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METALLICITY DETERMINATION FOR A GLOBULAR CLUSTER BY SPECTRAL INDICES

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ABSTRACT

In order to determine the metallicity of a globuar cluster, M3, by using the spectral indices, a kind of index grid has been establshed by stars in globular clusters, M3, M15, M71 and old open cluster, NGC 188. The indices were measured from the medium resolution spectra of about 2 Å.The summed indices were used to determine metallicity in order to increase signals. It is found that the core depth index is measured more accurately and leads result more accurate than the pseudo-equivalent width index. This method can be further improved by including many more calibration globular clusters of various metallicity to make finer grids. By this method, the metallicity of M3 is determined as [Fe/H] = −1.46 ±0.15.

Key Words: globular cluster, metallicity, spectral index,

I. INTRODUCTION

The metal-abundances of globular clusters have been determined by various techniques, which are the method related to the measurements of line blockings in the F,G,and K type stars by multicolor photoelectric broad-band photometry of UBV, DDO and Washington Systems(Sandage 1970;Hesser *et al.* 1977; Canterna and Schommer 1978), and by low resolution scanner(Searle and Zinn 1978), and low resolution spectroscopic method of delta S-measurements in the spectra of RR Lyrae variables(Butler 1975), and the spectroscopic method based on the detailed analysis of high-resolution spectra of coude spectragraph and more recently echelle spectrograph(Sneden *et al.* 1994; Sneden *et al.* 1991,1992; Kraft *et al.* 1992; Kraft *et al.* 1993).

It has been known from calculations of stellar evolution, that the metal abundance of a cluster is reflected in the morphology of its color-magnitude diagram. It leads several secondary abundance indicators which exploit the morphological depedances on metallicity. Those are δV, the height of the GB above the HB, at unreddened $(B - V) = 1.40$(Sandage and Wallerstein 1960); $(B - V)_o g$ the unreddend color of the GB at the luminosity of the HB(Sandage and Wallerstein 1966); the slope of GB above the junction of the HB and GB (Hartwick 1968); and the Dickens(1972) type, which measures the relative population of the HB blueward and redward of the RR Lyrae star gap. The δV and $(B - V)_o g$ are reddening dependent, while Hartwick slope S loses its sensitivity when [Fe/H] < -1.4 and Dickens type leads the second prameter problem which is still not completely solved the causes.

The other methods of metal abundance determination utilize the integrated spectra and photometric indices. The spectral types for clusters, based on the ratio of the G-band to Hγ, depend on [Fe/H] not only because of direct changes in metal-strength but also because of changes in cluster morphology. As [Fe/H] decreases, the integrated spectral types become earlier(Kinman 1959). Integrated pseudo-equivalent widths of spectral features CaII K and H, MgI b, MgH, CH, and Na-D, CaII triplet, also show close correlations with [Fe/H]. Their dependence on the metallicity is resulted by complex effects due to large contribution of luminouse red gaints in the integrated light of a globular cluster as well as the shift of the Hayashi line with metal abundance resulting lower surface gravity of metal-rich giants. Similar effects make the integrated $(V - K)_o$ of clusters a good correlation with

[Fe/H](Aaronson *et al.* 1978). Color indices $(V - R)$ and $(V - K)$ are sensitive primarily to Te and are almost independent of metallicity and surface gravity. The integrated V, K, and R magnitudes of clusters are all heavily dependent on light from giants and are relatively less affected by HB light than are U and B. And the giant branch moves redward with increasing metallicity. Thus the integrated $(V - K)_o$ of clusters are related with [Fe/H].

However all these methods give results of significantly diffrent metallicities for individual globular clusters. Although the quoted uncertainties in metal abundance determination of various methods range from 0.05 for the best to 0.3, an estimated metallicity significantly differs one result from other for some clusters.

However, globular clusters are extremely homogenous in their metallicities. The evidence for the chemical homogeneity has traditionally come from color–magnitude diagrams of clusters. The narrowness of the main sequence in M15 gave an analytical upper limit of 0.16 dex to the mean abundance variation of cluster stars(Sandage and Katem, 1977). More recent work of Suntzeff(1993) provides that most globular clusters are extremely homogenous in $[m/H]$ with $\sigma[m/H] - 0.04$ in the median, except two clusters, ω Cen and M22. So the large different metallicity is not due to the intrinsic disperson of metallicity in globular clusters for most cases.

The most accurate estimates of abundance of clusters are expected from high resolution spectroscopic anaylsis of individual cluster stars. Unfortunately, it is quite limited to the bright stars of few clusters. The medium resolution spectra for the cluster stars are more likely obtainable to give a reasonably accurate metal abundance. Therefore in this study, we intend to find the new ways of metallicity determination by using spectral indices measured in the medium resolution specra and apply it to a globular cluster, M3.

Although there is three ways to determine the metallicity of stars with with medium resolution spectra: comparison with a grid of model atmospheres, cross correlation against standard star templets and calibration of spectral indices. The first one is more desired for the high resolution and S/N specra, the second is required high and uniform S/N dataset, the last one is more appropriate for this stduy, of which data is limited to the observed spectra of cluster stars for other purpose of study. All of the observed spectra for this study was provided by Dr. Croswell, who obtained them for his thesis work. The observed spectra and their reduction is discussed in section II and analysis of spectral indices in section III and results and discussion is followed in section IV.

II. SPECTRAL DATA AND REDUCTION

Specra of stars in globular clusters, M15, M3, and M71, and open cluster NGC 188, used in this study was obtained with the Multiple Mirror Telescope atop Mountain Hopkins in Arizona by K. Croswell. The blue channel of the MMT spectragaph with an 832 l/mm grating blazed at 4300 Å in second order was used. The resolution was 1Å with 5 pixels per resolution element, and the wavelength coverage ranged from 3600 to 4400 Å. For all exposures, the 3" * 1" aperture is used and before and after each exposure, the comparison lamp exposures were obtained. The ideal lamp combination, which was used in the later observations, was helium-argon plus mercury-cadmium; the ealier observations lack the mercury-cadmium lamp, which gives several useful lines in the blue and near UV. The observed data was reduced using the standard NOVA package at the CFA(Center of Astrophysics). These wavelength calibrated spectra were provided by Dr. Croswell.

On the wavelength calibrated spectra, spectral equivalent width and core depth of most lines between 3600 and 4400 Å were measured by using SPLOT of IRAF(Image Reduction and Analysis Facility).

