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NTT V, I and Gunn z colour–magnitude diagrams of Liller 1: a globular cluster as metal-rich as the inner bulge stellar population?[⋆,⋆⋆]

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Abstract. We carried out VRI and Gunn z observations of the obscured globular cluster Liller 1. The cluster is so reddened ($A_V \approx 9.0$) that it is at the detection limit in V.

The RGB in I vs. (I–z) shows a strong curvature. Recalling that the nearly solar metallicity globular clusters NGC 6553 and NGC 6528 present similar blanketing effects only in the visible bandpasses, we conclude that Liller 1 is considerably more metal-rich than these clusters.

The CMD comparison of Liller 1 with the inner bulge field around it (located $\approx 5°$ from the nucleus), suggests that the cluster is as metallic as the most metallic fraction of this inner bulge population.

Similarly deep I and z observations at $\approx 0.5°$ away from Liller 1, at the nominal position of Grindlay 1 do not reveal any cluster.

Key words: Galaxy: globular clusters: individual Liller 1 – stars: HR diagram – stars: abundances

1. Introduction

The globular cluster Liller 1 (also designated IAU 7130-333) is located at $\alpha_{1950} = 17^h30^m07.0^s$, $\delta_{1950} = 33°21'17''$, very close to the galactic plane and center ($l = 354.81$, $b = -0.160$). It was discovered by Liller (1977) in a search of optical counterparts of X-ray burst sources; the source MXB 1730-33 appears to be associated to Liller 1.

Malkan (1982) carried out integrated infrared (IR) photometry, deriving $E(B–V) = 2.9$. Based on these IR measurements, Zinn (1985) estimated a metallicity of [Fe/H] = −0.21. From near-IR integrated spectra containing the Ca II triplet, Armandroff & Zinn (1988) estimated [Fe/H] = +0.20 and a reddening of $E(B–V) = 2.71$. An inspection of faint globular clusters or globular cluster candidates in the ESO R plates indicates that Liller 1 is among the most difficult ones to detect. Structurally it is a very compact cluster ($c = 2.30$), perhaps with a post-collapse core (Trager et al. 1993).

A colour–magnitude diagram (CMD) was first presented by Ortolani et al. (1994a) in I vs. (I–z), where it was concluded that it should be as metallic as its surrounding field which, in turn, is representative of the stellar population in the central regions of the bulge. Recently, JHK CMDs were presented by Frogel et al. (1995), where a metallicity [Fe/H] = +0.25 ± 0.3 was estimated.

In Sect. 2 we present the observations. In Sect. 3 we analyze the Liller 1 and field CMDs, and in particular one cluster CMD obtained under excellent seeing conditions. The concluding remarks are provided in Sect. 4.

2. Observations

The log-book of the observations of Liller 1 is presented in Table 1. The reported data are extracted from observations obtained at the ESO New Technology Telescope (NTT) in June 1993 and May 1994. A few images were also obtained with the 1.54 m Danish Telescope in 1991.

For the Danish observations, a CCD RCA 512×320, ESO #5, of frame size $3' \times 4.5'$, and pixel size of 30 μm (corresponding to $0.47''$ on the sky) was employed. In Fig. 1 the Danish R image is shown. Note that the appearance as a globular cluster is not obvious even in this red bandpass, owing to the very strong absorption.

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

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⋆ Observations collected at the European Southern Observatory, ESO, La Silla, Chile
⋆⋆ Table 2 is available in electronic form at the CDS via anonymous ftp 130.79.128.5.

Table 1. Log-book of observations

Filter	Date	Telescope	Exp. time (s)	Seeing ($''$)
Liller 1				
V	22.04.91	Danish	600	1.5
R	22.04.91	Danish	600	1.5
Gunn z	22.04.91	Danish	600	1.5
I	22.04.91	Danish	600	1.5
I	15.06.93	NTT+EMMI	180	1.1
I	15.06.93	NTT+EMMI	180	1.1
Gunn z	15.06.93	NTT+EMMI	100	1.2
Gunn z	15.06.93	NTT+EMMI	480	1.2
I	16.05.94	NTT+SUSI	60	0.8
I	16.05.94	NTT+SUSI	60	0.65
Gunn z	16.05.94	NTT+SUSI	60	0.65
V	16.05.94	NTT+SUSI	60	0.7
I	16.05.94	NTT+SUSI	60	0.7
I	16.05.94	NTT+SUSI	60	0.6
I	16.05.94	NTT+SUSI	300	0.6
Gunn z	16.05.94	NTT+SUSI	300	0.5
Grindlay 1				
I	14.06.93	NTT+EMMI	300	1.6
V	14.06.93	NTT+EMMI	480	1.6
Gunn z	16.06.93	NTT+EMMI	1200	1.0

2048×2048 pixels, but it was read out in the format 1700×1400 pixels ($9.9' \times 8.1'$ on the sky) excluding peripherical vignetted regions.

