ULTRAVIOLET OBSERVATIONS OF INTERACTING BINARY Be STARS

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ABSTRACT

Initial results from the analysis of a series of timed, high resolution IUE observations of HR 2142, ϕ Per, CX Dra, KX And, AU Mon, and TT Hya are presented. The data base for HR 2142 also includes *Copernicus* U1 and U2 observations. Variable absorption lines, indicative of mass flow in the system, are observed in all objects except ϕ Per. We also, in general, find evidence of mass outflow in the form of winds and/or discrete components. We observe variable N V absorption in CX Dra and AU Mon and emission features in KX And and ϕ Per (C IV only). U1 data reveals the presence of complex structure in the gas stream in HR 2142. These observations are compared with those of Be stars which are not thought to be interacting binaries.

1. INTRODUCTION

The ultraviolet spectra of interacting binary Be stars contain a wealth of data on the gas streams, general matter flow, and disks in these systems. In this paper, we present the initial results from a detailed study of the UV spectra of some of the brighter systems. The properties of the program stars and the phases at which the observations were obtained are given in Table 1. All IUE observations were made from 1979 October 23 to 1981 February 25. *Copernicus* observations of HR 2142 were from 1976 December to 1979 December.

2. RESULTS

a. HR 2142

Evidence that HR 2142 is an interacting binary and the behavior of the visible "gas stream" lines throughout the observed two-component shell phase are given in Peters (1976) and the references quoted therein. Orbital parameters for the system (which lend support to the proposed model) are included in Peters (1982). Striking phase dependent spectral variations have also been observed in the far ultraviolet (Peters 1981, Paterson-Beeckmans 1980, Polidan and Peters 1980). Some UV gas stream lines include the resonance lines of C II, Mg II, Al II,

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Table 1 - The Program Stars

Stars	Sp Types	Period	Phase coverage
HR 2142	B1IV-Ve+?	$80^{d}.860$	IUE (0.8 < ϕ < 0.1 : 11 obs. + ϕ = 0.17,0.42,0.45,0.47) <u>Copernicus</u> (0.8 < ϕ < 0.1 : 14 obs. + ϕ = 0.30,0.44,0.49.0.70)
ϕ Per	B0IV-Ve+?	$126^{d}.696$	0.00,0.22,0.25,0.46,0.46,0.66,0.85
CX Dra (HR 7084)	B3Ve+?	$6^{d}.697$	0.40,0.56,0.57,0.60,0.83,0.86,0.90
KX And (HD 218393)	B3IVe+K1III	$38^{d}.9$	4 obs., 3 close in phase, one $0^{P}.6$ later (ϕ arbitrary)
AU Mon (HD 50846)	B5Ve+F	$11^{d}.113$	0.30,0.48,0.85,0.93
TT Hya (HD 97528)	B9Ve+G5	$6^{d}.953$	0.40,0.90

Al III, Si II, III, IV, S II, III, Ti III, and Fe III and numerous subordinate lines of Fe III and Si III. In general, the variations in the strengths and velocities of the UV features parallel those observed in the visible. However, there are some important differences. The UV "shell phase" or <u>gas stream phase</u> persists from $0.80<\phi<0.10$. Gas stream features are observed prior to the visible <u>primary shell phase</u>, at conjunction, and after the short-termed visible <u>secondary shell phase</u>. IUE observations reveal that the absorbing stream and/or disk cuts into the line of sight abruptly between $0.83<\phi<0.86$. During this interval of time, many of the stronger resonance lines saturate. The strengths of the gas stream lines remain fairly constant between $0.90<\phi<0.95$. Then, from $0.95<\phi<0.97$, there is an additional strengthening of the UV gas stream lines which coincides in time with the appearance of the conspicuous Balmer shell spectrum ($\Phi_s \simeq 0.0$). The features subsequently weaken; at conjunction the column densities are about 100 - 150 times lower than the values observed from $0.91<\phi<0.96$. We further observe a strengthening of the gas stream lines after conjunction (coincident with the visible secondary shell phase) and the column densities from these features are comparable with those obtained from the lines observed during the primary shell phase. The UV gas stream lines disappear by $\phi = 0.10$.

