A&A 429, 607–612 (2005)
DOI: 10.1051/0004-6361:20041458

Astronomy & Astrophysics

The old open clusters Berkeley 36, Berkeley 73 and Biurakan 13 (Berkeley 34)*,**

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Received 12 June 2004 / Accepted 10 August 2004

Abstract. *BV* photometry of the faint open clusters Berkeley 36, Berkeley 73 and Biurakan 13 are studied. For these clusters no colour–magnitude analyses were previously available. The colour–magnitude Diagrams indicate that they are all old open clusters. The derived ages are ~4 Gyr for Berkeley 36, and ~2.3 Gyr for both Berkeley 73 and Biurakan 13. The clusters are not very reddened, with $E(B-V) = 0.25$, 0.10 and 0.30 respectively for Berkeley 36, Berkeley 73 and Biurakan 13. Berkeley 36 and Berkeley 73 are located at a distance from the Galactic center of ~10 kpc, while Biurakan 13 is much farther, at 15 kpc. A peak in the age distribution appears at 5 Gyr suggesting a distinct star forming event in the disk.

Key words. Galaxy: open clusters and associations: individual: Berkeley 36, Berkeley 73, Biurakan 13 – stars: Hertzsprung-Russell (HR) and C-M

1. Introduction

The Galactic open clusters are excellent probes of the structure and evolution of the disk. They can be seen at large distances, and ages and distances can be readily determined with a considerable precision, as compared to other disk tracers, such as HII regions, supernova remnants, pulsars, Cepheids, Asymptotic Giant Branch (AGB) stars, or bright Main Sequence (MS) stars (e.g. Georgelin & Georgelin 1976; Hron 1987; Taylor & Cordes 1993). The old open clusters, in particular, play a crucial rôle in constraining parameters for the early disk. Alter et al. (1970) and Lyngå (1987) catalogued about 1200 open clusters in the Galaxy. More recently, Dias et al. (2002) reported 1537 open clusters. Dutra & Bica (2000) compiled a list of 103 old open clusters, where by old it is meant that ages are above that of the Hyades (Friel 1995; Janes & Phelps 1994). Such objects are sometimes referred to as intermediate age clusters (IAC). Frinchaboy & Phelps (2002) analysed an additional 5 cluster sample from Saurer et al. (1994). The above reported known old open clusters are still a smaller sample than that of globular clusters in the Galaxy (Harris 1996). Identification of additional old open clusters is thus important to allow a better understanding of this population.

The present sample was selected by inspection of images of non-studied open clusters, with smooth appearance and showing evidence of red stars on B and R Digitized Sky Survey images (DSS).

The objects studied are Berkeley 36, Berkeley 73 and Biurakan 13 (Berkeley 34). Biurakan (Biu) clusters were discovered by Iscudarjan in 1959 and informed as private communication to Alter et al. (1970). The Berkeley (Be) clusters are from Setteducati & Weaver (1960).

Be 36 is located at J2000.0 $\alpha = 7^{h}16^{m}23s$ and $\delta = -13^{o}11'50''$ (l = 227.49°, $b = -0.57^{o}$); Be 73 is at $\alpha = 9^{h}31^{m}56^{s}$, $\delta = -50^{o}13'14''$, ($l = 273.63^{o}$, $b = 0.94^{o}$); Biu 13 is at J2000 $\alpha = 7^{h}00^{m}23^{s}$, $\delta = -0^{o}14'15''$, ($l = 214.16^{o}$, $b = 1.88^{o}$). These are improved coordinates redetermined by one of us (E.B.) based on inspection of DSS and XDSS images.

No parameters are currently available for these clusters according to the WEBDA open cluster database at http://obswww.unige.ch/webda (Mermilliod 1996).

In Sect. 2 the observations are described. In Sect. 3 the Colour–Magnitude Diagrams (CMDs) are presented. In Sect. 4

⋆ Observations collected at the Galileo National Telescope, La Palma, Spain.

⋆⋆ Table 2 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/429/607

Table 1. Log of observations.

