NTT VI photometry of the metal-rich and obscured bulge globular cluster Terzan 5[*]

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

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

Abstract. We study the metal-rich bulge globular cluster Terzan 5 by means of VI colour-magnitude diagrams, with images obtained under exceptional seeing conditions (0.34″–0.50″). Differential reddening is important across the cluster. We derive a reddening of $E(B - V) = 2.49$ and a distance from the Sun $d_\odot = 5.6$ kpc, closer than previous estimates. Based on the red giant branch curvature, we derive a metallicity somewhat higher than that of NGC 6553, probably solar.

Key words: globular clusters: individual: Terzan 5; general – HR diagram

1. Introduction

An important sample of globular clusters, most of them highly reddened, was discovered by A. Terzan. The globular cluster Terzan 5 (Terzan 1968) was reidentified as Terzan 11 in Terzan (1971) – see King (1972). In the present paper we will adopt the Terzan 5 designation. The cluster is also known as IAU 1745-247 and ESO 520-SC27. It is located at $\alpha_{1950} = 17^h45^m00.3^s$, $\delta_{1950} = -24°47'46''$, projected on the bulge at $l = 3.81°$ and $b = 1.67°$. Structurally it is a compact cluster with $c = 1.74$ (note that Trager et al. 1993 give $c = 2.05$) but does not appear to be post-core collapse (Trager et al. 1995). An inspection of sky survey plates indicates that the cluster is in a heavily obscured zone. No colour-magnitude diagram (CMD) is available in the literature. An infrared integrated photometry was given by Malkan (1982) obtaining a reddening $E(B - V) = 2.1$. Based on this photometry Zinn (1985) inferred a metallicity $[Fe/H] = +0.24$, which would place the cluster in the high

metallicity end of the chemical evolution of the Galaxy. Armandroff & Zinn (1988; hereafter AZ88), from near-IR integrated spectroscopy, obtained a metallicity of $[Fe/H] = -0.28$ using the Ca II triplet, and a reddening estimate of $E(B - V) = 1.65$ from the intensity of an interstellar band at $\lambda 8621$ Å. Webbink (1985) provides $E(B - V) = 2.14$ and a distance from the Sun $d_\odot = 7.1$ kpc, estimating the magnitude of the Horizontal Branch (HB) level using the bright giants method; Djorgovski (1993) reports $E(B - V) = 2.42$ and $d_\odot = 7.9$ kpc; Peterson (1993) reports $d_\odot = 14.6$ kpc using AZ88's value of $E(B - V) = 1.65$ and observed magnitude of the HB level $V_{HB} = 21.7$; Racine & Harris (1989) also used the latter value for the HB magnitude and $E(B - V) = 1.92$, as the result of a mean of AZ88 and Malkan's, which would imply $d_\odot = 9.4$ kpc. Clearly, a direct analysis of the HB from CMDs is fundamental to determine the distance and reddening of this bulge cluster.

In Sect. 2 we present the observations. The CMDs are discussed in Sect. 3. The cluster parameters are derived in Sect. 4. Finally, the concluding remarks are given in Sect. 5.

2. Observations and reductions

Terzan 5 was observed at the ESO New Technology Telescope (NTT) equipped with EMMI in June 1993 and with SUSI in May 1994. An unprecedented image quality was obtained for Terzan 5 in the May 1994 run, in particular for a 60 s I image with a seeing of 0.34″.

In the 1993 observations, the NTT was equipped with EMMI operating in the focal reducer mode, at the red arm. The detector was a LORAL front illuminated CCD (ESO # 34), with a pixel size of 15 μm (0.35″ on the sky). The whole size of the CCD is 2048×2048 pixels, but it was read out in the format 1700×1400 pixels (9.9′ × 8.1′ on the sky) excluding peripherical vignetted regions.

