THE PHOTOMETRIC BEHAVIOR OF Be STARS

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ABSTRACT

We present photometric data for 76 Be stars observed in UBV and in the Balmer lines $H\alpha$, $H\beta$, and $H\gamma$. An ultraviolet excess, derived from the Q value, appears as a common feature for nearly all them. From a statistical study of the data, the percentages of variability are: 77% in V, 48% in B-V, and 68% in U-B. The amounts of emission in the α and β indices, which we call e_{α} and e_{β} , are computed. It is demonstrated that both emission indices are very well correlated to the spectroscopic emission features, their equivalent widths, and possibly also to the ultraviolet excess. The correlation of the standard deviation of the V magnitude with the projected rotational velocity is in agreement with a model in which the Balmer line emission is due to a gaseous ring. The observed β values corrected for the emission indices become good indicators of the absolute magnitudes, as is confirmed by a sample of Be stars known to be members of clusters and associations. Some properties of the galactic distribution of the Be stars are then derived from our results.

I. INTRODUCTION

The study of Be stars permits us to obtain information on early-type stars with gaseous envelopes. Photometric changes and rapid variations of the structure of the emission lines indicate instabilities in their envelopes. Nevertheless, not all of them display the same activity.

As was pointed out by Feinstein (1968), and Ferrer and Jaschek (1971) about 50% of the Be stars show some kind of photometric variations. A survey of Hydrogen line indices from narrow band photometry revealed also changes of the H β line intensities (Feinstein 1973).

On the other hand, the separation of the Be-type stars from the supergiants using photometric methods was investigated several times with positive results (Abt and Golson 1966; Crawford, Barnes, and Perry 1975).

The present work tries to throw some light on the activity of the envelopes of bright Be stars with measures derived from the commonly used UBV system and from the Hydrogen Balmer lines. This gives us the possibility to compare them with normal stars, even though the UBV system is not the most appropriate one for these particular stars.

With this aim in mind, we present here an extended series of observations of about 76 stars in the *UBV* system covering over 15 years and narrow band Hydrogen line measures spanning over eight years.

The 76 selected stars are mostly those found to have

Hydrogen line emission by Jaschek, Jaschek, and Kucewicz (1964) in a systematic survey of B-type stars covering the years 1960–1962.

Section 2 includes the final results of the observations obtained in the *UBV*. Section 3 refers to the data on the Balmer lines. The definition of the emission indices is presented in Sec. 4, and in Sec. 5 their relation to the rotational velocities is indicated. Section 6 gives the galactic distribution properties, and finally a conclusion with regard to all the preceding information is presented in Sec. 7.

II. THE UBV DATA

The mean values of V, B-V, and U-B from all the measures between 1963 and 1976 are listed in Table I, which also includes the HD and HR designations, the number of measures, the dispersions in magnitude and in each color, and the spectral types taken mostly from Lesh (1968), and Hiltner, Garrison, and Schild (1969). The references to the sources of the spectral types are listed at the bottom of Table I. The data already published (Feinstein 1968, 1975) are also included in this table.

The errors of the listed values depend strongly on the place where the measures were obtained. They are smaller at Cerro Tololo $\epsilon_{\rm CT} = \pm 0.015$ than at La Plata $\epsilon_{\rm LP} = \pm 0.020$ (per single observations).

The two color (U-B, B-V) array for all the observed Be stars is presented in Fig. 1. The main sequence relation (FitzGerald 1970) appears as a left envelope for all of them. It is evident that the observed Be stars are affected by reddening to some extent, but it is obvious that in many of them another effect due to the ultraviolet excess is also present. This is clearly shown by Figs. 2 and

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TABLE I. UBV data for the Be stars.

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209409 8402 4.71 -0.11 -0.39 13 0.016 0.013 0.033 $B7 IVe_1$ a							0.048	0.011	0.023	B8 V .	
209322 8408 5.95 -0.1/ -0.65 13 0.029 0.011 0.027 B5 Vn c											a
	209522	8408	5.95	-0.17	-0.65	13	0.029	0.011	0.027	B5 Vn	c

TABLE I. (Continued).

HD	HR	V	B-V	U - B	n	σ_V	σ_{B-V}	σ_{U-B}	Sp. T.	Refs
212571 214748	8539 8628	4.49 4.17	$0.02 \\ -0.11$	-1.01 -0.31	4 18	0.037	0.013	0.029	B1 Ve ₁ B8 Ve	a c

a Lesh (1968).

e Polidan and Peters (1976).

3, where we plotted the spectral type versus the B-V color in the former, and versus the U-B color in the latter. In the first case, all the stars are below the standard sequence of FitzGerald, but in the second one the stars appear scattered around it. The clearest explanation for this particular distribution is the already mentioned ultraviolet excess affecting mainly the U-B color. The supergiant stars are not included in either diagram.

As the ultraviolet excess is independent of reddening, we can use this fact to measure its amount. This may be

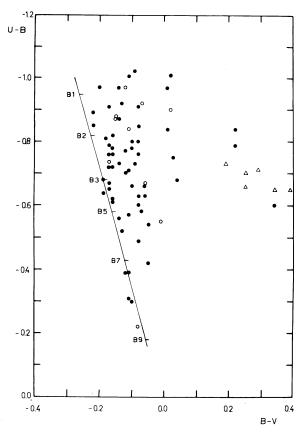


FIG. 1. The (U - B, B - V) diagram of the observed Be stars. The full circles correspond to dwarf stars, the open circles to giants, and the triangles to supergiants. The solid line represents the main sequence taken from FitzGerald (1970).

done through the reddening-free Q value which is defined by $Q_{\mathrm{UBV}} = U - B - (E_{U-B}/E_{B-V})(B-V)$. We can also get another value of Q from the spectral classification (Q_{ST}) , and the calibration of Gutierrez-Moreno (1975). Both Q's are given in Table II. The difference $Q_{\mathrm{ST}} - Q_{\mathrm{UBV}} = \Delta Q$ gives for each star a value which is related to the ultraviolet emission. This difference ΔQ is mostly negative as many of the Be stars have a smaller Q value (more negative) than the one which they would have if no ultraviolet excess was present.

