ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **132**, 333–340 (1998)

Terzan 3 and IC 1276 (Palomar 7): Two metal-rich bulge globular clusters uncovered⋆

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

[1] Universidade de São Paulo, C.P. 3386, São Paulo 01060-970, Brazil
[2] Università di Padova, Dept. di Astronomia, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy
[3] Universidade Federal do Rio Grande do Sul, Dept. de Astronomia, C.P. 15051, Porto Alegre 91500-970, Brazil

Received March 30; accepted April 27, 1998

Abstract. Colour magnitude diagrams of Terzan 3 and IC 1276 are presented for the first time. The morphology of the horizontal and red giant branches indicates that they are metal rich ([Fe/H] ≈ -0.7). They are considerably reddened, with $E(B-V) = 0.72$ (Terzan 3) and $E(B-V) = 1.16$ (IC 1276). Terzan 3 is located at a distance from the Sun $d_\odot \approx 6.5$ kpc, and IC 1276 at $d_\odot \approx 4.0$ kpc. Both clusters are in the Galactic Bulge. The photometries attain the main sequence turnoff regions, and a discussion of ages is given as compared to other bulge and halo globular clusters.

Key words: galaxies: globular clusters: Terzan 3; IC 1276 — HR diagram

1. Introduction

Terzan 3 and IC 1276 (Palomar 7) are globular clusters projected on the outskirts of the bulge, and the latter cluster is not far from the Galactic plane. Not much information is available for them, in particular there are no Colour-Magnitude Diagrams (CMD) available in the literature.

Terzan 3 was discovered by Terzan (1968) at the Haute-Provence Observatory. It is also known as ESO 390−SC6, GCL B1625−3514 and is located at $\alpha_{1950} = 16^{\rm h}\ 25^{\rm m}\ 22.9^{\rm s}$, $\delta_{1950} = -35^\circ\ 14'\ 37''$ ($l = 345.077^\circ$, $b = +9.187^\circ$).

From the bright giants method Webbink (1985) estimated a horizontal branch (HB) level $V_{\rm HB} = 18.8$, a reddening $E(B-V) = 0.32$ from the modified cosecant law, and a distance from the Sun $d_\odot = 27.2$ kpc. The recent compilation by Harris (1996) lists $d_\odot = 25.2$ kpc, $E(B-V) = 0.32$, and $V_{\rm HB} = 18.8$. To our knowledge, no metallicity estimates are given in the literature. The cluster is very loose and Harris (1996) gives a concentration parameter $c = 0.70$.

IC 1276, also designated as Palomar 7, GCL-90 (Alter et al. 1970) and GCL B1625−3514, is located at $\alpha_{1950} = 18^{\rm h}\ 08^{\rm m}\ 02^{\rm s}$, $\delta_{1950} = -07^\circ\ 13'\ 08''$ ($l = 21.832^\circ$, $b = +5.669^\circ$).

The cluster is loose with a concentration parameter $c = 1.29$, with a core radius $r_{\rm c} = 65''$ and half light radius $r_{\rm h} = 141''$ (Trager et al. 1995).

Webbink (1985) gives $V_{\rm HB} = 18.5$, $E(B-V) = 0.92$ deduced from integrated colours, a distance from the Sun $d_\odot = 9.8$ kpc and [Fe/H] $= -0.84$, whereas Harris (1996) reports $d_\odot = 8.9$ kpc, $E(B-V) = 0.92$ and $V_{\rm HB} = 18.4$.

Five variable stars were found in the cluster field by Kinman & Rosino (1962). One of them is a RR Lyrae, located close to the cluster center, and the other four are semi-regular or long period variables at about $r \approx 3' - 5'$ from the cluster center.

In the present study we report B, V photometry for Terzan 3 and IC 1276, in order to determine their basic parameters, in particular their location in the Galaxy and an estimation of metallicity. Given the relatively large angular distance from the Galactic center of 17.5° and 22.6° for Terzan 3 and IC 1276 respectively, it is important to verify if they are bulge clusters. In Barbuy et al. (1998) we gathered our series of CMD parameter derivations for essentially all clusters within a radius of 5° of the Galactic center, providing for the first time a reliable picture of the spatial distribution of these objects. The study of Terzan 3 and IC 1276 is part of a sample in a wider angular distribution where it is important to check which clusters belong to the bulge.

In Sect. 2 the observations are described. In Sects. 3 and 4 we study Terzan 3 and IC 1276 respectively.

Send offprint requests to: B. Barbuy

⋆ Observations collected at the European Southern Observatory - ESO, Chile.

In Sect. 5 the cluster ages are discussed and in Sect. 6 the concluding remarks are given.

