Late Time Spectra of SN 2011fe

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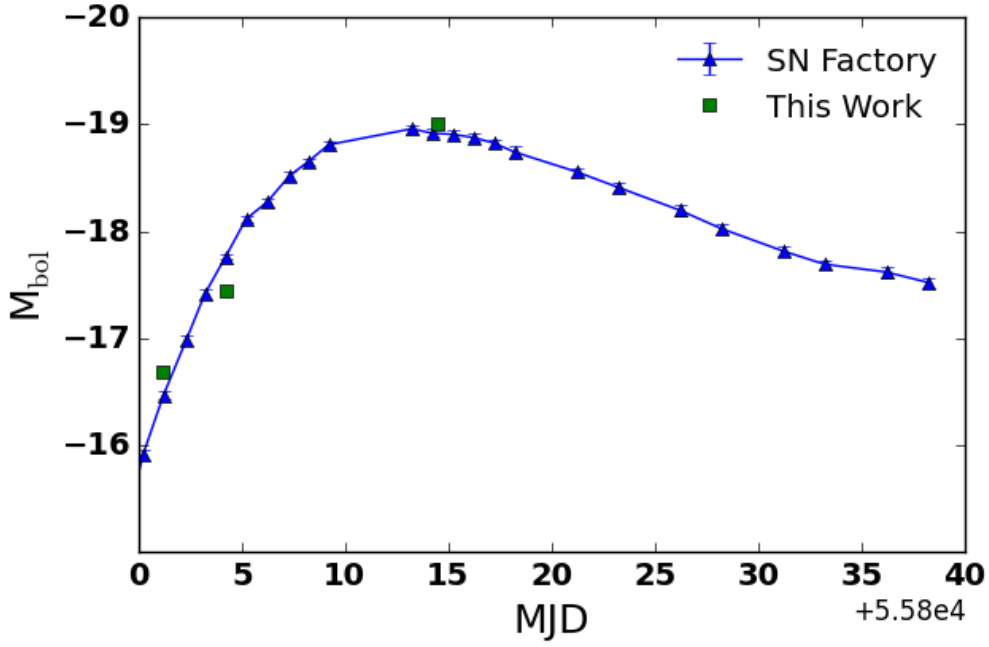
Collaborators

- PHOENIX Group
  - Peter Hauschildt
  - Travis Barman
  - Many others, . . .
- Carnegie Supernova Project
  - The Gang is all here
- Supernova Factory
  - Sebastien Bongard
- Former Students
  - Brian Friesen
  - Sebastien Bongard
  - Rollin Thomas
- Current Students
  - Jeremy Lusk
  - Malia Jenks
  - Lisa Simpson
  - Braden James
  - Patrick Vallely

SN 2011fe

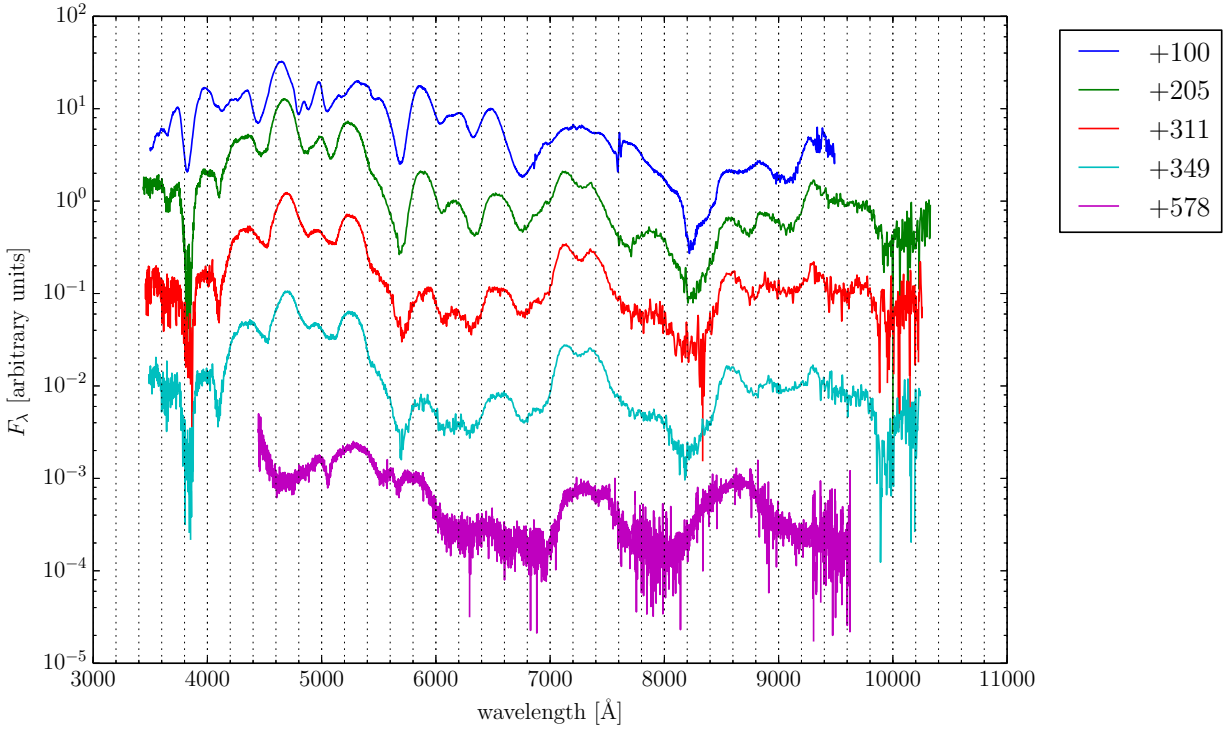
- Extremely Well Observed nearby (M101) Core Normal SN Ia
- Fit Early Times reasonably well with somewhat low metallicity DD model
  - $M_{MS} = 5\mathrm{M}_{\odot}$
  - $\rho_{tr} = 2.3 \times 10^{7}$ g cm^{-3}



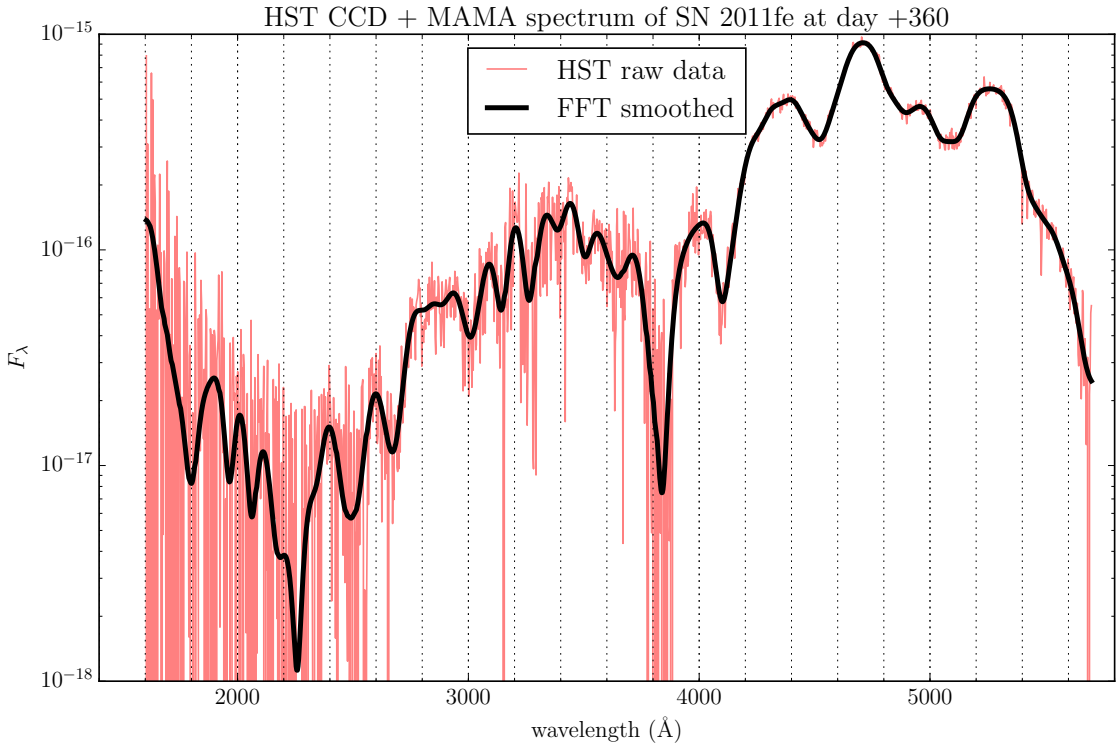
Push On to late times

UT Date	Phase (days)	Telescope +Instrument
2011 Dec 19	+100	WHT+ISIS
2012 Apr 2	+205	Lick 3-m+KAST
2012 Jul 17	+311	Lick 3-m+KAST
2012 Aug 23	+349	Lick 3-m+KAST
2013 Sep 4	+360	HST
2013 Apr 8	+549	Lick 3-m+KAST

