Be STARS IN THE REGION OF h AND CHI PERSEI*

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ABSTRACT

New spectrograms at classification dispersion for the region of h and χ Persei, a region of the sky known to be rich in Be stars, are discussed. On the basis of spectroscopic appearance, the Be stars are divided into two groups. The first group is shown to contain Be stars of varying spectroscopic appearance, including at least one shell star and two stars on the main sequence. Stars in the second group, called extreme Be stars, are found to show very little variation in spectroscopic appearance and to lie in a band centered approximately 1.5 mag. above the main sequence.

Several interpretations of the observations are considered, and the hypothesis that the extreme Be stars are rapidly rotating B stars undergoing rapid core contraction subsequent to hydrogen exhaustion in their cores is favored.

The $(B - V)$ colors of the extreme Be stars are found to have a positive excess of approximately 0.15 mag. Because no comparable deviation is observed in $(U - B)$ colors, it is not possible to attribute this color difference to systematic temperature differences or to circumstellar reddening according to the $1/\lambda$ law.

I. INTRODUCTION

The Be stars are already the subject of a large body of literature which has recently been reviewed by Underhill (1960). Progress in the understanding of these stars has been limited, largely because the phenomena exhibited by the Be stars are found to widely varying extents among stars, and because even considerable time variations of these phenomena in individual stars are observed. Although the observed emissions are generally thought to originate in a tenuous shell of gas surrounding a rapidly rotating star, no satisfactory model exists which explains and predicts quantitatively the observed phenomena. It is the purpose of this paper to separate out from the large body of diverse Be stars one group with distinct properties, and to attempt to relate the origin of the observed group to evolutionary processes in massive stars as they are now becoming understood.

In an earlier investigation of the nuclei of h and χ Persei (Schild 1965), which revealed a difference in evolutionary turnup between the two clusters, the location in the H-R diagram of the Be stars in χ Persei was shown. Bidelman (1947) has noted an apparent clustering of Be stars around χ Persei. The author's own maps of the distribution of known Be stars in the vicinity of the double cluster showed an apparent clustering $1\overset{\circ}{.}5$ in diameter centered approximately on χ Persei.

II. SPECTROSCOPIC OBSERVATIONS

All the known Be stars to photographic magnitude 11.5 in the $1\overset{\circ}{.}5$ field centered on 1900 coordinates 2^h15^m, $+56^\circ40'$ were observed in the summer of 1965 with slit spectrograms at classification dispersion using the 82-inch telescope of the McDonald Observatory. Identifications of Be stars were taken from the catalogues of Merrill and Burwell (1933, 1943, 1949) and from the list of González and González (1954). Stars within 15′ of the cluster centers as defined by Oosterhoff (1937) were not observed. In addition, all OB stars in the same region listed by Hiltner (1956) were observed. Completeness to limiting magnitude for this latter group of stars may not be assumed. Twenty-six stars were on the observing program.

Spectrograms of all the Be stars observed are reproduced in Figures 1 and 2 except that HD 13900, which has recently been announced to have hydrogen emission (Hardorp,

