X-ray spectral studies of the MC supernova remnants: Highlights from XMM-Newton

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The XMM-Newton X-ray observatory is the most powerful instrument for cosmic X-ray spectroscopy to date and particularly suited for spectral diagnostics of supernova remnants. We have chosen three bright, (relatively) young, supernova remnants in the Magellanic Clouds (N103 B, N132 D and 1E0102) to highlight it's capability. The high resolution grating spectra show *XMM-Newton* 's unique capability to perform high resolution spectroscopy on X-ray sources of a moderate (few arcminutes) angular extent The possibility of single ion spectroscopy permits independent measurements of electron temperature, density, ionisation age and velocity profiles. In addition, full spectral modeling also allows for elemental abundance determination.

1. Introduction

The well-determined distance and relative closeness of the Magelanic Clouds (MC) make it possible to determine accurate physical quantities (e.g. temperature, age and elemental abundances) for individual remnants. These are essential in the study of SNR properties such as evolution, nucleosynthesis and progenitor types. The salient features of the XMM-Newton X-ray observatory for supernova remnant (SNR) research in the MC comprise : (i) an outstanding spectral grasp brought about by the large effective collecting area and spectral resolving power of the X-ray telescopes, (ii) an unique capability for high resolution (R>100) spectroscopy of moderately extended ($\Delta\theta \leq 2$") sources.

In this overview we present results on the studies of the three Magellanic Cloud remnants N103B, N132D and 1E 0102.2-7219 (1E0102). We selected these remnants because they are bright, (relatively) young, objects which provide ample statistics to exploit in full the above mentioned XMM-Newton strengths in unraveling the physical properties and nature of SNRs. Observations with the reflection grating spectrometers (RGS) of N132D (LMC) [1] and 1E0102 (SMC) [2] constitute the first highly resolved X-ray spectra of extended SNRs. The high dispersion of the RGS allows almost all of the X-ray spectral features emitted by these two remnants to be resolved. Single ion spectroscopy permits independent measurements of astrophysical quantities that affect line shape and production, such as electron temperature, density and velocity profiles. We also exploit the high dispersion of the RGS to investigate the nature of the SNR progenitor of N103B. Full spectral modeling allows for elemental abundance determination of N103B. We compare the derived abundances to theoretical nucleosynthesis yields for various SNR models.

2. N103 B

The SNR N103 B (also known as SNR 0509-69) is the fourth brightest X-ray remnant in the LMC. It was first identified as a SNR by [3] based on the non thermal nature of its radio spectrum and the relative emission line strengths of S II and Hα. Earlier N103B ASCA observations [4] showed a spectrum with strong emission lines from Si, S, Ar, Ca, and Fe, and no emission from O, Ne and Mg. [4] thus suggested that the remnant is the result of a type Ia supernova. However, its proximity to the star cluster NGC 1850 and the H II region DEM 84 suggests that SNR N103B has an early type progenitor [5], providing contradictory evidence for the nature of the progenitor.

The RGS spectrum of N103B is shown in Fig. 1, with the identification of the brighter emission lines displayed in the plot. The data displays a spectrum dominated by a number of emission

