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Near IR photometry of the old open clusters Berkeley 17 and Berkeley 18*

Probing the Age of the Galactic Disc

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Abstract. We report on near IR (J and K bands) observations of two 8×8 $(arcmin)^2$ regions centered on the old open clusters Berkeley 17 and Berkeley 18, for which only optical photometry (in B,V and I bands) exists. J and K photometry allows us to obtain an independent estimate of cluster metallicity by means of the relationship between the spectroscopic metallicity and the Red Giant Branch (RGB) slope calibrated by Tiede et al (1997).
From the analysis of the colour magnitude diagram (CMD) and luminosity function (LF), Berkeley 17 turns out to have a metal content $[Fe/H] \sim -0.35$. It is 9 Gyr old, suffers from a reddening $E(B-V) = 0.58$ mag and has an heliocentric distance of 2.5 kpc. Berkeley 17 comes out to be substantially younger than in previous work (age ≈ 13 Gyr).
On the other hand Berkeley 18 is found to have solar metal abundance, and to be younger than Berkeley 17, with an age of about 4 Gyr. While we confirm Kaluzny (1997) reddening estimate, we significantly revise the distance of the cluster, which lies 4.5 kpc from the Sun. These results on two open clusters believed to be between the oldest put constraints on the age and the evolution of the Galactic Disc. The absence of clusters older than $8-9$ Gyr suggests the possibility that the Galaxy underwent a star formation minimum between 13 and 10 Gyr ago.

Key words: Galactic Disc: Formation and Evolution – Open clusters and associations: individual: Berkeley 17 and Berkeley 18

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* Based on observations taken at TIRGO.

1. Introduction

Whether the Galaxy formed by an homogeneous monolithic collapse *a lá* Eggen et al (1962), or by a series of merging and/or capture events *a lá* Searle & Zinn (1978) is still an open question. The traditional approach to investigate this fundamental issue is the comparative study of different stellar populations long ago recognized to exist inside the Milky Way (halo, disc - thin and thick - and bulge).
In particular a decisive step is to understand the formation and evolution of the Galactic Disc, and its relation with the Halo and the Bulge. Open clusters, especially the oldest ones, are the best candidates to trace the early stages of the disc development, the chemical and dynamical evolution of the disc, and the possible existence of a hiatus in the star formation history of the Milky Way between the formation of the halo/thick disc and the thin disc.
Janes & Phelps (1994) discussed in details some of these interesting questions, suggesting that :

- the age distribution of the open clusters overlaps that of globular clusters suggesting that the disc started to form before the end of the halo formation;
- captures events were responsible for the formation of the disc radial metallicity gradient;
- the overdensity of open clusters in the age range between 5-7 Gyr is probably due to a burst of star formation induced by a merging episode.

The first point is of particular interest. The conclusion of the authors completely relies on the existence of a cluster, Berkeley 17, whose age is estimated around 12 Gyr (Phelps 1997). The bulk of globular clusters has ages around 13 Gyr (Gratton et al 1997) with a tail down to 11 Gyr. This opens the possibility that there has been no hiatus at all between the formation of the halo/thick disc and the thin disc.

Table 1. Basic parameters of the studied clusters.

Cluster	$\alpha_{2000.0}$ *hh mm*	$\delta_{2000.0}$ ^{o}	l ^{o}	b ^{o}	Diameter ($'$)
Berkeley 17	05 17.4	30:33	175.65	-3.65	15
Berkeley 18	05 18.5	45:21	163.63	+5.01	26

In this paper we would like to address the issue of the age of Berkeley 17, analyzing IR photometry in J and K bands. We also discuss similar data for Berkeley 18, another old open cluster. This is part of a project to study northern open clusters in the IR. We report elsewhere (Vallenari et al 1998) on two very young open clusters, Berkeley 86 and NGC 1893.
The age of Berkeley 17 has been discussed by Carraro et al (1998) using published BVI photometry. From this study it emerges that Berkeley 17 is about 9 Gyr old, and the oldest open cluster, NGC 6791, is 3-4 Gyr younger than the bulk of globular clusters, suggesting the possibility that a real star formation minimum occurred between the halo and disc settling.
Berkeley 17 and Berkeley 18 were discovered by Setteducati & Waever (1962) in their search for unstudied open clusters. Both the clusters were never observed in the IR, whereas they have been studied in the optical (B, V and I). Berkeley 17 was studied by Kaluzny (1994) and Phelps(1997), whereas Berkeley 18 was studied by Kaluzny (1997). Their basic properties are summarized in Table 1.
This paper is organized as follows: Section 2 presents the observation and data reductions; Section 3 discusses CMDs of the clusters under investigation, whereas Sections 4 and 5 deal with the derivation of the clusters' fundamental parameters. Finally Section 6 gives some concluding remarks.

