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Star clusters in the Carina complex: $UBVRI$ photometry of NGC 3114, Collinder 228 and vdB-Hagen 99*

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Abstract. In this paper we present and analyze CCD $UBVRI$ photometry in the region of the three young open clusters NGC 3114, Collinder 228, and vdB-Hagen 99, located in the Carina spiral feature. NGC 3114 lies in the outskirts of the Carina nebula. We found 7 star members in a severely contaminated field, and obtain a distance of 950 pc and an age less than 3×10^8 yrs. Collinder 228 is a younger cluster ($8{\times}10^6$ yrs), located in front of the Carina nebula complex, for which we identify 11 new members and suggest that 30% of the stars are probably binaries. As for vdB-Hagen 99, we add 4 new members, confirming that it is a nearby cluster located at 500 pc from the Sun and projected toward the direction of the Carina spiral arm.

Key words. stars: evolution – stars: general – stars: Hertzsprung-Russel (HR) and C-M diagrams – open clusters and associations: NGC 3114: individual – open clusters and associations: Collinder 228: individual – open clusters and associations: vdB-Hagen 99: individual

1. Introduction

This paper continues a series dedicated to presenting CCD $UBVRI$ photometry for all the known and/or suspected open clusters in the Carina complex (Janes et al. 1988). According to Feinstein (1995) the region around η Carinae contains 14 open clusters, some of which still remain very poorly studied. For most of them no CCD photometry was available when we started our survey.

In Carraro et al. (2001) we discussed NGC 3324 and Loden 165, concluding that the latter has probably no relation with the Carina Complex, being much older and closer to the Sun than the bulk of the other clusters.

In Patat & Carraro (2001) we studied Bochum 9, 10 and 11, suggesting that Bochum 9 is a doubtful object, while Bochum 10 and 11 are two young and poorly populated open clusters.

In this work we present results for NGC 3114, Collinder 228 and vdB-Hagen 99, for which to our knowledge no multicolor CCD photometry is available.

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* Based on observations taken at ESO La Silla. Data are available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/379/136

Table 1. Basic parameters of the observed objects. Coordinates are for J2000.0 equinox.

Name	α	δ	l	b
	hh:mm:ss	°:′:″	°	°
NGC 3114	10:02:42.7	−60:06:32.1	283.34	−3.83
Collinder 228	10:43:01.3	−60:00:44.8	287.52	−1.04
vdB-Hagen 99	10:37:54.2	−59:11:37.1	286.56	−0.63

The aim is to provide accurate photometry for all these clusters, in order to derive precise age estimates. This is important to infer global properties and to study the clusters formation history in the very interesting Carina region.

The layout of the paper is as follows: Sect. 2 presents very briefly the data acquisition and reduction. In Sect. 3 we discuss the open cluster NGC 3114. Section 4 is dedicated to Collinder 228, whereas Sect. 5 deals with vdB-Hagen 99. Our conclusions are summarized in Sect. 6.

2. Observations and data reduction

Observations were conducted at La Silla on April 13–16, 1996, with the 0.92 m ESO–Dutch telescope. The observations strategy, the data reduction, the error analysis and a

Table 2. Journal of observations of NGC 3114 (April 13, 1996), Collinder 228 (April 14, 1996), and vdB-Hagen 99 (April 15, 1996).

NGC 3114				Collinder 228				vdB-Hagen 99							
Field	Filter	Exp. Time (s)	Seeing ('')	Field	Filter	Exp. Time (s)	seeing ('')	Field	Filter	Exp. Time (s)	seeing ('')	Field	Filter	Exp. Time (s)	seeing ('')
#1	*U*	1200	2.0	#1				#1				#3			
	U	120	1.8		*U*	60	2.0		*U*	180	2.3		*U*	300	1.7
	B	10	1.7		*B*	10	2.0						*B*	30	1.6
	B	900	1.7		*B*	300	1.6		*B*	30	2.1		*B*	300	1.5
	V	20	1.5		*V*	3	1.7						*V*	20	1.6
	V	300	1.6		*V*	120	1.8		*V*	15	2.0		*V*	120	1.6
	R	10	1.5		*R*	3	1.7						*R*	5	1.6
	R	180	1.4		*R*	60	1.8		*R*	10	1.9		*R*	120	1.6
	I	5	1.3		*I*	5	1.8						*I*	5	1.5
	I	300	1.3		*I*	120	1.6		*I*	20	1.7		*I*	120	1.6
#2	*U*	60	1.5	#2				#2	*U*	300	2.4				
	U	1200	1.6		*U*	60	1.6		*U*	60	2.0				
	B	10	1.4		*B*	10	1.6		*B*	300	2.3				
	B	900	1.4		*B*	300	1.8		*B*	30	2.3				
	V	10	1.4		*V*	3	2.0		*V*	120	2.1				
	V	300	1.5		*V*	120	2.0		*V*	10	2.0				
	R	5	1.4		*R*	3	1.8		*R*	5	1.8				
	R	180	1.2		*R*	60	1.9		*R*	120	1.8				
	I	10	1.2		*I*	5	1.9		*I*	120	1.8				
	I	300	1.3		*I*	120	2.0		*I*	5	1.8				

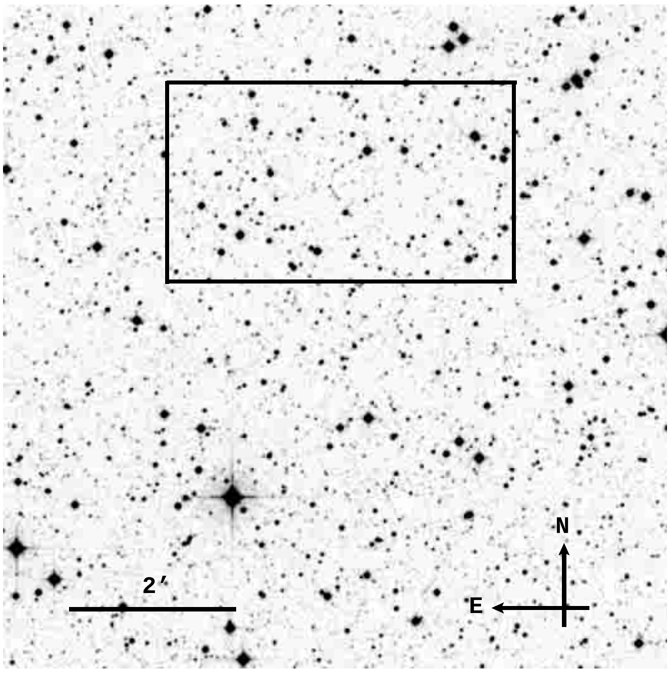

Fig. 1. DSS map of a region around NGC 3114. The box confines the field covered by our photometry.

