A Sino-German $\lambda 6$ cm polarization survey of the Galactic plane

V. Large supernova remnants

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ABSTRACT

Context. Observations of large supernova remnants (SNRs) at high frequencies are rare, but provide valuable information about their physical properties.

Aims. The total intensity and polarization properties of 16 large SNRs in the Galactic plane are investigated based on observations of the Urumqi $\lambda 6$ cm polarization survey of the Galactic plane with an angular resolution of $9''.5$.

Methods. We extracted total intensity and linear polarization maps of large SNRs from the Urumqi $\lambda 6$ cm survey, obtained their integrated flux densities, and derived the radio spectra by using these flux densities together with previously published flux densities at various frequencies. In particular, Effelsberg $\lambda 11$ cm and $\lambda 21$ cm survey data were used to calculate integrated flux densities. The $\lambda 6$ cm polarization data also delineate the magnetic field structures of the SNRs.

Results. We present the first total intensity maps at $\lambda 6$ cm for SNRs G106.3+2.7, G114.3+0.3, G116.5+1.1, G166.0+4.3 (VRO 42.05.01), G205.5+0.5 (Monoceros Nebula), and G206.9+2.3 (PKS 0646+06) and the first polarization measurements at $\lambda 6$ cm for SNRs G82.2+5.3 (W63), G106.3+2.7, G114.3+0.3, G116.5+1.1, G166.0+4.3 (VRO 42.05.01), G205.5+0.5 (Monoceros Nebula), and G206.9+2.3 (PKS 0646+06). Most of the newly derived integrated radio spectra are consistent with previous results. The new flux densities obtained from the Urumqi $\lambda 6$ cm, Effelsberg $\lambda 11$ cm and $\lambda 21$ cm surveys are crucial to determine the spectra of SNR G65.1+0.6, G69.0+2.7 (CTB 80), G93.7–0.2, and G114.3+0.3. We find that G192.8–1.1 (PKS 0607+17) consists of background sources, H II regions, and extended diffuse emission of thermal nature, and conclude that G192.8–1.1 is not a SNR.

Key words. ISM: supernova remnants – radio continuum: ISM – polarization – techniques: polarimetric

1. Introduction

A supernova explosion releases energy of about 10^{51} erg into the interstellar space. Observations of supernova remnants (SNRs) are important not only to the understanding of the objects themselves but also to the properties of the ambient interstellar medium. Many intense and large SNRs were identified in the first radio surveys at low frequencies (e.g. [Brown & Hazard 1953](#); [Westerhout 1958](#)). Sensitive and high angular resolution Galactic plane surveys subsequently revealed a large number of faint or compact SNRs (e.g. [Reich et al. 1988](#); [Brogan et al. 2006](#)). To date, 274 Galactic SNRs have been catalogued by [Green \(2009\)](#). Observations of SNRs at many wavelengths are needed to derive reliable spectra. Polarization observations of SNRs are useful to reveal the magnetic field properties of SNRs.

The Sino-German $\lambda 6$ cm polarization survey of the Galactic plane has been carried out with the Urumqi 25-m radio telescope since 2004. It covers $10^\circ \leq \ell \leq 230^\circ$ in Galactic longitude and $|b| \leq 5^\circ$ in Galactic latitude ([Sun et al. 2007](#); [Gao et al. 2010](#); [Sun et al. 2011](#); [Xiao et al. 2011](#)). The Urumqi $\lambda 6$ cm polarization system is suitable for observations of large and faint SNRs. The surface brightness limit for the survey is $\Sigma_{1\text{ GHz}} = 3.9 \times 10^{-23} \text{ W m}^{-2} \text{ Hz}^{-1} \text{ sr}^{-1}$, below the faintest SNRs known today. Using this system, we have studied the magnetic fields and the spectral index distribution of SNR G74.0–8.5 (Cygnus Loop, [Sun et al. 2006](#)), G126.2+1.6 and G127.1+0.5 ([Sun et al. 2007](#)), G156.2+5.7 ([Xu et al. 2007](#)), G180.0–1.7 (S147, [Xiao et al. 2008](#)), G130.7+3.1 (HB3, [Shi et al. 2008](#)), and G65.3+5.7

([Xiao et al. 2009](#)). In addition, [Foster et al. \(2006\)](#) disapproved G166.2+2.5 (OA 184) as being a SNR.

In this paper, we analyze and discuss 16 large SNRs in the survey region of $10^\circ \leq \ell \leq 230^\circ$ with an apparent size exceeding 1° in our map. Smaller SNRs will be discussed elsewhere ([Sun et al.](#), in prep.). We will briefly describe the survey and the SNR sample in Sect. 2. In Sect. 3, we present their total intensity and polarization images, and discuss the properties of each SNR in detail. A summary is given in Sect. 4.

2. The $\lambda 6$ cm survey and the large SNRs

The Sino-German $\lambda 6$ cm polarization survey of the Galactic plane has been performed with a dual-channel $\lambda 6$ cm receiving system constructed at MPIfR and mounted on the Urumqi 25-m radio telescope. The receiving system had a system temperature of about 22 K T_a , the central frequency was 4800 MHz, and the half power beam width (HPBW) was $9''.5$. The observations were made by scanning in both ℓ and b directions. Stokes parameters I , U , and Q were stored simultaneously for each map. The system set-up and the data reduction were described in detail by [Sun et al. \(2006, 2007\)](#) and [Gao et al. \(2010\)](#).

The total intensity and polarization calibration was made with observations of the primary polarization calibrator, 3C 286 (flux density at $\lambda 6$ cm $S_{6\text{ cm}} = 7.5$ Jy, polarization angle $\text{PA} = 33^\circ$, and percentage polarization $\Pi = 11.3\%$), and the secondary calibrators, 3C 48 ($S_{6\text{ cm}} = 5.5$ Jy, $\text{PA} = 108^\circ$, $\Pi = 4.2\%$) and

3C 138 ($S_{6\text{ cm}} = 3.9\text{ Jy}$, PA = 169° , $\Pi = 10.8\%$). Instrumental effects in Stokes U and Q maps were corrected for the leakage of total intensity I into the polarization channels as described by Sun et al. (2007).

The $\lambda 6\text{ cm}$ survey region covers $10^\circ \leq \ell \leq 230^\circ$ and $|b| \leq 5^\circ$ of the Galactic plane. According to the SNR catalog of Green (2009), twenty-two known SNRs in our survey region have a size larger than 1° . In the $\lambda 6\text{ cm}$ survey, the size of G43.9+1.6 is less than 1° , while G127.1+0.5, G166.0+4.3 (VRO 42.05.01), and G189.1+3.0 (IC443) are larger than 1° . Thus 24 SNRs are left. Four SNRs, SNR G126.2+1.6 and G127.1+0.5 (Sun et al. 2007), SNR G180.0–1.7 (Xiao et al. 2008), and G130.7+3.1 (Shi et al. 2008), have previously been studied. SNRs G13.3–1.3 is omitted in this paper because it was not reliably detected in the $\lambda 6\text{ cm}$ survey. G28.8+1.5 is omitted because only a small section of the radio shell is detected and is confused by strong diffuse Galactic emission. Faint diffuse emission is detected in the area of SNR G32.0–4.9 and only some bright knots above 3σ noise level were seen in the survey map. We cannot unambiguously associate the diffuse emission with the SNR and therefore do not study this object. SNR G108.2–0.6 (Tian et al. 2007) was also skipped because it is confused by strong thermal emission from nearby H II regions and cannot be separated. However, the two SNRs, G82.2+5.3 (W63) and G89.0+4.7 (HB21), are located at the $b = +5^\circ$ boundary of the $\lambda 6\text{ cm}$ survey and have been completely observed (Xiao et al. 2011). They were included. We therefore study 17 objects in this paper, where G192.8–1.1 is disproved as being a SNR in Sect. 3.1.

3. Results and discussions

The SNR images were obtained after we filtered out the large-scale Galactic diffuse emission by using the technique of “background filtering” (Sofue & Reich 1979). A twisted hyper-plane was defined by the average values of pixels without any obvious structure in the four map corners and subtracted for each SNR to remove the local-background Galactic diffuse emission in I , U , and Q maps. We obtained total intensity and polarization images of these SNRs as shown in Fig. 1.

