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THE CHEMICAL EVOLUTION OF THE SOLAR NEIGHBORHOOD: AGE-METALLICITY RELATION OF F-STARS*

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ABSTRACT

From the uvby, H_β photometry of intermediate popluation II F-stars in the catalogue of Olsen (1983), we derived age-metallicity relations for these stars, using Hejlesen's (1980) isochrone. The derived age-metallicity relations well coincide with the theoretical predictions by the unclosed two-zone model of Lee and Ann (1981). There are few extremely metal poor F-stars in the vicinity of the Sun, and it is very likely that the initial rapid metal enrichment in the galactic disk might have been processed through the fast collapse of the disk at the very early epoch.

I. INTRODUCTION

One of the most important observational constraints on the models of chemical evolution of the solar neighborhood is the age-metallicity relation (AMR) of stars in the galactic disk. Previous investigations of the AMR of the solar neighborhood are those of Powell (1972), Mayor (1974) and Twarog (1980b). All the investigations lack detailed information at the early stage of the chemical evolution of the galactic disk.

Another important observational constraint is the metallicity distribution of G-dwarfs, so called G-dwarf problem (Van den Bergh 1962; Schmidt 1963; Bond 1970; Pagel and Patchett 1975). Most of the theortical models of the chemical evolution of the solar neighborhood (Talbot and Arnett 1975; Tinsley and Larson 1978; Lee and Ann 1981) have been developed to interpret the G-dwarf problem.

Recent publications of the uvby, H_β photometry of a large number of intermediate pop-

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ulation II stars (Olsen 1983) include good observational data to be used for the understanding of the structure and evolution of the Galaxy, especially for the chemical evolution of the galactic disk. Therefore in this paper we aim to derive the AMR of F-stars in the solar neighborhood for a direct comparison with the theoretical models of the chemical evolution of the solar neighborhood, by making use of the physical parameters derived from the uvby, H_β photometry in combination with the theoretical isochrones of Hejlesen (1980). Selection and properties of the observational data are discussed in section II. Section III deals with the observational physical parameters ([Fe/H], $\log T_{eff}$, M_{bol}) derived from the photometric indices. We derive the AMR of F-stars and compare it with Lee and Ann's theoretical models (1981) in section IV.

II. OBSERVATIONAL DATA

The major observational material used for the present study comes from Olsen's catalogue (1983) of uvby, H_β photometry. This catalogue contains uvby photometry of complete samples of all HD stars of spectral type $A5$ to $G0$ and brighter than V=8.3mag (14816 stars) and about 2500 H_β photometric stars of which 2000 belongs to intermdiate population II. Detailed description of the photometry is given by Olsen (1983). Additional 400 stars were collected from the catalogue of Hauck and Mermilliod (1980) to include a large number of population I stars. Through this paper the definition of intermediate population II stars in Olsen's catalogue is followed by that of Strömgren (1966), i.e. $0.045 \leqslant \delta m_1 \leqslant 0.090$.

We define F-stars as the stars, which are in the range of $2.590 \leqslant H_\beta \leqslant 2.720$ and $-.190 \leq (b\text{-}y) \leq -.450$, following Crawford (1975) and Twarog (1980a, b). The relations between photometric indices of F-stars in the catalogues of Olsen (1983) and Hauck and Mermilliod (1980) are plotted in Figures 1 through 4. The standard relations of Carwford (1975) are drawn for comparisons. Figure 1 shows the relation between b-y and H_β, which are both the effective temperature parameters. The scatters in the figures are due to the obser-

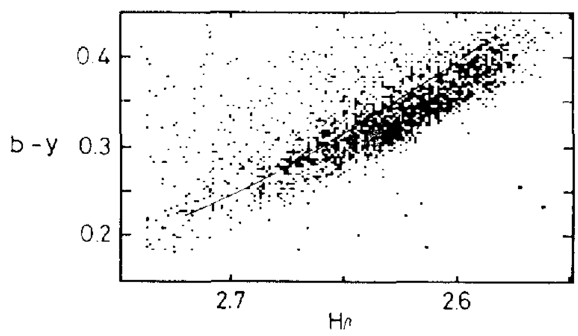

FIG. 1-The b-y vs H_β relation for the intermediate population II stars. The solid line denotes the standard relation of Crawford (1975).

