Bull. Natn. Sci. Mus., Tokyo, Ser. E, **15**, December 22, 1992

UBV Photometric Observations of Be Stars in the Open Cluster NGC663

By

Toshihiro HORAGUCHI

Department of Science and Engeneering, National Science Museum,
Ueno Park, Taito-ku, Tokyo 110

and

Ryuko HIRATA

Department of Astronomy, Faculty of Science,
Kyoto University, Sakyo-ku, Kyoto 606–01

Abstract

The Be stars in the young open cluster NGC663 were observed photometrically in 1989 and 1990 to study the evolutionary status of Be stars. The V magnitudes and colors of B−V and U−B are presented and compared with the observations in previous papers.

1. Introduction

NGC663 ($\alpha_{1950}=1^h42^m.6$, $\delta_{1950}=+61°00'$) is one of the young open clusters which contain many Be stars. The evolutionary status of Be stars is still unclear, and open clusters are the fields which are suitable to the study of evolutionary state of the members since the members are at the same distance and have the same age.

Schild and Romanishin (1976) have studied the Be stars in open clusters and concluded that the fraction of Be stars varies little during the first 80 percent of the main sequence phase but undergoes a fourfold increase at the onset of gravitational core contraction phase. On the other hand, Mermilliod (1982) analysed the absolute magnitudes and dereddened colors of Be stars in open clusters using new estimates of the distance moduli and color excesses of the open clusters (Mermilliod 1981a) and have yielded result that the Be stars occupy the whole main sequence band from ZAMS to TAMS and are not confined to the termination of the main sequence (core contraction phase). Slettebak (1985) also constructed color-magnitude diagrams for twelve open clusters and have shown that Be stars may exist in various evolutionary stages, including the essentially unevolved stage.

It is very important to know the intrinsic magnitude and colors to study the evolutionary state of Be stars but it is difficult since circumstellar reddening by the envelope and gravity darkening due to the rapid stellar rotation influence the observed magnitude and colors of Be stars. The fact that the emission strength of a Be star varies in the time scale of years or decades shows that the envelope grows up and down. One can hence see the influence of an envelope on the magnitude and colors by comparing observations obtained at different periods.

Table 1. List of object stars in NGC663

Wallenquist No.	VES No. DM No.	V	B−V	U−B	Reference
2		12.18	+0.65:	−0.23	1
6	VES 620	11.98:	+0.67:	−0.31	1
		12.23	+0.67	−0.20	3
		11.95	+0.72	−0.26	3
		11.06	+0.64	−0.40	3
8		12.12	+0.57	+0.02	1
10	VES 617	11.83	+0.69	−0.30	1
		12.10	+0.61	−0.22	3
21		10.38	+0.50:	−0.35:	1
30	VES 622	10.98	+0.61	−0.34	1
		11.06	+0.60	−0.32	3
53		11.5	—	—	4
67	VES 623	12.03:	+0.50	−0.19	1
		12.60	+0.55	−0.13	3
91	VES 615	—	—	—	
92	VES 614	10.29:	+0.56:	−0.20:	1
93	VES 613	11.90	+0.55	−0.05	4
107	+60° 340	10.17	+0.59	−0.21	1
		10.16	+0.60	−0.24	2
110	+60° 344	10.22	+0.55	−0.25	2
120	VES 624*	10.85	+0.92	+0.43	1
		10.89	+0.76	+0.38	3
121	VES 624*	13.39	+0.57:	+0.02	1
		13.44	+0.67	+0.02	2
124		12.21	+0.77	−0.20	1
130	VES 611	12.44	+0.72	−0.21	3
141	VES 619	10.65	+0.65	−0.34	2
170		11.98	+0.57	−0.37	4
194	VES 625	11.33	+0.82	−0.39	3
210	VES 610	12.10	+0.69	−0.32	3
222	VES 628	11.35	+0.66	−0.37	3
224	VES 630	12.42	+0.70	−0.19	3
297		11.55	+0.57	−0.22	4

* VES 624 is identified as Wallenquist No. 120 in Mermilliod (1982) but is marked on No. 121 in Coyne *et al.* (1978).

