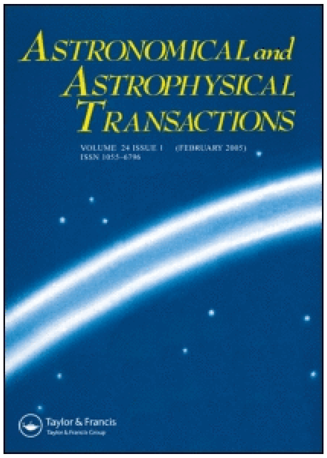

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SHOCKS IN A 2-PHASE INTERSTELLAR MEDIUM: 2D MODELLING

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We present results of 2-dimensional calculations of a supernova remnant expansion into a cloudy medium. We use direct single fluid simulation of a multiphase interstellar medium. We find some disagreements between our numerical results and theoretical predictions by White and Long (1991): the X-ray map does not reveal the property of centrally peaked luminosity of the remnant.

Keywords: Interstellar medium; Supernova remnants; Shock waves; Hydrodynamics

Supernova remnants (SNRs) are thought to be the major sources of a hot coronal gas and HI clouds formation in the interstellar medium (ISM). Much efforts have been done to study the SNR evolution in the uniform environment (Chevalier, 1974; Cioffi *et al.*, 1988; Chevalier and Blondin, 1995; Thornton *et al.*, 1998). In a self-consistent model of a multicomponent interstellar matter SNRs should expand into an inhomogeneous ISM with the scale of inhomogeneity much smaller than the characteristic SNR size (McKee and Ostriker, 1977). These theoretical constructions are corroborated by the numerous X-ray (ROSAT and Chandra), ultraviolet (FUSE) and HI (VLA) observations of episodes of interaction of isolated small ($\sim 1 \div 5$ pc) clouds with the SNR shock regions (Bocchino *et al.*, 1999; Reynoso *et al.*, 1999).

The study of the dynamics of SNRs in a two-phase ISM showed significant influence of the cloudy component both on dynamics and morphological properties of remnants (Cowie *et al.*, 1981; White and Long, 1991; Silich *et al.*, 1996). However, the multifluid (or the 'Sticky particle' cloud-fluid) approach adopted in the aforementioned papers utilizes too many simplified approximations. In the framework of the multifluid dynamics it is difficult to accurately assess the effects of interaction of small-scale clouds with the intercloud matter such as production of turbulent motion as well as mass, momentum and energy exchange between the ISM phases. A straightforward single fluid modelling of multiphase medium provides far detailed physics. In this paper we present the results of the direct simulation of dynamics of the multiphase ISM. This simulation is aimed to better understanding both the observational properties of the individual SNRs and the global characteristics of SNRs in various environments and their role in the global ISM dynamics.

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In order to model global evolution of multiphase medium we must use a hydrodynamical code able to resolve variations of density and temperature in a wide range. Hydrodynamical equations were solved by second order spatial and first order temporal resolution explicit TVD code (Harten, 1983). The ability of the scheme to handle contact discontinuities without substantial numerical diffusion guarantees accurate reproduction of clouds motion. The code has been tested through the strong adiabatic shock wave problem with the known solution (Sedov, 1959) and through the radiative SNR evolution with the known numerical solution by Cioffi *et al.* (1988).

We considered the axially symmetric model taking into account only radial and meridional dependencies of all the parameters. In this approach the clouds have the shape of coaxial tori. The computational grid consisted of 400 zones in horizontal, r, and 800 zones in vertical, z, directions with the size of each square zone equal to 0.2 pc.

The unperturbed ISM was assumed to be composed of warm ($T_{icm} = 9 \cdot 10^3$ K) intercloud medium and small randomly and uniformly distributed cold (mean cloud temperature $T_{cloud} \approx 70$ K) clouds. Both phases were considered to be initially in mechanical and thermal equilibrium. Concentration of the intercloud phase was set to $n_{icm} = 0.1\,\mathrm{cm}^{-3}$. The clouds radii were taken in the range between 0.4 and 2.5 pc, and the mean cloud/intercloud concentration ratio n_{cloud}/n_{icm} was 110 in number. The total masses of the cloud and intercloud phases were taken to be identically equal. The number of clouds within the computational domain was 300.

We included the following physics: (i) mixed electron-atomic heat conduction that is valid over the whole range of temperatures; the effect of saturated conductive heating was included; (ii) heating due to photoionization; for simplicity we set the heating function to be constant: $\Gamma = 1.6 \times 10^{-25}\,\mathrm{erg\,g^{-1}\,s^{-1}}$; (iii) radiative cooling function was taken from Raymond *et al.* (1976). The following effects were not taken into account: (i) turbulent magnetic fields which are able to suppress thermal conduction; (ii) the effect of cosmic-ray generation at the shock front that may lead to significant energy losses; (iii) magnetic and cosmic ray pressure; (iv) the effects of non-equilibrium ionization and cooling.

The initial state for the SN explosion was set as follows: $E_0 = 10^{51}$ erg as purely thermal energy and mass $M_0 = 10 M_\odot$ input were distributed uniformly over the spherical region $R < 5$ pc. Since we focus on a large-scale dynamics of SNR, the details of the very early, ejecta-dominated stage of SNR evolution remain beyond the scope of our simulation.

The computations were run till the moment $t = 10^6$ yrs.

