NLTE effects in the supernova envelopes

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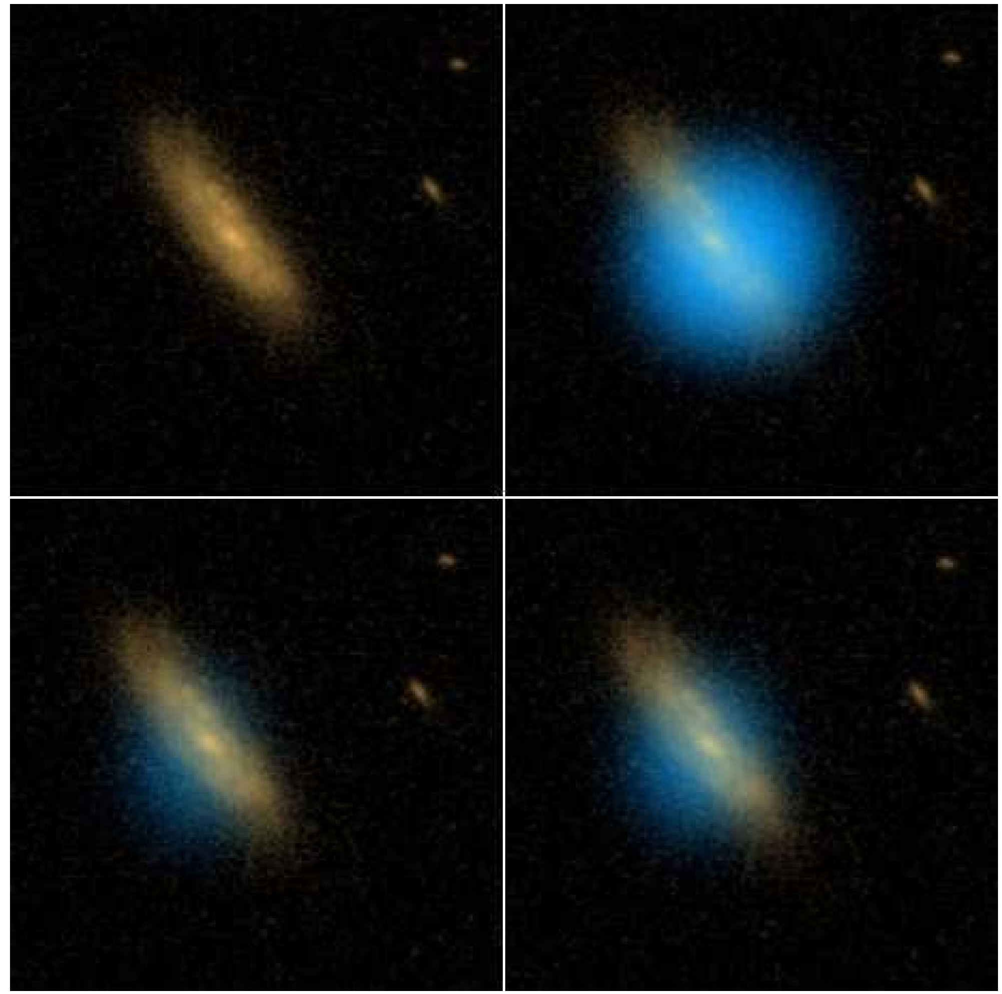
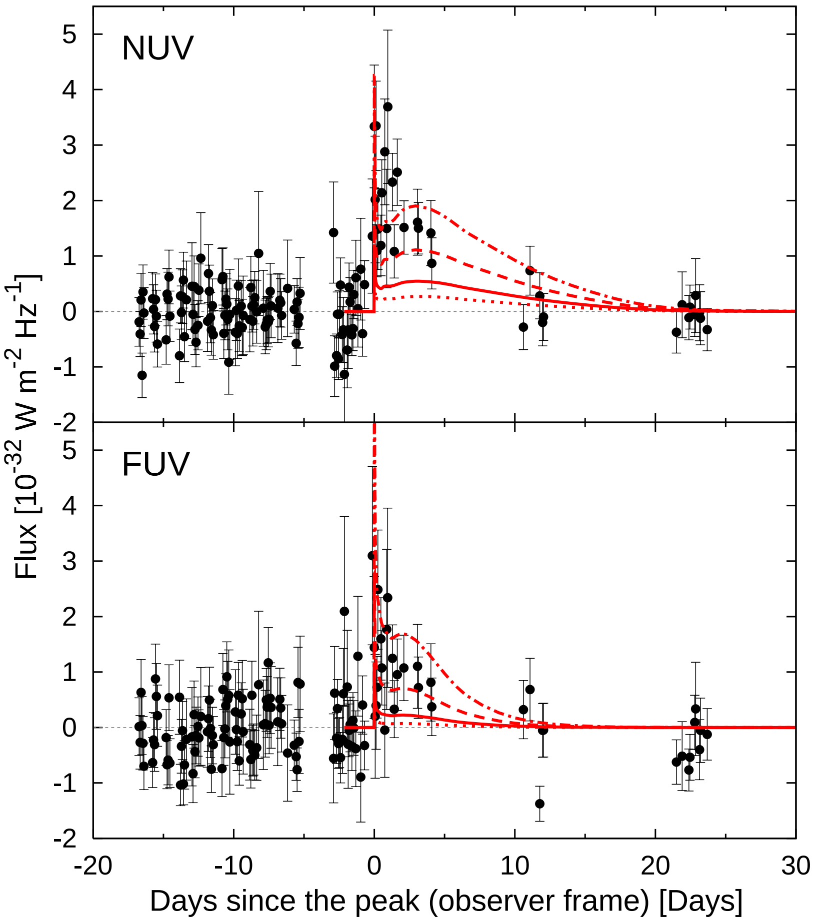
SNLS-04D2dc: discovery

In blue, the flash registered by ultraviolet Galex.
The red images are taken by Hubble of the host galaxy of NAS-04D2dc

