Near-infrared spectroscopy of Type Ia supernovae

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on behalf of the Carnegie Supernova Project and collaborations
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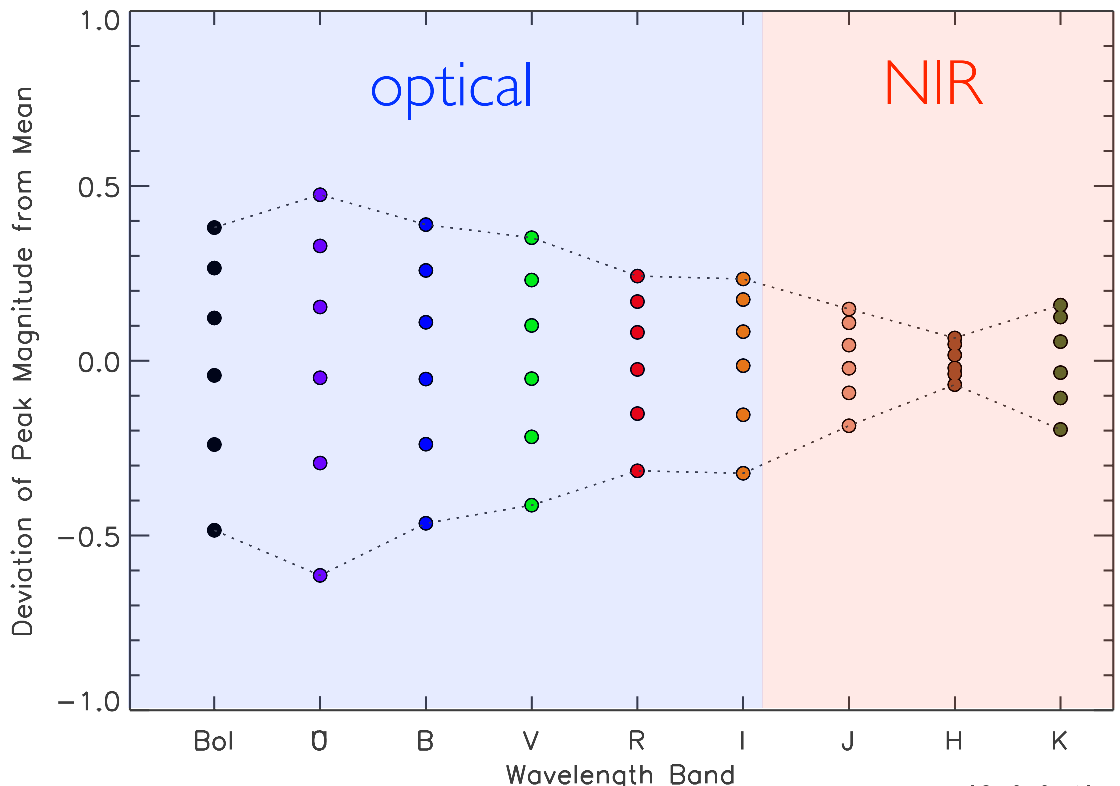
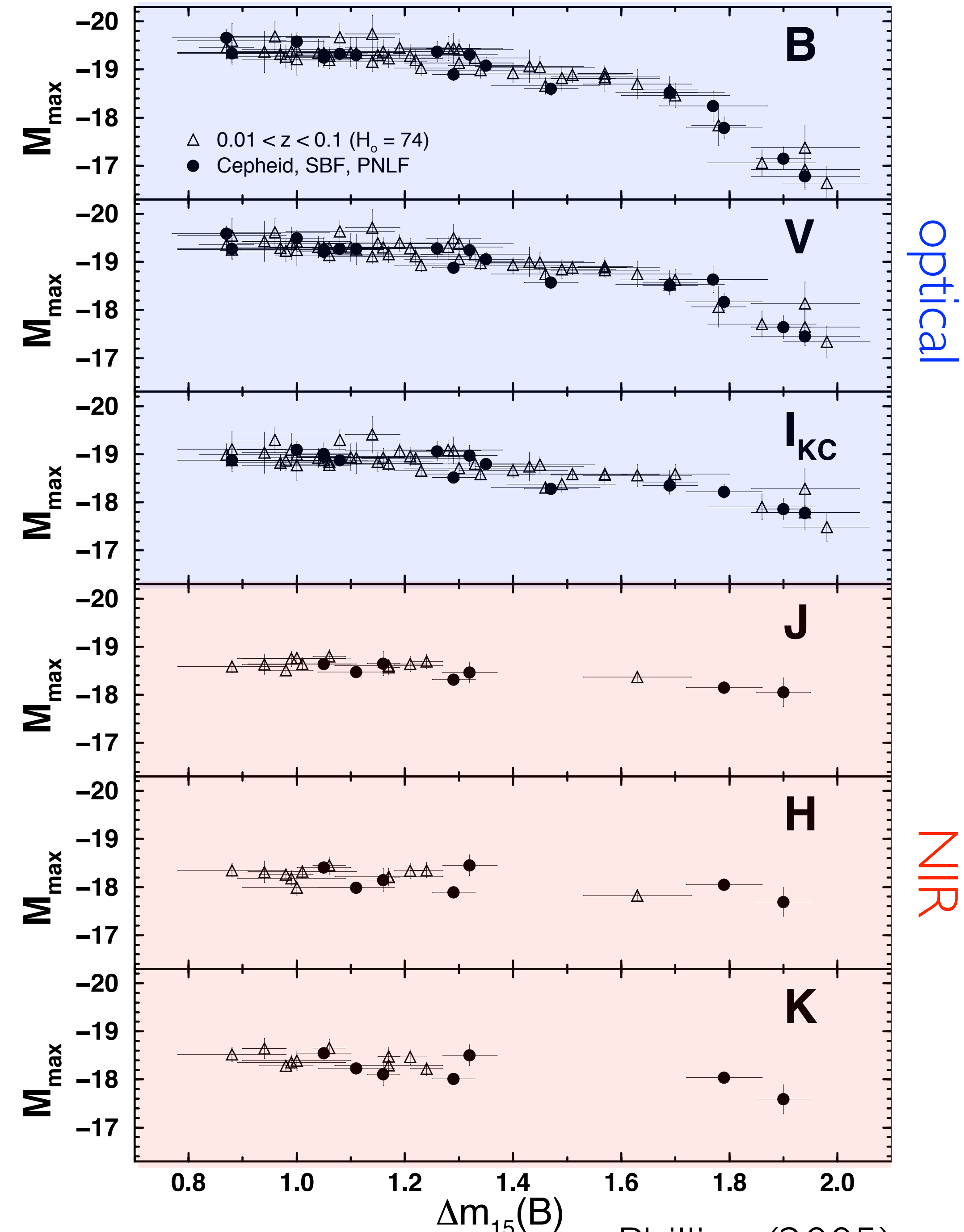
S. E. Persson, N. B. Suntzeff, W. L. Freedman
G. H. Marion, D. J. Sand, T. Diamond,
R. P. Kirshner, et al.

Why NIR?



