Mon. Not. R. Astron. Soc. **284**, 692–698 (1997)

HP 1: a blue horizontal branch globular cluster in the bulge

S. Ortolani,[1] E. Bica[2] and B. Barbuy[3]

[1] *Università di Padova, Dipartimento di Astronomia, Vicolo dell'Osservatorio 5, I-35123 Padova, Italy*
[2] *Universidade Federal do Rio Grande do Sul, Departamento de Astronomia, CP 15051, Porto Alegre, 91500-970, Brazil*
[3] *Universidade de São Paulo, IAG, Departamento de Astronomia, CP 9638, São Paulo 01065-970, Brazil*

Accepted 1996 September 11. Received 1996 August 28; in original form 1996 February 5

ABSTRACT

We present V, I colour–magnitude diagrams of the globular cluster HP 1 obtained at the European Southern Observatory New Technology Telescope under exceptional seeing conditions. The cluster shows blue horizontal branch (HB) and red giant branch morphologies very similar to clusters of intermediate metallicity such as NGC 6752; we therefore estimate $[Fe/H] \approx -1.5$ for HP 1. The blue HB morphology is extended, which is not unusual for a post-core-collapse cluster. We derive a reddening of $E(B-V)=1.19$ and a distance $d_{\odot}=6.85$ kpc. HP 1 might be a halo cluster crossing the bulge or belong to the low-metallicity tail of the bulge.

Key words: globular clusters: individual: HP 1 – Galaxy: halo – Galaxy: structure.

1 INTRODUCTION

The knowledge of the total population of globular clusters and the study of their spatial distribution are fundamental for understanding the early evolutionary history of our Galaxy (see e.g. Racine & Harris 1989). In order to achieve this, the precise determination of the cluster parameters such as reddening, distance and metallicity is necessary. With this in mind we have undertaken a systematic photometric study of those that require this information. In particular, several globular clusters projected on the bulge have been very little studied because of crowding and extinction problems. For this reason, in the last years, we have dedicated our efforts to the study of such globular clusters. We have already obtained deep CCD colour–magnitude diagrams (CMD) for (i) a series of clusters in the bulge which had only photographic studies before, e.g. NGC 6553 (Ortolani, Barbuy & Bica 1990, hereafter OBB90), NGC 6528 (Ortolani, Bica & Barbuy 1992, OBB92), Terzan 1 (Ortolani, Bica & Barbuy 1993a, OBB93a), NGC 6440 (Ortolani, Barbuy & Bica 1994a, OBB94a) and NGC 6522 (Barbuy, Ortolani & Bica 1994); (ii) clusters which were previously catalogued as open clusters but which turned out to be globular clusters, NGC 6540 (Bica, Ortolani & Barbuy 1994, hereafter BOB94), or are consistent with being the oldest open clusters or young globular clusters such as Lyngå 7 (Ortolani, Bica & Barbuy 1993b, OBB93b) and BH 176 (Ortolani, Bica & Barbuy 1995a, OBB95a); (iii) some globular cluster candidates that turned out to be open clusters such as AM-2 (OBB95a) and NGC 6603 (Bica, Ortolani & Barbuy 1993, BOB93); (iv) CMDs for several clusters projected on the bulge, NGC 6652 (Ortolani, Bica & Barbuy 1994b, OBB94b), Palomar 6 and Djorgovski 1 (Ortolani, Bica & Barbuy 1995b, OBB95b), Liller 1 (Ortolani, Bica & Barbuy 1996a, OBB96a) and Terzan 5 (Ortolani, Barbuy & Bica 1996b, OBB96b); (v) finally, by means of spectroscopy and images, the globular cluster candidates TJ5 and TJ23, as well as the one reported by Bica (1994), which turned out to be small emission nebulae in rich stellar fields (Bica et al. 1995).

The present study deals with the globular cluster HP 1, which was first reported by Dufay, Berthier & Morignat (1954), discovered on infrared films obtained at the Haute Provence Observatory Schmidt telescope. The cluster is also designated GCL B1727 – 2956, BH 229 and ESO 455-SC11, located at $\alpha_{1950}=17^h27^m53\overset{s}{.}2$, $\delta_{1950}=-29°56'41''$. It is projected at only $3\overset{\circ}{.}33$ from the Galactic Centre ($l=357\overset{\circ}{.}425$, $b=+2\overset{\circ}{.}115$).