2. Observations and Data reduction

J (1.2 μm) and K (2.2 μm) photometry of the two clusters was obtained at the 1.5m Gornergrat Infrared Telescope (TIRGO) equipped with Arcetri Near Infrared Camera (ARNICA) in October 1997. ARNICA is based on a NICMOS3 256$\times$ 256 pixels array (gain=20 e^-/ADU, read-out noise=50 e^-, angular scale =1$''$/pixel, and $4'^2$ field of view). Through each filter 4 partially overlapping images of each cluster were obtained, covering a total field of view of about 8 $\times 8'^2$, in short exposures to avoid sky saturation. The two fields are located close to the center of Berkeley 17 and Berkeley 18. The log-book of the observations is presented in Table 2 where the centers of the observed fields and the total exposure times are given. The nights were photometric with a seeing of 1$''$-1.5$''$. Fig.1a,b

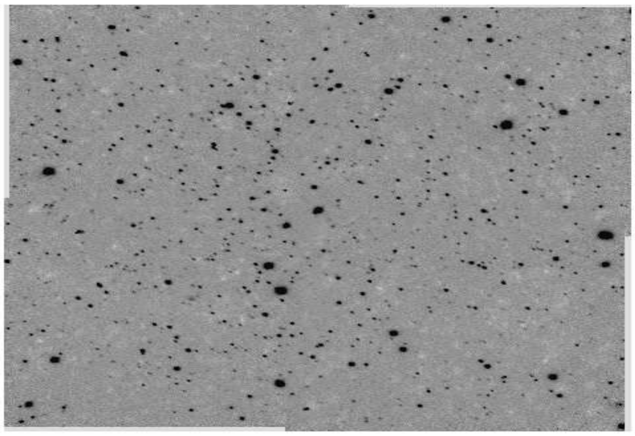

Fig. 1. A mosaic of the four regions observed in the field of Berkeley 17.

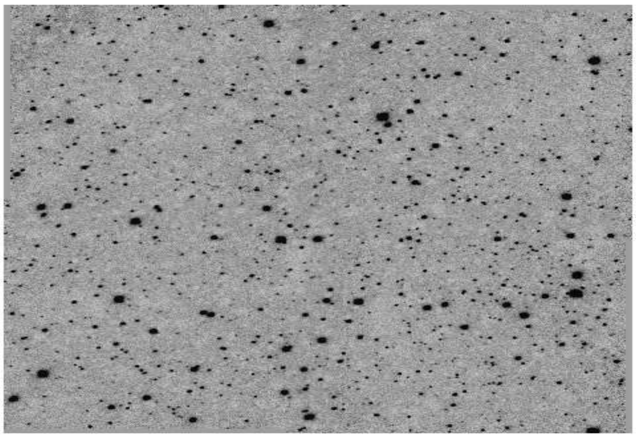

Fig. 2. A mosaic of the four regions observed in the field of Berkeley 18.

Table 2. Observation Log Book

Cluster	α	δ	Date	Exposure Times (sec)	
	(2000)	(2000)		J	K
Be 17	5 20 32	33 34 40	Oct, 27, 1997	840	844
Be 18	05 22 07	45 25 17	Oct,25, 1997	1020	960

presents the final mosaics of the 4 frames for both clusters in K passband.

The data were reduced subtracting from each image a linear combination of the corresponding skies and dividing the results by the flat-field. We make use of the Arnica package (Hunt et al 1994) in IRAF and Daophot II. The conversion of the instrumental magnitude j and k to the standard J, K was made using stellar fields of standard stars taken from Hunt et al (1998) list. About 10 standard stars per night have been used. The relations in usage per 1 sec exposure time are:

$$J = j + 19.51 \quad (1)$$

$$K = k + 18.94 \quad (2)$$

with standard deviation of the zero points of 0.03 mag for the J and 0.04 for the K magnitude. This error is only due to the linear interpolation of the standard stars. The calibration uncertainty is dominated by the error due to the correction from aperture photometry to PSF fitting magnitude. The standard stars used for the calibration do not cover the entire colour range of the data, because of the lack of stars redder than $(J-K) \sim 0.8$. From our data, no colour term is found for K mag, whereas we cannot exclude it for the J magnitude. Taking all into account, we estimate that the total error on the calibration is about 0.1 mag both in J and K pass-bands.

