X-Ray Reflection Nebulae with Large Equivalent Widths of the Neutral Iron Kα Line in the Sagittarius C Region

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Abstract

This paper reports on the first results of a Suzaku observation in the Sgr C region. We detected four diffuse clumps with strong line emission at 6.4 keV, Kα from neutral or low-ionized Fe. One of them, M 359.38–0.00, was newly discovered with Suzaku. The X-ray spectra of the two bright clumps, M 359.43–0.07 and M 359.47–0.15, after subtracting the galactic center diffuse X-ray emission (GCDX), exhibit a strong Kα line from Fe I with large equivalent widths (EWs) of 2.0–2.2 keV and a clear Kβ of Fe I. The GCDX in the Sgr C region is composed of the 6.4 keV- and 6.7 keV-associated components. These were phenomenologically decomposed by taking relations between the EWs of the 6.4 keV and 6.7 keV lines. Then, the former EWs against the associated continuum in bright clump regions were estimated to be $2.4^{+2.3}_{-0.7}$ keV. Since the two different approaches give similar large EWs of 2 keV, we strongly suggest that the 6.4 keV clumps in the Sgr C region are due to X-ray reflection/fluorescence (the X-ray reflection nebulae).

Key words: Galaxy: center — ISM: clouds — ISM: molecules — X-rays: ISM

1. Introduction

The Galactic Center (GC), the nearest galactic nucleus, hosts various classes of high-energy sources, such as a super-massive black hole, Sgr A*, X-ray binaries, supernova remnants, and non-thermal filaments (NTFs). GC is also the primary site of giant molecular clouds (MCs) and star formation inside the MCs. One of the most interesting characteristics in GC is prominent 6.4 keV emissions are found in the MCs of Sgr B2 (Koyama et al. 1996), G0.13–0.13 (Yusef-Zadeh et al. 2000), Sgr B1 (Nobukawa et al. 2008), and Sgr C (Murakami et al. 2001b). A number of small MCs in the GC region also emit strong 6.4 keV lines (Predehl et al. 2003; Park et al. 2004).

For the origin of the 6.4 keV emission line from MCs, two models have been proposed. One is the impact of low-energy cosmic-ray electrons (LECRE), followed by bremsstrahlung and 6.4 keV line emission, proposed for the origin of Galactic Ridge X-ray Emission (Valinia et al. 2000). Yusef-Zadeh et al. (2002) proved that this model can be applied to G0.13–0.13, assuming an Fe abundance of two solar. The other is that the hard X-rays and 6.4 keV lines are due to reflection/fluorescence from MCs irradiated by external hard X-ray sources (X-ray reflection Nebula: XRN) (Sunyaev et al. 1993; Markovitch et al. 1993; Koyama et al. 1996; Sunyaev & Churazov 1998; Park et al. 2004). Since no irradiating source capable of powering the 6.4 keV line was found, Koyama et al. (1996) proposed a scenario of a past X-ray outburst of the super-massive black hole at Sgr A*. The present luminosity is $2 \times 10^{33}$ erg s$^{-1}$ (Baganoff et al. 2001, 2003), and hence it would have been $10^6$ times brighter than now 300 years ago.

In fact, the Chandra observation shows that the 6.4 keV emission line of the giant MC Sgr B2 has a concave shape pointing to the GC direction (Murakami et al. 2001a). The broad band spectrum of Sgr B2 is well described by Compton-scattered and reprocessed radiation emitted in the past by Sgr A* (Revnivtsev et al. 2004). The morphology and flux of the 6.40 keV line of Sgr B2 have been time variable for 10 years (Muno et al. 2007; Koyama et al. 2008; Inui et al. 2009). Thus, observational results supporting the XRN rather than the LECRe model have been accumulating for Sgr B2. However, for the other regions, in particular Sgr C, observations have been limited, and hence the 6.4 keV line origin is still an open issue.

