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A photometric analysis of the Cepheus OB3 region

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Abstract. — Strömgren photometry is presented for 45 stars in the region of Cepheus OB3 and their relationship to the association is analysed. Five of these stars are suggested as members of the group. Spatial distribution of new suggested members enlarges the limits of the association. The color-magnitude diagram is consistent with the existence of two sub-groups with different evolutionary phases.

Key words: Cepheus OB3 — associations — photometry — early type stars.

1. Introduction.

This paper is part of our research on young stellar groups. In this line, a study of the open cluster α-Persei was also undertaken (Trullols *et al.* 1989).

The association Cepheus OB3, located at 725 pc from the Sun in the region R.A. 22^h44^m to 23^h8^m, Decl. +61° to +64°, is the youngest group of stars known within 1 kpc from the Sun. It has no central cluster and it is basically constituted by O and B type stars. The first systematic observations of this association were obtained by Münch (1954) and Brodskaja (1955) with an objective prism, covering the stars up to photographic magnitude 12.5. The region is rich in interstellar dust with noticeable differences in reddening and absorption (Johnson 1965; Becker 1966), so it was not used in absolute magnitude calibrations by Borgman & Blaauw (1964).

Blaauw *et al.* (1959) obtained *UBV* photometry for 83 stars present in the region and 8 faint companions. Among these, they classified 36 stars as members of the association. Crawford & Barnes (1970) obtained *uvby*-β photometry for 50 stars in the full list. There is good agreement between these two photometries when comparing the stars classified as members and those classified as non-members.

Blaauw (1964) pointed out that the association is composed of two subsets with different evolutionary phases, the youngest being connected to the nebulosity present in the region. This separation into two sub-associations was studied kinematically by Garmany (1973) using plates of the Astrographic Catalogue Series, Carte du Ciel and Yale Astrographic of New Haven.

Spectral classification in the MK system was performed by Garrison (1970) for 72 stars in the list of Blaauw *et al.* (1959) and it could be considered complete for stars earlier than A0 and brighter than visual magnitude 11.1. The spectra showed that one third of the members are binaries, which is a higher number than for other groups of stars.

In this study, we present *uvby*-β photometry for 45 stars covering an apparent area of 6° × 6° and lacking Strömgren photometry. This photometry allows us to determine their relationship to the association.

2. Observations and results.

The observations were made at Calar Alto (Almería, Spain) in runs in October and November 1989, 1990 with the 1.23m telescope of the Centro Astronómico Hispano-Alemán and the 1.52m telescope of the Observatorio Astronómico Nacional. Both telescopes are equipped with a one channel photomultiplier with a dry-ice cooled RCA 31034 in combination with the following filters:

u: UG11/8, WG345/1
v: 408/22 interference
b: 466/22 interference
y: 547/20 interference
H_β narrow: 487/3.4 interference
H_β wide: 487/12 interference

The secondary standard stars were taken from those observed by Blaauw *et al.* (1959) and Crawford & Barnes (1970). We added BD +63°1960, BD +59°2701 and BD +62°2223 (Hauck & Mermilliod 1990) in order to cover all the spectral types. The observations and data reduction were performed using standard procedures and the values obtained for β, (b-y), m_1, c_1 and V are shown in Table 1, as well as the number of observations for each star. Spectral types were taken from the C.D.S. data base and BL is the identification number in the Blaauw *et al.* (1959) list. The mean square residuals for the secondary standard stars are ± 0.008, ± 0.006, ± 0.006, ± 0.011, and ± 0.01 mag., for β, (b-y), m_1, c_1, and V respectively.

In order to correct for reddening and to determine the absolute magnitudes, we have classified our program stars into groups of different treatment as pointed out by Strömgren (1966), in the way indicated by Figueras *et al.* (1991). The method has been enlarged to discriminate the "F-type" stars (from F0 to G2) and the "G-type" stars (from G2). We have considered a star as "F-type" if its β value is between 2.72 and 2.58 and its $(b-y)_0 <$ 0.4 mag. which are the limits of application of Olsen (1988) calibration. If $\beta < 2.58$ or $(b-y)_0 > 0.4$ mag. the star was treated as "G-type". This separation into groups is in good agreement with the spectral types quoted for the stars in the C.D.S. data base.

