Diffuse X-Ray Emission
from the Carina Nebula Observed with Suzaku

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A number of giant HII regions are associated with soft diffuse X-ray emission. Among these, the Carina Nebula possesses the brightest soft diffuse emission. The required plasma temperature and thermal energy can be produced by collisions or termination of fast winds from main-sequence or embedded young O stars, but the extended emission is often observed from regions apart from massive stellar clusters. The origin of the X-ray emission is unknown.

The XIS CCD camera onboard Suzaku has the best spectral resolution for extended soft sources so far, and is therefore capable of measuring key emission lines in the soft band. Suzaku observed the core and the eastern side of the Carina Nebula (Car-D1) in 2005 Aug. and 2006 June, respectively. Spectra of the south part of the core and Car-D1 similarly showed strong L-shell lines of iron ions and K-shell lines of silicon ions, while in the north of the core these lines were much weaker. Fitting the spectra with an absorbed thin-thermal plasma model showed $kT \sim 0.2, 0.6$ keV and $N_H \sim 1 - 2 \times 10^{21}$ cm$^{-2}$ with a factor of 2-3 abundance variation in oxygen, magnesium, silicon and iron. The plasma might originate from an old supernova, or a super shell of multiple supernovae.

§1. Extended X-ray emission from the star forming region

Soft X-ray emission nebulae with $kT \sim 0.1$–0.8 keV, $\log L_X \sim 33$–35 ergs s$^{-1}$, and size of $\sim 1$–$10^3$ pc accompany a number of giant HII regions (see Table IV of Ref. 6). Chandra observations of extended emission in a few star forming clusters indicate that the emission may arise from the fast O star stellar winds thermalized either by wind-wind collisions or by a termination shock. However, the emission is often found outside of the massive stellar clusters, so that another origin, such as an otherwise unrecognized supernova remnant, cannot be ruled out.

In principle, the origin of the diffuse emission can be determined by measuring its composition. For example, the plasma should be overabundant in nitrogen and neon if it originates from winds from nitrogen-rich Wolf-Rayet stars (WN), while it would be overabundant in oxygen if it arises from a Type II SNR. The temperature of the plasma, typically a few million degrees, makes soft X-ray band studies highly desirable, because of the presence in this band of strong lines from these elements, plus carbon, silicon and iron.

The Carina Nebula, which contains several evolved and main-sequence massive stars such as η Car, WR 25 and massive stellar clusters such as Trumpler 14 (Tr 14), emits soft diffuse X-rays 10–100 times stronger than any other Galactic giant HII region ($L_X \sim 10^{35}$ ergs s$^{-1}$). The high surface brightness made possible the discovery of the diffuse emission by the Einstein Observatory in the late 1970’s. The Einstein observations revealed that the diffuse emission tends to be associated with optically
bright regions containing massive stars. Recent *Chandra* observations provided a point source free measurement of the diffuse flux,\(^1\) and suggested the presence of a north-south Fe and Ne abundance gradient.\(^5\)

The X-ray CCD cameras (XISs: X-ray Imaging Spectrometer) onboard the *Suzaku* observatory have the best spectral resolution for extended soft X-ray emission and thus they provide good diagnostics of emission lines especially below \(\sim 1\) keV.

\section*{§2. *Suzaku* and *XMM-Newton* observations of the Carina Nebula}

Figure 1 shows a mosaic image of the Carina Nebula between 0.4–7 keV created from 32 *XMM-Newton* observations. The image depicts several bright X-ray point sources: \(\eta\) Car (an LBV), WR25, WR22 (Wolf-Rayet stars), HD 93250, HD 93043 (O3 stars), and Tr 14, Tr 16 (massive stellar clusters). The image also clearly shows apparently extended emission toward the east-west direction. In a color image (e.g. Fig. 1 of Ref. 2), *XMM-Newton* Image Gallery\(^*\)) the emission is softer between Tr 14, WR 25 and \(\eta\) Car.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{mosaic_image.jpg}
\caption{Mosaic image (\(\sim 90' \times 60'\)) of the Carina Nebula between 0.4–7 keV created from 32 *XMM-Newton* observations. The image is created with the ESAS package, divided by the exposure map and smoothed with the adaptive smoothing technique. The dotted lines show the XIS FOVs of the *Suzaku* observations of \(\eta\) Car (right) and the Car-D1 field (left). The solid lines show source extraction regions for the spectral analysis.}
\end{figure}

