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RADIO-CONTINUUM OBSERVATIONS OF SMALL, RADIALLY POLARISED SUPERNOVA REMNANT J0519–6902 IN THE LARGE MAGELLANIC CLOUD

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SUMMARY: We report on new Australian Telescope Compact Array (ATCA) observations of SNR J0519–6902. The Supernova Remnant (SNR) is small in size (∼8 pc) and exhibits a typical SNR spectrum with $\alpha = -0.53 \pm 0.07$, with steeper spectral indices towards the northern limb of the remnant. SNR J0519–6902 contains a low level of radially orientated polarisation at wavelengths of 3 and 6 cm, which is typical of younger SNRs. A fairly strong magnetic field was estimated to ∼171 μG. The remnant appears to be the result of a typical Type Ia supernova, sharing many properties with another small and young Type Ia LMC SNR, J0509–6731.

Key words. ISM: supernova remnants – Magellanic Clouds – radio continuum: ISM – ISM: individual objects – SNR J0519–6902

1. INTRODUCTION

Supernova Remnants (SNRs) play an essential role in the ecology of the universe, enriching the interstellar medium (ISM) as well as having a significant impact on the ISM structure and physical properties. The study of SNRs in our own galaxy isn't ideal due to the high level of absorption, in addition to difficulties in achieving accurate distance measurements. Instead, we look to the small dwarf galaxy, the Large Magellanic Cloud (LMC), for our study, which is located at a distance of 50 kpc (Macri et al. 2006). This proximity to us is still far enough that we can assume all objects within the galaxy to be located at the same distance, making measurements of extent and surface brightness more reliable. LMC also offers us an environment that is outside of the galactic plane at an angle of 35° (van der Marel and Cioni 2001) and, as a result, a low foreground absorption.

One of the signatures of SNRs is their predominately non-thermal radio-continuum emission, typically exhibiting a spectrum with $\alpha \sim -0.5$ (defined by $S \propto \nu^{\alpha}$). However, this value can vary as there is a wide variety of SNRs in different stages of evolution (Filipović et al. 1998, Payne et al. 2008)

SNR J0519–6902 was observed by Tuohy et al. (1982) who recorded an integrated flux density measurement at 408 MHz of 150±30 mJy and 33±5 mJy at 5000 MHz. They make note that the SNR is Balmer dominated with a broad Hα component and reported an X-ray extent of $\sim$30″ and an optical extent of 28″. They estimate a shock velocity of 2900±400 km s^{-1} and an age of $\sim$500 years. It is also mentioned that the remnant is expanding into a low density region composed of neutral hydrogen, inferring Type I supernovae, and they estimate the progenitor mass to be between 1.2 and 4 solar masses. Mathewson et al. (1983) recorded a spectral index of –0.6. Mills et al. (1984) record a 843 MHz flux density measurement of 145 mJy, updating the spectrum of the remnant to –0.65. Chu and Kennicutt (1988) associated this SNR with the nearby (200 pc) OB – LH41 and classified it as population II. Smith et al. (1991) estimated an age between 500 – 1500 years, noting that this makes the remnant one of the youngest in the LMC. Dickel and Milne (1994) state that this SNR is similar to Tycho or Kepler SNR in the Milky Way. Dickel and Milne (1995) then observed this remnant at wavelengths of 20 and 13 cm, obtaining integrated flux densities of 100 mJy and 70 mJy, respectively. They also estimate the mean fractional polarisation across the remnant of 1.5±0.6% (20 cm) and 4.1±0.6% (13 cm), and make note of the radial magnetic field and similarities to other young galactic SNRs. Filipović et al. (1995) measured an integrated flux density measurement of 57 mJy at 3 cm. Filipović et al. (1998) reobserved this SNR with the Parkes radio-telescope at 6 cm, estimating an integrated flux density of 72 mJy. Haberl and Piestch (1999) observed this SNR with the ROSAT and gave the association [HP] 789. Borkowski et al. (2006) place the age of SNR at 600 years with a 30% error. Vukotić et al. (2007) estimated the magnetic field of this SNR using the classical equipartition formula (186 μG) as well as a revised equipartition formula (270 μG). Desai et al. (2010) found no young stellar object (YSO) associated with this SNR. Kosenko et al. (2010) used Chandra and the XMM Newton telescopes to estimate an age of 450±200 for this remnant. Most recently, Edwards et al. (2012) state that based on their current models, this SNR could have only been the result of a supersoft source or a double degenerate system mimicking a Type I SN event.

