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Star clusterings in the Carina complex: *UBVRI* photometry of Bochum 9, 10 and 11

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ABSTRACT

We report on the first *UBVRI* CCD photometry of three poorly known star clusterings in the region of η Carinae: Bochum 9, 10 and 11. We find that they are young, rather poor, loose open clusters.

We argue that Bochum 9 is probably a small and loose open cluster with about 30 probable members having $E(B-V) = 0.63 \pm 0.08$, located 4.6 kpc far from the Sun, beyond the Carina spiral arm.

Similarly, Bochum 10 is a sparse aggregate with 14 probable members having $E(B-V) = 0.47 \pm 0.05$ and at a distance of 2.7 kpc from the Sun.

Finally, Bochum 11 is a less than 4×10^6 yr old cluster for which we identify 24 members. It has a reddening $E(B-V) = 0.58 \pm 0.05$, and lies between Bochum 10 and 9, at 3.5 kpc from the Sun. We propose that in the field of the cluster some stars might be pre-main-sequence candidates.

Key words: open clusters and associations: individual: Bochum 9 – open clusters and associations: individual: Bochum 10 – open clusters and associations: individual: Bochum 11.

1 INTRODUCTION

Feinstein (1995) suggests that there are 14 known or suspected open star clusters probably related to the Carina spiral feature. Most of them are actually very well known.

Nonetheless, some remain very poorly studied, and our knowledge often does not extend beyond simple identification. As a consequence, the real nature of some of these star clusterings and their association with the Carinae complex are not well established.

The region of η Carinae, on the other hand, has long been recognized as an ideal laboratory for studying the formation of star clusters by obtaining precise photometry and age estimates (Massey & Johnson 1993).

Having this in mind, we have undertaken a photometric survey aimed at obtaining homogeneous high quality CCD data for all the known star clusterings in this region.

We have already reported on NGC 3324 and Loden 165 (Carraro, Patat & Baumgardt 2001), showing that Loden 165 probably does not belong to the Carina complex.

Here we report on three poorly studied objects: Bochum 9, Bochum 10 and Bochum 11, identified in the 1970s by Moffat & Vogt (1975). Only photoelectric photometry is available for these objects; in particular Bochum 9 deserves special attention since it is not clear whether it is a cluster or not. The other two clusters are young objects, with some evidence of a pre-main-sequence population (Fitzgerald & Mehta 1987). The basic parameters of all three objects are given in Table 1.

The plan of the paper is as follows. In Section 2 we describe the data acquisition and reduction, while Sections 3 to 5 are dedicated to Bochum 9, Bochum 10 and Bochum 11, respectively. In Section 6 we summarize our results, and in the Appendix we provide some additional details on the data reduction and photometric errors.

2 DATA ACQUISITION AND REDUCTION

Observations were conducted at La Silla on 1996 April 13–16, using the imaging Camera (equipped with a TK-coated 512×512 pixel CCD #33) mounted at the Cassegrain focus of the 0.92-m European Southern Observatory (ESO) Dutch telescope. All nights were photometric with a seeing ranging from 1 to 2 arcsec. The scale on the chip is 0.44 arcsec, and the array covers about 3.3×3.3 arcmin^2 on the sky. As a result of the projected diameter of the objects and the relatively small field of view, it was necessary to observe four fields for the same object. To allow for a proper photometric calibration and to asses the night quality, the standard fields RU149, PG1323, PG1657, SA 109 and SA 110 (Landolt 1992) were monitored each night. Finally, a series of flat-field frames on the twilight sky were taken. The scientific exposures

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have been flat-field and bias corrected by means of standard routines within IRAF. Further reductions were performed using the DAOPHOT package (Stetson 1987) in the IRAF environment.

The instrumental magnitudes have been transformed into standard Bessel *UBVRI* magnitudes using fitting coefficients derived from observations of the standard field stars from Landolt (1992), after including exposure-time normalization and airmass correction. Aperture corrections have also been applied. The observations log-book for the three clusters is presented in Table 2, whereas additional details of the photometric reduction and error analysis are provided in the Appendix.

3 BOCHUM 9

Bochum 9 appears as a sparse group of seven blue luminous stars westwards of η Carinae. This star clustering (Fig. 1) was identified and studied by Moffat & Vogt (1975) who provided photo-electric photometry for 22 stars. They concluded that 12 of them are O- and B-type stars, but the sample seems not to show any sequence, and this raises some doubts about the actual nature of this group. To our knowledge no other studies have been carried out so far.

We obtained *UBVRI* CCD photometry for about 4000 stars in the region of Bochum 9 down to $V = 22$. We have nine stars in common with Moffat & Vogt (1975), which are listed in Table 3.

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

Name	α hh:mm:ss	δ °:′:″	l °	b °
Bochum 9	10:35:45.7	−60:07:33.8	286.80	−1.58
Bochum 10	10:42:14.2	−59:08:43.7	287.02	−0.33
Bochum 11	10:47:15.2	−60:05:50.8	288.04	−0.87

The mean difference turns out to be

$$V_{\rm PC} - V_{\rm MV} = 0.006 \pm 0.018,$$

$$(B-V)_{\rm PC} - (B-V)_{\rm MV} = 0.024 \pm 0.015,$$

$$(U-B)_{\rm PC} - (U-B)_{\rm MV} = 0.030 \pm 0.025,$$

where PC refers to the present study and MV to Moffat & Vogt (1975). The agreement is very good both for magnitude and for colours.

The colour–magnitude diagrams (CMDs) for all stars detected in the region of Bochum 9 are shown in Fig. 2. The most prominent feature is a well-defined main sequence (MS) from $V = 10$ up to $V = 22$. The stars on the red side of the MS appear to form a sequence parallel to the MS, that can be ascribed to the He-burning evolved stars [red giant branch (RGB) stars] projected on to the line of sight with increasing reddening (see the F3 field CMD in Vallenari, Bertelli & Schmidtobreick 2000, which lies very close to Bochum 9 and has a fairly similar appearance). Moffat & Vogt (1975), from their small sample, suggested that probably we are considering stars located at different distances in the direction of Carina spiral arm, in a region of small reddening.

3.1 Colour–colour and colour–magnitude diagrams

The position of all the stars brighter than $V = 16.5$ in the colour–colour diagram is shown in Fig. 3. The solid line is the un-reddened Schmidt-Kaler (1982) sequence. There seem to be two distinct populations. The bulk of the stars are indicated by filled squares, and are fitted by an empirical zero-age main sequence (ZAMS) (long dashed line) shifted by $E(B-V) = 0.18$. This sequence is probably a result of stars in the Galactic disc located between us and the Carina spiral arm.

There is, however, another group of stars, plotted with open squares, sharing a common reddening $E(B-V) = 0.63 \pm 0.08$. There are 48 of these stars. The sequence (dashed line) crossing these stars is the same empirical ZAMS as above, but shifted by $E(B-V) = 0.63$.

Table 2. Journal of observations of Bochum 9 (1996 April 13), Bochum 10 (1996 April 14), and Bochum 11 (1996 April 15).