2. Observations

The 3.55 m New Technology Telescope (NTT) and Danish 1.54 m telescopes were used at the European Southern Observatory (ESO).

The NTT equipped with EFOSC2 was used with the coated Thomson CCD ESO # 17, of 1024×1024 pixels and pixel size 19×19 μm ($0.15''$); this configuration gave a field size of $2.5'$ vs. $2.5'$. The observations were binned in two-by-two pixels.

The Danish observations of 1985 June and 1986 June were carried out with the RCA ESO CCD # 1, of 512×320 pixels and pixel size 30×30 μm ($0.47''$), giving a field size of $4.0'$ vs. $2.5'$.

The Danish observations of 1988 March were carried out with the RCA ESO CCD # 8 (1024×640 pixels of pixel size 15×15 μm); the size on the sky is $0.23''$ and the field size is $4.0'$ vs. $2.5'$.

Besides Terzan 3 and IC 1276, a field $31'$ north of Terzan 3 was observed in binned two-by-two pixel mode.

The log of observations is given in Table 1.

The reductions and calibrations were carried out with the Midas package. The stellar photometry was made with the DAOPHOT code in MIDAS environment. Landolt (1983) standard stars were used for the calibrations.

The reductions were carried out in the standard way, and the calibration equations, where Landolt stars were used, are given in Ortolani et al. (1990) for the Danish 1988 data, Gratton & Ortolani (1988) in a study of Pal 12 for the Danish 1985 data, and for the June 1986 observations the transformation equations are

$$V = 25.0 + 0.09(B-V) + v$$

$$B-V = 0.66 + 1.075(b-v)$$

(numbers are for 15 (V) and 30 (B) sec exposures and airmass of 1.15).

The main sources of error in the photometry are the zero point accuracy (± 0.03 mags) and the magnitude transfer from the cluster images to the standard stars due to crowding mostly in the case of IC 1276, which can amount to 0.05 mags. An additional error source affecting observations obtained with the early CCD ESO # 1 was due to the charge transfer inefficiency, causing a slight elongation of the stars in the east-west direction.

For the Danish observations, photometric errors are approximately constant to $V = 19$, amounting to 0.02 mags; at $V = 20.5$ the error increases to 0.07 mags. In the case of the observations of Terzan 3 with the NTT the errors increase only for magnitudes fainter than 21.5.

In Fig. 1 a NTT V image of Terzan 3 and in Fig. 2 a Danish V image of IC 1276 are shown. It is clear that we are dealing with loose globular clusters as already indicated by their concentration parameters given above.

Table 1. Log-book of observations

Target	Filter	Date	Equipment	Exp. (sec.)	Seeing ($''$)
Terzan 3	B	18.03.1988	Danish	600	1.0
	V	"	"	1200	1.1
	B	29.05.1990	NTT	2×900	1.3
	V	"	"	2×300	1.2
Field	B	24.03.1988	Danish	1200	1.0
	V	"	"	600	1.0
IC 1276	B	15.06.1985	Danish	600	2.0
	V	"	"	300	2.0
	V	"	"	1200	2.0
	B	24.06.1985	"	1800	1.5
	B	"	"	600	1.4
	V	"	"	900	1.3
	V	"	"	420	1.3
	V	"	"	180	1.4
	B	02.06.1986	"	1200	1.8
	V	"	"	600	1.8

Note to the table: The long B and V observations of 24.06.85 were taken offcenter, west of the cluster.

3. Terzan 3

3.1. Colour-magnitude diagrams

In Fig. 3a and Fig. 3b we show V vs. $(B-V)$ diagrams for the NTT and Danish whole frames respectively. Both diagrams are deep attaining the cluster turn-off (TO), the NTT one being better defined. In turn, the Danish CMD presents a more populated red giant branch (RGB) as expected from the larger frame size.

The horizontal branch (HB) is red, suggesting that Terzan 3 is metal-rich. It is slightly elongated and tilted, which suggests some amount of differential reddening. The similarity to 47 Tuc ([Fe/H] $= -0.71$, Zinn 1985) is shown in Fig. 3b where the mean locus of 47 Tuc as given in Aurière & Ortolani (1988) and Desidera & Ortolani (1997) is superimposed in Fig. 3b. The subgiant and giant branches of Terzan 3 are steeper than those of the more metal-rich clusters such as NGC 6528 and NGC 6553 (Ortolani et al. 1995). From these comparisons we conclude that the metallicity of Terzan 3 is about the same as that of 47 Tuc ([Fe/H] ≈ -0.7).

