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# SPECTROSCOPIC STUDY OF THE GLOBULAR CLUSTERS IN M31

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RESUMEN

Hemos realizado un nuevo reconocimiento sistemático de cúmulos globulares (CG) en un área de $\sim 3° \times 3°$ centrada en M31. Usando datos fotométricos obtenidos con las observaciones del telescopio 0.9-m de KPNO con los filtros $CMT_1$ Washington, y datos espectroscópicos obtenidos de las observaciones del telescopio 3.5-m de KPNO/WIYN con el espetrógrafo de multifibras Hydra, hemos confirmado 544 CGs previamente conocidos y encontrado más de 600 CGs nuevos y candidatos. Más de cien candidatos se creen que son CGs genuinos. Presentamos la distribución de metalicidad de los conocidos previamente y de los CGs nuevos en M31, lo cual muestra un mejor ajuste a tres componentes comparados con los ajustes a dos componentes.

ABSTRACT

We have performed a new systematic globular cluster (GC) survey of M31 for $\sim 3° \times 3°$ area centered on M31. Using photometric data obtained from observations using the KPNO 0.9-m telescope + Washington $CMT_1$ filters, and spectroscopic data obtained from observations using the KPNO/WIYN 3.5-m telescope + Hydra multifiber spectrograph, we have confirmed 544 previously known GCs and found over 600 new GCs and candidates, of which more than one hundred are believed to be genuine GCs. We present the metallicity distribution of the previously known and new GCs in M31, which is better fit with three components than with two components.

*Key Words:* **GALAXIES: INDIVIDUAL (M31) — GALAXIES: STAR CLUSTERS — GLOBULAR CLUSTERS: GENERAL**

## 1. INTRODUCTION

Globular clusters (GCs) are among the oldest and brightest objects in galaxies, hence they can be a useful tool to study the formation and evolution of the host galaxies. While our Galaxy contains only about 153 GCs (Bica et al. 2006) and possibly a dozen more (Ivanov et al. 2005), M31 is known to contain more than 400 GCs (Barmby et al. 2000; Barmby & Huchra 2001; Kim et al. 2006).

While most of the previously known GCs in M31 were found before CCDs were widely used in the astronomical community (Sargent et al. 1977; Crampton et al. 1985; Battistini et al. 1987), there have been a few limited efforts to search for new GCs in M31 using CCD observations such as: Battistini et al. (1993), Mochejska et al. (1998), and Barmby & Huchra (2001). However, there still has not been any systematic CCD survey of GCs in M31; here we present some of the results from our wide-field survey of GCs in M31 for a $\sim 3° \times 3°$ area centered on M31. Details of the survey, along with photometric and spectroscopic analyzes, will be presented in future papers.

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## 2. OBSERVATIONS AND DATA REDUCTION

### 2.1. *Imaging*

We conducted our imaging observations with the 0.9-m telescope + T2KA CCD camera + Washington $C, M, T_1$ filters at KPNO on the nights of UT 1996 October 14 – 25 and 1998 October 19. The pixel scale of the CCD chip is $0.''68$ pixel$^{-1}$ and the CCD images have $2048 \times 2048$ pixels, corresponding $23.'2 \times 23.'2$. We observed mainly $7 \times 7$ fields nearly centered on the center of M31. For most of the fields, one exposure per each filter was made. Typical exposure times for the 1996 run were 1500 s in $C$ and 600 s in $M$ and $T_1$ bands, while those for the 1998 run were 1200 s in $C$ and 500 s in $M$ and $T_1$ bands.

Washington standard stars (Geisler 1996) were observed on the photometric nights for the standard calibration. The typical errors of the standard star calibration are 0.020, 0.022, and 0.019 mag for $T_1$, $(C - T_1)$, and $(M - T_1)$, respectively.

All the pre-processing, such as overscan correction, bias subtraction, and flat fielding were done using the IRAF/CCDRED package. For the photometry of the data, we have used the SExtractor package (Bertin & Arnouts 1996).