Bochum 9								Bochum 10				Bochum 11			
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	30	1.7	#3	U	30	1.9	#1				#1			
	U	600	1.7		U	600	1.9		U	60	2.1		U	30	1.8
	B	10	1.7		B	10	1.8		B	10	2.0		B	5	1.8
	B	600	1.3		B	600	1.9		B	300	1.9		B	300	1.7
	V	5	1.3		V	5	1.7		V	3	1.6		V	3	1.6
	V	300	1.4		V	300	1.7		V	120	1.6		V	120	1.7
	R	8	1.6		R	5	1.7		R	3	1.7		R	3	1.7
	R	180	1.6		R	180	1.7		R	60	1.5		R	60	1.6
	I	10	1.4		I	5	1.6		I	5	1.5		I	3	1.5
	I	300	1.5		I	300	1.7		I	120	1.5		I	120	1.5
#2	U	30	1.7	#4	U	30	2.0	#2				#2			
	U	600	1.7		U	600	1.7		U	60	1.5		U	30	2.0
	B	10	1.8		B	10	1.5		B	10	1.5		B	300	2.0
	B	600	2.1		B	600	1.6		B	300	1.9		B	5	1.9
	V	5	1.8		V	5	1.8		V	3	1.6		V	120	1.9
	V	600	1.7		V	300	1.7		V	120	2.3		V	3	1.8
	R	8	1.7		R	5	1.7		R	3	2.0		R	60	1.6
	R	180	1.7		R	180	1.8		R	60	1.9		R	3	1.6
	I	10	1.7		I	5	1.9		I	5	1.9		I	120	1.6
	I	300	1.7		I	300	1.9		I	120	1.7		I	3	1.6

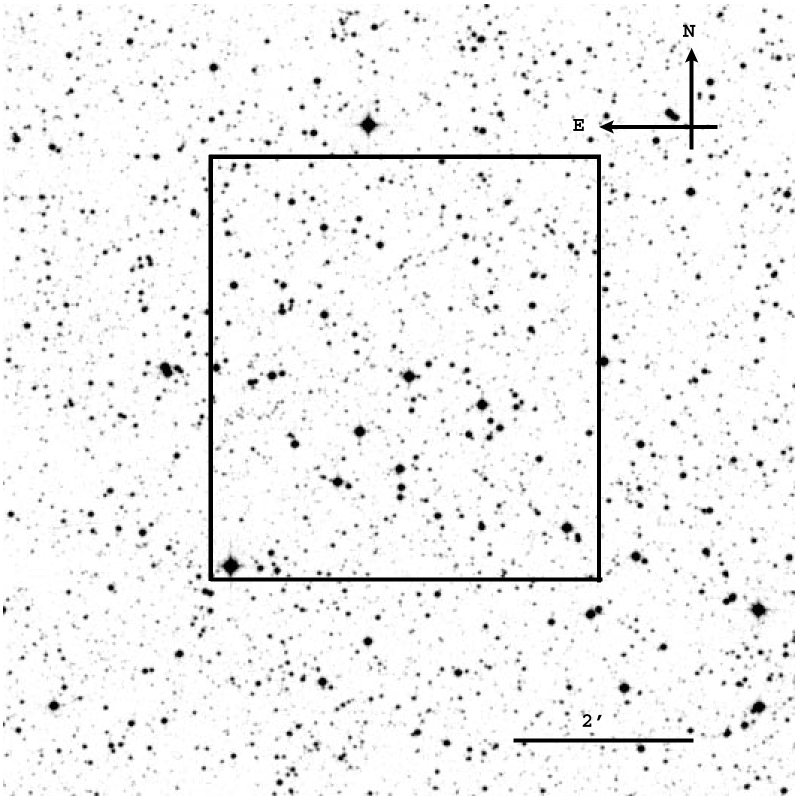

Figure 1. Digital Sky Survey (DSS) map of a region around Bochum 9. The box confines the field covered by our photometry.

Table 3. Photometry and astrometry of the brightest stars in the field of Bochum 9. Absolute proper motions are taken from Tycho 2, and are expressed in mas yr^{-1}.

ID	Star	V	$(B-V)$	$(U-B)$	$\mu_{\alpha*}$	σ_μ	μ_δ	σ_μ	Sp.Type
1		9.381	−0.003	−0.441					
2	HD 305364	9.767	0.025	−0.028	−12.90	5.30	1.10	1.90	B8
3	HD 305368	10.188	0.332	−0.645	−24.00		1.00		A0
4	HD 305366	10.828	0.017	−0.132	−16.00		0.00		G8
5	GSC08957-02702	11.071	0.123	0.205	−14.30	5.30	6.50	2.40	
6		11.388	0.339	−0.577					
7	HD 305383	11.394	0.367	−0.633	−12.50	7.50	2.50	1.80	A
8		11.531	0.316	0.326					
10	HD 305370	11.971	0.227	0.310	−25.00		0.00		B9
	HD 91025				−8.10	5.30	3.20	3.60	B1

We shall refer to the more reddened sequence as Bochum 9 candidate members. In order to better understand the nature of Bochum 9, we plotted the cluster candidate members in the colour–magnitude diagrams shown in Fig. 4. The selected stars define a tight sequence in the V versus $(B-V)$ plane (Fig. 4, left panel), where we superimposed an empirical ZAMS shifted by $E(B-V)=0.63$ and by the apparent distance modulus $(m-M)=15.3$. In the right panel we present the V versus (U_B) CMD for the same group of stars. It seems that they still follow a sequence, although somewhat scattered below $V=15.3$. In this panel the ZAMS has been shifted by $E(U-B)=0.44$ and by the apparent distance modulus $(m-M)=15.3$. The appearance of these CMDs suggests that Bochum 9 is probably a very young, loose, open cluster located about 4.6 kpc far from the Sun, beyond the Carina spiral arm. To better identify cluster members, we assumed that some of the stars in Fig. 4 might be binaries. Unresolved binaries populate a sequence 0.75 mag brighter than the single stars ZAMS, offering us the possibility of defining the width of the MS. The binaries sequence has been drawn in Fig. 4 as a dashed line. As a consequence, if we consider as non-members all the stars lying outside of the region defined by the two ZAMS, the number of candidate members turns out to be 29.

The projected spatial distribution of the candidate members in shown in Fig. 5. The stars do not show any cluster-like distribution, raising some doubts as to the cluster nature of Bochum 9.

3.2 Astrometric data

For seven of the most luminous stars (see Fig. 6), we have at our disposal the absolute proper motions provided by Tycho 2 (Høg et al. 2000), and they are listed in Table 3. First, we want to stress that the uncertainties in the measurements (arising from the fairly large distance) mean that these data are of limited use in drawing any firm conclusions. In any case, while the proper motions appear

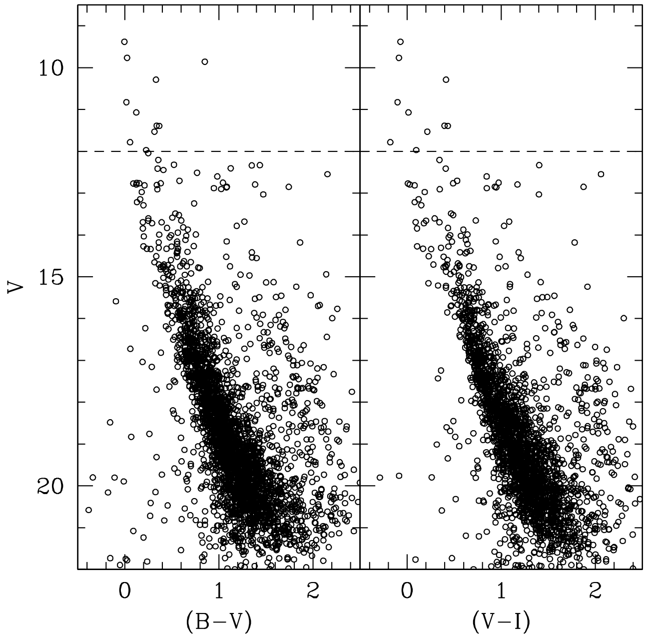

Figure 2. CMDs for all stars in the region of Bochum 9. The dashed line indicates the limiting magnitude reached by previous investigations.

