A&A 385, 471–478 (2002)
DOI: 10.1051/0004-6361:20020165

Astronomy & Astrophysics

Photometry of dissolving star cluster candidates

The cases of NGC 7036 and NGC 7772⋆,⋆⋆

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Received 23 November 2001 / Accepted 17 January 2002

Abstract. We present CCD UBVI observations obtained in the field of the two previously unstudied dissolving open cluster candidates NGC 7036 and NGC 7772. Our analysis suggests that both the objects are Open Cluster Remnants (OCR). NGC 7036 is an open cluster remnant with a core radius of about 3–4 arcmin. We derive for the first time estimates of its fundamental parameters. We identify 17 likely members that define a group of stars at 1 kpc from the Sun, with a low reddening $E(B-V) \approx 0.1$, and with an age of about 3–4 Gyr. As for NGC 7772, we identify 14 likely members, that define a group of stars with a very low reddening ($E(B-V) \approx 0.03$), are 1.5 Gyr old and are located about 1.5 kpc from the Sun.

Key words. open clusters and associations: individual: NGC 7036, NGC 7772 – open clusters and associations: general

1. Introduction

The dynamical evolution and the final fate of open star clusters in the Milky Way is nowadays a very active research field. Open star clusters are weakly bound objects with a typical lifetime of less than a Gyr (Dutra & Bica 2000; Bergond et al. 2001), which ultimately depends on the initial mass of the cluster, the birthplace and the fraction of primordial binaries (de la Fuente Marcos 1998, 2001).

Recently, Bica et al. (2001) drew attention to a sample of high Galactic latitude ($b > 15°$) star clusters presumably in an advanced stage of dynamic evolution, which they baptized *Probable Open Cluster Remants (POCR)*. The prototype of this class of objects is NGC 6994 (M 73), recently studied by Bassino et al. (2001) and Carraro (2001), who performed the first multicolor photometric studies of this cluster, but arrived at opposite conclusions on the nature of this object. While Bassino et al. suggest that M 73 is the remnant of a star cluster, Carraro (2000) proposes that it is just a chance alignment of four bright stars.

Although it is a difficult task to unravel the nature of a star concentration based only on photometry, it however remains the first necessary step. Indeed sometimes the Color Magnitude Diagrams (CMDs) and Color-Color Diagrams (CCDs) are sufficient to disentangle a real bound system or a random enhancement of stars (Carraro & Patat 1995; Piatti & Clarià 2001). In many cases however, photometry cannot help to decide unambiguously about the nature of a star concentration: in this situation radial velocities and/or proper motion studies are necessary (Baumgardt 1998; Baumgardt et al. 2000; Odenkirchen & Soubiran 2002).

The census provided by Bica et al. (2001) lists 20 candidate dissolving open clusters, some of which are completely unstudied. This is the case for NGC 7036 and NGC 7772, two high latitude objects traditionally considered genuine open clusters, which are the subject of the present study. The basic idea of this paper is to present the first photometric study of these clusters and to provide a list of probable member stars to be further studied with high resolution spectroscopy.

We note the recent spectroscopic follow-up of NGC 6994 by Odenkirchen & Soubiran (2002), who confirmed the Carraro (2000) suggestions that this object is a chance alignment of four bright stars.

In Sect. 2 we briefly present the observations and data reduction. Sections 3 and 4 illustrate our results for

⋆ Based on observations carried out at Mt Ekar, Asiago, Italy.

⋆⋆ Photometry is only 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/385/471`

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

Name	α	δ	l	b
	hh:mm:ss	$^\circ{:}'{:}''$	$^\circ$	$^\circ$
NGC 7036	21:10:02	+15:31:06	64.55	−21.44
NGC 7772	23:51:46	+16:14:48	102.74	−44.27

NGC 7036 and NGC 7772, and, finally, Sect. 5 draws some conclusions and suggests further lines of research.

2. Observations and data reduction

Observations were carried out with the AFOSC camera at the 1.82 m Copernico telescope of Cima Ekar (Asiago, Italy), on the photometric night of October 21, 2001. AFOSC samples a $8'.14 \times 8'.14$ field in a $1\,\mathrm{K} \times 1\,\mathrm{K}$ thinned CCD. The typical seeing was between 2.0 and 2.5 arcsec.

The basic data of the studied clusters are summarized in Table 1, and the details of the observations are listed in Table 2. The covered regions are shown in Figs. 1 and 6, where two DSS[1] maps are presented for NGC 7036 and NGC 7772, respectively.

