

# Photometric and Coravel observations of red giant candidates in three open clusters: membership, binarity, reddening and metallicity

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## ABSTRACT

**Aims.** We present new CORAVEL radial-velocity observations and photoelectric photometry in the *UBV* and *DDO* systems for a sample of potential members of the red-giant branches of NGC 6192, NGC 6208 and NGC 6268, three open clusters projected close to the Galactic center direction. We also examine the properties of a sample of 42 inner disk open clusters projected towards almost the same direction as the three clusters.

**Methods.** Cluster members and red field giants were discriminated by using the CORAVEL radial-velocity data and by applying two photometric criteria. Interstellar reddening and metal content of the clusters were derived from combined *BV* and *DDO* data.

**Results.** Cluster membership for five red giants in NGC 6192, three in NGC 6208 and three in NGC 6268 has been confirmed by the analysis of the photometric and kinematic data. Photometric membership probabilities show very good agreement with those obtained from CORAVEL radial velocities. Three new spectroscopic binaries were discovered among the red giants of NGC 6192 and NGC 6208. Mean radial velocities and  $E(B - V)$  colour excesses were derived.

**Conclusions.** The overall metallicities were found to be nearly solar for NGC 6208 and above solar for NGC 6192 and NGC 6268. Most of the clusters located closer than 2 kpc from the Sun in the considered direction are slightly more reddened than the absorption resulting from the Baade's window absorption law.

**Key words.** Galaxy: open clusters and associations: general – stars: binaries: spectroscopic – techniques: photometric – techniques: radial velocities – stars: abundances

## 1. Introduction

In this paper we discuss NGC 6192, NGC 6208 and NGC 6268 as part of a more extensive study of red giants in open clusters using CORAVEL radial velocity data and new photoelectric photometry. These three poorly studied, southern, open clusters are located near the Galactic plane and close to the Galactic center direction. Their corresponding equatorial and Galactic coordinates are given in Table 1, together with the Trumpler (1930) class according to Archinal & Hynes (2003), the  $E(B - V)$  colour excesses, distances from the Sun and ages given by the WEBDA open Cluster Database (Mermilliod & Paunzen 2003). These clusters are interesting in themselves because of the number of red giant candidates they contain. Neither radial-velocity determination nor *DDO* photometry for any of the stars of these three clusters has been published yet.

NGC 6192 (C1636-432) – also known as Mel 109 (Melotte 1915), Cr 309 (Collinder 1931) or BH 194 (van den Bergh & Hagen 1975) – has been the most thoroughly studied of our three targets. However, a remarkable disagreement about the cluster reddening value is found in the literature and, consequently, discrepancies in ages and distances have been reported. Kilambi & Fitzgerald (1983, hereafter KF83) and King (1987) derived a reddening of  $E(B - V) = 0.26$ , a rather old age

(~1.0 Gyr) and a distance from the Sun of about 1 kpc, based on photographic and *CCD* photometry, respectively. More recently, Kjeldsen & Frandsen (1991, hereafter KF91) obtained a much higher reddening of  $E(B - V) = 0.68$ , an age of scarcely 89 Myr and a distance of about 1.7 kpc. Paunzen et al. (2003) obtained *CCD* photometry in the *uvby* Strömgen's system to clarify the abovementioned discrepancies. They derived  $[Fe/H] = -0.10 \pm 0.09$  and  $E(b - y) = 0.40$ , equivalent to  $E(B - V) = 0.54$ , if the relation  $E(B - V) = 1.35E(b - y)$  given by Crawford (1978) is used. This reddening value seems to support KF91's estimate and apparently contradicts the values previously reported by KF83 and King (1987). Loktin et al. (2001) published a second version of their Open Cluster Catalogue (Loktin & Matkin 1994) reviewing the fundamental parameters of 423 clusters. Their updated distances are now based on a Hyades distance modulus of 3.27, this value being 0.06 mag lower than that found from Hipparcos parallaxes, namely  $V - M_V = 3.33 \pm 0.01$  (Perryman et al. 1998). By using the original data from KF91, Loktin et al. (2001) determined the following parameters for NGC 6192:  $E(B - V) = 0.637$ ,  $d = 1547$  pc and  $\log t = 8.13$  (Table 1).

NGC 6208 (C1645-537) – also designated Cr 313 or BH 198 – is located ~26° from the Galactic center direction in a very rich star field in Ara, which makes its membership and astrophysical properties rather difficult to investigate.

**Table 1.** Open clusters studied.

Cluster	$\alpha$ (J2000) (h:m)	$\delta$ (J2000) (°:′)	$l$ (°)	$b$ (°)	Trumpler class	$E(B - V)$ (mag)	$d$ (kpc)	$\log t$
NGC 6192	16 40.4	-43 22.0	340.7	2.1	I2r	0.637	1.5	8.13
NGC 6208	16 49.5	-53 43.0	333.8	-5.8	III2r	0.210	0.9	9.07
NGC 6268	17 02.7	-39 44.3	346.1	1.2	II2p	0.387	1.0	8.40 <sup>a</sup>

<sup>a</sup> The age given by WEBDA is incorrect (see Sect. 1).

To the best of our knowledge, the only photometric study was performed by Lindoff (1972), who obtained *UBV* photoelectric and photographic photometry for 17 and 286 stars, respectively, in the cluster field. Although he derived  $E(B - V) = 0.18$ , an age of  $\sim 1$  Gyr and a distance of about 1 kpc from the Sun, caution should be exercised when analyzing these results owing to the huge dispersion existing in the Lindoff ( $V, B - V$ ) colour-magnitude diagram (CMD, see Sect. 3.1). Using Lindoff's data, Loktin et al. (2001) obtained similar basic parameters for this cluster (Table 1). On the other hand, based on unpublished *DDO* photometric data of 3 red giant candidates, Piatti et al. (1995) obtained  $[\text{Fe}/\text{H}] = -0.03$ , while Twarog et al. (1997) revised this value to  $[\text{Fe}/\text{H}] = 0.00$ . More recently, Paunzen & Maitzen (2001) performed a *CCD* photometric search for chemically peculiar (CP) stars in NGC 6208 but no apparent peculiar object was found.

NGC 6268 (C1658-396) – also known as Cr 323 or BH 212 – is located at less than  $14^\circ$  from the Galactic center in Scorpius. As far as we know, the only photometric *UBV* study was done by Seggewiss (1968), based on photographic plates. Using the original photographic data obtained by Seggewiss, Loktin et al. (2001) derived  $E(B - V) = 0.387$ , a distance of 1029 pc from the Sun and an age of scarcely 17 Myr ( $\log t = 7.25$ ). As shown in Fig. 5, however, this age has been misestimated. So much so that adopting the theoretical metal content  $Z = 0.019$  and using the above mentioned reddening and distance, the Padova isochrone (Girardi et al. 2000) of  $\log t = 8.35$  ( $t = 224$  Myr) most accurately reproduces the cluster features in the ( $V, B - V$ ) CMD. Recently, McSwain & Gies (2005) identified one definite Be star in this cluster from observations performed with the Strömgren  $b$  and  $y$  and the narrow band  $H_\alpha$  filters, while Paunzen et al. (2005) detected several CP stars using the narrow band, three filter  $\Delta\alpha$  photometric system. By fitting theoretical isochrones for the  $\Delta\alpha$  system (Claret et al. 2003), Paunzen et al. (2005) derived  $E(B - V) = 0.40$ , a distance of 1080 pc from the Sun and an age of 40 Myr ( $\log t = 7.60$ ).

