

Spectral Line Imaging Observations of 1E0102.2-7219

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Abstract. E0102-72 is the second brightest X-ray source in the Small Magellanic Cloud and the brightest supernova remnant in the SMC. We observed this SNR for ~ 140 ksec with the High Energy Transmission Gratings (HETG) aboard the *Chandra* X-ray Observatory. The small angular size and high surface brightness make this an excellent target for HETG and we resolve the remnant into individual lines. We observe fluxes from several lines which include O VIII Ly α , Ly β , and O VII along with several lines from Ne X, Ne IX and Mg XII. These line ratios provide powerful constraints on the electron temperature and the ionization age of the remnant.

1E0102.2-7219 (hereinafter E0102-72) is the brightest X-ray SNR in the Small Magellanic Cloud (SMC) and was discovered with the Einstein Observatory's IPC [1]. Higher resolution observations showed that this SNR exhibits a shell-like structure [2]. Optical emission from E0102-72 was detected revealing that this is an oxygen-rich SNR [3] and thus the result of the explosion of a massive progenitor.

A moderate resolution CCD spectrum of this remnant was obtained with ASCA which observed this object for ~ 35 ksec. The X-ray spectrum shows clear lines of oxygen, neon, and magnesium [4]. Hayashi et al. use the NEI modeling code of Hughes & Helfand [5] and find that the data require at least two NEI plasmas. The assumption that each observed element has an independent nt and temperature lead them to the conclusion that the elements are not well mixed. Hayashi et al. find the NEI parameters for oxygen are $\log(nt) = 10.31 \text{ s cm}^{-3}$ and $\log(T) = 7.03 \text{ }^\circ\text{K}$ (0.93 keV) and those for Ne are $\log(nt)=11.37 \text{ s cm}^{-3}$ and $\log(T) = 6.78 \text{ }^\circ\text{K}$ (0.52 keV). The fact that the neon has a lower temperature and higher nt relative to oxygen leads them to the conclusion that the oxygen emission is related to the forward shock and the neon to the reverse shock. Our analysis below assumes that the emission is from a single τ plasma model.

CHANDRA HETG SPECTRA OF E0102-72

The Chandra X-ray Observatory (CXO) observed E0102-72 for a total of ~ 140 ksec with the High Energy Transmission Grating Spectrometer (HETGS) in the optical path of the telescope. The HETGS contains two types of gratings, the High and Medium Energy Gratings (HEG & MEG). These gratings provide an $E/\Delta E$ of 100-1000 for point sources over the energy range of 0.4 - 10 keV. The HEG and MEG are rotated with respect to each other so that the dispersed spectra form an “X” pattern on the detector. The problem of overlapping orders is resolved using the moderate energy resolution of the ACIS detector. Additional details of the analysis and results can be found in these proceedings [6] [7]. Here we present results from the MEG spectrum of E0102-72.

We extracted the line fluxes using an annular aperture that encloses the observed ring. The background was taken from an annular region outside the dispersed image of interest but with the same center as the region for the line flux.

X-RAY MORPHOLOGY

Figure 1 shows the dispersed image of the SNR in the O VIII Ly α line (18.97 Å). While the overall shape of the remnant can be described as a ring it is clear that this is not true on small scales. The ring has gaps on the eastern side and a bright knot can be seen in the southwest quadrant. The image of the SNR in the Ne X Ly α line (12.13 Å) is shown in Figure 2. The Ne X image shows fewer gaps in the rim than the O VIII image, but like the oxygen image shows deviations from a ring structure. We find no evidence that the different elements are stratified. However, we do find ionization structure in the remnant [7]. Despite these complexities a global analysis is useful as it allows us to determine integrated line fluxes for comparison with *ASCA* and *XMM* results, and to compare our models with earlier results.

LINE DIAGNOSTICS

Line ratios were calculated for pairs of hydrogen-like and helium-like lines and these are compared to the NEI model in XSPEC 11. Here we present results (Table 1) for the flux ratio of ions from the same element so that the results are independent of the abundances. We use the column density of 8.0×10^{20} atoms cm^{-2} [8] to correct the flux for interstellar absorption.

