Type Iax supernovae 2010ae and 2012Z: from the faint and fast to the bright and slow

Maximilian Stritzinger

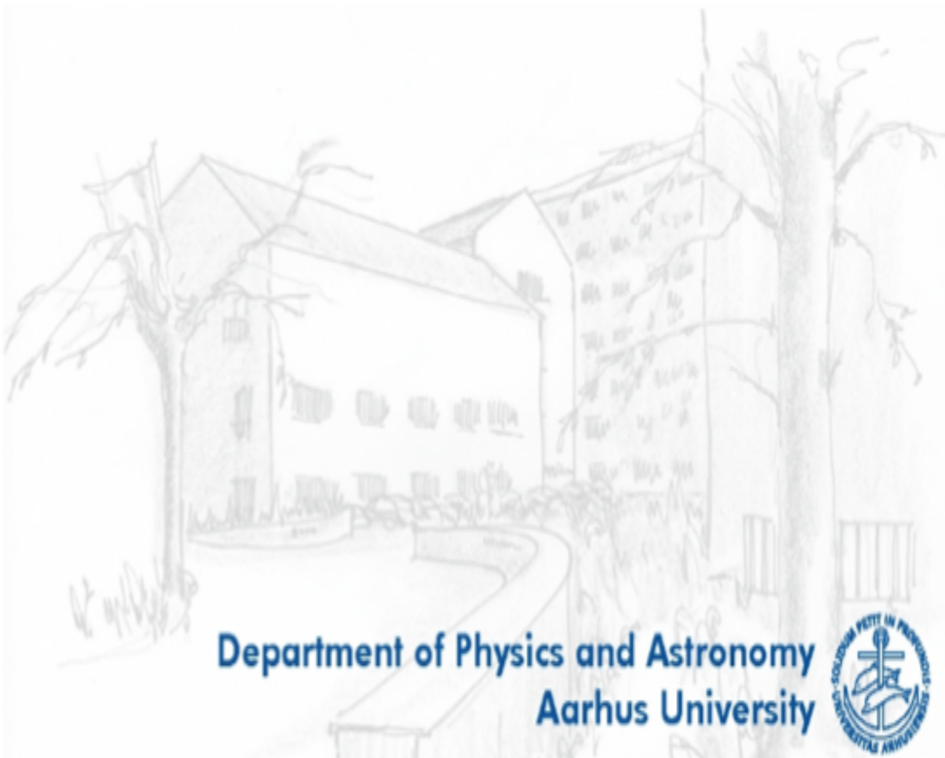
Carnegie Supernova Project

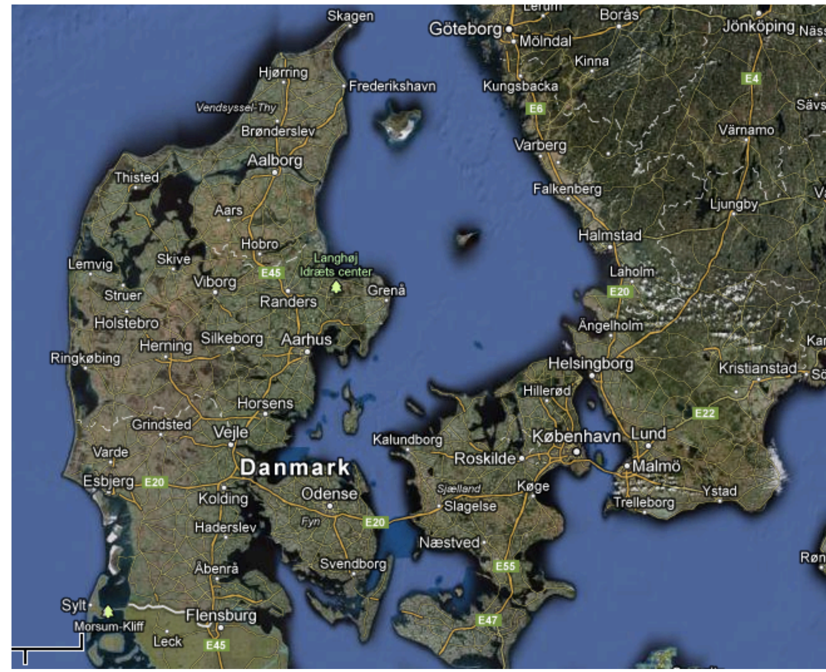
AARHUS UNIVERSITET

Supernova IaX properties

Stritzinger et al. 2014, A&A, 561, 146: SN 2010ae + new photometry of SN 2008ha

Stritzinger et al. 2015, A&A, 573, 2: SN 2012Z + updated photometry of SN 2005hk


Department of Physics and Astronomy
Aarhus University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Borås
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Värnamo
Aalborg
Varberg
Thisted
Falkenberg
Aars
Ljungby
Hobro
Halmstad
Lemvig
Skive
Langhøj
Idræts center
Viborg
Grenå
Laholm
Struer
Randers
Holstebro
Ängelholm
Silkeborg
Aarhus
Herning
Ringkøbing
Helsingborg
Kristianstad
Hillerød
Horsens
Grindsted
Vejle
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Roskilde
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Esbjerg
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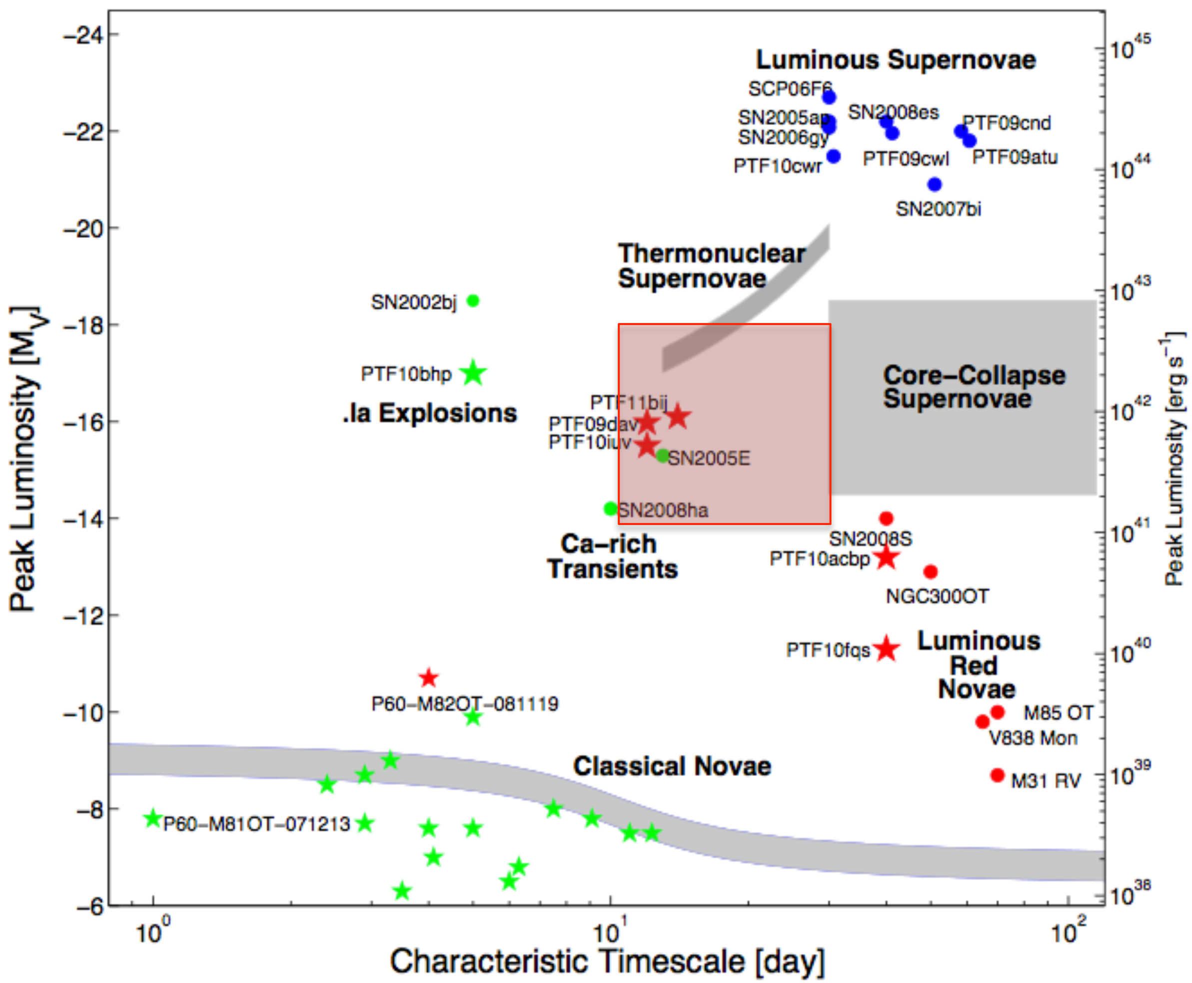
Køge
Kolding
Sjælland
Slagelse
Trelleborg
Ystad
Haderslev
Fyn
Næstved
Svendborg
Åbenrå
Rønne
Sylt
Flensburg
Morsum-Kliff
Leck
E45
E20
E55
E47
E22
E6
E4

Overview

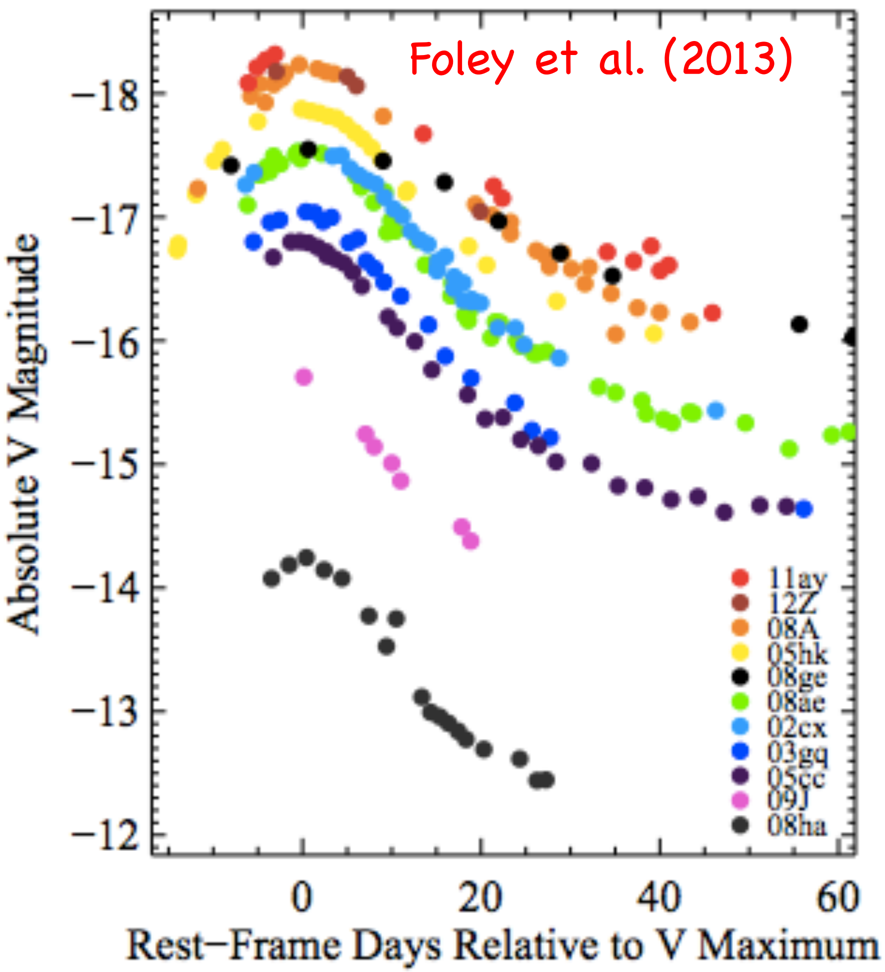
- Brief overview of the 2002cx / Type "Iax" class
- The bright Type Iax SN 2012Z and the faint Type IaX SN 2010ae
- Viable explosion scenarios
- Progenitor detections