In this paper we present new radio-continuum measurements and polarimetric analysis of SNR J0519–6902. The observations, data reduction and imaging techniques are described in Section 2. The astrophysical interpretation of newly obtained moderate-resolution total intensity images are discussed in Section 3.

2. OBSERVATIONS

We observed SNR J0519–6902 on November 15 and 16, 2011 with the Australian Telescope Compact Array (ATCA) using the new Compact Array Broadband Backend (CABB) receiver at the array configuration EW367 at and wavelengths of 3 and 6 cm (ν=9000 and 5500 MHz). Baselines formed with the 6$^{\text{th}}$ ATCA antenna were omitted while the other five antennas were arranged in a compact configuration. The observations were carried out in the so called "snap-shot" mode, totaling $\sim$50 minutes of integration over a 14 hour period. The source PKS B1934-638 was used for primary calibration and source PKS B0530-727 was used for secondary (phase) calibration. The MIRIAD (Sault et al. 1995) and KARMA (Gooch 1995) software packages were used for reduction and analysis. More information on the observing procedure and other sources observed in this session/project can be found in Bojičić et al. (2007), Crawford et al. (2008a,b, 2010), Čajko et al. (2009), De Horta et al. (2012), Grondin et al. (2012), Maggi et al. (2012) and Bozzetto et al. (2010, 2012a,b,c,d).

Images were formed using the MIRIAD multi-frequency synthesis (Sault and Wieringa 1994) and natural weighting. They were deconvolved using the MFCLEAN 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.

In addition to our own observations, we made use of two ATCA projects (C354 and C149) at wavelengths of 13 and 20 cm. Observations from project C354 were taken on September 18 (array 1.5B), 22 and 23 (array 1.5D), 1994. Observations from project C149 were taken on March 22 (array 6A) and April 2 (array 6C).

3. RESULTS AND DISCUSSION

SNR J0519–6902 exhibits a ring-like shell morphology with three brightened regions towards the northern, southern and eastern limb of the remnant (Fig. 1). The SNR is centred at RA(J2000)=5^{h}19^{m}34.9^s, DEC(J2000)=–69°02′07.9″. We estimate the spatial extent of SNR J0519–6902 at the 3σ (Table 1; Col. 2) level (0.9 mJy) along the major (N-S) and minor (E-W) axes. Its size at 13 cm is 34″×34″±4″ (8×8 pc with 1 pc uncertainty in each direction). We also estimate the ring thickness of the remnant to $\sim$7.3″ (1.8 pc) at 13 cm, about 43% of the SNR's radius.

We use the integrated flux density measurements from Table 1 to estimate the non weighted radio spectral index of this remnant (α=$-$0.53±0.07). The 408 MHz value has an error of 20%, while we assume a 10% error for the remaining values. The spectrum of this remnant (Fig. 2) is steeper than that of –0.44 measured by Dickel and Milne (1995). However, they make note that there was uncertainty in this measurement. The flux density at 408 MHz is slightly lower than expected for a linear fit. While it is most likely that this is due to the large error and missing short spacings, we can not rule out whether the absorption is responsible for this slight flattening of the spectrum. To see the change in flux across the remnant, we created a spectral map image (Fig. 3) between 20 and 13 cm wavelengths. The map was produced by reprocessing both 20 and 13 cm images to a common u – v range and then fitting $S \propto \nu^\alpha$ pixel by pixel in both images simultaneously. The emission falls predominately between –0.5 and –0.8, which is what we would generally expect of a younger SNR and is consistent with the overall spectrum of this image (–0.53). The white centre in this image is formed due to the SNRs ring morphology, where the emission towards the core of the remnant was less than the 3σ cutoff level.

