THE ASTROPHYSICAL JOURNAL, 382:L15–L17, 1991 November 20

METAL-RICH GIANT BRANCHES OF BULGE CLUSTERS: APPLICATION TO COLOR-MAGNITUDE DIAGRAMS OF M31 AND M32[1]

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Received 1991 June 27; accepted 1991 September 10

ABSTRACT

Color-magnitude diagrams for the metal-rich bulge clusters NGC 6528, NGC 6553, and Terzan 1 are calibrated in M_{I_o} versus $(V-I)_o$, and compared to that of 47 Tuc.

In such diagrams the blanketing effects for increasing metallicities are directly estimated.

Such studies are important for the interpretation of CMDs of metal-rich populations in Local Group external galaxies. We compare our results to literature color-magnitude diagrams of M31 and M32 bulges. The available CMDs are not deep enough to reveal the metal-rich populations similar to that of NGC 6553, which indicates that the determinations of average metallicities from the giant branch width in the M31 and M32 fields are lower limits.

Subject headings: clusters: globular — stars: abundances

1. INTRODUCTION

Detailed studies of metal-rich populations are crucial for the understanding of integrated properties of external galaxies. In order to achieve this, it is necessary to interpret photometric data of individual stars in the bulge of our Galaxy and in Local Group metal-rich systems (Frogel & Whitford 1987; Frogel 1990; Mould 1986). Recently we have started a systematic study of the Galactic bulge globular clusters, by means of CCD *BVRI* color-magnitude diagrams (CMDs), at the European Southern Observatory, ESO (Chile). Good seeing conditions are required, because of severe crowding.

Up to now, we have completed CMDs of NGC 6553 (Ortolani, Barbuy, & Bica 1990, hereafter Paper I), NGC 6528 (Ortolani, Bica, & Barbuy 1991a, hereafter Paper II), and Terzan 1 (Ortolani, Bica, & Barbuy 1991b, hereafter Paper III). These studies have revealed strong blanketing effects in the CMD morphology such as curved red giant branches (RGB). Lloyd Evans & Menzies (1977) had drawn attention to curvature effects in CMDs of some clusters, but the importance of this phenomenon has been overlooked ever since.

In the present *Letter*, we gather the different clusters in a composite diagram, where blanketing effects can be judged directly, and this is compared to CMDs of M31 and M32.

2. RELATIVE BLANKETING IN THE M_{I_o} VERSUS $(V-I)_o$ DIAGRAM

Reddenings and distances were discussed in detail in Papers I, II, and III, where excesses $E(B-V) = 0.73$, 0.55, and 1.58, and distances $d = 4.9$, 7.5, and 8.8 kpc were estimated for NGC 6553, NGC 6528, and Terzan 1, respectively. We note that the values for NGC 6553 were revised and slightly changed here relative to Paper I.

Assuming these values, we have derived the absolute magnitude M_{I_o} and the dereddened color $(V-I)_o$. In Figure 1 the M_{I_o} versus $(V-I)_o$ composite diagram is presented using the mean loci of these clusters; we also show that of 47 Tucanae using data from da Costa & Armandroff (1990). Color shifts, as well as RGB morphology changes, are present, owing to higher blanketing for increasing metallicities. 47 Tuc is the less metallic; NGC 6528 and NGC 6553 are similar and more metal-rich; and Terzan 1 must be extreme in metal content. Integrated spectra of 47 Tuc, NGC 6528, and NGC 6553 indicate that this ranking of metallicity is appropriate (e.g., Bica & Alloin 1986). Armandroff & Zinn (1988, hereafter AZ88) presented an integrated spectrum of Terzan 1 in the near-infrared Ca II triplet region which produced a result as weak-lined as that of 47 Tuc. This is in contradiction with our CMDs and Malkan's (1981) integrated infrared photometry. Malkan concluded that Terzan 1 was the most metal-rich globular cluster in the Galaxy, together with Liller 1. However, Liller 1 and other clusters in common between Malkan and AZ88 show a reasonable agreement. We point out that, superposed to Terzan 1 are two reddened blue stars, at 2″.5 and 10″ from the cluster center. These field stars are considerably brighter and bluer than the cluster red giants. In particular, the star at 2″.5 may have contaminated AZ88's integrated spectrum, since they have used N-S scannings with a long slit of 1″.5 width, set in the E-W direction. An early-type star can dilute metallic features in the near-infrared to a level like that of 47 Tuc, without much disturbing Malkan's infrared observations.

