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RADIO CONTINUUM OBSERVATIONS OF LMC SNR J0550-6823

L. M. Bozzetto,[1] M. D. Filipović,[1] E. J. Crawford,[1] J. L. Payne,[1] A. Y. De Horta,[1] and M. Stupar[2,3]

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RESUMEN

Reportamos nuevas observaciones del remanente de supernova J0550-6823 (DEM L328) en la Nube Mayor de Magallanes, realizadas con el Arreglo Compacto de Telescopios de Australia (ATCA). El objeto es un remanente de supernova típico, en forma de herradura, con un diámetro de $373'' \times 282'' \pm 4''$ ($90 \times 68 \pm 1$ pc), el cual lo distingue como uno de los más grandes remanentes de supernova en el Grupo Local. Estimamos un índice espectral en radio relativamente alto, $\alpha = -0.79 \pm 0.27$. Sin embargo, la polarización observada (50% $\pm$ 10%) es mayor a la esperada y es atípica para remanentes de supernova viejos y evolucionados. Notamos también una fuerte correlación entre [O III] y las imágenes de radio, lo cual permite clasificar a este remanente como dominado por el oxígeno.

ABSTRACT

We report on new Australia Telescope Compact Array (ATCA) observations of the Large Magellanic Cloud (LMC) supernova remnant (SNR) J0550-6823 (DEM L328). This object is a typical horseshoe SNR with a diameter of $373'' \times 282'' \pm 4''$ ($90 \times 68 \pm 1$ pc), making it one of the largest known SNRs in the Local Group. We estimate a relatively steep radio spectral index of $\alpha = -0.79 \pm 0.27$. However, its stronger than expected polarisation of 50% $\pm$ 10% is atypical for older and more evolved SNRs. We also note a strong correlation between [O III] and radio images, classifying this SNR as oxygen dominant.

Key Words: ISM: individual objects (DEM L328, SNR J0550-6823) — ISM: supernova remnants — Magellanic Clouds

1. INTRODUCTION

Located at approximately 50 kpc (di Benedetto 2008), the Large Magellanic Cloud (LMC) is considered to be an ideal laboratory to study Supernova Remnants (SNRs). Furthermore, the LMC is located in the direction of the South Celestial Pole, one of the coldest areas of the radio sky, making it possible to observe radio emissions without interference from galactic foreground radiation. Today's modern instruments make it possible to achieve detailed observations of these objects.

There are over 50 well established SNRs in the LMC (Klimek et al. 2010) with an additional ∼20 SNR candidates (Bozzetto et al., in preparation). This comprises one of the most complete samples of SNRs in external galaxies. Therefore, it is of prime interest to study LMC SNRs and compare them with their cousins in other galaxies such as M 33 (Long et al. 2010), M 38 (Dopita et al. 2010), the SMC (Filipović et al. 2005; Payne et al. 2007; Filipović et al. 2008) and our Galaxy (Stupar, Parker, & Filipović 2008; Green 2009).

Davis, Elliott, & Meaburn (1976) observed an object in the LMC named DEM L328 at Hα wavelengths and reported a nebulosity with a diameter of $25' \times 8'$. Savage (1976) detected this source in the Parkes 2700 MHz survey and reported a radio diameter of $\sim 3'$. Filipović et al. (1998b), using *ROSAT* All Sky Survey (RASS) observations, detected X-ray emission from this source (LMC RASS 309) and then calculated a spectral index from their Parkes data (Filipović et al. 1998a) of $\alpha = -0.37 \pm 0.06$.

Here, we present new medium-resolution observations of LMC SNR 0550-6823. Observations, data reduction and imaging techniques are described in § 2. The astrophysical interpretation of newly obtained moderate-resolution total intensity and polarimetric image is discussed in § 3.

[1]University of Western Sydney, Australia.
[2]Department of Physics, Macquarie University, Sydney, Australia.
[3]Australian Astronomical Observatory, Australia.