Optical Spectra

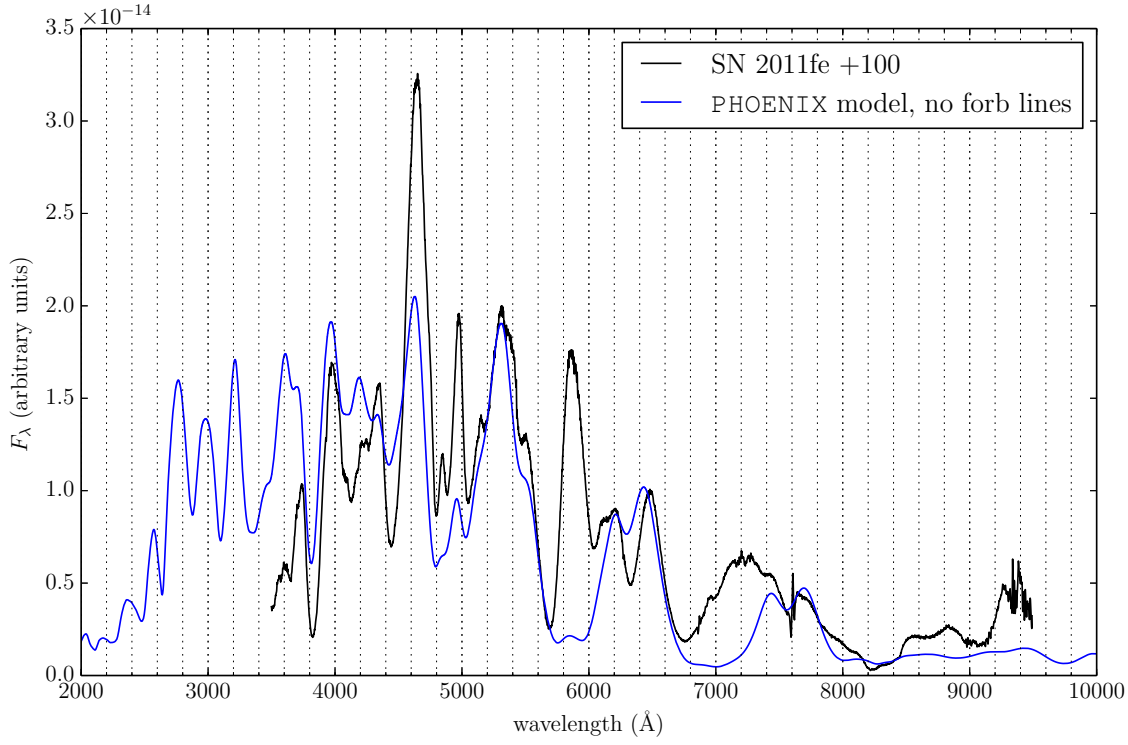


HST Spectra



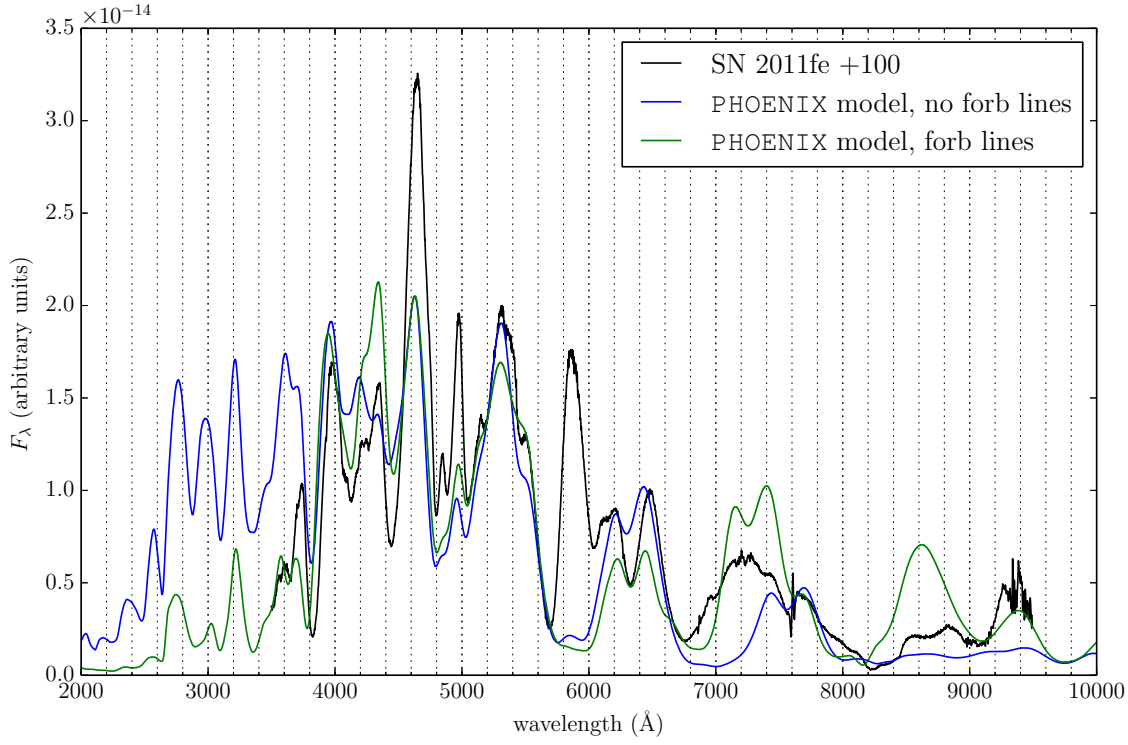
Smoothed spectrum using a low-pass filter technique (Marion et al., 2009).

