

NEAR-IR PHOTOMETRIC PROPERTIES OF HB, MSTO, AND SGB FOR METAL POOR GALACTIC GLOBULAR CLUSTERS

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ABSTRACT

We report photometric features of the HB, MSTO, and SGB for a set of metal-poor Galactic globular clusters on the near-IR CMDs. The magnitude and color of the MSTO and SGB are measured on the fiducial normal points of the CMDs by applying a polynomial fit. The near-IR luminosity functions of horizontal branch stars in the classical second parameter pair M3 and M13 indicate that HB stars in M13 are dominated by hot stars that are relatively faint in the infrared, whereas HB stars in M3 are brighter than those in M13. The luminosity functions of HB stars in the observed bulge clusters, except for NGC 6717, show a trend that the fainter hot HB stars are dominated in the relatively metal-poor clusters while the relatively metal-rich clusters contain the brighter HB stars. It is suggestive that NGC 6717 would be an extreme example of the second-parameter phenomenon for the bulge globular clusters.

Keywords: globular cluster, near-IR photometry, HB, MSTO, SGB

1. INTRODUCTION

The brightness and color of the main-sequence turn-off (MSTO) and the sub-giant branch (SGB) in near-IR color-magnitude diagrams (CMDs) would be age indicators as in optical plane of globular clusters (Chaboyer et al. 1996, Davidge & Courteau 1999). The magnitude difference between the MSTO/SGB and the red-giant branch tip (TRGB) would also be used to investigate the relative ages of globular clusters without cluster's distance and reddening (VandenBerg & Durrell 1990). The study of horizontal branch (HB) star of globular clusters plays a key role to provide the evidence of galaxy formation through the determination of globular cluster ages and abundances (Lee & Demarque 1990). In the near-IR CMDs, the HB forms an almost vertical but slightly slanted sequence from the upper right to the lower left position, which differs from the horizontal sequence that is seen at optical wavelengths. Therefore, the luminosity function (LF) of HB stars in the near-IR magnitudes provides a means of comparing HB content directly to the temperature of the HB stars (Davidge & Courteau 1999).

In this paper, we have used the near-IR CMDs of eight metal-poor Galactic globular clusters in Kim et al. (2006) to investigate the photometric properties of the HB, the MSTO, and the SGB. Note that, in Kim et al. (2006), we presented the details of near-IR photometry of a sample of five

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Table 1. Photometric parameters of the MSTO and the SGB for the observed halo clusters.

Name	M3	NGC 5897	M13
$(J - K)_o^{MSTO}$	-	0.42 ± 0.08	0.39 ± 0.09
$(J - H)_o^{MSTO}$	-	0.30 ± 0.07	-
M_K^{MSTO}	-	2.62 ± 0.14	2.64 ± 0.14
$(J - K)_o^{SGB}$	0.48 ± 0.07	0.48 ± 0.06	0.46 ± 0.06
$(J - H)_o^{SGB}$	0.38 ± 0.07	0.35 ± 0.04	0.38 ± 0.08
M_K^{SGB}	1.62 ± 0.14	1.67 ± 0.14	1.75 ± 0.14

metal-poor bulge clusters (NGC 6541, NGC 6642, NGC 6681, NGC 6717, and NGC 6723) and three halo clusters (M3, NGC 5897, and M13), and investigated the morphological properties of the stellar populations in the near-IR CMDs of the sample clusters. Several photometric parameters to describe the RGB shape, and the red giant branch (RGB) bump and tip were determined from the near-IR CMDs, and then we found the derived parameters follow the previous empirical calibrations to the cluster's metallicity (e.g., Ferraro et al. 2000, Valenti et al. 2004). In Sec. 2, we briefly present the data set of the near-IR CMDs of the sample clusters. Photometric features of the MSTO and the SGB are presented in Sec. 3, and the LFs of HB stars are discussed in Sec. 4. Results are summarized in Sec. 5.

