FINAL REPORT

"X-Ray Observations of Rapidly Rotating O Stars"

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SCIENCE OBJECTIVE:

Since the discovery of X-ray emission from early-type stars (Harnden *et al.* 1979; Seward *et al.* 1979), it has become clear that essentially all O stars are X-ray emitters (Chlebowski *et al.* 1989). The basic properties of this emission are determined by the intrinsic strength, X-ray temperature, and the X-ray optical depth of the material between the source and the observer. In general, this opacity source must include the ISM and any circumstellar (local) absorption. Recently, Waldron (1991), Corcoran *et al.* (1993), and MacFarlane *et al.* (1993), using IPC and BBXRT X-ray data, along with radio and UV data, have presented convincing evidence for the existence of local X-ray absorption in O stars. The implications are, regardless of which X-ray model is most appropriate, either coronal (Cassinelli & Olson 1979; Waldron 1984) or radiative shocks (Lucy & White 1980; Owocki, Castor, & Rybicki 1988; MacFarlane & Cassinelli 1989), all modeling efforts must incorporate the effects of local X-ray absorption. Hence, we argue that it is extremely important to determine the strength and distribution of this local absorption component.

One of the most interesting, and still unexplained, attributes of the X-ray emission from O stars is the apparent constant relationship between L_x (X-ray luminosity) and L_{Bol} (bolometric luminosity), i.e., $L_x/L_{Bol} \approx 10^{-7}$ (Harnden *et al.* 1979; Seward *et al.* 1979; Long & White 1980; Cassinelli *et al.* 1981; Pallavicini *et al.* 1981). The large O star sample analyzed by Sciortino *et al.* (1990), has confirmed the correlation between L_x and L_{Bol}. However, even after correcting for ISM absorption, they found that the observed scatter is statistically significant, and concluded that this scatter is most likely controlled by the intrinsic X-ray properties, implying additional parameters are important. **The goal of this proposed effort is to investigate possible sources of this observed spread. In particular, we will look into the effects of rotation, and how these effects can alter the local X-ray absorption.**

At first, one might suggest that the spread in L_x/L_{Bol} is just due to the differences in wind absorption. We agree that wind absorption is probably a key factor, but, we ask, why do stars with similar wind characteristics have widely varying differences in L_x/L_{Bol}? We propose, not only is the amount of wind absorption important, but that the distribution of this material relative to the observed line-of-sight is also very important, i.e., the local X-ray absorption is dependent on the inclination angle. Therefore, since O stars are known to be rapid rotators (Conti & Ebbets 1977), we argue that the stellar rotation rate, in conjunction with the inclination of the rotation axis relative to the observer can make a significant difference in the observed X-ray properties. For example, the recent study of Bjorkman & Cassinelli (1993) has demonstrated how rotation compresses the stellar wind in the equatorial regions, and in extreme cases, they found that rotation may lead to the formation of a static disk. In O stars, due to the strong radiation pressure, a true disk is not expected to form (Poe 1987). However, one would expect the wind density in the equatorial regions of O stars to become enhanced to some degree over the polar regions. Therefore, we suggest that this effect will alter the observed X-ray spectra of rapidly rotating O stars. In addition, rotational effects are also evident in IUE data. A clear example of a rotationally distorted O star wind is given by HD93521 (one of our targets). Massa (1992) analyzed the UV wind lines of this star and was able to demonstrate that it had a low speed, equatorial wind, coexisting with a high speed flow at higher latitudes.