Table 1. Flux Density of SNR J0519-6902.

λ (cm)	ν MHz	R.M.S (mJy)	Beam Size ($''$)	S_{Total} (mJy)
73	408	–	157×172	150.0
36	843	0.5	46×43	145.0
20	1376	0.3	20×19	121.8
13	2378	0.3	6×5	78.5
6	5500	0.3	38×24	46.5
3	9000	0.3	23×16	33.0

Linear polarisation images were created at 6 and 3 cm using Q and U stoke parameters (Figs. 4 and 5). The mean fractional polarisation was calculated using flux density and polarisation:

$$\mathrm{P}=\frac{\sqrt{S_Q^2+S_U^2}}{S_I}\cdot 100\%$$

where S_Q, S_U and S_I are integrated intensities for the Q, U and I Stokes parameters. Our estimated peak value is 8.1%±2.2% (7σ) at 6 cm and 9.3%±4.8% (6σ) at 3 cm. The polarisation from the remnant appears radial at both wavelengths. We estimate a mean polarisation across the remnant of ∼2.2% at 6 cm and ∼3.2% at 3 cm.

This radial polarisation is expected of smaller, younger, SNRs and is comparable to similarly small SNRs in our own galaxy (Tycho's SNR – Dickel et al. 1991) and SNRs in the LMC (SNR 0509-6731 – Bozzetto et al. in prep). The remnant's low level of radial polarisation is consistent with previous polarisation studies of SNR J0519–6902 at wavelengths of 20 and 13 cm by Dickel et al. (1995), who also found this radially orientated polarisation, with a mean fractional polarisation of 1.5±0.6% (20 cm) and 4.1±0.6% (13 cm) across the remnant.

The polarisation position angles from these 6 and 3 cm observations were used to estimate the Faraday rotation across the remnant (Fig. 6). Filled squares represent positive rotation measure, and open boxes negative rotation measure. Average rotation measure across the entire remnant was estimated at ∼10 rad m^{-2}. However, as there was a significant amount of both positive and negative rotation measure across the remnant, we have broken down the remnant into three regions and performed separate analysis on each. Field 01 (North-East region) – This region is dominated by negative rotation measure with an average value of –272 rad m^{-2}, and a peak of – 431 rad m^{-2}. Field 02 (North-West region) – In contrast, this region is dominated by positive rotation measure, with an average value of 462 rad m^{-2} and a peak of 624 rad m^{-2}. Field 03 (Southern region) – Similarly, this region is also dominated by positive rotation measure, with an average value of 697 rad m^{-2} and a peak of 784 rad m^{-2}. The two southernmost rotation measure pixels in this image were omitted from analysis as they were towards the edge of the remnant, where the polarised intensity is too weak to measure accurate rotation measure.

We used modified equipartition formula for SNRs (Arbutina et al. 2012) to estimate the magnetic field strength for the SNR J0519–6902. The derivation of the new equipartition formula is based on the Bell (1978) diffuse shock acceleration (DSA) theory. This derivation is purely analytical, accommodated especially for the estimation of magnetic field strength in SNRs. The average equipartition field over the whole shell of SNR J0519–6902 is ∼171 μG with an estimate of $\mathrm{E}_{min} = 1.82\times10^{49}$ ergs (see Arbutina et al. (2012); and corresponding "calculator"[1]). This value is typical of young SNRs with a strongly amplified magnetic field.

The surface brightness–diameter ($\Sigma - D$) relationship for this SNR can be seen in Fig. 7 at 1 GHz with theoretically-derived evolutionary tracks (Berezhko and Völk 2004) superposed. SNR J0519–6902 is positioned at $(\Sigma, D) = (5.5\times\ 10^{-20}$ W m^{-2} Hz^{-1} Sr^{-1}, 8.2 pc) on the diagram. The location on the diagram shows that this is a young SNR in the early Sedov phase of evolution. Also, this object evolves in a low density environment and the initial energy of explosion was low.

