Modelling supernova spectra (with the JEKYLL code).

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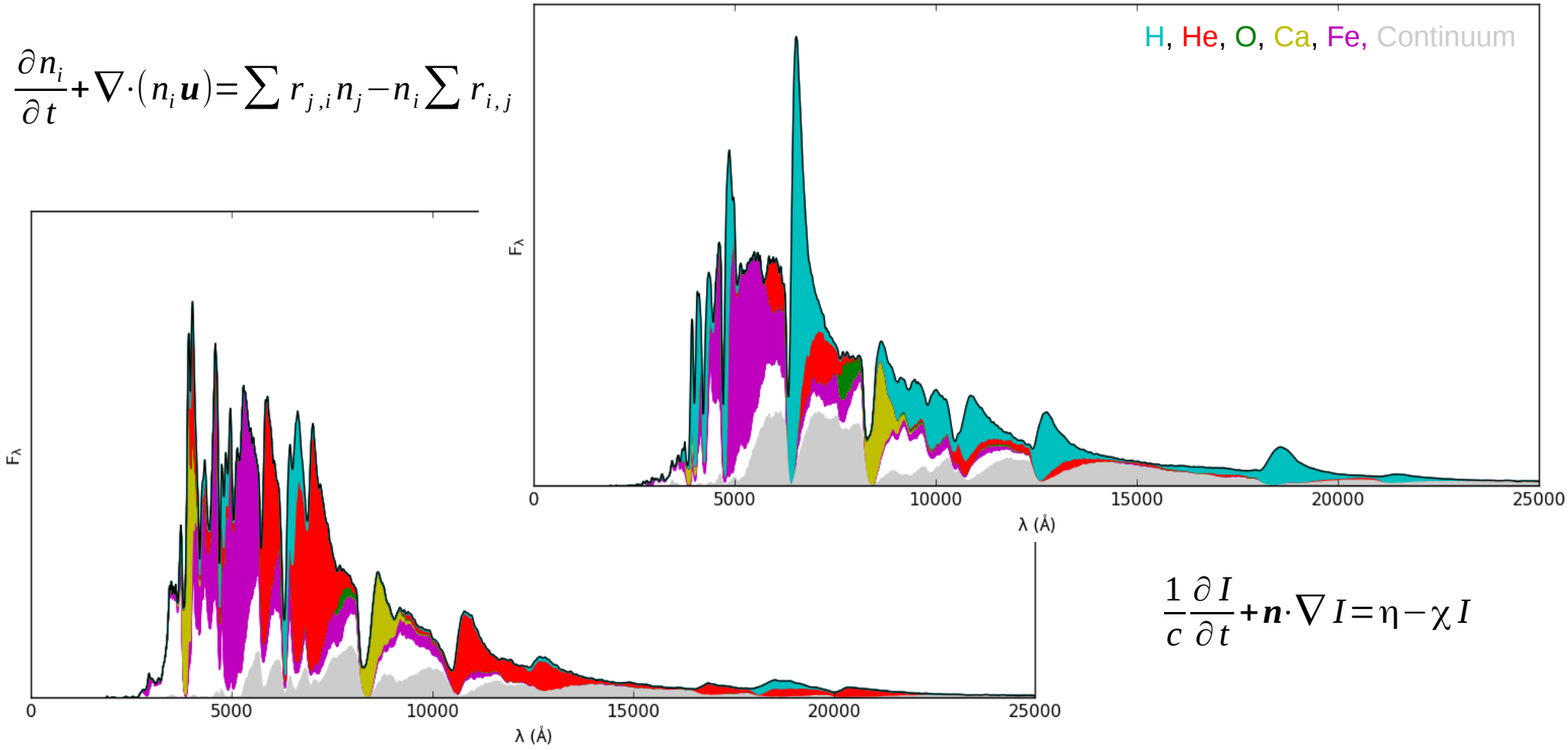
$$\frac{\partial n_i}{\partial t} + \nabla \cdot (n_i \boldsymbol{u}) = \sum r_{j,i} n_j - n_i \sum r_{i,j}$$



$$\frac{1}{c}\frac{\partial I}{\partial t} + \boldsymbol{n} \cdot \nabla I = \eta - \chi I$$

The JEKYLL code

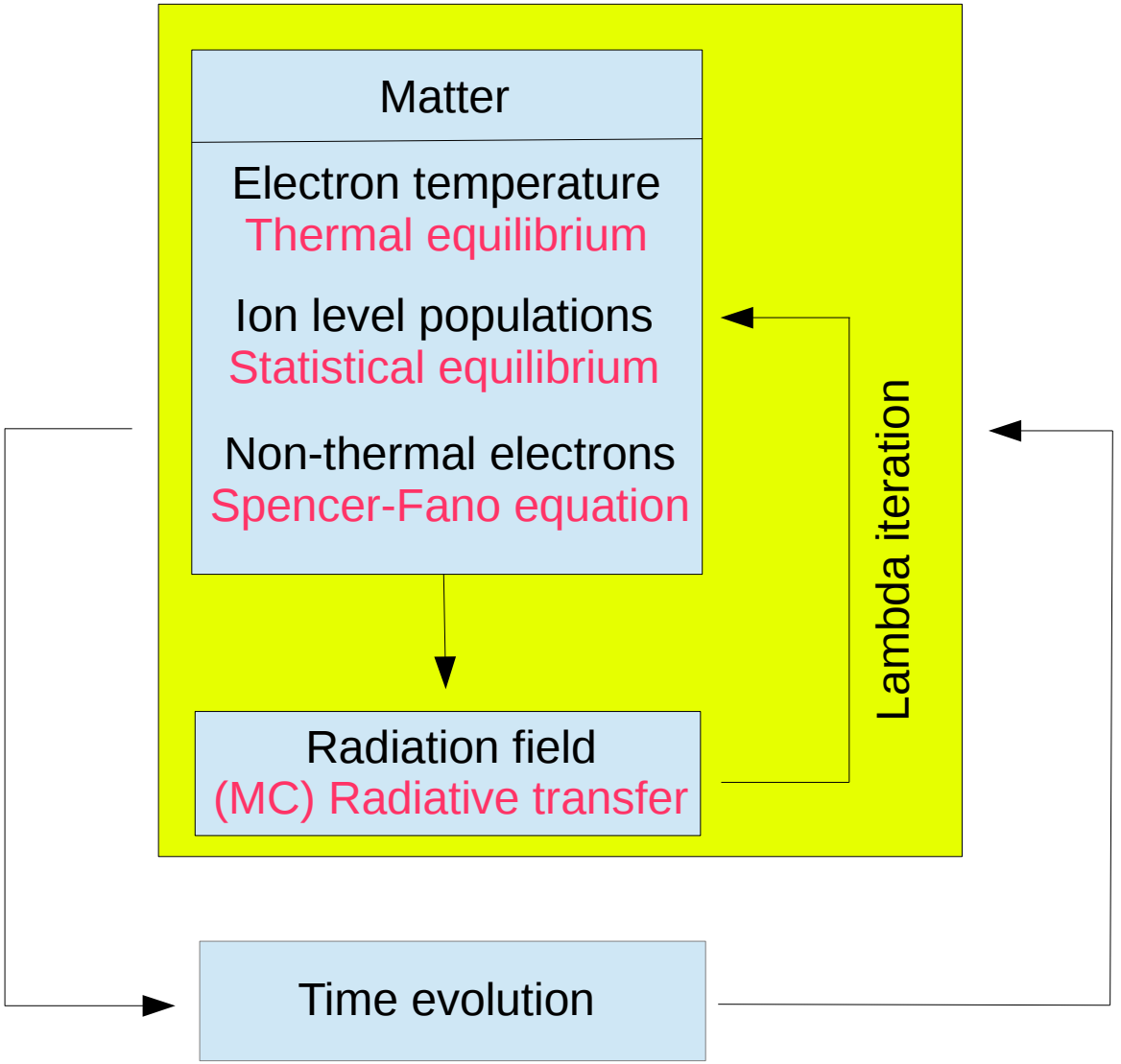
What: Realistic* simulations of the spectral evolution and lightcurves of SNe
in the photospheric and nebular phase.

How: Full NLTE-solution for the matter and the radiation field,
following (and extending) the MC method outlined by Leon Lucy (2002, 2003, 2005).

* Restrictions:

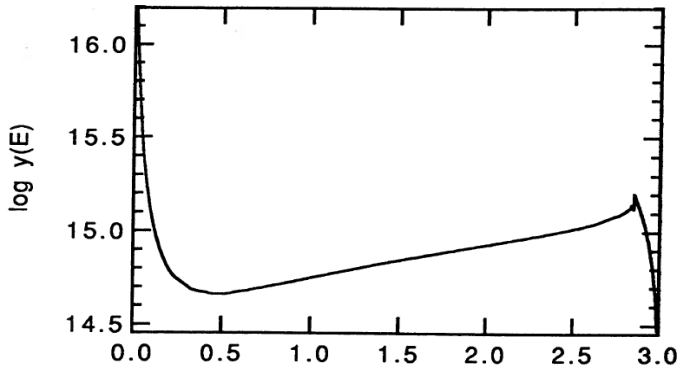
Homologous expansion.
Spherical symmetry.
Steady-state for the matter (Work in progress - partially done).

Method outline

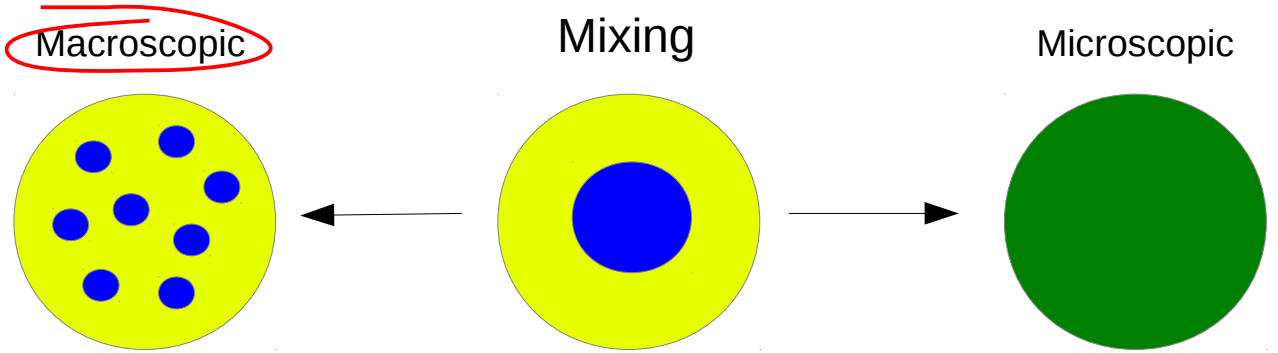


Key ingredients

Non-thermal electrons



Ionization and excitation rates calculated using the method by Kozma & Fransson (1992).



Taken into account in a statistical sense using the method by Jerkstrand et al. (2011).

Other similar codes

SEDONA (Kasen et al. 2006)

Geometry: 3-D
NLTE: No
Non-thermal ionization/excitation: No
Time-dependence: Radiation field
Macroscopic mixing: Yes
Phase : Photospheric

SUMO (Jerkstrand et al. 2011)

Geometry: 1-D
NLTE: Full
Non-thermal ionization/excitation: Yes
Time-dependence: No
Macroscopic mixing: Yes
Phase: Nebular

JEKYLL (Ergon et al. In prep.)