In June 1994 the observations were carried out at the Nasmyth focus B, with a 1024x1024 thinned Tektronix CCD (SUSI camera). The pixel size is 24 μm (0.13″ on the sky) with a total 2.2′ × 2.2′ frame size. We show in Fig. 1 the 0.34″ seeing I image of Terzan 5, which indicates that one is dealing with a
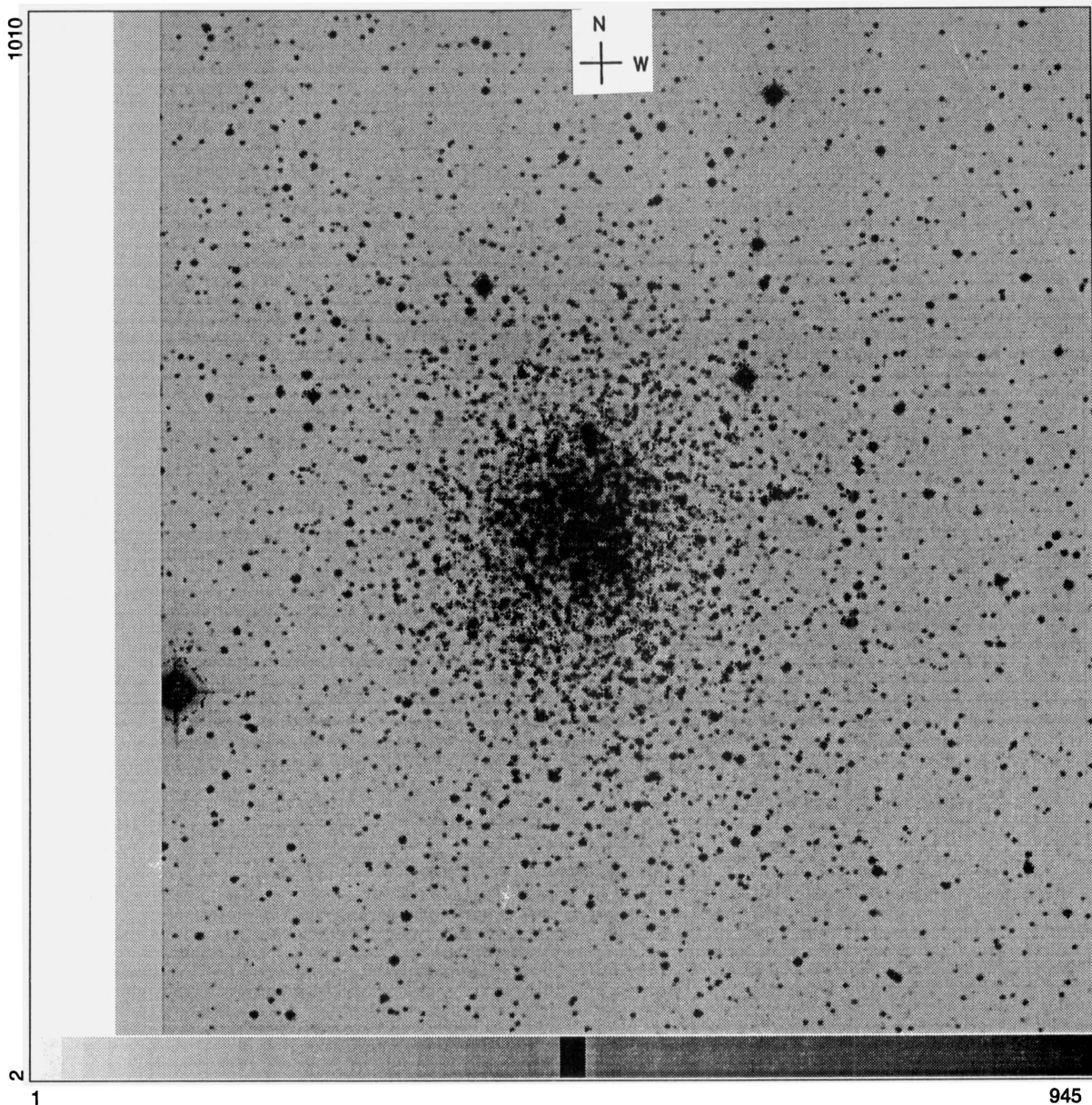
Fig. 1. NTT-SUSI *I* image of Terzan 5, with a seeing of 0.34″. Dimensions are 2.2′ × 2.2′

populous globular cluster. In Table 1 the log-book of observations is reported. The SUSI VI data are given in Table 2, only available in electronic form at CDS-Strasbourg.

The images have been processed at the ESO-Garching computer center, using the MIDAS package available on a Sparc SUN workstation. After the standard flatfield corrections, instrumental magnitudes have been obtained using DAOPHOT II. The details on the basic procedures for reductions in crowded fields for other globular clusters in the bulge are described in Ortolani et al. (1990, 1992, 1993, hereafter OBB), and in particular for Liller 1 (Ortolani et al. 1995, OBB95) observed in the same run as the present data.

