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THE RADIAL VELOCITIES AND SPECTRAL FEATURES OF TWENTY-ONE Be STARS WITH LARGE ROTATIONAL TERMS

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Presented here are the radial velocities of twenty-one Be stars with galactic longitudes such that the effect of galactic rotation on radial velocity is large. This programme came about in the following way. About 15 years ago it was believed that the emission line stars were intrinsically brighter than those lacking emission lines[1]. To test this hypothesis the writer in 1938 chose from the Mount Wilson Catalogue of Be- and Ae-type stars[1] a group of 84 stars of spectral types B3e to B5e for which velocities had been measured, and attempted to solve for the distances and absolute magnitudes by analysing the velocities for galactic rotation effects. The results were of little value because the stars were relatively bright and accordingly nearby, and because many of them were of such galactic longitudes as to have small rotational terms. To bolster this list of stars, then, those stars were chosen from the Mount Wilson Catalogue which are accessible at this Observatory, which are between the spectral classes B3e and B5e, and which lie within 14° of the galactic longitudes 10°, 100°, 190° and 280°. Radial velocity observation of these stars was commenced in 1938. Before the observations had been completed, R. E. Wilson published an investigation of the mean absolute magnitudes of O- and B-type stars[2] in which he used proper motion data as well as radial velocity data, and demonstrated that the emission stars were no brighter than stars of corresponding spectral class which lacked emission lines. Seyfert and Popper had reached a similar conclusion with respect to c-stars[3] at about the same time in the course of a study of new radial velocity measures of faint B-type stars. In this way the original intention of the programme undertaken here was anticipated, and so the observation of these stars was deferred in favour of other programmes. Now the observations have been completed, and the results are presented with a brief discussion of how they support the conclusions of others already referred to.

The spectra of most of these stars have very poor lines for velocity measures, and so at least five plates were taken for each

TABLE I

MWC	H.D.	α (1900)	δ (1900)	Vis. Mag.	Type M.W.	Velocity km./sec.	P.E.	Plates	Lines	$\bar{e}$	Inter-stellar Vel.	Remarks
		h m	° ′									
10	6343	00 59.4	+ 65 26	7.1	B5eβ	− 7.8	1.9	7	6-9	6.2		Ca^+ stellar
13	9105	01 24.6	+ 62 51	7.5	B5s(e)	(− 33.4) var.	—	6	5-11	3.7		Ca^+ stellar
23	12302	01 55.6	+ 59 12	8.2	B3e	+ 5.7	3.6	7	6-11	11.3	+ 2.3	See note
29	13661	02 08.1	+ 54 04	8.6	B(3)ne	− 50.5	7.1	6	5-6	11.4	− 12.1	
49	15472	02 24.4	+ 70 30	8.0	B4ne	(− 62.1) var.	—	6	4-8	10.7	− 17.6	
63	20017	03 07.9	+ 48 19	7.9	Bne	− 28.4	6.7	5	3-6	11.8	− 6.7	
76	23982	03 44.3	+ 63 11	8.1	B3e	− 13.2	3.6	6	5-7	9.9	− 0.6	
79	24560	03 49.3	+ 44 38	7.8	B(3)ne	− 10.4	2.1	6	5-8	7.2	− 1.9	
82	26420	04 05.7	+ 41 52	7.6	B3neα	+ 2.8	3.4	6	2-6	15.2	+ 20.8	
83	26906	04 10.1	+ 45 58	8.6	B(3)ne	− 14.1	8.3	5	2-5	14.7	− 1.2	
114	37115	05 31.0	− 5 41	8.2	B5ne	+ 36.7	5.4	5	4-7	10.1		
139	44637	06 17.7	+ 15 09	7.7	B3e	(+ 20.0) var.	—	8	2-7	10.4	+ 4.0	
159	50209	06 47.1	− 0 10	8.3	B(5)ne	− 11.7	7.1	5	2-5	10.7		
164	52721	06 57.2	− 11 09	6.6	B3e	+ 9.3	7.2	6	2-6	13.0		
188	65079	07 51.9	+ 3 14	7.7	B3ne	+ 2.6	5.2	7	3-7	14.3		
189	65176	07 52.4	− 1 20	8.1	B(5)ne	+ 96.1	10.2	6	2-4	12.9		poss. var. vel.
307	174886	18 47.7	− 10 21	8.1	B3e	+ 4.4	2.2	6	3-6	5.5		
312	180398	19 11.3	+ 12 56	7.7	B(3)ne	(− 32.7) var.	—	7	2-6	10.6		
320		19 41.3	+ 5 44	8.5	B5ne	− 27.0	7.1	6	2-6	12.0		
383	209296	21 57.2	+ 56 14	8.1	B(5)e	− 31.7	6.4	7	3-7	10.2		Ca^+ stellar
402	223501	23 45.0	+ 61 39	8.2	B3e	− 37.5	6.2	7	3-8	7.9	− 7.2	