The intrinsic values, interstellar absorption and absolute magnitudes for stars in the "early", "intermediate" and "late" groups defined by Strömgren, have been obtained as described by Figueras *et al.* (1991).

To deduce intrinsic colors for "F-type" stars we have compared Crawford (1975), Olsen (1988) and Schuster & Nissen (1989) calibrations. Olsen (1988) reviewed Crawford's calibration, extending it to G2 stars and to stars of intermediate Population II. Franco (1989) stated that Olsen's calibration can also be applied to stars with δc_0 between -0.045 and -0.020 mag. Schuster & Nissen (1989) gave a new calibration for late-F and G-type stars of intermediate and extreme Population II. Our program stars being of Population I, values deduced from Olsen's calibration were preferred. For these stars the calibration of Crawford (1975) gives basically the same results.

The absolute magnitudes of "F-type" stars have been obtained according to Olsen (1988), who extented the values of Crawford (1975).

Olsen (1984) gave preliminary standard values and absolute magnitudes for G, K and M unreddened stars. In order to use these values for our program stars, we have dereddened them with the average color excess of the association (0.6 mag.). This has allowed us to estimate intrinsic colors and corrected apparent magnitude, as if they were members of the association. The intrinsic colors and the distance modulus determined in this way do not agree with spectral types and the color excess imposed a priori, which means that these stars cannot belong to the group.

TABLE 1. *uvby-β photometry for 45 stars in the region of Cepheus OB3.*

BD	BL	SP	β	b-y	m_1	c_1	V	obs.
+61°2344		A	2.822	0.209	0.157	0.829	9.64	1
+64°1714		B	2.718	0.444	-0.071	0.420	10.57	2
+61°2345		F5	2.648	0.359	0.153	0.458	9.27	2
+63°1888		A5	2.822	0.250	0.135	0.968	9.58	2
+64°1717		B	2.611	0.290	-0.064	0.003	7.06	2
+62°2114		B8	2.665	0.379	-0.068	0.107	9.61	2
+62°2116		A0	2.799	0.283	0.034	1.087	9.29	2
+62°2117		A3	2.847	0.124	0.176	1.008	8.41	1
+61°2351		F0	2.652	0.287	0.162	0.419	8.87	3
+62°2118		K0	2.555	0.780	0.318	0.462	9.21	1
+63°1890		G5	2.616	0.376	0.163	0.434	9.04	1
+61°2353	6	A2	2.859	0.323	0.070	1.210	9.34	2
+63°1892		A2	2.801	0.323	0.027	1.029	9.79	1
+63°1893		A0	2.802	0.158	0.219	0.823	8.54	2
+63°1894		F0	2.671	0.292	0.139	0.465	9.48	3
+61°2354		F5	2.609	0.855	0.075	0.531	9.11	3
+62°2121		G5	2.582	0.476	0.238	0.322	6.66	3
+61°2359		G5	2.605	0.831	0.231	0.459	9.86	1
+63°1903		F0	2.698	0.251	0.145	0.661	9.58	3
+64°1729		A0	2.743	0.126	0.132	0.599	9.10	1
+62°2137		A7	2.830	0.188	0.180	0.969	9.49	1
+62°2139		K0	2.599	0.476	0.300	0.386	8.55	2
+61°2375		A5	2.809	0.264	0.159	0.915	9.54	1
+63°1909			2.608	0.931	0.376	0.323	10.72	1
+62°2149		F0	2.730	0.440	0.095	0.610	10.23	2
+62°2152	54	B1.5	2.623	0.430	-0.070	0.166	9.02	2
+62°2156	61	B0.5	2.612	0.410	-0.096	0.063	8.14	2
+62°2157		K4	2.587	0.890	0.656	0.442	7.21	2
+63°1915		A0	2.803	0.170	0.235	0.820	9.26	3
+63°1916			2.770	0.198	0.160	0.846	9.27	1
+63°1917		G5	2.627	0.538	0.271	0.408	8.03	2
+63°1918		F2	2.658	0.428	0.106	0.552	9.49	3
+63°1919		A	2.589	0.828	0.447	0.514	10.39	2
+63°1920		A0	2.888	0.059	0.156	1.004	8.99	4
+60°2473		A0	2.736	0.132	0.054	0.476	8.09	3
+63°1923		A2	2.852	0.199	0.167	0.984	8.91	2
+62°2165		K0	2.574	0.627	0.380	0.383	6.64	1
+63°1925		F0	2.673	0.371	0.092	0.767	7.59	3
+64°1751		A0	2.870	0.119	0.132	1.059	9.56	1
+62°2169		A3	2.804	0.184	0.168	0.843	8.99	3
+63°1929		A0	2.879	0.090	0.135	1.076	9.06	1
+62°2171	79	B3	2.682	0.023	0.077	0.285	6.27	2
+61°2397	82	B9.5	2.837	0.083	0.105	0.942	9.35	2
+60°2491		A	2.842	0.036	0.123	0.990	8.02	2
+62°2179		G0	2.494	0.666	0.256	0.433	8.15	1