References 1: Hoag *et al.* (1961) (photographic data)
2: Mermilliod (1976) and its revised version in magnetic tape
3: Coyne *et al.* (1978)
4: Mermilliod (1982) (see text)

2. Observations

UBV photoelectric observations of Be stars in NGC663 have been carried out with a single-channel photoelectric photometer attached to the Cassegrain focus of the 91-cm reflector at the Okayama Astrophysical Observatory from November to December, 1989, and from October to November, 1990. The observations of 24 object stars have been done differentially to a comparison star along with a check star. Since atmospheric condition is not very stable in Japan, differential observation is preferable to get results with higher precision. Photometry of a open cluster is favorable also in this meaning because we can easily find a comparison star in the same cluster, *i. e.*, in the neighborhood of the object stars. But for the photometry in a dense star cluster, the diaphragm must be carefully selected. In our observations, one of the two diaphragms of $\phi=1.5$ mm (26″) and 1.0 mm (17″) was chosen according to the closeness of nearby stars and the seeing condition of the night. The typical sequence of the observation is $V\times 6$, $B\times 6$, $U\times 6$, $U\times 6$, $B\times 6$, and $V\times 6$ for a star, and then $V\times 3$, $B\times 3$, and $U\times 3$ for the sky to be subtracted. The sky was observed for every star at the same position where no star is thought to exist.

The observed object stars are summerized in table 1. Column 1 is the star number in Wallenquist (1929). Column 2 is the Vatican Emission Star (VES) number in Coyne *et al.* (1978) and the DM number. Columns 3, 4, and 5 are the V magnitude and the colors, B—V and U—B, previously obtained by several observers. The references, Houg *et al.* (1961), Mermilliod (1976, 1982), and Coyne *et al.* (1978) are given in column 6. In Mermilliod (1982), only $(B-V)_0$ and $(U-B)_0$ are shown and hence we get B—V and U—B by the color excesses he used, E $(B-V)=0.76$ and E $(U-B)=0.7\times E\ (B-V)\ (=0.53)$ (Mermilliod 1981a). The comparison star and the check star are listed in table 2.

Table 2. List of comparison and check stars in NGC663

Wallenquist No.	VES No. DM No.	V	B—V	U—B	Reference
comparison star					
140		10.89	+0.47	−0.33	2
check star					
144	+60° 341	11.37	+0.54	−0.24	2

The reference number means as same as table 1.

Table 3. Photometric results for the program stars

Wallenquist No.	HJD (2440000+)	V	B−V	U−B
2	7863.965	12.229	+0.695	−0.256
	8185.166	12.259	+0.697	−0.246
	8211.010	12.275	+0.685	−0.252
6	7863.227	12.150	+0.696	−0.287
	8183.219	12.029:	+0.704:	−0.250
	8213.153	12.133:	+0.703	−0.270
8	7863.985	12.231	+0.705	+0.022:
	8185.177	12.247	+0.684	−0.013
	8213.093	12.054:	+0.688:	−0.045:
10	8183.288	11.902:	+0.626	−0.165
	8188.088	12.006	+0.597	−0.184
	8211.208	12.012	+0.561	−0.179
21	7863.205	10.669	+0.576	−0.303
	8187.110	10.697	+0.580	−0.306
	8187.977	10.695	+0.557	−0.275
	8211.130	10.728	+0.565	−0.275
30	8210.987	11.026	+0.611	−0.344
53	8183.272	11.269:	+0.572:	−0.222:
	8188.118	11.433	+0.747	−0.202
	8211.229	11.295:	+0.849:	−0.227
	8211.242	11.405:	+0.746	−0.271
67	7863.074	12.089	+0.559	−0.211
	8187.094	12.094	+0.558	−0.236
	8213.011	12.078	+0.542	−0.192
	8213.168	12.067	+0.513	−0.256
91	7864.018	10.961	+0.722	−0.071
	8185.219	10.950:	+0.730	−0.086
	8211.272	10.941:	+0.683	−0.273
92	8185.271	10.754	+0.643	−0.207
	8211.287	10.687	+0.682	−0.206
93	7863.128	11.875	+0.669	−0.328
	8187.047	11.949	+0.675	−0.273
	8211.098	11.924	+0.653	−0.300
107	7861.095	10.184	+0.574	−0.262
	8183.308	10.186:	+0.581	−0.254