The 1994 NTT observations were carried out at the Nasmyth focus B, with a 1024×1024 thinned Tektronix CCD (SUSI camera). The pixel size is 24 μm ($0.13''$ on the sky) with a total $2.2' \times 2.2'$ frame size. We show in Fig. 2 a Gunn z image of Liller 1 from SUSI. Note how clear the cluster appears as compared to Fig. 1, due to the much lower reddening effects.

We also report in Table 1 NTT-EMMI observations at $\approx 0.5°$ away from Liller 1, at the nominal position of Grindlay 1. Grindlay & Hertz (1981) suggested that this object, the JHK counterpart of the X-ray source GX354+0 should be a globular cluster. Recently, Djorgovski & Meylan (1993 and references therein) pointed out that the cluster is probably non-existing. Our deep Gunn z ($\lambda_{\rm eff} \approx 8500$Å) image confirms that the cluster is not detectable in the near-infrared (Fig. 3). Only a few very faint stars are present in the region, but they do not have a star cluster appearance. It may be that the cluster, if any, is so heavily obscured that it is only detectable at longer wavelengths.

In Table 2, available in electronic form at CDS-Strasbourg, we give the NTT-SUSI I and Gunn z data.

2.1. Reductions

The images have been processed at the ESO-Garching computer center, using the Midas package available on a Sparc2 SUN workstation. After the standard flatfield corrections, instrumental magnitudes have been obtained using the Daophot II. The details on the basic procedures are described in Ortolani et al. (1990, 1992, 1993, hereafter OBB).

2.2. Calibrations

2.2.1. NTT-EMMI

We used Landolt's (1992) standard stars in the fields PG 1323, G 1455 and T Phenix for the calibrations of the V and I colours. Colour coefficients $K_V = +0.02$ and $K_I = -0.015$, with an error of 0.01, were obtained. The final calibration derived from the standard stars is:

$$V = v + 0.02(V{-}I) + 23.86 \pm 0.015 \text{ mag}$$

$$I = i - 0.015(V{-}I) + 23.58 \pm 0.015$$

where v and i are the instrumental magnitudes for 1 s exposures at 1.2 airmasses. We estimate an uncertainty of about ±0.03 due to crowding effects. To this a shutter error of about 3% has to be added. Further details on the 1993 NTT run are given in Ortolani et al. (1994b, hereafter OBB94b).

2.2.2. NTT-SUSI

The calibration of NTT-SUSI observations is based on Landolt (1983 and 1992) fields. The resulting colour equations in V and I are:

$$V = v + 0.06(V{-}I) + 27.67$$

$$I = i + 26.89$$

where v and i are the instrumental magnitudes and the constant term is calculated for 20 s of exposure at 1.2 airmasses. The colour terms in the I band are smaller than in the case of EMMI data, but the accuracy of the calibration equations is slightly lower in SUSI due to the smaller field, and the small number of standard stars per frame (typically 3 or 4). The zero point accuracy is estimated to be of about ±0.03 magnitudes. The final accuracy of our SUSI calibration is, however, dominated by crowding effects in the aperture photometry required for the magnitude transfer from the cluster images to the standard stars. From a comparison of the theoretical growth curves with our measurements, we estimate that this source of error can amount to about 0.05 magnitudes. Also the relative photometry in Liller 1 fields is largely dominated by the crowding and it is a function of the relative position with respect to the cluster center. From frame to frame comparison we got an average relative error nearly constant at about 0.02 mag down to $I = 17.5$. Then it rapidly increases to 0.07 at $I = 18.5$. This error, however, must be considered as a lower limit since it was derived from images having very similar crowding. More details on photometry obtained on crowded fields in the galactic bulge are discussed for example in OBB90, OBB92, OBB93, OBB94b, OBB95, Bica et al. (1994).

The Gunn z magnitudes are instrumental; a calibration is not possible yet, due to a lack of measurements for standard stars in the literature.