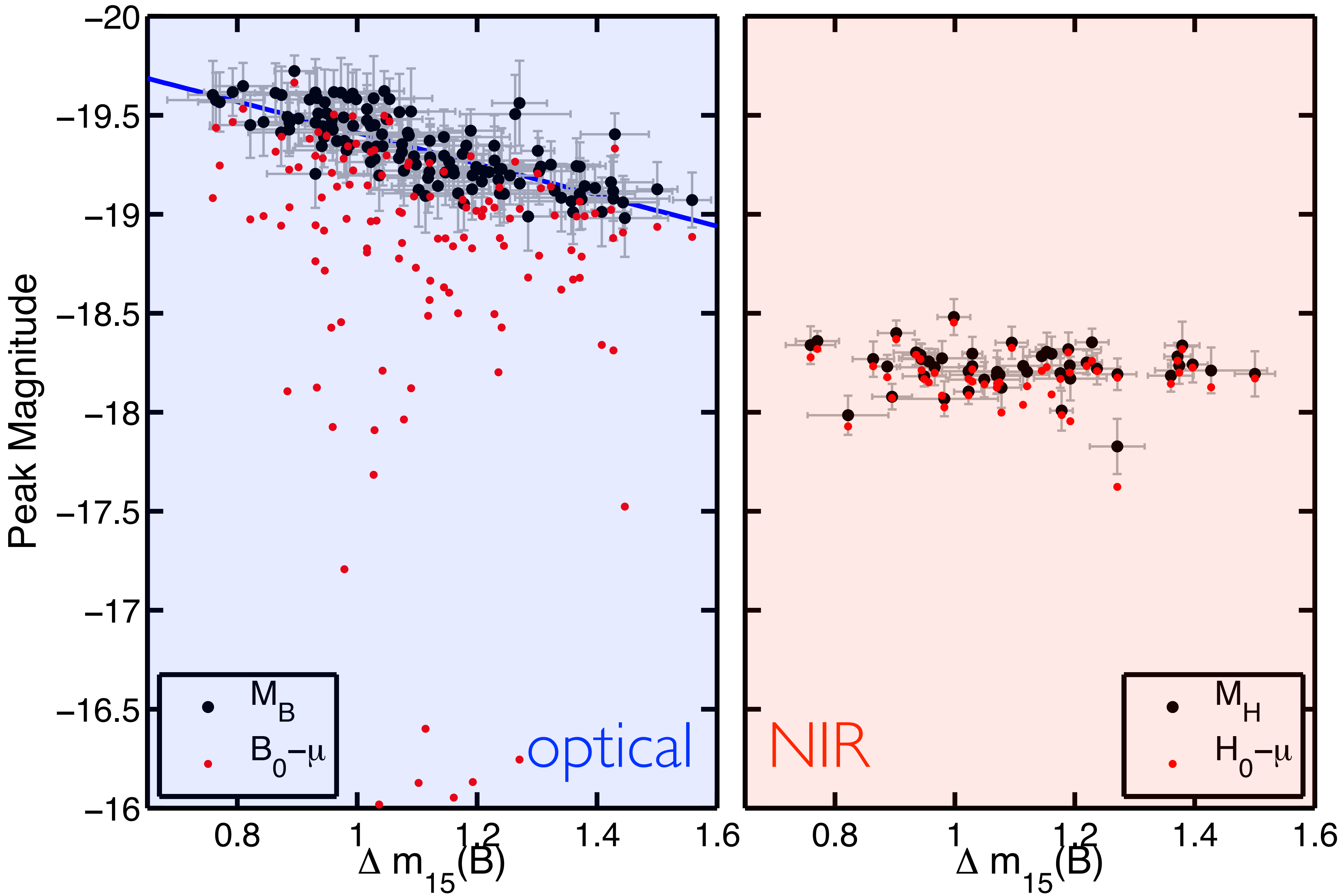
Kasen (2006)



Phillips (2005)

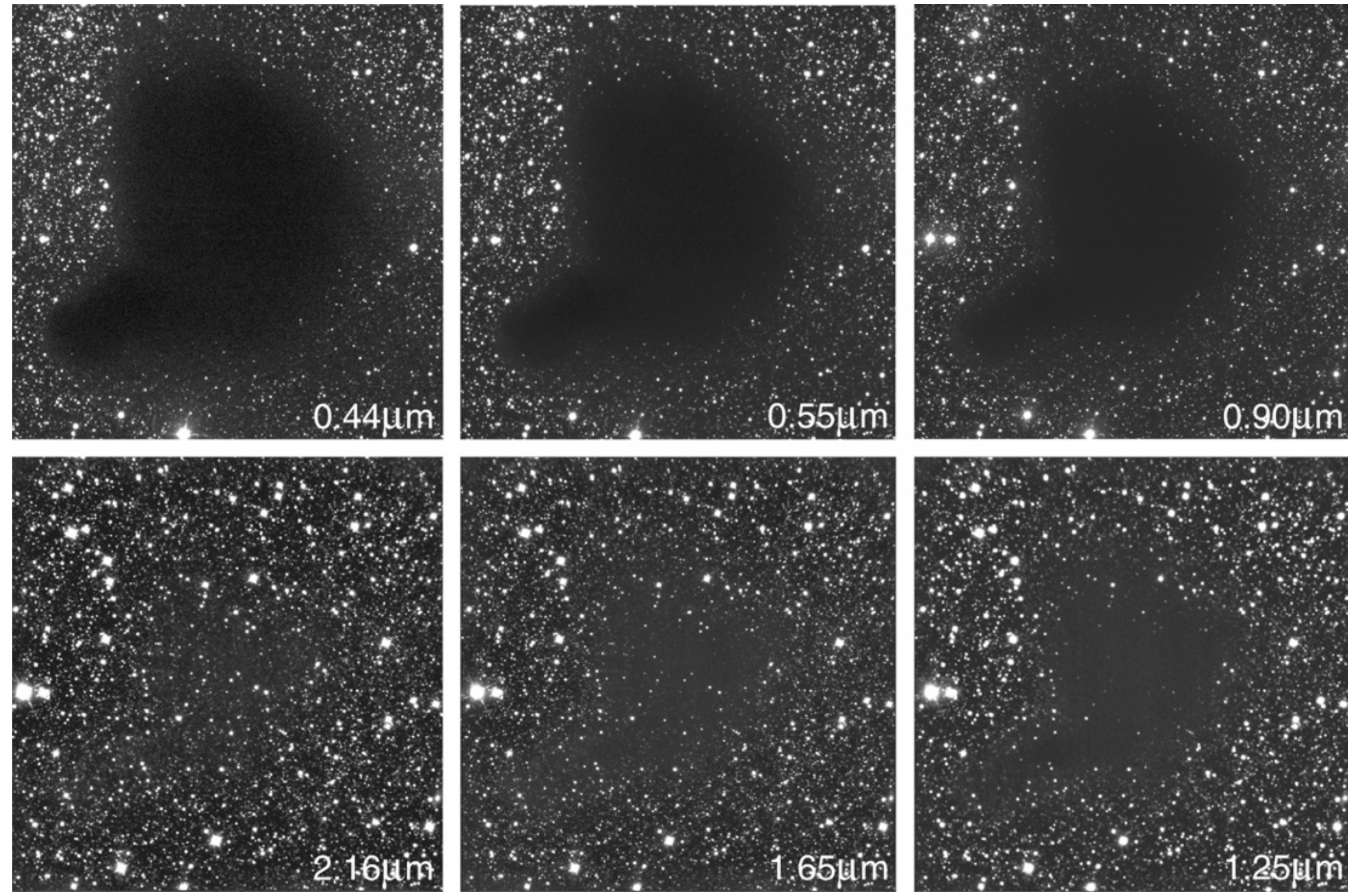
Theory Observation

Why NIR?



Mandel et al. (2011)

Why NIR?