The data have been reduced using the IRAF[2] packages CCDRED, DAOPHOT, and PHOTCAL. The calibration equations obtained by observing the Landolt (1992) PG 02331 field 3 times during the night, are:

$$\begin{aligned} u &= U + 3.707 \pm 0.054 + (0.201 \pm 0.060)(U-B) + 0.58\,X \\ b &= B + 1.545 \pm 0.006 - (0.068 \pm 0.007)(B-V) + 0.29\,X \\ v &= V + 0.893 \pm 0.029 + (0.010 \pm 0.011)(B-V) + 0.16\,X \\ i &= I + 1.624 \pm 0.017 - (0.051 \pm 0.015)(V-I) + 0.08\,X \end{aligned} \quad (1)$$

where $UBVI$ are standard magnitudes, *ubvi* are the instrumental ones, and X is the airmass. The standard stars in this field provide a very good color coverage, being $-0.329 \leq (B-V) \leq 1.448$. For the extinction coefficients, we assumed the typical values for the Asiago Observatory (Desidera et al. 2001). Photometric global errors have been estimated following Patat & Carraro (2001). For the V filter, they amount to 0.03, 0.05 and 0.07 at $V \approx 12.0$, 16.0 and 20.0, respectively.

3. NGC 7036

This object has never been studied before, and it is not included in the Lyngå (1987) open cluster catalog. NGC 7036 (see Fig. 1) appears as a weak star enhancement, confined within a 3 square arcmin area in a relatively rich stellar field.

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

[2] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

Table 2. Journal of observations of NGC 7036 and NGC 7772 and standard star field PG 02331 (October 21, 2001).

Field	Filter	Time integration (s)	Seeing ($''$)
NGC 7036			
	U	240, 600	2.2
	B	30, 300	2.3
	V	30, 300	2.3
	I	30, 200	2.3
NGC 7772			
	U	300	2.2
	B	30, 120	2.4
	V	5, 15, 60	2.3
	I	5, 15, 60	2.3
PG 02331			
	U	60, 120, 60	2.0
	B	60, 60, 120	2.1
	V	15, 15, 30, 30	2.0
	I	30, 30, 15	2.1

Fig. 1. A DSS red map of the covered region in the field of NGC 7036. North is up, East on the left.

3.1. Star counts

The first signature of the possible presence of a star cluster is recorded in star counts. Bica et al. (2001) compared star counts in the region of NGC 7036 with a Galactic model and DSS maps, showing that NGC 7036 significantly emerges from the surrounding field.

This is confirmed by star counts based on the present photometric data.

We derived the surface stellar density by performing star counts in concentric rings around star #17 (selected as the approximate cluster center) and then dividing by their respective surfaces. The final density profile and the corresponding poisson error bars are depicted in Fig. 2.

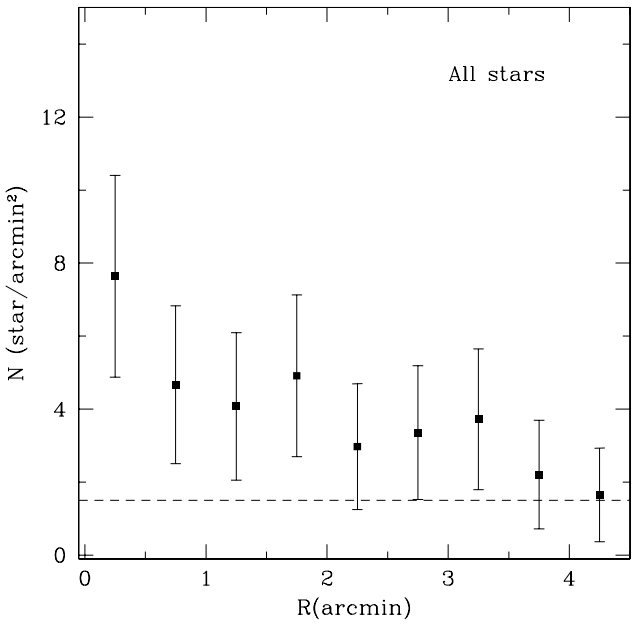

Fig. 2. Star counts in the field of of NGC 7036 as a function of the radius. The dashed line is the field number density estimate provided by Bica et al. (2001).

