# SN 2002cx-like Supernovae

## *The Power of Nebular Spectroscopy*


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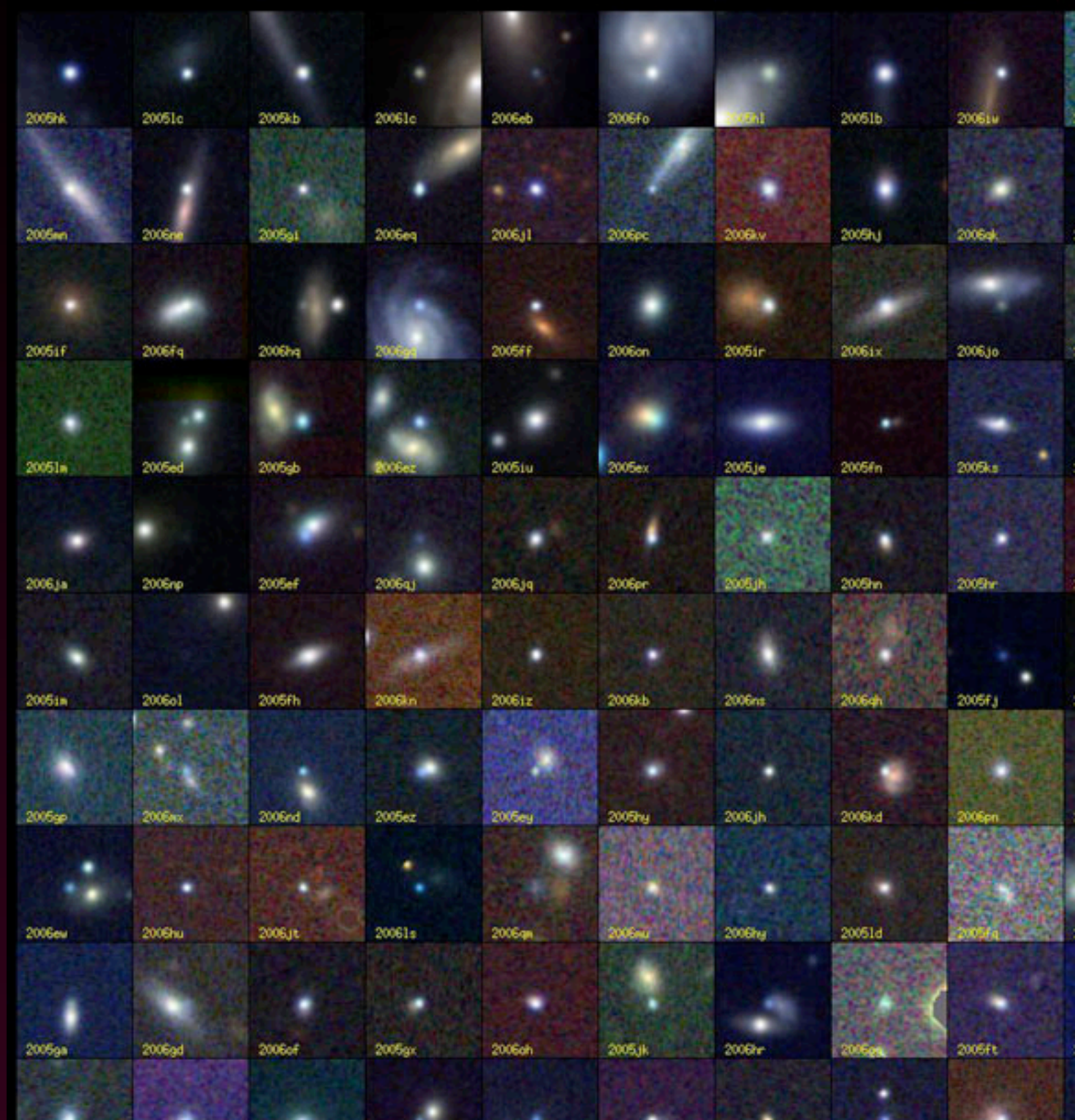
THE STATE UNIVERSITY OF NEW JERSEY

with

Curtis McCully (see poster),
A. Filippenko, R. Chornock,
W. Li, J. Silverman, T. Steele,
M. Ganeshalingam (UCB),
R. Foley (CfA),
D. Branch (Oklahoma),
P. Garnavich (Notre Dame),
A. Riess (JHU),
M. Phillips (Carnegie/LCO)
and the SDSS SN Survey
(incl. J. Holtzman, J. Frieman,
C. Wheeler, B. Dilday)



Stellar Death and Supernovae
KITP/UCSB August 19, 2009

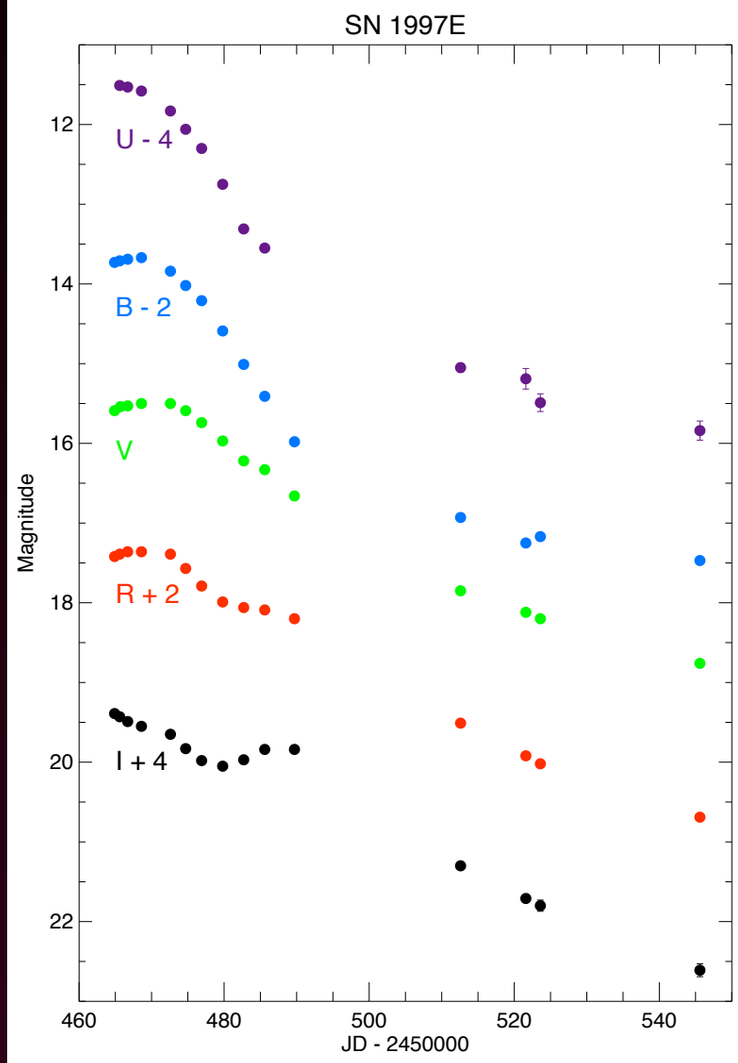



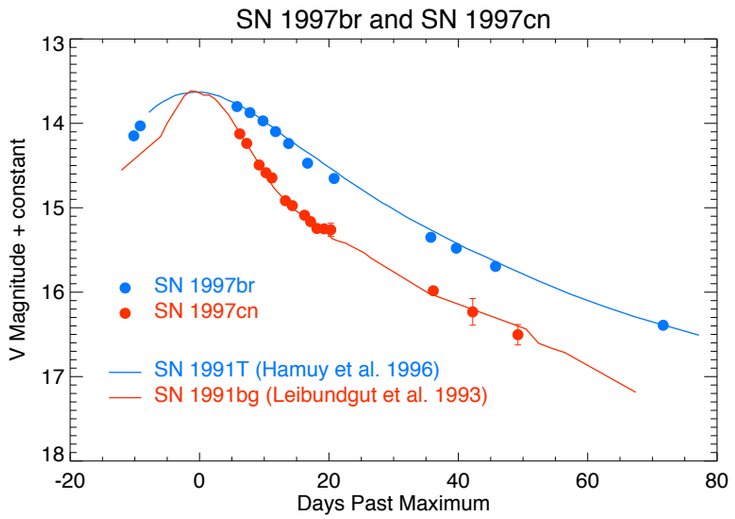
# Historical Interlude

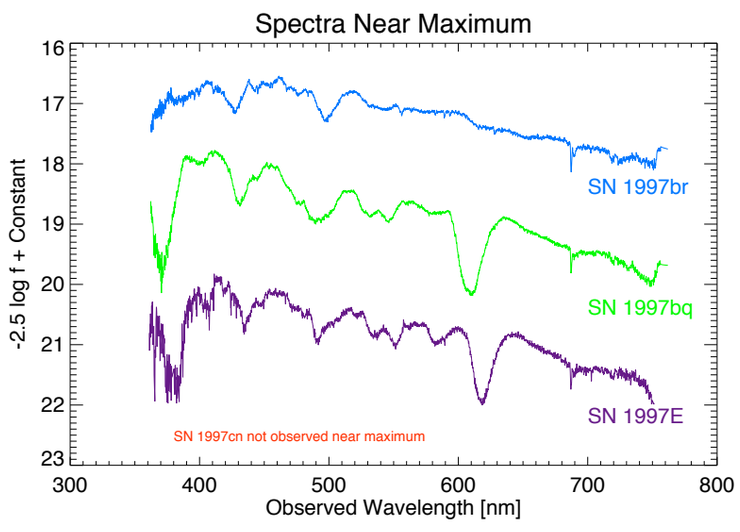
## Recent Type-Ia Supernova Light Curves

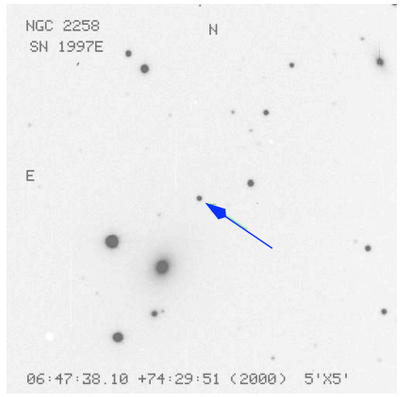
Saurabh Jha, Alicia M. Soderberg, Peter M. Challis,
Peter M. Garnavich and Robert P. Kirshner

