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MULTIFREQUENCY OBSERVATIONS OF ONE OF THE LARGEST SUPERNOVA REMNANTS IN THE LOCAL GROUP OF GALAXIES, LMC – SNR J0450–709

K. O. Čajko[1], **E. J. Crawford** [2], **M. D. Filipović**[2]

[1]*Faculty of Sciences, University of Novi Sad*
Trg Dositeja Obradovića 4, 21000 Novi Sad, Serbia
E–mail: *tinacaj@gmail.com*

[2]*School of Computing and Mathematics, University of Western Sydney*
Locked Bag 1797, Penrith South DC, NSW 1797, Australia
E–mail: *e.crawford@uws.edu.au, m.filipovic@uws.edu.au*

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SUMMARY: We present the results of new Australia Telescope Compact Array (ATCA) observations of one of the largest supernova remnants, SNR J0450–709, in the Local Group of galaxies. We found that this Large Magellanic Cloud (LMC) object exhibits a typical morphology of an old supernova remnant (SNR) with diameter D=102×75±1 pc and radio spectral index α=− 0.43±0.06. Regions of high polarisation were detected with peak value of ∼40 %.

Key words. ISM: supernova remnants – Magellanic Clouds – Radio Continuum: ISM – Polarisation – ISM: individual objects : SNR J0450–709

1. INTRODUCTION

The Magellanic Clouds (MCs) are one of the most favorable places for investigations of objects such as supernova remnants (SNRs). Beside their position, close to the South Pole, they are found in one of the coldest parts of the radio sky allowing us to investigate and detect radio emission without interruptions from Galactic foreground radiation (Haynes et al. 1991). The MCs are located out of the Galactic plane and thus the influence of dust, gas and stars is small, making detailed investigations of SNRs possible. The Large Magellanic Cloud (LMC) at a distance of 50 kpc (Hilditch et al. 2005), allows for analysis of the energetics of each remnant.

SNRs are usually characterised by their strong and predominately non-thermal emission that they emit at radio wavelengths. They have typical spectral index of $\alpha \sim -0.5$ defined by $S \propto \nu^{\alpha}$. SNRs have very important influence on the interstellar material (ISM). Appearances of shell-like filaments are very often perturbed by interaction with and non-homogeneous structure of the ISM. SNRs dictate behavior, structure, morphology and evolution of the ISM. But on the other hand, the evolution of SNRs is dependent on the environment which surrounds them.

Here we report on new moderate-resolution radio-continuum observations of SNR J0450–709, one of the largest SNRs in the Local Group of Galaxies. It was initially classified as SNR by Mathewson et al. (1985), based on optical observations (Hα) and, later, on radio-continuum survey with MOlonglo Synthesis Telescope – MOST. McGee et al. (1972) named this source MC 11 in their 4800 MHz MCs catalogue, but didn't attempt to classify it. Clarke et al. (1976) also included SNR J0450–709 in their 408 MHz MC4 catalogue. Wright et al. (1994) catalogued SNR J0450–709 as PMN J0450–7050 based on their observations within Parkes-MIT-NRAO (PMN) surveys at 4850 MHz. Filipović et al. (1995, 1996) added further confirmation with a set of radio-continuum observations (with Parkes telescope) over a wide frequency range. Filipović et al. (1998a), using *ROSAT* All Sky Survey (RASS) observations, did not detect X-ray emission from SNR J0450–709. Neither the *ROSAT* PSPC nor HRI observations covered the area of SNR J0450–709. Blair et al. (2006) reported detection at far ultraviolet wavelengths based on FUSE (Far Ultraviolet Spectroscopic Explorer) satellite, and labelled SNR as D90401. As very faint object SNR J0450–709 is detected at [CIII] and [OVI] wavelengths.

