PARTICLE ACCELERATION AND RADIO EMISSION OF THE SUPERNOVAE REMNANTS AT DIFFERENT STAGES OF THEIR EVOLUTION

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In this Paper, I consider physical processes, governing relativistic electrons in SNRs.

a) SNRs at the age $t > 10^2$ yr. I argue that the shock wave acceleration faces some difficulties. Then I show that the temporal evolution of the SNRs radio emission can be accounted for without involving the acceleration.

b) SNRs at the age $t < 10^2$ yr. I associate the lack of radio emission at this stage (Brown and Marscher, 1978) with the weakness of the magnetic field.

c) I infer that the most efficient particle acceleration and radio emission of the SNRs should occur at the stage $t \sim 10^2$ yr.

a) Relativistic electrons in the SNRs at the stage $t > 10^2$ yr.

These are just the SNRs we observe. The relative roles of adiabatic deceleration, acceleration and leakage of particles are still unclear. Shklovskii (1960) proposed a model, incorporating only adiabatic deceleration. The model qualitatively describes the secular evolution of SNR radio emission, but quantitatively disagrees with observations. This is why some models were suggested, incorporating particle acceleration either by the hydromagnetic turbulence (Chevalier et al., 1978), or by the shock front (Bell, 1978; Blandford and Ostriker, 1978). In this Section I would like to emphasize some difficulties, related to these mechanisms.

The shock acceleration mechanism requires efficient scattering of the particles on the small-scale hydromagnetic turbulence. A rough estimate of the characteristic acceleration time is (Toptygin, 1980): $\tau_a \sim D/U^2$, where D and U are the diffusion coefficient and shock velocity respectively. The problem is to determine the value of D in the SNRs. If the SNR shock wave propagates in an unperturbed ISM (see Fig. 1), it is necessary to amplify the level of the ISM turbulence in the upstream region, since otherwise $\tau_a \gg t$ (Toptygin, 1980).

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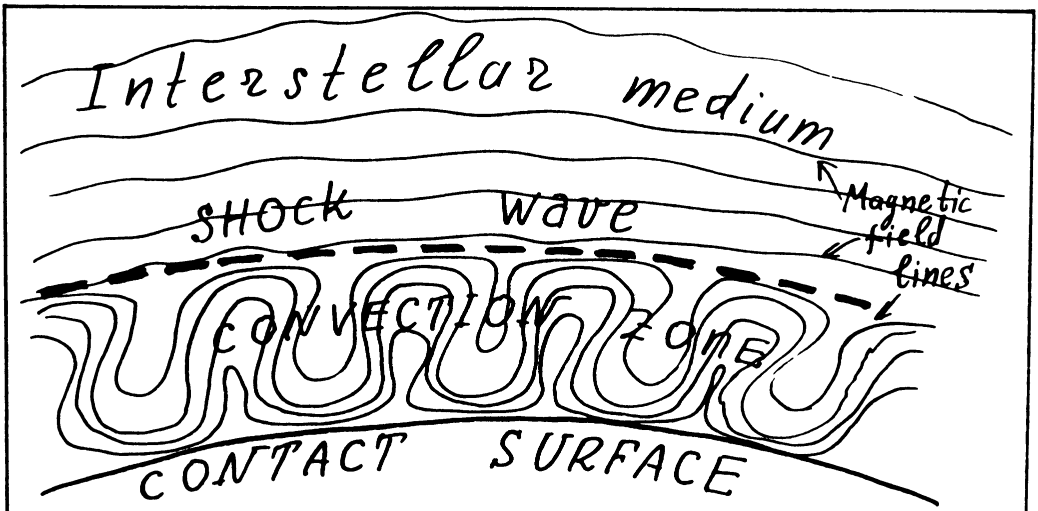

Fig.1. The interaction of the SNR with the ISM at the stage t $\gtrsim 10^2$ yr (after Gull,1973).

Figure 1. The interaction of the SNR with the ISM at the stage t > 10^2 yr. (after Gull, 1973).

For this purpose, Bell (1978) proposed the self-generated turbulence mechanism. However, as shown by Fedorenko (1981), to amplify the turbulence, a rather stringent condition must be satisfied: $\Gamma\, t_{pass} \gg 1$, Γ is the instability growth rate, and $Q_{pass} \sim D/U^2$ is the plasma element passage time in the upstream region. This results in very low values of the energy of the electrons, which experience the increased scattering: $E \ll 10^3 m_e c^2$. Thus, the radio-emitting electrons cannot be accelerated by this mechanism. The situation can be radically changed, if SN explodes into the region of the presupernova stellar wind (Chevalier, 1982). As in the solar wind, we might expect the continuous m.h.d. turbulence spectrum to be present with a typical scale length $L_0 \sim$ few pc. Then, estimations show (Fedorenko, 1982), that the acceleration condition $\tau_a \ll t$ is fulfilled. However, the existence of the pre-supernova stellar wind is still questionable, especially for the SN I (Chevalier, 1982).

