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XMM-NEWTON HIGH-RESOLUTION X-RAY SPECTROSCOPY OF THE WOLF-RAYET OBJECT WR25 (WN6ha+O4f)

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ABSTRACT

We report the analysis of the X-ray spectrum of the Wolf-Rayet star WR 25, observed by RGS and EPIC-MOS on board XMM-Newton. Temperatures up to 40 MK have been determined. Strong absorption, exceeding the value due to the Inter Stellar Medium (ISM) has been detected and assigned to the dense stellar wind.

INTRODUCTION

Wolf-Rayet (WR) stars represent massive stars in a late phase of their evolution. They are surrounded by dense stellar wind. They have been shown to be strong X-ray emitters with luminosities that cover a range of more than two orders of magnitude. Single WN stars (Wolf-Rayet stars with enhanced nitrogen abundance) have X-ray luminosities higher than WC stars (Wolf-Rayet stars with enhanced carbon abundance), while WR+OB binaries tend to be brighter than single WR stars. In these systems the colliding winds of the two sources are responsible for the X-ray emission. We have observed WR 25 with XMM-Newton using the Reflection Grating Spectrometers (RGS) (Jansen et al. 2001, den Herder et al. 2001) and the European Photon Imaging Cameras (EPIC-MOS) (Turner et al. 2001) and PN-detectors (Strüder et al. 2001). Plots of the high resolution RGS1+2 spectra and the low resolution EPIC-MOS1 (high-sensitivity) spectrum are shown in Figure 1, together with the best fit model.

SPECTRAL ANALYSIS

From Figure 1 we recognize the strong absorption in the wavelength range above 15 Å, due to the dense wind around the Wolf-Rayet star. Using SPEX90 (Kaastra et al. 1996a) in combination with MEKAL (Kaastra et al. 1996b and Mewe et al. 1995) a 2-T fit is carried out to the data of the three instruments. Results are collected in Table 1. From this table it is clear that the data of revolution 284 and 285 are very much the same. For both the observations the temperature regime is divided into two parts. One around 7 MK and a hot component around 35 MK. The hot temperature component produces the Fe K-shell line at 6.7 keV. The emission measure of the cooler temperature component is higher by a factor of 3 compared

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to the hot temperature component.

The abundances are relative to solar photospheric values (Anders and Grevesse 1989), except for Fe (Grevesse and Sauval 1999). Due to the severe absorption no abundance values could be obtained for C (33.7 Å) and N (24.8 Å). Their values are, together with that of He, taken from Crowther et al. (1995ab). From Table 1 we notice that the absorption is high indeed. We have determined two different values for the two temperature components. The higher absorption is related to the lower temperatures component, which is responsible for emission below 1 keV. This indicates that the cool plasma is formed lower in the wind. The low absorption is close to the value for the ISM (log $N_{\rm H}$ [cm^{-2}] = 21.54(.11)). Therefore the difference between the two derived values is supposed to be related with the dense stellar wind of WR25.

