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CCD *BV* photometry of the intermediate age open cluster NGC 1245*

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Abstract. A new CCD color magnitude diagram (CMD) for the intermediate age open cluster NGC 1245 is presented. The cluster appears to be rich, but loose, irregular and very broad. Adopting the metallicity value of $[Fe/H]$ = +0.14 from Lynga (1987) we obtain a color excess E_{B-V} = 0.26, an apparent distance modulus $(m - M)$ = 13.20, and an age of 8.0×10^8 yr. This puts NGC 1245 at a distance of about 3.0 Kpc from the Sun. The analysis of the CMD shows the presence of various field populations, and some evidences of differential absorption.

Key words: open clusters: NGC 1245 – HR diagram – stars: luminosity function

1. Introduction

The fundamental role of the family of intermediate age and old open clusters in probing Galactic Disk chemical and dynamical evolution has long time ago been recognized by King (1964), who firstly gave a list of possible old disk objects. In fact the ages of these clusters population span most of the disk lifetime and consequently this population traces the entire disk history till now. Moreover the age difference between the oldest disk clusters and the youngest halo globulars provides important clues on the formation, the structure and early evolution of the Galactic Disk. Subsequent more detailed lists have been proposed by Janes & Adler (1982), Janes (1988) and Janes & Phelps (1990). As a consequence of this a significant number of good quality CMDs of intermediate age and old open clusters are becoming available, due to the efforts of several researchers (Kaluzny 1990; Janes & Phelps 1990; Twarog et al. 1993 and references therein).

In the sixties at the Asiago Astrophysical Observatory a photographic UBV study of a sample of intermediate age open clusters (NGC 6939, NGC 1245 and others) has been performed by Chincarini (1963, 1964) using the 1.22m telescope. Nowadays the availability of a larger and CCD equipped telescope has given us the possibility to re–observe these objects to obtain more reliable CMDs. It is important to stress that these clusters are not observable with the technologically more advanced, best sited southern hemisphere telescopes. So we have decided to undertake an observational program of re–analysis of northern open clusters with the aim to obtain updated photometric data and more reliable age determinations.

The cluster here presented is NGC 1245 ($\alpha = 3^h\ 11^m.2$, $\delta = +47^o\ 4'$, $l = 146^o.6$, $b = -8^o.9$; Eq. 1950.0), also designated with the IAU denomination C0311+470, and has been previously studied by Hoag et al. (1961) and Chincarini (1964). The cluster occupies a large sky area (about $15' \times 15'$), shows an irregular structure and suffers most probably a differential reddening. It has a supersolar metal abundance, according to Lynga (1987), who gives $[Fe/H]$ = +0.14. Only another old cluster, NGC 6791, is known to be so metal rich (see Friel & Janes 1993, Table 4). It is clear that assigning to NGC 1245 a reliable age could improve our knowledge of the age–metallicity relation (AMR) holding for the Galactic Disk (Carraro & Chiosi 1994).

In Sect. 2 we present the observations and the data reduction; Sect. 3 discusses the cluster structure and density profile; Sect. 4 describes the features of the resulting CMD; the photometric incompleteness of the data, the field stars subtraction and the luminosity function are presented in Sect. 5. Finally Sect. 6 is devoted to the determination of color excess, distance modulus and age of NGC 1245, while some concluding remarks are given in Sect. 7.

2. Observations, data reduction and photometric errors

The major difficulty with NGC 1245 is its large extension on the sky with respect to the used instrumental setup. The observations have been performed by the Asiago CCD imaging camera mounted at the Cassegrain focus of the 1.82m telescope, equipped with a Tektronic AR–Coated 512×512 pixels array. The scale on the chip is $0''.34$/px, and consequently the sky area covered by a single frame is about $2'.9 \times 2'.9$. This fact has

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* Based on observations carried out at Mt. Ekar, Asiago (Italy)

