# Characterizing line profiles of late supernova explosions

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XI ESTALLIDOS workshop
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# Phases of a supernova explosion

time

1. Free expansion phase.

   *Ejected mass is higher than swept-up ISM mass.*

2. Sedov-Taylor phase.

   *Kinetic and thermal energies are ‘constants’.*

3. Radiative phases.

   *A dense, cold shell develops just behind the shock.*

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**2,5. The transition → Focus of this talk!**

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# Transition to radiative phases

The transition occurs when the age of the remnant is similar to the cooling time at the shock front.
A rough estimation is:

$$t_{\Lambda} \approx \left(\frac{\Lambda_{max}(Z)}{10^{-21} erg\, cm^3/s}\right)^{-1} \left(\frac{n_{ambient}}{cm^{-3}}\right)^{-1} \cdot 6.562\, kyr$$

P = pressure; n = number density; γ = adiabatic constant; Λ = cooling function.
T = temperature; $k_B$ = Boltzmann constant.

For these models, $t_{\Lambda}$ can vary between ~10 to ~100 kyr, depending of $n_{ambient}$ and metallicity Z.

# Simulation features and limitations

- ✔ 1D Eulerian hydrodynamic code that can handle spherical coordinates and radiative cooling.

- ✔ Ambient is kept at equilibrium:
  - ➔ Ambient velocity is zero.
  - ➔ We add a heating field in order to null ambient energy losses due to cooling.

- ✗ However, neither magnetic fields nor cosmic rays are modelled here.

# The ambient medium

- The next set of densities, pressures and metallicities are covered:

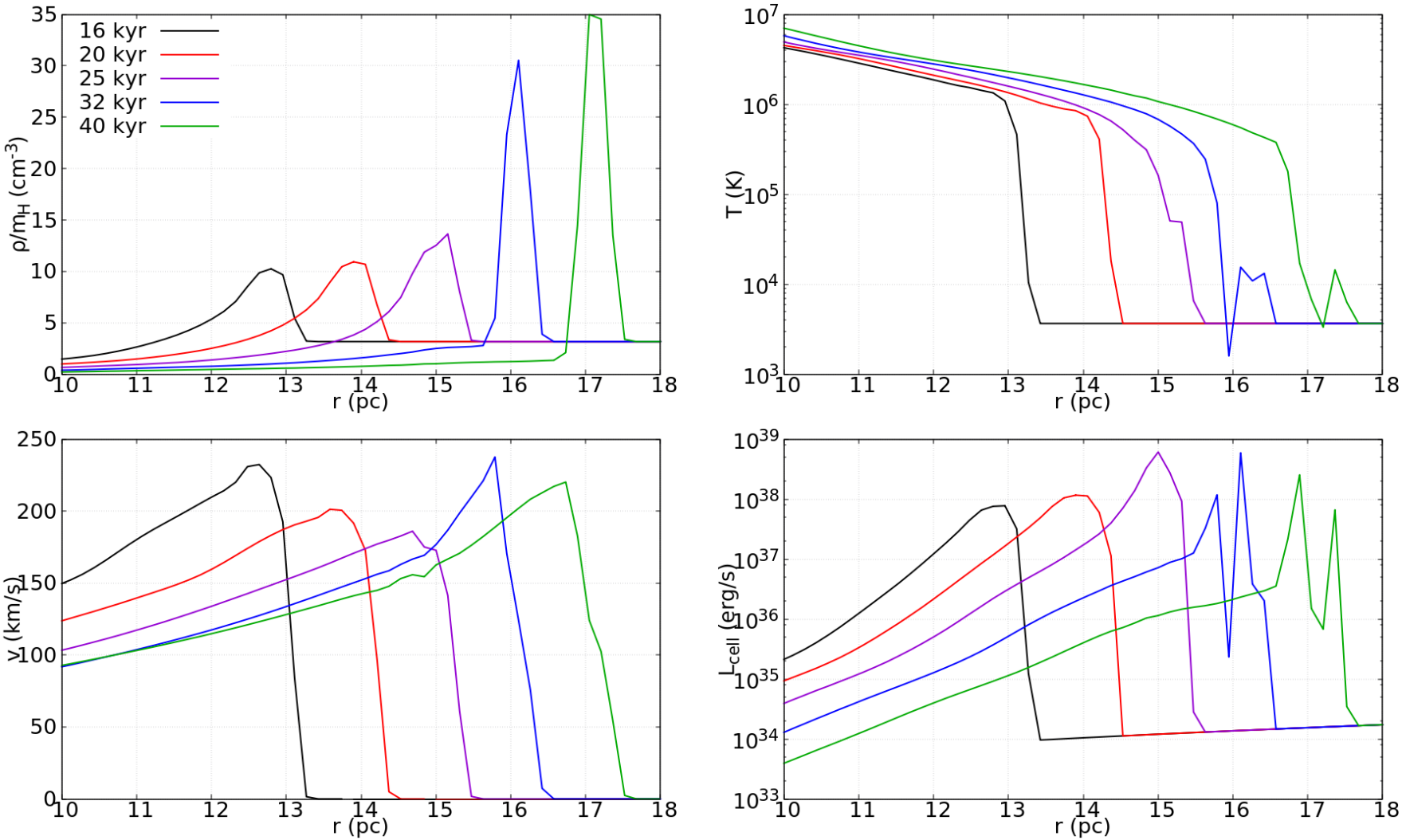
$$\frac{\rho}{m_H} = [0.1, 10^{-0.5}, 1, 10^{0.5}, 10] \ \ cm^{-3}$$