The [SII]/Hα ratio is 0.7, which according to Mathewson et al. (1985) satisfies one of the selection criteria for the large diameter class of SNRs. Hα emission from SNR J0450–709 shows typical well evolved shell-like appearance. Filipović et al. (1998b) presented Parkes low resolution multi-frequency analysis and estimated spectral index as $\alpha = -0.39 \pm 0.08$. Williams et al. (2004) added high resolution XMM-Newton X-ray results. Most recently, Payne et al. (2008) presented optical spectroscopy of a wide range of LMC SNRs including SNR J0450–709. They found an enhanced [SII]/H_α ratio of 0.5 typical for SNRs.

2. OBSERVATIONAL DATA

We observed SNR J0450–709 with the Australia Telescope Compact Array (ATCA) on 6th April 1997, with an array configuration EW375, at wavelengths of 8640 and 4800 MHz (λ=3 and 6 cm). Baselines formed with the 6th ATCA antenna were excluded, as the other five antennas were arranged in a compact configuration. The observations were carried out in the so called "snap-shot" mode, totaling ~1 hour of integration over a 12 hour period. Source PKS B1934-638 was used for primary calibration and source PKS B0530-727 for secondary calibration. The MIRIAD (Sault and Killeen 2006) and KARMA (Gooch 2006) software packages were used for reduction and analysis. More information on the observing procedure and other sources observed in this session can be found in Bojičić et al. (2007) and Crawford et al. (2008a,b).

Images were prepared, cleaned and deconvolved by means of the MIRIAD tasks, using multi-frequency synthesis (Sault and Wieringa 1994). The 4800 MHz image (Fig. 1) has a resolution of $21'' \times 19''$ and an estimated r.m.s. noise of 0.5 mJy/beam. As the remnant is larger than the primary beam response ($5'$) at 8640 MHz no reliable image could be prepared.

3. RESULTS AND DISCUSSION

The remnant has a shell like morphology centered at RA(J2000)=$4^h 50^m 33\overset{s}{.}4$, DEC(J2000)=$-70°50'43\overset{''}{.}5$ with a diameter of $420'' \times 310'' \pm 5''$ ($7' \times 5\overset{'}{.}16$ or $101.8 \times 75.2 \pm 1$ pc), which is in agreement with optical diameter of $6.5' \times 4\overset{'}{.}7$ reported by Williams et al. (2004). We note that it is elongated in north-south direction and "clump" along its western side (see Fig. 1 and Fig. 2).

Flux density measurements were made at 4800 MHz resulting in a value of 0.448 Jy. New measurements were also made at 843 MHz (from the LMC MOST image), 1400 MHz and 8640 MHz (both from the mosaics presented by Filipović et al. 2009 and Hughes et al. 2007). Using values of flux densities obtained from the observed frequencies in Table 1, a spectral index was plotted (Fig. 4) and estimated to be $\alpha = -0.43 \pm 0.06$, confirming the non-thermal nature of this object as the still dominant emission mechanism. However, our value is slightly "flatter" in comparison with typical and estimated value of -0.5 for SNRs (Mathewson et al. 1985).

Urošević and Pannuti (2005) showed models for two cases when SNRs could produce significant amount of thermal emission. Further on, they discuss the contribution of that thermal emission to the radio-continuum spectral index make-up of SNR. Urošević and Pannuti (2005) derived flatter empirical $\Sigma - D$ relation which is in a good agreement with previous modified theoretical relations. Discrepancies between theoretically derived and empirically measured $\Sigma - D$ relations may be partially explained by taking into account thermal emission at radio frequencies from SNRs at particular evolutionary stages and located in particular environments. In the case of SNR J0450–709, this may indicate an older age for the remnant where contribution of thermal component could be significant, similar to the example given in Urošević et al. (2007) and elaborated on in Onić and Urošević (2008). Also, SNR J0450–709 is most likely expanding in a denser and warmer medium of n $\sim 1 - 10\,\mathrm{cm}^{-3}$.