[1]The calculator is available on http://poincare.matf.bg.ac.rs/~arbo/eqp/

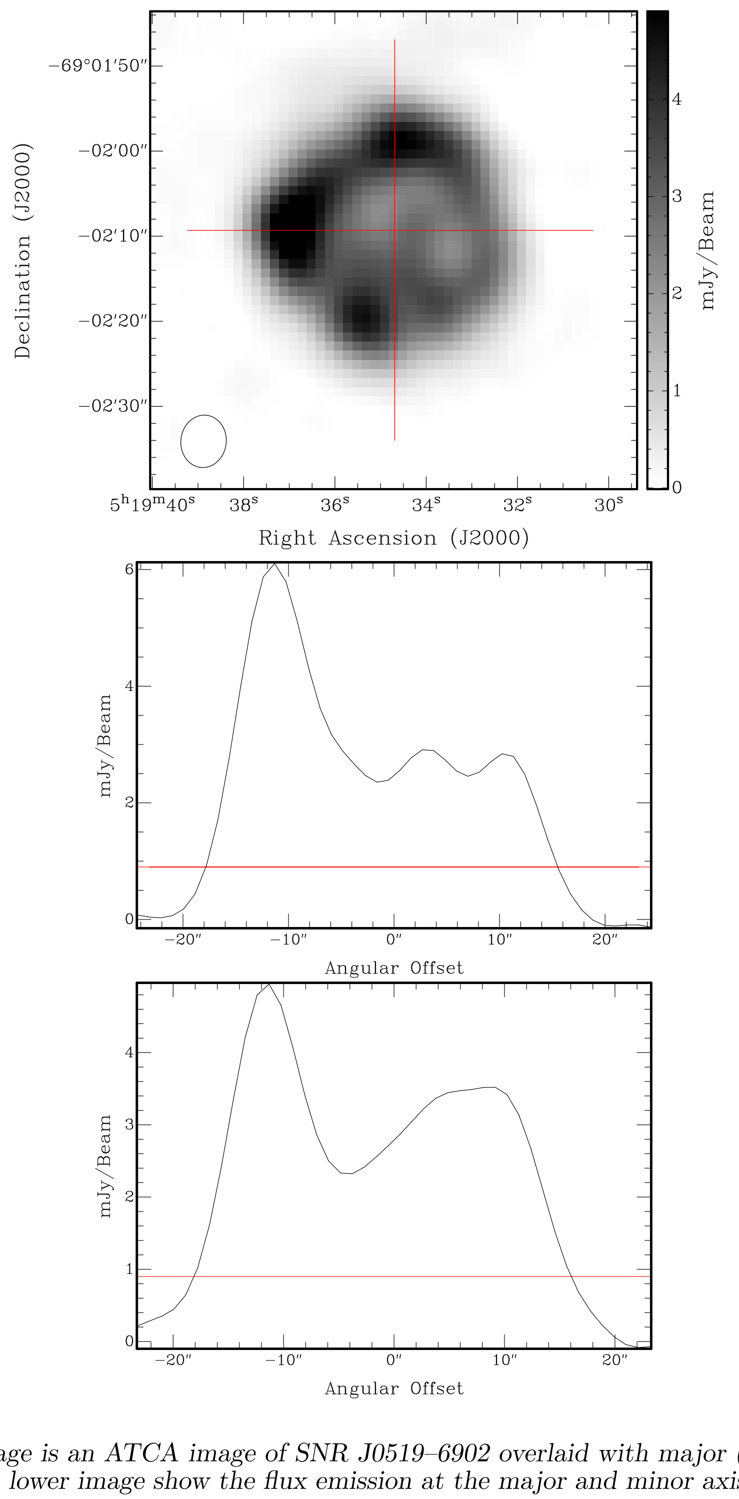

Fig. 1. *The top image is an ATCA image of SNR J0519–6902 overlaid with major (EW) and minor (NS) axis. The middle and lower image show the flux emission at the major and minor axis respectively, with an overlaid line at 3σ.*