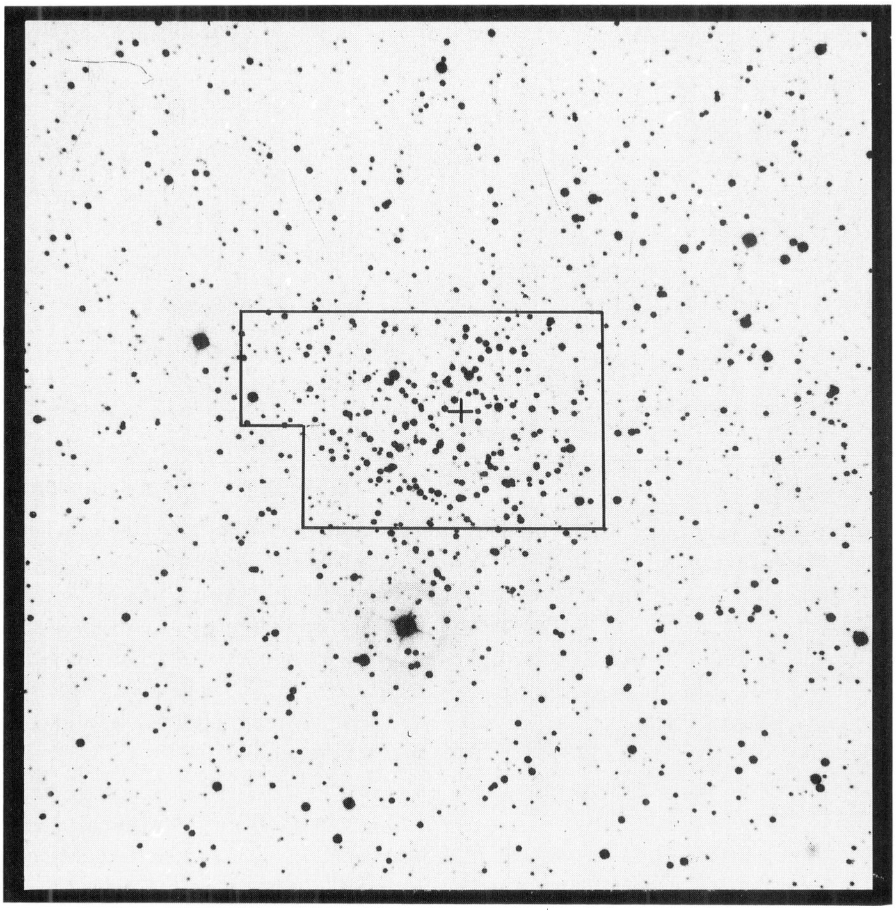

Fig. 1. Photographic B image of NGC 1245 from a plate of Chincarini (1964); the north is upward, the east lefttward. The scale on this chart is 23″.0/mm . The continued line defines the cluster portion studied while the cross indicates the adopted cluster center

forced on us to divide the cluster into 7 subregions, and then to join together the single fields.

The cluster was observed during three nights, only the first of which was photometric with an average seeing of 2″.0 (FWHM). Figure 1 shows a photographic B image of NGC 1245 with superimposed the area covered by our study, while Table 1 summarizes our observations. In this table each field is identified by its center coordinates (X_C and Y_C, expressed in arcmin) with respect to the adopted cluster center (see Fig. 1).

The photometric reduction has been performed at the Department of Astronomy in Padova using DAOPHOT II and the accompanying program ALLSTAR (Stetson 1991). The transformation equations from the instrumental (b-v) and v to the (B-V) and V Johnson system are:

$$V = v + 0.022 \cdot (B - V) - 1.968 \quad (1)$$

$$(B - V) = 1.227 \cdot (b - v) - 0.719 \quad (2)$$

The color coefficients in the above equations are derived from the Rubin 149 standard field (Landolt 1992) observed during the first night, while the zero points are derived by means of 9 stars in common with the photoelectric survey of Hoag et al. (1961). The errors affecting this calibration are expected to be of the order of 0.03 mag. The Rubin 149 standard stars $B - V$ indexes range from -0.129 to 1.115. Due to this the magnitudes and colors of the redder stars ($(B-V > 1.2)$) were extrapolated. All the observations have been reported to this calibration by means of stars in common between frames obtained in different nights.

