DIFFUSE HARD X-RAY SOURCES DISCOVERED WITH THE ASCA GALACTIC PLANE SURVEY

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ABSTRACT

We found diffuse hard X-ray sources G11.0+0.0, G25.5+0.0, and G26.6−0.1 in the ASCA Galactic plane survey data. The X-ray spectra are featureless with no emission line and are fitted with both models of a thin thermal plasma in nonequilibrium ionization and a power-law function. The source distances are estimated to be 1–8 kpc, using the best-fit N_H values under the assumption that the mean density in the line of sight is 1 H cm^{−3}. The source sizes and luminosities are then 4.5–27 pc and (0.8–23) × 10^{33} ergs s^{−1}. Although the source sizes are typical for supernova remnants (SNRs) with young-to-intermediate ages, the X-ray luminosity, plasma temperature, and weak emission lines in the spectra are all unusual. This suggests that these objects are either shell-like SNRs dominated by X-ray synchrotron emission, like SN 1006 or, alternatively, plerionic SNRs. The total number of these classes of SNRs in our Galaxy is also estimated.

Subject headings: acceleration of particles — ISM: individual (G11.0+0.0, G25.5+0.0, G26.6−0.1) — supernova remnants — X-rays: ISM

1. INTRODUCTION

Since the discovery of cosmic rays (Hess 1912), the origin and acceleration mechanism up to TeV or even more have been long-standing problems. The plausible acceleration sites in our Galaxy are shell-type supernova remnants (SNRs) with diffusive shock acceleration mechanisms (Wentzel 1974; Reynolds 1998), pulsars, and pulsar wind nebulae (de Jager & Harding 1992), although Reynolds & Keohane (1999) suggest that no SNR can accelerate electrons up to 10^{13.5} eV (the “knee” energy). Both of them are characterized by hard X-rays via synchrotron radiation, and we already have several samples of SNRs such as SN 1006 and some other SNRs, which accelerate cosmic rays on their shell (Koyama et al. 1995, 1997; Slane et al. 1999, 2001; Bamba, Tomida, & Koyama 2000; Borkowski et al. 2001b) and the plerionic SNRs (Asaoka & Koyama 1990; Weisskopf et al. 2000; Blanton & Helfand 1996). Together with the discoveries of inverse Compton γ-rays, which are upscattered cosmic microwave photons or synchrotron X-rays by high-energy electrons (Tanimori et al. 1998; Muraishi et al. 2000; Enomoto et al. 2002; Weekes et al. 1989), the hard X-ray emission supports the presence of extremely high energy electrons. The total and maximum energy of accelerated electrons in SN 1006 has been studied by ASCA (Allen, Petre, & Gotthelf 2001; Dyer et al. 2001) and Chandra (Bamba et al. 2003). In order to account for the total flux of the Galactic high-energy cosmic rays, a large number of SNRs with nonthermal X-rays must be still hidden in the Galactic plane and should be discovered.

The maximum electron energy in the SNRs is determined by the balance between the acceleration and radiative energy loss. The acceleration rate is proportional to the magnetic field strength (B). However, the synchrotron energy loss is proportional to B^2 and electron energy. Ages of SNRs, densities of circumstellar matter, and explosion energies also limit the maximum energy. Since the synchrotron X-rays are produced by electrons with higher energy than those responsible for the radio emission, SN 1006-like SNRs should have relatively weak magnetic field (B), and they must be generally radio-faint SNRs like SN 1006. In fact, new SN 1006-like SNRs such as G347.3−0.5, G266.2−1.2, and G28.6−0.1 are first found with X-rays, then later identified as radio-faint SNRs (Koyama et al. 1997, 2003; Slane et al. 1999; Bamba et al. 2001a). For the plerionic SNRs, the relation between the luminosity in X-ray and radio bands is an unknown problem (Hands et al. 2003). For example, 3C 58 has a radio luminosity 1000 times smaller than the Crab Nebula although both are strong X-ray emitters (Green 2001). Accordingly, the previous search for SNRs based on the radio observations (Green 2001) may not be the most optimized method.