Important characteristics of high-metallicity effects are (*a*) the bending of the descending RGB, and the luminosity weakening of the cooler giants. For example, the magnitude difference between the RGB tip of 47 Tuc and Terzan 1 is $\Delta M_{I_o} > 2$; (*b*) the blanketing estimates from the RGB color shifts at the horizontal branch (HB) level give values as high as $\Delta(V-I) \approx 0.92$ between Terzan 1 and 47 Tuc.

As pointed out by Frogel (1990 and references therein), the luminosity blanketing affects particular bands such as *R* and *I* owing to molecular blanketing, without affecting significantly the bolometric luminosity.

3. APPLICATION TO COLOR-MAGNITUDE DIAGRAMS OF M31 AND M32

Present-day large telescopes under excellent seeing conditions, in particular, the 3.6 m CFHT and Palomar 5 m tele-

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scopes, have been used to obtain CMDs for M32 (Freedman 1989) and the bulge of M31 (Mould & Kristian 1986).

For the interpretation of such diagrams, there were available so far only CMDs for metal-poor (e.g., M92) up to moderately metal-rich clusters, such as 47 Tuc. Theoretical diagrams for metal-rich populations, on the other hand, are not yet definite due to uncertainties in opacities. Figure 1 is therefore an important tool for the metal-rich fraction of composite stellar populations.

3.1. *The Case of M32*

I versus $(V-I)$ diagrams for M32 were obtained by Freedman (1989). From the tip of the RGB, she derived the metallicity distribution, and a lower limit for the mean metallicity $[M/H] > -0.5$ for a field at 2′ south of the nucleus. The lower limit is due to a V cutoff at $V \approx 23.5$ which, as suggested by the author, should affect the detection of a more metallic population.

The results presented in Figure 1 allow us to quantify the necessary V limit in order to have access to that kind of population. This is shown in Figure 2, where we superpose data from Figure 1 on Freedman's observed diagram, by transforming them through reddening $E(V-I) = 0.12$ and distance modulus 24.0 (Fig. 2). The uncertainty in the distance modulus of M32 (Freedman 1989) does not affect these conclusions. In fact for the distance modulus 24.3, the separation between the bulge cluster sequences and the observed M32 stars increases.

We see in this figure that the $V = 23.5$ cutoff does not allow us to detect a possible metal-rich component with metallicity similar to that of NGC 6553. According to population synthesis for the M32 nucleus using a library of star clusters, such a component is necessary to reproduce the integrated spectrum of this galaxy (Bica, Alloin, & Schmidt 1990). It is also shown that, in order to reach the RGB tip of populations of such metallicity, in M32, it would be necessary to have a fainter cutoff than $V = 25$ mag.

Also, due to the RGB bending effect, metallicity statistics based on the morphology of the composite population should not be performed at a constant magnitude limit, but instead it should be curved to include the cooler fainter RGB tip stars, for increasing metallicities. The Yale isochrones shown in the figure, also transposed from Freedman's paper, indicate the discrepancy between the theoretical RGB tip for the model at $[M/H] = -0.7$, appropriate for 47 Tuc, and the observed curved one. The discrepancy between the real and theoretical opacities for more metal-rich clusters should be more pronounced. Our observations of globular clusters can otherwise guide theoretical improvements.

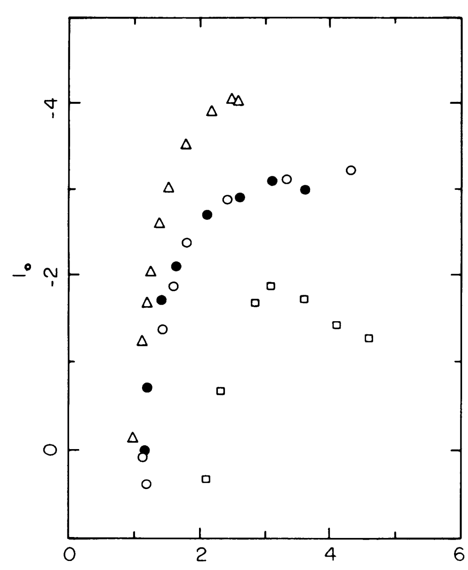

FIG. 1.—Mean locus of 47 Tuc (*open triangles*), NGC 6553 (*filled circles*), NGC 6528 (*open circles*), and Terzan 1 (*open squares*), in the absolute color-magnitude diagram M_{I_o} vs. $(V-I)_o$.

