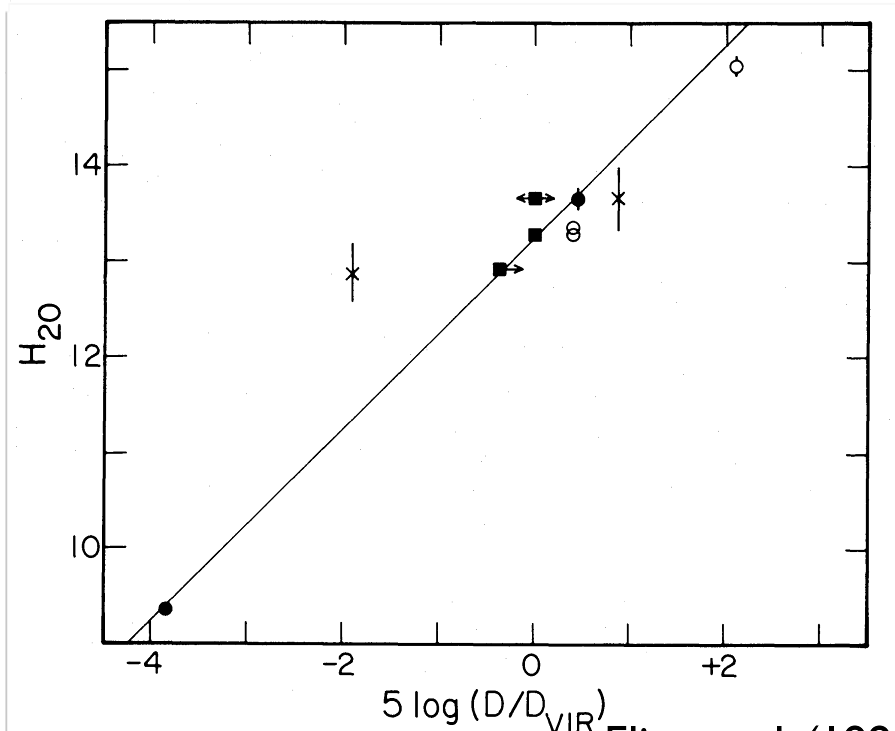
The best-damn NIR time-series spectroscopy of a SN Ia

THE EARLIEST NEAR-INFRARED TIME-SERIES SPECTROSCOPY OF A TYPE Ia SUPERNOVA

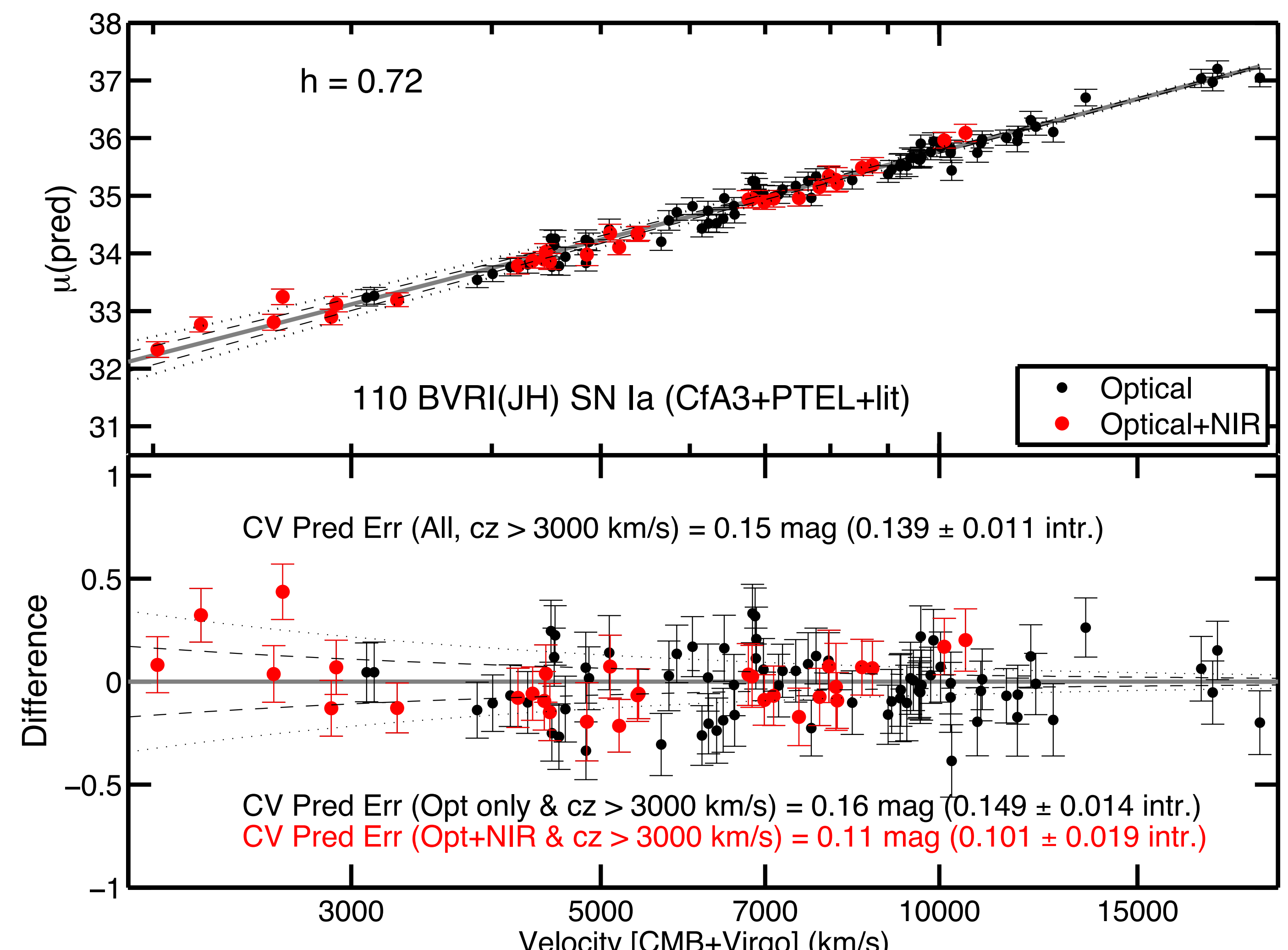
E. Y. HSIAO[1], G. H. MARION[2], M. M. PHILLIPS[1], C. R. BURNS[3], C. WINGE[4], N. MORRELL[1], C. CONTRERAS[1], W. L. FREEDMAN[3], M. KROMER[5], E. E. E. GALL[5,6], C. L. GERARDY[7], P. HÖFLICH[7], M. IM[8], Y. JEON[8], R. P. KIRSHNER[2], P. E. NUGENT[9,10], S. E. PERSSON[3], G. PIGNATA[11], M. ROTH[1], V. STANISHEV[12], M. STRITZINGER[13], N. B. SUNTZEFF[14]

CSP II NIR spectroscopy

Why NIR?



Elias et al. (1985)



Mandel et al. (2011)

Why NIR spec?

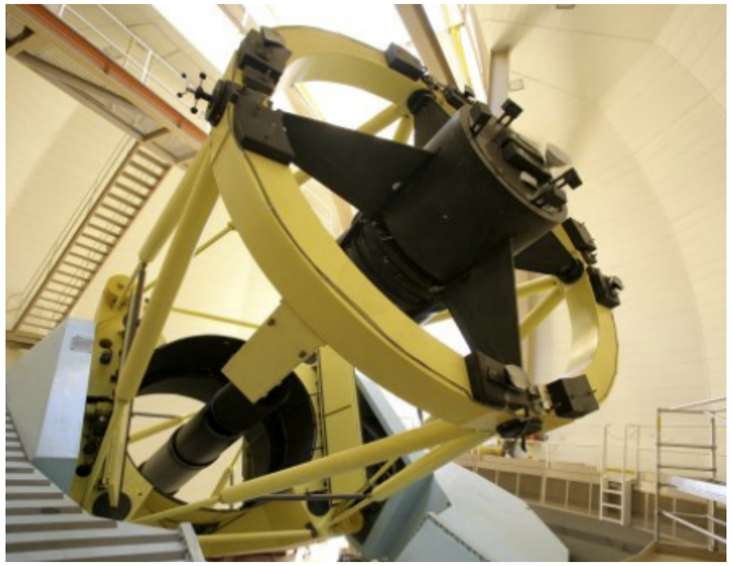
- cosmological utility
  - k-correction errors need to be minimized/understood

- physical diagnostics
  - probe of primordial material
  - accurate 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

CSP2: observing strategy

- 5 years, ~150 SNe Ia in total, 5 SNe/month
- each year: 6 months centered on summer (75% photometric nights)
- each month at the end of dark run:
  - 1 nights of spec screening
  - 6 nights YJH imaging: 2.5-m du Pont+RetroCam
  - nightly uBVgri imaging: 1-m Swope+e2v CCD
  - 3+ nights NIR spectroscopy



CSP2: NIR spectroscopy

- 6.5-m Baade + FIRE
  3+ nights/month
  CSP, CfA(Kirshner, Marion),
  Australia (Lidman), Chile (Förster)

- 8.1-m Gem-N + GNIRS
  3 hours/month
  GNIRS is kaput...

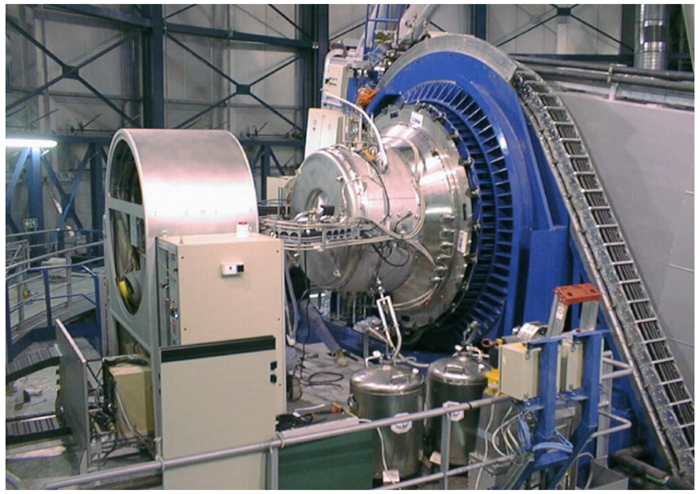
- 8.1-m Gem-S + FLAMINGOS-2
  FLAMINGOS-2 is kaput...

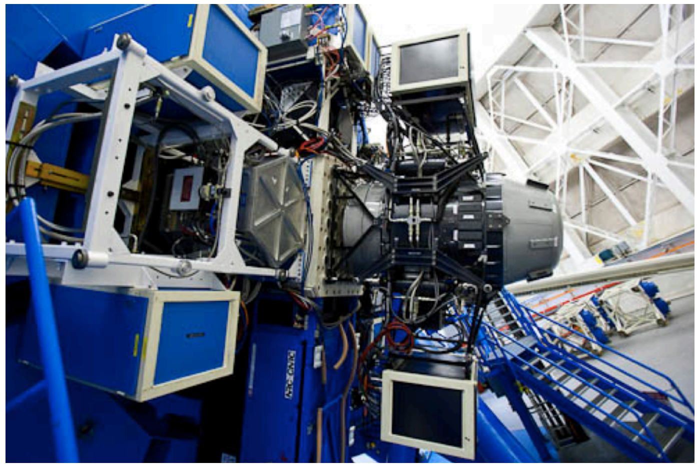
- 8.2-m VLT + ISAAC
  3 hours/month
  through Stritzinger, not continued

- 3.6-m NTT + SofI
  through PESSTO

- 3.0-m IRTF + SpeX
  through Marion et al., 2013A?

- 8.2-m Subaru + IRCS
  nebular phase, through Maeda et al.

