

NIR spectroscopy of SNe Ia

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Outline

- ▶ CSP2 observing strategy
- ▶ NIR spectroscopy of SNe Ia
 - ▶ normal Ia: SN 2011fe
 - ▶ high-velocity: SN2012fr
 - ▶ O2cx-like: SN2010ae
 - ▶ super-Chandrasekhar: SN2009dc, SN2013ao?
- ▶ SN2013ao

CSP2

- ▶ To obtain optical+NIR observations of 100 - 200 SNe Ia in the redshift range $0.03 < z < 0.08$ reducing the rms error due to peculiar motions
- ▶ NSF-funded for 5 years, starting in Nov 2011

Mark
Phillips

Eric
Hsiao

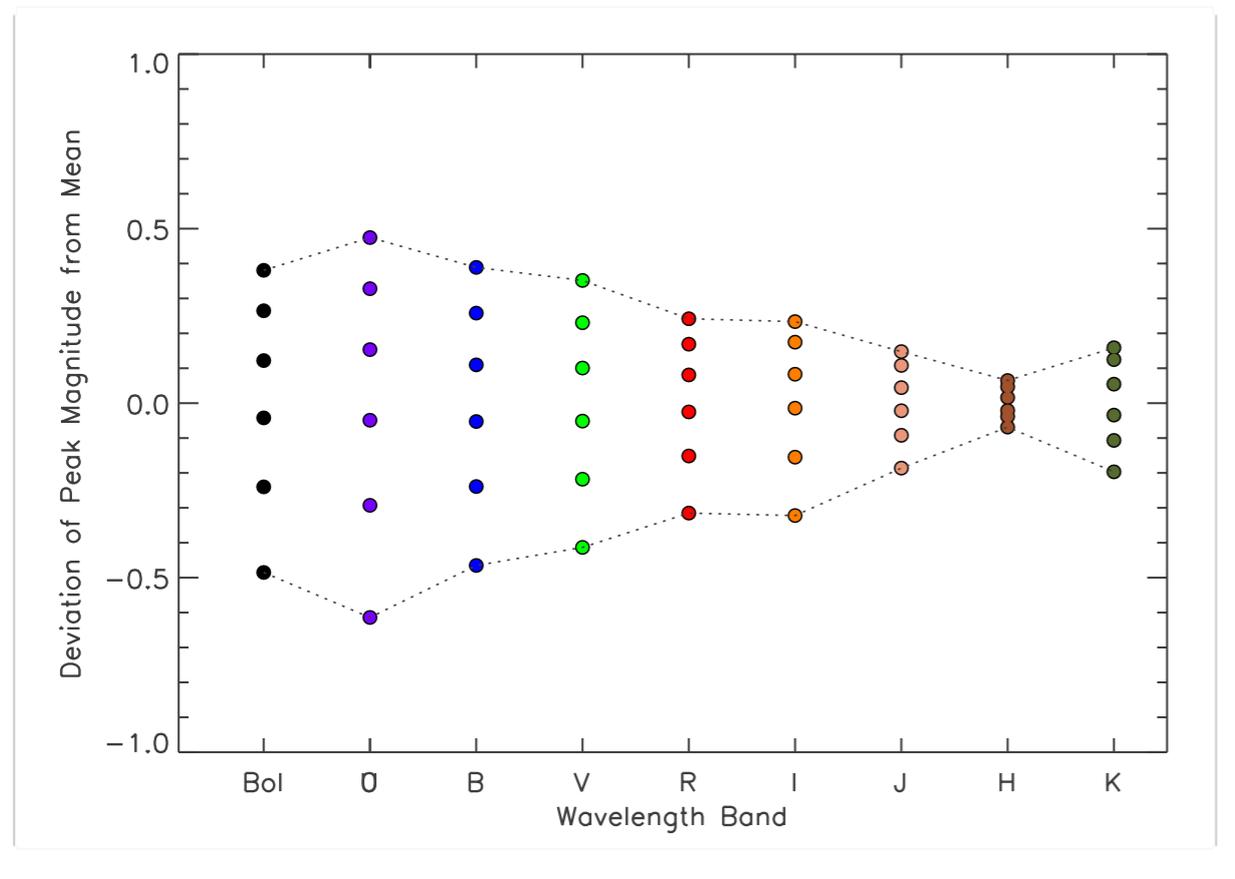
Nidia
Morrell

Chris
Burns

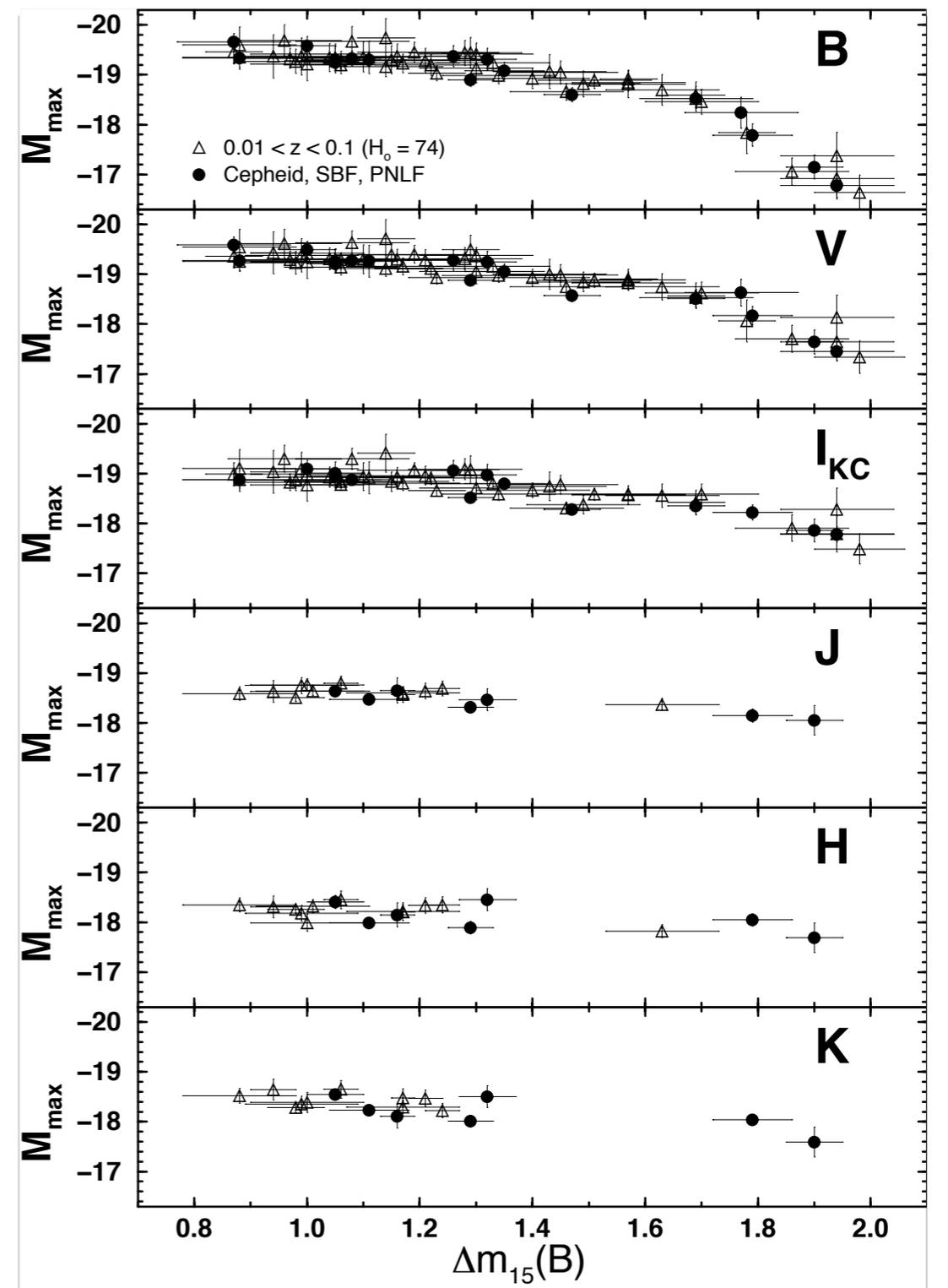
Carlos
Contreras



CSP2: why NIR?

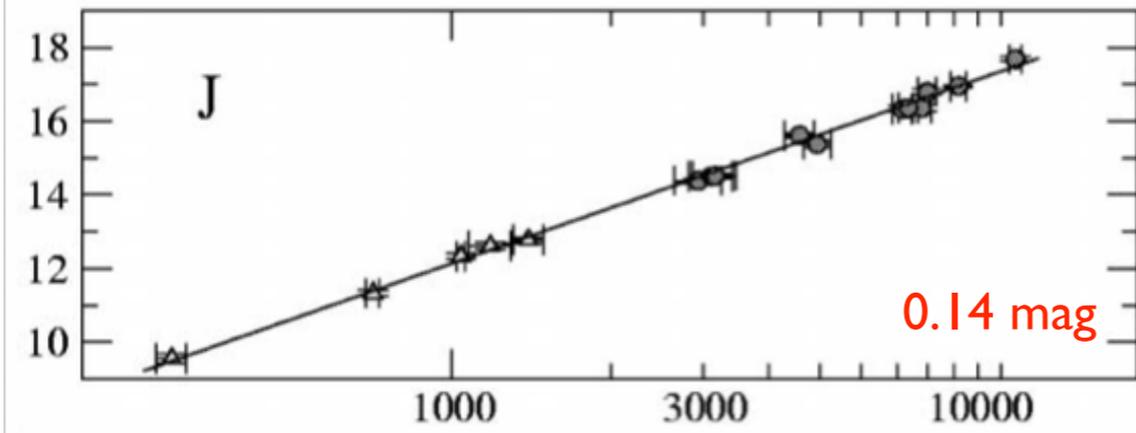


Kasen (2006)

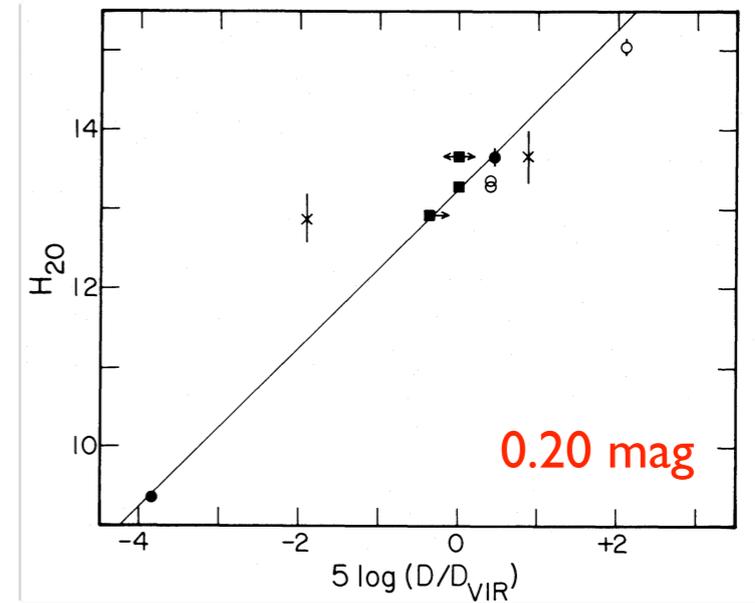


Phillips (2005)

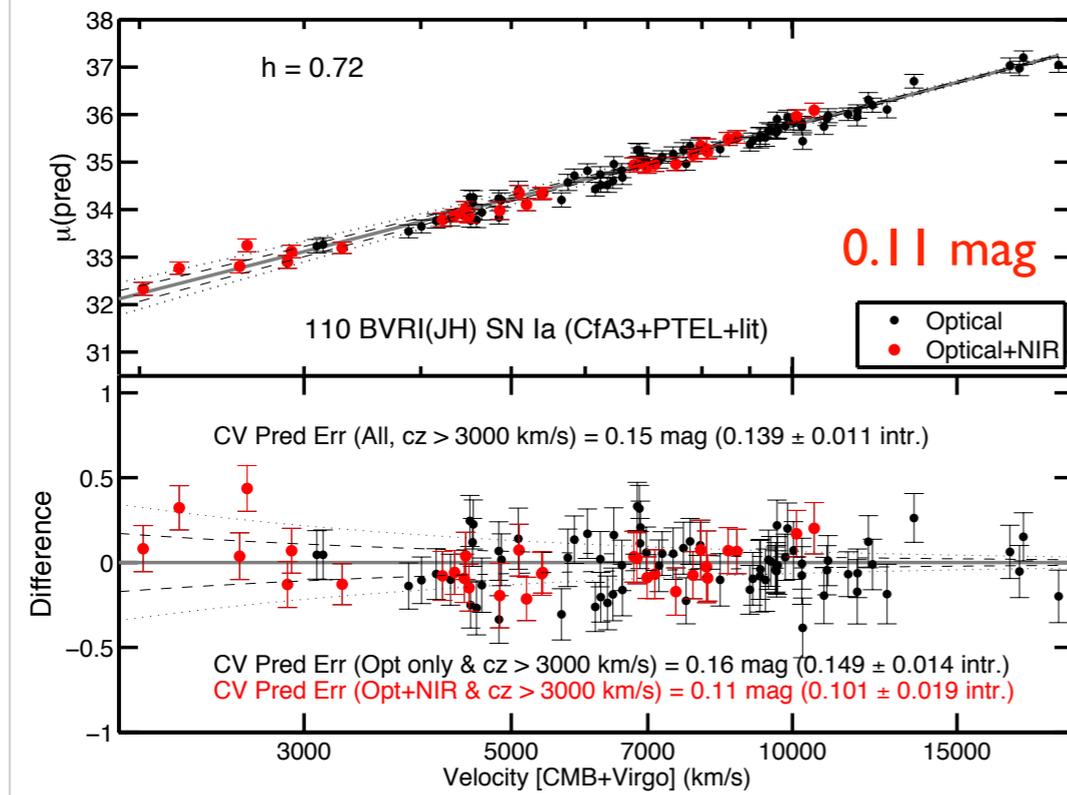
CSP2: why NIR?



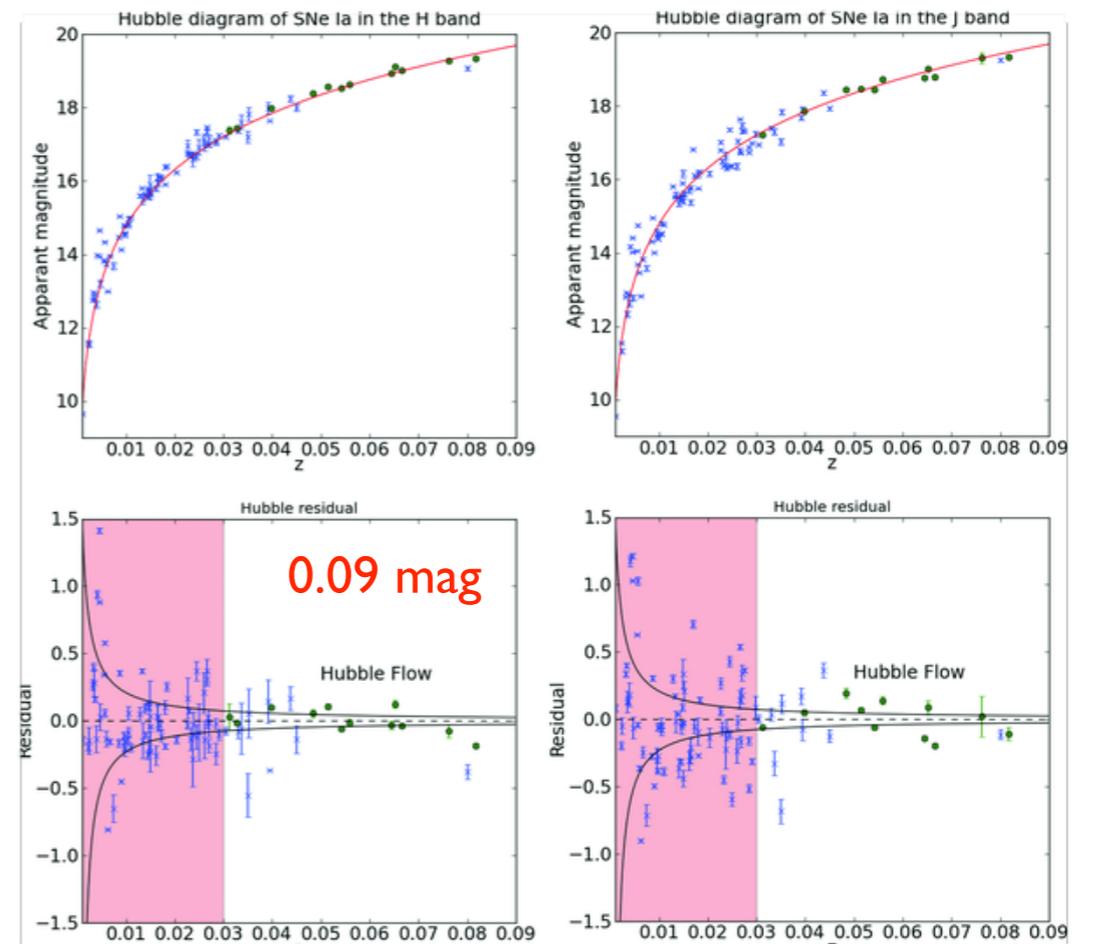
Krisciunas, Phillips, Suntzeff (2004)



Elias et al. (1985)



Mandel et al. (2011)



Barone-Nugent et al. (2012)

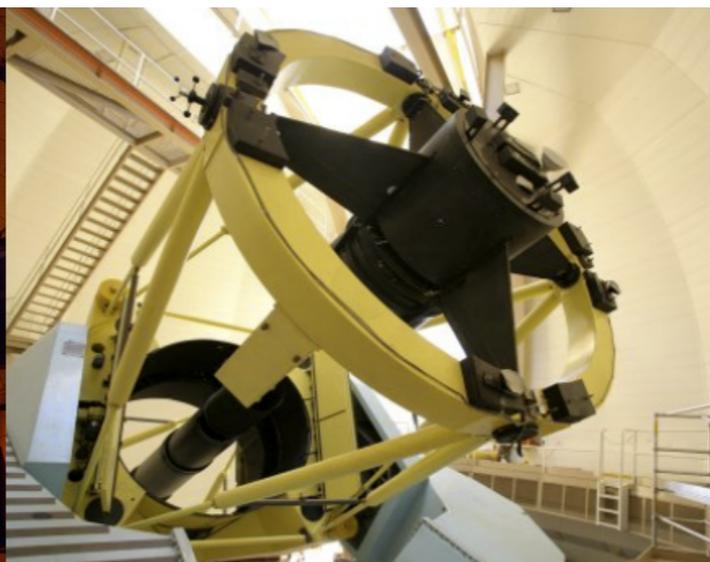
CSP2: improvements over CSP I

CSP2

- ▶ SNe from blind searches
 - ▶ young, unbiased sample in the Hubble flow
- ▶ improved k-corrections
- ▶ NIR imager on 2.5-m du Pont
- ▶ addition of FIRE and FourStar on 6.5-m Magellan

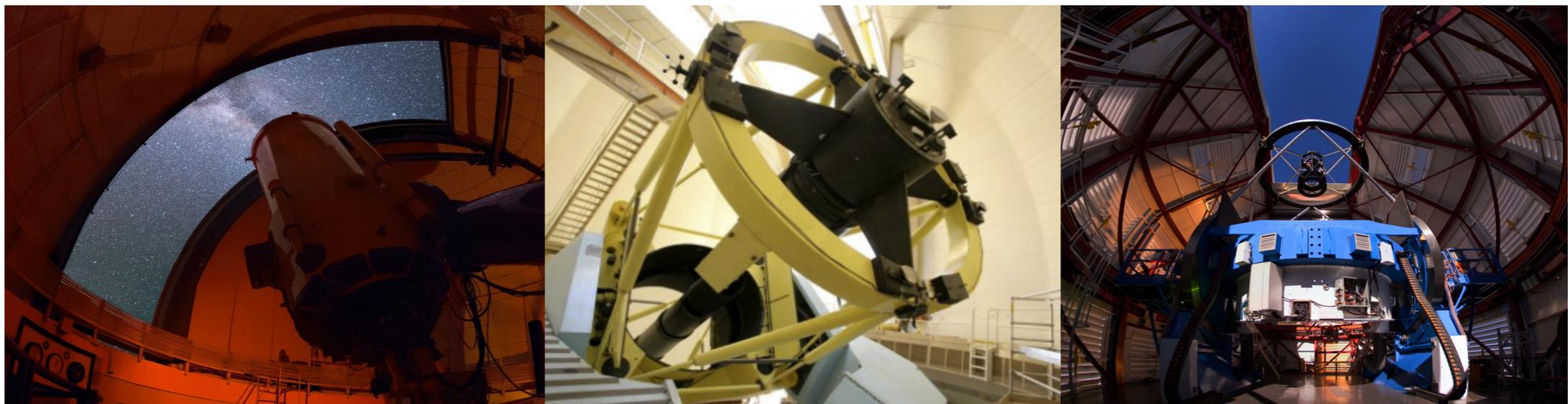
CSP I

- ▶ SNe from targeted searches
 - ▶ nearby sample, often miss NIR maximum
- ▶ old-school k-corrections
- ▶ NIR imager on 1-m Swope
- ▶ Magellan time was dedicated to the high-z project



