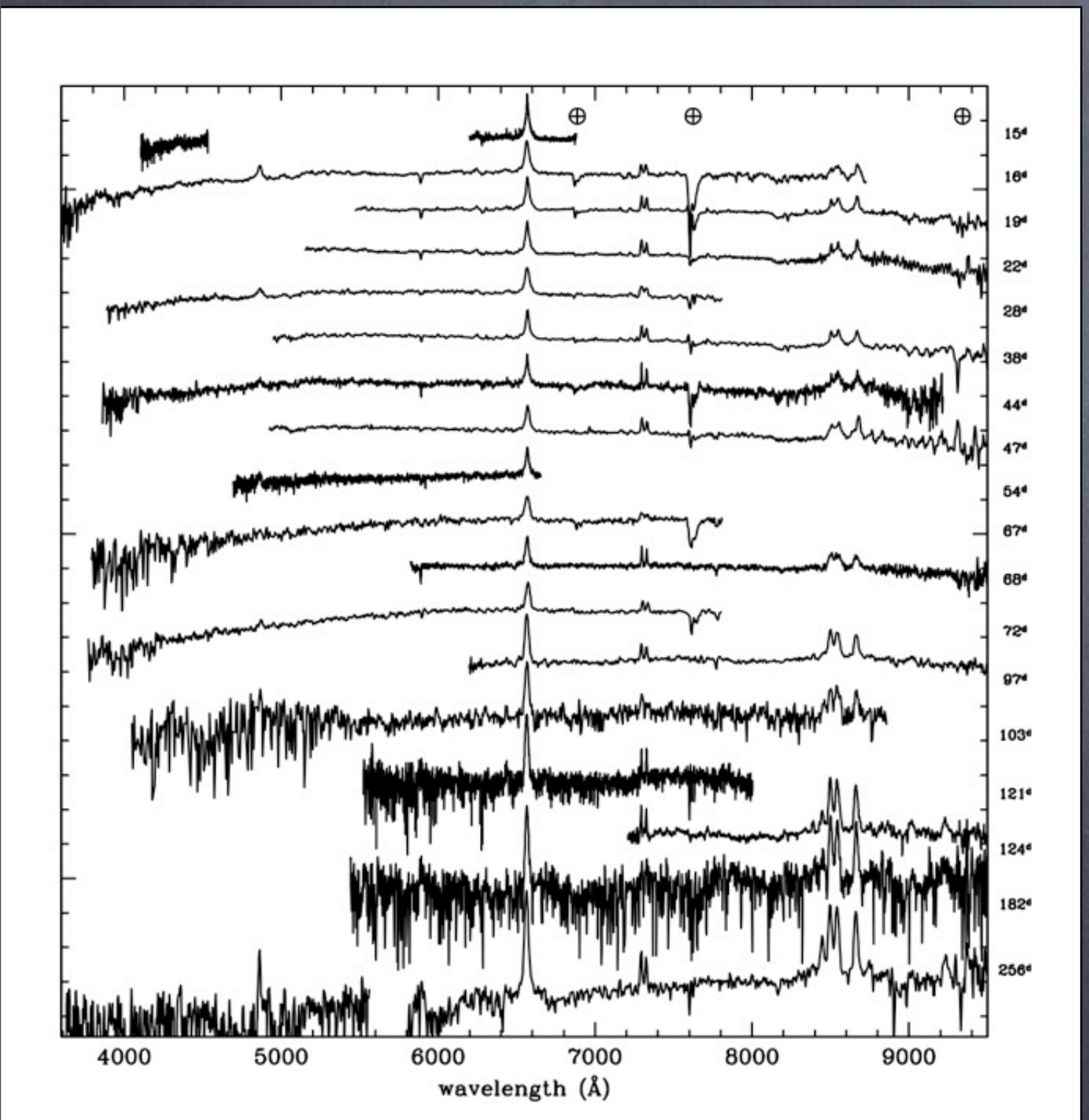
=> An ultra-faint CC-SN

(Pastorello et al. 2007, Nature, 449, 1)

SN impostors or ultrafaint SNe?
NGC300-2008OT & SN 2008S



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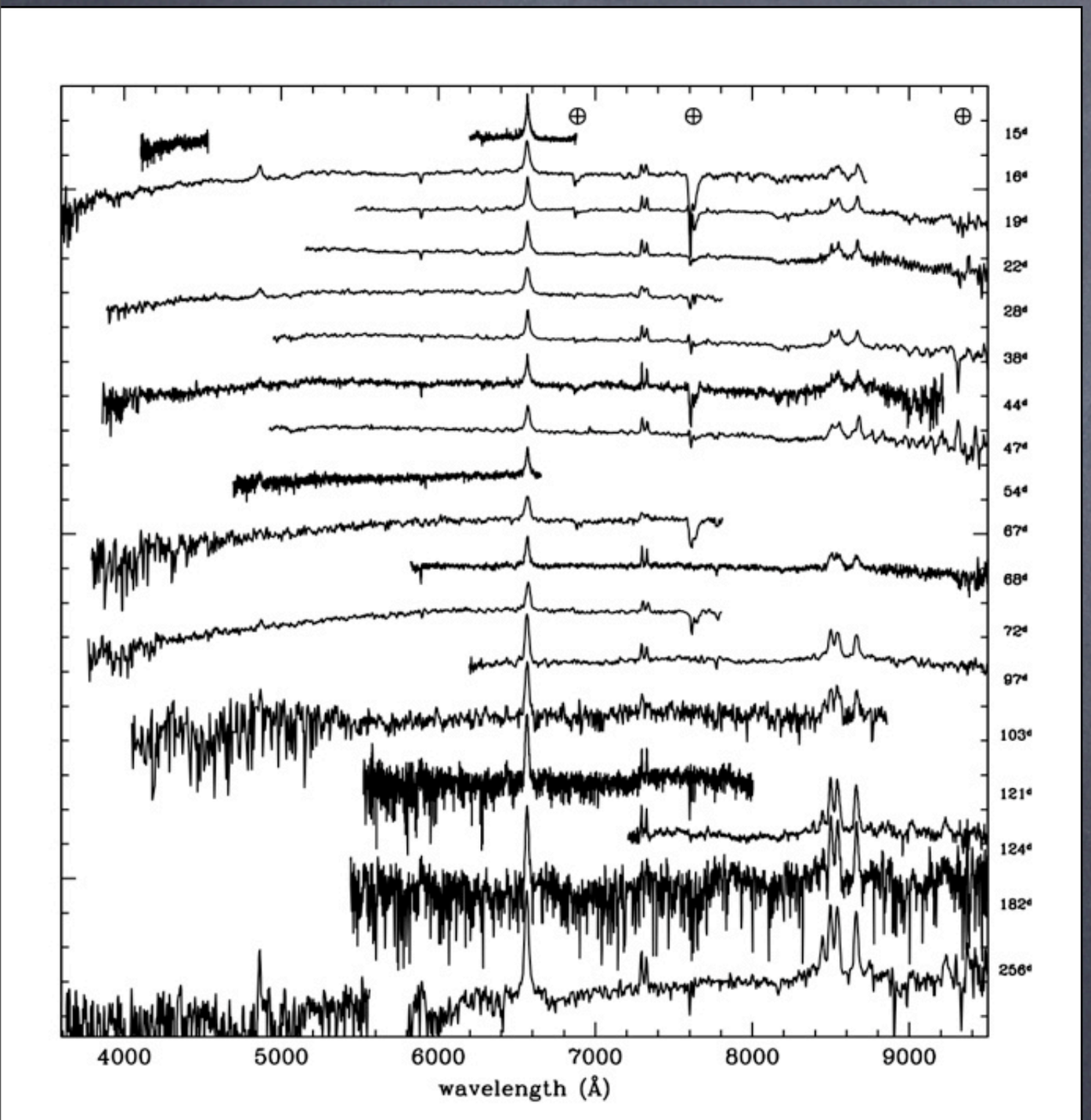

Botticella et al. 2009 MNRAS, 398, 1041;
see also Smith et al. 2009, ApJ, 697L, 49

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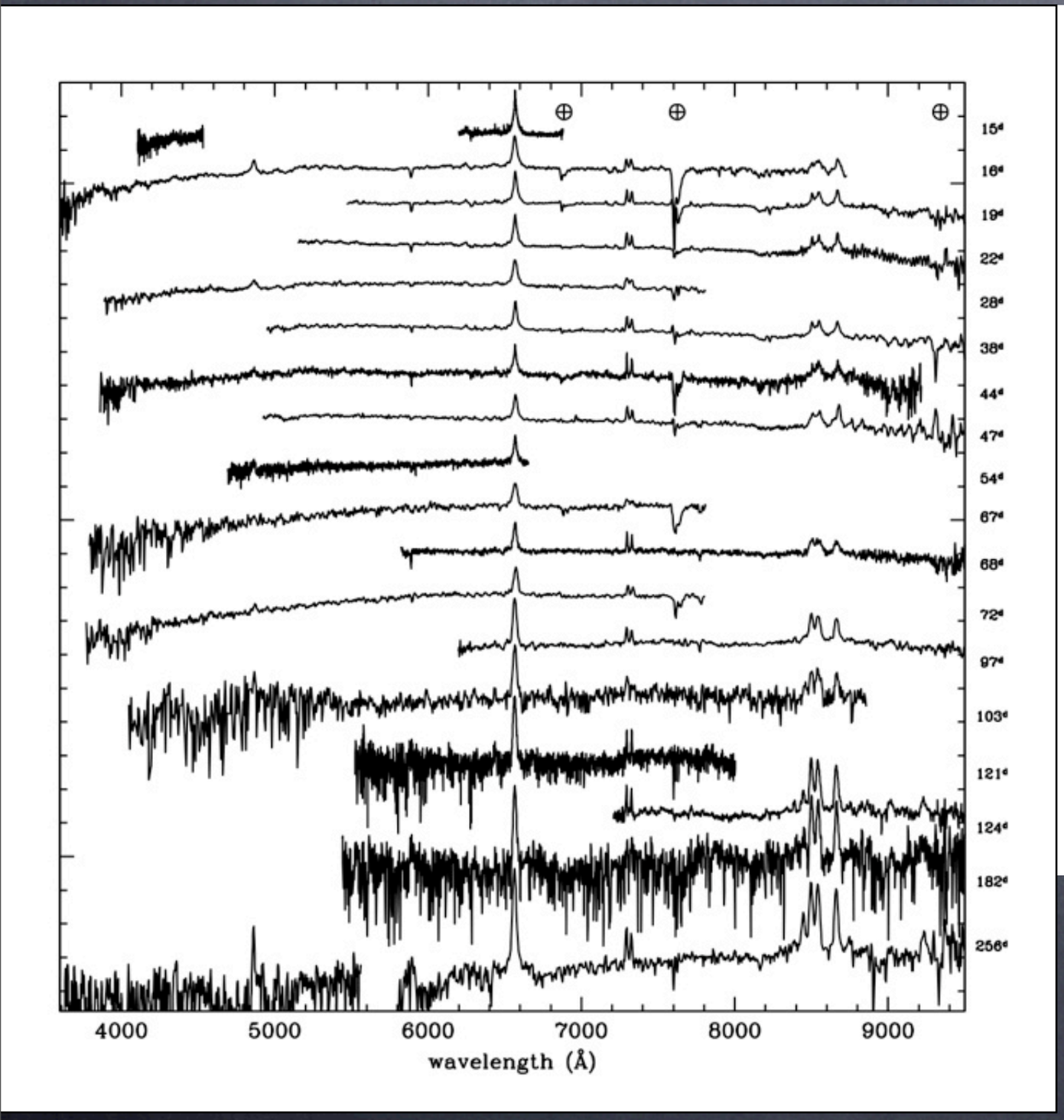

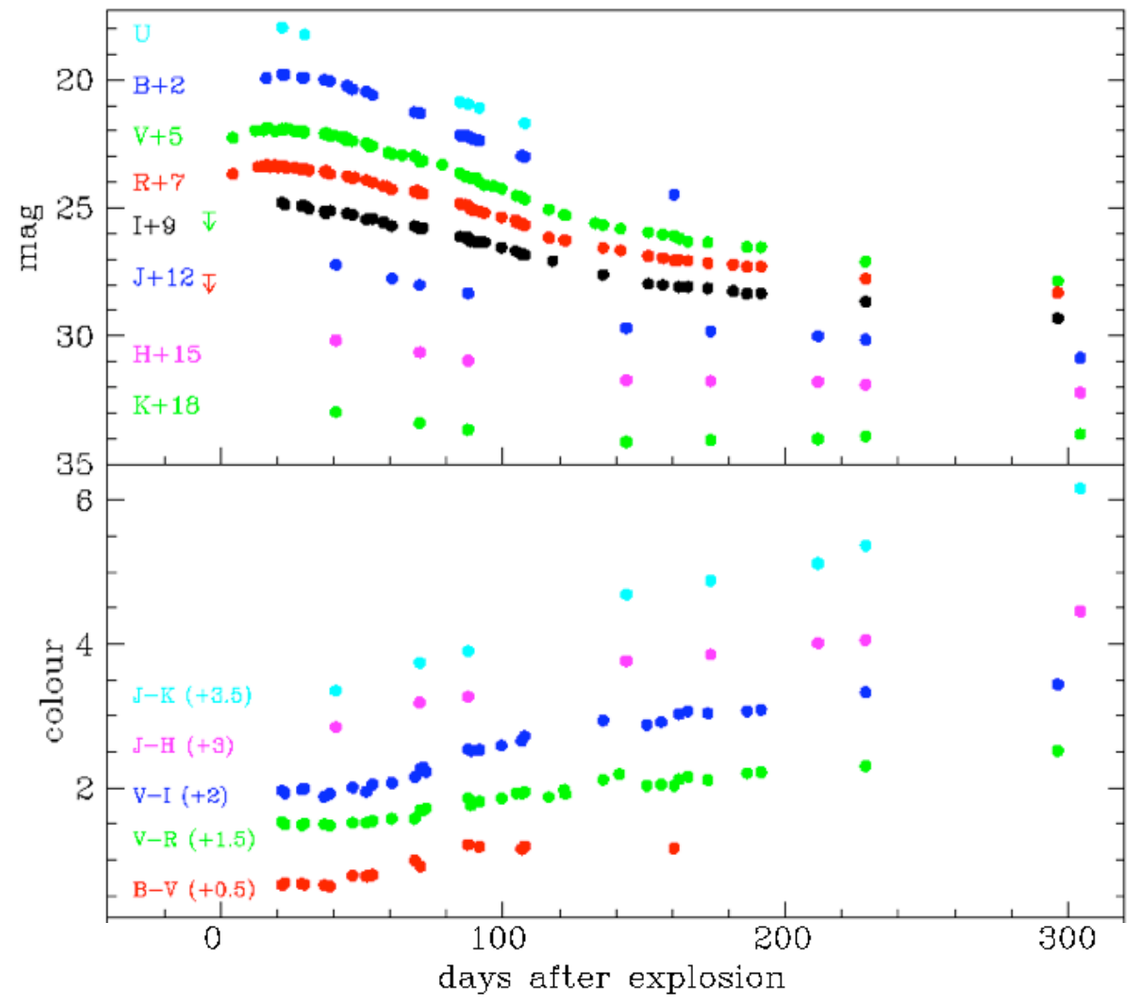

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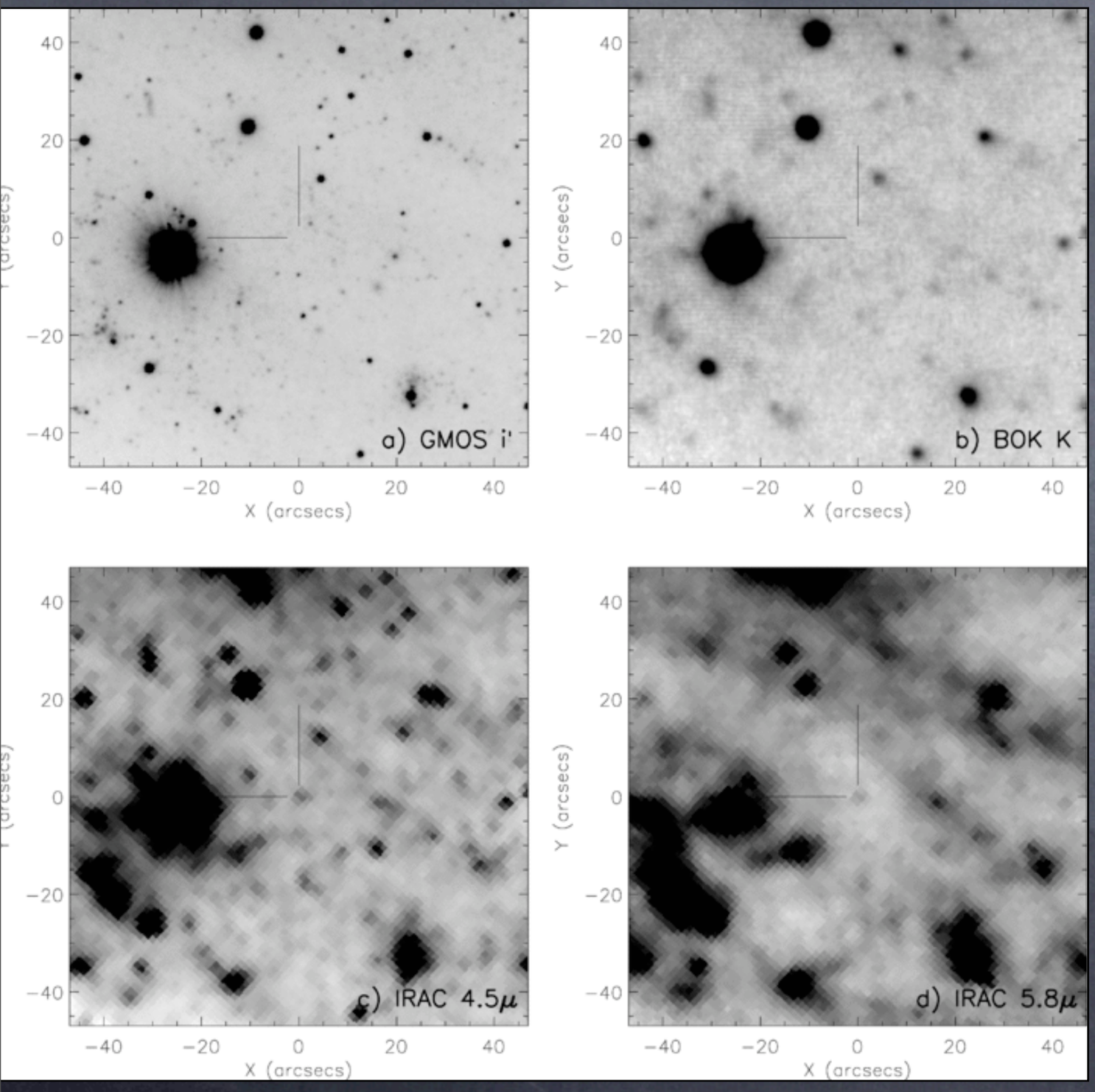
Dusty, massive progenitors



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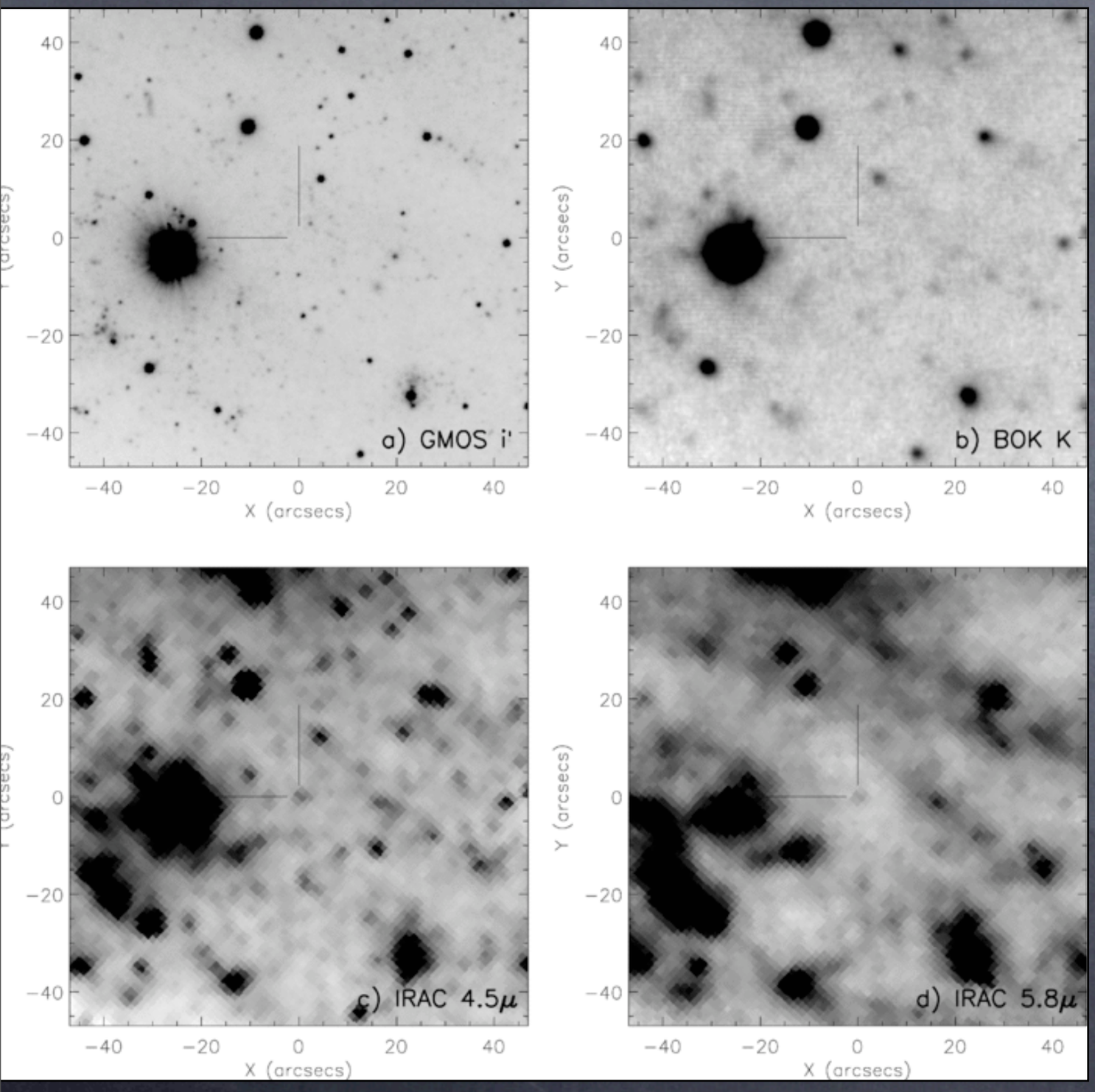

