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ASTRONOMY AND ASTROPHYSICS

V, I photometry of the metal-rich bulge globular cluster Terzan 2*

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

[1] Università di Padova, Dept. di Astronomia, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy
[2] Universidade Federal do Rio Grande do Sul, Dept. de Astronomia, CP 15051, Porto Alegre 91500-970, Brazil
[3] Universidade de São Paulo, CP 9638, São Paulo 01065-970, Brazil

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Abstract. We present for the first time optical colour magnitude diagrams of the globular cluster Terzan 2, in the V, I colours. The horizontal branch is red. The red giant branch morphology can be fitted with that of 47 Tuc, but definitely not that of NGC 6553.

We derive a reddening of E(B-V) = 1.54 and a distance $d_{\odot}$ = 7.7 kpc if R = 3.1, or 5.3 kpc if R = 3.6. Terzan 2 adds to the list of bulge metal-rich clusters now with reliable parameters.

Key words: globular clusters: Terzan 2 – HR diagram – Galaxy: abundances – Galaxy: center

1. Introduction

Terzan (1968) presented a list of new globular clusters discovered on Schmidt plates obtained at the Haute Provence Observatory, among which Terzan 2. The cluster is also known as GCL B1724-3045, HP3, BH228 and ESO454-SC29. The coordinates are $\alpha = 17^h\ 24^m\ 20.3^s$ and δ = -30^o 45′ 40″(B=1950.0). It is projected close to the Galactic center, at l = 356.320^o, b = +2.297^o.

Malkan (1982) derived E(B-V) = 1.3 from integrated infrared photometry, and Zinn (1985) based on the same data estimated a metallicity [Fe/H] = -0.47. Using near infrared integrated spectroscopy, Armandroff & Zinn (1988, hereafter AZ88) derived [Fe/H] = -0.25 from the near-infrared CaII triplet lines, and E(B-V) = 1.54 from the interstellar band at 8621 Å. By means of the bright giants method, Webbink (1985) estimated a horizontal branch (HB) level of V_{HB} = 19.8 which, combined to E(B-V) = 1.31 from Malkan's infrared data, led to a distance from the Sun of $d_{\odot}$ = 10.0 kpc. Webbink lists a metallicity of [M/H] = -0.54 for the cluster. Christian & Friel (1992) presented an infrared Colour-Magnitude Diagram (CMD), and detected red giant branch stars (RGB). Assuming AZ88's metallicity they estimated a reddening of E(B-V) = 1.25±0.10 and a distance modulus of $(m-M)_o$ = 15.05±0.2. On the other hand, in Kuchinski et al.'s (1995) K, (J-K) CMD, the HB is clearly detected. Assuming AZ88's reddening, they derive a distance modulus of $(m-M)_o$ = 14.37, implying a distance from the Sun of $d_{\odot}$ = 7.5 kpc. From the RGB slope they derived [Fe/H] = -0.25 for the cluster, a metallicity comparable to that of the Baade Window. They found that the field surrounding Terzan 2 is more metallic. No optical CMD is available for the cluster.

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

In the present paper we analyse CMDs of Ter 2 in the V and I passbands. We discuss the observations in Sect. 2. We present the colour-magnitude diagrams in Sect. 3, while the cluster parameters are measured in Sect. 4. The concluding remarks are given in Sect. 5.

2. Observations

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

The SUSI camera was employed at the NTT; it consists of a 1024x1024 thinned Tektronix CCD at the Nasmyth focus B. The pixel size is 24 μm (0.13″ on the sky), and the frame size is 2.2′x2.2′. We show in Fig. 1 a NTT V image of Ter 2. Notice the compact nucleus of this post-core-collapse cluster.

At the Danish we used the Tektronix CCD # 28 of 1024x1024 pixels, with pixel size 24 μm, corresponding to 0.37″/pixel. The full field is 6.3′x6.3′. The sky was photometric and the observations included Landolt (1983, 1992) standard stars, so that the zero-point calibrations for the NTT were obtained from the Danish observations, whereas the colour terms were derived from NTT data of previous nights. The reductions were carried out in the standard way, and the calibration equations, where Landolt stars were used, are: $V = 26.91 + 0.04(V - I) + v$; $I = 26.09 + i$ (numbers are for 30 sec exposures and airmass of 1.1).

