Chemical stratification of Type Iax SNe

Barnabás Barna[1], Tamás Szalai[1], Yssavo Camacho-Neves[2], Saurabh W. Jha[2]
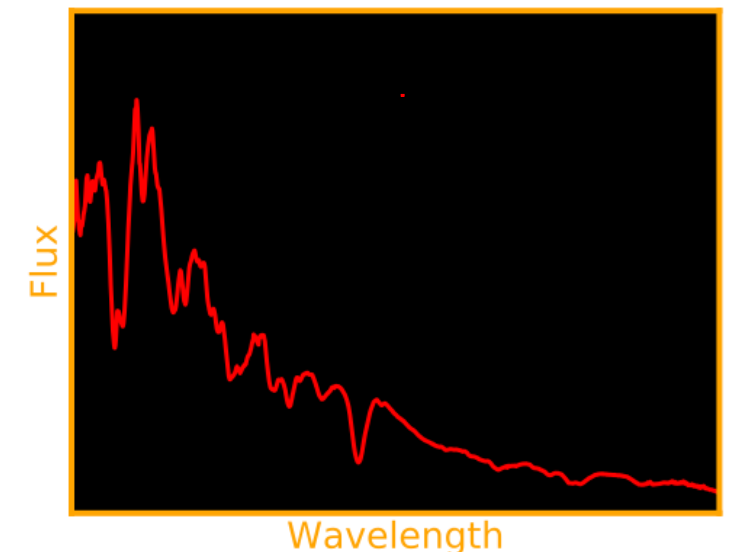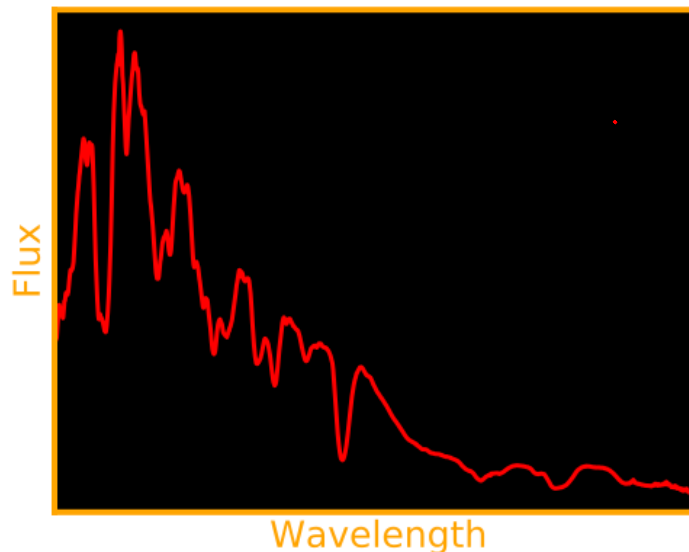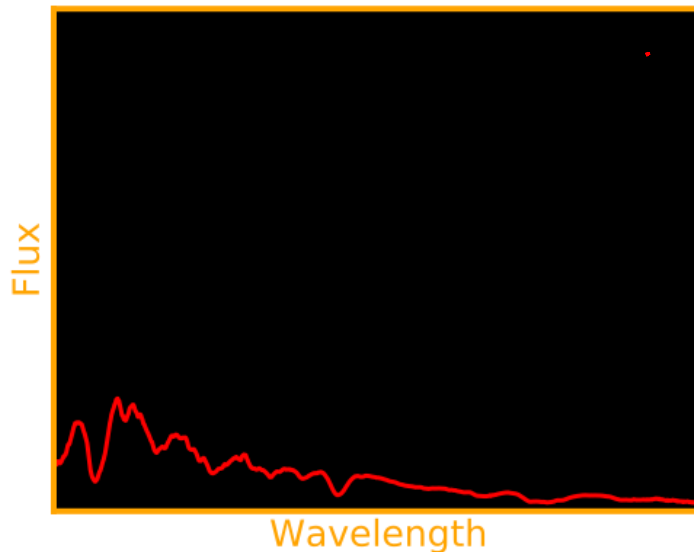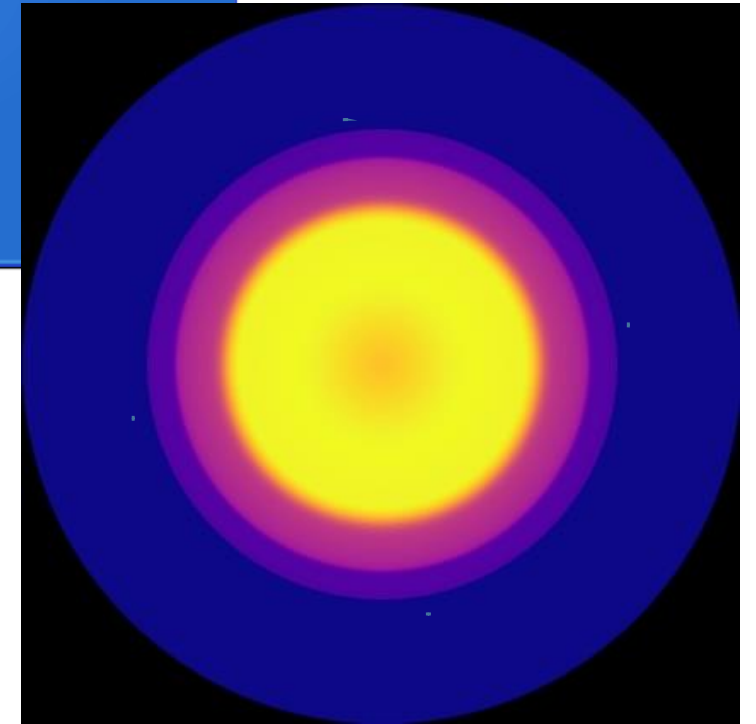
[1]University of Szeged, Hungary
[2]Rutgers, The State University of New Jersey, USA
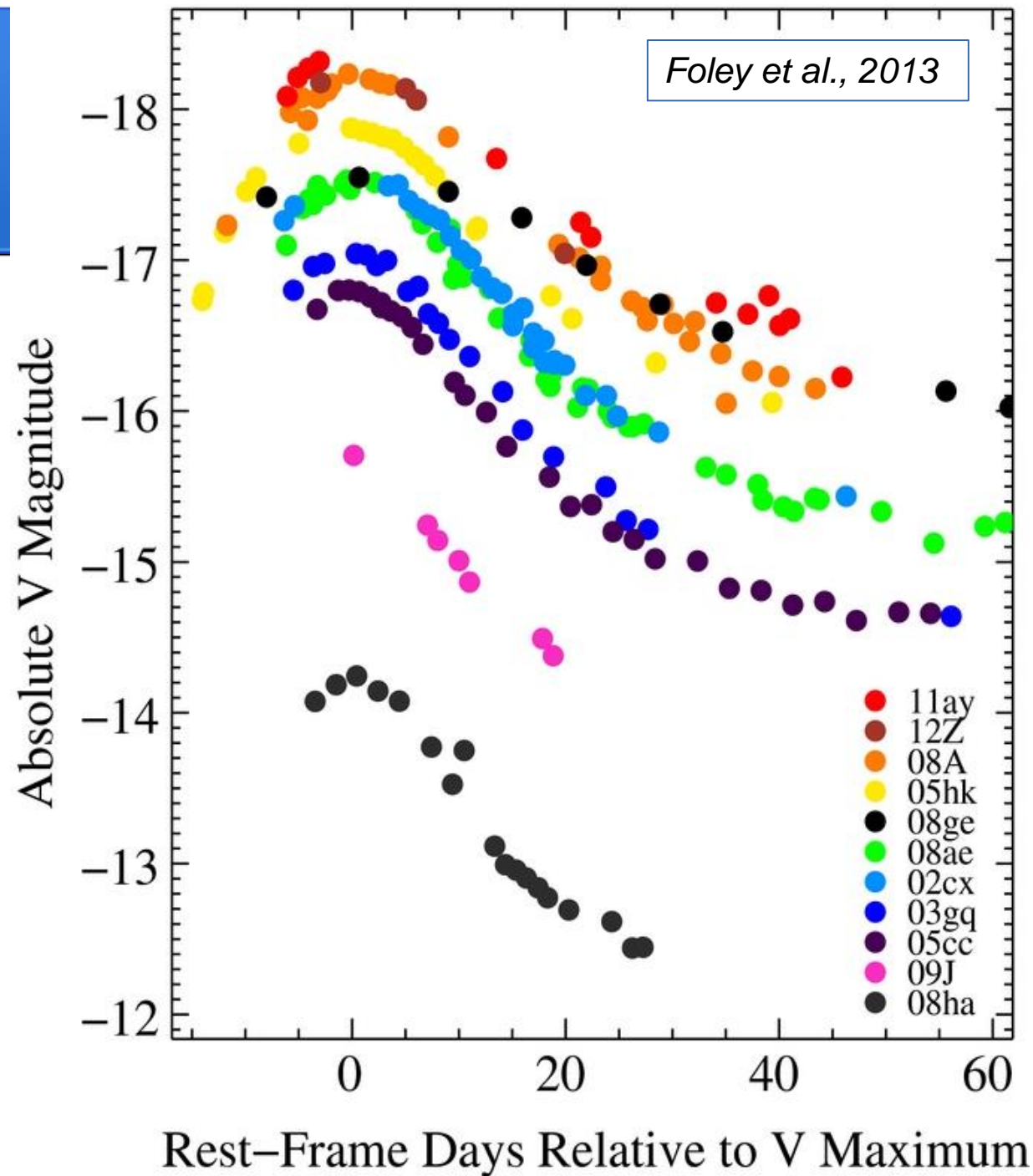
Abundance tomography

Structure: 1D, radial cells
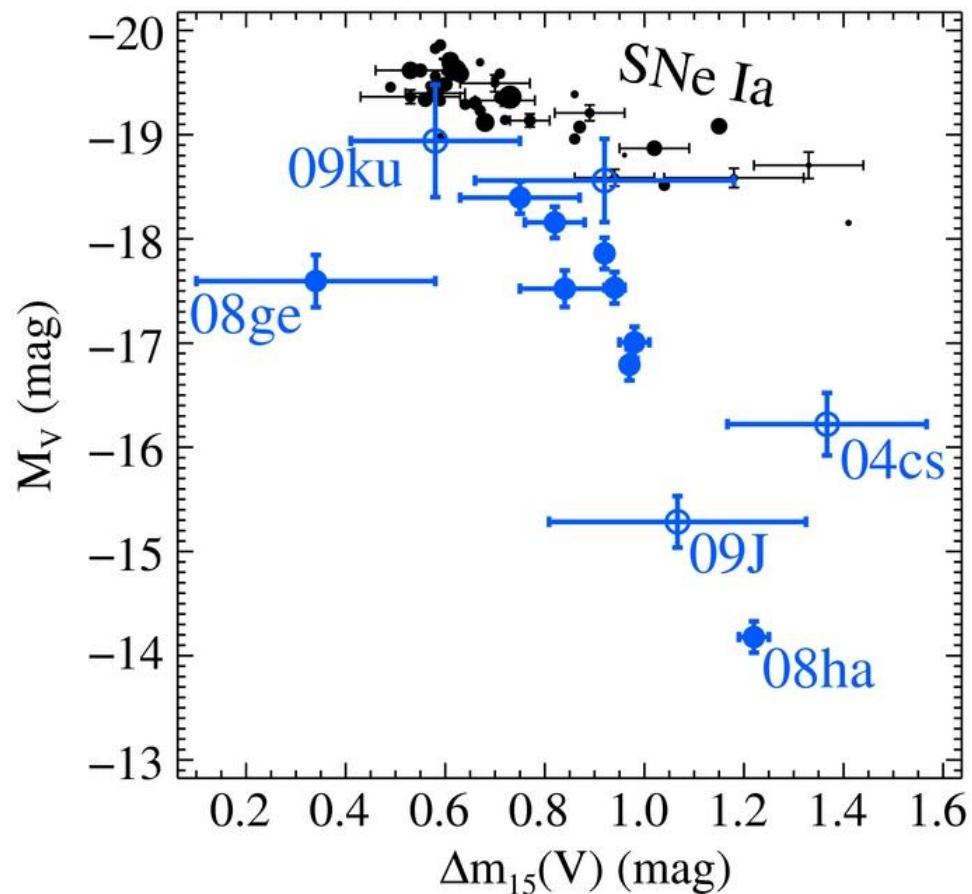- **Density-profile**
- **Chemical abundances**
(C, O, Si, Fe, 56Ni...)
- **+ Luminosity**
- **+ Photosphere**