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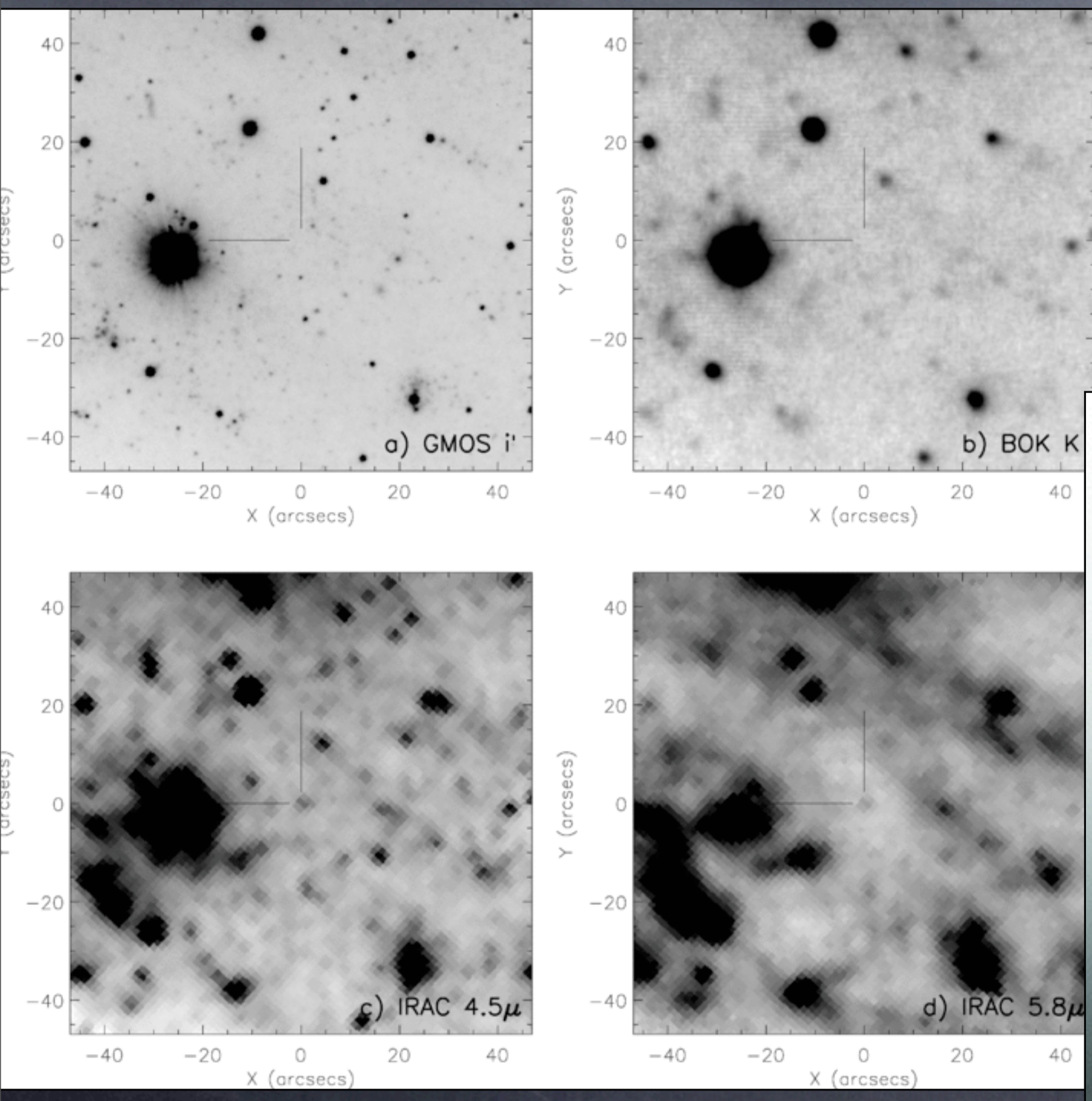
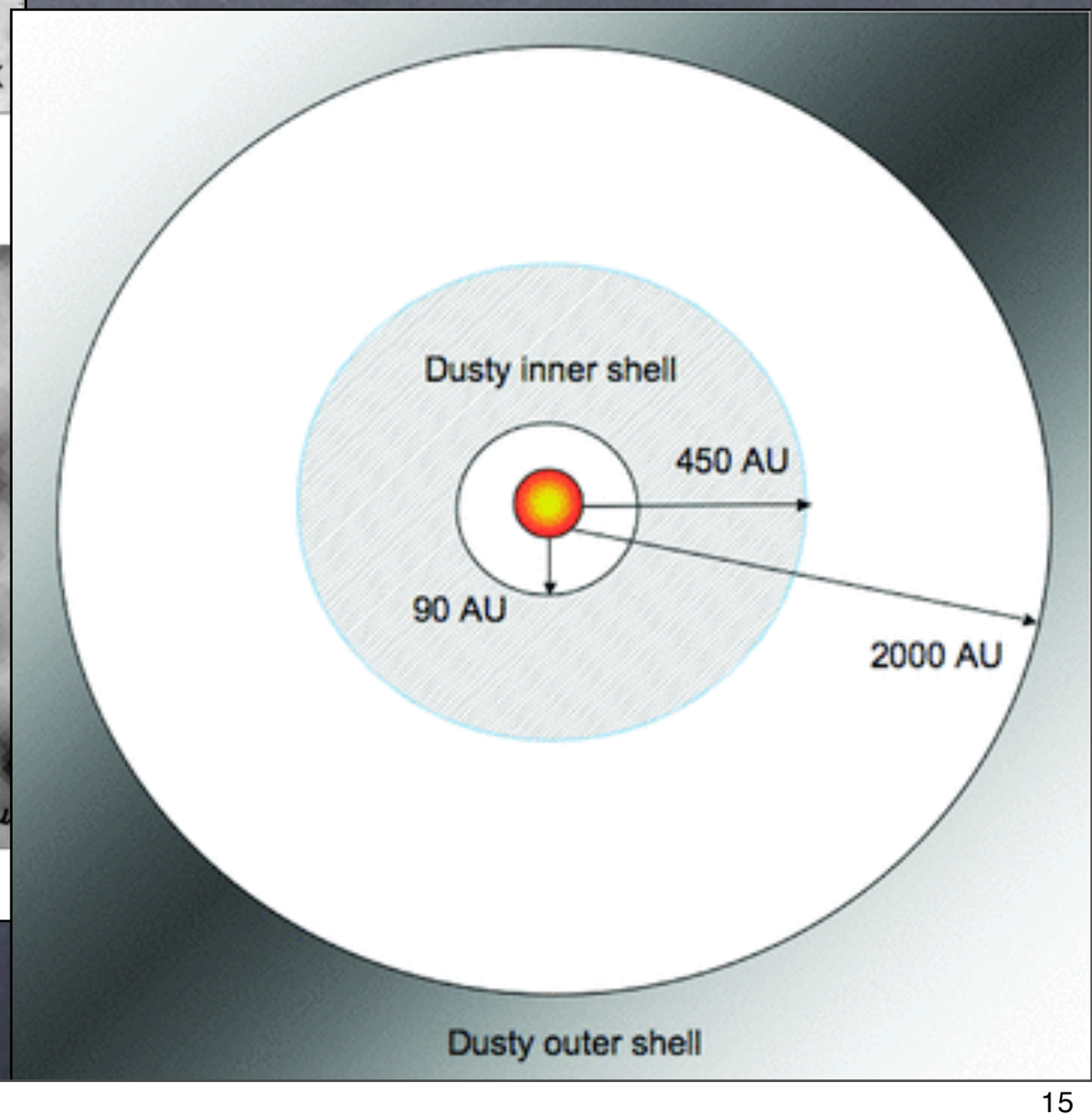
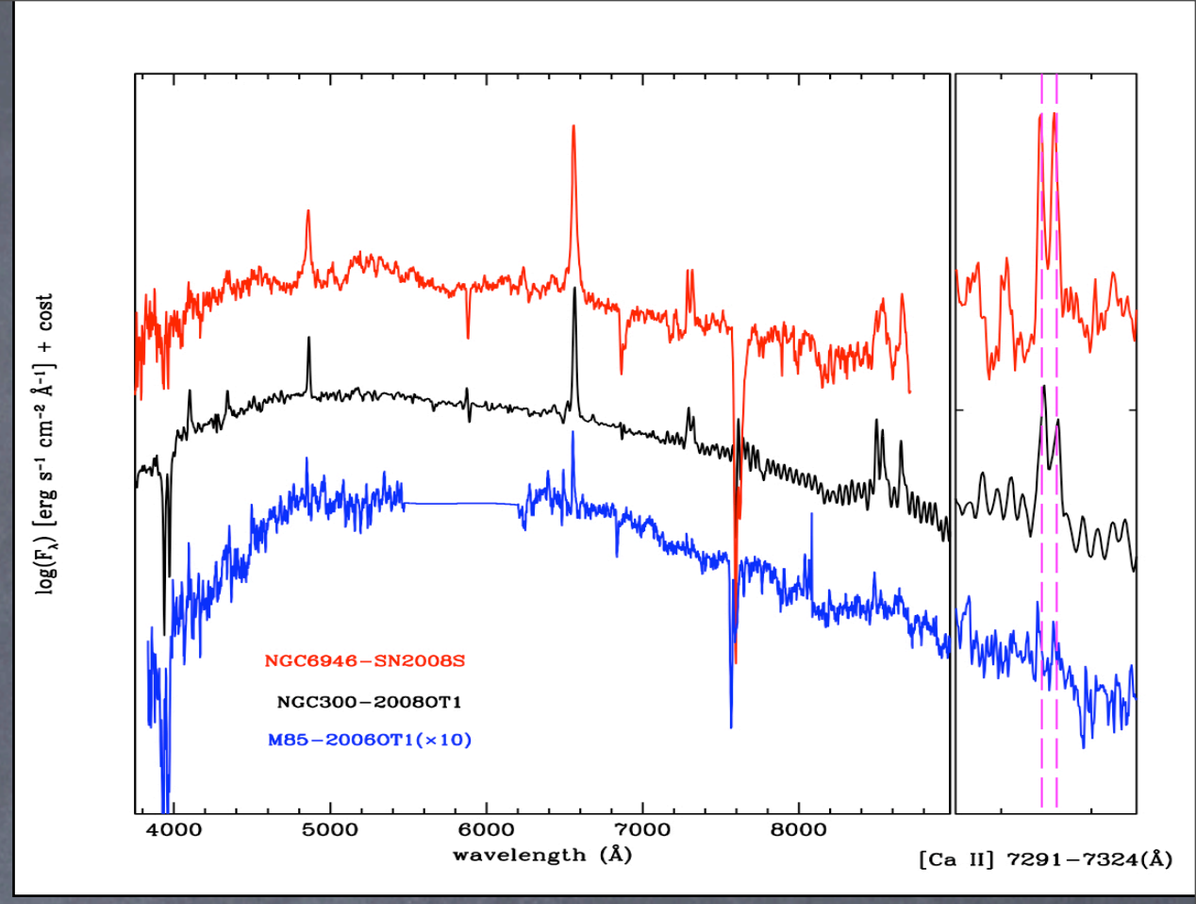




A new family of transients!

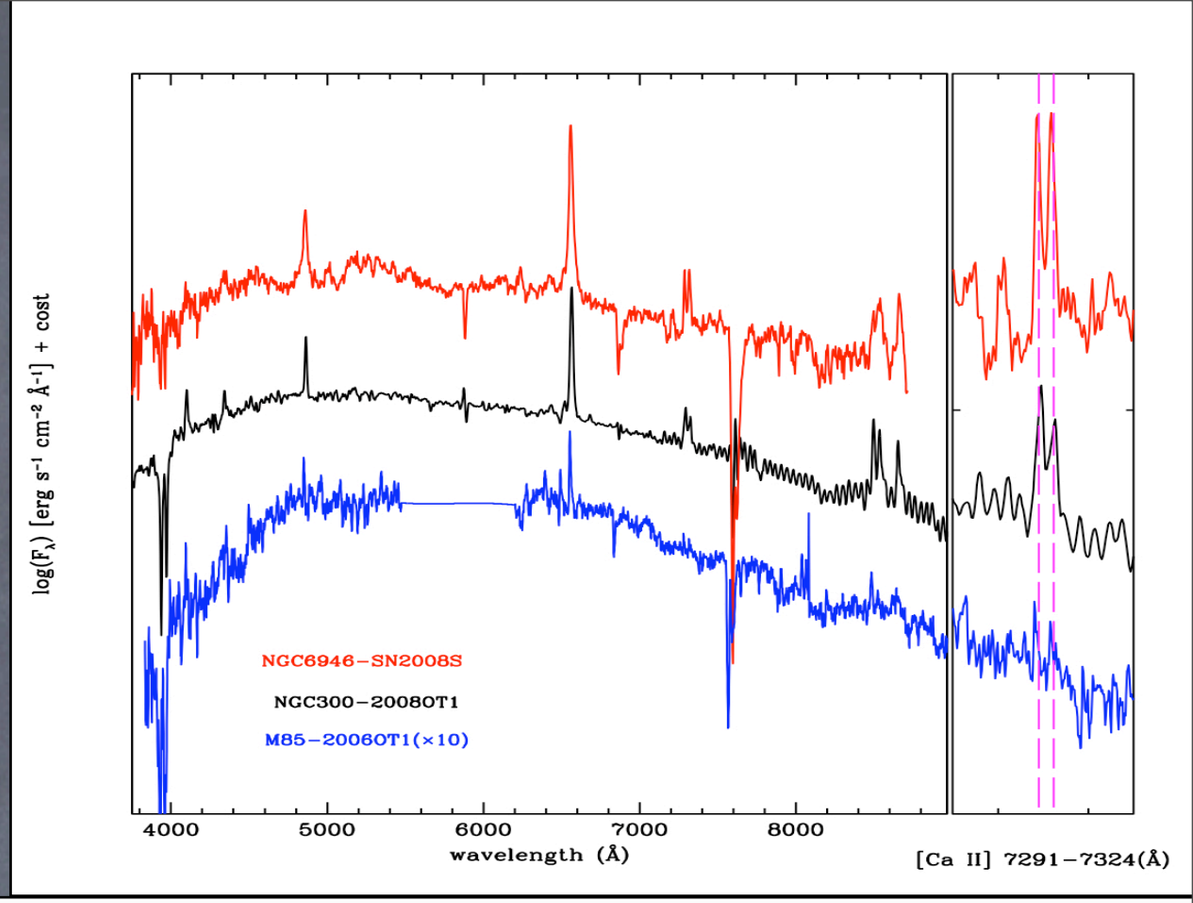


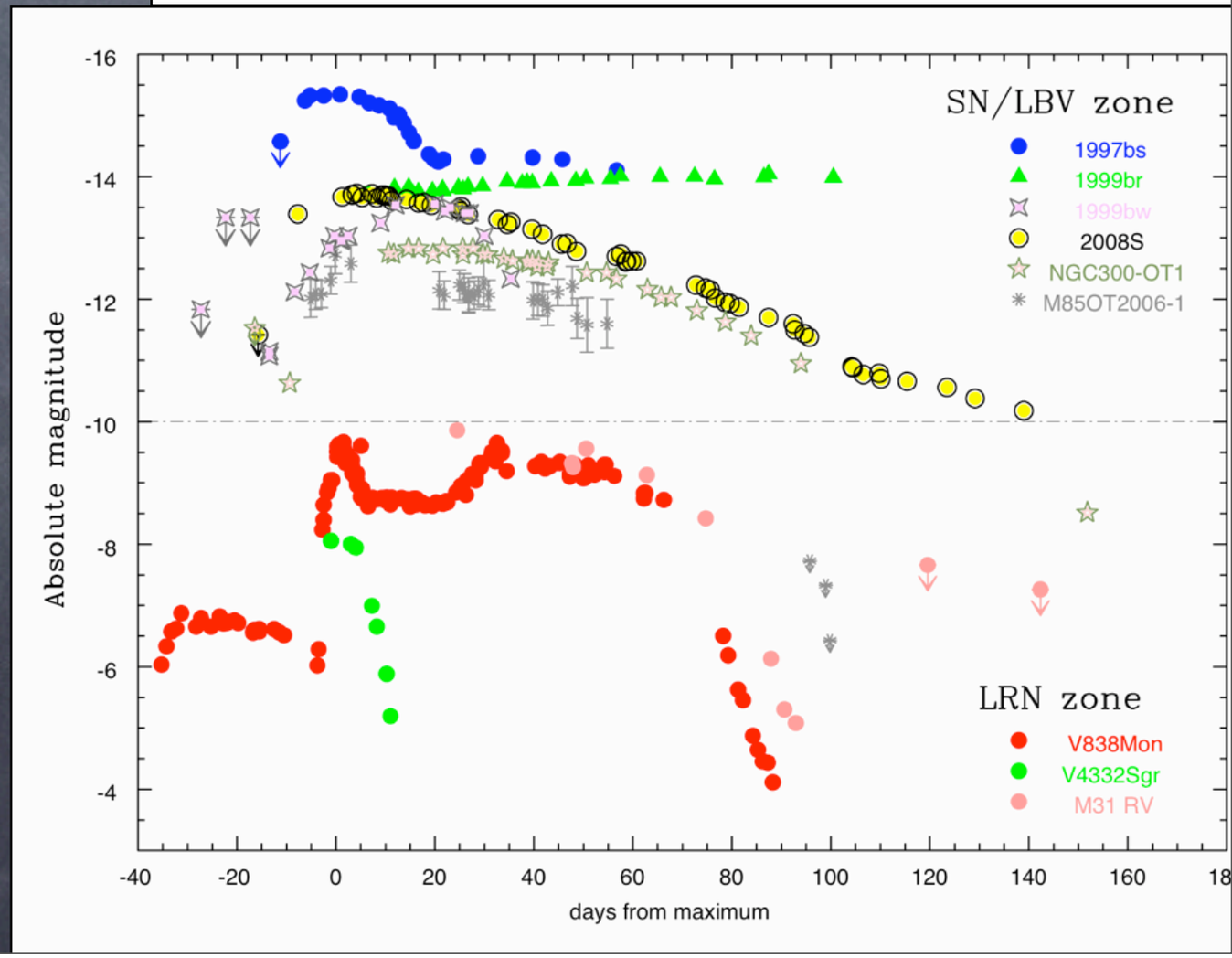
A new family of transients!

1. Narrow, emission-line spectra (IIn)
2. Faint and slow-evolving LCs
3. Dust-enshrounded 8-20Mo progenitors

=> Same class of transients!

(Prieto et al. 2008, 2009; Smith et al. 2009; Bond et al. 2009; Botticella et al.2009; Thompson et al. 2009; Berger et al. 2009, Bonanos et al. 2010; Kasliwal et al. 2010; Pastorello et al. in prep.)





SN impostors or ultra-faint SNe?

SN1999bw, M85-OT, SN2008S, NGC300-OT, PTF10fqs:

- Luminous red novae from low-mass mergers
- Eruptions triggered by mass transfer from an extreme-AGB to a main sequence companion
- eruptive birth of a massive (6-8Mo) WD + planetary nebula
- outbursts from moderate-mass LBVs (M~10-20 Mo) or B[e] hypergiants
- EC-SNe from ~9 Mo super-AGB stars (SNe IIL/IIn)
- Faint CC-SNe from 10-12Mo RSGs

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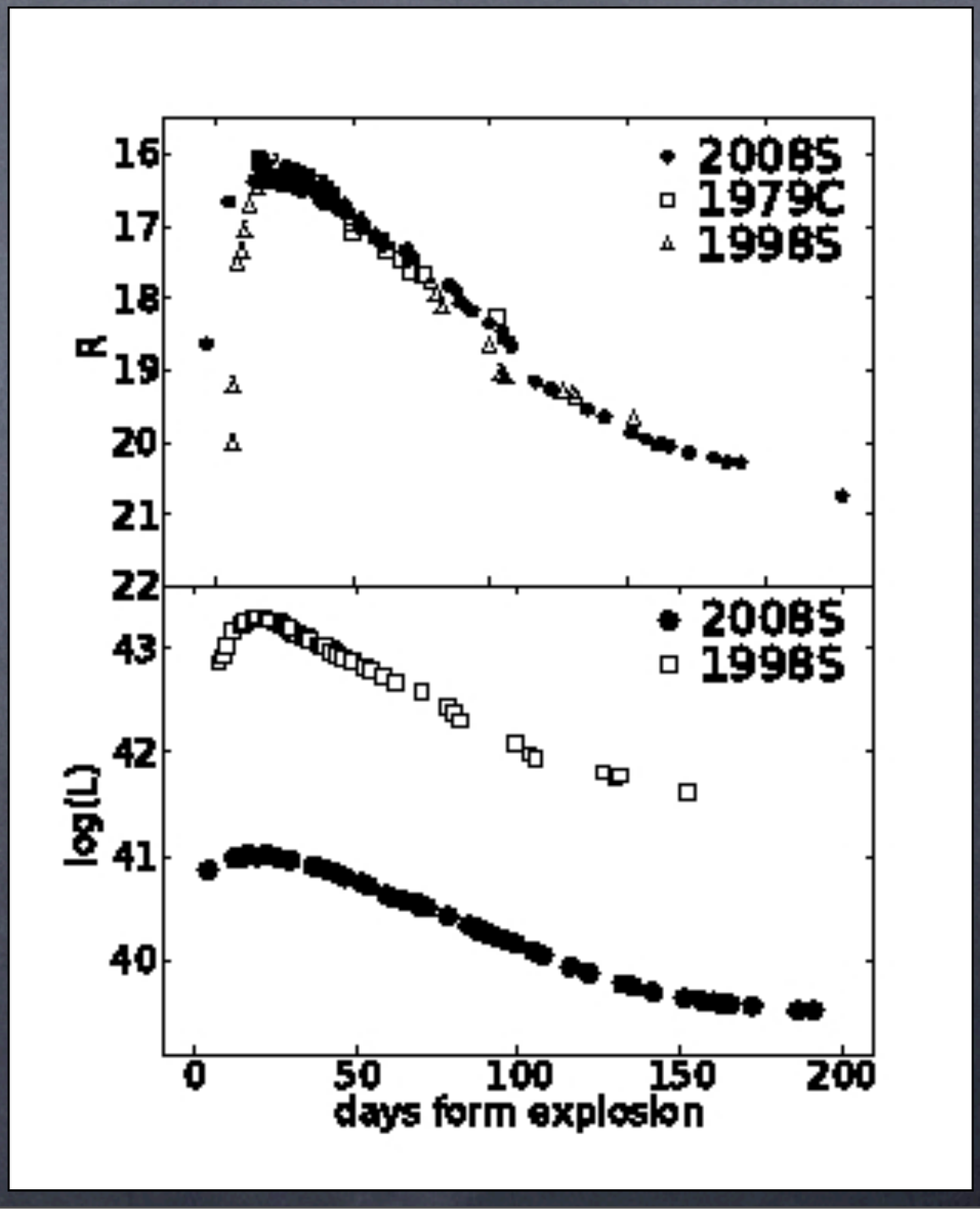
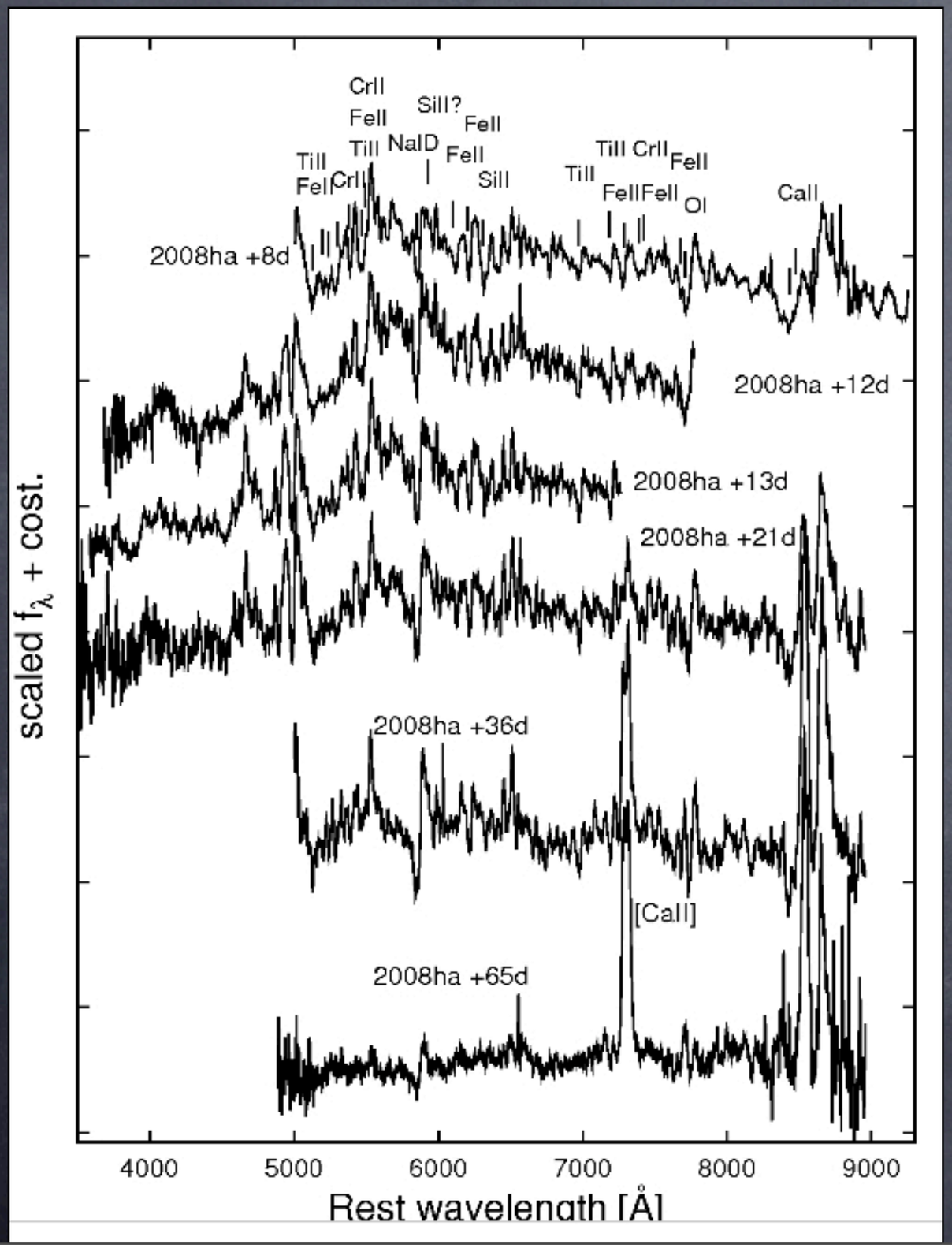
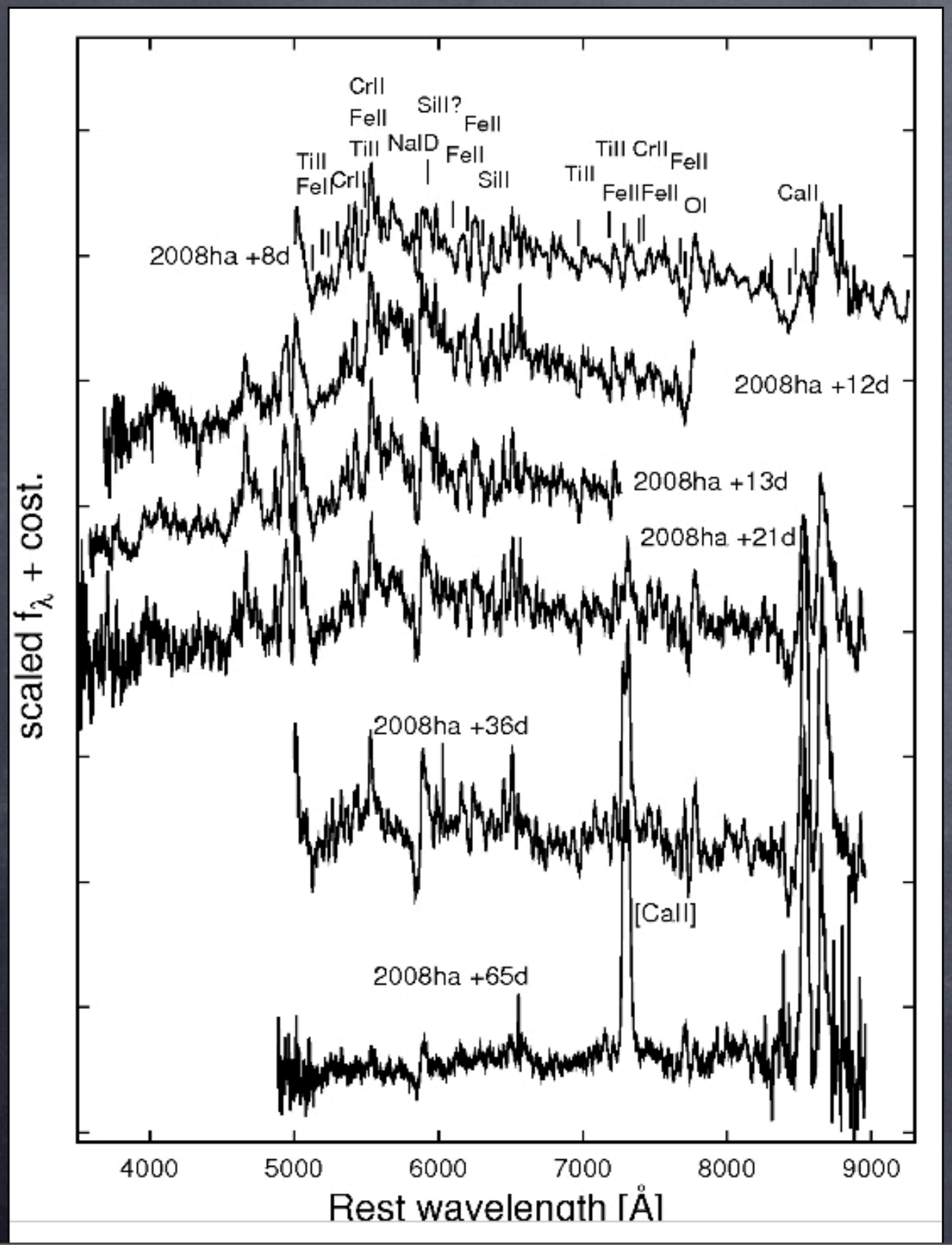
Botticella et al. 2009; see also Thompson et al. 2009; Pumo et al. 2009



