Spectral models of the "standard" type Ic supernova SN 1994I

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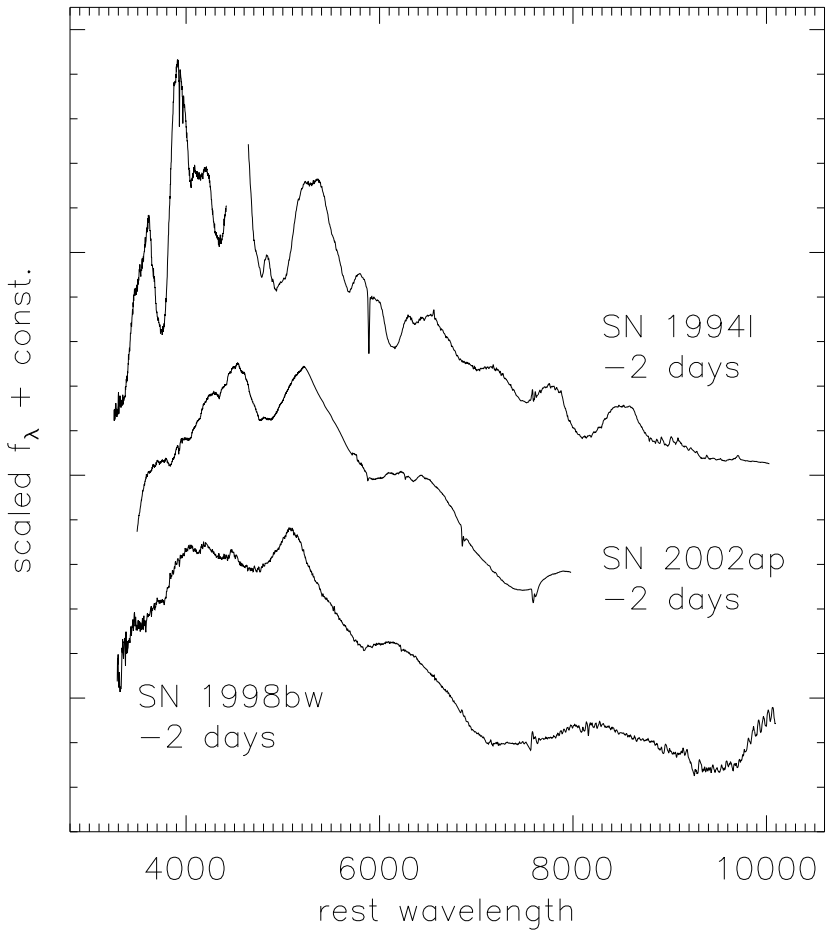
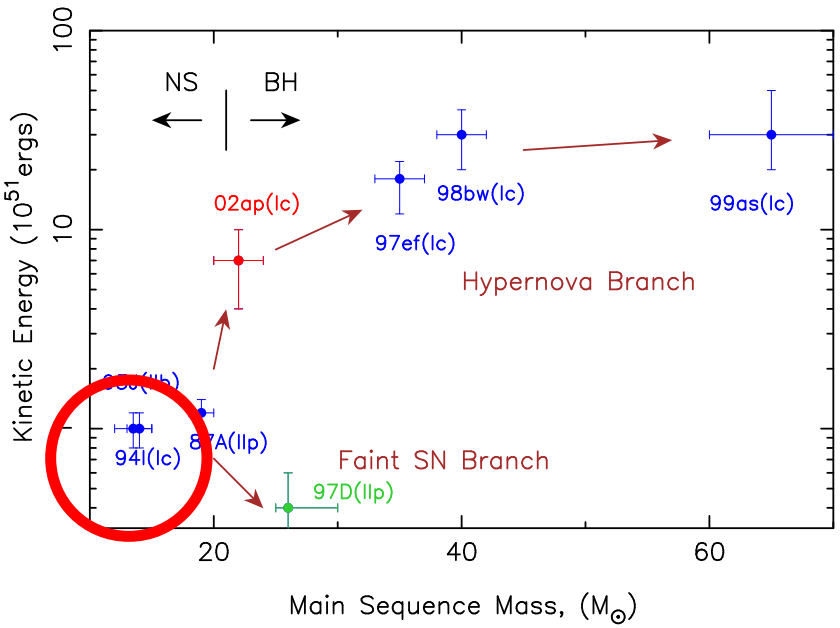
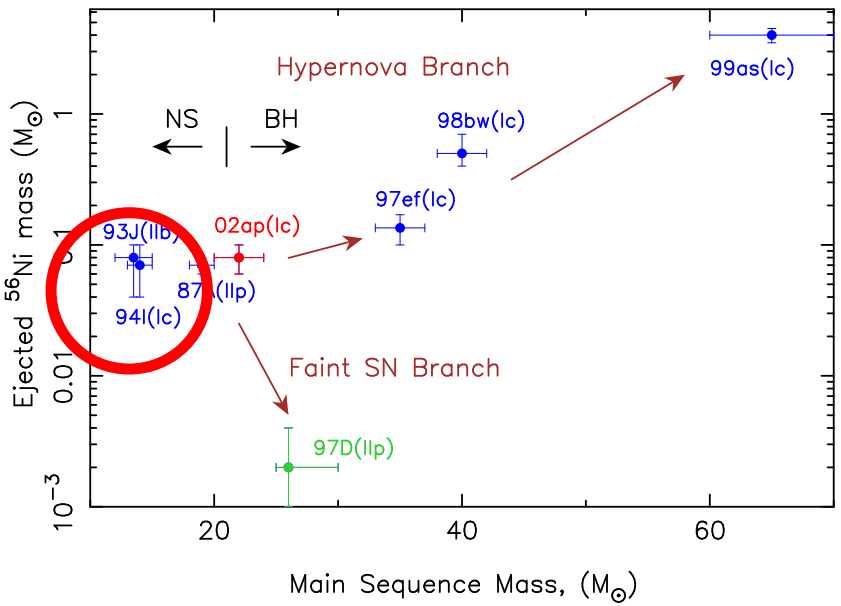
Type Ic SN and Hypernovae

- Core collapse
- SN Ic $\rightarrow$ no H, no He, Si II at 6100 Å less prominent than in SN Ia
- inhomogeneous class
- some very energetic SN Ic ($E_{\mathrm{kin}} \gtrsim 10^{52}$ erg)
  $\rightarrow$ “Hypernovae”
  $\rightarrow$ SN/GRB Connection



Why is SN1994I interesting?