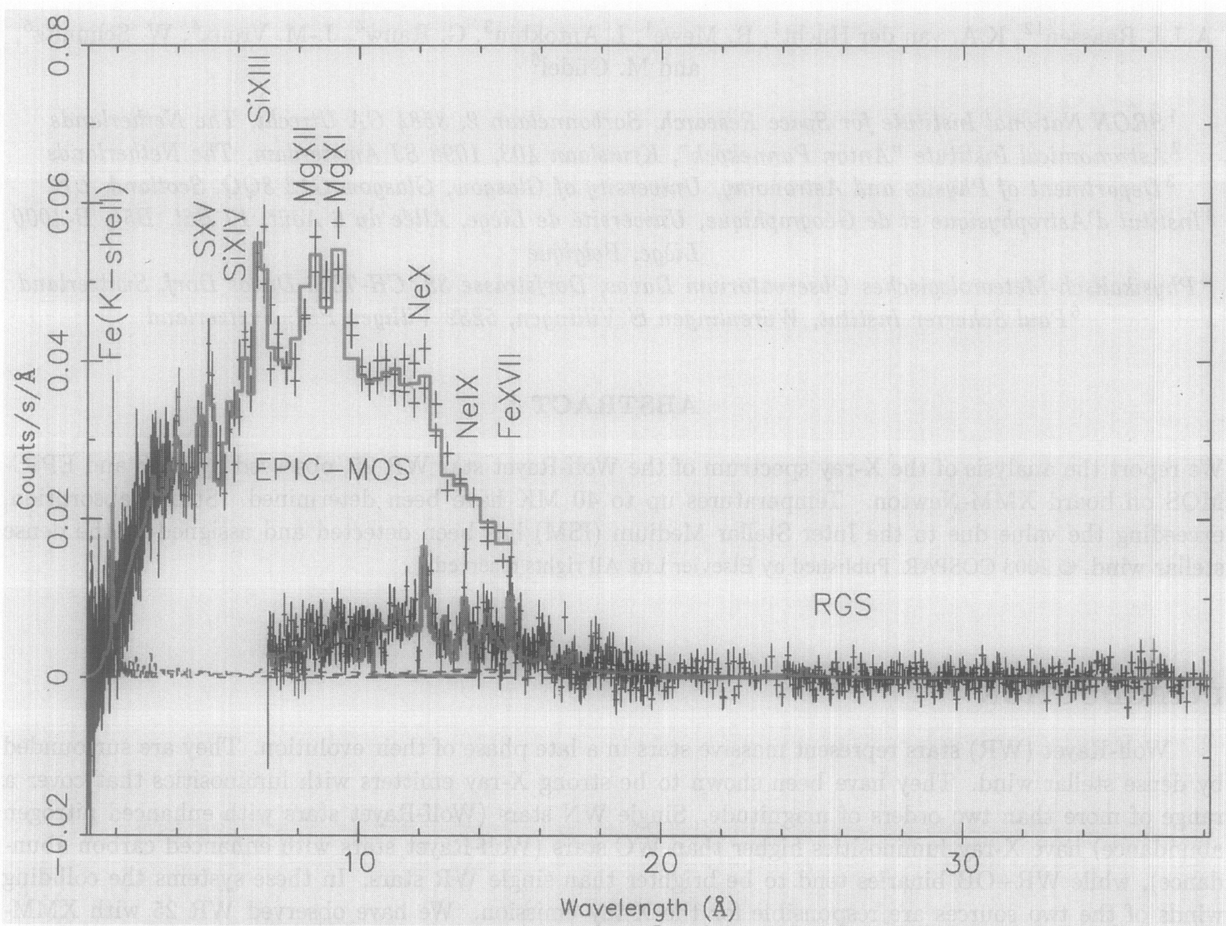

Fig. 1. RGS and EPIC-MOS spectra together with the best model fit (unbroken line). Dominant ions are indicated

Apart from the abundance anomalies determined in the optical spectrum of WR 25 (Crowther et al. 1995ab) no other anomalies (such as FIP or IFIP effects) are found on the basis of our observations.

To show the connectivity of the temperature components we applied a differential emission measure model using various inversion techniques (Kaastra et al. 1996b). We used the regularization algorithm and a polynomial fit of order 8 (see Figure 2). We assumed the same abundances as were used in the 2T-fit. Although the shapes are slightly different the results are identical in view of the statistical uncertainties, showing two emission concentrations around 8 and 35 MK.

Table 1. Best-fit parameters for a 4-T CIE model fit. Values are given with 1σ uncertainties. Elemental abundances are given relative to solar photospheric values (Anders & Grevesse 1989), except for Fe[a].

Parameter	284	285
$\log N_H1$ [cm^{-2}]	21.88(.10)	21.83(.10)
T_1 [MK]	7.1(.2)	7.4(.3)
EM_1 [10^{56}cm^{-3}]	7.0(1.4)	6.5(1.2)
$\log N_H2$ [cm^{-2}]	21.5(.1)	21.5(.1)
T_2 [MK]	34(3)	35(3)
EM_2 [10^{56}cm^{-3}]	2.6(.3)	2.4(.2)
L_x[0.1-10keV][b]	179	167
L_x[0.5-10keV][b]	125	117
Abundances[a]:		
He	2.27[c]	2.27[c]
C	0.15[c]	0.15[c]
N	5.9[c]	5.9[c]
O	<0.4	<0.4
Ne	0.6(.3)	0.5(.3)
Mg	0.7(.3)	0.6(.2)
Si	0.8(.2)	0.8(.2)
Fe1	0.6(.4)	0.4(.3)
Fe2	0.6(.2)	0.6(.2)

[a] Relative to solar photospheric values in logarithmic units ($\log_{10}$H=12.00;C=8.56;N=8.05;O=8.93; Ne=8.09;Mg=7.58;Si=7.55;Fe=7.50 (Grevesse & Sauval 1998).

[b] in units of 10^{32} erg/s. unabsorbed values.

[c] Fixed on literature values.

