

# Observations of Unusual Supernovae

Preliminary results with XShooter

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Queen's University Belfast

Como - October 19-22, 2010

# Collaborators

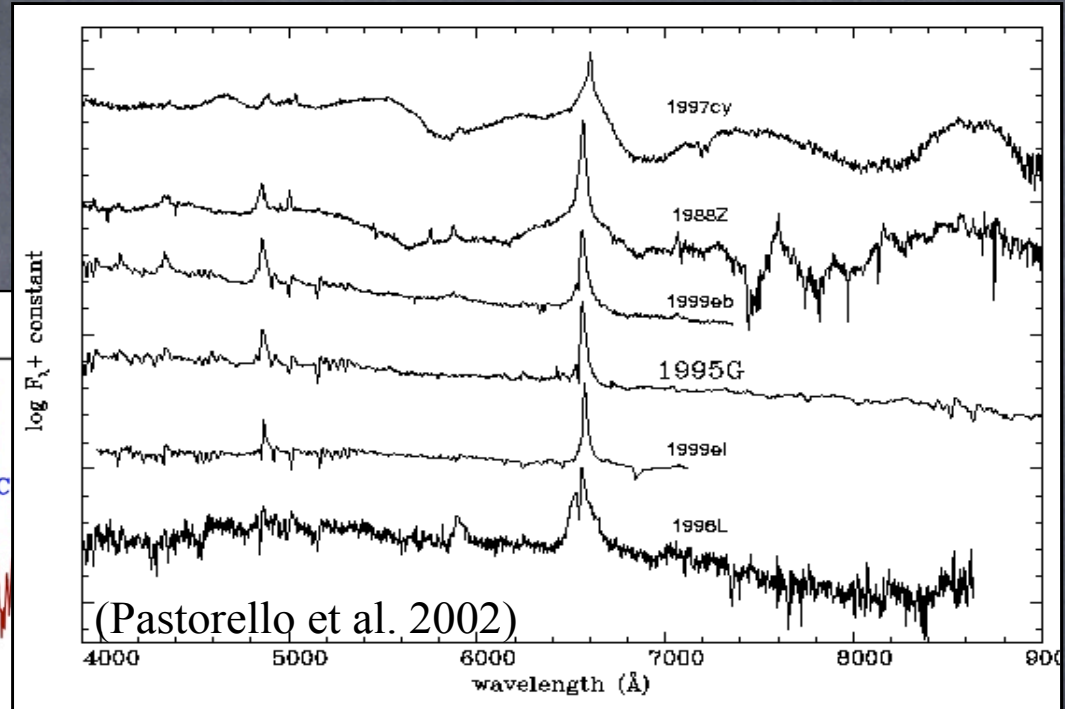
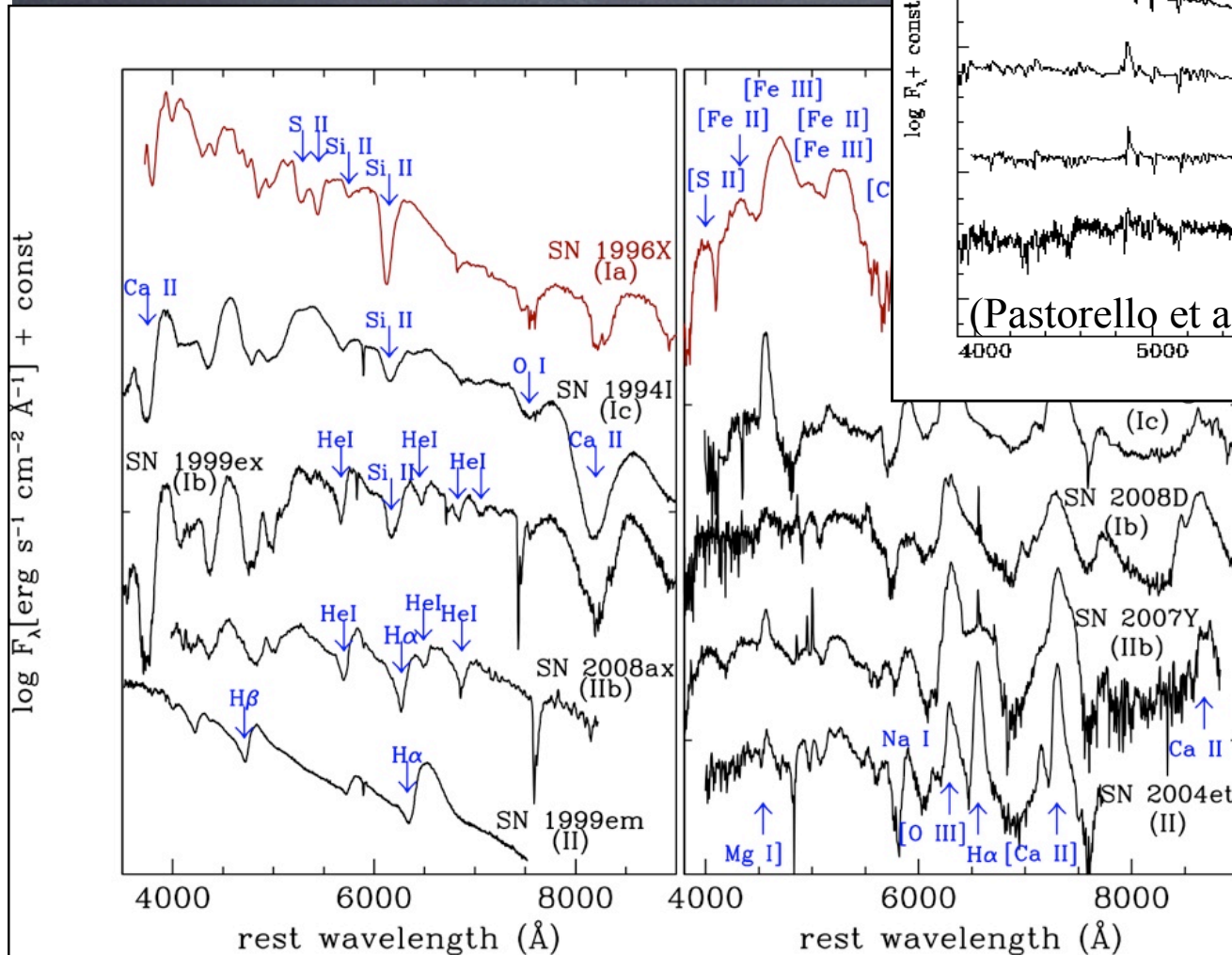
(ESO-NTT Large Program: "Supernova Variety and Nucleosynthesis Yields" – P.I. S. Benetti)

- OAPD/CT/TS ([Benetti](#), Bufano, Turatto, Cappellaro, Zampieri, Pumo, Inserra, Miluzio, Agnoletto, Navasardyan)
- Queen's University Belfast (Smartt, Kotak, Botticella, Valenti, Fraser, Maguire, Young)
- TNG (Harutyunyan)
- ESO/MPA (Patat, Taubenberger)
- Caltech (Elias-Rosa)
- Stockholm University (Stritzinger, Ergon, Sollerman, Fransson)
- CENTRA Lisbon (Stanishev)
- Turku Observatory (Mattila, Kankare)
- Universidad de Chile / Universidad Andres Bello (Hamuy, Pignata et al.)

# Overview

- Introduction: supernova classification criteria
- Transients in the luminosity gap novae–supernovae: Faint supernovae IIn or supernova impostors?
- Luminous ejecta–CSM interacting supernovae (IIn&Ibn)
- Super–Chandrasekhar mass type Ia supernovae?
- Summary

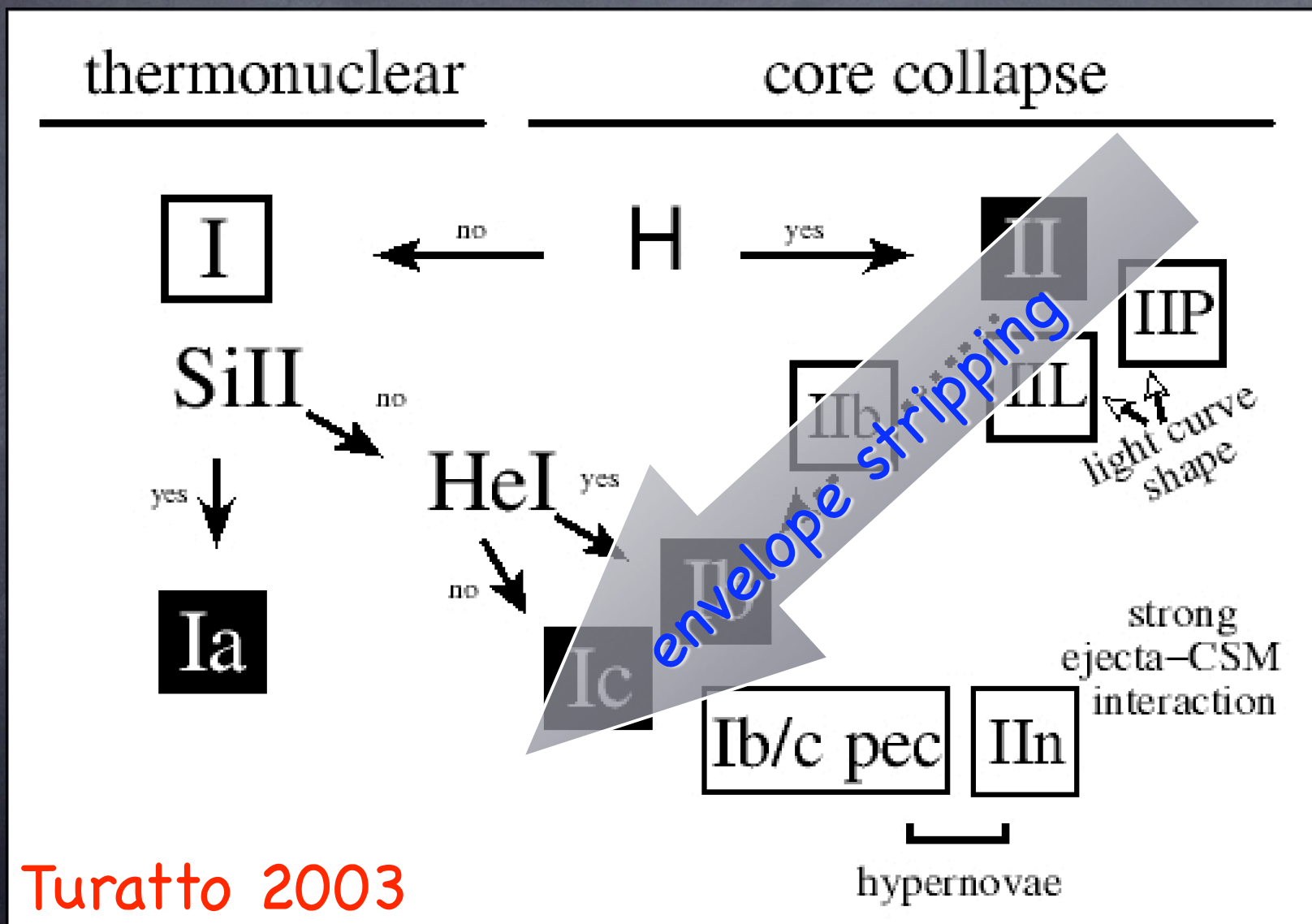
# Traditional SN classification



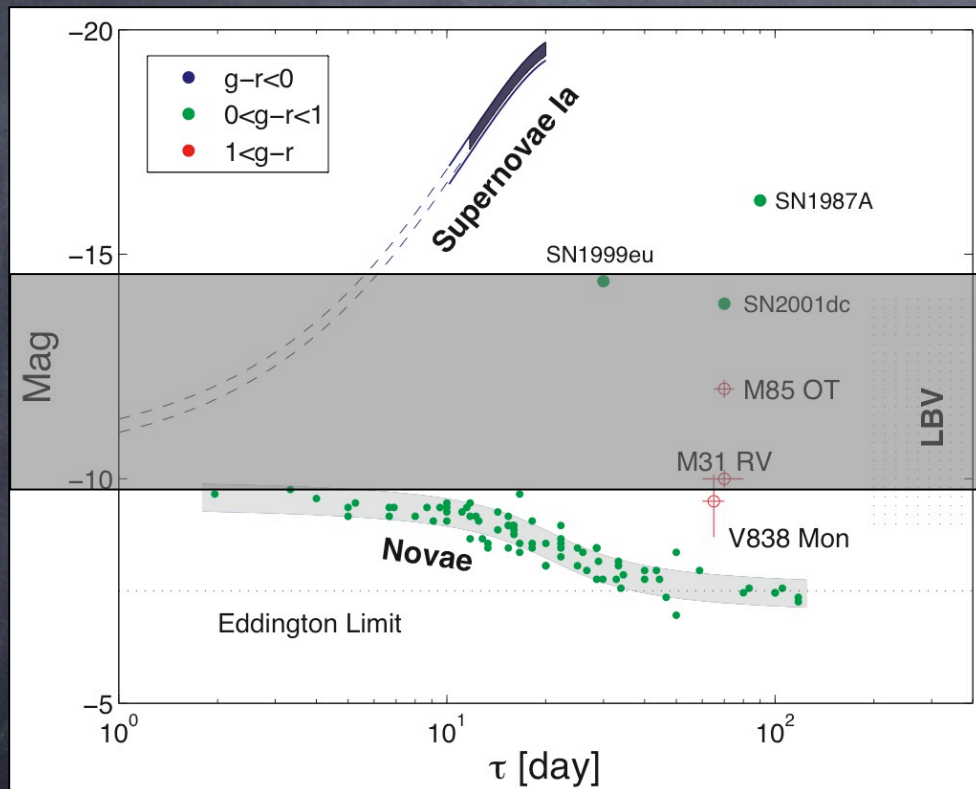
SNe II: SN ejecta & H-rich CSM interaction  
*(Schlegel, 1990)*

*Pastorello 2010*

# Traditional SN classification



# Faint SNe or SN impostors?

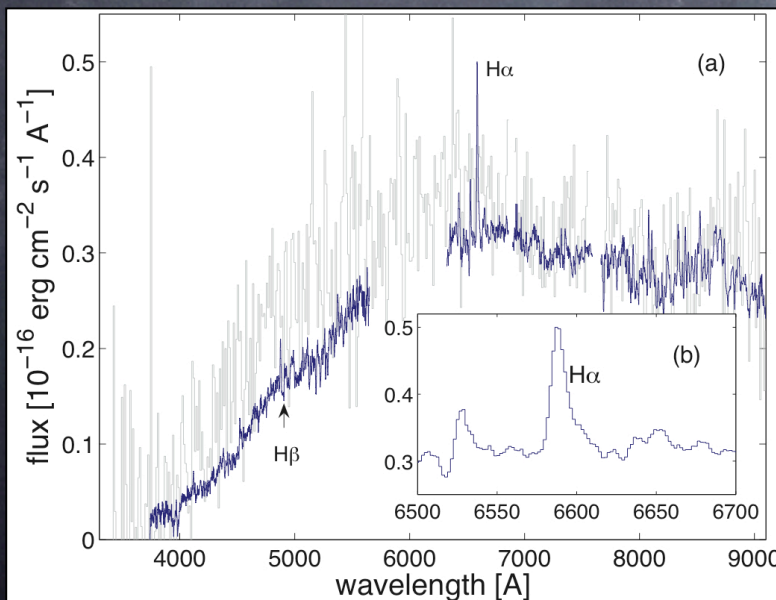
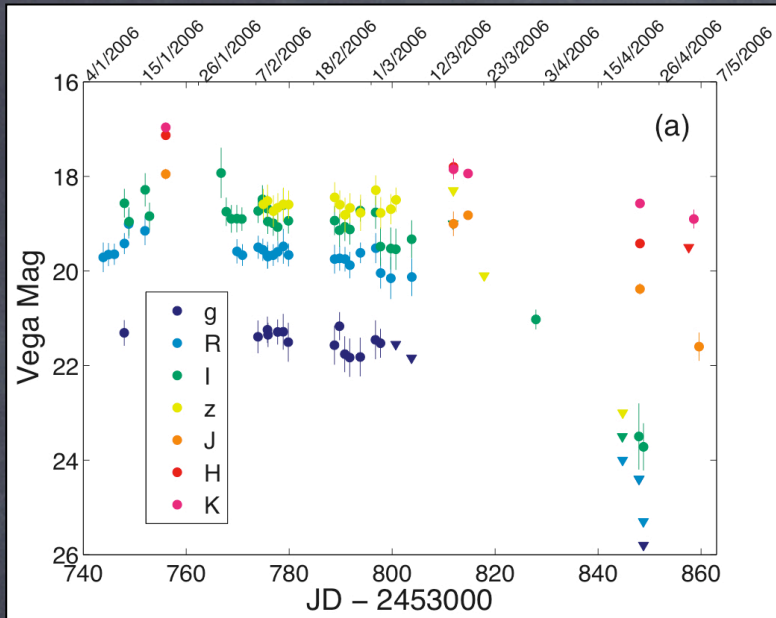


- CC-SNe:  $M < -14$
  - Luminous Novae:  $M > -10$
  - Grey zone:  $-10 > M > -14$
1. Ultra-faint supernovae