The Sgr C region consists of giant MCs and large H II regions. From the $^{13}$CO observations, Liszt and Spiker (1995) estimated $6.1 \times 10^5$ solar mass for the molecular gas. Murakami et al. (2001b) discovered a 6.4 keV clump with ASCA, and interpreted that the clump is an XRN because the X-ray spectrum exhibited a large equivalent width (EW) of...
the 6.4 keV emission line with strong absorption, like that in Sgr B2. On the other hand, Yusef-Zadeh et al. (2007) discussed possible associations of the 6.4 keV emission lines with some radio NTFs based on the Chandra observations, and argued that the 6.4 keV line is due to the impact of LECRe. These results and arguments are based on short-exposure observations (20 ks and 2.2 ks for the ASCA and Chandra, respectively). In order to fix the above debates, we therefore, made a long Suzaku observation of the Sgr C region.

For simplicity, we used “the east” as the positive galactic longitude side, and “the north” as the positive galactic latitude side. We assumed the distance to the Sgr C region to be 8.5 kpc, following the recommendation of IAU. We applied the solar abundance and photoelectric absorption cross-section from tables given by Anders and Grevesse (1989) and Bałucińska-Church and McCammon (1992), respectively.

2. Observation and Data Reduction

The Sgr C region was observed with the XIS (X-ray Imaging Spectrometer) from 2006 February 20 to 23. The telescope optical axis position was RA = 17h44m37.3s, Dec = -29°28′10.2″ (J2000.0). The XIS consists of four sets of X-ray CCD camera systems placed on the focal planes of the four X-Ray Telescopes (XRT) onboard the Suzaku satellite. One of the XIS sensors (XIS 1) has a back-illuminated (BI) CCD, while the other three sensors (XIS 0, 2, and 3) utilize front-illuminated (FI) CCDs. Detailed descriptions of the Suzaku satellite, XRT and XIS can be found in Mitsuda et al. (2007), Serlemitsos et al. (2007), and Koyama et al. (2007a), respectively.

A cleaned event list was obtained from the processed data with version of 2.0.6.13 by removing events taken during passage of the South Atlantic Anomaly, the elevation angles from the night Earth rim of < 5° and from the sun-lit Earth rim of < 20°, and the telemetry saturation. After these data screenings, the net exposure was 107 ks. We analyzed the screened data using the HEADAS software version 6.4, XSPEC version 11.3.2g. We utilized the calibration databases released on 2008 February 1.

3. Analysis and Results

The non–X-ray (particle) background (NXB) becomes serious in the hard X-ray band, in particular for diffuse sources.

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Fig. 1. Co-added GCDX spectrum of the FI (XIS 0+2+3) at the Sgr C region extracted from the 6:95 radius circle at the center of the XIS FOV. The NXB component was subtracted. The spectrum of BI (XIS 1) was simultaneously analyzed, but the figure is not shown here, for brevity.

Fig. 2. (a) 2.45 keV-line (Kα of S XV) image in the energy band of 2.35–2.50 keV and (b) 6.4 keV-line (Kα of Fe I) image in the 6.28–6.42 keV band. The source and background regions for the spectral analysis are shown with solid and dashed magenta ellipses, where the data within the blue ellipse (G359.41−0.12) were excluded to minimize the contamination from the strong 2.45 keV emission line and its associated continuum.

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1 [http://www.astro.isas.jaxa.jp/suzaku/process/].
2 [http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/].
3 [http://www.astro.isas.jaxa.jp/suzaku/caldb/].
The flux of the NXB is correlated with the geomagnetic cut-off rigidity (COR) (Tawa et al. 2008). We therefore made COR-sorted NXB data sets using night-Earth data released by the Suzaku XIS team.\textsuperscript{4} For the following imaging and spectral studies in the Sgr C region (subsections 3.1 and 3.2), we used the X-ray data after subtracting the NXB that were compiled to have the same COR distribution as that during the Sgr C observation.

To increase statistics, here and after, we co-added the four XIS data for an imaging study, in which exposure and vignetting corrections were made. For a spectral study, we co-added the three FI CCD data, and treated the BI data separately, because the response functions were significantly different between FI and BI.