We note that the point at 408 MHz (Table 1; Fig. 4) lies slightly off the line of best fit. This is most likely due to an older data (1970-ties) processing. Particularly in this case it may overestimate flux density due to a clean bias effect. We estimate that the combined flux density errors from all radio images used in this study, are less than 10% at each given frequency.

Linear polarisation image for SNR J0450–709 at 4800 MHz is shown on Fig. 3. Regions of fractional polarisation are quite strong. They are designated with polarisation vectors located at north-west side of the shell. Linear polarisation images for each frequency were created using Q and U parameters. While we do not have any measurements at 8640 MHz, the 4800 MHz image reveals some strong linear polarisation. Without reliable polarisation measurements at another wavelength, we could not determine the Faraday rotation. The mean fractional polarisation at 4800 MHz was calculated using flux density and polarisation:

$$P = \frac{\sqrt{S_Q^2 + S_U^2}}{S_I} \cdot 100\% \quad (1)$$

where S_Q, S_U and S_I are integrated intensities for Q, U and I Stokes parameters. Our estimated peak value is $P \cong 40\%$. Along the shell there is a pocket of uniform polarisation possibly indicating varied dynamics along the shell. This unordered polarisation is consistent with the appearance of an older SNR.

Table 1. Integrated Flux Density of SNR J0450–709.

	S_I (0.408 GHz)	S_I (0.843 GHz)	S_I (1.4 GHz)	S_I (4.8 GHz)	S_I (8.64 GHz)
SNR J0450–709	1470 mJy	837.3 mJy	643.7 mJy	448 mJy	360 mJy
Reference	Clarke et al. 1976	Mills et al. 1984	This Work	This Work	This Work

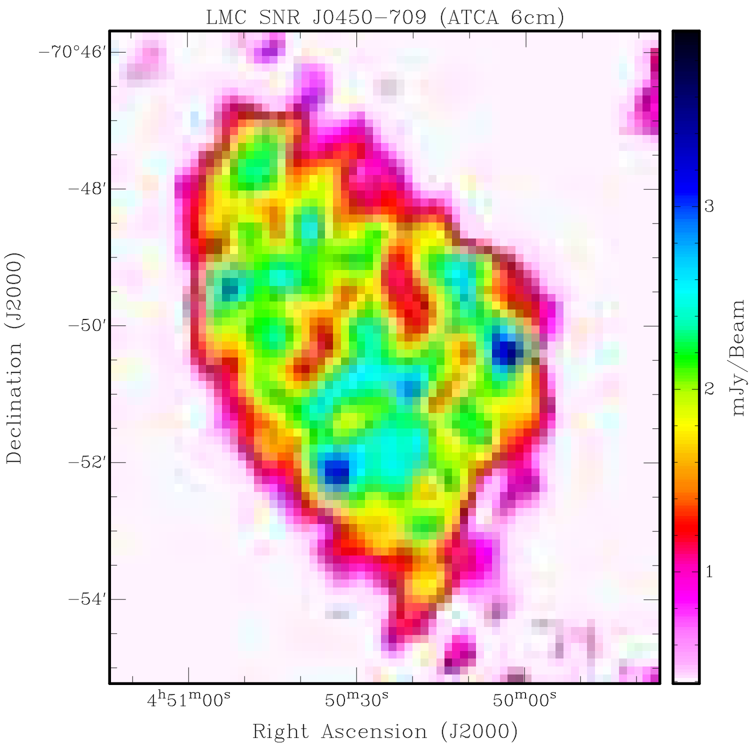

Fig. 1. *ATCA observations of SNR J0450–709 at 4800 MHz (6 cm). The side bar quantifies the pixel map and its units are mJy/beam.*

