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A Diffuse X-Ray Source, AX J1843.8−0352: Association with the Radio Complex G28.6−0.1 and Identification of a New Supernova Remnant

Aya Bamba[1] Masaru Ueno[1] Katsuji Koyama[1, 3] and Shigeo Yamauchi[2]
[1]*Department of Physics, Graduate School of Science, Kyoto University, Sakyo-ku, Kyoto, 606-8502*
bamba@cr.scphys.kyoto-u.ac.jp, masaru@cr.scphys.kyoto-u.ac.jp, koyama@cr.scphys.kyoto-u.ac.jp
[2]*Faculty of Humanities and Social Sciences, Iwate University, 3-18-34 Ueda, Morioka, Iwate 020-8550*
yamauchi@hiryu.hss.iwate-u.ac.jp
[3]*CREST, Japan Science and Technology Corporation (JST), 4-1-8 Honmachi, Kawaguchi, Saitama 332-0012*

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Abstract

ASCA discovered an extended source in the Scutum constellation. The X-ray morphology is an elliptical shape elongated from north to south with a mean diameter of about 10′. The image center is located at $\mathrm{RA}_{2000} = 18^{\mathrm{h}}43^{\mathrm{m}}53^{\mathrm{s}}$, $\mathrm{DEC}_{2000} = -03^\circ 52' 55''$ (hereafter, AX J1843.8−0352). The north and south rims of AX J1843.8−0352 are associated with non-thermal radio sources C and F of the G28.6−0.1 complex (Helfand et al. 1989). The X-ray spectrum was fitted with a model of either a thin thermal plasma in non-equilibrium ionization of a temperature 5.4 keV or a power-law of photon index 2.1. The absorption column is (2.4–4.0) $\times 10^{22}$ cm^{-2}, which probably places this source in the Scutum arm. With a reasonable distance assumption of about 7 kpc, we estimate the mean diameter and X-ray luminosity to be $\sim$ 20 pc and $\sim 3 \times 10^{34}$ erg s^{-1}, respectively. Although a Sedov solution for a thin thermal plasma model gives parameters of a young shell-like SNR, no strong emission lines are found with the metal abundances being $\sim$ solar. Thus, a more likely scenario for both the radio and X-ray spectra and the morphologies is that AX J1843.8−0352 is a shell-like SNR which predominantly emits synchrotron X-rays.

Key words: ISM: individual (AX J1843.8−0352) — supernova remnants — X-rays: ISM

1. Introduction

The most complete catalogue of the galactic supernova remnants (SNRs) is found in the radio band; about 220 radio SNRs are currently cataloged (Green 2000). In the X-ray band however, the cataloged number is less than half of the radio SNRs. On the other hand, recent surveys with ROSAT and ASCA found new X-ray SNRs (Koyama et al. 1997), which were later identified with radio-faint SNRs. We thus suspect that new SNRs which have escaped radio detection can be found in the X-ray band. Of particular interest are synchrotron X-rays from the shells of SNRs (e.g., SN 1006; Koyama et al. 1995), where electrons should be accelerated to high energies of up to about 1 TeV or even more, possibly with the first-order of the Fermi acceleration, which implies that the shell of SNRs can be the birthplace of cosmic rays. The gain (acceleration) rate of electrons is proportional to the magnetic field strength (B), while the synchrotron energy loss of electrons is proportional to B^2. Therefore, high-energy electrons responsible for the synchrotron X-rays are likely to exist in a shell with a rather weak B, where the radio flux should be faint, because the flux is proportional to B^2.

With these ideas in mind, we have searched for diffuse hard X-ray sources in the galactic plane from the ASCA survey data, and found a handful of candidates. For some of them, we have carried out long exposure observations to investigate whether these sources are new SNRs which emit synchrotron X-rays. This paper reports on a survey and pointing observations of the SNR candidate AX J1843.8−0352, and discusses the X-ray emission mechanisms of this source.