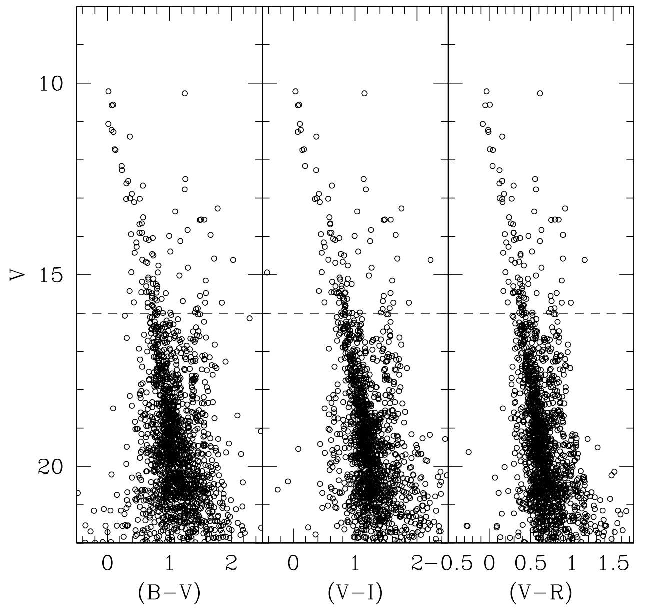

Fig. 2. CMDs for all stars in the region of NGC 3114. The dashed line indicates the limiting magnitude reached by Sagar & Sharpless (1991).

comparison between CCD and photoelectric photometry have been presented in Patat & Carraro (2001), which the reader is referred to for any detail. Finally, all the data are available upon request to the authors.

3. The open cluster NGC 3114

NGC 3114 is a sparse open cluster projected onto the outskirts of the Carina complex, in a fairly rich Milky Way field. Its membership to the Carina complex is actually not clear. It is a difficult object to study, due to the heavy contamination of Galactic disk field stars which does not

Table 3. Photometry of the stars in the field of the open cluster NGC 3114 in common with Jankowitz & McCosh (1963). The suffix CP refers to the present study, whereas JM indicates Jankowitz & McCosh (1963) photographic photometry.

ID	JM	$V_{\rm CP}$	$(B-V)_{\rm CP}$	$V_{\rm JM}$	$(B-V)_{\rm JM}$
3	105	10.580	0.069	10.59	−0.08
4	122	10.562	0.092	10.57	−0.03
5	137	11.274	0.097	11.27	0.10
6	73	11.065	0.014	11.12	0.00
7	130	11.393	0.364	11.38	0.22
9	83	11.222	0.068	11.24	0.11
10	76	11.726	0.118	11.78	0.02
11	96	10.268	1.250	10.22	1.12
13	109	12.272	0.235	12.12	0.36
18	128	13.004	0.302	12.90	0.36

allow one to unambiguously separate possible members and define the cluster size.

3.1. Previous results

NGC 3114 was studied several times in the past. The first investigation was performed by Jankowitz & McCosh (1963), who obtained photographic UBV photometry for 171 stars and photoelectric UBV photometry of 52 stars down to $V = 13$ mag. They estimated that the cluster is 910 pc distant from the Sun, has a mean visual extinction $E(B-V) = 0.27$, and an age between 6×10^7 and 2×10^8 yrs.

Afterward Schneider & Weiss (1988) got Strömgrem photometry of 122 stars down to $V = 12$ mag. This study strongly revises the cluster reddening, which the authors suggested to be $E(B-V) = 0.03$.

More recently, Sagar & Sharpless (1991) enlarged the sample of the measured stars, obtaining BV CCD photometry of about 350 stars up to $V = 16$ in seven $3\farcm6 \times 5\farcm4$ regions located quite far from the cluster center, where the contamination is expected to be more important. By assuming the reddening estimate suggested by Schneider & Weiss (1988), they found a cluster distance of 940 ± 60 pc, in agreement with Jankowitz & McCosh (1963), and an age of $1-2 \times 10^8$ yrs.

Finally, Clarià et al. (1989) estimated the cluster mean chemical abundance from UBV, DDO and Washington photometry of an handful of giant stars, finding that NGC 3114 is basically as metal rich as the Sun ([Fe/H] = -0.04 ± 0.04).

3.2. The present study

We provide $UBVRI$ photometry for 2060 stars in a $3\farcm3 \times 6\farcm5$ region centered in NGC 3114, up to about $V = 22$. The region we sampled is shown in Fig. 1, where a DSS[1] map is presented.

[1] Digital Sky Survey `http://archive.eso.org/dss/dss`

According to Jankowitz & McCosh (1963) the cluster should have a diameter of 32′, although this estimate is rather uncertain, due to the difficulty to isolate the cluster from the field. Anyhow, the cluster seems to be rather extended, and our photometry covers only the central region, with no overlap with Sagar & Sharpless (1991) photometry.

The CMDs for all the measured stars in the planes $V-(B-V)$, $V-(V-I)$ and $V-(V-R)$ are shown in Fig. 2. In the cluster center there are no stars brighter than $V = 10.0$. Therefore, with respect to Sagar & Sharpless (1991), who provided the deepest photometry before our study, we do not find any indication of a Red Giant (RG) clump (see Fig. 9a in Sagar & Sharpless 1991).

The Main Sequence (MS) extends from $V = 10$ up to $V = 22$, and gets wider at increasing magnitudes. Several causes concur to broaden the MS: the presence of unresolved binary stars, the photometric errors and the contamination of fore-ground and back-ground stars.

A probe of the heavy contamination is the Galactic disk RG branch population, readily recognizable in the almost parallel sequence which departs from the MS at $V \approx 20$. This is a common feature in the CMDs of stellar fields in the direction of the Carina spiral arm (see Vallenari et al. 2000).

We have 10 stars in common with Jankowitz & McCosh (1963), which are listed in Table 3. The mean differences turn out to be:

$$V_{\rm CP} - V_{\rm JM} = 0.020 \pm 0.062$$

$$(B-V)_{\rm CP} - (B-V)_{\rm JM} = 0.068 \pm 0.077$$

where CP indicates our photometry, and JM stands for Jankowitz & McCosh (1963). Taking into account the different techniques used in extracting the photometry, the agreement is good for both magnitude and colors.

We do not report the difference between the $(U-B)$ colors, since Jankowitz & McCosh (1963) measured the color $(U_{\rm c} - B)$, with the filter U defined in the Cousin system. This is quite different from the standard Johnson $(U-B)$, and the authors do not provide the Johnson color for the stars listed in Table 3.

3.3. Reddening

In order to obtain an estimate of the cluster mean reddening, we analyse the distribution of the stars in the $(B-I)-(B-V)$ plane, which is shown in Fig. 3.

