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Observations of the Solar Ca I 4227 Å Line

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Abstract. Our aim is to understand some interesting polarization features observed in the solar Ca I 4277 Å line. Here we only discuss the observational aspects. Observations have also been made in other chromospheric lines within a few hours of those in the Ca I 4227 Å line, in the same region near the north solar limb, to illustrate the potential of simultaneous observations in different lines.

1. Introduction

The Ca I 4277 Å line shows the largest linear polarization signatures in the visible spectrum. Historically this was the first line in which scattering polarization was detected with confidence (Brückner 1963). Also the Hanle effect was first detected on the solar disk in this line (Stenflo 1982). Bianda et al. (1998) observed the line in greater detail on the quiet Sun. With recent progress in the theoretical interpretation this line has been found to be a good diagnostic tool for explorations of magnetic fields in the mid chromosphere as well as for the investigation of local fluctuations in the anisotropy of the radiation field. The Hanle effect can be measured in the line core. Spatial fluctuations in the linear polarization were detected in the line wings by Bianda et al. (2003) and have recently been investigated by Sampoorna et al. (2009). Further details about the recent theoretical work with this line can also be found in Anusha et al. (2010a,b).

2. Instrumentational aspects

The observations reported here have been carried out at IRSOL with the ZIMPOL polarimeter. Regions close to the limb were observed in order to measure scattering polarization. The left side of Fig. 1 shows a white light slit jaw image of a region near the limb, at the entrance of the spectrograph. The schematic drawing on the right side shows that along the spectrograph slit we are observing regions that are at different distances from the limb: at A we are further inside the disk than at B. Thus the $\mu = \cos\theta$ value for each point along the slit changes slightly, which has to be taken into account when averaging quantities along the spatial direction. The only point where the slit is exactly parallel to the solar limb is point A (see Fig. 1). For all other points, for example B, the scattering polarization remains parallel to the solar limb but forms an angle with the slit, resulting in non-zero Stokes U values even in the case of non-magnetic scattering (disregarding local fluctuations in the radiation anisotropy). Moreover, note that the angle subtended by two straight lines tangent to the limb at two points $200''$ apart is about 6°. Observationally, positive Stokes Q is defined as the linear polarization parallel to the spectrograph slit. If we now define positive Stokes Q as the polarization parallel to the limb, then we need to perform a basis transformation. For every point on the slit, the angle formed by the tangent at the closest limb with the slit direction has to be calculated and used in the polarization rotation matrix.

Figure 1. Left: Slit jaw image of the solar limb. The vertical line is the entrance slit of the spectrograph, and the horizontal segment shows a $50''$ interval. Right: Illustration of the limb curvature effect.

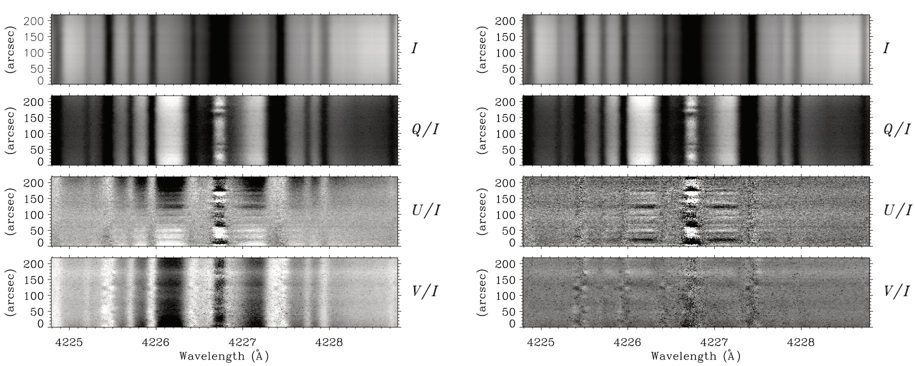

Figure 2. Full Stokes vector observations. Left: Data obtained after initial reduction of the ZIMPOL raw data. Only the intensity image has been corrected for flat-field. Right: The Stokes images after correction for the limb curvature effect and the cross talk. Note that no smoothing filter has been applied.

In the left part of Fig. 2 we show the initial reduction of an observation done on June 12, 2009 (during the Sunrise balloon mission) at geographic North, about 7″ inside the solar disk. Only a flat-field correction for Stokes I was used, without any corrections for the limb curvature effect or for the cross talks between Q, U, and V. In Q/I the polarization in the wings is stronger at the top and bottom edges of the image. This is due to the limb curvature effect. Around the central part of the slit we are further inside the solar disk, where the amount of scattering polarization is smaller. The curvature effect is most conspicuous in U/I: approaching the edges of the image we see typical Q/I like structures, which change sign as we go from one edge to the other. The Q/I like structures seen in V/I are due to instrumental cross talk.

