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NEAR-IR GIANT BRANCH SLOPE-METALLICITY RELATION OF OPEN CLUSTERS

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ABSTRACT

We derive a new relationship between the giant branch slope as measured in the color-magnitude diagram $(K, J-K)$ and [Fe/H] metallicity for old open clusters. Previously such relationships have been derived for globular clusters, while similar tendency has been expected for open clusters. New derived correlation, [Fe/H]$=-17.2(\pm0.23)$GB slope $-$ $1.95(\pm0.02)$, is based on a collection of data for 10 old open clusters. Most clusters behave as expected from the theoretical predictions.

Key words : giant branch, metallicity, IR photometry, open cluster

I. INTRODUCTION

The chemical evolution of galactic disk may be understood by studying the age and metallicity of a large sample of open clusters across the galactic disk. However, the required observations are not easy. Besides the difficulties involved with accurate age and metallicity determination, one major problem comes from the fact that most open clusters lie in the plane of the Galaxy and therefore suffer from serious interstellar extinction. This makes it difficult to sample and study open clusters at distant locations, and also to extract their intrinsic characteristics.

Therefore, near-infrared observations are the best choice in studying open clusters especially under heavy extinction. In K-band (2.2 μm), for instance, the extinction is only one-tenth of visual band. Bright giant stars in open clusters emit most of its radiation in this wavelength domain. Also, when combined with optical observations, the $V-K$ color provides a baseline which is much more sensitive to stellar temperatures than optical alone (Cohen et al. 1978).

The metallicity information can be extracted from near-infrared photometry by focusing on the slope of giant branch (GB) in color-magnitude diagrams (CMD). For globular clusters, Frogel et al. (1983) was the first to provide quantitative description of the red giant branch (RGB) location as a function of cluster metal abundance. This idea was extended to near-infrared by Kuchinski et al. (1995), who demonstrated that the globular cluster RGB slope in $(K, J-K)$ CMD is very sensitive to their metallicity. This relation was later refined by Ferraro et al. (2000) using 10 globular clusters to be

$$[\mathrm{Fe/H}]=(-21.93\pm1.84)\ \mathrm{Slope}_{RGB}-(2.70\pm0.15)$$

Recently, similar trend was observationally confirmed for open clusters. Using only 4 open clusters, Tiede et al. (1997) found that the slope of GB in $(K, J-K)$ CMDs correlates with [Fe/H] as it does for metal-rich globular clusters. They also showed that their open cluster data have systematically smaller slopes compared to globular clusters for a given [Fe/H].

In this paper, we present the result of our observations and analysis based on 10 open clusters. This is a part of our observational campaign focused on old galactic open clusters, for which we have carried out photometric observations in both optical and near-infrared wavelengths. As will be shown below, the observed correlation between GB slope and cluster metallicity agrees well with theoretical predictions.

In Section II we briefly describes our observation. Section III gives detailed information on data for each of sample clusters. The CMDs and giant branch slope in $(K, J-K)$ CMD – metallicity relation for 10 open clusters are presented in Section IV, followed by a summary in Section V.

II. OBSERVATIONS

Our observational campaign for open clusters is done both optical and near-infrared wavelengths. For near-infrared observations, we used CASPIR IR system of the 2.3m telescope at the Siding Spring Observatory. For optical, we used the 2K CCD camera of the 1m telescope at the same site. Both telescopes are operated by the Australian National University.

The CASPIR system has InSb 256 × 256 chip with pixel size of 0.5 arcsec at the Cassegrain focus. The readout noise and gain are 50 e^- and 9 e^-/ADU, respectively. More detailed description of the system can be found in McGregor (1995). Since the field of view is small (~2 arcmin), we usually employed 2 × 2 mosaic observation for the central region of each target cluster. Our observations were carried during two observational seasons, 1996 Dec. 23 - 25 and 1999 Dec. 16 - 21.