We integrated the flux density ($S_{6\text{ cm}}$) and polarization intensity ($PI_{6\text{ cm}}$) of SNRs within the boundary defined by the 3σ noise level around each SNR in total intensity (see Table 1), where σ is the rms of the map estimated from the surrounding areas of each SNR without obvious structure. For the SNRs G39.7–2.0 (W50), G65.1+0.6, G78.2+2.1, G82.2+5.3 (W63), G106.3+2.7, G189.1+3.0 (IC443), and G69.0+2.7 (CTB 80), diffuse emission adjacent to the SNR is detected in the $\lambda 6\text{ cm}$ map. We thus outline the SNR boundary according to published radio maps at other frequencies for flux density integration (see Fig. 1) to avoid possible confusion. For the complicated structure of SNR G205.5+0.5 (Monoceros Nebula), we outline only the western shell for the integration at $\lambda 6\text{ cm}$, $\lambda 11\text{ cm}$, and $\lambda 21\text{ cm}$ to determine its spectrum. The uncertainty of each integrated SNR flux density is calculated from the rms of a map and the pixel number of the integration area. The calibration and base-level uncertainties are assumed to be 10%, and added to the final value of the uncertainty. Compact sources exceeding a flux density of 20 mJy in the NVSS catalogue at 1.4 GHz (Condon et al. 1998) and located within the SNR boundary were discounted from the integrated SNR flux densities. The flux densities of point-like sources at $\lambda 6\text{ cm}$ were estimated from the extrapolation of the NVSS flux density at 1.4 GHz (Condon et al. 1998) using a spectral index either taken from Vollmer et al. (2005) or derived from the flux densities at 408 MHz and 1420 MHz

from the Canadian Galactic Plane Survey (CGPS) (Taylor et al. 2003). If no spectral index is available for a source, we adopted the mean value of $\alpha = -0.9$ according to Zhang et al. (2003) obtained from the NVSS and the WSRT source samples.

We obtained integrated flux densities of a number of SNRs (see Table 1) from the Effelsberg $\lambda 11\text{ cm}$ survey (Fürst et al. 1990; Reich et al. 1990a), $\lambda 21\text{ cm}$ survey (Reich et al. 1990b, 1997), and the $\lambda 21\text{ cm}$ Effelsberg Medium Latitude Survey (EMLS) (Uyaniker et al. 1999) within the same boundary as used for the $\lambda 6\text{ cm}$ integration.

Using the newly determined flux densities at $\lambda 6\text{ cm}$, $\lambda 11\text{ cm}$, and $\lambda 21\text{ cm}$, together with previously published integrated flux densities at other frequencies (see Table 1), we determined the spectral indices α (here $S_\nu \sim \nu^\alpha$) of 15 SNRs, except for SNR G205.5+0.5, where ν is the observing frequency. Flux densities and the determined spectra are shown in Fig. 2. The spectra of a few SNRs were verified by using the TT-plot method (Turtle et al. 1962), i.e. the brightness temperatures T_B at two frequencies are plotted against each other. The brightness temperature spectral index, β , is defined as $T_B = \nu^\beta$. In general, $\beta = \alpha - 2$.

3.1. G192.8–1.1 is not a SNR

G192.8–1.1 (PKS 0607+17) has been proposed as a SNR with an angular extent of about $80'$ (Milne & Hill 1969; Caswell 1970). The non-thermal spectral index derived was $\alpha \sim -0.5$ (Milne & Dickel 1974; Dickel & Denoyer 1975). Berkhuijsen (1974) suggested that G192.8–1.1 is a small part of an even larger SNR, which she called the “Origem Loop” with a diameter of about 5° , but later Caswell (1985) performed high angular resolution ($\sim 1'$) observations at $\lambda 21\text{ cm}$ using the DRAO synthesis telescopes and argued again that G192.8–1.1 is a discrete SNR with a radio spectral index of $\alpha \sim -0.55$. However, previous measurements were limited either by low sensitivity or too coarse angular resolution, which could lead to an incorrect conclusion.

Sensitive survey observations from Urumqi at $\lambda 6\text{ cm}$ (Gao et al. 2010), Effelsberg at $\lambda 11\text{ cm}$ (Fürst et al. 1990), and $\lambda 21\text{ cm}$ (Reich et al. 1997) all covered this object. The $\lambda 6\text{ cm}$ total intensity map shows G192.8–1.1 in the vicinity of a number of bright H II regions (Fig. 3). The H II region to the southeast, SH 2-261, has a distance of 1 kpc (Chavarria-K et al. 1987); the cluster of H II regions, SH 2-254 to 258, to the northwest have distances of about 2.5 kpc (Carpenter et al. 1995). Four individual objects, A ($\ell = 193^\circ 60', b = -1^\circ 50'$), B ($\ell = 193^\circ 20', b = -1^\circ 50'$), C ($\ell = 192^\circ 90', b = -0^\circ 60'$), and D ($\ell = 192^\circ 80', b = -0^\circ 90'$) as indicated in Fig. 3 were discussed by Day et al. (1972) based on their 2.7 GHz Galactic survey data obtained with the Parkes telescope. All of them except source A were believed to be parts of the SNR. The point-like source A was listed as an H II region by Paladini et al. (2003) according to Felli & Churchwell (1972). However, this source also named as 4C 16.15 clearly has a non-thermal spectrum (Vollmer et al. 2005) and is therefore not an H II region. The elongated source B is located west of source A. Caswell (1985) considered source B as part of the SNR shell of G192.8–1.1. We found that source B has a thermal spectrum according to the TT-plot between the Urumqi $\lambda 6\text{ cm}$ and the Effelsberg $\lambda 21\text{ cm}$ survey data. The brightness-temperature spectral index is $\beta = -2.06 \pm 0.06$. In addition, strong infrared emission (see Fig. 3, bottom plot) is visible, which proves its thermal nature.

The enhanced radio emission region where the source C and D reside is regarded as another part of the SNR shell of G192.8–1.1 (Caswell 1985). Source C consists of a few

Fig. 1. Polarization intensity (PI) in greyscale images overlaid by total intensity contours for 16 SNRs (more in next pages). Four of them, G69.0+2.7 (CTB 80), G89.0+4.7 (HB21), G160.9+2.6 (HB9), and G205.5+0.5 (Monoceros Nebula), are presented in page 5 by slightly larger plots. Observed polarization B -field vectors (i.e. PA of the observed E -vector plus 90°) of SNRs were overlaid every $6'$ in case PI exceeds a certain threshold (see below). Their lengths are proportional to PI. The stars indicate the pulsar in G114.3+0.3 and pulsar wind nebula inside G106.3+2.7, G189.1+3.0 (IC 443) and CTB 80. The thick dashed line marks the boundary for flux density integration for G39.7-2.0 (W50), G65.1+0.6, G78.2+2.1, G82.2+5.3 (W63), G106.3+2.7, IC 443, CTB 80, and the western shell of the Monoceros Nebula. All contour lines run from the local 3σ level (see values for each SNR below) in different steps. The contour start level, contour step, and PI threshold for plotted B -vectors (all in mK T_B) are for W50: 13.5, 13.5, 3.0; for G65.1+0.6: 3.9, 5.0, 4.0; for G78.2+2.1: 90.0, 120.0, 15.0; for W63: 9.0, 24.0, 8.0; for G93.7-0.2: 4.5, 12.0, 7.0; for G106.3+2.7: 6.0, 4.2, 3.2; for G114.3+0.3: 4.0, 4.0, 3.8; for G116.5+1.1: 3.6, 4.5, 7.0; for G166.0+4.3 (VRO 42.05.01): 2.1, 5.0, 3.5; for G179.0+2.6: 1.5, 3.5, 2.5; for G206.9+2.3 (PKS 0646+06): 3.0, 4.5, 3.0 for HB21: 3.3, 34.0, 7.5; for HB9: 3.0, 7.5, 7.0. For the Monoceros Nebula: 4.0, 6.0, 4.5. For IC 443, contours start at 7.2 mK T_B and run in steps of $2^{n-1} \times 4.8$ mK T_B ($n = 1, 2, 3, \dots$), the PI threshold is 7.0 mK T_B . For CTB 80, contours start at 3.3 mK T_B and run in steps of $2^{\frac{n-1}{2}} \times 3.3$ mK T_B , and the PI threshold is 10.0 mK T_B .