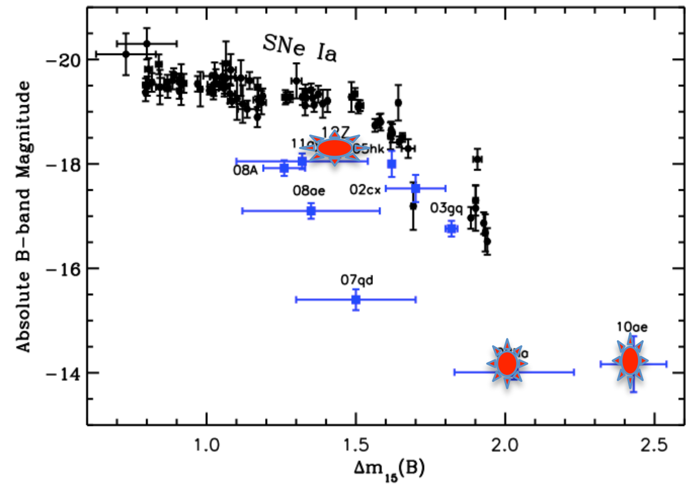
Transient luminosity vs. temporal phase space

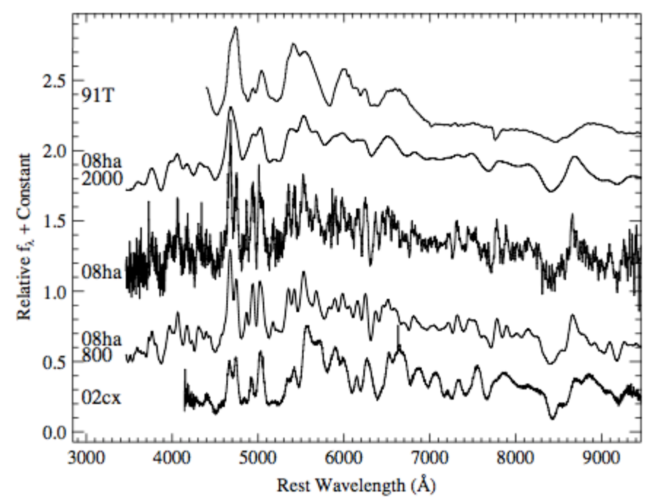


Adapted from SOXs science case (2015)

Properties of the Iax class







Foley et al. (2009); Valenti et al. (2009)

→ WD or CC origin?

Summary of SNe Iax (2002cx-like)

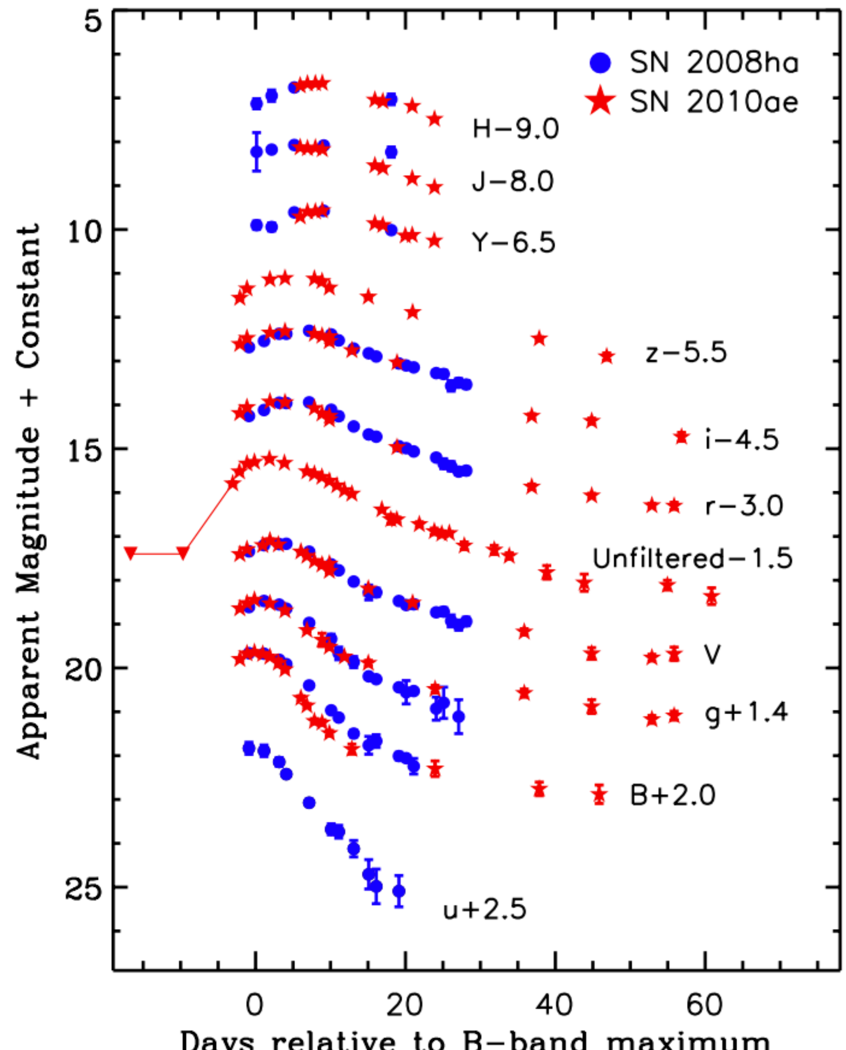
- Significant range in luminosity ($-18.5 < M_V < -14$ mag)

  → large variations in ^{56}Ni content, and do not obey a LWR

- NIR bands peak well after optical bands & no near-IR 2nd maxima
- Hot spectra with low velocities (narrow lines) of IME and Fe-group
- Late phase optical spectra are dominated by [Ca II] and not truly nebular!
- Tend to occur in young star forming galaxies with delay times of ≈50 million years (Foley et al. 2009; Lyman et al. 2013), low metallicity?
- 5-30% of the overall SNe Ia rate

