NIR perspectives of 2002cx-like supernovae

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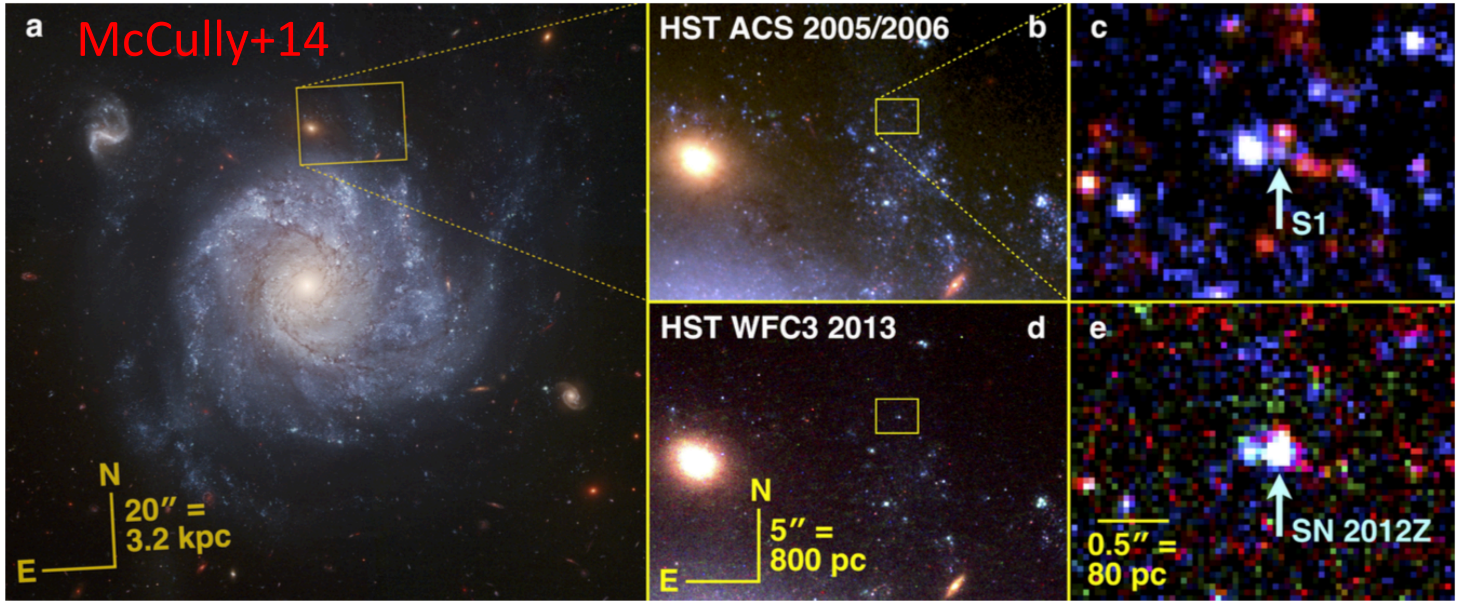
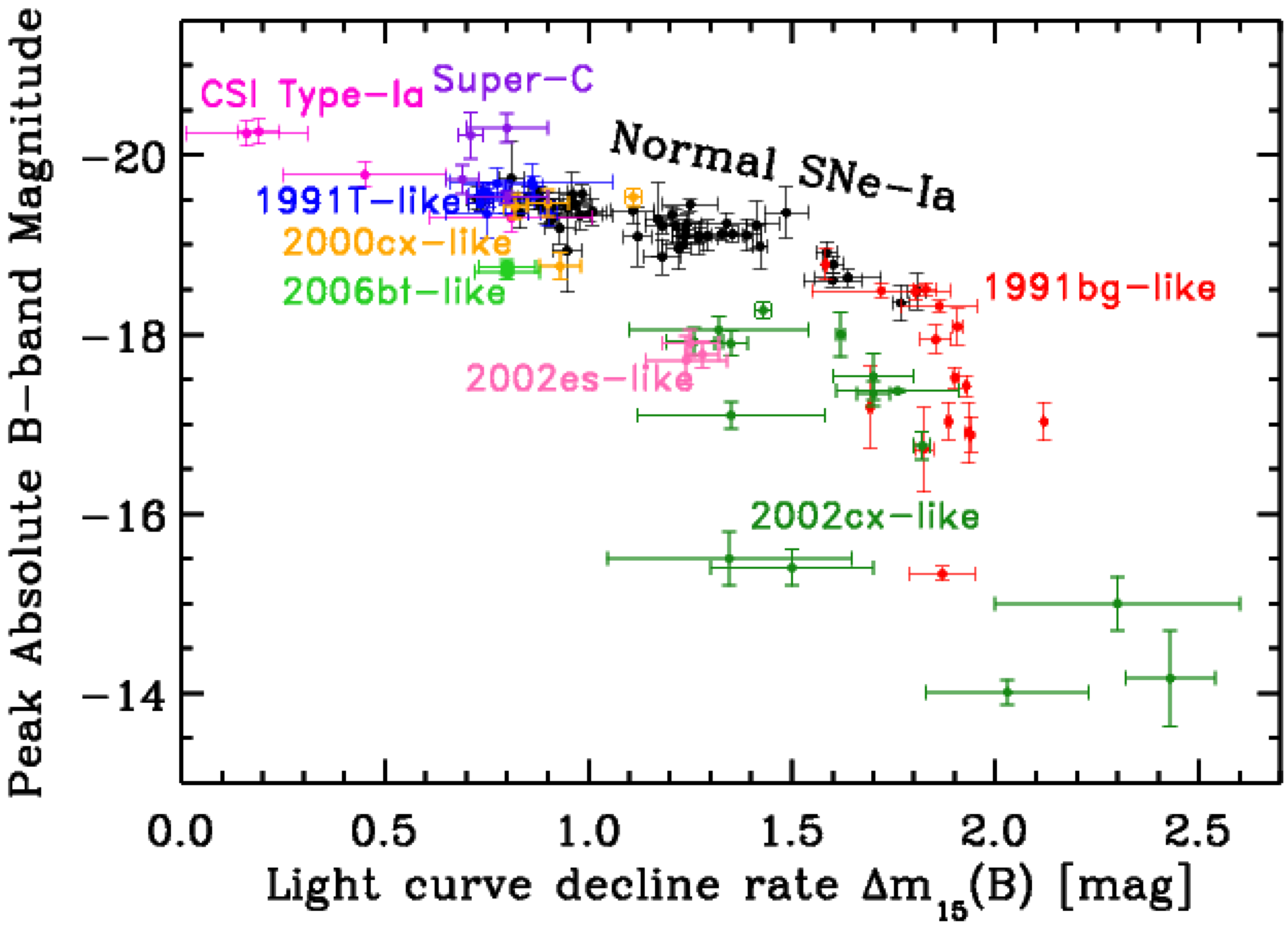