As part of a long-term project to determine abundances and astrophysical properties of red evolved stars in southern open clusters, we present here CORAVEL radial velocities and accurate *UBV* and *DDO* photometry of G and/or K giant candidates in the field of the abovementioned clusters. These data are used to discuss cluster membership, to detect new spectroscopic binaries, to make an independent estimate of the individual  $E(B - V)$  colour excesses, as well as to derive the metal content of the clusters.

In Sect. 2, we briefly describe the observational material. Section 3 presents the analysis and discussion of the photometric and CORAVEL data. Using the WEBDA Open Cluster Database (Mermilliod & Paunzen 2003), we examine in Sect. 4 the properties of a sample of open clusters located almost in the same direction as NGC 6192, NGC 6208 and NGC 6268. A short summary of our main conclusions is given in Sect. 5.

## 2. The observational material

### 2.1. Photometric *UBV* and *DDO* observations

Thirty seven potential members of the red-giant branches of NGC 6192, NGC 6208 and NGC 6268 were originally selected from their existing CMDs. These stars appear to be free from contamination by neighbouring stars and were observed in the *UBV* system, while only 22 of them were observed in the *DDO* photometric system (McClure 1976). Only the four primary filters of the *DDO* (41, 42, 45 and 48) system were used because they provide adequate information for the present purposes.

The *UBV* and *DDO* measurements were made with the 1.0-m telescopes of the Cerro Tololo Inter-American Observatory (CTIO) and La Silla (LS) Observatory, located in Chile, in April 1994 and June 1993, respectively. Single-channel pulse-counting photometers were used in both observatories in conjunction with dry-ice refrigerated Hamamatsu phototubes. Mean extinction coefficients for CTIO and LS were used, and between 11 and 18 standard stars from the lists of Cousins (1973, 1974), Graham (1982) and McClure (1976) were observed nightly to place the observations in the standard *UBV* and *DDO* systems. The external and internal mean errors of the *UBV* and *DDO* photometries are similar to those quoted in previous papers (e.g. Clariá et al. 2005). Some *UBV* measurements were also made in March 1988 with the LS 1.0-m telescope and a RCA 31034 (Quantacom) Ga-As photomultiplier. No evidence was found of systematic discrepancies either in  $V$  or in the colours among the stars observed in common at LS and CTIO. Therefore, mean values were used and are listed in Table 2, together with their mean internal errors  $\sigma$ , in units of 0.001 mag, and the number  $n_1$  on which each star was observed in the *UBV* system. Star designations are from KF83, Lindoff (1972) and Seggewiss (1967) for NGC 6192, NGC 6208 and NGC 6268, respectively, except for stars 255, 265 and 274 of NGC 6192, which are identified in Fig. 1.

Table 3 presents the observed *DDO* colours, along with their mean internal errors  $\sigma$ , in units of 0.001 mag, and the number  $n_2$  on which each star was observed in this system.

### 2.2. Comparison with other *UBV* data

The agreement between the present *UBV* data for the stars measured in NGC 6192 and those obtained photographically by KF83 is very poor. The mean differences ( $\Delta = \text{KF83}$  minus present value) and standard deviations from 8 stars measured in common are:  $\Delta V = -0.02 \pm 0.14$ ,  $\Delta(B - V) = -0.34 \pm 0.10$  and  $\Delta(U - B) = 0.13 \pm 0.25$ . These large differences, particularly in the  $B - V$  colours, are almost entirely due to the low accuracy of KF83's photographic data. Moreover, they seem to explain the abovementioned wide discrepancies found in the reddening values derived by other authors. There are only two stars

**Table 2.** *UBV* photometry of red giant candidates.

Star	<i>V</i>	$\sigma$	<i>B</i> - <i>V</i>	$\sigma$	<i>U</i> - <i>B</i>	$\sigma$	<i>n</i> <sub>1</sub>
NGC 6192							
4	11.588	6	1.334	15	1.161	4	3
9	11.430	8	1.510	16	1.876	34	2
28	10.663	8	1.991	8	2.339	24	2
45	11.743	3	1.546	13	1.481	33	2
91	11.207	1	1.632	10	1.388	11	2
96	11.306	6	1.502	12	1.341	20	2
137 <sup>a</sup>	11.223	7	1.758	8	1.633	4	3
253	11.130	9	1.111	10	0.749	10	2
255 <sup>b</sup>	11.945	10	1.597	16	1.363	11	3
265 <sup>b</sup>	11.849	29	1.451	3	1.323	10	2
274 <sup>b</sup>	11.300	13	1.650	13	1.512	13	3
NGC 6208							
9	12.563	12	1.386	11	1.405	45	2
19 <sup>a</sup>	11.111	26	1.308	19	1.045	16	3
20 <sup>a</sup>	12.449	14	1.394	19	1.316	31	3
27	11.151	7	1.265	4	0.873	1	2
31	11.643	10	1.203	17	0.882	9	3
44 <sup>c</sup>	12.907	18	0.958	8	0.347	33	3
48	11.632	19	1.325	17	1.098	11	3
119	12.616	10	1.815	21	2.124	80	5
124	12.309	22	1.363	5	1.232	12	3
127 <sup>c</sup>	12.927	28	1.469	23	1.377	84	3
132	14.586	15	2.169	53			2
133	11.575	1	1.331	2	1.328	22	2
150	12.461	19	1.375	7	1.152	15	2
165 <sup>a</sup>	12.804	13	1.707	15	1.804	65	2
166	12.158	16	1.253	2	1.023	30	2
178 <sup>c</sup>	13.093	12	1.375	8	1.169	78	3
179	12.987	15	1.471	12	1.535	63	3
209	12.575	9	0.644	12	0.125	16	3
267	12.550	29	1.646	24	1.716	70	2
NGC 6268							
13	10.415	5	1.242	3	0.979	13	2
22	10.811	27	1.435	2	1.181	15	2
35	10.349	7	1.685	23	1.669	3	2
44	9.965	25	1.395	9	1.137	5	2
48	11.311	17	1.218	5	1.016	5	2
73	11.189	23	1.465	7	1.380	1	2
76 <sup>c</sup>	9.749	15	1.394	15	1.075	15	2

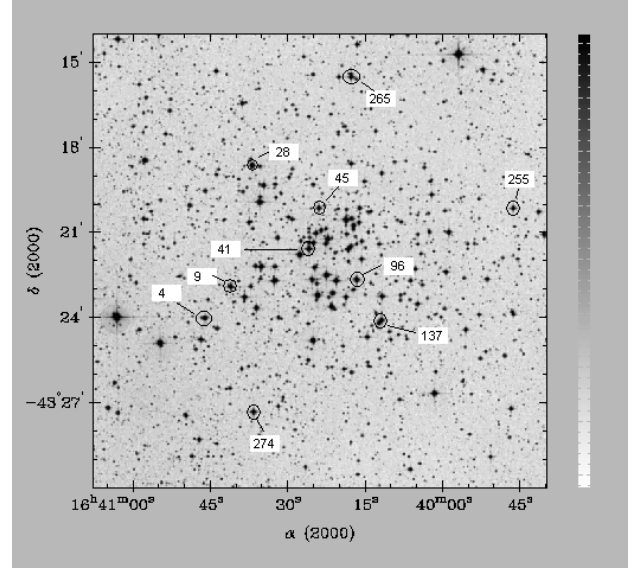
<sup>a</sup> Double star, only the bright component was measured.