Bizarre, though coarsely similar to normal SNe Ia

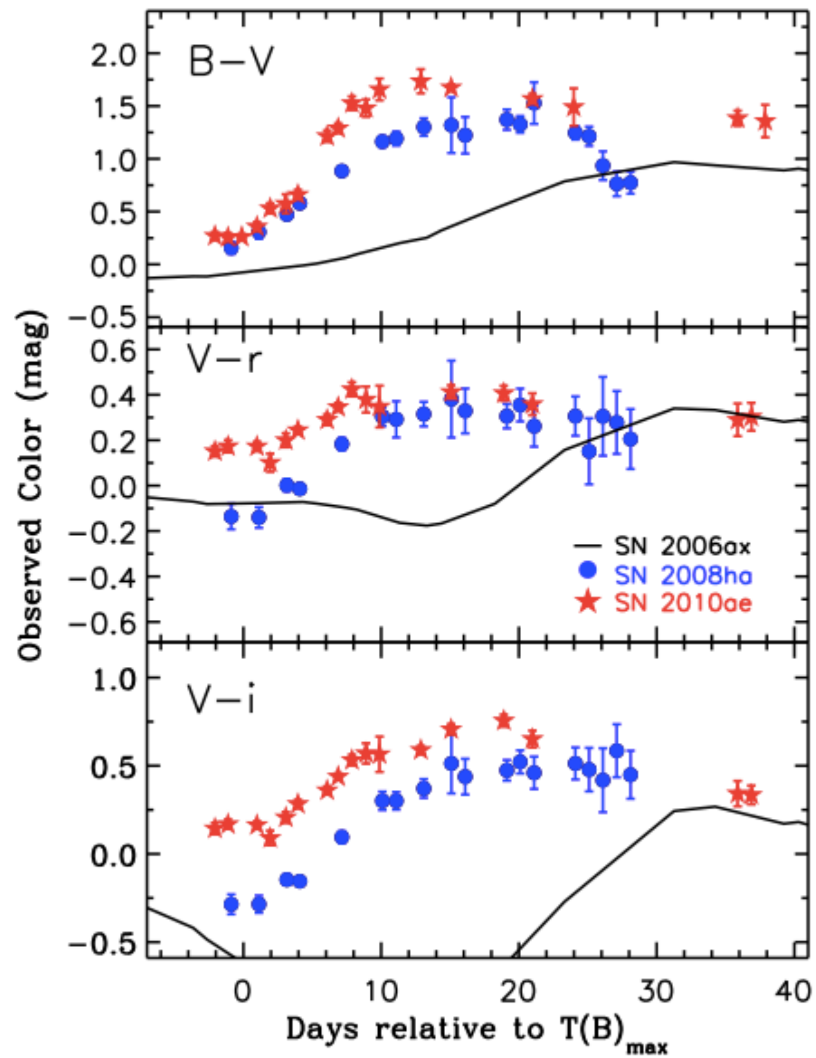
Supernova 2010ae: *the faint and fast*



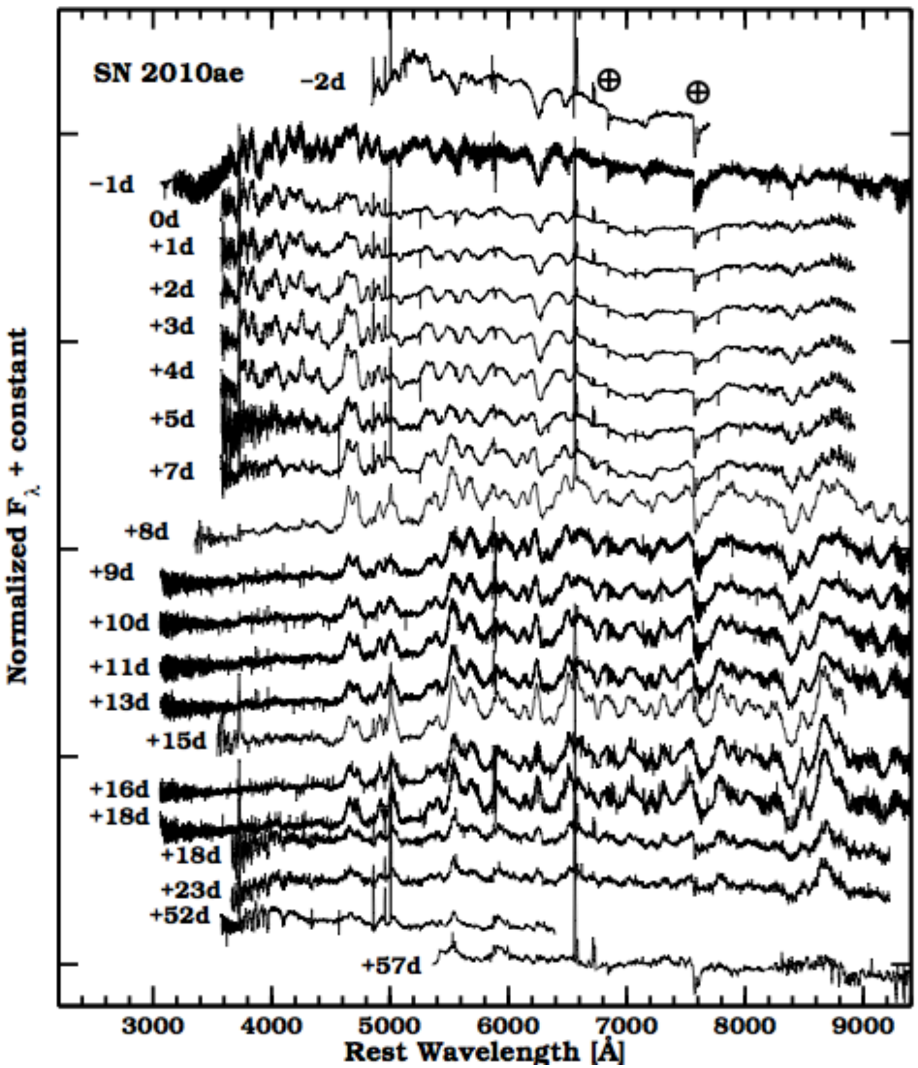
- NIR bands peak ≈ 7 days *after* the optical

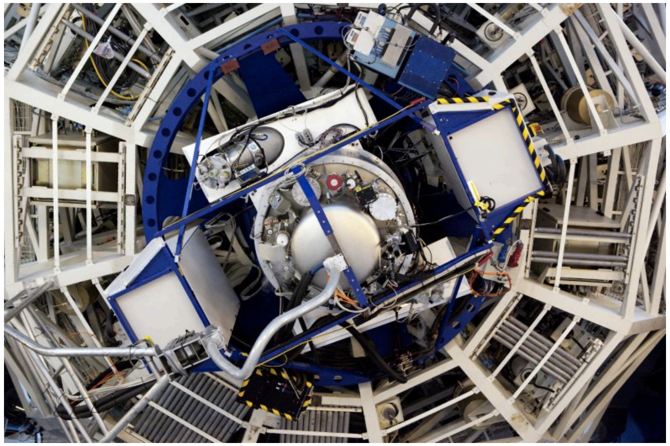
Reddening is *poorly* constrained

- NaID1 = 0.74±0.06 Å; NaID2 = 0.58±0.06 Å
- Galactic Na I and EBV relations imply EBV_{host}=0.45 mag
- Combined with Milky Way gives EBV_{tot}=0.62±0.42 mag
- Choice a range from MW to moderate to total