The reduction procedures were carried out with the DAOPHOT II package, as described in Ortolani et al. (1996). The main sources of error in the photometry are the zero point

* Observations collected at the European Southern Observatory - ESO, Chile; Table 2 is available only in electronic form at the CDS via anonymous ftp 130.79.128.5

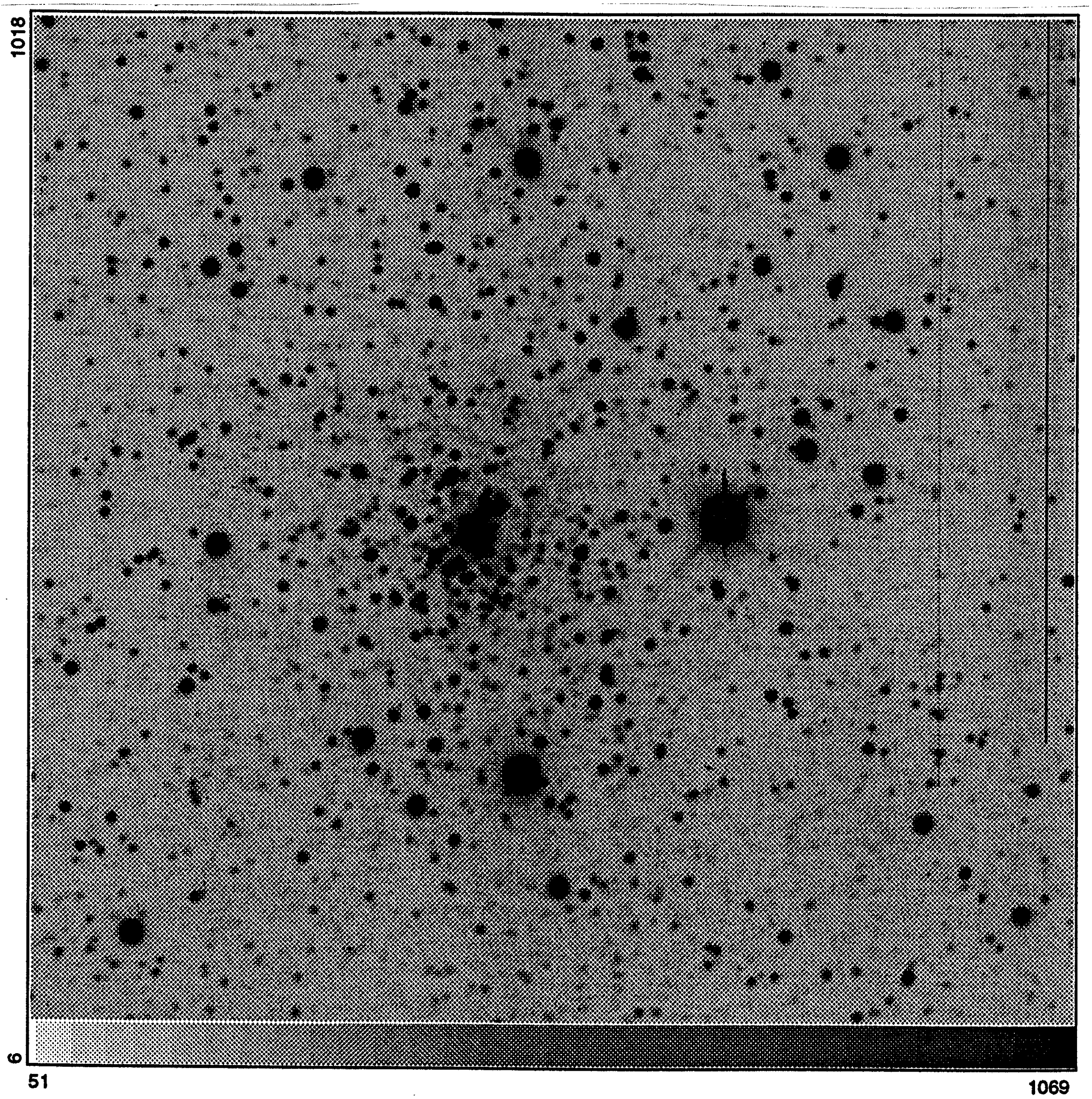


Fig. 1. NTT V image of Terzan 2. Dimensions are 2.2′x2.2′.

accuracy (±0.03 mags) and the magnitude transfer from the cluster images to the standard stars due to the crowded field, which can amount to 0.05 mags. The photometric errors are approximately constant to I = 17.5, amounting to 0.02 mags; at I = 18.5 the error increases to 0.07 mags.

We provide the log–book of observations in Table 1.

