# Chemical Composition and Distribution of Heavy Elements in a Supernova Remnant G359.1−0.5

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We present the result of the ASCA observation of a shell-like radio supernova remnant (SNR), G359.1−0.5. Unlike the radio morphology, X-rays from the SNR shows a center-filled structure. The spectrum of G359.1−0.5 has prominent K$\alpha$ lines of He-like silicon and H-like sulfur. The plasma requires at least two temperature components: a lower temperature plasma ($kT \sim 0.6$ keV $= 7 \times 10^6$ K) and a sulfur-rich plasma with higher temperature ($kT \sim 4.4$ keV $= 5 \times 10^7$ K). The chemical composition of sulfur is found to be unusually high, larger than that of the solar vicinity by, at least, more than 10 times. We can estimate the total mass of silicon and sulfur to be $0.1 M_\odot$ and $0.3 M_\odot$, respectively, where $M_\odot$ is the mass of the sun of about $2 \times 10^{33}$g. No current theory of nucleosynthesis in supernova explosions allows larger mass production of sulfur than that of silicon. This problem is solved with the assumption that the sulfur distribution is localized somewhere in SNR.

## 1 Introduction

How is chemical distribution in an supernova remnant (SNR)? It is said that an inner region of a progenitor star has an onion-like structure with layers of H, He, and heavy elements. However, nobody knows how these elements distribute in an SNR after supernova explosion, uniformly or non-uniformly with some blobs made with heavy elements. Recently, some evidence of non-uniform distribution is found, for example, Vela SNR (Aschenbach et al., 1995).

X-ray spectroscopy of SNRs provides a powerful nucleosynthetic tool for heavy elements such as O, Ne, Mg, Si, S, and Fe, because K-shell emission lines of these elements come into the relevant X-ray band (0.5 keV $\le h\nu \le$ 10 keV). ASCA is the first X-ray astronomical satellite which covers the full energy band, the resolutionto seperate the K-shell emission lines from these heavy elements. This paper reports the first detailed X-ray study of G359.1−0.5, a radio shell-like SNR near the center of our Milky Way Galaxy.

G359.1−0.5 was first identified as a SNR with the 4.9 GHz observation by Dowens et al. (1979). Uchida et al.(1992) found a shell-like structure surrounded by a $^{12}$CO ring. Although Sun (1997) and Egger and Sun (1998) discovered X-rays from G359.1−0.5 with ROSAT, the spectral parameters, such as temperature and chemical composition are not well constrained, due to the poor statistics and limited energy resolution.

## 2 Observation and Data Reduction

During the observation of the most prominent radio filament (the Snake) made on March 20–22 in 1997, G359.1−0.5 was located in the GIS field. However, it was only partially covered with SIS field. GIS was always operated in the normal PH mode. We excluded high-background data and non-X-ray events with the standard method according to the user guide by NASA Goddard Space Flight Center. In total, the available exposure time of GIS is ∼80ks for G359.1−0.5.

## 3 Analyses

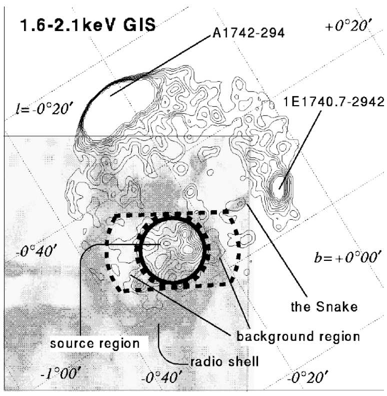


Figure 1: GIS contour map in the 1.6–2.1 keV band with Galactic coordinates, superposed on the gray-scale radio map by Gray(1994). Contour levels are linearly spaced and are saturated at A1742−294 and 1E1740.7−2942. Source and background regions for spectral analyses are shown with solid and dotted lines, respectively.

Figure 2: The background-subtracted GIS spectrum of G359.1−0.5. Crosses are the data points. The solid line represents the best-fit two-temperature model, while the dotted lines are those of the individual components.

We found that X-rays are emitted from the central part within the shell of the SNR G359.1−0.5, although it exhibits a completely shell-like structure in the radio band. Figure 1 shows the GIS contour map in the energy of 1.6–2.1 keV, in which diffuse X-ray excess inside the radio shell is most clearly seen.