Geometry: 1-D
NLTE: Full
Non-thermal ionization/excitation: Yes
Time-dependence: Radiation field
Macroscopic mixing: Yes
Phase: All

ARTIS (Kromer et al. 2009)

Geometry: 3-D
NLTE: Ionization
Non-thermal ionization/excitation: No
Time-dependence: Radiation field
Macroscopic mixing: Yes
Phase : Photospheric

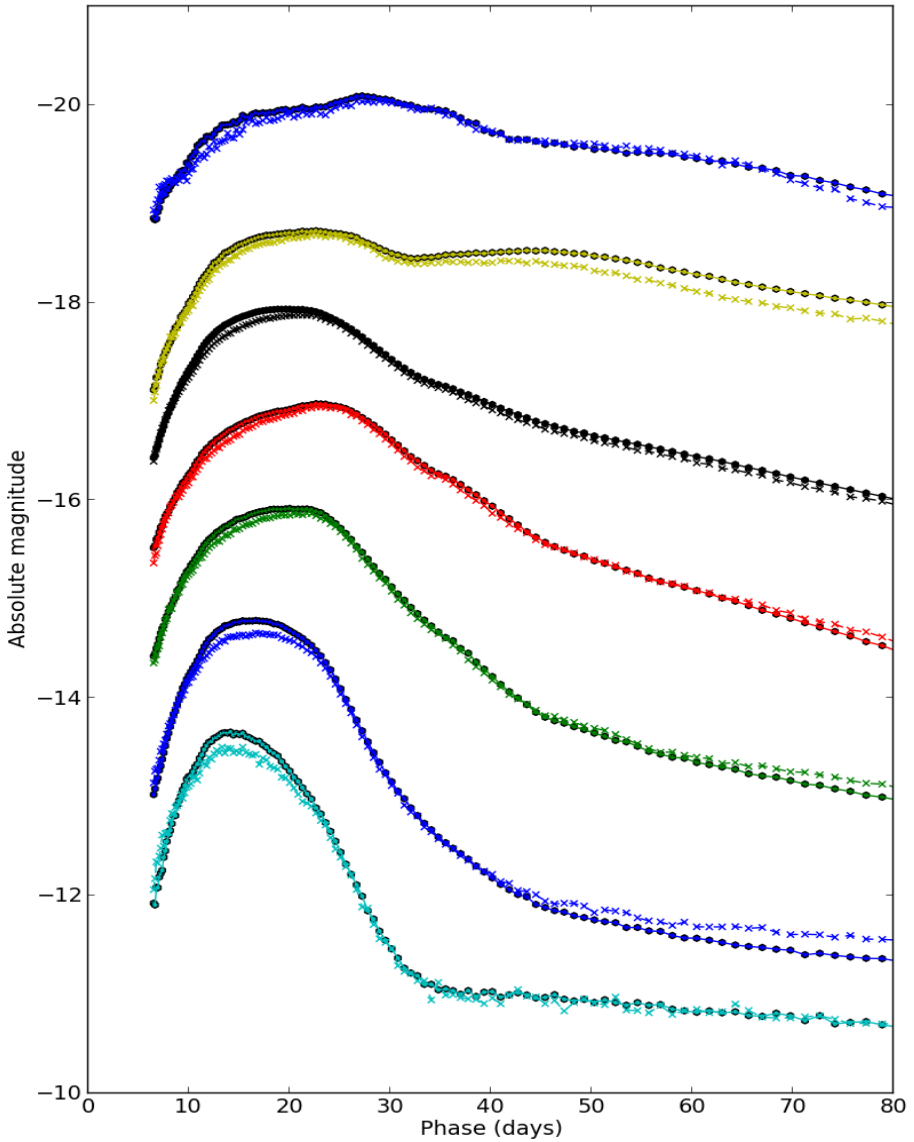
CMFGEN (Hillier 1998)

Geometry: 1-D
NLTE: Full
Non-thermal ionization/excitation: Yes
Time-dependence: Full
Macroscopic mixing: No
Phase: All

+ Mazzali (2000,2001), Kerzendorf et al. (2014) and more.

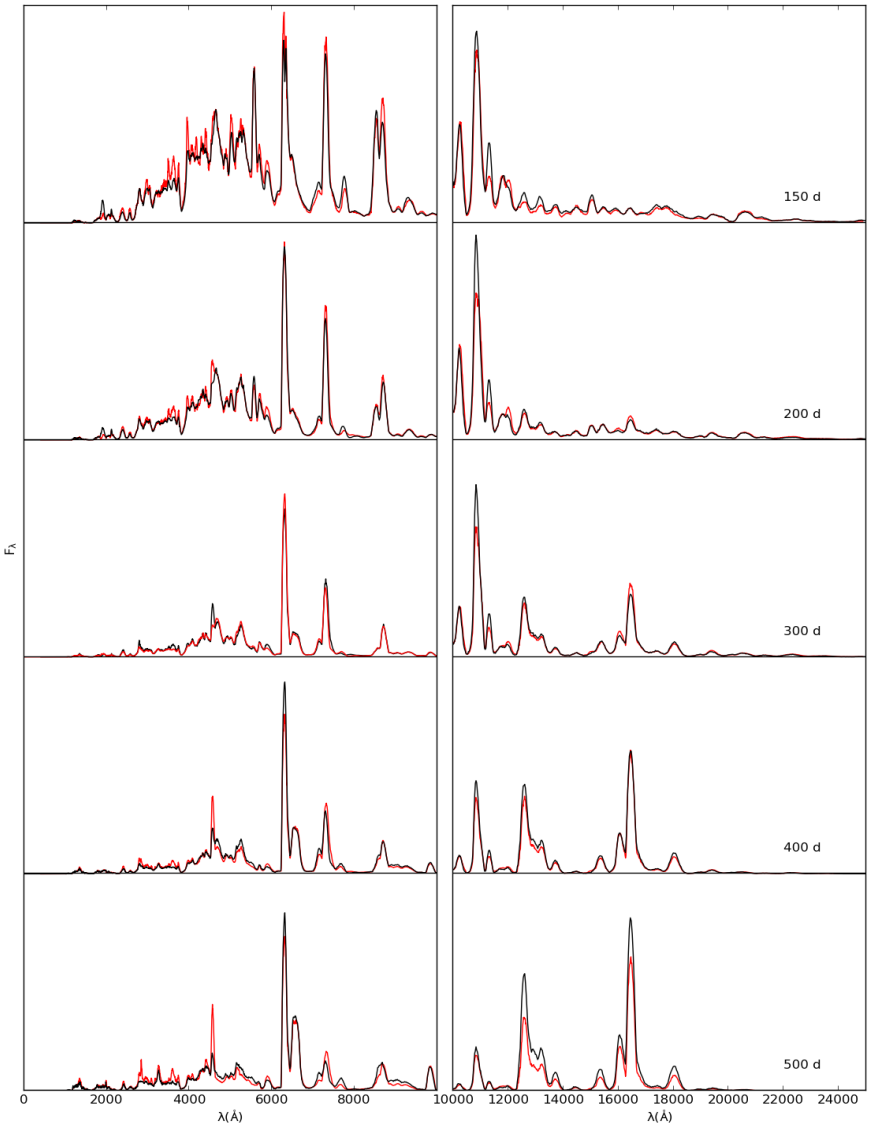
Comparisons

JEKYLL (circles) and ARTIS (crosses)