### 2.2. *Spectroscopy*

For the GC candidates obtained from the photometric data, the spectroscopic observations were made using the KPNO WIYN 3.5-m telescope + Hydra multi-fiber bench spectrograph + blue fiber cable + T2KC CCD on the nights of UT 2000 September 7 − 9 and UT 2001 November 2 − 4. Details on the observational configuration can be found in Kim et al. (2006). The total number of targets observed in the observing runs of these two years is 747, which are composed of 641 new GC candidates and 106 previously known clusters.

The reduction of the Hydra spectroscopic data was done using the Hydra data reduction task, DOHYDRA in the IRAF/NOAO.IMRED.HYDRA package which is specifically designed for multi-fiber spectral reduction (Valdes 1995). Radial velocities were measured for the spectroscopic target objects by cross-correlating their spectra against high signal-to-noise template spectra of M31 GCs 020−073 and 158−213, taken with the same telescope and instrument (Tonry & Davis 1979; Huchra, Brodie, & Kent 1991).

## 3. CLUSTER SEARCH METHOD

To search for GCs in M31 we have used both photometric and spectroscopic information. We have investigated various photometric parameters of the candidate GCs using the photometric data, and have obtained radial velocities from the spectroscopic data. The final classification as new GCs and candidates was made by careful visual inspection after training of the eyes using images of the previously known GCs, stars, and galaxies in our data. The final GC candidates are classified into three classes defined as: class 0 for objects believed to be genuine GCs, class 1 for probable clusters, and class 2 for possible clusters, which might be GCs or galaxies, and a few of them could even be other kinds of objects. We have confirmed 544 previously known clusters (331 class 0, 141 class 1, and 72 class 2), and found 620 new GCs and GC candidates (126 class 0, 263 class 1, and 231 class 2). We consider class 0 objects as M31 GCs and use them for our analyzes. Details on the search method and results are in Kim et al. (2006).

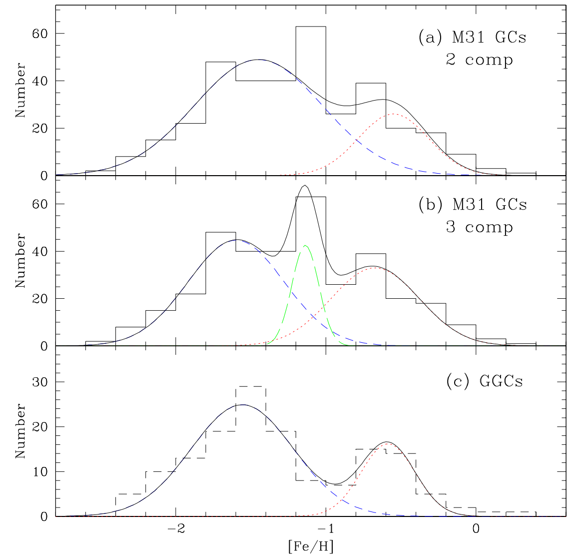


Fig. 1. (a) Metallicity distribution of the combined M31 GC sample of the previously known GCs of Barmby et al. (2000) and Perrett et al. (2002) plus class 0 objects found in this study (total N=354). Two-component Gaussian fits to the metal-poor peak (blue-dashed line) and the metal-rich peak (red-dotted line) are drawn. The sum of the two fit components is plotted as a black solid line. (b) Same as in panel (a), but now with three-component Gaussian function fitting including the intermediate-metallicity group (green long-dashed line). (c) The metallicity distribution of the Milky Way GCs (N=148) is plotted together with two-component Gaussian fits; metal-poor peak in blue-dashed line and metal-rich peak in red-dotted line.

