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High quality seeing V, I and Gunn z imaging of Terzan 4: a blue horizontal branch bulge globular cluster⋆

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Abstract. We study the globular cluster Terzan 4 projected close to the Galactic center, by means of V, I and Gunn z Colour-Magnitude Diagrams. The images were obtained under exceptional seeing conditions (0.35" - 0.55") at the ESO New Technology Telescope equipped with SUSI. We derive a reddening of E(B-V) = 2.35 amd a distance from the Sun $d_\odot$ = 8.3 kpc for Terzan 4.

From the similarity of the VI Colour-Magnitude Diagrams of Terzan 4 and M30, in particular the presence of a blue horizontal branch, it could be as metal-poor as [Fe/H] $\approx$ -2.0. It is therefore another blue horizontal branch globular cluster located close to the Galactic center.

Key words: globular clusters: individual: Terzan 4; M 30; general – HR diagram – Galaxy: center

1. Introduction

Terzan (1971 and references therein) provided a list of new globular clusters in the Galactic bulge, which in most cases appear to be very reddened. Terzan 4 is also designated GCL B 1727-3133, HP 4 and ESO 454-SC7. It is located at α_{1950} = 17^h 27^m 24.4^s, δ_{1950} = -31^o 33' 29", corresponding to l = 356.02^o, b = 1.31^o. No structural parameters are available in the literature. An inspection of R and I sky survey plates reveals a cluster with compact appearance. However, some bright stars are superimposed, masking the structure. Malkan (1982) derived from integrated infrared photometry a reddening of E(B-V) = 1.5. Zinn (1985), based on the latter data, estimated a metallicity [Fe/H] = -0.21. Armandroff & Zinn (1988, hereafter AZ88) by means of near-infrared integrated spectroscopy, derived a considerably lower value of [Fe/H] = -0.94. Webbink (1985) reports a magnitude for the Horizontal Branch (HB) V_{HB} = 21.6 (noted by uncertainty marks), estimated from the bright giants method, besides E(B-V) = 1.55 and a distance from the Sun $d_\odot$ = 16.1 kpc. Peterson (1993) and Djorgovski (1993) presented similar values. Racine & Harris (1989) classify Ter 4 in their Group III, i.e., clusters with unreliable information on distance.

In the present paper we carry out V, I and Gunn z photometry of this controversial cluster and derive accurate values for reddening and distance, and constrain its metallicity value. We also provide information on the cluster central structure, which was feasible thanks to the exceptional seeing under which the observations were obtained.

In Sect. 2 we describe the observations. Colour-Magnitude Diagrams (CMDs) of Terzan 4 are presented in Sect. 3. The cluster parameters are derived in Sect. 4. Finally, the concluding remarks are given in Sect. 5.

2. Observations and data reduction

Terzan 4 was observed in June 1993 and May 1994 at the ESO New Technology Telescope (NTT). An unprecedented image quality was obtained for Terzan 4 and Terzan 5 (Ortolani et al. 1996a) in May 1994, in particular I images with a seeing of 0.35"-0.55", reaching V $\approx$ 25 in the deepest exposures.

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 2048x2048 pixels, but it was read out in the format 1700x1400 pixels (9.9'x8.1' on the sky) excluding peripherical vignetted regions.

In May 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'x2.2' frame size.

In Fig. 1 the SUSI I image obtained with a seeing of 0.35" is shown.

The reductions with DAOPHOT II in Midas environment are described in Ortolani et al. (1996b), in a discussion of the