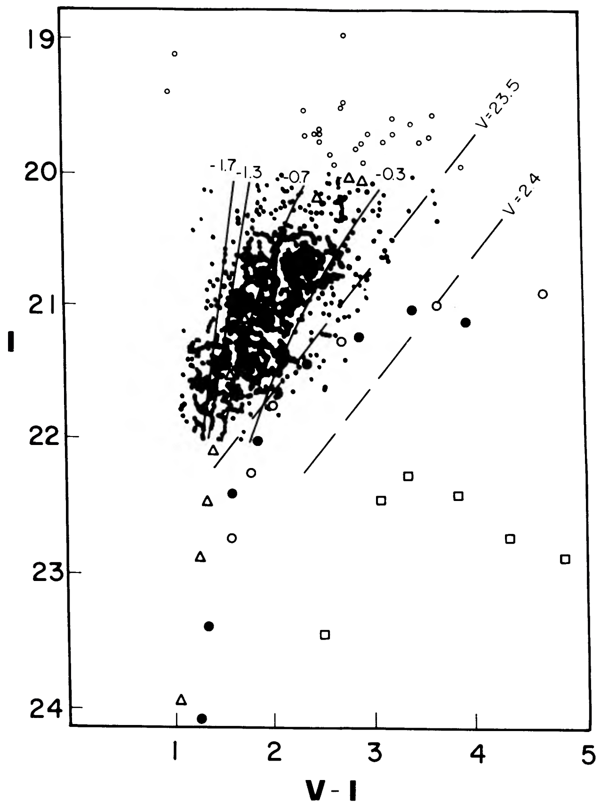

FIG. 2.—Transposition of data in Fig. 1 to the observed I vs. $(V-I)$ diagram of M32 (Freedman 1989) for distance modulus $(I-M_I) = 24.0$. V cutoffs are indicated. Symbols for mean locus of clusters CMDs are as in Fig. 1.

3.2. *The Case of M31*

We show in Figure 3 a transposition of our data (Fig. 1) to a field in M31, at 7 kpc on the minor axis in the southeast direction using $E(V-I) = 0.10$, $A_I = 0.14$ and $(m-M)_o = 24.4$ (Mould & Kristian 1986). The cutoff at $V = 24.5$ indicates that the detection of a possible population fraction as metal rich as that of NGC 6553 is considerably restrained. Consequently the average metallicity $[M/H] = -0.6$ obtained by Mould & Kristian from the giant branch width in this 7 kpc field should be considered as a lower limit. In inner bulge regions of M31 where very metal rich populations as that of Terzan 1 are expected, much deeper diagrams would be required, with much fainter cutoffs, as can be judged in Figure 3.

4. CONCLUSIONS

We compare metal-rich bulge globular clusters with 47 Tuc in the M_{I_o} versus $(V-I)_o$ diagram. In addition to the expected

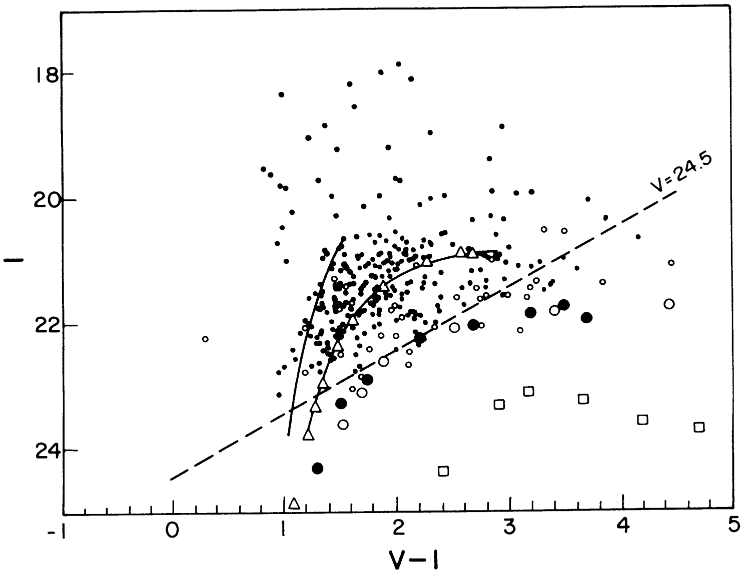

FIG. 3.—Same as Fig. 2, for M31 bulge at 7 kpc (Mould & Kristian 1986). The mean locus of the metal-poor cluster M92 is also shown. The cutoff at $V = 24.5$ is indicated.

red color shift and fading for increasing metallicity, the bulge clusters present a morphological change in the red giant branch which bends owing to blanketing effects. The star cluster CMDs are transposed to I versus $(V-I)$ diagrams available in the literature for the bulges of M31 and M32. We conclude that metal-rich population components similar to those of the star clusters NGC 6528 and NGC 6553 and Terzan 1 are below the observational cutoff.

We thank the referee Jay Frogel for interesting remarks.

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