<sup>b</sup> Star identified in Fig. 1.

<sup>c</sup> Double star, both components were measured together.

photoelectrically measured by both KF83 and by this study: Nos. 96 and 137. However, only the data for star 96 can be compared, since star 137 is a binary system for which only the brightest component was measured. The corresponding differences in *V*, *B* - *V* and *U* - *B* for star 96 are -0.02, -0.02 and -0.20, respectively.

Among the stars measured in NGC 6268, four (Nos. 19, 27, 31 and 48) were also observed photoelectrically by Lindoff (1972) in the *UBV* system. Their *V* magnitudes show a rather poor agreement with the present ones, while the *B* - *V* and *U* - *B* colours exhibit a relatively good agreement. The mean differences (Lindoff minus present values) are:  $\Delta V = -0.08 \pm 0.09$ ,  $\Delta(B - V) = -0.03 \pm 0.03$  and  $\Delta(U - B) = -0.03 \pm 0.10$ . Regarding NGC 6268, the mean differences for the stars measured in common between Seggewiss's (1967) photographic values and our own values are:  $\Delta V = 0.06 \pm 0.06$ ,  $\Delta(B - V) = -0.01 \pm 0.08$  and  $\Delta(U - B) = -0.25 \pm 0.09$ .

**Fig. 1.** *R* image of NGC 6192 from the Digitized Sky Survey (DSS). Stars 255, 265 and 274 are identified. North is up and east is to the left.**Table 3.** *DDO* photometry of red giant candidates.

Star	<i>C</i> 4548	$\sigma$	<i>C</i> 4245	$\sigma$	<i>C</i> 4142	$\sigma$	<i>n</i> <sub>2</sub>
NGC 6192							
4	1.301	10	1.334	12	0.233	11	2
9	1.343	22	0.931	9	0.293	7	2
28	1.563	11	1.320	8	0.302	12	2
45	1.392	17	0.921	10	0.309	4	2
91	1.432	11	0.990	16	0.359	4	2
96	1.351	22	0.851	17	0.338	15	2
137 <sup>a</sup>	1.483	8	1.057	12	0.430	1	2
253	1.196	10	0.807	10	0.223	14	2
255	1.353	8	1.003	11	0.213	12	2
265	1.300	6	1.048	9	0.145	10	2
274	1.424	12	1.056	10	0.247	8	2
NGC 6208							
19 <sup>a</sup>	1.279	6	0.935	11	0.233	3	2
27	1.261	3	0.853	4	0.171	27	2
31	1.250	8	0.851	4	0.177	3	2
48	1.266	8	0.953	1	0.200	7	2
133	1.288	4	1.007	21	0.308	1	2
NGC 6268							
13	1.235	12	0.887	16	0.227	15	2
22	1.318	11	0.924	14	0.303	3	2
44	1.330	12	0.932	1	0.333	8	2
48	1.206	11	0.937	6	0.240	16	2
73	1.365	13	0.976	11	0.353	17	2
76 <sup>b</sup>	1.312	6	0.904	12	0.248	5	2

<sup>a</sup> Double star, only the bright component was measured.

<sup>b</sup> Double star, both components were measured together.

### 2.3. CORAVEL radial velocities

High precision radial velocity observations have been obtained for the program stars between June 1984 and September 1996 as part of the regular observing campaign on red giants in open clusters, using the photoelectric scanner CORAVEL (Baranne et al. 1979) installed on the 1.54-m Danish telescope at LS (Chile). The radial velocities are in the system defined by Udry et al. (1999), and calibrated with high-precision data from the ELODIE spectrograph (Baranne et al. 1996). A total of 82 observations were obtained for 24 red giant candidates in

**Table 4.** CORAVEL radial-velocity data.

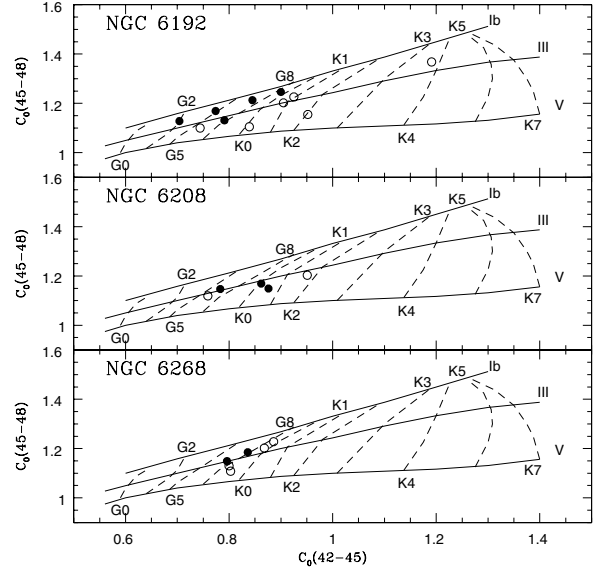
Star	$V_r$	$\epsilon$	$\sigma$	$E/I$	$P(\chi^2)$	$N$	Notes
NGC 6192							
4	+45.28	0.53	0.76	1.60	0.110	2	NM
9	-8.16	0.22	0.45	1.01	0.391	4	M
28	+24.81	0.39	0.55	1.35	0.179	2	NM
45	-8.06	0.23	0.43	0.96	0.435	4	M
91	-8.82	0.59	1.57	3.69	0.000	7	M, SB
96	-6.40	0.59	1.87	3.87	0.000	10	M, SB
137	-7.17	0.33	0.65	1.54	0.071	4	M
253	-19.32	0.26	0.45	1.00	0.365	3	NM
255	-88.51	0.34	0.19	0.40	0.687	2	NM
265	-59.69	0.33	0.26	0.57	0.571	2	NM
NGC 6208							
9	-26.29	0.31	0.21	0.49	0.627	2	NM
19	-32.17	0.21	0.12	0.34	0.889	3	M
20	+9.96	0.45	0.45			1	NM
27	-69.01	2.26	3.19	2.27	0.023	2	NM
31	-32.83	0.23	0.11	0.28	0.923	3	M
48	-31.63	2.30	6.89	17.14	0.000	9	M, SB
124	-49.12	0.41	0.41			1	NM
133	+29.30	0.37	0.37			1	NM
150	-113.92	0.46	0.46			1	NM
166	-43.48	0.40	0.40			1	NM
NGC 6268							
13	-2.59	0.19	0.30	0.77	0.623	4	NM
44	-15.28	0.23	0.38	0.82	0.581	4	M
76A	-14.97	0.23	0.12	0.31	0.907	3	M, VB
76B	-15.09	0.28	0.43	0.87	0.466	3	M, VB

