Modeling CSM interaction

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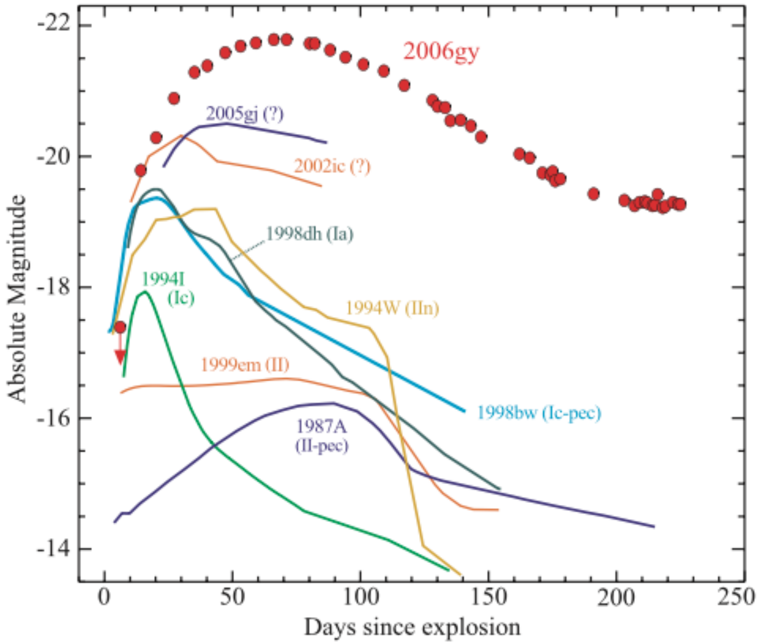
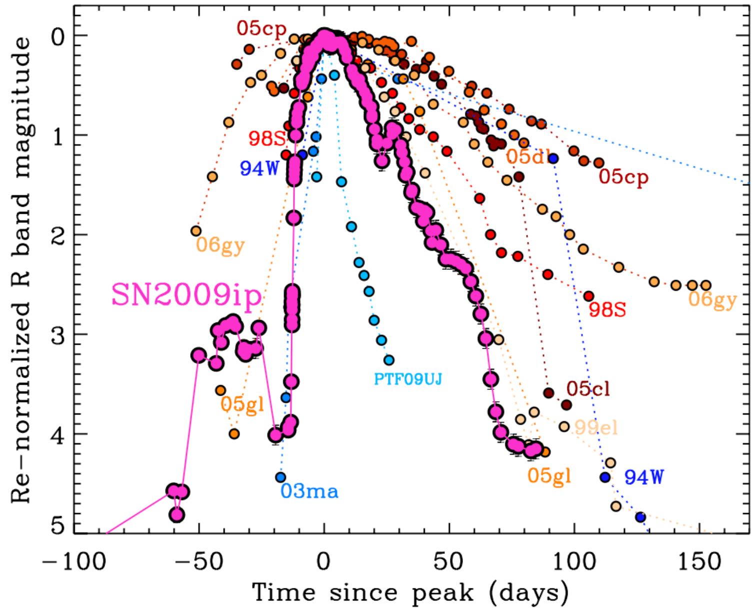
Observational context: **Light curves**

