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Cepheus OB3 association: faint members

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Abstract. From *UBVRI*-CCD photometry in the region of Cepheus OB3 association previously published by the authors, a search for faint members was performed. Colour-colour and colour-magnitude calibrations were used to estimate individual reddenings and distances. The comparison between these individual values and the average values for the known member stars led to a list of member candidates. Candidate members brighter than V=14 mag were observed in the *uvby*-β system to confirm or deny their membership. Members down to V=13.6 mag were found. The ages of the association subgroups were found to be 5.5 and 7.5 Myr.

Key words: open clusters and associations: individual: Cepheus OB3 – stars: early type – fundamental parameters – ages

1. Introduction

The term association was first introduced by Ambartsumian (1947) to refer to a sparsely populated group of very young stars whose spectral types, luminosities and positions indicate a common origin. In contrast to open clusters, stellar associations are characterized not by a general stellar density higher than the background, but by a relatively higher density of a certain type of stars: OB-stars in OB-associations and T-Tauri stars in T-associations. The stellar density in OB-associations is insufficient for gravitation to hold the group together, but since the group is young, the stars have not yet had time to disperse completely. OB-associations often have several subgroups at different evolutionary stages (Blaauw 1964), which can be distinguished by their spatial concentration, kinematics and interaction with surrounding molecular clouds. Cepheus OB3 is a good example of this.

Little is known about the membership of faint stars to associations. Because the star-field density is greater than the association density, member identification is not easy and requires considerable observational effort. However, the knowledge of the actual stellar content of the associations could provide important information about the process of star formation, the IMF and the PMS members (Garmany 1994).

To our knowledge, there are no studies of membership in Cepheus OB3 association for stars later than B5. Since late B, A and F-type stars were found in associations of similar ages like Sco OB2 and Ori OB1 (Garrison 1967; de Geus et al. 1989), the presence of late B or A-type stars in the association Cepheus OB3 cannot be ruled out.

Jordi et al. (1995; hereinafter referred to as Paper I), published *UBVRI*-CCD photometry for 1056 stars in 18 randomly selected fields of the two subgroups of the association.

In this paper we review the present knowledge of Cepheus OB3 association, analyze the *UBVRI*-CCD photometry from Paper I in order to look for faint members and redetermine the ages of the subgroups. Cross-identification with IRAS Point Source Catalogue and an updated list of members are also included.

2. Observational background of Cepheus OB3

The association Cepheus OB3 is one of the youngest stellar groups within 1 kpc from the Sun. The surrounding region is rich in interstellar dust and gas, and shows noticeable inhomogeneities of reddening and absorption. The presence of two subgroups at different evolutionary stages was first recognized by Blaauw (1964). The same author (Blaauw 1964, 1991) estimated the ages of these subgroups. The largest overall projected diameter for the young (b) and old (a) subgroups were quoted by Blaauw to be 10 and 17 pc, respectively, although the individual distances computed for the members range from 500 to 1000 pc (Crawford & Barnes 1970).

Cepheus OB3 is a good example of sequential star formation that fits the model of Elmegreen & Lada (1977). The western subgroup (b), closer to the galactic plane, is spatially more concentrated and shows a higher average absorption. At the same time, its kinematics suggests a general motion outwards from the nearby clouds. This subgroup should be younger and, if there were current star formation in the zone, it would be expected to

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be found at the south-eastern extreme of the association, where the interaction with the molecular clouds is more evident.

The studies in the radio wavelengths show that Cepheus OB3 is young. Sargent (1977, 1979) performed a general study of the ^{12}CO emission from the Cepheus molecular cloud. The second paper includes an analysis of the relation between the stars and their possible birth places. Sargent gave a mass estimate of $\sim 500 M_{\odot}$ for Cepheus A, the densest concentration inside the molecular cloud. This concentration shows signs of collapsing and a series of typical signatures of the star-forming regions (Hughes 1988), so it could be considered the nucleus of a future third stellar subgroup in Cepheus OB3. On the other hand, Testi et al. (1995), from radio and near infrared data found different manifestations of a group of young stars embedded in the Cepheus B concentration, and they concluded that a third generation of stars had already been formed at the interface between this concentration and the HII region S155.

2.1. Photometry

Blaauw et al. (1959; hereinafter referred to as BHJ) carried out the first systematic photometric study in the region of Cepheus OB3. They published *UBV* photoelectric photometry for 91 early type stars, mainly brighter than $B \approx 12.5$ mag. This paper became the chief reference for this association. BHJ dereddened their photometry to intrinsic colour and magnitude, $(B-V)_o$ and V_o, by the Q-method. They selected the association members by relying on their visual absorption A_v and on their distribution in the sky. They derived a list of 40 members, with apparent visual magnitudes ranging from 7.41 to 13.95. The average for the visual absorption obtained by BHJ for the association is 2.43 ± 0.41 mag[1]. Fitting a main sequence to the colour-magnitude diagram *by hand*, they deduced an average distance modulus of $\overline{V_o - M_v} = 9.3$ mag. BHJ did not identify members in the interval $9.0 < V_o < 9.5$ mag, and only three fainter than this, which are companions of brighter members. $V_o \approx 9.5$ mag corresponds to spectral type B5-B6.

Särg & Wrandemark (1970) published *UBV* photoelectric photometry of early stars in Cepheus, including 16 stars observed by BHJ, but they did not analyze the resulting data.

Crawford & Barnes (1970) published the first photometric study of the region in the Strömgren system. They performed photoelectric $uvby$-β photometry for more than 50 stars in Cepheus OB3, 26 of which are members and 24 are not, according to BHJ. The authors derived individual colour excesses and distance moduli for the stars they observed. They obtained the average values[2] $\overline{E(b-y)} = 0.56 \pm 0.10$ mag and $\overline{V_o - M_v} = 9.32 \pm 0.46$ mag.