The Carnegie Supernova Project

ASAS-SN

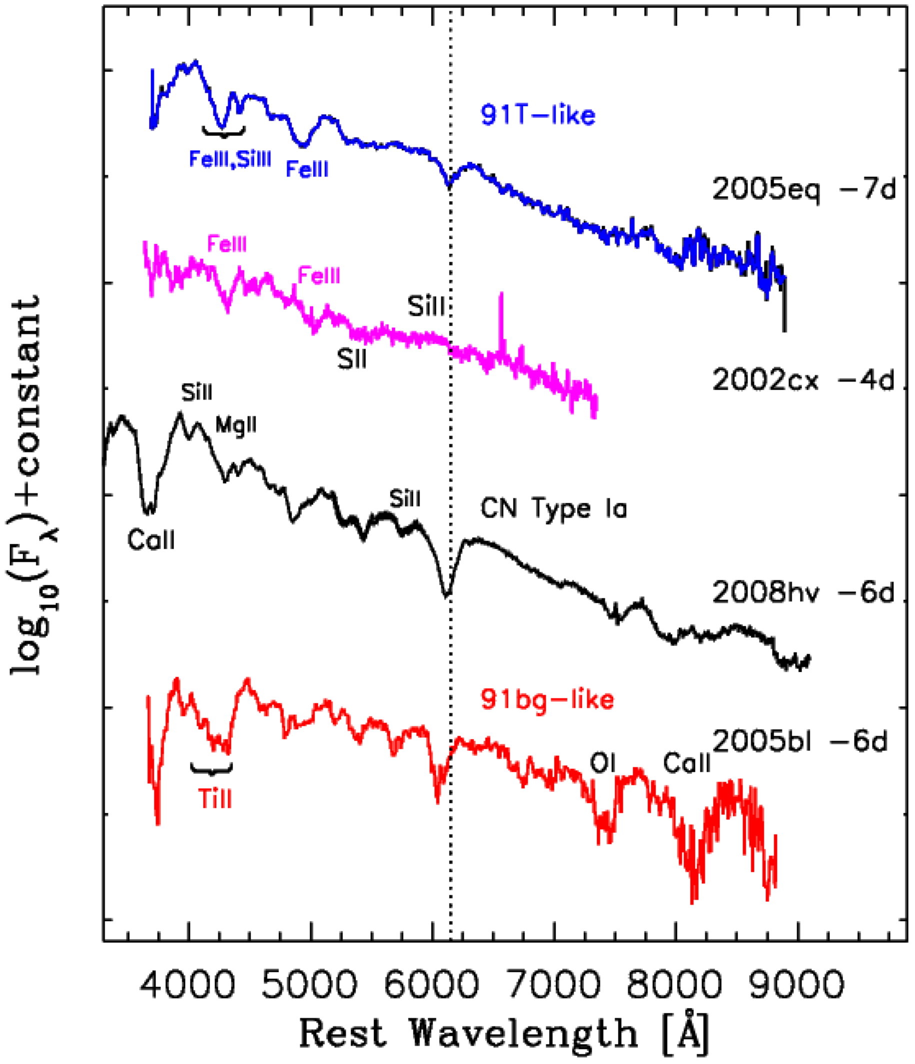
NOT Unbiased Transient Survey

Luminosity-width relation



Adapted from Stritzinger+15

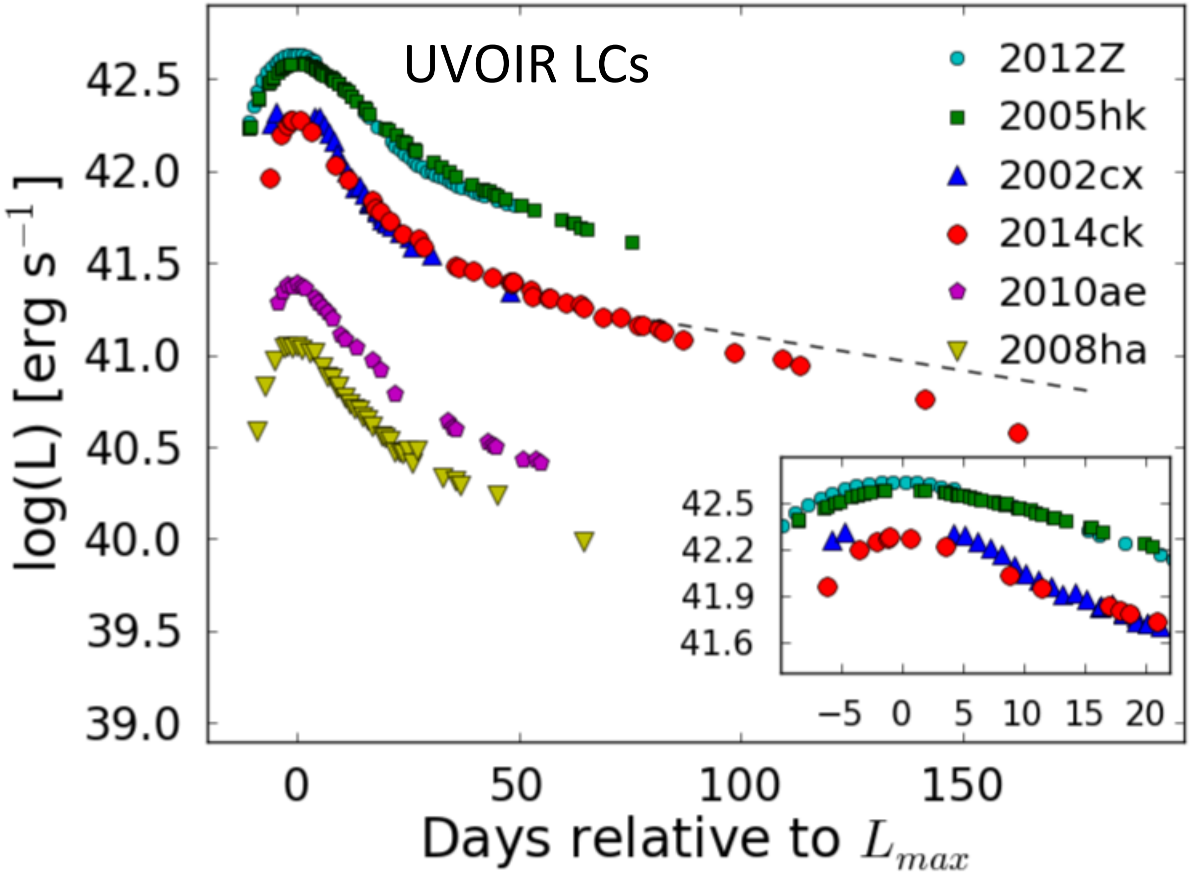
SN 2002cx: "The most peculiar known SN Ia", Li+03



- IME (Si, S, Ca, O, Mg, C) and Fe-group elements
- Hot spectra with prevalent Fe III and low-velocity Fe II lines
- Low-velocity compared to normal SNe Ia
- Low-level polarization Chornock+06, Maund+10

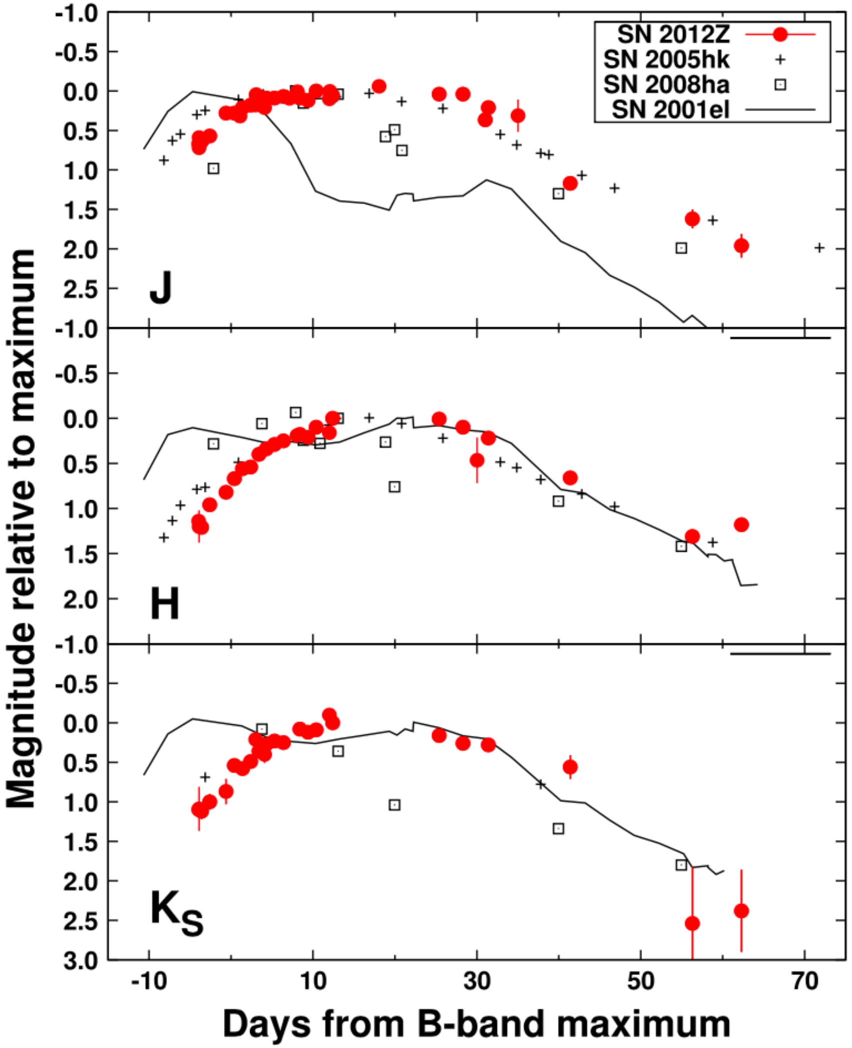
General light-curve characteristics

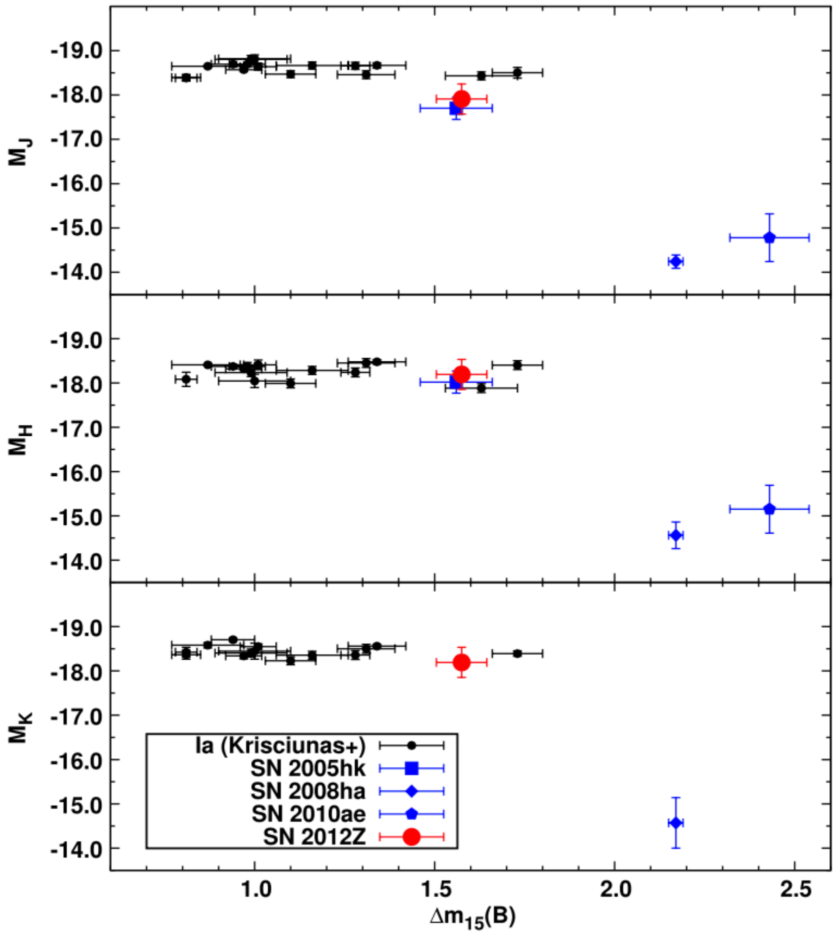
- Sub-luminous with a significant range of L_{max} → ^{56}Ni masses between 0.001 to 0.2 $M_{\odot}$
- No 2nd NIR maximum
- Optical peaks before NIR
- 1-2 week rise time
- UV blue compared to normal SNe Ia and evolve relatively quickly Milne+10
- Young upon explosion (tens to 100 Myr) & environments show sub-solar metalicities, extending to quite metal poor Lyman+18



