SPECTROPOLARIMETRIC OBSERVATIONS OF PROMINENCES AND SPICULES, AND MAGNETIC FIELD DIAGNOSTICS

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ABSTRACT

A large set of high precision full-Stokes spectropolarimetric observations of the He-D3 line in prominences and spicules have been performed with the ZIMPOL polarimeter at the Gregory-Coudé Telescope in Locarno. The observational technique allows to obtain measurements free from seeing induced spurious effects. The instrumental polarization is well under control and taken into account in the data analysis. The observed Stokes-profiles are interpreted according to the quantum theory of the Hanle and Zeeman effects with the aim of obtaining information on the magnetic field vector. To this end, we make use of a suitable Stokes inversion strategy technique. The results are presented giving emphasis on a few particularly interesting Stokes-profiles. Finally we show some novel prominence observations in the Hα and Hβ hydrogen lines.

Key words: spicules; prominences; polarimetry.

1. INTRODUCTION

Spectropolarimetry together with a suitable inversion technique of Stokes profiles, which takes into account the joint action of the Hanle and Zeeman effects, is a powerful diagnostic tool to obtain information about the three-dimensional geometry of the magnetic fields that are responsible for the confinement of the plasma in prominences and of the magnetic fields that channel the spicular motions. In particular the Helium multiplets at D3 and 10830 Å provide the most useful spectral lines for that purpose (see, e.g., the recent works by Trujillo Bueno et al. (2002), Casini et al. (2003), Ramelli & Bianda (2005), Trujillo Bueno et al. (2005) and López Ariste & Casini (2005)). Emission lines as Hα and Hβ are also of interest, but the interpretation of their Stokes profiles is much more complicated.

A few years ago, we started at the Istituto Ricerche Solari Locarno (IRSOL) an ambitious observational project, on both prominences and spicules, taking advantage of the outstanding performances of the Zurich Imaging Polarimeter (ZIMPOL) (Gandorfer et al., 2004). A preliminary physical interpretation of our observations based on suitable inversion techniques has been applied to the He-D3 data in order to obtain information on the magnetic filed vectors involved. The interpretation of Hα and Hβ Stokes profiles is however postponed to a future work.

2. THE OBSERVATIONS

The observations were performed with the Gregory-Coudé Telescope (45 cm of aperture) at IRSOL. The ZIMPOL polarimeter allowed precise measurements free from seeing induced spurious effects (modulation at 42 kHz). The solar image was rotated with a Dove prism set after the polarization analyzer in order to keep the limb parallel to the spectrograph slit. A limb tracker was used to maintain the distance from the limb constant. 53 spicules measurements were obtained at different latitudes and limb distances in the period between November 2004 and June 2005. The prominence measurements were performed between May 2003 and June 2005 in different positions and prominences: 49 measurements in the He-D3 line, 29 in Hα and 9 in Hβ. The total exposure time for each measurement ranged from 10 minutes to about 1 hour.

Calibrations measurements were performed regularly. These included polarimetric efficiency measurements, dark current, flat field and measurements of the instrumental polarization. In addition, after each prominence observation, a measurement of the intensity spectrum profile of the scattered light was usually taken in a nearby region at about the same limb distance.

The instrumental polarization could be carefully corrected for, taking advantage of the fact that for a given

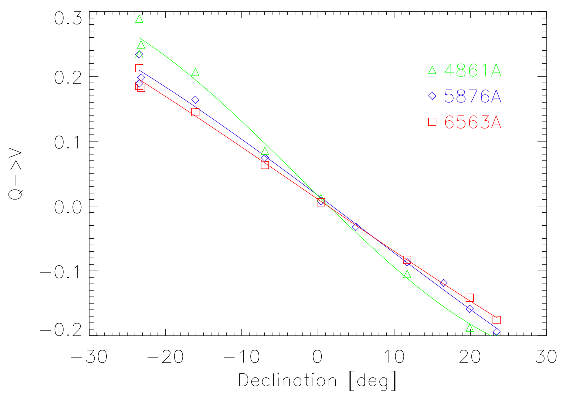

Figure 1. Measurement of the $Q \to V$ crosstalk as a function of declination for Hα, He-D3 and Hβ. To obtain this measurement a linear polarizer is placed before the entrance window of the telescope with the polarization axis parallel to the geographic equator which is our choice here for the positive direction of Stokes Q.