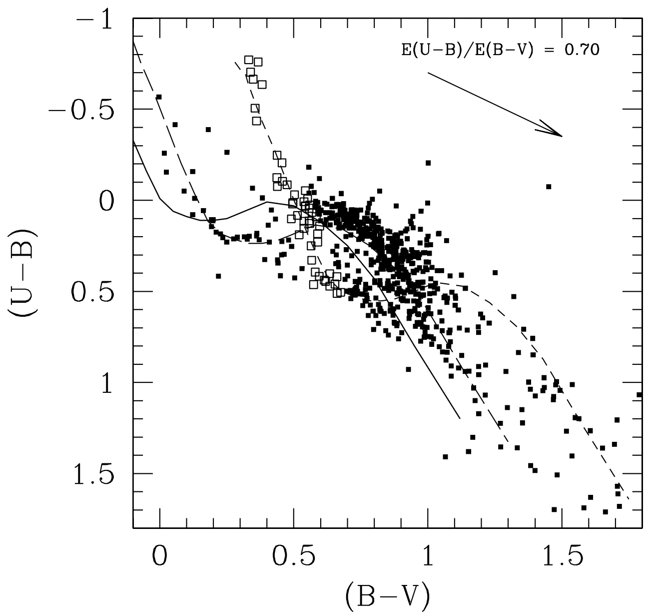

Figure 3. Two-colour diagram for all stars in the region of Bochum 9 having $V \leq 16.5$. The arrow indicates the reddening vector. The solid line is the empirical Schmidt-Kaler (1982) ZAMS. Open squares indicate stars having $E(B-V) = 0.63 \pm 0.08$, and the dashed line crossing these stars is an empirical ZAMS shifted by $E(B-V) = 0.63$. Most of the other stars lie along an empirical ZAMS (long dashed line) shifted by $E(B-V) = 0.18$. See text for additional details.

broadly consistent in μ_δ (except for GSC08957-0270), they seem to form two sub-groups in $\mu_{\alpha*}$. HD 305364 shares the same $\mu_{\alpha*}$ as HD 305383, HD 92025 and maybe HD 305366, while HD 305368 has basically the same $\mu_{\alpha*}$ as HD 305770. The star GSC08957-02702 is probably an isolated case.

The available data do not allow us to decide unambiguously about the nature of Bochum 9. It is clear that the Galactic disc

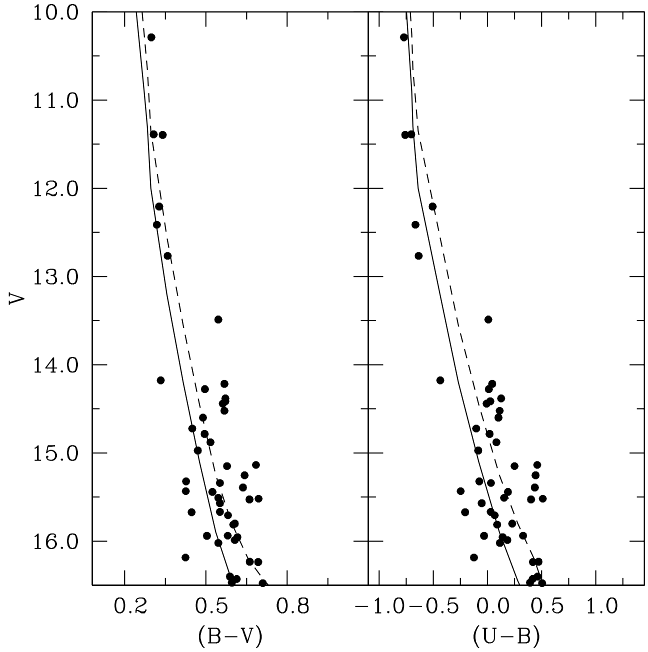

Figure 4. CMDs for all the stars in the region of Bochum 9 having $V \leq 16.5$ and sharing the reddening $E(B-V) = 0.63 \pm 0.08$. The empirical ZAMS from Schmidt-Kaler (1982) is shown as a solid line and has been shifted according to the reddening and the distance modulus. The dashed line represents the same ZAMS 0.75 mag brighter, which defines the locus of unresolved binaries. See the text for more details.

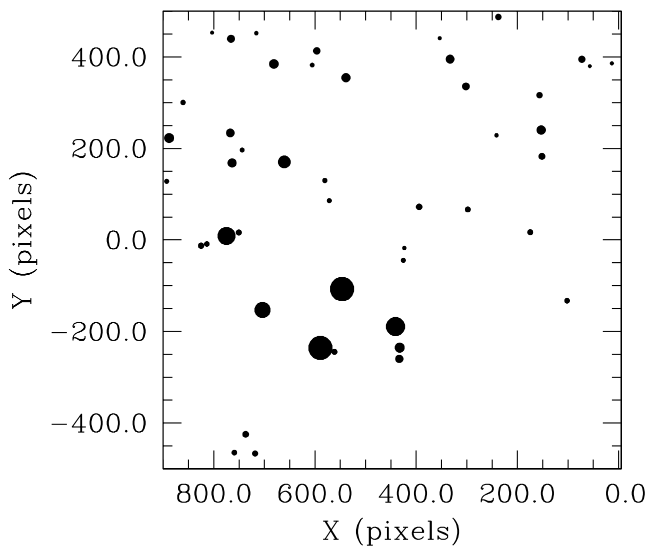

Figure 5. The projected spatial distribution of the candidate cluster members in the field of Bochum 9. The size of the circles is proportional to the magnitude of the stars. The field is about $6 \times 6\,\mathrm{arcmin}^2$.

component is rather strong in this direction (Vallenari et al. 2000). However, we believe that we are probably facing a young, loose, open cluster about 4.6 kpc far from the Sun, at odds with previous suggestions by Moffat & Vogt (1975).

We emphasize that proper motions provide only a weak suggestion, and that radial velocities for the brightest stars or a dedicated survey of relative proper-motions are needed to decide about the real nature of Bochum 9.

The position in the CMDs (see Fig. 4) of some stars below

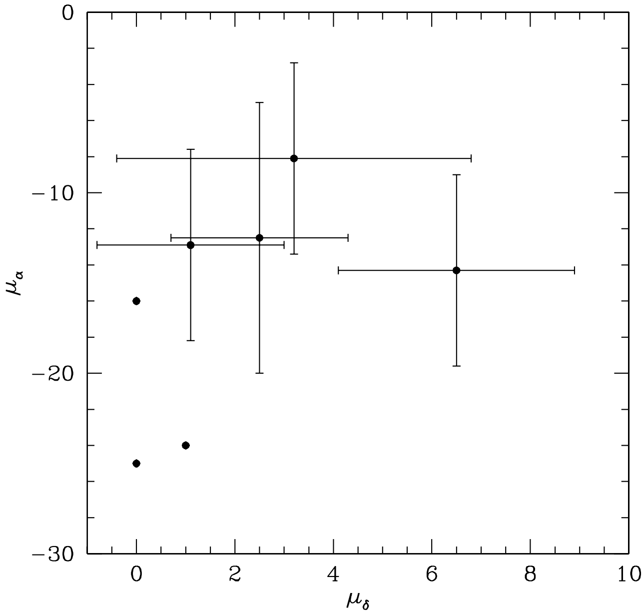

Figure 6. Vector point diagram for Tycho 2 stars in the field of Bochum 9. Proper motions are expressed in mas yr^{-1}, and crosses, where available, indicate the uncertainties.

Table 4. Photometry of the brightest stars in the field of the open cluster Bochum 10.

ID	V	$(B-V)$	$(U-B)$	$(V-R)$	$(V-I)$
1	9.349	0.187	−0.744	0.020	0.135
2	9.292	0.063	0.029	−0.064	−0.068
3	9.503	0.076	−0.801	−0.026	0.015
4	9.553	0.106	−0.758	−0.028	0.030
5	9.603	0.066	−0.702	−0.069	−0.066
6	8.782	1.482	1.650	0.588	9.999
7	10.194	0.099	−0.725	−0.032	0.018
8	10.550	0.160	−0.677	−0.001	0.096
9	11.172	1.142	0.973	0.456	0.976
10	11.563	0.167	0.160	−0.067	−0.007
11	11.871	0.668	0.088	0.292	0.605
12	11.959	0.541	0.022	0.209	0.459
13	12.265	0.233	−0.382	0.050	0.179
14	12.177	0.436	0.122	0.140	0.333
15	12.227	0.847	0.338	0.359	0.728
16	12.598	0.411	−0.389	0.205	0.491

$V = 14.5$ deserves a final note. The most plausible explanation for the scatter in this region is that these stars might be field stars. However, there is also the possibility that some of them might be pre-MS stars, an hypothesis which demands further investigations by H_α equivalent-width measurements or infrared photometry (see for instance Vallenari et al. 1999 and their discussion about Bochum 11 in section 5.2).

