Unburned Material in Normal Type Ia Supernovae

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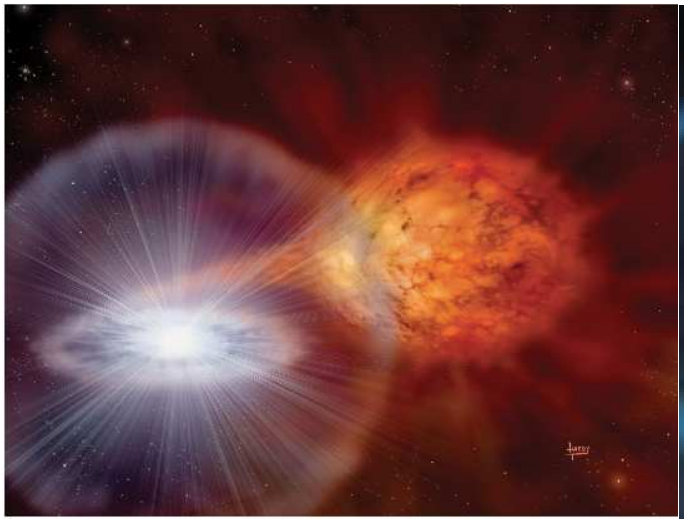


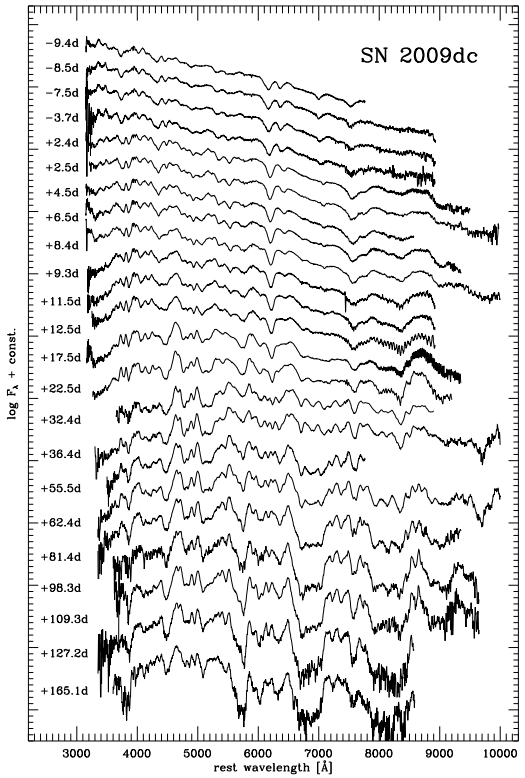
Supernova Ia Explosions

Normal SN-Ia models (Thermonuclear – 1D)

- What is left unburned of the C+O White Dwarf?
- Pure deflagration: lots of C/O left (visible at all times)
- Delayed detonation: little C in outermost layers (large velocities)

Peculiar carbon-rich SNe Ia

- Superluminous SNe
  e.g. 2003fg, 2006gz, 2007if, 2009dc
- Super-Chandra? Thermonuclear?
- Faint 2002cx-like SNe
- Pure deflagrations?



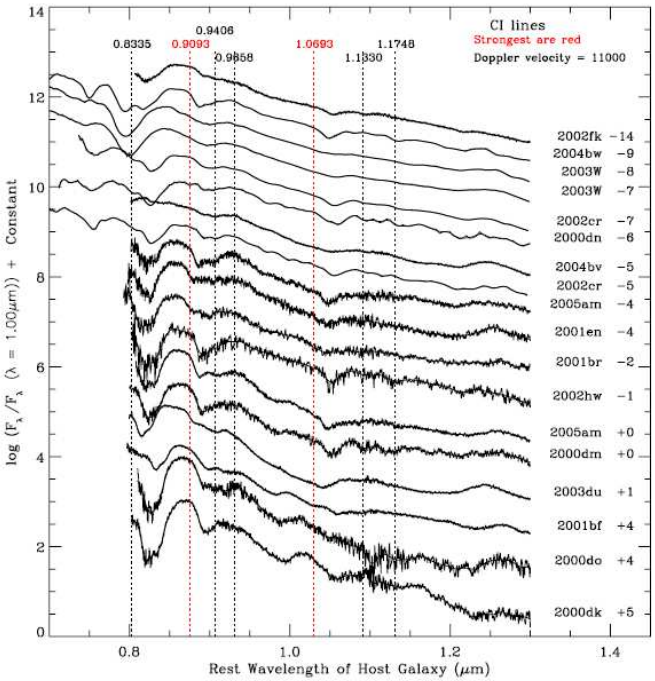
Taubenberger='11

Detection of Unburned Material

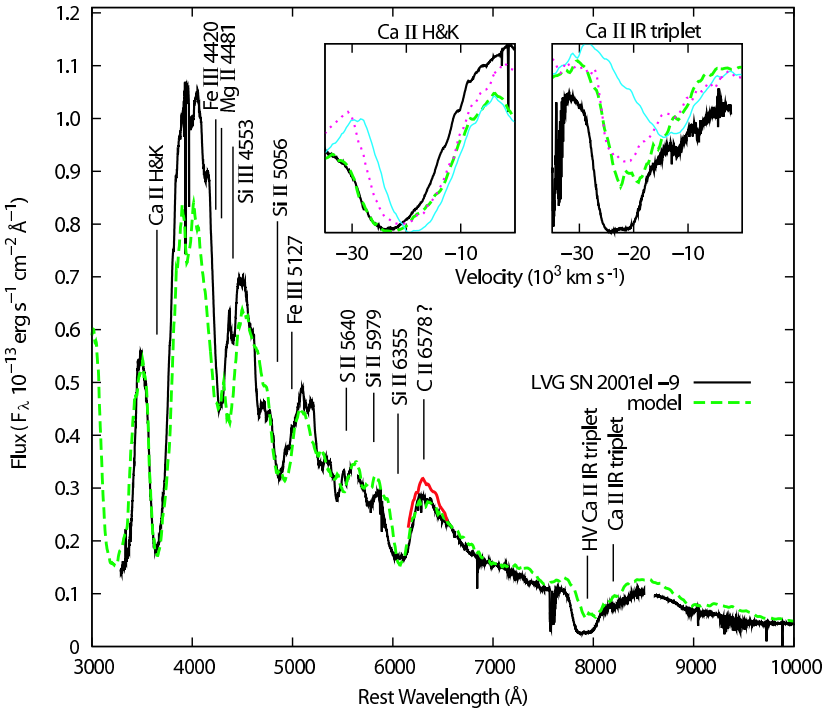
Elusive spectral features

- Enhanced O over Mg – Weak C II lines
- C I and O I in the NIR Marion+'09 – Subluminous SN 1999by Höflich+'02
- High-S/N spectra at early times – Spectral modeling