The spectra of 4 giants in M15, 11 giants in M3, 10 giants in M71 and 5 giants in NGC188, whose basic data are listed in Table 1, were smoothed to have resolution of about 2 Å and normalized to a unit continuum.

The pseudo-equivalent width and the core depth of lines were measured by fitting Gaussian functions. The two times of measurements have been done with interval of 6 months. The measurements errors of pseudo-equivalent width and core depth are varied. They are affected by the continuum fitting for both equivalent widths and core depths and by profile fitting methods for equivalent widths. Therefore, in general, the measurement errors of the core depths are much smaller than the equivalent widths of lines although they also varies from line to line.

Table 1. Basic Data for Clusters and Stars

Cluster	(m - M)$_o$	E($B-V$)	[Fe/H]	Star	V	($B-V$)
M15	15.11	0.05	-2.30			
				I-38	14.08	0.94
				I-50	13.41	1.11
				II-49	14.96	0.88
				S6	13.24	1.19
M3	15.02	0.01	-1.47			
				VZ164	13.72	1.10
				VZ194	13.82	0.98
				VZ238	12.66	1.57
				VZ265	13.23	1.30
				VZ297	12.84	1.42
				VZ320	15.97	0.81
				VZ323	14.65	0.83
				VZ334	13.21	1.20
				VZ1178	15.61	0.70
				VZ1275	15.40	0.81
				VZ1391	14.41	0.91
M71	12.96	0.28	-0.79			
				I-1	13.16	1.26
				I-14	12.90	1.26
				I-44	12.57	1.34
				I-45	11.49	1.76
				I-53	12.10	1.61
				I-56	12.27	1.38
				I-63	12.66	1.26
				I-67	13.41	1.23
				I-109	14.00	1.24
				KC-202	14.30	1.12
NGC188	11.50	0.12	-0.06			
				I-116	13.41	0.98
				II-26	13.21	1.10
				II-72	12.05	1.34
				II-76	12.02	1.18
				II-79	14.29	1.00

III. ANALYSIS OF SPECTRAL INDICES

(a) Spectral Indices

Although many lines were measured, only major indices frequently used in previous index studies are discussed below.

CaII H and CaII K : The indices of CaII H and Ca II K lines are mostly used in studies of integrated spectra to get metallicity of clusters and galaxies. But the pseudo-equivalent width and core depth of these lines on the late type stellar spectra can not be accurately measured due to their saturation. The average uncertainties of pseudo-equivalent width indices of these lines are around 15%, while those of core depth indices are less than 4 %. This value of uncertainty is a percentage of the difference between two measurements over the later measurement.

Since the CaII H and CaII K lines are saturated in most of the late giant, indices of core depth do not show any correlation with $(B-V)$ or metallicity. However the indices of pseudo-equivalent width for the metal poor globular clusters, show a strong correlation with color and metallicity. Especially M15 shows a tight relation with

Table 2. Pseudo-Equivalent Width Indices for Giants Stars

Cluster	Star	CaII K	CaII H	Fe 4045	Fe 4065	SrII 4077	H_δ	CaI 4225	H_γ	Fe 4372	Fe 4383
M15	I-38	7.04	5.64	0.53	0.43	0.26	1.08	0.41	1.20	0.44	0.36
	I-50	9.26	7.34	0.53	0.41	0.69	0.76	0.64	1.08	0.53	0.64
	II-49	6.49	4.88	0.53	0.30	0.49	1.32	0.57	1.11	0.23	0.21
	S6	9.97	7.74	0.57	0.46	0.80	1.03	0.74	1.29	0.42	0.60
M3	VZ164	12.20	11.92	0.90	1.03	1.45	1.42	1.33	1.17	1.15	1.43
	VZ194	13.40	10.08	0.85	0.34	1.34	0.86	1.10	1.16	0.51	1.20
	VZ238	...	...	1.45	1.13	2.11	...	2.29	1.39	1.06	1.40
	VZ265	...	12.07	1.08	0.73	1.72	1.66	1.98	1.15	0.81	1.22
	VZ297	...	...	1.05	1.22	1.69	1.92	1.94	1.33	0.83	1.54
	VZ320	10.47	9.86	0.82	0.70	0.78	1.12	0.96	1.12	0.90	0.98
	VZ323	13.59	11.14	0.66	0.65	0.96	1.15	0.94	0.98	0.82	1.07
	VZ334	...	11.61	1.04	0.73	1.42	1.26	1.64	1.00	0.67	1.37
	VZ1178	8.71	7.18	0.40	0.21	0.31	1.24	0.54	1.33	0.78	1.13
	VZ1275	11.24	8.93	0.59	0.39	0.78	1.23	0.85	1.32	0.70	0.89
	VZ1391	12.98	10.43	0.90	0.77	1.87	1.55	1.29	1.21	0.93	1.17
M71	I-1	...	...	1.30	1.08	1.40	1.34	2.55	1.27	1.10	1.60
	I-14	13.66	...	1.06	0.73	1.21	1.09	1.95	1.62	1.18	1.80
	I-44	...	13.91	0.98	0.85	1.43	1.13	1.82	1.13	1.32	1.71
	I-45	14.89	...	1.66	1.23	1.88	...	5.43	0.95	1.76	2.65
	I-53	...	...	1.23	1.39	1.78	...	2.92	...	1.23	2.06
	I-56	13.21	...	1.46	1.35	2.21	1.89	2.59	0.87	1.12	1.50
	I-63	...	...	1.21	0.87	1.63	1.63	1.62	1.37	1.05	1.60
	I-67	...	...	1.12	0.73	1.27	1.04	1.78	0.63	0.75	1.40
	I-109	...	...	1.10	0.82	1.34	0.86	1.53	...	0.99	1.48
	KC202	12.70	10.98	1.04	0.62	0.87	0.87	1.33	1.49	0.65	1.43
NGC188	I-116	...	...	0.98	1.03	0.89	1.39	2.21	1.60	0.92	2.14
	II-26	10.92	9.34	1.21	1.08	0.99	1.00	2.08	1.08	0.93	2.04
	II-72	13.06	14.07	1.85	1.99	1.98	2.14	3.87	1.03	1.44	3.29
	II-76	13.05	9.93	1.50	1.49	1.38	1.30	3.33	1.00	1.21	2.59
	II-79	14.76	12.94	1.11	0.87	0.87	0.88	1.99	1.02	0.81	1.92

color, for both CaII H and CaII K.

