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Deep CCD BV photometry of the poorly studied open cluster NGC 4815*,**

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Abstract. — We report BV Johnson CCD photometry of 2498 stars in the region of the poorly studied open cluster NGC 4815. This object appears in the Janes (1988) list of possible old open clusters. NGC 4815 lies in the galactic plane, in a region of strong absorption. The color magnitude diagram (CMD) we derive shows that NGC 4815 has about the Hyades age (5 10^8 yr) and a probable lower than solar metal abundance. The color excess E_{B-V} and the distance modulus $(m - M)$ turn out to be 0.70 and 14.10, respectively. Accordingly a distance of 2.5 Kpc from the Sun is derived. The luminosity function (LF) we obtain for the main sequence (MS) stars is consistent with a Salpeter (x=1.55) initial mass function (IMF).

Key words: open clusters: NGC 4815: HR diagram — luminosity function

1. Introduction

The population of Galactic intermediate age and old open clusters has been in the last years diffusively studied to investigate topics both in the Stellar Evolutionary Theory and in Galactic Structure and Evolution. For a review on these subjects see Friel & Janes (1993), Carraro & Chiosi (1994) and references therein.

The main problem one has to deal with is the paucity of clusters in this age range, due to both the past dynamical history of this population and selection effects, related to the fact that several objects are hardly detectable in that located in contaminated and strongly absorbed regions of the galactic plane.

Janes (1988) has compiled a list of possible old open clusters, on the base of an inspection of the Palomar Sky Survey charts.

Since that time, due to the efforts of many researchers, this list has been exhausted almost completely.

A new updated list has been proposed by Janes & Phelps (1990) with the aim to find the oldest open cluster.

In fact topics such as the chemical evolution and the structure of the galactic disk can been better settled only after a larger sample of photometrically studied clusters will be available.

With the aim to contribute to the progress in our understanding of this population we have undertaken an observational program to obtain reliable CMDs of those clusters that to our knowledge are unstudied or poorly studied.

In this paper we present CCD BV photometry for the southern open cluster NGC 4815 ($\alpha = 12^h54^m.6, \delta = -64°41', l^{II} = 303°.63, b^{II} = -2°.09$; Eq. 1950.0).
The resulting CMD is compared with theoretical isochrones in order to obtain an estimation of the age, the color excess and the distance modulus.

The crucial target is to assign to the cluster a reliable age and to place it in the right disk population.

In Sect. 2 we present the observations and the data reduction; Sect. 3 shows the CMD; Sect. 4 discusses the photometric incompleteness of the data and field stars subtraction; Sect. 5 is devoted to the determination of color excess, distance modulus and age of NGC 4815. Some concluding remarks are given in Sect. 6.

2. Observations, data reduction, and photometric errors

Six Johnson-Cousins BV CCD images (three in B and three in V) of NGC 4815 (long, medium and short exposures) have been obtained with the NTT 3.5 m telescope (equipped with the Thomson CCD ESO #17 , whose dimensions are 2000 × 2000) at the European Southern Observatory (ESO), La Silla, Chile, in June 1993.

*Based on observations carried out at the European Southern Observatory, La Silla, Chile

**Table 2 is available in electronic form: see the Editorial in A&A 1994, Vol. 280, No. 3, p. E1/ A&AS 1994, Vol. 103, No. 1