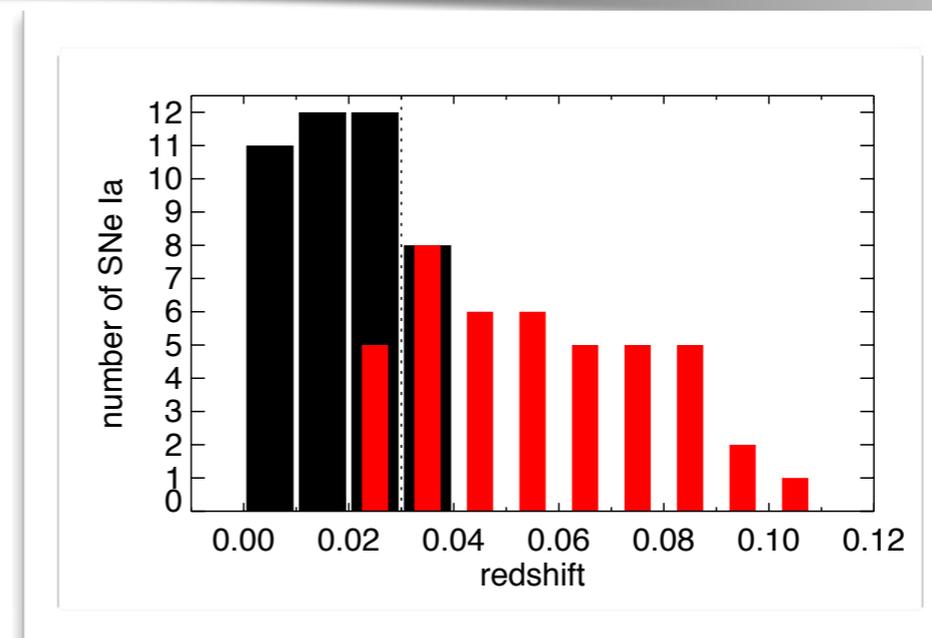
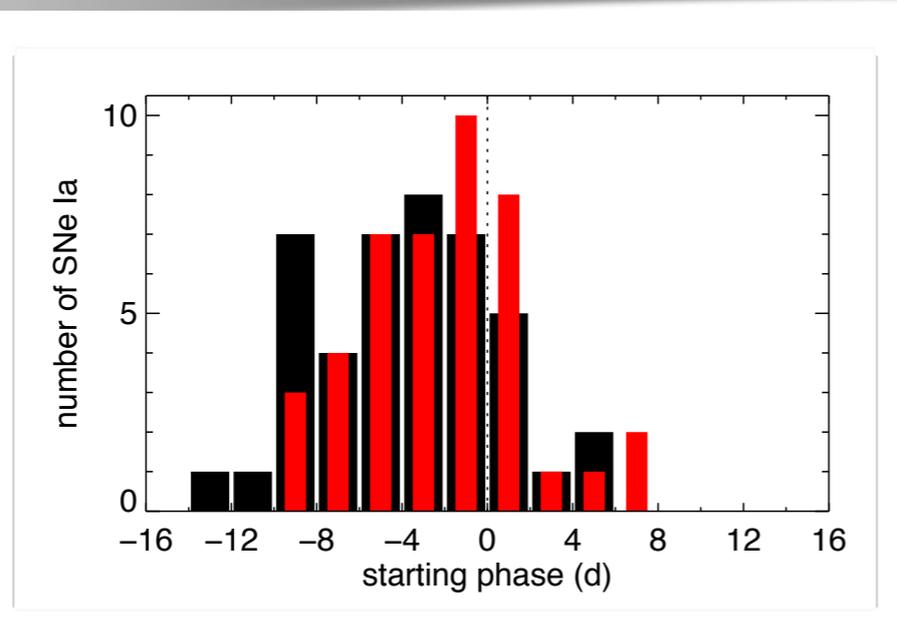
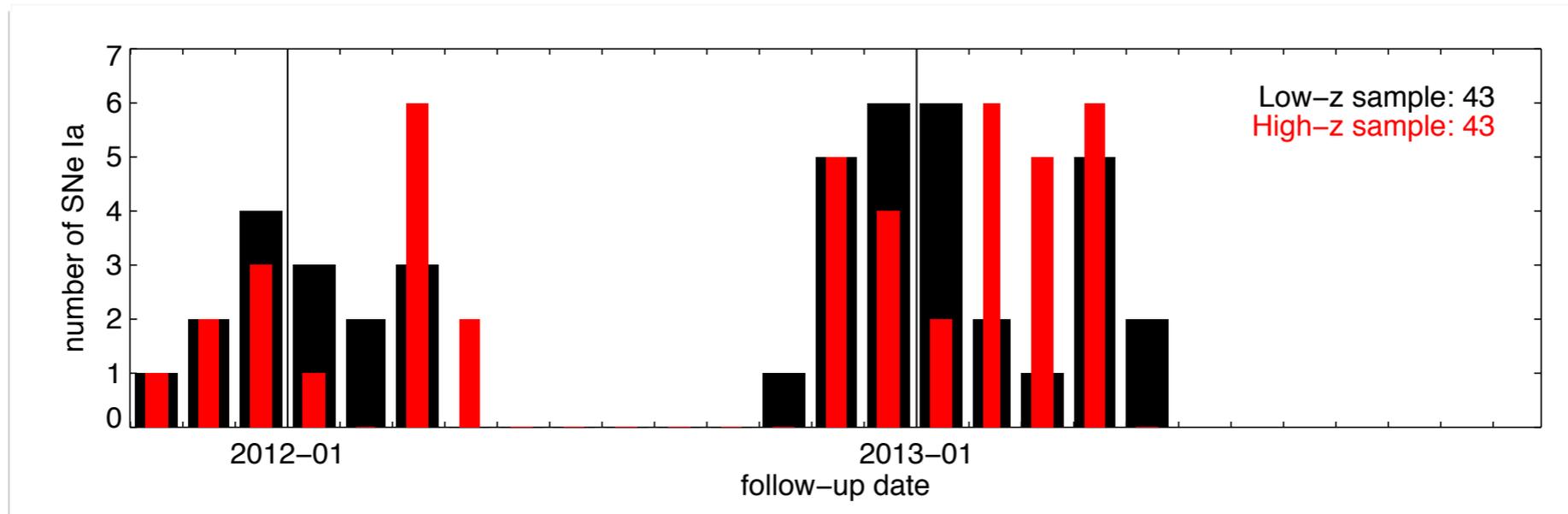
CSP2: observing strategy

- ▶ 5 years, ~150 SNe Ia in total
- ▶ each year, 6 months centered on summer
- ▶ each lunar cycle, centered on full moon:
 - ▶ ~1 night of optical spec screening: 2.5-m du Pont + WFCCD
 - ▶ ~8 nights of NIR YJH imaging: 2.5-m du Pont + RetroCam
 - ▶ nightly optical uBVgri imaging: 1-m Swope + CCD
 - ▶ ~4 nights NIR spectroscopy/imaging: 6.5-m Baade + FIRE/FourStar
(in collaboration with CfA and U Chile)



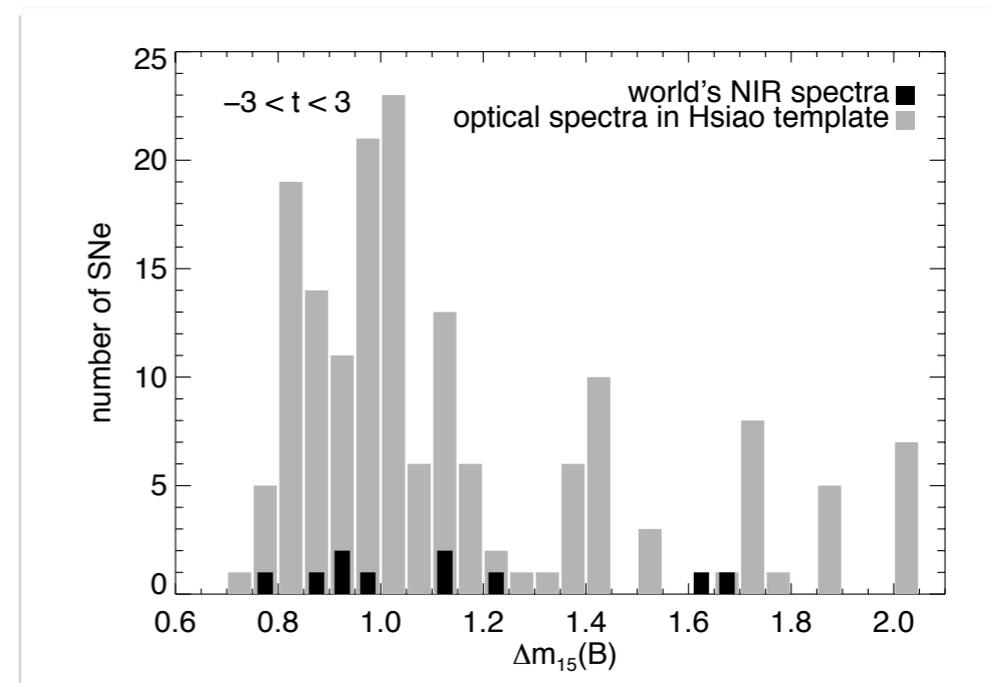
statistics

- ▶ low-z: nearby SNe Ia with detailed optical (+ NIR) light curves + NIR spectra
- ▶ high-z: SNe Ia in the Hubble flow with optical + NIR light curves



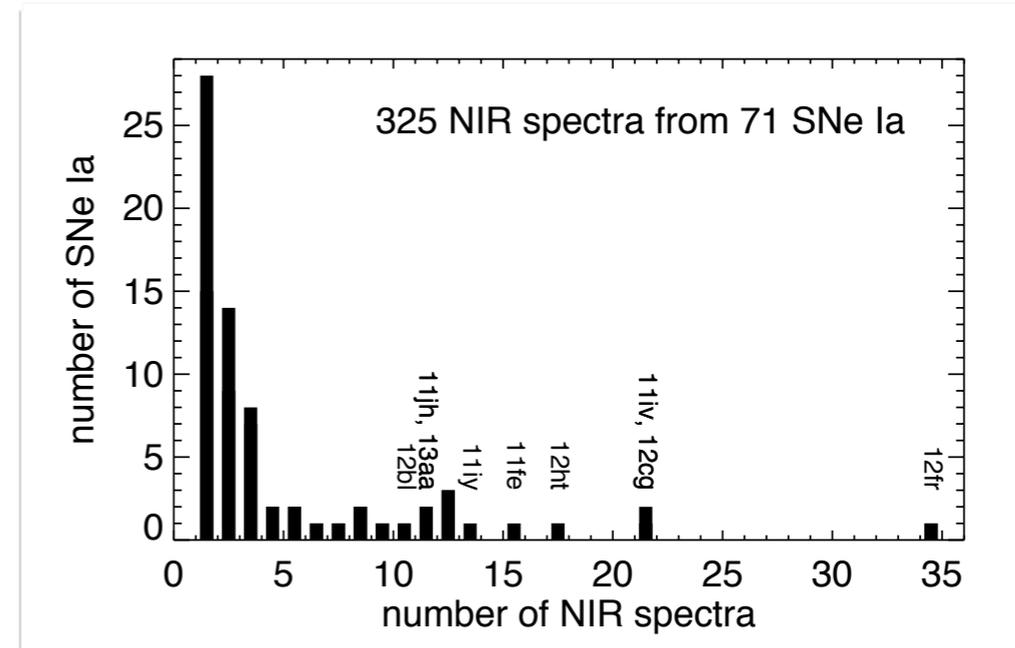
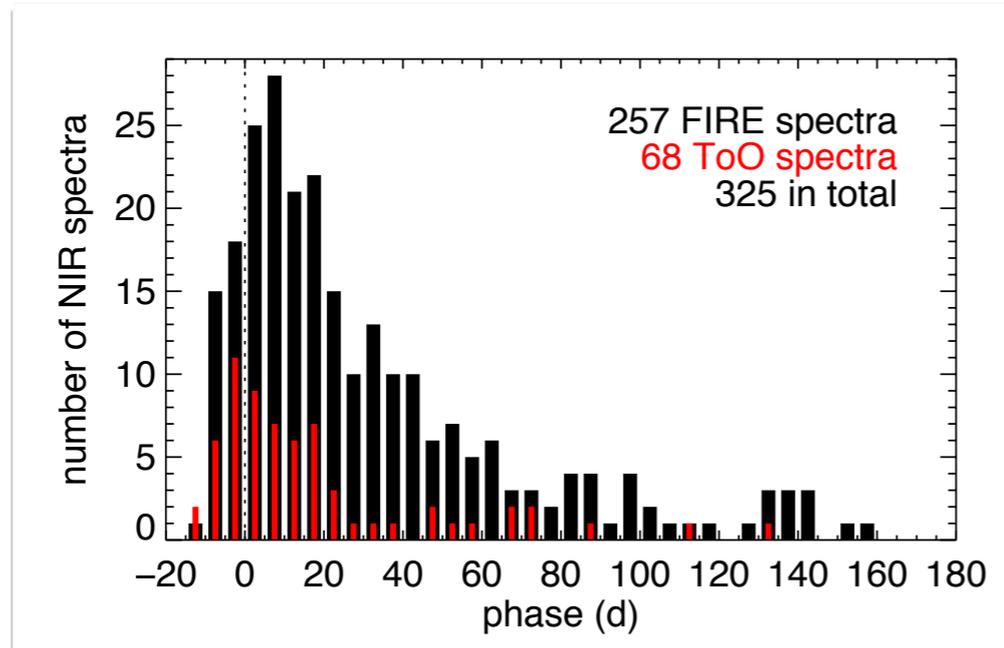
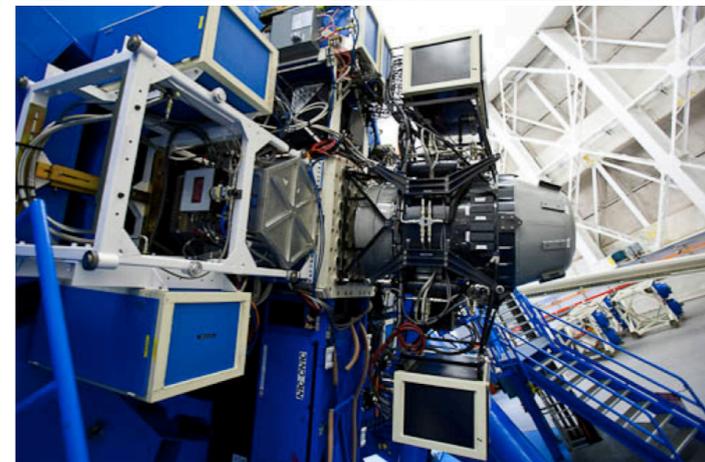
CSP2: why NIR spectroscopy?

- ▶ cosmological utility
 - ▶ k-correction errors need to be minimized/understood
- ▶ physical diagnostics
 - ▶ probe of primordial material
 - ▶ measure of boundary between C/O burning layers transition between sub/supersonic burning front
 - ▶ conditions of synthesized material in core
- ▶ NIR provides independent information not available in the optical: unique ion species, isolated lines



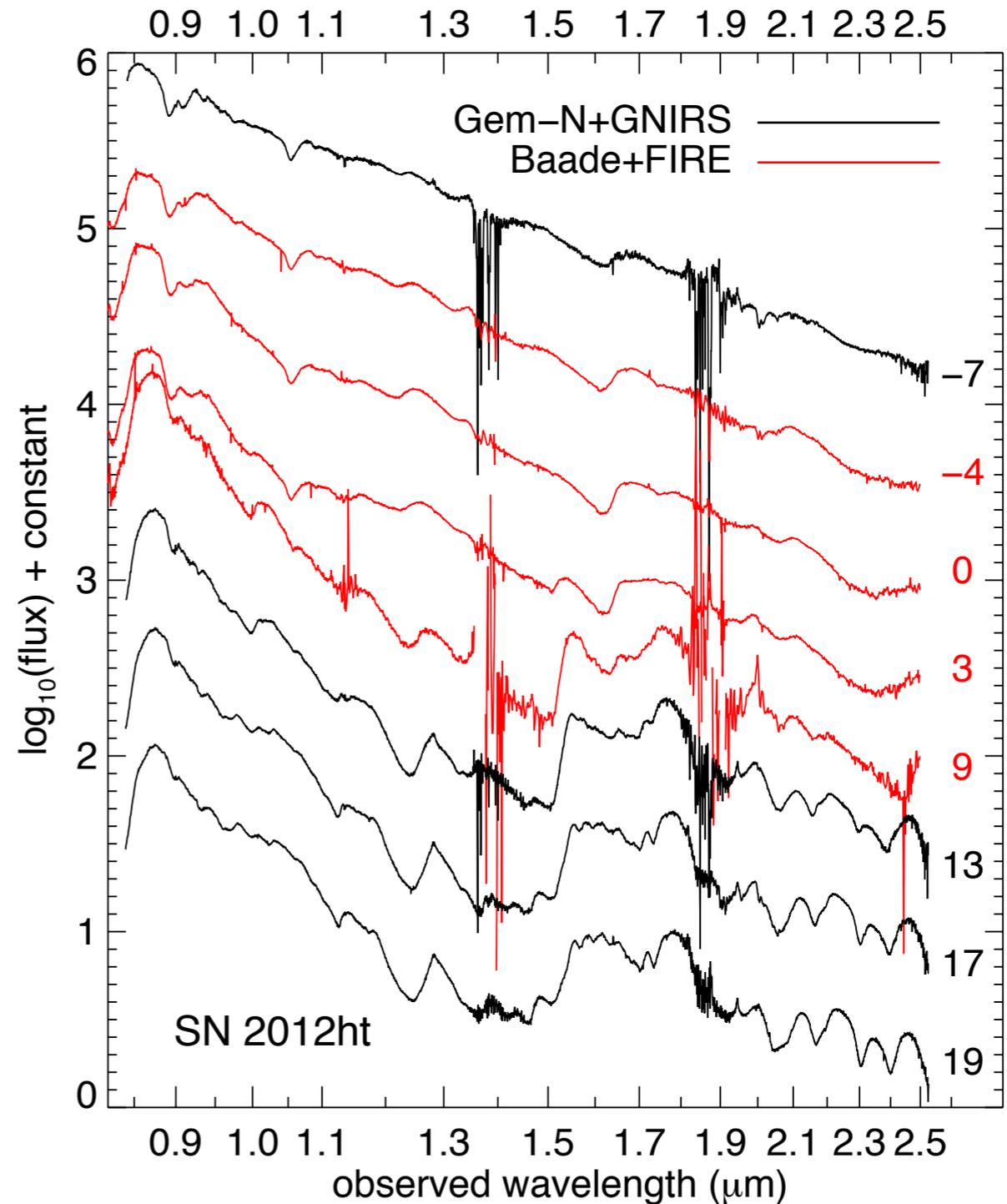
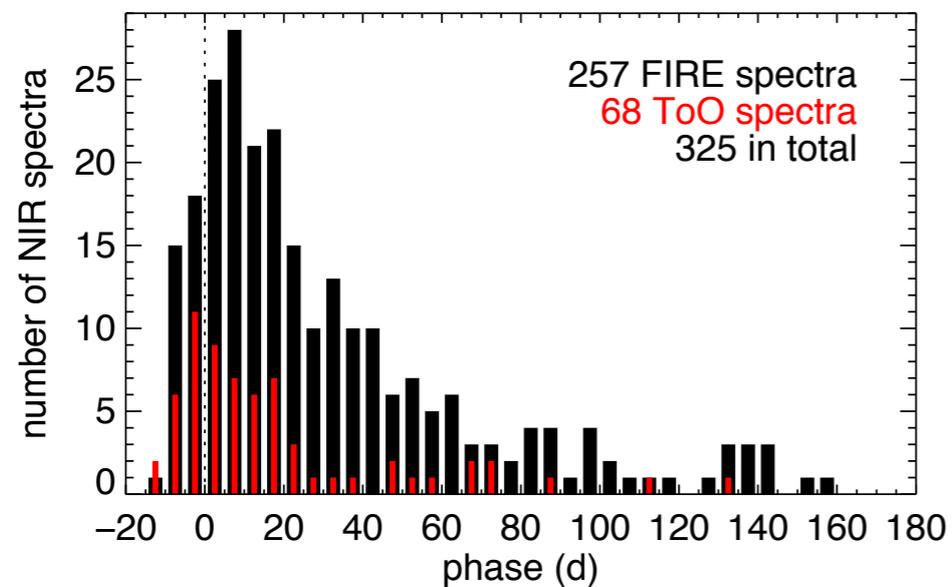
CSP2: NIR spectroscopy

- ▶ bigger telescopes
Magellan+ FIRE, Gemini-N+GNIRS
- ▶ bigger number
Marion 2009 in 5 years: 41 spectra
CSP2 in 2 years: 325 spectra
- ▶ time series
scheduled FIRE nights + ToO GNIRS time
- ▶ Hubble flow/blind-search objects
- ▶ accompanying opt/NIR LCs
- ▶ simultaneous optical spectra

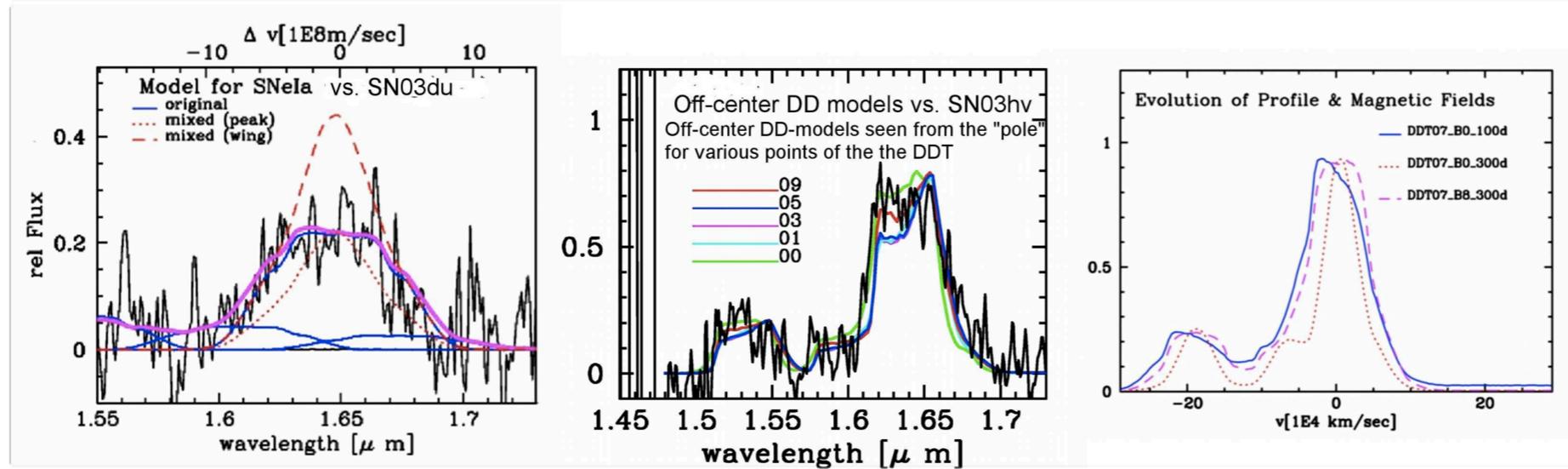


CSP2: NIR spectroscopy

- ▶ ToO capability of Gem-N allows GNIRS to fill in the temporal gaps



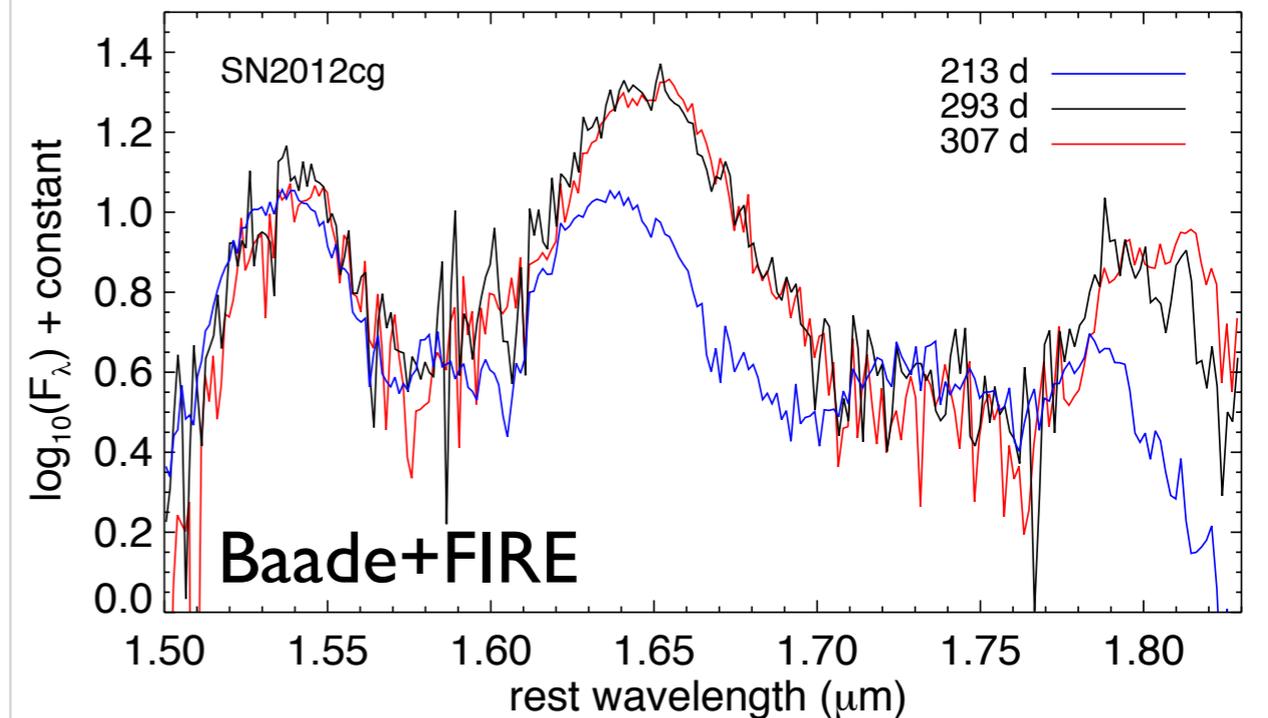
Nebular phase: [Fe II] 1.65



Hoeflich et al. (2004, 2006) Penney (2011)

