Berkeley 29, the most distant old open cluster

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ABSTRACT

We present CCD BVI photometry of the old open cluster (OC) Berkeley 29, located in the anticentre direction. Using the synthetic colour–magnitude diagrams (CMDs) technique we estimate at the same time its age, reddening, distance and approximate metallicity using three types of stellar evolutionary tracks. The best solutions give: age = 3.4 or 3.7 Gyr, (m − M)0 = 15.6 or 15.8 with E(B − V) = 0.13 or 0.10, and metallicity lower than solar (Z = 0.006 or 0.004), depending on the adopted stellar models. Using these derived values, Be 29 turns out to be the most distant OC known, with Galactocentric distance RGC = 21.4 to 22.6 kpc.

Hence, Be 29 qualitatively follows both the age–metallicity relation and the metal abundance gradient typical of Galactic disc objects. The cluster position and radial velocity, however, appear to link Be 29 to the family of the Canis Major debris.

Key words: Hertzsprung–Russell (HR) diagram – open clusters and associations: general – open clusters and associations: individual: Berkeley 29.

1 INTRODUCTION

As amply acknowledged (e.g. Friel 1995), open clusters (OCs) are among the best objects to describe the Galactic disc properties. In particular, old OCs may be used to trace the disc formation and evolution, and the history of its chemical enrichment. There is a metallicity gradient in the Galactic disc, with the inner regions being more metal rich than the outer ones, as established on the basis of different indicators, from H I regions (e.g. Shaver et al. 1983) and young B stars (e.g. Smartt & Rolleston 1997), to planetary nebulae (e.g. Pasquale & Perinotto 1993). OCs have been suggested to show a metallicity gradient as well (e.g. Janes 1979; Panagia & Tosi 1981; Friel 1995; Carraro, Ng & Portinari 1998; Friel et al. 2002), although Twarog, Ashman & Anthony-Twarog (1997) argue instead that what is observed is a step distribution in GC metallicity.

While there is quite a wealth of OCs with known metallicity in the vicinity of the Sun, only a few objects farther away have been measured: for instance, in the compilation of Friel (1995) there are only two OCs with Galactocentric distance larger than 15 kpc (Berkeley 20 and Berkeley 29, the latter being the farthest known OC) and another one is present in Twarog et al. (1997, Tombaugh 2). Finding and studying clusters at large distances from the Sun, both towards the Galactic centre and the anticentre is essential to define how the disc properties vary radially. Recently Frinchaboy & Phelps (2002) suggested that the most distant old OC is Saurer A (with Galactocentric distance of more than 19 kpc); Carraro & Baume (2003) confirmed their results, finding an age of approximately 5 Gyr, Z ∼ 0.008 and distance from the Sun of 13.2 kpc, implying a Galactocentric distance of approximately 21 kpc. Even more recently, all these old and distant OCs, and in particular Saurer A and Be 29, have been proposed to have originated in/from the Canis Major dwarf spheroidal galaxy, the satellite that is merging with the Milky Way near the Galactic plane (Bellazzini et al. 2004; Frinchaboy et al. 2004; Martin et al. 2004).

This paper is part of a long-term project dedicated to the study of (mostly old) OCs both with precision photometry (e.g. Bragaglia & Tosi 2003; Andreuzzi et al. 2004; Kalirai & Tosi 2004, and references therein) and with high-resolution spectroscopy (Bragaglia et al. 2001; Carretta et al. 2004). The old OC Be 29 (C0650+169, OCL486) has α2000 = 06°53′04″, δ2000 = +16°55′39″, l = 197.98, b = 8.03. We chose to observe it because it appeared to be the most distant OC known and to have old age and low metallicity (Kaluzny et al. 1994, hereafter K94). Even if Saurer A were the most distant OC, Be 29 would retain its importance, because it is more populous; moreover, as we will show in this paper, the distance to Be 29 has been underestimated in the past and we do find it to be slightly more distant than Saurer A. For these reasons Be 29 is of paramount importance in defining the disc abundance gradient (if its origin is completely Galactic) or the properties and formation history of accreted clusters (if it originates from the merged satellite).
Perhaps as a result of its faintness, Be 29 has not been the subject of extensive works in the past: the first and only calibrated colour–magnitude diagram (CMD) published to date is the one by K94. K94 observed in the \(B, V\), and \(I\) bands a small field (3 \(\times\) 8 arcmin) with the 2.1-m Kitt Peak National Observatory (KPNO) telescope, and presented deep and well-defined CMDs. From the projected density distribution of stars he derived a radius of approximately 1.5 arcmin on the sky. He estimated the following properties: age \(\simeq 4\) Gyr, distance from the Sun \(d = 10.5\) kpc, Galactocentric distance \(R_{GC} = 19\) kpc and low metallicity \([Fe/H] \leq -1\). To derive these figures he assumed \(E(B - V) = 0.21\) from Burstein \\& Heiles (1982). Note however that the new maps of interstellar absorption by Schlegel, Finkbeiner \\& Davis (1998), appropriate for \(b > 5\), give the much lower value \(E(B - V) = 0.093\), which would somewhat alter those figures (towards higher metallicity and larger distance from the Sun).