the three clusters, with an average of 3 observations per star. Columns (2) to (8) of Table 4 present in succession the mean radial velocity and its uncertainty in [ $\text{km s}^{-1}$ ], the dispersion in the mean radial velocities, the ratio of the external to internal errors ( $E/I$ ), the number of radial-velocity observations, the probability  $P(\chi^2)$  that the scatter is due to random noise and remarks on membership and duplicity. Individual observations, including the Julian date, are available from the WEBDA database (<http://www.univie.ac.at/webda/>) and upon request to the authors. All the stars in NGC 6192 were observed both photoelectrically and with the CORAVEL, while nine stars in NGC 6208 and one star in NGC 6268 were observed photoelectrically but not with the CORAVEL.

### 3. Analysis and discussion of the data

#### 3.1. Cluster membership and interstellar reddening

The separation of red giant cluster members from the field stars was carried out primarily on the basis of the radial velocity data. As shown in Table 4, five stars of NGC 6192 (Nos. 9, 45, 91, 96 and 137) have CORAVEL radial velocities in the narrow range  $-8.8 \text{ km s}^{-1} < V_r < -6.4 \text{ km s}^{-1}$ , including two new spectroscopic binaries (SBs). All these stars appear to be unambiguously red giant members of NGC 6192. On the other hand, only three stars of NGC 6208 (Nos. 19, 31 and 48) – including one new spectroscopic binary – and three stars of NGC 6268 (Nos. 44, 76A and 76B) show nearly similar radial velocities. Therefore, their physical membership to NGC 6208 and NGC 6268, respectively, appears to be highly probable. Mean radial velocities of  $(-7.7 \pm 0.38) \text{ km s}^{-1}$ ,  $(-32.21 \pm 0.28) \text{ km s}^{-1}$  and  $(-15.11 \pm 0.08) \text{ km s}^{-1}$  are here derived for NGC 6192, NGC 6208 and NGC 6268, respectively. To derive these values, the radial velocities of the new SBs were also considered.



**Fig. 2.** Red giants in NGC 6192, NGC 6208 and NGC 6268 plotted on the unreddened  $[C_0(45-48), C_0(42-45)]$  diagram. Solid lines are solar neighbourhood lines for luminosity classes Ib, III and V as defined by Clariá et al. (1994). Cluster members and field stars are represented by filled and open circles, respectively.

Clariá & Lapasset (1983) and Clariá (1985) have shown that the likelihood of membership of a G or K star located in or near an open cluster can be evaluated with fairly good certainty by using two independent criteria – denoted A and B – based on combined  $BV$  and  $DDO$  photometric data. To apply criteria A and B, we adopted the colour excesses for the main sequence stars and true distance moduli derived by Loktin et al. (2001) for the three clusters. The  $DDO$  colours were dereddened according to the reddening coefficients given by McClure (1973) and the predicted luminosity class (LC) for each cluster star was determined from the Straižys (1992) calibration assuming  $R = A_V/E(B-V) = 3.5$  for G-K III stars (Straižys 1992). Figure 2 illustrates the cluster giant branches in the unreddened  $[C_0(45-48), C_0(42-45)]$  diagrams. Also included in this figure are the solar neighbourhood loci of Clariá et al. (1994) for luminosity classes Ib, III and V. Stars considered to be giant members and red field objects are represented by filled and open circles, respectively.

Table 5 presents the results of applying the photometric criteria. The successive columns contain the star identification, the colour excess  $E(B-V)_{\text{GK}}$  derived from Janes (1977) iterative procedure using  $BV$  and  $DDO$  data, the standard deviation of the  $E(B-V)_{\text{GK}}$  colour excess calculated from Eq. (2) of Clariá & Lapasset (1983), the LC each star should have in order to be a cluster member, the spectral type derived from the  $DDO$  colours using the calibration of Clariá et al. (1994), the results from applying criteria A and B and the membership status finally assigned to each star. Star 96 of NGC 6192 falls slightly outside the range of Janes (1977) Table 1. If for this star we adopt the mean reddening derived from the other four cluster members, namely  $E(B-V) = 0.63$ , then it turns out to be a cluster member according to criterion B.

Although caution should be exercised when considering the results obtained from criterion A because of the probable non-uniform reddening in the cluster fields, there is good agreement between the photometric analysis and the kinematic data. With the exception of star 133 of NGC 6208 (photometric member

**Table 5.** Photometric membership results.

Star	$CE$ (mag)	$\sigma_{CE}$ (mag)	$LC$ (Pred)	$MKK$ (DDO)	Criteria		Mem
					(A)	(B)	
NGC 6192							
4	0.28	0.04	II-III	K1 III	NM	M	NM
9	0.60	0.06	II-III	G8 III	M	M	M
28	0.55	0.04	II	K3/4 III	NM	PM	NM
45	0.63	0.05	II-III	G5 II	M	M	M
91	0.62	0.04	II-III	G5/8 II	M	M	M
96	0.63 <sup>a</sup>	–	II-III	G2 III	–	M	M
137	0.67	0.03	II-III	G8/K0 III	M	M	M
253	0.27	0.04	II-III	G5/8 III-IV	NM	PM	NM
255	0.70	0.04	II-III	K0 IV-V	PM	NM	NM
265	0.41	0.02	II-III	K2 IV	NM	NM	NM
274	0.56	0.04	II-III	K1 III	NM	M	NM
NGC 6208							
19	0.31	0.05	III	K0/1 III-IV	PM	M	M
27	0.40	0.02	III	G5 III	NM	M	NM
31	0.29	0.04	III	G5/8 III	PM	M	M
48	0.33	0.06	III	K0/1 III	PM	M	M
133	0.24	0.03	III	K1/2 III	M	M	M
NGC 6268							
13	0.36	0.04	III	G9 IV-V	M	NM	NM
22	0.53	0.03	III	G8/9 III-IV	NM	PM	NM
44	0.41	0.03	III	G8 II-III	M	M	M
48	0.22	0.03	III	K0/1 IV	NM	PM	NM
73	0.46	0.03	III	K0 II-III	NM	M	NM
76	0.46	0.04	III	G8 III	PM	M	M