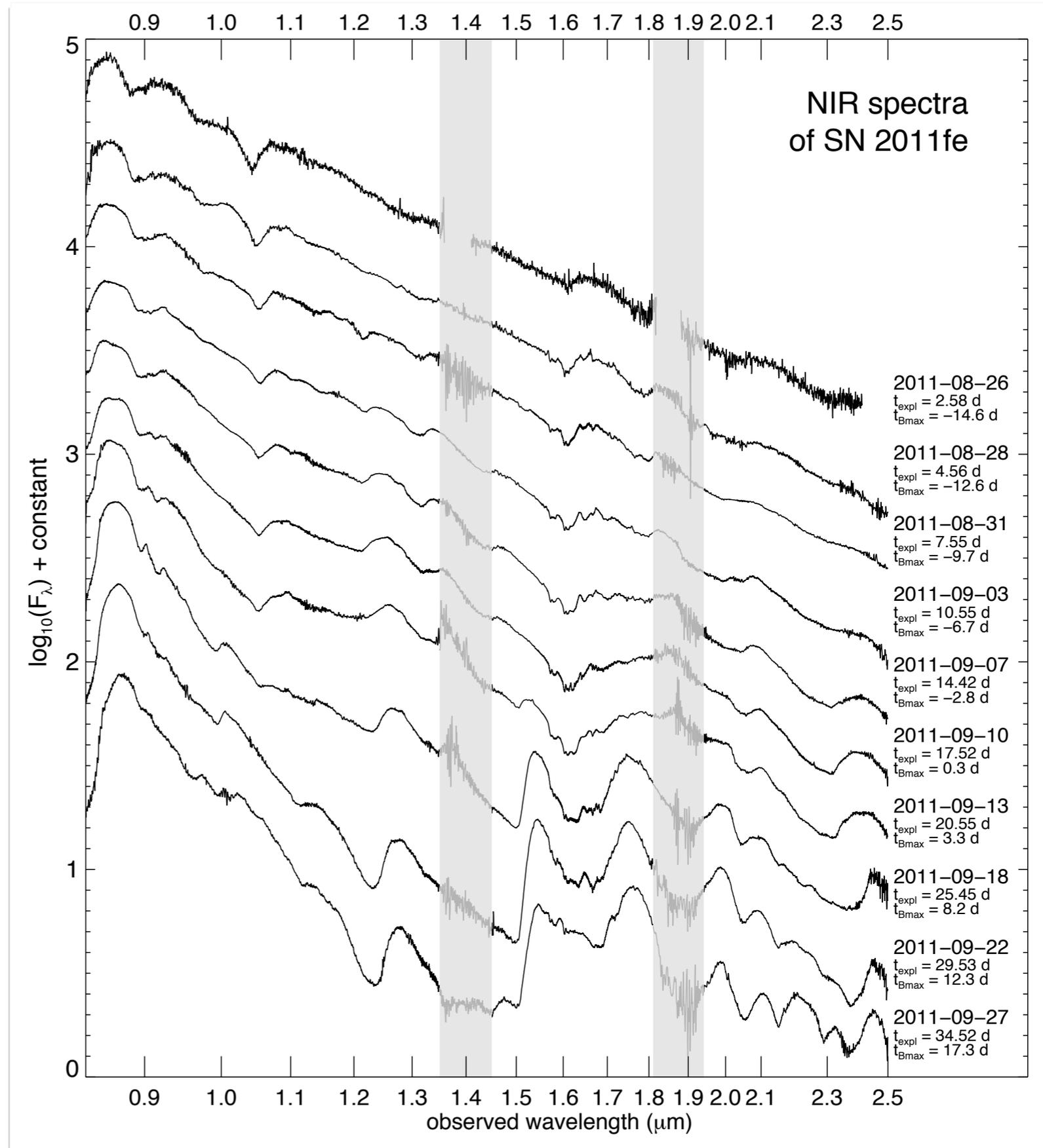
- ▶ mixing
- ▶ explosion geometry
- ▶ progenitor magnetic field

- ▶ extra 2-3 nights in Chilean winter to continue nebular phase time series (Carnegie, CfA, Chile)

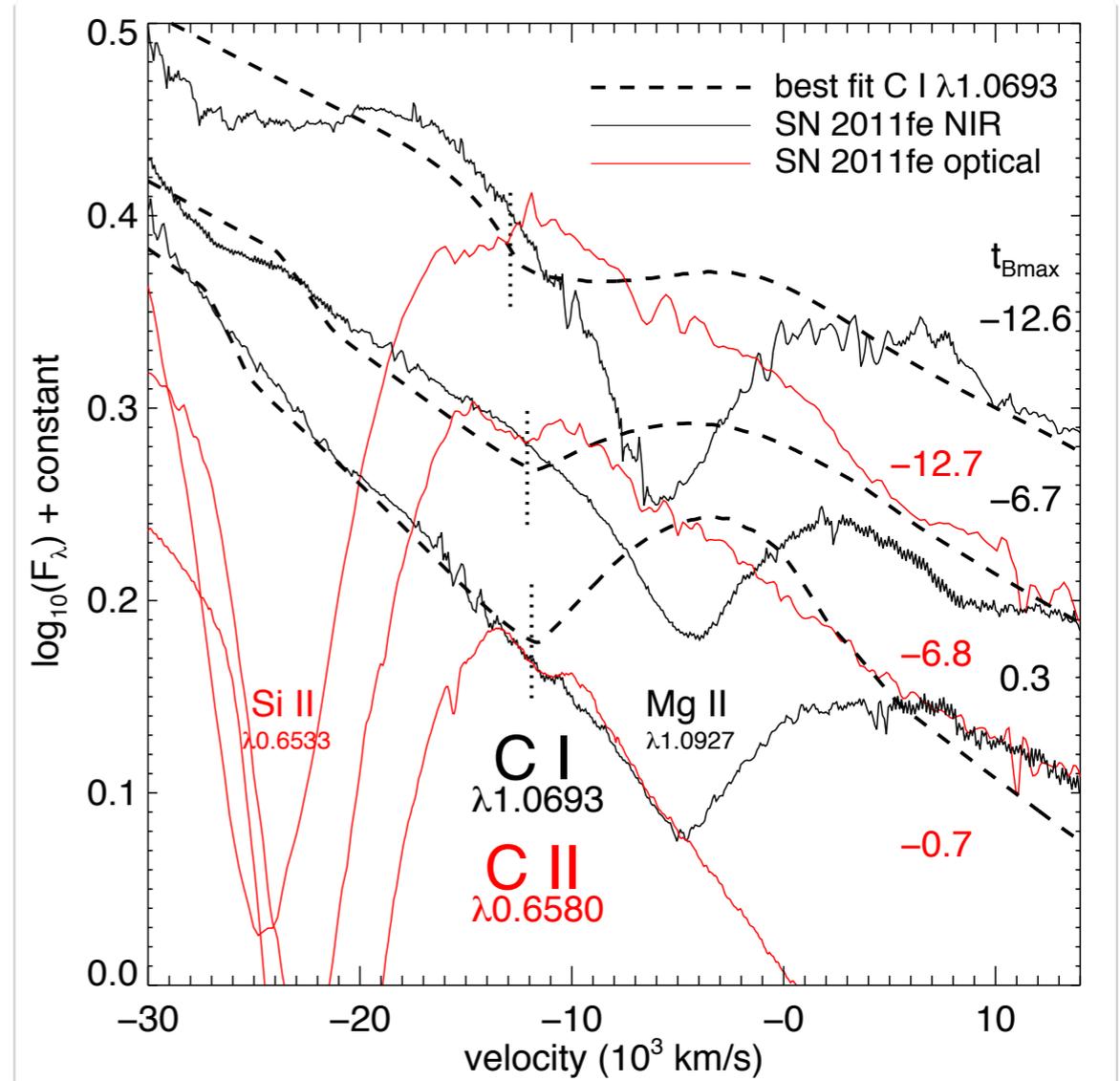
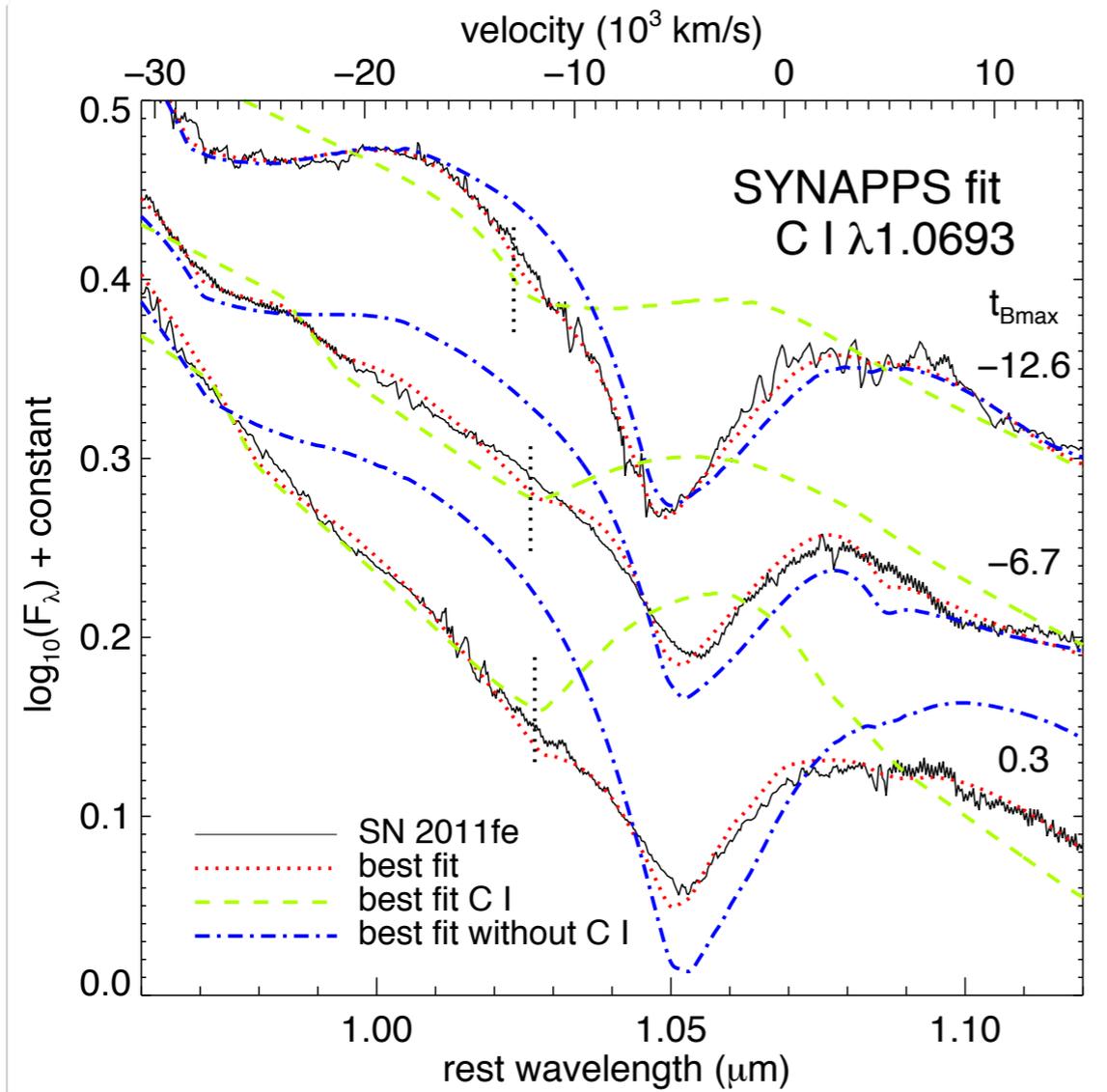


Normal Ia

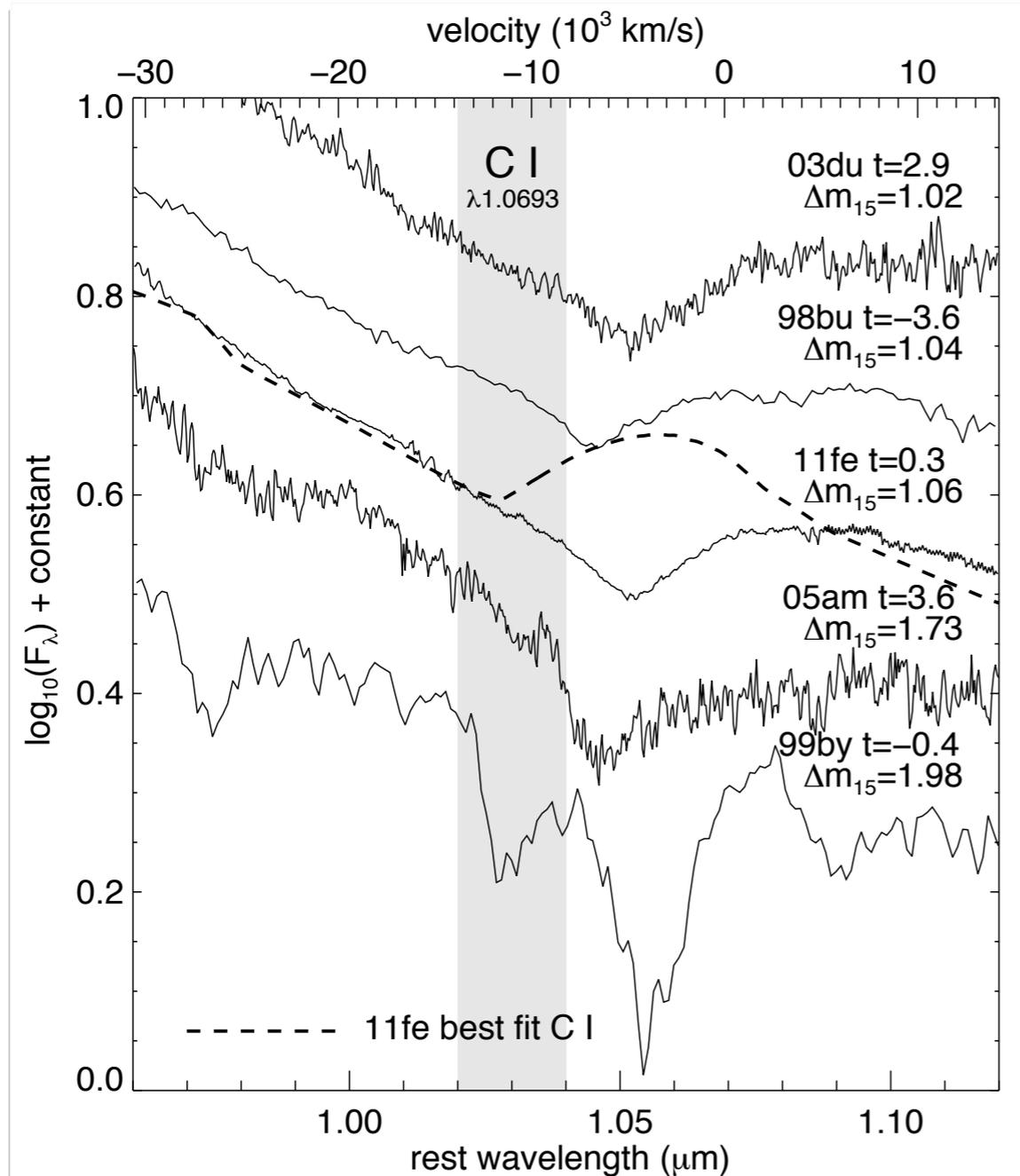
- ▶ NIR spec of 11fe Hsiao et al (2013)
- ▶ 1 SpeX+ 9 GNIRS NIR spectra
- ▶ earliest time series
- ▶ high S/N
- ▶ medium res
- ▶ 3-day cadence around max



Normal Ia: unburnt carbon

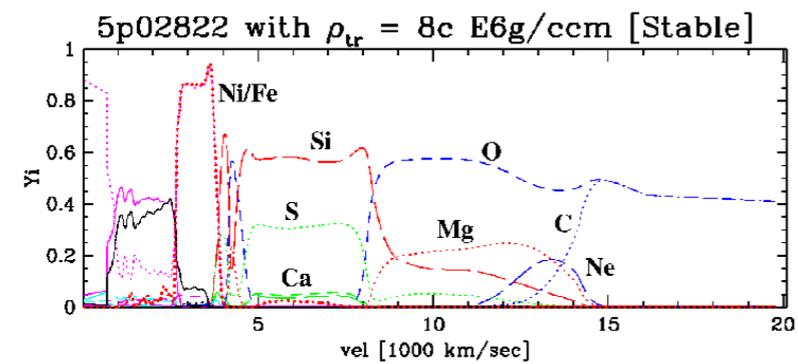
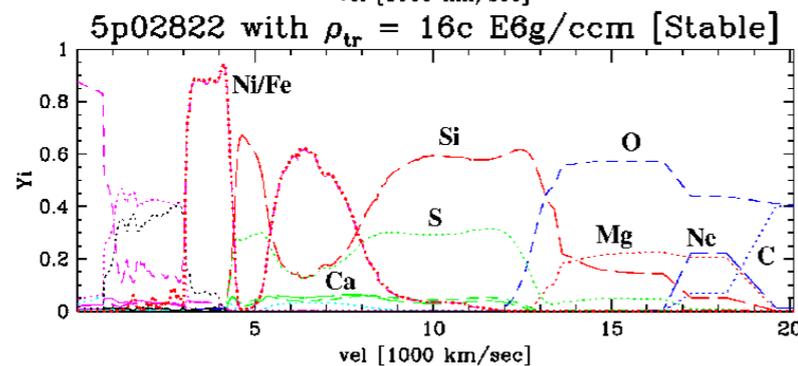
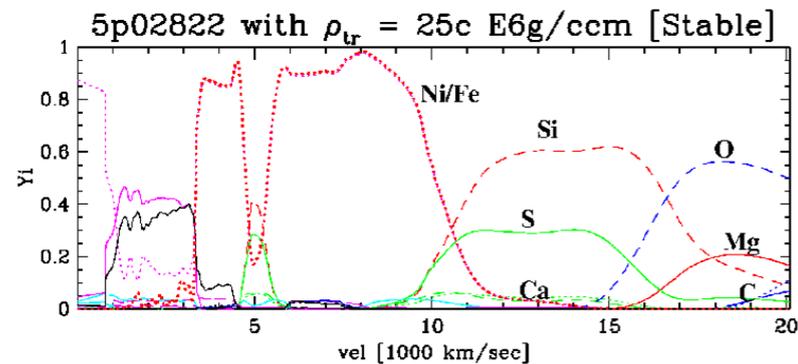
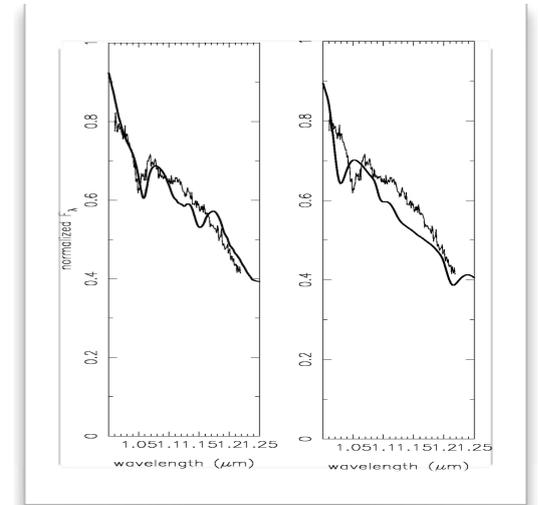


Normal Ia: unburnt carbon



- ▶ C I 10693 suppresses the emission wing of Mg II 10092 P Cygni
- ▶ C II to C I
- ▶ the delay in the onset of NIR C I makes it a better tracer of carbon
- ▶ optical studies yielded 20-30%
Thomas et al. 2011; Parrent et al. 2011;
Folatelli et al. 2012; Silverman & Filippenko 2012
- ▶ “flattened” feature is common
carbon ubiquitous in SNe Ia?

