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RADIO DETECTION OF THE SUPERNOVA REMNANT RX J0852.0−4622

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ABSTRACT

The X-ray source RX J0852.0−4622 has been recently proposed as a candidate for a young nearby supernova remnant on the basis of its X-ray (≥1.3 keV) morphology, inferred internal shock velocities, and the clear detection of ^{44}Ti emission lines. In this Letter, we report its detection at radio wavelengths (2.4 and 1.42 GHz). The radio images match the X-ray morphology very well and show a limb-brightened source with some elongated features protruding from the outer shell. These features could be explosion fragments similar to those detected in the Vela supernova remnant. At radio frequencies the source appears to be nonthermal, with an index $\langle\alpha\rangle \sim -0.3$. This synchrotron emission seems to extend up to X-ray energies, implying the existence of very high energy electrons locally accelerated in the remnant.

Subject headings: cosmic rays — radiation mechanisms: nonthermal — radio continuum: general — supernova remnants

1. INTRODUCTION

In a recent Letter, Aschenbach (1998) reported the discovery of a young nearby supernova remnant (SNR) in the *ROSAT* All-Sky Survey images of the Vela region. The new remnant is located at the southwest corner of the well-known Vela remnant and is visible only at $E > 1.3$ keV. At the standard *ROSAT* energy settings, the remnant is hidden by Vela's strong emission.

The new remnant, named RX J0852.0−4622, shows a circular emission region of ~2° in diameter and bright northern and southern limbs. The very high temperature observed in the source ($>3 \times 10^7$ K) indicates that the remnant must be young and, consequently, nearby because of its relatively large angular size in the sky.

The identification of RX J0852.0−4622 with a young SNR is supported by the direct detection of γ-ray emission lines from the decay chain of ^{44}Ti at 1.156 MeV, reported by Iyudin et al. (1998). The combined γ-ray line flux (^{44}Ti lifetime is ~90 yr) and X-ray diameter suggest an age of ~680 yr and a distance of ~200 pc for the remnant. RX J0852.0−4622 could be, consequently, the closest young remnant to Earth.

Despite its proximity, no radio counterpart has been detected up to now for this source. The Vela region, just visible from radio telescopes in the Southern Hemisphere, has been studied in detail by Milne (1968, 1980, 1995), Milne & Manchester (1986), and Duncan et al. (1996). The presence of contaminating radiation from the Galactic disk and from the Vela supernova remnant (which lies in the line of sight to RX J0852.0−4622 and has a diameter of ~8° at 2.4 GHz) makes impossible a straightforward radio detection.

In this Letter, we present results of a reanalysis of the 2.4 GHz deep continuum survey data obtained by Duncan et al. (1995) for the region of interest. We have used a well-proved filtering technique in order to eliminate the contaminating emission and emphasize the fine structure of the weakest radio features. By this procedure, we detected RX J0852.0−4622 at 2.4 GHz, and using new data at 1.42 GHz, we could compute an average spectral index for the source, which is consistent with a nonthermal nature as expected at radio wavelengths.

2. DATA, ANALYSIS, AND TOTAL-POWER RESULTS

In order to detect an extended (~2°), low surface brightness radio source such as a previously unnoticed SNR in a complex region of the Galactic plane (such as the Vela region), high-quality single-dish observations are required. We have used for this work data from the deep continuum survey of the southern Galactic plane made by Duncan et al. (1995) at 2.4 GHz with the Parkes 64 m radiotelescope (angular resolution of 10ʹ.4). The reader is referred to Duncan et al.'s paper for details of the survey.[2] They are presented in two separated components: a large-scale component of diffuse background emission, and a small-scale component from which the extended Galactic emission has been removed. We have added both components in order to recover the original data, and then we proceeded to apply a filtering technique, which is described in detail by Combi & Romero (1998), with the aim of disclosing a possible radio counterpart of RX J0852.0−4622 masked in the more extended emission from Vela. The employed technique is basically an iterative process that operates by successive convolutions and differences on the original map, eliminating diffuse structure on scales larger than a fixed filtering beam. Different tests were performed with Gaussian beams of $15' \times 15'$, $20' \times 20'$, $25' \times 25'$, $30' \times 30'$, and $45' \times 45'$ in l, b on the region of interest, and the results were calibrated with the nearby compact H II regions RCW 34 and RCW 36. After generating several series of filtered maps with variable number n of iterations, we determined that the best results for revealing a counterpart of the X-ray source are obtained for a filtering beamwidth of $30' \times 30'$ and $n \sim 10$. For these values, the emission from Vela (size scale of several degrees) is eliminated whereas the new remnant is maximally enhanced. Smaller beams eliminate some features of the remnant while larger ones are permeable to some diffuse contamination.