Table 2 shows the intrinsic values, color excess, corrected apparent magnitude, absolute magnitude, distance modulus, and d$M_{\rm bol}$ for our O, B, A and F type stars. Star BD +63°1925 is outside the limits of Olsen's (1988) calibration, so its intrinsic values and absolute magnitude should be regarded as uncertain.

3. Discussion.

The relationship of the stars to the Cepheus OB3 association was deduced according to the color excess and the distance modulus of the stars.

In Figure 1 we show the color excess *versus* $(b\text{-}y)_0$ for our program stars. We have also included the stars observed by Crawford & Barnes (1970) after being corrected for reddening according to the method described above. The stars are clearly distributed into two regions with a gap at about 0.4 mag. of color excess. The stars with color excess greater than 0.4 mag. are concentrated in $(b\text{-}y)_0$ and they are all young stars. In contrast, the stars in the lower region are dispersed in spectral types, as expected for field stars.

In Figure 2 we have plotted the distance modulus *versus* $(b\text{-}y)_o$ for our program stars as well as those of Crawford & Barnes (1970). Thirty of the stars with color excess greater than 0.4 mag. have a distance modulus between about 8.5 and 10.2 mag. So, they constitute a group of stars with similar reddening and placed at similar distance. Twenty-five of these stars were already considered as members of the association by Crawford & Barnes (1970). The other five, BD +62°2114, BD +62°2152, BD +62°2156, BD +64°1714 and BD +64°1717, are suggested as members in the present paper. Crawford & Barnes (1970) also considered star BL 11 as a member of the group, but they stated that photometry for this star was uncertain and that it was discordant in most of their figures. Because its color excess and its distance modulus do not agree with those of the stars of the group, it has not been classified as a member in the present work.

The average color excess and distance modulus of the group are 0.55 ± 0.09 mag. and 9.37 ± 0.39 mag. in good agreement with Crawford & Barnes (1970). For young stars, we used Crawford's (1978) calibration to deduce intrinsic colors and Balona & Shobbrook's (1984) calibration to compute absolute magnitudes, while Crawford & Barnes (1970) used a preliminary one. These two intrinsic color calibrations are rather similar for the stars of the group, and this explains the full agreement between color excesses. The coincidence between the two average distance moduli means that the zero points of the absolute magnitude calibrations are the same.

From the spatial distribution of the member stars, we can see that BD +62°2114, BD +62°2152 and BD ± 62°2156 are well placed on the general distribution of the association. BD +64°1714 and BD +64°1717 are slightly to the north-west of the association. The membership of these two stars to Cepheus OB3, would imply that the association covers a more extented region. Accordingly, we searched in the literature for photometric data of O and B type stars near the association and we found the *UBV* photoelectric data by Särg & Wramdemark (1970) covering a region situated between R.A. 21^h40^m and $23^h 5^m$ and Decl. +58.5° and +63.0°. Following the *Q*-method to determine reddening and interstellar absorption, the stars included in Table 3 could also be members of the association. As a consequence, it cannot be ruled out that the association covers a larger area, and the limits need further investigation.