The calibration of NTT-EMMI and SUSI observations is based on Landolt (1983 and 1992) fields. The colour equations and further details for EMMI are given in OBB94 and OBB95,

and for SUSI they are given in OBB95. The zero point accuracy is estimated to be about ±0.03 magnitudes. However, the final accuracy is dominated by crowding effects in the aperture photometry required for the magnitude transfer from the cluster images to the standard stars, which can amount to 0.05 magnitudes.
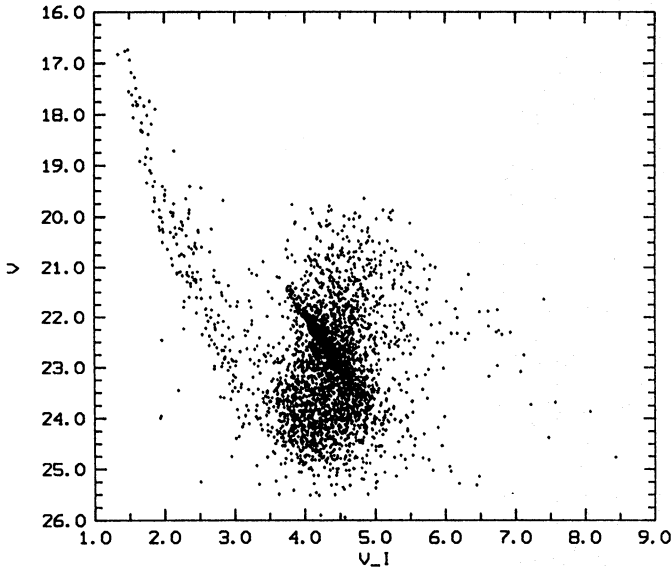
3. Colour–magnitude diagrams

Given that the cluster occupies an important fraction of the SUSI frame (Fig. 1), we provide in Figs. 2a and 3 respectively *V* vs. (*V* − *I*) and *I* vs. (*V* − *I*) CMDs for the whole frame. In Fig. 2b we show the EMMI *V* vs. (*V* − *I*) CMD plotted in a scale similar to Fig. 2a, with the purpose of showing the superb quality and the faint magnitude reached with the SUSI images of seeing

Table 1. Log-book of observations

Filter	Date	Telescope	Exp. time (s)	Seeing ('')
V	16.06.93	NTT+EMMI	10	0.7
V	16.06.93	NTT+EMMI	600	0.75
I	16.06.93	NTT+EMMI	10	2.5
I	16.06.93	NTT+EMMI	300	1.3
V	16.05.94	NTT+SUSI	60	0.5
V	16.05.94	NTT+SUSI	900	0.5
I	16.05.94	NTT+SUSI	60	0.34
I	16.05.94	NTT+SUSI	300	0.4

Fig. 2b. Terzan 5: EMMI whole frame (corresponding to $9.9' \times 8.1'$) V vs. $(V - I)$ plotted in the same scale as Fig. 2a, for a comparison

Fig. 2a. Terzan 5: SUSI whole frame (corresponding to $2.2' \times 2.2'$) in V vs. $(V - I)$

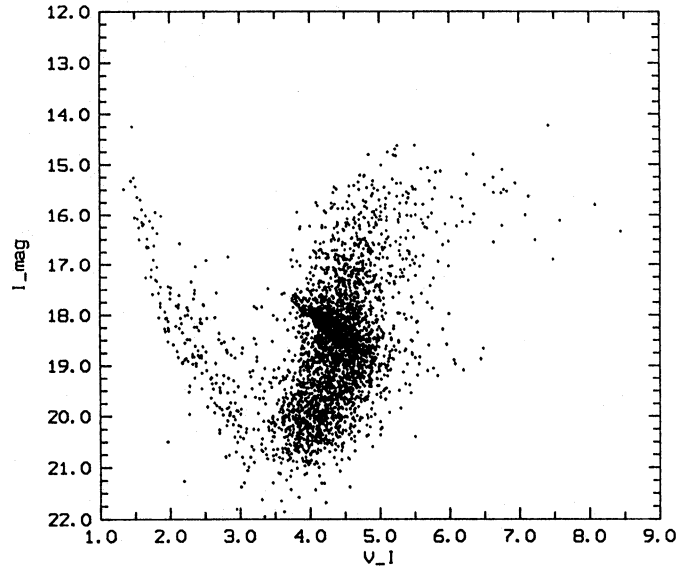**Fig. 3.** Terzan 5: Whole SUSI frame in I vs. $(V - I)$

$0.34''$ (note on the other hand that the EMMI frame size is larger and contains far more field stars). In these figures, the blue main sequence corresponds to the disk contamination in the field, and the red sequence corresponds to the cluster together with a contamination from the bulge field. A considerable differential reddening is evident from the width and inclination of the HB, and widths of the Red Giant Branch (RGB) and Subgiant Branch (SGB), which amount to $\Delta(V - I) \approx 0.92$, $\Delta V \approx 2.0$ and $\Delta I \approx 1.18$. The $(V - I)$ width converts to a differential reddening $\Delta E(B - V) \approx 0.69$, assuming $E(V - I)/E(B - V) = 1.33$ (Dean et al. 1978).