Fig. 1. continued.

point-like sources including the H II region SH 2-259. It appears slightly extended towards source D at 9.5 angular resolution. Source D was resolved into two sources in the NVSS, and its flux density mainly originates in the source NVSS J060951+172532, which has a spectral index of $\alpha \sim -0.73$ (Vollmer et al. 2005)

and is most likely extragalactic. In summary, sources A, B, C, and D do not seem to be related to the proposed SNR.

The diffuse emission plateau was regarded by Caswell (1985) as part of the SNR. We subtracted all point-like sources including source A and discarded the regions where sources B,

Fig. 1. continued.

C, and D are located. Using the TT-plot method, we found a well-defined flat spectrum with a slope of $\beta = -2.00 \pm 0.07$ between the Urumqi $\lambda 6$ cm and the Effelsberg $\lambda 21$ cm survey data, and $\beta = -1.87 \pm 0.06$ between $\lambda 6$ cm and Effelsberg $\lambda 11$ cm survey data (see Fig. 4). Taking the diffuse infrared emission in this area (Cao et al. 1997) into account, we conclude that the extended emission plateau is of thermal nature.

The diffuse polarization patch in Fig. 3 located between G192.8–1.1 and the H II region SH 2-261 is unrelated to G192.8–1.1.

To summarize, we found a thermal spectrum for the diffuse plateau of G192.8–1.1, which is in contradiction to the non-thermal spectrum reported in previous investigations. The extended source in the southeast, which was regarded as part of the SNR shell, is also identified as a thermal source. No polarized emission from G192.8–1.1 was detected at $\lambda 6$ cm. This “object”, G192.8–1.1, is evidently not a SNR, because it consists of several unresolved H II regions, background radio sources, and a thermal emission plateau.

3.2. G39.7–2.0 (W50)

W50 is an extended SNR located at about 5.5 kpc (Blundell & Bowler 2004; Lockman et al. 2007). It consists of a central

component with a diameter of about 1° and two “ears” extended to the northwest and southeast (see Fig. 1). The spectacular X-ray binary system SS 433 is located at the center of the SNR (e.g. Brinkmann et al. 1996). Two relativistic jets from SS 433 are precessing around the major axis of W50. According to Begelman et al. (1980), the “ears” of W50 are caused by the pressure of these two jets and interact with the ambient H I (Lockman et al. 2007). Jowett & Spencer (1995) mapped SS 443 at 5 GHz with the MERLIN array and detected ejected radio blobs moving away from SS 443. Downes et al. (1981) and Downes et al. (1986) observed the total intensity and the polarized emission of W50 at $\lambda 18$ cm, $\lambda 11$ cm, and $\lambda 6$ cm with the 100-m Effelsberg radio telescope. The spectral index and RM distributions of this SNR were studied in detail.

The Urumqi $\lambda 6$ cm survey clearly shows the SNR W50 with strong polarized emission along its northeastern shell of the central part. SS 433 is seen at the center, but the related radio jets (Jowett & Spencer 1995) cannot be resolved. We obtained integrated flux densities of $S_{6\text{ cm}} = 37.0 \pm 3.8$ Jy from the Urumqi survey data, $S_{11\text{ cm}} = 51.5 \pm 5.2$ Jy and $S_{21\text{ cm}} = 69.7 \pm 7.1$ Jy from the Effelsberg $\lambda 11$ cm and $\lambda 21$ cm survey data. All of these agree with the values obtained by Downes et al. (1981, 1986) and Dubner et al. (1998). Using these flux densities together with

Table 1. Integrated flux densities, polarization intensities and derived spectral indexes for 15 large SNRs (not including G205.5+0.5, see text).

SNR name	$S_{\lambda 6 \text{ cm}}$ (Jy)	$PI_{\lambda 6 \text{ cm}}$ (Jy)	$S_{\lambda 11 \text{ cm}}$ (Jy)	$S_{\lambda 21 \text{ cm}}$ (Jy)	New α	Prev. $S_{\lambda 6 \text{ cm}}$ (Jy)	Ref.	Prev. α	Ref.	Ref. for S_{ν} at other freq. (ν)
G39.7-2.0 (W50)	37.0 ± 3.8	5.3 ± 0.6	51.5 ± 5.2	69.7 ± 7.1	-0.48 ± 0.03	34 ± 4	2	-0.48 ± 0.03	3	1, 2, 3, 4
G65.1+0.6	3.2 ± 0.3	0.8 ± 0.1	...	5.4 ± 0.6	-0.45 ± 0.04	...	...	-0.61 ± 0.09	6	5, 6, 7
G69.0+2.7 (CTB 80)	35.6 ± 3.9	4.7 ± 0.5	47.6 ± 5.0	56.7 ± 6.3	...	44.0 ± 3.3	9	-0.45 ± 0.03	6	6, 8, 9, 10
G78.2+2.1	170 ± 18	1.2 ± 0.1	222 ± 23	...	-0.48 ± 0.03	150 ± 15	11	-0.51 ± 0.03	6	6, 11, 12, 13, 14
G82.2+5.3 (W63)	48.5 ± 4.9	7.5 ± 0.8	...	93.1 ± 9.5	-0.44 ± 0.04	$>38.5 \pm 4.0$	15	-0.48 ± 0.04	6	6, 15, 16
G89.0+4.7 (HB21)	107 ± 11	11.3 ± 1.1	...	...	-0.36 ± 0.03	103 ± 18	17	-0.38 ± 0.03	6	6, 16, 17, 18
G93.7-0.2	25.0 ± 2.5	5.2 ± 0.5	35.9 ± 3.6	39.6 ± 4.0	-0.52 ± 0.03	33.5 ± 4.0	14	-0.65 ± 0.03	6	6, 19, 20, 21, 22
G106.3+2.7	2.0 ± 0.3	0.4 ± 0.1	3.1 ± 0.3	5.0 ± 0.6	-0.64 ± 0.04	...	...	-0.61 ± 0.07	6	6, 23
G114.3+0.3	6.9 ± 0.7	0.9 ± 0.1	...	10.8 ± 1.1	-0.31 ± 0.10	...	...	-0.49 ± 0.25	6	24
G116.5+1.1	5.7 ± 0.6	1.6 ± 0.2	...	10.3 ± 1.1	-0.45 ± 0.05	...	...	-0.53 ± 0.08	6	6, 24, 25
G160.9+2.6 (HB9)	33.9 ± 3.4	5.3 ± 0.5	...	...	-0.59 ± 0.02	36 ± 8	26	-0.64 ± 0.02	6	6, 16, 26, 27, 28
G166.0+4.3 (VRO 42.05.01)	3.3 ± 0.3	0.6 ± 0.1	...	...	-0.33 ± 0.04	...	...	-0.37 ± 0.03	6	6, 18, 29
G179.0+2.6	3.2 ± 0.3	0.4 ± 0.1	5.0 ± 0.5	5.4 ± 0.6	-0.45 ± 0.11	3.6 ± 0.8	30	-0.30 ± 0.15	30	30
G189.1+3.0 (IC443)	84.6 ± 9.4	2.6 ± 0.3	...	...	-0.38 ± 0.01	79 ± 11	31	-0.36 ± 0.02	31	16, 31
G206.9+2.3 (PKS 0646+06)	2.9 ± 0.3	0.4 ± 0.1	3.9 ± 0.4	5.1 ± 0.6	-0.47 ± 0.04	...	...	-0.45 ± 0.03	32	32

Notes. The integrated flux densities at $\lambda 6$ cm, $\lambda 11$ cm and $\lambda 21$ cm are newly extracted from the Urumqi $\lambda 6$ cm survey and the Effelsberg surveys are also listed. The newly derived spectral indices and the previously published flux densities at $\lambda 6$ cm, spectral indices of SNRs and their references are listed for comparison. References for flux densities at other frequencies are given in the last column.

