IONIZATION EFFECTS IN STELLAR WINDS OF MASSIVE X-RAY BINARIES

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ABSTRACT. High resolution ultraviolet spectroscopy of the early-type X-ray binary Vela X-1/HD 77581 provides a unique example to study the ionization structure of the stellar wind which varies under influence of the X-ray source. New results for other early-type X-ray binaries will be presented and compared with the Vela X-1 model. These results show that the observed variations strongly depend on the intensity of the X-ray source and on the density structure of the stellar wind.

1. INTRODUCTION

During the first two years of IUE (1978-1979) all known X-ray binaries, bright enough to be detected, have been observed, during various phases of their binary periods. The massive X-ray binaries consist of an early-type star and a compact companion. The early-type star shows moderate to strong stellar wind. The X-rays in these systems originate from accretion onto the compact companion which travels through the stellar wind of the optical star.

More than five years ago, Mc Cray (1975) predicted that an X-ray source in a stellar wind may further ionize the relevant ions in its surroundings. This should be observable as a marked orbital phase dependence of the P-Cygni lines of these ions. Table 1 lists the massive X-ray binaries observed by IUE and which show indeed line profile vari-

Table 1. Massive X-ray binaries which show the ionization effects.

Source	Optical star	Spectral type	m_v	log L_x (max.)	L_x/L_{opt}	Binary period
Vela X-1	HD 77581	B0.5Ib	6.9	36.0	0.003	$8.^d97$
Cyg X-1	HDE 226868	O9.7Iab	8.9	37.3	0.02	5.60
SMC X-1	Sk 160	B0 I	13.3	38.8	1.2	3.89
LMC X-4	Ph-Sk	O8III-V	14.0	38.7	1	1.41

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ations which are consistent with the ionization of the stellar wind by X-rays.

2. VELA X-1/HD77581

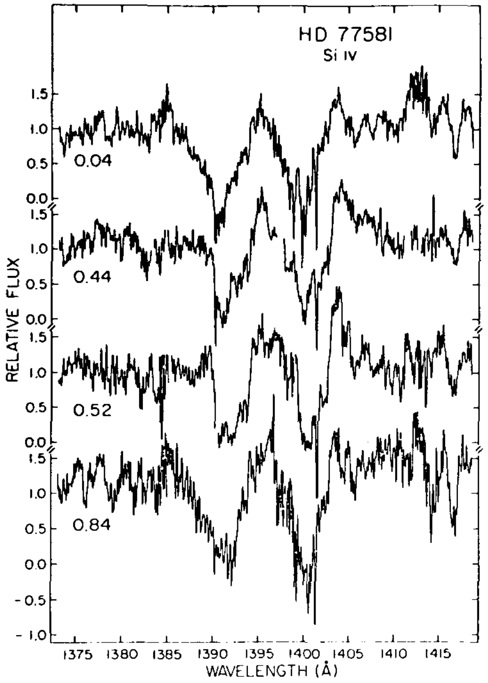

Figure 1. High resolution spectra of HD77581 showing the variation of the Si IV resonance doublet with binary phase. (From Dupree et al.,1980)

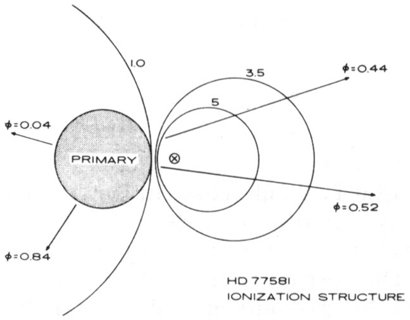

Figure 2. Model for the ionization structure of the stellar wind in HD77581. The spherical volumes around the X-ray source show the regions where Si IV is absent for different values of the parameter q. (From Dupree et al.,1980)

High dispersion IUE observations of the X-ray source HD77581 show a clear phase effect in the resonance lines, as demonstrated in figure 1 for Si IV. At X-ray eclipse (phase zero) the Si IV lines have an extended blue wing with an edge velocity of 1700 km/s, showing little evidence of emission. Around phase 0.5 the edge velocity has decreased to 850 km/s, while the emission has increased. Qualitatively, these variations are consistent with McCray's model.

I will give here a very short outline of the basic ideas underlying the calculation of the ionized volumes in the stellar wind of HD77581. Details of the calculations can be found in Dupree et al.(1980). In the model, the parameter $\xi = L_X/nr_X^2$ (where L_X = X-ray luminosity; n = local number density of the gas; r_X = distance from X-ray source) has been used to describe the ionized volumes in the wind. Hatchett and McCray (1977) have shown that surfaces of constant column density from the X-ray source are roughly congruent to surfaces of constant ξ, so that it is a good approximation to define the ionized volume in the wind by these surfaces. Figure 2 shows an example of such ionized volumes for different values

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of the parameter q (where $q\xi_0 = \xi$, see Dupree et al.,1980). The dimensions of the ionized volume depend on the X-ray luminosity, the density of the stellar wind, mass loss rate and observed velocity law. Computations of line profiles adopting the above model for ionization spheres show an overall agreement with the observed profiles.

