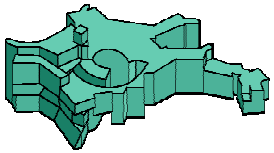
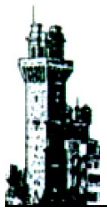


IAU Symp. 279: "Death of massive stars: SNe and GRBs"

SN Ic + x = SN Ib ?

How much H/He is in SNe IIb/Ib/Ic ?

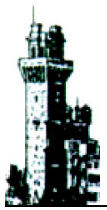
S. Hachinger, P. A. Mazzali, S. Taubenberger,
W. Hillebrandt, K. Nomoto and others
(Hachinger+ 2012)



Motivation

Analysis of H/He/… abundances in SNe IIb/Ib/Ic
from early-phase spectra + radiative transfer models

- clues about progenitors (+ explosion mechanisms) of stripped core-collapse SNe
- later: SN He content ⇔ GRBs ?
- rad. transfer: effect of nonthermal electrons on He must be modelled



Outline

- Photospheric SN spectra:
  NLTE (non - local thermal equilibrium)
  radiative transfer models

- Models for SNe 2008ax (IIb) / 1994I (Ic)

- Model sequence (synthetic spectra):
  "some stripping $\rightarrow$ complete stripping"
  How much H/He is hidden in (low-mass) SNe Ib/Ic?