3.1. X-Ray Image in the Emission Line

Figure 1 shows the energy spectrum of the whole Sgr C region, which was extracted from the circular region with a radius of 6.95 from the FOV center. The spectrum shows K-shell emission lines from He-like and/or H-like ions of S, Ar, Ca, and Fe. In addition, the 6.4 keV emission line and the K-edge absorption at 7.1 keV due to Fe I were detected. The three Fe K-shell emission lines at 6.4, 6.7, and 6.9 keV in the galactic center diffuse X-ray emission (GCDX) (Koyama et al. 1989; Yamauchi et al. 1990; Koyama et al. 2007b) were clearly resolved.

Since the Suzaku coordinates have 90\% confident error of 19" (Uchiyama et al. 2008), we made a coordinate correction using a Chandra observation. In the energy band of 0.7–1.5 keV, a point source with a flux of \(6 \times 10^{-15} \text{erg cm}^{-2} \text{s}^{-1}\) was detected at \((\text{RA, Dec})_{\text{J2000}} = (17^h44^m52^s1''', -29^\circ31'56''7'')\) in the XIS image. In the error circle of Suzaku, there was only one Chandra point source at \((\text{RA, Dec})_{\text{J2000}} = (17^h44^m53^s1'', -29^\circ31'45''5'')\). Since the flux was almost the same as that of the Suzaku source, we safely concluded that these point sources are identical. We then fine-tuned the Suzaku coordinates by shifting \(\Delta (\text{RA, Dec})_{\text{J2000}} = (13''7, 11''2)\).

Referring to figure 1, we made a narrow band image of the 2.45 keV-line (2.35–2.50 keV; \(\text{K}\alpha\) of S XV) and the 6.4 keV-line (6.28–6.42 keV; \(\text{K}\alpha\) of Fe I). Images after smoothing with a Gaussian kernel of 48 pixels (0.83) are shown in figure 2. In figure 2a, a bright 2.45 keV-line clump is found at \((l, b) = (359^h407^m, -0^\circ119'')\), and is hence designated as G359.41–0.12. Likely, four 6.4 keV-line clumps found in figure 2b are designated as M359.43–0.07, M359.47–0.15, M359.43–0.12, and M359.38–0.00, where M359.43–0.12 is in the region of G359.41–0.12.

3.2. Emission Line Feature in the Sgr C Region

The photon statistics are limited to make measurable spectra for M359.38–0.00 and M359.43–0.12. Furthermore, M359.43–0.12 is in the 2.45 keV-source, G359.41–0.12. Therefore we concentrated on two bright sources, M359.43–0.07 and M359.47–0.15, and the surrounding background regions.

As can be seen in figure 1, the GCDX with strong 6.7 keV line (\(\text{K}\alpha\) of Fe XXV) and 6.9 keV (\(\text{Ly}\alpha\) of Fe XXVI) lines is the largest background for local enhancements, such as the 6.4 keV clumps. In addition, the flux of the GCDX is not uniform, but variable from position to position. To see the flux distribution and nature of the GCDX near Sgr C, we examined the NXB-subtracted (GCDX is not subtracted) spectra in the 6.4 keV clumps and the surrounding areas including candidate background regions (see figure 2).

The spectra from the whole Sgr C region is already described in subsection 3.1 (figure 1). The spectra of M359.43–0.07 and M359.47–0.15 were extracted from the regions shown with solid magenta ellipses in figure 2b. The background...
The spectra of FIs and as those used in Koyama et al. (2007b, 2009): a single power background regions (hereafter, the outer region).