Marion+'09



SN 2003du – Tanaka+'08

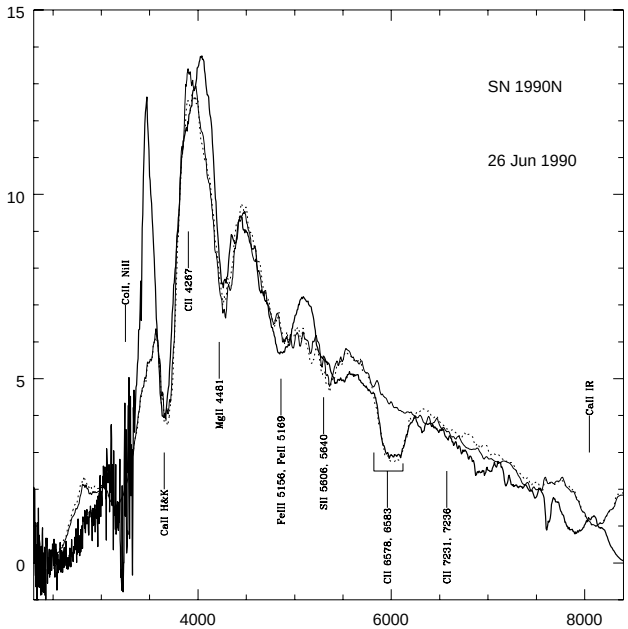


Detection of Unburned Material

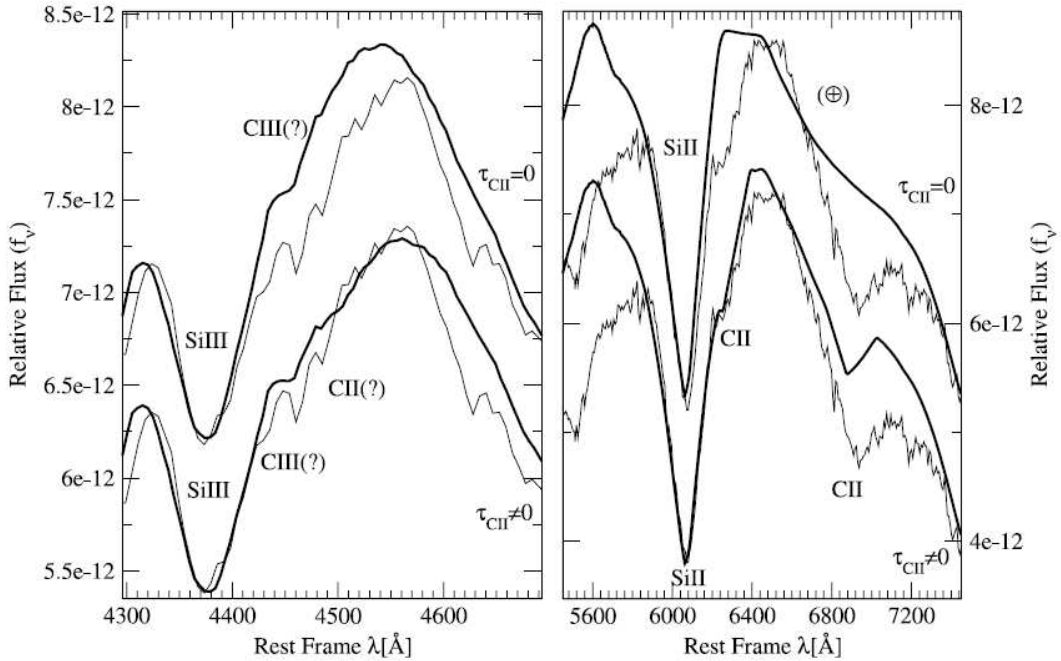
First hints

- Optical spectra: C II λ4267, λ4745, λ6580 and λ7234
- Hints of C II at very early phases – Spectral synthesis

SN 1990N at −15 d – Mazzali+'01



SN 1999ac at −15 d – Garavini+'05



SNe 1990N, 1994D, 1996X, 1998aq, 1999ac, 1999by (NIR)

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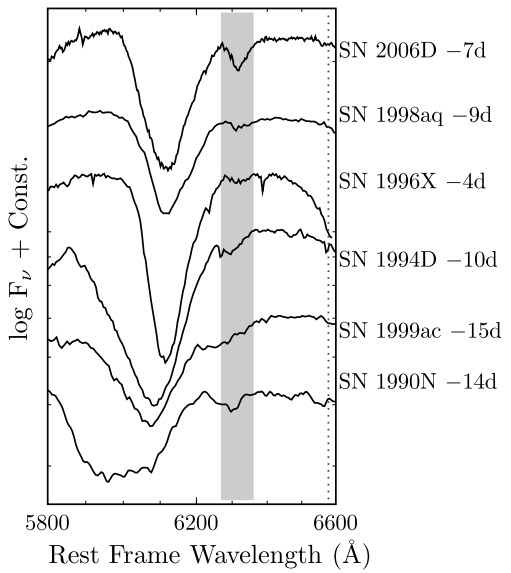
SN 2006D Thomas+'07

- Clear-cut C II λ6580 and λ7234 absorptions
- Carbon detections were sporadic in normal SN Ia

SN 2006D – Thomas+'07



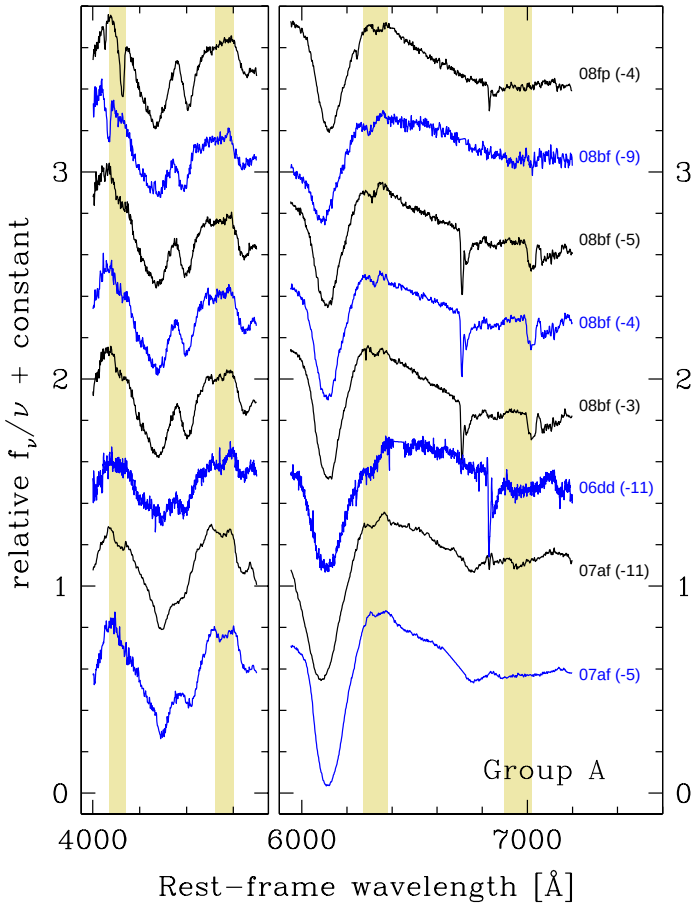
SNe 1990N, 1994D, 1996X, 1998aq, 1999ac, 1999by (NIR)

