INFLUENCE OF THE PASCHEN-BACK EFFECT ON THE STOKES PROFILES OF THE HE 10830 Å TRIPLET

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ABSTRACT

It has been shown that the Paschen-Back effect influences the Stokes profiles of the Zeeman sensitive He I 10830 Å multiplet lines. We demonstrate the relevance of this effect using synthetic profiles and investigate its influence on the inversion of polarimetric data obtained with the Tenerife Infrared Polarimeter (TIP) at the German Vacuum Tower Telescope (VTT). We find that 20% higher field strength values are obtained if we take the incomplete Paschen-Back effect into account. In addition, we show the area asymmetry exhibited by many He I 10830 Stokes V profiles is not dominantly due to the Paschen-Back effect, but has another main cause.

Key words: sun; chromosphere; magnetic field; Zeeman polarimetry; 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 vector 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

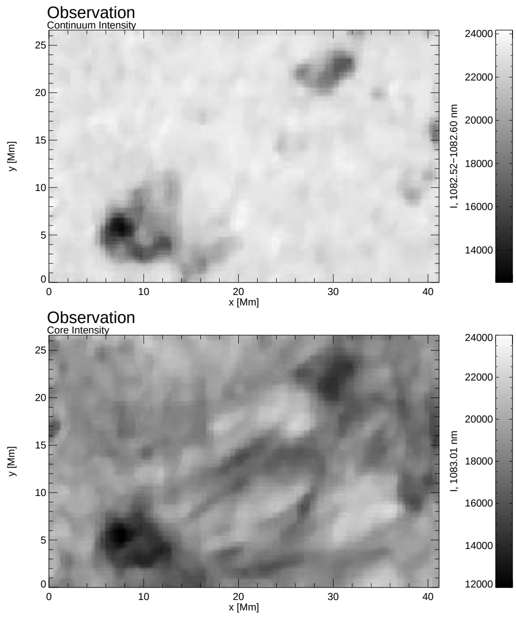

Figure 1. Continuum and He core intensity maps of an emerging flux region (NOAA active region 9451, 33°W, 22°S) derived from the Stokes I profile of the He I triplet at 10830 Å.

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 hundred 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. In particular, we have concentrated our analysis on the observation of the emerging flux region NOAA 9451 located at 33° W, 22° S (Fig. 1), because Socas-Navarro et al. (2004) suggest that, proba-

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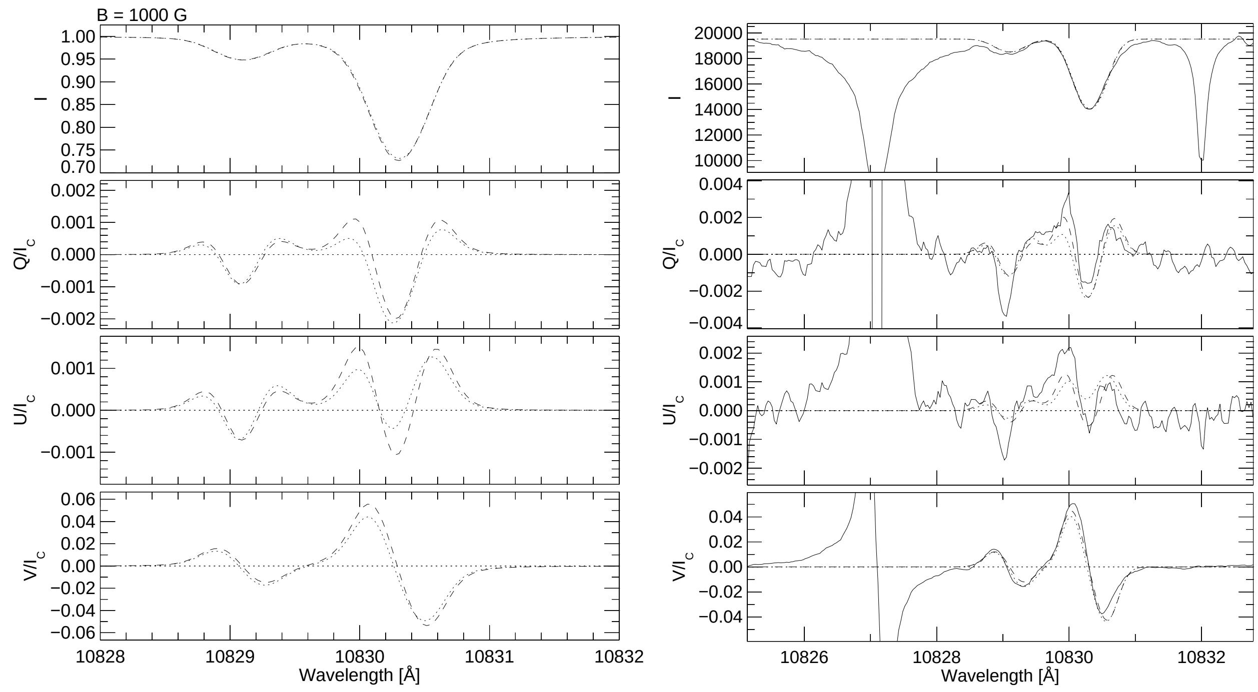