CaII H and CaII K have been used as metallicity indicators in most spectral index studies (Friel 1987; Beers *etal.* 1985; Beers *etal.* 1992). The usage of them should be confined to the cases of at least metal poorer than M71. This limit is a rather upper boundary found in this study because of small sample of globular clusters. Similar trend was found for the CaII triplet at infrared region by Armandroff and Zinn (1988) to measure globular cluster metallicies. When the CaII triplet is applied to individual gaints in LMC clusters and to the globular cluster calibrators, the calibration was brocken down for the metal-rich globular clusters. They cautioned the use of this CaII triplet method for [Fe/H] < -1.2.

Fe Lines : The index measurement of most Fe lines are better for pseudo-equivalent width and little bit worse for core depth than those of CaII H and CaII K, giving an average uncerainty of less than 10% and 5% respectively.

They all show a strong relation with color and metallicity, although their dependences on color and metallicity vary from line to line. The Fe lines are getting stronger not only as metallicity increases but also as the color becomes redder. Both indices, the pseudo-equivalent width and the core depth could be used as temperature indicator as well as metallicity indicator. These Fe indices apparently show a dependence on its's brightness too.

$H\gamma$ and $H\delta$: The measurement uncertainties of indices of hydrogen lines are less than 11% and 7% for the pseudo-equivalent width and core depth respectively. No particular overall trends, dependences upon color or metallicity or luminosity, are seen in the hydrogen line indices. The strength of hydrogen lines are expected to decrease with color and increase with luminosity at late type stars. It seems that the strengthening with luminoisity becomes to overwhelm the weakening with color for the stars of $(B-V) > 1.2$.

SrII 4077 : SrII 4077 line is sensitive to metallicity, even though it shows a strong dependence on color and luminosity. The measurement error for the pseudo-equivalent width is increasing as metallicity of cluster decreases, while that for core depth is almost constant for all clusters. It is due to that the measurement of pseudo-equivalent width of a weak line is more noiser than that of core depth. The uncertainties are less than 11% and 3% respectively.

CaI 4225 : Ca I line is very sensitive to metallicity and color. The measurement accuracies of the pseudo-equivalent width and core depth are 9% and 8% respectively.

The measured indices, CaII H, CaII K, Fe 4045, Fe 4065, SrII 4077, CaI 4225, Hγ, Hδ, Fe 4372, and Fe 4382 of pseudo-equivalent width and core depth for giant stars in four clusters are listed in Table 2, 3 respectively.

However the major important indices, which are used for metallicity determination in next section are based on Fe lines, Ca, and Sr lines only.

(b) Determination of Metallicity

In order to determine the metallicity of a globular cluster, the sumed index instead of the individual indices of Table 2, 3, are used to increase the signal for the noise spectra. All-Fe index is the sum of Fe 4045, Fe 4065, Fe 4372, and Fe 4383, while all-metal index is sum of those Fe lines and SrII 4077 and CaI 4225.

The giant stars in cluters are not randomly spread over the HR diagram as seen in Figure 1, which is a plot of all stars in the unreddened $(B-V)$ versus absolute magnitude M_v. The relations of the sumed indices with color and absolute magnitude for each metallicity cluster are derived.

Figures 2 -(a), -(b), -(c) and -(d) show the all-Fe index and all-metal index of the pseudo-equivalent width versus dereddened color and absolute magnitude, respectively, for the giant stars in M15, M3 and M71 globulars and NGC 188 open cluster. Figures 3 -(a), -(b), -(c), and -(d) are the same diagrams for those indices of core depth. In these figures, M15 is represented by open squares, M3 by filled triangles, M71 by open circles, and NGC188 by filled squares. The metallicity [Fe/H] of -2.30, −1.47, and −0.79 for M15, M3, and M71 globular cluster are taken from the results of recent high resolution studies of Sneden *et al.* (1991), Kraft *et al.* (1992), and Sneden *et al.* (1993) respectively, and [Fe/H] of −0.06 for NGC188 is taken from Eggen and Sandage(1969). The least square fit relations of each index with color and absolute magnitude for metallicity [Fe/H] of −2.30 −1.47, −0.79, and −0.06 are obtained.

Those are following.