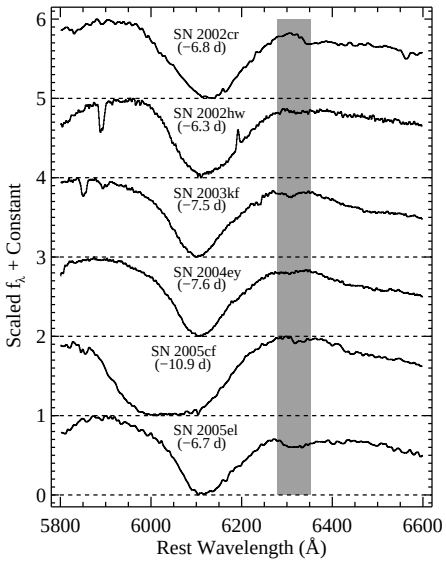
Systematic Searches

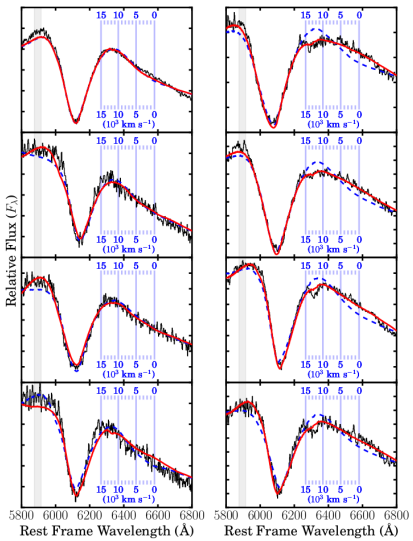
Surprisingly high incidence

- Larger data sets, high S/N, early
- Age – noise – velocity biases
- Detection statistics: 20–40%

CSP – Folatelli+'12







BSNIP Silverman+'12 – SNFactory Thomas+'11

Parrent+'11 – SNF: Thomas+'11 – CSP: Folatelli+'12 – BSNIP: Silverman+'12 – CfA: Blondin+'12

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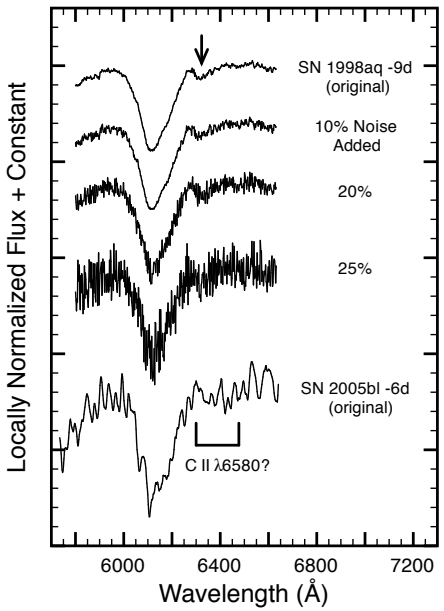

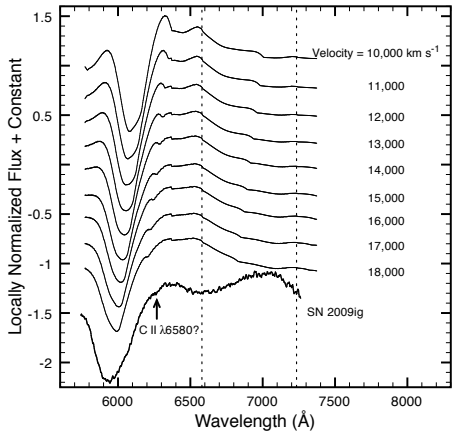

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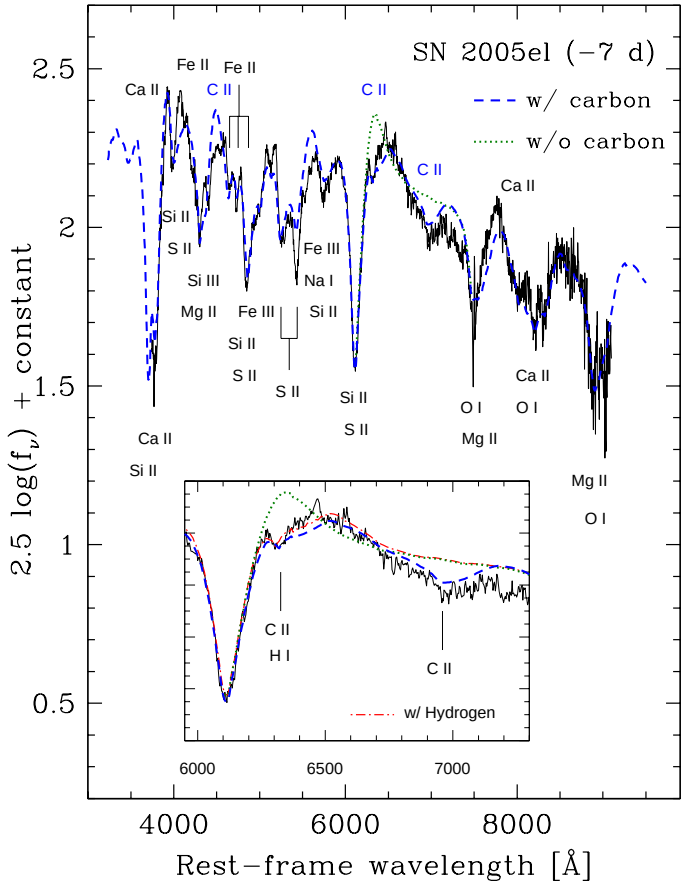

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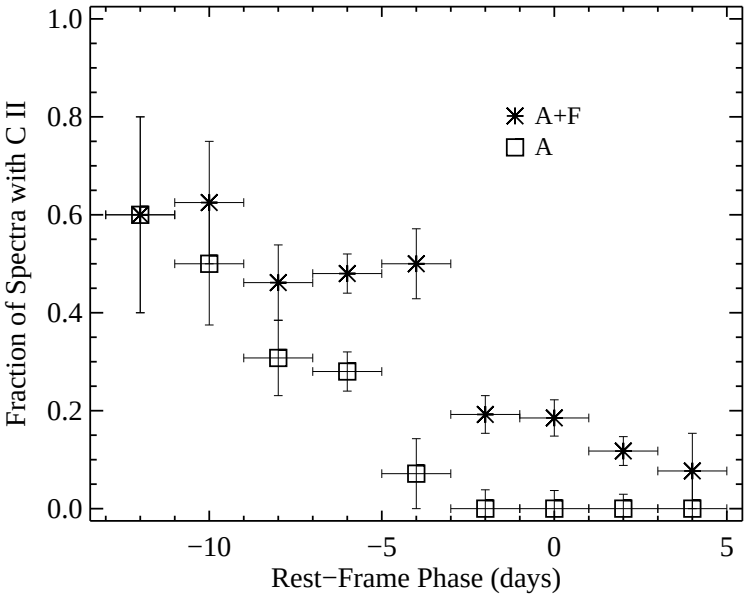

