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REVIEW

On the supernova remnants with flat radio spectra

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Abstract A considerable fraction of Galactic supernova remnants (SNRs) characterize flat spectral indices ($\alpha < 0.5$). There are several explanations of the flat radio spectra of SNRs in the present literature. The most of models involve a significant contribution of the second-order Fermi mechanism but some of them also discuss high compressions (>4), contribution of secondary electrons left over from the decay of charged pions, as well as the possibility of thermal contamination. In the case of expansion in high density environment, intrinsic thermal bremsstrahlung could theoretically shape the radio spectrum of an SNR and also account for observable curved—"concave up" radio spectra of some Galactic SNRs. This model could also shed a light on the question of flat spectral indices determined in some Galactic SNRs. On the other hand, present knowledge of the radio continuum spectra (integrated flux densities at different frequencies) of SNRs prevent definite conclusions about the significance of proposed models so the question on flat spectral indices still remains open. New observations, especially at high radio continuum frequencies, are expected to solve these questions in the near future. Finally, as there is a significant connection between the majority of Galactic SNRs with flat integrated radio spectrum and their detection in γ-rays as well as detection of radiative recombination continua in their X-ray spectra, the analysis of high energy properties of these SNRs is very important.

Keywords ISM: supernova remnants · Radio continuum: general · Radio continuum: ISM

1 Introduction

The spectra of SNRs in radio continuum are usually represented by a power-law, reflecting the pure synchrotron radiation from the SNR shell:

$$S_\nu \propto \nu^{-\alpha}, \tag{1}$$

where S_ν is the spatially-integrated flux density and α is the radio spectral index.

Test-particle diffusive shock acceleration (DSA) theory predicts that for strong shocks, radio spectral index α is approximately 0.5 (Bell 1978a, 1978b). Indeed, mean value of the observed radio spectral indices, for Galactic SNRs, is around 0.5 and correspondent distribution is roughly Gaussian (Green 2009). On the other hand, the dispersion in that distribution is non-negligible (see Fig. 1 in Reynolds et al. 2012).

In the case of shocks with sufficiently low Mach number (less than around ten), steeper spectra ($\alpha > 0.5$) are generally expected. In test-particle DSA, for the synchrotron spectral index α, the following relations hold:

$$\alpha = \frac{s-1}{2}, \quad s = \frac{\chi+2}{\chi-1}, \; \chi = \frac{\gamma+1}{\gamma-1+\frac{2}{M^2}} \approx \frac{\gamma+1}{\gamma-1}, \tag{2}$$

where γ is the post-shock thermal gas adiabatic index, χ is the compression ratio for parallel shock, M is the (upstream adiabatic) Mach number that represents the ratio of shock velocity to the local sound speed and s is the energy spectral index. On the other hand, only few old SNRs would be expected to have such weak shocks (Reynolds 2011). In fact, SNRs with steep spectrum ($\alpha > 0.5$) are usually young objects (Green 2009; Gao et al. 2011; Sun et al. 2011). Steeper radio spectra may be explained by a cumulative effect of non-linear and oblique-shock steepening in the case

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