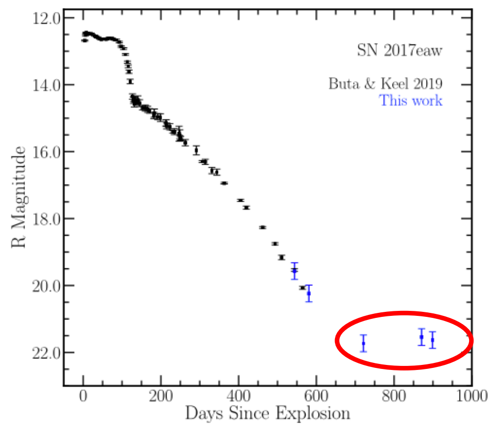
Super-luminous events



Light curve diversity

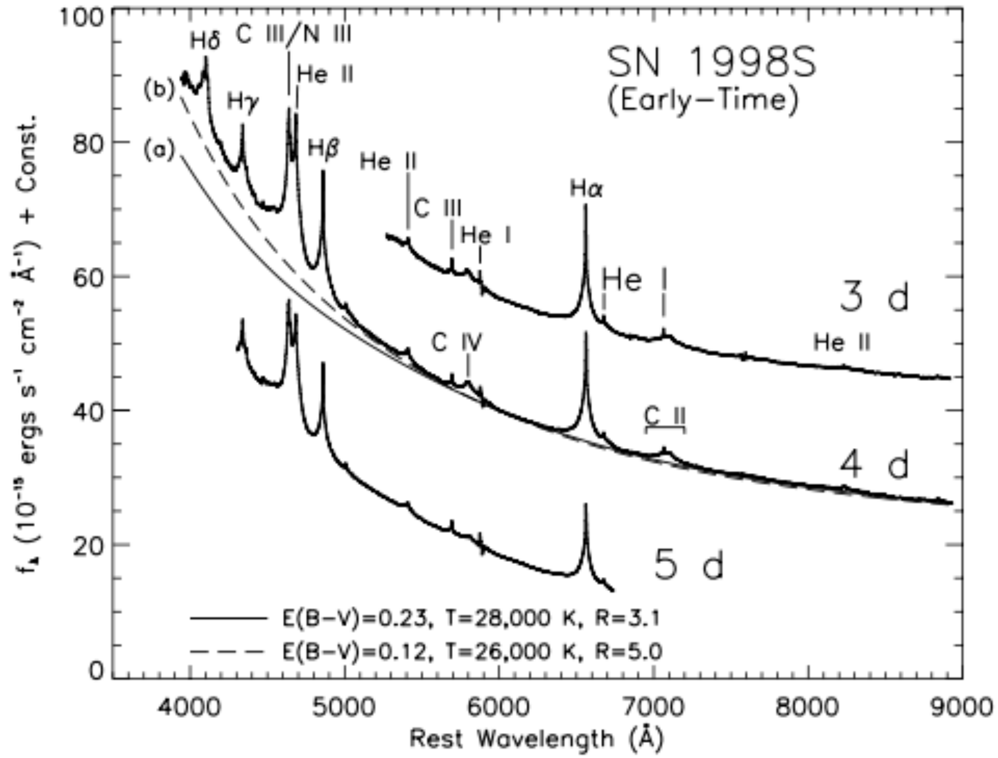


Late-time flattening

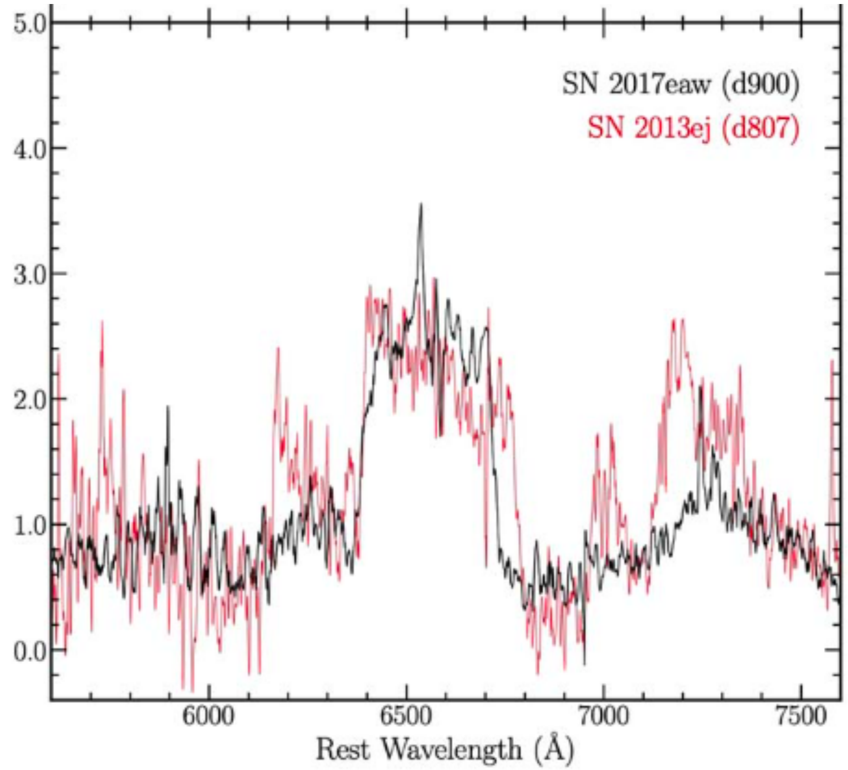


Observational context: **Spectra**

Narrow line profiles early-on



Broad-boxy profile at late times



The case of “standard” interacting SNe

High CSM mass/density/extent

$\Rightarrow$ τ (CSM) large

$\Rightarrow$ Ejecta deceleration (CDS velocity decreases with time)

$\Rightarrow$ Conversion Ekin to Erad and release on diffusion time

$\Rightarrow$ Reprocessing of radiation by CSM produces the narrow lines

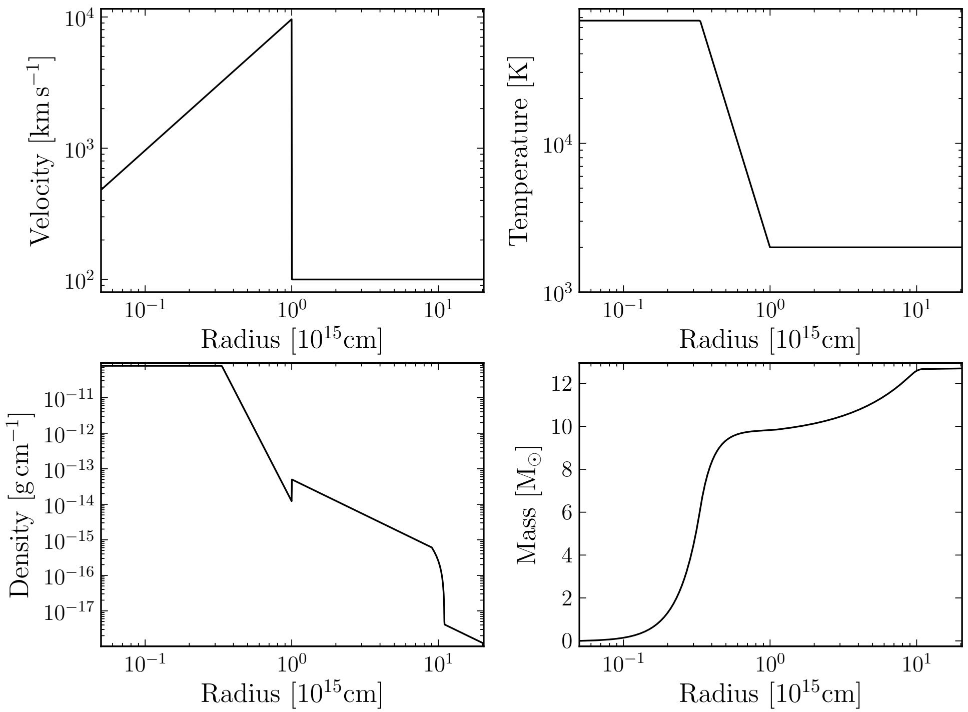
$\Rightarrow$ Treatment requires radiation hydrodynamics

Numerical Simulations of Interacting Supernovae with HERACLES

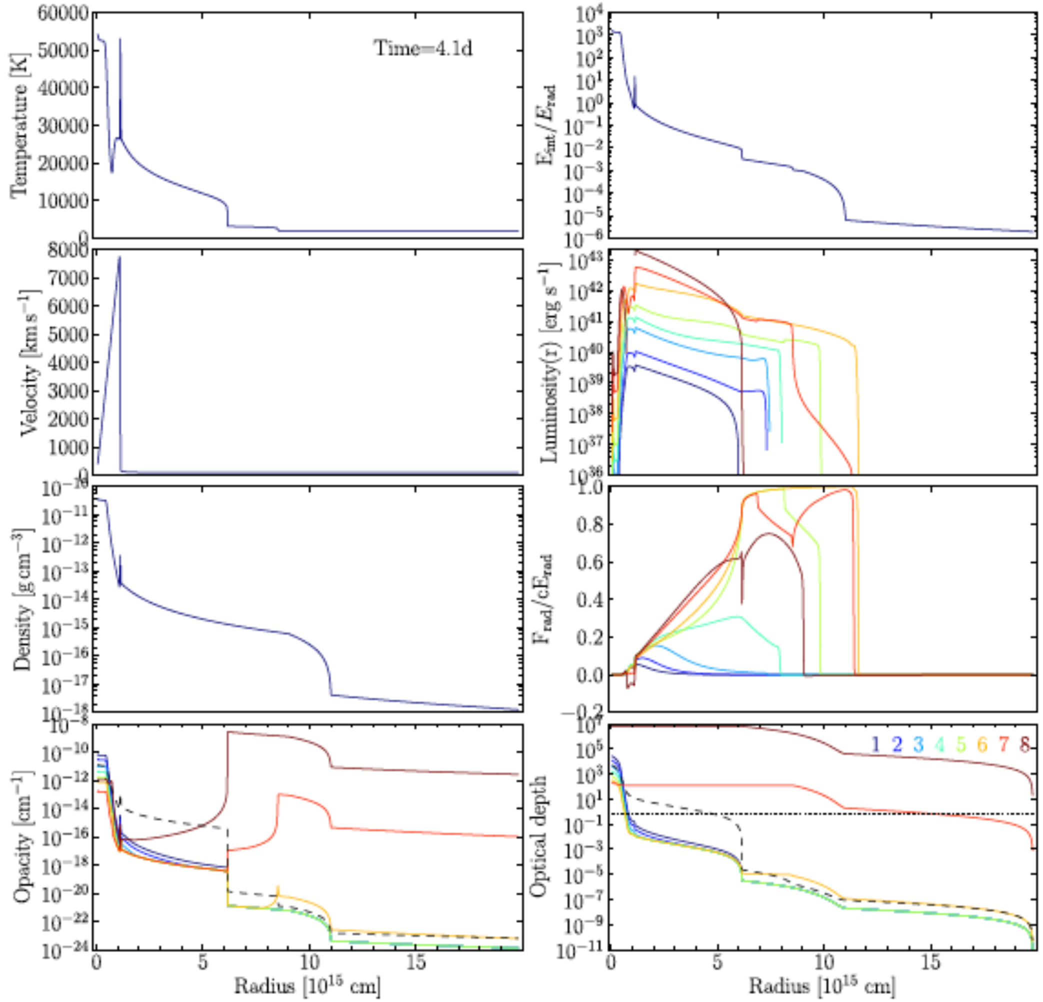
- Configuration: Faster inner shell (Ekin) and slower massive outer shell (Mass)
- Multi-group Radiation hydrodynamics with HERACLES (Audit/Gonzalez)
- Application to SLSN IIn 2010jl (Dessart, Audit, Hillier 2015)