2. THE DATA SET OF THE NEAR-IR CMDs

Since the details of the near-IR CMDs of the sample clusters are appeared in Kim et al. (2006), we briefly describe here the observations and basic properties of the data set. The images of target clusters were obtained during the nights of UT June 3-4, 2004 using the CFHTIR imager mounted on the 3.6 m CFHT. Data were recorded through J , H and K' filters. The total exposure times of the short and long exposures were 8 seconds and 240 seconds each per filter. The typical seeings were less than $0''.8$ FWHM. The brightnesses of individual objects in the target clusters were measured with the point-spread function fitting routine DAOPHOT II/ALLSTAR (Stetson 1987, Stetson & Harris 1988) applying on the reduced images. Figures 1 and 2 in the paper of Kim et al. (2006) showed near-IR $(J - K, K)$ and $(J - H, H)$ CMDs of the resolved stars in the central $3'.6 \times 3'.6$ area for the observed metal-poor globular clusters in the Galactic halo and bulge. The SGB sequence and MSTO were detectable in CMDs of most of the observed clusters. The slanted HB sequences were reasonably separated from the RGB for all clusters as we expected for the typical morphology of metal-poor globular cluster. Normal points through the RGB, the SGB and the MS were defined by taking the mean magnitude and color in the 0.25 magnitude bin of the CMDs. By using the adopted reddening and distance scale for each observed cluster, the normal points were converted into the absolute plane, from which we determine the positions of the MSTO and SGB on the CMD.

3. THE PHOTOMETRIC FEATURES OF THE MSTO AND SGB

We measured the near-IR brightness and color of the MSTO and the SGB for the observed clusters. The brightness and color of the MSTO are measured at the reddest point from the polynomial fit to the fiducial normal points around the MSTO in each CMD. The SGB brightness and color

Table 2. Photometric parameters of the MSTO and the SGB for the observed bulge clusters.

Name	NGC 6541	NGC 6642	NGC 6681	NGC 6717	NGC 6723
$(J - K)_o^{MSTO}$	-	0.43 ± 0.08	0.41 ± 0.07	0.41 ± 0.11	0.42 ± 0.09
$(J - H)_o^{MSTO}$	-	0.39 ± 0.09	0.37 ± 0.08	0.35 ± 0.11	0.34 ± 0.11
M_K^{MSTO}	-	2.81 ± 0.14	2.53 ± 0.14	2.77 ± 0.14	2.73 ± 0.14
$(J - K)_o^{SGB}$	0.46 ± 0.07	0.49 ± 0.07	0.47 ± 0.05	0.48 ± 0.09	0.50 ± 0.07
$(J - H)_o^{SGB}$	0.33 ± 0.06	0.44 ± 0.07	0.41 ± 0.05	0.40 ± 0.06	0.43 ± 0.09
M_K^{SGB}	1.79 ± 0.14	1.45 ± 0.14	1.65 ± 0.14	1.83 ± 0.14	1.60 ± 0.14

are measured at the inflection point of the fitted polynomial on the fiducial normal points around the SGB by applying the second derivative of the fitted fourth-order polynomial, while Davidge & Courteau (1999) measured the SGB magnitude and color at 0.1 mag redward of the MSTO on the fiducial ridge line of the CMDs.

Tables 1 and 2 list the measured magnitude and color of the MSTO and the SGB for the halo clusters and the bulge clusters, respectively. In cases of M3 and NGC 6541, we can not determine the magnitude and color of the MSTO, because the CMDs are not deep enough to reach the MSTO. The vertical $(J - H, H)$ CMD shape of M13 around the MSTO prevents determining the $(J - H)$ color index. The mean values of the color and magnitude for both clusters in halo and bulge are estimated to be $(J - K)_o^{MSTO} = 0.41 \pm 0.09$, $(J - H)_o^{MSTO} = 0.35 \pm 0.10$, $M_K^{MSTO} = 2.68 \pm 0.18$ for the MSTO, and $(J - K)_o^{SGB} = 0.48 \pm 0.06$, $(J - H)_o^{SGB} = 0.39 \pm 0.07$, $M_K^{SGB} = 1.67 \pm 0.18$ for the SGB. The estimated differences of the color indices and magnitudes for the MSTO and the defined SGB are $\Delta(J - K) \sim 0.07 \pm 0.11$, $\Delta(J - H) \sim 0.04 \pm 0.12$ and $\Delta K \sim 1.0 \pm 0.2$ magnitudes. We caution, however, that it is not easy to measure accurately the brightness and color of the MSTO and the SGB in the observed near-IR CMDs because the CMDs are almost vertical with a large photometric uncertainty at this level, as noticed by Davidge & Courteau (1999). High quality near-IR data are needed to obtain age constraints from the measurements of the MSTO and the SGB. Hence, we do not consider the results of the MSTO and the SGB further in this paper. However, the data can be used for a simple test of the theoretical isochrones in the near-IR bands for low mass stars in a globular cluster at low magnitude level.