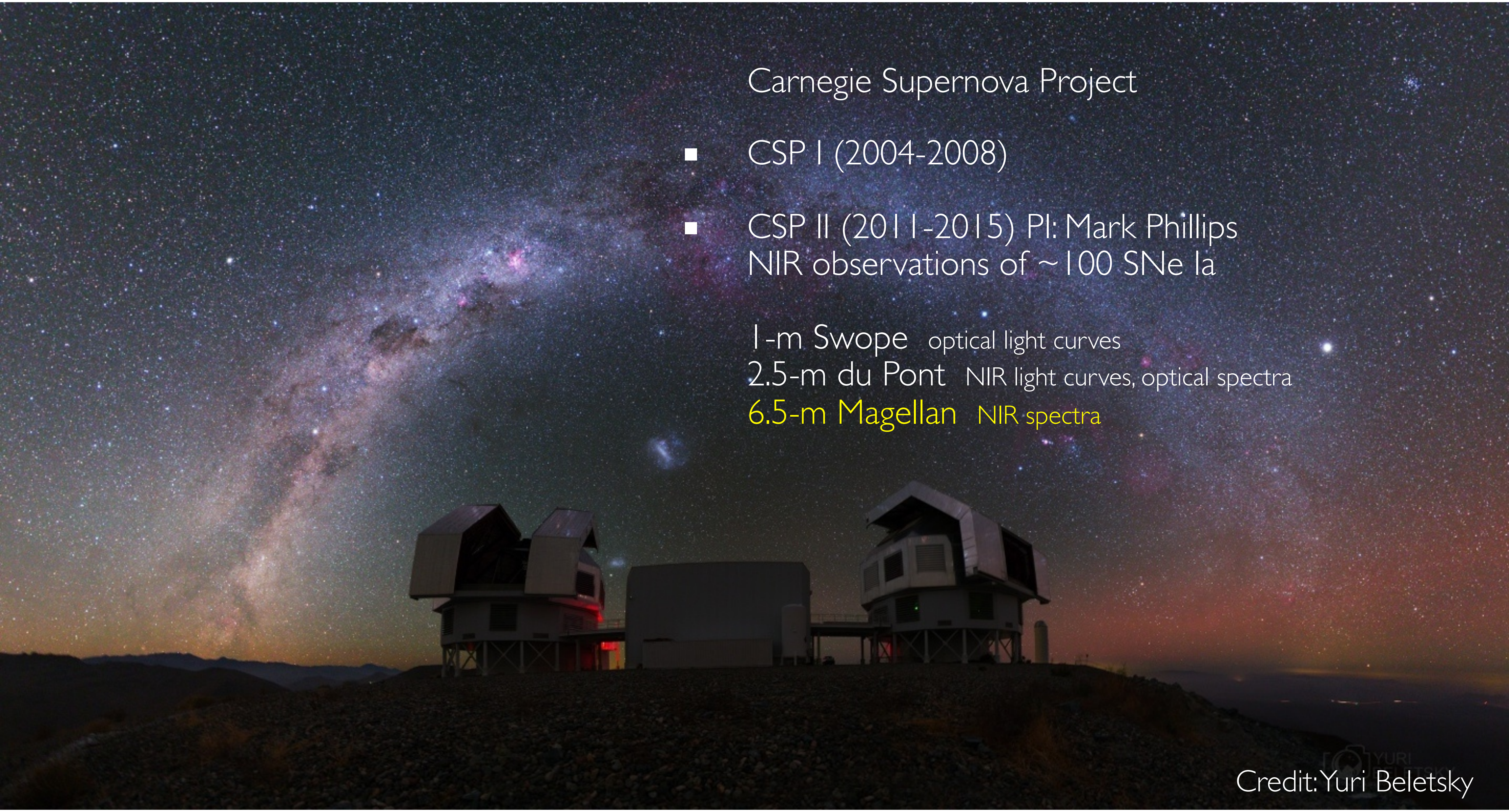


Credit: ESO

In the NIR, achieve higher precision through 2 routes:

- By avoiding things we do not understand (shortcut)
- By constraining the physics (more fun!)

CSP NIR spectroscopy



Carnegie Supernova Project

- CSP I (2004-2008)
- CSP II (2011-2015) PI: Mark Phillips
  NIR observations of ~100 SNe Ia

1-m Swope optical light curves
2.5-m du Pont NIR light curves, optical spectra
6.5-m Magellan NIR spectra

Credit: Yuri Beletsky

CSP NIR spectroscopy

of Ia
optical spectra

10^4

# of Ia
NIR spectra

10^2

41 from Marion et al. (2009)
+
91T, 94D, 98bu, 99by, 99ee, 02bo, 02dj,
03du, 05cf, 05df, 11fe, 13ebh, 14J

CSP NIR spectroscopy

Table 1. Number of NIR spectra by instrument and supernova type

Telecope	Instrument	Ia	Iax	Ibc	II	IIn	SLSN	Others	Total
Magellan Baade	FIRE	459	27	101	81	35	9	4	716
Gemini North	GNIRS	58	7	0	0	0	0	0	65
IRTF	SpeX	40	2	6	9	1	0	0	58
Mt Abu	NICS	31	0	0	0	0	0	0	31
Gemini South	FLAMINGOS2	17	0	0	1	0	0	0	18
Magellan Clay	MMIRS	7	1	2	1	0	0	1	12
VLT	ISAAC	8	4	0	0	0	0	0	12
NTT	SofI	4	1	2	0	0	0	0	7
Total spectra		624	42	111	92	36	9	5	919
Total SNe		151	9	44	33	11	5	2	255

Hsiao et al. in prep

Probing SN Ia physics

- Unburned material
  Premax C I 1.0693
  Marion et al. (2006)

- Boundary between C/O burning
  Premax Mg II 1.0927
  Wheeler et al. (1998)

- Radioactive nickel
  Postmax H-band break
  Wheeler et al. (1998), Höflich et al. (2002)

- Stable nickel
  Transitional phase [Ni II]
  Friesen et al. (2014)

- Companion signature
  Postmax P-beta
  Maeda et al. (2014)

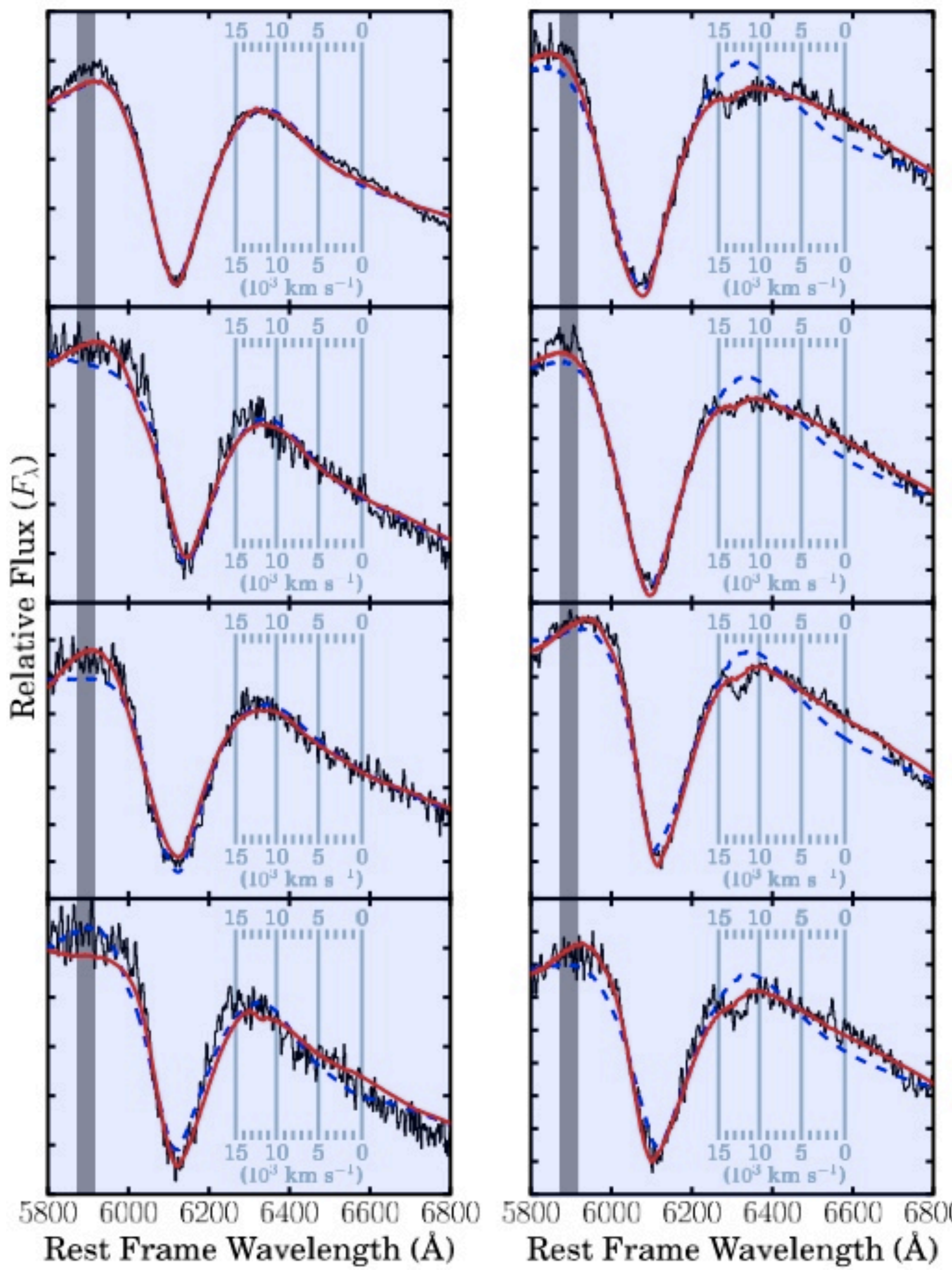
- Central density and B-field
  Nebular phase [Fe II] 1.6440
  Penney & Höflich (2014), Diamond et al. (2015)