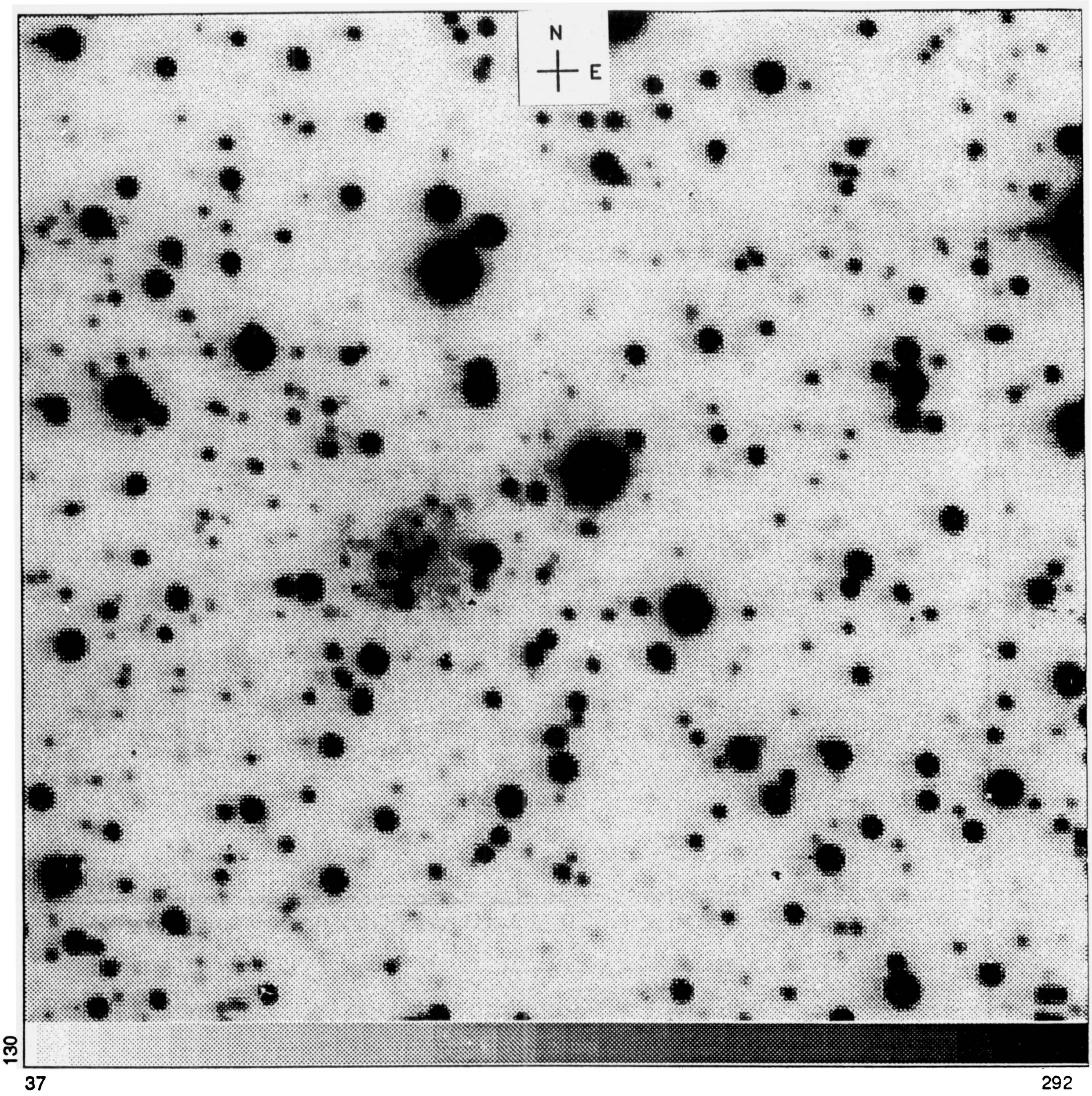

Fig. 1. Danish R image of Liller 1. Extraction of dimensions $2' \times 2'$

3. CMDs of Liller 1 and surrounding fields

3.1. The field

We show in Fig. 4 the I vs. (I–z) CMD (NTT-EMMI) for an extraction of $9.9' \times 8.1'$, centered on Liller 1, containing about 30 000 stars. Since the main body of the cluster is very small ($\approx 50''$), in such a large extraction most stars belong to the field. The most populated feature is the field disk main sequence (MS), since we are basically observing at the latitude of the Galactic plane. The populated region in the red is dominated by the bulge red giant branch (RGB) and the red horizontal branch (HB), centered at $I \approx 19.9 \pm 0.20$.

In Fig. 5 we show a deep V vs. (V–I) CMD corresponding to an extraction of $6' \times 6'$ (NTT-EMMI) centered on Liller 1. The disk MS is clearly seen but the red sequences are essentially absent, making evident the strong reddening effect in the V filter.

