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Estimating the Metallicity of Old Star Clusters in M33

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Abstract Based on the method proposed by Kong et al. and on the multi-color spectrophotometry by Ma et al., we estimate the metallicities of 16 old star clusters in the nearby spiral galaxy M33, ten of which are halo globular clusters. These old clusters are all metal poor, the range of metallicity ([Fe/H]) is from −0.14 to −2.12. In general, our results are consistent with those derived by other methods, such as integrated spectra and photometry, and our study confirms the reliability of the method of Kong et al.

Key words: galaxies: individual (M33) — galaxies: evolution — galaxies: star clusters

1 INTRODUCTION

Globular clusters are thought to be among the oldest radiant objects in the Universe. The studies of these systems have played a key role in the development of our understanding of the Universe, including the fundamental question of the age of the Universe. The globular clusters of Milky Way can be used to probe the way in which our Galaxy formed. Studies of similar clusters in other galaxies can also provide us the properties of those galaxies in the early period after their formation.

M33 is a small Local Group galaxy, at a distance of 850 kpc from the Earth, and is classified as a late-type ScII-III spiral (van den Bergh 1999). M33 is interesting and important because it represents a morphological type intermediate between the largest "early-type" spirals and the dwarf irregulars in the Local Group (Chandar, Bianchi & Ford 1999). The Beijing-Arizona-Taiwan-Connecticut (BATC) Multicolor Sky Survey (Fan et al. 1997; Zheng et al. 1999) has this spiral galaxy as a part of its galaxy calibration program which uses the 60/90 cm Schmidt telescope at the Xinglong Station of Beijing Astronomical Observatory to do spectrophotometry on pre-selected 1 deg^2 regions in the northern sky. A Ford Aerospace 2048×2048 CCD camera with 15 custom-designed intermediate-band filters is mounted at the Schmidt focus of the telescope. The view field of the CCD is $58' \times 58'$ with pixel scale of $1.7''$. For M33, a database of star clusters have been available from both ground-based work (Hiltner 1960; Kron & Mayall 1960; Melnick & D'Odorico 1978; Christian & Schommer 1982, 1988), and the *Hubble Space Telescope* (HST) images (Chandar, Bianchi & Ford 1999, 2001).

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Kong et al. (2000) studied the age, metallicity, and interstellar-medium reddening distribution for M81. They found that among all the BATC filter bands the color index centered at 8510Å is much more sensitive to the metallicity than to the age. The center of this filter band is near the Ca II triplets ($\lambda\lambda = 8498, 8542, 8662$Å), the strength of which depends on the effective temperature, surface gravity, and the metallicity of late-type stars (Zhou 1991). A very good correlation between the flux ratio $I_{8510} \equiv L_{8510}/L_{9170}$ and the metallicity was found for stellar populations older than 1 Gyr in Kong et al. (2000).

In this paper, we estimate the metallicities of the 16 older star clusters in M33 detected by Christian and Schommer (1982) or by Chandar, Bianchi and Ford (1999), using the relation between the flux ratio and metallicity for the stellar populations older than 1 Gyr given in Kong et al. (2000). The rest of this paper is as follows. Sample selection, observations and data reduction are given in Section 2. In Section 3, we provide a brief description of the method of Kong et al. (2000). The metallicity estimates are given in Section 4.

2 SAMPLE OF STAR CLUSTERS, OBSERVATIONS AND DATA REDUCTION

2.1 Sample of Old Star Clusters

Our sample of star clusters is from Ma et al. (2001a, 2001b). The positions of these clusters have been given by Christian and Schommer (1982) or by Chandar, Bianchi and Ford (1999). Christian and Schommer (1982) detected more than 250 nonstellar objects using 14×14 inch^2 unfiltered, unbaked, IIa-O focus plate exposed for 150 minutes with the Kitt Peak 4 m Richey-Chrétien (R-C) direct camera. Chandar, Bianchi and Ford (1999) used 20 multiband *Hubble Space Telescope* (HST) WFPC2 fields to search for star clusters much closer to the nucleus of M33 than had been done in previous studies. Ma et al. (2001a, 2001b) obtained their SEDs by aperture photometry, and estimated the ages of 66 clusters using the theoretical evolutionary population synthesis methods. In Ma et al. (2001a), there are ten clusters, with ages older than 1 Gyr. Three of the ten clusters have low signal-to-noise ratios, and we have excluded them. Also, cluster 54 in Ma et al. (2001a) is U137 in Ma et al. (2001b). Altogether, there are 16 old star clusters used in this paper. Figure 1 shows the image of M33 in filter BATC07 (5785Å), the circles mark the positions of the sample clusters. From this figure we can see that the sample star clusters populate a variety of environments from the outer regions to spiral arms and central regions, they can be used to probe the global chemical properties of the parent galaxy. Moreover, the star clusters from Ma et al. (2001b) are halo globular clusters, which were selected from Schommer et al. (1991) by Sarajedini et al. (1998), from the difference between the cluster velocity and the disk velocity as a function of the integrated cluster color.