Trullols (1990) and Jordi et al. (1992) obtained $uvby$-β photometry for 45 stars in the region, with $6.3 < V < 10.7$ mag, only 5 belonging to the list by BHJ. They decided the membership from individual colour excess and distance modulus calculations. Two new members were identified. Two additional stars satisfy the distance and colour excess criteria for being members, but their location, north-west from the association, would increase the angular diameter of the association.

Moreno-Corral et al. (1993) studied the region in the near infrared and in H_α. Their *JHKL'M* photometry for 40 stars from BHJ's list, combined with the previous photometry in other bands, allowed them to measure directly the total-to-selective absorption (largely discussed by former authors) $R_{B-V} = A_v / E(B-V)$ individually for each star. Their average value for the association members is $R_{B-V} = 2.96 \pm 0.07$. From H_α CCD-observations they suggested a PMS cluster in the area between BHJ 40 and BHJ 41 close to the HII S155 region. This conclusion seems to be confirmed by the radio and near infrared study of the zone by Testi et al. (1995).

2.2. Spectroscopy

Garrison (1970) obtained spectra of 72 stars from the list by BHJ. Since then, this work is the chief reference for spectral classification of the stars in Cepheus OB3 region. He found that 10 of the 40 association members that he observed were probable spectroscopic binaries.

Garmany (1972) carried out a second spectroscopic survey in the region, oriented to the detection of new spectroscopic binaries and to the measurement of radial velocities. She observed 37 stars from BHJ's list.

2.3. Astrometry

The only published kinematical study of Cepheus OB3 is that by Garmany (1973). She used the radial velocity data from her spectroscopic study and she derived proper motions from two plate sets with an epoch difference of 47 years. The two subgroups of the association show a radial velocity difference of 4 km s^{-1}. Members and non-members are not clearly separated from their kinematics, their only difference being the expansive tendency shown by the members (absent in the field population). This expansion occurs along the l direction, giving a kinematical age of 0.72 Myr. The proper motions of the stars in the b subgroup show a certain trend to be oriented outwards from the neighbouring clouds, indicating their probable place of formation.

3. Analysis of membership

The photometric sample analyzed in this work consists of 1056 stars observed in 18 randomly selected fields in Cepheus OB3. The sample is complete in V down to 19 mag, although the completeness in all colours is down to V=15.5 mag. We refer to Paper I for more details about the observations and the resulting photometry.

3.1. Individual reddening

As is well known, the matter between the stars and the observer makes their intrinsic colours change. This phenomenon, known as *interstellar reddening*, makes the representative points of the

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[1] Average calculated without including the star BHJ 11, whose absorption is abnormally large.

[2] Again excluding the star BHJ 11.

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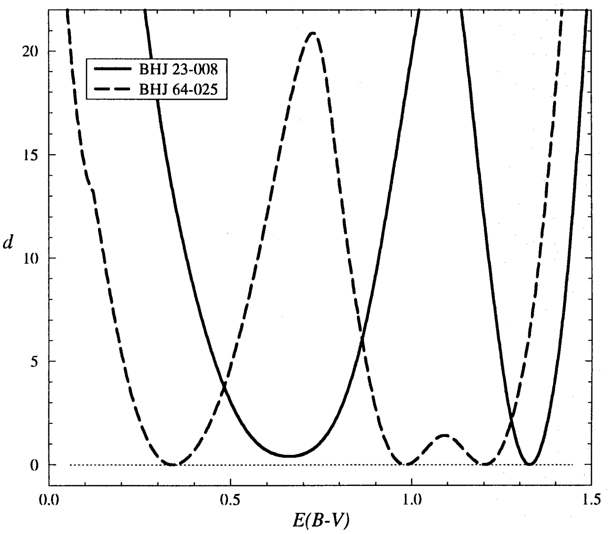

Fig. 1. Proximity parameter to the shifted calibration for the stars BHJ 23-008 and BHJ 64-025. BHJ 23-008 shows two solutions in the range of reddening explored while BHJ 64-025 shows three solutions

stars on colour-colour diagrams move away from the calibrations (which represent relations between intrinsic colours) following paths that, in a first approximation, can be considered straight lines: the *reddening lines*. The usual way to determine individual reddening values is to take each observational point on a colour-colour diagram, and to move it back along reddening lines. The intersection of the reddening line with a standard calibration gives the intrinsic colours and the amount of reddening. This simple idea is suitable for the *(B–V,U–B)* diagram, but it is difficult to apply on observational planes as *(B–V,R–I)* or *(V–I,B–V)*, since the reddening lines are almost parallel to the standard calibrations. Due to the shape of the *(B–V,U–B)* calibration the intersection may not be unique and some ambiguity remains in the dereddening procedure.

In order to consider the errors in the observed colours we took into account a certain interval of reddening values and looked for the most probable ones for each star. The standard calibration was represented by n discrete points $[(B-V)_{oi},(U-B)_{oi};\ i=1,\cdots,n]$ and was shifted by a given amount of reddening which yields a reddened calibration $[(B-V)_i,(U-B)_i;\ i=1,\cdots,n]$. Adapting Luri et al. (1992), we defined a proximity parameter d to the shifted calibration as:

$$d^2 = MIN_{i=1,\ldots,n}\left(\frac{(B-V)-(B-V)_i}{\sigma_{B-V}}\right)^2 + \left(\frac{(U-B)-(U-B)_i}{\sigma_{U-B}}\right)^2$$

where *(B–V)* and *(U–B)* are the observed colours of the star and σ_{B-V} and σ_{U-B} are their observational errors.

Scanning a range of possible amounts of reddening, for a given star, we found the distance parameter for each reddening value. Local minima of this parameter gave the most probable reddening values for the star. We considered the colour excess interval $-0.050 < E(B-V) < 4.000$ mag explored by steps of 0.001 mag. This includes the whole range of reddening values expected for Cepheus OB3 members. Negative values of reddening were introduced in order to take into account observational errors and cosmic dispersion for the stars close to the calibration lines.