Early lightcurves for Type IIb model 12C

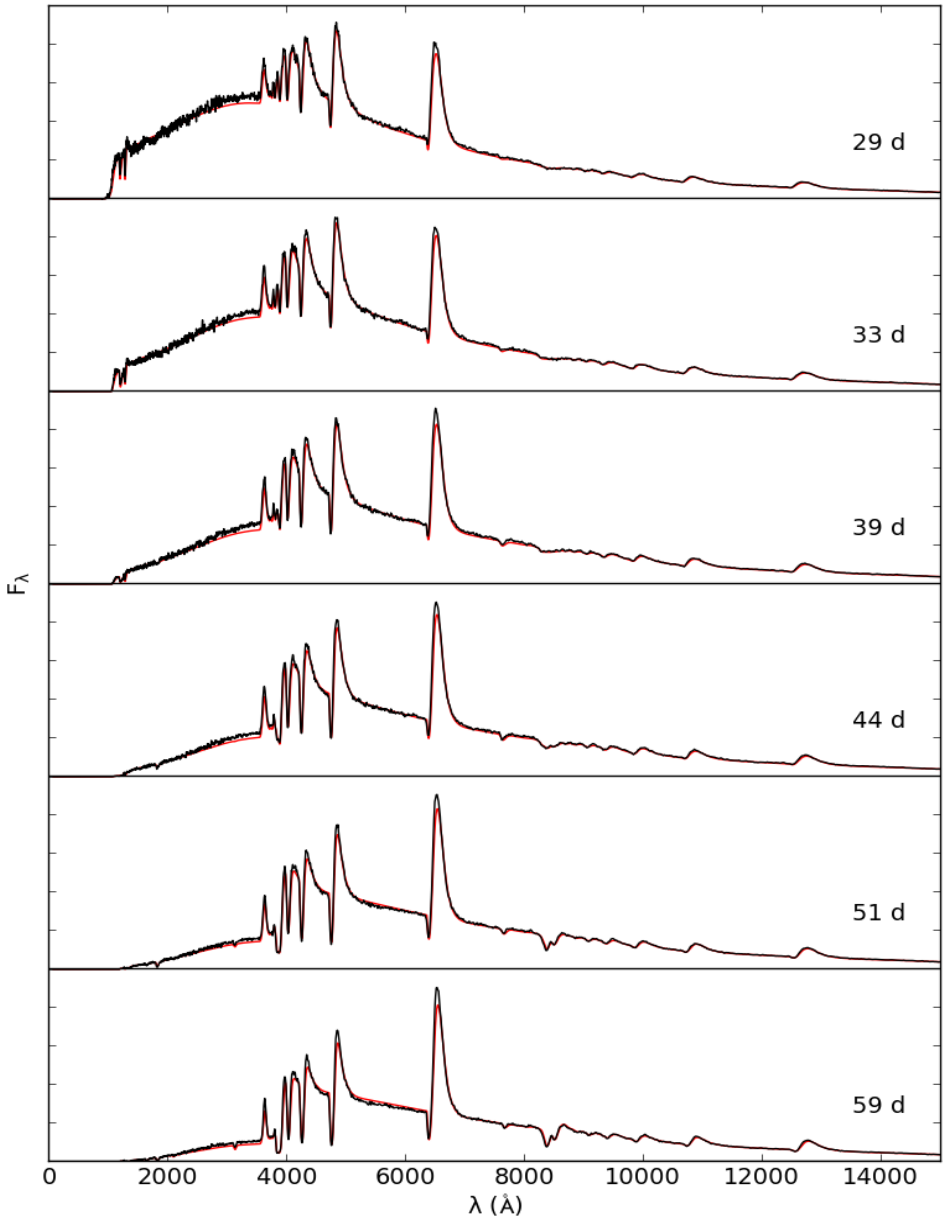
JEKYLL and SUMO

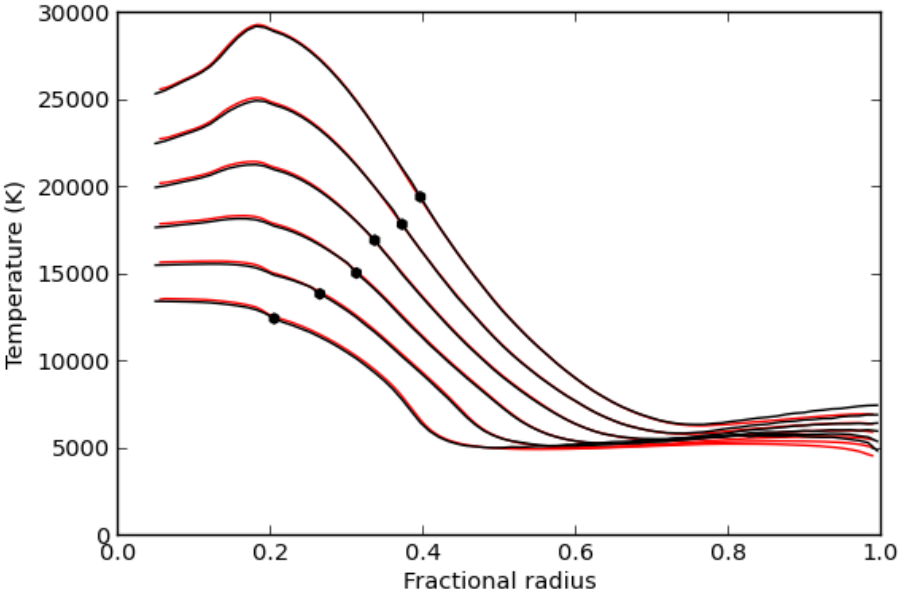


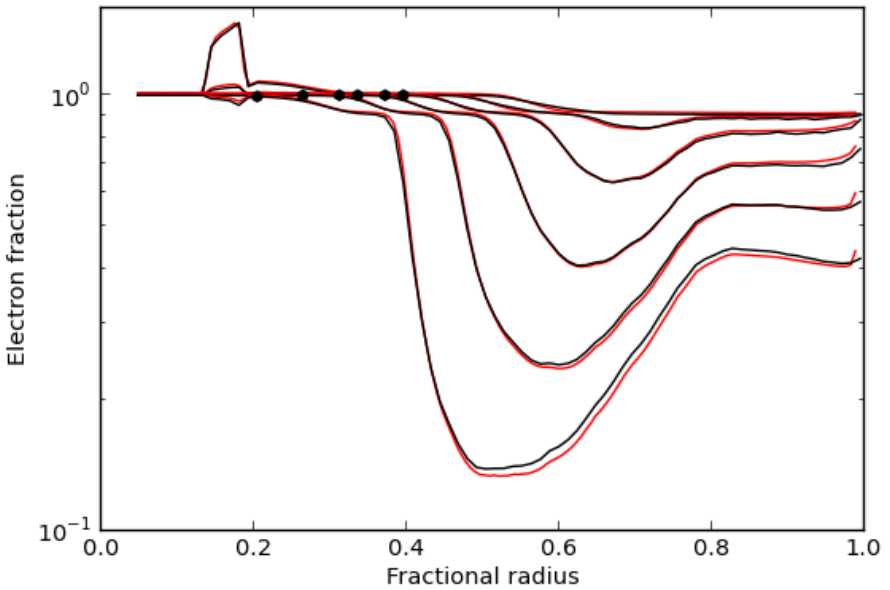
Nebular spectra for Type IIb model 13G

Comparisons

JEKYLL and CMFGEN



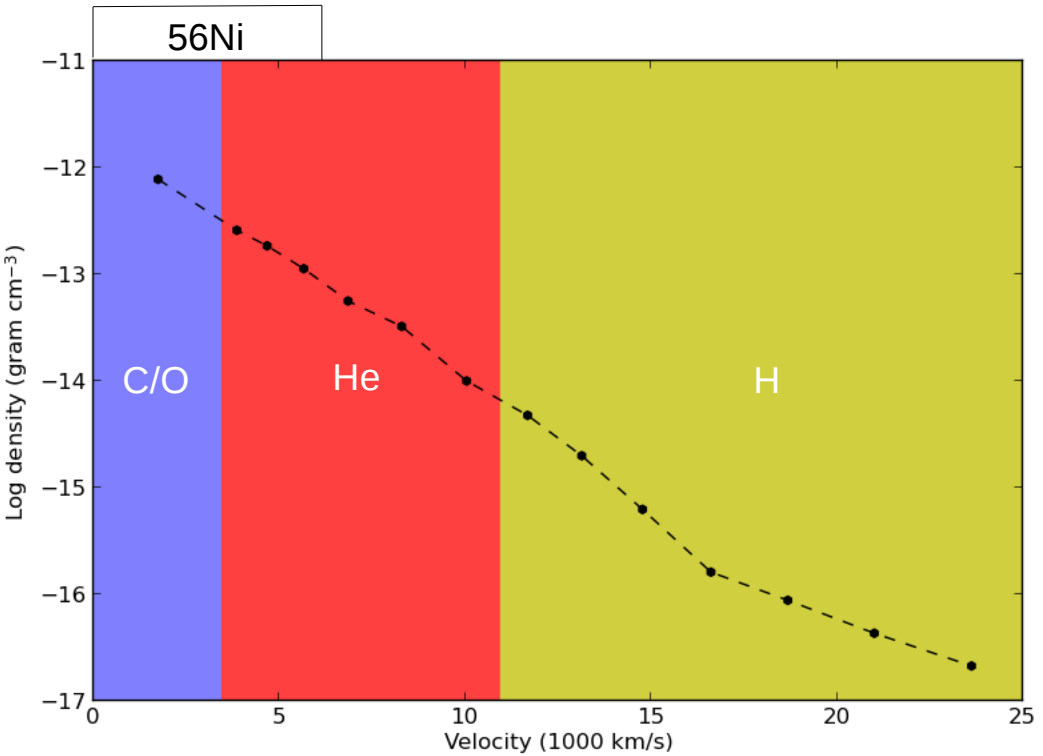




Type IIb model: Background

Preferred model (12C) for SN 2011dh from Jerkstrand et al. (2015), where it was evolved through the nebular phase with SUMO.

Evolved through the early phase with JEKYLL in Ergon et al. (In prep.)