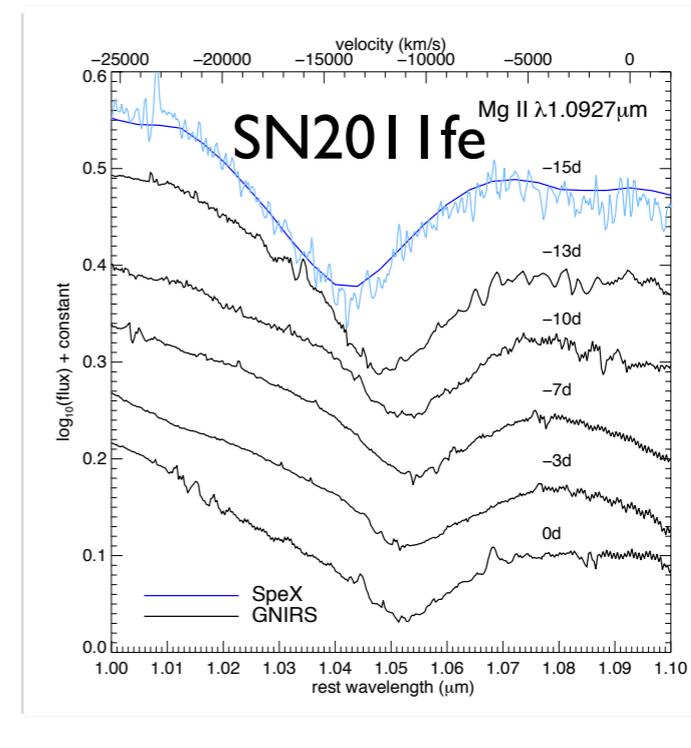
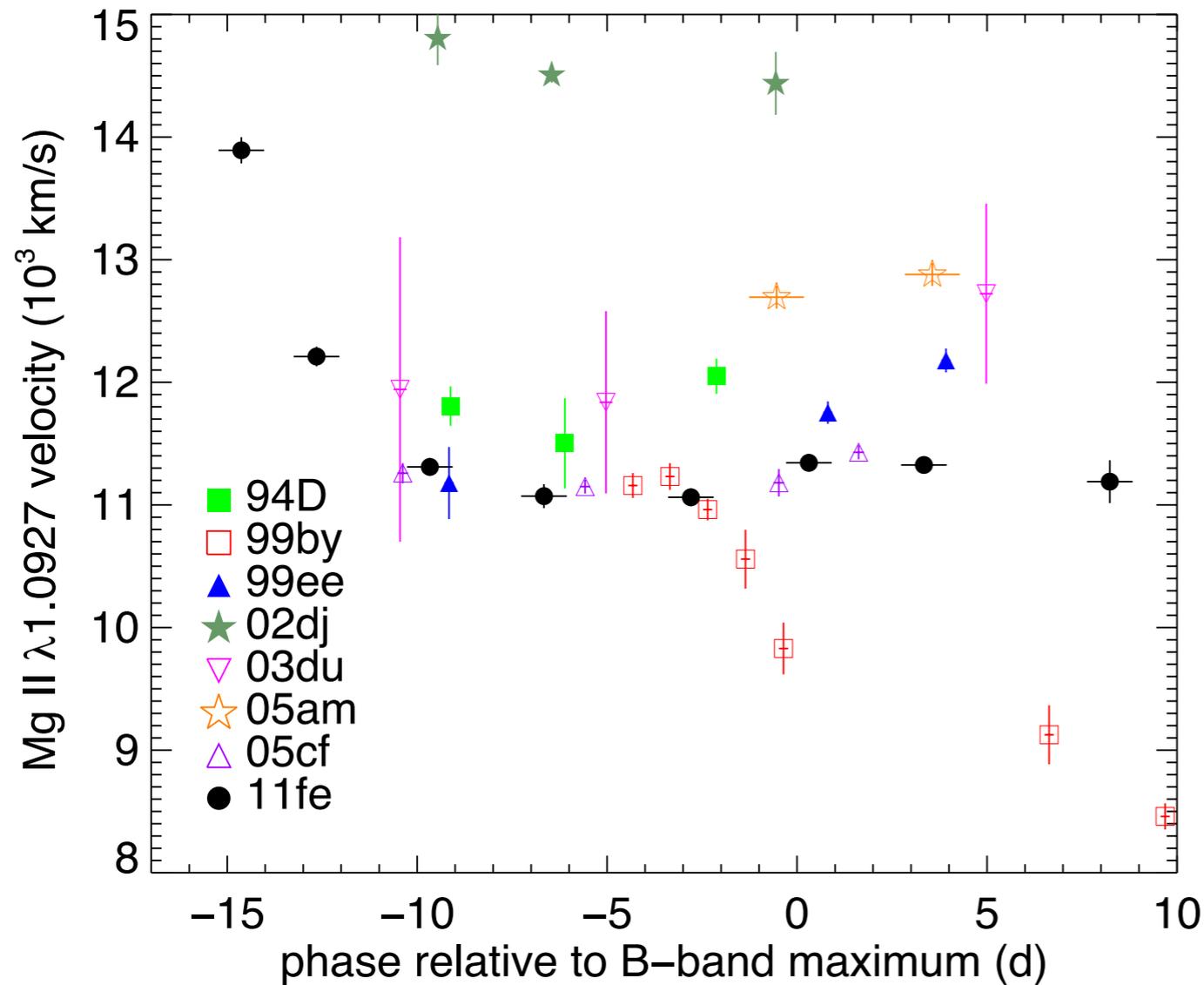
Normal Ia: Mg II 10927 velocity



- ▶ photosphere recedes below inner edge of Mg distribution
- ▶ constant velocity
- ▶ accurate measure of the inner edge of C burning
- ▶ probing deflagration to detonation transition density
- ▶ transition density sets amount of expansion during deflagration, sets amount of ^{56}Ni

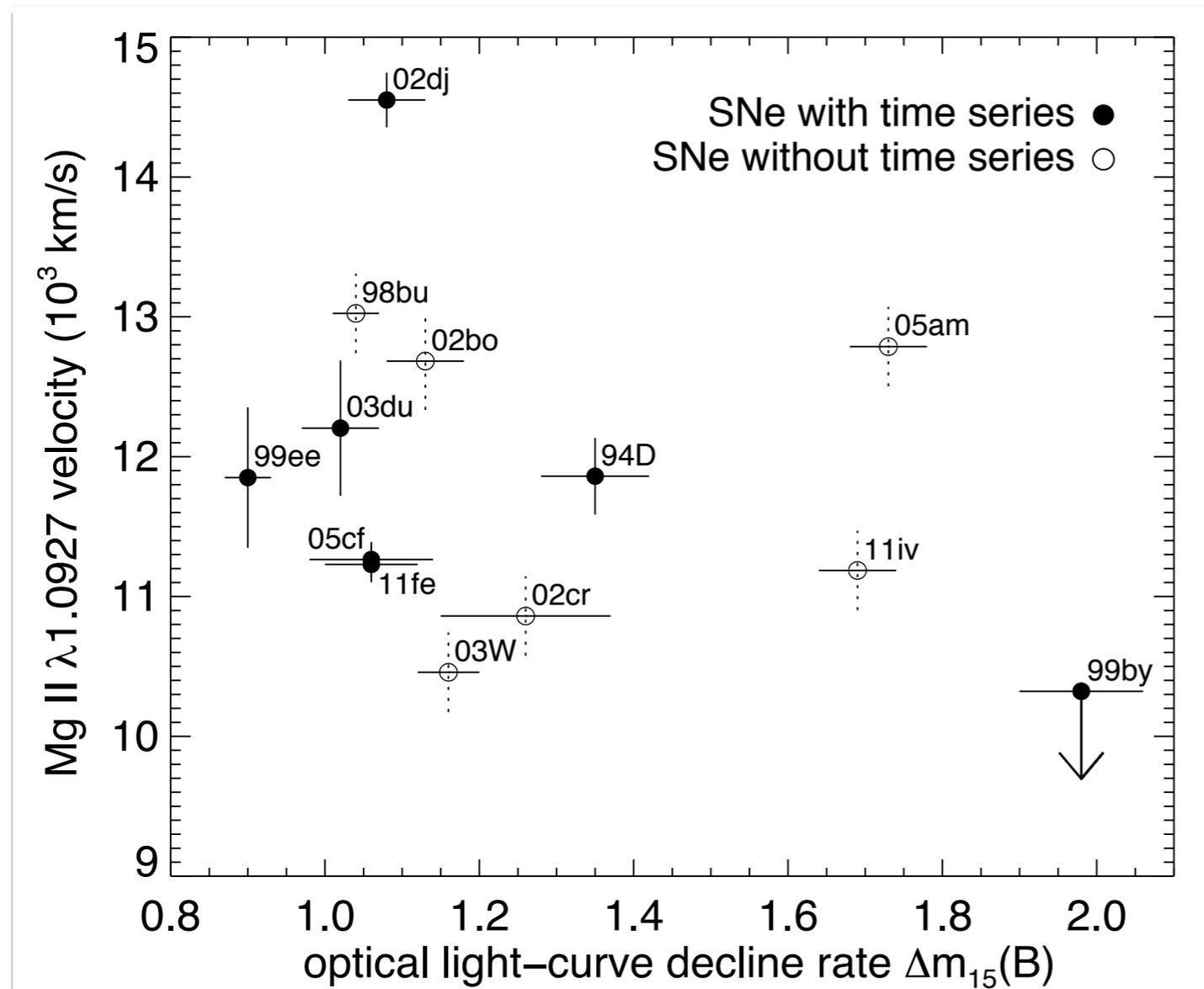
Wheeler et al. (1998)
 Marion (2001)
 Höflich et al. (2002)

Normal Ia: Mg II 10927 velocity



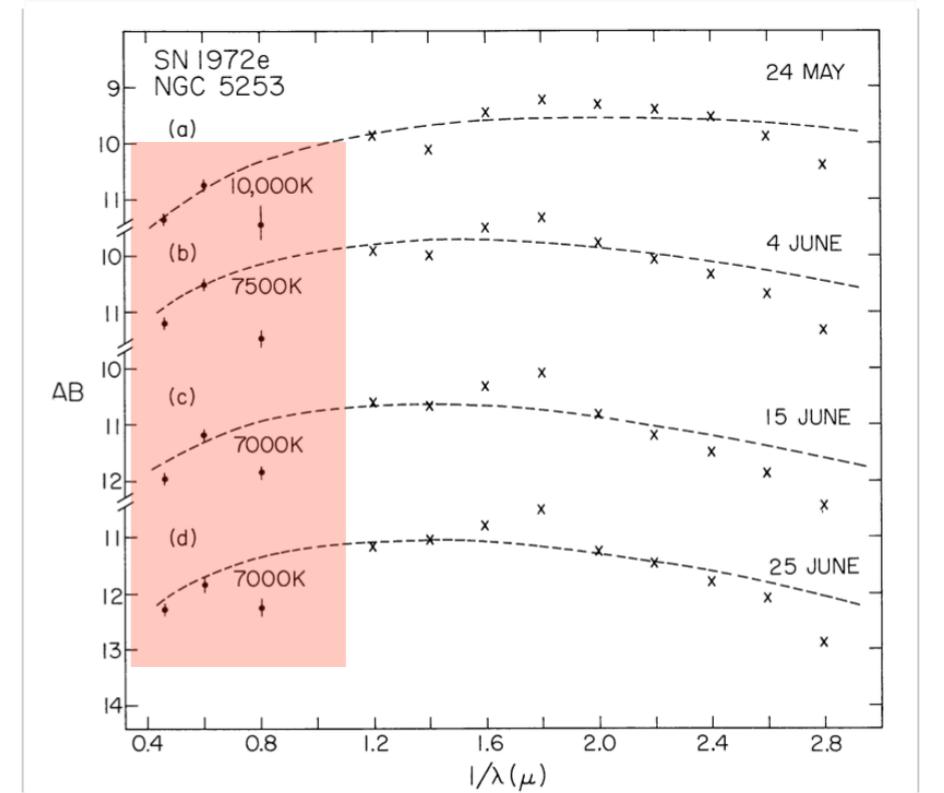
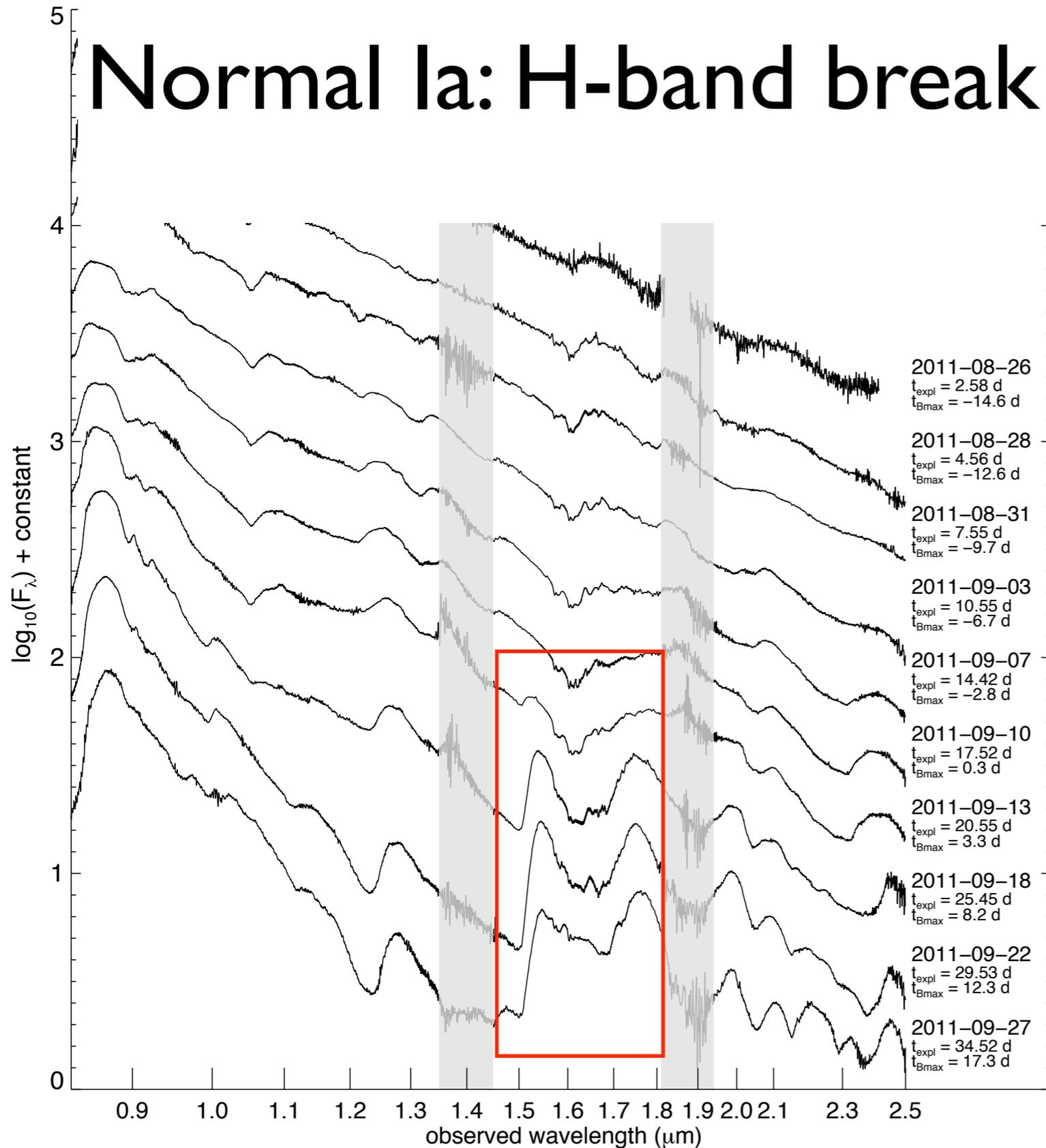
▶ velocity remarkably constant from -10 to 10 d until line disappears

Normal Ia: Mg II $\lambda 10927$ velocity



► Is DDT transition density the main driver for SN Ia luminosity variation?

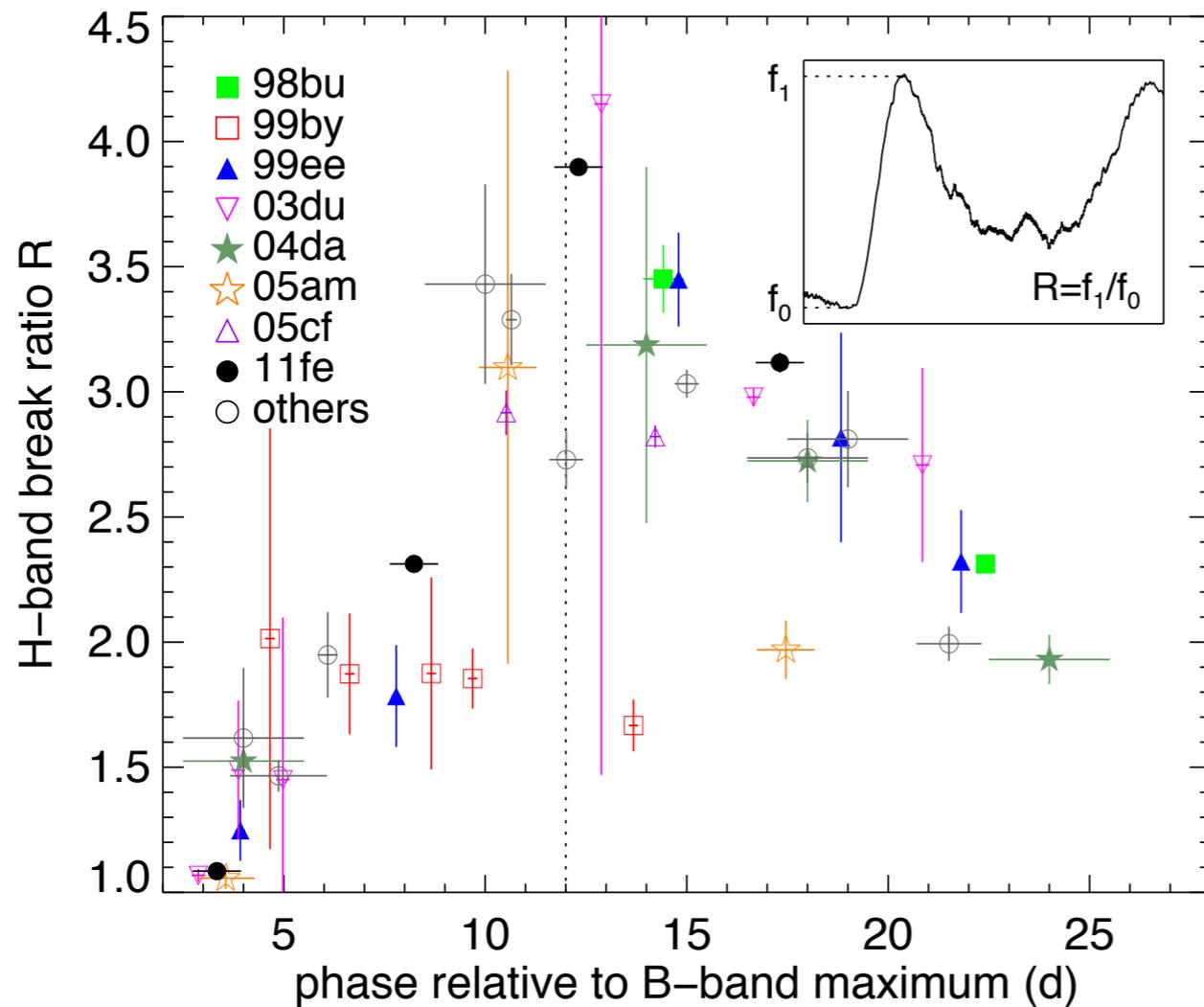
Normal Ia: H-band break



Kirshner et al. (1973)

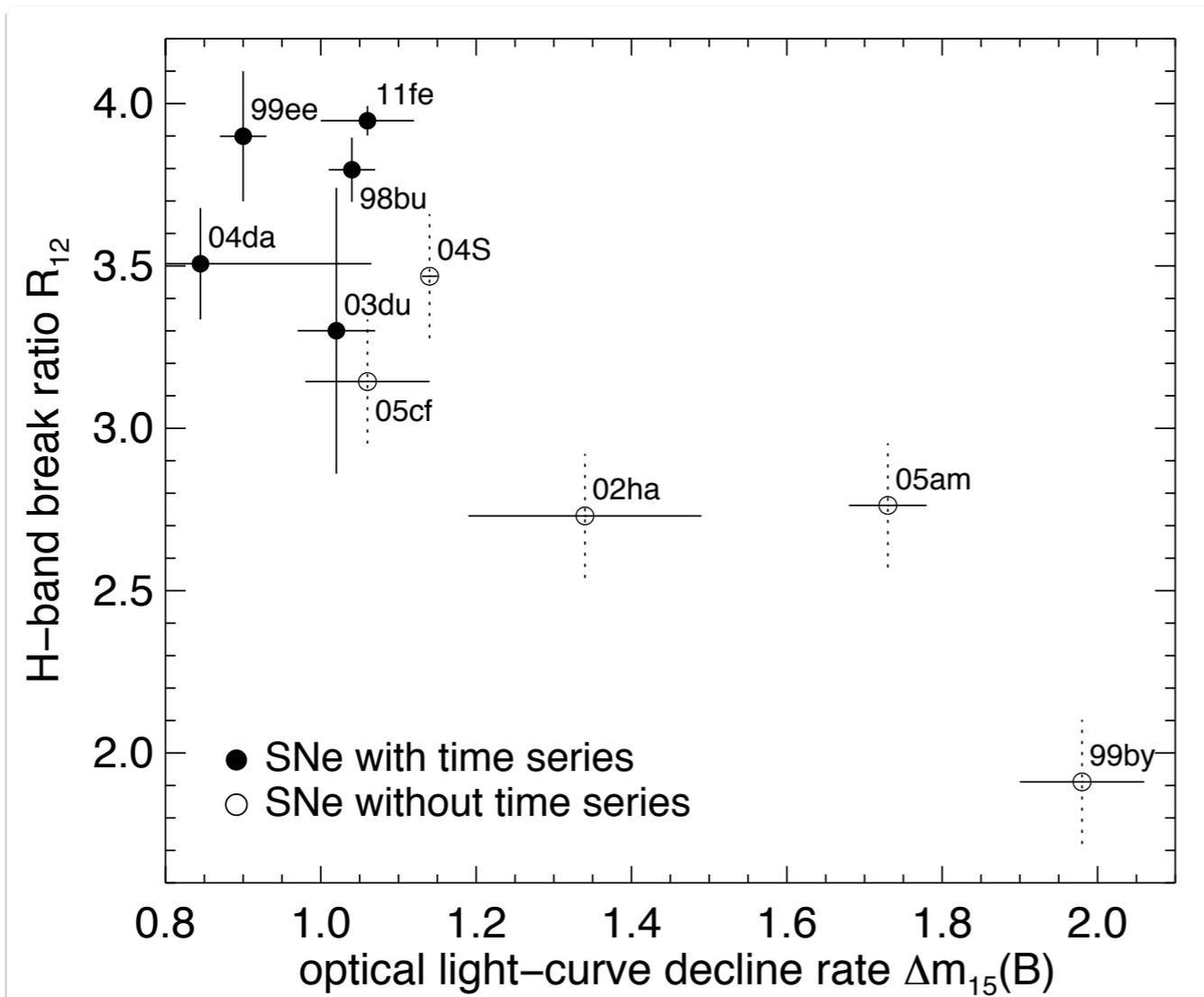
- ▶ contrasting opacity
- OR -
- ▶ fluorescence (Gall et al 2013)