Table 1. Slope of reddening line on *(B–V,U–B)* diagram vs. spectral type (Crawford & Mandwewala 1976)

SP	:	A0	A5	F0	F5	G0	G5
$\frac{E(U-B)}{E(B-V)}$	:	0.744	0.775	0.822	0.848	0.902	0.923

As standard calibration we used the *[(B–V)$_o$,(U–B)$_o$]* relation by Schmidt-Kaler (1982) for the ZAMS, fitted by a cubic polynomial. This calibration is rather similar to that by Mermilliod (1981) but it covers a wider range of colour indices, and it is also very similar to that by Schmidt-Kaler (1982) for luminosity class V. So, the derived individual reddening is independent of the adopted calibration.

Each point of the calibration was reddened along a line whose slope was assigned depending on the spectral type. For early type stars, García et al. (1988) proposed the expression $E(U\text{–}B)/E(B\text{–}V)$=0.72+0.05$E(B\text{–}V)$, but we preferred to use the classical slope value of 0.72 because it gives a better agreement with the colour excess obtained from Strömgren photometry (see Sect. 3.4). For spectral types later than A0, we adopted the slopes given by Crawford & Mandwewala (1976) (see Table 1). In order to obtain a continuous function, all slopes were fitted by a fifth degree polynomial on *(B–V)$_o$*, using Schmidt-Kaler (1982) to relate intrinsic colours and spectral types.

As mentioned above, due to the shape of *(B–V,U–B)* calibration, the proximity parameter for a given star can have more than one local minimum. We call each one of these local minima *reddening solution*. In Fig. 1 we show a representative graph for two stars, one of them with two reddening solutions and another with three.

3.2. Individual distances

Each reddening solution yields a value of *E(B–V)* for the observed star and also its intrinsic colours *(B–V)$_o$* and *(U–B)$_o$*. From this, the interstellar absorption A_v is derived using the ratio of the total-to-selective absorption directly determined by Moreno-Corral et al. (1993).

The intrinsic visual magnitude (free of absorption) is easily computed as $V_o = V - A_v$, and the distance modulus of the stars, $V_o - M_v$, is derived using a colour-magnitude calibration *[(B–V)$_o$,M_v]*. Since the association Cepheus OB3 is very young, the faint members we are looking for should be still placed on the ZAMS, that is why we used the colour-magnitude calibration for the ZAMS by Mermilliod (1981). This calibration fits better than that by Schmidt-Kaler (1982) in the region of the faintest known members and agrees rather well with the theoretical ZAMS from evolutionary models by Schaller et al. (1992) (see Figs. 4 and 6).

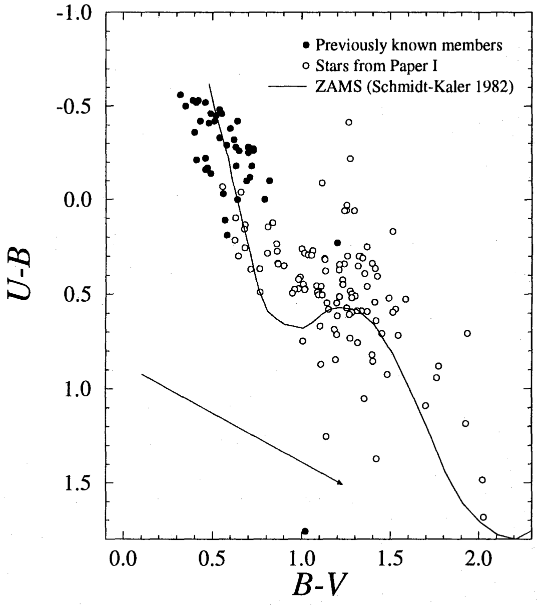

Fig. 2. Observational colour-colour diagram for stars in 18 randomly selected fields of Cepheus OB3. Solid line represents the ZAMS calibration by Schmidt-Kaler (1982) shifted by $E(B-V)$=0.809 mag and taking $E(U-B)/E(B-V)$=0.72. The arrow indicates the average reddening

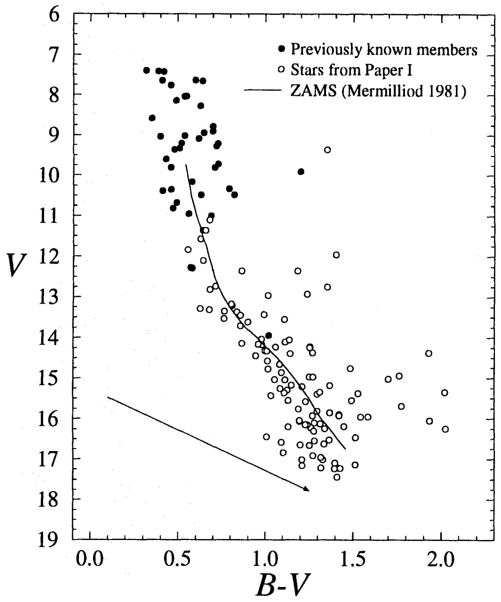

Fig. 3. Observational colour-magnitude diagram for stars in 18 randomly selected fields of Cepheus OB3. Solid line represents the ZAMS calibration by Mermilliod (1981) shifted by $E(B-V)$=0.809 mag, A_v=2.96$E(B-V)$ and V_o-M_v=9.32 mag. The arrow indicates the average reddening

3.3. Membership

The method explained in the previous sections to obtain reddenings and distances was applied to the 130 stars with $V \leq 15.5$ mag included in the observational photometric sample of Paper I. Colour-colour and colour-magnitude diagrams for these stars are shown in Fig. 2 and Fig. 3. Solid lines represent the adopted ZAMS calibrations shifted by the average values of colour excess and distance modulus. We adopted $E(U-B)/E(B-V)$=0.72 and A_v=2.96$E(B-V)$. The arrows indicate the average reddening. Members from BHJ and Jordi et al. (1992) were included for reference.

