Chapter 4

Is there a Consistent Picture of the Inner kpc of the Milky Way?

THE HOT GAS IN THE GALACTIC BULGE

- *Diffuse X-rays with complex K-shell transition lines from the Bulge* -

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Abstract. X-ray imaging spectroscopic observations near the Galactic center region were carried out with the ASCA satellite. We found two bright spots very close to the Galactic center (Sgr A*); one is extended and has a soft spectrum associated with strong emission lines from highly ionized irons, while the other is a point-like object with a harder spectrum and a larger absorption. We also found extended emission with K-shell transition lines from highly ionized Si, S, Ar, Ca and Fe. Remarkable feature found with ASCA is an extended emission of 6.4 keV lines of low ionization irons. The 6.4 keV line fluxes are found to be well correlated to the region of cool clouds. We interpret that the 6.4 keV line is due to florescence from the cool clouds irradiated by strong (and obscured from our line of sight) X-ray beams.

1. Introduction

With the Ginga satellite, we found 6.7 keV lines from a highly ionized iron near the Galactic center. This indicates that the Galactic center region is surrounded by a thin hot plasma with a tilting elliptical distribution. The plasma temperature is determined to be about 10 keV, with the total luminosity in the 6.7 keV line and 2-10 keV bands to be 1×10^{36}, and 2×10^{37} erg s^{-1} , respectively. With a simple assumption that the plasma density is uniform, we can estimate that the energy of the plasma is as large as 10^4 SN and the dynamical age is 10^{4-5} yr (Koyama et al. 1989, Yamauchi et al., 1990). Due to a limited spatial and energy resolution of Ginga, we cannot study further detail of the Galactic center plasma. Using the ASCA satellite, we have obtained new pictures near the Galactic center. We will review the early ASCA results. Brief descriptions of the ASCA satellite and onboard instruments are found in Tanaka et al. (1994).

L. Blitz and P. Teuben (eds.), Unsolved Problems of the Milky Way, 287–295.

2. Results

2.1. SGR A* AND HARD SOURCE NEAR THE GALACTIC CENTER

Figure 1 shows an X-ray mosaic picture near the Galactic center region of about 1°×1° in the 0.7-10 keV band obtained with the GIS instrument. Although no correction of non-uniform efficiency over the detector field was made on the mosaic picture, we see several bright spots as well as an extended emission. The three brightest spots correspond to the point-like objects, which are already catalogued with the Einstein and Ariel 5 satellites (Watson et al. 1981). Another bright source at the center of the map corresponds to the Galactic center (Sgr A*). In addition to these point like sources, we found a diffuse emission extending very largely. The peak flux of the extended emission comes near Sgr A*.

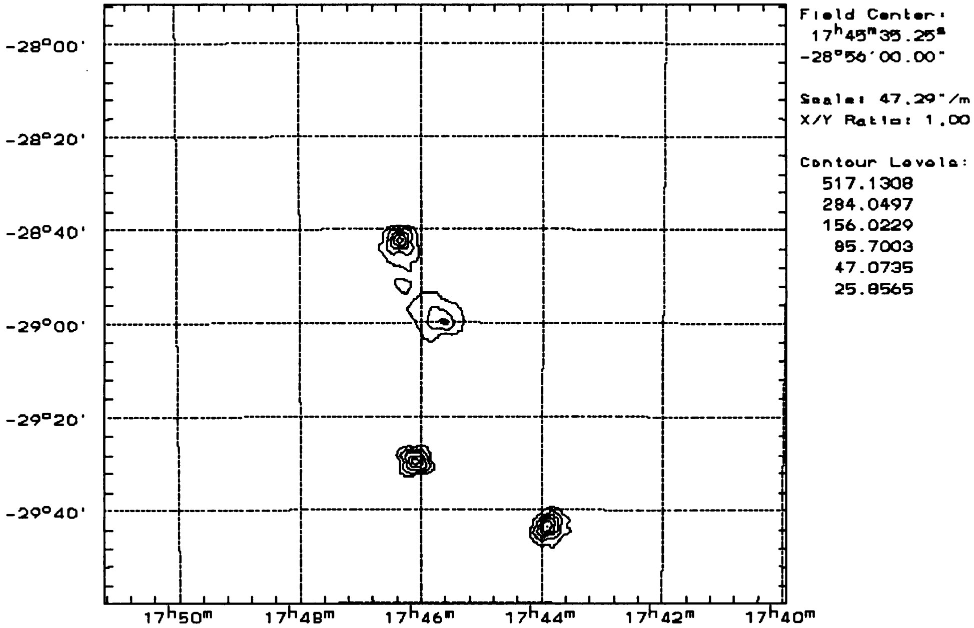

Figure 1. GIS image (1° × 1°)