Target	Date	Filter	Exp. (s)	Seeing ($''$)
Be 36	3/2/00	*V*	30	1.2
		V	600	1.3
		B	30	1.3
		B	600	1.4
Be 36 field	3/2/00	*V*	30	1.3
		V	420	1.6
		B	30	1.3
		B	420	1.6
Be 73	2/2/00	*V*	30	1.7
		V	600	1.8
		B	60	2.6
		B	600	2.7
Be 73 field	2/2/00	*V*	30	1.6
		V	420	1.7
		B	30	1.6
		B	420	1.5
Biu 13	2/2/00	*B*	60	1.7
		B	600	1.7
		V	30	2.0
		V	600	1.9
	4/2/00	*V*	600	1.1
		B	900	1.0
Biu 13 field	2/2/00	*V*	300	1.3
		V	30	1.0
		B	300	1.5
		B	30	1.3

we derive and discuss cluster parameters. Concluding remarks are given in Sect. 5.

2. Observations and reductions

The log of observations is presented in Table 1. The observations were carried out on 2000, February 2–5, using the 3.5 m Galileo National Telescope operating at La Palma. The instrument is the Galileo Optical Image Camera (OIG) installed at the Nasmyth focus. The nights were photometric, allowing accurate absolute calibrations via standard stars observations. OIG uses two EEV 42–80 CCDs with 2048×4096 pixels, with pixel size of 13.5 μm. The readout of the CCD was binned into 2×2 pixels, and the total field of view is $4.9' \times 4.9'$. The projected binned pixel size on the sky is $0.144''$.

In order to check for possible systematic effects in the calibrations, due to different focus, seeing and exposure time combinations, a large number of standard star fields from Landolt (1983, 1992) were observed. On the first night, 40 such images, and in the following nights 20 to 30 images, distributed during the night, were observed. The final number of independent standard star images, taken during the whole observing run, amounts to about 300. The analysis of the images revealed

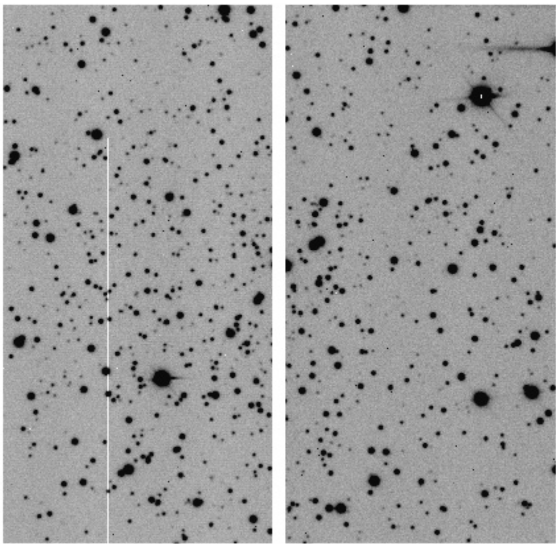

Fig. 1. *B* image (10 min) of Berkeley 36. The field size is $\approx 4.9' \times 2.45'$ each, with a gap of $2.8''$ between the two frames. North is down and east to the right.

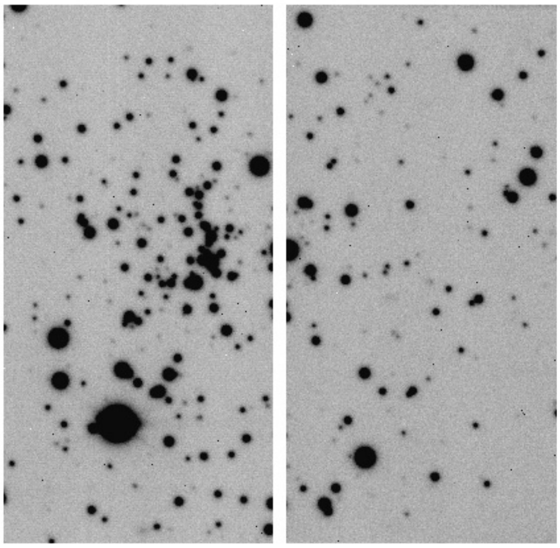

Fig. 2. *B* image (10 min) of Berkeley 73. Field size is the same as in Fig. 1.

a very good photometric performance of the system with almost negligible shutter time delay down to 1% at the minimum exposure time of 0.2 s. All the standard stars in the images were measured with aperture photometry and used to derive the calibration equations.

In Figs. 1–3 we show the cluster images.

The observing frame is a mosaic of two CCD chips, separated by a gap of $2.8''$. Note that we avoided overlapping the cluster center with the gap. Offset fields at $5'$ south were also observed.

