

Radio continuum observations of the galactic supernova remnant Vela Z (G266.2-1.2)

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Received 29 October 2004; received in revised form 21 February 2005; accepted 21 February 2005

Abstract

We present multi frequency radio-continuum observations of Galactic SNR Vela Z (G266.2-1.2), associated with the prominent X-ray source RX J0852.0-4622 discovered in 1998. Our study of this Galactic supernova remnant (SNR) is based on low-resolution mosaic observations with the ATCA radio interferometer at 1384 and 2496 MHz, Parkes 4850 MHz and MOST 843 MHz survey data. We determine the radio spectral index for the most prominent features of this SNR and compare these features with X-ray observations. We note a sudden spectral turnover at higher than expected frequencies of ~ 1384 MHz.

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Keywords: ISM: supernova remnants – radio continuum; ISM: individual (RX J0852-4622/G266.2-1.2)

1. Introduction

Using selective higher energy X-ray bands of the *RO-SAT* All-Sky Survey (RASS), [Aschenbach \(1998\)](#) reported the discovery of a new object designated as RX J0852.0-4622. The X-ray image showed a disk-like, partially limb-brightened emission region, which is typical for the appearance of shell-like SNRs ([Figs. 1 and 2](#)). This SNR is also known as SNR G266.2-1.2 or Vela Z (Vela Junior). The X-ray spectrum indicated that it is a young object and probably close-by because of the large angular diameter of $\sim 2^\circ$. Comparison with historical SNRs limits the age to about ~ 1500 years and the distance to < 1 kpc. This was supported by the detection of γ -ray line emission ([Iyudin et al., 1998](#)) from ^{44}Ti (which is produced exclusively in supernovae). Using the mean lifetime of ^{44}Ti (90.4 years), the observed radio

(and X ray) angular diameter, and adopting a mean expansion velocity of 5000 km s^{-1} and a ^{44}Ti yield of $5 \times 10^{-5} M_\odot$, [Iyudin et al. \(1998\)](#) derived an age of ~ 680 years and a distance of ~ 200 pc, which would make Vela Z the closest supernova to Earth to have occurred during recent human history. [Aschenbach et al. \(1999\)](#) estimated upper limits of 1100 years for the age and 500 pc for the distance. However, [Duncan and Green \(2000\)](#), on the basis of 1.40, 2.42 and Parkes–MIT–NRAO (PMN) survey 4.85 GHz data, concluded that it is difficult to reconcile properties of G266.2-1.2 with other young SNRs: the shell is incomplete of low surface brightness and with flatter spectral index comparing with other young remnants. [Pellizzoni et al. \(2000\)](#) reported a possible association between the central part of Vela Z, the observed $\text{H}\alpha$ nebula and a candidate neutron star AX J0851.9-4617.4. Recent Chandra observations ([Kargaltsev et al., 2002](#)) suggest a possible neutron star in the central part of Vela Z similar to the central source in Cas A.

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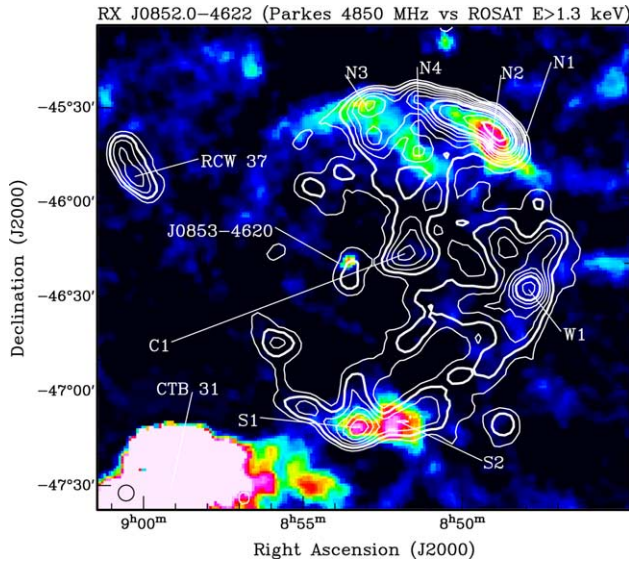


Fig. 1. The combined Parkes (from PMN survey) image of RX J0852.0-4622 at 4850 MHz overlaid with contours of ROSAT PSPC ($E > 1.3$ keV) data (Aschenbach, 1998). The synthesized beam of the Parkes observations is $5'$ (lower left corner) with r.m.s. noise (1σ) of ~ 10 mJy. X-ray contour levels are 0.8, 1, 1.2, 1.4, 1.6, 1.8, 2, 2.3, 2.6 and 3 in units of 10^{-4} ROSAT PSPC counts s^{-1} arcmin $^{-2}$.