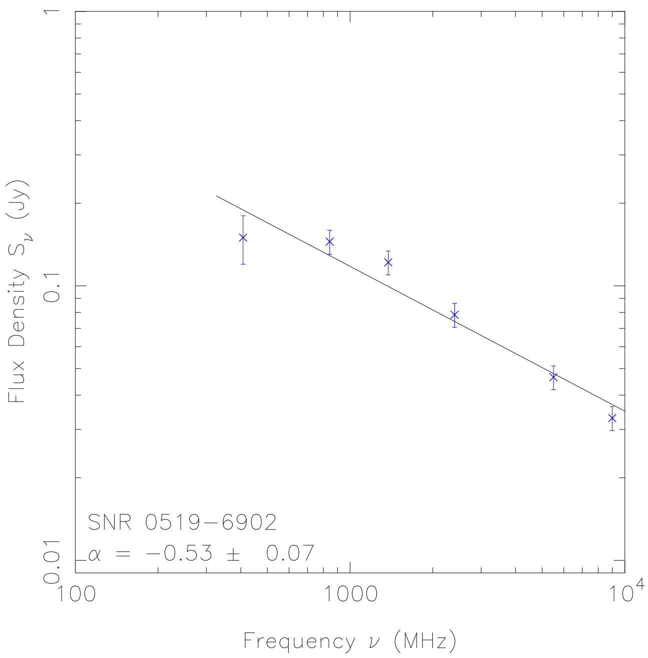

Fig. 2. *Radio-continuum spectrum of SNR J0519–6902.*

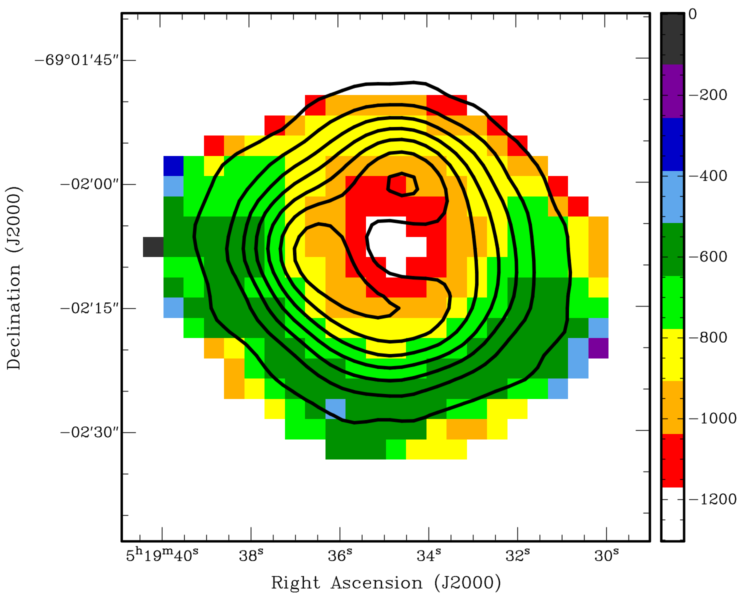

Fig. 3. *Spectral map of SNR J0519–6902 between 20 and 13 cm with overlaid contours at 13 cm of 3, 9, 15, 21, 27, 33 and 39σ. The sidebar quantities indicate the change in spectral index. For example: -200 represents α=–0.2.*