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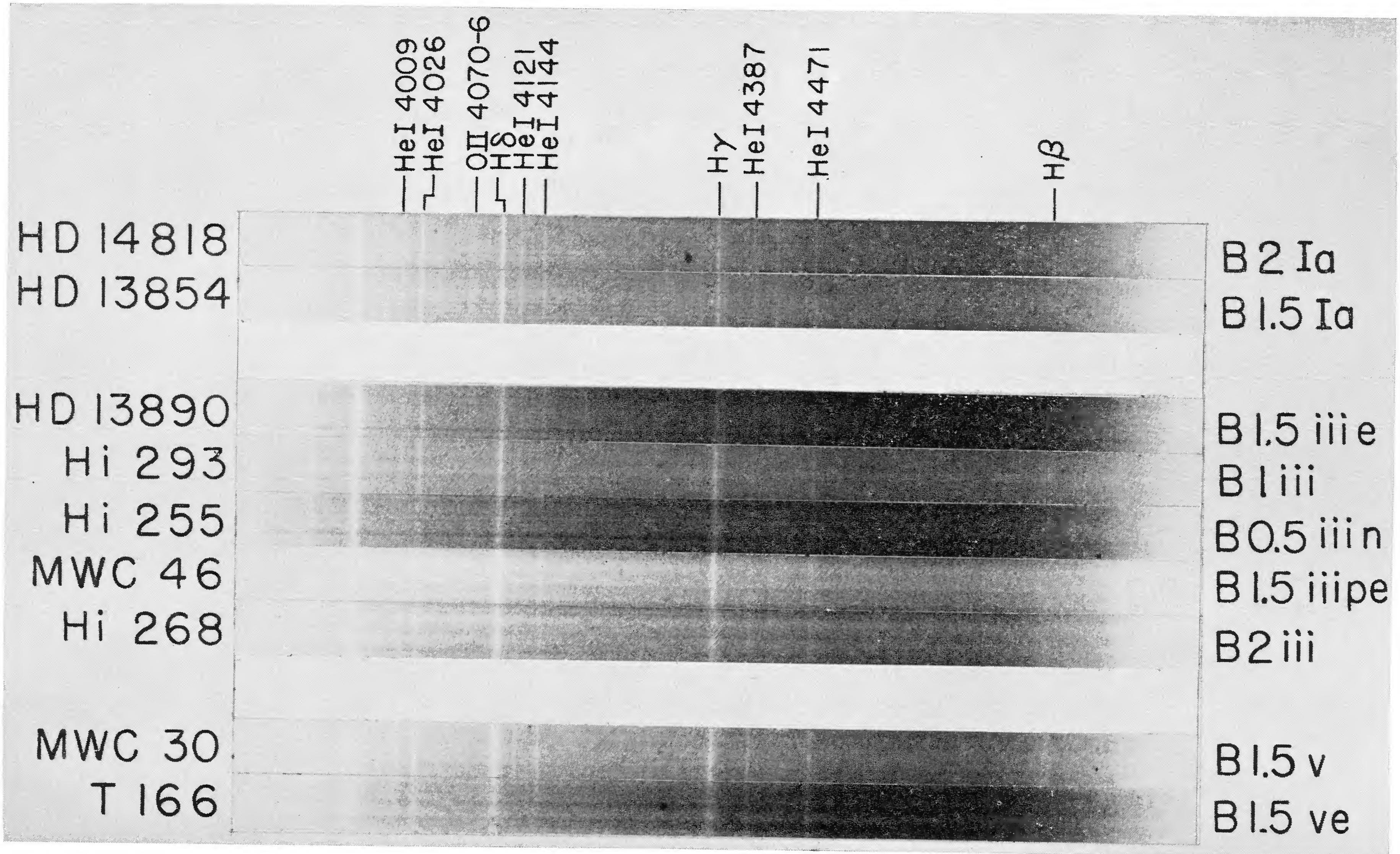