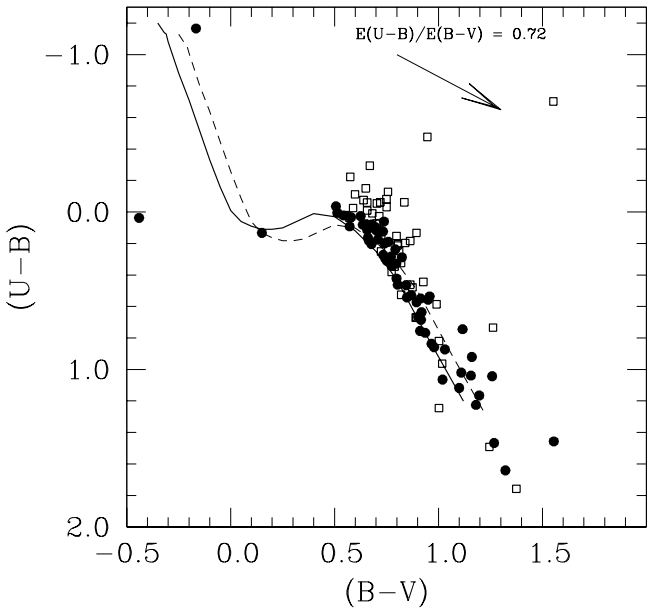

Fig. 3. Color-color diagram for all the stars in the field of NGC 7036 having UBV photometry. Filled circles indicate stars brighter than $V = 17$, whereas open squares indicate the remaining stars. The solid line is a Schmidt-Kaler (1982) empirical ZAMS, whereas the dashed line is the same ZAMS, but shifted by $E(B-V) = 0.1$.

In this figure we take into account all the measured stars. The surface density decreases smoothly over the region we covered, suggesting that the cluster has a radius of about 3.5–4 arcmin, and actually emerges significantly from the background. We count 5 stars brighter than $V = 13.7$ in a field of about 9 square arcmin, exactly the same number reported by Bica et al. (2001, Table 1). However we notice that these stars are not in the cluster central region, but populate a sort of ring between 2 and 3 arcmin. The cluster center is on the other hand populated by fainter stars presumably belonging to the field. This can be interpreted as an indication of the dissolution the cluster is undergoing.

3.2. Color-Color and Color-Magnitude Diagrams

In order to better understand the nature of NGC 7036, we constructed CCDs and CMDs. The goal is to get some information about the cluster reddening, age and distance. A hint of the cluster reddening is derived from the Schlegel et al. (1998) dust emission reddening maps. In the direction of NGC 7036 the reddening is 0.08. This is basically confirmed by the analysis of the $(B-V)$ vs. $(U-B)$ diagram presented in Fig. 3. Here we consider the stars brighter than $V = 17$ (filled circles) which lie very close to to the empirical Schmidt-Kaler (1982) ZAMS (solid line), and therefore are weakly reddened. The remaining stars (open squares) are much more dispersed.

To guide the eye, we plotted also an empirical ZAMS (dashed line) shifted by $E(B-V) = 0.1$.
It seems that when looking for possible members one has to consider the brightest stars. It is not possible on the other hand to select cluster members by using individual

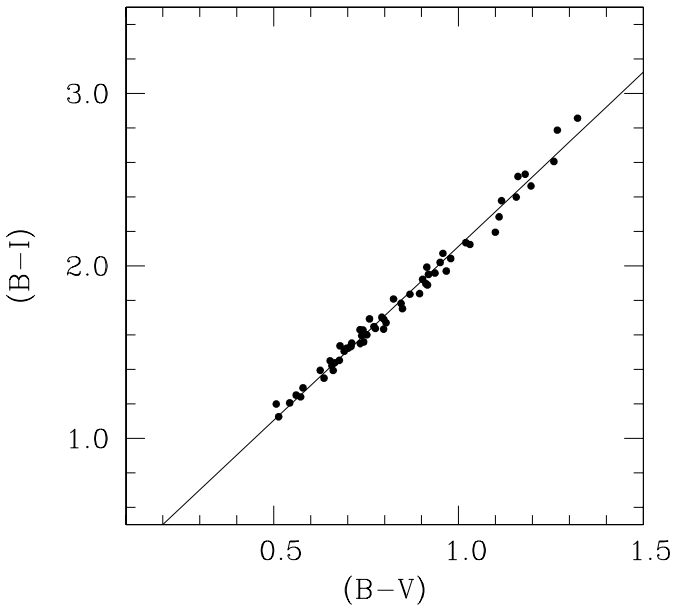

Fig. 4. NGC 7036 stars brighter than $V = 17$ in the $(B-V)$ vs. $(B-I)$ plane.

reddenings, since the stars in Fig. 3 are probably of spectral type later than G.

The same indication about the reddening derives from the analysis of the BVI photometry, following the method devised by Munari & Carraro (1996), which yields $E(B-V) = 0.10 \pm 0.05$.