Kerzendorf & Sim, 2014

TARDIS

Flux

Wavelength
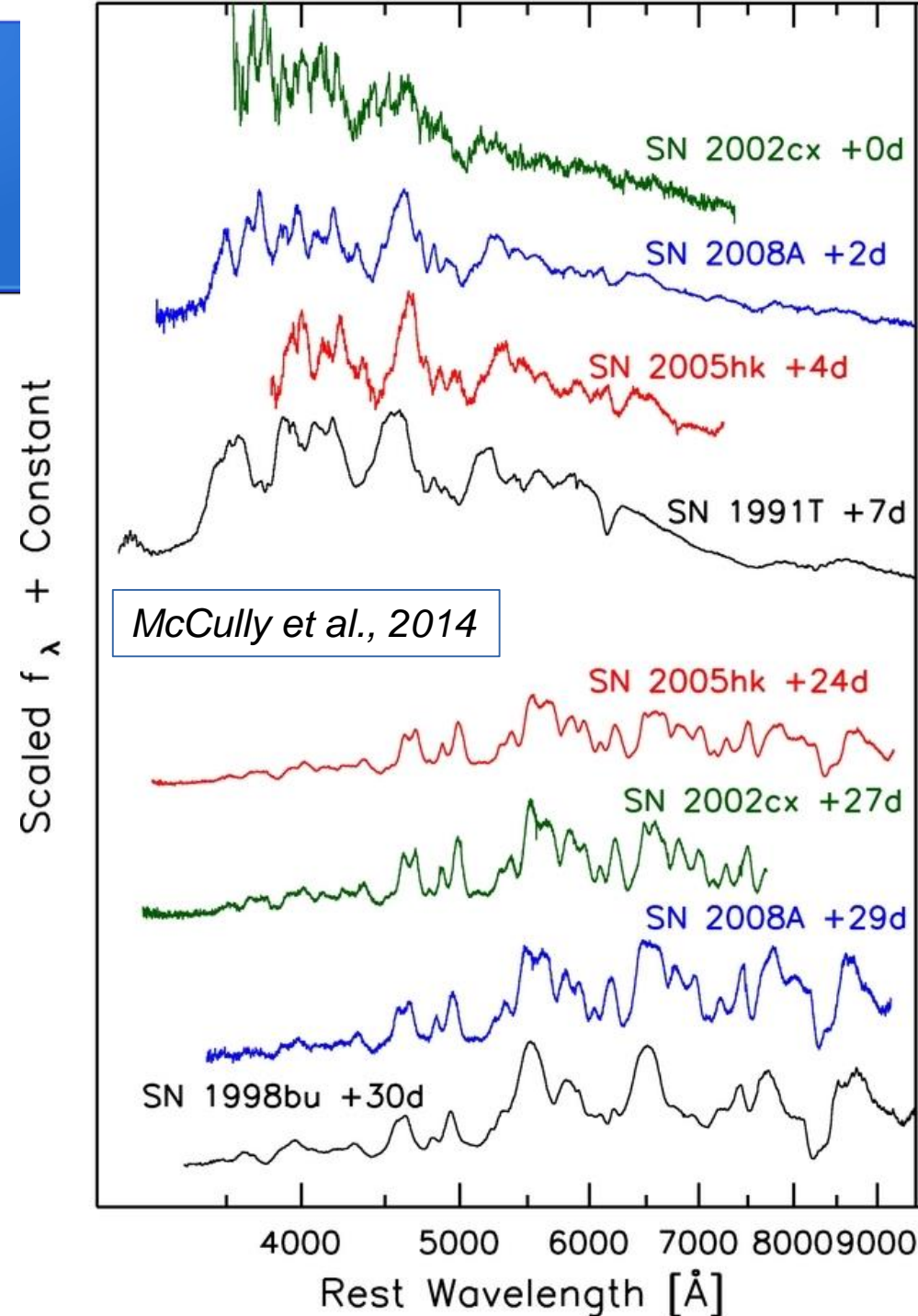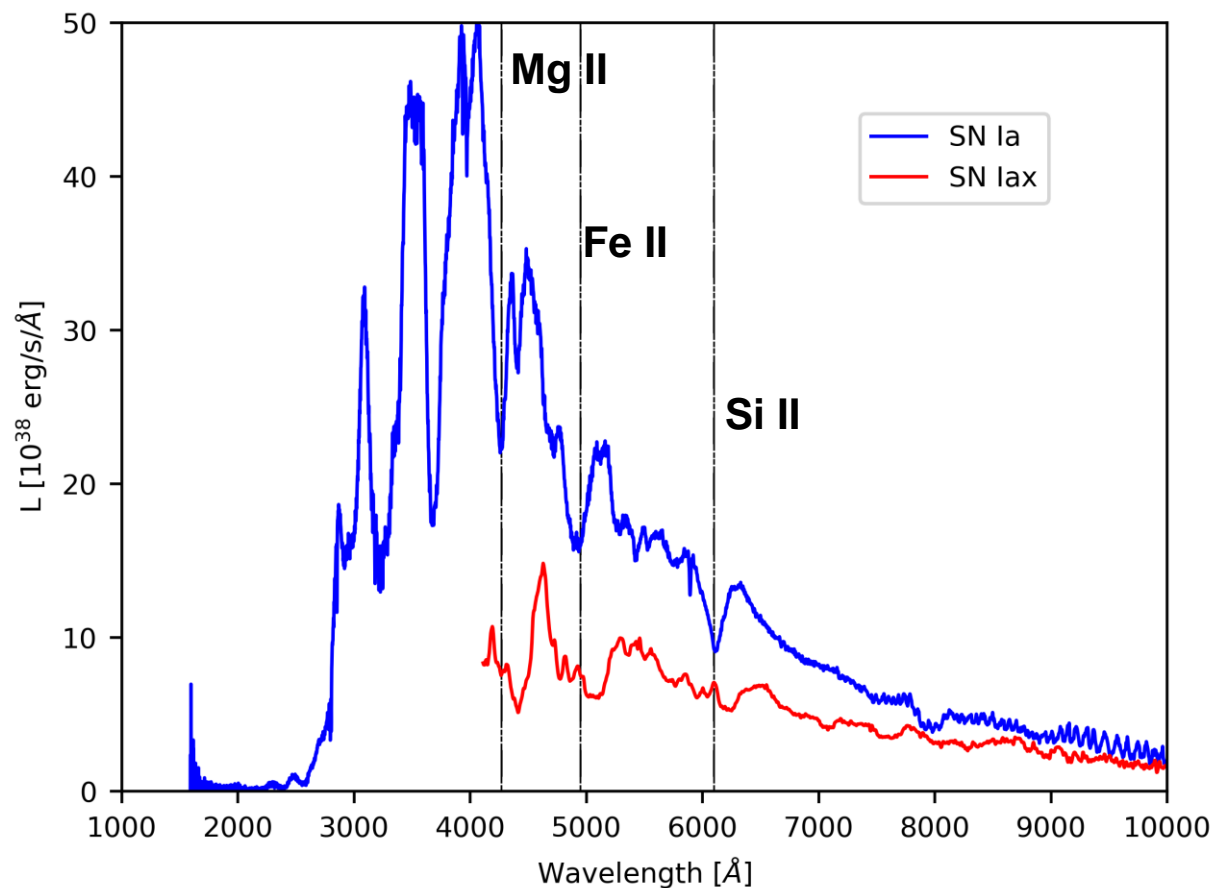
Flux

Wavelength

Flux

Wavelength

Type Iax SNe

- Faint objects: high diversity

- $-14.5 > M_V > -18.5$ mag

Foley et al., 2013

Type Iax SNe

- Low expansion velocities: high diversity

- 2000 km/s $< v_{phot} < 9000$ km/s

McCully et al., 2014

Deflagration models

Ignition region inside WD

2.5e7 cm

N1def N3def N5def N10def N20def N40def

N100def N150def N200def N300Cdef N1600def N1600Cdef
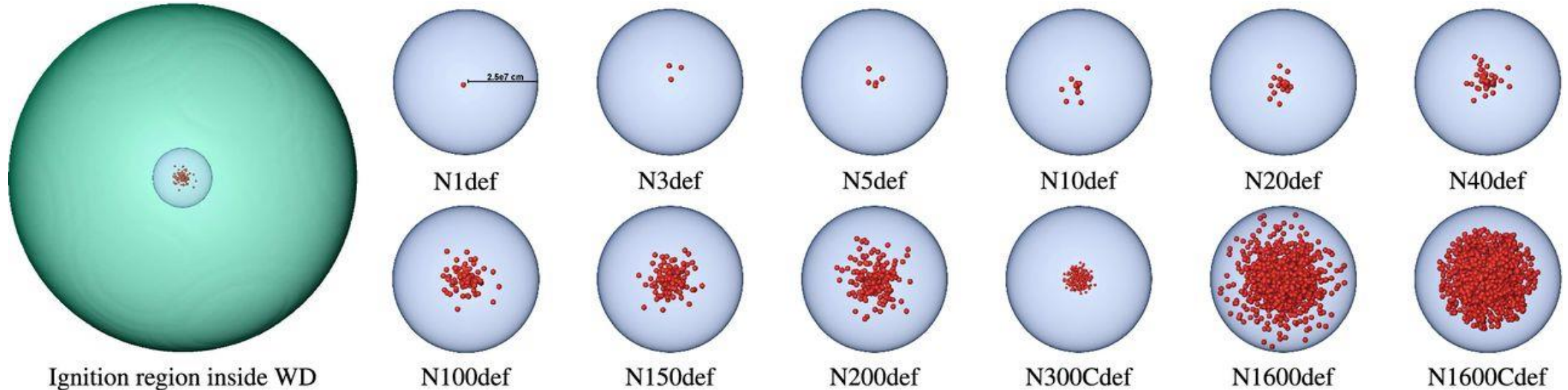
- Wide range of physical properties
- "Failed" SNe
- Strongly mixed ejecta
- <u>Uniform abundances</u>
- <u>Strong carbon abundance</u>

more energetic explosions

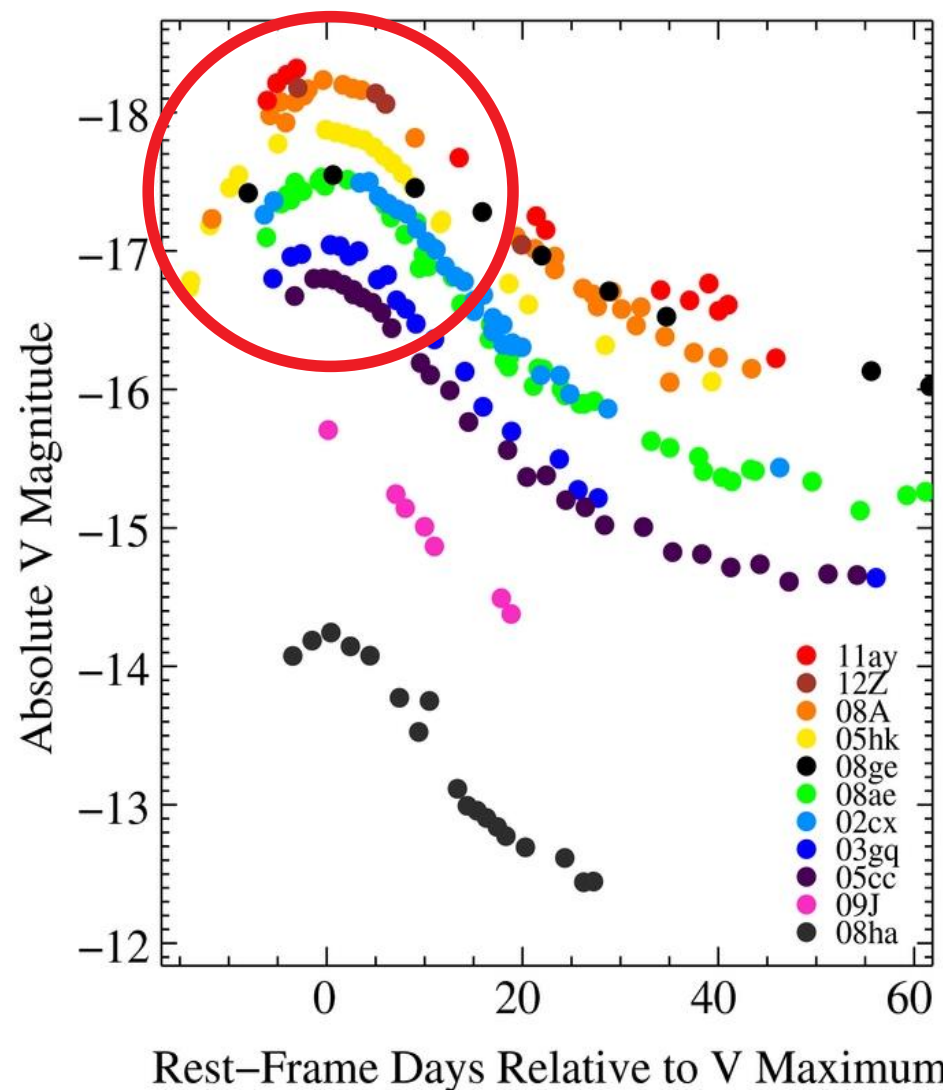| Model	M_{ej}	M_b	M_{56Ni}	M_{IGE}	M_{IME}
N1def	0.0843	1.32	0.0345	0.0468	0.00893
N3def	0.195	1.21	0.0730	0.106	0.0257
N5def	0.372	1.03	0.158	0.222	0.0416
N10def	0.478	0.926	0.183	0.267	0.0581
N20def	0.859	0.545	0.264	0.394	0.125

Iax abundance tomography

Foley et al., 2013

- Spectral series: 3+ epochs
- Early epochs: before 5 weeks after explosion
- Distance & reddening
- Iax sample: *Barna et al., 2018*
- SN 2011ay, SN 2012Z, SN 2005hk, SN 2002cx, SN 2015H
- Starting values for the fitting process

Structure: 1D, radial cells
- **Density-profile**
- **Chemical abundances**
(C, O, Si, Fe, 56Ni...)
- **+ Luminosity**
- **+ Photosphere**

TARDIS

Legend:
- 11ay
- 12Z
- 08A
- 05hk
- 08ge
- 08ae
- 02cx
- 03gq
- 05cc
- 09J
- 08ha