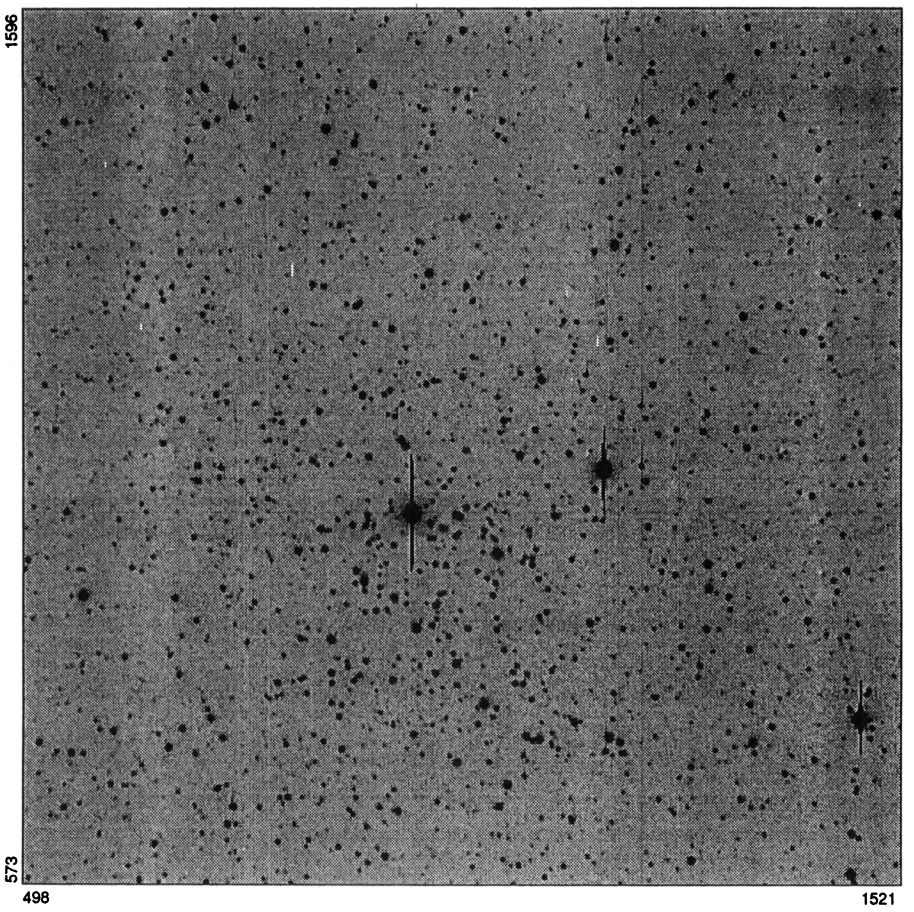

Fig. 1. V NTT image of NGC 4815; the north is upward, the east rightward. The field is $6'.2 \times 4'.2$

The pixel size is $0''.37$. Correspondingly the field is $12'.3 \times 12'.3$. The night was only partially photometric with a seeing of about $1''.1$.

Table 1 presents the Journal of the observations, while Fig. 1 shows an NTT image of NGC 4815 in the V passband.

The photometric reduction has been performed with the VAX/4000 at the Department of Astronomy in Padova using DAOPHOT II and the routine ALLSTAR (Stetson, 1991).

The transformation equations from the instrumental $(b\text{-}v)$ and v to the $(B-V)$ and V Johnson system are:

$$V = v + 0.00(B-V) + 2.745 \quad (1)$$

$$(B-V) = 0.91(b-v) - 0.909 \quad (2)$$

Table 1. Observationnal log, 3.5 m NTT, ESO La Silla

Date (UT)	Time (UT)	Filter	Exposure Time (secs)	Seeing (arcsec)
Jun. 16, 1993	$01^h37^m18^s$	V	6	1.30
Jun. 16, 1993	$01^h43^m33^s$	V	60	1.10
Jun. 16, 1993	$02^h02^m24^s$	B	300	1.20
Jun. 16, 1993	$02^h17^m03^s$	B	300	1.10
Jun. 16, 1993	$02^h28^m00^s$	V	300	1.00
Jun. 16, 1993	$02^h52^m55^s$	B	600	1.00

The color coefficients in the above equations are derived from Landolt (1992) fields, while zero points are determined by comparison with 10 stars in common with the photometric study of Kjeldsen & Frandsen (1991, Table A3). The standard deviations affecting the zero points in these equations are 0.03 mag.