References. (1) Downes et al. (1981), (2) Downes et al. (1986), (3) Dubner et al. (1998), (4) Kovalenko et al. (1994), (5) Landecker et al. (1990), (6) Kothes et al. (2006b), (7) Tian & Leahy (2006b), (8) Castelletti et al. (2003), (9) Mantovani et al. (1985), (10) Velusamy et al. (1976), (11) Wendker et al. (1991), (12) Higgs et al. (1977), (13) Pineault & Chastenay (1990), (14) Zhang et al. (1997), (15) Higgs et al. (1991), (16) Reich et al. (2003), (17) Hirabayashi & Takahashi (1972), (18) Willis (1973), (19) Velusamy & Kundu (1974), (20) Mantovani et al. (1982), (21) Landecker et al. (1985), (22) Mantovani et al. (1991), (23) Pineault & Jocas (2000), (24) Tian & Leahy (2006a), (25) Reich & Braunsfurth (1981), (26) Dwarakanath et al. (1982), (27) Roger et al. (1999), (28) Leahy & Tian (2007), (29) Leahy & Tian (2005), (30) Fürst & Reich (1986), (31) Erickson & Mahoney (1985), (32) Graham et al. (1982).

Fig. 2. Flux densities at various frequencies were used to derive the integrated radio spectra for 15 SNRs (not including G205.5+0.5). The black dots indicate the newly derived flux density at $\lambda 6$ cm from the Urumqi observations, and the triangles for the newly derived flux densities from the Effelsberg $\lambda 11$ cm and $\lambda 21$ cm surveys. The open circles are integrated flux densities taken from literature (see references in Table 1).

previously published integrated flux densities, we derived an overall spectral index of $\alpha = -0.48 \pm 0.03$, consistent with that found by [Dubner et al. \(1998\)](#). The TT-plot using the Urumqi $\lambda 6$ cm and Effelsberg $\lambda 11$ cm survey data gave $\beta = -2.41 \pm 0.01$ for the central part, $\beta = -2.52 \pm 0.02$ for the southeast “ear”, and $\beta = -2.57 \pm 0.14$ for the northwest “ear”, respectively. The central part appears to have a slightly flatter spectrum than the southeast “ear”, confirming the finding of [Downes et al. \(1986\)](#).

3.3. G65.1+0.6

G65.1+0.6 was first identified as a faint shell-type SNR by [Landecker et al. \(1990\)](#) from 408 MHz and 1420 MHz observations with the DRAO Synthesis Telescope. It shows strong southern shell emission, while its emission in the north is rather diffuse. [Tian & Leahy \(2006b\)](#) analyzed CGPS H I data and proposed a SNR distance of 9.2 kpc. Polarization from the southern

Fig. 3. *Top:* total intensity (I) image at $\lambda 6$ cm for G192.8–1.1 (PKS 0607+17) and its surroundings. The “background filtering” technique was used to remove large-scale emission. Contours start at $3.0 \text{ mK } T_B$ (3σ level) and run in steps of $5.0 \text{ mK } T_B$. The big rectangle area includes the G192.8–1.1, which was used for the TT-plot analysis by excluding the two areas marked by white small rectangles. *Middle:* PI image of G192.8–1.1 area (PKS 0607+17) at $\lambda 6$ cm. The same total intensity contours are overlaid as in the *top* plot. Bars are plotted for observed B -vectors (i.e. $PA + 90^\circ$) at $\lambda 6$ cm if $PI \geq 6 \text{ mK } T_B$. *Bottom:* infrared image at $60 \mu\text{m}$ of the same area (Cao et al. 1997) overlaid by $\lambda 6$ cm I contours.

Fig. 4. TT-plot for the G192.8–1.1 “plateau” using the Urumqi $\lambda 6$ cm and the Effelsberg $\lambda 21$ cm (1408 MHz) survey data (*top panel*) and the $\lambda 6$ cm and the Effelsberg $\lambda 11$ cm (2695 MHz) survey data (*bottom panel*).

shell was already observed at $\lambda 6$ cm with the Effelsberg 100-m telescope (Seiradakis et al. 1985). Despite a smaller beam, no polarized emission was detected with the Effelsberg 100-m telescope at $\lambda 11$ cm (Duncan et al. 1999) indicating significant depolarization at that wavelength. This is not unexpected in view of the large distance of the SNR.

Our $\lambda 6$ cm data confirm the oval shape of G65.1+0.6 (see Fig. 1). We obtained an integrated flux density at $\lambda 6$ cm of $S_{6 \text{ cm}} = 3.2 \pm 0.3 \text{ Jy}$. We also calculated the $\lambda 21$ cm integrated flux density from the Effelsberg $\lambda 21$ cm survey to be $S_{21 \text{ cm}} = 5.4 \pm 0.6 \text{ Jy}$. This value is consistent with those quoted by Landecker et al. (1990) and Tian & Leahy (2006b) from the CGPS, which used the Effelsberg $\lambda 21$ cm survey for missing zero-spacings. Using these flux densities together with the flux densities at 408 MHz (Landecker et al. 1990; Kothés et al. 2006b; Tian & Leahy 2006b) and other bands (see references in Table 1), we obtained a radio spectral index of $\alpha = -0.45 \pm 0.04$ (see Fig. 2).

We detected very weak polarization at $\lambda 6$ cm (see Fig. 1), which seems to be related to the SNR shell, as the magnetic field direction is almost tangential.

3.4. G69.0+2.7 (CTB 80)

CTB 80 is a SNR with an enigmatic shape. It consists of a bright pulsar wind nebula (PWN) in its center, a diffuse emission plateau and three major arms (Angerhofer et al. 1981; Mantovani et al. 1985). Its distance is 2 kpc (Koo et al. 1990). A young energetic pulsar, PSR B1951+32, with $\dot{E} = 3.7 \times 10^{36} \text{ erg s}^{-1}$ was discovered in the central core region (Kulkarni et al. 1988). Strong polarized emission of CTB 80 was observed, which varies with frequency (Mantovani et al. 1985). The overall radio spectral index is $\alpha = -0.45 \pm 0.03$ (Kothés et al. 2006b). A possible spectral break at a low frequency below 1 GHz was noted by Mantovani et al. (1985) and Castelletti et al. (2003).

The morphology of CTB 80 from the $\lambda 6$ cm observations (see Fig. 1) generally agrees with previous results. We see faint extended emission from the eastern arm (E-arm) extending to about $\ell \sim 70^\circ 0$, in agreement with the observations by

Mantovani et al. (1985). This part of CTB 80 is highly polarized at $\lambda 6$ cm, and seen in the polarization map at 1.4 GHz (Kothes et al. 2006b). The apparent size of this SNR measured from the $\lambda 6$ cm map is about $128'$ from east to west and about $96'$ in the south-north direction, which implies that it has a physical size of $74 \text{ pc} \times 56 \text{ pc}$ at 2 kpc. In the $\lambda 6$ cm map, we detected diffuse extended emission in the southwest between the W-arm and S-arm.

We investigated the spectral index distribution in the central core region and the three arms using Urumqi $\lambda 6$ cm and Effelsberg $\lambda 21$ cm survey data for TT-plots (not shown in this paper). We confirmed the flat spectrum in the central core with a brightness temperature spectral index of $\beta = -1.97 \pm 0.20$. We derived $\beta = -2.49 \pm 0.03$ for the western arm (W-arm), $\beta = -2.38 \pm 0.04$ for the southern arm (S-arm), and $\beta = -2.28 \pm 0.01$ for the eastern arm (E-arm) and the outer extension.