TABLE 1

INTEGRATED FLUX DENSITY OF SNR 0550-6823 AND POINT SOURCE ATCA J0550-6820

ν (MHz)	λ (cm)	R.M.S (mJy)	Beam Size (arcsec)	S_{SNR} (mJy)	S_{PS} (mJy)	Reference
0408	73	–	156×156	980	—	Clarke et al. (1976)
0843	36	1.5	43.0×43.0	643	132	This Work
1377	20	1.5	45.0×45.0	593	86	This Work
4800	6	0.15	40.2×35.3	346	24	This Work
8640	3	0.17	40.2×35.3	83	7	This Work

2. OBSERVATIONS

We observed SNR J0550-6823 with the Australia Telescope Compact Array (ATCA) on the 2nd and 5th of October 1997 (project C634), using the array configuration EW375, at wavelengths of 3 and 6 cm (ν = 8640 and 4800 MHz). Baselines formed with the 6th ATCA antenna were removed from the imaging and the remaining five antennas were arranged in a compact configuration. Observations were taken in "snap-shot" mode, totalling ~1.5 hours of integration over a 12 hour period. Source PKS B1934-638 was used for primary calibration and source PKS B0530-727 provided secondary (phase) calibration. The MIRIAD (Sault & Killeen 2010) and KARMA (Gooch 2006) software packages were used for reduction and analysis. It is well established that interferometers such as the ATCA will suffer from missing flux due to the missing short spacings. To compensate for this short-coming, we combined our new ATCA observations with Parkes observations from Filipović et al. (1995) and ATCA mosaic survey data from Dickel et al. (2005).

In addition to our own observations at 6 cm and 3 cm, we also used 73 cm (ν = 408 MHz) observations from Clarke, Little, & Mills (1976), 36 cm (ν = 843 MHz) observations from Turtle & Mills (1984) taken by the Molonglo Observatory Synthesis Telescope (MOST), and 20 cm (ν = 1400 MHz) observations from the mosaics presented by Hughes et al. (2007) combining observations from ATCA and Parkes (Filipović et al. 1995). We remeasured flux values for the 36 cm and 20 cm observations as shown in Table 1.

Our new images at 6 and 3 cm were initially created using only ATCA observations from project C634 and then processed using MIRIAD multi-frequency synthesis (Sault & Wieringa 1994) and natural weighting. They were deconvolved using the CLEAN and RESTOR algorithms with primary beam correction applied using the LINMOS task. A similar procedure was used for both U and Q Stokes parameter maps. Due to the low dynamic range[4], self-calibration could not be applied. The 6 cm image (Figure 1) has a resolution of $36'' \times 33''$ at PA=0° and an estimated rms noise of 0.15 mJy/beam. This image was used for the polarisation study only. Similarly, we made an image of SNR J0550-6823 at 3 cm, matching the resolution to the 6 cm image (Figure 2).

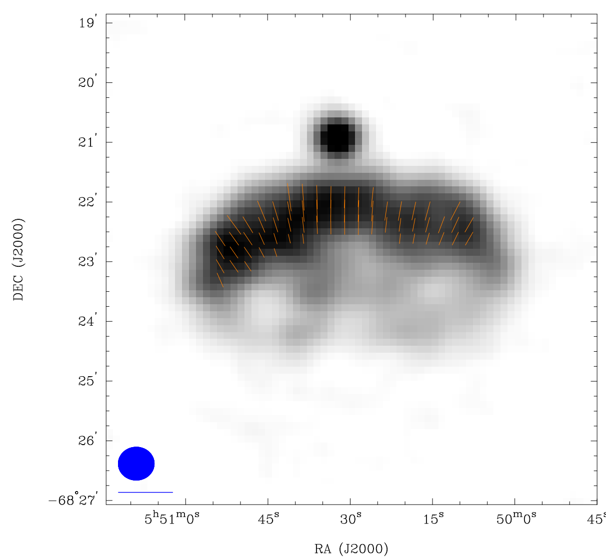

Fig. 1. ATCA "snap-shot" observations (C634 project only) of SNR J0550-6823 at 6 cm (4.8 GHz) overlaid with polarisation vectors. The ellipse in the lower left corner represents the synthesised beam width of $36'' \times 33''$, and the line below the ellipse is a polarisation vector of 100%.

[4]Defined as the ratio between the source flux and noise level.