FIG. 1.—Spectrograms of ordinary Be stars in the region of h and χ Persei

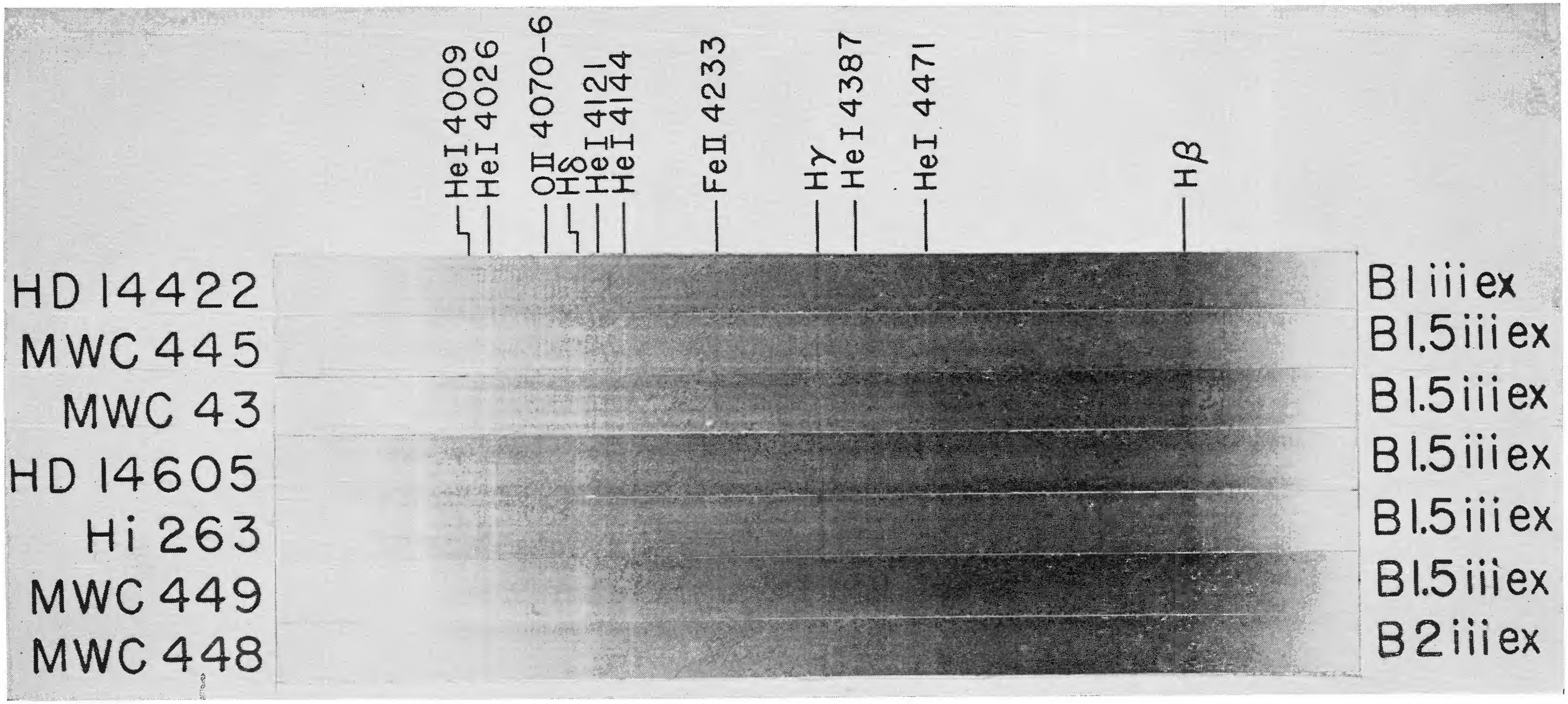

FIG. 2.—Spectrograms of extreme Be stars

Theile, and Voight 1965), has not been illustrated. Considerable care was exercised in preparing the reproductions to preserve the level of contrast. The spectrograph camera was adjusted to give good focus from approximately Hζ to λ 4481. Hβ is out of focus, but its strong emissions can nevertheless be seen. All spectrograms were taken on IIaO emulsions, some of which were baked.

III. DESCRIPTION OF SPECTROGRAMS

Stars in Figure 1 range in spectral type from B0.5 to B2. Two of the stars are supergiants which show emission on Hα plates. Of the five luminosity class III stars illustrated, three, Hi 255, Hi 293, and Hi 268, show the spectroscopic appearance of ordinary giants. On the other hand, in the spectrum of HD 13890, Hβ is partly filled in by emission and Hγ shows an emission core. Star MWC 46 is a shell star. The spectra of the two main-sequence stars are typical except that T166 has Hβ filled in by emission, and MWC 30 weakly shows shell characteristics.

The spectra in Figure 1 are typical of the diverse types found among Be stars and will, for purposes of this paper, be referred to as "ordinary" Be stars. In contrast to the above are the stars illustrated in Figure 2. These are seen to be strikingly similar to one another and different from the stars illustrated in Figure 1. All of the stars in Figure 2 show certain phenomena typical of emission B stars to a marked degree, and they will be referred to in the present discussion as "extreme" Be stars (Bex). The following spectroscopic features characterize the extreme Be stars:

1. Hβ, Hγ, and Hδ have emission components in all of the extreme Be stars. Both the strength of the Balmer emission and its decrement seem unusually similar for emission stars. It is not possible to say whether or not Hε is in emission because of blending with the sharp interstellar H-line of calcium.
2. The wings of the underlying hydrogen absorptions are broader than those of the stars illustrated in Figure 1. The higher members of the Balmer series, not visible in the reproductions, continue to show great breadth. The breadths of the hydrogen absorption lines do not appear to vary systematically with the widths of the He I absorption lines.
3. The emissions in Hγ appear to be systematically displaced to the short-wavelength sides of the centers of the absorption wings. This does not appear to be due to blending of O II λ 4349Å with the redward wings of the hydrogen profiles. This effect is most pronounced in the spectrum of HD 14422. Hδ profiles appear to be symmetrical.
4. The He I lines are quite weak compared to those of ordinary Be stars of similar spectral type.
5. The lines of all elements other than hydrogen are surprisingly narrow and among the seven stars observed show some variation in width. This variation may be comparable to that found among the ordinary Be stars of luminosity class III; however, the samples are small.
6. The blue emission lines of Fe II are faintly seen in all of the spectra of Figure 2. Fe II λ 4233Å is strongest in MWC 43, MWC 445, and MWC 449, and all the Fe II emission lines are somewhat weaker in HD 14605.

Some of the characteristics listed above are less well developed in HD 14605. In the spectrum of this star, the iron emission is faint, the veiling of the He I lines is weaker, and the shifting of the emission from the center of the absorption in Hγ is not pronounced.

Stars of spectroscopic appearance similar to that of the extreme Be stars have been called pole-on stars by Slettebak (1949; Slettebak and Howard 1955). Some non-emission B stars have subsequently been interpreted as pole-on stars (Guthrie 1965). Slettebak's pole-on hypothesis and the relationship of his pole-on stars to the extreme Be stars are to be considered in some detail below.

The uniform appearance of the extreme Be stars suggests that they are structurally similar to one another and, as a group, are different from the ordinary Be stars. Before adopting this as a hypothesis it is desirable to consider the permanence of the observed features, for some Be stars are known to vary their spectroscopic appearance appreciably in time intervals of the order of 10 years.

