SEARCH FOR NEW SNR CANDIDATES IN THE GALACTIC CENTER REGION WITH CHANDRA

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Abstract

We report the diffuse X-ray features which are possible SNR candidates near the Galactic Center (GC) observed with *Chandra*. G0.570−0.018 has a extremely small (20″ diameter) shell-like morphology. The X-ray spectrum exhibits a strong Fe-K line emission and is well fitted by NEI model with a temperature of about 6 keV. These features suggest that G0.570−0.018 is a quite young ($t \sim 100$ year) SNR. Diffuse hard X-ray were also detected from G359.92−0.09. The X-ray spectrum exhibits strong Fe-K line emission. The X-ray excess coincides with the shell-type feature observed with radio continuum (e.g. Ho et al. 1985), which is attributable to a new SNR. In addition, we have also discovered several soft X-ray clumps. Their X-ray spectra are thermal ($kT \sim 1$ keV) and clearly show atomic line features such as Si, S, Ar and Ca.
The origin of the diffuse X-ray emission from the GC region is still an unresolved issue over a decade. Hard clumps such as G0.570−0.018 are likely to be young/middle-aged SNRs, could produce the hot component of the GC plasma, while relatively soft (~ 1 keV) clumps, which also may be SNRs, could contribute to the cool component of the GC plasma.

1 Introduction

The origin of the diffuse X-ray emission from the GC region has been an open issue over decades. *Ginga* and *ASCA* found the large-scale (1°× 1.8°) thin-thermal plasma with strong line emissions from highly ionized atoms (Koyama et al. 1989, 1996; Yamauchi et al. 1990). Total thermal energy of the plasma is as large as 10^{54} ergs and, as source(s) of such a huge energy injection, Koyama et al. (1996) proposed that either an energetic explosion occurred at the central Massive Black Hole (Sgr A*) or multiple supernova explosion took place within the past $\sim 10^5$ year.

With its superior spatial resolution, *Chandra* successfully resolved thousands of point sources from the GC region. However, the most ($\sim$ 90%) of X-ray flux from the GC region are attributable to the diffuse component (Ebisawa et al. 2002; Wang et al. 2002). On the other hand, *Chandra* also revealed that the diffuse X-rays from the GC region has rather clumpier than uniform distribution (Bamba et al. 2002). The presence of the clumpy structures may favor the multiple-SNe scenario. In fact, new X-ray SNRs have been discovered by observations with *Chandra* (e.g. Sgr A East; Maeda et al. 2002). In this paper, we investigate newly discovered clumpy structures near the GC to reveal the origin of the diffuse X-ray emission.

2 Observations

We used archive data of the 7 field of views (FOVs) of *Chandra* ACIS-I observations; Sgr B2, Sgr A*, and 5FOVs of *Chandra* GC Survey. The on-axis position and total exposure time of each observations are given in Tab. 1.

Table 1: *Chandra* ACIS observations

Target Name	Position (l, b) [deg]	Exposure [sec]
Sgr A*	(359.94, −0.05)	48720
Sgr B2	(0.59, −0.02)	98989
GCS 13	(0.00, −0.20)	10762
GCS 14	(0.00, 0.00)	10762
GCS 16	(359.80, −0.20)	10762
GCS 17	(359.80, 0.00)	11261
GCS 19	(359.61, −0.20)	11261

3 Results and Discussions

3.1 G0.570−0.018

G0.570−0.018 is discovered by *ASCA* (Sakano et al. 2002). *Chandra* observation resolved this source as a small shell-like structure with the diameter of ∼20″. The X-ray spectrum which exhibits extremely strong Fe-K line emission with equivalent width of about 4 keV. The X-ray spectra are well reproduced by a high temperature (∼ 6 keV) thin-thermal NEI model, hence the source is likely to be a young SNR. Detailed discussion of G0.570−0.018 appeared in Senda et al. (2002).