Tomasella+15

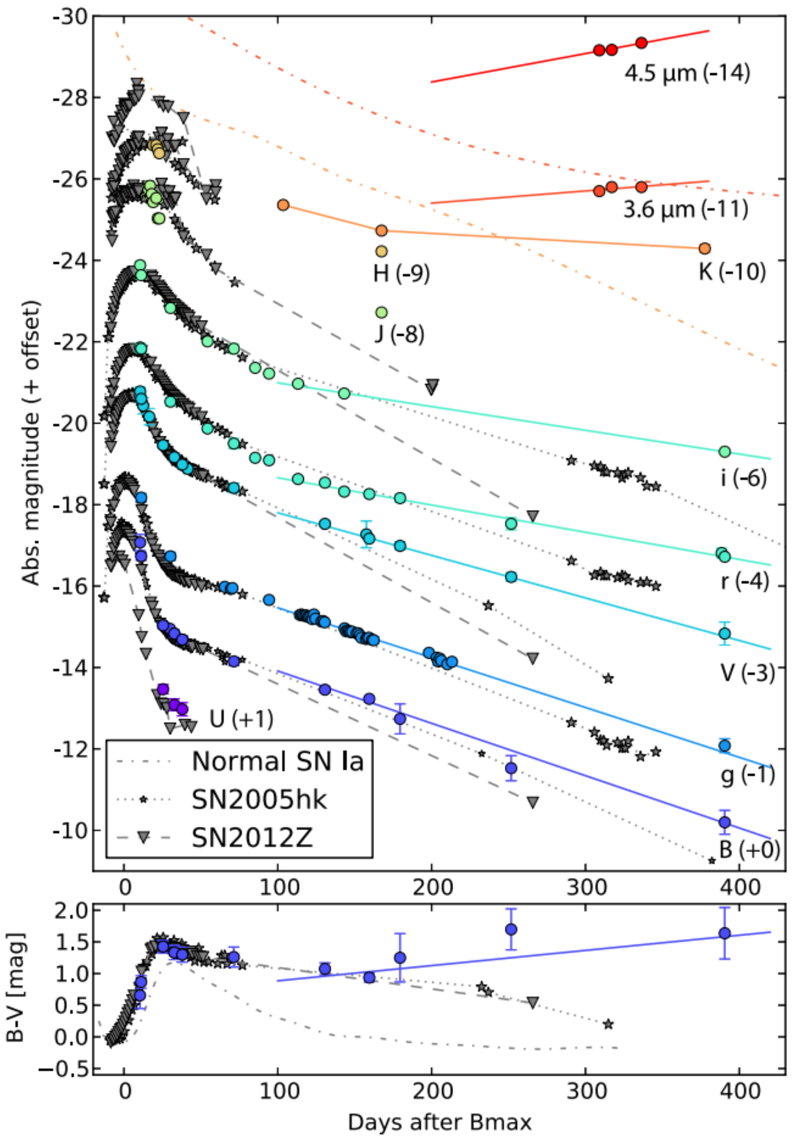
NIR light curves & LWRs

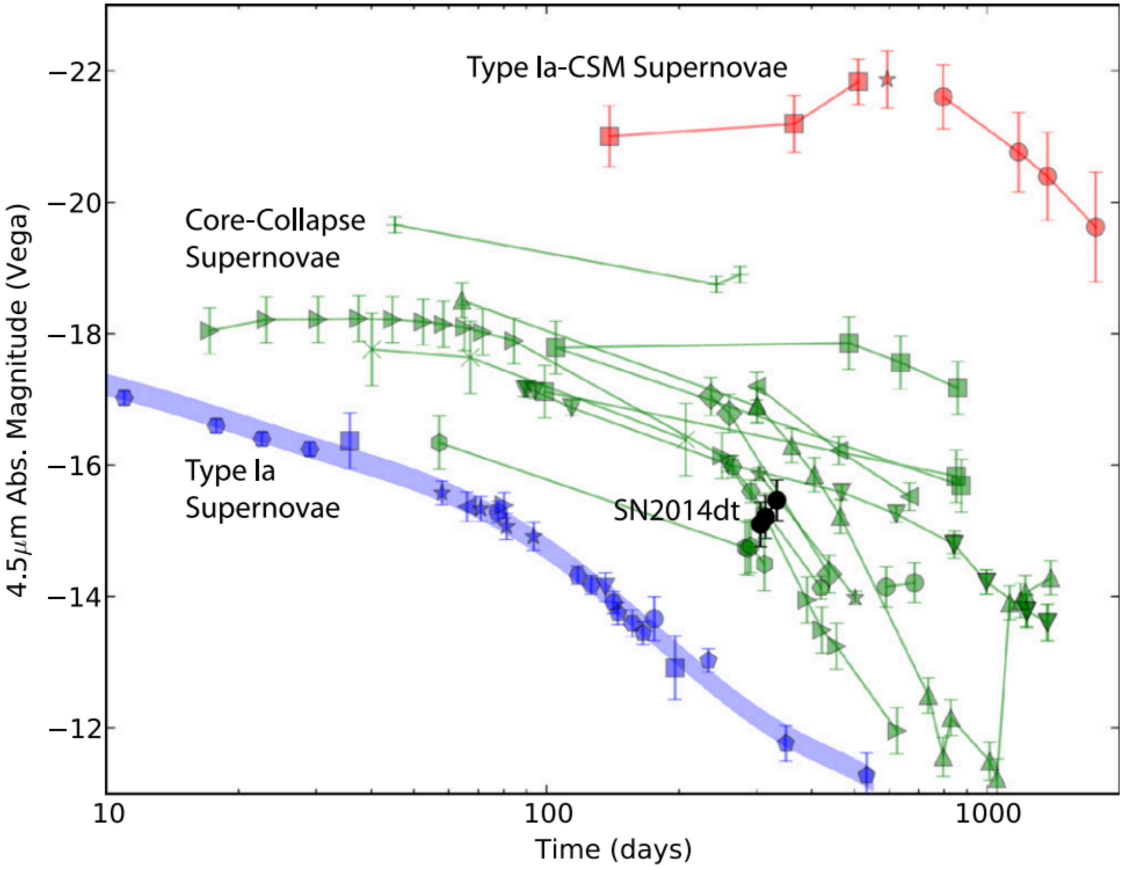




Yamanaka+15

SN 2014dt: Spitzer MIR excess

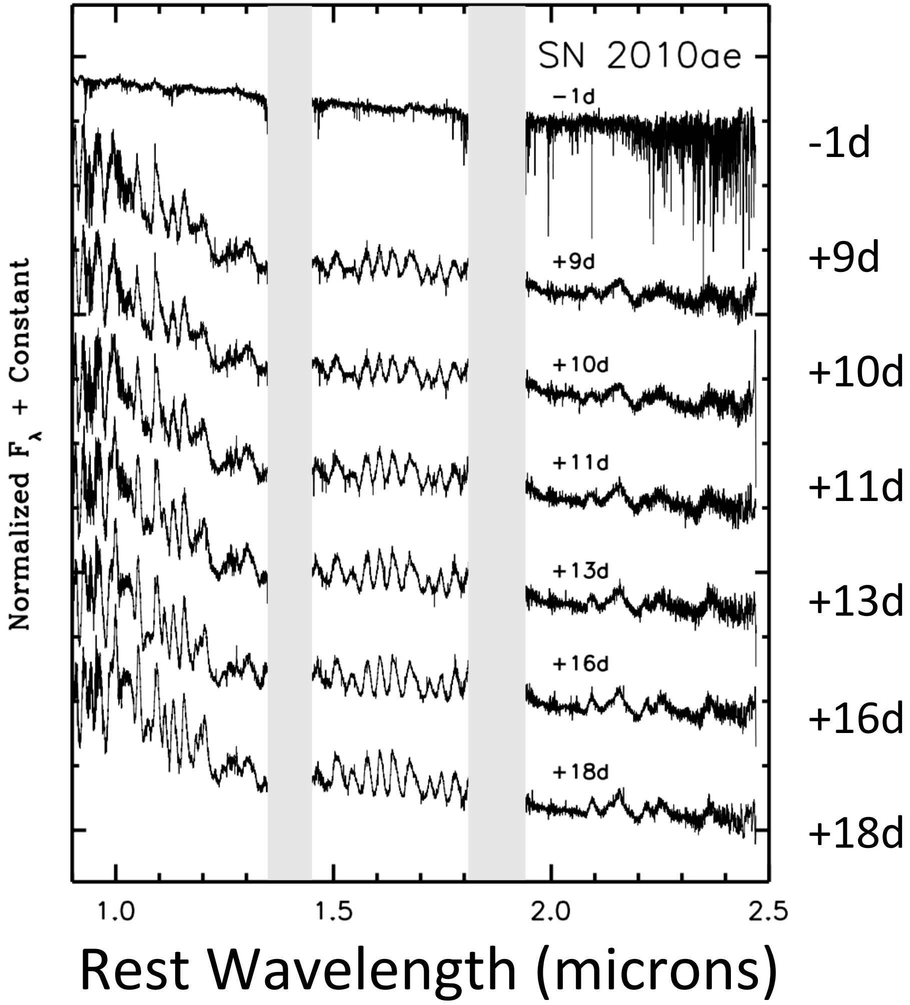




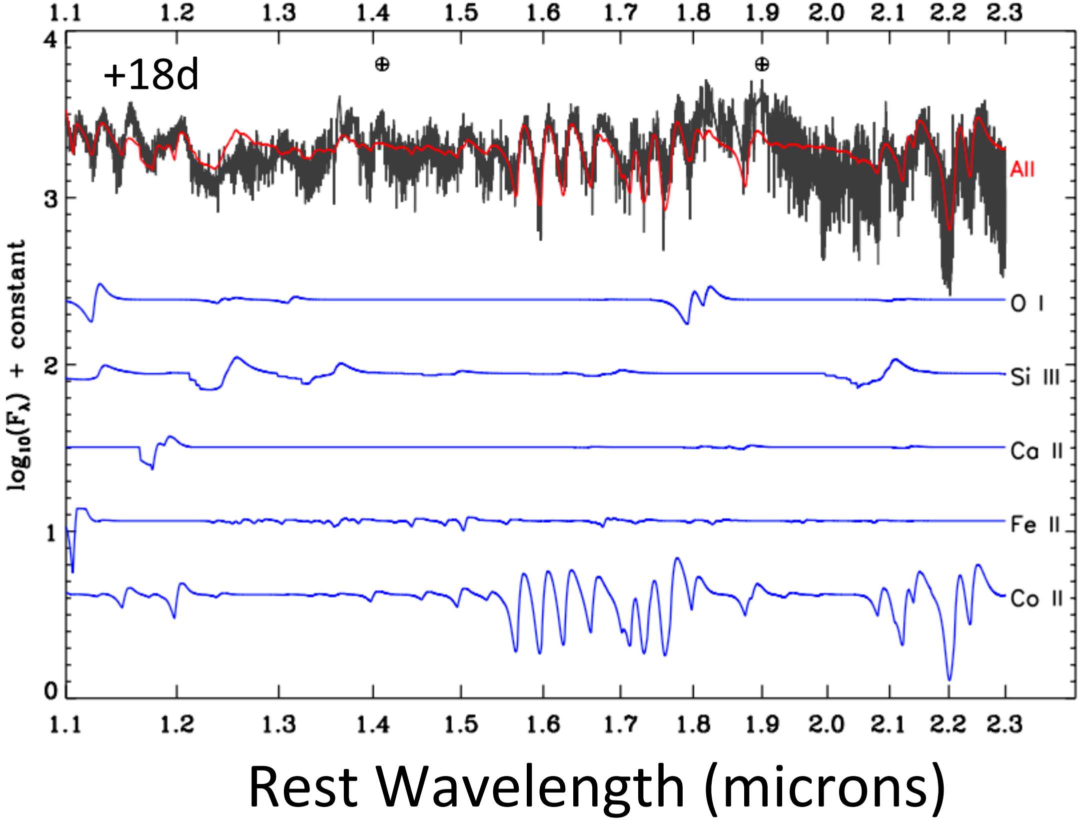
Fox+16

NIR spectroscopy

SN 2010ae: X-shooter



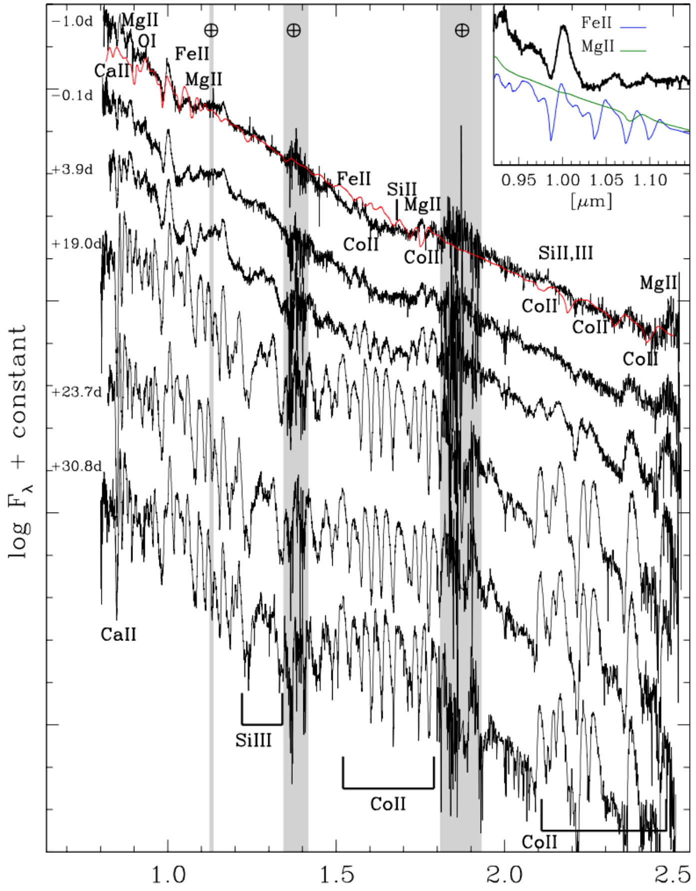
SYNAPPS fits



Stritzinger+14

Co II features are ubiquitous

SN 2014ck

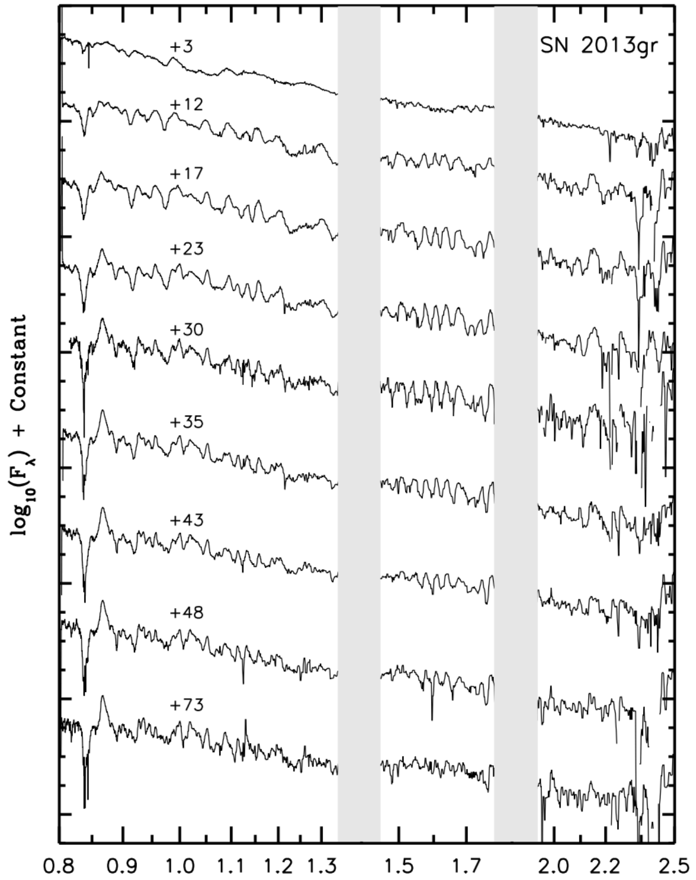


-1d
0d
+4d
+19d
+24d
+31d

Rest Wavelength (microns)