The reductions (flat fielding, trimming, aperture magnitudes) were carried out in the standard way, using MIDAS. The calibration equations for the first and second nights are:

$$B = 26.0 + 0.07(B - V) \ + b$$
$$V = 25.90 - 0.025(B - V) \ + v;$$

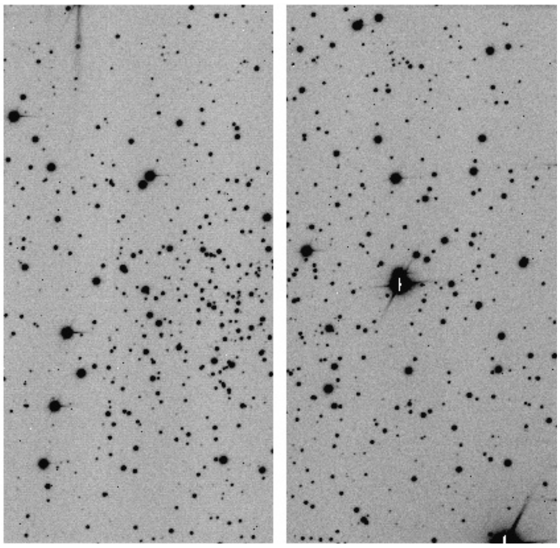

Fig. 3. *B* image (15 min) of Biurakan 13. Field size is the same as in Fig. 1.

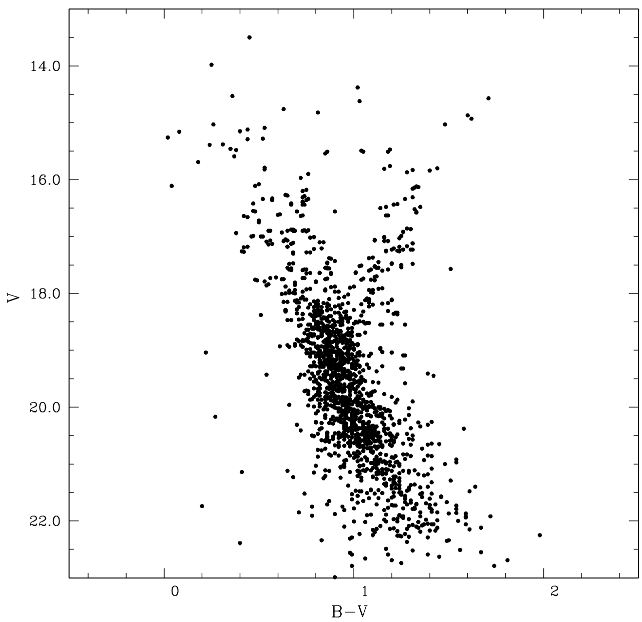

Fig. 4. Whole frame V, $B-V$ diagram for Be 36.

where the coefficients are for 1 s. exposures and at airmass of 1.1. For the third night, the zero points are 0.05 larger in B and V. We verified that there was a slight elongation of the stellar images possibly due to small oscillations of the telescope in altitude direction. This may introduce zero point uncertainties of a few hundredths of a magnitude in the aperture corrections used in the calibration of the cluster images.

3. Colour–magnitude diagrams

The CMDs in this secttion are a result of combinations of short and deep exposures, in order to maximize the dynamical range.

The whole frame V vs. $B-V$ CMD of Be 36, is shown in Fig. 4. The cluster sequences of Be 36 are clearly visible in terms of MS, Turnoff (TO) and Red Giant Branch (RGB).