Table 3 (continued)

Wallenquist No.	HJD (2440000+)	V	B−V	U−B
110	7861.068	10.017	+0.556	−0.231
	8183.181	9.996:	+0.560	−0.237
120	7861.118	10.935	+0.865	+0.376:
	8188.209	10.922:	+0.839	+0.394:
	8213.045	10.928:	+0.869:	+0.382:
	8213.185	10.941:	+0.847:	+0.439:
121	7862.043	13.396	+0.704	+0.029:
	8188.172	13.526	+0.701	+0.017
	8213.060	13.477	+0.616	−0.067:
	8213.195	13.493:	+0.707:	+0.077:
124	7862.003	12.308	+0.664	−0.221
	8188.025	12.366	+0.650	−0.225
	8211.042	12.332	+0.638	−0.210
130	7863.102	12.426	+0.710	−0.150
	8185.305	12.434	+0.706	−0.152
	8211.111	12.411	+0.731	−0.160
141	7861.057	10.602	+0.617	−0.342
	8188.082	10.802	+0.596	−0.309
	8211.177	10.722	+0.602	−0.324
170	7862.964	11.984	+0.496	−0.325
	8187.075	11.786	+0.559	−0.384
194	7862.094	11.362	+0.681	−0.340
	8188.040	11.274	+0.667	−0.360
	8213.025	11.312	+0.690	−0.359
	8213.213	11.311:	+0.686	−0.368
210	7863.050	12.290	+0.584	−0.310
	8185.292	12.315	+0.581	−0.306
	8211.053	12.332	+0.581	−0.322
222	7861.992	11.519	+0.581	−0.276
	8188.066	11.116	+0.657	−0.311
	8211.071	11.306	+0.671	−0.373
224	7862.106	12.356	+0.695	−0.190
	8188.007	12.359	+0.714	−0.180
	8213.138	12.421:	+0.706	−0.166
297	7863.938	10.895	+0.553	−0.280
	8185.144	10.877	+0.544	−0.277
	8213.033	10.882	+0.561	−0.297