Sub-luminous stripped-envelope SNe



Sub-luminous stripped-envelope SNe



Valenti, Pastorello et al. 2009, Nature, 459, 674

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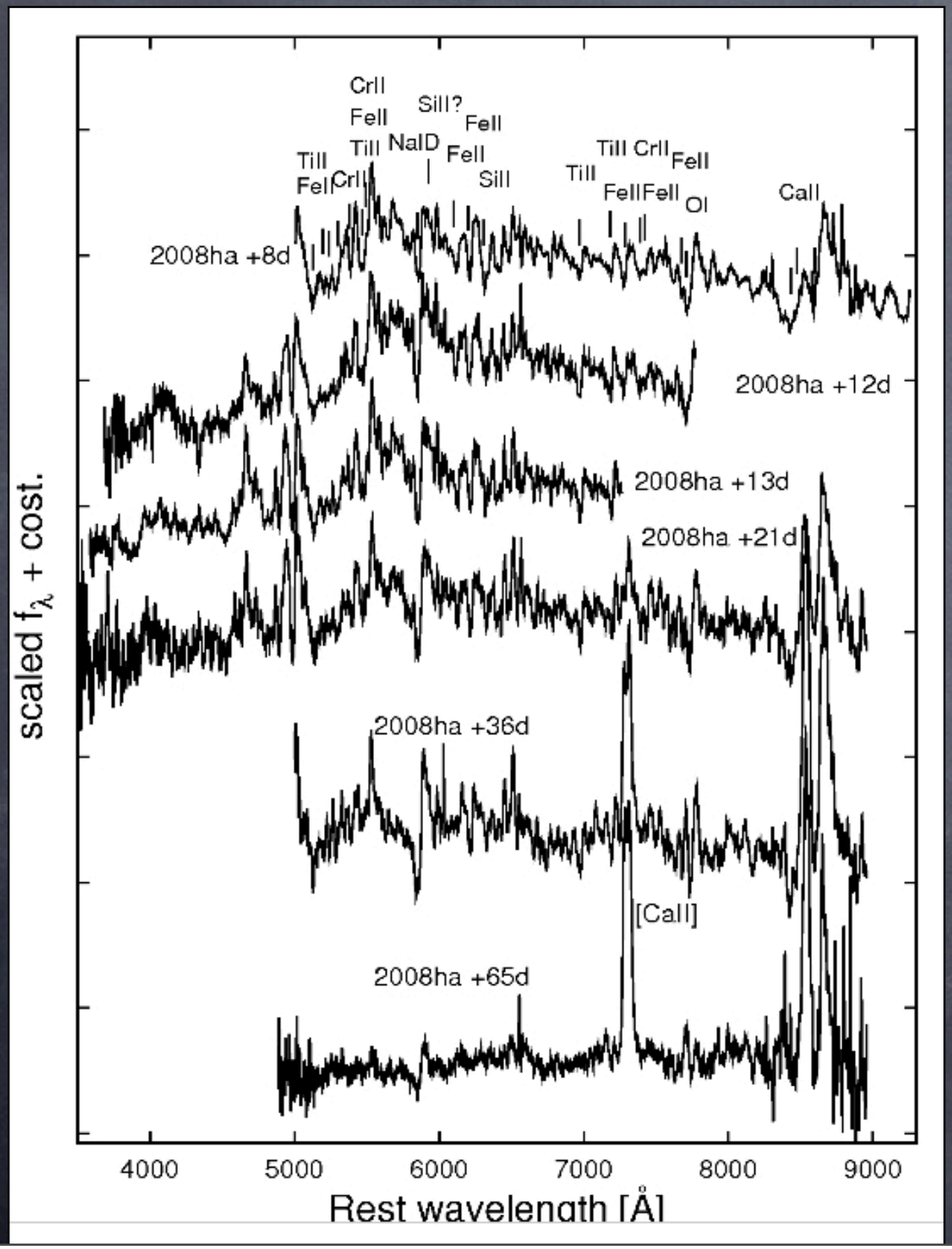
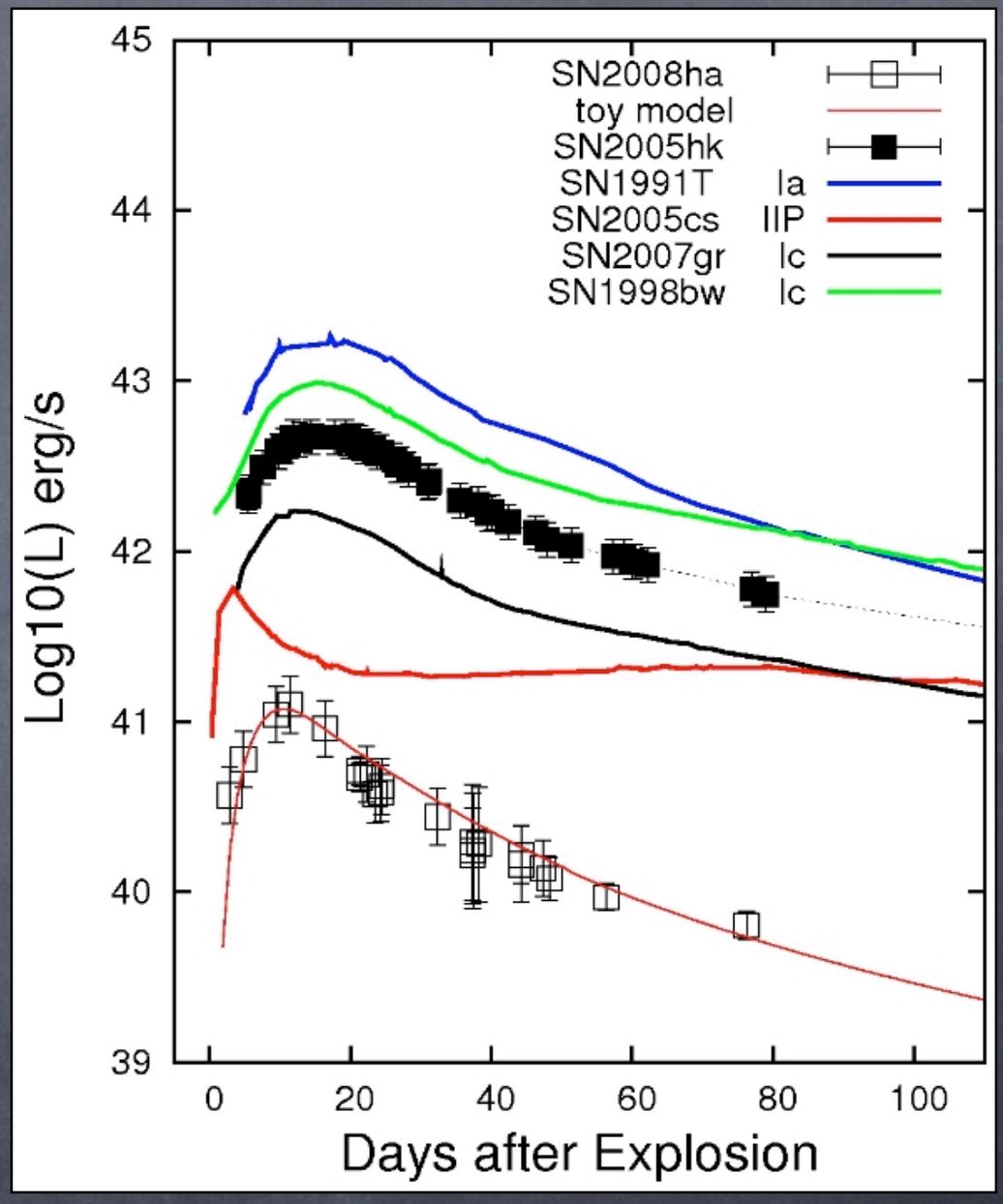
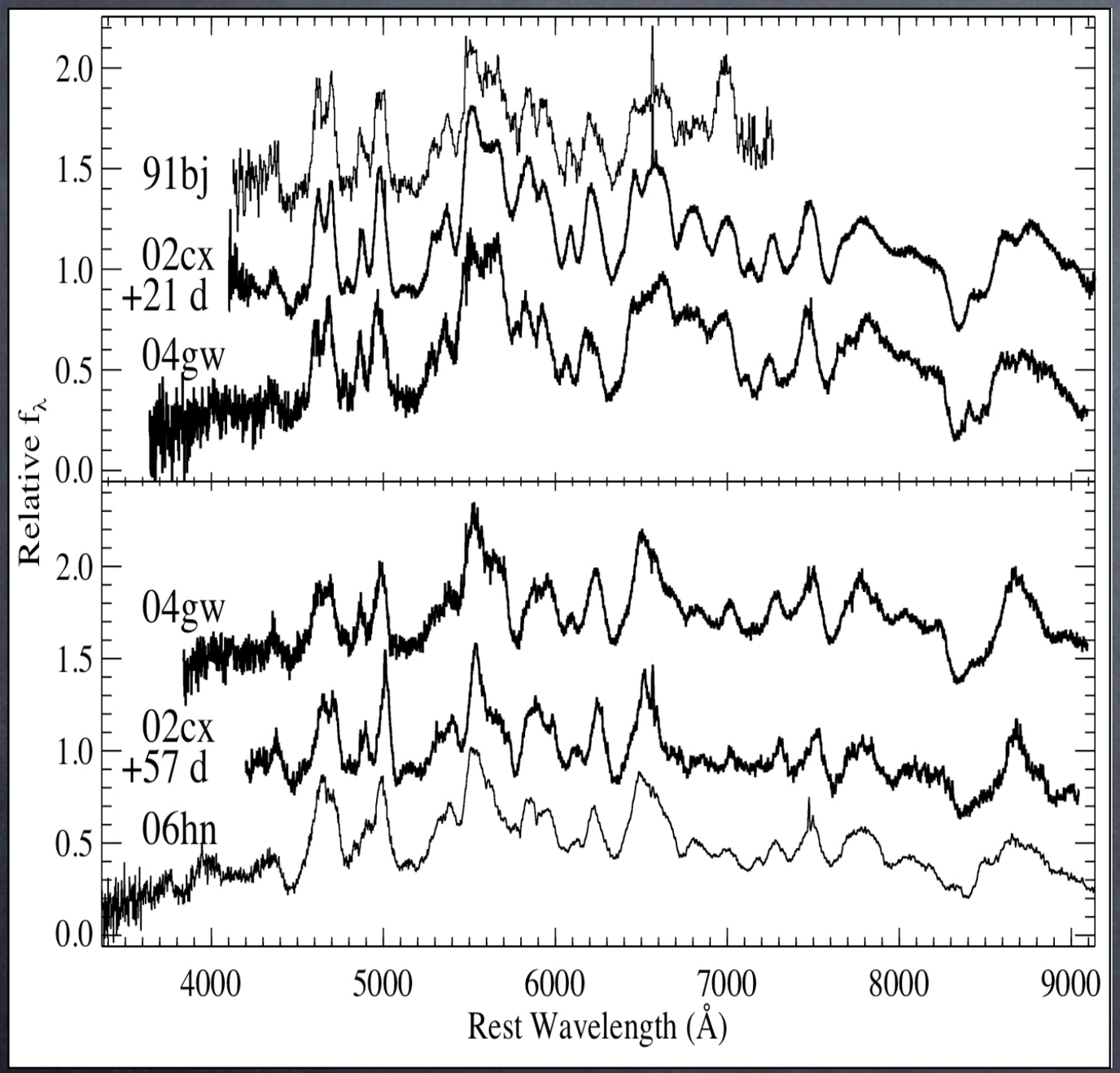


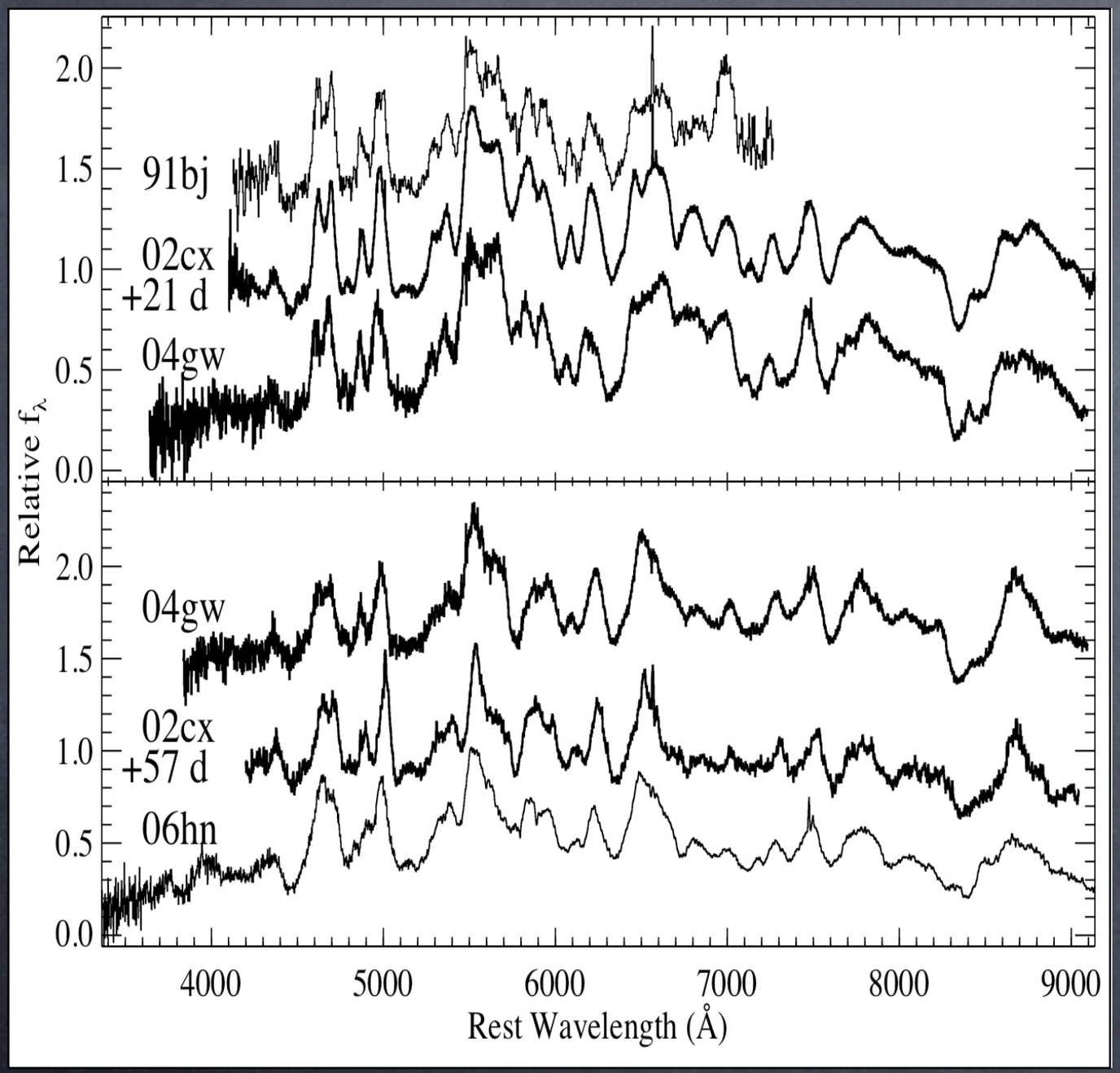


Valenti, Pastorello et al. 2009, Nature, 459, 674

Sub-luminous stripped-envelope (Ia/Ic) SNe



Sub-luminous stripped-envelope (Ia/Ic) SNe



Foley et al. 2009, AJ, 138, 376
Foley et al. 2010, ApJ, 708, 1748.
but see Ryan's Talk