4 BOCHUM 10

Bochum 10 is a loose open cluster located north-west of η Carinae, and surrounded by a diffuse nebulosity (Smith et al. 2000). We therefore expect to find signatures of variable extinction across the cluster. Bochum 10 was first reported by Moffat & Vogt (1975), who obtained *UBV* photoelectric photometry for 17 stars and found 12 possible members (see Table 4). Later, Feinstein (1981) obtained photoelectric *UBVRI* photometry for 39 stars down to $V = 13$, recognizing 15 members. Finally, Bochum 10 has been studied by Fitzgerald & Mehta (1987), who provide photoelectric *UBV* photometry of about 20 stars down to $V = 13.5$. They suggest that the cluster is rather sparse and includes O and B stars only. No members are expected to exist below $V = 13.5$.

While all these studies give the same estimate of the reddening, i.e. $E(B-V) \approx 0.35$, there are some discrepancies in the distance modulus, which ranges from $(m-M)_o = 12.03$ to 12.80. According to Moffat & Vogt (1975), the cluster is 2.56 kpc from the Sun, whereas Feinstein (1981) gives a distance of 3.6 kpc and Fitzgerald & Mehta (1987) one of about 2.8 kpc. The precise distance of Bochum 10 is crucial in assessing its membership in the Carina complex. As for the age of Bochum 10, there is some agreement in the literature, the cluster being as old as 7×10^6 yr.

For this object we obtained *UBVRI* photometry for about 600 stars down to $V = 20$. The comparison of our data with those of Feinstein (1981) for 17 common stars (see the details in Table 5) yields the following results.

$$V_{PC} - V_F = -0.05 \pm 0.05,$$

$$(B-V)_{PC} - (B-V)_F = 0.06 \pm 0.03,$$

$$(U-B)_{PC} - (U-B)_F = 0.05 \pm 0.05,$$

$$(V-R)_{PC} - (V-R)_F = -0.09 \pm 0.02,$$

$$(V-I)_{PC} - (V-I)_F = -0.12 \pm 0.03$$

where F refers to Feinstein (1981). Our field (see Fig. 7) comprises the region defined by the seven brightest stars mentioned by Moffat & Vogt (1975), but it is much smaller than the fields studied by Feinstein (1981) and Fitzgerald & Mehta (1987). By inspecting a DSS map it appears, however, difficult to define the cluster centre, since there are several bright stars evenly distributed within a radius of 20 arcmin from the assumed cluster centre which seem to form separate clumps. However, if we are really sampling the cluster core, our photometry supersedes all previous studies and we can obtain improved estimates of the fundamental parameters of the cluster.

4.1 Colour–magnitude diagrams

The CMDs for all detected stars in the field of Bochum 10 are shown in Fig. 8, where the dashed line indicates the limiting magnitude of previous investigations. The CMD looks very similar to that of Bochum 9, as shown in Fig. 2. Since the field is much smaller, there are fewer stars, but their distribution is practically identical, with a thin MS extending from $V = 9$ to $V = 20$.

The contribution of field stars is negligible up to $V = 14.0$. At fainter magnitudes, the MS is dominated by the Galactic disc population. As in the case of Bochum 9, there are some indications of Galactic disc RGB stars, at least looking at the scarcely populated vertical sequence which departs from the MS at V about 20.

The most prominent difference from Bochum 9 is the presence of a clump of stars in the bright end of the MS in the field around Bochum 10.

4.2 Two-colour diagram

All the stars having *UBV* photometry have been plotted in the two-colour diagram in Fig. 9. Most of them exhibit basically no reddening, like the bulk of stars in Bochum 9. However, the clump

Table 5. Photometric and astrometric data for the brightest stars in the region of Bochum 10. Data is taken from Tycho 2. Fe indicates Feinstein (1981) numbering, while *m* stands for members, as identified by Feinstein.

ID	Fe	Star	$\mu_{\alpha *}$	σ_μ	μ_δ	σ_μ	V	$(B-V)$	$(U-B)$	Sp.Type
1	5m	HD 92894	−2.30	3.60	1.40	1.60	9.394	0.187	−0.744	B01V
2	6	HD 92909	−15.90	2.10	−0.20	1.90	9.292	0.063	0.029	B9.5V
3	4m	HD 303297	0.40	4.40	−1.20	3.20	9.503	0.076	−0.801	A2
4	3m	HD 303296	−0.10	3.60	2.80	2.70	9.553	0.106	−0.758	Be
5	15m	HD 92852	−13.50	8.70	0.60	1.80	9.603	0.066	−0.702	B4
6	14	HD 92835	−15.50	9.60	−1.50	2.60	8.782	1.482	1.650	K2III
7	8m	HD 302989	−11.00		−4.00		10.194	0.099	−0.725	A
	9	HD 303188	−6.10	6.70	−0.60	4.30				B3
	10m	HD 92739	−12.60	2.90	2.50	2.60				B1/B2
	11m	HD 303190	−12.70	7.40	2.50	3.10				B5
	23	HD 303295	−9.00		−3.00					B8
	1m	HD 93002	1.10	2.90	5.60	2.10				B2III
	35m	HD 93026	−1.70	4.70	1.80	3.90				B2III
	18	HD 303291	−19.00		0.00					
	33	HD 93055	−6.00	2.90	5.30	1.60				B8/B9
	34	HD 93114	−25.70	3.00	5.50	2.30				A7II
	38	HD 303290	−13.00		−2.00					

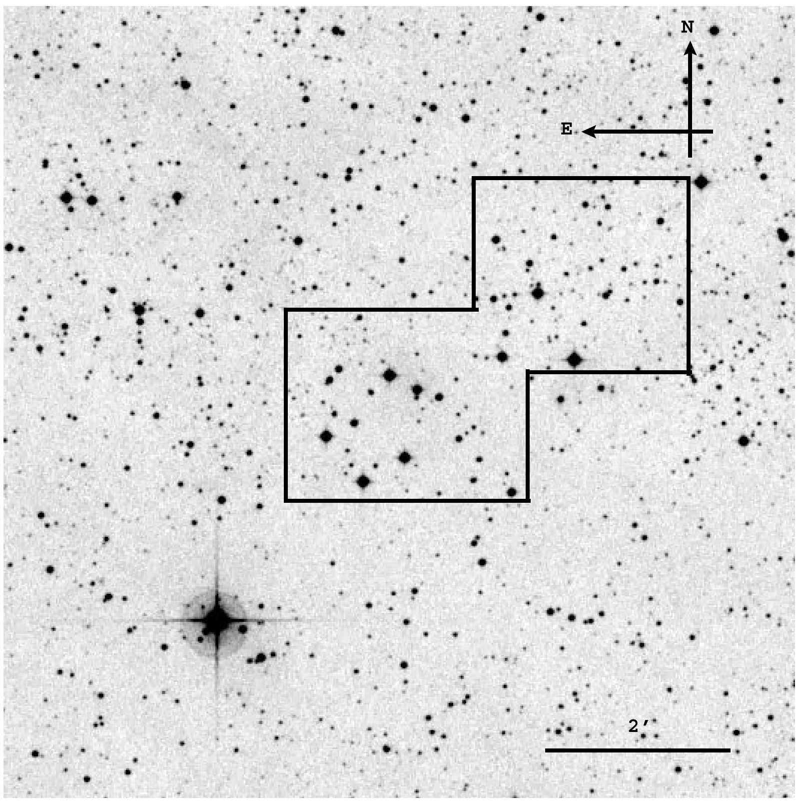

Figure 7. DSS map of a region around Bochum 10. The solid line confines the field covered by our photometry.

of stars at $(B-V)=0.1$ and $(U-B)=-0.7$ has a larger reddening $E(B-V)=0.47$, and is identified by an empirical ZAMS shifted by this amount (dotted line). Since these stars have a common extinction, which is significantly larger than that undergone by the bulk of the stars, it is reasonable to see whether they define a distinct sequence in the colour–magnitude diagram.