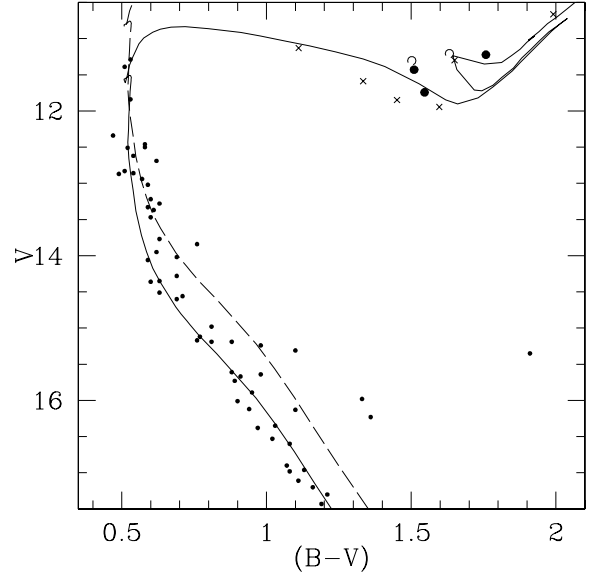
<sup>a</sup> Outside the range of Janes (1977) calibration.

but CORAVEL non-member), all the stars considered to be cluster members according to the radial velocities, also are red giant members according to the photometric criteria. Therefore, as shown in previous papers (see, e.g. Clariá et al. 2003), criteria A and B lead to reliable membership results for G and K giants provided their  $BV$  and  $DDO$  photometric data are of high quality. The discrepancy found for star 133 of NGC 6208 may be due to the reddening adopted for the main sequence stars, i.e.  $E(B - V)_{MS} = 0.21$  (Loktin et al. 2001). According to the individual  $E(B - V)_{GK}$  values obtained for the CORAVEL members of NGC 6208, the cluster reddening seems to be  $\sim 0.1$  mag larger than that obtained by Loktin et al. (2001).

The mean  $E(B - V)_{GK}$  values derived here for the confirmed red giants of NGC 6192, NGC 6208 and NGC 6268 are  $0.63 \pm 0.02$ ,  $0.31 \pm 0.02$  and  $0.43 \pm 0.02$ , respectively. The present reddening values for NGC 6192 and NGC 6268 are in good agreement with those adopted for their main sequence stars, i.e.  $E(B - V)_{MS} = 0.64$  and  $0.39$ , respectively. The present measurements specifically allow us to resolve the strong discrepancies existing in the literature regarding the reddening of NGC 6192. On the other hand, the reddening derived here for the red giants of NGC 6208 is clearly larger than that derived either by Lindoff (1972) or Loktin et al. (2001), namely  $0.18$  and  $0.21$ , respectively. As shown in Fig. 4, if instead of  $0.21$ , a colour excess  $E(B - V) = 0.32$  is adopted for NGC 6208, the ischrone of  $\log t = 9.10$  fits very well the position of the cluster giants.

### 3.2. Colour-magnitude diagrams

The selection of the red star candidates for cluster membership was based on their positions in the CMDs. Therefore, the non-member giants in NGC 6192 and NGC 6208 tend to be located in the same CMD region as the true members. This demonstrates



**Fig. 3.** The observed CMD for NGC 6192. The solar metallicity isochrone for  $\log t = 8.25$  from Girardi et al. (2000) has been adjusted to  $E(B - V) = 0.63$  and  $V - M_V = 13.00$  (Loktin et al. 2001). The dashed curve is the same isochrone shifted by  $0.75$  mag to reproduce the upper binary ridge. For the red giants, filled and open circles stand for single and binary members respectively, crosses, for non-members.

once again that radial velocity is a very strong membership criterion for red giants.

The fact that these red giants appear to be located at distances comparable to those of the clusters indicates that the clusters are embedded in a stellar field that has about the same age. This feature has been observed in other clusters, for example in Melotte 71 (Mermilliod et al. 1997) and in NGC 2324 and NGC 6259 (Mermilliod et al. 2001).

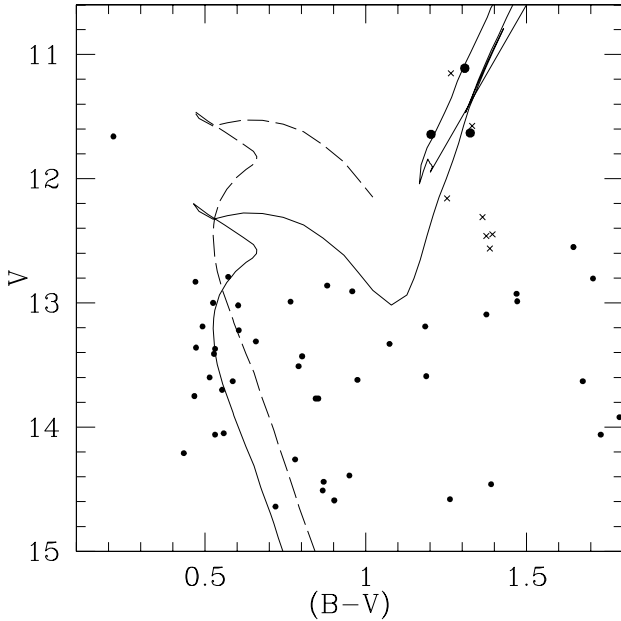
#### 3.2.1. NGC 6192

To plot the main sequence in the CMD of NGC 6192 (Fig. 3) we have chosen the UB $V$  CCD data of King (1987) after comparison of the various data sets. Given the value of  $E(B - V) = 0.63$ , the best fit is obtained with the isochrone for  $\log t = 8.25$ ,  $Z = 0.019$  of Girardi et al. (2000) and  $m - M = 13.00$ . The dashed curve is the upper binary limit, i.e. the isochrone shifted by  $0.75$  mag.

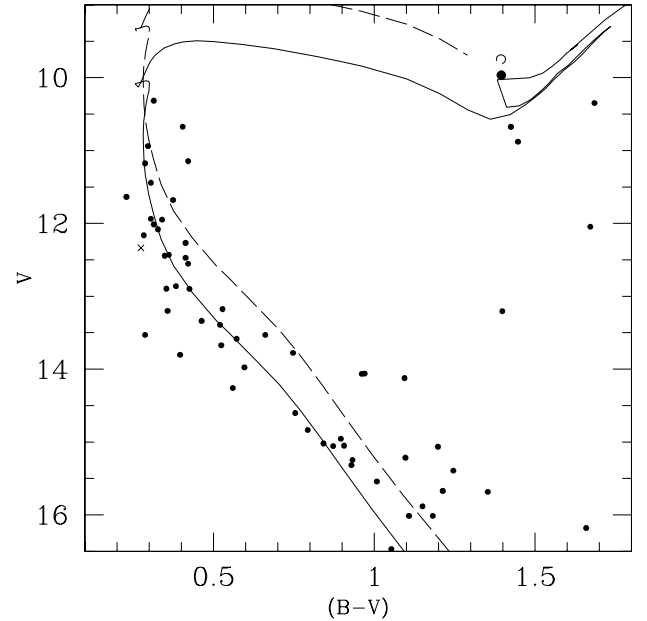
Fitting an isochrone of higher metallicity is not possible for this value of the reddening. With an isochrone for  $Z = 0.030$ ,  $E(B - V) = 0.63$ ,  $m - M = 13.25$  and  $\log t = 8.20$ , the red giant loop is much too red. The metallicity needed to reproduce the observed CM diagram in the red giant region should be intermediate between  $Z = 0.008$  and  $Z = 0.019$ .