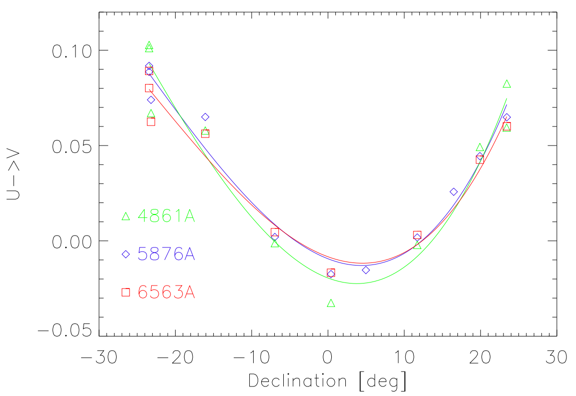

Figure 2. Measurement of the $U \to V$ crosstalk as a function of declination for Hα, He-D3 and Hβ. To obtain this measurement the linear polarizer is rotated by 45° with respect to the geographical equator.

wavelength it is a function of declination and stays therefore almost constant over one day. The crosstalks $I \to Q$, $I \to U$ and $I \to V$ were determined through the measurements performed on the solar disc in quiet regions near the center. The crosstalks $Q \to V$ and $U \to V$ were determined applying a linear polarization filter in different positions before the entrance window of the telescope. The results as a function of the declination are shown in the Figs. 1 and 2. The $V \to Q$ and $V \to U$ crosstalks were extracted from the $Q \to V$ and $U \to V$ crosstalk measurements taking into account the symmetries of the theoretical Müller matrix of a GCT which is given by Sánchez Almeida et al. (1991).

3. INFERENCE OF THE MAGNETIC FIELD FROM THE HE-D3 PROFILES

A database containing the theoretical Stokes profiles for different limb distances, magnetic field orientations and strengths has been created, with the theoretical Stokes profiles calculated via the application of the quantum theory of the Hanle and Zeeman effects (see, e.g., Landi Degl'Innocenti & Landolfi, 2004).

Both structures (spicules and prominences) were assumed to be optically thin. The theoretical profiles that better fit the measured profiles are carefully searched in the database, in order to infer the magnetic field vector.

Future planed improvements in our analysis will include the introduction of non thermal motions to better fit the intensity profiles and a detailed study of the so-called Van Vleck ambiguity which may occur in addition to the well known 180° ambiguity. We will eventually evaluate the opportunity to introduce some radiative transport simulations in order to take into account optical thickness, although this is usually very small for the He-D3 line.

4. RESULTS FROM THE MEASUREMENTS OF SPICULES

A preliminary analysis of our observations of spicules in quiet regions shows that generally the measured He-D3 Stokes profiles are compatible with a magnetic field strength of approximately 10 gauss (see example in Fig. 3), which is in good agreement with the results obtained from the 10830 Å He-line by Trujillo Bueno et al. (2005). The Stokes V profiles are usually dominated by the symmetric signature due to the alignment-to-orientation transfer mechanism discussed by Kemp et al. (1984) and Landi Degl'Innocenti & Landolfi (2004) (see Figs. 3 and 4).

Only in one measurement the Stokes profiles indicate magnetic field strengths as high as 50-60 gauss (Figs. 5, 6, 7). In this particular case the Stokes V profile shows a typical Zeeman-like antisymmetric shape. Note that Stokes Q is affected by a strong depolarization. It is

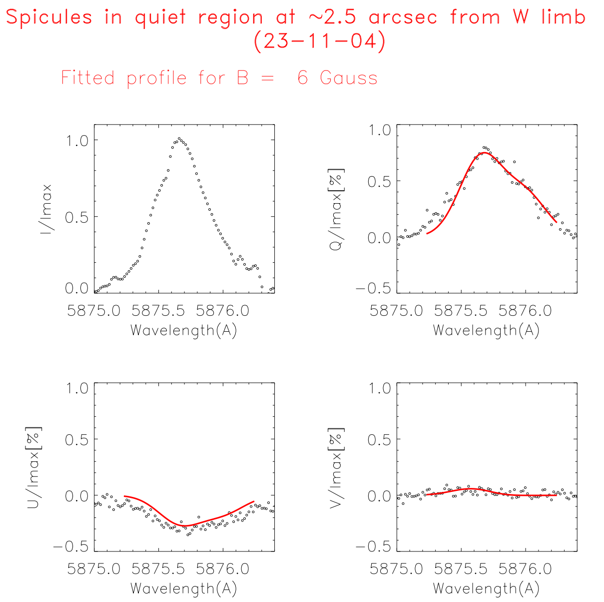

Figure 3. Example of an observation of spicules in a quiet region. The profiles are obtained integrating a region of 60 arcseconds. In red it is shown a fit with theoretical profiles corresponding to a magnetic field of 6 gauss. Measurements in quiet regions indicate magnetic field strengths around 10 gauss.