M15 : [Fe/H] = −2.30

Pseudo-Equivalent Width Index

$$All - FeIndex = 2.34 \cdot (B-V) - 0.50 \qquad (r = 0.893)$$

$$All - metalIndex = 4.48 \cdot (B-V) - 1.44 \qquad (r = 0.986)$$

$$All - FeIndex = -0.48 \cdot M_v + 1.23 \qquad (r = -0.988)$$

$$All - metalIndex = -0.77 \cdot M_v + 2.03 \qquad (r = -0.913)$$

Core Depth Index

$$All - FeIndex = 0.60 \cdot (B-V) - 0.00 \qquad (r = 0.978)$$

$$All - metalIndex = 1.14 \cdot (B-V) - 0.16 \qquad (r = 0.963)$$

$$All - FeIndex = -0.11 \cdot M_v + 0.46 \qquad (r = -0.993)$$

$$All - metalIndex = -0.18 \cdot M_v + 0.75 \qquad (r = -0.826)$$

M3 : [Fe/H] = −1.47

Pseudo-Equivalent Width Index

Table 3. Core Depth Indices for Giants Stars

Cluster	Star	CaII K	CaII H	Fe 4045	Fe 4065	SrII 4077	H_δ	CaI 4225	H_γ	Fe 4372	Fe 4383
M15	I-38	0.90	0.86	0.17	0.14	0.09	0.35	0.15	0.35	0.12	0.13
	I-50	0.85	0.85	0.17	0.14	0.20	0.28	0.20	0.32	0.16	0.18
	II-49	0.89	0.83	0.19	0.13	0.17	0.36	0.19	0.32	0.08	0.08
	S6	0.90	0.83	0.21	0.16	0.25	0.35	0.24	0.38	0.15	0.15
M3	VZ164	0.88	0.85	0.33	0.18	0.32	0.36	0.44	0.36	0.30	0.40
	VZ194	0.86	0.86	0.32	0.13	0.31	0.23	0.36	0.37	0.18	0.30
	VZ238	···	···	0.47	0.40	0.54	···	0.64	0.46	0.28	0.42
	VZ265	0.87	0.85	0.38	0.29	0.41	0.41	0.54	0.40	0.23	0.47
	VZ297	···	···	0.41	0.41	0.44	0.43	0.59	0.42	0.23	0.47
	VZ320	0.91	0.87	0.23	0.21	0.22	0.31	0.30	0.36	0.22	0.30
	VZ323	0.86	0.86	0.29	0.23	0.21	0.34	0.34	0.31	0.22	0.34
	VZ334	···	0.86	0.42	0.30	0.29	0.38	0.50	0.34	0.24	0.41
	VZ1178	0.89	0.88	0.18	0.11	0.13	0.36	0.21	0.35	0.21	0.23
	VZ1275	0.92	0.83	0.22	0.16	0.27	0.35	0.30	0.37	0.22	0.28
	VZ1391	0.88	0.84	0.31	0.20	0.32	0.39	0.39	0.35	0.23	0.32
M71	I-1	0.93	0.85	0.40	0.36	0.37	0.35	0.62	0.39	0.24	0.47
	I-14	0.94	0.84	0.40	0.28	0.38	0.34	0.55	0.34	0.29	0.44
	I-44	0.91	0.87	0.36	0.30	0.37	0.36	0.51	0.36	0.32	0.50
	I-45	0.96	0.90	0.52	0.45	0.46	0.49	0.85	0.32	0.37	0.66
	I-53	···	···	0.46	0.45	0.49	···	0.68	0.39	0.29	0.56
	I-56	0.92	0.93	0.54	0.45	0.43	0.43	0.65	0.30	0.28	0.45
	I-63	0.92	0.90	0.45	0.32	0.40	0.41	0.47	0.40	0.28	0.43
	I-67	0.90	0.88	0.46	0.28	0.40	0.31	0.54	0.22	0.24	0.47
	I-109	0.89	0.89	0.41	0.32	0.36	0.24	0.50	0.26	0.26	0.43
	KC202	0.92	0.85	0.37	0.26	0.27	0.28	0.43	0.26	0.18	0.46
NGC188	I-116	···	···	0.40	0.30	0.26	0.38	0.54	0.44	0.26	0.53
	II-26	0.84	0.83	0.46	0.39	0.32	0.34	0.62	0.36	0.26	0.57
	II-72	0.91	0.87	0.59	0.55	0.44	0.47	0.63	0.36	0.37	0.73
	II-76	0.89	0.85	0.56	0.50	0.42	0.38	0.76	0.29	0.38	0.69
	II-79	0.88	0.86	0.38	0.35	0.25	0.32	0.56	0.28	0.24	0.58

Table 4. Metallicity Derived from All-Fe and All-Metal Pseudo-Equivalent Width Indices

Star	$(B-V)$	M_v	AllFe	Allm	$[Fe/H]_{AF_{(B-V)}}$	$[Fe/H]_{Am_{(B-V)}}$	$[Fe/H]_{AF_{M_v}}$	$[Fe/H]_{Am_{M_v}}$	$<[Fe/H]>\pm\sigma$
VZ164	1.09	-1.30	4.51	7.29	-1.17	-1.29	-1.43	-1.53	-1.36±0.16
VZ194	0.97	-1.20	2.90	5.34	-1.72	-1.56	-1.85	-1.81	-1.74±0.13
VZ238	1.56	-2.36	5.04	9.44	-1.60	-1.62	-1.49	-1.45	-1.54±0.08
VZ265	1.29	-1.79	3.84	7.54	-1.72	-1.60	-1.68	-1.60	-1.65±0.06
VZ297	1.41	-2.18	4.64	8.27	-1.58	-1.66	-1.55	-1.58	-1.59±0.05
VZ320	0.80	0.95	3.40	5.14	-0.95	-1.02	-1.22	-1.26	-1.11±0.15
VZ323	0.82	-0.37	3.50	5.40	-0.94	-1.00	-1.52	-1.63	-1.27±0.35
VZ334	1.19	-1.81	3.81	6.87	-1.62	-1.59	-1.69	-1.70	-1.65±0.05
VZ1178	0.69	0.59	2.52	3.37	-1.19	-1.36	-1.57	-1.73	-1.46±0.24
VZ1275	0.80	0.38	2.56	4.19	-1.56	-1.47	-1.66	-1.65	-1.59±0.09
VZ1391	0.90	-0.61	3.77	6.93	-1.06	-0.76	-1.49	-1.42	-1.18±0.34
<M3>									-1.47±0.21

Table 5. Metallicity Derived from All-Fe and All-Metal Core Depth Indices

Star	$(B-V)$	M_v	AllFe	Allm	$[Fe/H]_{AF_{(B-V)}}$	$[Fe/H]_{Am_{(B-V)}}$	$[Fe/H]_{AF_{M_v}}$	$[Fe/H]_{Am_{M_v}}$	<[Fe/H]>±σ
VZ164	1.09	-1.30	1.20	1.96	-1.42	-1.35	-1.57	-1.55	-1.47±0.11
VZ194	0.97	-1.20	0.92	1.59	-1.71	-1.54	-1.85	-1.81	-1.73±0.14
VZ238	1.56	-2.36	1.57	2.75	-1.53	-1.43	-1.39	-1.23	-1.40±0.12
VZ265	1.29	-1.79	1.38	2.33	-1.45	-1.36	-1.48	-1.40	-1.42±0.05
VZ297	1.41	-2.18	1.52	2.55	-1.42	-1.37	-1.41	-1.33	-1.38±0.04
VZ320	0.80	0.95	0.97	1.49	-1.25	-1.22	-1.34	-1.32	-1.28±0.06
VZ323	0.82	-0.37	1.08	1.63	-1.04	-1.06	-1.51	-1.57	-1.30±0.28
VZ334	1.19	-1.81	1.37	2.15	-1.82	-1.35	-1.52	-1.53	-1.43±0.11
VZ1178	0.69	0.59	0.72	1.06	-1.56	-1.55	-1.81	-1.82	-1.69±0.15
VZ1275	0.80	0.38	0.88	1.45	-1.46	-1.28	-1.59	-1.45	-1.45±0.13
VZ1391	0.90	-0.61	1.06	1.76	-1.30	-1.11	-1.59	-1.53	-1.38±0.22
<M3>									-1.45±0.14

