VARIATION OF ANOMALOUS STAGES OF IONIZATION WITH SPECTRAL TYPE FOR Be STARS

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One of the interesting results of ultraviolet (UV) astronomy was the discovery of ions from unexpected stages of ionization in spectra of O,B stars. The most common ions concerned are O VI and N V, but also C IV and Si IV in B stars. The presence of these ions is anomalous because generally their abundance is expected to be negligible if they are produced by photoionization by stellar radiation, either in the photosphere or in a cool circumstellar envelope (CE). The same ions are observed in the UV spectra of Be stars. Previous investigations, largely with Copernicus spectra, have reported O VI and N V in late Oe and early Be stars and Si IV in stars as cool as B5 (Marlborough, 1981 and references therein). In this paper we present the results of a preliminary survey of IUE spectra of Be stars covering a wide range of spectral type.

We have high resolution IUE spectra, $1150 \leq \lambda \leq 1950$A of 23 Be stars, spectral types O9-B8, luminosity classes III-V. The stars are listed in Table 1. We have two observations separated by about 6 months

TABLE 1
Ultraviolet Spectra Surveyed for N V, C IV, and Si IV

Spectral Type	Stars: v sin i > 150 km s^{-1}	Stars: v sin i < 150 km s^{-1}
O9	ζ Oph	
B0	γ Cas	
B1	59 Cyg, HD28497, HR4009, π Aqr	
B2	υ Cyg, 66 Oph, 48 Per	ω CMa, 31 Peg, 11 Cam, χ Oph
B3	α Eri, 28 Cyg, ω Ori, 16 Peg	6 Cep, HD58343
B5	ψ Per, ε Cap	
B8	o Aqr, α Col	

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for both ψ Per and HD58343; hence our sample consists of 25 UV spectra.

Each spectrum was examined for the presence of the resonance lines, in each instance a doublet, of N V, C IV, and Si IV. Our procedure consisted in assigning a number to each spectrum to indicate the presence of the particular ion. We assigned a '1' if both components of the doublet of a particular ion were present and a '0' if there was no indication of the ion. For some spectra, a weak feature is located at or near the rest wavelength of the stronger component of the doublet. For such cases we assigned '0.5' to indicate the ion may be present. We have computed the weighted mean of these numbers for each spectral subdivision, the weighted mean thus reflecting the chance of detecting the ion in stars of the specific subtype. Our results are illustrated in Figure 1. The vertical dashed lines represent the coolest spectral types at which the appropriate ion can exist under radiative equilibrium conditions with a sufficient abundance to produce a detectable photospheric absorption line (Marlborough, 1982 and references therein). Therefore the presence of N V in early Be stars and of both C IV and Si IV in Be stars as cool as B8 demonstrates that at least some Be stars in almost all spectral subdivisions show anomalous stages of ionization

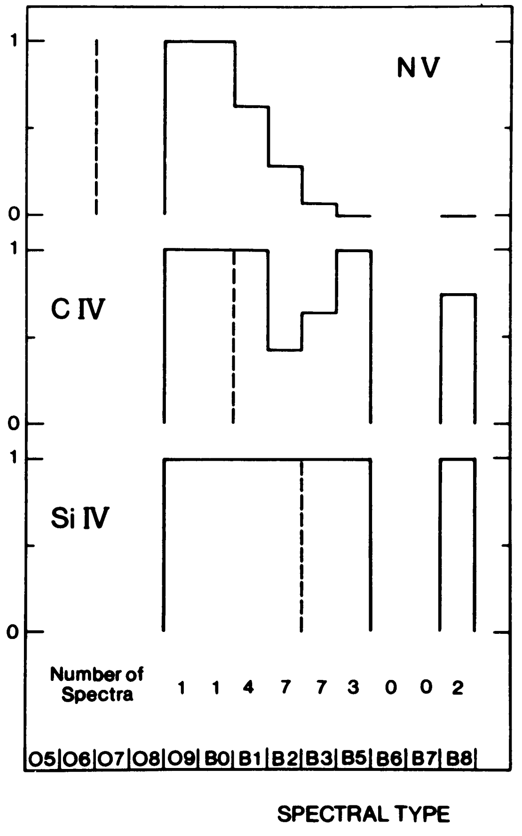

Figure 1. The chance of detecting N V, C IV, and Si IV in Be stars based upon 25 IUE spectra. The vertical dashed line represents the coolest spectral type at which the ion would be expected under radiative equilibrium conditions, either in the photosphere or in a cool circumstellar envelope.

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in their UV spectra and thus require ionization sources in addition to the photospheric radiation field.

Marlborough (1982) has summarized the evidence to date regarding variability of N V, C IV, and Si IV in UV spectra. Although the strength, profile, and radial velocity of the lines vary there is no evidence presently to suggest that lines disappear totally. In each star cooler than about B3, Si IV lines were detected. Thus we suggest that the absence of N V in Be stars cooler than about B2 together with the presence of C IV and Si IV in later types is a real phenomenon and reflects some dependence of the additional ionization source on basic stellar parameters.

It is clear from Figure 1 that C IV lines seem to occur less frequently at B2 and B3 than at other subtypes. All stars in our sample, excluding types B2 and B3, have moderate to large v sin i. Only at B2 and B3, where we have a modest number of stars, is there a significant range of v sin i.

We have attempted to determine whether the behaviour at B2 and B3 might reflect some dependence on v sin i. Visual inspection of spectra reveals that the range of strengths of C IV lines depends on v sin i. While stars of large v sin i may have a range of C IV line strengths, stars of low v sin i seem to have only weak C IV lines. Furthermore there is some weak evidence, especially at B3, that the C IV line strength decreases with decreasing v sin i. The strength of Si IV lines at B3 seems to vary in a similar manner; however at B3 a photospheric contribution to Si IV may not be negligible. This apparent dependence of C IV line strength on v sin i is similar to the variation of Fe III line strength and linear polarization with v sin i. One possible interpretation is that the hot component of the CE is not distributed with spherical symmetry. More data however are needed to confirm this suggestion.

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REFERENCE

Marlborough, J.M.: 1982, in M. Jaschek and H.G. Groth (eds.), 'Be Stars, IAU Symp. 98', pp. 361.

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DISCUSSION

Viotti: I presume that in your analysis you used spectral types derived from optical spectra. Have you looked at the presence of high ionization lines as a function of the strength of the UV excited lines, which could be a better indication of the far_UV radiation flux?

Marlborough: We have not done so yet.

Thomas: 1. You know as well as I the difficulties in detecting N V in 59 Cyg on some of the plates; so I would be very cautious in your conclusion.
2. I note that before IAU Montreal no N V had been observed in T Tau stars; since then it has been seen in majority of those well-observed, if my memory is correct.

Marlborough: 1. Our conclusions were based only upon the sample of stars we observed. If the sample is not representative, the conclusions may not be correct.
2. Due to the low apparent brightness of T Tauri stars, there were probably few, if any, ultraviolet observations of high resolution obtained before the availability of IUE.

Viotti: I think that you have to include in your list of anomalous stages of ionization Si II resonance lines which are present in X Per and γ Cas and should not be present in their photospheres.

Marlborough: Conspicious changes in the Si II resonance lines occured during the shell phase of 59 Cyg. Photospheric Si II would not be strong in a star as hot as 59 Cyg either. Hence the Si II resonance lines arise in the cool regions of the circumstellar envelope.

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