Day +100



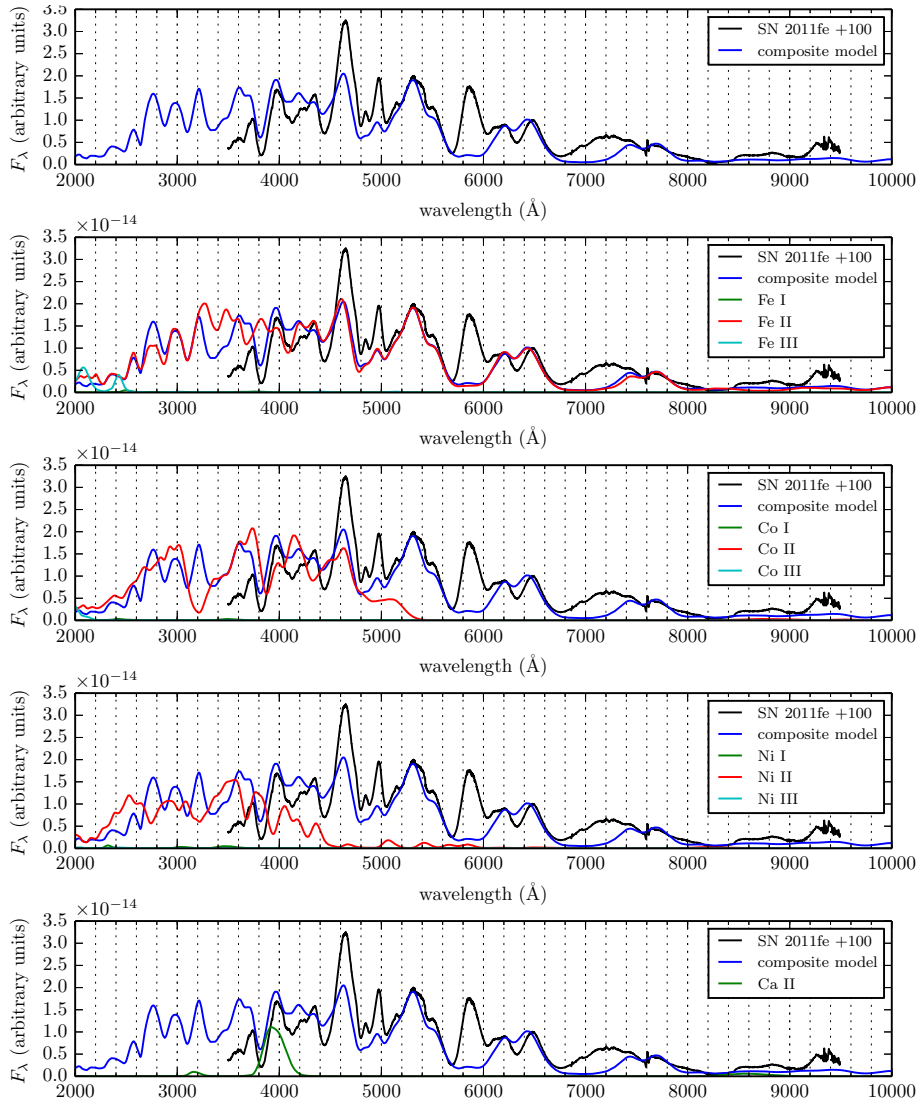
Synthetic spectrum of delayed-detonation model of Domínguez et al. (2001) at day 116 vs. SN 2011fe at day +100. No forbidden lines were included in this calculation.

Day +100



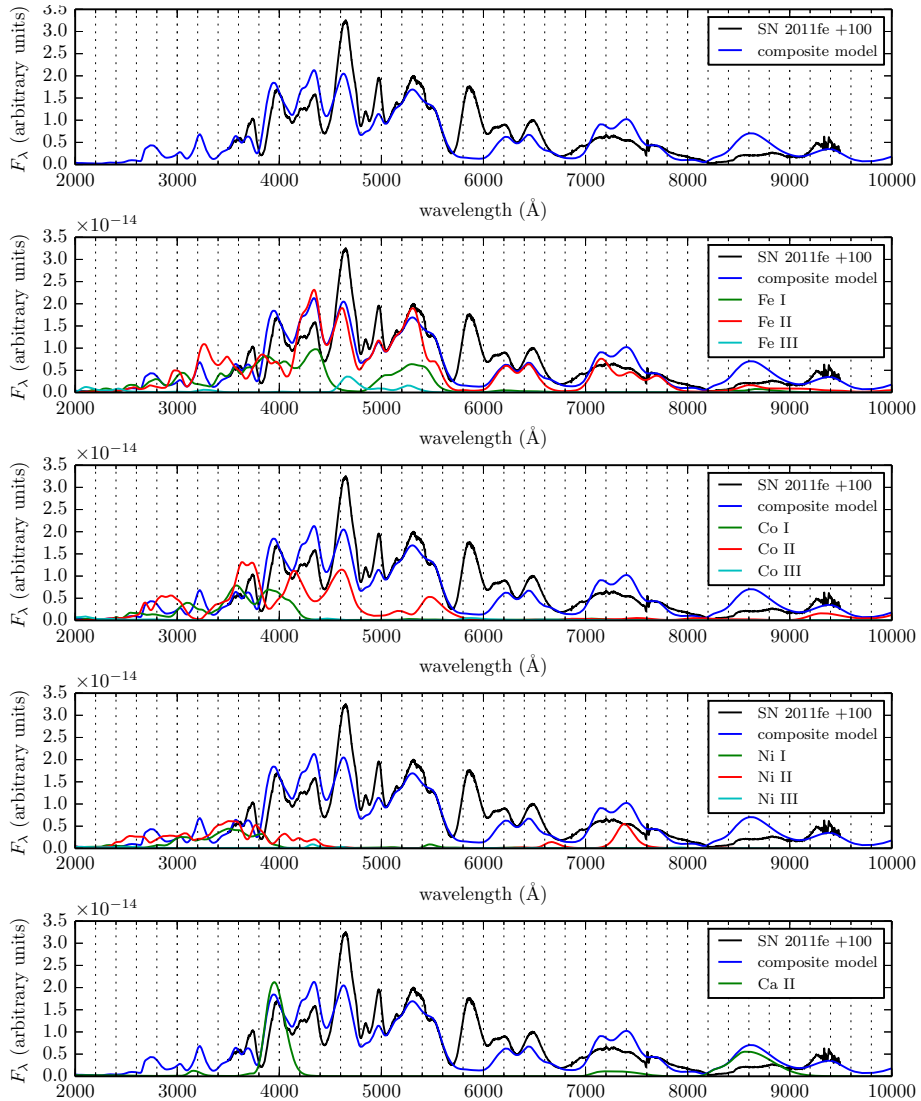
Comparison of PHOENIX spectra with and without forbidden lines at day 116.

Day +100 Line IDs



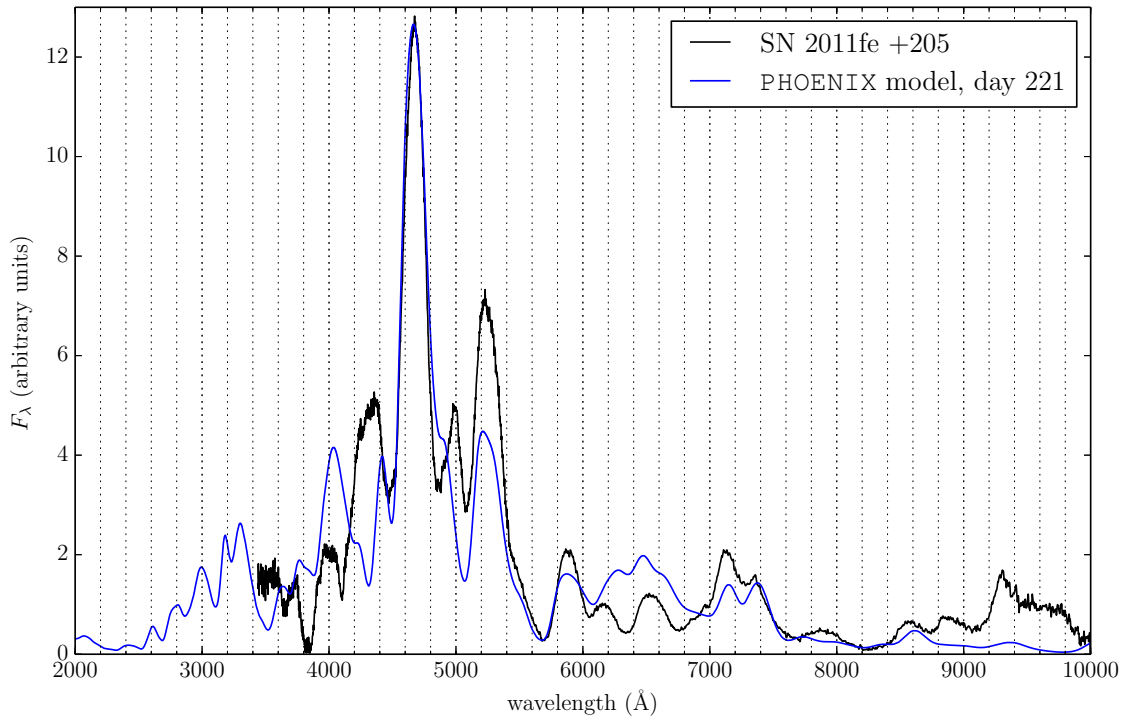
No forbidden lines were included in this calculation.