3. Colour-magnitude diagrams

We show in Fig. 2 a V vs. (V-I) diagram for the NTT whole frame. A blue disk main sequence (MS), a red tilted HB, and two RGB sequences can be seen.

In Fig. 3a is given a V vs. (V-I) extraction of radius $r < 26''$ centered on the cluster where the cluster sequences are better defined than in Fig. 2. Comparing Figs. 2 and 3a we conclude that the fainter and redder RGB belongs to the bulge, a more metal-rich population, confirming Kuchinski et al. (1995) conclusions regarding a metallicity difference between field and cluster. In Fig. 3b, for the same extraction of Fig. 3a, we show a fitting, by superimposing their HBs, of the mean loci of 47 Tuc (Bica et al. 1994) on the cluster CMD, and NGC 6553 (Ortolani et al. 1995) on the field CMD. The 47 Tuc mean locus resembles that of Ter 2 (see further discussion in Sect. 4).

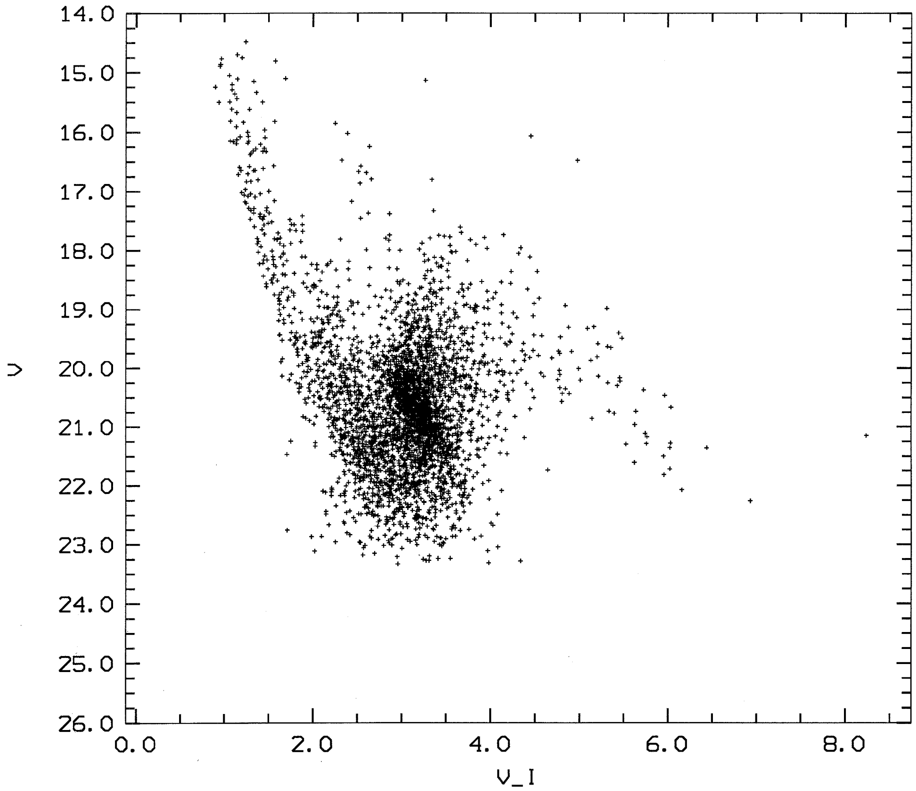


Fig. 2. NTT V vs (V-I) diagram for the whole frame (2.2′x2.2′).

Table 1. Log-book of observations

Target	Filter	Date	Equipment	Exp. (sec.)	Seeing (")
Ter 2	V	17.05.1994	NTT+SUSI	30	0.8
	V	"	"	720	0.9
	B	"	"	60	0.9
	B	"	"	900	0.9
	I	"	"	60	0.8
	I	"	"	420	0.8
	V	20.05.1994	Danish	180	1.2
	I	"	"	60	1.2

The cluster HB is located at V $\approx$ 20.3$\pm$0.12 and (V-I) $\approx$ 2.95$\pm$0.05 (Fig. 3). It is red, almost superimposed on the RGB, with a slightly elongated and tilted shape, which suggests some amount of differential reddening. Note that the bulge field HB (Fig. 2) is fainter and redder than that of the cluster.

In Fig. 4 we show the Danish whole frame (6.3′x6.3′), excluding the cluster (r $>$ 110″), where the bulge RGB and the disk blue MS dominate the CMD, and the cluster sequences cannot be distinguished. The mean loci of 47 Tuc and NGC 6553 indicate that the field resembles NGC 6553, of metallicity [Fe/H] $\approx$ -0.2 (Barbuy et al. 1992). Differential reddening is present, indicated by the elongated and tilted HB.