Phips, Janes \\& Montgomery (1994, hereafter PJM94) observed the cluster, but published only non-calibrated CMDs (instrumental \(B, V, I\) magnitudes). They found a 2.1 difference in magnitude between the red clump and the main sequence (MS) turn-off (TO), and did not give any value for reddening and metallicity. With the Janes \\& Phips (1994) formula to convert the magnitude difference into age, this corresponds to an age of \(4.9\) Gyr. Janes \\& Phips (1994) assign to Be 29 a distance of \(8.6\) kpc from the Sun but, based on the assumption of a mean diameter of \(5\) pc for the old cluster population, this is not very significant.

Noriega-Mendoza \\& Ruelas-Mayorga (1997) applied to Be 29 a technique for the simultaneous determination of metallicity and reddening, similar to the one developed by Sarajedini (1994) for globular clusters, useful in stellar systems with a well-defined giant branch and helium burning clump. At variance with the suggestion by K94, they derived \([Fe/H] = -0.30\), and \(E(B - V) = 0.01\); their estimated uncertainties in these values are \(\pm 0.04\) in \([Fe/H]\) and \(\pm 0.02\) in \(E(B - V)\). These results are at odds with what has been obtained by all other studies.

Recently, we have obtained intermediate resolution spectra of 20 stars in the direction of the cluster and have been able to confirm membership for 12 objects in the crucial evolutionary phases of the red giant branch (RGB) and red clump (Bragaglia, Held \\& Tosi 2004). This information will be used in the present analysis. Furthermore, comparison of the confirmed members to other well-studied clusters has permitted us to derive indication for reddening and metallicity (and distance) much more consistent with K94 than with Noriega-Mendoza \\& Ruelas-Mayorga (1997).

We will present our photometric data and the reduction procedure in Section 2; the CMD, the presence of binaries and the field contamination will be discussed in Section 3. In Section 4, results for age, reddening and distance based on the synthetic CMD technique will be presented, and a summary of results and discussion will be given in Section 5.

### 2 Observations and Data Reduction

Be 29 was observed on the night of 1995 March 9 with the 1.54-m Danish telescope (La Silla, Chile) and a direct camera, mounting the CCD No. 28, a chip Tek 1024 \(\times\) 1024 pixel, with scale 0.377 arcsec pixel\(^{-1}\) and field of view of 6.4 \(\times\) 6.4 arcmin\(^2\). The night was part of a run dedicated to OCs; sky conditions were photometric and seeing varied from 0.83 to 1.02 arcsec (see Table 1 for a log of the observations). We observed a single field, centred on Be 29 (see Fig. 1); given the small size of the cluster, we did not obtain a separate pointing for field stars decontamination.

#### Table 1. Log of the observations.

| Telescope | Date              | Exp \(B\) | Exp \(V\) | Exp \(I\) |
|-----------|-------------------|-----------|-----------|-----------|
| Danish    | 1995 March 9      | 1200      | 20,60,900 | 20,60,900 |
| NTT       | 2002 January 16   | 1800      | 2 \(\times\) 900 | 300, 2 \(\times\) 900 |
|           | 2002 January 17   | 1         | 900       |           |

To reach fainter magnitudes, these data were supplemented with new ones taken on 2002 January 16–17 with the New Technology Telescope (NTT; La Silla), mounting the Super Seeing Imager 2 (SuSI2), which uses two chips (CCDs Nos 45 and 46, EEV44-80, 2048 \(\times\) 4096 pixel) with a scale 0.161 arcsec pixel\(^{-1}\) and total field of view of 5.5 \(\times\) 5.5 arcmin\(^2\), with a small vertical gap of 8 arcsec at the junction. In this case seeing varied from 0.66 to 1.16 arcsec.