Tomasella+15

SN 2013gr

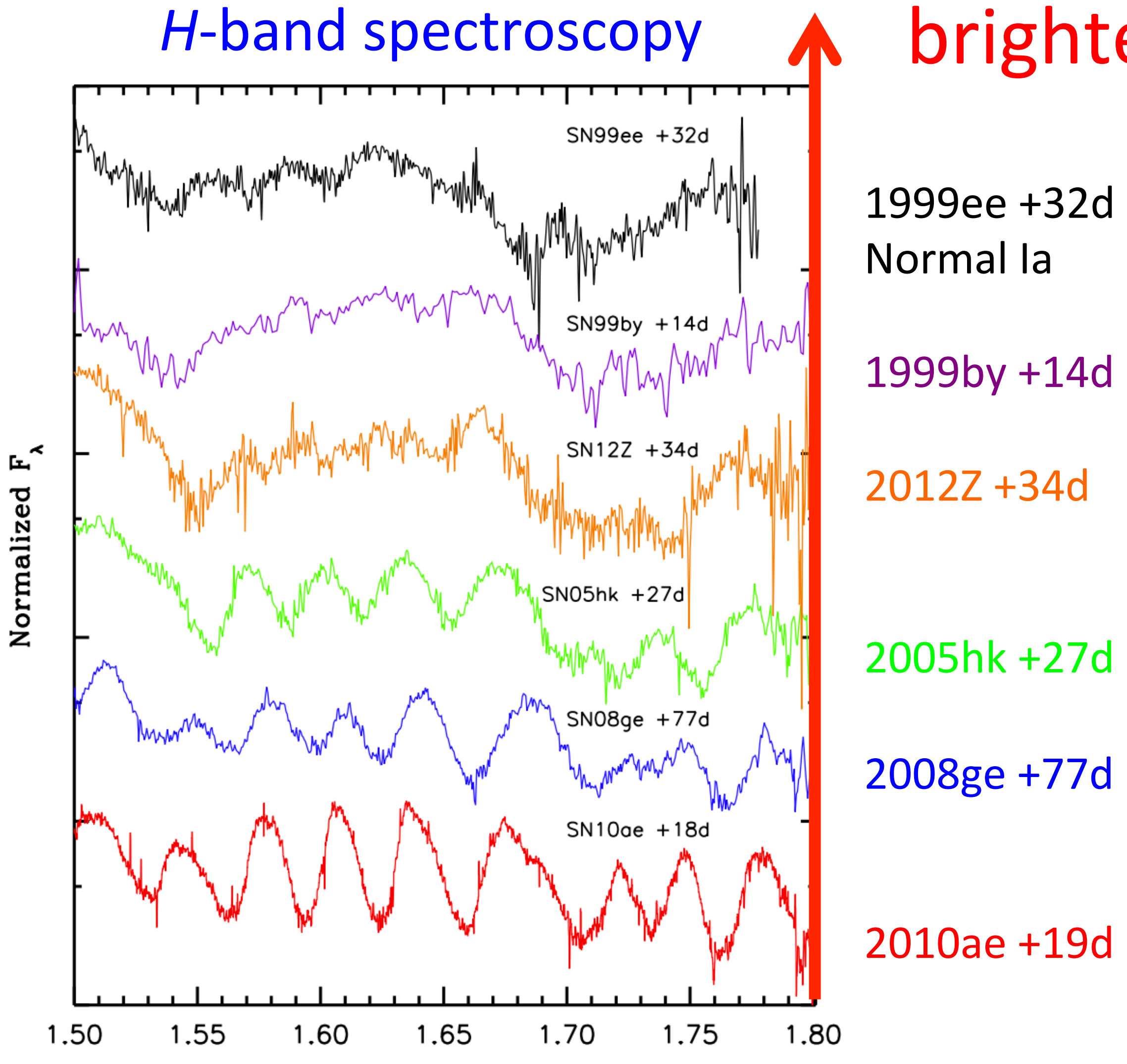


Rest Wavelength (microns)

Stritzi, in prep

2002cx-like: thermonuclear or massive star origin?

H-band spectroscopy



Rest Wavelength (microns)

- Smaller velocities

→ less blending
→ more prevalent features!

- Faint-and-fast objects are linked to the brighter objects *and* to normal SN Ia

Stritzinger+14

Distribution of IMEs in SN 2012Z, evidence for a layered structure?

- Velocity space

➢ Si II blue wing velocity:

-8d = -11,000 km/s

+1.8d = -10,000 km/s

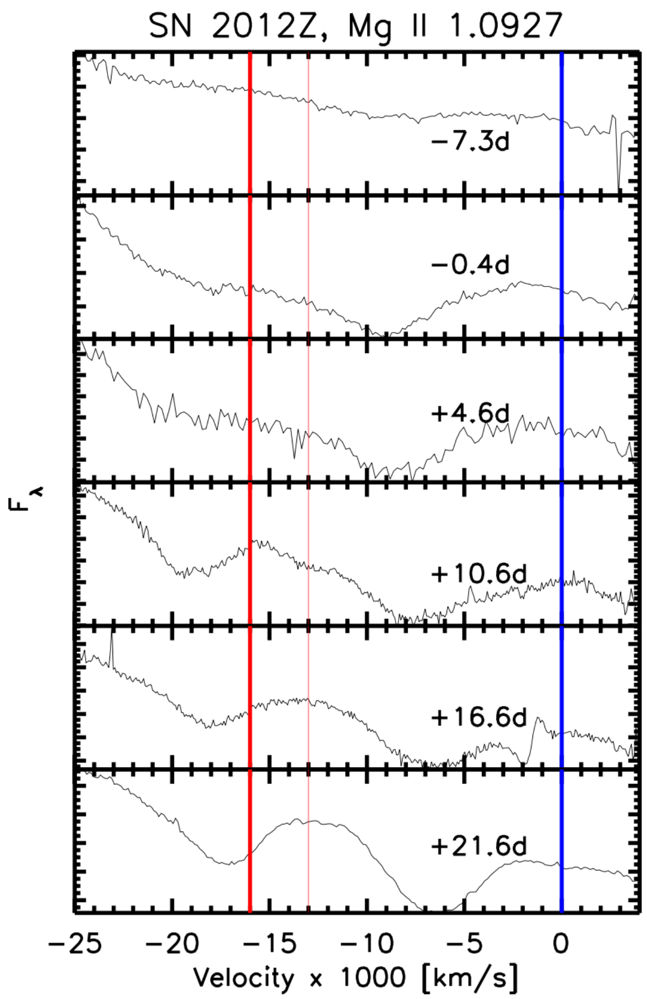
➢ Mg II

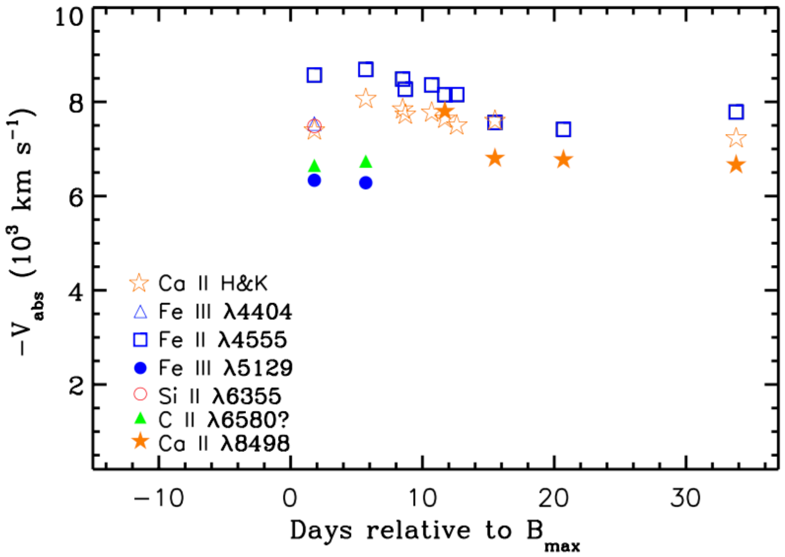
-0.4d = -13,5000 km/s

- Velocity evolution is flat

→ layered structure of the IMEs in the outer ejecta

→ Evidence for a detonation phase of burning

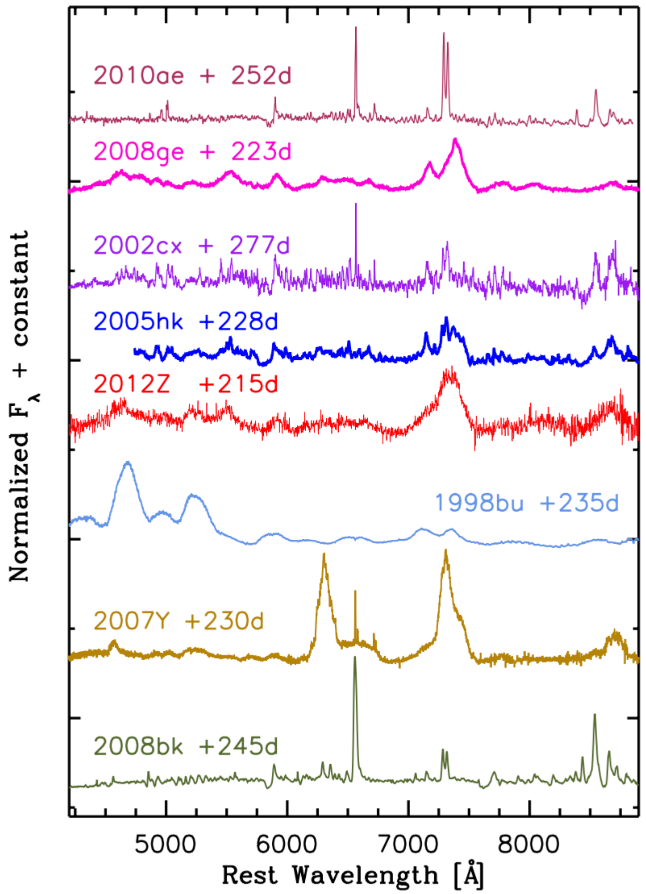




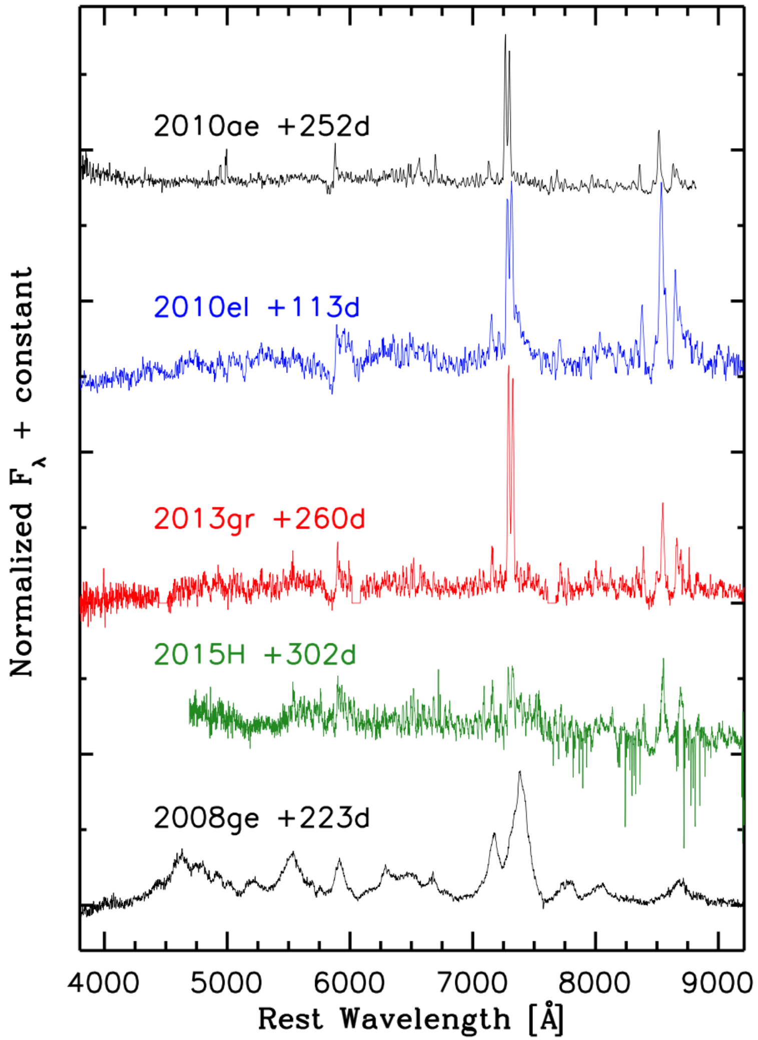
Stritzinger+15

Late-phase visual-wavelength spectroscopy

- Optical spectra never really go nebular
- Significant cooling via [Ca II]