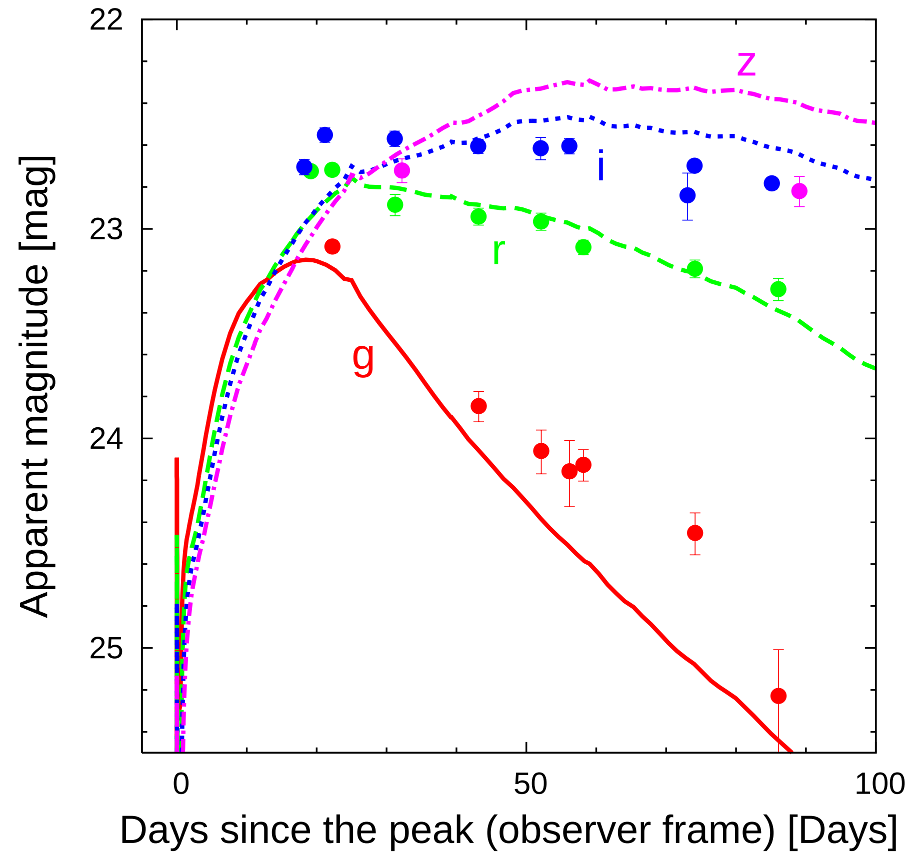


SNLS-04D2dc: sb and plateau

shock breakout



plateau stage

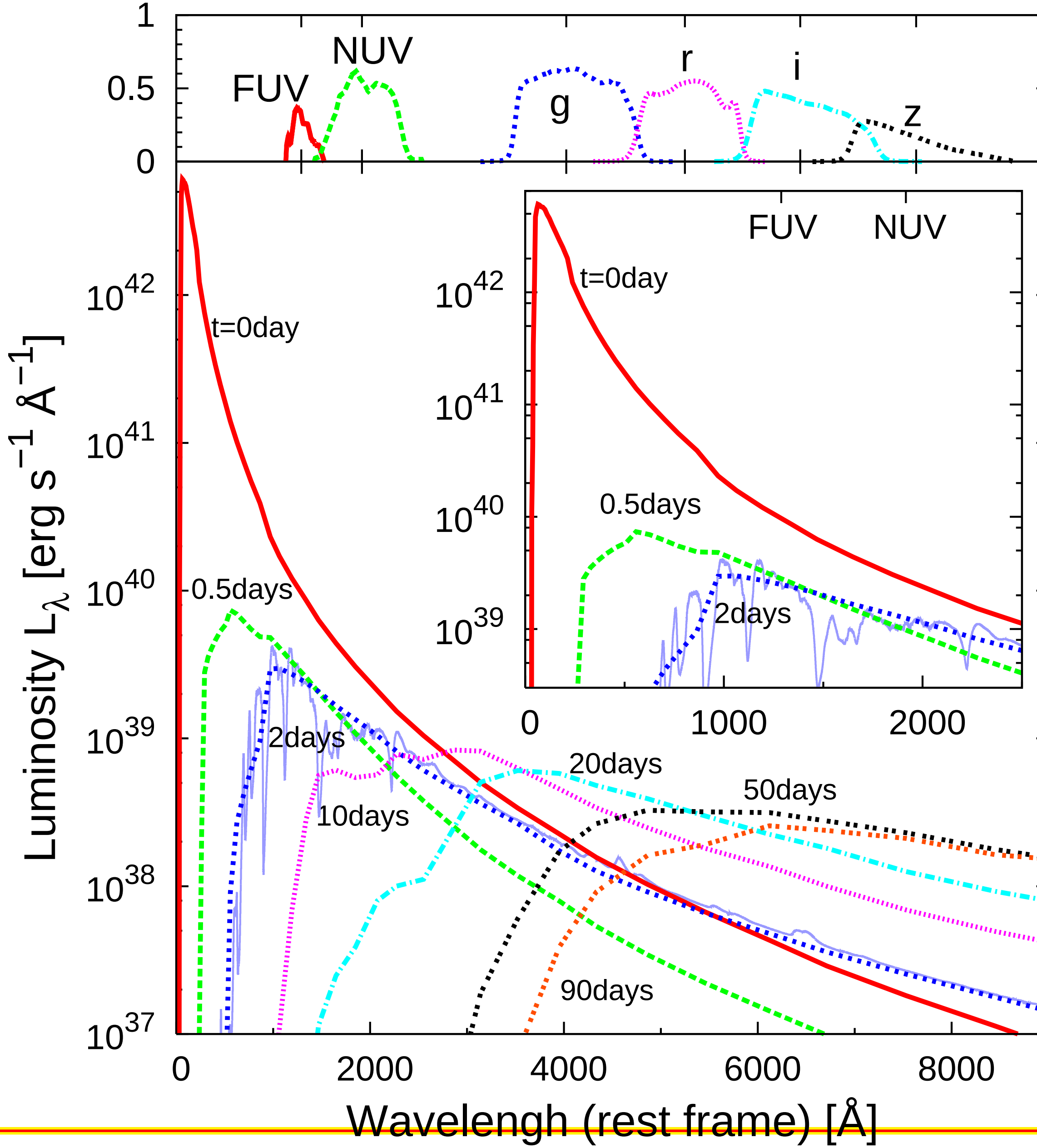


This is the first study to reproduce the ultraviolet light curve of the shock breakout and the optical light curve of the plateau consistently.