The spectral fittings were made in the same energy band obtained from all of the spectra. The FI spectra and the best-fit obtained from the annuli of Sgr A region (adopted from figure 2d of Koyama et al. 2009). The open and filled circles show the whole Sgr C region and the source regions of M 359.43 2009). From table 1, we plotted the E W_{6.4} and E W_{6.7} relation of the six regions (figure 4). The outer region, the whole Sgr C and the background region for M 359.43–0.07 follow to, but the M 359.43–0.07 and M 359.47–0.15 regions come above the best-fit correlation line of the Sgr A region; these are systematically larger E W_{6.4} than the Sgr A region. The best-fit linear relation between E W_{6.7} and E W_{6.4} for all cited regions except the whole Sgr C is

\[ E W_{6.7} + 0.22(\pm 0.12) \times E W_{6.4} = 0.53(\pm 0.06) \]  

Fig. 4. Correlation between the E W_{6.4} of the Fe i-Kα line (E W_{6.4}) and Fe XXV-Kα line (E W_{6.7}). The dashed line shows the best-fit relation in the Sgr A region (adopted from figure 2d of Koyama et al. 2009). The open and filled circles show the whole Sgr C region and the outer region, respectively. The source regions of M 359.43–0.07 and M 359.47–0.15 are plotted with an open square and a triangle, while their background regions are given by filled marks. The solid line is the best-fit relation for all regions except the whole Sgr C of E W_{6.7} = 0.22 + E W_{6.4} = 0.53 [keV].

The spectral fittings were made in the same energy band with the same phenomenological model and free parameters as those used in Koyama et al. (2007b, 2009): a single power law and 10 Gaussian emission lines. The spectra of FIs and BI were simultaneously fitted, and acceptable \( \chi^2 \) values were obtained from all of the spectra. The FI spectra and the best-fit model of M 359.43–0.07 and M 359.47–0.15, and the outer region of Sgr C are shown in figure 3 as examples. The best-fit parameters are listed in table 1.

Koyama et al. (2009) found that the GCDX in the Sgr A region is phenomenologically decomposed into the 6.7-keV line plus an associated continuum (6.7-component) and the 6.4-keV line plus an associated continuum (6.4-component); the E W_{6.4} of the 6.4 keV (E W_{6.4}) and the 6.7 keV (E W_{6.7}) lines are given by the relation E W_{6.7} = 0.50(\pm 0.06) \times E W_{6.4} = 0.62(\pm 0.07) [keV]. Then, in the limit of E W_{6.4} \to 0, E W_{6.7} was estimated to be 0.62 \pm 0.07 keV. On the other hand, in the limit of E W_{6.7} \to 0, E W_{6.4} is 1.2 \pm 0.2 keV. They also obtained the GCDX-subtracted spectra of the two 6.4 keV clumps in the Sgr A region (sources 1 and 2 in Koyama et al. 2009), and obtained consistent E W_{6.4} values as those estimated from the phenomenological relation.

Stimulated by the successful approach of Koyama et al. (2009), we used the same method to decompose the GCDX in the Sgr C region into a 6.4-component and a 6.7-component. Using the data in table 1, we plotted the E W_{6.4} and E W_{6.7} relation of the six regions (figure 4). The outer region, the whole Sgr C and the background region for M 359.43–0.07 follow to, but the M 359.43–0.07 and M 359.47–0.15 regions come above the best-fit correlation line of the Sgr A region; these are systematically larger E W_{6.4} than the Sgr A region. The best-fit linear relation between E W_{6.7} and E W_{6.4} for all cited regions except the whole Sgr C is

\[ E W_{6.7} + 0.22(\pm 0.12) \times E W_{6.4} = 0.53(\pm 0.06) \]  

where the errors mean the 90% confidence levels.

This relation indicates that E W_{6.7} in the 6.7-component is 0.53 \pm 0.06 keV (at E W_{6.4} \to 0) for the Sgr C region, consistent with that of the Sgr A region of 0.62 \pm 0.07 keV (Koyama et al. 2009). On the other hand, E W_{6.4} in the 6.4-component is 2.4^{+0.7}_{-0.3} keV (at E W_{6.7} \to 0), larger than those in the Sgr A region (Koyama et al. 2009).