3.2 G359.92−0.09

Ho et al. (1985) detected non-thermal radio filament called "wisp" at 4′ south of the Sgr A* with radio continuum observation. In addition, an inward curve of Sgr A East and the other condensations (include "wisp") aligned in a circular shape imply a shell-like structure as shown in the solid circle of Fig. 1. The later NH_3 observations of the dynamics of molecular cloud supported the scenario, hence Coil & Ho (2000) named it G359.92−0.09 as a new SNR candidate. As shown in Fig. 1, *Chandra* observation reveals X-ray excess fills eastern half (EH) and southwest(SW) part of the radio shell of G359.92−0.09 (Murakami 2002). Although northwest part shows no significant excess within the shell, it is due to the contamination of the intense X-ray emission from SNR Sgr A East (Maeda et al. 2002). In the southwest edge of the shell, an X-ray bright filament are also discovered, which clearly corresponds with a non-thermal radio filament called "wisp". We extracted X-ray spectra from three different region; Eastern half (EH), Southwest quadrant (SW), and "wisp" . A thermal NEI model yields an acceptable fit for a spectrum from each region (Fig. 2 and Tab. 2).

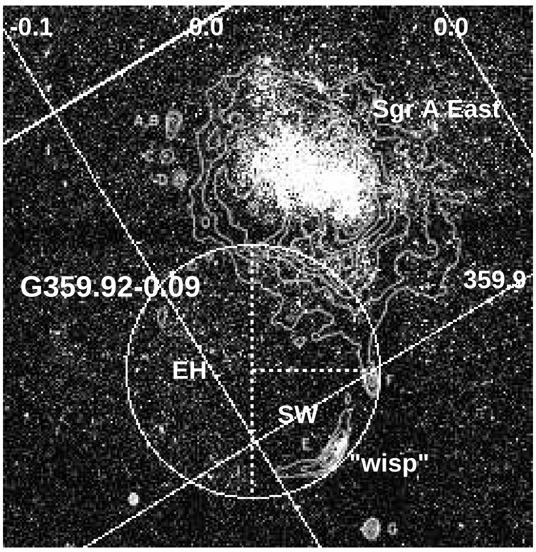

Figure 1: The *Chandra* ACIS grayscale image of G359.92−0.09 in the 3.0−8.0 keV band. The overlaid contours are VLA 6 cm continuum map (Ho et al. 1985).

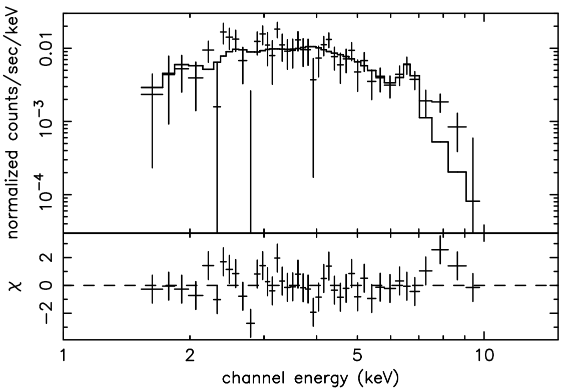

Figure 2: The X-ray spectrum of the Eastern-Half (EH) of the G359.92−0.09 obtained with *Chandra* ACIS. The best-fit spectrum with NEI model is shown by solid line.

Table 2: Best-fit Results of the X-ray Spectra of G359.92−0.09 with *Chandra*

	Eastern Half	Southwestern Quadrant	"wisp"
kT (keV)	11.4 (3.4 <)	2.6 (1.9 <)	12.7 (7.9 <)
τ (10^{11} s cm^{-3})	1.4 (0.8–5.4)	2.1(0.01 <)	88 (0.001 <)
$N_{\rm H}$ (10^{22} cm^{-2})	6.0 (3.7–8.3)	18 (7.0–33)	37 (32–44)
Flux^a (10^{-12} erg s^{-1} cm^{-2})	1.5	0.4	0.4

An NEI model is applied to reproduce each data. Values in parentheses indicate 90% confidence limits.
^{a}Flux (no correction of absorption) in the 2.0–10.0 keV band.