To explore the impact of rotation on the X-ray emission, we have analyzed the HEAO-2 O star data base assembled by Chlebowski *et al.* (1989) and the observed values of vsini. Scatter plots of L_x/L_{Bol} (observed and ISM corrected) versus the ratio of vsini to v_{crit} (critical velocity = escape speed/$\sqrt{2}$) are shown in Figures 1a and 1b for 54 O stars (vsini and escape speeds from Conti & Ebbets 1977 and Howarth & Prinja 1989). The plots are suggestive that L_x/L_{Bol} may be dependent on vsini/v_{crit} (the large degree of scatter, as discussed previously, is also evident). In fact, there appears to be two distinct populations with the discriminator at vsini/$v_{crit} \approx 0.4$. The inclusion of both observed and ISM corrected L_x illustrates that the behavior is independent of the degree of ISM absorption, i.e., the two populations maintain their integrity, as verified by their statistics (see discussion below). Therefore, the observed behavior must be intrinsic to the X-ray production mechanism and the stellar wind environment. Keep in mind, that the X-ray emission from a cylindrically symmetric wind may depend upon the intrinsic rotation rate of the star **AND** the inclination angle, and these individual dependencies could be significantly different than the observed vsini dependence. For example, if the wind is optically thin to X-rays, then L_x/L_{Bol} may depend **ONLY** on rotational velocity and be independent of sini. Consequently, one might expect considerable scatter at low vsini, where intrinsically slower rotating stars are mixed with intrinsically rapid rotators, viewed near sini ≈ 0. However, for the most rapidly rotating stars, sini **MUST** be near 1. Therefore, a clear distinction is expected for these stars, and the observations, shown in Figure 1, seem to support this scenario.

Figures 1a and 1b show that the mean levels of L_x/L_{Bol} are significantly lower at high vsini. The mean value of the ISM corrected L_x/L_{Bol} for stars with vsini/$v_{crit} < 0.4$ is -6.59 dex with an RMS scatter of ± 0.33 dex. For stars with vsini/$v_{crit} > 0.4$, the mean ISM corrected $L_x/L_{Bol} = -7.07$ dex. If the high vsini group came from the same population as the low vsini group, one would expect the same mean within ± $0.33/\sqrt{5} = \pm 0.15$, since there are 5 stars in the latter group. Therefore, the ISM corrected L_x/L_{Bol} for the high vsini stars is about 3.3σ below what one would expect if they came from the same population as the low vsini stars. However, even though we have some physical basis for expecting this difference, analyses

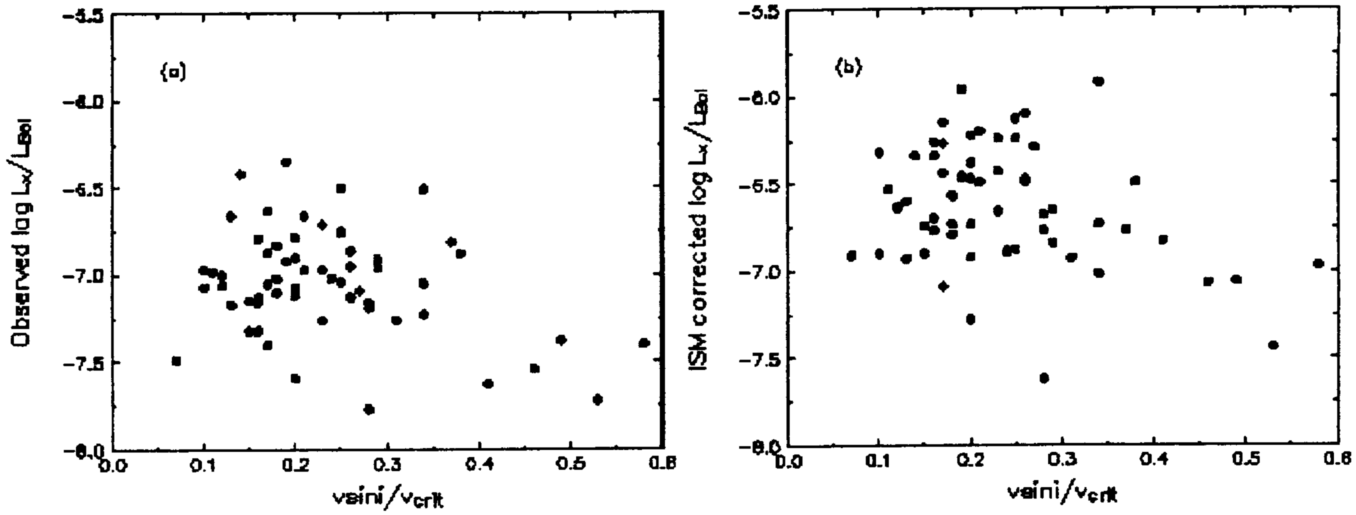

Figure 1. Scatter plots of the observed and ISM corrected L_x/L_{Bol} vs. vsini/v_{crit} for O stars. The general decrease in L_x/L_{Bol} as vsini increases is shown to be independent of the ISM correction.

here a group is arbitrarily divided in half, are always suspect to *a posteriori* statistics. The only way to verify that this is a real effect is to draw additional samples from the high vsini population and determine whether they have abnormally low L_x/L_{Bol} ratios. Correspondingly, we have also looked at the statistics of the observed L_x/L_{Bol}, and found them to be essentially the same as the ISM corrected values (i.e., the results are independent of the ISM absorption). A few HEAO-2 upper limits are available in the high vsini region, ranging from -6.0 to -6.8 dex. The errors in Figure 1 are ≈ ± 0.2 dex. Also, as expected, none of the observed high vsini stars have soft X-ray spectra.