Let us now consider the photometric variability. The 73 Be stars of Table I with five or more observations were compared to 10 B-type stars purposely observed at the same nights along with the Be stars' program.

In order to obtain the percentage of Be stars that are variable, we proceeded as follows: (1) The dispersion distribution of the Be stars in each color and in the V magnitude was thought of as being the sum of two distributions: that of the nonvariable and that of the variable Be stars. (2) The shape of the nonvariable Be stars distributions was adopted from the comparison B-type stars. (3) The contribution of the variable star distri-

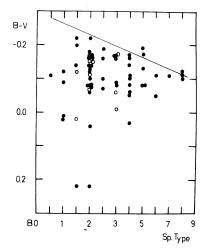


FIG. 2. The observed B - V color vs the spectral type for the Be stars. FitzGerald's main sequence is indicated by a solid line. The symbols for the stars are the same as in Fig. 1.

b Hiltner et al. (1969)

c Bright Star Catalogue.

^d Burnichon et al. (1967).

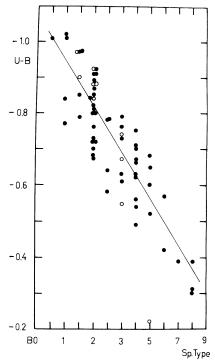


FIG. 3. The observed U - B color vs the spectral type. The symbols are the same as in Fig. 2.

bution was considered negligible between zero and a certain limit. (4) These limits were chosen as close as possible to the maximum of the non-variable stars distribution. Their values are 0.025, 0.015, and 0.020 in the V, B - V, and U - B, respectively. (5) The dispersion distributions for the Be and the comparison B-type stars were matched between zero and the quoted limits using the χ^2 criterion. (6) The percentage of variable Be stars was obtained by subtracting both distributions appropriately scaled.

Table III shows the percentage of variability derived from every magnitude and color. As a comparison, the results obtained by Ferrer and Jaschek (1971) are also included. The limits used in both investigations not only have different values but also different meanings as explained in the notes to the Table.

Our data are presented in Fig. 4, where the dark area is the inferred distribution of the fraction considered nonvariable. The χ^2 distribution was used to represent the shape of the dark area for values larger than the limits quoted above.

III. BALMER LINE PHOTOMETRY

It is well known that some physical properties of the early-type stars can be derived from the H_{β} line. One very important parameter is the absolute magnitude, but for the Be stars this is not easy if we are employing the common procedure of measuring the H_{β} line (Crawford et al. 1975).

TABLE II. Determination of the ultraviolet excesses through the Q values.

HD	Q_{UBV}	$Q_{ m ST}$	ΔQ
28497	-0.875	-0.754	-0.121
30076	-0.746	-0.722	-0.024
35165	-0.561 -0.796	-0.456	-0.105
41335	-0.796	-0.722	-0.074
42054	-0.471	-0.522	0.051
43544	-0.675	-0.656	-0.019
44458	-0.847	-0.785	-0.062
48917	-0.780	-0.722	-0.058
50013	-0.834	-0.754	-0.080
52437	-0.689	-0.722	0.033
54309	-0.776	-0.722	-0.054
56014	-0.630	-0.589	-0.041
56139	-0.636	-0.722	0.086
57150	-0.733	-0.722	-0.011
58155	-0.562	-0.522	-0.040
58343	-0.534	-0.656	0.122
58978	-0.933	-0.830	-0.103
60606	-0.672	-0.589	-0.083
60855	-0.620	-0.722	0.102
61925	-0.389	-0.393	0.004
63462	-0.958	-0.785	-0.173
65875	-0.715	-0.656	-0.059
66194	-0.706	-0.722	0.016
67888	-0.508	-0.522	0.014
68980	-0.889	-0.754	-0.135
72067	-0.606	-0.722	0.116
75311	-0.650	-0.589	-0.061
77320	-0.680	-0.589	-0.091
78764	-0.713	-0.722	0.009
83953	-0.502	-0.393	-0.109
86612	-0.597	-0.522	-0.075
88661 88825	-0.856 -0.439	-0.722 -0.522	-0.134 0.083
	-0.439 -0.544	-0.522 -0.589	
89890 91465	-0.544 -0.640	-0.589 -0.522	0.045 -0.118
102776	-0.507	-0.522 -0.589	0.082
105435	-0.833	-0.722	-0.111
105521	-0.578	-0.589	0.011
106911	-0.439	-0.456	0.017
110432	-0.987	-0.722	-0.265
112078	-0.518	-0.522	0.004
112070	-0.550	-0.454	-0.096
113120	-0.914	-0.754	-0.160
120307	-0.743	-0.722	-0.021
120324	-0.796	-0.722	-0.074
120991	-0.873	-0.722	-0.151
124367	-0.592	-0.522	-0.070
127972	-0.701	-0.754	0.053
131492	-0.769	-0.522	-0.247
137387	-0.688	-0.785	0.097
142983	-0.170	-0.456	0.286
148184	-0.938	-0.754	-0.184
155806	-0.977	-0.908	-0.069
157042	-0.766	-0.722	-0.044
158427	-0.613	-0.722	0.091
167128	-0.631	-0.589 -0.722	-0.042
173948	-0.780	-0.722	-0.058
178175	-0.630	-0.722	0.092
205637	-0.516	-0.656	0.140
209409	-0.322	-0.323	0.001
212571	-1.024	-0.785	-0.239

To resolve this problem, in addition to the H_{β} line, the H_{α} and H_{γ} lines were measured with the same method outlined by Crawford (1958).