In Figure 1 we show the filtered radio image of RX J0852.0−4622 at 2.4 GHz (with an rms noise of 12 mJy beam^{-1}) superposed on the *ROSAT* X-ray image for photon energies greater than 1.3 keV. There is a striking correspondence between both images. At radio wavelengths the source

[1] Member of CONICET.

[2] The data are available on the World Wide Web at http://www.atnf.csiro.au/~duncan.

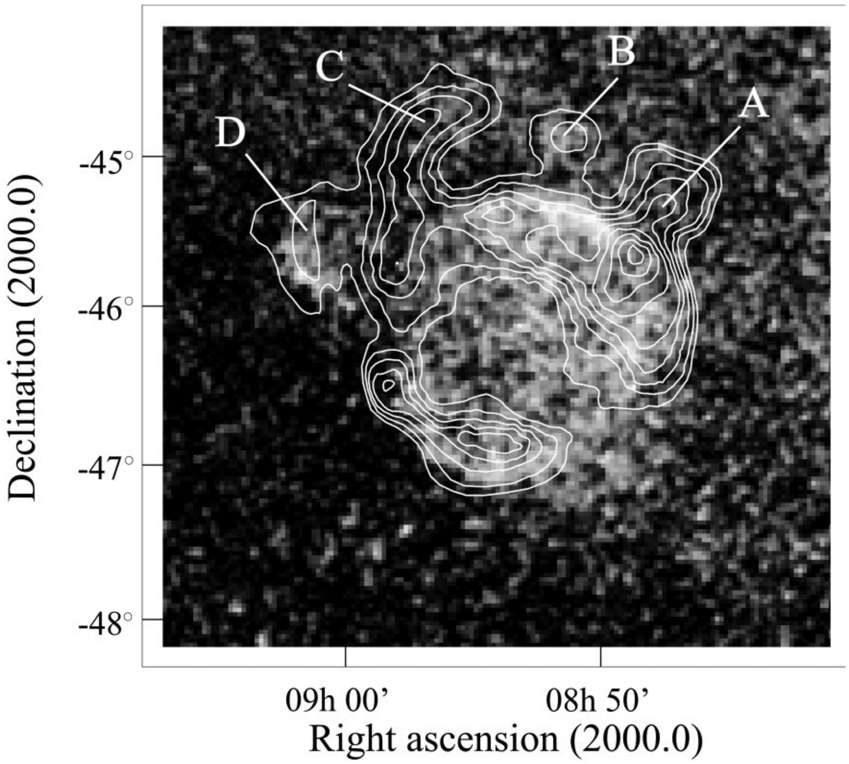

FIG. 1.—Radio image of RX J0852.0−4622 at 2.4 GHz (angular resolution of 10.′4) superposed on the *ROSAT* $E > 1.3$ keV image. A filtering beam of $30' \times 30'$ has been used for removing contaminating radiation from Vela. Radio line contours are shown at steps of 0.15 Jy beam^{-1}, from 0.2 to 1.4 Jy beam^{-1}. The nominal rms noise is 12 mJy beam^{-1}.

also appears as limb brightened, with stronger emission in the northern limb. The integrated flux density at 2.4 GHz is ∼34.7 ± 2.8 Jy. This flux can be compared with the 1100 ± 90 Jy measured in Vela X by Duncan et al. (1996) in order to understand why the new remnant has remained undetected until now: Vela emission completely outshines the smaller remnant if it is not filtered.

Four interesting extensions to the general radio emission of RX J0852.0−4622 are clearly visible in the northern part of the source. These elongated features, named A to D in Figure 1, are similar to the recently detected X-ray–emitting fragments found outside the Vela shock-wave boundary (Aschenbach, Egger, & Trümper 1995). Actually, radio feature D is coincident with the homonymous X-ray feature. At X-rays there are two objects, D and D′, partially overlapped in the energy range 0.1–0.2 keV. At energies greater than 1.3 keV just D appears (it is visible in Fig. 1 below the radio emission). Since at 2.4 GHz feature D is clearly connected to RX J0852.0−4622, we suggest that the same is true for the X-ray counterpart. This hypothesis is supported by the discrepancy between observed and expected temperatures resulting when the feature is attributed to Vela, something that does not occur with the other X-ray "bullets"[3] (Aschenbach et al. 1995).

In Table 1 we summarize the main radio properties of RX J0852.0−4622 at 2.4 GHz. We provide entries for the entire source and the extended features.