The cluster HB is located at $V \approx 17.3 \pm 0.1$ and the $(B-V)$ colour of the RGB at the HB level is $\approx 1.63 \pm 0.05$ (Fig. 3). The reddening is derived with respect to 47 Tuc for which $(B-V)_{\rm g} = 0.95$ and $E(B-V) = 0.04$ (Hesser et al. 1987; Aurière & Ortolani (1988)). There results $E(B-V) = 0.72$ for Terzan 3, a value considerably higher than previous determinations (Sect. 1).

Absolute magnitudes of the horizontal branch $M_V^{\rm HB}$ are metallicity dependent. We adopted Jones et al. (1992)'s relation, slightly modifying the zero point in order

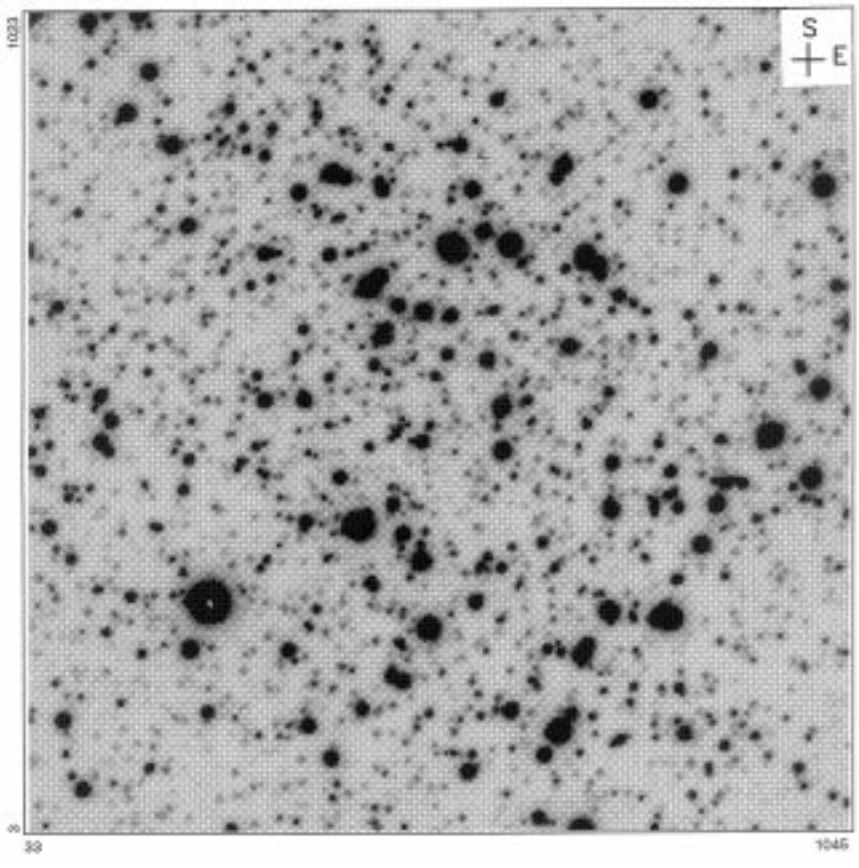


Fig. 1. NTT V image of Terzan 3. Dimensions are $2.5' \times 2.5'$. South is at the top and west to the left

to fit the results by Guarnieri et al. (1998) for NGC 6553: $M_V^{\rm HB} = 0.16$[Fe/H] + 0.98. The metallicity of Terzan 3 implies $M_V^{\rm HB} = 0.87$, and the observed distance modulus is $(m - M)_V = 16.43$. The selective-to-total absorption dependence on the reddening and metallicity as discussed in Barbuy et al. (1998), results for Terzan 3 the value $R = 3.3$ and $A_V = 2.38$. The true distance modulus is then $(m - M)_0 = 14.05$ and the distance to the Sun $d_\odot \approx$ 6.5 kpc.

Assuming the distance of the Sun to the Galaxy center of $R_\odot = 8.0$ kpc (Reid 1993), the Galactocentric coordinates are $X = -1.8$ ($X < 0$ refers to our side of the Galaxy), $Y = -1.7$ kpc and $Z = 1.0$ kpc. This indicates that Terzan 3 is not far in the halo as the early determinations suggested (Sect. 1), but it is instead located in the bulge. We conclude that it is a bulge cluster which is revealed by its location and metallicity.

3.2. Field

In Fig. 4 is shown the CMD of a field $31'$ north of Terzan 3. There are too few stars in the brighter sequences but the bulge TO is well populated. Considering the high latitude of this field ($b \approx 10°$), not much contamination from the disk is expected.

Assuming 47 Tuc as reference, the mean locus of Hesser et al. (1987) indicates an $E(B - V) = 0.54$ for this field, corresponding to $A_V = 1.78$. The reddening results slightly lower than that of the cluster. This difference is not unexpected, given that this field is slightly higher in b than the cluster itself. The TO shows some spread, with a mean value around $V \approx 20.4$, corresponding to a HB of $V \approx 16.9$. The resulting true distance modulus of $(m - M)_0 = 14.25$ gives a distance from the Sun $d_\odot \approx$ 7.1 kpc. This value implies that the bulk of these field stars is located slightly closer to us than the Galactic center, as expected from its l and b values.