3.2. The cluster

We show in Figs. 6a,b,c Liller 1 I vs. (I–z) CMDs (NTT-SUSI) respectively for the whole field ($2.2' \times 2.2'$), and circular extractions of radius $r = 60''$ and $r = 45''$. This series allows one to progressively minimize the bulge contamination. A tight Hayashi limit denoting a well defined cluster sequence is seen. This result was possible in Figs. 6 thanks to the high quality seeing in the 1994 run. The improvement can be seen by comparing the present figures with Fig. 2 in Ortolani et al. (1994).

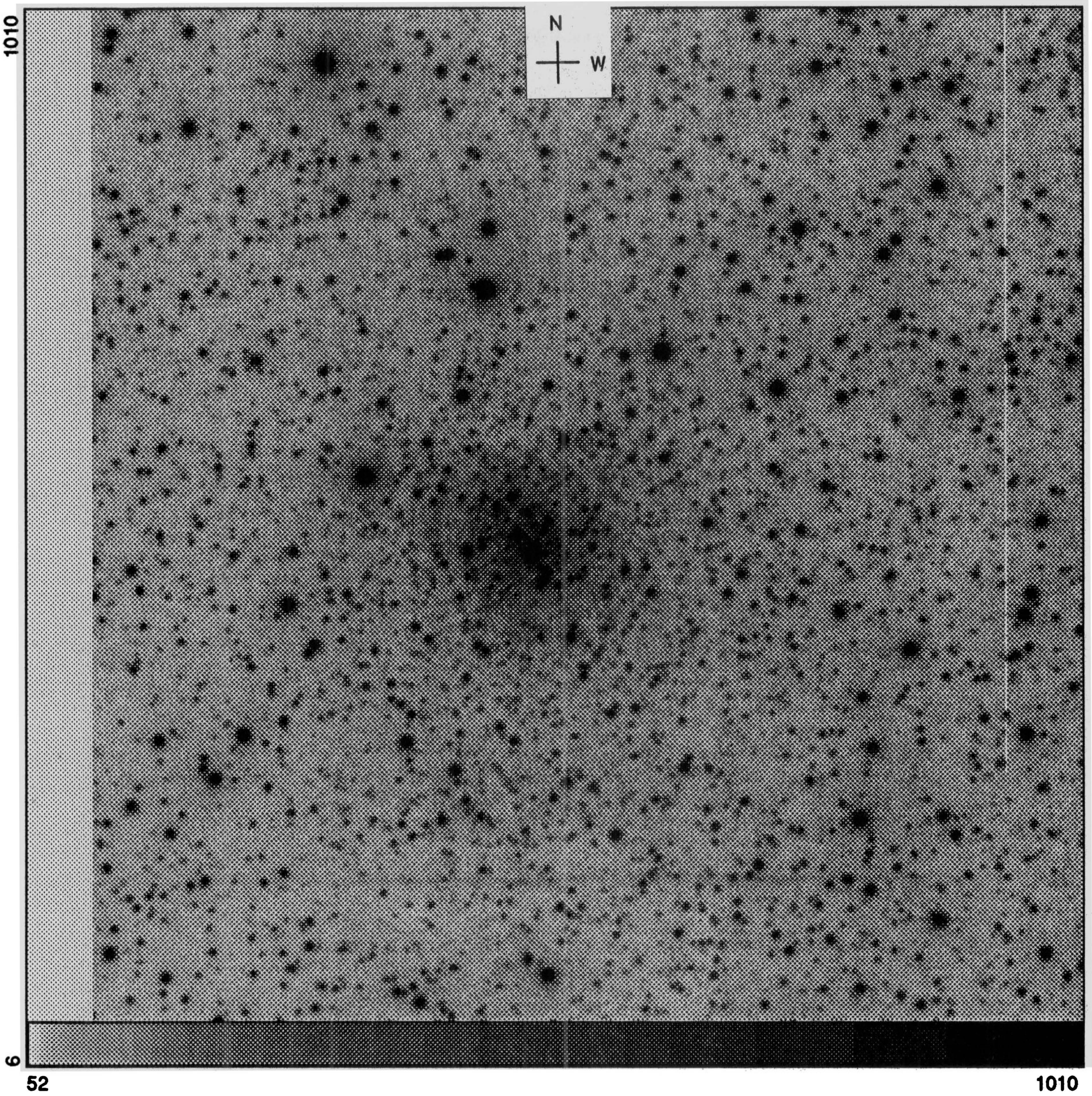

Fig. 2. NTT-SUSI Gunn z image of Liller 1. Dimensions are $2.2' \times 2.2'$

Note in Figs. 6 the RGB strong curvature. Such strong RGB curvatures were first detected for NGC 6553 by OBB90, in visible colours (V vs. $(B-V)$), where the RGB tip was as faint as the HB. For the RGB of NGC 6553, NGC 6528 and NGC 6440 (OBB90, 92, 94b), in the I band, the curvature is much less pronounced, and the RGB tip is about 2.5 magnitudes brighter than the HB. Terzan 1 (OBB93) showed a slight curvature in I vs. (V–I), and the difference between the RGB of NGC6528 and Terzan 1 is shown in Ortolani et al. (1991).