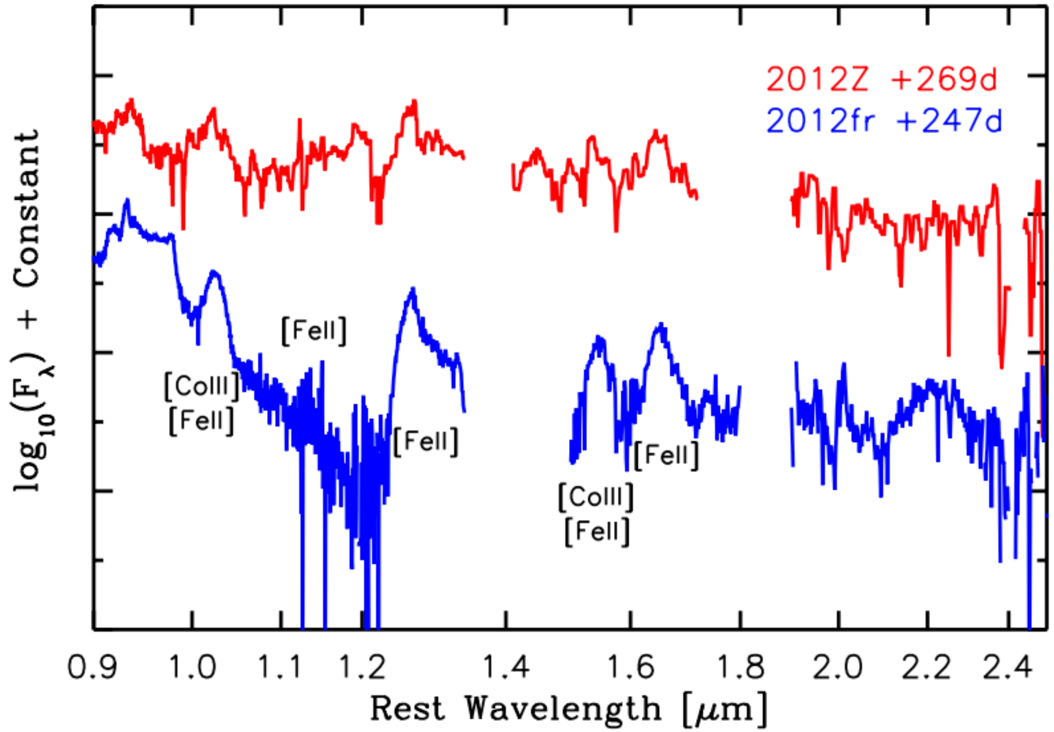
Stritzinger+15



Stritzi, in prep

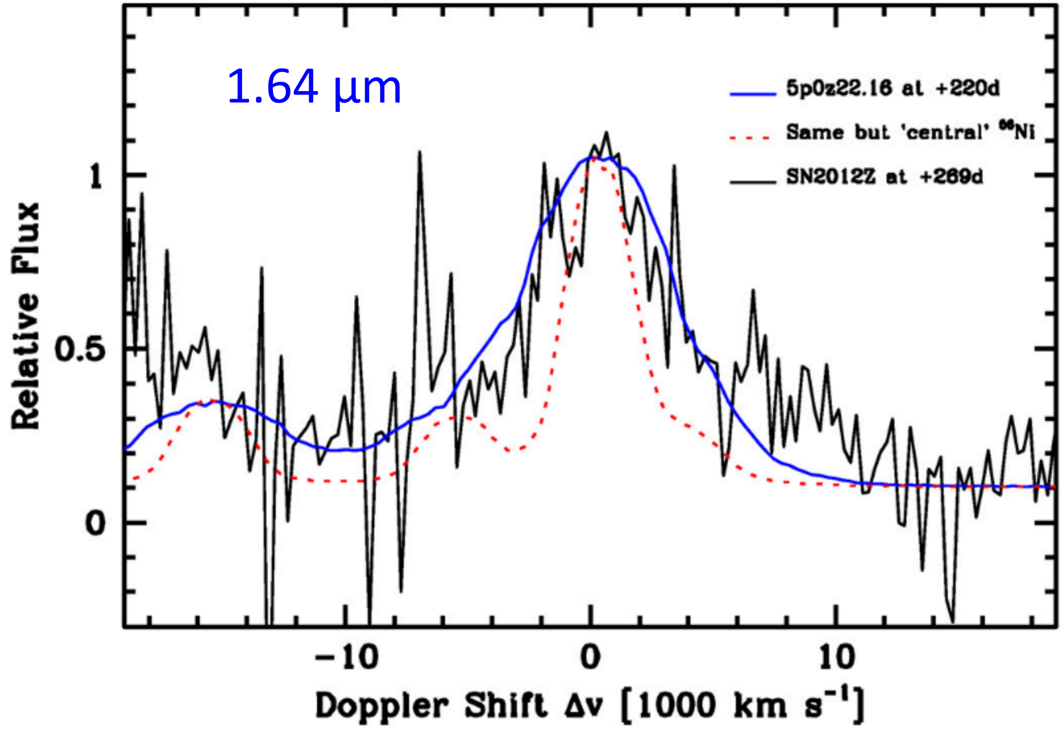
Late phase NIR spectrum of SN 2012Z

Late phase NIR spectroscopy vs. normal-ish SN Ia



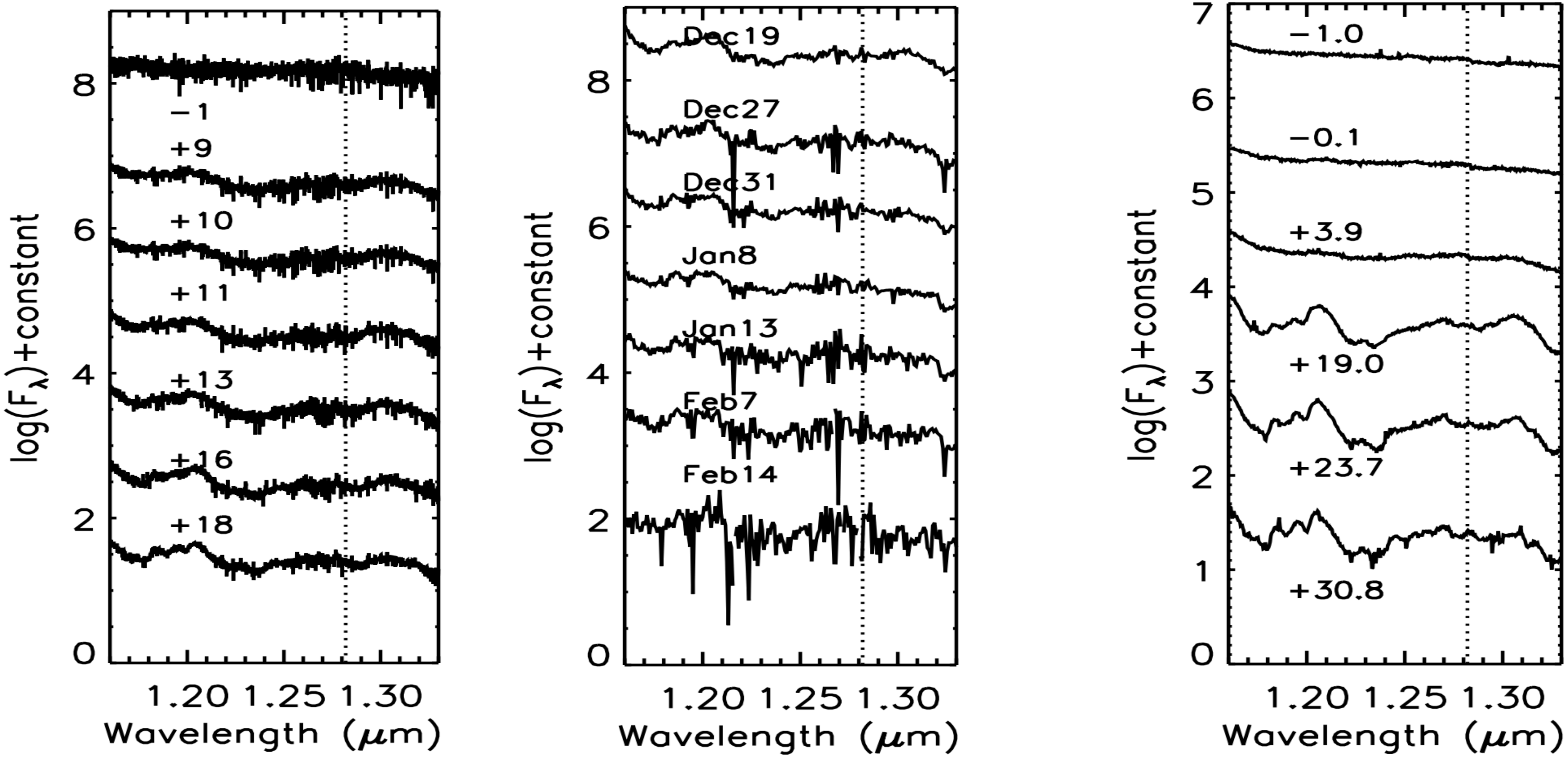
Stritzinger+15

Pot-bellied vs. core line profiles



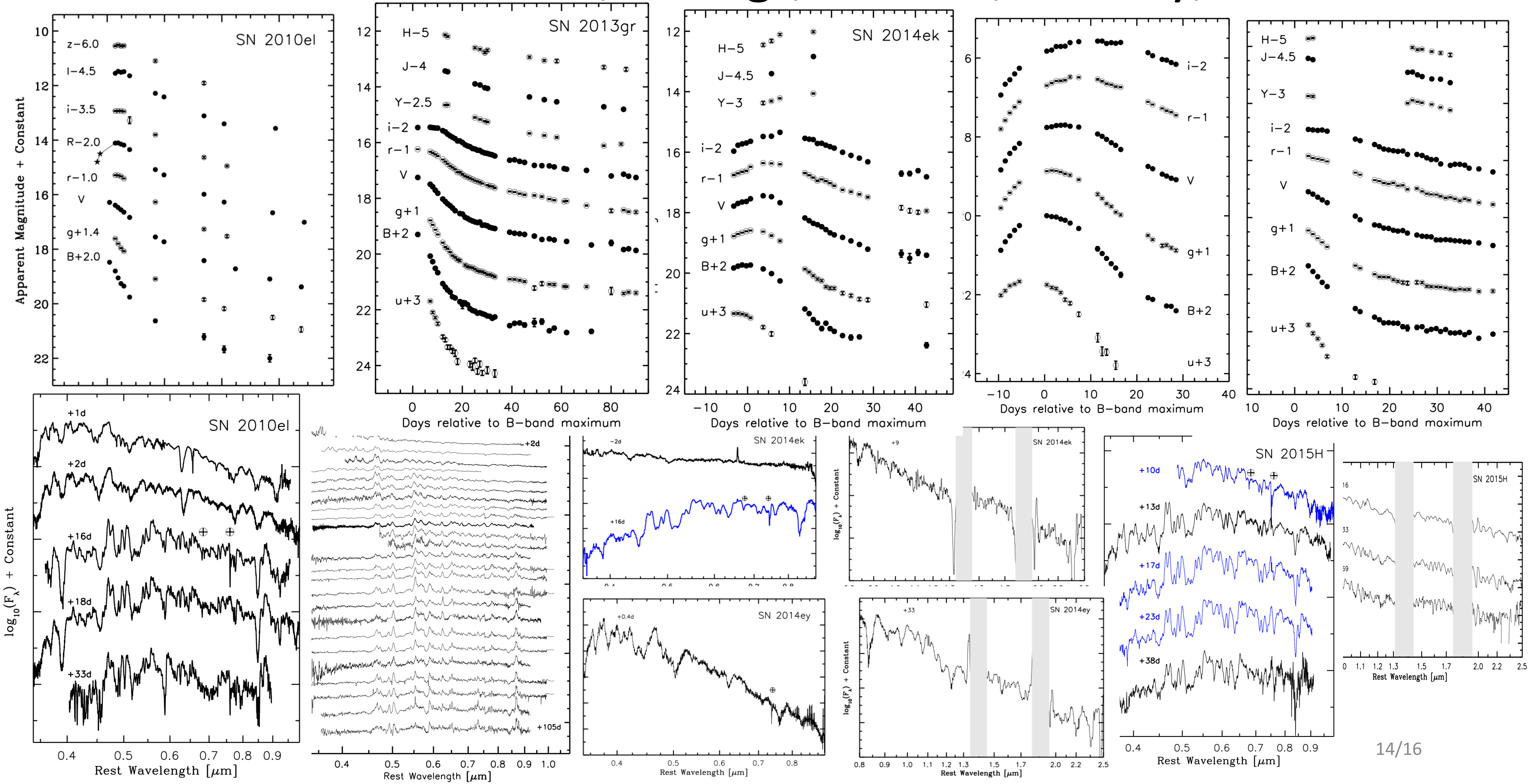
- Pot-bellied line profile signature of high-density burning → M_{CH}

Searching for signatures of Hydrogen: P-beta



In collaboration with D. Sand-man

Current work: SN 2010el, 2013gr, 2014ek, 2014ey, 2015H



Progenitor models

Deflagration Phillips+07

- Produces moderate amount of ^{56}Ni
- However, uniform abundance model does not provide fits to pre-max spectra Barna+17

Bound remnant Jordan+12, Kromer+13, Fink+14

- Early phase emission powered by ejected ^{56}Ni
- Late phase emission powered by bound remnant
- Oxygen is bound in the remnant
- Late phase spectrum is a combination of emission from disrupted material and bound remnant

PDD Stritzinger+15

- Low velocities due to pulsation (lack of Fe lines at late phases)
- Provides a layered chemical structure, with ^{56}Ni mixed to the base of the IME layers
  → explains the early blue colors and hot spectra
- Pot-bellied late phase NIR profiles due to high-density burning
- Little unburned C/O → CO formation soon after maximum?
- Range of possible ^{56}Ni mass from near 0 to 0.8 $M_\odot$

What difficulties do these models have in account for observational properties?