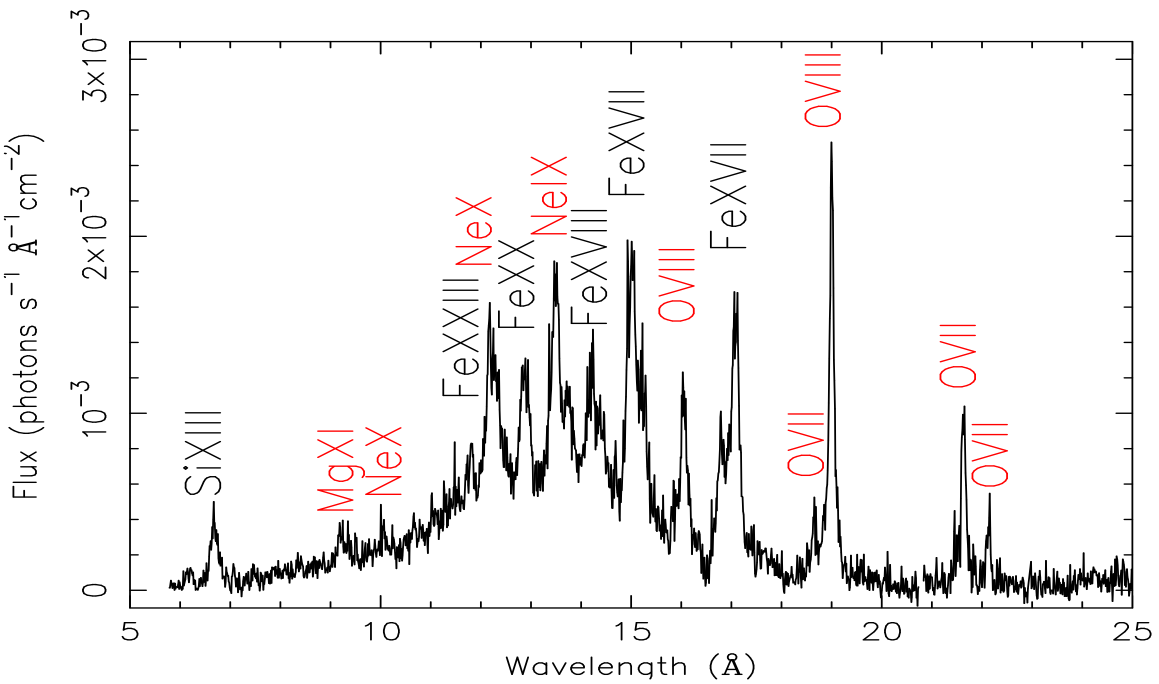

Figure 1. The fluxed RGS spectrum of N103 B. Line identification of the most prominent lines are indicated. The RGS unambiguously detects emission from O, Ne and Mg.

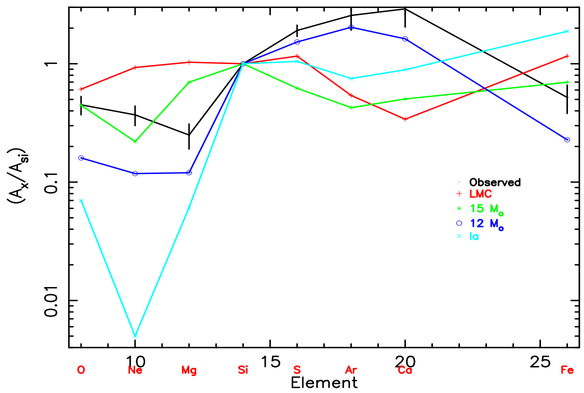

Figure 2. Element abundance ratios as derived from NEI fits (black) to the data compared to the LMC abundances (red) and theoretical yield for type Ia W7 (light blue) and type II (for 12 (dark blue) & 15 (green) $M_\odot$ progenitors) models. The ratios are all normalised to Si and relative to their solar ratios [13].

lines from highly ionised species of O, Ne, Si & Fe. We do not detect any emission longward of 23 Å. This is probably due to line-of-sight absorption towards the LMC. An important point to note is that we clearly detect O, Ne and Mg emission, features which were undetected in previous ASCA [4] and more recent *Chandra* ACIS observations [6].

Spectral analysis was performed using the SRON SPEX package [7]. Our model consists of several non-equilibrium plasma components. For each component, we fit for the volume emission measure ($n_e n_H V$), the electron temperature (T_e), the ionisation age ($n_e t$) and elemental abundances. Here, n_e is the electron density, n_H is the hydrogen density, V is the volume of emitting gas and t is the time since the material has been shocked and heated to its current temperature.