Fig. 1. The mosaic picture in the 0.7 - 10 keV band with GIS2 & GIS3. The background is not substracted. The image is smoothed with σ=4pixel (1 pixel ~ 15") with the angular resolution of about ~ 1'. Four bright peaks are respectively (in the order from north to south) 1E1743.1-2843, SgrA, A1742-294, and 1E1740.7-2942. (RA,Dec)$_{2000}$

In figure 2, we show a zoomed-up SIS picture near Sgr A* with the energy band of 3-10 keV. One bright part (north east) is elliptically extended, in which our Galactic center Sgr A* lies. Since this emission region seems extended, we refer to be the Center plasma. The other bright spot (south west) is point-like. This source is clear only in the hard X-ray band, hence is referred to be the Hard source in this paper.

The X-ray spectrum from the Center plasma exhibits many emission lines. This indicates that the X-rays come from a high temperature thin hot plasma. On the other hand, the line fluxes of the Hard source are about 3 times smaller than that of the Center plasma. These lines would be due to the diffuse X-rays in which the Hard source is also embedded. If we assume that the X-ray spectrum of the Hard X-ray source is composed of two components; one is the similar shape as the Center plasma and the other is a power-law spectrum with no line emission, we found that the power-law component should be highly absorbed with N_H value of $\sim 2 \times 10^{23}$ H cm^{-2}. Therefore, the Hard source would be behind a gas of high column. Unabsorbed X-ray luminosity in the 2 - 10 keV band is estimated to be about 4×10^{35} erg s^{-1}. Recently the Hard source emitted a type 1 X-ray burst (Maeda et al. private communication) and therefore is classified to be a neutron star binary. From the positional conicidence, we suggest the Hard source to be in a quiescent state of the transient source A1742-289 (Eyles et al. 1975).

Figure 2 & 3
SIS image (20' × 20')

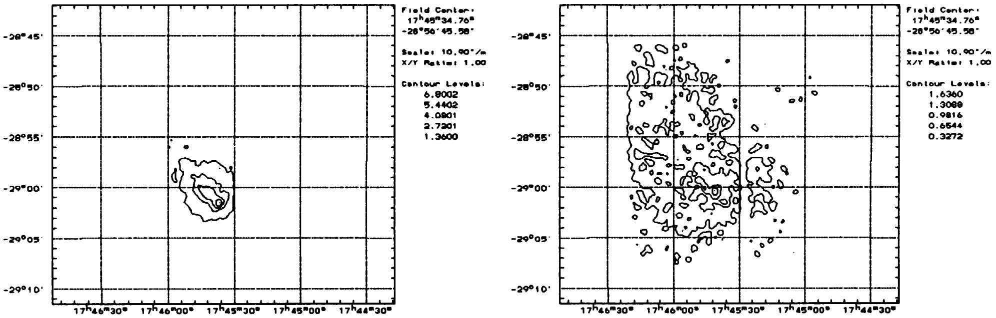

Fig. 2. : SIS0 image near SgrA* in the hard band (3-10 keV). A bright elliptical shape region is associated with SgrA-West. $(RA,Dec)_{2000}$

Fig. 3. : SIS0 image near SgrA* in the soft band (0.7-3 keV). $(RA,Dec)_{2000}$

2.2. SPECTRUM OF DIFFUSE HOT PLASMA

If we make the X-ray image with a lower energy band, we can see clear diffuse emission as is given in figure 3 (0.7-3 keV). This diffuse emission is extended to nearly 1-2 degree, consistent with the Ginga results. Therefore we refer to this as the Bulge plasma. We have made a spectrum using all the data of the Bulge plasma and compared it to the Center plasma. A remarkable difference was found only in the Fe line feature as is shown in figure 4.

Figure4
Bulge plasma spectrum

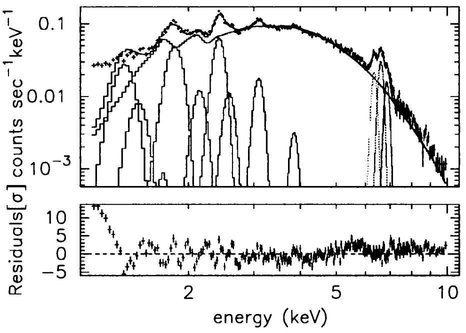

Table 1

Line Energy	Identification
(1.35 keV)	He-like Mg Kα
(1.47 keV)	H-like Mg Kα
1.86 keV	He-like Si Kα
(2.00 keV)	H-like Si Kα
(2.18 keV)	He-like Si Kβ
2.45 keV	He-like S Kα
(2.63 keV)	H-like S Kα
(2.93 keV)	He-like S Kβ
3.14 keV	He-like Ar Kα
3.90 keV	He-like Ca Kα
6.40 keV	Neutral Fe Kα
6.70 keV	He-like Fe Kα
6.95 keV	H-like Fe Kα