## 4. GLOBULAR CLUSTER METALLICITY DISTRIBUTION

For the derivation of the metallicity values of the GCs we have measured the line indices from the WIYN/Hydra spectra. We have used the six line indices (CNB, Δ, CH, MgH, Mg2, and Fe 5270) with higher correlation coefficients, which are recommended as primary metallicity calibrators by Brodie & Huchra (1990). The calibrating relations of Brodie & Huchra (1990) and Huchra et al. (1996) are used.

Figure 1 shows the metallicity distribution of M31 GCs (panels (a) and (b)) and Milky Way GCs (panel (c)). The data for M31 GCs are the combined sample of Barmby et al. (2000), Perrett et al. (2002), and this study (total N=354 including 100 new objects from this study). The metallicity data of 148 Galactic (Milky Way) globular clusters (GGCs) from the Harris (1996; 2003 February version) catalog[7] are used for panel (c), of which mean value is

[7]See http://physun.physics.mcmaster.ca/Globular.html.

[Fe/H] $= -1.298 \pm 0.564$. The range of metallicities of class 0 objects found from this study agrees well with that of metallicities of the previously known M31 GCs and GGCs.

We have performed two-component Gaussian fittings of the data and plotted them as blue-dashed and red-dotted lines for the metal-poor and metal-rich peaks, respectively, in Fig. 1(a). The peaks and dispersions of the metal-poor and metal-rich sub-populations are [Fe/H]$= -1.450$ and $-0.550$ and $\sigma = 0.425$ and 0.234, respectively. The black solid line in Figure 1(a) is the sum of these two Gaussian functions. Compared to the metallicity distribution of the GGCs, M31 GCs show a larger number of clusters at intermediate-metallicity near [Fe/H]$\sim -1$ dex. Both galaxies show lower amplitude peaks in the metal-rich zone.

To analyze the metallicity distribution quantitatively, we have used the KMM algorithm (McLachlan & Basford 1988; Ashman, Bird, & Zepf 1994). The KMM algorithm takes as inputs the individual data points, the number of Gaussian groups to be fit, and an initial guess for the groups' means and dispersions. It gives as output the presence (in a quantified way) of bi-modality in the datasets (Barmby et al. 2000, Perrett et al. 2002). We have employed the KMM test using two-group and three-group fitting for our full sample of spectroscopic metallicities (N=354). The hypothesis of a unimodal metallicity distribution can be rejected at the 74.6% confidence level from the two-group test, and at the 94.5% confidence level from the three-group test. The three-component Gaussian fitting, therefore, can be said to be an improvement over the two-component fitting.

We thus fitted triple-Gaussian functions onto the M31 GCS metallicity distribution and the result is shown in Figure 1(b). The metal-poor, intermediate-metallicity, and metal-rich GCs denoted in blue dashed, green long-dashed, and red dotted lines, respectively, have means of [Fe/H]$= -1.598 \pm 0.011$, $-1.137 \pm 0.004$, and $-0.672 \pm 0.693$, respectively, and have dispersions of $\sigma = 0.754 \pm 0.025$, $0.211 \pm 0.017$, and $0.693 \pm 0.014$, respectively.

Figure 1(c) shows two-Gaussian function fittings onto the GGC data from the Harris catalog, which gives the mean metallicities of [Fe/H]$= -1.557$ and $-0.586$ and dispersions of $\sigma = 0.341$ and 0.180 for the metal-poor and metal-rich peaks, respectively.

## 5. SUMMARY

We have briefly introduced our M31 globular cluster search project. Using KPNO 0.9-m telescope imaging data and WIYN 3.5-m spectral data, we have searched for clusters in M31 and found more than 120 new GCs. We have presented the metallicity distribution of the previously known (N=254) and newly found (N=100) M31 GCs, for which spectroscopic metallicity could be estimated. While the metallicity distribution of GGCs shows clear bimodality, that of the M31 GCs shows three components: metal-poor, intermediate-metallicity, and metal-rich. The photometric and kinematic properties of the M31 GCs including newly found objects will be presented in future papers.

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