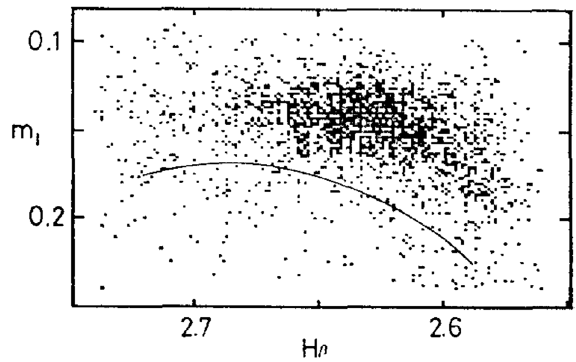

FIG. 2-The m_1 vs H_β relation for the intermediate population II stars. The solid line denotes the standard relation of Crawford (1975).

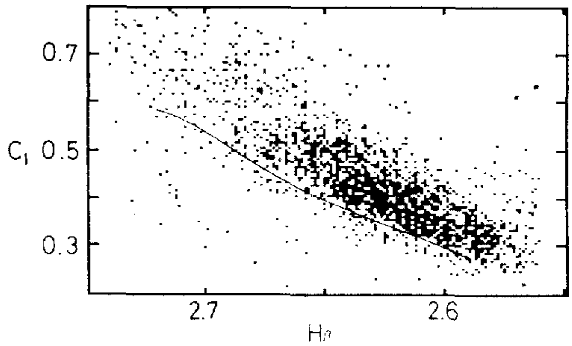

FIG. 3-The C_1 vs H_β relation for the intermediate population II stars. The solid line denotes the standard relation of Crawford (1975).

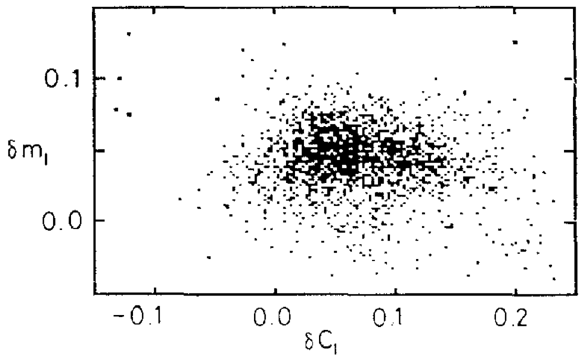

FIG. 4-The δm_1 vs δc_1 relation. There seems no interdependence between the two parameters.

vational error and also to unresolved binarity. Figure 2 shows the relation between m_1 and H_β. We easily see that there are a fairly large number of metal deficient stars with large δm_1. This property critically distinguishes Olsen's F-star sample from that of Twarog (1980a). The relation between luminosity parameter C_1 and H_β is plotted in Figure 3. There appear a few stars with large δc_1 and the relation between M_v and δc_1 for population I stars (Crawford 1975) is applicable to our data without much uncertainties. Figure 4 shows the plot of δc_1 versus δm_1 and it strongly suggests that there is no interdependency between them.

III. PHYSICAL PARAMETERS

a) Metallicity ([Fe/H])

In the uvby, H_β photometric systems, the metallicity of a star is estimated from the m_1 index which is defined as $m_1=(v-b)-(b-y)$. From this index we can define δm_1 as $\delta m_1=m_1(\text{standard})-m_1(\text{observed})$ for a given H_β, in which $m_1(\text{observed})$ is a reddening corrected value. This δm_1 is correlated with the spectroscopically determined [Fe/H] (Cayrel et al. 1980), and also with photoelectrically determined [Me/H] (Nissen 1981). The calibration of the δm_1 index in terms of spectroscopically determined [Fe/H] was derived by Crawford (1975) as

$$[Fe/H]=0.15-11\ \delta m_1. \tag{1}$$

The above equation was used by Twarog (1980b) for the derivation of AMR of F-stars. However, Nissen (1981) showed that there is a systematic variation of [Me/H] with T_{eff}. Assuming that the slope coefficient varies linearly with H_β, he derived the correlation between [Me/H] and δm_1 as

$$[Me/H] = -(10.5+50(H_\beta-2.626))\delta m_1+0.16 \quad (2)$$

for stars with $2.59<H_\beta<2.73$ and $\delta c_1<0.20$. As shown by Nissen (1981), the photoelectrically determined [Me/H] is well correlated with the spectroscopically determined [Fe/H]. Hence we used the notation [Fe/H] for the both metallicities in the following sections. In the derivation of δm_1 we did not apply the interstellar reddening correction, because most of the stars in our sample lie within 100pc from the sun.

b) Effective Temperature(T_{eff})

