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V, I photometry of the bulge metal-rich globular clusters NGC 6380 and Terzan 12*

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Abstract. We present V, I photometry of the bulge globular clusters NGC 6380 and Terzan 12, using the ESO NTT telescope. For the first time colour-magnitude diagrams are obtained for these clusters, allowing us to derive reliable cluster parameters. From the colour-magnitude diagram morphology both clusters result to be metal-rich. For NGC 6380 we estimate [Fe/H] ≈ -0.5, a reddening of $E(B-V) = 1.07$ and a distance $d_\odot = 9.8$ kpc. For Terzan 12 we obtain [Fe/H] ≈ -0.5, $E(B-V) = 2.06$ and $d_\odot \approx 3.4$ kpc.

Key words: globular clusters: NGC 6380, Terzan 12 — HR diagram

1. Introduction

Globular clusters towards the bulge can be used as tracers of the Galaxy subsystems in that direction. In recent years CCD and infrared detectors allowed a great improvement in colour-magnitude diagrams of clusters in such crowded and reddened regions. Among the main questions concerning the bulge is the possible presence of a bar (Blitz & Spergel 1991). A possible way to test the scenario of bulge being identified with a bar, is to determine characteristics of globular clusters located on opposite sides of the Galactic center. In the present paper we study NGC 6380 and Terzan 12, which are suitably located for this purpose in terms of galactic coordinates.

The globular cluster NGC 6380, also known as Tonantzintla 1, Pismis 25 (Pismis 1959), GCL B1731 − 3902, BH 233 (van den Bergh & Hagen 1975), and ESO 333 − SC14 (Holmberg et al. 1978), has coordinates $\alpha_{1950} = 17^{\rm h}\ 31^{\rm m}\ 00.4^{\rm s}$, $\delta_{1950} = -39^\circ\ 02'\ 10''$ ($l = 350.181^\circ$, $b = -3.420^\circ$).

Terzan 12 (Terzan 1971a) was renamed as Terzan 11 at the publication of a second list by Terzan (1971b), because in the first list Terzan 11 was actually the same as Terzan 5 (Terzan 1968) (see also King 1972). In Terzan (1971b) a new Terzan 12 appeared which is in fact NGC 6256. We adopt the designation Terzan 12 as given in Terzan (1971a). It is also designated as ESO522 − SC1, GCL B1809 − 2245. The coordinates are $\alpha_{1950} = 18^{\rm h}\ 09^{\rm m}\ 14.0^{\rm s}$, $\delta_{1950} = -22^\circ\ 45'\ 18''$ ($l = 8.358^\circ$, $b = -2.101^\circ$).

Previous studies provided the following information on NGC 6380: Malkan (1982) derived $E(B-V) = 1.4$ from integrated infrared photometry, and Zinn (1985), based on the same data, estimated a metallicity of [Fe/H] = −1.0. By means of the bright giants method, Webbink (1985) estimated a Horizontal Branch (HB) level of $V_{\rm HB} = 18.0$ which, combined to a reddening of $E(B-V) = 1.38$ deduced from Malkan's data, led to a distance from the Sun of $d_\odot = 4.0$ kpc. Webbink indicates a metallicity of [Fe/H] = −1.30.

Concerning Terzan 12, by means of the bright giants method Webbink (1985) estimated a horizontal branch level of $V_{\rm HB} = 22.5$ which he marked as very uncertain. He also presents a reddening of $E(B-V) = 1.57$ that was estimated from the modified cosecant law, and he derived a distance from the sun of $d_\odot = 23.7$ kpc.

Trager et al. (1995) studied cluster structure for a large sample, deriving a concentration parameter of $c = 1.55$ for NGC 6380, and they did not exclude the possibility of a post-core-collapse morphology. Terzan 12 (therein called Terzan 11) is not concentrated ($c = 0.57$).

No Colour-Magnitude Diagrams (CMDs) are available for these two clusters.