Only recently some cluster properties have been estimated, but no optical CMD is available so far. Webbink (1985) estimated a horizontal branch (HB) level of $V_{HB}=20.0$ by means of the bright giants method, and a reddening of $E(B-V)=1.41$ using the modified cosecant law, deriving a distance from the Sun of $d_{\odot}=9.5$ kpc. Webbink lists a metallicity $[M/H]=-1.68$. On the other hand, using integrated near-infrared spectroscopy, Armandroff & Zinn (1988, hereafter AZ88) derived $[Fe/H]=-0.56$ from the near-infrared Ca II triplet lines, and $E(B-V)=1.44$ from the interstellar band at 8621 Å. Minniti (1995) carried out spectroscopy in the range

4700–5400 Å of six stars in the cluster region, deriving a metallicity of [Fe/H] = -0.30 ± 0.20. Minniti, Olszewski & Rieke (1995) presented an infrared CMD in K versus $(J-K)$ for HP 1: the HB was not detected; the red giant branch (RGB) properties alone could not be used to decouple reddening and metallicity, but based on previous results, they favoured $E(B-V) = 1.25$ and [Fe/H] = -0.5.

The cluster structure is very concentrated, with $c = 2.50$, and it presents a post-core-collapse morphology (Trager, King & Djorgovski 1995).

In the present paper we provide V and I photometry for HP 1 obtained under exceptional seeing conditions at the European Southern Observatory (ESO) New Technology Telescope (NTT).

In Section 2 the observations are described. In Section 3 the CMDs are discussed and in Section 4 the cluster parameters are derived. The concluding remarks of this work are given in Section 5.

Table 1. Logbook of observations.

Filter	Day	Instrument	Exp. time (s)	Seeing (")
V	16.05.1994	NTT + SUSI	60	0.55
V			600	0.45
I			60	0.55
I			300	0.60
I	19.05.1994	Danish	60	1.3
I			420	1.3
V			900	1.3
V			60	1.3

2 OBSERVATIONS

The observations were carried out in 1994 May at ESO, using the 3.55-m NTT and the 1.54-m Danish telescopes.

At the NTT, the Nasmyth focus B, with a 1024 × 1024 thinned Tektronix CCD (SUSI camera) was employed. The pixel size is 24 μm, which corresponds to 0.13 arcsec on the sky. The frame size is 2.2 × 2.2 arcmin^2.

The data were collected under exceptional seeing conditions (0.45 to 0.60 arcsec), which is crucial for such a compact cluster projected on a crowded bulge field.

The DAOPHOT II package was used for the reductions, with particular care taken for the crowded field extractions and calibrations, as described in detail in the Liller 1 study (OBB96a), which was also observed in the same run. The zero-point accuracy is ±0.03 mag. Crowding effects in the aperture photometry required for the magnitude transfer from the cluster images to the standard stars can amount to 0.05 mag. The photometric errors in the stellar extractions are approximately constant to $I = 17.5$, which amount to 0.02 mag; at $I = 18.5$ the error increases to 0.07 mag. The