Figure 3 shows the color magnitude diagram for the members of the association. We have used different symbols for the stars belonging to two different sub-associations according to the spatial distribution pointed out by Blaauw (1964). BD +64°1714 and BD +64°1717 have been assigned to the older sub-association because it is the more dispersed. The dashed line represents the ZAMS determined using Balona & Shobbrook (1984). It can be seen that the stars of the younger group follow the ZAMS, while the stars of the older have evolved from it. It is necessary to emphasize that separation into two sub-groups should not be based on photometry, because of binarity and errors involved in absolute magnitudes. The position of binary stars in the diagram could be confused with evolutionary effects. We have used underlining in Figure 3 to mark spectroscopic binaries.

Absolute magnitudes and consequently Figure 3, depend on the calibration adopted. Balona & Shobbrook (1984) pointed out that their values are accurate to 0.4 mag. In order to avoid the effects of different calibrations and their errors, in Figure 4 we have plotted the same stars in a diagram β *versus* c_0. This diagram should be independent of distance, rather insensitive to reddening effects, as β is reddening free and $E(c_1)$ is only 19% of $E(b\text{-}y)$, and independent of the calibration used. Both diagrams seem to confirm that the two spatially defined sub-groups of Blaauw (1964) have different evolutionary phases.

4. Conclusions.

This paper presents original measurements of Strömgren-Crawford photometry for 45 stars in the region of Cepheus OB3. The computed values of color excess and distance modulus allow us to determine the relationship of these stars to the association. BD +62°2114, BD +62°2152 and BD +62°2156 have been identified as members according to these criteria. BD +64°1714 and BD +64°1717 could also be members of the association but their spatial distribution implies a larger area involved in the Cepheus OB3 association. This point needs further investigation.

Intrinsic colors and absolute magnitudes for member stars are consistent with former studies (Blaauw 1964 and Garmany 1973) in their hypothesis of the existence of two sub-groups with different evolutionary phases.

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TABLE 2. *Intrinsic colors, absolute magnitude, distance modulus and bolometric correction for 34 stars in the region of Cepheus OB3.*

BD	E(b-y)	$(b-y)_0$	m_0	c_0	δm_0	δc_0	Vo	Mv	Vo-Mv	dM_{bol}
+61°2344	0.084	0.125	0.186	0.813	0.020	-0.034	9.28	2.91	6.37	-0.21
+64°1714	0.529	-0.085	0.104	0.320	-0.008		8.30	-0.76	9.06	-0.09
+61°2345	0.045	0.314	0.168	0.450	0.011	0.064	9.08	3.25	5.83	0.67
+63°1888	0.138	0.112	0.182	0.942	0.024	0.090	8.99	1.78	7.21	0.92
+64°1717	0.413	-0.123	0.072	-0.076	0.004		5.28	-3.73	9.01	0.13
+62°2114	0.494	-0.115	0.095	0.013	-0.014		7.49	-2.29	9.78	-0.36
+62°2116	0.301	-0.018	0.133	1.030	0.010		8.00	0.04	7.96	1.42
+62°2117	0.039	0.085	0.189	1.001	0.018	0.115	8.24	1.44	6.80	1.15
+61°2351	-0.020	0.287	0.162	0.419	0.015	0.024	8.96	3.60	5.36	0.25
+63°1890	0.026	0.350	0.171	0.429	0.028	0.107	8.93	3.23	5.70	1.19
+61°2353	0.306	0.017	0.174	1.152	0.000		8.02	-0.05	8.07	1.84
+63°1892	0.348	-0.025	0.142	0.963	-0.006		8.29	0.16	8.13	1.13
+63°1893	0.013	0.145	0.223	0.821	-0.021		8.48	1.89	6.59	0.69
+63°1894	0.018	0.274	0.145	0.462	0.026	0.019	9.40	3.40	6.00	0.19
+63°1903	0.017	0.234	0.151	0.658	0.021	0.135	9.51	2.03	7.48	1.27
+64°1729	0.114	0.012	0.171	0.577	-0.001		8.61	0.73	7.88	0.40
+62°2137	0.083	0.105	0.208	0.953	-0.001	0.120	9.13	1.48	7.65	1.19
+61°2375	0.136	0.128	0.205	0.889	-0.001	0.093	8.96	1.79	7.17	0.94
+62°2149	0.218	0.222	0.169	0.569	0.011	-0.075	9.29	3.61	5.68	-0.58
+62°2152	0.540	-0.110	0.108	0.063	-0.025		6.70	-2.84	9.54	0.62
+62°2156	0.530	-0.120	0.079	-0.038	-0.001		5.86	-3.48	9.34	0.33
+63°1915	0.020	0.150	0.242	0.816	-0.041		9.17	2.02	7.15	0.64
+63°1916	0.034	0.164	0.172	0.840	0.020	0.095	9.12	1.89	7.23	0.96
+63°1918	0.139	0.289	0.152	0.527	0.023	0.117	8.89	2.57	6.32	1.20
+63°1920	0.046	0.013	0.172	0.995	-0.001		8.79	1.17	7.62	0.42
+60°2473	0.206	-0.074	0.122	0.437	-0.020		7.18	-0.44	7.62	0.00
+63°1923	0.114	0.085	0.206	0.962	0.000	0.088	8.42	1.66	6.76	0.90
+63°1925	0.122	0.249	0.132	0.745	0.039	0.298	7.07	0.61	6.46	2.96
+64°1751	0.109	0.010	0.169	1.038	-0.001		9.09	0.62	8.47	0.98
+62°2169	0.047	0.137	0.184	0.834	0.020	0.022	8.79	2.45	6.34	0.30
+63°1929	0.105	-0.015	0.170	1.056	-0.024		8.61	1.02	7.59	0.49
+62°2171	0.113	-0.090	0.114	0.263	-0.021		5.78	-1.36	7.14	0.28
+61°2397	0.113	-0.030	0.142	0.921	-0.010		8.86	0.66	8.20	0.50
+60°2491	0.059	-0.023	0.143	0.979	-0.005		7.77	0.68	7.09	0.66