SNLS-04D2dc: SED evolution

SED evolution at times 0^d, 0.5^d, 2^d, 10^d, 20^d, 50^d, 90^d days of the explosion.

The thin solid blue line shows the synthetic non-LTE spectrum (Gezari et al. 2008). (g-band, r-band, i-band, z-band in AB magnitude system).



Physical classification

Thermonuclear and Core-collapse SNe.

SN Ia = thermonuclear SN.

The light curves of SNe Ia are formed under the action of the radioactive energy input produced in the chain of reactions: ^{56}Ni decays to ^{56}Co, and then to ^{56}Fe.

SN II = core collapse.

The light from a Type II SN displays much larger variety than the light curves of SN I. It is produced by the shock wave, by the recombination of ions and only to a minor degree by ^{56}Ni and ^{56}Co decays.

Initial data

We study both the thermonuclear and the core-collapse SNe.

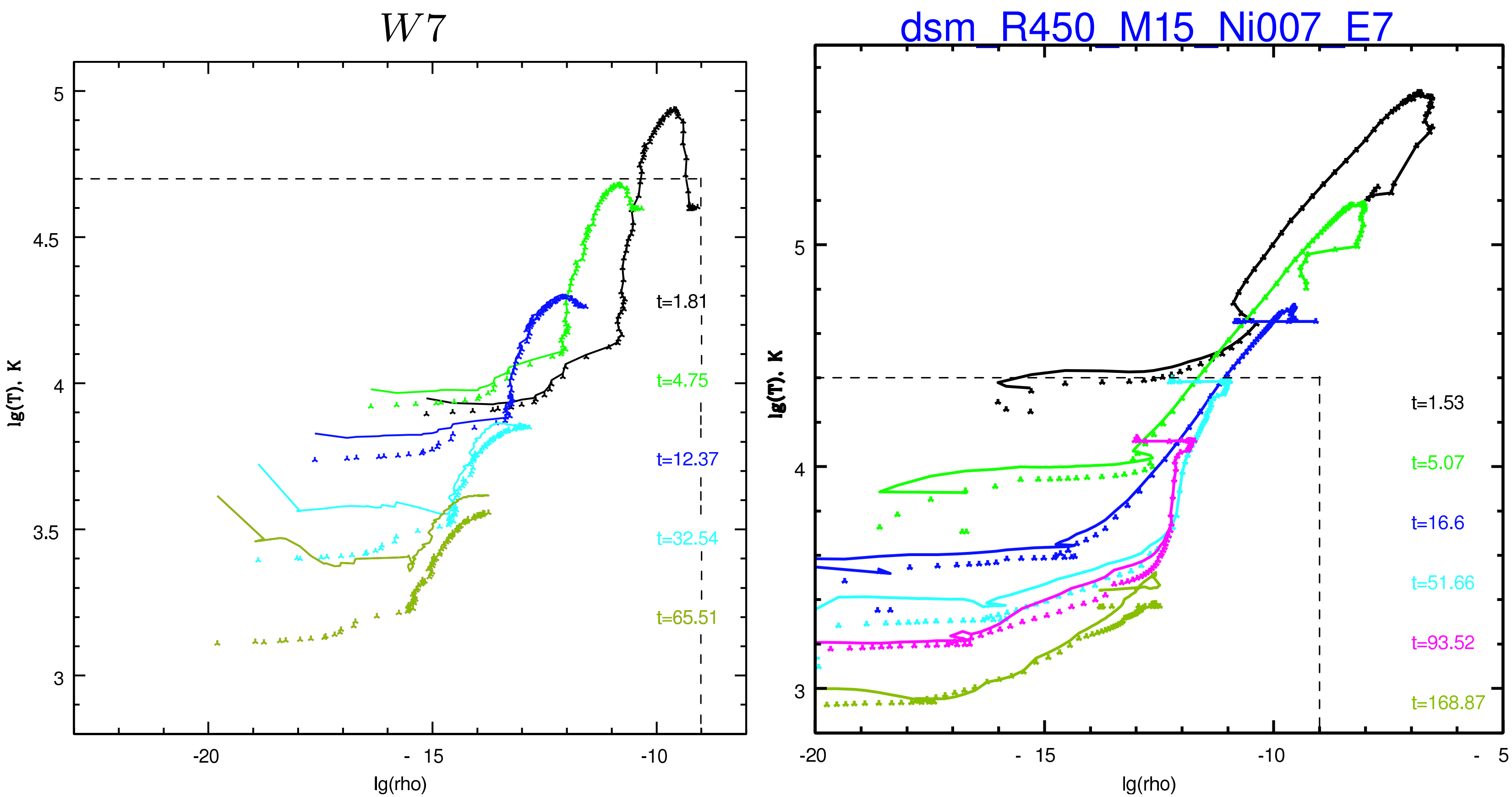
SN Ia

Progenitor was the classical 1D deflagration model W7 (Nomoto, Thielemann, Yokoi, 1984)

SN II

Progenitor was the massive star with parameters corresponding to the classical Sn IIP, Sn1999em.
We've used our model dsm_R450_M15_Ni007_E7.