$M_{In} = 12\,M_{\odot}$

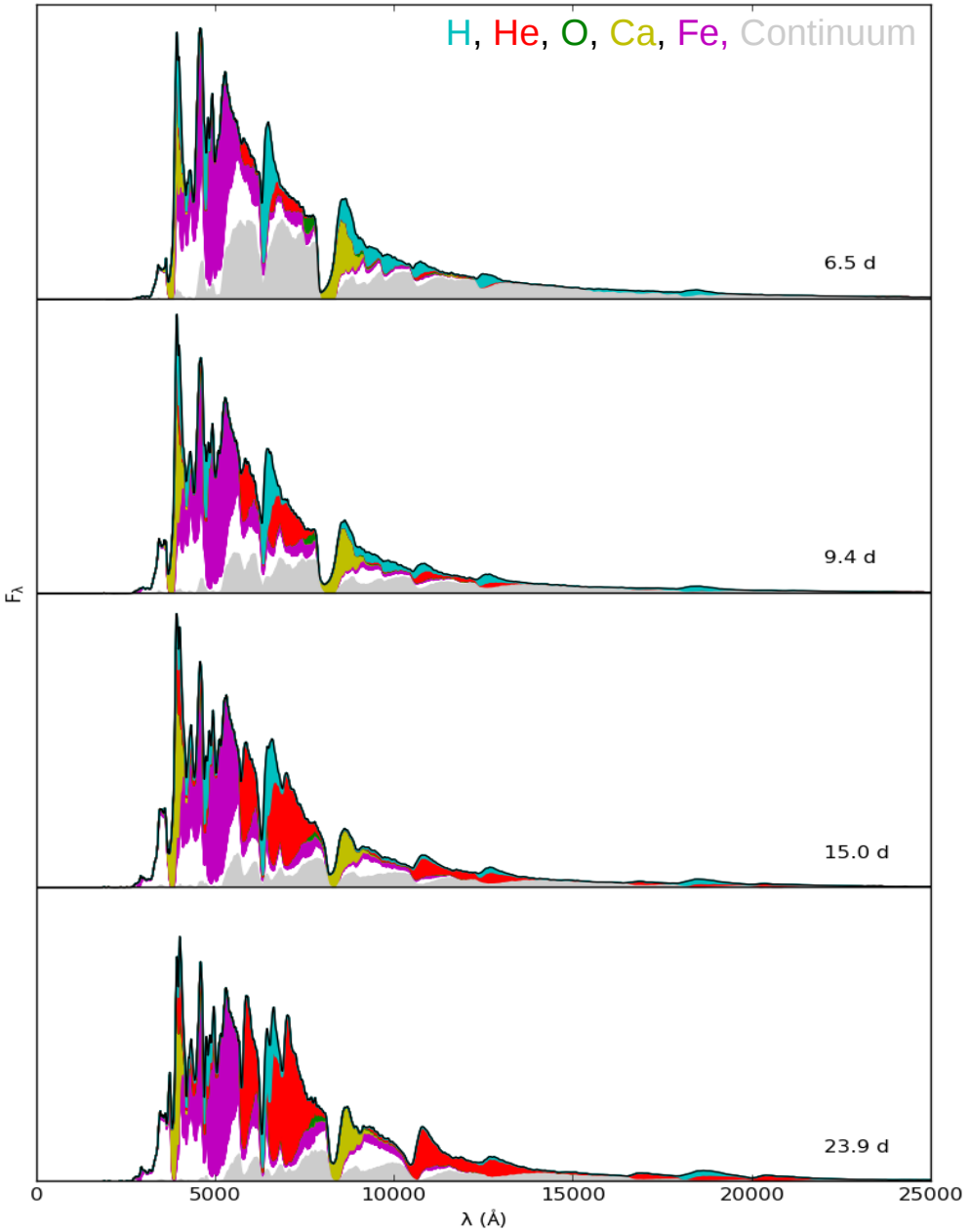
$M_{Ej} = 1.7\,M_{\odot}$

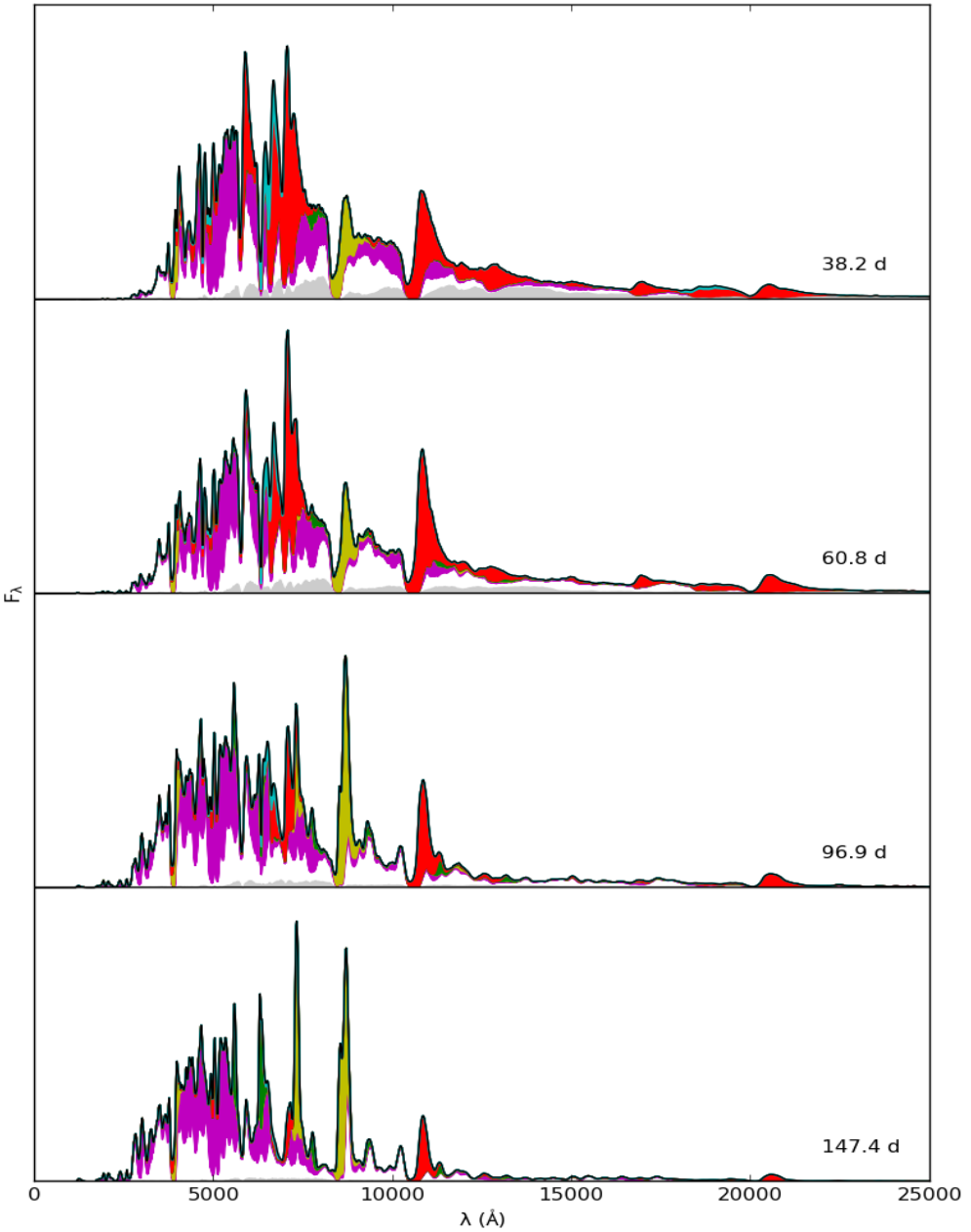
$M_{Ni} = 0.075\,M_{\odot}$

$E_K = 6.8 \times 10^{50}\,\mathrm{erg}$

Type IIb model: Spectral evolution

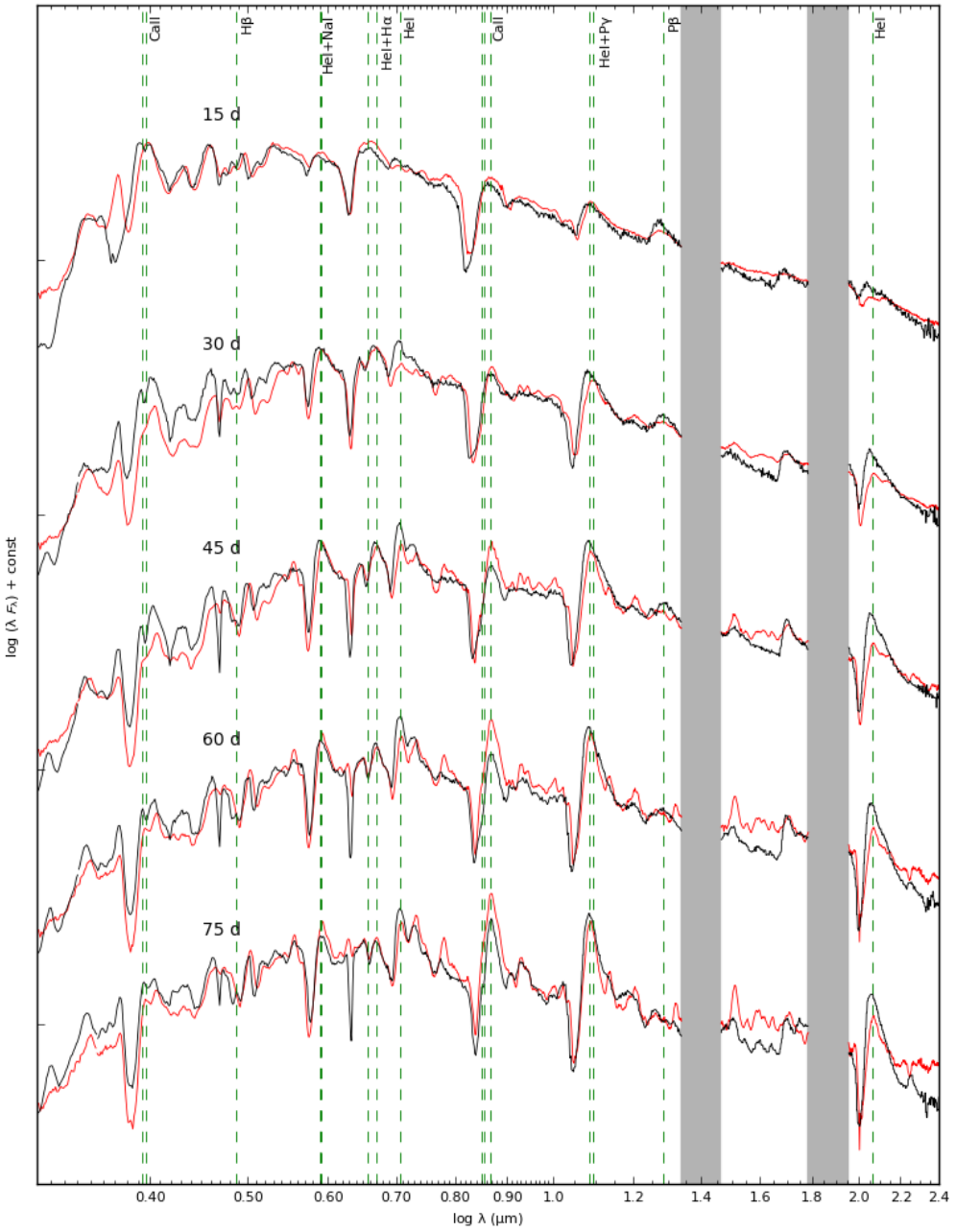
Model: Before 150 days

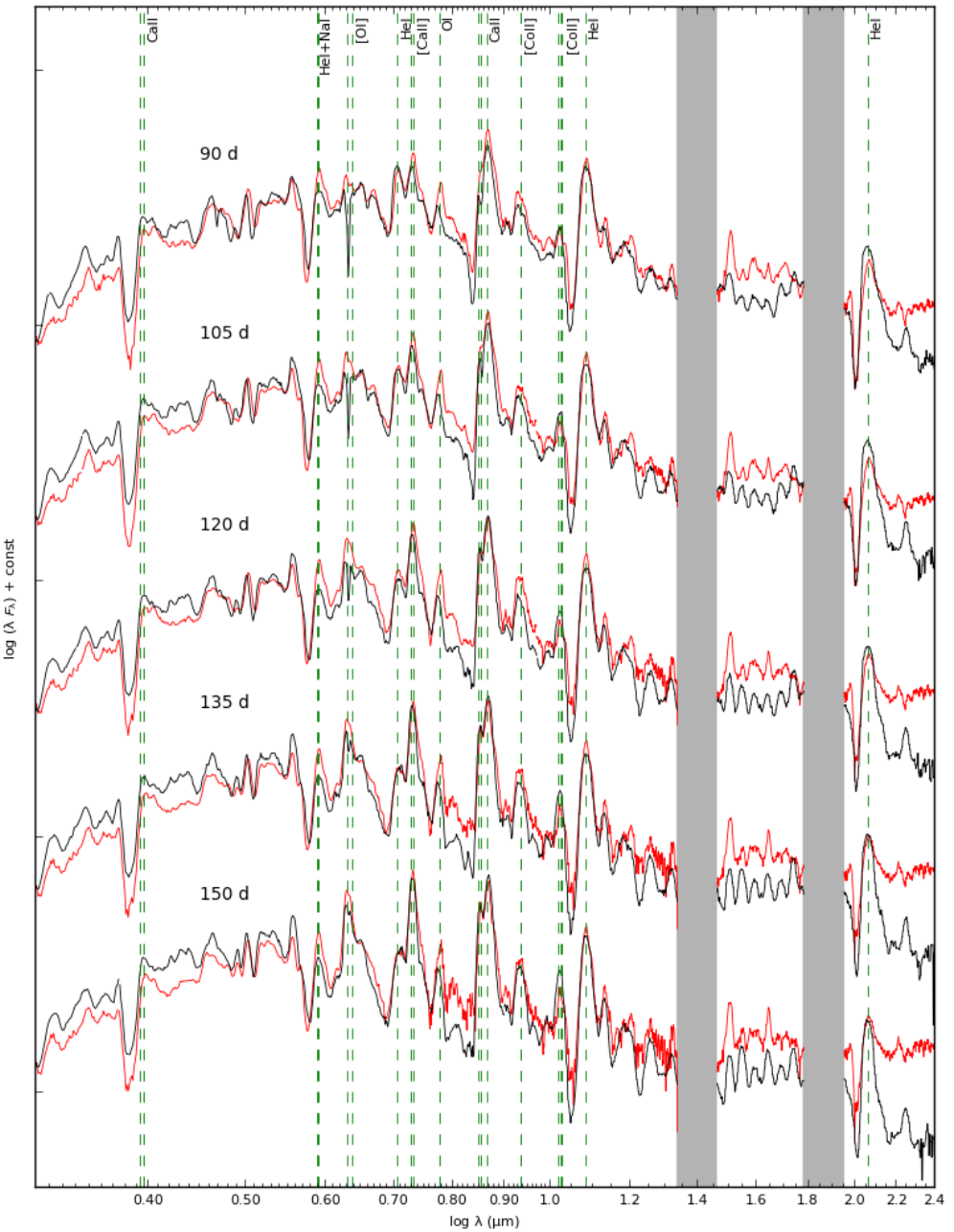




Comparison to SN 2011dh: Spectral evolution

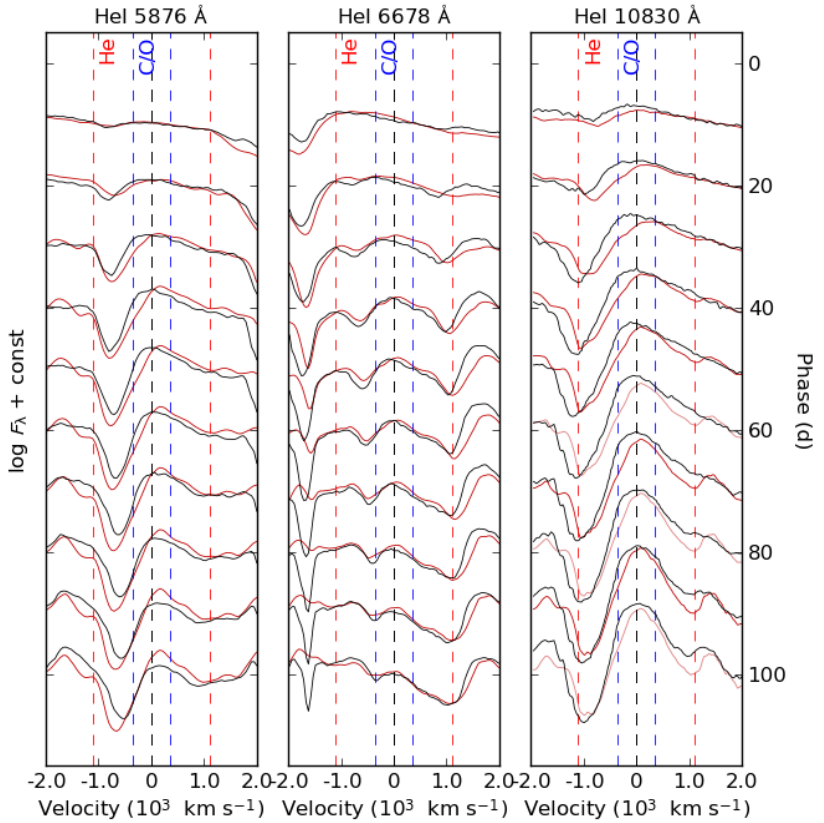
