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V, I and Gunn z photometry of faint bulge globular clusters: Terzan 10, ESO 456 – SC 38 and UKS 1*

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Abstract. We present optical colour-magnitude diagrams for the faint bulge globular clusters Terzan 10, ESO 456 – SC 38 and UKS 1. The giant branches are detected but the horizontal branch is near the observational cutoff for the former two clusters and is not detected in UKS 1. We provide estimates of metallicity, reddening and distance for these clusters, some of these values determined for the first time.

Key words: globular clusters: Terzan 10, ESO 456 – SC 38, UKS 1 — HR diagram

1. Introduction

Some globular clusters in the direction of the bulge are so much reddened and/or are located in very crowded fields, that only scanty or preliminary values for metallicity, reddening and distance are available in the literature. The present study provides results from an observational effort with the NTT telescope to obtain optical colour-magnitude diagrams (CMD) of Terzan 10, ESO 456 – SC 38 and UKS 1.

Terzan 10 (GCL B1759 – 2604, ESO 521 – SC 16) was discovered by Terzan (1971). The coordinates are $\alpha_{1950} = 17^{\rm h}\ 59^{\rm m}\ 51^{\rm s}$, $\delta_{1950} = -26°\ 04'06''$ ($l = 4.421°$, $b = -1.864°$).

Very few information is available for this cluster. By means of the bright giants method Webbink (1985) estimated an horizontal branch level of $V_{\rm HB} = 21.9$ which, combined to a reddening of $E(B-V) = 1.71$ from the modified cosecant law, led to a distance from the Sun of $d = 14.6$ kpc. The cluster is not concentrated, with $c = 1.12$, as estimated from the core and limiting radii presented by Webbink. Liu et al. (1994) presented infrared photometry deriving a reddening of $E(B-V) = 2.6$, a metallicity close to that of 47 Tuc, and a true distance modulus of $(m-M)_0 = 14.5$.

ESO 456 – SC 38 (GCL B1758 – 2749, Djorgovski 2) is located at $\alpha_{1950} = 17^{\rm h}\ 58^{\rm m}\ 40.0^{\rm s}$, $\delta_{1950} = -27°\ 49'34''$ ($l = 2.763°$, $b = -2.508°$). ESO 456 – SC 38 was first reported in the sixth list of the ESO/Uppsala survey of the ESO B Atlas of the southern sky (Holmberg et al. 1978). It was described as an open cluster with a diameter of 1.4′. It is also the cluster n° 2 in Djorgovski (1987), for which he presented R and I CCD images, suggesting that it might be a globular cluster. An estimate of reddening $E(B-V) = 0.87$ was given by Djorgovski (1993). In terms of structure, it is rather loose, with a moderate concentration parameter $c = 1.50$, and it does not present a post-core-collapse morphology (Trager et al. 1993).

UKS 1 or UKS 1751 – 241 (GCL 1751 – 2408) is projected near the Galactic center and is located in the ESO/SERC field 521. The coordinates are $\alpha_{1950} = 17^{\rm h}\ 51^{\rm m}\ 23.5^{\rm s}$, $\delta_{1950} = -24°\ 08'12''$ ($l = 5.125°$, $b = 0.764°$). It was discovered on infrared plates taken with the 1.2 m UK Schmidt telescope, where it appeared as a small, round and hazy patch (see Malkan et al. 1980). In the latter paper they obtained infrared images with an InSb detector and derived a core radius of 13″ and estimated a visual extinction of $A_V = 9.7$ or 11.4, depending on whether the cluster was metal-rich or metal-poor, respectively.

Malkan (1982) derived $E(B-V) = 3.1$ from integrated infrared photometry, and Zinn (1985) based on the same data estimated a metallicity [Fe/H] = −1.18. Webbink (1985) estimated an horizontal branch level of $V_{\rm HB} = 25.5$, and assuming a reddening of $E(B-V) = 3.07$ from Malkan's infrared data, he derived a distance of 10.4 Kpc from the Sun. Webbink also lists a metallicity of $[M/H] = -1.22$. Minniti et al. (1995) presented

* Observations collected at the European Southern Observatory - ESO, Chile; Tables 2, 3 and 4 are available only in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

an infrared CMD in K' vs. $(J - K')$. The horizontal branch is not clearly detected. They point out that the locus of the red giant branch (RGB) is consistent with $E(J-K) = 1.72$ ($E(B-V) = 3.26$), assuming Webbink's (1985) metallicity value. Liu et al. (1994) also observed UKS 1, and gives $E(B-V) = 2.8$, [Fe/H] $= -1.2$ and a true distance modulus $(m-M)_0 = 14.7$. In terms of structure, it is compact, with a concentration parameter $c = 2.10$, and it may have a post-core-collapse morphology (Trager et al. 1995).

