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A MULTILINE METHOD TO DETERMINE STELLAR MAGNETIC FIELDS

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INTRODUCTION

In the past, much effort has been devoted to determine stellar magnetic fields by means of the analysis of two spectral lines with different magnetic sensitivities (see, e.g., Robinson, 1980; Saar, 1988; Basri and Marcy, 1988). However, these methods are largely influenced by the uncertainties caused by, for instance, the presence of blends, uncertainties of atomic parameters, etc. Gray (1984) and, more recently, Basri *et al.* (1992) used a multiline analysis to measure stellar magnetic fields, reducing the importance of those uncertainties, thus increasing, in a statistical sense, the confidence of the results.

Here we present a new method based on the analysis of the equivalent widths of many Fe I spectral lines. The central idea is to obtain information on the magnetic field from the magnetic strengthening of the equivalent width of spectral lines. This technique has been applied to a weak-emission-line T Tauri star (TAP35) and a main sequence star (ξ Boo A), using data published by Basri *et al.*, (1992).

MAGNETIC FIELD DETECTION

The equivalent width (W^o) of a spectral line changes by an amount ΔW, when effective temperature ($\mathrm{T_{eff}}$), microturbulence (ξ), (Fe/H) abundance (m) and/or magnetic field strength (B) are modified by $\Delta\mathrm{T_{eff}}$, $\Delta\xi$, Δm, and/or ΔB. In first order approximation, ΔW is given by

$$W = W^o + \frac{\partial W^o}{\partial \mathrm{T_{eff}}}\Delta\mathrm{T_{eff}} + \frac{\partial W^o}{\partial \xi}\Delta\xi + \frac{\partial W^o}{\partial m}\Delta m + \frac{\partial W^o}{\partial B}\Delta B.$$

The values of the derivatives can be calculated for a given model atmosphere at the same time the transfer equation is integrated, using the code developed by Ruiz Cobo and del Toro Iniesta (1992).

Thus, the method operates iteratively accordingly to the following scheme: starting with an initial guess model atmosphere one can estimate the amount by which these magnitudes must be changed, by a least-squares minimization, obtaining thus a second model atmosphere. Starting again with this new model atmosphere, this procedure is iterated until a convergence is reached. It is important to note that this technique provides all the free parameters simultaneously and so, they are self-consistent.

SIMULATIONS

We have carried out several numerical tests of the method with different model atmospheres, with $T_{eff} \approx 5500$K, $\log m \approx -4.5$, $\xi \approx 1.3$ km·s^{-1}, and $B \approx 1000$ Gauss. Noise was added to the simulated data ($S/N \sim 100$). We have synthesized 16 spectral lines, which cover a large range of excitation potentials, equivalent widths and magnetic sensitivities, to ensure that they behave in a different manner to variations of the different free parameters of the model atmospheres. The results show that convergenge is reached after few iterations, with uncertainties of 100 K in T_{eff}, 0.10 in $\log m$, 0.30 km·s^{-1} in ξ and 60 Gauss in B. The standard deviation of the difference of the assumed true equivalent widths and the recovered ones is $\sim$ 1.5 mA.

OBSERVATIONAL RESULTS

TAP35

In a recent paper, Basri *et al.* (1992) have studied TAP35, a T Tauri star with weak-emission-lines, and give arguments which may suggest the presence of surface magnetic fields. We have used the equivalent widths measured by them on this star to compare their results with ours. As in their case, we have used 61 Uma, a low active G8V star to calibrate the oscillator strength of the lines observed. Using the above method, but neglecting the presence of magnetic field, we have obtained $T_{eff} = 5500$ K, $\xi = 0.5$ km · s^{-1}, and $\log(m) = -4.07$ (Basri *et al.* obtain $T_{eff} = 5250$ K and $\log(m) = -4.53$). This model atmosphere was used to re-calculate the oscillator strengths, so that the measured equivalent widths matched exactly those synthesized.

Our final model estimates $T_{eff} = 5350 \pm 200$ K, $\log m = -4.45 \pm 0.03$, $\xi = 2.3 \pm 0.3$ km ·s^{-1}, and $B = 1100 \pm 300$ Gauss for TAP35. Fig. 1 shows the relationship between the observed equivalent widths and those obtained with the best fit atmosphere. The standard deviation of the difference of equivalent widths is 11 mA. Basri *et al.* obtain a magnetic field value of 1000 ± 500 Gauss for TAP35, which is in agreement with our result.

ξ Boo A

The same analysis, with the same lines (taking again data from the paper by Basri *et al.*), and with the gf-values derived from 61 Uma, has been done on ξ Boo A (spectral type G8V). The final results show that $T_{eff} = 5400 \pm 70$ K, $\log m = -4.17 \pm 0.01$, $\xi = 0.15 \pm 0.15$ km ·s^{-1}, and $B = 330 \pm 90$ Gauss.

Fig. 2 shows the relationship between the simulated equivalent widths and those obtained with the best fit atmosphere. The standard deviation of the difference of equivalent widths is 3.2 mA.

Basri *et al.* can just give an upper limit to the mean magnetic field strength on this star ($B \leq 500$ Gauss).We detect a mean magnetic field of $B = 330 \pm 90$ Gauss, which is in agreement with Basri *et al.* again, and is a more accurate value.

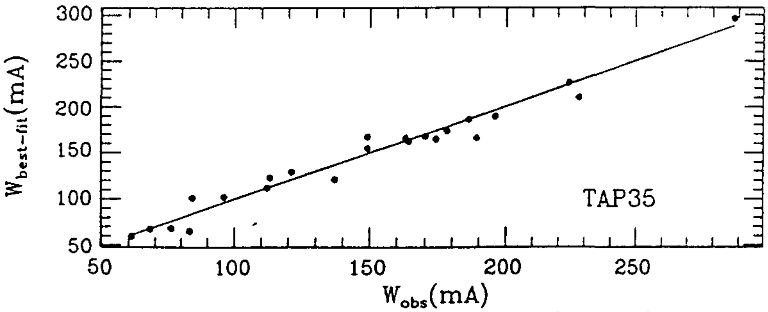

FIGURE I Relationship between the measured equivalent widths and those obtained with the best fit atmosphere for TAP35. The standard deviation of the difference of equivalent widths is 11 mA.

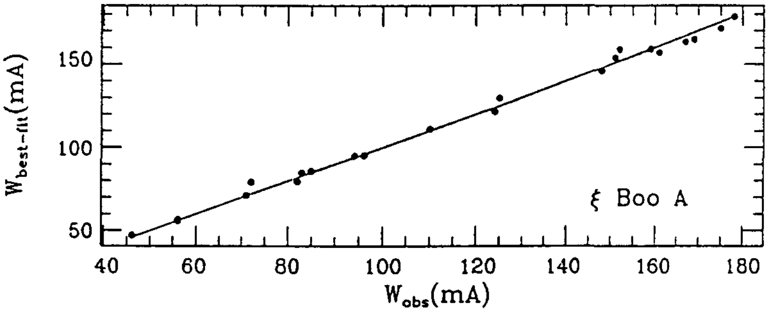

FIGURE II Relationship between the measured equivalent widths and those obtained with the best fit atmosphere for ξ Boo A. The standard deviation of the difference of equivalent widths is 3.2 mA.

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