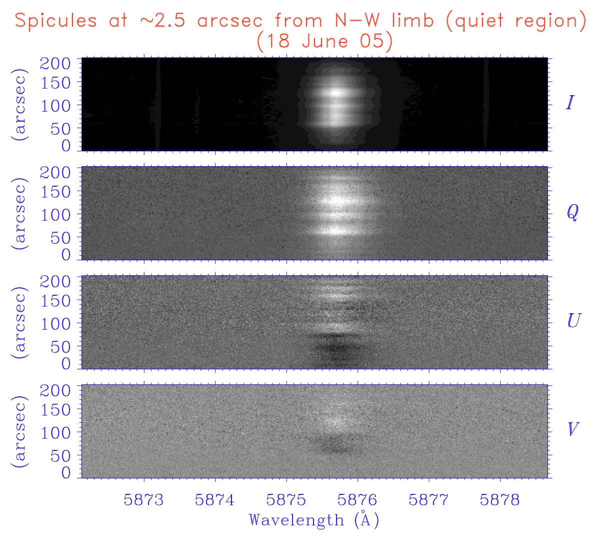

Figure 4. A measurement of spicules in a quiet region. Note that the V-profile is dominated by the alignment-to-orientation conversion mechanism explained in Kemp et al. (1984) and Landi Degl'Innocenti & Landolfi (2004).

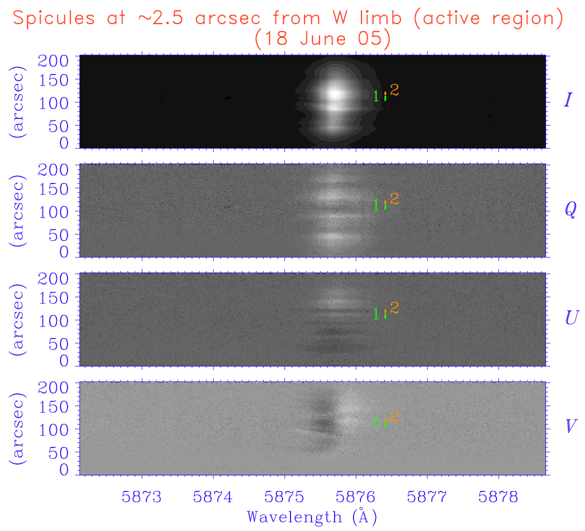

Figure 5. A measurement of spicules near an active region shows antisymmetric Zeeman-like Stokes V profiles indicating stronger magnetic fields. Two regions are selected for inversions, which are shown in the next two figures.

very important to point out that this measurement was obtained near the equator in the proximity of an active region.

5. RESULTS IN PROMINENCES

A preliminary inversion has been applied to part of our He-D3 observations in prominences. In this first analysis the Stokes profiles used for the inversion are obtained integrating several arcseconds along the spatial region observed through the spectrograph slit where, in the center of the He-D3 line, we have more than half of the maximum intensity. Two examples of He-D3 Stokes profiles with inversions are shown in Figs. 8 and 9. Also in these measurements we find usually magnetic fields of the order of 10 gauss.

Concerning our Hα measurements, interesting is that the Stokes V profiles show usually a typical antisymmetric Zeeman like structure (e.g. Figs. 10, 11, 12). In the only example we have found a symmetric Stokes V profile (Fig. 13), the amplitude was very small (a few 10^{-4}). Therefore, our observational results are different to those presented by López Ariste et al. (2005), whose observed V profiles show generally a larger symmetric signature often dominating the antisymmetric Zeeman effect signal. We also find interesting to note that it is quite common to observe self-absorption in the center of the Hα line, which suggests radiative transfer effects (see, e.g., Fig. 11).