It is well known that the effective temperature, T_{eff} is more accurately determined by H_β parameter than $(b-y)$ color since H_β index is less sensitive to metal abundance and interstellar reddening. We used the compilation of the relations between T_{eff} and H_β by Hauck and Magnenat (1975), which is based on the work of Oke and Conti (1966). To test the effects of T_{eff} calibrations on the resulting AMR, we derived another $T_{eff}-H_\beta$ relations for F-stars by using $T_{eff}-(B-V)$ relation of Böhm-Vitense (1981) for the solar abundance and the reduced solar abundance, $Z=0.1\ Z_\odot$ through empirical relations between $(B-V)$ and H_β as

$$(B-V)=7.80-2.77\ H_\beta \text{ for } \delta m_1<0.045 \quad (3)$$

$$(B-V)=6.32-2.22\ H_\beta \text{ for } \delta m_1\geq 0.045 \quad (4)$$

where $(B-V)$ colors were taken from the Nicolet Catalogue(Nicolet 1978).

c) Absolute Magnitude(M_v)

The calibration of uvby, H_β photometric indices in terms of absolute magnitude by Crawford (1975) is the only one that can be used for galactic structure. The relation is

$$M_v=M_v(\text{ZAMS, } H_\beta)-f\ \delta c_1(H_\beta) \quad (5)$$

where $f=9+20(2.720-H_\beta)$ and M_v (ZAMS, H_β) is the standard relation of Crawford (1975). The parameter δc_1 (H_β) is defined as $\delta c_1=c_1(\text{observed})-c_1(\text{standard})$ for a given H_β. This parameter is well correlated with the magnitude difference relative to ZAMS M_v. For the age determination in the next section, we used the $\delta M_v=f\delta c_1$ rather than M_v, because uncertainty involved in the zero point calibration of M_v is not included in δM_v.

IV. AGE-METALLICITY RELATION

Using the physical parameters discussed in the preceeding section and the theoretical isochrones with helium abundance $Y=0.2$ by Hejlesen (1980), we derived the AMR of F-stars in the solar neighborhood as follows. Assuming [CNO/Fe]=0 for the stars in our sample, the calculated [Fe/H] is converted to give metal abundance Z, taking solar abundance $Z_{\odot}=0.02$, although the above assumption is not entirely correct for the stars with extreme metallicity.

The observable luminosity parameter, δM_v should be converted to δM_{bol} for direct comparison with theoretical isochrones in (δM_{bol}, log T_{eff})-plane. For this we assumed $\delta M_{bol}=\delta M_v$ with some confidence because the bolometric correction for F-stars does not heavily depend on the luminosity class of a star. Using this parameter, ages of stars were estimated from the isochrone sequences in log $T_{eff}-\delta M_{bol}$ diagrams for a given metal abundance (Twarog 1980b). Stars with δM_{bol} larger than 2.0 or smaller than 0.2 are excluded in the age determination because the stars with larger δM_{bol} have evolved beyond the limit of δc_1 calibration (Crawford 1975), and stars with smaller δM_{bol} have large uncertainties in their age determination.

We applied a volume correction (Twarog 1980b) to the [Fe/H] of each star before the calculation of the mean [Fe/H] at each age bin is made. To test the effects of [Fe/H] and T_{eff} calibration on the resulting AMR we derived AMRs, using all the relations discussed in section III. From this test we learned that the derived AMRs do not heavily depend on the detailed relations between photometric indices and physical parameters. However, somewhat uncertain calibration of M_v for intermediate population II stars may produce relatively large errors in the derived AMR from Olsen's (1983) data.

TABLE 1. Age-Metallicity Relation for F-stars*

Age(10^9 yr)	No.	[Fe/H]	$\sigma_{[Fe/H]}$	Age(10^9 yr)	No.	[Fe/H]	$\sigma_{[Fe/H]}$
4.5	273	−0.29	0.13	10.5	40	−0.44	0.19
5.5	268	−0.34	0.12	11.5	30	−0.53	0.09
6.5	150	−0.34	0.13	12.5	13	−0.59	0.07
7.5	68	−0.37	0.14	13.5	9	−0.60	0.05
8.5	74	−0.43	0.15	15.0	17	−0.72	0.08
9.5	43	−0.48	0.16				

* T_{eff} is calculated from Hauck and Magnenat's (1975) calibration and [Fe/H] from Nissen's (1981) calibration.