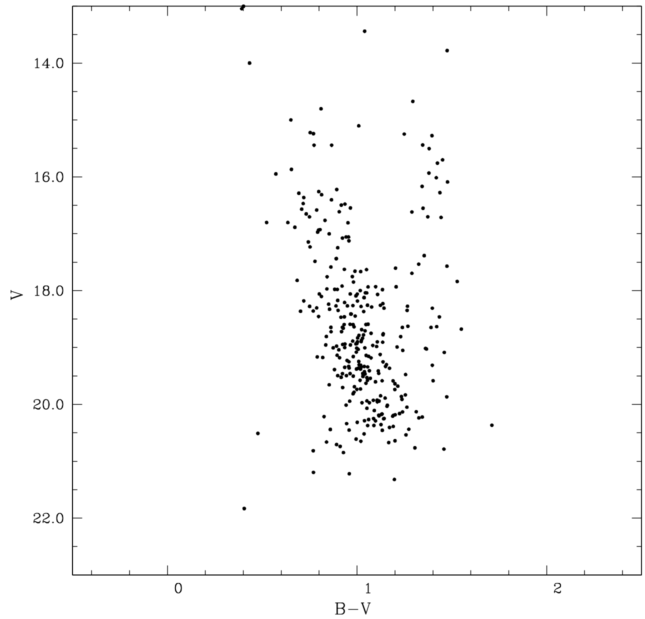

Fig. 5. Offset field V, $B-V$ located at 5′ south of Be 36.

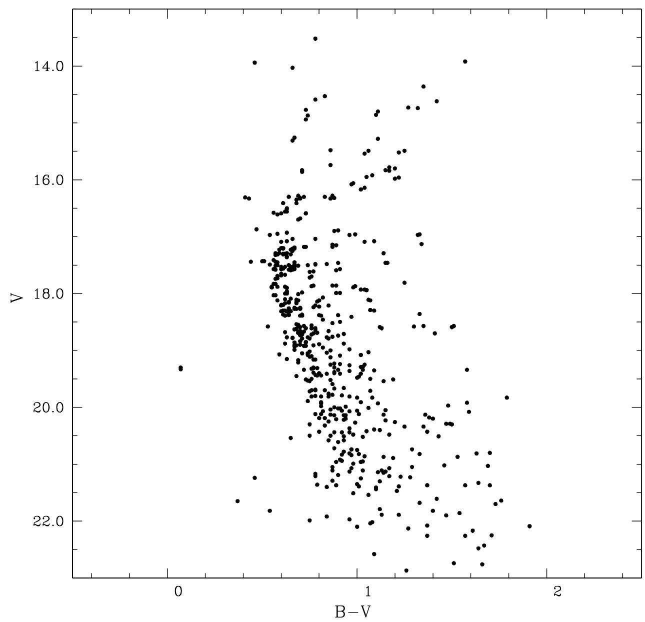

Fig. 6. Whole frame V, $B-V$ diagram for Be 73.

The contamination of the field is however important, particularly along the MS, as checked in the offset field (Fig. 5), which is more vertical and wider, as expected given the spread in distance.

The whole frame CMD for Be 73 (Fig. 6) shows clear cluster MS and RGB sequences. There is much less field contamination compared to Be 36.

For Biu 13 (Fig. 7), the CMD is contaminated by field stars. The evolutionary sequences MS, TO and RGB are clearly seen, showing a somewhat higher scatter relative to that seen in the CMD of Be 36.

The data (Table 2) are only available electronically at the CDS.

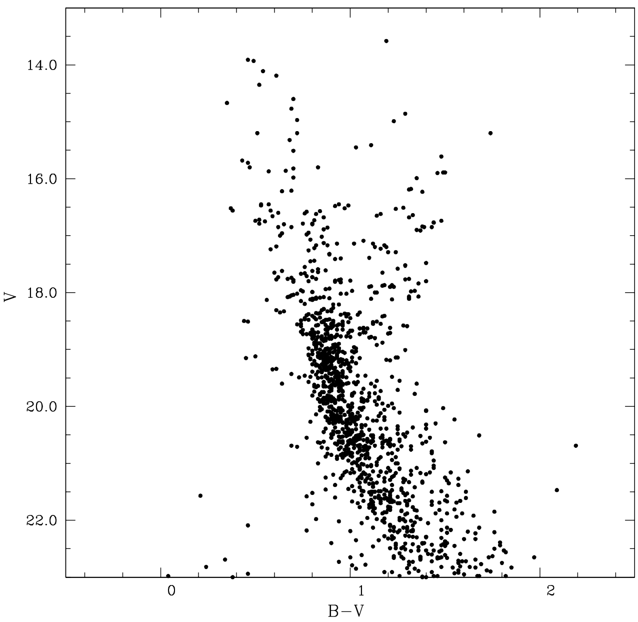

Fig. 7. Whole frame V, $B-V$ diagram for Biu 13.