Unburned material

Premax C I 1.0693

- Carbon: pristine material from the progenitor
- Incomplete burning: constraints for explosion models
- Optical C II 6580 detected in 20-30% of SNe Ia

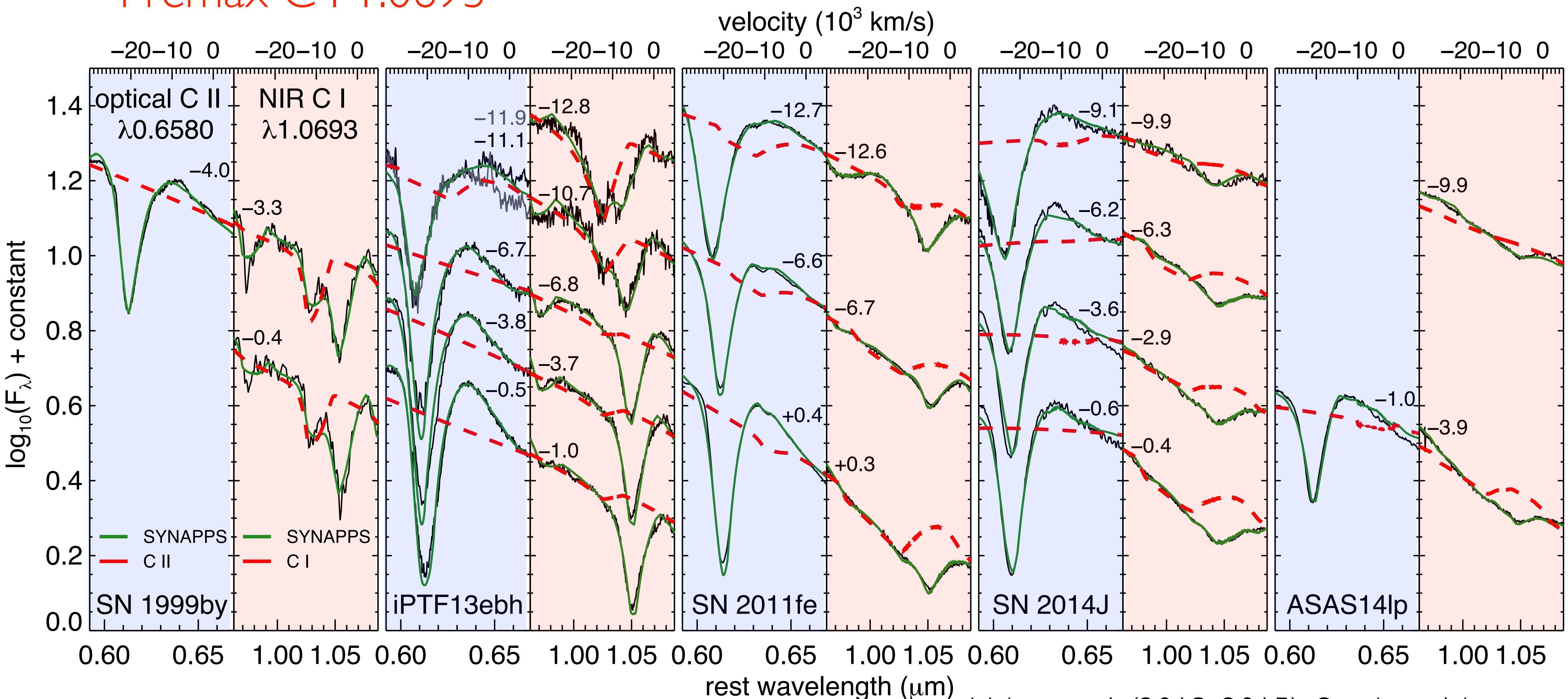
Thomas et al. (2011)
Folatelli et al. (2012)
Silverman et al. (2012)



Thomas et al. (2011)

Unburned material

Premax C I 1.0693



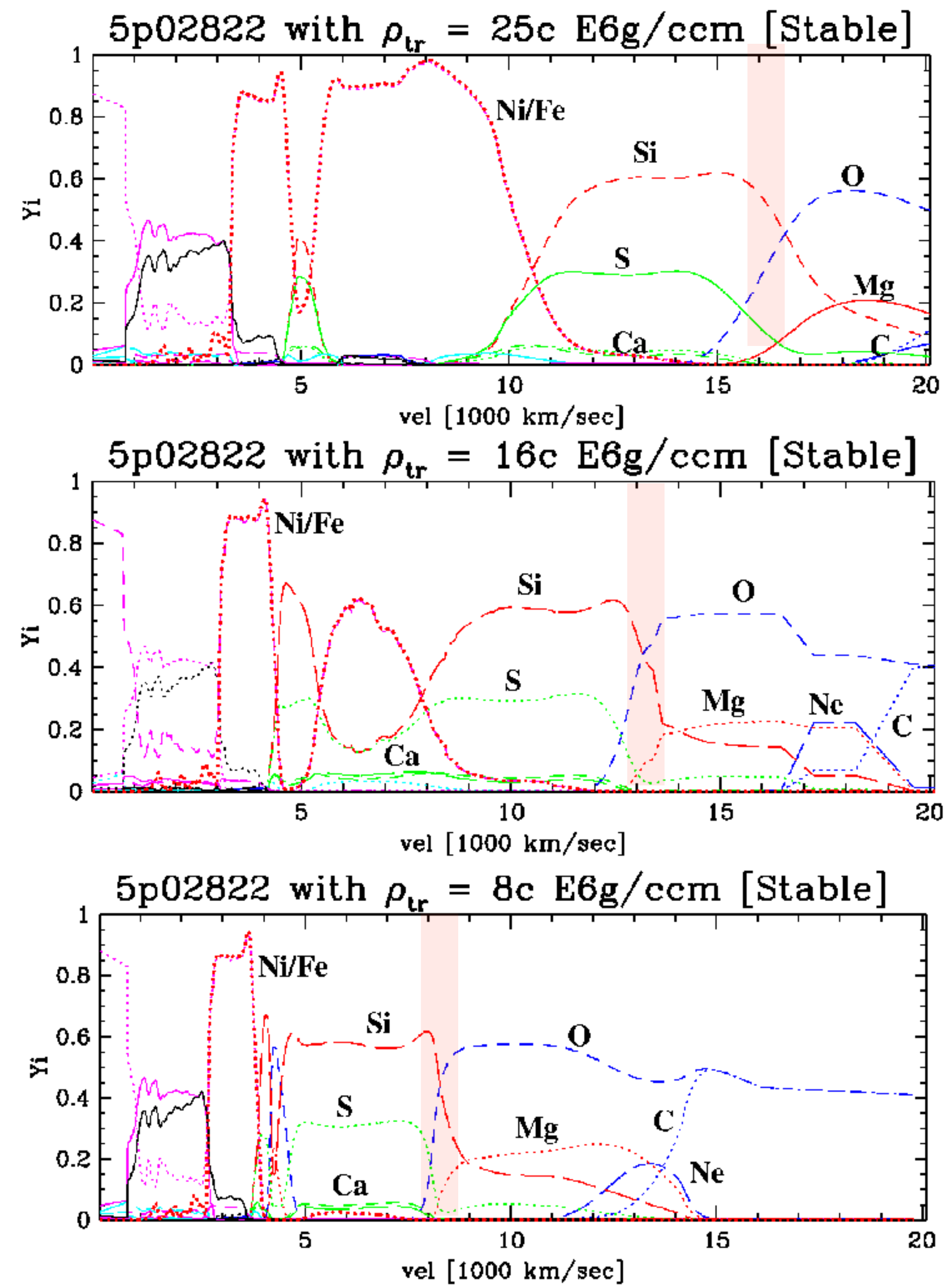
Hsiao et al. (2013, 2015), Sand et al. in prep

- NIR provides a more complete census of carbon than the optical
- Unburned material ubiquitous?