4. IC 1276 (Palomar 7)

4.1. Colour-magnitude diagrams

In Fig. 5a we show a V vs. $(B-V)$ diagram for the whole Danish frame (1986 run). The TO region is detected but at the limit of the photometry and will be used to estimate the age-related magnitude difference between TO and HB (Sect. 5).

The horizontal branch (HB) is red, suggesting that, like in the case of Terzan 3, it is metal-rich. Again, like in the Terzan 3 case, the best fit with mean loci of globular

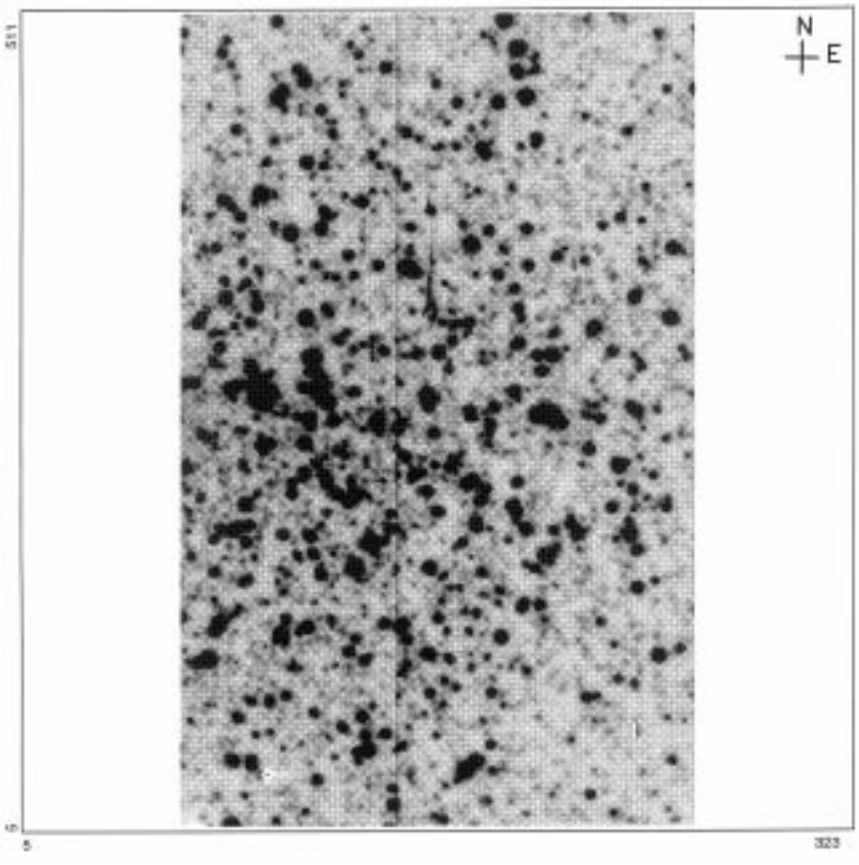


Fig. 2. Danish V image of IC 1276. Dimensions are $4.0' \times 2.5'$. North is at the top and west to the left

clusters templates of different metallicity occurs with that of 47 Tuc (mean locus from Desidera & Ortolani 1997), as shown in Fig. 5b, where is given a deeper diagram corresponding to slightly offcenter frames taken in the 1985 run. In conclusion, IC 1276 presents [Fe/H] ≈ -0.7 similarly to 47 Tuc, as well as Terzan 3 discussed above.

The cluster HB is located at $V \approx 17.7 \pm 0.1$ and the $(B-V)$ colour of the RGB at the HB level is $(B-V)_{\rm g} \approx 2.07 \pm 0.07$ (Fig. 5). Likewise for Terzan 3, we adopt 47 Tuc as reference, obtaining $E(B-V) = 1.16$.

Using the same prescription as for Terzan 3, the derived observed distance modulus is $(m-M)_V = 16.83$. Using $R = 3.3$, we get $A_V = 3.83$. The true distance modulus is then $(m-M)_0 = 13.0$ and the distance to the Sun $d_\odot \approx 4.0$ kpc. The Galactocentric coordinates are $X = -4.3$, $Y = 1.5$ kpc and $Z = 0.4$ kpc.

IC 1276 is therefore a bulge cluster located near the plane, nearly half way between the Sun and the Galactic center, which is also the case of Terzan 5 and NGC 6553 (Ortolani et al. 1996; Guarnieri et al. 1998).