SN impostors

Kulkarni et al. 2007, Nature, 447, 458

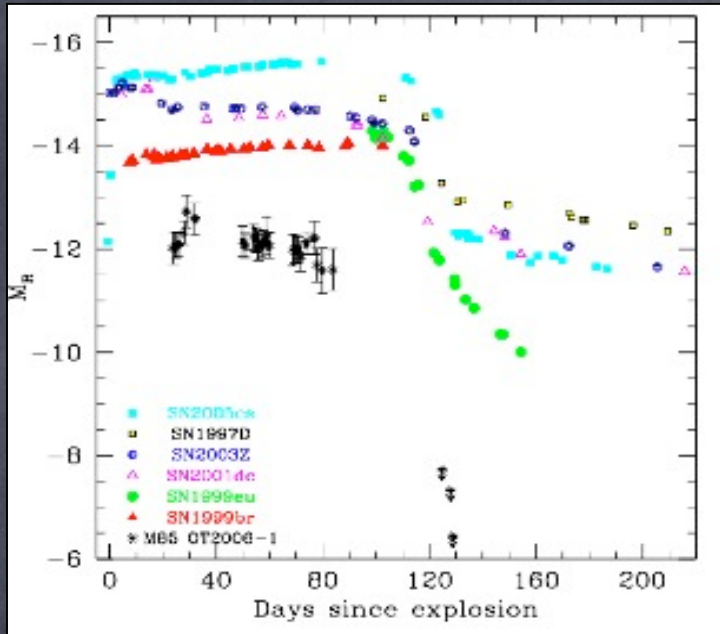
# M85-2006OT



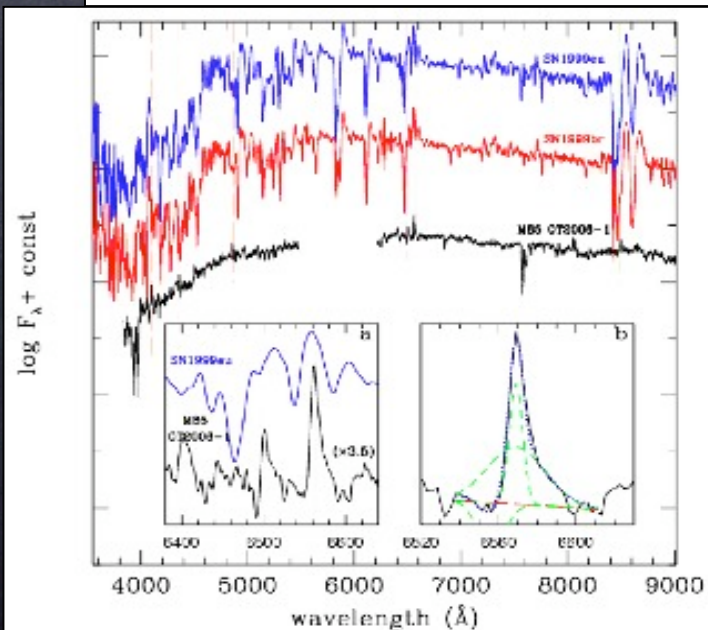
- Modest peak luminosity ( $M_I \sim -13$ )
- Red colour
- Featureless spectrum (only weak, narrow lines of H, CaII, KI, FeII)
- Analogies with V838 Mon, M31 RV, V4332 Sgr ("Luminous Red Novae")
- Old stellar population
- Low mass progenitor

⇒ Exotic outburst from a low-mass ( $<2M_{\odot}$ ) star (stellar merger?)  
(Kulkarni et al. 2007, Nature, 447, 458)

# M85-2006OT



- Modest peak luminosity ( $M_I \sim -13$ )
- Red colour
- Featureless spectrum (only weak, narrow lines of H, CaII, KI, FeII)
- Analogies with subluminous SNe IIP
- Minor star formation in M85
- Relatively high-mass ( $\sim 8M_{\odot}$ ) progenitor?

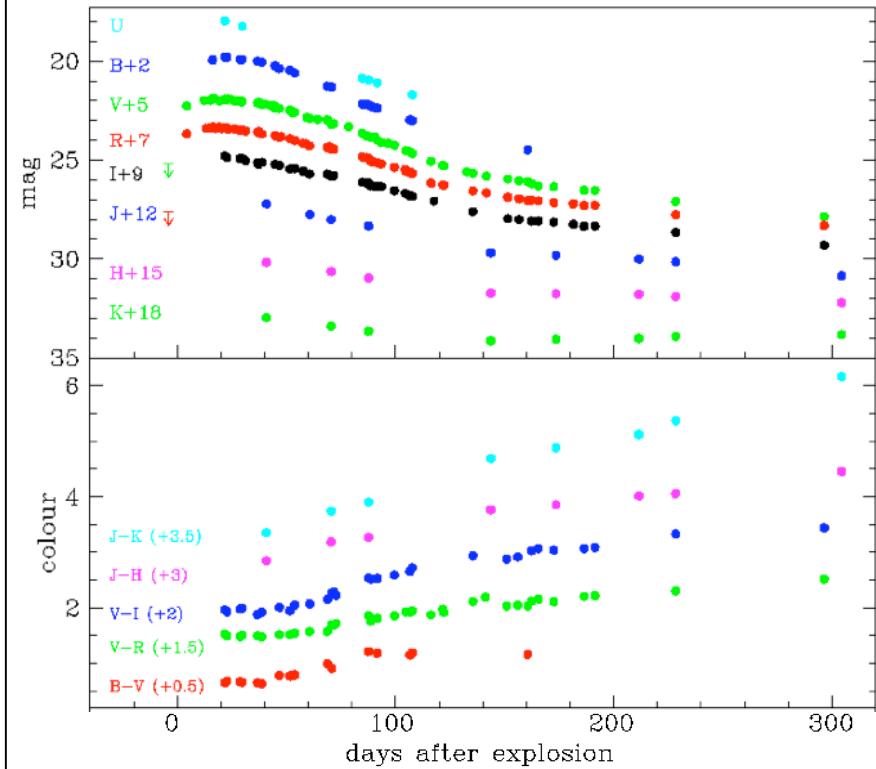
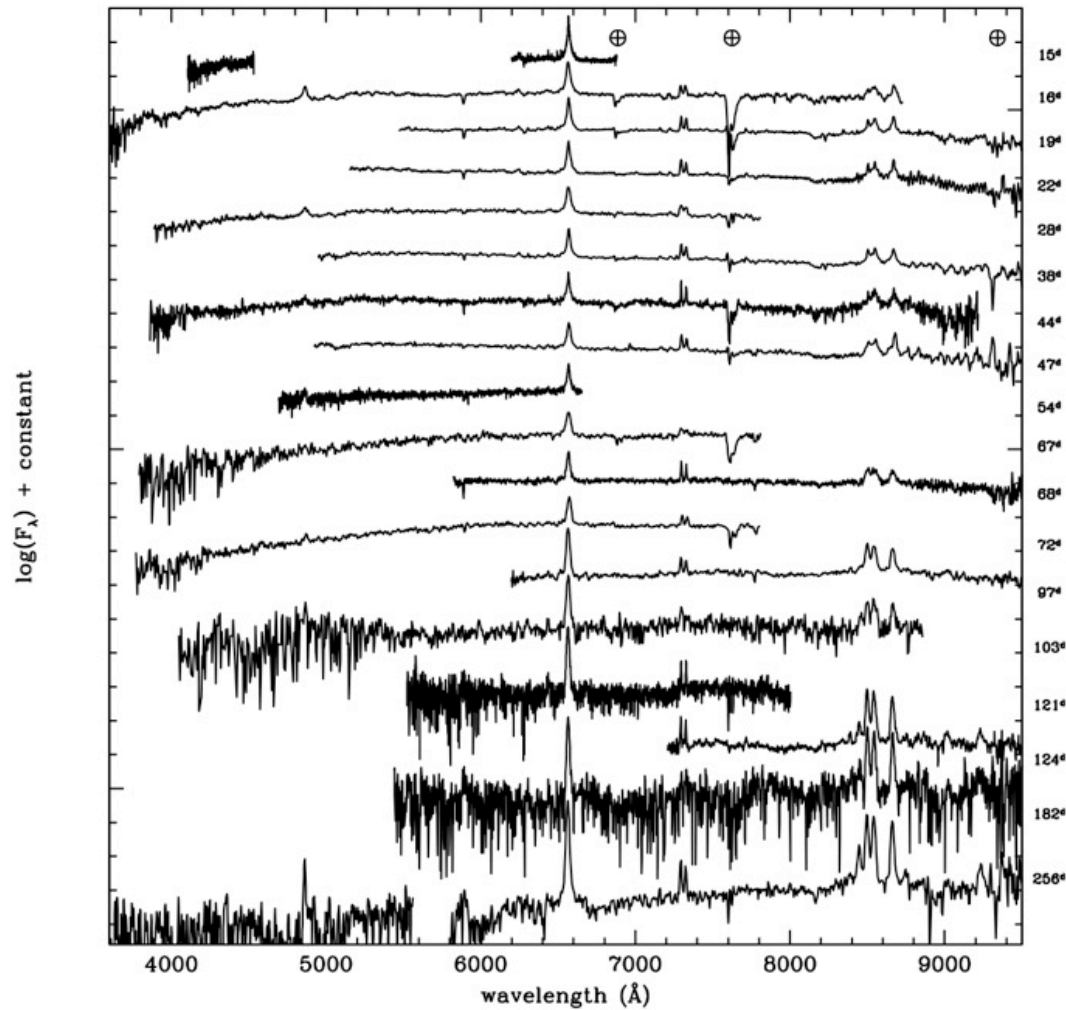


=> An ultra-faint CC-SN  
(Pastorello et al. 2007, Nature, 449, 1)



# SN impostors or ultrafaint SNe?

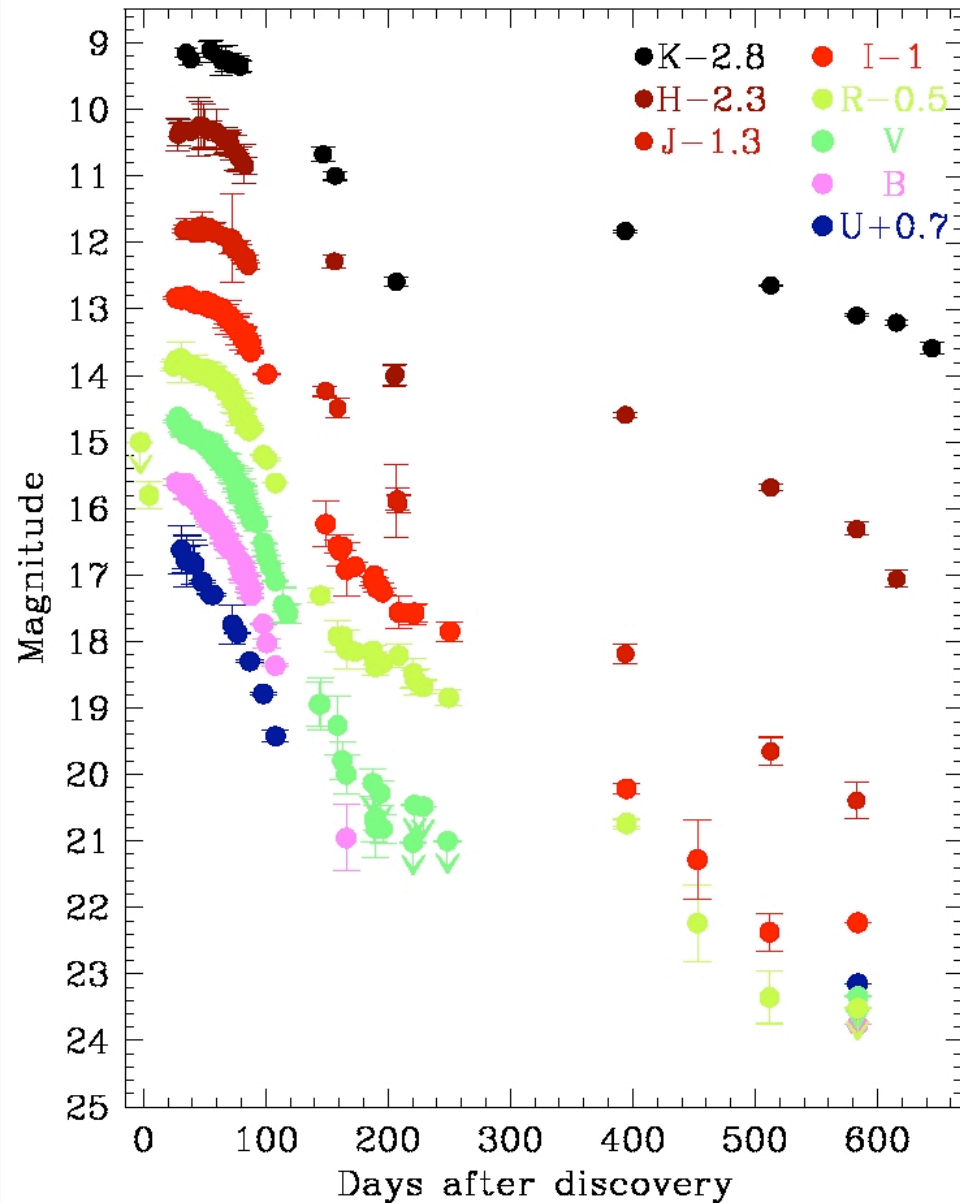
## SN 2008S



Botticella et al. 2009 MNRAS, 398, 1041

# SN impostors or ultrafaint SNe?

## NGC300-2008OT

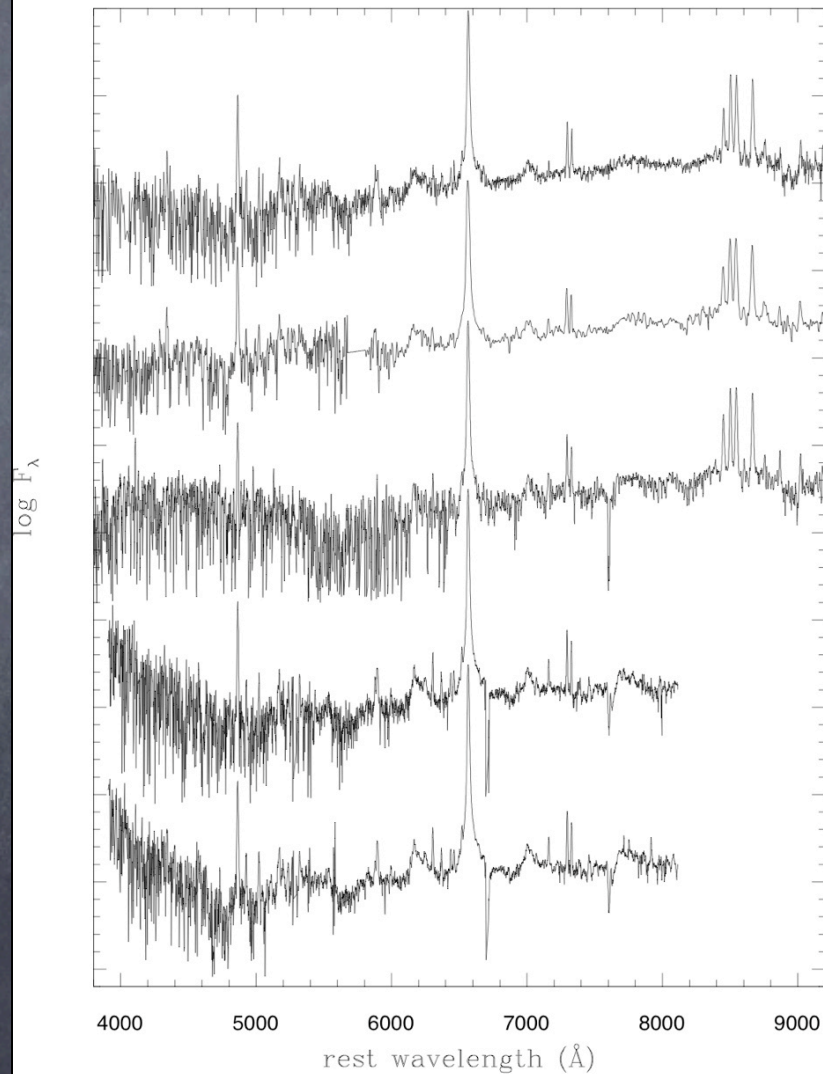
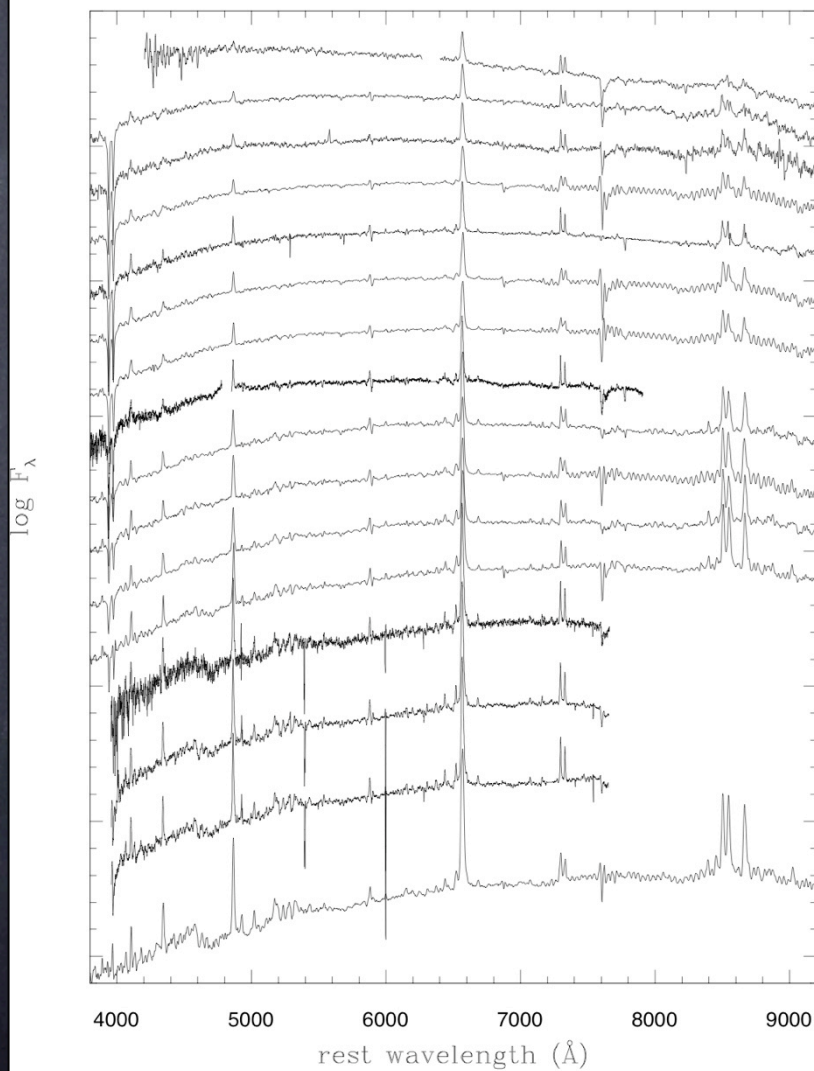