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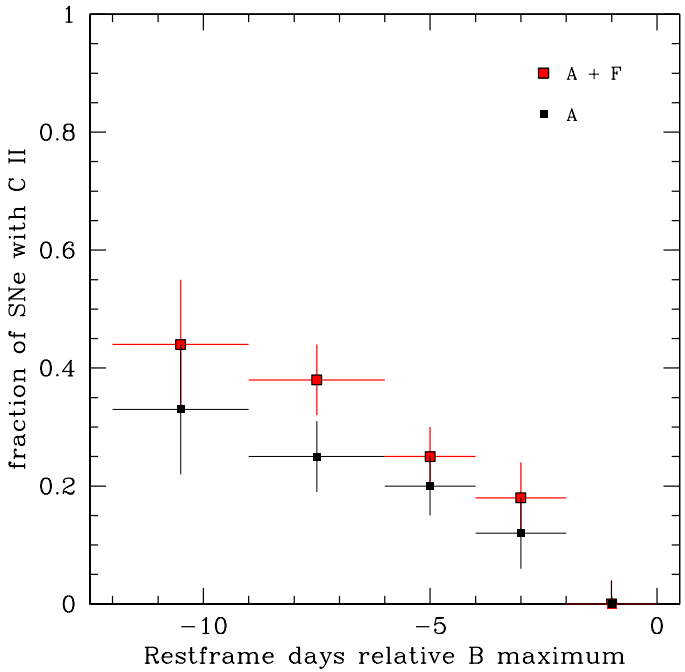

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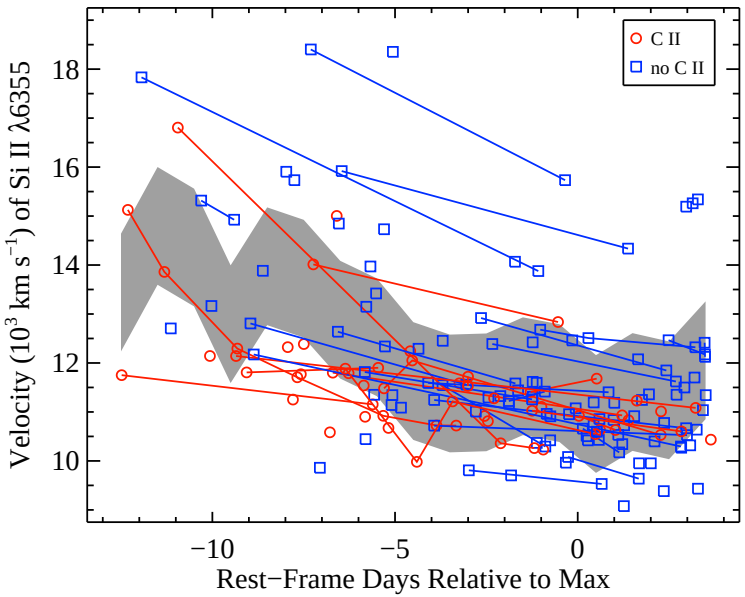
Distribution of Unburned Material

Doppler velocities

- Low Si II velocities
- C II slightly above Si II
- C is mixed down - Clumping?
- C mass from models



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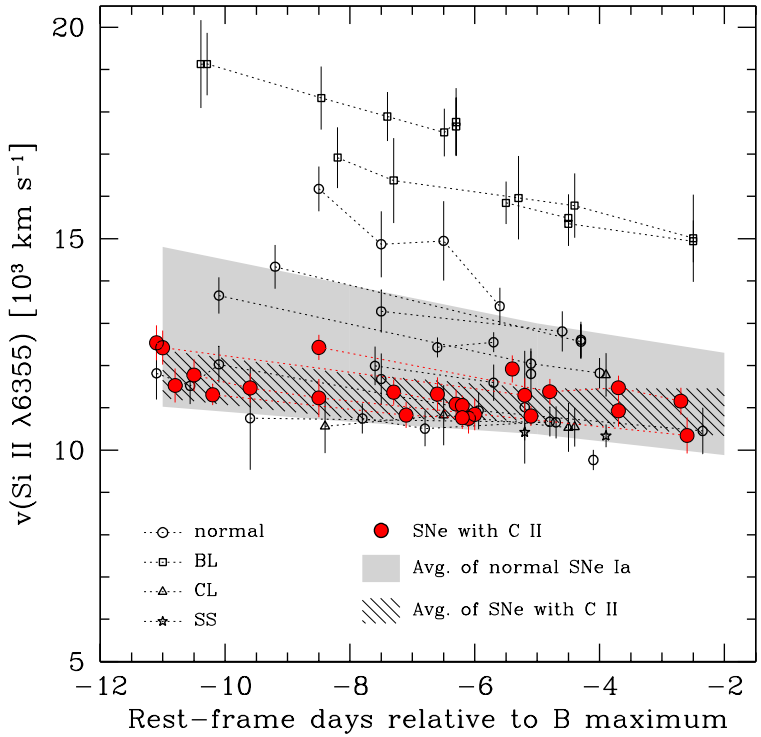

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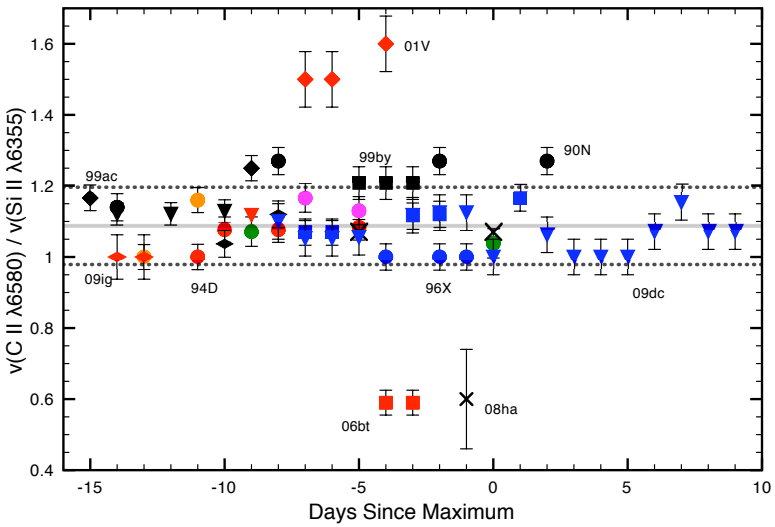
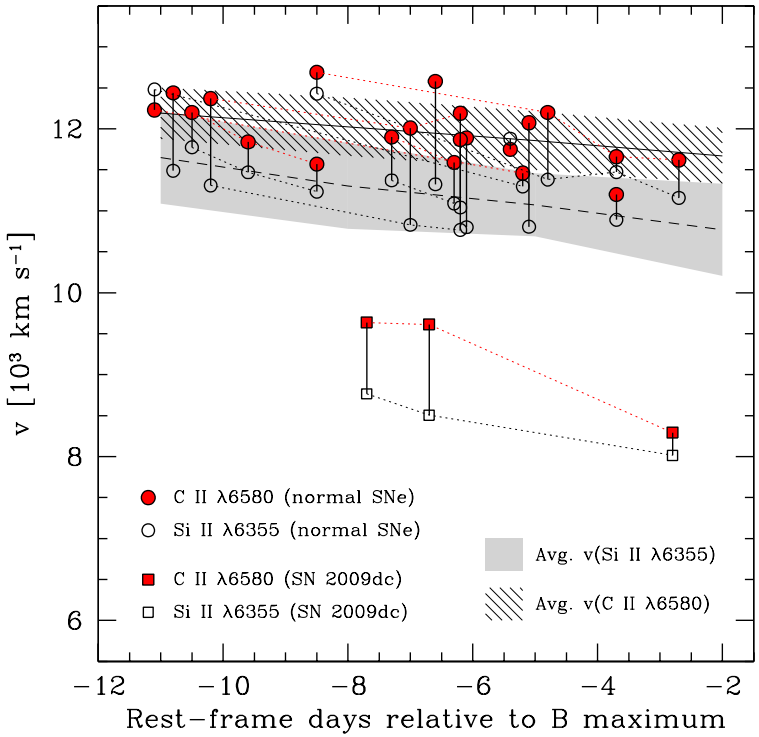


