ASCA X-RAY OBSERVATIONS OF THE WOLF-RAYET STARS HD 193793 AND HD 93162

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Abstract. The Japan-U.S. satellite *ASCA* was launched in February 1993 and provides a new capability to obtain high-resolution X-ray spectra of Wolf-Rayet stars in the 0.5 – 10 keV band. We present spectra of the wide binary HD 193793 (WC7+O4-5) obtained three months after periastron with the WC7 star in front, and of the WN7 star HD 93162 in Carina. The spectrum of HD 193793 is heavily absorbed below 2 keV by the WC7 wind and shows a prominent emission line from He-like iron at 6.7 keV. Acceptable fits were obtained using a Raymond-Smith model with kT $\approx$ 3 keV and non-solar abundances. In contrast, the spectrum of HD 93162 is softer and shows very little emission above $\approx$2 keV. The relatively low signal-to-noise precludes emission line analysis, and an acceptable spectral fit was obtained using a simple *Bremsstrahlung* model with kT $\approx$ 1.6 keV. No significant variability was detected in the X-ray light-curves of either star.

Key words: stars: Wolf-Rayet – X-rays – individual: HD 193793, HD 93162

1. Introduction

ASCA (*Advanced Satellite for Cosmology and Astrophysics*) is Japan's fourth X-ray astronomy mission. A significant portion of the scientific payload is being provided by U.S. institutions. The observatory consists of four X-ray telescopes (XRTs) employing gold-coated aluminum foil mirrors, with a combined effective area of 1300 cm^2 at 1 keV. All four XRTs observe the same target simultaneously. The four focal plane instruments are two Solid-state Imaging Spectrometers (SIS0, SIS1) and two Gas Imaging Spectrometers (GIS2, GIS3). We focus here on the high spectral resolution SIS spectra. Each SIS consists of four 420 $\times$ 422 pixel CCDs arranged in a square grid, giving a maximum SIS field-of-view of 22 $\times$ 22 arc-minutes. The SIS passband is 0.5 – 10 keV, with an energy resolution of 2% at 5.9 keV and an on-axis spatial resolution of better than 1 arcminute.

2. HD 193793 (WR140)

ASCA observed the binary HD 193793 (WC7+O4-5) for 40 ksec on 10-11 June 1993, about three months after periastron (Koyama *et al.* 1994). At this orbital phase the WC7 star is nearly in front of the O star (Williams *et al.* 1992). In the colliding wind picture, the X-ray emitting shock then lies behind the WC7 star and the X-rays are predicted to be heavily absorbed by the chemically-anomalous WC7 wind. Figure 1 shows the background-subtracted SIS0 spectrum, which is heavily absorbed below 2 keV as expected. Background subtraction removed most of the soft component peak-

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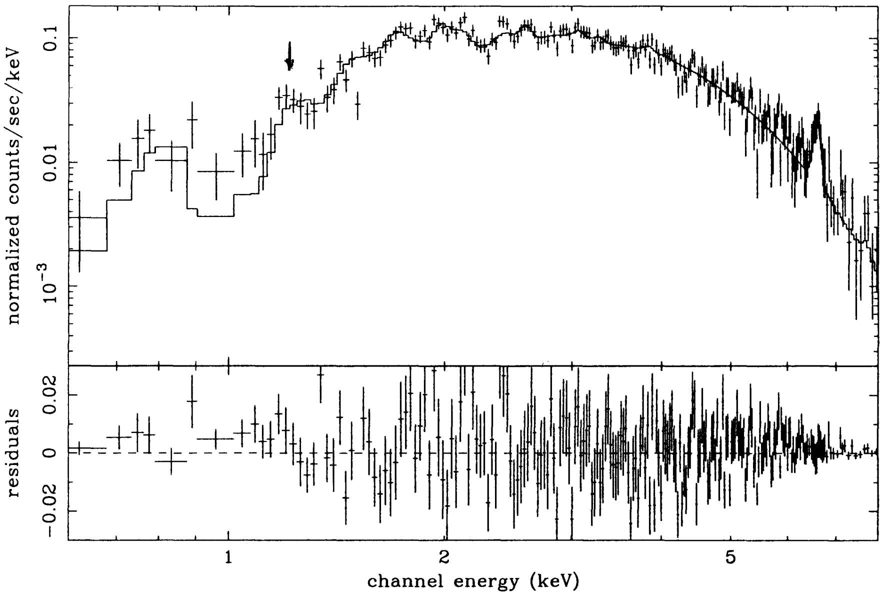