The original photoelectric measures for those lines carried out in 1970 and 1972 were already presented (Feinstein 1974). Later on, more measures were obtained at different observatories: Cerro Tololo, La Silla (both in Chile), and Porto Alegre (Brazil). Also additional

TABLE III. Percentage of variability.

	Ferrer and .	Jaschek (1971)	This work		
	Limita	% variable	Limitb	% variable	
V	0,m04	53	0,m025	77	
B-V	0.022	56	0.015	48	
U - B	0.04	35	0.020	68	

a All stars with dispersions larger than this limit are considered vari-

measures in H_{β} made in 1968, but not presented before, are included here.

As usual, the instrumental system of the β index was transformed into the standard system through the list of standard stars given by Crawford and Mander (1966), plus a few more stars in the southern hemisphere from the list of Crawford, Barnes, and Golson (1970). The α and γ indices for the standard stars were taken from Table II of Feinstein (1974).

The filters for the H_{α} and H_{γ} lines employed at Cerro Tololo were always those which defined the system (Feinstein 1974), but for the H_{α} measures at Porto Alegre, a set of interference filters made by Infrared Industries was used. A good agreement from the comparison of the measures suggests that there are no systematic effects in the transformation.

The average values of the indices for the Be standard stars, the dispersion in each index and the number of measures are presented in Table IV. The mean-square

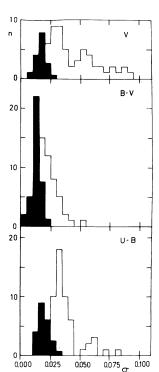


FIG. 4. The distribution of the observed dispersions of the V, B - V, and U - B for the Be stars. The dark area is the inferred distribution of the fraction considered nonvariable

errors for the indices measured at different observatories and for stars not extrapolated in the reductions, are about $\epsilon_{\text{PA}} = \pm 0.012$ (Porto Alegre), $\epsilon_{\text{CT}} = \pm 0.007$ (Cerro Tololo), and $\epsilon_{LS} = \pm 0.005$ (La Silla).

The β vs α diagram for all measured Be stars is plotted in Fig. 5, where the sequence for the normal stars obtained by Feinstein (1976) is also presented.

The Be stars may have changes in the emission of the Balmer lines. In this case the variations displayed by the α and β indices appear in two different ways. Some of the Be stars show differences between the average of our measures and those reported in the literature (see i.e., Lindemann and Hauck 1973). Another possibility of detecting the amount of variation in the indices is through the analysis of the frequency histograms of the dispersions.

But, before doing this, we have to look for possible causes of errors in these quantities. Because of the particular location of Be stars in the β vs α diagram relative to normal stars (see Fig. 5), and as standard stars are selected only amongst the normal stars, we have the unfortunate situation that, in the photometric reduction of each observing night, the solution obtained with the standard stars must be extrapolated to give the indices of most emission-line stars. This situation is five times worse in the α index than in the β index. To look for errors introduced by this circumstance, we have plotted the observed dispersion in each index versus the proper index in Figs. 6 and 7. A dashed line was also drawn to distinguish the stars extrapolated in the solution $\alpha < 1.$ ^m44 and β < 2.53, from those that are not. The foreseen effect is clearly present in the α index dispersions but no effect appears in β . Therefore the σ_{α} should be used with extreme care for statistical purposes as it is clearly contaminated by extrapolation errors.

Figure 8 shows the distribution of the observed dispersions in the α , β , and γ indices of the Be stars, as well as those of a suitable number of non-emission comparison stars observed simultaneously with the former. Leaving aside the σ_{α} , the distribution of the emission and non-emission dispersions are similar, and we find that about 15% of the Be stars have β indices indicating variability, the fraction being smaller for the γ index.

This result is obtained over a 4- to 8-year interval of measurements that is shorter than the 13 year interval quoted by Feinstein (1973), which gives a larger percentage of variations. This fact indicates that the H β line variations are mostly of long-term character.

The stars with dispersions $\sigma_{\alpha} > 0.04$ and $\sigma_{\beta} > 0.03$ are listed in Table V, with an indication of some other data which presumably may denote peculiarities. We notice that in many cases such stars are characterized by small α indices ($\alpha < 1.^{m}40$), but also large σ_V which suggests that in all of them the changes are displayed in the H α emission as well as in the magnitude.

ables.

b Values used as upper limits for the matchings between the B and Be dispersion distributions.

TABLE IV. Observed α , β , and γ indices of the Be stars.