Normal Ia: H-band break



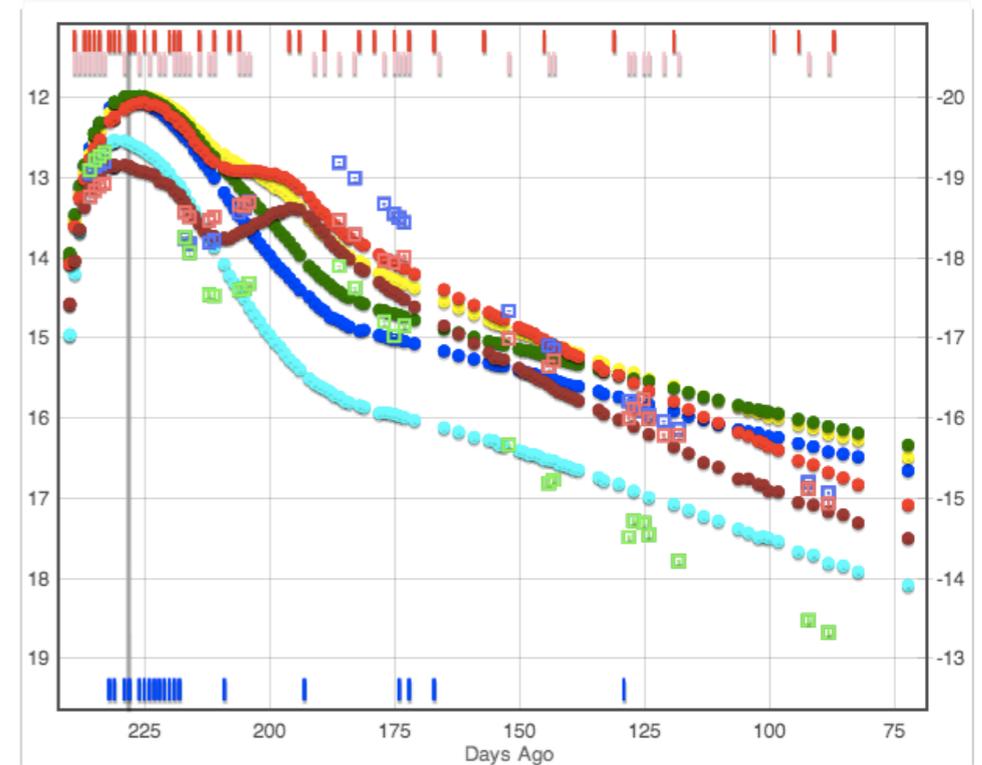
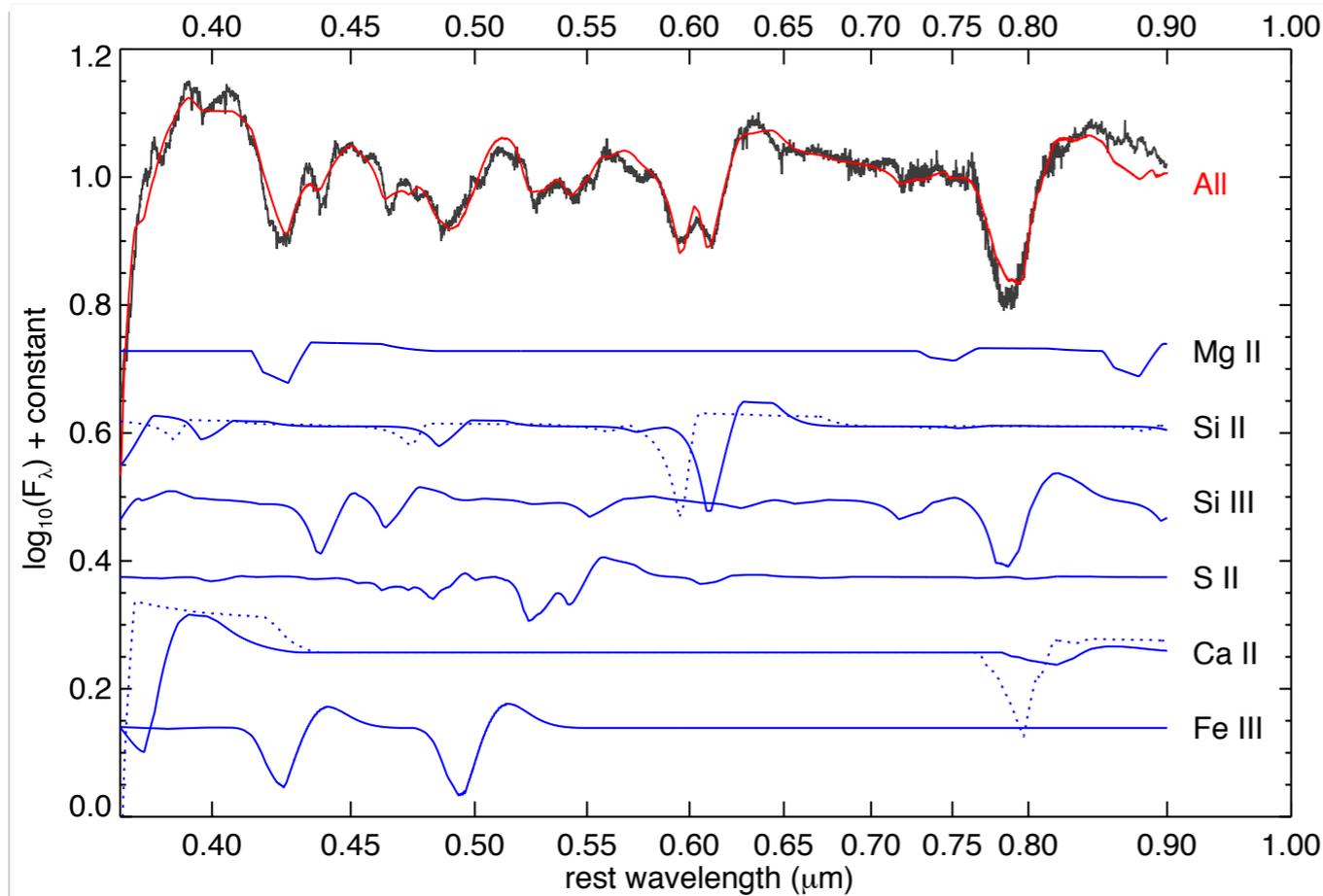
- ▶ ratio has uniform evolution
- ▶ at 12 d, the iron-peak structure is completely exposed
- ▶ post peak decline reflects temperature decline

Normal Ia: H-band break



- ▶ ratio strengths at their peaks correlates with Δm_{15}
- ▶ more time-series data is needed
- ▶ first step toward improved k-corrections

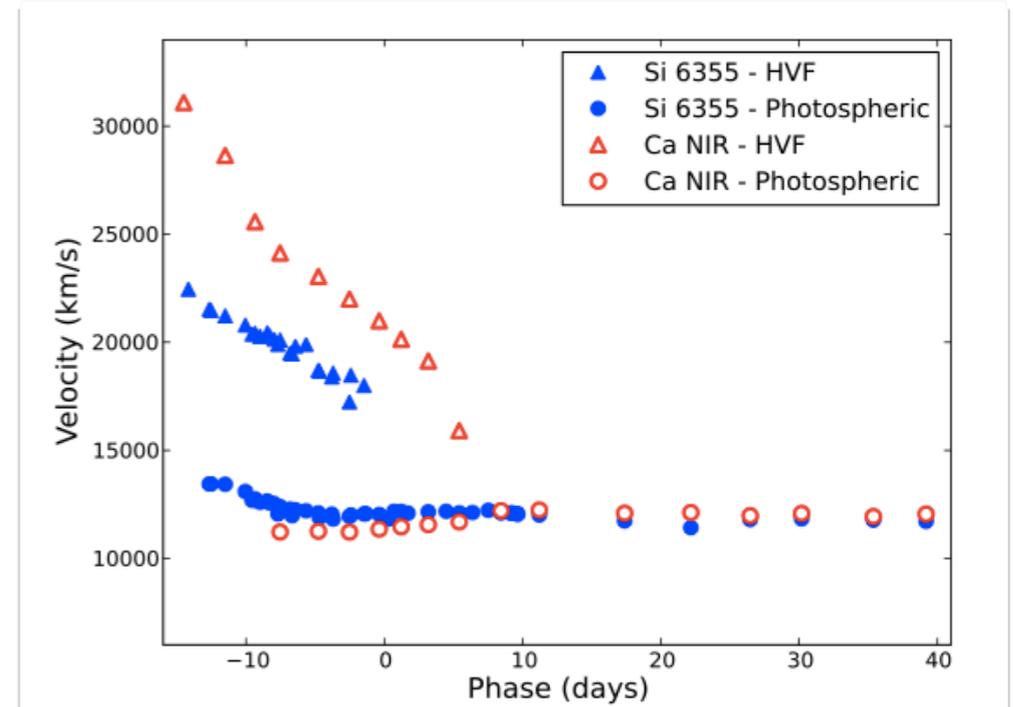
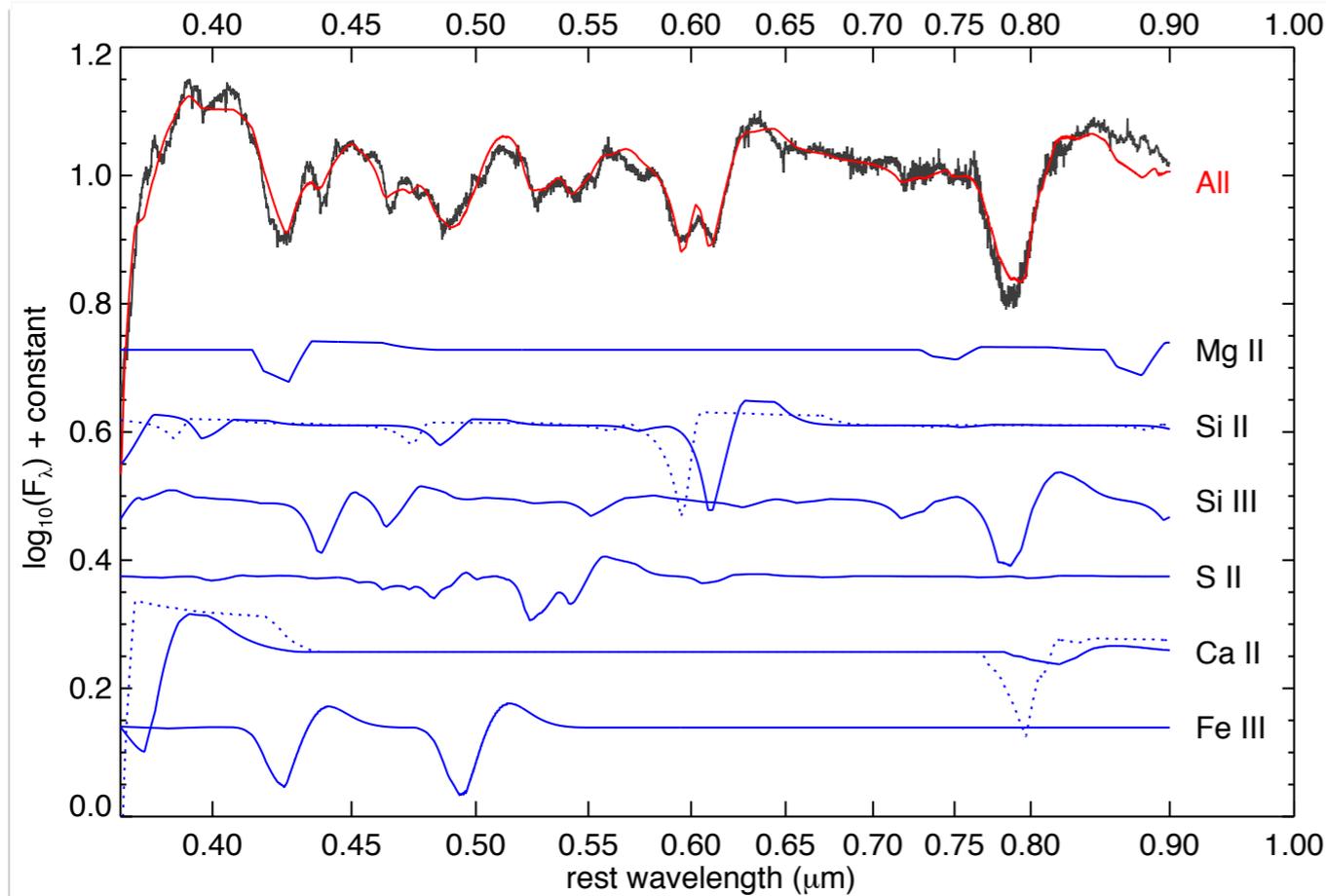
High- v : SN2012fr



Contreras et al in prep

- ▶ optical light curves and spectra similar to SN2009ig
- ▶ most clear example of detached Si II
- ▶ near relativistic- v detached Ca II may be better explained by Si III

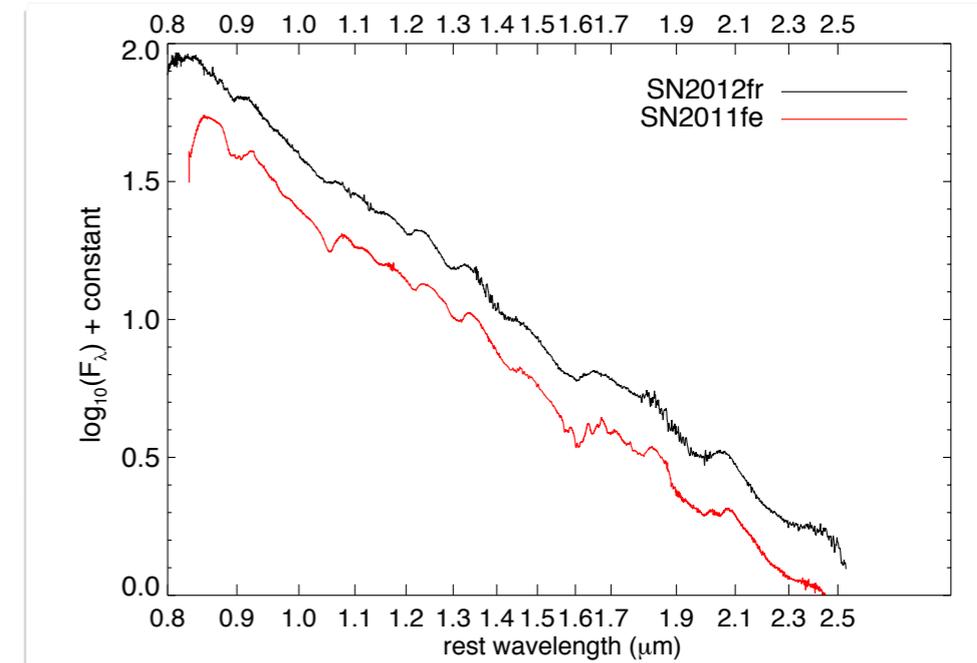
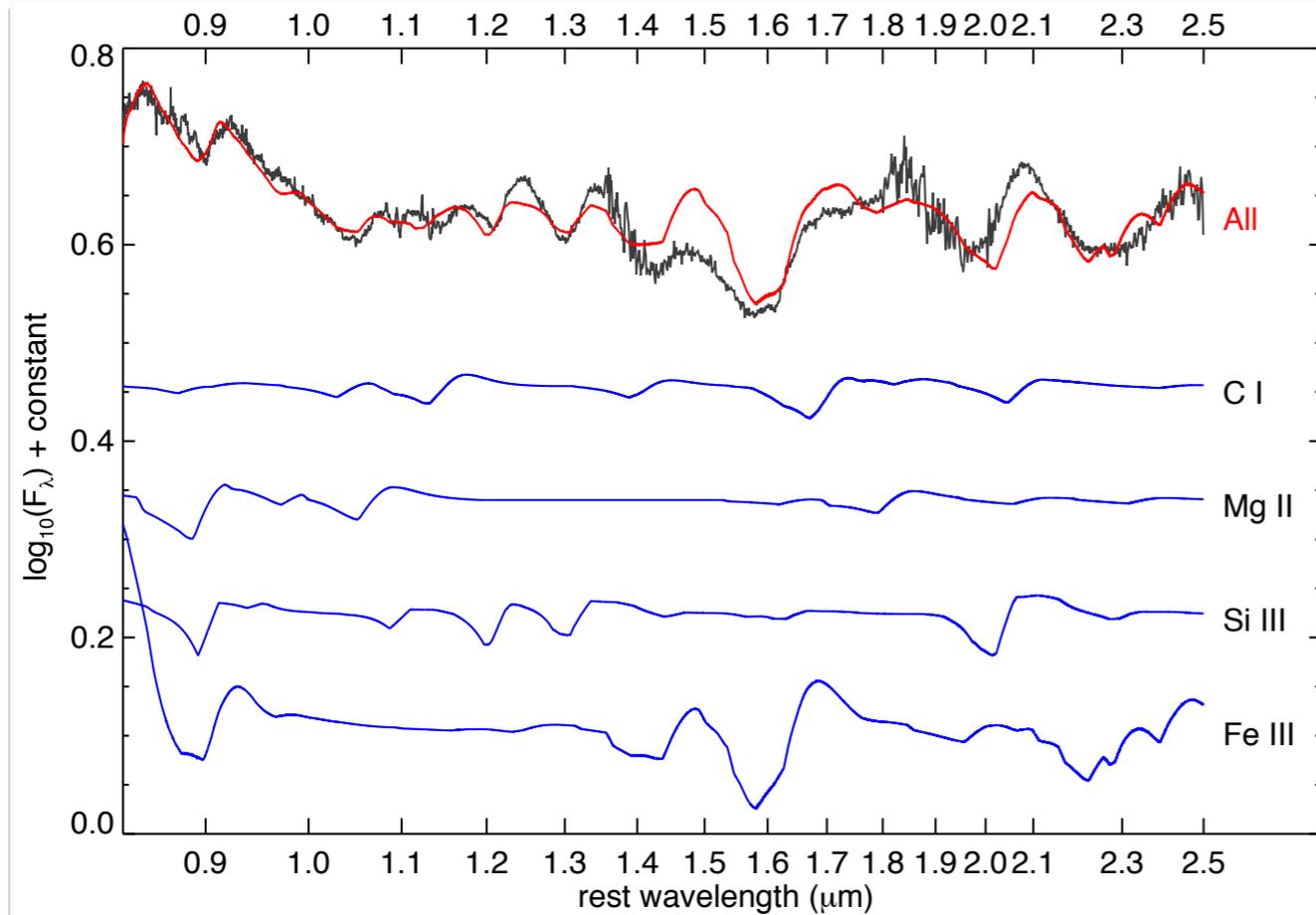
High- v : SN2012fr



Childress et al (2013)

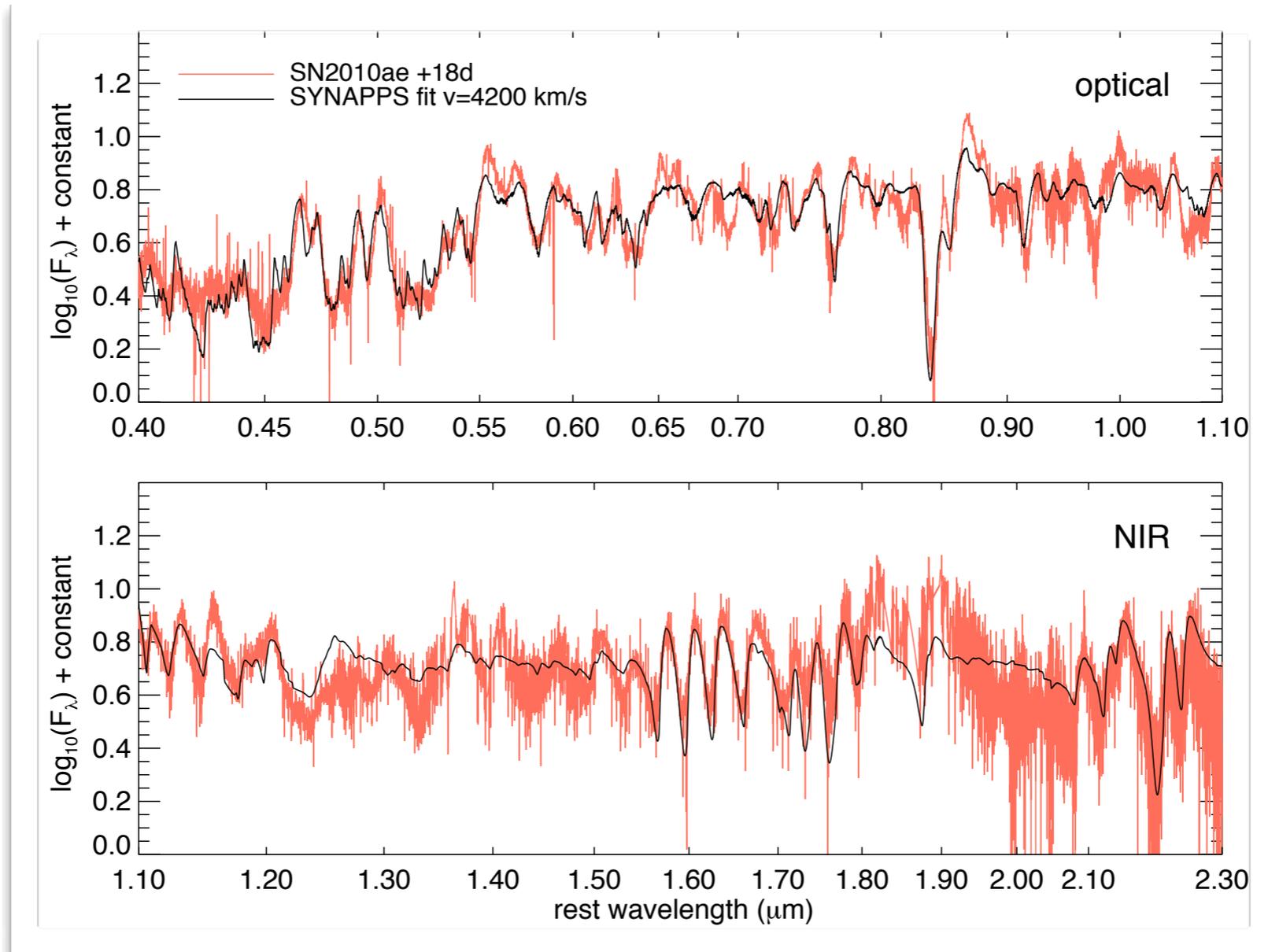
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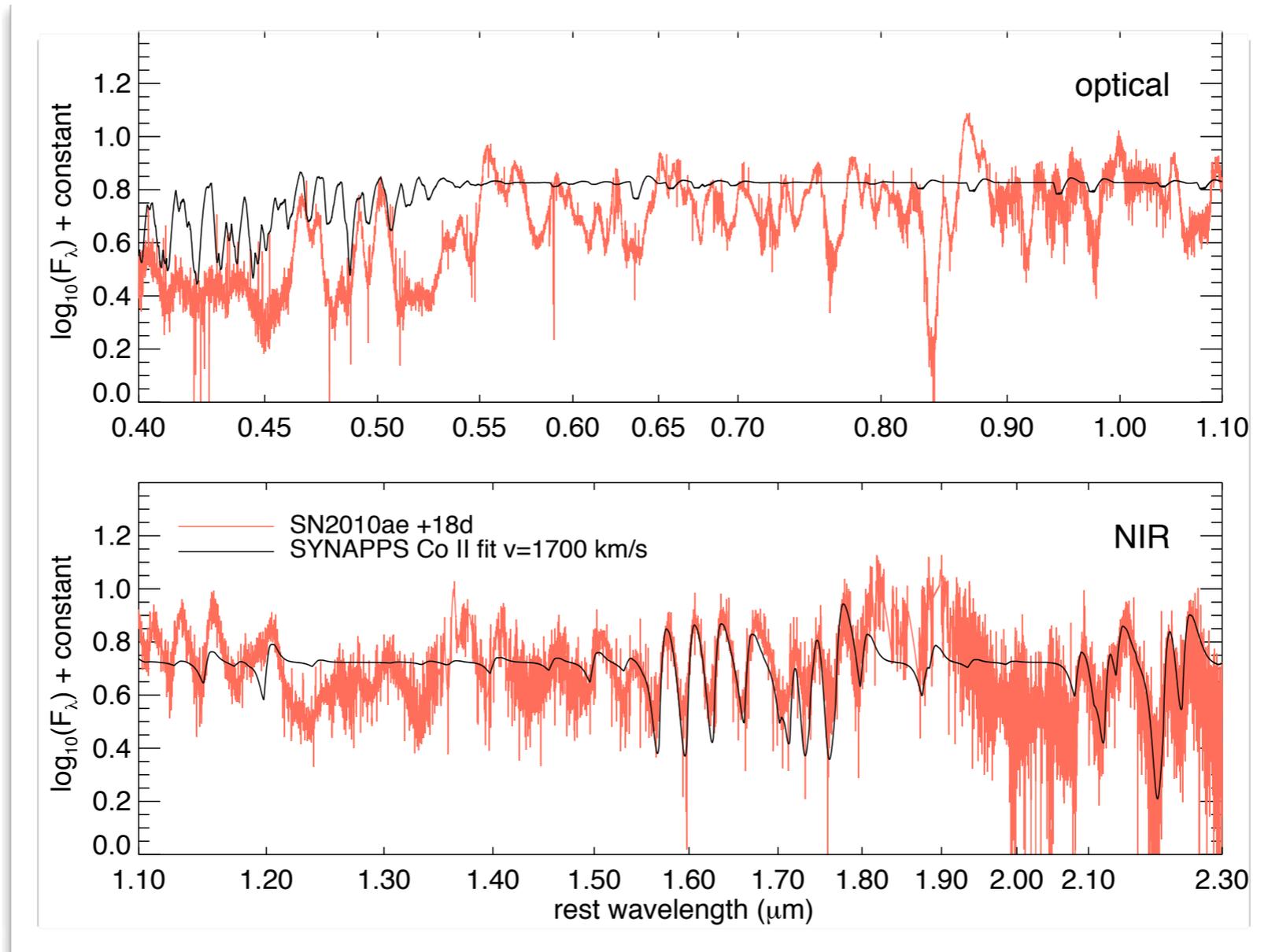
- ▶ NIR Si III consistent
- ▶ Absence of detached Si III may provide temperature diagnostics for the detached layer