4.2. Variables

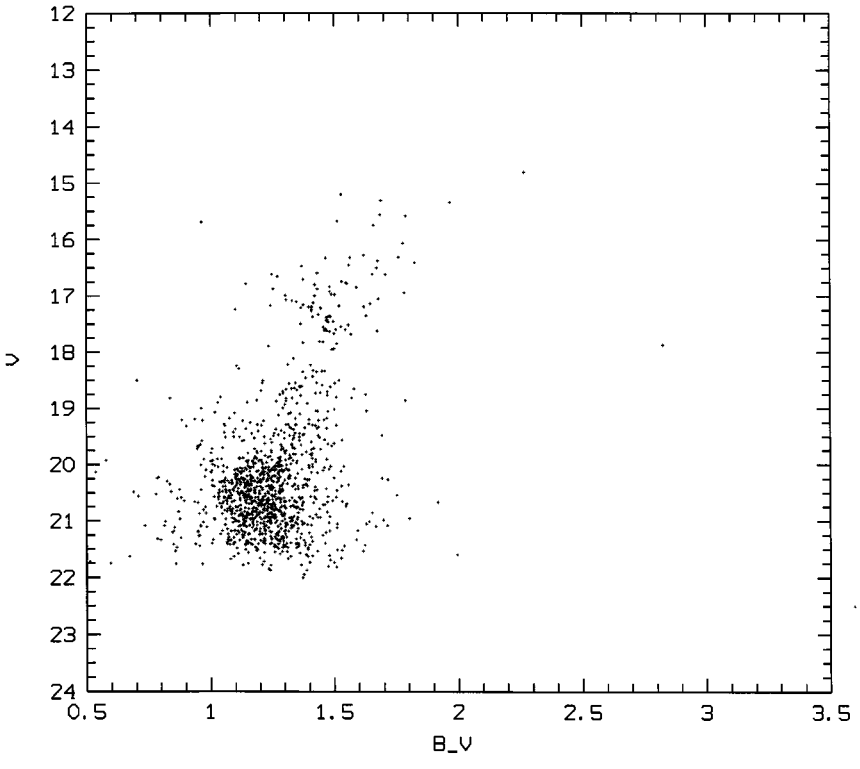
Five variable stars were identified in the cluster area by Kinman & Rosino (1962), four of them indicated in Fig. 5a (variable number 5 is outside the field).

In order of brightest to faintest, the stars identified in Fig. 5a correspond to numbers 4, 2, 1 and 3. Number 2 was suggested to be an RR Lyrae by Kinman & Rosino, which corresponds very well to its location in our diagram. The other three ones are semiregular or long-period variables. Number 4 probably is a cluster long-period variable. Stars number 1 and 3 are in peculiarly reddened location in the diagram - these are more probably non-members.