Fig. 1. Background-subtacted SIS0 spectrum of HD 193793 from 27 ksec of usable data (≈10,700 counts). Solid line is a best-fit Raymond-Smith model ($\chi^2 = 1.17$) with $kT = 2.8$ keV that allows Fe and Ne abundances to vary in emission and absorption. Abundances in emission are Fe = 0.7 [0.4–1.2, 90% conf.] and Ne = 76 [46–131]. Arrow points to 1.19 keV feature.

ing at 0.85 keV that is due to the Cygnus superbubble (Cash *et al.* 1980). Best fits were obtained using an absorbed single-temperature Raymond-Smith (RS) model with non-solar abundances, as discussed below. Spectral fits of three different detectors (SIS0/1, GIS2) give a plasma temperature in the range 2.8–3.4 keV and an equivalent hydrogen column density $N_H = 3.3$ (±0.2) × 10^{22} cm^{-2}. This N_H is a factor of 10 larger than the interstellar value (Williams *et al.* 1990), confirming that the absorption is predominantly circumstellar and most likely due to the WC7 wind because of the viewing geometry. The light-curve shows no fluctuations above the 3σ level when binned to four minute intervals, and no periodicity was found for periods in the range 100–5000 s. The observed (absorbed) X-ray flux is 2.4 (±0.5) × 10^{-11} ergs cm^{-2} s^{-1} (1–10 keV) and 1.6 (±0.3) × 10^{-11} ergs cm^{-2} s^{-1} (2–6 keV). Although the observed luminosity and N_H are in good agreement with colliding wind predictions, we note that the observed 2–6 keV flux is nearly identical to that measured by *GINGA* in 1987 far from periastron (Koyama *et al.* 1990). Thus, we find no convincing evidence that the hard flux above 2 keV is changing with binary separation. A follow-up *ASCA* observation in a year or two at wider binary separation will hopefully provide an additional flux measurement for comparison.

A solar abundance RS model is overluminous in the He-like Fe line at 6.66

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± 0.04 keV and is rejected. Acceptable fits were obtained using a variable abundance RS model combined with a variable abundance absorption model that uses Morrison and McCammon cross sections. The best fit (Fig. 1) was obtained by allowing Fe and Ne abundances to vary in both absorption and emission, with all other abundances fixed at solar. For SIS0, this fit converges to kT = 2.8 keV and the following abundances: Fe (emission) = 0.7 [0.4–1.2, 90% confidence] and Ne (emission) = 76 [46–131], with reduced χ^2 = 1.17. Similar results were obtained for SIS1 and with the Mewe-Kaastra plasma code.

The Ne overabundance improves the fit to the emission feature at 1.19 ± 0.02 keV (internal error), which is consistent in energy with the 1.21 keV Lyβ transition of NeIX/X. Although there are Fe and Ni transitions near this energy, we were unable to fit this feature with variable Fe and Ni abundances while freezing Ne at solar. Thus, our initial models point toward a Ne overabundance in HD 193793. However, the derived Ne abundance is larger than values of ~9–44 solar predicted by evolutionary models (Maeder 1987). Several factors could account for this, including (i) underestimates of the flux from Fe-L transitions near 1.1 keV due to inaccuracies in the existing plasma codes (Liedahl *et al.* 1994), (ii) blending of FeXXIV/XXV and NeIX/X lines, and (iii) uncertainties in the evolutionary models.