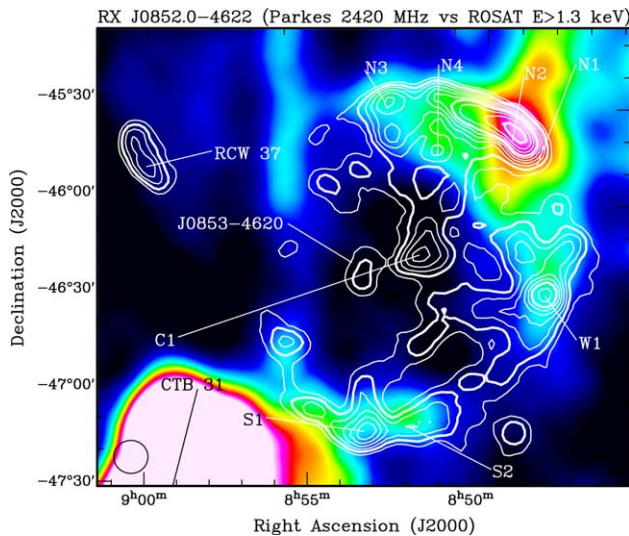


Fig. 2. The Parkes 2420 MHz image (Duncan et al., 1995) of RX J0852.0-4622 overlaid on ROSAT PSPC ($E > 1.3$ keV) contours (Aschenbach, 1998). The synthesized beam is $10.5'$ (lower left corner) with r.m.s. noise (1σ) of 17 mJy. X-ray contour levels are the same as in Fig. 1.

To investigate the radio structure of Vela Z, and to determine the connection between the X-ray and radio observations, we undertook direct radio observations of this object at 1384, 2496 and 4850 MHz. We also make use of existing radio observations at 843 and 2420 MHz published elsewhere.

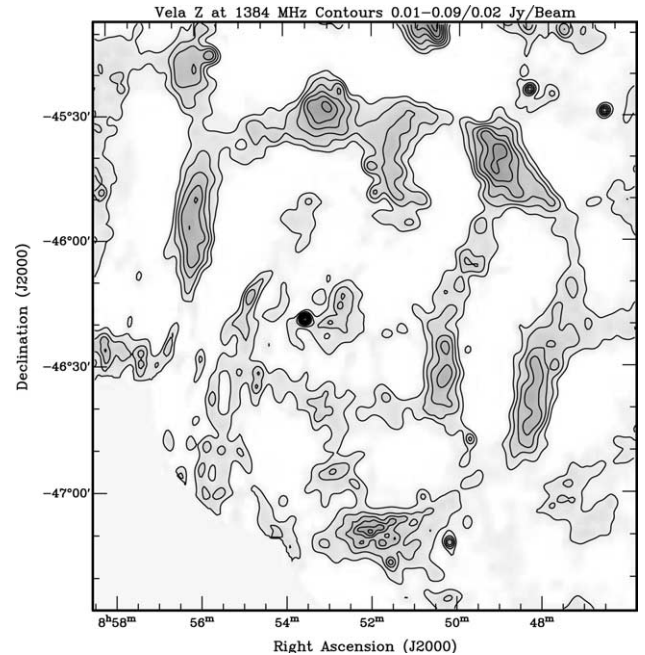


Fig. 3. ATCA mosaic image of Vela Z at 1384 MHz. Contours are from 0.01 to 0.9 in steps of 0.02 Jy/Beam. Due to better presentation of features inside Vela Z, RCW 37 is not shown.