Member candidates were selected comparing the resultant colour excess and the distance modulus with the average values of the previously known Cepheus OB3 members: $\overline{E(B-V)} = 0.809 \pm 0.137$ mag (from BHJ) and $\overline{V_o - M_v} = 9.32 \pm 0.46$ mag (from Crawford & Barnes 1970). Taking into account that BHJ's sample is magnitude and spectral type limited, the most obscured members were not observed and the average reddening could be underestimated. So, we set a wide acceptance margin of $\pm 3\sigma$ and we considered as member candidates of Cepheus OB3 those stars having reddening and distance values inside these intervals and proximity parameter $d < 1.0$. Table 2 lists the selected stars. The quantities $n_{\sigma(E)}$ and $n_{\sigma(DM)}$ were defined as follows:

$$n_{\sigma(E)} = \left| \frac{E(B-V) - \overline{E(B-V)}}{\sigma(E)} \right| \; ; \; n_{\sigma(DM)} = \left| \frac{(V_o - M_v) - (\overline{V_o - M_v})}{\sigma(V_o - M_v)} \right|$$

where $\sigma(E)$ and $\sigma(V_o - M_v)$ are the standard deviations of the mean colour excess and distance modulus. The column labelled N_s gives the total number of reddening solutions (some of them not compatible with the membership). The last column indicates the cross-identification with the Guide Star Catalogue. Observed BHJ stars are not included since their relationship to Cepheus OB3 is already known. Only BHJ 27 has been reanalyzed due to the discrepancy in the photometry noticed in Paper I.

Two stars (BHJ 23-042 and BHJ 54-023) have their two reddening solutions compatible with membership and can, therefore, be considered members. The other stars need further analysis in order to confirm or deny their membership.

3.4. Strömgren photometry

The Strömgren photometry gives reddening values without ambiguity. This allows us to decide which of the multiple reddening solutions given by the procedure applied on Johnson photometry is the true value, and classify the candidate as member or non-member.

We observed the 19 brightest ($V \lesssim 14$) candidates in the *uvby-β* system. The instruments were the Jacobus Kapteyn Telescope at El Roque de los Muchachos (La Palma, Canary Islands, Spain), equipped with the People's Photometer, and the 1.52 m telescope of the Observatorio Astronómico Nacional at Calar Alto (Almería, Spain) equipped with a one channel photometer with a dry-ice cooled RCA 31034 photomultiplier. The observations were carried out in June 1994, July 1995 and September 1995.

From *uvby-β* photometry a spectral classification and the colour excess $E(b\text{–}y)$ were obtained as described by Masana

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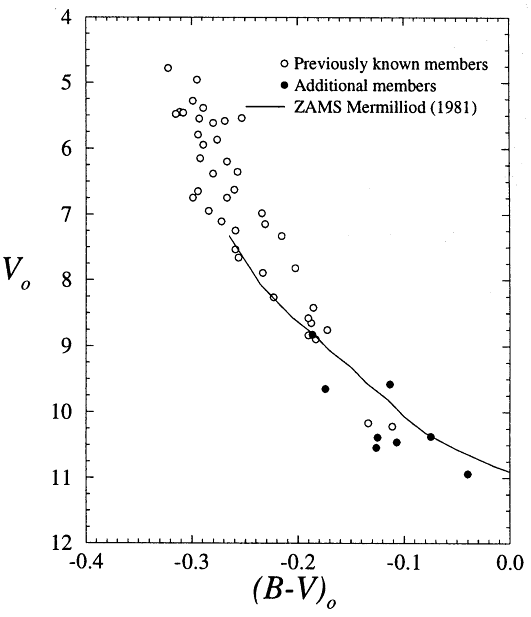

Fig. 4. Intrinsic colour-magnitude diagram for previously known members and additional members from this work. Solid line corresponds to the ZAMS by Mermilliod (1981) shifted by the mean distance modulus of the association

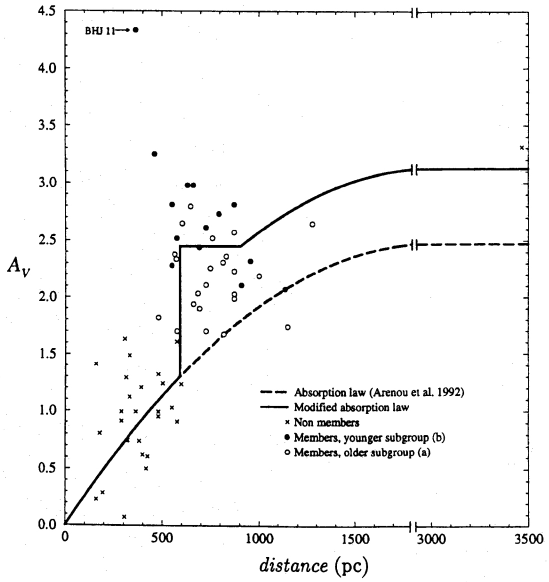

Fig. 5. Absorption as a function of distance in the direction of Cepheus OB3 association

(1994). The results are summarized in Table 3, N being the number of observations.

Computed reddening values confirm the membership of 8 stars labelled "M" on Table 3. The candidate BHJ 27-048 (= BHJ 27) was classified as non-member by BHJ. As pointed out in Paper I, our measurement of $U\text{–}B$ value is different from that given by these authors. The *uvby-β* photometry presented now is consistent with our former Johnson photometry, and it should therefore be considered a member of Cepheus OB3. Strömgren photometry for BHJ 70-081 candidate also includes the star BHJ 70-083, too close to it to be separated in the instruments used. The difference in magnitude between these two stars is small enough to prevent a significant modification of Strömgren colours and so, the classification and the colour excess of the brightest star, allowing us to determine which of the multiple Johnson reddening solutions is the true value.