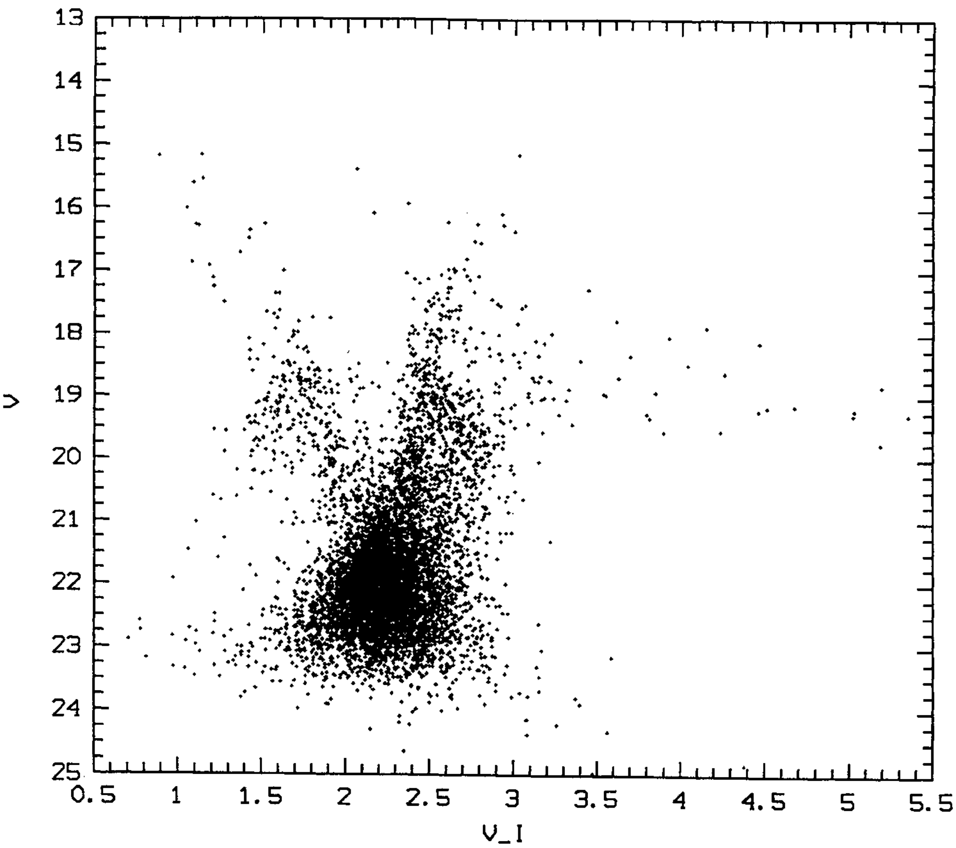

Figure 1. V versus $(V-I)$ CMD for the NTT whole frame.