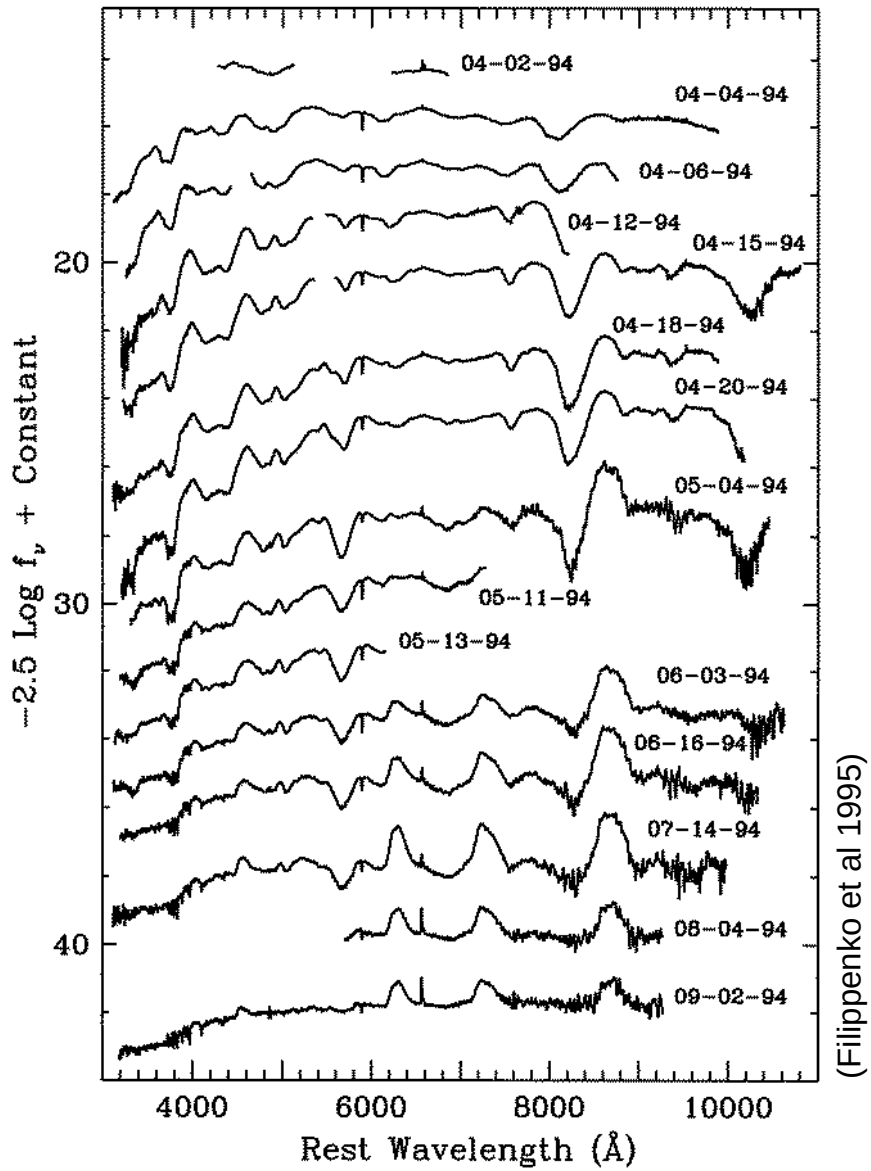




(Nomoto et al 2002)

Observations of SN 1994I in M51

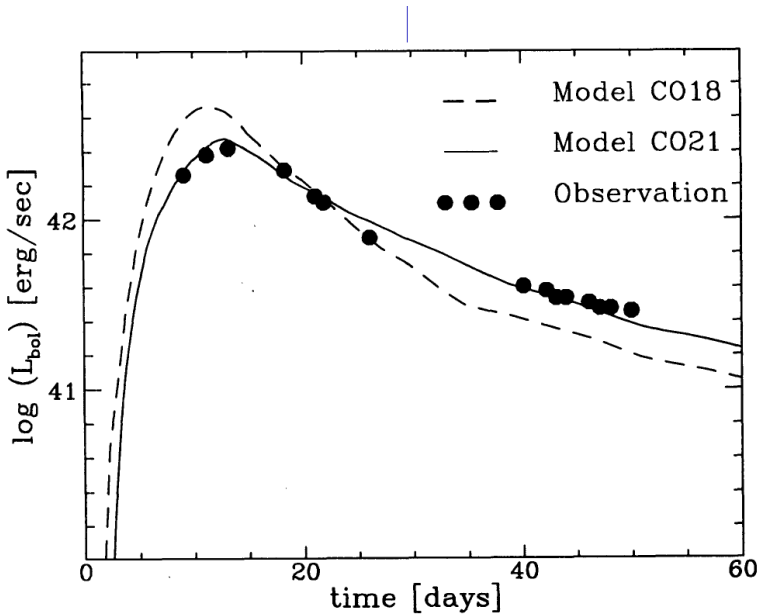
- V-band max 12.9 mag on April 9th 1994
- narrow, fast light curve
- spectrum reddens quickly with time
- large extinction?
- HeI identification?



(Filippenko et al 1995)