The fact that the RGS is able to resolve prominent O, Ne and Mg emission suggests that N103 B could in fact be the result of a core collapse SNe. To investigate this further, we compare the abundance yields as obtained from the fits to that predicted by theory for type Ia and type II nucle-

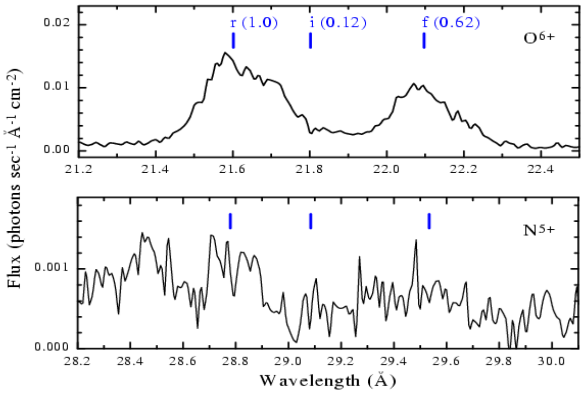

Figure 4. The RGS spectrum of N132 D in the limited wavelength range corresponding to the He-like triplets of O VII and N VI ($\lambda_{expected}$ indicated by horizontal bars). Relative line intensities are given for O VII. [1]

osynthesis models. We also compare these abundances to the average LMC abundances. All LMC abundance values are from [8] except for Ar and Ca which are from [9]. We use the relative abundances because they are more consistent among the various models than the absolute abundances [10]. The abundances for the classical W7 type Ia model are from [11], while the type II models for 12 and $15 M_{\odot}$ zero age main sequence progenitors are taken from [12]. The ratio comparisons are given in Fig. 2. All abundances are normalised to Si and relative to solar ratios [13]. Our derived abundance ratios do not compare well with those of the LMC. The absolute abundances are also larger than those of the LMC, indicating that the emission is from (or mostly from) ejecta material. The abundance ratios compare better to the type II than to the type Ia models. Our abundance ratios for O/Si, Ne/Si and Mg/Si are almost an order of magnitude larger than those predicted for type Ia explosion while the Fe/Si ratio is about a factor 3 lower than predicted by the W7 model. The O/Fe-L and O/Fe-K ratios are also in much better agreement with the type II models.

3. N132 D

N132 D is one of the brightest soft X-ray sources in the LMC and was first identified as a type II SNR by [14]. The size of the remnant is ~1.6 arcminutes and the age, estimated from the expansion and size of it's oxygen rich filaments, is estimated to be 3000 years.

An EPIC ratio image of O VII/O VIII illustrates an excess of O VII emission on the north-eastern rim. The O VII brightness might simply be due to relatively cold gas. However, the special morphology in that region may, alternatively, suggest that the shock wave is interacting with relatively dense and cold O-rich material, possibly from a pre-SN stellar wind. The total RGS spectrum of N132 D [1] is plotted in Fig. 3. The strongest lines originate from the Ne X Ly-α-series, O VIII Ly-α-series and Fe-L. Also of interest is the detection of strong lines from the O VII He-α triplet and C VI Ly-α-series. Further evidence that the oxygen rich gas in the north-eastern part of N132 D is in the process of being ionised, as described above, comes from examination of the O VII He-α triplet in the RGS spectrum. These lines are at 21.602, 21.804, and 22.097 Å (Fig. 4) and are referred to as the resonant (r), intercombination (i), and forbidden (f) lines, respectively. The i line is very weak in the N132 D spectrum, whereas the r and f lines are strong. Fitting the O VII He-α spectrum with the most appropriate line-profile model available yields line intensity ratios of $f : i : r = 0.62 : 0.12 : 1.0$. However, since the model can not very well reproduce the observed line shapes, uncertainties of about $\pm 20\%$ should be associated with these values. It is found that both hot (e.g., 0.6 keV) ionising gas, as well as a cooler (0.15 keV) gas in equilibrium can emit these lines with the observed ratios. For completeness, it should be noted that the current spectrum at least rules out a cooling plasma for N132 D because in that case the upper levels of the i and f lines are populated by recombination resulting in much higher f/r and i/r ratios than are observed here.