We have two primary goals in this effort. First, and most important, we need to determine the statistical significance of the results shown in Figure 1. This will be accomplished by obtaining PSPC observations of 3 high vsini O stars. In addition, our predicted PSPC count rates will yield enough counts to determine hardness ratios for comparison with other O stars, i.e., if our hypothesis is true, none of these stars should appear soft. Second, we will carry out basic X-ray analysis procedures on our data, and we will also use IUE data of these stars to look for peculiarities in their spectra. Although, significant disks structures are not expected in these stars, using the Bjorkman & Cassinelli (1993) model, we can estimate the dependence of the stellar wind column density on inclination angle. We have done a preliminary study of this effect and found that the spread, and vsini dependence shown in Figure 1 can be explained reasonably well by an X-ray absorption model which allows for angular dependence in the stellar wind column density.

Verifying the existence of non-spherical wind flows in O stars have several important ramifications. For example, the mass loss rates calculated by fitting UV line profiles will be incorrect, since the character of the absorption will be highly dependent upon the angle at which the star is viewed. Mass loss rates determined from the radio emission (currently considered the most model independent), will also be affected. This is because the observed emission depends upon the mean electron density, and the derived rates rely upon the assumption of spherical symmetry. The existence of compressed equatorial regions could alter the derived mass loss rates by more than a factor of 2 (see Abbott *et al.* 1981). Rotation may also decrease the terminal velocity of the wind and increase the overall mass loss rate and mean density (Friend & Abbott 1986; Poe 1987). This could also affect the subsequent evolution of rapidly rotating O stars (Conti 1988). Because the wind geometry is expected to affect the UV wind lines, radio, IR and X-ray emissions differently, we argue that X-ray observations are essential for obtaining a comprehensive picture of the geometry of O star winds.

With regards to the all-sky survey, the low X-ray emission expected from these high vsini stars (see Table 1), suggests that the ASS should not have detected these stars. We have also looked into the possibility of using the HRI, but since these stars are strong UV emitters, the HRI UV contamination flux is found to be comparable to the expected X-ray fluxes (using the estimating procedure outlined in the ROSAT appendices).

As outlined above, we need to verify the apparent low L_x/L_{Bol} ratios of rapidly rotating O stars. Since these stars are rare, our choices are limited. However, we have found 3 targets that are relatively close, have low ISM column densities, and are representative of the range, $0.4 < vsini/v_{crit} < 0.6$ (see Table 1). These targets will almost double the sample of high vsini O stars observed at X-ray wavelengths, and will be sufficient to test the statistical significance of the low vsini population. The PSPC count rates were determined by assuming the mean ISM corrected L_x/L_{Bol} value (7.07 dex), an X-ray temperature of 5×10^6K (Chlebowski *et al.* 1989), and the distances and ISM column densities given in Table 1. The predicted PSPC count rates and requested exposure times are listed in Table 1. These estimates were obtained from the MIPS routines. The ISM corrected X-ray fluxes are also given (F_x). The requested exposure times serve two purposes. First, if our estimated flux level is representative of these stars, we should get a $S/N \approx 10$. At this level, the corresponding hardness ratios will be sufficiently useful for comparisons with low vsini O stars, and PSPC spectral analyses can be used to place reasonable limits on the wind attenuation. Second, if we get no detections, the associated upper limits will be roughly 10 times smaller than the detections given in Figure 1. This would be extremely interesting since we have no reason to believe that these stars should not be detected. Also, only one of these targets has an HEAO-2 upper limit; HD14434 has an ISM corrected $L_x/L_{Bol} < -6.03$ dex (Chlebowski *et al.* 1989). The others with HEAO-2 upper limits are found to be too distance and have large ISM column densities, which would require very large exposure times. One of these may be picked up as a field object in a planned ROSAT observation, provided the exposure time is large. Clearly, the suggestive nature of the results shown in Figure 1 are very interesting, and our proposed targets represent the best opportunity to obtain the necessary additional information on high vsini O stars.