Boundary between C/O burning

Premax Mg II 1.0927

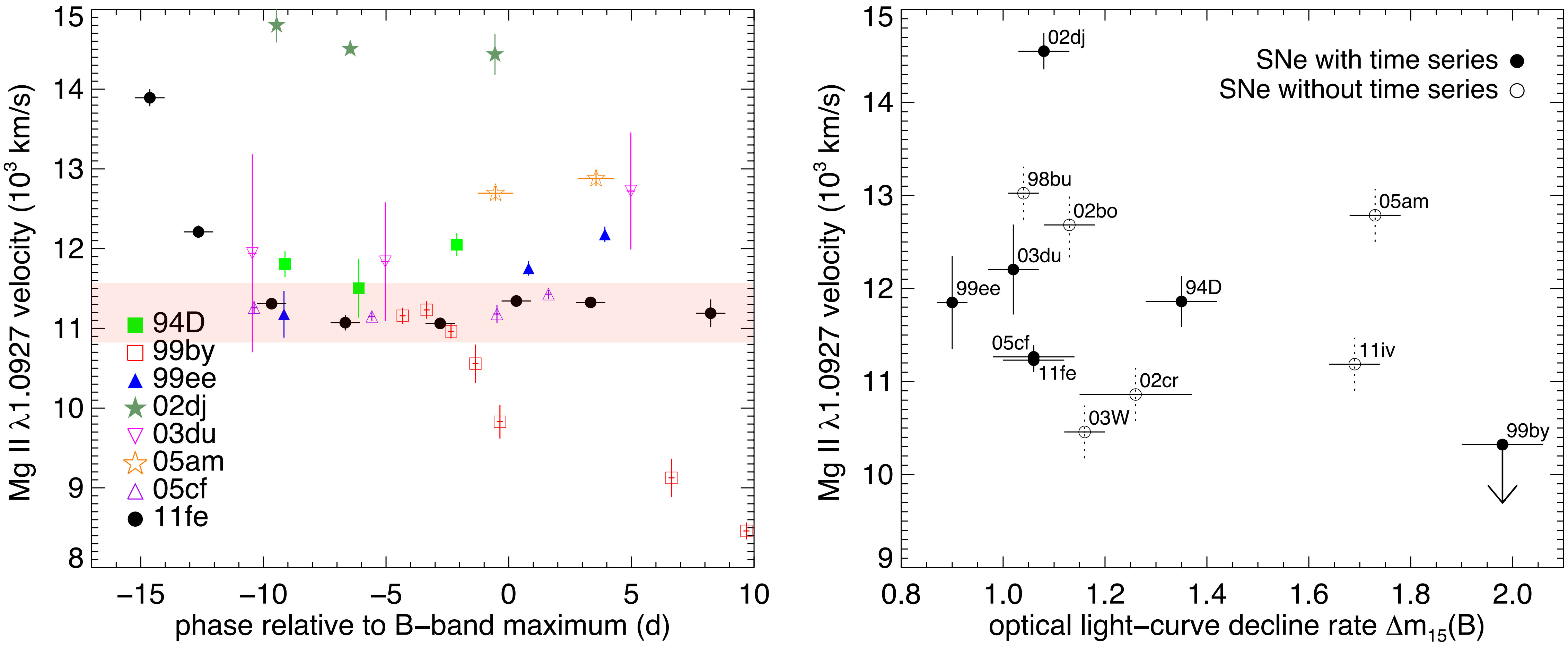
- Strong, isolated line
- Flat Mg velocity evolution: bottom of C burning layer
- Boundary between C/O burning
- Sensitive to transition density



Wheeler et al. (1998), Höflich et al. (2002)

Boundary between C/O burning

Premax Mg II 1.0927

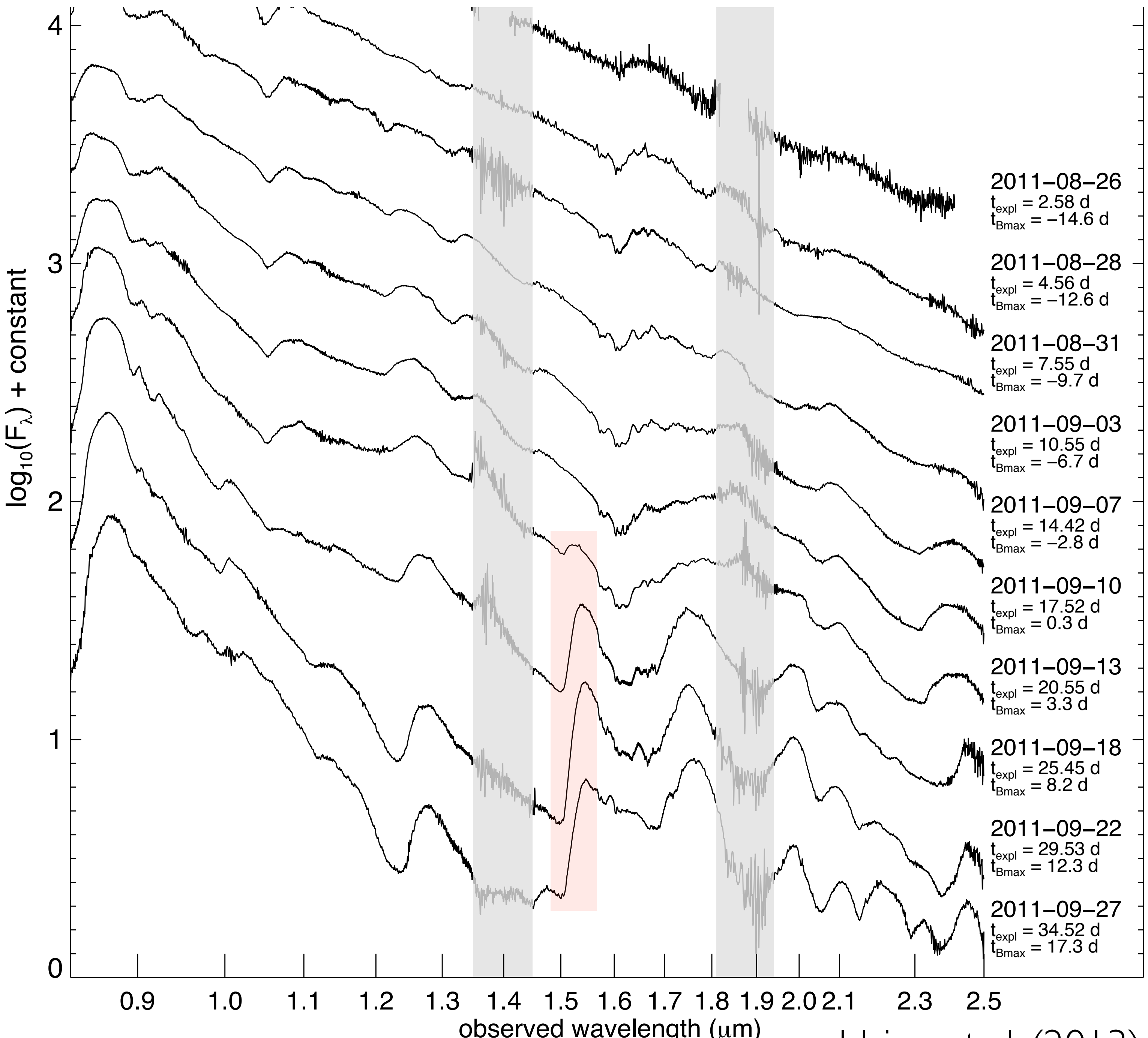


Hsiao et al. (2013)