$$\frac{P}{k_B} = [10^4, 10^{4.5}, 10^5, 10^{5.5}, 10^6] \ \ K/cm^3$$

$$Z = [0.005, 0.01, 0.02, 0.04]$$

- Different combinations of density and pressure (temperatures) decide if a shock evolves to a radiative phase or not.

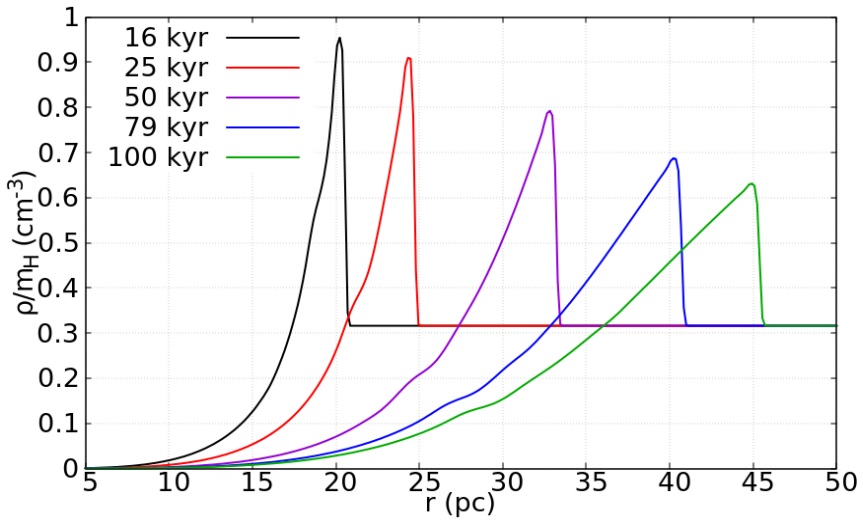
