CHANDRA OBSERVATIONS OF A NEW SUPERNOVA REMNANT AX J1843.8−0352/G28.6−0.1

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Abstract

AX J1843.8−0352 is a new X-ray SNR identified to the radio complex G28.6−0.1 with the *ASCA* satellite. *Chandra* discovered two distinct components from this SNR: non-thermal and thin thermal X-ray emissions. The non-thermal component is fitted with a power-law spectrum of photon index 2.0. The morphology is complicated, but roughly an elliptical shape with a mean diameter of about $7'$–$10'$. The east to south rims of the ellipse are associated with the non-thermal radio sources C, F and G (Helfand et al. 1989). The power-law slope of the radio spectrum can be smoothly connected to that of X-rays with a break at around the optical-IR band, hence would be due to synchrotron X-rays accelerated probably to ≥ 1 TeV at the shell of the SNR.

The thermal component near the southeast rim is a thin plasma of about 0.8 keV temperature. It has the appearance of a "Tadpole" figure with a head of $30'' \times 40''$-size and a tail of $30''$-long. Although this emission is associated with the west part of the radio source F, the absorption is about two times larger than that of the non-thermal X-rays, the bulk of the SNR emission. Therefore, together with the peculiar morphology, whether the thermal plasma is a part of the SNR or a background object is unclear.

Key words: SNR: individual (AX J1843.8−0352) — X-rays: ISM — Particle Acceleration

1. Introduction

Supernovae (SNe) and their remnants (SNRs) play essential roles for the structure and evolution of the Galaxy. SNRs may be the major sources of the Galactic hot (10^5–10^8K) medium. The blast wave of SNe may compress the interstellar medium, and trigger the successive star formations. They produce and distribute heavy elements in the whole Galaxy and even in the intergalactic space.

SNRs would also be the most plausible sites of cosmic ray production near to the knee energy ($\sim 10^{15.5}$ eV); supporting evidence is the detection of synchrotron X-rays from the shell of some of the SNRs (Koyama et al. 1995; 1997) and the detection of inverse Compton gamma rays (Tanimori et al. 1998; Muraishi et al. 2000). High energy electrons up to about 1 TeV or even more are produced possibly by the Fermi acceleration process. The energy loss rate of electrons, hence the synchrotron flux, is proportional to B^2, while the gain (acceleration) rate is proportional to B, where B is strength of the magnetic field. High energy electrons responsible to the synchrotron X-rays can therefore exist in a shell of rather weak magnetic field where the radio flux should be faint. Synchrotron X-rays are, in fact, found in radio faint shell-like SNRs.

SNRs may be the major origin of the Galactic ridge X-rays (GRXs). The GRXs are diffuse X-rays extending along the Galactic inner disk. The spectrum shows a thin thermal plasma of about 10^8 K having a prominent K-shell line from highly ionized irons. There is mounting evidence that the GRXs are attributable to diffuse sources, not an integrated emission of many point sources. No cataloged diffuse source, however, can account the observed spectrum and flux of the GRXs. Therefore the GRXs predict possible presence of either new X-ray SNRs or new category of X-ray sources. Sensitive surveys with *ROSAT* and *ASCA* found several new diffuse X-rays, which were later identified with radio faint SNRs. At present, the number of Galactic SNRs in X-ray is less than a half of that in radio (Green 2001). It is plausible that more diffuse X-ray structures can be found with highly sensitive X-ray surveys with *Chandra*. The *Chandra* deep exposure observations were performed with these idea and found a diffuse structure (Ebisawa et al. 2001, also in this Proceedings), which corresponds to the new SNR AX J1843.8−0352 (Bamba et al. 2001). This paper reports the results of the diffuse structure and discusses possible implication on the origin of high energy cosmic rays and the GRXs.

2. Observations and Data Reduction

The *Chandra* deep observations on the Galactic ridge were performed on Feb. 24–25, 2000 (AO1, here Observation 1) and on May 20, 2001 (AO2, here Observation 2), with respective targeted positions of $(l, b) = (28.^\circ450, -0.^\circ200)$, and $(28.^\circ550, -0.^\circ029)$. The satellite and instrument are described by Weisskopf et al. (1996) and Garmire et al. (2000), respectively. The observations were made with the ACIS-I array, which covers a $17' \times 17'$ field. AX J1843.8−0352 lies near the northwest edge and the east half of the ACIS-I array of Obs. 1 and Obs. 2, respectively. Data acquisition from the ACIS-I was made in the

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Timed-Exposure Faint mode with the chip readout time of 3.24 s. The data reduction and analysis were made using the *Chandra* Interactive Analysis of Observations (CIAO) software version 2.1. Using the Level 2 processed events provided by the pipeline processing at the *Chandra* X-ray Center, we selected the ASCA grades 0, 2, 3, 4 and 6, as the X-ray events; the other events, which are due to charged particles, hot and flickering pixels, are removed. The effective exposure is ~ 100 ks for each observation.

