ASCA observation of the Cygnus Loop Supernova Remnant

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\textbf{ABSTRACT}

We present here the results of the mapping observation of the Cygnus Loop with the Gas Imaging Spectrometer (GIS) onboard the ASCA observatory. The data covered the entire region of the Cygnus Loop. Spatial resolution of the GIS is moderate whereas the energy resolving power is much better than those used in the previous observations. The ASCA soft-band image shows the well-known shell-like feature whereas the ASCA hard-band image shows rather center-filled morphology with a hard X-ray compact source at the blow-up southern region.

\section{INTRODUCTION}

The Cygnus Loop is a proto-type shell-like supernova remnant. Its large apparent size and the low interstellar absorption feature allow us the detailed investigation of the spatially-resolved plasma with the ASCA observatory. Previous ASCA observation reveals that hot plasma containing rich Si, S, and Fe exists at the center region, suggesting the ejecta in origin (Miyata et al. 1998a). They estimated that only 1\% of ejecta is still present at the center region, resulting that a major part of ejecta is distracted inside the shell region. Therefore, a mapping of the entire region is important to investigate the distributions of heavy elements.

A part of the ASCA results was summarized in Miyata (1996). In this paper, we report the preliminary result of the complete mapping observation of the Cygnus Loop with the ASCA GIS.

\section{OBSERVATION AND DATA ANALYSIS}

We observed the Cygnus Loop from the PV phase (April 1993) to AO-5 (June 1997). Total number of observation is 30. We re-analyzed all data sets with the ASCA\textsubscript{ANL}. We excluded all the data taken at elevation angle below 5° from the night earth rim and 25° from the day earth rim, a geomagnetic cutoff rigidity lower than 6 GeV c\textsuperscript{-1}, and the region of the South Atlantic Anomaly. We also applied the 'flare-cut' described in the ASCA News letter No.5. Total exposure time is 180ksec after the data screening. We made four kinds of images for each region: a total count image, a non-X-ray background
image, a cosmic X-ray background image, and an exposure map. The image of non-X-ray background was produced with the H02-sorting method in DISPLAY45 (the detailed description of this method is in Ishisaki (1996)). The image of cosmic X-ray background was extracted from the LSS survey data. We also subtracted the non-X-ray background image from the LSS data to produce the mean cosmic X-ray background image solely. We used the day earth image to correct the vignetting effect of the ASCA telescopes and the grid structure of the GIS since the X-ray spectrum of the day earth is very soft and is quite similar with that of the Cygnus Loop. The data were combined into a single image using DISPLAY45 and DIS45userlib.

3 OVERALL STRUCTURE

We constructed the X-ray images in the energy band of 0.7-1.5 and 1.5-5 keV as shown in figure 1. These images were corrected both for the exposure and the effective area after subtracting the background properly. The 0.7-1.5 keV image shows a limb-brightening structure and is similar to the previously well-known image of the Cygnus Loop (Ku et al. 1984; Aschenbach 1994). On the contrary, the 1.5-5 keV image shows a center-filled structure rather than the well-known shell-like structure. We find two bright regions: a compact source in the southern region (AX J2049.6+2939) and a north-east (NE) region. The X-ray spectrum of AX J2049.6+2939 is much harder than those of shell regions and can be fitted with a power-law function with a photon-index of 2.1 (Miyata et al. 1998b). Except AX J2049.6+2939, the hardest emission can be found at the NE region ($\alpha \simeq 313^\circ, \delta \simeq 31^\circ$; hereafter we call this region as the northern hot spot).

Hatsukade & Tsunemi (1990) performed the scanning observation with Ginga in the energy band above 1.5 keV and found the center-filled morphology rather than the shell-like morphology for the Cygnus Loop. The Ginga intensity profile has a maximum at ($l \simeq 74.9^\circ, b \simeq 8.6^\circ$), which well coincides with the northern hot spot we found ($l \simeq 74.9^\circ, b \simeq 8.6^\circ$). The Ginga intensity profile also showed a tail structure toward the southern region, which was probably due to AX J2049.6+2939.

4 HARDNESS RATIO MAP

Figure 2 shows the hardness ratio map obtained with 1.5-5 keV band image dividing by 0.7-1.5 keV band image. Contour map overlaid was constructed with 0.7-1.5 keV band image. The northern hot spot clearly extends toward the north. Comparing the contour map of the 0.7-1.5 keV image, the northern hot spot is just inside both of the brightest NE limb and of the northern bright shell region. Miyata et al. (1998c) investigated the radial profile from the NE limb toward the center region and found that the kTe distribution showed maximum of $\simeq 1$ keV at $\simeq 0.4 R_s$, where $R_s$ is the shock radius. This hard spot coincides with the hottest region.

There is a hard X-ray emitting region at the center portion of the Loop. Miyata et al. (1998a) investigated the center portion in detail and found hot ($\approx 0.8$ keV) and metal rich plasma. Such plasma account for the hard X-ray emitting region we found.

5 SUMMARY

We summarize results of our preliminary analysis of the entire Cygnus Loop.

- ASCA soft-band image in 0.7-1.5 keV shows the well-known shell-like structure.
• ASCA hard-band image in 1.5-5 keV shows rather center-filled morphology and well coincides with the Ginga scanning observation.

• AX J2049.6+2939 is the hardest compact source inside the Cygnus Loop in the ASCA energy band.

• There is a hot spot in the ASCA hard-band image. The hot spot is located in the inner region of the bright NE limb.

6 REFERENCES

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Figure 1: The X-ray image of the Cygnus Loop supernova remnant observed with the ASCA GIS in the energy band of (a) 0.7 – 1.5 keV band and (b) 1.5 – 5 keV band. Both images were smoothed with a Gaussian function of (a) $\sigma = 1'$ and (b) $\sigma = 2'$.

Figure 2: Hardness ratio map of the Cygnus Loop (1.5-5 keV band / 0.7-1.5 keV band). Overlaid contour map was constructed with 0.5-1.5 keV band image as shown in figure 1. 1 – 100% of the peak brightness is linearly divided into 15 levels.
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