The RGB curvature in I vs. (I–z) for Liller 1 (Figs. 6) is an evidence for a very strong blanketing, even in near-infrared bandpasses, implying a very high metallicity.

The red HB has probably been detected close to the CMD limit in Fig. 6.

A comparison between the CMDs of Liller 1 (Fig. 6) and the bulge field (Fig. 4) can provide an estimate of their ranking in metallicities. The bulge CMD is somewhat dispersed by differential reddening and depth effects, but it can be concluded that Liller 1 would be comparable to the most metallic fraction of the stellar population in this inner bulge field located $\approx 5°$ from the nucleus of the Galaxy. As a matter of fact, the RGB slope of Liller 1 (Fig. 6) seems to be the same as that of the field (Fig. 4, Fig. 6a).

3.3. Distance

Comparing the cluster CMD with that of the surrounding field (Figs. 4 and 6), we notice that Liller 1 appears to be at a comparable distance with respect to the bulk population of the bulge,

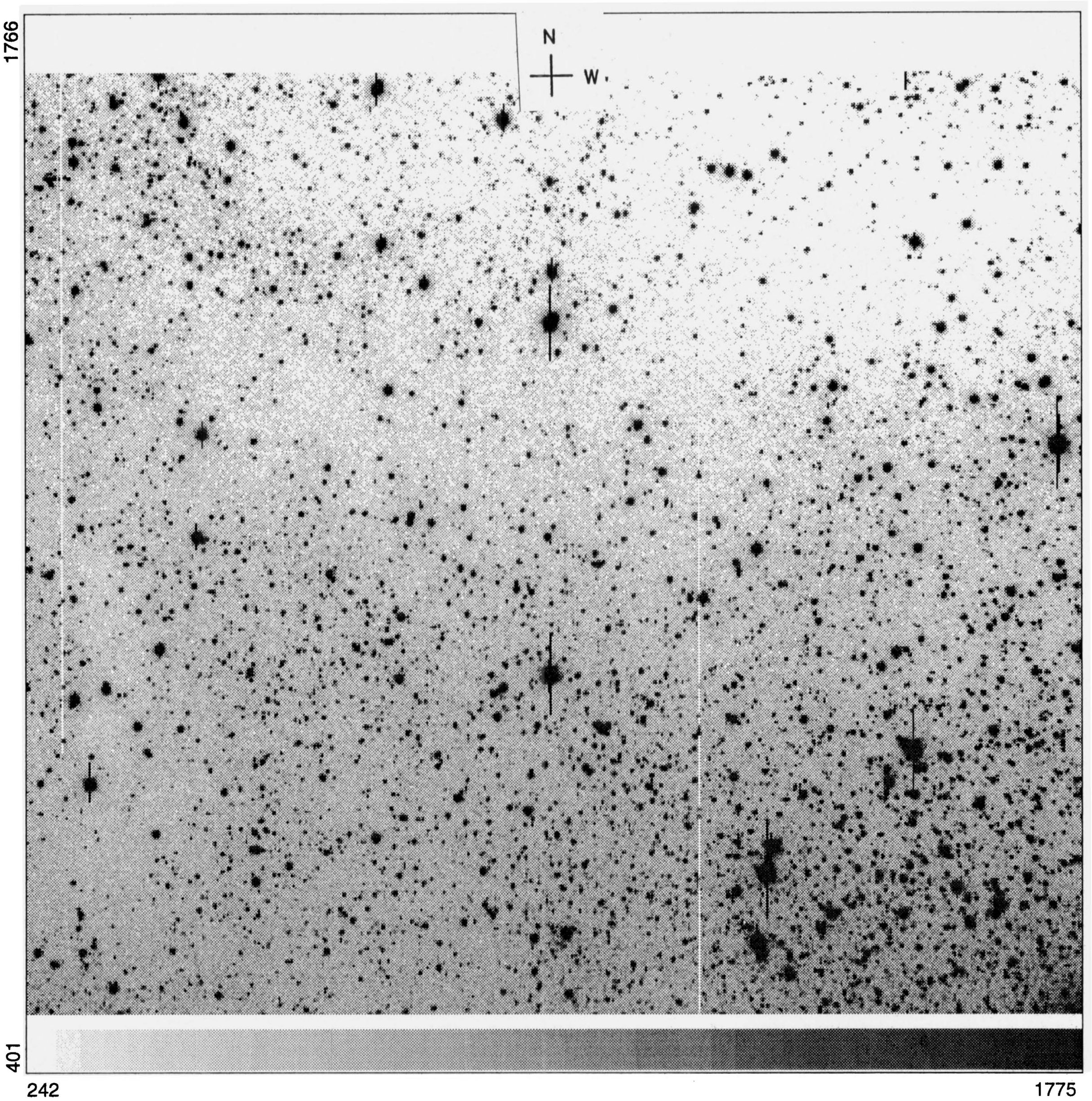

Fig. 3. NTT-EMMI z image at the nominal position of Grindlay 1, at $\approx 0.5°$ away from Liller 1. Dimensions are $9' \times 8'$

which should be approximately at the Galactic center. Based on this piece of evidence, we suggest that Liller 1 is located very close to the Galactic center, at 8 kpc (Reid 1993), basically in agreement with the JHK result by Frogel et al. (1995) of 8.6 kpc.

3.4. Cluster reddening

