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THIRTEEN-COLOR PHOTOMETRY OF SUBDWARF STARS. II. CALIBRATION OF THE 37-45 EXCESS USING SPECTROSCOPIC [Fe/H] ABUNDANCES

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RESUMEN

Se calibra el diagrama (*37–45, 45–63*) con la composición química empleando los valores [Fe/H] de Morel *et al.* (1976). Se determinan cuidadosamente las correcciones de temperatura para δ (*37–45*). La calibración final comprende desde las composiciones aproximadamente solares ([Fe/H] $\approx$ 0.0) hasta las composiciones de las subenanas extremas ([Fe/H] < -1.5).

ABSTRACT

The (*37–45, 45–63*) diagram has been calibrated for chemical composition using the [Fe/H] values of Morel *et al.* (1976). Care has been taken to obtain temperature corrections for δ (*37–45*). The final calibration extends from solar-like compositions ([Fe/H] $\approx$ 0.0) to extreme subdwarf compositions ([Fe/H] < -1.5).

Key words: **PHOTOMETRY — STARS, ABUNDANCES — STARS, SUBDWARFS.**

I. INTRODUCTION

In the previous paper (Schuster 1979) we showed that the (*37–45*) versus (*45–63*) diagram could be useful for obtaining stellar chemical compositions, especially [Fe/H] values. *45–63* is a good temperature index with blanketing corrections less than about 0.02 magnitude. *37–45* is insensitive to gravity for $+0.60 <$ *45–63* $< +0.95$ and yet contains nearly the full blanketing effect. Some extreme subdwarfs have ultraviolet excesses δ *(37–45)*, greater than $+0.40$ magnitude.

We will first examine carefully the temperature corrections for δ *(37–45)* as derived from the preliminary calibration of Schuster (1976*a*). The final calibration will then be an iteration of the earlier calibration but having better temperature corrections and using the [Fe/H] values of Morel *et al.* (1976).

II. THE TEMPERATURE CORRECTIONS

The lower solid curve "A" of Figure 1 shows the dependence of δ (*37–45*) on *45–63* as derived from the calibration of Schuster (1976*a*). For (*45–63*) <0.81 this earlier calibration used compositions of G stars and subdwarfs from the studies of Wallerstein (1962), Alexander (1967), and Aller and Greenstein (1960), 13-color photometry from Mitchell and Johnson (1969), Schuster (1976*b*) and Schuster (1979), and theoretical 13-color photometry from Kurucz (1975). This preliminary calibration was extended over the range $0.81 <$ *45–63* < 1.04 using the two stars HD 103095 (BS 4550, Groombridge 1830) and τ Cet (HD 10700, BS 509) both of which have been well studied with spectroscopy and with 13-color photometry.

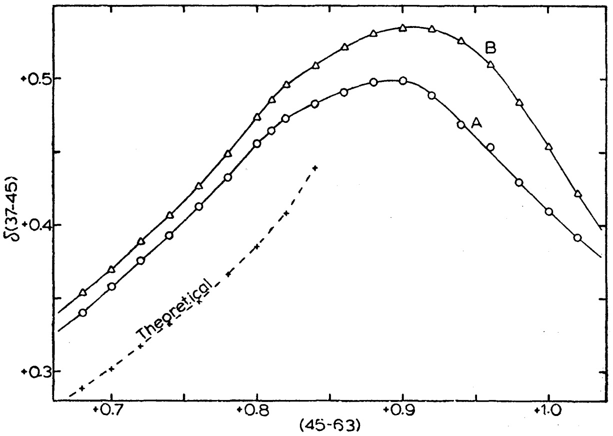

FIG. 1. δ(37–45) as a function of 45–63. Curve "A" follows from the [Fe/H] = −2.0 curve of the preliminary calibration, and curve "B" from Figure 4.

In Figure 1 curve "A" gives the δ (*37–45*) values for [Fe/H] = −2.0, and the dashed curve shows the theoretical excesses of the 0.01× model over the 1× model ([Fe/H] = 0.0). (The curve "B" comes from the final calibration to be derived in the next section). The theoretical photometry comes from Kurucz (1975) and has been discussed by Relyea and Kurucz (1976) and Schuster (1979). We see that the theoretical excesses are not realistic for *45–63* > 0.81; these excesses would have produced a sharp upturn in the constant composition lines of the *(37–45, 45–63)* diagram, which would not have allowed a smooth, physically realistic extension of the curves to the δ *(37–45)* 's and [Fe/H]'s of HD 103095 and τ Cet. The observational excesses give a much more realistic curve but are based on very limited data.