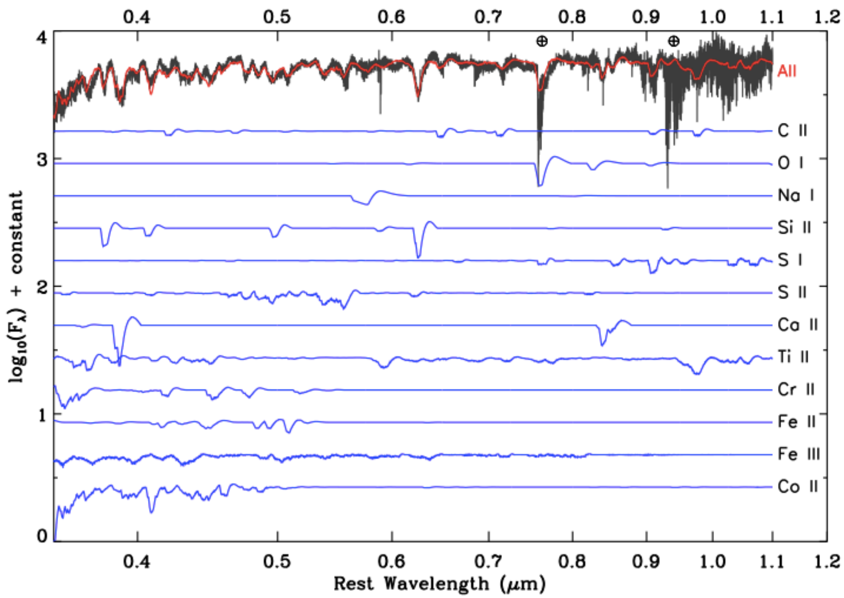


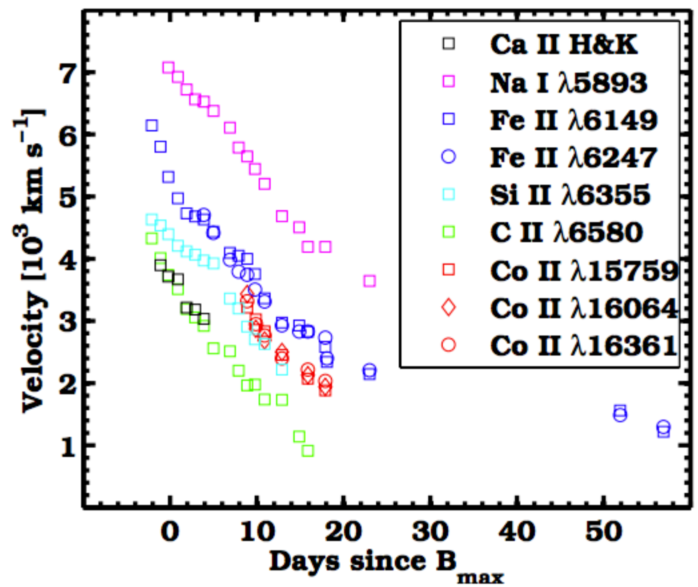
Supernova 2010ae: *optical spectra*





Supernova 2010ae: line IDs at maximum and line velocities



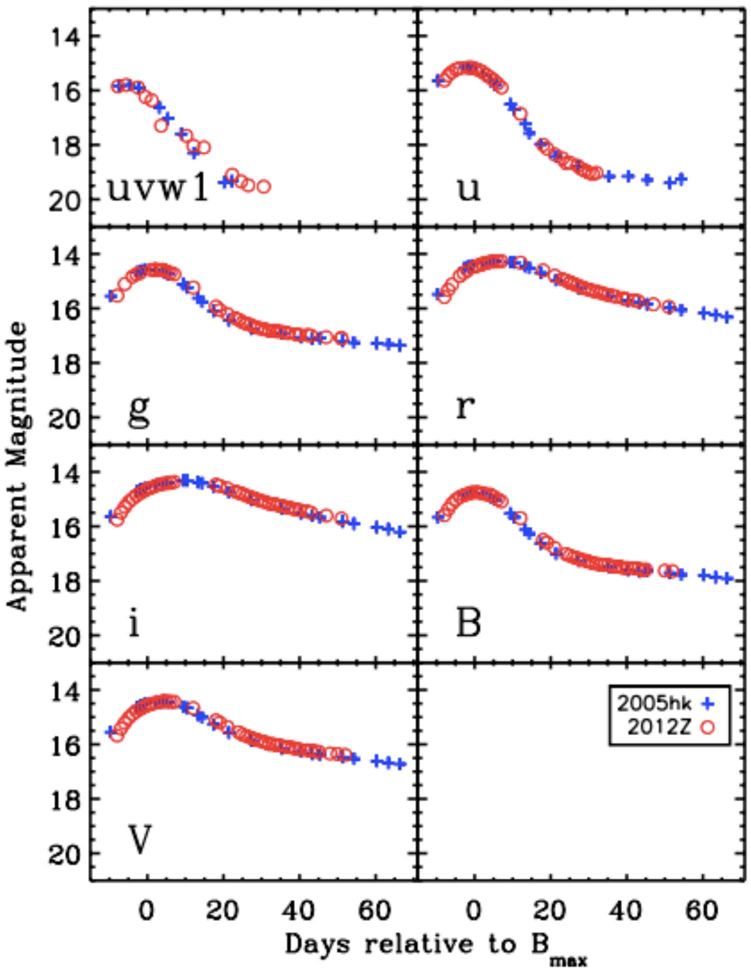


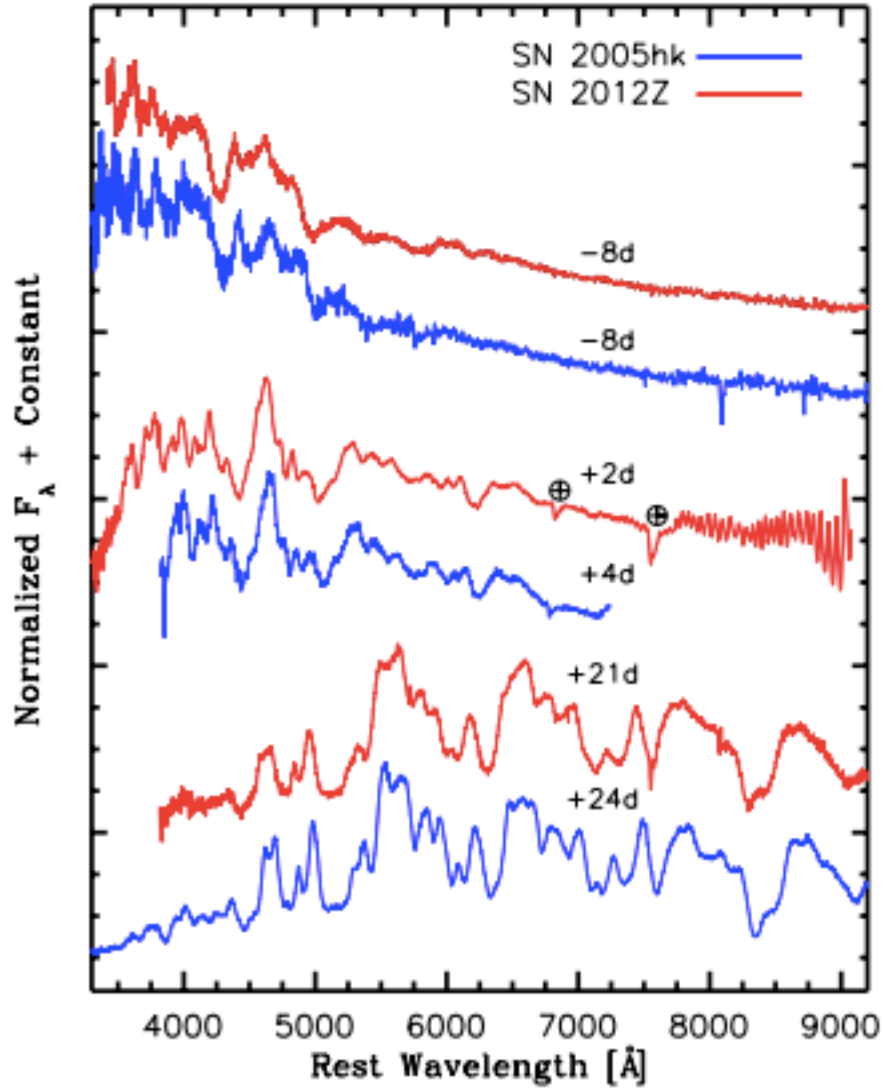
via SYNAPPS

SN 2012Z

Observed as part of CSP II

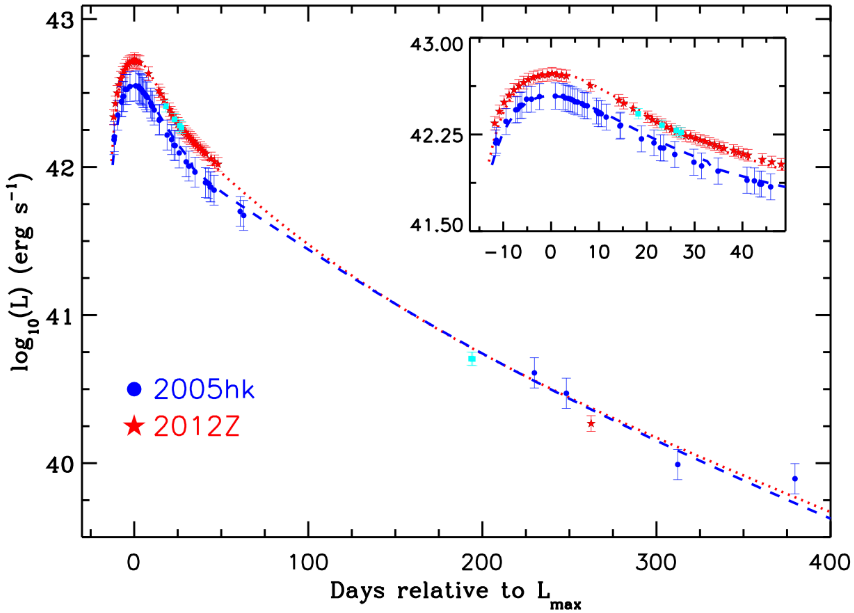
SN 2012Z: A proto-typical bright IaX



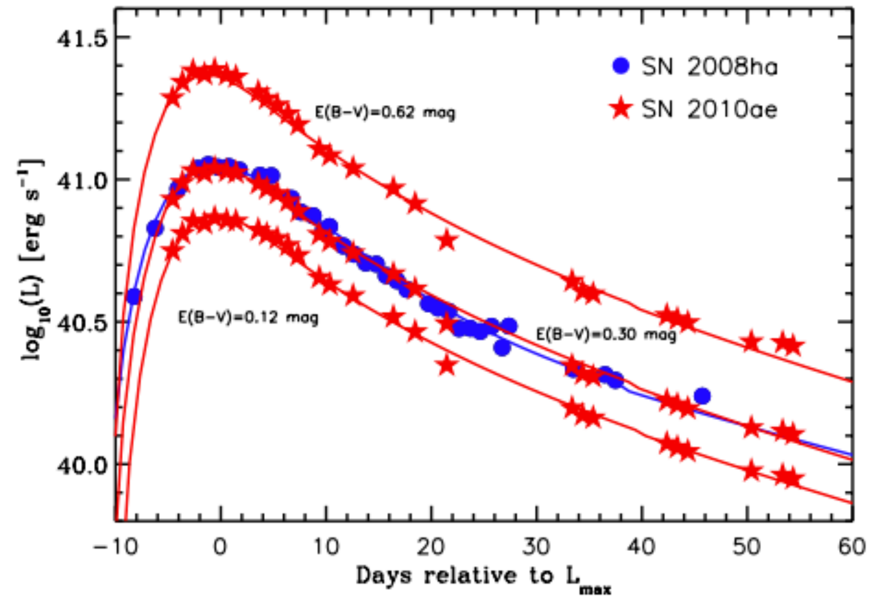


Physical parameters of SNe Iax from toy model

SNe 2005hk & 2012Z



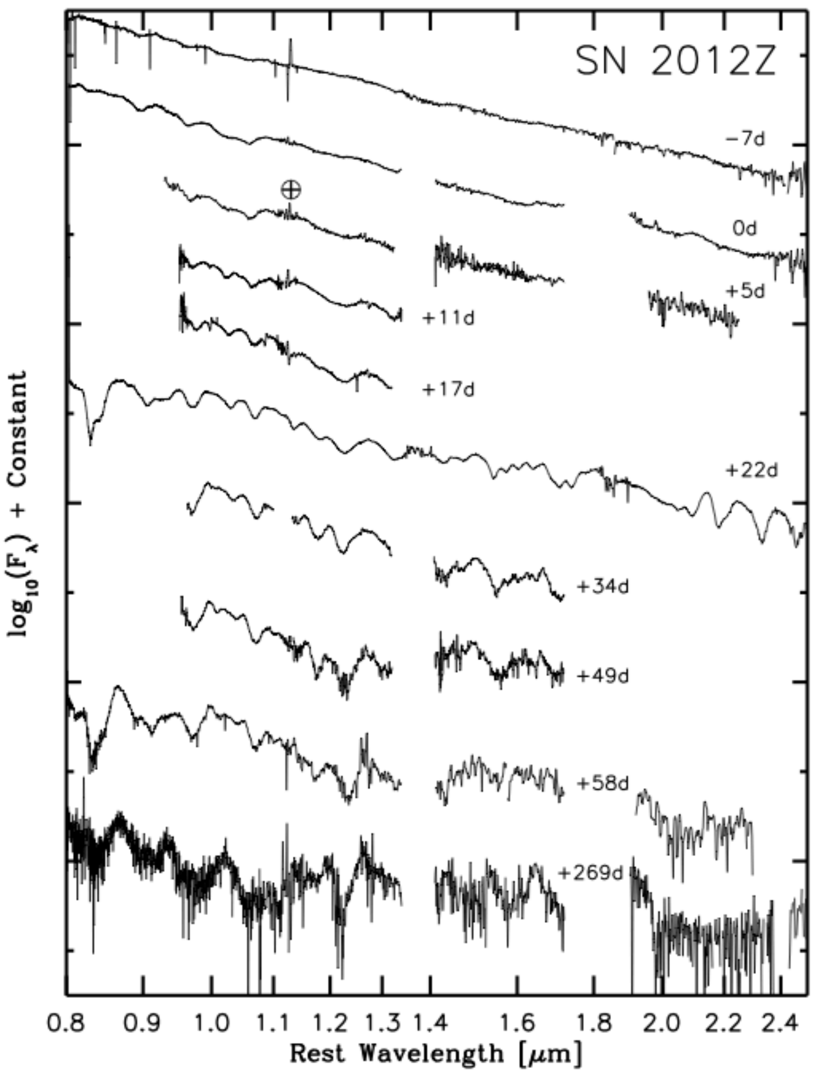
SNe 2008ha & 2010ae

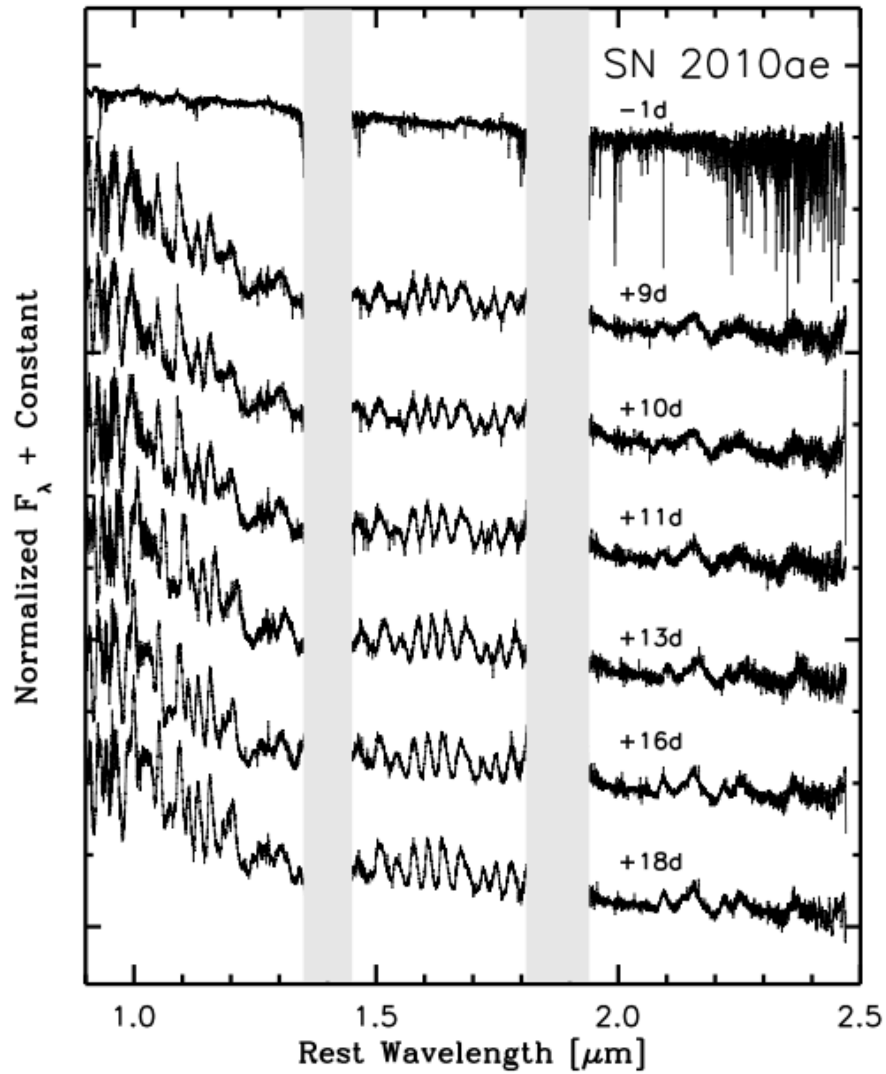


- 0.15–0.20 $M_\odot$ of ^{56}Ni
- $M_{ej} \approx M_{CH}$
- KE ≈ 10^{51} erg

- ≈0.005 $M_\odot$ of ^{56}Ni
- $M_{ej} \approx 0.5\ M_\odot$
- KE ≈ 0.04–0.30x10^{51}

