PART II

Be STARS AS ROTATING STARS

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Be STARS AS ROTATING STARS: OBSERVATIONS

(Review Paper)

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Abstract. The classical rotational hypothesis for Be stars is reviewed and discussed. Methods of measuring rotational velocities are considered and the particular difficulties that Be stars pose in this respect are pointed out. Several tests of the rotational hypothesis are discussed and shown to support this idea. New observations of Balmer emission-line widths in the spectra of 46 Be stars show a correlation with rotational velocity, also in support of the rotational hypothesis. The very large emission widths found for some Be stars are discussed and possible reasons for the broadening are presented.

1. Introduction

Over 40 years ago, Otto Struve wrote his classical paper, 'On the Origin of Bright Lines in Spectra of Stars of Class B' (Struve, 1931), in which he stated in the Abstract:

> It is found that stars of class B, having widely separated double bright lines are characterized by extremely flat and broad absorption lines suggestive of rapid axial rotation, of the order of several hundred km s^{-1}. Stars having narrow, single emission lines, few in number, show little rotation.
>
> The suggestion is now offered that rapidly rotating single stars of spectral class B are unstable, and form lens-shaped bodies which eject matter at the equator, thus forming a nebulous ring which revolves around the star and gives rise to emission lines. The inclination of the star's axis would then be responsible for the observed range in width of the emission lines.

In view of a considerable number of observations plus some new ideas about Be stars (including the binary hypothesis being discussed at this symposium) which have been developed since the above words were written, it seems appropriate to review and discuss the observational evidence for the classical rotational hypothesis for Be stars at this time.

2. Rotational Velocities of Be Stars

2.1. Profile Analysis

If we exclude Galileo's observations of sunspots (1613), profile analysis is the oldest method for estimating stellar rotation. Abney (1877) first demonstrated that stellar rotation would result in a broadening of spectrum lines and suggested that "... other conditions being known, the mean velocity of rotation might be calculated". The first list of rotational velocities, $v \sin i$, was given by Elvey (1930), following a graphical method suggested by Shajn and Struve (1929).

Rotational velocity determinations based on the Shajn-Struve graphical method assume that the flux profile of a sharp-lined star can be used to approximate the non-rotating intensity profile at each place on the disk of a rotating star. Most of the rotational velocities in the literature have been determined using this method; references may be found in the catalog of $v \sin i$'s by Uesugi and Fukuda (1970). With large computers now available, it has become feasible to calculate rotationally

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broadened line profiles directly from model atmosphere results, without recourse to the assumptions implicit in the graphical method. Such calculations will be discussed later in this section.

A different approach was first suggested by Carroll (1933), in which the integral equation relating the observed line profile to the true line profile is solved using Fourier analysis, thereby yielding the equatorial velocity in the line of sight. More recently, Gray (1973) has used a Fourier transform technique to distinguish between microturbulence, macroturbulence, and rotation. The difficulty with such profile analysis methods is that the observed line profile must be known with a very high degree of accuracy in order to extract the required information.

The Be stars as a class represent a special problem with respect to rotational velocity measurements. The very large line broadening in Be stars presumably corresponds to large axial rotation, which suggests that they must be flattened objects. This in turn suggests that the effective gravity must vary across the stellar surface, being high at the poles and low in the distended equatorial regions. If von Zeipel's theorem, or a variation thereof, is valid, the surface brightness, and therefore the effective temperature, is related to the local effective gravity. Thus, the temperature and pressure will vary across the stellar surface. Corrections for such shape distortion and gravity darkening have been applied to line profiles by Slettebak (1949), Collins and Harrington (1966), Friedjung (1968), Stoeckley (1968a), Hardorp and Strittmatter (1968), and others.

Collins (1974) has recently computed a large set of line profiles from rotating model atmospheres, using the ATLAS program (Kurucz, 1970). He assumed a Roche model (Harrington and Collins, 1968) with polar radius and luminosity specified by the interior models of Sackman and Anand (1970), taking shape distortion and gravity darkening (assuming von Zeipel's theorem to hold) into account. Collins computed line profiles for He I λ 4471 Å, Mg II λ 4481 Å, and Fe I λ 4476 Å for models of spectral type ranging from O9 to F8 for various values of the fractional angular velocity and the inclination of the rotation axis. He found that the helium and iron lines are very sensitive to rotation whereas the magnesium line is not, and pointed out that these effects can lead to ambiguities in spectral classification.

The work of Collins was used to establish a system of standard rotational velocity stars (Slettebak *et al.*, 1975), in which high-resolution line profiles in the spectra of 217 bright, early-type stars were compared with his theoretical profiles to estimate rotational velocities. The new $v \sin i$'s obtained in this way are systematically smaller than those derived using the graphical method: about 5% for the A-type and F-type stars and approximately 15% for the B-type stars (cf. Slettebak *et al.*, 1975, Figure 7).