4. Cluster parameters

4.1. Metallicity

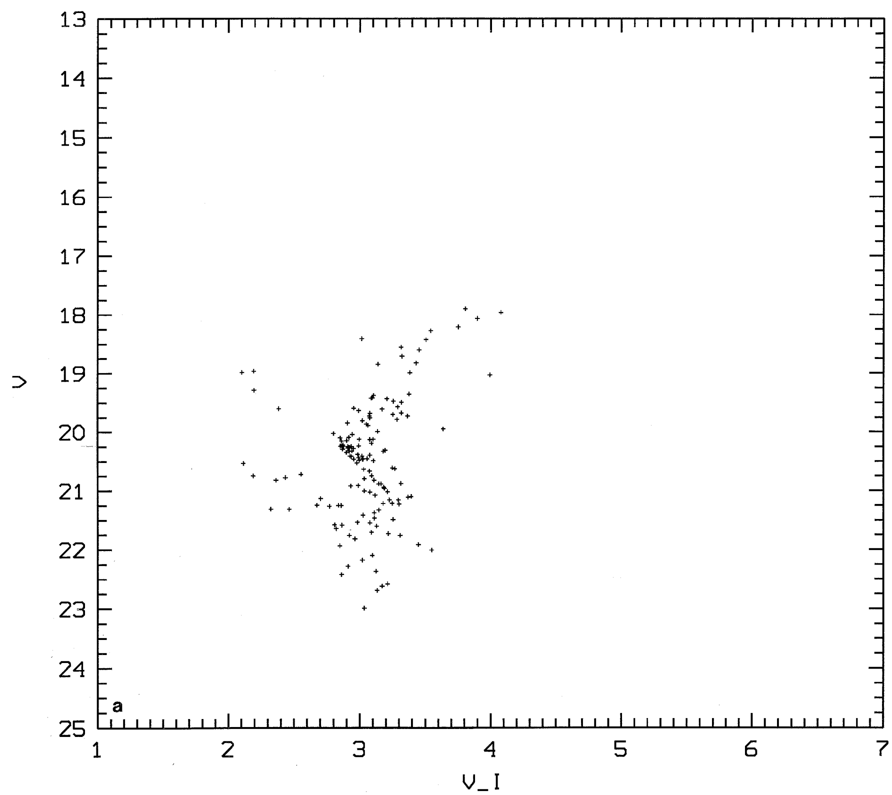
The RGB morphology can be used to estimate the metallicity of metal-rich clusters. However in the case of Ter 2, the RGB slope method (Ortolani et al. 1991) cannot be applied since the cluster is poor in stars and cool giants are essentially absent in the CMD (see Figs. 3).

A second indicator of metallicity is the magnitude difference between the HB level and the top (brightest stars) of the RGB, as illustrated by the mean loci of 47 Tuc and NGC 6553 (Figs. 3b and 4).

For Ter 2, $\Delta V_{\rm HB}^{\rm RGB}$ = 2.2, a value intermediate between those for 47 Tuc of 2.3 and NGC 6356 of 2.1 (Bica et al. 1994). This would place Ter 2 with a metallicity intermediate between those of 47 Tuc ([Fe/H] = -0.7) and NGC 6356 ([Fe/H] = -0.4), in agreement with the value given by Zinn (1985), but somewhat lower than other recent estimates (See Sect. 1).

4.2. Reddening and distance

We take 47 Tuc as reference (Desidera 1996; Bica et al. 1994). The (V-I) colour of the RGB at the HB level for Ter 2 is 3.02$\pm$0.05. and that of 47 Tuc (V-I) = 0.98$\pm$0.04, yielding Δ(V-I)$_{\rm Ter2}^{\rm 47Tuc}$ = 2.04, and given E(V-I) = 0.05 for 47 Tuc, E(V-I)$_{\rm Ter2}$ = 2.09. Adopting E(V-I)/E(B-V) = 1.33 (Dean et al. 1978), we obtain E(B-V) = 1.57, in good agreement with the value estimated by AZ88. For the distance estimation, two possibilities for R = A_V/E(B-V) are tested. If R = 3.1 (Savage & Mathis 1979) we