star. Most of these were taken with dispersion of 66 A. /mm. at Hγ, the rest with 33 A. /mm. dispersion. The observations were all in the periods 1938-40 and 1946-50, and all the stars are represented by plates in both intervals. Thus any long-period velocity variations or spectrum variations may have been detected.

The Radial Velocities

The radial velocity data are presented in Table I. MWC refers to Mount Wilson Catalogue of Be and Ae stars. P.E. is the probable error of the mean velocity calculated by Peters' formula; $\bar{e}$ is the average of the probable errors of the plates calculated from agreement of the lines. The interstellar velocities are listed only for stars in the spectra of which the K-line was distinct and sharp on several plates. For some other stars the interstellar nature of the K-line may have been missed because of weakness of the exposures in the violet region.

Four of the stars are regarded as having variable velocities, and an additional one as possibly having variable velocity. The separate velocity measures of the four variable-velocity stars are listed in Table II.

TABLE II

Star	J.D. 24....	Vel. km./sec.	Star	J.D. 24....	Vel. km./sec.
M.W. 13	29130.875	− 34.1	M.W. 139	29319.583	+ 97.9
H.D. 9105	29166.762	− 27.5	H.D. 44637	29582.929	+ 14.2
	29170.717	− 32.6		29675.620	+ 74.6
	29185.764	− 12.6		32101.939	− 31.7
	29278.476	− 56.9		32977.559	− 38.7
	29907.760	− 39.1		33378.575	+ 7.8
				33381.551	+ 15.4
M.W. 49	29199.753	− 8.8		33385.542	+ 20.0
H.D. 15472	29214.678	− 116.5			
	29625.581	− 165.0	M.W. 312	29447.717	− 78.6
	29912.747	− 39.6	H.D. 180398	29494.623	− 96.6
	32068.901	− 18.5		29851.632	− 64.0
	32077.875	− 24.0		29862.603	+ 12.2
				32001.769	− 14.4
				32473.511	+ 9.8
				32817.571	+ 3.0

THE ANALYSIS OF THE ROTATIONAL TERMS

To analyse this group of velocities and thus to determine the mean absolute magnitude, the following procedure was used. For each star the term sin $(l - l_0)\cos^2 b$ was computed, using the value $l_0 = 325°$ for the longitude of the galactic centre and the values of the galactic coordinates, l and b, as listed in the Mount Wilson Catalogue. The measured radial velocities were corrected for solar motion by means of the graphical method of Pearce and Hill.[4] Calling this reduced velocity ρ', equations were written of the form

$$\bar{r}A.\sin 2(l - l_0)\cos^2 b + K = \rho',$$

where r is the mean distance of the group of stars, A is the rotational term at unit distance and K is the residual constant which is usually included in these solutions.

One star in Table I, M.W. 63, is classified by Mount Wilson as Bne; it was excluded from the solution. This left 20 equations of the form given above, representing stars of fairly homogeneous apparent magnitude and spectral type. The solution of these equations gave

$$\bar{r}A = 15.0 \pm 4.4,$$
$$K = 0.0 \pm 3.8.$$

Accepting R. E. Wilson's value of the constant of rotation, $A = 17.7$ km./sec. per kiloparsec[5], we have

$$\bar{r} = 850 \text{ pscs.},$$

and from this we get the value of the mean absolute magnitude uncorrected for galactic absorption,

$$\bar{M}' = -1.65 \pm 0.6.$$

If we correct this for absorption by Wilson's method[2] of allowing 0.65 mags. per kiloparsec for stars within 10° of the galactic equator and no absorption for stars at higher galactic latitude, we get