For stars labelled "NM" on Table 3 the Strömgren reddening values point to another Johnson reddening solution not compatible with their membership, and so not quoted in Table 2. They should be considered as non-members of the association.

The difference between the reddening values computed from *UBV* and from Strömgren photometry is 0.00 ± 0.07, being 0.06 ± 0.04 for the confirmed members, which are all of them early type stars.

Two of the new members (BHJ 24-052 and BHJ 27-048) are located in the young subgroup (b) and the others in the old subgroup (a). The faintest members belong to the old subgroup and, as a whole, the members found in this work are fainter than the stars previously suggested as PMS[3] (Garmany 1973, Sargent 1979). This indicates that the actual PMS members should be searched for below or around V_o=10 mag and V_o=11 mag for the young and old subgroups, respectively.

Fig. 4 displays the intrinsic colour-magnitude diagram for the previously known members and for additional members from this work. Photometry of previously known members was taken from BHJ and Särg & Wrandemark (1970) and was dereddened using the procedure described above for candidate members. The ZAMS by Mermilliod (1981) was overplotted on the diagram.

Including the new members, the mean absorption of the young and old subgroups are 2.59±0.48 and 2.28±0.34 respectively[4], being these values under the same consideration made in Sec. 3.3 for BHJ's average. Fig. 5 shows the absorption in the direction of Cepheus OB3 as a function of distance. The absorption law proposed by Arenou et al. (1992) is overplotted. The law fits well enough the absorption in the foreground of the association but the effect of the interstellar matter present in Cepheus OB3 for larger distances should be taken into account. Our proposed modification is shown.

4. Ages of the subgroups

The first tentative ages of Cepheus OB3 subgroups were quoted by Blaauw (1964). On the basis of colour-magnitude diagrams, this author proposed ages of 8 Myr for the a subgroup, and 4 Myr for the b. In a later work (Blaauw 1991), the same author gave new estimates of 10 and 7 Myr.

We used the evolutionary models by Schaller et al. (1992) to evaluate the ages of the subgroups. We generated a set of isochrones with solar metallicity and ages ranging from 0 to 14 Myr, in steps of 0.5 Myr, and we translated them onto the

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[3] BHJ 9, BHJ 37, BHJ 42, BHJ 44br, BHJ 45 and BHJ 50

[4] Omitting the star BHJ 11.

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Table 2. Reddening solutions compatible with membership and with proximity parameter $d < 1$. N_s gives the total number of reddening solutions

Ident.	$E(B–V)$	$n_{\sigma(E)}$	$(B–V)_o$	V_o	$V_o–M_v$	$n_{\sigma(DM)}$	d	N_s	GSC
BHJ 11-024	1.12	2.2	0.37	11.42	8.10	2.7	0.0	3	
BHJ 20-059	0.92	0.8	0.40	13.39	9.89	1.2	0.0	3	
BHJ 20-061	1.03	1.6	0.08	12.28	10.28	2.1	0.3	3	
BHJ 23-008	0.66	1.1	0.54	14.08	9.70	0.8	0.6	2	
BHJ 23-039	0.82	0.1	–.14	8.63	8.49	1.8	0.1	2	428200339
BHJ 23-042	0.41	2.9	0.30	11.50	8.55	1.7	0.0	2	428200701
	0.79	0.2	–.08	10.37	9.33	0.0	0.1		
BHJ 24-027	0.58	1.7	0.44	13.05	9.30	0.0	0.0	3	
BHJ 24-050	0.57	1.7	0.40	12.31	8.79	1.2	0.0	3	
	1.09	2.0	–.11	10.78	10.13	1.8	0.1		
BHJ 24-052	1.13	2.3	–.11	9.58	9.05	0.6	0.0	3	428200429
BHJ 25-044	0.57	1.7	0.54	13.32	8.92	0.9	0.4	2	
BHJ 27-020	0.85	0.3	0.34	13.48	10.30	2.1	0.0	3	
BHJ 27-027	0.58	1.7	0.38	12.44	9.04	0.6	0.0	3	
	1.06	1.8	–.10	10.99	10.26	2.1	0.1		
BHJ 27-035	0.51	2.2	0.47	12.65	8.66	1.4	0.0	3	428200695
	1.10	2.1	–.12	10.86	10.45	2.5	0.1		
BHJ 27-047	0.55	1.9	0.54	13.20	8.80	1.1	0.0	2	
BHJ 27-048[a]	0.73	0.6	–.17	9.65	9.96	1.4	0. 1	2	428200501
BHJ 27-051	0.54	2.0	0.47	12.72	8.77	1.2	0.0	3	428200456
	1.13	2.3	–.12	10.95	10.53	2.6	0.0		
BHJ 28-024	0.60	1.5	0.60	14.84	10.10	1.7	0.0	3	
	0.74	0.5	0.46	14.44	10.52	2.6	0.0		
BHJ 28-035	0.59	1.6	0.35	12.68	9.43	0.2	0.0	3	
	1.04	1.7	–.09	11.35	10.48	2.5	0.0		
BHJ 30-014	0.77	0.3	–.14	9.27	9.13	0.4	0.0	2	428200393
BHJ 30-039	0.74	0.5	0.54	14.09	9.69	0.8	0.7	2	
BHJ 34-011	0.99	1.3	–.12	9.39	8.99	0.7	0.0	3	428200319
BHJ 34-039	1.00	1.4	–.14	10.72	10.53	2.6	0.0	2	
BHJ 43-007	0.54	2.0	0.62	13.57	8.74	1.3	0.0	3	
	0.70	0.8	0.45	13.07	9.25	0.2	0.0		
BHJ 43-009	1.12	2.3	–.13	10.06	9.73	0.9	0.0	2	428200895
BHJ 44-028	0.55	1.9	0.54	13.61	9.21	0.2	0.2	2	
BHJ 44-081	0.42	2.8	0.48	12.35	8.34	2.1	0.0	3	
	1.03	1.6	–.13	10.54	10.18	1.9	0.1		
BHJ 44-097	0.75	0.4	0.64	14.97	10.01	1.5	0.0	3	
BHJ 54-020	0.93	0.9	–.12	10.38	10.00	1.5	0.1	3	
BHJ 54-023	0.53	2.0	0.23	11.75	9.12	0.4	0.0	2	
	0.81	0.0	–.04	10.94	9.61	0.6	0.1		
BHJ 64-005	1.01	1.4	–.15	10.43	10.42	2.4	0.1	2	
BHJ 64-020	0.88	0.6	0.39	12.31	8.88	1.0	0.0	3	
BHJ 64-025	0.98	1.3	0.21	12.81	10.28	2.1	0.0	3	
	1.20	2.9	–.01	12.16	10.63	2.9	0.0		
BHJ 65-004	0.73	0.6	–.08	9.93	8.96	0.8	0.0	2	
BHJ 65-023	0.61	1.5	0.54	12.58	8.20	2.4	0.0	2	
BHJ 70-030	0.55	1.9	0.54	14.92	10.52	2.6	0.2	2	
BHJ 70-031	0.79	0.2	–.11	10.46	9.82	1.1	0.0	2	428201038
BHJ 70-041	0.42	2.9	0.45	12.89	9.08	0.5	0.0	3	428201017
BHJ 70-080	0.98	1.2	–.17	10.29	10.48	2.5	0.0	2	
BHJ 70-081	0.84	0.3	–.19	8.82	9.34	0.0	0.0	2	428200778
BHJ 70-083	0.73	0.6	–.10	11.09	10.44	2.4	0.0	2	
BHJ 80-008	0.81	0.0	–.14	10.87	10.64	2.9	0.0	3	
BHJ 80-009	0.43	2.8	0.34	12.25	9.10	0.5	0.0	3	
	0.85	0.3	–.09	10.97	10.09	1.7	0.0		