SNe IaX @ NIR wavelengths





Insight on progenitor from NIR: H-band spectroscopy

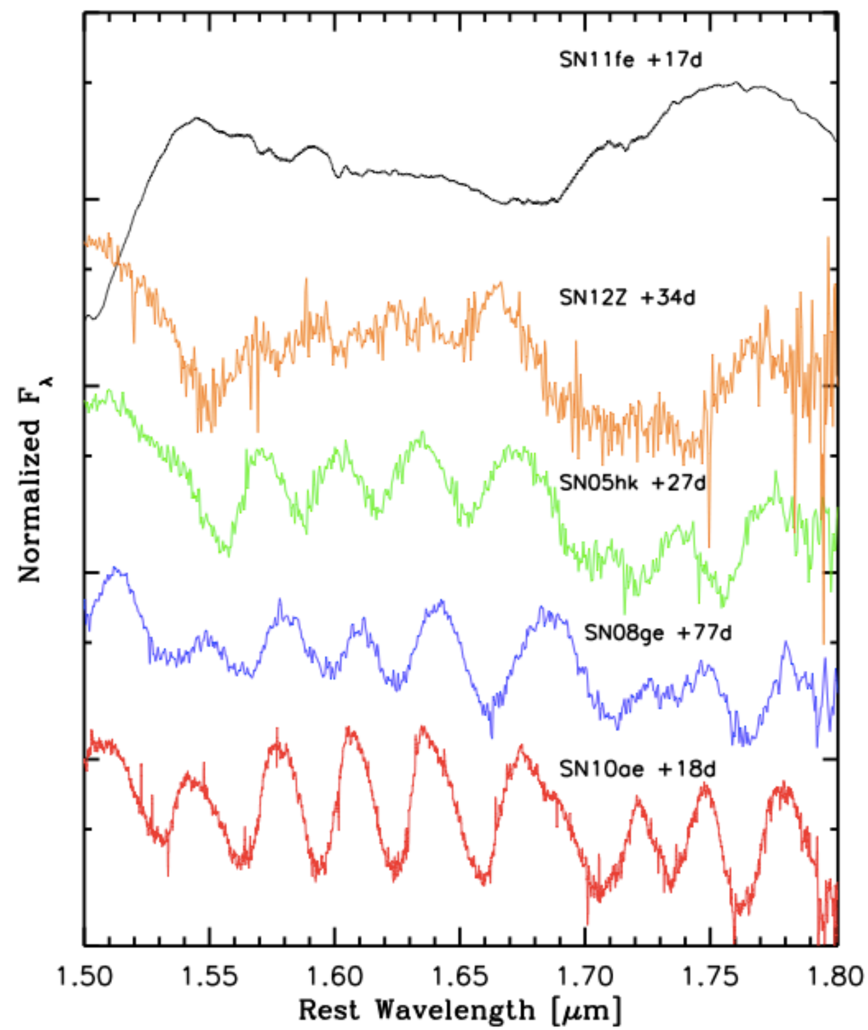
- Co II features are ubiquitous to SN Iax!

- Smaller velocities

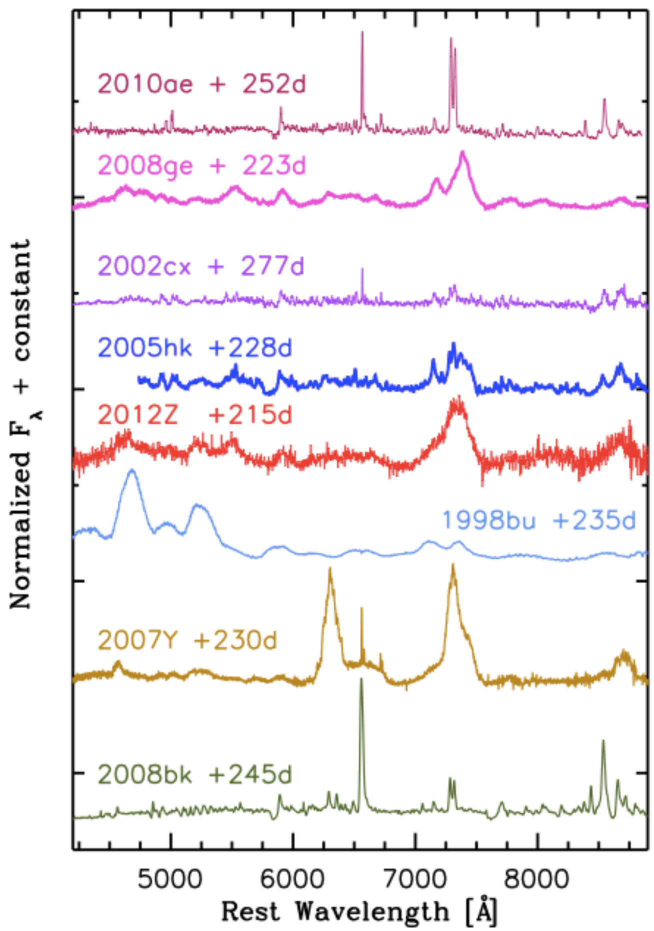
→ less blending
→ more prevalent features!

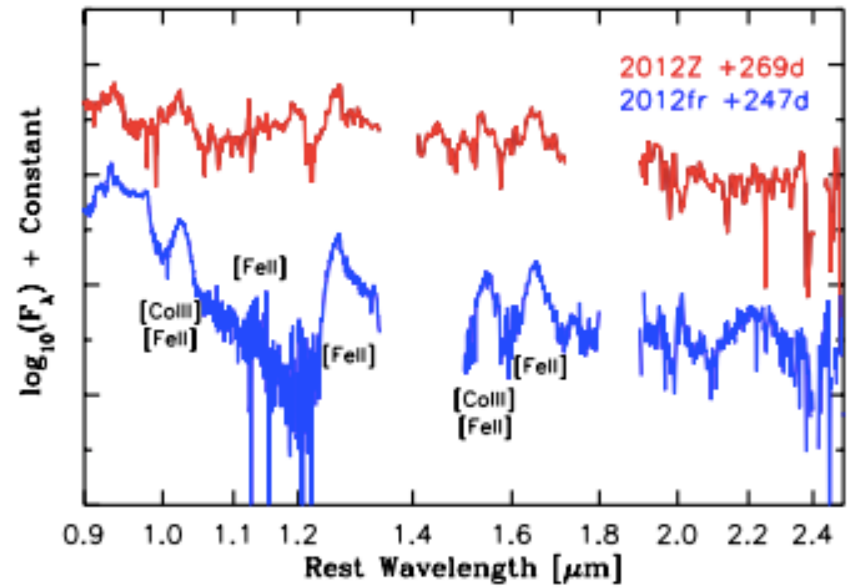
- Faint and fast objects are clearly linked to the brighter end of the SN Iax distribution *and* to normal SN Ia

- Spectra of SN 2012Z indicate a layered structure: Mg, Si, and then Fe-group elements



SNe Iax @ late phases





- No [Fe III[/[Fe II[
- No Oxygen
- Prevalent cooling via calcium

SN Ia explosion physics in a nut shell

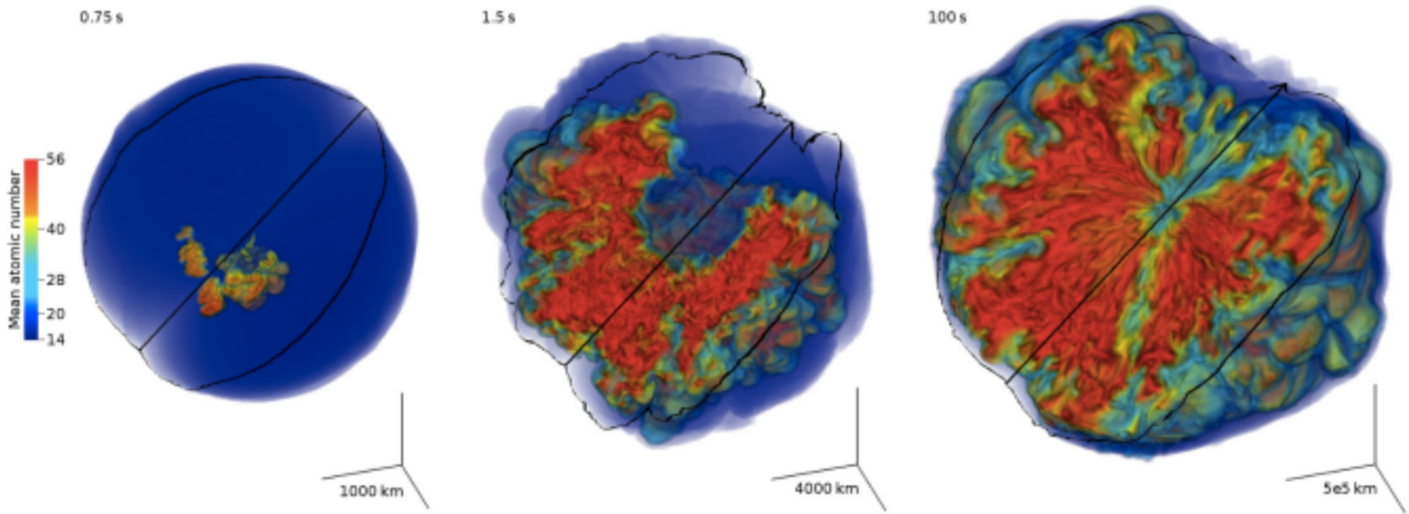
- Pure deflagration: flame < $v_{cs,}$ limited ^{56}Ni & enhanced mixing

- Pure detonation: flame > $v_{sp,}$ mostly ^{56}Ni, limited IMEs

- Delayed-detonation: combination of both, layered structure & increased ^{56}Ni mass