In the Hβ measurements smaller polarization signals than in Hα line are observed. In the linear polarization profiles the largest amplitudes found in the Stokes profiles

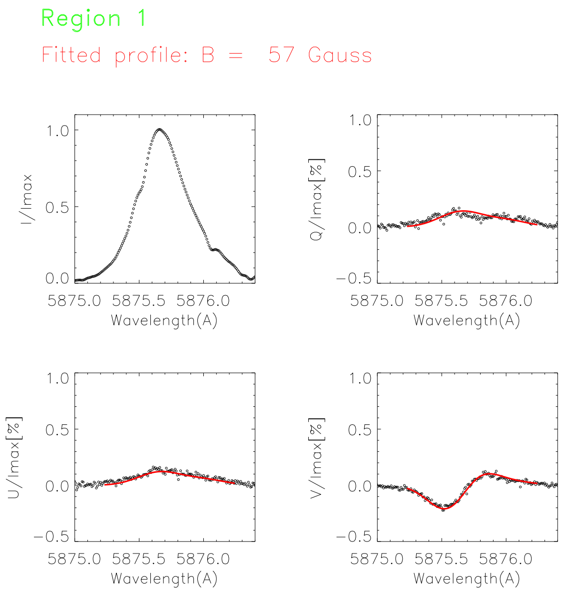

Figure 6. Stokes profiles obtained integrating the region 1 in Fig. 5 together with fitted theoretical profiles (in red) corresponding to a magnetic field of 57 gauss.

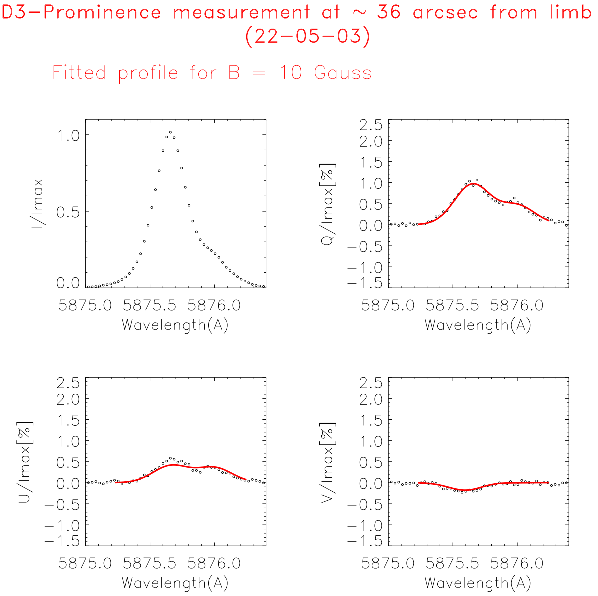

Figure 8. Example of He-D3 Stokes profiles observed in prominences and fitted profiles (in red).

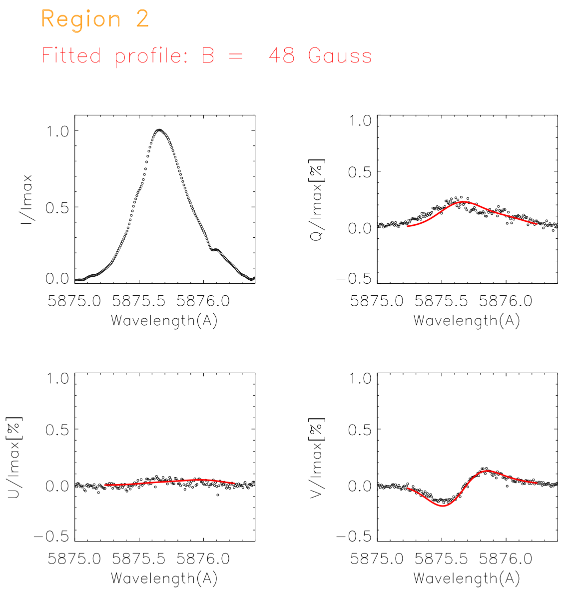

Figure 7. Stokes profiles obtained integrating the region 2 in Fig. 5 together with fitted theoretical profiles (in red) corresponding to a magnetic field of 48 gauss.

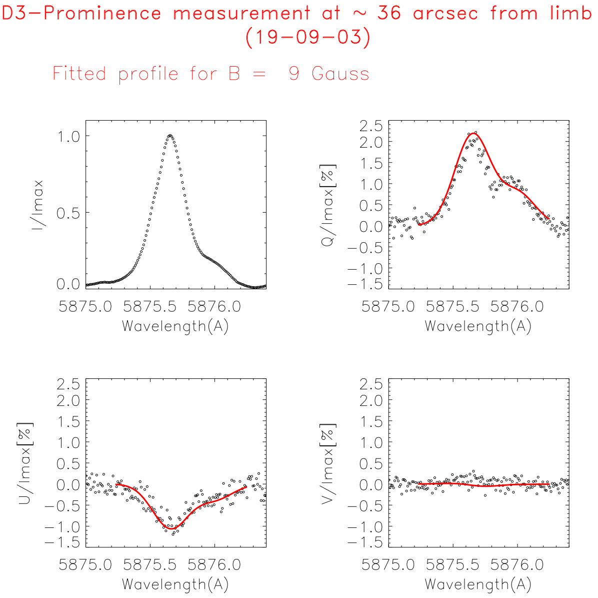

Figure 9. Example of He-D3 Stokes profiles observed in prominences and fitted profiles (in red).