Table 6. Average Metallicity of Each Star and M3

VZ164	VZ194	VZ238	VZ265	VZ297	VZ320	VZ323	VZ334	VZ1178	VZ1275	VZ1391	M3
-1.41 ±0.14	-1.73 ±0.12	-1.47 ±0.12	-1.54 ±0.13	-1.49 ±0.12	-1.20 ±0.14	-1.28 ±0.30	-1.54 ±0.14	-1.57 ±0.22	-1.52 ±0.13	-1.28 ±0.29	-1.46 ±0.15

$$All-FeIndex = 2.47 \cdot (B-V) + 1.10 \qquad (r = 0.847)$$

$$All-metalIndex = 6.01 \cdot (B-V) + 0.02 \qquad (r = 0.942)$$

$$All-FeIndex = -0.55 \cdot M_v + 3.20 \qquad (r = -0.768)$$

$$All-metalIndex = -1.39 \cdot M_v + 5.09 \qquad (r = -0.884)$$

Core Depth Index

$$All-FeIndex = 0.93 \cdot (B-v) + 0.18 \qquad (r = 0.952)$$

$$All-metalIndex = 1.80 \cdot (B-V) - 0.00 \qquad (r = 0.979)$$

$$All-FeIndex = -0.21 \cdot M_v + 0.96 \qquad (r = -0.883)$$

$$All-metalIndex = -0.41 \cdot M_v + 1.52 \qquad (r = -0.907)$$

M71 : $[Fe/H] = -0.79$

Pseudo-Equivalent Width Index

$$All-FeIndex = 4.96 \cdot (B-V) - 0.26 \qquad (r = 0.956)$$

$$All-metalIndex = 11.08 \cdot (B-V) - 3.89 \qquad (r = 0.945)$$

$$All-FeIndex = -1.01 \cdot M_v + 4.92 \qquad (r = -0.877)$$

$$All-metalIndex = -2.40 \cdot M_v + 8.63 \qquad (r = -0.864)$$

Core Depth Index

$$All-FeIndex = 1.06 \cdot (B-V) + 0.41 \qquad (r = 0.959)$$

$$All-metalIndex = 1.90 \cdot (B-V) + 0.48 \qquad (r = 0.957)$$

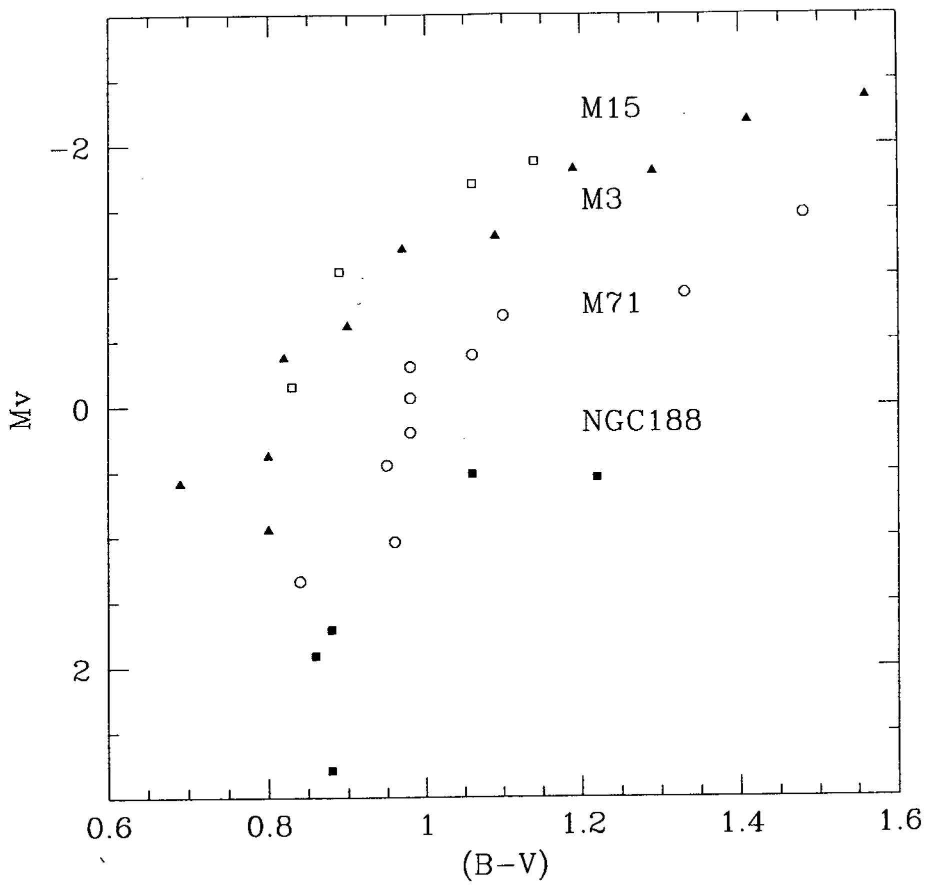

Fig. 1. Distribution of calibration cluster stars in dereddened (B-V) versus M_v diagram. Open squares represent stars in M15, filled triangles those in M3, open circles those in M71, and filled squares those in NGC188.

$$All - FeIndex = -0.22 \cdot M_v + 1.52 \quad (r = -0.887)$$

$$All - metalIndex = -0.39 \cdot M_v + 2.47 \quad (r = -0.890)$$

NGC 188 : [Fe/H] = -0.06

Psuedo-Equivalent Width Index

$$All - FeIndex = 10.06 \cdot (B - V) - 3.77 \quad (r = 0.988)$$

$$All - metalIndex = 18.36 \cdot (B - V) - 7.98 \quad (r = 0.992)$$

$$All - FeIndex = -1.45 \cdot M_v + 8.25 \quad (r = -0.875)$$

$$All - metalIndex = -2.65 \cdot M_v + 13.96 \quad (r = -0.882)$$

Core Depth Index

$$All - FeIndex = 2.21 \cdot (B - V) - 0.40 \quad (r = 0.952)$$

$$All - metalIndex = 3.39 \cdot (B - V) - 0.80 \quad (r = 0.969)$$

$$All - FeIndex = -0.32 \cdot M_v + 2.30 \quad (r = -0.913)$$

$$All - metalIndex = -0.47 \cdot M_v + 3.29 \quad (r = -0.886)$$

The absolute values of correlation coefficient of above relations are all larger than 0.768. Based on those relations, relations of metallicity with all-Fe index and with all-metal index for a given color and a given abosolute