The resulting magnitudes and colors, together with the frame X and Y coordinates and the standard deviation σ, are reported in Table 2 (accessible in electronic form). 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). Following the same procedure we obtain errors of 0.01, 0.04 and 0.08 at $B = 15.5$, 17.5 and 19.5 respectively, and of 0.02, 0.05 and 0.07 at the same values of the V magnitude. These uncertainties are consistent with the DAOPHOT outputs, which for the V passband at the same magnitute levels gives , on the average, errors of 0.02, 0.03 and 0.06 respectively.

Another estimation of the photometric errors derives from the MS natural width. At the same above magnitude levels we found dispersions in color of 0.05, 0.11 and 0.14, respectively. These latter values clearly take into account also the effect of a possible age dispersion ,the presence of a fraction of unresolved binary stars and a possible internal reddening.

From a comparison between the DAOPHOT outputs and the errors derived from the artificial stars experiments the residual errors at the same magnitude levels turn out to be about 0.02, 0.04 and 0.07, respectively. If these latter are tentatively attributed to a metallicity spread effect, the dispersion in abundance in NGC 4815, measured by the index [Fe/H], would be lower than 0.05 dex.

3. The c-m diagram

The resulting CMD for NGC 4815 is shown in Fig. 2.

Despite the presence of a considerable number of field stars, the principal features of the CMD are visible. The main sequence extends 5 magnitudes below the turn off point, located at $V \simeq 14.7$, $B - V \simeq 0.70$, while a red clump of probable He-burning stars is at $V \simeq 14.3$, $B - V \simeq 1.5$.

The overall morphology of this CMD resembles those of NGC 2477 (Hartwick et al. 1972), NGC 5822 (Twarog et al. 1993) and NGC 2660 (Hartwick & Hesser 1973), suggesting that NGC 4815 is of intermediate age.

The scatter of the main sequence band is probably due to the presence of a field stars component (see the discussion below) and unresolved binary stars.

The cluster appears to be strongly reddened: this results is in agreement with the predictions of Neckel & Klare (1980) that propose for the galactic disk in the direction of NGC 4815 a visual absorption $A_V(R) \simeq 1.0$ kpc^{-1}.

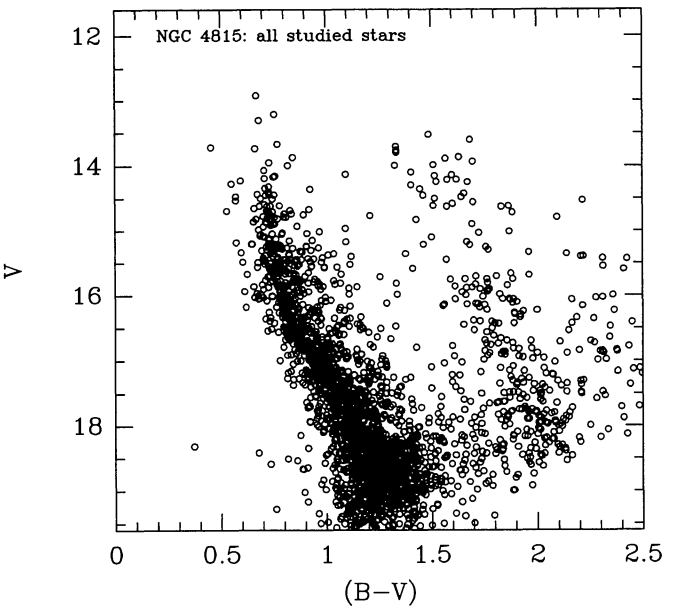

Fig. 2. CMD for all the stars studied in the region of NGC 4815

This CMD is consistent with that obtained by Kjeldsen & Frandsen (1991) , who studied 599 stars in the same region. But due to the larger number of objects detected better results can be derived from the present study.

Finally we recall the photometric study by Moffat & Vogt (1973) , who measured only 9 stars and do not recognized any sequence.

4. Correction for incompleteness and field stars subtraction

4.1. *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.

In Table 3 are shown the completeness parameter Λ for magnitude B and V respectively. They have been computed following the method described by Vallenari et al. 1991. Going in some details we have introduced in the original frames a number (usually 100) 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 incompleteness problems arise only at faintest magnitudes.