No optical colour-magnitude diagram (CMD) is available for any of the three clusters.

In Sect. 2 the observations are reported. In Sects. 3, 4 and 5 the CMDs are presented and cluster parameters are derived for Terzan 10, ESO 456 – SC 38 and UKS 1 respectively. Concluding remarks are given in Sect. 6.

2. Observations

The observations were obtained in 1994 May and 1995 June at the European Southern Observatory (ESO), using the 3.55 m New Technology Telescope (NTT) equipped with the SUSI camera and a 1024×1024 thinned Tektronix ESO CCD # 25 at the Nasmyth focus B; the pixel size is 24 μm ($0.13''$ on the sky), and the frame size is $2.2' \times 2.2'$. Observations were also obtained at the 1.54 m Danish telescope in 1994 May, using the Tektronix CCD ESO # 28 of 1024×1024 pixels, with pixel size 24 μm ($0.37''$ on the sky). The full field is $6.3' \times 6.3'$. The log-book of observations is given in Table 1.

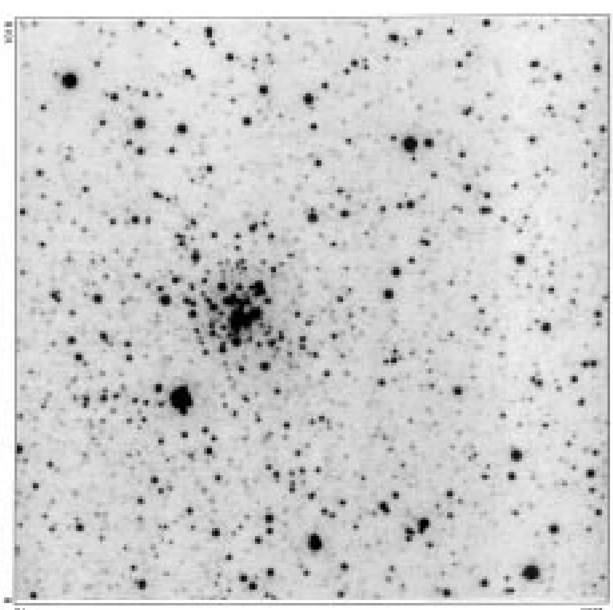

Fig. 1. NTT-SUSI V image of Terzan 10. The field size is $2.2' \times 2.2'$. North is up and West is to the right

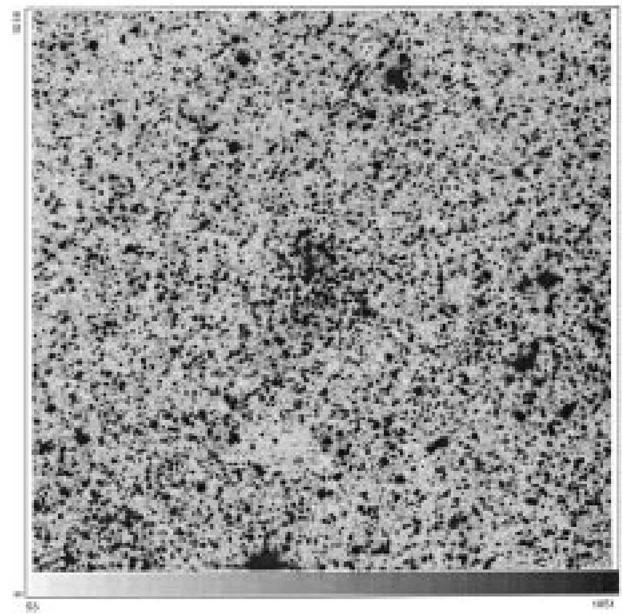

Fig. 2. Danish V image of ESO 456 – SC 38. The field size is $6.3' \times 6.3'$. North is up and West is to the right

