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THE ANALYSIS OF THE POSSIBLE THERMAL EMISSION AT RADIO FREQUENCIES FROM SUPERNOVA REMNANTS G39.2-0.3 (3C396) AND G156.2+5.7

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Abstract. The presence of thermal emission at radio frequencies (10 MHz-100 GHz) may be a useful tool for identifying interactions between supernova remnants (SNRs) and molecular clouds, and also for estimating the ambient density near SNRs by using only radio continuum data. In this paper possible thermal emission at radio frequencies from Galactic SNRs G39.2-0.3 (3C396) and G156.2+5.7 is analyzed. A model including the sum of non-thermal (purely synchrotron) and thermal (bremsstrahlung) component is applied to fit the integrated radio spectrum of the SNR. For SNR 3C396 the contribution of thermal component to the total volume emissivity at 1 GHz is estimated to be 47.6 %. Our ambient density estimates can support the hypothesis that the SNR is embedded in the dense molecular cloud material. In the case of the SNR G156.2+5.7, the available flux density values at only four different radio frequencies are insufficient for a detailed statistical analysis. Despite the inability to get firmer conclusions about contribution of thermal component to the total volume emissivity we calculated its value to be 31.5 % and estimated the average ambient density.

1. INTRODUCTION

The radio emission from supernova remnants is believed to be mainly due to non-thermal synchrotron radiation. The radio spectrum is well fitted by the simple power low. On the other hand, the X-ray radiation from SNRs is produced by the thermal bremsstrahlung radiation as well as, for several young SNRs, by the non-thermal synchrotron radiation. In this paper we investigate the possibility of the significant production of thermal bremsstrahlung radiation at radio frequencies from two Galactic SNRs.

In the case of some SNRs, the observations over a very broad range of radio frequencies reveal a curvature in the spectra of these sources. It is possible that SNRs can be sources with the significant amount of thermal radiation and as Urošević and Pannuti (2005) stated, there are two basic criteria for the production of a significant amount of radio emission through the thermal bremsstrahlung process from an SNR: the SNR must evolve in an environment denser than the average and its temperature should be lower than the average (but always greater then the recombination temperature).

Two cases have been considered: thermal emission at radio frequencies from a relatively young SNR evolving in a dense molecular cloud interclump environment ($\approx 100 - 1000$ cm^{-3}), and an extremely evolved SNR (approximately $10^5 - 10^6$ years old) expanding in a dense warm medium ($\approx 1 - 10$ cm^{-3}). It is clear that in the both cases SNRs have to expand in the high density environment such as in the case of molecular clouds. As an SNR expends into molecular cloud environment, the increasing in density will cause the increasing in thermal radiation, so that the significant presence of the thermal emission at the radio frequencies may be a useful tool for identifying interactions between supernova remnants and molecular clouds.

2. ANALYSIS AND RESULTS

In order to distinguish the contribution of thermal and non-thermal component to the total radiation, the SNR radio integrated spectrum was fitted by a simple sum of these two components. If the frequencies are given in GHz, the relation for the flux density can be written as follows:

$$S_\nu = S^{\rm NT}_{\rm 1\,GHz}\ (\nu^{-\alpha} + \frac{S^{\rm T}_{\rm 1\,GHz}}{S^{\rm NT}_{\rm 1\,GHz}}\ \nu^{-0.1}), \tag{1}$$

where: $S^{\rm T}_{\rm 1\,GHz}$ and $S^{\rm NT}_{\rm 1\,GHz}$ are the flux densities corresponding to the thermal and non-thermal component, respectively. The radio spectral index α is considered to be constant in the SNR shell. It is also taken that the thermal radiation is optically thin and has the spectral index equal to 0.1 at any point. As the radio frequency increases, the amount of synchrotron radiation from an SNR decreases and the contribution of thermal bremsstrahlung emission becomes more significant. If the observable thermal radio spectrum differs from theoretical, e.g. thermal spectral index is less than 0.1, the effect will be more prominent. In our model it is also considered that the synchrotron radiation, optically thin at any point, is not absorbed or scattered by thermal gas.

The most important repercussion of our analysis is the possibility of density calculation from the radio observations. If we can isolate thermal component and find its contribution to the total volume emissivity we can easily estimate ambient density. The volume emissivity of the thermal bremsstrahlung radiation for an ionized gas cloud is proportional to the square of the electron (or ion) volume density n:

$$\varepsilon_\nu = 7 \times 10^{-38} n^2 T^{-\frac{1}{2}}, \tag{2}$$

where n is in cm^{-3} and the thermodynamical temperature T in K. By determining the total ε_ν and the thermal component contribution to the total volume emissivity, at 1 GHz, the density of the interstellar medium (ISM) can be estimated using Eq. (2). High ambient density imply the high electron (or ion) densities. For a detailed discussion about the model see Onić and Urošević (2008).