2. Observations and Data Reduction

ASCA observations near the galactic Scutum arm (l=28°–29°) were made on 1993 October 22 (obs. 1) and on 1997 April 22 (obs. 2) as a part of the galactic plane survey project. We then proceeded to a follow-up observation with deeper exposure on 1999 May 23 (obs. 3). ASCA carries four XRTs (X-Ray Telescopes, Serlemitsos et al. 1995) with two GISs (Gas Imaging Spectrometers, Ohashi et al. 1996) and two SISs (Solid-state Imaging Spectrometers, Burke et al. 1994) on the focal planes. Since our target is a diffuse source with a size comparable to or larger than the SIS field of view, we do not refer to the SIS in this paper. In all of the observations, the GISs were operated in the nominal PH mode. We rejected the GIS data obtained in the South Atlantic Anomaly, in low cut-off 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 screening, the total available exposure times of obs. 1, 2, and 3 were $\sim$19 ks, $\sim$10 ks, and $\sim$42 ks, respectively. To increase the statistics, the data of the 3 observations and those of two detectors, GIS-2 and GIS-3, were all combined.

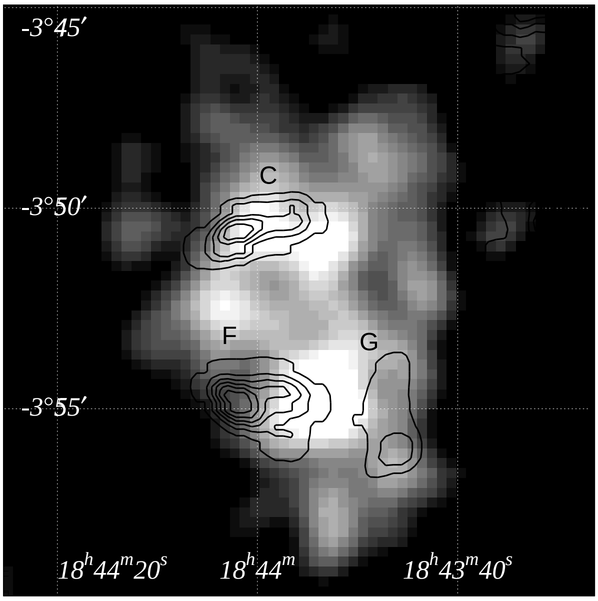

Fig. 1. ASCA GIS image in the 0.7–7.0 keV band overlaid on the NVSS 20 cm radio contours. (This map was retrieved from the web site of the NRAO VLA Sky Survey, http://www.cv.nrao.edu/˜jcondon/nvss.html.) Radio sources are labeled following Helfand et al. (1989).

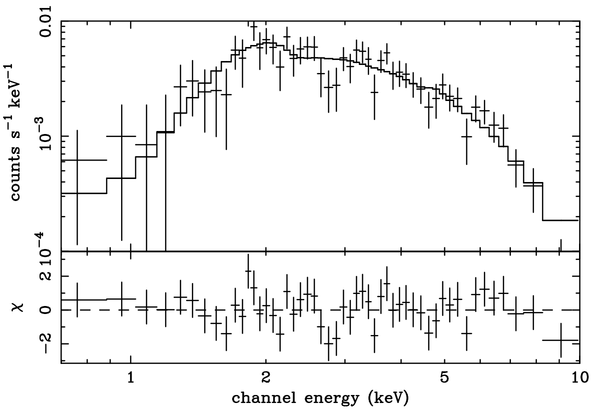

Fig. 2. Background-subtracted spectrum of the combined GIS 2 and 3 data of the 3 observations. The solid line is the best-fit power-law model (upper panel). Lower panel shows the data residuals from the best-fit model.

3. Analysis and Results

The GIS image in the 0.7–7.0 keV band near the Scutum region is given in figure 1. We can see diffuse X-rays with an elliptical shape of its center at $(\mathrm{RA}, \mathrm{DEC})_{\mathrm{J2000}} = (18^{\mathrm{h}}43^{\mathrm{m}}53^{\mathrm{s}}, -03^{\circ}52'55'')$. We hence designate this source as AX J1843.8−0352.

The X-ray spectrum is made using the photons in an ellipse area of 13′ (major axis) by 9′ (minor axis), while the background spectrum is obtained from an elliptical ring around the source. The background-subtracted spectrum is given in figure 2, where the total photons in the 0.7–10 keV band are 2.7×10^3 counts. We then fit the spectrum with two models of a power-law and a thin thermal plasma in non-equilibrium ionization (NEI plasma; coded by Masai 1984). The NEI condition is characterized by the ionization parameter, $n_{\mathrm{e}}t$, where n_{e} and t are the electron density and elapsed time after the plasma has been heated-up. The collisional ionization equilibrium is achieved when $\log(n_{\mathrm{e}}t)$ becomes larger than ~ 12. The absorption column is calculated using the cross sections of Anders, Grevesse (1989) with solar abundances. These two models are statistically acceptable with the best-fit parameters given in table 1. In figure 2, we show the best-fit power-law model (the solid line).

