Suzaku and XMM-Newton Observations of the Cygnus Loop

Hiroyuki Uchida[1], Hiroshi Tsunemi[1], Satoru Katsuda[2],
Masashi Kimura[1], Hiroko Kosugi[1] and Hiroaki Takahashi[1]

[1] Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan
[2] Code 662, NASA Goddard Space Flight Center, Greenbelt, MD 20771
E-mail(HU): uchida@ess.sci.osaka-u.ac.jp

Abstract

We performed a comprehensive study of the Cygnus Loop, which is one of the largest (R∼80′) and the brightest supernova remnants (SNRs) in the X-ray sky. In spite that it is a middle-aged SNR (∼10,000 yr), there is a substantial amount of fresh metal ejected from the progenitor. We have been observing this SNR since 2002 with Suzaku and XMM-Newton observatories, and now we have 41 pointing observation data sets in total. Here we report the results of our observations.

Key words: ISM: abundances — ISM: individual (Cygnus Loop) — supernova remnants

1. Introduction

The origin of the Cygnus Loop is considered to be a cavity explosion (McCray et al. 1979) and some previous studies suggest the progenitor mass to be $15M_\odot$ (Levenson et al. 1998). However, the SN type of the Cygnus Loop is still unclear because a compact source has not been detected yet in the Cygnus Loop.

As shown in Fig.1., we have 32 and 9 observation data obtained by Suzaku and XMM-Newton, respectively. Example spectrum (Fig.2) shows various emission lines originated from either swept interstellar medium (ISM) or ejecta heated by reverse shock. The spectra are generally well fitted by two component non-equilibrium ionization (NEI) model (Fig.2). We concluded the plasma structure of the Cygnus Loop as follows: the high-kT_e ejecta component is surrounded by a low-kT_e ISM component (Tsunemi et al. 2007). Fig.3 shows the flux distribution calculated from each component. In this figure, limb-brightening structure is clearly seen in the distribution of the low-kT_e component (left) while that of the high-kT_e component is almost uniform (right).

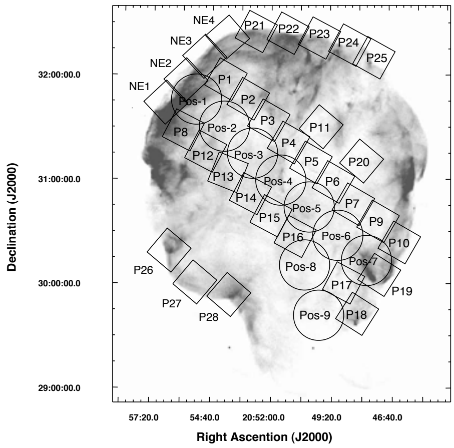

Fig. 1. ROSAT HRI image of the entire Cygnus Loop. The circles and rectangles represent our FOV of the XMM-Newton MOS and the Suzaku XIS, respectively.

2. Shell Structure of the Cygnus Loop

2.1. South Blowout Region

The Cygnus Loop is a typical shell-like SNR and it is almost circular in shape. However, a large break is seen in the south, known as "blowout" region (Aschenbach et al. 1999). They explained this extended structure as a breakout into a lower density ISM. On the other hand, based on a radio observation, Uyaniker et al. (2002) suggested the existence of a secondary SNR in the south. We observed this region with XMM-Newton and found that the X-ray spectra of this region consist of two plasma components with different temperatures (Uchida et al. 2008). Judging from the plasma structures and the metal distributions, we concluded that the X-ray emission is consistent with a Cygnus Loop origin. We also showed that the X-ray shell is thin in our fields of view (FOV) and concluded that the origin of the blowout can be explained as a breakout into a lower density ISM.

2.2. Abundance-enhanced Region

We also found the evidence of smaller break in other region. We found a part of the limb regions show relatively high abundances which are close to the ISM abundances measured around the Cygnus Loop (Katsuda et

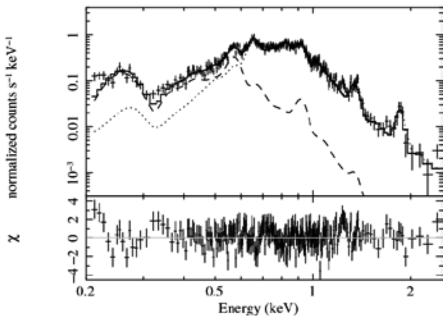

Fig. 2. Example XIS1 spectrum obtained from an inner region of the Cygnus Loop. The best-fit curve for the two-component VNEI model is shown by solid line. The dashed and the dotted lines represent the low-kT_e component and the high-kT_e component, respectively.