We have thus searched for diffuse hard X-ray sources in the Galactic plane survey with ASCA (Sugizaki 1999) and found a handful of SNR candidates with hard X-rays. We have carried out long exposure observations on the selected four candidates to investigate whether these are new SNRs. One of the candidates, AX J1843.8+1.2, and G28.6−0.1 are first found with X-rays, while the others are confirmed as new SN 1006–like SNR (Bamba et al. 2001a) with the aid of the radio continuum emission of G28.6−0.1 (Helfand et al. 1989), and the result is confirmed by the Chandra follow-up observations (Koyama et al. 2003; Ueno et al. 2003).

This paper reports on the results on the other three candidates (G11.0+0.0, G25.5+0.0, and G26.6−0.1) in § 3 and discusses the mechanisms of their X-ray emissions (see § 4.1 and § 4.2). The implications on the total number of SNRs with hard X-rays in our Galaxy are also discussed in § 4.3.

1 Available at http://www.mrao.cam.ac.uk/surveys/snrs/.
2. OBSERVATIONS AND DATA REDUCTION

The _ASCA_ Galactic plane survey has covered the area of the Galactic plane of \(|l| \leq 45^\circ\) and \(|b| \leq 1^\circ\), with the exposure time of \(\sim 10\) ks each. In the mosaic map shown by Sugizaki (1999), we searched for SNRs in hard X-rays excluding about 10% of the surveyed area, which suffered from stray lights of bright X-ray sources. We selected the four brightest diffuse hard X-ray sources and performed follow-up deep-exposure observations. The observation dates and the on-axis positions are summarized in Table 1.

_ASCA_ carried four X-ray telescopes (XRTs; Serlemitsos et al. 1995) with two Gas Imaging Spectrometers (GISs; Ohashi et al. 1996) and two Solid-State Imaging Spectrometers (SISs; Burke et al. 1994) on the focal planes. Since our targets are diffuse sources with sizes comparable to the SIS field of view (FOV), we do not refer to the SIS data in this paper. In all of the observations, GISs were operated in the nominal pulse height (PH) mode. We rejected the GIS data obtained in the South Atlantic Anomaly, in low cutoff rigidity regions (\(< 6\) GV), or when the target's elevation angle was low (\(< 5^\circ\)). Particle events were removed by the rise-time discrimination method (Ohashi et al. 1996). After these screenings, the total available exposure time of each observation is shown in Table 1. To increase the statistics, the data of the GIS-2 and GIS-3 detectors were co-added in the following study.

### Table 1

| R.A. (J2000.0) | Decl. (J2000.0) | Date (UT) | Exposure (ks) | Observation Type | Observation Number |
|---------------|---------------|-----------|---------------|-----------------|-------------------|
| 18 09 50.4     | –19 24 39.6   | 1996 Aug 4 | 10.3          | Survey          | 1                 |
| 18 09 36.0     | –19 27 07.6   | 1999 Sep 28 | 39.0          | Follow-up       | 2                 |
| 18 37 48.0     | –06 36 41.8   | 1997 Oct 14 | 12.4          | Survey          | 3                 |
| 18 37 45.6     | –06 36 43.2   | 1999 Sep 28 | 37.3          | Follow-up       | 4                 |
| 18 39 43.2     | –05 42 57.6   | 1997 Apr 20 | 9.8           | Survey          | 5                 |
| 18 40 14.4     | –05 40 44.4   | 1999 Oct 3  | 35.9          | Follow-up       | 6                 |

**Note.** Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

### 3. ANALYSES AND RESULTS

#### 3.1. X-Ray Images and Source Detection

The GIS images in the 0.7–7.0 keV band around the SNR candidates are shown in Figure 1. Diffuse enhancements can be seen with the centers at about \((l, b) = (11^\circ, 0^\circ), (25^\circ, 0^\circ), (26^\circ, -0^\circ),\) and \((26^\circ, 0^\circ);\) hence, they are referred to as G11.0+0.0, G25.5+0.0, and G26.6–0.1.