The linear fit to the main sequence in the $(B-I)-(B-V)$ plane,

$$(B-I) = Q + 2.25 \times (B-V) \quad (1)$$

can be expressed in terms of $E(B-V)$ for the $R_V = 3.1$ extinction law as

$$E(B-V) = \frac{Q - 0.014}{0.159}, \quad (2)$$

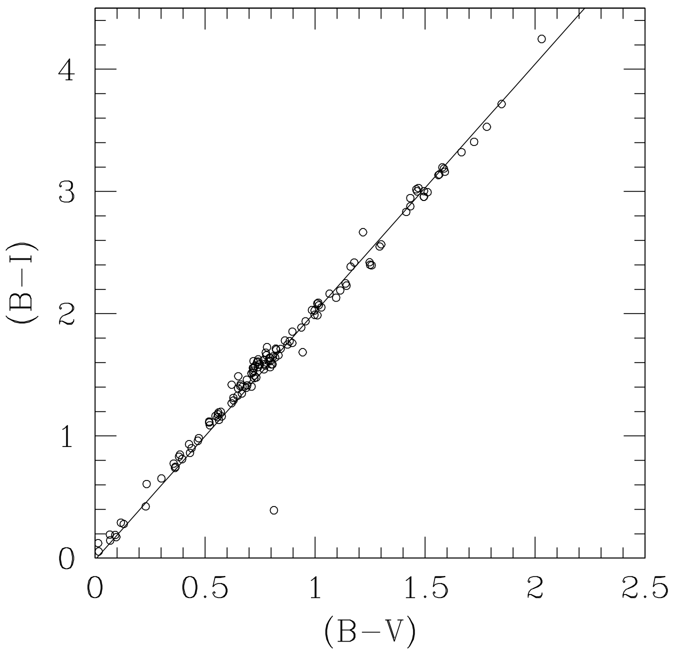

Fig. 3. NGC 3114 stars brighter than $V = 17.0$ in the $(B - I) - (B - V)$ plane.

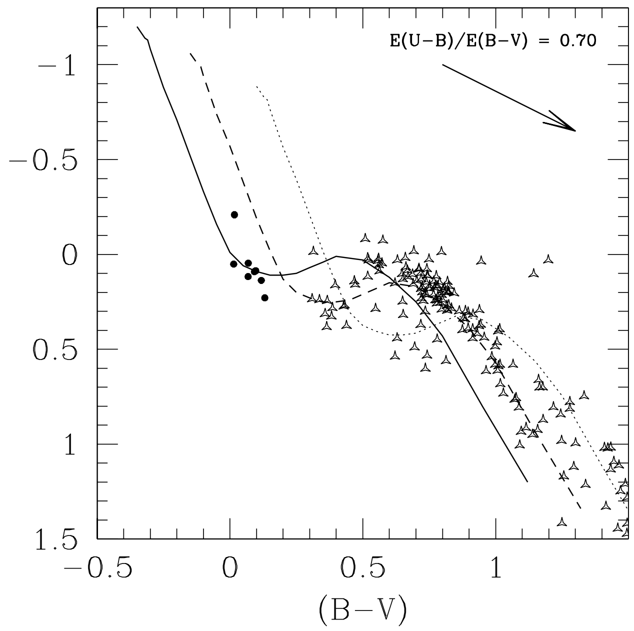

Fig. 4. Two color diagram for the stars in the field of NGC 3114 with $V \leq 17.0$. The arrow indicates the reddening vector. The solid line is the empirical un-reddened ZAMS from Schmidt-Kaler (1982), whereas the dashed and dotted lines are the same ZAMS, but shifted by $E(B-V) = 0.20$ and $E(B-V) = 0.60$, respectively.

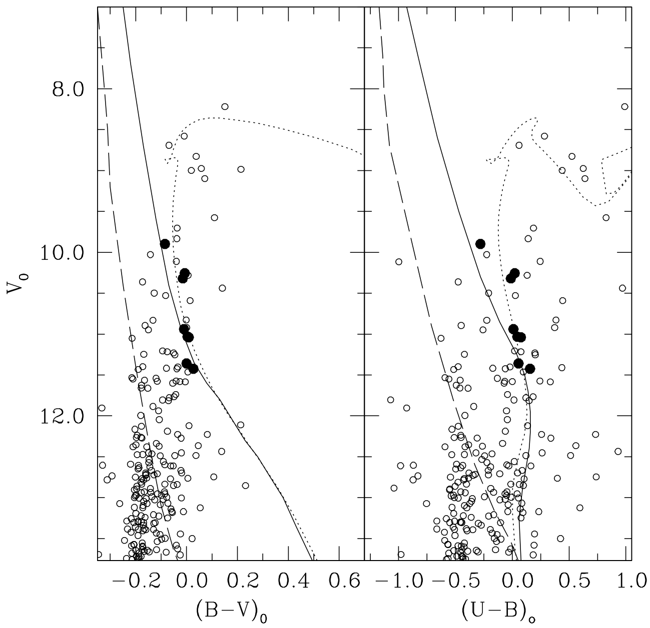

Fig. 5. Reddening corrected CMDs for the stars in the field of NGC 3114 with $V \leq 17.0$ The dashed line is a ZAMS shifted by $(m - M) = 12.50$, whereas the solid one is the same ZAMS, but shifted by $(m - M) = 9.80$. Filled circles indicate cluster candidate members, while empty circles indicated field stars. Finally, the dotted line is an isochrone for the age of 300 Myr.

following the method proposed by Munari & Carraro (1996a,b).

This method provides a rough estimate of the mean reddening and, as amply discussed in Munari & Carraro (1996a), can be used only for certain color ranges. In particular Eq. (2) holds over the range $-0.23 \leq (B - V)_0 \leq +1.30$. A least squares fit through the stars brighter than $V = 17$ gives Q = 0.041, which, inserted in Eq. (2), provides $E(B - V) = 0.17 \pm 0.12$.

The uncertainty is rather large, and is due to the scatter of the stars in this plane, which indicates the presence of stars with different reddening, presumably a mixture of stars belonging to the cluster and to the field.

To better derive the reddening distribution and identify cluster members, we plotted all the stars brighter than $V = 17$ in the two color diagram of Fig. 4. With filled circles we indicated stars having a common low reddening $E(B - V) = 0.07 \pm 0.03$. They lie very close to the unreddened empirical ZAMS (solid line) taken from Schmidt-Kaler (1982).

Open triangles represent all the other stars, which exhibit a much larger reddening. These stars do not suffer from the same amount of reddening. To have an idea of the reddening of the field stars we have overimposed the same ZAMS, but shifted by $E(B - V) = 0.20$ (dashed line), and by $E(B - V) = 0.60$ (dotted line), respectively.

In conclusion, two populations seem to exist: seven stars sharing a common low reddening, which are presumably cluster members, and all the other stars having larger reddening, which are field stars.

3.4. Age and distance

We estimate the age of NGC 3114 by studying the reddening corrected CMDs (see Fig. 5). In this plot filled circles are our candidate members, whereas empty circle are field stars. The bulk of this latter is fitted by a ZAMS shifted

Table 4. List of the candidate members of NGC 3114 obtained in the present study. Two of them (#3 and #8) are newly discovered members.