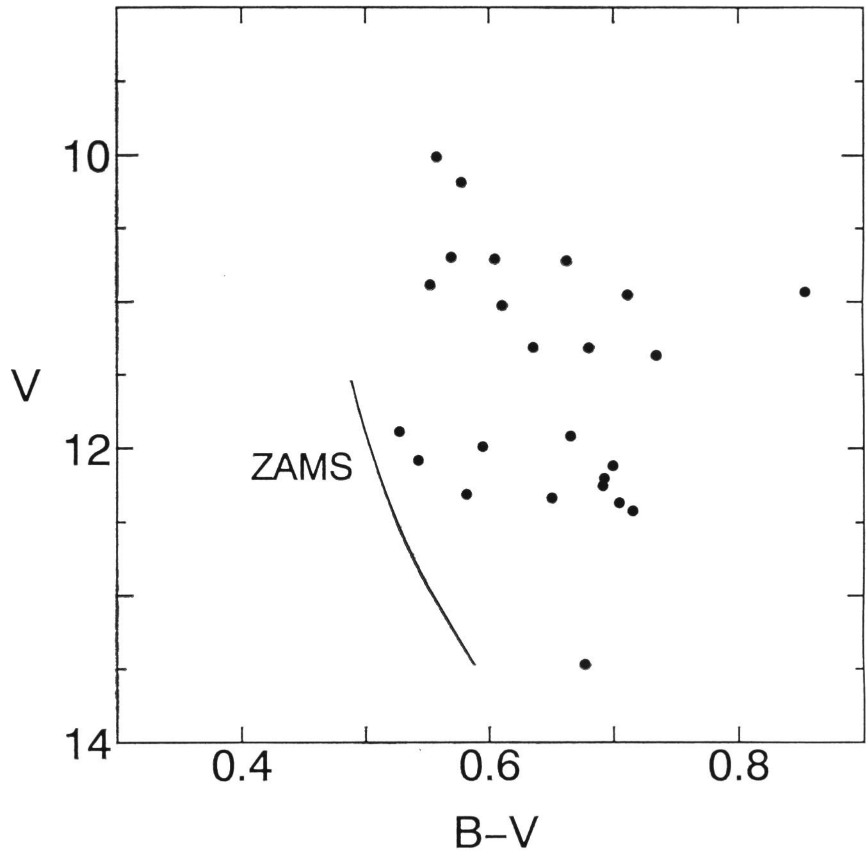

Figure 1. The color-magnitude diagram of the object stars in NGC663. The zero-age main sequence (ZAMS) is from Mermilliod (1981b), with the distance modulus of 13.75 mag and the color excess of E(B−V)=0.76 (Mermilliod 1981a).

3. Results and Discussion

Table 3 shows our result of differential observation. A colon is added to the values the probable error of which is more than 0.015 magnitude. For the other values, the probable error is less than 0.015 magnitude but may not be less than 0.01 magnitude, since the V magnitude and colors of the check star are fluctuating in the range of about ±0.01 magnitude. The stars, Wallenquist No. 10, 53, 91, and 92, have another star in the respective neighborhood and it was not easy to hold the