# Evolution to radiative phase

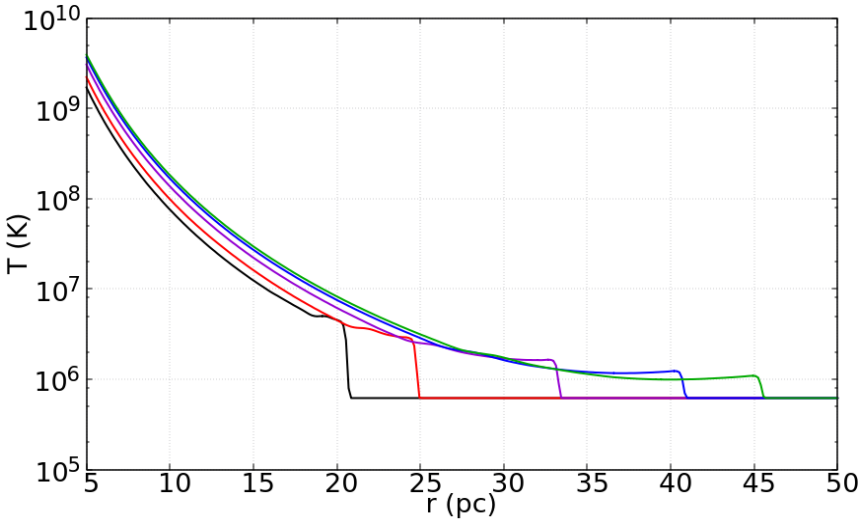


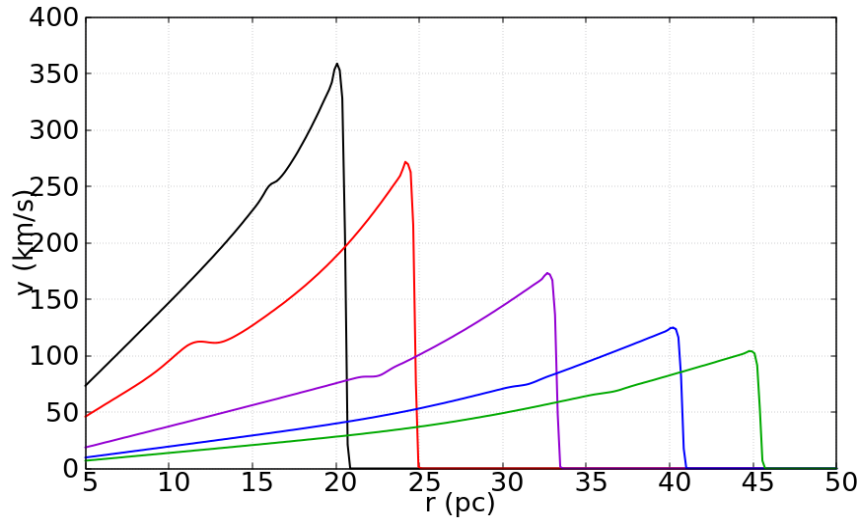

## Ambient values:

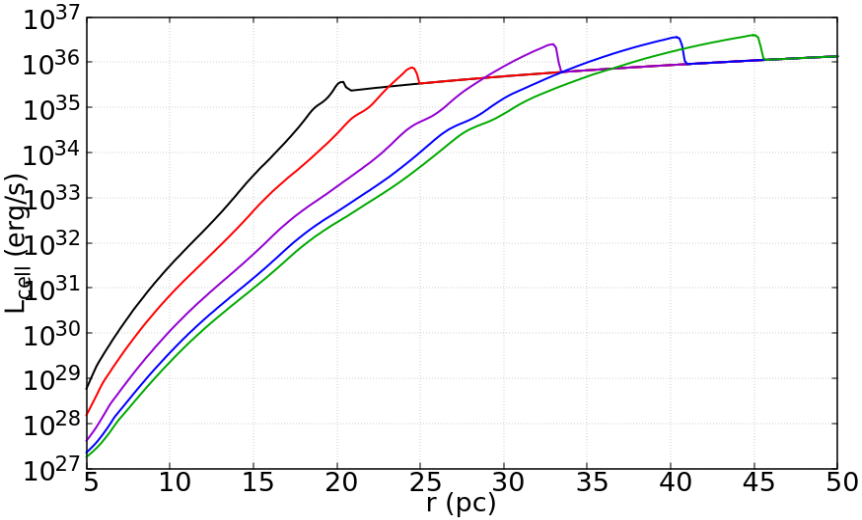
$\rho/m_H = 10^{0.5}$ cm$^{-3}$ ; $P/k_B = 10^4$ K/cm$^3$ ; Z = 0.02