Day +100 Line IDs

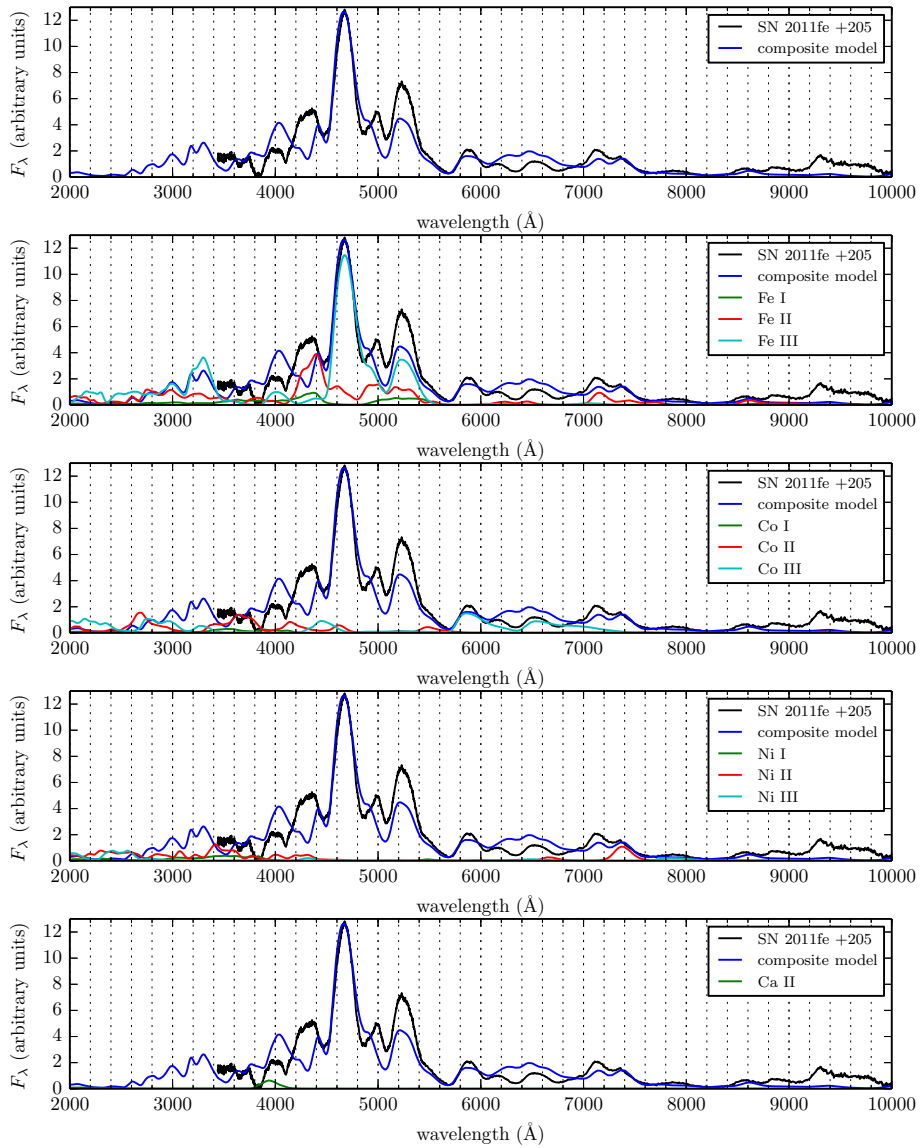


Permitted and Forbidden Lines

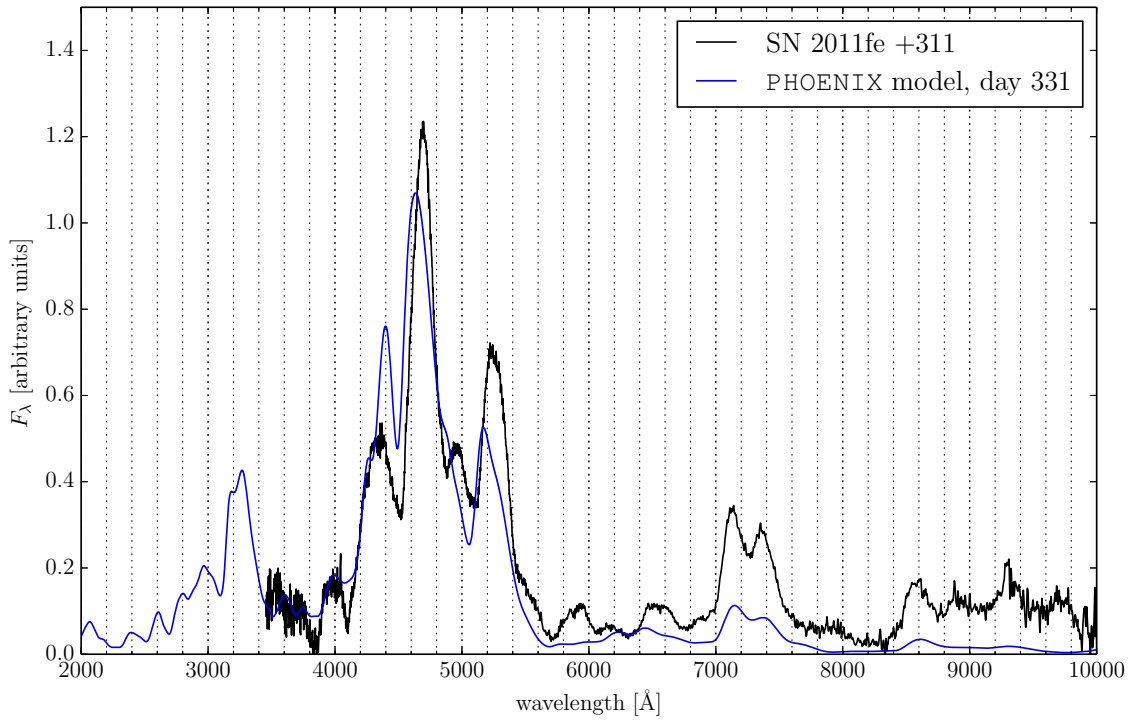
Day +205


SN 2011fe +205
PHOENIX model, day 221
F_λ (arbitrary units)
wavelength (Å)
0
2
4
6
8
10
12
2000
3000
4000
5000
6000
7000
8000
9000
10000