Weak pointlike sources 1, 7, and 12 are detected in G11.0+0.0, G25.5+0.0, and G26.6–0.1, respectively. We also checked the _ROSAT_ \(^2\) and _Einstein_ \(^3\) point-source catalogs and found only one source, _RXS_ J184049.1–054336, in G26.6–0.1 (the same source as 12) from 15\(^3\) circles of the diffuse sources. The flux of these pointlike sources contributes about 10% of the diffuse flux (see the Appendix). We thus made the radial profiles in the 0.7–7.0 keV band, including the pointlike sources, then fitted with a Gaussian plus constant (for the background) model (Fig. 2). The diffuse components are detected with the confidence level of 10.2 \(\sigma\) for G11.0+0.0, 5.7 \(\sigma\) for G25.5+0.0, and 7.5 \(\sigma\) for G26.6–0.1, respectively. The best-fit FWHM is 12.2 (\(>6.3\),

\(^2\) Available at http://www.xray.mpe.mpg.de/cgi-bin/rosat/src-browser.

\(^3\) Available at http://heasac.gsfc.nasa.gov/docs/einstein/archive/heao2_archive.html.

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**Fig. 1.** Shows GIS images with Galactic coordinates around (a) G11.0+0.0, (b) G25.5+0.0, and (c) G26.6–0.1 in the 0.7–7.0 keV band, where exposure time and vignetting effect are corrected. The images are smoothed with a Gaussian profiles of \(\sigma = 0.5\). The contour levels are linearly spaced with 6.4 \(\times\) \(10^{-4}\) counts arcmin\(^{-2}\) interval from the lowest level of 1.9 \(\times\) \(10^{-3}\) counts arcmin\(^{-2}\) s\(^{-1}\) for G11.0+0.0, 1.5 \(\times\) \(10^{-3}\) counts arcmin\(^{-2}\) s\(^{-1}\) for G25.5+0.0, and 2.4 \(\times\) \(10^{-3}\) counts arcmin\(^{-2}\) s\(^{-1}\) for G26.6–0.1. For bright point sources, the higher contour levels are truncated. The source and background regions for the spectral study (see text) are shown with the solid and dashed-line circles. The crosses indicate the position of pointlike sources shown in the Appendix (Table 5).
10.8 (>4.9), and 8.9 (>5.7) for G11.0+0.0, G25.5+0.0, and G26.6−0.1, respectively (parentheses indicate single-parameter 90% confidence regions). The FWHM sizes are significantly larger than that of the point-spread function of \( \text{ASCA} \) GIS (3'); hence, we confirm the diffuse nature for G11.0+0.0, G25.5+0.0, and G26.6−0.1.

To confirm the \( \text{ASCA} \) results, we checked the \( \text{ROSAT} \) all-sky survey images. However, no counterparts of G11.0+0.0 or G25.5+0.0 are found, mainly because of the large absorption and/or short exposure time. As for G26.6−0.1, a \( \text{ROSAT} \) counterpart is found. However, no pointing observation was made. Thus, all the available data with reasonable spatial resolution and exposure are provided solely from our \( \text{ASCA} \) observations; hence, we concentrate on the \( \text{ASCA} \) results hereinafter.

3.2. X-Ray Spectra

For the spectral analyses, we combined the survey and the follow-up observation data: Observation 1 and 2 for G11.0+0.0, Observation 3 and 4 for G25.5+0.0, and Observation 5 and 6 for G26.6−0.1 (see Table 1). The spectra were made using the photons in the circular regions of diameters 15' for G11.0+0.0 and 12' for both G25.5+0.0 and G26.6−0.1, respectively, which are equal to \( \sim 3 \sigma \) width of the radial profiles (Fig. 2). These source regions are shown with solid circles in Figure 1. X-ray photons of point source 1 for G11.0+0.0, 7 for G25.5+0.0, and 12 for G26.6−0.1 were extracted from a 3' radius circle each and were removed from the diffuse source data.

In order to properly subtract the Galactic ridge X-rays (Koyama et al. 1986; Kaneda et al. 1997), the background data were extracted from the source-free regions near the targets with the same FOVs and at the same distance from the Galactic plane (Fig. 1, dashed lines). For the background of G11.0+0.0, we selected the annual region between 9' and 12' radius but excluded the circular regions of 6' radius around sources 3 and 4.