We present V, I photometry for NGC 6380 and Terzan 12, using the ESO NTT telescope, and determine reliable cluster parameters.

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

In Sect. 2 the observations are reported. In Sect. 3 the CMD morphology and cluster parameters are discussed for NGC 6380. In Sect. 4 a similar analysis is given for Terzan 12. In Sect. 5 we discuss the results obtained for these two clusters and neighbouring ones in the context of the bar/bulge question. Finally, 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 $2.2' \times 2.2'$. The log-book of observations is given in Table 1. In Fig. 1 the NTT V image of NGC 6380 is shown. An inspection of this image suggests that bright individual giants appear to be present in the central regions, and we do not see evidence of a post-core-collapse. In Fig. 2 an I image of Terzan 12 is provided.

The 1.54 m Danish telescope was also used for observations of Terzan 12, where the Tektronix CCD # 28 of 1024×1024 pixels, with pixel size 24 μm ($0.37''$ on the sky) was used. The field is $6.3' \times 6.3'$.

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 Danish calibration equation $V = 26.91 + 0.04(V - I) + v$ and $I = 26.095 + i$ (for 30 s) was used, together with the NTT colour equation of previous photometric nights; the colour equations are (20 s, 1.2 airmass): $V = v + 27.67 + 0.06(V - I)$; $I = i + 26.89$. For the 1995 run, the equations are (20 s, 1.06 airmass): $V = v + 27.45 + 0.06(V - I)$; $I = i + 26.72 - 0.01(V - I)$. The observations of NGC 6380 were obtained at the NTT in a photometric night.

The photometric errors arise mostly from the zero point accuracy (± 0.03 mag) 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 V, I data are given in Table 2 for NGC 6380 and in Table 3 for Terzan 12, available only in electronic form at the CDS-Strasbourg.

Table 1. Log-book of observations

Target	Filter	Date	Equipment	Exp. (s)	Seeing ($''$)
NGC 6380	I	22.06.95	NTT+SUSI	60	1.1
	I			480	1.3
	V			600	1.0
Terzan 12	I	17.05.94	NTT + SUSI	60	0.7
	I			300	0.8
	V			600	0.8
	V	20.05.94	Danish	180	1.1
	I			60	1.0

3. NGC 6380

3.1. Colour magnitude diagrams

In Fig. 3 is shown the V vs. $(V - I)$ diagram for the whole frame. The cluster is large and occupies most of the field (Fig. 1). Nevertheless there is a field contamination, as can be seen from the field disk Main Sequence (MS). A metal-rich red giant branch (RGB) and red HB morphology is seen, which is dominated by the cluster, probably combined to a bulge field, with features similar to those of the cluster. In order to verify more precisely the cluster sequences we show in Fig. 4 the V. vs. $(V - I)$ diagram for a circular extraction of radius $r < 33''$. NGC 6380 is clearly a metal-rich cluster with a red HB superimposed on the RGB, and a curved RGB.

3.2. Metallicity

Using the metallicity criterion described in Ortolani et al. (1991), we measured the RGB inclination: $\Delta V/\Delta(V - I) = 1.0 \pm 0.07$, indicating a metallicity close to that of NGC 6553 (Ortolani et al. 1996b). Another method is the measurement of the magnitude difference between the brightest giants and the HB: $\Delta V_{\rm HB}^{\rm BG} = 2.25$ for NGC 6380, which would imply a metallicity comparable to that of 47 Tuc (Barbuy et al. 1997). An intermediate metallicity value between these two indicates [Fe/H] ≈ -0.5, adopted as a compromise value. Thus it is not an intermediate metallicity cluster as it was previously classified (Sect. 1).

