Study of the Ejecta Distribution in the Vela SNR with MAXI

Hiroya Yamaguchi,[1] Satoru Katsuda,[2,3] Junko S.Hiraga,[1] Asami Hayato[1,4] and Toru Tamagawa[1,4]

[1] RIKEN, Wako, Saitama, Japan
[2] Osaka University, Toyonaka, Osaka, Japan
[3] NASA/GSFC, Greenbelt, MD, USA
[4] Tokyo University of Science, Shinjyuku, Tokyo, Japan
E-mail(HY): hiroya@crab.riken.jp

Abstract

The Vela supernova remnant (SNR) is a very ideal target for studying the detailed structure, since it has a quite large angular diameter ($\sim 8°$). In this proceeding, we first review the previous observations of several "shrapnels", the fragments of the ejecta protruding beyond the primary blast-shock front. Then, we report the preliminary results of shrapnel B with Suzaku. The elemental abundances are found to be significantly higher than the solar values for the first time, indicating the shrapnel originates from the supernova ejecta. Finally, we discuss the scientific significance of MAXI observations of the Vela SNR. The most part of the SNR has not yet been observed by the recent satellites, since it is too large to be covered with their limited exposure times. MAXI will be the first X-ray mission allowing us to study the ejecta distribution in the entire SNR as well as to search other ejecta fragments hiding inside the shell by the projection effect. Those information must become a key to solve the mechanism of the supernova explosions.

KEY WORDS: ISM: individual (Vela Supernova Remnant) — supernova remnants

1. Introduction

Mechanism of supernova (SN) explosions has not yet been understood completely. Therefore, we are motivated to study the distributions of the ejected nucleosynthesis products in supernova remnants (SNRs), because the information of them is essentially important to understand the explosion mechanism.

The Vela SNR is one of the brightest celestial soft X-ray sources. The origin of the SNR is considered to be Type II-P SN explosion of the progenitor star with the mass of < 25 solar mass (Gvaramadze 1999). Its age has been estimated to be $\sim 1.1 \times 10^4$ yr from the spin down rate of PSR B0833–45 (the Vela pulsar: Taylor et al. 1993). In such old SNRs, all ejecta had already been heated by reverse shock. Therefore, the evolved SNRs are suitable for the study of the global ejecta distribution, even though the emission from shocked interstellar medium (ISM) is dominantly strong. Furthermore, the Vela SNR has the largest angular size ($\sim 8°$: Aschenbach et al. 1995) among observable SNRs, and hence it is the most ideal target for studying the detailed structure.

2. Previous results

Figure 1 shows the X-ray image of the entire Vela SNR, obtained with the ROSAT all-sky survey (RASS). With the RASS observation, Aschenbach et al. (1995) discovered six ejecta fragments, named "shrapnels" A to F, which are protruding beyond the primary blast shock front. The opening angles of the shrapnels suggest supersonic motion in tenuous matter. The center line of each shrapnels can be traced back to the center of the SNR, which is close to the Vela pulsar. Therefore, they are considered to originate from clumps of SN ejecta.

Tsunemi et al. (1999a) observed shrapnel A with ASCA, and found a strong Si K-shell emission line with relatively weak emission from other elements. Using XMM-Newton, Katsuda & Tsunemi (2006) confirmed that the Si abundance was a few times higher than the solar value, while the abundances of the other elements were sub-solar values. Therefore, they concluded that shrapnel A originated from a deep (Si-rich) layer of the progenitor star. The XMM-Newton spectra of shrapnel A are shown in figure 2a. Katsuda & Tsunemi (2006) also found that the temperature increases toward the "head" region of the shrapnel, which is contrast to the temperature distribution generally seen behind the shock front of the blast wave.

Figure 2b shows the XMM-Newton spectra of shrapnel D, the brightest and largest of the ejecta fragments. Katsuda & Tsunemi (2005) found extreme overabundances of O, Ne, and Mg, while the abundance of Fe was consistent with the solar value. Therefore, they