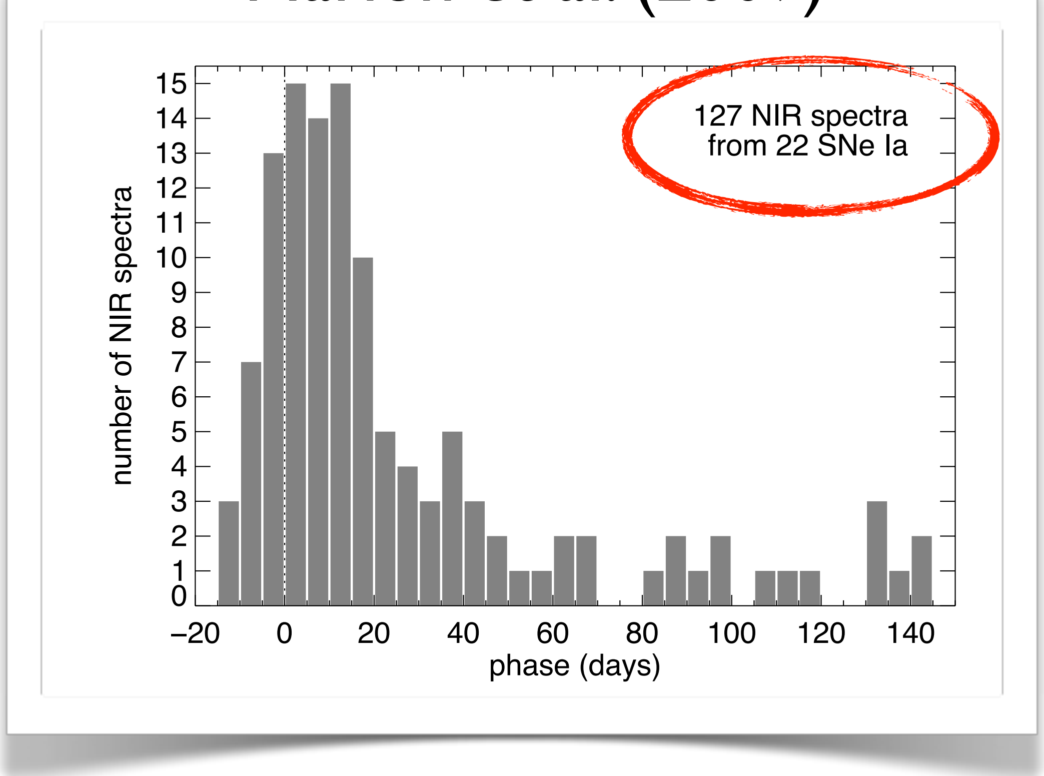


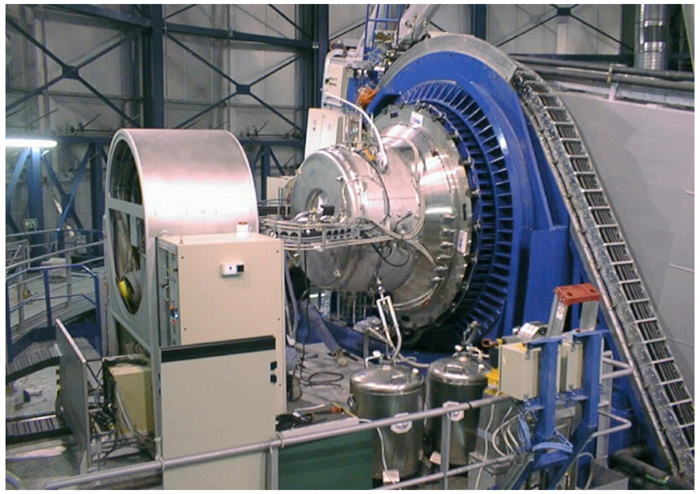


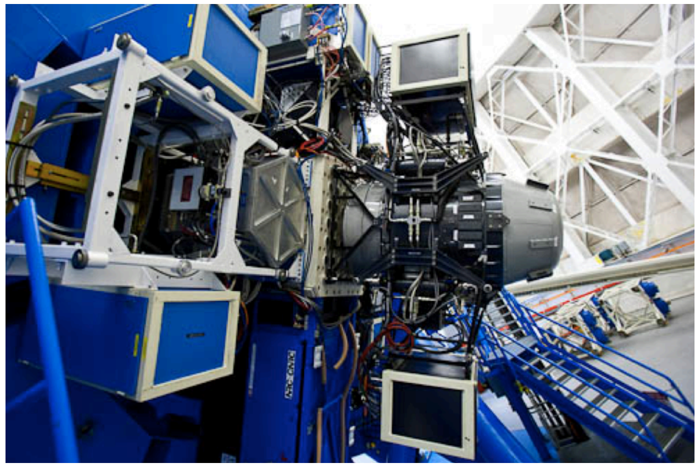
CSP2: NIR spectroscopy

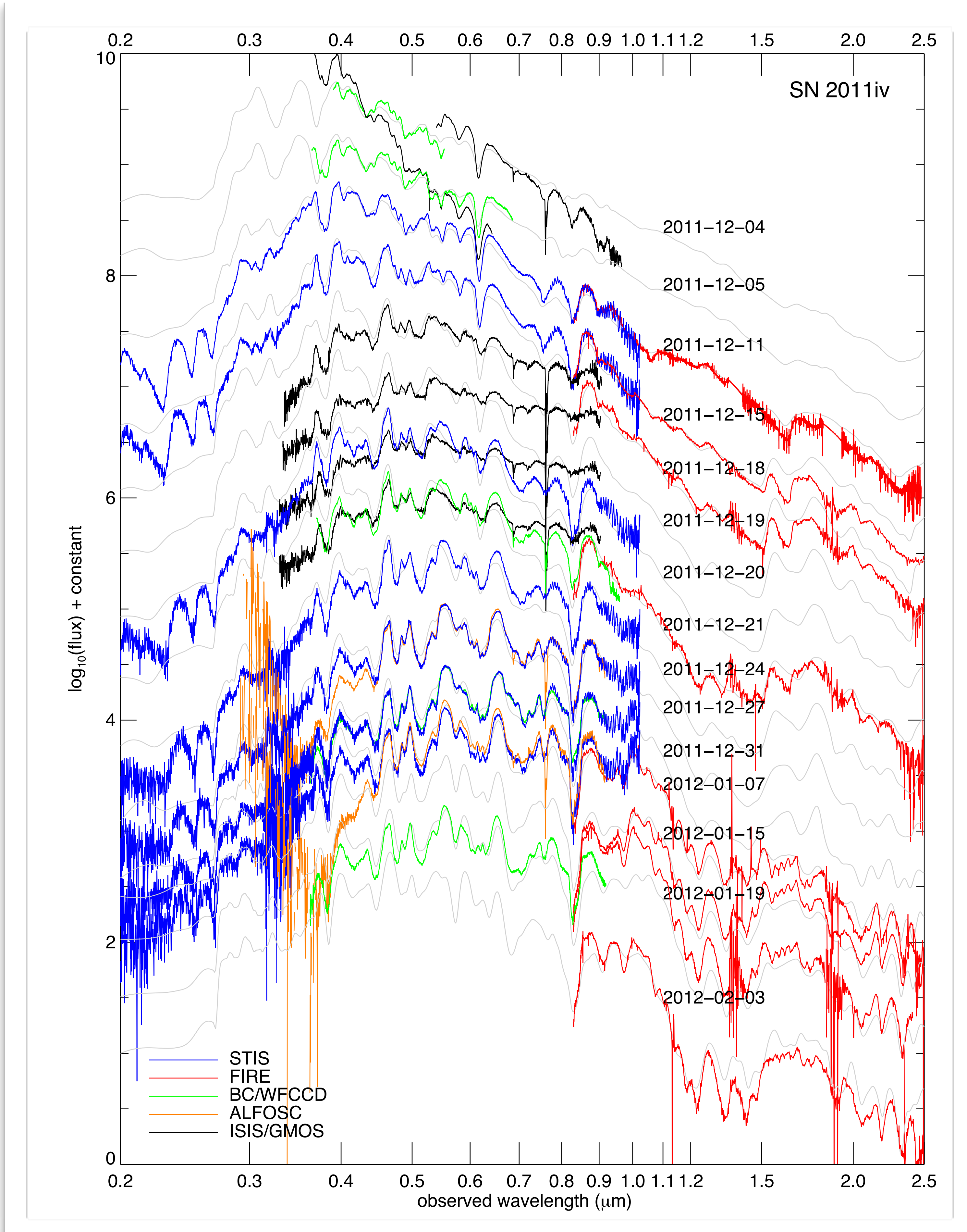
- time series
- accompanying opt/NIR LCs
- simultaneous optical spectra
- Hubble flow objects

Year 1 already tripled Marion et al. (2009)





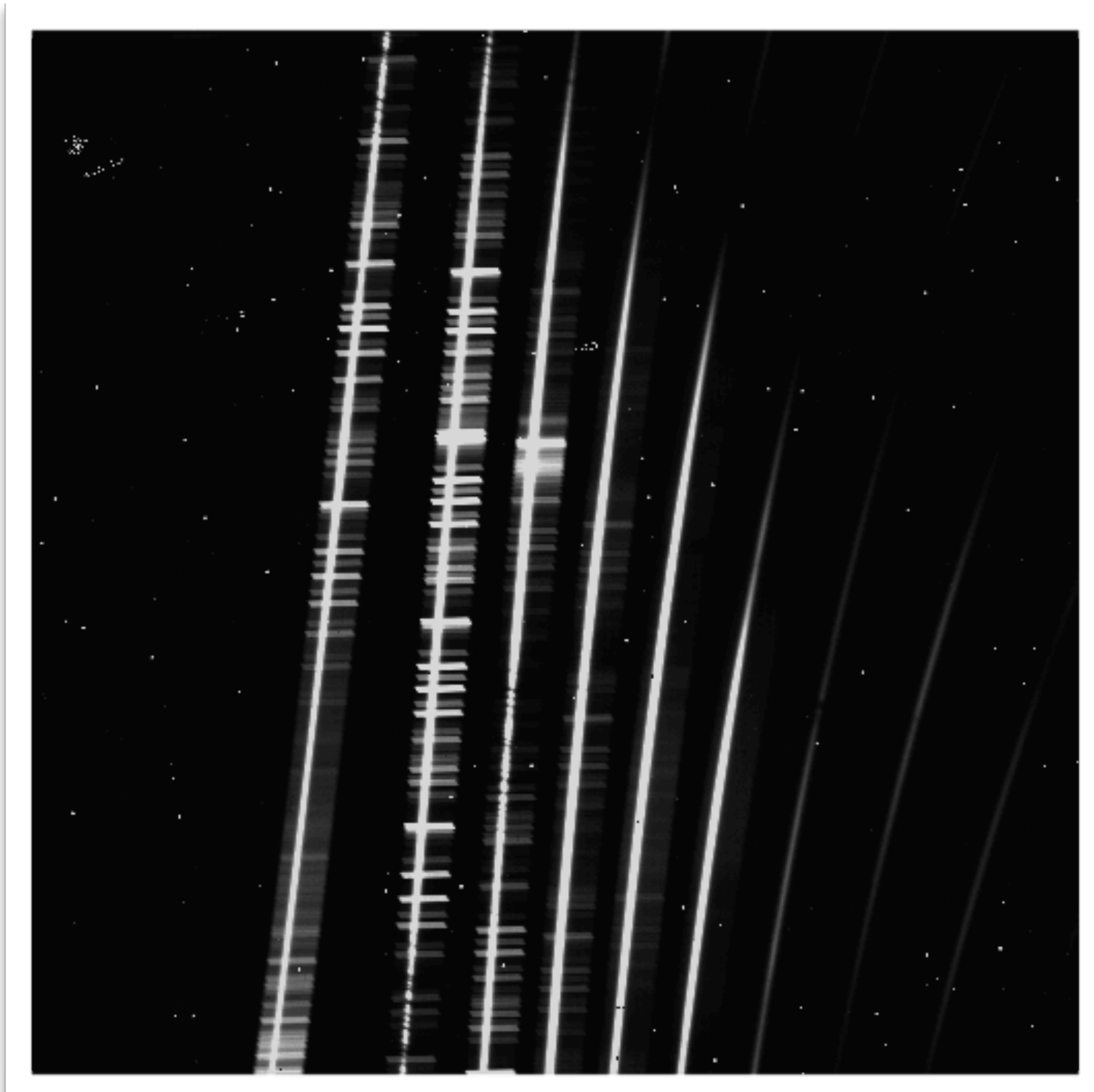



SN 2011iv
2011–12–04
2011–12–05
2011–12–11
2011–12–15
2011–12–18
2011–12–19
2011–12–20
2011–12–21
2011–12–24
2011–12–27
2011–12–31
2012–01–07
2012–01–15
2012–01–19
2012–02–03
STIS
FIRE
BC/WFCCD
ALFOSC
ISIS/GMOS
log10(flux) + constant
observed wavelength (μm)