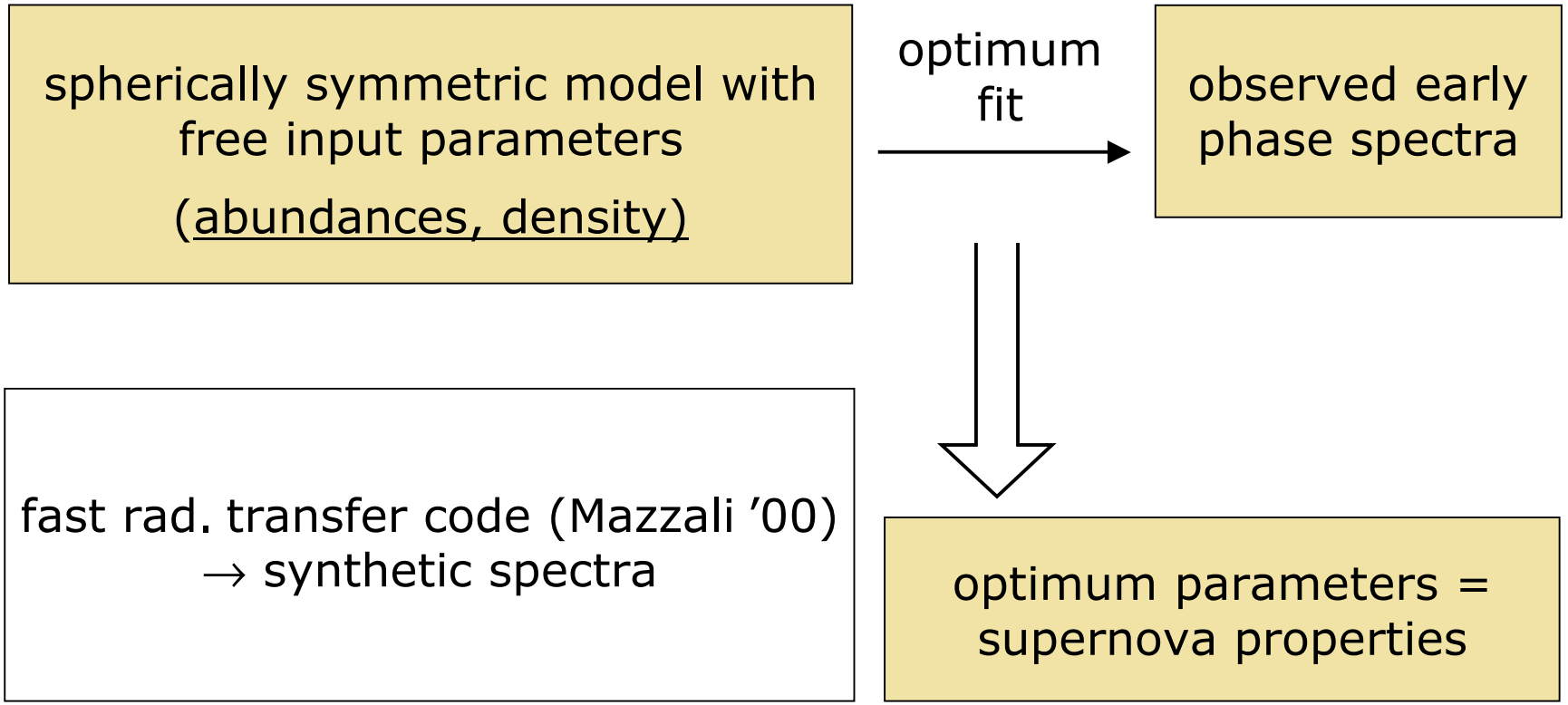
- Conclusions

Spectral modelling of SNe

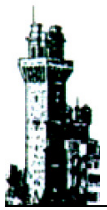
"normal" and NLTE models

SN modelling "data → models "

Concept (e.g. Stehle+ '05 – abundance tomography):



+ Use models for parameter studies (model sequences)



Radiative transfer

Lucy (1999), Mazzali (2000), Stehle+ (2005)

Monte-Carlo code:

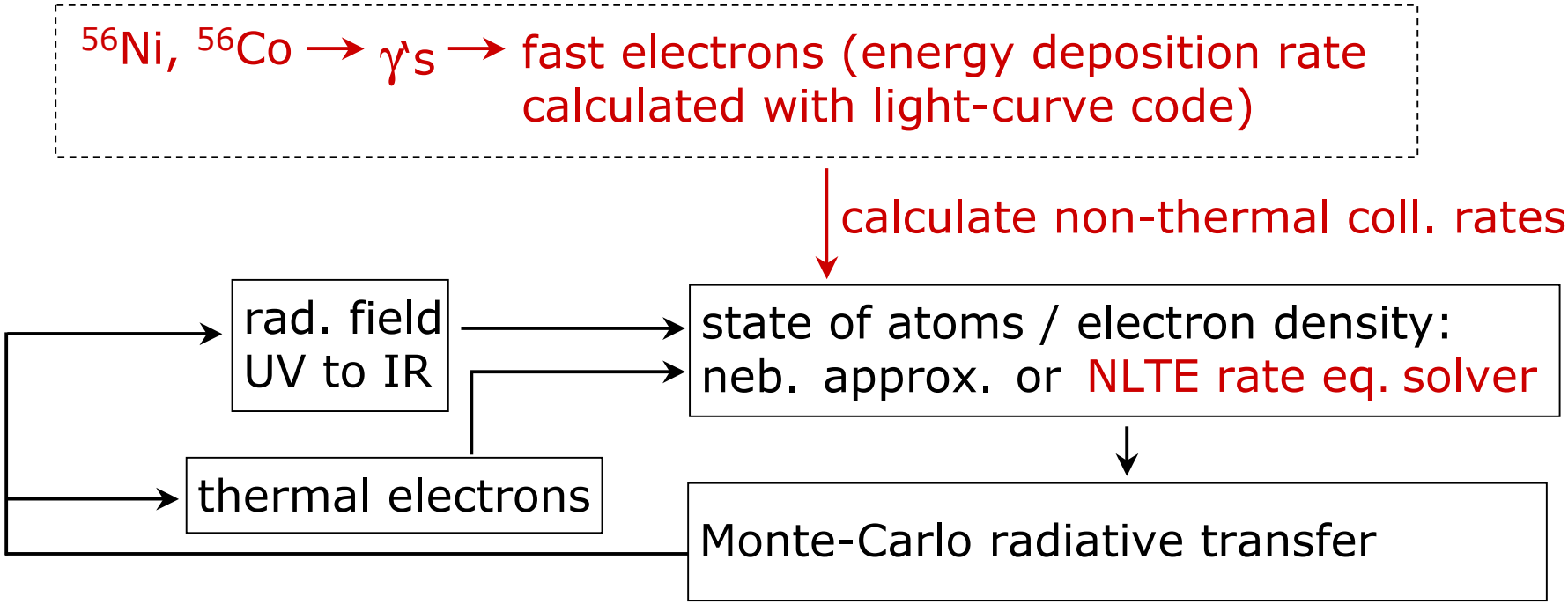
calculates a stationary-state atmosphere ("snapshot") above a sharp photosphere (where a black body is emitted: $I^+ = B_\nu$)

- Radiation field: line interactions (with branching), scattering with e^-
- State of matter: nebular approximation consistent with radiation field