Model and SN 2011dh – Before 150 days



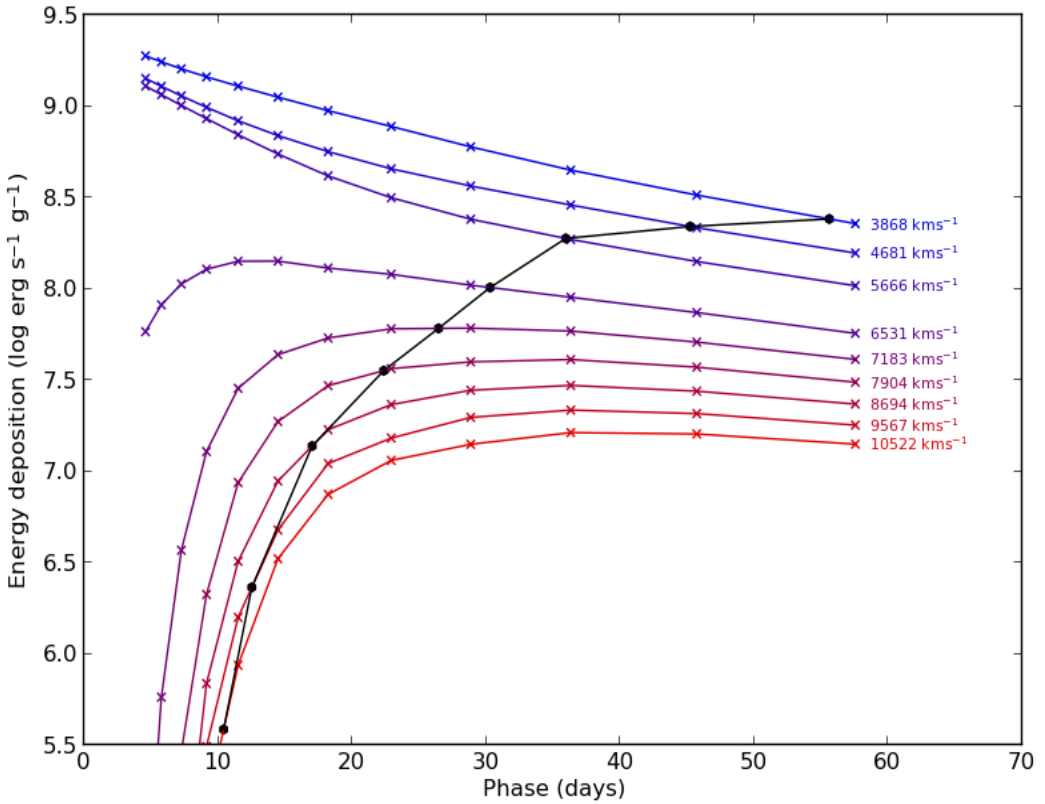


Comparison to SN 2011dh: Helium lines

Model and SN 2011dh – Before 100 days

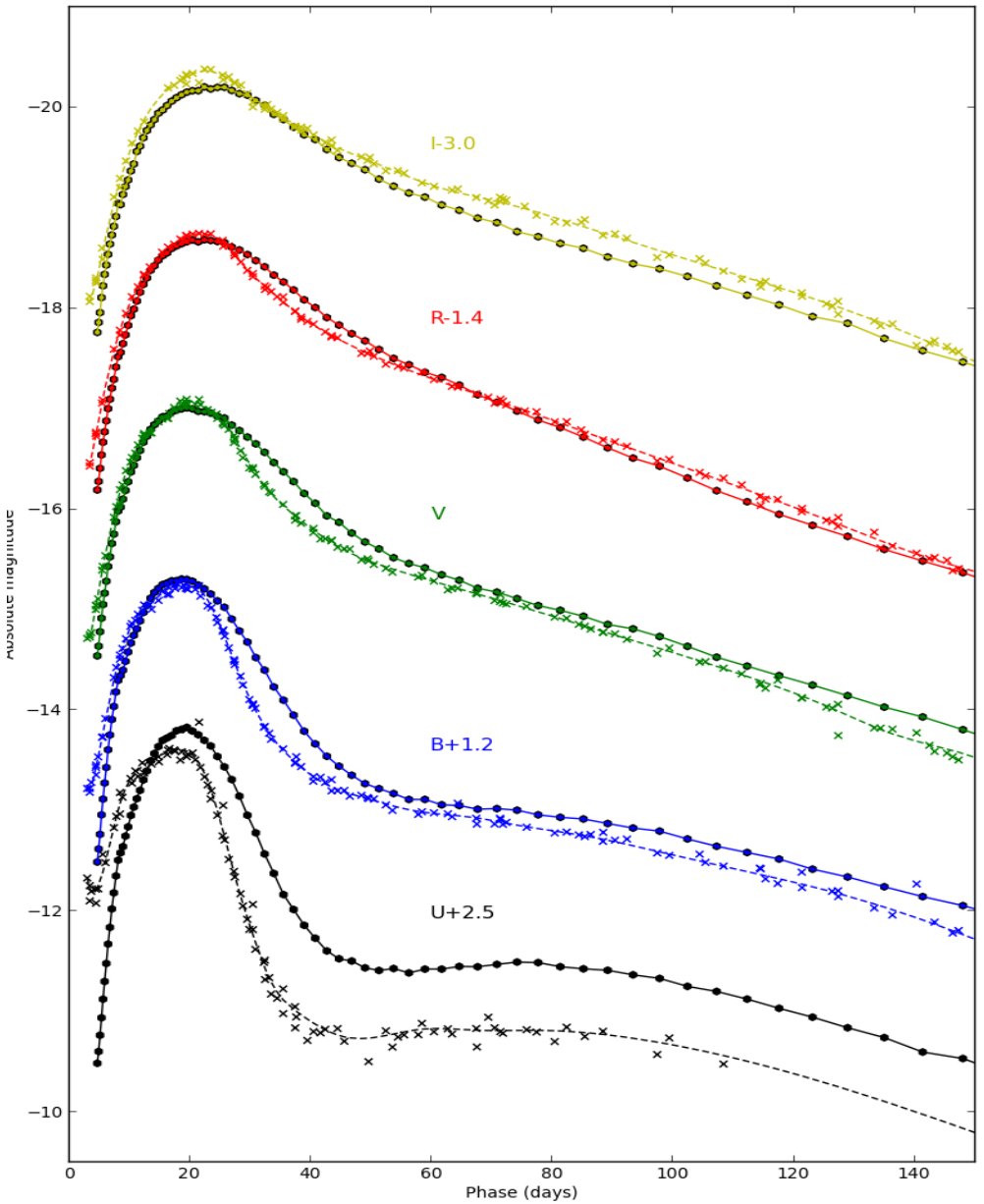


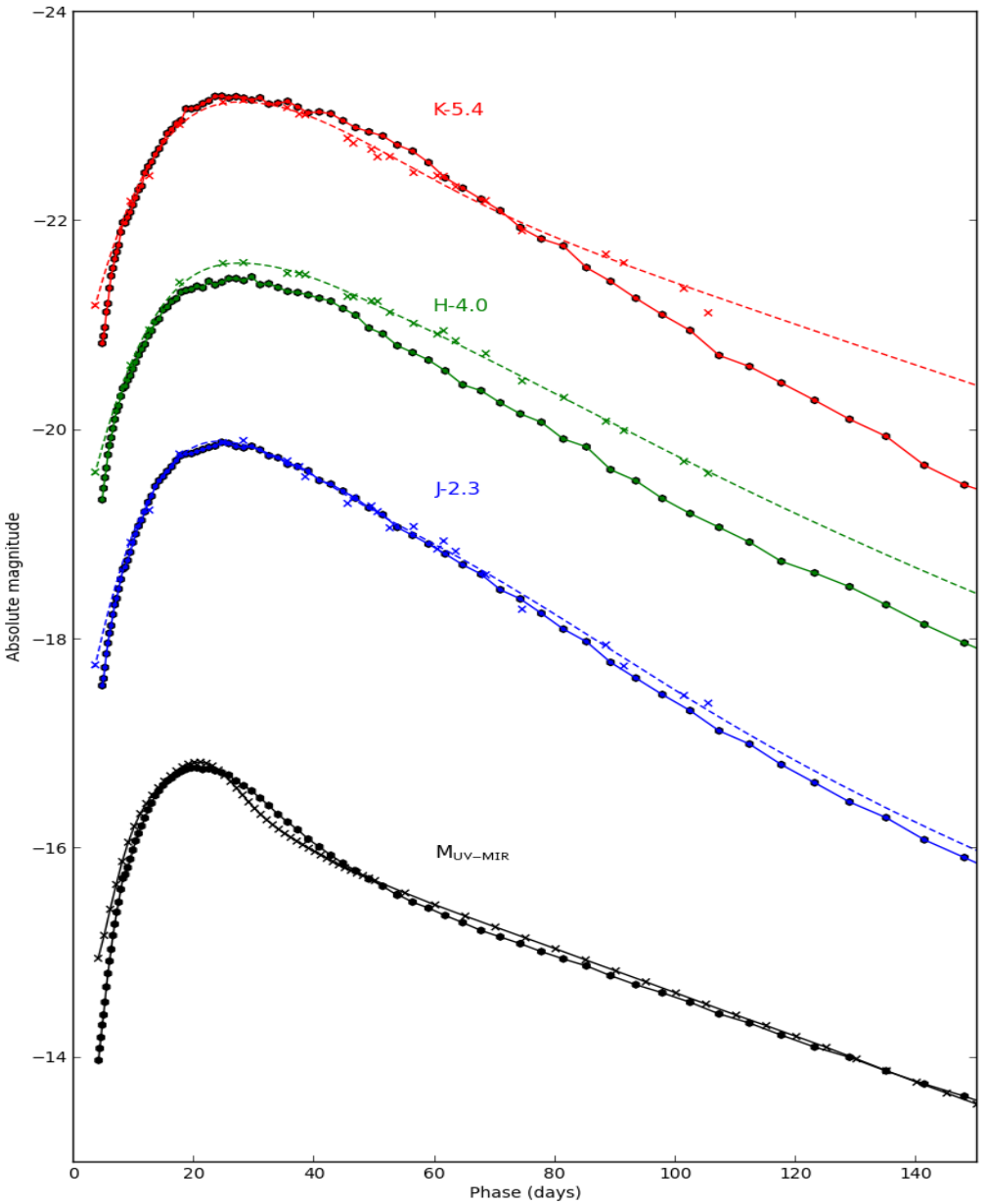
Radioactive energy deposition in the helium envelope



Comparison to SN 2011dh: Lightcurves

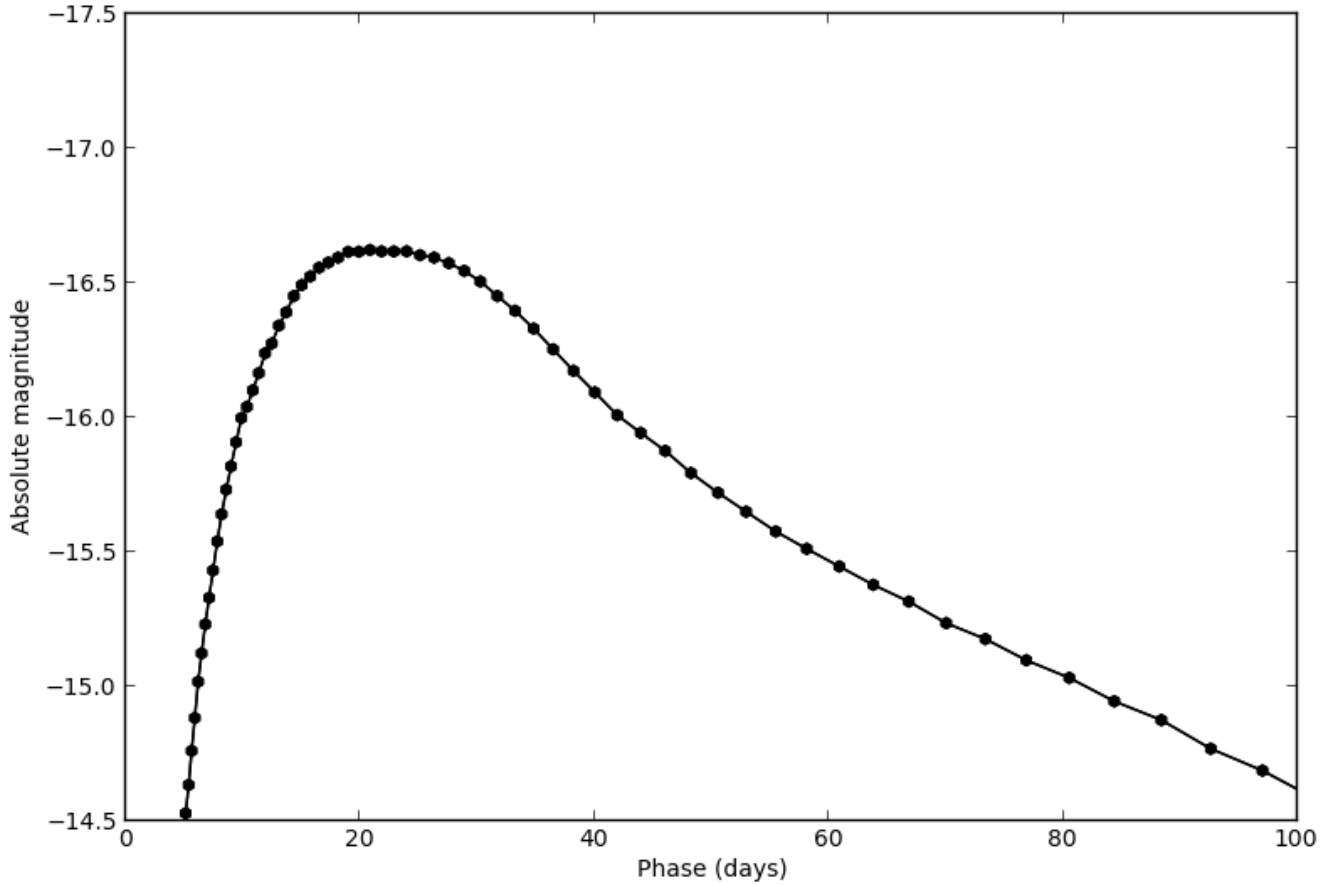
Model (circles) and SN 2011dh (crosses): Before 150 days