Unfortunately, the Be stars present the biggest problems. Observationally, the broad and shallow line profiles from the underlying star are difficult to measure accurately and may be distorted by both absorption and emission effects from the shell. On the theoretical side, the computed line profiles for gravity-darkened, distorted stars may show considerable changes in equivalent width (and therefore to a lesser degree also in the half-intensity width) depending upon aspect angle, which leads to additional ambiguities in assigning the proper $v \sin i$ to the star (cf. Slettebak *et al.*, 1975, Figure 2). All $v \sin i$'s derived from line profiles for Be stars must therefore be considered rather uncertain.

2.2. Periodicities in light or spectrum

A more direct way of measuring stellar rotation is by detecting a periodicity in the total light or color or line profile from a nonuniform stellar surface. The idea of starspots to explain photometric variability was first proposed by Pickering in 1880 but not confirmed until more recent times (see Vogt, 1975 for references). Thus, Krzeminski (1969), using UBV photometry, found equatorial velocities of 10 to 15 km s^{-1} for dMe stars, and Dr Butler, who reported to us on his Hα photometry yesterday, finds a 40-day periodicity which may be due to rotation in a K3 III star (Butler, 1976). Deutsch (1954) first suggested that for the peculiar A-type spectrum variable stars "we observe the rotation of A stars that exhibit intensely magnetic areas, within which the peculiar line strengths are produced".

In view of the ambiguities associated with the determination of rotational velocities from line profiles in the Be stars, it would be of great importance to measure their rotations more directly. Hutchings (1970) reported a periodicity of 0.7 days in the peak separation and V/R ratio of the double emission profiles of Hγ and Hβ in γ Cas, which he attributed to rotation. Additional measurements of this type for a number of Be stars, using scanners or narrow-band photometry, would be very desirable to help answer the question of how nearly the rotation of Be stars approximates the critical velocity at which the centrifugal force at the equator balances the gravitational force.

2.3. Tests of the rotational hypothesis

We can now raise the question: do the observed $v \sin i$'s for Be stars confirm Struve's rotational hypothesis? Several tests are possible.

Assuming that all Be stars of a given type rotate with the same equatorial velocity v_0 and that their axes of rotation are randomly distributed in space, Struve (1945) showed that the frequency distribution would be expected to show a pronounced maximum at v_0. A sample of 42 Be stars of spectral types B6–B9 (Slettebak, 1966) does indeed show such a distribution. Furthermore, the percentage of stars that show shell absorption increases with increasing $v \sin i$, as would be expected if the shells are equatorial features and the stars with small observed $v \sin i$ are viewed nearly pole-on while those with large $v \sin i$ are seen essentially equatorially. Studies of the distribution of rotational velocities by Stoeckley (1968b) and Hardorp and Strittmatter (1970) reach similar conclusions. Statistical studies by Bernacca (1970), Balona (1975), and Massa (1975) suggest, however, that Be star rotational velocities do not reach the critical velocity.

I recently made visual estimates of $v \sin i$ on the new system (Slettebak *et al.*, 1975) for all the Be stars for which I have spectrograms and plotted the frequency vs $v \sin i$. The stars and estimated rotational velocities are listed in Table I, where standard rotational velocity stars are identified with an asterisk after their $v \sin i$. It should be emphasized that the values listed are of varying quality, since a number of different dispersions were used. Values of $v \sin i$ followed by a colon are considered

TABLE I
Be-star rotational velocities and velocities corresponding to one-half the emission widths

Star	HD	Hβ v_T (km s^{-1})	Hβ v_E (km s^{-1})	Hβ v_S (km s^{-1})	Hγ v_T (km s^{-1})	Hγ v_E (km s^{-1})	Hγ v_S (km s^{-1})	$v \sin i$ (km s^{-1})
10 Cas	144							150
o Cas	4 180							220
γ Cas	5 394	340	180	85	315	180	95	230:
ϕ And	6 811							60
	9 709							320
α Eri	10 144							225*
ϕ Per	10 516	360	205	120	320	185	125	400
	13 867	–	–	–	105	65	–	60
HR 894	18 552							270
HR 985	20 336	–	–	–	205	170	140	320
	21 641							140
ψ Per	22 192	300	150	85	205	145	100	350
17 Tau	23 302							190
23 Tau	23 480							260
HR 1160	23 552							210
28 Tau	23 862	310	175	115	220	175	135	320
HR 1204	24 479							100
48 Per	25 940	200	100	45:	145	95	55:	200
	26 398							160
11 Cam	32 343	180	90	–	165	65	–	100
25 Ori	35 439							260
120 Tau	36 576	325	190	90	215	165	120	280
ζ Tau	37 202	305	215	145	225	180	140	300
ω Ori	37 490	295	210	115	245	200	155	160*
α Col	37 795	200	140	85	160	135	115	180*
HR 2142	41 335	405	190	65	305	190	110	400
HR 2309	44 996							100
ν Gem	45 542							180
β Mon A	45 725	345	175	110	240	175	130	260*
HR 2418	47 054							240
κ CMa	50 013	325	175	90	265	180	105	150*
ψ^9 Aur	50 658							230
ω CMa	56 139	170	75	20:	150	85	35	80*
β CMi	58 715	215	175	130	160	–	–	245*
HR 2932	61 224							230
HR 3034	63 462	390	250	145	335	235	150	320*
HR 3135	65 875	290	115	30	215	115	50	170
HR 3237	68 980	240	85	30	190	85	35	115*
HR 3498	75 311							240*
HR 3642	78 764	240	150	90	170	140	110	120*
HR 3858	83 953	305	215	140	210	185	160	260*
ω Car	89 080	220	170	120	155	145	135	200
	89 884	285	190	115	190	150	120	300
HR 4123	91 120							270
HR 4140	91 465	305	175	90	200	145	105	250*
HR 4460	100 673							125*
HR 4537	102 776							205*
HR 4618	105 382							65*
δ Cen	105 435	270	125	55	200	120	60	220*
κ Dra	109 387	275	165	95	180	–	125	200
λ Cru	112 078							280*
μ Cen	120 324	160	80	40	120	80	45	155*
	127 617	155	70	–	–	–	–	150:
η Cen	127 972							260*