Sub-luminous stripped-envelope (Ia/Ic) SNe

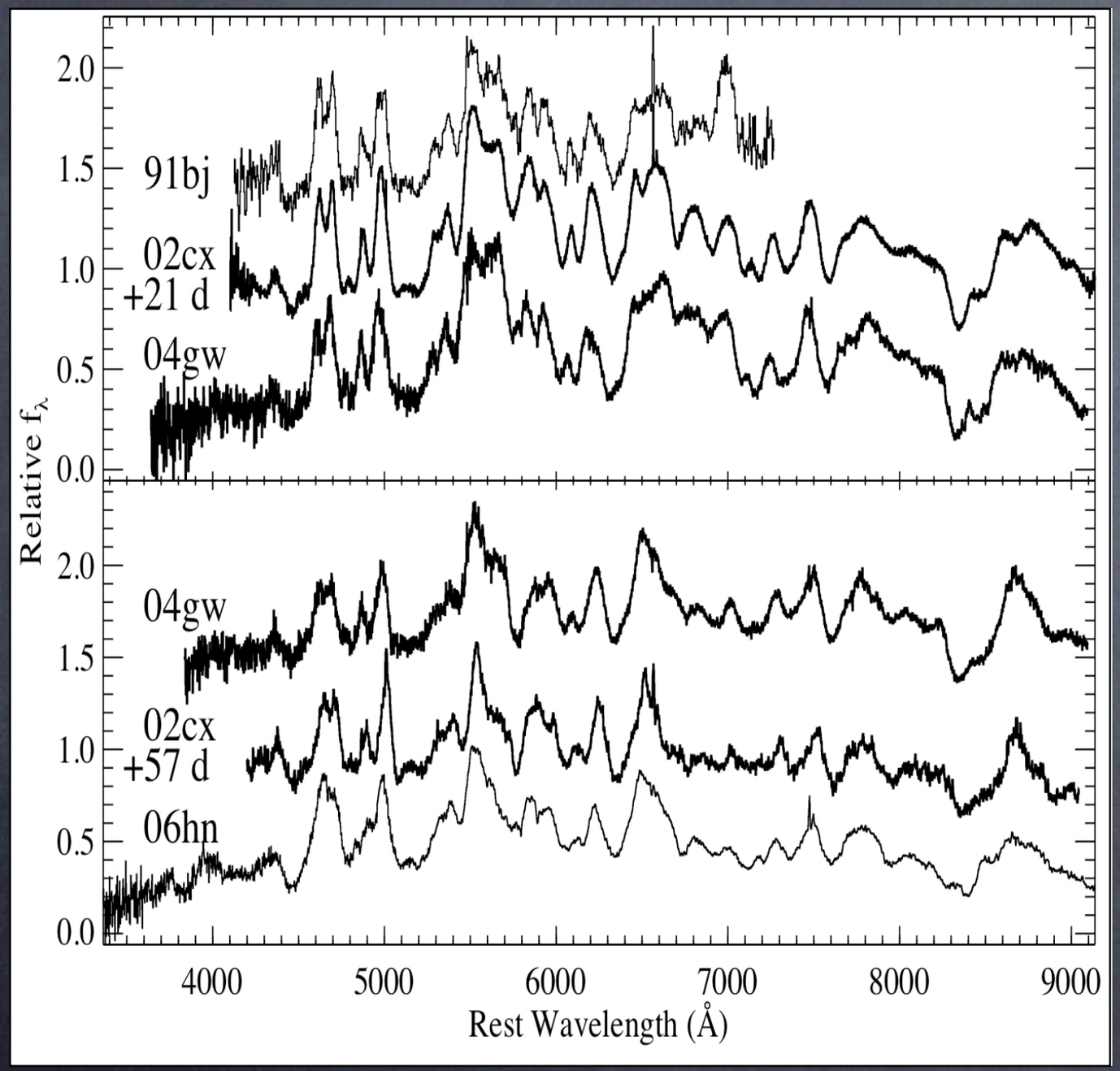


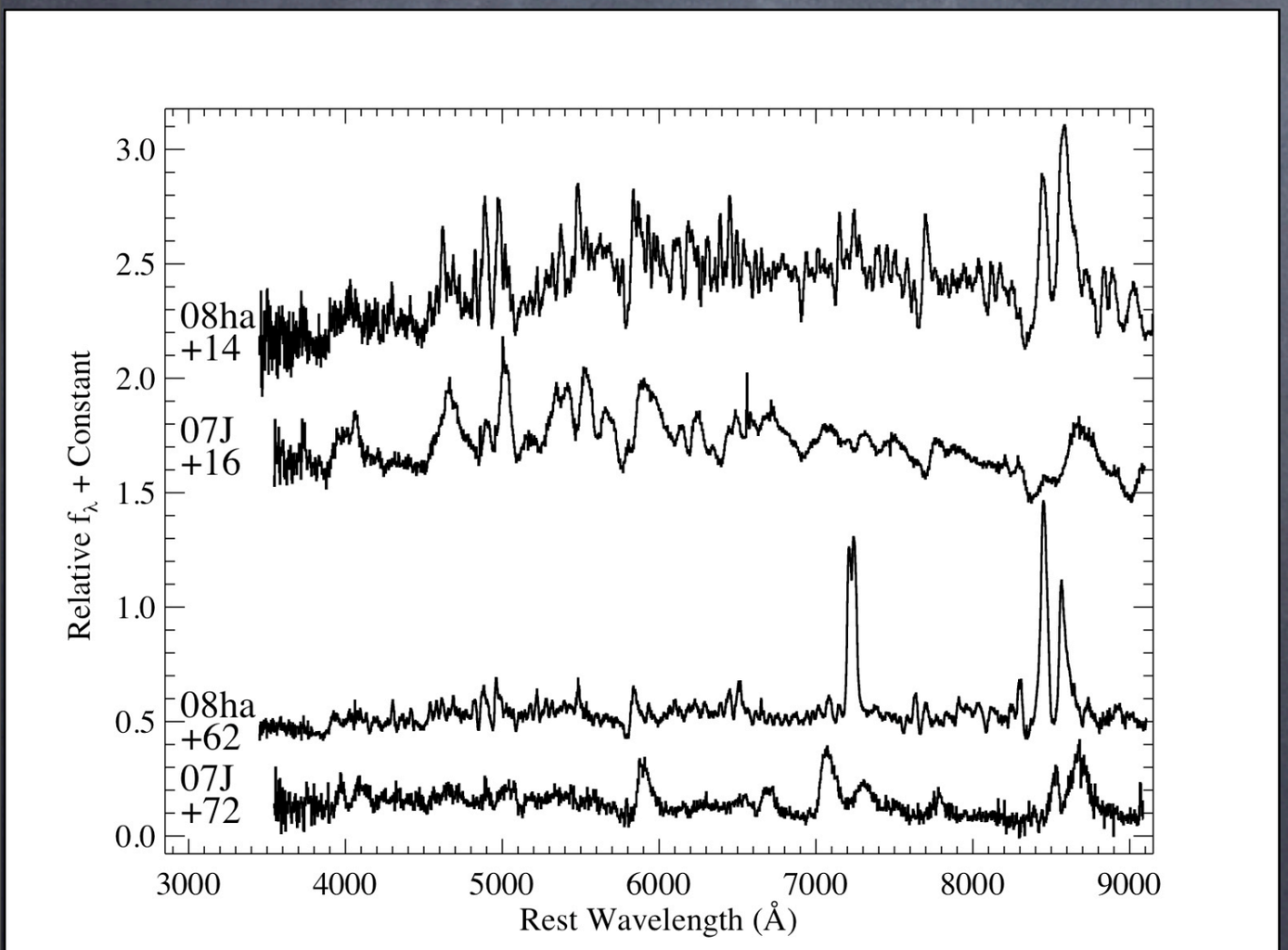
Table 9
Host-Galaxy Properties of SN 2002cx-like Objects

SN Name	Reference	Host-Galaxy Name	Morphology
1991bj	1,2,3	IC 344	Sb
2002cx	4,5,6	CGCG 044-035	Sb
2003gq	7,8	NGC 7407	Sbc
2004gw	1,9,10	PGC 16812	Sbc
2005P	6	NGC 5468	Scd
2005cc	11	NGC 5383	Sb
2005hk	12,13,14	UGC 272	Sd
2006hn	1,15	NGC 6154	Sa
2007J[a]	16,17	UGC 1778	Sd
2007qd	18	SDSS J020932.74-005959.6	Sc
2008A	19	NGC 634	Sa
2008ae	20	IC 577	Sc
2008ge	21	NGC 1527	S0
2008ha	1,22,23	UGC 12682	Irr
2009J	24	IC 2160	Sbc

References. (1) This paper; (2) Pollas et al. 1992; (3) Stanishev et al. 2007; (4) Li et al. 2003; (5) Branch et al. 2004; (6) Jha et al. 2006; (7) Filippenko et al. 2003b; (8) Filippenko & Chornock 2003; (9) Foley & Filippenko 2005; (10) Filippenko & Foley 2005; (11) Antilogus et al. 2005; (12) Chornock et al. 2006; (13) Phillips et al. 2007; (14) Sahu et al. 2008; (15) Foley et al. 2006; (16) Filippenko et al. 2007a; (17) Filippenko et al. 2007b; (18) Goobar et al. 2007; (19) Blondin & Berlind 2008; (20) Blondin & Calkins 2008; (21) Stritzinger et al. 2008; (22) Foley 2008; (23) Valenti et al. (2009); (24) Stritzinger 2009.
[a] Shows He I emission lines at late times and may not be a true member of the class. It has been removed from the sample when discussing host-galaxy properties.

Foley et al. 2009, AJ, 138, 376
Foley et al. 2010, ApJ, 708, 1748.
but see Ryan's Talk

Sub-luminous stripped-envelope (Ib-IIb) SNe



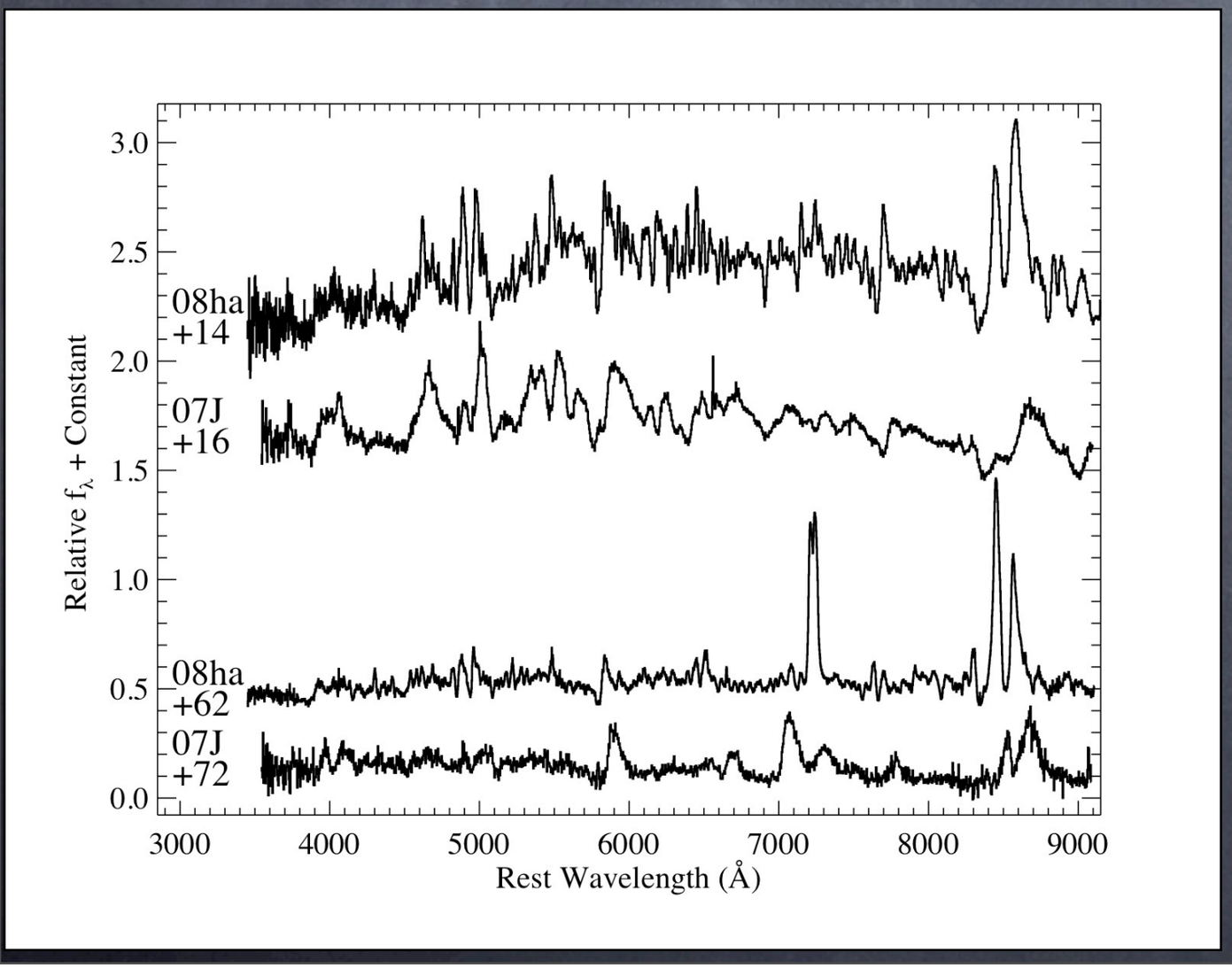
Sub-luminous stripped-envelope (Ib-IIb) SNe

Foley et al. 2009, AJ, 138, 376

Poznanski et al. 2009, Science, 327, 58 (2002bj - too bright, uncertain classification, maybe Ibn)

Peretz et al, 2010, Nature, 465, 326

Kawabata et al. 2010, Nature, 465, 322



Sub-luminous stripped-envelope (Ib-IIb) SNe

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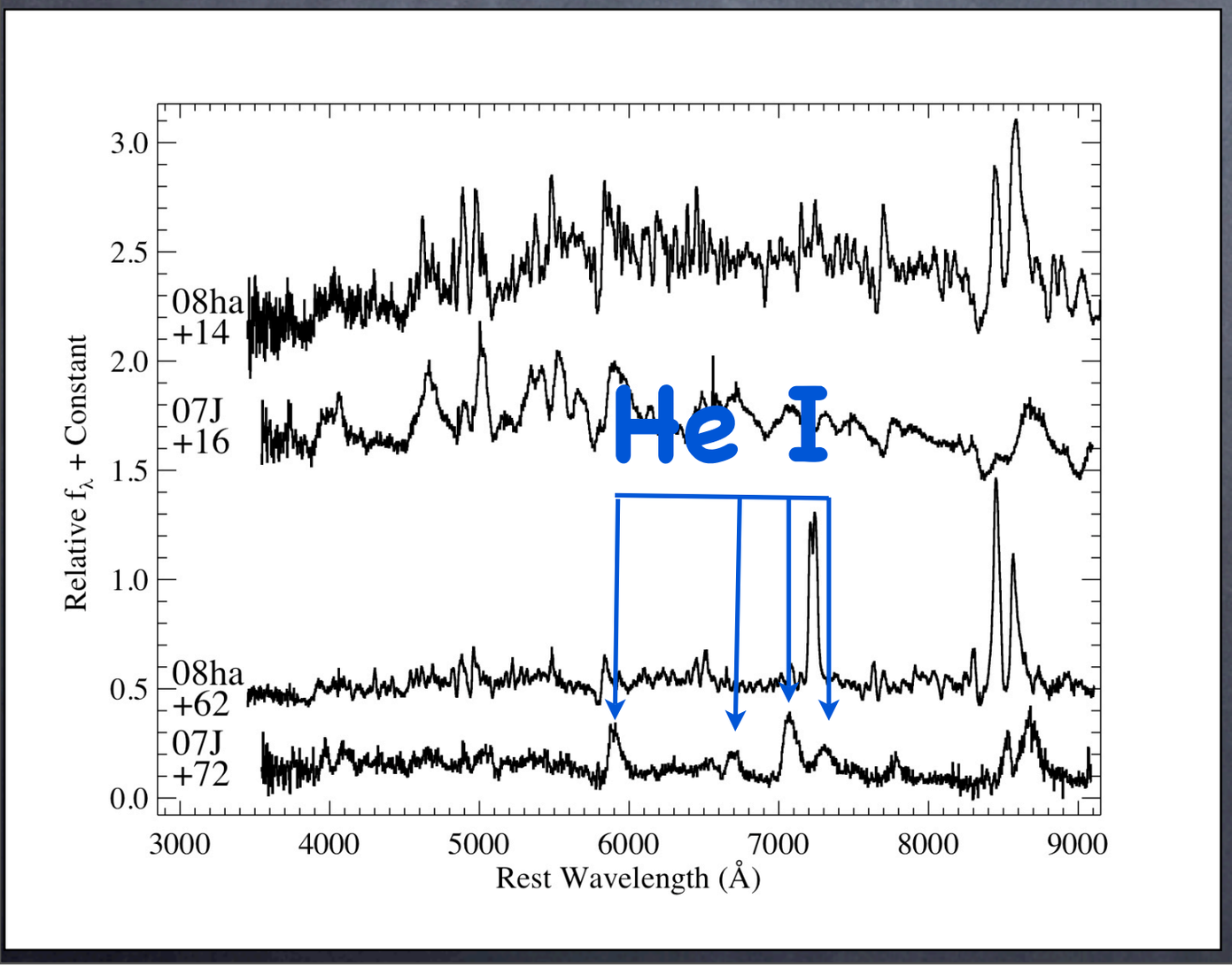

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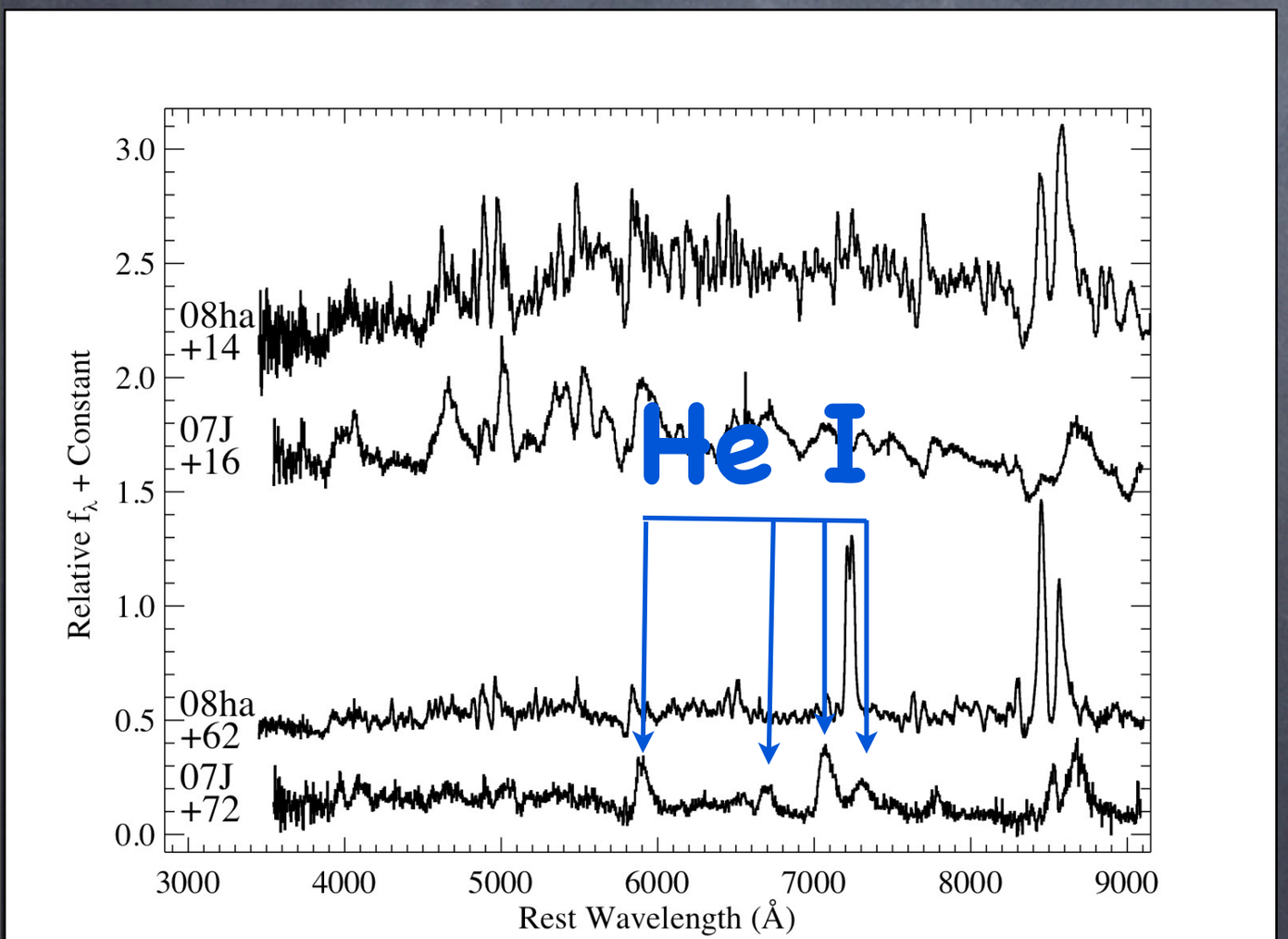
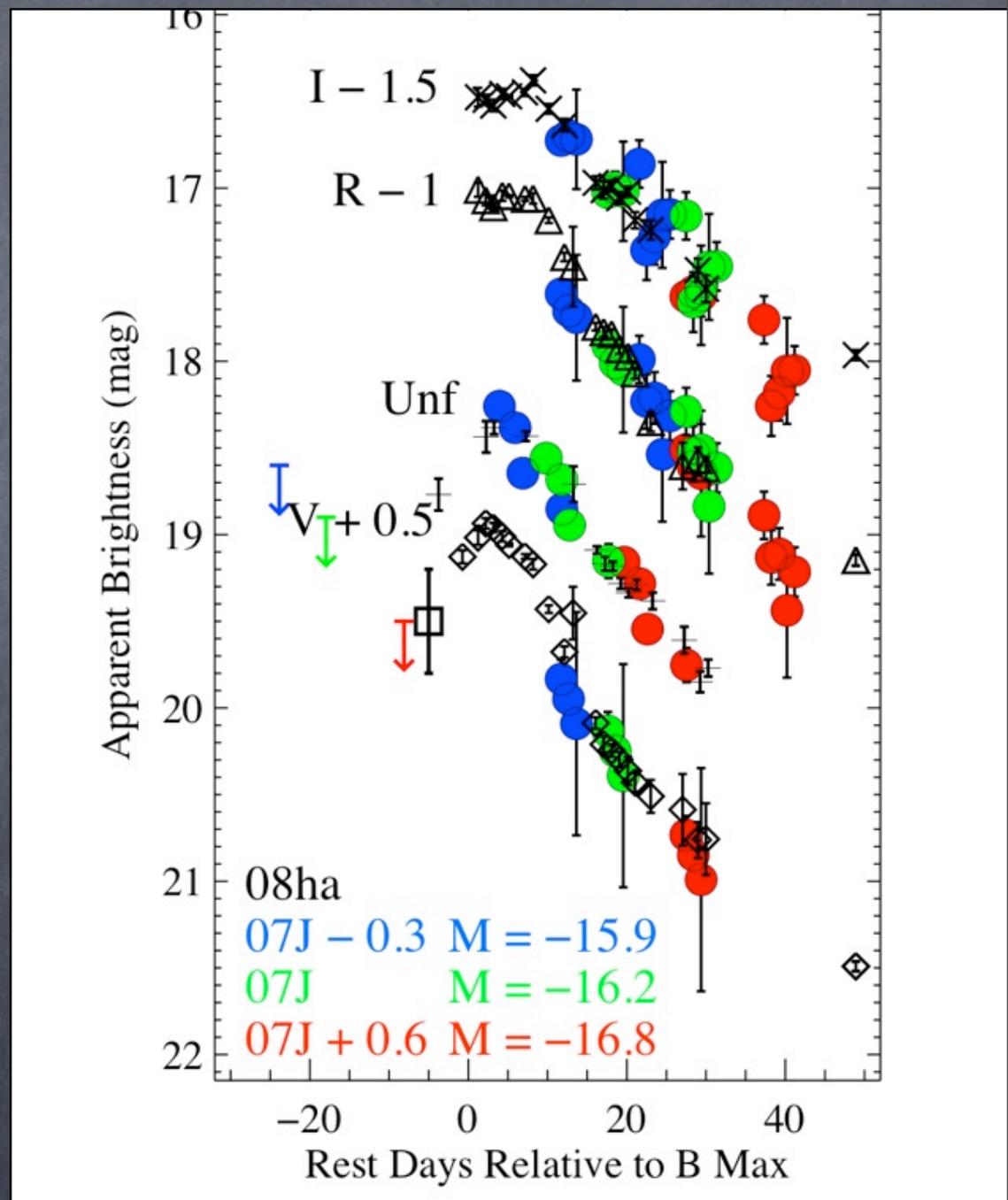
Kawabata et al. 2010, Nature, 465, 322



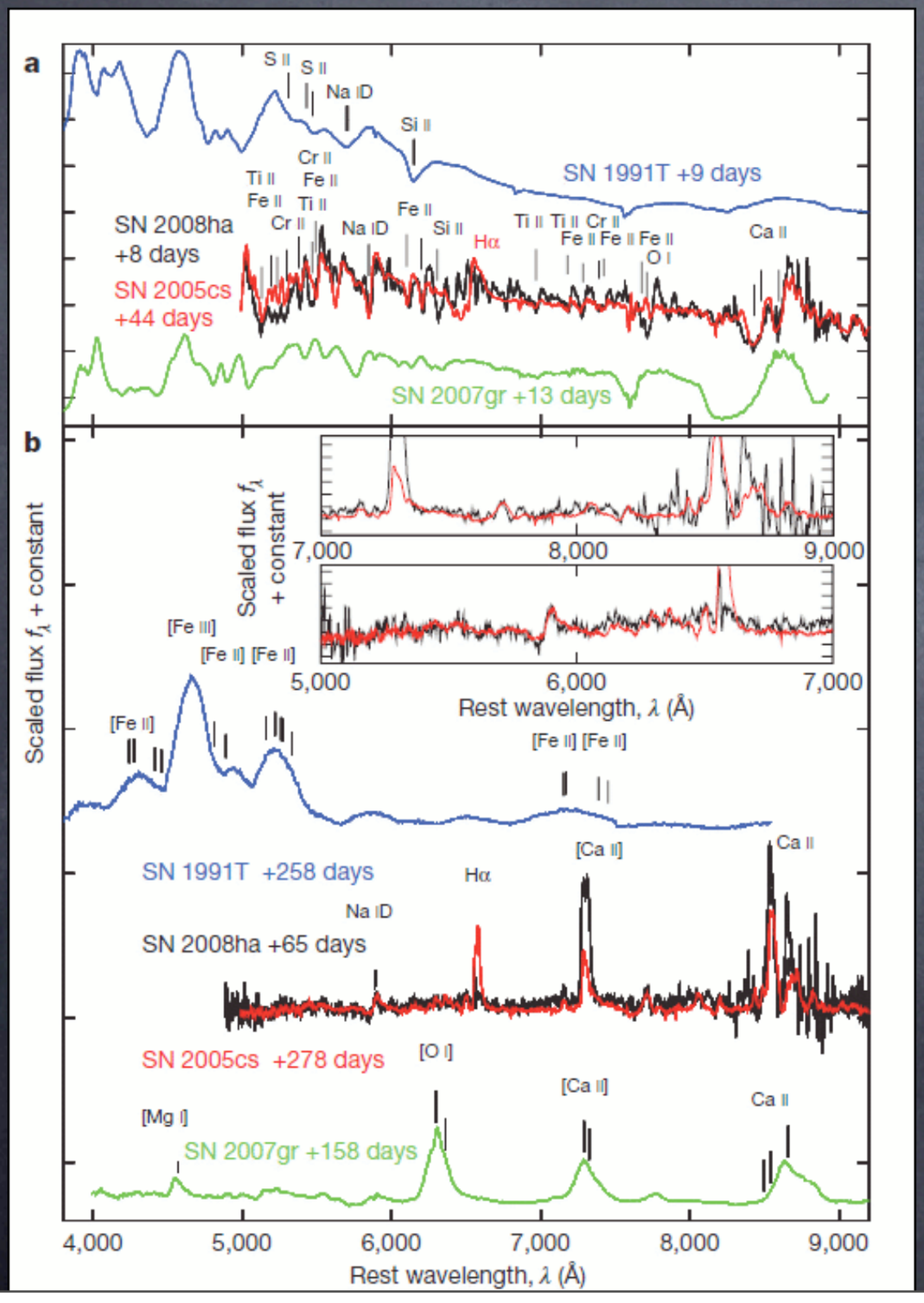


Underluminous stripped-envelope SNe

SN 2008ha (and other SE-SNe)

