LONG-TERM VARIATION OF Be STARS ON THE COLOR-MAGNITUDE DIAGRAM

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Abstract The ratios $\alpha=\Delta V/\Delta(B-V)$ and $\beta=\Delta(U-B)/\Delta(B-V)$ for the long-term variation of Be stars have been derived. The inclination effect on α is found. The dependence of α on the spectral type is also inferred. The signs of α and β are essentially the same.

The long-term variations of Be stars on the color-magnitude and color-color diagrams have been re-examined, by adding newly published data (e.g.,Harmanec et al. 1980) after the work of Nordh and Olofsson(1977). Taking into consideration of the influence of the short-term variation and the photometric accuracy, we selected the Be stars which fulfil the following three conditions, i) total span of observations$\gtrsim$10 years, ii) number of years in which the observations were made$\gtrsim$5, iii) total range of variation, $\Delta V \geq 0^m.15$ or $\Delta(B-V) \geq 0^m.05$. 37 Be stars were thus selected. The values of V, B-V, and U-B were plotted against time to check whether they reflect the long-term variation or not. When many data were available in one observational season, the average was taken. Then, the regression curve for $\alpha=\Delta V/\Delta(B-V)$ was obtained for 32 stars. We could determined the regression curves of 25 stars for both α and $\beta=\Delta(U-B)/\Delta(B-V)$. In figure 1a,we plot α against Vsini. The rotational velocities, Vsini, are taken from Uesugi(1978). The broken line corresponds to $\alpha=-3$. The dependence of α on Vsini is clearly seen, i.e., $\alpha<-3$ for the stars with Vsini<270 km/s except one star(HD184279), and $\alpha>-3$ for the stars with Vsini>270 km/s with one exception(CX Dra). The mean Vsini values are shown in table 1, together with the numbers of stars in parentheses. The Vsini-dependence of α is seen in each spectral type. It is also noticed

Table 1. Mean rotational velocities (*HD184279)

	B0-B1.5	B2-B2.5	B3	B4-B5	B6-B8
$\alpha<-3$	153(2)	193(6)+?(1)	170(3)+?(1)	270(3)	-
$-3<\alpha<0$	323(2)	350(2)	285(2)+?(2)	?(1)	-
$\alpha>0$	228(1)*	-	295(2)	369(1)	323(3)

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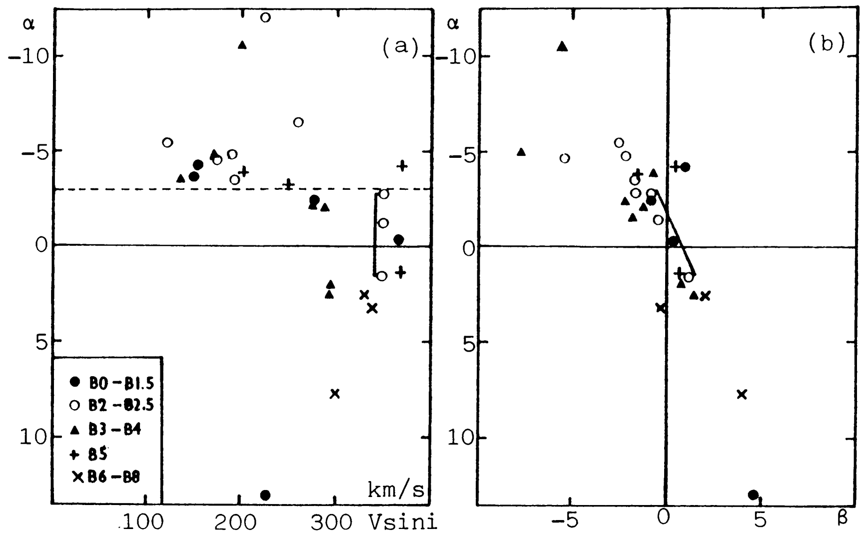

Fig.1 a) $\alpha=\Delta V/\Delta(B-V)$ vs. Vsini, b) α vs. $\beta=\Delta(U-B)/\Delta(B-V)$.

that $\alpha<0$ for B0-B2 stars except HD184279, $\alpha>0$ for B6-B8 stars, and B3-B5 stars take all signs for α. This is a tentative suggestion, because our sample stars contain only several early Be stars with large Vsini values, and no late Be stars with small Vsini values. Figure 1b shows the correlation between α and β. The signs of α and β are essentially the same.