2. 1. SNR 3C396

In Green's (2006) catalogue SNR 3C396 is marked as C (composite) type. Data points for the integrated radio flux density are from Patnaik et al. (1990) and Scaife et al. (2007) for a used range of 0.327-33 GHz in our work. The 10.6 GHz point from Patnaik et al. (1990) was not considered due to a great associated error. The catalogued flux

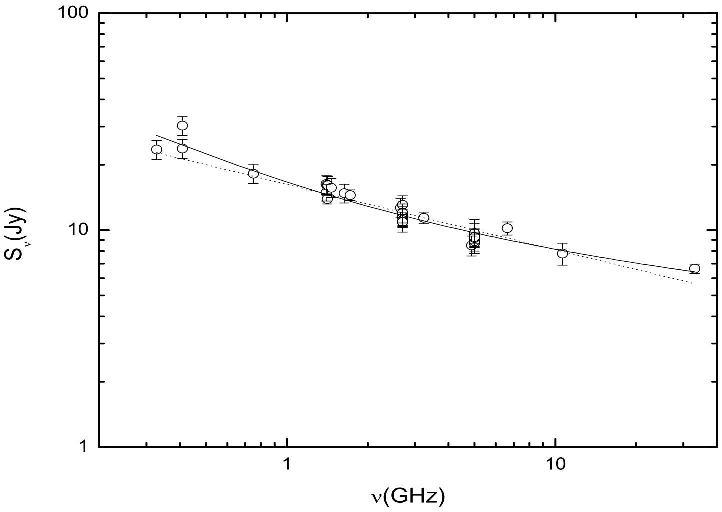

Figure 1: The integrated spectrum of SNR 3C396. The full line represents a fit by non-thermal plus thermal model, while the dotted line represents fit by a purely non-thermal model.

densities for SNR 3C396 are contaminated by the nearby steep-spectrum pulsar, PSR 1900+0.5, below 30 MHz (Scaife et al. 2007) or 100 MHz (Patnaik et al. 1990). Olbert et al. (2003) emphasized that the pulsar wind nebula, near the center of the SNR, has only a small contribution to the SNR radio central emission.

A lower limit of 7.7 kpc for the distance to 3C396 is available from H I absorption observation (Caswell et al. 1975). From the VLA observation, Patnaik et al. (1990) yield mean angular diameter for the SNR of 7.8 arcmin, which leads to a 17.47 pc for SNR diameter (for accepted lower distance value in this work).

The parameters of our model fit (Eq. (1)) in the case of SNR 3C396 are shown in Table 1. The parameters of purely non-thermal model fit can be seen in Table 2. Adj. R^2 represents the adjusted coefficient of determination. In Fig. 1 the full line represents a fit to SNR 3C396 data by non-thermal plus thermal model, while the dotted line represents fit by a purely non-thermal model. The thermal component contributes 47.6 % of the total volume emissivity at 1 GHz.

Table 1: The fit parameters for our model for SNR 3C396.

α	$S^{\mathrm{NT}}_{1\mathrm{GHz}}$ (Jy)	$S^{\mathrm{T}}_{1\mathrm{GHz}}/S^{\mathrm{NT}}_{1\mathrm{GHz}}$	Adj. R^2
0.67 ± 0.09	8.74 ± 0.97	0.91 ± 0.19	0.933

Table 2: The fit parameters for purely non-thermal model for SNR 3C396.

α	$S^{\mathrm{NT}}_{1\mathrm{GHz}}$ (Jy)	Adj. R^2
0.30 ± 0.02	16.25 ± 0.44	0.894

From Green (2006) the value of the radio spectral index is 0.6 and the flux density at 1 GHz is 18 Jy. Patnaik et al. (1990) found the radio spectral index value of 0.42 which is also preferred by Scaife et al. (2007).

Gosachinskii and Khersonskii (1987) analyzed the distribution of neutral hydrogen in the vicinity of the SNR 3C396 with RATAN-600 and concluded that it is a relatively young SNR inside the old extended H I shell. On the other hand Harrus and Slane (1999) concluded from the *ASCA* study of the SNR that it is a middle-aged remnant, about 7000 year old, in the adiabatic phase of evolution. The previous estimation of the SNR age, done by Clark and Caswell (1976), gave about 2500 years.

Using Eq. (2) we estimated ambient density (≈ 600 cm^{-3} for the assumed post-shock temperature value of 10^6 K) which can support the hypothesis that the SNR is indeed expanding in a dense ISM such as in the case of interaction with the molecular cloud material.

It should be emphasized that the further measurements at the radio frequencies higher than 10 GHz are required for a firmer conclusion.

