EVIDENCE FOR MASS LOSS AT POLAR LATITUDES IN ω Ori AND 66 Oph

Geraldine J. Peters
Department of Astronomy
University of Southern California
Los Angeles, CA 90007 USA

ABSTRACT

IUE observations of the "pole-on" Be stars ω Ori and 66 Oph have revealed the unexpected presence of high velocity ($v \simeq -750$ km s^{-1}), relatively narrow ($\Delta\lambda \simeq 1$A) absorption components in the resonance lines of C IV, Si III, and Si IV. The C IV features show structure indicative of multiple shells or clouds. Similar high velocity lines were not observed in other pole-on Be stars considered in the program. The nature of these unusual features and the column densities and mass loss rates implied by them are discussed in this paper.

1. INTRODUCTION

Recently, the importance of rapid rotation in the establishment of the circumstellar envelopes in Be stars has been a subject for debate. Whereas it was previously assumed that all the matter in the envelope was ejected from the equatorial region of a rapidly rotating star, ultraviolet observations of variable spectral lines from super-ionized species (Doazan, et al. 1980, Doazan, et al. 1982) and the repeated failure of researchers to find observational evidence that Be stars rotate in excess of 0.85 V_{cr} (Hutchings, Nemec, and Cassidy 1979, Slettebak 1979) have inspired a search for other explanations for the Be phenomenon.

In order to establish the extent of mass loss at polar latitudes and gain some insight into the mechanism of mass loss in Be stars, twelve "pole-on" (vsin i $\leq$ 280 km s^{-1}) stars were observed at high resolution ($\Delta\lambda \simeq .15$A) with IUE. The UV spectra of two of the program stars, ω Ori and 66 Oph, were found to contain highly violet shifted, shell-type features of C IV, Si III, and Si IV. These observations are discussed in this paper.

The visible spectra of ω Ori and 66 Oph have a history of variability (Hubert-Delplace and Hubert 1979). ω Ori recently displayed unusual variable polarization (Hayes 1980) while 66 Oph was reported

M. Jaschek and H.-G. Groth (eds.), Be Stars, 401–404.

to have shown optical flares (Page and Page 1970). Values of vsin i are 160 and 280 km s^{-1}, respectively, for ω Ori and 66 Oph (Slettebak 1976); if $V_{eq} \simeq 400$ km s^{-1}, then inclinations of 24° and 44°, respectively, are implied.

2. NATURE OF THE IUE OBSERVATIONS

The C IV and Si IV resonance features observed in ω Ori and 66 Oph are shown in Figures 1 - 4. Superimposed on the C IV profiles (dotted lines) is the C IV feature observed in υ Cyg, a Be star of comparable spectral type and rotational velocity (B2IVe, vsin i ≃ 175 km s^{-1}). It can be said with confidence that the C IV lines in ω Ori and 66 Oph are almost entirely circumstellar. Multiple components are clearly seen in C IV. In ω Ori, the "clouds" responsible for the C IV absorp-

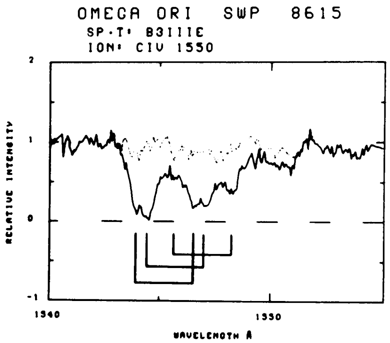

Fig. 1 -- The C IV doublet in ω Ori. Multiple components are indicated. Rest wavelengths are 1548.2A and 1550.8A.

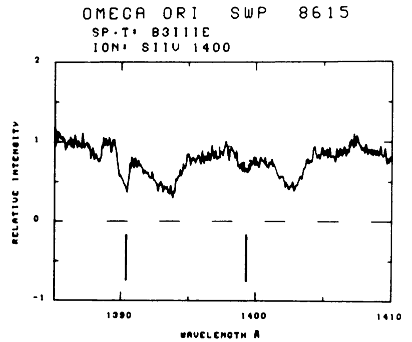

Fig. 2 -- The Si IV doublet in ω Ori. Vertical lines point to the violet shifted shell components. The broader features are photospheric.

