

The soft and hard X-rays thermal emission into star cluster winds with a supernova explosion

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Introduction

Masive O-B type stars inject a considerable amount of mechanical energy into the ISM in form of stellar winds or supernova (SN) explosions. This energy drives strong shocks that expand into the ISM generating a structure called bubble (Weaver1977 model). The shocked material in the interior of the bubble emits in X-rays. The outer shell emits at optical wavelengths. The simplest model of superbubble formation is (Chu1990,Chu1995,Canto2000 and Silich2004.):

$$L_w = \sum_{i=1}^N \frac{1}{2} \dot{M}_{w,i} v_{w,i}^2.$$

As supershell expands creates a superbubble structure:

1. The innermost region producing thermal hard X-ray emission. Driving the expansion of the bubble due to a pressure difference.
2. The free wind zone. The X-ray emission is important only close to the cluster radius. Mainly soft X-rays.
3. Behind the main shock a reverse shock is formed. The reverse shock encounters the freely expanding wind and compress and heats it to a temperature where the emission in X-rays dominates the emission in X-rays.
4. The outermost region of the superbubble. As the bubble expands, the emission in X-rays decreases.

However, when this theoretical models has been applied to observations, it has been found that the case that only cluster wind is considered, underestimates the X-ray emission (see for example the work of Harp-Clark & Velázquez et al. (2013))

The total X-ray luminosity predicted by the star cluster models (about one order of magnitude) as in the case of the cluster NGC 604 (see for example et al. (2009)).

In other cases (see the work of Rodriguez-Gonzalez2011, which do not consider thermal conduction) the X-ray emission predicted is less than the observed values.

Macro for creating a block node:

`\blocknode{Block Title}{Block Content}`

Macro `\blocknode` has three parameters. The first one is optional and it is the position of the block. The first block will be automatically placed to `(\firstrow)-(\xshift)-(\yshift)`, which is the left corner below the title block. In most of the templates, `(\firstrow)` is set to `(\title.south)`, where `title` is the alias for the title block. Each subsequent block is automatically placed to `(\box.south)-(\yshift)`, i.e., below the previous block aliased `box`. You can also use an explicit parameter, e.g., `(-10,30)` (note that `(0,0)` is the center of the poster). The second parameter is the title of the block. Finally, the last parameter is the actual content.

Numerical Setup.

Numerical simulations

We performed a series of numerical simulations, and estimated the soft and hard X-ray emission that would be produced. We used the `HUACHO` code which solves the hydrodynamic equations on a three dimensional Cartesian mesh, including radiative losses and isotropic thermal conduction:

$$\begin{aligned} \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) &= 0, \\ \frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u} \mathbf{u} + P) &= 0, \\ \frac{\partial E}{\partial t} + \nabla \cdot [\mathbf{u} (E + P)] &= L_{\text{rad}}(Z, T) + \nabla \cdot \mathbf{q}, \\ E &= \rho |\mathbf{u}|^2 / 2 + P / (\gamma - 1) \end{aligned}$$

For the energy loss rate, we use a tabulated cooling function from the freely available `CHIANTI` database

Numerical data

The computational domain is a cube of 140 pc on a side, discretized by 256^3 cells in a uniform grid, yielding a resolution of 0.5469 pc.

We include 15 stellar wind sources placed randomly:

$$\begin{aligned} R_w &= 1.95 \text{ pc.} \\ T_w &= 10^5 \text{ K.} \\ \dot{M}_w &= 10^{-6} M_{\odot} \text{ yr}^{-1}. \\ v_w &= 1500 \text{ km s}^{-1}. \end{aligned}$$

The environment:

$$\begin{aligned} T_0 &= 10^4 \text{ K} \\ n_0 &= 2 \text{ cm}^{-3}. \end{aligned}$$

Variable Width Block Nodes

Adding the metallicity

We estimate the cooling by interpolating a tabulated cooling curve which is, for a given metallicity, a function of the temperature.

We consider the metallicity Z as a passive scalar by including an extra equation of the form

$$\frac{\partial Z \rho}{\partial t} + \nabla \cdot (Z \rho \mathbf{u}) = 0. \quad (1)$$

The average metallicity in each region can be calculated (using Silich2001)

$$Z = \frac{M_{z,ej}}{M_{ej}} + \frac{M_{z,ism}}{M_{ism}} \quad (2)$$

Thermal conduction

We add a heat flux term ($\nabla \cdot \mathbf{q}$) in the right hand side of the energy equation.

The heat conduction due to collisions with free electrons in a plasma Spitzer1962 ($\lambda \ll T/|\nabla T|$)

$$\mathbf{q} = -k \nabla T, \quad (3)$$

$k \rightarrow$ the thermal conductivity:

$$k = \beta T^{5/2}. \quad (4)$$

$\beta \approx 6 \times 10^{-7} \text{ erg s}^{-1} \text{ K cm}^{-1}$

If $\lambda \ll T/|\nabla T|$ (Cowie1977),

$$q_{\text{sat}} = 5 \phi_s c_s P, \quad (5)$$

Block Nodes in the Second Column

To start the second column or the third column use commands

`\startsecondcolumn`, and `\startthirdcolumn`.