3. The Color-Magnitude Diagrams

$K-(J-K)$ relationship for Berkeley 17 and Berkeley 18 are shown in Fig 3 and Fig 4, respectively.

3.1. Berkeley 17

The CMD of Berkeley 17 shows all the features of a very old open cluster, namely a scarcely populated extended Red Giant Branch (RGB) and a clump of He-burning stars. Some field stars contamination from the galactic disc is visible in the main sequence (MS), which extends almost vertically well above the cluster Termination Point (TO) up to $K = 11$.
The cluster TO is most probably located at $K \approx 14.5$ and $(J-K) \approx 0.50$, whereas the clump of He-burning stars is visible at $K \approx 11.20$ and $(J-K) \approx 0.90$. It is composed by 4-5 stars, which are the counterpart of the group of stars located at $V \approx 14.5$, $(V-I) \approx 1.7$ in the BVI photometry of Phelps (1997). The brighter part of our CMD is somewhat more populated than Phelps (1997) study, because of the larger field coverage ($8' \times 8'$ compared to $5.1' \times 5.1'$). As a consequence, the RGB is better defined in our study.
The widening of the MS is due to many causes (binaries, differential reddening and so forth), the predominant one being the photometric errors, which are 0.06, 0.12 and 0.17 at $K = 16$, 17 and 18, respectively. The magnitude difference ΔK between the TO and the clump turns out to be about 3.2 *mag*.

3.2. Berkeley 18

As for Berkeley 17, Berkeley 18 shows to be an old cluster. It appears to be less contaminated in field foreground/background stars, the MS turning off at $K \approx 15.00$ and $(J-K) \approx 0.40$. The RGB shows some gaps, whereas the clump of He-burners (about 10 stars) is located at $K \approx 12.25$ and $(J-K) \approx 0.80$. The magnitude difference ΔK turns out to be about 2.7, suggesting that Berkeley 18 is younger than Berkeley 17. We notice that the CMD shows the presence of a group of stars above the clump, which does not lie along the RGB. These are probably field stars, which are also present in the photometric BVI survey of Kaluzny (1997).
Also in the case of Berkeley 18 we ascribe the MS widening to binary and field stars contamination, possible differential reddening and photometric errors. These latter are 0.08, 0.10, 0.18 at $K = 15$, 17 and 18, respectively.

4. Berkeley 17: cluster parameters

4.1. Metallicity

Friel et al (1995) measured Berkeley 17 metal abundance using moderate resolution spectroscopy of 12 stars. They obtained $[Fe/H] = -0.29 \pm 0.13$. It is possible to derive the cluster abundance photometrically in the IR using the calibration of Tiede et al (1997). This relation correlates the abundance $[Fe/H]$ with the slope $\Delta(J-K)/\Delta K$ of rhe RGB.
It reads:

$$[Fe/H] = -2.98(\pm 0.70) - 23.84(\pm 6.83 \times (RGBslope) \quad (3)$$

This relation has been proved to hold for both metal rich globular clusters and open clusters. For the latter the RGB slope tends to present less negative values at decreasing age. We applied this relation to Berkeley 17, for which