For this purpose we selected all the stars having $0.42 \leq E(B-V) \leq 0.52$ (18 stars in total). These are plotted in Fig. 10, and seem to actually define a clear sequence. There are six stars which lie off the MS, and they are plotted with open circles. The ZAMS has been superimposed by adopting $(m-M)_o = 12.20$, which implies a distance of 2.7 kpc from the Sun. The dashed line in Fig. 10 represents the same ZAMS 0.75 mag brighter, and it defines the ZAMS of unresolved binaries. Accordingly the two stars at $V_0 \approx 12.3$, $(B-V)_0 \approx -0.8$ may be binaries.

We looked for the relative positions of these stars within the cluster, and found that, with the exception of the two binaries, they lie in the outskirts of the area we covered. Therefore we suggest that these stars probably do not belong to Bochum 10.

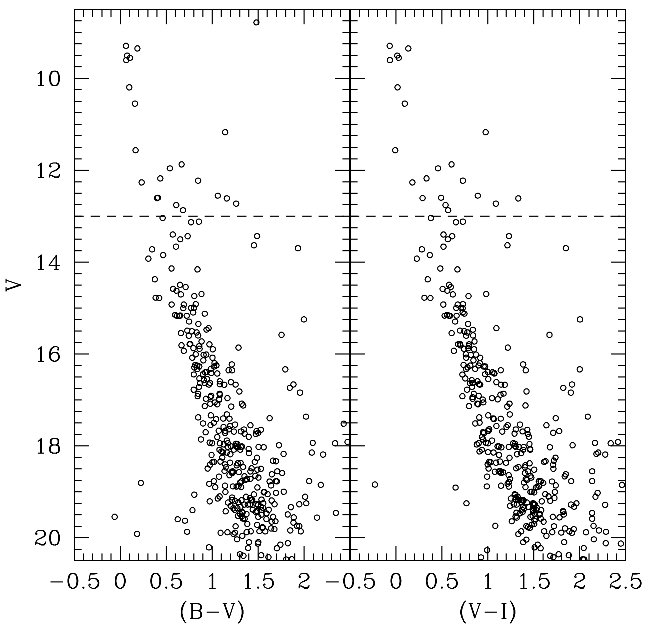

Figure 8. CMDs for all the stars in the region of Bochum 10. The dashed line defines the limit of previous photometries.

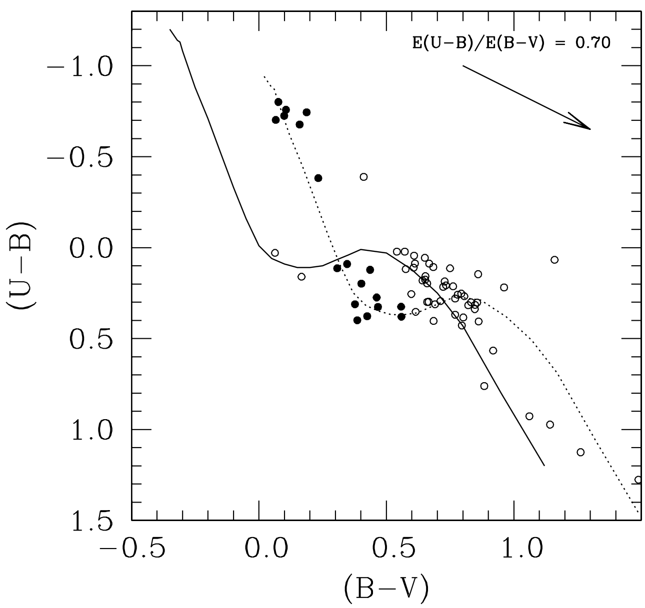

Figure 9. Two-colour diagram for all the stars in the region of Bochum 10. The arrow indicates the reddening vector. The solid line is the empirical Schmidt-Kaler (1982) ZAMS, whereas the dotted line is the same ZAMS, but shifted by $E(B-V)=0.47$. Filled circles indicate candidate members.

4.3 Astrometric data

Tycho 2 provided measurements of proper motions for 17 stars in the field of Bochum 10. They are listed in Table 5, and plotted in the vector point diagram in Fig. 11. Also in this case we stress that the uncertainties in the proper motions are large. Nevertheless, the distribution of the points in Fig. 11 is conducive to an argument for there being two separate clumps with a large spread, while there is one object (HD 93114) that clearly deviates from the bulk.

If these clumps are real, we are most likely looking at a group of objects which do not share the same motion properties.

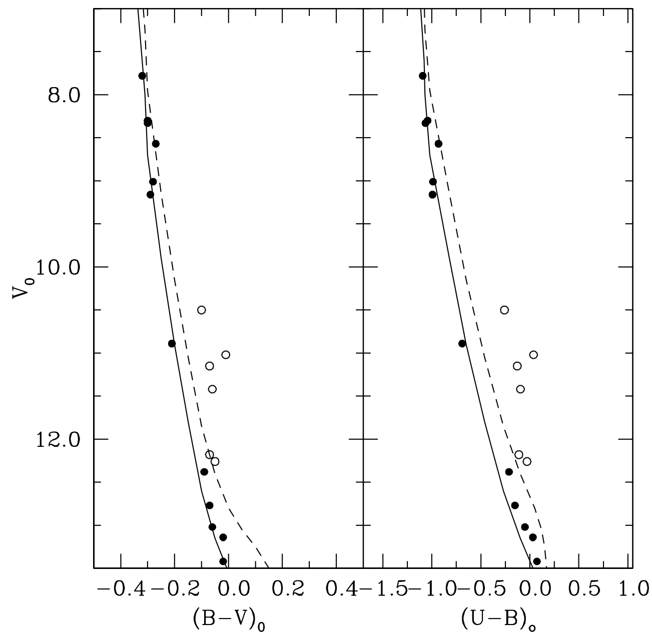

Figure 10. Reddening-corrected CMDs for the candidate member stars in the region of Bochum 10. The solid line is the empirical ZAMS from Schmidt-Kaler (1982), whereas the dashed line is the same ZAMS, but shifted by 0.75 mag to define the locus of unresolved binaries. Open circles indicate probable non-members. See text for details.

Interestingly, Feinstein (1981) on a purely photometric basis attributed membership to stars having discrepant motion (see Fig. 11). Finally, by closely inspecting the spatial distribution of these stars in the sky (see Feinstein 1981, fig. 1), it is possible to see how presumed members are not distributed in the central region of the cluster, but members and non-members are mixed together.

In conclusion, the results we obtained for Bochum 10 are as follows: as in the case of Bochum 9, there are indications that we are not looking at a really bounded open cluster, but simply at a loose group of bright stars embedded in a rich Galactic disc field. We found 14 probable members, fewer than Fitzgerald & Metha (1987), probably because we have sampled a region too small to be really representative. The cluster seems to be quite young, with no stars in the act of leaving the MS.

In order to better clarify the nature of Bochum 10, we suggest further investigations in two directions: a radial velocity survey for the brightest stars and a larger area of study for the photometric coverage.

5 BOCHUM 11

Bochum 11 is a compact, very young group of stars around the double star HD 93962 (see Fig. A1, below). The diffuse nebulosity (see Fig. 12) which surrounds Bochum 11 is possibly what remains of the cloud from which the cluster was born. It was first investigated by Moffat & Vogt (1975), who provided *UBV* photoelectric photometry for eight probable members. Soon after, Forte (1976) obtained *UBV* photoelectric photometry for two stars already studied by Moffat & Vogt (1975). Interestingly, Moffat & Vogt (1975) pointed out that the cluster suffers from differential reddening, being $E(B-V)=0.54\pm0.13$. Moreover, they suggested that the stars fainter than $V=12$ may be pre-MS stars in contraction phase.

Finally, additional photoelectric photometry has been carried out

Table 6. Photometry and astrometry of the brightest stars in the field of Bochum 11. Proper motions are taken from Tycho 2 and are expressed in mas yr^{-1}.