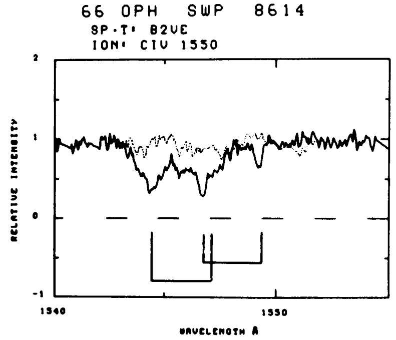

Fig. 3 -- Same as Fig. 1 for 66 Oph.

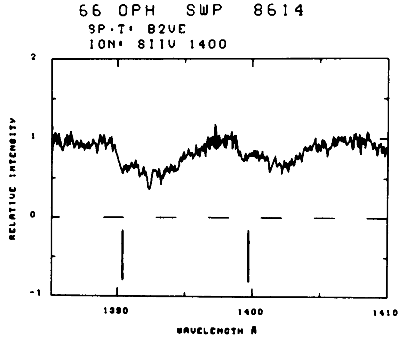

Fig. 4 -- Same as Fig. 2 for 66 Oph.

https://doi.org/10.1017/S0074180900038109 Published online by Cambridge University Press

tion have outflow velocities (relative to the photosphere) of 850, 750, and 550 km s^{-1}. Similarly, in 66 Oph, the features are violet shifted by 700 and 250 km s^{-1}. In Figures 2 and 4, one can easily see the shift of the narrower shell component of Si IV relative to the photospheric feature. This shift is -800 km s^{-1} in ω Ori and -670 km s^{-1} in 66 Oph. Violet shifted components are also seen in the Si III resonance line at 1206.5 A. In ω Ori the outflow velocity is -795 km s^{-1}, while in 66 Oph one measures a velocity of -685 km s^{-1}. The Si IV and Si III velocities in ω Ori agree with the mean of the two more negatively shifted components in C IV and, thus, imply the presence of unresolved structure in the former features. In general, the velocity data for both stars strongly suggests that C IV, Si IV, and Si III are formed in the same region. Furthermore, the fact that the shell features are narrow ($\Delta\lambda \simeq$ 1A = 200 km s^{-1}) indicates that the mass is being lost in discrete "clouds" or "shells" instead of via a conventional wind.

3. ANALYSIS

The interpretation of the high velocity features is complicated by the fact that the lines are on the flat portion of the curve of growth. Although fine structure cannot be seen in the individual components,their strengths imply that each is composed of numerous closely spaced saturated lines. The observed half-width of the features suggest b values of 80 and 128 km s^{-1}, respectively, for ω Ori and 66 Oph. Using these values, we obtain the following column densities in C IV, Si IV, and Si III, respectively: 1) $4x10^{14}$, $9x10^{13}$, and $4x10^{13}cm^{-2}$ for ω Ori, and 2) $4x10^{14}$, $7x10^{13}$, and $2x10^{13}$ cm^{-2} for 66 Oph. These values should be regarded as lower limits. If unresolved fine structure exists, then the actual column densities could be as much as two orders of magnitude higher.

A non-LTE situation most certainly exists in the line formation region. In LTE, the observed Si III/Si IV implies that T≃15000K. At such a temperature, one would not expect to observe C IV. C IV/Si IV ≃ 5 in both stars. Bruhweiler, Kondo, and McCluskey (1980) observe a similar ratio in some parts of the interstellar medium and suggest that a temperature of 40,000K prevails in the line forming region. However, the presence of the Si III line in the spectra of the Be stars suggests a lower temperature for these objects.