Fig. 4: The SIS0 & SIS1 spectrum of the Bulge region. Emission lines are He-like Si, S, Ar, Ca and Fe Kα and H-like Fe Kα line and cold Fe Kα line (see Table 1). (RA,Dec)$_{2000}$

In table 1, we listed emission lines found from the Bulge plasma. We have never seen so many lines from any object of X-ray astronomy except for the very young SNRs such as Cas A and Tycho. All these lines other than the 6.4 keV line are attributable to the K-shell transitions from H-like or He-like Si, S, Ar, Ca and Fe. The co-existing of these lines from wide range of atomic numbers indicates that the plasma is multi-temperature. For example, K-shell resonance lines from He-like Si are most prominent at 0.8 keV temperature while those from H-like iron become dominant at a temperature of about 15 keV.

Another possibility is non equilibrium ionization (NEI) plasma as is often found in the young supernova remnants. We tried NEI model fits to the Bulge plasma excluding 6.4 keV line and found reasonable fits with roughly solar abundance (except for Si). The best fit temperature (kT) and ionization parameter nt (n is the electron density and t is the elapsing time after the plasma was heated up to the temperature kT) are estimated to be about 5-10 keV and 10^{10} cm^{-2} s, respectively. This indicates that the plasma is very young.

2.3. SPATIAL DISTRIBUTION OF HOT PLASMA

Fig 5 shows narrow band energy maps including important emission lines: He-like S, Fe and 6.4 keV iron. Since the first two of these lines come mainly from a thin hot plasma, these images show a spatial distribution of the thin hot plasma. The shape of the 6.7 keV line emitting region is elliptical, while that of S has more complicated structure. The complicated structure may be due absorption, because the energy of this line comes critical values of the low energy-cut by a typical Galactic absorption of 10^{23} H cm^{-2}. We tried to compare the ^{12}CO map with two different velocity taken by Hasegawa et al.(private communication) at Nobeyama 45m radio telescope and found an indication that expanding molecular clouds are in front at negative latitude and in behind at positive latitude.

2.4. SCATTERING X-RAYS - POSSIBILITY OF OBSCURED LUMINOUS X-RAY SOURCE-

Molecular clouds also play another important role to the X-ray emission from the Galactic Bulge. A new (and important) discovery with ASCA is a strong 6.4 keV line from the Bulge region. This line is due to neutral or low ionization states of iron. Therefore we need cool gas and high energy source to excite the K-shell electron of the cool iron. The source of the cool iron would be molecular clouds. In fact, we see good spatial correlation of the molecular cloud and the 6.4 keV line distribution. Since the Sgr B2 cloud is near the edge of the Bulge plasma which emits the 6.7 keV line, contribution of the hot plasma may be relatively small and therefore suitable for the study of the origin of the 6.4 keV line. Fig 6 is the spectrum of the Sgr B2 region. A strong 6.4 keV line emission is found with an equivalent width (EW) of about 2 keV. This large EW of the 6.4 keV line can resonably be predicted by the scattering X-rays model (see also Mrkevitch, M. et al. 1993). Suppose that the X-ray spectrum of Sgr B2 is due to the scattering, optical depth of the scattering material is estimated to be 0.1 using the radio data. The absorption corrected luminosity in the 10′ × 10′ region is 5 × 10^{35} erg s^{-1} (at 8.5 kpc distance). Then we can estimate the contribution of the nearby bright sources to the Sgr B2 emission to be only a few percent. Larger contribution is due to the thin thermal Bulge emission. The estimated value depends on the shape of the Bulge plasma. Our best estimate for the contribution of the Bulge emission to Sgr B2 does not exceed about 10 % of the observed flux. Thus we need unseen bright X-ray source. If we put the source at the Galactic center, the X-ray luminosity of the source is estimated to be larger than 10^{39} erg s^{-1}. This exceeds the luminosity of Eddington limit of any Galactic binary sources. Thus our suggestion is that the Galactic center would be either a low luminosity Seyfert 2 (obscured AGN) or an AGN which was bright in near past but quiescent at present.