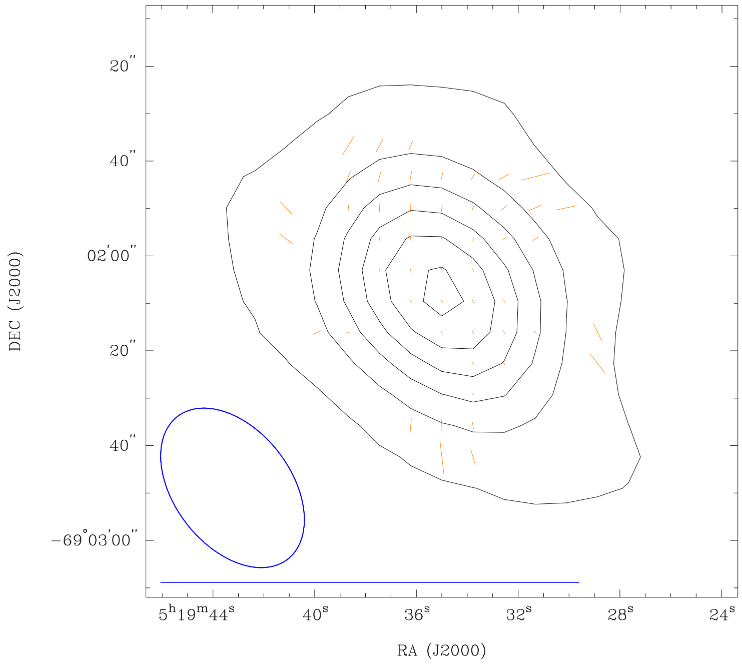

Fig. 4. *Polarisation vectors overlaid on 6 cm ATCA observations of SNR J0519–6902. The contours used are 3, 23, 43, 63, 83 and 103σ. The ellipse in the lower left corner represents the synthesised beamwidth of 23.1″×16.1″ and the line below the ellipse represents a polarisation vector of 100%.*

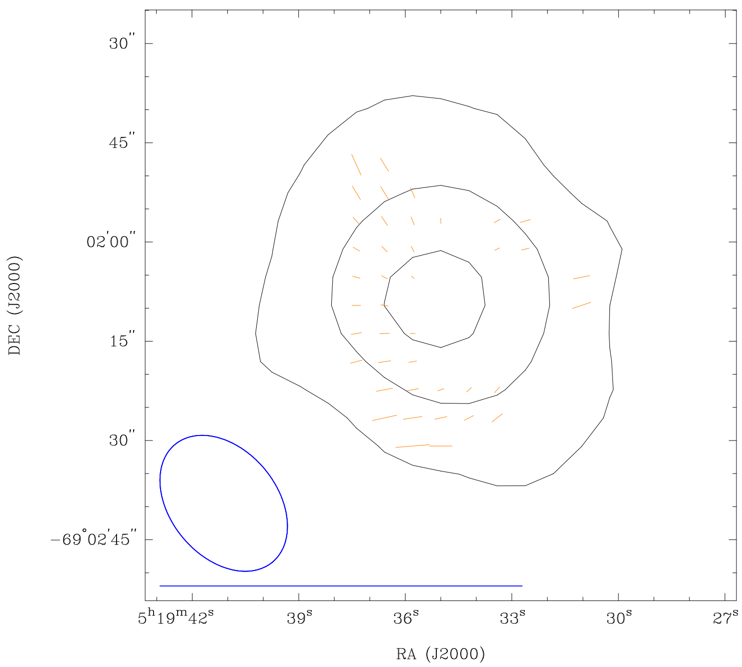

Fig. 5. *Polarisation vectors overlaid on 3 cm ATCA observations of SNR J0519–6902. The contours used are 3, 23 and 43σ. The ellipse in the lower left corner represents the synthesised beamwidth of 38.0″×24.6″ and the line below the ellipse represents a polarisation vector of 100%.*