To get the spectrum of CTB 80 from integrated flux densities, we set the SNR boundary according to the maps at four frequencies above 1 GHz published by Mantovani et al. (1985), and outlined by the dashed line in Fig. 1. After subtracting all background radio sources, we calculated an integrated flux density at $\lambda 6$ cm of $S_{6 \text{ cm}} = 35.6 \pm 3.9 \text{ Jy}$, slightly lower than that quoted by Mantovani et al. (1985). In the same area, we got the $\lambda 11$ cm and $\lambda 21$ cm flux densities from the Effelsberg survey data as $S_{11 \text{ cm}} = 47.6 \pm 5.0 \text{ Jy}$ and $S_{21 \text{ cm}} = 56.7 \pm 6.3 \text{ Jy}$, respectively. Using these three well-determined new flux densities, we got the spectral index of $\alpha = -0.38 \pm 0.13$ (see Fig. 2). As noticed by Mantovani et al. (1985), the spectral index of CTB 80 at higher frequencies should be considerably flatter than previously thought (Velusamy & Kundu 1974; Sofue et al. 1983).

Flux densities available from literatures are shown in Fig. 2. Taking the three newly obtained flux densities into account, the spectrum of this SNR seems to be flat below about 1 GHz. However, owing to the scattered data at low frequencies the spectral shape is difficult to assess. Castelletti & Dubner (2005) discussed a possible low-frequency spectral turn-over. However, free-free thermal absorption, which may produce such a spectral break, would be inconsistent with the low DM of the central pulsar, PSR B1951+32 ($\text{DM} = 45 \text{ pc cm}^{-3}$, Hobbs et al. 2004).

Intense $\lambda 6$ cm polarized emission pervades nearly the entire SNR. We found B -field vectors running almost continuously along the southern and the western arm, but vary in the eastern arm. The weaker and discontinuous polarized emission in the middle of the eastern arm is probably due to internal cancellation by the superposition of polarization vectors orientated in different directions. In the outer extension of the eastern arm the percentage polarization is up to 50%. In the western arm, the polarization fraction is about 14%, while in the southern arm, the percentage increases from north to the south with an average value of about 21%.

3.5. G78.2+2.1

The SNR G78.2+2.1 is located in the direction of the Cygnus X region. It was suggested and confirmed to be a large SNR by Higgs (1977) and Higgs et al. (1977) based on radio maps at $\lambda 3$ cm and $\lambda 21$ cm. Its distance is about 1.5 kpc (Landecker et al. 1980). A few H II regions were detected near its shell. The well-known H II region γ Cygni Nebula overlaps with the bright southern shell. The H II region G78.3+2.8 (Sabbadin 1976) is located to the north of the SNR, while the H II region IC 1318b is seen in the southeast direction. Several methods have been tried to separate non-thermal and thermal emission in the Cygnus X area (Wendker et al. 1991; Zhang et al. 1997;

Fig. 5. TT-plot for G78.2+2.1 using the Urumqi $\lambda 6$ cm and Effelsberg $\lambda 11$ cm survey data.

Ladouceur & Pineault 2008) to study the SNR emission without the dominating thermal background. Spectral index variations within the SNR were discussed in detail by Zhang et al. (1997) and later by Ladouceur & Pineault (2008) with a higher angular resolution of $4'.5 \times 2'.9$.

The Urumqi $\lambda 6$ cm total intensity image (see Fig. 1) shows two bright unresolved shell sections in the north and south and the central weak extended emission. Not many detailed structures can be recognized because of the angular resolution of $9'.5$. The boundary of the SNR is difficult to determine in the Urumqi $\lambda 6$ cm map, since the shell sections of the SNR merge with ambient H II regions. We subtracted the H II region G78.3+2.8 from the map using Gaussian fitting, and removed point-like sources as described in Sect. 3. After discounting the flux density of the γ Cygni Nebula, $S_{6 \text{ cm}} = 4.3 \text{ Jy}$ (Wendker et al. 1991), we obtained an integrated flux density of this SNR as $S_{6 \text{ cm}} = 170 \pm 18 \text{ Jy}$, consistent with the value of $S_{6 \text{ cm}} = 150 \pm 15 \text{ Jy}$ measured by Wendker et al. (1991). We derived $S_{11 \text{ cm}} = 222 \pm 23 \text{ Jy}$ for the Effelsberg $\lambda 11$ cm survey data. Combining the flux densities reported at other wavelengths, we obtained an overall spectral index of $\alpha = -0.48 \pm 0.03$, consistent with the result of Kothes et al. (2006b). The TT-plot for the SNR using Urumqi $\lambda 6$ cm and Effelsberg $\lambda 11$ cm survey data (Fig. 5) gives $\beta = -2.47 \pm 0.04$, which agrees with the spectrum derived from integrated flux intensities.

The $\lambda 6$ cm polarization data in this area are largely confused with residual instrumental effects, e.g., some horizontal stripes from the strong Cygnus X region emission.

3.6. G82.2+5.3 (W63)

W63 is a shell-type SNR located at a high Galactic latitude north of the Cygnus X complex. In this area, filamentary structures and strong diffuse Galactic background emission exist, which might confuse with emission from this SNR. Some radio filaments coincide with optical emission. They are most probably thermal and unrelated to the SNR (Wendker 1971). Angerhofer et al. (1977) mapped W63 at $\lambda 6$ cm, but did not present a complete map. They reported a lower flux density limit of $S_{6 \text{ cm}} \geq 38.5 \pm 4.0 \text{ Jy}$. From the Urumqi $\lambda 6$ cm observations, we obtained complete total intensity and polarization maps for W63 at $\lambda 6$ cm (see Fig. 1). We checked the properties of the two major filaments centered at $\ell = 81^\circ 80', b = 6^\circ 10'$ and $\ell = 83^\circ 20', b = 5^\circ 60'$ (marked with “W-fila” and “E-fila” in

Fig. 6. TT-plot for the two filaments aside of G82.2+5.3 (W63) indicated in Fig. 1 using the Urumqi $\lambda 6$ cm and Effelsberg $\lambda 21$ cm data.

Fig. 7. $H\alpha$ emission (from Finkbeiner 2003) overlaid by Urumqi $\lambda 6$ cm total intensity contours and B vectors (i.e. PA + 90°) from the SNR G82.2+5.3 (W63). Contours start at 9.0 mK T_B and run in steps of 24.0 mK T_B . B-field vector lengths are proportional to the polarization intensities.

Fig. 1). The brightness-temperature spectral index from the TT-plot (Fig. 6) using the Urumqi $\lambda 6$ cm and Effelsberg Medium Latitude Survey (EMLS) $\lambda 21$ cm data (Uyaniker et al. 1999) is $\beta = -2.05 \pm 0.07$ for the western filament (W-fila) and $\beta = -2.05 \pm 0.01$ for the eastern filament (E-fila) (Fig. 6). The $H\alpha$ map (Fig. 7) clearly shows the two bright filaments and their extensions beyond W63, which proves their thermal nature. Therefore, we discounted these two filaments in the flux density integration and got $S_{6\text{ cm}} = 48.5 \pm 4.9$ Jy. We also calculated the integrated flux density at $\lambda 21$ cm for the same area from the EMLS (Uyaniker et al. 1999), $S_{21\text{ cm}} = 93.1 \pm 9.5$ Jy. Combining all available flux densities, we obtained a spectral index of $\alpha = -0.44 \pm 0.04$.

Strong polarized $\lambda 6$ cm emission was detected within the SNR, where the strongest polarized emission coincides with the area of minimum total intensity, similar to what was seen at $\lambda 11$ cm by Velusamy & Kundu (1974). Polarized emission at

$\lambda 21$ cm is visible within the SNR with a percentage polarization of about 4% to 11% in the area, where the $\lambda 6$ cm polarization is up to 66%. We noticed that the $H\alpha$ emission (Finkbeiner 2003) is relatively low in an area almost coinciding with the high polarization of W63 (see Fig. 7). This suggests that the observed $H\alpha$ emission is probably in the foreground of W63 and causes depolarization in other parts of the SNR.

3.7. G89.0+4.7 (HB21)

HB21 is a strong, large, and evolved SNR with an unusual complex morphology (see Fig. 1). It has been observed at many frequencies from 38 MHz (Crowther 1965) to 5 GHz (Kundu 1971). The distance to the SNR was estimated to be about 800 ± 70 pc (Tatematsu et al. 1990). HB21 resides in an area of relatively low Galactic emission and has a well-defined outer boundary, which allows us to obtain integrated flux densities without any confusion problem.