3.3. Spectra of M 359.43–0.07 and M 359.47–0.15

From table 1, we can see that the 6.7 keV line fluxes in M 359.43–0.07 and M 359.47–0.15 are almost identical to those of the respective background regions. The 6.7 keV flux differences are 16% and 6% of those in M 359.43–0.07 and M 359.47–0.15, respectively. Since the 6.7 keV line flux is a good indicator of the flux of the GCDX (Koyama et al. 2007b, 2009), we conclude that the background regions were properly selected within a possible systematic error of 6%–16%, which is smaller than the statistical errors.

| Region | Area (arcmin^2) | Γ | Line flux | Line equivalent width (eV) |
|--------|-----------------|---|-----------|---------------------------|
| (1)    | 152             | 1.72 (1.65–1.78) | 0.79 (0.77–0.81) | 0.68 (0.65–0.70) | 458 (448–470) | 420 (401–430) |
| (2)    | 121             | 1.70 (1.63–1.82) | 0.55 (0.53–0.57) | 0.68 (0.66–0.71) | 346 (333–363) | 345 (441–471) |
| (3)    | 7.09            | 1.82 (1.65–2.06) | 1.91 (1.79–2.06) | 1.08 (0.96–1.22) | 670 (625–720) | 400 (357–454) |
| (4)    | 11.7            | 1.64 (1.47–1.93) | 1.00 (0.92–1.08) | 0.93 (0.86–1.03) | 397 (365–428) | 388 (360–431) |
| (5)    | 6.91            | 1.96 (1.59–2.24) | 2.16 (2.03–2.31) | 0.63 (0.53–0.73) | 966 (909–1030) | 298 (253–348) |
| (6)    | 22.4            | 1.75 (1.59–1.97) | 1.02 (0.97–1.08) | 0.67 (0.62–0.72) | 587 (554–620) | 404 (374–437) |

* 90% confidence limits are in parentheses.
* (1) the whole Sgr C region, (2) the outer region, (3) M 359.43–0.07, (4) background region for M 359.43–0.07, (5) M 359.47–0.15, (6) background region for M 359.47–0.15.
* Absorption-uncorrected line flux in units of 10^{−6} ph cm^{-2} s^{-1} arcmin^{-2}.
Table 2. Best-fit parameters for the GCDX subtracted spectra.\textsuperscript{a}

| Parameter | M 359.43–0.07 | M 359.47–0.15 |
|-----------|--------------|--------------|
| Absorbed power-law model: | | |
| Column density $N_H$ ($10^{23}$ cm\(^{-2}\)) | 0.92 (0.48–1.41) | 0.82 (0.65–1.18) |
| Photon index | 1.67 (1.51–1.82) | 1.61 (1.52–1.86) |
| Gaussian 1 (Fe I $\alpha$): | | |
| Line energy (keV) | 6.41 (6.39–6.42) | 6.41 (6.40–6.42) |
| Line flux ($10^{-6}$ ph cm\(^{-2}\) s\(^{-1}\))\textsuperscript{b} | 6.43 (5.27–7.39) | 8.82 (7.87–10.0) |
| Equivalent width (keV) | 2.18 (1.79–2.51) | 1.96 (1.75–2.23) |
| Gaussian 2 (Fe I $\beta$): | | |
| Line energy (keV)\textsuperscript{b} | 7.07 | 7.07 |
| Line flux ($10^{-6}$ ph cm\(^{-2}\) s\(^{-1}\))\textsuperscript{b} | 1.05 (0.43–2.14) | 1.91 (1.22–3.00) |
| Flux ($10^{-13}$ erg cm\(^{-2}\) s\(^{-1}\))\textsuperscript{b} | 2.70 | 4.11 |
| $\chi^2$/d.o.f. | 27.92/41 | 49.67/46 |

\textsuperscript{a} 90\% confidence limits are in parentheses.
\textsuperscript{b} Line fluxes are not corrected for the absorption.
\textsuperscript{c} The line center is fixed so that the energy ratio is 1.103 ($K\beta/K\alpha = 7.058$ keV/6.400 keV).
\textsuperscript{d} Observed flux of the diffuse emission in the energy band of 3–10 keV. Absorption is not corrected.