First 7×10^4 years clouds within the remnant remain almost motionless. Small clouds with size ~ 1 pc rapidly evaporate in 4×10^4 years, while larger clouds being substantially compressed (the peak density builds up to 100 times) survive till the end of computations. Due to the heat conduction and high density of the clouds they play a role of effective coolers radiating energy of the ambient hot gas. Dense shell forms behind the shock front at $t \approx 9 \times 10^4$ years when SNR radius reaches $R_{SNR} \approx 40$ pc, after that the remnant significantly decelerates.

At late stages [$t \sim (10 \div 20) \times 10^4$ years] radial acceleration of clouds becomes visible. Temperature and pressure of the coronal gas within the cavity drop, consequently clouds expand and evaporate. Further SNR expansion ($t > 20 \times 10^4$ years) follows an approximate law $t^{0.15}$. To the beginning of this stage the total kinetic energy of the coronal gas has been declined considerably. This is not the case for the kinetic energy of accelerated clouds which eventually overtake the shell. These clouds form a thick layer of evaporated material, while in the interior the cavity is almost free of clouds.

At the final stage ($t \sim 10^6$ yrs), just before the termination of calculations SNR radius reaches ~ 70 pc and the velocity falls to $3 \div 5\,\mathrm{km\,s^{-1}}$. A typical structure of the flow is shown in Figure 1a. Figure 1b depicts the X-ray luminosity of SNR calculated at the

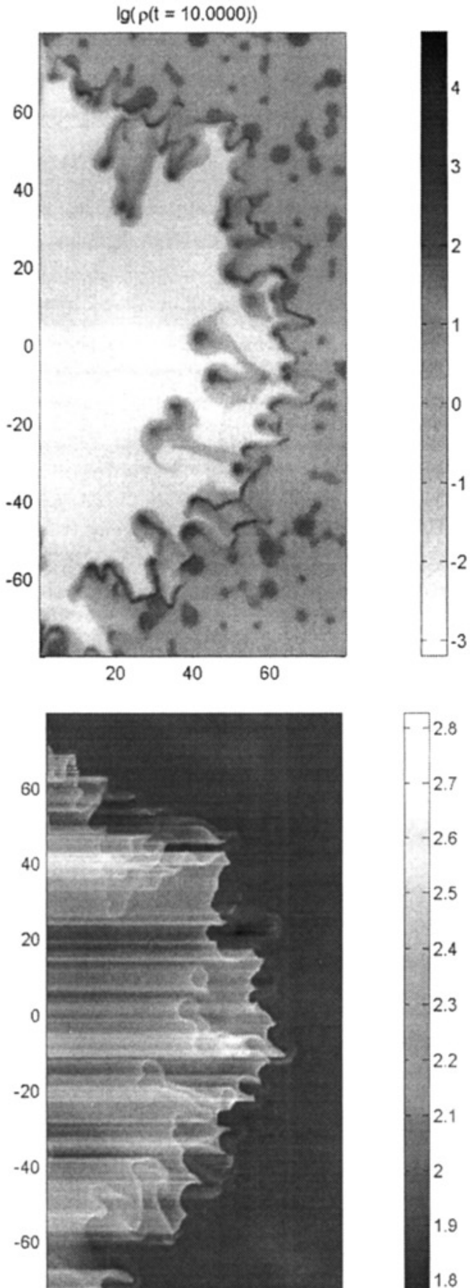

FIGURE 1 The gray-scale image of the concentration (a) and the column luminosity (b) in $\mathrm{erg\,cm^{-2}\,s^{-1}}$ in logarithmic scale for a SNR at $t = 10^6$ yrs.

same moment. The striped structure of the image is explained by the torical shape of clouds in our model. As is seen, the most luminous part of the SNR is the shell. This result questions the conclusion of White and Long (1991) that centrally bright X-ray morphology of SNRs presumably thermal emission can be explained by their evolution in a cloudy environment.

References

Bocchino, F., Maggio, A. and Sciortino, S. (1999). *Astron. Astrophys.*, **342**, 839.
Chevalier, R. A. (1974). *Astrophys. J.*, **188**, 501.
Chevalier, R. A. and Blondin, J. M. (1995). *Astrophys. J.*, **444**, 312.
Cioffi, D. F., McKee, C. F. and Bertschinger, E. (1988). *Astrophys. J.*, **334**, 252.
Harten, A. (1983). *J. Comput. Phys.*, **49**, 357.
McKee, C. F. and Ostriker, J. P. (1977). *Astrophys. J.*, **218**, 148.
Raymond, J. C., Cox, D. P. and Smith, B. W. (1976). *Astrophys. J.*, **204**, 290.
Reynoso, E. M., Velaézquez, P. F., Dubner, G. M. and Goss, W. M. (1990). *Astron. J.*, **117**, 1827.
Sedov, L. I. (1959). *Similarity and Dimensional Methods in Mechanics*. Academic Press, New York.
Silich, S. A., Franco, J., Palous, J. and Tenorio-Tagle, G. (1996). *Astrophys. J.*, **468**, 722.
Thornton, K., Gaudlitz, M., Janka, H.-Th. and Steinmetz, M. (1998). *Astrophys. J.*, **500**, 95.
White, R. L. and Long, K. S. (1991). *Astrophys. J.*, **373**, 543.