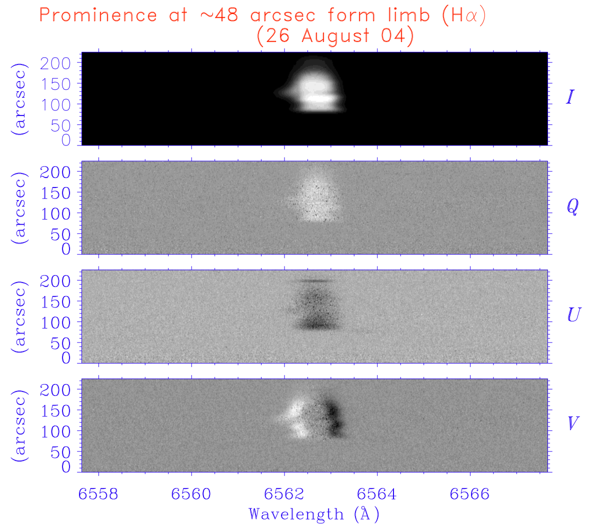

Figure 10. Example of an Hα spectropolarimetric observation in prominences showing a clear antisymmetric V profile.

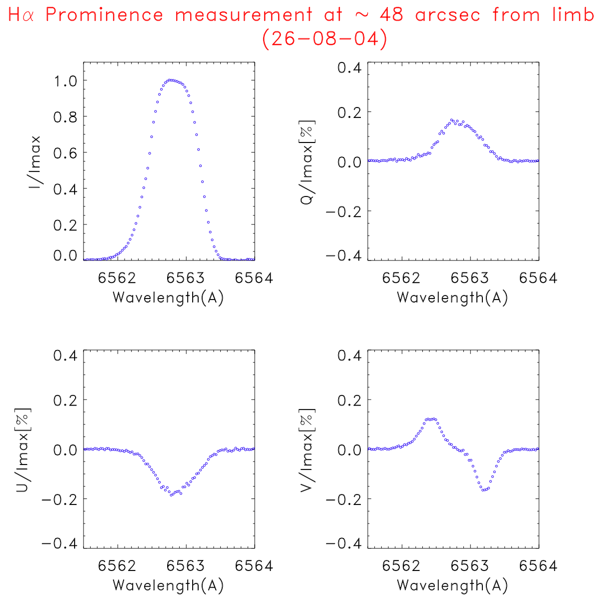

Figure 12. Example of Hα Stokes profiles obtained in prominences showing a clear antisymmetric V profile.

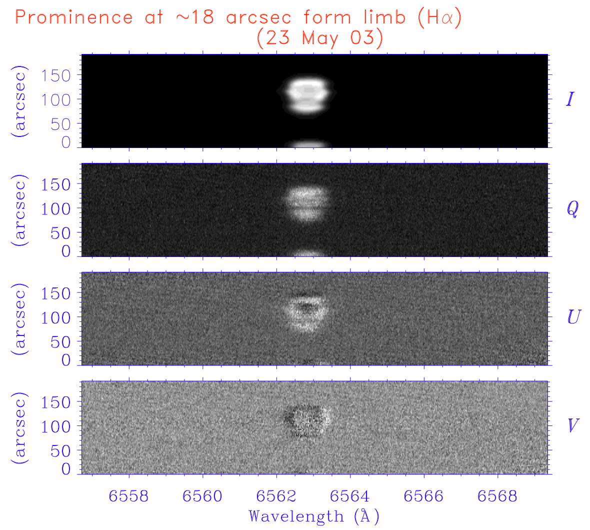

Figure 11. Example of an Hα spectropolarimetric observation in prominences. Note a strong self-absorption in the center of the line.

