INTENSITY PROFILES IN FLUXTUBES

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Here we present a method for reconstructing the intensity profile, I, formed in the magnetic elements which have diameters smaller than the best presently achievable spatial resolution. It follows the same line as in Solanki and Stenflo (1984). As a starting point we use I and V (fourth Stokes parameter, which originates only in magnetic regions) of the facula and the I observed in the quiet Sun. The filling factor, and the ratio between the continuum intensity of the magnetic and non-magnetic parts of the photosphere can be obtained indirectly. For that purpose only the Unno equations, a triplet Zeeman pattern, a longitudinal magnetic field and a two-component model are needed. The method has been applied to some Fourier transform spectrometer (FTS) data (Stenflo et al., 1984) with promising results. As the absolute continuum intensities are unknown, rendering inaccurate the evaluation of the filling factor and the continuum contrast, only the normalised I profile is obtained.

1. INTRODUCTION

Nowadays it is generally accepted that both network and faculae are composed of a magnetic component, with a discrete character, and a non-magnetic one, very often assumed to be similar to the quiet photosphere, although it could be slightly darker according to several calculations (Deinzer et al., 1984). For a review see e.g. Stenflo (1984). The main problem when trying to study the properties of magnetic elements is their small size (less than 0".2 if one associates them with the facular bright points observed e.g. by Mehltretter, 1974), which makes them unresolvable for spectroscopic observations. For this reason a polarimetric analysis must be done in order to separate both components.

Up till now, several properties of these magnetic elements have been obtained from the first order approximation to their line profiles (Solanki and Stenflo, 1984; 1985). However, the true spectral line shape has not yet been found for lines with a sizeable Zeeman splitting and if it were it would be a very powerful tool for the diagnosis of the magnetic atmosphere. Here we present a very simple method to obtain the intensity profile of Fe I 5247 and Fe I 5250 inside the fluxtubes, which clearly reveals the differences between the magnetic elements and their non-magnetic surroundings.

2. THE METHOD

In order to facilitate the analysis, several assumptions must be made. Those made by us and which are usual in studies of this sort are:

(1) The magnetic field points towards the observer (longitudinal field).
(2) The studied lines behave as normal Zeeman triplets.
(3) The lines are formed in local thermodynamic equilibrium.
(4) The strength of the magnetic field is constant over the height range in which the spectral lines are formed.

In our case the Unno equations (Unno, 1956) are valid. Furthermore, under these conditions the system of transfer equations can be reduced to two independent transfer equations, one for I_m+V and another for I_m-V (I_m and V are the first and fourth Stokes parameters, respectively. Note that I_m represents the Stokes I profile arising in the magnetic region only). Both have the same solution but are separated in wavelength by twice the Zeeman splitting. The result is even valid in the presence of a velocity field. For a purely longitudinal field, magneto-optical effects need not be taken into account, since the respective terms in the transfer equation vanish (see e.g. Wittmann, 1974). Therefore equation (1) is fairly general:

$$[I_{om} - (I_m - V)]\,(\lambda) = F\,(\lambda + \Delta\lambda), \qquad (1.a)$$

$$[I_{om} - (I_m + V)]\,(\lambda) = F\,(\lambda - \Delta\lambda), \qquad (1.b)$$

where $\Delta\lambda$ = constant $\lambda_o^2.g.B$ (λ_o is the central wavelength of the transition, g the Landé factor, B the magnetic field strength), and I_{om} is the continuum intensity of the magnetic region. We have assumed the V profile to exhibit no area asymmetry.

$F(\lambda)$ is a function which coincides with the intensity profile of the line in the case of zero Landé factor. It follows directly from equations (1) that

$$(I_{om} - I_m)\,(\lambda) = 1/2\,[\,F(\lambda + \Delta\lambda) + F(\lambda - \Delta\lambda)\,], \qquad (2.a)$$

$$V(\lambda) = 1/2\,[\,F(\lambda + \Delta\lambda) - F(\lambda - \Delta\lambda)\,]. \qquad (2.b)$$

The Fourier transform (we use the definition of Bracewell, 1965) of the last equations leads to

$$\widetilde{(I_{om} - I_m)}\,(s) = \tilde{F}(s)\,\cos(2\pi\, s\Delta\lambda), \qquad (3.a)$$

$$\tilde{V}(s) = \tilde{F}(s)\; i\,\sin(2\pi s\,\Delta\lambda), \qquad (3.b)$$

where $\tilde{F}(s)$ is the Fourier transform of the function $F(\lambda)$. In principle one can reconstruct $\widetilde{(I_{om} - I_m)}(s)$ and afterwards $(I_{om} - I_m)\,(\lambda)$ as follows:

$$\widetilde{(I_{om} - I_m)}(s) = \tilde{V}(s)\,\cos(2\pi\, s\Delta\lambda)/[i\,\sin(2\pi\, s\Delta\lambda)] \qquad (4)$$