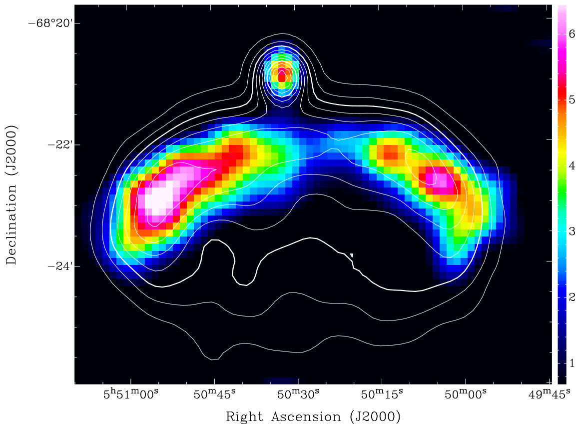

Fig. 2. SNR J0550-6823 at 3 cm (8.6 GHz) overlaid with 6 cm (4.8 GHz) contours. The contours are from 1 to 21 mJy/beam in steps of 2 mJy/beam. The sidebar quantifies the pixel map and its units are mJy/beam.

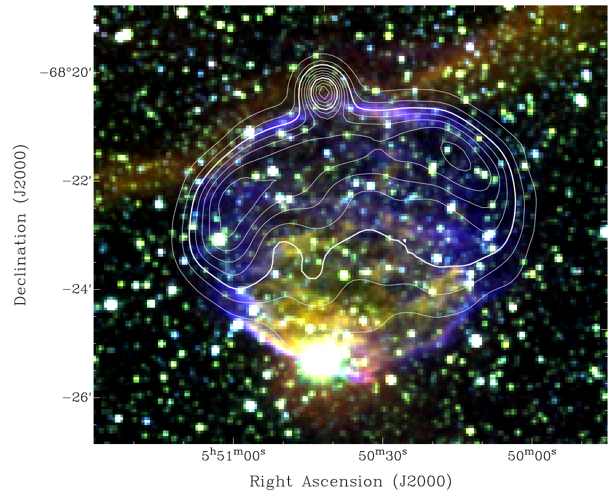

Fig. 3. MCELS composite optical image (RGB=Hα,[SII],[OIII]) of SNR J0550-6823 overlaid with 6 cm contours from our new combined image of all ATCA and Parkes observations. The contours are from 1 to 21 mJy/beam in steps of 2 mJy/beam.

Our analysis also made use of the Magellanic Cloud Emission Line Survey (MCELS) by Smith, Points, & Winkler (2006). This survey was carried out with the 0.6 m University of Michigan/CTIO Curtis Schmidt telescope, equipped with a SITE 2048×2048 CCD having a field of 1.35° at a scale of $2.4''$ pixel^{-1}. They mapped both the LMC and SMC in narrow bands corresponding to Hα, [OIII] (λ=5007 Å) and [SII] (λ=6716,6731 Å), matching red and green continuum bands in order to subtract most of the stars from the images to reveal the full extent of the faint diffuse emission. All of the data have been flux-calibrated and assembled into mosaic images, a small section of which is shown in Figure 3. Further details regarding the MCELS are given by Smith et al. (2006) and at `http://www.ctio.noao.edu/mcels`. Here, for the first time, we present optical images of this object in combination with our new radio-continuum data.

3. RESULTS AND DISCUSSION

SNR J0550-6823 exhibits a one sided shell brightened morphology, dissipating in the southern region (Figure 2). We note what is likely an unrelated background point source in its northern region. The remnant is centred at RA(J2000) = $5^h50^m30.7^s$, DEC(J2000) = $-68^\circ23'37.0''$ with a diameter at 6 cm measuring $373'' \times 282'' \pm 4''$ ($90 \times 68 \pm 1$ pc). We estimate the extent at the 3σ noise level (0.15 mJy) along the major (E-W) and minor (N-S) axis (PA=90°) as presented in Figure 4. However, we notice that at optical wavelengths SNR J0550-6823 extends further south and appears to have a near circular shape with the minor axis of ∼75–80 pc. Also, it appears that this SNR is more prominent in the [OIII] image and therefore is an excellent candidate for an oxygen dominant type of SNR such as N 132D or 1E0102-72. New observations similar to Vogt & Dopita (2011) will confirm the true nature of this object.