Summary

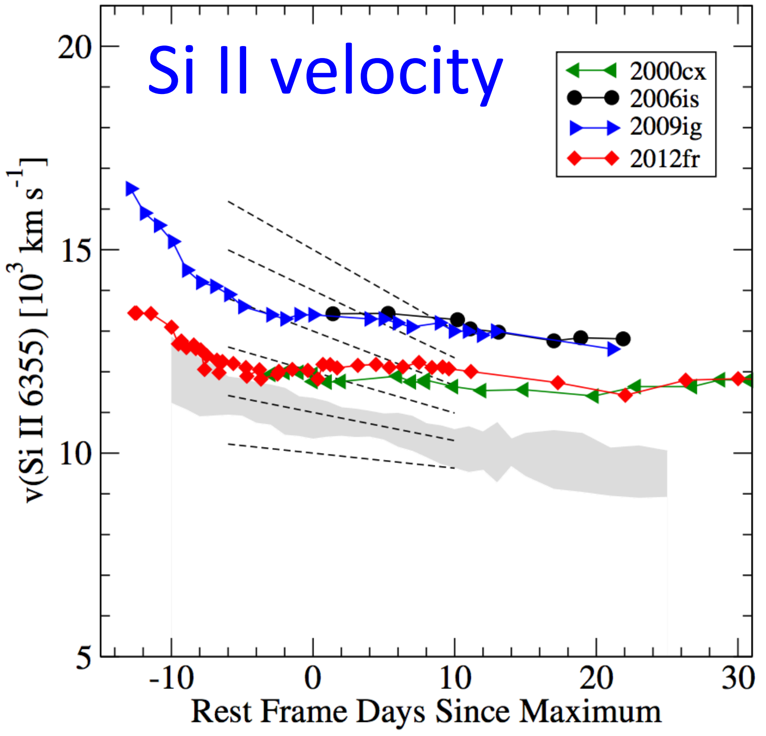
- Discovery of about 50+ 2002cx-like and now a ton of papers published on this sub-class of cosmic explosions
- NIR spectroscopy provides a real benefit to an expanded understanding of all supernovae(!)
- Significant range in physical parameters → diversity in the explosion physics and/or progenitors???
- Various progenitor scenarios have been suggested ranging form core collapse, pure deflagrations, deflagrations leaving a bound remnant, to PDD model
- I would not be surprised if nature has different progenitor channels to realize the brightest and faintest 2002cx-like and 2008ha-like, respectively

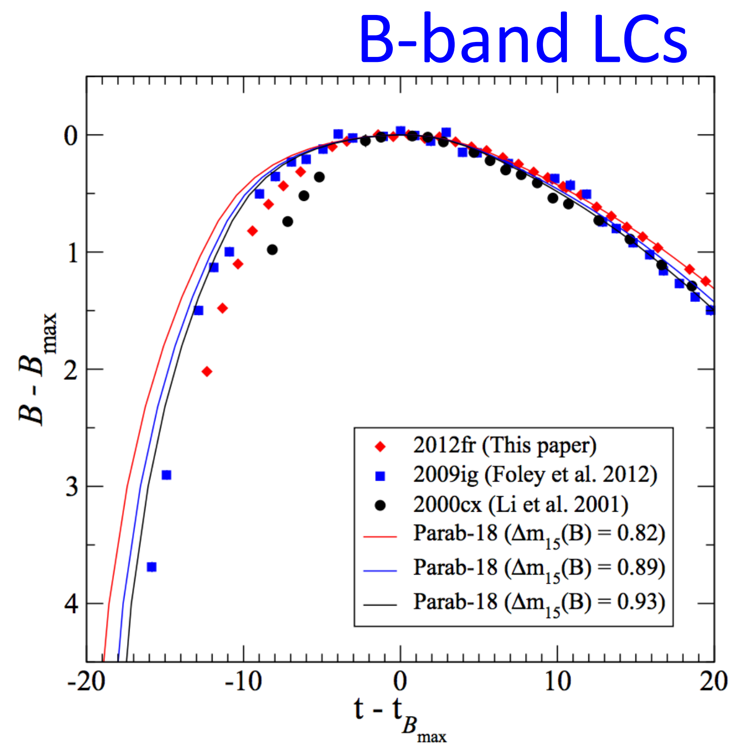
Hilsner fra Aarhus

Ole Rømer Observatory

Bonus slide: 2000cx-like a bona fide SN Ia subclass?

SNe 2000cx, 2006is, 2009ig, 2013bh, **2012fr**?





- Between SS+CN in Branch diagram
- HV but LVG (<10% of SNe Ia)
- Only 5% of SN Ia are HV and are SS+CN; < 10% are HV and LVG
- Slow-decliners & persistent HVFs
- 2012fr is similar to 2000cx, but not identical → see right panel and also Branch diagram

Carnegie Supernova Project II study of SN 2012fr

Contreras+18, arXiv:1803.10095v1

SNe Ia spectroscopic sub-typing

- Core Normal (CN)

→ 'Normal' in v_{SiI} criteria of Wang+06
→ Low Velocity Gradient (LVG; Benetti+05)

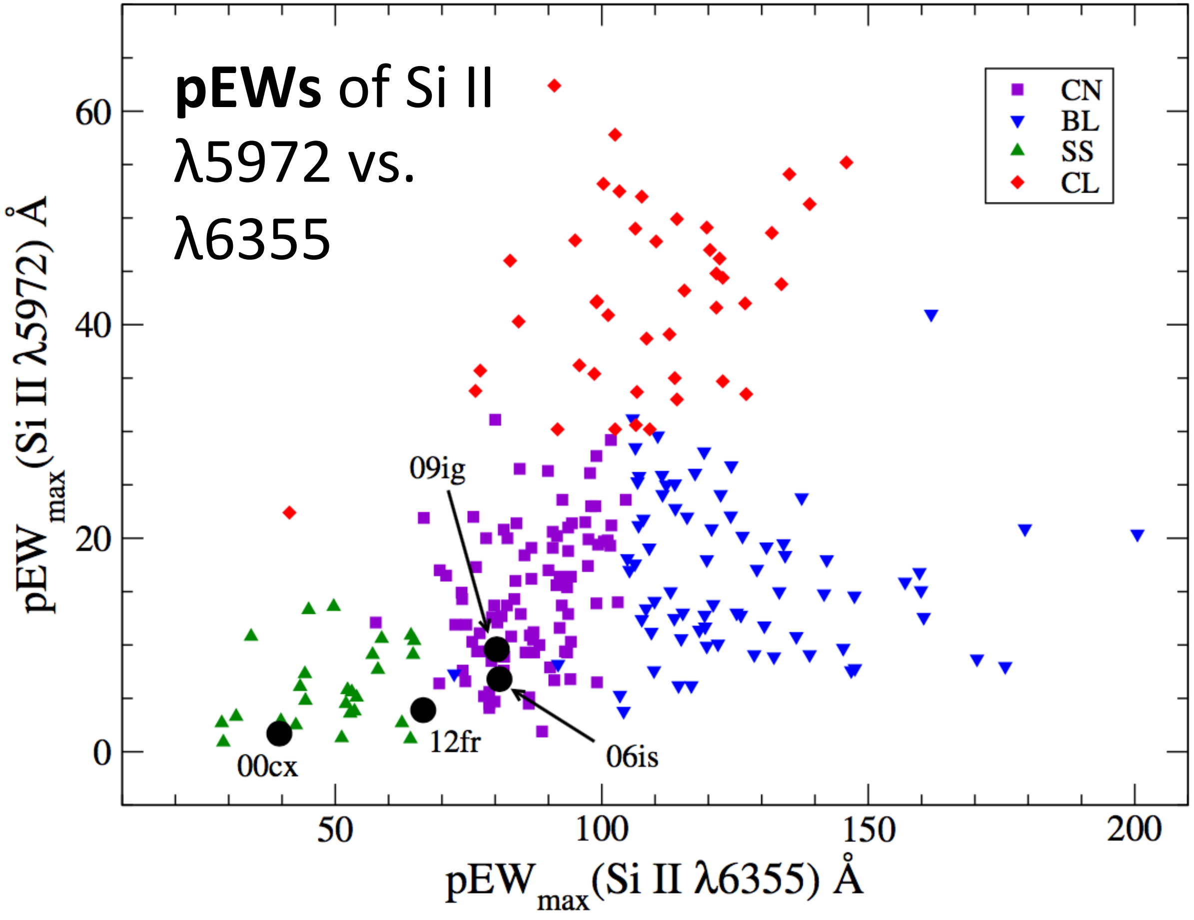
- Broad Lined (BL)

i. BL objects are High-Velocity (HV; v_{SiII}>11,800 km/s) objects in Wang+06
ii. ≈85% of HV are HVG objects (Foley+11, Silverman+12)