Pastorello et al. 2010a in preparation

# SN impostors or ultrafaint SNe?

## NGC300-2008OT

Pastorello et al. 2010a in preparation



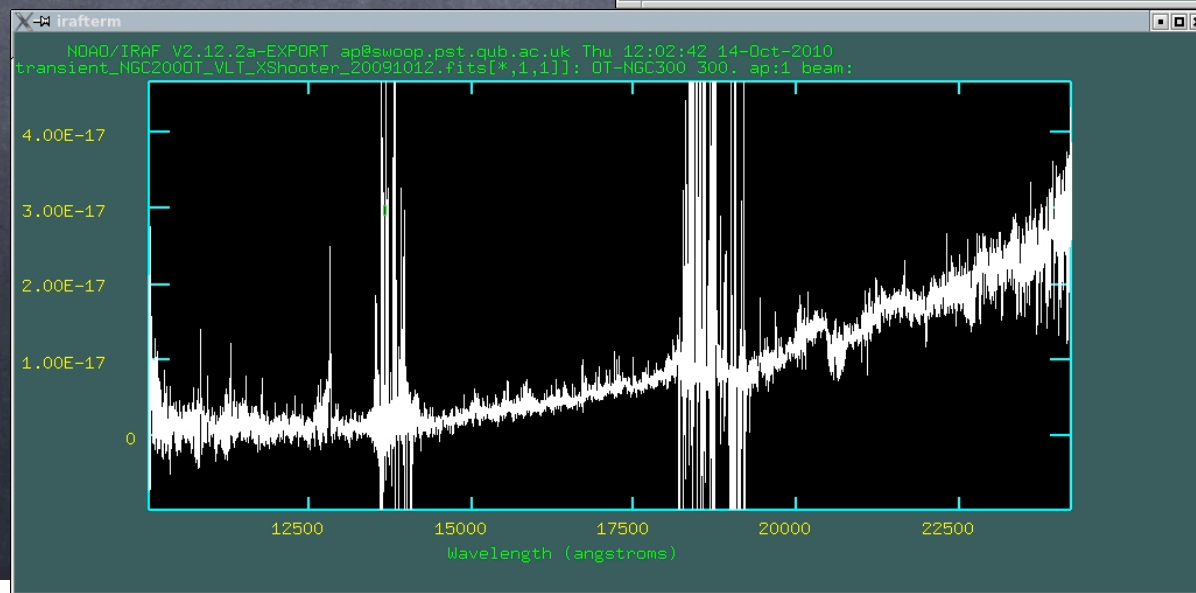
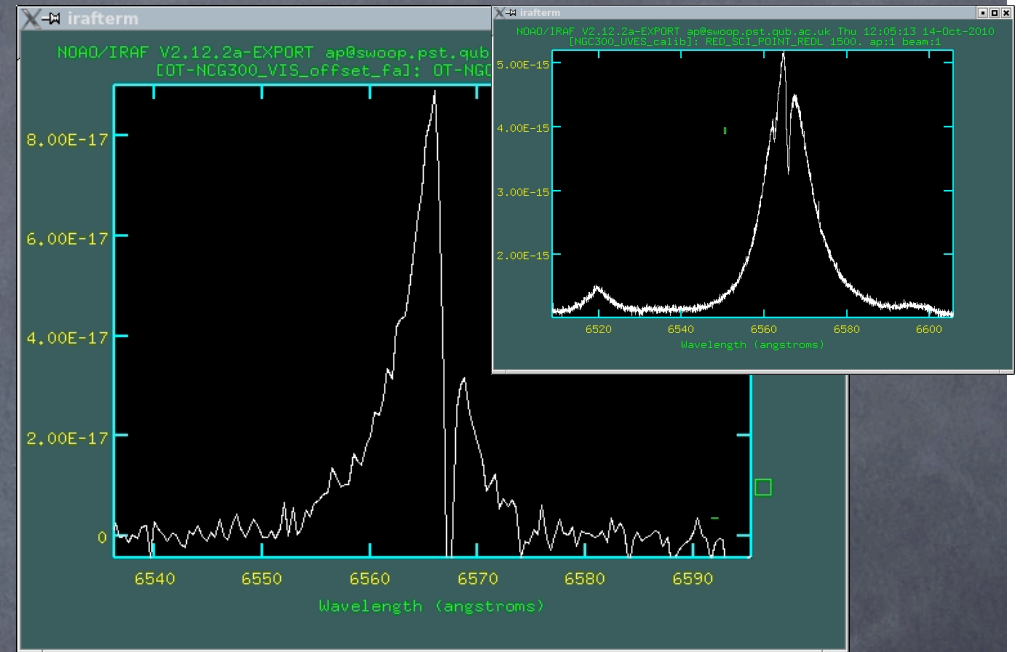
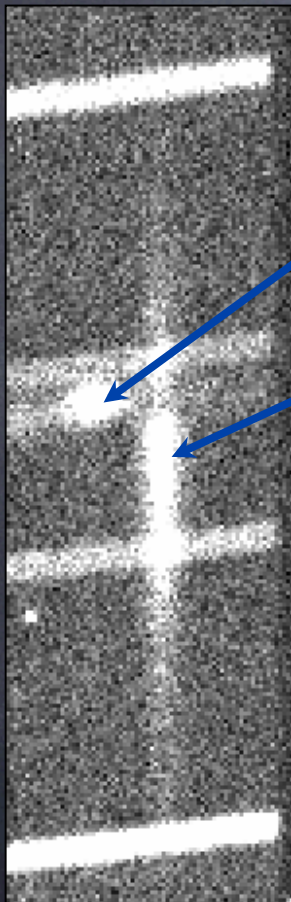
# SN impostors or ultrafaint SNe? NGC300-2008OT

Pastorello et al. 2010a in preparation

XShooter spectrum  
1.5ys past discovery

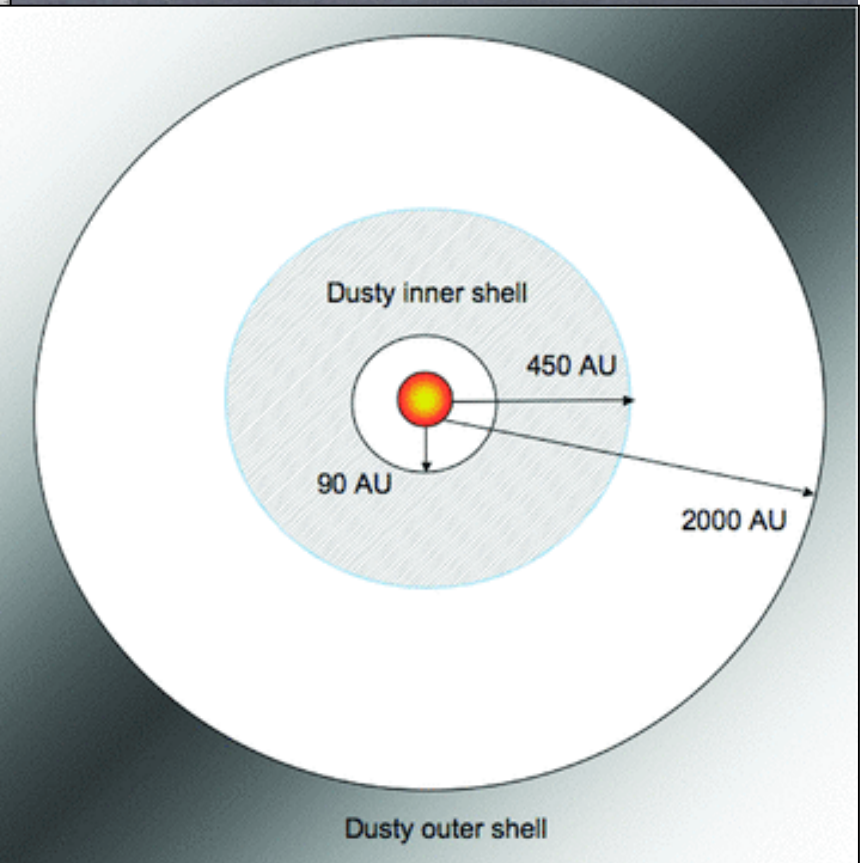
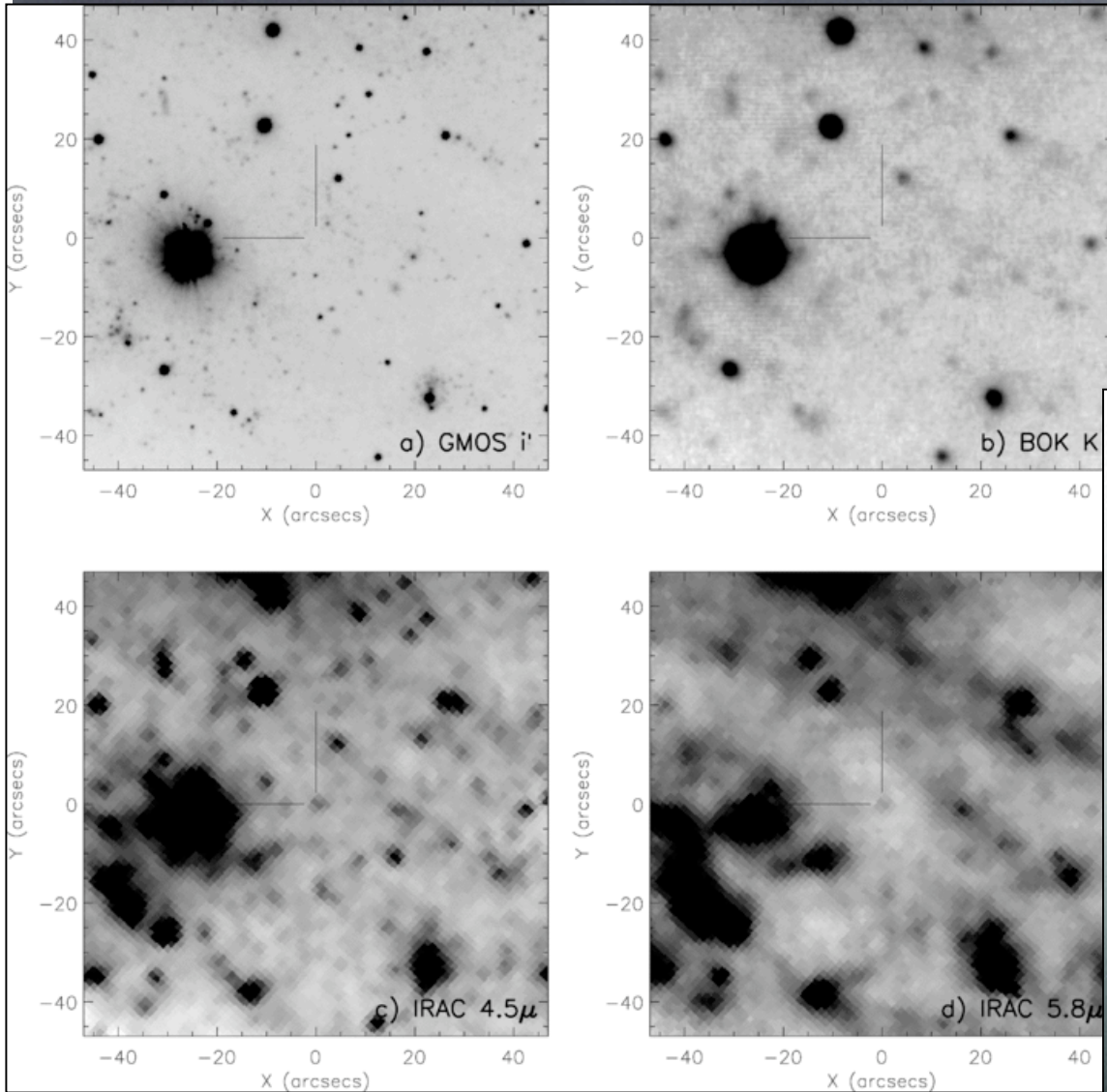
H $\alpha$  HII region

H $\alpha$  NGC300OT  
preliminary!

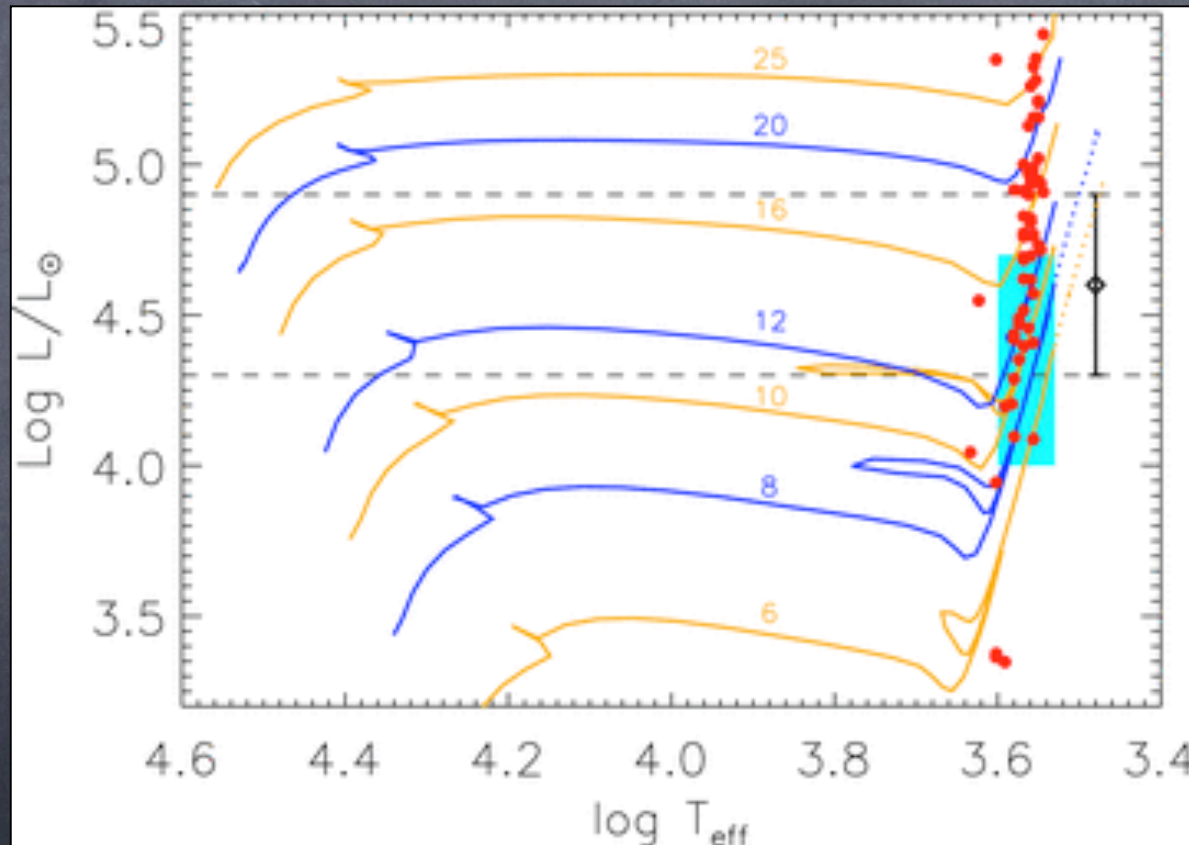


# Dusty, massive progenitors

Botticella et al. 2009, see also Thompson et al. 2008, Prieto et al. 2008, Smith et al. 2008, Bond et al. 2008, Berger et al. 2008, Wesson et al. 2010...