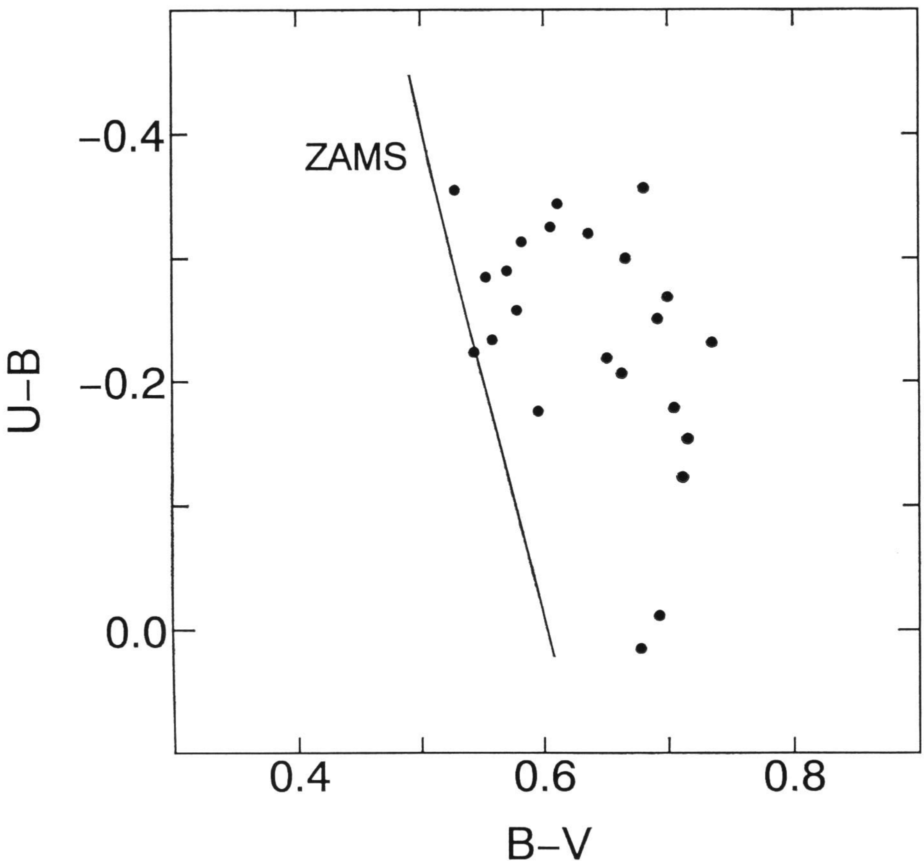

Figure 2. The color-color diagram of the object stars in NGC663. The zero-age main sequence (ZAMS) is from Mermilliod (1981b), with the color excesses of E (B−V)=0.76 and E (U−B) =0.53 (Mermiliod 1981a).

object star in the diaphragm during the observation without invasion of the light of another star. Observation with an electronic imaging device like CCD may provide more reliable data for such stars.

Figures 1 and 2 show the color-magnitude and color-color diagrams of the object stars respectively. In both figures, such weighted means that the weight is reduced to half for the data with a colon in table 3 are plotted for each star. The line of the zero-age main sequence (ZAMS) is also drawn in the figures using the set of values of M_V, $(B–V)_0$, and $(U–B)_0$ for ZAMS in Mermillod (1981b) and the distance modulus and color excesses of $m-M=13.75$, E (B−V)=0.76, and E (U−B)=0.53 (Mermilliod 1981a).

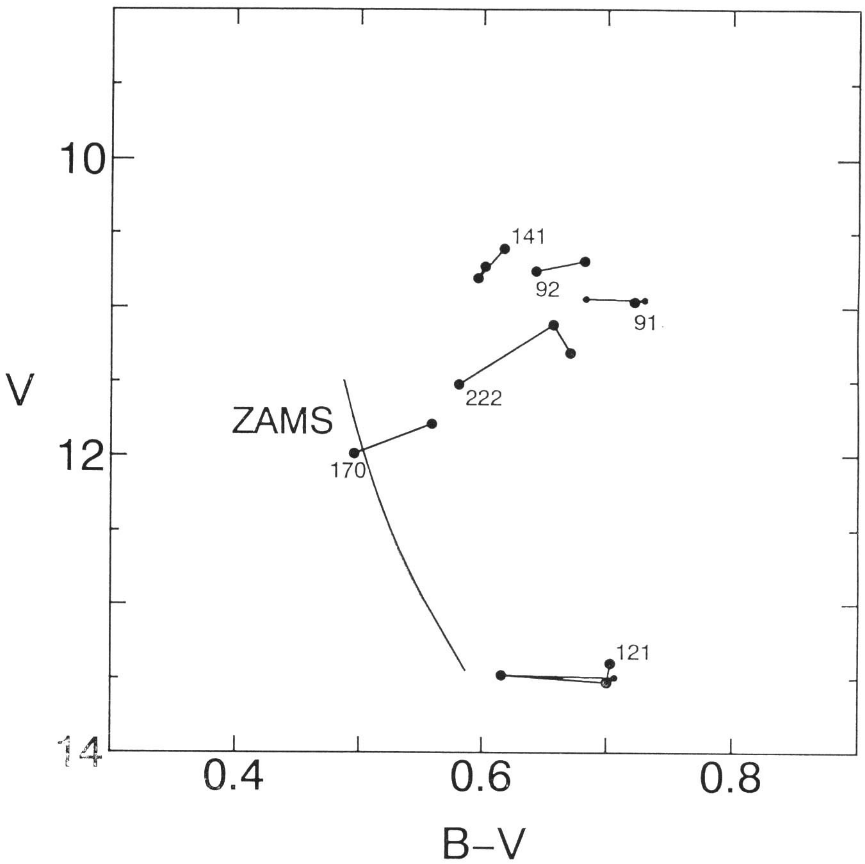

Figure 3. The color-magnitude variations of the object stars in our observational period. Small dots indicate the values of low accuracy and numbers denote Wallenquist No. of the star.