A detailed line profile analysis of <u>Copernicus</u> U1 observations of the Fe III 1130 A resonance line has clearly shown that the gas stream features are complex. Each line is composed of at least 2 - 3 components, one of which yields a column density 100 times greater than the others. The denser component (at $\phi = 0.91$, 0.96, and 0.03), which appears to be fixed in velocity prior to conjunction ($V - V_{phot} = 30$ km^{-1}), suggests a column density (in 1130 only) of about 10^{18} cm^{-2}. If the path length is about $10R_{\odot}$, then the latter value implies a particle density in excess of 10^{12} cm^{-3}. The velocity shifts of the <u>weaker</u> 1130 components (at $\phi = 0.91, 0.96$) are more in accordance with those from the Balmer lines.

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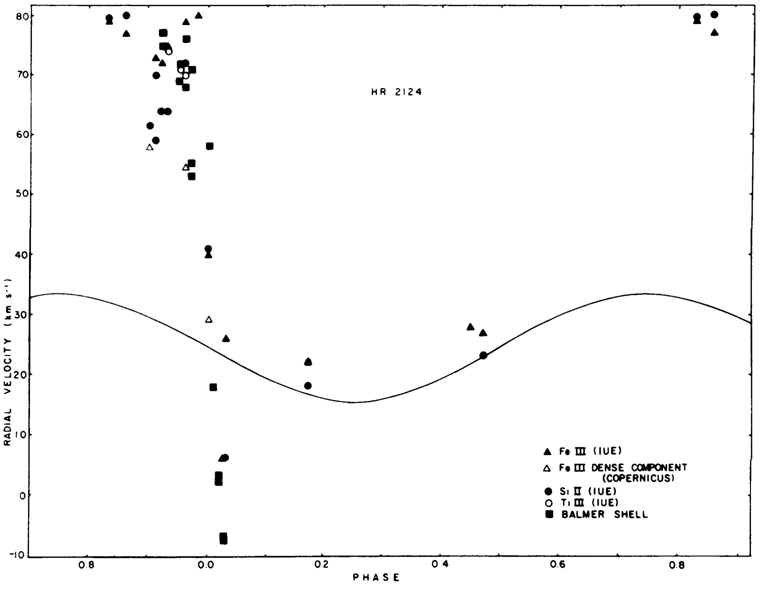

Fig. 1 - Radial velocities from selected gas stream lines versus phase. The solid curve shows the motion of the primary.

The radial velocity data from various gas stream features is summarized in Figure 1. Note that without exception the motion of the absorbing matter is toward the photosphere before conjunction; the opposite is observed after conjunction. However, if the lines are indeed formed in a conventional gas stream and counter stream, the velocities are significantly lower than theory predicts. Perhaps, the streams have large inclinations with respect to the line of centers or we are simply viewing through a density enhancement in the disk which results from a stream/disk interaction. Many resonance lines show evidence of outflow in discrete components near $\phi = 0.5$ (Paterson-Beeckmans 1980). Our observations suggest that this outflow phase peaks at $\phi \simeq 0.45$ (before L_3). Subordinate lines do not show the outflow (cf. Fig. 1). We also observe an overall stellar wind (in C IV, Si III, IV) which appears to enhanced at conjunction.

b. ϕ Persei

An orbit and model for this enigmatic binary have recently been published by Poeckert (1981). Whereas striking phase dependent spectral variations are observed in the visible, our IUE observations show this star to be relatively invariant in the UV (unlike HR 2142). With one exception, the UV spectrum of ϕ Per is typical for a Be-shell star. The C IV resonance doublet stands as unique, however. As shown in Fig. 2, the C IV lines have P Cygni profiles with a peak emission line strength of twice the continuum value. Of the twenty-five classical Be stars observed to date with IUE, only ϕ Per displays C IV emission. Perhaps even more novel is that we do not observe emission at N V or Si IV. Our IUE observations were obtained over four orbital cycles and, in general, no statistically significant profile variations were observed.

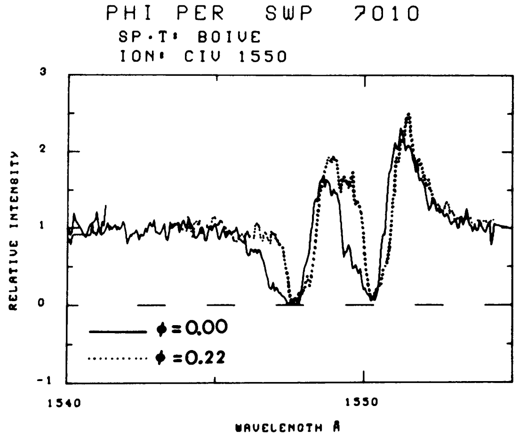

Fig. 2 - The resonance lines of C IV in ϕ Per at two phases.