TABLE 3. *Color excess and distance modulus derived from Johnson photometry by Särg and Wramdemark (1970) being SW their identification number.*

SW	HD/BD	V	(B-V)	(U-B)	Q	$(B-V)_0$	E(B-V)	Av	Vo	Mv	Vo-Mv
6	207538	7.31	0.32	-0.64	-0.87	-0.30	0.62	2.02	5.29	-4.12	9.41
8	297872	7.98	0.43	-0.44	-0.75	-0.26	0.69	2.25	5.73	-3.23	8.96
26	211880A	7.74	0.31	-0.61	-0.83	-0.29	0.60	1.95	5.79	-3.80	9.59
27	211880B	8.57	0.31	-0.49	-0.71	-0.25	0.56	1.82	6.75	-2.80	9.55
28	+60°2380	9.04	0.39	-0.50	-0.78	-0.27	0.66	2.15	6.89	-3.44	10.33
36		10.40	0.87	0.01	-0.62	-0.22	1.09	3.57	6.83	-1.96	8.79
43	+62°2078	9.73	1.11	-0.02	-0.82	-0.29	1.40	4.57	5.16	-3.70	8.86
47		10.69	1.37	0.11	-0.88	-0.30	1.67	5.49	5.20	-4.22	9.41
49		10.77	0.41	-0.21	-0.51	-0.18	0.59	1.93	8.84	-1.32	10.16
50	+62°2088	9.91	0.55	-0.24	-0.64	-0.22	0.77	2.53	7.38	-2.10	9.48
51	+62°2089	9.72	0.38	-0.30	-0.57	-0.20	0.58	1.90	7.82	-1.65	9.47
53		10.28	0.76	-0.12	-0.67	-0.23	0.99	3.25	7.03	-2.32	9.35
54		10.51	0.54	-0.13	-0.52	-0.18	0.72	2.37	8.14	-1.38	9.52
55	+60°2405	9.85	0.53	-0.19	-0.57	-0.20	0.73	2.39	7.46	-1.63	9.09
57	213757	8.38	0.26	-0.44	-0.63	-0.22	0.48	1.56	6.82	-2.03	8.85
58	+62°2093	9.91	0.67	-0.13	-0.61	-0.22	0.89	2.90	7.01	-1.93	8.94
59		10.77	0.41	-0.24	-0.54	-0.19	0.60	1.96	8.81	-1.46	10.27
63	+59°2547	10.13	0.44	-0.13	-0.45	-0.16	0.60	1.97	8.16	-1.04	9.21
65	+62°2101	9.99	0.53	-0.30	-0.68	-0.24	0.77	2.51	7.48	-2.42	9.90
75	+59°2570	10.48	0.45	0.04	-0.28	-0.10	0.55	1.83	8.65	-.19	8.84
77	+62°2114	9.60	0.43	-0.42	-0.73	-0.25	0.68	2.23	7.37	-3.01	10.38
92		10.34	0.40	-0.21	-0.50	-0.18	0.58	1.89	8.45	-1.29	9.74
115	217490	8.73	0.79	-0.28	-0.85	-0.30	1.09	3.54	5.19	-3.90	9.09
116		10.37	0.42	-0.16	-0.46	-0.16	0.58	1.92	8.45	-1.12	9.58
125	+62°2159	10.64	0.60	-0.17	-0.60	-0.21	0.81	2.66	7.98	-1.85	9.83
132	+58°2537	10.32	0.56	-0.01	-0.41	-0.15	0.71	2.33	7.99	-.87	8.87
141		11.10	0.54	0.11	-0.28	-0.10	0.64	2.12	8.98	-.17	9.15
146		10.41	0.41	-0.31	-0.61	-0.21	0.62	2.03	8.38	-1.88	10.25