Data reduction was done using the usual IRAF\(^1\) routines to perform bias subtraction, flat field correction and cleaning of cosmic rays hits. The SuSI2 I images were also corrected for fringing.

We then applied the procedure for point spread function (PSF) study and fitting available in DAOPHOT-II, also in the IRAF environment (Stetson 1987; Davis 1994). The building of the initial catalogue was slightly different for the two data sets: we searched the Danish frames independently with DAOFIND and a threshold of 3\(\sigma\) over the local sky value, while for the SuSI2 frames we used STARFINDER (Doliatii et al. 2000), which is very powerful for finding all stars, excluding at the same time false identifications (i.e. extended objects, blends, cosmic rays, defects, etc.), but is also quite slow. The following steps were identical, except that the two SuSI2 chips were analysed separately.

Approximately 20 well-isolated, bright stars were used in each frame to define the best analytical PSF model, which was then applied to all the detected objects. The resulting magnitude file was selected both in magnitude, to avoid saturated stars, and in sharpness, a shape-defining parameter, to avoid cosmic rays and false identifications of extended objects (this was relevant mostly for the Danish data).

All output catalogues were aligned in coordinates and forced on a reference frame for each filter applying a zero point shift to the instrumental magnitude, using dedicated programs developed at the Bologna Observatory by P. Montegriffo (private communication). Special care had to be taken in aligning the SuSI2 \(B\) magnitudes, for which we had to take into account a colour term.

We computed a correction to the PSF derived magnitudes to be on the same system as the photometric standard stars, performing aperture photometry on a few isolated stars in the reference images. The correction to be applied to the PSF magnitudes was found to be: \(-0.233\) in \(B\), \(-0.204\) mag in \(V\), and \(-0.207\) in \(I\) (in the sense aperture minus PSF). The final magnitude catalogue in each band is the result of the (weighted) average of all measures for each star.

The conversion from instrumental magnitudes to the Johnson–Cousins standard system was obtained using the same equations already derived for this observing run in the case of Pismis 2 (Di Fabrizio et al. 2001, to which we refer for details):

\[
B = B + 0.187 \cdot (b - v) - 7.326 \quad (rms = 0.014),
\]

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\(^1\) IRAF is distributed by the National Optical Astronomy Observatories (NOAO), which are operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation (NSF).
### 3 THE COLOUR–MAGNITUDE DIAGRAM

The final catalogue contains 1649 stars, of which 1144 have $B$, $V$ and $I$ magnitudes, 1182 have at least $B$ and $V$ magnitudes and 1611 have at least $V$ and $I$ magnitudes. The pixel positions of all objects were transformed to equatorial coordinates using software written by P. Montegriffo at the Bologna Observatory and using the Guide Star Catalogue 2 (GSC2) as the reference frame: residuals of the transformation between the two systems (as deduced from the stars in common) are of 0.14 arcsec in right ascension and 0.10 arcsec in declination. Tables containing the photometry, the pixel and equatorial coordinates will be available in electronic form through the Base Des Amas\(^2\) (BDA, Mermilliod 1995).

The resulting CMDs are shown in Fig. 2: the cluster sequences are very well delineated, with an MS extending from $V \approx 16.8$ and $B - V \approx 0.45$ or $V - I \approx 0.60$ at the TO point down to $V \geq 23$ or $23.5$, for approximately 4–5 mag. The subgiant branch (SGB) and RGB are also visible, even if suffering more from field contamination (the Galactic disc), which appears like a scattered MS, positioned mostly on the red side of the cluster MS, and extending to redder colours and to luminosities much brighter than the MS TO of Be 29. The red clump, i.e. the locus of core-He burning stars, is present at $V \approx 16.6$ and $B - V \approx 0.98$, $V - I \approx 1.1$. Three stars stand out, at $V \approx 14.5$, $B - V \approx 1.6$, $V - I \approx 1.6$: as already noted by K94, they seem to represent the brighter part of the RGB, if not its tip.

