ROTATIONAL VELOCITY VERSUS MASS LOSS IN Be STARS.*

V. Doazan, M.L. Franco, R. Stalio, R.N. Thomas
Observatoire de Paris, France; Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste, Italy; Osservatorio Astronomico and SISSA, Trieste, Italy; Institut d'Astrophysique, Paris, France.

ABSTRACT

C IV and Si IV resonance line profiles of 21 Be, B-shell and normal stars are studied with the aim of detecting evidences for mass loss. We found that almost all our sampled stars are loosing mass. A relation between an estimated lower limit for the rate of mass loss and the observed rotational velocity was searched but not found.

I. INTRODUCTION

A large portion of the literature on Be stars is characterized by attempts to relate their rotational velocities to a number of observed phenomena and models. The reason for this lies in the fact that Be stars have statistically larger v sin i than their "normal" counterparts. Thus one asks if the origin of the extended atmospheres, where emission lines are formed, is due to rotation. More specifically one asks if the origin of the displacements of the superionized lines observed in the UV in terms of the stellar wind produced by various mechanisms, like radiation pressure, could become more efficient in a rapidly rotating star where the effective gravity is lower. One also asks if it is possible to explain the observed variability of lines, continua, polarization, etc in terms of a rotationally oblated shape of the outer atmosphere of the star.

These questions persist despite increasing evidence from UV, X-ray, high-dispersion visual, IR, and radio data that most of these phenomena are related to the non-thermal structure of the atmospheres and sub-

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TABLE 1.

STAR	SP. TYPE	V sini	OBSERV.	IONS
X Per	O9.5e	150	4/4/78	Si IV, C IV
ζ Oph	O9.5Vnn	380	3/8/78	Si IV
τ Sco	BOV	25	Copernicus	Si IV
HR 2678	B0.5III	155	23/1/79	Si IV
γ Cas	B0.5IVe	300	18/10/79	Si IV
κ CMa	B1.5IVne	200	23/1/80	Si IV, C IV
χ Oph	B1.5Ve	120	23/1/80	Si IV
216 Pup	B1.5Vp	275	3/6/78	Si IV, C IV
59 Cyg	B1.5Ve	375	12/12/78	Si IV, C IV
HR 5223	B2IIIe	85*	23/1/80	Si IV
δ Cen	B2IVne	180	23/1/80	Si IV
HR 4009	B2IVpne	360	23/1/80	Si IV, C IV
HR 2142	B2Ve	415	21/8/78	Si IV, C IV
ι Her	B3IV	8	Copernicus	Si IV
ζ Tau	B4IIIp	310	21/8/78	Si IV
τ Ori	B5III	35	6/1/79	Si IV
δ Per	B5III	259	11/9/78	Si IV
48 Lib	B5IIIp	390	23/1/78	Si IV
κ Dra	B6IIIp	250	27/3/79	Si IV
θ CrB	B6Vnn	395	20/5/80	Si IV, C IV
η Tau	B7III	215	4/1/80	Si IV

* Dachs et al. (1981).

atmospheres of stars in all the HR diagram. In a subsequent paper Doazan, Stalio and Thomas will present a proposed gross structural pattern for the atmospheres of Be Stars. Here we only want to emphasize in a qualitative way the lack of any observed relation between mass loss and rotational velocities for a group of Be, B-shell and B normal stars.

II. OBSERVATIONS AND DATA ANALYSIS

IUE high resolution spectra taken in the short wavelength region of 19 Be, B-shell and normal B stars of spectral type between O9.5 and B 7 and classes luminosity III to V, and two Copernicus spectra of τ Sco (BOV) and ι Her (B3IV) have been used in order to detect mass loss from asymmetric and/or displaced Si IV and C IV resonance absorption lines. The list of stars, their spectral type taken from Lesh (1968,1972), v sini values taken from Uesugi (1976) and the day of observation are presented in Table 1. Note that only one observation per star has been considered, thus ignoring the fact that most of our stars may have

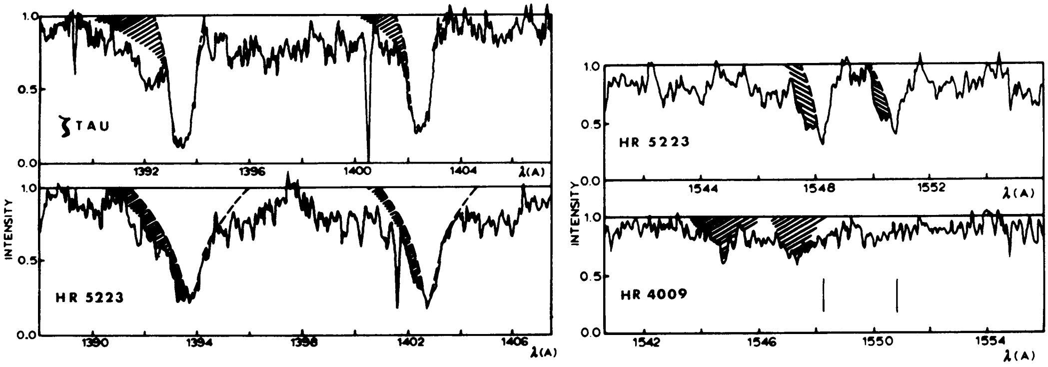

Figure 1.: Si IV and C IV resonance profiles. The shaded areas are the estimated wind contributions.

variable amount of mass loss; for our purposes this is enough in view of the qualitative character of our considerations.