In Fig. 5 we present three CMDs for the stars in the field of NGC 7036. In the left panel we plot all the stars, in the middle panel we plot the stars lying in the ring

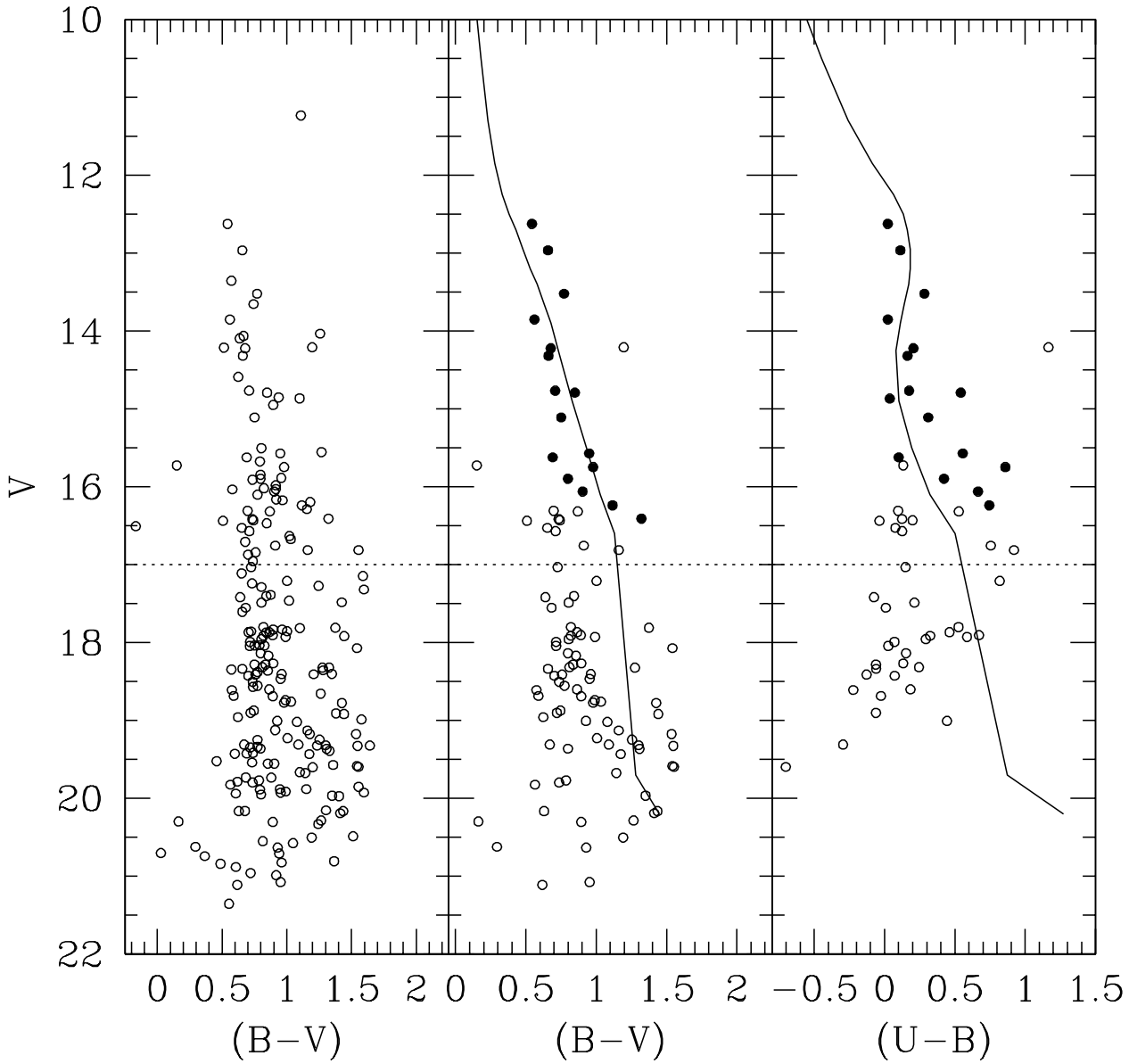

Fig. 5. CMDs of the stars in the region of NGC 7036. In the left panel we plot all the stars. In the middle and right panel we consider only the stars in the ring defined by $1.5 \leq r \leq 3.5$. The dotted line provide a magnitude limit for probable cluster members. Finally, the solid line is a ZAMS shifted by $E(B-V) = 0.1$ and $(m-M) = 10.7$. Filled circles identify likely members.

$1.5 \leq r \leq 3.5$ where we have seen that the brightest stars are confined. Finally, in the right panel we plot the same stars, but in the plane $(U-B)$ vs. V. The dotted line indicates a magnitude limit for probable members. These latter are indicated with filled symbols.

