ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **122,** 483-488 (1997)

NTT V, I, z photometry of the metal-rich bulge globular cluster Terzan 6*

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Received June 28; accepted August 21, 1996

Abstract. We present for the first time optical (V, I and Gunn z) colour magnitude diagrams for Terzan 6, which were collected under excellent seeing conditions with the ESO NTT telescope. The horizontal branch morphology is red, nearly superimposed on the red giant branch. The red giant branch morphology presents characteristics intermediate between those of 47 Tuc and NGC 6528/ NGC 6553.

We derive a reddening of $E(B-V) = 2.24$ and a distance $d_{\odot} = 7.0$ kpc (assuming $R = 3.1$). We conclude that Terzan 6 belongs to the metal-rich bulge globular cluster system.

Key words: globular clusters: Terzan 6; general — HR diagram

1. Introduction

The globular cluster Terzan 6 was discovered by Terzan (1968) with Schmidt plates obtained at the Haute-Provence Observatory. The cluster is also known as GCL B1747-3115, HP5, BH249 and ESO455-SC49. The coordinates are $\alpha_{1950} = 17^{\rm h}\ 47^{\rm m}\ 32.1^{\rm s}$, $\delta_{1950} = -31^{\rm o}\ 15'\ 44''$, and it is located at $l = 358.571^{\rm o}$, $b = -2.162^{\rm o}$.

By means of the bright giants method, Webbink (1985) estimated an horizontal branch level of $V_{\rm HB} = 20.8$, and a reddening of $E(B-V) = 1.46$ from the modified cosecant law, deriving a distance from the Sun of $d = 12.8$ kpc. Using integrated near–infrared spectroscopy, Armandroff & Zinn (1988, hereafter AZ88) derived [Fe/H] = -0.61 from CaII triplet lines, and $E(B-V) = 2.93$ from the interstellar band at 8621 Å.

Fahlman et al. (1995) presented JHK photometry of Terzan 6, deriving a reddening $E(B-V) = 2.04$, distance modulus (m-M) = 20.53 and distance to the Sun $d_{\odot} = 6.80 \pm 0.46$ kpc, and they conclude that the metallicity would be similar to that of M71 ([Fe/H] ≈ -0.60, Zinn & West 1984). The cluster structure is very concentrated, with $c = 2.50$, and it presents a post-core-collapse morphology (Trager et al. 1995). An X-ray source is present (Predehl et al. 1992).

In the present paper we analyse CMDs of Ter 6 in the V, I and Gunn z passbands. In Sect. 2 we describe the observations. In Sect. 3 we present the colour-magnitude diagrams. In Sect. 4 the cluster parameters are measured. The conclusions of this work are given in Sect. 5.

2. Observations and data reduction

The observations were obtained at the European Southern Observatory (ESO), using the 3.55 m New Technology Telescope (NTT) and the Danish 1.54 m telescope.

At the NTT we used the SUSI camera, which employs a 1024×1024 thinned Tektronix CCD at the Nasmyth focus B. The pixel size is 24 μm (0.13$''$ on the sky), and the frame size is $2.2' \times 2.2'$. The data were collected under excellent seeing conditions (0.6$''$), which is fundamental for the photometry of crowded bulge fields. We provide the log–book of observations in Table 1. We show in Fig. 1a a NTT z image of Ter 6.

At the Danish we used the Tektronix CCD # 28 of 1024×1024 pixels, with pixel size 24 μm, corresponding to 0.37 arcsec/pixel. The full field is $6.3' \times 6.3'$. In Fig. 1b the Danish V image is shown, where it can be seen that differential reddening effects are present across this larger field and that the cluster is located in an obscured area; the cluster nucleus looks almost stellar-like due to its post core collapse nature. The Danish observations were taken under photometric conditions, including Landolt (1983, 1992) stars, whereas the NTT data were not photometric. For this reason the zero-point calibrations were

* 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.