If we assume that C IV is the dominant ion of carbon in the "high velocity" region, we obtain a minimum hydrogen column density of $3x10^{18}$ cm^{-2}. If $N_p = N_e \geq 10^9 cm^{-3}$, small path lengths ($<1R_\odot$) are implied (even if fine structure prevails). The rate of mass loss is uncertain because we lack information on the density in the line formation region. However, if $N_e \simeq 10^9 cm^{-3}$, then $\dot{M} \simeq 10^{-9}$ $M_\odot$ yr^{-1}.

4. CONCLUDING REMARKS

At the onset of this investigation, the existence of such high velocity features, some of which greatly exceed the escape velocity of the star, was not predicted. Their presence is not compatible with models of Be envelopes based upon rapid stellar rotation or binary mass exchange. Evidence that matter does exist at polar latitudes in some Be stars has already been presented (Peters 1976, Snow, Peters, and Mathieu 1979) but, until now, only low outflow velocities were observed in the "pole-on" stars. High velocity, "narrow" features have been seen in 59 Cyg (Doazan, Kuhi, and Thomas 1980) and γ Cas (Henrichs 1980) but these stars have higher values of vsin i.

If ω Ori and 66 Oph are indeed viewed "pole-on", then the observations presented in this paper demonstrate that mass loss in Be stars is not restricted to the star's equatorial regions and, perhaps, rotation does not play an important role in the establishment of the circumstellar envelope. But if this is the case, then ω Ori and 66 Oph may not be rapidly rotating after all and could instead be viewed equator-on! The large polarization sometimes observed in ω Ori (Hayes 1980) seems to be compatible with the latter suggestion.

Future IUE observations are planned to search for similar high velocity features in other "pole-on" Be stars and to assess the stability of the line formation region. At a velocity of 700 km s^{-1}, the absorbing "cloud" will travel in excess of $10R_*$ in one day. One should, therefore, be able to observe profile variations between observations spaced a few days apart. An interpretation of this phenomenon will be deferred until the forthcoming observations have been completed. At this time, one cannot rule out that we are observing a "chromospheric" phenomenon similar to the one suggested for 59 Cyg (Doazan, Kuhi, and Thomas 1980). Although ω Ori and 66 Oph were only observed once, N V, a signature of such "chromospheric" activity, was not detected. There may be several explanations for what we call the Be phenomenon. Continued observations of the strong UV resonance lines in Be stars should allow us to determine which of these are valid.

This project is being supported, in part, by NASA grant NSG 5422.

REFERENCES

Bruhweiler, F. C., Kondo, Y., and McCluskey, G. E.: 1980, Astrophys. J. 237, pp.19-25.

Doazan, V., Kuhi, L.V., Thomas, R.N.: 1980, Astrophys.J. 235,pp.L17-L20.

Doazan, V., Grady, C., Kuhi, L. V., Marlborough, J. M., Snow, T. P., and Thomas, R. N.: 1982, this volume, pp.415-418.

Hayes, D. P.: 1980, Publ. Astron. Soc. Pacific 92, pp.661-665.

Henrichs, H. F.: 1982, this volume, pp.431-435.

Hubert-Delplace, A. M. and Hubert, H.: 1979, An Atlas of Be Stars, Observatoire de Meudon, France.

Hutchings, J.B., Nemec, J. M., and Cassidy, J.: 1979, Publ. Astron. Soc. Pacific 91, pp. 313-318.

Page, A. A. and Page, B.: 1970, Proc. Astron. Soc. Austral. 1,pp.324-325.

Peters, G. J.: 1976, in A. Slettebak (ed.), 'Be and Shell Stars' IAU Symp. 70, pp.209-217.

Slettebak, A.: 1976, in A. Slettebak (ed.), 'Be and Shell Stars' IAU Symp. 70, pp.123-135.

Slettebak, A.: 1979, Space Science Reviews 23, pp.541-580.

Snow, T. P., Peters, G. J., and Mathieu, R. D.: 1979, Astrophys. J. Suppl. 39, pp.359-376.