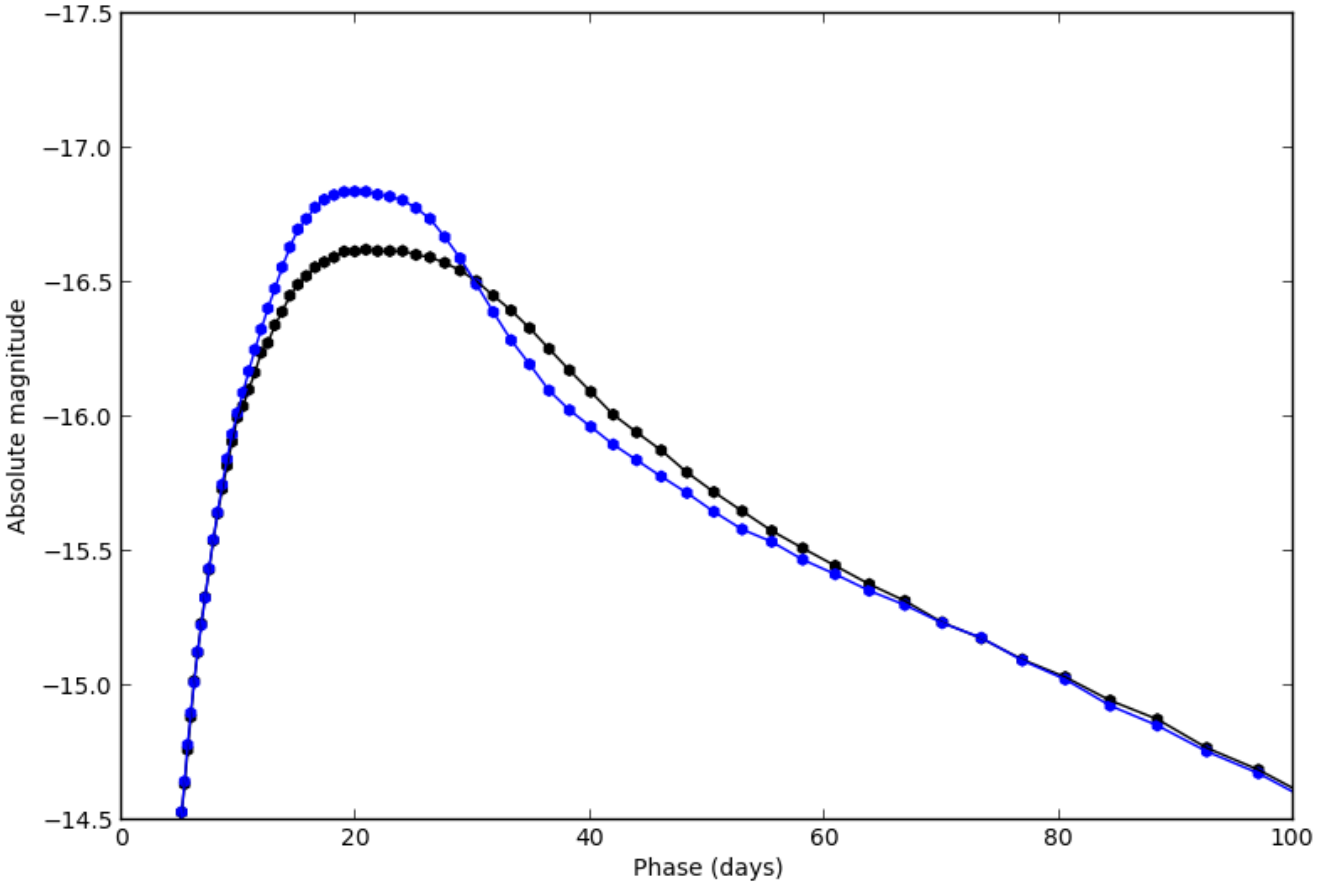
Effect of NLTE: Bolometric lightcurve

Model: Before 100 days



Effect of NLTE: Bolometric lightcurve

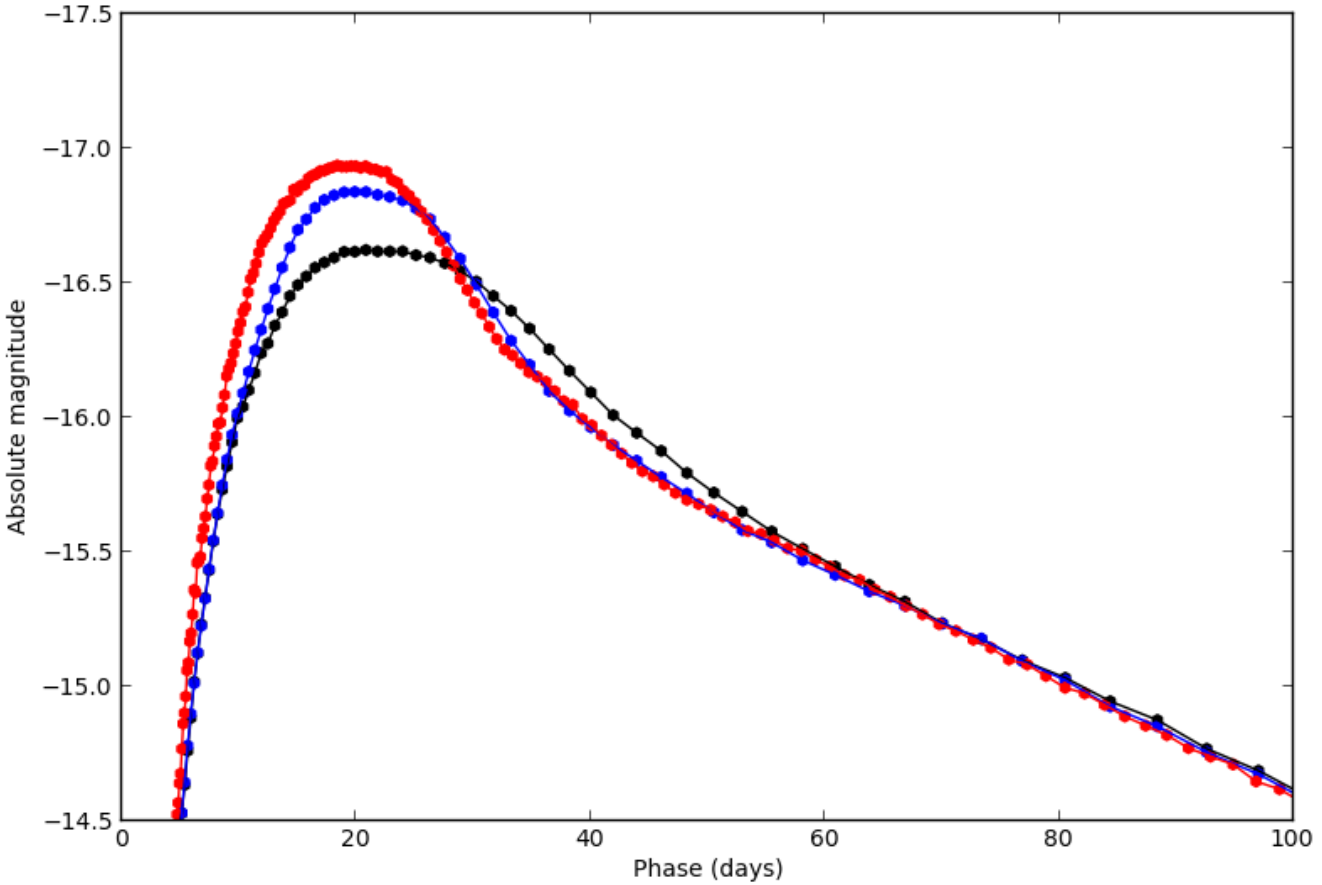
Model: Before 100 days



Non-thermal ionization/excitation - Off

Effect of NLTE: Bolometric lightcurve

Model: Before 100 days

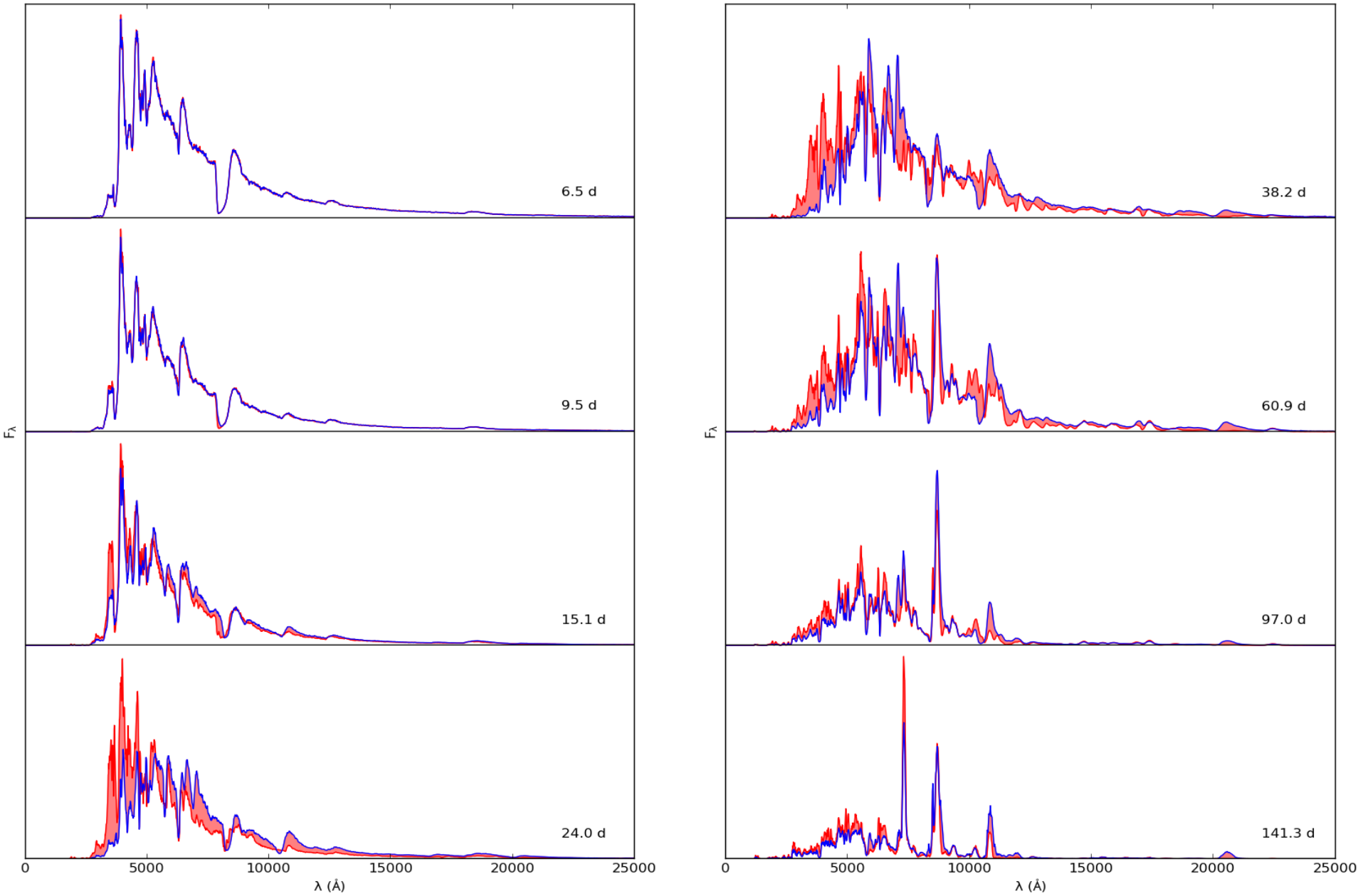


Non-thermal ionization/excitation - Off

LTE

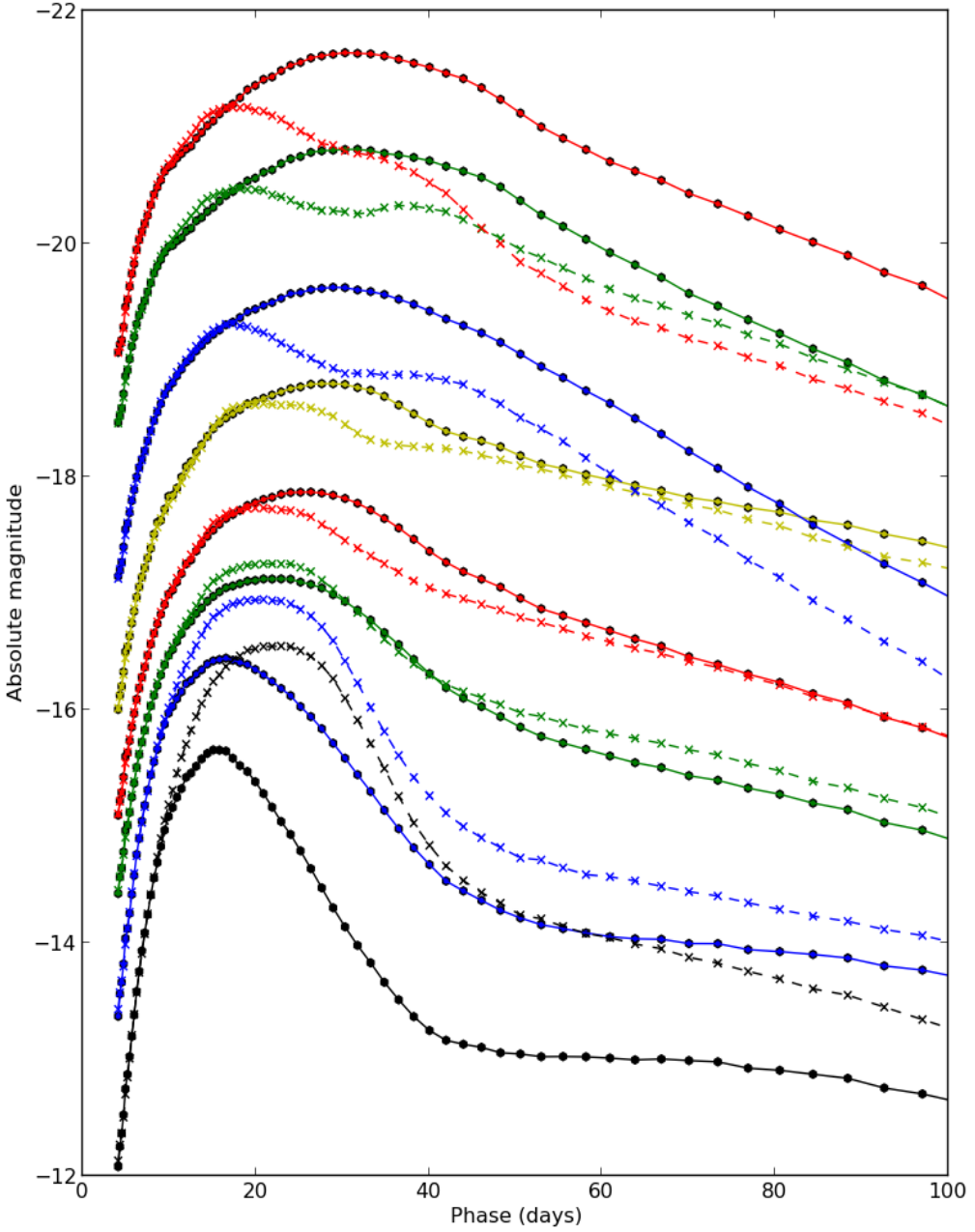
Effect of NLTE: Spectral evolution

Non-thermal ionization/excitation - On/Off

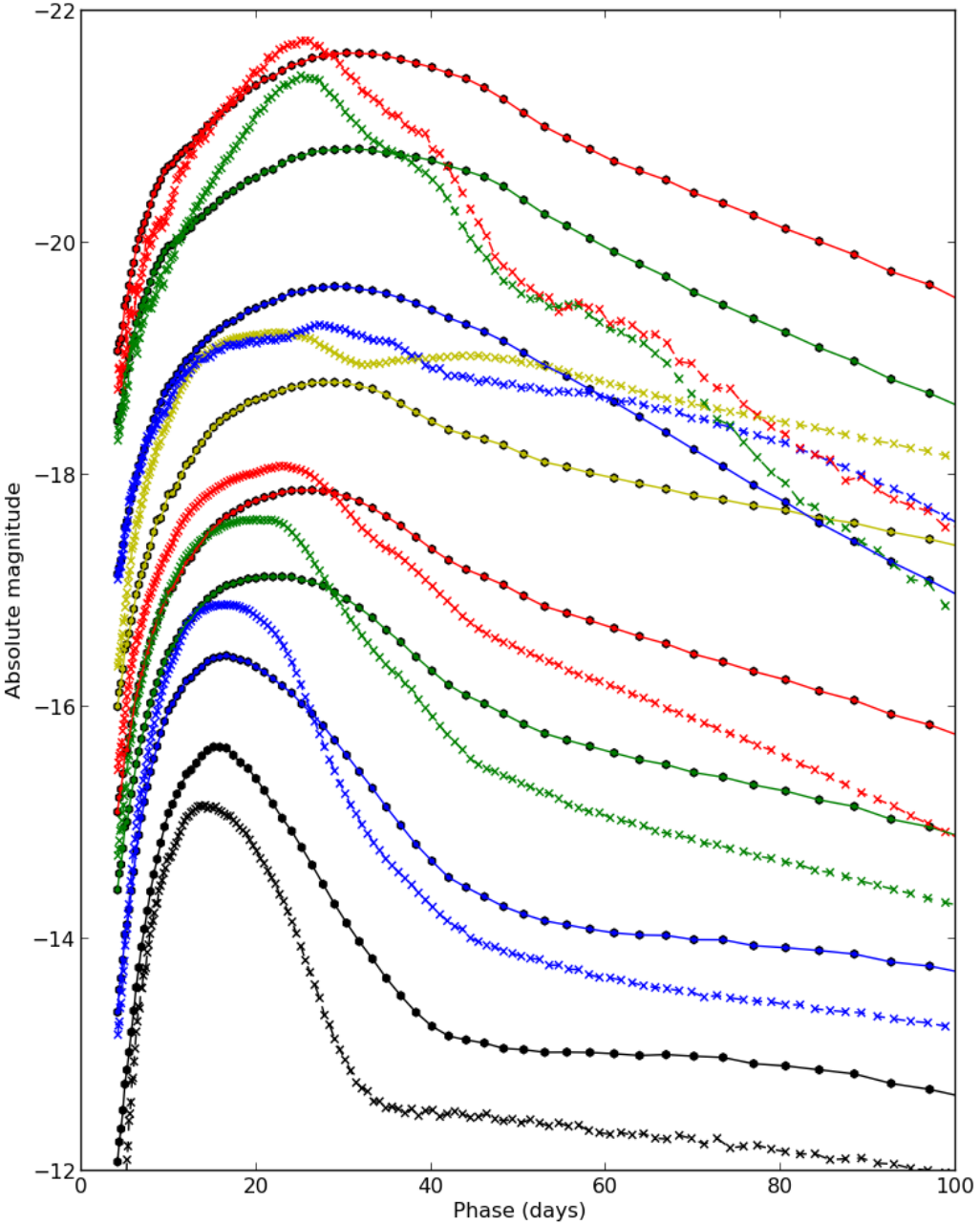


Effect of NLTE: Broadband lightcurves

Non-thermal processes - On (circles) / Off (crosses)