TABLE 1. High vsini O Star Targets

star	Sp. Type	log L_{bol}	d (kpc)	log N_{ISM}	vsini/ v_{crit}	F_x/ 10^{-13}	PSPC cnts/s	Exp. time
HD93521	O9V	38.48	1.6	20.08	0.55	0.86	0.0078	12.9 ks
HD175876	O6.5III	39.18	2.3	21.11	0.46	2.08	0.0104	9.7 ks
HD14434	O5.5V	38.91	2.3	21.45	0.49	1.12	0.0032	31.4 ks

A significant number of ROSAT observations of O stars have been made, based on discussions with colleagues and inspection of the ROSAT Pointed Log. But these stars are in the range of vsini/$v_{crit} < 0.4$. We found only two O stars with vsini/$v_{crit} > 0.4$ that have been observed or are scheduled to be observed. We have searched the ROSAT previous and planned targets, and found no targeted object within 60 arcminutes of our proposed targets. Obviously, the large number of O stars already observed at low vsini will be useful for comparison with the large HEAO-2 data base. However, without a statistically significant number of O stars at large vsini, the proposed effort cannot be accomplished.

OBSERVATION:

We were granted PSPC exposure time for one of our requested targets, HD93521. The star was scheduled to be observed on November 28, 1993 for 3240 seconds. Unfortunately, approximately two weeks prior to this date, the PSPC instrument experienced a gyro problem and was shut down, and remained down during our scheduled time. The satellite did not perform useful observations for over a month after this failure. For more than a year, the status of our observation was not clear. Finally on 2/15/95 I contacted Dr. Petre by e-mail to determine the status of our target and was informed that our target was not re-scheduled, and since the PSPC is officially retired, the observation will not be performed (see enclosures).

MODIFIED CONTRACT WORK:

We decided that without at least one more detection of a high vsini X-ray source, the arguments proposed could not be substantiated. We will pursue other avenues to finish this research, such as a ROSAT HRI or ASCA observation.

Since the primary scientific objective could not be achieved, we have used the funding under this contract to initiate other related X-ray studies. In particular we have:

1) set up a remote access to the GSFC ROSAT Data Analysis Facility;
2) extracted archived PSPC spectra for 15 O stars;
3) carried out a preliminary analysis of 6 re-processed PSPC spectra, which were recently obtained;

4) improved our X-ray analysis code with particular emphasis stellar wind absorption, and;
5) the improved wind absorption code allowed us to incorporate this effect in our analysis of ASCA observations of O stars (Corcoran et al. 1994; this contract was cited in this publication).

Other than the ASCA publication, the remainder of the work preformed under this contract are incomplete, since the funding level requested was not designed to carry out the modified work. It is planned to propose to the ADP to finish the work started under this contract.

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From:SMTP%"PETRE@lheavx.gsfc.nasa.gov" 15-FEB-1995 09:18:05.82
To:WALDRON
CC:
Subj:RE: Status of AO-4 Target HD93521

Date: Wed, 15 Feb 1995 9:14:53 -0500 (EST)
From: PETRE@lheavx.gsfc.nasa.gov
To: WALDRON@FOSVAX.ARCLCH.COM
CC: PETRE@lheavx.gsfc.nasa.gov
Message-Id: <950215091454.40408064@lheavx.gsfc.nasa.gov>
Subject: RE: Status of AO-4 Target HD93521

Hi Wayne:

Regarding your PSPC observation of HD93521, scheduled for 11/28/93: It was approximately two weeks before this that ROSAT experienced the loss of one of its gyros. The satellite did not perform useful observations for over a month after the failure. Many, but not all, of the missed PSPC observations were rescheduled. Apparently, yours was not. As the PSPC is now officially retired, there is no possibility that your observation will be performed.