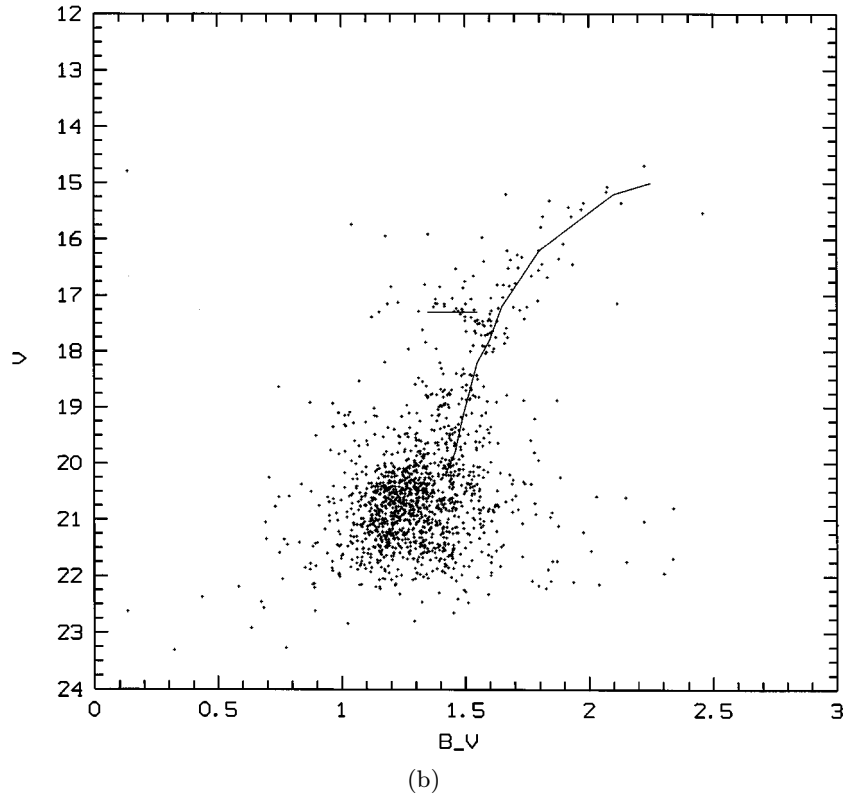
5. Ages

The magnitude difference between the HB and the TO is a good age indicator (Iben 1974; Sandage 1986 and references therein), and is particularly suitable for reddened globular clusters (Ortolani et al. 1995). Recently Chaboyer et al. (1996) gathered this parameter for a series of globular clusters, most of them in the halo. Chaboyer et al. report the following clusters with $-1.0 <$ [Fe/H] < -0.5 and the corresponding $\Delta V_{\rm HB}^{\rm TO}$: 47 Tuc (3.61), NGC 6171 (3.75), NGC 6352 (3.67), M 71 (3.56) and NGC 6652 (3.35). Kinematical arguments would make distinction as to whether some of them belong to halo or bulge, but we shall leave aside this point.

For Terzan 3, using the NTT CMD, we obtain $\Delta V_{\rm HB}^{\rm TO} \approx 3.35 \pm 0.15$ and for IC 1276 $\Delta V_{\rm HB}^{\rm TO} \approx 3.45 \pm 0.20$.



(a)



(b)

Fig. 3. V vs. $(B-V)$ CMD of Terzan 3: **a)** NTT data, **b)** Danish data, where the solid line is a fit of the mean locus of 47 Tuc

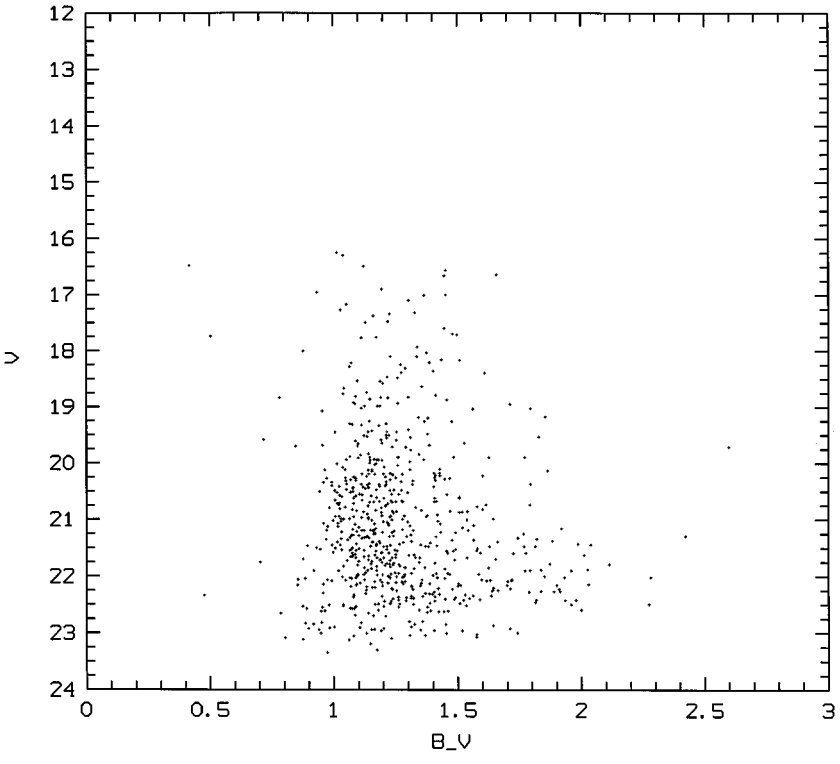


Fig. 4. V vs. $(B-V)$ CMD of the field 31′ North of Terzan 3 (Danish data)

In metallicity terms they are similar to Chaboyer et al.'s clusters above, although spatially they are more internal in the bulge.

We point out that recently some additional metal-rich clusters have photometry down to the MS region. In Rich et al. (1997) a HST CMD for NGC 5927 was presented, where we measure $\Delta V_{\rm HB}^{\rm TO} = 3.50 \pm 0.10$. Tonantzintla 2 was studied in Bica et al. 1996; we measure $\Delta V_{\rm HB}^{\rm TO} = 3.15 \pm 0.20$. Finally, in Ortolani et al. (1995) we obtained $\Delta V_{\rm HB}^{\rm TO} \approx 3.7 \pm 0.15$ for the nearly solar metallicity bulge clusters NGC 6528 and NGC 6553.