Parrent+'11



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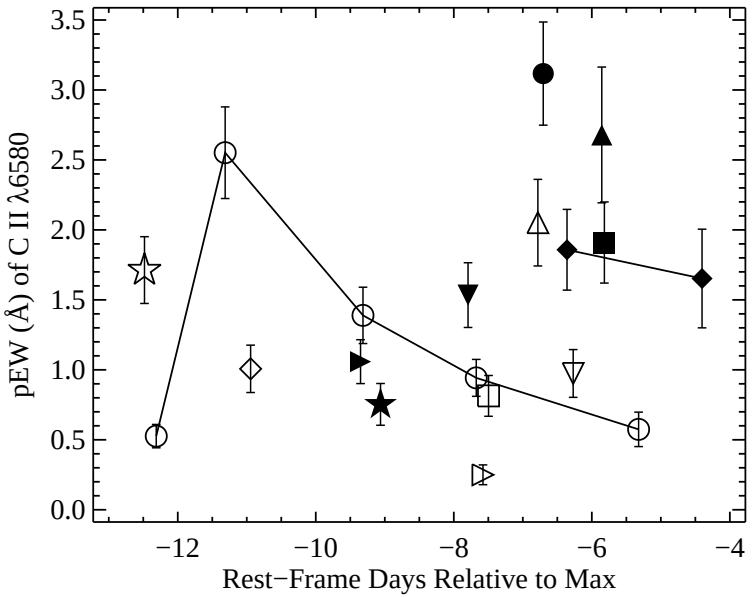

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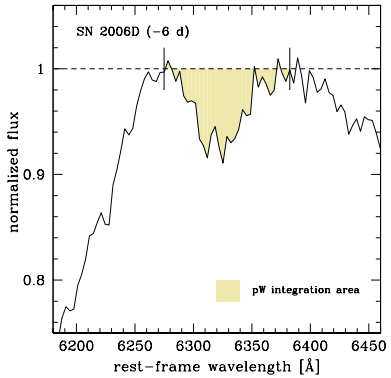
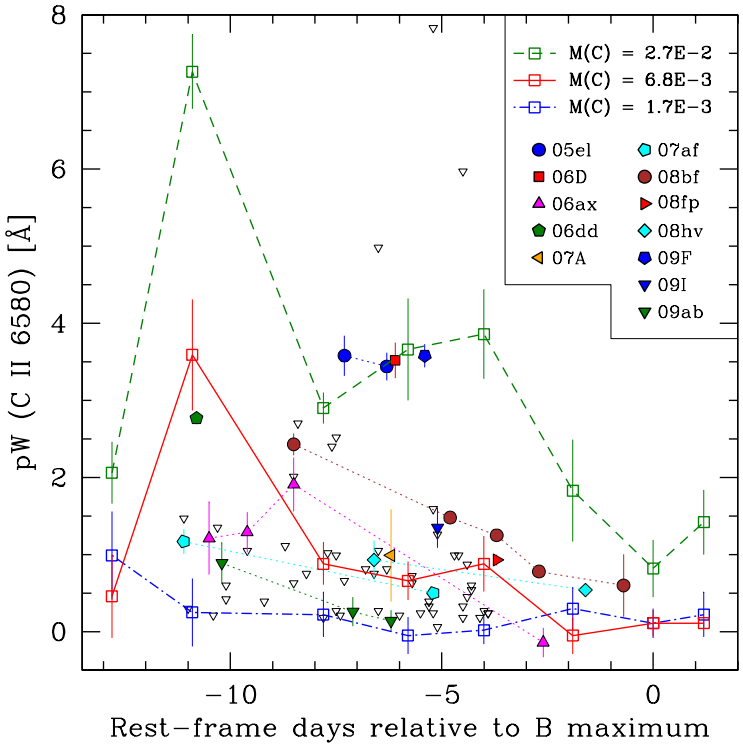