We also identified stars in common between our sample and K94, and a comparison of the two photometries is shown in Fig. 3: they appear to be in perfect agreement, with average zero point shifts of much less than 0.01 mag in all the three filters.

Recently Bragaglia et al. (2004) derived radial velocities to determine membership for a subsample of 20 stars, including the three bright RGB ones: 4 were definitely found to be field objects, 4 have uncertain status and 12 appear to belong to the cluster RGB and clump. These stars are indicated with different symbols in Fig. 4.

This information is not sufficient to define a clean and safe cluster sample, so to further check on the field fore/background contamination we have plotted the CMDs, selecting stars near the cluster centre or far from it (see Fig. 5): the cluster sequences are even easier to locate and this will be used in next section, when selecting the sample of stars to simulate.

To further test the identification of cluster and field components, we have also used the Besançon models for the Galaxy stellar structure (Robin et al. 2003, available at the web site www.obs-besancon.fr/wwwmodele/modelle_ang.html). Results of a query on an area equivalent to our field of view located at $I = 200$, $b = 8$ are shown in Fig. 6, where we have applied our same incompleteness factors. It is easy to appreciate the similarity of the model to what we have defined as field population in our data. In other words, we are seeing the normal components of the Milky Way, without indications of extra contribution from, for example, the Canis Major galaxy, seen in the background of other OCs (Bellazzini et al. 2004). On the other hand, our field of view is very small (approximately 0.011 deg\(^2\)) and Be 29 is not near the supposed nucleus of the disrupted satellite (located at galactic coordinates $l, b \sim 240, -7$).

Even if not so evident from Figs 2 and 5, a population of binary systems is present in Be 29, as in all the other OCs examined to date. Fig. 7 shows an enlargement of the MS, plotting the $B$, $B - I$ CMD, which allows for a better discrimination of the MSs of the single and binary stars. The fraction of binary systems will be derived together with the cluster parameters in the next section.

### 4 CLUSTER PARAMETERS

Age, distance and reddening of Be 29 have been derived with the same procedure applied to all the clusters of our project (see Andreuzzi et al. 2004; Kalirai & Tosi 2004, and references therein), namely the synthetic CMD method originally described by Tosi et al. (1991). The best values of the parameters are found by selecting the cases providing synthetic CMDs with morphology, colours,

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**Table 2.** Completeness of our photometry in the three filters.

| $B$ Compl$_B$ | $V$ Compl$_V$ | $I$ Compl$_I$ |
|---------------|---------------|---------------|
| \(< 16.75\)   | 1.000         | 1.000         |
| 17.25         | 1.000         | 1.000         |
| 17.75         | 0.991         | 0.968         |
| 18.25         | 0.994         | 0.974         |
| 18.75         | 0.987         | 0.974         |
| 19.25         | 0.983         | 0.971         |
| 19.75         | 0.978         | 0.967         |
| 20.25         | 0.980         | 0.963         |
| 20.75         | 0.974         | 0.946         |
| 21.25         | 0.969         | 0.938         |
| 21.75         | 0.954         | 0.932         |
| 22.25         | 0.949         | 0.912         |
| 22.75         | 0.915         | 0.858         |
| 23.25         | 0.829         | 0.753         |
| 23.75         | 0.608         | 0.428         |
| 24.25         | 0.271         | 0.081         |
| 24.75         | 0.014         | 0.002         |
| 25.25         | 0.000         | 0.000         |

\[ V = V + 0.037 \cdot (b - v) - 6.693 \quad (rms = 0.012), \]

\[ V = V + 0.032 \cdot (v - i) - 6.646 \quad (rms = 0.014), \]

\[ I = I - 0.018 \cdot (v - i) - 7.528 \quad (rms = 0.016), \]

where $b, v, i$ are instrumental magnitudes, while $B, V, I$ are the corresponding Johnson–Cousins magnitudes. We calibrated the $B$ magnitudes using the relation involving $(b - v)$, and the $I$ and $V$ magnitudes with the ones involving $(v - i)$ [except for the stars missing $i$, for which we used the $(b - v)$ colour to calibrate $V$].

