Radio and X-ray Study of SNRs in the Magellanic Clouds

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Abstract. We present our high-resolution radio-continuum and X-ray study of supernova remnants (SNRs) in the Magellanic Clouds (MCs). These investigations are based on Australia Telescope Compact Array (ATCA) radio-continuum and ROSAT X-ray observations. Our main aim is to study a complete sample of the MC SNRs and H II regions.

1. Introduction

Statistical studies of objects such as SNRs in our Galaxy, despite their large number ($\sim$220), have problems due to incompleteness and uncertain distances. Objects in the MCs have approximately the same distance and foreground absorption. However, they are still close enough to allow detailed spatially resolved investigations. The MCs contain all types of SNRs and H II regions in various stages of evolution. Also, the MCs fortunately lie in a direction well out of the Galactic plane and the foreground densities of dust, gas and stars are small. SNRs in other galaxies such as M31 or M33 appear about ten times smaller and one hundred times fainter than SNRs in the MCs.

From our low-resolution comparison between the Parkes radio and ROSAT All-Sky survey (RASS), we found that the majority of sources in common are SNRs (60 per cent) and background objects (30 per cent). A source-intensity comparison of radio and X-ray source flux densities shows very little correlation, but we note that the strongest SNRs at both frequencies are young SNRs from Population I (Filipović et al. 1998a).

About 80 SNRs and SNR candidates in the MCs have been identified in our recent studies (Filipović et al. 1998b). Of these, there are 23 SNR candidates in the LMC and 6 in the SMC which need to be confirmed as SNRs.

2. The ATCA Observations of SNRs in the MCs

The ATCA mosaic observations of the SMC were taken in October 1992. The baseline of 375 m was used at frequencies of 1.42 and 2.37 GHz with angular resolution of $\sim 90''$ and $45''$, respectively. The total of 320 pointings covered an area of $\sim$20 square degrees (Staveley-Smith et al. 1997). More details about the LMC mosaic observations can be found in Kim et al. (1998). The SMC mosaic
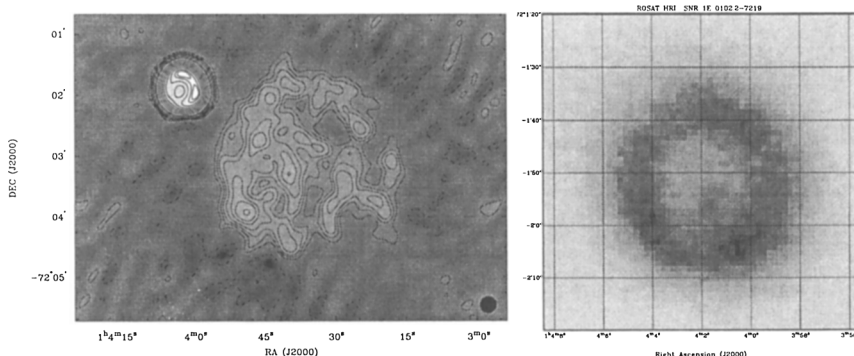
Figure 1. The snapshot image of the SMC region N 76 (Fig. 1a - left) at 8.64 GHz. The r.m.s. noise (1σ) of the image is 0.15 mJy and the observed beam size is $15''$ (lower right corner). The resolved source in the north-east is SNR 1E 0102.2–7219 and a more detailed radio-continuum study can be found in Amy & Ball (1993). The extended superbubble in the center of Fig. 1a is H II region N 76A. Contours are: -3σ, 3σ, 5σ, 7σ, 10σ, 15σ, 20σ, 30σ, 50σ, 70σ and 95σ. Fig. 1b (right) shows a high-resolution ROSAT HRI image of the SNR 1E 0102.2–7219 which contains two merged observations with a total exposure time of 36 ks.

images at both frequencies are "corrected" for missing short spacings by adding Parkes survey data. Over seven hundred sources were found in these surveys (Filipović et al. in prep.).

As a continuation of the Parkes radio-continuum investigations of sources intrinsic to the MCs and as an addition to the mosaic surveys, we used the ATCA in snapshot mode at ν=4.79/8.64 GHz with the 375 m configuration. These observations, together with the ATCA mosaic surveys at 1.42/2.37 GHz and the MOST survey at 843 MHz, will give us wide frequency coverage with sufficient resolution for detailed studies.