regards,
Rob

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ASCA SOLID STATE IMAGING SPECTROMETER OBSERVATIONS OF O STARS

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ABSTRACT

We report *ASCA* Solid State Imaging Spectrometer (SIS) X-ray observations of the O stars δ Ori and λ Ori. The energy resolution of the SIS allows us to resolve features in the O star X-ray spectra which are not apparent in spectra obtained by X-ray spectrometers with lower energy resolution. SIS spectra from both stars show evidence of line emission, suggesting the thermal nature of the X-ray source. However, the observed line strengths are different for the two stars. The observed stellar X-ray spectra are not well described by isothermal models although absorbed thermal emission models with two or more temperatures can provide an adequate fit to the data. For both stars we present evidence of absorbing columns significantly larger than the known ISM columns, indicative of absorption by a circumstellar medium, presumably the stellar winds. In addition, the λ Ori spectrum shows the presence of emission at energies >3 keV which is not seen in the δ Ori spectrum.

Subject headings: stars: early-type — stars: individual (λ Orionis, δ Orionis) — X-rays: stars

1. INTRODUCTION

Early observations with the imaging instruments on the *Einstein Observatory* (Seward et al. 1979; Harnden et al. 1979) verified that luminous O and B stars are sources of X-ray emission. Although X-ray emission is now well established for all O stars and early B stars (Rosner, Golub, & Vaiana 1985), the origin and location of the X-ray emission is less certain. Initial attempts to explain this emission ranged from deeply embedded coronal models (Cassinelli & Olson 1979; Waldron 1984), which predicted a large wind absorption at the O K-shell edge (~0.6 keV), to distributed shock models (Lucy & White 1980). The major discriminator between these models relies on determining the amount of wind X-ray attenuation which in turn places constraints on the location of the X-ray source (see Cassinelli et al. 1981). The large absorption predicted by the coronal model was not supported by the *Einstein Observatory* Solid State Spectrometer (SSS) data (Cassinelli & Swank 1983). The strong instabilities associated with radiatively driven winds (Owocki & Rybicki 1984) suggest that a distribution of hot shocked gas throughout the wind should develop and, in principle, could produce the observed X-rays (Owocki, Castor, & Rybicki 1988). However, spectra produced by distributed shock models have also had problems matching the observed X-ray spectra (Casinelli & Swank 1983).

Thus, after nearly 15 years of study, we still do not have a clear understanding of the mechanisms responsible for the characteristics seen in OB star X-ray spectra. This is in part due to the limited bandpass and energy resolution of X-ray detectors like the IPC and PSPC which have observed the largest number of OB stars in X-rays (Chlebowski, Harden, & Sciortino 1989; Grillo et al. 1992). Generally the X-ray spectra obtained by the IPC and PSPC can be fitted with single-temperature coronal emission models without absorption, although exceptions to this generalization do exist (Cassinelli et al. 1981; Waldron 1984; MacFarlane et al. 1993). Hillier et al. (1993) analyzed a well-exposed PSPC spectrum of ζ Pup and showed that the spectrum required the presence of absorption by the circumstellar wind material. X-ray spectra of a limited number of OB stars have been obtained by detectors with higher energy resolution, and these data have generally indicated significant complications to the simple picture. Cassinelli & Swank (1983) published moderate resolution ($E/\Delta E \sim 6$) observations of three OB stars (δ Ori, ϵ Ori, and ζ Ori) obtained by the SSS, while Corcoran et al. (1993) published a moderate-resolution ($E/\Delta E \sim 11$) spectrum of ζ Pup obtained by the Broad-Band X-ray Telescope (BBXRT). These observations show that the X-ray spectra from OB stars are far richer than could be discerned in the IPC and PSPC data. In particular, Cassinelli & Swank reported the detection of line emission in ζ Ori, while Corcoran et al. noted line emission in ζ Pup and found the first detection of a wind absorption K-shell edge due to ionized oxygen. However, the presence of ice on the SSS (which caused uncertainties in measuring spectral features near 0.5 keV), the high background of the SSS (which caused uncertainties in determining the high-energy emission above 2 keV), and the limited observing time available to BBXRT meant that important issues (e.g., the ubiquity of circumstellar absorption, the nature of the spectrum above 2 keV, etc.) could not be addressed with these data sets.