The most evident reference point for Liller 1 in Figs. 6 is the brightest level of the RGB. For very high metallicities such as that of Terzan 1, this corresponds to the turn-over of the RGB in I (OBB93). For slightly less metallic clusters like NGC 6553 and NGC 6528 (OBB90, 92) this point corresponds to that of maximum curvature in I vs. $(V-I)$. Assuming that such point of the RGB occurs at approximately constant magnitude in the high metallicity regime, we can make reddening estimates. For Liller 1, Terzan 1 and NGC 6528 this point is respectively at $I \approx 18.0$, $I \approx 13.8$ and $I \approx 13.1$, with an uncertainty of about ± 0.2. Considering that $E(B-V) \approx 1.67$ for Terzan 1 and 0.55 for NGC 6528, and that Liller 1 is at the Galactic center distance (Sect. 3.1), we derive $E(B-V) = 3.05 \pm 0.25$. This value is slightly higher than those given by Malkan (1982) and Armandroff & Zinn (1988), of respectively $E(B-V) \approx 2.90$ and 2.71, and comparable to the value of $E(B-V) = 3.0$ derived by Frogel et al. (1995).

The derived reddening implies $A_V \approx 9.15$ (adopting $A_V = 3.1\,E(B-V)$) which explains why Liller 1 (and the bulk of the bulge population) is not detected in Fig. 5. The brightest red giants in Fig. 5 should be the bulge and Liller 1 brightest giants in V.

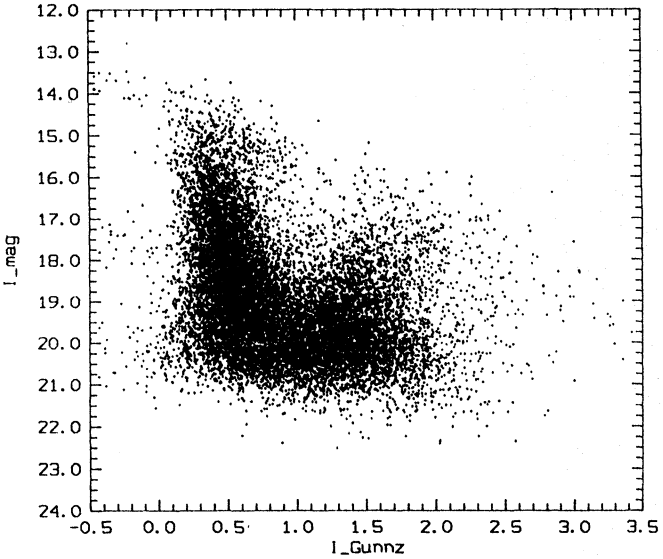

Fig. 4. I vs. (I–z) CMD (NTT-EMMI) from a $9.9' \times 8.1'$ extraction centered on Liller 1, containing ≈ 30 000 stars, which are dominated by the field disk MS and bulge red stars