Lastly, we constrain the carbon abundance in the WC7 wind by assuming that the absorption is due solely to C enrichment. Using the above RS model, but now allowing only C to vary in absorption and Fe and Ne in emission (all other values fixed at solar), the best-fit gives kT = 2.9 keV and abundances: C (abs) = 31 [28–33], Fe (emission) = 0.8 [0.4–1.5], Ne (emission) = 99 [53–188], with χ^2 = 1.22. Since other elements such as O may also be enhanced in the wind, we derive an upper limit C $\leq$ 31 solar. This value is below evolutionary predictions (Prantzos *et al.* 1986), but is consistent with values ~15–55 solar obtained from infrared observations of other WC stars (Smith and Hummer 1988).

3. HD 93162 (WR25)

ASCA observed the Carina nebula for 40 ksec on 24-25 August, 1993, detecting several sources including the WN7 star HD 93162. Data analysis of this complex region is still in progress, and we present here only preliminary results. Figure 2 shows the SIS1 spectrum, which has been background-subtracted to remove the diffuse nebular emission. The spectrum is considerably softer than that of HD 193793. Also, the signal-to-noise is lower and there are no obvious emission lines. For the SIS spectral fits, N_H was fixed at the interstellar value 2× 10^{21} cm^{-2}. A solar-abundance single-temperature RS model is rejected (χ^2 = 2.1). If the abundance is allowed to vary globally, the RS model converges to a low abundance of 0.1 solar. This suggested a simple *Bremsstrahlung* fit (Fig. 2), which was acceptable with kT = 1.6

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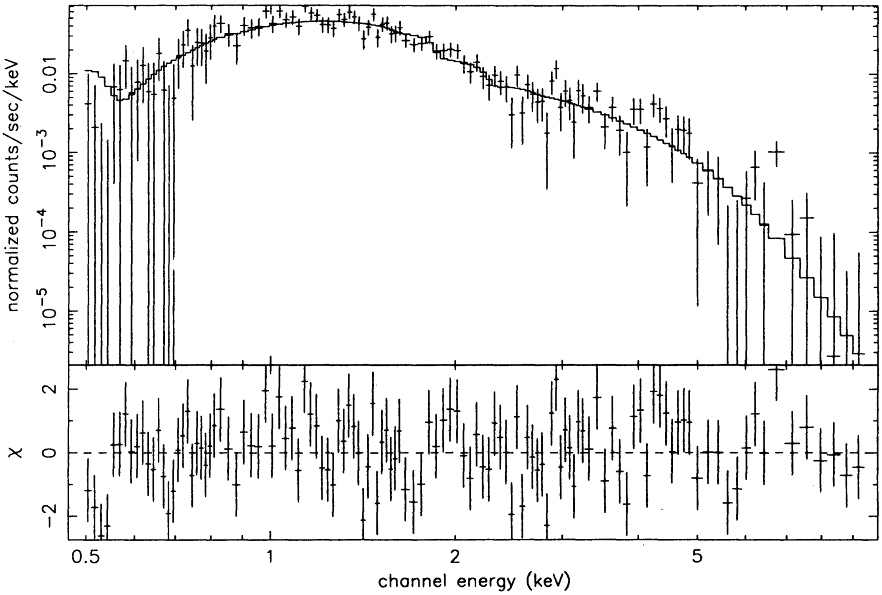

Fig. 2. **Background-subtracted SIS1 spectrum of HD 93162 from 28 ksec of usable data (~1800 counts). Solid line is best-fit *Bremsstrahlung* model (χ^2 = 1.16) with kT = 1.6 keV and $N_H = 2 \times 10^{21}$ cm^{-2}.**

(±0.1) keV and $\chi^2 = 1.16$. This *Bremsstrahlung* model gives a slightly better fit than a two-temperature solar-abundance RS model, which yields kT_1 = 0.8 (±0.1) keV, kT_2 = 3.5 (±0.4) keV, and χ^2 = 1.24. The observed (absorbed) flux in the 0.5–4 keV band is 2.4× 10^{-12} ergs cm^{-2} s^{-1}, corresponding to log L_x = 33.3 ergs s^{-1} at 2.6 kpc. Binning the light-curve to 512 s intervals shows no fluctuations larger than 20%, and we thus find no evidence for short-term (~1 day) variability.