3.3. Reddening and distance

In Fig. 4 we can measure the HB level at $V_{\rm HB} \approx 19.5 \pm 0.1$ and the RGB colour at the HB level $(V - I)_{\rm HB} = 2.52 \pm 0.04$. Assuming an intrinsic value $(V - I)_0^{\rm HB} = 1.2$ (Bica et al. 1994) for a metallicity of [Fe/H] $= -0.5$, we obtain $E(V - I) = 1.42$. Adopting $E(V - I)/E(B - V) = 1.33$ (Dean et al. 1978), we get $E(B - V) = 1.07$. 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. Using also the reddening dependence $\Delta R = 0.05E(B - V)$ (Olson 1975), we obtain $R = 3.4$ and $A_V = 3.64$.

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): $M_V^{\rm HB} = 0.16$[Fe/H]$ + 0.98$. The derived absolute distance modulus is $(m - M)_0 = 14.96$ and the distance $d_\odot = 9.8 \pm 1.0$ kpc. We point out that

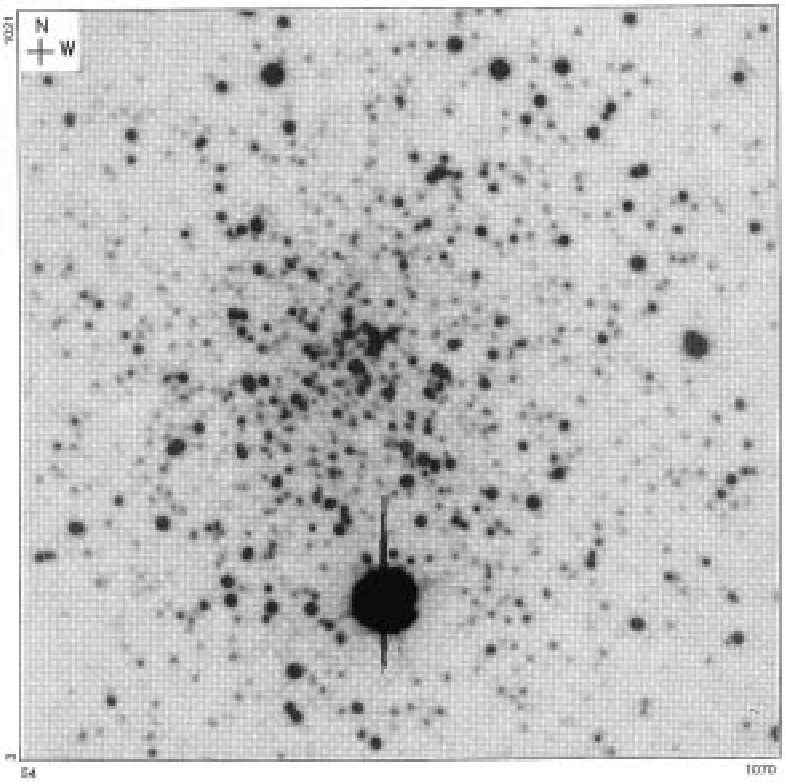

Fig. 1. NTT – SUSI V image of NGC 6380. The field size is $2.2' \times 2.2'$

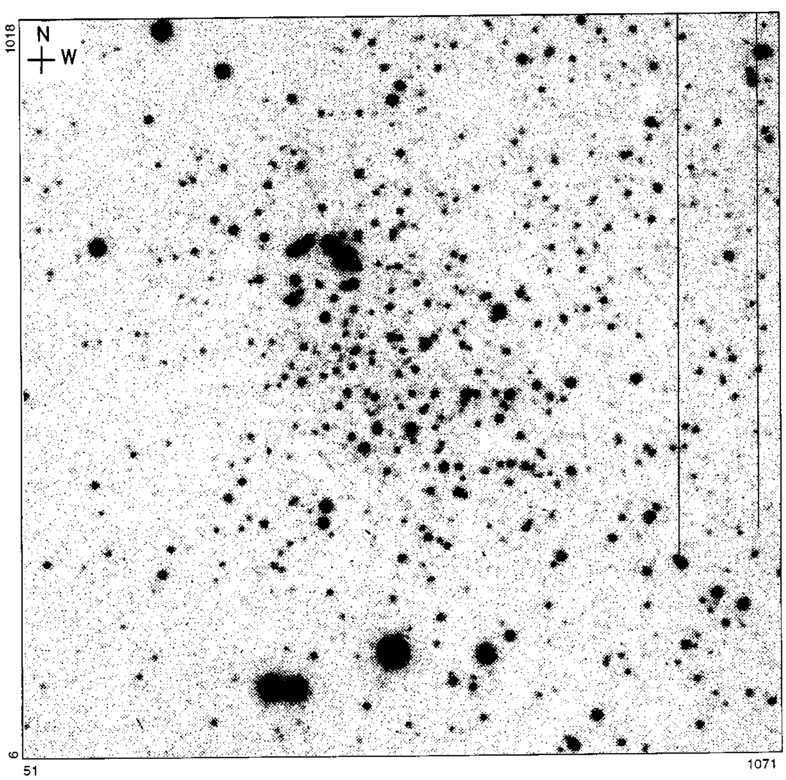

Fig. 2. NTT – SUSI V image of Terzan 12. Same field size as in Fig. 1

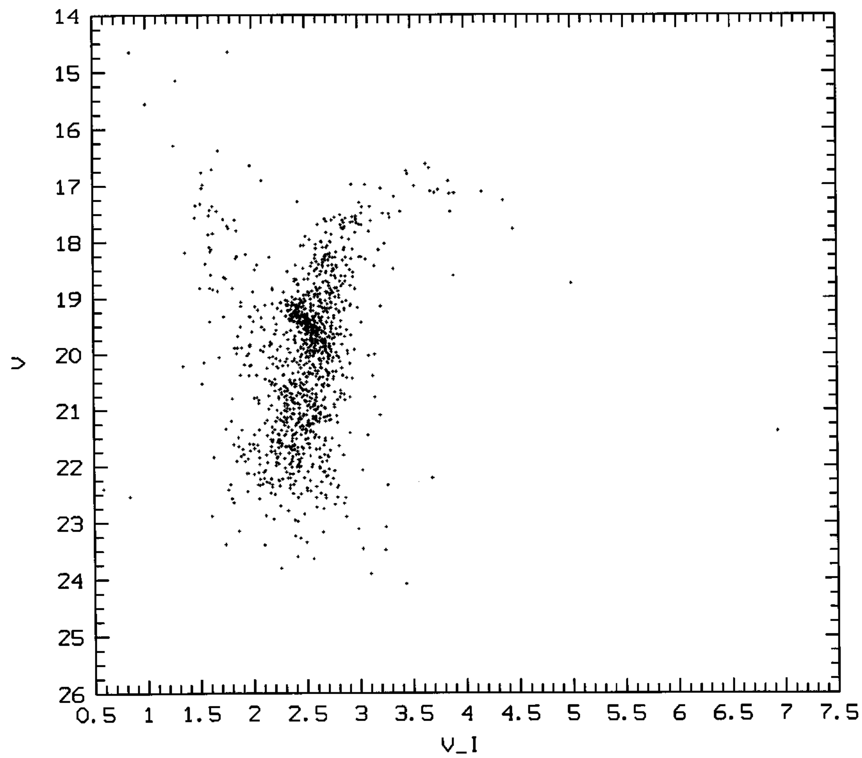

Fig. 3. NGC 6380: Whole frame V vs. $(V-I)$ colour-magnitude diagram, which is dominated by the cluster