→ all lead to disruption of white dwarf

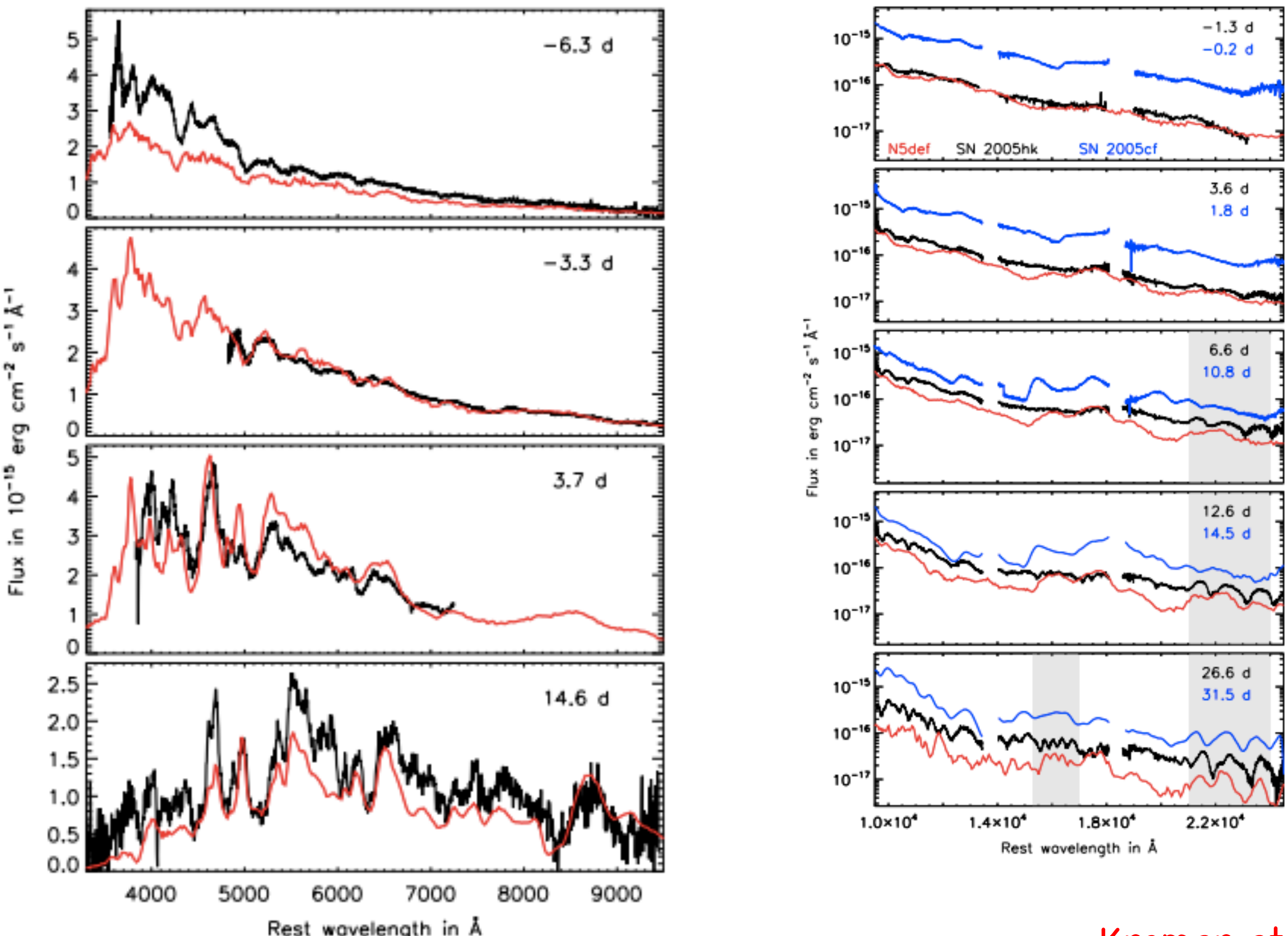
Progenitor: Bound Remnants



- Early phase emission powered by ejected ^{56}Ni
- Late phase emission powered by bound remnant

Kromer et al. (2013)

Bound Remnants: Model Spectra of SN 2005hk



Kromer et al. (2013)

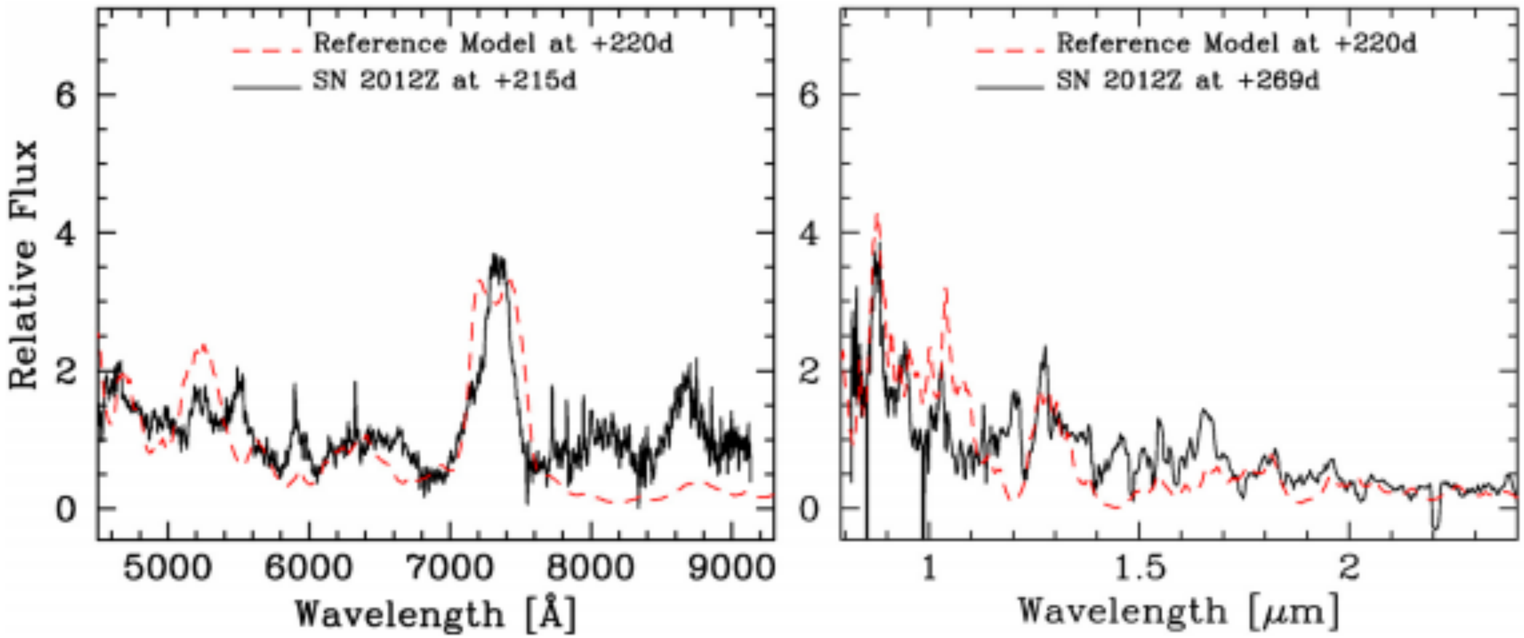
Alternative: Pulsational Delayed Detontation (PDD) of M_{CH} white dwarf

- Start with a deflagration at high density; producing Fe-group elements (opposite of SNe Ia)
- Expansion followed by shell fall back
- Detonation is ignited (little to no ^{56}Ni is produced here)

Provides for:

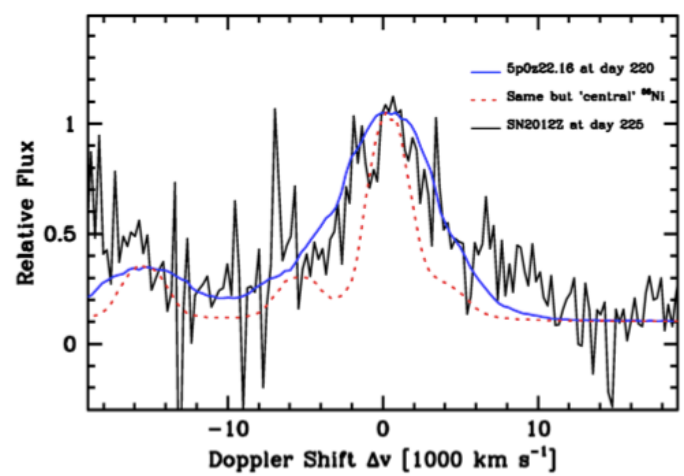
- Low velocities (lack of forbidden Fe lines at late phases)
- Gives observed layered chemical structure, with ^{56}Ni in outer layers
  → explains the early blue colors and hot spectra
- Pot-bellied late phase NIR profiles
- Little unburned C/O
- Range of possible ^{56}Ni mass from near 0 to 0.8 $M_{\odot}$