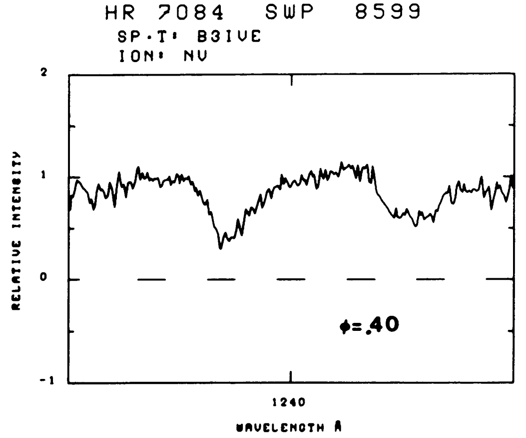

Fig. 3 - The N V resonance lines in CX Dra on 1980 March 30.

In order to determine whether the C IV feature is associated with the proposed high temperature secondary (Poeckert 1981), radial velocities were measured for the C IV doublet using neighboring interstellar lines for wavelength calibration. Reference points on the profile included the emission line peak and wings and the cores of the lines. The data clearly show that the feature is associated with the primary. Within the uncertainties of the measurements, the motion of the C IV region follows the radial velocity curve of the primary. Motion with respect to the secondary would be quite conspicuous since $K_s = 100$ km s^{-1}. Possibly the only observed UV features associated with He II object (secondary) are redshifted cores to Si III (UV 4) observed at ϕ = 0.66.

c. CX Draconis (HR 7084)

Koubsky (1978) proposed that this object is a mass transfer binary system. IUE observations reveal redward displaced absorption components, indicative of a gas stream, in the resonance lines of C II, Si II,III,IV, and Al III and the subordinate lines of Fe III at $\phi = 0.83, 0.86$, and 0.90. These features are broader than their counterparts in HR 2142 and show a larger velocity shift from the photospheric lines (V≃200-250 km s^{-1}). We also observe violet asymmetries in the above mentioned lines at $\phi = 0.56, 0.57$, and 0.60 which suggest the presence of mass loss.

Quite unexpected was the discovery of strong N V features in the spectrum of this "B3e" star (Fig. 3). Under normal circumstances, a temperature of at least 40000K is required to form N V. The strength of the N V doublet is quite variable ($0.25<r_v<0.95$) but does not appear to be phase dependent. Since the radial velocities from the N V lines apparently follow Koubsky's published radial velocity curve, we conclude that the N V is formed close to the stellar photosphere (perhaps the result of an impacting gas stream). Plavec (personal communication) recently has found CX Dra to be a soft X-ray source. We suggest that the X-rays and N V both arise in an accretion heated region near the primary.

d. KX Andromedae (HD 218393)

Observations of this system at essentially two different phases ($\Delta\phi = 0.6$) reveal the presence of broad emission at the resonance lines of C II, Si IV, Al III, and Mg II. Numerous shell lines which vary in strength and width, pervade the UV spectrum. The IUE data support the spectral classification of B2 (Doazan and Peton 1970).

e. AU Monocerotis (HD 50846)

If AU Mon were not an eclipsing binary, it would be considered an average B5e star. IUE observations show this system to be quite similar to CX Dra. A similar gas stream is seen ($\phi = 0.85, 0.93$) and equally strong, variable N V (and C IV) resonance lines are found.

f. TT Hydrae (HD 97528)

TT Hya is a well-known Algol-type eclipsing binary. The prominent Hα emission feature observed in this system displays phase dependent V/R variations (Peters 1980). A rich shell spectrum, which does not appear to be highly variable, is seen in the UV. The gas stream was detected in the resonance lines of C II and Si II.

3. DO THE UV SPECTRA OF INTERACTING BINARY Be STARS DIFFER FROM THOSE OF "SINGLE" Be STARS?

IUE observations of six Be stars which are known to be mass transfer binaries have, unfortunately, not revealed a single spectral feature, set of features, or spectroscopic behavior which alone can be considered a signature of an interacting system. However, there are a number of criteria which can be employed to find possible binaries. These include the presence of 1) numerous shell lines, especially those which arise from low lying and/or metastable levels, 2) redward asymmetries in the resonance features, and 3) variable N V absorption. Normally, N V features are not observed in Be stars later than B1 (Marlborough and Peters 1982) but, among our program binaries, we have observed strong N V as late as B5!

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