3. Results and Analyses

Figure 1 is the mosaic ACIS-I image of Obs 1 and 2 in the 1.5–8 keV band overlaid on the 20 cm VLA contours. The new *ASCA* SNR, AX J1843.8−0352 is clearly observed at the radio complex G28.6−0.1. Here and after we refer the radio source names (A-I) by Helfand et al. (1989).

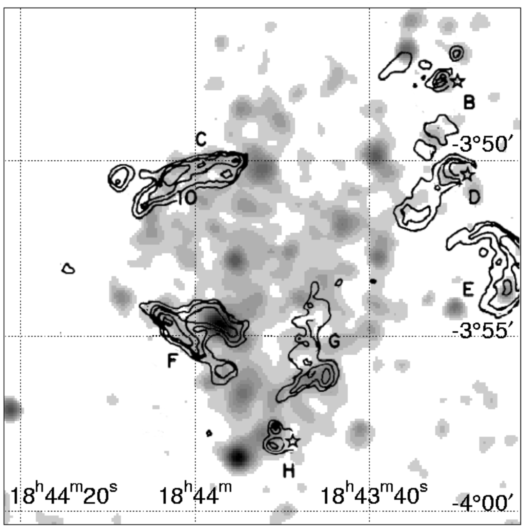

Figure 1. The ACIS-I image in the 1.5–8.0 keV band with logarithmic gray scale. The contours are the 20 cm radio fluxes (Figure 6 of Helfand et al. 1989). Large diffuse structure associated with the radio complex G28.6−0.1 is a new SNR AX J1843.8−0352. The brightest spot at the south is a discrete source, which may be unrelated object to the SNR. A bright diffuse clump at the radio source F is a thin thermal plasma.

The X-ray morphology is complicated with many clumps, which are filled along and in the elliptical region of the radio continuum complex. The association with the X-ray clumps is found at C and F at the east rim. The south tail of the radio source G is also followed by X-rays. The bright spot at the south is a discrete source, which may be unrelated to the SNR.

Figure 2 is the closed-up view of the brightest clump near the southeast rim in the 1.0–6.0 keV band. We see the appearance a "Tadpole" with a $30'' \times 40''$-size head at around $(18{:}43{:}57, -03{:}54{:}38)_{J2000}$ and a tail of $30''$-long

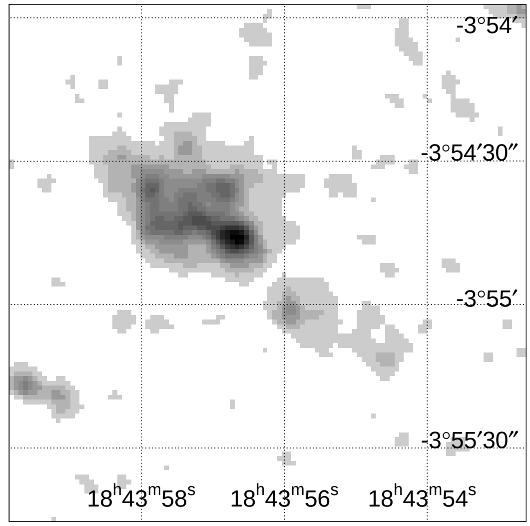

Figure 2. Closed-up view of the Tadpole in the 1.0–6.0 keV band with linear scale. This shows a peculiar shape, an elliptical head with a jet-like tail of 30″-long toward the southeast.

(here the Tadpole). The Tadpole shows clear association with the west tail of the radio source F.

The radio source E, which has a non-thermal spectrum and a crescent shell in radio, is the most secure candidate of a radio SNR. However no X-ray is found near here. Other radio sources B and D, possibly compact HII regions, are not associated with X-rays.

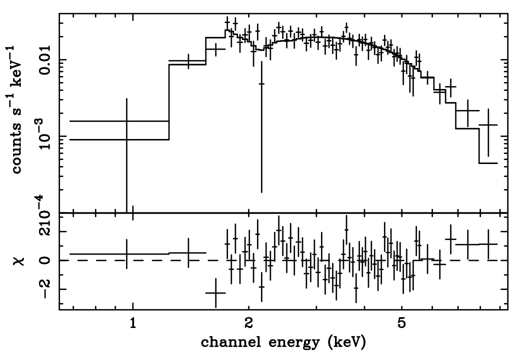

Figure 3. The X-ray spectrum of AX J1843.8−0535 (crosses) with the best fit power-law model (solid histogram).