- Deflagrations of sub-Chandrasekhar mass WDs
- He shells detonation in close WD binaries (.Ia SNe - unburned He in the ejecta!)
- EC-SNe from ~9 Mo super-AGB stars (SNe I b/c)
- Faint CC-SNe from > 20-25Mo stars + fall-back with BH formation

Underluminous stripped-envelope SNe



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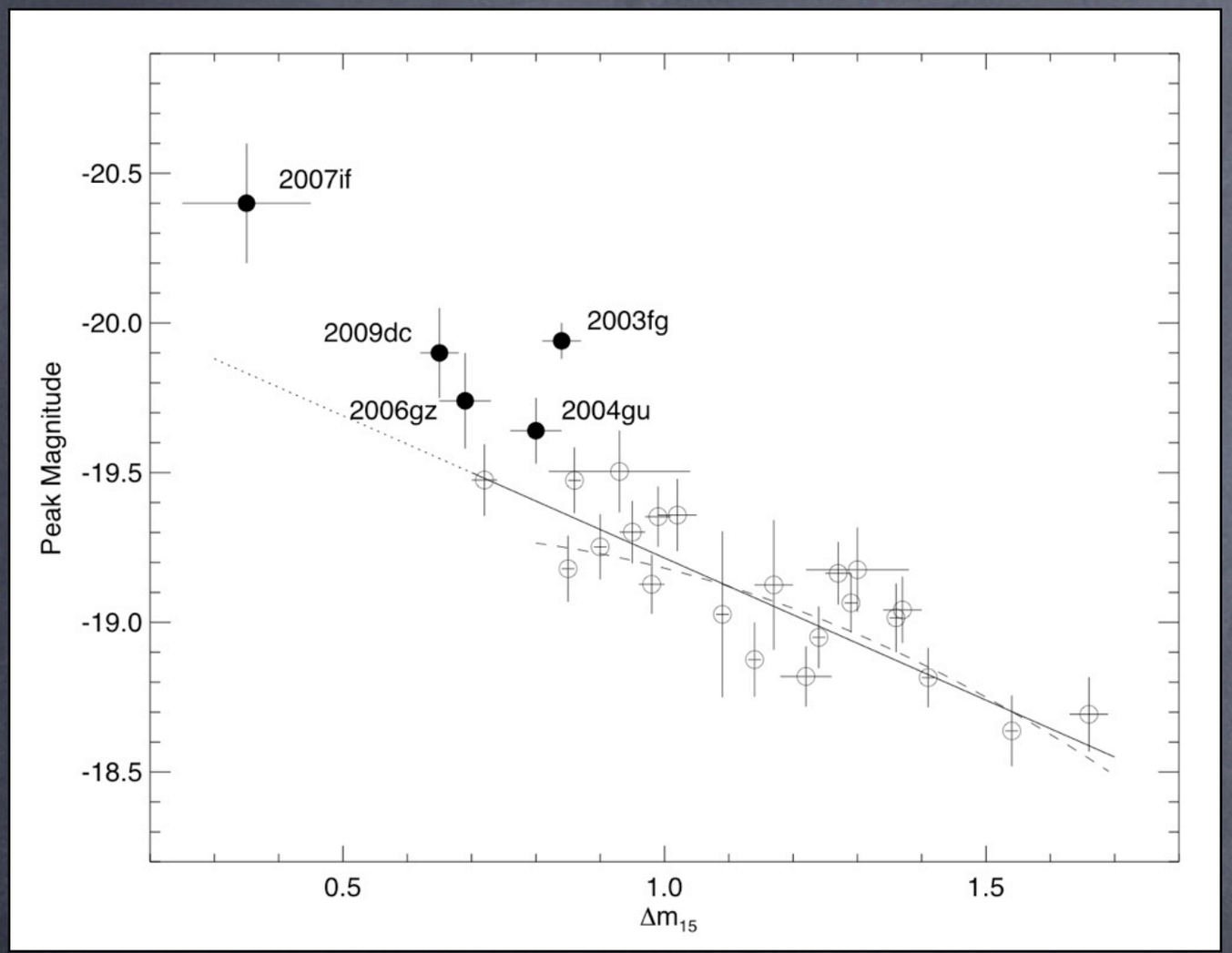
Valenti, Pastorello et al. 2009, Nature, 459, 674

^{56}Ni masses in faint SNe

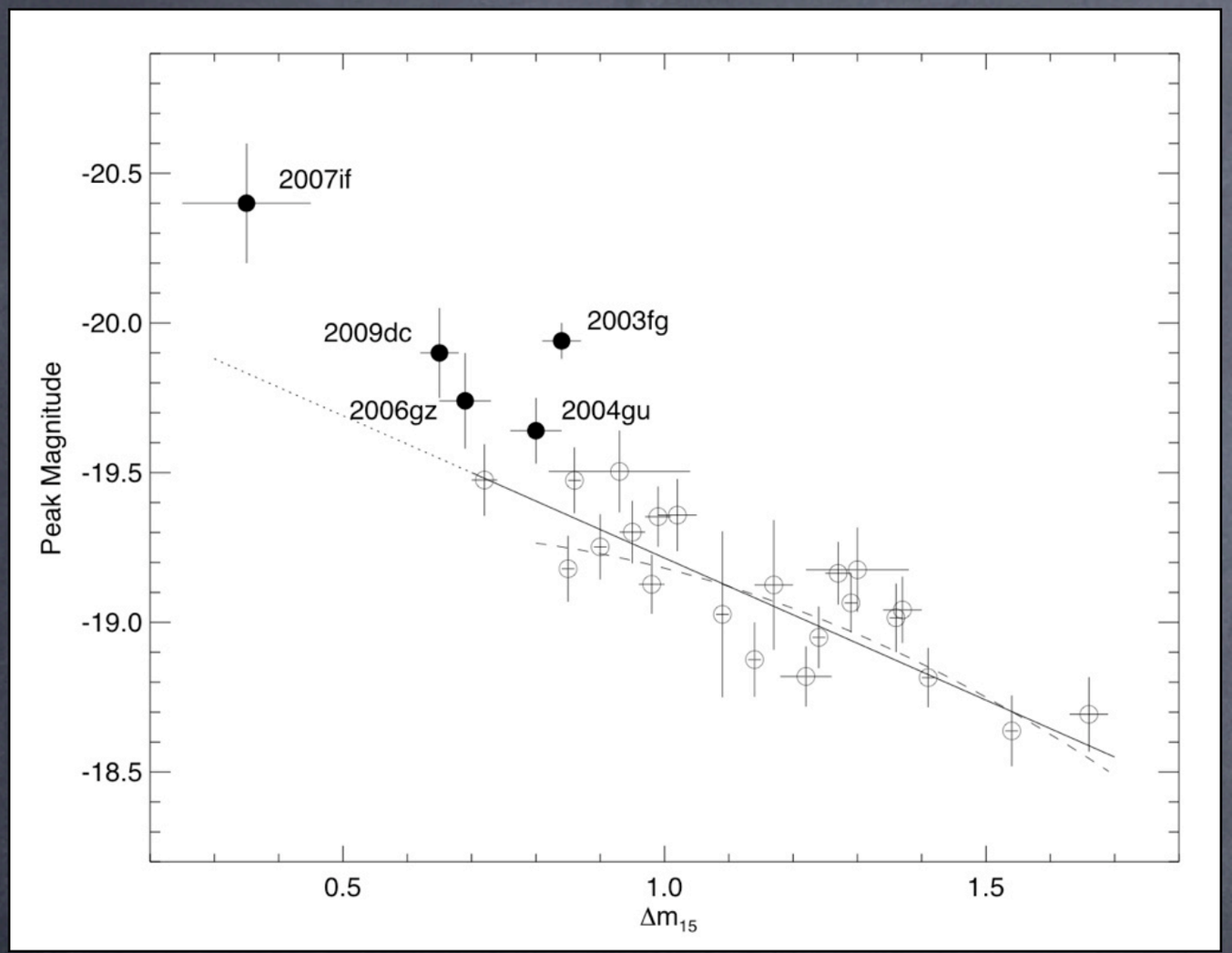
- LL SNe IIP: 2-8 x 10^{-3} Mo
  - SN 2005cs: 2-4 x 10^{-3} Mo
  - SN 1999br: 2 x 10^{-3} Mo
- SN 1999ga (IIL): 10^{-2} Mo
- Ultrafaint SNe IIL/n?: $\leq 10^{-3}$ Mo
  - SN 2008S: 1-2 x 10^{-3} Mo
  - NGC300-OT: 8-10 x 10^{-4} Mo
  - M85-OT: < 5 x 10^{-4} Mo
- SN 2005cz (IIb): 5-20 x 10^{-3} Mo
- LL SNe Ib: 3-10x10^{-3} Mo
- SN 2008ha (Ia/c): 2-5 x 10^{-3} Mo
- 2002cx-like: a few x 10^{-2} Mo

Ultra-luminous Supernovae

Super-Chandrasekhar Mass Type Ia SNe?

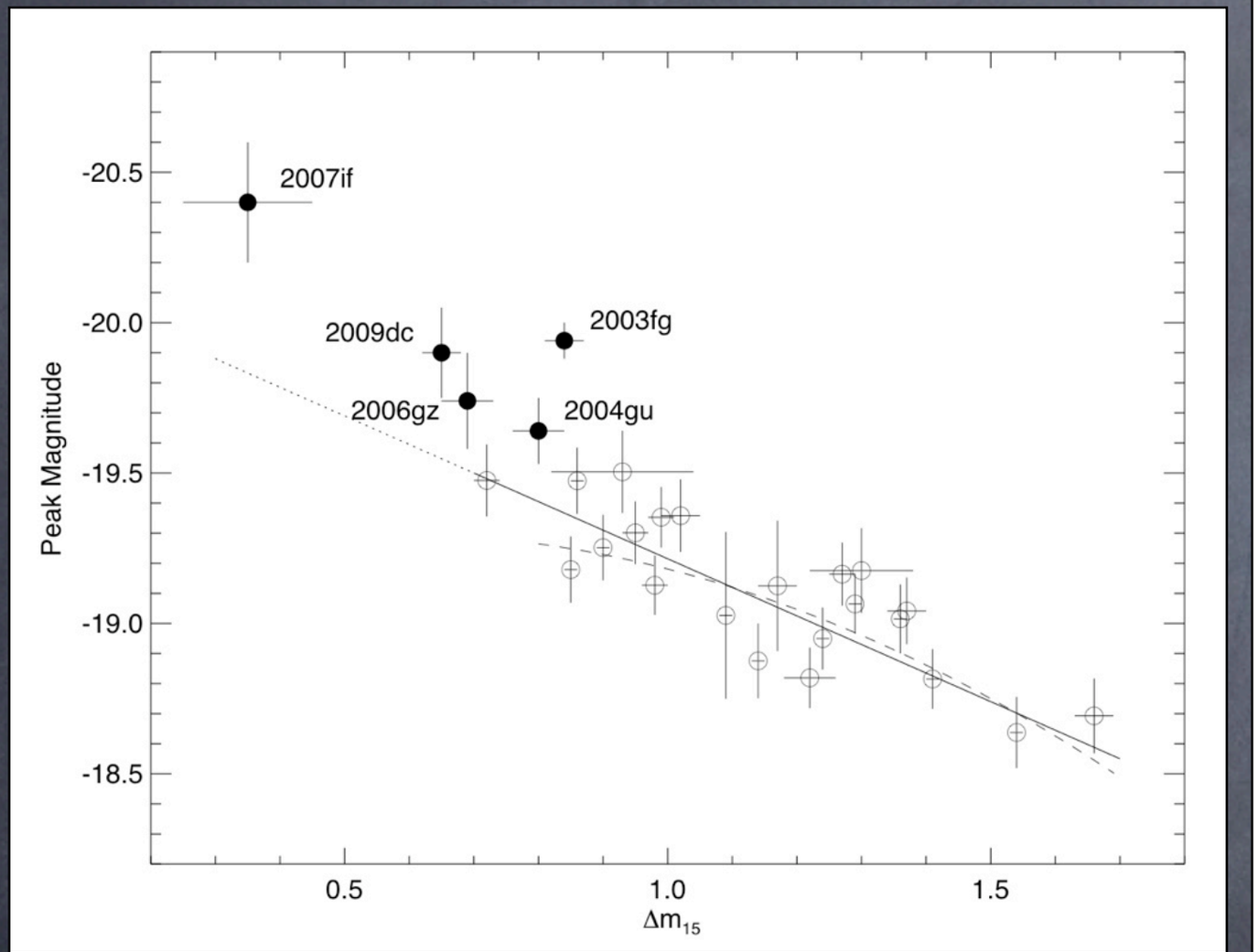


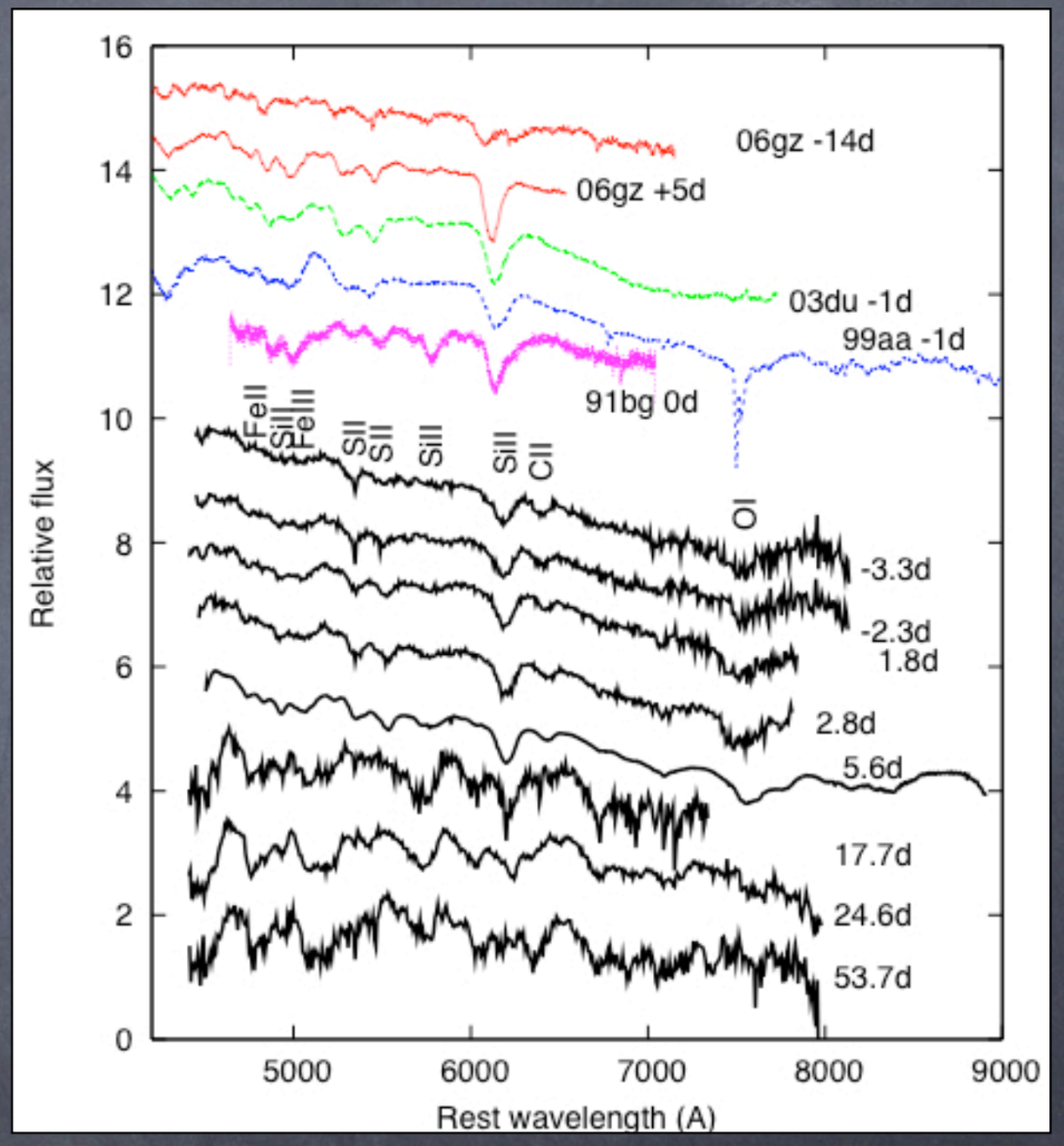
Super-Chandrasekhar Mass Type Ia SNe?



Howell et al. 2006, Nature, 443, 308; Hillebrandt et al. 2007, A&A, 465, L17; Hicken et al. 2007, ApJ, 669, L17; Maeda et al. 2009; ApJ, 702, 686; Chen & Li 2009, ApJ, 702, 686; Yamanaka et al. 2009; ApJ, 707, L118; Tanaka et al. 2010, ApJ, 714, 1209; Scalzo et al. 2010, ApJ, 713, 1073; Silverman et al. 2010 (arXiv:1003:2417); Yuan et al. 2010; ApJ, 715, 1338

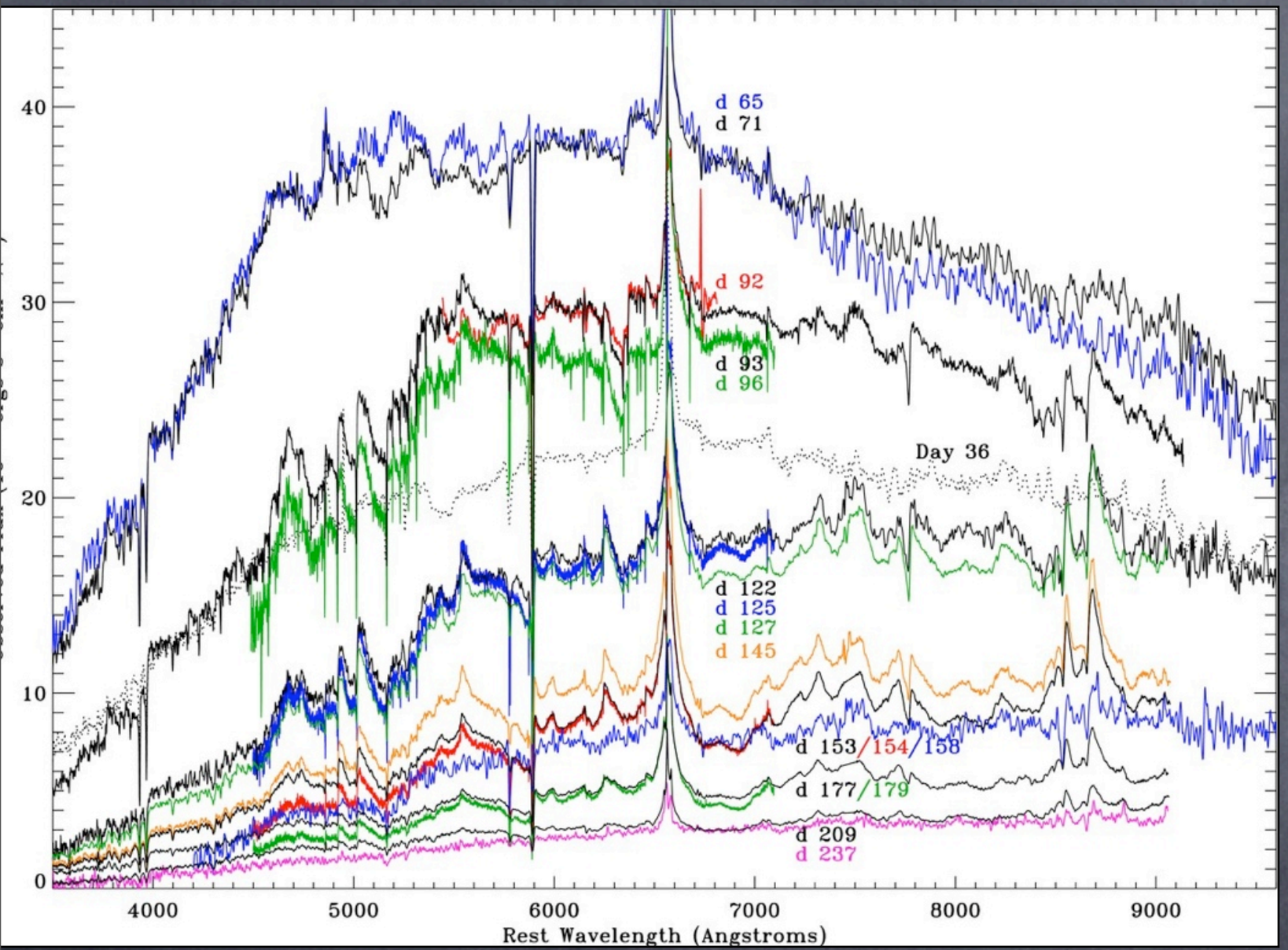
Super-Chandrasekhar Mass Type Ia SNe?