ID	Name	V	$(B-V)$	$(U-B)$	$\mu_{\alpha*}$	σ_μ	μ_δ	σ_μ	Type
1	HD 93632	8.326	0.231	−0.762	−129.80	2.70	112.00	2.60	O^+
2	HD 93576	9.661	0.163	−0.727					
3	HD 305612	10.288	0.270	−0.729	−55.00		−3.00		B
4	HD 93632B	10.489	0.122	−0.711	−7.90	3.30	5.80	1.70	B2V
5		10.582	0.303	−0.600					
6	CPD 592704	10.841	0.347	−0.596					
7		10.420	1.375	1.582					
8		11.321	0.080	−0.702	−1.40	5.60	7.20	1.60	B
9		11.819	0.372	−0.447					

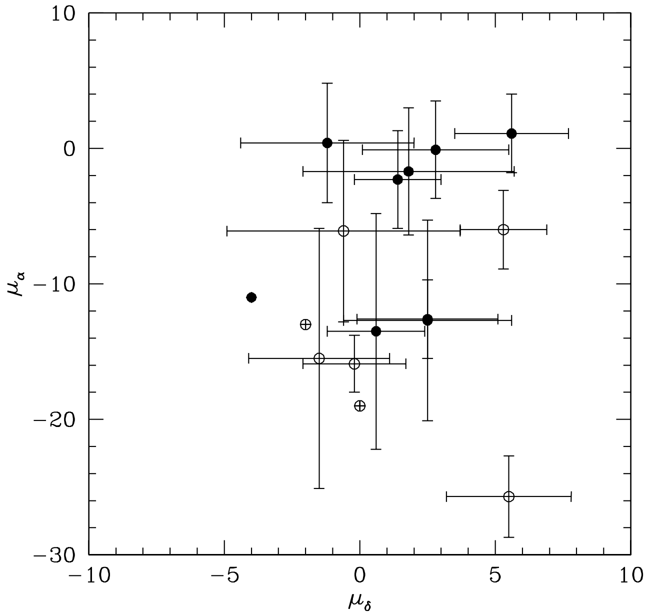

Figure 11. Vector point diagram for Tycho 2 stars in the field of Bochum 10. Filled symbols indicate cluster members according to Feinstein (1981), whereas open symbols indicate cluster non-members. Crosses indicate the uncertainties in the measurement. Proper motions are in mas yr^{-1}.

by Fitzgerald & Mehta (1987), who added 9 more stars. By increasing to 15 the number of members, they confirmed that Bochum 11 is very young and pre-MS stars may be present below $V = 12$.

A comparison with the work of Fitzgerald & Mehta (1987) for nine stars in common (see the details in Table 6), yields the following results.

$$V_{PC} - V_{FM} = -0.044 \pm 0.042,$$

$$(B-V)_{PC} - (B-V)_{FM} = -0.055 \pm 0.037,$$

$$(U-B)_{PC} - (U-B)_{FM} = -0.001 \pm 0.029,$$

where FM refers to Fitzgerald & Mehta (1987).

Our study covers a region of 3×6 $arcmin^2$ (see Fig. 12) and we obtained CCD *UBVRI* photometry for about 780 stars down to $V = 21$ (see Fig. 13), superseding all previous investigations. The CMD in Fig. 12 looks quite similar to those of Bochum 9 and 10, so that the same kind of consideration holds also for the Bochum 11 CMD.

The data we collected allow us to determine the fundamental parameters of the cluster.

5.1 Cluster reddening

We isolated Bochum 11 possible members on the basis of their positions in the two-colour diagram (see Fig. 14) and in the map in Fig. A1, below.

By considering the distribution of the stars as projected on to the sky (see Fig. A1, below), we selected four regions, namely a circle centred in HD 93632 with a radius of 50 arcsec (upper left panel in Fig. 13), two coronae defined by $50 \leq r \leq 110$ arcsec (upper right panel) and $110 \leq r \leq 150$ arcsec (lower left panel), and finally the region outside the last corona, defined by $r \geq 150$ arcsec.

In all these figures, the empirical Schmidt-Kaler (1982) ZAMS is plotted as a solid line, whereas the same ZAMS, shifted by $E(B-V) = 0.58$, is drawn as a dotted line. The central region seems indeed to consist of a group of 5–10 stars sharing the same reddening $E(B-V) = 0.58$, whereas the majority of stars lying outside the cluster core have basically no reddening, as in the case of most of the Bochum 9 and 10 stars. It is reasonable to conclude that these are field stars.

We have indicated candidate cluster members with filled circles, on the basis of common reddening. Noticeably, we find probable cluster members also in the outer rings. In total, there are candidate members. By considering all the probable members, the reddening turns out to be $E(B-V) = 0.58 \pm 0.05$.

This value is in good agreement with previous estimates. In fact Moffat & Vogt (1975) found $E(B-V) = 0.54 \pm 0.13$, whereas Fitzgerald & Mehta (1987) derived $E(B-V) = 0.588 \pm 0.032$.

5.2 Age and distance

Age and distance have been inferred by fitting the reddening-corrected CMDs with solar metallicity isochrones (Girardi et al. 2000). This is shown in Fig. 15, where we plotted all the candidate members according to reddening. Some stars that lie apart from the MS are indicated with open circles and are considered probable non-members, reducing to 24 the number of cluster members.

In this figure the dashed line is an isochrone for the age of 8×10^6 yr, and the dotted line an isochrone for the age of 4×10^6 yr, both shifted by $(m-M)_o = 12.70$, in fair agreement with previous estimates. In fact Moffat & Vogt (1975) suggested $(m-M)_o = 12.80$, whereas Fitzgerald & Mehta (1987) derived $(m-M)_o = 12.70$. The distance from the Sun is estimated to be 3.5 kpc and therefore Bochum 11 lies between Bochum 10 and 9. The comparison with isochrones suggests that Bochum 11 is a very young cluster with an age less than 4×10^6 yr.

The possibility that pre-MS stars are present in Bochum 11

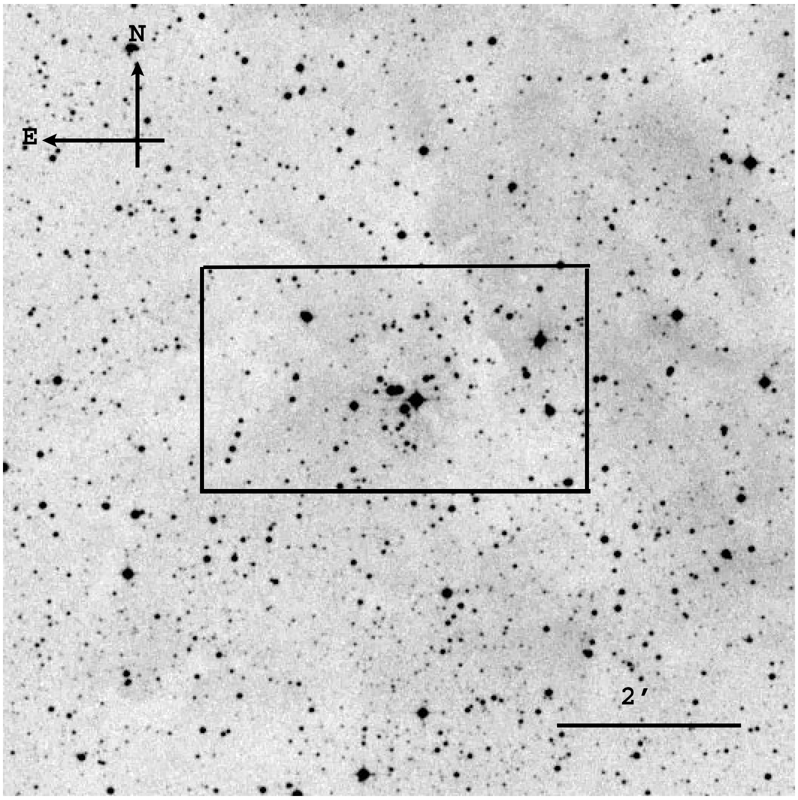

Figure 12. DSS map of a region around Bochum11. The box confines the field covered by our observations.