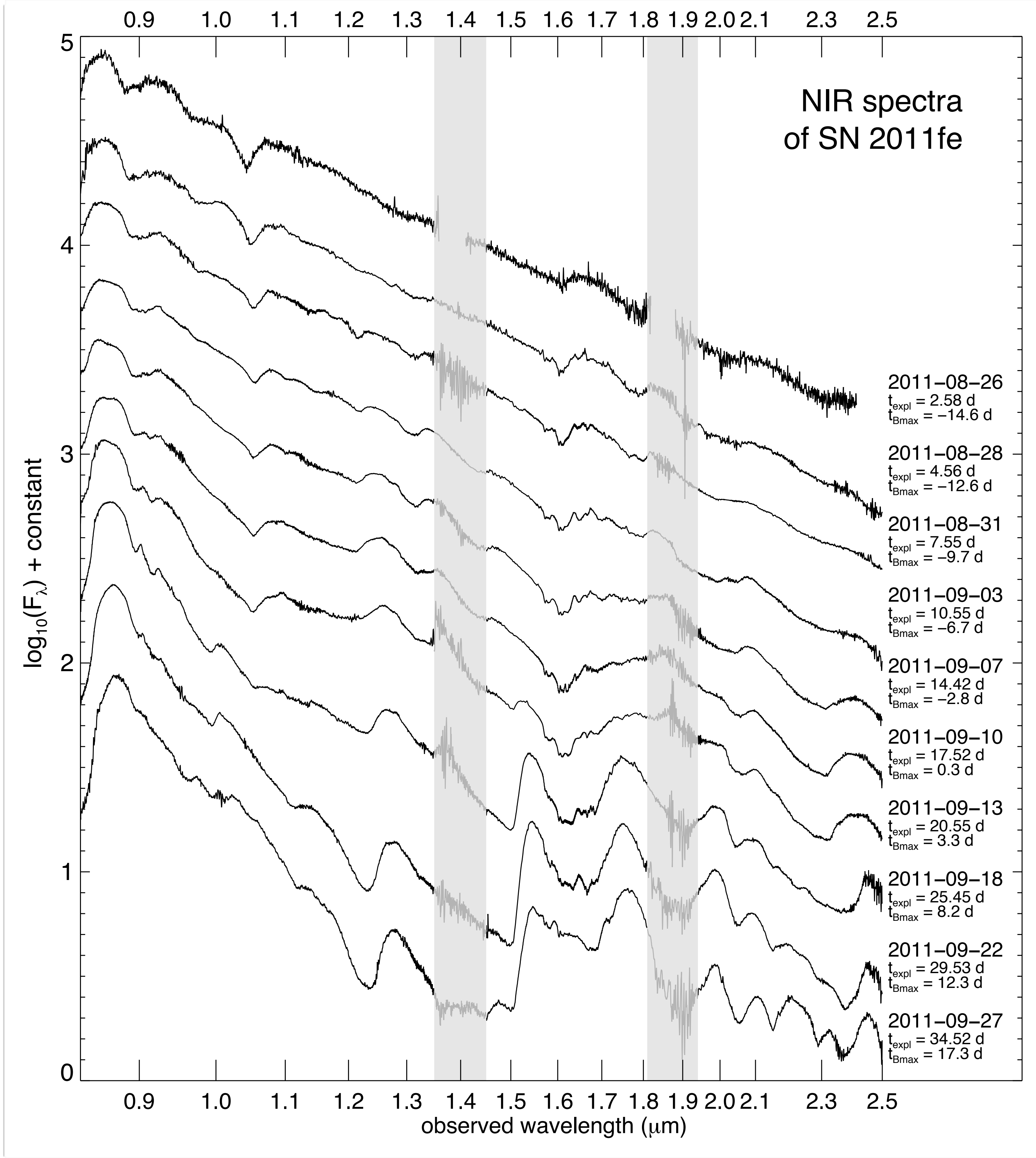
- SN 2011iv

NIR spectra of SN2011fe

GNIRS observations of SN2011fe

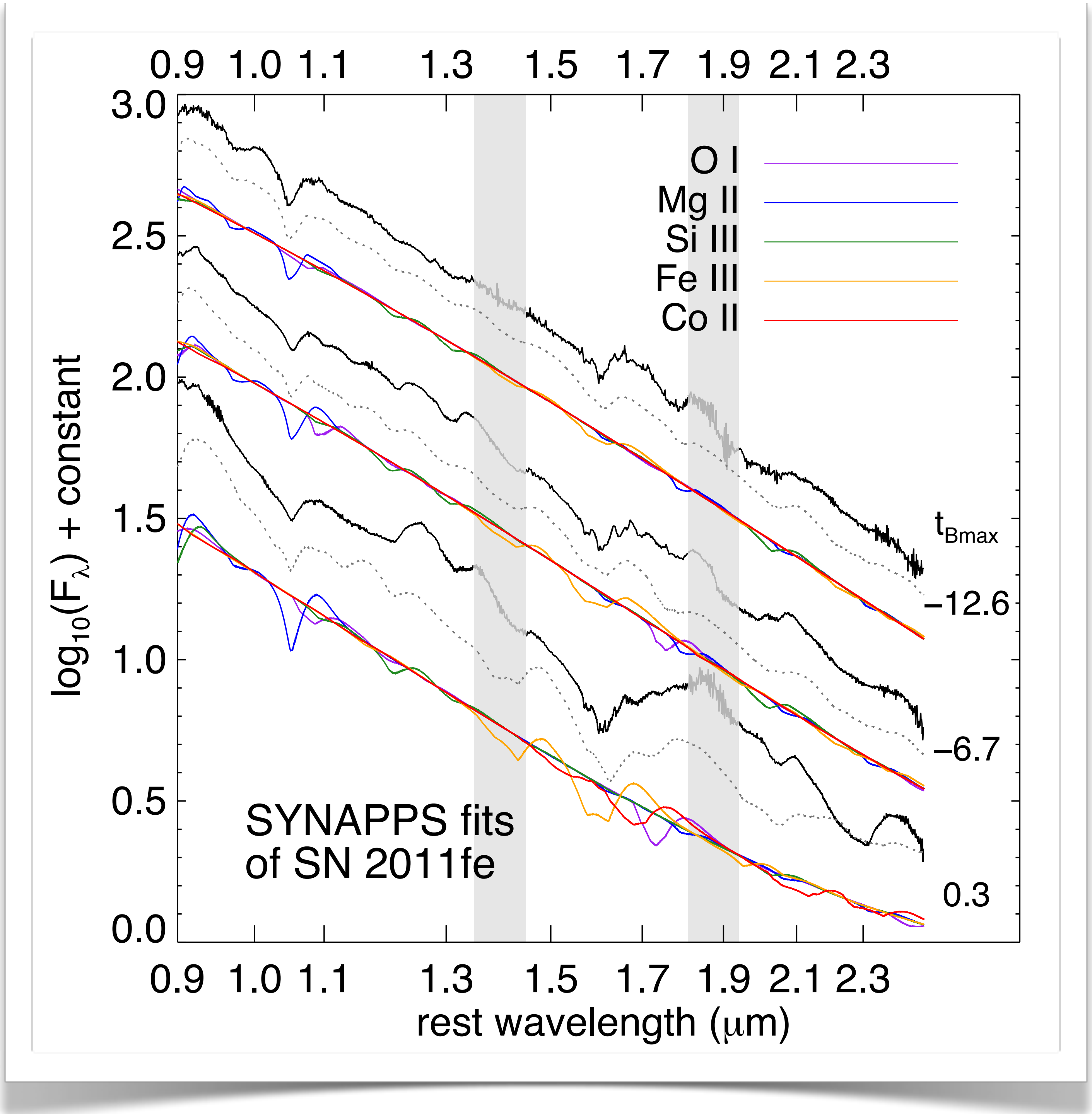


- short blue camera 0.15''/pixel
- cross-dispersing prism
- 32 l/mm grating
- 6 orders
- simultaneous 0.9-2.5 µm coverage
- R~1700



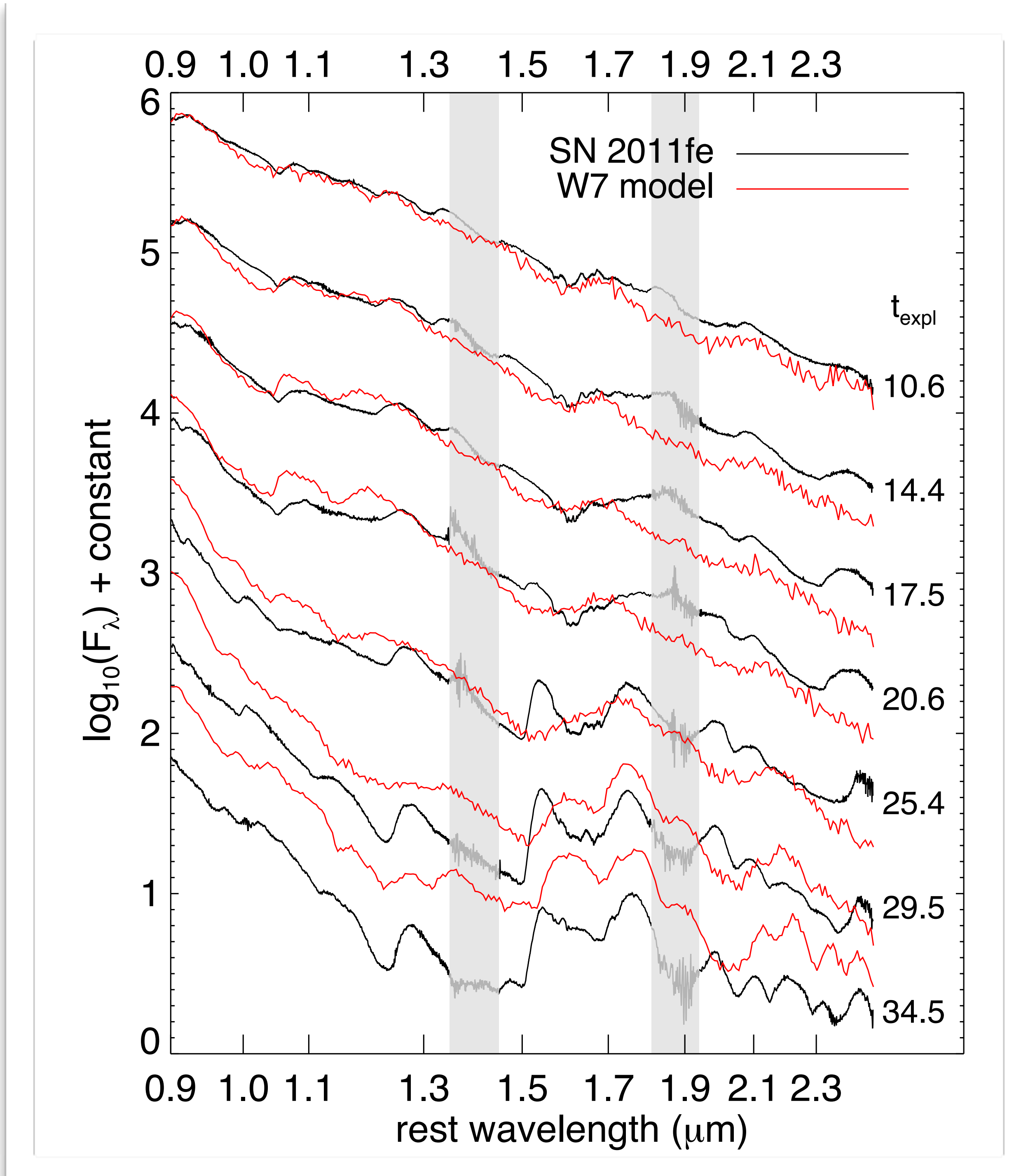
- 1 SpeX (Howie) and 9 GNIRS NIR spectra
- earliest time series
- high S/N
- medium res
- 3-day cadence around max