# Dusty, massive progenitors



Botticella et al. 2009, MNRAS, 398, 1041

# A new family of transients!

SN2008S, NGC300-OT, SN1999bw,

M85-OT, PTF10fqs, SN2010dn

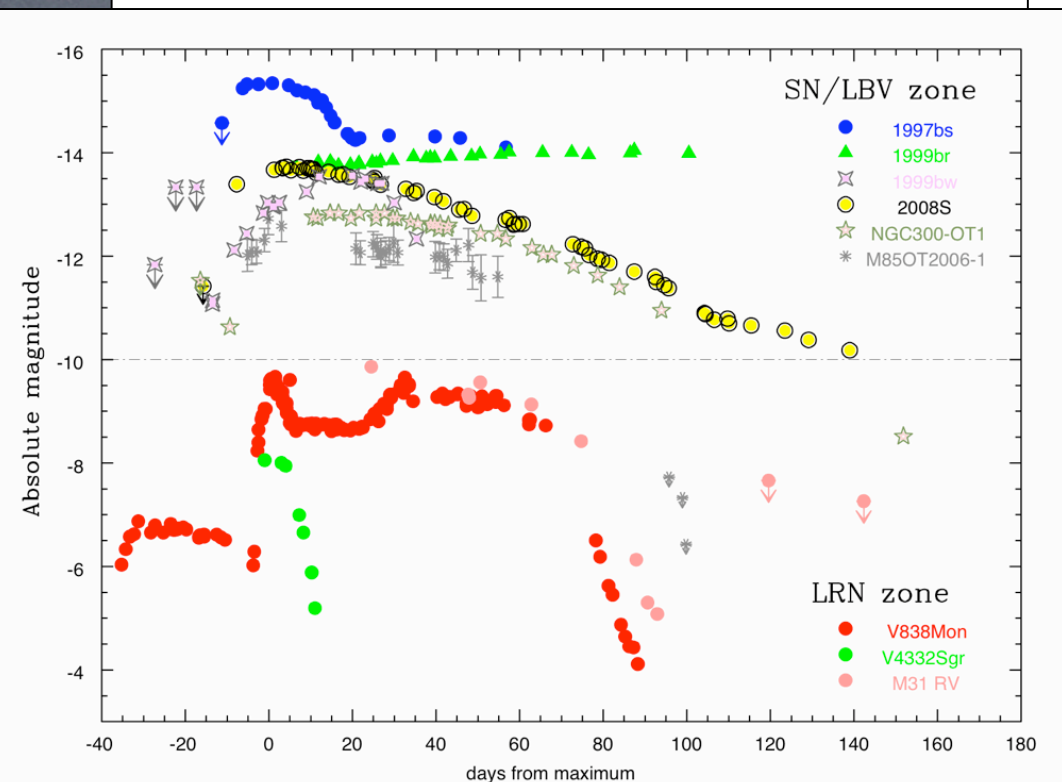
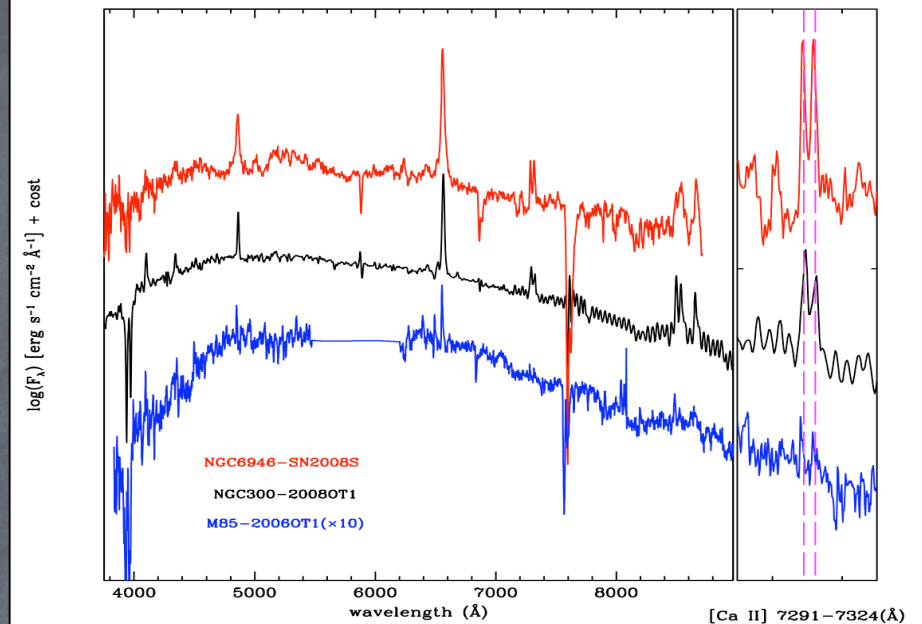
1. Narrow, emission-line spectra (IIn)

2. Faint and slow-evolving LCs

3. Dust-enshrouded 8–20 $M_{\odot}$  progenitors

=> Same class of transients!

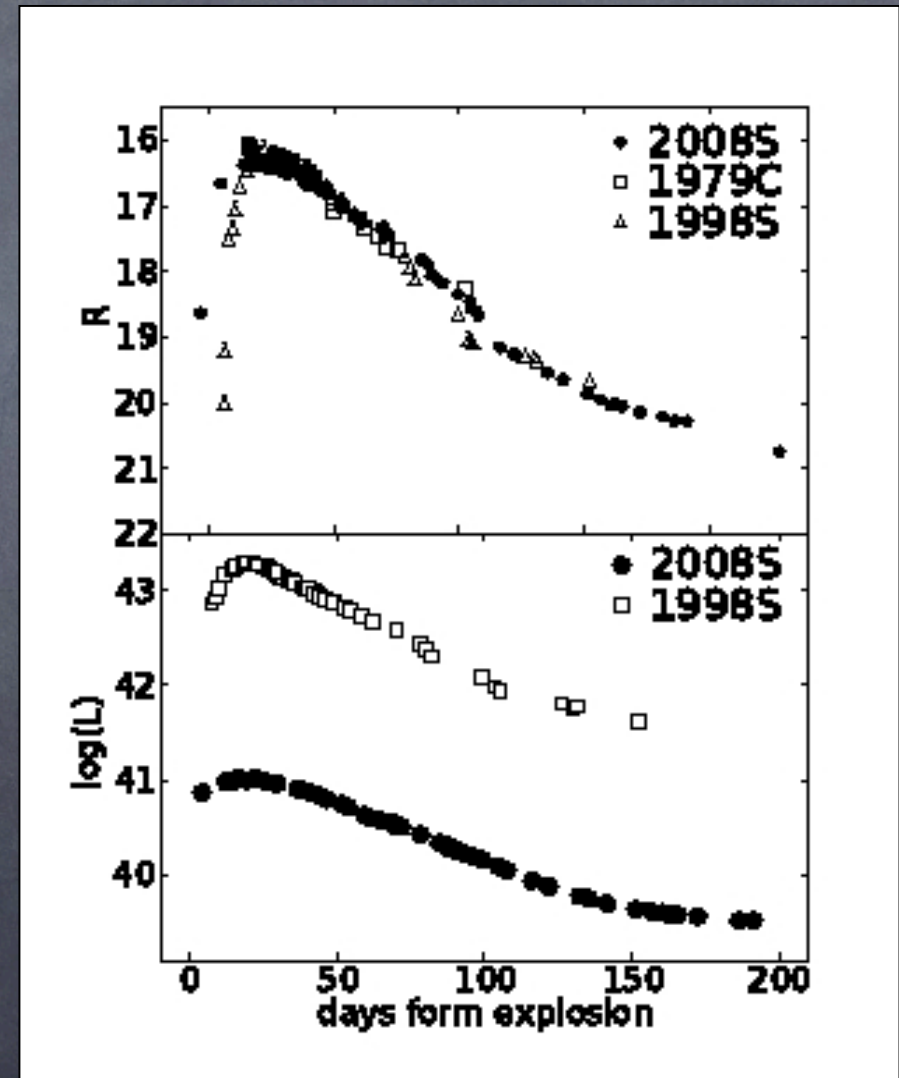
(Prieto et al. 2008, 2009; Smith et al. 2009; Bond et al. 2009; Botticella et al. 2009; Thompson et al. 2009; Berger et al. 2009, Bonanos et al. 2010; Kasliwal et al. 2010, Pastorello et al. in prep.)



# SN impostors or ultra-faint SNe?

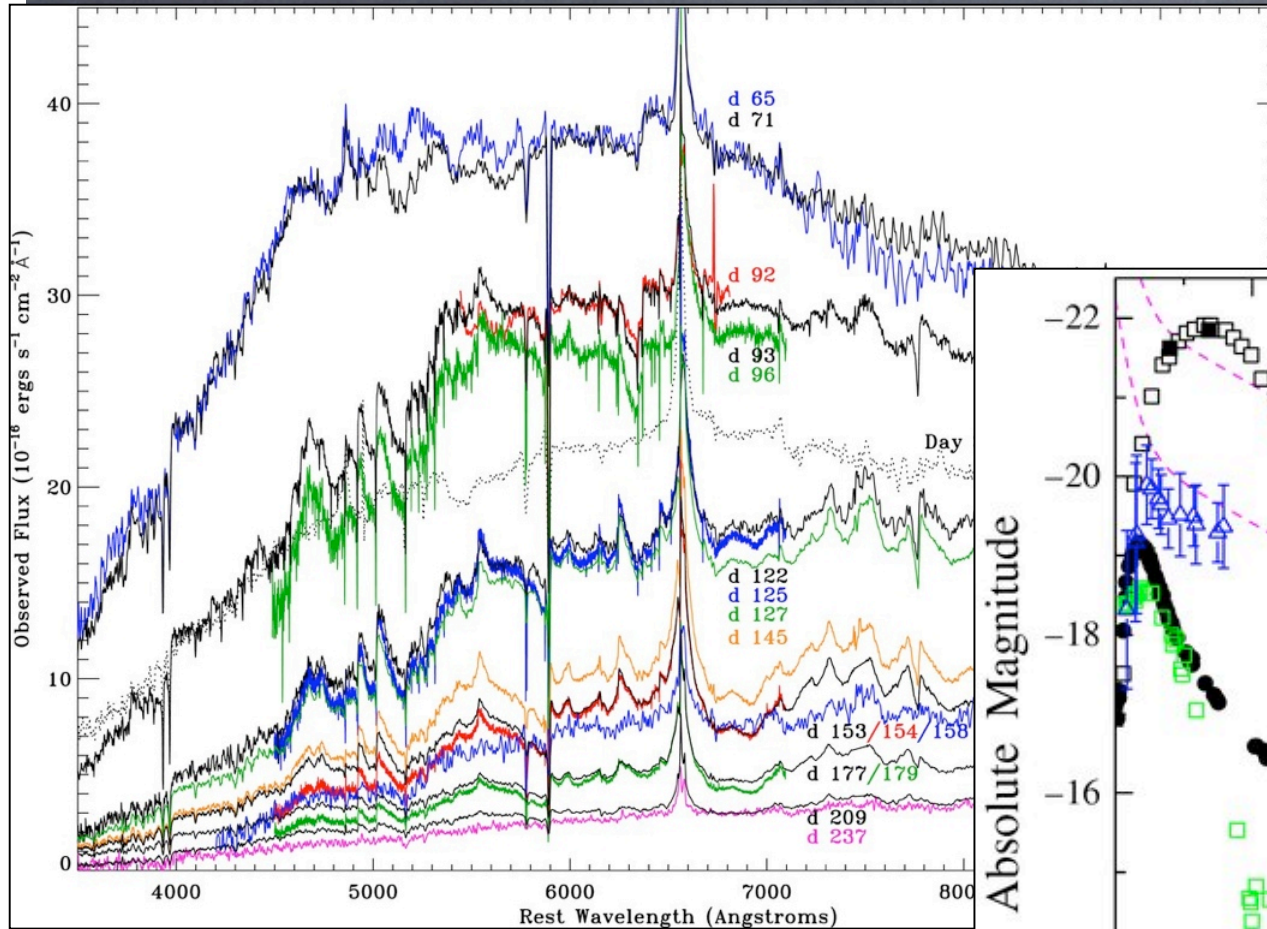
- Luminous red novae from low-mass mergers (Kulkarni et al. 2007, Nature)
- Eruptions triggered by mass transfer from an extreme-AGB to a main sequence companion
- eruptive birth of a massive WD + planetary nebula
- outbursts from moderate-mass LBVs (M~10-20 Mo) or B[e] hypergiants
- EC-SNe from ~9 Mo super-AGB stars (SNe IIL/IIn)
- Faint CC-SNe from 10-12Mo RSGs