Diagrams $\lg(T)$-$\lg(\rho)$

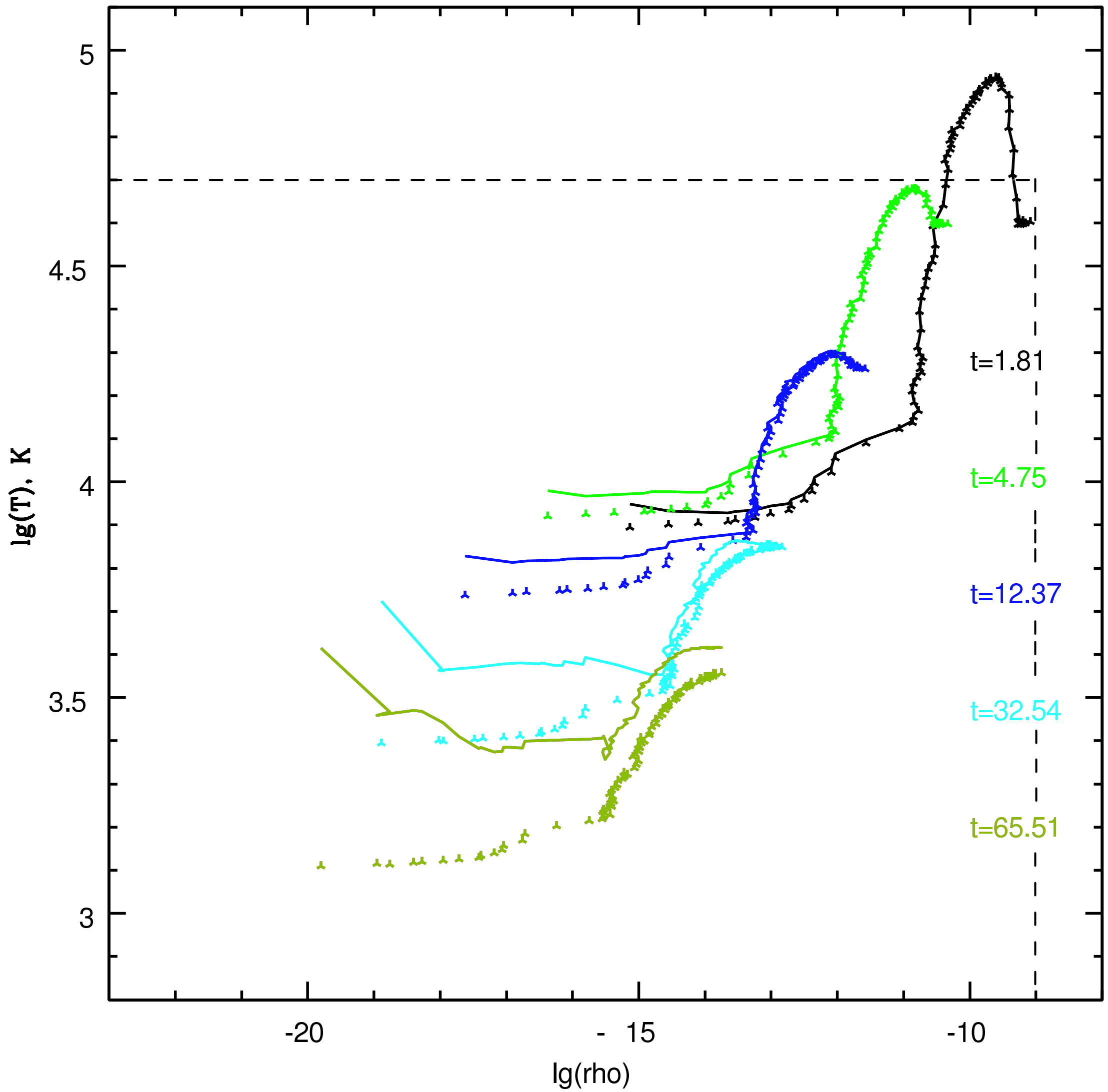


Evolution of $\lg(T)$-$\lg(\rho)$ for case LTE. Star marks the radiative temperature T_J ($J = aT_J^4$)
For a given t, each point at the (T, ρ) curve corresponds to some value of the Lagrangian mass m changing along the curve.

Scopes:

$$\rho < 10^{-9} g\, cm^{-3}; \qquad T < 4 \times 10^4 K$$

Diagrams $\lg(T)$-$\lg(\rho)$ for W7



Evolution of $\lg(T)$-$\lg(\rho)$. Star marks the radiative temperature T_j.