SYNAPPS fits of early spectra



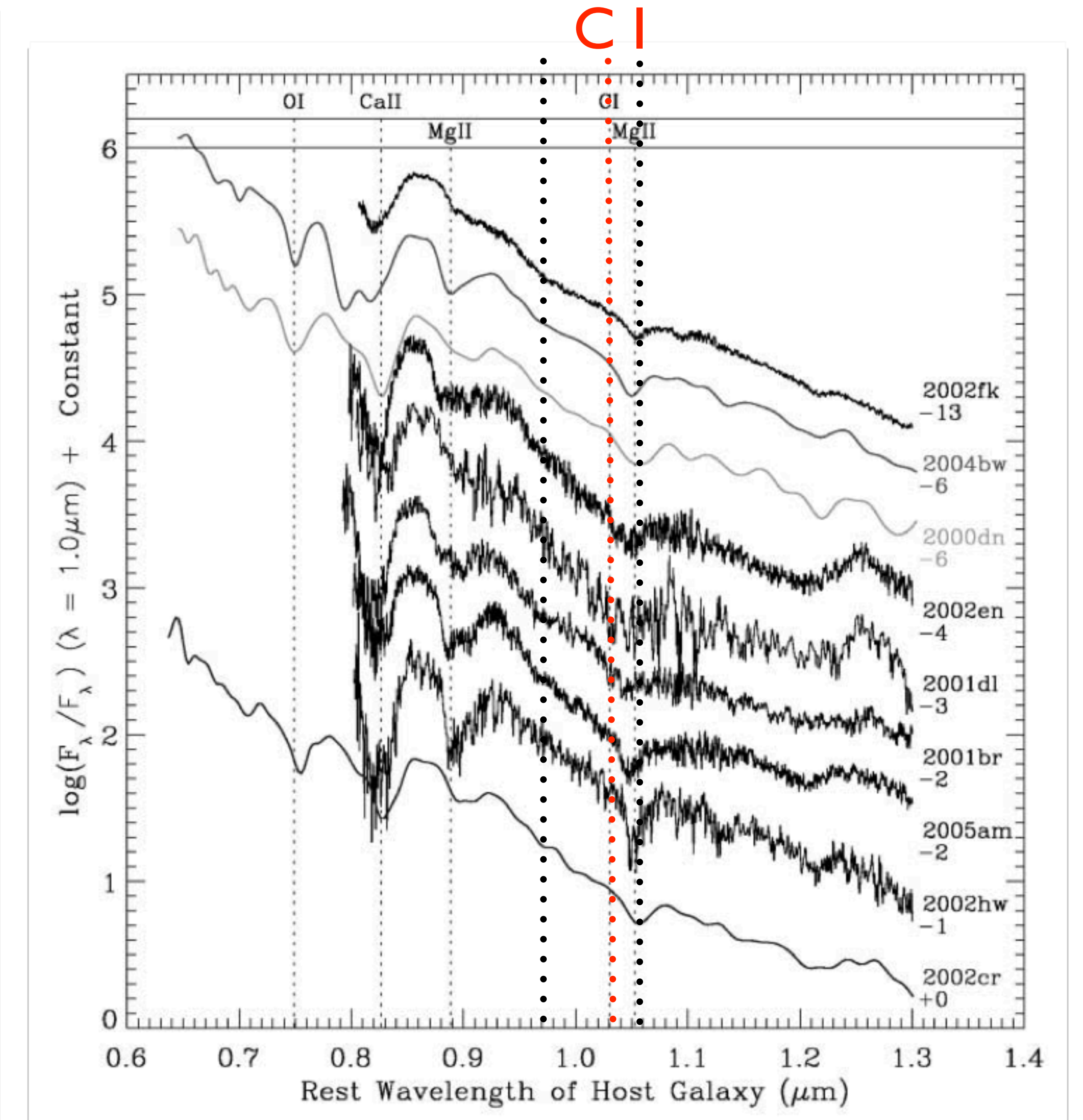
- dominated by IME
- presence of Fe III (previously identified as Si III)
- presence of increasing Co II
- absence of Ni

W7 model + ARTIS RT



- ARTIS radiative transfer (Kromer & Sim 09)
- Monte Carlo code
- time-dependent spectral synthesis
- no free parameters
- low opacity in NIR
- features formed by fluorescence

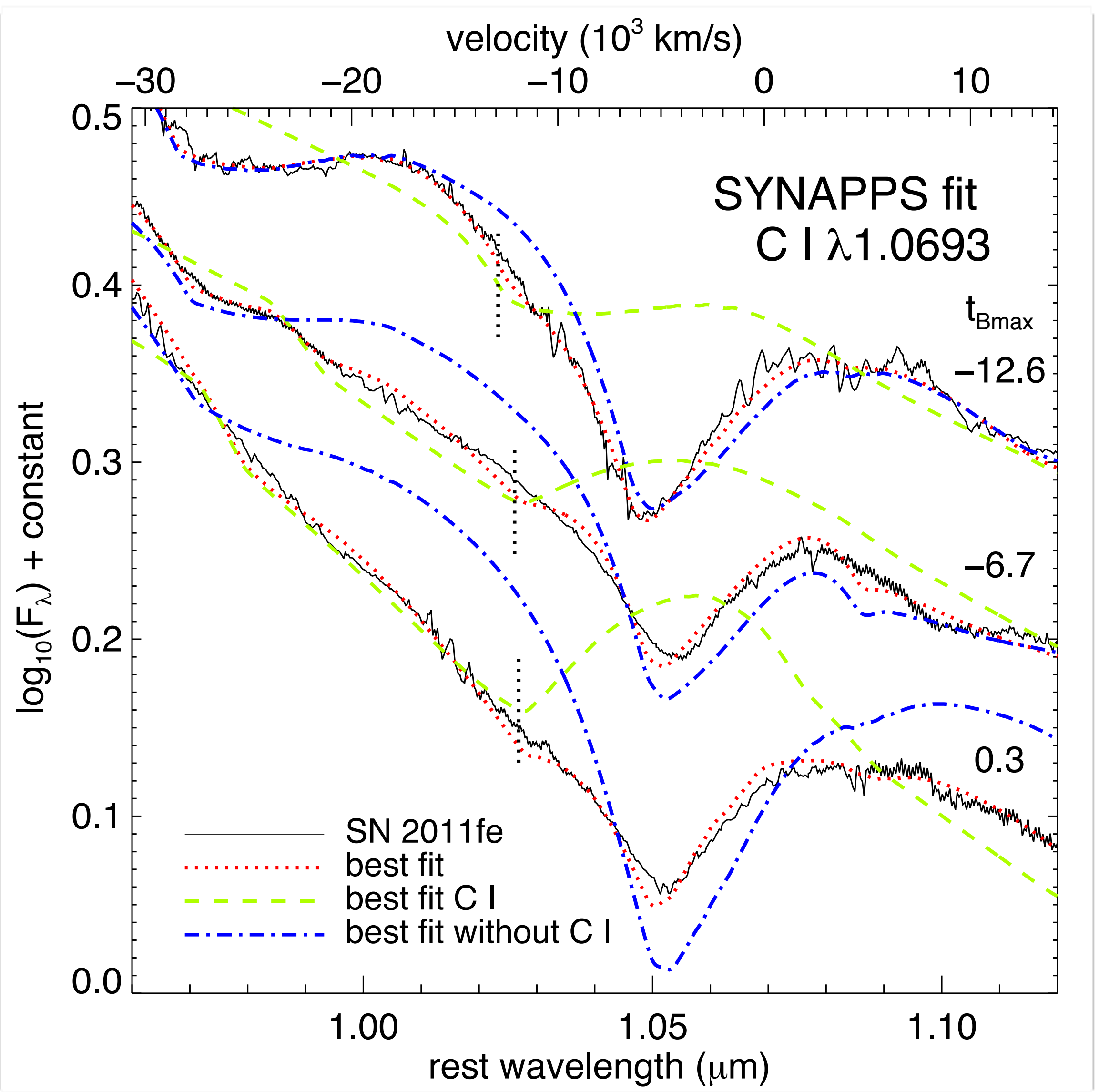
unburnt carbon

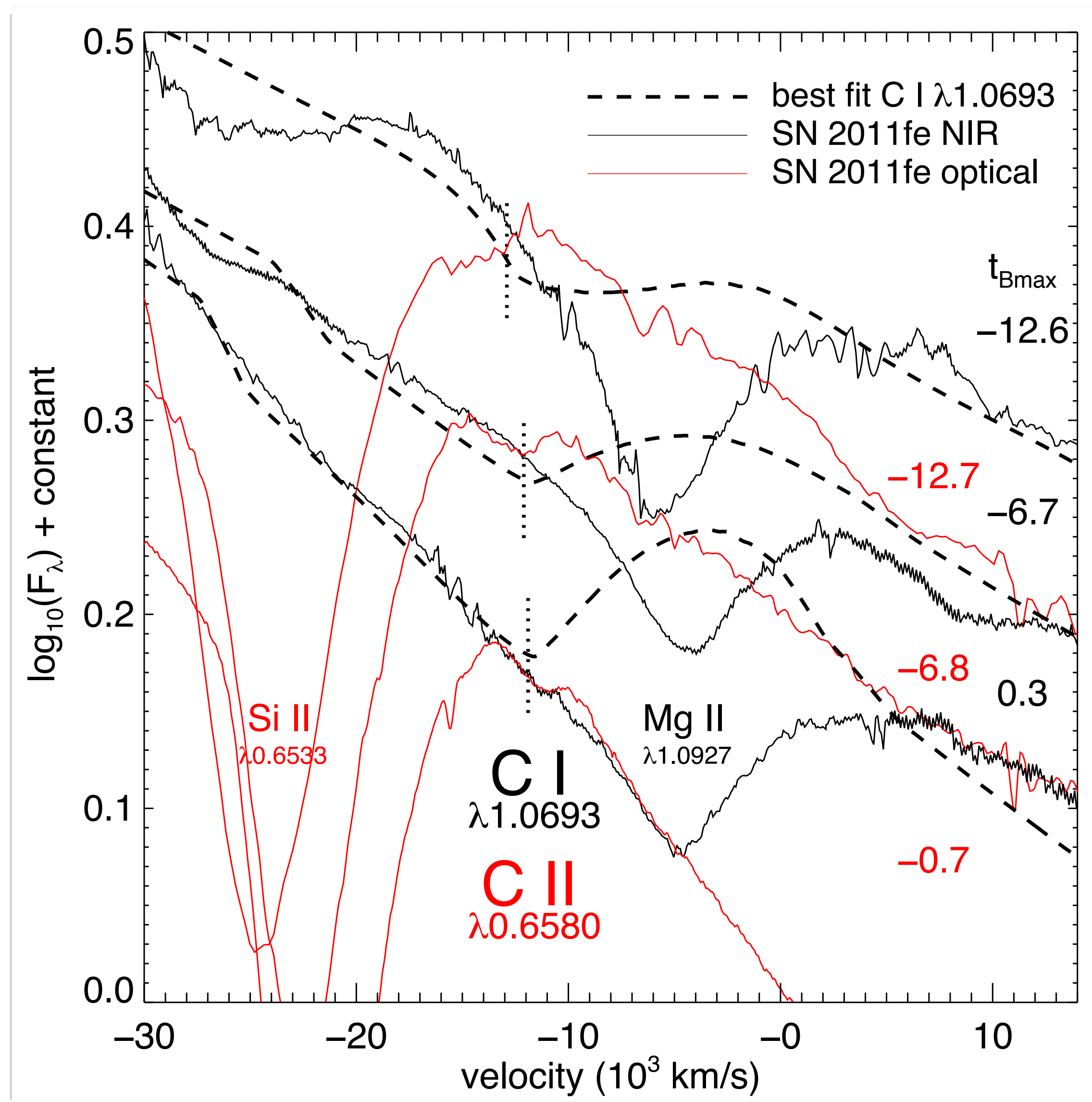


Marion et al. (2006)