HB21 was partly covered by the 1.4 GHz polarization survey of the Galactic plane by Landecker et al. (2010) with $1'$ angular resolution, where data from the DRAO interferometer were combined with Effelsberg 100-m and DRAO 26-m telescope data. At that frequency, HB21 appears almost depolarized with the possible exception of a few discrete patches in this direction.

The $\lambda 6$ cm total intensity and polarization intensity maps resemble the previous $\lambda 6$ cm observations presented by Kundu (1971). We obtained an integrated flux density of $\lambda 6$ cm map as $S_{6\text{ cm}} = 107 \pm 11$ Jy. Including other available flux densities for a wide frequency range (see references in Table 1), we fitted a spectral index of $\alpha = -0.36 \pm 0.03$. The $\lambda 6$ cm polarization map shows that polarization angles are not regularly ordered. Some depolarized “canals” are visible, where the PAs on both sides differ by 90° . At the angular resolution of $9.5'$ of the $\lambda 6$ cm observations, details are smoothed out.

3.8. G93.7–0.2

SNR G93.7–0.2 is a shell-type SNR with two major thick brightened limbs and a few diffuse extensions. The extensions were regarded as possible “break-out” phenomenon (Uyaniker et al. 2002). Polarized emission of G93.7–0.2 is found to be widely spread at 4.75 GHz (Mantovani et al. 1991) and patchy at 1.4 GHz because of depolarization (Uyaniker et al. 2002). The distance to G93.7–0.2 was found to be about 1.5 kpc (Uyaniker et al. 2002).

The $\lambda 6$ cm I map (Fig. 1) shows all extensions previously reported. The eastern extension at about $\ell = 94^\circ 50'$, $b = 0^\circ 30'$ is not part of the SNR but is an H II region (Uyaniker et al. 2002). We found another H II region at $\ell = 94^\circ 85'$, $b = -0^\circ 05'$, where the TT-plot between the Urumqi $\lambda 6$ cm and the Effelsberg $\lambda 21$ cm survey data (not shown in this paper) gave a brightness-temperature spectral index of $\beta = -2.11 \pm 0.11$. Discarding point-like sources and the thermal extensions, we obtained an integrated flux density of $S_{6\text{ cm}} = 25.0 \pm 2.5$ Jy, lower than that reported by Mantovani et al. (1991). We obtained $S_{21\text{ cm}} = 39.6 \pm 4.0$ Jy and $S_{11\text{ cm}} = 35.9 \pm 3.6$ Jy from the Effelsberg survey data in the same area. Combining these new flux densities with those in the literature, we obtained an overall spectral index for G93.7–0.2 of $\alpha = -0.52 \pm 0.03$.

The polarized emission of SNR G93.7–0.2 we detected at $\lambda 6$ cm agrees with the observational results by Mantovani et al. (1991).

Fig. 8. TT-plot of the SNR G114.3+0.3 using the Urumqi $\lambda 6$ cm and Effelsberg $\lambda 21$ cm survey data.

Fig. 9. The same as shown in Fig. 8, but for the SNR G116.5+1.1.

3.9. G106.3+2.7

G106.3+2.7 is a comet-shaped SNR discovered by [Joncas & Higgs \(1990\)](#) from the DRAO northern Galactic plane survey at 408 MHz, and further studied by [Pineault & Joncas \(2000\)](#). The SNR consists of a compact “head” region containing an off-center PWN G106.6+2.9 in the north, the so-called “Boomerang” and a diffuse “tail” region (see Fig. 1). On the basis of the linearly polarized emission of the SNR, H I, and CO measurements, [Kothés et al. \(2001\)](#) argued that both the PWN and the SNR resulted from the same SN event at a distance of 800 pc. The “head” region is created by the interaction between the expanding blast wave and the ambient dense material, while the “tail” region is an outbreak to the interior of an H I bubble. [Kothés et al. \(2006a\)](#) performed a multi-frequency analysis towards the PWN and found a spectral break at about 4.3 GHz. The overall spectral index of the whole SNR is $\alpha \sim -0.6$, while the compact “head” region has a flatter spectrum than the “tail” region ([Pineault & Joncas 2000](#)).

Observations of the entire SNR at $\lambda 6$ cm have never been made. The Urumqi $\lambda 6$ cm map shows a compact “head”, while the elongated “tail” region is confused by diffuse emission in the west. The PWN, as indicated by a star in Fig. 1, cannot be resolved in the $\lambda 6$ cm map. To determine the integrated flux density of G106.3+2.7 at $\lambda 6$ cm, we adapt the integration boundary from the Effelsberg $\lambda 21$ cm survey map, which can be more clearly defined. We obtained $S_{6\text{ cm}} = 2.0 \pm 0.3$ Jy from the Urumqi map, and both $S_{11\text{ cm}} = 3.1 \pm 0.3$ Jy and $S_{21\text{ cm}} = 5.0 \pm 0.6$ Jy from the Effelsberg maps. Using these flux densities, together with published flux densities at other frequencies, we obtained an integrated spectral index of $\alpha = -0.64 \pm 0.04$.

Strong polarized emission of SNR G106.3+2.7 was detected at $\lambda 6$ cm. The average percentage polarization is about 25% with maxima around 42%.

3.10. G114.3+0.3

G114.3+0.3 was identified as a low surface brightness shell-type SNR by [Reich & Braunsfurth \(1981\)](#). It is located in the local arm at about 700 pc distance ([Yar-Uyaniker et al. 2004](#)). The pulsar B2334+61, indicated by a star in Fig. 1, is located near the SNR center, and physically associated with the SNR ([Fürst et al. 1993](#); [Kulkarni et al. 1993](#)). The spectral index of this SNR cannot be clearly determined because of its low surface brightness. [Reich & Braunsfurth \(1981\)](#) quoted a spectral index

$\alpha = -0.31 \pm 0.1$ from flux densities at $\lambda 21$ cm and $\lambda 11$ cm. [Tian & Leahy \(2006a\)](#) used the TT-plot method for the 408 MHz and 1420 MHz CGPS data and obtained $\alpha = -0.16 \pm 0.41$.

No other $\lambda 6$ cm observations of G114.3+0.3 have so far been reported. The map of this elliptical-shaped SNR is presented in Fig. 1. The ridges of strong continuum emission in the southwest and southeast directions are clearly visible. After removing all point-like sources including the bright H II region, SH 2-165, in the eastern part of SNR ([Reich & Braunsfurth 1981](#)), we calculated an integrated flux density of $S_{6\text{ cm}} = 6.9 \pm 0.7$ Jy. From the Effelsberg $\lambda 21$ cm survey, we obtained an integrated flux density $S_{21\text{ cm}} = 10.8 \pm 1.1$ Jy, which agrees with that obtained by [Tian & Leahy \(2006a\)](#). Using these flux density data, as well as the value measured at 408 MHz from [Tian & Leahy \(2006a\)](#) despite its large uncertainties, we got a spectral index of $\alpha = -0.31 \pm 0.10$ (see Fig. 2). This spectrum index can be verified by the TT-plot between the Urumqi $\lambda 6$ cm and Effelsberg $\lambda 21$ cm survey data as $\beta = -2.30 \pm 0.12$ (Fig. 8).

Polarized emission of this SNR mainly comes from the central and southern parts, and is very strong along the southern edge. When we compared the PA = -15° at $\lambda 11$ cm ([Reich & Braunsfurth 1981](#)) in a region centered at about $\ell = 114^\circ 50'$, $b = 0^\circ 25'$ with the PA = 45° we observed at $\lambda 6$ cm, we found that $RM = -120$ rad m^{-2} for the SNR, which is consistent with RM of the pulsar PSR B2334+61, $RM = -100 \pm 18$ rad m^{-2} ([Mittra et al. 2003](#)).