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

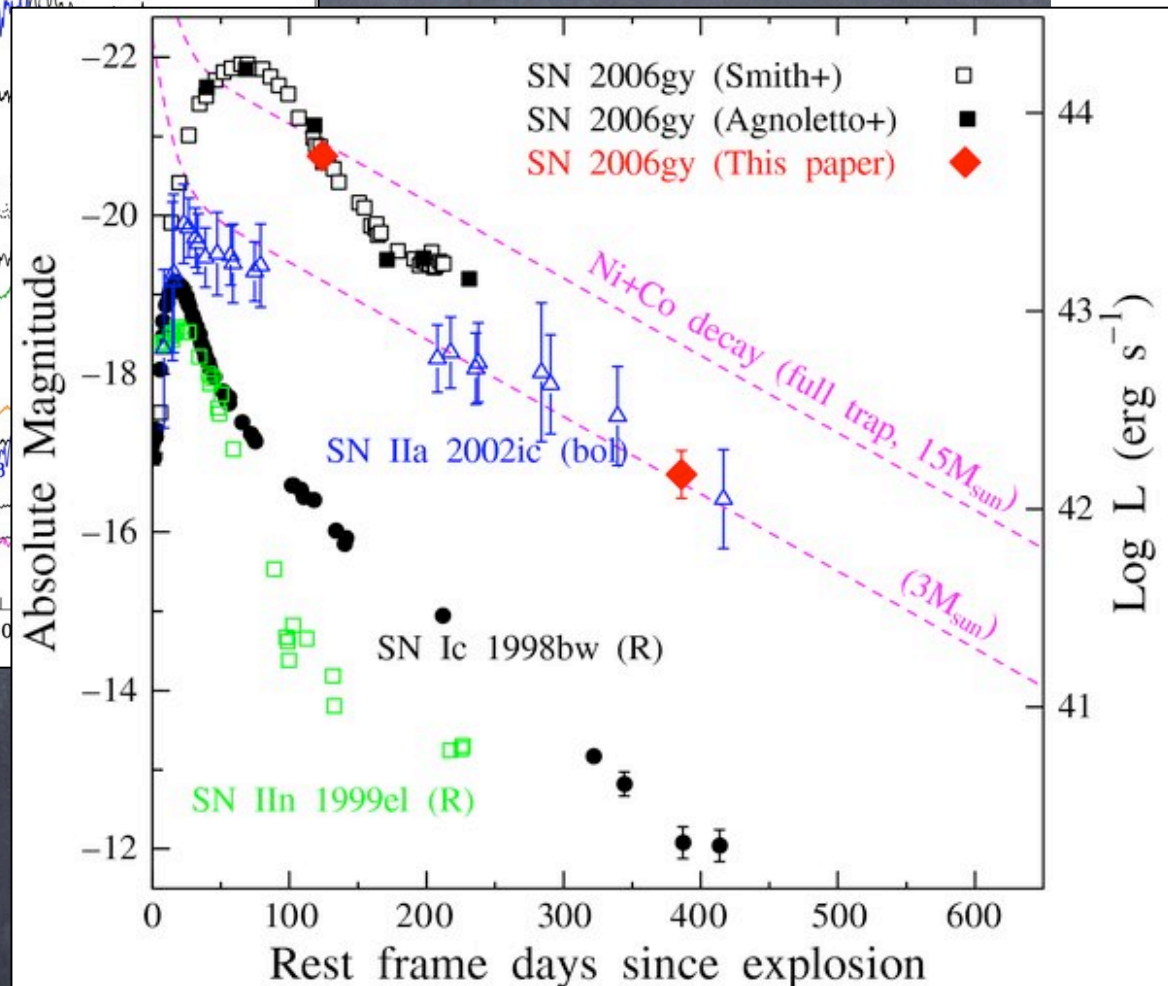




# SN 2006gy and bright IIn events



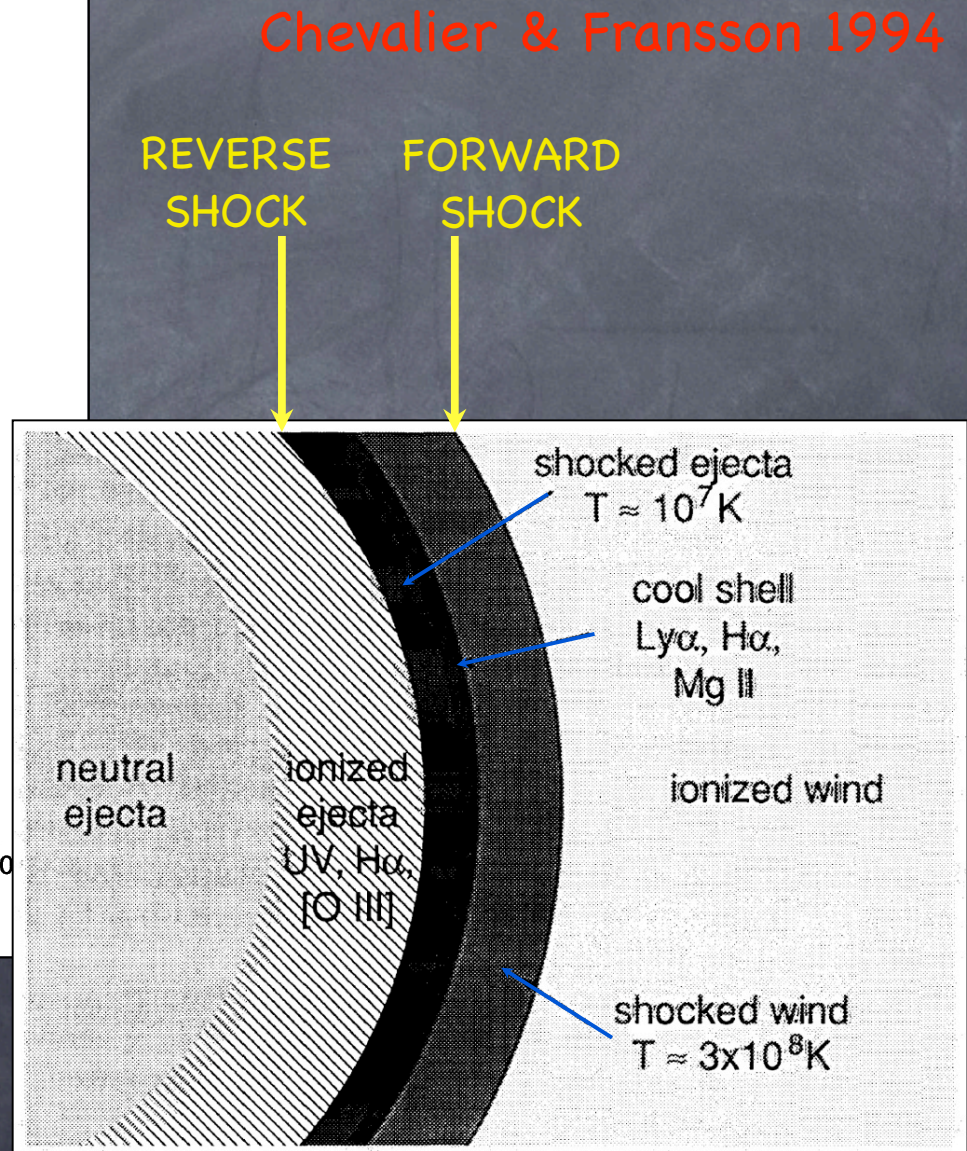
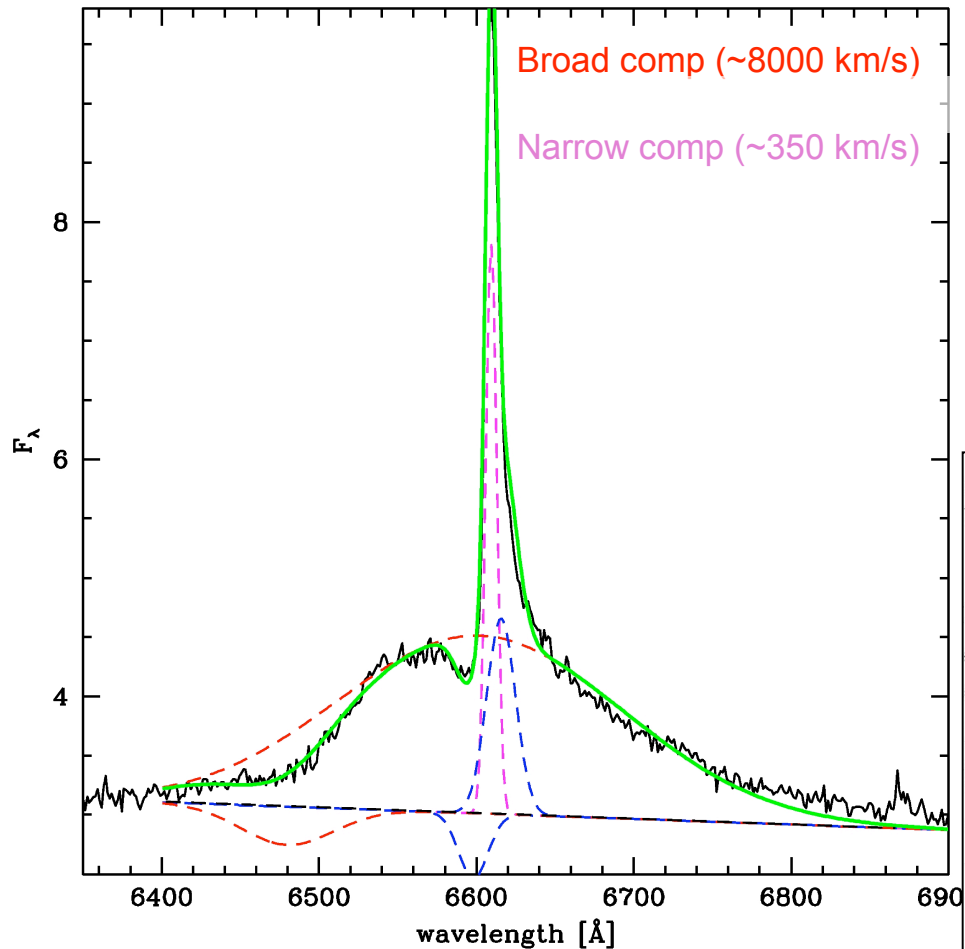
Smith et al. 2007, 2008, 2010;  
see also Ofek et al. 2007



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

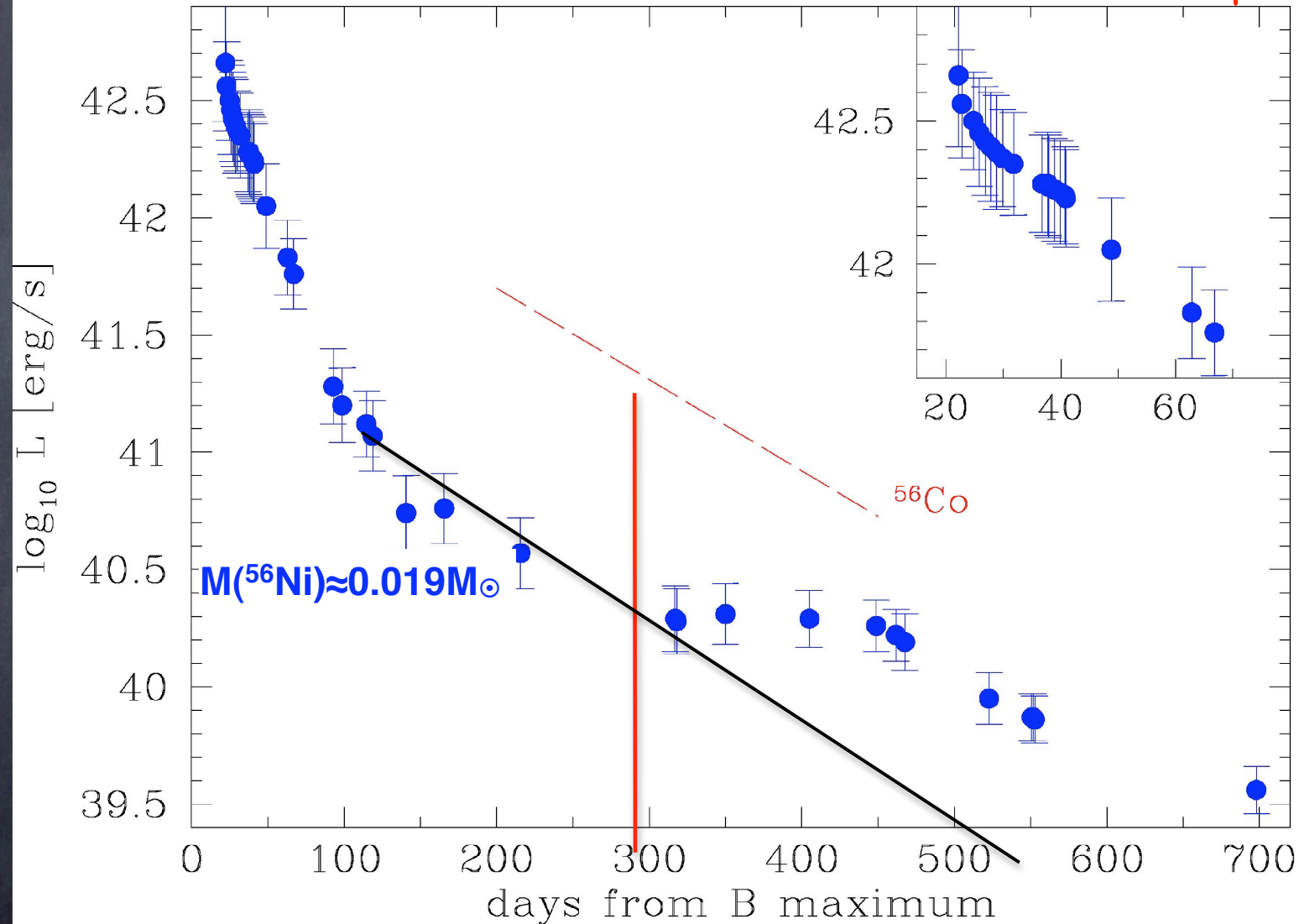
# Type II<sub>n</sub> Supernovae

Chevalier & Fransson 1994



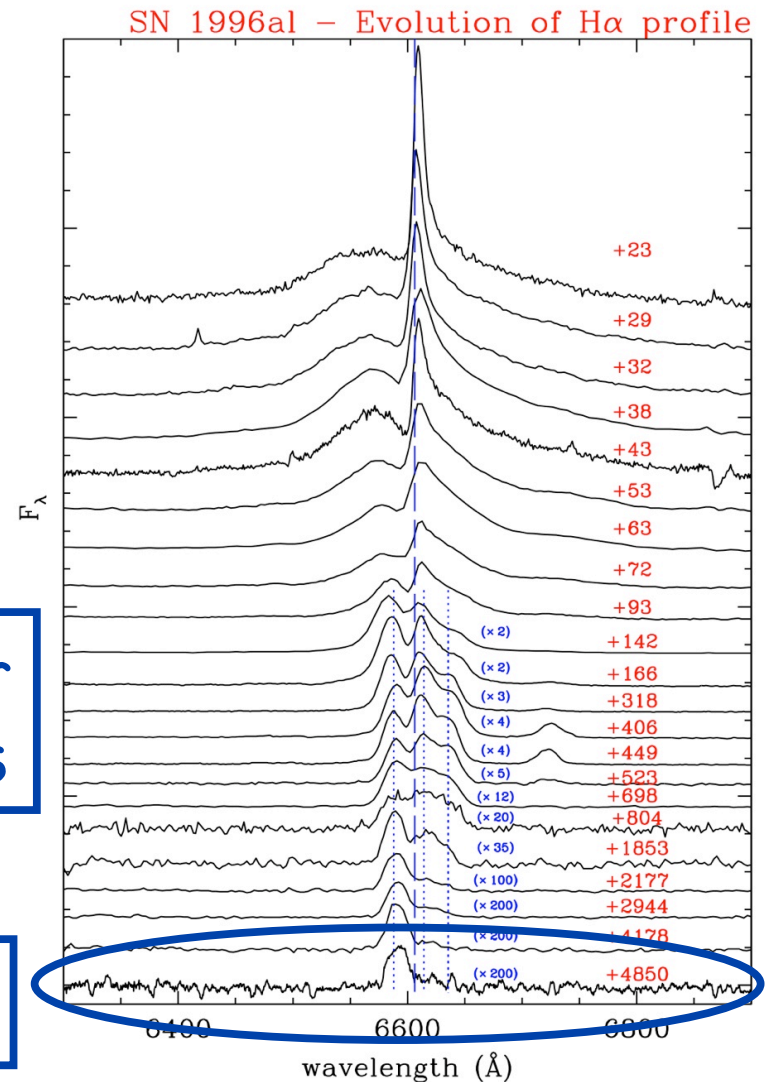
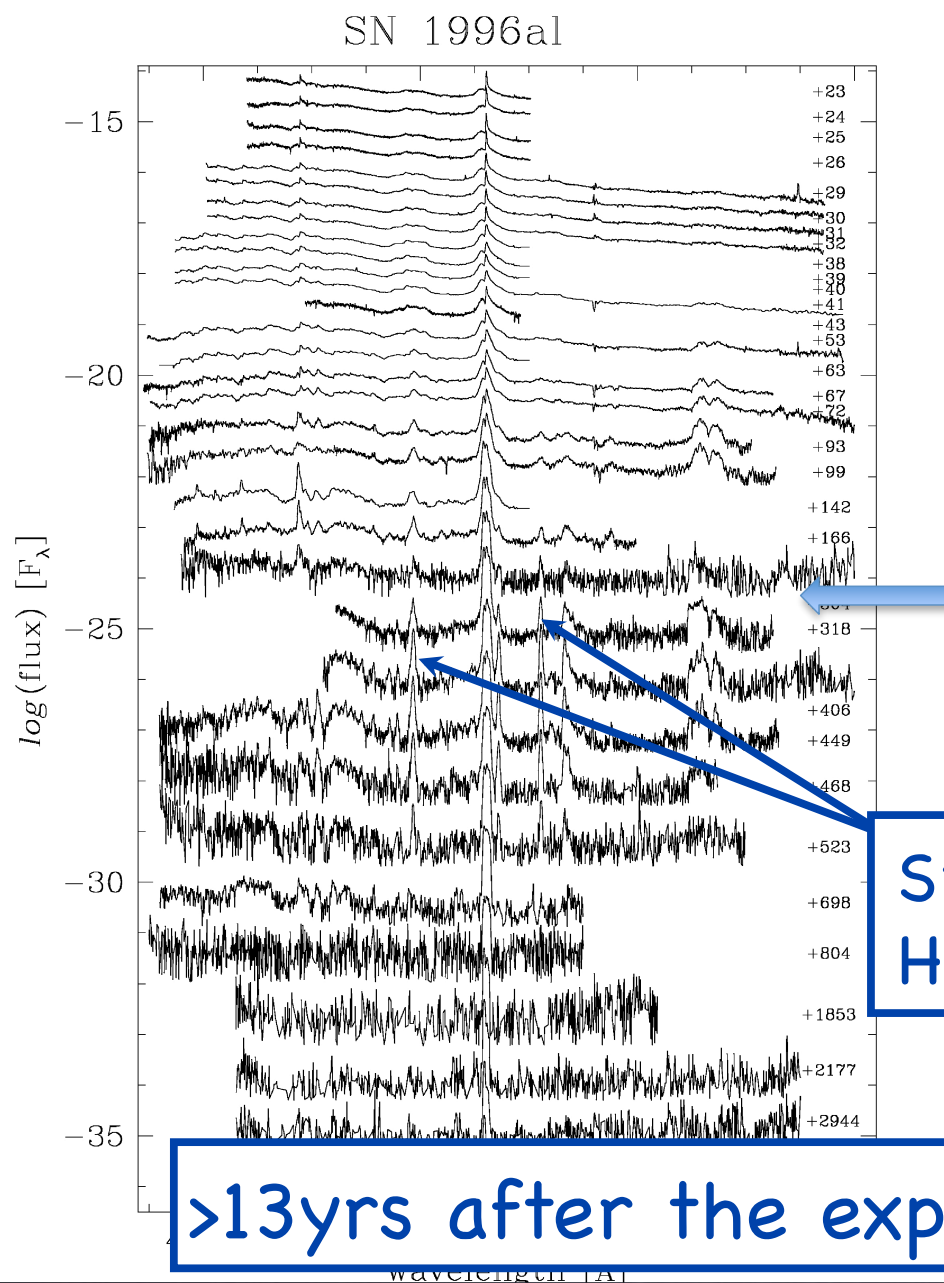
# The type IIn SN 1996al

Benetti et al. 2010 in prep.



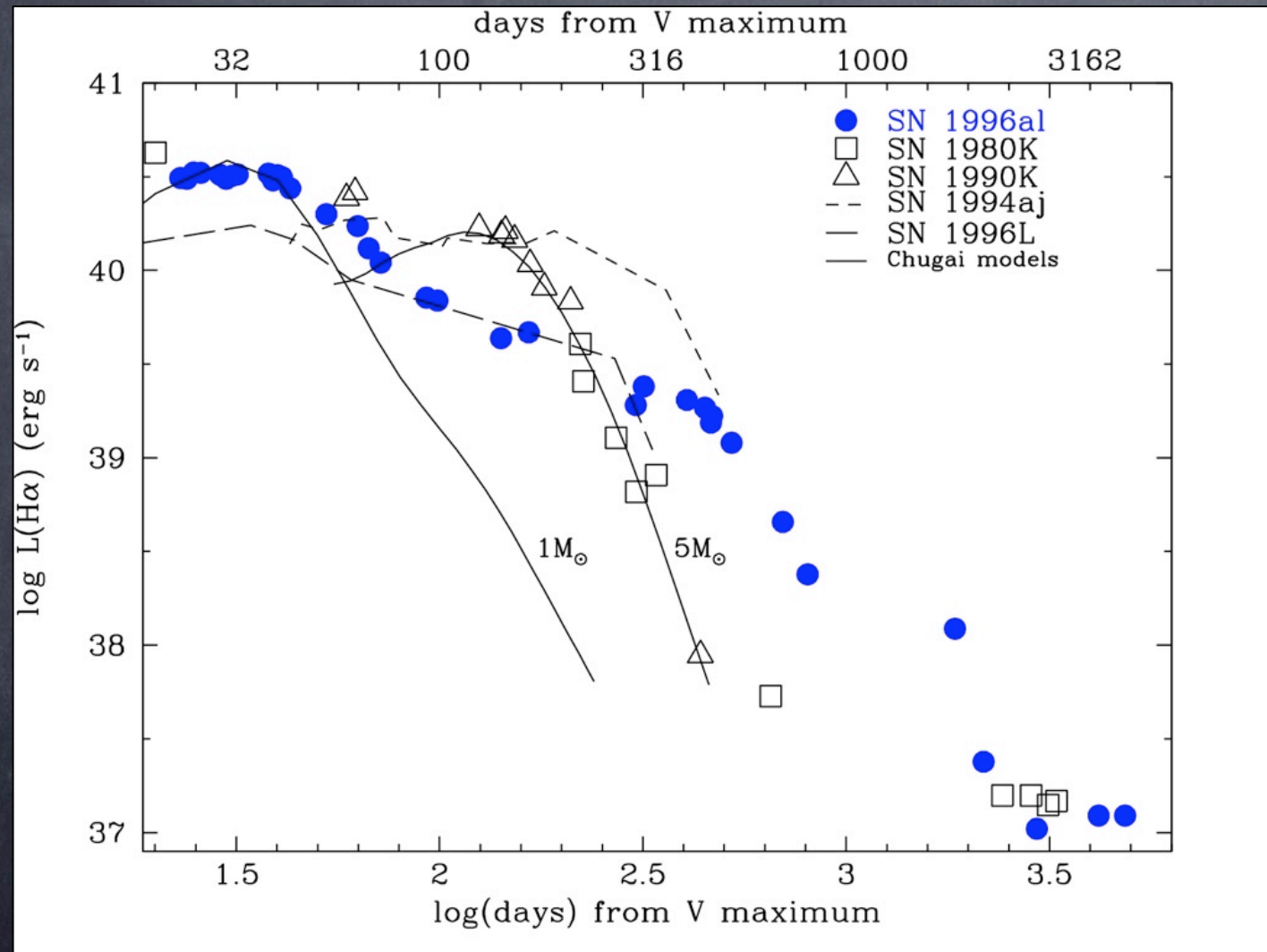
# The type IIIn SN 1996al

Benetti et al. 2010 in prep.