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Table I (*cont.*)

Star	HD	Hβ			Hγ			
		v_T (km s^{-1})	v_E (km s^{-1})	v_S (km s^{-1})	v_T (km s^{-1})	v_E (km s^{-1})	v_S (km s^{-1})	$v \sin i$ (km s^{-1})
θ CrB	138 749							320*
4 Her	142 926							300
48 Lib	142 983	310	230	170	205	175	145	400*
χ Oph	148 184	255	75	30:	220	75	35:	140*
ζ Oph	149 757							320*
α Ara	158 427	370	180	100	235	170	115	230*
	162 428							350
88 Her	162 732							300
	163 848							300:
66 Oph	164 284	370	200	85	335	230	120	280
HR 6720	164 447							220
HR 6873	168 797							240:
	168 957							50:
HR 6881	169 033							200
	171 219							260
	173 371							350
λ Pav	173 948	265	200	150	215	195	170	170*
	174 105	–	–	–	170	150	125	220
HR 7084	174 237							170:
HR 7249	178 175							150
	179 343	–	–	–	210	170	–	320:
HR 7415	183 656							300:
β^2 Cyg	183 914							240
11 Cyg	185 037							340
12 Vul	187 811							260
25 Cyg	189 687							200
	189 689							130
	190 150							270:
28 Cyg	191 610	355	240	160	255	215	175	280
20 Vul	192 044							300
	192 954							330:
25 Vul	193 911	275:	110:	–	–	–	–	210
HR 7843	195 554							220
HR 7890	196 712							220
λ Cyg	198 183							120
59 Cyg	200 120							350:
60 Cyg	200 310							320
υ Cyg	202 904	285	135	55	235	140	75	200
	203 356							300:
6 Cep	203 467	280	145	70	225	170	125	150
HR 8259	205 551							150
ε Cap	205 637	320:	240:	155:	–	–	–	260
	207 232							300
16 Peg	208 057							120
o Aqr	209 409	305	190	115	200	160	130	320
25 Peg	210 129							170
31 Peg	212 076	230	115	50	170	120	80	110
π Aqr	212 571	365:	200:	85:	300:	200:	130:	300:
HR 8682	216 057							320
HR 8731	217 050	335	200	120	235	175	125	300
o And	217 675							280
β Psc	217 891	175	85	–	135	75	35	100
	220 300							350:
	220 582							300