*Harvard-Smithsonian Center for Astrophysics*

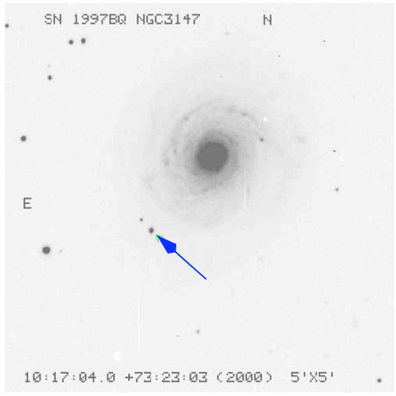


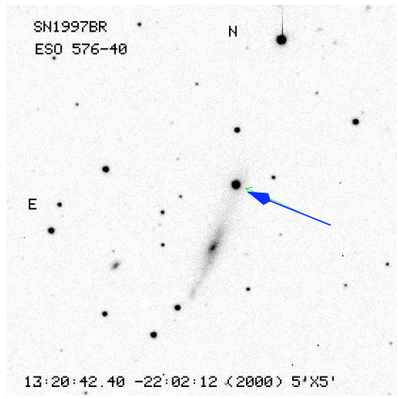




SN 1997E

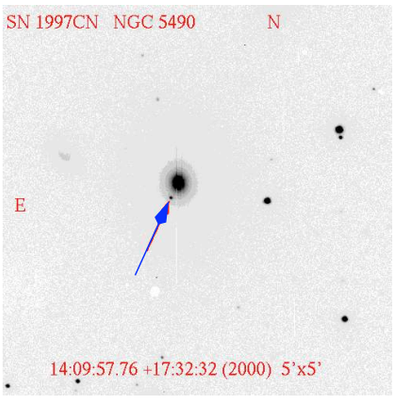



SN 1997bq

SN 1997br




SN 1997cn

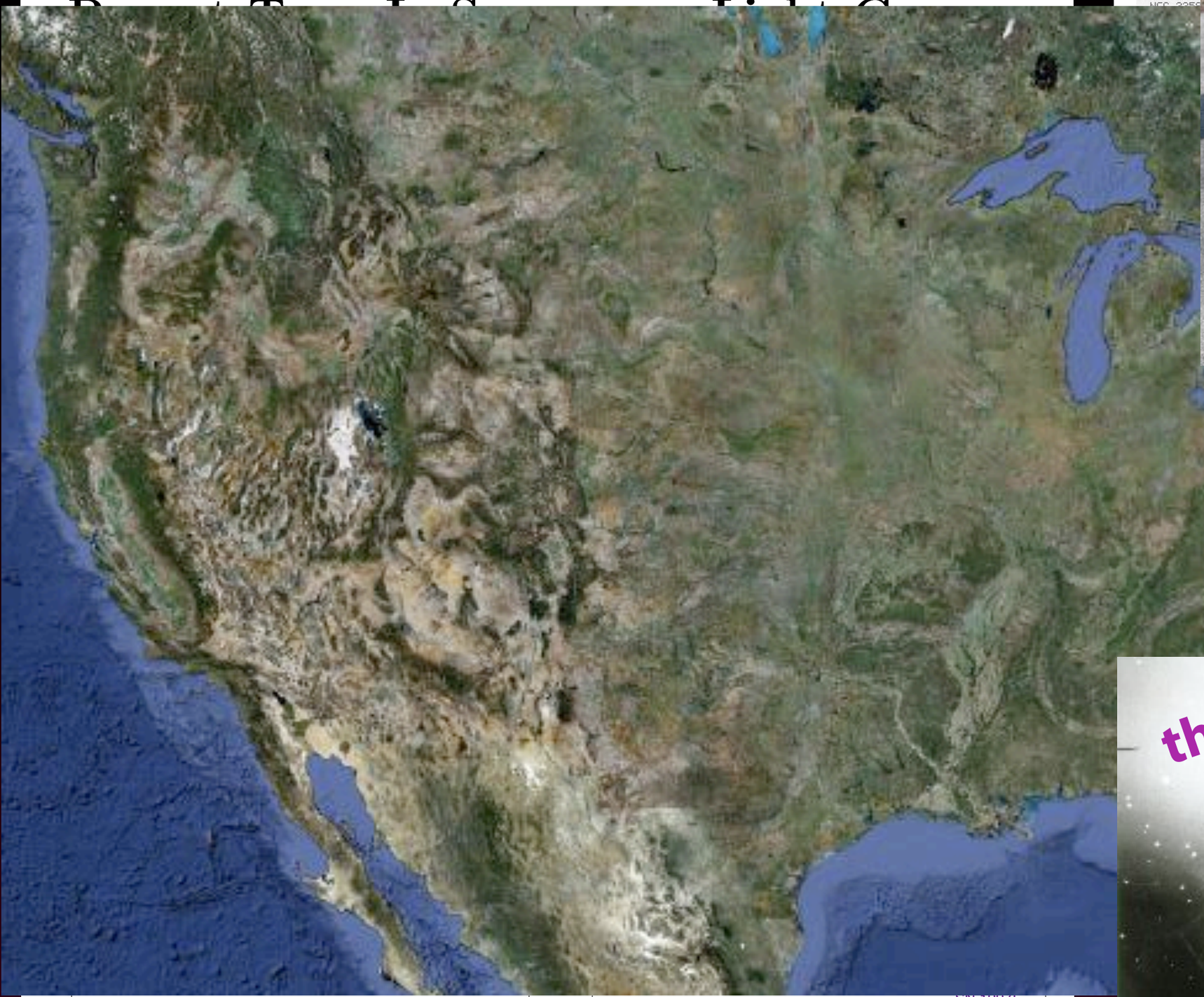


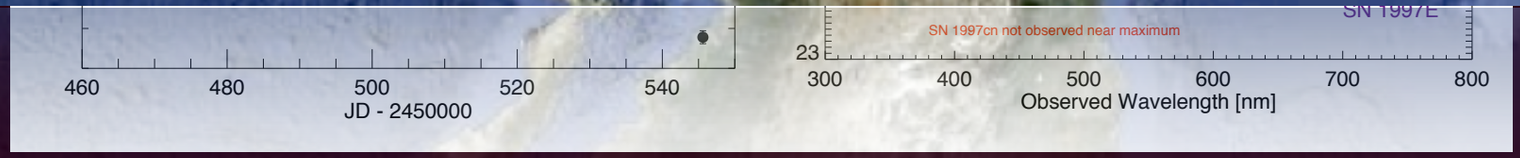


poster @ KITP Supernova Explosions: Their Causes and Consequences 1997

RPK, ca. 1997 (?)

# Historical Interlude



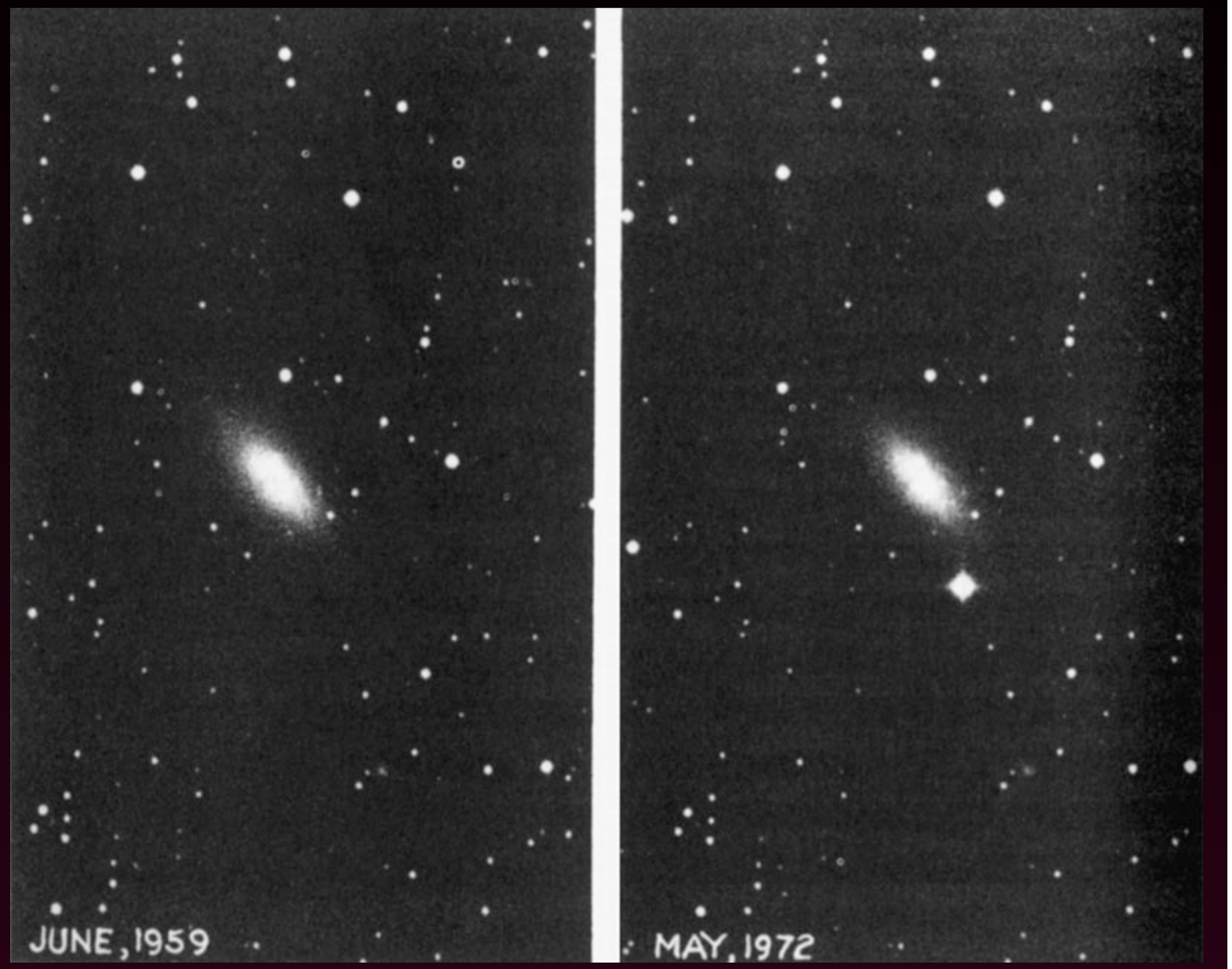




poster @ KITP  Supernova Explosions: Their Causes and Consequences  1997

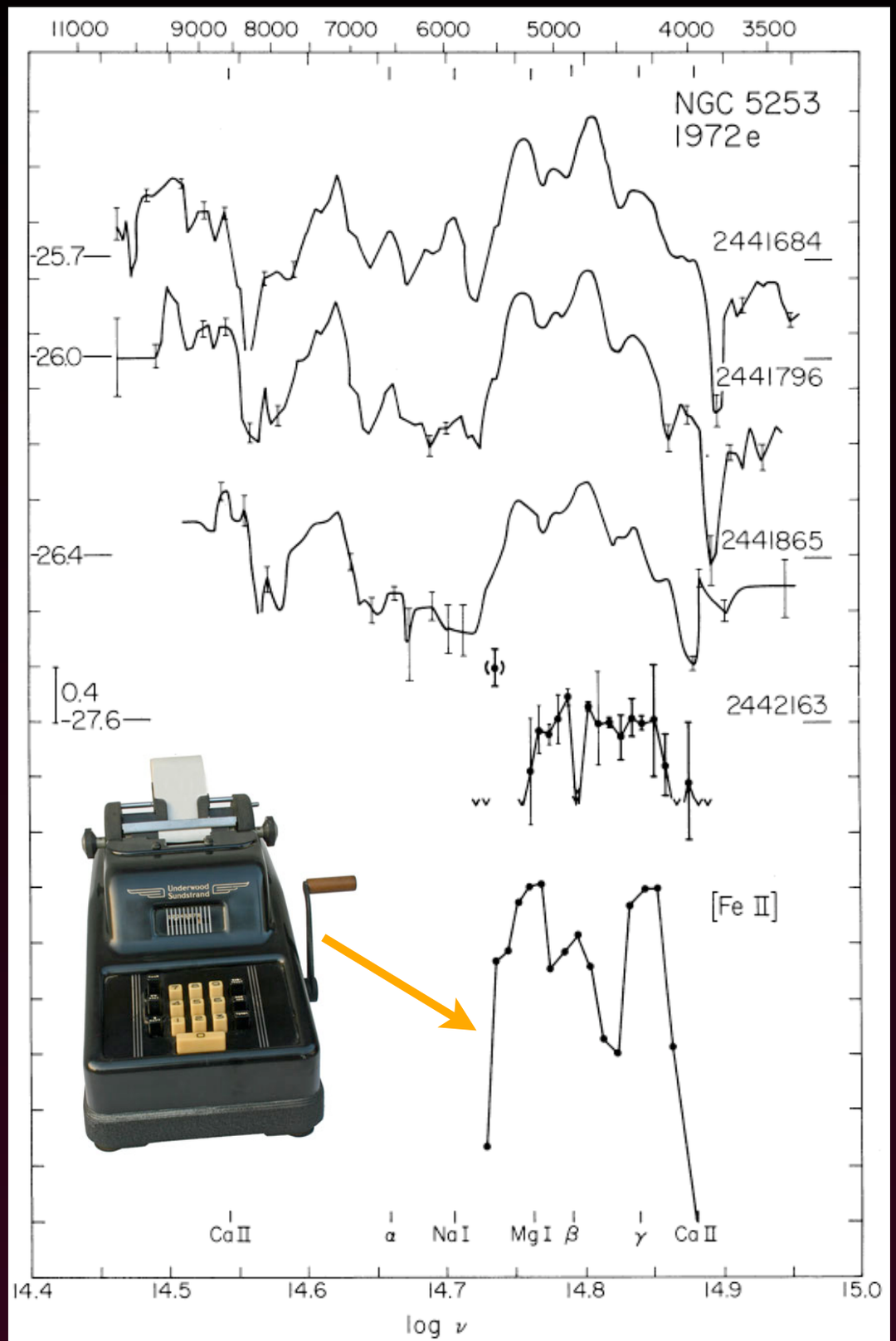
RPK, ca. 1997 (?)

# The Power of Nebular Spectroscopy

## forbidden lines, optically thin → see "through" the ejecta




SN 1972E in NGC 5253




Kirshner & Oke (1975)

