Suzaku Discovery of Two Peculiar Clumps at the South End of the Radio Arc

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Abstract

Radio non-thermal filaments and diffuse X-ray emission in the 6.4 keV line from neutral irons are unique structures seen only in the Galactic center (GC) region. These features are sites of high-energy activity, and hold the clue to clarify the structure of GC. To search for a correlation of radio non-thermal filaments and 6.4 keV or any other X-ray band emission, Suzaku observed the GC region near the Radio Arc at $\sim 20'$ southeast of Sagittarius A*. In the 18'×18' field of view, we found a small clump in a higher energy band (4–6 keV), and a peculiar clump in the 6.4 keV line band. Both of them are located at the south end of the Radio Arc. We report on the results, and discuss the origin of these X-ray sources.

Key words: Galaxy: center — ISM: clouds — radio continuum: ISM — X-rays: ISM

1. Introduction

Radio non-thermal filaments (NTFs; e.g. LaRosa et al. 2000) are unique structures seen only in the Galactic center (GC) region. The most striking and large-scale NTF is the Radio Arc threading the Galactic plane at $l \sim 0.2^\circ$ (Yusef-Zadeh et al. 1984). The Radio Arc may be a site of high-energy activity: acceleration to relativistic electrons in an enhanced magnetic field.

Another feature of the high-energy activity in the GC is diffuse X-ray emission in the 6.4 keV line from neutral irons (Fe_{I}). Koyama et al. (1996) proposed that these 6.4 keV clumps are X-ray reflection nebulae (XRNe), which are molecular clouds irradiated by hard X-ray from super-massive black-hole Sagittarius A* (Sgr A*) at the GC. On the other hand, Yusef-Zadeh et al. (2007) proposed that the 6.4 keV emission comes from low-energy cosmic-ray electrons (LECRs) bombarding the clouds. In the latter scenario, a possible correlation of NTFs and the 6.4 keV or the other X-ray band emissions should be found, because NTFs may be sites of relativistic electrons, and hence LECRs may also be abundant.

To search for the X-ray emission from the Radio Arc, we performed a Suzaku observation at the south end of the Radio Arc.

2. Observation

We conducted a deep Suzaku observation centered at the southeast direction of the GC by $\sim 20'$, which is near the south end of the Radio Arc. The observation was performed with the X-ray Imaging Spectrometer.

3. Analysis and Results

3.1. Images

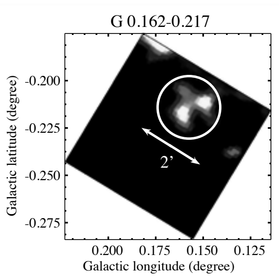

Fig. 1. The 4.0–6.0 keV energy band image of G 0.162−0.217.

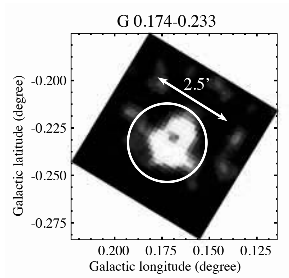

Fig. 2. The 6.4 keV-line band image of G 0.174−0.233.

In the hard X-ray band (4–6 keV) image, we can see an excess emission (G 0.162−0.217) as shown in figure 1. Interestingly, we found another clump (G 0.174−0.233) in the 6.4 keV-line band image (figure 2).

We examined whether these two sources are point-like or diffuse. We first checked possible contamination from faint point sources while referring to Muno et al. (2006). Point sources were found to explain only $\sim 6\%$ of the photon flux of G 0.174−0.233 and only $\sim 10\%$ of that of G 0.162−0.217, respectively. We then fitted the radial profiles of the sources with the point-spread function (PSF) plus a constant component model. These single point-source models are rejected with $\chi^2/\mathrm{d.o.f} = 36.4/10$ for G 0.174−0.233 and with $\chi^2/\mathrm{d.o.f} = 16.9/6$ for G 0.162−0.217. We therefore conclude that the sources are both diffuse.

3.2. Spectra

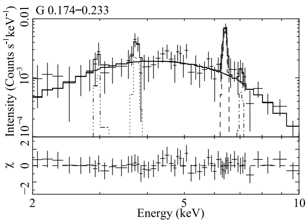

Fig. 3. Background-subtracted spectrum of G 0.174−0.233. The data and the best–fit model are shown by the crosses and the solid line, respectively. The lower panels show the data residuals from the best-fit model.

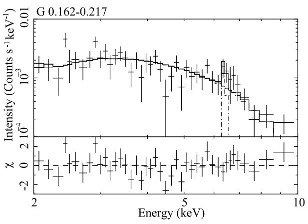

Fig. 4. Same as figure 4, but for the G 0.162−0.217 spectrum.

