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ESTIMATION OF STELLAR MAGNETIC FIELDS FROM LINE-STRENGTHS: REFINED HENSBERGE-DE LOORE METHOD

YOICHI TAKEDA
Institute of Astronomy, The University of Tokyo,
Mitaka, Tokyo, 181 Japan

ABSTRACT A method for determining the strength of a stellar magnetic field is presented, which is based on the requirement that the scatter of abundances from various lines should be minimized on the best choice of the field strength and the microturbulence. This procedure is applied to o Peg and cool Ap stars, showing that the resulting solutions are consistent with those derived from other methods.

1. INTRODUCTION

Since the strength of a spectral line is intensified in the presence of a magnetic field, it is in principle possible to spectroscopically estimate the strength of a stellar magnetic field by examining the equivalent widths of various spectral lines. The first attempt following this thought was performed by Hensberge and De Loore(1974). Based on the classical coarse analysis, they exploited this effect for the determination of field-strengths by concentrating only on the well-saturated lines, in which the magnetic sensitivity was represented by only one parameter g_{eff} (effective Landé factor) without accounting for the polarization effect. Here, we present an alternative method (being founded on a fine-analysis approach) for investigating stellar magnetic fields from the strengths of spectral lines, *which takes the detailed Zeeman patterns of individual lines fully into account with an approximate (but sufficiently accurate) treatment of the polarization effect.* Thus, this method deserves the name of "refined Hensberge-De Loore method".

2. METHOD

The fundamental procedure in an abundance determination is

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to calculate the equivalent width (W_λ) of a line for a given abundance; we can obtain from an observational line-strength the corresponding element-abundance by iterating this process until a convergence. For this purpose, we propose here a practical method of W_λ-calculation in the presence of a magnetic field, which is an application of the usual *scalar* equation of radiative transfer instead of the correct *vector* equation but presents results being sufficiently accurate at least for the present purpose. Let us start by considering in which cases the magnetic intensification for a given field-strength achieves its maximum or minimum. The maximum intensification occurs on the complete neglect of the polarization effect [i.e., equivalent to the case of "microturbulent magnetic field" described in Takeda(1991)], where each of the σ_+, σ_-, and π components normally absorb or emit unpolarized radiations at their positions. Henceforth, we refer to this extreme as Case(c). On the other side, the minimum intensification is realized when the magnetic field is viewed from the direction of its line of force (i.e., ψ=0° or 180°; ψ is the angle between the field vector and the line of sight). In this case, which we hereinafter call Case(a), π components turn out to disappear completely, leaving only σ_+ and σ_- components which do not interact with each other. It should be here pointed out that solving the normal (scalar) transfer equation (as in a usual line-analysis program) suffices to calculate W_λ for these two extreme cases (c) and (a). Interestingly, we found by detailed calculations that the reasonably accurate approximation for the equivalent width corresponding to the radiation integrated over a stellar disk is provided by the simple average of these two, $W_b=(W_a+W_c)/2$, which we call the W-value of Case(b). [See Takeda(1992) for more details.] The essential characteristics of our method lies in the fact that we adopt this Case(b) as the standard W-calculation method.

Determination procedures are as follows: Suppose that we have observational data of equivalent widths for N lines ($W^l_{\rm obs}$, $l=1,\ldots,N$) belonging to the same species (for example, FeI). Given some trial values of ξ(microturbulence) and H(field strength) with an appropriate model atmosphere, the corresponding abundances ($\log\varepsilon^l_b$, $l=1,\ldots,N$) are calculated based on the usual fine-analysis technique where the effect of H upon W is taken into consideration assuming Case(b). Then, we compute the averaged abundance $\langle\log\varepsilon_b\rangle$ and the rms scatter σ_b defined as

$$\langle\log\varepsilon_b\rangle=\Big(\sum_{l=1}^{N}\log\varepsilon^l_b\Big)/N \qquad (1)$$

and

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$$\sigma_b = \left[\sum_{l=1}^{N}(\log\varepsilon_b^l - <\log\varepsilon_b>)^2/N\right]^{1/2} \quad (2)$$

This procedure is repeated with various choices of (ξ, H), and the most appropriate combination for these parameters is determined as the one showing the minimum σ_b among all trials.