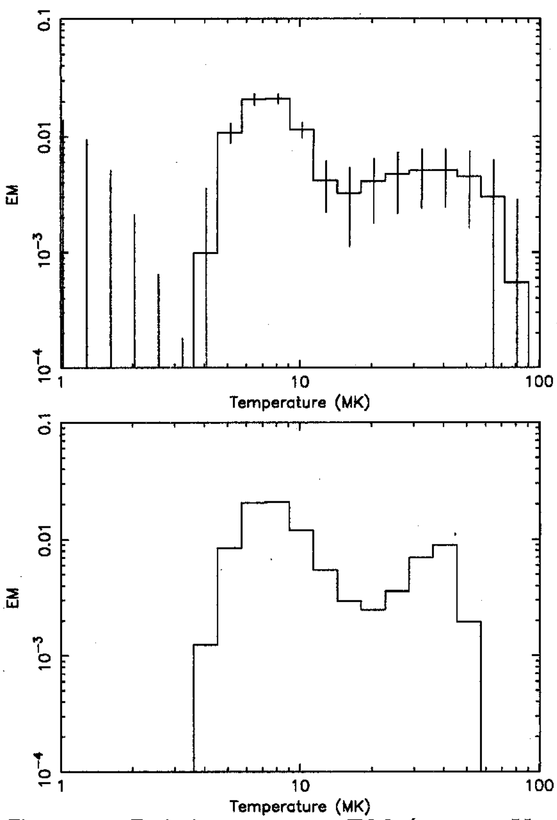

Fig. 2. Emission measure EM (= $n_e n_H V$ per logarithmic temperature bin) (in units of 10^{58} cm^{-3}) of WR25 derived from a fit to the RGS and EPIC-MOS spectra; EM resulting from a fit with the regularization method is shown in the top panel with error bars. The other EM results from a fit with the polynomial method and is shown in the bottom panel. Figures are taken from Raassen et al. (2003). The two methods are indentical in view of the statistical uncertainties, showing strong emission around 8 and 35 MK.

VARIABILITY

WR 25 may be a long-period binary. Therefore we might expect variations of its X-ray flux. If the X-ray flux is produced by wind-wind collision it may show a phase-locked variability either as a result of changing wind absorption in the line of sight or due to different separation in an eccentric orbit. To search for variabilities we have compared our fluxes and luminosities from XMM-Newton with those from observations by ROSAT (between December 1991 and December 1992) and ASCA (August 1993 and January 1997). The results are show in Table 2. No significant flux variabilities have been noticed from these observations made at different times.

CONCLUSIONS

The X-ray radiation is associated with a broad temperature range between 5 and 60 MK with maxima around 8 and 35 MK and a total emission measure of 9.5*10^{56}cm^{-3}. Above 15 Å the radiation is absorbed

Table 2. Time variability of WR 25 observed by ROSAT, ASCA, and XMM-Newton, taken from Raassen et al. 2003

observatory	MJD_{av}	L_x (10^{32} erg s^{-1}) for $d = 3.24$ kpc		
		absorbed ($N_H = 0.0 \times 10^{21}$ cm^{-2})		
ROSAT	48802	28.7 ± 4.9	-	-
ASCA	50015	30.7 ± 11.2	19.2 ± 9.2	48.6 ± 19.9
XMM-Newton	51921	32.2 ± 1.4	19.9 ± 1.0	51.8 ± 2.2
XMM-Newton	52089	34.3 ± 3.4	22.4 ± 2.2	56.5 ± 5.6
		unabsorbed ($N_H = 3.5 \times 10^{21}$ cm^{-2})		
ROSAT	48802	55.5 ± 4.9	-	-
ASCA	50015	46.0 ± 10.2	19.4 ± 0.4	65.5 ± 10.7
XMM-Newton	51921	64.5 ± 2.7	21.6 ± 1.1	86.1 ± 3.9
XMM-Newton	52089	59.0 ± 4.2	23.9 ± 1.7	83.0 ± 5.9

by the dense wind around the WR star and no features are observed in that region. The data are consistent with two different N_H values: $3*10^{21}$cm^{-2} for the hot temperature component and $7*10^{21}$cm^{-2} for the cool component. The first value is comparable to the value of the ISM $N_H = 3.5(1.1)*10^{21}$cm^{-2} (Diplas & Savage 1994). The latter, however, is considerably higher, implying that the radiation from the cooler plasma is absorbed by the dense wind of the Wolf-Rayet star. This indicates that the cool plasma is formed deeper in the wind of the Wolf-Rayet star, while the hot plasma with the highly ionized ions is formed in the outer layers.

No abundance anomalies have been noticed. For C and N no values could be obtained due to the strong absorption.

By comparing ROSAT, ASCA and our XMM-Newton data no significant flux variations over the last decade could be established. This could indicate a very long period binary or a circular orbit in combination with a pole-on observation.

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