ID	X	Y	V	$(B-V)$	$(U-B)$	$(V-R)$	$(R-I)$
2	289.93	159.96	10.216	0.017	−0.209	−0.142	0.070
3	60.20	129.03	10.580	0.069	0.046	−0.047	0.124
4	271.54	495.20	10.562	0.092	0.091	0.012	0.090
5	408.86	238.26	11.274	0.097	0.086	−0.011	0.087
6	−384.24	137.45	11.065	0.014	0.051	−0.077	0.196
8	213.23	346.53	11.746	0.131	0.229	0.045	0.013
9	−173.94	442.02	11.222	0.068	0.117	−0.014	0.118

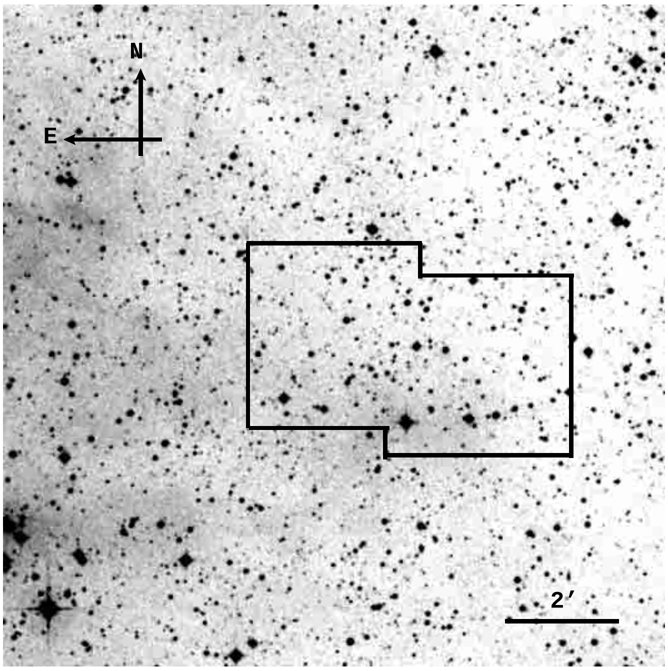

Fig. 6. DSS map of a region around Collinder 228. The box confines the field covered by our photometry.

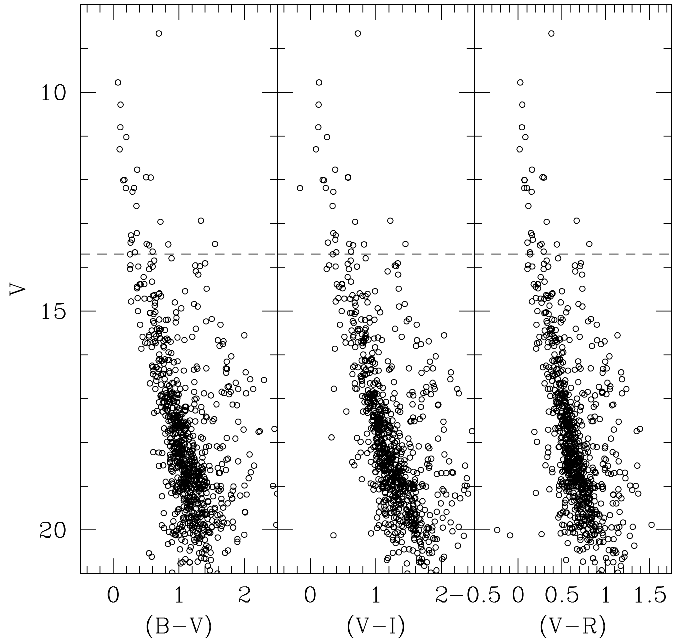

Fig. 7. CMDs for all stars in the region of Collinder 228. The dashed line indicates the limiting magnitude reached by Feinstein et al. (1976).

by $(m-M) = 12.50$ (dashed line), basically at the distance of the Carina spiral arm. Nevertheless, there seem to be stars located basically at any distance between us and the Carina spiral arm, confirming previous indications that the cluster is heavily contaminated by stars from the Galactic disk field.

The candidate members form a tight sequence, close to a ZAMS shifted by $(m-M) = 9.80$ (solid line).

In order to estimate the cluster age, we over-imposed a solar metallicity isochrone (dotted line) from Girardi et al. (2000), for the age of 3×10^8 yrs. In fact, the brightest members lie off the ZAMS, and are clearly leaving the MS.

In conclusion, NGC 3114 is a rather poorly populated star cluster, heavily contaminated by field stars. From the study of the cluster candidate members (see Table 4), in our field we derive a reddening $E(B-V) = 0.07 \pm 0.03$ and a distance of 920 ± 50 pc from the Sun, in fair agreement with previous investigations.

4. The open cluster Collinder 228

Collinder 228 was discovered by Collinder (1931) during a systematic search of open clusters in the Milky Way, and lies between us and the group formed by Trumpler 14, Trumpler 16 and η Carinae (Smith et al. 2000). Therefore we expect the cluster to be dominated by back and foreground stars contamination. Differential reddening is also expected, since the cluster is surrounded by a large nebula (see Fig. 6).

4.1. Previous results

Feinstein et al. (1976) reported on UBV photoelectric photometry of 99 stars in the region of Collinder 228. They found that the bulk of the cluster is located in front of the complex of Trumpler 14 and 16, at about 2.5 kpc from the Sun. They also pointed out that some stars in the field of Collinder 228 might be members of that complex and hence more distant than the cluster. They assign to Collinder 228 an age of 5×10^6 yrs. While the bulk of the

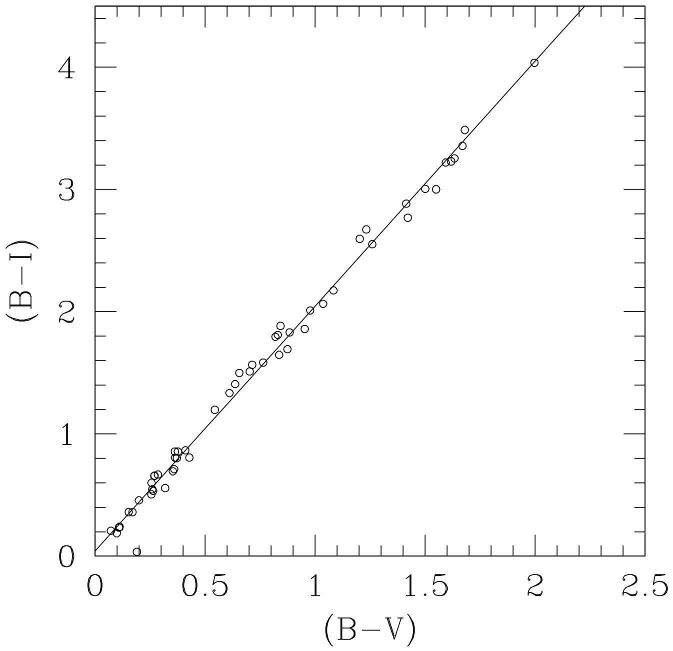

Fig. 8. Collinder 228 stars brighter than $V = 17$ in the $(B - I) - (B - V)$ plane.

stars is closer and has a mean reddening $E(B-V) = 0.30$, the stars lying beyond the cluster have a larger reddening $E(B - V) \approx 0.50$.