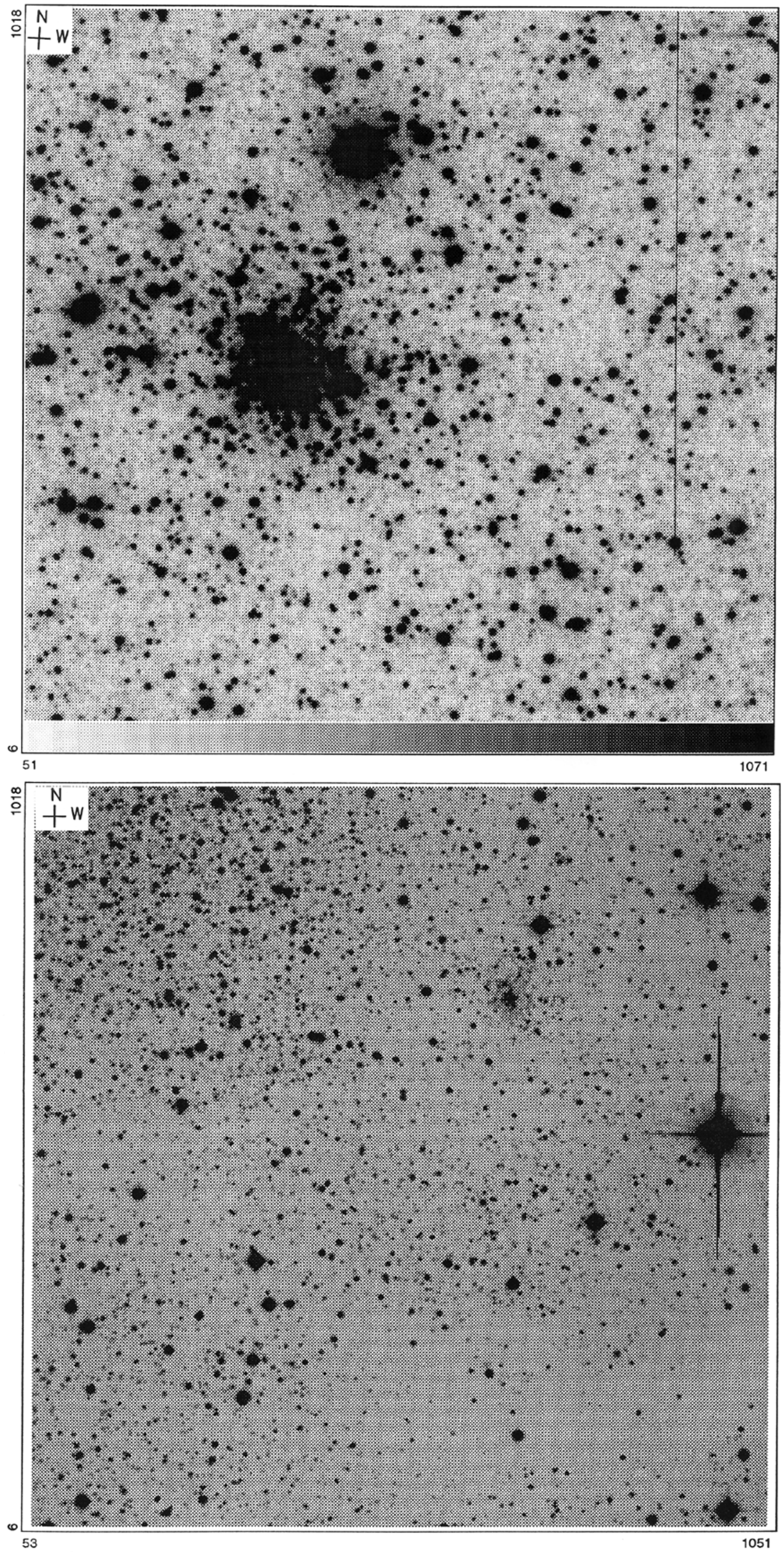

Fig. 1. Image of Terzan 6: **a)** NTT-SUSI Gunn z image; dimensions are $2.2' \times 2.2'$. **b)** Danish V image; dimensions are $6.3' \times 6.3'$