4. THE NEAR-IR LF OF HB STARS

To construct the near-IR LF of HB stars in each cluster, we empirically selected the HB star candidates on the near-IR CMDs by a careful eye-fit of the border line to separate from the RGB, the SGB and the MS stars. The completeness correction, which depends both on the crowding condition and the stellar brightness, is not applied in this analysis. We simply note that artificial star experiments for a few sample images indicate the typical recovery rates of input artificial stars to be $\sim 80\%$ at $K \approx 14$ and $\sim 60\%$ at $K \approx 16$ for the observed clusters.

The LFs of HB stars in M_K and M_H for each cluster, normalized according to the total number of detected HB stars per cluster, are compared in Figure 1. For the HB LFs of the classical second parameter pair M3 and M13, HB stars in M13 are dominated by hot stars that are relatively faint in the infrared, whereas HB stars in M3 are brighter than those in M13 both in M_K and M_H LFs. This result is in a good agreement with the near-IR observations of Davidge & Courteau (1999). As

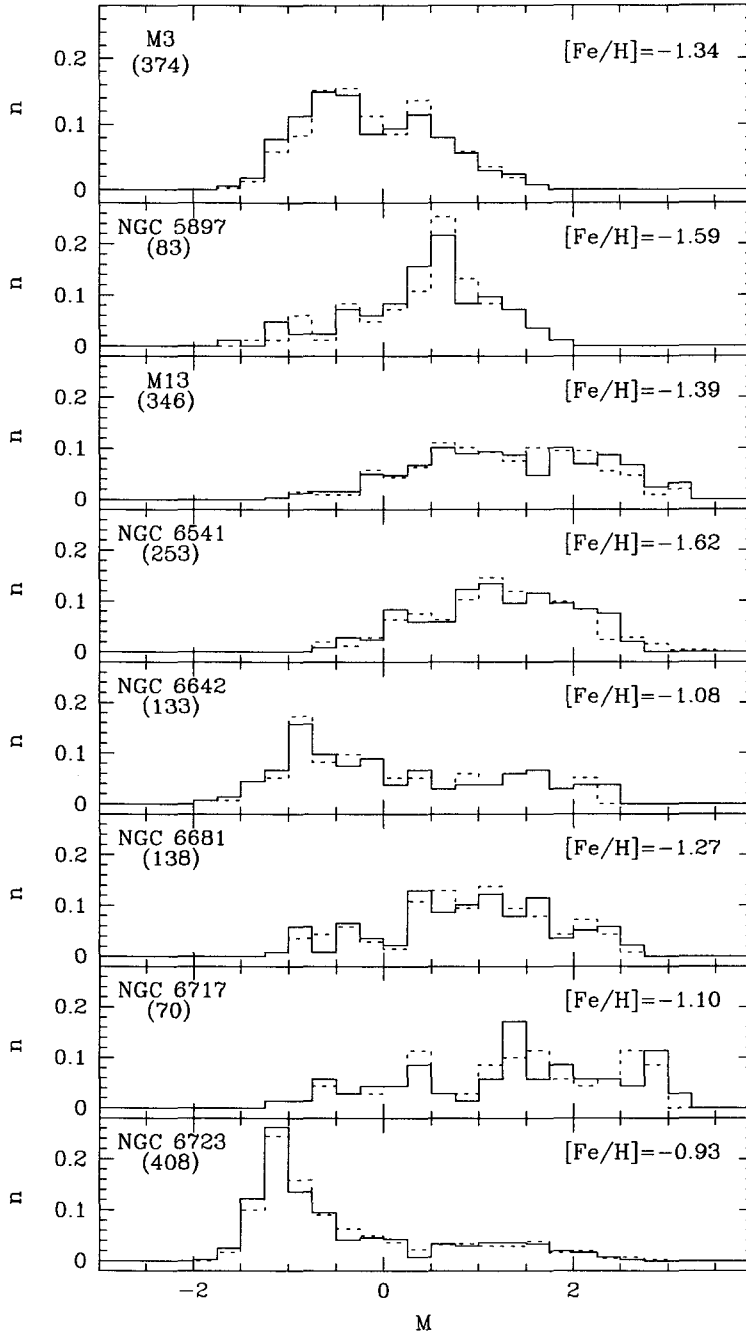


Figure 1. The normalized LFs of HB stars for the observed clusters in 0.25 mag bin. Histograms with solid and dotted lines are the LFs in M_K and M_H , respectively. Numbers in parentheses are the total number of the HB stars detected in each field.