Radiative transfer …
… including H and He in NLTE

Lucy (1999), Mazzali (2000) radiative transfer code

Harkness+ ('87), Chugai ('87), Graham (88), Lucy+ ('91):
He lines appear in SNe because of extremely nonthermal level population



iterative solution for radiative transfer / gas state

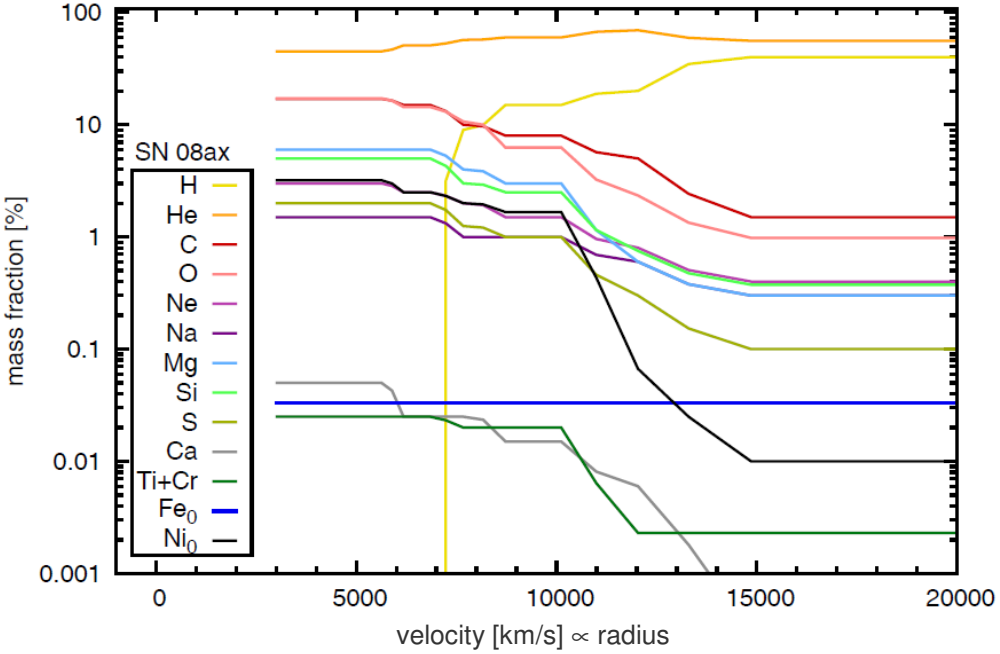
Models for SNe 2008ax (IIb) and 1994I (Ic)

Models: SN IIb 08ax

assume density profile: 4H47
(Shigeyama+ 1994 explosion model)