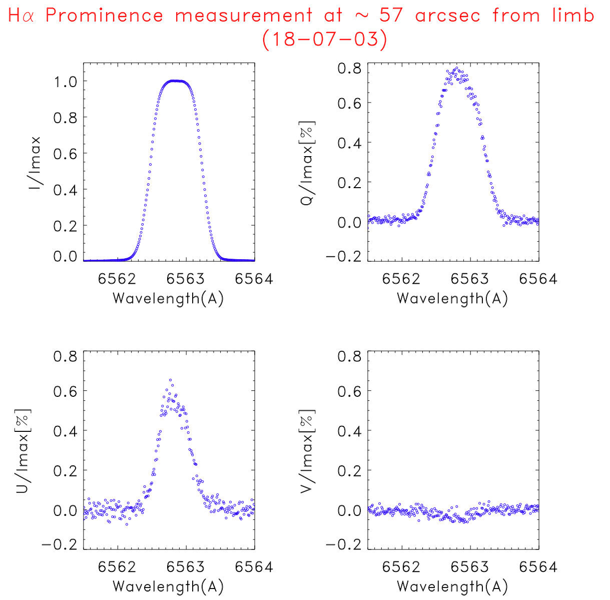

Figure 13. Example of Hα Stokes profiles obtained in prominences showing a small symmetric V profile with amplitude $\sim 10^{-4}$.

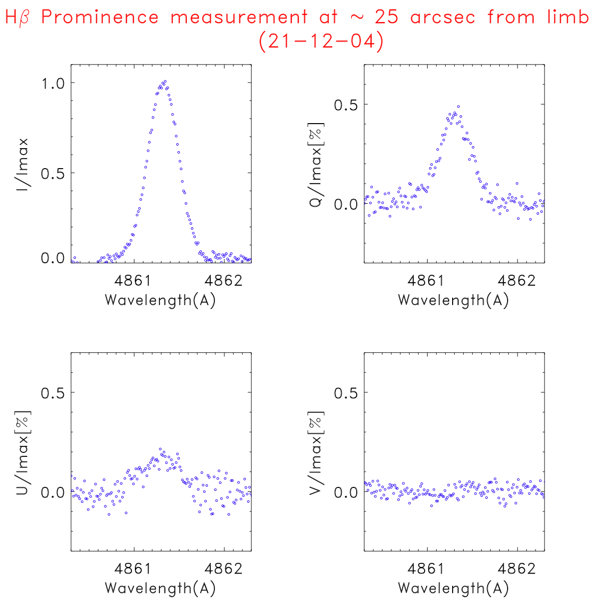

Figure 14. Example of Hβ Stokes profiles obtained in prominences.

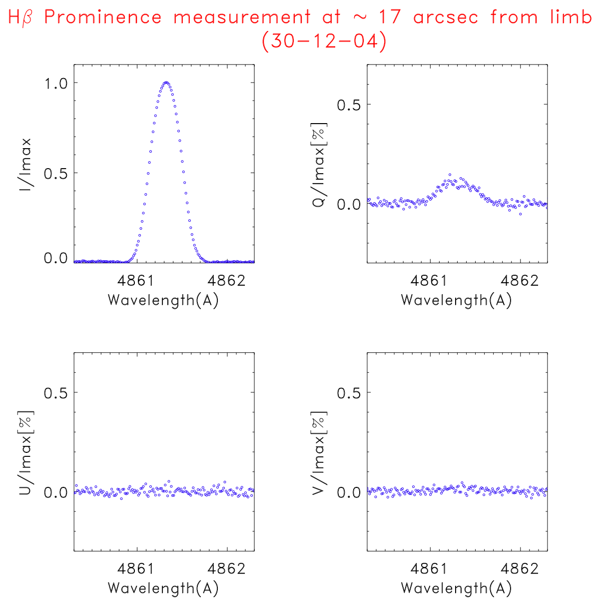

Figure 15. Example of Hβ Stokes profiles obtained in prominences.

are around 0.4%. No signal above the noise level could be detected in the circular polarization. Examples of Hβ Stokes profiles are shown in Figs. 14 and 15.

6. CONCLUSION

Using ZIMPOL at the GCT telescope in Locarno it was possible to obtain a large set of high quality full Stokes spectropolarimetric measurements of prominences in the He-D3, Hα and Hβ lines and of spicules in He-D3.

Presently the main results that we want to point out are the following.

The observations of spicules in quiet regions indicate that the magnetic fields involved are around 10 gauss. In one measurement taken in the proximity of an active region, magnetic fields up to 50-60 gauss were found.

Another interesting result is that the Stokes V profiles obtained in Hα in prominences are generally dominated by the antisymmetric signature typical of the Zeeman effect. A symmetric signature, if present, does not exceed an amplitude of a few times 10^{-4}. This result does not agree with other observations reported recently in the literature.

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