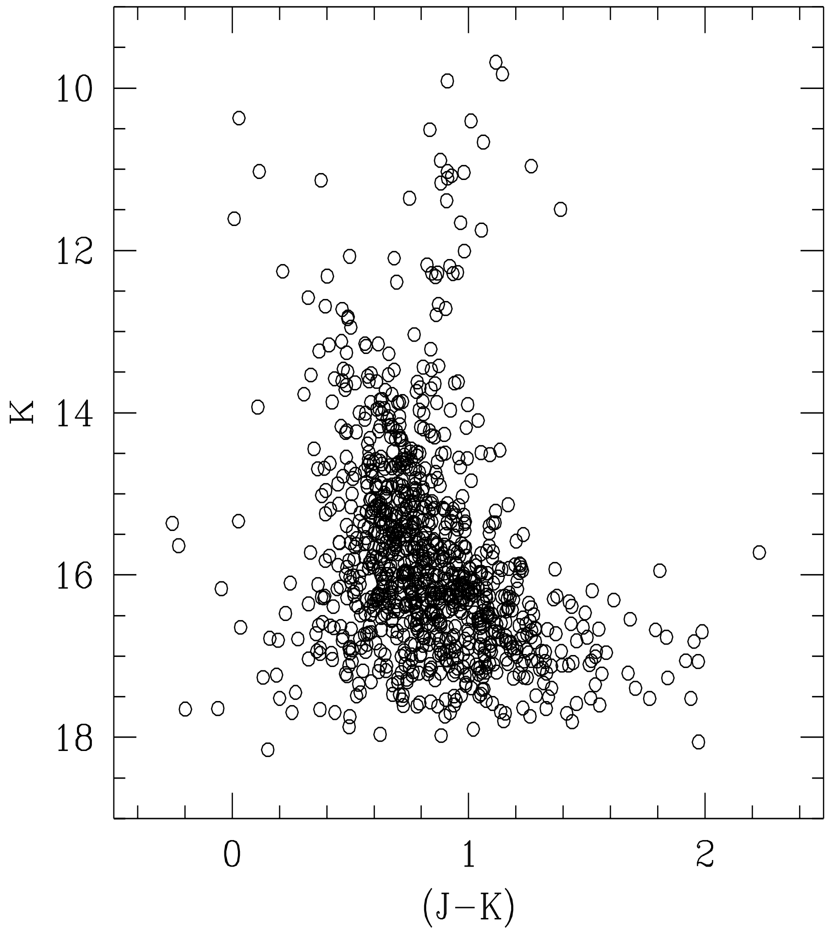

Fig. 3. The CMD of Berkeley 17.

the RGB slope is $\Delta(J-K)/\Delta K = -0.11 \pm 0.02$. This results in $[Fe/H] \sim -0.35$, consistent with spectroscopic estimates.

4.2. Age, Distance and Reddening

Berkeley 17 was studied in the optical by Kaluzny (1994) and Phelps (1997).
Kaluzny(1994) compared Berkeley 17 with NGC 6791 and, assuming that the former is metal poorer than the latter, concluded that the two clusters are probably coeval (around $9\,Gyr$ old). Moreover he suggested a distance modulus $(m-M) > 15.0\,mag$ and a reddening $E(V-I) > 0.70\,mag$. On the other hand, Phelps (1997) reached considerably different results, although the two photometric studied were not significantly different (see Carraro et al 1998). In details he found an age of $12^{+1}_{-2}\,Gyr$, a distance modulus $(m-M) \approx 13.9\,mag$ and a reddening in the range $0.52 < E(B-V) < 0.68\,mag$ and $0.61 < E(V-I) < 0.71\,mag$.

Adopting the relation (Girardi et al 1998):

$$[Fe/H] = log\frac{Z}{0.019} \qquad (4)$$

we can derive a theoretical metal abundance $Z \approx 0.008$. This value is adopted to generate isochrones from the theoretical models by Girardi et al (1998). The best fit is