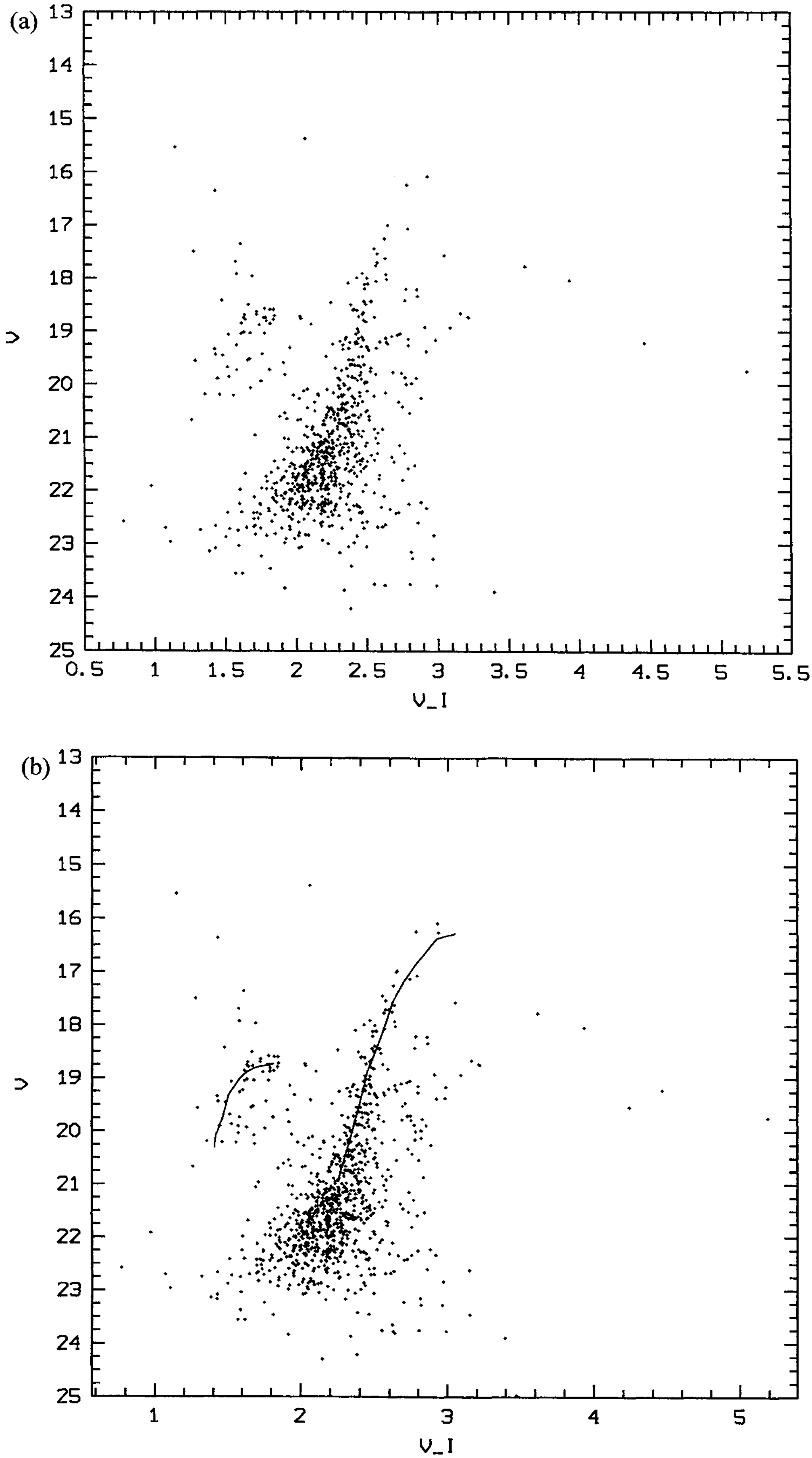

Figure 2. (a) V versus $(V-I)$ CMD for an extraction of radius $r < 23$ arcsec centred on the cluster; (b) same as (a), with the mean locus of NGC 6752 superimposed on the metal-poor sequences.

photometry in the core-collapse central regions is not complete. We checked the nature of residual stars, in a subsequent extraction iteration, reaching completeness at $V < 19.5$, and we found a number of intermediate magnitude stars which do not affect the CMD morphology, so that we preferred not to use stars from the second iteration, to avoid spurious points.

At the Danish telescope we used the Tektronix CCD #28 of 1024 × 1024 pixel, with a pixel size of 24 μm, corresponding to 0.37 arcsec pixel^{-1}. The full field is 6.3 × 6.3 arcmin^2. The reductions were carried out in the standard way, and the calibration equations, where Landolt (1983, 1992) stars were also used, are: $V = 26.91 + 0.04(V - I) + v$; $I = 26.09 + i$ (the numbers are for 30-s exposures and airmass of 1.1). The logbook of observations is given in Table 1.

3 COLOUR–MAGNITUDE DIAGRAMS

We show in Fig. 1 a V versus $(V-I)$ diagram for the whole frame. The main CMD features are (i) a blue disc main sequence (MS) which appears to be crossed by a blue HB, and (ii) two RGBs, a very red and curved bulge one, and a vertical one which can be identified with an intermediate metallicity cluster (Section 4.2).

In Fig. 2(a) we present the V versus $(V-I)$ diagram for a smaller region centred on the cluster (radius $r < 23$ arcsec). The cluster features are dominant in the diagram, showing a clear blue HB and a vertical RGB. This strongly suggests that HP 1 is *not* a metal-rich bulge cluster. The CMD features of the cluster are very similar to those of NGC 6752, as shown in Fig. 2(b) which is the same as Fig. 2(a) except for the superimposed mean locus of NGC 6752. HP 1 shows a blue tail characteristic of a post-core-collapse globular cluster (Fusi Pecci et al. 1993), as also seen in NGC 6752 (Aurière & Ortolani 1989). The brighter parts of the blue HB of HP 1 are located at $V = 18.6 \pm 0.1$ and $(V-I) = 1.75 \pm 0.05$. The RGB slope and extent are almost coincident with those of NGC 6752, indicating that HP 1 should have a comparable intermediate metallicity, i.e. [Fe/H] ≈ -1.5, given that [Fe/H] $= -1.54$ for NGC 6752 is reported by Zinn (1985). This metallicity value is compatible with the estimate for HP 1 of Webbink (1985), [Fe/H] $= -1.68$. The high metallicities obtained by AZ88 ([Fe/H] $= -0.56$) and Minniti (1995) ([Fe/H] $= -0.30$) could be explained by a contamination of bulge giants – see the extended metal-rich RGB in Figs 2(a) and (b). We also considered the possibility of a projected metal-rich cluster or even a merger between the metal-poor cluster with a less massive metal-rich one. These hypotheses are tested in Section 4.

