Diffuse X-Rays from the Galactic Center Environment

- A Zoo of Iron Line Clumps, Non-Thermal Filaments, and Hot Plasmas -

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1. Introduction

In the Galactic center (GC) region, Ginga and ASCA found the large-scale thin-thermal plasma with strong lines from ionized iron (Koyama et al. 1989; 1996). On the other hand, Murakami et al. (2000; 2001a; 2001b) discovered clumps with a neutral (6.4 keV) iron line, suggesting that these clumps would be X-ray reflection nebulae (XRNe). Moreover, clumps with He-like (6.7 keV) iron line are also discovered with Chandra and inferred to be young SNRs (e.g. Senda et al. 2001).
In this paper, we report on diffuse X-ray structures around the Sgr A, the molecular cloud Sgr B2 and Sgr C, and the Radio Arc region observed with Chandra and summarize their characteristics.

2. Observations

We use the Chandra data of the Radio Arc, the GC, Sgr B2, and Sgr C (as the Galactic plane survey). The FOV of each observation is drawn in Figure 1 and the total exposure time of each observation is in Table 1.

Table 1: Exposure time in each observation.

Region	Radio Arc	Sgr A*	Sgr B2	Sgr C region
Exposure [ksec]	49	46	99	20

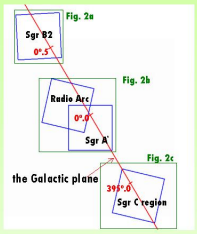
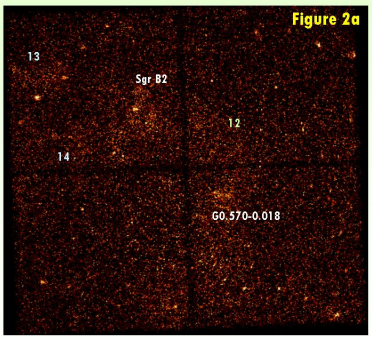
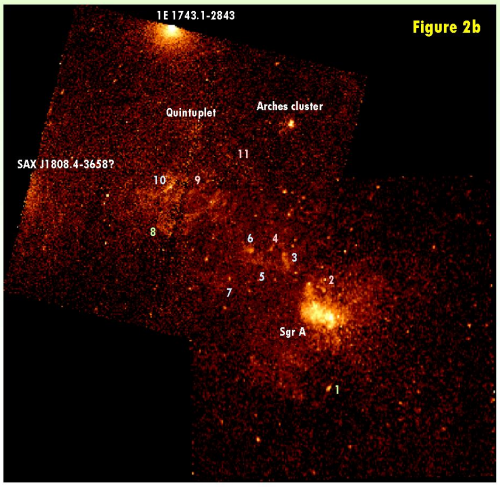


Figure 1:
The FOVs of the observations.

3. 3.0 – 8.0 keV Images





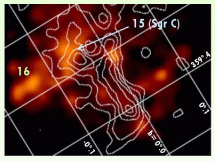
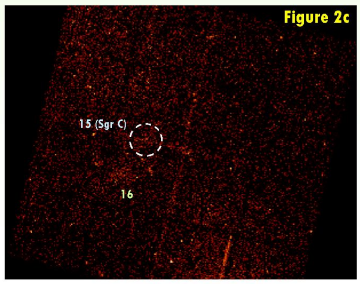


Figure 3:
Color:
the 6.0 – 7.0 keV image
White contour:
CS J=1- 0 map (Tsuboi et al. 1999)



Many clumps are found! (No.1 – 16)

red: No emission line
blue: 6.4 keV line
green: 6.7 keV line
(see section 4)

4. Spectral Fittings

We fitted the spectra of all sources in Figure 2a, 2b, and 2c.
spectral model = (power-law + Gaussian) x absorption

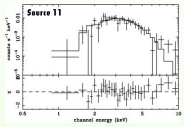
classified by the center energy of the line

- No emission line clumps (Table 2a)
- 6.4 keV clumps (Table 2b)
- 6.7 keV clumps (Table 2c)

Table 2a. No emission line clumps*

Target No.	Γ	N_H [10^{22}cm^{-2}]	Flux† [ergs cm^{-2}s^{-1}]
2	2.5 (1.3 – 4.5)	11 (7 – 21)	2.9×10^{-13}
4	2.5 (0.8 – 5.0)	7 (3 – 18)	1.1×10^{-13}
9	1.0 (-0.9 – 6.5)	2 (< 15)	5.9×10^{-14}
11	1.3 (0.78 – 2.0)	5.5 (3.4 – 8.9)	4.7×10^{-13}

*: Errors are in 90%.
†: In 2 – 10 keV band.



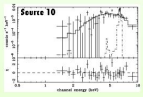
- No emission line
- Filamentary structure

Non-thermal emission from high energy cosmic rays in rather weak magnetic field?