The background-subtracted spectra are shown in Figure 3. We see relatively flat spectra and no line feature. The spectra were fitted with two models of a thin thermal plasmas in nonequilibrium ionization (NEI) (Borkowski, Lyerly, & Reynolds 2001a) and a power-law function. The absorption column densities are calculated using the cross sections by Morrison & McCammon (1983) of solar abundances (Anders & Grevesse 1989). These two models are statistically acceptable for all the spectra. The best-fit parameters are given in Table 2, while the best-fit power-law models are shown in Figure 3 with the solid-line histograms.

3.3. Physical Parameters of the Diffuse Sources

We searched for radio, optical, and infrared (IR) counterparts from the SIMBAD database at the positions of diffuse X-ray sources G11.0+0.0, G25.5+0.0, and G26.6−0.1 but found no candidates. We therefore cannot derive the source distances with the aid of other wavelength information and have to rely solely on our X-ray spectra. The absorption column densities of G11.0+0.0 and G26.6−0.1 are significantly smaller than, while that of G25.5+0.0 is comparable to, that

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Fig. 2.—Radial profiles (crosses) of (a) G11.0+0.0, (b) G25.5+0.0, and (c) G26.6−0.1 after correcting the vignetting effect. Solid lines are the best-fit curves (see text). The dashed lines show the lowest contour level in Fig. 1. The units of horizontal and vertical axes are arcminutes from the center and counts arcmin\(^{-2}\) s\(^{-1}\), respectively.

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Available at http://www.xray.mpe.mpg.de/cgi-bin/rosat/rosat-survey.
through the Galactic inner disk ($\sim 10^{23}$ H cm$^{-2}$; Ebisawa et al. 2001). Therefore, the former two sources are likely located at the near side of the Galactic plane, while the latter would be in the Galactic Scutum arm.

To be more quantitative, we assumed that the average density in our Galaxy toward the inner disk is $1$ H cm$^{-3}$ (Ebisawa et al. 2001) and estimated the distances using the best-fit absorption column densities in Table 2. The results, together with the source diameters and total luminosities, are listed in Table 3. Although the results are based on the best-fit power-law model, essentially no difference is found from those based on the NEI model.

4. DISCUSSIONS

From Table 3, we conclude that G11.0+0.0, G25.5+0.0, and G26.6--0.1 are diffuse Galactic sources with large sizes of 5--30 pc and moderate luminosities of $10^{33}$--$10^{34}$ erg s$^{-1}$. For the nature of these diffuse sources, a key question is whether the spectra are thermal. Unfortunately, from a statistical point of view the observed spectra do not provide an answer. We hence discuss both the cases in §4.1--4.3.

4.1. Are Diffuse Sources Thermal?

If the spectra are thermal, one possibility for the diffuse sources is unresolved emissions of many young stars in star-forming regions. The typical example of this class, the Orion Nebula, has the total X-ray luminosity of $10^{33}$ erg s$^{-1}$ and mean temperature of 3--4 keV (Yamauchi et al. 1996), which are in the error ranges of the diffuse sources (Table 2 and Table 3). Since G11.0+0.0 and G26.6--0.1 are in the near side of the Galactic ridge, they should be detected as emission nebulae or H II regions but have no optical, IR, or radio band counterparts. On the other hand, since G25.5+0.0 is at a far distance in the Galactic inner arm, lack of detection in the other wavelength may not be surprising. However, the source size of $\sim 30$ pc is exceptionally large as a star-forming region. We thus conclude that the diffuse sources are not likely to be star-forming regions.

Another possibility of the nature of G11.0+0.0, G25.5+0.0, and G26.6--0.1 is that they are either shell-like SNRs in the adiabatic phase or mixed morphology SNRs of young-to-middle age ($10^{2}$--$10^{3}$ yr). Usual SNRs of this class emit thermal X-rays with the temperature less than 1 keV. However, the spectra of G11.0+0.0 and G26.6--0.1 are very hard (approximately several keV) and have no strong emission line from highly ionized ions, which are not in favor of thermal SNRs. On the other hand, G25.5+0.0 has a relatively mild temperature and reasonable abundance.