PDD reference model predictions



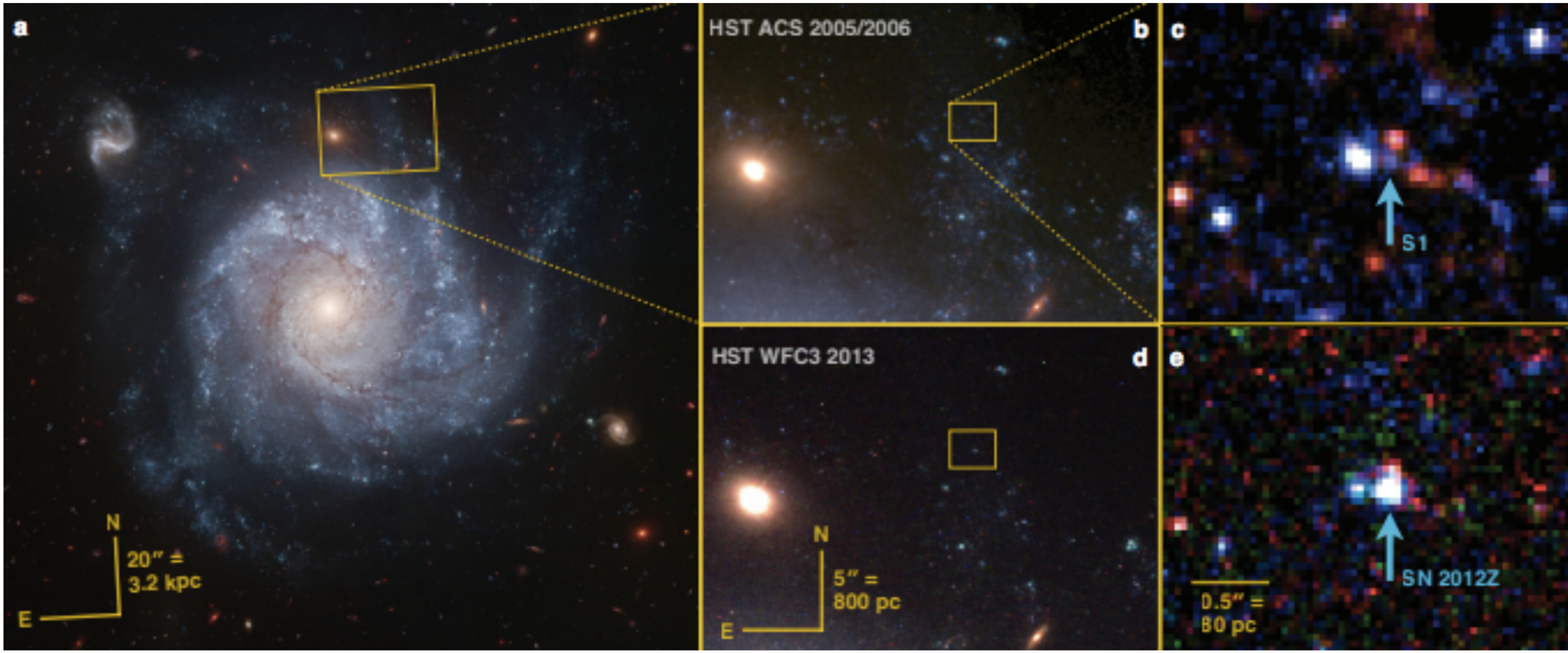
Pot-bellied 1.64 μm line profile

→ ^{56}Ni hole in the center
→ Signature of high density
→ M_{CH}



Pre-explosion progenitor detection: Curious Case of SN 2012Z

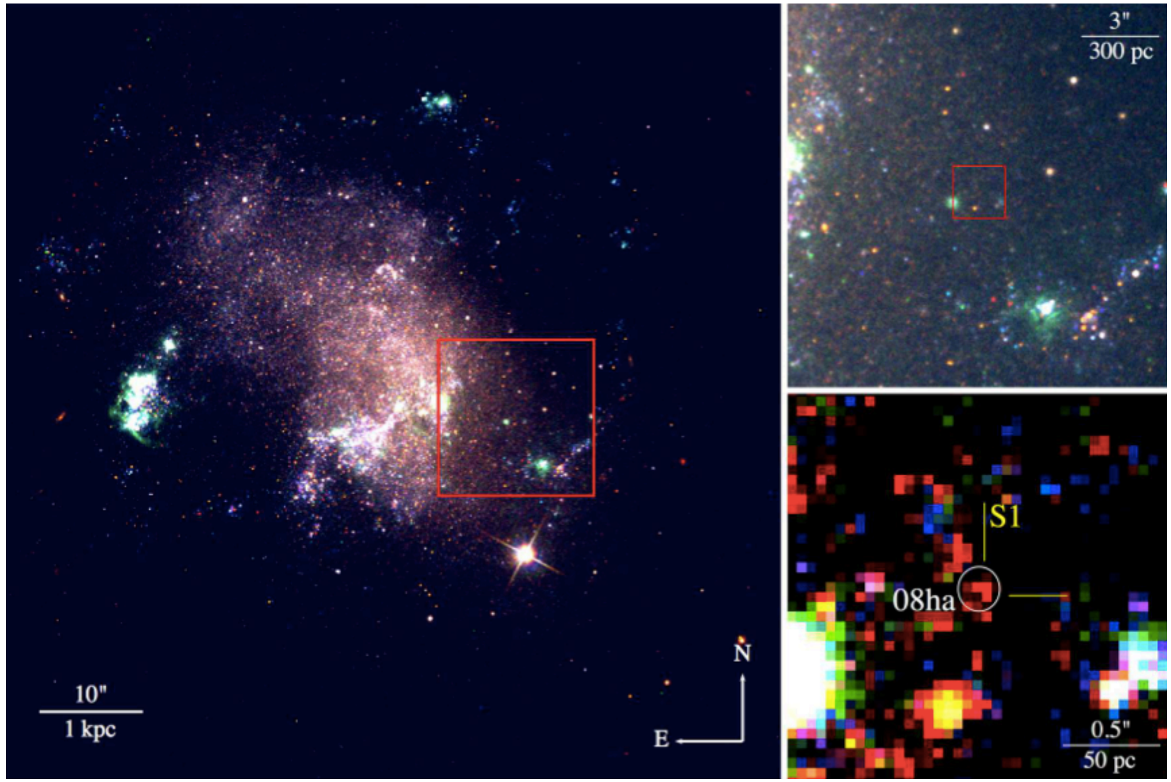
McCully et al. (2014)



Luminosity, color, and environment of S1 are all similar to the Galactic helium nova V455 Puppis

→ 2 $M_\odot$ He star companion to white dwarf?

Post-explosion detection (+4.1 yr): SN 2008ha



If S1 is connected to SN 2008ha

- Diversity in SN IaX progenitors
- Bound remnant of the white dwarf that expanded significantly

Foley et al. (2014)

Summary

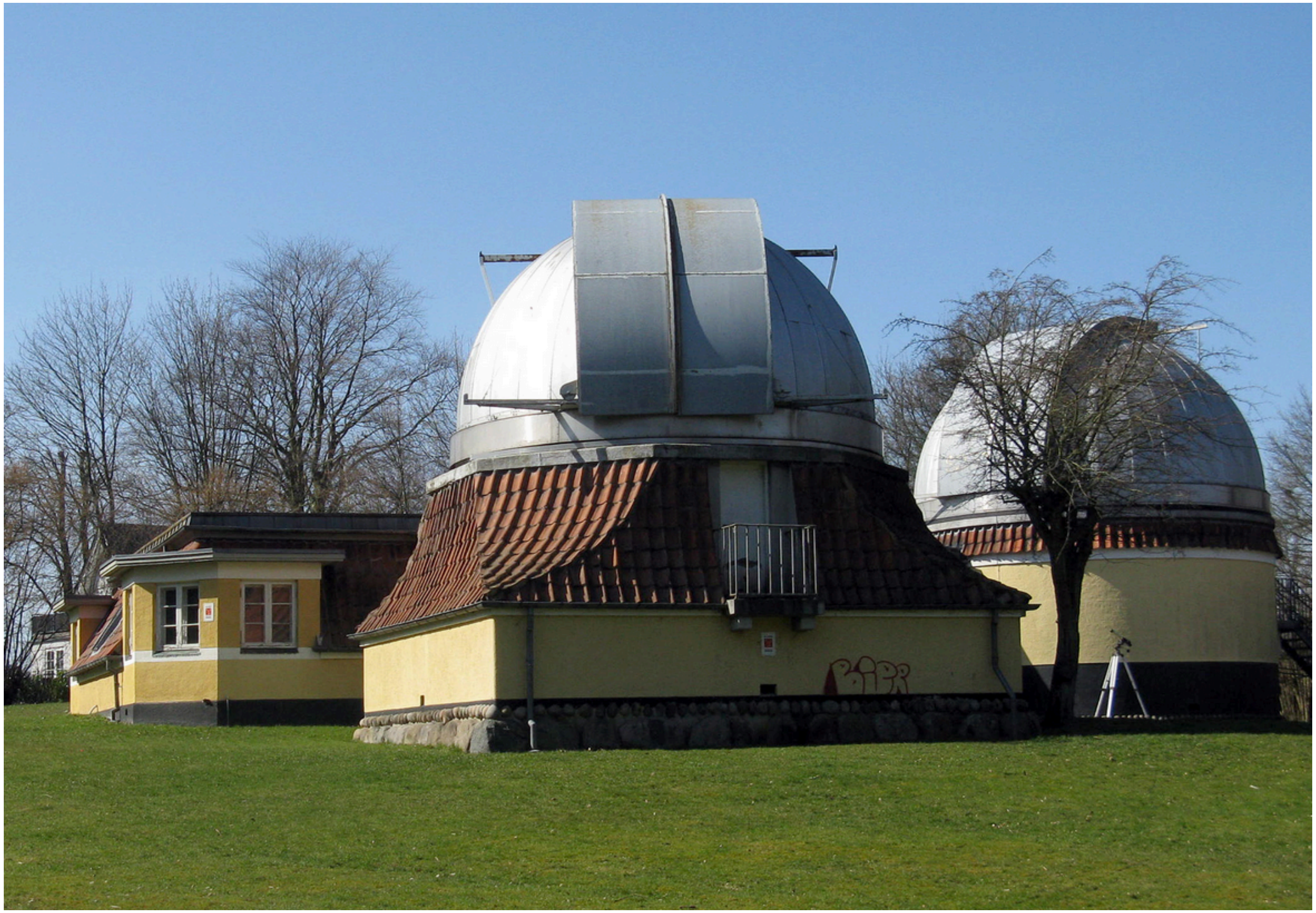
- NIR spectroscopy provides a number of powerful constraints e.g., layered chemical structure, pot-bellied profile, Co II lines…
- SN IaX appear to have a white dwarf origin
- Range in physical parameters suggest diversity in the explosion physics and/or progenitors
- Future HST observations of 2008ha and 2012Z could confirm the final fate of their progenitors:

Has the progenitor disappeared or does a bound remnant remain?