Therefore, we obtained the GCDX-subtracted spectra of these 6.4 keV clumps (figure 5). The energy-dependent vignetting was the corrected by multiplying the effective-area ratio of the source region to corresponding background region for each energy bin of the GCDX spectra.

We first applied a model of a power-law and a narrow Gaussian line at 6.4 keV with absorption. The metal abundances of the inter-stellar medium were fixed to the solar value (Anders & Grevesse 1989), while the center energy of the 6.4 keV line and its flux were free parameters. We simultaneously fit this model to the FI and BI spectra, and found a line-like residual at 7.0–7.1 keV, with a flux of $\sim$10–20\% of the 6.4 keV (Fe I $\alpha$) line. From the energy and flux, the residual is likely to be the $K\beta$ of neutral Fe. We then added a second narrow Gaussian for the Fe I $K\beta$ line, fixing its center energy to 1.103-times of that of $K\alpha$. This model was accepted, as is shown in figure 5, while the best-fit parameters are listed in table 2.

4. Discussion

We detected four 6.4 keV clumps (M 359.43–0.07, M 359.47–0.15, M 359.43–0.12, and M 359.38–0.00) with Suzaku. From the former bright clumps, M 359.43–0.07 and M 359.47–0.15, we found $K\alpha$ and $K\beta$ lines from Fe I. The most important fact is that the EWs of the $K\alpha$-lines are extremely large, $\sim$2 keV (subsection 3.3). These large EWs are independently supported by an analysis of the GCDX in the Sgr C regions (subsection 3.2), and hence are highly reliable. We note that Yusef-Zadeh et al. (2007) reported small EWs values from all of the clumps, but their estimation was based on spectra where no GCDX was subtracted.

4.1. Comparison with Past X-Ray Observations

Murakami et al. (2001b) found excess emission at $(l, b) = (359^\circ 43, -0^\circ 04)$ in an X-ray image of the 5.8–7.0 keV band. Although the energy resolution was limited, an emission line
Fig. 6. Contours of channel map of the CS $J = 1–0$ emission line overlaid on the narrow band image at 6.4 keV shown in figure 2b. The first contour level and the contour interval are 14.3 and 4.8 K km s$^{-1}$, respectively. Emission in the velocity ranges of $-90$ to $-130$ km s$^{-1}$ is shown with green, and that of $-30$ to $-80$ km s$^{-1}$ is magenta, respectively.

at an energy consistent with Fe $\text{t-Kr}$ line was found. Hence, Murakami et al. (2001b) regarded this clump as an XRN.

The Suzaku source M 359.43$–$0.07 is located in the ASCA clump, but the peak position is systematically shifted. For a comparison, we extracted the Suzaku spectrum from the same source and background-regions as those of the ASCA clump (Murakami et al. 2001b). The background subtracted spectrum has a 6.4 keV line flux of $1.8^{+0.3}_{-0.2} \times 10^{-5}$ ph cm$^{-2}$ s$^{-1}$ (absorption uncorrected), which agrees with that of the ASCA clump ($3.5^{+1.4}_{-1.2} \times 10^{-5}$ ph cm$^{-2}$ s$^{-1}$). With Suzaku, we found that the surface brightness ratio of the 6.4 keV emission lines between M 359.43$–$0.07, the ASCA clump and the outer background region are approximately 3:2:1 (1.9, 1.4, and 0.6 in units of $10^{-6}$ ph cm$^{-2}$ s$^{-1}$ arcmin$^{-2}$). Hence, no significant detection of the full region of the ASCA clump in figure 2b may be due to its relatively lower surface brightness than M 359.43$–$0.07. On the other hand, no ASCA detection of M 359.43$–$0.07 is puzzling, although a possible time variability can not be excluded. ASCA also detected no flux from the other bright Suzaku source, M 359.47$–$0.15. However, this source is near the edge of the ASCA field.