Assuming a uniform density plasma sphere, we estimate the emission measures (EM), dynamical times ($t = \text{radius} / \text{sound velocity}$), electron densities ($n_e$), total masses ($M$), and thermal energies ($E$), which are listed in Table 4. We find that total masses of G11.0+0.0 and G26.6--0.1 are only a few times solar, consistent with young SNRs of high-temperature plasma. However, the total energies are significantly smaller than the canonical supernova explosion. Therefore, only a small fraction of the explosion energy must be converted to the thermal energy; hence, they may be in the earlier phase than adiabatic. In this case, the X-ray–emitting plasma should be attributable to the SN ejecta with large metallicity, but the observations show no large metal excess. Thus, thermal SNRs are unlikely for these diffuse sources.

For G25.5+0.0, the physical parameters are consistent with the adiabatic phase SNR; however, the plasma density ($<0.1$ H cm$^{-3}$) is much smaller than that of the interstellar gas in the Scutum arm. We thus regard that a thermal SNR for this diffuse source is also unlikely.
4.2. Nonthermal Diffuse Sources?

We now discuss a possibility of nonthermal origin. The most likely case is SNRs with nonthermal X-rays, like SN 1006 and the Crab Nebula. In Table 3, we also list the physical parameters of a newly established SN 1006–like SNR, AX J1843.8–0352 = G28.6–0.1 (Bamba et al. 2001a), for comparison.

First, we discuss the possibility that they are SN 1006–like SNRs. Photon indices of G11.0+0.0 and G25.5+0.0 are ∼2, which are smaller than those of typical SN 1006–like SNRs, SN 1006 itself, G347.3−0.5, and G266.6−1.2, but are similar to that of G28.6−0.1. This may indicate that the synchrotron X-rays are due to the electrons with higher energy than that of the acceleration cutoff, which is expected from the first-order Fermi acceleration (expected Γ = 1.5; Wentzel 1974). The diameters and total luminosities also resemble those of G28.6−0.1. These facts strongly support that at least G11.0+0.0 and G25.5+0.0 are SN 1006–like SNRs.

To establish the SN 1006–like SNRs, the presence of synchrotron radio emission is essential. However, no cataloged radio source is found in the NRAO VLA Sky Survey 20 cm survey archival data.5 If the magnetic field is weaker than the other SN 1006–like SNRs, the radio surface brightness would be below the current detection limit.

In order to estimate the radio flux band for the SN 1006–like SNRs, we tried the spectral fittings with a srcut model (Reynolds 1998; Reynolds & Keohane 1999). The spectral index at 1 GHz was frozen to α = −0.5, the expected value by first-order Fermi acceleration. The fittings were statistically accepted, and the best-fit parameters are listed in Table 2. We also tried the same fittings with α = −0.6 and found no essential difference in the best-fit parameters. The best-fit flux density for each source suggests that the expected surface brightness at 1 GHz is 9.8 × 10−24, 1.7 × 10−23, and 9.8 × 10−24 W m−2 Hz−1 sr−1 for G11.0+0.0, G25.5+0.0, and G266.6−0.1, respectively. On the other hand, the minimum surface brightness of the cataloged radio SNRs in our survey field is 2 × 10−21 W m−2 Hz−1 sr−1 (for G3.8+0.3; Case & Bhattacharya 1998), which is similar to that for SN 1006 (3 × 10−21 W m−2 Hz−1 sr−1; Long, Blair, & van den Bergh 1988; Winkler & Long 1997) and G347.3−0.5 (3 × 10−21 W m−2 Hz−1 sr−1; Ellison, Slane, & Gaensler 2001; assuming α = −0.5), but is 2 or 3 orders of magnitude larger than our new sources. Even the minimum surface brightness of the all cataloged radio SNRs is larger than our sample, 6.2 × 10−23 W m−2 Hz−1 sr−1 (for G156.2+5.7; Case & Bhattacharya 1998). Therefore, no radio counterpart for