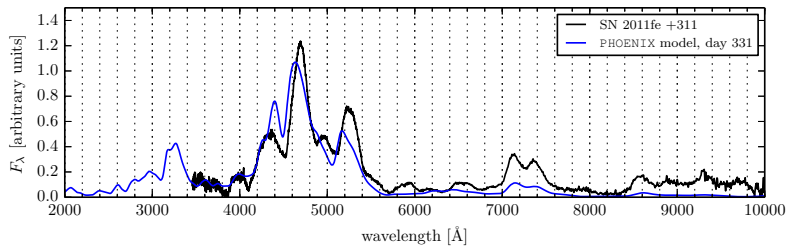
Day +205 Line IDs

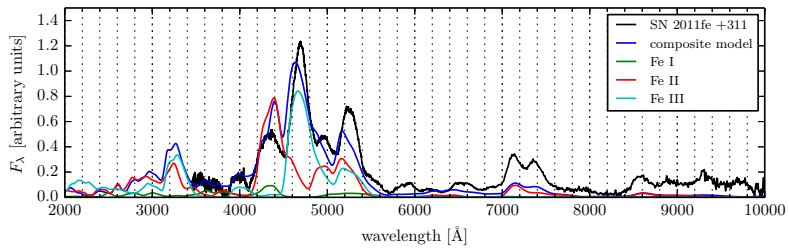


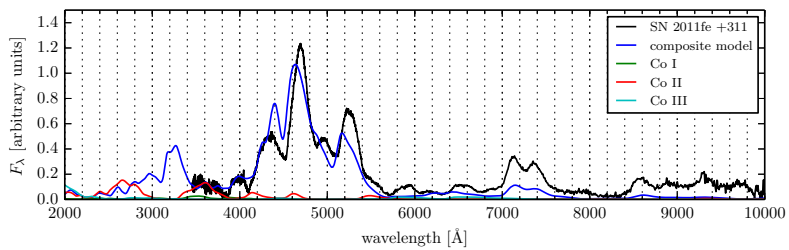
Day +311

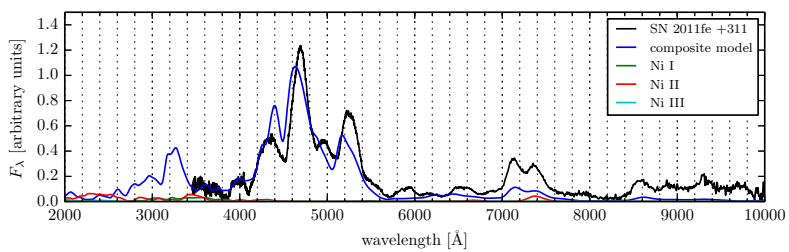

SN 2011fe +311
PHOENIX model, day 331
F_λ [arbitrary units]
wavelength [Å]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
2000
3000
4000
5000
6000
7000
8000
9000
10000

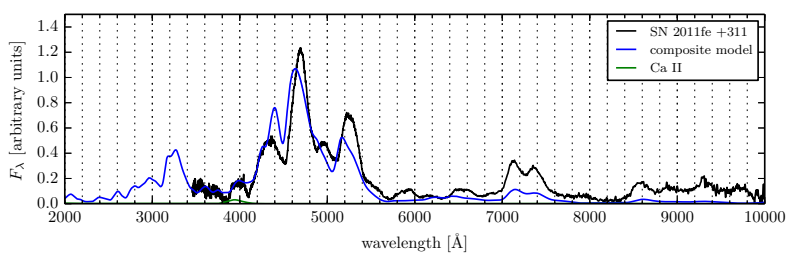
Day +311 Line IDs



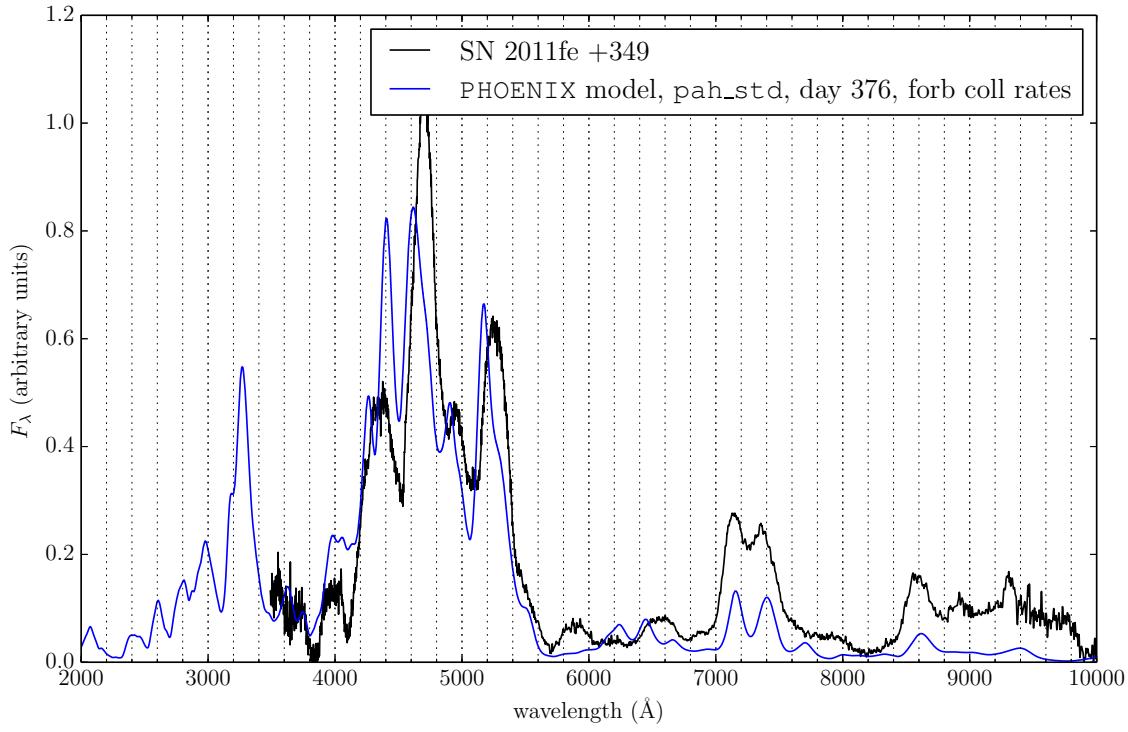




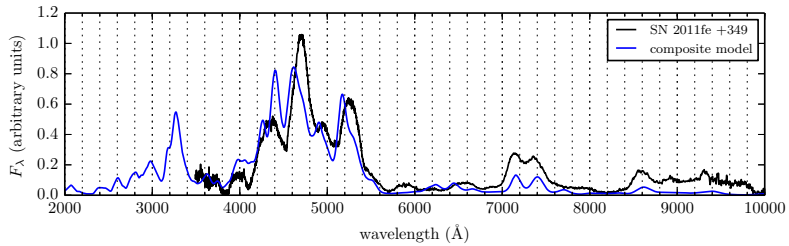


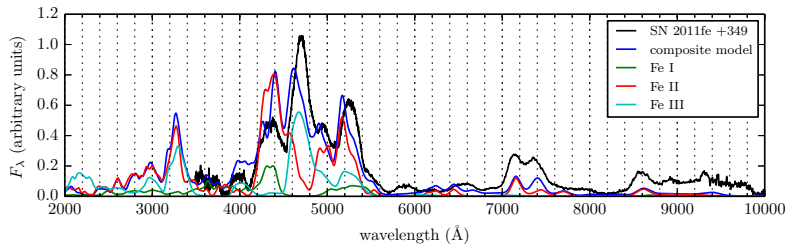


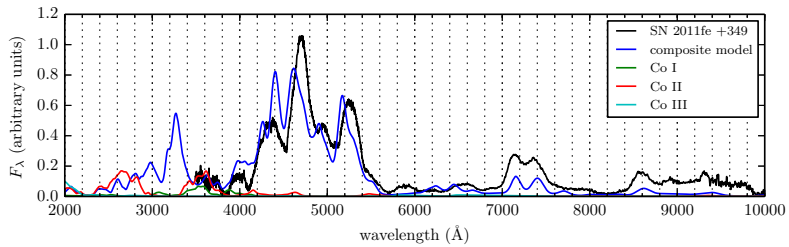
Day +349

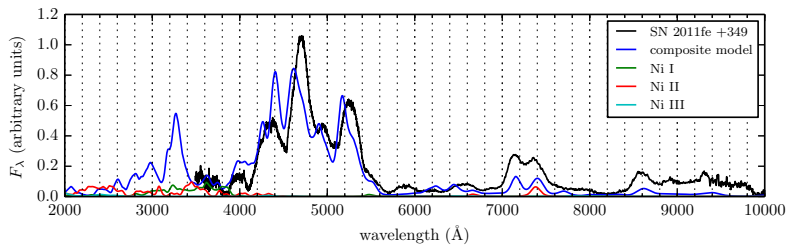

SN 2011fe +349
PHOENIX model, pah_std, day 376, forb coll rates
F_λ (arbitrary units)
wavelength (Å)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2000
3000
4000
5000
6000
7000
8000
9000
10000