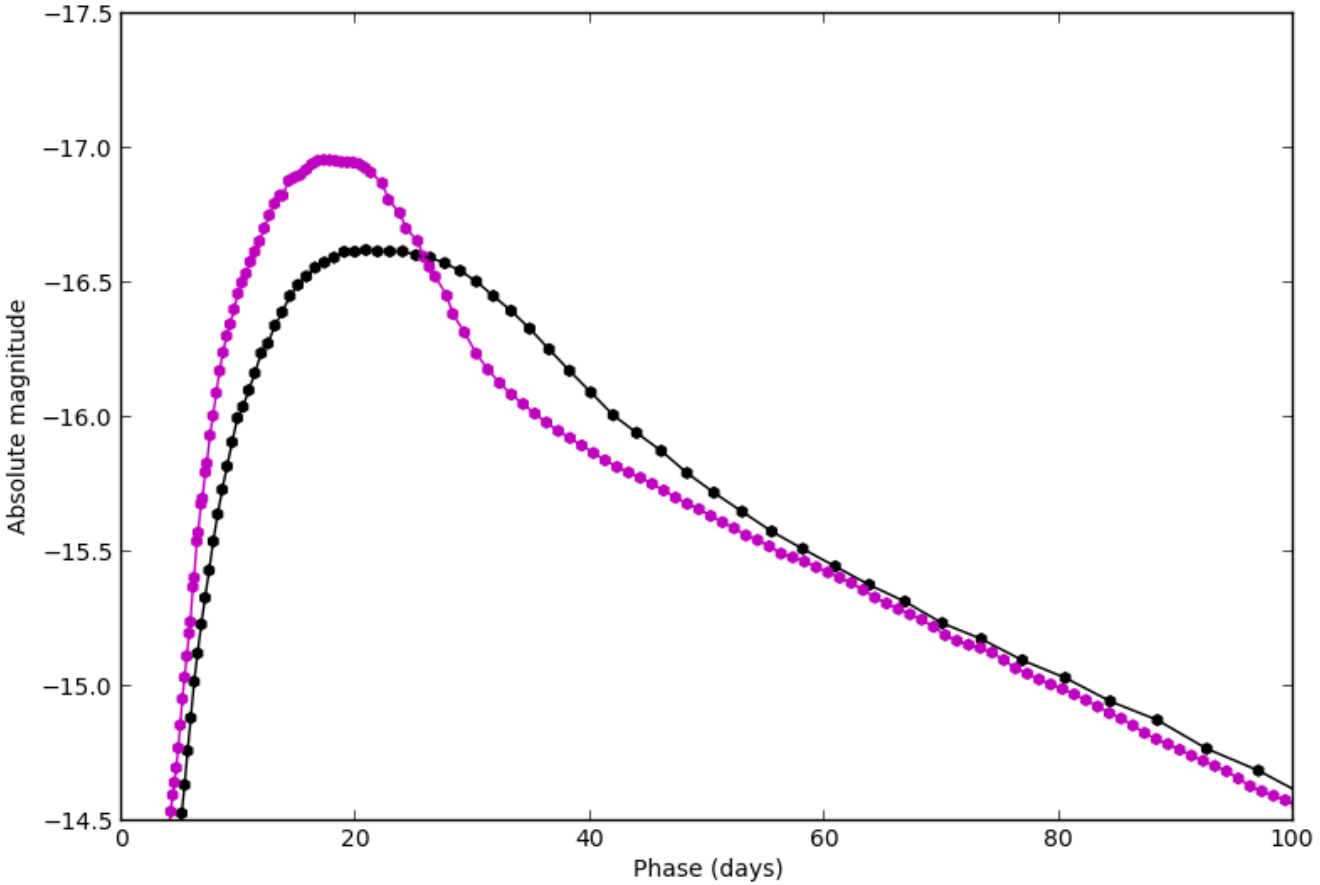


NLTE (circles) / LTE (crosses)



Effect of NLTE: Bolometric lightcurve

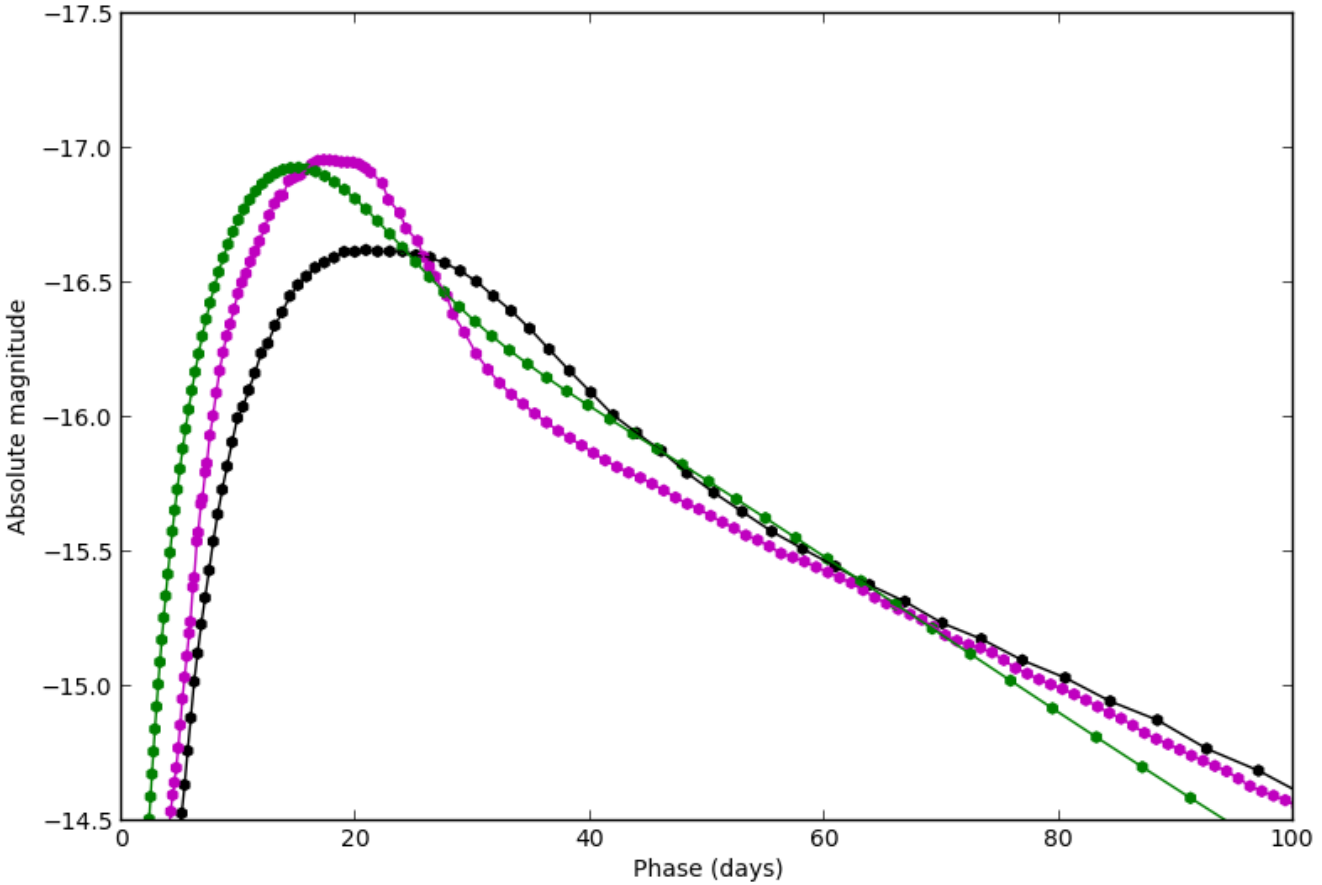
Model: Before 100 days



LTE + Opacity floor (HYDE)

Effect of NLTE: Bolometric lightcurve

Model: Before 100 days

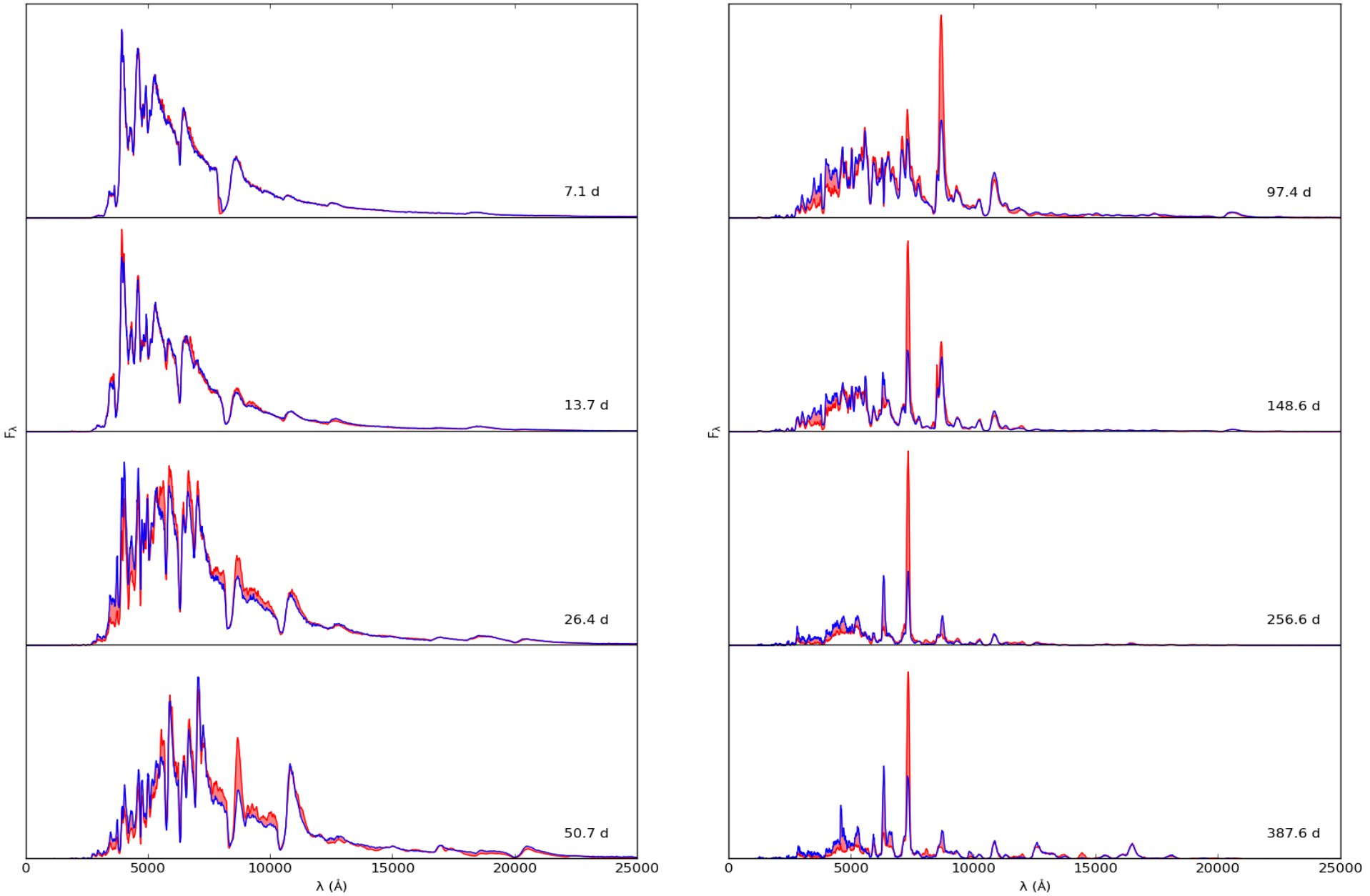


LTE + Opacity floor (HYDE)

Arnett (1982) + Popov (1991)