It is very difficult to get an estimate of the cluster age and distance since apparently there are no evolved stars. This can be explained statistically, since the cluster is intrinsically poorly populated, and therefore the absence of evolved stars is not completely unexpected. The only star that stays in the evolved region of the CMD is also the brightest one, and is very probably a field star located between us and NGC 7036, since it appears projected apart from the cluster central region.

To have a rough estimate of cluster distance we have to rely only on MS stars, and we proceed as follows.

From the location of stars in the $(B-V)$ vs. $(U-B)$ plane, we infer that the stars' spectral types range from about $G0$ to $M2$ by deriving the absolute colors from the ZAMS at the same position of the stars. This implies that the distance modulus is $(m-M) \approx 10.7 \pm 0.5$, which corresponds to a distance of about 1 kpc. Moreover, if the stars having $G0$ spectral type are still along the Main Sequence (MS), we infer a probable age of about 3–4 Gyr.

In conclusion, we are tempted to suggest that NGC 7036 is indeed an OCR having 17 likely members, whose properties are summarized in Table 3. Star counts seem to support this suggestion. CCDs and CMDs are

Table 3. Photometry of likely member stars in the field of NGC 7036 deserving further spectroscopic investigation.

ID	$\alpha(J2000.0)$	$\delta(J2000.0)$	V	$(B-V)$	$(U-B)$	$(V-I)$
	hh:mm:ss	°:′:″				
2	21:10:06.898	+15:30:38.06	12.624	0.543	0.022	0.662
3	21:10:03.892	+15:32:24.83	12.965	0.657	0.112	0.765
5	21:09:47.118	+15:31:01.14	13.521	0.771	0.283	0.878
6	21:09:47.002	+15:30:59.42	14.866	-0.440	0.037	2.009
8	21:09:49.301	+15:30:08.71	13.854	0.560	0.023	0.690
13	21:09:49.755	+15:29:52.80	14.221	0.677	0.204	0.775
14	21:09:44.580	+15:29:52.80	14.318	0.660	0.162	0.733
18	21:09:47.613	+15:33:10.43	14.767	0.709	0.175	0.823
20	21:09:48.684	+15:30:59.42	14.791	0.848	0.542	0.904
23	21:09:50.022	+15:31:52.51	15.109	0.751	0.310	0.849
28	21:10:09.531	+15:32:22.10	15.571	0.950	0.556	1.071
29	21:10:01.266	+15:28:26.44	15.622	0.690	0.101	0.815
32	21:10:09.286	+15:32:37.38	15.747	0.979	0.858	1.064
35	21:10:00.299	+15:33:42.61	15.897	0.798	0.422	0.892
42	21:10:04.397	+15;31:31.97	16.061	0.903	0.665	1.020
44	21:09:54.668	+15:33:16.41	16.239	1.116	0.744	1.262
47	21:09:59.729	+15:33:15.34	16.410	1.322	1.641	1.535

Fig. 6. A red DSS map of the covered region in the field of NGC 7772. North is up, East on the left.

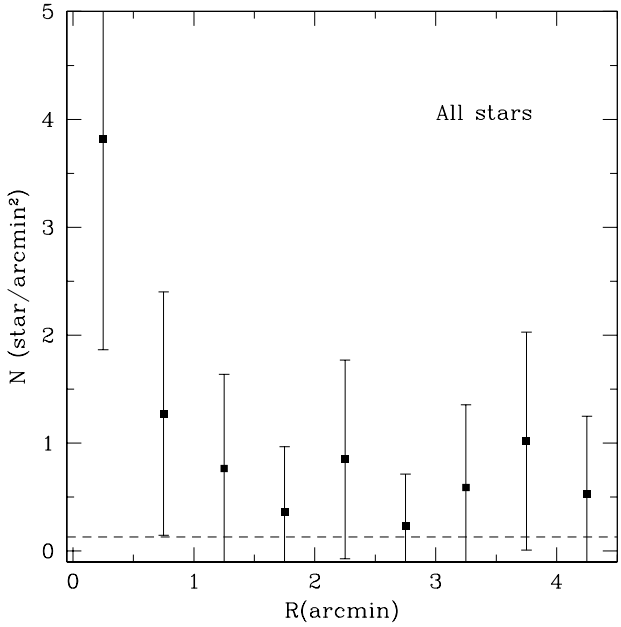

Fig. 7. Star counts in the field of of NGC 7772 as a function of the radius. The dashed line is the field number density estimate provided by Bica et al. (2001).

more difficult to interpret. Anyway, if NGC 7036 is a bound stellar aggregate, what remains is an old, weakly reddened star cluster 1 kpc away from the Sun.