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

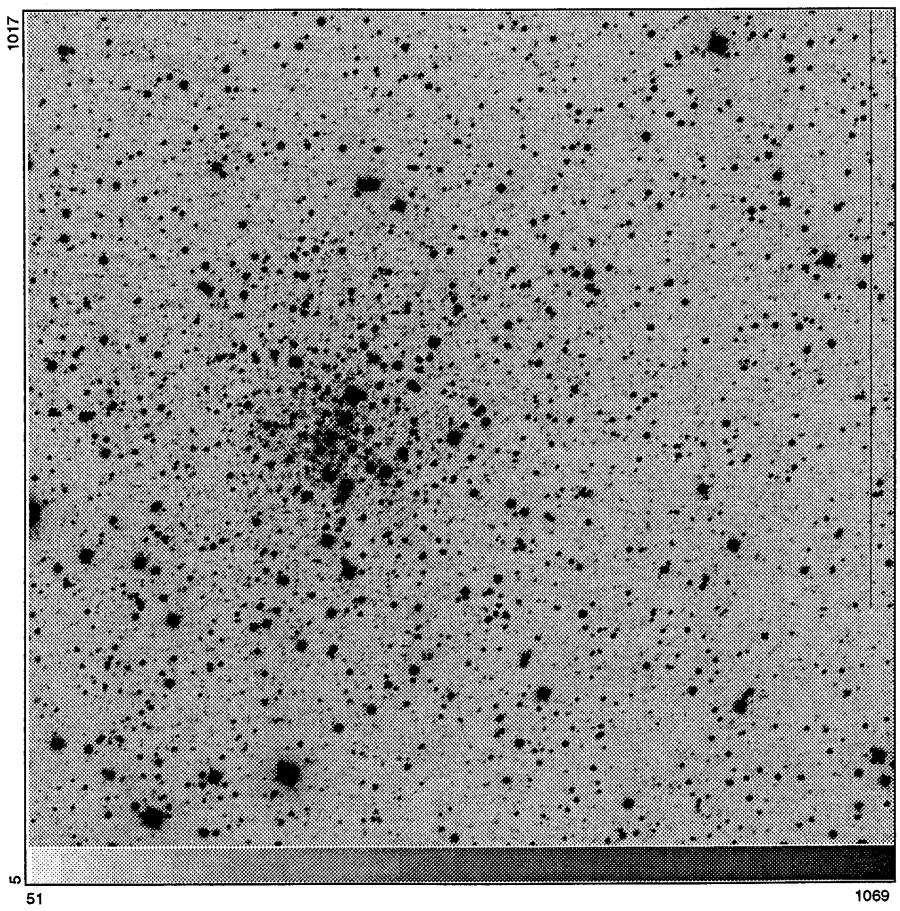

Fig. 1. NTT-SUSI I image of Terzan 4, with a seeing of 0.35". Dimensions are 2.2'x2.2'.

cluster Liller 1, observed in the same run; standard stars given in Landolt (1983, 1992) were observed for the calibrations. The final calibration equations (Ortolani et al. 1996b) are based on standards with colours covering the interval V-I = -0.2 - 1.2. This interval does not cover all the stars in our photometry, but reliable redder V and I standards are not available in the literature. The majority of them are, in fact, long period variables. The few stars available in Landolt catalogues and not yet detected as variables, show a very large spread in our tests. Considering that our colour terms are quite small (around 0.06 mag. in V and negligeably small in I), it seems that our photometric system is not so different from the standard Johnson-Cousins. For these reasons, we have extrapolated the equations in a linear fitting for the redder stars.

In Table 1 the log-book of observations is reported.

Table 1. Log-book of observations

Filter	Date	Equipment	Exp. time (sec.)	Seeing (")
V	16.06.93	NTT + EMMI	40	1.1
V	16.06.93	NTT + EMMI	300	1.2
I	16.06.93	NTT + EMMI	240	1.1
I	16.06.93	NTT + EMMI	10	1.1
V	16.05.94	NTT + SUSI	60	0.55
V	16.05.94	NTT + SUSI	600	0.50
I	16.05.94	NTT + SUSI	60	0.35
I	16.05.94	NTT + SUSI	300	0.40
Gunn z	16.05.94	NTT + SUSI	120	0.50

3. Colour magnitude diagrams

In Fig. 2 is shown the whole frame SUSI I vs. (V-I) CMD of Terzan 4, which is dominated by the surrounding field. A blue foreground Main Sequence (MS) and a cluster plus field Red Giant Branch (RGB) reaching the Subgiant Branch (SGB) are the most pronounced features. In Fig. 3 is shown the SUSI V vs. (V-I) CMD for the whole field, where a very metal-rich bulge RGB (populating (V-I) $>$ 4.5) contrasts with the cluster vertical RGB, which indicates its lower metallicity; a comparison of RGBs of different metallicities is illustrated in Fig. 1 of Bica et al. (1991).

In Fig. 4 we show the V vs. (V-I) CMD for Terzan 4 in an extraction for a radius r $<$ 16". Terzan 4 shows a blue HB at (V-I) = 3.30$\pm$0.05 and V = 22.65$\pm$0.10. Note that the detection of this blue HB was possible only due to the exceptional seeing combined with the SUSI pixel projection on the sky.

