Interaction of SNe Bubbles in Disc Galaxies

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Abstract. Bubbles driven by multiple supernova explosions (SNe) can interact each other in galactic discs. We study numerically mergings of such bubbles depending on the distance between the stellar clusters that give them rise and power their growth. Such merged bubbles form dense gaseous layers being potential sites of star formation.

Keywords: supernovae: general; galaxies: star formation

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1 Introduction & Model

Bubbles driven by supernova explosions (SNe) are widely observed in both face-on disc and dwarf galaxies (Walter et al. 2008; Pokhrel et al. 2020). Some of such bubbles merge each other (e.g., Dawson et al. 2013; Gaczkowski et al. 2015; Egorov et al. 2017), and these mergers are belived to induce further star formation in their shells (Inutsuka et al. 2015). Dense gaseous layers formed by merging shells are supported by continous SNe explosions in the bubbles. At the same time SNe shock waves can break the layers (Chernin et al. 1995; Vasiliev & Shchekinov 2017), so the possibility of stimulation of star formation looks questionable.

In a stratified interstellar disc the energy injected by SNe is re-distributed over the vertically inflating bubbles, and gas in their walls carries signs of stratification (Shchekinov 2018; Fielding et al. 2018). When neighbour bubbles merge, the dynamical state of gas in layered walls, and its ability to fragment vary along the merged area. Here we show evolution of colliding SNe bubbles of approximately equal age and equal mass in a stratified medium. The merged shells form a vertically stratified wall broken onto denser clumps and filaments. We briefly discuss the related aspects.

We carry out 3-D hydrodynamic simulations (Cartesian geometry) of a collision of two clusters located in the galactic disc. The gaseous disc is set up in the hydrostatic equilibrium under the gravitational potential of a baryonic disc (the DM halo is unimportant at low heights considered here). The baryonic disc is assumed to be self-gravitating with an isothermal velocity dispersion. The stellar surface density equals to $\Sigma_* = 10\ M_\odot\ \mathrm{pc}^{-2}$, and gas surface density $\Sigma_g \simeq 9\ M_\odot\ \mathrm{pc}^{-2}$, the scale height of the stellar disc is $z_0 = 0.1$ kpc. Initially the midplane density is 0.9 cm^{-3}, the gas temperature is 9×10^3K, the metallicity is kept constant equal to the solar value.

Each cluster contains one hundred of SNe randomly distributed within radius 30 pc. The time gap between subsequent SNe explosions in each cluster is ($\sim 2 \times 10^5$ yr), what corresponds in average to the lifetime of massive stars, e.g., $\sim$ 24 Myr for a star of 8 $M_\odot$. The centers of the clusters are located at the midplane ($z = 0$ and $x = 0$) and separated by the distance $d = 384$ and 576 pc, consequently, their bubbles merge at different ages.

The code is based on the unsplit total variation diminishing (TVD) approach implemented the Monotonic Upstream-Centered Scheme for Conservation Laws (MUSCL)-Hancock scheme and the Haarten-Lax-van Leer-Contact (HLLC) method as an approximate Riemann solver. The simulations are performed with a physical cell size of 4 pc. Simulations are run with a tabulated non-equilibrium cooling function for gas cooling isochorically from 10^8 K down to 10 K (Vasiliev 2013). We apply a diffuse heating term representing the photoelectric heating of dust grains (Bakes & Tielens 1994), which is thought to be the dominant heating mechanism in the interstellar medium.

2 Results

Figure 1 presents the gas density for two merging bubbles in three perpendicular planes at $\sim$11.2 Myr after the collision. The shells of the two bubbles separated by 384 pc (left) and 576 pc (right column) start to collide when their ages are is $\sim$7.2 and 14.8 Myr, respectively. One can distinguish three different regions in the gas layer formed by the merger – the wall: one is located in the central part of the layer – the middle circle, and the others are nearly symmetrically in the disc plane, where the shells meet – two edge circles. For the collision of close SNe clusters the middle part of the wall contains small fraction of a gas with density higher than the initial midplane value (for clarity, higher density values are marked by yellow-red part of the color bar). During next $\sim$ 1 Myr this fraction drops to zero. In case of more separated SNe clusters the central part of the wall consists of several fragments with higher density $\sim 3 - 10\ \mathrm{cm}^{-3}$. These fragments survive within next several million years. Similar densities can be found in two regions located in the disc plane where the shells meet. Physical conditions in the edge regions weakly depend on the distance between the SNe