These numbers indicate that the 47 Tuc-like $-1.0 <$ [Fe/H] < -0.5 clusters are old or in some cases possibly slightly younger than the halo of $\Delta V_{\rm HB}^{\rm TO} = 3.55$ (Buonanno et al. 1989). On the other hand the nearly solar ones have a value comparable to that of the halo. In conclusion, metal-rich globular clusters, at least as can be deduced from available measurements of $\Delta V_{\rm HB}^{\rm TO}$, appear to be typically old, and not intermediate age, as has been sometimes suggested for the field bulge population (e.g. Holtzman et al. 1993; Kiraga et al. 1997).

6. Conclusions

Colour-Magnitude Diagrams for the globular clusters Terzan 3 and IC 1276 are presented for the first time.

Both clusters are considerably reddened with $E(B-V) = 0.72$ (Terzan 3) and 1.16 (IC 1276), and they are metal-rich with [Fe/H] ≈ -0.7, like 47 Tuc.

Although their angular location with respect to the Galactic center is relatively large, they are nearby clusters, in particular Terzan 3 is not far away in the halo as given in early estimations. The clusters are on our side of the Galaxy at distances from the Galactic center of $R_{\rm G} \approx 2.7$ and 4.3 kpc, respectively.

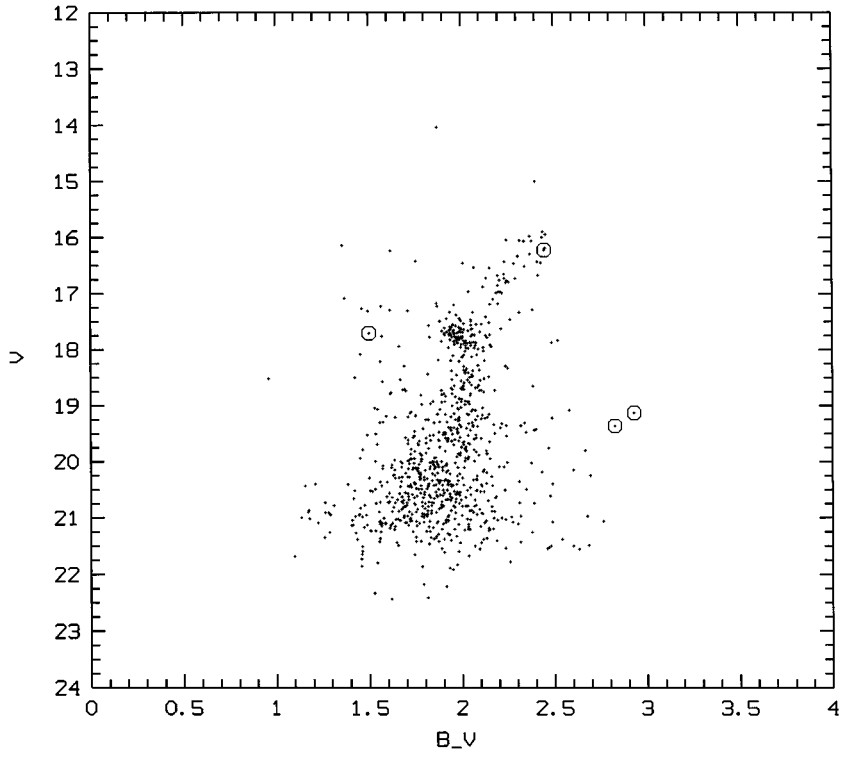
Given all these characteristics they appear to be members of the bulge family of metal-rich globular clusters.

In Armandroff (1989), a list of 19 bona fide metal-rich globular clusters in the bulge was presented. Recently, Barbuy et al. (1998) have analysed the clusters in a radius of 5° from the Galactic center, where several additional clusters relative to the Armandroff (1989) study were added: Terzan 1, Terzan 2, Terzan 5, Terzan 6, Palomar 6, Liller 1, Djorgovski 1 and ESO456−SC38. Besides, in the recent years we presented CMDs for other metal-rich clusters around the 5° part of the bulge: Tonantzintla 2 (Bica et al. 1996), NGC 6380 and Terzan 12 (Ortolani et al. 1998). Together with Terzan 3 and IC 1276, 13 clusters are added to the previous list available in Armadroff (1989).