Howell et al. 2006, Nature, 443, 308; Hillebrandt et al. 2007, A&A, 465, L17; Hicken et al. 2007, ApJ, 669, L17; Maeda et al. 2009; ApJ, 702, 686; Chen & Li 2009, ApJ, 702, 686; Yamanaka et al. 2009; ApJ, 707, L118; Tanaka et al. 2010, ApJ, 714, 1209; Scalzo et al. 2010, ApJ, 713, 1073; Silverman et al. 2010 (arXiv:1003:2417); Yuan et al. 2010; ApJ, 715, 1338

SN 2006gy and bright IIn events



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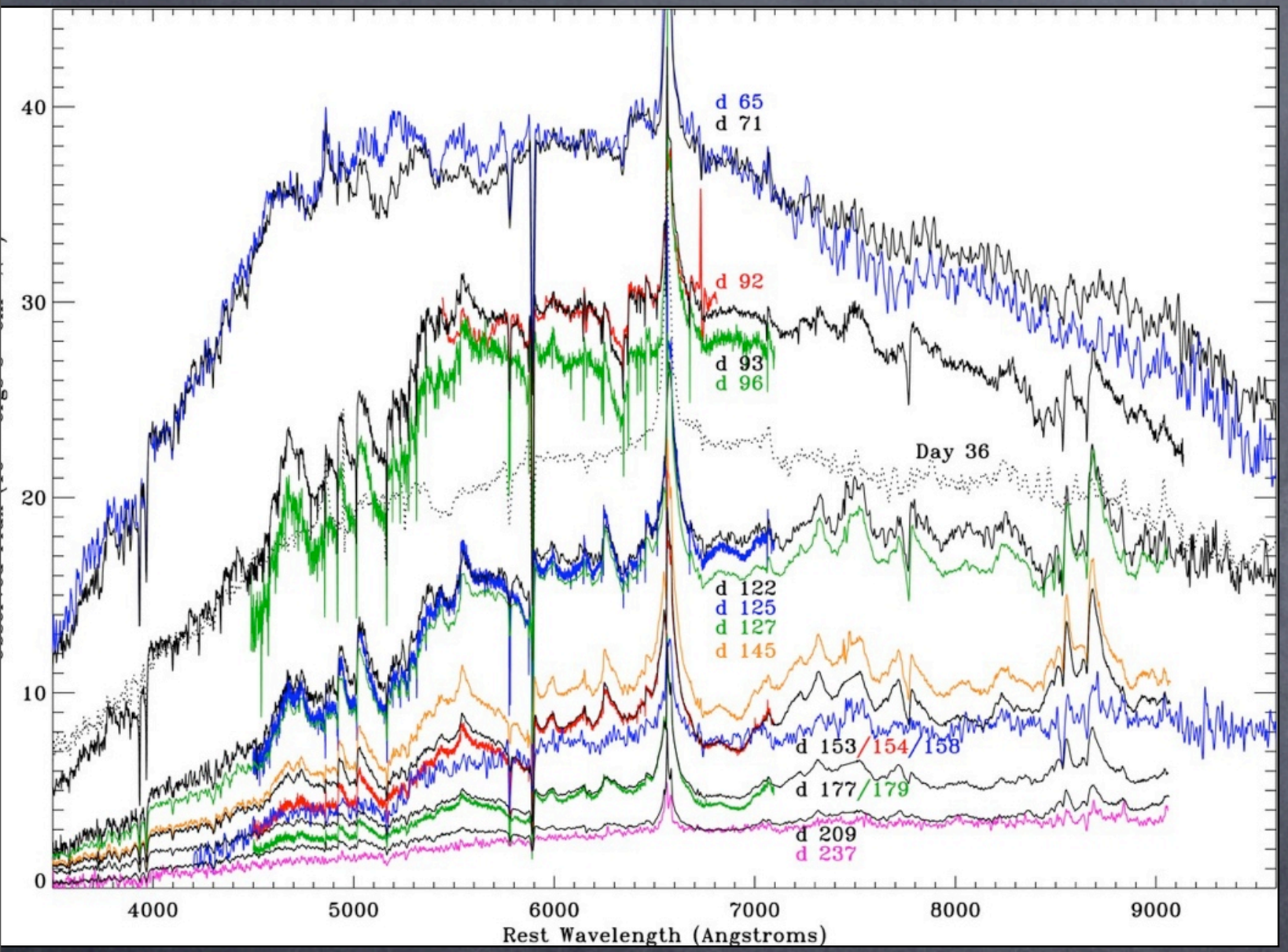

Smith et al. 2007, 2008, 2010; see also Ofek et al. 2007

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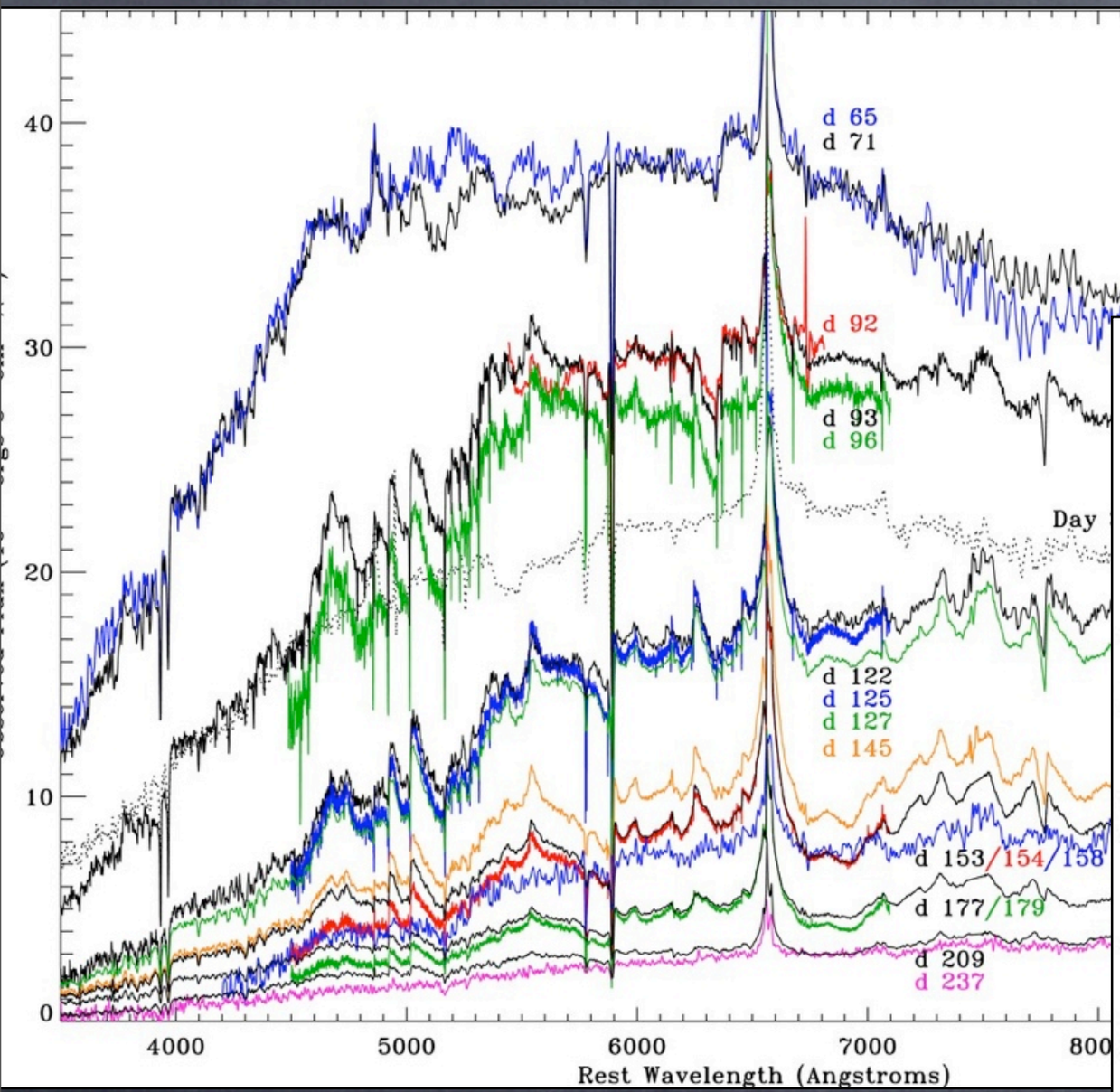
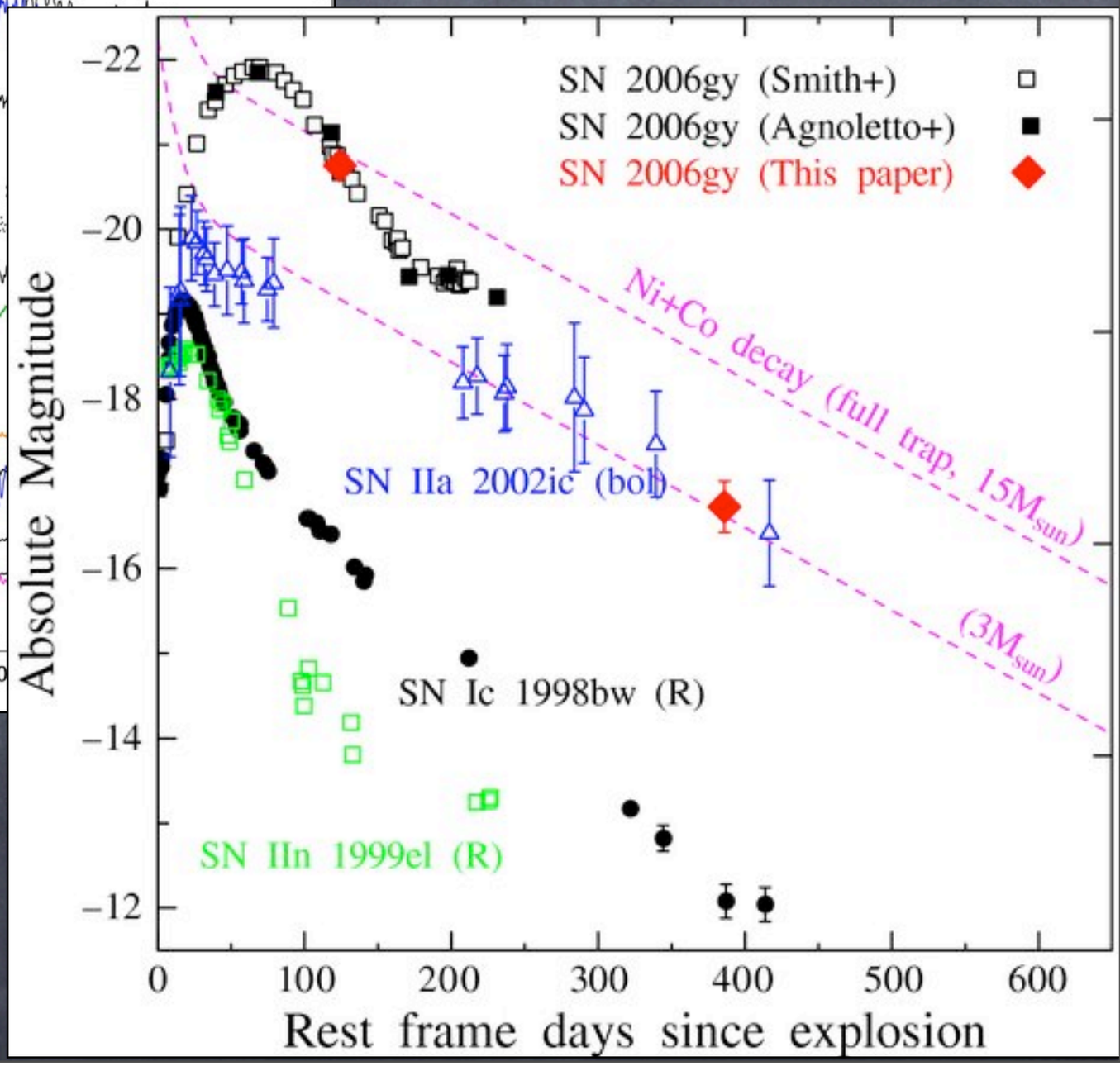
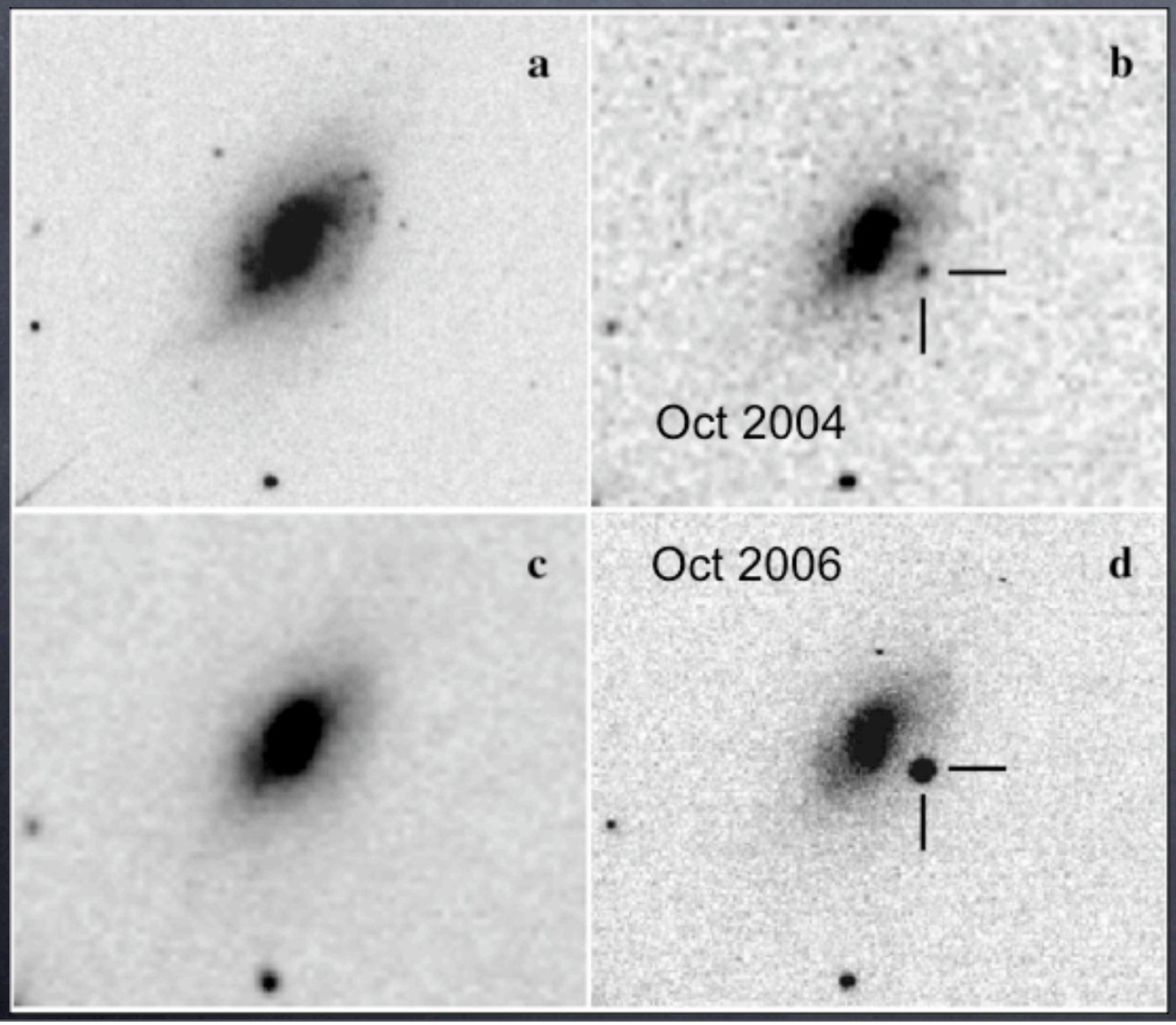


Kawabata et al. 2009, see also
Agnoletto et al. 2009
Alternative model (Pulsational PI):
see Woolsey et al. 2007



SN 2006jc and type Ibn SNe



Pastorello et al. 2007, Nature, 447, 829

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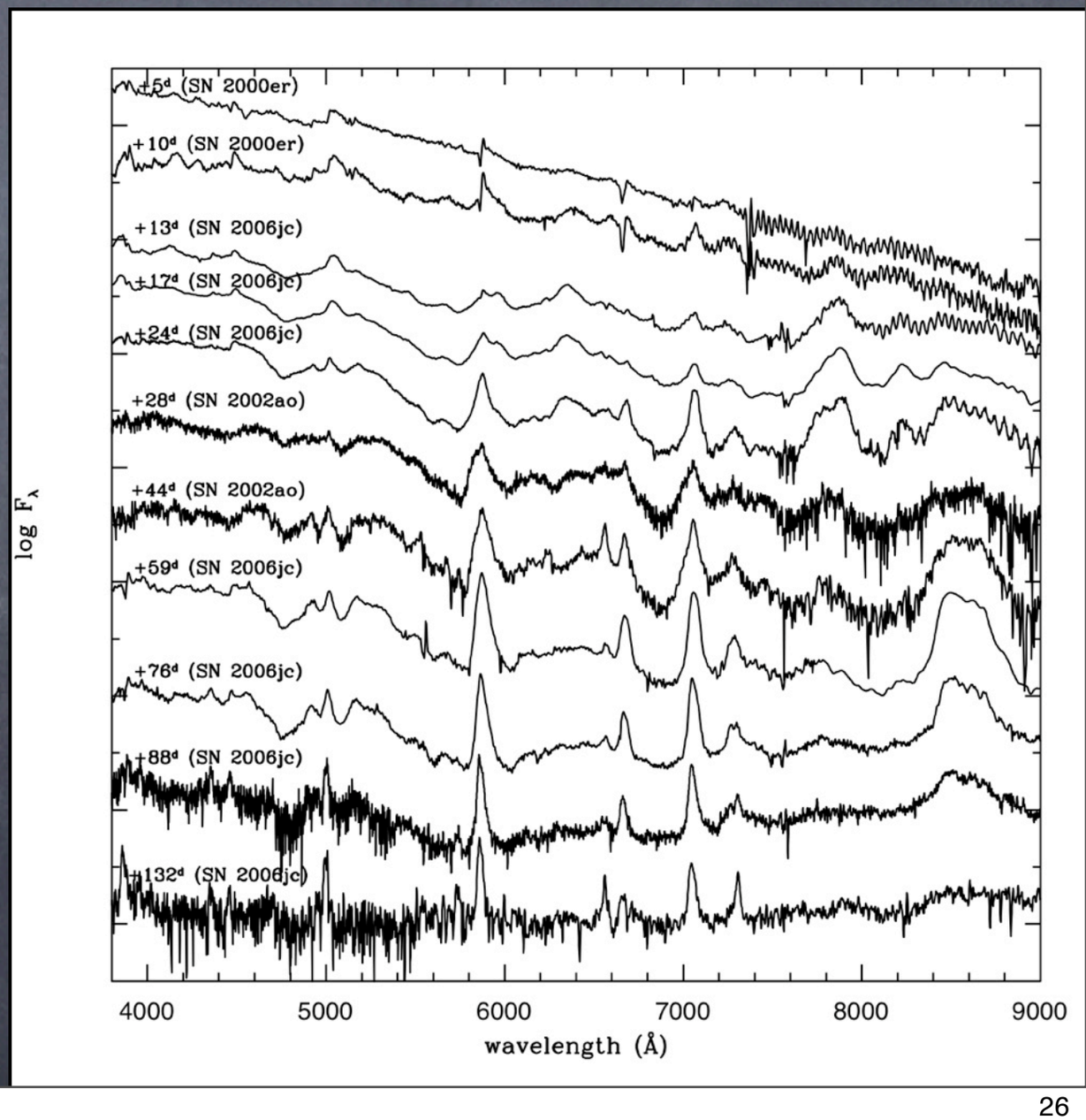
Pastorello et al. 2007, Nature, 447, 829; Foley et al. 2007, ApJ, 657, L105; Smith et al. 2008, ApJ, 680, 568; Pastorello et al. 2008a, MNRAS, 389, 113; Pastorello et al. 2008b, MNRAS, 389, 131; Mattila et al. 2008, MNRAS, 389, 141; Immler et al. 2008, ApJ, 674, L85; Di Carlo et al. 2008, ApJ, 684, 471; Nozawa et al., 2008, ApJ, 684, 1343; Tominaga et al. 2008, ApJ, 687, 1208; Anupama et al. 2009, MNRAS, 392, 894; Sakon et al. 2009, ApJ, 692, 546; Chugai 2009, MNRAS, 400, 866