Unfortunately, the other binary systems with known periods are too faint to be observed in high resolution. However, low dispersion spectra of Cyg X-1 show that line variations, correlated with binary phase, are clearly present (Treves et al.,1980).

3. LMC X-4 AND SMC X-1

During the last two years we concentrated on IUE observations of LMC X-4 and SMC X-1 in an international collaboration with colleagues from UCL, London and Meudon, France. I will present here the first results.

I made large-scale plots of all available low dispersion spectra of Vela X-1, Cyg X-1, SMC X-1 and LMC X-4 in order to measure equivalent widths of the NV, SiIV and CIV profiles. To have an error estimate, I also measured the interstellar line of CII 1335. Figure 4 represents the variations found for each star as percentage deviations from the mean equivalent width. The figure shows that also SMC X-1 and LMC X-4 have minimum equivalent widths around phase 0.5, as is also demonstrated in figure 3.

In figure 4, I did not include measurements of 1980 for LMC X-4, because they show a larger variation than earlier measurements in 1978 and 1979, as shown in figure 5. Figure 6 indicates that also the UV light curve of LMC X-4 in 1980 is different from the one of 1979. Both results suggest that the X-ray luminosity of the source was stronger in

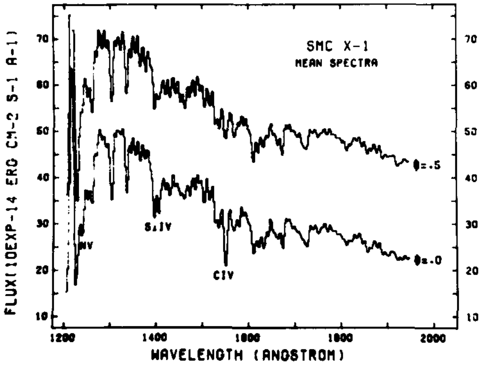

Figure 3. Mean low dispersion spectra of SMC X-1. Binary phases are indicated at the right.

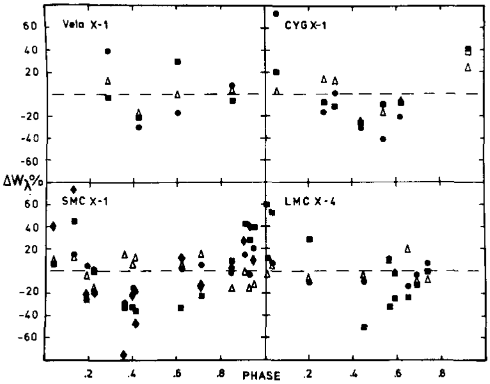

Figure 4. Equivalent width measurements for the four massive binaries under study. The ordinate gives the deviation from the mean in percentage. Δ = interstellar CII 1335; ♦ = NV 1240; ● = SiIV 1400; ■ = CIV 1550.

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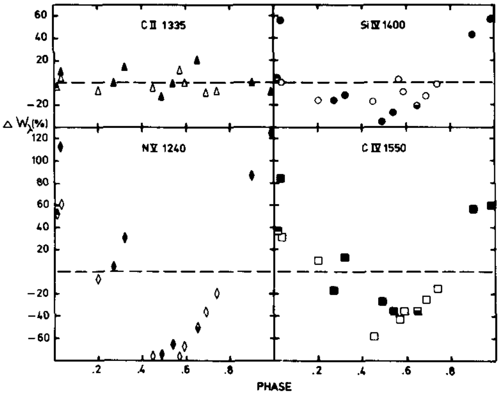

Figure 5. Equivalent width measurements for different lines in spectra of LMC X-4. Half-open symbols indicate observations of 1978, open symbols those of 1979, and filled symbols those of 1980.

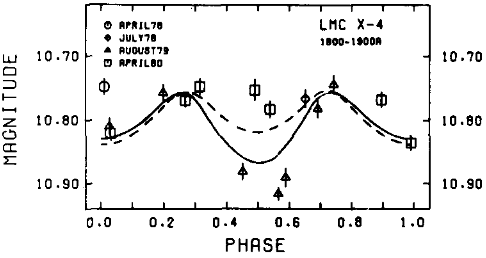

Figure 6. UV light curve for LMC X-4 in the region 1800-1900Å. Symbols denote the observations. The filled line indicates a theoretical light curve fitted to the system parameters with no X-ray heating. The dashed light curve takes an X-ray heating factor $L_x/L_{opt} = 0.3$ into account.

1980, which implies larger ionization volumes in the stellar wind.

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DISCUSSION

HOWARTH: What fraction of the total luminosity of LMC X-4 is attributable to the accretion disk?

HAMMERSCHLAG: We do not know if an accretion disk is present in LMC X-4, but if it is there it will only represent a small fraction of the total light. Van Paradys and Zuiderwyk (Astron. & Astrophys. 61, L19, 1977) have shown that an accretion disk is present in SMC X-1 which gives a deeper minimum in the light curve at binary phase 0.5 because it hides part of the light of the primary at that phase. It could be that an accretion disk is present in August 1979 in LMC X-4, but we did not yet make detailed theoretical light curves including the presence of an accretion disk.

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