$M_{ej} \sim 3 M_\odot$, $E_k \sim 10^{51}$ erg

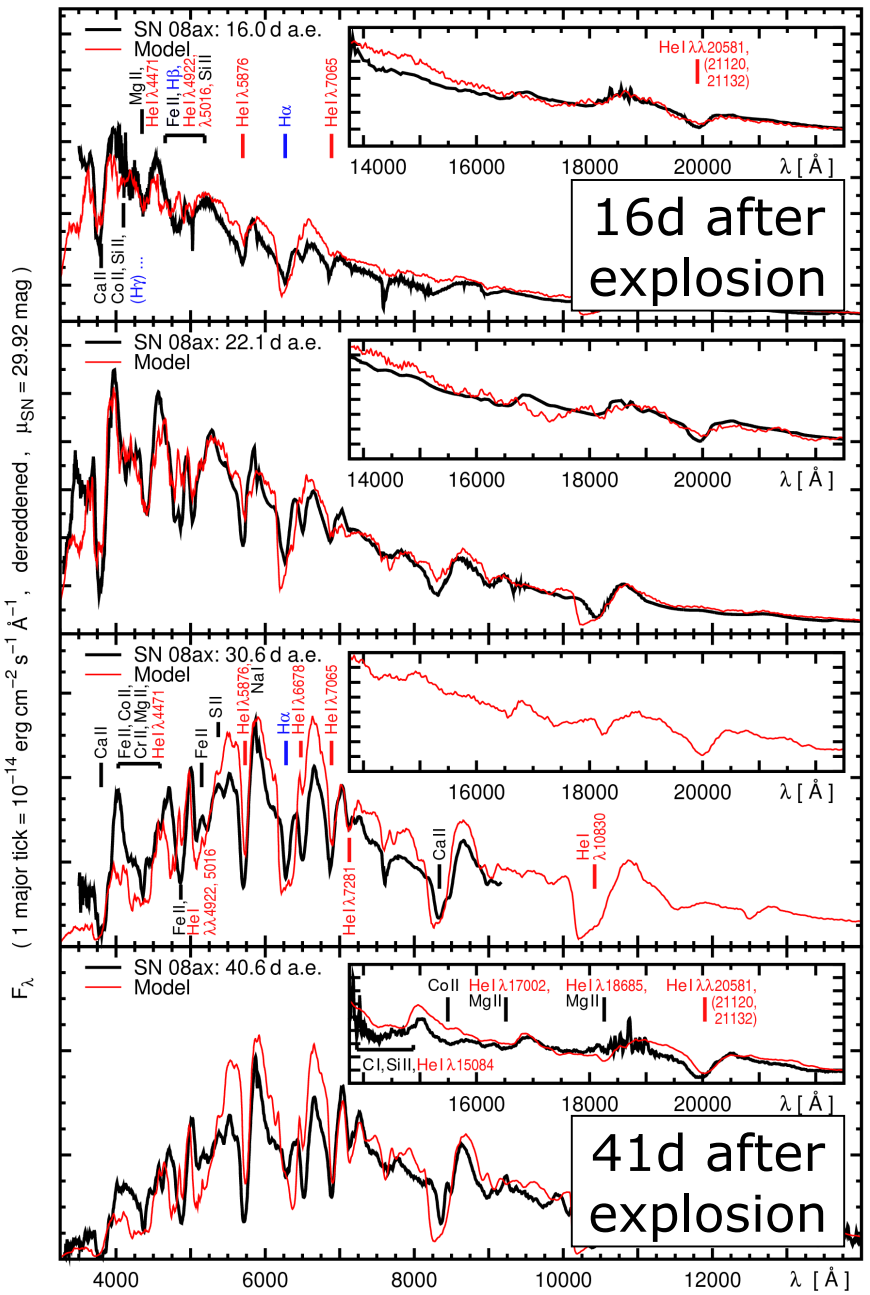
optimum
abundances:



<0.1$M_\odot$ H 1.2$M_\odot$ He
1.1$M_\odot$ C/O/IME 0.08$M_\odot$ ^{56}Ni

spectra:

Taubenberger+ ('11), Chornock+ ('10),
observations: Roming+ ('09), Pastorello+ ('08)

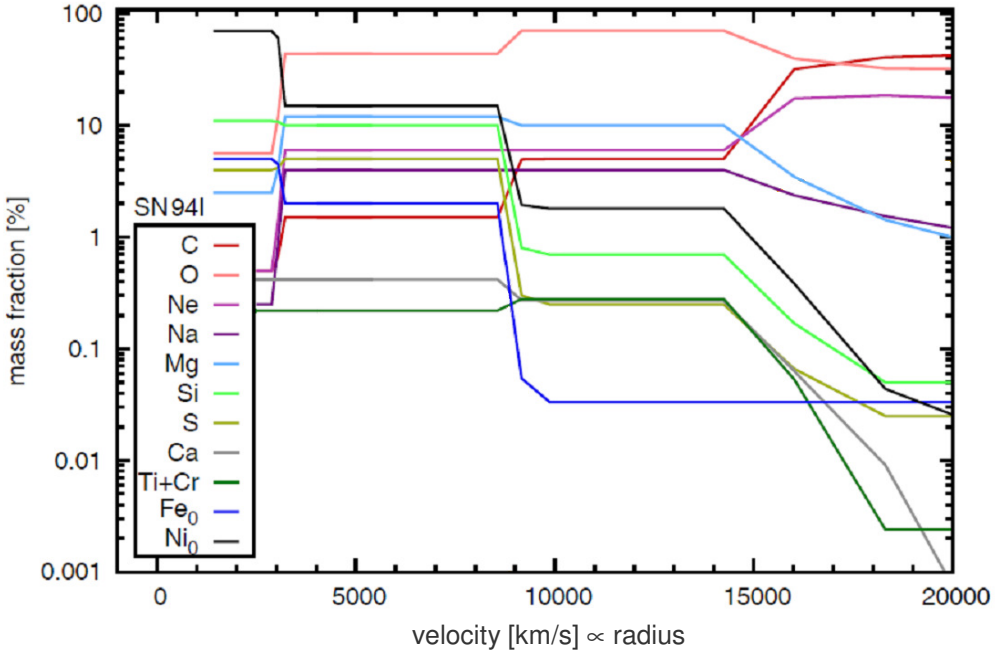


Models: SN Ic 94I

assume density profile: CO21 (Iwamoto+ 1994)