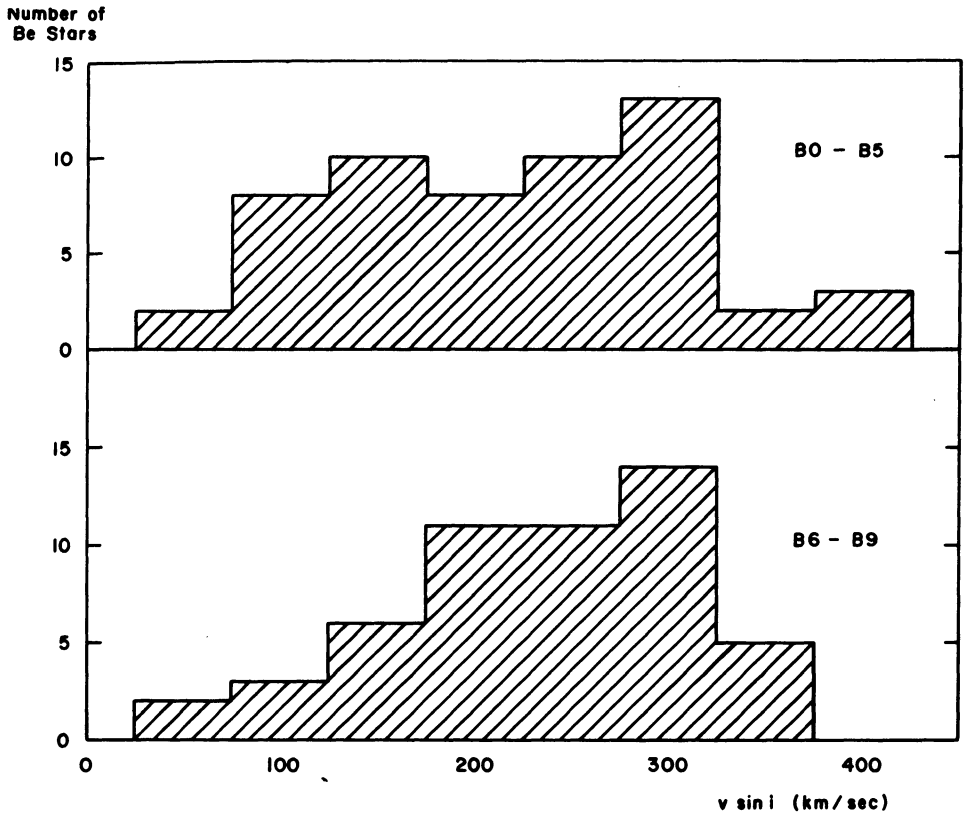

Fig. 1. Histograms showing the frequency distribution of observed rotational velocities for 56 Be stars of spectral type B0–B5 and 52 Be stars of spectral type B6–B9.

to be rather uncertain, usually because of inferior plate quality. The 56 B0–B5 and 52 B6–B9 stars are plotted in Figure 1. Again, the B6-B9 distribution shows the expected maximum at large $v \sin i$. The B0–B5 distribution shows a tendency in that direction but it is not as pronounced. There are several reasons for not expecting the observed distributions to look exactly as predicted by Struve. First, the observational material is not strictly homogeneous and may contain an observational bias. Secondly, the critical rotational velocity v_0 varies with spectral type, particularly for the B0–B5 stars (cf. Figure 2); therefore the histograms in Figure 1 cannot be expected to come to a sharp maximum at a single v_0. Thirdly, a number of Be stars with strong absorption shell spectra are not included in Figure 1 because the underlying stellar absorption lines were obscured on the spectrogram and no $v \sin i$ estimate was possible. But these are precisely the stars with large $v \sin i$, since they are being viewed essentially equatorially. Finally, as has already been stated, ambiguities in the line profile method of estimating $v \sin i$ make values of 300 km s^{-1} and higher quite uncertain. In summary, it seems to me that the observed frequency of Be stars having various $v \sin i$'s is consistent with the rotational hypothesis.

As another test, the largest observed rotational velocities for stars of various spectral types (assumed to be viewed equatorially) may be compared with the computed equatorial critical velocities for stars of corresponding type. If the rotational hypothesis for Be stars is correct, the curves should intersect for those spectral types which include the Be stars. Such a comparison was made some years ago (Slettebak, 1966b) and while the curves representing the computed equatorial breakup velocities and the largest observed rotational velocities did not actually touch, the region of minimum difference was approximately that occupied by the Be stars. Recently, Collins (1974) recomputed the equatorial critical velocities for main sequence Roche models and found values which are considerably lower than in the earlier work. This would tend to bring the curves closer together, but the observed rotational velocities on the new scale should also be reduced by about 15%. Figure 2

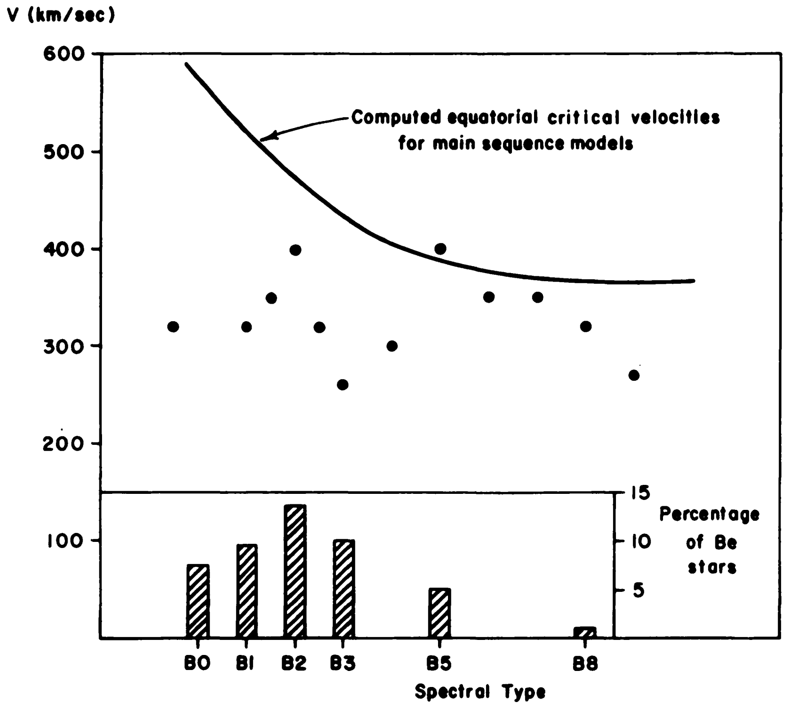

Fig. 2. Comparison of the largest observed rotational velocities for Be stars of spectral types O9.5 to B9 with computed equatorial critical velocities (at which the centrifugal force balances the gravitational force) for main sequence models of the same spectral type range. The relative frequency of Be stars is also shown.