The RGB curvature is more pronounced in Fig. 2a than in Fig. 3, as expected from the different opacities in the V and I bandpasses. This effect can be used as a metallicity indicator, as defined in Ortolani et al. (1991, OBB91) – see Sect. 4.1.

In order to minimize the effect of differential reddening, we show in Fig. 4 the I vs. $(V - I)$ diagram for the central parts of the cluster $(r < 26'')$. A comparison of Figs. 3 and 4 indicates that the widths of the cluster sequences become narrower in Fig. 4,

but differential reddening is still considerable, which suggests that the dust distribution in the line of sight is patchy rather than smoothly varying across the cluster.

The field contamination can be investigated by comparing Fig. 4 to Fig. 5, this latter showing the CMD for the outer regions of the frame $(r > 65'')$; the relative proportion of red sequence to blue sequence (disk) stars is far higher in Fig. 4 (inner cluster region). If the red sequence in Fig. 5 (outer region) has an important contribution of bulge field stars, they must be very similar to the cluster.

The HB of Terzan 5 (Fig. 4) is essentially superimposed on the RGB, a characteristic shared with globular clusters of
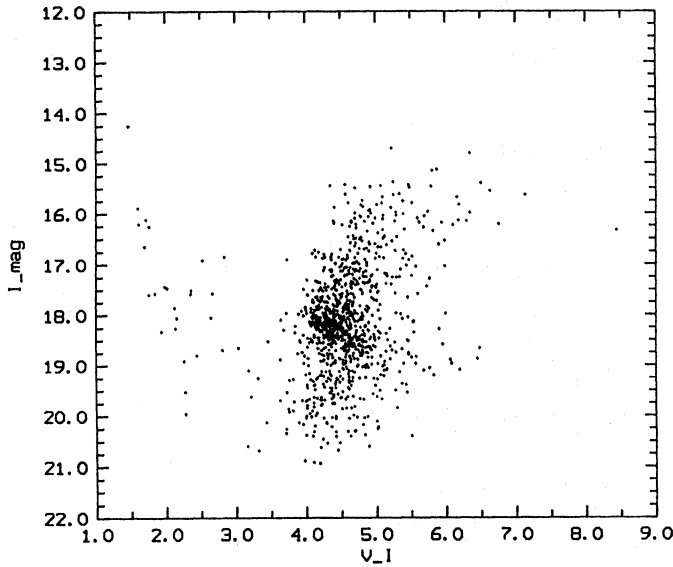
Fig. 4. Terzan 5: SUSI central parts ($r < 26''$) in I vs. $(V - I)$
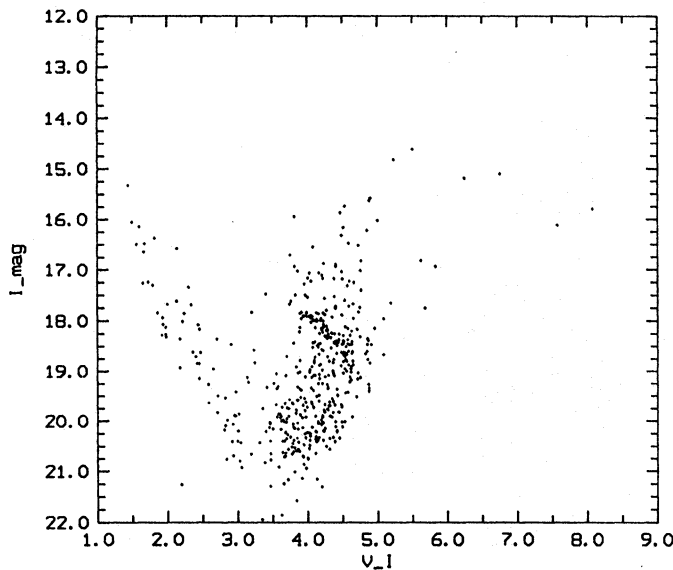

Fig. 5. Outer parts of SUSI frame ($r > 65''$) in I vs. $(V - I)$

metallicities like those of NGC 6528 and NGC 6553 (OBB92, OBB90), or higher.