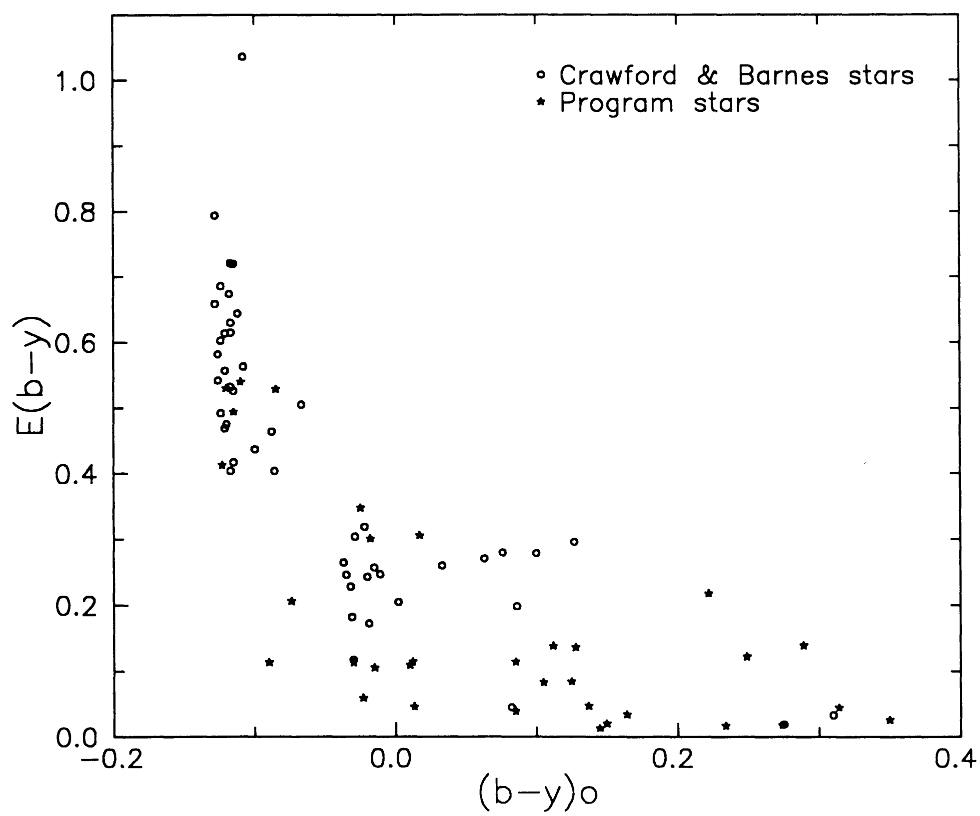

FIGURE 1. Color excess *versus* $(b-y)_0$ for our program and Crawford & Barnes stars.