Table 1. Physical parameters of selected open clusters

Name	RA(J2000)	Dec(J2000)	[Fe/H]	$E(B-V)$	$(m-M)_0$	Age (Gyr)	Ref.
Mel 66	$07^h\ 26.^m3$	$-47°\ 44'$	−0.51	0.14	13.0	6.3	1
M67	08 50.4	+11 48	−0.09	0.03	9.6	4.2	1
NGC 2204	06 15.7	−18 39	−0.38	0.12	13.1	1.6	1,6
NGC 2243	06 29.8	−31 17	−0.63	0.04	12.9	5.0	1,7,8,10
NGC 2477	07 52.3	−38 33	−0.02	0.22	10.5	1.0	1
NGC 2141	06 03.1	+10 26	−0.39	0.30	13.2	4.0	5,7
NGC 2660	08 42.3	−47 09	+0.07	0.41	12.2	1.0	1,2,9
To 2	07 03.4	−20 51	−0.32	0.24	14.6	2.0	3
NGC 7789	23 57.0	+56 44	−0.25	0.31	11.3	1.6	4
NGC 2506	08 00.1	−10 47	−0.40	0.04	12.5	1.8	1

Sources : 1. Houdashelt et al. (1992) 2. Kyeong et al. (2001) 3. Kyeong & Byun (2000) 4. Frogel & Elias (1988) 5. Rosvick (1995) 6. Kassis et al. (1997) 7. Friel & Janes (1993) 8. Janes (1979) 9. Sandrelli et al. (1999) 10. Hawarden (1975)

The near-infrared data were preprocessed using routines in IRAF CCDRED package. The stellar photometry was done by the point spread function fitting packages, DAOPHOT and ALLSTAR, followed by star matching process with DAOMATCH and DAOMASTER routines (Stetson 1992). Instrumental magnitudes were transformed into standard system using formulae we derived from the aperture photometry of standard stars. More detailed description of data reduction can be found in Kyeong & Byun (2000).

III. SAMPLE CLUSTERS

Our observations are targeted to old open clusters with age greater than 1 Gyr as classified by Friel (1995). In order to increase the giant star sample size for the present study, we combined our data with a few published data sets (Houdashelt et al. 1992, Frogel & Elias 1988). The final sample consists of giant stars in 10 clusters for which both optical and near-infrared data are available. The description of data source and the adopted physical parameters are given below for each cluster (see also Table 1).

To 2 : We derived its characteristics by combining Kubiak et al. (1992) V band data with our data (Kyeong & Byun 2000). For metallicity, Friel et al.(1995) determined [Fe/H]=−0.35 from spectroscopic observation, while Friel & Janes (1993) estimates −0.60. Kyeong & Byun (2000) derived [Fe/H] = −0.37 from isochrone fitting to multi-color CMD using both optical and IR data. The adopted metallicity, distance modulus and reddening value are −0.37, 14.6, 0.24, respectively.

NGC 2660 : Most star data are from our own observations some are from Houdashelt et al.(1992). [Fe/H] values found in the literature varies greatly. Geisler et al.(1992) considers it as a metal poor cluster of [Fe/H] = −1.05 from their Washington photometry of seven assumed members. Hesser & Smith (1987) derived −0.4 from DDO photometry, while Sandrelli et al. (1999) argues for near solar metallicity based on synthetic CMD method. Kyeong et al. (2001) derived +0.07 from isochrone fitting method applied to $(V, B-V)$ CMD. We adopted [Fe/H] = +0.07, $E(B-V)$ = 0.41, $(m-M)_0$ = 12.2 from our analysis.

NGC 2141 : We adopted the metallicity of −0.39 as given by Friel & Janes (1993)'s spectroscopic data. The reddening value and distance modulus by other authors are consistent around 0.30, 13.1, respectively.

NGC 2243 : Our K band data are combined with Houdashelt et al. (1992)'s photoelectric data. Friel & Janes (1993) estimates its metallicity as −0.56 while Janes (1979) and Hawarden (1975) derived −0.63. The latter is adopted in our analysis. $E(B-V)$=0.04, $(m-M)_0$=12.9 are also from previous studies (Norris & Green 1989, van den Berg & McClure 1980, Friel & Janes 1993).

NGC 2204 : Houdashelt et al. (1992) data are combined with our K band. Janes (1979), Hawarden (1976) and Dawson (1981) derived $E(B-V)$=0.08, [Fe/H]=−0.38, $(m-M)_0$=13.1. We adopted values from Kassis et al. (1997), who derived 0.12, −0.38, 13.1, respectively from their deep CCD observations.