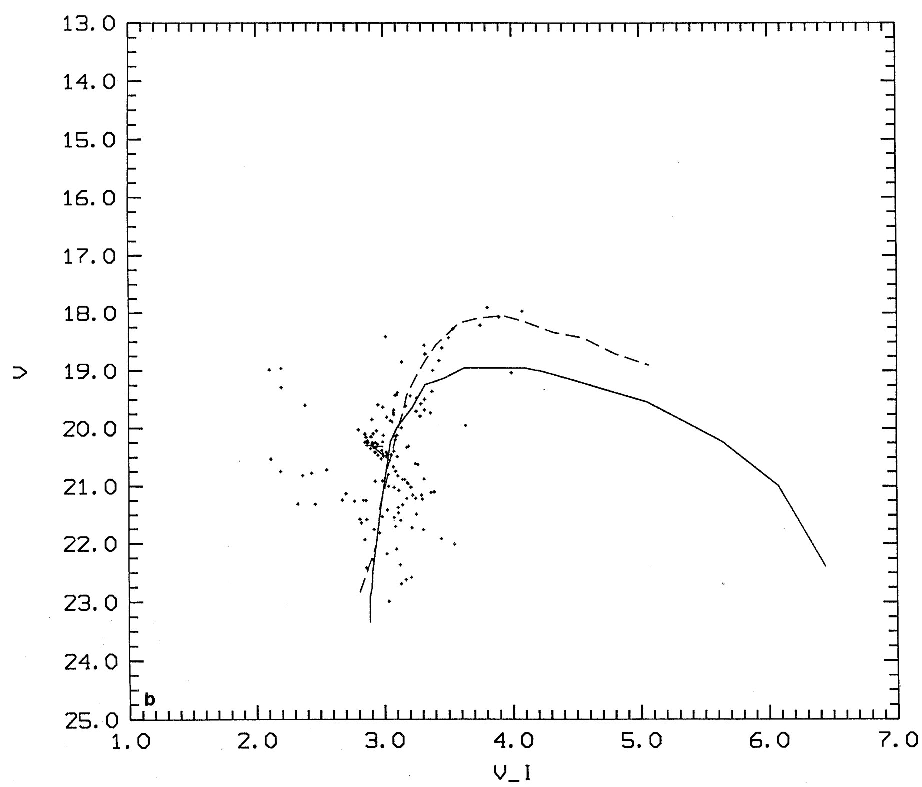


Fig. 3a and b. V vs. (V-I) CMD of Terzan 2: **a** extraction of radius r $< 26''$; **b** same extraction as in Fig. 3a, where the solid lines are fits of the mean loci of 47 Tuc and NGC 6553.

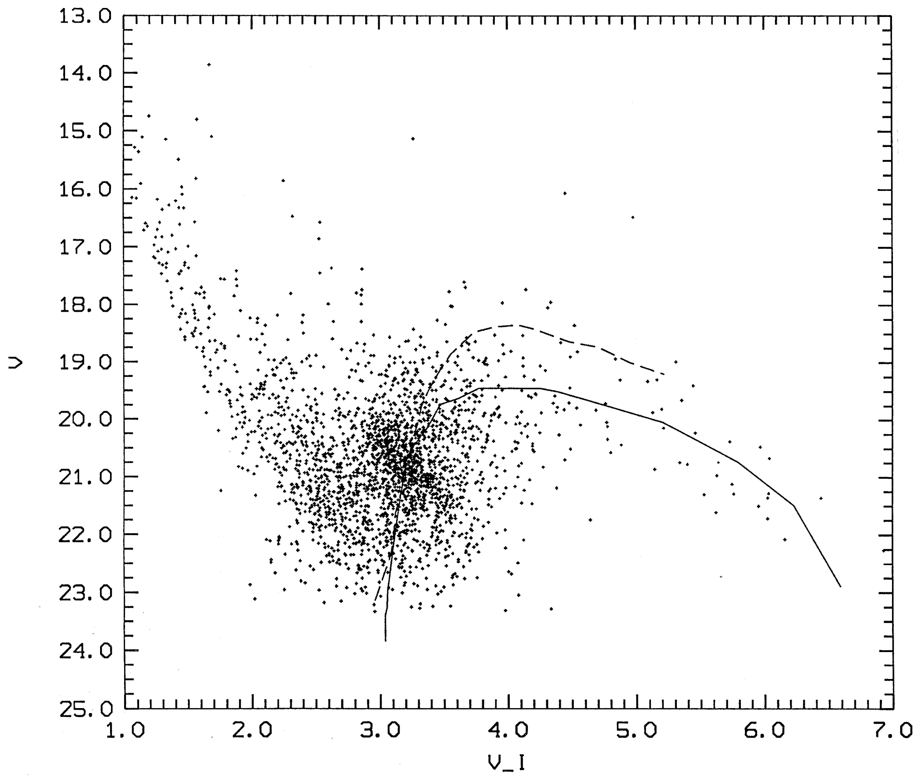


Fig. 4. V vs. (V-I) CMD corresponding to the Danish telescope whole frame (6.3′x6.3′), excluding the cluster (r > 110″), dominated by the field stars.