3.1 The surrounding field

In Fig. 3 we present the V versus $(V-I)$ CMD for the Danish whole frame, of 6.3 × 6.3 arcmin^2, dominated by the field. The mean locus for the metal-rich globular cluster

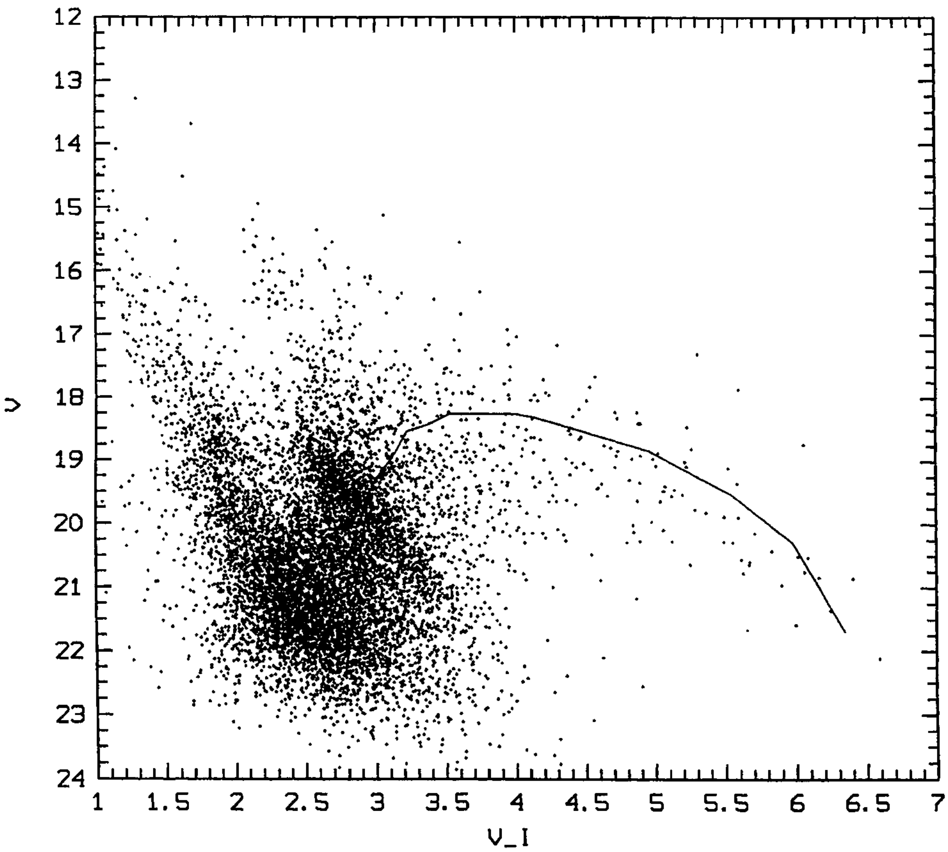

Figure 3. V versus $(V-I)$ CMD from the Danish whole frame (6.3 × 6.3 arcmin^2), essentially dominated by field stars. The mean locus of NGC 6553 is superimposed by fitting the HB locus.

NGC 6553 (Ortolani et al. 1995c) is superimposed, by fitting the HB locus. The mean RGB locus is an upper envelope, meaning that the field giants are more blanketed, which indicates that this bulge field is more metal rich than NGC 6553 ([Fe/H] ≈ −0.2, Barbuy et al. 1992).

The comparison of this field with Terndrup's (1988) Baade Window field suggests that the present bulge region is more metal rich. It is interesting to note that this field is more internal (3°.3 from the Galactic Centre) and closer to the Galactic plane, relative to the Baade Window.

4 REDDENING AND DISTANCE

We calculate the cluster reddening taking NGC 6752 as reference. The $(V-I)$ colour of the RGB at the HB level for HP 1 is 2.48 ± 0.03, whereas for NGC 6752 it is $(V-I)=0.95 \pm 0.04$, and the difference is $\Delta(V-I)=1.53$. Adopting $E(B-V)=0.04$ for NGC 6752 (Zinn 1985), and $E(V-I)/E(B-V)=1.33$ (Dean, Warren & Cousins 1978), we get $E(V-I)=1.58$ and $E(B-V)=1.19$ for HP 1. This value, based on the direct detection of the HB level, is somewhat lower than previous estimates (Section 1).

The magnitude difference between the HB levels of HP 1 and NGC 6752 is $\Delta V=5.0 \pm 0.15$. The absolute V absorption for HP 1 is $A_V=3.69$ [$R=A_V/E(B+V)=3.1$, Savage & Mathis 1979]. The absolute distance modulus of NGC 6752 is $(m-M)_0=12.84$ (Zinn 1985), which leads to $(m-M)_0=14.15 \pm 0.2$ and a distance from the Sun of $d_\odot=6.75 \pm 0.6$ kpc for HP 1. An alternative method is the use of the absolute magnitude of the HB for [Fe/H] = −1.5, of $M_V=0.7$ (Buonanno, Corsi & Fusi Pecci 1989; Lee, Demarque & Zinn 1990; Sandage & Cacciari 1990). In this case the distance would be $d_\odot=6.95$ kpc ($R=3.1$).