The right part of Fig. 2 shows the Stokes images after the corrections have been applied to the original data. At every point along the slit the rotation matrix with the appropriate angle has been applied to both Q/I and U/I to transform them to the new basis (where Q/I is parallel to the limb). Clearly the global Q/I like structures in U/I disappear. Only spatially localized structures remain and cannot be removed by any cross talk correction. The nature of these structures (noticeable also as depolarization structures in Q/I) have been explored by Sampoorna et al. (2009), who find that they cannot be explained by the Hanle effect, but are probably due to local variation of anisotropy in the incident radiation field. We also note the structural richness in the line center, caused by the Hanle effect, reflecting the spatial morphology of the magnetic field. The cross talk from the linear polarization into V/I has been removed. Only very faint anti-symmetric profiles remain.

3. Solar origin of the wing signatures

To eliminate doubts about the solar origin of the spatially varying signatures in the wings, we did observations on October 2, 2007, with the center of the slit placed 7″ inside the solar disk. Two exposures were taken with the solar image shifted along the slit direction by 10″ between the exposures. The results are shown in Fig. 3, where we see that the faint structures in the wings of Stokes Q/I and U/I have been shifted by 10″, as expected when the signature is of solar origin. As counter example we see unshifted structures in the I images, which contain residual effects from an imperfect flat field.

4. Observations carried out "simultaneously"

In Fig. 4 we show measurements in other lines, obtained on the same day (June 12, 2009) and at the same location (geographic north pole) as the Ca I 4227 Å observation reported in Fig. 2 (measured during UT 12:24 - 13:05). The recording of Ca II 3933 Å was made during UT 10:15 - 10:49, that of Sr II 4078 Å during UT 11:14 - 12:00. We notice that structures like the strong signature around 180″ can be seen in all the lines, but there are also significant differences. The various chromospheric lines have different line formation properties and therefore respond differently to the structures in the magnetized chromosphere. They therefore place different and complementary constraints on the Sun's atmospheric structure. The diagnostic potential of observations

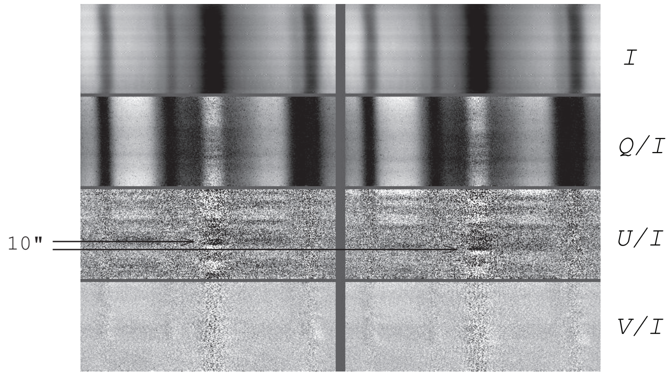

Figure 3. Stokes vector observations, before (left half) and after (right half) spatially shifting the solar image by 10″ along the spectrograph slit direction. Solar signatures are shifted while instrumental effects remain unshifted.

in the Ca I 4227 Å line will therefore be greatly enhanced if used in combination with observations in other lines.

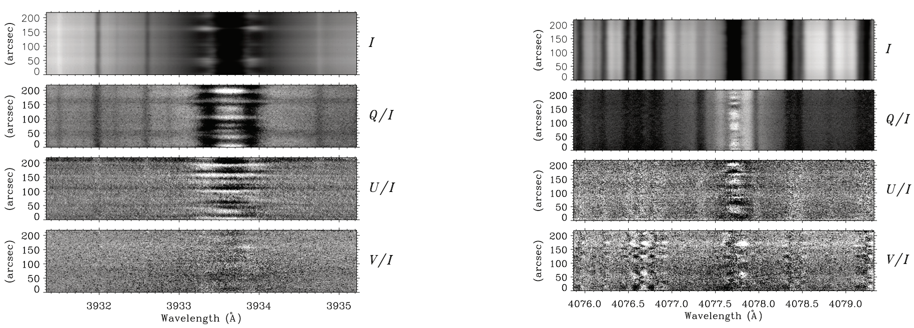

Figure 4. Stokes vector observations done within a few hours of the observation reported in Fig. 2. Left : Ca II 3933 Å. Right : Sr II 4078 Å.

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References

Anusha, L. S., Nagendra, K. N., Stenflo, J. O., Bianda, M., Sampoorna, M., Frisch, H., Holzreuter, R., & Ramelli, R. 2010a, ApJ, 718, 988

Anusha, L. S., Stenflo, J. O., Frisch, H., Bianda, M., Holzreuter, R., , Nagendra, K. N., Sampoorna, M., & Ramelli, R. 2010b, in these proceedings
Bianda, M., Solanki, S. K., & Stenflo, J. O. 1998, A&A, 331, 760
Bianda, M., Stenflo, J. O., Gandorfer, A., & Gisler, D. 2003, in Current Theoretical Models and Future High Res. Solar Observations: Preparing for ATST, edited by A. A. Pevtsov & H. Uitenbroek, vol. 286 of Astr. Society of the Pacific Conf. Series, 61
Brückner, G. 1963, ZAp, 58, 73
Sampoorna, M., Stenflo, J. O., Nagendra, K. N., Bianda, M., Ramelli, R., & Anusha, L. S. 2009, ApJ, 699, 1650
Stenflo, J. O. 1982, Sol. Phys., 80, 209