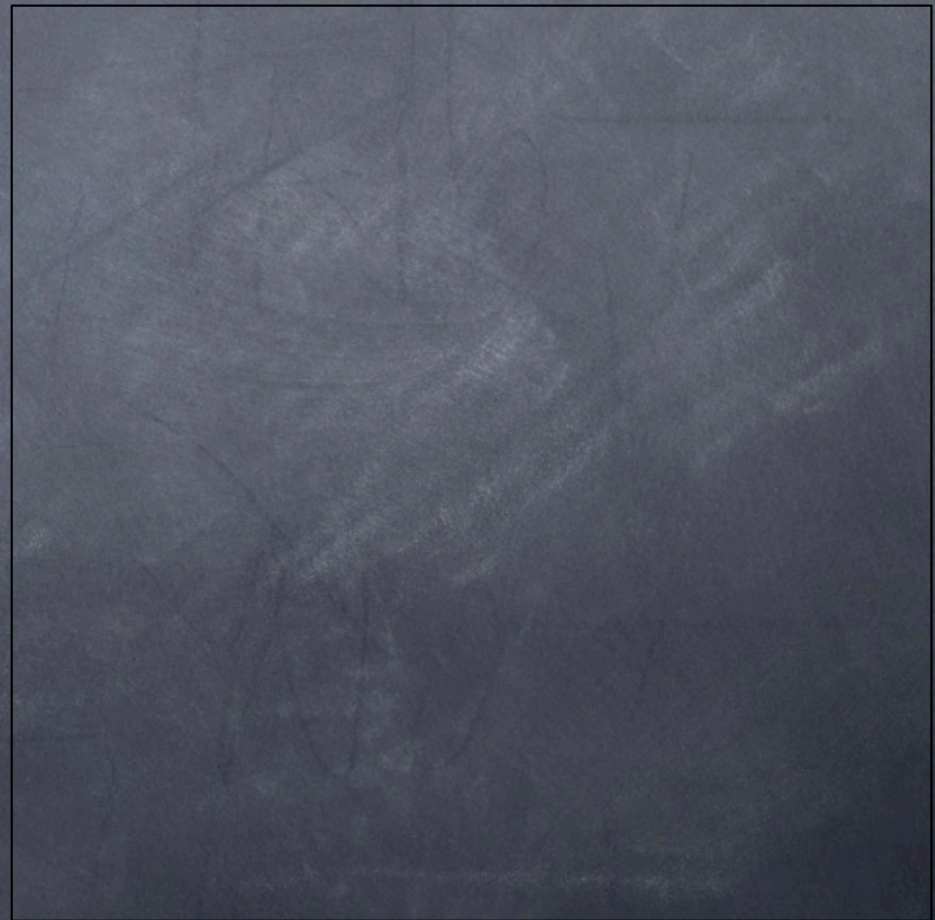
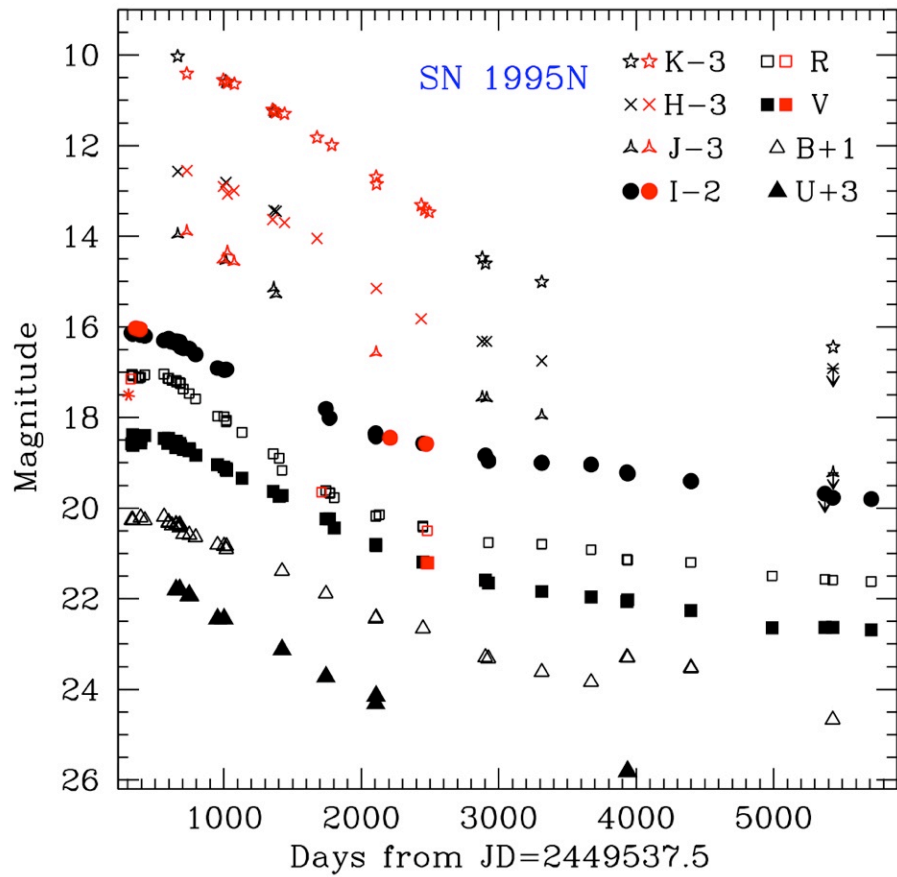


# The type IIIn SN 1996al

Benetti et al. 2010 in prep.

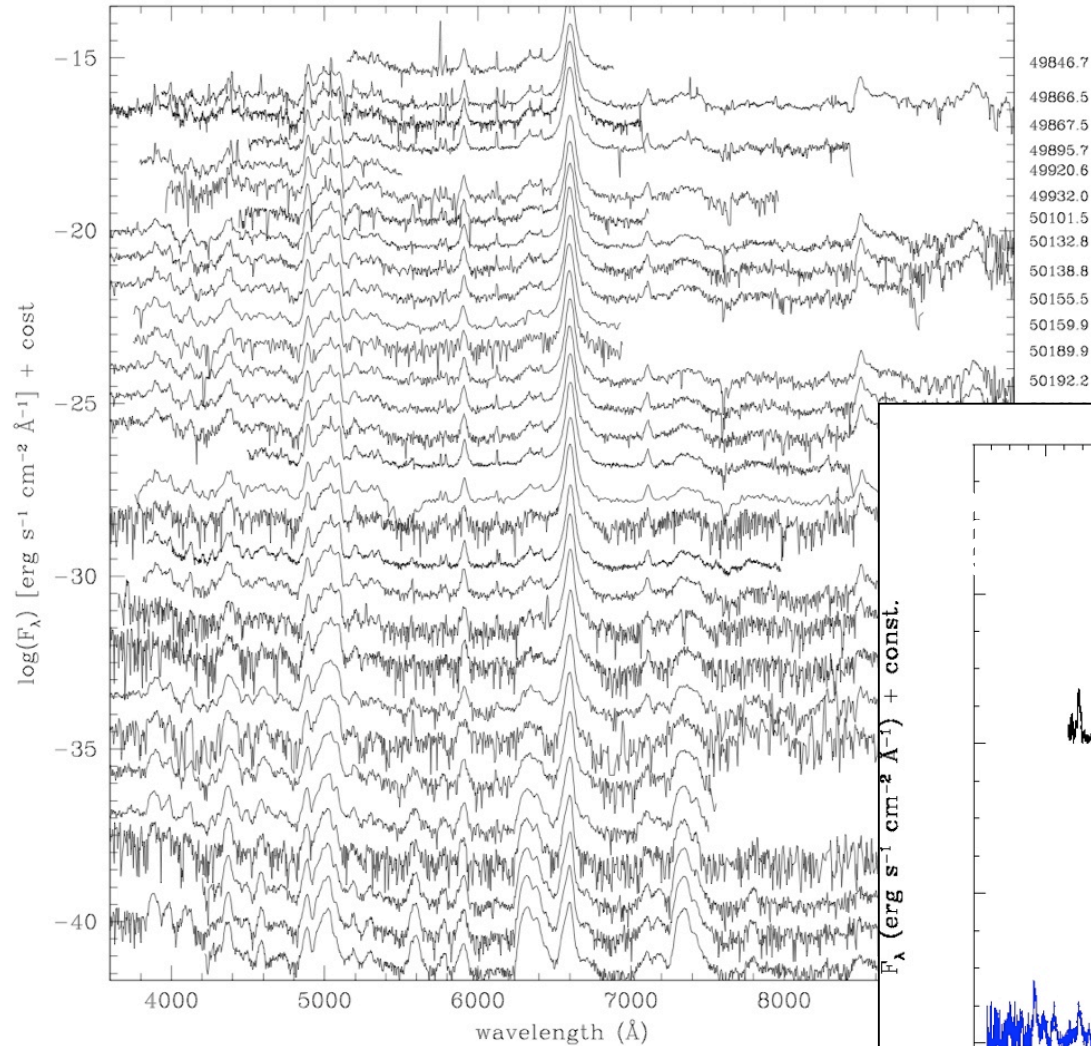


# The type IIn SN 1995N

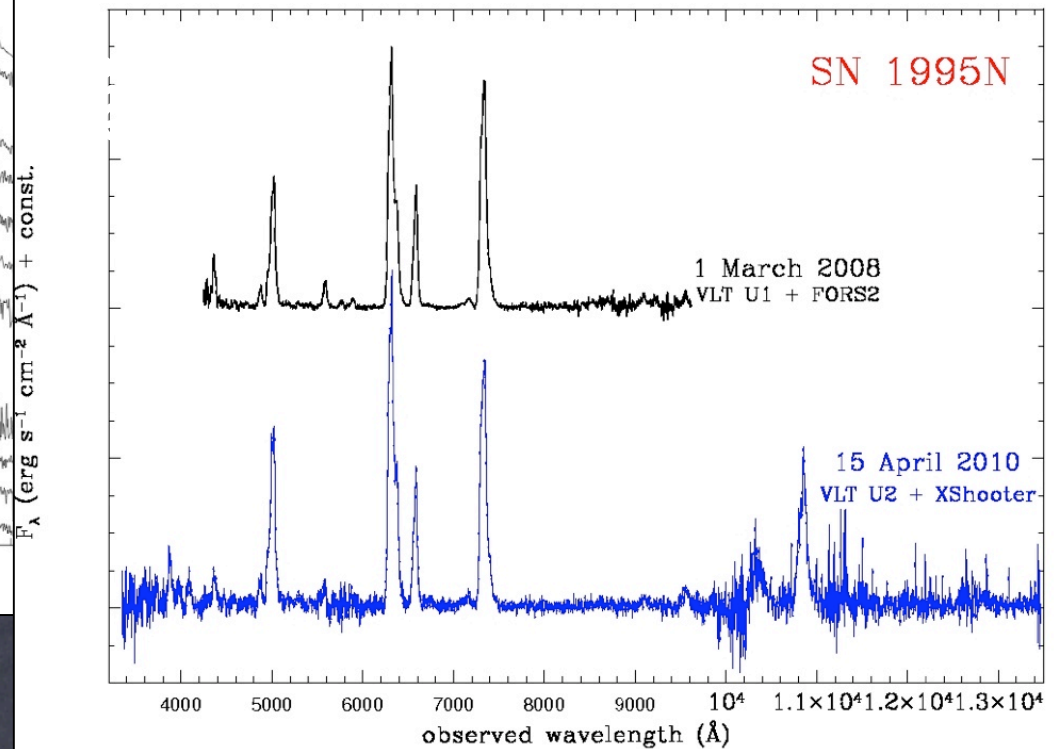


# The type IIn SN 1995N

Pastorello et al. 2010b in preparation

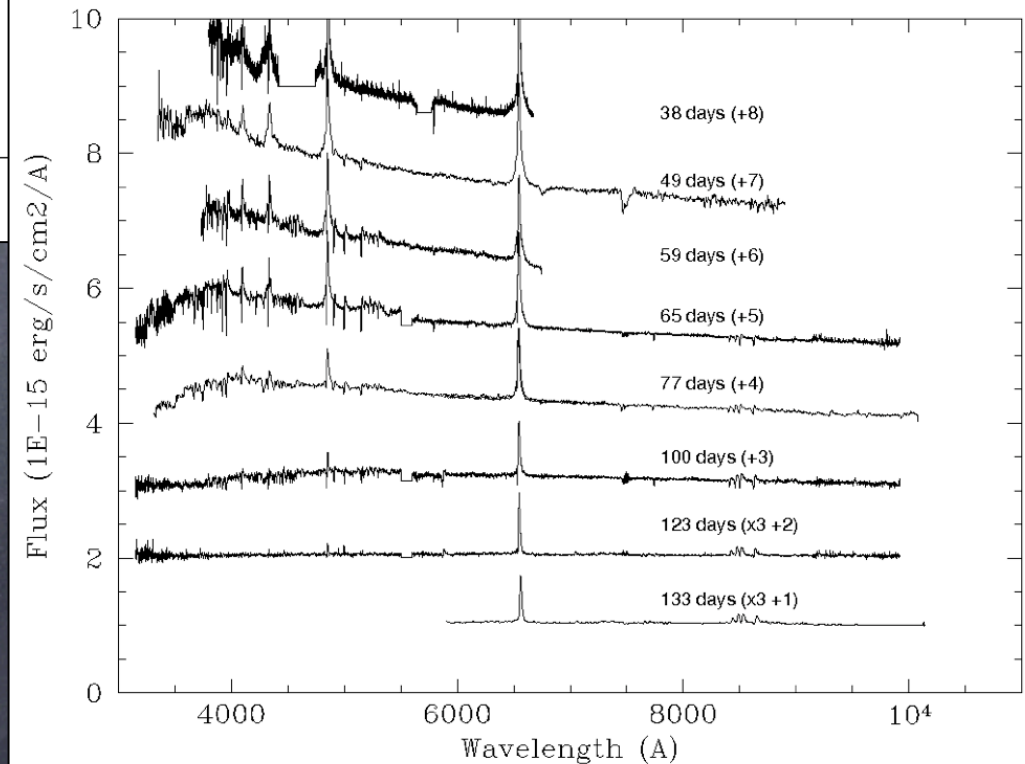
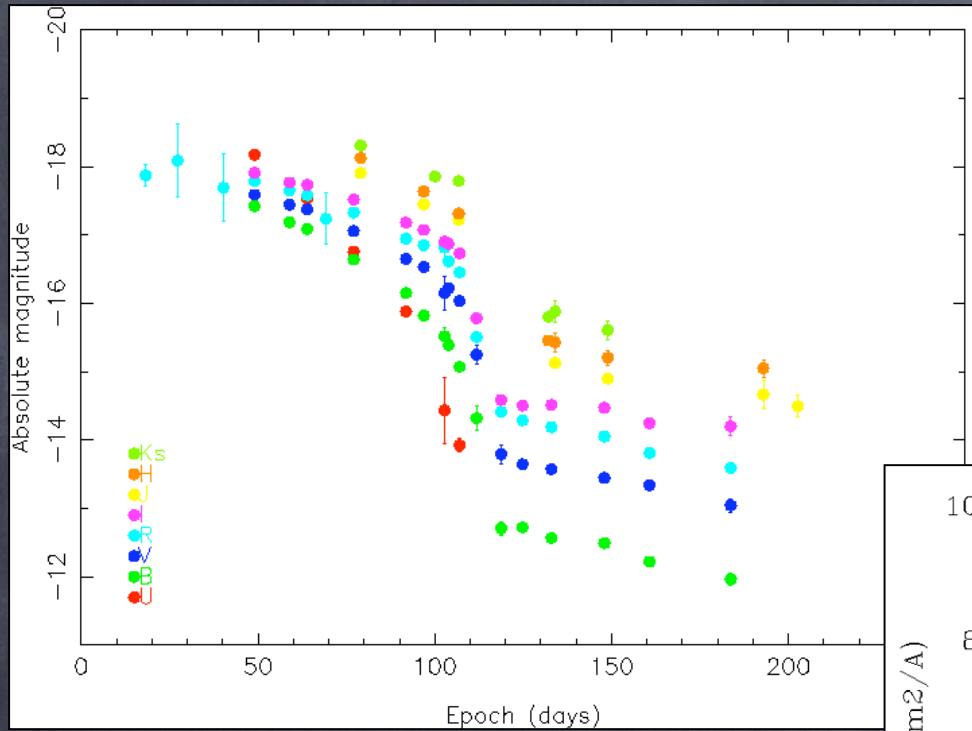


Preliminary Results!