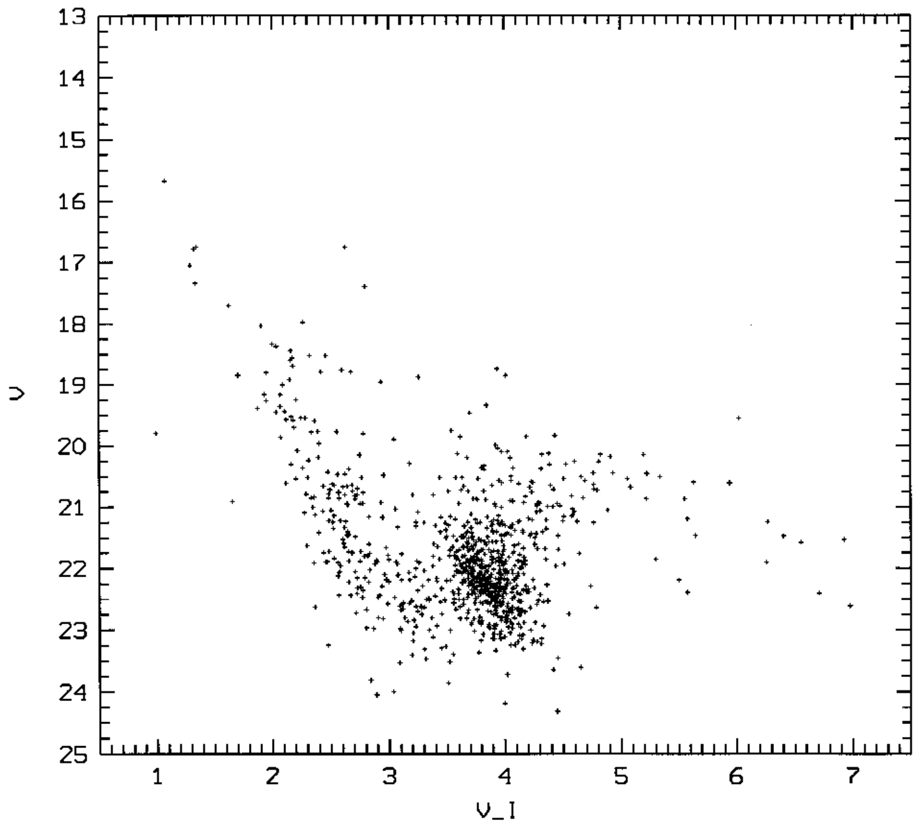

Fig. 2. Cluster V vs. $(V - I)$ diagram for the NTT whole frame

obtained based on the Danish observations, whereas the colour terms were obtained from NTT data of previous nights. The reductions were carried out in the standard way, and the calibrations equations, where Landolt stars were also used, are: $V = 26.91 + 0.04\,(V - I) + v$ and $I = 26.09 + i$ where the numbers are for 30 s exposures and airmass of 1.1.

We carried out the reductions with the DAOPHOT II package. The reduction procedure was described in detail in the Liller 1 and Ton 2 studies (Ortolani et al. 1996a; Bica et al. 1996), which were observed in the same run. The main sources of error in the photometry are the zero point accuracy ($\pm$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. The photometric errors are approximately constant to $I = 17.5$, amounting to 0.02 mag; at $I = 18.5$ the error increases to 0.07 mag.

Table 1. Log-book of observations

Target	Filter	Date	Equipment	Exp. (s)	Seeing ($''$)
Ter 6	I	17.05.1994	NTT + SUSI	60	0.65
	I			300	0.6
	V			480	0.6
	z			120	0.6
	I	20.05.1994	Danish	60	1.5
	I			360	1.5
	V			60	1.5
	V			900	1.5

3. *V*, *I* and Gunn *z* colour magnitude diagrams

We show in Fig. 2 a V vs $(V - I)$ diagram for the whole frame; the V and I data are given in Table 2, available only in electronic form at the CDS-Strasbourg. Figure 2 shows a blue disk main sequence (MS), and a dispersed red giant branch (RGB) plus a Horizontal Branch (HB), in which the cluster and the bulge population are mixed.

In Fig. 3 is shown a V vs. $(V - I)$ diagram for an extraction of radius $r < 39''$, where the cluster sequences are better defined than in Fig. 2. The center of the HB is located at $V \approx 22.25$ and $(V - I) \approx 3.85$; the RGB is curved down indicating a high metallicity and reaching $(V - I) \approx 7$. The coolest RGB tip star is still present in a smaller extraction of radius $r < 17''$.