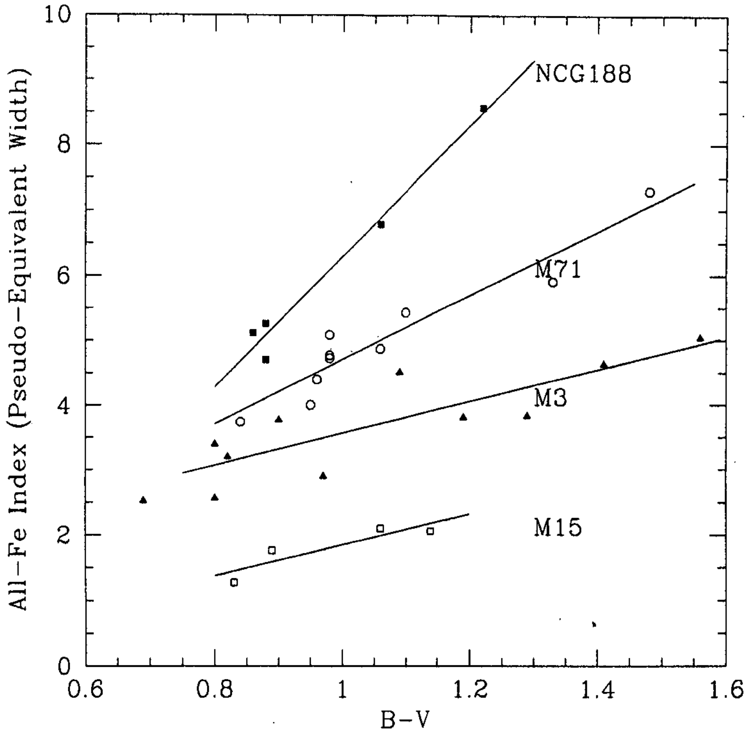

Fig. 2(a). All-Fe index of pseudo-equivalent width versus dereddened (B-V) for cluster giants. The symbols are same as Figure 1.

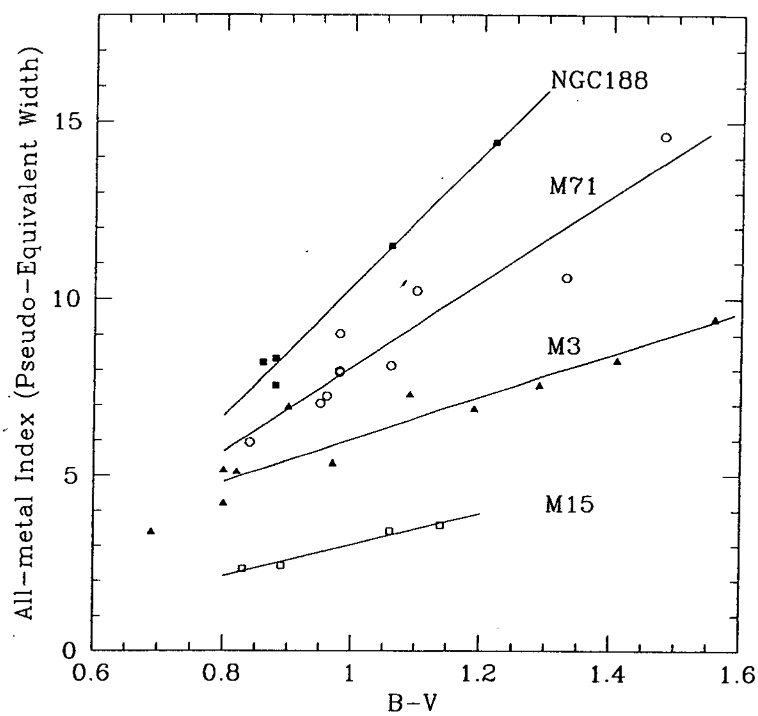

Fig. 2(b). All-metal index of pseudo-equivalent width versus dereddened (B-V) for cluster giants. The symbols are same as Figure 1.

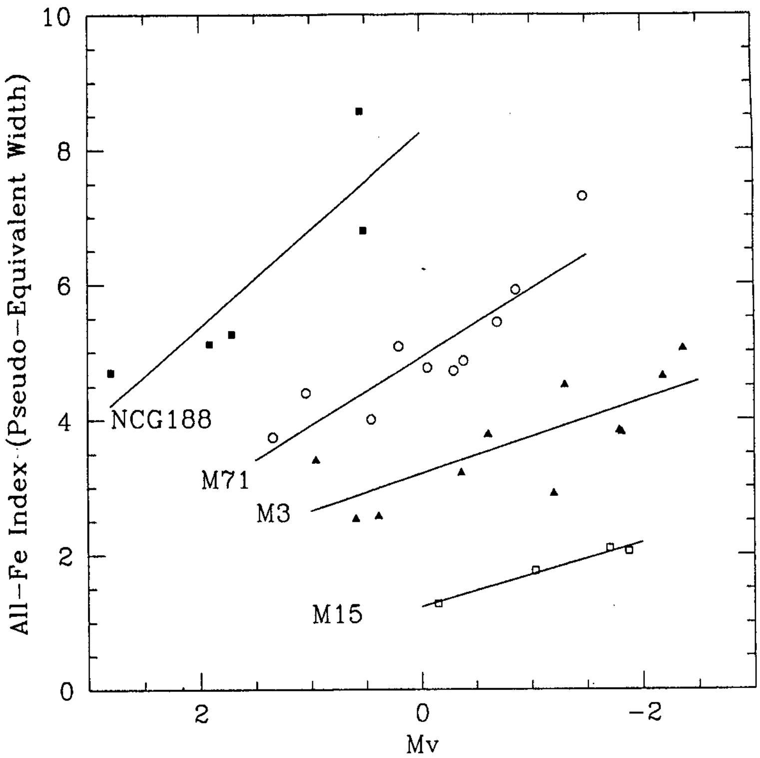

Fig. 2(c). All-Fe index of pseudo-equivalent width versus M_v for cluster giants. The symbols are same as Figure 1.

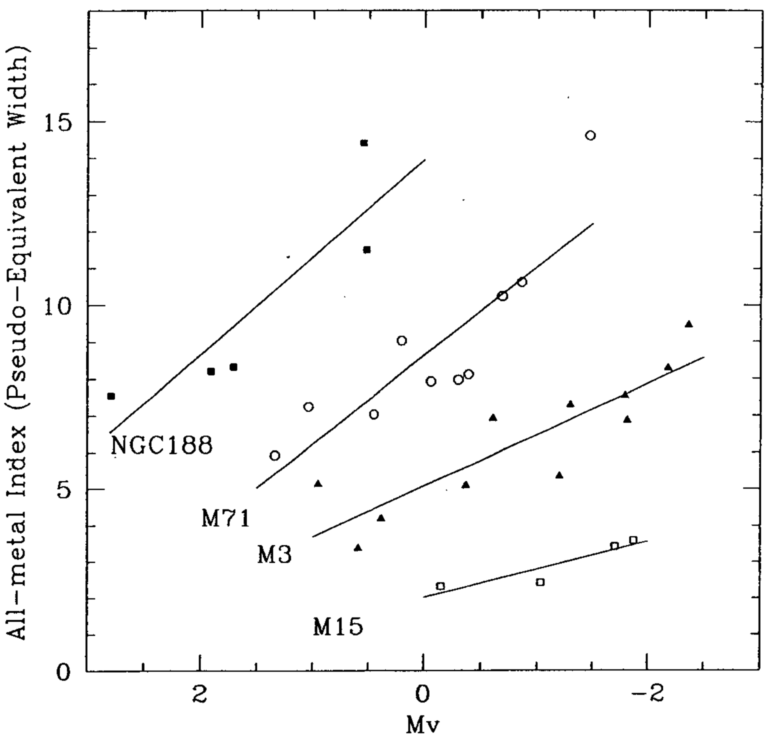

Fig. 2(d). All-metal index of pseudo-equivalent width versus M_v for cluster giants. The symbols are same as Figure 1.