# The type IIn SN 2009kn

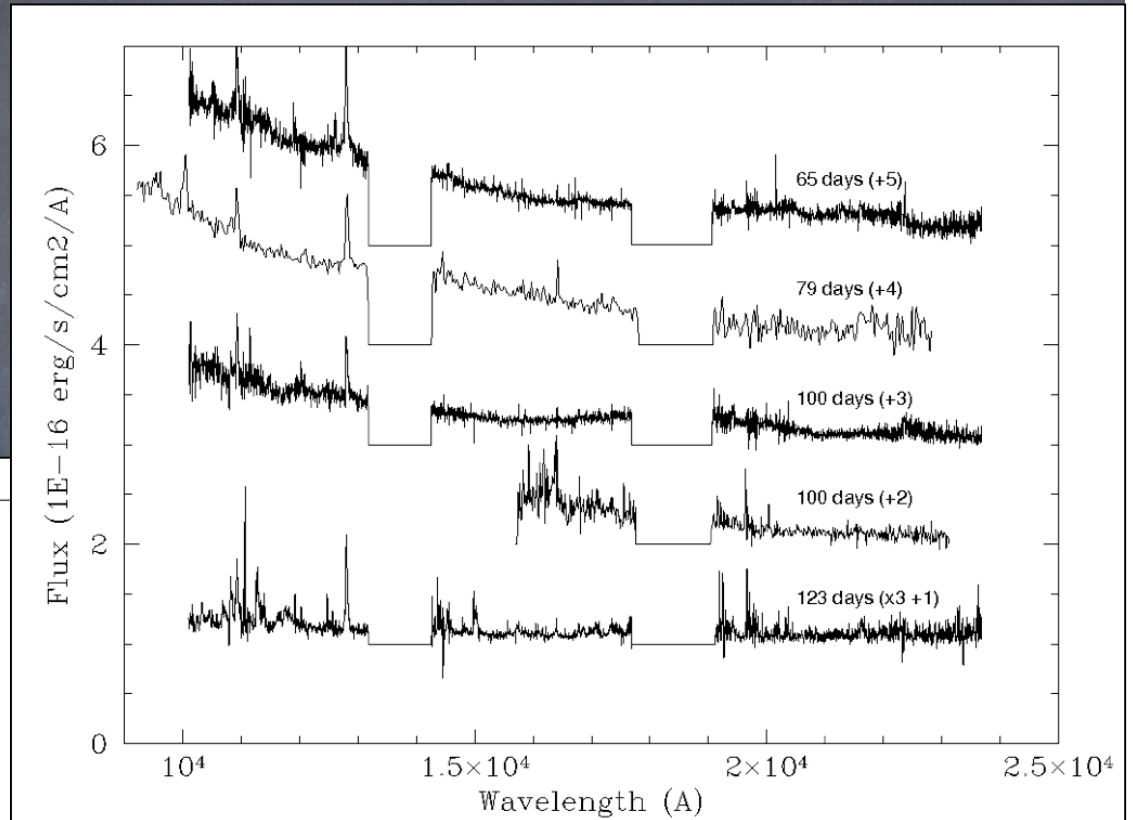
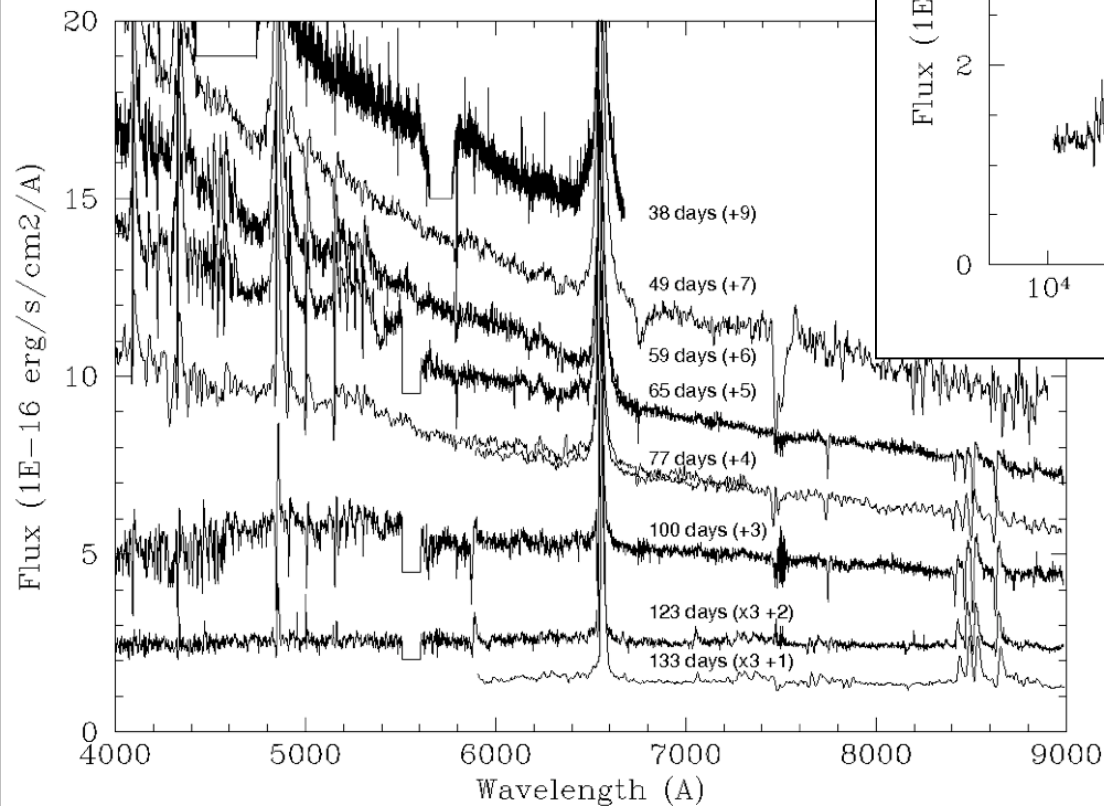
Kankare et al. 2010 in prep.





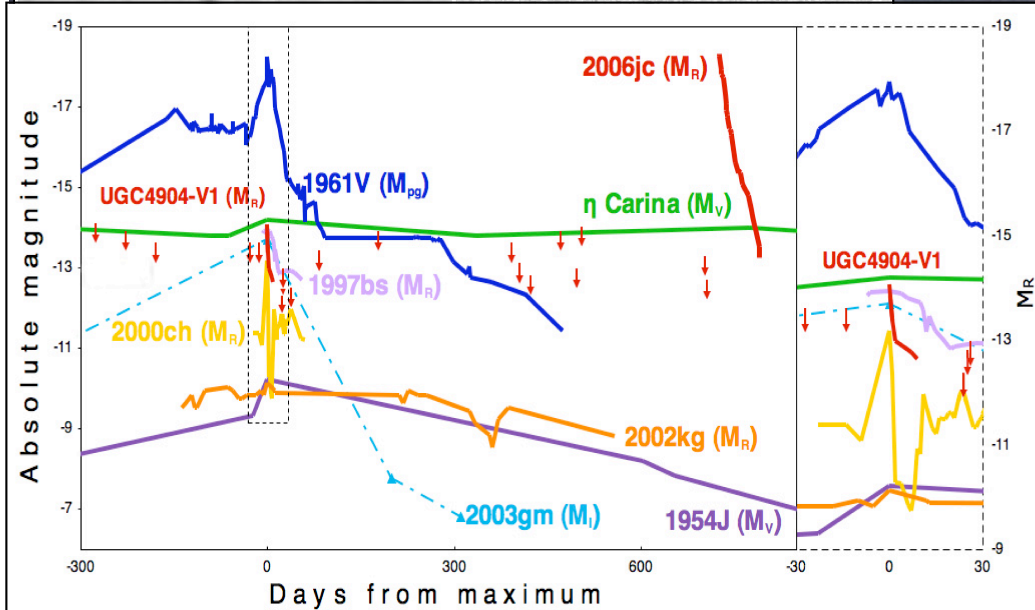
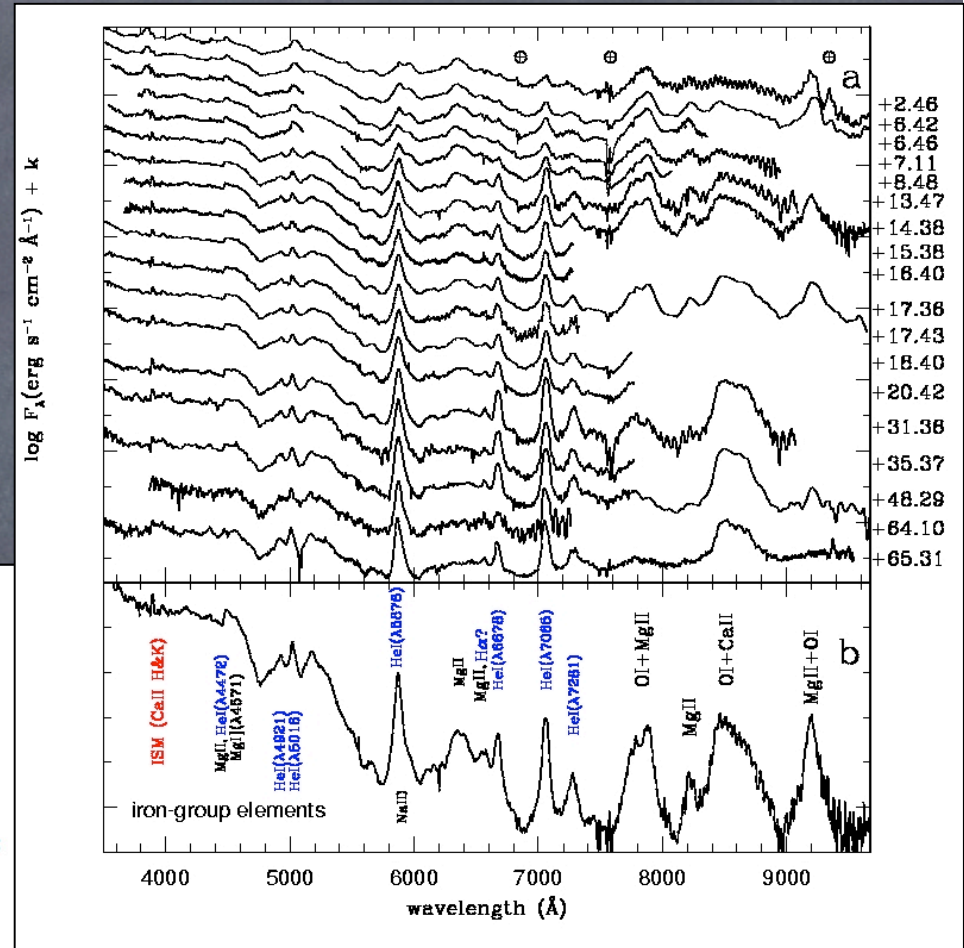
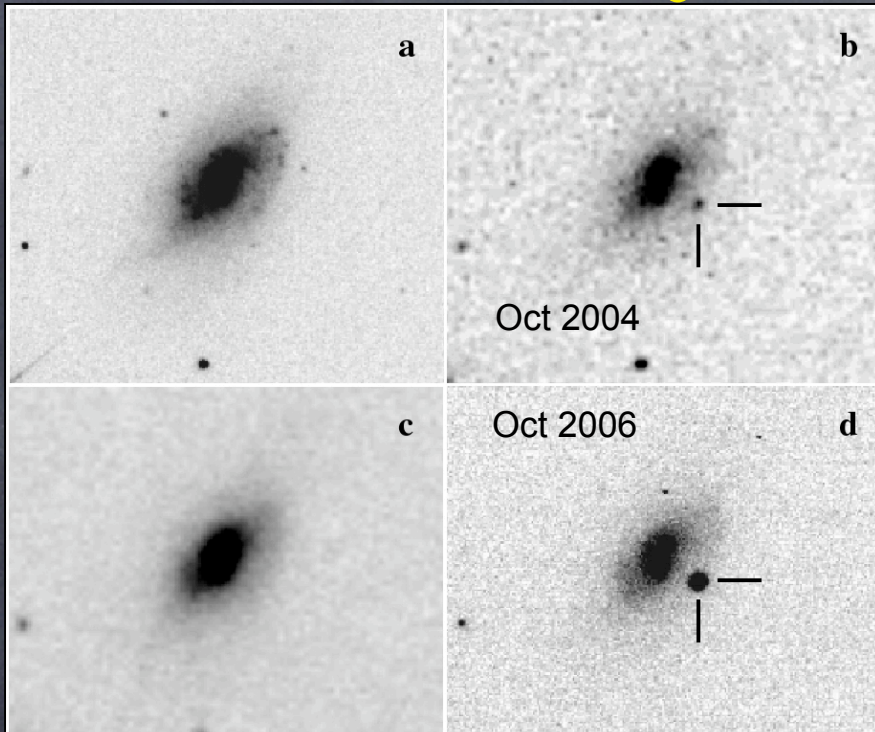
# The type IIn SN 2009kn

Kankare et al. 2010 in prep.  
Preliminary Results!



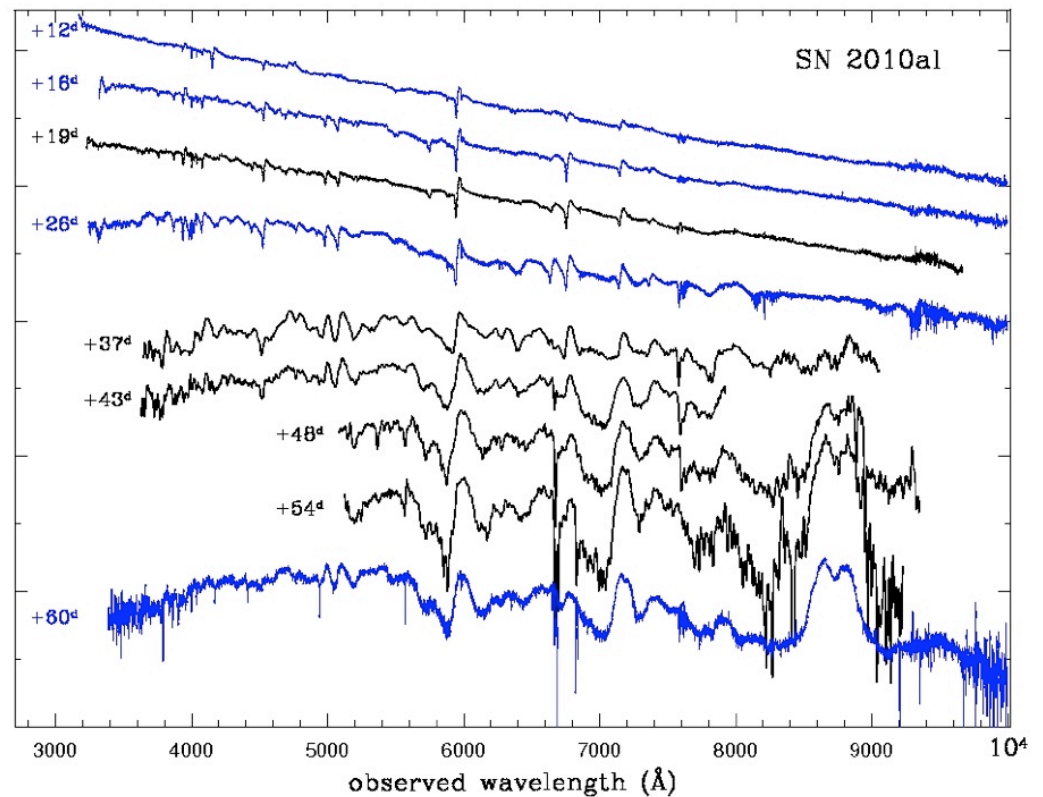
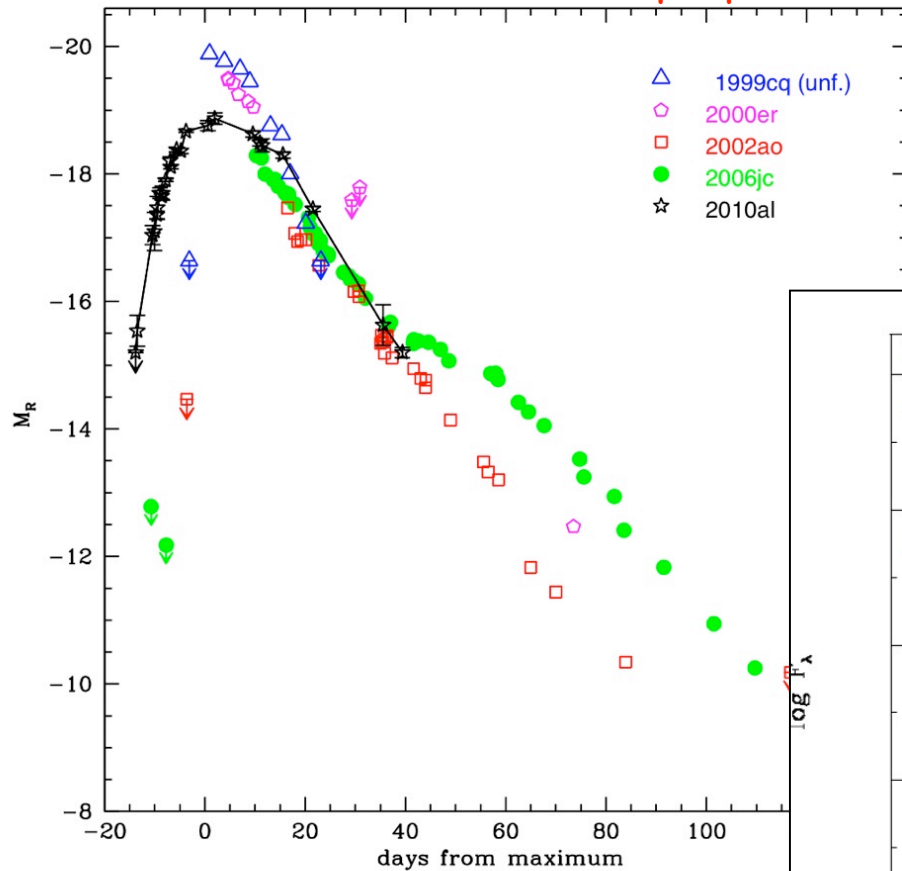
# SN 2006jc and type Ibn SNe