HD	α	β	γ	σ_{α}	σ_{eta}	σ_{γ}	n	n	n
28497	1.320	2.464	2.044	0.017	0.016	0.008	11	12	11
30076	1.302	2.470	2.058	0.027	0.024	0.008	11	18	11
35165	1.452	2.597	2.114	0.026	0.014	0.007	8	11	8
37795	1.420	2.643	2.171	0.016	0.009	0.004	7	16	8 7
41335	1.294	2.456	2.054	0.048	0.015	0.022	9	8	9
42054	1.408	2.605	2.153	0.015	0.035	0.005	6	7	6
43544	1.436	2.579	2.131	0.034	0.016	0.038	7	7	7
44458	1.292	2.453	2.035	0.063	0.007	0.013	6	6	6
45677	0.992	2.305	2.021	0.070	0.048	0.027	10	10	8
45910	1.290	2.440	2.059	0.076	0.029	0.020	9	9	8 9 5 4
48917	1.384	2.519	2.051	0.020	0.025	0.004	5	5	5
50013	1.361	2.478	2.043	0.011	0.013	0.005	4	4	4
52437	1.469	2.612	2.167	0.021	0.017	0.006	6	6	6
54309	1.291	2.460	2.065	0.044	0.073	0.015	6	6	6
56014	1.417	2.568	2.096	0.009	0.019	0.009	10	12	10
56139	1.345	2.522	2.083	0.027	0.020	0.018	8	9	8
57150	1.341	2.502	2.089	0.076	0.072	0.033	5	6	5
58155	1.438	2.606	2.103	0.016	0.025	0.012	5	6	5 5 4
58343	1.351	2.566	2.114	0.025	0.014	0.001	4	4	
58978	1.357	2.494	2.044	0.032	0.011	0.008	4	4	4
60606	1.258	2.469	2.061	0.036	0.005	0.007	4	4	4
60855	1.472	2.614	2.106	0.018	0.010	0.008	5	5	5
61925	1.460	2.612	2.139	0.024	0.013	0.011	5	5	5
63462	1.368	2.479	2.030	0.025	0.011	0.008	4	4	5 4 4 3 5 4
65875	1.195	2.445	2.053	0.032	0.010	0.006	4	3	4
66194	1.410	2.548	2.098	0.025	0.033	0.012	3	3	3
67888	1.386	2.562	2.117	0.023	0.016	0.005	5	4	5
68980	1.282	2.405	2.017	0.035	0.031	0.005	4	5	
72067	1.444	2.624	2.124	0.015	0.008	0.026	5	4	5
75311	1.463	2.620	2.139	0.018	0.022	0.007	6	6	6
77320	1.387	2.549	2.080	0.015	0.011	0.007	6	7	6
78764	1.428	2.552	2.078	0.015	0.016	0.021	6	6	6
83953	1.366	2.591	2.145	0.029	0.014	0.006	17	18	8
86612	1.326	2.580	2.147	0.040	0.026	0.019	9	10	9
88661	1.283	2.445	2.035	0.022	0.020	0.008	6	7	5
88825	1.364	2.578	2.129	0.027	0.005	0.006	7	8	6
89890	1.470	2.612	2.134				2	2	2 5
91465	1.314	2.501	2.073	0.037	0.011	0.009	6	6	5
92964	1.453	2.517	2.033	0.013	0.016	0.008	9	9	9
102776	1.452	2.636	2.160	0.013	0.015	0.007	8	8	6
105435	1.306	2.460	2.051	0.023	0.014	0.009	9	7	7
105521	1.449	2.578	2.106	0.020	0.016	0.008	9	9	7
106911	1.488	2.693	2.204	0.015	0.014	0.006	8	8	6
110432	1.264	2.372	1.990	0.023	0.010	0.006	8	8	6
112078	1.483	2.676	2.172	0.004	0.012	0.014	6	5	4
112091	1.309	2.591	2.166	0.031	0.018	0.004	8	8	6
113120	1.353	2.491	2.043	0.024	0.046	0.008	4	4	3
115842	1.426	2.510	2.047	0.009	0.041	0.005	5	5	3
120307	1.476	2.614	2.125	0.005	0.012	0.002	6	6	3
120324	1.398	2.558	2.083	0.065	0.053	0.012	5	5	3
120991	1.345	2.486	2.057	0.039	0.008	0.003	4	4	3
124367	1.245	2.532	2.124	0.028	0.007	0.007	5	5	3
127972	1.471	2.607	2.108	0.003	0.008	0.005	4	4	4
131492	1.406	2.597	2.121	0.025	0.027	0.011	5	5	4
137387	1.288	2.497	2.060				3	3	3
142983	1.340	2.565	2.131	0.035	0.005	0.003	4	4	4
148184	1.181	2.399	2.021	0.056	0.046	0.004	4	8	4
148379	1.454	2.499	2.045				3	3	3
148688	1.428	2.521	2.052	0.014	0.011	0.008	4	4	4
149404	1.418	2.514	2.004				2	2	2
152235	1.443	2.524	2.057				3	3	3
152236	1.416	2.474	2.025	0.005	0.012	0.010	4	4	4
152667	1.424	2.502	2.041				2	2	2
154090	1.433	2.534	2.060	0.001	0.013	0.005	2 2 2	4	2 2
155806	1.300	2.498	2.035					3	2
157042	1.255	2.473	2.064				1	1	1
158427	1.206	2.485	2.100				1	1	1
167128	1.419	2.582	2.104	0.019	0.012	0.004	3	9	3
173948	1.425	2.574	2.085	0.023	0.011	0.007	2	15	2
178175	1.426	2.564	2.099	0.021	0.008	0.006	2	9	2 2 4
205637	1.384	2.566	2.107	0.030	0.010	0.005	$\bar{4}$	13	$\bar{4}$
209014	1.410	2.678	2.201	0.014	0.005	0.015	3	ii	3
209409	1.347	2.598	2.166	0.032	0.010	0.005	5	9	5
209522	1.463	2.593	2.138	0.007	0.012	0.013	4	9	4
			2.130	0.007	0.012	0.013		,	7

TABLE	IV. ((Continued)	١.

