X–RAY EMISSION OF THE SUPERNOVA REMNANTS IN A NON–UNIFORM INTERSTELLAR MEDIUM

B. Hnatyk and O. Petruk

Institute for Applied Problems in Mechanics and Mathematics, NAS of Ukraine
3-b Naukova St., 79053 Lviv, Ukraine
e-mail: hnatyk@lms.lviv.ua, petruk@astro.franko.lviv.ua

Large-scale gradient of the interstellar medium density distribution essentially affects the evolution of supernova remnants. To model this influence, a new approximate analytical method for the full hydrodynamical description of 3D point-like explosions in the non-uniform media with arbitrary density distribution is developed. General features of the evolution of the adiabatic supernova remnants in the medium with a large-scale density gradient are investigated. Real anisotropy of the remnants increases with age, but the visible shape remains close to spherical. X-ray emission characteristics from the entire SNR (luminosity, spectral index) are close to those in the spherical Sedov case with the same initial data. However, the surface distribution of the X-ray emission characteristics is very sensitive to the initial density distribution around the Supernova progenitor.

INTRODUCTION

Investigation of supernova remnants (SNRs) as non-spherical 3-dimensional objects is one of the most actual tasks in studies on these objects [1]. Most important reason for the non-sphericity of adiabatic SNRs is a non-uniformity of ISM. In such cases, self-similar solutions cannot be used, and a real possibility to perform an investigation of the evolution of non-spherical SNRs bases on approximate methods for hydrodynamics. In [2] we have proposed a new approximate analytical method for the complete hydrodynamical description of a point explosion in a medium with an arbitrary large-scale density distribution. On the basis of this method, we investigate here the general features of the thermal X-ray emission of adiabatic SNRs in ISM with a large-scale density gradient. Equilibrium thermal X-ray emission model is taken from [3].

SNR IN A NON-UNIFORM MEDIUM

The exponential density distribution is frequently encountered in ISM. We will use this distribution in the form:

$$\rho^{\mathrm{o}}(z) = \rho^{\mathrm{o}}(0) \cdot \exp\Big(-\frac{z}{H}\Big), \quad z = r\cos\theta, \tag{1}$$

where r is the distance from the center of explosion, θ is the angle between the considered direction and z-direction (opposite to the density gradient) and H is the scale height.

We show in Fig. 1 the evolution of X-ray luminosity and spectral index α. It is easy to see that both X-ray characteristics of non-spherical SNR (NSNR) evolve analogously to the Sedov case ($H \to \infty$).

We have calculated a grid of NSNR models which confirms that this analogy in evolution is an intrinsic property of NSNR X-ray radiation [2]. For a wide range of number density at the point of explosion $n_{\mathrm{H}}^{\mathrm{o}}(0) = 0.1 - 10\ \mathrm{cm}^{-3}$, the X-ray luminosity of adiabatic NSNR evolving in a medium with strong enough density gradient ($H = 10$ pc) in different energy ranges is not far from the X-ray luminosity of SNR in a uniform density medium with the same initial model parameters. The difference increases with age of the SNR and with decreasing of $n_{\mathrm{H}}^{\mathrm{o}}(0)$. But even for old NSNR (*e.g.*, $t = 3{\times}10^4$ years) in a relatively low density medium ($n_{\mathrm{H}}^{\mathrm{o}}(0) = 0.1\ \mathrm{cm}^{-3}$), the maximal difference reach only about 60% aat the end of adiabatic phase. The difference in spectral index of adiabatic NSNR does not exceed 10%. Luminosity in range > 4.5 KeV is close to the Sedov case too. These last two facts reveal the similarity of total spectra of non-spherical SNR and its Sedov counterpart.

Therefore, we emphasize here a remarkable fact of proximity of total fluxes and spectrum shapes of SNRs in uniform and non-uniform media even in case of considerable anisotropy of adiabatic NSNRs. The reason of this phenomenon is mutual compensation of emission deficit from low density regions of NSNR and enhanced emission from high density regions, since X-ray emission mainly depends on the emission measure $EM \simeq n_{\mathrm{e}}^2 V \simeq M^2 V^{-1}$, but both masses of swepted up gas M and volume V of NSNR remain close to those of Sedov SNR [2]. This explains the strange circumstance that integral X-ray characteristics of the majority of SNRs with evident