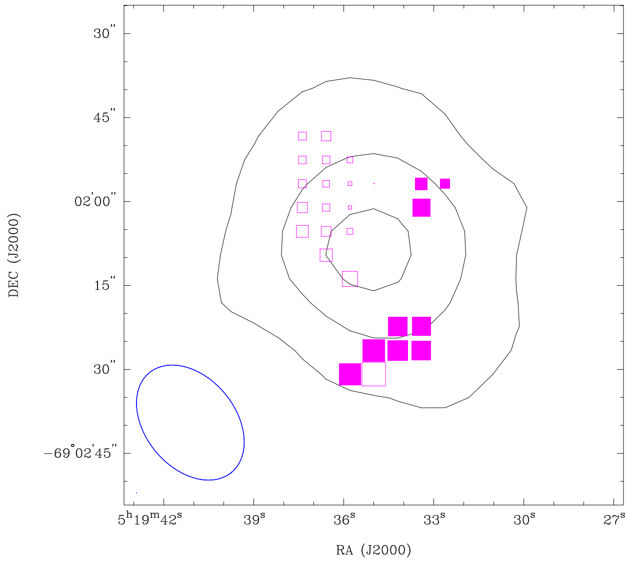

Fig. 6. *Faraday rotation measure of SNR J0519–6902 overlaid on 3 cm image contours. The contours used are 3, 23 and 43σ. Filled squares represent positive rotation measure while open squares represent negative rotation measure. The ellipse in the lower left represents the synthesised beamwidth of 38.0″×24.6″.*

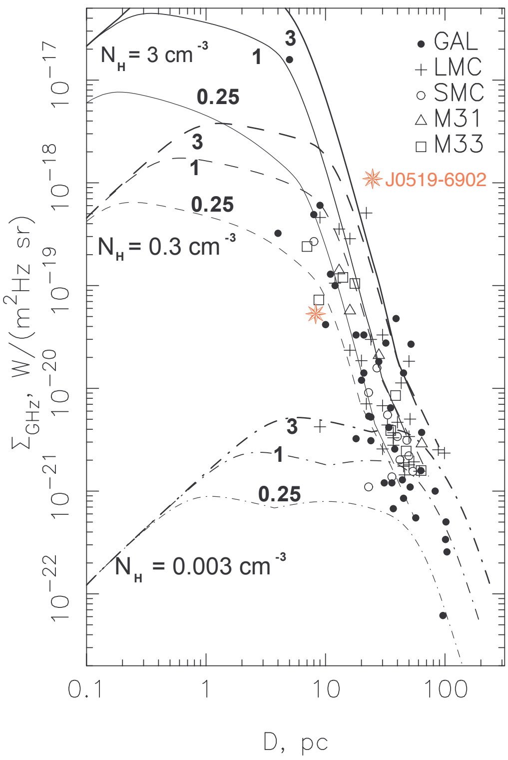

Fig. 7. *Surface brightness-to-diameter diagram from Berezhko and Völk (2004), with SNR J0519–6902 added. The evolutionary tracks are for ISM densities of* N_H= *3, 0.3 and 0.003* cm^{-3} *and explosion energies of* E_{SN} *= 0.25, 1 and* $3{\times}10^{51}$ *erg.*

4. CONCLUSION

This remnant appears to exhibit a ring-like shell morphology with an extent of D=(8×8)±1 pc, radial polarisation at 6 and 3 cm with a mean integrated polarisation of ∼2.2% and ∼3.2% respectively, a typical spectrum of α = –0.53±0.07, areas of positive (mean = 544 rad m^{-2}) and negative (mean = –290 rad m^{-2}) rotation measure. The estimated value of the magnetic field and location in the $\Sigma - D$ diagram show that this SNR is young, in the early Sedov phase of evolution. It expands in a less dense environment and the initial energy of probably Type Ia explosion was low.

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МУЛТИФРЕКВЕНЦИОНА ПОСМАТРАЊА ОСТАТАКА СУПЕРНОВИХ У ВЕЛИКОМ МАГЕЛАНОВОМ ОБЛАКУ – СЛУЧАЈ SNR J0519–6902

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Оригинални научни рад

Представљамо нова ATCA посматрања остатка супернове (ОС) у Великом Магелановом Облаку – SNR J0519–6902. Овај ОС је малих димензија (∼8 pc) и има типичан спектар са спектралним индексом α =–0.53±0.07, као и са стрмијим спектралним индексом на северној ивици остатка.

SNR J0519–6902 емитује низак ниво радијално оријентисаног поларизованог зрачења на таласним дужинама од 3 и 6 cm, карактеристичног за млађе ОС. Процењено је да има прилично јако магнетно поље у вредности од 171 μG. Овај остатак је типичан резултат експлозије супернове типа Ia, који има више заједничких особина са исто тако младим и у својим димензијама малим ОС типа Ia, LMC SNR J0509-6731.