2.2 Observations and Data Reduction

The large field multi-color observations of the spiral galaxy M33 were obtained in the BATC photometric system. The multi-color BATC filter system, which was specifically designed to avoid contamination from the brightest and most variable night sky emission lines, includes 15 intermediate-band filters, covering the whole optical wavelength range from 3000 Å to 10 000 Å. The images of M33 covering the whole optical M33 in 13 intermediate band filters were accumulated with a total exposure time of about 32.75 hours over the period 1995–09–23 to 2000–08–28. The dome flat-field images were taken by using a diffuse plate in front of the correcting plate of the Schmidt telescope. For flux calibration, the Oke-Gunn primary flux standard stars

HD19445, HD84937, BD+262606 and BD+174708 were observed on photometric nights.

The data were reduced with standard procedures, including bias subtraction and flat-fielding of the CCD images, with an automatic data reduction software named PIPELINE I developed for the BATC multi-color sky survey. For each star cluster, aperture photometry was used to obtain the magnitudes. Considering the imperfect scale of seeing of Xinglong station, aperture corrections were computed using isolated stars (see Ma et al. 2001a, 2001b for detail).

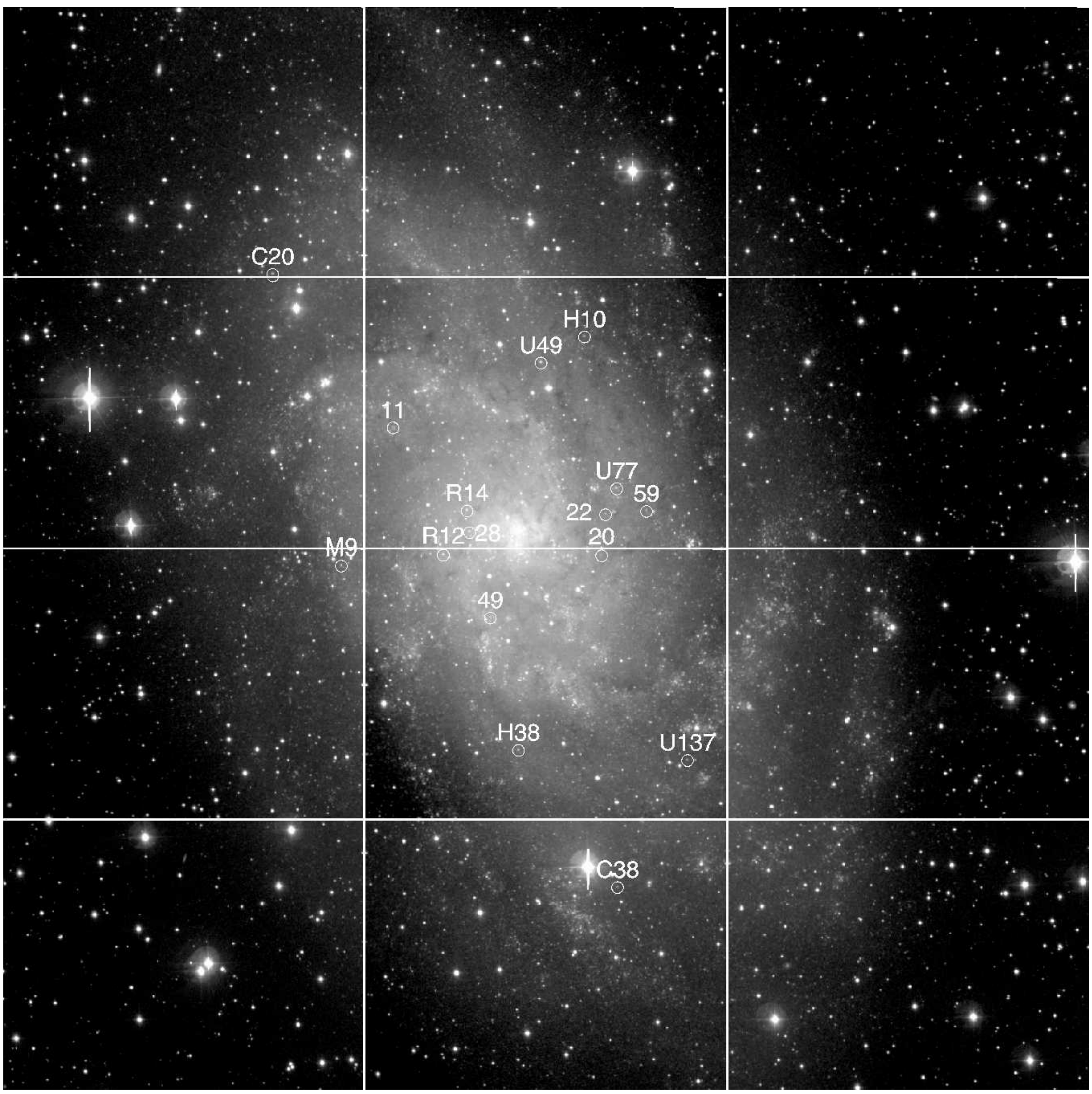

Fig. 1 M33 in filter BATC07 (5785 Å) and the positions of the sample star clusters. The center of the image is located at RA = $01^h33^m50.58^s$, DEC=$30°39'08.4''$ (J2000.0). North is up and east is to the left.

3 CORRELATION BETWEEN COLOR INDEX AND METALLICITY

For examining the integrated properties of the stellar population in M81, Kong et al. (2000) used the simple stellar populations (SSPs) of GISSEL96 (Charlot & Bruzual 1991; Bruzual & Charlot 1993; GSSP). First, Kong et al. (2000) convolved the SED of GSSP with BATC filter profiles to obtain the optical and near-infrared integrated luminosity. In order to decrease the effects of the uncertainties in the extinction along the line of sight in space, they worked with the colors. They found that among all the BATC filter bands, the color index centered at 8510Å is much more sensitive to the metallicity than to the age. The center of this filter band (8510Å) is near the Ca II triplets ($\lambda\lambda = 8498, 8542, 8662$Å).

As we know, for an old stellar system, the effect of metallicity on the Ca II triplet is important. A very good correlation between the flux ratio $I_{8510} \equiv L_{8510}/L_{9170}$ and the metallicity for stellar populations older than 1 Gyr was found (Kong et al. 2000),

$$Z = (0.83 - 0.84 \times I_{8510})^2. \tag{1}$$

4 METALLICITY ESTIMATES