TABLE 1
MEASURED PROPERTIES OF THE SNR DETECTED AT 2.4 GHz

Source	Center (J2000) α	Center (J2000) δ	Size (deg × deg)	$S_{2.4\,\mathrm{GHz}}$ (Jy)	$\sigma_{2.4\,\mathrm{GHz}}$ (Jy)
SNR (entire source)	8 52	−46 18	2.1 × 2.1	34.7	2.8
Feature A	8 48	−45 24	0.5 × 0.7	4.2	0.9
Feature B	8 51	−45 06	0.4 × 0.4	1.7	0.4
Feature C	8 55	−44 59	0.4 × 0.9	4.76	0.7
Feature D	9 00	−45 30	0.7 × 0.8	4.46	0.5

NOTE.—Units of right ascension are hours and minutes, and units of declination are degrees and arcminutes.

3. SPECTRAL INDICES

We have carried out 1.42 GHz continuum observations of RX J0852.0−4622 with the aim of establishing, at least in a rough way, the dominant spectral index in the new remnant. We used a 30 m telescope belonging to the Instituto Argentino de Radioastronomía at Villa Elisa, Argentina. This instrument (see Combi & Romero 1998 for details) has a half-power beamwidth of ∼34′ at 1.42 GHz. The observations were performed during two sessions on 1998 December 10 and 17 and reduced following standard procedures (see, e.g., Combi & Romero 1997; Combi, Romero, & Benaglia 1998). A filtering with a beamwidth of $90' \times 90'$ was applied. Just the northern limb section of RX J0852.0−4622 and the associated D-C features are visible at 1.4 GHz above 3 rms in the filtered data. The flux density of the northern limb is $S_{1.42\,\mathrm{GHz}} \approx 31.1 \pm 3.1$ Jy.

In order to find an average spectral index for this part of the source (a detailed distribution cannot be computed because of the low resolution of the 1.42 GHz observations), we have filtered again the original 2.4 GHz data now with the same beam used at the lower frequency, $90' \times 90'$. We then computed the integrated flux density of the region detected at 1.4 GHz, which gives us $S_{2.4\,\mathrm{GHz}} \approx 26.2 \pm 2.4$ Jy. The average

[3] It is also worth mentioning that the X-ray luminosity of feature D exceeds, by far, the luminosity of the remaining features when a distance of 500 pc (i.e., Vela's) is assumed.

spectral index over the northern limb section is $\langle\alpha\rangle \sim -0.3$, where the convention $S_\nu \propto \nu^\alpha$ has been adopted. Errors are difficult to estimate; formally they are ∼0.2, but uncertainties related to the filtering technique also should contribute. We recommend, at the present stage, to adopt a conservative total error $\epsilon_\alpha \sim 0.3$. If a flat average index of ~ -0.3 is confirmed for the entire source, it would be by far the flattest one observed in any young shell remnant and one of the flattest of any shell-type SNR in the Galaxy (of course, values as steep as -0.6 are still possible within the current observational errors; more sensitive observations are required to make clear the point).

The above crude estimate of the spectral index is enough to show that radio emission from the northern limb of RX J0852.0−4622 is compatible with a nonthermal nature. However, flat indices (unprecedented for young SNRs) cannot be completely ruled out on the sole basis of our data.

Additional support for the synchrotron origin of the observed emission comes from the polarization maps presented by Duncan et al. (1996) for this region. In Figure 2*b* of their paper, Duncan et al. provide the orientation of polarization vectors (magnetic field) over the source. The polarized emission rises to ∼50% in the unfiltered map of the northern limb of RX J0852.0−4622. Part of this polarized radiation certainly originates on larger size scales and does not contribute to the filtered images. However, the remaining, small-scale polarized flux seems to be still high enough (perhaps at the level of 20%–30%) to provide evidence for a synchrotron origin of the emission. Interestingly, the degree of polarization significantly lessens toward the center of the remnant, falling to a few percent, which could be entirely originated in the background emission of Vela.

Faraday rotation, both internal to the source and arising from the interstellar medium, does not significantly change the observed magnetic field directions. At 2.4 GHz, the rotation is $\theta \approx 0.7\langle n_e\rangle\langle B_\parallel\rangle L$ degrees, where $\langle n_e\rangle$ is the average electron density in cm^{-3}, $\langle B_\parallel\rangle$ is the line-of-sight component of the magnetic field in μG, and L is the path length of the radiation in parsecs. Assuming for $\langle n_e\rangle$ and $\langle B_\parallel\rangle$ the mean values given by Spitzer (1978)—0.03 cm^{-3} and 1 μG, respectively—we obtain an interstellar rotation of $\theta_{\mathrm{ISM}} \approx 4°$. In the source, if the shell thickness is ∼1 pc and $\langle n_e\rangle$ is as high as 1 cm^{-3}, we have an additional rotation of $\theta_{\mathrm{SNR}} \approx 1°$. So, the total effect can be neglected in a first approximation.