Tapia et al. (1988) obtained $JHKL$ near-infrared photometry of 200 stars in the η Carinae region, which comprises Trumpler 14, 15, 16 and Collinder 228 and 232. Out of these, 45 are in the field of Collinder 228. By analyzing the two color diagrams, the authors concluded that this cluster is 2.09 ± 0.38 kpc far from the Sun, and hence closer to us than the bulk of η Carinae region population. Moreover they found that the mean reddening is $E(B - V) = 0.64 \pm 0.26$, much larger than the value previously reported by Feinstein et al. (1976).

Finally, a radial velocity survey has been conducted by Levato et al. (1990), who suggested that 30% of the cluster stars are binaries.

4.2. The present study

We provide $UBVRI$ photometry for about 1100 stars in a $3'.3 \times 6'.5$ region centered in Collinder 228, up to about $V = 21$. The covered region is shown in Fig. 6.

The CMDs for all the measured stars are shown in Fig. 7 in the planes $V-(B-V)$, $V-(V-I)$ and $V-(V-R)$. The MS extends from $V = 10$ down to $V = 21$. As for NGC 3114, the MS gets wider at increasing magnitude, and there is evidence of a secondary sequence on the red side of the MS, generated by the RG stars in the field.

We have 5 stars in common with Feinstein et al. (1976), which are listed in Table 5. The mean differences turn out to be:

$$V_{\rm CP} - V_{\rm FMF} = 0.021 \pm 0.054$$

$$(B - V)_{\rm CP} - (B - V)_{\rm FMF} = 0.019 \pm 0.041$$

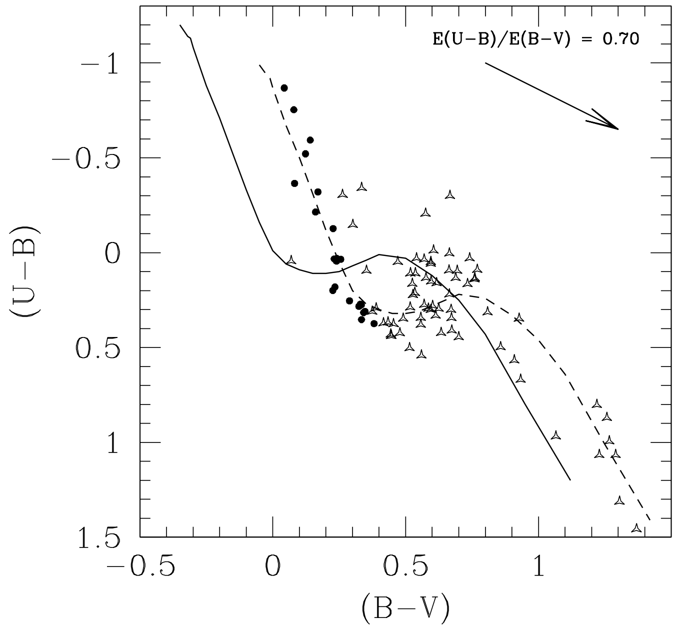

Fig. 9. Two color diagram for the stars in the field of Collinder 228 brighter than $V = 17$. The arrow indicates the reddening vector. The solid line is the empirical un-reddened ZAMS from Schmidt-Kaler (1982), whereas the dashed line is the same ZAMS, but shifted by $E(B - V) = 0.30$. See text for details.

$$(U - B)_{\rm CP} - (U - B)_{\rm FMF} = 0.073 \pm 0.046,$$

where CP indicates our photometry, and FMF stands for Feinstein et al. (1976). Taking into account the different techniques used in extracting the photometry, the agreement is very good both for magnitude and colors.

4.3. Reddening

In order to obtain a rough estimate of the cluster mean reddening we consider the distribution of the stars brighter than $V = 17$ in the $(B - I)$ vs. $(B - V)$ plane (see Fig. 8). The selection in magnitude is done to limit the field stars contamination. By applying the same technique described in Sect. 3.3, we find that the bulk of stars have $E(B - V) = 0.40 \pm 0.20$. The uncertainty is due to the scatter of the stars in this plane, and indicates the presence of stars with different reddening, in agreement with Feinstein et al. (1976) findings.

We use the $(U - B) - (B - V)$ diagram for all the stars brighter than $V = 17$ to separate cluster candidate members (see Fig. 9). The solid line in this plot represents the empirical un-reddened ZAMS from Schmidt-Kaler (1982), whereas the dashed line is same ZAMS, but shifted by $E(B - V) = 0.30$.

Two distinct populations seem to exist. With filled circles we plotted all the stars having $E(B-V) = 0.30 \pm 0.05$, and we shall refer to them as to cluster candidate members. A second population is defined by stars having larger reddening and is plotted with open triangles. All these stars are probably just field stars.

These findings confirm Feinstein et al. (1976) results.

Table 5. Photometry of the stars in the field of the open cluster Collinder 228 in common with Feinstein et al. (1976). The suffix CP refers to the present study, whereas FMF indicates Feinstein et al. (1976) photometry.

ID	FMF	Name	$V_{\rm CP}$	$(B-V)_{\rm CP}$	$(U-B)_{\rm CP}$	$V_{\rm FMF}$	$(B-V)_{\rm FMF}$	$(U-B)_{\rm FMF}$
1	15	HD 305544	8.656	0.694	0.192	8.59	0.66	0.08
2	28	HD 305543	9.778	0.073	−0.768	9.74	0.05	−0.77
3	29	HD 305451	10.284	0.112	−0.265	10.21	0.07	−0.36
4	30		10.801	0.109	−0.653	10.80	0.05	−0.69
5	49		11.125	0.200	−0.220	11.20	0.26	−0.34

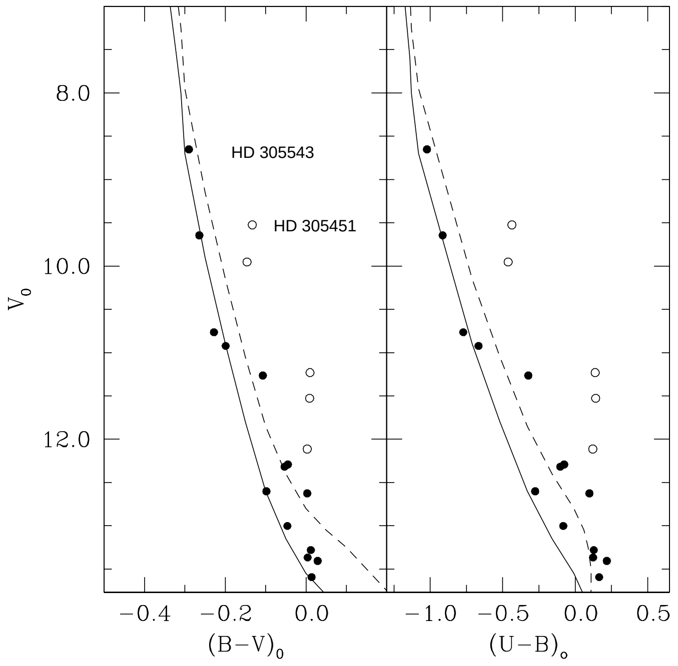

Fig. 10. Reddening corrected CMDs for the candidate member stars in the field of Collinder 228. Over-imposed are solar abundance isochrones for an age of 8×10^6 yrs. See text for details.