Using Eq. (1) we calculate the metallicities of these old star clusters, and we list the results in Table 1 ([Fe/H] $= \log Z - \log Z_\odot$). For checking the reliability of this equation, we will compare our results with others' for the clusters in common. So, in Table 1, we also list the results of other authors (Cohen, Persson & Searle 1984; Christian & Schommer 1988; Brodie & Huchra 1991; Sarajedini et al. 1998). Using two reddening-independent techniques, Cohen, Persson and Searle (1984) obtained abundance estimates for four globular clusters. Their abundances for M9, U49, H38, and C20 are listed in column 3 of Table 1. Comparing the results for these four clusters, we find marked discrepancy only in one, M9: we estimated it to be moderately metal rich, while Cohen, Persson and Searle (1984) estimated it to be very metal poor. The results of Christian and Schommer (1988) and Sarajedini et al. (1998) for M9 are intermediate between Cohen, Persson & Searle (1984) and us. Christian & Schommer (1988) and Brodie & Huchra (1991) estimated the metallicities for ten globular clusters using integrated spectra. The mean metallicity difference ("this paper" minus "theirs") is $\langle\Delta[\mathrm{Fe/H}]\rangle = 0.153 \pm 0.192$. Sarajedini et al. (1998) estimated the metallicities for these ten globular clusters based on the shape and color of the red giant branch. Our results are consistent with Sarajedini et al. (1998) except C38, which we find to be very metal poor, while they found to be the most metal rich of all. The mean metallicity difference ("this paper" minus Sarajedini et al. 1998) is $\langle\Delta[\mathrm{Fe/H}]\rangle = 0.148 \pm 0.216$. Sarajedini et al. (2001) estimated the cluster metallicities using the integrated $B-V$ colors from Christian & Schommer (1998) and the equations of Couture, Harris & Allwright (1990). Sarajedini et al. (2001) argued that the metallicity of R12 obtained using the equations of Couture, Harris and Allwright (1990) is very metal rich. Except this cluster, our results are consistent with those obtained by using $B-V$ colors, and the mean difference ($\langle[\mathrm{Fe/H}]_{\mathrm{This\ paper}} - [\mathrm{Fe/H}]_{B-V}\rangle$) is 0.056 ± 0.273.

5 SUMMARY AND DISCUSSION

In this paper, based on the results of multi-color spectrophotometry in Ma et al. (2001a, 2001b) and the method of Kong et al. (2000), we estimate the metallicities of 16 old star clusters in M33, of which ten are halo globular clusters. The results show that all these old clusters are metal poor, the range of metallicity ([Fe/H]) is from −0.14 to −2.12. At the same time, we compare our results with others' results (Cohen, Persson & Searle 1984; Christian & Schommer 1988; Brodie & Huchra 1991; Sarajedini et al. 1998) derived by different methods, such as integrated spectra and photometry. In general, our results are consistent with these authors' and confirm the reliability of the method of Kong et al. (2000).