In the case of a not completely antisymmetric V profile $\tilde{V}(s)$ is complex, which will lead to a certain asymmetry in $I(\lambda)$ as well. The main problem with this restoration of the intensity profile, which comes directly from magnetic elements, is the presence of zeros in the denominator. Nevertheless, this difficulty can be overcome by using two identical lines in their thermodynamic properties but with different g factors. In this case, one can rewrite equation (4) as

$$\widetilde{(I_{om} - I_m)}_j(s) = \widetilde{(V_1+V_2)}(s)\,\frac{\cos(2\pi\, s\Delta\lambda_j)}{i[\sin(2\pi s\Delta\lambda_1)+\sin(2\pi s\Delta\lambda_2)]} \qquad (5)$$

$j = 1, 2$

and then, if the ratio between their Zeeman shifts is not a ratio between integers, the denominators never vanish, except for zero frequency. In (5) it has been implicitly assumed that both lines have the same central wavelength. The reconstruction obtained making use of equation (5) is still affected by the lack of knowledge on the continuum and the filling factor. This problem afflicts also all other possible schemes for the reconstruction of the I_m profile from averaged data. Again the problem can be eluded with a new hypothesis: a two-component model

$$I(\lambda) = \alpha I_m(\lambda) + (1 - \alpha) I_s(\lambda), \quad (6)$$

where I is the average intensity profile in the plage, α the filling factor, and I_s the the non-magnetic intensity profile.

I_m can be decomposed as

$$\alpha I_m = \alpha I_{om} - \alpha (I_{om} - I_m), \quad (7)$$

in which I_{om} is the continuum intensity in the tube and $\alpha (I_{om} - I_m)$ the profile obtained by means of (5).

Assuming I_s to be the quiet photospheric profile, all the quantities in equation (6) are known except the continuum intensity and the filling factor. Acccording to Table 1 of Schüssler and Solanki (1987) this assumption is reasonable, although not completely correct. Using a simple least-squares fit, the equation will provide the last two parameters (i.e. α and I_{om}) required for the full magnetic profile. We wish to warn that the α and I_{om} values so determined do not necessarily correspond to the true values of these quantities, as long as we do not know the true $I_s(\lambda)$ profile.

3. TESTING THE METHOD

The method explained above has been applied to some FTS data (Stenflo et al., 1984) using the spectral lines Fe I 5247 and Fe I 5250 which meet the required conditions (Stenflo, 1973). Although the S/N ratio of the data makes them suitable, a new problem arises: the spectrum has been normalised and the information about the absolute intensity of the continuum has been lost. This fact does not allow an absolute determination but, instead, provides a normalised profile. The value of the magnetic field strength needed in equation (5) has been obtained via a simplified version of the Line Ratio Method (Sánchez Almeida, 1987).

Figures 1 and 2 show the observed profiles together with the reconstructed I in the tubes. Figures 1 correspond to a $B \sim 1200$ G. This region has a V signal 4.5 times stronger than the region of Figures 2, for which a field ~ 1000 G has been used. Figures 1a and 2a correspond to Fe I 5250 the line with larger g for which the Zeeman splitting can be clearly distinguished. Figure 1b and 2b are for Fe I 5247, with smaller Zeeman splitting. Figures 1c and 2c show both lines as if they were not sensitive to the magnetic field (g=0). A velocity field is apparent from the asymmetries (although slightly different in both plages) but the general shape and the equivalent width (40 mA) is preserved. Note that, as the observed V profiles are asymmetric, similar corrections to those made by Solanki and Stenflo (1984) have to be carried out in order to place the continuum on both sides of the reconstructed profile at the same level.

4. CONCLUSIONS

Spectroscopic analysis of the light coming from an atmosphere is a powerful tool for revealing its properties. The problem when using conventional spectroscopy for solar fluxtubes is their unresolved character: magnetic and non-magnetic regions of a plage have to be observed as a whole. With the aim of obtaining the true intensity spectrum of an unresolved tube, we have developed a simple method which can reconstruct the intensity generated in the magnetic component. Only observed parameters are used: intensity and circular polarization in the plage and intensity in the quiet photosphere. The technique makes use of two lines identical in their thermodynamic properties but with different Landé factors. This is just the case of Fe I 5250 and Fe I 5247, which are used and their profiles restored.

The test of the technique with experimental data shows its applicability and power.

On the other hand, two reconstructed profiles, from two different plages (one shows a circular polarization 4.5 times smaller than the other), look very similar. The lines appear weakened and a velocity gradient is also appreciable from their asymmetries.