We derive tight constraints of the physical state of the plasma from measurements of O VIII Ly β /O VIII Ly α and from the ratio of O VII Forbidden + IC to O VII Resonance. Using Figure 3 we find that the temperature must be above ~ 0.68 keV and $\log(\tau)$ is between 9.85 and 10.05 s cm^{-3} . The ratios of Ne X Ly α to Ne IX Res along with Ne X Ly β /Ne X Ly α also provide tight constraints on the physical state of the plasma. They do not overlap the allowed region for oxygen. The allowed region of parameter space is shown in Figure 4; the width of the regions

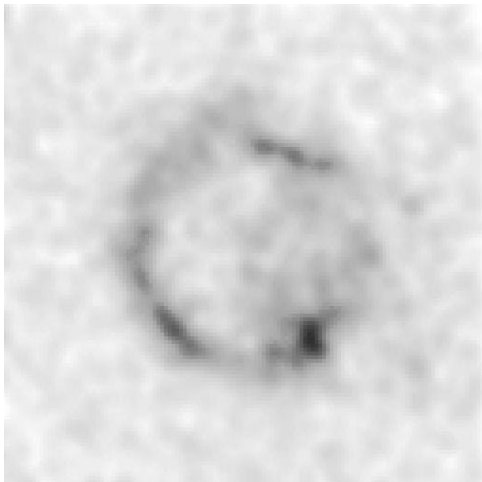


FIGURE 1. The OVIII Ly α image of E0102-72 from the MEG -1 order. Note the bright knot in the southwest.

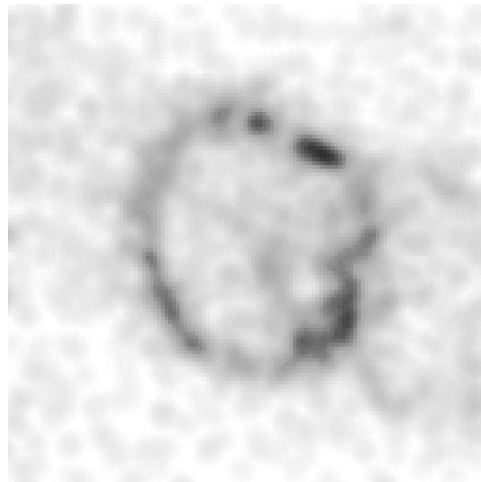


FIGURE 2. The Ne X Ly α image of E0102-72. This is the data from the MEG -1 order.

is determined by the three σ limits on the line ratios. The lower limit on the temperature of the plasma is 0.54 keV from the oxygen ratio and 0.97 keV from the neon ratio and is consistent with the *ASCA* analysis of this remnant [4]. The lower limits for the temperature are robust even for a multi- τ plasma.

Line Ratio	Flux Ratio	3σ range
O VIII Ly β /O VIII Ly α	0.138	0.122 – 0.154
O VII (For + IC)/ OVII Res	0.593	0.422 – 0.764
O VII (4 \rightarrow 1)/O VIII Ly α	0.338	0.089 – 0.587
Ne X Ly β /Ne X Ly α	0.141	0.124 – 0.158
Ne X Ly α /Ne IX Res	0.723	0.603 – 0.843

Table 1: The flux ratios for oxygen and neon.

CONCLUSIONS

We have measured the strong emission lines of O and Ne in the SNR E0102-72. The detected flux ratios from these lines are consistent with emission from a young SNR that has not yet reached ionization equilibrium. Our global analysis yields an electron temperature that is above ~ 0.54 keV and an ionization age between $9.85 < \log(\tau) < 10.6$, consistent with this being a young remnant.

We find that the line emission from each element, measured globally, can be described by an NEI plasma using a simple plane parallel shock model. Our analysis is consistent with the oxygen and neon emission both being from the reverse shock and we find no compelling evidence that oxygen and neon are not well mixed. Future work will include analysis of other lines present in this spectrum. We also

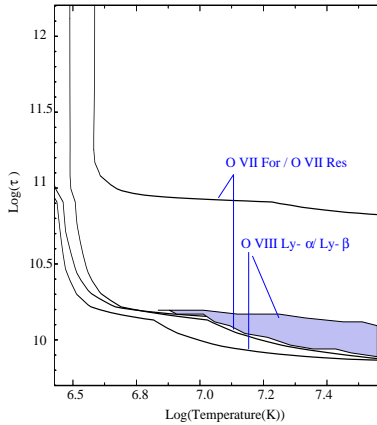


FIGURE 3. The allowed parameter space in τ Temperature (K) from the oxygen lines is shown as the shaded region.

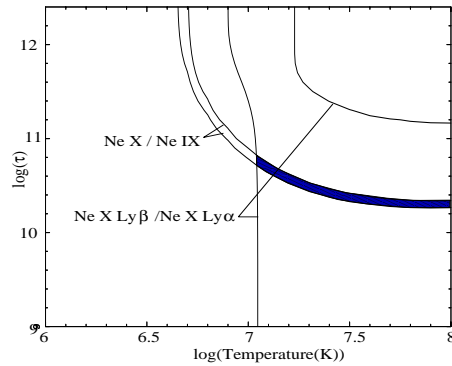


FIGURE 4. The allowed parameter space in τ Temperature (K) from the neon lines. Note that the ranges for the x and y axis are not the same as those in Fig 3.

will use the imaging capability of the HETGS to explore how the plasma diagnostics vary around E0102-72 and map the temperature and ionization age of this remnant.

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