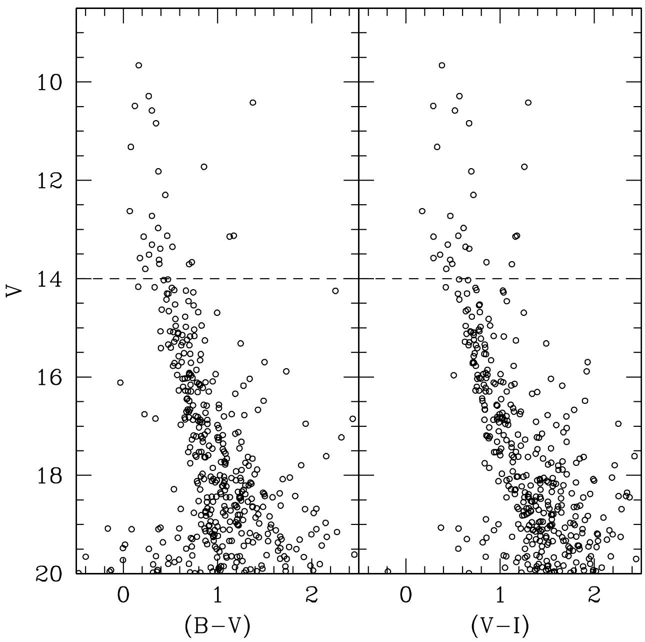

Figure 13. CMDs for all the stars in th region of Bochum 11. The dashed line indicates the limiting magnitude of previous investigations.

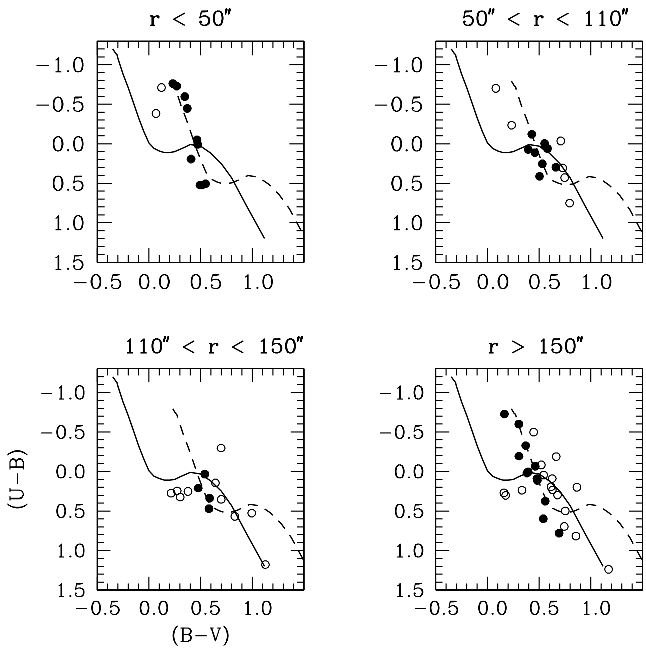

Figure 14. Two-colour diagram for the stars lying within different circles centred in Bochum 11. Solid circles identify candidate cluster members.

has already been suggested by Fitzgerald & Mehta (1987), who argued that these stars have to be fainter than $V = 12$. The position of the stars in Fig. 15 below $V = 12$ seems to support this hypothesis, which demands further investigation by H_α equivalent-width measurements or infrared photometry (see, for example, Vallenari et al. 1999).

5.3 Astrometric data

Tycho 2 provided proper motion measurements for four stars in the region of Bochum 11. Since the sample is very small, we refrain from any discussion, and simply report them in Table 6 for the sake of completeness. We note only that HD 93632 has very high

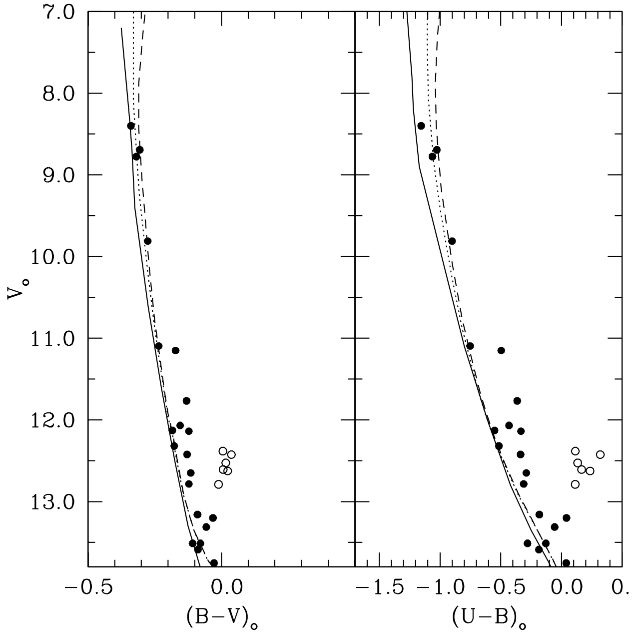

Figure 15. Reddening-corrected CMDs for the stars in the region of Bochum 11. The solid line is the empirical ZAMS from Schmidt-Kaler (1982), whereas the dotted and dashed lines are 4 and 8×10^6-yr isochrones from Girardi et al. (2000). Open circles indicate cluster non-members.

proper-motion components, which may be a result of measurement errors, since it is actually in a binary system. Looking at our photometric data, there is no reason to believe that this star does not belong to Bochum 11.

6 CONCLUSIONS

We have presented the first *UBVRI* CCD photometry for three star clusters in the region of η Carinae: Bochum 9, Bochum 10 and Bochum 11.

Bochum 9 is a puzzling object. It seems to be a group of 30 stars sharing common reddening located beyond the Carina spiral arm, although the projected spatial distribution and the poor kinematical data at our disposal seem to imply that we are simply looking at a field star population.

Our analysis suggests that Bochum 10 is a very young and poorly populated open cluster. As is the case with many other young poor clusters, it is certainly an unbounded object and will gradually disrupt. We provide estimates of interstellar reddening and distance compatible with previous studies.

As for Bochum 11, we find that it is a young open cluster, less than 4×10^6 yr old, and confirm previous estimates for the cluster mean reddening and distance.

From our photometry, we find indications of possible pre-MS candidates in Bochum 9 and 11. This issue will be addressed in a forthcoming paper (Romaniello et al., in preparation), in which *UBVRI* photometry for all the other star clusters known to lie in the Carina spiral feature will be presented and compared with theoretical models.

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APPENDIX A: PHOTOMETRIC SOLUTION AND ERRORS ESTIMATE

To allow for a precise photometric calibration, we observed five multistar fields from the list of Landolt (1992) each night during the observing run. After bias, flat-field correction and exposure time normalization, the instrumental magnitudes of the standard stars were measured using the QPHOT task in IRAF. To match Landolt's observations we used a 14-arcsec circular aperture. The same size has been used later to correct DAOPHOT magnitudes obtained for the scientific targets.

From these measurements we have computed the zero points and the colour terms of our photometric system via linear least-squares fits; the results are presented in Table A1. Since the airmass range covered by our observations was not large enough to secure a good determination of the extinction coefficients, we have adopted the average values for La Silla (cf. Patat 1999), which are also reported in Table A1.