The metal-rich population has $V_{HB}=19.25 \pm 0.25$, and $(V-I)_{HB}=2.60 \pm 0.12$. The difference between the metal-rich population (bulge) and the metal-rich reference cluster NGC 6553 (Ortolani et al. 1995c) is $\Delta(V-I)^{6553}_{bulge}=(2.60\text{–}2.05)=0.05$; given that from *Hubble Space Telescope*

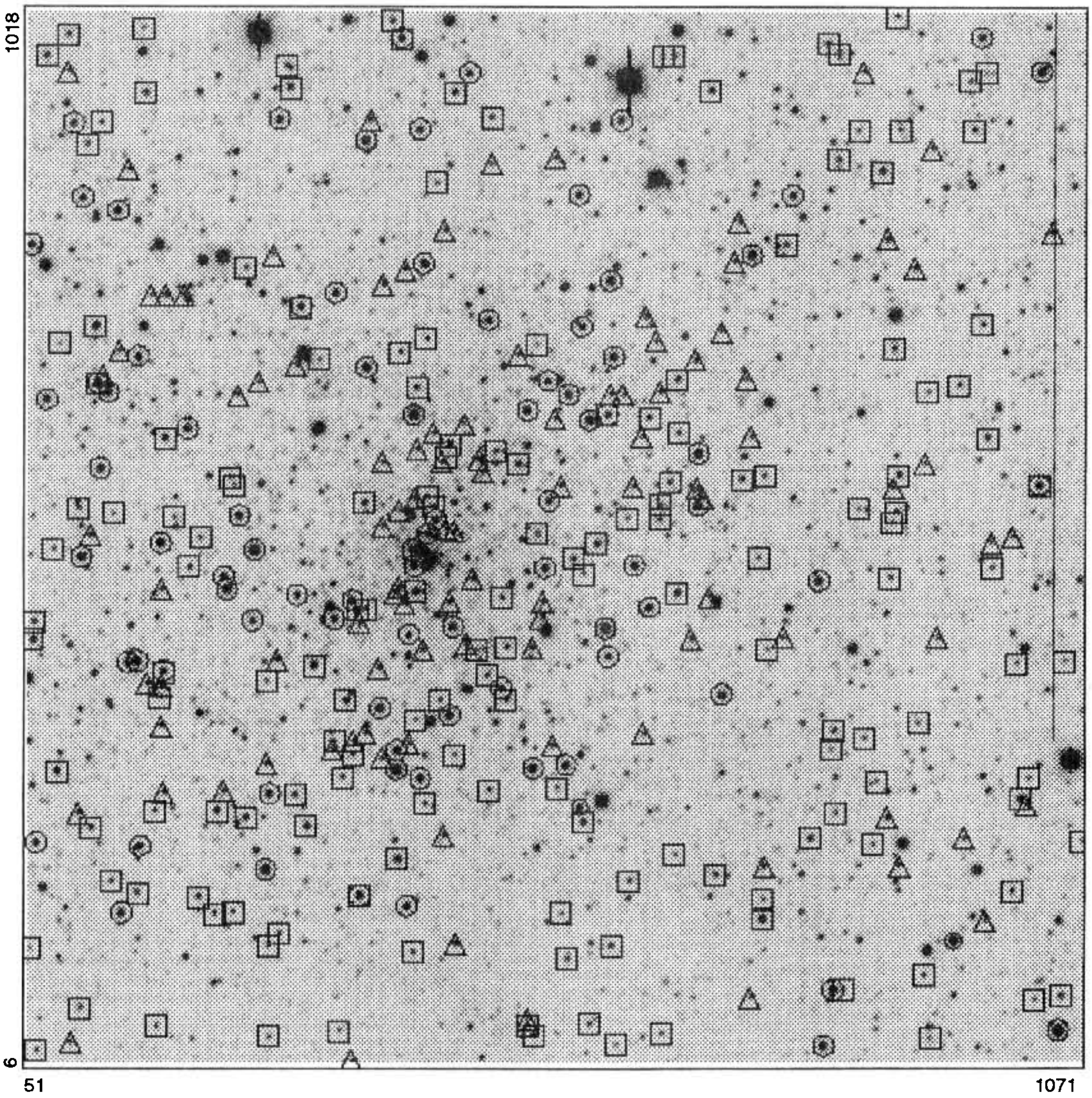

Figure 4. Same as Fig. 1, where stars of different evolutionary sequences are identified. Symbols: circles are metal-poor RGB; triangles are blue extended HB; squares are metal-rich RGB.