O2cx-like: SN2010ae



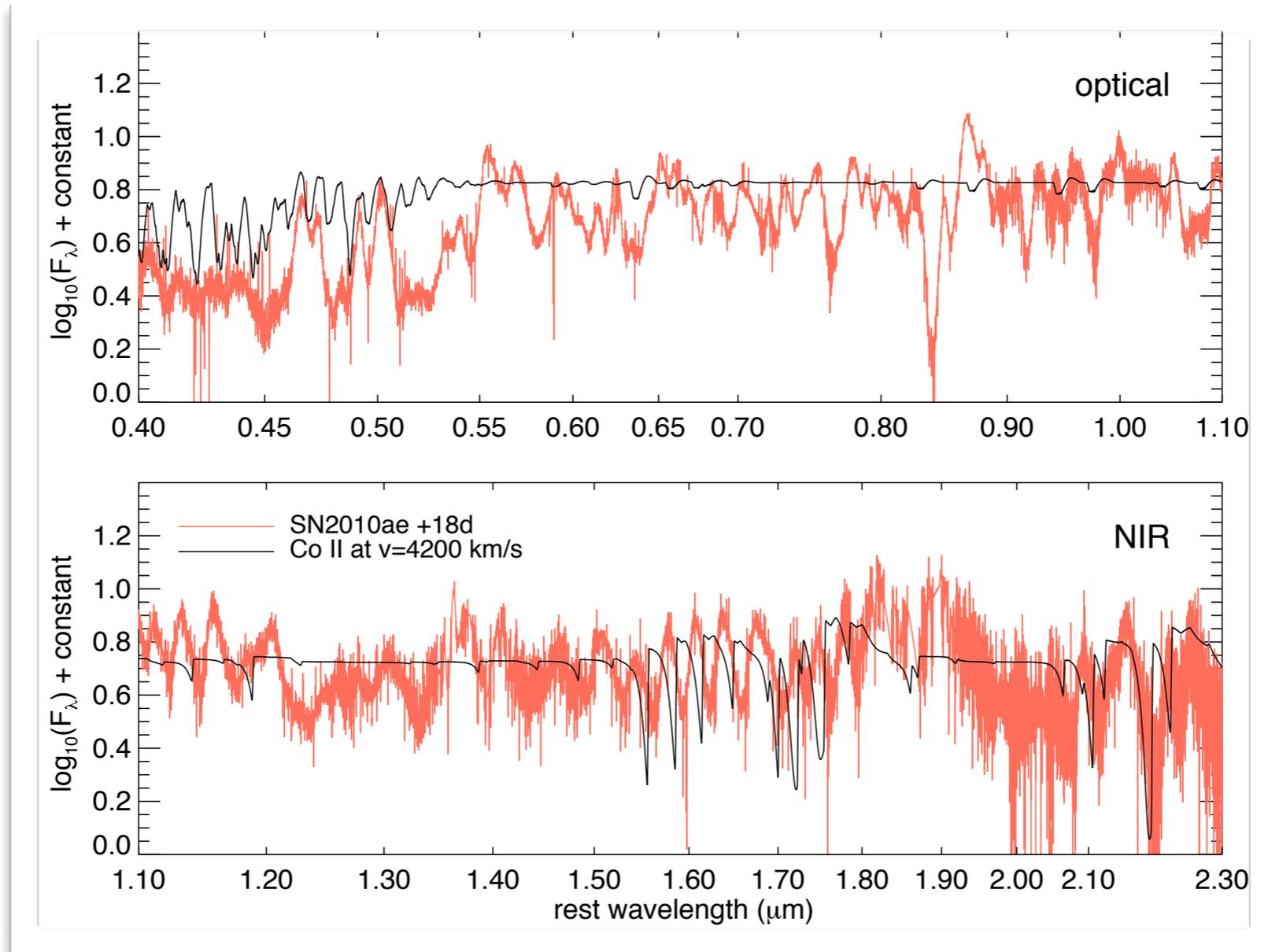
Stritzinger et al in prep

02cx-like: constraints on Co II



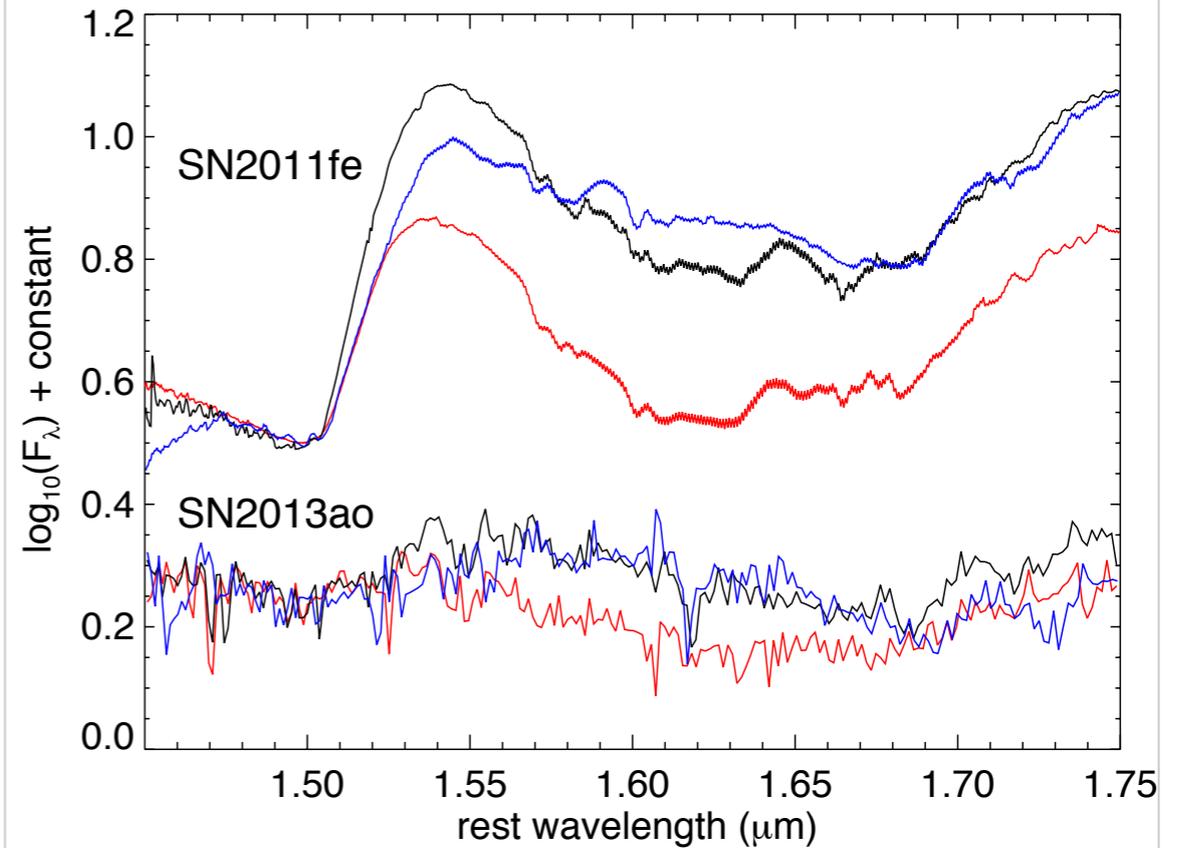
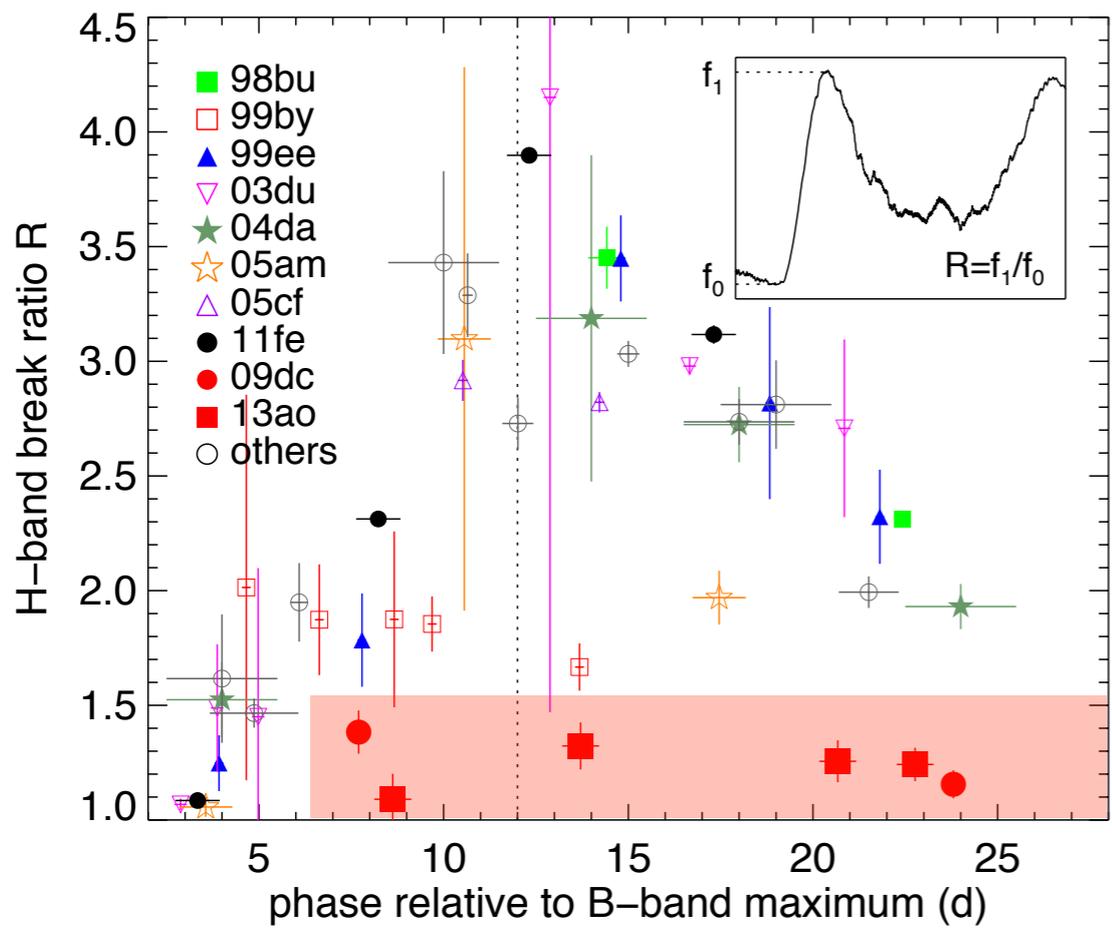
Stritzinger et al in prep

02cx-like: velocity offset

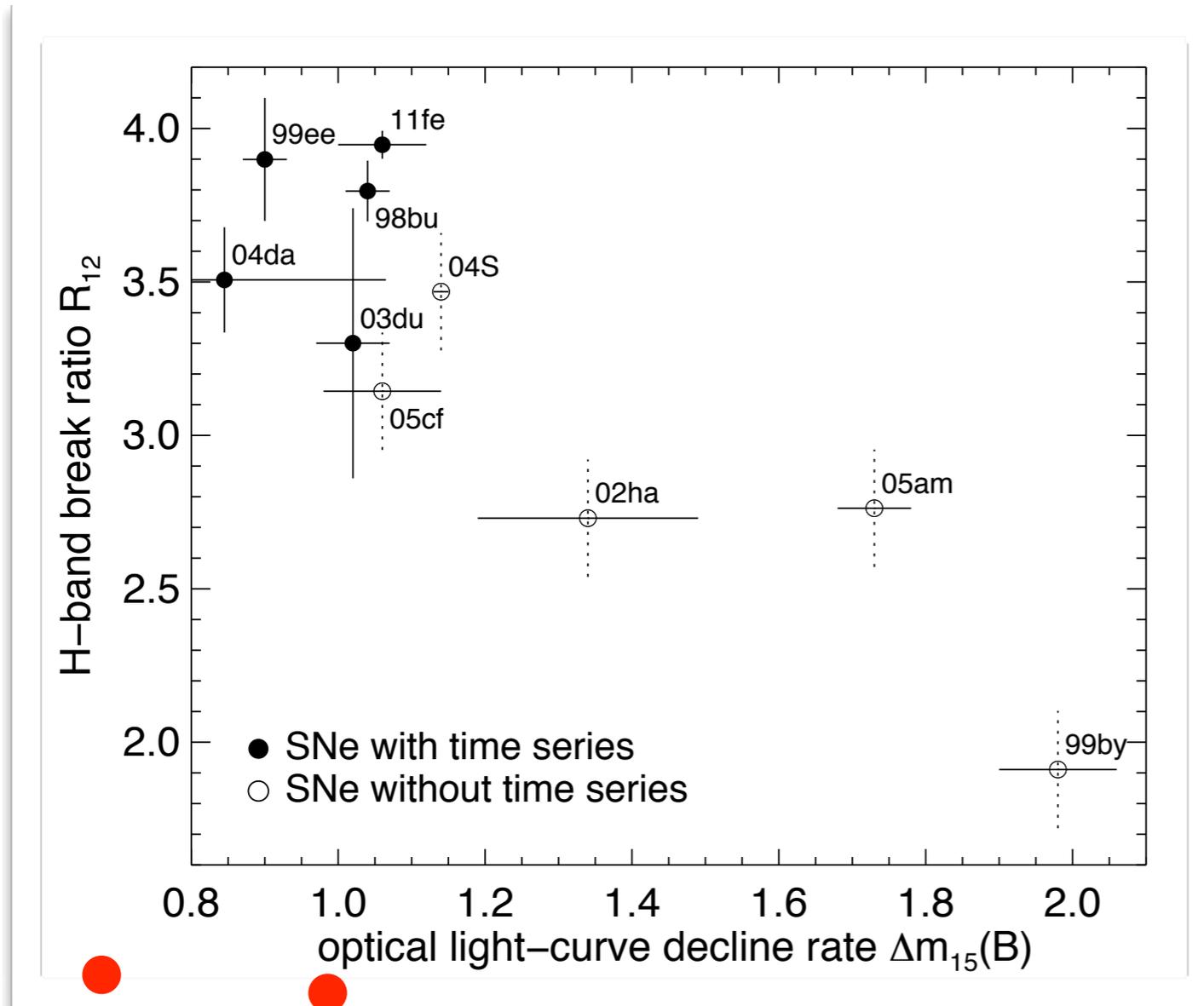


Stritzinger et al in prep

Super-C: NIR H-band break



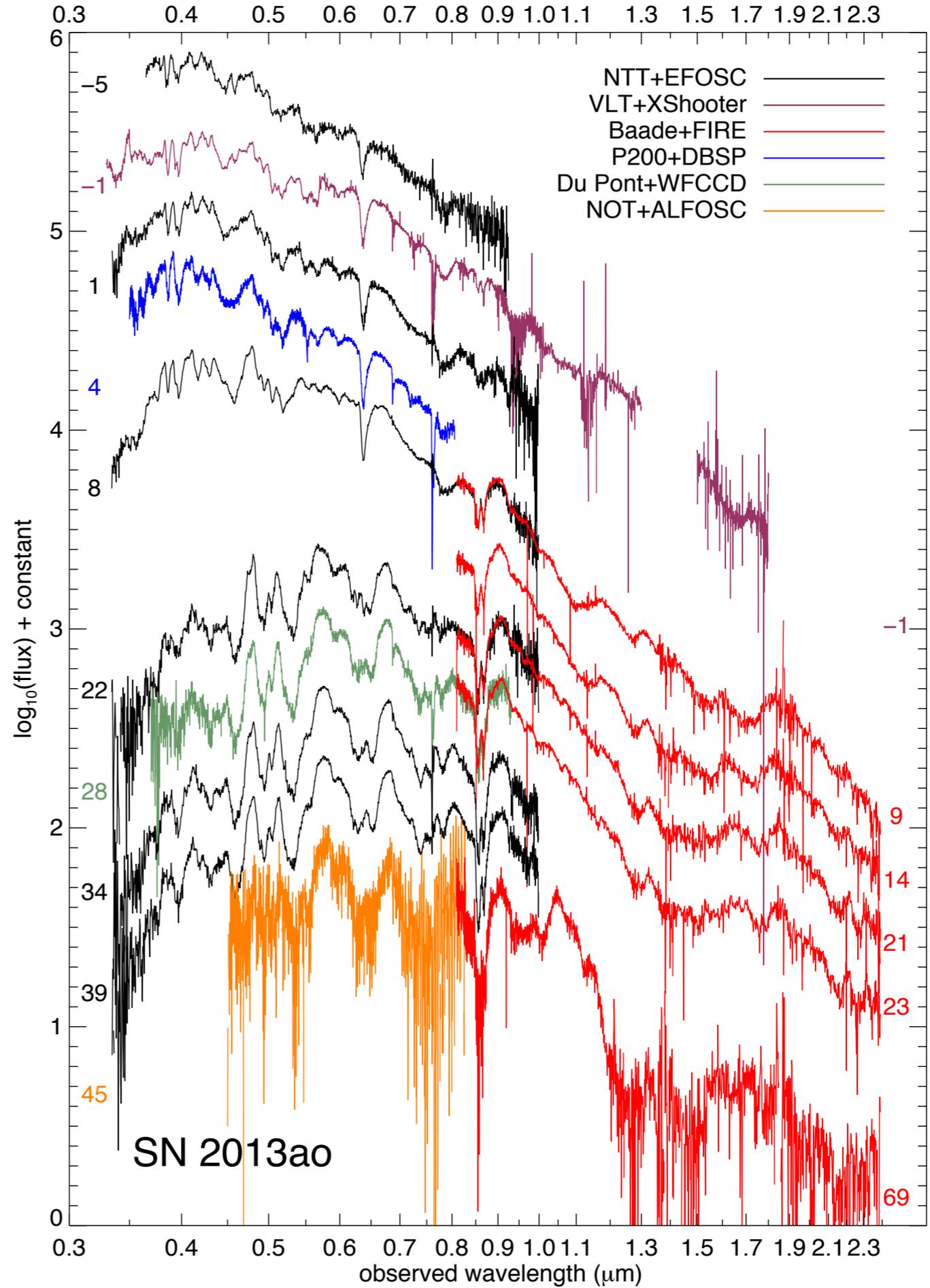
Super-C: NIR H-band break



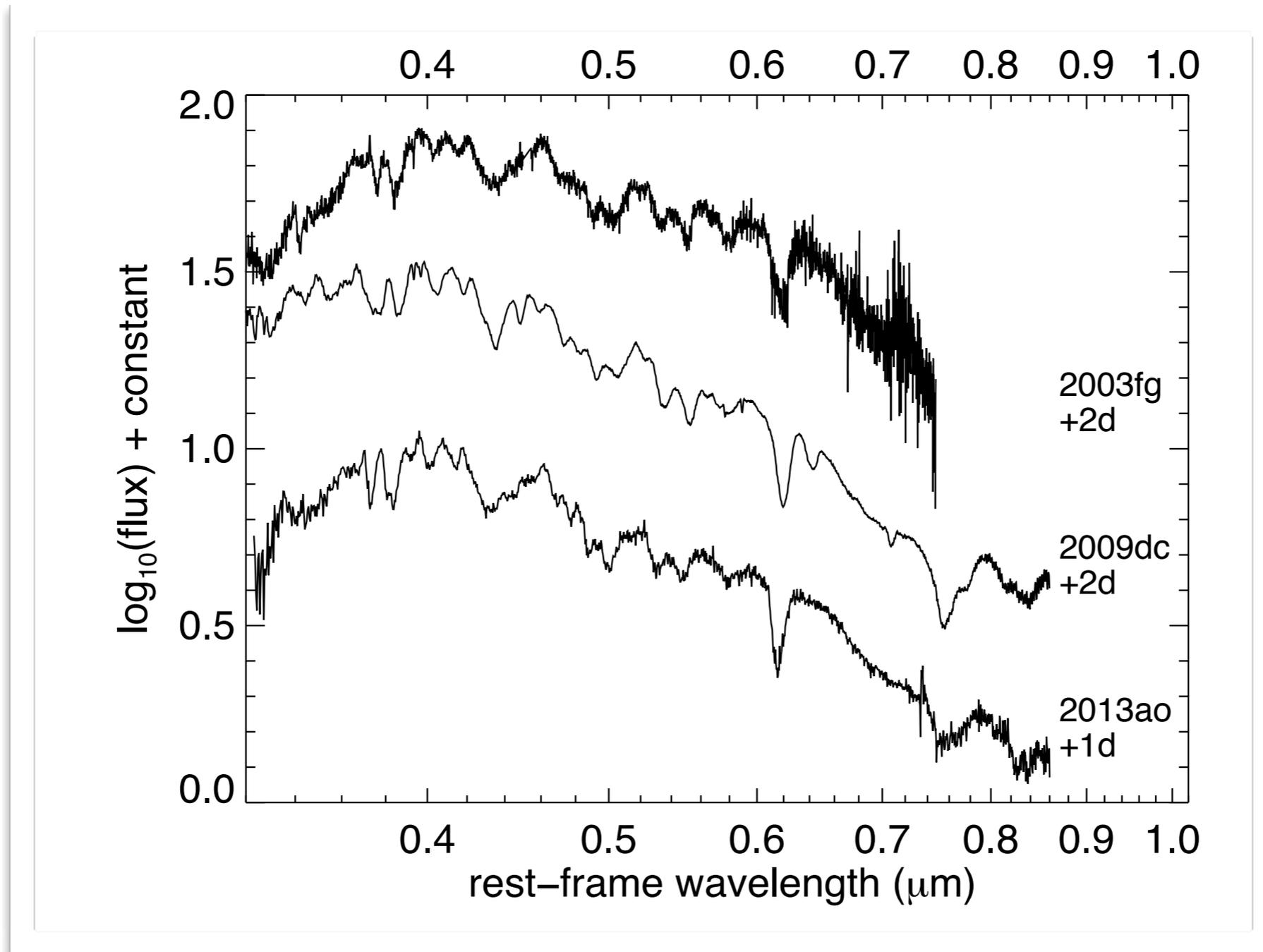
09dc 13ao

- ▶ SNe 2009dc and 2013ao are well off the chart
- ▶ different temperature regime in the Si layer