$$\Delta M = -0.44,$$

whence the corrected value of the mean absolute magnitude is

$$\bar{M} = -2.1.$$

This value of mean absolute magnitude is probably a little too bright owing to the tacit assumption that the mean value of log r

is the same as the logarithm of the mean value of r, a point which has been discussed by Greenstein[6]. However, Greenstein has estimated that this error will be not more than one or two tenths of a magnitude for stars as distant as these. If we make a small correction for this effect we have

$$\bar{M} = -2.0.$$

The mean spectral type of these 20 stars is B3.8e. Absolute magnitude -2.0 is normal for main sequence stars of this type. This supports the conclusions of R. E. Wilson and Seyfert and Popper, referred to earlier, that the presence of emission lines is not an indication of abnormal luminosity.

The fact that the K-term turns out to be zero may be taken as an indication that this group of stars is not subject to any systematic atmospheric expansion or subsidence.

Spectral Features

Most, if not all, Be stars are believed to be subject to variations in their spectra, especially as regards strength and character of the emission lines. For this reason brief descriptions of the emission features in the spectra of these stars and any suspected changes are recorded in the following list.

M.W. 10 Single emission at $H\beta$ and $H\gamma$; no change 1938-46.

M.W. 13 Sharp absorption lines; no emission at $H\beta$; no change 1938-46.

M.W. 23 $H\beta$ emission is sometimes single, sometimes a close double. $H\gamma$ emission usually appears as an emission border on the violet side of a sharp absorption line. Other hydrogen lines are sharp absorption. The helium lines are broad, vary in intensity and sometimes have faint emission borders. There is a marked disparity in the velocities from hydrogen and helium absorption lines; the mean velocity of the five plates from hydrogen lines is + 34 km./sec., from helium lines − 45 km./sec. This star will be studied further.

M.W. 29 $H\beta$ has strong, close, double emission on broad absorption, and there are traces of similar emission structure, much weaker, at the other hydrogen lines. There have been no marked changes between 1939 and 1947.

M.W. 49 $H\beta$ has weak double emission in which there are probably changes in relative intensity. Other hydrogen lines show traces of emission.

M.W. 63 Emission at Hβ in 1938-40 indicated only by weakening of the absorption line; stronger double emission at Hβ and Hγ in 1946-1950.

M.W. 76 Emission at Hβ in 1939-40 very weak; stronger double emission at Hβ and some emission at Hγ in 1946-48.

M.W. 79 No evidence of emission lines at Hβ etc. in 1938-40 or 1946-49.

M.W. 82 No evidence of emission lines at Hβ etc. in 1938-40 or 1946-50.

M.W. 83 Strong double emission at Hβ, much weaker at Hγ; no change 1939-49.

M.W. 114 Strong emission (probably double) at Hβ, much weaker at Hγ; emission stronger in 1938 than in 1939 and subsequently.

M.W. 139 Fairly strong narrow emission at Hβ, much weaker at Hγ; probably no change 1939-50.

M.W. 159 Weak narrow emission at Hβ and Hγ; probably stronger in 1949 than in 1939.

M.W. 164 Narrow emission at Hβ, Hγ, Hδ in 1939, weaker in 1949 and barely detectable in 1950.

M.W. 188 Narrow, moderately strong emission at Hβ, very weak at Hγ. Some faint emission at helium lines. No marked change between 1939 and 1949-50.

M.W. 189 No distinct emission at Hβ etc., but hydrogen absorption lines extremely weak. No change 1940 to 1949-50.

M.W. 307 Narrow emission at Hβ and Hγ, stronger in 1946-47 than in 1939-40.

M.W. 312 Faint emission at Hβ and Hγ. In 1947-50 the larger dispersion shows these double with equal intensity; on earlier plates of 1939-40 and 1946 doubling is not certain and emission is probably weaker.

M.W. 320 Double emission at Hβ and Hγ. Red component stronger than violet in 1946, 1947, equal in 1948, weaker in 1950. Emission character uncertain on earlier plates.

M.W. 383 No emission at Hβ etc. in 1938-40 or 1946.

M.W. 402 Double emission at Hβ and Hγ which is clearly resolved only on larger dispersion plates of 1946-50; there are changes of relative intensity of the two components in this period.

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