The resulting magnitudes and colors, together with the RMS errors σ, are not reported here, but are available upon request. The standard deviations σ are a direct output of the ALLSTAR program and have to be considered as lower limit for the photometric errors. More realistic estimates are achievable by means of experiments with artificial stars (see Vallenari et al. 1991 for a detailed description of the adopted procedure). Applying the same procedure to the field #3 (see Fig. 4), that shows the better Main Sequence (MS), we obtain errors of 0.05, 0.09 and 0.13 at B = 14.5, 16.5 and 18.5 respectively, and of 0.05, 0.08 and 0.14 at the same values of the V magnitude. These uncertainties are consistent with the DAOPHOT outputs, which for the V passband at the same magnitude levels gives, on the average, errors of 0.05, 0.06 and 0.10 respectively.

Finally another estimation of the photometric errors derives from the MS natural width measured on the reference field #3. At the same above magnitude levels we found color dispersions of 0.15, 0.20 and 0.25, respectively. These latter values clearly take into account various effects, such as possible metallicity

Table 1. Journal of observations, 1.82m , Mt. Ekar, Asiago (Italy)

Field	X_C (′)	Y_C (′)	Date (UT)	Time (UT)	Filter	Exposure (secs)	FWHM (″)
#1	0.0	1.3	Dec. 09, 1993	21^h15^m	V	300	2.0
#1			Dec. 09, 1993	21^h35^m	B	900	1.9
#2	1.3	1.3	Dec. 09, 1993	21^h56^m	V	300	1.9
#2			Dec. 09, 1993	22^h11^m	B	900	2.1
#3	-1.3	1.3	Dec. 09, 1993	22^h33^m	V	300	2.1
#3			Dec. 09, 1993	22^h46^m	B	900	2.0
#0	-18.0	18.0	Dec. 09, 1993	23^h22^m	B	1200	2.2
#0			Dec. 09, 1993	23^h42^m	V	400	2.1
#5	-1.3	-1.3	Dec. 11, 1993	22^h41^m	V	300	2.4
#5			Dec. 11, 1993	22^h55^m	B	900	2.6
#6	1.3	-1.3	Dec. 11, 1993	23^h07^m	B	900	2.9
#6			Dec. 11, 1993	23^h30^m	V	300	2.6
#4	0.0	-1.3	Jan. 15, 1994	18^h51^m	V	300	3.0
#4			Jan. 15, 1994	19^h03^m	B	900	2.7
#7	-2.6	1.3	Jan. 15, 1994	22^h10^m	B	900	2.7
#7			Jan. 15, 1994	22^h23^m	V	300	2.6