# Skipping the radiative phase



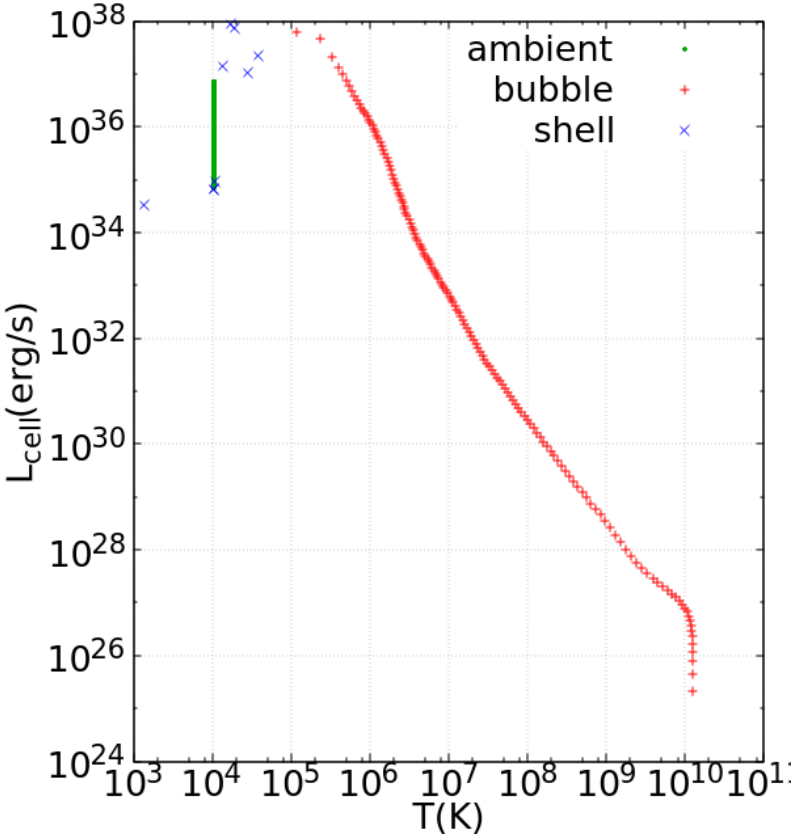



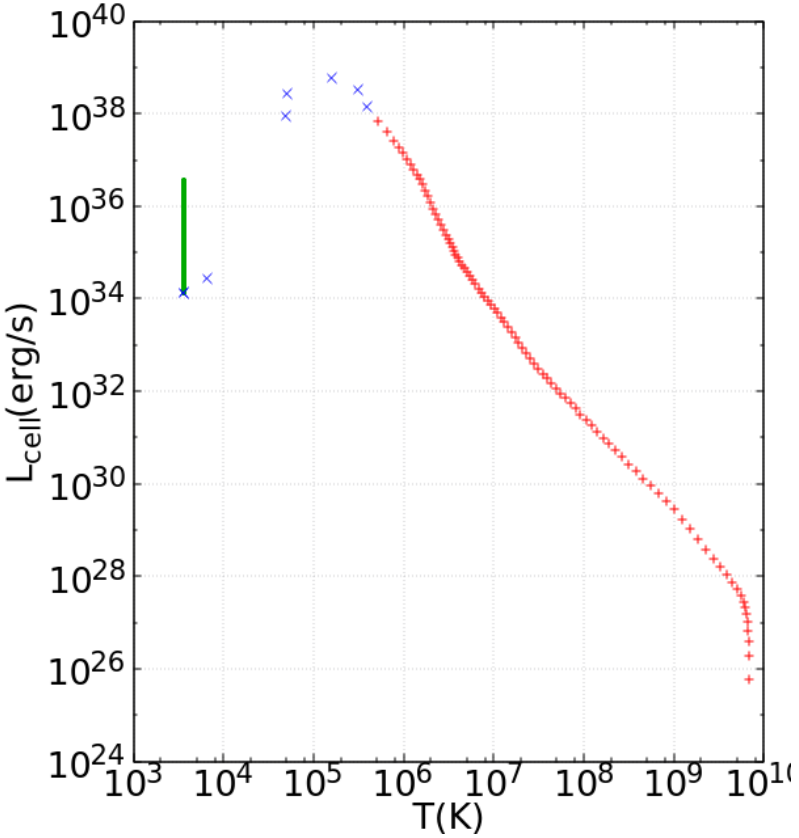

## Ambient values:

$\rho/m_H = 10^{-0.5}$ cm$^{-3}$ ; $P/k_B = 10^{5.5}$ K/cm$^3$ ; Z = 0.02