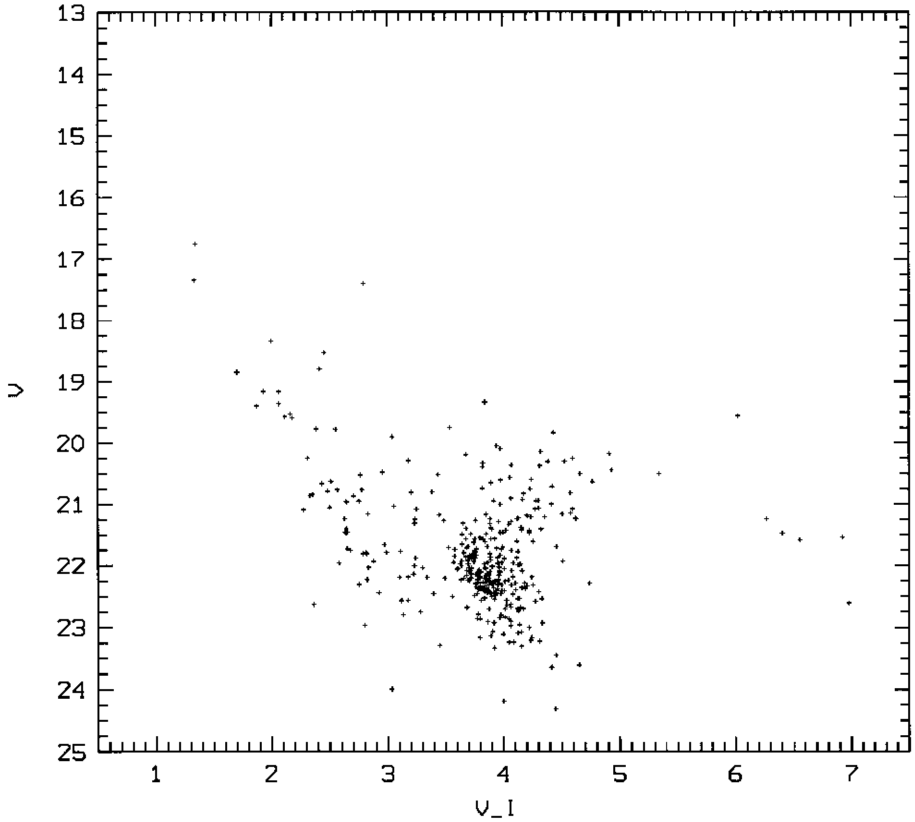

Fig. 3. Cluster V vs. $(V-I)$ diagram for an extraction of radius $r < 39''$

In Fig. 4 we plot I vs. $(I-z)$, where the open circles correspond to stars inside a radius of $r < 26''$ (cluster) and crosses to stars of $r > 39''$ (mostly field), where the cluster sequences are more defined than for the field. The Subgiant Branch (SGB) is reached, the red HB is almost superimposed on the RGB, and the RGB is almost flat.

In Fig. 5 we show the Danish whole field. A strong differential reddening is present, indicated by the very elongated and tilted HB ($\Delta(V-I) > 1$ mag). The field RGB morphology suggests it to be somewhat more metal-rich than Ter 6 itself.

4. Cluster parameters

4.1. Metallicity

We measured the slope of the cool part of the RGB, and obtained $\Delta V/\Delta(V-I) = 0.9 \pm 0.1$. Comparing these values to those given in Ortolani et al. (1991) and Ortolani et al. (1996b), we would assign to Ter 6 a metallicity similar to that of NGC 6553.

An alternative indicator of metallicity is the magnitude difference between the HB level and the top (brightest stars) of the RGB. We find $\Delta V_{\rm HB}^{\rm RGB} = 3.1$ for M30 (Rosino et al. 1996), 2.3 for 47 Tuc, 2.1 for NGC 6356 (Bica et al. 1994), 1.4 for NGC 6528 and 1.3 for NGC 6553 (Ortolani et al. 1995) whereas $\Delta V_{\rm HB}^{\rm RGB} = 2.0$ for Ter 6. This would place Ter 6 with a metallicity intermediate between those of 47 Tuc and NGC 6553/ NGC 6528. The cluster is probably more metallic than previously estimated by AZ88.