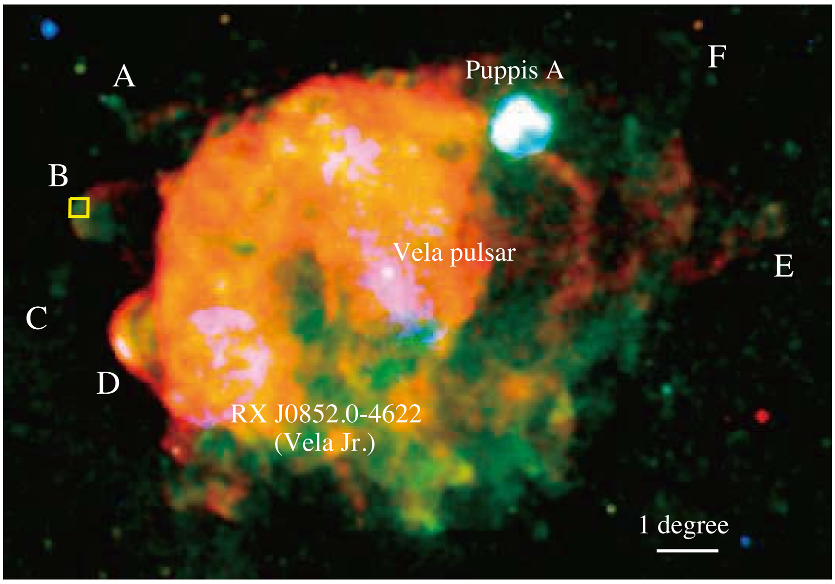

Fig. 1. ROSAT all-sky survey image of the entire Vela SNR. Red, green, and blue correspond to 0.1–0.5 keV, 0.5–1.3 keV, and 1.3–2.0 keV, respectively. The labels A–F indicate the "shrapnels" discovered by Aschenbach et al. (1995). The yellow square shows the field of view of Suzaku/XIS on Vela shrapnel B (see section 3).

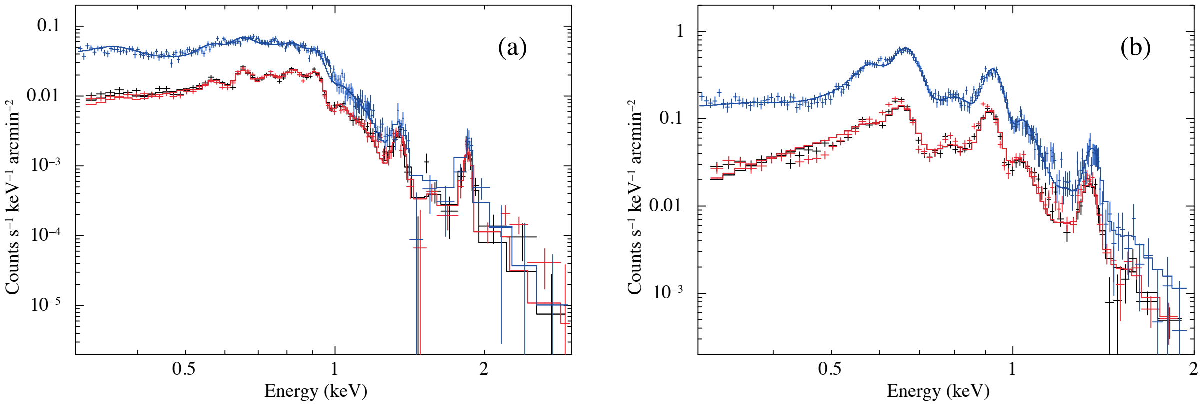

Fig. 2. XMM-Newton spectra of shrapnels A (a) and D (b). Black, red, and blue represent MOS1, MOS2, and PN, respectively.

concluded that shrapnel D is a fragment of ejecta from the shallow (O-Ne-Mg-rich) layer of the progenitor.

Recently, XMM-Newton observation of the northern part of the Vela SNR discovered the ejecta knots (Miceli et al. 2008), which are possible candidates of "new" shrapnels hidden inside the Vela main shell by the projection effect. The relative abundances of these knots were found to be quite similar to those observed in shrapnel D: O, Ne, and Mg were much more abundant than those of the other elements.

3. Suzaku preliminary results of Shrapnel B

Suzaku observed Vela shrapnel B on 2006 November 5 for ~ 60 ksec. The field of view of XIS (Koyama et al. 2007) on board Suzaku is shown as the yellow square in the RASS image (figure 1). Although Tsunemi et al. (1999b) observed this shrapnel with ASCA, they could not determine the elemental abundances due to the poor photon statistics. Utilizing the good sensitivity of XIS, we investigated the detailed spectral properties of shrapnel B. Here, we present the preliminary results of our analysis. The more extended results will be reported in a future paper (Yamaguchi & Katsuda, in preparation).

Figure 3 shows the vignetting-corrected XIS image in 0.5–2.0 keV band. We extracted X-ray spectra from the brightest region indicated as the green ellipse. The result is shown in figure 4, where the non X-ray background are subtracted. These spectra are considered to include two of X-ray background components: the cosmic X-ray background (CXB) and the local hot bubble

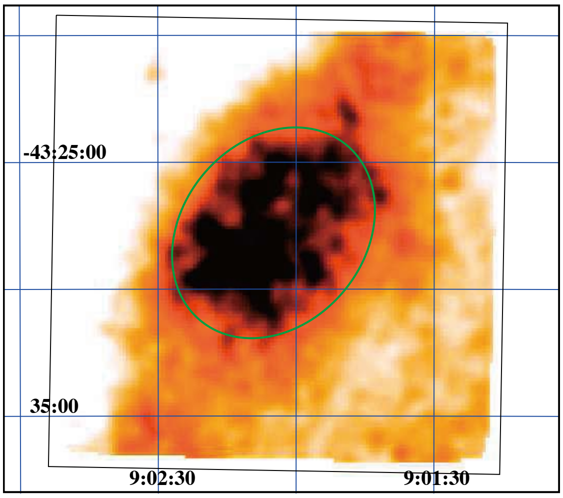

Fig. 3. XIS image of Vela shrapnel B in 0.5–2.0 keV band. The vignetting effect is corrected after the subtraction of non X-ray background. The coordinates (RA and Dec) refer to epoch J2000. The black square and green ellipse are respectively indicate the field of view of XIS and the spectrum extraction region.