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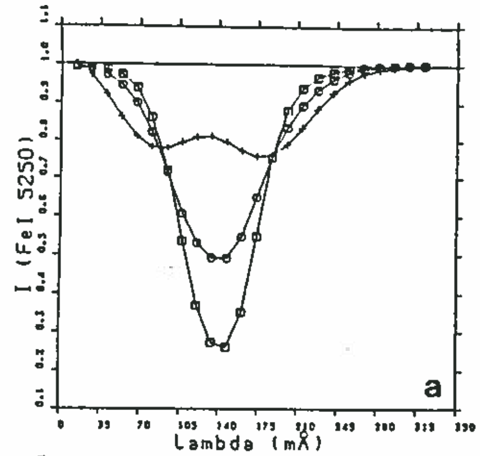
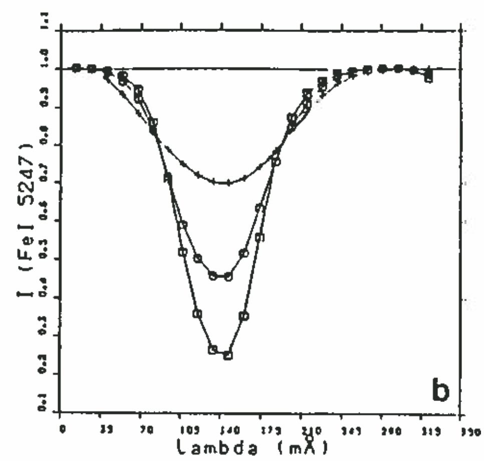




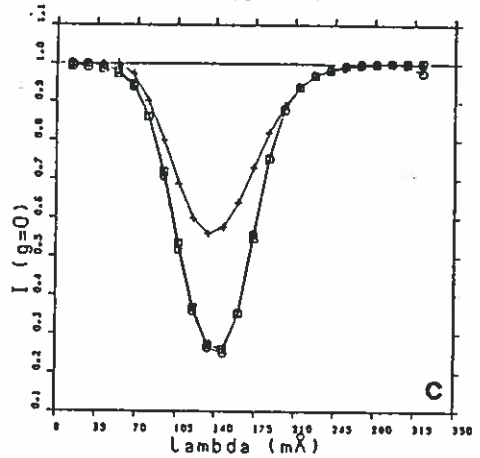
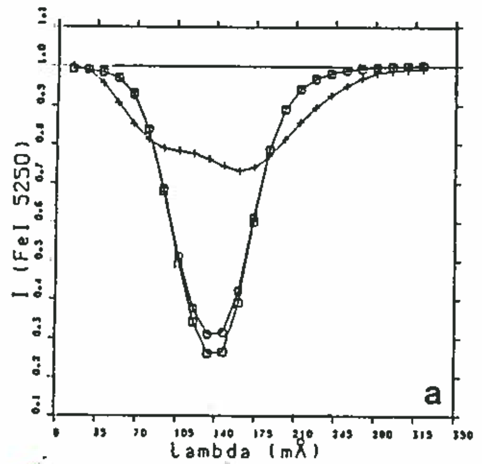
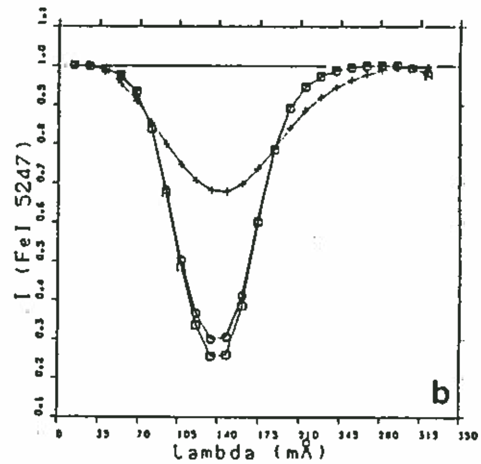


Figure 1: Reconstruction of the intensity profile in the fluxtubes of a strong plage: B ~1200 G. (a) FeI 5250 (g = 3) is shown from a quiet region (□), from the plage (o) and the reconstructed fluxtube profile (+) in which the Zeeman splitting is clearly visible. (b) The same for the second line FeI 5247 with g = 2. (c) Here are shown quiet FeI 5250 (□) and FeI 5247 (o) together with the "tube" profile if g were zero. It can be appreciated that a significant weakening and a velocity gradient are present.





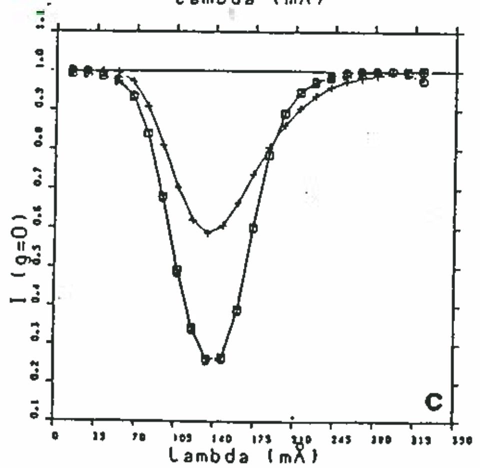


Figure 2: Intensity profile reconstruction of enhanced network fluxtubes (the V signal is 4.5 times smaller than in the strong plage) for which B ~1000 G. The same symbols are used as for Figure 1.