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ATOMIC ORIENTATION IN CHROMOSPHERIC LINES

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ABSTRACT Observations of the Stokes I and V profiles of the Ca II H and K lines in solar magnetic regions are presented. Least-squares fits of $dI/d\lambda$ to V are obtained and the wavelength variation of the residuals, i.e. $V - k dI/d\lambda$, calculated. We find significant *symmetric* residuals in umbrae, which are in agreement with the effect on the V profiles due to *atomic orientation*, i.e. with the existence of an unequal population of the Zeeman sublevels with M>0 with respect to those with M<0.

INTRODUCTION

Basically, there are two distinct mechanisms capable of generating polarization in the radiation emitted by an atom at a point in the solar atmosphere:

a) One is due to the presence of a splitting of the atomic levels, e.g. due to the Zeeman effect. Here, the different components of the line emit radiation with different polarization properties according to the ΔM-values of the atomic transitions. Under these circumstances, and in the *absence* of velocity gradients, the Stokes-V profile would be antisymmetric.

b) The other mechanism is due to the presence of population differences and/or coherences among the sublevels, i.e. to the presence of *atomic polarization*. For instance, for a transition like that of the Ca II H line (i.e. $J_u = J_l = 1/2$), if the sublevel with M=1/2 of the upper level is more populated than the sublevel with M=−1/2, then the emission process would contribute to the Stokes-V profile with a *symmetric* signal.

In fact, atomic polarization involves in general both *alignment* and *orientation* (see e.g. Landi Degl'Innocenti, 1983). To produce *alignment* it is sufficient to have a limb-darkened radiation field. This property, induced by an anysotropic illumination of the atoms, can lead to significant linear polarization signals (Q and U Stokes profiles), like for instance those observed by Stenflo *et al.* (1980) in non-magnetic regions close to the solar limb.

On the other hand, to produce *orientation* it is necessary that the sublevels with M>0 be illuminated by a radiation field that is different from the radiation field which illuminates the sublevels with M<0. For this one needs a magnetic field (which splits the sublevels) and an agent capable of breaking the *symmetry* of the incident radiation field with respect to the center of the split line, like e.g.

the presence of mass-motions of the material inside the magnetic regions with respect to the surrounding atmosphere (see e.g. Landi Degl'Innocenti, 1985).

In this contribution we show the first results of a research project aimed at investigating whether atomic orientation signatures are present in chromospheric lines. Here, we present results for the Ca II H and K lines, which are known to exhibit measurable circular polarization (e.g. Martinez Pillet *et al.* , 1990).

STRATEGY

Under the physical conditions typical of solar magnetic regions the coherences between the different Zeeman sublevels vanish, because the magnetic field is sufficiently strong (B>10 Gauss). Thus we will have to assign the measured polarization signals to the combined influence of the Zeeman effect and the possible presence of population differences in the magnetic sublevels.

The observational signature of the presence of *atomic orientation* is a symmetric contribution to the V-profile. However, such contributions may also result from:

a) cross-talk effects of Q and U in V, since Q and U have symmetric profiles as due both to the Zeeman effect and to atomic alignment. To exclude this instrumental-polarization possibility we have observed with the Gregory Coudé Telescope (Tenerife, Spain) at an epoch of zero declination (see Sánchez Almeida *et al.* , 1991), and performed a very precise alignment of the IAC Stokes I and V analyzer (Sánchez Almeida and Martinez Pillet, 1990).

b) the effect of Zeeman polarization in the presence of velocity gradients combined with magnetic field gradients. Disentangling this effect from that due to atomic orientation is not a simple matter. In a forthcoming work we will investigate whether combinations of such gradients in sunspot chromospheric models can be responsible for the observed Stokes I and V profiles.

The first strategy we have attempted is the following. Assuming that there is no atomic orientation, it is known that in the weak field limit (a limit which applies to the CaII H and K lines in solar magnetic regions), and for a *constant* value of the longitudinal component of the magnetic field along the line of sight, the V-profile is proportional to the derivative with respect to wavelength of the I profile, i.e.

$$V = k dI/d\lambda, \tag{1}$$

where $k = -4.67 \times 10^{-13} B(\text{Gauss}) g \lambda^2(\text{Å})$, with B the longitudinal field strength and g the effective Landé factor. Note that this equation remains valid even if the atmosphere where the lines are formed presents a velocity gradient.

The presence of atomic polarization invalidates Eq. (1) (Landi Degl'Innocenti et al, 1991). Then, our strategy is based on the theoretical result that atomic orientation transforms Eq. (1) into

$$V(\lambda) = k \frac{dI(\lambda)}{d\lambda} + S(\lambda), \tag{2}$$

where the residual $S(\lambda)$ should be a symmetric function with respect to the central wavelength of the line.