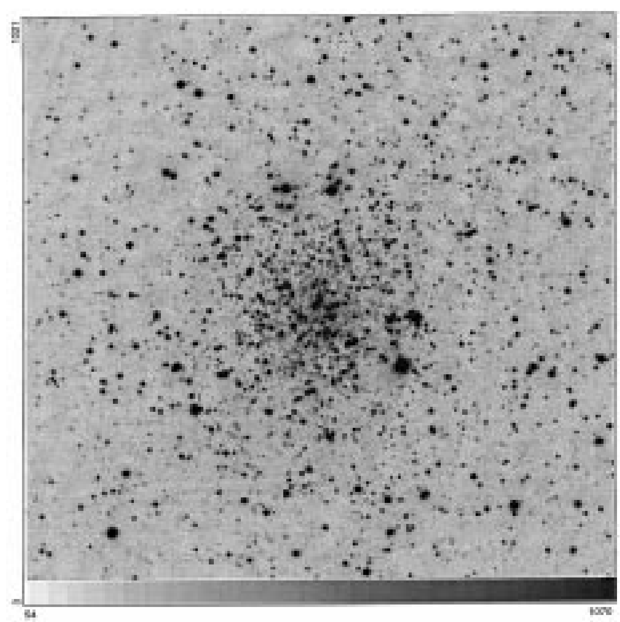

Fig. 3. NTT-SUSI Gunn z image of UKS 1. The field size is the same as in Fig. 1. North is up and West is to the right

In Figs. 1, 2 and 3 are shown respectively a NTT V image of Ter 10, a Danish V image of ESO 456 – SC 38 and a NTT Gunn z image of UKS 1.

The reductions were carried out using DAOPHOT II. For the calibrations standard stars by Landolt (1983, 1992) were used. Details on the procedures are given in

Ortolani et al. (1996a). For the 1994 run, the calibrations were carried out using the Danish observations, since the NTT observations were not photometric (see also the study of Terzan 2 observed in the same run by Ortolani et al. 1997). The photometric errors arise mostly from the zero point 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 mag at the fainter magnitudes. The magnitude calibrations concern only V and I, whereas Gunn z magnitudes are instrumental.

The V, I and Gunn z data are given in Tables 2, 3 and 4 respectively for Terzan 10, ESO 456 – SC 38 and UKS 1 (where magnitudes, colours and X, Y coordinates corresponding to pixels in Figs. 1, 2 and 3 are reported), available only in electronic form at the CDS-Strasbourg.

Table 1. Log-book of observations

Target	Filter	Date	Equipment	Exp. (s)	Seeing ($''$)
Ter 10	I	17.05.1994	NTT + SUSI	60	0.7
	I			360	0.7
	V			600	0.8
	I	20.05.1994	Danish	60	1.5
	V			900	1.5
ESO 456	I	17.05.1994	NTT + SUSI	60	0.9
−SC 38	V			180	0.8
	z			60	0.8
	I	20.05.1994	Danish	60	1.5
	V			120	1.5
UKS 1	I	23.06.1995	NTT + SUSI	60	0.7
	I			300	0.75
	V			600	0.8
	z			300	0.7
	z			30	0.7

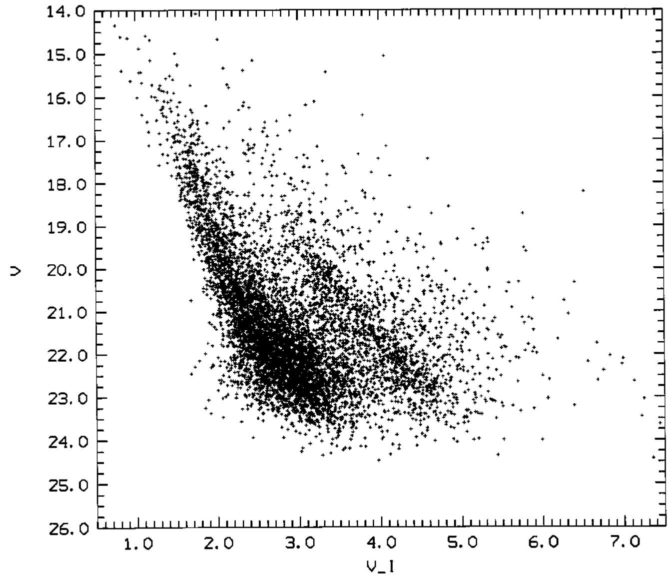

Fig. 4. Terzan 10: V vs. $(V - I)$ colour-magnitude diagram for the Danish whole frame excluding the cluster ($r > 44''$)