The star, Wallenquist No. 120, is identified as VES No. 624 in Mermilliod (1982). But in figure 1 in Coyne *et al.* (1978), VES 624 is marked on the star, Wallenquist No. 121. No. 120 shows very red colors in B−V and U−B and No. 121 also shows rather large U−B compared with the other object stars. Which star of No. 120 and 121 is a Be star needs to be confirmed.

One can easily see from table 3 that several stars show changes in the magnitude and colors in our observational period. Figures 3 and 4 show the variations in the color-magnitude and color-color diagrams for these stars. Small dots indicate the values of low accuracy and numbers denote Wallenquist No. of the star. One can also find changes between the values of table 1 and table 3 for several other stars.

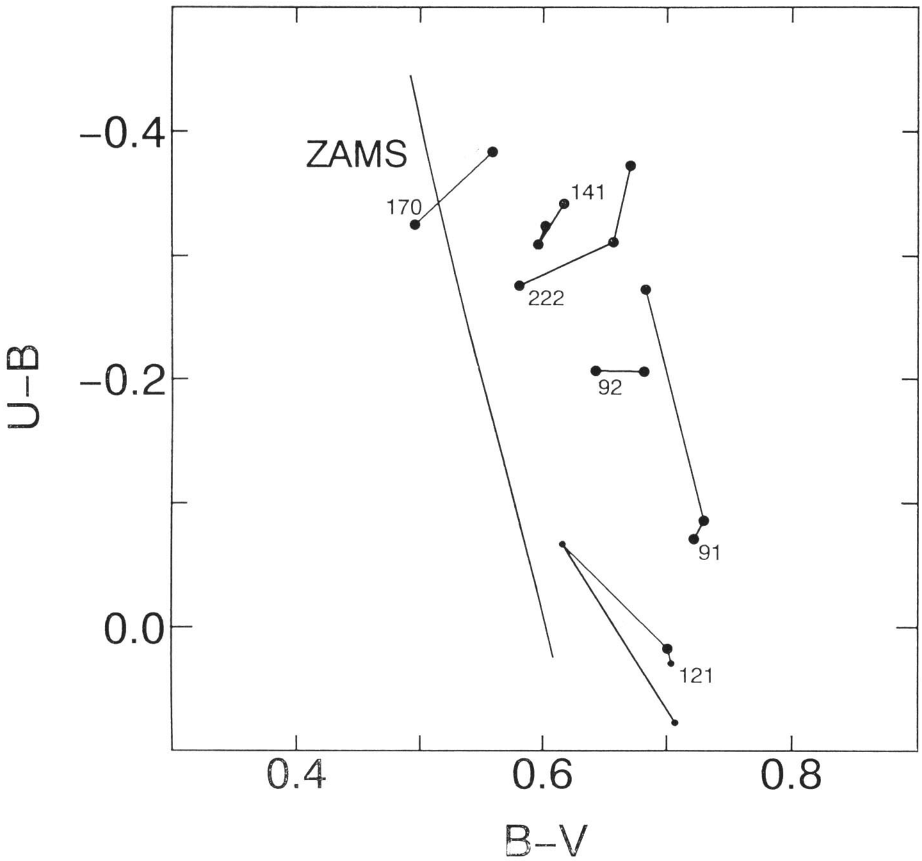

Figure 4. The color-color variations of the object stars in our observational period similar to figure 3.

Figures 5 and 6 show the variations from the previous observations in the color-magnitude and color-color diagrams similar to figures 3 and 4. Open circles denote the values in table 1 and filled circles denote the weighted means of the present observations.

The variations of the magnitudes and colors are thought to be due to circumstellar reddening by the envelope of Be stars. Hirata (1982) has examined the ratios $\alpha = \Delta V/\Delta(B-V)$ and $\beta = \Delta(U-B)/\Delta(B-V)$ for the long-term variation of Be stars and found that α relates to the inclination angle i of the stellar rotation axis, *i. e.*, for the stars with larger $V_e \sin i$, α becomes large and that the signs of α and β are the same. Slettebak (1985) has measured rotational velocities of several Be stars in open clusters.