The transformation from instrumental magnitudes to the standard Kron–Cousins system was obtained with expressions of the form

$$M_i = m_i + \mathrm{zp}_i + \gamma_i(M_i - M_j) - k_i z \qquad \text{(A1)}$$

where M_i, m_i, zp_i, γ_i and k_i are the calibrated magnitude, instrumental magnitude, zero point, colour term and extinction coefficient for the *ith* passband and z is the airmass. The transformation requires of course the knowledge of the reference colour $(M_i - M_j)$, which is easily computed from the instrumental magnitudes through the following relation.

$$(M_i - M_j) = \frac{m_i - m_j + \mathrm{zp}_i - \mathrm{zp}_j - (k_i - k_j)z}{\gamma_{ij}}, \quad \text{(A2)}$$

where we have set $\gamma_{ij} = 1 - \gamma_i + \gamma_j$. If σ_{mi}, $\sigma_{\mathrm{zp}i}$, $\sigma_{\gamma i}$ and σ_{ki} are the rms errors on the instrumental magnitude, zero point, colour term and extinction coefficient for the *ith* passband, formal uncertainties on calibrated colours are then obtained by propagating the various errors through equation A2,

$$\sigma^2_{(Mi-Mj)} \simeq \frac{\sigma^2_{m,ij} + \sigma^2_{ps,ij} + (M_i - M_j)^2\sigma^2_{\gamma,ij}}{\gamma^2_{ij}}. \quad \text{(A3)}$$

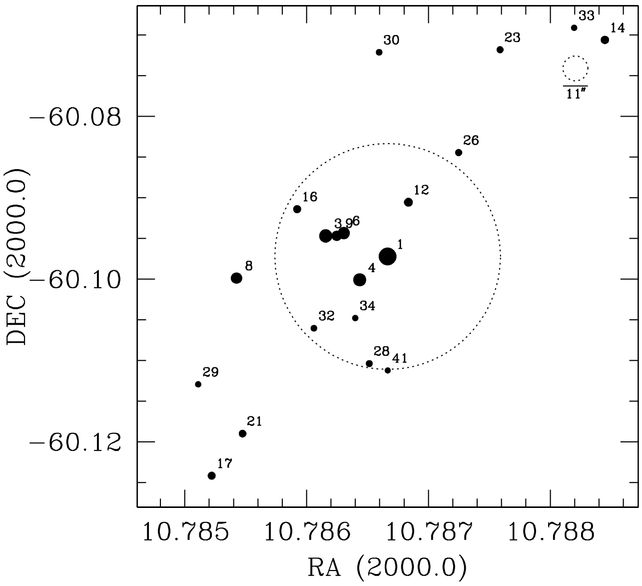

Figure A1. Map of the central region of Bochum 11. The dashed circle in the upper right corner indicates the size of the diaphragm adopted by Moffat & Vogt (1975), whereas the large circle (50 arcsec) centred in HD 93632 encloses the cluster core.

Table A1. Average photometric coefficients obtained during 1996 April 13–16. ESO Dutch 0.92-m telescope, TK CCD #33.

Filter	Ref. Colour	*zp*	γ	*k*
U	$(U-B)$	19.85 ± 0.02	0.095 ± 0.020	0.46 ± 0.02
B	$(B-V)$	21.93 ± 0.01	0.079 ± 0.010	0.27 ± 0.02
V	$(B-V)$	22.19 ± 0.01	0.030 ± 0.006	0.12 ± 0.02
R	$(V-R)$	22.18 ± 0.01	0.025 ± 0.014	0.09 ± 0.02
I	$(V-I)$	21.11 ± 0.01	0.062 ± 0.006	0.06 ± 0.02

Table A2. Global photometric rms errors as a function of magnitude.

Mag	σ_U	σ_B	σ_V	σ_R	σ_I
9–11	0.04	0.03	0.03	0.03	0.03
11–13	0.04	0.03	0.03	0.03	0.03
13–15	0.04	0.03	0.03	0.03	0.03
15–17	0.05	0.03	0.03	0.03	0.03
17–19	0.08	0.03	0.04	0.04	0.05
19–20	–	0.04	0.05	0.07	0.09
20–21	–	0.07	0.09	0.15	0.22
21–22	–	0.12	0.18	0.27	–

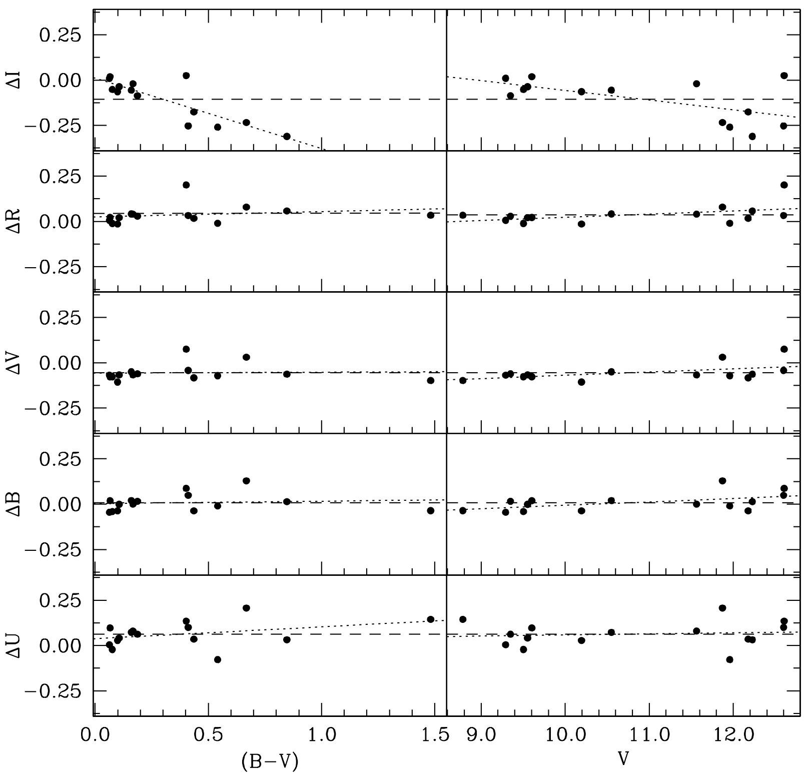

Figure A2. Deviations of photometric measurements presented in this work from the results published by Feinstein (1981) for Bochum 10. Dotted lines represent a linear least-squares fit to the points, while the dashed lines indicate the average deviation.

For sake of simplicity, we have set $\sigma^2_{m,ij} = \sigma^2_{mi} + \sigma^2_{mj}$, $\sigma^2_{\gamma,ij} = \sigma^2_{\gamma i} + \sigma^2_{\gamma j}$ and $\sigma^2_{ps,ij} = \sigma^2_{zp,ij} + z^2\sigma^2_{k,ij}$.

Finally, the rms uncertainties on the calibrated magnitudes are given by

$$\sigma^2_{Mi} \simeq \sigma^2_{mi} + \sigma^2_{psi} + (M_i - M_j)^2\sigma^2_{\gamma i} + \gamma_i^2\sigma^2_{(Mi-Mj)}, \quad \text{(A4)}$$

where we have neglected the error on z and assumed that the images in different passbands have been obtained at very similar airmasses, as was in fact the case.

Estimated uncertainties as a function of magnitude are reported in Table A2, from which it appears clearly that down to $V \simeq 17$ they are dominated by the errors on the photometric solution, while at fainter magnitudes the contribution by the Poissonian photon shot-noise σ_m (estimated by DAOPHOT) becomes relevant.

As we have already discussed in Sections 3, 4 and 5, comparison with the data published by other authors has shown that some deviations exist for the stars which are common to the different data sets. Discrepancies concerning single stars are probably a result of the relatively large diaphragm coupled with the photoelectric photometer (11–14 arcsec, Moffat & Feinstein, private communications). This is the case, for instance, for the star pairs #3-#6 and #6-#9 of Bochum 11, as shown in Fig. A1. One other example can be found in Carraro et al. (2001) for NGC 3324.

On the other hand, systematic deviations seem to exist. To investigate this problem we have analysed the magnitude deviations as a function of magnitude and colour for Bochum 10, for which a comparison with published data is possible in all passbands. The results are presented in Fig. A1, where the differences between our measurements and the results by Feinstein (1981) have been plotted as a function of $(B - V)$ (left panel) and V magnitude (right panel). With only the exception of the I filter, all passbands show small systematic deviations which are consistent with the estimated photometric errors. For the I filter a colour dependency seems to exist, and this would indicate the presence of an unaccounted colour term in the photoelectric measurements.

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