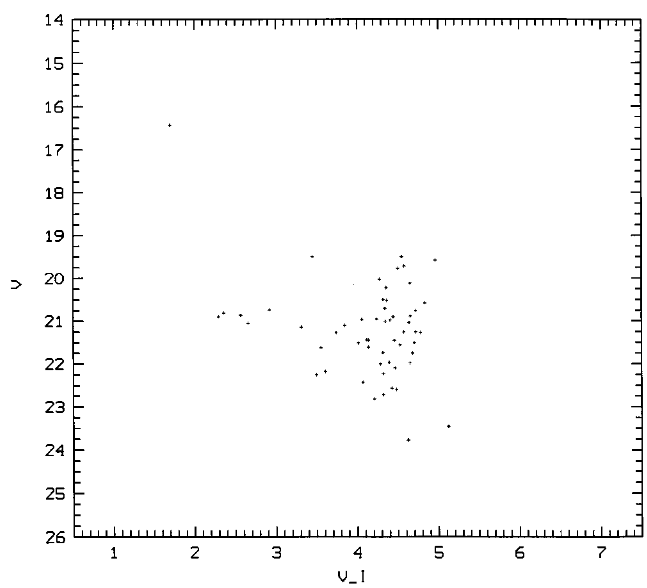

Fig. 5. Terzan 10: V vs. $(V - I)$ colour-magnitude diagram using the NTT data, for a circular extraction of radius $r < 10''$

3. Terzan 10

3.1. Colour magnitude diagrams

We show in Fig. 4 the V vs. $(V - I)$ diagram for the Danish whole frame excluding the cluster ($r > 44''$). Two striking sequences are seen: the disk main sequence (MS) and a very extended red horizontal branch (HB) of the bulge population. The extension of the bulge HB is due to a differential reddening as large as $\Delta(V - I) \approx 1.8$. A few bulge giants are seen attaining very red colours.

An extraction of the cluster for $r < 10''$, using the NTT data, is given in Fig. 5. The cluster red giant branch (RGB) can be recognized but not the HB. The brightest giants (BG) are located at $V_{\rm BG} = 19.7 \pm 0.20$ and $(V - I)_{\rm BG} = 4.55 \pm 0.10$.

3.2. Metallicity

The RGB sequence is wide and not much populated, so that it is difficult to estimate its metallicity from Fig. 5. It could be fitted by the CMD mean loci of an intermediate metallicity cluster like NGC 6752 ([Fe/H] = −1.54) as well as that of 47 Tuc ([Fe/H] = −0.71), taking Zinn (1985) metallicity values.

On the other hand, Liu et al. (1994) derived a metallicity similar to that of 47 Tuc, and Bica et al. (1997)

obtained [Fe/H] $\approx$ -1.2 from integrated spectra. Gathering the available results we adopt [Fe/H] $= -1.0$.

3.3. Reddening and distance

Given the uncertainty in metallicity, in order to derive reddening, we compared the V, I CMD of Terzan 10 both with 47 Tuc and NGC 6752 ones (Bica et al. 1994; Rosino et al. 1997). Comparing to 47 Tuc we obtain $E(V-I) = 3.30$, which converts to $E(B-V) = 2.48$ ($E(V-I)/E(B-V) = 1.33$, Dean et al. 1978), whereas $E(V-I) = 3.07$ and $E(B-V) = 2.31$ using NGC 6752. A mean value of $E(B-V) = 2.40 \pm 0.15$ is adopted. The ratio of selective-to-total extinction $R = A_V/E(B-V)$ is dependent on metallicity and reddening. A dependence of R on the metallicity for giants was shown by Grebel & Roberts (1995). For the globular clusters we assumed $R = 0.42$ [Fe/H] $+ 3.52$, valid for [Fe/H] ≥ -1.0, and $R = 3.1$ for [Fe/H] < -1.0. Using also the reddening dependence $\Delta R = 0.05\ E(B-V)$ (Olson 1975), we obtain $R = 3.2$ and $A_V = 7.68 \pm 0.45$.