Because the stars of the present study are relatively faint, they have not been extensively studied. Only one of the stars is remarked on in the extensive lists of comments accompanying the catalogues of Merrill and Burwell, to describe past spectral appearances. Thus on the basis of a spectrogram taken in 1946 by Sanford, HD 14422, an extreme Be star, is reported to have shown emission in Hβ, Hγ, and Hδ (Merrill and Burwell 1949). This is also an apt description of the 1965 spectroscopic appearance.

In our search for spectral changes, we compared the 1965 plates with spectrograms of some of the extreme Be stars taken in 1952 with the same spectrograph camera. I am indebted to Dr. W. A. Hiltner for making these plates available. Because of the homogeneity of the plate material accurate comparisons could be made. It appears that the hydrogen emission was somewhat weaker in the spectrum of HD 14605 in 1952 but that the spectroscopic appearance has not otherwise changed. Other extreme Be stars, HD 14422 and Hi 263, have not suffered spectral changes in the intervening 13 years.

Thus with the exception of the strength of hydrogen emission in HD 14605, the above evidence is consistent with the hypothesis that the spectral characteristics cited in § III are permanent features of the extreme Be stars, and that the spectroscopic appearance reflects some basic structural difference from the ordinary Be stars.

IV. THE H-R DIAGRAM FOR THE REGION AROUND h AND χ PERSEI

The spectral types assigned to all the stars observed are listed in Table 1. These spectral types were determined on a classification system presently being revised (Morgan and associates, to be published) but do not differ appreciably in any systematic way from spectral types presently used. To indicate that the types are on the new system, lower-case Roman numerals have been used to denote the luminosity classes except for the supergiants, which remain unchanged. The main sequence of NGC 2244, with spectral types determined by Morgan, Hiltner, Neff, Garrison, and Osterbrock (1965) was used as the standard for luminosity class v stars. Luminosity class iii standards used were κ Aql (B0.5 iii), o Per (B1 iii), and π^4 Ori (B2 iii). The primary supergiant standards used were HD 14143 (B2 Ia) and the cluster member HD 13841 (B2 Ib). The B8 supergiants were not reclassified; spectral types for these stars were taken from Johnson and Morgan (1955).

Classification of the extreme Be stars is difficult because the He I lines are faint and because some absorption lines of singly ionized metals are known to be enhanced in the spectra of some stars with extended envelopes. The primary criteria adopted in the present study were the strength of the O II spectrum and the ratios of the strengths of singlets to triplets, especially λ 4121 and λ 4144 Å, of He I. These two criteria are known to vary with both temperature and luminosity, but it appears to have been possible to classify these stars with no significant loss in accuracy. At least two plates for each extreme Be star where classified with reasonably consistent results, but the possibility of systematic errors cannot be ruled out.

Two of the ordinary Be stars show shell characteristics. Star MWC 30 has a narrow, sharp absorption core in Hγ and is probably a poorly developed shell star. Star MWC 46 has Hβ filled in with emission, weak Hγ and Hδ with sharp deep absorption cores, and enhanced absorption in Si II $\lambda\lambda$ 4128–4130 Å and, possibly, in Mg II λ 4481 Å. Similar enhancement has been noted by Underhill (1952, 1954) in the spectra of shell stars ζ Tau and 48 Lib.

UBV data given in Table 1 are from Hiltner (1956) and from my measurements. My values were derived from four photoelectric measurements per star made on two nights and were finally corrected using HD 13841 and HD 13854 as cluster standards. The magnitudes and colors adopted for these two stars were simple averages of the published values

TABLE 1

OBSERVATIONAL DATA

Star*	Sp**	V	B-V	U-B	E_{B-V}	V_o
HD 14818	B2Ia	6.21	+0.31	-0.61	0.48	4.8
HD 14542	B8Ia	6.95	.61	.13	.63	5.1
HD 13854	B1.5Ia	6.47	.28	.67	.46	5.1
HD 14899	B8Ib	7.38	.44	.10	.46	6.0
HD 13841	B2Ib	7.37	.23	.65	.40	6.1
HD 13866	B2Ib	7.48	.19	.65	.36	6.4
HD 14422	B1iiiex	8.99	.51	.64	.77	6.7
HD 14357	B1iii	8.52	.31	.52	.57	6.8
HD 14302	B1iii	8.57	.26	.56	.52	7.0
HD 13890	B1.5iiie	8.47	.19	.63	.44	7.2
MWC 445	B1.5iiiex	9.30	.46	.56	.71	7.2
HD 13831	B1.5II	8.26	.10	.81	.33	7.3
Hi 293	B1iii	9.46	.41	.48	.67	7.4
MWC 43	B1.5iiiex	9.91	.56	.52	.81	7.5
Hi 255	B0.5iiin	9.07	.24	.63	.52	7.5
HD 14605	B1.5iiiex	9.34	.27	.75	.52	7.8
HD 14092	B2iii	9.23	.23	.59	.47	7.8
MWC 46	B1.5iiipe	9.65	.35	.41	.60	7.8
HD 13900	B1iii	9.17	.16	.66	.42	7.9
Hi 263	B1.5iiiex	9.62	.32	.72	.57	7.9
MWC 449	B1.5iiiex	10.58	.62	.43	.87	8.0
MWC 448	B2iiiex	10.88	.67	.44	.91	8.1
Hi 278	B2iii	9.82	.33	.50	.57	8.1
Hi 258	B2iii	9.62	.19	.66	.43	8.3
T 166	B1.5vne	11.18	.56	.31	.81	8.8
MWC 30	B1.5v	10.59	+0.36	-0.41	+0.61	8.8

* HD=Henry Draper Catalogue; MWC=Merrill and Burwell 1933, 1943, 1949; Hi=Hiltner 1956; T = Gonzalez and Gonzalez 1954.