3. The ROSAT X-ray Observations of the MCs

The ROSAT archive contains over 240 PSPC and over 650 HRI pointing observations in the direction of the MCs. These observations were carried out with the ROSAT detectors (energy range 0.1–2.4 keV) from October 1991 until June 1998. A catalogue of more than 500 RASS X-ray sources towards the LMC is given in Pietsch et al. (in prep.). Kahabka et al. (1998) used part of the ROSAT PSPC observations towards the SMC and detected 248 objects which were included in the first version of the SMC catalogue of point and moderately extended soft X-ray sources. Two new updated X-ray catalogues (based on PSPC observations) of sources in the LMC (Haberl et al. in prep.) and the SMC (Filipović et al. in prep) revealed over 750 and 520 X-ray sources in the fields of the LMC and the SMC, respectively.
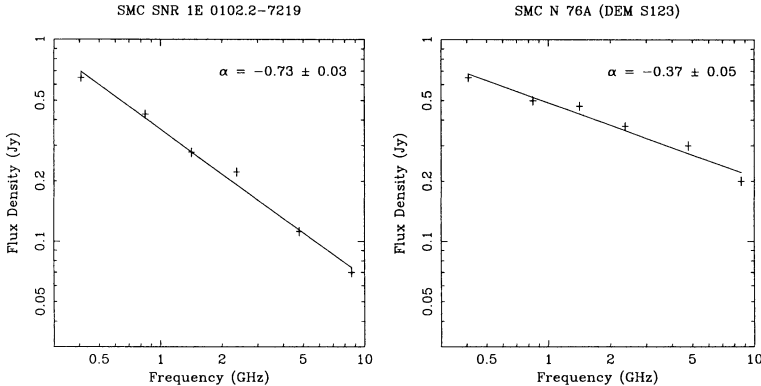
SMC SNR 1E 0102.2−7219   SMC N 76A (DEM S123)

Figure 2.   The radio-continuum spectrum of SNR 1E 0102.2–7219 (Fig. 2a – left) and H II region N 76A (Fig. 2b – right) in the SMC. The spectral index α is defined by the relation $S_\nu \sim \nu^\alpha$, where S_ν is the integrated flux density and ν is frequency. The integrated flux densities were estimated from our mosaic surveys (1.42 and 2.37 GHz), snapshot surveys (4.79 and 8.64 GHz) and from the MOST survey at 408/843 MHz (Amy & Ball 1993).

4.   Results

In Figs. 1a and 1b we present images from our study of the N 76 region in the SMC. The image in Fig. 1a is taken with the ATCA in snapshot mode at ν=8.64 GHz (beam size=15″). N 76 (DEM S123; SMC B0102–7218) is located in the northern part of the SMC and consists of a large H II superbubble (south-west) and SNR 1E 0102.2–7219 (north-east) (Amy & Ball 1993). In Fig. 1b we show the ROSAT HRI image of the SNR 1E 0102.2–7219. Here, we can clearly see a ring-like structure typical for the oxygen-rich class of SNRs. With a radio spectral index of α=−0.73±0.03 (Fig. 2a) we confirm this source as a SNR. Also, we note an "anti-correlation" between radio-continuum and X-ray emission from this SNR. This may be a typical characteristic for this class of SNRs. Some ∼3′ south-west from the SNR is the source N 76A which has been previously classified as an H II region. No X-ray emission can be detected from this superbubble and we estimate the radio spectral index to be α=−0.37±0.05 (Fig. 2b) which is rather steep for H II regions.

A similar object to the SMC H II region N 76A can be found in the LMC as the superbubble 30 Doradus C (also known as SNR 0536–69.2). Both objects are similar in size and spectra (30 Dor C – α=−0.42±0.07). However, the SNR/superbubble 30 Dor C has extended X-ray emission (Fig. 3b) which is not the case in SMC N 76A. Also, we note that there is a brightness displacement between radio and X-ray emission which is not due to the positional uncertainties of either X-ray or radio observations. This displacement was initially discovered in *Einstein* surveys (Mathewson et al. 1985) and we believe that it represents different physical mechanisms being triggered inside this SNR/superbubble.
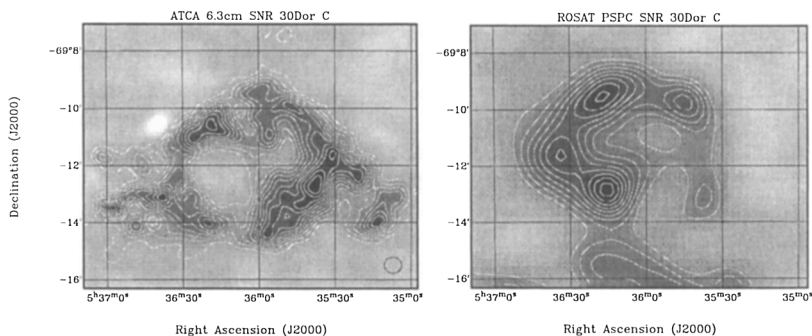
Figure 3. The radio-continuum (4.79 GHz) and ROSAT PSPC X-ray images of the superbubble 30 Dor C. The r.m.s. noise (1σ) of the radio-continuum image (left) is 0.5 mJy and the observed beam size is $30''$ (lower right corner). The noise on the X-ray image (right) is 0.7 cts. The positional displacement and anti-correlation between radio and X-ray emission is due to a different production mechanisms triggered in this SNR/superbubble.

5. Future Work

Individual SNRs will be studied in more detail. Some of their characteristics may be related to peculiar properties of the interstellar medium around the explosion site and/or different precursor stars. Theoretical models indicate that changes in most properties of the surrounding medium can have a significant effect upon the evolution of an SNR and its emission. However, the collective properties of the SNRs in the MCs studied to date are surprisingly consistent and quite similar to the population of Galactic SNRs (Dickel & Milne 1994), despite major differences between these galaxies.

The luminosity-diameter distribution will be used to study the evolution of SNRs in a statistical sense. Also a comparison with the optical and IR surveys such as Hα, [S II], [O III], IRAS and DENIS are planned as well.

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