Absolute V Magnitude

Rest−Frame Days Relative to V Maximum

Iax abundance tomography

- Testing the predictions of deflagration models
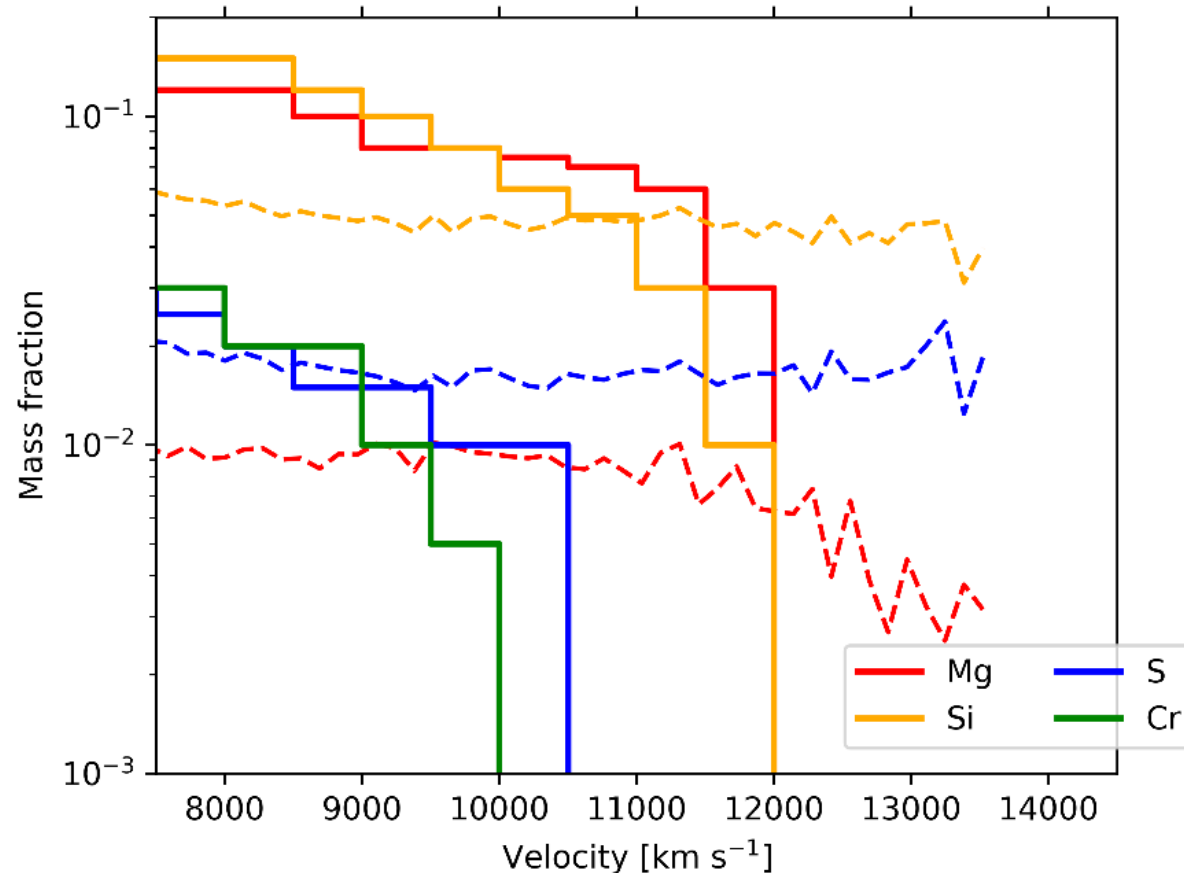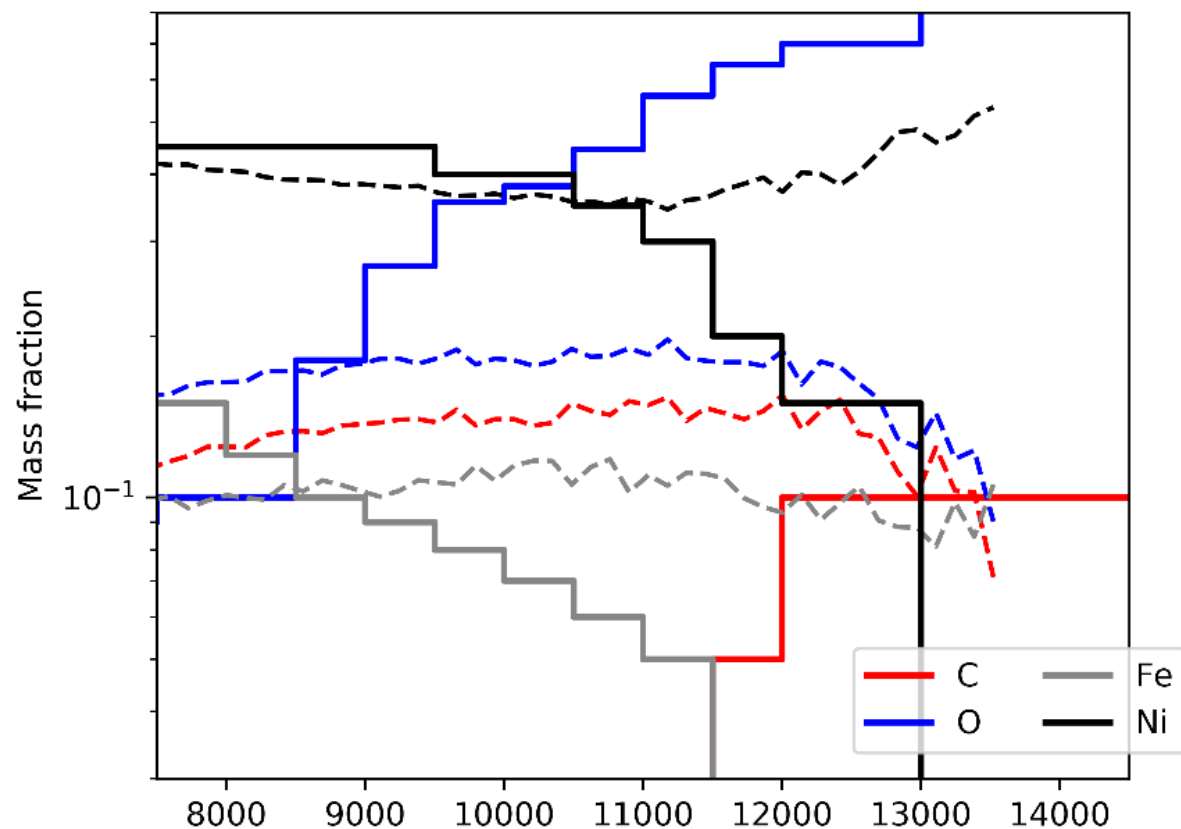- Precise line identification
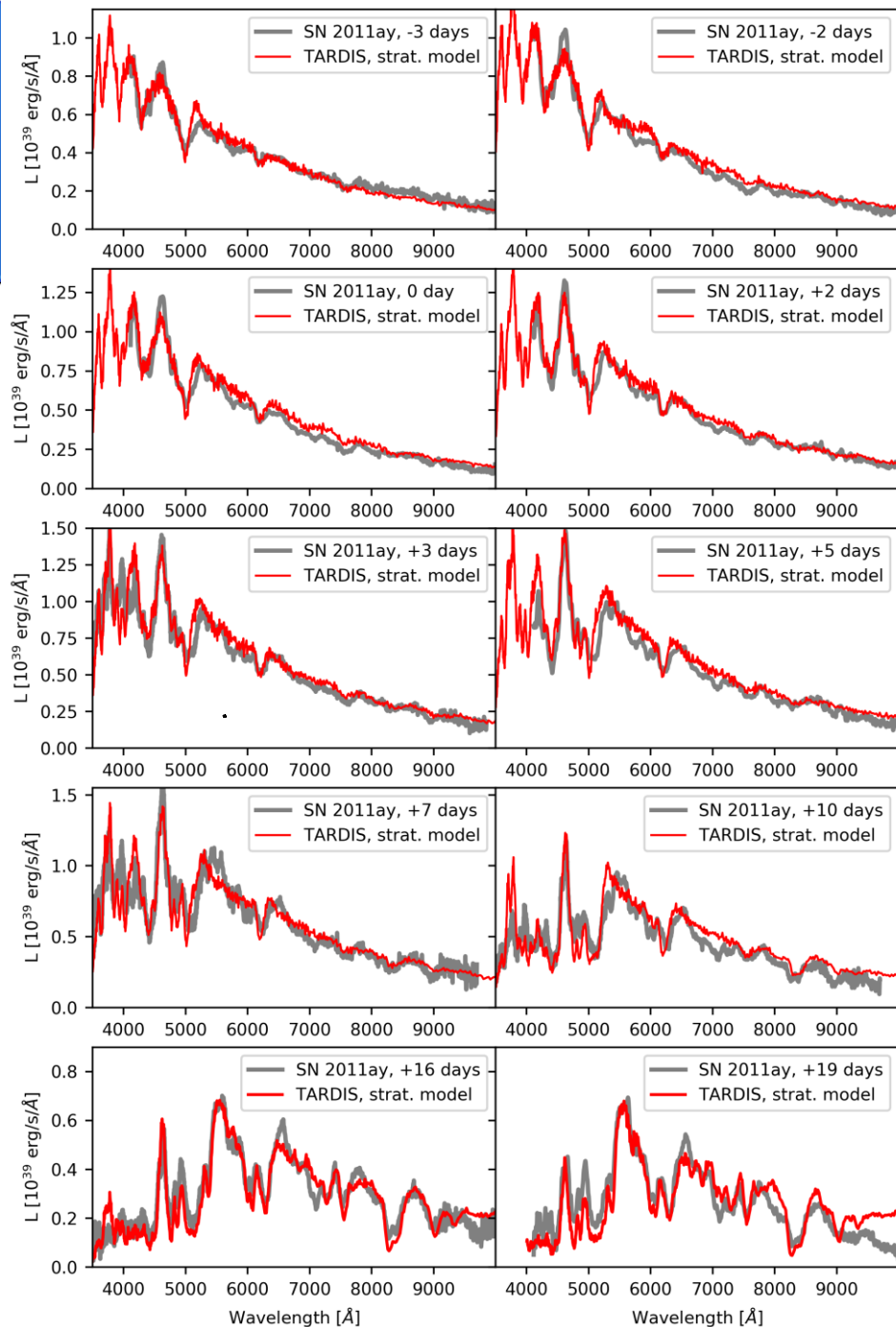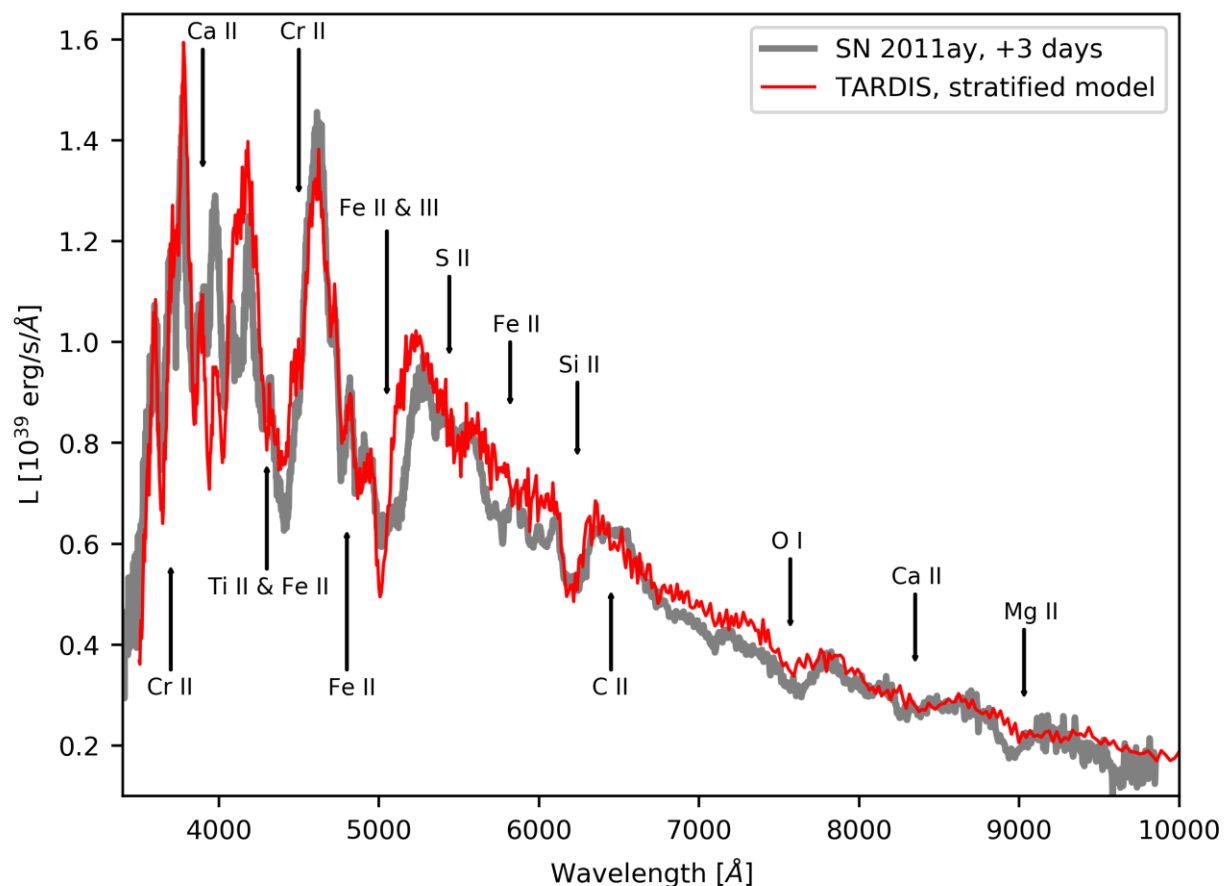
Best-fit abundance profile

- Not constant profiles in the outer region
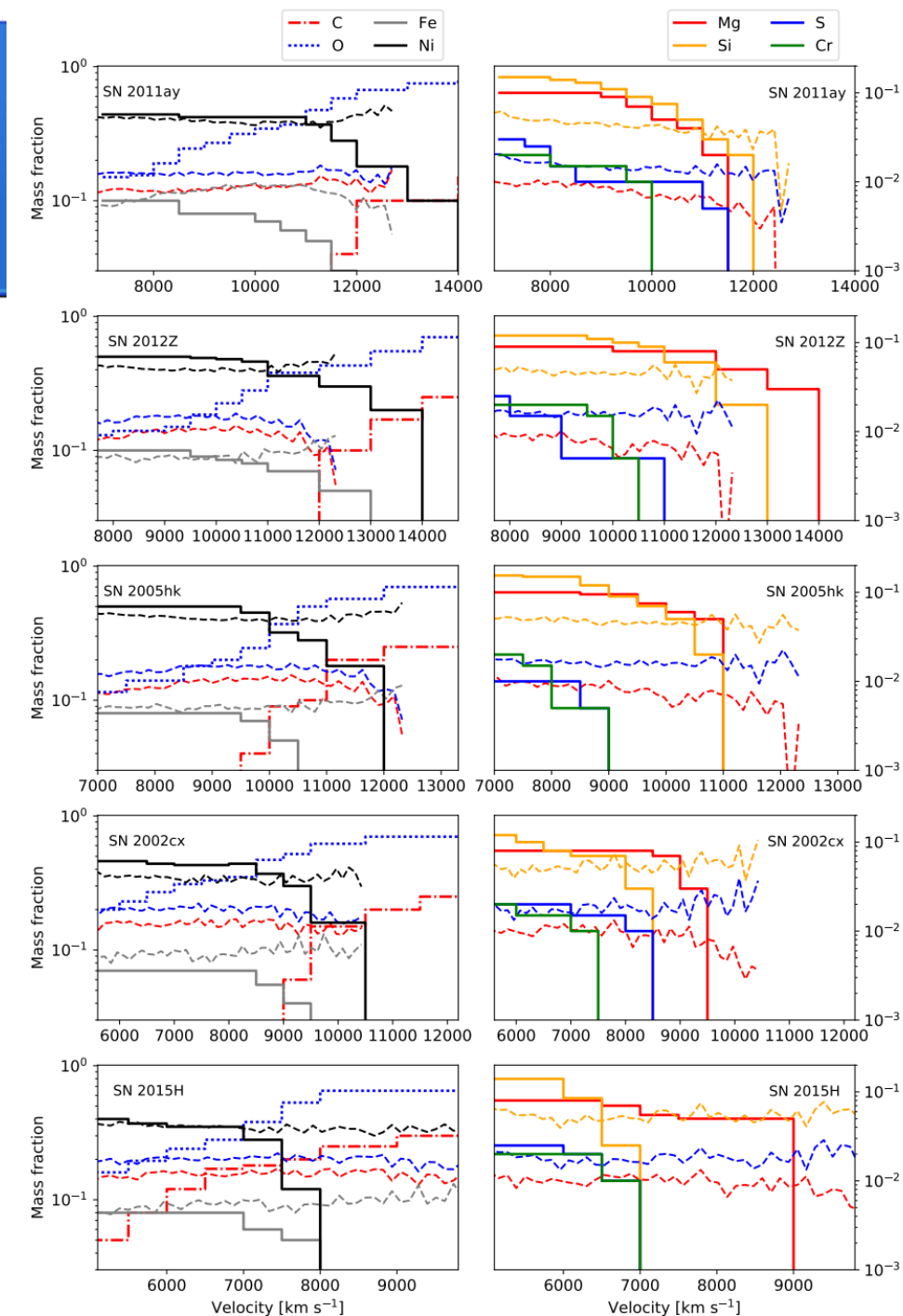- Lack of carbon in the inner region

Contradicting the predictions...