# Where to look?



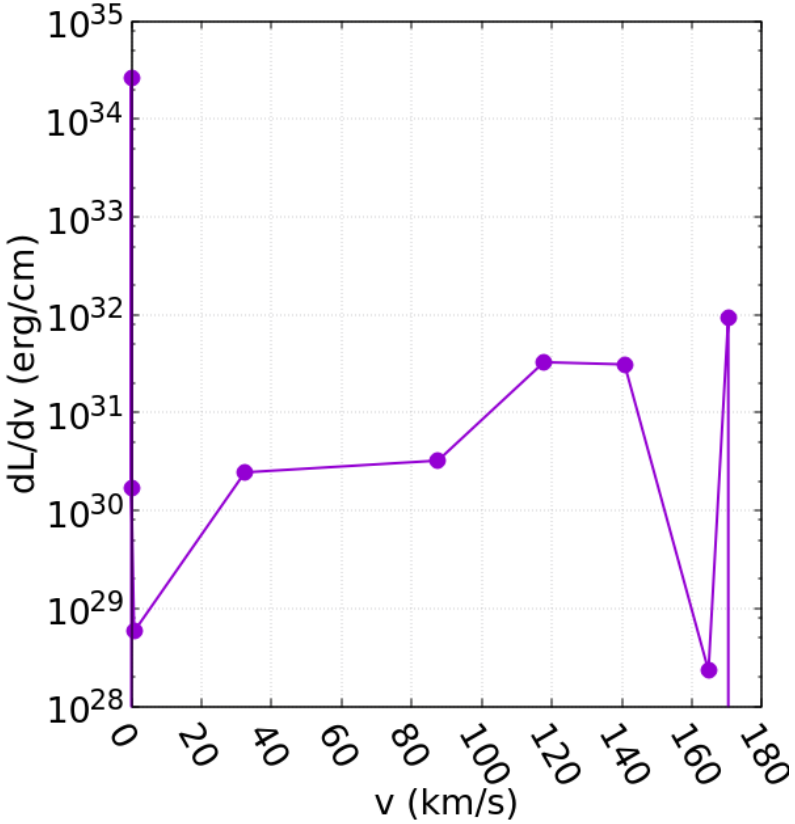

$\rho/m_H$ = 1 cm$^{-3}$ ; $P/k_B$ = $10^4$ K/cm$^3$
Z = 0.02 ; t = 50 kyr



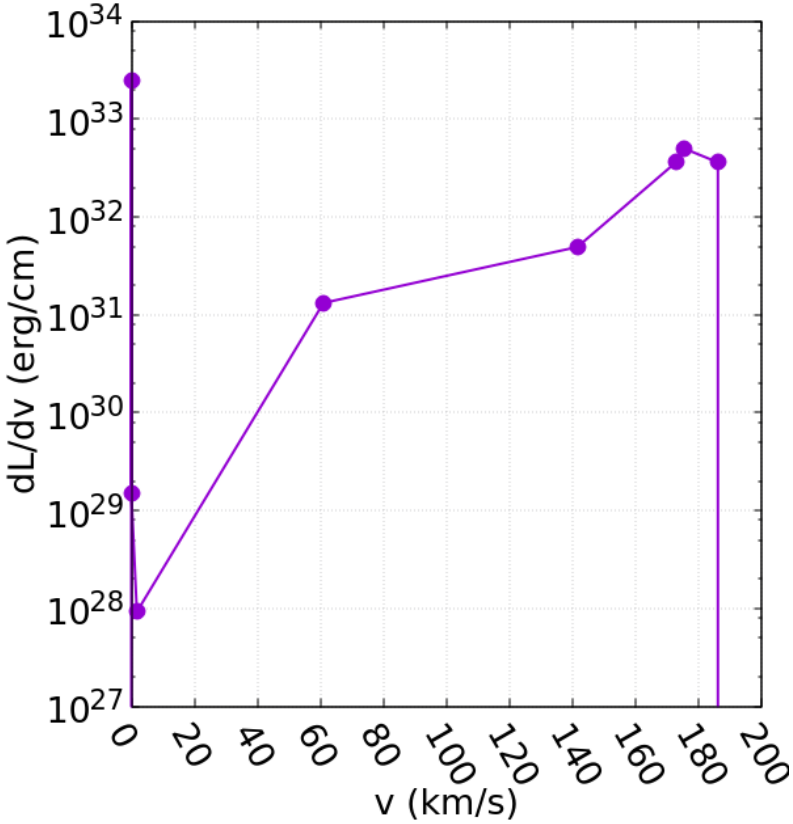

$\rho/m_H$ = $10^{-0.5}$ cm$^{-3}$ ; $P/k_B$ = $10^4$ K/cm$^3$
Z = 0.02 ; t = 25 kyr