We pick up many point sources using the "wavdetect" software and exclude all these point-like sources for the analysis of the diffuse structures. The integrated flux of the point sources in the AX J1843.8−0352 region is less than 10% of the diffuse emission of the SNR, hence the residual contamination, if any, is negligible. The spectrum of AX J1843.8−0352 is made from an ellipse of $10'$(major axis) by $7'$(minor axis), where diffuse emission from the Tadpole is also excluded. The background spectrum is made from the same size of the ellipse at the same distance

Table 1. Power-law model of AX J1843.8−0352

Index α	N_H 10^{22} Hcm^{-2}	F_X^* 10^{-12}erg cm^{-2}s^{-1}
2.0 (1.6–2.3)	3.5 (2.9–4.1)	4.3

*Unabsorbed X-ray flux in the 0.7-10.0 keV band.
Parentheses are the 90% error regions.

from the Galactic plane as those of AX J1843.8−0352, which is selected so as to properly subtract the GRXs (Koyama et al. 1986).

The background-subtracted spectrum, as is given in Figure 3, shows no significant emission line, hence is fitted with a power-law model. The fitting is acceptable with the best-fit parameters given in Table 1, and the best-fit model shown in Figure 3 (the solid line).

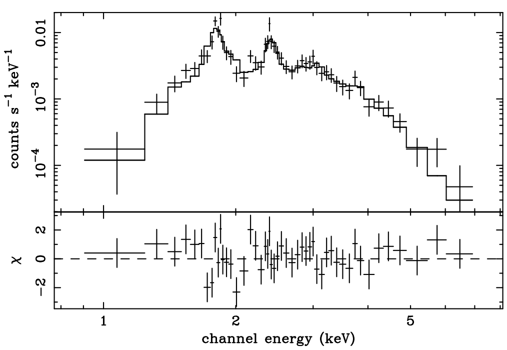

Figure 4. X-ray spectrum of the Tadpole (crosses) with the best fit NEI model (solid histogram).

Table 2. Thin thermal model of the Tadpole

kT keV	N_H 10^{22}Hcm^{-2}	$nt^\dagger$ 10^{10}s.cm^{-3}	F_X^* 10^{-11}erg cm^{-2}s^{-1}
0.84 (0.73–0.95)	6.4 (5.8–7.2)	7.8 (2.6–20)	1.6

†Ionization parameter; n and t are the electron density and elapse time of the plasma.
*Unabsorbed X-ray flux in the 0.7–10.0 keV band.
Parentheses are the 90% error regions.

The X-ray spectrum of a peculiar source, the Tadpole is given in Figure 4, where the background taken from around the source is subtracted. The Tadpole, in contrast to AX J1843.8−0352, shows clear emission lines at 1.85 keV and 2.36 keV, which are equal or slightly lower than those from He-like Si and S. We therefore fit the spectrum with an NEI (non equilibrium ionization) plasma model of the solar abundances. This model is acceptable with the best-fit parameters given in Table 2 and the best-fit model shown in Figure 4 (solid line).

4. Discussion

4.1. AX J1843.8−0352

We found that the new SNR AX J1843.8−0352 has many hard X-ray clumps, which are along and in the elliptical region of the radio complex G28.6−0.1. The X-ray spectrum is well fitted with a power-law model of photon index 2.0 (1.7-2.4), consistent with the *ASCA* results. Since the *ASCA* spectrum could not exclude a thin thermal model (NEI) of solar abundances, we try this model to the *Chandra* spectrum and find that the abundances must be very low (≤0.4 solar), which does not favor a thin thermal origin. The constraint on the AX J1843.8−0352 model is thus improved due to the separation of the diffuse thermal clump (the Tadpole) with the superior spatial resolution of *Chandra*.

The absorption (N_H) of 3.5(±0.6) × 10^{22} Hcm^{-2} is slightly larger than, but roughly similar to the *ASCA* result. Therefore, we adopt the source distance to be 7 kpc (Bamba et al, 2001). The X-ray luminosity (0.7–10.0 keV) and the source size are then estimated to be 2.3×10^{34} erg s^{-1} and 14 × 20 pc^2, respectively.