2. Observations and data analysis

2.1. The Parkes radio-continuum data and observations

The PMN survey at 4850 MHz mapped the southern sky from -87.5° to $+10^\circ$ declination (Griffith and Wright, 1993). Due to the problem of spillover temperature and the need to subtract “running-median baselines” in the PMN survey (Condon et al., 1989, 1993), the fluxes of extended objects are somewhat unreliable (Stupar et al. in prep.). In order to minimize this problem, we made additional observations of the northern limb of Vela Z using the Parkes 64-m telescope at 4850 MHz in March 2000. The additional observations covered the area between (J2000) RA = 08^h46^m to 08^h55^m and Dec = $-45^\circ30'$ to $-46^\circ00'$. Calibration was achieved using Hydra A as the primary calibrator and B0843-336 as the secondary calibrator.

We also make use of the Duncan et al., 1995 survey (Fig. 2) of the Vela region to unveil radio continuum presence of Vela Z. They used the Parkes 64-m dish at 2420 MHz and achieved a resolution of $10.4'$.

2.2. ATCA radio-continuum observations

Mosaic observation of Vela Z with the Australia Telescope Compact Array (ATCA) were undertaken in November 1999 at frequencies of 1384 and 2496 MHz (Figs. 3 and 4). Both images are mosaics from 110 pointings. Final images suffer from sidelobes originating

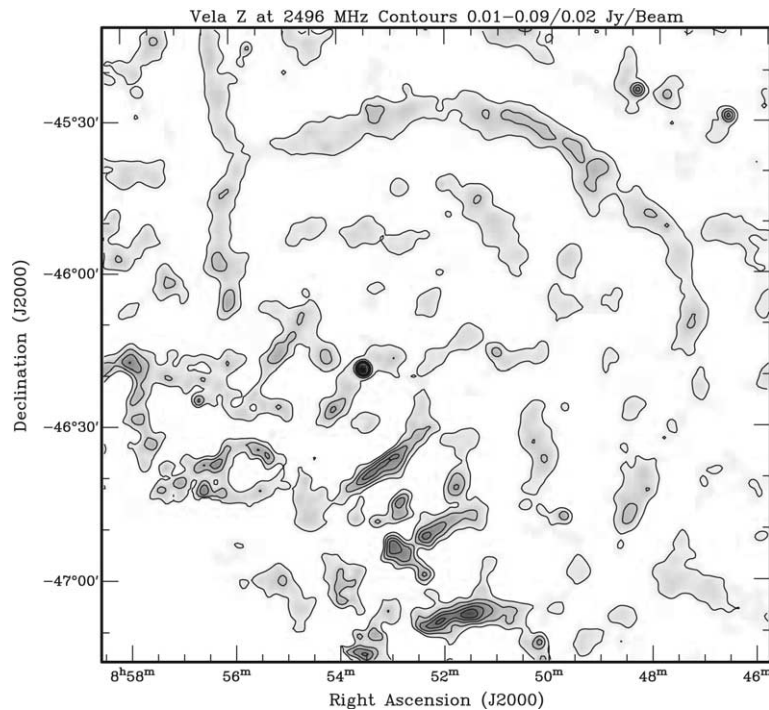


Fig. 4. ATCA mosaic image of Vela Z at 2496 MHz. Contours are from 0.01 to 0.09 in steps of 0.02 Jy/Beam. Due to better presentation of features inside Vela Z, RCW 37 is not shown.

from the strong radio source CTB 31 (RCW 38). The calibrators used were 1934-638 as a primary and 0823-500 as a secondary. The FWHM of the ATCA observations was set to $120''$. We excluded antenna 6 to use the low resolution (short-spacings) images from the 214-m array. These images allow us to more efficiently study the larger scale components of this SNR.

2.3. MOST radio-continuum observations

An observation of Vela Z was made by Walker at 843 MHz with the MOST (Molonglo Observatory Synthesis Telescope) on 20 February 1997. The image size is $163' \times 236'$ with a beam of $43'' \times 62''$. For the spectral analysis work we convolved this image to a resolution of $5'$ to match that of the PMN. The MOST image is not displayed here since it is very similar to the ATCA mosaic images but at lower signal to noise ratio.

3. Results

We compare the radio-continuum images with the *ROSAT* PSPC ($E > 1.3$ keV) image and find several features to coincide. In order to discuss the distinct features seen in either X-ray or radio maps we introduce names for the components (using X-ray data) of Vela Z as N1–N4 (north), W1 (west), C1 (central), E1–E2 (east) and S1–S2 (south) as shown in Figs. 1 and 2. We list in Table 1 the source positions and peak surface bright-

nesses at the given radio frequency. Two source regions (W1 and C1) are seen only in the *ROSAT* images at position $RA = 08^h 51^m 48.5^s$ and $Dec = -46^\circ 17' 50''$. For several small features the integrated flux density was measured using the IMFIT/IMSTAT tasks from the MIRIAD software package (Sault and Killeen, 2003).