3. RESULTS

The present method was first applied to o Peg; the first Am star in which the existence of a magnetic field was evidenced. As to the basic line-analysis program, we used the WIDTH6 program which was modified to incorporate the W-calculation procedures (with respect to flux profiles) of Case(b). We adopted the line-blanketed model calculated by Kurucz(1979) with T_{eff}=9500K, log$g$=3.5, and the normal metallicity. Regarding the observational data, we adopted the equivalent widths of TiII, FeI, and FeII lines presented by Adelman(1988). The Zeeman pattern of each line was computed with the assumption of LS-coupling. With regard to the sources of gf-values, we exclusively relied upon the recent compilation of Martin et al.(1988) for TiII and that of Fuhr et al.(1988) for FeI and FeII. It is natural to adopt (as the final solution) the result of (H, ξ) determined for the ion which gives the smallest σ_b^{min} among all studied species (i,e., TiII, FeI, and FeII). Then, we found that the best solution is provided by FeII as ξ_b=1.5km·s^{-1} and H_b=2kG (corresponding to $\sigma_b^{min}\sim$0.14). Encouragingly, this value (2kG) of the magnetic field in o Peg is in good agreement with the estimation of Mathys and Lanz(1990) as well as of Takeda(1991), indicating the consistency of the present method.

We also investigated the magnetic fields of five cool Ap stars and compared the results with those derived from other techniques. Regarding the observational data, we adopted the equivalent widths (of FeI and FeII lines) measured by Kuznetsova(1987) for 52 Her and those (of TiII, FeI, and FeII lines) by Adelman(1973b) for HD2453, HD8441, HD110066, and HD118022. We determined the best solutions of H_b and ξ_b for each star, which are given in table I. Comparing our H_b-values with the field-strengths (H_A) derived by Adelman(1973a) from resolved Zeeman-split doublets or by use of the technique of differential Zeeman broadening, we see that both results agree with each other satisfactorily. Furthermore, the comparison of the solutions (H_{HD} and ξ_{HD}) obtained by Kuznetsova(1987) or Ryabchikova and Piskunov(1986) based on the classical Hensberge-De Loore method with the results from our method (H_b and ξ_b) tells us that both solutions may be regarded as being more or less in

Table I. Comparison of H and ξ derived for cool Ap stars with other estimates.

Star	Model	Ion	H_b(kG)	ξ_b(km·s^{-1})	H_{HD}(kG)	ξ_{HD}(km·s^{-1})	H_A(kG)
52 Her	(9000,4.0,0.5)	FeI	~5	~2.5	1.80(FeI) 1.44(FeII)	2.0(FeI) 2.0(FeII)	***
HD2453	(9000,4.0,0.5)	FeII	~3	~0.0–0.5	2.80(FeI) 2.32(FeII)	2 (FeI) 2 (FeII)	3.8
HD8441	(9500,3.5,0.5)	FeI	~0	~1.0:	1.23(FeI) 0.70(FeII)	0 (FeI) 0 (FeII)	0
HD110066	(9500,4.0,1.0)	TiII	~3:	~1.0:	2.46(FeI) 2.16(FeII)	2 (FeI) 2 (FeII)	3.6
HD118022	(9500,4.0,1.0)	TiII	~2–3	~0.0–0.5	2.30(FeI) 1.63(FeII)	1 (FeI) 1 (FeII)	2.9

Notes.

The notation of the parameters for the adopted Kurucz's(1979) ATLAS6 model atmospheres in the 2nd column denotes (T_{eff}, log$g$, [$X/X_\odot$]), where [$X/X_\odot$] is the enhancement factor of metallicity (in dex) relative to the solar abundance. In the 3rd column are presented the ions from which the listed values of H_b and ξ_b were derived. Determinations with rather large uncertainties are indicated with ":".

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accord with each other. (One exception is the case of 52 Her for which the discordance of H_b and H_{HD} is appreciably large.) We notice, however, that each listed H_{HD} tends to be generally smaller as compared to the corresponding H_b (or H_A). The reason for this tendency may be attributed to the fact that the polarization effect is not taken into account in the basic W vs. H relation in their classical method, leading to an overestimation of W for a given H (i.e., an underestimation of H for given W-values).

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