The *ASCA* Solid State Imaging Spectrometers (SIS) have the highest energy resolution ($E/\Delta E \sim 17$) and widest bandpass (0.4–10 keV) of any X-ray spectrometer yet flown and are ideal for addressing the outstanding questions concerning the X-ray emission from OB stars. In this letter we report our initial investigation of the X-ray spectra of two

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TABLE 1

SUMMARY OF *ASCA* OBSERVATIONS

Parameter	δ Ori	λ Ori
Observation start (MJD)	49426.09212	49423.16398
Observation end (MJD)	49426.62515	49423.71525
Exposure time (s)	17764	21168
Net counting rate, SIS0 (counts s^{-1})......	0.29	0.12

nearby O stars, δ Ori and λ Ori, obtained with the SIS0 detector. More detailed analyses of these observations, including the SIS1 and GIS data, along with a more extensive modeling effort, will be presented in a later paper.

2. OBSERVATIONS AND DATA REDUCTION

Table 1 lists the exposure times and counting rates for each observation. δ Ori is a spectroscopic and eclipsing binary (09.5 II + B0 III) with a 5.7 day period. The *ASCA* observation of δ Ori started at phase 0.75 and ended at phase 1.10, where phases are calculated from the ephemeris given in Koch & Hrivnak (1981). During this time we detected no strong evidence of significant variability. While variable X-ray emission from δ Ori has been reported (Snow, Cash, & Grady 1981), this variability is not known to be phase locked (Haberl & White 1993). λ Ori (O8 III((f))) has a B0.5 V companion 4″ away, which is unresolved by *ASCA*. Since X-ray luminosity scales as bolometric luminosity (Sciortino et al. 1990), the X-ray luminosity of the B stars is expected to be about 10% of the luminosity of the O stars. However, because low-luminosity early B stars are generally very soft X-ray sources (peaking below 0.3 keV; Cassinelli et al. 1994) and because of the fact that the low-energy cutoff for the SIS is >0.3 keV, the B stars should contribute much less than 10% of the observed counts in the *ASCA* bandpass.

For each star, data from the SIS0 detector were obtained and cleaned of hot and flickering pixels. The data were further selected based on appropriate values of object elevation and magnetic rigidity. An image was extracted from the cleaned photon events, and the sources of interest were identified. In each image the target stars were the brightest sources in the field, although at least one fainter source was apparent in the λ Ori field. A spectrum was extracted from all photons lying within a 4′ radius circle centered on the source (excluding any serendipitous sources). Background spectra were created by extracting all photons within the source region from a cleaned "blank sky" observation provided by the *ASCA* Guest Observer Facility. The net spectra were then binned before analysis so as to have more than 10 counts in each bin.

3. DISCUSSION

Figure 1 shows the net SIS0 source spectra for δ Ori and λ Ori. The shape of the continua are different, with λ Ori showing significantly more emission at $E > 3$ keV than δ Ori. Resolved line emission at 1.3 keV (due primarily to Mg XI) and at 1.86 keV (due primarily to K-shell emission from Si XIII) is clearly seen in the δ Ori spectrum, with evidence for K-shell emission from S XV at 2.46 keV. Line emission in the λ Ori spectrum is less obvious. In order to look for the presence of lines, we tried to fit the λ Ori spectrum in the interval 1.2–2.8 keV with a smooth power-law continuum and Gaussian lines near 2.5, 1.9, and 1.3 keV. We applied an *F*-test to determine the significance of the emission lines. For a pure power-law continuum, the best fit in this energy range is $\chi^2 = 53.3$ with 57 degrees of freedom. A fit with a power-law plus Gaussian line near 2.5 keV yielded $\chi^2 = 45.5$ with 55 degrees of freedom. We then fitted the restricted spectrum with a power-law continuum plus a Gaussian line near 2.5 and an additional Gaussian line near either 1.9 or 1.3 keV. These fits resulted in values of $\chi^2 = 45.5$ with 54 degrees of freedom. We conclude that there is a significant line feature near 2.5 keV in the λ Ori spectrum, but no significant line features near 1.9 or 1.3 keV. From our best fit, the energy of the line near 2.5 keV is determined to be 2.42 ± 0.06 keV which is consistent with energy of the S XV K-shell line.