In Fig. 4 the mean locus of M30 is superimposed to the CMD of Ter 4. In Rosino et al. (1996) we presented the V

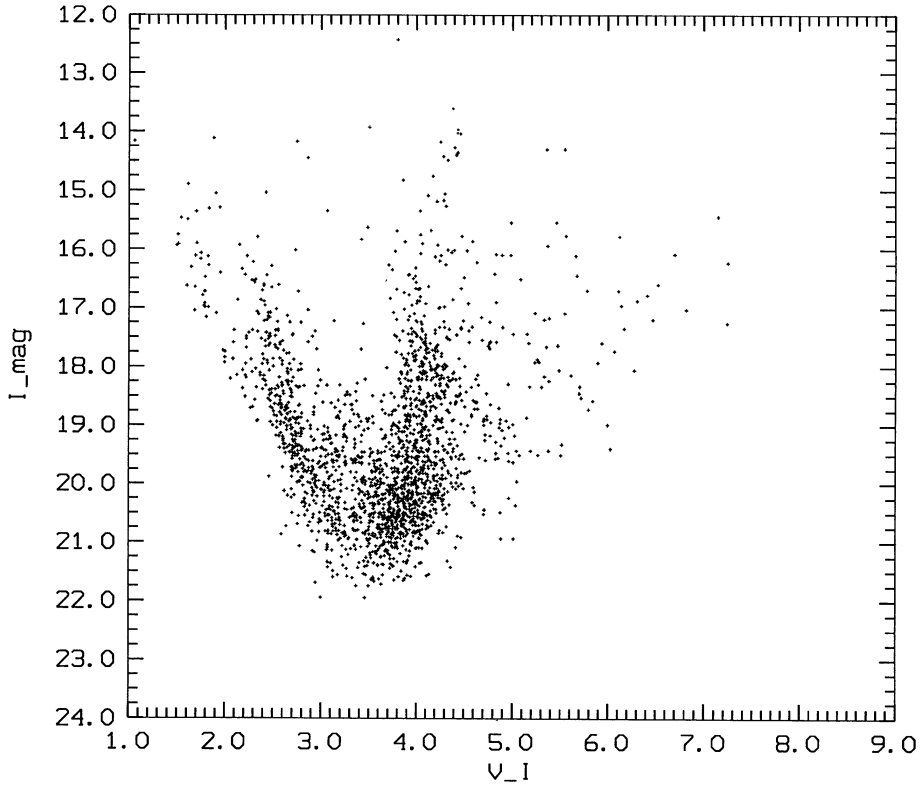

Fig. 2. Terzan 4: I vs (V-I) SUSI whole frame

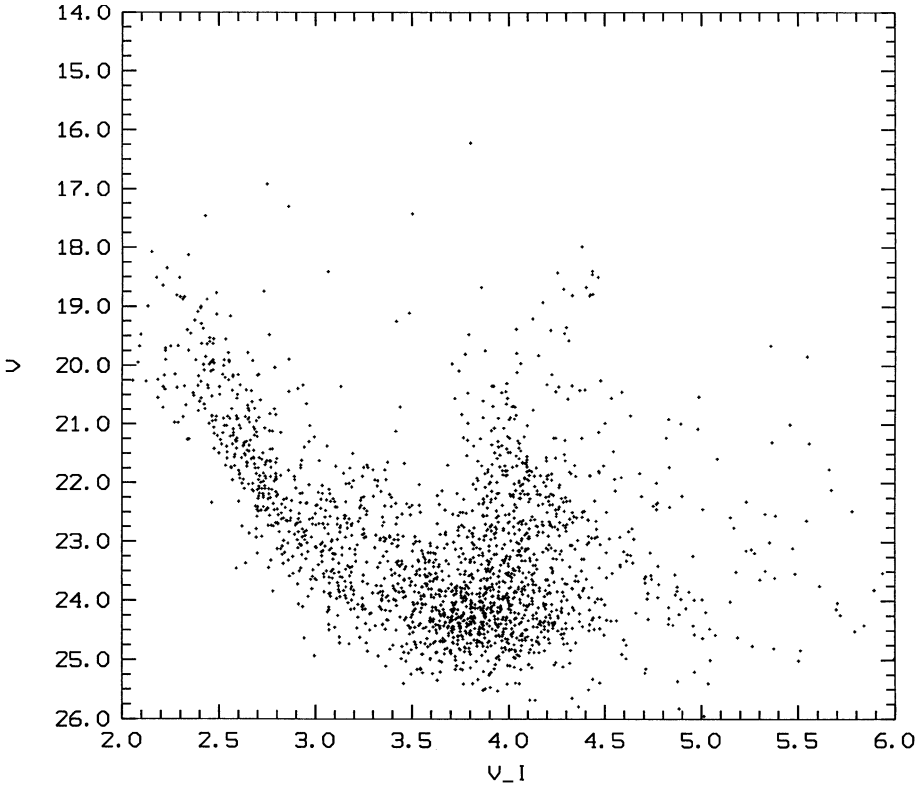

Fig. 3. Terzan 4: V vs. (V-I) CMDs for the whole field

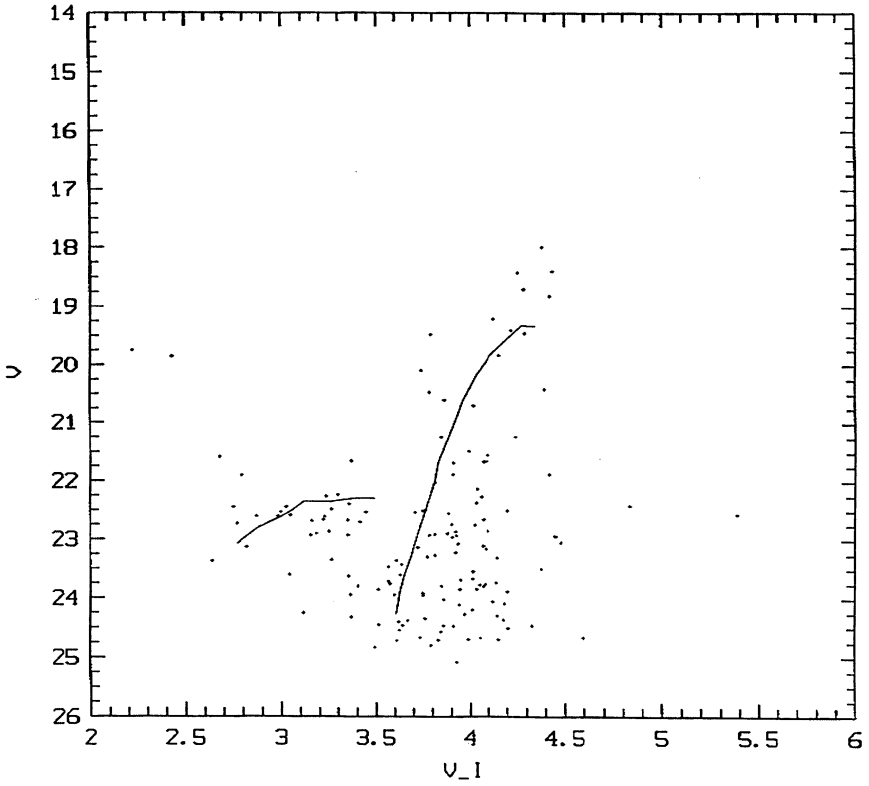

Fig. 4. Terzan 4: V vs. (V-I) CMDs for an extraction of r $<$ 16" (cluster) around the cluster center. The mean locus of the metal-poor cluster M30 is superimposed.

vs. (V-I) CMDs of M30 and NGC 6752 of metallicities [Fe/H] = -2.13 and -1.54 respectively, according to Zinn (1985). The close agreement between the RGB and HB between M30 and Ter 4 suggests that this latter is metal-poor ([Fe/H] $\approx$ -2.0). Very bright stars at the RGB tip appear to be non-members (see Sect. 3.1).

3.1. The bright superimposed stars

We show in Fig. 5 the spatial distribution of the 8 brightest stars superimposed on the cluster in the same scale of Fig. 1, where we also report their V magnitudes and (V-I) colours. Stars labeled 2 and 7 are much bluer than cluster satrs and consequently are non-members. Stars fainter than V $\approx$ 18.5 in the cluster RGB region (numbers 5,8) are probably members. However, stars brighter than 18.5 (1, 3, 4, 6) appear to be too bright for the extent of the RGB (Fig. 4). They are probably field red giants.