4. 1E 0102.2-7219

The SNR 1E0102 is a young (~1000 years), bright oxygen rich remnant in the SMC. *Chandra* observations, show the X-ray morphology to be a 25-30 arcseconds in diameter (8-9 pc) fragmented shell of reverse-shock-heated ejecta with emission mainly from O VII and O VIII.

The grating spectrum [2] shown in Fig. 5 is dominated by emission lines predominantly from

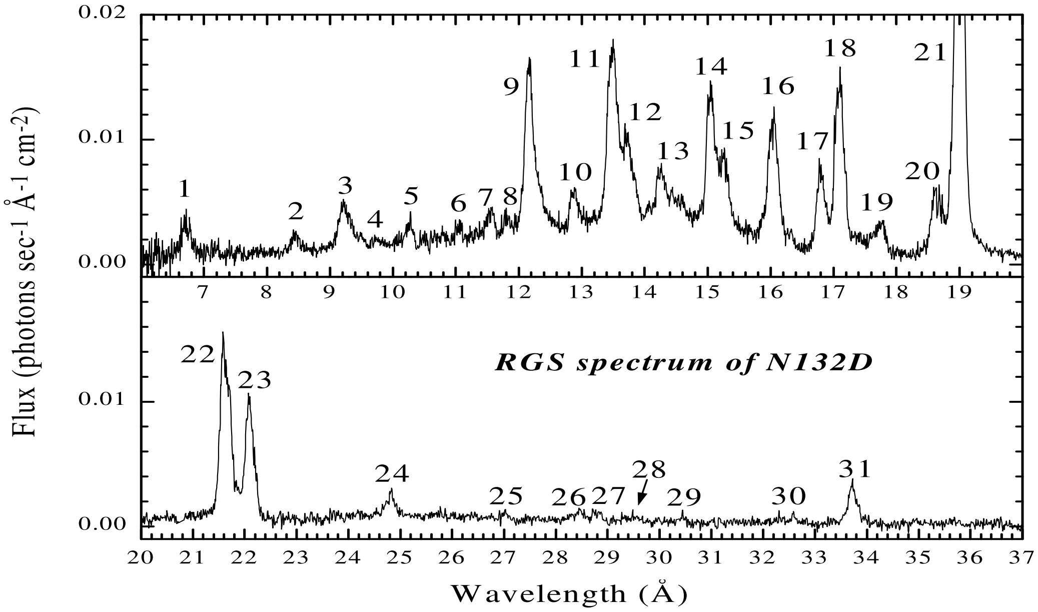

Figure 3. The RGS spectrum of N132 D with emission line identifications. [1]

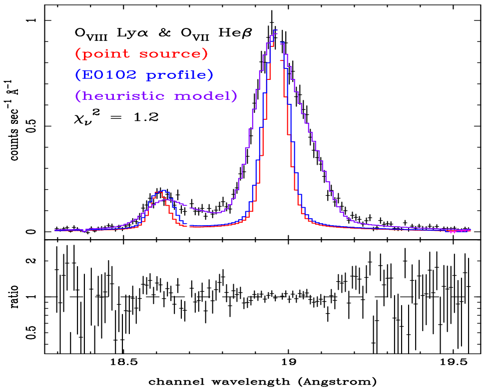

Figure 6. Illustration of the line profile used for fitting the O VIII Ly-α line (left) and the O VII He-α triplet (right) used for the derivation of the f/i (density) and (i+f)/r (temperature) line ratio diagnostics for 1E0102. [2]

the Lyman series of C VI, O VIII, Ne X and Mg XII and from the He-series of O VII, Ne IX, Mg XI and Si XIII. By comparing the predicted line shape (taking into account the point spread function, the monochromatic line profile based on the remnant's angular distribution and heuristic wavelength broadening) with the measurement of the bright, isolated O VIII emission line profile (see Fig. 6), one is able to resolve a velocity distribution. Using a square velocity profile model of an expanding shell allows a lower limit of $v_{exp} \geq 1350$ kms^{-1} to be placed on the expansion of the ejecta material.