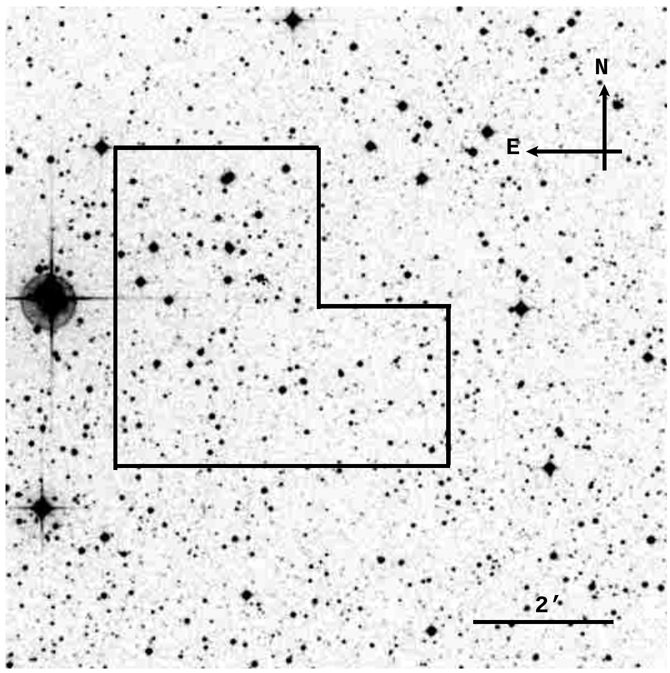

Fig. 11. DSS map of a region around vdB-Hagen 99. The box confines the field covered by our photometry.

4.4. Age and distance

In Fig. 10 we plot the reddening corrected CMDs for the stars of Collinder 228 having $E(B-V) = 0.30 \pm 0.05$ (i.e. the candidate members). They actually seem to form a tight sequence, confirming our suggestion that they are good candidate members. Over-imposed is a theoretical solar metallicity isochrone (solid line) from Girardi et al. (2000) for an age of 8×10^6 yrs. The same isochrone has been shifted by 0.75 mag (dashed line) to have an idea of the MS broadening due to unresolved binaries. It is well known, in fact, that binary stars define a sequence 0.75 mag brighter than the single stars MS. This permits us to suggest that five stars (indicated by open circles) are probably non members, and that the four stars which lie close to the binary sequence are probably unresolved binaries.

All the stars fainter than $V = 10.5$ in these plots have not been measured by Feinstein et al. (1976), and hence we provide 11 new candidate members. As a by-product, we infer an apparent distance modulus $(m-M) = 12.55 \pm 0.25$, which, once corrected for extinction, provides a distance of 1.9 ± 0.2 kpc, in agreement both with Feinstein et al. (1976) and with Tapia et al. (1988).

This corroborates the conclusion that Collinder 228 is closer to us than the Carina nebula complex.

In conclusion, in the observed region we identified 14 members, 3 in common with Feinstein et al. (1976) and 11 new, whose properties are summarized in Table 6. Out of these, 4 are probably binaries. Unfortunately, there is no overlap between our suggested binaries and the study of Levato et al. (1990). Only two stars are in common: HD 305543, which is a member and HD 305451, which probably is a field star. Nevertheless our result, which comes from photometry, although based on a small sample confirms their spectroscopic investigation that about 30% of the member stars are probably unresolved binaries.

5. The open cluster vdB-Hagen 99

During a blue-red photographic survey of the southern Milky Way van den Bergh & Hagen (1975) provided a

Table 6. List of the new candidate members of Collinder 228 obtained in the present study.

ID	X	Y	V	$(B-V)$	$(U-B)$	$(V-R)$	$(R-I)$
4	−80.27	410.73	10.801	0.109	−0.653	0.043	0.081
5	73.19	205.14	11.025	0.200	−0.220	0.084	0.174
8	283.84	268.06	12.012	0.153	−0.421	0.072	0.140
9	−228.80	332.70	12.002	0.171	−0.493	0.071	0.118
12	−249.81	193.19	12.275	0.293	−0.206	0.154	0.198
13	109.62	331.36	12.190	0.191	−0.114	0.070	−0.226
14	−386.07	261.02	12.187	0.319	0.354	0.100	0.138
15	−227.63	41.27	12.599	0.354	0.383	0.118	0.223
18	268.82	85.25	13.269	0.270	0.145	0.160	0.227
19	−277.53	447.27	13.218	0.360	0.371	0.147	0.206
20	484.68	411.66	13.369	0.286	0.135	0.168	0.214

list of 262 known or suspected open clusters. Among them, 64 groups were newly recognized. One of this is the scarcely populated and loose open cluster vdB-Hagen 99, which lies in the outskirts of the Carina complex.

5.1. Previous investigation

vdB-Hagen 99 was studied by Landolt et al. (1990), who emphasize the importance of this cluster due to the probable membership of four known or suspected variables. They obtained multicolor broad-band $UBVRI$ photoelectric photometry for 48 stars, and intermediate- and narrow-band photometry for 56 stars up to $V = 12$. Moreover they obtained spectra for 21 stars in the region of the cluster and additional photometry for 11 fainter stars, with $13 \leq V \leq 16$. The main results of their investigation are that vdB-Hagen 99 is a sparse open cluster with at least 24 candidate members. The real existence of the cluster is argued on the basis of the narrow sequences the bright stars form in different color-color diagrams. Although dominated by variable extinction, vdB-Hagen 99 has a low mean reddening $E(B-V) = 0.05$. Moreover it is 10^8 yrs old and at a distance of about half a kpc. Finally it contains 8 photometric variables.

5.2. The present work

We obtained CCD $UBVRI$ photometry for 900 stars in the region shown in Fig. 11, up to $V = 20$. Our survey supersedes the previous one, whose limiting magnitude was about $V = 12$.