5 Available at http://www.cv.nrao.edu/.

### Table 2: The Best-Fit Parameters of the Diffuse Sources

| Parameter                  | G11.0+0.0 | G25.5+0.0 | G266.6−0.1 | G28.6−0.1* |
|----------------------------|-----------|-----------|------------|------------|
| Photon index               | 1.6 (1.4–1.9) | 1.8 (1.6–2.2) | 1.3 (1.2–1.5) | 2.1 (1.7–2.4) |
| Absorption column density (10^22 H cm⁻²) | 0.8 (0.5–1.1) | 2.4 (1.8–3.2) | 0.4 (0.2–0.6) | 2.7 (2.0–3.5) |
| Flux (ergs cm⁻²s⁻¹)         | 3.8 × 10⁻¹² | 2.0 × 10⁻¹² | 3.5 × 10⁻¹² | 1.8 × 10⁻¹² |
| χ²/dof                    | 42.2/42 | 55.4/48 | 73.2/55 | 45.4/47 |

*Note.* Parentheses indicate single-parameter 90% confidence regions.

### Table 3: Physical Parameters of the Diffuse Sources

| Parameter                  | G11.0+0.0 | G25.5+0.0 | G266.6−0.1 | G28.6−0.1* |
|----------------------------|-----------|-----------|------------|------------|
| Distance (kpc)             | 2.6       | 7.8       | 1.3        | 7.0        |
| Diameter (pc)              | 11        | 27        | 4.5        | 20         |
| Luminosity (ergs s⁻¹)      | 3.7 × 10³¹ | 2.3 × 10³⁴ | 8.1 × 10³² | 2.2 × 10³⁴ |

*Available at http://www.cv.nrao.edu/.
our new X-ray sources would be simply due to limited detection threshold of the current radio observations.

The power-law spectra and luminosities \((10^{34}–10^{35} \text{ ergs s}^{-1})\) suggest that the new sources are also Crab-like (plerionic) SNRs, although no radio pulsar is found (Chevalier 2000). The luminosity ratio between the radio and X-ray band is largely different among the plerionic SNRs; the radio luminosity of 3C 58, for example, is about 10 times smaller, while that of X-ray is about 1000 times smaller than that of the Crab Nebula (Hands et al. 2003). We estimated the expected surface brightness using the flux density of 3C 58 and the Crab Nebula (Green 2001). For the 3C 58-like case, the surface brightnesses of G11.0+0.0, G25.5+0.0, and G26.6–0.1 at 1 GHz are expected to be 2.5, 5.1, and \(1.9 \times 10^{-20}\) W m\(^{-2}\) Hz\(^{-1}\) sr\(^{-1}\), respectively. Since these values are larger than the detection limit in the surveyed region (see previous paragraph), we exclude the 3C 58-like case. On the other hand, for the Crab-like case, their respective surface brightness becomes to be \(7.3 \times 10^{-23}\), \(1.5 \times 10^{-22}\), and \(5.6 \times 10^{-23}\) W m\(^{-2}\) Hz\(^{-1}\) sr\(^{-1}\). Therefore, a possibility of the Crab-like case cannot be excluded.

The photon index of G26.6–0.1 is unreasonably small for a typical SNR. The diameter and total luminosity are also smaller than those of G28.6–0.1 and the other SNR candidates with nonthermal X-rays. Thus, G26.6–0.1 may be of a different class. Uchiyama et al. (2002) found hard X-ray clumps in \(\gamma\) Cygni, an SNR interacting with molecular clouds (Fukui & Tatematsu 1988) and an EGRET source (Esposito et al. 1996); all the sizes (approximately a few parsecs), photon indices (\(\sim 1.2\)), and luminosities (\(\sim 4 \times 10^{32}\) ergs s\(^{-1}\) in the 2.0–10.0 keV band) of the clumps resemble those of G26.6–0.1. Uchiyama et al. (2002) concluded the mechanism to be bremsstrahlung from MeV electrons colliding with dense clouds. This mechanism is usually accompanied by line emission, but no evidence for an emission line from G26.6–0.1 is found. Assuming a wide-band spectrum of G26.6–0.1 to be the same as that of \(\gamma\) Cygni, we estimate the 0.1–2 GeV band flux to be \(6.1 \times 10^{-8}\) photons cm\(^{-2}\) s\(^{-1}\). This value is smaller than the EGRET detection limit in our survey regions (Esposito et al. 1996). Therefore, the lack of a counterpart of a MeV gamma-ray source in the EGRET third catalog (Hartman et al. 1999) near G26.6–0.1 provides no constraint on the above discussion. Thus, to establish the nonthermal bremsstrahlung origin for G26.6–0.1, detection of molecular clouds and MeV-\(\gamma\) source near at G26.6–0.1 is essential.