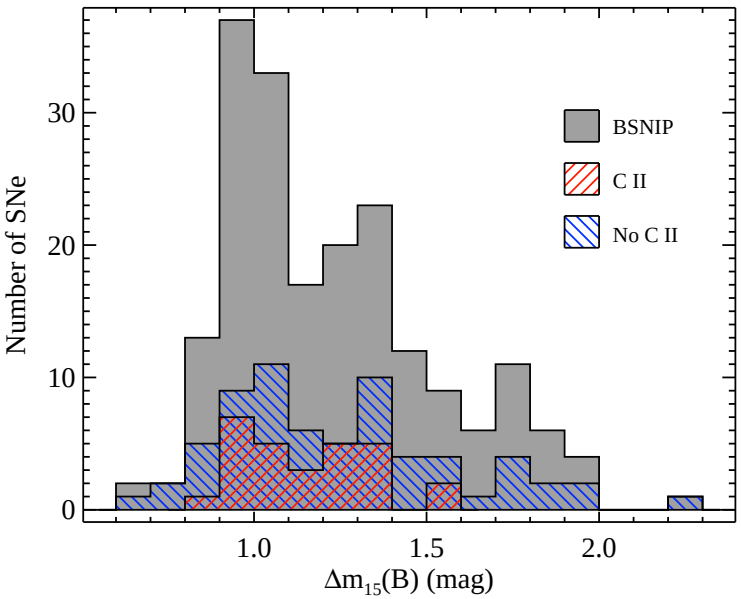


CSP – Folatelli+'12

Type Ia Supernovae with Carbon

Photometric Properties

- Light-curve shapes
- Blue colors – cf. Blondin+'12
- Reddening and luminosity



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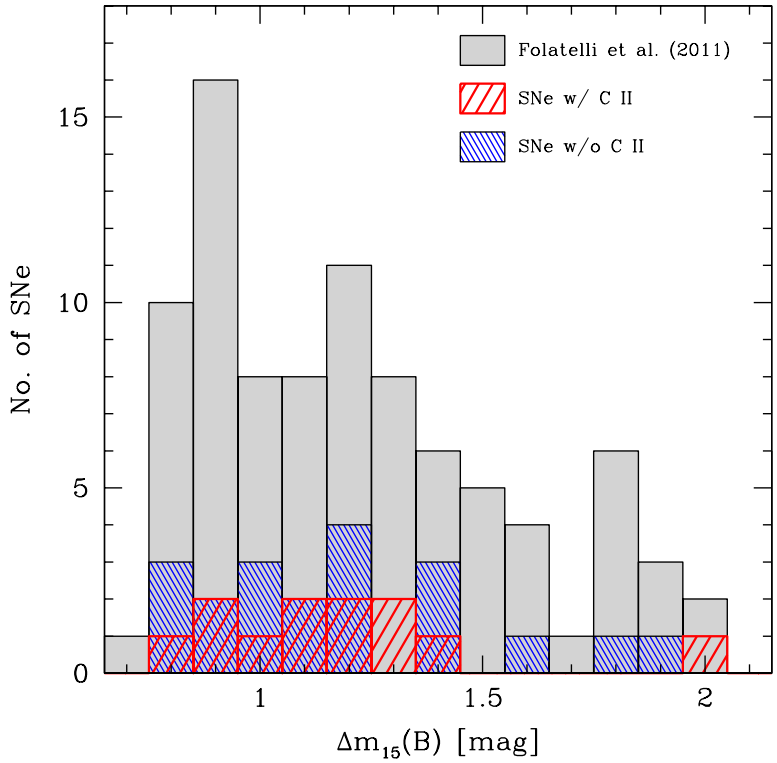

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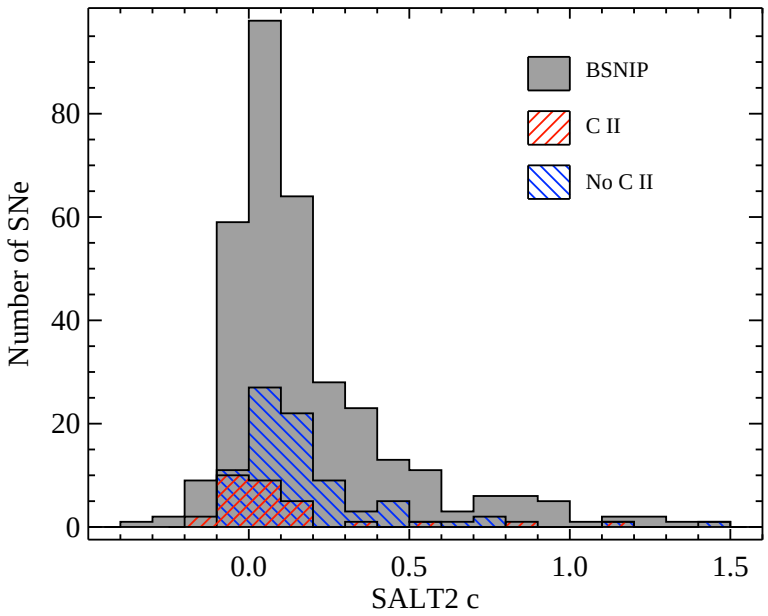

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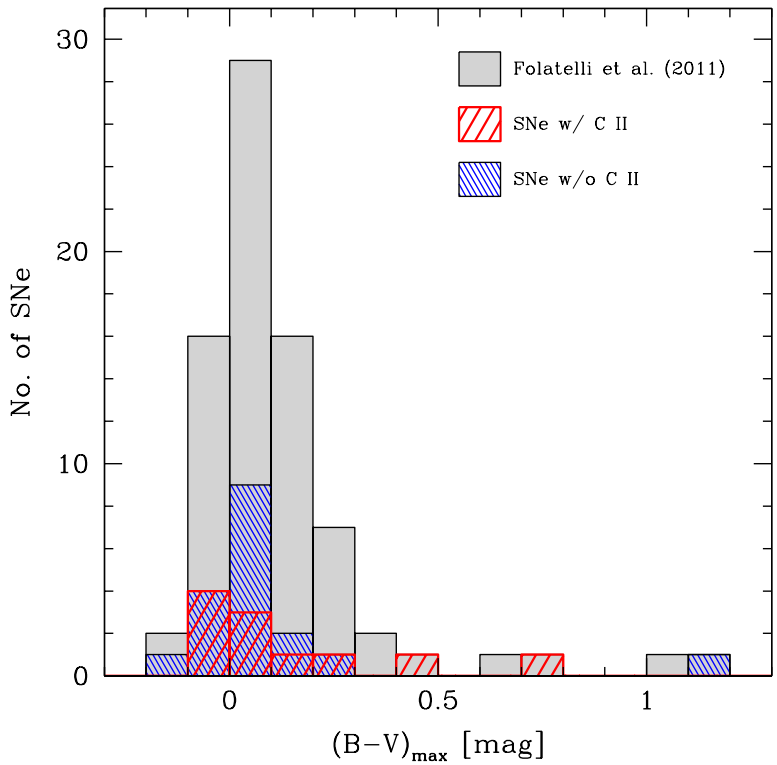

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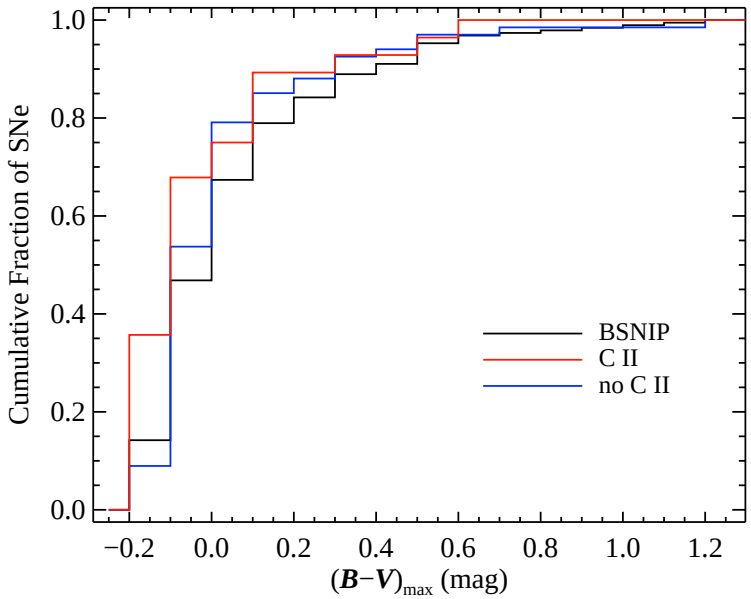