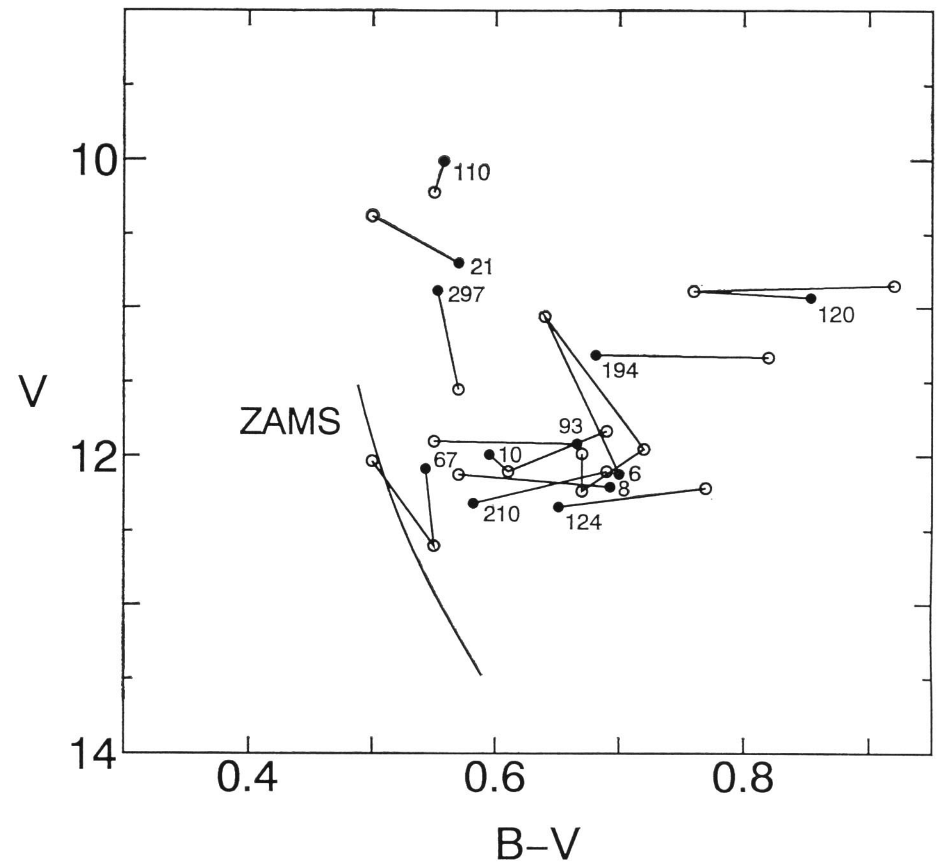

Figure 5. The color-magnitude variations of the object stars from the previous observations. Open circles denote the previous observations in table 1 and filled circles denote the present observations. Numbers indicate Wallenquist No. of the star.

It is important of determine rotational verocities of much more Be stars in open clusters to reduce the envelope effect from the observed values and to know the intrinsic magnitude and colors. It is also important to confirm that the observed variation is really due to the envelope effect.