In spite of the angular extent of the source and the velocity broadening of the line, the RGS is also capable of resolving the He-α complexes of O VII and Ne IX sufficiently well to estimate contributions from the forbidden, intercombination and resonance transitions that provide robust diagnostics for the temperature and density of the emitting medium. Fig. 7 shows the He-like triplet of O VII and a model fit using the known line wavelengths, and the line velocity profile adopted above. The ratio f/i (density diagnostic) obtained for O VII equals 3.4±0.6 and is consistent with

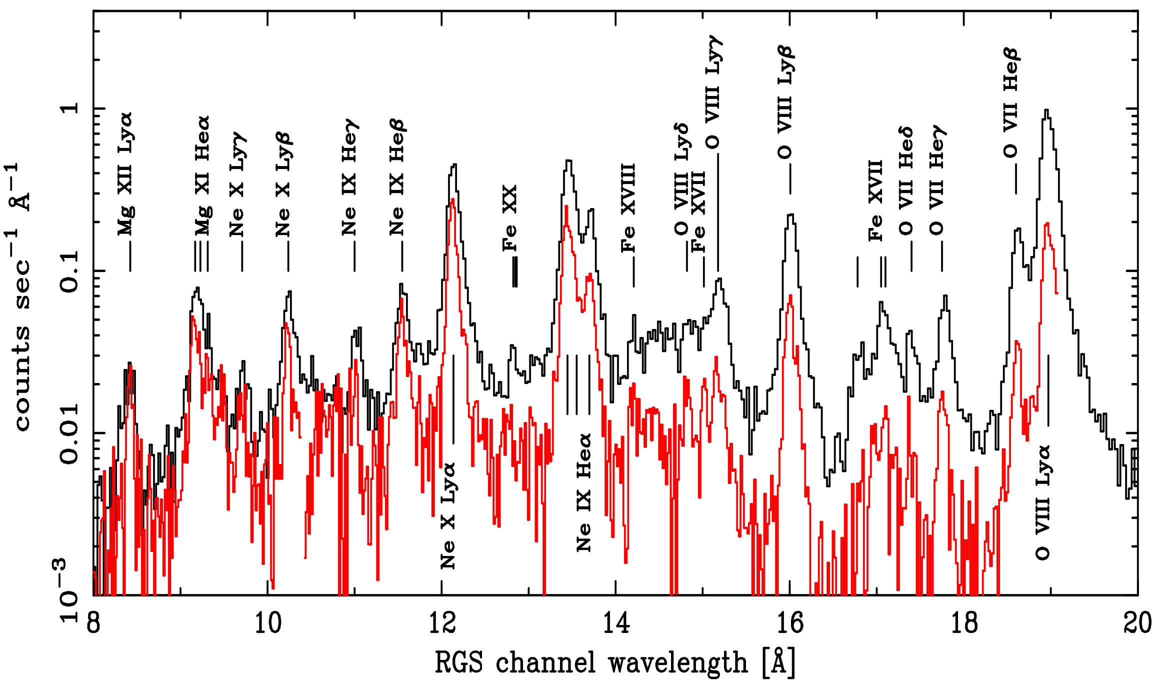

Figure 5. The RGS spectrum of 1E0102. First and second orders are plotted seperately (m=-1 in black, m=-2 in red). [2]

the low density limit. The ratio (i+f)/r (temperature diagnostic) is 0.55±0.03 for O VII and 0.49±0.05 for Ne IX. The electron temperatures corresponding to these ratios are approximately 3.5 million K and 7.5 million K for O VII and Ne IX respectively.

5. Summary & Concluding remarks

The N103 B RGS spectrum unambiguously reveals emission from species of O, Ne and Mg. The absence of these elements in previous ASCA observations led to this remnant being designated as being the result of a type Ia SNe. The presence of these lines in *XMM-Newton* and in particular in the RGS data suggests that N103 B might actually be the result of a type II SNe. Indeed, the abundance patterns obtained from our model fits agree more closely to those of a type II SNe.