Saludos from Las Campanas

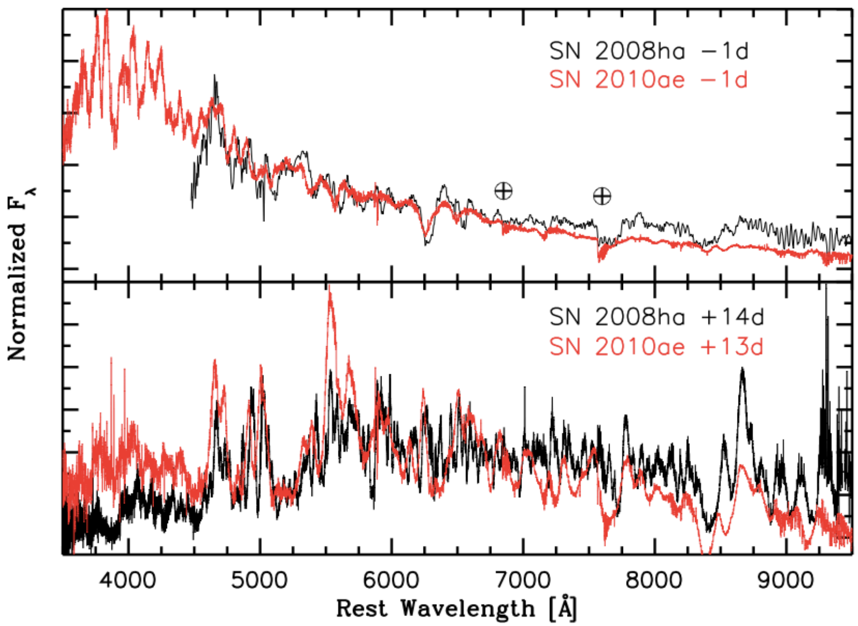
Las Campanas Observatory

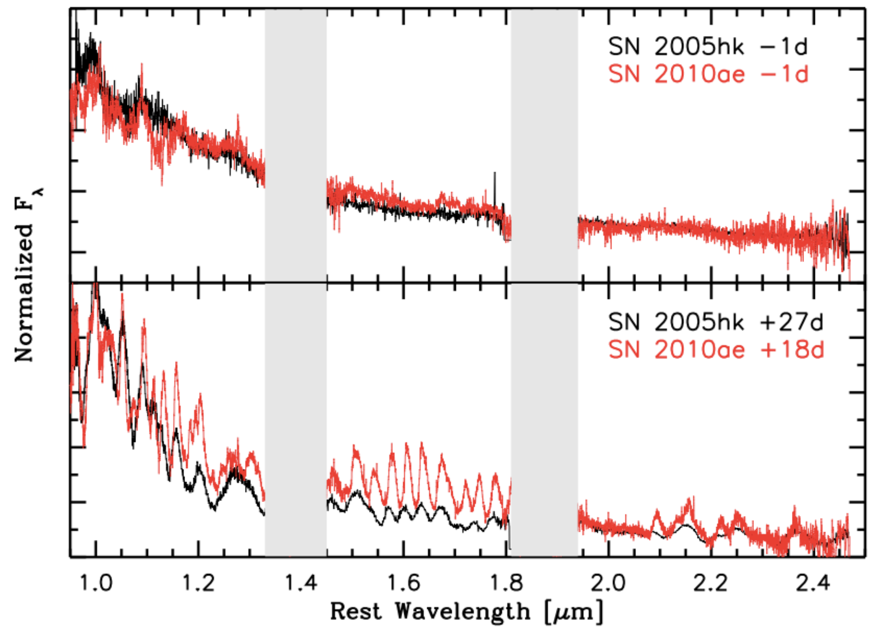
Hilsner fra Aarhus



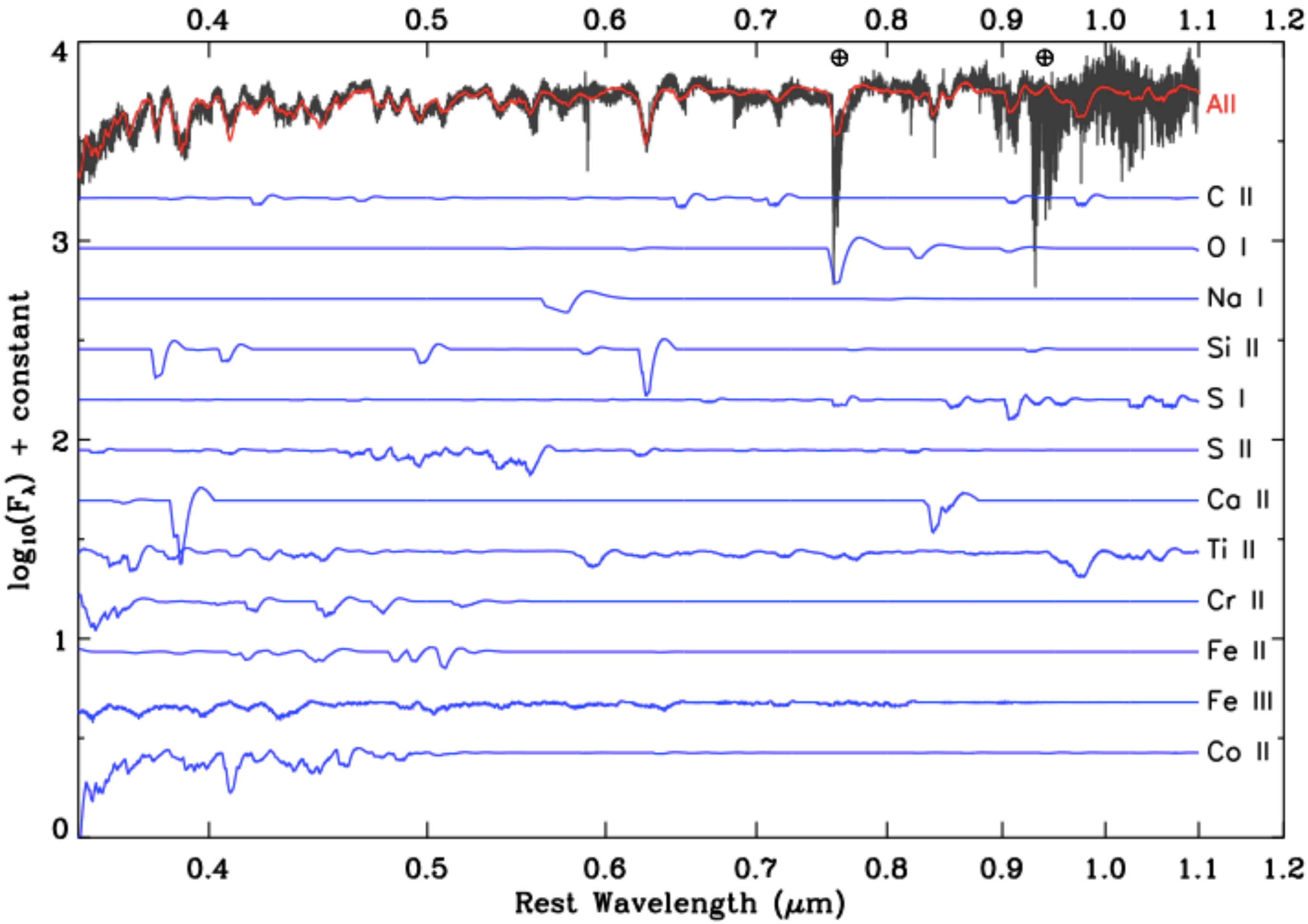
Ole Rømer Observatory

Spectral comparison to SN 2008ha



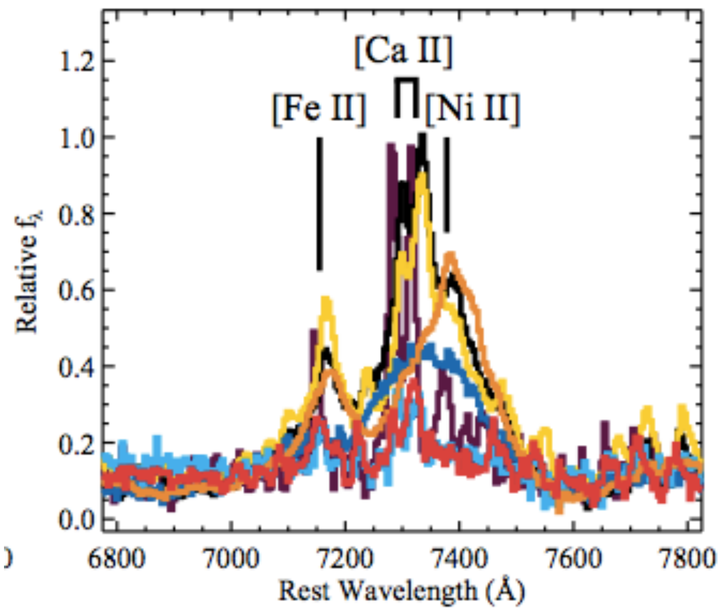


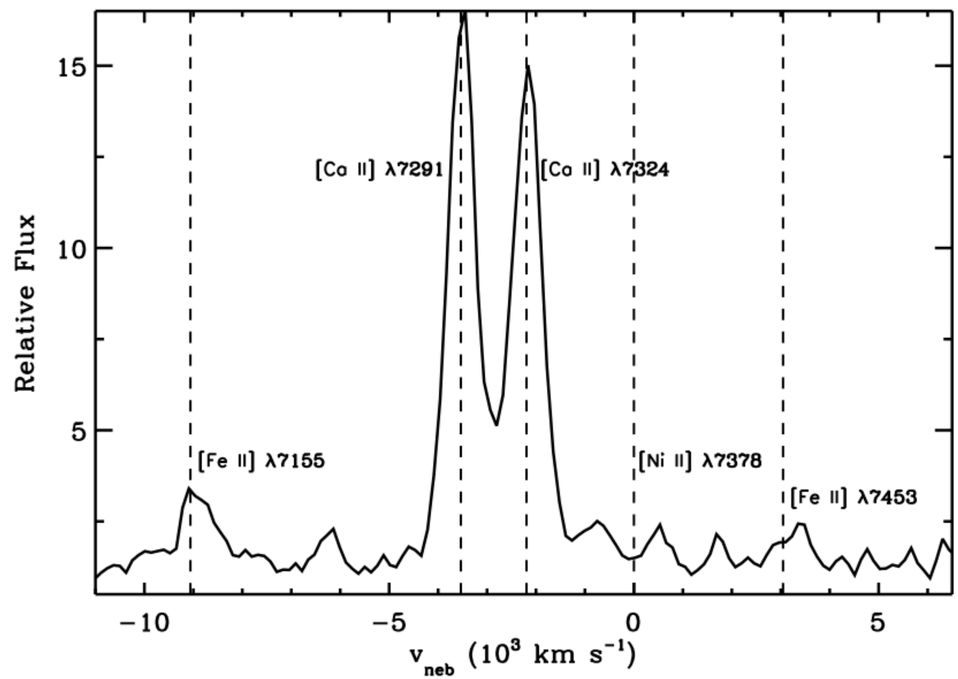
ID of spectral features I.



via SYNAPPS

What does late phase spectrum reveal?

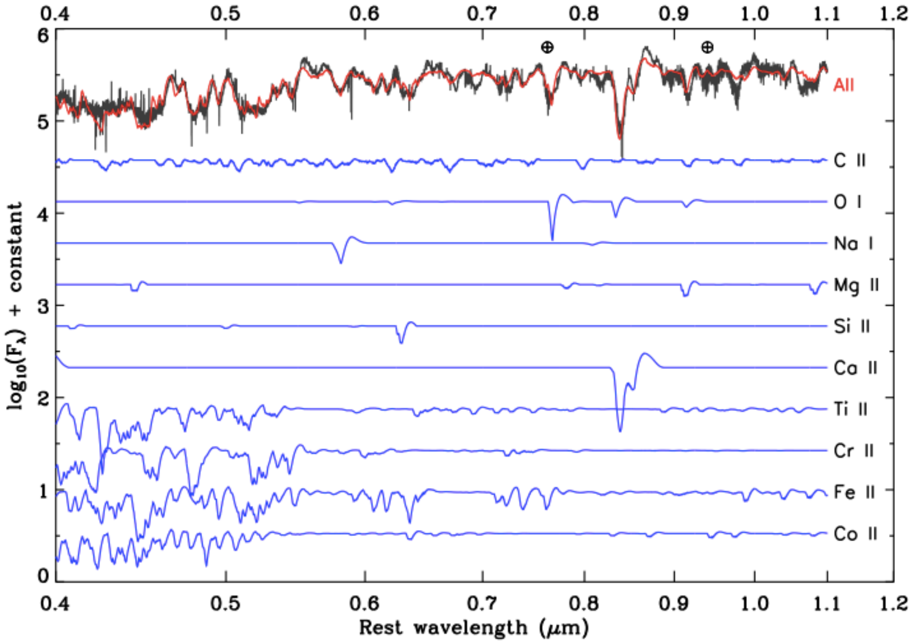


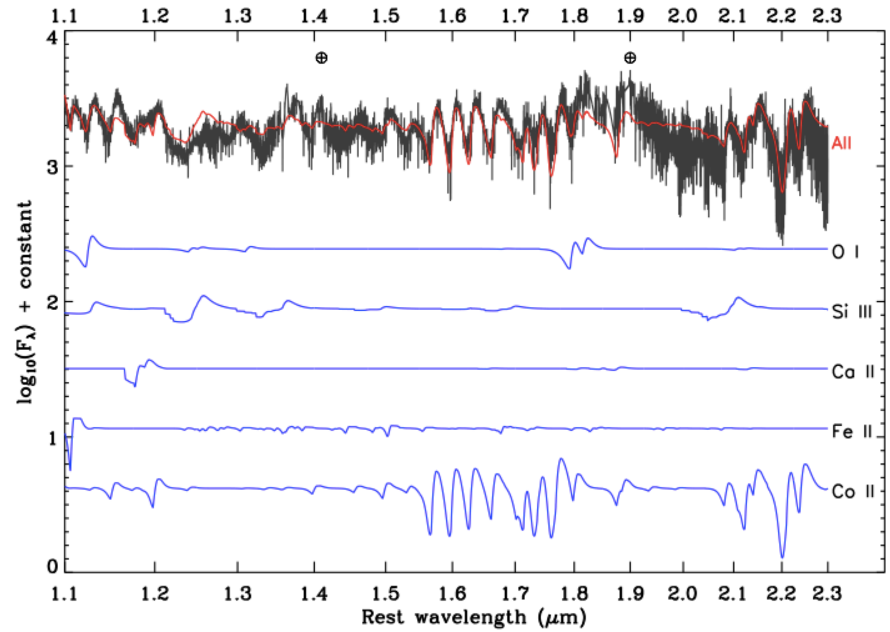


Foley et al. (2013)

- No stable Ni (like 2002cx and unlike 2008ge), no O I no [Fe III]+[Fe II]
- No appreciable velocity offsets for [Fe II], [Ca II], Ca NIR tripet
- Diversity in stable Ni (+Fe) could be either consistent or not with failed-deflagration?

ID of spectral features after maximum





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