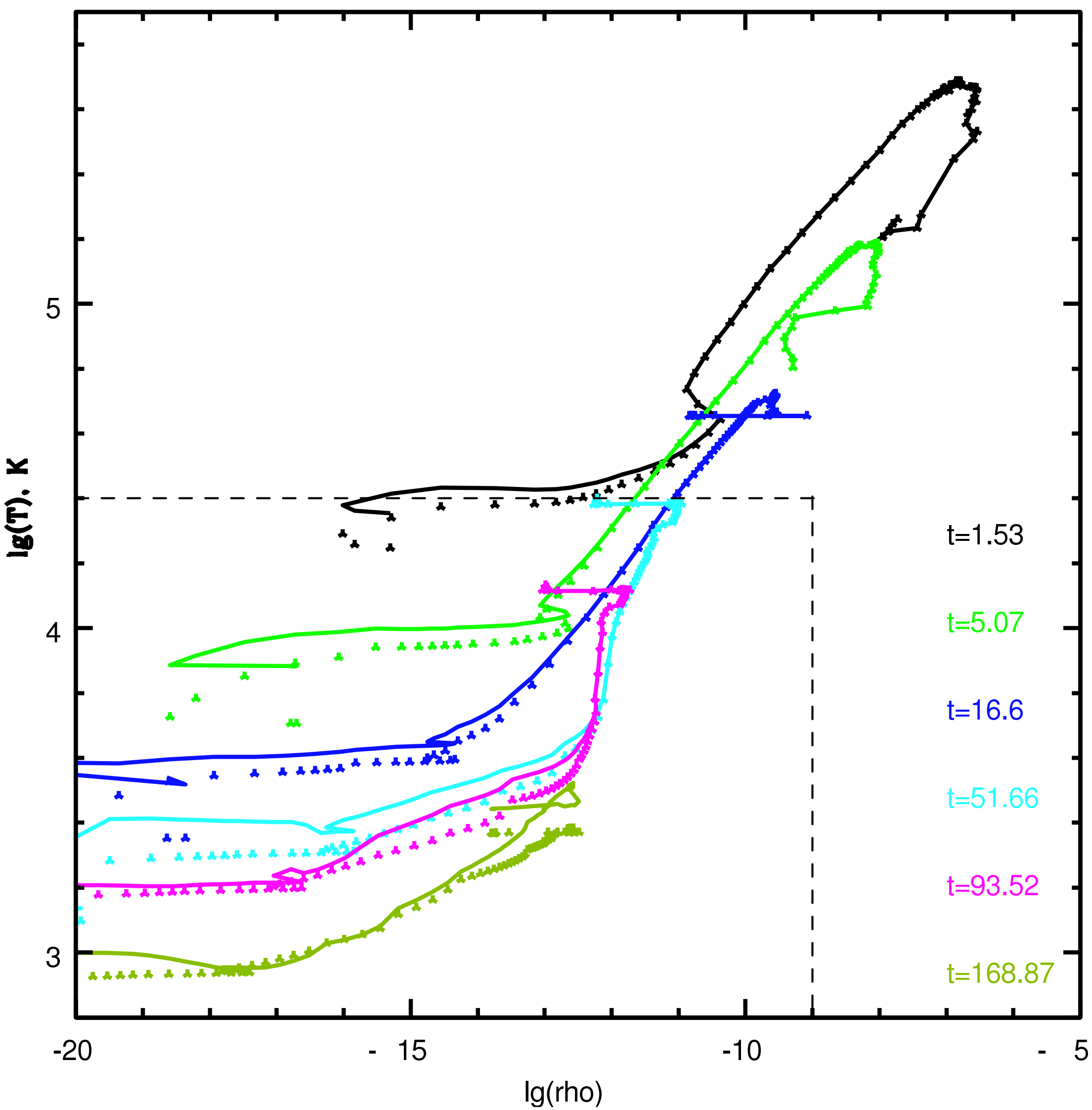
For a given t, each point at the (T, ρ) curve corresponds to some value of the Lagrangian mass m changing from $6 \times 10^{-6}\ M_\odot$ to $1.38\ M_\odot$ along the curve.

Scopes:

$\rho < 10^{-9} g\, cm^{-3}$;

$T < 4 \times 10^4 K$

Diagrams $\lg(T)$**-**$\lg(\rho)$ **for** dsm_R450_M15_Ni007_E7



Evolution of $\lg(T)$-$\lg(\rho)$. Star marks the radiative temperature T_j.

For a given t, each point at the (T, ρ) curve corresponds to some value of the Lagrangian mass m changing from $1.4 M_\odot$ to $15 M_\odot$ along the curve.

Scopes:

$\rho < 10^{-9} g\, cm^{-3}$;

$T < 4 \times 10^4 K$

Comparison of photo and collision rates of ionization - 1

Photoionization rate:

$$R_c^{ij} = 4\pi \int_{\nu_{th}^{ij}}^{\infty} \alpha_{ph}^{ij} \frac{J_\nu}{h\nu} d\nu \ ,$$

ν_{th}^{ij} - ionization threshold, J_ν - mean intensity, α_{ph}^{ij} - cross section for photoionization.

Collision rate:

$$C_c^{ij} = n_e \langle \sigma v \rangle = n_e \int_{v_{th}^{ij}}^{\infty} \sigma^{ij}(v) f(v) v dv$$

σ^{ij} - cross section for collision.

Comparison of photo and collision rates of ionization - 2

T, K	H I	He I	Fe I
$3.5 \cdot 10^3$	3.6×10^{-9}	$< 10^{-20}$	9.2×10^{-8}
$1.2 \cdot 10^4$	7.6×10^{-3}	2.5×10^{-4}	3.3×10^{-8}
$4.0 \cdot 10^4$	5.0×10^{-3}	3.2×10^{-4}	$1. \times 10^{-1}$

$\frac{C_i^{jc}}{R_i^{jc}}$ computed for H I, He I, FeI at the ground level for $\rho = 10^{-9} \frac{\text{g}}{\text{cm}^{-3}}$ and $T = 3.5 \cdot 10^3, 1.2 \cdot 10^4, 4 \cdot 10^4$ K.

NLTE: nebula approach

Lucy (1999)

Adopted excitation formula:

$$\frac{n_i^{ju}}{n_i^{jl}} = W \frac{g_i^{ju}}{g_i^{jl}} e^{-\frac{h\nu_{ul}}{kT_{rad}}}$$

Adopted ionization formula:

$$\frac{N_i^{j+1} n_e}{N_i^j} = \eta W \frac{2U_i^{j+1}}{U_i^j} \frac{(2\pi m_e k T_{rad})^{3/2}}{h^3} \left(\frac{T_e}{T_{rad}}\right)^{1/2} e^{-\frac{\chi_j^i}{kT_{rad}}}$$

where

W - dilution factor

$T_{rad} = \frac{h<\nu>}{x}, \; <\nu> \equiv \int_0^\infty \nu J_\nu d\nu \; / <J>$