Light Curve Model for SN 1994I

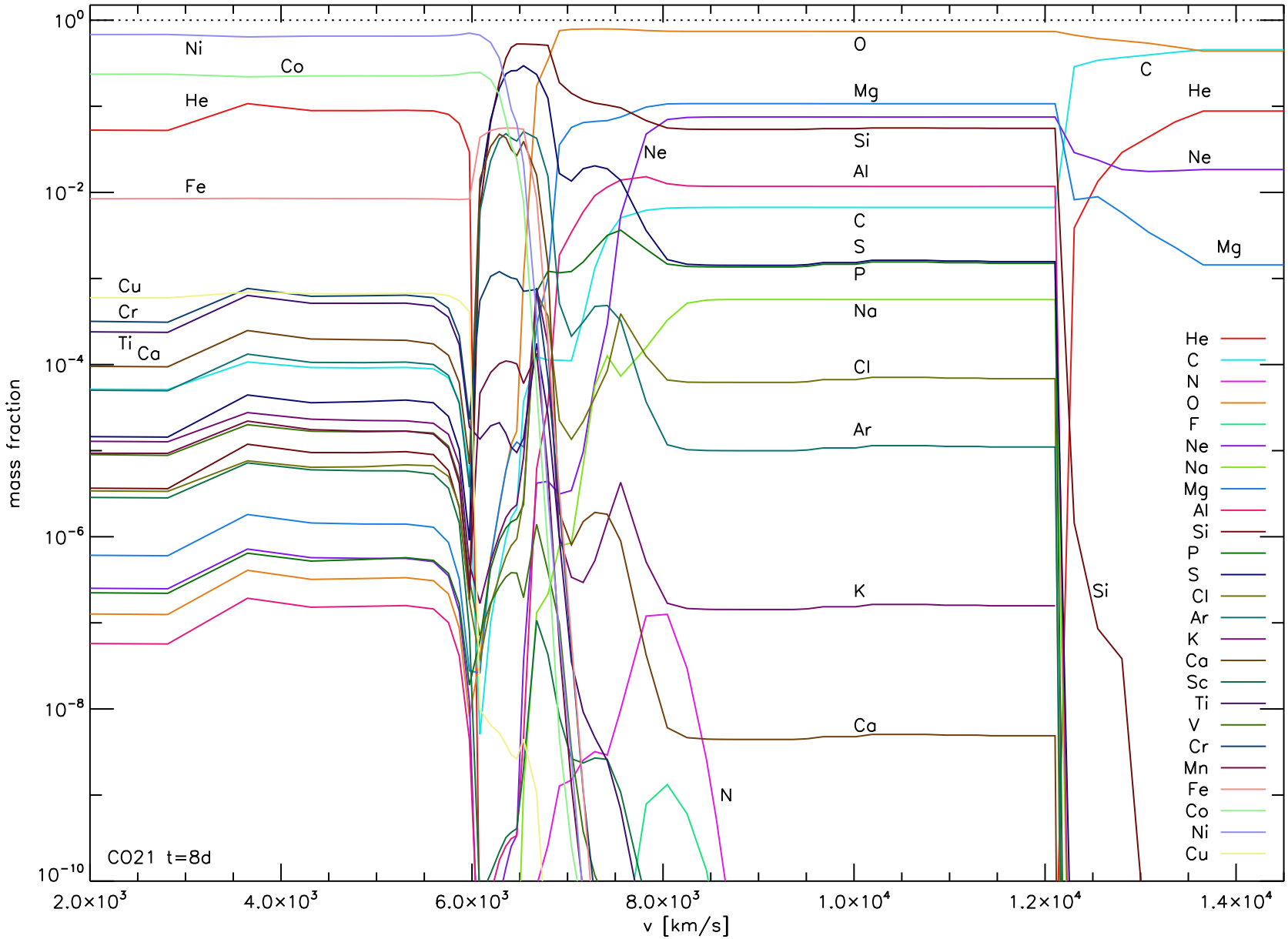
- C-O star ($M_{C+O} = 2.1 M_\odot$) from $M_{ms} \sim 15\, M_\odot$ $\rightarrow$Fe-core collaps
- LC entirely due to γ from $^{56}Ni \rightarrow ^{56}Co \rightarrow ^{56}Fe$
- $E_{kin} = 1 \times 10^{51}$ erg
- $M_{ej} = 0.88 M_\odot \left(\frac{E_{kin}}{10^{51} \text{erg}} \right)^{1/2}$
- $M(^{56}Ni) = 0.077 M_\odot$



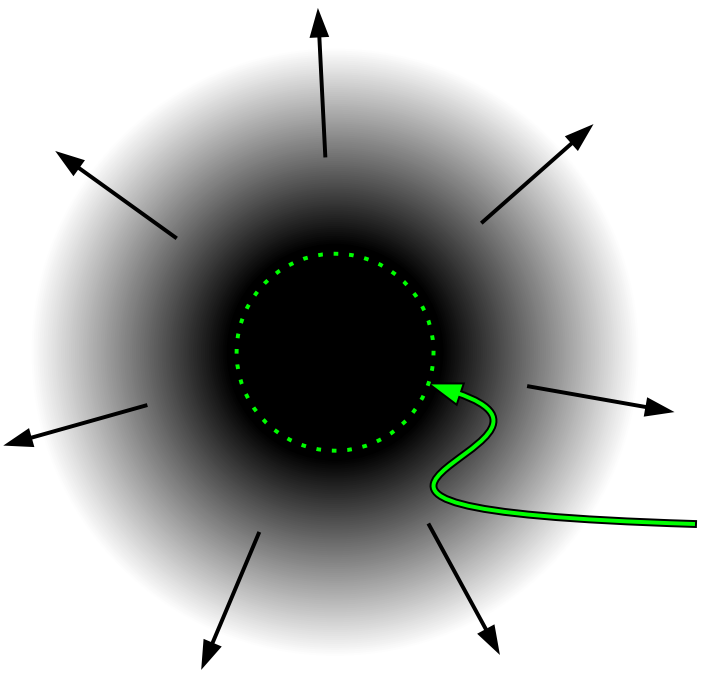
(Iwamoto et al (1994))

FIG. 2.—Bolometric light curves in comparison to observations (Schmidt & Kirshner 1994).