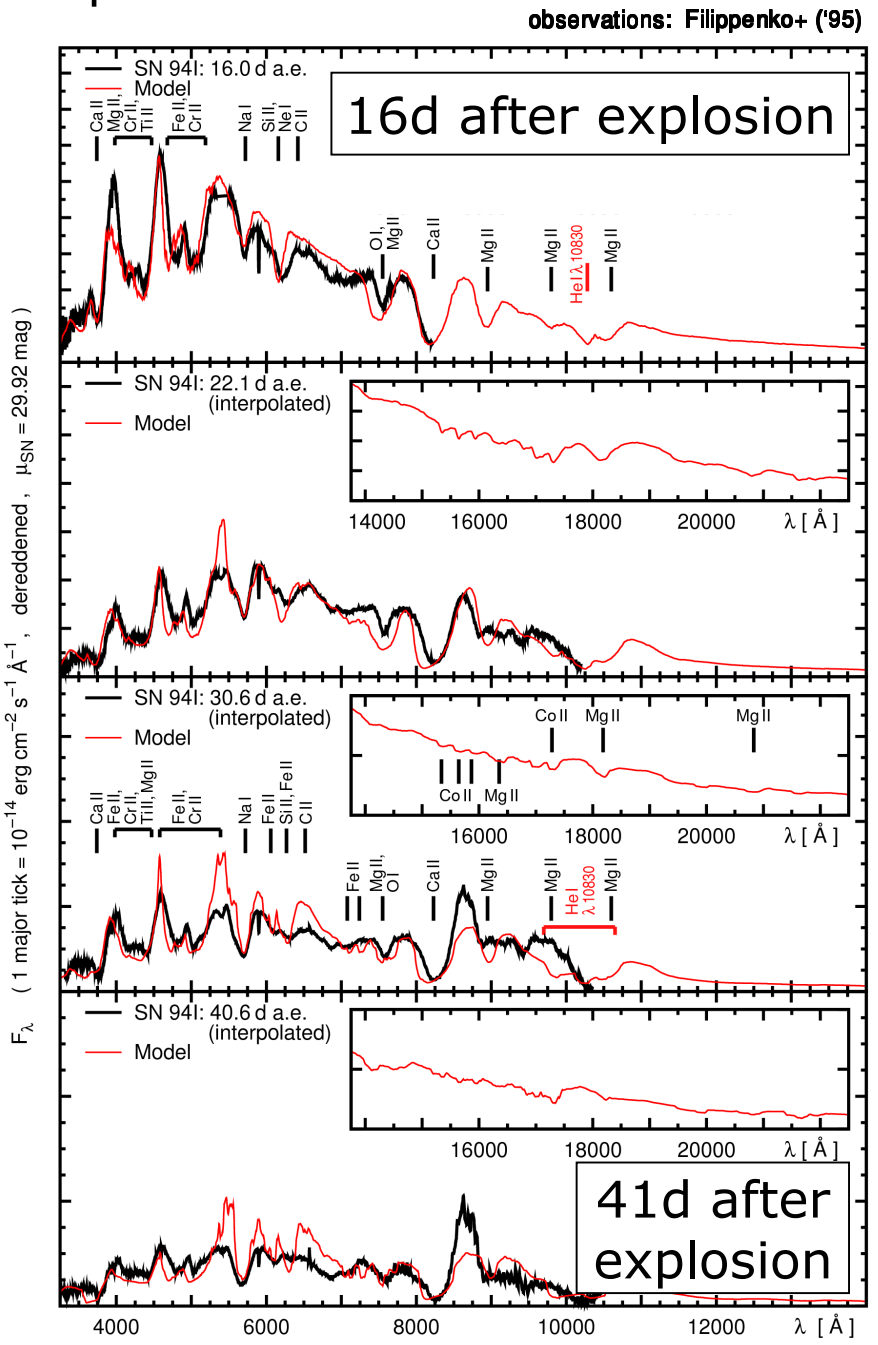
$M_{ej} \sim 1 M_\odot$, $E_k \sim 10^{51}$ erg

optimum abundances:



$0.5 M_\odot$ C/O $0.3 M_\odot$ IME $0.09 M_\odot$ ^{56}Ni

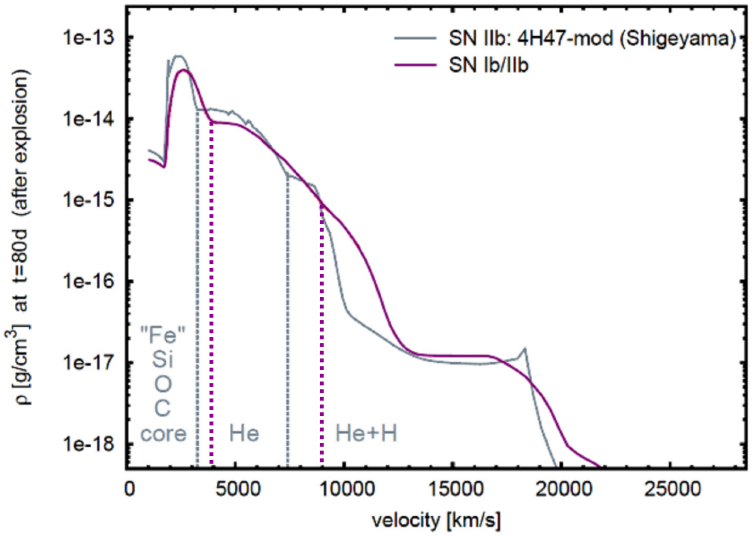
spectra:

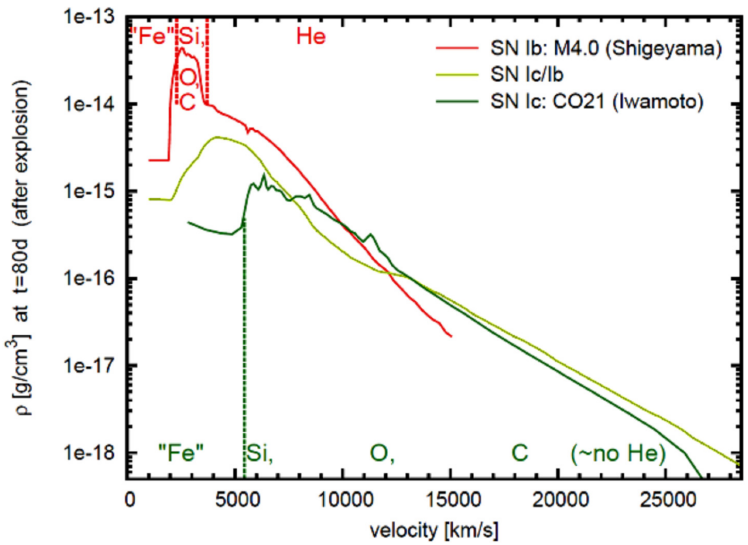


Model sequence IIb-Ib-Ic

(and interpretation)

Model sequence: Density/abundance structure

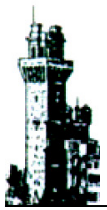




Aim:
40 abundance/density models
→ synthetic spectra SN IIb → Ib → Ic
(we only show the most interesting ones)

- density structure:
  smooth transition
  4H47 (IIb) → M4.0 (Ib) → CO21 (Ic)
  all models have $E_{\mathrm{k}} = 10^{51}\,\mathrm{erg}$

- abundance structure:
  interpolate between
  08ax and 94I models
  (at each mass coordinate)