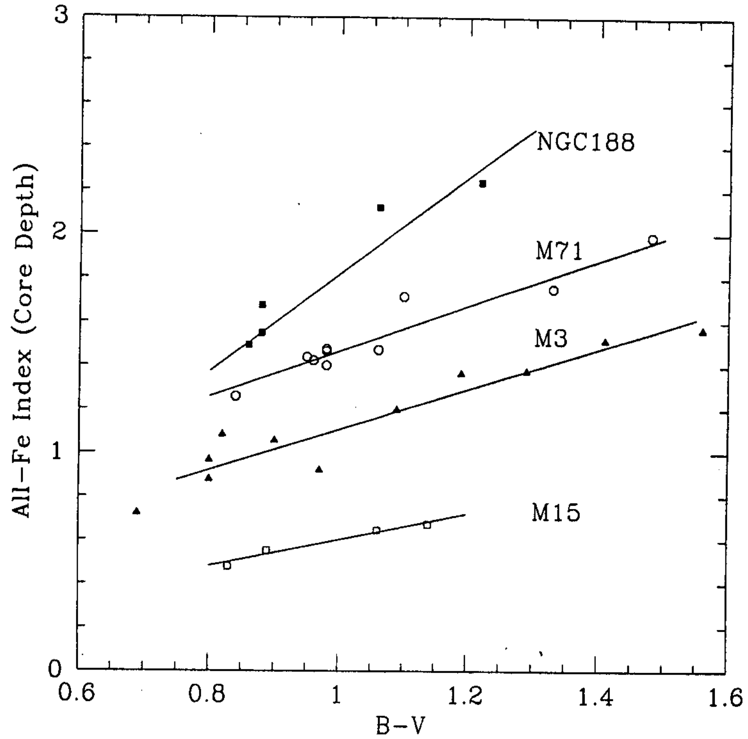

Fig. 3(a). All-Fe index of core depth versus dereddened (B-V) for cluster giants. The symbols are same as Figure 1.

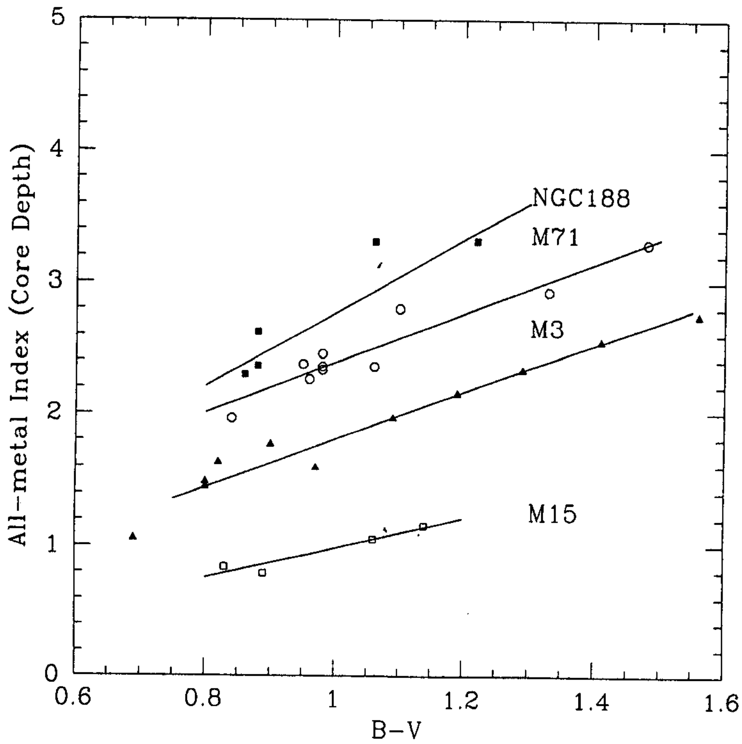

Fig. 3(b). All-metal index of core depth versus dereddened (B-V) for cluster giants. The symbols are same as Figure 1.

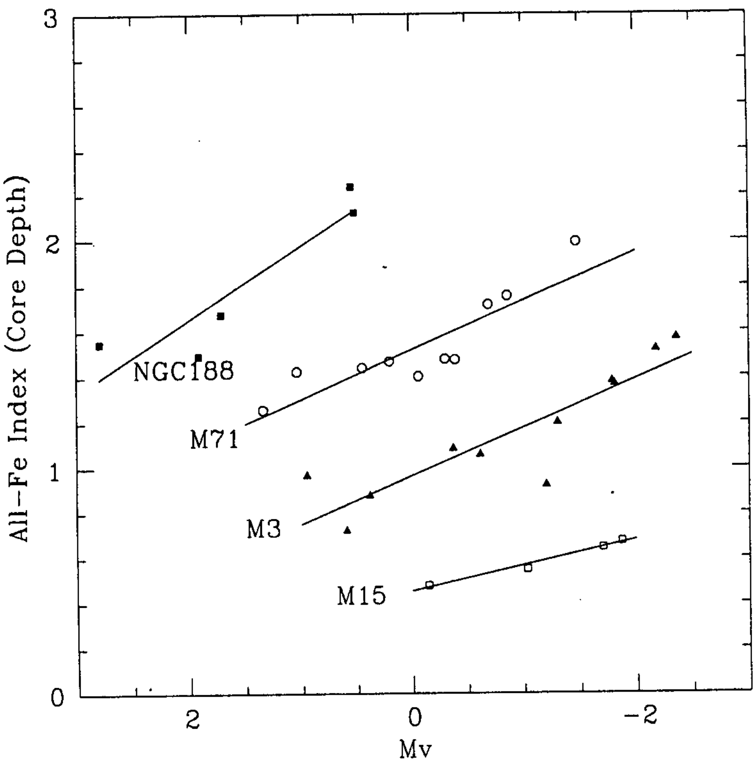

Fig. 3(c). All-Fe index of core depth versus M_v for cluster giants. The symbols are same as Figure 1.