Table 3. NGC 4815: Completeness Factors Λ

mag. int.	Λ_B	Λ_V
≤ 15.0	100%	100%
15.0 ÷ 16.5	99%	100%
16.0 ÷ 17.5	99%	97%
17.0 ÷ 18.5	98%	85%
18.0 ÷ 19.5	64%	71%
19.0 ÷ 20.5	5%	7%

4.2. *Field stars subtraction and MS luminosity function*

The CMD of NGC 4815 shown in Fig. 2 clearly indicates the presence of a significant fraction of field stars.

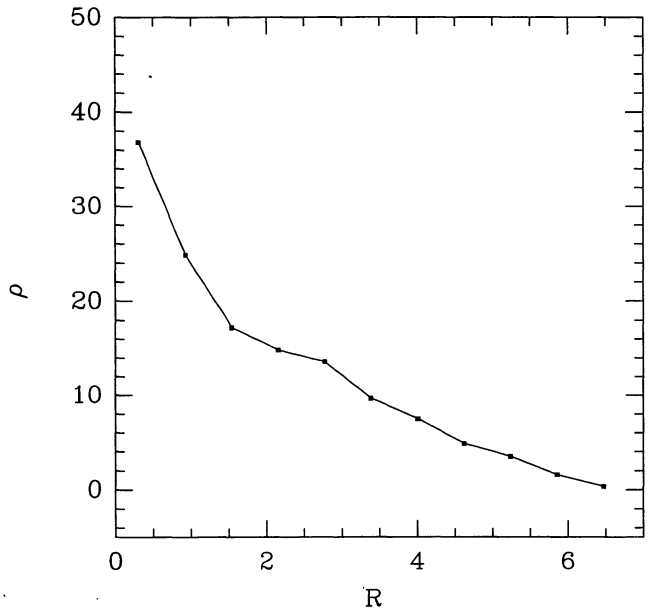

Fig. 3. Star counts in NGC 4815 as a function of the radius. The radius is in arcmin, the density in arcmin^{-2}

To isolate the cluster members we have operated in the following way.

In Fig. 3 we show the density profile (number of stars per unit of area at increasing distance from the cluster center).

Looking carefully at this plot one can see that the slope of the density profile becomes lower than the average at about 4′.6 (750 pixels). This fact allows us to reasonably infer that the cluster radius is lower than about 4′.6, and out of this distance there is only field. A confirmation of this result derives from an inspection of the ESO charts, from which a cluster radius of about 3′ can be measured. Finally Janes (1988) gives for NGC 4815 a diameter of 5′.0.

The CMD for the stars within 4′.6 of the center (2105 objects) is shown in Fig. 4, while in Fig. 5 we have plotted the same diagram for the stars out of the same distance (393 in total).

It could be of some interest to compute the number of stars per unit of area in this field within a certain magnitude interval. We have chosen the stars between $V = 15.00$ and $V = 17.00$ to avoid incompleteness problems. The stars density we found turns out to be about 1.2× arcmin^{-2}, and basically agrees with the results of star counts on the galactic plane at $l = 180$ and $l = 90$ by Ortolani (private communication).