#### 3.2.2. NGC 6208

Because there are no modern CCD data available for NGC 6208, we have computed  $(B - V)$  indices from the  $g_1 - y$  indices of Paunzen & Maitzen (2001) with the relation:  $(B - V) = 2.508 + 2.772 * (g_1 - y)$  (Paunzen 2006). The number of members appears to be small and the main sequence fit is not well constrained (Fig. 4). Given  $E(B - V) = 0.32$ , one solution results in  $m - M = 11.15$  and  $\log t = 9.10$ , with the isochrone of Girardi et al. (2000) for  $Z = 0.008$ . It would be very useful to observe



**Fig. 4.** The observed CMD for NGC 6208. The isochrone for  $\log t = 9.10$  and  $Z = 0.008$  from Girardi et al. (2000) has been adjusted to  $E(B - V) = 0.32$  and  $V - M_V = 11.15$ . The dashed curve is the same isochrone shifted by 0.75 mag to reproduce the upper binary ridge. Symbols are as in Fig. 3.



**Fig. 5.** The observed CMD for red evolved stars in NGC 6268. The solar metallicity isochrone for  $\log t = 8.35$  from Girardi et al. (2000) has been adjusted to  $E(B - V) = 0.38$  and  $V - M_V = 11.25$ . The dashed curve is the same isochrone shifted by 0.75 mag to reproduce the upper binary ridge. Filled and open circles have the same meaning as in Fig. 3.

the field of NGC 6208 to identify the members and improve the parameter determination.

### 3.2.3. NGC 6268

In a similar manner, we have computed  $(B - V)$  indices from the  $(g1 - y)$  with the relation:  $(B - V) = 0.40 + 4.25(g1 - y) - 3.55(g1 - y)^2$  (Paunzen 2006). The resulting main sequence is rather well defined (Fig. 5). With the value of the colour excess determined from the red giants,  $E(B - V) = 0.38$ , we obtained  $m - M = 11.25$  and  $\log t = 8.35$  for the isochrone of Girardi et al. (2000) for  $Z = 0.019$ . These parameters are in good agreement with those published by Loktin et al. (2001).

With an isochrone of higher metallicity ( $Z = 0.030$ ), it is not possible to fit simultaneously the main sequence and the red giants. The main sequence fit gives  $E(B - V) = 0.35$ ,  $m - M = 11.35$  and  $\log t = 8.40$ , but the red giant loop is too red and too faint.

Note that star #76 is a close visual binary formed by two red giants which have very similar radial-velocity values. This pair has not been numbered by Seggewiss (1967) and is located between stars #28 and 30 on the Seggewiss (1967) map (see the scanned version on WEBDA). This cluster too would be a fruitful candidate for a modern CCD study.

### 3.3. Metal content

We have used the dereddened *DDO* colour index  $C_0(41-42)$  as an abundance indicator since it measures the strength of the  $\lambda 4216$  cyanogen band, so that the larger the index, the greater the absorption by this band. Using this parameter, we have computed for each cluster giant the cyanogen anomaly,  $\Delta CN$ , defined by Piatti et al. (1993, hereafter PCM) as the difference between the dereddened  $C_0(41-42)$  index of the observed star and the standard value of this index, which corresponds to a star

with the same temperature and surface gravity, but not with the same  $C_0(42-45)$  and  $C_0(45-48)$  indices as the star in question. The successive columns of Table 6 show the star identification, the standard *DDO* colours defined and derived as described by PCM, the resulting  $\Delta CN$  values, the number of iterations performed until the  $[\text{Fe}/\text{H}]$  values converged within 0.01 dex and the membership status assigned to each star. No  $\Delta CN$  values could be determined for stars 96, 253 and 255 of NGC 6192 because they fall either outside the range of Janes (1977) Table 7 or outside the PCM calibration. The mean cyanogen anomalies for the confirmed cluster giants are:  $\langle \Delta CN \rangle = 0.120 \pm 0.016$  ( $\sigma_p$ ),  $0.030 \pm 0.015$  ( $\sigma_p$ ) and  $0.100 \pm 0.017$  ( $\sigma_p$ ), for NGC 6192, NGC 6208 and NGC 6268, respectively, where  $\sigma_p$  is the standard deviation of the mean. The cluster metallicities derived from the  $[\text{Fe}/\text{H}]$  versus  $\Delta CN$  relation given by PCM are:  $[\text{Fe}/\text{H}] = +0.29 \pm 0.06$ ,  $-0.05 \pm 0.05$  and  $+0.22 \pm 0.06$ , respectively. Therefore, NGC 6192 and NGC 6268 lie in the metal-rich side of the metallicity distribution of open clusters, while NGC 6208 is found to be of nearly solar metal content.

The metallicity determined for NGC 6192, i.e.,  $[\text{Fe}/\text{H}] = +0.29$ , does not agree with the value recently obtained by Paunzen et al. (2003), i.e.  $[\text{Fe}/\text{H}] = -0.10$ , based on uvby Strömgren's photometry. The latter, however, was determined without previously proving the membership status of the stars used to reach that conclusion. Thus, it is not possible to disregard the fact that such a result can have been influenced by the inclusion of non members of the cluster. As observable in Table 6, all CORAVEL non members of NGC 6192 have negative  $\Delta CN$  values, which in turn imply negative values for the iron-to-hydrogen ratios. The marked differences between the metallicities of the field stars and those of NGC 6192 make the present metallicity determination more reliable.

The metallicities resulting from the *DDO* analysis usually show a good agreement with spectroscopic determinations. However, for NGC 6192 and NGC 6268, the above solar values deduced from the photometric analysis does not permit us to

**Table 6.** Standard *DDO* colours and cyanogen anomalies.

Star	$C_s(45-48)$	$C_s(42-45)$	$C_s(41-43)$	$\Delta CN$	$I$	Mem
NGC 6192						
4	1.208	0.917	0.229	-0.014	2	NM
9	1.099	0.726	0.081	0.172	3	M
28	1.384	1.125	0.328	-0.062	2	NM
45	1.150	0.734	0.167	0.100	2	M
91	1.197	0.813	0.233	0.085	3	M
137	1.223	0.853	0.264	0.122	4	M
265	1.162	0.968	0.136	-0.018	4	NM
274	1.240	0.955	0.267	-0.037	2	NM
NGC 6208						
19	1.165	0.853	0.167	0.036	3	M
27	1.115	0.752	0.113	0.032	2	NM
31	1.151	0.791	0.162	-0.004	3	M
48	1.140	0.858	0.120	0.058	4	M
133	1.185	0.913	0.190	0.102	3	NM
NGC 6268						
13	1.080	0.746	0.055	0.148	4	NM
22	1.094	0.727	0.082	0.186	3	NM
44	1.162	0.788	0.182	0.124	3	M
48	1.241	0.913	0.276	-0.051	3	NM
73	1.180	0.822	0.203	0.120	2	NM
76	1.136	0.770	0.142	0.076	2	M

obtain satisfactory fits to the whole CMDs, especially in the red giant region. Isochrones with solar metallicity better reproduce the observations.