4.2. Reddening and distance

We calculate the cluster reddening taking NGC 6553 and 47 Tuc as references (Ortolani et al. 1995; Desidera 1996; Bica et al. 1994). The $(V-I)$ colour of the RGB at the HB level for Ter 6 is 4.0 ± 0.05, while that of NGC 6553 is $(V-I) = 2.05 \pm 0.04$ and for 47 Tuc $(V-I) = 0.98 \pm 0.04$. The difference between NGC 6553 and Ter 6 is $\Delta(V-I)_{\rm Ter6}^{6553} = 1.95$; given that from HST data the revised value $E(V-I) = 0.95$ for NGC 6553 (Guarnieri et al. 1997), this leads to $E(V-I)^{\rm Ter6} = 2.9$. Relative to 47 Tuc, $\Delta(V-I)_{\rm 47Tuc}^{\rm Ter6} = 3.02$, and given $E(V-I) = 0.05$ for 47 Tuc, $E(V-I)^{\rm Ter6} = 3.07$. Adopting the average value $E(V-I)^{\rm Ter6} = 2.98$, and using equation A1 of Dean et al. (1978) which leads to $E(V-I)/E(B-V) = 1.36$, we obtain $E(B-V) = 2.14$ for Ter 6. Assuming $R = A_V/E(B-V) = 3.1$ (Savage & Mathis 1979) we get $A_V = 6.64$; if $R = 3.6$ suitable for red stars (Terndrup

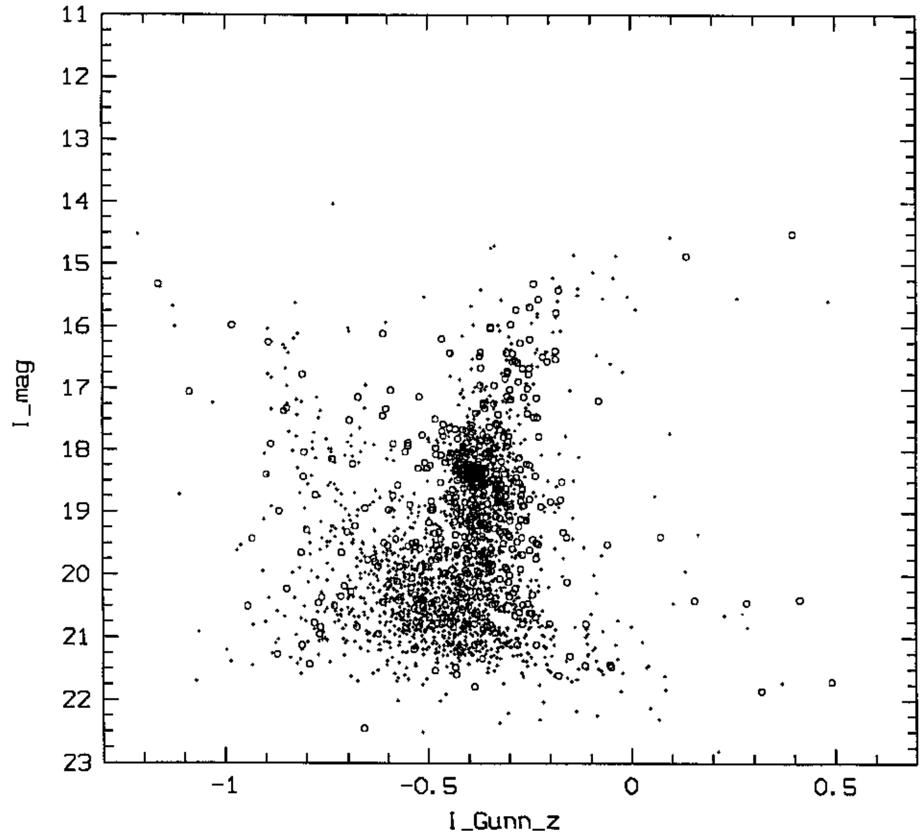

Fig. 4. Cluster I vs. $(I-z)$ diagram: where the open circles correspond to stars inside a radius of $r < 26''$ (cluster) and crosses to stars of $r > 39''$ (mostly field)

1988; Grebel & Roberts 1995), we get $A_V = 7.7$. This difference dominates over all other error sources, amounting to 1.1 magnitudes.

The HB magnitude of Ter 6 is at $V \approx 22.25$; assuming that the absolute magnitude of the HB for a metallicity of about [Fe/H] ≈ -0.4 is 0.92 (Chaboyer et al. 1996), and applying a 0.14 blanketing correction which matches bolometric magnitudes (see discussion in Guarnieri et al. 1996), there results $M_V^{\rm HB} = 1.06$. This value is in good agreement with values given by Buonanno et al. (1989), where however the correction due to the colour difference between the RR Lyraes and our redder stars was not included. We obtain an apparent distance modulus of $(m-M) = 21.19$. The true distance modulus will depend on the A_V adopted, resulting $(m-M)_0 = 14.25$ for $R = 3.1$ and 13.13 for $R = 3.6$. This corresponds to a distance of $d_\odot = 7.0 \pm 0.6$ kpc ($R = 3.1$) and $d_\odot = 4.2 \pm 0.6$ kpc ($R = 3.6$). These distance values are considerably smaller than the value indicated by Webbink (1985) and more compatible with the value given by Fahlman et al. (1995).