4. Cluster parameters

4.1. Metallicity

By measuring the morphological parameters defined in OBB91, the slope of the descending RGB (cooler giants) can indicate the cluster metallicity. The values obtained for Terzan 5 for the slopes $\Delta V/\Delta(V - I)$ and $\Delta I/\Delta(V - I)$ (see OBB91) are given in Table 3, where we also include the measurements for nearly solar metallicity globular clusters; they are NGC 6528 (OBB92),

Table 3. RGB slope following definition of Ortolani et al. (1991), indicating a metallicity scale for the reported clusters

Name or NGC	$\Delta V/\Delta(V - I)$	$\Delta I/\Delta(V - I)$
NGC 6528	0.82 ± 0.07	-0.06 ± 0.07
NGC 6553	0.92 ± 0.20	-0.02 ± 0.10
NGC 6440	1.17 ± 0.08	$+0.21 \pm 0.05$
Terzan 5	1.35 ± 0.15	$+0.39 \pm 0.13$

NGC 6553 (OBB90) and NGC 6440 (OBB94). This RGB slope ranking (Table 3) places Terzan 5 highest among the 4 clusters. As NGC 6553 appears to have [Fe/H] ≈ -0.2 (Barbuy et al. 1992; Santos Jr. et al. 1995), we suggest that Terzan 5 probably has solar metallicity. It would be important to test this interesting possibility through spectroscopy of individual stars in the cluster.

4.2. Reddening

In spite of the considerable differential reddening, a mean position of the HB can be estimated to be $V \approx 22.52$, $I \approx 18.24$ and $(V - I) \approx 4.33 \pm 0.15$.

In Table 3 we see that NGC 6440 is the closest to Terzan 5 in metallicity, and we adopt it as reference for reddening derivation of Terzan 5. The mean $(V - I)$ colour of the giant branch at the level of the HB for NGC 6440 is $(V - I) = 2.35$ (OBB94). The relative reddening results in $\Delta(V - I) = 1.984$, which converts to $\Delta E(B - V) = 1.49$. Adding to this value the reddening of $E(B - V) = 1.00 \pm 0.10$ for NGC 6440, we obtain $E(B - V) = 2.49 \pm 0.18$ for Terzan 5. Among the values available in the literature (Sect. 1), our value compares very well with that reported by Djorgovski (1993). Assuming $R = 3.1$, our value implies $A_V = 7.72$, which is considerably high.

4.3. Distance

The mean position of the HB being at $V \approx 22.52 \pm 0.20$, and adopting a HB absolute magnitude $M_V^{HB} = 1.06$ for solar metallicity (Buonanno et al. 1989), we obtain a true distance modulus of $(V - M_V) = 13.74 \pm 0.27$. This yields a distance from the Sun $d_\odot = 5.6 \pm 0.7$ kpc. Adopting a distance for the Galactic center of 8 kpc (Reid 1993), the Galactocentric coordinates in kiloparsecs are $X = 2.41$ ($X > 0$ is our side of the Galaxy), $Y = 0.37$ and $Z = 0.16$.

The distance of Terzan 5 from the Sun is smaller than those reported in Sect. 1. As discussed by Racine & Harris (1989), in order to study the spatial distribution of the Galactic globular clusters, and its implications on the shape of the system and distance of the Sun to the Galactic center, precise determinations of cluster distances, using the HB level directly measured from CMDs is necessary. In the present work, a more accurate (direct) estimate of distance is provided for Terzan 5.

5. Concluding remarks

We determined accurate reddening and distance for the bulge globular cluster Terzan 5: $E(B-V) = 2.49$, $d_\odot = 5.6$ kpc. This value for the distance is closer than previous estimates, based on less reliable methods.

The metallicity was estimated using the slope of the descending red giant branch (cooler giants) criterion for metal-rich clusters. From this slope measurement Terzan 5 is ranked more metal-rich than NGC 6528, NGC 6553 and NGC 6440. Since different studies converge to [Fe/H] = −0.2 for NGC 6553, Terzan 5 probably has solar metallicity.

Our values of reddening and distance add Terzan 5 to the list of well-studied obscured and metal-rich bulge clusters. Accurate values for all bulge clusters would be necessary to constrain fundamental issues like the globular cluster inner system shape, and distance of the Galactic center from the Sun. The metallicity derivation is also very important for understanding the chemical enrichment of these inner regions.

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