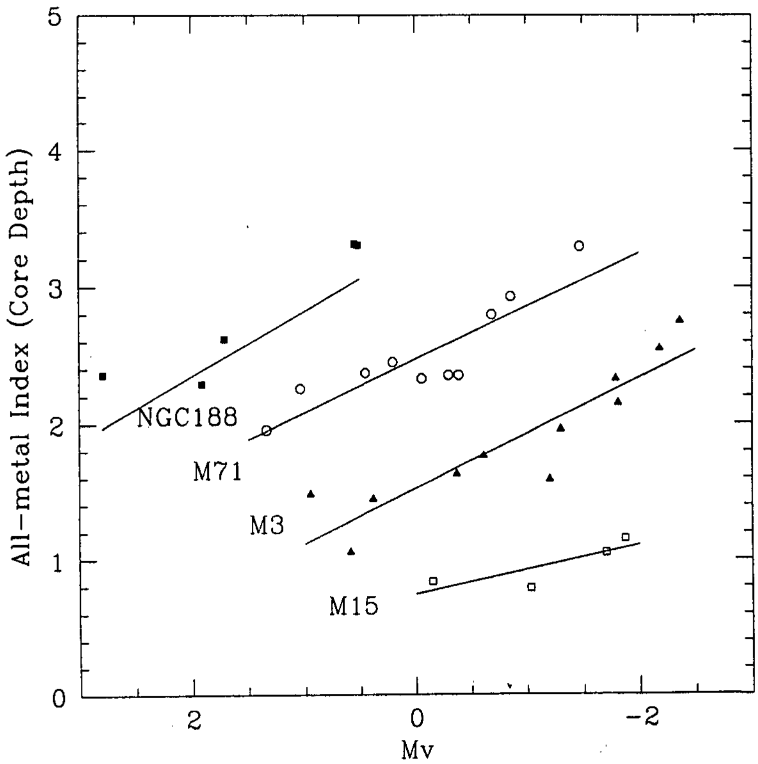

Fig. 3(d). All-metal index of core depth versus M_v for cluster giants. The symbols are same as Figure 1.

magnitude could be derived.

The metallicity of globular cluster M3 has been rederived by averaging the metallicities of individual stars in M3 which were derived from the relations of metallicity with all-Fe index and with all-metal index for each giant star.

The metallicity of each star with all-Fe and all-metal indices of pseudo-equivalent width is listed in Table 4. Table 5 is the same one for core depth indices. The metallicity of individual star derived from the pseudo-equivalent width index varies from −1.11±0.15 for VZ320 star to −1.74±0.12 for VZ194 star and the average metallicity of M3 is obtained as −1.47±0.21. For core depth index, metallicity varies from −1.28±0.06 for VZ320 to −1.73±0.14 for VZ194, and the average of all stars leads metallicity of M3 to be [Fe/H] −1.45±0.14. It is interesting to note that core depth index gives better result than pseudo-equivalent width index.

The average metallicity of both results for each individual star is listed in Table 6 where [Fe/H], −1.20 of VZ320 is the richest and [Fe/H], −1.73 of VZ194 is the poorest, which leads the average metallicity of M3 −1.46±0.15.

IV. RESULTS AND DISCUSSION

¿From the medium resolution spectra of 30 giant stars in 4 clusters, metal sensitive indices, all-Fe and all-metal indices are defined by summing up several metal-sensitive lines. These indices are much less noiser than individual line indices and lead to better determination of metallicity.

These indices are obtained from both pseudo-equivalent width and core depth of individual lines. However,it is found that measurement of core depth of a line is more accurate than that of pseudo-equivalent width, therefore, the final result of metallicity is derived more accurately by summed indices of core depth than those of pseudo-equivalent width.

Relations between metallicity and summed spectral indices are derived from the relations of summed indices and unreddened color or absolute magnitude for each cluster. With those metallicity versus index relations, metallicty of individual stars in M3 is derived and by averaging them, that of M3 is derived −1.46±0.16. The metallcity of individual star of M3 varies from −1.20±0.14 for VZ320 to −1.73±0.12 for VZ194. For both stars same trend is shown for core depth index and pseudo-equivalent width index. However only one spectrum for each star were used for this study, it is difficult to say that metallicty of VZ320 is really [Fe/H]= −1.20 and that of VZ194 is [Fe/H]= −1.73, but it is not improbable that VZ320 is metal richer and VZ194 is metal poorer than others. So far it has been known that metallicity of individual stars of the most globular cluters is within a narrow range of cluster metallicity. ω Cen and M22 are the exceptions to have internal dispersion of σ[Fe/H] = 0.30 (Norris 1980), 0.11(Norris and Freeman 1983) respectively. The internal dispersion of metallicity of M3 is found σ[Fe/H] = 0.03 from recent high resolution study of Kraft *etal.*(1992). However the result was derived from a sample of 7 stars. The narrowness of color-magnitude diagram dose support the extreme chemical homogeneity of globular cluters, but could suggest only the upper boundary of internal dispersion of σ[Fe/H] = 0.16 for M15 (Sandage and Katem 1977). From Table 2 of Sunzeff(1993), which is a collection of dispersion studies for clusters and galaxies, we can easily notice that the more sample stars were studied in a globular cluster or galaxy, the larger chemical inhomogenity was found. Therefore until statistically sufficient sample of stars in M3 is studied in high resolution spectroscopy, it can not be ruled out that metallicities of VZ320 and VZ194 are not entirely due to the observational errors.

For determination of the relations between metallicity and indices, stars in M3 are also used because of small sample of calibration clusters. Therefore the result of M3 is not independent from the value of input metallicity of M3. It is not suprising that the result value is close to the input value. However the standard deviation, dex 0.15 of result implies that this method leads better result than most photometric methods. And this method could derive more accurate metallicity, if we increase the number of calibation globular clusters.

In summary, a new method of metallicity determination for a globualr cluster is obtained by using summed indices, measured on the medium resolution spectra. Especially the result that the core depth index, which is more easily measurable and less subjective in measurements, leads more accurate determination of metallicity, is quite promising. And this method can be improved by adding more calibration clusters in future study. The metal abundance of M3 is derived [Fe/H] = −1.46±0.15, from this method.

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