Inner shell: SN ejecta
$10M_{\odot}$, 10^{51}erg

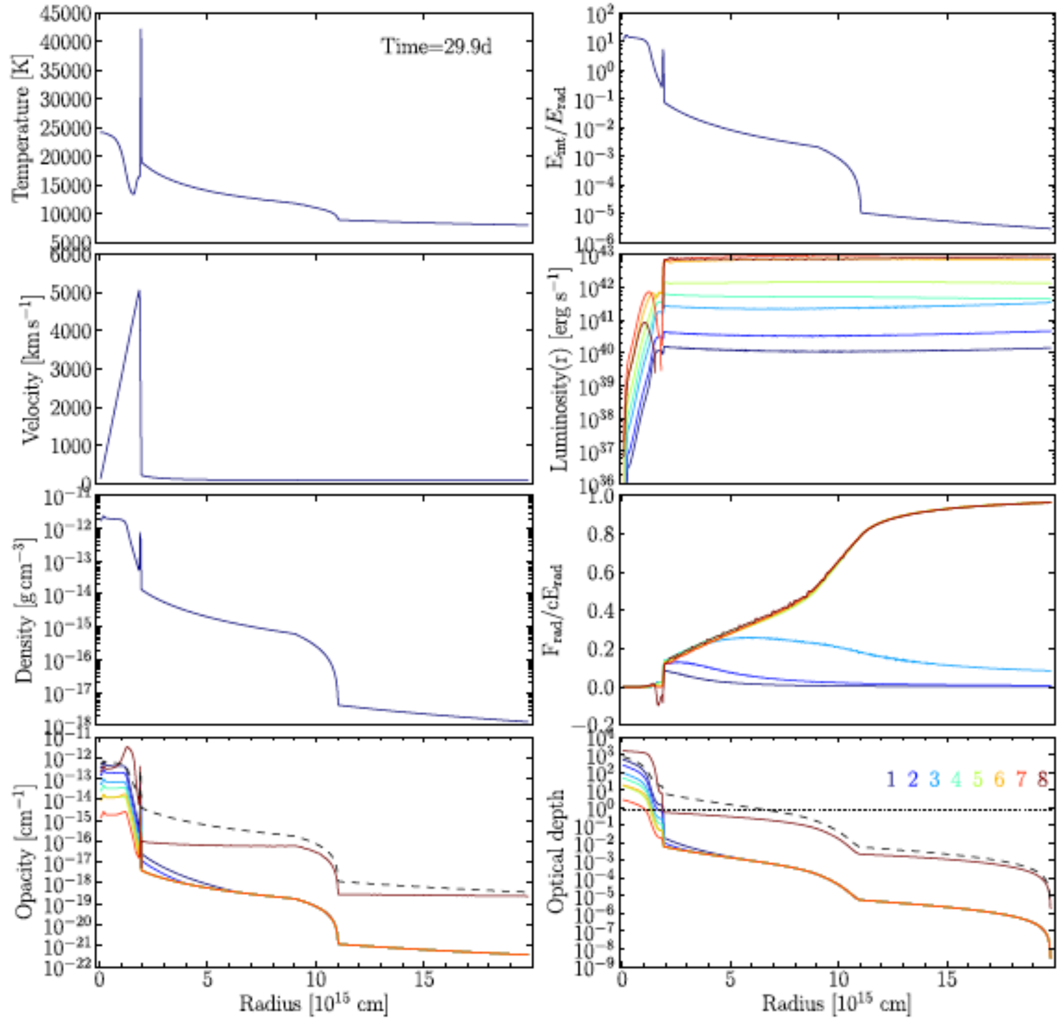
Outer Shell: strong wind
$0.1M_{\odot}$/yr, $3M_{\odot}$, vel=100km/s
Uniform H-rich composition