4.3. How Many Supernova Remnants with Hard X-Rays in Our Galaxy?

We have found four diffuse X-ray sources, and their hard X-ray spectra are not consistent with SNRs dominated by thermal emission but suggest either SN 1006-like, plerionic SNRs or possibly SNRs dominated by nonthermal bremsstrahlung.

The \textit{ASCA} Galactic plane survey covered the region of \(|l| \leq 45°0\) and \(|b| \leq 0°4\), but about 10% of the fields should be excluded for the faint-source survey because of the stray lights from bright point sources. In the above survey region, we found five new SNRs; the three sources in this paper, G28.6–0.1 by Bamba et al. (2001a), and G347.3–0.5 by Koyama et al. (1997). Therefore, the number of expected SNRs in the surveyed field is \(5 \times 1/(1 – 0.1) \approx 5.6\). If we assume that the spatial density of SNR is uniform in the inner Galactic disk of the \(|l| \leq 60°0\) and \(|b| \leq 1°0\) fields, then the expected number is \(5.6 \times (120/90) \times (2/0.8) = 19\). Since the X-ray surface brightness of the new SNR is only 2–3 times the background Galactic ridge emission, we may miss detections of more samples with lower surface brightness (see § 4.2). Thus, the number of SNRs with nonthermal X-rays in our Galaxy would far exceed 20.

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APPENDIX

SERENDIPITOUS SOURCES

Thirteen pointlike sources above the 6\(\sigma\) threshold are found in the same GIS fields as shown with crosses in Figure 1. Some have been already reported by Sugizaki et al. (2001), while the others are newly reported sources.

### TABLE 4

| Parameters for Thermal Plasma Scenario |
|---------------------------------------|
| Parameters                        | G11.0+0.0 | G25.5+0.0 | G26.6–0.1 |
| Emission measure \((\text{EM})^a\) \(\text{cm}^{-3}\) | \(2.3 \times 10^{56}\) | \(1.5 \times 10^{57}\) | \(4.9 \times 10^{55}\) |
| Dynamical time \((t)^b\) \(\text{s}\) | \(1.3 \times 10^{11}\) | \(3.9 \times 10^{11}\) | \(4.7 \times 10^{10}\) |
| Electron density \((n_e)^c\) \(\text{cm}^{-3}\) | 0.11 | 0.070 | 0.18 |
| Total mass \((M)^d\) \((\text{M}_\odot)\) | 1.8 | 18 | 2.3 |
| Thermal energy \((E)^e\) \((\text{ergs})\) | \(1.2 \times 10^{50}\) | \(7.3 \times 10^{50}\) | \(1.9 \times 10^{49}\) |

\(a\) Emission measure, \((\text{EM}) = n_e^2 V\), where \(n_e\) is the electron density and \(V\) is the plasma volume.

\(b\) The ratio of the radius to the sound velocity.

\(c\) \(E = (3/2)(n_i + n_e) V k T\), where \(n_i\) is the ion density.

\(d\) The ion density.

\(e\) The plasma energy.
We performed the spectral analyses of the pointlike sources. The source regions were selected as 3’ circles except for sources 1 and 8. For these two sources, we made the source regions with the 1.5 circular regions around the sources because the contaminations from G11.0+0.0 are large. We made background spectra from source-free regions near the sources. We fitted the background-subtracted spectra with a power-law function, and the results are summarized in Table 5.