T_e - electron temperature

$T_J = W^{1/4} T_{rad}$

$W = \frac{\pi <J>}{\sigma T_{rad}^4}$

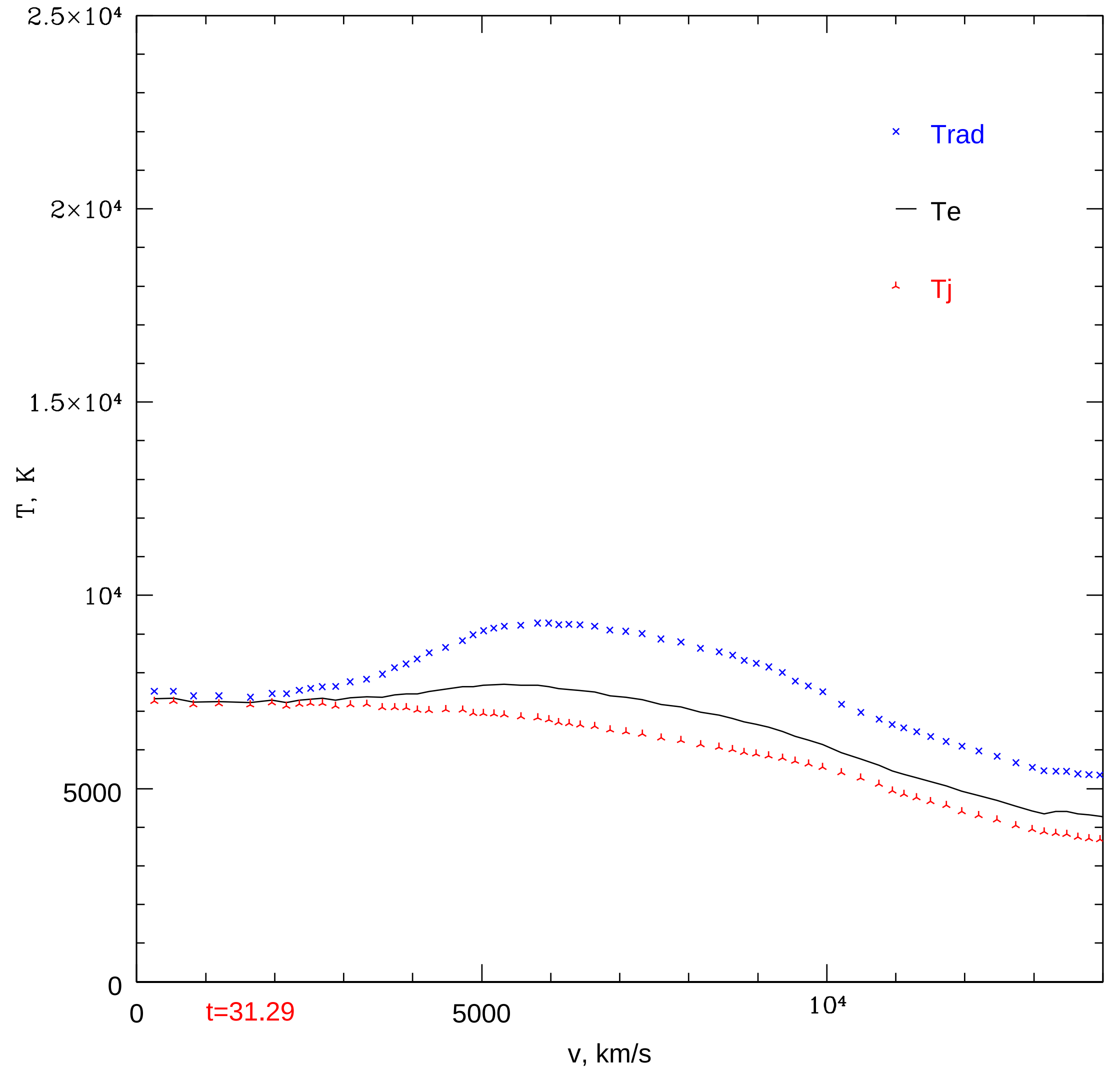
$<J> \equiv \int_0^\infty J_\nu d\nu$

$\eta = \zeta + W(1-\zeta)$, ζ - fraction of recombinations going directly to the ground state,