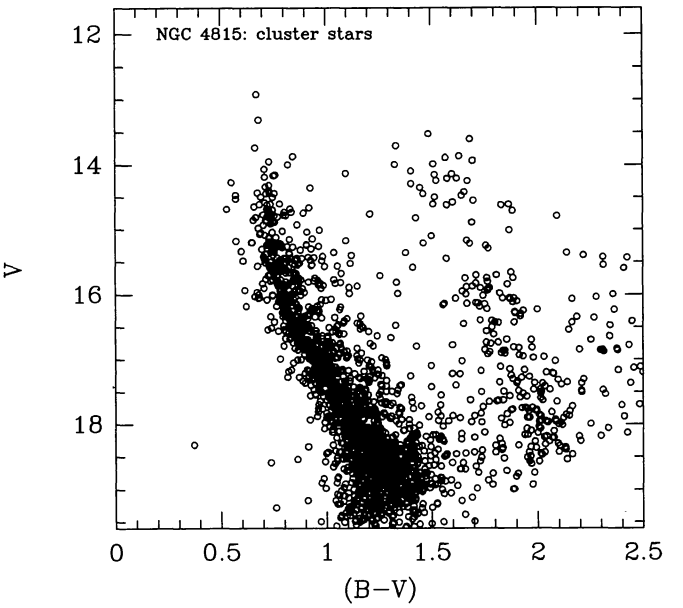

Fig. 4. CMD of NGC 4815 for all the stars within 4′.6 of the center

After having normalized the two samples to the same area, we have subtracted from the MS luminosity function of the cluster the luminosity function of the field, taking into account the effect of the data incompleteness in the *B* passband.

The integrated LF (ILF) is plotted in Fig. 6. The error bars take into account errors from the number counts and from incompleteness corrections. In order to compare this LF with the theoretical counterpart we have cut the MS at magnitude V=19.00, where the incompleteness corrections became higher than 50%.

5. Color excess, distance modulus and age of NGC 4815

Our analysis of NGC 4815 is based on the CMD shown in Fig. 4.

The major problem in determining the age of NGC 4815 is the absence of data about the metal abundance [Fe/H]. What we know is that this cluster is very low in the galactic plane and is projected on the Galactic Center direction.

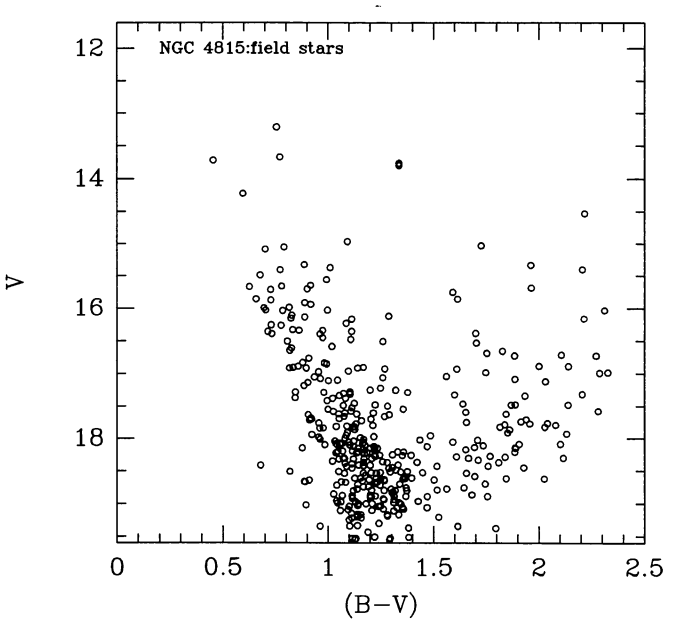

Fig. 5. The same as Fig. 4, but for all the stars beyond 4′.6 from the center

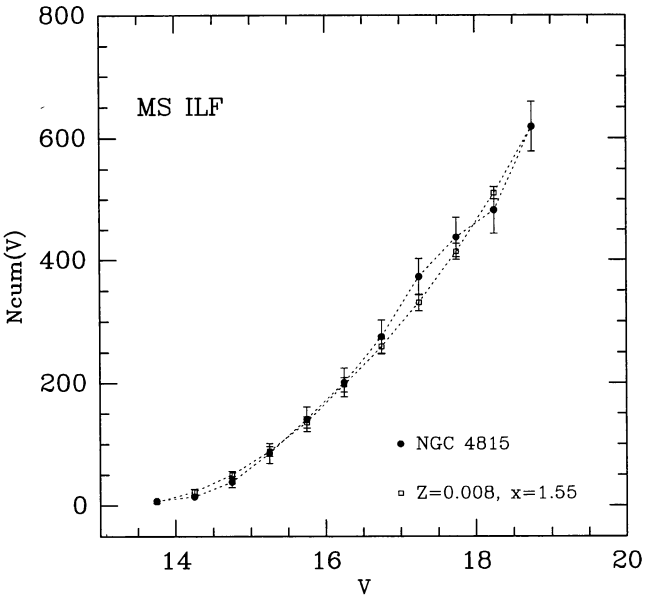

Fig. 6. MS ILF for NGC 4815: only MS cluster stars. The theoretical ILF is for an age of 5 10^8 yr, Z=0.008 and x=1.55. See the text for more details