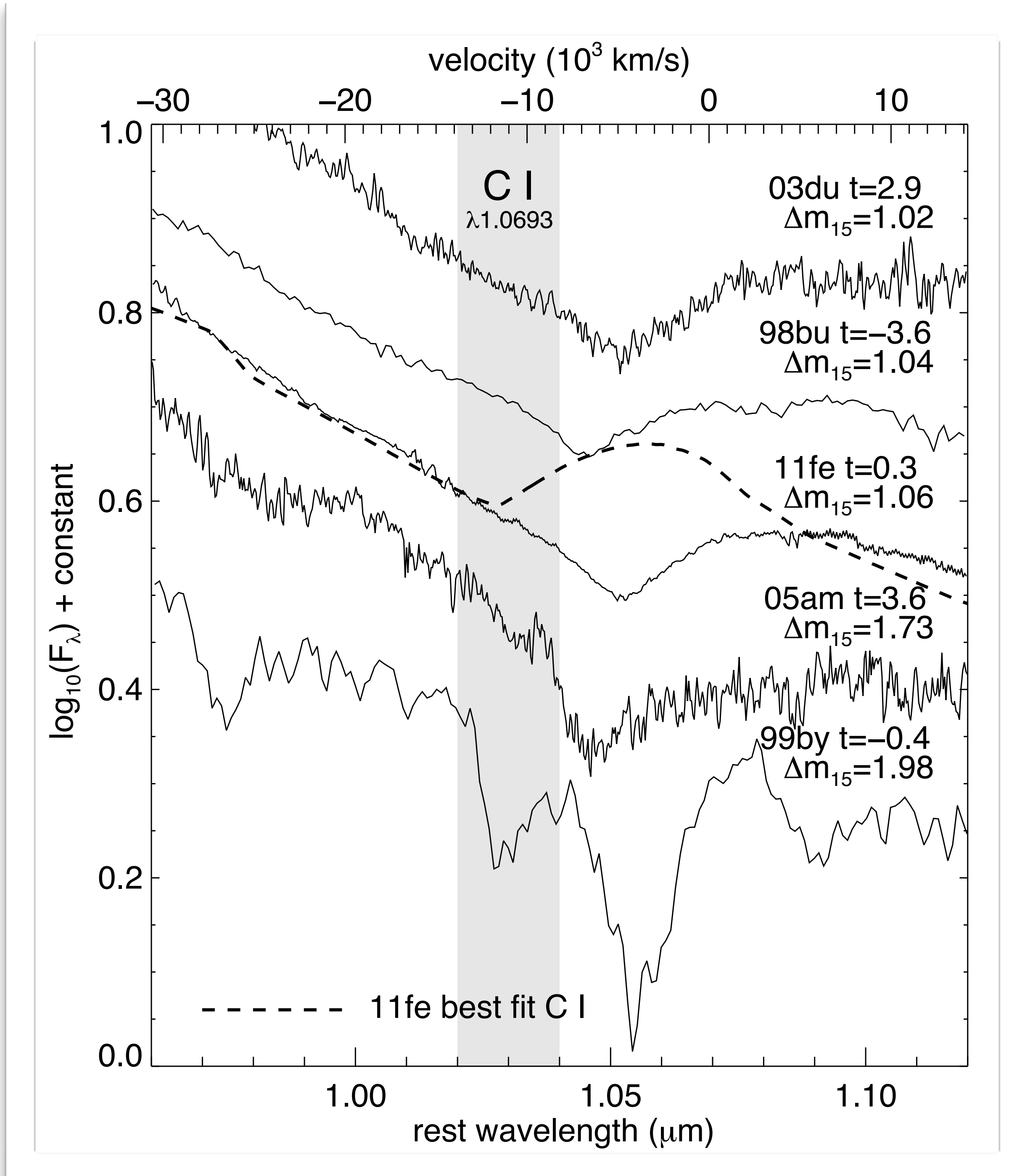
- strongest NIR line C I 10693
- between 2 Mg II features
- unblended at high velocities
- non-detections by Marion et al. (2006)

unburnt carbon



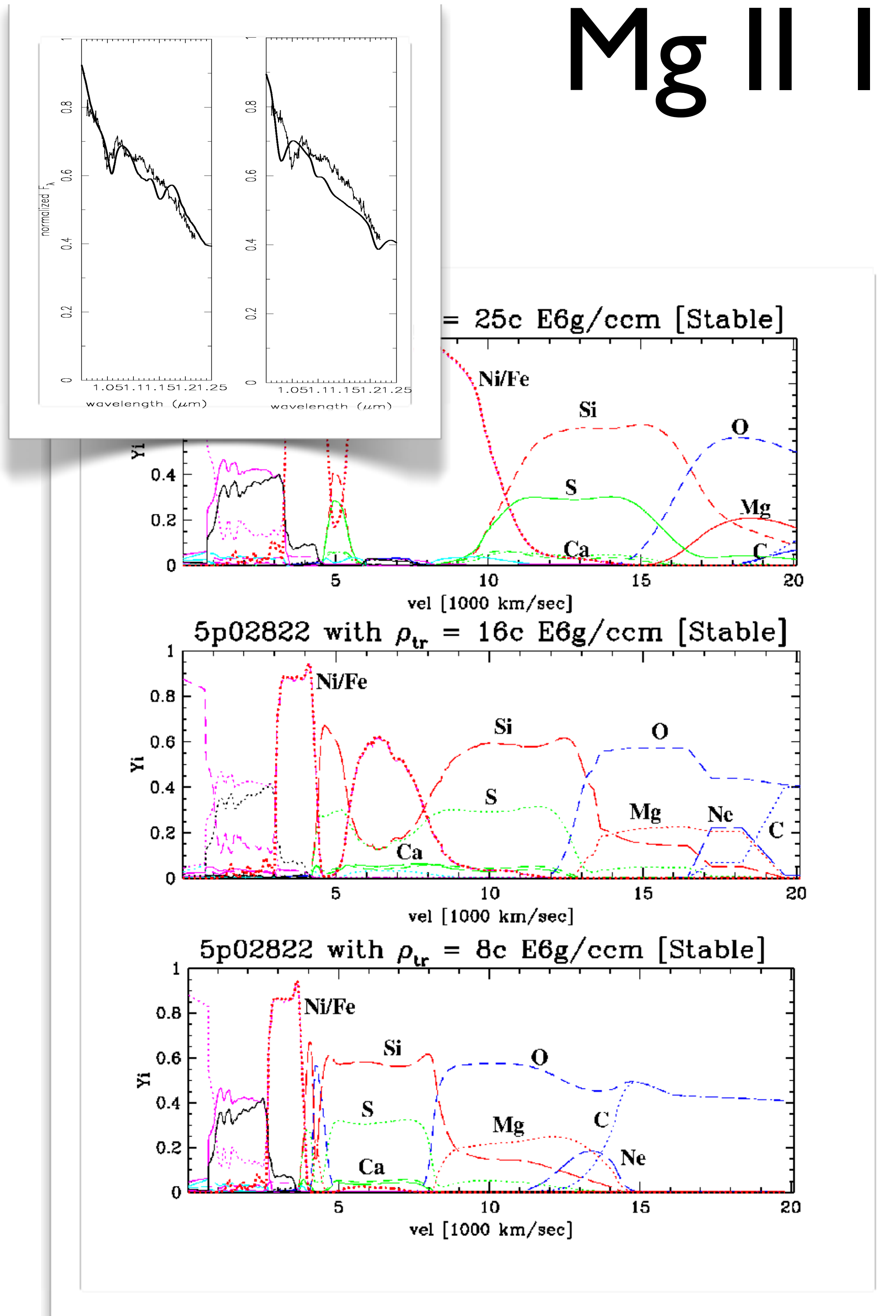


unburnt carbon



- C I 10693 suppresses the emission wing of Mg II 10092 P Cygni
- While optical C II decreases in strength with time, NIR C I strongest near max
- matches photospheric velocity
- NIR C I and optical C II have same velocity
- C II to C I recombination?
- 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?