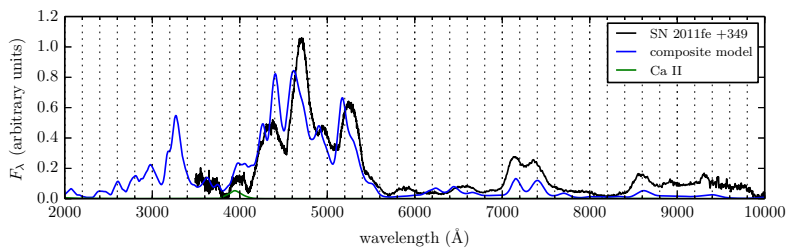
Day +349 Line IDs



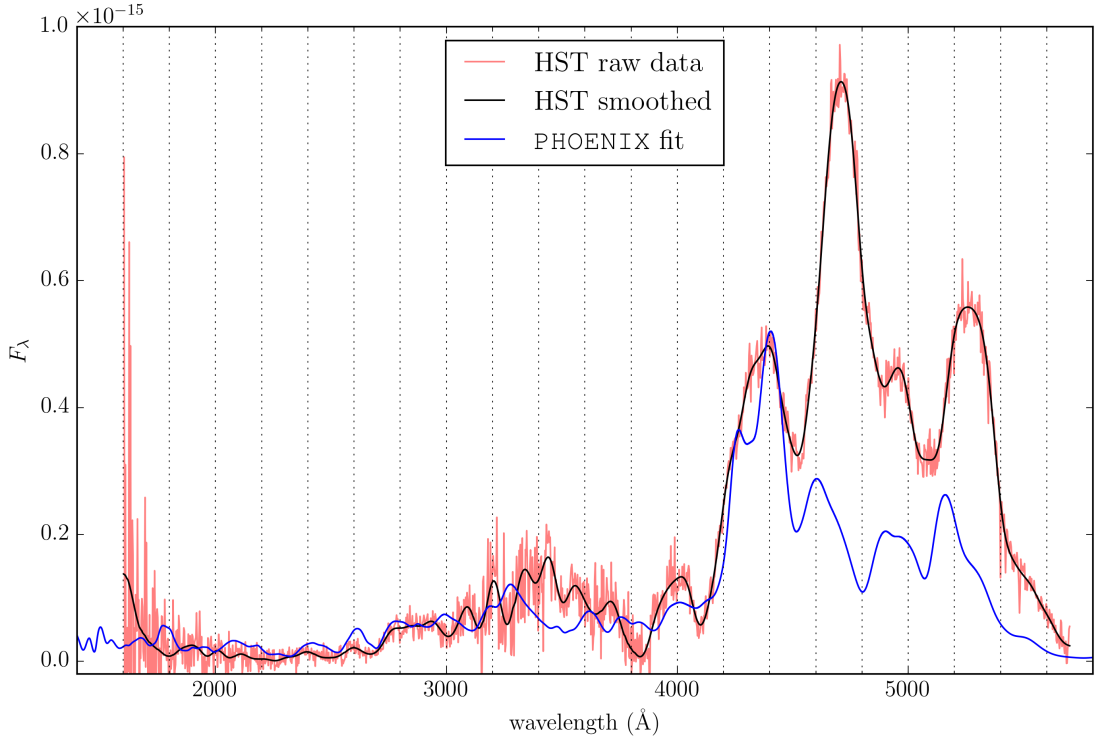




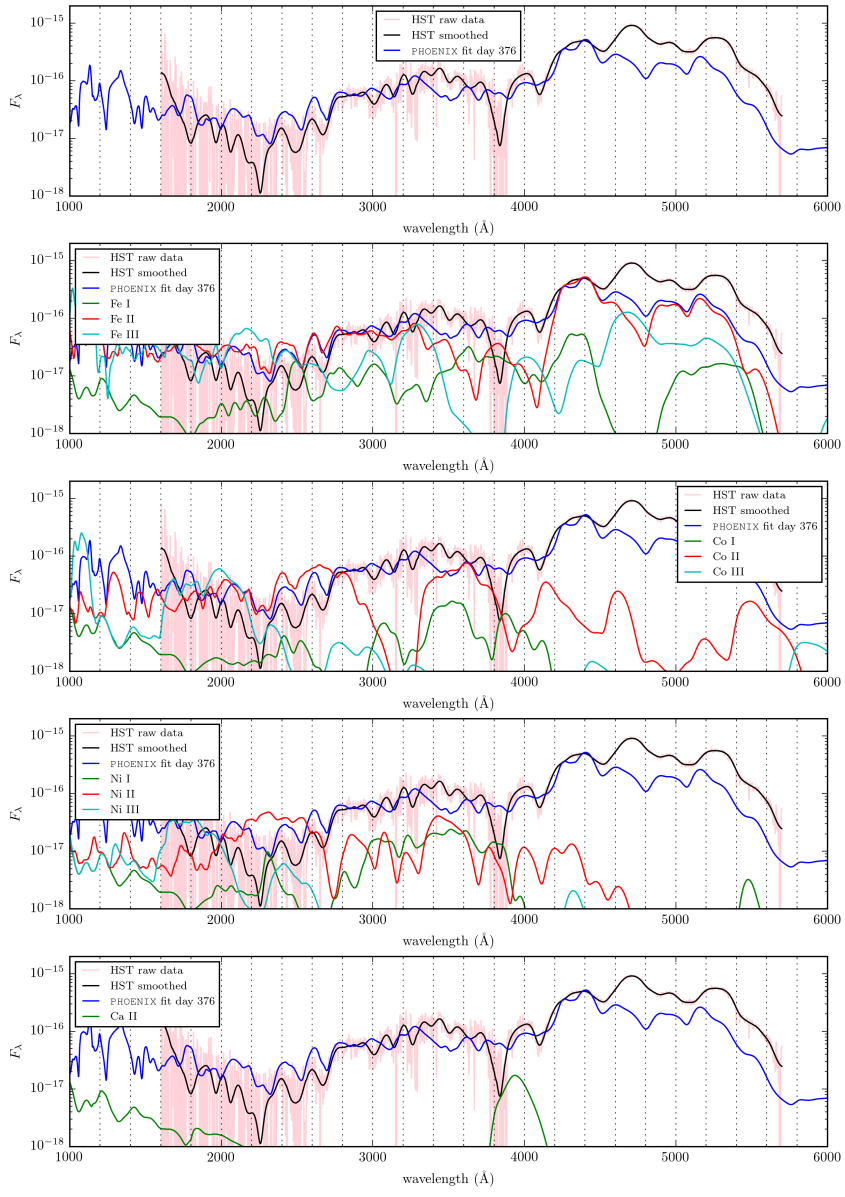




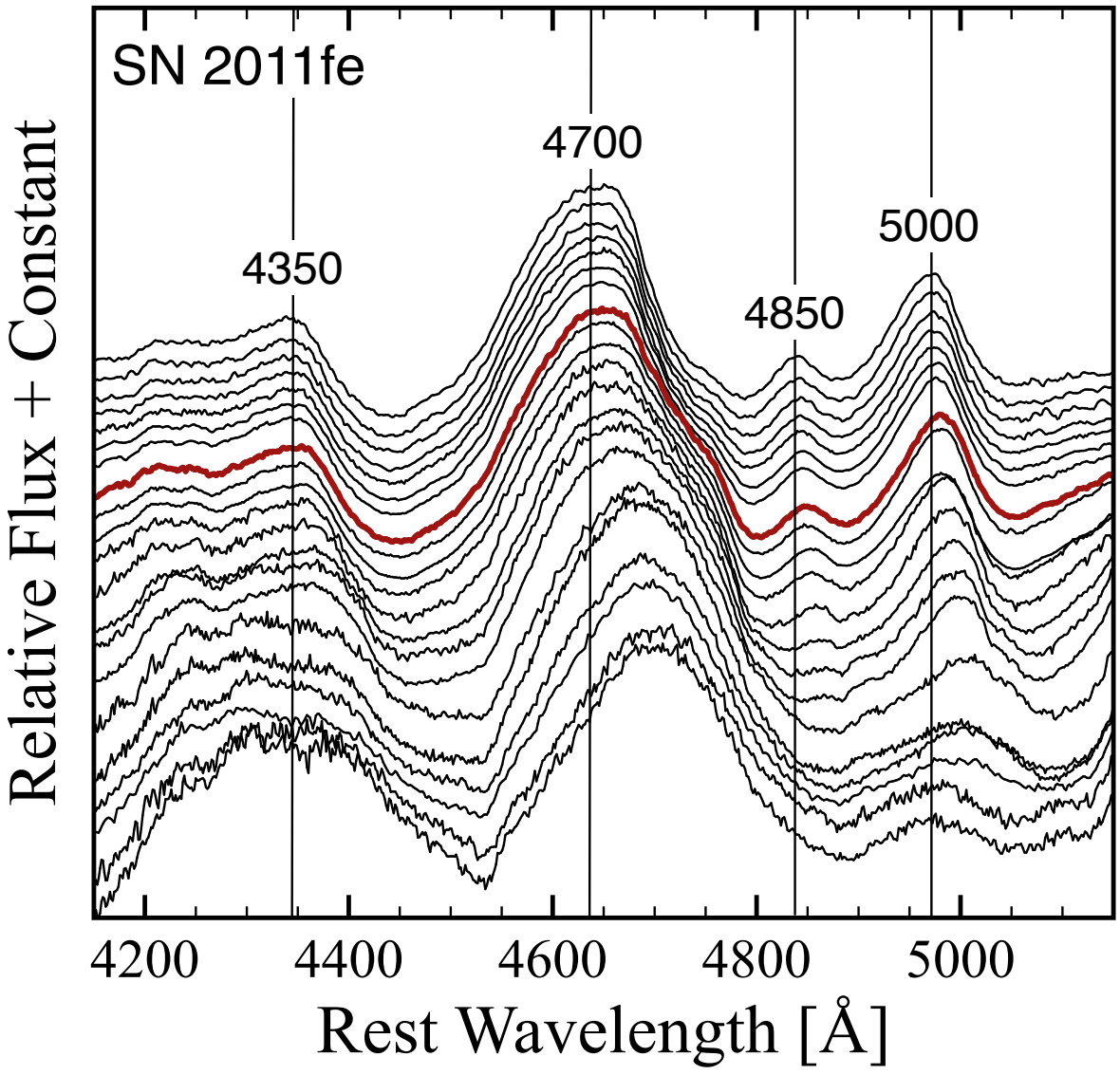
Day +360


HST raw data
HST smoothed
PHOENIX fit
$\times 10^{-15}$
1.0
0.8
0.6
0.4
0.2
0.0
F_λ
2000
3000
4000
5000
wavelength (Å)