** Emission is indicated after the spectral types only if it was noted on spectrograms of the present survey. All of the stars whose spectra are illustrated in Figures 1 and 2, and HD 13900, have shown hydrogen emission.

of Hiltner (1956) and Johnson and Morgan (1955). In deriving magnitudes V_0 corrected for interstellar reddening from color excesses, intrinsic colors were taken from Johnson (1963). A ratio of absorption to $(B - V)$ color excess of 3.0, derived by Hiltner and Johnson (1956) for stars in the double cluster, was used.

The H-R diagram of the stars around h and χ Persei is shown in Figure 3. The luminosity calibration of unevolved main-sequence stars by Johnson and Iriarte (1938) was used with a cluster distance modulus of 11.8 (Blaauw 1963) to indicate the position of the main sequence. This H-R diagram and the relationship of the stars studied to the

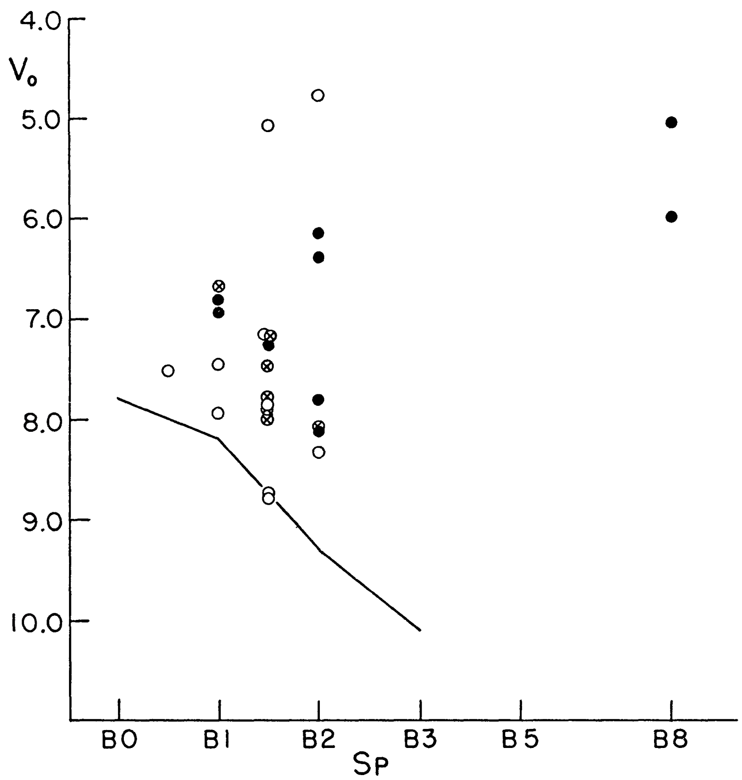

FIG. 3.—H-R diagram of the region surrounding h and χ Persei. *Filled circles*, non-emission B stars; *open circles*, ordinary Be stars; *crossed circles*, extreme Be stars.

nuclear clusters h and χ Persei are to be the subject of a forthcoming paper. For the present the following may be noted:

1. The extreme Be stars lie in a band approximately parallel to, but at least a magnitude above, the main sequence. Because of accidental and possible systematic errors in classification it does not seem possible to specify accurately either the width of the band or its position in relation to the main sequence. An arithmetic value for the mean position found for the extreme Be stars above the main sequence is 1.1 mag. with an uncertainty of 0.3 mag. (probable error assuming a unique value exists). Because the main sequence given by Johnson is a mean relation for main-sequence stars in unevolved clusters and the lower envelope, used in theoretical studies, is several tenths of a magnitude below it, the band containing the Be stars may be an additional several tenths above the theoretical age-zero main sequence.
2. Within this band are found at least two ordinary Be stars including a shell star.
3. Also within this band are found several non-emission B stars.
4. Among the stars on the main sequence or between the main sequence and the band

containing the extreme Be stars are found ordinary Be stars including one possible shell star.

5. With the exception of the most luminous early B-type supergiants, the stars to the low-temperature side of the extreme Be star band do not show emission.