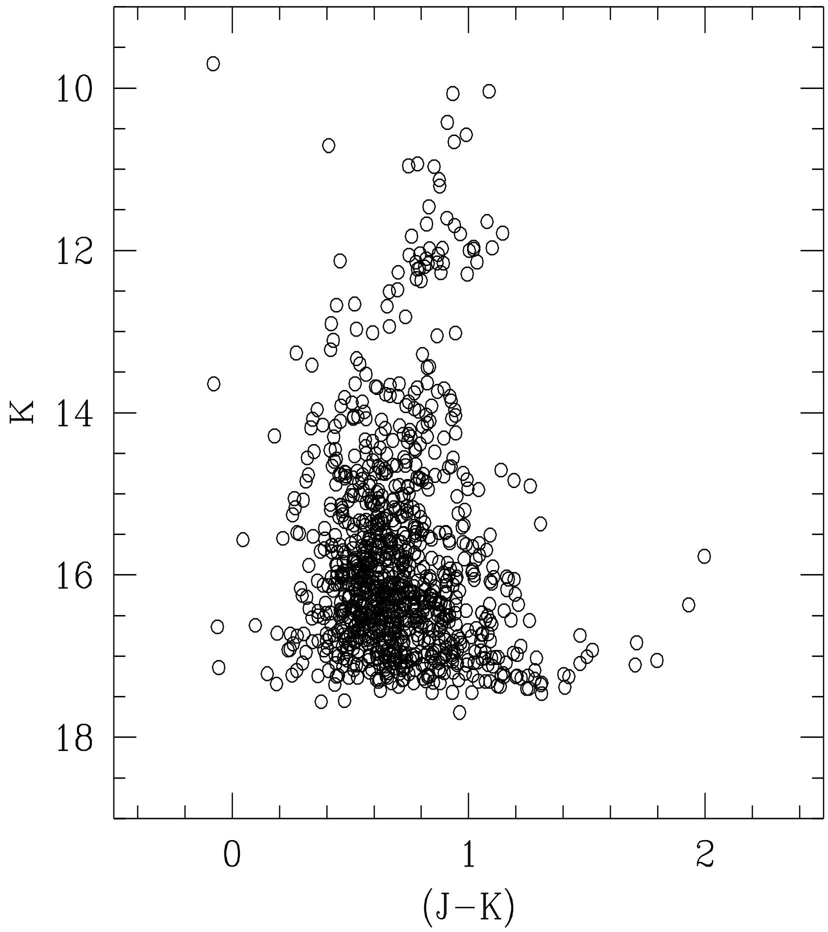

Fig. 4. The CMD of Berkeley 18

show in Fig 5, panel a). It has been obtained overimposing an 9 *Gyr* isochrone shifted by $(m-M)_K = 12.90$ and $E(J-K) = 0.30$. These value are uncertain within 0.1 *mag*.
From the relation

$$\frac{E(J-K)}{E(B-V)} = 0.52 \tag{5}$$

taken from Cardelli et al (1989), $E(J-K)$ transforms into $E(B-V) = 0.58$ *mag*. As a consequence, $(m-M)_o$ becomes 12.00. This puts Berkeley 17 2.5 *kpc* away from the Sun. Reddening and distance are in agreement with Phelps (1997) results.
As for the age, we find a value consistent with Kaluzny (1994) suggestions, but significantly lower than Phelps (1997) estimate. We believe that this difference arises from the poor fit of the clump stars in the Phelps (1997) study. To cast light on this point, we overimposed (see Fig. 5, panel a)) to the cluster CMD a 13 *Gyr* isochrone. Fixing the clump color and magnitude, the TO appears too faint, and the RGB too red. On the other hand, trying to fix the color and magnitude of the TO, which is more blurred, the RGB clump turns out to be bluer and brighter than observed. This is confirmed by Carraro et al (1998), who find that Berkeley 17 is about 9 *Gyr* old analyzing published *BVI* photometry.

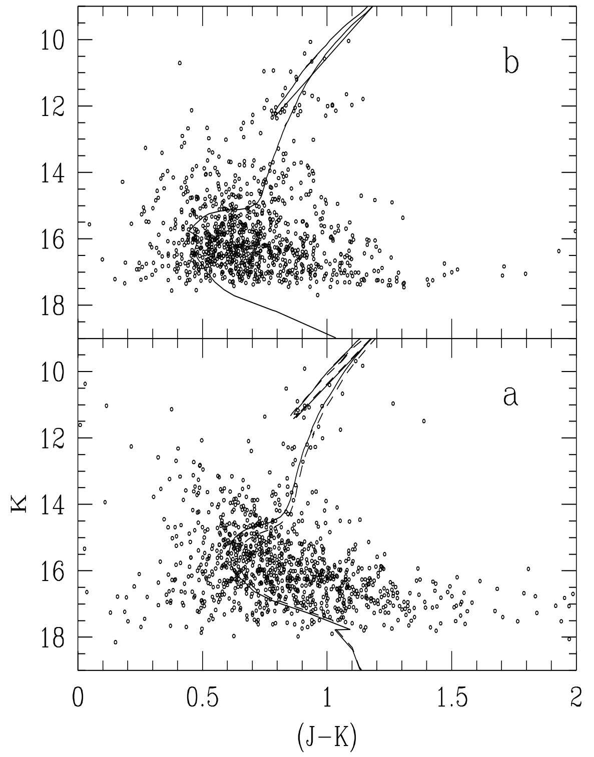

Fig. 5. Comparison of clusters' CMD with theoretical isochrones. Panel a) shows the CMD of Berkeley 17, with overimposed two $Z = 0.008$ isochrones for the ages of 9 *Gyr* (solid line) and 13 *Gyr* (dashed line). Reddening and distance modulus are 0.30 *mag* and 12.90 *mag*, respectively. Panel b) shows the CMD of Berkeley 18, with overimposed a $Z = 0.019$ isochrone of 4 *Gyr*. Reddening and distance modulus are 0.25 *mag* and 14.00 *mag*, respectively.