2. 2. SNR G156.2+5.7

G157.2+5.7 represents the first discovered Galactic SNR through its X-ray emission due to its high X-ray brightness and large diameter of 108 arcmin. It is discovered in the X-rays by the *ROSAT* all-sky survey and named RX 04591+5147. It is very important to point out that the radio observations are rare due to SNR's low radio surface brightness (5.8×10^{-23} W m^{-2} Hz^{-1} sr^{-1} at 1 GHz) and large size (Reich, Fürst and Arnal 1992). From Green (2006) the value of the radio spectral index is 0.5, $S_{1\,\mathrm{GHz}} = 5$ Jy, size is 110 arcmin and the SNR is marked as S (shell) type.

Reich et al. (1992) indicated that the large amount of local H I gas along the line of sight suggests that distance of 3 kpc is the upper limit, pointing that the most likely distance to the SNR is between 1 and 3 kpc. There is no indication for a central component inside the SNR.

The data points for the integrated radio flux density are taken from Xu et al. (2007), Kothes et al. (2006) and Reich et al. (1992).

In the case of the SNR G156.2+5.7, only four available data points and their associated uncertainties prevent us from getting a firmer conclusions about contribution of the thermal component in the total volume emissivity. Despite that fact, we calculated its contribution to 31.5 % at 1 GHz.

The parameters of our model fit (Eq. (1)) in the case of SNR G156.2+5.7 are shown in Table 3. The parameters of purely non-thermal model fit can be seen in Table 4. In Fig. 2 the full line represents a fit to SNR G156.2+5.7 data by non-thermal plus thermal model, while the dotted line represents fit by a purely non-thermal model.

Table 3: The fit parameters for our model for SNR G156.2+5.7.

α	$S^{\mathrm{NT}}_{1\mathrm{GHz}}$ (Jy)	$S^{\mathrm{T}}_{1\mathrm{GHz}}/S^{\mathrm{NT}}_{1\mathrm{GHz}}$	Adj. R^2
0.69 ± 0.17	3.43 ± 0.95	0.46 ± 0.36	0.994

Table 4: The fit parameters for purely non-thermal model for SNR G156.2+5.7.

α	$S^{\mathrm{NT}}_{1\mathrm{GHz}}$ (Jy)	Adj. R^2
0.48 ± 0.02	5.22 ± 0.13	0.991

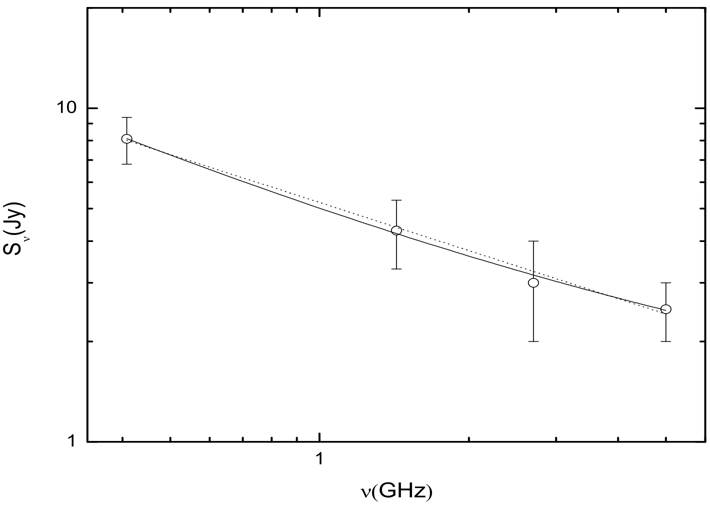

Figure 2: The integrated spectrum of SNR G156.2+5.7. The full line represents a fit by non-thermal plus thermal model, while the dotted line represents fit by a purely non-thermal model.

Again, using Eq. (2) we estimated the average ambient density ($\approx 0.64-2.03$ cm^{-3} for the assumed post-shock temperature values of $10^4 - 10^6$ K and 3 kpc distance).

More data, especially at the at the radio frequencies higher than 10 GHz, will alow us to make firmer conclusions about thermal contribution and estimated densities. On the other hand, a detailed multifrequency analysis of this SNR is needed.

3. CONCLUSIONS

The main conclusions of this work are:

1. In the case of SNR 3C396 we isolated thermal component and estimated its contribution to the total volume emissivity at 1 GHz to be 47.6 %. Our ambient density estimates can support the hypothesis that the SNR evolves in a dense ISM so our results can support a possible SNR interaction with the molecular cloud material.

2. In the case of the SNR G156.2+5.7, the available flux density values at only four different radio frequencies, are insufficient for a detailed statistical analysis. Despite the inability to get firmer conclusions about contribution of thermal component to the total volume emissivity at 1 GHz we calculated its value to be 31.5 % and estimated the average ambient density.

3. The lack of data at at the radio frequencies higher than 10 GHz hinders us from giving a definite conclusion about the issue.

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