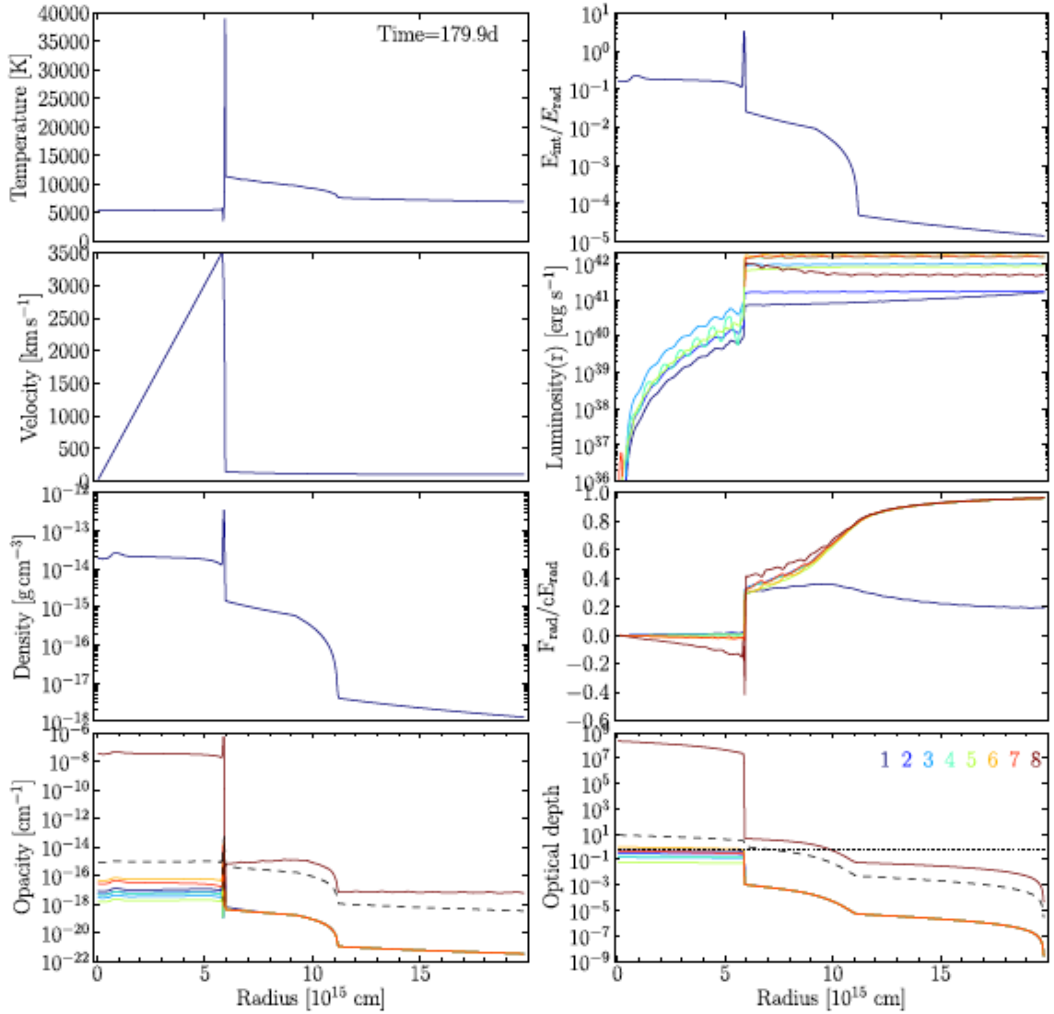
Evolution of interaction: Day 4.1



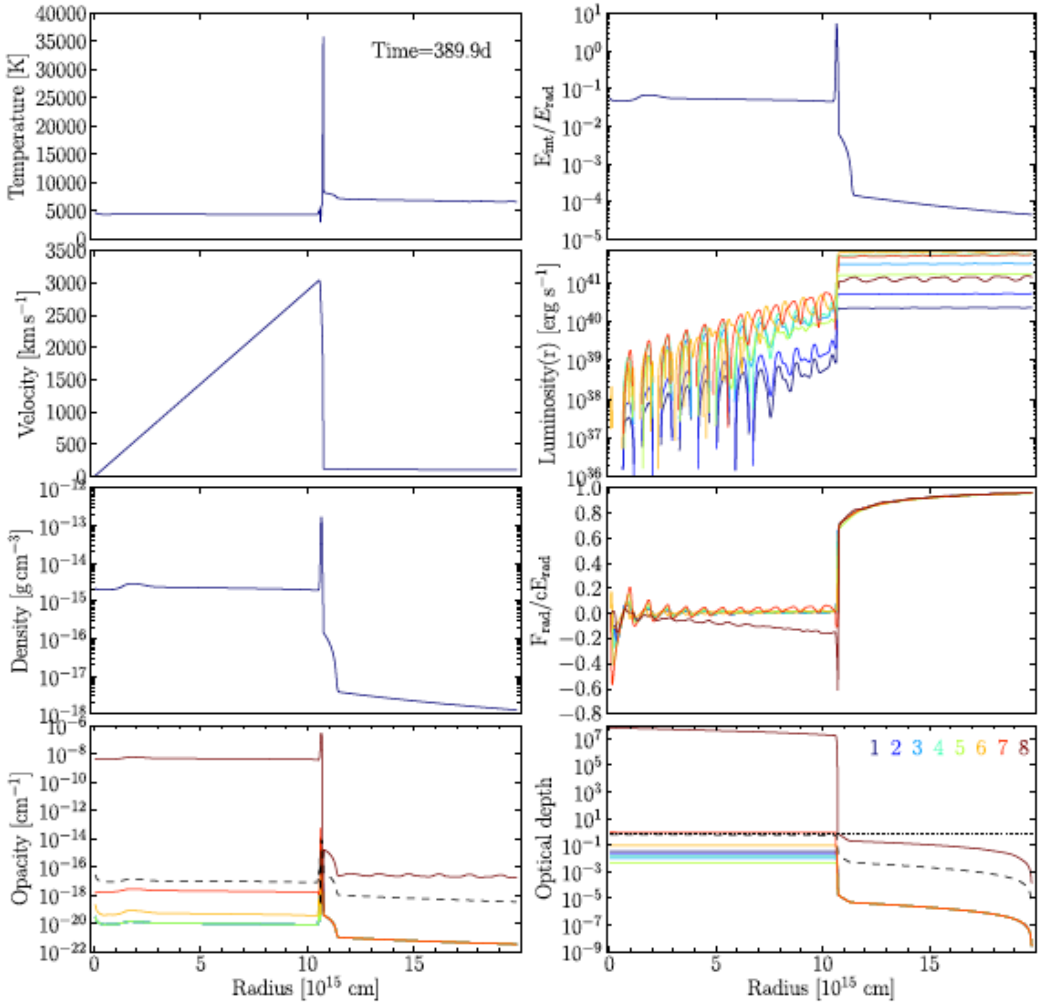
Evolution of interaction: Day 29.9



Evolution of interaction: Day 179.9

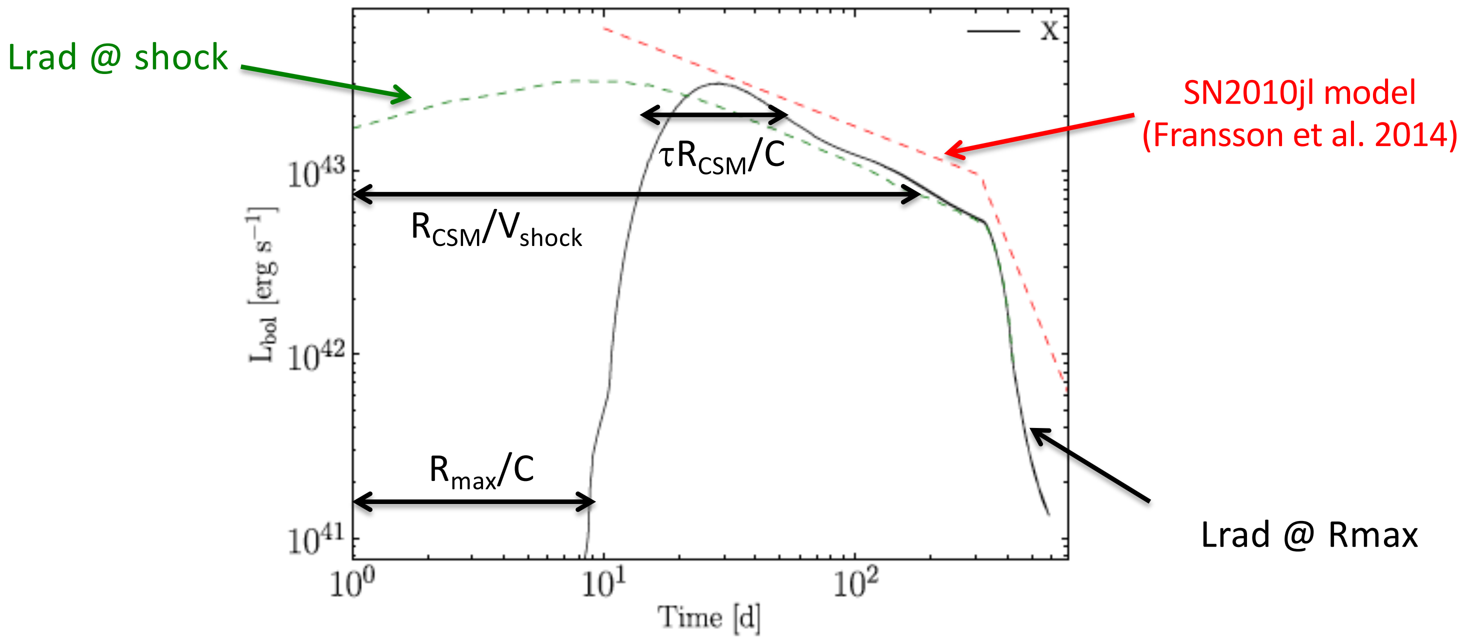


Evolution of interaction: Day 389.9

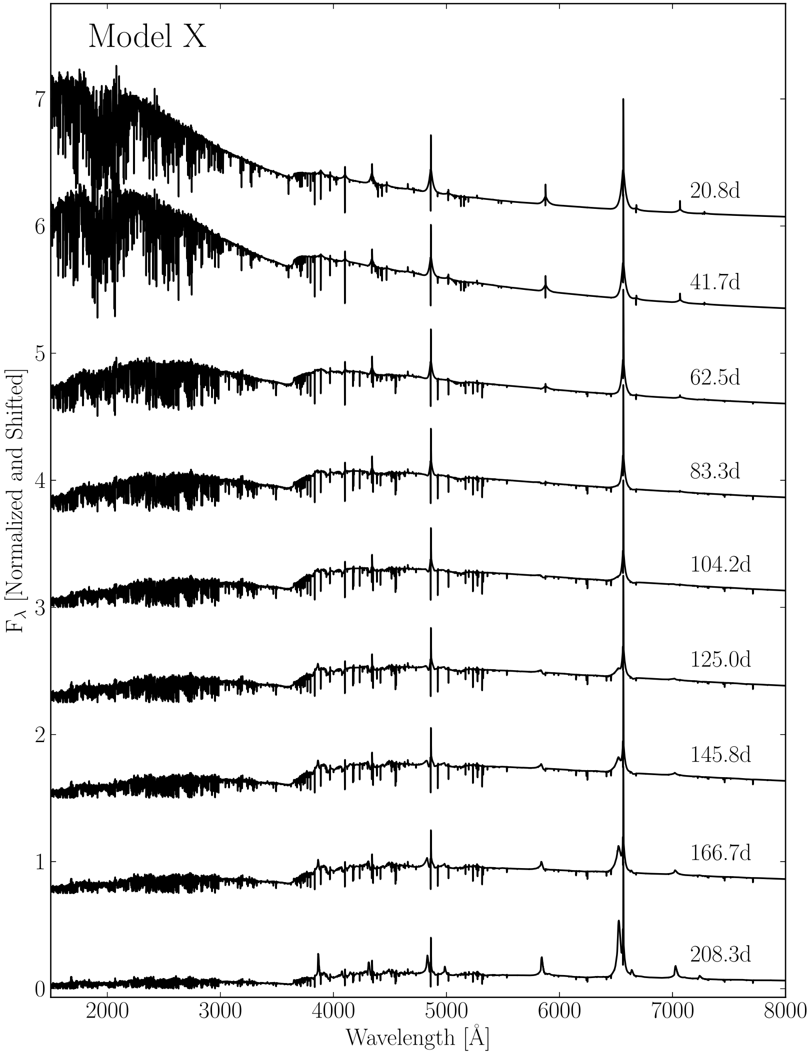


Numerical Simulations of Interacting Supernovae

- Shock powered luminosity: $L_{\mathrm{shock}} \sim 2\pi r^2 \rho_{\mathrm{csm}} v_{\mathrm{shock}}^3$
- Optical depth effects : $L_{bol}<L_{shock}$ for $t<t_{diff}$