HD	α	β	γ	σ_{lpha}	σ_{eta}	σ_{γ}	n	n	n
212571	1.302	2.413	2.025	0.039	0.031	0.008	7	14	7 5
214748	1.433	2.666	2.187	0.013	0.005	0.008	5	16	

IV. THE EMISSION INDICES

We define here the emission indices e_{α} and e_{β} of the Be stars as the differences between the observed values of the indices α and β and those of a normal star with the same spectral type characteristics but without emission: α_0 and β_0 . These balmer line indices for stars without emission are approximated by the expression:

$$\alpha_0 = c\beta_0 + d,\tag{1}$$

where
$$c = 0.2133$$
 and $d = 0.912$. (2)

The emission-line ratio e_{β}/e_{α} was studied by Feinstein (1976), cf Table II of that paper, and here we use the approximation

$$e_{\beta}/e_{\alpha} = (\beta_0 - \beta)/(\alpha_0 - \alpha) = b\beta_0 + a, \qquad (3)$$

where
$$a = 9.667$$
 and $b = -3.333$. (4)

Therefore, the observed indices α , β of the emissionline stars can be converted in the values α_0 , β_0 of the same stars after subtracting the emission line effects. The procedure consists in solving the system of equations formed by (1) and (3). Then, the β_0 value is obtained as one of the roots (using the negative value of the square root) of the second-degree equation:

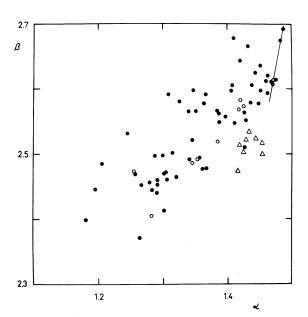


FIG. 5. The β versus α diagram for the Be stars. The line is the sequence for the normal stars taken from Feinstein (1976). The symbols are the same as in Fig. 1.

$$A\beta_0^2 + B\beta_0 + C = 0, (5)$$

where A = bc,

$$B = b(d - \alpha) + ac - 1,$$

$$C = a(d - \alpha) + \beta.$$
(6)

 α_0 can then be obtained from Eq. (1), and the emission indices simply through

$$e_{\alpha} = \alpha_0 - \alpha, \quad e_{\beta} = \beta_0 - \beta. \tag{7}$$

The computed values of β_0 , e_{α} , and e_{β} are listed in Table VI.

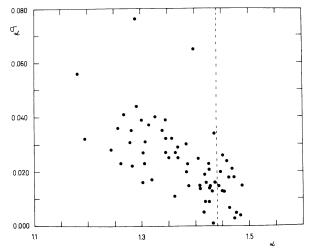


FIG. 6. The dispersion σ_{α} versus α for the Be stars.

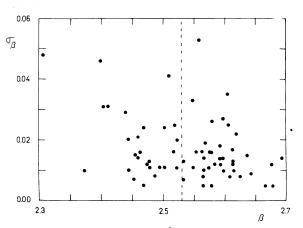


FIG. 7. The dispersion σ_{β} versus β for the Be stars.

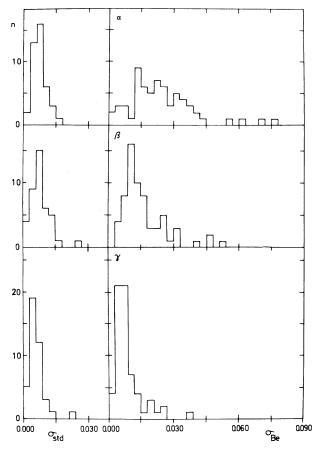


FIG. 8. The frequency distribution of the observed dispersions in α , β , and γ indices for the Be and B stars.

We shall demonstrate here that the de-emissioned value β_0 of a Be star is an absolute magnitude indicator as good as the β value of normal stars. Twelve Be stars belonging to clusters and associations were selected because their distances are well known. For those stars the computations were made with only α and β indices measured simultaneously. In Fig. 9 their absolute magnitudes are plotted against the de-emissioned index β_0 . The results are tabulated in Table VII. The observed β values were also included in the same figure and con-

TABLE V. Be stars with dispersions $\sigma_{\alpha} > 0.^{m}04$ or $\sigma_{\beta} > 0.^{m}03$.

HD	σ_{lpha}	σ_{eta}	α	σ_V
42054	0.015	0.035	1.408	0.028
44458	0.041	0.007	1.269	0.041
45677	0.070	0.048	0.992	0.161
45910	0.076	0.029	1.290	0.039
54309	0.044	0.021	1.291	0.055
66194	0.025	0.033	1.410	0.034
68980	0.035	0.031	1.282	0.106
86612	0.040	0.026	1.326	0.076
115842	0.009	0.041	1.426	0.022
120324	0.065	0.053	1.398	0.123
148184	0.056	0.046	1.181	0.079
212571	0.039	0.031	1.302	

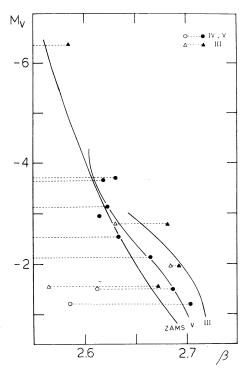


FIG. 9. The relation of M_V vs the β_0 index for the Be stars belonging to clusters and associations (see text).

nected to the corresponding β_0 values by dashed lines. The (β, M_V) calibration of Crawford (1978), as represented in his Fig. 24, is also plotted. It is noted that stars of different luminosity are clustered along the corresponding lines.