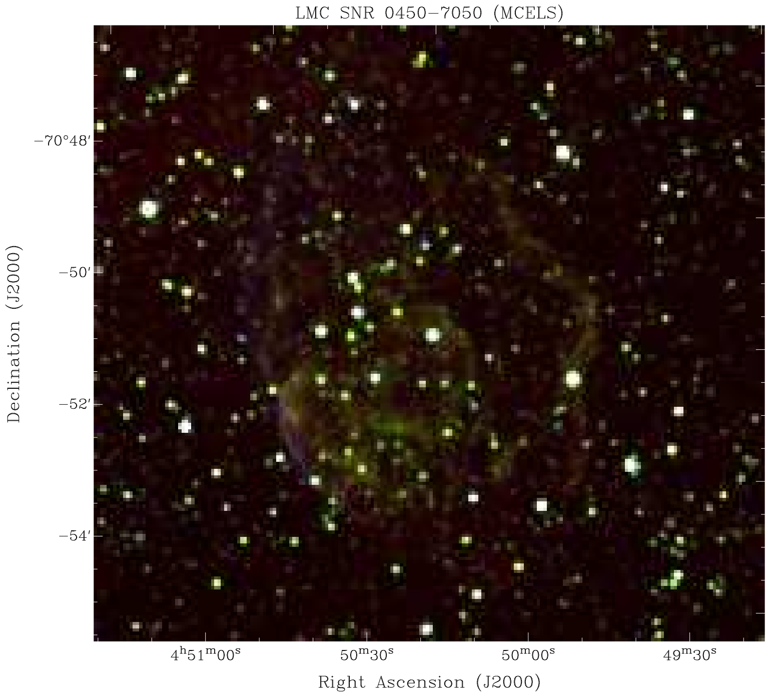

Fig. 2. *MCELS composite optical image* (RGB =H_α,[SII],[OIII]) *of SNR J0450–709.*

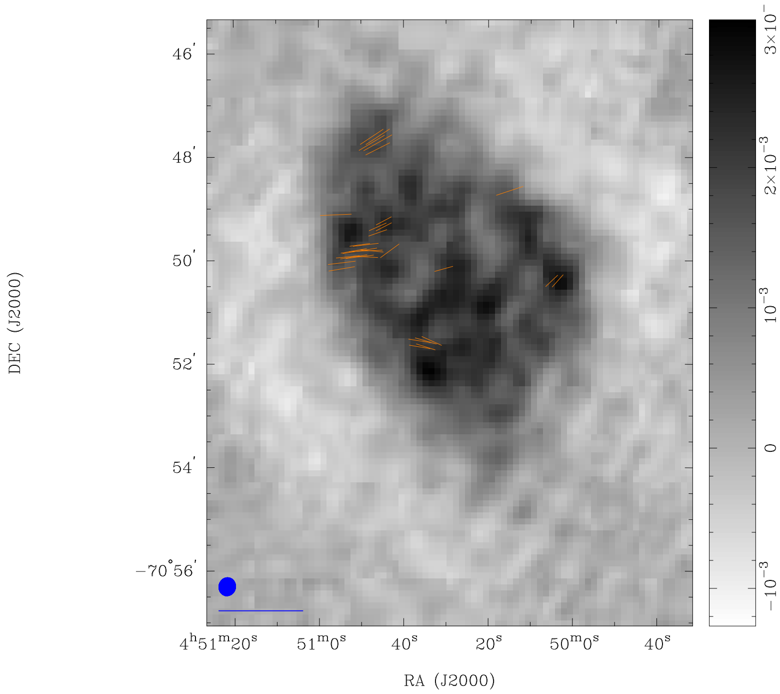

Fig. 3. *ATCA observations of SNR J0450–709 at 4800 MHz (6 cm). The blue circle in the lower left corner represents the synthesised beam-width of 21″×19″, and the blue line below the circle is a polarisation vector of 100%. The sidebar quantifies the pixel map and its units are Jy/beam.*