Using the BG magnitude and colour, and the mean loci of the reference clusters (47 Tuc, NGC 6752), we conclude that the HB is at the detection threshold of our data. The HB level should be $V_{\rm HB} \approx 21.9$, while the colour of the RGB at the HB level should be $(V-I) \approx 4.0 \pm 0.15$.

For the distance derivation we adopt a relation for the absolute magnitude of the HB as a function of metallicity by Jones et al. (1992), with a zero point shift as explained in Guarnieri et al. (1997): $M_V^{\rm HB} = 0.16[{\rm Fe/H}] + 0.98$, resulting $M_V = 0.82$. The derived absolute distance modulus is $(m-M)_0 = 13.40$ and the distance $d_\odot = 4.8 \pm 1.0$ kpc. The Galactocentric coordinates are $X = 3.2$ ($X > 0$ refers to our side of the Galaxy), $Y = 0.4$ and $Z = -0.2$ kpc, having adopted for the distance of the Galactic center $R_{\rm GC} = 8.0$ kpc (Reid 1993).

4. ESO 456 – SC 38

4.1. Colour magnitude diagrams

In Fig. 6 is shown the V vs. $(V-I)$ diagram for the Danish whole frame. Similarly to the field of Terzan 10 (Fig. 4) the disk main sequence and the extended bulge HB are the most conspicuous features, but differential reddening is much less important, with $\Delta(V-I) \approx 0.55$. Accordingly, the bulge cool giants define a narrow sequence.

From the NTT data, the V vs. $(V-I)$ diagram for ESO 456 – SC 38 in an extraction of radius $r < 26''$ is shown in Fig. 7. The RGB is clearly detected and possibly the HB is reached although near the detection limit. The brightest giants are found at $V_{\rm BG} = 15.5 \pm 0.20$ and $(V-I)_{\rm BG} = 2.80 \pm 0.10$.

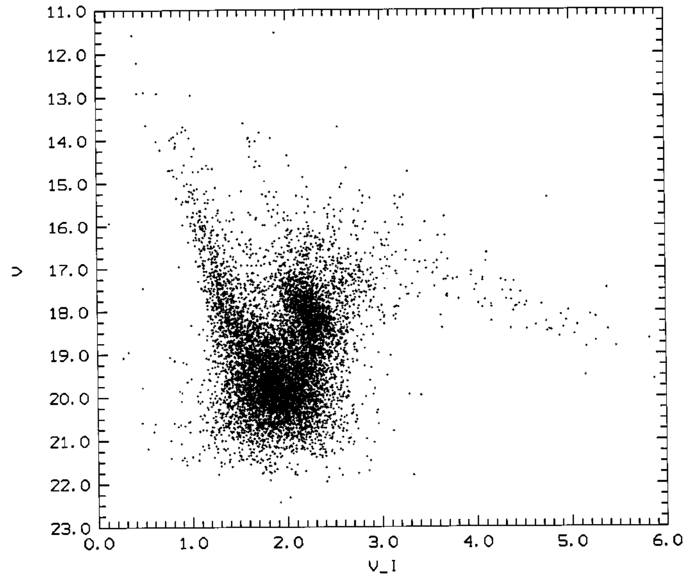

Fig. 6. ESO 456 – SC 38: V vs. $(V-I)$ colour-magnitude diagram for the Danish whole frame