The integrated flux density at a given radio frequency was determined as the sum of the flux densities in a box around the defined source region. We kept the same fitting area/shape of the particular region at all frequencies. From the flux densities of the noted features we estimated the radio spectral index for different observational frequencies (Table 1). For the features S1 and S2 no flux density was estimated at 1384 and 2496 MHz. This is due to confusion by strong sidelobes from CTB 31. The errors in spectral index (α) have been calculated from the estimated uncertainties in flux density of $\leq 10\%$. The spectral index α and flux densities of the well known H II region CTB 31 (Rodgers et al., 1960) have been reported elsewhere (Wilson and Bolton, 1960). Here, we use these published observations to check the flux scales at 2420 and 4850 MHz (Figs. 1 and 2). CTB 31 was earlier observed at similar radio-continuum frequencies (2700 and 5000 MHz) and we find that our flux densities at 2420 and 4850 MHz are within 10% of these earlier measurements. Also, similar uncertainties in flux estimate ($\leq 10\%$) was found in our ATCA mosaic observations (1384 and 2496 MHz). We have checked flux calibration of the MOST and ATCA data for several point sources in the field, and found no

Table 1

Measured radio-continuum properties of labelled source features in Vela Z. Flux densities at 843 MHz are estimated from the image which was convolved to 5'

Feature	RA (J2000)			Dec (J2000)			S_{843}	S_{1384}	S_{2420}	S_{2496}	S_{4850}	$\alpha_{843-1384}$	$\alpha_{1384-4850}$	α
	h	m	s	°	'	''								
N1	08	48	02.6	-45	50	28	0.492	2.291	-	0.992	0.236	+3.1 ± 0.1	-1.8 ± 0.2	-
N2	08	49	10.6	-45	41	10	1.363	3.753	1.514	1.734	0.653	+2.1 ± 0.01	-1.4 ± 0.1	-
N3	08	53	10.9	-45	29	41	1.080	2.637	1.176	0.843	0.506	+1.8 ± 0.1	-1.3 ± 0.3	-
N4	08	51	22.7	-45	46	55	-	0.831	-	0.664	0.217	-	-1.1 ± 0.4	-
S1	08	53	12.8	-47	12	25	0.566	-	-	-	0.418	-	-	-0.2 ± 0.1
S2	08	51	58.3	-47	11	59	1.040	-	1.347	-	0.701	-	-	-0.2 ± 0.1
J0853-4620	08	53	30.6	-46	20	05	0.292	1.022	-	0.913	0.099	+2.5 ± 0.1	-1.9 ± 0.2	-
RCW 37	09	00	11.4	-45	54	55	-	0.307	-	0.439	0.074	-	-1.2 ± 0.2	-
RCW 38	08	59	05.2	-47	30	33	-	-	215.7	-	178.7	-	-	-0.3 ± 0.1
W1	08	47	56.2	-46	27	33	-	-	-	-	-	-	-	-
C1	08	51	48.5	-46	17	50	-	-	-	-	-	-	-	-

significant relative calibration problems which would explain the sudden turn-over in the Vela Z spectra we have found as discussed below.

4. Discussion

In Fig. 5 we present spectral index plots obtained for the various identified components. Most of the Vela Z components have a spectral index break (turnover) around 1384 MHz. This is a very high shift of spectral turnover for a Galactic SNR and is significantly different to the more common spectral turnover observed at much lower frequencies (~ 100 MHz) explained by Dulk and Slee (1975). The fitting curve of RCW 37 (Fig. 5) indicate that due to the spectral index breaks this distant

component is indeed part of the Vela Z SNR as it is suggested by Redman et al. (2002) and partially supported by Sankrit et al. (2003). This break is rather unusual and may be in connection with SNR detected non-thermal X-ray emission and/or from suggested young age. There are some indications that X-ray non-thermal SNRs tend to have 'earlier' (frequencies around 1 GHz) then expected break in radio spectral index.