Using all values of integrated flux density estimates (except for 73 cm; Table 1), a spectral index ($S \propto \nu^\alpha$) distribution is plotted in Figure 5. The overall radio-continuum spectrum (Figure 5; black line) from SNR 0550-6823 was estimated to be $\alpha = -0.79 \pm 0.27$, while the typical SNR spectral index is $\alpha = -0.5 \pm 0.2$ (Filipović et al. 1998a). This somewhat steeper spectral index would indicate a younger age despite its (large) size of $90 \times 68 \pm 1$ pc, suggesting it is an older (more evolved) SNR. We also note that this may indicate that a simple model does not accurately describe the data, and that a higher order model is needed. This is not unusual, given that several other Magellanic Clouds SNR's exhibit "curved" spectra (Crawford et al. 2008a; Bozzetto et al. 2010). Noting the breakdown of the power law fit at shorter wavelengths, we decomposed the spectral index estimate into two components, one (α_1) between 36 and 20 cm, and the other (α_2) between 6 and 3 cm. The first component (Figure 5; red line), $\alpha_1 = -0.16 \pm 0.41$ is a reasonable fit and typical for an evolved SNR, whereas the second (Figure 5; green line), $\alpha_2 = -2.43 \pm 0.34$, is a poor fit, and indicates that non-thermal emission can be described by different populations of electrons with different energy

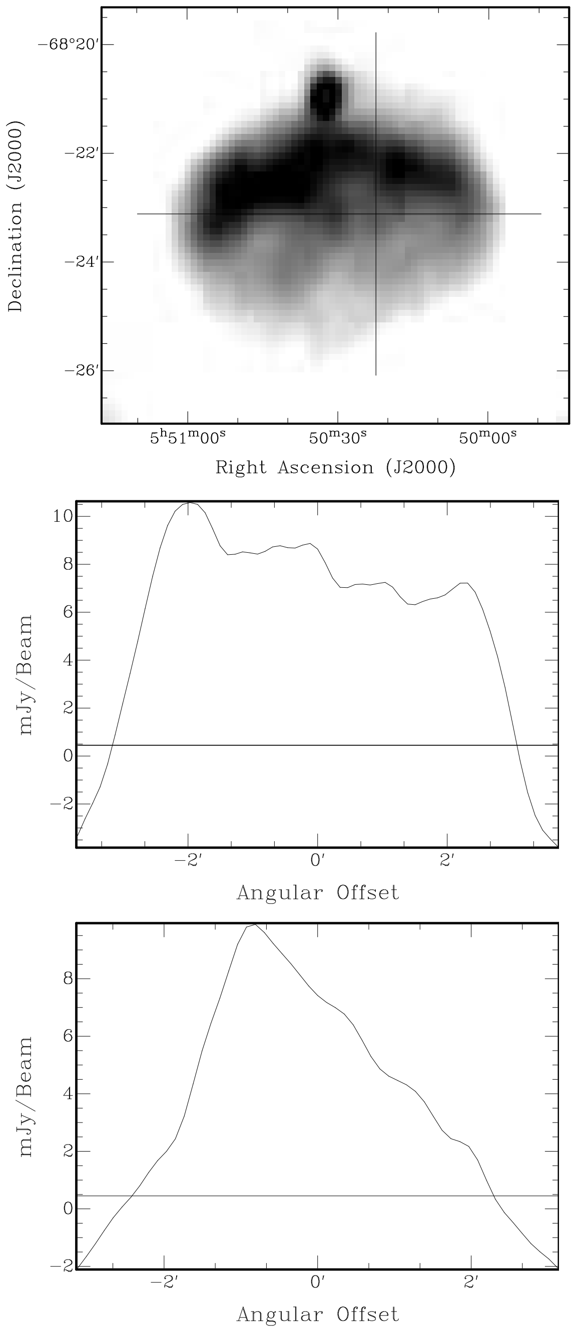

Fig. 4. The top image shows the major and minor axis, with the major axis starting at the E end and the minor axis starting at the N end. The center image shows the I-Profile of the major axis with the 3σ line shown. The bottom image shows the I-Profile of the minor axis with the 3σ line shown.

indices. Although the low flux at 3 cm (and to a lesser extent at 6 cm) could cause the large deviations, an underestimate of up to $\sim$50% would still lead to a "curved" spectrum.