The CO21 explosion model — Composition

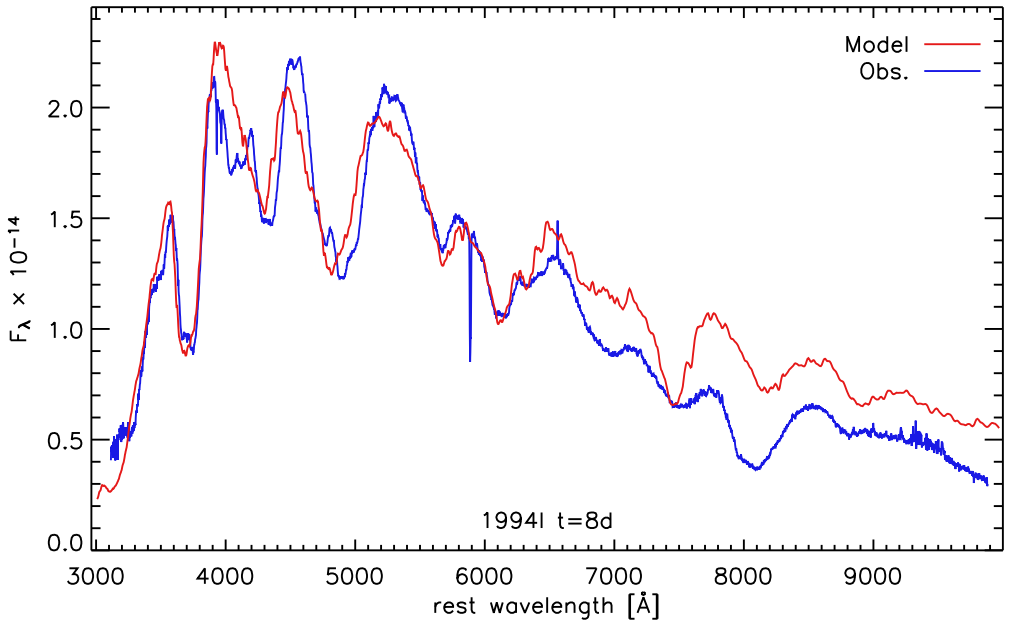


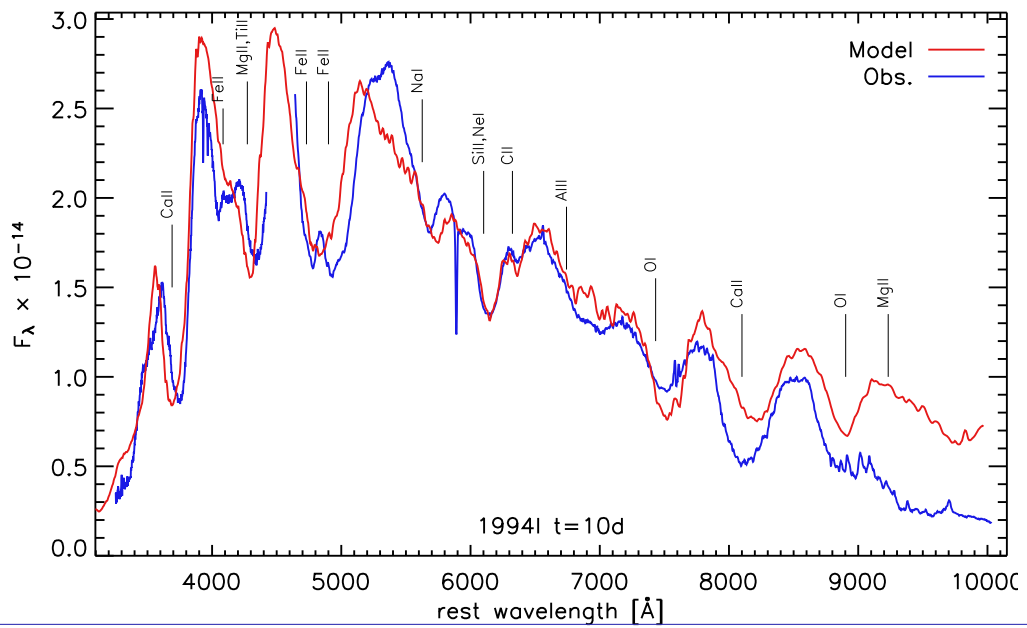
Spectral Models of 1994I



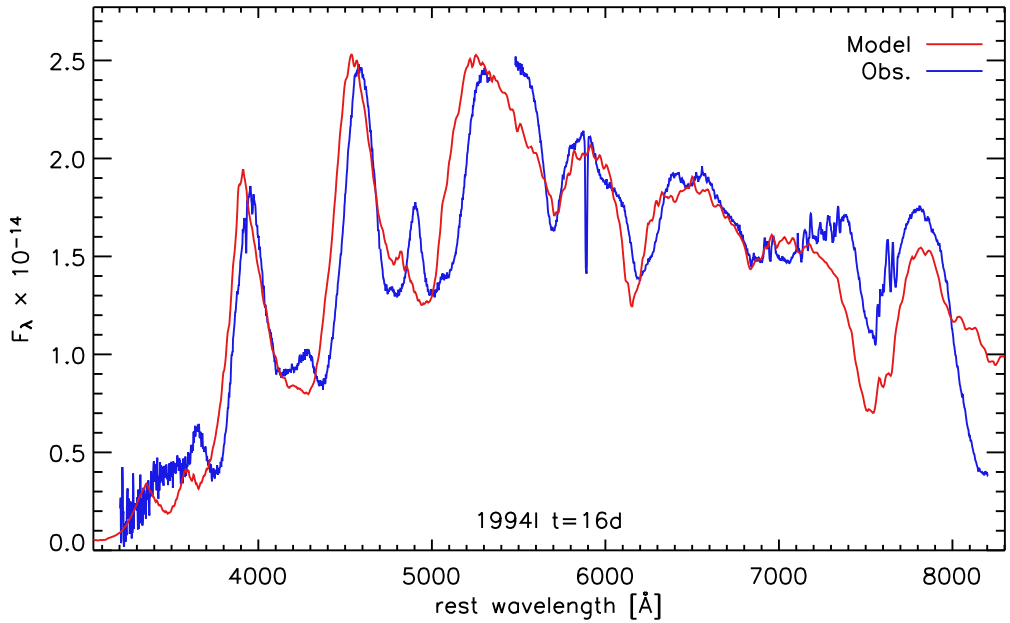
- Monte Carlo radiation transfer code
  (Lucy, Mazzali (1993,2000))
- Spherical symmetry, uniform composition
- General parameters:
  - $m - M = 29.6$ (8.3 Mpc)
  - $E(B-V) = 0.30$
  - $t = 0$: Mar 28, 1994
  - $\rho(v)$ from CO21 model
- Individual input:
  L, v_{ph}, composition

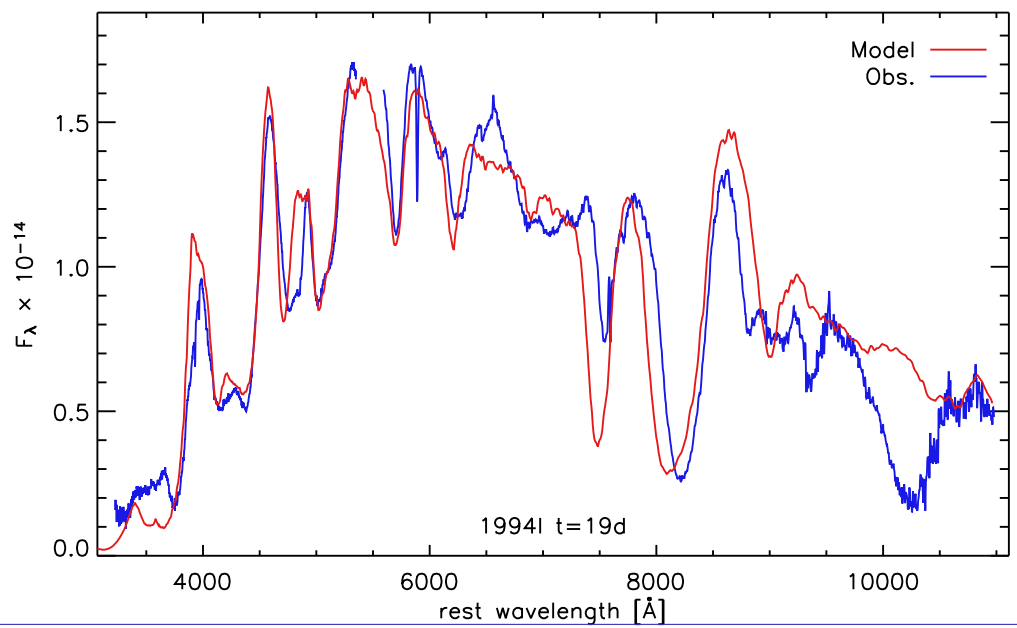
Spectral Models of 1994I (I)