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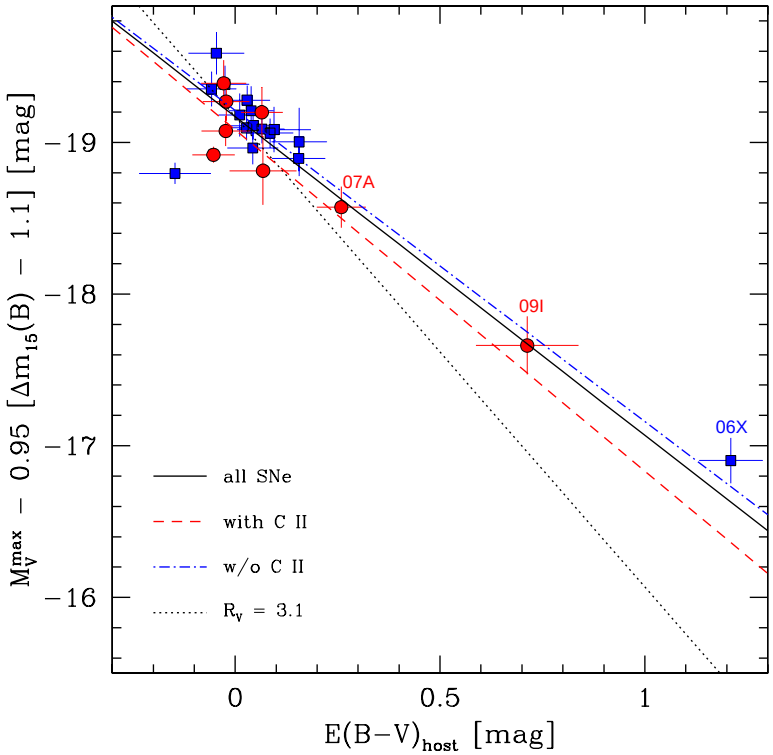
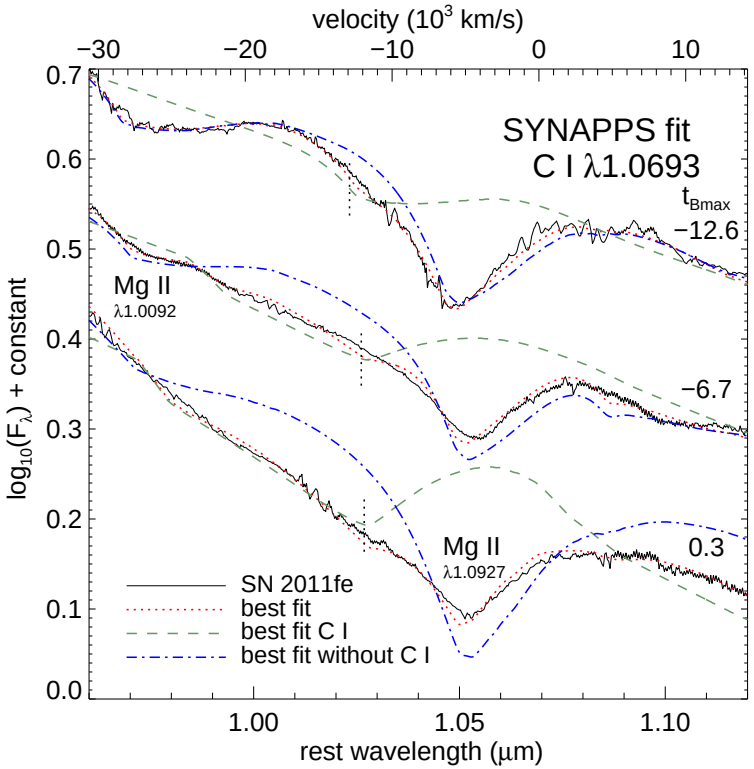


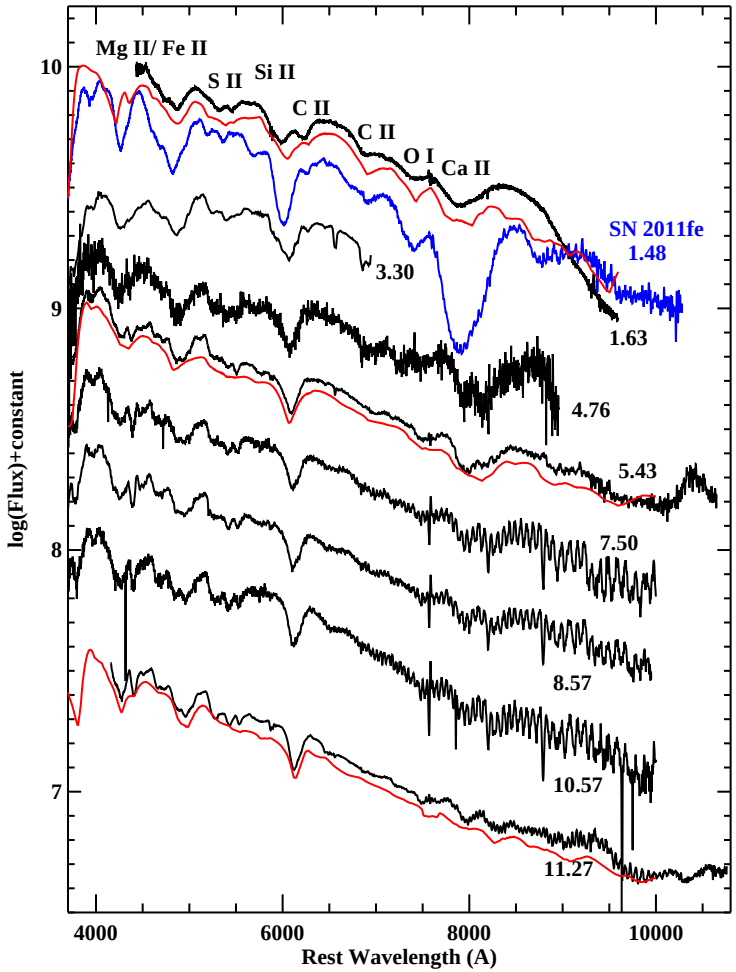
Further Detections

SNe 2011fe – 2013cy – 2014J

- Very early, high S/N spectra
- C I in the NIR with SYNAPPS



SN 2011fe – Hsiao+'13



SN 2013cy – Zheng+'13

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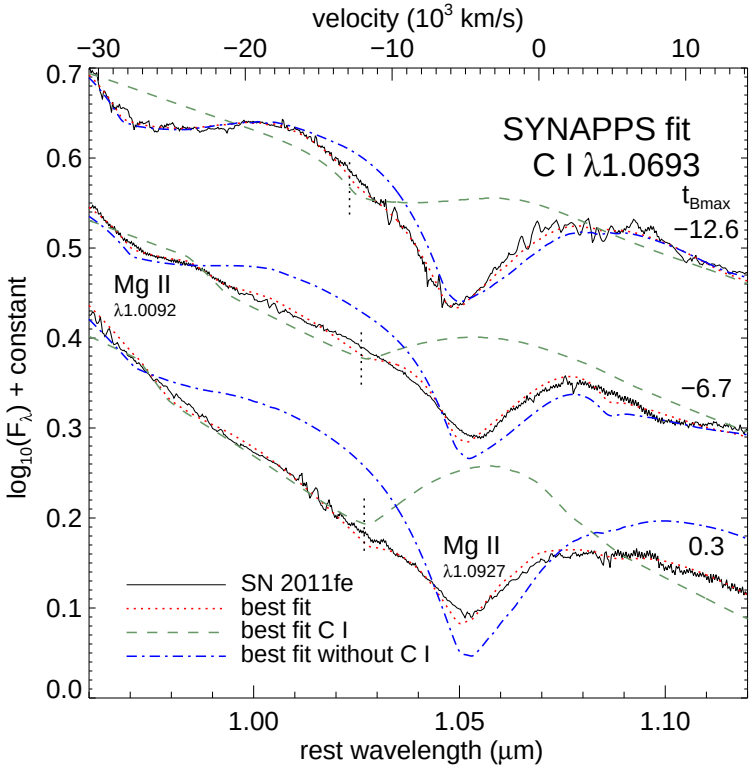