Figure 2. On the left: Synthetic Stokes profiles of the He I 10830 Å triplet, assuming a 1000 G field, inclined $30°$ *with respect to the line of sight. The dotted profile is obtained considering incomplete Paschen-Back splitting (IPBS), while the dashed one is obtained considering the linear Zeeman splitting (LZS) approximation. On the right: Stokes I, Q, U and V profiles at position* $x = 9$ *Mm,* $y = 4$ *Mm of Fig. 1. The observed profile is the solid line, the profile obtained from the inversion done considering the LZS is the dashed line and the one obtained using IPBS is the dotted line.*

bly, some Paschen-Back signatures described in their paper are present in this observation referring, in particular, to profile asymmetries. This active region, recorded with the Tenerife Infrared Polarimeter mounted behind the Echelle spectrograph on the Vacuum Tower telescope at the Teide observatory on Tenerife, was previously studied assuming LZS (Solanki et al. 2003; Lagg et al. 2004).

2. RESULTS

Fig. 2 shows the synthetic Stokes profiles (left panel) of the He I 10830 Å multiplet for 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 obtained considering the IPBS or the LZS approximation is evident.
On the right panel of Fig. 2 we have plotted the Stokes I, Q, U and V profiles at position $x = 9$ Mm, $y = 4$ Mm of Fig. 1. We tried to reproduce the observed profile (solid line) by doing the inversion in two different ways, considering the LZS approximation (dashed line) or IPBS (dotted line). For the case where the IPBS is included, the fit appears to be worse. In the V profile, in particular, the inversion including IPBS is not able to reproduce the asymmetries of the observed profile and the Stokes V zero-crossing for the 'red' components of the triplet (Tr2+Tr3), contrary to the conjecture of Socas-Navarro et al. (2004).
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 magnetic field vector, etc.) by using LZS instead of IPBS. For this purpose we calculated synthetic profiles in the IPBS approximation, which are taken to represent an observation. We then inverted this IPBS profile considering LZS only. The result of this analysis regarding the field strength is summarized in Fig. 3 (top). The value of the magnetic field strength, as obtained from the LZS inversion of a synthetic IPBS profile, is plotted as a function of the magnetic field strength for different values of the inclination and of the azimuthal angle of the magnetic field (indicated in the figure). We see a significant deviation of the retrieved values from the correct ones (the expectation values are indicated by the solid line). More precisely, there is an underestimation of the retrieved magnetic field values that depends on the magnetic field strength and to a lesser extent on the value of its inclination. In particular, the error introduced by neglecting the IPBS, increases with the strength of the magnetic field.

We can now do a similar analysis using the observational data. As we can see in Fig. 3 (bottom), we find that the magnetic field values are higher if the analysis is carried out 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 shows that the effect of the IPBS approximation on