#### 4. Open clusters aligned along the line-of-sight of NGC 6192

The derived metallicities for the three inner disk open clusters studied here seem to be compatible with the widely recognized existence of a radial abundance gradient in the Galactic disk (see, e.g. Chen et al. 2003), the inner regions being metal richer than the outer ones.

To examine the properties of a sample of inner disk open clusters located nearly in the same direction as the three clusters studied, we first searched the WEBDA Open Cluster Database (Mermilliod & Paunzen 2003) for clusters with well determined  $E(B - V)$  colour excesses and distances from the Sun. We limited the search to objects located at  $(l, b)_{\text{NGC 6192}} \pm 10^\circ$ . When the  $E(B - V)$  colour excesses and distances from the Sun were not provided by WEBDA, we used either the recent catalogue of Kharchenko et al. (2005) or appealed to the recent literature available. The catalogue of Kharchenko et al. (2005) is a result of studies of wide neighbourhoods of 513 open clusters and of 7 compact associations registered in a high precision homogeneous all sky catalogue ASCC-2.5 (Kharchenko 2001). We found a sample of 42 open clusters within the desired  $(l, b)$  range that have well-determined fundamental parameters. In Table 7 we present the final cluster list (ranked according to increasing Galactic longitudes) with the values of the adopted parameters.

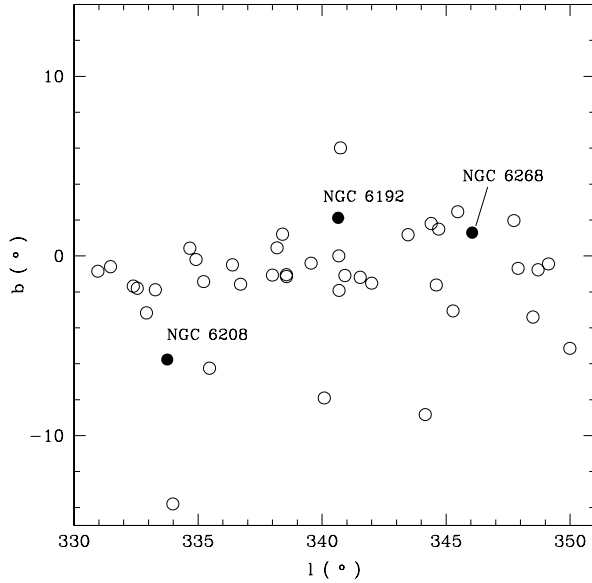
The distribution of the selected clusters in the  $(l, b)$  plane is shown in Fig. 6. Those clusters are represented by open circles, whereas NGC 6192, NGC 6208 and NGC 6268 are depicted with filled circles. Most of the clusters projected towards the considered direction lie close to the Galactic plane, within  $\pm 3^\circ$ . Their distribution in the Galactic  $(X, Y)$  plane is illustrated in Fig. 7. In addition, the Carina spiral arm and the line-of-sight from the Sun to NGC 6192 are represented by a solid line and by a straight line, respectively. Note that the distance between

**Table 7.** Fundamental parameters of selected open clusters.

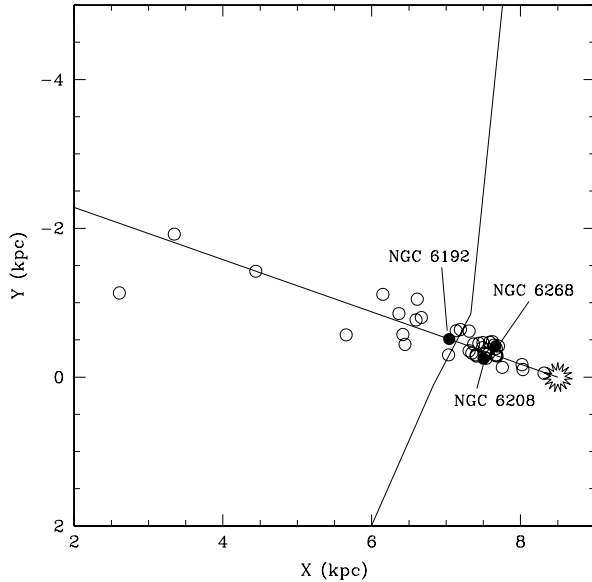
Cluster	$l$ ( $^\circ$ )	$b$ ( $^\circ$ )	$E(B - V)$ (mag)	$d$ (kpc)	Ref.
Ruprecht 115	330.96	-0.85	0.65	2.16	1
Pismis 22	331.47	-0.60	2.00	1.00	1
Ruprecht 116	332.39	-1.68	0.10	0.90	4
Ruprecht 118	332.55	-1.80	0.41	0.34	1
NGC 6152	332.92	-3.17	0.20	1.03	4
Ruprecht 119	333.28	-1.88	0.57	0.96	1
NGC 6208	333.78	-5.77	0.31	0.94	1, 6
ESO 139-13	333.98	-13.81	0.20	1.50	4
Pismis 23	334.67	0.43	2.00	2.60	1
NGC 6134	334.92	-0.20	0.40	0.91	1
NGC 6167	335.22	-1.43	0.78	1.11	1
NGC 6253	335.46	-6.25	0.20	1.51	1
Ruprecht 120	336.39	-0.49	0.70	2.00	1
NGC 6193	336.71	-1.57	0.48	1.16	1
NGC 6200	338.00	-1.07	0.58	2.05	1
Lynga 11	338.18	0.45	0.70	2.30	2
NGC 6178	338.41	1.21	0.22	1.01	1
NGC 6204	338.56	-1.04	0.43	1.09	1
Hogg 22	338.56	-1.14	0.65	1.22	1
Westerlund 1	339.56	-0.40	3.87	5.50	5
IC 4651	340.09	-7.91	0.12	0.89	1
NGC 6192	340.65	2.12	0.64	1.55	1
NGC 6216	340.67	0.01	0.45	4.30	1
NGC 6250	340.68	-1.92	0.35	0.87	1
NGC 6124	340.74	6.02	0.75	0.51	1
Lynga 14	340.92	-1.09	1.43	0.88	1
NGC 6249	341.54	-1.19	0.44	0.98	1
NGC 6259	342.00	-1.52	0.50	1.03	1
NGC 6231	343.46	1.18	0.44	1.24	1
Alessi 9	344.16	-8.83	0.07	0.20	1
ESO 332-08	344.40	1.81	0.20	1.20	4
BH 205	344.60	-1.62	0.30	2.16	4
Trumpler 24	344.70	1.50	0.42	1.14	1
NGC 6322	345.28	-3.06	0.59	1.00	1
NGC 6242	345.47	2.47	0.38	1.13	1
NGC 6268	346.05	1.30	0.39	1.03	1
NGC 6281	347.73	1.97	0.15	0.48	1
NGC 6318	347.90	-0.69	1.20	2.10	3
Ruprecht 125	348.50	-3.40	0.10	1.50	4
Havlen-Moffat 1	348.70	-0.77	1.85	2.90	1
BH 222	349.13	-0.44	1.85	6.00	1
Trumpler 29	349.99	-5.15	0.19	0.76	4