NGC 2477 : This cluster is known to have variable reddening. Houdashelt et al. (1992) data are combined with our data, after their reddening correction. For our observation field, relatively small central area, we used a fixed reddening value ($E(B-V)$=0.20). Hirshfeld et al. (1978), Smith & Hesser(1983) and Kassis et al. (1997) derived similar metallicity of [Fe/H] = −0.02.

NGC 2506 : Our data and Houdashelt et al. (1992)'s data are combined to increase the number of giant branch sample. $E(B-V)$=0.05, [Fe/H]=−0.52 (Hirshfeld et al. 1978, McClure et al. 1981) and $(m-M)_0$=12.2 (van den Berg & McClure 1980) are adopted.

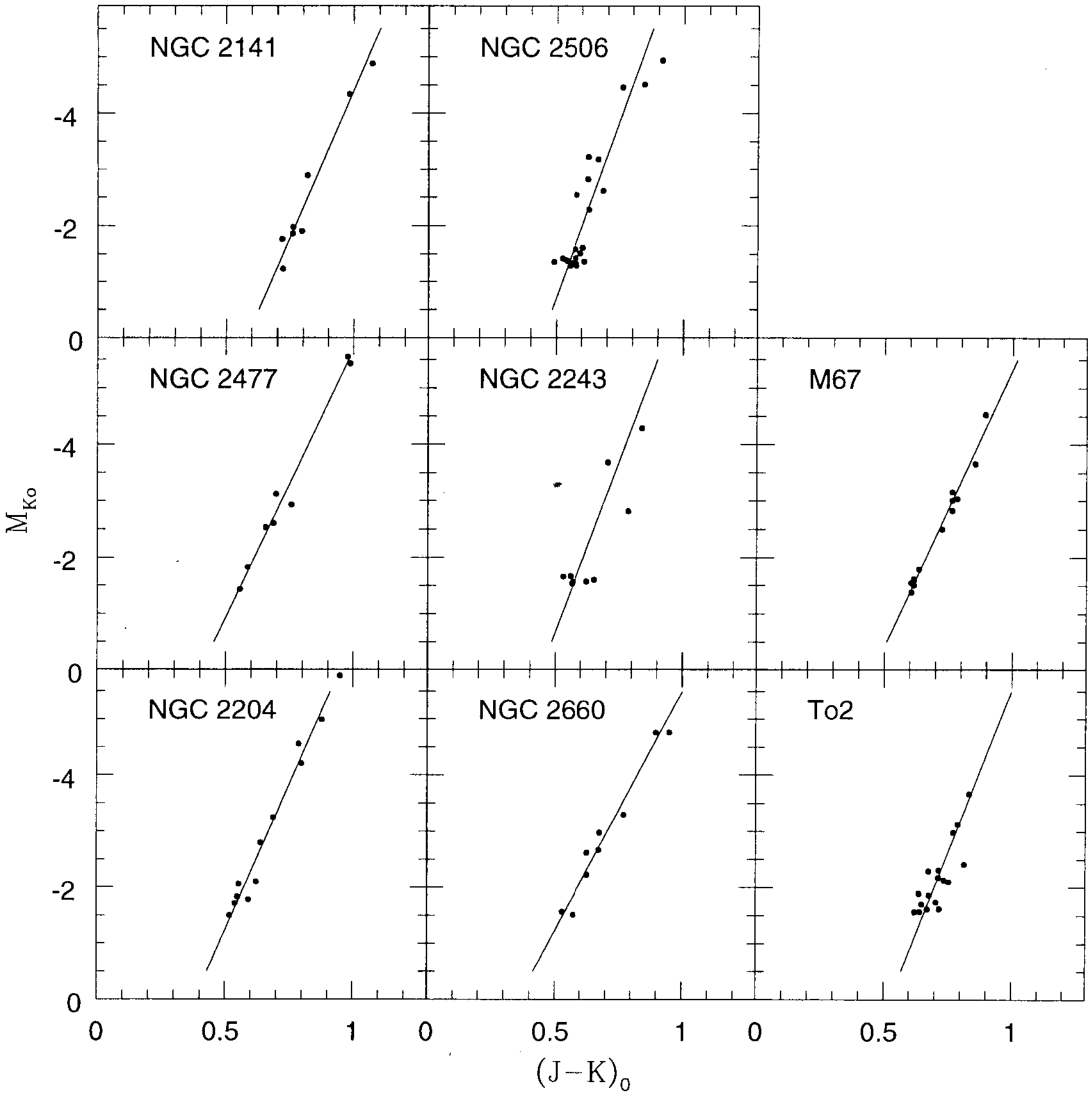

Fig. 1.— $(K, J-K)$ CMD of the giant branch of each target cluster. The solid lines are least-square fit to the giant branch.