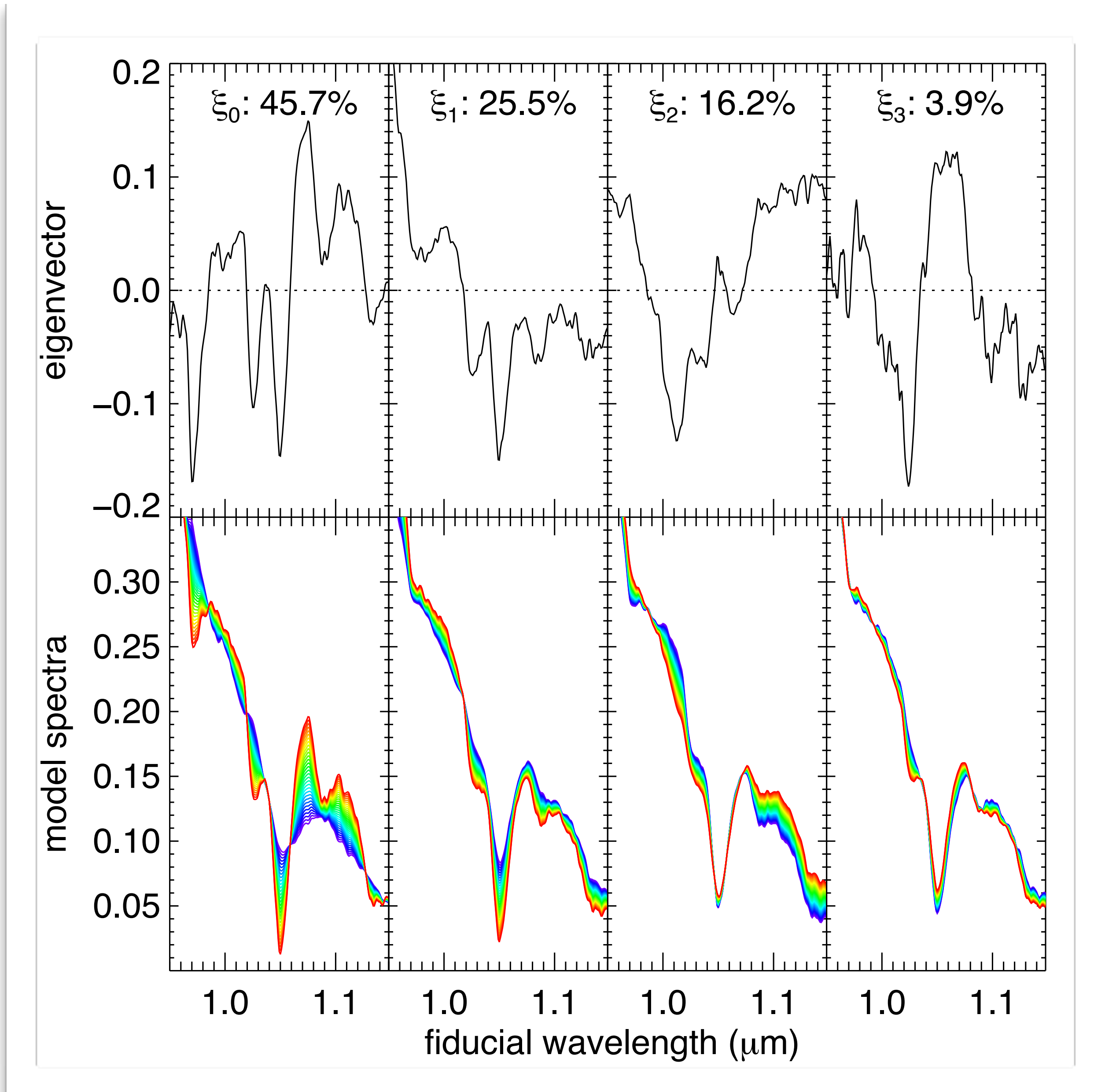
Mg II 10927 velocity



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

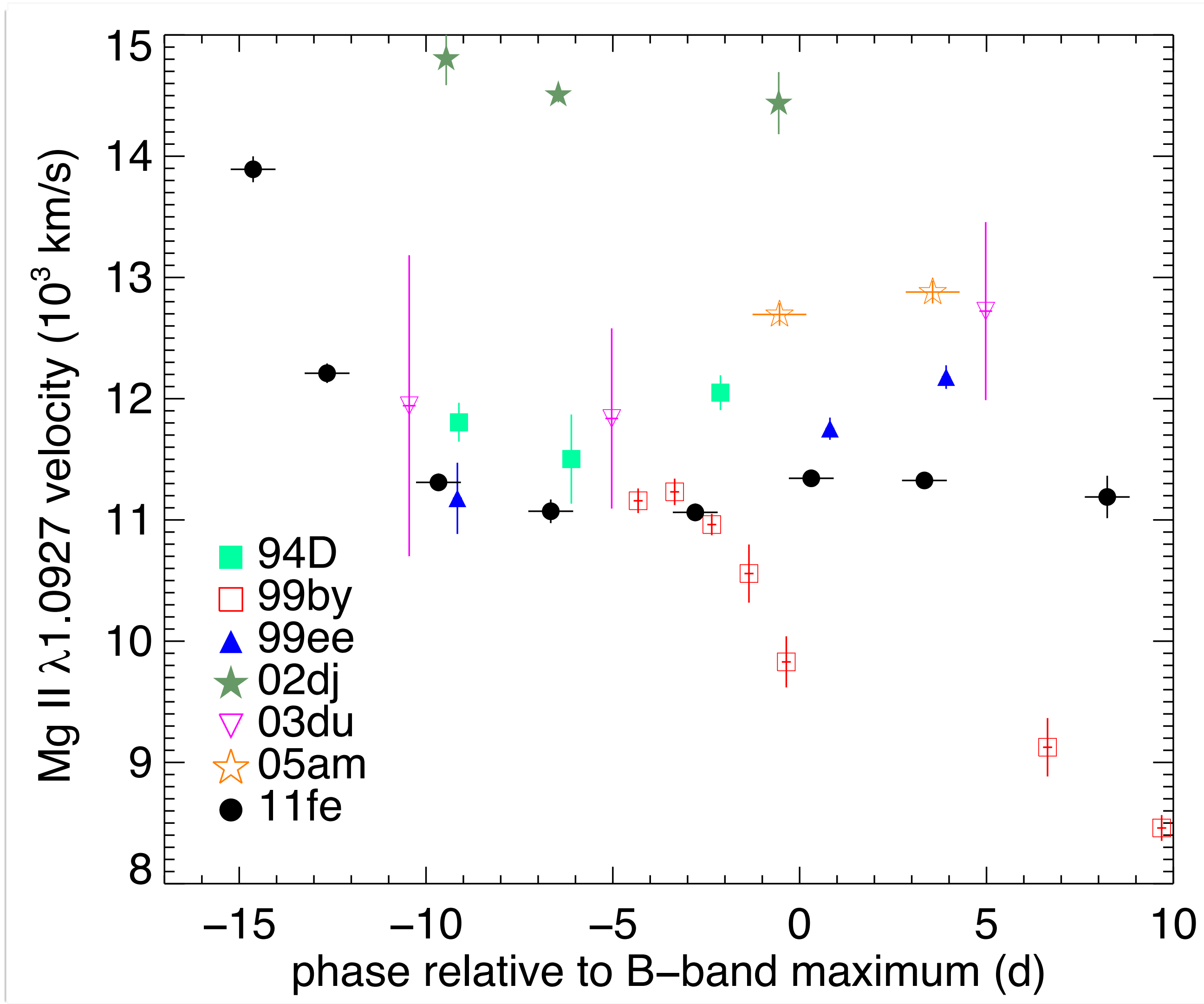
- photosphere recedes below inner edge of Mg distribution
    - constant velocity
- accurate measure of the inner edge of C burning
- probing deflagration to detonation transition density
- transition density sets amount of expansion during deflagration, sets amount of 56Ni

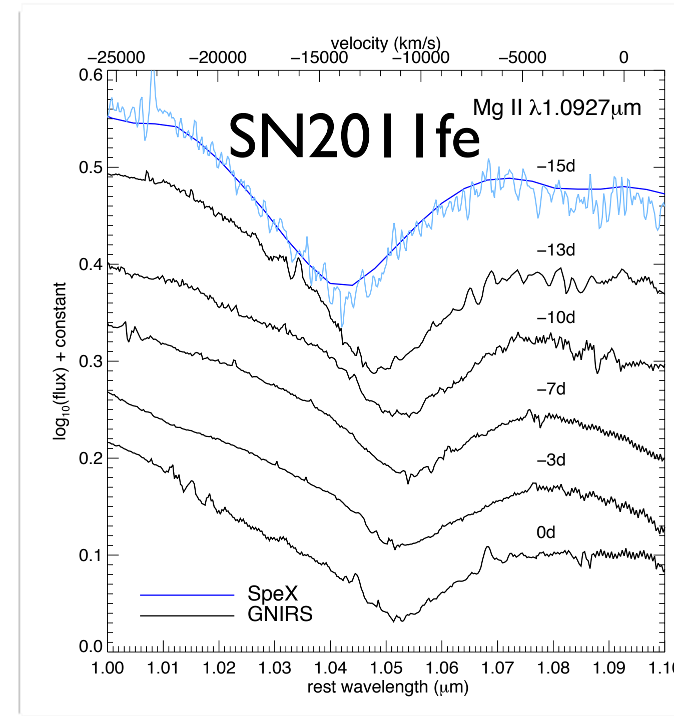
Mg II 10927 velocity



- line profiles not Gaussian
- use observed line profiles to build PCA model
- least-squares fit with PCA projections and velocity as fit arameters

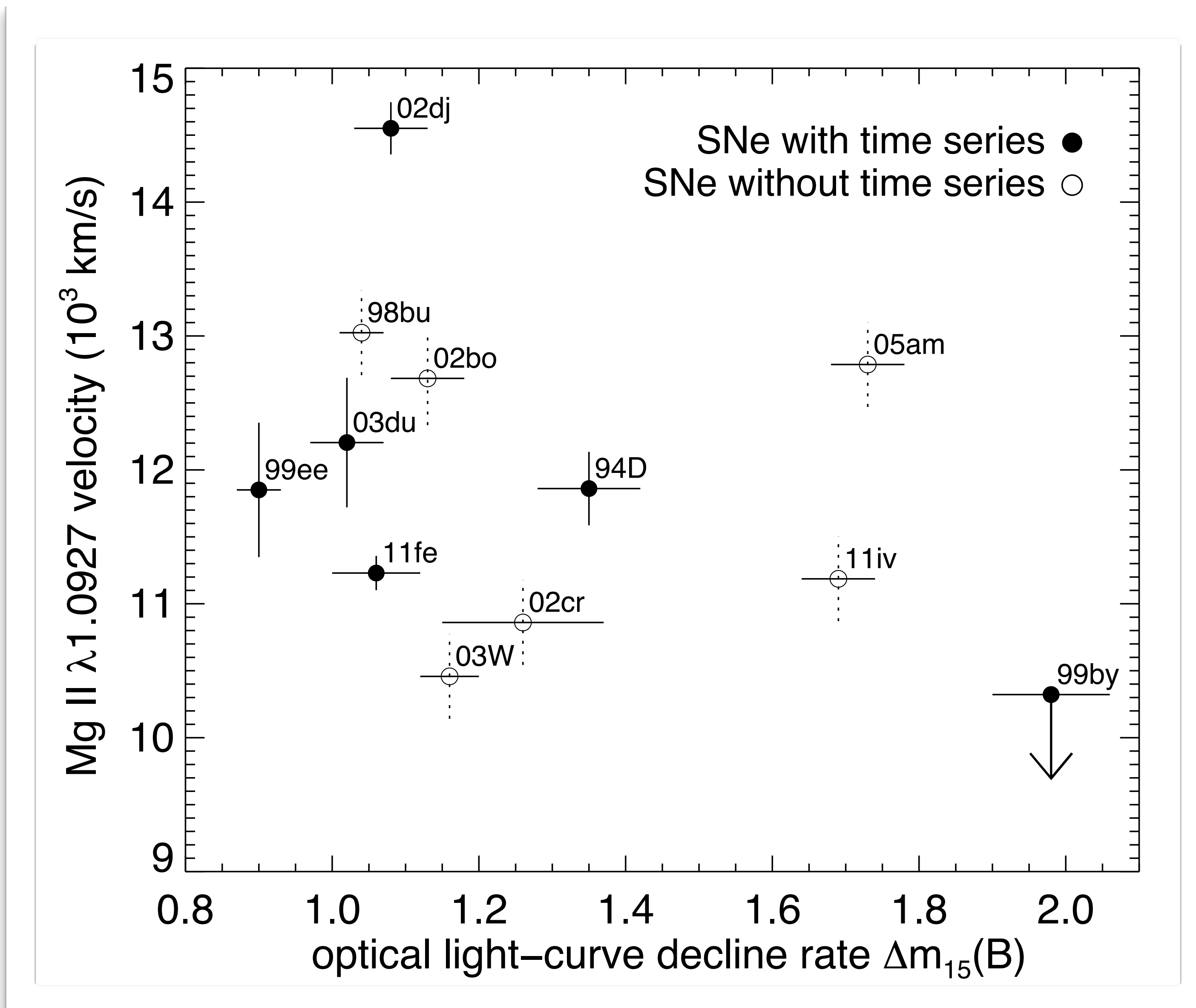
Mg II 10927 velocity





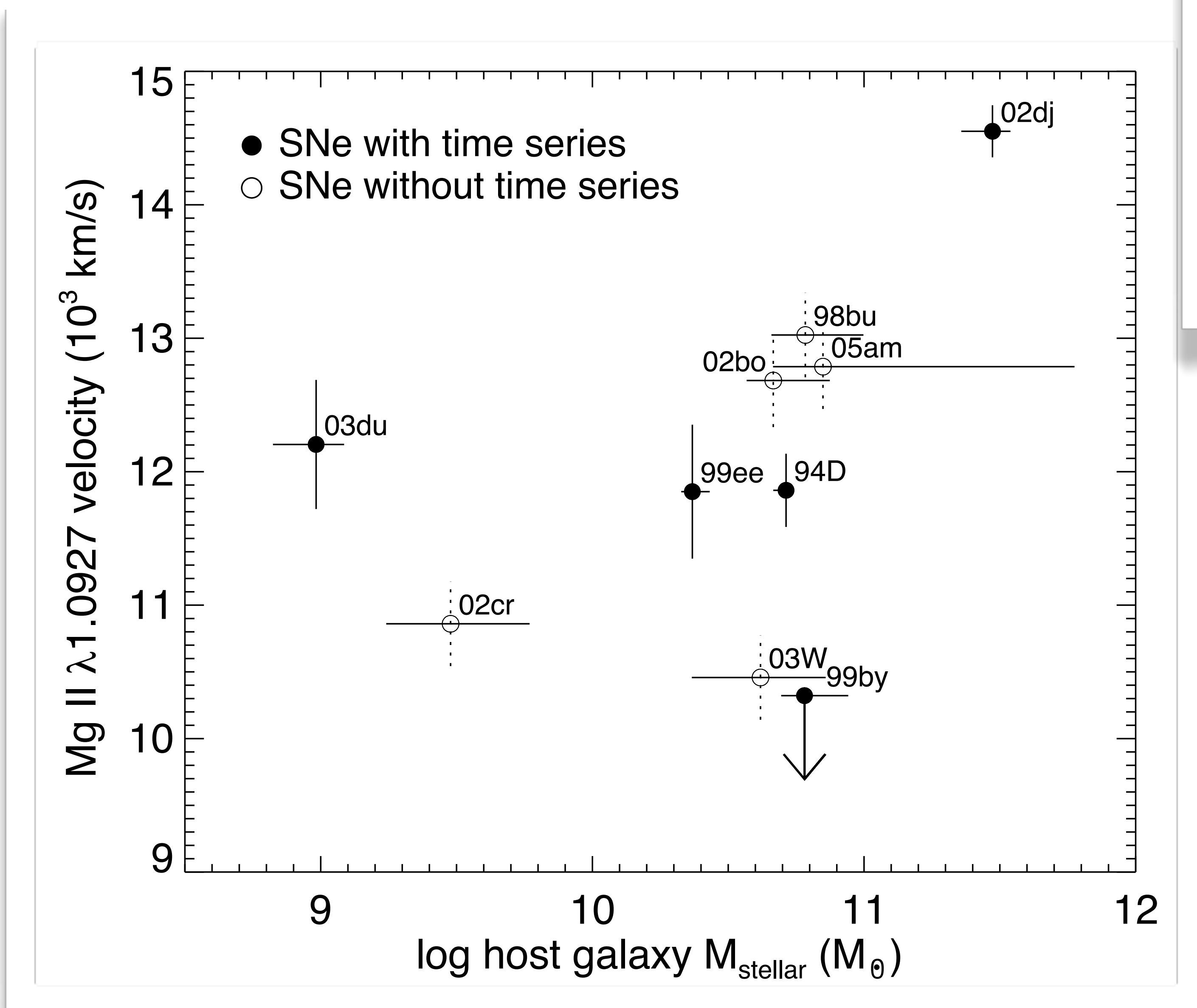
- velocity remarkably constant from -10 to 10 d until line disappears