shows Collins' theoretical curve with the largest observed rotational velocities from Table I and the percentage of Be stars as a function of spectral type also plotted. The observed rotational velocities may lie somewhat closer to the computed curve than in the earlier work but, on the average, are still smaller than the computed critical velocities. Three factors may play a role: (1) The equatorial critical velocities were computed for main sequence models whereas there is evidence that some Be stars at least have evolved off the main sequence into the subgiant and giant regions of the

H-R diagram. Such evolution would increase their radii without a change in mass, thereby lowering the critical rotational velocity. (2) The spectral types for a number of the stars plotted in Figure 2 are rather uncertain because absorption shell features make it difficult to classify the underlying stellar spectrum. (3) The largest observed rotational velocities are also the most uncertain, for reasons already discussed.

In any case, a mechanism in addition to rapid rotation appears to be necessary to transport material from the star into the shell. Ostriker (1970) has shown, for example, that a contracting rotating star in which viscous and magnetic forces may be neglected will never shed mass at the equator. The observed rotational velocity need then only be close to the equatorial critical velocity, with a pulsational instability or radiation pressure or some other mechanism giving the material the final push.

3. Observations and Interpretation of Be Emission-Line Widths

In his 1931 paper, Struve showed that there was a correlation between axial rotation, as shown by the widths of stellar absorption lines, and the widths of the emission lines in Be stars. This conclusion was based on three independent sets of data: (1) spectrograms from the collection of the Yerkes Observatory; (2) the emission-line widths of R. H. Curtiss (1923); and (3) the observations of P. W. Merrill (Merrill *et al.*, 1925). Some years later, Underhill (1953) found her measurements of Hα and Hβ emission in the spectra of five Be stars to be consistent with Struve's rotational hypothesis and, more recently, Gray and Marlborough (1974) obtained a good correlation between their emission widths and $v \sin i$ for 12 Be stars.

But Doazan (1970), from measurements of the Balmer emission lines in 26 Be stars, found that "no correlation exists between the widths of the Hα, Hβ and Hγ emission lines and the velocity due to the rotation of the central stars ($v \sin i$) when this velocity is less than 350 km s^{-1}". Since this conclusion casts considerable doubt on the rotational hypothesis, Doazan's work stimulated me to collect my Be star spectrograms of the past 25 years together and measure emission-line widths to see if my material shows a correlation with $v \sin i$.

It should be emphasized that my spectrograms were not originally taken for the purpose of measuring emission-line widths. Thus, they do not include Hα (which always shows the strongest emission in Be stars) and often had no intensity calibration. The spectrograms also include a variety of dispersions, ranging from 9 to 46 Å mm^{-1}, with the projected slit width at the plate taking values between 0.2 Å and 0.9 Å.

Transmission microphotometer tracings of all Be stars showing emission on my plates were made with the University of Vienna Observatory PDS-1000 microphotometer and PDP-12 computer combination in 1975. The three emission widths measured for each line when a measurement was possible are shown schematically in Figure 3. The quantity $(\Delta\lambda)_E$, measured from the steepest slopes of the emission profile, is essentially the same quantity measured by Curtiss (1923), and a comparison of 9 stars in common shows good agreement. This quantity should also be expected to represent the emission width best, since $(\Delta\lambda)_S$ is strongly affected by self-absorption and $(\Delta\lambda)_T$ is a rather uncertain quantity to measure.

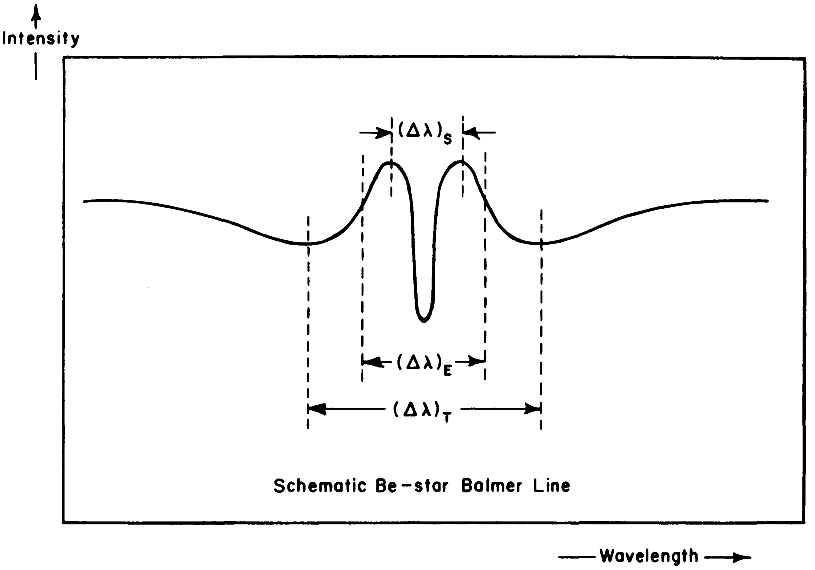

Fig. 3. A schematic Be-star Balmer line, showing the three emission widths measured in this paper.

