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THE PROBLEMS IN THE USUAL METHOD OF CLASSIFICATION FOR METAL POOR STARS

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ABSTRACT

The usual method of classification for metal poor stars is based on the normal standard stars. In this study, we show that among the sample of stars classified by this method, a systematic bias in the observed classes of metal weakness is found and, also that this method is not appropriate for classification of metal poor stars, by showing that the spectral line dependences on the temperature and pressure in the extreme metal poor stars are different from those in the normal standard stars. Therefore, we suggest that the 3-dimensional classification system, like 2-dimensional MK system, is necessary for an accurate classification of metal poor stars.

I. INTRODUCTION

In a study of high-velocity stars of type F, Roman (1954) found their spectra to show extreme line weakening, and further the large UV excesses. The UV excesses have been found to be a consequence of the weakening of the metallic lines (Sandage and Eggen 1959; Eggen and Sandage 1962; Melbourne 1960; Wildey, Burbidge, Sandage, and Burbidge 1962). Further the weakening of the metallic lines has been proved to be due to an actual deficiency of heavy elements in their composition (M. and B. Schwarzschild 1950; Chamberlain and Aller 1951; E. and G. Burbidge 1956; Greenstein and Keenan 1958). Therefore, the weak metallic line stars are believed to be the important local representations of the oldest objects, which provide the valuable clues of the earliest phase of the Galaxy formation.

However, before Roman's (1954) study, most weak metallic line stars have been classified too early for their temperature. Even after that the types for the same metal poor stars are classified differently by various classifiers (Lee 1984), although they used the same criteria and the same process to classify these stars. That is, the temperature class of a star was usually estimated first, based on the strength of the Balmer lines of hydrogen and the Ca II lines. Then, for the

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luminosity classes the strength of Sr II was used. After that, the weakness of metals was estimated by comparing with the spectra of the same temperature and luminosity class of the normal stars. Therefore, in principle, the strengths of Balmer lines of hydrogen and Ca II lines of the metal poor stars have to match those of the normal stars of the same temperatures. However spectrograms of the standard stars of the every types are not always available for the classification. The different spectral types for a given metal poor star can be easily resulted by various authors, depending on how easily the change of the line strengths are noticed on their classification spectrograms. But as seen in Lee's (1984) study, the difference is not random, rather systematically increases towards the extreme metal poor stars. At this moments, it is difficult to figure out the cause of this systematic increase. However we can accept that this implies the usual method of classification for metal poor stars is not quite appropriate.

In this study, we would like to present one another evidence that the usual method of classification for metal poor stars is not appropriate for temperature and luminosity classes. So that leads the systematically different metal weakness for dwarfs and giants. That is presented in section II.

The usual method of classification for metal poor stars is based on the assumption that the strength of the spectral lines is most easily affected by the temperature change, then by the pressure change, and then by the metallicity change. However, if a star has an extremely low metalicity, the electrons are too few to form H minus for the continuum opacity. Therefore it is expected that the dependences on the temperature and luminosity of the spectral lines are quite different from those of the normal stars.

Therefore, we will disscuss in the section III, the temperature and pressure dependences of spectral lines in the extreme metal poor stars are different from those in the normal stars, and then in section IV, conclude the results of this study.

II. THE OBSERVED BIAS OF THE METAL WEAKNESS

In this section we would like to prove that the usual method of classification for metal poor stars is not appropriate by showing that the classified metal weakness by that method is found to be systematically biased.

Bidelman and MacConnell (1973) have classified kinematically unbiased sample of the metal poor stars on the objective-prism plates. They classified the metal weakness of the metal poor stars, slight, moderate, and extreme, after determination of the temperature class of a star first, as usual method. Since their spectral dispersion is too low for the luminosity class, they only have given the spectral types with the metal weakness classes.

If the usual classification for the metal poor stars is appropriate, then we could expect that the average metal abundances of the metal weakness classes are approximately the same for the dwarfs and giants. But it turns out that's not the case.

We adopted the published abundance and photometric data of Norris *et al.* (1985), and Carney

(1978, 1980), for the metal abundnance and the luminosity class of each star among the Bidelman-MacConnell sample of the metal poor stars. Among the sample of metal poor stars of Bidelman-MacConnell stars, horizontal branch stars, red giants, subgiants, subdwarfs, a few blue stragglers, and even RV Tauri variables are included. Therefore among them, 139 dwarfs and 110 red giants are selected for this study.