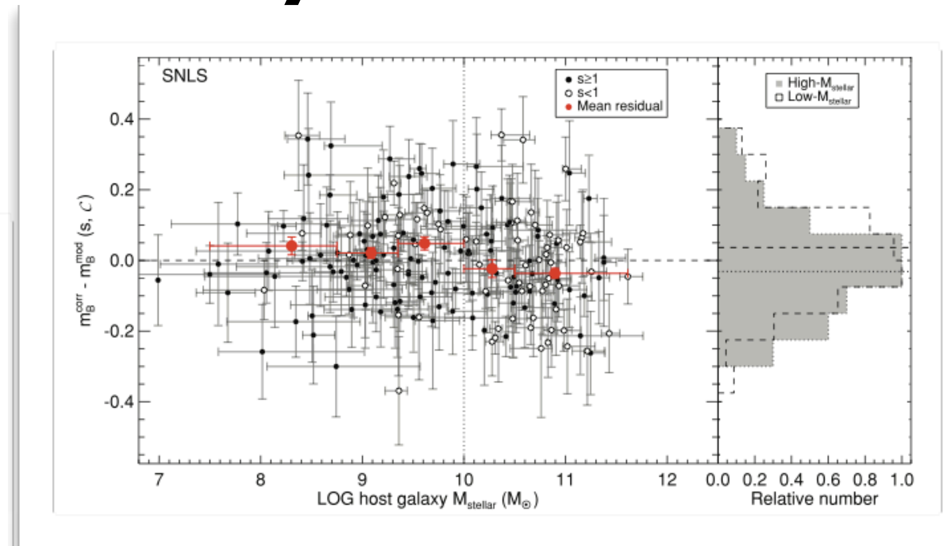
Mg II 10927 velocity



- Is DDT transition density the main driver for SN Ia luminosity variation?
- secondary effect?

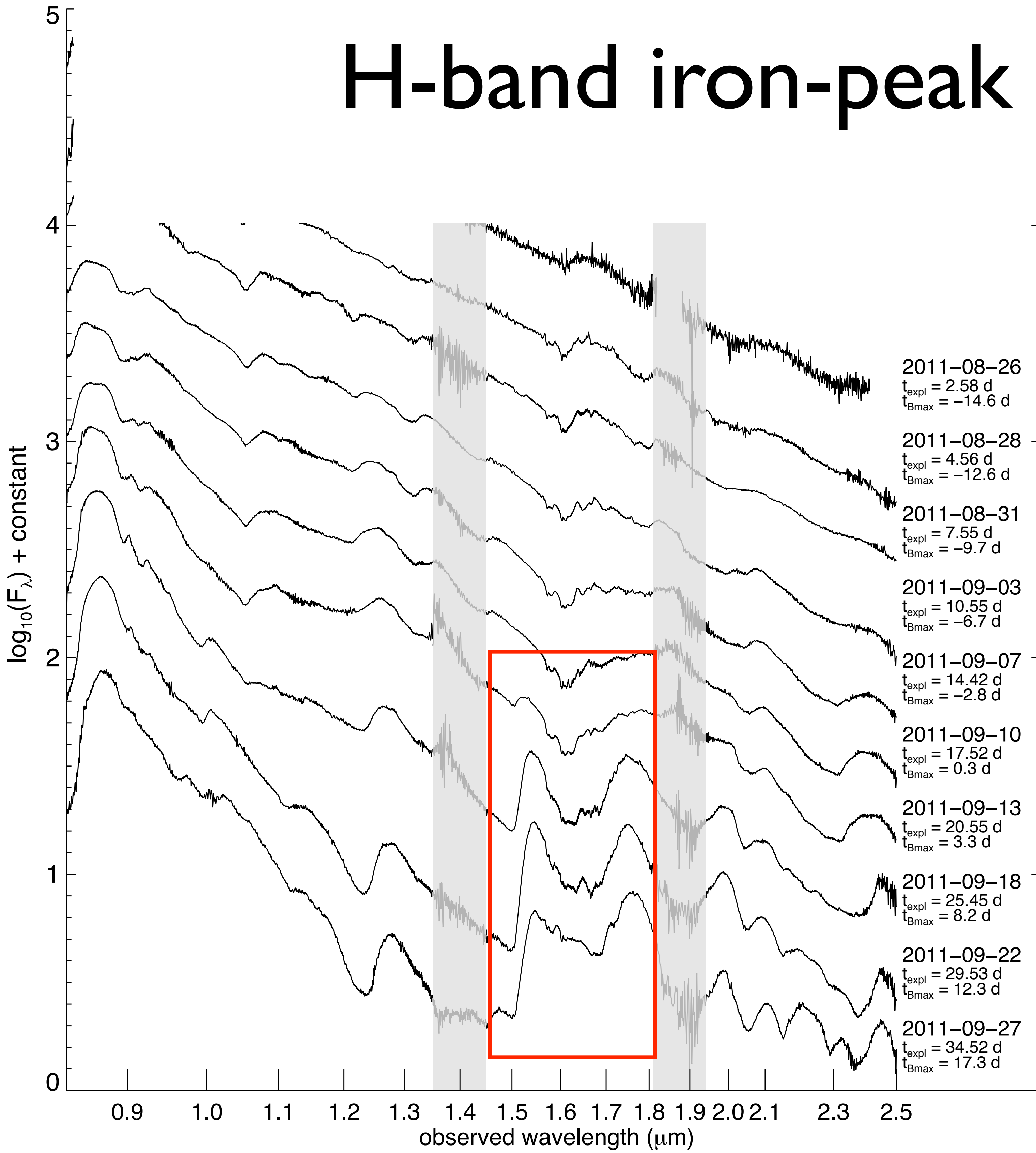
Mg II 10927 velocity



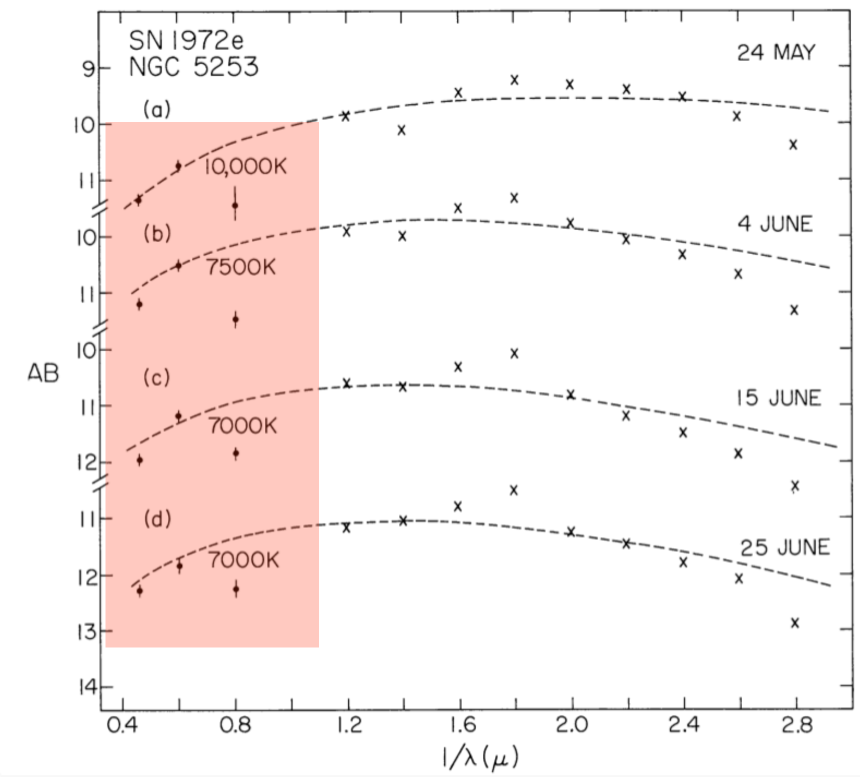


- Sullivan et al. (2010): dependence of SN Ia luminosity on host galaxy mass, in addition to LC shape, color dependence
- Jackson et al. (2010): metallicity affects transition density
- Mg II velocity more direct probe of this secondary effect?

H-band iron-peak feature



Kirshner et al. (1973)