We were unable to estimate the flux density for all the Vela Z features at all five frequencies (843–4850 MHz) due to source confusion. Table 1 gives spectral indices where available up to the turning point (between 843 and 1384 MHz) and after the turning point (between 1384 and 4850 MHz). The overall spectral index is given for S1 and S2 (where S1 has a significantly flatter spectrum). However, whether the S1 component is part of Vela Z can not be conclusively determined on radio flux grounds despite clearly forming part of the observed SNR in X-rays. This is likely due to the components close proximity to the contaminating strong radio source CTB 31. The spectral index break in the S2 spectrum (2420 MHz) is similar to the turnover seen in N1–N4 (but on another frequency) indicating that S2 is very likely part of this SNR.

From our radio-continuum images (Figs. 1–4) and from the ROSAT PSPC X-ray image ($E > 1.3$ keV), we conclude that the eastern limb of Vela Z is essentially missing, at all frequencies. This makes Vela Z a so called barrel-shaped (bilateral) remnant similar to SN 1006 (Winkler and Long, 1997). The radio diameter of Vela Z is measured from the 4850 MHz image to be $116' \pm 2'$ in Dec and $108' \pm 2'$ in RA. The brightest radio and X-ray component (N2) is at a position angle of $320^\circ \pm 5^\circ$. The long axis of the SNR ellipse is also at approximately 320° ; parallel to and 1.2° south of the Galactic plane. The X-ray diameter of RX J0852.0-4622 is larger than the radio diameter by about 10%. The difference of measured diameter, and the small displacement of radio to X-ray peaks, also makes Vela Z similar to SN 1006.

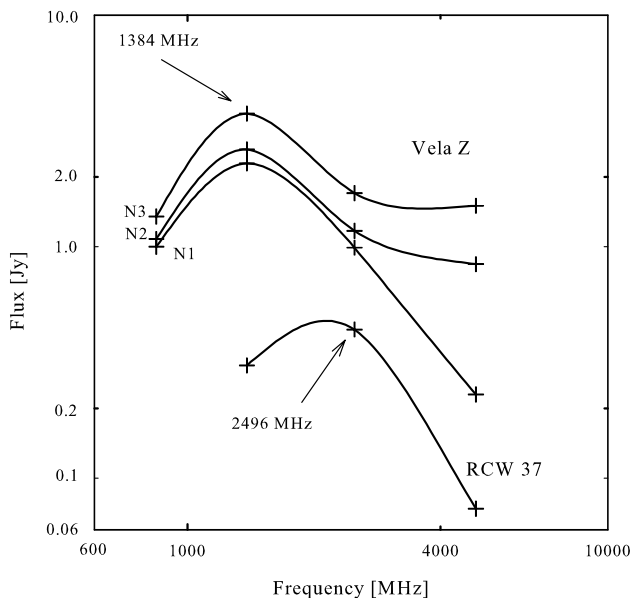


Fig. 5. Spectral index turnover of RX J0852.0-4622 (G266.2-1.2) at the frequency of 1384 MHz. We used fluxes from Table 1 for features N1 to N3 as they (almost) cover observations at all 5 frequencies.

The western limb of Vela Z is represented in the X-ray image as the W1 X-ray luminous feature. However, elongated emission is noticed at 1384 and 2420 MHz but very weak at 2496 MHz. This absence of stronger radio-continuum emission suggests that synchrotron radiation makes a negligible contribution to the dominant X-ray emission of this feature.

5. Conclusion

We present a radio continuum study at five frequencies of SNR Vela Z with arcminute resolution. We found that this SNR shows a spectral index turnover at higher than expected (~ 100 MHz) frequencies of ~ 1384 MHz. This may be associated with the suggested young age of Vela Z. Also, we did not detect any radio-continuum emission from the central regions of this SNR. Comparing the Vela Z radio diameter with the X-ray diameter we noticed a small displacement of radio to X-ray peaks similar to SN 1006 (Winkler and Long, 1997) i.e., $\sim 10\%$. It is also shown that some of the features on the rim of Vela Z recognized by Combi et al. (1999) are indeed part of this remnant. Finally, we did not detect any significant (peak) flux intensity at 1384/2496 MHz around the suggested position of the neutron star (Pellizzoni et al., 2000; Kargaltsev et al., 2002).

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