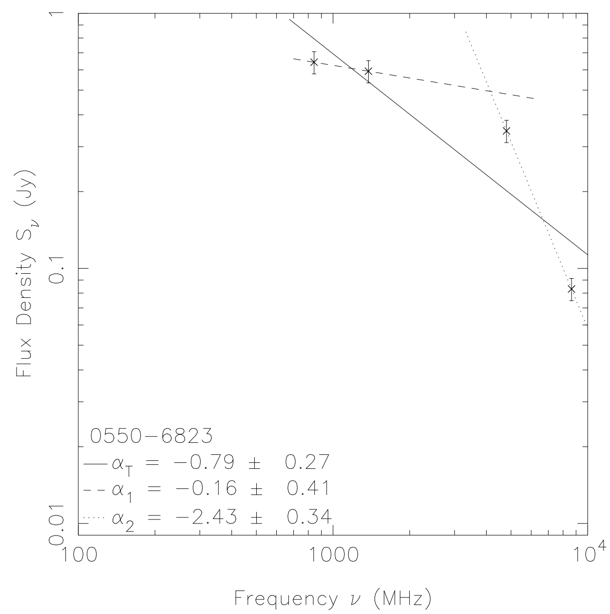

Fig. 5. Radio-continuum spectrum of SNR J0550-6823. The 73 cm (408 MHz) value was disregarded in this estimate due to confusion from the strong point source in the northern region of the SNR.

SNR J0550-6823 is located on the eastern side of the LMC, far away from the main body of this dwarf galaxy. We also point out the dissipating shell in the southern region of the remnant. Therefore, it is reasonable to assume that this SNR is expanding in a very low density environment.

We estimate the spectral index of the point source (ATCA J0550-6820) in the northern region of the SNR to be $\alpha = -1.2 \pm 0.2$ (Table 1). This significantly steeper spectrum adds further evidence that the point source is unrelated to SNR 0550-6823 and is most likely a background AGN. Hence, this background source may "contaminate" correct spectral index estimates of SNR J0550-6823, especially in low-resolution studies such as that of Filipović et al. (1998a) (-0.37 ± 0.06 previous vs. -0.79 ± 0.27 this paper). For this reason we do not include the 73-cm flux density measurements in the new spectral index estimate, as the beam size (resolution) is over $2.5'$.

We also considered this point source to be a runaway pulsar related to SNR 0550-6823. We ruled out this scenario due to a lack of prominent trails (or pulsar wind nebulae) as found in LMC SNR N206 (Klinger et al. 2002) or SMC SNR IKT 16 (Owen et al. 2011).

Linear polarisation images were created for each frequency using the Q and U parameters (Figure 1).

Relatively strong linear polarisation is evident in the 6 cm image and is greater than in many LMC SNRs (Bojičić et al. 2007; Crawford, Filipović, & Payne 2008b; Crawford et al. 2008a; Čajko, Crawford, & Filipović 2009; Crawford et al. 2010) but somewhat weaker than in LMC SNR J0527-6549 (DEM L204) (Bozzetto et al. 2010).

The mean fractional polarisation at 6 cm was calculated using flux density and polarisation:

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

where S_Q, S_U and S_I are the integrated intensities for the Q, U and I Stokes parameters. Our estimated peak value at 6 cm is $50\% \pm 10\%$ (Figure 1) while there is no reliable detection at 3 cm. Without reliable polarisation measurements at a second frequency we could not determine the Faraday rotation and thus cannot deduce the magnetic field strength. We also note that the point source in the northern region is not polarised. This is also consistent with it being an unrelated background source.

4. CONCLUSION

We carried out a radio-continuum study of SNR J0550-6823. From this analysis, we found that the SNR followed a one sided shell brightened morphology with a diameter of $373'' \times 282'' \pm 4''$ ($90 \times 68 \pm 1$ pc). It has a relatively flat spectral index ($\alpha = -0.79 \pm 0.27$) and a strong 6 cm polarisation of $\sim$50% ± 10%. We also note correlations between the optical ([O III]) and radio observation of this object, with the optical observations accounting for the seemingly "missing" southern emission seen in the images at radio wavelengths. These new observations will further improve our knowledge of this SNR as well as SNRs in general.

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L. M. Bozzetto, M. D. Filipović, E. J. Crawford, J. L. Payne and A. Y. De Horta: School of Computing and Mathematics, University of Western Sydney, Locked Bag 1797, Penrith South DC, NSW 1797, Australia (luke.bozzetto@gmail.com).

M. Stupar: Department of Physics, Macquarie University, Sydney 2109, NSW, Australia.