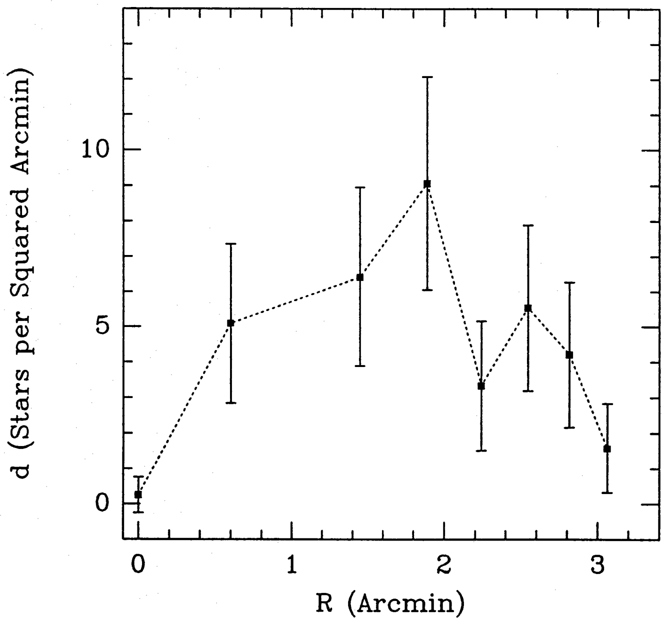

Fig. 2. Star counts in NGC 1245 as a function of the radius

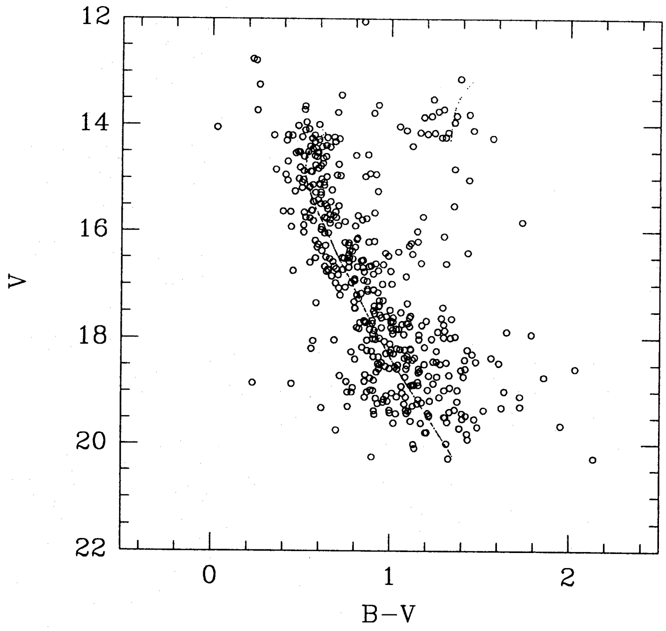

Fig. 3. CMD for all the stars studied in the region of NGC 1245. The isochrone on the plot has been drawn adopting E_{B-V}=0.26 and $(m-M)$=13.20. See the discussion in the text

and age dispersions, the presence of a fraction of unresolved binary stars and a suspected differential reddening.

3. Cluster structure

We have investigated the geometrical structure of NGC 1245 selecting from the covered area a circular region of radius 3′.0 with the center as in Fig. 1. At a first glance the cluster appears to be distorted toward the North-West direction and presents a lack of stars near the center. In order to study the stars distribution we have computed a radial density profile, counting the stars confined in concentric coronae of constant area at increasing distances from the cluster center. We have chosen the stars in the magnitude interval $15 \leq V \leq 17$ and taken into account the effects of the possible field stars contamination. This has been possible thanks to the availability of a field (frame #0, see below) far away from the cluster (25′ from the center, in the N–W direction). The star counts in this field show that the number of stars per squared arcmin in the range $15 \leq V \leq 17$ is about 1.1. By the way this result is in good agreement with the values reported by Ortolani (1994 private communication) in different directions of the Galactic Disk (Ortolani et al. 1993). After these corrections the radial profile turns out to be as in Fig. 2 and shows an irregular shape with the maximum density at about 2′ out of the center.

4. The color–magnitude diagram

4.1. General features

The resulting CMD of NGC 1245 for all the studied stars (454) is shown in Fig. 3, while in Fig. 4 we have plotted the CMDs derived for the single frames. The global CMD has been obtained using the stars belonging to each subregion, while for the stars in common between two or more frames we have computed the mean magnitudes.

Despite the presence of a certain amount of field stars both on the right and on the left of the MS, the principal features of the CMD are visible. The main sequence extends 5 magnitudes below the turn off point, located at $V \simeq 14.5$, $B-V \simeq 0.60$, while a red clump of probable He-burning stars is at $V \simeq 14.1$, $B-V \simeq 1.4$. Moreover the Hertzsprung gap appears to be