To test the accuracy of curve "A" we have plotted in Figure 2 uncorrected δ (*37–45*)'s versus the [Fe/H] values from Morel *et al.* (1976) for four *45–63* intervals chosen so that each group would have at least one star with [Fe/H] < −0.5. The curves in Figures 2*c* and 2*d* were extrapolated keeping the same shape for [Fe/H] < −0.5 as the preliminary calibration of Schuster (1976*a*). The slopes given are the change in δ (*37–45*) divided by the change in [Fe/H], and in Figure 1 the respective slopes of curve "A" are 0.17, 0.19, 0.22, and 0.18 at the average (*45–63*)'s of groups *a, b, c,* and *d* of Figure 2. We see that the agreement between curve "A" and the

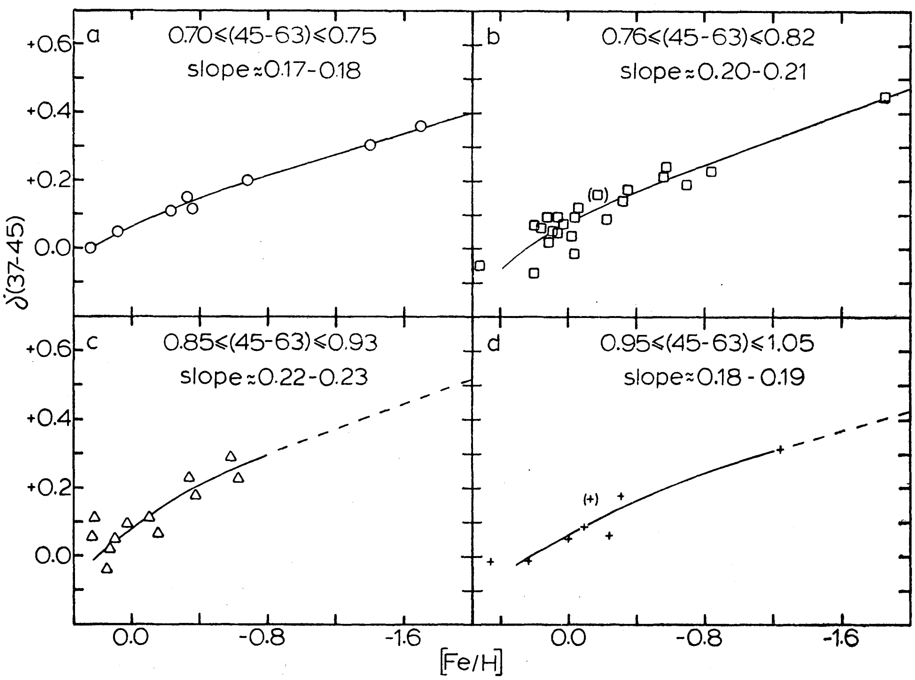

FIG. 2. δ(37–45) versus [Fe/H] for various 45–63 intervals. The δ(37–45)'s are uncorrected. Graphs *c* and *d* have been extrapolated keeping the same shape as in the preliminary calibration (Schuster 1976*a*). The slopes are the averages of Δδ(37–45)/Δ[Fe/H] over the range [Fe/H] = +0.30 to −2.0.

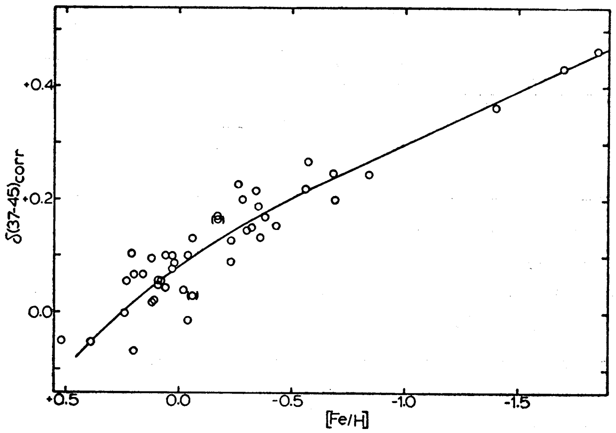

FIG. 3. Final δ(37–45) versus [Fe/H] calibration. The δ(37–45)'s have been corrected to (45–63) = 0.81 using curve "A" of Figure 1.

curves of Figure 2 is very good both qualitatively and quantitatively and that any temperature corrections, δ (*37–45*) ratios, taken from curve "A" can be used with confidence.