# The Power of Nebular Spectroscopy

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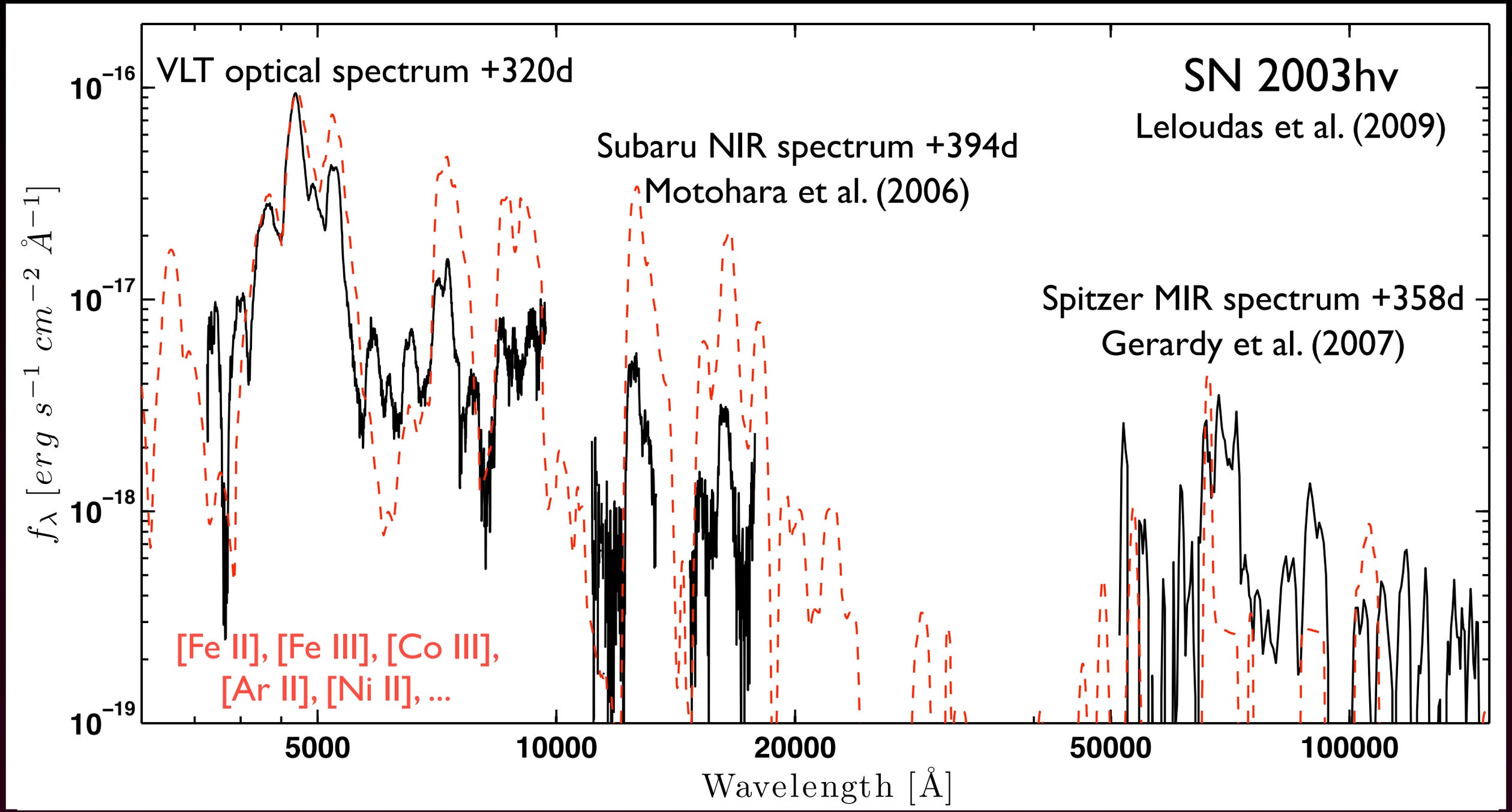
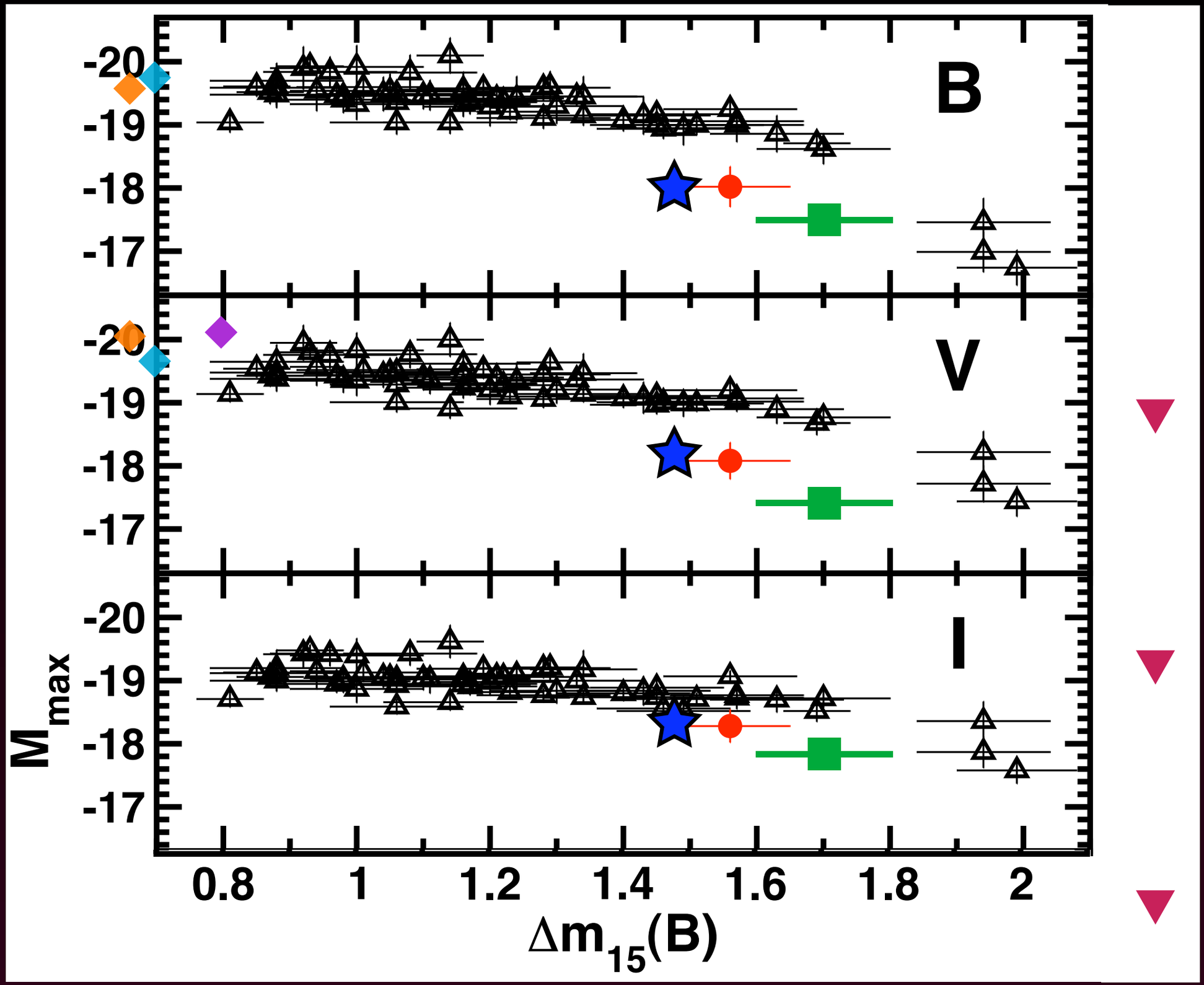



can directly probe spatial and velocity distribution of ejecta,
as well as $^{56}$Ni production (e.g., Mazzali et al. 2007)

# Peculiar SNe Ia

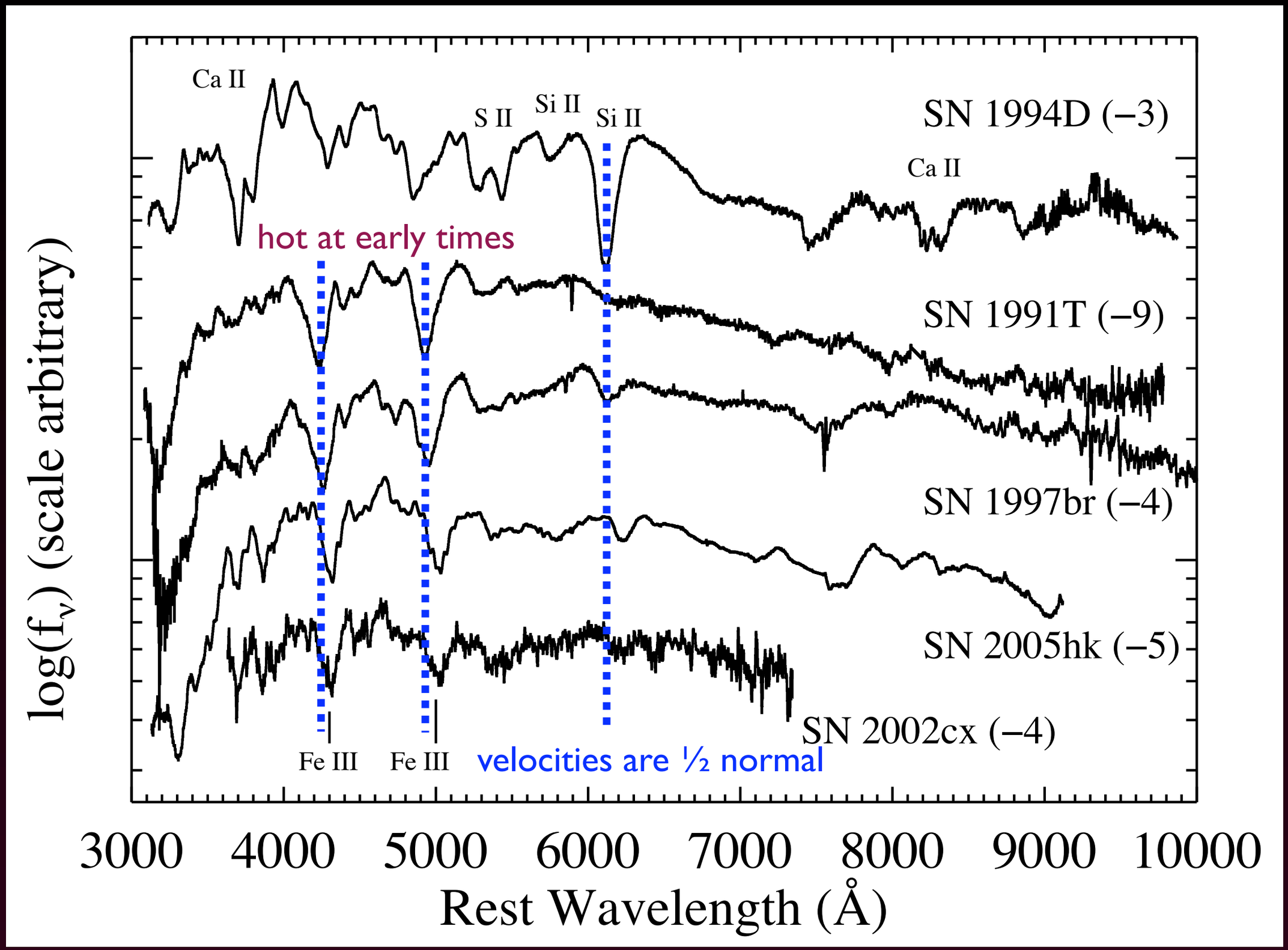



SN 2002cx
SN 2005hk
SN 2008A
SN 2008ha
SN 2003fg
SN 2006gz
SN 2009dc

Li et al. (2003)
Foley et al. (2009)
Howell et al. (2006)
Hicken et al. (2007)
Yamanaka et al. (2009)

adapted from Phillips et al. (2007)

# These are Type Ia Supernovae



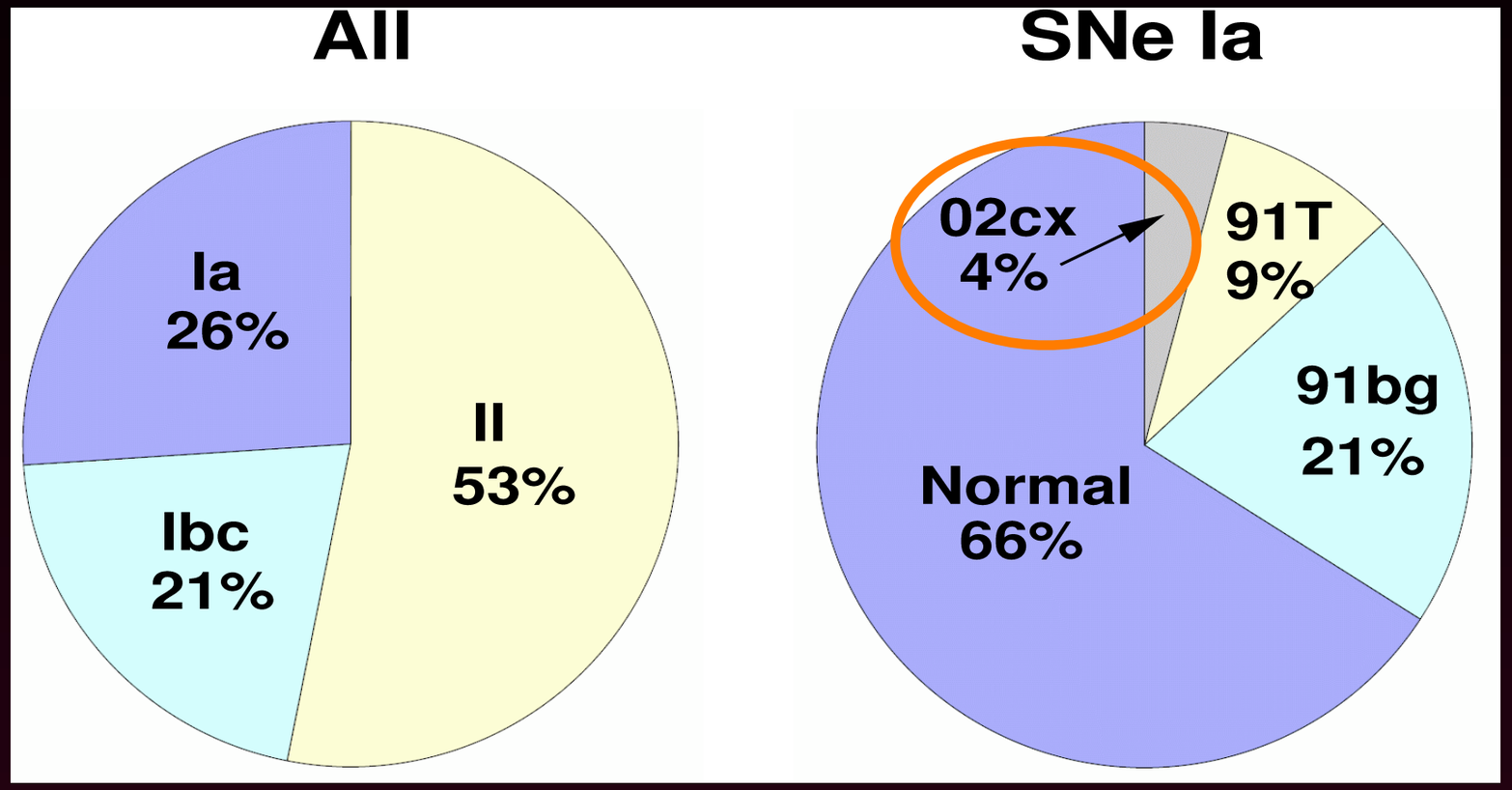

Chornock et al. (2006)

# These are a Class

SN 1991bj
SN 2002cx
SN 2003gq
SN 2004gw
SN 2005P
SN 2005cc
SN 2005hk
SN 2006hn
SN 2007J (?)
SN 2007qd
SN 2008A
SN 2008ae
SN 2008ge
SN 2008ha (?)
SN 2009J
SN 2009ho (?)
...