We tested the completeness of our luminosity function (LF) in the $B, V$ and $I$ band on the deepest images, i.e. the SuSI2 ones, adding artificial stars to the frames and repeating the procedure of extraction of objects and PSF fitting used for the original frame. Stars were added at random positions and selected in magnitude according to the observed luminosity function, approximately 120 at a time, in order not to significatively alter the crowding conditions, and we repeated the process until a total of approximately 50 000 artificial stars was reached. To the output catalogue of the added stars, we applied the same selection criteria in magnitude and sharpness as done for the science frames. The completeness degree of our photometry at each magnitude level was computed as the ratio of the number of recovered stars to the number of simulated ones (considering as recovered objects only those found within 0.5 pixels of the given coordinates and with magnitudes differing from the input ones less than $\pm0.75$ mag) and is given in Table 2.

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\(^2\) http://obswww.unige.ch/webda/webda.html
Figure 1. Position of our fields: the slightly larger one is for the Danish observations, the other for the SuSI2 ones (notice that in this case there is a small vertical gap between the two CCDs); the map is $15 \times 15$ arcmin and is oriented with north up and east left.

Figure 2. CMDs of the Be 29 field based on our photometry, combining the Danish and SuSI2 exposures. Note the well-populated main sequence (MS) of the cluster, easy to distinguish from that of the field stars, which is redder and with a much brighter TO (around $V \simeq 15.5$). The RGB and red clump regions are also clearly visible, but more difficult to disentangle from the field component.
number of stars in the various evolutionary phases and LFs in better agreement with the observational ones.

As usual, to test the effect of different input physics on the derived parameters, we have run the simulations with three different types of stellar evolutionary tracks, assuming different prescriptions for the treatment of convection and ranging from no overshooting to high overshooting from convective regions.

Be 29 is known to be rather metal poor (see the Introduction, Section 1), but to avoid biases in the parameter determinations, we have created the synthetic CMDs adopting, for each type of stellar model, metallicities ranging from solar down to 1/20 of solar. Notice that we consider as solar metallicity tracks those with $Z = 0.02$, because they are the ones calibrated by their authors on the Sun, independently of the circumstance that nowadays the actual solar metallicity is supposed to be lower (see Asplund et al. 2004). We recall that the position of a stellar model in the CMD depends only on its mass, age and metallicity, but the formal effect of metallicity actually includes that of the opacities adopted in the stellar evolution models. Metallicities attributed to clusters via comparison with stellar models or isochrones therefore are always to be taken with caution. This is why we consider the metallicities derived from our photometric studies to be only indicative and prefer to use high-resolution spectroscopy for a safe determination of the chemical abundances.

The adopted sets of stellar tracks are listed in Table 3, where the corresponding references are also given, as well as the model metallicity and the information on their corresponding overshooting assumptions. The transformations from the theoretical luminosity and effective temperature to the Johnson–Cousins magnitudes and colours have been performed using Bessell, Castelli & Plez (1998) conversion tables and assuming $E(B-V) = 1.25$ $E(B-V)$ (Dean, Warren & Cousins 1978) for all sets of models. Hence, the different results obtained with different stellar models must be ascribed fully to the models themselves and not to the photometric conversions.

The synthetic stars are attributed the photometric error derived from the tests of the artificial stars performed on the actual images. They are retained in (or excluded from) the synthetic CMD according to the photometry completeness factors listed in Table 2. All the synthetic CMDs have been computed either assuming that all the cluster stars are single objects or that a fraction of them are members of binary systems with random mass ratio. We find, as in many other clusters, that a binary fraction around 30 per cent well reproduces the observed distribution along the MS. All the synthetic CMDs shown in the figures assume this fraction of binaries.

Membership to the cluster has been proven (Bragaglia et al. 2004) for 12 stars, including the 3 brightest red giants of the CMD. We have run the simulations both for the CMD corresponding to the whole field covered by our images (using the more external part of the field to estimate back/foreground contamination) and to the inner cluster region, practically unaffected by contamination. The results are absolutely consistent with each other and therefore we present here only the cases corresponding to the inner cleaner region. The examined field has a radius of 2 arcmin from the cluster centre. After removing the stars that, on the basis of the radial velocities and of the external field CMD, appear not to be cluster members, this field contains 553 stars measured in all the $B$, $V$ and $I$ filters. The corresponding CMDs are shown in Figs 8(a) and (b). The synthetic CMDs have therefore been created with this number of objects.

