Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies
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X-ray evidence for wind-wind collision in the Wolf-Rayet binary V444 Cygni

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Abstract. We present results on the eclipsing binary V444 Cyg (WN5+O6) with the X-ray satellite *ASCA*. The observations were performed at orbital phases 0.0, 0.25 and 0.5 (the O6 star is in front at phase 0.5 and *vice versa* at phase 0.0). Two-temperature plasma model could reproduce X-ray spectra in each phase. The temperature of the soft component is lower ($kT \simeq 0.6$ keV), which is attributed to the individual O6/WN5 stars. The temperature of the hard component is higher ($kT \simeq 2$ keV), which exhibited phase-related time-variabilities in absorption column $N_{\rm H}$ and luminosity $L_{\rm X}$; $N_{\rm H}$ was maximal at phase 0.0 while $L_{\rm X}$ was minimal at phase 0.5. These variabilities are consistent with the scenario that X-rays are emitted from plasma heated-up by wind-wind collision near the surface of the O6 star.

1. Phase-related spectra

ASCA-GIS and -SIS observations of V444 Cyg were performed at orbital phases 0.0, 0.25 and 0.5. The SIS spectra at phases 0.0 and 0.5 are shown in Figure 1.

We first attempted to separately fit the SIS spectra for each phase with a one-temperature plasma model, but this simple model was rejected (with at least 95% confidence).

Then we tried a model of soft- and hard-component plasmas, where global abundance Z, temperatures kT, column densities $N_{\rm H}$, and emission measure for each phase were allowed to vary. The fit was improved. We found that Z, kT for both components and $N_{\rm H}$ of the soft component were constant with orbital phase. Therefore we further assumed that they were constant, and simultaneously fitted the GIS and SIS spectra for each phase. The GIS spectra allowed us to constrain the parameters for the hard component more precisely. The best-fit parameters and spectra for phases 0.0 and 0.5 are given in Figure 1.

2. Origin of the X-ray emission

The temperature of the soft component ($kT \simeq 0.6$ keV) is similar to that of single massive stars. The bolometric luminosity of the O6 star, $L_{\rm bol} \simeq 10^{39}\,{\rm erg\,s^{-1}}$ (Marchenko *et al.* 1997), gives a predicted $L_{\rm X} \simeq 7\times 10^{32}\,{\rm erg\,s^{-1}}$ (Sciortino *et*

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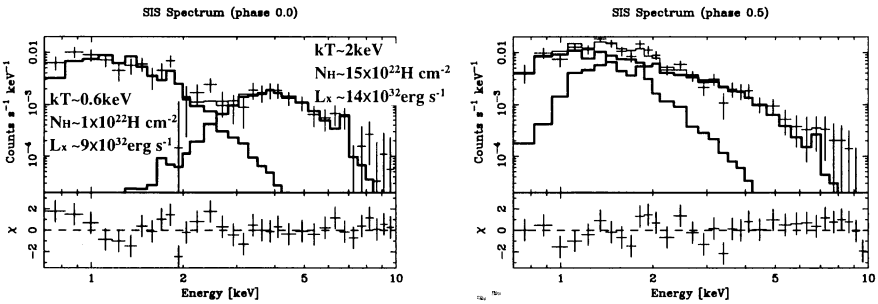

Figure 1. *ASCA*-SIS spectra of V444 Cyg at phases 0.0 and 0.5. Crosses are data points, and solid lines are best-fit of two-temperature plasma model (see text). The best-fit parameters and luminosities (absorption is corrected; $d = 1.7$ kpc assumed) are also given in the figures.

al. 1990). On the other hand, the average X-ray luminosity of nine WN stars analyzed by Pollock (1987) is $\sim 2 \times 10^{32}\,\mathrm{erg\,s^{-1}}$. These values are consistent with the X-ray luminosity of a soft component ($\sim 10^{33}\,\mathrm{erg\,s^{-1}}$). Therefore we conclude that this component is attributed to the individual O6 and WN5 stars. Since neither large absorption nor orbital variability of the luminosity was found, the soft-component plasma is located in outer regions of the binary system, and is most likely produced by radiative wind shocks.

The temperature of the hard component ($kT \simeq 2$ keV) is higher than that usually found in single massive stars. The absorption and luminosity are maximum when the WN5 star is in front (phase 0.0), and minimum when the O6 star is in front (phase 0.5). These variabilities together with the high temperature can be understood with a wind-wind collision scenario; strong stellar winds from both the O6 and WN5 stars with wind speeds of a few thousand $\mathrm{km\,s^{-1}}$ collide near the surface of the O6 star (on the line connecting both stars). This collision produces a high temperature plasma (the hard component) by shock-heating. X-rays from the collision layer are heavily absorbed by the denser stellar wind of the WN5 star at phase 0.0, while a part of the X-rays are occulted by the O6 star at phase 0.5. This all in good analogy with the case of the WC7+O4-5 colliding wind binary WR 140 (Williams *et al.* 1990; van der Hucht 1992).

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