- LC break when shock leaves dense CSM



Spectral evolution: post-processing with CMFGEN

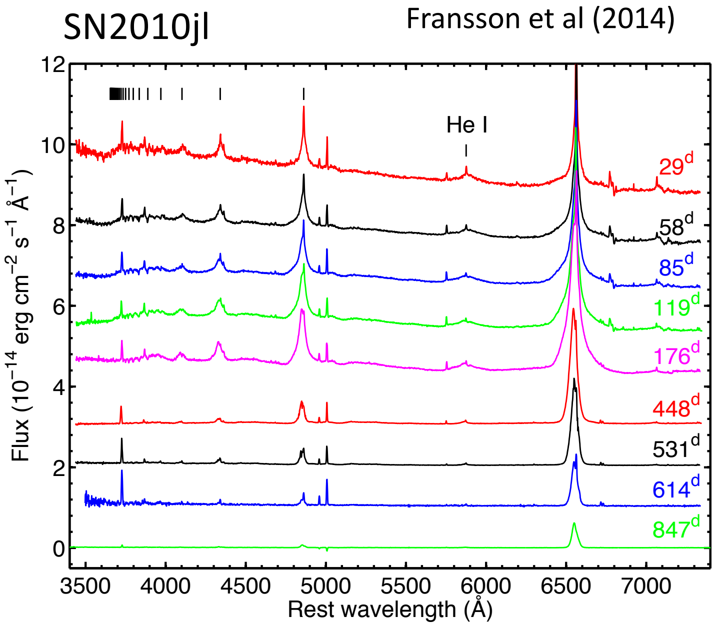


Post-processing with CMFGEN non-monotonic solver

Reproduction of narrow symmetric profiles

Very slow spectral evolution

Evolution to lower T/color (fixed R_{phot})



Problems

- Post-processing with CMFGEN only works when $\tau > 1 - 10$
- T from hydro is LTE

$\Rightarrow$ Method good only at early times

$\Rightarrow$ Method will eventually fail at some late time (depending on Mdot)