[a] BHJ 27-048 = BHJ 27

$[(B–V)_o, M_v]$ plane. Afterwards the isochrones were shifted by the average distance modulus of the association (9.32 mag).

Adapting Flannery & Johnson (1982) and Brown et al. (1994), we defined a photometric distance Δ from a star sample to a given isochrone as $\Delta^2 = \sum_i \delta_i^2$, where δ_i is the euclidean distance from the star i to the isochrone in the $[(B–V)_o, V_o]$ plane. The isochrone with minimum Δ gives the age of the star sample.

The ages obtained were 5.5 and 8 Myr for *b* and *a* subgroups respectively. When the known spectroscopic binaries (Garrison 1970, Garmany 1972) were removed from the samples, the resulting ages became 5.5 and 7.5 Myr. The colour-magnitude diagram with the corresponding isochrones is shown in Fig. 6.

The same set of isochrones were fitted to the sample of member stars in the ($\log T_{\rm eff}$, $\log g$) plane. To this end, temperatures and gravities were computed using the Strömgren photometry from Crawford & Barnes (1970), Jordi et al. (1992) and from this paper. We applied the algorithm by Jordi et al. (1994), which uses the transformations by Napiwotzki et al. (1993). However, in this plane almost all the members of the younger (*b*) subgroup are placed below the ZAMS and, thus, the age cannot be computed for this set of stars. The uncertainties in $\log g$ for the hottest stars shown by Jordi et al. (1994) could explain this. The resulting age for the older (*a*) subgroup is fully consistent with 7.5 Myr. The results are the same if we introduce $\log T_{\rm eff}$ as a weight in the calculation of Δ, as recommended by Brown et al. (1994).

Table 3. *uvby*-β photoelectric photometry for the 19 candidates brighter than V=14 mag

Ident.	$b-y$	m_1	c_1	β	N	$E(b-y)$	SP	Membership
BHJ 23-039	0.440 ± .007	0.186 ± .012	0.295 ± .019	2.608 ± .007	9	0.05	F0-G2	NM
BHJ 23-042	0.528 ± .007	0.004 ± .016	1.030 ± .037	2.931 ± .026	10	0.56	B	M*(a)*
BHJ 24-050	0.597 ± .005	0.272 ± .042	1.248 ± .117	2.923 ± .017	6	0.29	A0-A2	NM
BHJ 24-052	0.751 ± .018	–.178 ± .022	1.258 ± .067	2.847 ± .039	4	0.76	B	M*(b)*
BHJ 27-048	0.439 ± .001	–.076 ± .011	0.702 ± .025	2.737 ± .005	4	0.49	B	M*(b)*
BHJ 30-014	0.420 ± .009	0.149 ± .015	0.304 ± .015	2.620 ± .014	10	0.07	F0-G2	NM
BHJ 34-011	0.621 ± .001	0.194 ± .031	0.298 ± .020	2.596 ± .023	4	0.19	≥G3	NM
BHJ 34-039	0.633 ± .031	–.039 ± .041	0.406 ± .068	2.563 ± .077	3	0.28	≥G3	NM
BHJ 43-009	0.714 ± .002	0.047 ± .004	0.405 ± .030	2.639 ± .022	4	0.38	F0-G2	NM
BHJ 44-081	0.615 ± .028	0.097 ± .005	0.724 ± .071	2.984 ± .062	4	0.66	B	M*(a)*
BHJ 54-020	0.568 ± .007	–.033 ± .025	0.682 ± .040	2.762 ± .035	9	0.62	B	M*(a)*
BHJ 54-023	0.486 ± .008	–.008 ± .019	1.052 ± .042	2.840 ± .018	10	0.51	B	M*(a)*
BHJ 64-005	0.591 ± .010	0.172 ± .002	0.290 ± .005	2.590 ± .014	3	0.17	≥G3	NM
BHJ 65-004	0.410 ± .008	0.106 ± .009	0.835 ± .031	2.847 ± .018	9	0.30	A3-A9	NM
BHJ 70-031	0.445 ± .005	0.009 ± .023	0.988 ± .029	2.930 ± .012	10	0.48	B	M*(a)*
BHJ 70-080	0.561 ± .001	0.123 ± .009	0.411 ± .011	2.545 ± .011	3	0.14	≥G3	NM
BHJ 70-081[a]	0.492 ± .007	–.059 ± .015	0.645 ± .001	2.787 ± .025	5	0.55:	B	M*(a)*
BHJ 80-008	0.565 ± .017	0.051 ± .009	0.426 ± .047	2.602 ± .068	3	0.21	F0-G2	NM
BHJ 80-009	0.455 ± .021	0.347 ± .020	0.092 ± .026	2.582 ± .023	6	0.02	≥G3	NM