For 139 dwarfs, Bidelman and MacConnell classified their metal weakness, 47 stars (34%) slight, 71 stars (51%) moderate, and 21 stars (15%) extreme, respectively. While for 110 red giants, they did 19 stars (17%) slight, 70 stars (64%) moderate, and 21 stars (19%) extreme, respectively. However the average metal abundances of the each metal weakness class of dwarfs are quite different from the same metal weakness class of the red giants as seen in Table 1.

Table 1. The Number of Stars and the Average Metal abundance of Stars in each Metal Weakness Class among Dwarfs and Giants.

	Metal Weakness Class	Slight	Moderate	Extreme
Dwarfs	Number of Stars (%)	47 (34%)	71 (51%)	21 (15%)
	⟨[Fe/H]⟩	-0.38 ± 0.41	-0.52 ± 0.51	-1.31 ± 0.63
Giants	Number of Stars (%)	19 (17%)	70 (64%)	21 (19%)
	⟨[Fe/H]⟩	-1.38 ± 0.54	-1.80 ± 0.50	-2.23 ± 0.32

The average metal abundances of metal weakness classes, slight, moderate, and extreme for dwarfs are found to be $[Fe/H]=-0.38\pm0.41$, -0.52 ± 0.51, and -1.31 ± 0.63 respectively. The values of the same classes for red giants are $[Fe/H]=-1.38\pm0.54$, -1.80 ± 0.50, and -2.23 ± 0.32 respectively.

The same bias among the sample of the Bidelman and MacConnell metal poor stars has been noticed by Norris *et al.* (1985), which is that the metal abundnances for the red giants and dwarfs are [Fe/H] ~ -2.0 and ~ -0.4 respectively —a difference in abundnance of 1.6 dex. They have explained that the cause of this difference is due to the selection effect which is related to the critical abundance at which line weakness becomes apparent. It has been known that cooler stars must be more metal poor in order to show the same apparent line weakening. That means the apparent line weakness is a function of effective temperature too. Therefore, Norris *et al.* (1985) explained the average abundance difference between red giants and dwarfs is due to the average temperature difference between them. This explanation is quite right, but can not explain all the observed facts. If it is the only cause for that, it is expected that among the giants or dwarfs the cooler ones have lower average metal abundance in either case. But it is not turned out that way. Table 2-a and 2-b give the number of stars and the average metal abundance of the stars in each color among dwarfs and red giants. Figure 1-a and 1-b are the plots of number distribution and average metal abundance distribution along the *B-V* color for dwarfs and giants. Solid lines are for dwarfs and dashed lines for giants.

As seen in Figure 1-b, the average metal abundance distribution along the *B-V* color of dwarfs

Table 2-a. The Number of Stars and the Average Metal Abundance of Stars in each *B-V* Color among Dwarfs.

	(*B-V*)	≤0.40	≤0.45	≤0.50	≤0.55	≤0.60	≤0.65	≤0.70	≤0.75	≤0.80	≤0.85
Slight	Number of Stars	2	9	15	6	8	3	3	—	1	—
	〈[Fe/H]〉	−0.27	−0.49	−0.23	−0.46	−0.53	−0.45	−0.53	—	−0.42	—
Moderate	Number of Stars	4	17	19	16	9	6	—	—	—	1
	〈[Fe/H]〉	−0.59	−0.56	−0.47	−0.44	−0.66	−0.43	—	—	—	−0.39
Extreme	Number of Stars	1	8	11	1	—	—	—	—	—	—
	〈[Fe/H]〉	−0.43	−1.57	−1.29	−0.81	—	—	—	—	—	—
Total	Number of Stars	7	34	45	23	17	9	3	—	1	1
	〈[Fe/H]〉	−0.48	−0.78	−0.59	−0.46	−0.60	−0.43	−0.53	—	−0.42	−0.39

Table 2-b. The Number of Stars and the Average Metal Abundance of Stars in each *B-V* Color among Giants.