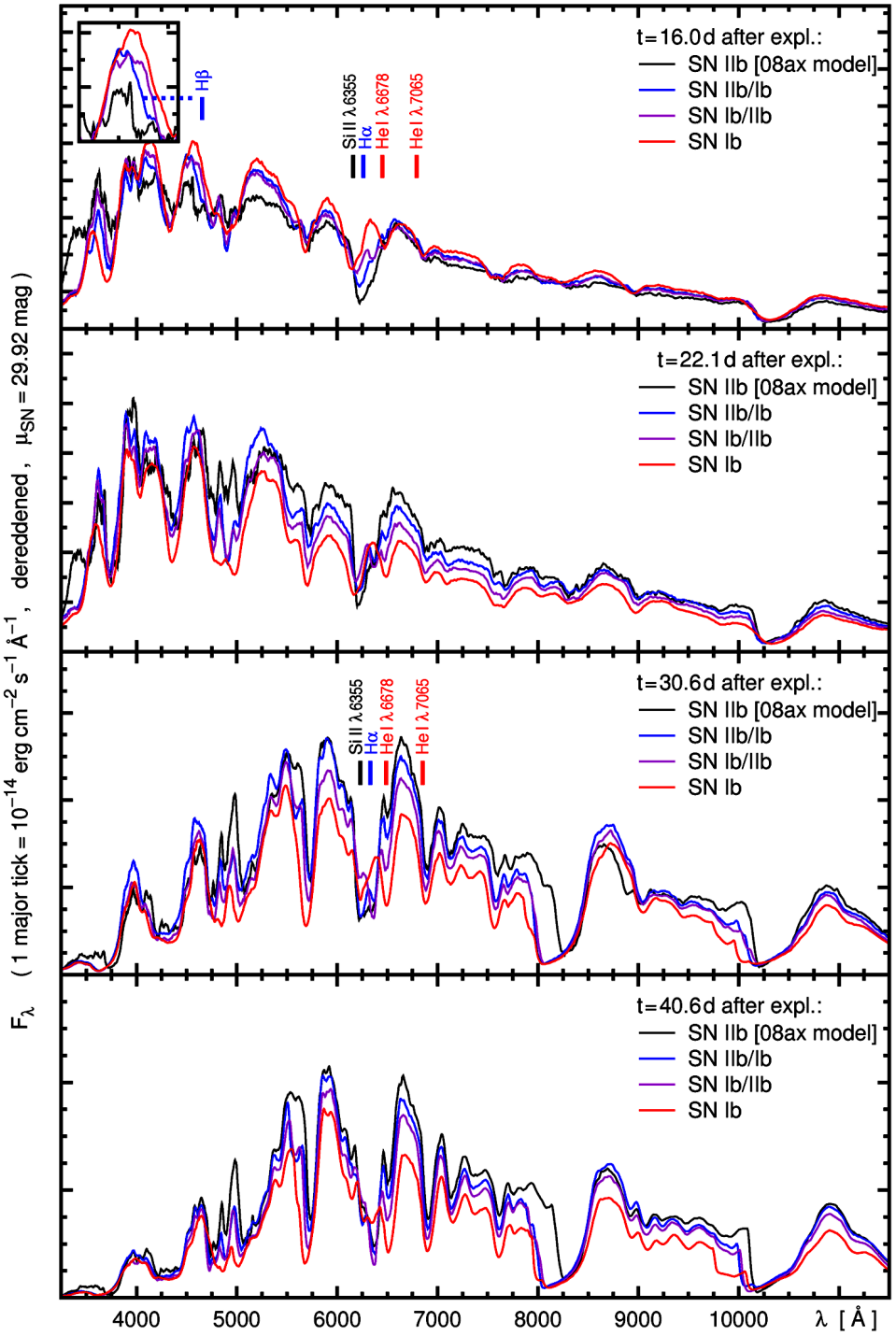


IIb – Ib transition
and H estimate

SN IIb/Ib and SN Ib/IIb models are "transitional" cases.

To see Hα, $\leq 0.03 M_{\odot}$ of H are sufficient.

consistent with estimates of Claeys+ ('11) or Chevalier & Soderberg ('11)