4. Discussion

The best-fit N_{H} value of (2.4–4.0) $\times 10^{22}$ cm^{-2} is similar to the nearby SNRs, Kes 73 [(1.6–2.3) $\times 10^{22}$ cm^{-2}; Gotthelf, Vasisht 1997] and Kes 75 [$(2.9 \pm 0.4) \times 10^{22}$ cm^{-2}; Blanton, Helfand 1996], both are located near the same galactic coordinate as AX J1843.8−0352, at (27.°4, 0.°0) and (29.°7, −0.°3), respectively. Using the H I absorption data, the distances of Kes 73 and Kes 75 are estimated to be 6–7.5 kpc (Sanbonmatsu, Helfand 1992) and 9–21 kpc (Caswell et al. 1975; Becker, Helfand 1984), respectively. Koyama et al. (1990) found many transient sources at the tangent point of the Scutum arm (about 8.5 kpc) with absorptions of around 10^{23} cm^{-2}, which are larger than that of AX J1843.8−0352. Accordingly, we infer that the distance of AX J1843.8−0352 is in between 6–8.5 kpc. Hereafter, we assume the distance to be 7 kpc. The X-ray luminosity (0.1–10.0 keV) and the source size (the mean diameter) are then estimated to be 3×10^{34} erg s^{-1} and 20 pc, respectively. These parameters are similar to those of shell-like young SNR.

In the survey data of 6 cm and 20 cm bands (Becker et al. 1994; Reich et al. 1990), we find some sources near AX J1843.8−0352. These radio sources, however, are not cataloged as SNRs (Green 2000). Helfand et al. (1989) resolved the radio complex called G28.6−0.1 into individual radio sources, A–I, with the VLA 20 cm band observations. Combining with the 6 cm band data by Altenhoff et al. (1978), the spectral indices of C and F were estimated to be 0.5–0.6, or non-thermal radio sources; the morphology of F, at least, was a cluster head-tail source, although possibility a part of a galactic SNR was not excluded. Our present observation strongly suggest that AX J1843.8−0352 is an X-ray SNR and the non-thermal radio sources C and F are the radio counterparts. Because source G has a more flat radio spectrum, it would be thermal, possibly an H II region and an unrelated source, although located inside of AX J1843.8−0352.

The flux densities of the radio complex G28.6−0.1 at the 6 cm and 20 cm bands are 0.9 Jy and 2.1 Jy, respectively (Altenhoff et al. 1978; Helfand et al. 1989). Extrapolating these values, we estimate the surface brightness of AX J1843.8−0532 to be 9.7×10^{-22} W m^{-2}Hz^{-1}sr^{-1} at 1 GHz (in 30 cm band). This value is lower than those of the typical galactic SNRs with a diameter $\sim$ 20 pc, and is similar to that of SN 1006 (Case, Bhattacharya 1998; Winkler, Long 1997).

Assuming a thin thermal NEI plasma model, and applying a Sedov model to AX J1843.8−0352, the ambient density, age, explosion energy, and total mass are estimated to be 0.2 cm^{-3}, 2700 yr, 0.9×10^{51} erg, and 20 $M_{\odot}$, respectively. If the remnant is the result of a core collapse explosion, 20 $M_{\odot}$ could be comparable to the original mass of the progenitor, hence the remnant would be in between the free-expansion and Sedov phases. Accordingly, the age and density inferred with the Sedov assumption should be regarded as upper limits.

For a Type Ia explosion, like SN 1006, the 20 $M_{\odot}$ is significantly larger than the ejecta mass, and is hence in the Sedov phase. This remnant (at 7 kpc) has a similar physical size to that of SN 1006 (30′ at 2 kpc). However, the X-ray luminosity is about an order of magnitude less; hence, the density and possibly the age would be smaller than those of SN 1006.

Thus, in any case (whether core collapsed or type Ia SNRs), the real age and ambient density of AX J1843.8−0532 are significantly smaller than the inferred values of 2700 yr and 0.2 cm^{-3}, respectively. The best-fit ionization parameter of $\log(n_e t)$ is ~ 10, which also supports a smaller age and density.