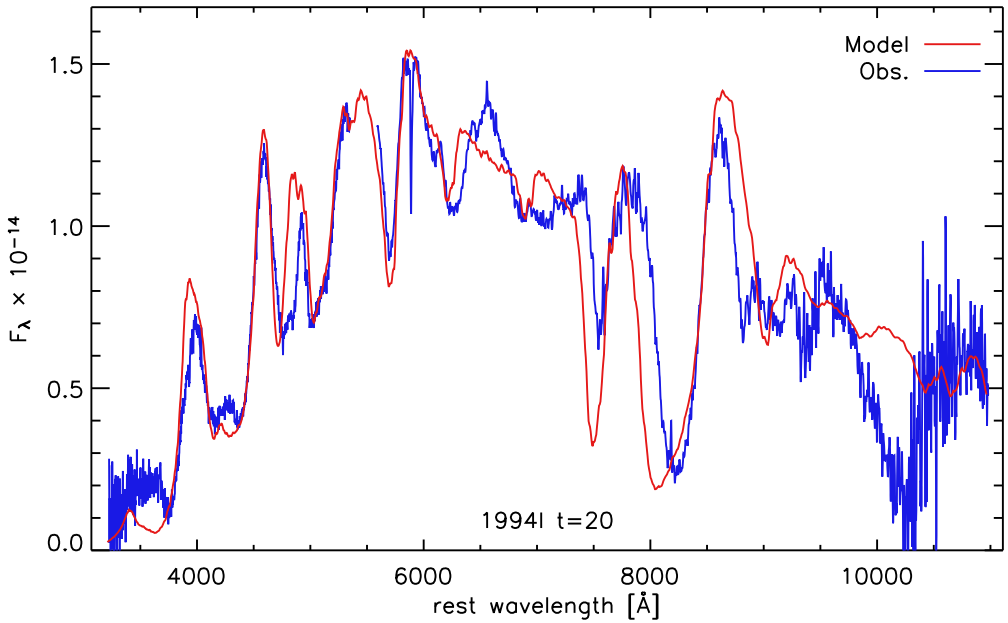


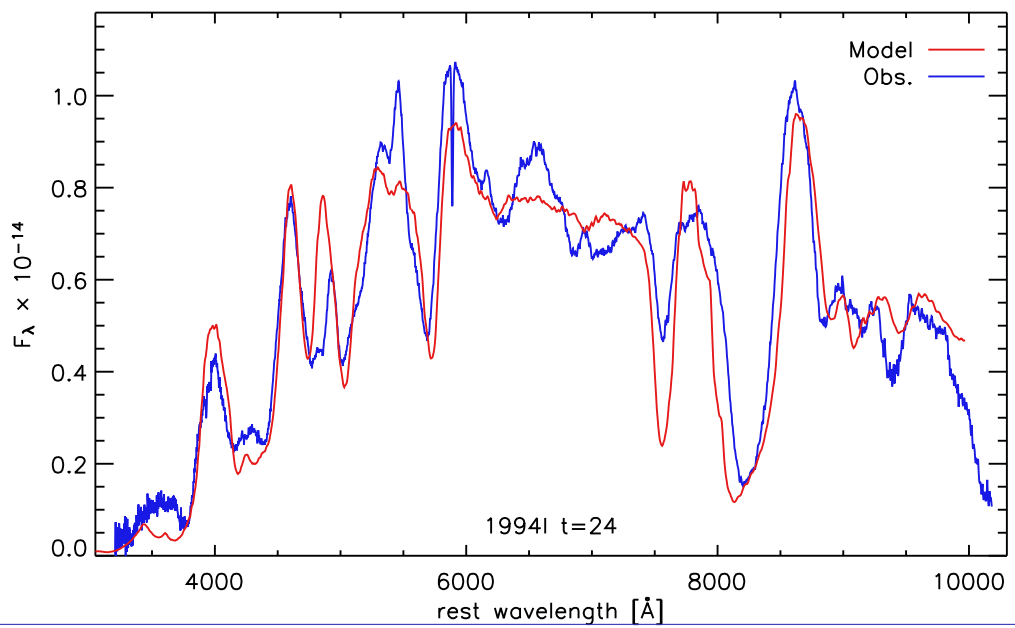
Spectral Models of 1994I (II)



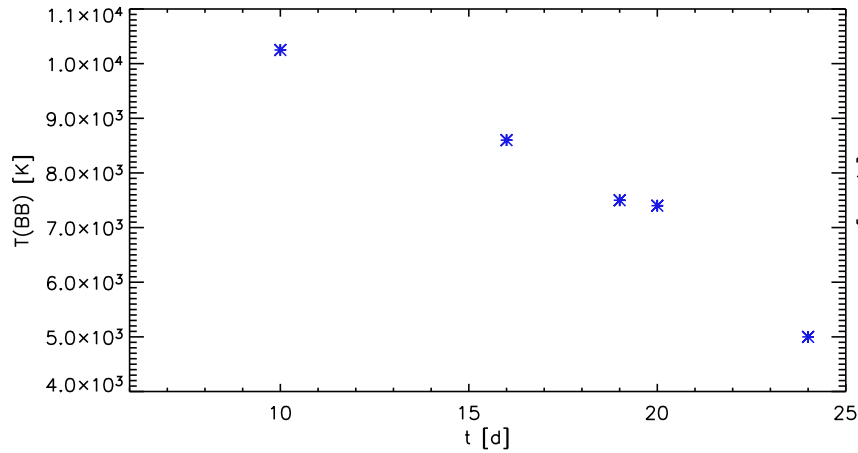


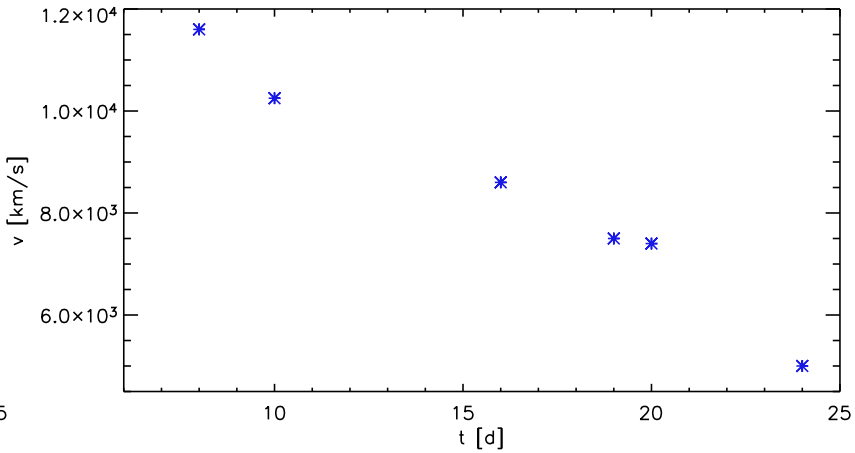
Spectral Models of 1994I (III)