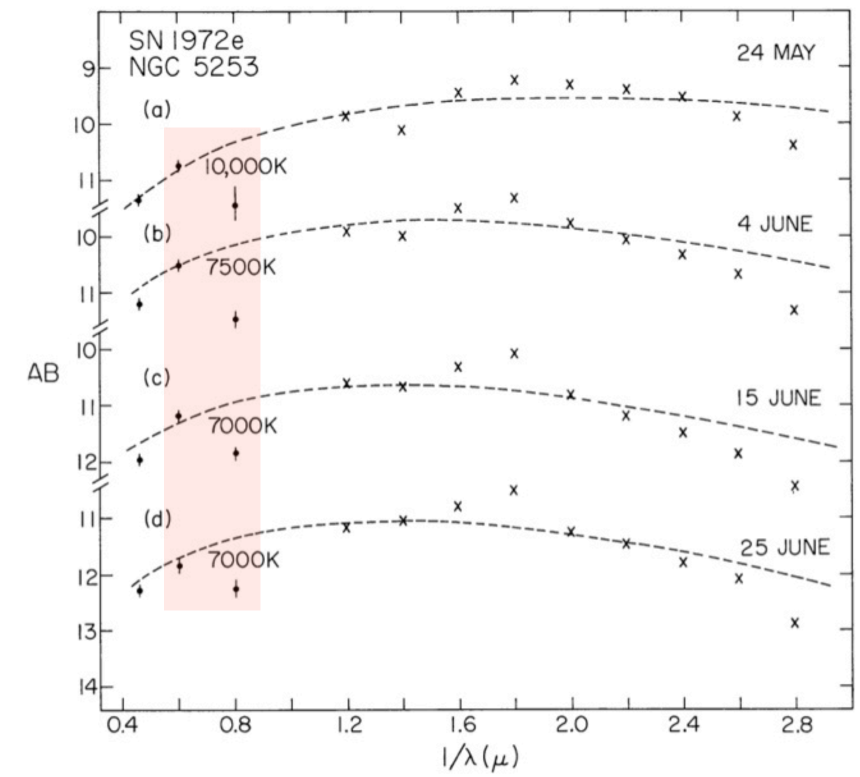
- No correlation with light-curve decline rate
- Transition density not the main driver of SN brightness?

Radioactive nickel

H-band break



Hsiao et al. (2013)

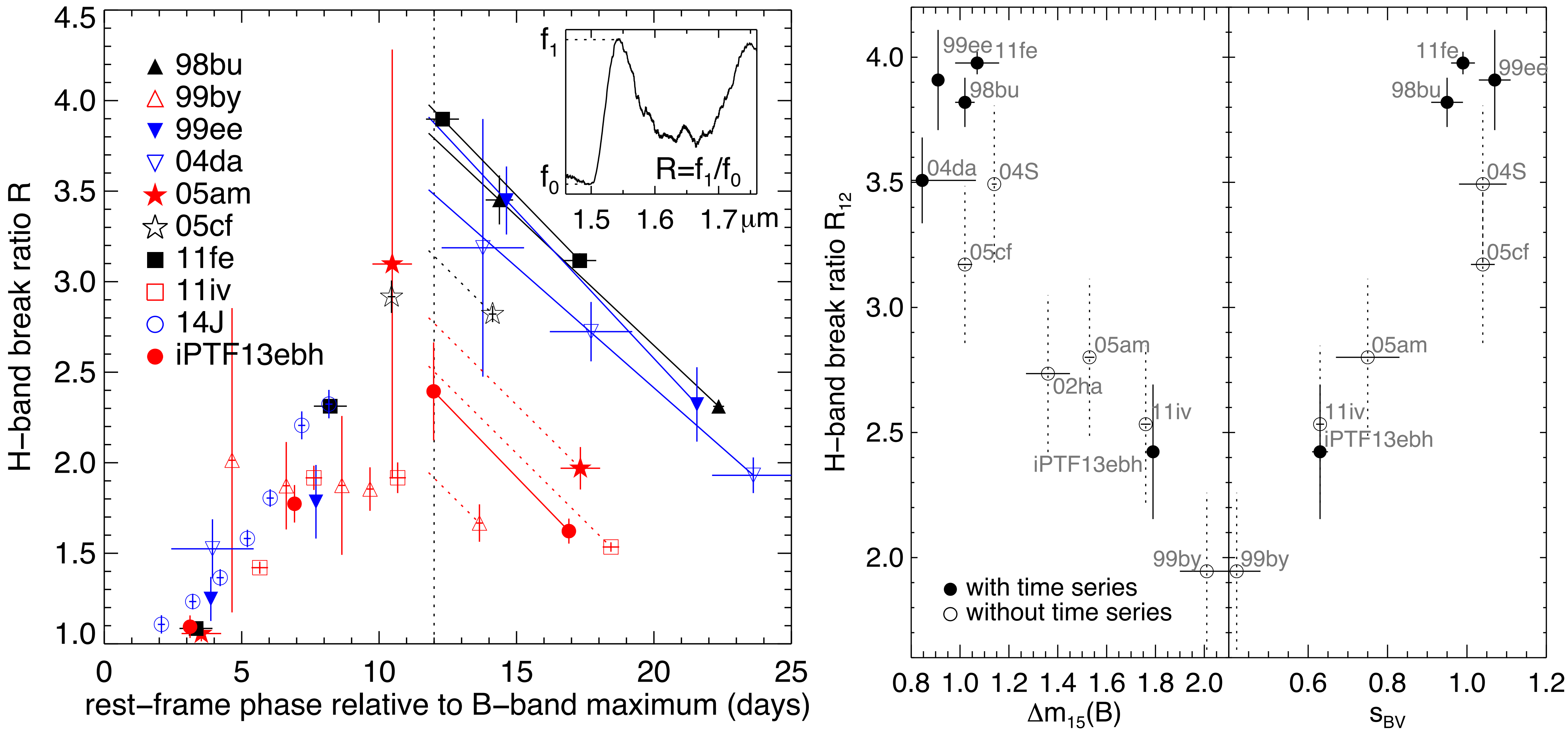


Kirshner et al. (1973)