\(^*\) http://xmm.esac.esa.int/external/xmm_science/gallery/public/
We analyzed the *Suzaku* data of the core and the eastern side (named Car-D1) of the Carina Nebula taken on 2005 Aug. 29 and 2006 June 5. The XIS FOVs of these observations are shown in Fig. 1 with dotted lines. To investigate the color variation in detail, we divided the core region into two and thus extracted three spectra from two *Suzaku* observations (core-north, core-south and Car-D1). The background was reproduced with the night earth data. The spectra showed strong emission between 0.3 and 2 keV, which is probably dominated by soft diffuse emission associated with the Carina Nebula, while the spectra above 2 keV may be explained with CXB, Galactic Ridge X-ray Emission, X-ray point sources resolved with *Chandra* and unresolved pre-main-sequence stars.

Figure 2 shows an overlay of the BI spectra between 0.3–2 keV. The left panel compares spectra of the core-north region with the core-south region. A strong difference is seen between 0.7 keV and 1.2 keV, which apparently is the source of the two colors of diffuse emission. The band in which the difference is found is dominated by emission lines from the iron L-shell complex. Additionally, the core-south spectrum shows a stronger Si line. The Car-D1 spectrum shows similar intensity in the Si and Fe lines to the core-south spectrum (right panel of Fig. 2) while it shows relatively strong magnesium and oxygen lines. All these spectra look similar except for these emission lines. This suggests that the differences represent an elemental abundance variation, and not a temperature difference.

This is supported by spectral fits of the individual spectra. All three spectra between 0.3–2 keV were reproduced by an absorbed 2T thin-thermal plasma models although the best-fit models are not formally acceptable. The plasma temperatures of all three regions are \( \sim 0.2 \) and \( \sim 0.6 \) keV, and their column densities are \( \sim 3 \times 10^{21} \) cm\(^{-2}\), which is consistent with extinction toward the Carina Nebula. The abundances of some elements show a factor of 2–4 variations: the core-north region

![Fig. 2. Comparison of the XIS1 spectra between the fields – left: the core-north region (black) and the core-south region (grey), right: the Car-D1 field (black) and the core-south region (grey). The above labels demonstrate energies of emission lines detected (black) or concerned (grey) with this result. Emission lines with the solid lines showed variation in their line intensity. Low count rates of the Car-D1 spectrum below 1 keV is caused by degradation of soft response by progressive contamination on the XIS.](image-url)
has a factor of 2 lower silicon abundance and a factor of 4 lower iron abundance than the core-south region, while the Car-D1 region has a factor of 2 higher oxygen and magnesium abundances. On the other hand, spectral fits of the core region with higher sensitivity around 0.5 keV gave small upper-limits ($\lesssim 0.02$ solar) of the nitrogen abundance.

§3. Origin of the diffuse plasma

The N/O abundance ratio inferred from the spectral fits is $\lesssim 0.4$, over 20 times less than around $\eta$ Car. The abundance distribution is totally contrary to that expected from stellar winds from evolved massive stars, unless the winds somehow heat the interstellar matter without enriching it, thus leaving the X-ray plasma with abundances typical of interstellar matter. At the same time, the X-ray luminosity of the Carina Nebula is about two orders of magnitude higher than that of other Galactic star forming regions, but the number of early O stars is only an order of magnitude higher (see Table IV in Ref. 6). These results suggest an additional energy source is needed to power the X-ray emission in the Carina Nebula.

An obvious possibility is one or more core-collapse supernovae (i.e. Type Ib, c or II), mentioned as a possibility by Ref. 6). The regions vary strongly in oxygen, magnesium, silicon, and iron abundances. These elements are products of core-collapse supernovae, and young SNRs such as Cas A and Vela show strong abundance variation from location to location. The total energy content in the hot gas of $\sim 2 \times 10^{50}$ ergs is a modest fraction of the $\sim 10^{51}$ ergs of kinetic energy produced by a canonical supernova, while assuming an iron abundance of 0.30 solar, the total iron mass in the diffuse gas requires at least 3-5 supernovae.

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