Turning now again to the emission indices e_{α} and e_{β} , we have compared them with the corresponding values obtained through the visual inspection of spectrograms by Lesh (1968), and by Hiltner, Garrison, and Schild (1969). This system ranges from no indication of emission to the strongest emission features indicated by the symbols 1, 1+, 2, 2+, 3, 3+, and 4, subindexed to the letter e at the end of the MK spectral type designation. The Balmer lines observed for emission are those confined to the blue, and of course the H α line is not included.

Figure 10 shows the comparison of both systems for only those stars which have 4 or more photometric measures. Part a shows the comparison with the e_{α} index, while part b with the e_{β} index. Assigning the values 1.5, 2.5, and so on to the symbols $1+, 2+, \ldots$, the regression lines of the spectroscopic emission index (em) against the photometric indices were computed. For 47 stars the results become:

em =
$$12.72 e_{\alpha} - 0.03$$
, $r = 0.81$, $\sigma_{em} = 0.69$, (8)

em =
$$15.52 e_{\beta} - 0.07$$
, $r = 0.86$, $\sigma_{\text{em}} = 0.60$, (9)

where r is the correlation coefficient and σ_{em} the dis-

TABLE VI. The corrected eta_0 index and the emission indices e_lpha and

HD	eta_0	e_{α}	e_{β}
29407	2 600	0.149	0.145
28497 30076	2.609 2.626	0.148 0.170	0.145 0.156
35165	2.614	0.018	0.130
37795	2.690	0.066	0.017
41335	2.630	0.193	0.174
42054	2.662	0.072	0.057
43544	2.611	0.033	0.032
44458	2.635	0.205	0.182
45677	2.674	0.490	0.369
45910	2.612	0.179	0.172
48917	2.602	0.083	0.083
50013	2.586	0.103	0.108
52437	2.613	0.000	0.001
54309	2.648	0.186	0.156
56014	2.619	0.054	0.051
56139	2.636	0.129	0.114
57150	2.627	0.169	0.155
58155	2.639	0.037	0.033
58343	2.667	0.130	0.101
58978	2.604	0.110	0.110
60606	2.651	0.220	0.182
60855	2.612	0.003	0.002
61925	2.623	0.012	0.011
63462	2.580	0.094	0.101
65875	2.667	0.286	0.222
66194	2.605	0.058	0.057
67888 68980	2.640	0.089	0.078
	2.593 2.652	0.183	0.188
72067 75311	2.629	0.034 0.010	0.028 0.009
77320	2.627	0.010	0.009
78764	2.590	0.037	0.038
83953	2.678	0.117	0.087
86612	2.692	0.160	0.112
88661	2.621	0.188	0.17ϵ
88825	2.669	0.117	0.091
89890	2.612	-0.001	0.000
91465	2.641	0.161	0.140
92964	2.510	-0.005	-0.007
102776	2.658	0.027	0.022
105435	2.616	0.164	0.156
105521	2.595	0.017	0.017
106911	2.692	-0.002	-0.001
110432	2.583	0.199	0.211
112078	2.676	0.000	0.000
112091	2.707	0.181	0.116
113120	2.614	0.129	0.123
115842	2.545	0.029	0.035
120307	2.607	-0.008	-0.007
120324	2.626	0.074	0.068
120991	2.607	0.123	0.12
124367	2.697	0.242	0.165
127972 131492	2.604	-0.004	-0.003 0.060
131492	2.657 2.654	0.073 0.190	0.060
13/38/	2.654	0.190	0.13
148184	2.648	0.142	0.100
148184	2.482	-0.013	-0.249
148688	2.555	0.029	0.034
149404	2.560	0.040	0.03
152235	2.537	0.010	0.013
152236	2.516	0.010	0.042
152667	2.538	0.029	0.036
154090	2.563	0.026	0.029
155806	2.647	0.177	0.149
157042	2.656	0.223	0.183
158427	2.685	0.279	0.200
167128	2.631	0.054	0.049
173948	2.617	0.045	0.043
178175	2.606	0.042	0.042
205637	2.645	0.092	0.079
209014	2.727	0.084	0.049
209014	2.121	0.007	0.04.

TABLE VI. (Continued).

HD	eta_0	e_{α}	e_{β}
209522	2.596	0.003	0.003
212571	2.583	0.161	0.170
214748	2.703	0.056	0.037

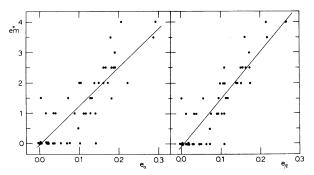


FIG. 10. The emission from visual inspection of spectrograms (em) vs the photoelectric emission indices e_{α} and e_{β} .

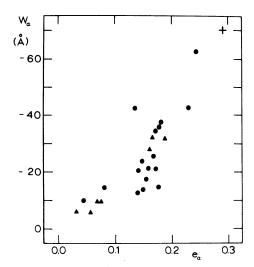


FIG. 11. The emission index e_{α} versus the equivalent width $W\alpha$. Circles are used for photographic determinations of $W\alpha$, triangles for photoelectric. The plus sign corresponds to χ Oph determined photoelectrically by Gray and Marlborough (1974).

persion of the spectroscopic emission indices relative to the regression line. As expected, the best correlation is obtained with the e_{β} index, since the spectroscopic observations are confined to the blue.