According to Chevalier et al. (1978), the power spectrum of the relativistic electrons is produced by the joint action of the adiabatic deceleration and the Fermi acceleration processes. However, it was pointed out by Fedorenko (1981a), that in such a model the spectral index depends on many model parameters. It seems unlikely that they naturally combine to give $\gamma = 2.0 \div 2.6$.

These considerations induced me to investigate the possibility of a model without particle acceleration. This was done in Fedorenko (1981a). The main assumptions were: 1) spherical expansion with $R(t) \propto t^{\alpha}$, R is the SNR radius, and $2/5 < \alpha < 1$; 2) relativistic particles with initial power spectrum are decelerated due to expansion; acceleration and leakage were not considered; 3) magnetic field B evolving as $B \propto R^{-\beta}$; $3/2 < \beta < 2$, which assumes turbulent amplification - see Gull (1973), and Fig. 1. The particle distribution function is governed by a kinetic equation, in contrast to the model of Shklovskii (1960). Varying the parameters α and β enabled me to fit such a model to the observational data. As in the Shklovskii model, particle power spectrum is conserved during the SNR expansion, but additional consideration of the self-generated turbulence enabled me to explain the flattening of the Cas-A spectrum (see Fedorenko 1979, 1981). The same effect provided particle confinement in the SNRs.

Evidently, at the stage of $t > 10^2$ yr., particle acceleration is either absent, or weak compared to the adiabatic deceleration. Therefore, the acceleration of particles in SNRs should occur at the stage $t < 10^2$ yr.

b) <u>Relativistic electrons in the SNRs at the epoch with $t < 10^2$ yr.</u>

The radio observations of such objects in our Galaxy are absent. Brown and Marscher (1978) establish very low limits of the radio emission for nearly 50 SNRs with ages 1 yr < t < 30 yr in the external galaxies. According to Brown and Marscher, this result may be connected either with the lack of accelerated particles, or with the weakness of the magnetic field. Simple considerations of Fedorenko (1981a) seem to clear up the situation. According to Gull (1973), the turbulent amplification of the ISM magnetic field at the shock front (see Fig. 1), occurs at the stage $t < 10^2$ yr., due to convective motions. Maximum magnetic energy corresponds to the epoch with $t \sim 10^2$ yr (see Fig. 2).

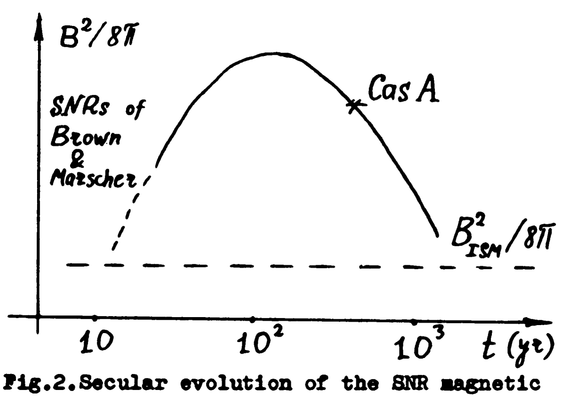

Fig.2. Secular evolution of the SNR magnetic energy density after Gull (1973).

Figure 2. Secular evolution of the SNR magnetic energy density after Gull (1973).

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Therefore, the SNRs of Brown and Marscher correspond to the epoch with rather weak magnetic field and have low radiation fluxes. It is also possible that these SN explode into a very dilute ISM, such as the "coronal" phase in our Galaxy (McCray and Snow, 1979). Thus, in this case, the SNR magnetic field and radio-emission will be very weak. Nevertheless, three "radio supernovae" with ages $t \sim 1$ yr. were detected in the external galaxies (Weiler et al., 1981). This phenomenon might be connected with the pulsar activity at this stage. Probably, "radio-supernovae" cease at the age of few years (Weiler et al., 1981).

c) Scenario of the SNR evolution

The considerations mentioned above, lead us to the following inference: the most efficient pumping of the SNRs with accelerated particles occurs at the stage $t \sim 10^2$ yr. Probably, acceleration takes place at the shock front, the scattering rate being increased compared to the stage $t > 10^2$ yr (see Sec. a). This is compatible with the model of Gull (1973). According to him, at the stage $t \sim 10^2$ yr the shock wave makes contact with the convection zone, so the latter may be efficiently filled with the accelerated particles (see Fig. 1). At $t > 10^2$ yr the convection zone is removed from the shock region causing the injection rate of particles to be decreased. At this stage, adiabatic deceleration of the captured particles is dominant. Therefore, the maximum of the radio emission of the SNRs should occur at $t \sim 10^2$ yr. Remember that all of this refers to the SNRs without pulsars.

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