We extracted the spectra of G 0.174−0.233. We then fitted the spectra with a model of absorbed power-law plus four Gaussians for the Kα lines of Fe_{I}, Ca_{I}, and Ar_{I} (6.40 3.69 and 2.96 keV) and the Kβ line of Fe_{I} (7.06 keV) in the 2.0–10 keV energy band (figure 3). The best-fit parameters and the errors at the 90% confidence level are N_{H} (absorbing column) = $7.5^{+2.0}_{-1.7} \times 10^{22}$ H cm^{-2}, Γ (photon index) = $1.7^{+0.1}_{-0.2}$, EW_{Fe} (equivalent width of Fe-Kα line) = $0.95^{+0.18}_{-0.19}$ keV, EW_{Ca} = $0.18^{+0.10}_{-0.10}$ keV. Although the detection of the Ar-Kα line is marginal ($\sim 1\sigma$ significance), the Ca-Kα line was surely detected for the first time with $\sim 3\sigma$ significance.

We also obtained the spectra of G 0.162-0.217, and then fitted with the model of an absorbed power-law plus two narrow Gaussian lines at 6.4 keV and 7.06 keV in the 2.0–10 keV energy band (figure 4). The best-fit parameters and the errors at the 90% confidence level are $N_{\mathrm{H}} = 5.5^{+0.8}_{-1.0} \times 10^{22}$ H cm^{-2}, $\Gamma = 2.5^{+0.2}_{-0.6}$, and EW_{Fe} = $0.36^{+0.26}_{-0.19}$ keV. The spectra have weaker emission lines and steeper continuum than those of G 0.174−0.233, although the interstellar absorption is almost the same.

4. Discussion

4.1. Nature of G 0.174−0.233

The neutral lines (Ca_{I}- and Fe_{I}-Kα lines) indicate that the emission comes from a molecular cloud. Two models for the diffuse X-ray emission from the molecular cloud have been proposed. One is the irradiation of molecular clouds by external X-ray sources (the XRN model; Koyama et al. 1996). The other is the impact of LECRs on molecular clouds (the LECR model; Yusef-Zadeh et al. 2007).

To discuss quantitatively, we compare the equivalent width (EW) of the neutral Kα line with the theoretical value. With respect to the Fe_{I}-Kα line, the observed EW is $\sim$ 950 eV, while the XRN model and the LECR model expect EWs of $\sim$ 1 keV (e.g. Murakami et al. 2000) and $\sim$ 290 eV (Tatischeff 2003), respectively. Thus, the XRN scenario is more favored because it does not require any over abundance. With respect to the Ca_{I}-Kα line, the observed EW is 80–280 eV at the 90% confidence level. The EWs of the XRN model and the LECR model are estimated to be 50–60 eV and $\sim$ 10 eV (Tatischeff 2003), respectively. Although it needs the Ca abundance a factor of more than $\sim$ 1.5 for the solar one, the XRN model is more likely for the origin than the LECR model.

4.2. Nature of G 0.162−0.217

The absorbing column of G 0.162−0.217 is consistent with the typical value of $\sim 6 \times 10^{22}$ H cm^{-2} in the GC region. Therefore, this source is likely to be near the GC. Since G 0.162−0.217 is only $\sim 1.2'$ from the strong 6.4 keV-line source G 0.174−0.233, we estimated 6.4 keV-line contamination. We then estimated for the real EW of G 0.162−0.217 to be $\sim$ 0.2 keV.

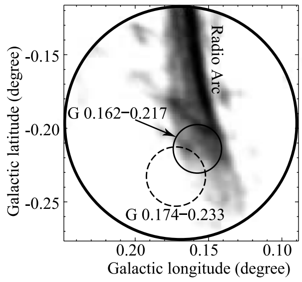

Fig. 5. 4.735 GHz radio continuum map from the National Radio Astronomy Observatory / Very Large Array archive survey image. The Very Large Array field is shown with the thick solid circle. The positions of G 0.174−0.233 and G 0.162−0.217 are shown by the dashed and thin-solid circles on the Radio Arc.

The X-ray origin is uncertain, but, interestingly, G 0.162−0.217 is located at adjacent to the south end of the Radio Arc (LaRosa et al. 2000) as shown in figure 5. Since the Radio Arc is a site of relativistic electrons, which may also include LECR. Thus, it may be conceivable that the X-rays of G 0.162−0.217 are due to the LECRs. The observed EW of Fe_{I} Kα of $\sim$ 0.2 keV is consistent with the LECR model (EW of $\sim$ 0.3 keV).

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