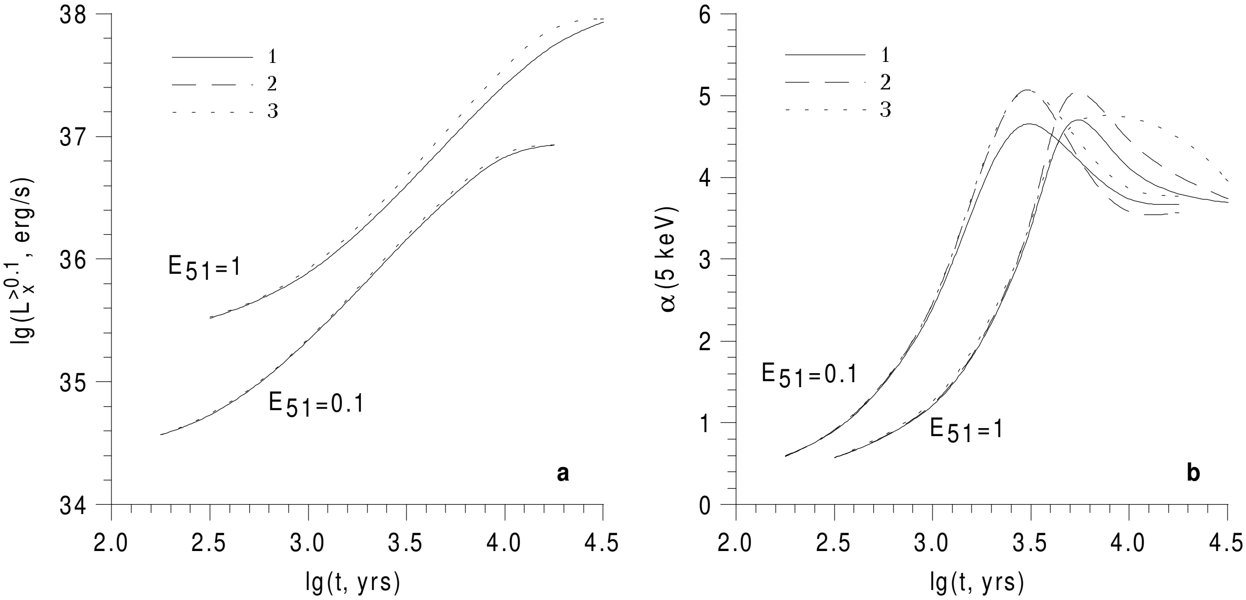

Figure 1: Evolution of luminosity $L_{\rm x}$ in range > 0.1 KeV and spectral index $\alpha(5$ KeV) of SNR in a uniform medium (line 1), in an exponential medium Eq. (1) with $H = 80$ pc (line 2) and $H = 10$ pc (line 3). In all cases $n_{\rm H}^{\rm o}(0) = 1$ cm^{-3}. E_{51} is the explosion energy in 10^{51} erg. $\gamma = 5/3$

asymmetry in shape and/or surface brightness distribution are described with sufficient accuracy by the Sedov [4] model of SN explosion in a uniform medium. For more correct modelling of physical conditions inside and outside the SNR, it is necessary to analyze the characteristics of X-ray emission distributed over the SNR surface.

Such investigation have been carried out in [2]. The main results are following. 1. The distribution of surface brightness of NSNR differs essentially from a spherical one. 2. The contrast of surface brightness increases with the age of the SNR and may reach a few tens of thousands. 3. Projection effects hide real contrasts of surface characteristics of NSNR's emission. Observational morphology of NSNR depends essentially on its orientation with respect to the line of sight. 4. A harder X-ray range (> 4.5 KeV) is less sensitive to the influence of the non-uniformity of surrounding medium than a range which includes soft emission. This fact may be used for testing ISM non-uniformity. 5. The surface distribution of spectral index α may also be an effective tool for NSNR diagnostics.

CONCLUSIONS

It is shown that the real anisotropy of adiabatic SNR in non-uniform ISM increases with time, but the visible shape remains close to spherical even for strong real asymmetry (ratio of maximal to minimal shock radii) and surface brightness contrast. Projection effects on the sky plane decrease the real shape anisotropy. It is shown also that the integral characteristics of X-ray radiation from the entire SNR (luminosity, spectral index) are close to those in the Sedov case with the same initial data. However, the surface distribution of the X-ray emission parameters is very sensitive to the initial density distribution around the SN progenitor. Therefore, the X-ray maps are needed for recovering of the physical conditions inside and outside of the non-spherical SNR.

REFERENCES

[1] *Jones T., Jun B., Borkowski K., et al.* 10^{51} Ergs: The Evolution of Shell Supernova Remnants // Publs Astron. Soc. Pacif.–1998.–**110**.–P. 125–151.

[2] *Hnatyk B., Petruk O.* Evolution of supernova remnants in the interstellar medium with a large-scale density gradient. I. General properties of shape evolution and X-ray emission. // Astron. and Astrophys.–1999.–**344**.–P. 295–309.

[3] *Raymond J., Smith B.* Soft X-ray spectrum of a hot plasma // Astrophys. J. Suppl. Ser.–1977.–**35**.–P. 419–439.

[4] *Sedov L.* Similarity and Dimensional Methods in Mechanics.–New York: Academic, 1959.