	(*B-V*)	≤0.65	≤0.70	≤0.75	≤0.80	≤0.85	≤0.90	≤0.95	≤1.00
Slight	Number of Stars	—	—	—	1	8	3	—	3
	〈[Fe/H]〉	—	—	—	−2.00	−1.58	−0.83	—	−0.95
Moderate	Number of Stars	—	6	10	8	9	6	6	6
	〈[Fe/H]〉	—	−2.02	−1.98	−1.88	−1.91	−1.78	−1.38	−1.43
Extreme	Number of Stars	3	2	7	—	1	1	3	1
	〈[Fe/H]〉	−2.27	−2.04	−2.20	—	−2.58	−2.45	−2.47	−1.31
Total	Number of Stars	3	8	17	9	18	10	9	10
	〈[Fe/H]〉	−2.27	−2.02	−2.07	−1.87	−1.80	−1.56	−1.74	−1.27
	(B−V)	≤1.05	≤1.10	≤1.15	≤1.20	≤1.25	≤1.30	≤1.35	>1.40
Slight	Number of Stars	—	1	1	1	—	1	—	—
	〈[Fe/H]〉	—	−1.09	−1.48	−2.66	—	−1.85	—	—
Moderate	Number of Stars	4	3	2	—	4	1	2	2
	〈[Fe/H]〉	−1.89	−1.47	−1.48	—	−1.96	−1.76	−2.33	−2.10
Extreme	Number of Stars	—	—	—	1	1	1	—	—
	〈[Fe/H]〉	—	—	—	−2.47	−2.31	−1.89	—	—
Total	Number of Stars	4	4	3	2	5	3	2	2
	〈[Fe/H]〉	−1.87	−1.38	−1.48	−2.57	−2.03	−1.83	−2.33	−2.10

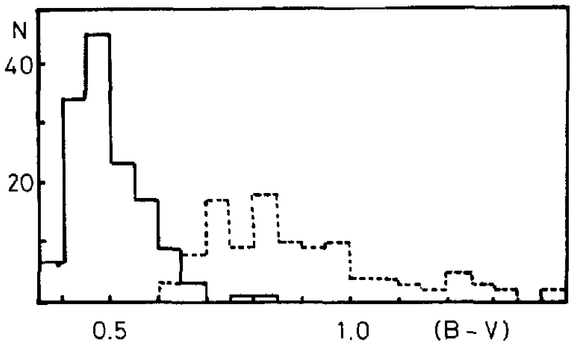

Fig. 1-a. The Number distribution along the B-V color for dwarfs and giants. Solid lines are for dwarfs and dashed lines for giants.

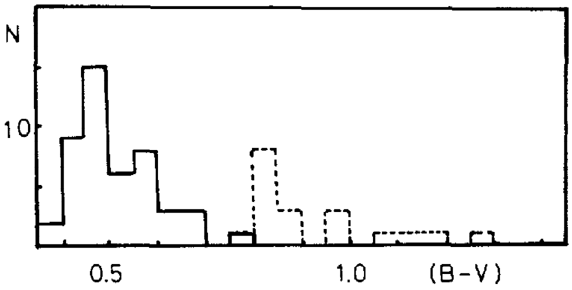

Fig. 2-a. The Number distribution of the metal weakness class, *slight*, along the B-V color for dwarfs and giants. Solid lines are for dwarfs and dashed lines for giants.

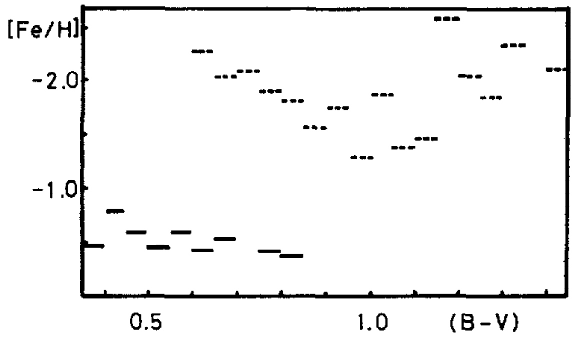

Fig. 1-b. The average metal abundance distribution along the B-V color for dwarfs and giants. Solid lines are for dwarfs and dashed lines for giants.

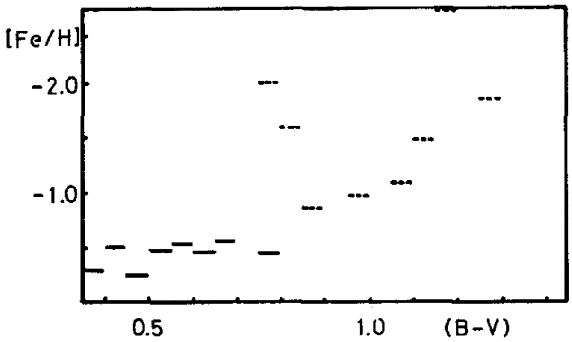

Fig. 2-b. The average metal abundance distribution of the metal weakness class, *slight*, along the B-V color for dwarfs and giants. Solid lines are for dwarfs and dashed lines for giants.

and red giants does not show that the average metal abundance of stars decreases towards the cooler ones both in dwarfs and red giants. It is unfortunate that this Bidelman-MacConnell sample of metal poor stars is the magnitude-limited. The fact that the sample is magnitude-limited strongly biases it in favor of giants because of their greater intrinsic brightness. Therefore among the sample, the coolest dwarfs stars are not as cool as the coolest red gaints. But fortunately there is the color region of $0.6 \leq B\text{-}V \leq 0.85$ where both dwarfs and giants are found. In this region, it is seen in Figure 1-b that the average metal abundances of giants are much lower than that of dwarfs too. That means, even in the same temperature region, the average metal abundance difference between giants and dwarfs is found.