In connection with point 2 above it may be noted that the shell star MWC 46 may have been incorrectly classified by half a tenth of a spectral division, since criteria indicating both earlier and later spectral type are to be found in its spectrum. Thus it may lie between the interval containing Be stars and the main sequence, more like the other possible shell star MWC 30. In connection with point 3 it should be remarked that selection in this program strongly favored Be stars over non-emission B stars near the low luminosity limit of the survey. Thus there may be many non-emission B stars in the interval $8.0 \leq V_0 \leq 9.0$ which have not been observed. Finally, it seems likely that the

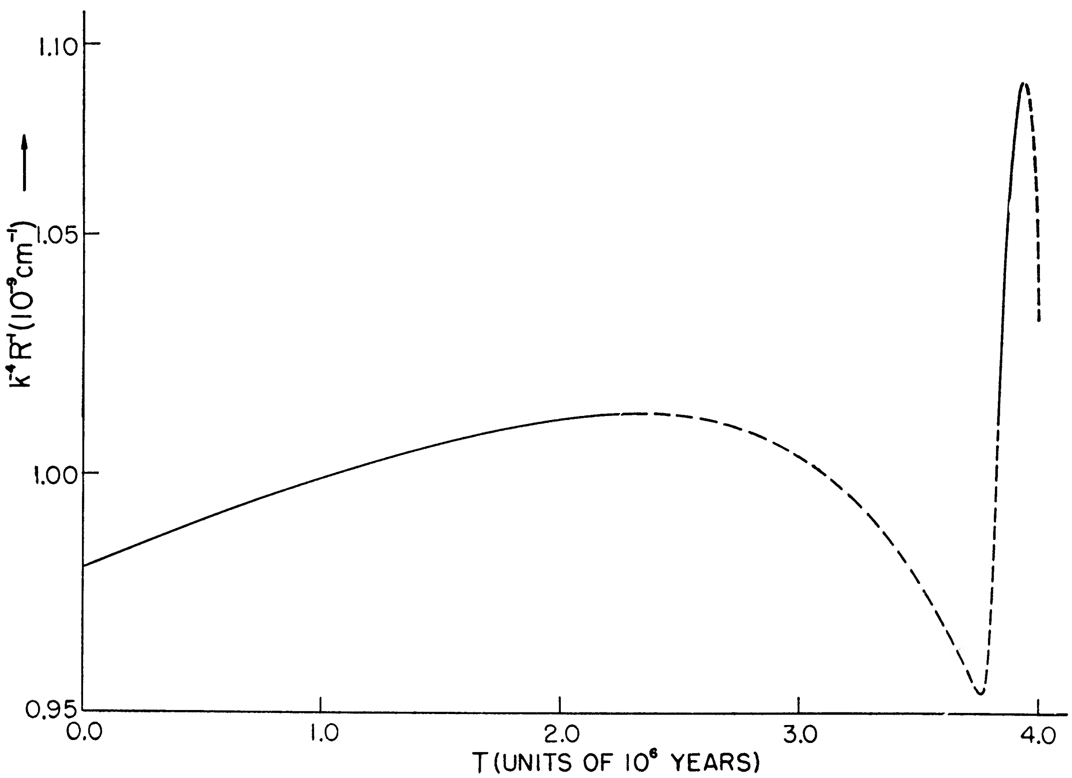

FIG. 4.—Variation of $k^{-4}R^{-1}$ during the hydrogen-burning evolution of a 4 $M_\odot$ star. Data are from Crampin and Hoyle (1960). Forced rotational ejection from rapidly rotating stars is likely when $k^{-4}R^{-1}$ is increasing (solid portion of curve).

stars noted in remark 5 are intrinsically non-emission B stars, since they are bright enough to have been observed in the numerous surveys for emission stars in the region of the double cluster.

The localization of the extreme Be stars to a particular region of the H-R diagram is an interesting result and is, fortunately, subject to a further observational test. The galactic cluster NGC 6530 is in many ways similar to χ Persei, although its evolutionary turnup is a tenth of a spectral class earlier. Both NGC 6530 and the double cluster have outlying O stars, and the former is known to be rich in Be stars, many of which may simply have the semblance of emission-line character due to contamination of spectrograms by bright nebular emission (Hiltner, Morgan, and Neff 1965). However, in a reexamination of spectrograms, one star was found, on the basis of spectroscopic appearance alone, to be similar to the extreme Be stars in the region of h and χ Persei. This star, Walker No. 65, lies approximately 1.5 mag. above the main sequence, in a position corresponding to the band in which extreme Be stars are found in the H-R diagram for stars in the region of the double cluster.