Emission lines of C, N, O, Ne, Mg, Si, S, and Fe ion species are identified in the grating spectrum of N132 D. O VIII is present throughout the remnant, while the brightest spot of O VII emission is near the northeastern rim, probably indicating recently shocked material that is in the process of being ionised.

Bright emission lines from C VI, O VII, O VIII, Ne IX and Ne X allow for single ion spectroscopy of 1E0102. Peculiar Lyman and He-series line ratios are inconsistent with collisional equilibrium and indicate underionisation (i.e. non-equilibrium ionisation) even at the estimated age of 1000 years. This is consistent with the measured triplet ratios for He-like O and Ne which correspond to temperatures well above the ion temperatures, again indicating a purely ionising plasma.

The Magellanic clouds are ideal hunting grounds for studying SNR properties e.g. nucleosynthesis, evolution, temperatures etc. High resolution spectroscopy has already proven to be a good tool to unravel these properties. The ability of the RGS to perform high resolution spectroscopy on moderately extended sources makes this instrument very well suited to investigate the MC SNRs.

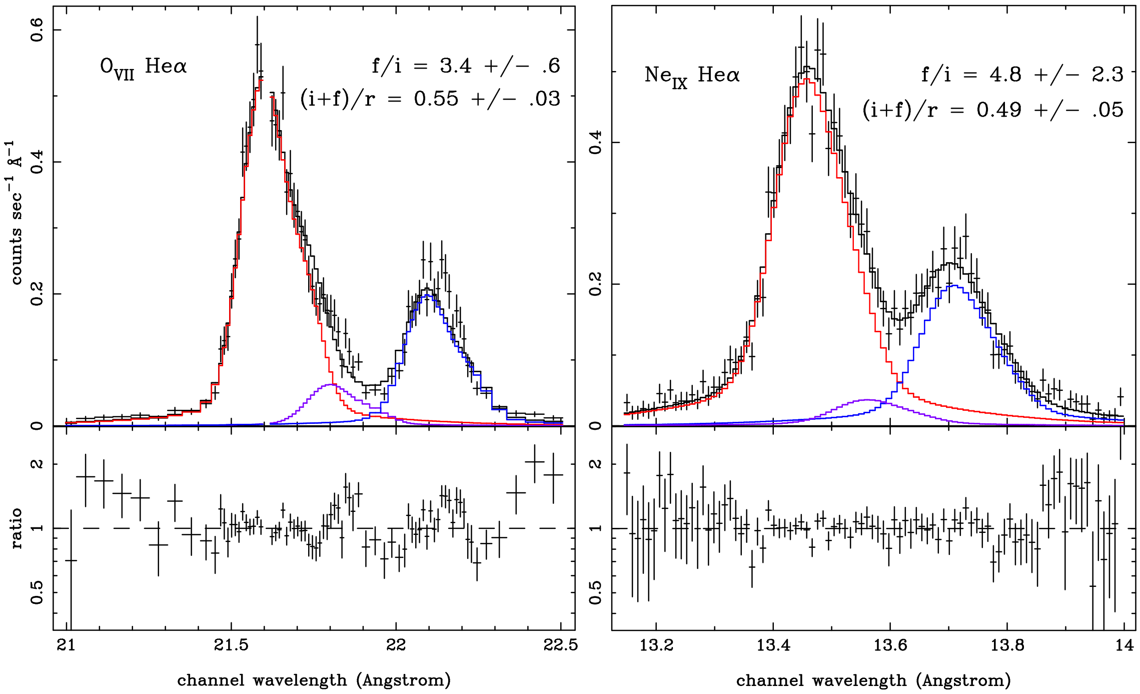

Figure 7. Derivation of the R (density) and G (temperature) line ratio diagnostics for O VII (left) and Ne IX (right). Individual contributions from the f, i and r lines are shown. [2]

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