GLOBULAR CLUSTERS OF THE INNER GALACTIC BULGE

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Abstract. Deep CCD photometry for a number of bulge-projected metal rich globular clusters and their nearby field background have been obtained . The V/V-I or I/V-I color-magnitude diagrams of the observed clusters are similar to the background fields and show high metallicity peculiar features. They are all very compact and slightly elongated.

1. Introduction

We recently started a program (Ortolani et al. 1990), to study, photometrically and spectroscopically the obscured, metal rich globular clusters projected in the direction of the inner galactic bulge clusters with the aim to investigate the high metallicity effects on the c-m diagrams morphology and to check the properties of the metal rich old population of the bulge. Here we present only the photometric results while the spectroscopy is discussed in the same volume by Barbuy and Bica.

Only little information is so far available for these clusters because of the difficulties in observing very dense stellar fields. Since the reddening in the direction of the Bulge is quite high, we took advantage of the high red sensitibity of the recent CCD detectors available at ESO La Silla to observe the most reddened clusters in the V and I bands using the color index V-I as temperature indicator instead of the classical B-V which is heavily affected by the B extinction. In some cases the observations have been carried out also in the extreme red band Gunn z.

In our previous study of the BVRI c-m diagrams of the bulge cluster NGC 6553 (Ortolani et al., 1990) we found a number of peculiar features connected with high metallicity effects such as the curvature of the red giant branch with a faint tip going down, in the visual band, almost at the level of the horizontal branch. This feature has been interpreted as due to blanketing effects in the cool metal rich giants. Recent high dispersion spectroscopic observations of a relatively bright giant in NGC 6553 (Barbuy et al., 1991) gave an almost solar metallicity, confirming the hypothesis that we are dealing with high metallicity clusters. The interpretation of the tilted, red horizontal branch, is, on the contrary, not yet clarified.

2. Observations

The observations have been obtained at La Silla European Southern Observatory with the 1.5 m Danish telescope equipped with the RCA CCDs ESO n.8 and n.5 which provide the highest near infrared quantum efficiency. The field of view projected on the sky of the single CCD image is about 3 x 4 arcminutes. The I band observations have been tied in the Cousins system through Landolt standard star observations.

Eight globular clusters and two open clusters have been observed in the direction of the inner bulge at galactic latitudes ranging from -4 to +4 degrees, with some of them within two degrees from the galactic plane, selected on the base of high metallicity indications coming from the literature or from the integrated spectra obtained from one of us (E.B.).

B. Barbuy and A. Renzini (eds.), The Stellar Populations of Galaxies, 47–50.
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https://doi.org/10.1017/S007418090012008X Published online by Cambridge University Press

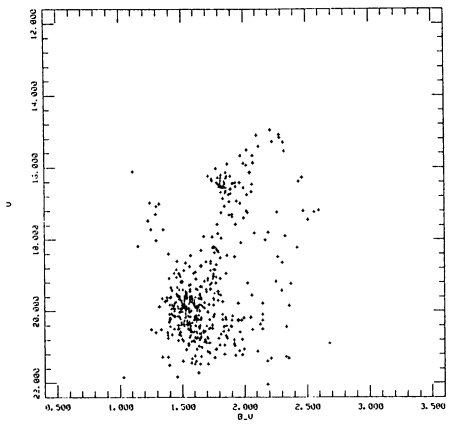

Fig. 1. NGC 6553 c-m deep diagram. Only the best 500 fitted stars have been selected.

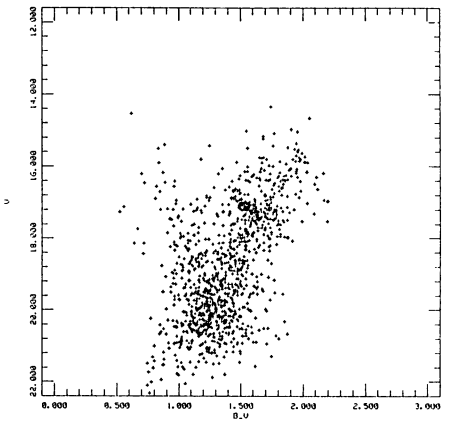

Fig. 2. NGC 6528 c-m diagram. Circular extraction of the inner 90" radius circle.

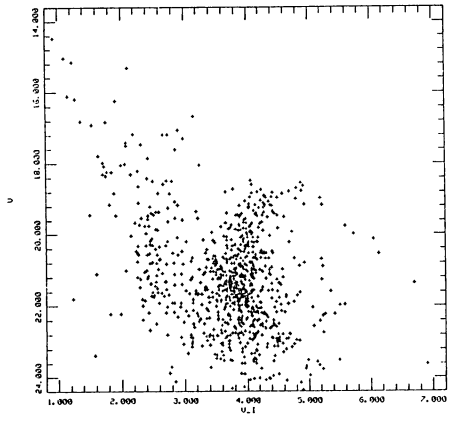

Fig. 3. Terzan 1 V/V-I c-m diagram.

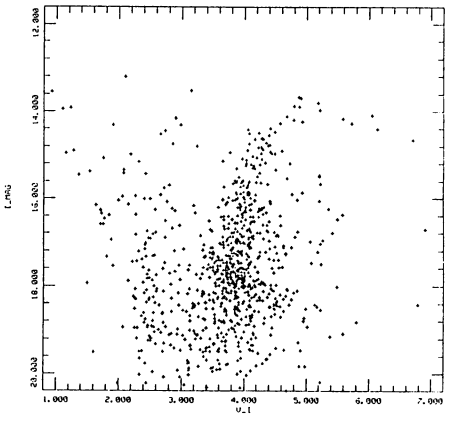

Fig. 4. Terzan 1 I/V-I diagram.

https://doi.org/10.1017/S007418090012008X Published online by Cambridge University Press

One degree projected on the sky corresponds at the distance of the Galactic center (8 kpc) to about 140 pcs.
Here we will discuss the results from three clusters (NGC 6553, NGC 6528 and Terzan 1) which have been completely reduced.