We checked the profiles of these bright objects, especially those closer to the cluster center and concluded that they are stellar. Therefore, no cusp is evident, and the cluster structure is probably not post core-collapse.

4. Cluster parameters

4.1. Reddening and distance

From the fit of the M30 V vs. (V-I) CMD to that of Terzan 4, we derive the colours (V-I) of the RGB at the HB level of 3.95$\pm$0.05 for Ter 4 and 0.88$\pm$0.02 for M30, resulting in a Δ(V-I) $\approx$ 3.07. Assuming comparable metallicities for the two clusters (see Sect. 4.2) and given E(B-V) = 0.04 for M30 (Zinn 1985), using E(V-I)/E(B-V) = 1.33 (Dean et al. 1978), we directly derive E(V-I) $\approx$ 3.12 for Terzan 4. This corresponds to E(B-V) $\approx$ 2.35 and $A_V \approx 7.3$. This reddening value based on a direct CMD comparison, therefore more reliable than other methods, is considerably higher than previous estimates (Sect. 1). Since the true distance modulus of M30 is $(m\text{-}M)_o^{M30} = 14.44$ (Zinn 1985), then $(m\text{-}M)_o^{Ter4} = 14.59\pm0.2$, corresponding to a distance from the Sun of d $\approx 8.3^{+0.8}_{-0.7}$ kpc. The Galactocentric coordinates, assuming a distance to the Galactic center of $R_\odot$ = 8.0 kpc (Reid 1993), are: X = -0.26 (X$>$0 refers to our side of the Galaxy), Y = -0.57 kpc and Z = 0.19 kpc. Therefore Terzan 4 is located close to the Galactic center. This distance is considerably closer to the Sun than previous estimates of 16 kpc (Sect. 1), which were based on an underestimated reddening.