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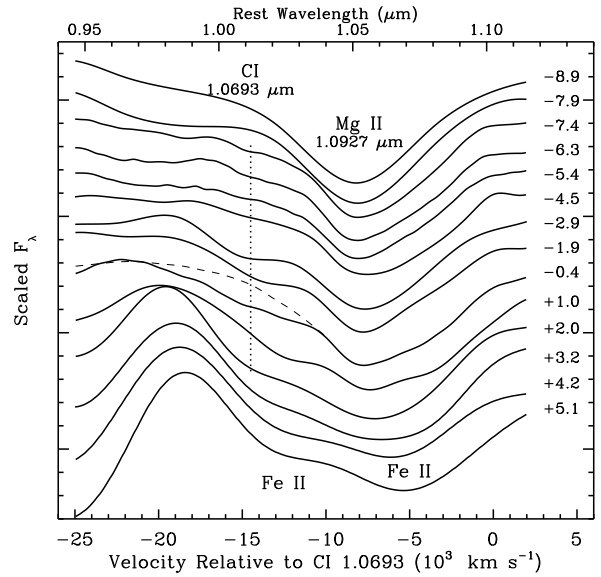
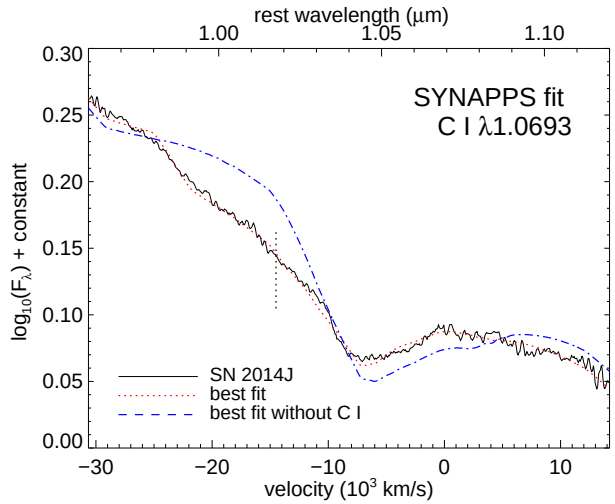




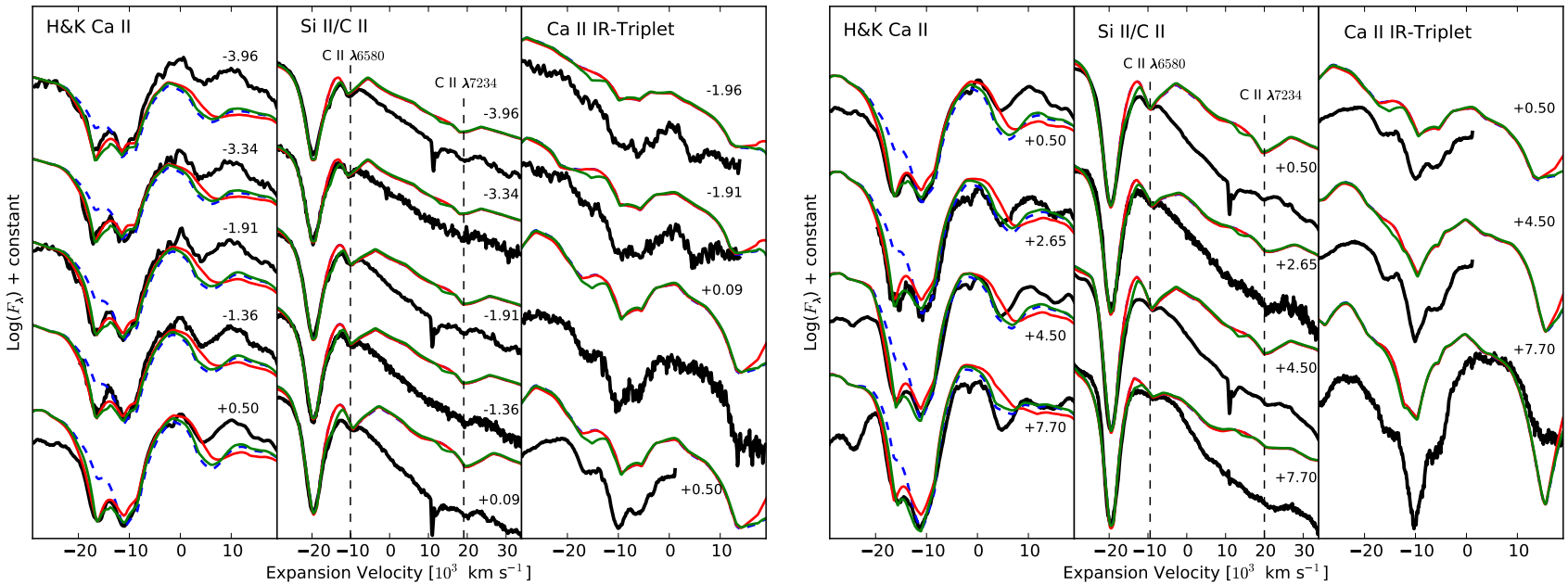
SN 2014J – Marion+'14

Further Detections

SN 2002fk

- Persistent C II features until 8 days
- Photometrically normal SN Ia

SN 2002fk – Cartier et al.



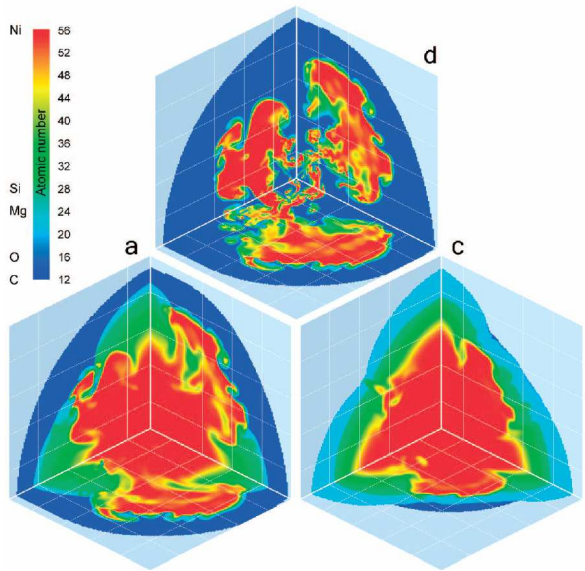
Implications and Prospects

Pending questions

- What's the fraction of SNe Ia that show carbon?
- How much carbon is left unburned?
- Why does it appear at low velocity?
- Multi-dimensional effects
- Effect on distance determination

Future

- Systematic search for carbon
- Early, high-S/N spectra are crucial
- Optical and NIR: C II $\longrightarrow$ C I
- Relative abundances and distribution of C, O and Mg.



Gamezo+'05