New Spectropolarimetric Observations of Solar Coronal Filaments in the He I 10830 Å Multiplet

M. Collados¹, J. Trujillo Bueno¹,² and A. Asensio Ramos¹
¹Instituto de Astrofísica de Canarias, 38205 La Laguna, Tenerife, Spain
²Consejo Superior de Investigaciones Científicas (Spain)

Abstract. Two solar coronal filaments located close to the center of the solar disk have been observed using the Tenerife Infrared Polarimeter. Maps of the full Stokes vector have been obtained in the 1083.0 nm spectral region, which includes the photospheric Si I 1082.7 nm spectral line and the chromospheric He I 1083.0 nm multiplet. The observed linear polarization at the solar disk center is created by the Hanle effect in forward scattering (see Trujillo Bueno et al. 2002), which allows us to to infer the azimuth of the magnetic field vector directly from the spectropolarimetric observations. We find that the magnetic field is approximately orientated along the filament axes.

1. Introduction

In a recent letter, Trujillo Bueno et al. (2002) presented spectropolarimetric observations of a solar coronal filament that was located at the center of the solar disk, showing the first observational demonstration that the Hanle effect in forward scattering at the solar disk center creates linear polarization signals in spectral lines (cf. Trujillo Bueno 2001). These authors selected the He I 1083.0 nm multiplet, which has three components: a “blue” line at λ1082.909 nm with \( J_l = 1 \) and \( J_u = 0 \), and two “red” lines at \( \lambda 1083.025 \) nm (with \( J_u = 1 \)) and at \( \lambda 1083.034 \) nm (with \( J_u = 2 \)) that appear blended at the plasma temperatures of prominences and filaments. They found circular polarization signals induced by the longitudinal Zeeman effect. The observed Stokes-V amplitudes were very low, suggesting that the magnetic field vector was nearly horizontal. They also found linear polarization of the same order of magnitude in both lines (i.e., in the blue and red components), with \( Q > 0 \) for the ‘red line’ and \( Q < 0 \) for the ‘blue line’ when choosing as reference direction for Stokes-Q that which minimizing Stokes-U was the closest to the filament axis. The chosen reference direction for Stokes-Q results to be aligned with the horizontal component of the magnetic field vector. In other words, when observing the Hanle effect in solar coronal filaments at the solar disk center we have that the mere detection of linear polarization implies the presence of an inclined magnetic field whose azimuth can be estimated from

\[
\chi_B = \frac{1}{2} \arctan(U/Q),
\]

468
Figure 1. \( \text{H}_\alpha \) slit-jaw images of the observed filaments. Filament 1 (left) was located at \( \mu = 0.98 \), and filament 2 (right) was at \( \mu = 0.94 \). The vertical line is the entrance slit of the spectrograph and the two horizontal lines limit the field of view of the detector.

where \( Q \) and \( U \) are the observed Stokes profiles with respect to an arbitrary reference system.

Here we apply this useful strategy (cf. Trujillo Bueno 2003) to new spectropolarimetric observations of solar coronal filaments in the He i 1083.0 nm multiplet. To this end, we have used again the Tenerife Infrared Polarimeter attached to the German Vacuum Tower Telescope (see Martínez Pillet et al. 1999 for a brief description of the IAC polarimeters, which are based on liquid crystals retarders). Together with the good performance of the German Vacuum Tower Telescope (VTT) at the Observatorio del Teide (Tenerife; Spain), which allows for image stabilization (Ballesteros et al. 1996) and scanning (Collados et al. 1996), two filaments were observed to determine their magnetic field structure and that of the underlying photosphere by using the observed polarization in the helium lines and in the photospheric Si i line at 1082.7 nm.

2. Observations

The observations were done on 6 July 2002. We observed two filaments located very near disk center (\( \mu = 0.98 \) for filament 1, and \( \mu = 0.94 \) for filament 2). Figure 1 shows the \( \text{H}_\alpha \) slit-jaw images of both filaments. The spectrograph was rotated such that the slit was approximately perpendicular to the main axis of the filaments. Scanning in a direction perpendicular to the slit was accomplished, at steps of 0.4 arcsec, giving rise to a total scanned area of 35.5 arcsec (slit height) by 100 arcsec for filament 1, but 65.6 arcsec for filament 2. At each position, five cycles of four images were taken with individual integration times of 150 ms. Each image represented a given linear combination of the four Stokes parameters, with the spatio-temporal modulation carried out with the help of two ferroelectric liquid crystals and a polarization beamsplitter. All the images corresponding to the same linear combination were added to increase the signal to noise ratio up a value better than 1000. The demodulation matrix was measured at the telescope using adequate calibration optics at an appropriate location (Collados 2003). The instrumental polarization introduced by the coelostat was taken into account using a statistical analysis (Collados 2003),
Figure 2. Observed Stokes profiles (four upper panels) for a given point in one of the filaments, in units of the continuum intensity. The photospheric Si I line is close to pixel Nr. 50 (see the horizontal axes), while the blue and red lines of the He I 1083.0 nm multiplet are situated approximately at pixel Nr. 110 and 150, respectively. The two lower plots represent the linear polarization profiles after rotating the reference frame to minimize Stokes-U as indicated in Section 1. Note that the polarization signal in the Si I line is mainly observed in Stokes-V, while that of the helium lines is mainly seen in Q and U.