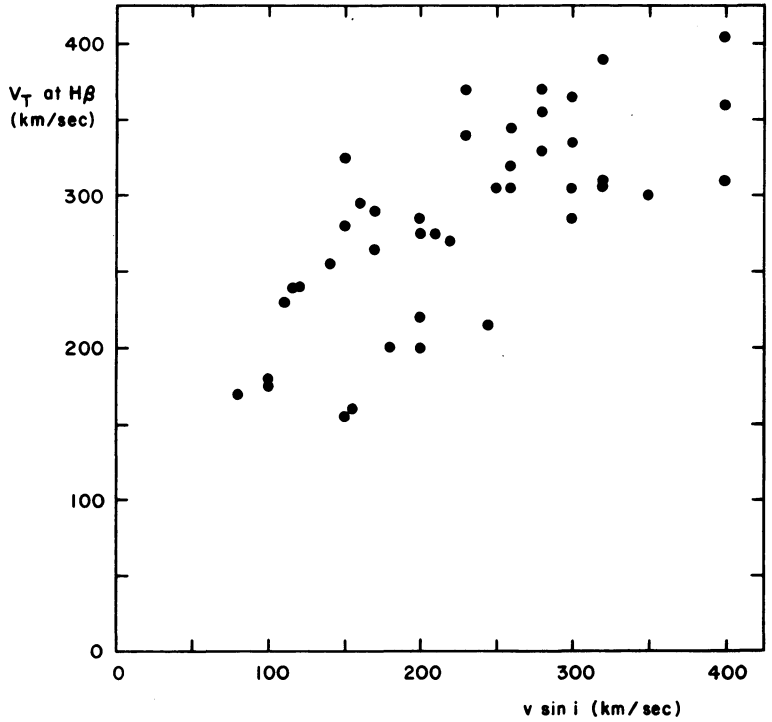

Fig. 4. Comparison of the velocity v_T corresponding to one-half the emission width $(\Delta\lambda)_T$ of Hβ in 42 Be stars.

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A comparison of emission-line width measurements from spectrograms of different dispersions for the same star showed good agreement for plates with projected slit widths in the range 0.2–0.6 Å, but greater emission widths for the plates of poorer resolution, particularly in the quantity $(\Delta\lambda)_T$. Measurements from spectrograms with projected slit widths greater than 0.6 Å were therefore discarded.

In a few cases where the strength of the emission in a given star varied from plate to plate, there were no striking changes in the emission widths. McLaughlin (1962) in his study of π Aqr found the same to be true of that star, for which he states "The total measured width of the emission remains roughly constant". Emission widths from different plates for each star were therefore simply averaged.

Average emission-line widths for Hβ and Hγ in 46 Be stars are listed in Table I, expressed as velocities corresponding to the half-width of the emission, $1/2(\Delta\lambda)$. Figures 4–7 show these values plotted against $v \sin i$. Although there is not a strict correlation, there does appear to be a correlation in the sense that Struve stated: wide emission lines are generally associated with large $v \sin i$ and narrow emission lines with small $v \sin i$.

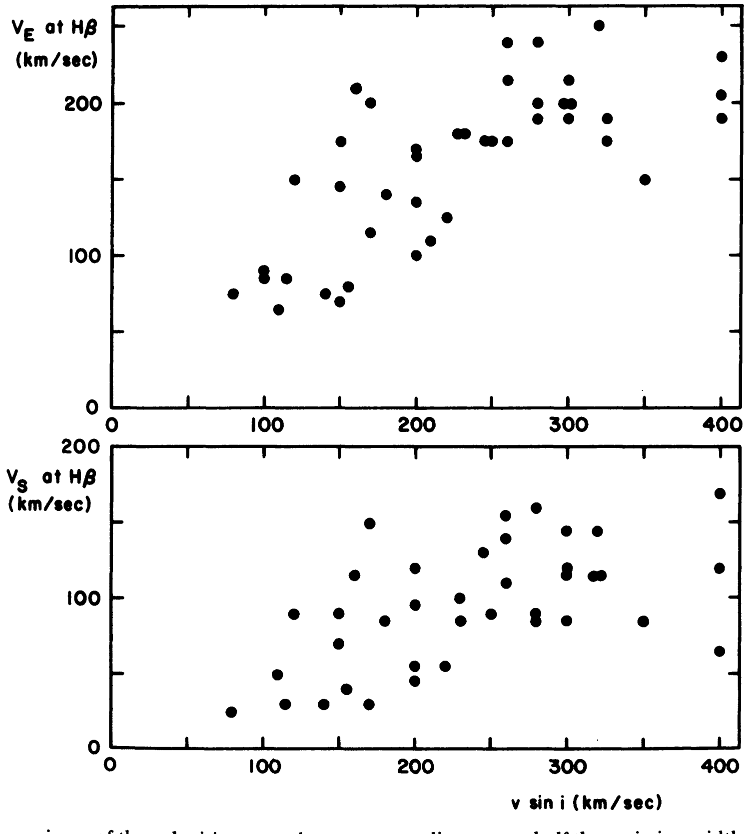

Fig. 5. Comparisons of the velocities v_E and v_S corresponding to one-half the emission widths $(\Delta\lambda)_E$ and $(\Delta\lambda)_S$ of Hβ in 42 and 38 Be stars, respectively.