4.3. The Luminosity Function of Berkeley 17

To confirm the age determination based on the CMD, we compare the luminosity function (LF) of the MS of the cluster (defined as stars fainter than $K = 15$ or bluer than $(J-K) = 0.75$) with the simulations of two populations of age 8 *Gyr* and 13 *Gyr* having $Z = 0.008$.

First, by means of the usual experiments with artificial stars we derive the incompleteness correction γ for Be 17, defined as the ratio of recovered on added stars. It turns out to be $\gamma = 1, 0.86, 0.20$ for $K < 15.5$, 16, 17 *mag*. The theoretical LFs are corrected for incompleteness due to crowding, dividing them by γ.

Second, we derive the LF of the disc stars contaminating the cluster using the model of the Galactic disc proposed by Ng et al (1995) as modified by Vallenari et al 1998. This model has been tested fitting CMD and luminosity functions of low latitude Galactic fields (see Schmidtobreick et al 1998 for details). Since this cluster is located at low Galactic latitude, the main contamination is given by the thin disc. Starting from a double exponential density distribution of the Galactic thin disc, assuming a scale height of 250 *pc*, a scale length of 2000 *pc*, constant star formation rate from 10 *Gyr* to 0.1 *Gyr*, we derive the simulated LF of the disc component, imposing the number of stars observed in the range $12 < K < 14$. Changing the input parameters of the simulations (scale height and scale length of the disc), we estimate that the error on the disc LF at the level of the expected turnoff of Berkeley 17 (i.e. between 14 and 15 *mag*) is about $10 - 15\%$.

Finally the observational LF of the MS is obtained, subtracting the disc MS contamination by the initial LF. In Fig. 6 we compare the simulated LFs with the data. For magnitudes fainter than $K \sim 16$ the incompleteness correction becomes relevant and the comparison is not significant. For brighter magnitudes, the oldest age gives a turnoff fainter than the observed one, whereas the youngest one is in reasonable agreement with the data. This result might be weakened by the fact that the LF of the disc population has not been derived from observations, but simulated. However, to reproduce the data with an age of 13 Gyr, we need to increase the disc population of about 30%, which is much higher than the estimated uncertainty.

As a conclusion, on the basis of the analysis of the CMD and LF, although an age of 13 *Gyr* cannot be completely ruled out, a much younger age ($\sim$ 8 Gyr) seems to be favored.

5. Berkeley 18: cluster parameters

5.1. Metallicity

No spectroscopic determinations of Berkeley 18 metallicity are available, so we rely only on the slope of the RBG, and derive metallicity from eq. (3). We obtain $\Delta(J-K)/\Delta K = -0.125 \pm 0.05$, which translates in solar metal abundance $[Fe/H] \approx 0.0$.

5.2. Age, Distance and Reddening

Berkeley 18 has been studied by Kaluzny (1997). From this preliminary work, Kaluzny suggested that Berkeley 18 is as old as M 67 (4 *Gyr*, Carraro et al 1996), its reddening $E(B-V)$ is probably higher than 0.46 *mag*, and the distance from the Sun is around 5.8 *kpc*.
In Fig. 5 (panel b) we present the CMD of Berkeley 18 with a best fitting isochrone of 4 *Gyr* for the metal abundance $Z = 0.019$. From this fit we derive a reddening $E(J-K) = 0.25$ *mag* and an apparent distance modulus $(m-M)_K = 14.00$ *mag*.The errors in these estimates are around 0.1 *mag*.
The corresponding visual reddening $E(B-V)$ turns out to be 0.40 *mag* from eq. (5), in agreement with Kaluzny's