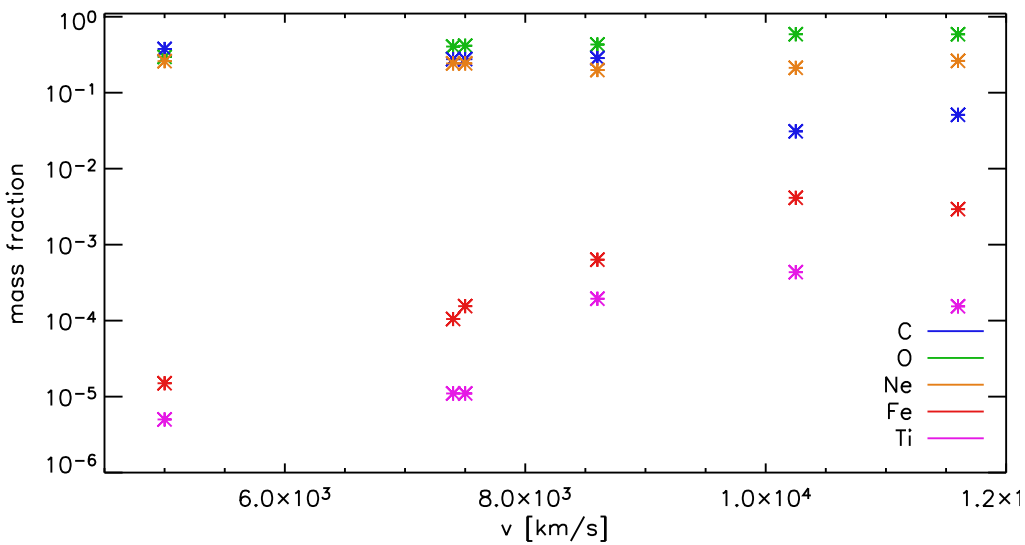




Spectral Models of 1994I – Results





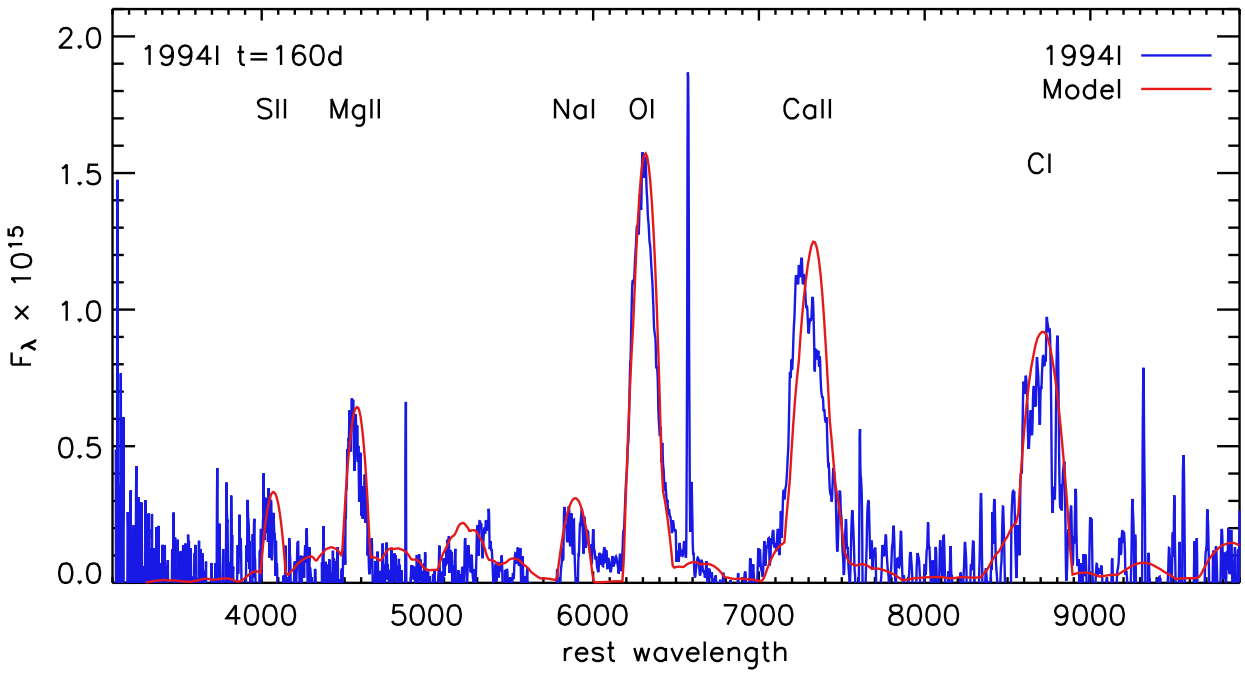


Spectral Models of 1994I – Results

- density overall ok for early phase
- Lower reddening (but larger distance) than for LC model
  $\longrightarrow$ net effect on ^{56}Ni-mass?
  $\longrightarrow$ estimate from rescaling of CO21: $M(^{56}\mathrm{Ni}) \sim 0.06 M_{\odot}$
- Composition: $\sim 20 - 30\%$ C, $\sim 40\%$ O, $\sim 20\%$ Ne