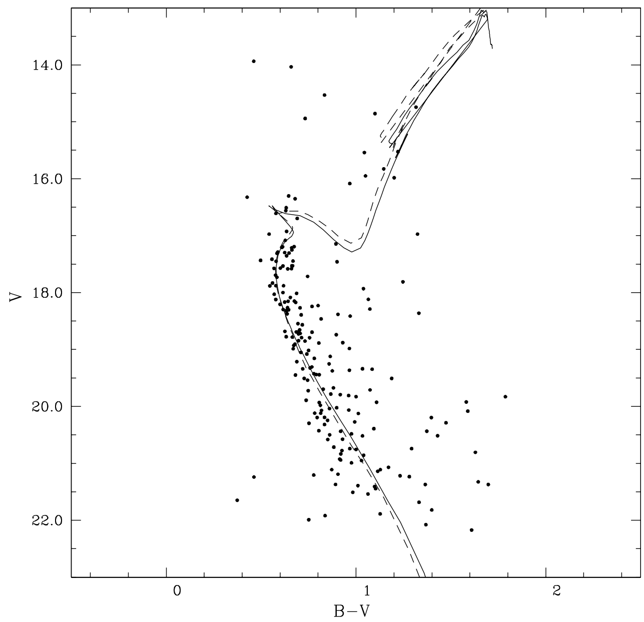

Fig. 9. V, $B-V$ diagram for Be 73 corresponding to an extraction of $r < 100''$. The Padova isochrones of 2.3 Gyr and $Z = 0.019$ (solid line) and 0.008 (dashed line) are shown.

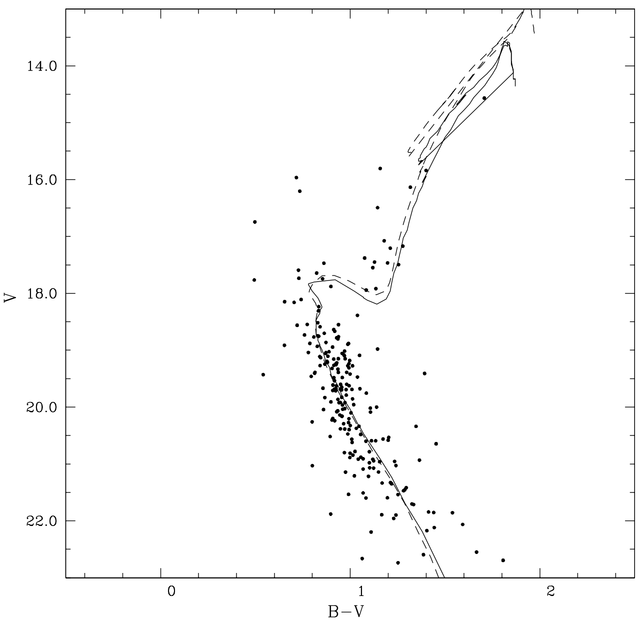

Fig. 8. V, $B-V$ diagram for Be 36 corresponding to an extraction of $r < 71''$. Padova isochrones of 4 Gyr and metallicity $Z = 0.019$ (solar) (solid line) and 0.008 (dashed line) are overplotted on the diagram.

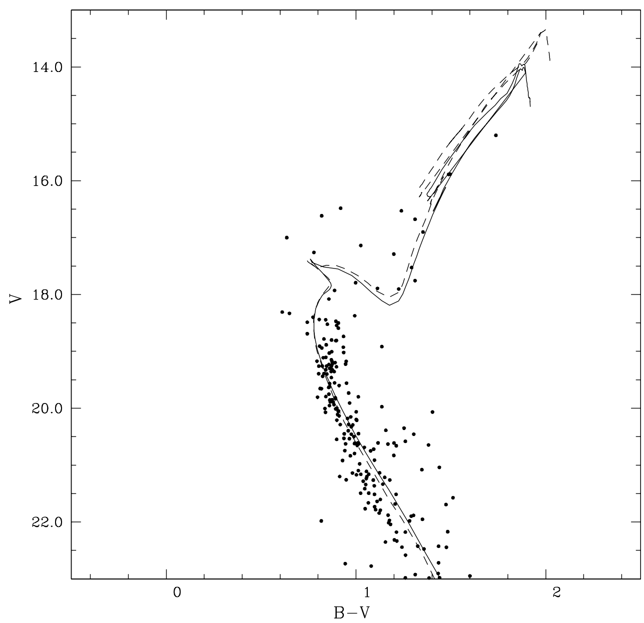

Fig. 10. V, $B-V$ diagram for Biu 13 corresponding to an extraction $r < 58''$. The Padova isochrones of 2.3 Gyr and $Z = 0.019$ (solid line) and 0.008 (dashed line) are shown.