get A_V = 4.87; if R = 3.6 suitable for red stars (Olson 1975; Grebel & Roberts 1995), we get A_V = 5.65.

According to Sect. 3, $V(HB)_{Ter2}$ = 20.3, and assuming that the absolute magnitude of the HB $M(HB)_V$ = 0.92 (Chaboyer et al. 1996), and applying a 0.14 blanketing correction which matches bolometric magnitudes (Guarnieri et al. 1997), so that $M(HB)_V$ = 1.06, we get (m-M) = 19.24. The true distance modulus will depend on the A_V adopted, resulting $(m\text{-}M)_o$ = 14.44 for R = 3.1 and 13.64 for R = 3.6. This corresponds to a distance of $d_\odot = 7.7\pm0.6$ kpc (R = 3.1) and $d_\odot = 5.3\pm0.6$ kpc (R = 3.6), thus closer than the distance estimated by Webbink (1985), and more in agreement with the value of 7.5 kpc given by Kuchinski et al. (1995).

Assuming the standard value of R = 3.1, which places the cluster close to the Galactic center, and assuming the distance of the Sun to the Galaxy center of $R_\odot$ = 8.0 kpc (Reid 1993), the Galactocentric coordinates are X = 0.32 (X>0 refers to our side of the Galaxy), Y = -0.49 kpc and Z = 0.31 kpc.

4.3. Parameters for the field

The bulge field sequences are unusually well-defined (Figs. 2 and 4), and the mean locus of NGC 6553 provides a good fit (Sect. 3). These facts offer an opportunity to estimate the distance of the bulk of the bulge population in the direction of Ter 2.

We adopt NGC 6553 as reference, for which the colour of the HB at the RGB level $(V\text{-}I)(HB)_{RGB} = 2.05\pm0.04$, E(V-I) = 0.95 (Guarnieri et al. 1997), and [Fe/H] = -0.2 (Barbuy et al. 1992). For the present bulge field, $(V\text{-}I)(HB)_{RGB} = 3.15\pm0.07$, implying $\Delta(V\text{-}I)^{bulge}_{N6553}$ = 1.10, and $E(V\text{-}I)_{bulge} \approx 2.05$, which converts to E(B-V) = 1.54 (Dean et al. 1978). Guarnieri et al. (1997) assume M_V = 0.94 for NGC 6553, from which we derive an observed distance modulus of (m-M) ≈ 19.5. For R = 3.1, we get $(m\text{-}M)_o$ = 14.73 and a distance $d_\odot$ = 8.8 kpc, and for R = 3.6, $(m\text{-}M)_o$ = 13.96 and $d_\odot$ = 6.2 kpc. An intermediate value of R would place the bulge field at the distance of the Galactic center (see Reid 1993 and references therein).

Ter 2 seems to be foreground to this bulge field, and in spite of that, it has essentially the same reddening. This would suggest that the inner regions in that direction are dust free. However we point out that since the R value is metallicity dependent, Ter 2 and the field might be at comparable distances.

5. Conclusions

For the first time optical Colour-Magnitude Diagrams of the globular cluster Terzan 2 are presented. The horizontal branch morphology is red, and from the RGB morphology we conclude that its metallicity is intermediate between those of 47 Tuc ([Fe/H] = -0.7) and NGC 6356 ([Fe/H] = -0.4).

A reddening of E(B-V) = 1.57 and a distance $d_\odot$ = 7.7 kpc (for R = 3.1) or $d_\odot$ = 5.3 kpc (for R = 3.6) are found.

Terzan 2 belongs to the bulge metal-rich population. The field background is more metal-rich than Terzan 2, confirming previous results (Kuchinski et al. 1995). The distance of the bulk of this population is $d_\odot$ = 7.5 kpc (R = 3.4), which is compatible with the value given by Reid (1993) for the Galactic center.

The cluster and its field are important for the understanding of the bulge structure.

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