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DISCUSSION:

White: For WR 140 and other colliding wind systems I would not expect the X-rays to be characterized by a single temperature. Along the shock the obliqueness changes the shock strength and temperature. Have you considered models with a range of temperatures for WR 140?

Skinner: At present, we have only tried to fit the spectrum with Raymond-Smith models using a single-temperature, because of the strong absorption below 1 KeV. A two temperature model using a cool component $kT \leq 1$ KeV and a hotter component $kT \approx 3$ KeV does not provide a better fit than a single-temperature model. More sophisticated models employing a continuous temperature distribution would be useful and may yield different abundances.

Conti: Any explanation for anomalous X-ray emission in WR25?

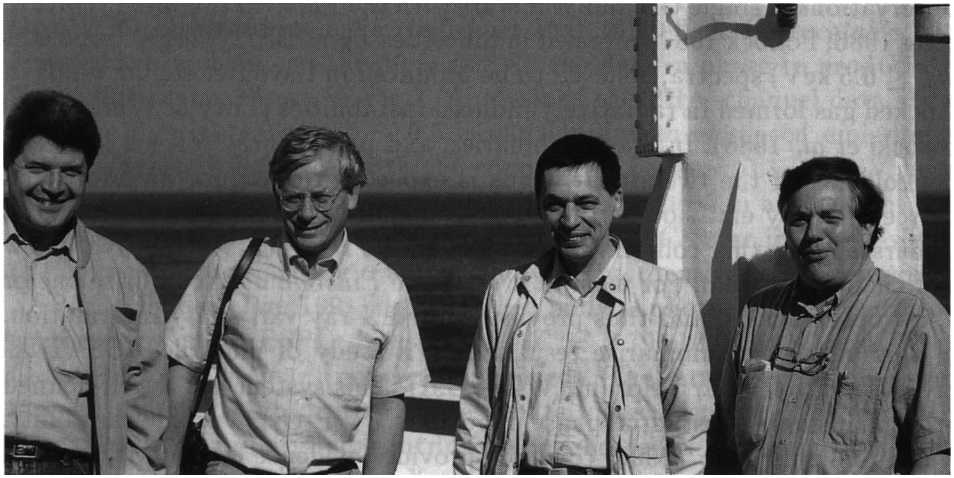
Skinner: The observed (absorbed) luminosity measured from the ASCA spectrum is $L_x = 10^{33.3}$ ergs/s [0.5-4 KeV], assuming distance = 2.6 kpc. [flux (0.5-4 KeV) = 2.4×10^{-12} ergs/cm^2/s]. I do not have an explanation for the anomalously high X-ray luminosity of WR25. (Could the distance be wrong?) I have noticed that distances used by Seward & Chlebowski are different than distances quoted in recent reviews of WR stars.

Usov: What is the X-ray luminosity of WR 140. Why your value of the X-ray luminosity is an order smaller than the value given by Pollock for this binary.

Skinner: ASCA observation of WR 140 on June 10, 1993 gives an attenuated (i.e. absorbed) luminosity of $L_x = 4.8 \times 10^{33}$ ergs/s [1-10 KeV band], at distance = 1.3 kpc. I do not have an explanation for the data of Pollock. Before comparing his value with our value given above, please make sure that both values are absorbed, 1-10 keV band, and use distance = 1.3 kpc.

Niemela: Regarding WR25 which is more luminous in X-rays than other WR stars, how does it compare with O stars or Be stars in the X-ray domain?

Skinner: I do not have information on X-ray luminosities of O and Be stars. Please consult the published work of Chlebowski et al. The observed (attenuated) X-ray luminosity of WR25 obntained by ASCA on August 24, 1993 is $L_x = 10^{33.3}$ ergs/s (0.5-4 KeV), assuming a distance of 2.6 kpc.



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