A hard X-ray view of Vela X with Suzaku

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We present Suzaku observations of the Vela X central region. In the soft X-ray band, ROSAT found a diffuse elongated structure, “soft X-ray filament”, in this region. Recently, H.E.S.S. detected an extended TeV emission which appears to be spatially coincident with the soft X-ray filament. However, our Suzaku observations, as well as ASCA archival data, discovered a “hard X-ray hook” which is morphologically different from the soft X-ray filament. Spectral analysis showed that the soft X-ray filament and the hard X-ray hook are thermal and non-thermal in origin, respectively. Suzaku also detected faint extended non-thermal X-ray emission from the edge of Vela X which is not on an extension of the hard X-ray hook. It is hard to interpret these features assuming a single relativistic particle population.

§1. Introduction

Vela X is a 2°-wide, radio bright, filamentary structure located at the center of the Vela supernova remnant (SNR). Figure 1 shows radio images of Vela X and the Vela SNR. The structure of the radio Vela X is asymmetric to the Vela pulsar and more extended to the south. The origin of this structure may be attributable to an interaction between pulsar wind outflow and confining reverse shock propagating back to the center of the SNR.\textsuperscript{4}

Fig. 1. a) 2.4 GHz Parkes map of the Vela SNR containing Vela X, Puppis A, and Vela Jr.\textsuperscript{12} The cross and the arrow indicate the pulsar location and the direction of the pulsar proper motion, respectively. b) Combined VLA and Parkes 1.4 GHz image of Vela X.\textsuperscript{3} The cross and white boxes indicate the pulsar location and the FOV of our Suzaku observations.
Figure 2a shows a H.E.S.S. \(\gamma\)-ray excess map of the Vela X region.\(^5\) This TeV \(\gamma\)-ray source, HESS J0835–455, is extended to the south of the pulsar approximately along the brightest radio filament of Vela X, and appears to be spatially correlated with a “soft X-ray filament” observed by ROSAT\(^6\) in Figure 2b. The soft X-ray filament had been thought to be an X-ray jet originating from the pulsar until Chandra observations revealed that the true pulsar jet is running along the direction of the pulsar proper motion (NW–SE).\(^7\) Thus, the nature of the soft X-ray filament still remains unknown.

Stimulated by the discovery of HESS J0835–455, we made a hard X-ray image of this region using ASCA archival data as shown in Figure 2c (Mori et al. in preparation), and found a “hard X-ray hook” that has a striking morphological difference from the soft X-ray filament. A deep Chandra image revealed a faint diffuse emission extended southwest of the bright compact pulsar wind nebula (PWN; see inset in Fig. 2c),\(^9\) which smoothly connects to the hard X-ray hook. Thus, the hard X-ray hook is likely a southwestern extension from the Chandra-viewed compact PWN.

\section{Observations & Analysis}

Previous observations have shown that the central region of Vela X has an energy-dependent appearance even within the relatively narrow 0.5–10.0 keV band. Utilizing the high sensitivity, good energy resolution, and low and stable background of the XIS,\(^10\) we performed 4 Suzaku observations to cover the Vela X central region in the period of 2006 July 9–18. Figure 1b shows the fields of view (FOV) of the observations. We hereafter call the 4 observations as P1, P2, P3, and P4 in the order of declination from north to south.

We analyzed cleaned event excluding data with values of cut-off rigidity less than 6 GV. Net exposure times of the P1, P2, P3, and P4 observations are 48, 50, 16, and 24 ksec, respectively. We used the Lockman Hole data taken at 2006 May 18 as a background data in our spectral analysis. The low-energy efficiency of the XIS is known to gradually decline in time because the optical blocking filter attached above the XIS CCD is being contaminated by out-gassing from the satellite.\(^10\) However, at the time of 2006 May–July, the contamination build-up rate had declined significantly compared to its initial value so that the changes in the contaminant that occurred
within the 2-month period are negligible. For making RMF and ARF files, we used `xisrmfgen` and `xissimarfgen` (version 2006-10-26), respectively.

§3. Results

Figure 3 shows Suzaku XIS images in the soft (0.5–2.0 keV) and hard (2.0–10.0 keV) X-ray bands. Our Suzaku observations confirmed and strengthened the morphological differences between the two different bands, particularly with better spatial resolution and statistics in the hard X-ray band. In this figure, all the colored area represent the emission that is significantly detected above the background level, indicating that both the soft and hard X-ray emission fill out the region within the FOV of our observations. A structure seen in P4 in the soft X-ray band is likely the same as that observed by ROSAT\(^{11}\).

Figure 4 shows the XIS1 spectra taken from P2, P3, and P4 (the spectrum from P1 is almost dominated by the bright compact PWN). Each spectrum was taken from a 6'-radius circle roughly at the center of the each FOV. The P3 spectrum, which is taken from the heads of the soft X-ray filament and the hard X-ray hook, is well fitted with a thin-thermal plasma plus power-law model. This confirms that the soft X-ray filament and the hard X-ray hook are thermal and non-thermal in origin. The P2 and P4 spectra are also well fitted with the same model, indicating that the non-thermal X-ray emission is seen not only from the hard X-ray hook but also throughout the whole FOV of our observations, even from the P4 region which is about 30' apart from the end of the hook and located at the edge of the radio Vela X (see Fig. 1b). The photon indices, $\Gamma$, of the non-thermal component in
P3 and P4 are 2.15 ± 0.07 and 2.2 ± 0.3, respectively, and statistically indistinguishable. This is in contrast with the clear softening between P1 (Γ ~ 1.6) and P3.

§4. Discussion

Our Suzaku observations as well as the ASCA archival data revealed that the hard X-ray view of the Vela X central region is different from that in the soft X-ray band. The imaging and spectral properties of the hard X-ray hook indicate that it is a fainter extension of a bright compact PWN. On the other hand, the soft X-ray filament has a thermal spectrum, and thus could be unrelated to pulsar (e.g., it may correspond to a deformation in the SNR shell which is projected by chance near the pulsar12). In this view, however, it is puzzling that the TeV γ-ray and radio emission appear to be much better correlated with the soft X-ray filament than with the hard X-ray hook. This may suggest that the hard X-ray and TeV γ-ray emission originate from different populations of relativistic particles. Further detailed comparisons between radio, X-ray, and TeV γ-ray data will allow us to understand the nature of Vela X.

The southwestern location of P4 appears not to be on an extension of the hard X-ray hook which is toward south and there is no clear hard X-ray structure observed such as seen in the soft X-ray image. In addition, a clear spectral softening is seen along the hard X-ray hook from P1 to P3, but not seen between P3 and P4. Thus, it is not so obvious if the faint diffuse non-thermal emission detected in P4 is a component that has diffused out from the hook. However, if it would be, these observational facts may put interesting constrains on variations of magnetic fields and particle diffusion speeds along the wind flow. Mapping X-ray observations covering the neighboring regions are strongly demanded to clarify the relation between the hook and the faint diffuse non-thermal emission.

Acknowledgements

We would like to thank S. Katsuda for his technical supports on our imaging analysis. The work of K.M. is partially supported by the Grant-in-Aid for Young Scientists (B) of the MEXT (No. 18740108).

References