For a core collapse young SNR, the abundances of Si and S would be enhanced, because the ratio of the stellar mass to the swept-up mass is high. For a Type Ia, Fe should be enhanced, because iron is the most dominant element in the ejected material. No strong lines from these elements are, however found, and the abundances are nearly one solar. We hence conclude that the thin thermal plasma scenario is unlikely for this young SNR. The best-fit NEI temperature of 5.4 keV is higher than any other young SNRs, such as Cas A, Tycho, Kepler, and W 49B [2.56±0.05 keV (Bleeker et al. 2001), 2.3±0.3 keV (Decourchelle et al. 2001), $3.1^{+0.5}_{-0.4}$ keV (Kinugasa, Tsunemi 1999), and 2.2–2.7 keV (Hwang et al. 2000), respectively], but is similar to the best-fit thermal model temperature for SN 1006 and G347.3−0.5, the typical SNRs of non-thermal X-rays [7–10 keV (Ozaki et al. 1994) and 3.8±0.3 keV (Koyama et al. 1997), respectively]. Thus, by analogy, we expect the emission from this remnant to be also non-thermal. In fact, a power-law model with a photon index of 2.1 (an energy index of 1.1) also fit well to the X-ray spectrum of AX J1843.8−0352. The combined radio spectrum of sources C and F is smoothly connected to the X-ray spectrum of AX J1843.8−0352 with a power-index break between the radio and X-ray bands. The power-law index of about 0.5 in the radio band is explained by synchrotron emissions of high-energy electrons having a power index of 2.0. The larger power-law energy index of 1.1 (photon index = 2.1) in the X-ray band should be due to the synchrotron energy loss; higher energy electrons loose their energy more rapidly than lower energy electrons.

Thus, the spectra and morphologies in both the radio and the X-ray bands are fully consistent with the scenario that AX J1843.8−0352 is a shell-like SNR with synchrotron X-rays, following well-established examples: SN 1006 (Koyama et al. 1995), G347.3−0.5 (Koyama et al. 1997) and RX J0852.0−4622 (Allen et al. 1999).

The physical size of AX J1843.8−0352 is comparable to that of SN 1006; still, the X-ray luminosity is lower than that of SN 1006. This may lead to a lower magnetic field strength (B) and/or a smaller electron number density (n_e), possibly due to a lower density of the inter-stellar medium (ISM). In the low-density ISM, the forward shock velocity remains high for a sufficiently long enough time to produce TeV electrons, which emit synchrotron (non-thermal) X-rays. The lower is n_e, the lower is the thermal X-ray flux from the forward shock. Also, a strong reverse shock might not form, because the velocity difference between the ejecta and the shock may not be dramatic; hence, thermal X-rays would be suppressed.

For further quantitative studies of the synchrotron scenario, we need a more detailed comparison of the X-ray spectrum and morphology with those of the radio band, which can be achieved with future observations of Chandra and/or XMM-Newton, which have better spatial resolution and a larger effective area than ASCA.

5. Summary

1. We found a diffuse hard X-ray source, AX J1843.8−0352, associated with the non-thermal radio complex G28.6−0.1 in the galactic Scutum arm.
2. The X-ray spectrum is fitted with either a high-temperature (5.4 keV) NEI plasma model or a non-thermal power-law model of index 2.1.
3. The N_H absorption is (2.4–4.0) $\times10^{22}$ cm^{-2}, which constrains the source distance to be 6–8.5 kpc.
4. The morphology (20 pc diameter sphere), association with the non-thermal radio sources, X-ray spectrum and luminosity strongly support that AX J1843.8−0352 is a newly identified SNR.
5. A high-temperature thin thermal plasma for this SNR is unlikely, and a non-thermal process from the shell is a more plausible scenario; AX J1843.8−0352 predominantly emits synchrotron X-rays from the shells.

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Table 1. Best-fit parameters of AX J1843.8−0352 for a power-law, a thin thermal plasma in non-equilibrium ionization (NEI) models *.

Model	Γ / kT .../(keV)	$N_{\rm H}$ (10^{22} cm^{-2})	Abundance†	log $n_{\rm e}t$ s cm^{-3}	χ^2 /degrees of freedom
Power-law	$2.1^{+0.3}_{-0.4}$	$2.6^{+0.8}_{-0.6}$	...	...	45.4/47
NEI plasma	$5.4^{+3.4}_{-1.8}$	$4.0^{+1.8}_{-1.2}$	$1.5^{+1.9}_{-1.2}$	$9.6^{+0.3}_{-0.3}$	32.5/46

* Errors and upper-limits are at the 90% confidence for one relevant parameter.
† Assuming the solar abundance ratio (Anders, Grevesse 1989).

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