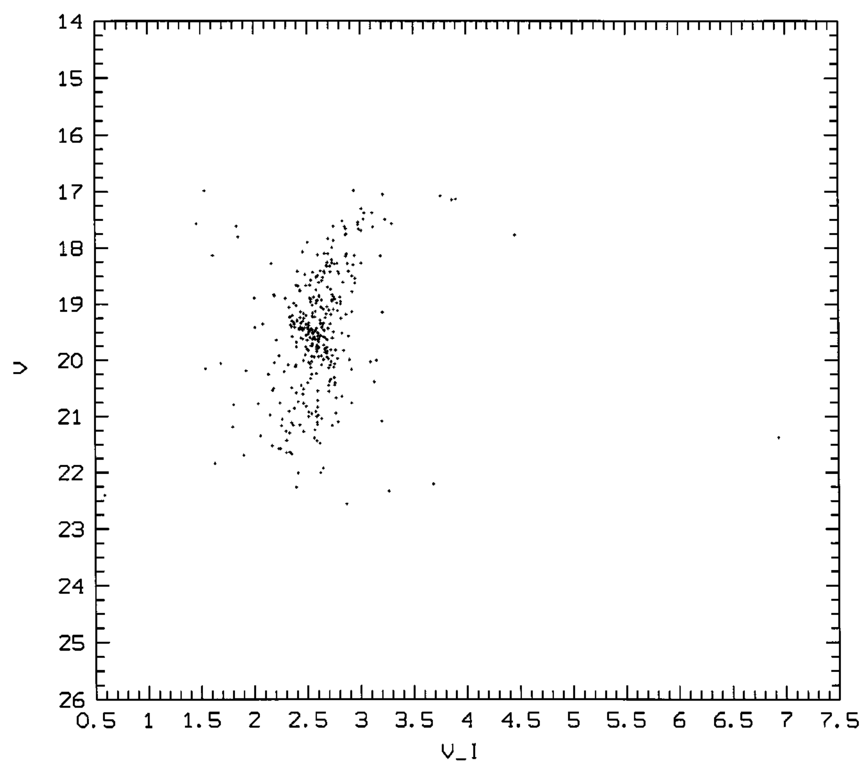

Fig. 4. NGC 6380: same as Fig. 3, for a circular extraction of radius $r < 33''$

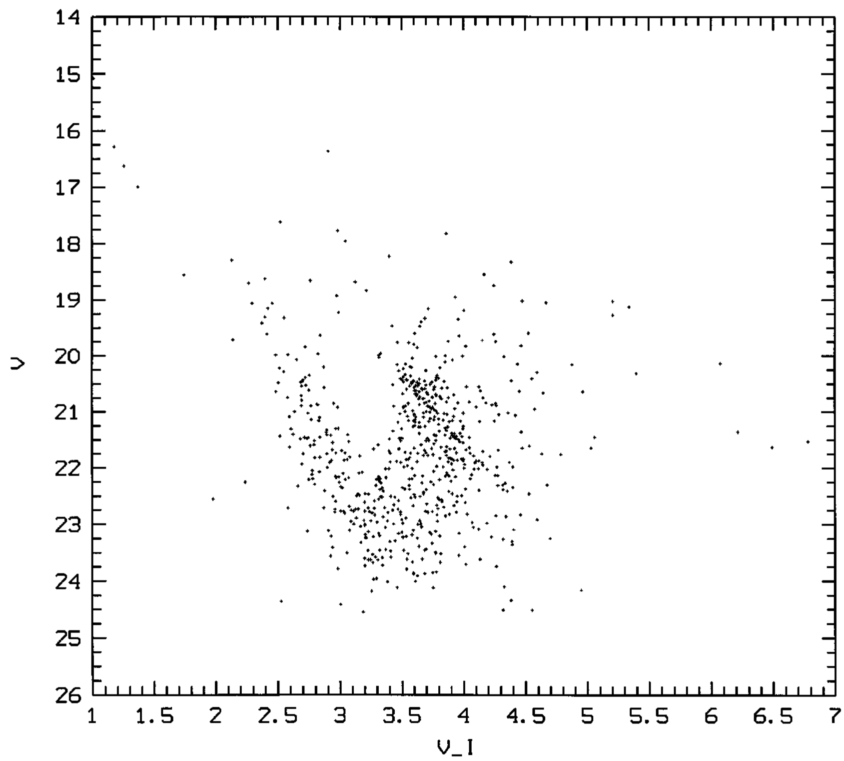

Fig. 5. Terzan 12: Whole frame V vs. $(V-I)$ colour-magnitude diagram, which is dominated by the bulge field stars