expected for the metal-poor halo cluster, hot HB stars are dominated in the HB LFs of NGC 5897.

For the bulge clusters, it commonly has been thought that the HB content does not show a second-parameter effect (e.g., Searle & Zinn 1978), but it can be characterized by a single parameter of the metallicity (Lee 1992, Rich et al. 1997). Among the five observed bulge clusters, the HB LFs of four clusters, NGC 6541, NGC 6642, NGC 6681 and NGC 6723, show a trend that the fainter hot HB stars are dominant in the relatively metal-poor clusters while the relatively metal-rich clusters contain the brighter HB stars. Similar to the HB LFs of the halo cluster M13, the HB stars in the bulge clusters NGC 6541 and NGC 6681 are distributed over a broad range of near-IR brightness and hence temperatures, as shown in their HB LFs of Figure 1. The interesting feature of the HB LFs for the bulge clusters is that NGC 6717, in spite of a rather high metallicity, contains more faint hot HB stars, compared with the HB LFs for NGC 6642 as a reference, which has a similar metallicity to NGC 6717. Brocato et al. (1996) also found that NGC 6717 shows a completely extended blue HB in the $(B - V, V)$ CMD. This is suggestive that NGC 6717 would be an extreme example of the second-parameter phenomenon for the bulge clusters. Note, however, that Ortolani et al. (1999) suggested that NGC 6717 is coeval with the halo from the measurements of ΔV_{HB}^{MSTO} on the optical CMD. On the other hand, the fact that NGC 6717 is a compact post-core-collapse cluster (Trager et al. 1995) may support a suggested correlation that more concentrated cluster has bluer HB morphology (Fusi Pecci et al. 1993, Rich et al. 1997, 1998). We note that the origin of the HB morphology now faces a new era, particularly with respect to interpreting the extreme hot HB stars. Recently, Lee et al. (2005) suggested the presence of super helium rich population to reproduce the extreme hot HB in some globular clusters, implying a third parameter, other than metallicity and age, for the CMD morphology of globular clusters. More accurate deep near-IR photometry of globular clusters in the Galactic bulge will answer such questions as, Does the HB content of bulge clusters depend on a single parameter? or Is there any evidence for a second or third parameters?

5. SUMMARY

We have used near-IR CMDs to investigate the photometric features of the HB, the MSTO, and the SGB of five metal-poor globular clusters in the Galactic bulge and three halo clusters. Photometric parameters to describe the color and magnitude of the MSTO and the SGB, and the LF of HB stars have been measured from the obtained near-IR CMDs and fiducial normal points of the observed clusters. The magnitudes and colors of the MSTO and the SGB are measured on the fiducial normal points of the CMDs by applying a polynomial fit. The mean differences of the color index and the magnitude for the MSTO and the defined SGB are estimated to be $\Delta(J - K) \sim 0.07 \pm 0.11$, $\Delta(J - H) \sim 0.04 \pm 0.12$ and $\Delta K \sim 1.0 \pm 0.2$.

For the near-IR HB LFs of the classical second parameter pair M3 and M13, HB stars in M13 are dominated by hot stars that are relatively faint in the infrared, whereas HB stars in M3 are brighter than those in M13, both in M_K and M_H LFs. The HB LFs of the observed bulge clusters show a trend that the fainter hot HB stars are dominant in the relatively metal-poor clusters, while the relatively metal-rich clusters contain the brighter HB stars, except for the HB LF of the bulge cluster NGC 6717. The HB LF of NGC 6717 contains more faint hot HB stars, compared with the HB LF for NGC 6642 with a similar metallicity. This is suggestive that NGC 6717 would be an extreme example of the second-parameter phenomenon for the bulge clusters.

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