Table 5

| Source | Name | Photon Indexa | Absorption Columnb (10^{22} H cm^{-2}) | Fluxb (ergs cm^{-2} s^{-1}) | Reduced χ^2 |
|--------|------|---------------|-----------------------------------|-----------------|-------------|
| 1....... | AX J1809.7–1918 | 3.1 (1.9–5.0) | 1.6 (0.4–3.3) | 3.1 × 10^{-13} | 9.1/16 |
| 2....... | AX J1809.8–1943 | 8.8 (>5.9) | 1.7 (0.7–2.5) | 6.1 × 10^{-13} | 9.8/20 |
| 3....... | AX J1810.4–1921 | 2.2 (1.5–3.2) | 0.6 (0.1–1.4) | 6.3 × 10^{-13} | 15.4/17 |
| 4....... | AX J1810.5–1917 | 3.4 (2.4–4.8) | 0.5 (<1.3) | 5.7 × 10^{-13} | 11.7/17 |
| 5....... | AX J1811.4–1926 | ... | ... | ... | ... |
| 6....... | AX J1837.3–0652 | 2.3 (1.6–3.2) | 5.9 (3.8–9.0) | 1.8 × 10^{-12} | 43.1/42 |
| 7....... | AX J1837.4–0637 | 0.8 (0.5–1.1) | 0.5 (0.1–1.2) | 9.3 × 10^{-13} | 48.8/59 |
| 8....... | AX J1837.5–0653 | 1.1 (0.5–1.9) | 5.3 (2.8–8.8) | 4.1 × 10^{-12} | 20.6/29 |
| 9....... | AX J1838.0–0655 | 0.8 (0.4–1.2) | 4.0 (2.8–5.7) | 1.1 × 10^{-11} | 12.9/12 |
| 10....... | AX J1838.1–0648 | 2.1 (1.6–2.8) | 3.9 (2.7–5.6) | 1.5 × 10^{-12} | 48.3/47 |
| 11....... | AX J1840.4–0537 | 3.4 (>1.6) | 0.6 (<4.0) | 1.4 × 10^{-13} | 6.8/13 |
| 12....... | AX J1840.4–0545 | 2.3 (0.9–4.7) | 5.8 (1.7–9.2) | 6.2 × 10^{-13} | 6.6/13 |
| 13....... | AX J1841.0–0536 | 1.0 (0.3–1.9) | 3.2 (1.1–6.4) | 2.1 × 10^{-11} | 13.2/21 |
| 13....... | AX J1841.0–0536 | ... | ... | ... | ... |

Note.—Source 1: Sugizaki et al. 2001 identified this source as an A-type star HD 160677, although the X-ray spectrum was much harder than those of normal stars. In this paper, we selected the background region around the source to remove the hard X-ray contamination from G11.0+0.0 and obtained a softer spectrum, consistent with a normal star. Source 2: The count rates and photon indices with ROSAT (Voges et al. 1999; 1RXS J189951.5194345) and ASCA (Sugizaki et al. 2001) are consistent with the present results. Source 3: AX J1810.5–1917 was brighter than AX J1810.4–1921 in observation 1 but was fainter in observation 2 (see Table 1); hence, it is a transient or a variable source. Source 5: This source is a bright SNR in both radio and X-ray bands (Dowens 1984) with a pulsar at the center (Tori et al. 1997). No pulsation is found with the fast Fourier transform and epoch-folding search, which may be due to the limited statistics. Also, no spectral analysis is available due to location at the edge of the GIS FOV. Source 9: This is the Einstein, IPC (Hertz & Grindlay 1988), and ASCA (Sugizaki et al. 2001) source. The count rates in all the observations have been constant. Source 13: This is a transient X-ray pulsar detected in both observations 5 (quiescent) and 6 (quiescent + flare). The 4.7 s pulsation is found at the flare phase (Ramba & Koyama 1999; Bamba et al. 2001b).

a Parentheses indicate single-parameter 90% confidence regions.
b In the 0.7–10.0 keV band.

We performed the spectral analyses of the pointlike sources. The source regions were selected as 3’ circles except for sources 1 and 8. For these two sources, we made the source regions with the 1.5 circular regions around the sources because the contaminations from G11.0+0.0 are large. We made background spectra from source-free regions near the sources. We fitted the background-subtracted spectra with a power-law function, and the results are summarized in Table 5.

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