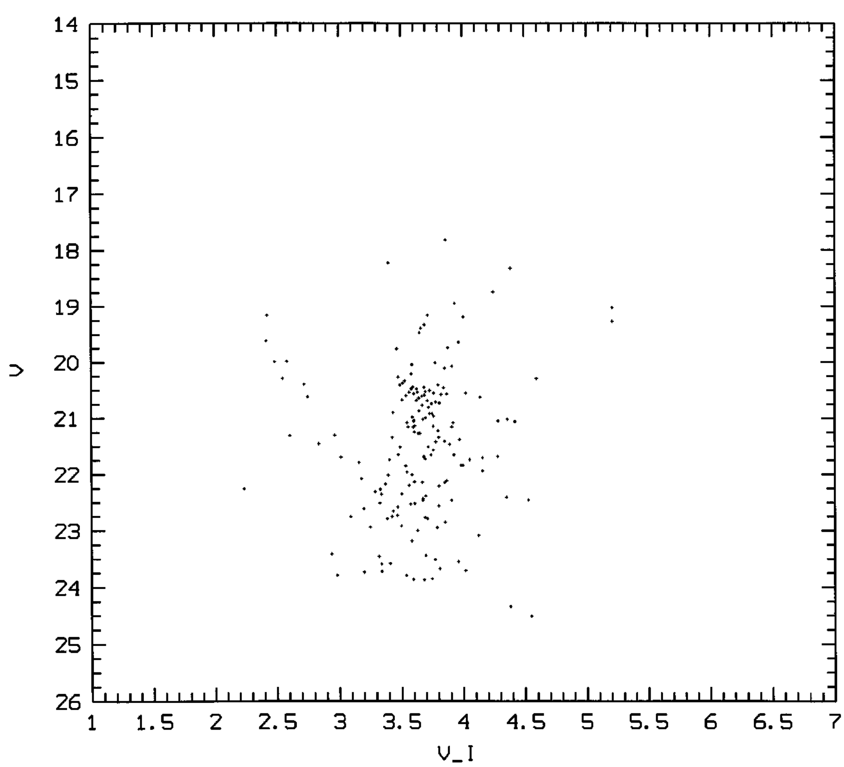

Fig. 6. Terzan 12: V vs. $(V-I)$ CMD for an extraction $r < 26''$

the major error source in the distance determination is the reddening law. This error is far larger than the other uncertainty sources which are the HB absolute magnitude, the zero point calibration, and the scatter of points affecting the HB fitting procedure.

The Galactocentric coordinates are $X = -1.6$ ($X > 0$ refers to our side of the Galaxy), $Y = -1.7$ and $Z = -0.6$ kpc, having adopted for the distance of the Galactic center $R_{\rm GC} = 8.0$ kpc (Reid 1993).

4. Terzan 12

4.1. Colour magnitude diagrams

In Fig. 5 is shown the V vs. $(V - I)$ diagram for the whole frame, which is dominated by the bulge field. The Ter 12 field is located at lower galactic latitude ($\Delta b = 1.3°$) than NGC 6380, which accounts for its larger surface density of field stars and more pronounced differential reddening.

In Fig. 6 the V. vs. $(V - I)$ diagram of Terzan 12 for a circular extraction of radius $r < 13''$ is plotted. We measure a red horizontal branch at $V_{\rm HB} = 20.5 \pm 0.2$ and a colour of the RGB at the HB level of $(V - I) = 3.75 \pm 0.1$. The red HB characterizes a metal-rich cluster.

4.2. Metallicity

The RGB extent for Terzan 12 is not as clearly defined as that of NGC 6380. If the few cool giants belong to the cluster, its metallicity would be similar to that of NGC 6553; if not, the metallicity would be like that of 47 Tuc. We tentatively adopt [Fe/H] ≈ -0.5.