Deflagartion model: - - - lines
TARDIS model: lines

Stratified abundance profile

- Extending the analysis for the sample of 5 SNe
- Similar abundance features at different velocities
- Choosing a reference velocity

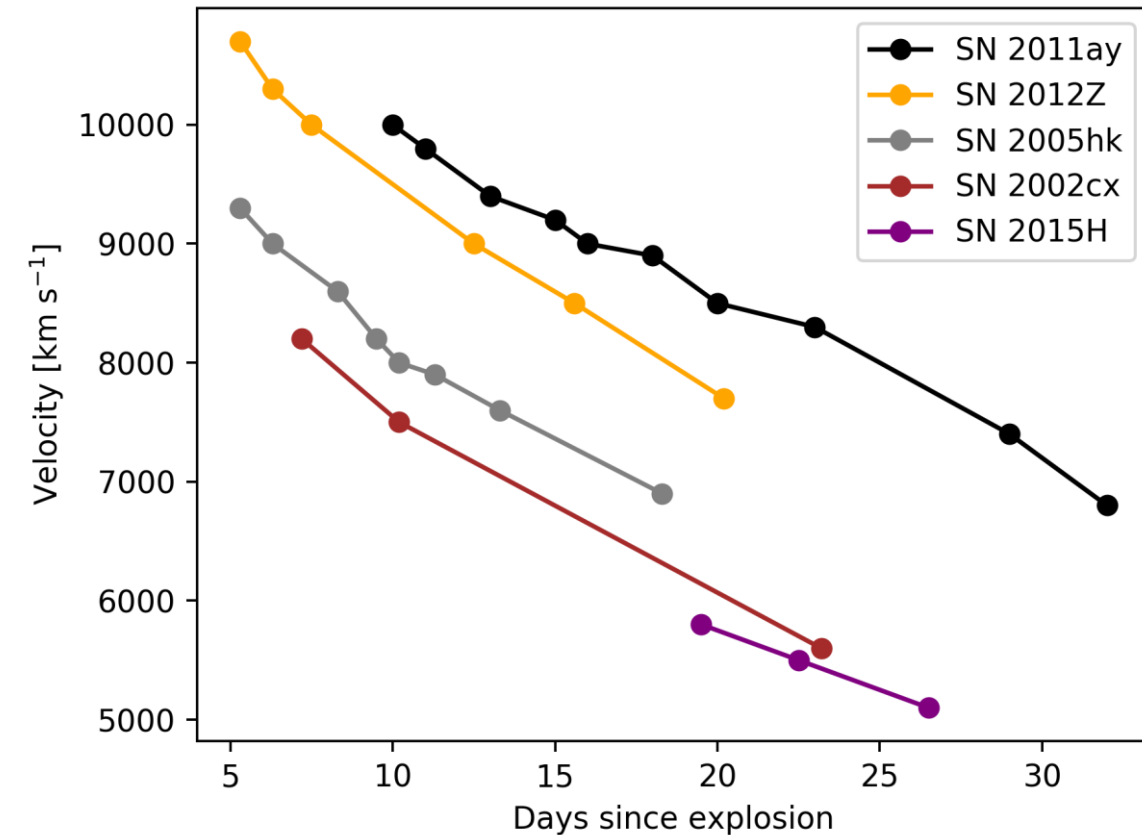# Stratified abundance profile

- Extending the analysis for the sample of 5 SNe

- Similar abundance features at different velocities

- Choosing a reference velocity

- "Averaged" abundance template >>> almost same goodness of fit for each SN

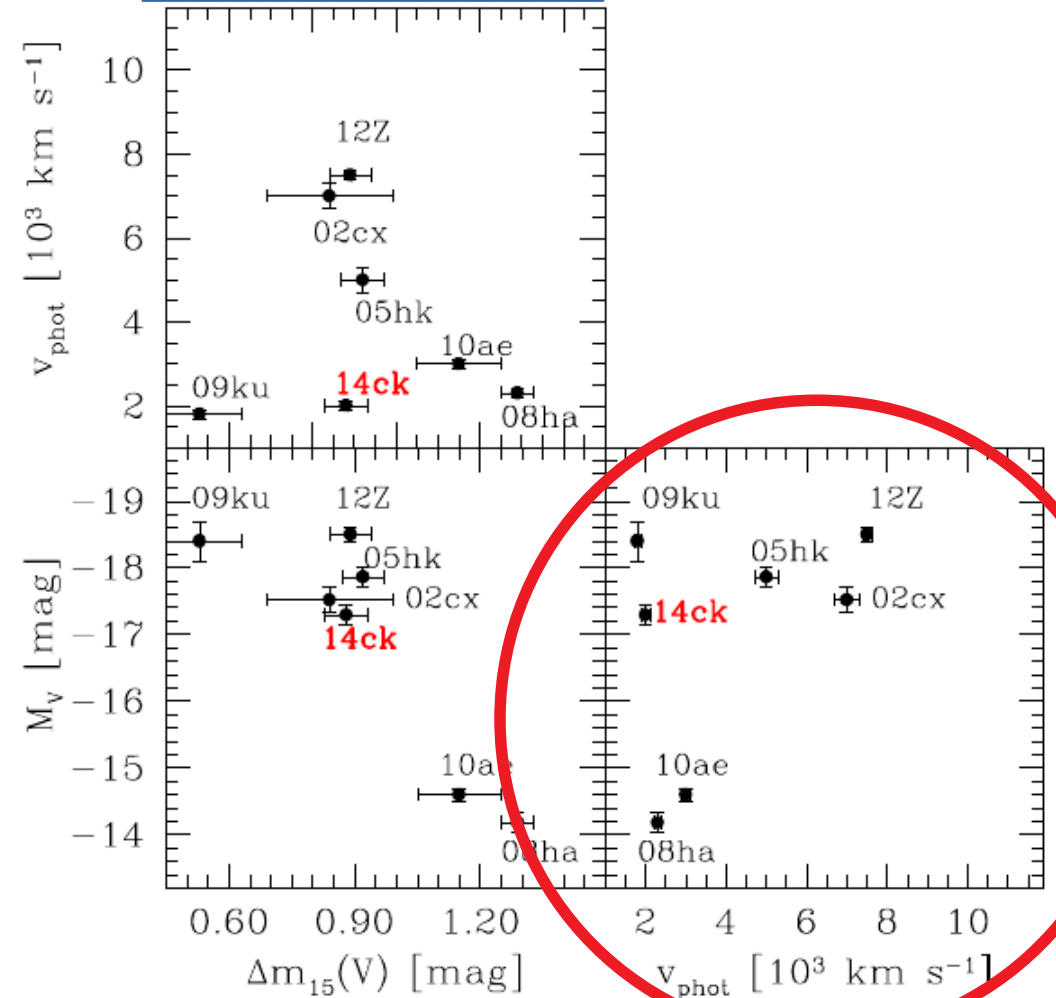**1 parameter for any lax abundance structures!**
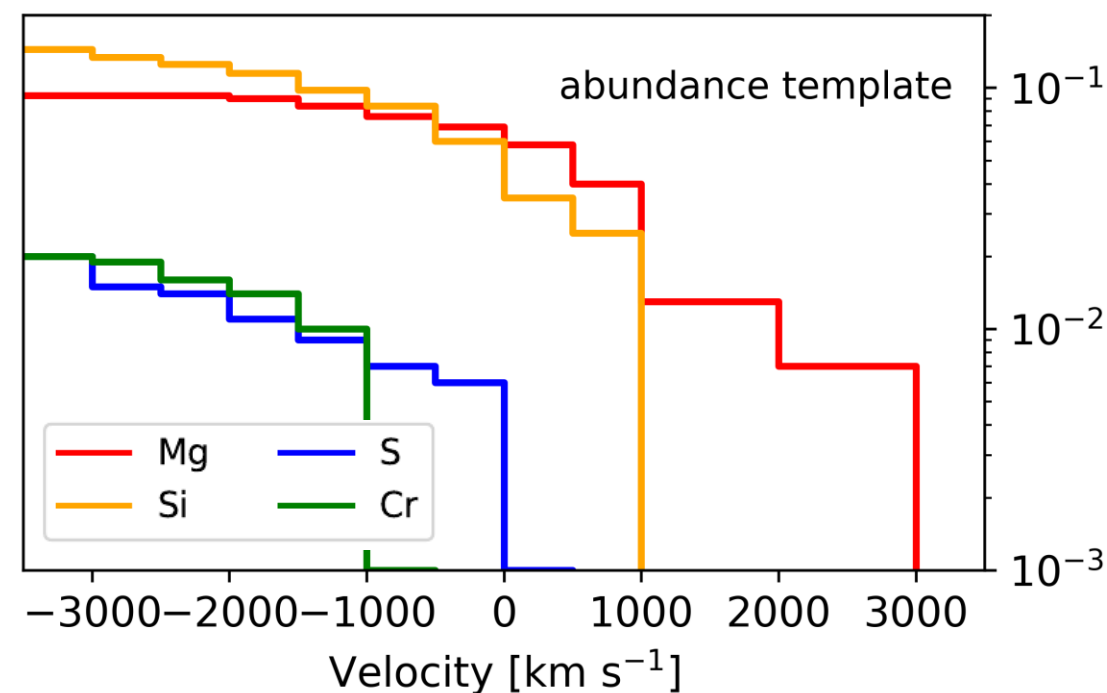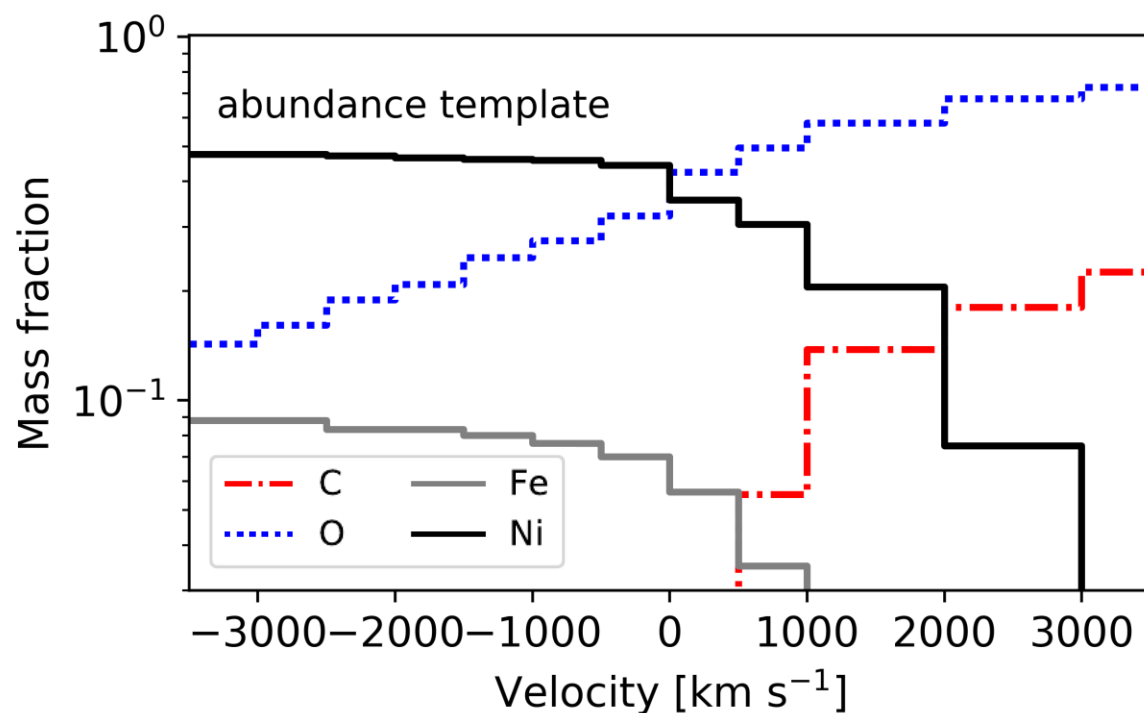
Luminosity - velocity relation?

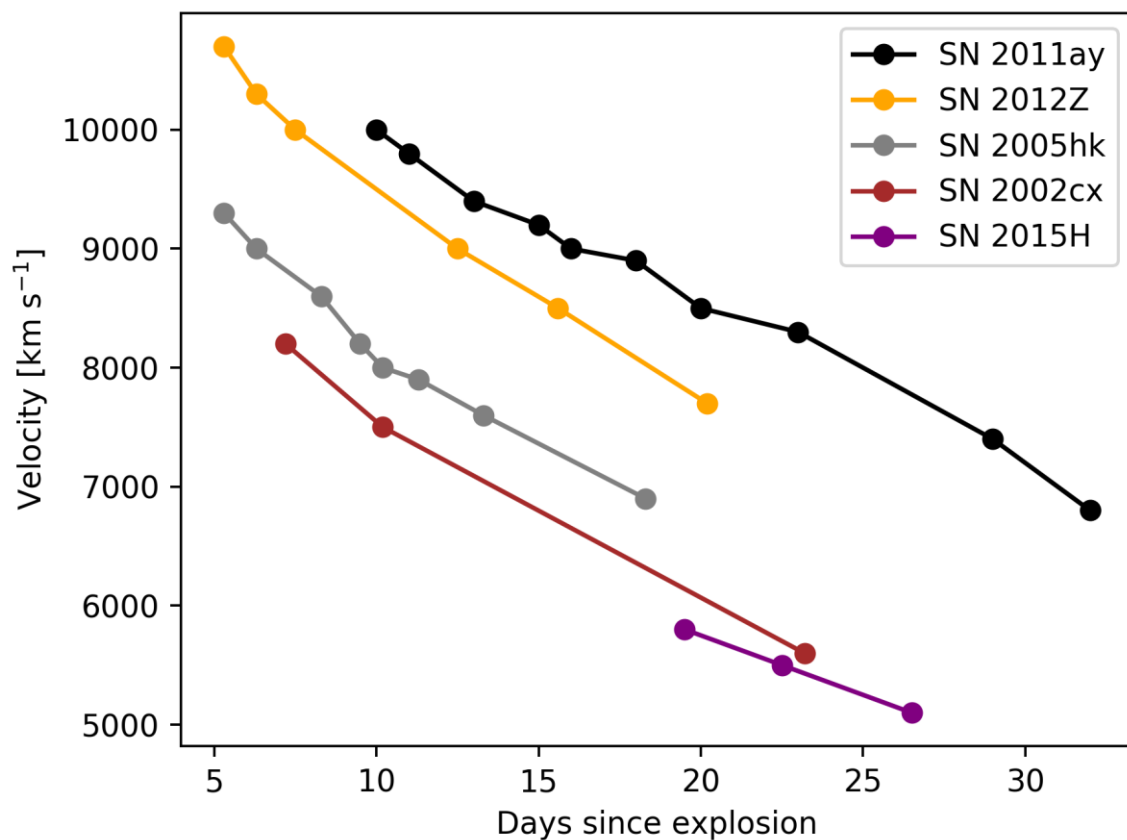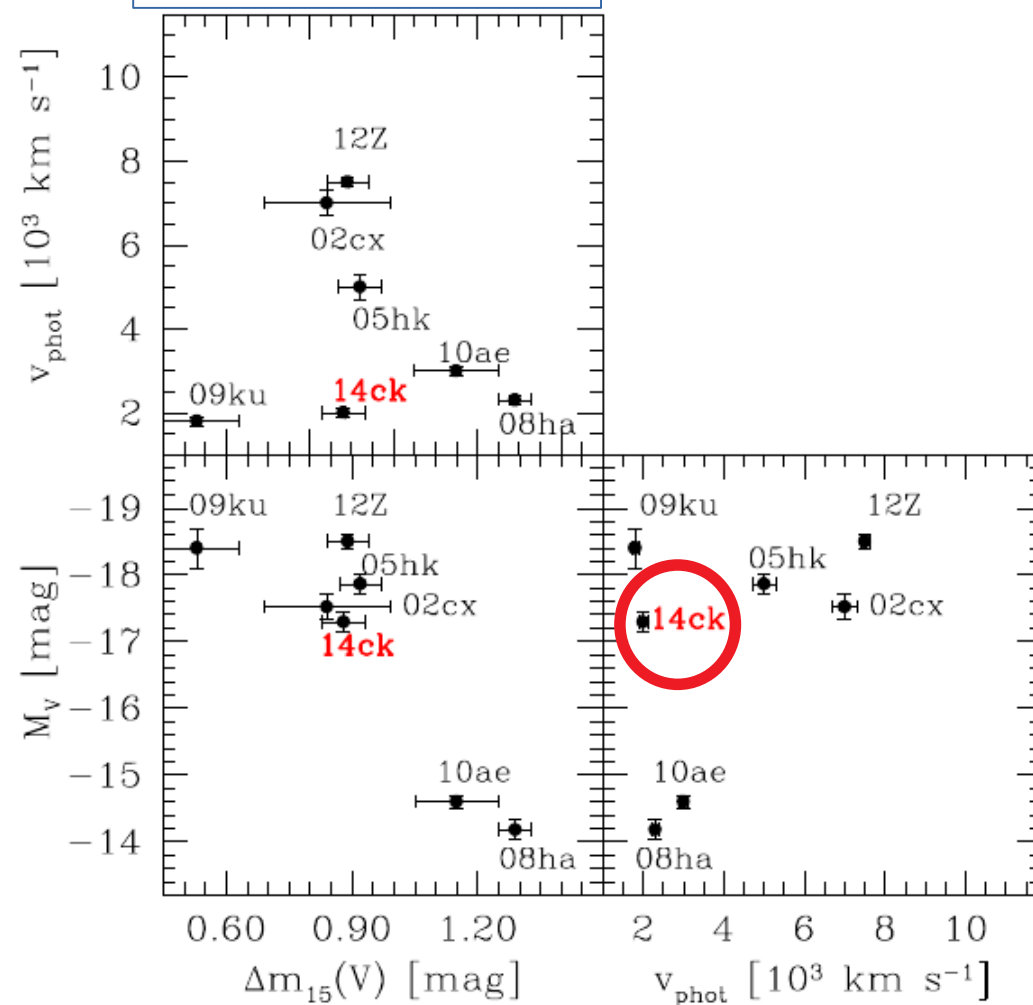- Outliers: SN 2014ck, SN 2009ku
- Tighter correlation