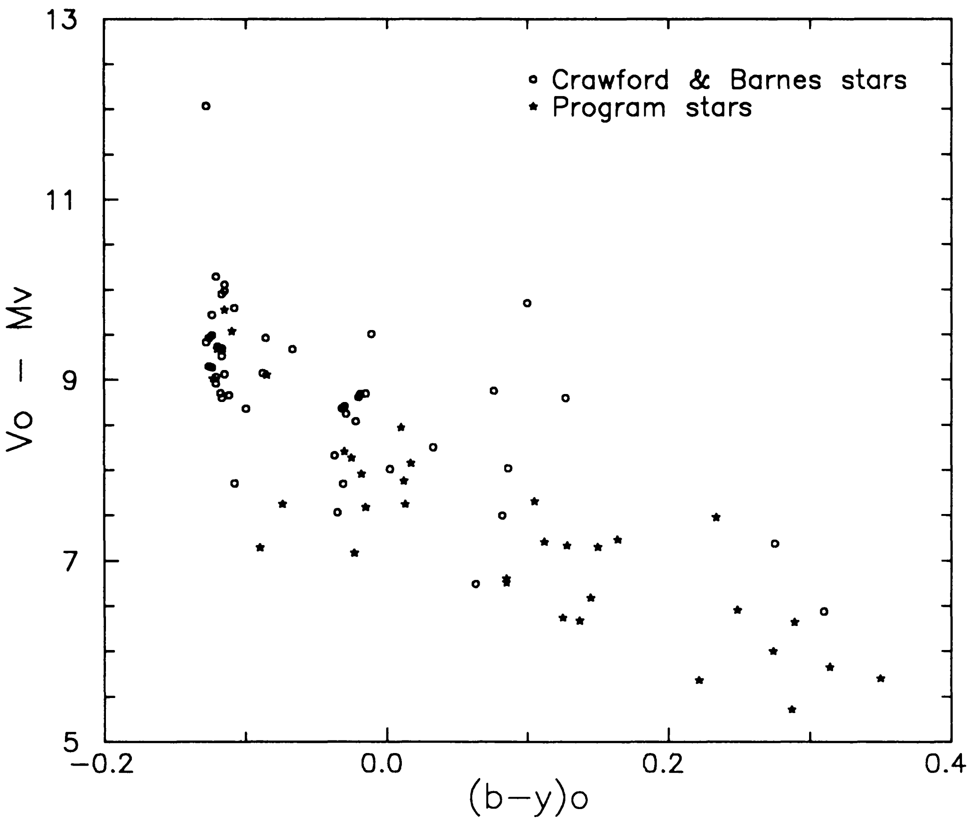

FIGURE 2. Distance modulus *versus* $(b-y)_0$ for our program and Crawford & Barnes stars.

