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Influence of the Paschen-Back effect on the results of polarimetric inversions of the He I 10830 triplet

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Abstract. The He I triplet at 10830 Å has a great potential for determining the magnetic field vector in the upper chromosphere. The triplet is Zeeman sensitive (Landé factors 2.0, 1.75 and 1.25) and shows the signature of the Hanle effect under appropriate conditions. Additionally, the Zeeman sublevels are influenced by the Paschen-Back effect leading to changes in strength and in position of the Zeeman components of the transitions forming the triplet. In this work we calculate the influence of the Paschen-Back effect on the Stokes profiles and investigate its relevance to inversions on spectro-polarimetric data obtained with the Tenerife Infrared Polarimeter (TIP) at the German Vacuum Tower Telescope (VTT).

Key words. Sun: chromosphere – Sun: Magnetic field – Sun: Zeeman Polarimetry – Sun: Paschen-Back

1. Introduction

The study of the magnetic field in the upper chromosphere is of major importance to understand the coupling between the relatively cool photosphere and the hot corona. A new technique to reliably determine the magnetic field in this region is the analysis of the observed polarization in the He I 10830 Å multiplet. The He I 10830 Å multiplet originates between the atomic levels 2^3S_1 and $2^3P_{2,1,0}$. It comprises a 'blue' component at 10829.09 Å with $J_u = 0$ (Tr1), and two 'red' components at 10830.25 Å with $J_u = 1$ (Tr2) and at 10830.34 Å with $J_u = 2$ (Tr3) which are blended at solar atmospheric temperatures.

In previous papers (Solanki et al. 2003; Lagg et al. 2004) the observed polarization in the He I 10830 Å multiplet was analysed by considering the linear Zeeman splitting (LZS) approximation. Socas-Navarro et al. (2004) demonstrated that the determination of the magnetic field vector from spectropolarimetry in the He I 10830 Å multiplet must be done considering the Zeeman splitting in the incomplete Paschen-Back effect regime. Neglecting the Paschen-Back effect results in significant errors in the calculation of its polarization profiles, since the positions and strengths of the Zeeman components are strongly influenced by the Paschen-Back effect, especially for magnetic field strengths above a few hun-

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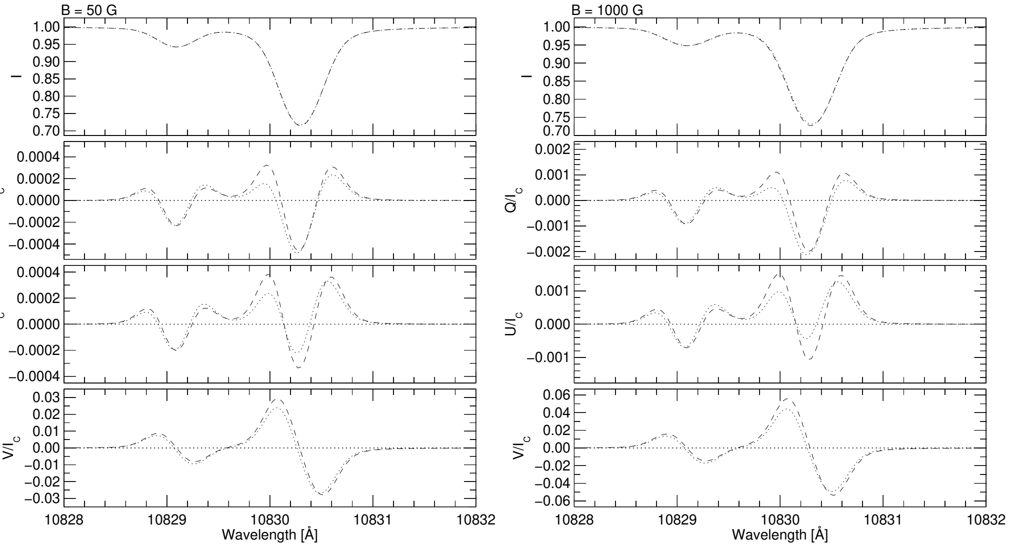

Fig. 1. Synthetic Stokes profiles of the He ɪ 10830 Å triplet, assuming a 50 G and a 1000 G field, respectively, inclined 30°with respect to the line of sight. The difference between the profiles obtained considering incomplete Paschen-Back splitting (IPBS; dotted line) or LZS (dashed lines) approximation is evident and increases for bigger fields.

dred Gauss. The shift in wavelength-position and the asymmetric change of the strengths between the blue and the red Zeeman sublevels introduces asymmetries in the resulting Stokes Q, U and V profiles.
Here we present systematic tests of the influence of the Paschen-Back effect on parameters retrieved from the He I triplet.