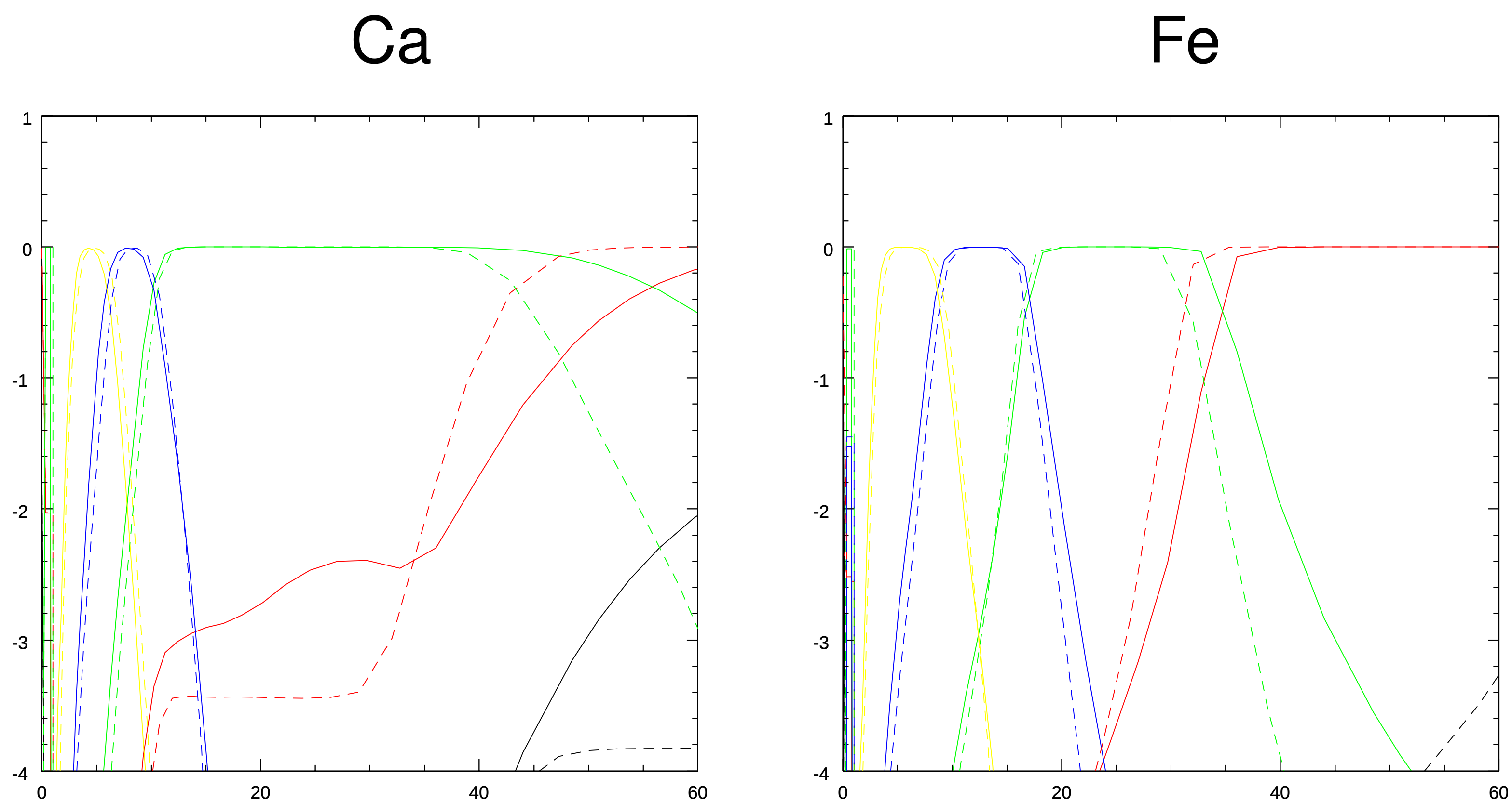
$x \approx 3.8324$

T_{rad}, T_e, T_J in W7

The panels show the radial thermal structure in the W7 explosion model at 31 days after the explosion.



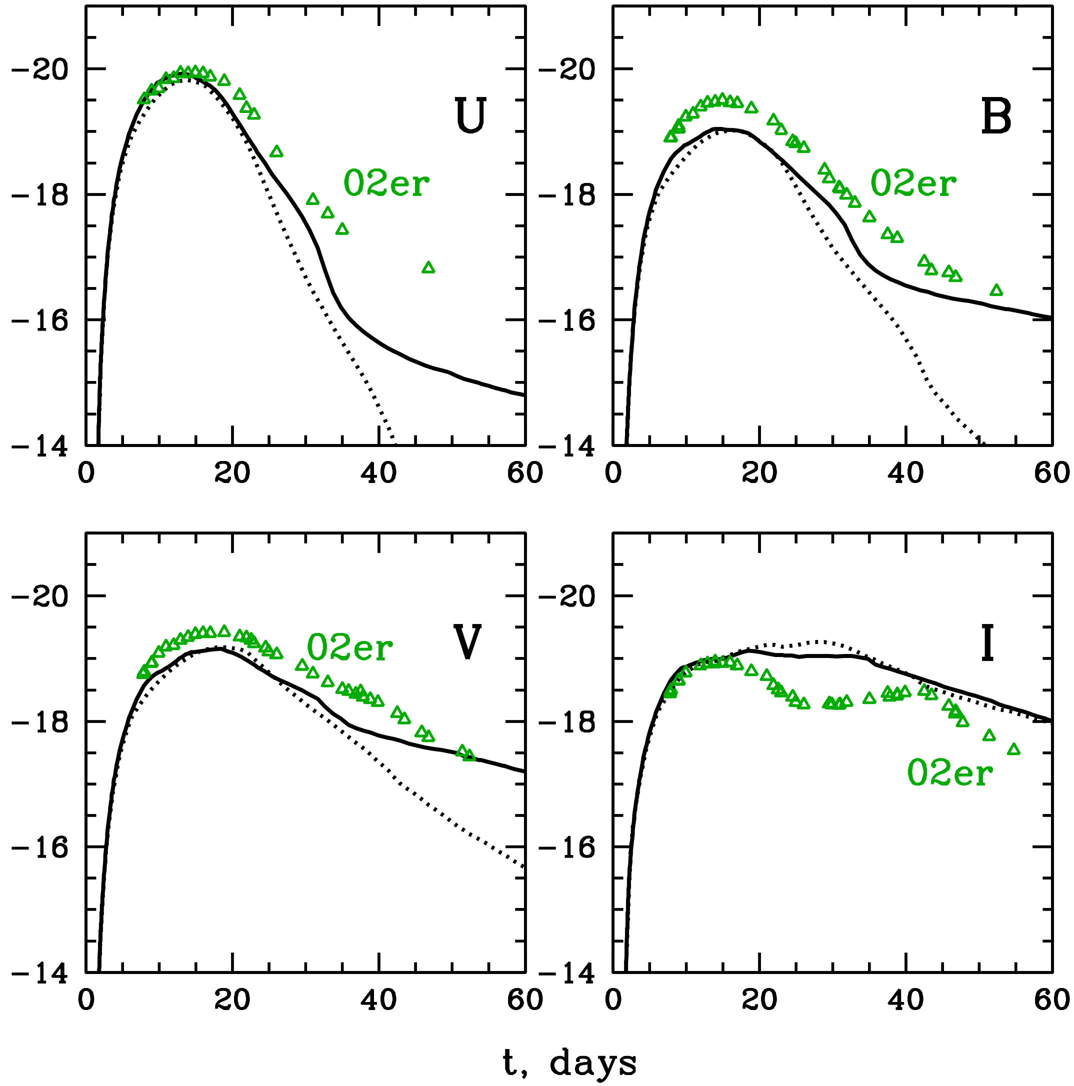
NLTE effects: LTE VS NLTE of ions Ca, Fe of W7



The panels show the time evolution of the ionization structure of Ca(left) and Fe(right) in the W7 explosion model at a velocity of 9590 km s^{-1}. Solid line and dashed line were calculated using the NLTE and LTE ionization treatment respectively. Black/red/green/blue/yellow lines represent Ca[or Fe] i/ii/iii/iv/v.