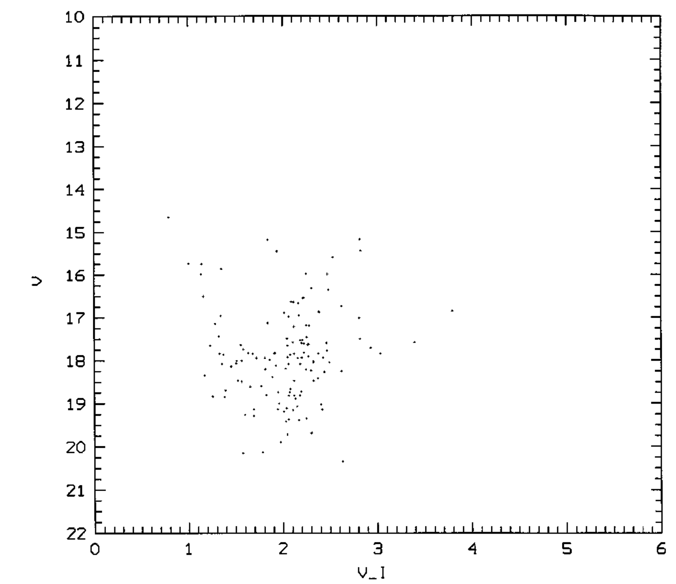

Fig. 7. ESO 456 – SC 38: V vs. $(V-I)$ colour-magnitude diagram for an extraction of radius $r < 26''$ from the NTT data

4.2. Metallicity

The fit to the mean loci of reference clusters (see Sect. 3.2) indicates that ESO 456 – SC 38 is similar to 47 Tuc. From an integrated spectrum, Bica et al. (1997) estimated [Fe/H] ≈ -0.4. Hence we adopt a metallicity of [Fe/H] ≈ -0.5.

4.3. Reddening and distance

From the fit to the mean locus of 47 Tuc, the HB level should be located at $V_{\rm HB} \approx 17.6$ and the RGB colour at the HB level $(V-I)_{\rm HB} = 2.2 \pm 0.15$. Using the same prescriptions as in Sect. 3.3, taking only 47 Tuc as reference in this case, we obtain for ESO 456 – SC 38, a reddening of $E(V-I) = 1.18 \pm 0.1$ and $E(B-V) = 0.89 \pm 0.08$. For the adopted metallicity and reddening, we derive $R = 3.35$ leading to $A_V = 3.0 \pm 0.2$. The absolute magnitude of the HB results $M_V = 0.90$, implying a true distance modulus of $(m-M)_0 = 13.70$ and a distance $d_\odot = 5.5 \pm 0.8$ kpc. The Galactocentric coordinates are $X = 2.5$, $Y = 0.3$ and $Z = -0.2$ kpc.

5. UKS 1

5.1. Colour magnitude diagrams

In Fig. 8 is shown the I vs. $(I-z)$ diagram for the whole frame. We note that the Gunn z magnitudes are instrumental, and consequently the zero-point of $(I-z)$ is arbitrary. Differently from the Danish CMD fields shown in Figs. 4 and 6, the NTT frame corresponds to a much smaller field, and the cluster occupies most of the frame (Fig. 3). The RGB should correspond to that of the cluster plus bulge.

An extraction of radius $r < 16''$ centred on the cluster is shown in Fig. 9. The cluster RGB, which basically coincides with that of the bulge plus cluster (Fig. 8), is clear. The brightest giants are found at $I_{\rm BG} = 17.5 \pm 0.20$. Interestingly, this value is similar to that of Liller 1, which is reported to have almost the same reddening (Ortolani et al. 1996a; Frogel et al. 1995).

5.2. Metallicity

In the UKS 1 discovery work, Malkan et al. (1980) pointed out that the cluster might be metal-rich or metal-poor, each assumption led to $A_V = 9.7$ and 11.4 respectively. All subsequent metallicity derivations in the literature are based on Malkan's (1982) integrated infrared photometry, which suggested [Fe/H] ≈ -1.2.

However, the similarity of the cluster and field CMDs (Figs. 8, 9), together with the coincidence of reddening and bright giants I magnitude of Liller 1, indicates that UKS 1 might be metal-rich. Moreover, an integrated spectrum by Bica et al. (1997) indicates [Fe/H] ≈ -0.3. We adopt [Fe/H] $= -0.5$.

5.3. Reddening and distance

We assume a reddening of $E(B-V) = 3.1$ (see Sect. 1). We use 47 Tuc as reference for the distance. The bright giants in 47 Tuc are at $I_{\rm BG} = 10.0$, and with $E(B-V) = 0.04$, together with $A_I/A_V = 0.61$, there results an intrinsic magnitude $I_0 = 9.92$. Using the cluster distance modulus $(m-M)_0 = 13.31$, we obtain an absolute magnitude for the brightest giants in 47 Tuc of $M_I = -3.39$.