Pastorello et al. 2007, Nature, 447, 829



# The type Ibn SN 2010al

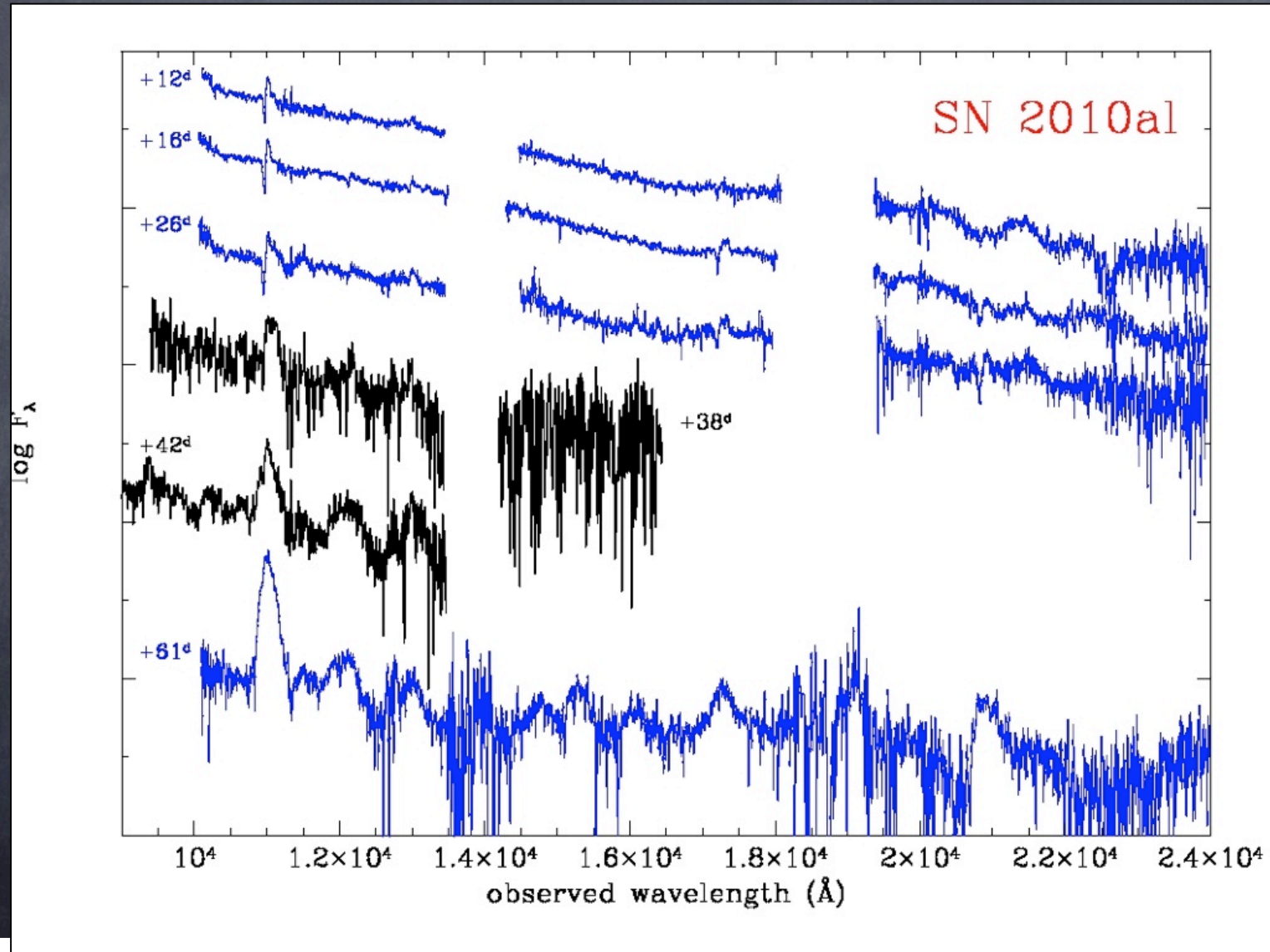
Pastorello et al. 2010c in preparation



# The type Ibn SN 2010al

Pastorello et al. 2010c in preparation

Preliminary Results!





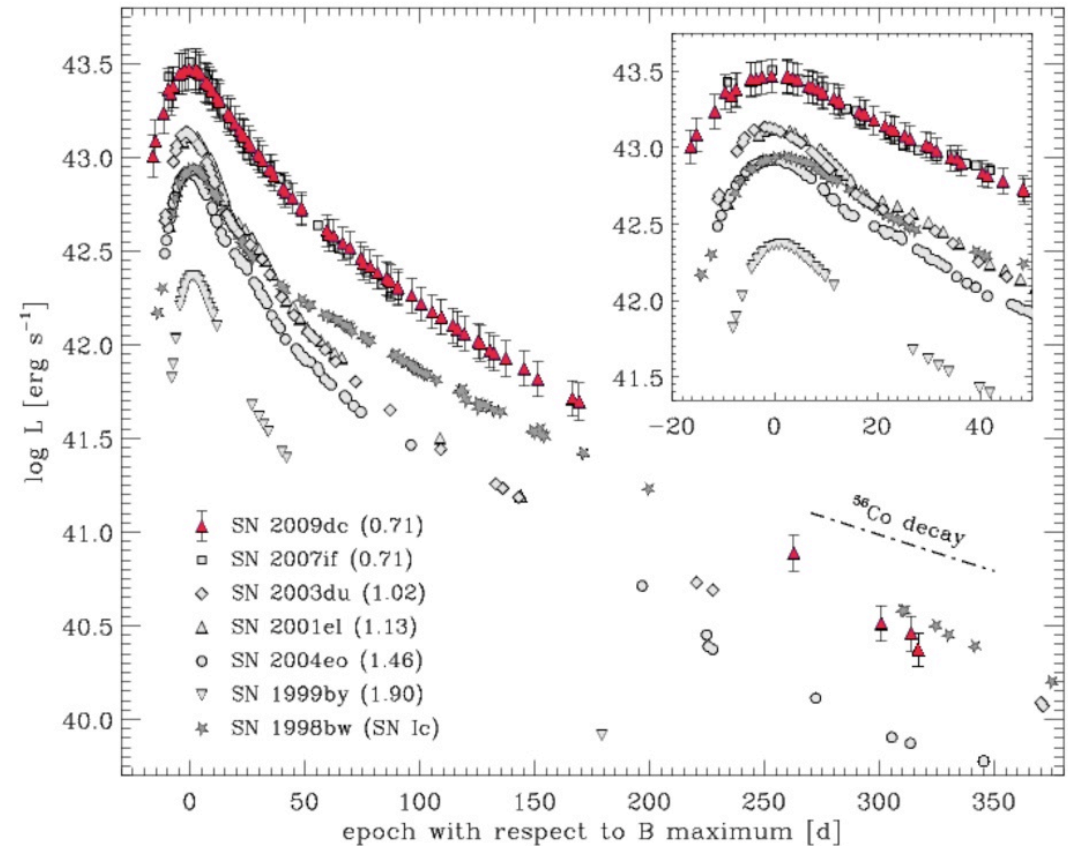
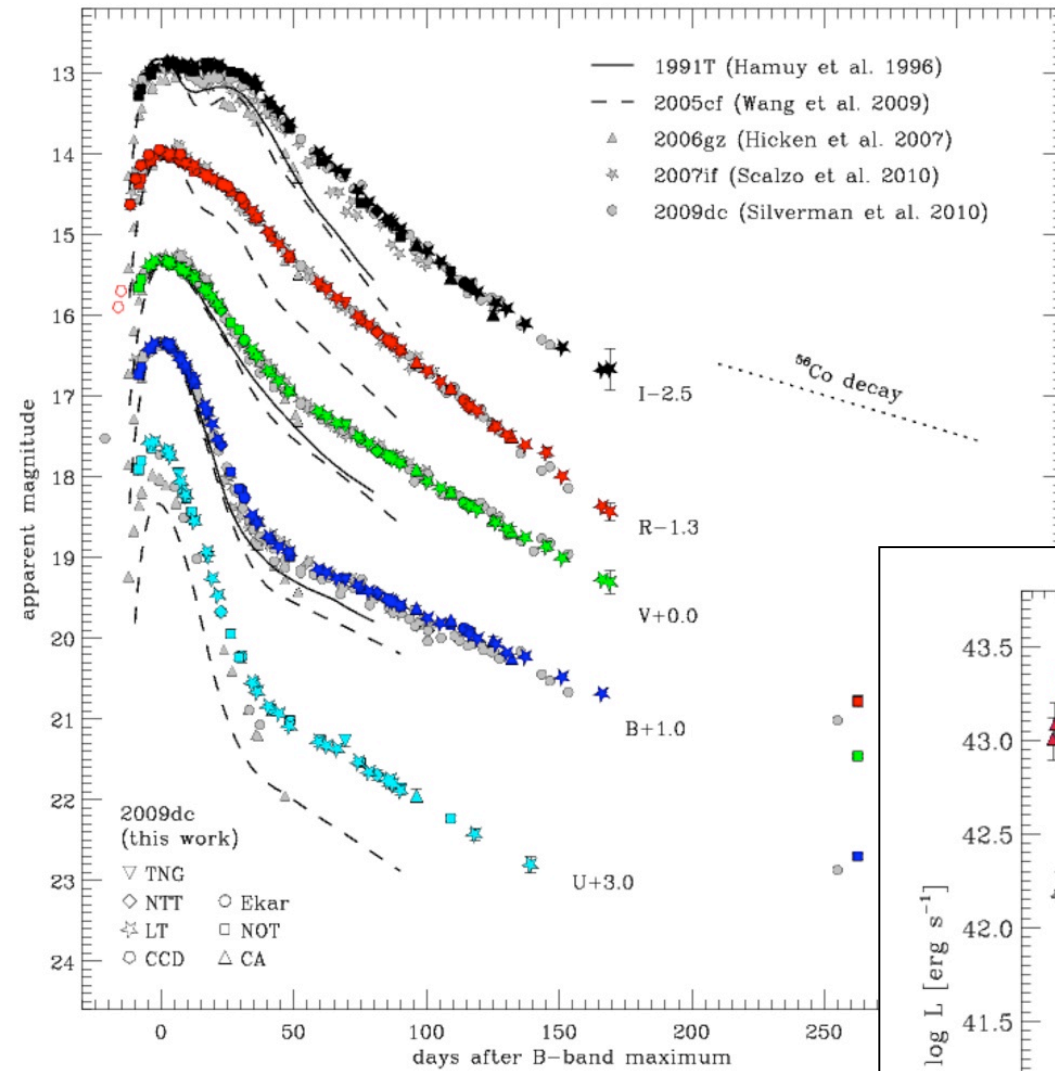
# Super-Chandrasekhar Mass Type Ia SNe?

## MODELS

- Off-center explosions of canonical Chandrasekhar mass WDs
- Rapidly rotating super-Chandra WDs
- WD mergers (about  $1.2M_{\odot}+1.2M_{\odot}$ )
- Type I<sub>1/2</sub> SNe (thermonuclear explosions of  $2.5-3M_{\odot}$  AGB-star cores)
- Core-collapse SNe from stripped-envelope, massive stars

# SN 2009dc

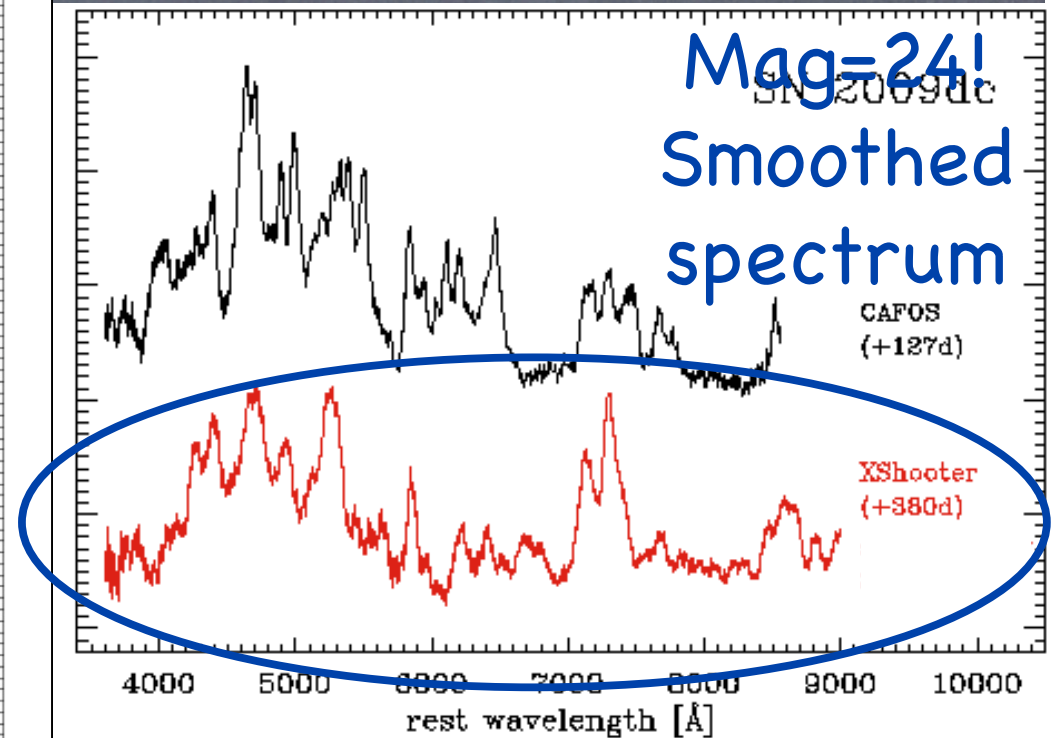
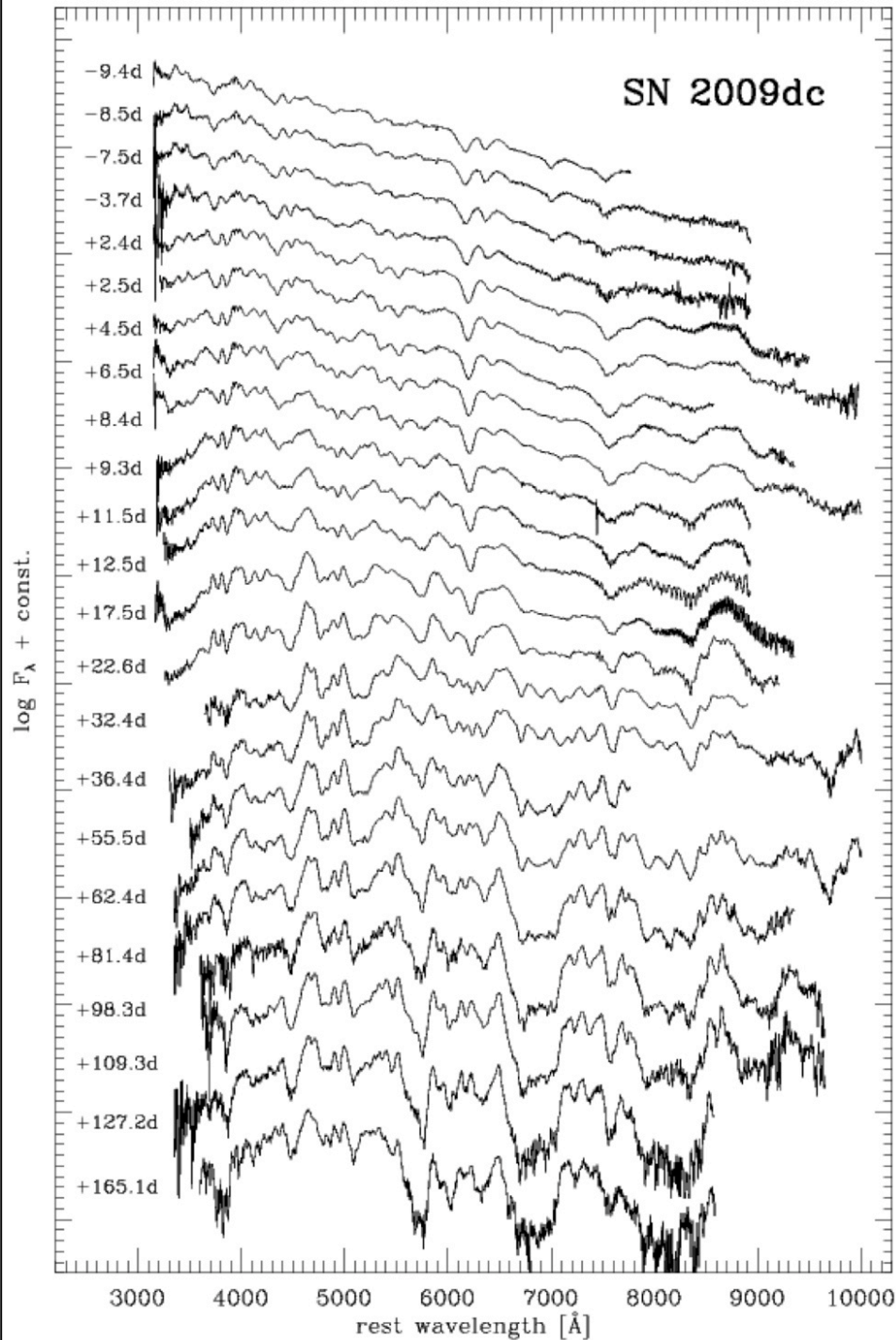
Taubenberger et al. 2010,  
MNRAS, submitted



# SN 2009dc

Taubenberger et al. 2010

Preliminary Results!





# Summary

Discoveries of new SN types are revolutionizing our knowledge of how massive stars end their lives

\* Contribution of XShooter:

1. Characterization of SNe in a wide range of wavelengths => SED
2. Spectral resolution for narrow-lined (IIn/Ibn) SNe (e.g. SNe 1996an, 2009kn, 2010al)
3. Great efficiency to follow faint SNe until late phases (see the spectrum of SN 2009dc at mag 24!)