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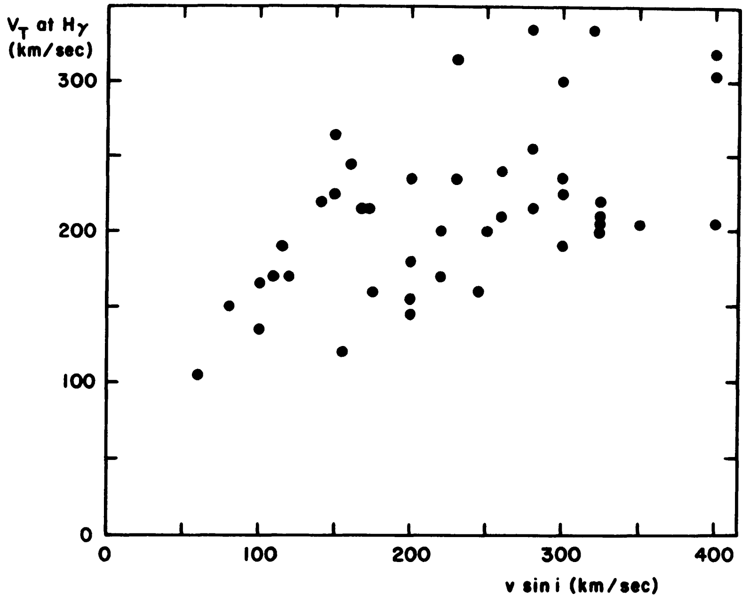

Fig. 6. Comparison of the velocity v_T corresponding to one-half the emission width $(\Delta\lambda)_T$ of Hγ in 43 Be stars.

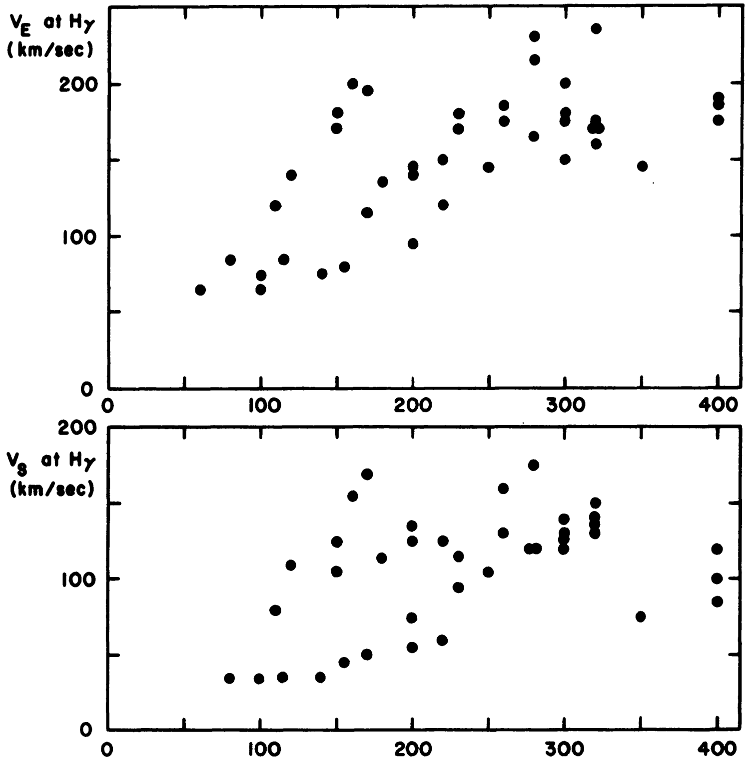

Fig. 7. Comparisons of the velocities v_E and v_S corresponding to one-half the emission widths $(\Delta\lambda)_E$ and $(\Delta\lambda)_S$ of Hγ in 41 and 39 Be stars, respectively.

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This conclusion does support the rotational hypothesis for Be stars but the lack of a strict correlation suggests that other factors must also be involved. This is also evident from Table I, where the velocities corresponding to the emission half-widths are sometimes larger than $v \sin i$, particularly for Hβ. Doazan (1970) found a similar effect for her 26 Be stars: "For all the stars studied, the rotational velocities corresponding to the Hα emission line width are larger than that due to the rotation of the central star ($v \sin i$). This is also the case for the Hβ line of 17 stars and for the Hγ line of 12 stars". Indeed, Underhill in 1953 pointed out the very extensive wings of Hα in some shell stars and suggested that "it is possible that the extra broadening of the emission at Hα is caused by large chaotic motions of the emitting material". But turbulent velocities of 100 km s^{-1} and larger in the shell imply a degree of disorder which does not seem consistent with the Be phenomenon.