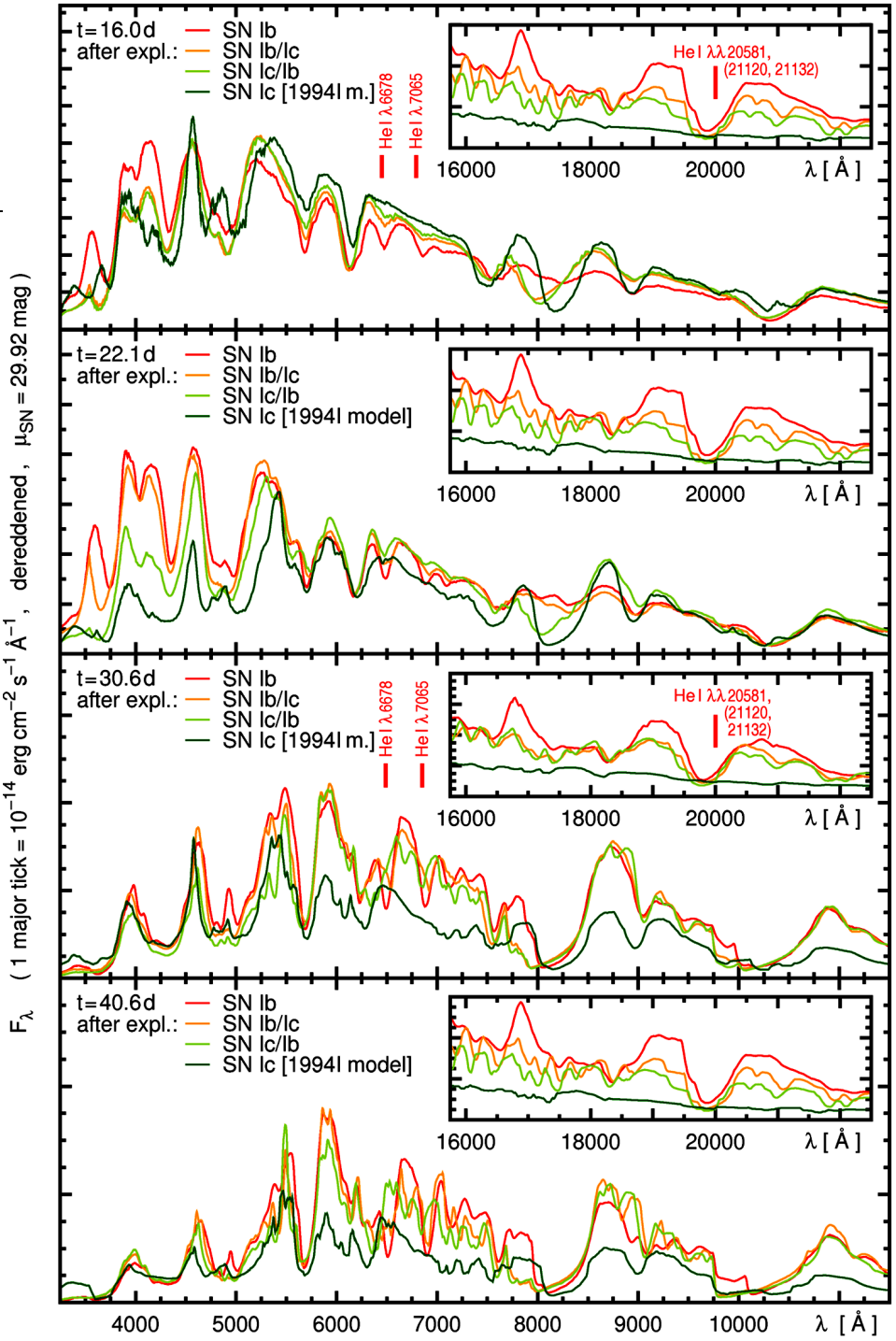


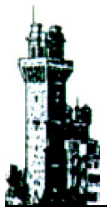
Ib – Ic transition
and He estimate

SN Ib/c model and SN Ic/Ib model:

$0.1 M_{\odot}$ of He suffice to make lines [departures from LTE by factors > 10^5 !].

2μ feature is an excellent diagnostic for He content!



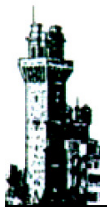


Conclusions: spectral analysis

- Radiative transfer treatment of He/H
  $\rightarrow$ abundance analysis of He-rich SNe possible

- Analysis of ioinisation/excitation state (Hachinger+ '12).
  $\rightarrow$ results especially on He can be considered quite robust

- He I λ20581 recommended as abundance diagnostic
  - not strongly saturated
  - little blending with other elements (λ10830 line: C I ?)



Conclusions: stripped CC progenitors

- SNe Ib with $M_{\rm ej}$ ~ 2..3 $M_\odot$: max. hidden H mass: some 0.01$M_\odot$

- SNe Ic with $M_{\rm ej}$ ~ 1 $M_\odot$: max. hidden He mass: ~0.1$M_\odot$

  → problem for progenitor models:

  Georgy+ (2009): single stars: $M_{\rm He,final}$ > 0.3$M_\odot$

  Yoon+ (2010): binaries (up to 3 case A/B mass transf. episodes): models + observed SN Ic / SN Ib ratio: require $M_{\rm He,Ic}$ up to 0.5$M_\odot$

  → "exotic" binaries with a NS companion (Nomoto+ '94) ?

- Will extend this kind of studies

  → more massive models

  → extremely aspherical cases

Thank you !