4.2. Metallicity

From the CMD analysis in Sect. 3 we favour for Ter 4 a metallicity like that of M30 ([Fe/H] $\approx$ -2.0). This is much lower than the previous estimate of [Fe/H] = -0.21 and -0.94 by Zinn (1985) and AZ88. The -0.21 value, arising from integrated infrared photometry, is clearly overestimated since the reddening was underestimated. The -0.94 value derived from integrated spectroscopy in the near-infrared could be contaminated by bulge field stars, since the field in the direction of the bulge is very dense, and non-member stars are possibly superimposed (see Sect. 3.1). In order to decide if the cluster is of intermediate metallicity or metal-poor, spectroscopy of individual member stars will be necessary, but the brightest stars have V $\approx$ 19 and

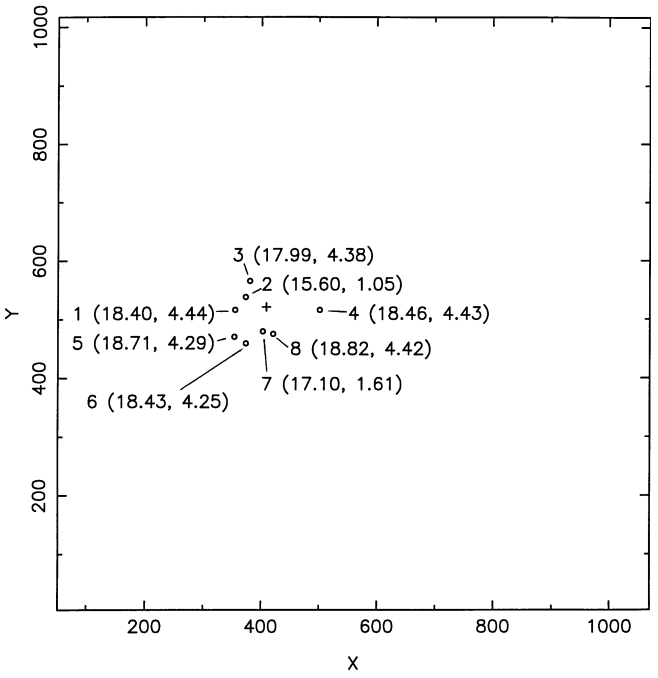

Fig. 5. Spatial distribution of the 8 brightest stars superimposed on the cluster, in the same scale as Fig. 1. Stars are labeled, together with their V and (V-I) values. The cross indicates the cluster center location.

they can be observed only with large telescopes. If the very low metallicity of this cluster is confirmed, then Terzan 4 might belong to the halo population, now crossing the bulge. Among the 17 clusters within 5^o of the Galactic center, we have already studied 13 of them, from which only 4 (including Ter 4) turn out to show a blue HB: NGC 6522, which is projected in the center of the Baade Window (Barbuy et al. 1994; Terndrup & Walker 1994), NGC 6540 (Bica et al. (1994), HP1 (Ortolani et al. 1996c).

5. Concluding remarks

We have obtained the first CMD for the near-Galactic center globular cluster Terzan 4. An unprecedented V, I and Gunn z image quality was reached with the NTT, with a superb 0.35"-0.55" seeing. The CMDs reveal a blue HB morphology; the CMD similarity with M30 suggests that Ter 4 is metal-poor ([Fe/H] $\approx$ -2.0). The HB yielded a reddening E(B-V) $\approx$ 2.35 and a distance $d_\odot \approx 8.3$ kpc. Terzan 4 is therefore located very close to the Galactic center. Kinematical parameters for Terzan 4 could solve the question whether this is a halo cluster in a perigalactic location.

Among the blue HB intermediate/metal-poor clusters in the bulge, Terzan 4 is the fourth within 5^o of the Galactic center, together with NGC 6522, NGC 6540 and HP1. These four clusters are more internal to the Galaxy than other metal-poor ones recently studied such as NGC 6517 (Kavelaars et al. 1995) and NGC 6287 (Stetson et al. 1994).

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