Acknowledgements

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References

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DISCUSSION

J. Binney: Prof. Sunyaev has argued, I believe, that all the diffuse radiation is scattered and that there is no diffuse hot plasma. What is the strongest argument against this point of view, or is it one or sympathetic too.

Koyama: Since we definitely found many emission lines from highly ionized atoms and the overall spectrum can be fitted with NEI model with reasonable abundance, we are quite sure that the most of the diffuse emission is thin hot plasma. Of course some part of the X-Ray emission such as the 6.4 keV line is due to scattering.

M. Morris: Do the ASCA data give the same picture for the extended (200×300 pc) bulge X-ray source as Ginga had previously given?

Koyama: Yes, ASCA data surely indicate the similar picture of largely extended X-ray emission. In this talk, we have concentrated on the fine structure near the Galactic Center.

L. Ozernoy: An important question that you raised in your talk as to why the temperature of hot gas looks the same for the hot bubbles of different ages finds an answer in the starburst interpretation of the origin of the hot gas developed by Ozernoy, Ramaty and Titarchuk 1993 ("Back to the Galaxy", AIP Conf. Proc. 278, 73). The temperature of the gas passing through a shock at the adiabatic stage of the hot bubble is $T \sim 10^8$ K $(E_{SN}/10^{51}$ erg$)(M_{ej}/10M_{\odot})^{-1}$ and it is kept the same as long as the parameters of a SN explosion are more or less identical. Interestingly, similar temperatures of hot gas have been observed in the near by starburst galaxies NGC253 and M82 (for details, see Ozernoy 1994 in "multi-Wave length Continuum Emission of AGN", Ed. T. J.-L. Courvoisier and A. Blecha, eds. Kluwer Acad. Publ., p. 351)

Figure 5
Nallow band images

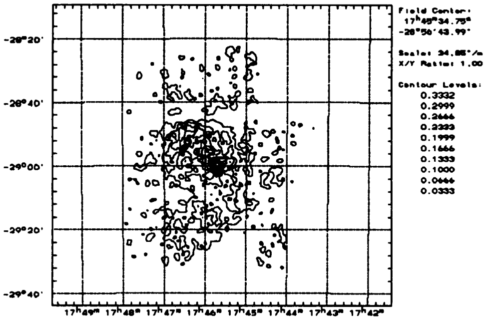

Figure 5-a
S-He like K-shell transition line
(2.46 keV)

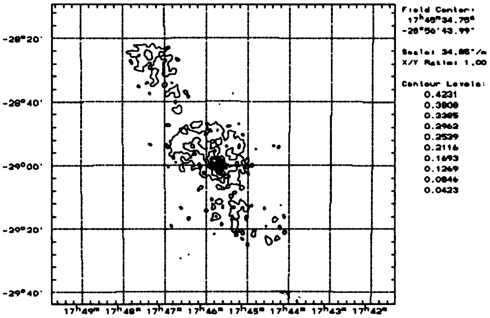

Figure 5-b
Cold Fe K-shell transition line
(6.4 keV)

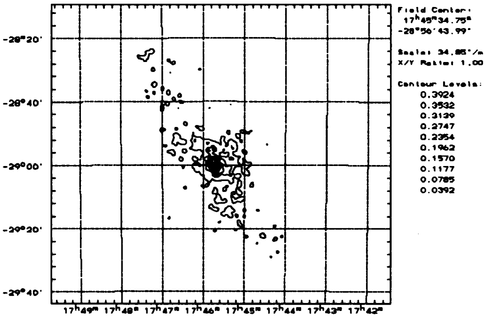

Figure 5-c
He-like Fe K-shell transition line
(6.7 keV)

Fig. 5 : X-ray images of the energy band 2.37-2.54 keV (5-a), 6.20-6.55 keV (5-b),and 6.55-6.90 keV (5-c). The bright X-ray binaries A1742-294, 1E1743.1-2843 and A1742-289(Hard source) are removed from these images. (RA,Dec)$_{2000}$

Figure 6
SgrB2 spectrum

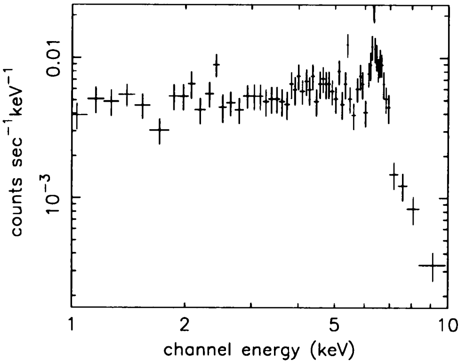

Fig. 6 : The spectrum of Sgr B2 cloud obatined with SIS0 & SIS1.