Table 1 Metallicities of Old Star Clusters in M33

Cluster	[Fe/H][a]	$[Fe/H]^{b}_{CPS}$	$[Fe/H]^{c}_{CS}$	$[Fe/H]^{d}_{BH}$	$[Fe/H]^{e}_{S}$
U49	-1.75 ± 0.036	-1.4	-0.8 ± 0.3	-1.70 ± 0.53	-1.64 ± 0.20
R12	-1.46 ± 0.036	...	-1.2 ± 0.3	...	-1.19 ± 0.24
R14	-0.63 ± 0.036	...	-1.5 ± 0.3	...	-1.00 ± 0.50
M9	-1.17 ± 0.108	-2.2	-1.7 ± 0.3	...	-1.64 ± 0.28
U77	-0.76 ± 0.048	...	...	-1.77 ± 0.77	-1.56 ± 0.30
H38	-0.84 ± 0.036	-1.0	-1.5 ± 0.3	...	-1.10 ± 0.10
C20	-1.30 ± 0.072	-1.1	-2.2 ± 0.3	-1.25 ± 0.79	-1.25 ± 0.22
C38	-2.12 ± 0.108	...	-1.2 ± 0.3	...	-0.65 ± 0.16
H10	-0.74 ± 0.036	...	...	-0.91 ± 0.90	-1.44 ± 0.26
U137	-0.20 ± 0.072	...	...	-0.12 ± 0.38	-0.98 ± 0.16
11..	-1.30 ± 0.240	...	...	...	...
20..	-0.44 ± 0.240	...	...	...	...
22..	-1.03 ± 0.481	...	...	...	...
28..	-1.94 ± 0.240	...	...	...	...
49..	-1.69 ± 0.481	...	...	...	...
59..	-0.14 ± 0.120	...	...	...	...

[a] This paper; [b] Cohen, Persson & Searle 1984; [c] Christian & Schommer 1988; [d] Brodie & Huchra 1991; [e] Sarajedini et al. 1998

It is important to ensure the validity of Eq. (1), because the relation shown in Eq. (1) is crucial for our metallicity estimates. As we know, the old stellar populations and the nuclei of spiral galaxies are dominated by G, K and M stars and therefore they emit the bulk of their light in the near infrared region of the spectrum. The important feature of this part of the spectrum is the Ca II triplet (hereafter CaT) at λλ 8498, 8542 and 8662Å. The CaT feature has been the subject of several analyses. Different authors emphasized its different uses, as a luminosity indicator, or as a possible discriminator between the light contribution due to dwarfs and giants in a given population mix (Idiart et al. 1997). Bica and Alloin (1987) presented CCD spectra with 12.5Å resolution for 30 star clusters, and measured the near-infrared continuum distribution and the equivalent widths of 13 absorption features. They reached the conclusion that in the near-infrared, metallicity is the dominant parameter. Based on the analysis of stars (giants, supergiants and dwarfs), star clusters, and galaxy nuclei, Alloin and Bica (1989) showed that the equivalent widths of CaT is metallicity dependent, although not as much as other metallic or molecular features (CN or Mg+MgH). Armandroff and Zinn (1988) found that the strength of the CaT in the integrated spectra of globular clusters forms a one-parameter family, the parameter being metallicity. Erdelyi-Mendes and Barbuy (1991) calculated synthetic spectra for the Ca II lines in the local thermodynamic equilibrium approximation using the model atmospheres computed by interpolation in the grids of models by Gustafsson et al. (1975) and an unpublished grid of dwarf models (see Erdelyi-Mendes & Barbuy 1991 for details). By a detailed analysis of the behavior of the strength of Ca II lines as a function of stellar parameters, Erdelyi-Mendes and Barbuy (1991) concluded that the CaT has a weak dependence on the effective temperature, a modest dependence on surface gravity, but a quite strong dependence on metallicity, i.e., there exists an exponential dependence between the flux of the two strongest Ca II lines ($\lambda\lambda$ 8542Å and 8662Å) and metallicity. Mallik (1994) presented the observational results of the infrared triplet lines of ionized Ca for 91 stars in the spectral range F8 − M4 of all luminosity classes and in the metallic range $-0.65 \sim +0.60$, and reached the conclusion that the dependence of the Ca II triplet fluxes on gravity and metallicity is intricately intertwined, but, for supergiants a distinctly strong relationship can be found. He also indicated that when a large metallicity range is considered (i.e., ≥ 1.0 dex), the influence of the metallicity on the Ca II triplet lines becomes conspicuous. Idiart et al. (1997) also confirmed the strong dependence of CaT index on metallicity.

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