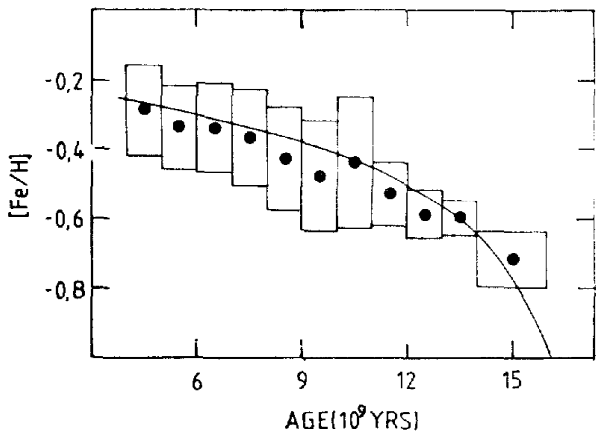

FIG. 5-The age-metallicity relation (AMR) of F-stars in the solar neighborhood. The rectangular boxes represent the standard deviation of the mean at each age bin. The theoretical prediction by Lee and Ann's (1981) model is shown by a solid line.

One typical AMR derived from Olsen's data using Hauck and Magnenat's T_{eff} scale and Nissen's [Fe/H] calibration are given in Table 1. With the standard deviation at each age bin (rectangular box) the AMR (closed cicle) is plotted in Fig. 5. For a comparison, the theoretical AMR given by the B-3 disk model of Lee and Ann (1981) is presented, which is indicated as a solid line. The good coincidence between the observational AMRs and the theoretical ones supports the two-phase scenario of the chemical evolution of the galactic disk by the unclosed two-zone model of Lee and Ann (1981). According to this model, a rapid enrichment of metallicity in the galactic disk appears to take place at the early phase of the galactic evolution. This initial enrichment is resulted from the rapid collapse of the Galaxy, which causes the burst of massive star formation. At the later phase of the disk evolution, the metallicity in the disk is very slowly increased over the periods of $\sim 10^{10}$ yrs if the Galaxy age is taken to be 15 Gyrs.

Considering that Olsen's data are a complete sample of the intermediate population II stars brighter than 8.3 mag, the AMR derived from his data suggests that in the vicinity of the sun there are few extremely metal deficient stars. For further detailed information at the very early stage of the chemical evolution of the galactic disk, we should extend our sample stars to fainter magnitudes, say $V=10.0$ mag or so. It seems also important to investigate the chemical properties of the more distant G, K stars along with F-stars.

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REFERENCES

Böhm-Vitense, E. 1981, Ann. Rev. Astr. Ap., **19**, 295.

Bond, H.E. 1970, Ap. J. Suppl., **22**, 117.

Cayrel de Strobel, G., Bentolila, C., Hauck, B., and Curchod, A. 1980, Astr. Ap. Suppl., **41**, 405.

Crawford, D.L. 1975, A.J., **80**, 955.

Hauck, B., and Magnenat, P. 1975, Dudley Obs. Report No. 9, p. 171.

Hauck, B. and Mermilliod, M. 1980, Astr. Ap. Suppl., **40**, 1.

Hejlesen, P.M. 1980, Astr. Ap. Suppl. **39**, 347.

Lee, S.W., and Ann, H.B. 1981, J. of Korean Astr. Soc., **14**, 55.

Mayor, M. 1974, Astr. Ap., **32**, 321.

Nissen, P.E. 1981, Astr. Ap., **97**, 145.

Nicolet, B. 1978, Astr. Ap. Suppl., **34**, 1.

Oke, J.B., and Conti, P. 1966, Ap. J., **143**, 134.

Olsen, E.H. 1983, Astr. Ap. Suppl., **54**, 55.

Pagel, B.E.J., and Patchett, B.E. 1975, M.N.R.A.S., **172**, 13.

Powell, A.L.T. 1972, M.N.R.A.S., **155**, 483.

Schmidt, M. 1963, Ap. J., **137**, 758.

Strömgren, B. 1963, in *Basic Astronomical Data*, ed. K. Aa. Strand(Chicago: Univ. Chicago), p. 123.

Strömgren, B. 1966, Ann. Rev. Astr. Ap., **4**, 133.

Talbot, B.J., and Arnett, W.D. 1975, Ap. J., **186**, 51.

Tinsley, B.M., and Larson, R.B. 1978, Ap. J., **221**, 554.

Twarog, B.A. 1980a, Ap. J. Supp., **44**. 1.

Twarog, B.A. 1980b, Ap. J., **242**, 242.

van den Bergh, S. 1962, A.J., **67**, 486.