Bypassing Radiation Hydrodynamics

- Mdot from 1e-5 to 1e-3Msun/yr: optically thin but huge shock power

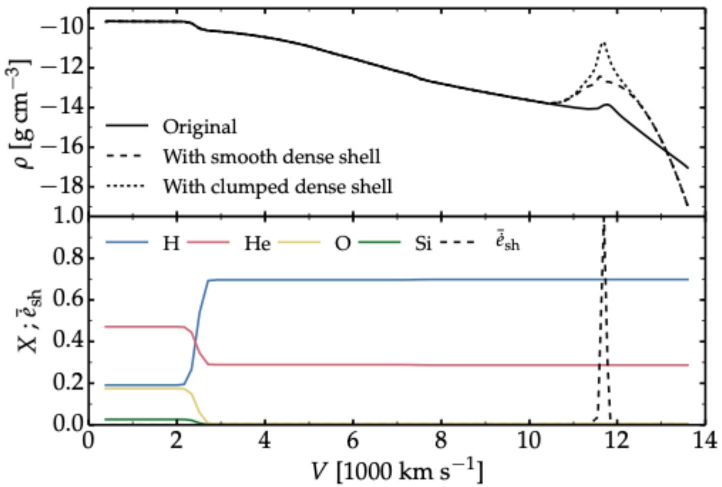
⇒Neglect CDS growth in mass

⇒Neglect absorption emission/absorption from unshocked CSM

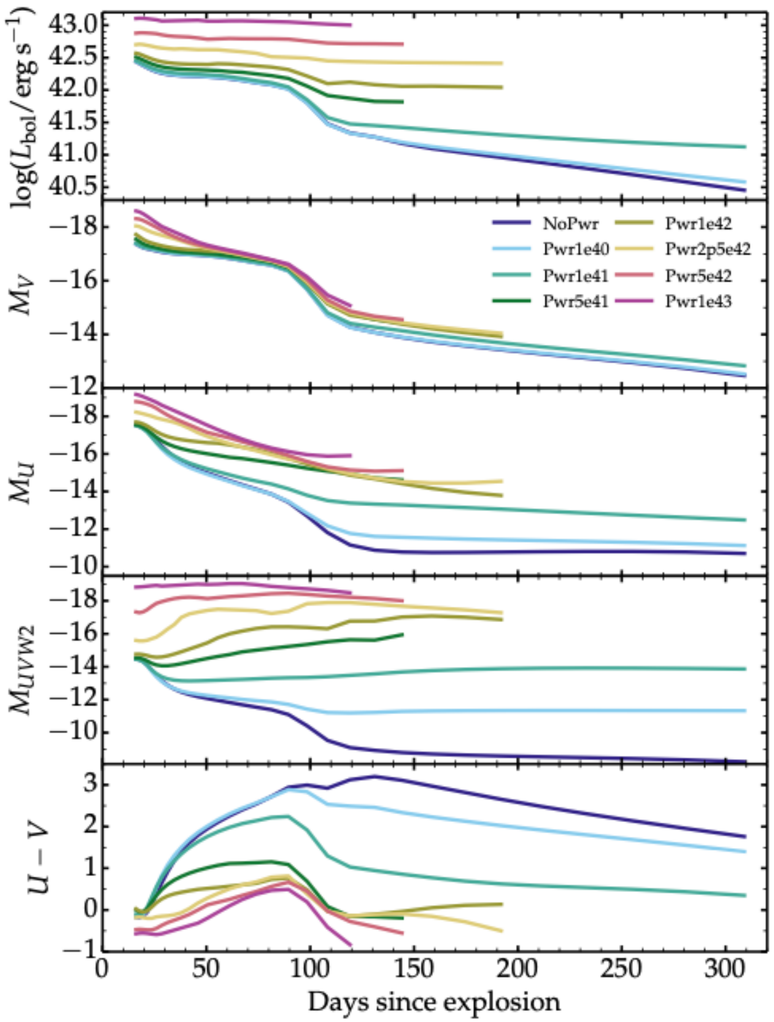
⇒Introduce solely shock power. Treat as decay power

Benefit: focus on thermalized shock radiation only, treat the full problem in non-LTE

Minuses: no signatures from unshocked CSM, no X-rays, not fully consistent



Photometric impact for various constant shock powers



- Weak impact in optical though depends on thermalization, clumping etc
- Strong impact on the blue (UV, U-band)
- Impact on color

