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INTERACTION OF SUPERNOVA REMNANTS WITH THE SURROUNDING STELLAR POPULATION

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In this paper, we study the interaction of the expanding supernova remnant (SNR) with the stars in the surrounding medium. We show that the regions of interactions of SNRs shock wave with O-B stars are energetically most important sources in the galaxy after the areas near relativistic objects; therefore it is natural to expect the observable in various wavebands consequences of such interactions. In the case of low mass stars the interaction with SNRs may have impact on the origin of life and the habitability of such type stellar systems.

Keywords: Supernova remnants – Stars – ISM

The vast majority of stars are born and die in stellar associations [1], so the interaction of the expanding remnants of supernova explosions, SNRs, with different type of stars in the surrounding them medium is expected to be a common phenomenon, although little or no attention has been paid in the literature to this problem. There are two aspects of this problem: 1) the impact of the stellar component on the evolution of SNRs; 2) the effect of the SNR on the properties of interacting stars. The influence of the stellar component on the evolution of SNRs is expected to occur only at specific conditions when SNRs evolve in the region of intensive star formation where the concentration of stars is high and large number of stars inside the supernova remnant gravitationally slow down the expansion of the shell. Physically, the interaction of shock waves of SNR with stars of various types can lead to completely different results from both theoretical and observational points of view. This is because, on the one hand, the characteristics of the shock waves of SNRs vary over a very wide range: speeds - from several thousand km/s to tens of km/s, sizes – from several AU up to 100 pc. At the same time, the structure of SNR changes from an adiabatic self-similar strong shock wave to a radiative cold shell surrounded by a relatively weak shock front. On the other hand, in the region of SNR expansion, there can be stars of completely different masses, sizes and types. In addition, from the observational point of view, both the distance to the interaction area and the orientation of this area with respect

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to the line of sight are of critical importance. Physically, the result of interaction of SNR with a given type of stars strongly depends on the stage at which the SNR is. It is obvious that the result of the interaction of a strong shock wave with a star of any mass and size may be a “stripping” of the external atmosphere of the star and its further occurrence and following evolution in the interior of the SNR - in a region of very high pressure. For a wide range of SNR characteristics, the result of the interaction of a shock wave with a star will be the formation of a bow shock around the star during its passage through the SNR shell.

Bow shocks around stars moving relative the surrounding interstellar gas are commonly observed as curved arcs of emission at different wavebands, from radio to X-rays (For the one of the most recent works on astrophysical bow shocks, see [2]). The physics of bow shocks is very different but in general it is understood (see, e.g., [3]). In present paper we apply the results on the star bow shocks to the case when the SNR's shock wave impact a star with wind mass loss.

Observational detection and identification of such structures may turn out to be an important information channel for studying both SNRs and stars in the region of the remnant evolution. Young massive O and B stars with a strong stellar wind are the most favorable for observations.

1. EXPANSION OF SNR IN THE MEDIUM WITH HIGH STELLAR CONTENT

In active starburst regions (SBs) both birth and death of massive stars take place almost in the same place and at the same time. In SBs the main active component is the massive stars which evolves to the end of their life in short period of time and explodes as type II and Ib/c SNe. According to [1] 90% of stars form in clusters with sizes of 1pc. These stars are expected to stay spatially associated for timescales greater than the lifetimes of CC-SNe progenitors. Therefore it is clear that the SNRs, the remnants of the death explosions of massive stars, play very important role in the life of SBs. Also, it is clear that they can be responsible for the observational properties of the SBs. The evolution of SNRs in active SBs occurs in extreme conditions of high pressure and high matter density that strongly differs from the case of evolution in the standard ISM of normal galaxies.

The matter in the central parts of SBs consists of diffuse interstellar gas and stars.The SN blast wave propagating in such environs will sweep up the diffuse component into the shell and strips off the nearby stars of their H-rich envelopes leaving them inside the SNR. The SNR's shell made mainly up of diffusive gas component quickly enters the radiative phase of evolution and the following evolution can be described with the help of pressure driven snowplow theory [4] with taking into account the gravitation from the stars inside the SNR. The main result of the analyses of a standard system of deferential equations describing the mentioned processes [5] is that in the fate of a supernova remnant under realistic conditions the diffusive gas component plays a more important role than the stellar component. For gas densities $\sim\ 10^4$ cm^{-3}, characteristic for the regions of active star formation, the sizes of the SNRs reaches several parsecs, which are larger than the characteristic sizes of compact SBs; the lifetime of SNRs decreases with increasing density of the stellar component. The SNRs can play very important role in regulating the structure of the SBs. Because SBs consist of massive stars, which live for a few, the first SN explosions occur in very high densities of both components and, possible, at lower ambient pressures. The SNRs, evolving in such conditions create the relativistic component of matter in SB regions, but the following generation of SNRs will evolve at higher ambient pressure and lower gas densities, and their shells easily can easily leave the system.

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2. INTERACTION OF SNR WITH STARS

One of the main features of the processes of interaction of the incoming gas flow in the shell of the SNR with the star of any type with stellar wind will be the forming of bow shock (Fig. 1).