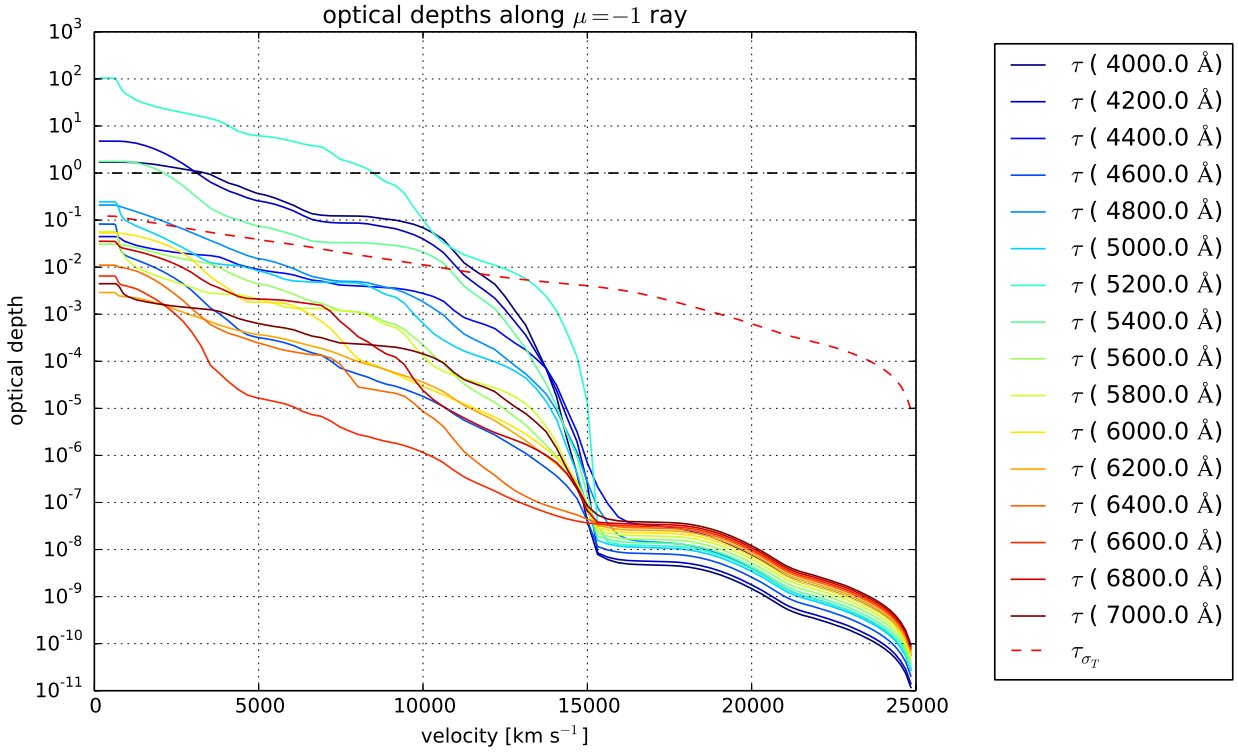
Day +360 Line IDs



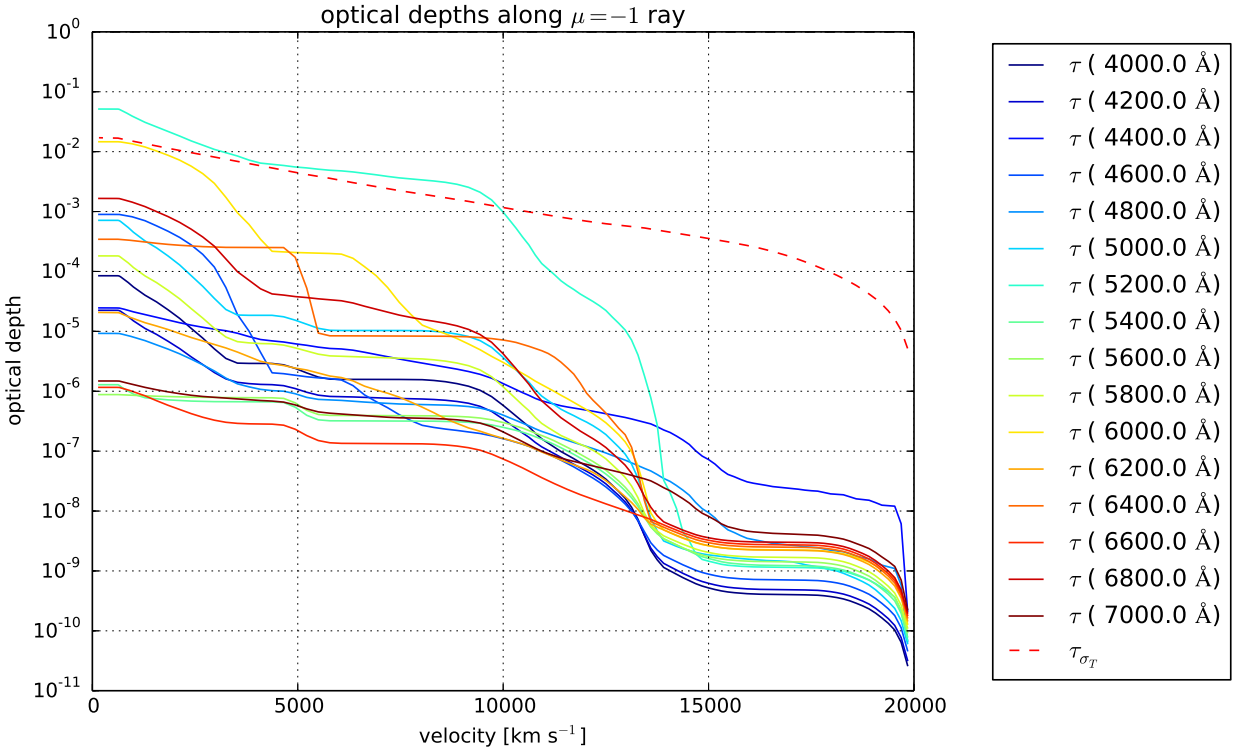
Black et al 2016



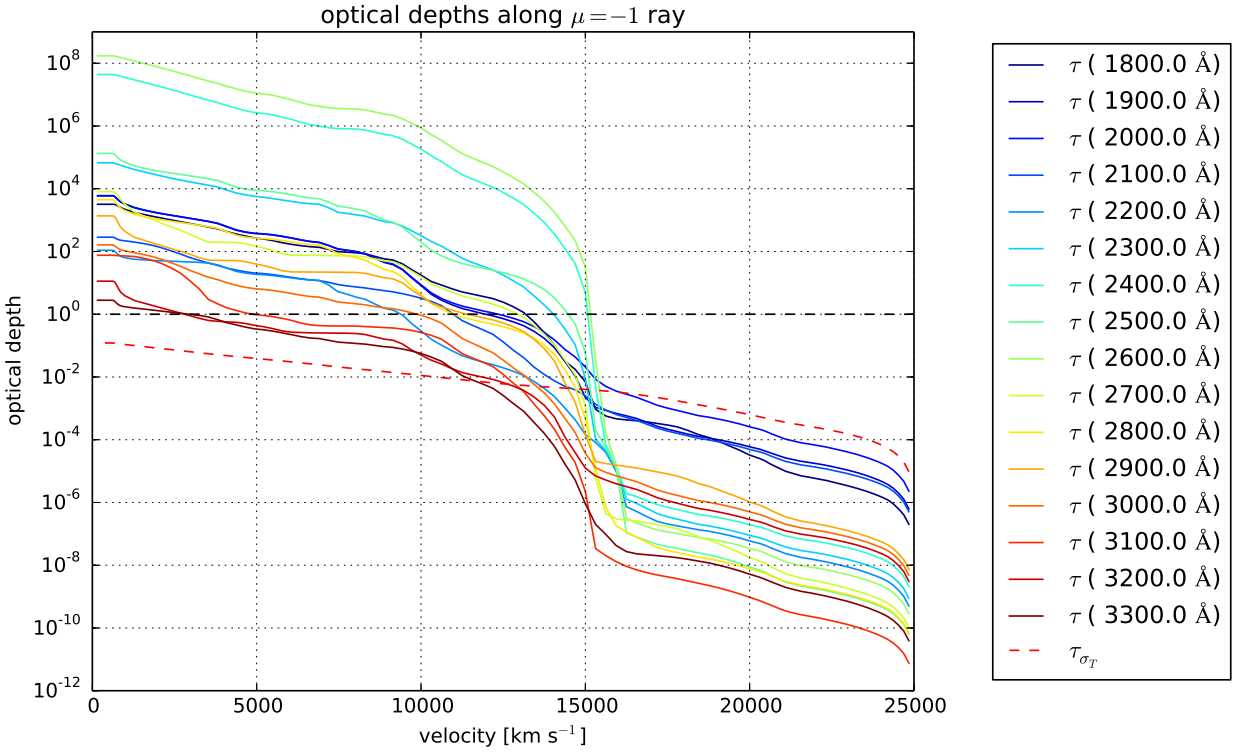
Optical τ Day +100



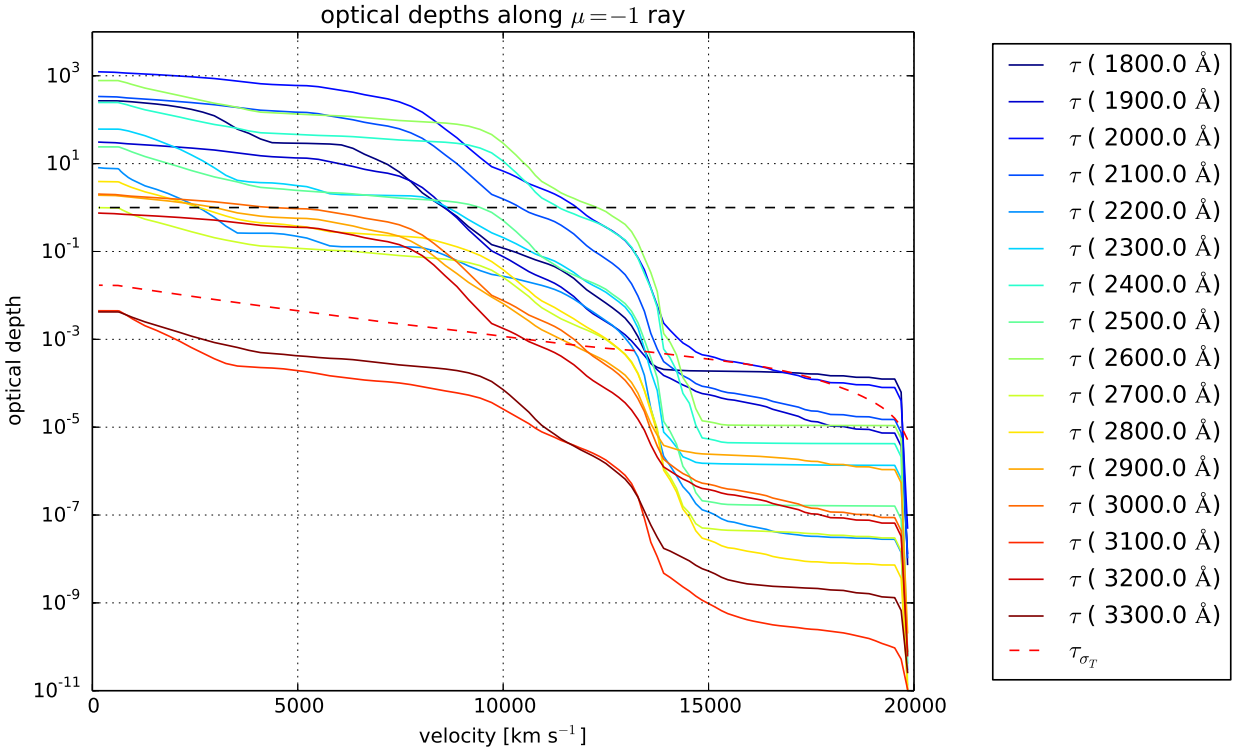
Optical τ Day +349



UV τ Day +100



UV τ Day +349



Summary

- SN 2011fe Core Normal SN Ia
- Reasonably well fit from early to late times with DD with somewhat low metallicity
- Thick to nebular transition is complex and wavelength dependent
- Late time Line IDs are complex

Domínguez, I., Hoeflich, P., & Straniero, O. 2001, ApJ, 557, 279

Marion, G. H., Höflich, P., Gerardy, C. L., Vacca, W. D., Wheeler, J. C., & Robinson, E. L. 2009, AJ, 138, 727