The measured stars are shown in Fig. 12, in the planes $V-(B-V)$, $V-(V-I)$ and $V-(V-R)$. These CMDs resemble those of NGC 3114 (see Fig. 2) and Collinder 228 (see Fig. 7), with a MS extending from $V = 10$ up to $V = 20$ and with some evidence of the RG branch of the field stars population. The similarity is not surprising, since all the clusters are projected toward the Carina spiral arm.

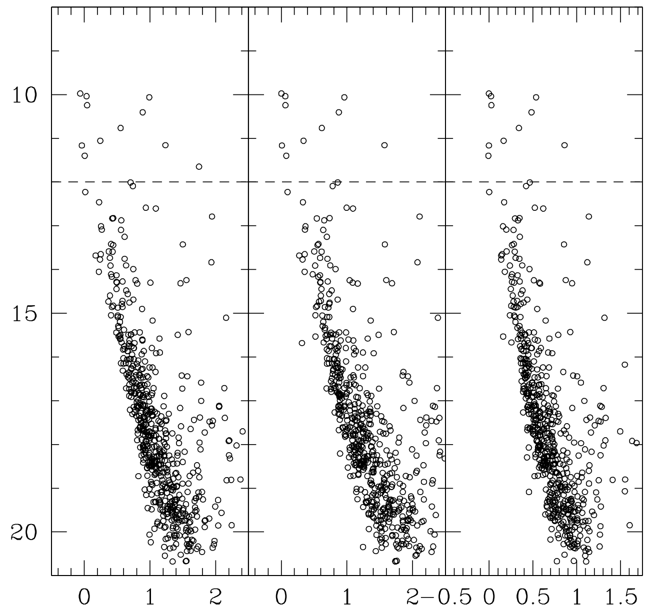

Fig. 12. CMDs for all stars in the region of vdB-Hagen 99. The dashed line indicates the limiting magnitude reached by Landolt et al. (1990).

We have 6 stars in common with Landolt et al. (1990), which are listed in Table 7. The mean differences turn out to be:

$$V_{\rm CP} - V_{\rm LPLM} = -0.023 \pm 0.016$$

$$(B-V)_{\rm CP} - (B-V)_{\rm LPLM} = -0.053 \pm 0.025$$

$$(U-B)_{\rm CP} - (U-B)_{\rm LPLM} = -0.044 \pm 0.017,$$

where CP indicates our photometry, whereas LPLM stands for Landolt et al. (1990). Taking into account the different techniques used in extracting the photometry, the agreement is very good both for magnitude and colors.

Table 7. Photometry of the stars in the field of the open cluster vdB-Hagen 99 in common with Landolt et al. (1990). The name of the stars follow Landolt et al. (1990). The suffix CP refers to the present study, whereas LPLM indicates Landolt et al. (1990) photometry.

ID	Name	$V_{\rm CP}$	$(B-V)_{\rm CP}$	$(U-B)_{\rm CP}$	$V_{\rm LPLM}$	$(B-V)_{\rm LPLM}$	$(U-B)_{\rm LPLM}$
2	CPD −58 2451	10.037	0.086	0.047	10.078	0.114	0.093
4	CPD −58 2452	10.062	0.990	0.788	10.101	1.068	0.803
6	CPD −58 2447	10.765	0.553	0.127	10.782	0.648	0.175
7	CPD −58 2442	11.056	0.283	0.024	11.077	0.333	0.071
8	CPD −58 2440	10.244	0.094	0.012	10.236	0.127	0.085
11	VV Car	11.748	1.747	1.319	11.775	1.784	1.356

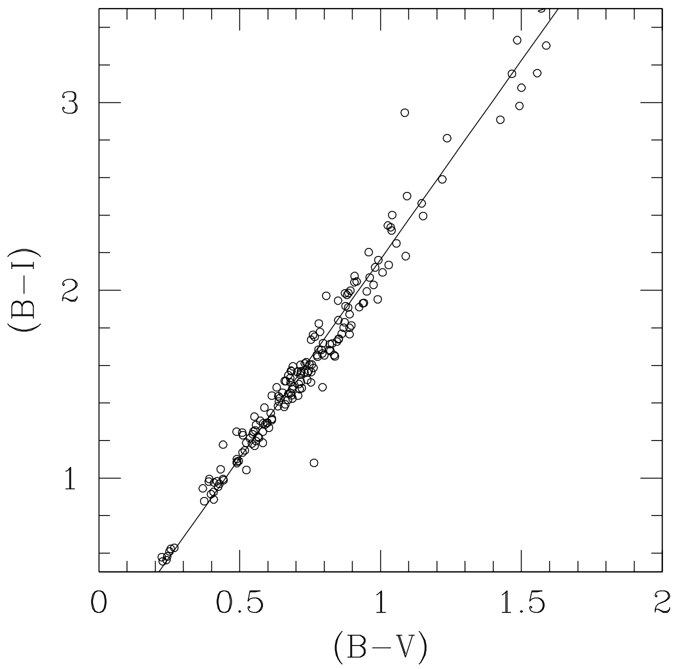

Fig. 13. vdB-Hagen 99 stars brighter than $V = 17$ in the $(B-I)-(B-V)$ plane.

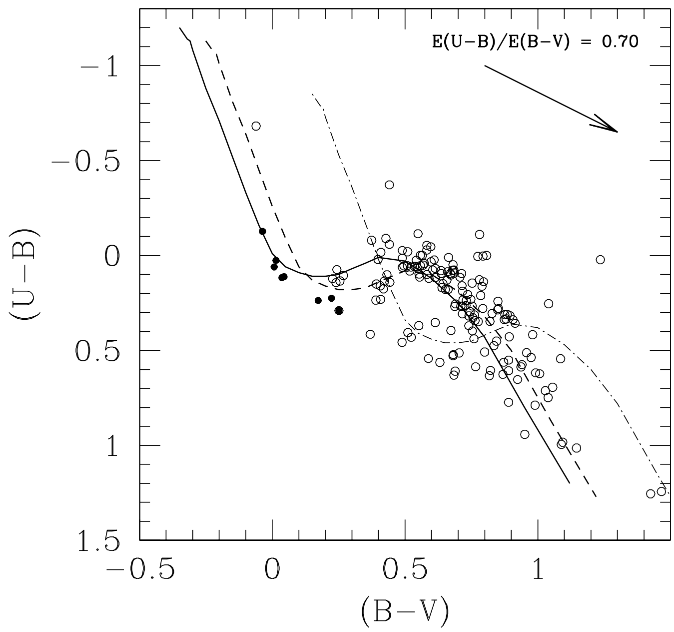

Fig. 14. Two color diagram for the stars in the field of vdB-Hagen 99 brighter than $V = 17$. The arrow indicates the reddening vector. The solid line is the empirical un-reddened ZAMS from Schmidt-Kaler (1982), while the dashed and dashed-dotted lines are the same ZAMS, but shifted by $E(B-V) = 0.10$ and $E(B-V) = 0.50$, respectively.