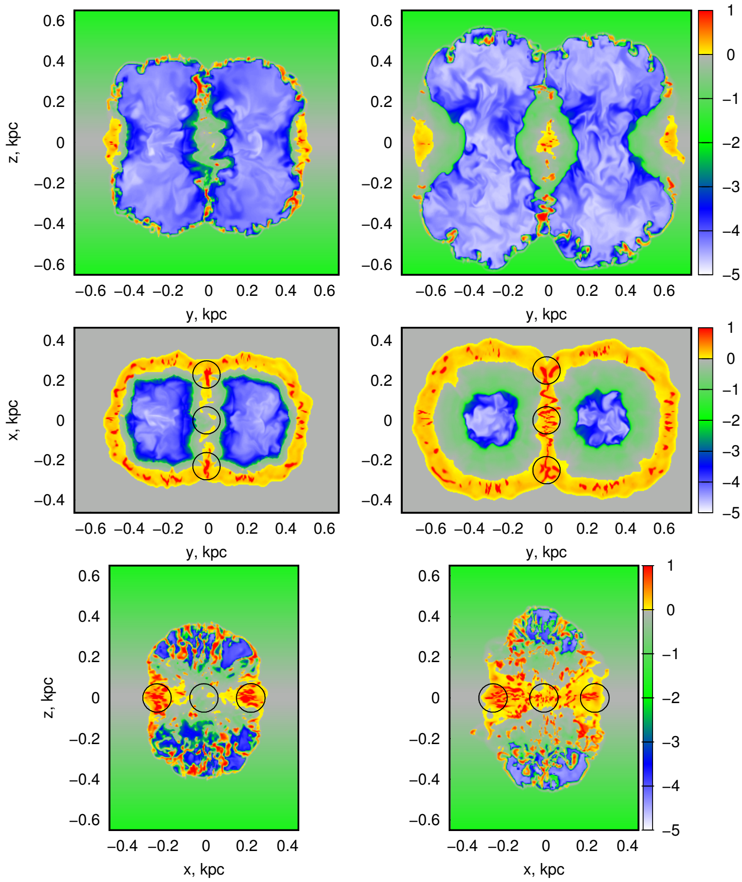

Fig. 1. 2D slices showing gas density, $\log(n,\ \mathrm{cm}^{-3})$, in three planes: (y,z) – upper row, (x,y) – middle row and (x,z) – lower row, passed through the center of the domain $(x,y,z)=(0,0,0)$ for two colliding bubbles driven by 100 SNe each. *Left:* the distance between the bubble centers is 384 pc, the age 18.4 Myr; *Right:* 576 pc, the age 26 Myr. In both cases the snapshot is taken at 11.2 Myr after the mergers started. Three regions are marked by circles in the middle and bottom panels (see details in the text).

clusters. However, the thickness of the dense layer at equal time elapsed since the merging is larger for more separated clusters. The overall picture is determined by the ratio of the distace between SNe clusters d to the gaseous scale height z_0: d/z_0. In case of a low ratio $d/4z_0 \lesssim 1$ the bubbles merge being young and do not inflate significantly perpendicular to the disc. As a result, the wall between bubbles is getting destroyed by strong shocks. For larger ratio $d/4z_0 \gtrsim 1$ bubbles have enough time to inflate vertically before the merging. In this case the energy of SNe shocks channels predominatly in the vertical direction, and the shocks do not destroy the gas layer close to the midplane. The wall is supported by pressure of the hot cavities. The cooling time in the cavities is longer than 10 Myr, so that even after SNe explosions exhaust, the pressure in the cavities seem to remain sufficient to support the gas layer over timescale ($\sim 10-30$ Myr) needed for molecule formation in the gas layer (e.g., Glover & Jappsen 2007) and its further cooling and collapse. Similar conditions take place inside the two boundary regions, where the shells meet. These regions are even more massive than the middle part of the wall. Certainly, this picture is envitably manifested in emission of hydrogen recombination lines. In observations these regions can be recognized in high Hα intensity with low velocity dispersion along the line of sight (Egorov et al. 2017).

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