Table 2. Radial distribution of giants and HB stars. Values are number densities per pixel, to be divided by 10^4.

Bin (pixels)	metal – rich RGB	metal – poor RGB	blue HB
0 – 100	1.05	5.1	5.1
100 – 200	1.65	1.75	1.45
200 – 300	1.075	1.60	1.60

(*HST*) data the revised value $E(V-I)=0.95$ for NGC 6553 (Guarnieri et al. 1996), this leads to $E(V-I)^{\rm bulge}=1.5$ and $E(B-V)=1.13$. Assuming $R=3.1$ we get $A_V=3.5$; if $R=3.6$ suitable for red stars is adopted (Terndrup 1988; Grebel & Roberts 1995), we get $A_V=4.07$. Assuming that the absolute magnitude of the HB for a metallicity of about [Fe/H] ≈ -0.2 is 0.80 (Chaboyer et al. 1996), and applying a 0.14 blanketing correction which matches bolometric magnitudes (see discussion in Guarnieri et al. 1996), there results $M_V^{\rm HB}=0.94$. The distances are $d_\odot=9.15$ kpc ($R=3.1$) and $d_\odot=7.05$ kpc ($R=3.6$). The latter value would be more appropriate for red stars, in which case the bulge population distance basically coincides with that of HP 1. The possible presence of a projected metal-rich cluster (or a merger) was tested by isolating in the CMD of Fig. 1 (whole frame) the following features as shown in Fig. 4: (i) the metal-poor RGB, (ii) the blue extended HB, and (iii) the metal-rich RGB (all stars with $(V-I)>2.8$ and $V>19.7$). We carried out an analysis of the number density of such stars in concentric rings centred on the cluster. The results for three bins of 100 pixels are reported in Table 2. We conclude that both the metal-poor RGB and HB are strongly concentrated towards the cluster centre, which is not the case of the metal-rich giants. This confirms the presence of a metal-poor cluster, and the metal-rich component is the bulge field rather than a superimposed metal-rich cluster.

HP 1 is therefore closer than previously estimated by Webbink (1985). The galactocentric coordinates of the cluster, assuming a distance from the Sun to the Galactic Centre of $R_\odot=8.0$ kpc (Reid 1993), are $X=1.25$ ($X>0$ refers to our side of the Galaxy), $Y=-0.30$ and $Z=0.25$ kpc. If $R_\odot=7.0$ kpc (Zinn 1985), then $X=1.09$, $Y=-0.26$ and $Z=0.22$ kpc. Interestingly, the use of $A_V/E(B-V)=3.6$ for the bulge population provides a distance of 7 kpc similar to that of HP 1, and coincident with the Galactic Centre if $R_\odot=7.0$ kpc.

5 CONCLUSIONS

We present high-quality CMDs of the globular cluster HP 1, obtained under superb seeing conditions, which show for the first time the cluster optical HB and RGB morphologies. The HB is blue extended, which is not unusual for a post-core-collapse cluster. The CMD resembles that of NGC 6752, which suggests a comparable intermediate metallicity around [Fe/H] ≈ -1.5. The cluster is not metal rich, contrary to previous estimates, where the overestimation was very probably caused by contamination of bulge giants. We derive a reddening of $E(B-V)=1.19$ and a distance from the Sun of $d_\odot=6.85\pm0.2$ kpc.

HP 1 is another case of a blue HB cluster in the bulge. Other such cases projected within 5° of the Galactic Centre are NGC 6522 (Barbuy et al. 1994) and NGC 6540 (BOB94). HP 1 is either a halo cluster crossing the bulge, or belongs to the metal-poor tail of the bulge.