We tried to model these spectra with simple combinations of absorbed coronal plasma emission models. For comparison purposes, Figure 1 shows the best fit to the observed data for a single-temperature Mewe-Kaastra plasma model (Mewe, Gronenschild, & van den Oord 1985; Kaastra 1992) with absorbing columns fixed at the known ISM values ($N_{\rm H} = 1.5 \times 10^{20}$ for δ Ori and $N_{\rm H} = 7 \times 10^{20}$ for λ Ori; Shull & Van Steenberg 1985). One of the important results of the present

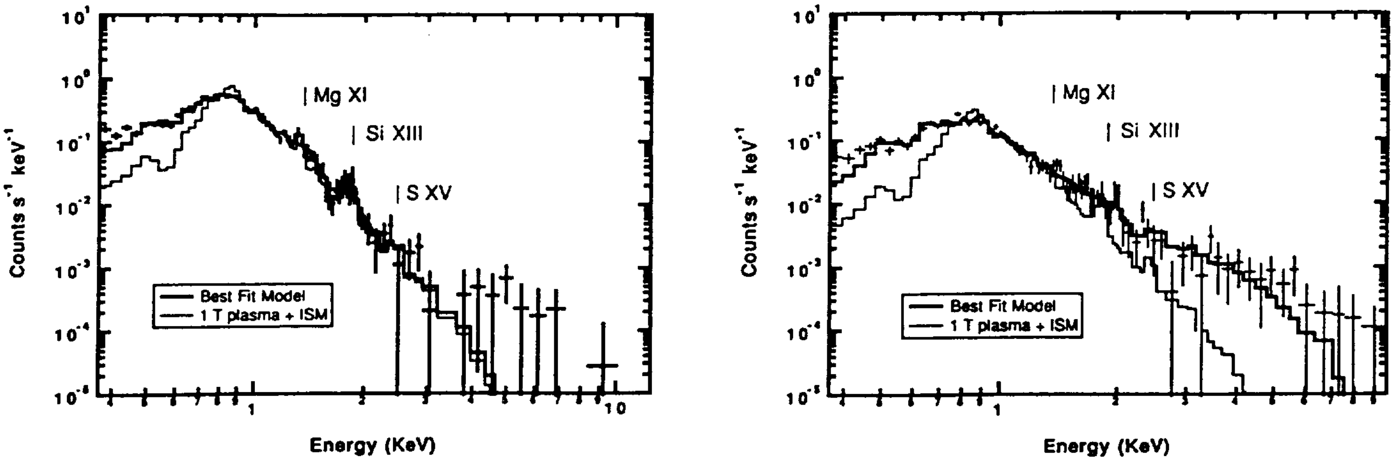

FIG. 1*a* FIG. 1*b*

FIG. 1.—The observed SIS0 spectrum of δ Ori along with the best-fit solar abundance model in which absorption is due to the ISM alone (*thin line*) and the best fit two-temperature, "warm" absorption model described in text. (*b*) The observed SIS0 spectrum of λ Ori along with the best-fit solar abundance model in which absorption is due to the ISM alone (*thin line*) and the best fit two-temperature, "warm" absorption model described in text.

TABLE 2

BEST-FIT PARAMETERS FOR ASSUMED MODEL SPECTRA

Parameter	δ Ori	λ Ori
ISM N_H (10^{21} cm^{-2}) (fixed)	0.15	0.70
log T_{hot} (K)	6.84 ± 0.12[a]	7.42 ± 0.30
log EM_{hot} (cm^{-3})	54.73 ± 0.14	54.24 ± 0.23
Wind N_H, hot component (10^{21} cm^{-2})	<0.1	<1.0
log T_{cool} (K)	6.46 ± 0.08	6.53 ± 0.07
log EM_{cool} (cm^{-3})	55.20 ± 0.17	55.09 ± 0.12
Wind N_H, cool component (10^{21} cm^{-2})	3.90 ± 0.50	2.83 ± 0.20
log L_X (ergs s^{-1})	32.63	32.37
$\chi^2 \nu$	1.29[b]	1.27[b]

[a] Errors and upper limits are 90% confidence for one parameter of interest.

[b] Fit to spectrum above 0.5 keV.

work is that emission from a single-temperature plasma plus ISM absorption alone *cannot* fit the observed spectra for either δ Ori or λ Ori. In each case, a plasma which is hot enough to produce the emission at $E > 1$ keV produces too much emission near 0.8 keV and does not produce enough X-ray emission at lower energies.