Supernova explosions that skip radiative phases can only be seen in X rays

# Line profiles (Work in Progress)

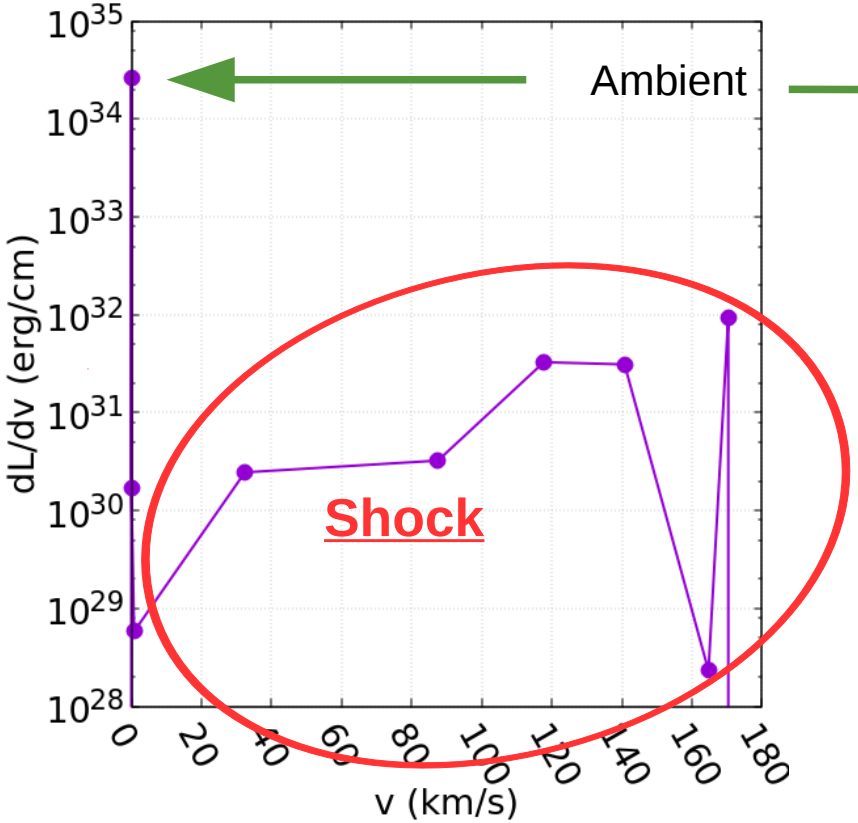



$\rho/m_H$ = 1 $cm^{-3}$ ; $P/k_B$ = $10^4$ $K/cm^3$
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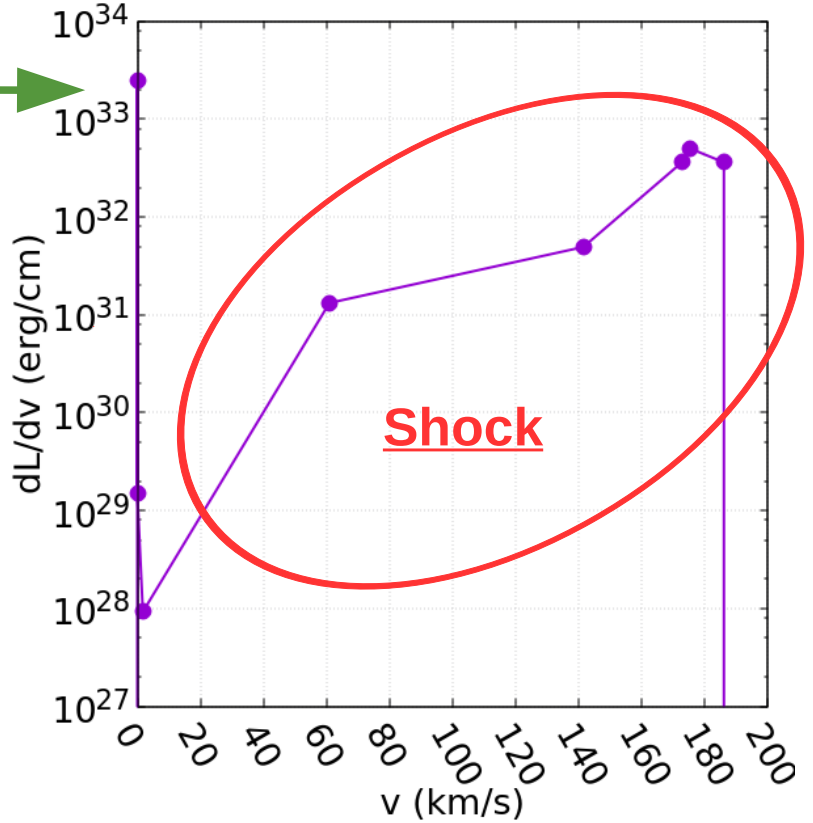



$\rho/m_H$ = $10^{-0.5}$ $cm^{-3}$ ; $P/k_B$ = $10^4$ $K/cm^3$
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# Line profiles (Work in Progress)




$\rho/m_H$ = 1 $cm^{-3}$ ; $P/k_B$ = $10^4$ K/$cm^3$
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$\rho/m_H$ = $10^{-0.5}$ $cm^{-3}$ ; $P/k_B$ = $10^4$ K/$cm^3$
Z = 0.02 ; t = 25 kyr

Expect a **non-gaussian shock contribution** in addiction to ambient contribution.

# Summary

- Supernova-explosion outcome depends heavily on ambient values. If a transition occurs, that happens when cooling time is similar to the age of the remnant.

- Emission less energetic than X rays is restricted to the shock front for shocks that evolve to a radiative phase, in which luminosity peaks at the transition.

- Line profiles have a peak dominated by the ambient with ‘box’-shaped wings that come from the shock.