Tomasella et al., 2016

Luminosity - velocity relation?
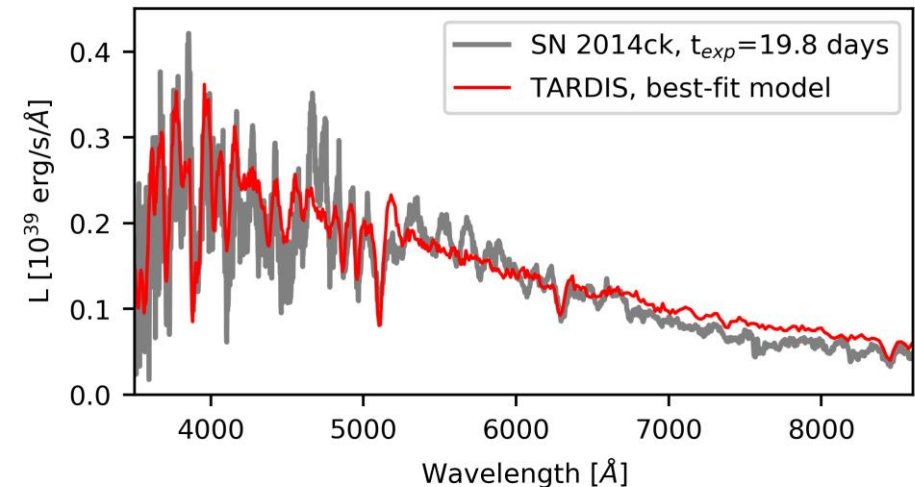
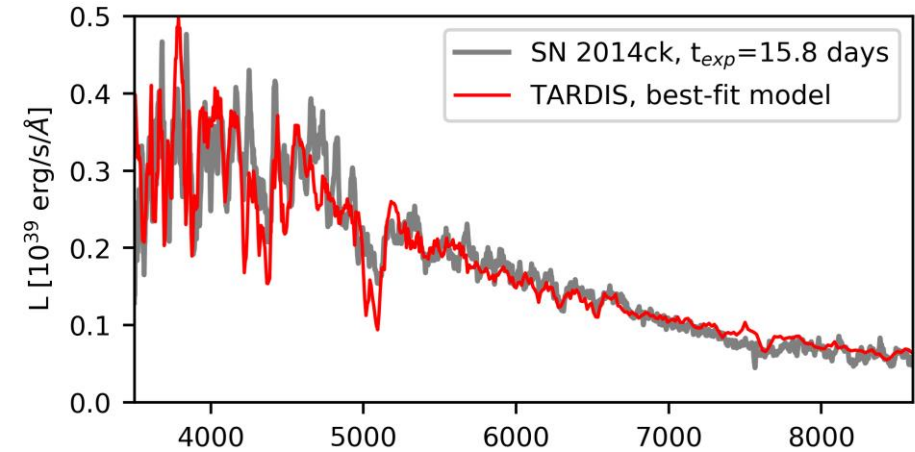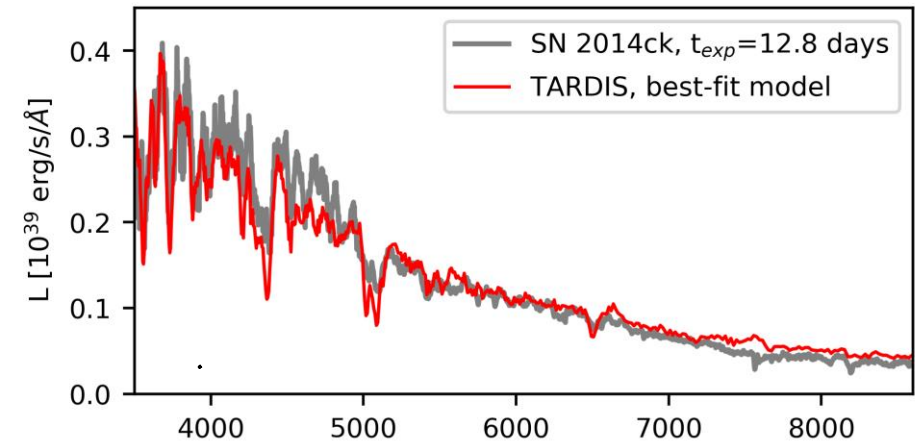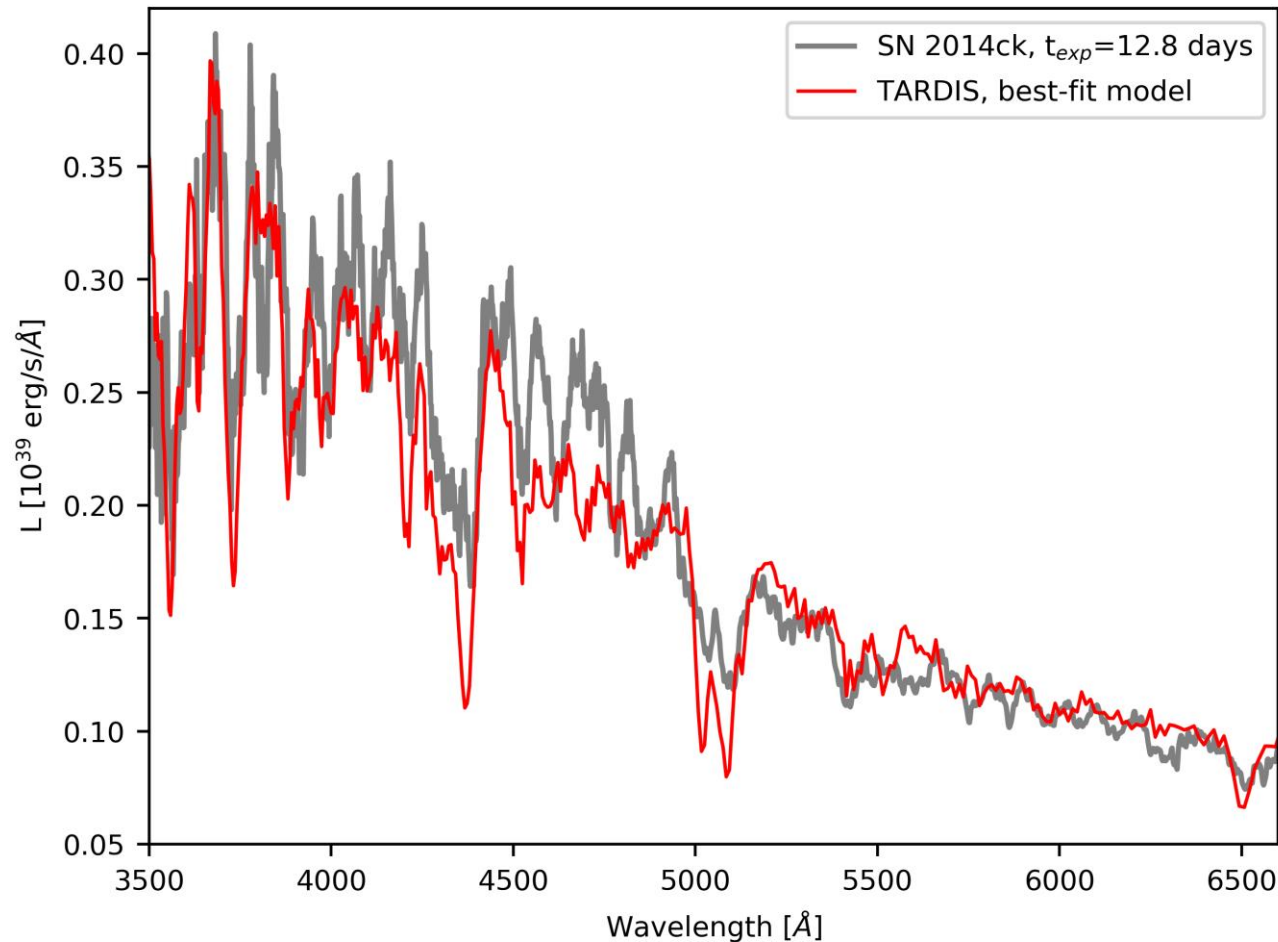- Outliers: SN 2014ck, SN 2009ku
- Tighter correlation

Tomasella et al., 2016

more luminous SNe

Luminosity - velocity relation?
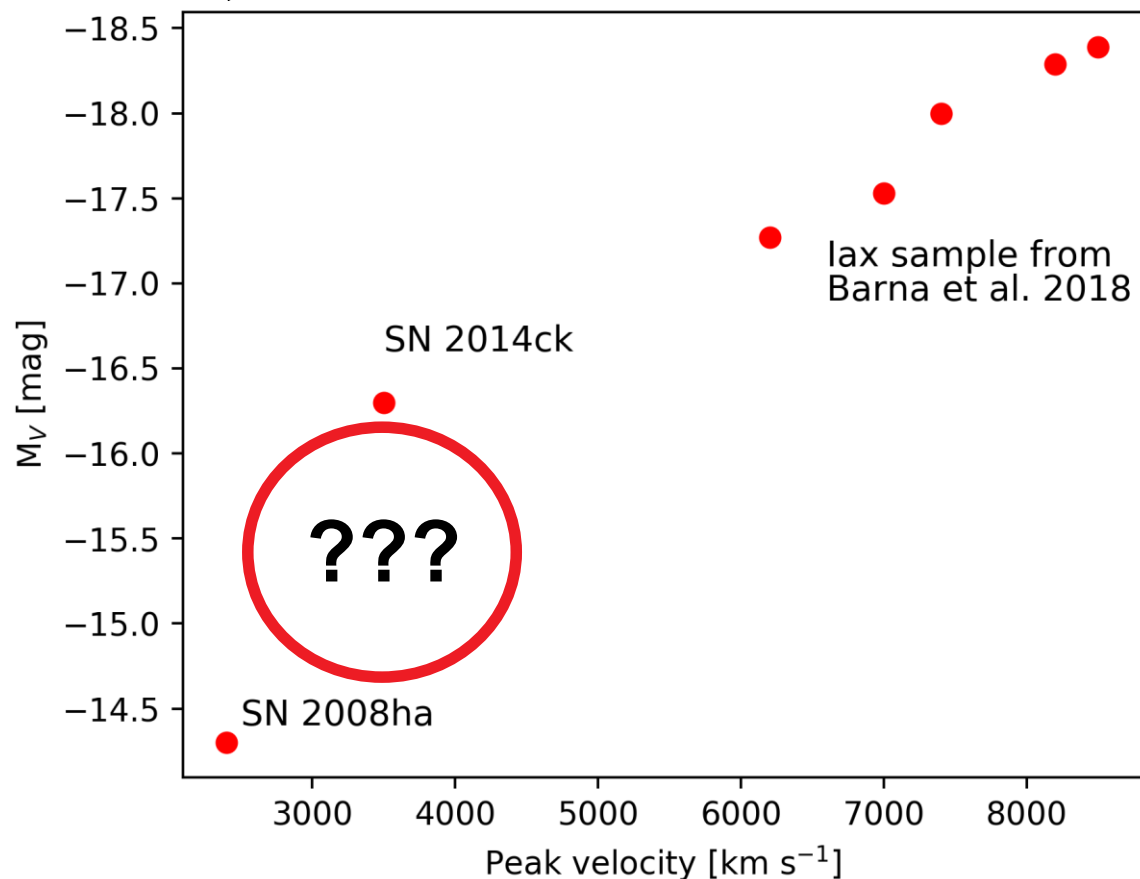
- Tighter correlation
- Outliers: SN 2014ck, SN 2009ku

Luminosity - velocity relation?