Foley et al. (2009)
and references therein

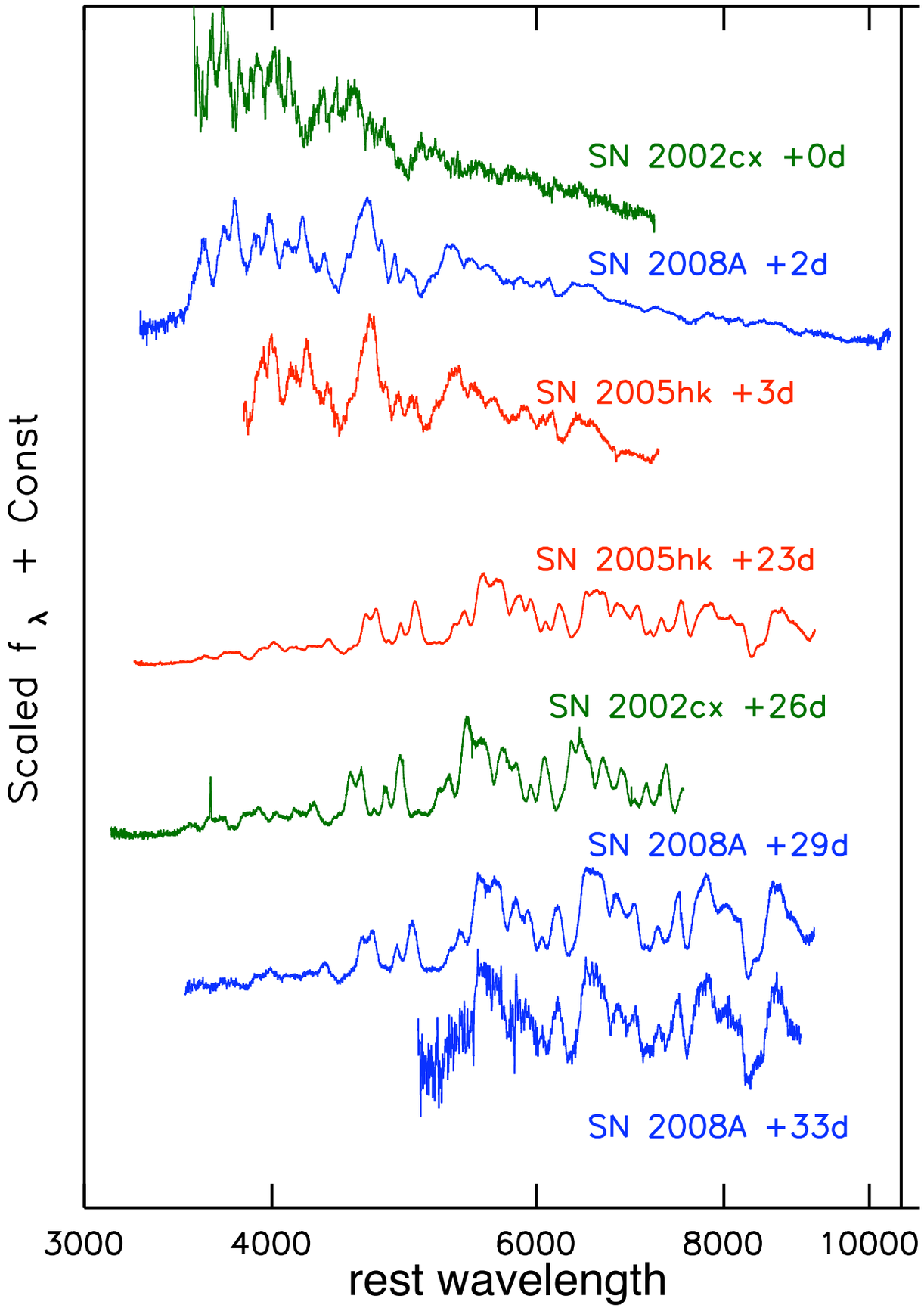
Lick Observatory SN Search
Volume-limited subtype frequencies

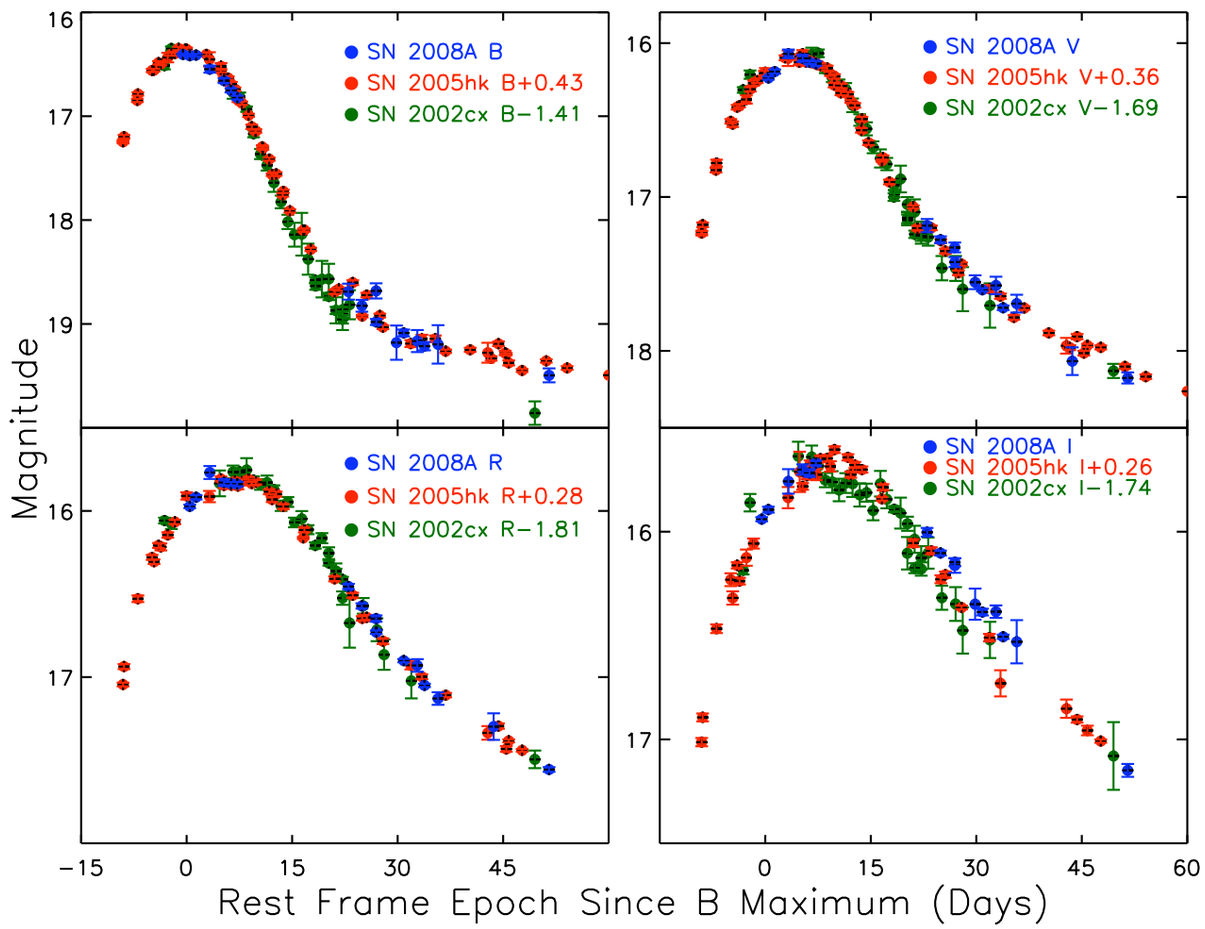


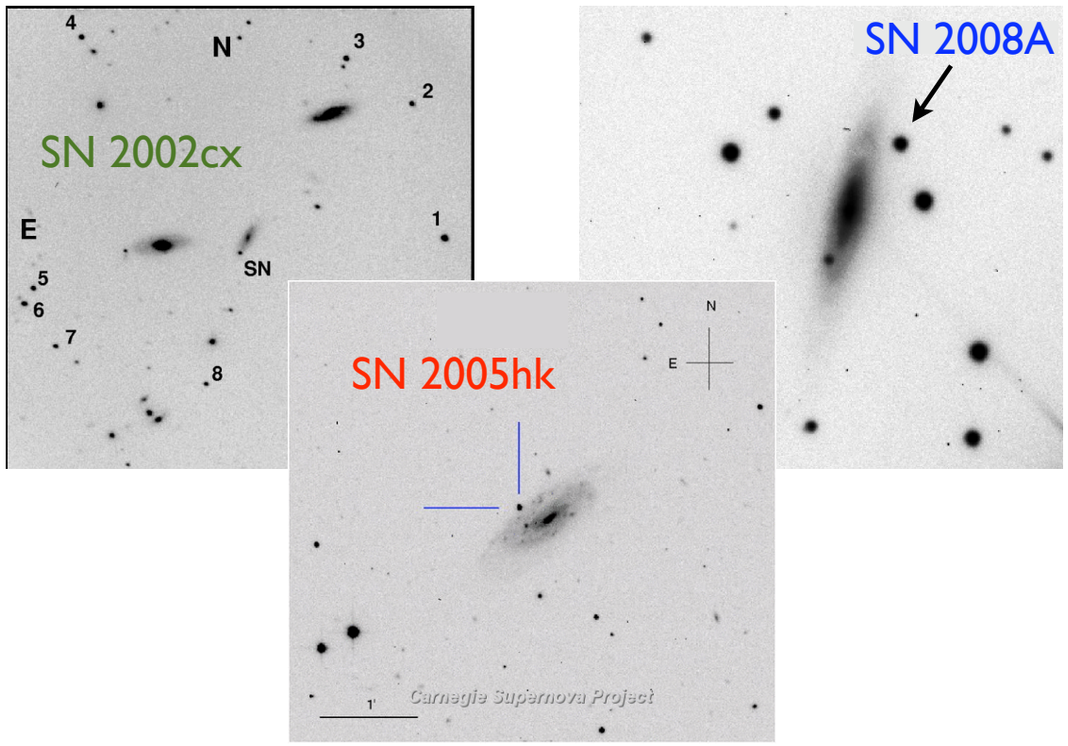

Li et al. (2009, in prep)

# Head of the Class

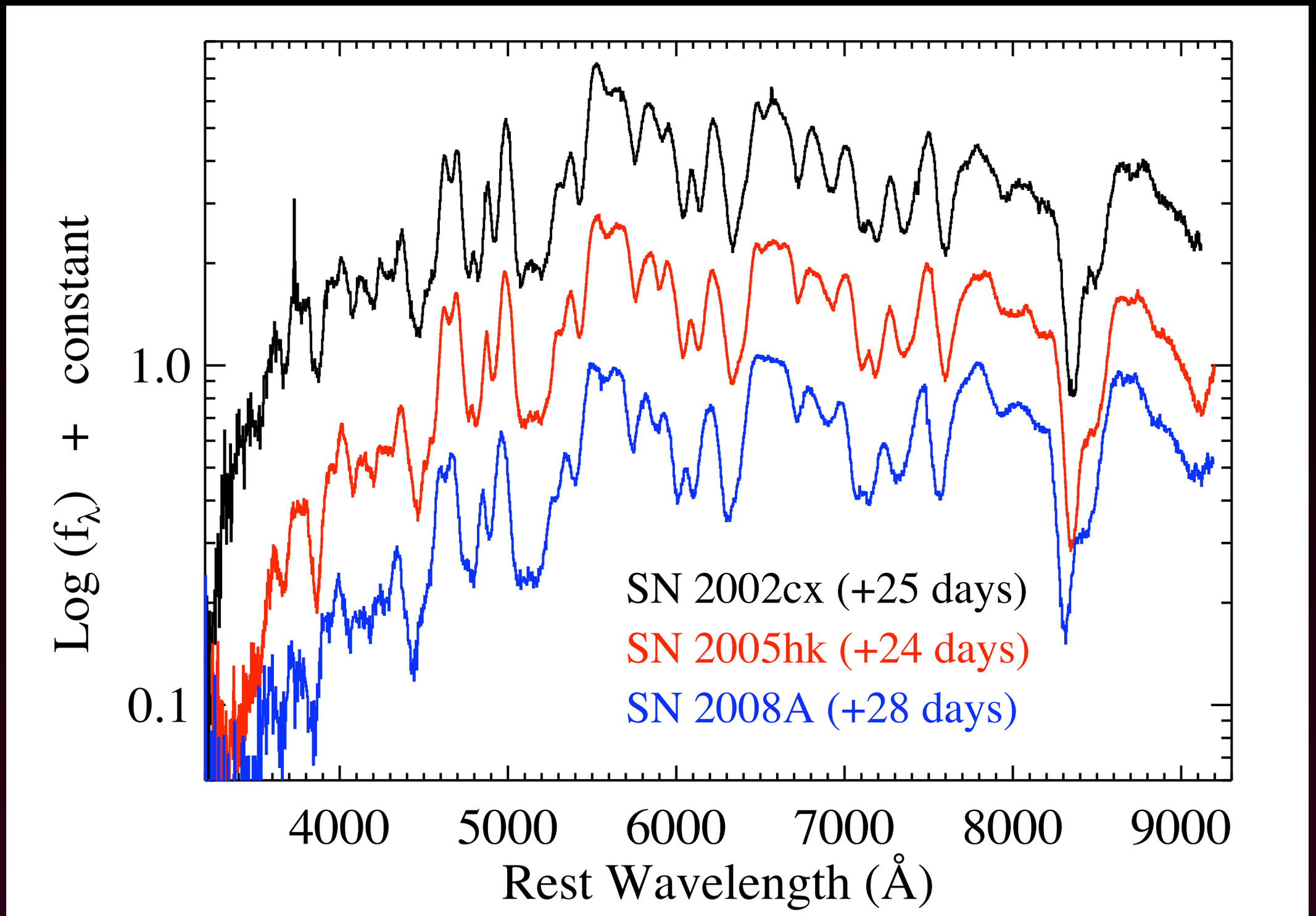
Li et al. (2003), Phillips et al. (2007), McCully et al. (in prep)