The observed emission measure from the EH part is 1.1×10^{57} cm^{-3} assumed G359.92−0.09 is located at the GC region (D=8.5 kpc). From the radius of the shell ($2' \sim 5$ pc), the total volume of the plasma is determined to be $V_{total} \sim 1.6 \times 10^{58}$ cm^3. Assuming that an X-ray emission from half of the total plasma contributes to the emission measure of the EH part, then we can calculate the electron density of the EH part to be $n_e \sim 0.4$ cm^{-3} and the thermal energy of the EH part to be $E_{\rm EH} = 3 n_e kT V_{\rm EH} \sim 1.6\times10^{50}$ ergs, where kT is the best fit value for the EH spectrum. Even though we cannot estimate the X-ray property of the NW quadrant, the brief extrapolation of the EH result to the rest part suggests that the thermal energy from the whole shell is reasonable value as an yield of a typical supernova explosion. Supposed an expanding velocity of the SNR shock front can be described by a sound velocity (1000 km s^{-1} at $\sim$ 10 keV), an age of the G359.92−0.09 are determined to be $\sim$ 3800 year. On the other hand, the ionization parameter indicates that an age of the plasma at EH is 1.2×10^4 year, however, the fitting result of this parameter contains large error.

3.3 G359.79−0.26 and G359.77−0.09

Soft band image of the *Chandra* GC Survey shows that diffuse emissions extended from Sgr A East to the southward direction. The extended emission is relatively soft and clumpy distributed (Fig. 3).

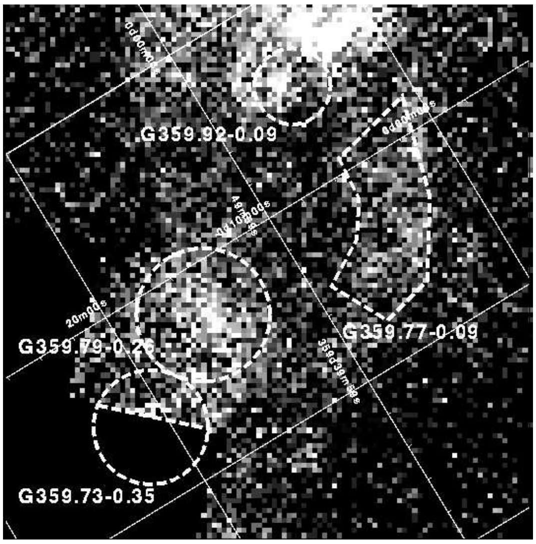

Figure 3: The ACIS mosaicked image of the soft (1.0-3.0 keV) band near the GC region. The image center corresponds to an on-axis position of the FOV of GCS16.

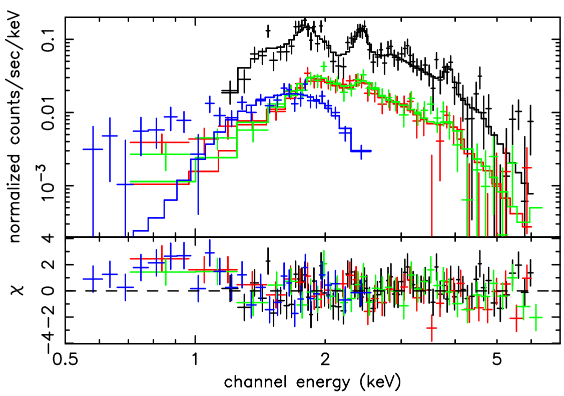

Figure 4: Combined X-ray spectrum of G359.79-0.26 obtained with ACIS-I (black), *ASCA* GIS2 (red), GIS3 (green), and *ROSAT* PSPC (blue). Solid lines show the best-fit thermal NEI model.