M67 : Houdashelt et al. (1992) data are used. The metallicity, reddening, distance modulus are as given in the same paper.

NGC 7789, Melotte 66 : Frogel & Elias (1988)'s data are used exclusively. The GB slope values of these two clusters are as given by Tiede et al. (1997).

IV. GB SLOPE AND METALLICITY

Using the extinction law given by Bessell & Brett (1988), we corrected the collected photometric data for the reddening and also derived the absolute K magnitudes based on the adopted distance moduli. Although both the reddening and distance moduli contain errors, the derived GB slope is hardly affected by these errors; such errors will shift the location of GB either horizontally or vertically without changing its slope.

Figure 1 shows the CMD of giant branch for each sample cluster. The GB slope is defined as $\Delta(J-K)/\Delta K$ in $(K, J-K)$ CMD. We performed a least square fit to the selected GB stars, and iterated the process with 2σ rejection. The resulting best fit is indicated in Figure 1. The derived intercept, slope and their uncertainties are given in Table 2.

In the present analysis, it should be noted that we included those stars in the giant branch only with absolute magnitudes in the range $-1.5 \leq M_K \leq -6.5$. This is similar to Tiede et al. (1997)'s approach. This criteria excludes both red giant clump stars and bright asymptotic giant branch (AGB) stars. In this magnitude range, $V-K$ color is also used to separate AGB stars from the giant stars.

Table 2. Fitting parameters of giant branch slope ($J - K = b + a \times K$)

Name	intercept(b)	σ(intercept)	slope(a)	σ(slope)
M67	0.457	0.01	−0.102	0.004
Mel 66[1]			−0.077	0.014
NGC 2204	0.382	0.02	−0.096	0.004
NGC 2477	0.402	0.02	−0.105	0.006
NGC 2141	0.580	0.02	−0.095	0.008
NGC 7789[1]			−0.099	0.004
NGC 2660	0.356	0.03	−0.117	0.008
NGC 2243	0.443	0.04	−0.083	0.014
To 2	0.525	0.03	−0.086	0.015
NGC 2506	0.443	0.02	−0.079	0.007

Note : 1. Adopted from Tiede et al. (1997)

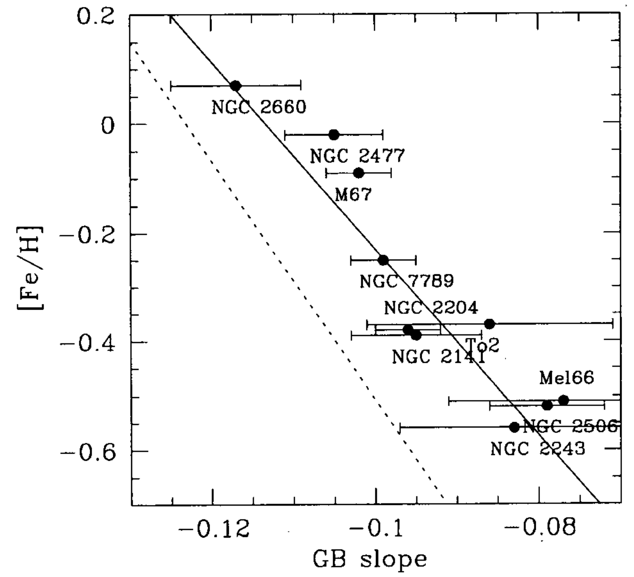

Fig. 2.— Plots of [Fe/H] *vs.* giant branch slope for sample open clusters. The dotted line is the relation from Ferraro et al. (2000) derived for globular clusters given here for comparison. The solid line is a weighted least square fit for open cluster sample only. The error bars represent uncertainties in our GB slope determination.