3.11. G116.5+1.1

G116.5+1.1 is a shell-type SNR discovered by [Reich & Braunsfurth \(1981\)](#). Its distance is 1.6 kpc ([Yar-Uyaniker et al. 2004](#)). [Tian & Leahy \(2006a\)](#) derived a spectral index of $\alpha = -0.28 \pm 0.15$ from the 408 MHz and 1420 MHz CGPS data, while [Kothés et al. \(2006b\)](#) calculated $\alpha = -0.16 \pm 0.11$. By supplementing the flux densities measured at $\lambda 21$ cm and $\lambda 11$ cm ([Reich & Braunsfurth 1981](#)), [Kothés et al. \(2006b\)](#) found a steeper overall spectral index of $\alpha = -0.53 \pm 0.08$.

We obtained the first total intensity and polarization measurements for G116.5+1.1 at $\lambda 6$ cm. The integrated flux density was found to be $S_{6\text{ cm}} = 5.7 \pm 0.6$ Jy. We also obtained $S_{21\text{ cm}} = 10.3 \pm 1.1$ Jy from the Effelsberg $\lambda 21$ cm survey data and calculated an overall radio spectral index of $\alpha = -0.45 \pm 0.05$. The TT-plot was used to verify this result (see Fig. 9).

Intense polarized emission is detected from the western and northern parts of the shell of this SNR. In the western part,

B -field vectors (i.e. $PA + 90^\circ$) are aligned tangentially to the shell at $\lambda 6$ cm. By comparing them with the PAs observed at $\lambda 11$ cm by Reich & Braunsfurth (1981, see their Fig. 2b), we estimated the RM . The PA values in the region around $\ell = 116^\circ 05', b = 1^\circ 25'$ at $\lambda 11$ cm and $\lambda 6$ cm are $PA_{11\text{ cm}} \sim 40^\circ$ and $PA_{6\text{ cm}} \sim 100^\circ$, so the calculated $RM \sim -120 \text{ rad m}^{-2}$, is the same as that for SNR G114.3+0.3.

3.12. G160.9+2.6 (HB9)

HB9 is a strong large nearby SNR that has been mapped at radio frequencies from 10 MHz (Caswell 1976) to 5 GHz (DeNoyer 1974). We note that the designation G160.9+2.6 is based on early radio maps. The center of HB9 is at $\ell = 160^\circ 4', b = 2^\circ 8'$. The SNR has a distance of 0.8 ± 0.4 kpc (Leahy & Tian 2007). HB9 has multiple fragmented shells and internal filamentary structures. Reich et al. (2003) reported a spectral index of $\alpha = -0.57 \pm 0.03$ based on a TT-plot between 865 MHz data and 4750 MHz Effelsberg data. Kothes et al. (2006b) compiled integrated flux densities at many frequencies and obtained a spectral index of $\alpha = -0.64 \pm 0.02$.

From the Urumqi $\lambda 6$ cm survey we calculated an integrated flux density of $S_{6\text{ cm}} = 33.9 \pm 3.4$ Jy, which is consistent with the value of 36 ± 8 Jy previously reported by DeNoyer (1974) at 5 GHz. Using our $\lambda 6$ cm flux density and those at lower frequencies (see Table 1), we calculated a spectral index of $\alpha = -0.59 \pm 0.02$, in agreement with that of Reich et al. (2003).

The polarized emission of HB9 at $\lambda 6$ cm was previously mapped with the 100-m Effelsberg telescope to find the intrinsic magnetic field configuration within the SNR, by using in addition polarization data at $\lambda 11$ cm and $\lambda 21$ cm (Fürst & Reich 2004). Our polarization map at $\lambda 6$ cm of HB9 has lower angular resolution. Strong polarization is seen in a few patches near the southern, northern, and eastern periphery of the shell.

3.13. G166.0+4.3 (VRO 42.05.01)

VRO 42.05.01 has an unusual morphology as it consists of two shells with significantly different radii (see Fig. 1). Pineault et al. (1987) interpreted this unusual morphology by modeling the southern shell (wing region) expanding from the dense warm medium surrounding the northern shell into a hot tunnel of very low density (see their Fig. 3). Kothes et al. (2006b) calculated an overall radio spectral index of $\alpha = -0.37 \pm 0.03$. Leahy & Tian (2005) studied the distribution of the spectral indices across the SNR and found that the spectral index in the southern wing is steeper than elsewhere.

We measured an integrated flux density of $S_{6\text{ cm}} = 3.3 \pm 0.3$ Jy, and derived an overall spectral index of $\alpha = -0.33 \pm 0.04$ using available data (see references in Table 1), which is consistent with previous results. By comparing the Urumqi $\lambda 6$ cm and Effelsberg $\lambda 21$ cm survey data, we confirm that the southern wing has a steeper spectral index. We calculated a brightness-temperature spectral index of $\beta_{6-21} = -2.33 \pm 0.05$ for the northern shell (head region) and $\beta_{6-21} = -2.49 \pm 0.09$ for the southern wing.

Both the northern head region and the southern wing region of VRO 42.05.01 emit strong polarized emission. B -field vectors in the head region and the eastern part of the wing region run almost tangential to the shell, while significant deviations are seen for the western part of the wing region indicating a significant RM within the SNR. Assuming the initial B -fields run tangential

along the wing, the deviation of B -field vectors indicates that $|RM|$ is about 130 rad m^{-2} .

3.14. G179.0+2.6

G179.0+2.6 is a thick shell-type SNR identified and studied by Fürst & Reich (1986) using $\lambda 21$ cm, $\lambda 11$ cm, and $\lambda 6$ cm data observed with the Effelsberg 100-m telescope. A polarized triple source near the center of the SNR was identified from high angular resolution VLA observations and by optical identification as a background double-sided radio galaxy (Fürst et al. 1989). The overall spectral index of the SNR was found to be about $\alpha = -0.30 \pm 0.15$.

After we discounted the flux contribution of 15 point-like sources listed in the NVSS catalogue (Condon et al. 1998), we obtained an integrated flux density of SNR G179.0+2.6 as $S_{6\text{ cm}} = 3.2 \pm 0.3$ Jy. The flux densities we obtained from the Effelsberg $\lambda 21$ cm and $\lambda 11$ cm survey are $S_{21\text{ cm}} = 5.4 \pm 0.6$ Jy and $S_{11\text{ cm}} = 5.0 \pm 0.5$ Jy. Because Fürst & Reich (1986) removed only the strongest source 4C 31.21 within the area of the SNR when calculating the integrated flux density, our results with an improved assessment of background source contribution are more accurate and reveal an overall spectral index for SNR G179.0+2.6 of $\alpha = -0.45 \pm 0.11$ (see Fig. 2).

A radial configuration of the magnetic field of SNR G179.0+2.6 was revealed by Fürst & Reich (1986) that is confirmed by the Urumqi $\lambda 6$ cm polarization observations. Such a magnetic field configuration is usually seen in young SNRs, although the low surface brightness of G179.0+2.6 indicates that it is an evolved object. When the SNR is barrel-shaped, but viewed along its poles as described by Whiteoak & Gardner (1968) the magnetic field appears radial, although the magnetic field lines are tangential to the compressed shell. The observed radio emission is weak. This scenario would require that the regular Galactic magnetic field in the area of G179.0+2.6 is orientated along the line of sight. This is unexpected for the Galactic anti-center, where the regular magnetic field is believed to run almost tangential to the line of sight.

3.15. G189.1+3.0 (IC 443)

IC443 is a “mixed-morphology” type SNR (Rho & Petre 1998), that is distinct from the three well-defined SNR types: shell-like, Crab-like, and composite. It interacts with a molecular cloud (Burton et al. 1988; van Dishoeck et al. 1993; Cesarsky et al. 1999). This SNR has been extensively observed throughout the whole electromagnetic spectrum (e.g. Mufson et al. 1986; Albert et al. 2007). Kundu & Velusamy (1968) collected flux densities at five frequencies from 430 MHz to 5 GHz, and suggested a spectral break around 750 MHz towards the brightened north-western shell. Erickson & Mahoney (1985) proposed a possible overall spectral break below 20 MHz. According to Green (1986), spectral indices vary across IC 443. Leahy (2004) found that the brightened northwestern shell region has a radio spectral index of $\alpha = -0.43 \pm 0.02$, while in the fainter southern part α varies with values ranging from -0.2 to -0.6 .