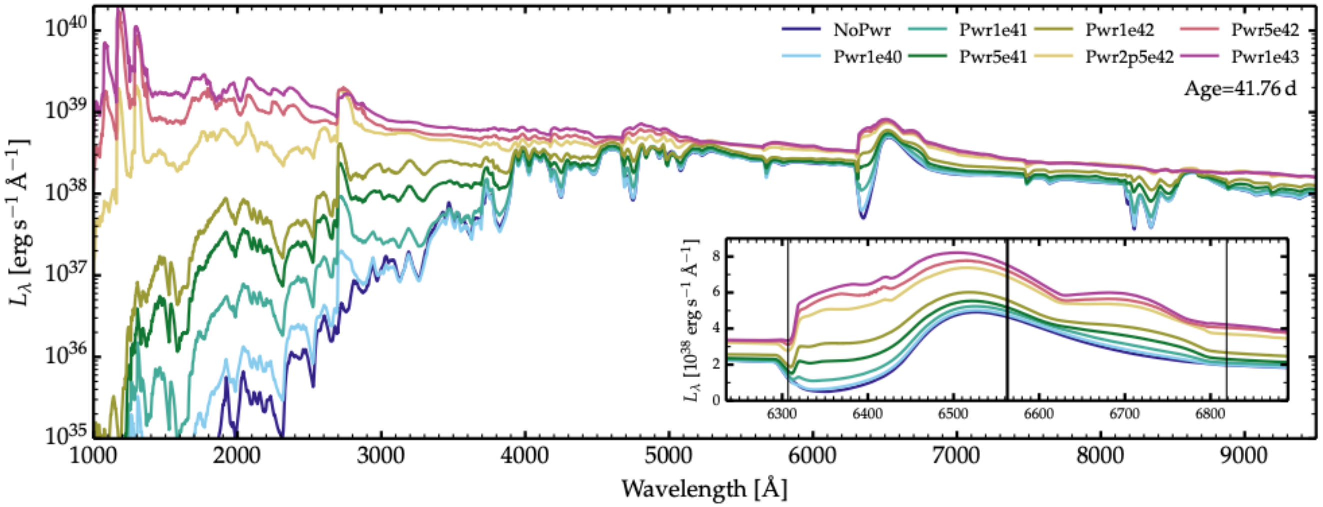
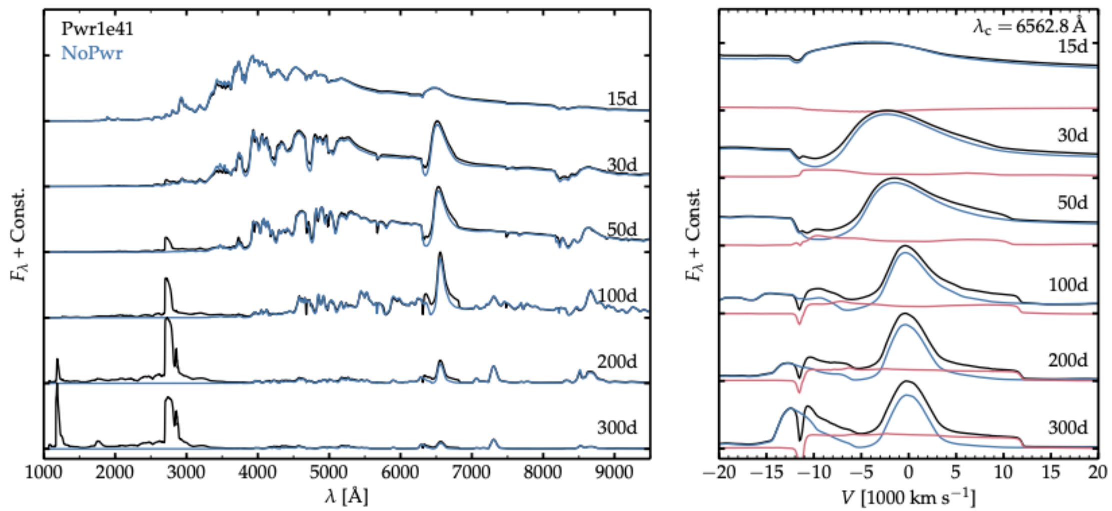
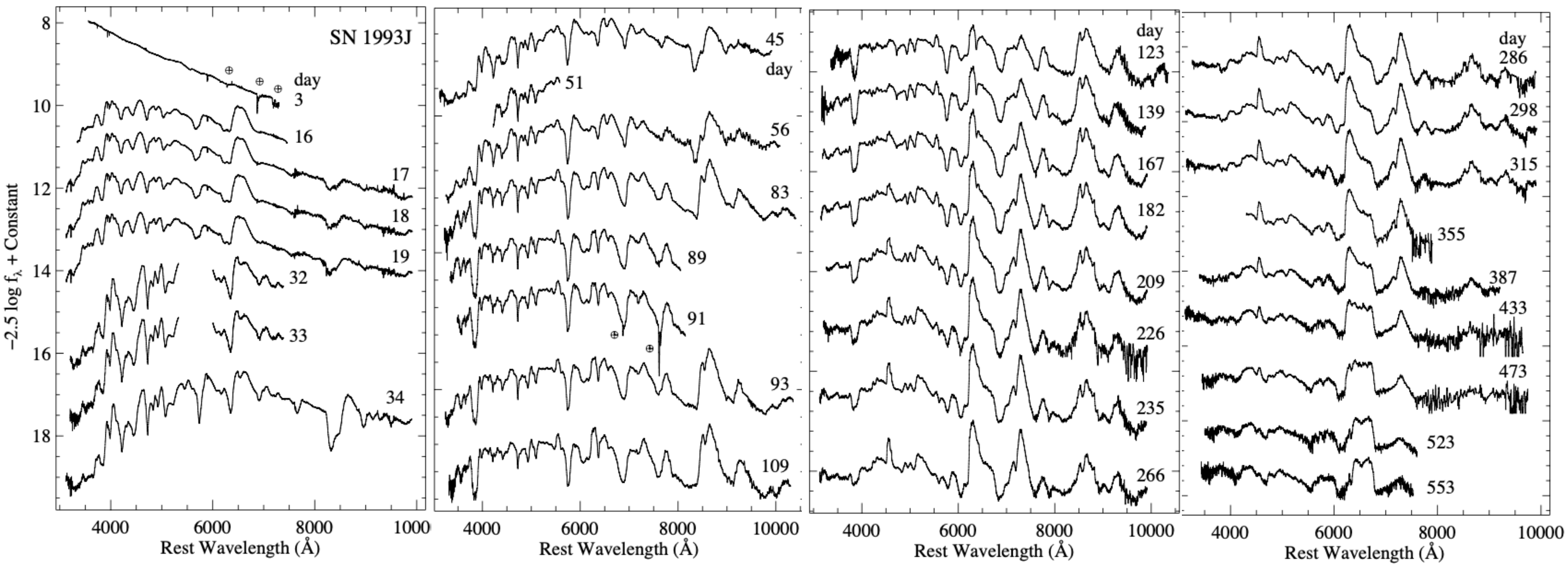


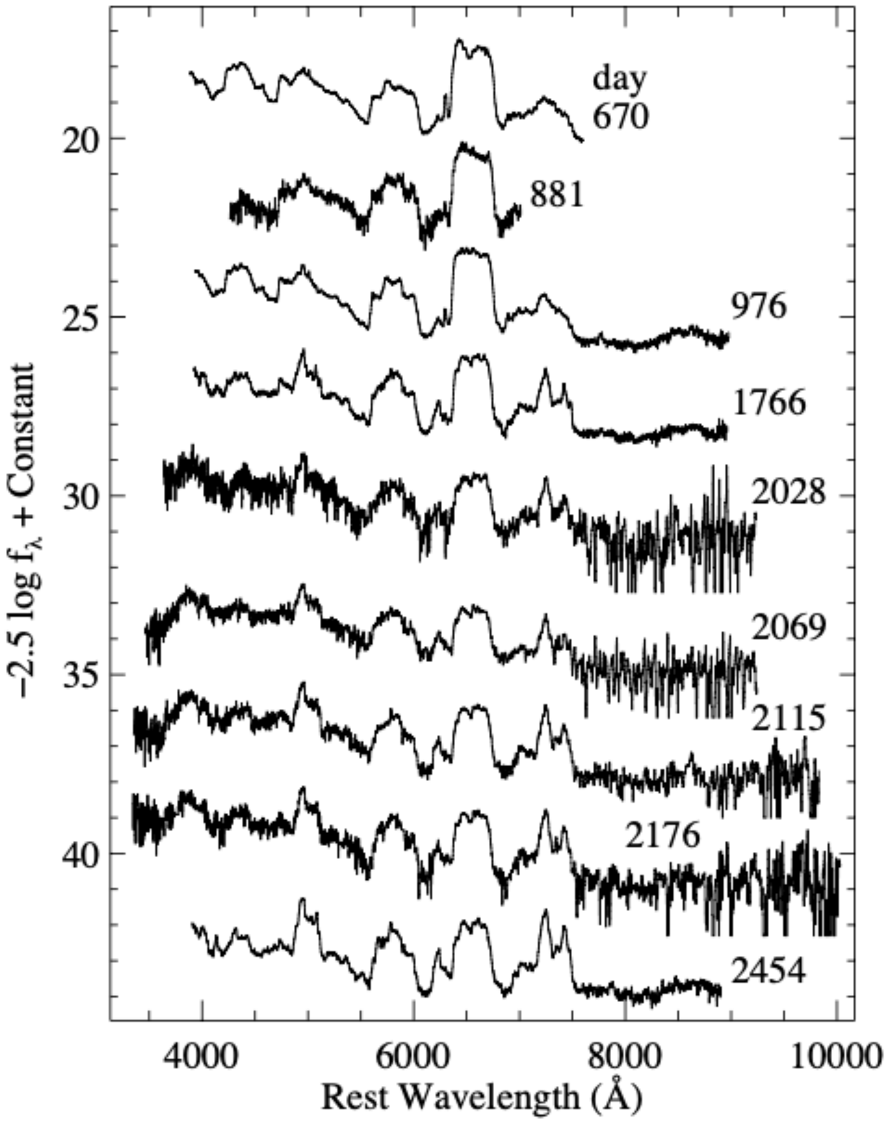
Fig. 3. Comparison of the observer's frame luminosity in the UV and optical ranges for our set of models with an interaction power covering from zero to 10^{43} erg s^{-1} and at a time of 41.76 d. The inset zooms on the Hα region. The thick vertical line represents the rest wavelength of Hα, and the thin vertical lines indicate the wavelength at ± 11700 km s^{-1} away from that rest wavelength.