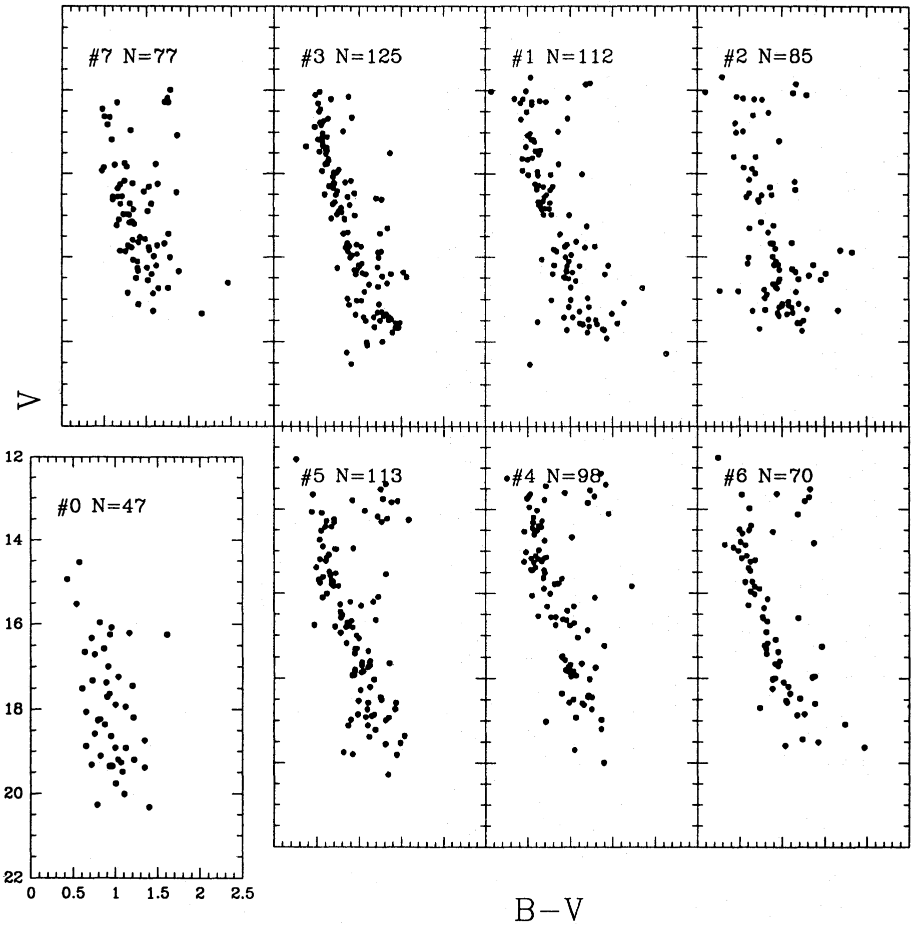

Fig. 4. CMDs for the single frames distributed as on the sky. Frame #0 refers to a field 25′ distant from the center of NGC 1245 (see Fig. 1 and Table 1)

poorly populated, in agreement with the results of Chincarini (1964).

The overall morphology of this CMD closely resembles those of NGC 2477 (Hartwick et al. 1972), NGC 2660 (Hartwick & Hesser 1973), and NGC 4815 (Carraro & Ortolani 1994) suggesting that NGC 1245 is of intermediate age. The scatter of the main sequence band is likely due to several reasons, e.g. the presence of a field stars component and unresolved binary stars. Looking carefully at Fig. 4 one can see that the population on the blue side of the MS comes randomly from all the frames, suggesting that these stars belong to a field population less absorbed and probably located between us and the cluster. Moreover the frames #2 and #6 appear to be the major contributors to the field population on the red side of the MS, and it is reasonable in that these portions are at the border of the cluster: the same argument holds for the frame #7. The frames #1, #3 and #4 are the cleanest ones, suggesting that the cluster center is inside this region. Finally the frame #0 has been taken far away from the cluster and represents a disk field population toward the direction of NGC 1245.

The CMD in Fig. 3 is consistent with that obtained by Chincarini (1964) who studied about 500 stars on a region nearly two times larger, and with that of Hoag et al. (1961) who studied about 200 stars. The present work supersedes the previous ones for the larger number of detected objects and the limiting magnitude ($\sim$ 3 mag deeper).

4.2. Differential reddening in NGC 1245

Another interesting feature which emerges from Fig. 4 is the systematic difference in stars number between the northern and the southern region of the cluster. In other words we found that the lower frames are 10 $\div$ 15% less populated than the upper ones. The same suspicion arises looking at the Palomar Sky Survey chart in the NGC 1245 neighborhoods. To explain this appearance we propose that the cluster may be differentially obscured.

In order to check the reliability of this work hypothesis we have performed the following series of tests. Firstly we have separately plotted the CMDs for the upper and lower portions of the cluster and compared them with those obtained using the data of Chincarini (1964). As one can see from Fig. 5, the southern sequences appear to be systematically redder than the northern ones for both the data sets.

To quantify this trend we have studied the $(B-V)$ color distribution along the N-S direction, selecting the central frames #1 and #4 for the MS stars in the magnitude bin $15 \leq V \leq 17$ (see Fig. 6). A least squares fit on this sample gets a color gradient of 0.04 mag arcmin^{-1} southward. On the basis of this