III. THE FINAL CALIBRATION

The final calibration of the (*37–45, 45–63*) diagram is given in Figures 3 and 4. For Figure 3 we have corrected the δ(*37–45*)'s of stars having 0.72 < *45–63* < 0.88 to *45–63* = 0.81 using the temperature corrections of curve "A" in Figure 1, and then these δ (*37–45*)'s were plotted versus the [Fe/H] values of Morel *et al.* (1976). We used strictly the average of the [Fe/H] values for each star; no attempt to weigh the data of Morel *et al.* (1976) was made. In Figure 3 the standard deviation of one star in [Fe/H] about the mean curve is ±0.16; if the temperature corrections are not used, the standard error would be ±0.19.

The mean curve of Figure 3 implies a Hyades [Fe/H] of +0.25 and a δ (*37–45*) of +0.081 at a solar composition. The preliminary calibration of Schuster (1976*a*) implied a Hyades [Fe/H] of +0.30 and a solar-composition δ (*37–45*) of +0.107. Schuster (1976*b*, also Mitchell, 1974) found *45–63* = 0.857 for the Sun, which gives the actual solar excesses of +0.087 and +0.113 respectively using δ (*37–45*) ratios from Figure 1. These values should be compared to the value δ(*37–45*) = +0.180 which Schuster (1976*b*) obtained from derived 13-color photometry for the Sun. This discrepancy arises from difficulties in interpolating medium-narrow-band solar colors using broad-band UBVRI and Kron 6-color photometry; not enough information is available through five or six broad-band filters to derive accurate photometry for thirteen medium-narrow-band filters.

Only one Hyades star, the well-studied G2V star HD 28344 (H73), is plotted in Figure 3, and so the results from this figure should be fairly independent of previous Hyades studies. As pointed out by Cayrel de Strobel (1976), and our deductions are certainly no exception, photometric systems always indicate that the Hyades iron/hydrogen abundance is approximately twice the solar ratio, while the high dispersion spectroscopic studies lead to nearly solar abundances

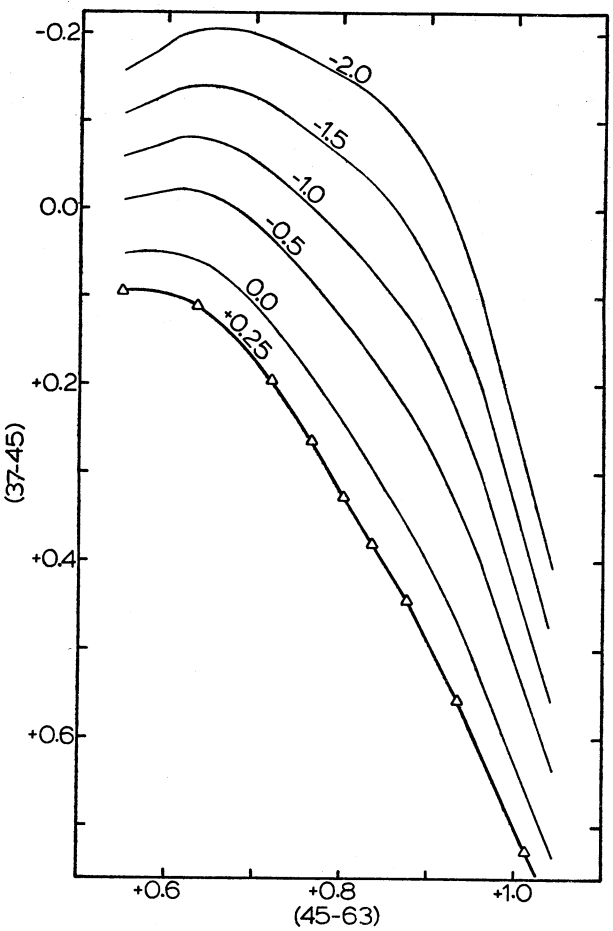

FIG. 4. Final chemical composition calibration of the (37–45, 45–63) plane. The curves are labelled with their respective [Fe/H] values.

for the Hyades stars. For comparison *u v b y* observations of F stars have implied a Hyades abundance of +0.15-0.40 (Strömgren 1963; Strömgren 1966; Nissen 1970; Gustafsson and Nissen 1972; Crawford 1975, Crawford and Perry 1976) while the high dispersion spectroscopic values of Morel *et al.* (1976) for the F, G and K-type Hyades stars have an average of approximately [Fe/H] = +0.1.

In Figure 4 the calibration is fixed at *45–63* = 0.81 by the curve of Figure 3, and for *45–63* < 0.81 the calibration has been extended using ratios from the theoretical 13-color photometry. For *45–63* > 0.81 the twelve stars of Table 1 have been used to set the calibration. All of these stars have

[Fe/H] < −0.25 and 0.82 < *45–63* < 1.003.