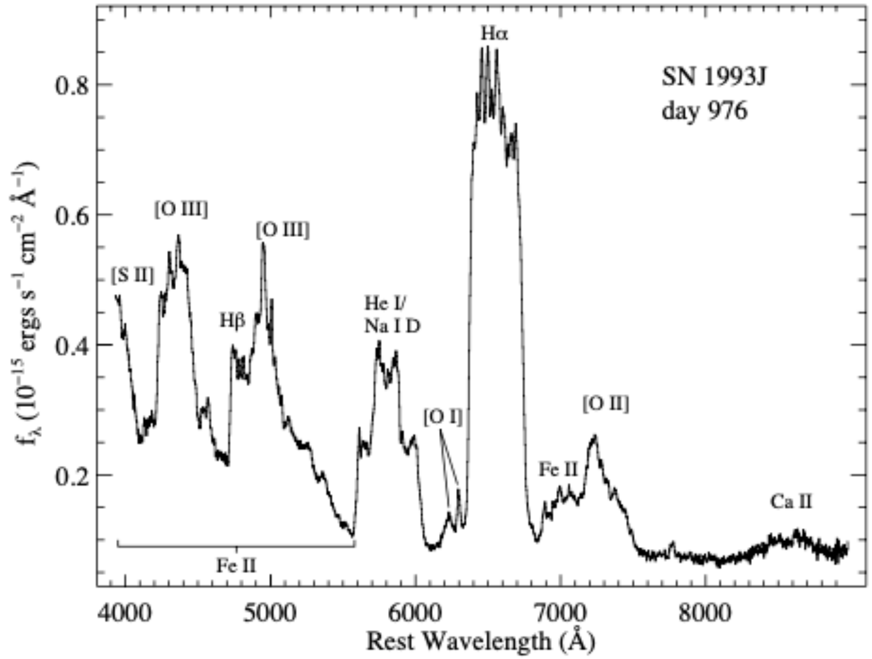


Application to SN1993J at late times

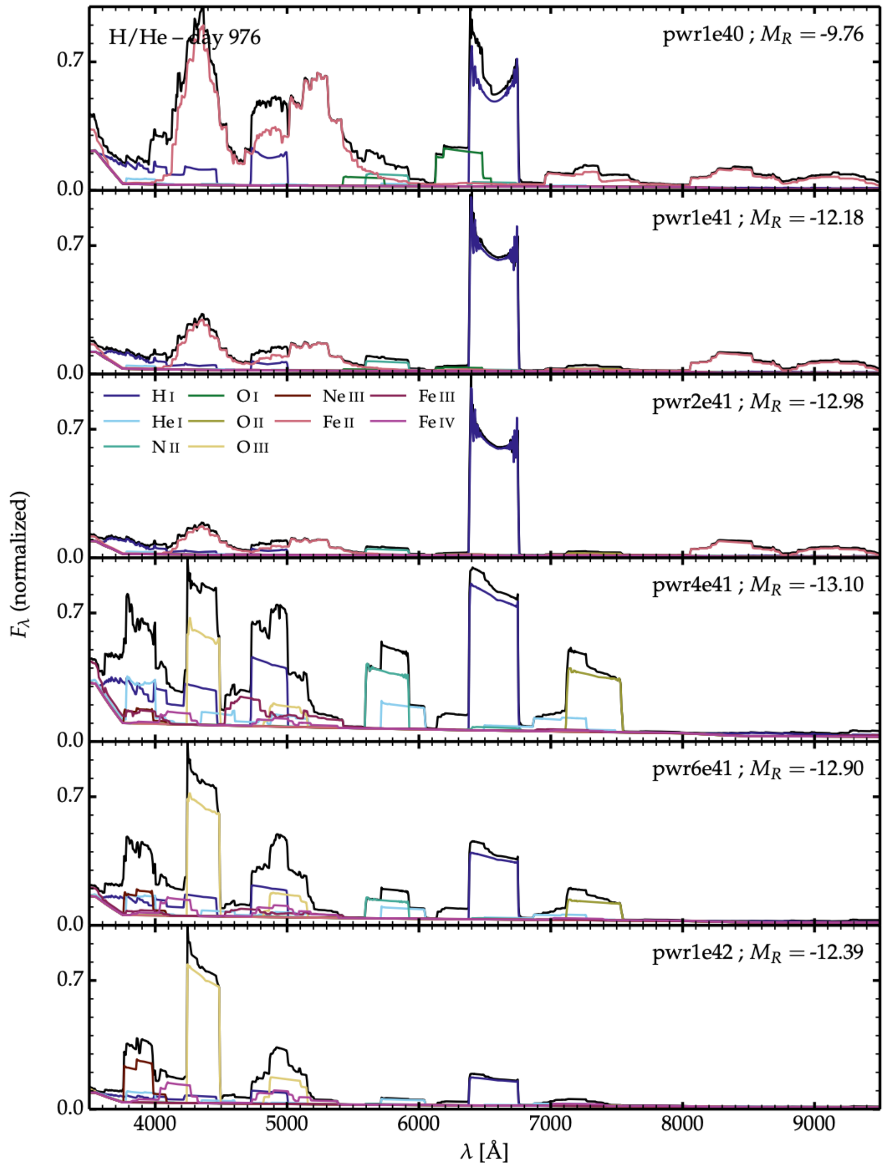
- Modeling of the interaction with CMFGEN. Ignore decay.
- Dense shell of 0.2Msun moving at 8500km/s at 976d
- Vary power, clumping, composition




day
670
881
976
1766
2028
2069
2115
2176
2454
20
25
30
35
40
−2.5 log f_λ + Constant
4000
6000
8000
10000
Rest Wavelength (Å)


SN 1993J
day 976
Hα
[O III]
[O III]
[S II]
Hβ
He I/
Na I D
[O I]
[O II]
Fe II
Ca II
Fe II
0.8
0.6
0.4
0.2
f_λ (10^−15 ergs s^−1 cm^−2 Å^−1)
4000
5000
6000
7000
8000
Rest Wavelength (Å)

Variation in power



The 976d spectrum of 1993J