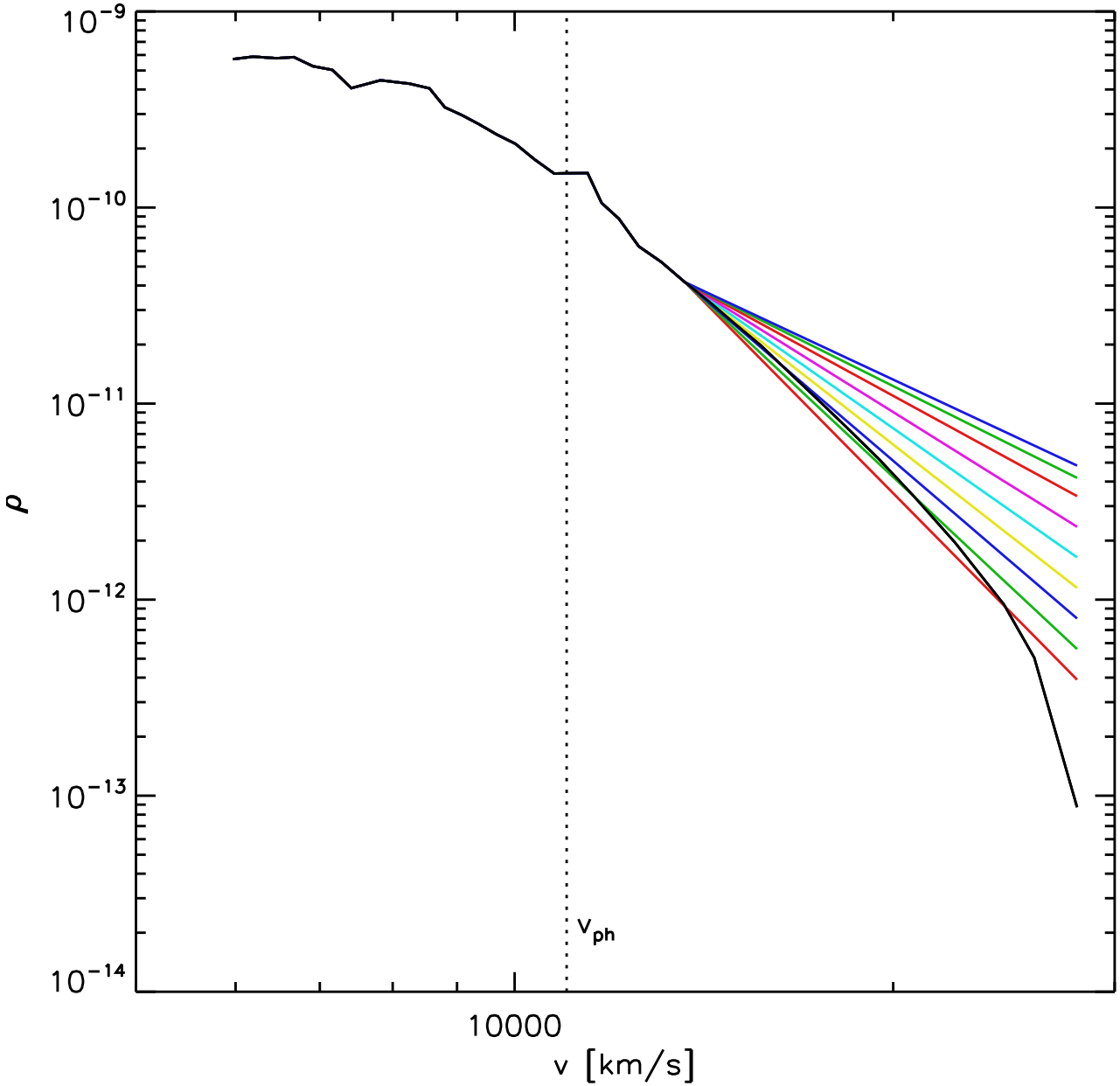
  but especially for Ne no strong constraint!
- Fe-group enhanced in the outer part

Nebular Spectrum

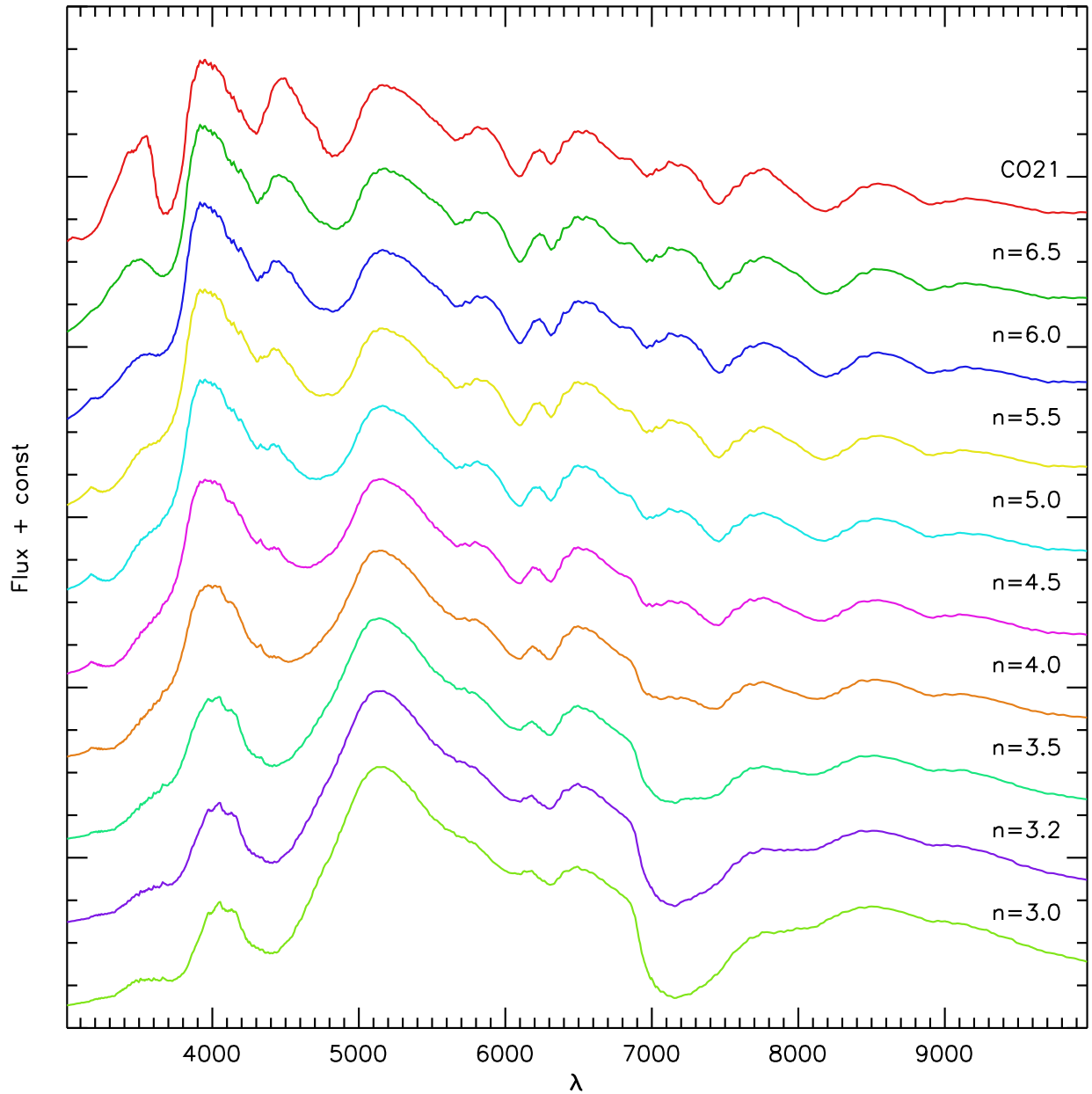


- single zone $\longrightarrow$ to 5000 km s^{-1}
- $M(^{56}\mathrm{Ni}) \sim 0.06 M_\odot$
- required total mass: $\sim 1.2 M_\odot$