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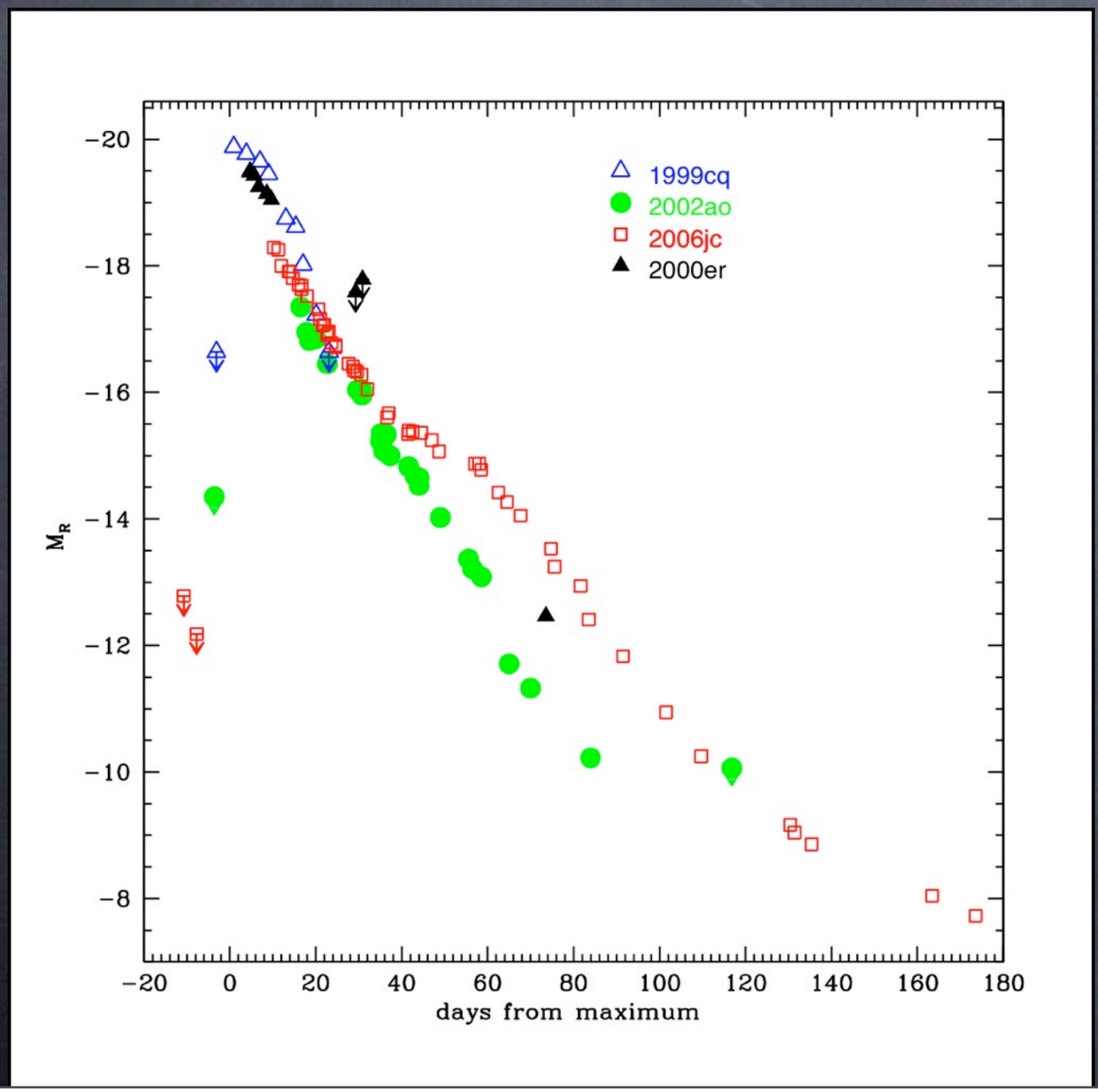
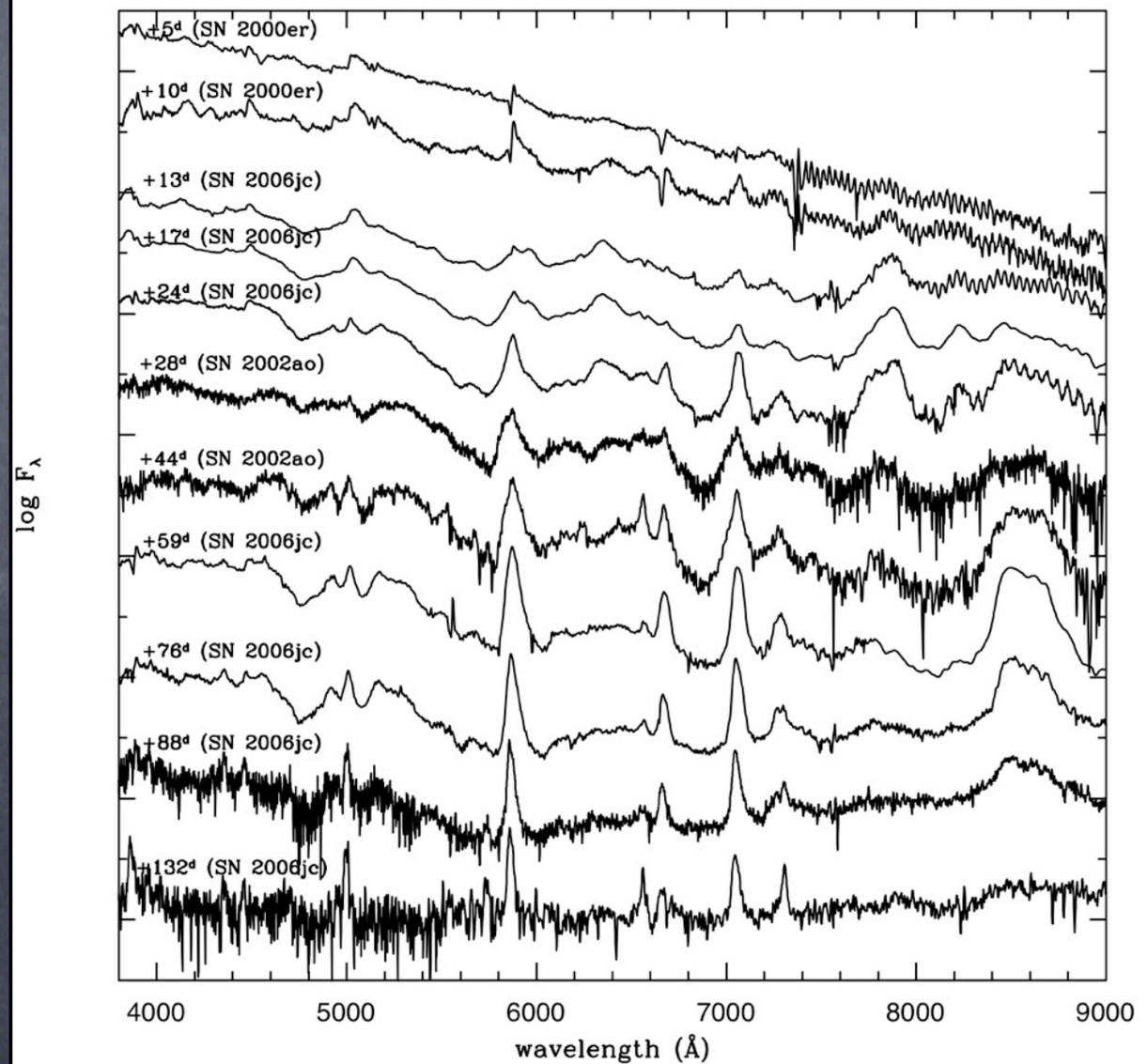
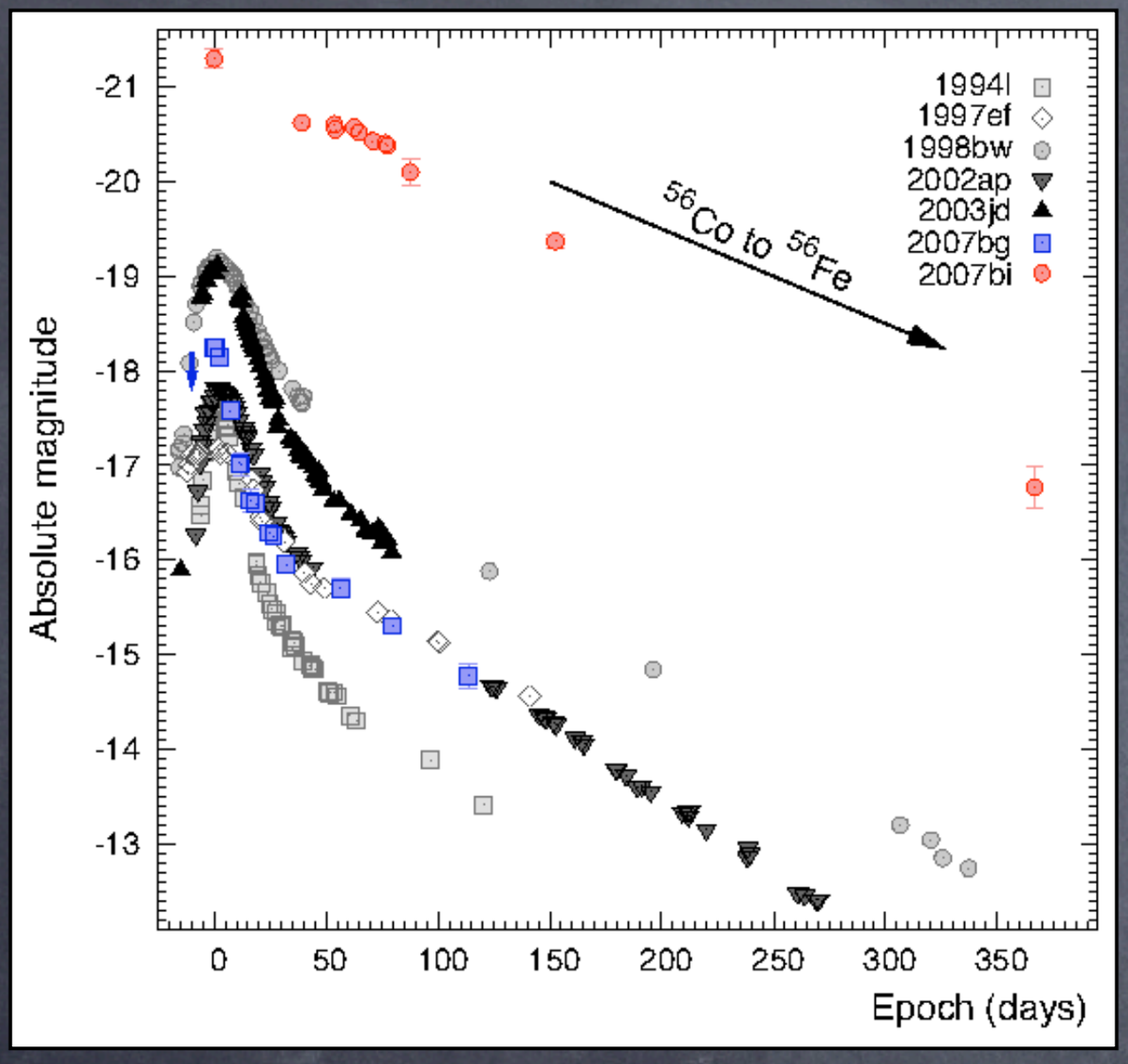
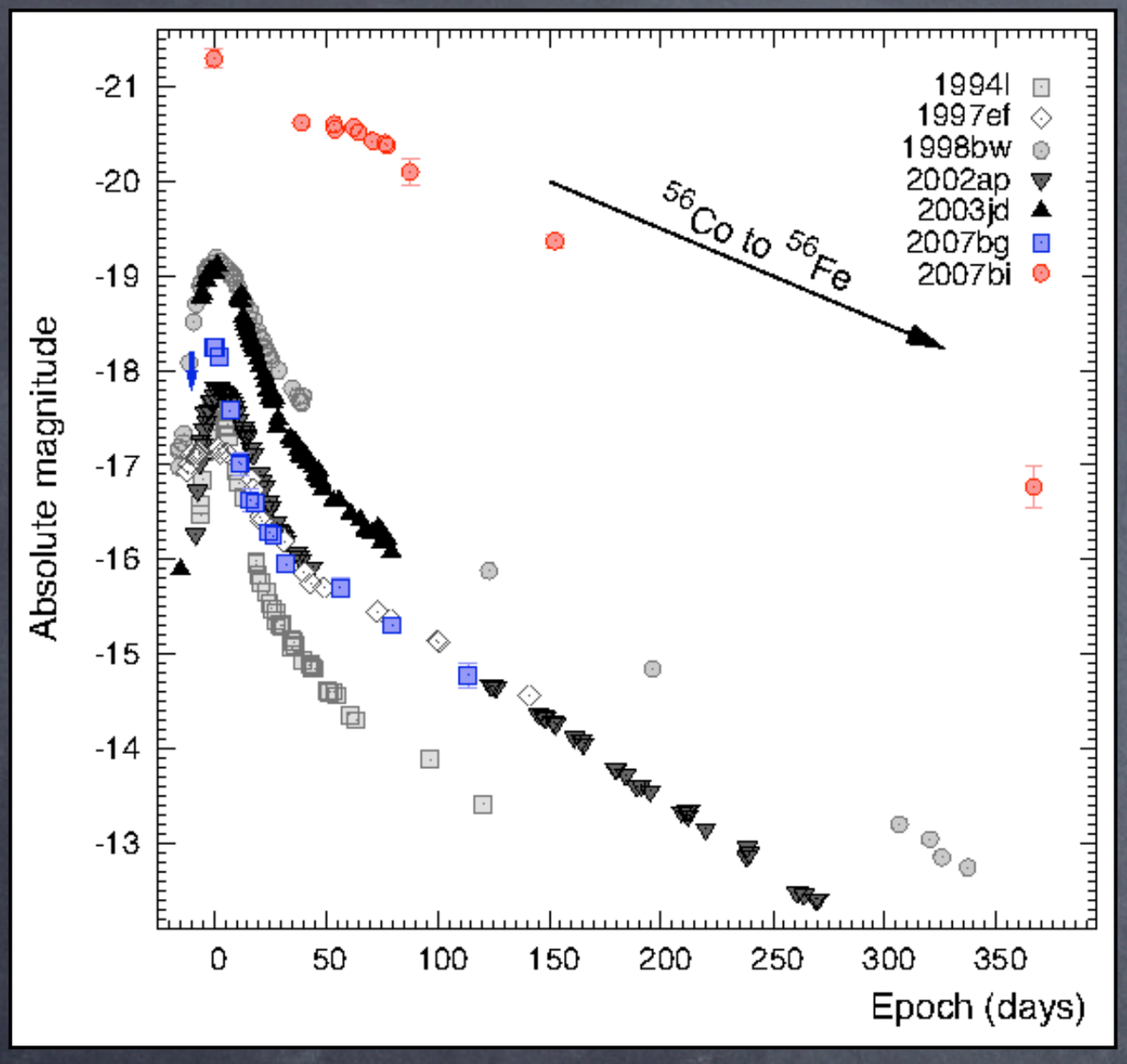




SN Ic 2007bi: the first pair-instability SN?



SN Ic 2007bi: the first pair-instability SN?



Gal-Yam et al. 2009, Nature, 462, 624; Young et al. 2010, A&A, 512, 70; see also Moriya et al. 2010, ApJ, in press (arXiv: 1004.2967) for an alternative CC SN model

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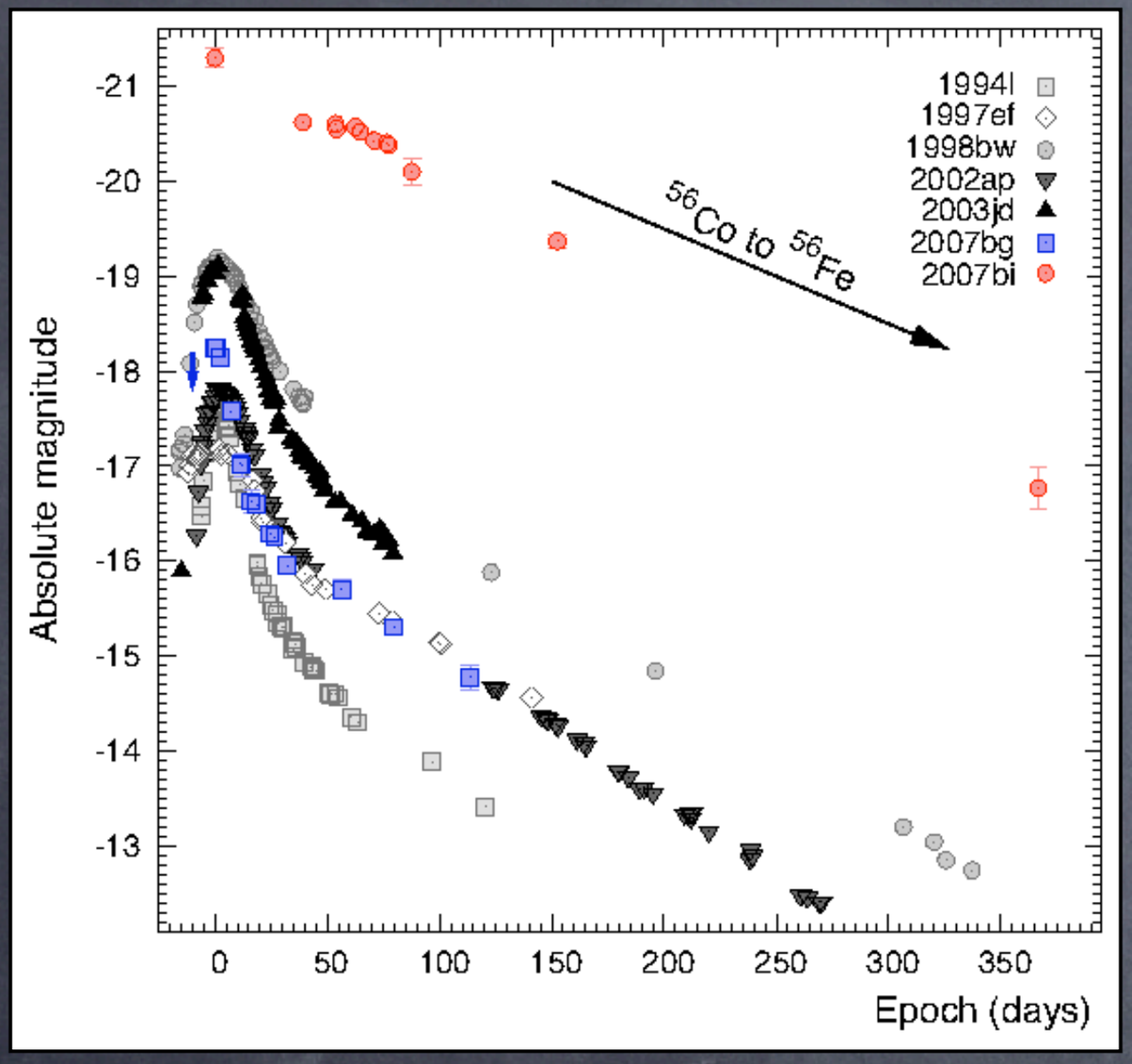

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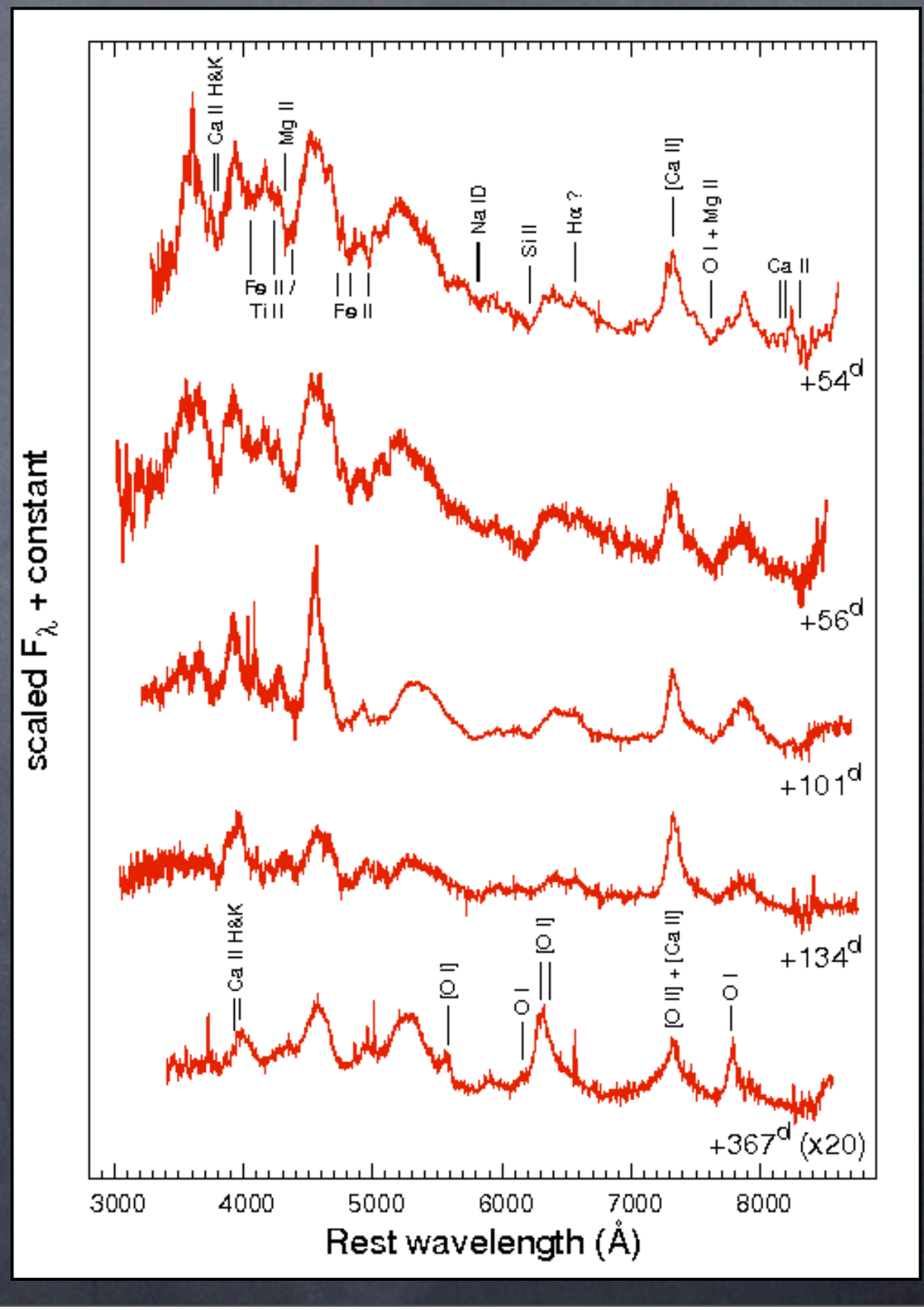
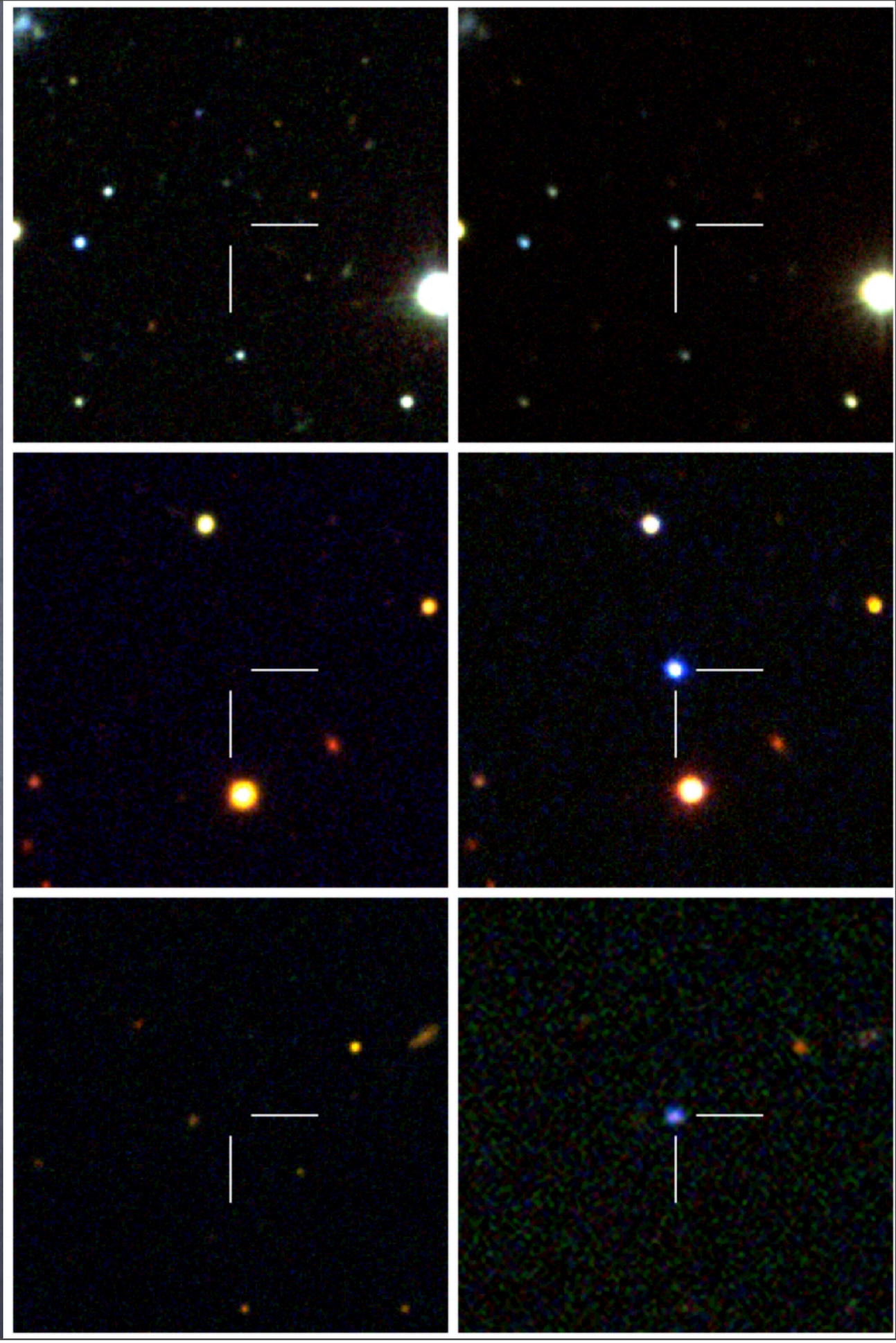


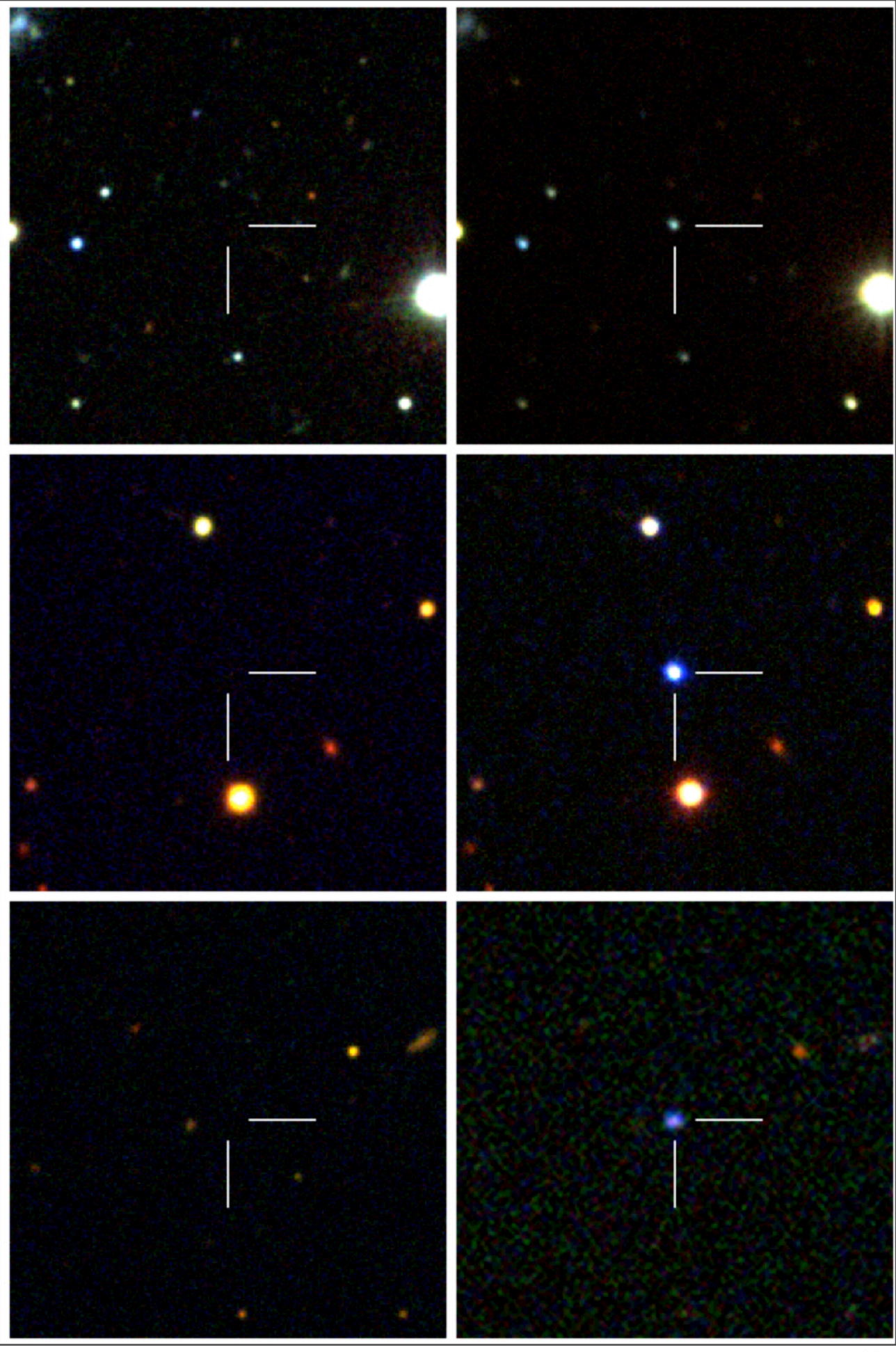
An enigmatic family of transients: 2005ap & SCP 06F6 (et similia)



An enigmatic family of transients: 2005ap & SCP 06F6 (et similia)

Galactic explosions vs. extra-galactic transients (high-z, M=-22/-23, like pulsational pair-instability outbursts, SN ejecta-CSM interaction or PISNe...)