The radio non-thermal sources C and F come near the east rim, although the association with X-rays is not good in detail. The south part of the radio source G is also associated with the X-ray rim. We therefore make a combined spectrum from the radio to the X-ray bands and find that the radio (energy index = 0.5) and X-ray band spectra (1.0) are smoothly connected with a break near at the optical-IR band. The energy index of 0.5 in the radio band is explained by synchrotron emission of high-energy electrons having a power-law distribution of index 2.0. The larger energy index of 1.0 (photon index, 2.0) in the X-ray band should be due to the synchrotron energy loss of higher energy electrons. The wide band spectrum resembles those of SN 1006, G347.3−0.5 and RX J0852.0−4622, the well established shell-like SNRs as a site of high energy electrons (Koyama et al.1995; Koyama et al.1997; Allen, Markwardt & Petre 1999). We hence propose that AX J1843.8−0352 is another synchrotron X-ray dominant shell-like SNR.

4.2. The Tadpole

The Tadpole has a thin thermal spectrum of 0.8 keV temperature with the solar abundances, which is typical of a young SNR. Also the projected position is in the SNR AX J1843.8−0352, hence a naive scenario is that the Tadpole is a thermal component of this SNR. Then using the distance of 7 kpc, the X-ray luminosity is estimated to be ∼ 10^{35} erg s^{-1} (0.7–10 keV). The physical size is ∼ 0.9 × 1.3 pc^2 of head and ∼1.3 pc-long tail, then the mean plasma density is $\sim 10^{1.5}$ cm^{-3}. This value is extremely high compared with any other SNRs. The jet (tail)-like morphology resembles the hot plasma associated with the jet source SS433. We however see no central source at the head of the Tadpole.

Since the absorption toward the Tadpole (6.7×10^{22} Hcm^{-2}) is nearly two times larger than that of the host SNR AX J1843.8−0352 (3.5×10^{22} Hcm^{-2}), and is more typical of those thorough the Galactic plane (Ebisawa et al. 2001), the possibility is not rejected that the Tadpole is a background object at either a far-side of the Scutum arm or out of our Galaxy.

4.3. The Origin of GRXs and Cosmic Rays

Present discovery of the low surface brightness diffuse X-ray sources both in the hard (AX J1843.8−0352) and soft (the Tadpole) bands may have important implication on the origin of GRXs and cosmic rays.

The GXRs are prominent in the inner disk of the Galactic longitude $l = \pm 30°$, near the same position of AX J1843.8−0352 and the Tadpole. The GRXs have been found to exhibit two components (Kaneda et al. 1997). One is a thin thermal plasma of 0.8 keV temperature with prominent K-shell lines from He-like silicon and sulfur (here, the soft component), similar to the Tadpole. If the "Tadpole"-like sources are omnipresent, they may largely contribute to the soft component of the GRXs.

The other component of GRXs is a 7–10 keV temperature plasma, which emits strong K-shell line from highly ionized iron (the hard component). AX J1843.8−0352, if fitted with a thin thermal model, shows about 6 keV temperature, similar to that of the hard component of the GRXs. The surface brightness of AX J1843.8−0352 is about twice the GRXs at this position. Therefore, a part from the iron K-shell line, significant contribution to the hard component (continuum emission) of GRXs should be inferred.

We find that AX J1843.8−0352 is a new candidate of synchrotron X-rays. Since the radio and X-ray luminosity is the same order of SN 1006, the contribution to the Galactic cosmic rays should also be the same. The surface brightness of AX J1843.8−0352 in radio and X-ray is near or bellow the detection limit of the previous instruments. We thus can predict many more "AX J1843.8−0352" in the Galactic plane, which may ultimately account most of the cosmic rays in our Galaxy.

In order to see, whether the diffuse X-ray sources, like AX J1843.8−0352 and the Tadpole are omnipresent or not, and to approach the real origin of the GRXs and cosmic rays, we encourage to perform further deep exposure observations on the Galactic inner disk.

5. Summary

1. We separately detected diffuse hard X-rays from many discrete sources in a new SNR AX J1843.8−0352, which are associated with the non-thermal radio complex G28.6−0.1 in the Galactic Scutum arm.

2. The X-ray spectrum is fitted with a non-thermal power-law model of photon index 2.0. Together with the morphology of 14–20 pc diameter ellipse and the radio spectrum, we conclude that AX J1843.8−0352 is a synchrotron X-ray dominant SNR.

3. We discovered a 0.8 keV plasma (the Tadpole) at the east rim of AX J1843.8−0352 with a peculiar morphology of a elliptical head and jet-like tail.

4. $N_{\rm H}$ absorption of the Tadpole is nearly two times larger than that of the non-thermal SNR AX J1843.8−0352. Together with the peculiar morphology, whether the Tadpole is a thermal component of AX J1843.8−0352 or unrelated background source is debatable.

5. The new sources AX J1843.8−0352 and the Tadpole provide important implication on the origin of the the GRXs and the Galactic cosmic rays.

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