In order to decide whether a star loses mass or not we have estimated lower limits for the mass loss rate using the simple curve of growth approach. The assumptions we made are numerous; some of them act in the sense we require, i.e. of establishing lower limits for the mass loss rates.

a) From asymmetric profiles with violet extended wings we have substracted a symmetric profile created by transferring the long wavelength wing to the violet side. We have then assumed that the result represents the contribution of the stellar wind to the total profile; the position of the minimum absorption gives the velocity regions where there is the maximum concentration of the ions considered. In the case of multiple components (most frequently two), which are found often, we have taken only those at maximum blue displacement, thus neglecting the contribution to the mass loss rate from the low velocity components. In Figure 1 we present as examples the Si IV profiles and the resulting wind components of ζ Tau and HR 5223; the same has been done for the C IV profiles of HR 5223 and HR 4009.

b) The mass loss rates has been estimated by assuming the following:

- all wind components have equivalent widths falling in the linear part of the curve of growth,
- the wind velocity is measured at the minimum absorption of the wind profiles,
- the photospheric radius of all stars has been taken to be 6.3 $R_\odot$,
- solar Si and C abundances have been adopted.

Under these assumptions, the equivalent widths give us column densities and by adopting the equation of mass continuity we derive the following expression for the mass loss rate:

$$\dot{M} = 2.347\times10^{-12} \times \frac{W_\lambda \quad v_o}{f\,\lambda^2 \left(\frac{n_{ion}}{n_{el}}\right)\left(\frac{n_{el}}{n_H}\right)} \qquad M_\odot\ yr^{-1}$$

with W_λ, the equivalent width, measured in A, v_o in km s^{-1}, λ in A. (n_{el}/n_H) is the element abundance and (n_{ion}/n_{el}) the ionization fraction of Si IV and C IV in the wind.

c) We then have adopted an ionization fraction $(n_{Si\ IV}/n_{Si}) = 1$; this value gives very conservative rates of mass loss. For example the rate of mass loss we obtained from τ Sco is 1.7 10^{-11} $M_\odot\ yr^{-1}$. If instead we use the Si IV ionization fraction of 0.01 derived by Lamers and Rogerson (1978) we obtain a rate 100 times langer which is much close to their 5-8 10^{-9} $M_\odot\ yr^{-1}$. The ionization fraction of C IV has been scaled to that of Si IV by adopting the same ratio $(n_{CIV}/n_C)\big/(n_{SiIV}/n_{Si})=0.25$ as for τ Sco in Lamers and Rogerson analysis. Three stars ζ Tau, 48 Lib and HR 5223 require a much smaller ratio in order to give rates consistent with those derived from Si IV. For these stars we have adopted the rates derived from the Si IV profiles.

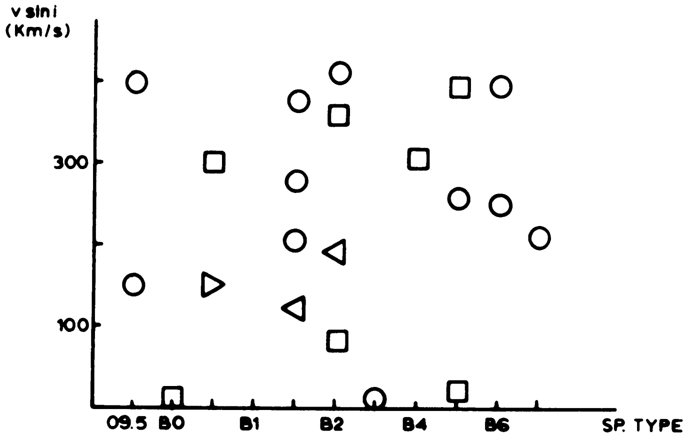

Figure 2. : v sin i versus spectral type diagram. The symbols indicate values of $\dot{M} \leq 10^{-12}$ $M_\odot\ yr^{-1}$ (◁), $10^{-12} < \dot{M} \leq 10^{-11}$ (○), $10^{-11} < \dot{M} \leq 10^{-10}$ (□), $10^{-10} < \dot{M}$ (▷). $\dot{M}$ has been estimated as described in the text.

III. RESULTS

The results of our study are shown in Figure 2, where in a diagram v sin i versus spectral type we have plotted all stars using different symbols for different ranges of mass loss rates.

There appears to be a complete lack of any correlation between our lower limits of mass loss rates and the rotational velocity. If instead of lower limits we would be able to give a real estimate of the rates, the situation would not be expected to change very much: the same large scattering is present also in the more restricted range of spectral types from B1.5 to B2.

This result seems to be in contradiction with a similar diagram presented at the previous IAU Symposium on Be Stars by Marlborough and Snow (1976), in which however they used only Si IV. In that diagram mass loss seemed to occur from the hotter and more rapidly rotating stars. The apparent contradiction arises from the fact that: (1) our sample of objects is larger than theirs, (2) we measure the C IV doublet in addition to Si IV.

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DISCUSSION

Snow: There are at least two very uncertain assumptions in this. First, you assumed that the equivalent widths lie on the linear part of the curve of growth, yet in the figure you showed, this is obviously not the case; the two C IV lines in the figure had about equal equivalent widths, indicating substantial saturation. Second, you have assumed that the ionization balance in the wind is the same for all your stars, from O9 to B7. This is almost certainly not correct. Both of these uncertainties, and others, will by themselves create a lack of correlation between M and v sin i.

Franco: It is true that for some of the stars in our sample the equivalent widths are not in the linear part of the curve of growth and it is certainly true that the ionization balance in the wind is not the same for all the stars. We have assumed that all the Si is present in the wind in the form of Si IV; this is a very conservative estimate: in τ Sco this fraction is 1/loo; in all stars of our sample that show C IV profiles formed in the wind (that are the most) the ionization fraction of Si IV showed not to be different from τ Sco. This, in our opinion, makes us confident that we are estimating lower limits of mass loss rates; this is our goal. From lower limits we can calculate that there are stars with low v sin i values losing mass as well as stars with high v sin i values.