The Suzaku spectrum of the whole Sgr C region (figure 1) shows $EW$s of $458^{+15}_{-16}$ eV and $420^{+19}_{-19}$ eV for the 6.4 keV and 6.7 keV emission lines, respectively. The surface brightness in the 5–8 keV energy band is $7.1 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ arcmin$^{-2}$. The Chandra analysis of the same region, in which point sources cataloged in the list of Muno et al. (2006) are excluded, shows that the $EW$s of the 6.4 keV and 6.7 keV emission lines are $460 \pm 100$ eV and $\sim 400$ eV, respectively. The surface brightness in the 5–8 keV band is $\sim 7.5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ arcmin$^{-2}$ (figure 1b in Yusef-Zadeh et al. 2007). These are very similar to those of Suzaku, and hence the point-source contribution with a flux level larger than $10^{-13}$ erg cm$^{-2}$ s$^{-1}$ (Muno et al. 2006) may not be large, at least in the whole Sgr C region.

A detailed comparison in smaller scale emission, however, shows significant differences. M 359.47$–$0.15 and a part of M 359.43$–$0.07 can be seen in a narrow-band image at 6.4 keV with Chandra (figure 5a in Yusef-Zadeh et al. 2007). However, M 359.43$–$0.07 is not found in the $EW$ map of Chandra (figure 5c in Yusef-Zadeh et al. 2007). This is a puzzle, because the Suzaku $EW$ of M 359.43$–$0.07 is one of the largest among cited regions in the NXB-subtracted spectra. One possibility is a time variability, as was found in Sgr B2 and Radio Arc regions (Muno et al. 2007; Koyama et al. 2008; Inui et al. 2009). In a Chandra image of the 2–6 keV band (figure 1a of Yusef-Zadeh et al. 2007), a clump named G359.45$–$0.07 is found. However, Suzaku found no excess...
in this region with the 6.4 keV line, and hence G359.45–0.07 would not be 6.4 keV line emitter. Conversely, no excess from M 359.38–0.00 has been found with either Chandra or ASCA, possibly due to the limited flux, and hence this is a new 6.4 keV clump found with the Suzaku satellite.

4.2. Ionization Mechanism

Two scenarios have been proposed for the origin of the 6.4 keV emission line from MCs in the GC region. One is X-ray photo ionization by external X-ray sources (the XRN scenario) (Koyama et al. 1996; Sunyaev & Churazov 1998; Park et al. 2004). The other is inner-shell ionization by the impact of LECRe (the electron bombardment scenario) (Valinia et al. 2000; Yusef-Zadeh et al. 2002). The LECRe scenario expects an $E_{6.4}$ value of $\sim 300$ eV for the solar-abundance Fe (Tatischeff 2003; Yusef-Zadeh et al. 2007), and hence it is difficult to explain the observed large $E_{6.4}$ of $\sim 2$ keV, unless Fe is extremely over-abundant by a factor of 6–7. We found no observational evidence for such over-abundance. On the other hand, the XRN scenario naturally explains the large $E_{6.4}$ of M 359.43–0.07 and M 359.47–0.15, and hence is more likely.

4.3. Photo-Ionization Source

Since the typical absorption toward GC is $\sim 0.6 \times 10^{23}$ H cm$^{-2}$ (Rieke et al. 1989; Sakano et al. 2002), the intrinsic absorption depths of M 359.43–0.07 and M 359.47–0.15 are $\leq 0.8 \times 10^{23}$ H cm$^{-2}$ and $\leq 0.6 \times 10^{23}$ H cm$^{-2}$, respectively. The areas of M 359.43–0.07 and M 359.47–0.15 shown in figure 2b are 7 arcmin$^2$, and thus their masses are estimated to be $\leq 4 \times 10^4$, $\leq 3 \times 10^4$ solar mass, respectively. From these masses and fluxes of the 6.4 keV lines, the luminosity of the photo-ionizing source can be estimated following Sunyaev and Churazov (1998) as $\geq 1 \times 10^{38}$ erg s$^{-1}$ and $\geq 2 \times 10^{38}$ erg s$^{-1}$.