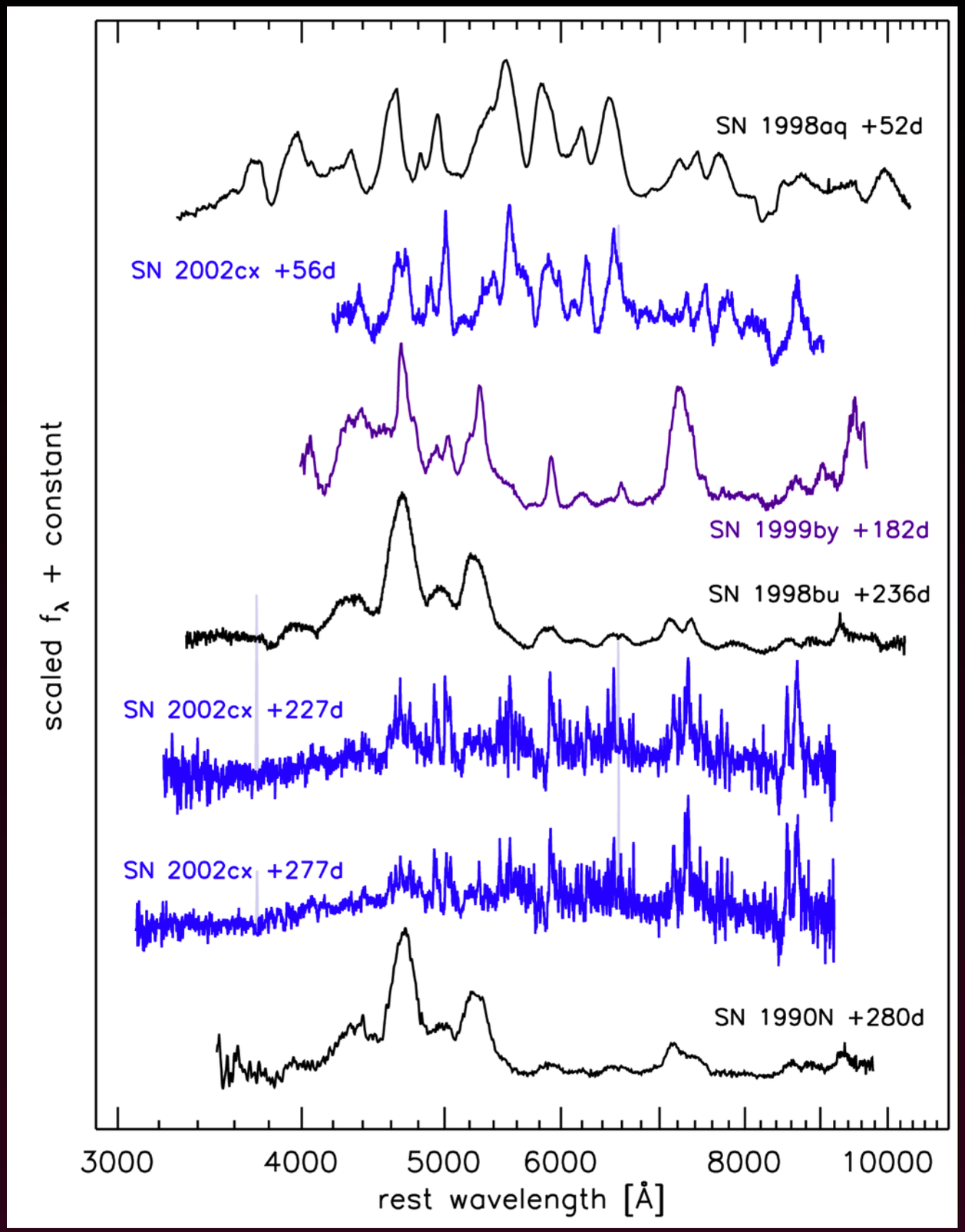



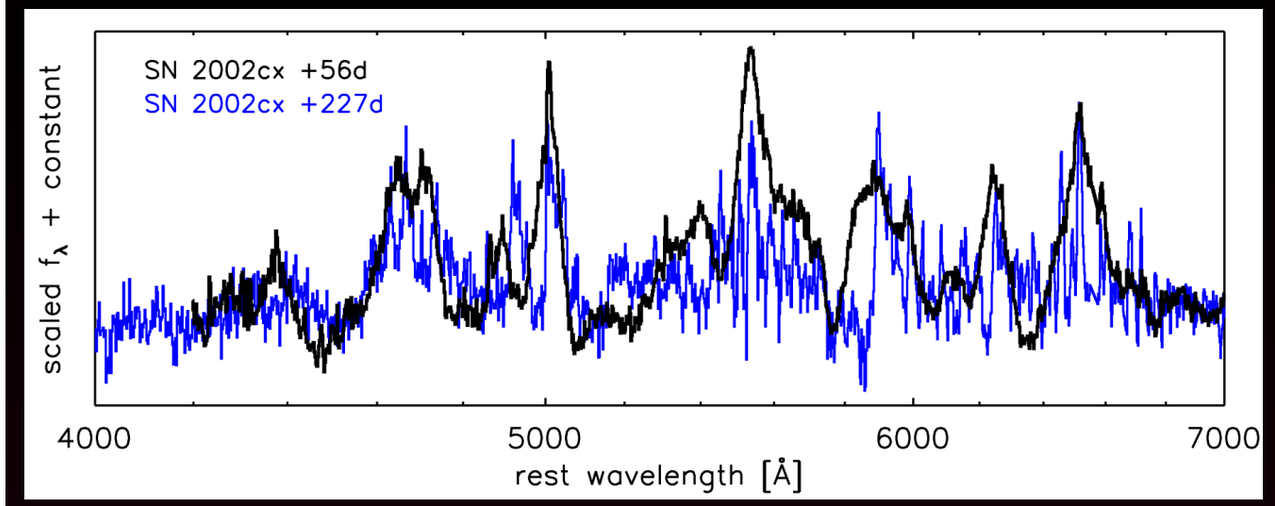
# Remarkable Homogeneity

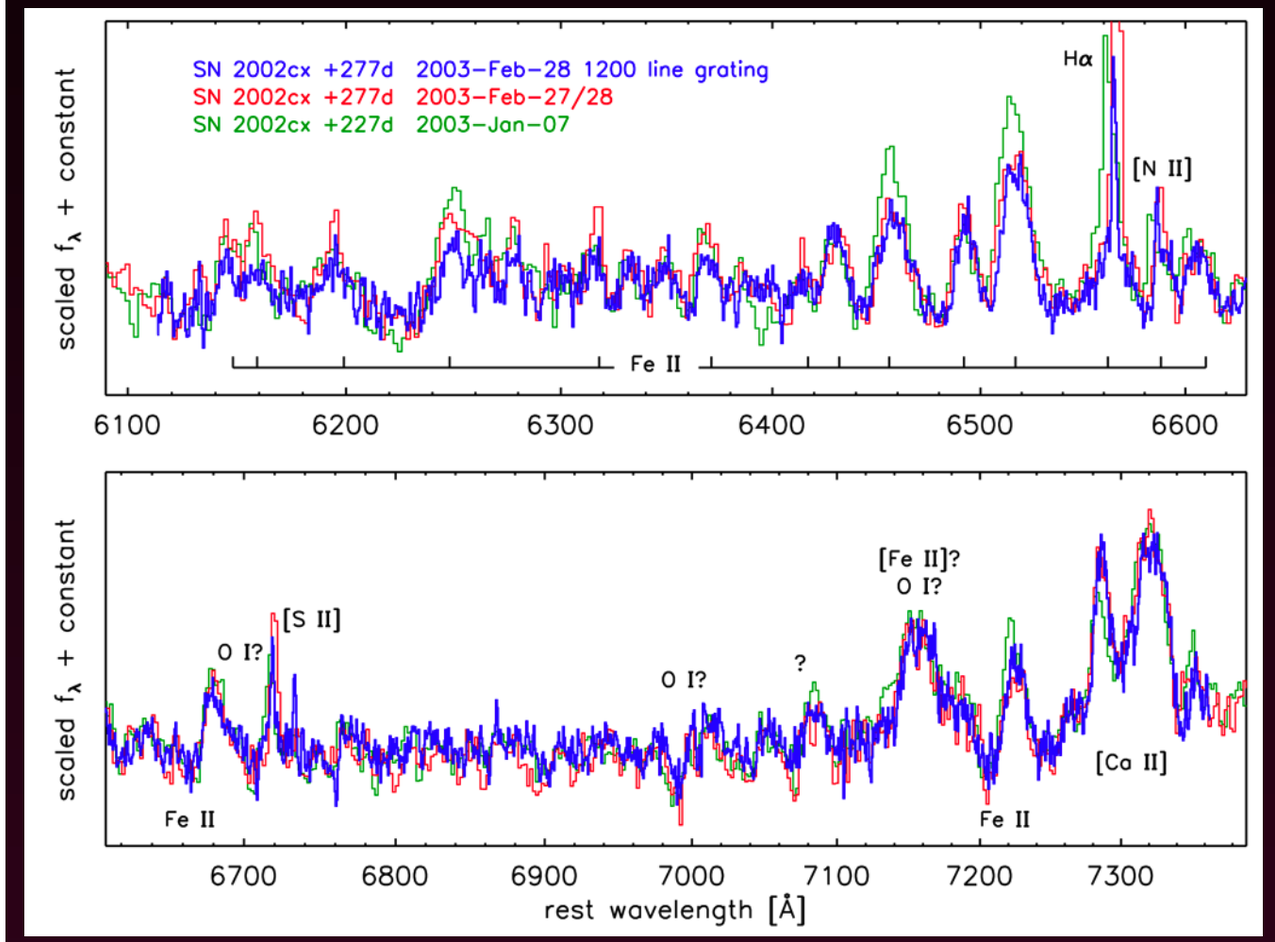



SN 2002cx-like objects more similar to each other than normal SNe Ia are!

# The Power of Nebular Spec...wait, what?!

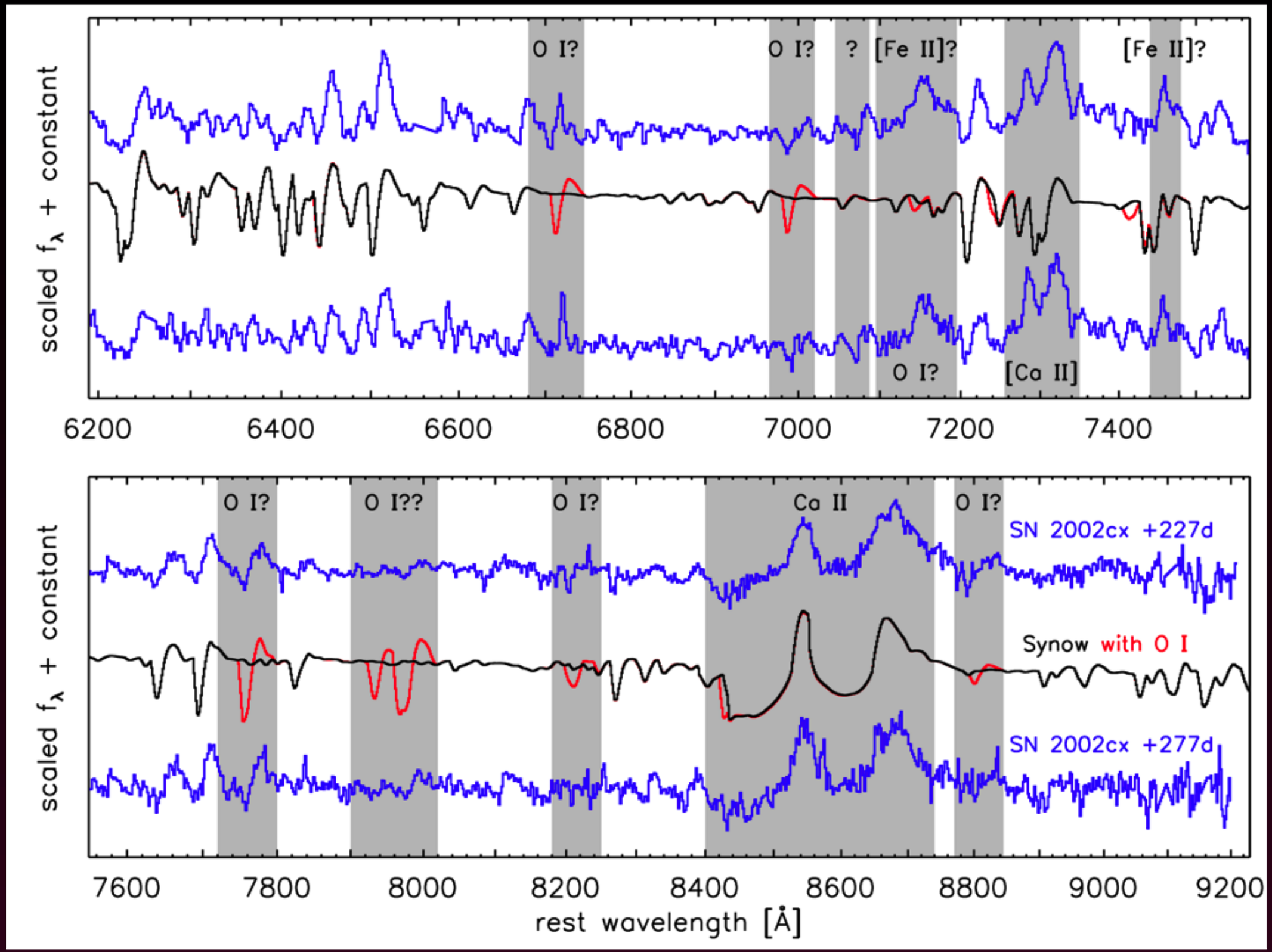


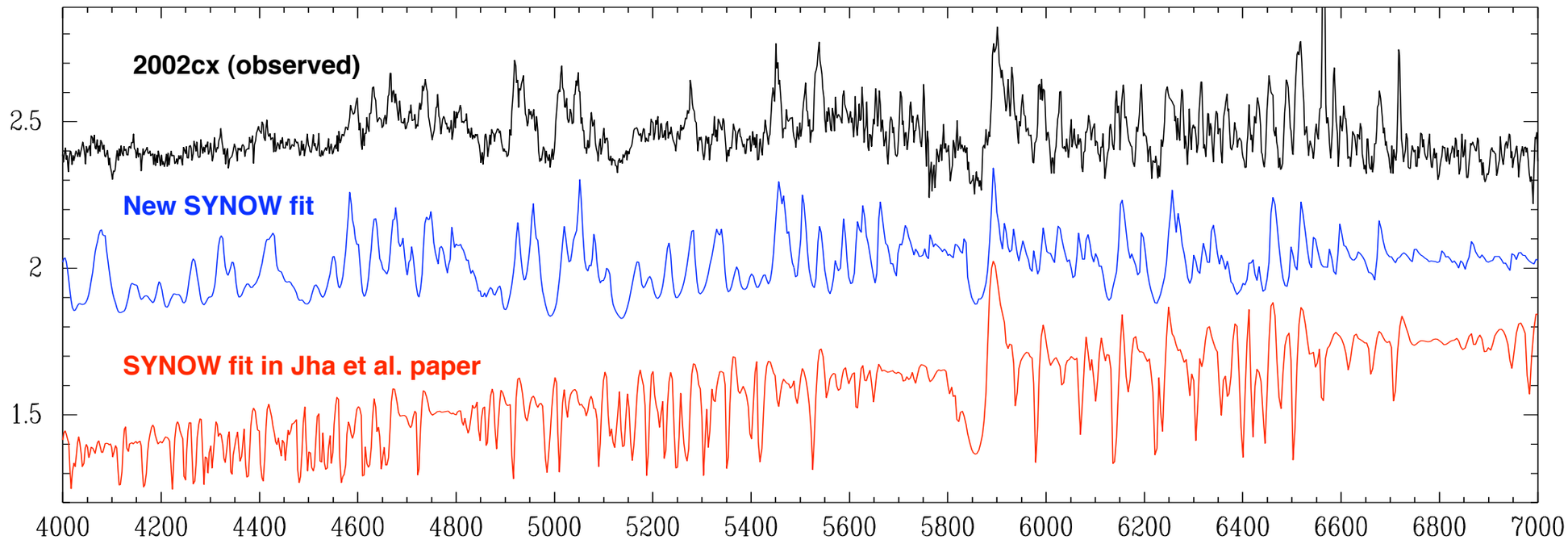

Jha et al. (2006)