minimizing the crosstalk form linear to circular polarization and vice versa. To this end, the presence of the photospheric line of Si I at 1082.7 nm, and the He I multiplet at 1083.0 nm, was very useful for two reasons. First, their polarization signals come from different atmospheric regions, the latter from the filaments themselves, while the former sampling the underlying photosphere. On the other hand, the linear polarization of the Si I line is generated by the transverse Zeeman effect, while that of He I is produced by scattering processes and the Hanle effect, which produces different Stokes-Q shapes. Therefore, any residual instrumental polarization crosstalk could easily be identified and corrected.

The four upper panels of Fig. 2 show the Stokes profiles at a given point along the spectrograph slit. It is important to note that the Si I line shows a polarization signal that is mainly seen in circular polarization (Stokes-V). On the other hand, the helium lines show linear polarization, Q and U, suggesting that the magnetic field orientation is different from that of the positive Q direction defined by our reference system, which points towards the celestial north pole.
A small $V$ signature is observed in the helium lines, suggesting that the magnetic field is mainly horizontal in the observed filaments. Of especial relevance is the negative linear polarization of the blue component of the He I 1083.0 nm multiplet, which had been marginally detected previously by Lin et al. (2000) in filaments located far away from the solar disk center, and was considered 'enigmatic' and 'inexplicable'. Its physical origin is selective absorption (i.e., dichroism) caused by the presence of population imbalances in the lower-level of that 'blue line', which are induced by the anisotropic illumination of the filament atoms (Trujillo Bueno et al. 2002). Note that this lower level is metastable because it is the ground-level of the triplet system of neutral helium. Therefore, it is a relatively long-lived atomic level whose atomic polarization is vulnerable (via the lower-level Hanle effect) to magnetic fields of very low intensity ($\sim 10^{-3}$ gauss!).

3. Results

As explained above, the azimuth of the magnetic field in the observed filaments can be found after finding the reference direction for $Q > 0$ that minimizes Stokes-$U$. To that aim, we rotated our polarization reference system to obtain new $Q'$ and $U'$ profiles, related with the original ones ($Q$ and $U$) by

$$
\begin{pmatrix}
Q' \\
U'
\end{pmatrix} = \begin{pmatrix}
\cos 2\chi & \sin 2\chi \\
-\sin 2\chi & \cos 2\chi
\end{pmatrix} \begin{pmatrix}
Q \\
U
\end{pmatrix},
$$

where $\chi$ is the rotation angle. In the new reference system, we look for the value of $\chi$ that makes $U' = 0$. This condition allows to write the second equation of the above system as

$$
\tan 2\chi = \frac{U}{Q}.
$$

Figure 3 shows the value of the magnetic field azimuth ($\chi_B$) obtained for both filaments at all the observed points. The values of $\chi_B$ are given with respect to the positive X-axis in the figures, with positive values corresponding to the counterclockwise direction. The bars displayed at the right side of the images give the scale used for $\chi_B$. More interesting is the relative orientation of the magnetic field with respect to the filament axis. Figure 4 shows the histogram of this relative orientation, $\chi_B - \chi_{axis}$, for both filaments. It is worth noting that, in both cases, the magnetic field azimuth is smaller than that of the filament axis by an angle that lies between 15° and 25°, approximately. This means that the magnetic field vector is rotated counterclockwise with respect to the filament. As both filaments were located in the northern hemisphere, it would be interesting to find out, in future studies, whether this is the case for all filaments and whether there is a sign reversal in the southern hemisphere.

4. Concluding remarks

The diagnostic technique we have applied here to solar coronal filaments can also be applied to other chromospheric plasma structures (e.g., plages, enhanced net-
Figure 3. Azimuth ($\chi_B$) of the magnetic field in filament 1 (top panel) and filament 2 (bottom panel). It was determined at each observed point as explained in the text. The values of $\chi_B$ are given with respect to the positive X-axis in each figure, with positive values corresponding to the counterclockwise direction. The scaling bars at the right of each image give the $\chi_B$-range for each case.
work elements, $H_\alpha$ fibrils, etc.) that can be investigated via spectropolarimetry in the He I 1083.0 nm multiplet, as well as using other spectral lines (see Trujillo Bueno 2003). At present, we are pursuing the determination of the full magnetic field vector in solar coronal filaments via Hanle and Zeeman diagnostics, as well as in the underlying photospheric plasma, in order to get insight not only on the three-dimensional geometry of the magnetic fields that confine the plasma of solar prominences, but also concerning any possible magnetic coupling between the photosphere and the upper solar chromosphere.

Acknowledgments. Research partially funded by the Spanish Ministerio de Ciencia y Tecnología through project AYA2001-1649.

References


Trujillo Bueno, J. 2003, this volume