[a] joint photometry with BHJ 70-083

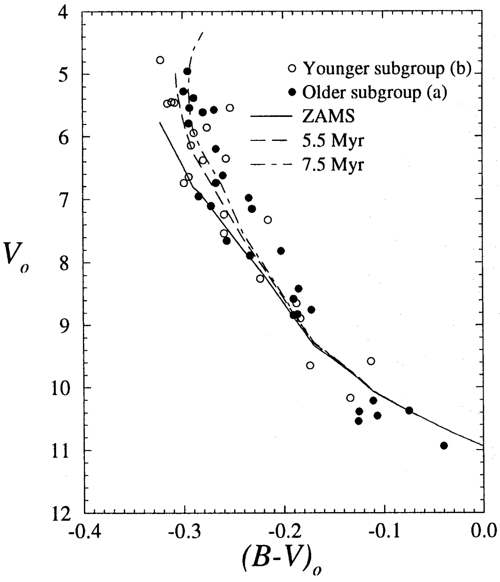

Fig. 6. Intrinsic colour-magnitude diagram for the two subgroups of Cepheus OB3. Isochrones by Schaller et al. (1992) corresponding to the ZAMS, 5.5 and 7.5 Myr are overplotted

5. Cross-identification with IRAS PSC

We cross-identified the IRAS Point Source catalogue with BHJ stars and our photometric sample of 1056 stars. Five positional coincidences were found. They are listed in Table 4, where we also quote the relationship with Cepheus OB3 association ("M" for members and "NM" for non-members).

Table 4. Cross-identification between BHJ, Paper I and IRAS Point Source Catalogue

Paper I	BHJ	IRAS	Membership
	15br	22513+6152	M (*b*)
BHJ 15-019	15ft	22513+6152	NM
BHJ 20-016	17br	22516+6221	M (*b*)
BHJ 24-044	24	22526+6220	M (*b*)
BHJ 44-089	44br	22561+6305	M (*a*)
	61	22591+6240	M (*a*)

These positional coincidences were already quoted in the IRAS Point Source catalogue, except for BHJ 20-016 and BHJ 15ft, which are new. Two stars (BHJ 15br and BHJ 15ft) fall in the 95% confidence uncertainty ellipse of the IRAS 22513+6152 source. The association reported by IRAS catalogue is with the bright component.

Two sources (22513+6152 and 22516+6221) have high quality flux at 12 and 25 μm, and the remaining three at 25 and 60 μm. The 12/25 ratio and [12]-[25] colours for the first group indicate that these sources cannot be associated with normal stars. They are far from the standard relation by Waters et al. (1987) in the combined Johnson-IRAS *(V*-[12],*B-V)* photometric diagram. This should be understood either as a presence of circumstellar shells or a lack of physical coincidence between IRAS sources and BHJ stars. The three sources with reliable photometry at 25 and 60 μm bands have greater values at 60 μm than at 25 μm, as corresponds to warm sources. IRAS low detection of normal stars and preferential detection of stars with abnormal infrared emission were reported by Habing (1987) and Trullols & Jordi (1993).

6. Updated list of members

Since the information about the members of Cepheus OB3 association is spread over different papers ranging from the 50's to