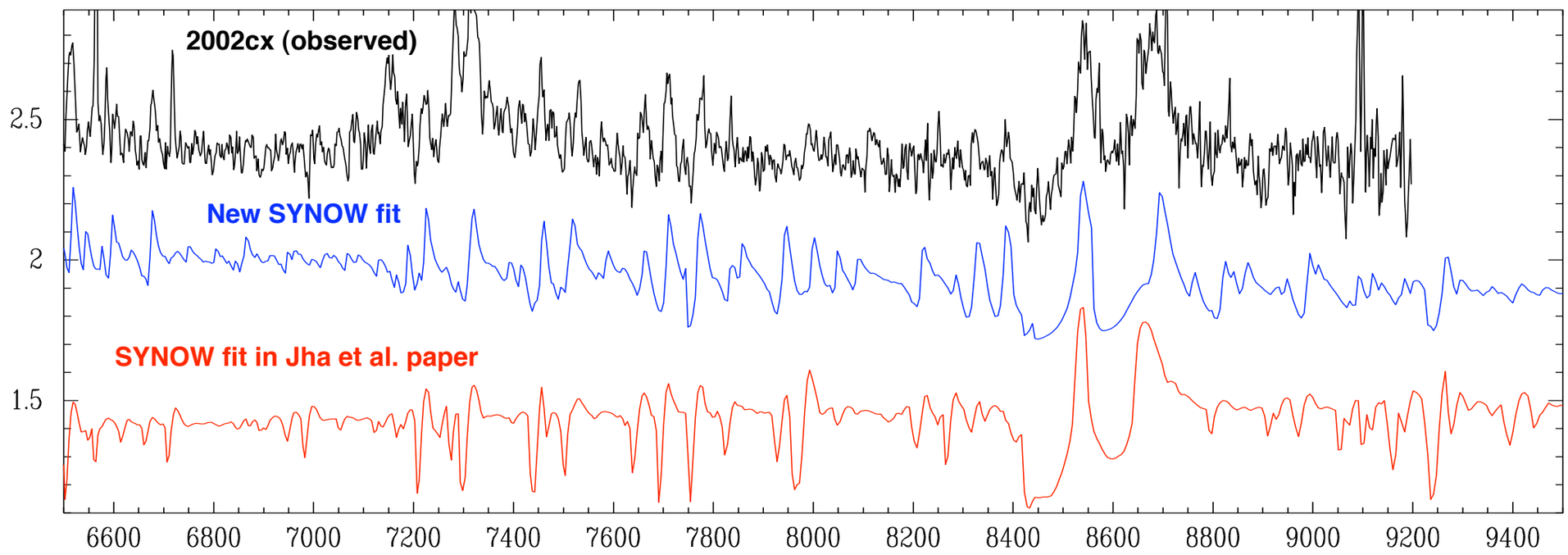
# SN 2002cx Late-Time Spectra




Jha et al. (2006)

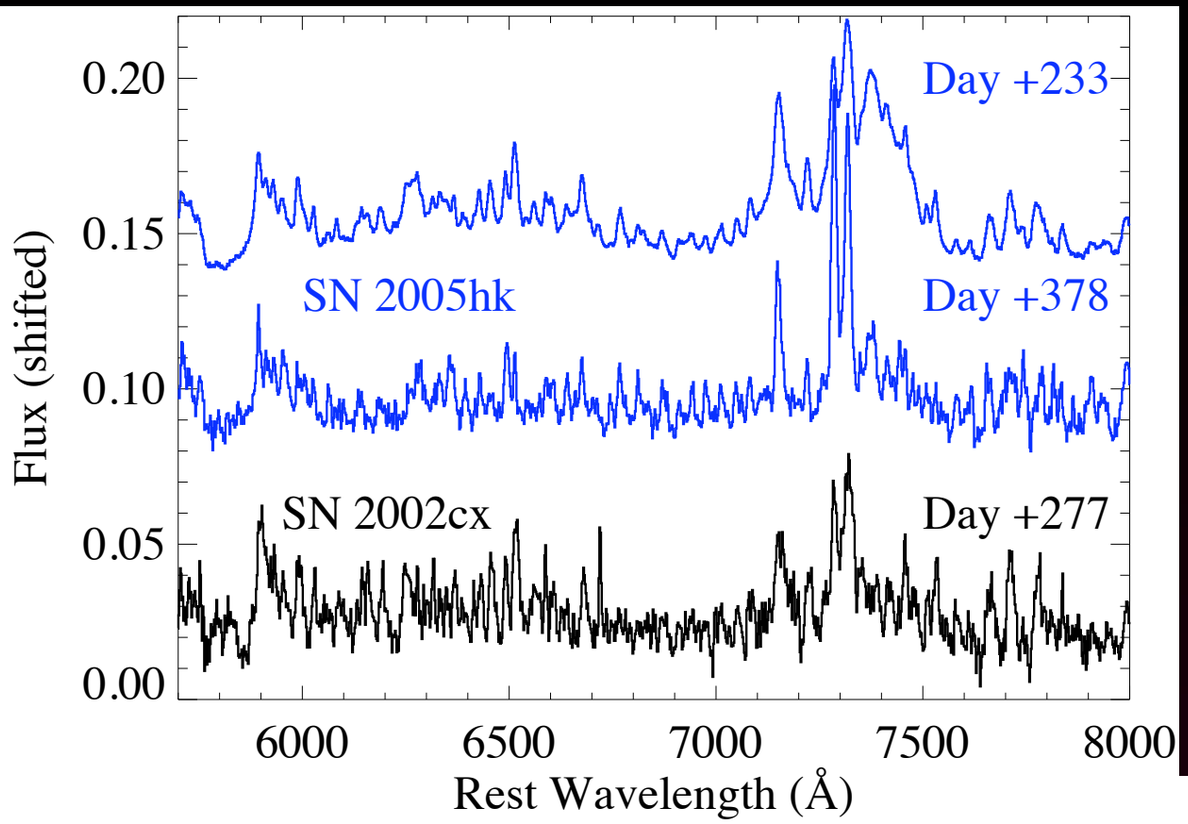
# SN 2002cx: full of iron



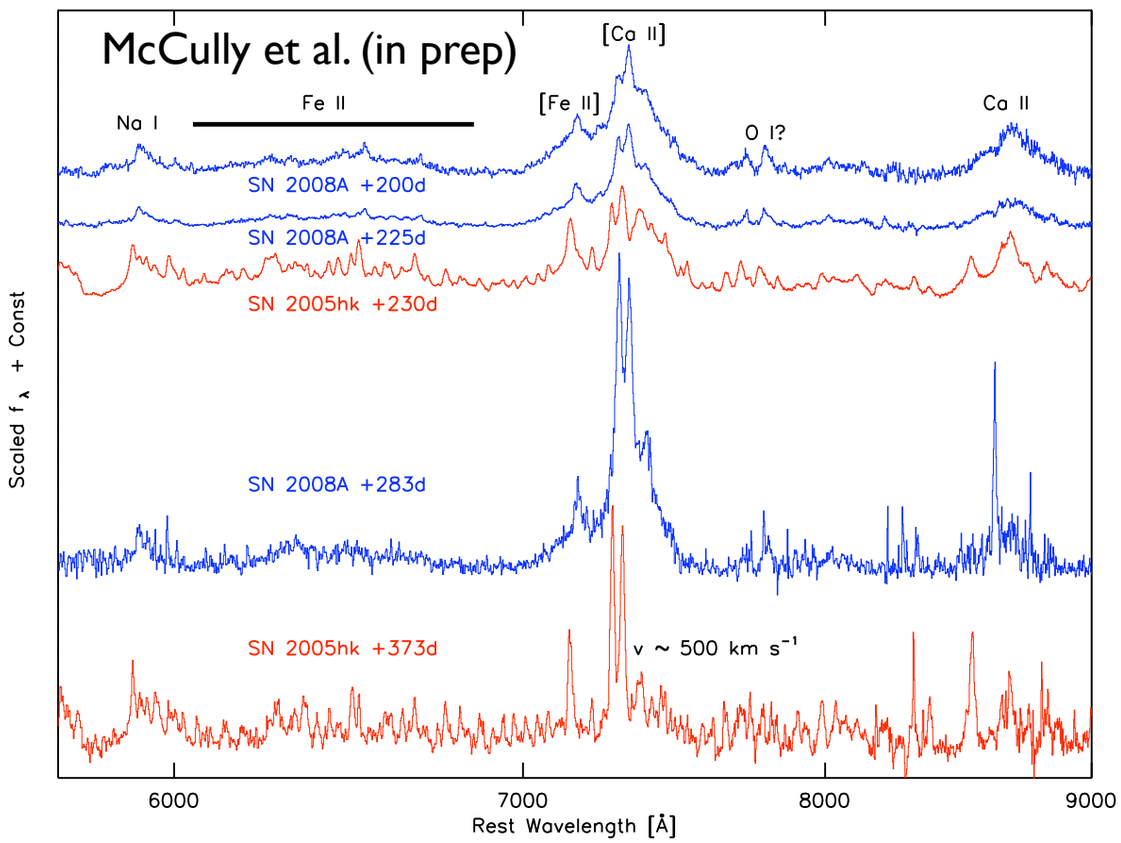



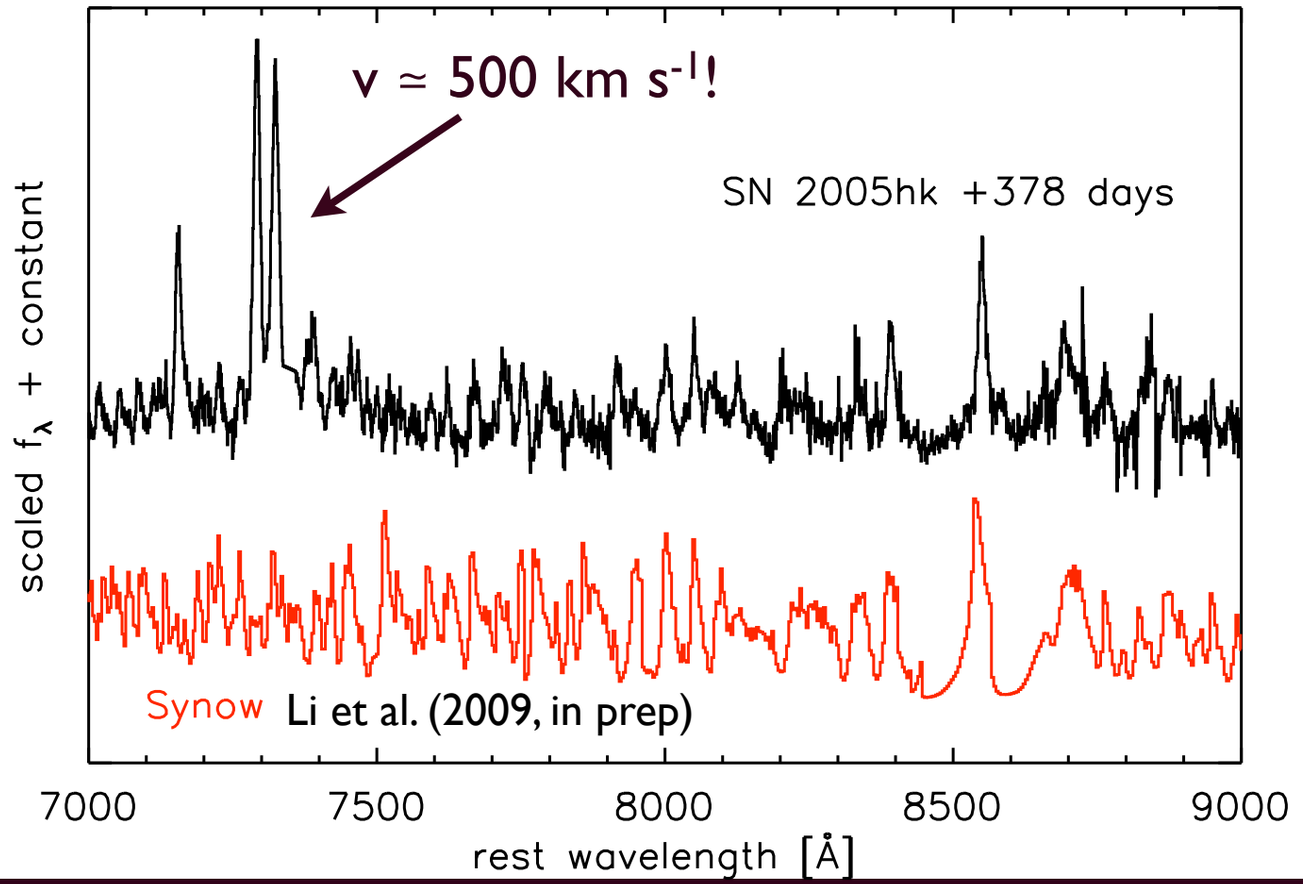

Li et al. (2009, in prep)