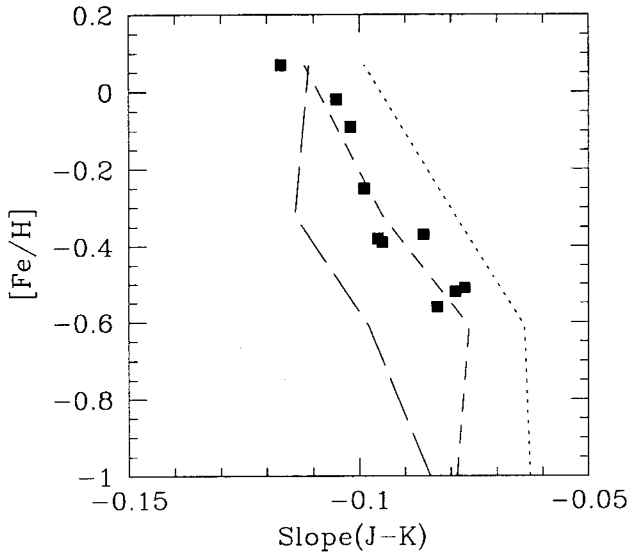

Fig. 3.— ($K, J-K$) Theoretical GB slope vs. Metallicity from Bertelli et al. (1994) isochrone. The dotted line is for 1 Gyr, short-dash line for 5 Gyr, and long-dash line for 8 Gyr. The point we obtained is overimposed.

The derived GB slopes are plotted against metallicity [Fe/H] in Figure 2. The relationship for globular clusters, as taken from Ferraro et al. (2000), are also shown. The solid line given in Fig. 2 is an error weighted least square fit to open cluster data. This defines the correlation between GB slope and metallicity as

$$[\mathrm{Fe/H}] = -17.2(\pm 0.23)\ \mathrm{GB\ slope} - 1.95(\pm 0.02)$$

In order to make theoretical examination of the relationship between giant branch slope and cluster metallicity, we constructed ($M_K, J-K$) CMDs using Padova isochrones. We considered models with ages = 1, 5, 8 Gyr and [Fe/H] = −1.58, −1.19, −0.61, −0.32, +0.07. Padova isochrones do not permit construction of theoretical models older than 8 Gyr. The isochrones include the transformed observable infrared magnitude from theoretical plane using the response functions for JHK passbands (Bessell & Brett 1988, Bertelli et al. 1994). We demonstrated previously that the Padova isochrones show good description for old open clusters in the near-infrared domain (Kyeong & Byun 2000). The calculated GB slope – [Fe/H] relation for each age group are shown in Fig. 3. All the sample open clusters lie close to the theoretically constructed relationship for age of 5 Gyr. More detailed age dependence would require a larger sample.

For globular clusters, Kuchinski et al. (1995) reported that the age spread of $10 \leq t(\mathrm{Gyr}) \leq 16$ is too small to show differences in the RGB−metallicity relation. However, for open clusters, having an age span of $1 \leq t(\mathrm{Gyr}) \leq 10$, it appears that the theoretical lines between different age groups are wildly different in this parameter space. If this can be observationally proved, we may be able to use the GB slope – metallicity relation as an age indicator for those open clusters which are so heavily extinct that optical age estimates are not possible. This would however require further investigation on larger number of open clusters with good age determinations.

For clusters younger than ~ 1 Gyr, the upper giant branch does not terminate at helium flash and tends to curve toward hotter temperatures at higher luminosities. Therefore, the upper giant branch would not be linear but more likely a second order curve in $(K, J-K)$ CMD (Tiede et al. 1997).

V. SUMMARY

In this paper we have examined the GB slope – [Fe/H] relation in $(K, J-K)$ CMD using a sample of 10 old open clusters. Previously a similar study was done by Tiede et al. (1997) but with only 4 clusters. Our J, K band data and published data of Houdashelt et al. (1992) and Frogel & Elias (1988) are used to derive GB slopes and subsequently correlated with cluster [Fe/H] values.

The sample clusters show GB slope and [Fe/H] relation in the range predicted by theoretical models of compatible ages. According to our models, the age is very likely to be an important third parameter. However, the number of our sample is too small to examine more general three dimensional relationship among age, [Fe/H], and GB slopes. The sensitivity of GB slope – [Fe/H] relationship to age is not significant for old stellar population like globular clusters but becomes much more serious for younger ages. Further investigation is necessary to observationally verify what models predict, and the GB slope – [Fe/H] relation may turn out to be very useful age indicator for galactic open clusters.

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