We find that in all cases a solar metallicity must be excluded for Be 29, because all the synthetic CMDs with $Z = 0.02$ are too red and we would need a non-physical negative reddening to account for the observed colours. Stellar tracks with metallicity lower than solar can reproduce the observed MS colours, if an appropriate reddening is
Figure 5. \( V, B - V \) CMDs in different zones of our field. From left to right: only the inner 1-arcmin radius, the inner 2 arcmin and the external part, the best approximation we have of a comparison field. Be 29 appears very concentrated, even if a few main sequence (MS) stars are present also in the farthest regions. We can easily discriminate between the cluster and the fore/background.

Figure 6. \( V, B - V \) and \( V, V - I \) CMDs obtained using the Besançon model for the Galaxy, useful to understand the fore/background contamination.

adopted, but only those with \( Z = 0.004–0.006 \) are able to reproduce both in \( B - V \) and in \( V - I \) the colours of the observed RGB. All the other metallicities lead to excessively red RGBs either in one colour or in both. Moreover, metallicities outside the indicated range sometimes lead also to less consistent features in the CMD sequences.

More in detail, the Bressan, Bertelli & Chiosi (BBC) models with \( Z = 0.004 \), age = 3.7 Gyr, \( E(B-V) = 0.12 \) and \( (m-M)_0 = 15.60 \).
reproduce quite well both the morphology and the number of objects of the CMD evolutionary sequences (MS, SGB, RGB and clump), as well as their colours, both in $B - V$ and in $V - I$ (see Figs 8c and f). The synthetic sequences are slightly tighter than the empirical ones, but this may be the result of residual contamination from back/foreground stars (see also the LFs below). This aspect is found also for all the types of examined models.

The full spectrum turbulence (FST) models with $Z = 0.006$ and moderate overshooting reproduce equally well the data, for age = 3.4–3.5 Gyr, $E(B - V) = 0.10$ and $(m - M)_0 = 15.80$ (see Figs 8e and h). They need a slightly younger age than the BBC models because they have a somewhat lower overshooting and a slightly lower reddening because they are slightly more metal rich. The FST models with same $Z = 0.006$ metallicity but higher overshooting $= 0.006$ reproduce rather well the cluster CMD and LF, but their RGB in $V - I$ are redder than observed. For these FRA models, the best case assumes age = 2.5 Gyr, $E(B - V) = 0.15$ and $(m - M)_0 = 15.80$ (Figs 8d and g). This age is much younger than that of the BBC and FST models because stars of the same mass are fainter than in the overshooting case.

Also the FST tracks with $Z = 0.01$ lead to RGBs too red in $V - I$. In addition, they have too flat SGBs and excessive curvature of the upper MS. The FRA models with $Z = 0.001$ have RGB and clump excessively red both in $B - V$ and in $V - I$ and a non-satisfactory shape of the TO. The FRA models with $Z = 0.01$ also have excessively red RGB and clump and the tendency to overpopulate them.

The LFs of the best cases for the BBC, FRA and FST models are shown in Fig. 9 (lines) and compared to that of the CMD of Fig. 8(a), assumed to be the empirical one (dots). In no case is the fit to the data really good: the models tend to underestimate the number of stars brighter than $V = 20$ and to overestimate the number of stars fainter than $V \approx 21$. We ascribe the first problem to the fact that the synthetic CMDs assume that all the stars of the CMDs of Figs 8(a) and (b) are actual members of Be 29, whilst it may well be that some objects are not, especially on the brighter parts where the field star sequence intersects the cluster sequences. Indeed, the spread around the SGBs and RGBs does suggest the presence of some residual contamination. This explanation makes the second problem more significant, because contaminating objects may be present also in the fainter regions of the empirical CMD, thus making the intrinsic LF of Be 29 lower than the shown one. We

**Figure 7.** Left panel: enlargement on the main sequence (MS) of the $B, B − I$ CMD. The dotted line above the MS is simply the MS ridge line shifted by 0.75 mag, to indicate the position of the equal-mass binaries. Right panels: histograms in colour of stars in bins of 0.5 mag from $B = 20$ to $22$; the indication of a secondary peak, indicative of binary systems, is well visible in the upper panel, while its presence is less obvious, as a result of the smaller numbers, in the others.