- H-band break: most prominent SN Ia NIR feature

Radioactive nickel

H-band break

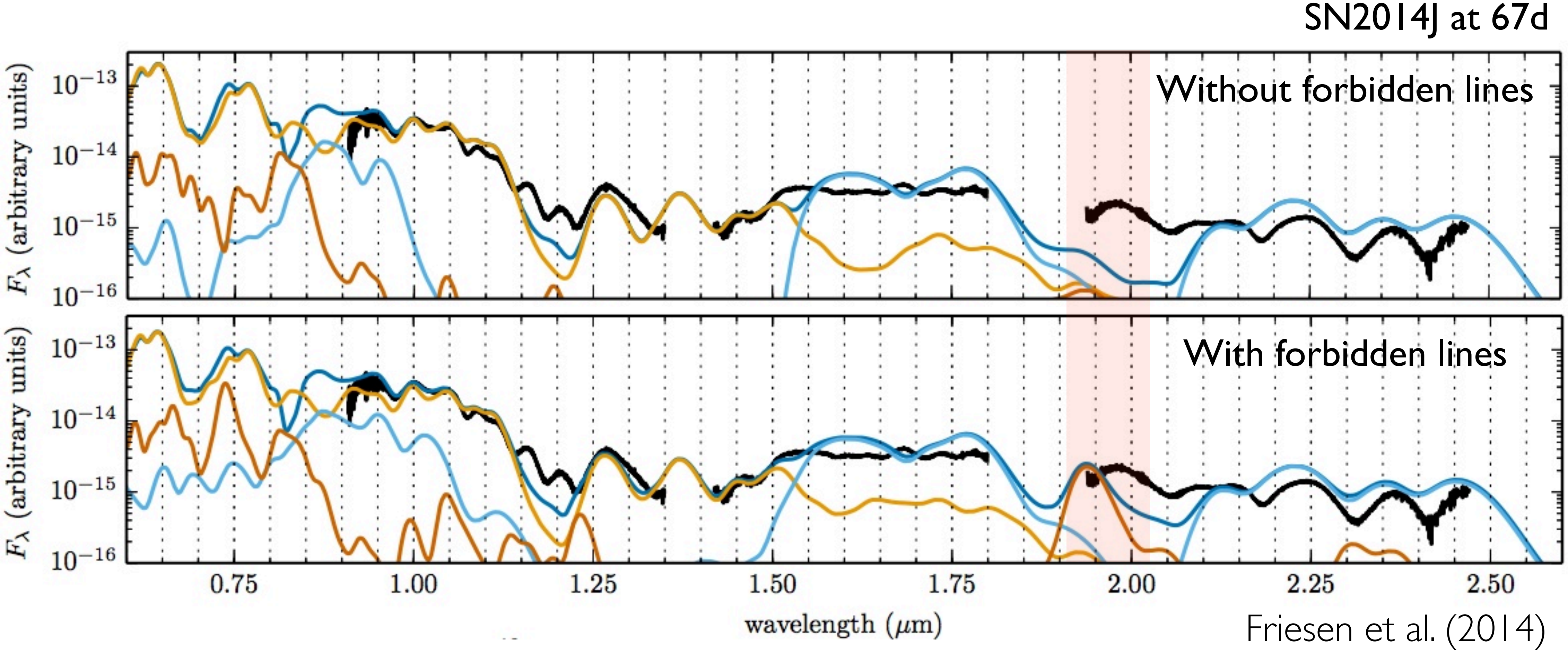


Hsiao et al. (2013, 2015)

- The strong correlation is consistent with Chandrasekhar-mass delayed detonation
- Dynamical merger would yield the opposite trend and weaker correlation

Stable nickel

Transitional phase [Ni II]

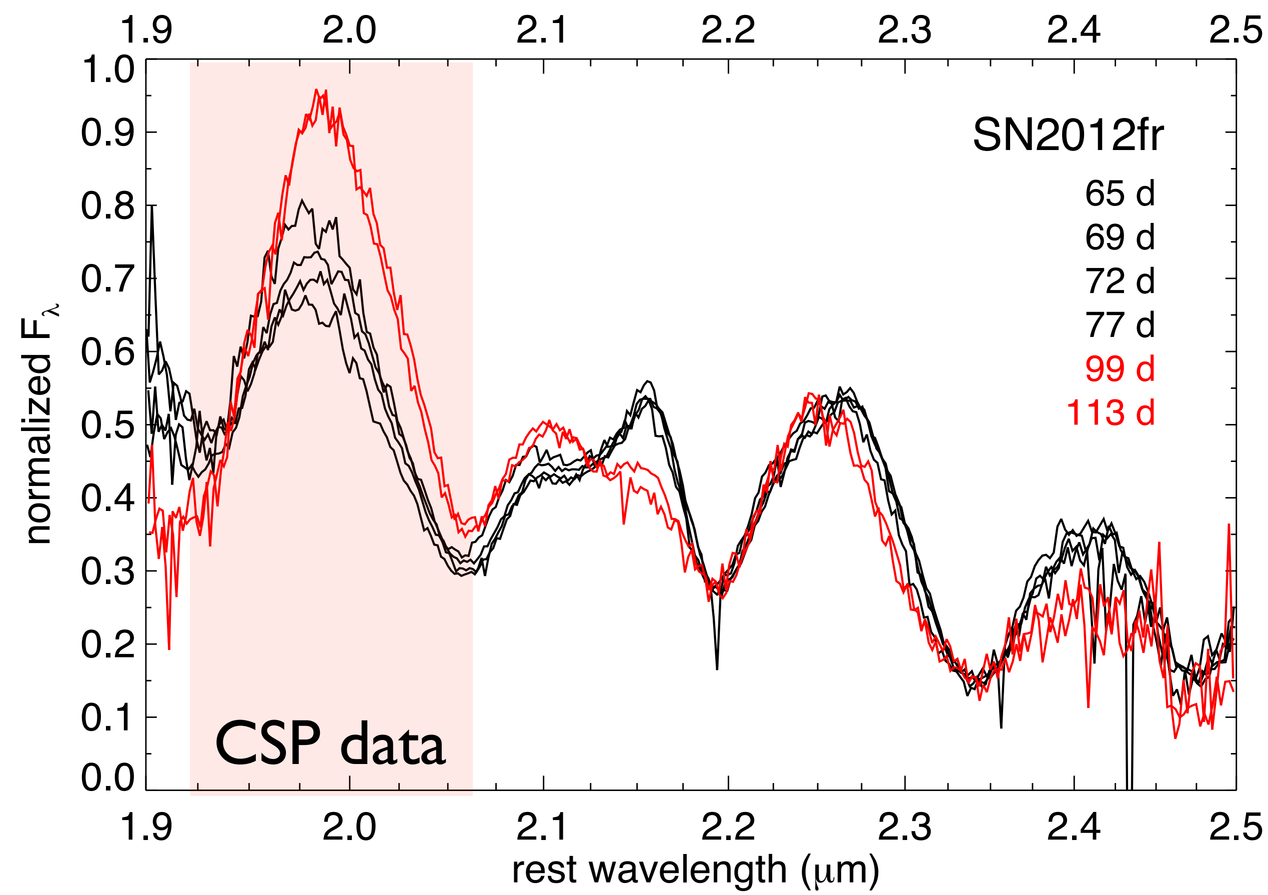


Friesen et al. (2014)

- 1.98 micron feature: possible [Ni II]
- Nickel at late phase most likely stable nickel

Stable nickel

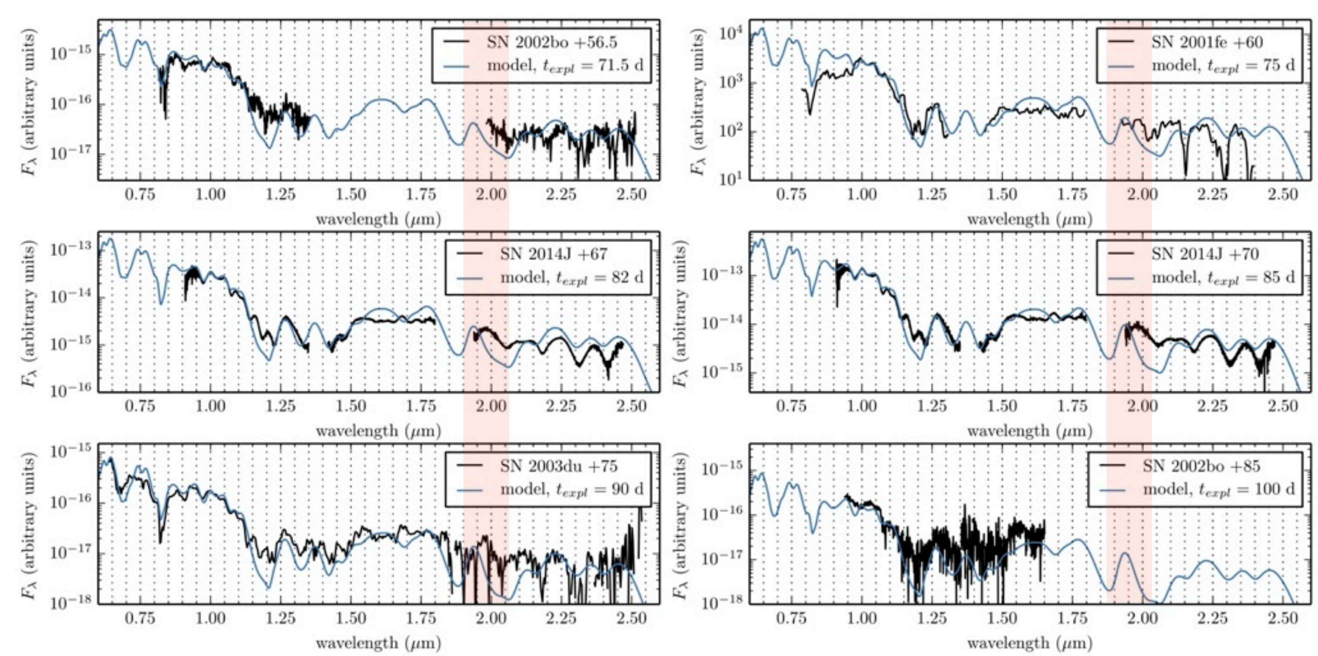
Transitional phase [Ni II]