The number distributions and the metal abundance distributions of stars are plotted separately according to their metal weaknesses, slight, moderate, and extreme in Figure 2-a and 2-b, Figure 3-a and 3-b, and 4-a and 4-b, respectively. Here again, solid lines are for dwarfs and dashed lines

Fig. 3-a. The Number distribution of the metal weakness class, *moderate*, along the *B-V* color for dwarfs and giants. Solid lines are for dwarfs and dashed lines for giants.

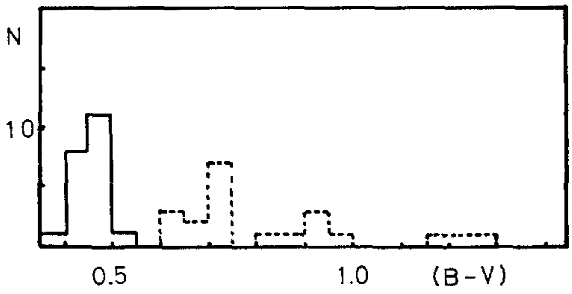

Fig. 4-a. The Number distribution of the metal weakness class, *extreme*, along the *B-V* color for dwarfs and giants. Solid lines are for dwarfs and dashed lines for giants.

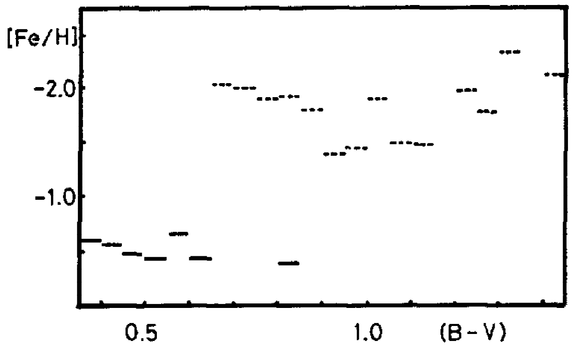

Fig. 3-b. The average metal abundance distribution of the metal weakness class, *moderate*, along the *B-V* color for dwarfs and giants. Solid lines are for dwarfs and dashed lines for giants.

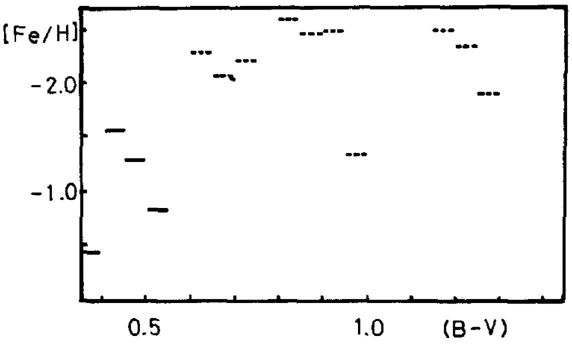

Fig. 4-b. The average metal abundance distribution of the metal weakness class, *extreme*, along the *B-V* color for dwarfs and giants. Solid lines are for dwarfs and dashed lines for giants.

for giants.

It is also found in Figure 2-b and 3-b that the dwarf and red giants of the same metal weakness and the almost same temperature show ~ 1.5 dex difference in abundance. It surely shows that the temperature can not explain this difference in abundance between dwarfs and giants.

However at this point we can not explain explicitly the cause of this, but we can infer that there are some problems in the classification of the metal poor stars by the usual method.

In the next section, we will consider an extreme case, where the metal is so scarce that electrons are not enough to produce H minus and compare this case with the normal stars to suggest that the usual method of classification for metal poor stars is not appropriate.

III. THE DEPENDENCE OF THE SPECTRAL LINES ON THE TEMPERATURE AND PRESSURE IN THE EXTREME METAL POOR STARS

In this section, we would like to show that when the metals decrease in the star of near solar type, not only the line absorption coefficient but also the continuum absorption coefficient are affected. Therefore, the dependence of the spectral lines on the temperature and pressure will be changed as the metallicity decreases. However, the detailed change of this dependence according to the decrease of metallicity will be discussed in the next paper. We only present here that the dependence of the spectral lines on the temperature and pressure in the extreme metal poor stars is different from that of normal standard stars, by showing that the continuum opacity in the extreme metal poor stars is different from that of the normal stars.