With the prescriptions of Sect. 3, $R = 3.46$, $A_V = 10.73$ and $A_I = 6.54$. Since for UKS 1 the bright giants level is $I_{\rm BG} = 17.5 \pm 0.20$, the intrinsic magnitude of brightest giants of UKS 1 is $I_0 = 10.96$. Therefore, the true distance modulus of UKS 1 is $(m-M)_0 = 14.35$, and the distance $d_\odot = 7.4 \pm 1.2$ kpc. The Galactocentric coordinates are $X = 0.6$, $Y = 0.7$ and $Z = 0.1$ kpc.

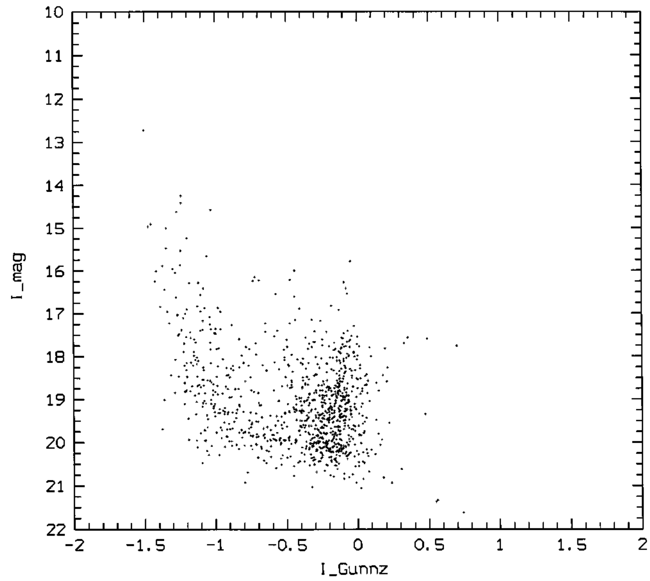

Fig. 8. UKS 1: I vs. $(I-z)$ colour-magnitude diagram for the NTT whole frame. Note that the Gunn z magnitudes are instrumental

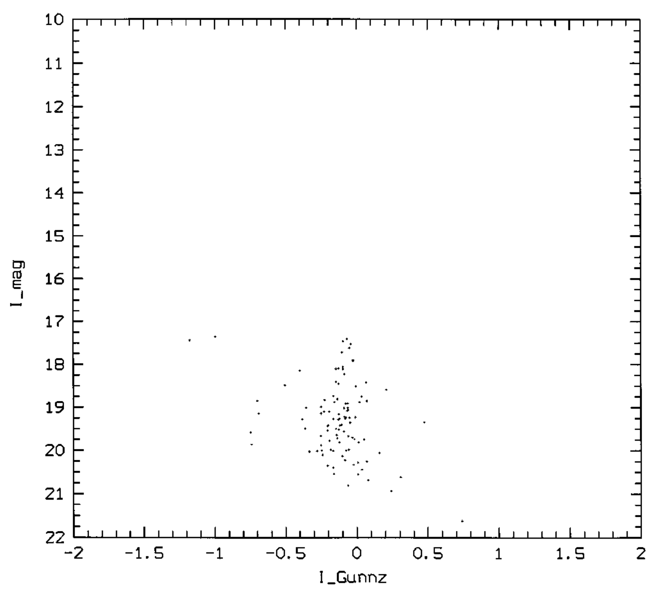

Fig. 9. UKS 1: I vs. $(I-z)$ colour-magnitude diagram for an extraction of radius $r < 16''$ from the NTT data

6. Concluding remarks

For the first time optical colour-magnitude diagrams of the faint bulge globular clusters Terzan 10, ESO 456 – SC 38 and UKS 1 are presented. The giant branches are clearly detected, but deeper photometries are necessary to reach the horizontal branches and fainter sequences. This could be achieved by using larger ground-based telescopes or the Hubble Space Telescope, especially in the infrared.

The three clusters are located in the near side of the Galaxy, and such conclusion has been systematically obtained in recent studies of other central bulge clusters (e.g. Terzan 5 and Terzan 6, Ortolani et al. 1996b; Barbuy et al. 1997 and references therein).

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