If the number of columns is 2, then the last command will not have effect.

You can also start a new column with an arbitrary x-coordinate by specifying explicitly the coordinate of the new block node as follows:

`\blocknode{(\firstrow)-(\yshift)+(\x,0)}{Block Title}{Block Content}`

Useful Macro Within Block Nodes

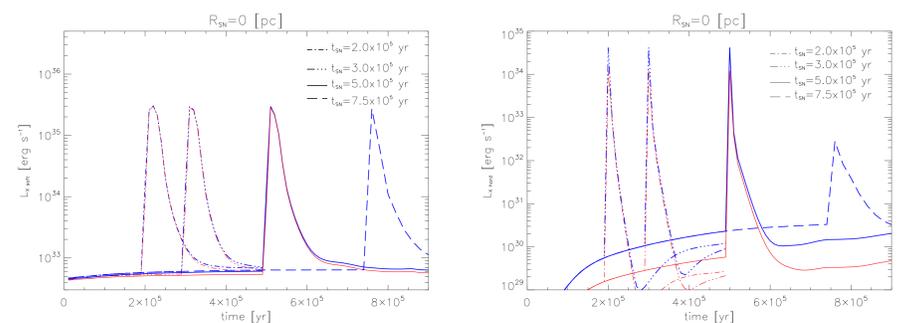


Fig 1. Evolution of the total soft (left) and hard (right) X-ray luminosities for models with the supernova explosion occurring at the centre of the star distribution. The red lines are the models with homogeneous metallicity. The blue lines are the models with different metallicities.

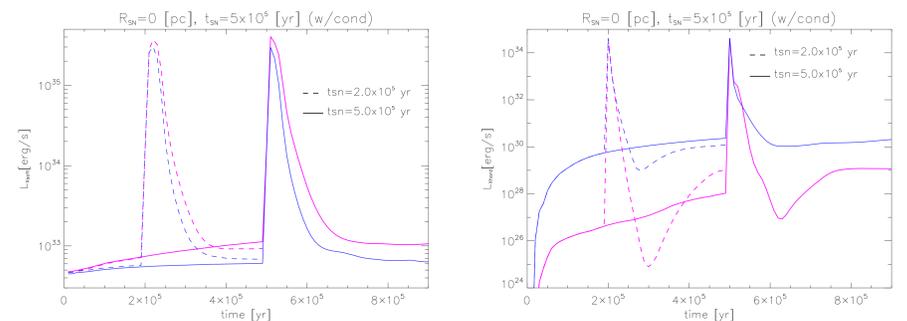


Fig. 2 Evolution of the total soft (left) and hard (right) X-rays luminosities for models with supernova explosion in the centre of the star distribution with no-homogeneous metallicity. The magenta line are the models with thermal conduction and the blue lines are the models without thermal conduction.

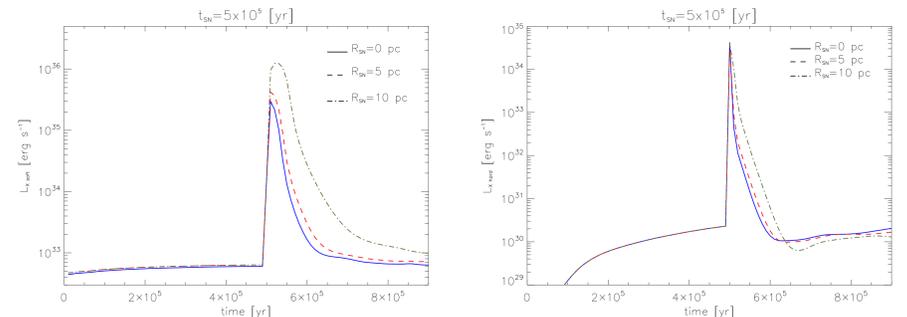


Fig. 3 Evolution of the total soft (left) and hard (right) X-rays luminosities for models with supernova explosion at $t=5 \times 10^5$ yr, and with non-homogeneous metallicity. The blue, red and olive lines are the model with supernova event in $R=0, 5$ and 10 pc, respectively.

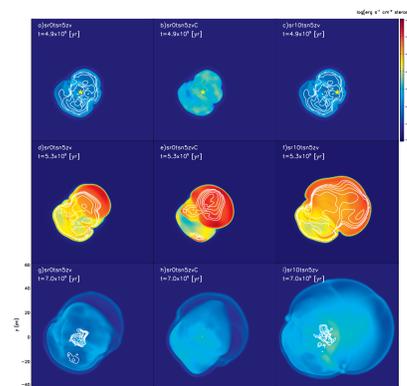


Fig. 7: A shaded circle



Fig. 8: A shaded circle