So a reasonable working hypothesis could be to assume a solar (Z=0.020) metal content.

Adopting the synthetic CMD technique (see Chiosi et al. 1989 for a detailed description) we have built up several theoretical CMDs matching the number of stars that lie between 15.50 and 17.50 in the MS of our NGC 4815 CMD: this interval has been chosen in order to avoid incompleteness problems at faintest magnitudes and evolutionary effects at brightest magnitudes, and all foreground stars have been removed.

Moreover we have included the presence of a fraction of binary stars (33%) with mass ratio in the range $0.5 \div 1.5$.

A small age dispersion of 5 10^7 year 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) and from Fagotto et al. (1993).

The best fit is obtained with an age of 5 10^8 yr, and simultaneously we get a color excess $E_{B-V} = 0.70$ and a distance modulus $(m - M) = 14.10$.

With the same technique CMDs are computed adopting the lower than solar metal contents Z=0.008 and Z=0.004. The results are shown in Table 4 and summarized in Fig. 7.

The range in age of isochrones that make an acceptable fit to the observed CMD is approximately 10%. A similar result comes out using the age calibrator built up by Carraro & Chiosi (1994): from a measured $\Delta V = 0.20$ (the magnitude difference between the clump and the turn off), an age of 4.8 10^8 yr can be derived.

The global best fit CMD is obtained for Z=0.008, a metal content lower than solar, and an age of 5 10^8 yr.

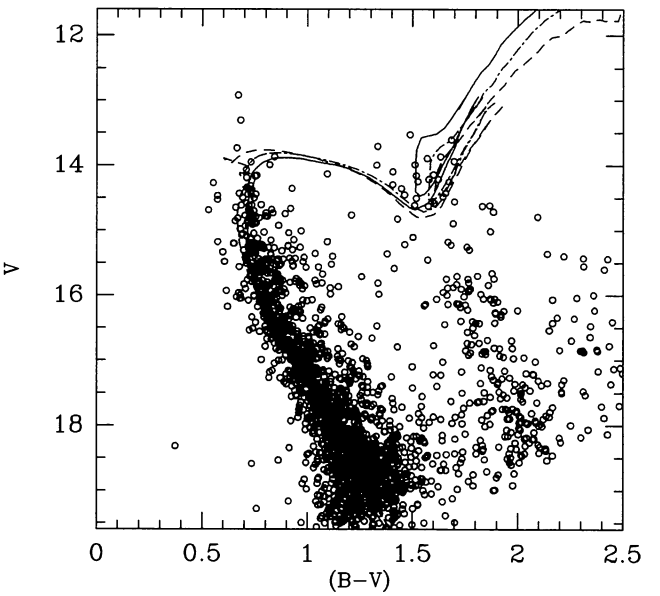

Fig. 7. The CMD of NGC 4815. Superimposed are isochrones of different metal abundance Z. Dashed line represents a Z=0.020 isochrone for an age of 500 Myr, plotted adopting $E_{B-V} = 0.65$ and $(m - M) = 14.20$. Dashed-dotted line represents a Z=0.008 isochrone for an age of 500 Myr, plotted adopting $E_{B-V} = 0.70$ and $(m - M) = 14.20$. Solid line represents a Z=0.004 isochrone for an age of 600 Myr, plotted adopting $E_{B-V} = 0.75$ and $(m - M) = 14.10$

Table 4. Age determination of NGC 4815

Z	E_{B-V}	$m-M$	Age (Myrs)
0.004	0.75	14.05	600
0.008	0.70	14.10	500
0.020	0.65	14.10	500

This is shown in Fig. 8.