Another possible explanation of the excessive emission-line broadening in Be stars may involve electron scattering. Münch (1948) showed that electron scattering in early type supergiants can modify absorption lines by producing very extended and shallow wings, while the Burbidges (1953) held electron scattering responsible for the broad wings of the Balmer absorption lines in pole-on Be stars. Marlborough (1969) also suggests that "electron scattering seems to be a reasonable mechanism to explain the extensive emission wings of Hα" in Be stars. Gray and Marlborough (1974), from an analysis of photoelectric profile measurements of Hα and Hβ in 14 Be stars, suggest that "more likely we observe a combination of shell rotation and a velocity distribution either of mass elements or electrons".

4. Conclusions

The classical picture of a Be star as an object rotating near the verge of instability, with an equatorial shell responsible for the emission characteristics, appears still to be supported by the observations of absorption and emission line widths, at least in a qualitative way. Other factors, including duplicity, undoubtedly modify this simple picture in many individual cases, however.

The observed fact that Be stars are rotating near but probably not at the critical velocity does not contradict the above picture since recent theoretical work suggests that a star will not shed mass equatorially through rotation alone in any case. A number of ejection mechanisms have been suggested but none has been worked out in any detail as yet.

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DISCUSSION

Doazan: I have two remarks to make: (1) I would like to emphasize that Merrill's and Struve's results are based on line widths estimated by visual inspection of the plates, and that the only previous quantitative results are those of Curtiss, who measured line widths of only 11 stars, I think. (2) The way you measure the line widths of the emission lines underestimates these widths. It is necessary to trace the photospheric absorption lines to determine the position of the beginning of the depression caused by the emission. If you do so your line widths will be greater.

Slettebak: That is correct. I was less interested in the absolute values of the emission widths, however, than in whether or not they show a correlation with rotational velocity.

Doazan: Our spectra indicate that a certain number of Be stars show emission in the helium lines as, for example, γ Cas, which was also observed by Hutchings. My question is: have you observed many Be stars of this kind and can the observed $v \sin i$'s really be interpreted then as rotation?

Slettebak: Certainly there are stars like γ Cas, where the helium profile shapes are peculiar. I did not find such line profiles as a common thing, however, nor did I find emission in the helium lines (at least, not in He I 4471). By and large, the profiles looked like the dish-shaped profiles that are predicted under the rotational hypothesis.

Peters: Concerning He I emission, we have been observing Be stars at λ 7065 of He I and, although the survey is far from complete, the only star which appears to have significant He I emission is ϕ Per.

Plavec: As a matter of curiosity, I know that high velocities of rotation are somewhat uncertain, but which star is rotating fastest?

Slettebak: We have assigned several stars velocities of 400 km s^{-1}, including 48 Lib, ϕ Per, and HR 2142. It looks from Collins' models as though that is the largest numerical value we can assign.

Bidelman: I wonder whether your emission-line measurements depend at all on the emission intensity. Have you measured the same star at times when the emission strengths were different?

Slettebak: Yes, in a few cases, and there seems to be little difference in the emission widths. McLaughlin noted the same thing: for stars showing V/R variations he noted that the total measured width of the emission remains roughly constant. But I do not have a lot of data to support that; just a few plates.

Coyne: When one goes to the catalogue material on $v \sin i$, one finds large differences in the various catalogues. Is there a recommendation among the people who use $v \sin i$'s as to which catalogue gives a homogeneous set of values?

Slettebak: As you know there are several. Originally there was the Boyarchuk-Kopylov catalogue of $v \sin i$'s, and more recently the Bernacca catalogue and the Uesugi and Fukuda catalogue. In each case they weight the various $v \sin i$ values and try to put them all on one system. Our hope in the paper which I just presented is to establish a system which people would use much like a system of standards for spectral classification and that if everyone stuck with these stars we would have a consistent system. At the present time I think that the Bernacca and the Uesugi-Fukuda catalogues are the best.

Coyne: How does one relate your recent work to those two catalogues?

Slettebak: The new scale, which is based on Collins' theoretical work and our new measures, is about 15% lower for the B stars and about 5% lower for the A and F stars. So if you believe this work you could take values from those catalogues and apply corrections to them of about that amount.

Heap: The ultraviolet region of the spectrum has many strong lines which can be used both for spectral classification and for rotational-velocity determinations. The profiles of these lines are easily measured even in rapidly rotating stars. Some of these lines are lines of high ionization state, like Si IV, so you do not have the problem of shell emission or shell absorption superimposed on them. I would like to persuade anyone who is theoretically inclined to compute gravity-darkened profiles for these ultraviolet lines.

Hutchings: Can you distinguish between pole-on rotating stars and non-rotating stars?

Slettebak: Normally no, but in the case of Be stars, if you accept the hypothesis that they are all rotating near a certain critical velocity, then the sharp-line stars are, by definition, pole-on stars.

Hutchings: Do you believe that Be stars are rotating at breakup velocity?

Slettebak: No. I think the best evidence now is that they are not. They still seem to rotate below the critical velocity but I do not think this is a problem since there now seem to be a number of mechanisms to get material out into the shell, even if the star's rotation does not reach the critical velocity.