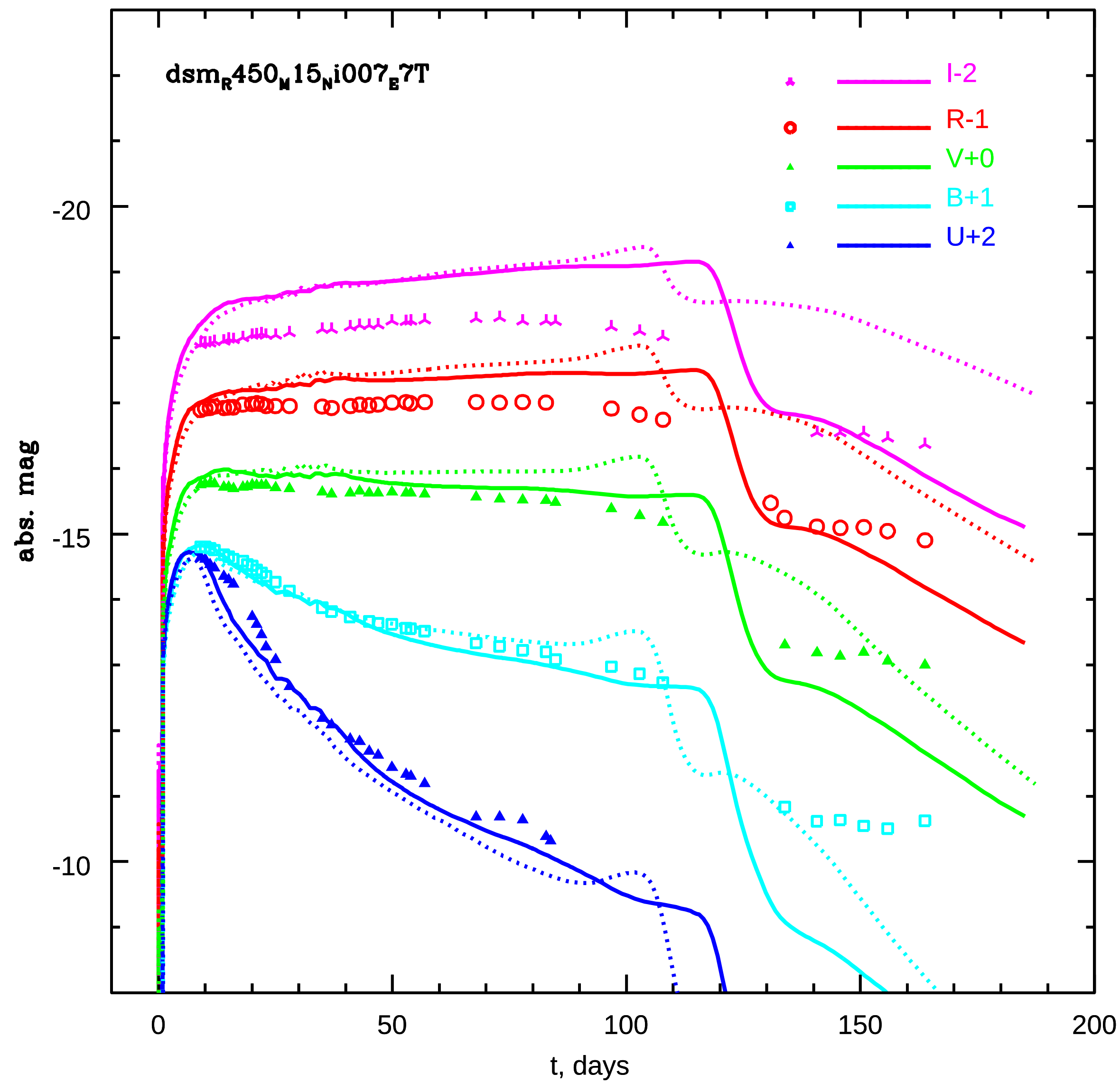
UBVRI light curves of W7

Comparison of NLTE (solid) and LTE (dashed) the UBVRI light curves of W7.



UBVRI light curves of dsm_R450_M15_Ni007_E7

Comparison of NLTE (solid) and LTE (dashed) the UBVRI light curves of dsm_R450_M15_Ni007_E7. It's not stable simulations yet.



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STELLA VS others

- S.Blinnikov, P.Baklanov, etc: Stella [RadHydro, LTE+NLTE, 1D, Eq]
- L.Lucy, P.Mazzali [None RadHydro, NLTE, Spectrum, 3D, MC]
- S. Sim, M.Kromer: Nero, ARTIS [None RadHydro, NLTE, Spectrum, 3D, MC]
- J.Hillier, L. Dessart: code CMFGEN [RadHydro?,NLTE,1D,Eq]
- P.Hauschildt, E.Baron: Phoenix [None RadHydro, NLTE, Spectrum, MC]
- R.Eastman: code Eddington [None RadHydro, 1D, Eq]
- D.Sauer, Pauldrach: code WM-basic [None RadHydro, NLTE, Spectrum, Eq]
- Kasen: SEDONA [None RadHydro, NLTE, Spectrum, 3D, MC]
- Fisher: SYNOW [None RadHydro, LTE, Spectrum, 1D, Eq]
- M.Pumo,L.Zampieri [None RadHydro, LTE, Grey Ath, TOPS, 1D, Eq]
- P.Utrobin [RadHydro, Grey Ath, NLTE+LTE, 1D, Eq]
- S.Woosley: code Kepler [Nuc.syn.,RadHydro, Trad, NLTE,1D,Eq]
- D.Whalen, C.Fryer: RAGE [RadHydro, TOPS, LTE, 3D, Eq]