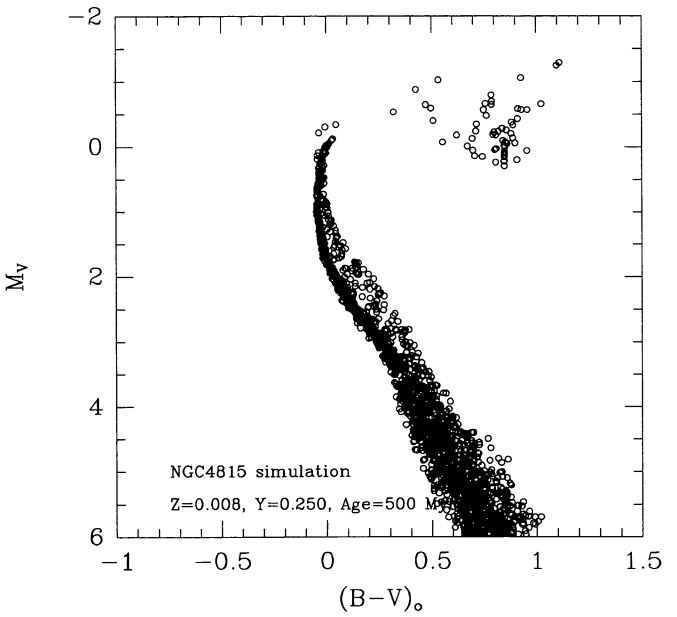

Fig. 8. A best fit synthetic CMD: the age is 5 10^8 and the metallicity is Z=0.008

Finally, we have built up an integrated main sequence luminosity function averaging the results of 50 synthetic CMDs. In constructing this theoretical ILF we have adopted a Salpeter-like IMF with different slopes. The best fit is reached adopting a coefficient $x = 1.55 \pm 0.20$. Care has been taken to test the sensitivity of our technique to field stars subtraction, and we have seen that different choices of field portion do not alter sensibly the IMF exponent. The final ILF is consistent with a Salpeter $x = 1.55$ IMF within the experimental uncertainties. The comparison with our NGC 4815 ILF is made in Fig. 6.

6. Discussion and conclusion

In this paper we have determined a new CMD for the poorly studied open cluster NGC 4815.

The cluster was previously studied by Moffat & Vogt (1973) and by Kieldsen & Frandsen (1991). The present study supersedes the previous ones for the larger number of objects detected.

NGC 4815 appears to be a rich cluster, strongly absorbed and of intermediate age. It appears in the Janes (1988) list of probably old open clusters, but our analysis shows that NGC 4815 has the Hyades age and its CMD is similar to NGC 2477 and NGC 2660, suggesting that NGC 4815 is a probable member of the intermediate age thin disk population.

Going into some details we found that NGC 4815 is slightly metal poor (Z=0.008) and the best fit age turns out to be 500 Myr, together with a color excess $E_{B-V} = 0.70$ and a distance modulus $(m-M) = 14.10$: this puts NGC 4815 about 2.5 Kpcs distant from the Sun.

The models with Z=0.008 and Z=0.020 produce the same ages, but the detailed main sequence and turn off (slope and curvature) morphologies are better reproduced by the Z=0.008 models. The greater age we found with respect to the study of Kieldsen and Frandsen (1991) is tied to the different stellar models in use. In fact they use a combination of classical isochrones from different authors. Without taking into account the spurious effects that arise from using non homogeneous grids of stellar models, it is well known that models accounting for convective overshoot provide ages greater (of about 30%) than classical ones (see Carraro et al 1993 for an exaustive discussion of this subject).

The ILF we derive for the cluster MS, after having corrected the star counts for data incompleteness and field stars contamination, shows that the underlying IMF has a slope $x = 1.55 \pm 0.20$. This result is in agreement with the classical Salpeter IMF within the uncertainties.

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