4. NGC 7772

NGC 7772 (OCL 230, see Fig. 6) appears as an asterism of 8 bright stars in a poorly populated field. It resembles very closely NGC 6994 (Carraro 2000; Bassino et al. 2000). As for NGC 7036, this cluster has never studied insofar.

In the field of the cluster there is the star GSC 01722-01669 (TYC 1722 1669 1), #1 in our numbering system, which presumably has no relation with NGC 7772, since it lies outside the cluster core. It is probably a blue star located between us and NGC 7772.

4.1. Star counts

We derived the surface stellar density by performing star counts in concentric rings around stars #8 (selected as the approximate cluster center) and then dividing by their respective surfaces. The final density profile and the corresponding poisson error bars are depicted in Fig. 7. In this figure we take into account all the measured stars.

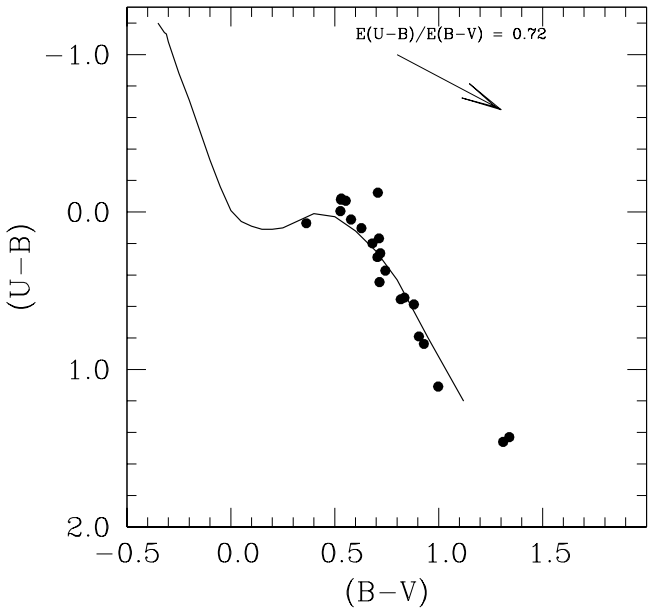

Fig. 8. Color-color diagram for all the stars in the field of NGC 7772 having UBV photometry. The solid line is a Schmidt-Kaler (1982) empirical ZAMS.

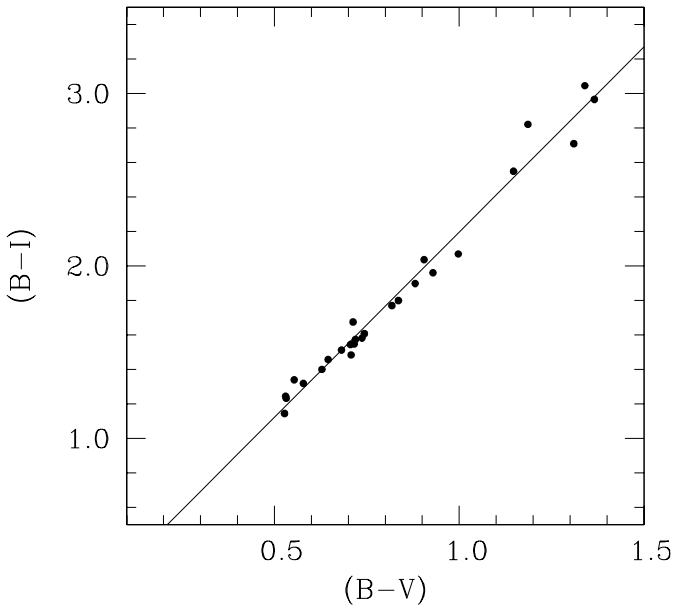

Fig. 9. NGC 7772 stars in the $(B-V)$ vs. $(B-I)$ plane.

The surface density decreases sharply up to a radius of about 2 arcmin, afterwards the density profile is basically flat. Therefore NGC 7772 appears to be very compact with a core radius which at maximum amounts to 2 arcmin.
Also in this case star counts indicate that we are facing a significant density contrast with respect to the field, whose bright stars ($B = 13.5$, $V = 13.0$) density in this direction is represented by the dashed line in Fig. 7. We count 5 stars brighter than $V = 13.0$ in a field of about 9 squared arcmin, basically the same number reported by Bica et al. (2001, Table 1).