Finally, the emission indices e_{α} and e_{β} are compared in Figs. 11 and 12 with the emission equivalent width $W\alpha$ and $W\beta$, respectively. The equivalent widths were obtained from the works of Briot (1971), Bahng (1976), and Dachs *et al.* (1977). The shape of the observed

B5/IIIp

6.34

HD

22192

23302

23480

23630 60855 66194

105435

110432

112091

120324

142983

148184

cluster

α Per

Pleiades Pleiades

Pleiades NGC 242

NGC 251

NGC 4609

Sco-Cen

Sco-Cen

Sco-Cen

Sco-Cen

Sco-Cen

•	$V-M_v$	M_v	β	eta_0	Sp. T.
	6.35	-2.12	2.483	2.665	B2/Ve ₂
	5.65	-1.95	2.684	2.693	B6/III
	5.65	-1.49	2.613	2.687	B6/IV
	5.65	-2.78	2.631	2.682	B7′/III
22	8.65	-2.95	2.615	2.615	$B2/Ve_{1+}$
16	8.36	-2.54	2.547	2.634	B2/IVpne ₁₊
	6.17	-3.65	2.463	2.619	$B2/IVne_{2+}$
09	11.68	-6.38	2.371	2.585	B2/?pe ₄
	6.30	-1.20	2.586	2.704	$B5/Vne_{1+}$
	7.16	-3.69	2.515	2.631	$B2/IV-Ve_3$

2.565

TABLE VII. Data for Be stars in clusters and associations.

relation can be understood if we remember certain features: (a) In contrast to the case for the spectroscopic emission index whose comparison we have just presented, the observations were not obtained simultaneously. (b) The equivalent width corresponding to $e_{\alpha} = e_{\beta} = 0$ is not constant but varies with spectral type. As a consequence, we are expecting a kind of band rather than a narrow regression line. (c) When the emission line is weak, the observer carefully assumes the shape of the underlying absorption line and gives the equivalent width of the emission feature only. As the emission gets stronger the absorption line is filled in and finally it disappears completely; no correction is then applied. We notice in Figs. 11 and 12 that the transition between weak and strong emission lines occurs at about $e_{\alpha} = 0.$ ^m12 and e_{β} = 0.^m10. This situation breaks the relation into two different sections and automatically forces the weak line portion to pass through the origin.

Figure 13 is a plot of the ultraviolet excess, as measured by ΔQ , and the emission in the Balmer lines represented by the e_{α} index. We must remember here that observational errors, which usually are believed to be ± 1 subclass for the spectral type determination (Jaschek and Jaschek 1973), lead to a dispersion of ± 0.07 in the ΔQ . In spite of having used always the spectral types from the same authors for the sake of consistency, there are some obvious cases of possible errors in the classifications. The two most extreme cases of deviation we have detected from the relation e_{α} vs ΔQ : HD 131492 and 137387,

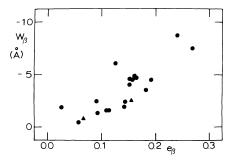


FIG. 12. The emission index e_{β} versus the equivalent width $W\beta$. The symbols are the same as in Fig. 12.

were examined. We have searched for other spectral type classifications for both stars using the MK Catalogues of Jaschek et al. (1964), Kennedy and Buscombe (1974), and Buscombe (1977), and also the Michigan Spectral Catalogue (Houck and Cowley 1975). From these spectral types we conclude that the most likely classification for HD 131492 is one subclass earlier, and for HD 137387 two subclasses later than those assigned in Table I. Using the revised data we have plotted the corrected positions for these two stars together with the original ones in Fig. 13. The new positions (open circles) are in much better agreement with the general trend of the remaining points

2.673

It is clear that a correlation exists between both sets of data in the sense that the ultraviolet excess (Balmer continuum emission) is produced by the same mechanism as Balmer line emission: the gaseous envelope. A few positive ΔQ values give an indication that some stars have the Balmer discontinuity in absorption by an amount larger than predicted by the spectral type (i.e., "shell" stars), while we have no analogous situation in the lines. This fact can be explained if we recall that "shell" absorption lines are too narrow to be detected by the line measuring technique used here.

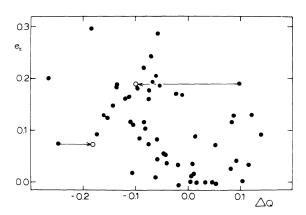


FIG. 13. The emission index e_{α} versus the ultraviolet excess ΔQ (see text).

V. THE ROTATIONAL VELOCITY V SIN i

Using the $V \sin i$ data from Uesugi's (1978) compilation we have represented in Fig. 14 a plot of the observed dispersion in visual magnitude, σ_{ν} , versus the projected rotational velocity. Within the frame of the presently accepted model for Be stars, the observed decrease of overall brightness variations for the stars of high-projected rotational velocity can be explained in the following way. As it is assumed that Be stars rotate close to break-up velocity, which is almost the same for all masses, the value of $V \sin i$ is mainly a function of the inclination. Therefore, stars with high-projected rotational velocity are, on the average, seen from the equator. Two kinds of variations in the visible continuum can be foreseen for Be stars surrounded by ring-like equatorial gaseous envelopes: short- and long-term variations. The short-term variations are caused by inhomogenities in the gaseous ring, which are responsible for the variations in equator-on Be stars. On the other hand, long-term variations can be explained by an overall change of the scattering optical depth of the gaseous ring. This variation is almost cancelled for stars seen equator-on, as the observer "sees" the star dimmed when the ring is bright and viceversa. For perfect scattering and spherically symmetrical shells, the observed overall flux is independent of the shell's optical depth. For stars seen pole-on the variations in the extent and density of the gaseous ring may be detected as overall changes in the observed flux.