5.3. Reddening

To have an idea of the cluster mean reddening we selected all the stars brighter than $V = 17$, and use their position in $(B-I)-(B-V)$ plane, following the method described in Sect. 3.3. The least squares fit yields $E(B-V) = 0.10 \pm 0.08$. Again, the large uncertainty is due to the scatter of the stars in this plane, and indicates the presence of stars with different reddening, as already argued by Landolt et al. (1990).

Candidate members can be searched for by considering the color color diagram in Fig. 14, where filled circles represent stars having $E(B-V) = 0.04 \pm 0.03$, whereas open circles indicate stars having larger reddening. Tentatively, we suggest the possibility that two distinct populations are actually present: a group of eight bright stars which have the same low reddening (filled circles), and all the other stars which have a larger reddening with a significant scatter.

We argue that the brighter stars are candidate members of vdB-Hagen 99, whereas all the other stars having larger value of $E(B-V)$ (see Fig. 14) are probably field stars.

5.4. Distance and age

In order to test this hypothesis, we construct the reddening corrected CMDs in the $V_0-(B-V)_0$ and $V_0-(U-B)_0$ planes for all the stars for which we could obtain a reddening estimate (see Fig. 15). Filled symbols indicate cluster candidate members, whereas open symbols indicated background stars.

As suggested above, two distinct populations are readily visible.

Most of the stars we measured are located beyond vdB-Hagen 99, at the distance of the Carina spiral arm (2.5–3.0 kpc). They are indicated with open symbols, and fitted with an empirical ZAMS shifted by $(m-M)_0 = 12.20$.

Table 8. List of the new candidate members of vdB-Hagen 99 obtained in the present study.

ID	X	Y	V	$(B-V)$	$(U-B)$	$(V-R)$	$(R-I)$
3	182.75	235.10	10.244	0.044	0.212	0.026	0.027
8	106.44	341.37	11.165	−0.037	−0.027	−0.005	0.005
10	−7.76	−166.28	11.399	0.007	0.160	0.008	0.080
13	242.58	−76.50	12.229	0.014	0.126	0.000	0.081

With filled triangles we indicate Landolt et al. (1990) candidate members, 20 stars in total. They define a tight sequence along the empirical ZAMS (solid line) shifted by $(m-M)_0 = 8.30$. Noticeably, all the empty triangles, which identify stars that have been suggested by Landolt et al. (1990) not be cluster members, actually lie close to the field stars sequence.

The stars indicated with filled circles are probable cluster members observed by us. Four of them – namely CPD −58 2451, CPD −58 2440, CPD −58 2442 and CPD −58 2447 – are in common with Landolt et al. (1990). The other 4 are probable new candidate members, and their properties are summarized in Table 8. The remaining two common stars (CPD −58 2452 and VV Car) are red stars of GK spectral type belonging to the field.

This way we increased the number of cluster members, suggesting that they are at least 28. Finally, the stars redder than vdB-Hagen 99 members are probably interlopers stars, located between us and the cluster.

As for the age, most of the stars lie close to the ZAMS, with the exception of the brightest ones. This is an indication that the cluster is young, as already claimed by Landolt et al. (1990). To have an idea of the cluster age, we over-imposed in Fig. 15 a solar metallicity isochrone (dotted line) from Girardi et al. (2000) for the age of 1.25×10^8 yrs, which nicely fits the evolved stars.

In conclusion, these results confirm that vdB-Hagen 99 is a young cluster projected toward the Carina spiral arm, at a distance of about 500 pc from the Sun. The mean reddening of cluster members turns out to be $E(B-V) = 0.04 \pm 0.03$, in agreement with the findings of Landolt et al. (1990).

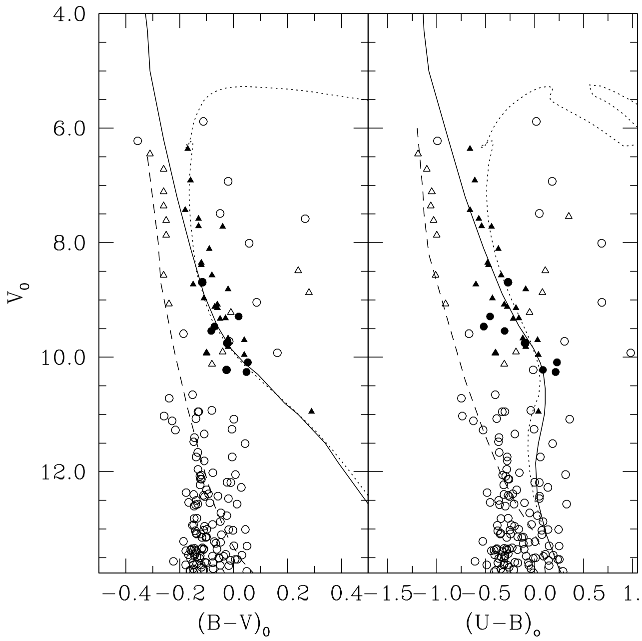

Fig. 15. Reddening corrected CMD for the stars in the field of vdB-Hagen 99. Filled symbols indicate cluster members, whereas open circles are field stars. Triangles refer to Landolt et al. (1990) photometry, whilst circles indicate stars whose photometry has been presented in this study. Finally, the dotted line is an isochrone for the age of 1.25×10^8 yrs, whereas the other two lines are the same empirical ZAMS, shifted by $(m-M) = 12.20$ (dashed line) and $(m-M) = 8.30$ (solid line). See text for additional details.

6. Conclusions

In this paper we presented $UBVRI$ CCD photometry for three young clusters in the direction of the Carina spiral feature: NGC 3114, Collinder 228 and vdB-Hagen 99. Our results can be summarized as follows:

- NGC 3114 lies in the outskirts of the Carina nebula, at a distance of 920 pc from the Sun. In the field we studied, we isolate 7 cluster members, which has a low reddening ($E(B-V) = 0.07 \pm 0.03$) and a maximum age of 3×10^8 yrs.
- Collinder 228 is a younger (8×10^6) yrs cluster located in front of the Carina nebula complex. We identify 11 new candidate members and confirm that 30% of the cluster members are probably unresolved binaries.
- Finally, vdB-Hagen 99 is a loose open cluster about 10^8 yrs old, and with a fairly low mean reddening. We confirm previous results, and add 4 new members.

Putting together the results of this paper and those of previous works (Patat & Carraro 2001; Carraro et al. 2001), the Carina complex turns out to be populated by very young clusters (like Collinder 228, NGC 3324 and Bochum 11) in its inner region, and by young or intermediate age objects (like NGC 3114, vdB-Hagen 99 and Loden 165) in its outskirts.

This confirms previous suggestions by Feinstein (1995) about the existence of an age gradient in the Carina complex. We shall discuss this issue in more details in forthcoming papers, when all the clusters observed in our survey will be analysed.

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