References: (1) WEBDA (Mermilliod 2005); (2) Piatti et al. (2006); (3) Piatti et al. (2005); (4) Kharchenko et al. (2005); (5) Clark et al. (2005); (6) this work.

the outermost and the innermost clusters is more than 5 kpc although their directions are close to that of the Galactic center. NGC 6192 is located behind the Carina spiral arm as seen from the Sun, while NGC 6208 and NGC 6268 are placed in front of this feature. Figure 8 was built taking advantage of this relatively long baseline in distance along this line of view, to examine the behaviour of the interstellar extinction along the direction considered. This figure shows the relationship between the visual interstellar absorption  $A_V (=3.0E(B - V))$  and the distance  $d$  from the Sun. For comparison, we represented with a solid line the relationship for the Baade's window  $[(l, b) = (1^\circ, -3.9^\circ)]$  obtained by Ng et al. (1996). A close look at this figure revealed the following features: (1) BH 222 and Westerlund 1 are the farthest open clusters of the selected sample. They are located at  $\sim 6$  kpc (Piatti & Clariá 2002) and  $\sim 5.5$  kpc (Clark et al. 2005) from the Sun and at  $\sim 2.8$  kpc and  $\sim 3.2$  kpc from the Galactic center, respectively. (2) At the distance of these two clusters from the

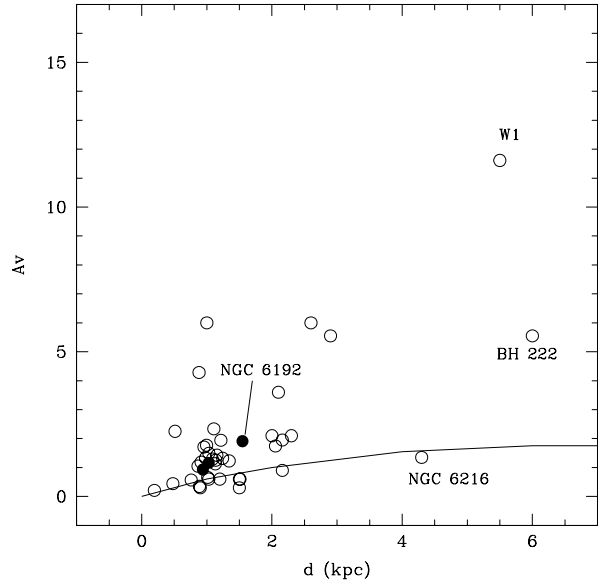


**Fig. 6.** Galactic coordinates ( $l$ ,  $b$ ) of inner disk open clusters located in the direction of NGC 6192 is.



**Fig. 7.** The Galactic plane with the ( $X$ ,  $Y$ ) positions of the open clusters located in the direction of NGC 6192. The Carina spiral arm (solid line), the line-of-sight from the Sun to NGC 6192 (straight line) and the position of the Sun are indicated.

Sun, the visual interstellar absorption towards the Baade's window – not far from the direction of NGC 6192 – is between 4 and 9 mag smaller. It is surprising that, in spite of being located at approximately the same distance, these two clusters appear to be affected by such different visual absorptions. Although significant differential reddening across the field of Westerlund 1 has been recently confirmed by Clark et al. (2005) and according to the same authors its distance of 5.5 kpc represents only an upper limit, the difference of  $\sim 5$  mag in their visual absorptions still appears to be too high. The reddening of Westerlund 1 – the most massive compact young cluster identified in the Local Group up to now (Clark et al. 2005) – is produced in front of the Carina spiral arm, probably caused by a single small dark cloud (Piatti et al. 1998). (3) NGC 6216, located farther than 4 kpc from the Sun, is reddened as expected if it were situated exactly in the



**Fig. 8.** Visual interstellar absorption  $A_V$  vs. distance  $d$  from the Sun. The relationship corresponding to Baade's window is indicated.

Baade's window direction. (4) Although most of the clusters located closer than 2 kpc from the Sun are usually more reddened than what would correspond to the Baade's window absorption law, they are close to it.

## 5. Summary and conclusions

New  $UBV$  and  $DDO$  photometry and CORAVEL radial-velocity data of a sample of red giant candidates in the fields of the inner disk open clusters NGC 6192, NGC 6208 and NGC 6268 have allowed us to determine the membership of red giants in these three clusters. Three new spectroscopic binaries have been discovered among the red giants of NGC 6192 and NGC 6208. Mean radial velocities and  $E(B - V)$  colour excesses of  $(-7.72 \pm 0.38)$  km s $^{-1}$ ,  $(-32.21 \pm 0.28)$  km s $^{-1}$  and  $(-15.11 \pm 0.08)$  km s $^{-1}$  and  $0.63 \pm 0.03$ ,  $0.31 \pm 0.02$  and  $0.44 \pm 0.03$  mag were derived for NGC 6192, NGC 6208 and NGC 6268, respectively.

NGC 6192 is a good example of how different estimates of the interstellar reddening in the field of an open cluster influence the derived cluster parameters. Previous estimates of the cluster  $E(B - V)$  colour excess vary between 0.26 and 0.68 mag, which imply very discrepant distances and ages. The reddening here derived for NGC 6192, i.e.,  $E(B - V) = 0.63$ , supports the cluster parameters derived by KF91. On the other hand, NGC 6208 is found to be  $\sim 0.1$  mag more reddened than was previously believed, while the reddening derived here for NGC 6268 shows good agreement with the one quoted in the literature.

$DDO$  abundance indices yield mean cluster metallicities of  $[Fe/H] = +0.29 \pm 0.06$ ,  $-0.05 \pm 0.05$  and  $+0.22 \pm 0.06$  for NGC 6192, NGC 6208 and NGC 6268, respectively, which appear to be compatible with the existence of a radial abundance gradient in the Galactic disk. An inspection of the properties of 42 known open clusters nearly aligned along the line-of-sight of NGC 6192 as seen from the Sun shows that BH 222 and Westerlund 1 are the farthest ones, their absorptions being between 4 and 9 mag larger than the values that would correspond if these clusters were located exactly in the direction of Baade's window. Evidence is presented that most of the clusters located closer than 2 kpc from the Sun are slightly more



reddened than the absorption resulting from the Baade's window absorption law.

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