4. Cluster parameters

We employed solar metallicity Padova theoretical isochrones from Bertelli et al. (1994), and Girardi et al. (1996, 2000), that can be found at `http://pleiadi.pd.astro.it`, to derive cluster parameters.

In Figs. 8–10 best fit isochrones are overplotted on the CMDs of Be 36, Be 73 and Biu 13, where circular extractions to minimize this contamination were made. For Be 36 an extraction of $r < 450$ pixels ($r < 71''$) was applied, for Be 73 the extraction was $r < 700$ pixels ($r < 100''$) and for Biu 13, the extraction was of $r < 400$ pixels ($r < 58''$). The central cluster positions adopted are for Be 36: $X = 739$, $Y = 870$, for Be 73: $X = 709$, $Y = 1099$, and for Biu 13: $X = 890$, $Y = 910$ pixels. A field decontamination is not recommended in these CMDs because the clusters are spread over a large area, and the offset fields, at $5'$ from the clusters' centers, contain a mixture of cluster and field stars.

The basic isochrones have solar metallicities. Given that the clusters are beyond the solar circle (Sects. 4.1–4.3), they may have sub-solar metallicities, since according to Friel et al. (2002), there is a metallicity gradient of -0.06 dex kpc^{-1} over

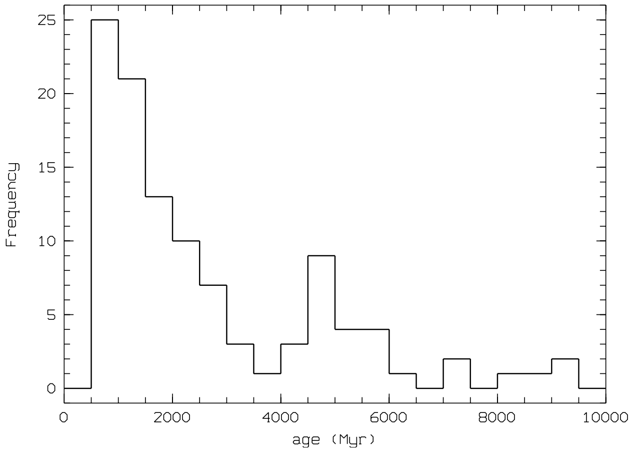

Fig. 11. Age histogram for old open clusters.

the Galactic distances of 7 to 16 kpc from the Galactic center. Essentially this same gradient is confirmed by Salaris et al. (2004). For this reason, in Figs. 8–10, isochrones of sub-solar metallicity of $Z = 0.008$ are also overplotted.

4.1. Berkeley 36

This cluster results to be considerably old with 4 ± 1 Gyr.

We derive a reddening $E(B-V) = 0.25 \pm 0.05$ and an observed distance modulus $(m-M) = 14.7 \pm 0.1$ and a distance from the Sun of $d_\odot = 6.1 \pm 0.3$ kpc. For the $Z = 0.008$ isochrone, the distance modulus increases to $(m-M) = 14.85$, and the reddening to $E(B-V) = 0.36$; therefore the cluster would be closer at $d_\odot = 5.6$ kpc. We adopt throughout this study a total-to-selective absorption $R = 3.1$.

The Galactocentric coordinates are $X = -12.1$ ($X < 0$ means our side of the Galaxy), $Y = -4.5$ and $Z = -0.1$ kpc, considering the distance to the Galactic center to be $R_\odot = 8$ kpc (Reid 1993; Eisenhower et al. 2003). The cluster distance from the Galactic center is $R_{GC} = 12.9$ kpc, thus outside the solar circle.

4.2. Berkeley 73

A cluster age of 2.3 ± 0.4 Gyr is obtained, as illustrated in Fig. 9, where an isochrone of 2.3 Gyr is overplotted, on an extraction of radius $r < 100''$ ($r < 700$ pixels). We derive a reddening $E(B-V) = 0.10 \pm 0.05$ and an observed distance modulus $(m-M) = 14.5 \pm 0.1$ and a distance from the Sun of $d_\odot = 6.8 \pm 0.6$ kpc. For the $Z = 0.008$ isochrone, the distance modulus increases to $(m-M) = 14.7$, and the reddening to $E(B-V) = 0.21$; therefore the cluster would lie somewhat closer at $d_\odot = 6.5$ kpc.