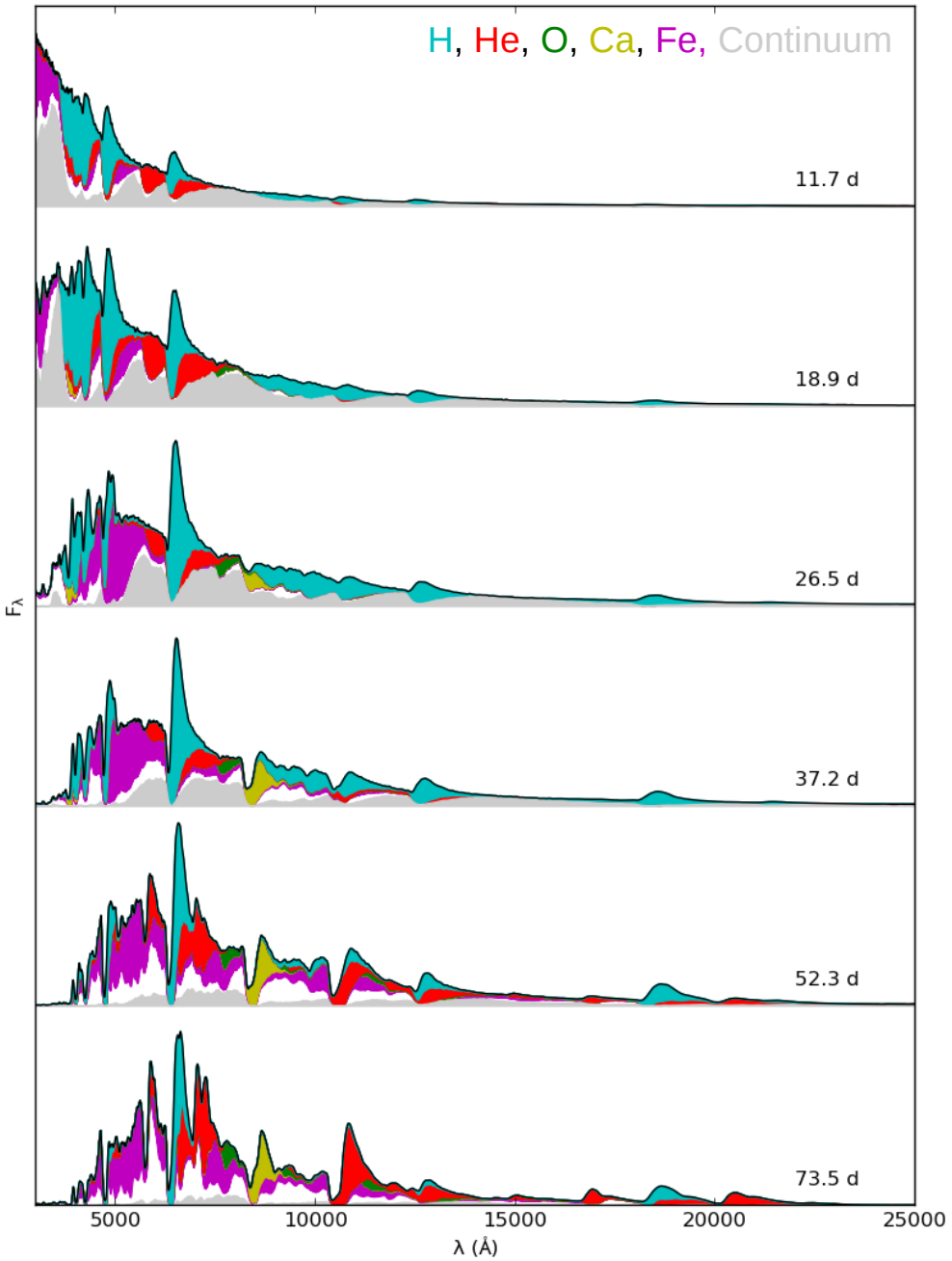
Effect of macroscopic mixing: Spectral evolution

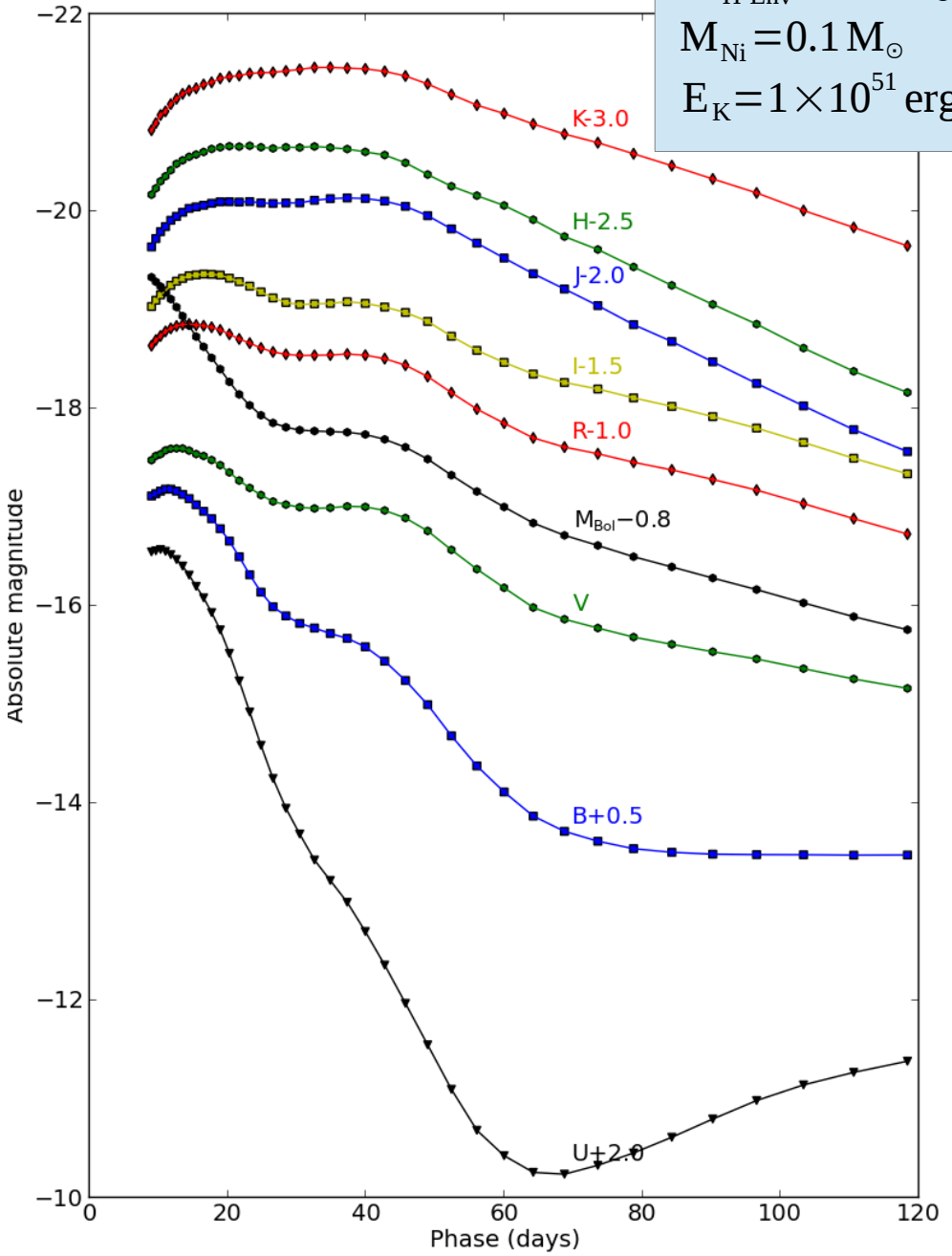
Macroscopic mixing - On/Off



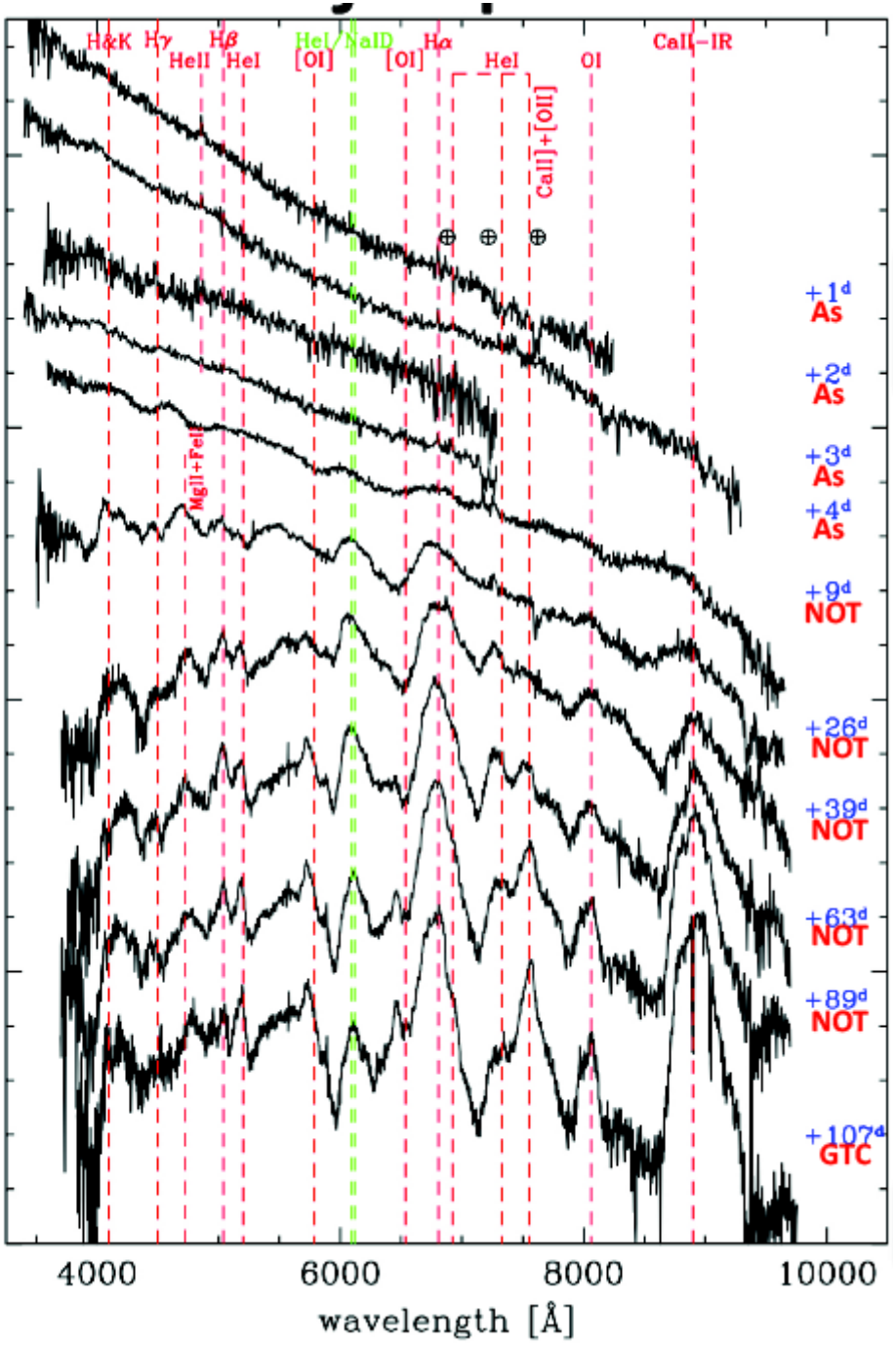
Type IIL SNe: A model with strong He lines

$M_{\text{He-Core}} = 4.0\,M_{\odot}$
$M_{\text{H-Env}} = 0.8\,M_{\odot}$
$M_{\text{Ni}} = 0.1\,M_{\odot}$
$E_{K} = 1 \times 10^{51}$ erg



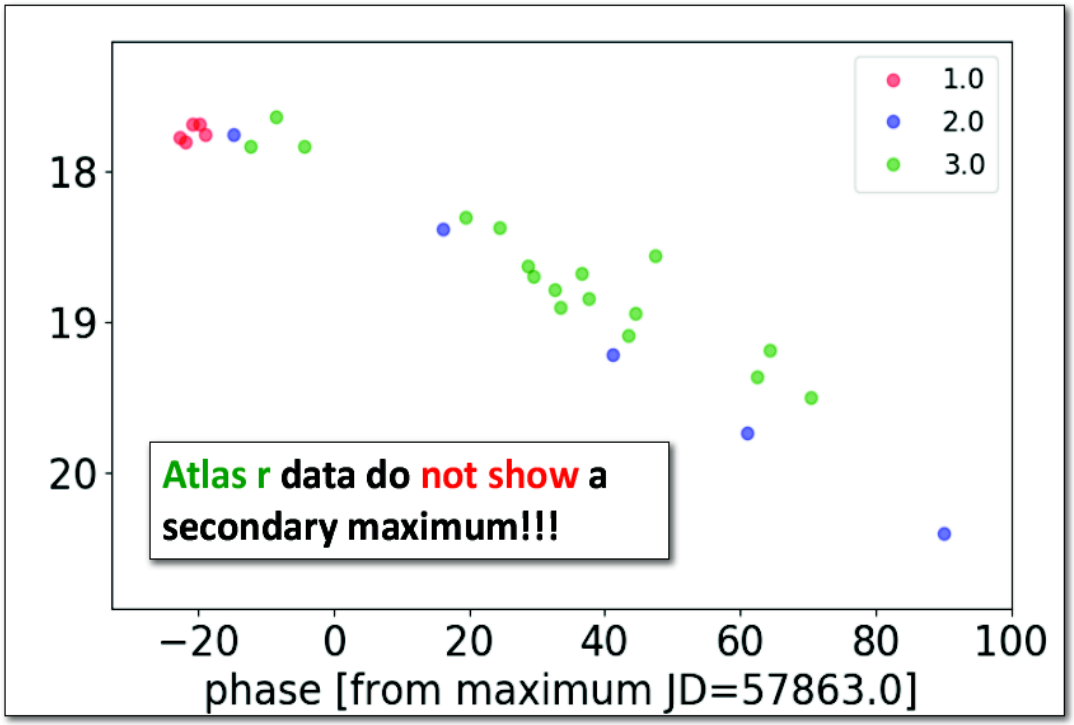


Type IIL SNe: Possible example with strong He lines



Spectral sequence (left) and r lightcurve (below) for SN 2017ckj.

From a presentation by Stefano Benetti & Lina Tomasella at the NUTS Meeting 2017 in Stockholm.



Thanks ...