From these clumpy structures, we figured out three prominent soft clumps named G359.79−0.26, G359.77−0.09, and G359.73−0.35. X-ray spectrum of each clumps exhibits K-line emissions from He-like and/or H-like ions such as Si, S, Ar, and Ca. These clumps were also detected previous observations with *ASCA* and *ROSAT*, so we made combined X-ray spectra and tried to fit with the same model. Best fit results are shown in Fig. 4 and Tab. 3. Large ($N_{\rm H} \sim 5 \times 10^{22}$ cm^{-2})

absorption column of G359.79−0.26 and G359.77−0.09 indicate they are located near the GC, while a significantly small ($N_\mathrm{H} \sim 10^{22}$ cm^{-2}) absorption column of G359.73−0.35 suggests that this clump is a foreground object.

The results of the spectral fitting with thermal NEI model show that physical parameters of G359.79−0.26 and G359.77−0.09 (N_H and metal abundances) are similar to each other. In addition, the 1−3 keV band image shows as if G359.79−0.26 and G359.77−0.09 are southeast and northwest part of the large ($\sim$ 30 pc) elliptical shell, respectively. These indicate that the two clumps have the same origin, an energetic explosion such as a supernova occurred at the center of the large shell. However, their temperatures are slightly different, so the interpretation of their origin is still preliminary.

Table 3: Best-fit Results of the Combined X-ray Spectra of the Soft Clumps

	G359.79−0.26	G359.77−0.09	G359.73−0.35
kT (keV)	0.84 (0.75–0.93)	1.31 (1.03–1.79)	1.4 (1.12–1.52)
τ (10^{11} s cm^{-3})	64 (5.6 <)	0.5 (0.1–1.6)	9.9 (—)
N_H (10^{22} cm^{-2})	4.9 (4.6–5.2)	5.8 (5.1–6.5)	1.2 (0.8–1.4)
Flux^a (10^{-12} erg s^{-1} cm^{-2})	2.3^b	2.2^b	1.1^c
—Abundances (solar)—			
Si	0.4 (0.3–0.6)	0.6 (0.4–0.9)	2.1 (1.2–3.8)
S	0.8 (0.5–1.0)	0.8 (0.5–2.1)	5.4 (3.5–9.3)
Ar^d	1.3 (0.4–2.2)	0.3 (< 1.0)	11 (3.1–27)
Ca	3.2 (1.4–5.6)	1.4 (< 3.3)	9.3 (< 34)

Values in parentheses indicate 90% confidence limits.
^{a}Flux (no correction of absorption) in the 2.0–10.0 keV band.
^{b}The best-fit value when normalizations of the each data are fixed to the same value.
^{c}Flux obtained with ASCA GIS data. ^{d}A VMEKAL model is applied to obtain the results.

4 Summary

- With *Chandra*, also with archive data of *ASCA* and *ROSAT*, we newly discovered several X-ray clumps from the GC region.
- Some of these clumps show thermal spectra from high temperature (∼10 keV) plasma (G0.570−0.018 and G359.92−0.09), others show that from lower temperature (∼1 keV) plasma (G359.77−0.09 and G359.79−0.26).
- X-ray emission from G359.92−0.09 has a counterpart of a non-thermal radio shell. Its energetics suggest that G359.92−0.09 is a young/middle-aged (3800–1.2×10^4 year) SNR.
- X-ray properties of G359.77−0.09 and G359.79−0.26 exhibits those of typical Galactic SNRs, while their nature are still uncertain.
- The X-ray spectra of G0.570−0.018 and G359.92−0.09 are similar to that of hard component of GC plasma, while G359.77−0.09 and G359.79−0.26 are similar to that of soft component. These features suggest that GC plasma may resolve into individual clumps, which is likely to SNRs. However, total diffuse emission from the GC region is grater than sum of detected GC SNRs by 1−2 order of magnitude now.

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