The Galactocentric coordinates are $X = -7.6$, $Y = -6.8$ and $Z = 0.1$ kpc. The distance from the Galactic center is $R_{GC} = 10.2$ kpc, thus also outside the solar circle.

4.3. Biurakan 13

An age of 2.3 ± 0.4 Gyr is derived. The reddening is $E(B-V) = 0.30 \pm 0.05$ and the observed distance modulus is $(m-M) = 15.4 \pm 0.1$, with a distance from the Sun of $d_\odot = 7.8 \pm 0.8$ kpc. For the $Z = 0.008$ isochrone, the distance modulus increases to $(m-M) = 15.62$, and the reddening to $E(B-V) = 0.41$; therefore the cluster would be at $d_\odot = 7.6$ kpc.

The Galactocentric coordinates are $X = -14.5$, $Y = -4.4$ and $Z = 0.3$ kpc. The cluster is rather high above the plane. The distance from the Galactic center is $R_{GC} = 15.1$ kpc thus Biu 13 is one of the most distant known open clusters (Frinchaboy & Phelps 2002).

4.3.1. Age distribution of old open clusters

The compilation of old open clusters by Dutra & Bica (2000) included 103 objects. Janes & Phelps (1994) defined "old" clusters as being older than the Hyades of 787 Myr according to the WEBDA database. This definition is such that the clusters contain red giants, and the main sequence turnoff luminosity is fainter than the red giants, in contrast to "young" clusters where the dominating brighter stars are at the top of the main sequence. By excluding the 9 clusters younger than 790 Myr from the list of Dutra & Bica (2000) and on the other hand, by including 5 Saurer clusters analysed by Frinchaboy & Phelps (2002), the Hyades, and the present clusters, an age histogram of old open clusters is given in Fig. 11. Friel (1995) carried out a similar analysis with a sample of 74 old clusters. The present sample containing 103 clusters is 40% larger. Two peaks are seen (as also suggested by Friel 1995), which may be related to two bursts of star formation in the disk. However, the rate of open cluster formation, combined to the dissolution rate, could attenuate the peaks in a few Gyr time. According to Bergond et al. (2001) open clusters may be dissolved in a typical timescale of 600 Myr. The young peak may not necessarily correspond to a burst, but rather to a combination of a continuum formation and destruction rates, or it may be an artifact resulting from the age cut at 790 Myr.

The peak at 5 Gyr is more prominent in the present histogram as compared to that of Friel (1995). This peak has a width of about 1.5 Gyr at half maximum, which is comparable to uncertainties in the current age determinations. Clusters in the range 3 to 9 Gyr are still rare, suggesting that dissolution has been an important effect for such old clusters, as confirmed by the fact that most open clusters are located outside the solar circle. Clusters such as Be 36 from the present study, at 4 Gyr, are important additions to the sample of very old clusters, enhancing the importance of the peak around 5 Gyr.

5. Conclusions

We carried out *BV* photometry of three old open clusters: Be 36, Be 73 and Biu 13. They are not very reddened clusters, Be 36 has $E(B-V) = 0.25$, Be 73 has $E(B-V) = 0.10$ and Biu 13 $E(B-V) = 0.30$. Be 36 is among the oldest open clusters, with an age of 4 Gyr, while Be 73 and Biu 13 are about 2 Gyr old. The sample clusters are all beyond the solar circle, and in particular Biu 13 is a very distant cluster at 15 kpc from the Galactic center.

We updated the sample of the old open clusters in the Galaxy now amounting to 103. The age distribution shows peaks at about 1 Gyr and 5 Gyr, possibly giving clues to the history of disk star formation.

Acknowledgements. We acknowledge partial financial support from the Brazilian agencies Fapesp and CNPq, and the Italian Ministero dell'Università e della Ricerca Scientifica e Tecnologica (MURST) under the program on "Stellar Dynamics and Stellar Evolution in Globular Clusters: a Challenge for New Astronomical Instruments". Based on observations made with the Italian Telescopio Nazionale Galileo (TNG), operated on the island of La Palma by the Centro Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica) at the Spanish Observatory del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.

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