Assuming the standard value of $R = 3.1$ ($d_\odot = 7.0$ kpc), and assuming the distance of the Sun to the Galaxy center of $R_\odot = 8.0$ kpc (Reid 1993), the Galactocentric coordinates are $X = 1.0$ ($X > 0$ refers to our side of the Galaxy), $Y = -0.17$ and $Z = -0.26$ kpc.

5. Conclusions

For the first time optical CMDs of the globular cluster Terzan 6 are presented. It was observed in the V, I and Gunn z bands, under excellent seeing conditions. The horizontal branch morphology is red, and from the RGB morphology we conclude that its metallicity is intermediate between those of 47 Tuc and NGC 6528/NGC 6553.

A reddening of $E(B-V) = 2.24$ and a distance $d_\odot = 7.0$ kpc (for $R = 3.1$) are found.

Terzan 6 adds to the list of bulge metal-rich clusters with accurate optical photometric data. This is important for the understanding of the bulge structure, and provides the basic information for spectroscopy of individual stars, which will become possible with the new generation of large telescopes.

Acknowledgements. BB and EB acknowledge partial financial support from CNPq, Fapesp and Fapergs.

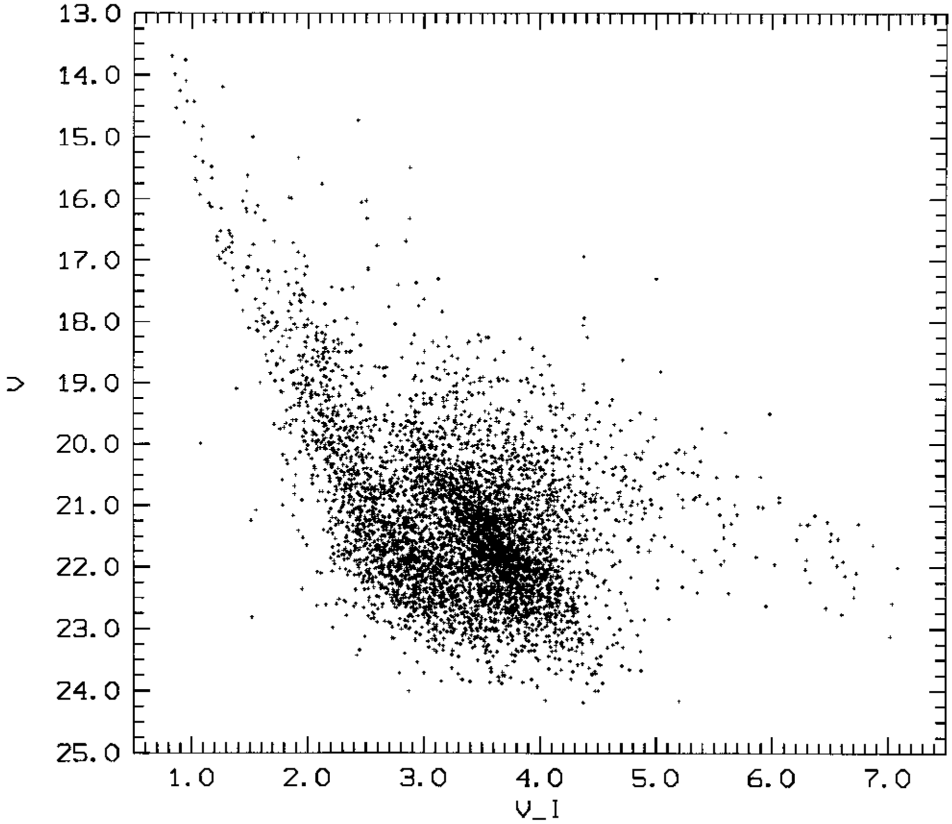

Fig. 5. V vs. $(V-I)$ diagram corresponding to the Danish telescope whole frame ($6.3' \times 6.3'$), essentially dominated by the field stars

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