- Shallow Silicon (SS): 1991T-like

- CooL (CL): 1991bg-like

Branch Diagram



Contreras+*18, data from* Blondin+12

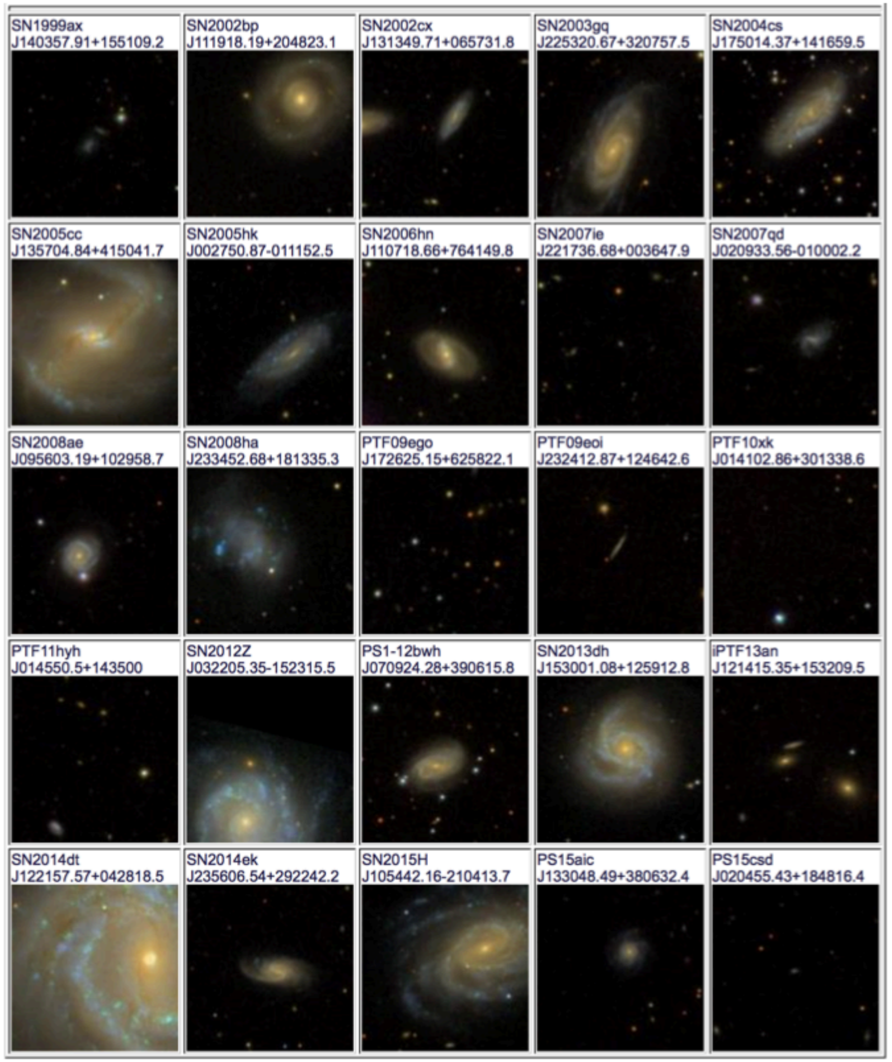
Explosion sites I

Previous environment work

- Strong preference for late-type galaxies Perets+10, Foley+13, Lyman+13

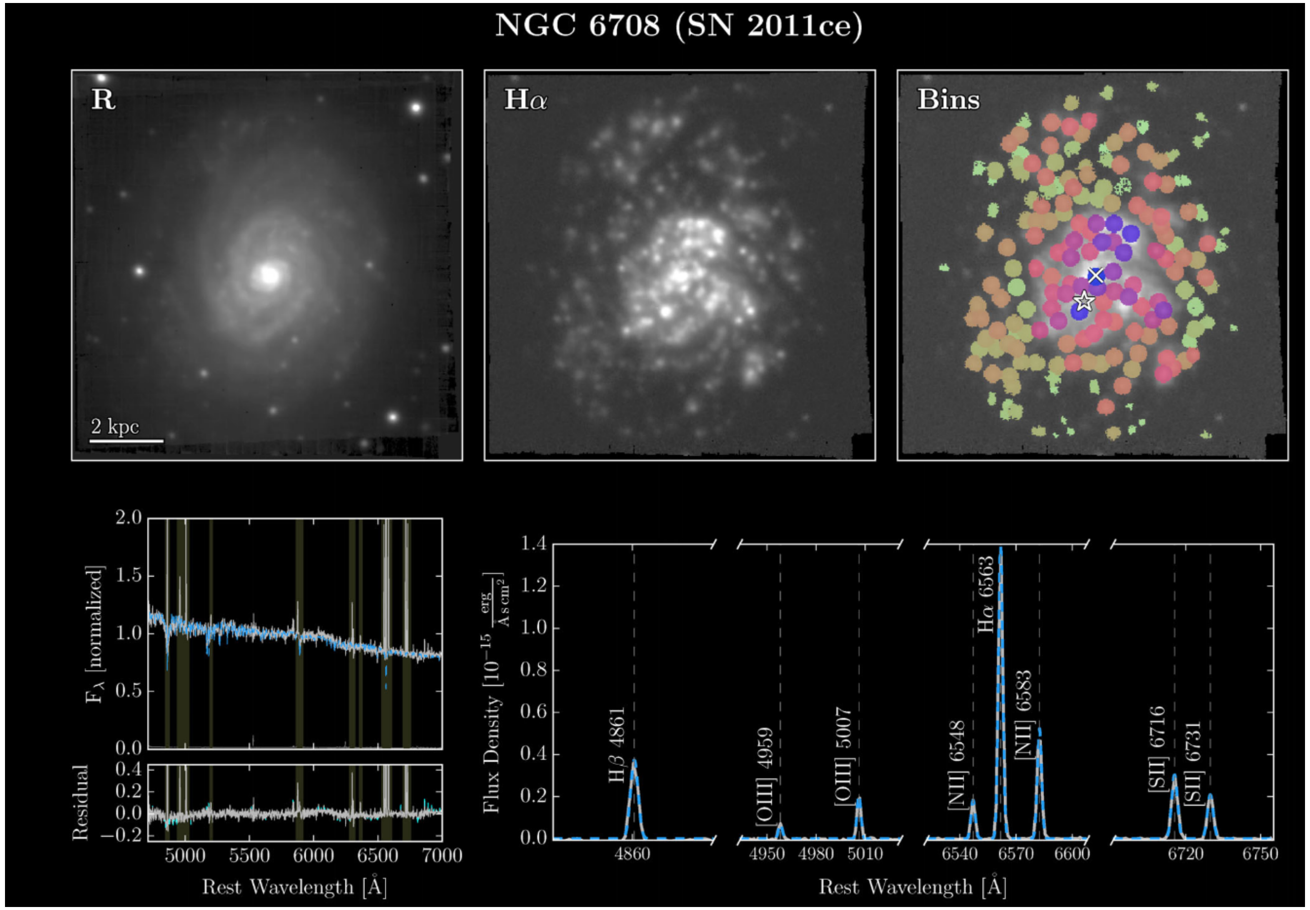
- Spatial association to SF in hosts Lyman+13

- Resolve stellar populations at 2 nearby examples ages ~ 10-80 Myr McCully+14, Foley+14



Jha+18

Explosion sites II: MUSE NOT Study



- remove stellar continuum
- measure emission line properties at explosion sites and across host/slit

SN Iax Progenitors:

- Young upon explosion (tens to 100 Myr)
- Sub-solar metalicities, extending to quite metal poor
- Some indication that fainter-faster Iax arise from different environments

Model Implications:

- ages consistent with single-degenerate WD progenitor systems (e.g. CONe WD + MS, WD + He star) Wang+13, Meng&Pods+14, Liu+15
- age and low Z consistent with stripped-envelope electron capture SNe (particularly the low-luminosity sample) Pumo+09, Moriya+16
- inconsistent with very massive stars exploding with significant fall-back

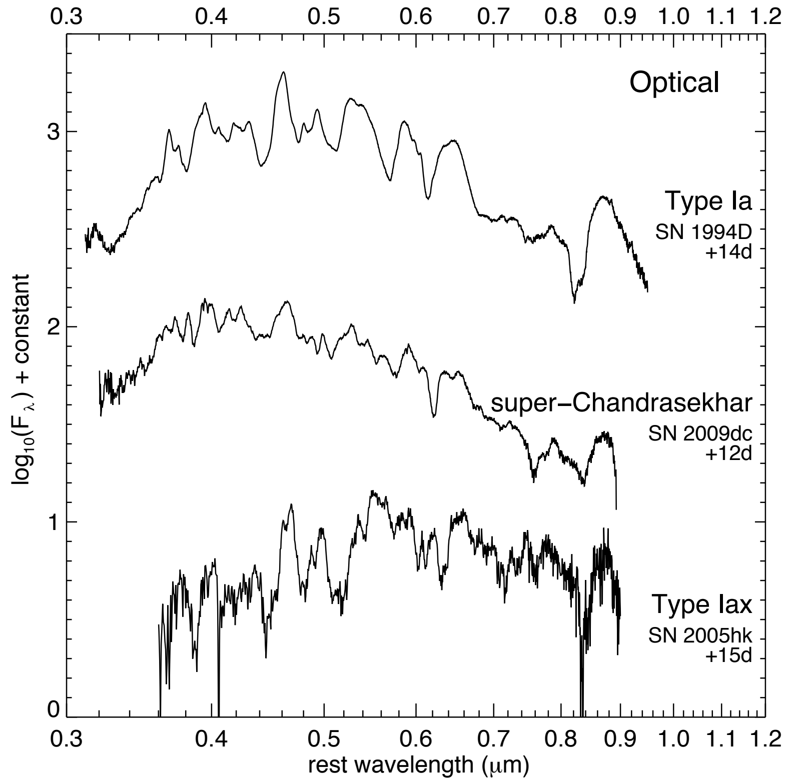
Lyman+18

State-of-the-art: NIR spectroscopy

Courtesy of E. Hsiao

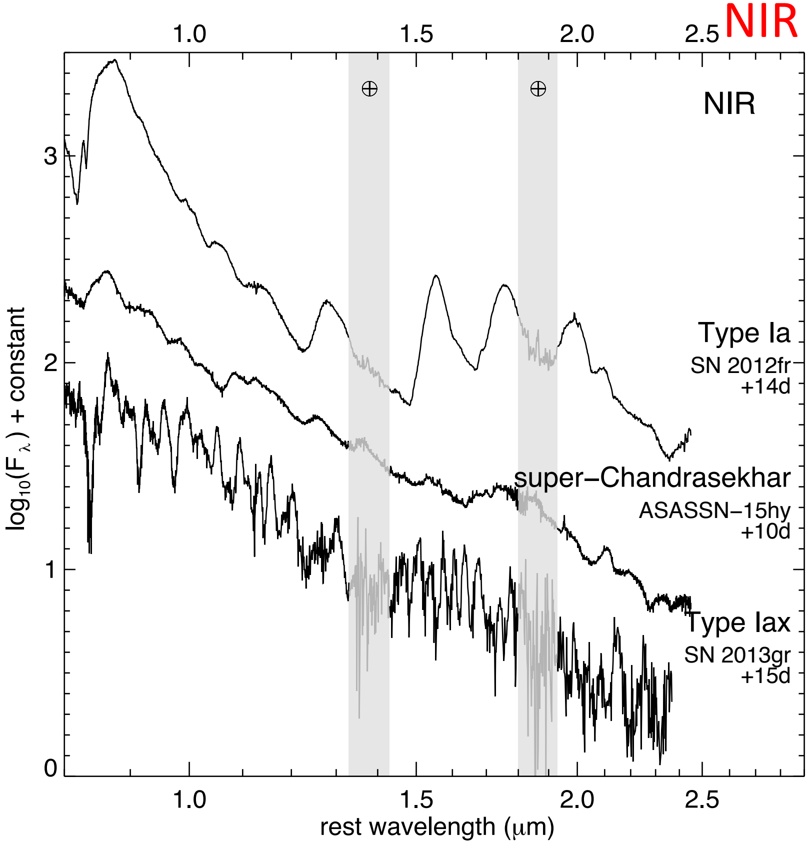
- The difference between normal, super-C, and IaX are somewhat subtle in the optical
- At NIR wavelengths the spectra are significantly different: suggesting different progenitors/mechanisms?

optical



Rest Wavelength (microns)

NIR



Normal

Super-C

IaX

Rest Wavelength (microns)