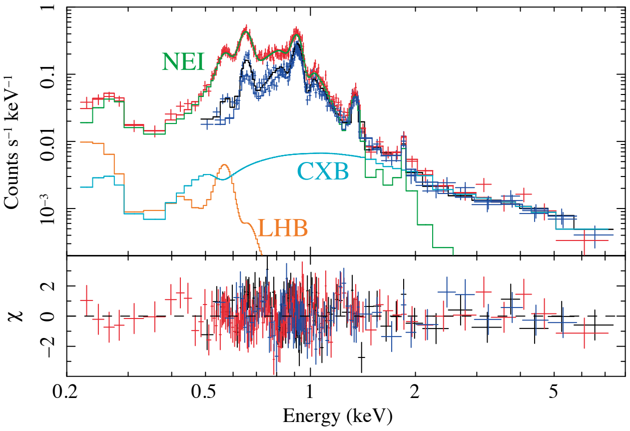

Fig. 4. NXB-subtracted XIS spectra extracted from the elliptical region shown in figure 3. The black, red, and blue data points represent XIS0, 1, and 3 spectra, respectively. The solid lines, colored green, light blue, and orange show the components of the NEI (emission from the shrapnel), CXB, and LHB.

(LHB), in addition to the emission from the shrapnel. As the CXB component, we introduced a power-law model with photon index of $\Gamma = 1.412$, following Kushino et al. (2002). As the LHB component, we assumed a thin-thermal plasma (an APEC model) with a temperature of 0.1 keV and an elemental abundances of the solar values. From the surface brightness in the ROSAT PSPC R1 and R2 bands, the emission measure of the LHB component around the Vela SNR was estimated to be 1.7×10^{16} cm^{-5}; we use this value in the following spectral analysis.

Since several strong emission lines can be clearly seen below 2 keV, we used a model of optically thin-thermal plasma at a non-equilibrium ionization (an NEI model) for the emission from the shrapnel. Then, the acceptable fit was obtained with χ^2/d.o.f. of 332/318. The best-fit parameters are listed in table 1, where the solar abundances are assumed to be those of Anders & Grevesse (1989). The 2–10 keV surface brightness of the CXB component was obtained to be $(5.3 - 6.2) \times 10^{-8}$ ergs cm^{-2} s^{-1} sr^{-1}, which is consistent with the value derived by Kushino et al. (2002).

The absolute abundances of heavy elements are found to be significantly enhanced from the solar values, for the first time. This fact suggests that shrapnel B is one of the ejecta fragments originating from an explosion of Vela SN, similarly to shrapnel A and D (Katsuda & Tsunemi 2005; 2006). The relative abundances of Ne/Fe and Mg/Fe are higher than those of the solar, which are similar to shrapnel D rather than A.

Table 1. Best-fit parameters for Vela shrapnel B

Parameter	Value
$N_{\rm H}$ (cm^{-2})	2.0 (1.3–2.7) $\times 10^{20}$
kT_e (keV)	0.55 (0.52–0.62)
O (solar)	1.9 (1.6–2.5)
Ne (solar)	5.1 (4.3–7.4)
Mg (solar)	3.6 (2.8–4.7)
Si, S (solar)	3.2 (2.3–3.9)
Fe, Ni (solar)	1.6 (1.4–2.4)
$n_e t$ (cm^{-3} s)	4.9 (3.9–5.7) $\times 10^{10}$
$\int n_e n_p \, dl$ (cm^{-5})	3.5 (3.2–3.9) $\times 10^{16}$

4. Available results with MAXI

Although ROSAT observed the entire SNR, the global ejecta distribution had not been determined, because of its poor energy resolution. On the other hand, since the angular size of the Vela SNR is extremely large, observing the entire remnant with the recent pointing satellites (e.g., XMM-Newton, Chandra, or Suzaku) is difficult due to their limited exposure times.

Solid State Camera (SSC) on board MAXI has good energy resolution with the wide energy range of 0.5–10 keV (Katayama et al. 2005). Thus, it will be the first X-ray mission allowing us to study the ejecta distribution in the entire SNR, by spatially resolved spectroscopy. We will also be able to search other ejecta fragments hiding inside the shell by projection, similar to those found in the northern part of the SNR by the XMM-Newton observation. Those information will help us to understand the detailed mechanism of the core-collapse SN explosions.

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