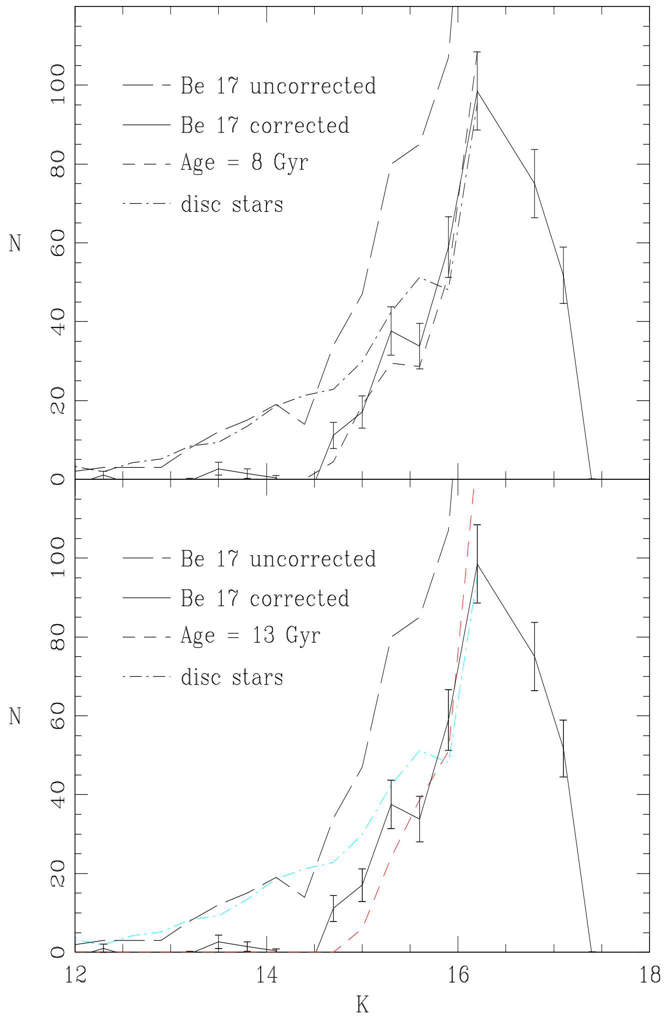

Fig. 6. The LF of MS of Berkeley 17 is compared with theoretical simulations with ages of 8 and 13 *Gyr* corrected for incompleteness. The disc population is simulated and subtracted from the observed LF. The long dashed line represents the original data, dashed-dotted the disc population, solid the MS LF of Berkeley 17 decontaminated by disc stars, and finally short-dashed the simulation of the cluster for the labelled age,

(1997) suggestions. Using this value, we estimate the distance of Berkeley 18 to the Sun to be about 4.5 *kpc*, significantly lower than Kaluzny's (1997) estimate.

Table 3. Derived parameters of the studied clusters.

Cluster	$[Fe/H]$	Age	$E(B-V)$	$(m-M)_o$	Distance
	dex	Gyr	mag	mag	kpc
Berkeley 17	~ -0.35	9 ± 1	0.58	12.00	2.5
Berkeley 18	~ 0.00	4 ± 1	0.48	13.25	4.5

6. Conclusions

We have presented and discussed near IR photometry of two poorly studied old open clusters, Berkeley 17 and Berkeley 18. From the analysis of the CMDs we derived cluster fundamental parameters which are listed in Table 3. In details, we derived a photometric estimate of the cluster metal abundance (column 2), new age estimates with uncertainties derived from the fit of several isochrones of different ages (column 3), reddening (column 4), distance modulus (column 5) and heliocentric distance (last column).

The main results of this study can be summarized as follows.

- using the calibration between the slope of the RGB and the metallicity (Tiede et al 1997), we estimate that Berkeley 17 has a metal abundance $[Fe/H] \sim -0.35$, while Berkeley 18 has about solar metal abundance;
- Berkeley 17 is found to be 9 Gyr old. The difference with Phelps (1997) age estimate (about 12 Gyr)is probably due to a better fitting of the clump stars, which are more clearly visible in our study. This younger age is also suggested by the analysis of the cluster LF corrected for the disc star contamination. This new age determination implies that Berkeley 17 is no longer the oldest known open cluster, and suggests the possibility that the Milky Way experienced a minimum of star formation between 10 and 13 Gyr ago;
- Berkeley 18 is as old as M 67, but its distance is significantly lower than previous estimates.

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