**Table 3.** Stellar evolution models adopted for the synthetic CMDs; the FST models actually adopted here are an updated version of the published ones (Ventura, private communication).

| Set | Metallicity | Overshooting | Reference |
|-----|-------------|--------------|-----------|
| BBC | 0.02        | Yes          | Bressan et al. (1993) |
| BBC | 0.008       | Yes          | Fagotto et al. (1994) |
| BBC | 0.004       | Yes          | Fagotto et al. (1994) |
| FRA | 0.02        | No           | Dominguez et al. (1999) |
| FRA | 0.01        | No           | Dominguez et al. (1999) |
| FRA | 0.006       | No           | Dominguez et al. (1999) |
| FRA | 0.001       | No           | Dominguez et al. (1999) |
| FST | 0.02        | $\eta = 0.02$| Ventura et al. (1998) |
| FST | 0.02        | $\eta = 0.03$| Ventura et al. (1998) |
| FST | 0.01        | $\eta = 0.02$| Ventura et al. (1998) |
| FST | 0.01        | $\eta = 0.03$| Ventura et al. (1998) |
| FST | 0.006       | $\eta = 0.02$| Ventura et al. (1998) |
| FST | 0.006       | $\eta = 0.03$| Ventura et al. (1998) |
suggest that the discrepancy between synthetic and empirical LF at faint magnitudes be the result of evaporation of low-mass stars from the cluster.

5 SUMMARY AND DISCUSSION

From comparison of the observed and synthetic CMDs, we obtain the following results.

(i) Of the three different sets of evolutionary tracks used, the best reproductions come from the BBC and FST ones, i.e. the ones taking overshooting from convective regions into account.

(ii) The best solutions are obtained for abundances lower than solar ($Z = 0.02$ is excluded), with formal metallicity $[\text{Fe/H}] \simeq -0.5$ or $-0.7$. This is higher than estimated by K94 (whose adopted reddening was overestimated, see below) and in very good agreement with the results of Bragaglia et al. (2004, $[\text{Fe/H}] = -0.74 \pm 0.18$) obtained in a completely independent way.

(iii) The age of Be 29 is found to be approximately 3.5 Gyr (best synthetic CMDs provide values from 3.4 to 3.8 Gyr) and this is in reasonable agreement with the value given by K94.

(iv) The best reddening value is approximately 0.1 mag [$E(B-V) = 0.10$ to 0.13], that well compares to the Schlegel et al. (1998) value of 0.093. The strong disagreement with the 0.21 value adopted by K94 explains the different distance moduli.

(v) The best solutions for the absolute distance modulus of Be 29 give $(m - M)_0 = 15.6$ or 15.8. This puts the cluster at least as far as, or even farther than, Saurer A from the Galactic centre, with $R_{GC} = 21.4$ or 22.6 kpc, thus reinforcing its place as the most distant in the still scarce family of very far and old OCs known in the Milky Way.

Be 29 is then an old, relatively metal-poor, distant OC. This makes it nicely consistent with what is expected from simple chemical evolution arguments, predicting that old stars are more metal poor than younger stars formed in the same place and that the
metallicity of coeval objects decreases with increasing distance from the Galactic centre. The precise and detailed metal abundance of Be 29, derived from high-resolution spectroscopy and fine abundance analysis, would be very valuable in defining the metallicity gradient along the entire disc.

The conclusion that Be 29 appears as a well-behaved object in the framework of Galactic chemical evolution is challenged by a recent analysis, would be very valuable in defining the metallicity gradient along the entire disc.

Our current data do not allow us to discriminate between the Galactic or external origin of Be 29. The circumstance that this cluster actually is not of truly Galactic origin, but is somehow connected to the interaction between the Galaxy and its merging satellite Canis Major. Frinchaboy et al. (2004) suggest that the old and far OCs, especially those located in the two Galactic quadrants towards the anticentre, lie along a string-like configuration that the old and far OCs, especially those located in the two Galactic quadrants towards the anticentre, lie along a string-like configuration that the old and far OCs, especially those located in the two Galactic quadrants towards the anticentre, lie along a string-like configuration that the old and far OCs, especially those located in the two Galactic quadrants towards the anticentre, lie along a string-like configuration that the old and far OCs, especially those located in the two Galactic quadrants towards the anticentre, lie along a string-like configuration.
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