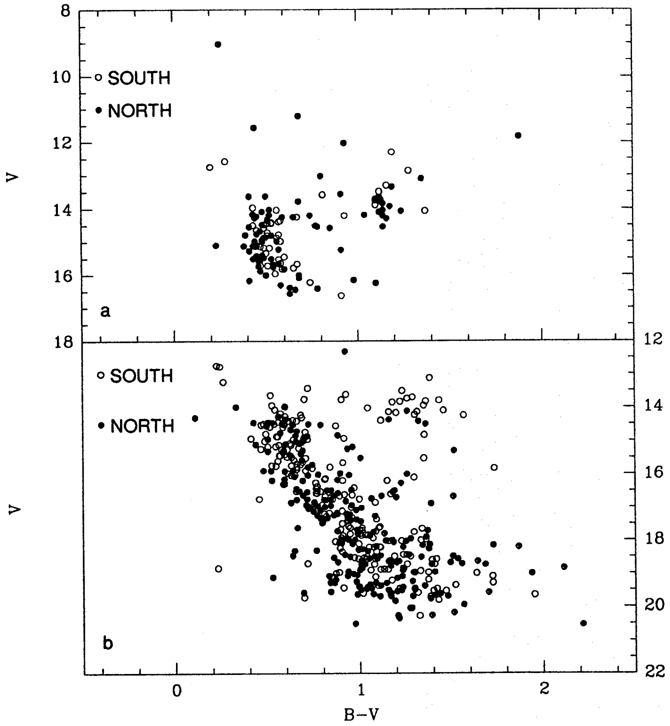

Fig. 5a and b. CMDs for the northern and southern portions of NGC 1245. Panel **a** Chincarini (1964); panel **b** present work

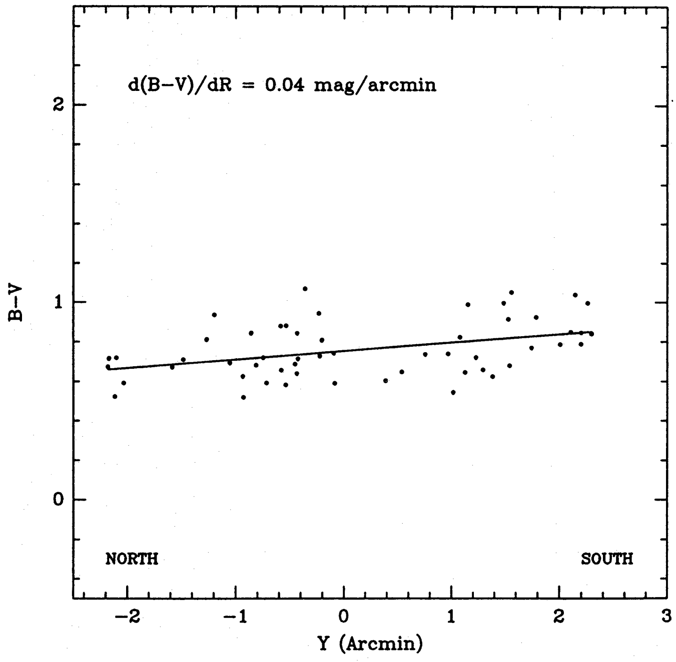

Fig. 6. (B-V) Color distribution in NGC 1245 along the North–South direction

Table 2. Individual color excesses and distance moduli

Field	E_{B-V}	$(m-M)$	A_V
#1	0.24	13.1	0.72
#2	0.24	13.1	0.72
#3	0.26	13.2	0.78
#4	0.31	13.3	0.93
#5	0.31	13.3	0.93
#6	0.33	13.4	0.99

Note: A_V has been computed as $3.0 \times E_{B-V}$

Table 3. Completeness factors Λ relative to the template frame #3

mag. int.	Λ_V	Λ_B
≤ 15.0	100%	100%
$15.0 \div 16.5$	91%	90%
$16.0 \div 17.5$	73%	70%
$17.0 \div 18.5$	53%	50%
$18.0 \div 19.5$	10%	10%
$19.0 \div 20.5$	2%	1%

estimate we expect to find the lower cluster region CMDs ~0.1 mag redder than the upper ones. A similar test performed in the E-W direction shows no trends.

As a final check we have superimposed on each CMD a best fit isochrone (see the discussion below) to obtain the individual values of E_{B-V} and $(m-M)$ reported in Table 2. The difference between the average northern and southern E_{B-V} turns out to be $\Delta(E_{B-V}) = 0.07 \pm 0.04$. This finding is in agreement with the previous results, and suggests that the broadness of the MS could be also explained by the presence of a differential absorption across the cluster. Analogous results have been obtained by Hartwick et al. (1973) in their analysis of NGC 2477, a thin disk cluster of the same generation.