There is no X-ray object bright enough inside or nearby the Sgr C region. Even the brightest near-by sources, KS 1741–293 and the Great Annihilator (1E 1740.7–2943), are impossible to explain this luminosity. Thus, we arrive at the same conclusion as the 6.4 keV clumps origin near Sgr B2, a past Sgr A* activity of $\geq 1 \times 10^{38}$ erg s$^{-1}$ at 240 years ago.

4.4. Comparison with Molecular Line Observations

The absorption column derived from the background-subtracted spectra of M 359.43–0.07 and M 359.47–0.15 are $N_{\text{H}} \sim 1 \times 10^{23}$ H cm$^{-2}$. We require similar amounts of column in the MCs that correspond to M 359.38–0.00 and M 359.43–0.12. Referring to the CS molecular line map over the velocity range of $V_{\text{LSR}} = -200$ to $+200$ km s$^{-1}$ (Tsuboi et al. 1999, and the electric data), we searched for a possible counterpart of the 6.4 keV clumps with $N_{\text{H}} \geq 10^{23}$ H cm$^{-2}$ (figure 6).

M 359.43–0.07: MCs of $N_{\text{H}} \sim 10^{23}$ H cm$^{-2}$ are seen both in the velocity ranges of $-50$ to $-70$ km s$^{-1}$ (also Yusef-Zadeh et al. 2007) and $-90$ to $-110$ km s$^{-1}$ (also Murakami et al. 2001b).

M 359.47–0.15: An MC with $N_{\text{H}} \geq 10^{23}$ H cm$^{-2}$ in the velocity range of $-50$ to $-70$ km s$^{-1}$ exists in this region. M 359.47–0.15 is located at the western edge of $-65$ km s$^{-1}$ MC, as also noticed by Yusef-Zadeh et al. (2007). There is no other MC of $\sim 10^{23}$ H cm$^{-2}$ in another velocity range.

M 359.38–0.00: No MC is seen in the $-50$ to $-70$ km s$^{-1}$ band, but an MC in the velocity range of $-110$ to $-130$ km s$^{-1}$ is associated with the 6.4 keV clump. The column density of this radio cloud is roughly half those in the directions of M 359.43–0.07 and M 359.47–0.15.

M 359.43–0.12: There is a weaker peak in the $-120$ to $-130$ km s$^{-1}$ band than that at M 359.38–0.00.

Sofue (1995) and Sawada et al. (2004) proposed that molecular gases in the GC region consist of two arms, Arm I and Arm II. The $-90$ to $-130$ km s$^{-1}$ MC is physically associated with Arm I, while the $-30$ to $-80$ km s$^{-1}$ MC is a part of Arm II. M 359.38–0.00 and M 359.47–0.15 belong to Arm I and Arm II, respectively, while M 359.43–0.07 has both possibilities. Since Arm II is located far side of Arm I (Sofue 1995; Sawada et al. 2004), X-rays from Sgr A* of several hundred years ago arrived at M 359.47–0.15 probably earlier than at M 359.38–0.00.

5. Summary

1. We found four diffuse 6.4 keV clumps (M 359.43–0.07, M 359.47–0.15, M 359.43–0.12 and M 359.38–0.00) in the Sgr C region. The last one, M 359.38–0.00 was newly discovered.

2. The spectra of the two bright clumps, M 359.43–0.07 and M 359.47–0.15, have a power-law of photon index 1.6–1.7 with a very large $E_{6.4}$ of 2.0–2.2 keV, the largest $E_{6.4}$ among the 6.4 keV clumps in the GC.

3. The large $E_{6.4}$ supports that the origin of the 6.4 keV clumps is due to X-ray reflection irradiated by hard X-ray sources.

4. M 359.38–0.00 and M 359.47–0.15 possibly associate with MCs in different velocity ranges, indicating these are located in different molecular arms.

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