Our observations were on purpose spaced sparsely in time as we have in mind to detect long-term variations, therefore, it is not surprising that the observed dispersion of the brightness in the continuum is larger for those stars seen pole-on, i.e., those with $V \sin i \le 285 \text{ km/sec.}$

If the adopted model is correct the intensity variations of the emission lines such as $H\beta$, which is an indicator of the gaseous envelope's extent and density, should be correlated with the visual magnitude dispersion. The plot of the σ_V versus σ_β , only for stars seen pole-on ($V \sin i \le 285$ km/sec), presented in Fig. 15 shows a good correlation between both quantities, even though both sets of observations are not simultaneous.

In Fig. 16 the strength of the Balmer line emission is plotted against the projected rotational velocity. Dif-

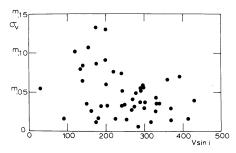


FIG. 14. The visual magnitude dispersion σ_V vs $V \sin i$.

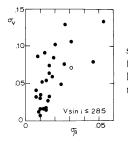


FIG. 15. The magnitude dispersion σ_V vs the β index dispersion σ_β for the Be stars with $V \sin i < 285$ km/sec. The open circle corresponds to π Aqr (Nordh and Olofsson 1977).

ferent causes of mass loss place the stars in different locations in the e_{α} versus $V\sin i$ plane. Supergiant emission-line stars, shown as open circles, fall in the small velocity-little emission lower left corner; extreme Be stars (Schild 1973) shown as triangles, are located in the low velocity-high emission upper left corner. The remaining stars depicted by filled circles fill up the rest of the plane. If we ascribe the majority of the remaining 13 circles located in the upper left quadrant to the extreme Be class, then we have that emission increases with $V\sin i$ for the other stars.

The final conclusion regarding the photometric data

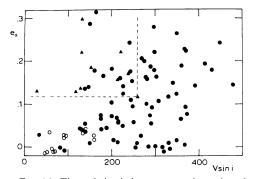


FIG. 16. The emission index e_{α} versus the projected rotational velocity $V \sin i$ for the Be stars. The open circles correspond to supergiant stars, the triangles are extreme Be stars according to the classification of Schild (1973), and the full circles are dwarf Be stars.

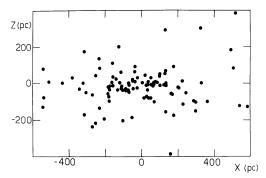


FIG. 17. The Be stars projected in a plane perpendicular to the galactic plane and in the direction centeranticenter.

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and $V \sin i$ suggests that the structure of the material outside the star is distributed in a ring. When its density changes, the modification in brightness is evident only when the ring is not in the same plane as the observer.

VI. GALACTIC DISTRIBUTION

With the method outlined above, that is using β_0 and Crawford's (1978) calibration, the absolute magnitude and distance of each dwarf Be star was derived.

In Fig. 17 the Be stars are plotted in the X - Z plane as defined by Stothers and Frogel (1974). No indication of the Gould's Belt appears in the distribution, but the number of stars is too low to draw any definite conclusion.

As all the observed stars are listed in the Bright Stars Catalogue (V < 6.2) and the intrinsically faintest Be stars have absolute magnitudes of about $M_V = -0.8$, we have a complete sample for all the Be stars that have distance modules smaller than $V - M_v = 7.0$. Assuming no interstellar absorption, our sample is complete to about 250 pc from the Sun. Taking into account this limit, we have performed a Z distribution statistic in a cylinder 200 pc radius to avoid incompleteness effects. The resulting galactic concentration parameter for the dwarf Be stars is $\beta = 40$ pc. This parameter is completely similar to that of early type B stars of population I from which the Be stars are recruited.

VII. CONCLUSIONS

The present study has been devoted to obtain information on the behavior of bright Be stars over a long period of time. From about 15 years of observations in the UBV and six to eight years in the Balmer lines, the resulting main conclusions are as follows.

- (1) It is possible to obtain for each star the ultraviolet excess by means of the reddening free Q value, assuming that the spectral type is reliable.
- (2) About 70% of the Be stars are variable in V and U - B. For B - V the variability decreases to 50%. In a shorter time interval the H_{β} line shows variations in 15% of the Be stars. Most of the variations in the continuum and in the lines are of long-term character.
- (3) The α and β values provide a way to detect the presence of hydrogen emission, the amount of which can be measured by the indices e_{α} and e_{β} . These indices appear to be well correlated to some spectroscopic features, such as equivalent widths. A dependence of e_{α} on the ultraviolet excess derived from the Q value also appears possible.
- (4) For stars seen pole-on, the variations of the H_{β} line (σ_{β}) are correlated with the variations in the continuum (σ_V) , which is in accord with a model of Be star having a ring-like gaseous envelope.
- (5) For each Be star, the observed β index corrected for the emission index e_{β} is a good indicator of absolute magnitude. Thus it becomes possible to study the Be stars in the same way as non-emission B-type stars.

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