Could come from:

- High density progenitor
  Friesen et al. (2014)
- Metallicity of progenitor
  Timmes et al. (2003)
- Neutronization in simmering phase
  Piro & Bildsten (2008)

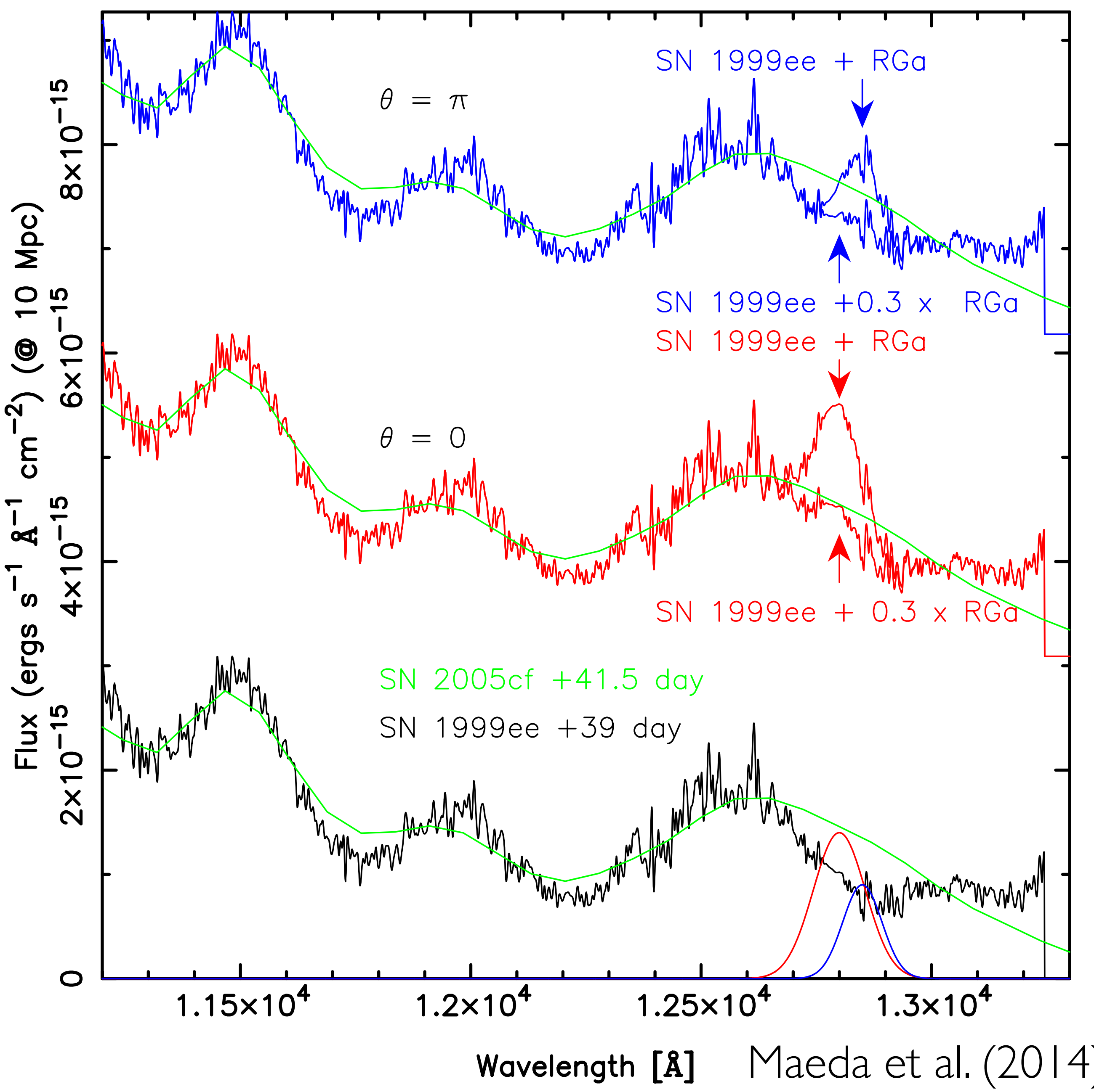
Archival data



Friesen et al. (2014)

Companion signature

Postmax P-beta

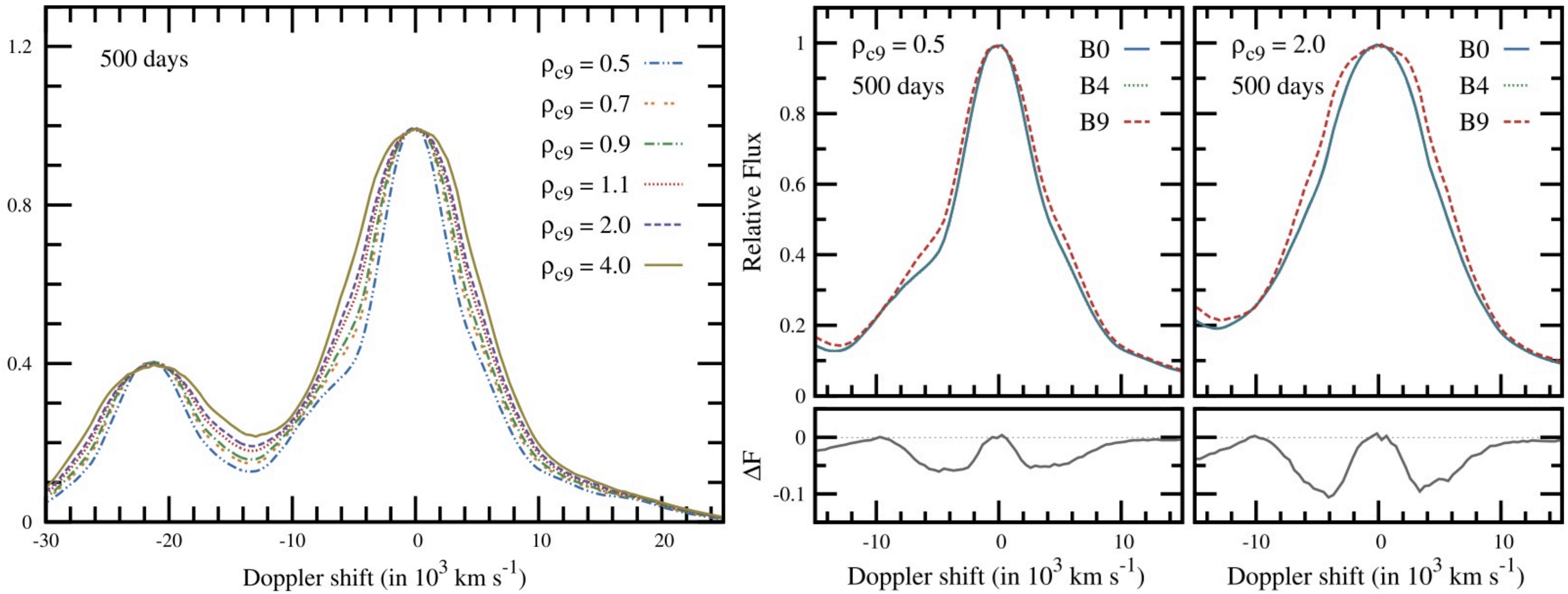


Maeda et al. (2014)

- H stripped off non-degenerate companion, embedded at low velocity
- Optical depth higher for optical than NIR
- P-beta stronger and appear above photosphere earlier than H-alpha

Central density and B-field

Nebular phase [Fe II] 1.6440



Diamond et al. (2015)

- Extract central density and B-field through [Fe II] line width
- Central density constraints accretion rate and progenitor system

- How can NIR spectroscopy help?
- Don’t stop at the optical!