# SN 2005hk observed even later

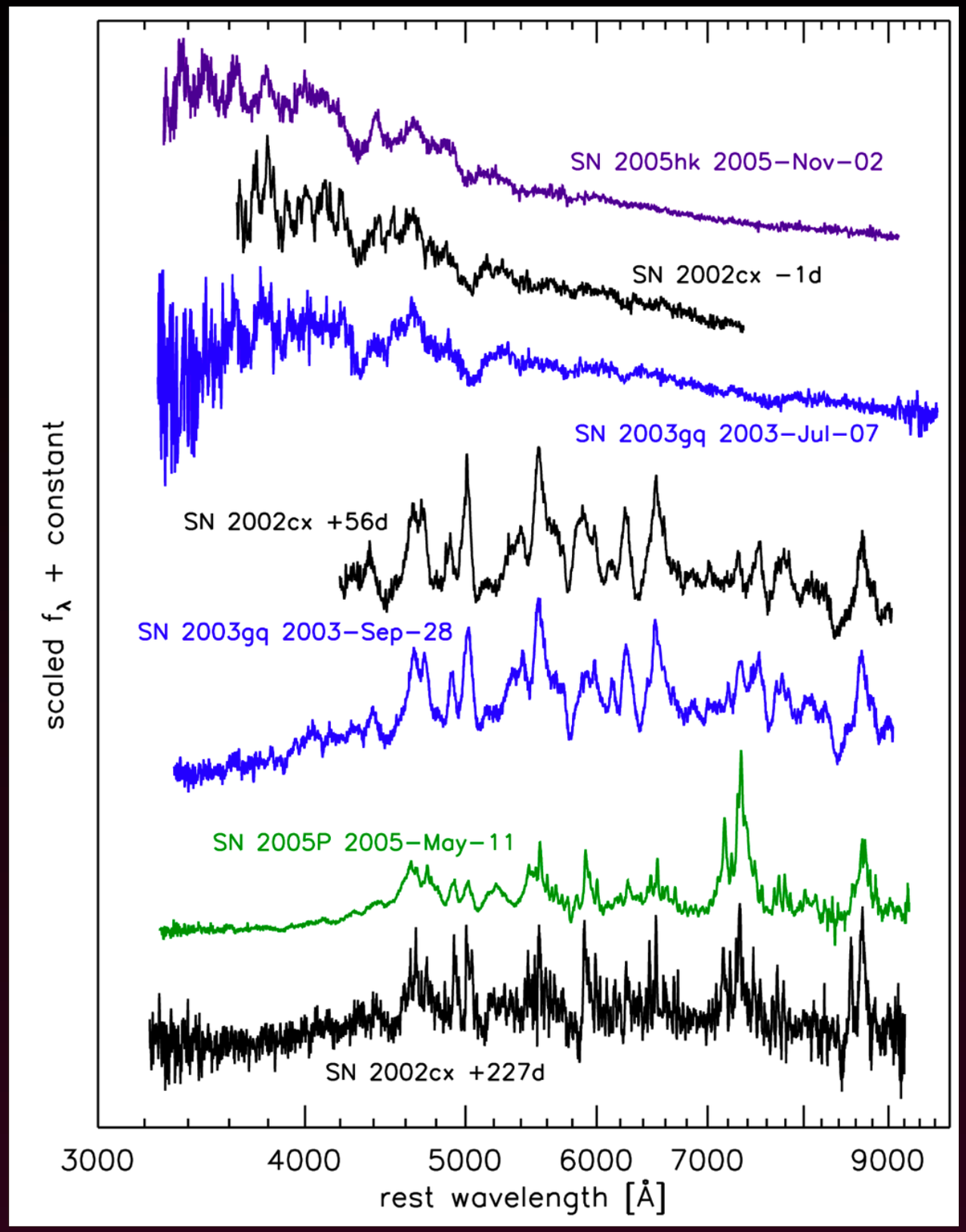



- unprecedentedly low velocities
- still dominated by permitted Fe
- no sign of [O I] 6300 A
- good density diagnostics:
  [Ca II]/Ca II, [Fe II]/Fe II,
  $\gtrsim 10^2$-$10^3$ higher than normal SN Ia



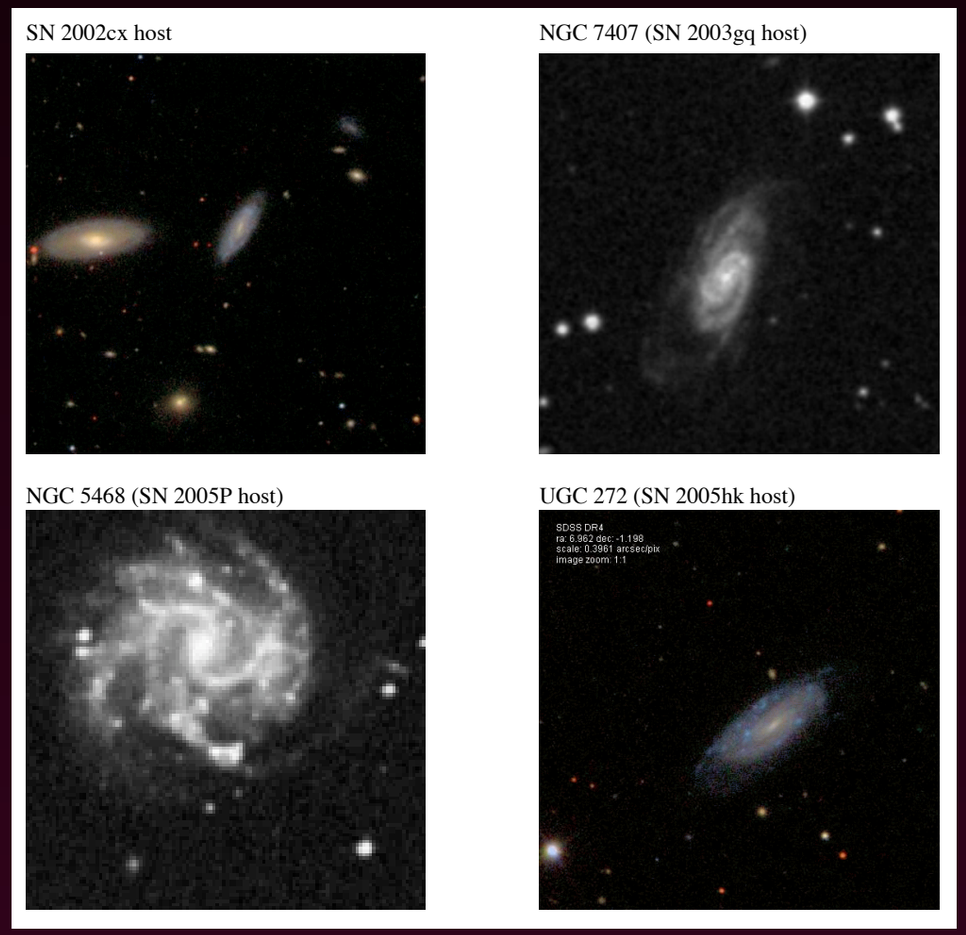



# Properties of the Subclass




Jha et al. (2006)

- like normal SNe Ia, 2005hk has low polarization (Chornock et al. 2006)
- very low velocities and luminosities
- mixed ejecta at all velocities (Fe-peak, IMEs, unburned?)
- low $^{56}$Ni mass, ~ 0.2 $M_\odot$
- majority in late-type hosts

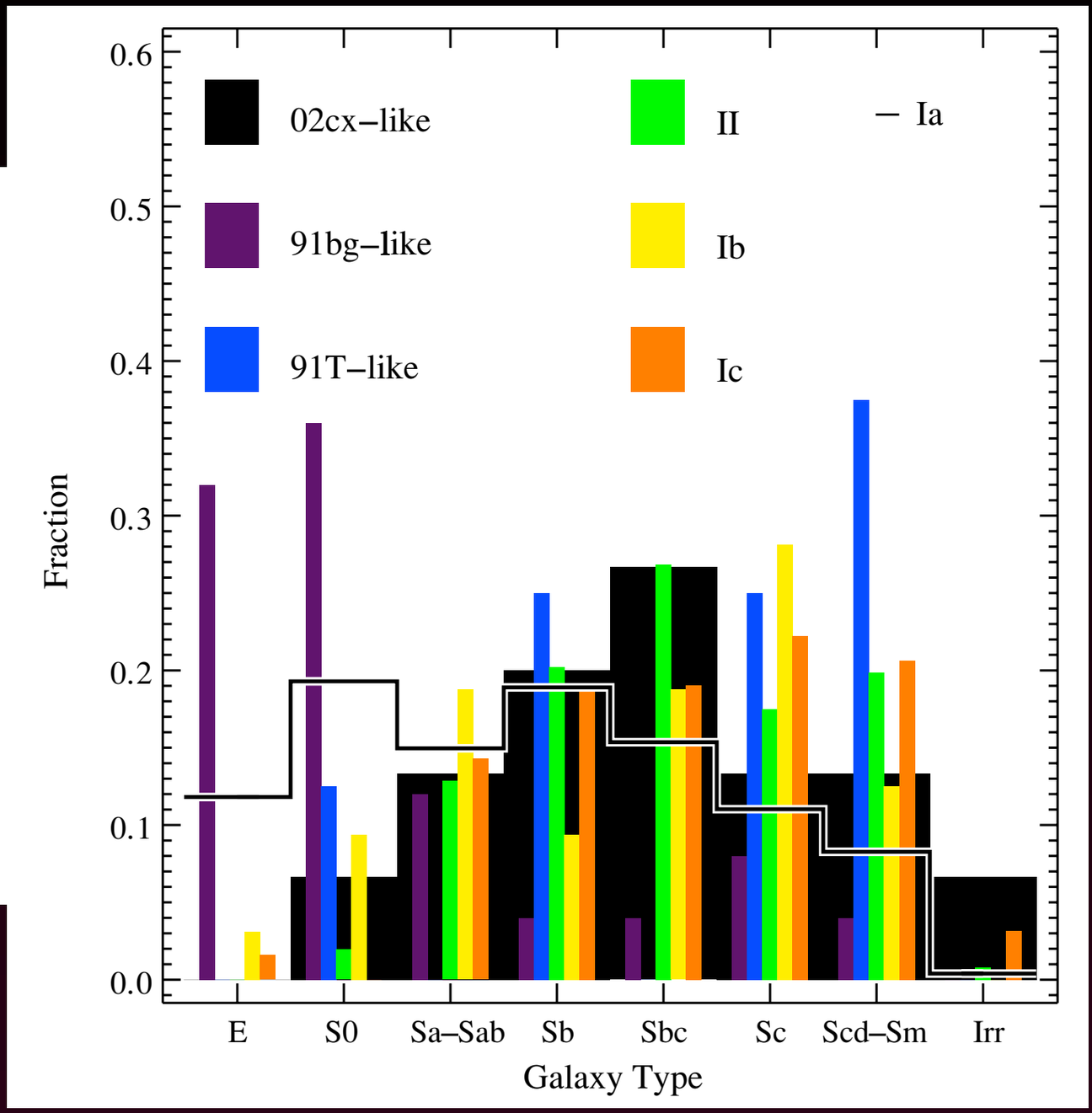


# Host Galaxies: Morphology

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 |

Foley et al. (2009)




consistent with CC SNe distribution, but also 91T-like distribution

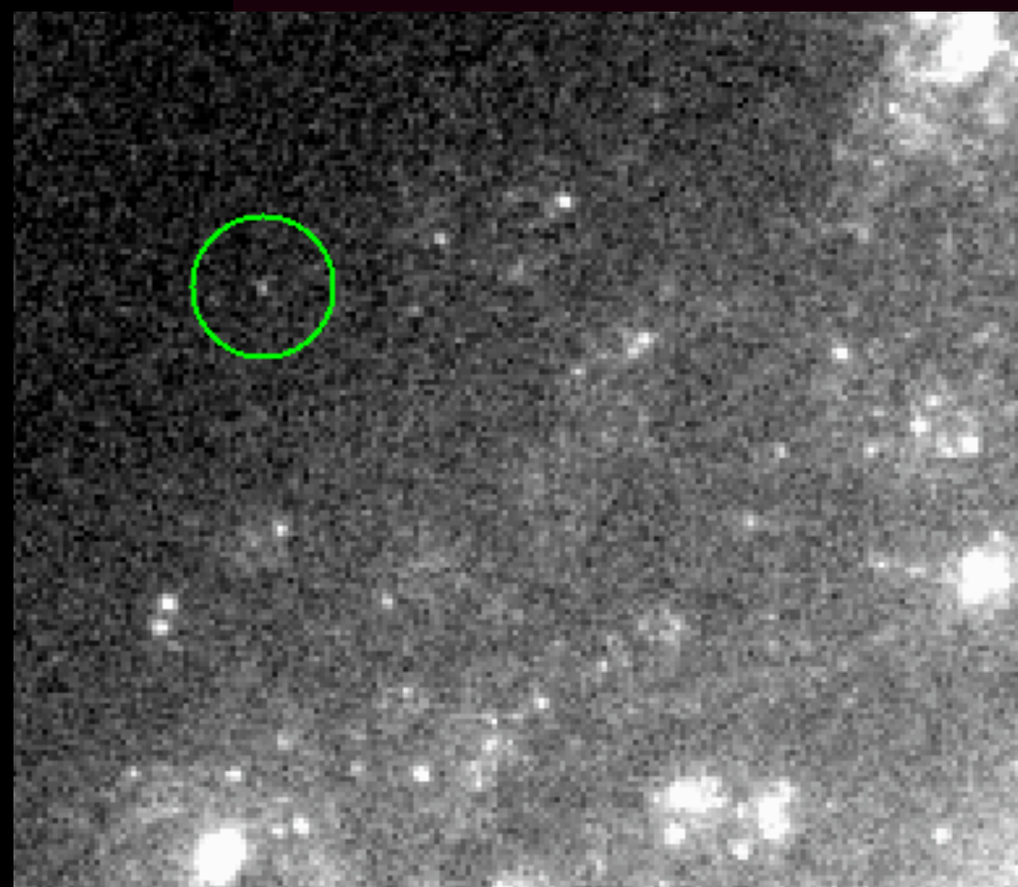
# Pinpointing SN 2005hk

Jha, McCully et al. (in prep)