In the remnant, the magnetic field seems to be radial over features A and B, whereas within the limb-brightened region it is mostly parallel to the inner limb edge, an effect that could be due to shock compression. In feature C the field aligns with the major axis of the structure. The overall polarization images match the filtered total-power map very well, reinforcing the hypothesis that the synchrotron mechanism is the main source of radio emission in RX J0852.0−4622, something that was already noted by Duncan et al. regarding feature D. It should be noted, however, that high polarized emission and tangential magnetic fields are not typical of young remnants.[4]

4. DISCUSSION

The analysis of the X-ray spectrum of RX J0852.0−4622 reveals that the emission from the northern limb can be represented by a power law with index $\alpha = -2.6^{+0.3}_{-0.4}$ (Aschenbach 1998). Although a thermal interpretation with a two-temperature model is also possible, our detection of possibly nonthermal radio emission from the same region suggests a synchrotron origin for the spectrum from radio to X-ray photon energies. Inverse Compton scattering can be ruled out as a possible source of the X-rays because the slope at X-rays is very different from what is observed at centimeter wavelengths ($\Delta\alpha \gtrsim 1.5$). The conclusion, consequently, seems to be that extremely energetic electrons (energies ≥1 TeV) are present in the source. Since these particles must be locally accelerated, RX J0852.0−4622 constitutes an outstanding natural laboratory (because of its proximity and short age) to test cosmic-ray acceleration models.

In the case of a very young remnant as RX J0852.0−4622, the maximum energy attainable by electrons accelerated in the expanding shock front is limited by the remnant lifetime to (see, e.g., Reynolds 1996)

$$E_{\max} \approx 1.9 \times 10^7 B f^{-1} v_8^2 t \text{ eV}, \tag{1}$$

where B is the preshock magnetic field strength in gauss, the shock velocity is $v = v_8 \times 10^8$ cm s^{-1}, t is the age of the SNR, and f relates the electron mean free path along the field $\lambda_\parallel$ to the gyroradius r_g: $\lambda_\parallel = f r_g$ ($f = 1$ in the strong turbulence limit). In the case of the remnant here under consideration we have $v_8 \sim 5$ and $t \sim 2.1 \times 10^{10}$ s (Aschenbach 1998; Iyudin 1998), so for a typical upstream field $B \sim 3$ μG and $f = 10$ we obtain a maximum electron energy of $\sim 3 \times 10^{12}$ eV. Above this energy, the electron distribution will roll off exponentially, producing a slowly steepening photon distribution out to very high energies. Recent detailed calculations of the synchrotron emission of young SNRs show that the spectrum steepens gradually over many decades in frequency, yielding changes in the spectral index of $\Delta\alpha \sim 1.5$ or even more, as observed in our case (Reynolds 1996).

An important point is that the same diffuse shock acceleration mechanism that operates over the electrons must certainly accelerate protons and ions as well. These latter particles can produce observable γ-rays at energies greater than 100 MeV through hadronic interactions with nuclei from nearby H I clouds. Future high-sensitivity γ-ray observations could be very useful to compare the energy distributions of leptons and hadrons in the source and shed light on details of the acceleration process.

Another interesting aspect of RX J0852.0−4622 is the presence of the already mentioned radio features protruding from the shock-wave boundary of the remnant. These features could be the result of shocks formed beyond the outer shell of the remnant by the interaction of high-density clumps of ejecta created during the supernova explosion with the interstellar medium (Strom et al. 1995). A supersonically moving knot would produce a shock where diffuse particle acceleration can take place. The shock-parallel component of the magnetic field in the Mach cone created by the fragments would be amplified as roughly observed in Duncan et al.'s images, and the resulting synchrotron emission would provide a nonthermal spectrum. An objection to this scenario is that the symmetry axes of features C and D do not intersect each other near the remnant's geometrical center, as it does with features A and B. It could happen, perhaps, that just these two features have a common origin.

A different explanation could be posed on the effects of the Rayleigh-Taylor instability at the interface between ejected and swept-up material. These instabilities could generate radial motions that would lead to a stretching which will enhance the radial field component (Gull 1973). Future multifrequency ra-

[4] D. A. Green 1998, A Catalog of Galactic Supernova Remnants, Mullard Radio Astronomy Observatory, Cambridge, England, UK (available on the World Wide Web at http://www.mrao.cam.ac.uk/surveys/snrs/).

dio observations with good angular resolution can be used to test these speculations.

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