5. Correction for incompleteness and field stars subtraction

5.1. Photometric completeness

In order to test the degree of completeness in the present study we have performed some experiments with artificial stars by means of the ADDSTAR routine of DAOPHOT II. Also in this case we have adopted the CMD from the field #3. In Table 3 the completeness parameter Λ for B and V magnitude is shown respectively. It has been computed following the method described by Vallenari et al. (1991), introducing in the original frames a number (usually 30) of artificial stars randomly distributed in a fixed magnitude interval. Then we have re–reduced the frames in the same way, and derived the ratio between the stars recovered and the stars injected. This is an important step in order to compare the observed CMD with the theory. Looking at Table 3 one can see that severe incompleteness problems arise starting from the magnitude $V = 18.5$.

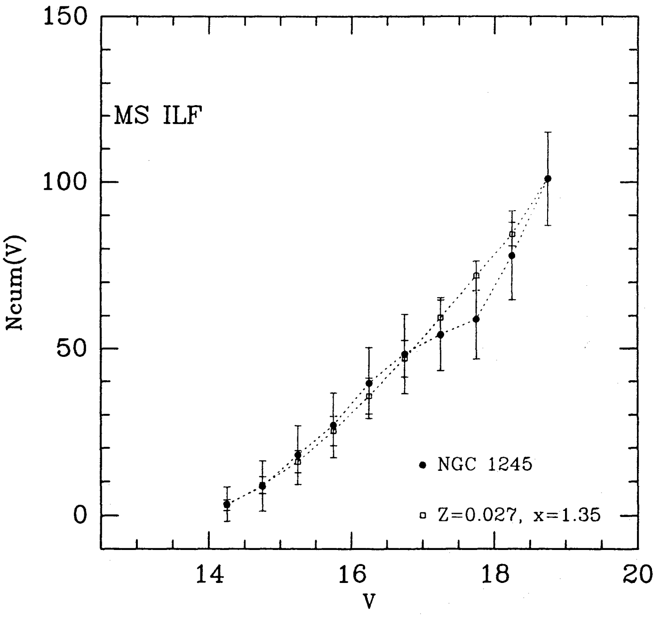

Fig. 7. MS integrated luminosity function (ILF) for the frame #3. A theoretical ILF computed adopting a Salpeter x = 1.35 index for the initial mass function is superimposed. See the text for more details

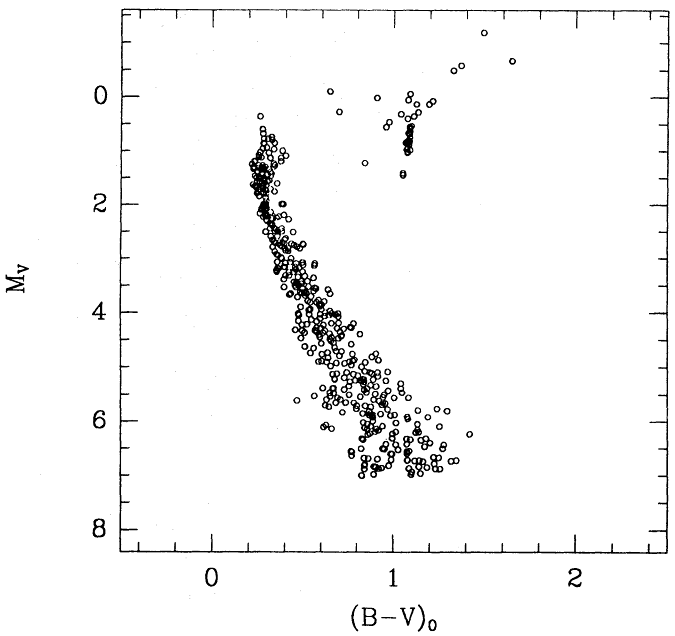

Fig. 8. A best fit synthetic CMD: the age is $8.0 \cdot 10^8$ yrs and the metallicity is Z=0.027

5.2. Field stars subtraction and MS luminosity function

In Fig. 7 we present an integrated luminosity function (ILF) of the MS for the template field #3. It has been derived subtracting the MS luminosity function of the field population (frame #0) to the frame #3, after correcting for the incompleteness factors obtained in the B passband. The error bars take into account the errors in star counting and the errors arising from the incompleteness corrections. The MS has been cut at $V \simeq 18.50$ to avoid incompleteness corrections greater than 50%.