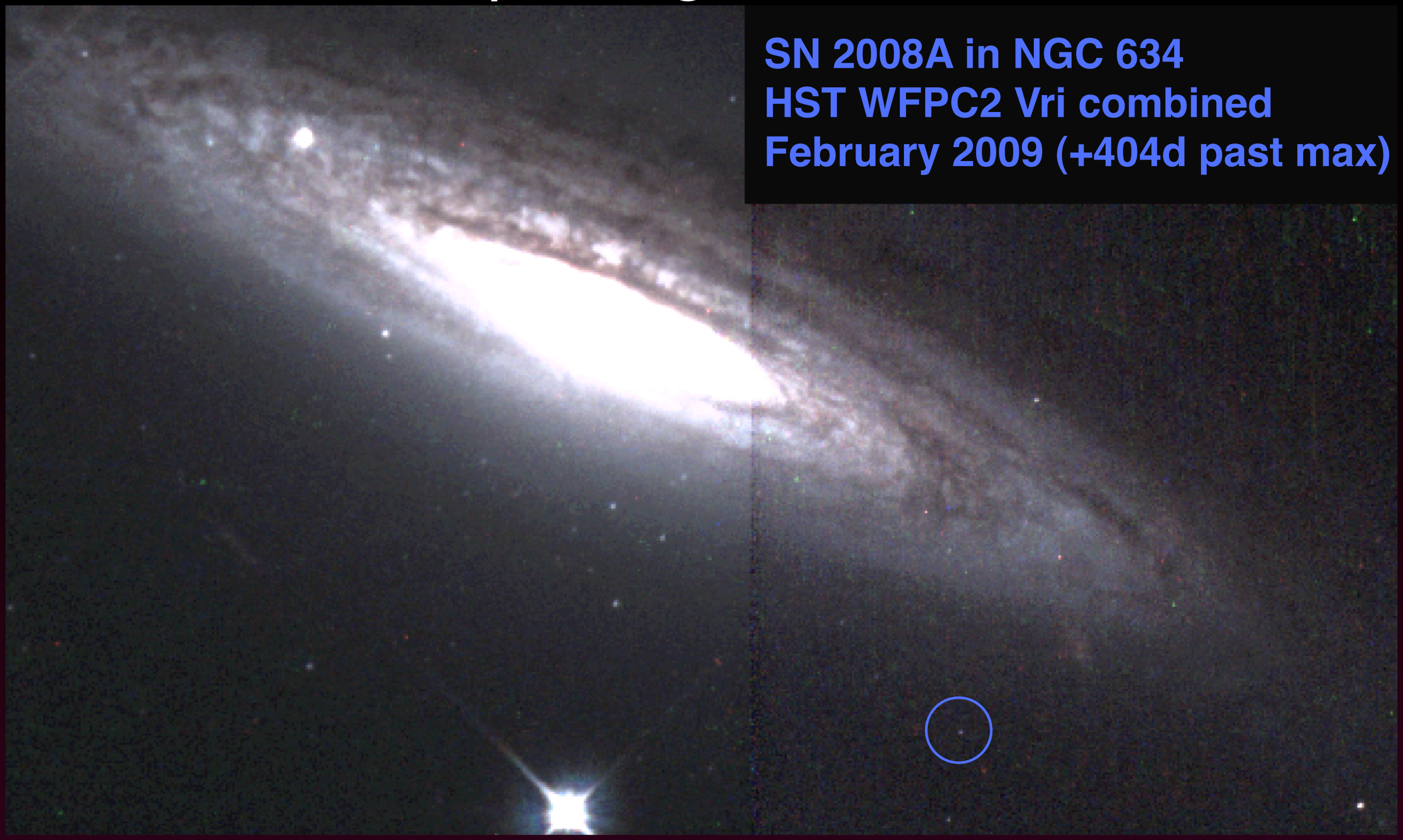
HST WFPC2 August 2007

+633 days past $B_{max}$

F606W = 26.40 ± 0.15 mag



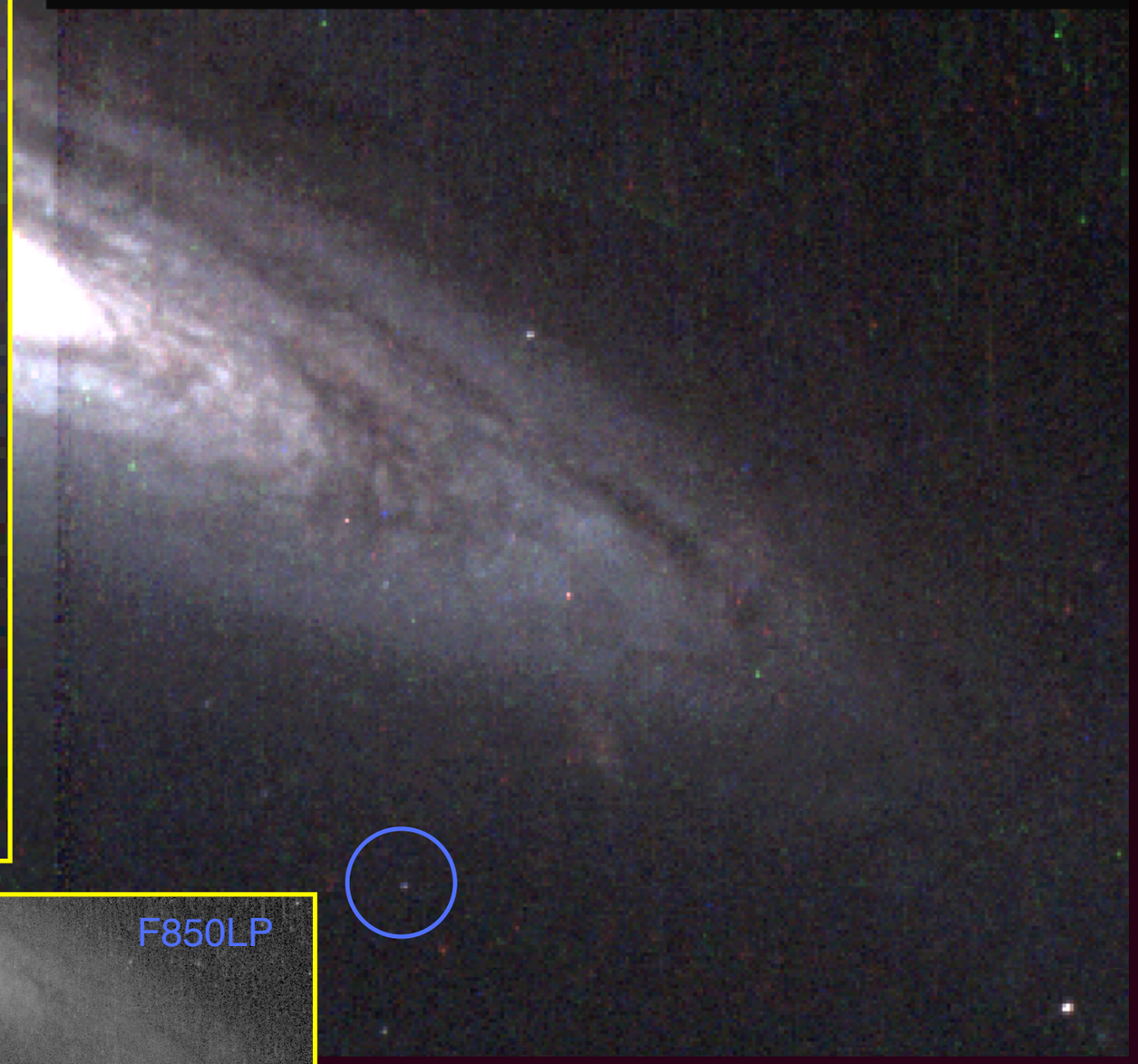
# Pinpointing SN 2008A

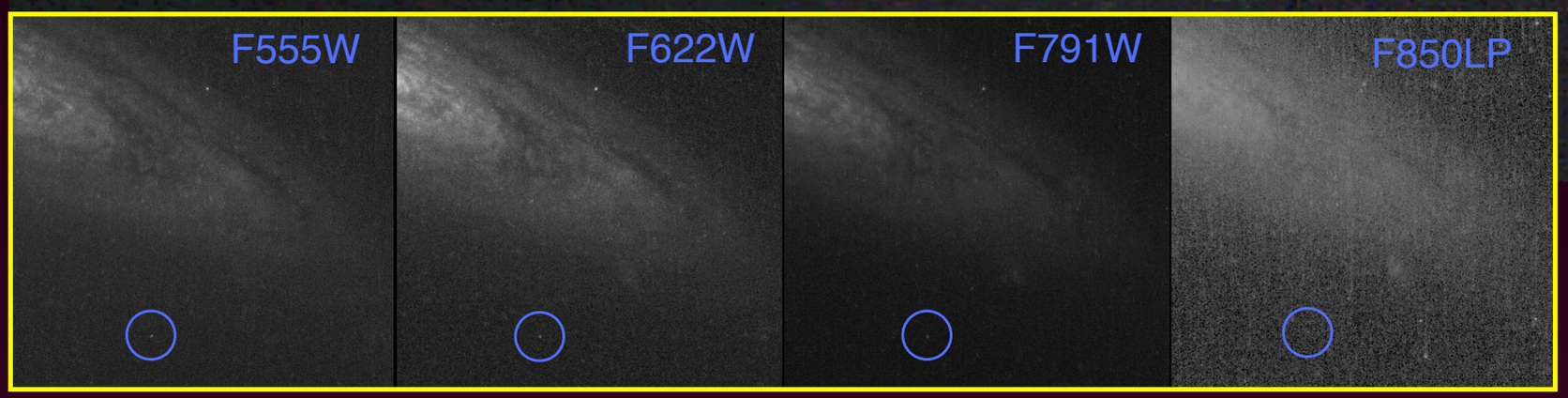



McCully et al. (in prep)

# Pinpointing SN 2008A

**SN 2008A in NGC 634**
**HST WFPC2 Vri combined**
**February 2009 (+404d past max)**

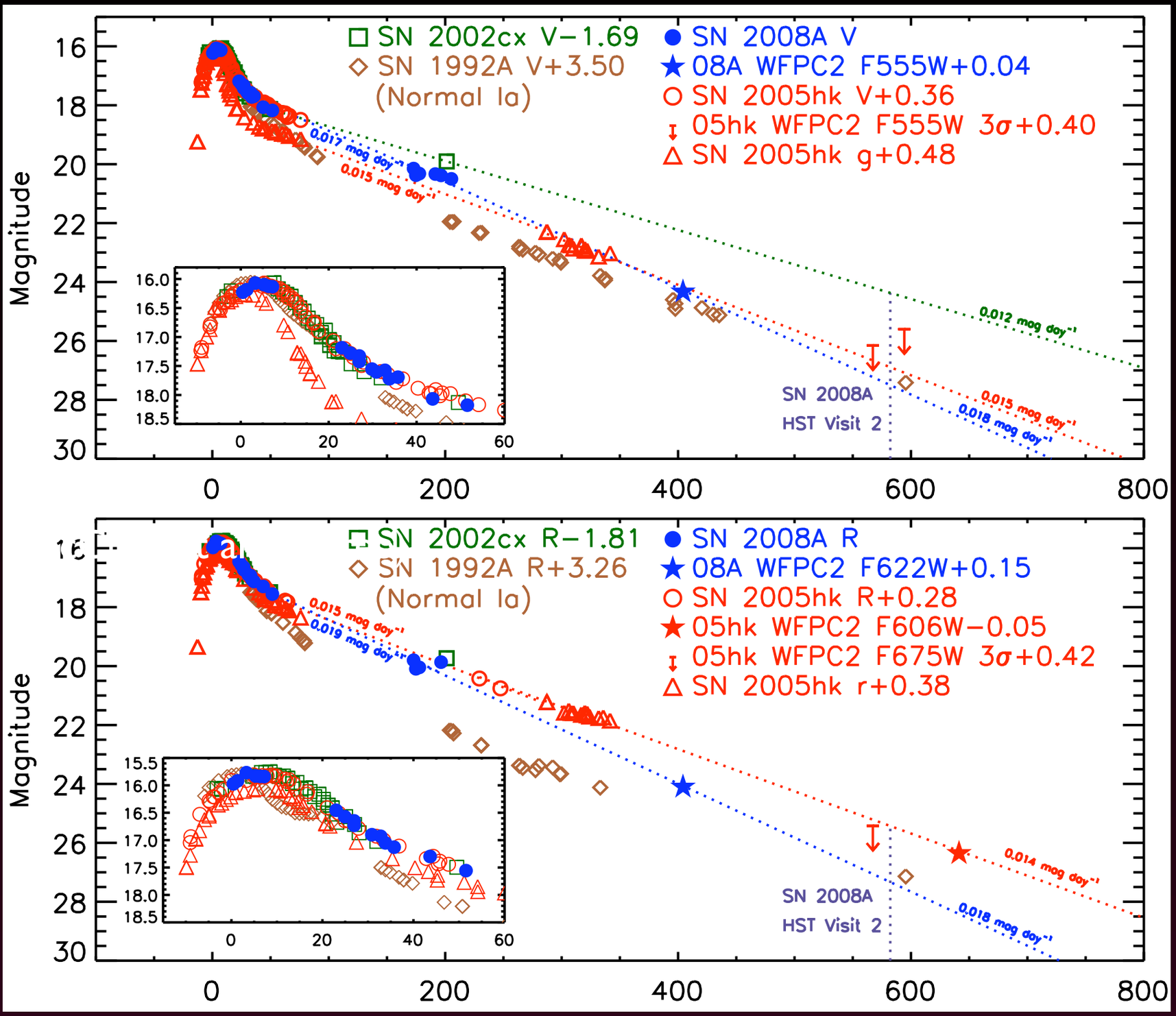





McCully et al. (in prep)

# Very late-time light curves

McCully et al. (in prep)




- Still no evidence for [O I] 6300 from r-band light curve
- faster decline in optical relative to normal SN Ia in some cases?
- good candidates to observe the IR catastrophe? (high $\rho$ → more cooling)
- new HST data taken two days ago!

# Summary... so what are they?

| Core-collapse (e.g., Valenti et al. 2009) | Thermonuclear (e.g., Branch et al. 2004) |
|---|---|
| BH/NS fallback > 30 $M_\odot$ star | pure deflagration (prompt channel only?) |
| O+Ne+Mg core 8-10 $M_\odot$ star | SN 2008ha needs "failed" deflagration |

- *Power of Nebular Spectroscopy:* why don't these become nebular? why is the density so high at late time? why is [O I] missing?
- if they are deflagrations, do normal SNe Ia then require DDT? what makes the difference?
- SN 2002cx-like objects are a bona fide class that need explaining