V. POSSIBLE INTERPRETATIONS

Two possible interpretations of the observations are to be investigated in some detail in this section. A third possibility, that the extreme Be stars are more rapidly rotating than, but otherwise structurally similar to, ordinary Be stars, seems unlikely if rotation is the principal cause of the Be phenomenon; this interpretation will not be further considered.

a) Extreme Be Stars as Pole-on Stars

The observations may result from an orientation effect, whereby the extreme Be stars are ordinary Be stars viewed along their axes of rotation. In this interpretation the sharpness of the spectral lines, including the hydrogen emissions, may result from small line-of-sight motions in a rapidly rotating star. Veiling of the absorption spectrum would be expected when a rotationally distorted star is viewed pole on, since the surface gravity would vary over the photospheric regions visible from Earth, and the formation of a particular spectral feature would occur over only a limited portion of the stellar surface (Huang and Struve 1956). Moreover, stars of very similar spectroscopic appearance such as 56 Eri and ω CMa have been interpreted as pole-on stars in the past (Slettebak 1949).

However the pole-on hypothesis seems incorrect in the light of the present observations. We note the following:

1. Aproximately half the Be stars observed are, in this interpretation, pole on. Although the number of objects observed is small, this would seem to indicate a strong tendency toward alignment. Kraft (1965) finds little evidence for a strong tendency of stars in the Hyades and Coma clusters to have their axes of rotation aligned. Moreover, one would expect stellar axes of rotation to parallel the Galaxy's if any direction were preferred; then stars in a cluster so near the galactic plane would be viewed along their equators.
2. The extreme Be stars show among themselves approximately the same variation in line width as do the ordinary luminosity class III Be stars. However, in the spectra of the former the widths of the He I lines do not appear to be correlated with the strengths of the Fe II and hydrogen Balmer emissions. If enhancement of Fe II emission and hydrogen emission results when Be stars are viewed along their axes of rotation, and if the spread in widths of He I lines reflects the distribution of the orientations of these axes, the strengths of the emissions should be correlated with the He I line widths.
3. The limitation of the extreme Be stars to a band in the H-R diagram remains unexplained. Collins (1963) has shown that stars rotating at the limit of equatorial ejection may be a magnitude brighter when viewed along their poles than when viewed along their equators. However, no estimates are given of the effects that viewing the high-temperature parts of a star will have on spectral type, and it is likely that stars which appear brighter because of inclination effects will display corresondingly earlier spectra.
4. The absence of intermediate cases casts further doubt on this hypothesis.

b) Extreme Be Stars as Stars Undergoing Rapid Core Contraction

Schmidt-Kaler (1964) has suggested all Be stars in the spectral region B0–2 III–V are in the evolutionary state where core contraction subsequent to hydrogen exhaustion is rapid. While the existence of Be stars on or near the main sequence contradicts this hypothesis, it may be that rapid core contraction is responsible for the phenomena exhibited by the extreme Be stars. We may suppose that the extreme Be stars are rotating at the limit of equatorial ejection of matter. They may have extended atmospheres with sufficient optical thickness to mask very broad photospheric absorption lines and to superimpose the observed early-type sharp-lined absorption spectrum. Their broad hydrogen absorption wings may result from broadening of the photospheric absorptions by electron scattering (Münch 1948). The similarity of the observed spectra, the lack of intermediate types, and the band in the H-R diagram wherein the extreme Be stars are located, as well as other features of the H-R diagram, could be explained in terms of the major structural changes which stars are thought to undergo when their evolution has brought them to a position approximately 1.5 mag. above the main sequence.

Crampin and Hoyle (1960) have shown in a simplified theory that forced rotational ejection is likely to occur in the most rapidly rotating stars during those evolutionary stages in which the quantity $k^{-4}R^{-1}$, where k is the radius of gyration and R is the stellar radius, is increasing in time. Radii of gyration and stellar radii for a 4 $M_\odot$ star have been tabulated by Crampin and Hoyle, who state, on the basis of similar calculations for more massive stars, that the results can be scaled homologously with reasonable accuracy. Their data for the variation of $k^{-4}R^{-1}$ with time have been plotted in Figure 4.

Figure 4 shows that the rotating stars show some tendency to lose mass for the first three-fifths of their main-sequence lifetimes. In the present interpretation, this period sees the development of hydrogen Balmer emissions in those stars which lose mass at their equators, and even the formation of shells (in the sense of the specific spectroscopic phenomena described by Merrill 1949) in some cases. In the next quarter of their hydrogen-burning lifetimes, in which the stars evolve from a position about a magnitude above the main sequence to the region of the H-R diagram where contraction becomes important, the stars are stable against forced rotational ejection. This is followed by a brief period of rapid core contraction in which $k^{-4}R^{-1}$ increases so rapidly that many stars have to shed mass at their equators at such a rate as to give the characteristic spectroscopic appearance of the extreme Be stars. This is followed by a period of stability against mass loss and subsequent rapid evolution.

On this picture it follows that there should be no ordinary Be stars in the extreme Be star band. The presence of two ordinary Be stars in this band may possibly be attributed to small errors in classification and to cosmic scatter. It may be objected that the proportion of extreme Be stars is too great in view of the very short time in which stars pass through their core-contraction phase. In this regard we note:

1. Many stars may not encounter an angular-momentum problem until they reach the core-contraction phase.

2. The selection of stars studied strongly favored emission stars, and the extreme Be stars are more likely to be discovered because of both the strength and apparent permanence of their hydrogen emissions.