According to this, Stokes I and V profiles have to be analyzed as follows:

1) Subtracting from the V profile the quantity kdI/dλ, with k obtained by means of a least-squares fit. From the obtained value of k, and assuming a filling factor equal to unity, we obtain estimates of the longitudinal magnetic field strength.

2) The shape of the residuals will tell us whether they are compatible with the atomic orientation hypothesis (i.e., are the residuals symmetric?).

RESULTS

We have obtained I and V spectra of the Ca II H and K lines in solar magnetic regions (exposure time with a CCD=5 sec, spatial resolution $\approx 1.3''$). In what follows, we summarize the main results of the above-mentioned analysis.

1) For most of the observed umbrae, the Stokes V-profiles of the Ca II H and K lines show significant departures from Eq. (1). The resulting residuals are always symmetric (see examples in Fig. 1). We have detected changes in the sign of these residuals when moving along the spatial direction.

2) A possible relation between the magnitude of the symmetric residuals in umbrae and the intensity of the emission peaks of the I-profile has been detected. For instance, the residual was substantially more important near the instant of maximum emission of an umbral flash than a few minutes earlier. However, this initial result deserves further investigation.

3) The longitudinal magnetic field strength for sunspot umbrae varies in the range 900 - 1600 G.

4) All the V-profiles observed in penumbrae are approximately proportional to the derivative of the I profiles. For a sunspot close to disc center values between 500 and 900 G were found.

5) Some of the observed V-profiles in plages follow the Stokes I derivative, while others show a complicated behaviour. Plages far from sunspots never showed magnetic field strengths larger than 400 G.

CONCLUSIONS

We have found that the residuals of umbral spectra are always symmetric. Although it has yet to be investigated whether plausible variations of the velocity and of the component of the magnetic field along the line of sight in sunspot chromospheric models can generate symmetric residuals of the same importance and shape as the ones we have obtained, we believe that the atomic orientation hypothesis offers the most natural explanation. Both observational and theoretical research is under way, which will certainly be of interest for the investigation of solar chromospheric magnetic fields.

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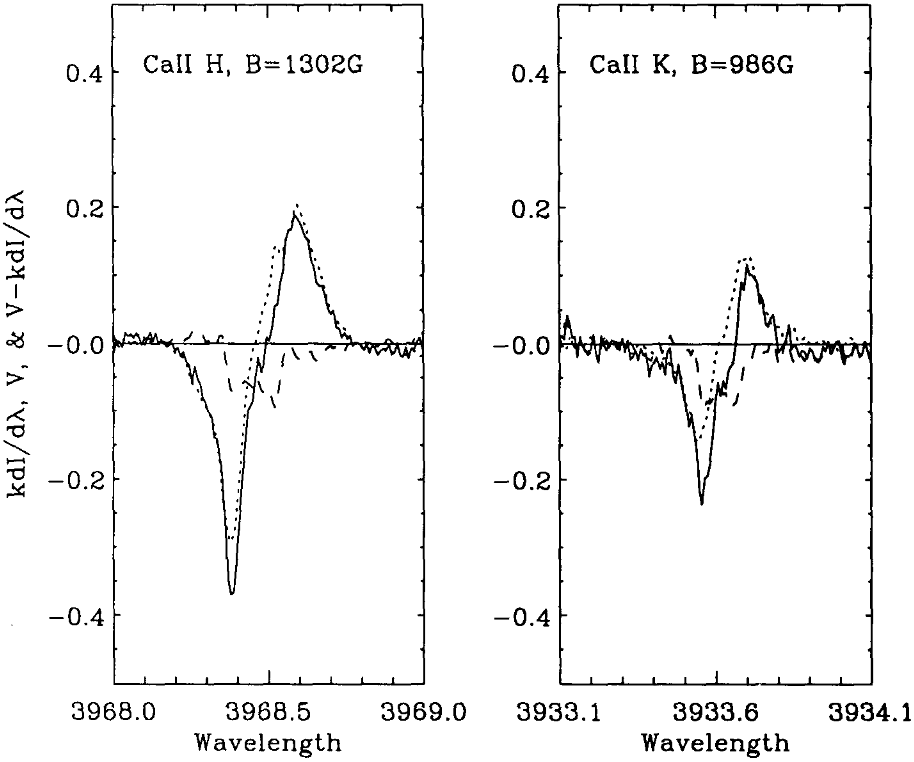

Fig. 1 Stokes V-profiles of the Ca II H and K lines observed in an umbra near disc centre. Solid lines: observed Stokes-V; dotted lines: the derivative with respect to wavelength of Stokes I; dashed lines: the residuals. The roughly symmetric shape of the residuals might be produced by atomic orientation.

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