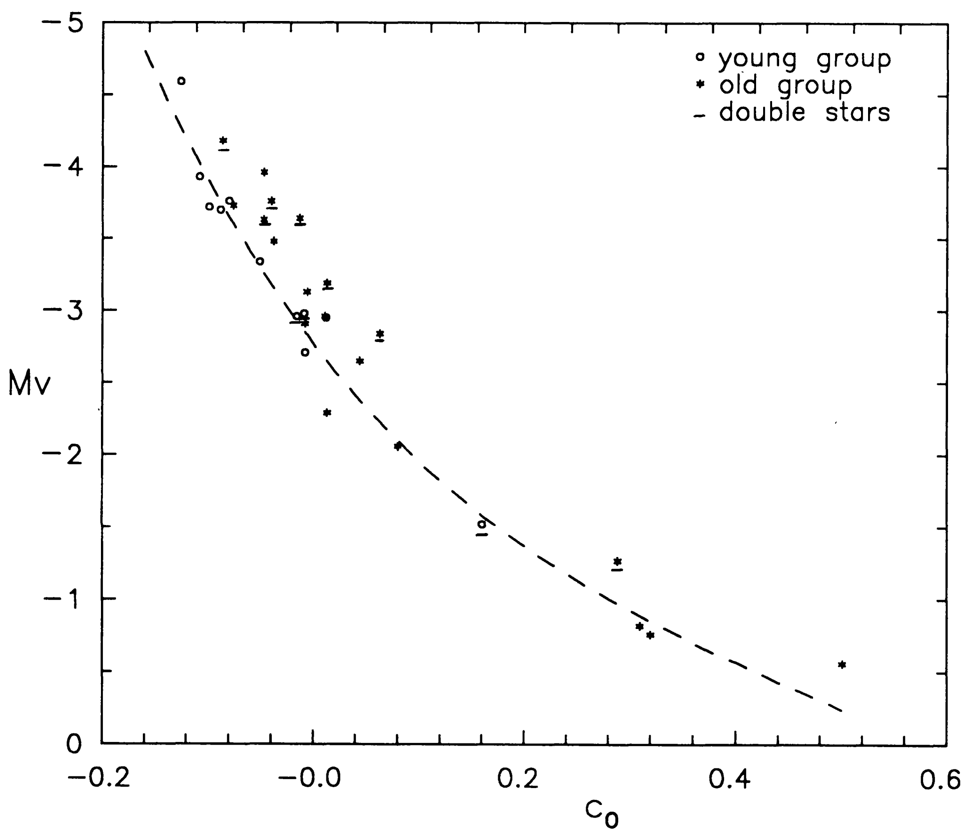

FIGURE 3. Color magnitude diagram for member stars. Different symbols have been used for the two spatially defined sub-groups. Underlining means that the star is a spectroscopic binary. Dashed line is the ZAMS.

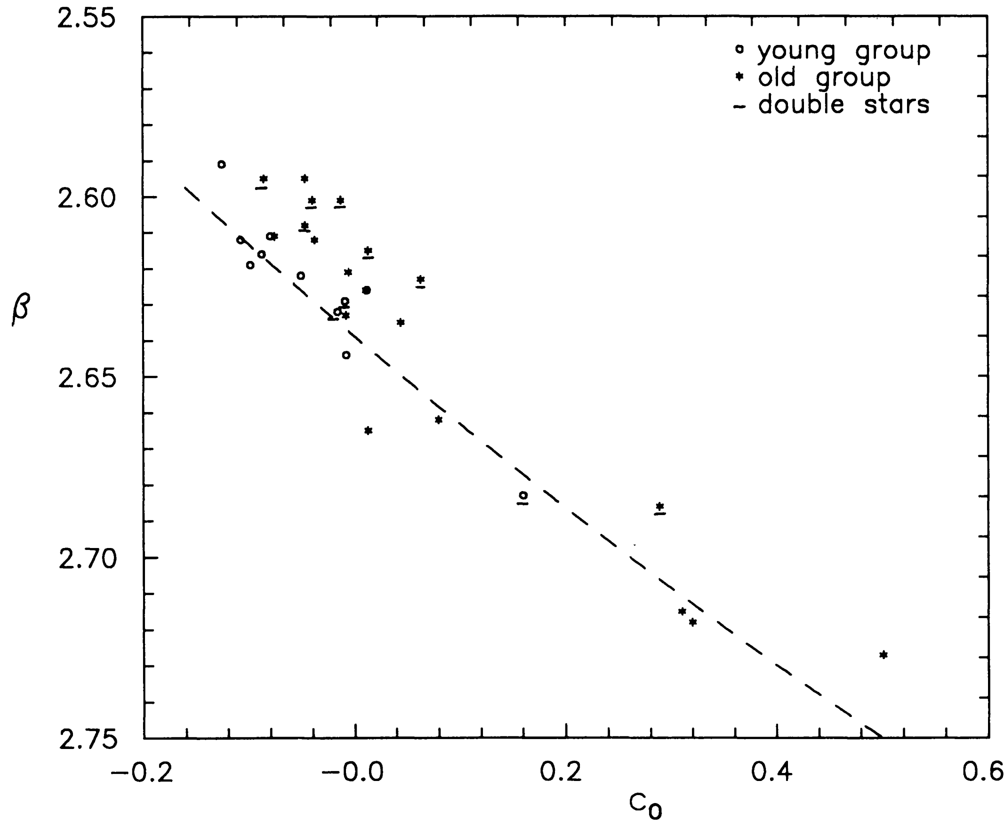

FIGURE 4. Relation between β and c_0 for member stars. Different symbols have been used for the two spatially defined sub-groups. Underlining means that the star is a spectroscopic binary. Dashed line is the ZAMS.