6. Color excess, distance modulus and age of NGC 1245

Chincarini (1964) by means of the two colors diagram found a color excess E_{B-V}=0.26 and an apparent distance modulus $(m-M)$=12.63. Making use of an analytical expression he estimated an age of $8.0 \cdot 10^8$ yrs. At the same time he demonstrated that the cluster should be metal rich because the ultraviolet excess $\delta(U-B)$ is near to zero. This result is confirmed by Lynga (1987) that gives a metal abundance $[Fe/H]$ = +0.14. Using the relation

$$logZ = 0.977 \cdot [Fe/H] - 1.699 \tag{3}$$

from Bertelli et al. (1994), a Z value of 0.027 is derived.

Adopting the synthetic CMD technique (see Carraro et al. 1993 for a detailed description of the method) we have built up several theoretical CMDs imposing the number of stars that lie between 15.50 and 16.50 in the MS of our NGC 1245 CMD (Fig. 3): this interval has been chosen in order to avoid incompleteness problems at fainter magnitudes and evolutionary effects at brighter magnitudes. All the foreground stars have been removed. Moreover we have imposed the presence of a fraction of binary stars (15%) with mass ratio in the range 0.9 ÷ 1.1. A small age dispersion of $5.0 \cdot 10^7$ yrs and a simulation of the photometric errors are also included. The models adopted are those including the convective overshoot, and are from Bressan et al. (1993). The best fit is obtained with an age of $8.0 \cdot 10^8$ yrs, and simultaneously we get a color excess E_{B-V} = 0.26, an apparent distance modulus $(m-M)$ = 13.20 and a correspondent true distance modulus $(m-M)_0$=12.42. A typical synthetic CMD is shown in Fig. 8.

A similar result comes out using the age calibrator built up by Carraro & Chiosi (1994): from a measured ΔV = 0.40 (the magnitude difference between the clump and the turn off), an age of about 7.0×10^8 yrs can be derived.

We have finally computed a theoretical ILF for the MS stars, averaging the results of star counts in 50 simulated CMDs. This ILF has been derived adopting the Z=0.027 metal abundance, the age above obtained and an initial mass function (IMF) of Salpeter type, with a variable coefficient x. We found that for $x = 1.35 \pm 0.10$ a good agreement with the experimental ILF can be achieved: the result is shown in Fig. 7. Looking carefully at this plot one can see a lack of stars in the magnitude interval $17.5 \leq V \leq 18.0$. This fact reproduces the presence of a gap in the MS of NGC 1245 at the same magnitude level (see Figs. 3 and 4).

7. Discussion and conclusions

This paper has been devoted to the presentation of a new CCD CMD for the intermediate age open cluster NGC 1245, previously studied by Hoag et al. (1961) and Chincarini (1964). The new CMD supersedes the previous ones for the larger number of objects detected and for the greater extension of the MS, down to $V \simeq 20.0$. This fact allows us to better estimate the fundamental parameters of the cluster, such as the color excess, the distance modulus and the age. Adopting the metal abundance $[Fe/H] = +0.14$ from Lynga (1987) we get a color excess $E_{B-V} = 0.26$, a distance modulus $(m - M) = 13.20$ and an age of 800 Myrs. While the color excess is consistent with the values from Chincarini (1964) and Hoag et al. (1961), the distance modulus turns out to be significantly greater and this puts NGC 1245 about 0.5 Kpc farther. The ILF we have obtained for the MS stars confirms that the IMF for NGC 1245 is a classical Salpeter one, with a coefficient $x = 1.35$. The inclusion of NGC 1245 in the AMR for the Galactic Disk does not alter significantly the global trend (see Carraro & Chiosi 1994, Fig. 4).

We have discussed the various features of the CMD, showing that NGC 1245 most probably suffers a differential reddening, that together with the photometric errors provide an explanation of the broadness of the MS band, and that the cluster CMD is contaminated by different field populations. Finally the radial density profile shows that NGC 1245 has an irregular and inhomogeneous structure.

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