Let's consider an extreme metal poor stars of near solar temperature. Then we can assume that there are so few metals around that the electrons from the metal are too few to form H minus. Therefore H minus, which is the major source of the continuum opacity in the normal stars is no longer predominant continuum absorption source. Then the most important continuum absorption source in the extreme metal poor stars is the bound-free absorption of H atoms, rather than that of H minus.

Adopting it from Gray (1976), it is

$$K(H_{bf}) = \sum_{n_0}^{\infty} \frac{\lambda^3 g_n'}{n^3} e^{-\chi_n/kT}$$

whre g_n' is the Gaunt factor.

As he showed, neglecting the n dependence of g_n', it becomes

$$K(H_{bf}) = \alpha_0 \lambda^3 \Big[\sum_{n_0}^{n_0+2} \Big(\frac{g_n}{n^3} 10^{-\theta\chi} \Big) + \frac{\log e}{2\theta I} \big(10^{-\chi_3\theta} - 10^{-I\theta} \big) \Big]$$

where $\alpha_0 = 1.044 \times 10^{-26}$ for λ in angstroms.

Comparing it with $K(H^-_{bf})$, the dominent continuum absorption coèfficient of the normal stars of near solar type, which is

$$K(H^-_{bf}) = 4.158 \times 10^{-10} \alpha_{bf} P_e \theta^{5/2} 10^{0.754\theta}.$$

we can notice that the temperature and pressure dependences are changed. For the temperature, $K(H^-_{bf})$ is proportional to $(\theta^{5/2} . 10^{0.754\theta})$, while $K(H_{bf})$ depends on $\Big[\sum_{n_0}^{n_0+2} \Big(\frac{g_n}{n^3} 10^{-\theta\chi} \Big) + \frac{\log e}{2\theta I} \big(10^{-\chi_3\theta} - 10^{-I\theta} \big) \Big]$. And for the pressure, $K(H^-_{bf})$ is related to P_e, while $K(H_{bf})$ does not show any relation with P_e.

Since the line strength is proportional to the ratio of line absorption coefficient to continuum absorption coefficient, $n_\nu = \frac{l_\nu}{K_\nu}$, we can expect that as the metallicity decreases, not only the line absorption coefficient l_ν, changes, but also K_ν changes from $K(H^-_{bf})$ to $K(H_{bf})$. That means, the spectral line dependences on the temperature and pressure are changed as the metallicity decreases. Even for the hydrogen lines, whose change in abundance from the normal stars to the extreme metal poor stars does not much affect the line absorption coefficient l_ν, their dependences of line strength on the temperature and pressure are changed due to the change of the dominant continuum opacity source. Therefore the usual method of classification for metal poor stars, which is based on the same strength of Balmer lines of hydrogen atoms and Ca II lines of the normal standard stars for temperature class, is not appropriate to get the proper temperature class of the metal poor stars. Then it will consequently mislead the luminosity class as well as the class of metal weakness.

At this time, we can not give the quantitative value of metallicity, at which the dominant continuum opacity change from $K(H^-_{bf})$ to $K(H_{bf})$. This will be discussed in the next paper. We only conclude here that since the dependence of spectral lines on the temperature and pressure changes as the metallicity decreases, the usual classification method for metal poor stars is not appropriate and the part of the reason for the systematic bias found in previous section also seems to be due to this.

IV. CONCLUSION

Up to now, the spectral classification for metal poor stars has been carried out on the basis of the normal stars. Usually by matching the strength of Balmer lines of hydrogen and Ca II lines of the normal stars to those of the metal poor stars, the temperature class is decided. Then by matching the luminosity sensitive lines of the normal stars to those of the metal poor stars, the luminosity class is estimated. And then, the class of metal weakness is classified.

However this method leads the systematic bias of the abundance in metal weakness classes of the dwarfs and giants, which suggests, as discussed in section II, the cause is not entirely due to the temperature difference between the dwarfs and giants as discussed by Norris *et al.* (1985).

And considering the case of the extreme metal poor stars in the previous section, we show that the spectral line dependence on the temperature and pressure changes as metallicity decreases.

Therefore we suggest that we have to use the standard metal poor stars, a sort of 3-D MK like system, for classification of metal poor stars, rather than use the normal standard stars as in the usual method of classification.

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