2. Results

Fig. 1 compares the synthetic Stokes profiles of the He ɪ 10830 Å multiplet for a 50 G and a 1000 G field, inclined by 30° with respect to the line of sight, obtained considering incomplete Paschen-Back splitting (IPBS; dotted line) or LZS (dashed line) approximation. The difference between the profiles is clearly evident. Moreover, if we compare the two panels we can see that the difference between the profiles calculated using IPBS and LZS, increases with increasing magnetic field strength.
We analyse the effect of the IPBS on synthetic Stokes profiles by estimating the error we make when retrieving the values of the physical parameters (such as the LOS-velocity, the magnetic field vector, etc.) by using LZS instead of IPBS. For this purpose we calculated synthetic profiles in the IPBS approximation, that should represent the case of a real observation. We then inverted this IPBS profile considering LZS only. The results of this analysis are summarized in Fig. 2. The value of the magnetic field and the velocity along the line of sight, as obtained from the LZS inversion of a synthetic IPBS profile, are plotted as a function of the magnetic field strength for different values of the inclination and of the azimuthal angle of the magnetic field. We see, in both graphics, a significative deviation of the retrieved values from the correct ones, indicated by a solid line. More precisely, there is an underestimation of the retrieved magnetic field values and an overestimation of the LOS-velocity that depends on the magnetic field strength and on the value of its inclination. In particular, the error introduced by neglecting the IPBS, increases with the strength of the magnetic field for both parameters and, for the

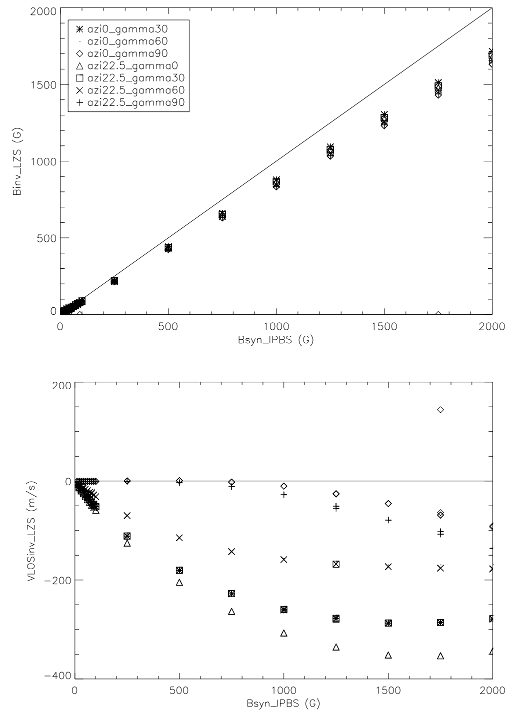

Fig. 2. Magnetic field strength (top) and line-of-sight velocity (bottom) for different inclination (γ) and azimuthal angles of the magnetic field vector (in degrees) as obtained from inverting a synthetic profile. The synthetic profile was obtained considering IPBS, whereas the inversion was done with LZS only. The retrieved values for magnetic field (top) and LOS-velocity (bottom) deviate significantly from the correct values (solid black line).

LOS-velocity, decreases with bigger values of the inclination of the magnetic field.

We can now do the same analysis for a measured profile. We choose the observation of the emerging flux region NOAA 9451 located at 33°W, 22°S that was recorded with the Tenerife Infrared Polarimeter mounted behind the Echelle spectrograph on the Vacuum Tower telescope at the Teide observatory on Tenerife. This active region was previously studied assuming LZS (Solanki et al. 2003; Lagg et al. 2004).

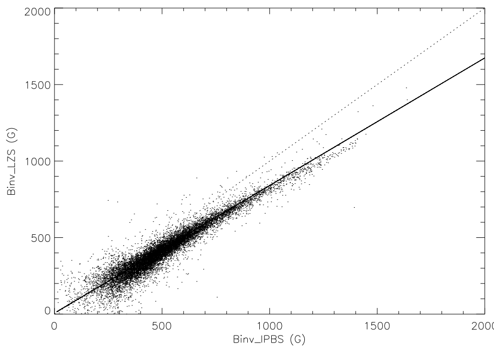

Fig. 3. Influence of IPBS on the retrieval of the magnetic field strength for NOAA 9451. The values retrieved from inversions neglecting the IPBS underestimate the magnetic field strength. The error we have assuming LZS (solid line) instead of IPBS (dashed line) is approximately 20%. This reflects the behaviour from the analysis of synthetic profiles presented in the upper panel of Fig. 2.

As we can see in Fig. 3, we find that the magnetic field values are higher if the analysis is made by using IPBS instead of LZS and that this effect is larger for bigger magnetic fields. Comparing the results obtained for a synthetic profile with those of a measured one (Fig. 2, upper panel) shows that the effect of the IPBS approximation on the retrieved values is the same for both.
The error we have by assuming LZS instead of IPBS on the field strength values retrieved from inversions is approximately 20%.

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