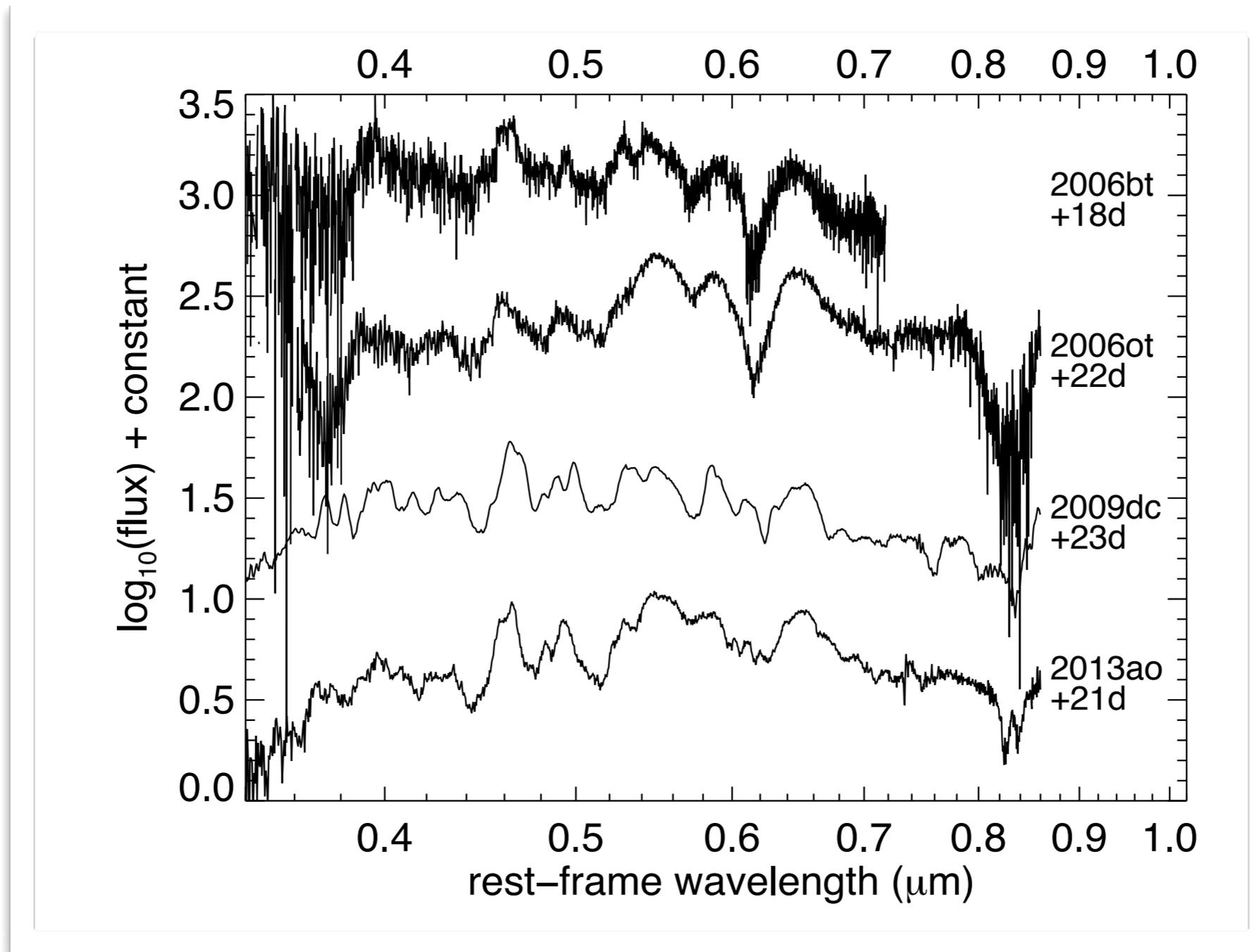
SN2013ao

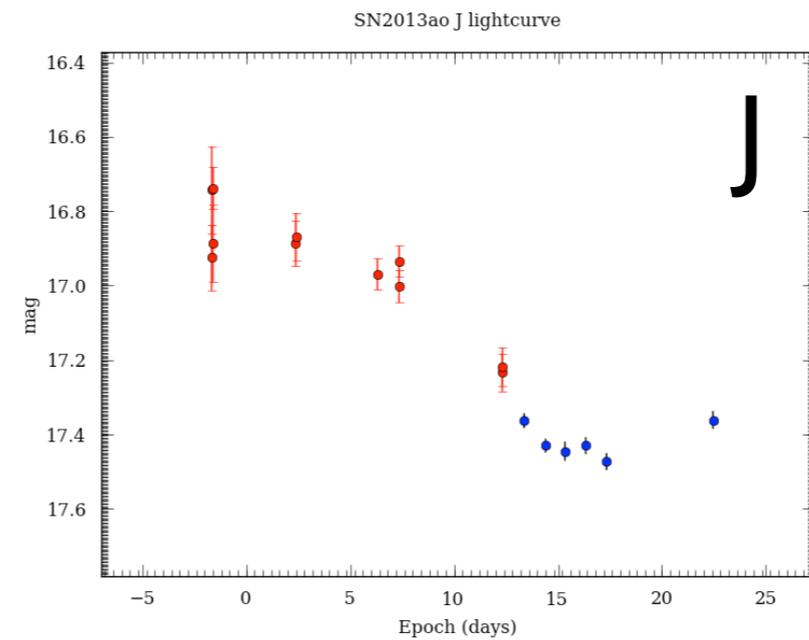
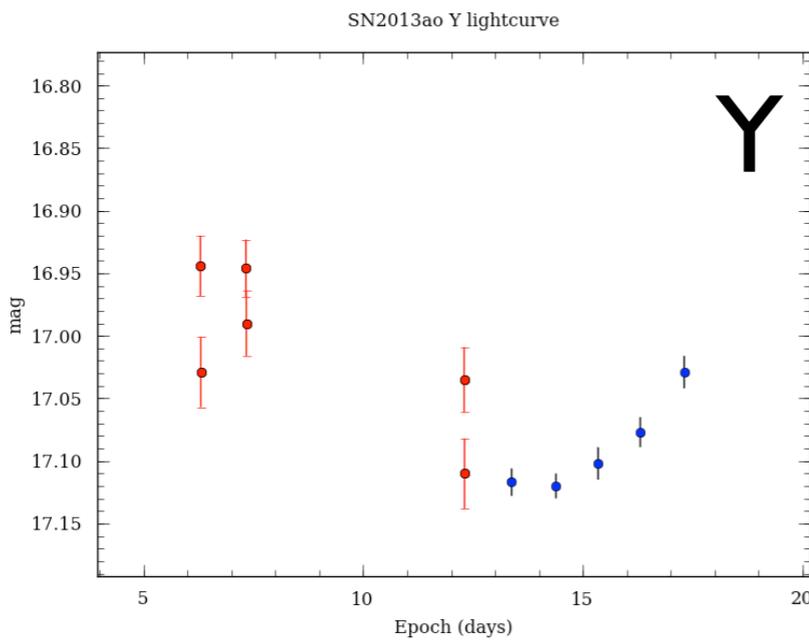
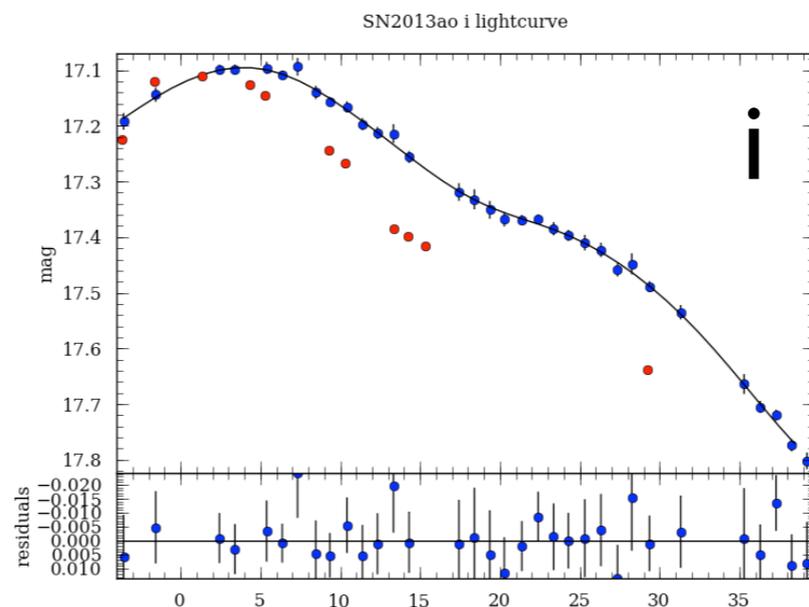
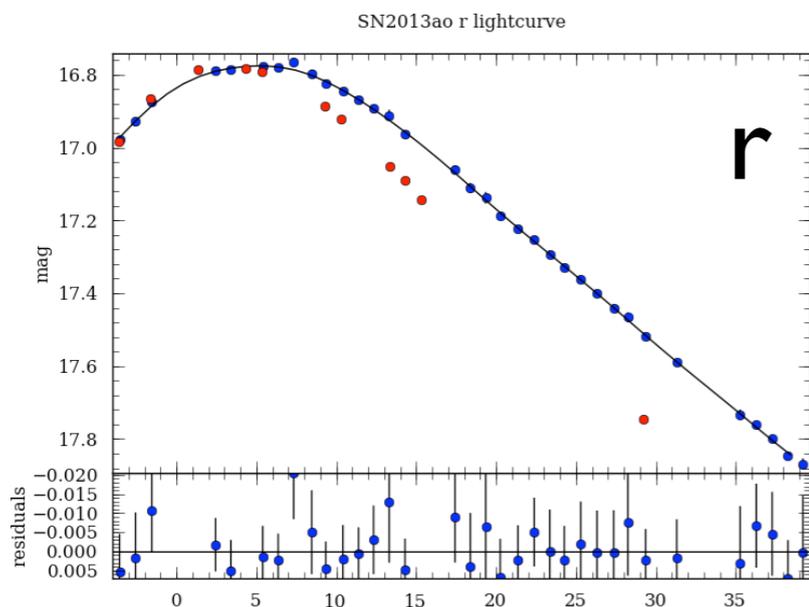
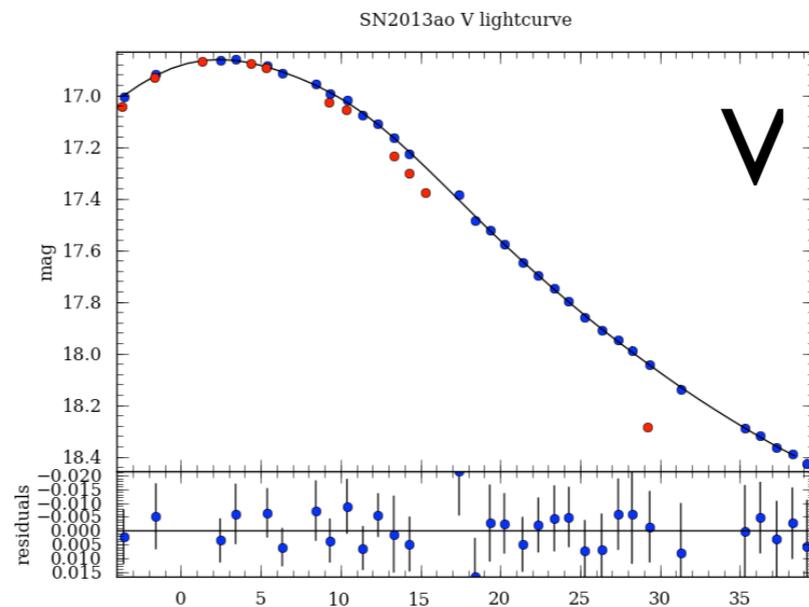
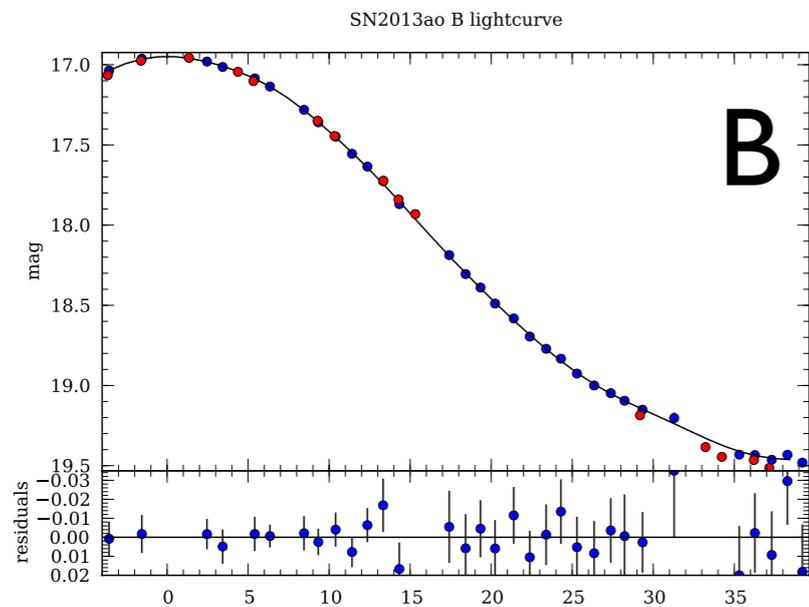