Deep *VI* photometry with the *HST* permitting us to reach the turn-offs of metal-poor bulge clusters would allow us to derive their ages. In fact, van den Bergh (1993) suggested that the metal-poor cluster NGC 6287, projected at 11° from the Galactic Centre, could be the oldest cluster in the Galaxy, if Larson's (1990) scenario for the formation of our Galaxy is correct. Deep CMDs for clusters such as HP 1, at 3°.3 from the Galactic Centre and metal poor, are important to provide hints on the formation scenario of our Galaxy.

ACKNOWLEDGMENTS

We are grateful to an anonymous referee for interesting suggestions. BB and EB acknowledge partial financial support from CNPq, Fapesp and Fapergs. The observations on which this paper is based were collected at the European Southern Observatory.

REFERENCES

Aurière M., Ortolani S., 1989, A&A, 221, 20
Armandroff T. E., Zinn R., 1988, AJ, 96, 92 (AZ88)
Barbuy B., Castro S., Ortolani S., Bica E., 1992, A&A, 259, 607
Barbuy B., Ortolani S., Bica E., 1994, A&A, 285, 871
Bica E., 1994, A&A, 285, 868
Bica E., Ortolani S., Barbuy B., 1993, A&A, 270, 117 (BOB93)
Bica E., Ortolani S., Barbuy B., 1994, A&A, 283, 67 (BOB94)
Bica E., Clariá J. J., Bonatto Ch., Piatti A. E., Ortolani S., Barbuy B., 1995, A&A, 303, 747
Buonanno R., Corsi C. E., Fusi Pecci F., 1989, A&A, 216, 80
Chaboyer B., Demarque P., Kernan P. J., Krauss L. M., 1996, Sci, 271, 957
Dean J. F., Warren P. R., Cousins A. J., 1978, MNRAS, 183, 569
Dufay J., Berthier P., Morignat B., 1954, Comptes Rendus Acad. Sci., 259, 478
Fusi Pecci F., Ferraro F. R., Bellazzini M., Djorgovski S., Piotto G., Buonanno R., 1993, AJ, 105, 1145
Grebel A. K., Roberts W., 1995, A&AS, 109, 293
Guarnieri M. D., Ortolani S., Montegriffo P., Renzini A., Barbuy B., Bica E., Moneti A., 1996, A&A, in press
Landolt A. U., 1983, AJ, 88, 439
Landolt A. U., 1992, AJ, 104, 340
Larson R. B., 1990, PASP, 102, 709
Lee Y.-W., Demarque P., Zinn R., 1990, ApJ, 350, 155
Minniti D., 1995, A&A, 303, 468
Minniti D., Olszewski E. W., Rieke M., 1995, AJ, 110, 1680
Ortolani S., Barbuy B., Bica E., 1990, A&A, 236, 362 (OBB90)
Ortolani S., Bica E., Barbuy B., 1992, A&AS, 92, 441 (OBB92)
Ortolani S., Bica E., Barbuy B., 1993a, A&A, 267, 66 (OBB93a)
Ortolani S., Bica E., Barbuy B., 1993b, A&A, 273, 415 (OBB93b)
Ortolani S., Barbuy B., Bica E., 1994a, A&AS, 108, 659 (OBB94a)
Ortolani S., Bica E., Barbuy B., 1994b, A&A, 286, 44 (OBB94b)
Ortolani S., Bica E., Barbuy B., 1995a, A&A, 300, 726 (OBB95a)
Ortolani S., Bica E., Barbuy B., 1995b, A&A, 296, 680 (OBB95b)
Ortolani S., Renzini A., Gilmozzi R., Marconi G., Barbuy B., Bica E., Rich R. M., 1995c, Nat, 377, 701
Ortolani S., Bica E., Barbuy B., 1996a, A&A, 306, 134 (OBB96a)

Ortolani S., Barbuy B., Bica E., 1996b, A&A, 308, 733 (OBB96b)
Racine R., Harris W. E., 1989, AJ, 98, 1609
Reid M., 1993, ARA&A, 31, 345
Sandage A., Cacciari C., 1990, ApJ, 350, 645
Savage B., Mathis J., 1979, ARA&A, 17, 73
Terndrup D., 1988, AJ, 96, 884
Trager S. C., King I. R., Djorgovski S., 1995, AJ, 109, 218
van den Bergh S., 1993, ApJ, 411, 178
Webbink R. F., 1985, in Goodman J., Hut P., eds, IAU Symp. 113, Dynamics of Star Clusters. Reidel, Dordrecht, p. 541
Zinn R., 1985, ApJ, 293, 424