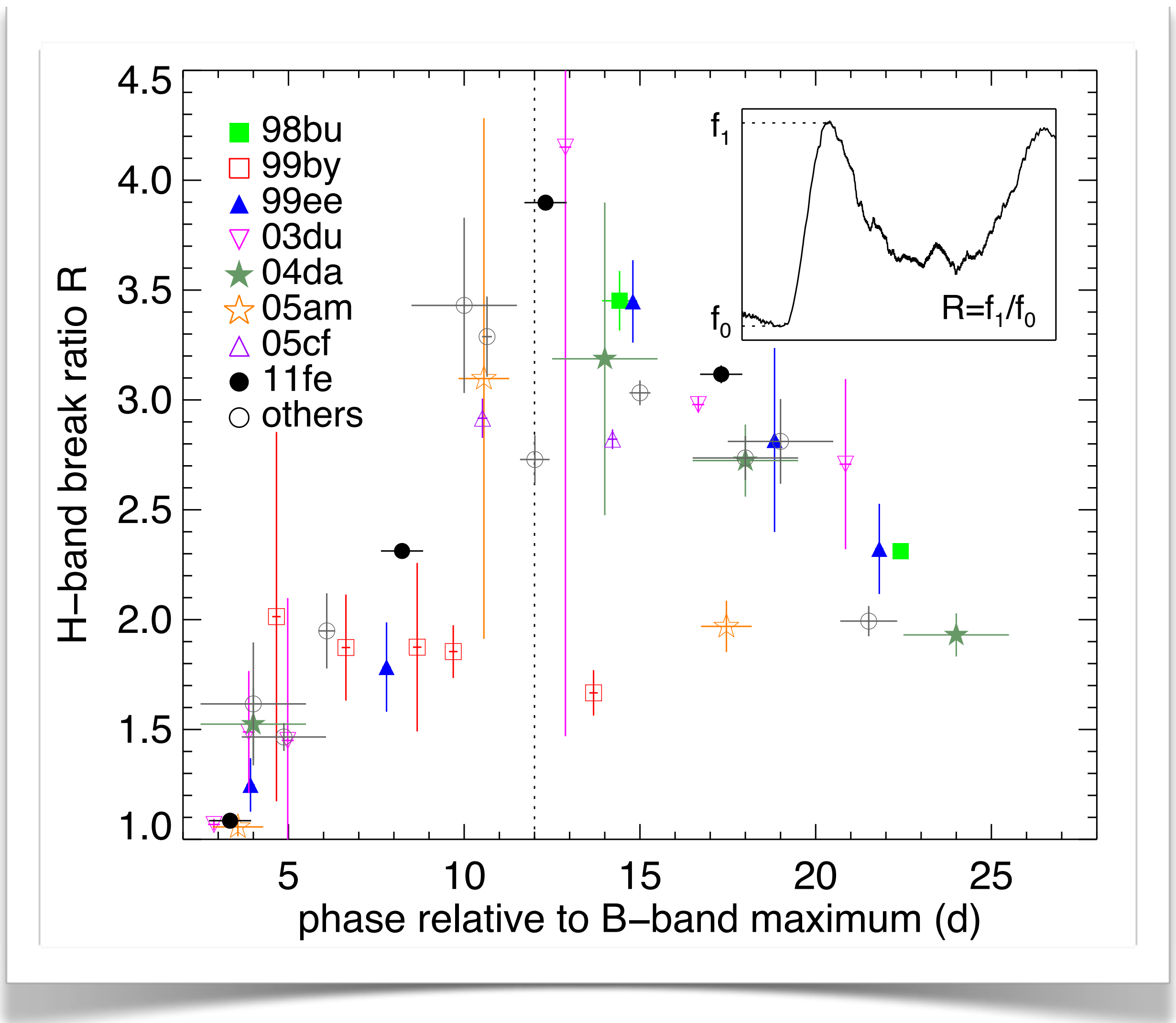


- contrasting opacity

  - OR -

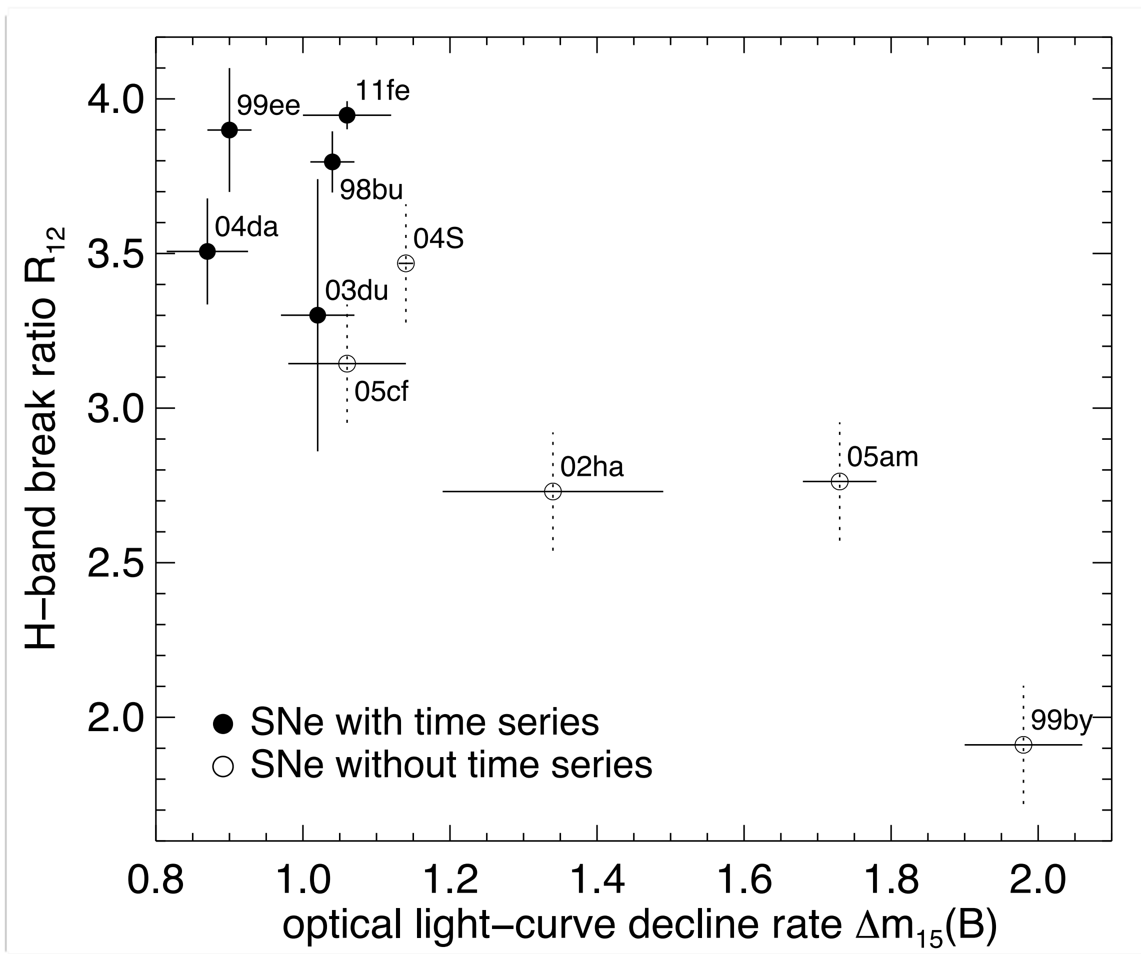
- fluorescence

H-band iron-peak feature



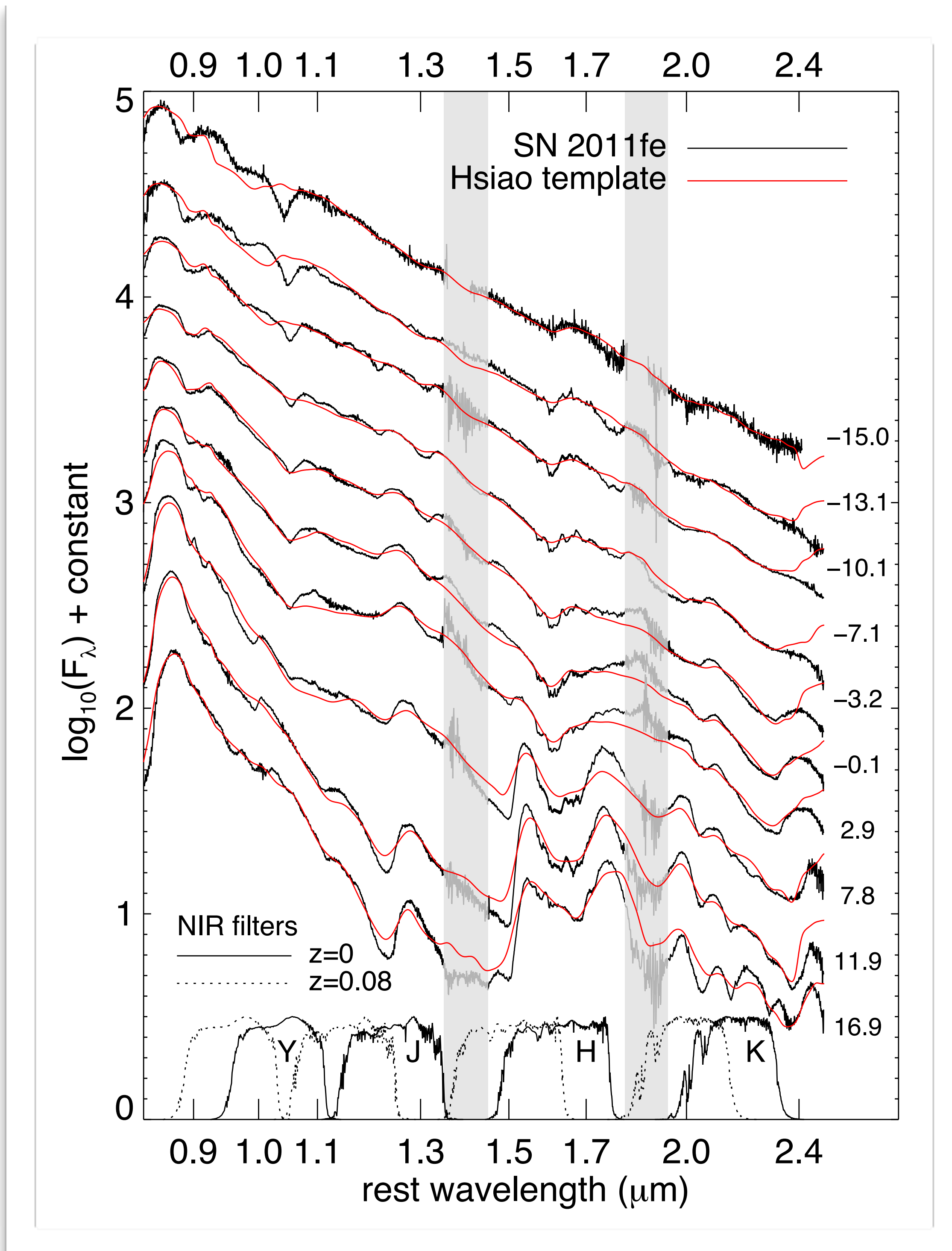
- ratio has uniform evolution
  - begins at 3 d
  - peaks at 12 d at various strengths
  - uniform linear decline
- at 12 d, the iron-peak structure is completely exposed
- decline reflects temperature decline

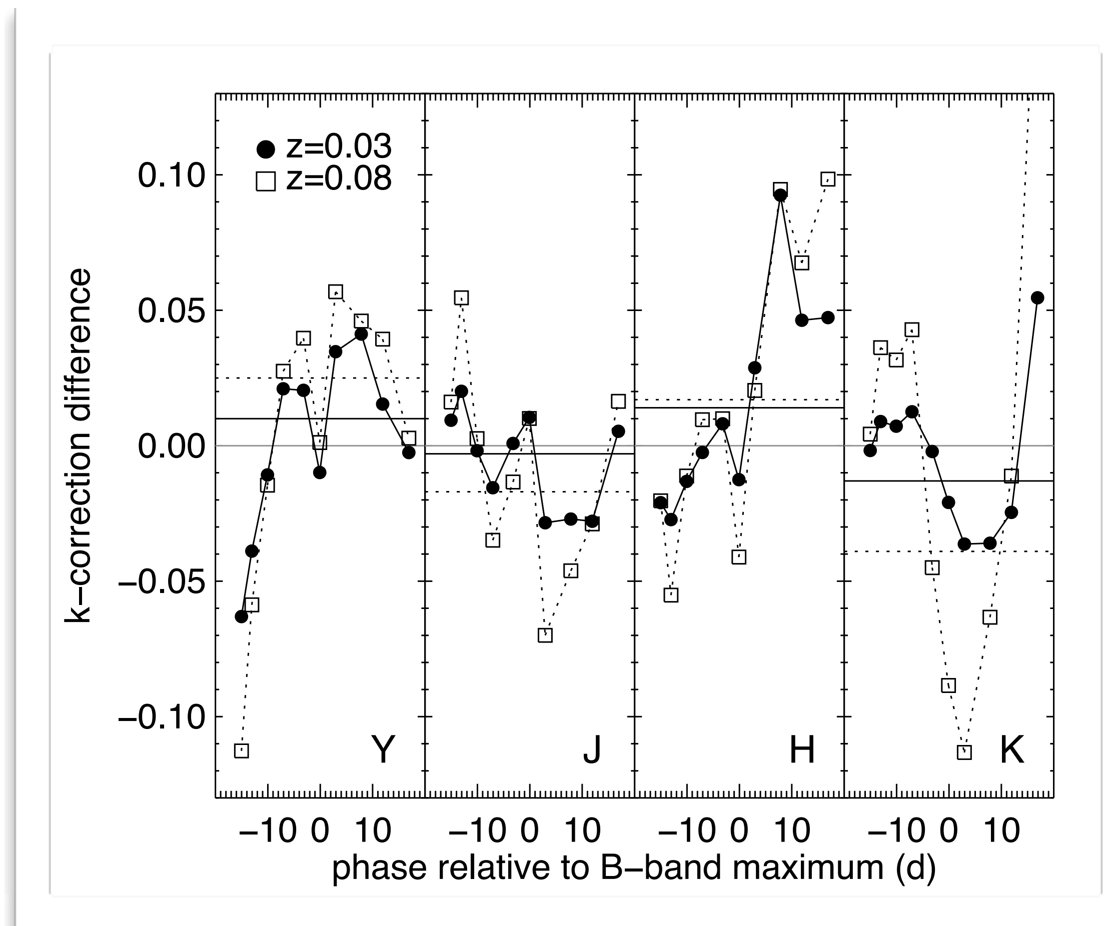
H-band iron-peak feature



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

NIR k-correction





summary

- primordial carbon from WD
  - NIR C I 10693 detected at the same velocity as optical C II 6580
  - The relative isolation and delayed onset of NIR C I 10693 make it a better probe of unburnt carbon than optical C II 6580
  - Unburnt carbon ubiquitous in SNe Ia?
- Mg II velocity as probe of boundary between C/O burning
  - Rapid decline, then stays constant for an extended time
  - Does not correlate with Δm_{15}
  - Affects SN luminosity on a secondary level?
- ratio across H-band iron-peak break
  - Uniform evolution
  - Correlates with Δm_{15}
  - First step toward improving k-corrections