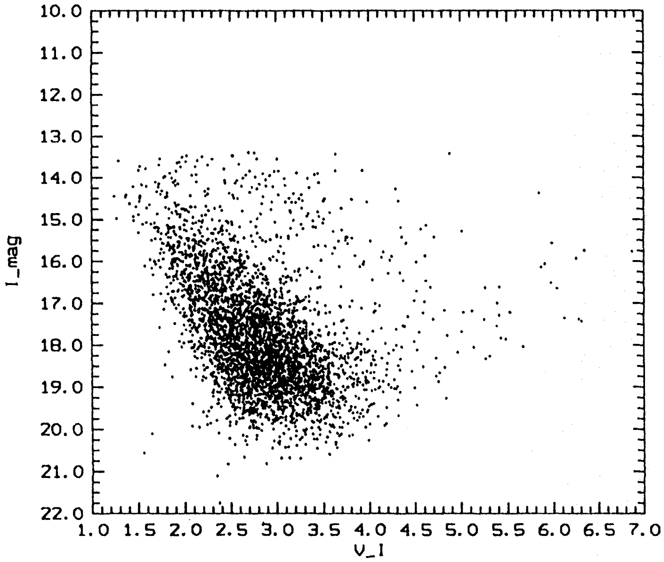

Fig. 5. I vs. (V–I) CMD (NTT-EMMI) from a $6' \times 6'$ extraction centered on Liller 1. As in Fig. 3 it is dominated by field stars. The brighter RGB stars are at $V \sim 23$ level

In Fig. 5 a parallel less populated reddened MS appears to be present. It is worth noting that Terzan 1 is projected a few degrees away from Liller 1, but somewhat higher in the Galactic plane ($b \approx 1°$) and with considerable lower reddening ($E(B–V) \approx 1.67$). In Fig. 5 there is evidence of a redder less populated disk MS at $\Delta E(V–I) \approx 1.2$, which would convert to $\Delta E(B–V) \approx 1.14$. Adding this to the reddening of Terzan 1, one gets $E(B–V) \approx 2.81$, i.e., comparable to that of Liller 1. The most populated disk MS in Fig. 5 compares well in observed values to that of Terzan 1's field MS (OBB93). Possibly we are

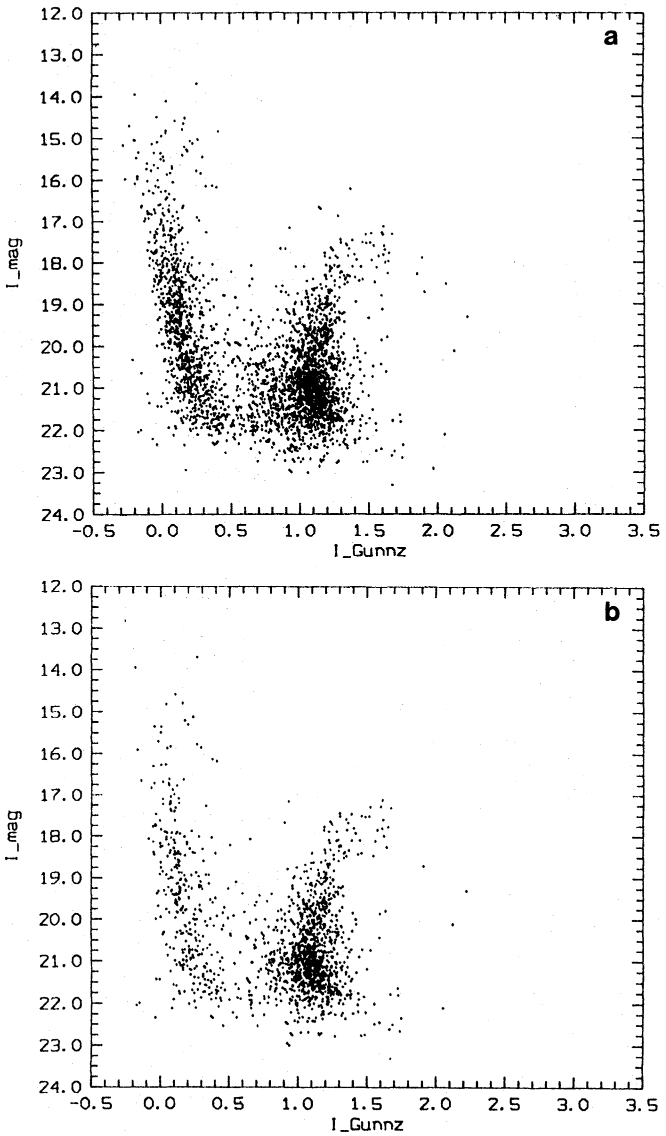

Fig. 6a–c. I vs. (I–z) CMD (NTT-SUSI): **a** whole frame ($2.2' \times 2.2'$); **b** circular extraction of $r \leq 60''$; **c** circular extraction of $r \leq 45''$. Note that in this series the bulge field contamination is minimized from **a** to **c**

looking at an additional thick dust complex in the inner parts of the disk, which affects Liller 1 and its surrounding fields.

4. Concluding remarks

The NTT equipped with SUSI combined to a high quality seeing permitted us to obtain a very good I vs. (I–z) CMD of the very reddened and compact globular cluster Liller 1. The RGB shows a strong curvature, observed before only in visible bandpasses of nearly solar metallicity globular clusters such as NGC 6553 and NGC 6528 (OBB90, 92). We conclude that Liller 1 is therefore considerably more metal-rich than these clusters.