3. Results

In Fig. 1 a deep, selected c-m diagram of NGC 6553, containing only good quality measurements, is plotted. The main features of a very metal rich population are present: in particular the red giant turnover at about V=15, the B-V color saturation at about 2.4 due to blanketing effects and the red, tilted horizontal branch. The main sequence is also detected with the turnoff at about V=20 and B-V=1.5. The blue bright stars above the turnoff are main sequence stars from the contaminating foreground galactic disk field population. This diagram can be used as observational template for old metal rich populations.
The age can be obtained from the comparison with the c-m diagrams of other metal rich clusters (Ortolani et al., 1990) or from isochrone fitting.
Solar abundance isochrones have been recently calculated by VandenBerg and Laskarides (1987) and, using new overshooting models, by Bressan et al. (1991). While VandenBerg and Laskarides isochrones are calculated only in effective temperatures and bolometric luminosities, Bressan et al. transformed them into the observative plane in the UBVRI colors. The simultaneous fitting of the complete solar metallicity isochrone with t=15 BY and Y=0.28 is excellent from the main sequence up to the turnover of the giants where the transformation equations do not seem to be able to take into account the strong blanketing effects due to the molecular bands. At present there are no isochrones able to reproduce this feature. From the fitting a distance modulus (m-M)v=15 and a reddening E(B-V)=0.8 is obtained, almost coincident with the values found by empirical comparison with other metal rich cluster c-m diagrams. Due to the photometric spread at the turnoff and the uncertainties due to the assumption in the models (in particular the helium content and the CNO abundances) this result does not esclude a slightly younger age as found by Terndrup (1988) in his analysis of bulge field images.
In Fig. 2 the analogous c-m diagram for the cluster NGC 6528 is presented. This cluster is projected on the direction of the Baade Window, it is more concentrated than NGC 6553 and, at the same time, intrinsically fainter. Even if the images are better than those of NGC 6553 the diagram is not very well defined due to the more crowded field. The c-m diagram shows the same features of NGC 6553 and it is very similar to the diagrams obtained by Terndrup (1988) from images of selected fields in the Baade Window. Again the fitting with solar isochrones gives the same results previously obtained from empirical comparisons (Ortolani et al., 1991). For this cluster we have a distance modulus of about (m-M)v=15.9 and a reddening around E(B-V)=0.6. A distance of 7.5 Kpc from the Sun is derived, locating NGC 6528 in the inner bulge. It should be noted that NGC 6553, at 4.1 Kpc from the Sun is not so close to the Galactic Center.
The highly reddened cluster Terzan 1 is projected at only 1 degree from the Galactic plane. It is severely contaminated by field stars and, in particular, three bright, young disk main sequence stars are superimposed on the cluster at a few arcseconds from its center. For this cluster the integrated spectra or photometry in the visual-red bands can be seriously contaminated and the deduced reddening and metallicity should be considered with some care. Infrared measurements, where the flux from blue stars are reduced, are more reliable. The V, I c-m diagrams are presented in Fig. 3 and 4. The strong blanketing effect of the coolest giant stars, showing the turnover in both the diagrams, seems to suggest that we are dealing with a cluster probably more metallic than NGC 6553 and 6528. Another peculiarity is the considerable luminosity difference between the disk main sequence upper limit and the red giant turnover, indicating a strong absorption of the cluster stars. If the concentration of points located at about V=21.4 and V-I=3.8 is assumed as horizontal branch of the cluster, adopting an absolute magnitude of the HB around I=0 (Bressan et al., 1991), and the reddening derived from integrated IR photometry E(B-V)=1.5 (Malkan, 1982), we get a distance d=8.5 kpc, locating Terzan 1 approximately at the distance of the Galactic Center. These values are, however, incompatible with the fit of solar metallici-

https://doi.org/10.1017/S007418090012008X Published online by Cambridge University Press

ty isochrones, suggesting that the assumed HB position or other parameters (metallicity, helium abundance, reddening) could be wrong.
An alternative possibility is that the main concentration of points is just due to a crowding effect of the field population while the true horizontal branch of the cluster is considerably brighter, corresponding to the sparse clump located at about V=20.0 and V-I=3.8. In this case the isochrone fitting is quite good. The derived distance from the Sun is reduced to 2-3 Kpc and the reddening rises to about E(B-V)=2.3 (Av=7), clearly much higher than the currently adopted Malkan's value. If the higher value is adopted, considering that the reddest giants of Terzan 1 have B-V=4.1, a dereddened saturation color value of the giants of B-V=1.8 is obtained. It is easy to see from Fig. 1 and 2 that this value is almost identical for NGC 6553 and 6528.

4. Conclusions

From the analysis of three clusters projected on the direction of the inner Galactic bulge we found evidence of a number of common c-m diagram peculiar features due to blanketing effects connected with high metallicity (probably around the solar value), in spite of their line of sight distance spread. They are relatively old, heavily reddened and show a peculiar tilted HB. The dereddened color index saturation, for the giants, occurs at B-V=1.7-1.8 while the luminosity of the giants reaches about Mv=-0.1, -0.5.
The turnover of the red giants implies that the brightest stars of the old metal rich population, in the visual band, are not the coolest, as predicted by the current theoretical models. In the Cousins I band the luminosity of the coolest giants as a function of the temperature is almost constant because the reduced blanketing effects in this spectral range are not strong enough to produce the turnover at solar metallicity. For higher values, however, it seems that the turnover can be produced also in the I band (Ortolani et al., 1991).

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