4.2. Color-Color and Color-Magnitude Diagrams

In order to better understand the nature of NGC 7772, we constructed CCDs and CMDs. The goal is again to get information about the cluster reddening, age and distance. A hint of the cluster reddening is derived from the Schlegel et al. (1998) dust emission reddening maps. In the direction of NGC 7772 the reddening is 0.04. This is basically confirmed by the analysis of the $(B-V)$ vs. $(U-B)$ diagram presented in Fig. 8, where all the stars having UBV photometry are plotted. One can readily see that these stars lie along the empirical ZAMS (solid line) taken from Schmidt-Kaler (1982).

The same result is obtained by considering the distribution of the stars in the $(B-V)$ vs. $(B-I)$ diagram (see Fig. 9). By applying the Munari & Carraro (1996) method we infer a reddening $E(B-V) = 0.05 \pm 0.03$.

As in the case of NGC 7036, we can infer the approximate spectral type by analysing colours in the $(B-V)$ vs. $(U-B)$ plane. It turns out that the spectral type of possible members ranges from about $A8$ to $M3$. In Fig. 10 we present three CMDs for the stars in the field of NGC 7772. In the left panel we plot all the stars, in the middle panel we plot the stars lying within $r \leq 2.5$ where we have seen that the brightest stars are confined. Finally, in the right panel we plot the same stars, but in the plane $(V-I)$ vs. V.

Most of the stars in all the panels above $V = 16$ are probable MS stars. There is only one exception, which is star #2, which lies within the cluster core, and that we consider as a giant star probable member of the cluster. In the three panels of Fig. 10 we have overlaid a solar metallicity isochrone taken from Girardi et al. (2001) for the age of 1.5 Gyr. This isochrone provides a good fit of the data down to $V = 16.0$ by adopting $E(B-V) = 0.03$ and $(m-M) = 11.1 \pm 0.3$. Below $V = 16.0$, the MS starts to be ill defined. This is a clear signature of low mass star depletion, in nice analogy with – for instance – the cases of NGC 3680 (Anthony-Twarog et al. 1991) and NGC 7762 (Patat & Carraro 1995).

In conclusion, we confirm previous suggestions by Bica et al. (2001) that NGC 7772 is an OCR 1.5 Gyr old. We identify 14 likely members, which are plotted with filled symbols in Fig. 10, and whose properties are summarized in Table 4.

5. Conclusions

We have presented the first CCD $UBVI$ observation of the Probable Open Cluster Remnants NGC 7036 and NGC 7772.
Our analysis suggests that:

- NGC 7036 and NGC 7772 are two examples of intermediate-age open clusters in advanced stages of dynamical evolution.
- NGC 7036 is a 3–4 Gyr open cluster located 1 kpc far from the Sun. However, we stress the fact that this