- Tighter correlation! **Distance indicators?**
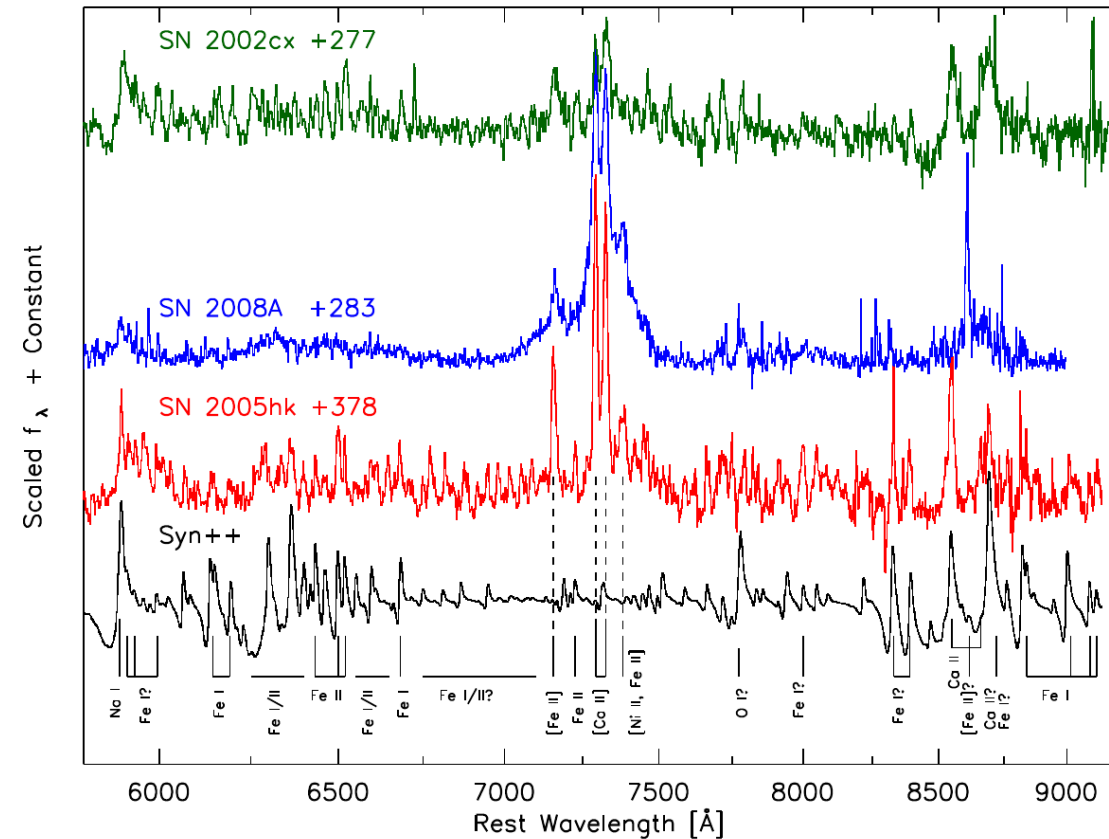- Outliers: SN 2014ck, SN 2009ku
- Fainter objects?
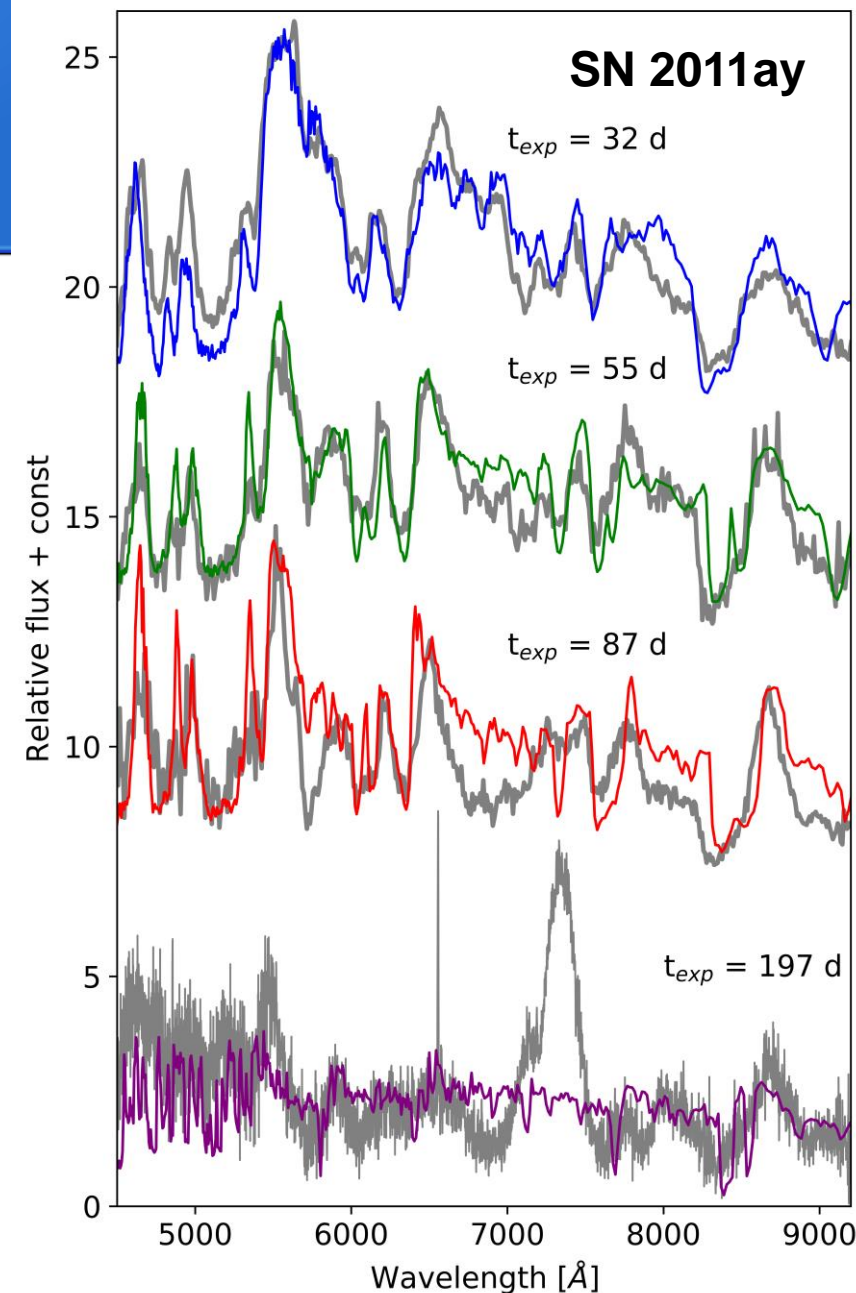
Tomasella et al., 2016
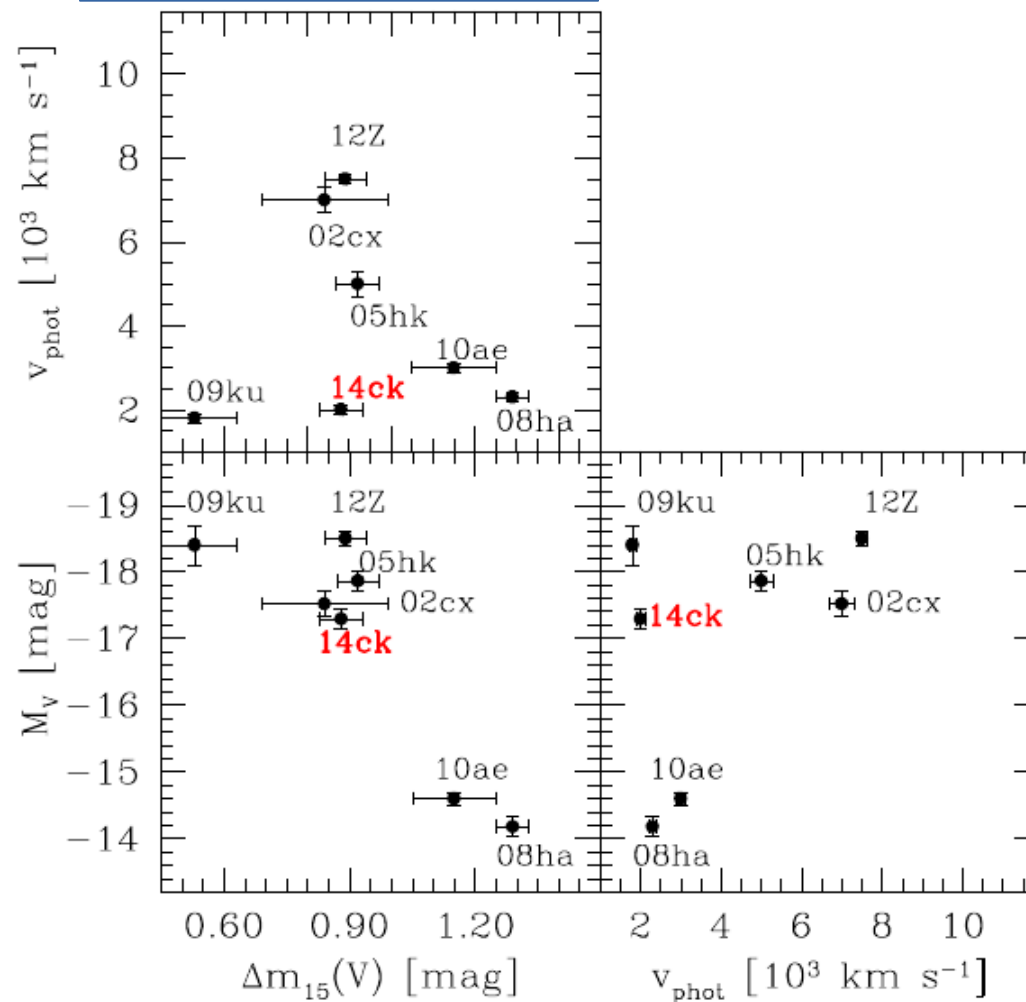
Late-time evolution

- Forbidden emission lines & permitted P Cygni profiles
- Extra continuum source?

Bunch of week permitted Fe lines…

… require a source of continuum

Late-time evolution

- Forbidden emission lines & permitted P Cygni profiles
- Extra continuum source?
- How about that bound remnant?
- TARDIS modeling for SN 2011ay
- Perfect match before t_{exp} = 100 days >>> Something happens
- Characterizing the transition?
- Missing epochs from 100 days < t_{exp} < 200 days
- VLT & Gemini proposals

SN 2011ay
t_{exp} = 32 d
t_{exp} = 55 d
t_{exp} = 87 d
t_{exp} = 197 d

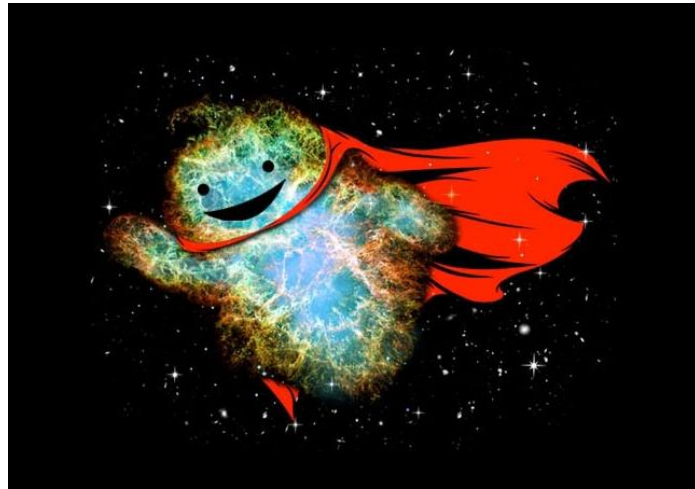Relative flux + const
Wavelength [Å]

Supernova Remnants II:
An Odyssey in Space after Stellar Death

Thank you for your attention!

Any questions?

Take away notes

- <u>Type Iax SNe:</u> faint and very diverse subclass of thermonuclear explosion
- <u>Abundance tomography:</u> powerful technique, but too many parameters

Results:

- Stratified abundance profiles / lack of carbon
- Possible contradiction with deflagration models
- Same abundance features for all objects
- Luminosity – velocity relation
- Strange late-time evolution, but possible modeling
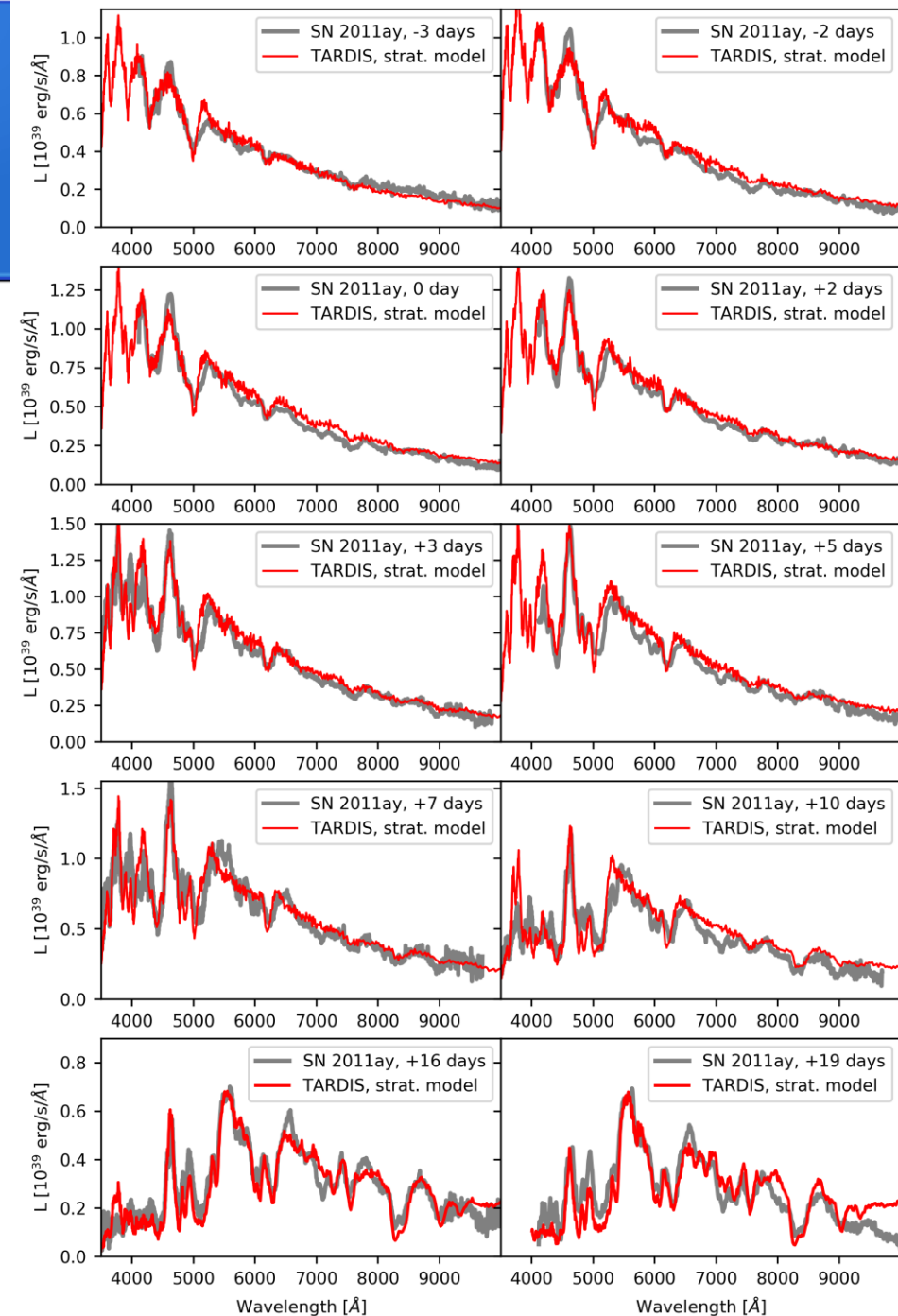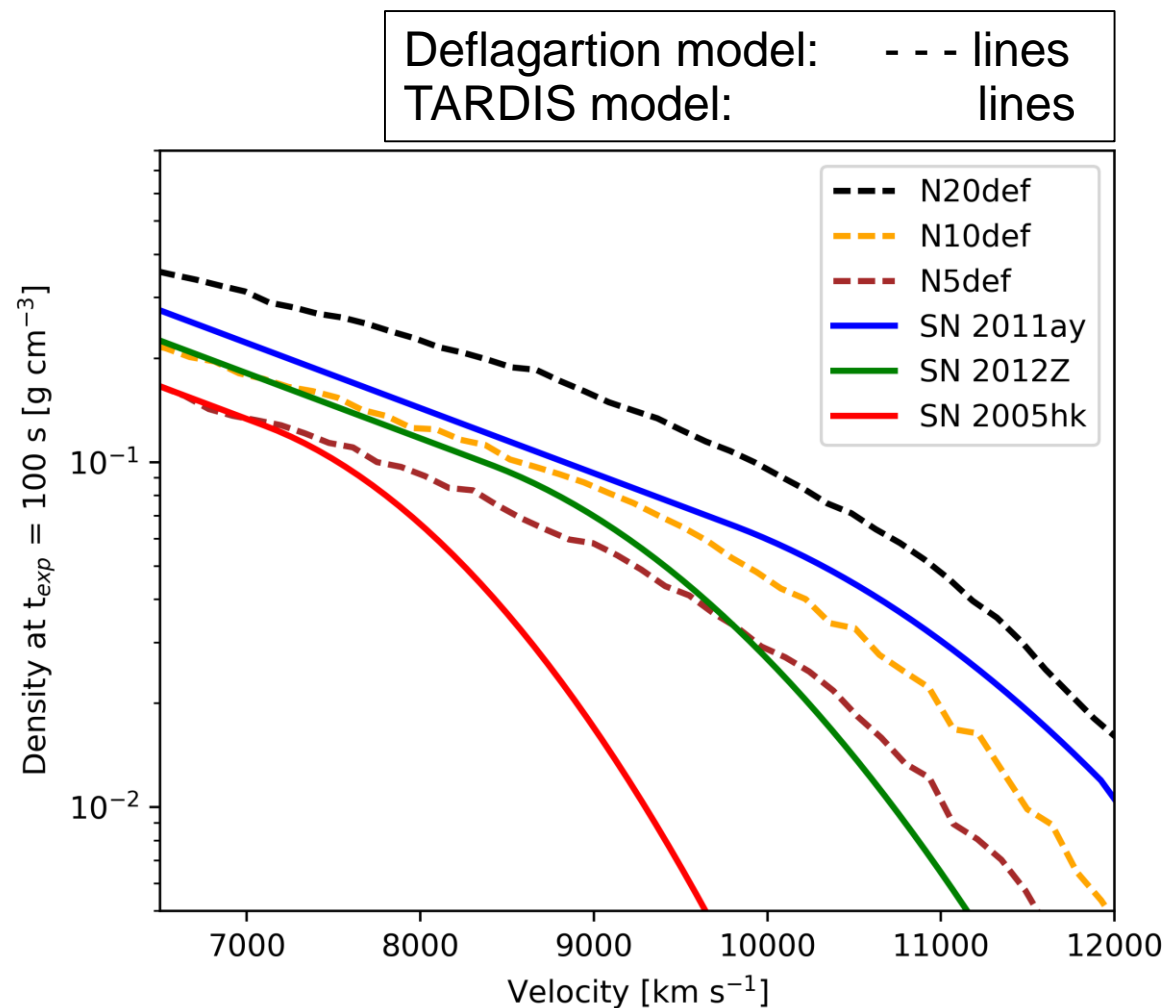
- **Missing epochs and objects**

SN 2012Z
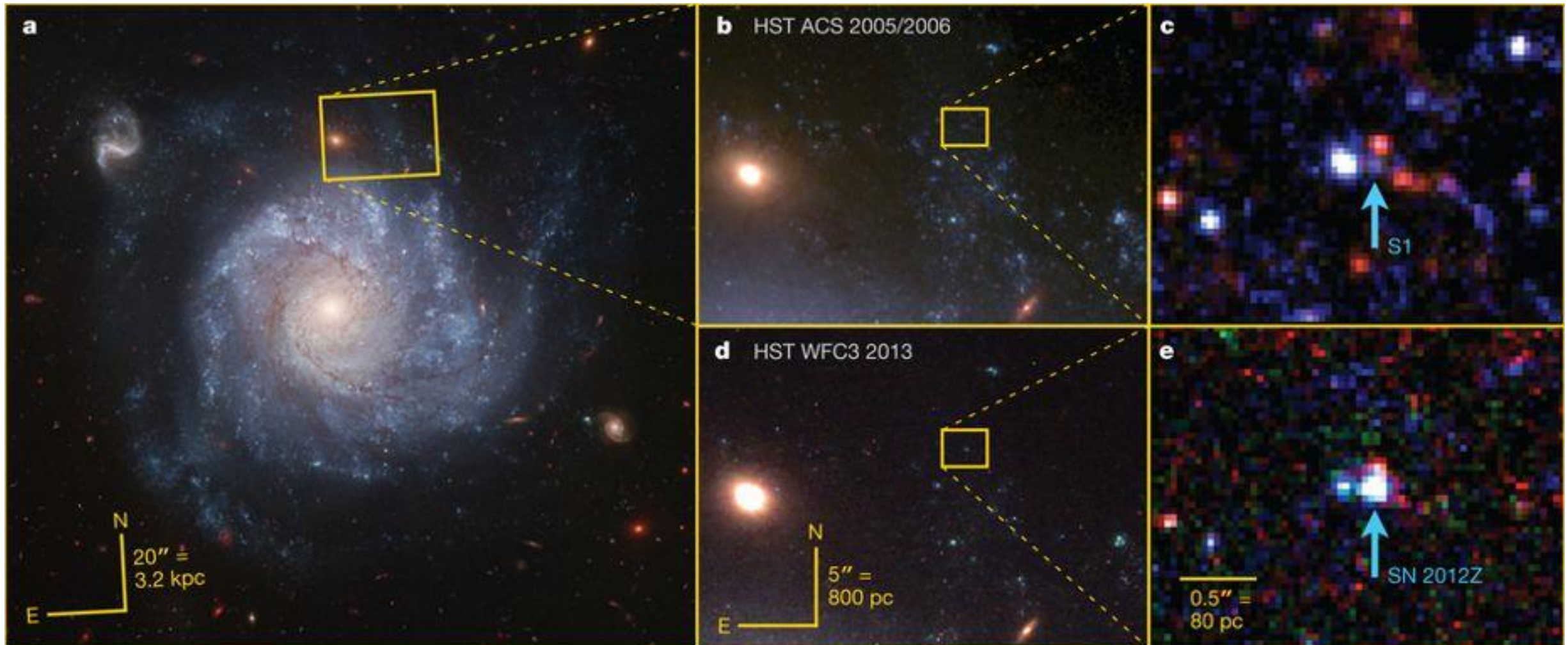
Iax abundance tomography
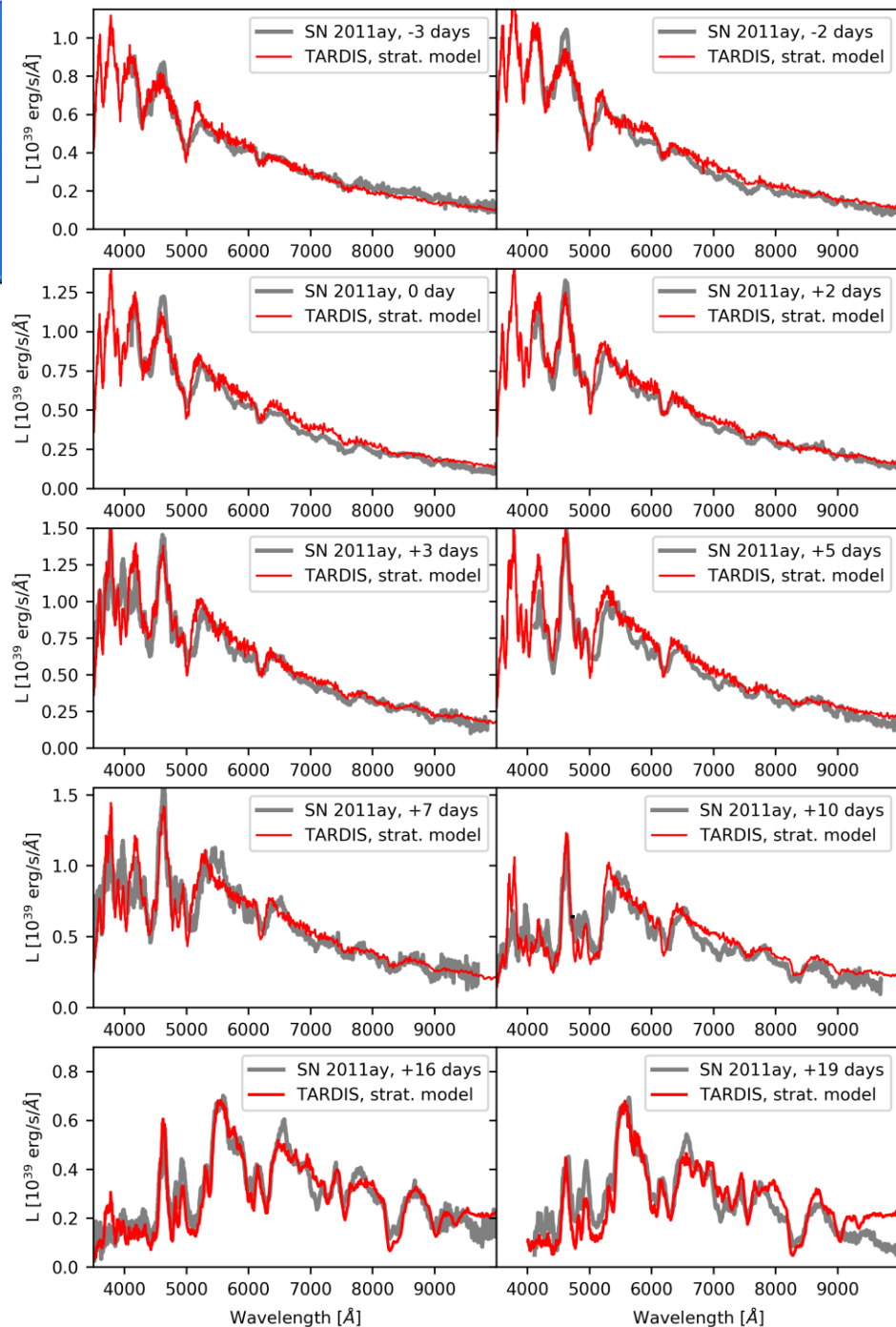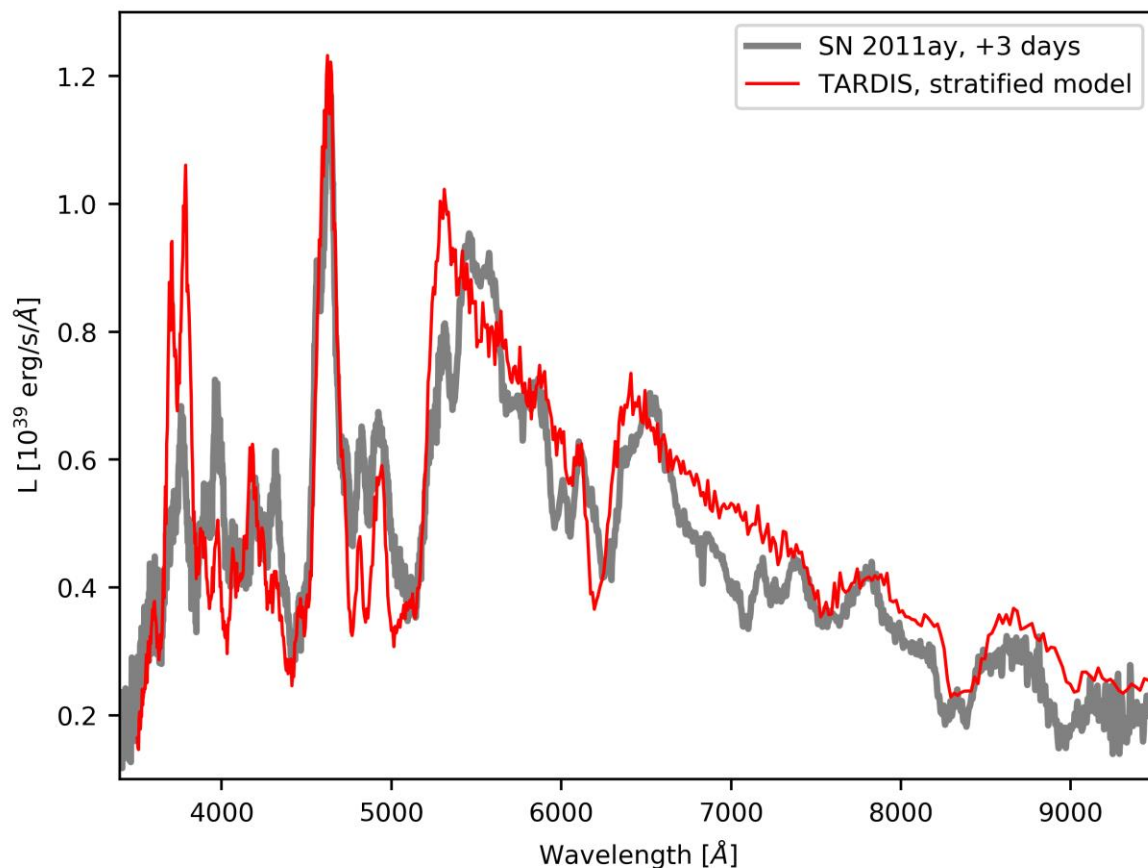
- Testing density-profiles