Barbary et al. 2009, ApJ, 690, 1358
Gansicke et al. 2009, ApJ, 679,L, 129
Chatzopoulos et al. 2009, ApJ, 704, 1251
Quimby et al. 2007, ApJ, 668, L99
Quimby et al. 2010, Nature submitted (arXiv:0910.0059)
Soker et al. 2010 New A., 15, 189



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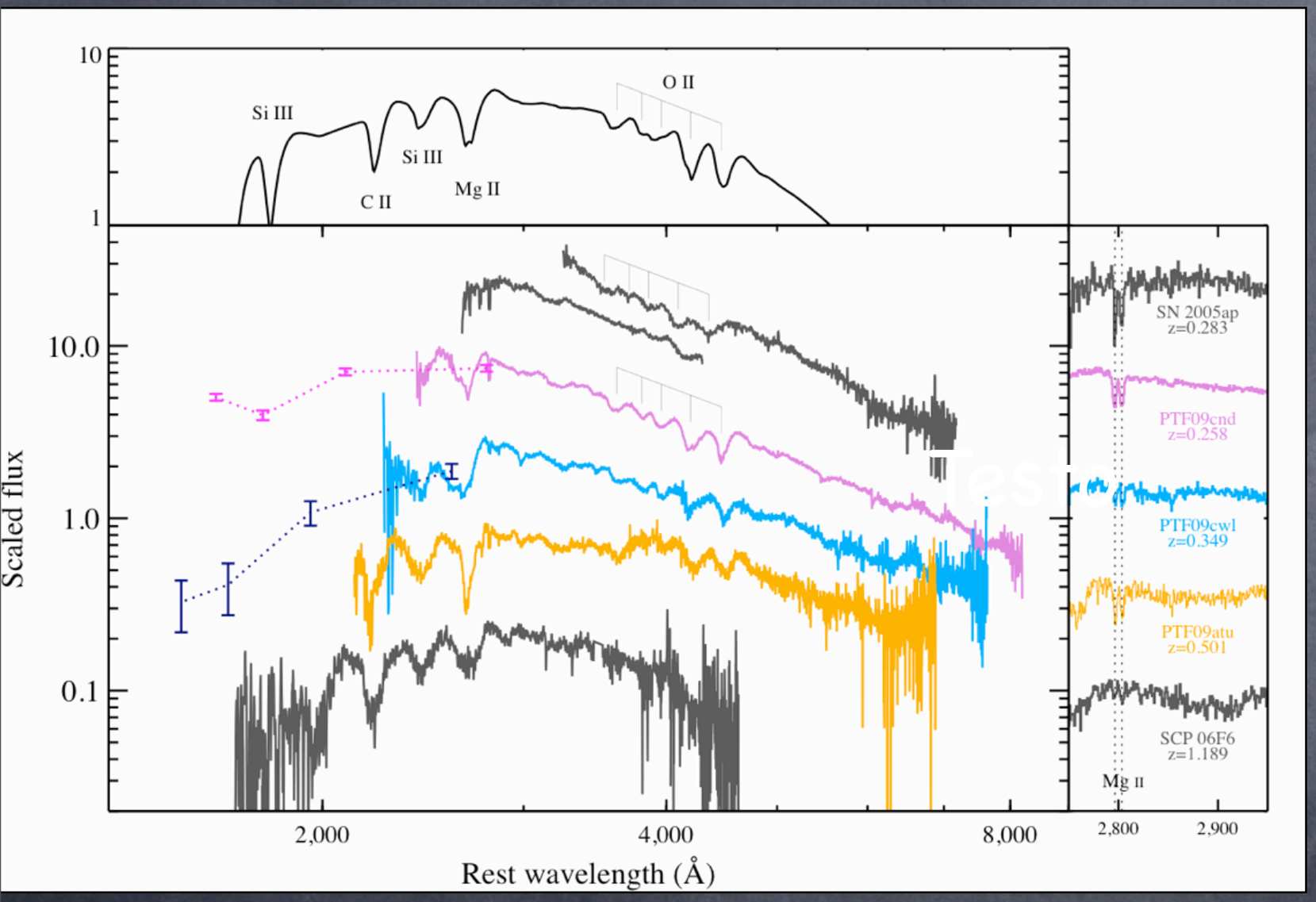
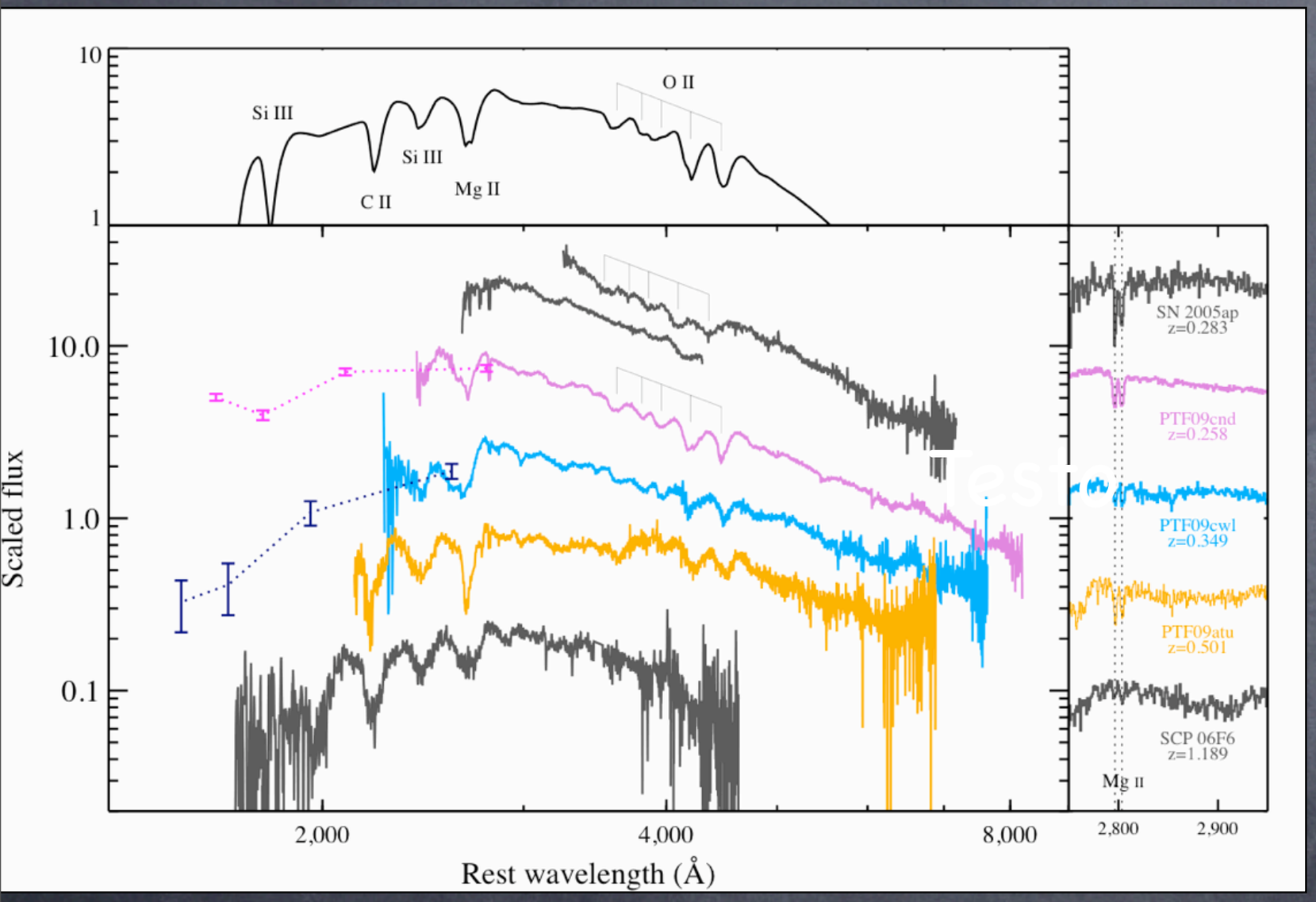
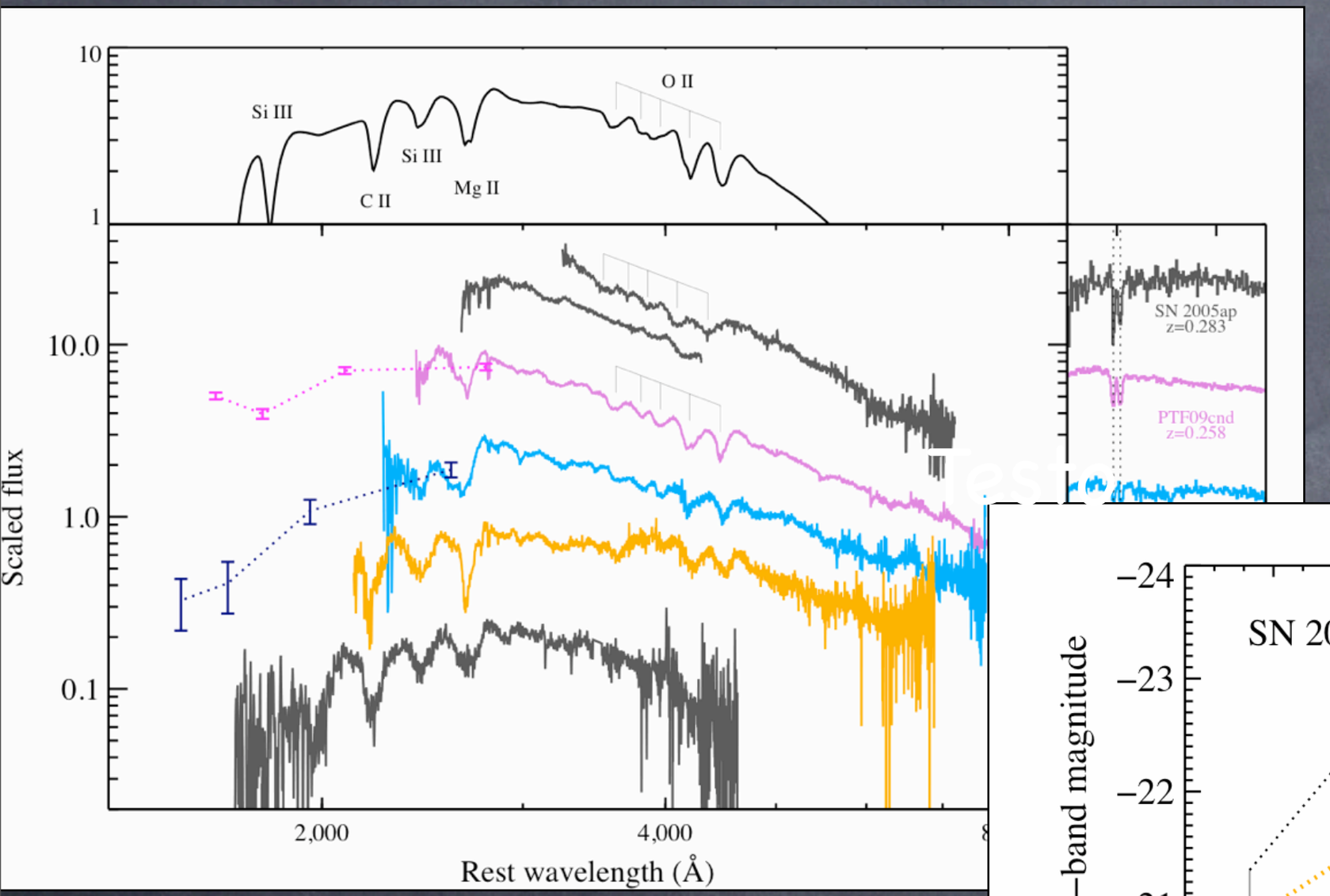


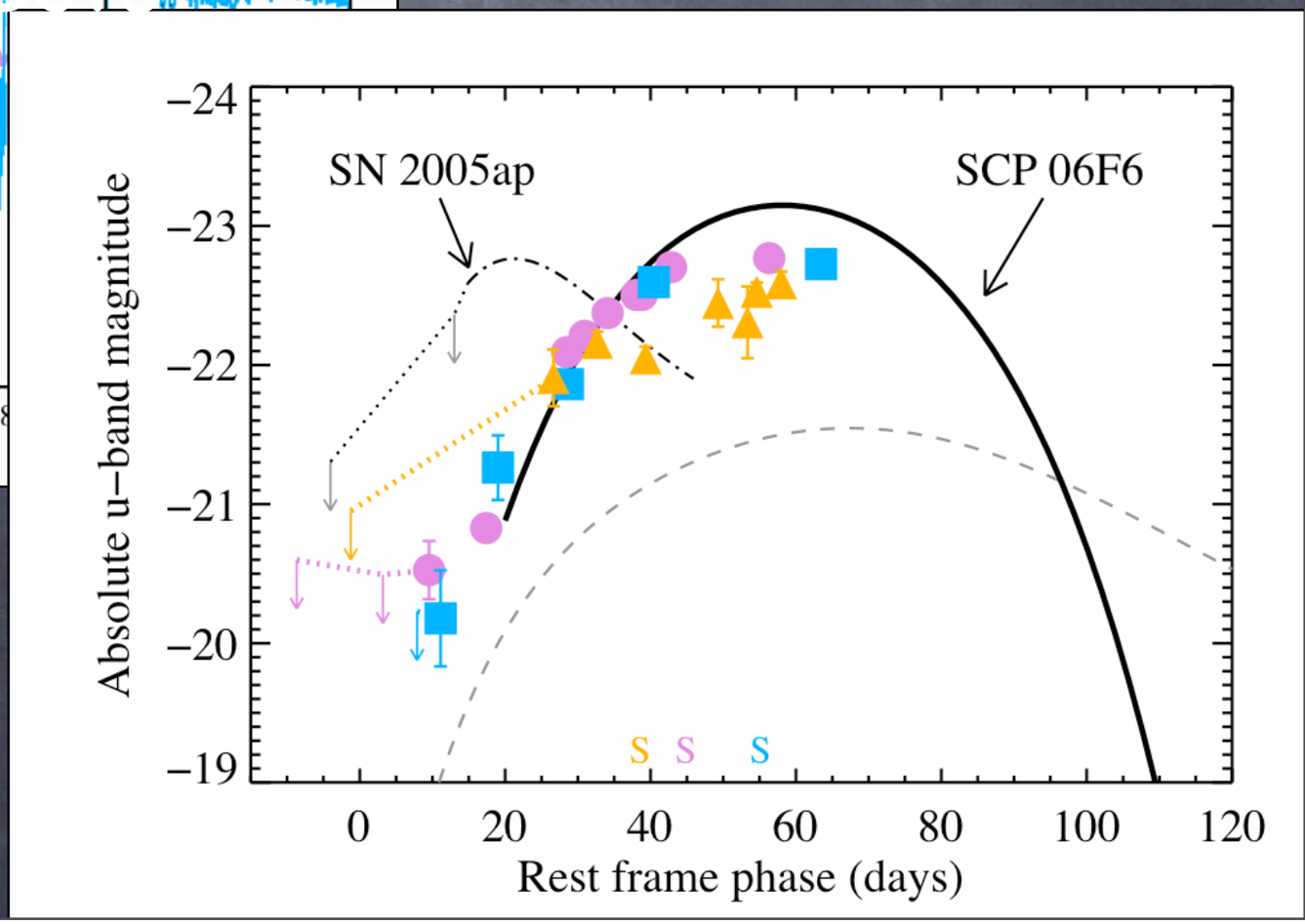
An enigmatic family of transients: 2005ap & SCP 06F6 (et similia)



Quimby et al. 2010, Nature submitted (arXiv:0910.0059)

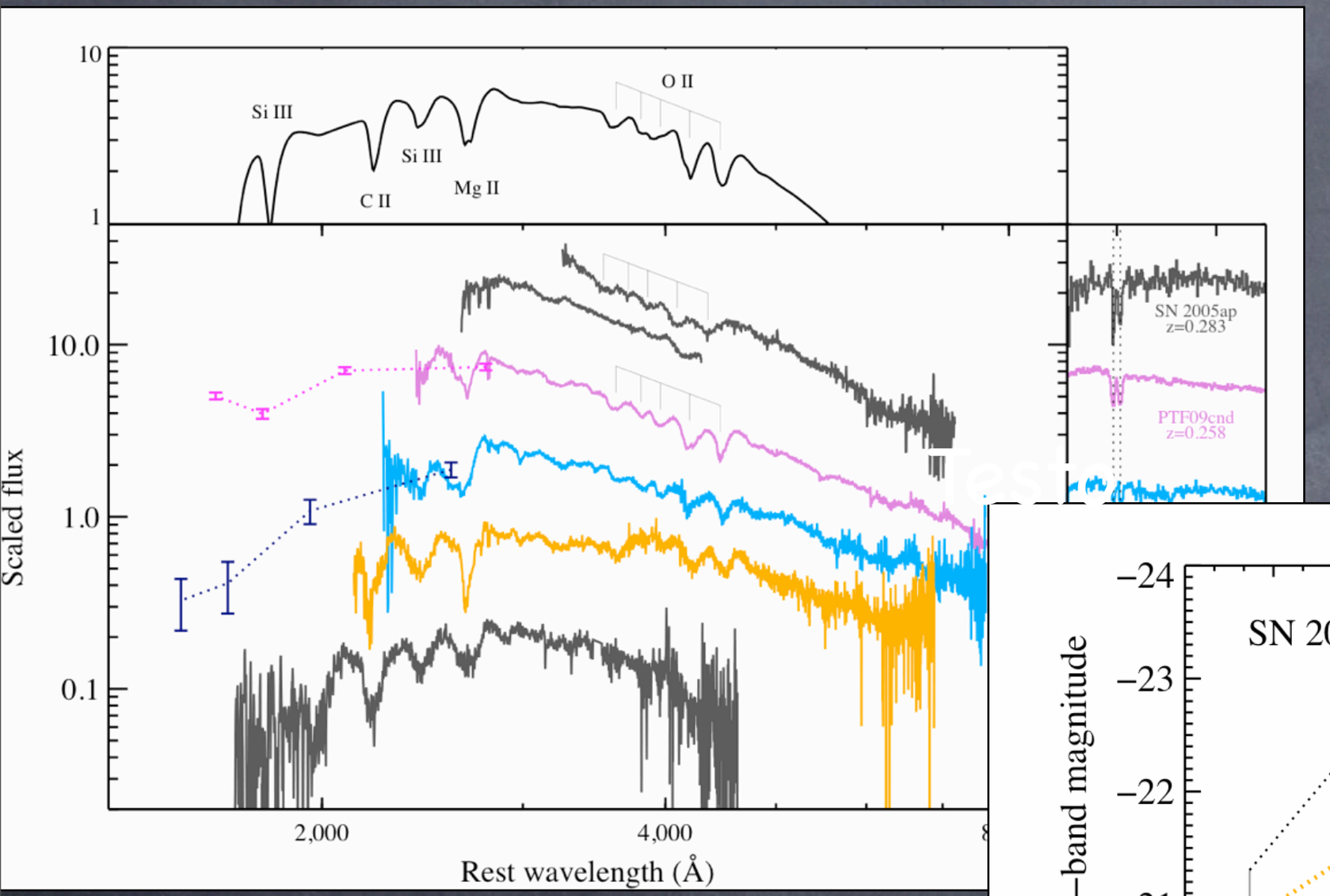
An enigmatic family of transients: 2005ap & SCP 06F6 (et similia)



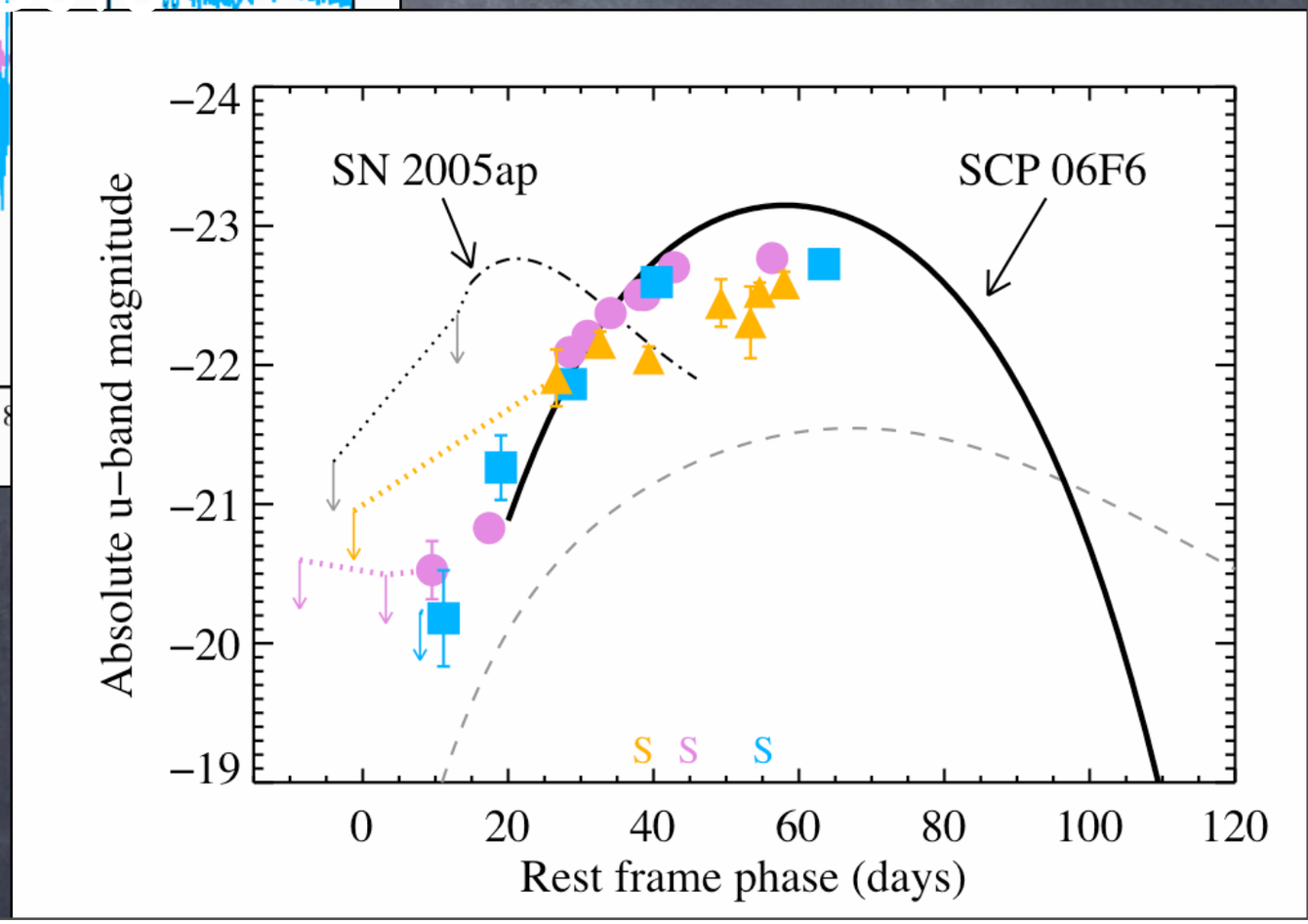


Quimby et al. 2010, Nature submitted (arXiv:0910.0059)

An enigmatic family of transients: 2005ap & SCP 06F6 (et similia)



Pulsational pair-instability?



Quimby et al. 2010, Nature submitted (arXiv:0910.0059)

Summary

NEW RESULTS from recent surveys

1) Discovery of new types of stellar explosions

2) Low- and high-luminosity tails in the luminosity distribution do probably exist for all SN types!

3) CCSNe (and probaly even type Ias) span 3-4 orders of mag in ^{56}Ni masses

=> These discoveries are revolutionizing our knowledge on how massive stars end their lives