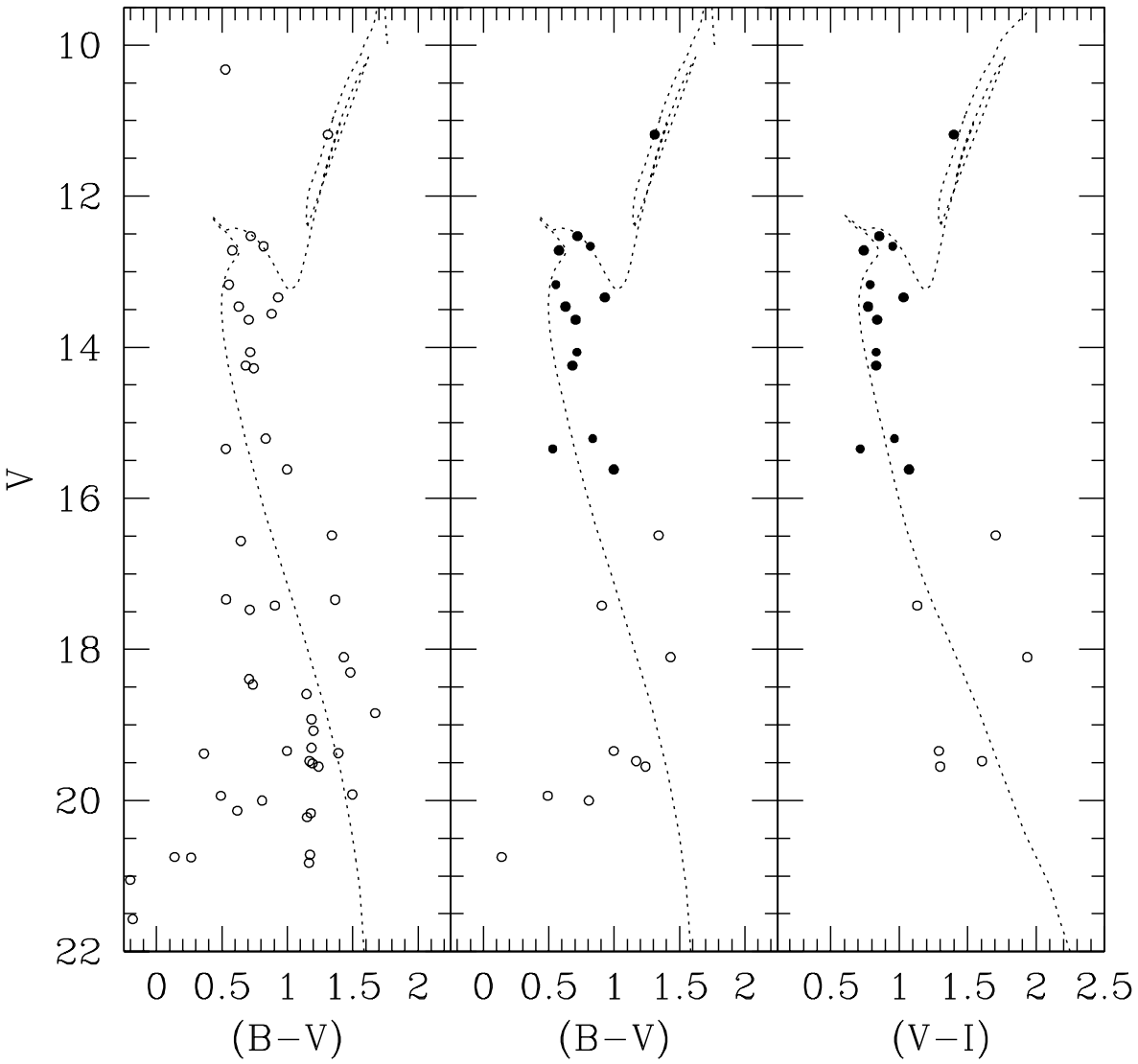

Fig. 10. CMDs of the stars in the region of NGC 7772. In the left panel we plot all the stars in the $(B-V)$ vs. V plane. In the middle and right panel we consider only the stars within $r \leq 2.5$. The dotted line is a solar metallicity isochrone for the age of 1.5 Gyr taken from Girardi et al. (2001), and shifted by $E(B-V) = 0.03$ and $(m-M) = 11.1$. Filled circles identify likely members.

Table 4. Photometry of likely member stars in the field of NGC 7772 deserving further spectroscopic investigation.

ID	$\alpha(J2000.0)$	$\delta(J2000.0)$	V	$(B-V)$	$(U-B)$	$(V-I)$
	hh:mm:ss	$^\circ:':''$				
2	23:51:42.816	+16:14:10.40	11.183	1.310	1.459	1.399
3	23:51:46.129	+16:14:23.22	12.529	0.719	0.262	0.855
4	23:51:47.355	+16:15:53.19	12.718	0.578	0.047	0.741
5	23:51:52.413	+16:11:17.04	12.662	0.817	0.554	0.953
6	23:51:39.154	+16:18:11.99	13.171	0.553	−0.071	0.786
7	23:51:48.158	+16:15:05.47	13.340	0.929	0.837	1.031
8	23:51:46.383	+16:14:58.90	13.461	0.628	0.102	0.772
9	23:51:35.455	+16:12:49.35	13.557	0.880	0.587	1.018
10	23:51:48.000	+16:14:00.87	13.635	0.705	0.286	0.839
11	23:51:57.916	+16:17:28.75	14.065	0.715	0.444	0.831
12	23:51:44.723	+16:14:45.51	14.242	0.681	0.199	0.831
13	23:51:48.862	+16:10:58.80	14.278	0.743	0.372	0.864
14	23:51:52.312	+16:11:71.07	15.209	0.835	0.543	0.964
15	23:51:37.259	+16:18:02.02	15.346	0.532	−0.077	0.715
16	23:51:47.501	+16:12:48.21	15.618	0.997	1.108	1.072

cluster still remains a somewhat doubtful case, due to the absence of clear features in the CMDs.
– NGC 7772 is a less doubtful case. We showed that the cluster underwent strong low mass star depletion. What remains is a group of 14 stars 1.5 Gyr old and located 1.5 kpc away from the Sun.

It is worth noting that the present results must be considered with some caution, and that the list of members must be better constrained by determining individual star radial velocities and proper motions. In this way these objects can become templates for *N*-body simulation aimed at investigating the dynamical evolution of open star clusters and the origin of the field star population

Acknowledgements. I am deeply indebted to Nando Patat and Sandro Villanova for numerous very useful conversations. I acknowledge Giorgio Martonara and Franco Bocchi for the kind night assistance. This study made use of the Simbad database.

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