Table 2b. 6.4 keV clumps*

Target No.	Γ	E_I [keV]	EW [keV]	N_H [10^{22}cm^{-2}]	Flux† [ergs cm^{-2}s^{-1}]
3	1.8 (-1.0 – 5.8)	6.34 (6.26 – 6.41)	0.9 (0.5 – 1.3)	33 (17 – 51)	1.2×10^{-12}
5	0.5 (-0.6 – 1.1)	6.43 (6.37 – 6.55)	1.3 (0.8 – 1.8)	4 (1 – 10)	7.2×10^{-13}
6	1.6 (-0.7 – 6.6)	6.35 (6.29 – 6.41)	1.6 (0.8 – 2.4)	12 (3 – 30)	4.6×10^{-13}
7	3.5 (2.0 – 4.5)	5.97 (5.85 – 6.42)	1.1 (0.6 – 2.4)	8 (5 – 12)	4.9×10^{-13}
10	-0.1 (-1.1 – 1.3)	6.41 (6.36 – 6.45)	0.8 (0.5 – 1.1)	10 (2 – 27)	1.1×10^{-12}
13	1.0 (0.2 – 1.7)	6.41 (6.37 – 6.45)	1.7 (0.3 – 88)	40 (20 – 63)	6.6×10^{-13}
14	0.7 (-2.0 – 4.6)	6.42 (6.38 – 6.47)	1.9 (> 0.08)	20 (12 – 43)	4.1×10^{-13}
15 (Sgr C)	2.6 (> -0.7)	6.40 (6.30 – 6.47)	31 (> 12)	5 (not determined)	1.4×10^{-13}

*: Errors are in 90%.
†: In 2 – 10 keV band.



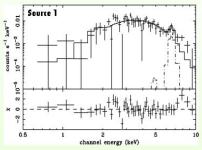
- Neutral iron line
- Large absorption column

They are new XRN candidates!

Table 2c. 6.7 keV clumps*

Target No.	Γ	E_I [keV]	EW [keV]	N_H [10^{22}cm^{-2}]	Flux† [ergs cm^{-2}s^{-1}]
1	1.9 (0.9 – 2.2)	6.63 (6.48 – 6.83)	1.3 (0.6 – 1.9)	6 (3 – 8)	2.1×10^{-12}
8	1.9 (0.3 – 4.3)	6.83 (6.63 – 7.01)	2.6 (0.4 – 4.6)	4 (2 – 12)	1.6×10^{-13}
12	9.4 (> 5.8)	6.62 (6.58 – 6.63)	19 (> 6.6)	44 (21 – 52)	3.5×10^{-13}
16	2.6 (1.1 – 4.3)	6.63 (6.05 – 6.67)	2.0 (0.3 – 3.9)	7 (3 – 12)	2.0×10^{-12}

*: Errors are in 90%.
†: In 2 – 10 keV band.

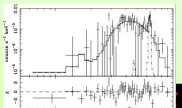


- Line from ionized iron
- Diffuse structure (shell like?)

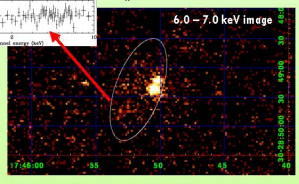
They are young SNRs?

Problem:
Thermal fittings indicate that kT are higher than ordinary SNRs.

5. Diffuse Emissions around Arches Cluster



E_I = 6.38 (6.34 – 6.42) keV
EW = 1.7 (0.9 – 2.2) keV
N_H = 3.4 (1.3 – 5.9) x10^{23} H cm^{-2}
L_X = 4.1x10^{34} ergs s^{-1}



The emission is XRN, too!

The irradiating source……inner clusters?
The required source luminosity is ~ 10 times of that of clusters (~ 10^{34}ergs s^{-1}).

The clusters were more brighter than now (~ a few years)?
Flaring? and/or Bursting?

6. The XRN, Sgr C Region

We fitted the spectrum of Sgr C with XRN model. We fixed the photon index to 2.0 (Murakami et al. 2000) and the equivalent width to 2.0 keV (Inoue 1985), expected value in the case of XRNe.

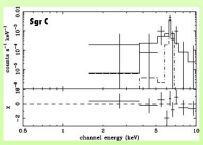


Table 3: XRN model fitting of Sgr C

parameters	
Γ	2.0 (fixed)
E_I [keV]	6.40 (6.30 – 6.47)
EW [keV]	2.0 (fixed)
N_H [x10^{23} H cm^{-2}]	7.6 (> 1.1)
L_X [ergs s^{-1}]	1.5 x 10^{-12}

- 6.4 keV line
- deep absorption
- correlation with molecular clouds (see Figure 3)
- offset of the emission to the GC

We confirmed that Sgr C is an XRN!

7. Summary

1. With Chandra data, we found many diffuse structures.
2. Their spectra are full of variety; we classified them with iron lines into 6.4 keV, 6.7 keV, and lineless clumps.
3. The 6.4 keV line clumps are suggested to XRNe, similar to Sgr B2. For many of them, the molecular clouds and the external X-ray sources have not been found.
4. The 6.7 keV clumps may be young SNRs, although the kT is higher than ordinary SNRs.
5. We suggest that lineless clumps may emit X-rays by synchrotron process (X-ray filaments) in rather weak magnetic field. The diffuse emission around Arches cluster has 6.4 keV line emission, indicating that it is also an XRN. The irradiating X-ray sources may be a flaring and/or bursting star in the cluster.
6. The Sgr C region is also an XRN, as suggested by Murakami et al. (2001a).

8. References

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