Table 5. Members of Cepheus OB3 association

BHJ	Paper I	BD	GSC	PPM	α_{2000}	δ_{2000}	V	Notes
		+64°1714		23940	22 46 05.626	+64 47 43.24	10.57	a
		+64°1717		23953	22 47 52.932	+65 03 43.54	7.06	a
		+62°2114		23956	22 47 59.998	+62 51 48.07	9.61	
2		+61°2350	426900340	23979	22 49 36.461	+62 19 57.37	9.21	
8			428200598		22 51 46.66	+62 24 43.38	11.00	
9		+61°2355	428200774	24011	22 52 29.247	+62 41 10.59	9.63	c
10		+61°2356	428200342	24016	22 52 30.626	+62 26 25.92	8.03	
11	11-017	+61°2357	428200996	24019	22 52 33.653	+62 18 46.99	9.84	e
14		+62°2125	428200564	24021	22 52 50.130	+63 24 48.29	8.95	
15br		+61°2361		24029	22 53 15.631	+62 08 44.76	9.28	
16ft					22 53 28.67	+62 08 05.63	13.95	g
16br		+61°2363		24030	22 53 30.814	+62 08 05.63	8.91	
17br	20-016		428200930		22 53 38.18	+62 36 57.56	10.45	
18		+61°2127	428200674		22 53 41.34	+63 25 05.27	10.16	
19			428200295		22 53 50.98	+63 11 13.13	10.38	
20	20-056	+61°2364	428200941	24036	22 53 53.944	+62 35 48.64	9.06	
	23-042				22 54 09.9	+63 16 49.	12.74	
22		+61°2365	428200772	24043	22 54 17.988	+62 39 54.26	9.20	
23	23-067		428200989		22 54 18.24	+63 14 50.64	10.80	
24	24-044	+61°2366	428200710	24049	22 54 36.324	+62 36 44.00	9.73	
25	25-052		428200544		22 54 40.44	+62 45 03.20	10.60	
	24-052				22 54 42.4	+62 37 55.	12.96	
26					22 54 57.3	+62 34 16.	10.34	h
27	27-048		428200501		22 55 03.98	+62 49 33.82	11.84	
31		+61°2370	428200758	24060	22 55 42.381	+62 18 23.05	8.04	
33ft	34-019		428200563		22 55 47.75	+62 51 04.14	12.31	
33br	34-020		428200551		22 55 49.35	+62 51 13.61	11.38	
37			428200471		22 56 14.28	+63 09 56.77	10.95	d
39		+62°2136	428200313	24070	22 56 30.907	+62 52 06.99	7.76	
40	40-111	+61°2372	428200933	24072	22 56 42.525	+62 37 29.24	8.71	
41		+61°2373	428200617	24074	22 56 47.188	+62 43 37.42	7.66	
42			428200945		22 57 27.68	+62 48 10.15	11.44	c
	44-081				22 58 01.4	+63 19 47.	13.62	
44br	44-089	+62°2142	428200415	24088	22 58 03.818	+63 21 44.19	9.01	d
44ft	44-093		428200704		22 58 06.34	+63 21 50.83	10.34	
45		+62°2143	428200694		22 58 12.85	+63 22 33.60	10.56	b
47		+62°2146	428200253	24093	22 58 33.206	+63 42 24.65	7.41	
46br		+62°2147	428200468	24098	22 58 39.765	+63 04 37.14	7.42	
50		+62°2150	428200362		22 59 16.47	+62 51 49.43	9.80	d
54	54-016	+62°2152	428200548	24108	22 59 42.753	+62 46 38.32	8.98	
	54-020				22 59 49.0	+62 45 35.	13.17	
	54-023				22 59 53.7	+62 47 01.	13.35	
56		+62°2154	428200338	24117	23 00 32.182	+63 30 58.72	9.33	
59		+62°2155	428200638		23 00 54.48	+62 52 54.19	9.81	
61		+62°2156	428200636	24120	23 01 11.940	+62 56 31.08	8.14	
66		+62°2161	428200228	24148	23 03 01.474	+63 41 53.79	8.27	
68		+62°2162	428200158	24150	23 03 20.138	+63 33 01.88	8.59	
69ft			428201032		23 03 49.03	+63 23 26.09	12.29	
69br		+62°2163	428200419	24162	23 04 02.249	+63 23 48.98	7.65	
	70-031				23 04 27.6	+63 22 11.	12.82	
	70-081				23 04 43.8	+63 21 31.	11.36	
70	70-086	+62°2166	428200449	24169	23 04 45.435	+63 21 05.11	9.32	
75		+63°1928	428600306	24185	23 05 56.725	+64 17 42.25	7.64	f
76		+62°2170	428200391	24186	23 06 08.974	+63 12 46.14	7.43	
77br			428200099		23 07 06.55	+63 19 37.00	10.48	

Notes to Table 5:

a: Possible member, proposed by Jordi et al. (1992). Its membership to Cepheus OB3 would imply that the association covers a more extended region
b: Classified as non-member by BHJ. Proposed as possible pre-main sequence member by Garmany (1973)
c: Classified as non-member by BHJ. Proposed as possible pre-main sequence member by Garmany (1973) and Sargent (1979)
d: Classified as member by BHJ. Proposed as pre-main sequence member by Sargent (1979)
e: Classified as member by BHJ. Its membership is considered 'extremely doubtful' by Sargent (1979). Classified as non-member by Jordi et al. (1992)
f: Classified as member by BHJ. Its membership is considered doubtful by Sargent (1979)
g: Coordinates computed from BHJ 16br by adding the offset quoted by BHJ ($\theta \approx 270^\circ$, $\rho \approx 15''$)
h: Position measured on a paper copy of the POSS plate containing the association, using as reference the surrounding stars with known coordinates

now, we found it useful to compile the updated list of members shown in Table 5. We include different cross-identifications, apparent visual magnitude and positional information.

Most of the BHJ stars were visually searched for and identified comparing the finder chart published by BHJ with the Guide Star Catalogue (GSC, Jenkner et al. 1989). The coordinates of the stars cross-identified with the Positions and Proper Motions Catalogue (PPM, Röser & Bastian 1989) were taken from this source. Coordinates for the other stars were obtained from the GSC and from Paper I, except for the stars BHJ 26 and BHJ 16ft. The position of BHJ 26 was measured directly on a paper copy of the POSS plate containing the association[5]. The position of BHJ 16ft was computed from the position angle

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[5] The photograph was measured with a Nikon Measurescope micrometric device. A linear transformation from x and y to α and δ was computed using the stars with known coordinates surrounding BHJ 26.

and angular distance from BHJ 16br quoted by BHJ ($\theta \approx 270°$, $\rho \approx 15''$).

Visual magnitudes were taken from Paper I, Jordi et al. (1992) and BHJ.

7. Conclusions

From *UBVRI*-CCD photometry of stars in 18 randomly selected fields in Cepheus OB3 individual reddening solutions were found for 130 stars. The selection of the solutions compatible with the mean excess and distance modulus of the association yields a list of 42 member candidates with apparent visual magnitudes $11.1 < V < 17.2$ mag.

The 19 brightest candidates were observed in the $uvby$-β system. Eight of them were confirmed as members of Cepheus OB3 association and 11 were found to be non-members. The apparent visual magnitude of the new members ranges from V=11.36 mag to V=13.62 mag. Both Johnson and Strömgren photometries indicate that all of them are of spectral type B. The presence of a member at V=13.62 mag suggests that the turn on of the association is located down to this magnitude and PMS stars could be searched for below or around this value.

The ages of the subgroups were found to be 5.5 and 7.5 Myr, younger than quoted in previous works.

The confirmation of the membership of some of our member candidates justifies undertaking observations oriented to decide the relationship to Cepheus OB3 of the candidates fainter than $V = 14$ mag. The extension of this investigation to larger zones of the association would greatly improve our knowledge of the stellar content, the IMF, the structure and the history of Cepheus OB3.

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