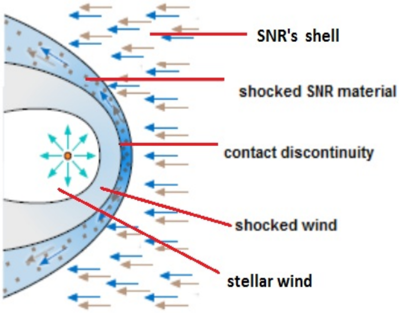

Fig. 1. Schematic structure of two-shock bow shock around the star with stellar wind

We consider here the bow shocks appearing when shock wave of the SNRs encounters the stars of different type with the wind or with magnetic field. The structure of an interaction region at early times can be described in much by the same manner as is done for bow shock of high velocity runaway OB stars or for Earth bow shock, but in the case of SNRs the energetics of the physical processes taking place at the zone of interaction is expected to be higher.

The typical length scale of bow shock is considered to be the so called stand off distance, the distance from the star where the wind momentum flux $\rho_w \cdot v_w^2$ balances the ram pressure in the SNR shock, $\rho_{snr} \cdot v_{snr}^2$:

$$\rho_w \ v_w^2 = \rho_{snr} \ v_{snr}^2 \tag{1}$$

where ρ_w (v_w), ρ_{snr} (v_{snr}) are the density (speed) of matter in the wind and in the SNR shell, respectively. We adopt an isothermal profile for the stellar wind, $\dot{M} = 4\pi R^2 \rho_w v_w$, after which by using the Equ. 1 we can find the value of stand off radius

$$R_{so} = \sqrt{\frac{\dot{M} \cdot v_w}{4\pi \rho_{snr} v_{snr}^2}} = 1.74 \cdot 10^{16} \sqrt{\frac{\dot{M}_{-8} \ v_{w10}}{\mu \ n_{snr} \ v_{snr}^2}} \quad (\mathrm{cm}) \tag{2}$$

where $\dot{M}_{-8}$ is the mass loss rate in 10^{-8} $M_\odot/\mathrm{yr}$, n_{snr} is the particle density in the SNR shell, v_{w10} is the wind velocity in 10 km/s, v_{snr} is the shell velocity in 100 km/s, μ is the mean molecular weight. As it was noted before, we expect very high energy density in the region of the bow shock. The mechanical energy flux to the stand off zone from the SNR is

$$\dot{E}_{snr} = \pi R_{so}^2 \cdot \rho_{snr} \frac{v_{snr}^3}{2} = \ \dot{M} \frac{v_w v_{snr}}{8} = 7.91 \cdot 10^{29} \ \dot{M}_{-8} \ \ v_{w10} \cdot \ v_{snr} \quad (\mathrm{erg/s})$$

from wind

$$\dot{E}_w = \pi R_{so}^2 \cdot \rho_w \frac{v_w^3}{2} = \ \dot{M} \frac{v_w^2}{8} = 7.91 \cdot 10^{28} \dot{M}_{-8} \ v_{w10}^2 \quad (\mathrm{erg/s})$$

Most of this mechanical energy is converted into thermal energy of the compressed between two shock fronts gas which become the sources of high-energy photons of X-Ray and gamma ranges as well as of synchrotron radio and X-ray emissions. It is well known that SNRs are one of the main accelerators of cosmic rays with energies up to at least $\sim 10^{15}$ eV. Although direct observations show only the presence of CR electrons in the shells of SNRs, one generally assumes that protons are present with at least comparable numbers and greater energy content. Thus, in the case of the interaction of SNRs with stars, in the region of the bow shock a strong increase in cosmic rays is expected both due to acceleration of new particles, as well as due to additional compression of existing in the flow CRs accelerated before at the shock front by the DSA mechanism. Depending on the energy of SNR and the type of interacting star the region of bow shock can be the sources of hard emissions – synchrotron radio, high energy thermal and non-thermal X-ray, proton-proton and inverse Compton gamma-ray.

This is the main difference between the bow-shock structures "ISM - star" and "SNR - star".

Let us consider the general energy content of the region of the bow shock for some extreme cases. For massive O/B type stars with $\dot{M} \sim 10^{-6}\ M_{\odot}/\mathrm{yr}$, $v_w \sim 100$ km/s interacting with the middle-aged SNR with $v_{snr} \sim 500$ km/s, $n_{snr} \sim 4\ \mathrm{cm}^{-3}$ we have estimations for $R_{so} = 5.50 \cdot 10^{16}$ (cm), $\dot{E}_{snr} = 3.96 \cdot 10^{33}$(erg/s) and $\dot{E}_w = 7.91 \cdot 10^{32}$(erg/s). With a resolution of 0.5 arcsec on-axis, the Chandra X-ray Observatory can resolve these cites out to a distance of 7.3 kpc. If we assume $\sim 10^{-4}$ of the incoming kinetic power goes to the radio emission then these cites can be detected with the radio telescope with sensitivity 1 mJy at 1 GHz wavebands out to distances 30 kpc.

For solar type stars ($\dot{M} \sim 10^{-14}\ M_{\odot}/\mathrm{yr}$, $v_w \sim 400$ km/s) we have for $R_{so} = 1.10 \cdot 10^{13}$ (cm) $\sim$ 1AU, $\dot{E}_{snr} = 1.58 \cdot 10^{26}$(erg/s), and $\dot{E}_w = 1.27 \cdot 10^{26}$(erg/s). In this case, although the energy content is not so large, the proximity of the bow shock wave to the star and the expected high concentration of cosmic ray component can become an obstacle to the origin of life and and the habitability of solar type systems.

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