Because of the inadequacy of the single-temperature models, we tried more complicated models. We were unable to fit the spectra with two-temperature emission models absorbed by the ISM column alone. Since the X-ray source is most likely buried inside the massive stellar wind, we next considered adding additional absorption. We could not fit the observed spectra with either a single- or two-temperature emission model using additional absorption from an un-ionized ("cool") medium. We therefore tried to model the spectrum using absorption from an ionized ("warm") absorbing medium (Waldron 1984), as representative of the photoionized stellar wind material. We found that we could achieve a satisfactory fit to the δ Ori and λ Ori spectra above 0.5 keV for a two-temperature plasma model with warm absorption plus an overlying ISM column, letting the amount of absorption to the cooler emission component be independent of the amount to the hotter component. The parameters for our best-fit models are given in Table 2 for each star. The luminosities listed in Table 2 have been corrected for ISM + circumstellar absorption and are in the range 0.4–4.0 keV, using distances of 500 pc for both stars. The absorbing columns we derive are significantly larger than the ISM values. Taking the derived column densities at face value, simple modeling (see, e.g., Corcoran et al. 1993) of the wind absorption means that most of the X-rays originate from a region <2 stellar radii above the photosphere (consistent with the results obtained for ζ Pup by MacFarlane et al. 1993). However, in order to achieve a formally acceptable fit to both the δ Ori and λ Ori spectra, we needed to reduce the abundance of Fe to one-fifth the solar value and allow the Mg abundance to depart from the solar value as well. Changing the model abundances in this way does not necessarily indicate the presence of noncosmic abundances in either δ Ori or λ Ori; the abundances derived could be artifacts of uncertainties in the plasma models (for, e.g., radiation transfer effects) or instrumental calibration (or any combination). We point out that analysis of the photospheric spectrum of δ Ori fixed the abundance of He (and presumably other metals as well) at the solar value (Voels et al. 1989).

Although our best fit required emission from plasma at two temperatures, we could not rule out the presence of additional temperature components. Note that the distribution of temperatures in δ Ori is significantly different from that in λ Ori; λ Ori exhibits significantly hotter emission than δ Ori. The reason for this difference is not known. Since λ Ori does lie in a fairly crowded field, some of this emission could be due to the presence of an unresolved X-ray source such as a late-type or pre–main-sequence star (which generally show high-temperature emission). We note that an image of λ Ori obtained by the *ROSAT* PSPC (observation sequence number 200200) indicates the presence of two X-ray sources separated from λ Ori by about 1′ and 2′. Since these sources could not be resolved in the SIS, it is possible that one or both make some contribution to the observed X-ray emission for λ Ori.

Chen & White (1991) have suggested that inverse Comptonization of the photospheric UV field by a population of fast particles accelerated by a distribution of shocks should produce a nonthermal tail at high energies which could be observable in the SIS spectra. We see no unambiguous evidence for such a nonthermal tail, although addition of a nonthermal component can slightly improve the reduced χ^2 for both δ Ori and λ Ori (from roughly $\chi^2 = 1.3$ to 1.1 for both stars).

Haberl & White (1993) fitted the PSPC spectrum of δ Ori with 2 components as well, although their derived temperatures were 0.1 and 0.2 keV. However, simultaneous fits to the *ASCA* SIS0 and PSPC spectra of δ Ori require at least three components, with temperatures near 0.1, 0.3, and 0.6 keV. The latter two components contribute in the *ASCA* bandpass, while the 0.1 keV component makes little contribution. Similarly, the PSPC spectrum is dominated by the 0.1 and 0.3 keV components, with little contribution from the 0.6 keV component.

The SIS0 spectra of δ Ori and λ Ori clearly illustrate the richness of OB star X-ray spectra when this emission is measured with sufficient energy resolution. The observed spectral details suggest that a complexity of physical processes may be responsible for the observed X-ray emission. Though it is not yet possible to fully discern the nature of these processes, further studies of X-ray spectra from OB stars with ASCA will provide necessary and heretofore unobtainable information on the composition, location, and dynamics of the hot plasma.

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HEAO-2 results suggest that high vsini O stars appear to be signficantly fainter x-ray sources. We proposed to observe additional high vsini O stars to test this hypothesis. Unfortunately, the PSPC was shot down during our scheduled observation time, and the observation was not re-scheduled. The contract work was modified to carry out other related x-ray tasks.

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