SN2013ao: optical spectra



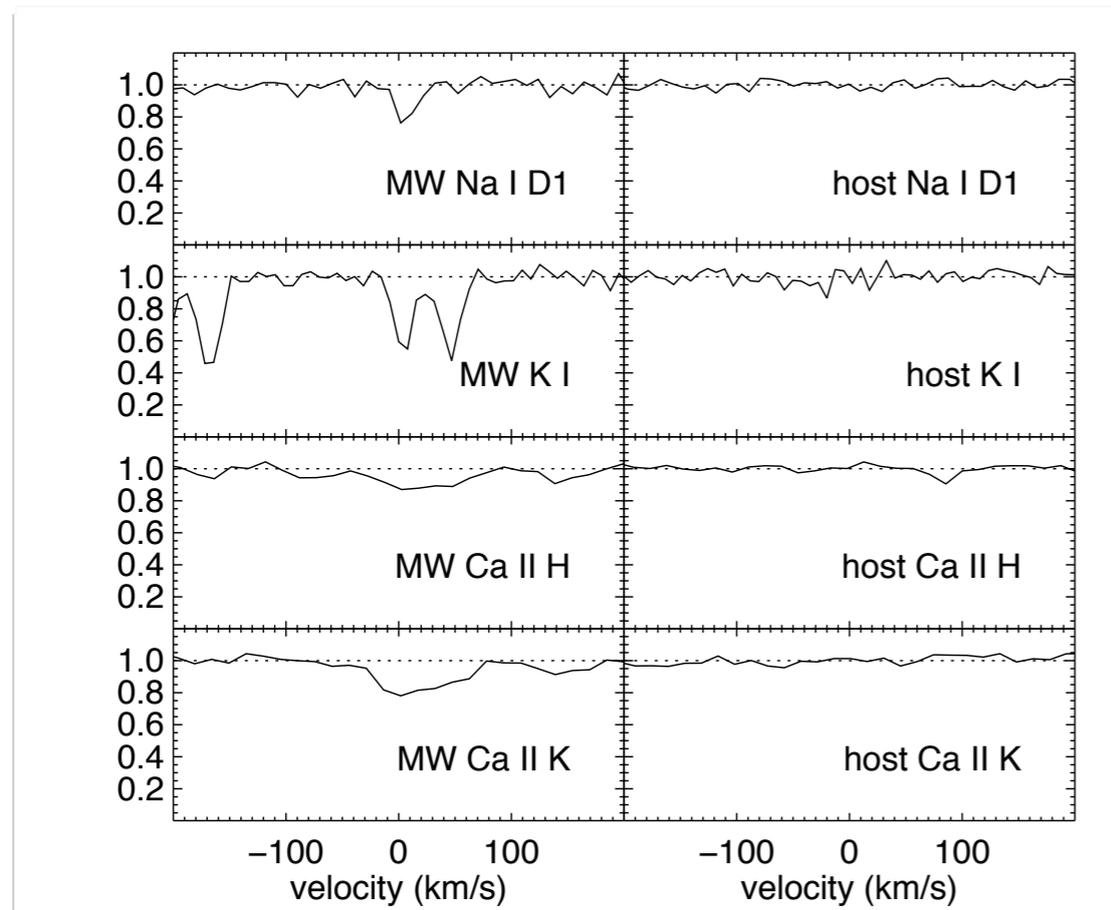
SN2013ao: optical spectra



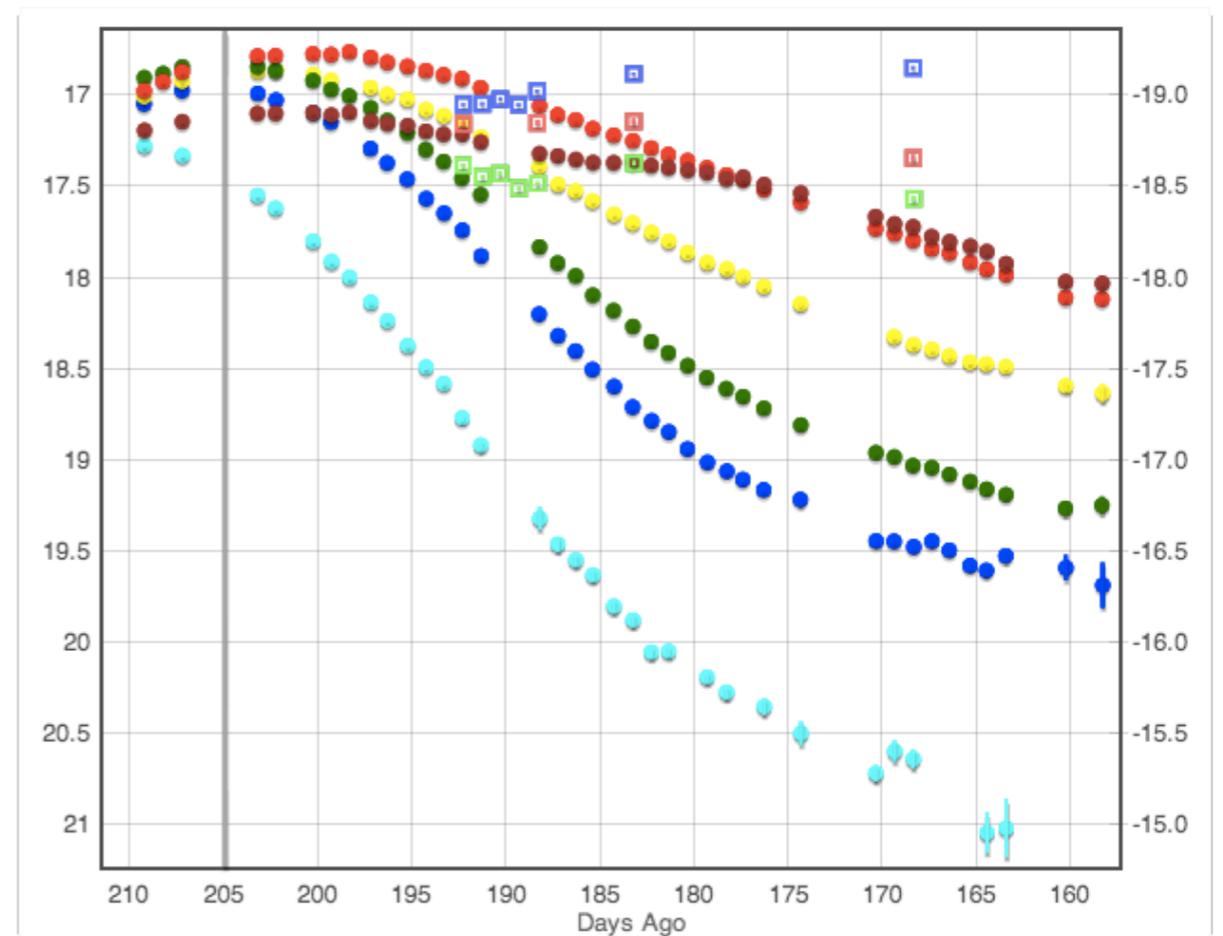


SN2013ao
SN2006bt

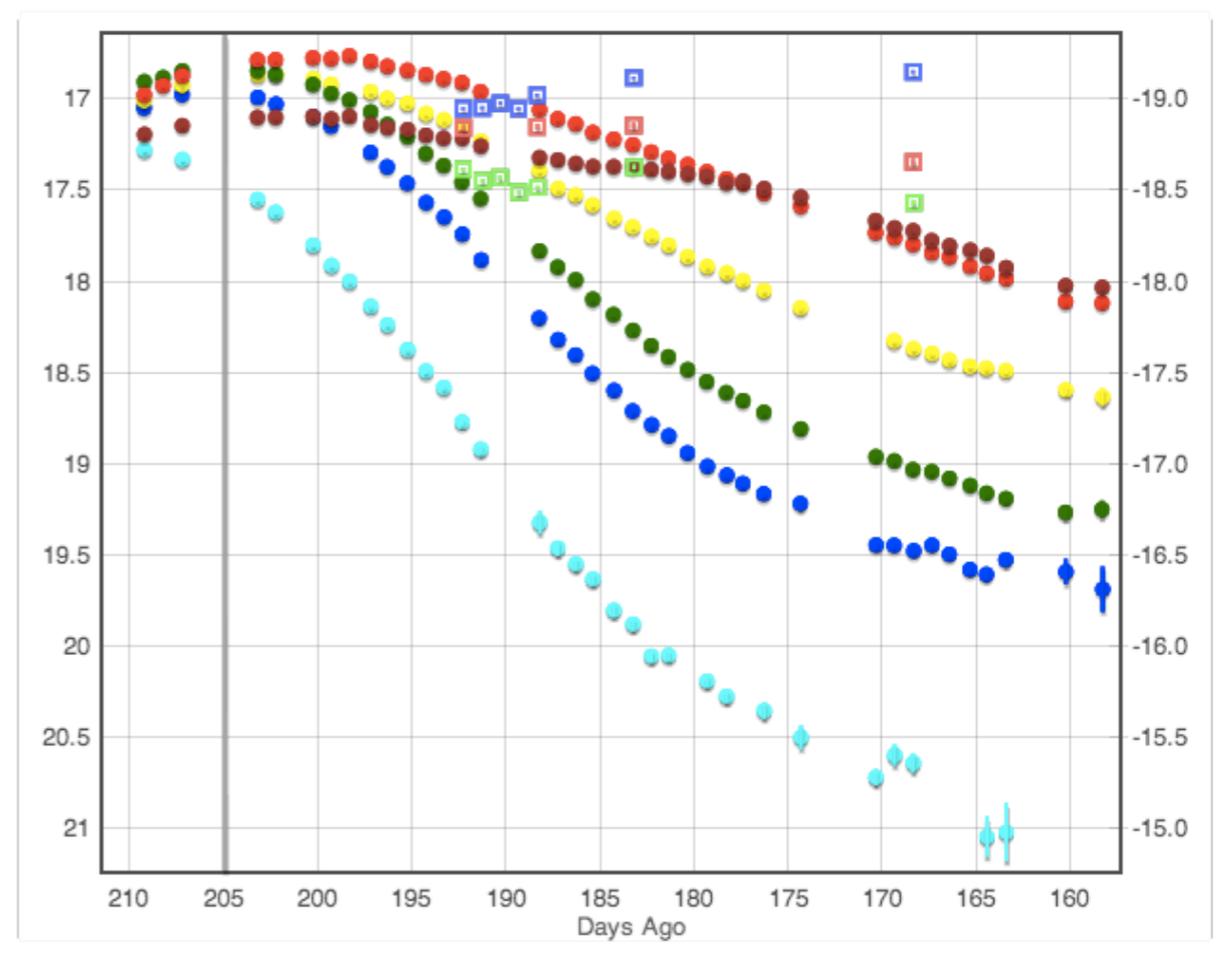
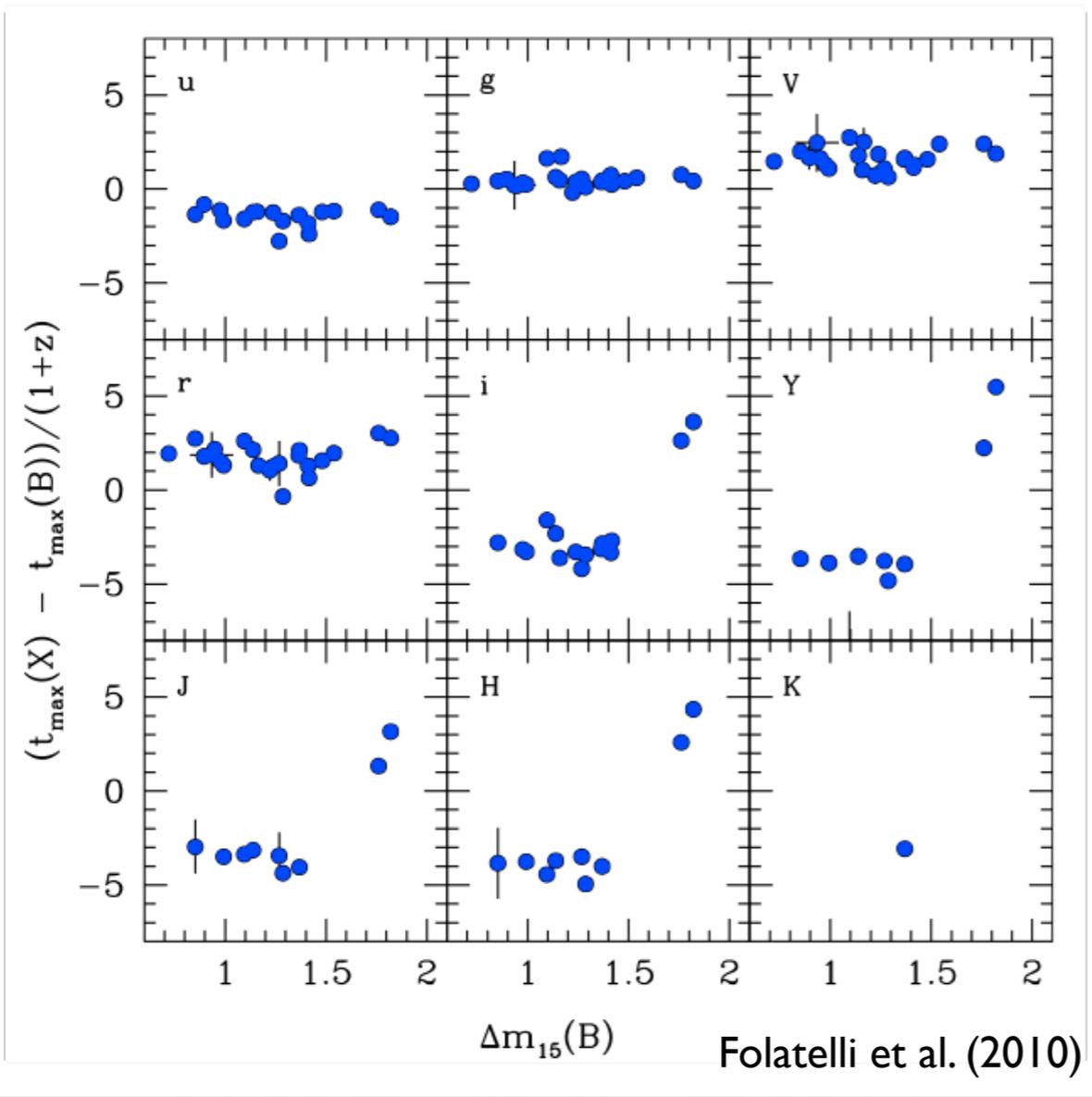
SN2013ao: peak mag



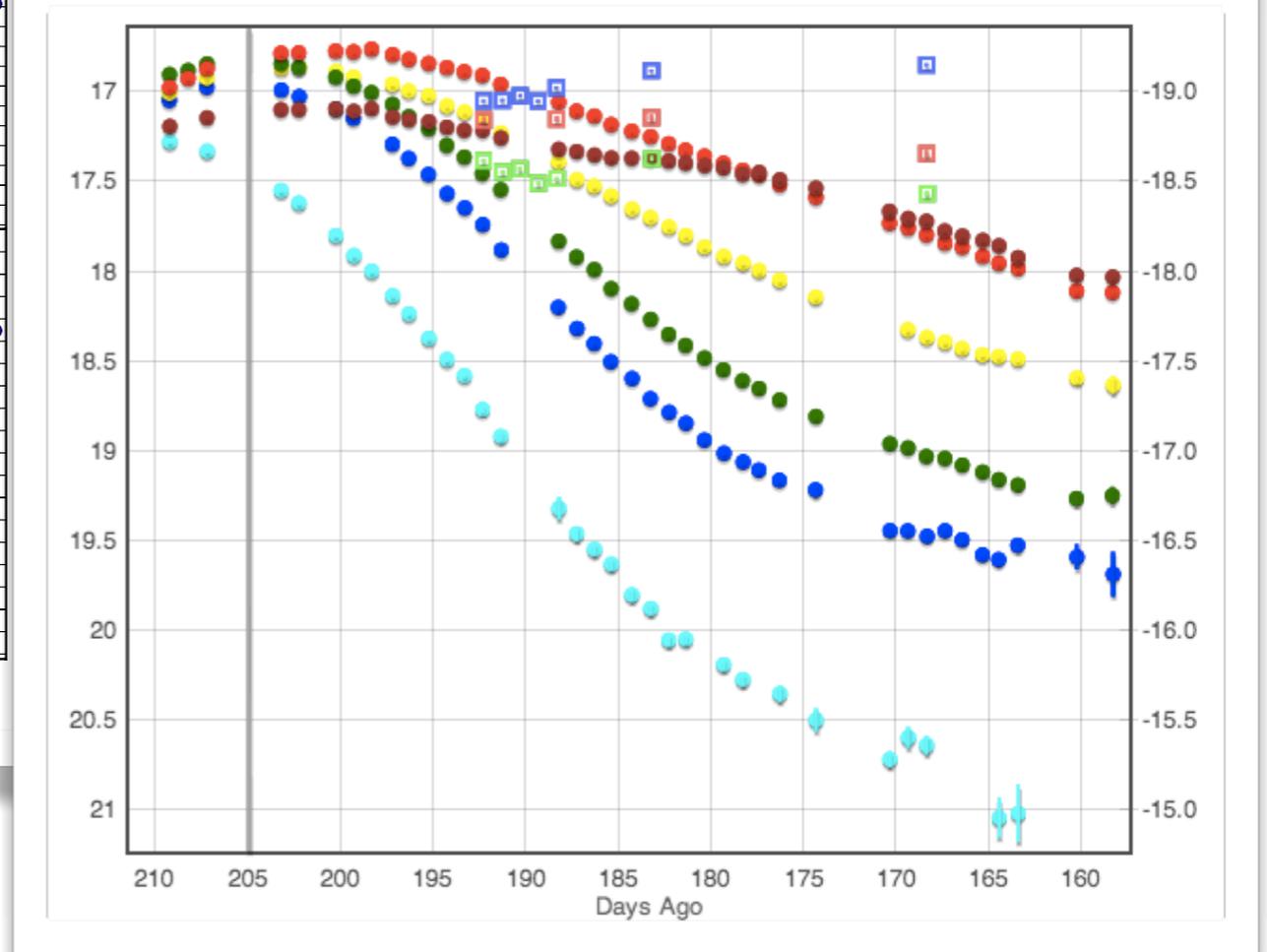
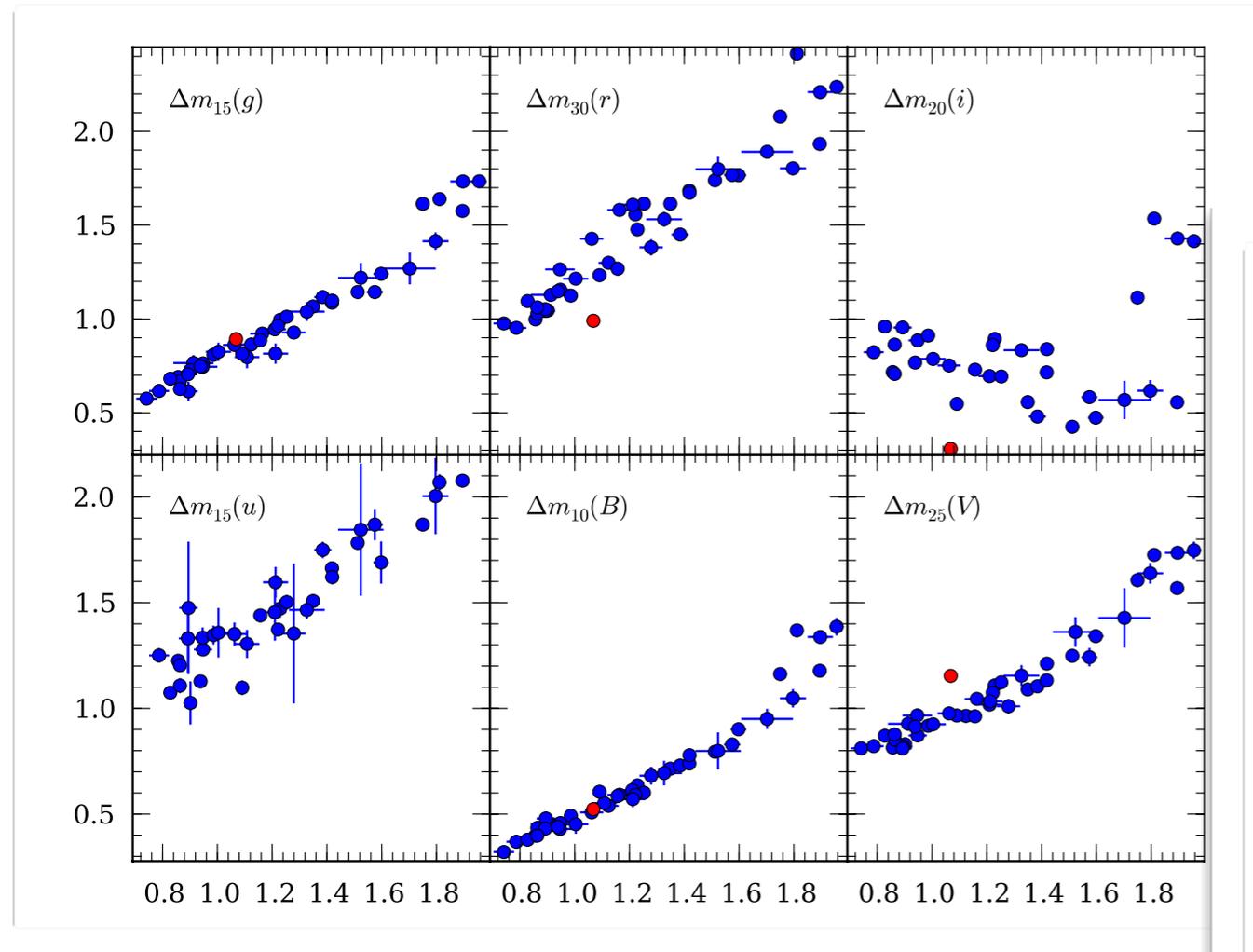
- ▶ much fainter than super-C SNe, such as 03fg, 07if, 09dc



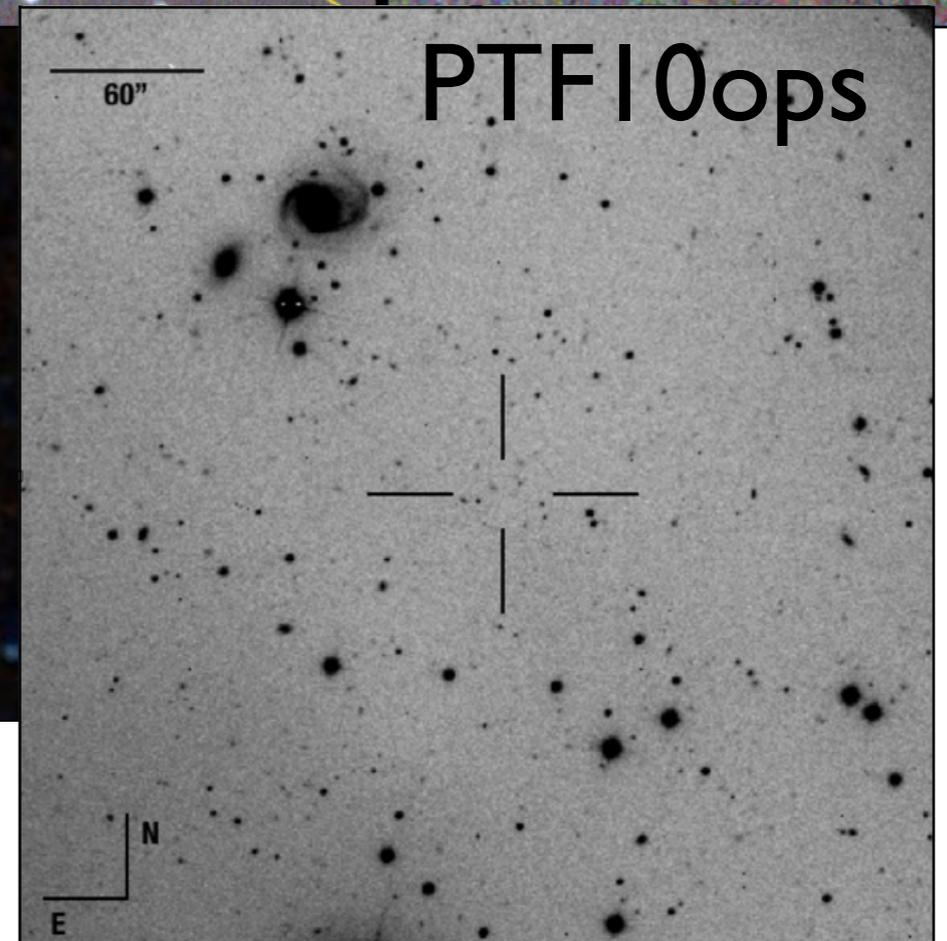
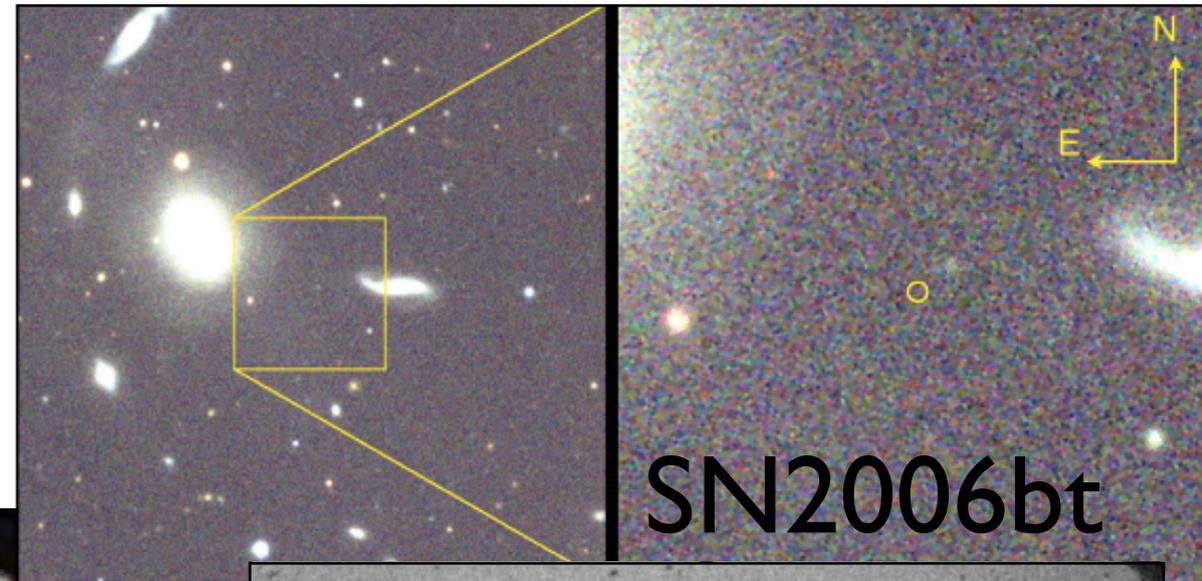
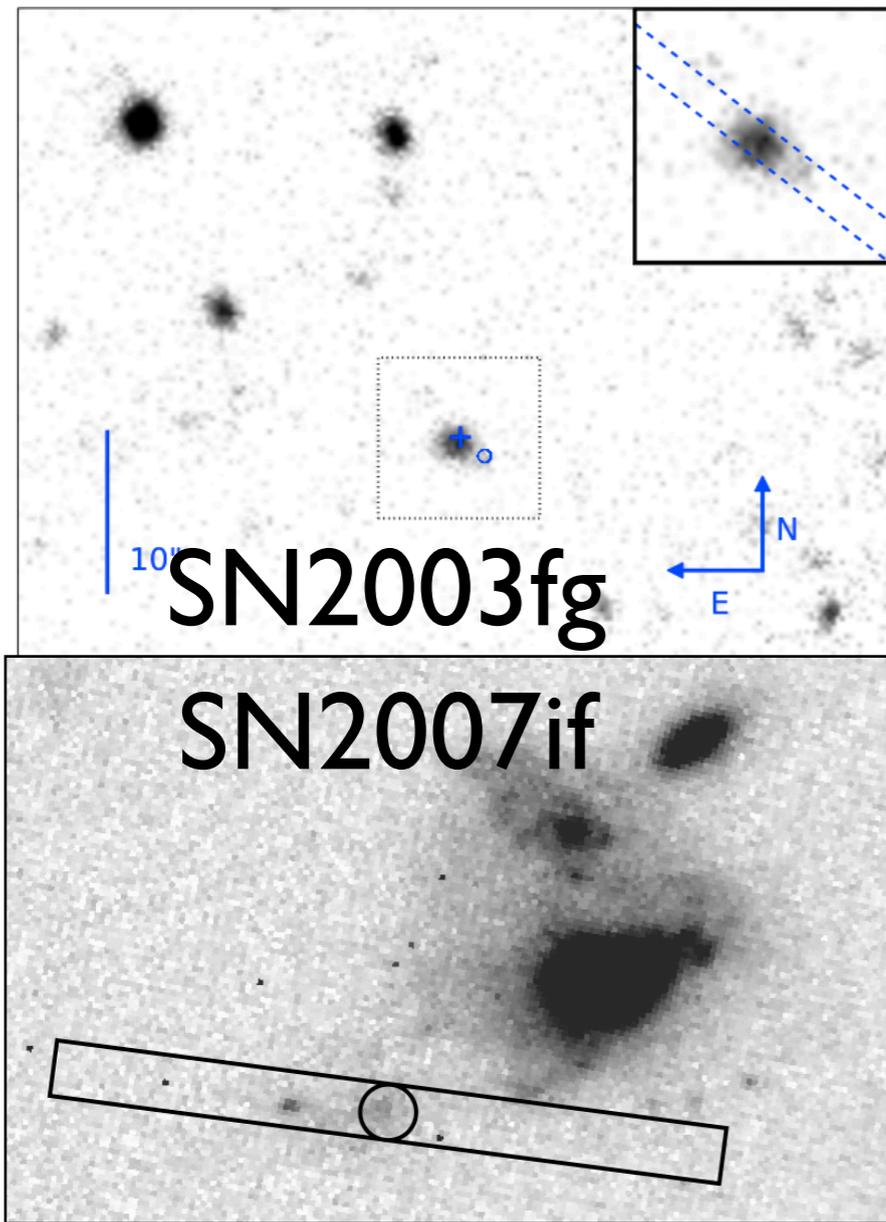
SN2013ao: timing of i-band peak



SN2013ao: broad light curves



SN2013ao: host



SN2013ao: what the heck is it?

	Super-Chandra	SN2013ao	06bt-like
Si II velocity	low	low	normal
C II presence	yes	yes	yes
Ti II presence	no	no	yes
weak H-band break	yes	yes	?
B-band decline rate	~0.7	1.1	1.1
weak i-band 2nd max	yes	yes	yes
timing of i-band 1st max	after B max	after B max	after B max?
V-band peak mag	~< -20	-19.3	> -19.3
Host characteristic	low luminosity	low luminosity	no host or large separation