We made the GIS spectrum of the SNR center, selecting the source and the background regions as shown by the solid and dotted lines in figure 1, respectively. In the spectrum of G359.1−0.5 (figure 2), we can notice two emission lines at $1.86^{+0.03}_{-0.04}$ keV and $2.61^{+0.07}_{-0.07}$ keV (here and after errors are at 90 % confidence level, unless otherwise mentioned). These line center energies are consistent with those of K$\alpha$ emission from helium-like silicon (He-like Si; 1.86 keV) and hydrogen-like sulfur (H-like S; 2.63 keV), respectively.

The presence of K-shell lines supports that X-rays from this SNR are due to a thin thermal plasma. However, these two lines can hardly coexist in a single temperature plasma because a higher temperature is required to ionize sulfur atoms than that to ionize silicon atoms. Therefore, we applied a two-temperature plasma model (a plasma code established by Mewe et al.(1985) and Kaastra (1994)) with an interstellar absorption. The abundances of Si and S in each plasma were treated to be free parameters, whereas those of the other elements were fixed to the solar values (Anders and Grevesse, 1989). This model is statistically accepted within 90 % confidence level. The best-fit model and parameters are given in figure 2 and table 1, respectively. A remarkable result is that the sulfur abundance in the higher temperature plasma (here component 2) is larger than tens of solar.

Table 1: Best-fit parameters for G359.1−0.5 for the model of two thin thermal plasmas with an absorption.

| component | $kT$ (keV) | Si/H$^{\dagger}$ | S/H$^{\dagger}$ | $N_{\rm H}$ ($10^{22}$H cm$^{-2}$) | Flux (0.7–10 keV) (erg s$^{-1}$cm$^{-2}$) |
|---|---|---|---|---|---|
| 1 ......... | 0.6(0.4–0.9) | 2.5(1.2–8.4) | <0.9 | 5.9(4.1–8.4) | $7.8 \times 10^{-13}$ |
| 2 ......... | 4.4(2.2–13.2) | not determined | >38 | ‡ | $6.1 \times 10^{-13}$ |

Parentheses indicate 90 percent confidence regions for one relevant parameter.
† Abundance ratio relative to the solar value.
‡ Common with component 1.

## 4 Results and Discussion

G359.1−0.5 is found to exhibit a large absorption column of $\sim 5.9 \times 10^{22}$Hcm$^{-2}$. Since Uchida et al.(1992) reported that G359.1−0.5 is surrounded by the $^{12}$CO ring of the total mass of about $2.5 \times 10^{6} M_{\odot}$, local absorption due to the $^{12}$CO ring may not be ignored. Assuming that the $^{12}$CO ring is a homogeneous shell with nearly the same shape of the G359.1−0.5 radio shell, the absorption column due to the $^{12}$CO ring is estimated to be $\sim 3 \times 10^{22}$Hcm$^{-2}$. Therefore, we infer that the column density of the foreground interstellar matter is about $\sim 3 \times 10^{22}$Hcm$^{-2}$. We can estimate the distance to the SNR from this value to be $\sim 8.5$ kpc, (where 1 pc is about $3 \times 10^{18}$cm). Then the diameter of the radio shell is estimated to be $\sim 57$ pc, while that of the X-ray emitting central sphere is $\sim 28$ pc.

We found that G359.1−0.5 has at least two temperature plasmas; the cooler plasma (component 1) is abundant in Si, whereas the hotter one (component 2) is extremely over-abundant in S. Assuming that about 10 % of $\sim$ 28 pc-diameter of sphere is filled with a plasma, we estimate the total mass of Si and S to be about $0.1 M_{\odot}$ and $0.3 M_{\odot}$, respectively. However, no current theory of nucleosynthesis in supernova explosions predicts such large mass of S than Si (see e.g. Thielemann et al. 1990). Plausible scenario is that the sulfur distribution should be localized somewhere in the SNR, as is already found in the Vela SNR (Aschenbach et al. 1995) and called "shrapnel". We made a narrow band image including only the S-line (2.1–3.2 keV). However, it shows no spatial structure, mainly due to a lack of photon statistics.

We expect to solve this problem with next generation satellites such as XMM or ASTRO-E, which will provide better photon statistics than ASCA.

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