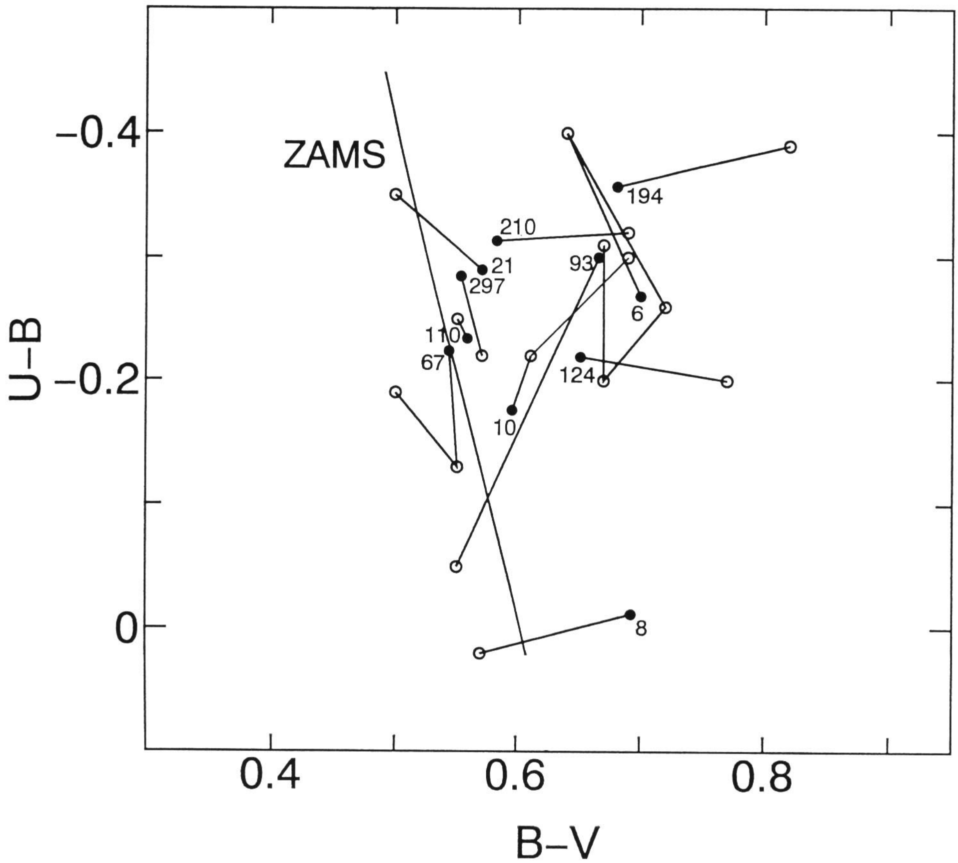

Figure 6. The color-color variations of the object stars from the previous observations similar to figure 5.

References

COYNE, G. V., WISNIEWSKI, W. and OTTEN, L. B. O., 1978. A survey for Hα emission objects in the Milky Way V. Perseus. *Publ. Vatican Obs.*, **1**: 257–265.

HIRATA, R., 1982. Long-term variation of Be stars on the color-magnitude diagram. In: M. Jaschek and H.-G. Groth (Eds.), IAU Symp. No. 98, Be stars, D. Reidel Publishing Company, Dordrecht, pp 41–43.

HOAG, A. A., JOHNSON, H. L., IRIATE, B., MITCHELL, R. I., HALLAM, K. L. and SHARPLESS, S., 1961. Photometry of stars in galactic cluster fields. *Publ. U.S. Naval Obs.*, 2nd Ser., **17**, 349–536.

MERMILLIOD, J.-C., 1976. Catalogue of UBV photometry and MK spectral types in open clusters. *Astron. Astrophys. Suppl.*, **24**: 159–297.

MERMILLIOD, J.-C., 1981a. Comparative studies of young open clusters. II. An atlas of composite colour-magnitude diagrams. *Astron. Astrophys. Suppl.*, **44**: 467–500.

MERMILLIOD, J.-C., 1981b. Comparative studies of young open clusters. III. Empirical isochronous curves and the zero age main sequence. *Astron. Astrophys.*, **97**: 235–244.

Mermilliod, J.-C., 1982. Stellar content of young open clusters II. Be stars. *Astron. Astrophys.*, **109**: 48–65.

Schild, R. and Romanishin, W., 1976. A study of Be stars in clusters. *Astrophys. J.*, **204**: 493–501.

Slettebak, A., 1985. Be stars in open clusters. *Astrophys. J. Suppl.*, **59**: 769–784.

Wallenquist, Å., 1929. A photometric research on two open clusters in Cassiopeia (Messier 52 and N. G. C. 663). *Kungle. Svenska Vetenskaps Akademiens Handlingar*, **6**, No. 5.