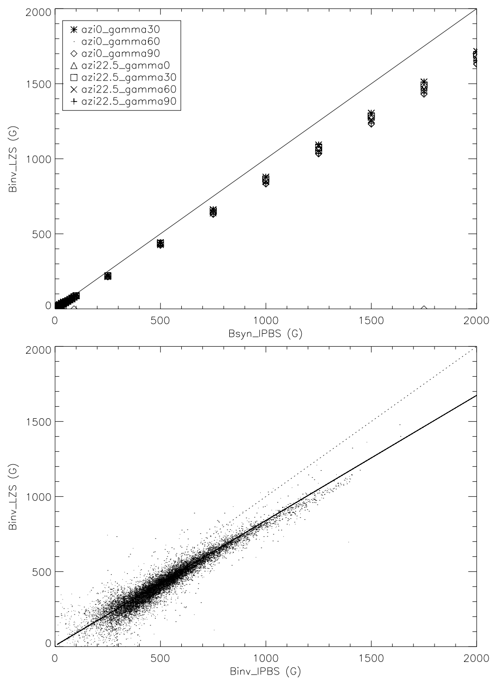

Figure 3. Upper panel: Magnetic field strength for different inclination (γ) and azimuthal angles of the magnetic field vector (in degrees) as obtained from inverting a synthetic profile. The synthetic profile was obtained considering IPBS, whereas the inversion was done with LZS only. The retrieved values for magnetic field deviate significantly from the correct values (solid black line). Lower panel: Influence of IPBS on the retrieval of the magnetic field strength for NOAA 9451 (Fig. 1). The values retrieved from inversions neglecting the IPBS underestimate the magnetic field strength. The error induced by 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 left panel.

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%.

2.1. Area asymmetry

In order to evaluate the influence of the Paschen-Back effect on the Stokes V-profile area asymmetry, defined as:

$$\mathcal{A} = \frac{\int_{-\infty}^{+\infty} V(x)dx}{\int_{-\infty}^{+\infty} |V(x)|dx}, \quad (1)$$

we plot the absolute value of the area asymmetry ($|\mathcal{A}|$) of synthetic IPBS V-profiles as a function of the magnetic field strength for different ranges of the values of the Doppler broadening of the lines (Fig 4). The synthetic

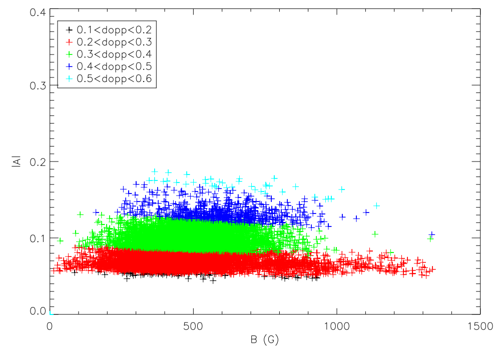

Figure 4. Absolute value of the area asymmetry ($|\mathcal{A}|$) of synthetic IPBS V-profiles as a function of the magnetic field strength for different ranges of the values of the Doppler broadening of the lines.

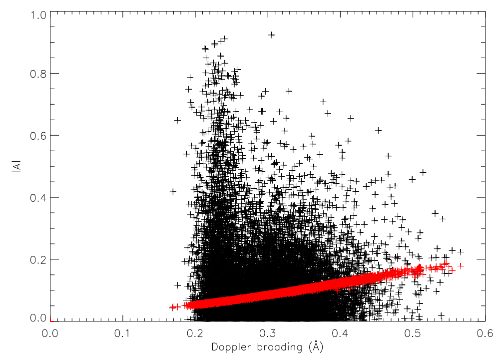

Figure 5. Absolute value of the area asymmetry of synthetic IPBS V-profiles (red) and of the observed V-profiles (black) as a function of the Doppler broadening of the lines. For the observed V-profiles the area asymmetry is not a function of the Doppler broadening.

profiles are obtained from an inversion to fit the observed profiles. The area asymmetry for a synthetic IPBS V-profile is clearly a function of the Doppler broadening of the lines, as indicated by the different colours. We try to find the same dependence of the V-profile area asymmetry from the Doppler broadening for the observed values. In Fig. 5 we compare the absolute value of the area asymmetry of synthetic IPBS V-profiles (red) with that of the observed V-profiles (black) as a function of the Doppler broadening of the lines. The area asymmetry of the observed V-profiles is not a function of the Doppler broadening. This behaviour for the observed profiles shows that there must be some effect stronger than the Paschen-Back itself that drives the area asymmetry. Possible candidates are gradients of atmospheric parameters like the magnetic field vector, the velocity or macroturbulences.

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