Let us discuss briefly some possible interpretations of the present results. Variations in the B and V bands have their origin in the inner dense part of the envelope(Poekert and Marlborough 1978), or even in the photosphere. The U-mag. is affected also by the outer part of the envelope because of the larger opacity and emissivity in the Balmer continuum. The existence of the stars with $\alpha>0$ indicates the opaqueness of the continuum formation region.

1) Variation of density and temperature in the envelope. Models of Poekert and Marlborough(1978) give $\alpha,\beta<0$ for the density change(Teff= 25000K), which is in accordance with the observational results in early Be stars. It is to be noted that the brightness increases when i<45°, and decreases when i>60°, while the emission-line intensity always increases as the density increases in their model. It is interesting to calculate the analogous models for the late Be stars.

2) Variation in the photospheric level. The weakening of the Balmer-line wings and the appearance of the very broad component of the CaII K line, accompaning the brightness decrease, in the shell phase of Pleione imply such a possibility. It is interesting to point out that the rapidly rotating model atmospheres of Collins and Sonneborn(1977) can account the observed tendencies on both Vsini- and spectral type- dependencies of α. Figure 2 shows the variations on the color-magnitude diagram for the change of ω/ω_c (ω_c :critical angular velocity) from 0.9 to 1.0(i=0°,30°, 45°,60°, and 90°). The pole-on case is designated by open circle. In this

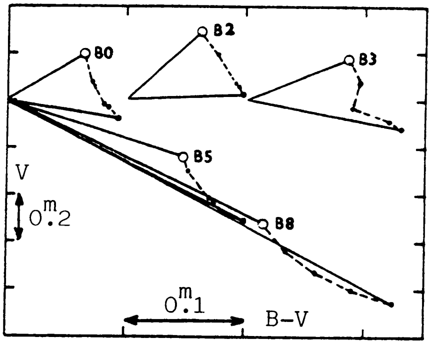

Fig.2 Photometric behaviors of the rapidly rotating stars for the change of ω/ω_c:0.9→1.0(Collins and Sonneborn 1977).

picture, the photometric variation is caused by the gravity darkening due to the angular momentum transport.

3) Precession of the elongated disk. When mostly extended region faces to the observer, one can expect the considerable diminution in the continuum, especially in the Balmer continuum. Shell stars accompaning cyclic V/R variation are the most probable candidates. In fact, such an effect was detected in the U-mag. of 48 Lib(Delplace and Chambon 1976, Feinstein 1968,1970,1975), and in the far-ultraviolet region of ζ Tau(Beeckmans 1978).

It is obvious that the comparative study of the spectroscopic and photometric materials is absolutely necessary to clarify the mechanism of the long-term photometric variations of the Be stars. In fact, it now becomes clear that, in some well-observed stars like EW Lac and 88 Her, their photometric behaviors depend on their spectral phases.

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NOTE ADDED IN PROOF: During the Symposium, Dr.A.Feinstein provided me additional photometric data of a number of southern Be stars. Preliminary analysis, after adding these data, indicates,a) the number of sample stars, which fulfil the conditions (i) and (ii), increases to about 70 stars, b) almost all stars observed by Dr.A.Feinstein fulfil the third condition, c) present conclusions on Vsini- and spectral type- dependencies of α are not altered for total 50 stars.

DISCUSSION

Snow: I have a comment and a question. The comment is that it is clear from this morning's talks and, I am sure, from what we will hear from the rest of the week, that time variability is a very important feature of Be stars, and must be included in our efforts to understand these objects. In your study you have deliberately overlooked short-term variations, and it is worth keeping in mind that they do occur, and should not be ignored. My question is whether you looked at any stars that did not show variability, and if so, what percentage of your sample fell into that category?

Hirata: We must make an effort to reveal the nature of the short-time variations, as well as that of the long-term variations. There are many Be stars which do not show large variations in V or B-V. But it is uncertain whether it reflects no real variation or the lack of the data.

Endal: Is there any observational evidence for Be stars changing their rotational velocities (as measured by absorption line width, for example)?

Hirata: Not obvious. It is difficult to detect the change of absorption widths by the conventional method. But I think that the appearance of a very broad component of the CaIIK line in Pleione, prior to the shell appearance, gives such a clue.

Hubert-Delplace: It seems to me that in the case of Be stars in a shell phase, the relation $\Delta V / \Delta(B-V)$ which separate early Be stars from late Be stars, breaks down.

Hirata: Sample stars could be added in future. I also showed phase dependency in the case of 88 Her, and future data can clarify such details.