In Table 1 the column labelled NP/NS gives the number of photometric (8C) and spectroscopic observations, respectively, for each star, and the [Fe/H]'s are merely the averages of values given by Morel *et al.* (1976). Six of these stars have little effect on the extension of the calibration due to their closeness to *45–63* = 0.81. The other six stars, indicated by asterisks or double asterisk in Table 1, have carried most of the weight, especially HD 10700 and HD 103095. We have drawn the constant-composition lines maintaining the same shape as the calibration in Figure 3 while matching as closely as possible the [Fe/H]'s and (*37–45*)'s of the twelve stars. Morel *et al.* (1976) give only two [Fe/H] values for HD 103095 having an average of

$$[Fe/H] = -1.25,$$

while in the preliminary calibration we used the well-determined value of −1.30 from Tomkin and Bell (1973), who were not listed in Morel *et al.*'s catalogue. These values are almost identical and so for *45–63* > 0.81, Figure 4 is very similar to the preliminary calibration of Schuster (1967*a*). The twelve stars of Table 1 give a standard deviation of one star in [Fe/H] of ±0.20, as calculated from the differences between the spectroscopic and photometric abundances.

Curve "B" of Figure 1 gives the excess of the [Fe/H] = −2.0 curve in Figure 4 as a function of *45–63*. The slopes, $\Delta\delta$*(37–45)* /Δ[Fe/H]'s, of Curve "B" are 0.18, 0.20, 0.24 and 0.21 at the average *(45–63)*'s of groups *a, b, c,* and *d* in Figure 2, respectively, which have the revised slopes (according to the shape of the curve in Figure 3) of 0.18, 0.21, 0.25 and 0.20. As expected the agreement is very good. Curve "B" maximizes at approximately *45–63* = 0.91 which corresponds to an effective temperature of about 5250° if we use a slight extrapolation of the theoretical calibration of paper 1,

TABLE 1

STARS WITH 45-63> 0.81 AND SPECTROSCOPIC ABUNDANCES

HD	Other	Names	(37-45)	(45-63)	δ(37-45)	[Fe/H]	NP/NS
2151	BS 98		0.230	0.837	+0.152	-0.30	2/2
6582	BS 321	+54°223	0.301	0.920	+0.228	-0.63	4/3*
10700	BS 509	-16°295	0.425	0.958	+0.182	-0.31	8/4**
13974	BS 660		0.184	0.856	+0.228	-0.34	2/4
20794	BS 1008		0.391	0.945	+0.189	-0.34	2/1*
30649		+45°992	0.128	0.822	+0.230	-0.26	4/2
101501	BS 4496		0.474	0.949	+0.116	-0.27	5/2*
103095	BS 4550		0.390	1.003	+0.319	-1.25	55/2**
142267	BS 5911		0.176	0.838	+0.207	-0.28	2/1
152792		+43°2659	0.229	0.853	+0.178	-0.38	4/2
157214	BS 6458		0.232	0.842	+0.159	-0.43	2/3
224930	BS 9088	+26°4734	0.240	0.922	+0.292	-0.59	5/5*

or 5450° if we use the observational calibration of Schuster (1976*a*). For Curve "A" the maximum falls at approximately *45–63* = 0.89 which corresponds to 5350° and 5500°, respectively.

IV. CONCLUSIONS

We have seen in paper 1 and in the present analyses that the (*37–45, 45–63*) plane is especially suited for measuring [Fe/H] values of stars. The δ(*37–45*) excess has a greater sensitivity to metallicity than any other photometric index given in the literature. We have seen that for *45–63* < 0.81 we can determine [Fe/H] values accurate to about $\pm$0.1-0.2 for one star (Figure 3 gives $\pm$0.16). For *45–63* > 0.81 the errors are larger, perhaps $\pm$0.2-0.3 (the stars of Table 1 give $\pm$0.20), due to the lack of good theoretical colors, due to a smaller number of spectroscopic [Fe/H]'s for calibration, and due to a guillotining of δ(*37–45*) in the (*37–45, 45–63*) plane.

Our calibrations give a solar δ(*37–45*) of +0.08 to +0.12, which differs significantly from the value which Schuster (1976*b*) obtained from derived 13-color photometry for the Sun. This discrepancy points out the danger in using broad-band photometry to derive narrow-band colors for any star.

The calibration implies a Hyades [Fe/H] of about +0.25, well within the limits of previous investigations. The sensitivity of δ(*37–45*) maximizes at about *45–63* = 0.91 (Te $\approx$ 5250-5450°) with an approximate change of 0.24 magnitude for a change of 1.0 in [Fe/H].

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