The CMD comparison of Liller 1 with the inner bulge field around it (located ≈ 5° from the nucleus), suggests that the

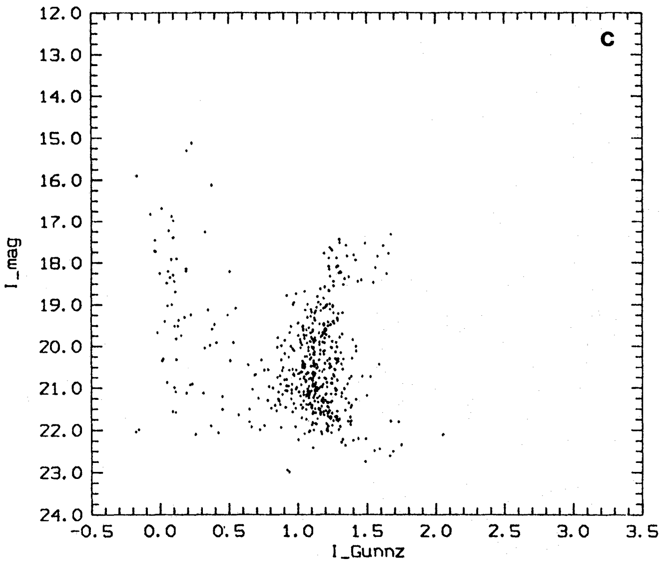

Fig. 6a–c (continued).

cluster is as metallic as the most metallic fraction of this bulge population given the locus and curvature of the RGB.

An interesting comparison can be made with the spectroscopic results on the M31 bulge and semistellar nucleus (Bica et al. 1990), and the very metal-rich globular cluster G177 located in the bulge of M31 (Jablonka et al. 1992). In terms of equivalent widths of absorption lines in the visible and near-infrared, G177 is comparable to the inner bulge of M31, and consequently to most giant elliptical nuclei. Liller 1 and G177 might be counterparts in terms of metallicity. The semistellar nucleus, on the other hand, is still more metal-rich than these objects. Such ranking of high metallicities is a fundamental intermediate step in view of establishing the metallicity scale. The metallicity scale for globular clusters is basically established for metallicities below that of NGC 6553, for which [Fe/H] = −0.2 was found from high-resolution spectroscopy (Barbuy et al. 1992); we emphasize that NGC 6553 shows CMD characteristics of metallicities clearly below that of Liller 1.

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References

Armandroff T.E., Zinn R., 1988, AJ 96, 105
Barbuy B., Castro S., Ortolani S., Bica E., 1992, A&A 259, 607
Bica E., Alloin D., Schmidt A., 1990, A&A 228, 23
Bica E., Ortolani S., Barbuy B., 1994, A&A 283, 67
Djorgovski S., Meylan G., 1993, Structure and Dynamics of Globular Clusters, Djorgovski S., Meylan G. (eds.). ASP Conference Ser. 50, p. 325
Frogel J.A., Kuchinski L.E., Tiede G.P., 1995, AJ 109, 1154
Grindlay H., Hertz P., 1981, ApJ 247, L17
Jablonka P., Alloin D., Bica E., 1992, A&A 260, 97
Landolt A.U., 1992, AJ 104, 340
Liller W., 1977, ApJ 213, L21
Malkan M.A., 1982, in: Astrophysical Parameters for Globular Clusters, IAU Coll. 68, Philip A.G.D., Hayes D.S. (eds.). Schenectady, Davis, p. 533
Ortolani S., Barbuy B., Bica E., 1990, A&A 236, 362 (OBB90)
Ortolani S., Barbuy B., Bica E., 1991, A&A 249, L31
Ortolani S., Bica E., Barbuy B., 1992, A&AS 92, 441 (OBB92)
Ortolani S., Bica E., Barbuy B., 1993, A&A 267, 66 (OBB93)
Ortolani S., Bica E., Barbuy B., 1994a, The Messenger, 75, 26
Ortolani S., Barbuy B., Bica E., 1994b, A&AS 108, 653 (OBB94b)
Ortolani S., Bica E., Barbuy B., 1995, A&A 296, 680 (OBB95)
Reid M., 1993, ARA&A 31, 345
Trager S.C., Djorgovski S., King I.R., 1993, in: Structure and Dynamics of Globular Clusters, Djorgovski S., Meylan G. (eds.). ASP Conference Ser. 50, p. 347
Zinn R., 1985, ApJ 293, 424