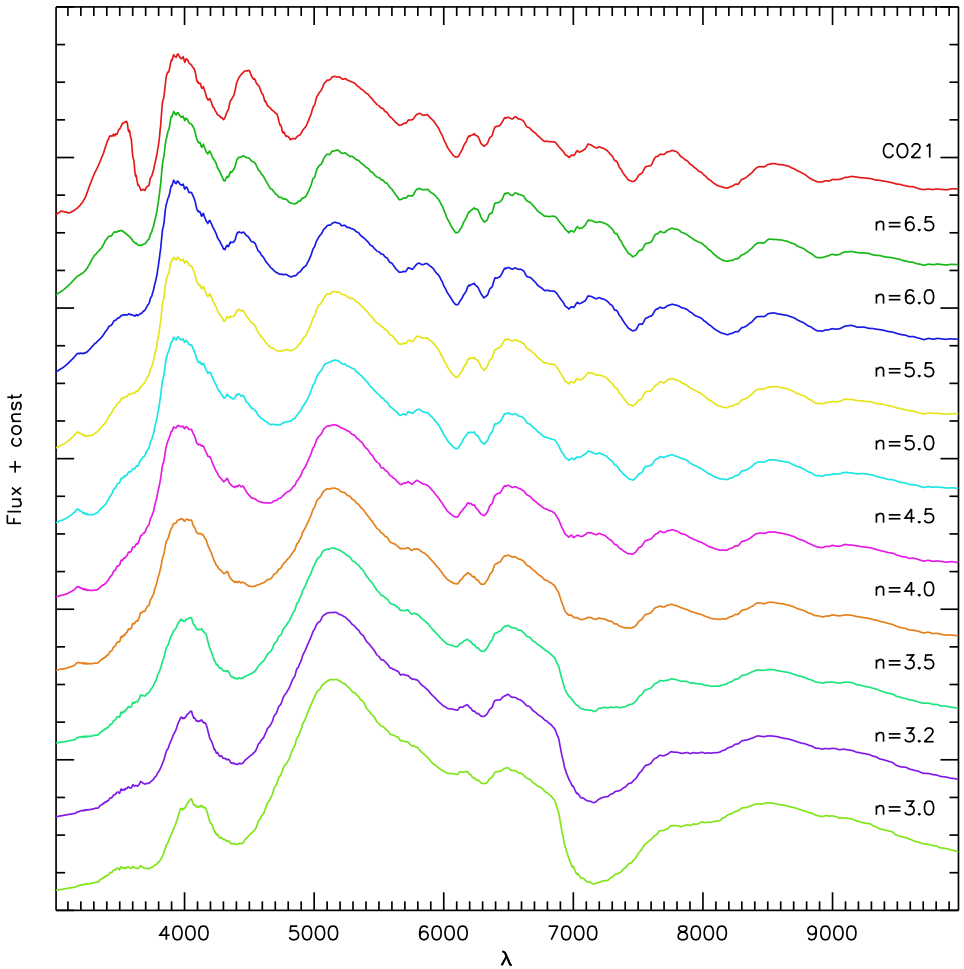
From SNIc to hypernovae

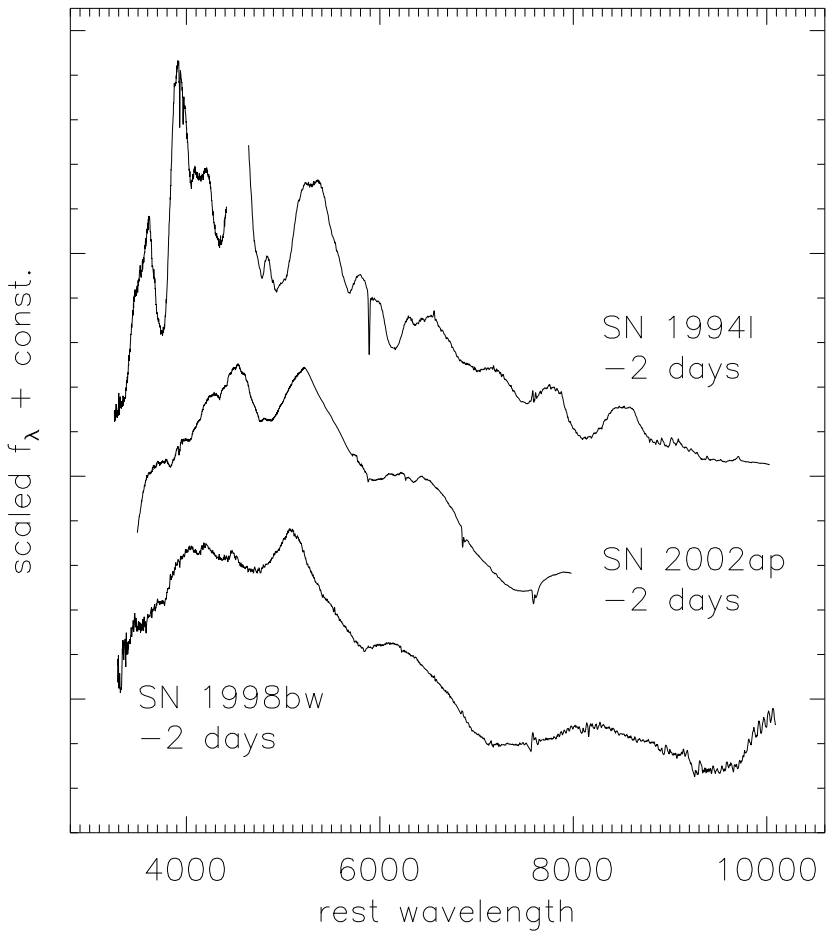


From SNIc to hypernovae



From SNIc to hypernovae





Summary

- Lower reddening, larger distance $\rightarrow$ lower $M(^{56}\mathrm{Ni})$?
- Nebular spectrum: total ejecta mass in CO21 too low!
- Composition: enhanced Fe-group in outer part.
  ($\rightarrow$ inhomogeneity, small asphericity?)
- Transition SN $\rightarrow$ HN by increasing the mass at high velocity