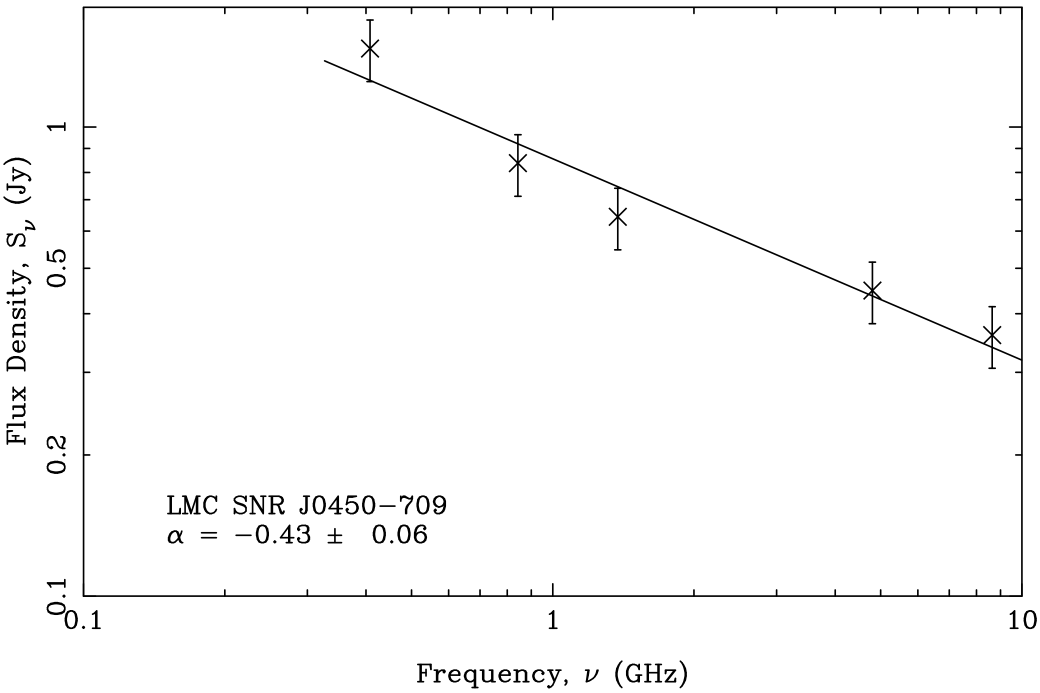

Fig. 4. *Radio-continuum spectrum of SNR J0450–709.*

4. CONCLUSION

We analysed one of the largest SNRs in the Local Group of Galaxies – SNR J0450–709. Here, the new radio-continuum observations of this SNR together with the multi-frequency analysis are presented. From these new observations, we found SNR diameter of 101.8×75.2±1 pc, spectral index of α=–0.43±0.06 and relatively strong level of linear polarisation with peak value of $\sim$ 40%. We concluded that these are all indicators of an older SNR.

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МУЛТИФРЕКВЕНЦИОНА ПОСМАТРАЊА ЈЕДНОГ ОД НАЈВЕЋИХ ОСТАТАКА СУПЕРНОВИХ У ЛОКАЛНОЈ ГРУПИ ГАЛАКСИЈА – LMC SNR J0450–709

K. O. Čajko[1], E. J. Crawford[2] M. D. Filipović[2]

[1]*Faculty of Sciences, University of Novi Sad*
Trg Dositeja Obradovia 4, 21000 Novi Sad, Serbia
E–mail: *tinacaj@gmail.com*

[2]*School of Computing and Mathematics, University of Western Sydney*
Locked Bag 1797, Penrith South DC, NSW 1797, Australia
E–mail: *e.crawford@uws.edu.au, m.filipovic@uws.edu.au*

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Оригинални научни рад

У овој студији представљамо нове ATCA резултате радио-посматрања у континууму остатка супернове у Великом Магелановом Облаку – SNR J0450–709. Нашли смо да овај остатак супернове има љускасту морфологију која је типична за старије остатке супернових. Измерена вредност радио спектралног индекса износи $\alpha = -0.43 \pm 0.06$, а дијаметра D= $101.8 \times 75.2 \pm 1$ парсека. Детектовали смо релативно висок степен поларизације где максимална вредност износи око 40%.