4.3. Reddening and distance

The HB level is at $V_{\rm HB} \approx 20.5 \pm 0.15$ and the RGB colour at the HB level $(V - I)_{\rm HB} = 3.75 \pm 0.08$. Using the same prescriptions as in Sect. 3.3 for NGC 6380, we obtain for Terzan 12 $E(V - I) = 2.74 \pm 0.08$ and $E(B - V) = 2.06 \pm 0.06$. This leads to $R = 3.4$, $A_V = 7.0$, a true distance modulus $(m - M)_0 = 12.65$ and a distance $d_\odot = 3.4 \pm 0.5$ kpc. The Galactocentric coordinates are $X = 4.6$ $Y = 0.5$ and $Z = -0.1$ kpc.

5. Discussion

We gather in Fig. 7 the projection on the disk of globular clusters located at $8° < |l| < 12^0$ and $|b| < 4°$: NGC 6380, Terzan 12, NGC 6440 and Tonantzintla 2. For the latter two clusters we used V, I CMDs from Ortolani et al. (1994) and Bica et al. (1996), and their distances were revised in the same way as described in Sect. 3.3. The resulting distances from the sun for NGC 6440 and Ton 2 are respectively $d_\odot = 7.1$ and 6.9 kpc. In the figure is also shown the outer contours of the bar as proposed by Blitz & Spergel (1991). That bar appears to be tilted in the sense of its near side to be around $l \approx 10°$, and the far side at $l \approx 350°$. The location of the clusters are not incompatible with a connection with the bar, however for further conclusions it would be important to measure their kinematics, and to extend the sample to all clusters in the area of the proposed bar, taking into account their possible orbits.

We also remark that NGC 6380 and Ton 2 are closely projected on the sky ($\sim 40'$), but the derived distances show that they do not form a physical pair.

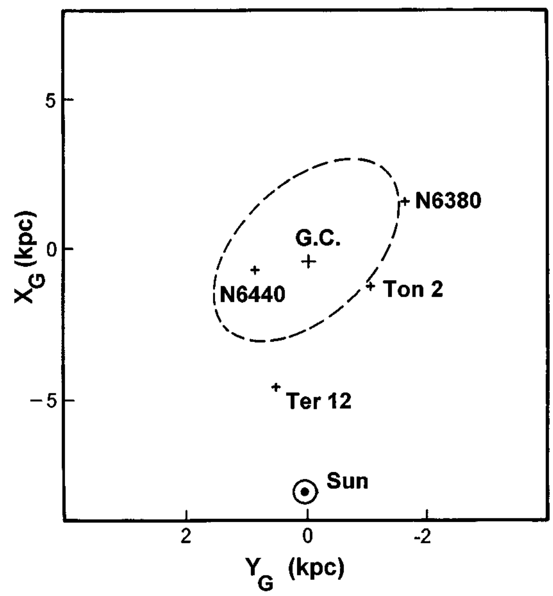

Fig. 7. Projection on the disk of the sample globular clusters. The ellipse corresponds to the outer contours of the bar as proposed by Blitz & Spergel (1991). The position of the Sun and Galactic center are also indicated

6. Conclusions

For the first time colour-magnitude diagrams are presented for NGC 6380 and Terzan 12. We find that they are metal-rich ([Fe/H] ≈ -0.5). These clusters are therefore to be included in the family of metal-rich clusters, recalling that the metal-rich class of clusters can trace the cluster subsystems in the Galaxy (Zinn 1985; Armandroff 1989; Ortolani et al. 1993). We derive the cluster parameters $E(B - V) = 1.07$ and $d_\odot = 9.8$ kpc for NGC 6380 and $E(B - V) = 2.06$ and $d_\odot = 3.4$ kpc for Terzan 12.

It would be interesting to obtain kinematical data for these clusters, as well as colour-magnitude diagrams and velocities of all bulge clusters for further study of the bulge structure and dynamics.

Given that NGC 6380 is a metal-rich bulge cluster not extremely reddened, and not too much affected by the differential reddening, it is a suitable target for the Hubble

Space Telescope, in view of reaching the cluster turn-off, for age determination.

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