3. It is evident that the group of stars is in a state of evolution where stars in the spectral range B1–2 are evolving away from the main sequence. If, further, the dispersion in ages of the stars is small, the relative proportion of extreme Be stars may not be discrepant with theory.

VI. COLORS OF THE EXTREME Be STARS

Mendoza V.'s (1958) study showed that the Be stars of earliest spectral type all showed reddening and large amounts of scatter about the reddening line in the two-color plot. An abnormal amount of reddening could be attributed to selection effects since the selection of stars was to a limiting magnitude instead of to a volume of space. Collins (1963) has shown that inclination effects, especially in stars rotating at the limit of equatorial ejection, may have important effects on the colors, and that the ultraviolet magnitudes are affected more strongly relative to the visual than are the blue magnitudes. Some scatter about the reddening trajectory may be due to differences reported by Edwards (1956) between the color temperature and the ionization temperature indicated by the line spectrum, although Dokutchaeva (1957) finds the energy distributions of B and Be stars to be similar.

Mean color excesses for the extreme Be stars, the ordinary Be stars, and the non-emission B stars are shown in Table 2. The probable errors are quite large because of the large variation in reddening in the region of the double cluster. Nevertheless, it appears likely that the extreme Be stars show a systematic color excess in $(B - V)$ with respect to the ordinary Be stars, which themselves may be systematially redder than the non-emission B stars. The mean excesses in $(U - B)$ do not seem to differ significantly for the three classes of stars.

A more sensitive test may be made with maps of the color excesses in the vicinities of the extreme Be stars. Such maps for the vicinities of four extreme Be stars where the reddening is reasonably well defined by color excesses of nearby stars consistently give a residual color excess of approximately $\delta(B - V) = 0.15$ mag., in the sense that the extreme Be stars are too red. No comparable residual excesses in $(U - B)$ are found. These results are confirmed by a similar map of the distribution of color excesses in the vicinity of Walker 65, the extreme Be star in NGC 6530. Spectral types used to determine color excesses in $(B - V)$ and $(U - B)$ are those of Hiltner *et al.* (1965).

TABLE 2

MEAN COLOR EXCESSES

	Bex	Be	B
$E_{B-V}\pm$p.e......	0 74±0 09	0.56±0 08	0 48±0 05
$E_{U-B}\pm$p.e......	0.34±0.07	0.41±0.07	0.34±0.04

Absence of a systematic $(U - B)$ excess of amount comparable to the observed $(B - V)$ excess indicates that the extreme Be stars do not show circumstellar reddening according to the $1/\lambda$ law. Large temperature differences, which might result from large systematic errors in spectral classification, are also excluded by the absence of residual $(U - B)$ color excesses. Because of the small size of the sample and the large variation in reddening across the region, no significant conclusions can be reached from the probable errors computed for the color excesses about the possible influence of inclination on the colors, especially since little is known about the effect of inclination on spectral type. If the residual excess in $(B - V)$ is due to very strong Hα emission not entirely excluded from the V band pass in the UBV system, an interpretation consistent with the observations, values of V_0 derived using intrinsic colors of non-emission B stars may be a half magnitude too bright.

VII. CONCLUDING REMARKS

The present study has been limited to stars in two distant clusters. If the proposed interpretation of the extreme Be stars is correct, it would be helpful to look for corresponding objects in the solar neighborhood to permit studies at higher dispersion of the hydrogen profiles and of the mechanisms causing line broadening. To this end it may be noted that the fourth-magnitude star χ Oph, a member of the Scorpio-Centaurus association, occupies a similar position in the H-R diagram, shows a similar red excess in the two-color plot, and has a similar spectroscopic appearance to the extreme Be stars in h and χ Persei. However, we may note the following features in which the spectrum of χ Oph differs from those of the extreme Be stars: (1) it is somewhat later in spectral type; (2) the veiling of the He I lines is absent or much less pronounced; (3) the hydrogen Balmer emission is stronger and has cores at least as far as Hζ on spectrograms taken by Dr. W. A. Hiltner in 1964; (4) the underlying hydrogen absorptions are stronger; (5) the emission core of $H\gamma$ shows only a slight, or no, displacement from the center of the absorption.

The star χ Oph and other stars of similar spectroscopic appearance have been called pole-on stars by Slettebak (1949). Spectra of the other stars so classified show considerable similarity to χ Oph. The fact that all of Slettebak's pole-on stars are emission stars of relatively uniform spectroscopic appearance, in spite of the known large range in spectroscopic phenomena exhibited by rapidly rotating B stars, together with the similarity of this appearance to that of the extreme Be stars, may indicate that the evidence in support of the pole-on hypothesis should be re-examined.

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