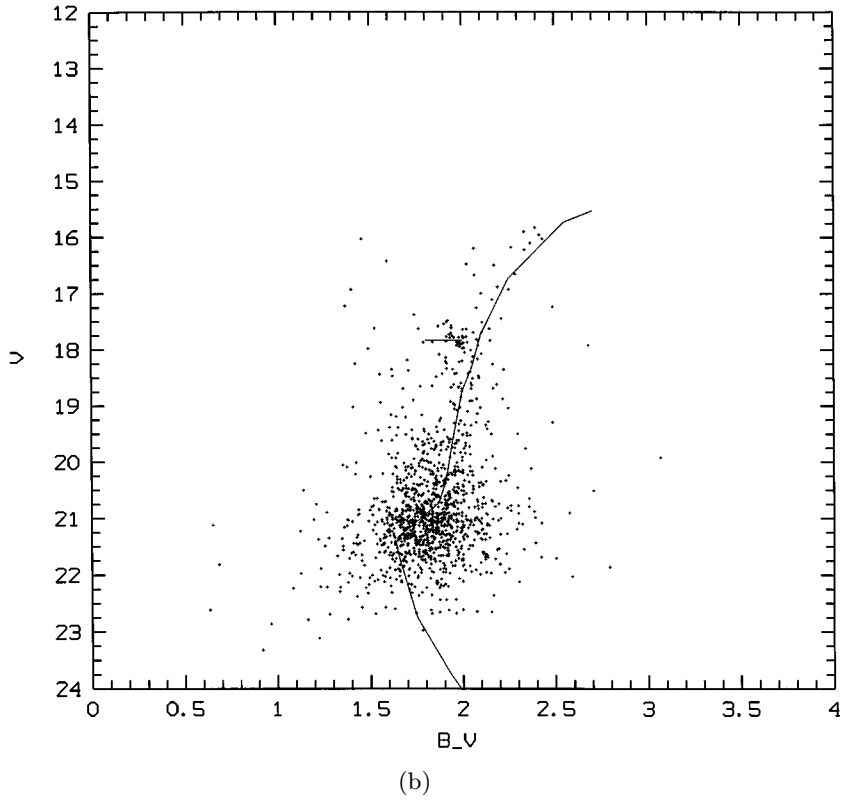
Acknowledgements. BB and EB acknowledge partial financial support from CNPq and Fapesp.

References

Alter G., Ruprecht J., Vanysek V., 1970, Catalogue of Star Clusters and Associations, Alter G., Balasz B., Ruprecht J. (eds.). Akademiai Kiado, Budapest



(a)



(b)

Fig. 5. V vs. $(B-V)$ CMD of IC 1276. **a)** June 1986 run (Danish data), where four variables given in Kinman & Rosino (1962) are identified; **b)** May 1985 run, where the solid line is a fit of the mean locus of 47 Tuc

Armandroff T.E., 1989, AJ 97, 375
Aurière M., Ortolani S., 1988, A&A 204, 105
Barbuy B., Bica E., Ortolani S., 1998, A&A 333, 117
Bica E., Ortolani S., Barbuy B., 1996, A&AS 120, 153
Buonanno R., Corsi C.E., Fusi Pecci F., 1989, A&A 216, 80
Chaboyer B., Demarque P., Sarajedini A., 1996, ApJ 459, 558
Desidera S., Ortolani S., 1997, in IAU Symp. 189, Fundamental stellar parameters: the interaction between observations and theory, Bedding T., Booth A., Davis J. (eds.), poster papers, p. 164
Gratton R.G., Ortolani S., 1988, A&AS 73, 137
Guarnieri M.D., Ortolani S., Montegriffo P., Renzini A., Barbuy B., Bica E., Moneti A., 1998, A&A 331, 70
Harris W.E., 1996, AJ 112, 1487
Hesser J.E., Harris W.E., Vandenberg D.A., Allwright J.W.B., 1987, PASP 99, 739
Iben I. Jr., 1974, ARA&A 12, 215
Jones R.V., Carney B.W., Storm J., Latham D.W., 1992, ApJ 386, 646
Holtzman J.A., Light R.M., Baum W.A., et al., 1993, AJ 106, 1826
Kinman T.D., Rosino L., 1962, PASP 74, 499
Kiraga M., Paczynski B., Stanek K.Z., 1997, ApJ 485, 616
Landolt A.U., 1983, AJ 88, 439
Ortolani S., Barbuy B., Bica E., 1990, A&A 236, 362
Ortolani S., Barbuy B., Bica E., 1996, A&A 308, 733
Ortolani S., Bica E., Barbuy B., 1998, A&AS 127, 471
Ortolani S., Renzini A., Gilmozzi R., Marconi G., Barbuy B., Bica E., Rich R.M., 1995, Nat 377, 701
Reid M., 1993, ARA&A 31, 345
Rich R.M., et al., 1997, ApJ 484, L25
Sandage A., 1986, ARA&A 24, 421
Terzan A., 1968, Comptes Rendus Acad. Sci. 267, 1245
Trager S.C., King I.R., Djorgovski S., 1995, AJ 109, 218
Webbink R.F., 1985, in Dynamics of Star Clusters IAU Symp. 113, Goodman J. & Hut P. (eds.). Dordrecht: Reidel, p. 541
Zinn R., 1985, ApJ 293, 424