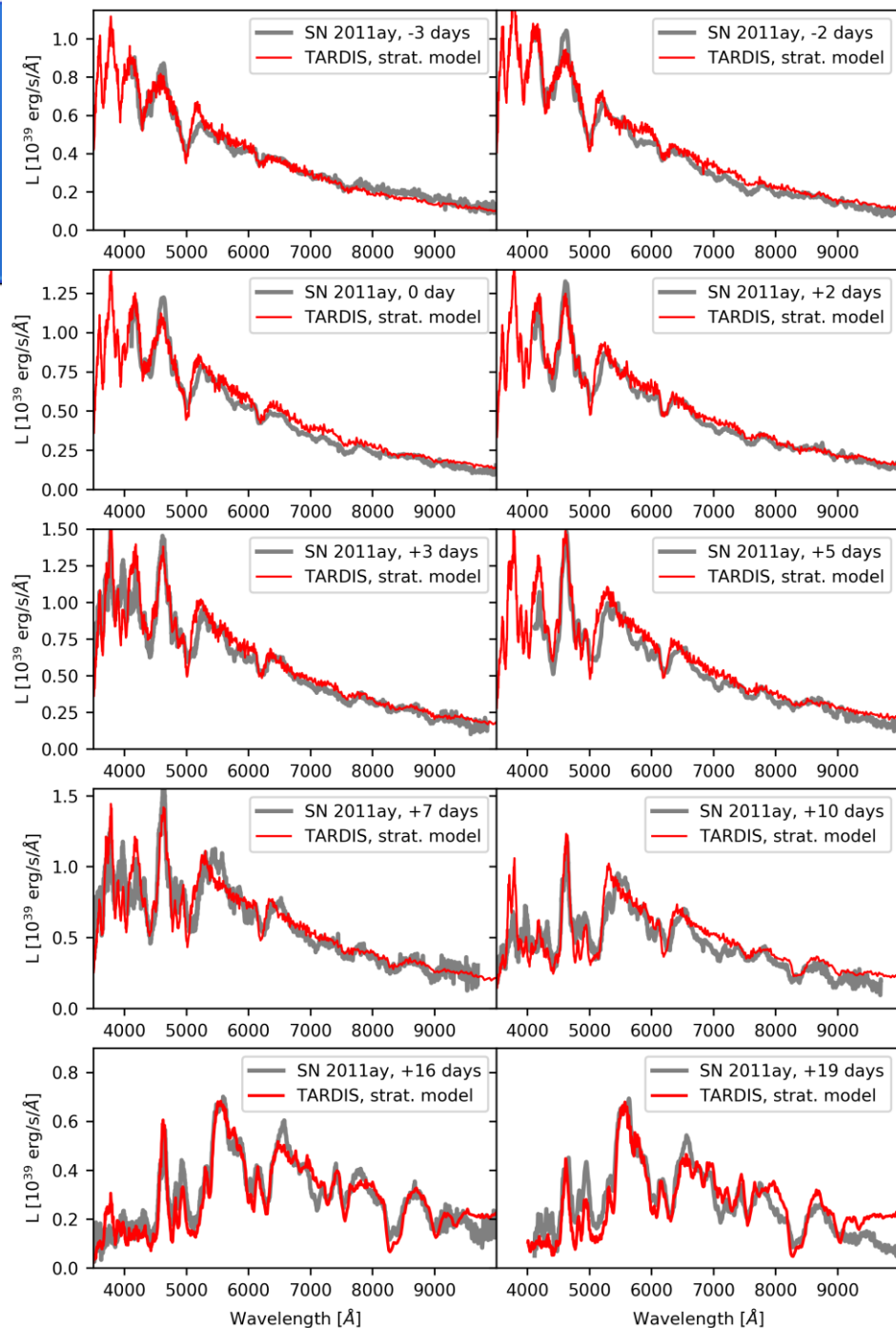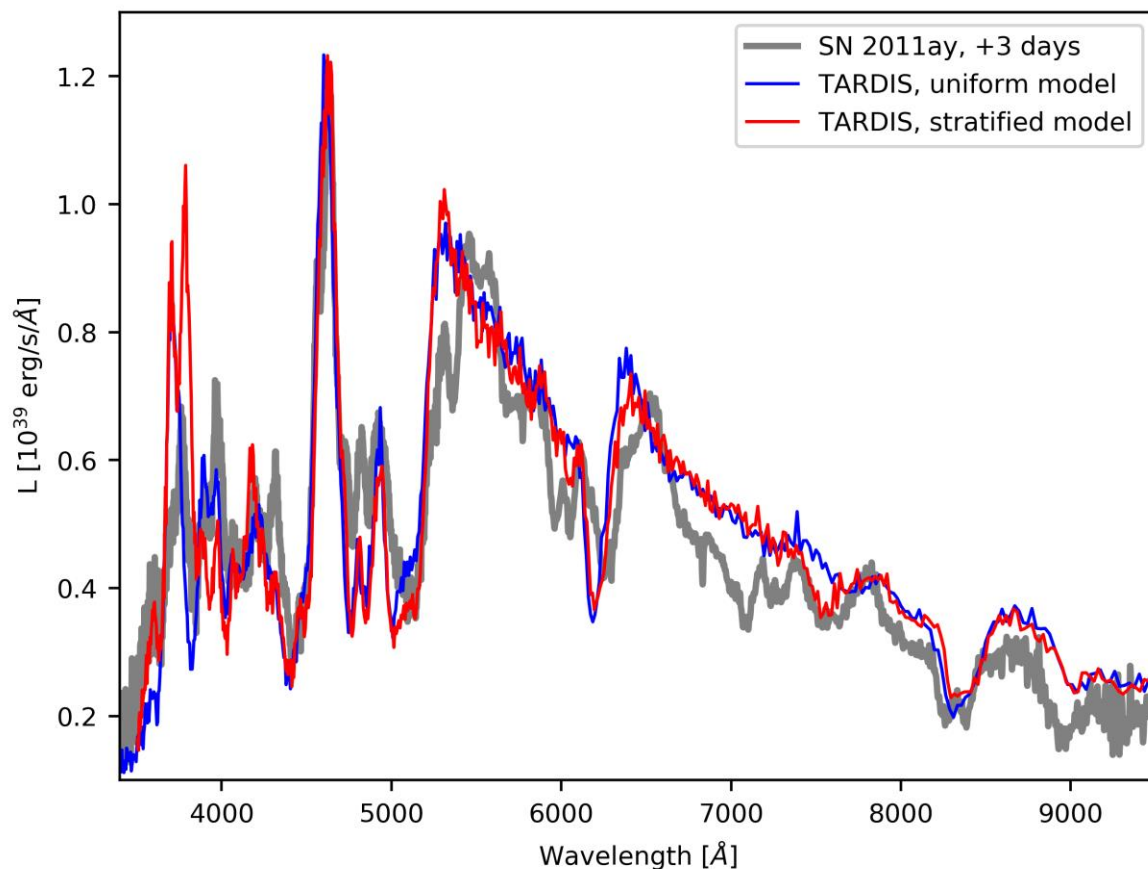| Deflagartion model: | - - - lines |
| TARDIS model: | lines |

Iax abundance tomography

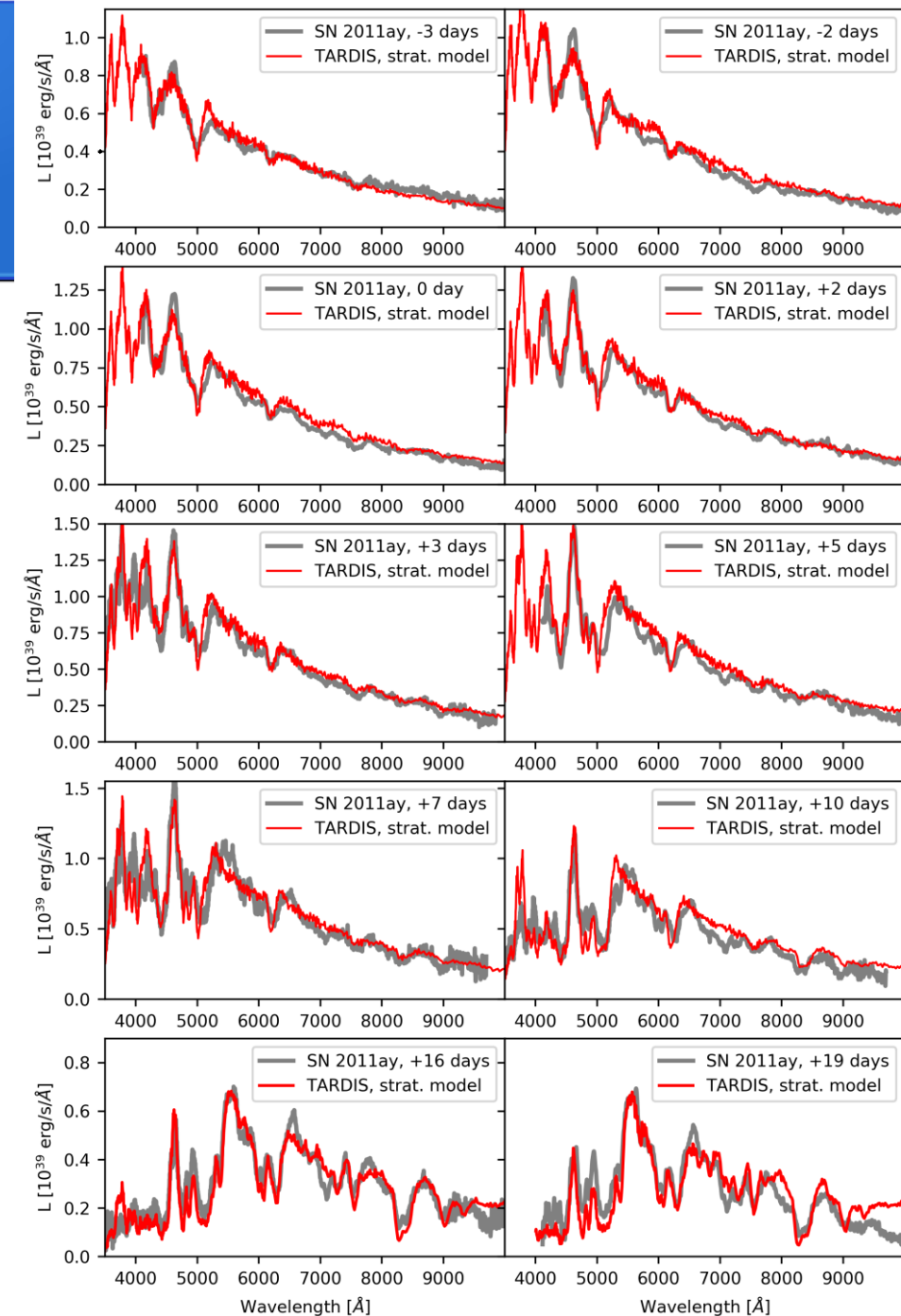- Test: applying photospheric abundances for the whole model ejecta from a late epoch

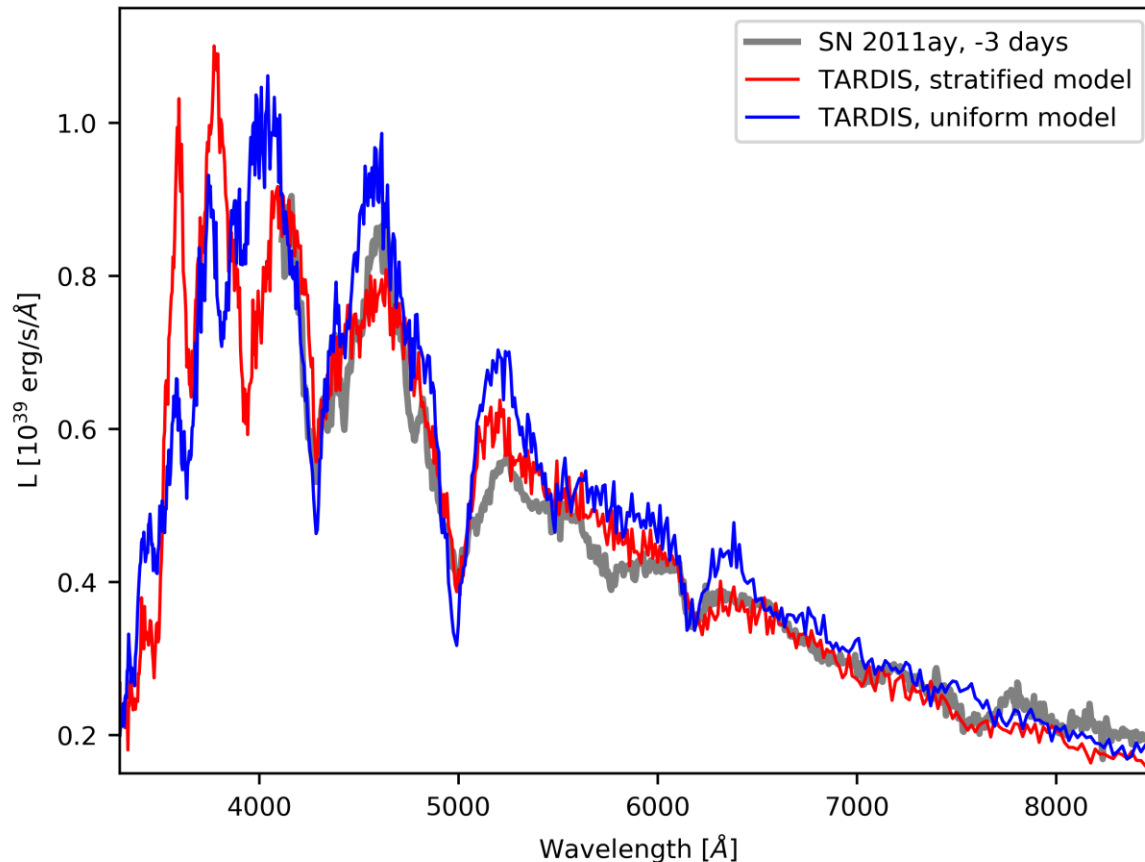# Iax abundance tomography

- Result: fine for the same epoch…
- Adopting the constant abundances for the early epochs

Iax abundance tomography

- Result: terrible for the early epochs…
- Too much IGEs for the outer layers

Late-time evolution

- Forbidden emission lines & permitted P Cygni profiles
- Extra continuum source: bound remnant?
- TARDIS modelling for SN 2011ay and SN 2014dt
- Perfect match before t_{exp} = 100 days >>> Something happens
- Characterizing the transition

- **Missing epochs from 100 days < t_{exp} < 200 days**
- VLT & Gemini proposals

Camacho-Neves et al. in prep.

SN 2014dt

t_{exp} = 22 days

SN2014dt 2014-10-31 +6day
Best TARDIS fit, t_explosion=22 days, v_photosphere=5500 km/s

Telluric Lines →

t_{exp} = 143 days

SN2014dt 2015-03-02 +127d
Best TARDIS fit, t_explosion=143 days, v_photosphere=350 km/s
Forbidden Nebular Emission (TARDIS can not model)