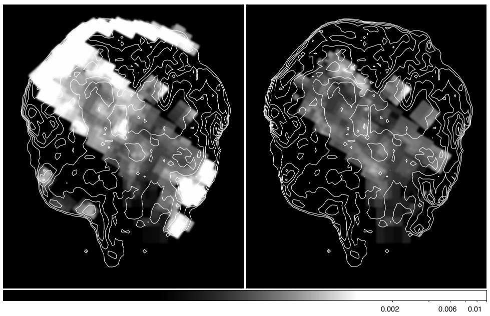

Fig. 3. 0.2-3.0 keV flux distribution of the low-kT_e (left) and the high-kT_e (right) component overlaid with the a contour of ROSAT HRI image. The values are in units of counts cm^{-2}s^{-1}arcmin^{-2} (Uchida et al. 2009c).

al. 2008a; Tsunemi et al. 2009; Uchida et al. 2009b). We call these regions "abundance-enhanced regions". From the morphological point of view, we speculate that the break or thinness of cavity wall exists in the abundance enhanced regions, like the south blowout. However, the abundance depletion in other regions still remain a problem.

3. Ejecta Distribution of the Cygnus Loop

3.1. Asymmetric Ejecta Distribution

From the best-fit parameters of all the spectra, we calculated the emission measure (EM) distributions of various elements. The results indicate the Fe and Si are concentrated on the center of the Loop, while Mg is abundant at the outside. We consider these results reflect the onion structure of the progenitor star before the explosion. we also found a discrepancy between the center of Fe and the geometric center, suggesting the asymmetric explosion (Uchida et al. 2009a).

3.2. Estimation of the Progenitor Mass

We also estimated the progenitor mass of the Cygnus Loop (Uchida et al. 2009a). The results show that Ne/O, Mg/O, S/O and Si/O are well fitted by the $12M_{\odot}$ core-collapse (CC) model, while Fe/O is a few times higher than that of the model (Fig.4). Such over abundances of observed Fe is still remain open question.

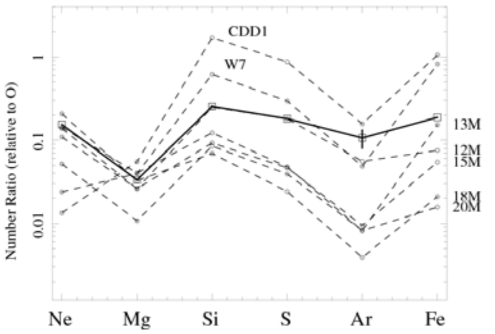

Fig. 4. Number ratios of the heavy elements relative to O of the high-kT_e component (solid line). Dotted lines represent the CDD1 and W7 Type Ia models of (Iwamoto et al. 1999), and the CC models with progenitor masses of 12, 13, 15, 18, and $20M_{\odot}$, respectively (Woosley et al. 1995).

4. Conclusion

In summary, we observed the Cygnus Loop with Suzaku and XMM-Newton observatories. From the spectral analysis, we found that the Cygnus Loop spectra are generally consists of two plasma models with different temperatures: the low-kT_e component and the high-kT_e component originated from the surrounding cavity material and the ejecta, respectively. From the best-fit parameters, we found the ejecta are surrounded by swept material which shows non-uniform structure. We also found an asymmetric ejecta distribution suggesting an asymmetric explosion. We also estimated the progenitor mass of the Cygnus Loop. As a result, we conclude the origin of this SNR is most likely to be a core-collapse explosion of $\sim 12M_{\odot}$ star.

References

Aschenbach, B., et al. 1999, A&A, 341, 602
Iwamoto, K., et al. 1999, ApJ, 125, 439
Katsuda, S., et al. 2008a, PASJ, 60S, S107
Katsuda, S., et al. 2008b, PASJ, 60S, S115
Kimura, M., et al. 2009, PASJ, 61S, S137
Levenson, N. A., et al. 1998, ApJ, 118, 541
McCray, R., et al. 1979, ARA&A, 17, 213
Tsunemi, H., et al. 2007, ApJ, 671, 1717
Tsunemi, H., et al. 2009 PASJ, 61S, S147
Uchida, H., et al. 2008, ApJ, 688, 1102
Uchida, H., et al. 2009a, PASJ, 61, 301
Uchida, H., et al. 2009b, PASJ, 61, 503
Uchida, H., et al. 2009c, ApJ, 705, *in prep*
Uyaniker, B., et al. 2002, A&A, 389, L61
Woosley, S. E., et al. 1995, ApJ, 101, 181