As in the $\lambda 11$ cm map by Fürst et al. (1990), the $\lambda 6$ cm map of IC 443 in Fig. 1 shows strong radio emission from the SNR, as outlined by the dashed line, and also the weaker unpolarized thermal emission from the extended H II region SH 2-249 north of the remnant. For IC 443, we obtained an integrated flux density from the $\lambda 6$ cm map of $S_{6\text{ cm}} = 84.6 \pm 9.4$ Jy. Together with

flux densities at other frequencies (see references in Table 1), we calculate an overall radio spectral index of $\alpha = -0.38 \pm 0.01$.

The Urumqi $\lambda 6$ cm polarization image (Fig. 1) shows a similar dipole-shaped magnetic field configuration as earlier noted by Kundu & Velusamy (1969) and Dickel & Milne (1976). The radial configuration of the magnetic fields observed at $\lambda 6$ cm seems to be intrinsic. The question is whether and how the field structure is related to the PWN inside IC 443. Olbert et al. (2001) and Bocchino & Bykov (2001) identified the PWN from hard X-ray observations with a compact head at about $\ell = 189^\circ.2$, $b = 2^\circ.9$ near the center of the dipole-shaped B fields (as indicated by a star in Fig. 1). Gaensler et al. (2006) found that inside IC 443 the X-ray source G189.22+2.9 is a thermally emitting neutron star moving through the hot plasma. The distance to the SNR IC 443 was noted to be about 1.5 kpc (Fesen 1984). At this distance, a 1° scale corresponds to the size of 26 pc, much larger than the typical PWN size of a few pc. It is thus unlikely that the PWN is responsible for the whole dipole-shaped B field observed (see Fig. 1). However, our data have insufficient angular resolution to clarify the role of the PWN inside IC 443 and determine the origin of the radial magnetic field configuration seen in IC 443.

From the X-ray image of ROSAT, Asaoka & Aschenbach (1994) detected a large ($\sim 1.5^\circ$ in diameter) and very faint X-ray shell that overlapped with IC 443. They proposed that this shell is another SNR, G189.6+3.3. Near the IC 443 boundary, a filament was seen both in the optical image from the Digital Sky Survey and the radio at 1.4 GHz (Leahy 2004) that might be a part of this proposed SNR. At $\lambda 6$ cm, only a very short narrow radio rim appears at $\ell = 189^\circ.1$, $b = 3^\circ.6$, i.e. along the optical filament emerging from IC 443. This short rim is also seen in the Effelsberg $\lambda 11$ cm and $\lambda 21$ cm surveys. Using the TT-plot, we obtained $\beta_{6-11} = -2.49 \pm 0.25$ and $\beta_{6-21} = -2.35 \pm 0.22$. No radio emission from other parts of the proposed SNR G189.6+3.3 is detected at $\lambda 6$ cm and the Effelsberg surveys. Therefore, these observations cannot clarify the existence of the proposed large SNR G189.6+3.3.

3.16. G205.5+0.5 (Monoceros Nebula)

The SNR Monoceros Nebula is located in the area of the bright Rosette Nebula (SH 2-275), a famous H II region. Odegard (1986) suggested that the SNR is at the same distance as the H II region of about 1.6 kpc and that both objects interact with each other. On the basis of the radio absorption, he also argued that the SNR is situated behind the H II region. The SNR was studied at low and intermediate radio frequencies by Holden (1968), Milne & Hill (1969), and Dickel & Denoyer (1975). The radio structures are quite complicated in this region. The Rosette Nebula overlaps with the southern part of the SNR. The southern ridge of the H II region SH 2-273 is also mixed with the edge of the western shell of the SNR as shown by Graham et al. (1982). The extended nebula 0641+06 with the center at about $\ell = 206^\circ.35$, $b = 1^\circ.35$ was identified to be an H II region (Graham et al. 1982) and be unrelated to the SNR. Therefore, it was difficult to determine the boundary of the SNR, and reliable integrated flux densities could not be obtained. Early $\lambda 11$ cm polarization observations were made by Milne & Dickel (1974), but no significant polarized emission was detected.

The $\lambda 6$ cm Urumqi survey provides the shortest wavelength observations of the Monoceros Nebula and shows polarized emission, mainly towards the western shell of the SNR. After subtracting point-like sources, we obtained flux densities of the shell (integration area indicated in Fig. 1) from the

Fig. 10. Integrated radio flux densities of the western shell of SNR G205.5+0.5 (Monoceros Nebula) (as marked in Fig. 1).

Urumqi $\lambda 6$ cm, Effelsberg $\lambda 11$ cm, and $\lambda 21$ cm survey data. These were well fitted by a non-thermal spectrum with $\alpha = -0.43 \pm 0.12$ (see Fig. 10).

3.17. G206.9+2.3 (PKS 0646+06)

G206.9+2.3 is a discrete SNR close to the Monoceros Nebula that has a bright northwestern radio shell. The distance was estimated to be from about 3 kpc to 5 kpc (Graham et al. 1982). In earlier studies, G206.9+2.3 was believed to be a possible extension of the Monoceros Nebula, until Davies et al. (1978) identified it as a distinct SNR based on optical observations. Graham et al. (1982) quoted flux densities at different radio frequencies from 38 MHz to 2.7 GHz and obtained a spectral index of $\alpha = -0.45 \pm 0.03$. On the basis of this result, Odegard (1986) argued for a spectral turnover below 38 MHz because of the lower flux density he measured at 20.6 MHz.

Observations of this SNR at $\lambda 6$ cm or shorter wavelength bands were not yet available. The Urumqi survey showed strong polarized emission of up to 27% in the northwestern shell of the SNR (see Fig. 1). The B -field vectors are not tangential to the shell. The RM value for the shell of PKS 0646+06 may be high if the intrinsic B -field direction follows the shell.

After subtracting point-like sources including the strong point source NVSS J064935+053823 in the east of the SNR G206.9+2.3, we obtained a flux density of $S_{6\text{ cm}} = 2.9 \pm 0.3$ Jy from the Urumqi $\lambda 6$ cm, and $S_{11\text{ cm}} = 3.9 \pm 0.4$ and $S_{21\text{ cm}} = 5.1 \pm 0.6$ Jy from the Effelsberg $\lambda 11$ cm and $\lambda 21$ cm survey data, respectively. Combining the available flux densities in the literature, we got a spectral index of $\alpha = -0.47 \pm 0.04$, which agrees with that derived by Graham et al. (1982).

4. Summary

We have studied 16 SNRs larger than 1° based on maps from the Sino-German $\lambda 6$ cm polarization survey of the Galactic plane carried out with the Urumqi 25-m telescope. We have found that G192.8–1.1 consists of compact sources and thermal components, and conclude that G192.8–1.1 is not a SNR.

For the SNRs, we obtained integrated flux densities when possible, derived their spectral indices, and analyzed the polarization data. Our results for the SNRs W50, G78.2+2.1, HB21, and IC 443, are consistent with previous observations. The Urumqi $\lambda 6$ cm flux densities of SNRs, G65.1+0.6, W63, G93.7–0.2, G106.3+2.7, G114.3+0.3, G116.5+1.1, HB9, VRO 42.05.01, and G206.9+2.3, are those of the highest frequency available and are valuable for deriving the SNR spectra. All SNRs are polarized by more than 10% with the exception

of G78.2+2.1, which is located towards the thermal Cygnus region and IC 443. The polarization images of W63, G106.3+2.7, G114.3+0.3, G116.5+1.1, HB9, and VRO 42.05.01, are those observed at the highest frequency so far, including those of the Monoceros Nebula and G206.9+2.3, which are the first polarization images at a radio band.

At $\lambda 6$ cm, the polarization observations trace the intrinsic magnetic field configuration of SNRs when Faraday rotation can be neglected, which seems to be the case for most SNRs.

The $\lambda 6$ cm total intensity and polarization data of the 16 SNRs and G192.8–1.1 are available from the NAOC website¹.

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¹ <http://zmtt.bao.ac.cn/6cm/>

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